Speed of Light and Rates of Clocks in the Space Generation Model of Gravitation, Part 1

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Abstract. —
General Relativity's Schwarzschild solution describes a spherically symmetric gravitational field as an utterly static thing. The Space Generation Model (SGM) describes it as an absolutely moving thing. The SGM nevertheless agrees equally well with observations made in the fields of the Earth and Sun, because it predicts almost exactly the same spacetime curvature. This success of the SGM motivates deepening the context—especially with regard to the fundamental concepts of motion. The roots of Einstein's relativity theories thus receive critical examination. A particularly illuminating and widely applicable example is that of uniform rotation, which was used to build General Relativity (GR). Comparing Einstein's logic to that of the SGM, the most significant difference concerns the interpretation of the readings of accelerometers and the rates of clocks. Where Einstein infers relativity of motion and spacetime symmetry, it is argued to be more logical to infer absoluteness of motion and spacetime *a*symmetry. This approach leads to reassessments of the essential nature of matter, time, and the dimensionality of space, which lead in turn to some novel cosmological consequences. Special emphasis is given to the model's deviations from standard predictions *inside matter*, which have never been tested, but could be tested by conducting a simple experiment.

PACS 04.80.Cc – Experimental tests of gravitational theories.

1. – Introduction; Intended Audience

> *Beware ye, all those bold of spirit who want to suggest new ideas.* — BRIAN JOSESPHSON, Nobel Laureate [1]

The fate of the Space Generation Model (SGM) hinges on the result of an experiment proposed by Galileo in 1632. Galileo wondered what would happen "if the terrestrial globe were pierced by a hole which passed through its center, [and] a cannon ball [were] dropped through [it]." [2] Testing the idea would be easier, of course, in a laboratory or satellite with bodies of more convenient size. My intended audience are those who can imagine that it is not only worthwhile, but important to conduct this simple gravitational experiment. If only out of respect for the spirit of Galileo, it seems obvious to me that doing the experiment is important, regardless of the existence of a model (the SGM) that predicts a non-standard result.

Though my attempts are still in progress, I have yet to succeed in convincing any physicists on this point. To my knowledge, there are no plans among physicists to do the experiment. Possibly others would be interested. Therefore, I reach out to science-oriented lay readers who have an appetite for new ideas. The experiment is not easily done in a garage-converted laboratory. I've tried. Ultimately, the idea needs to be judged by physicists who have the most direct access to laboratories and other resources needed to do the experiment. Therefore, I reach out to physicists and physics students who have an appetite for new ideas.

The material to follow may often be too basic for physicists and may often be too technical for lay readers. On average, the level is about that of a *Scientific American* article. In science, as in life, being momentarily in over one's head is often beneficial. When lay readers feel overwhelmed, I would therefore recommend sticking with it as long as possible, because almost everything in this essay is covered from a variety of levels and approached from a variety of angles. If the first approach is hard, please be patient; it will eventually make sense.

As for the more technically savvy readers, I hope they share the view that starting from the beginning can be enlightening and refreshing. Much of the territory we explore is familiar. This time around, however, the basics are presented with an eye on opening a new perspective—a perspective that may sometimes seem to be impossible because it conflicts with prior knowledge. I intend to show that where such conflict exists, it is with *theoretical* "knowledge," not with empirical knowledge.

The best example is Galileo's experiment itself. The presumed result is standard fare in first year college physics courses. All that is known, however, is the *theoretical* answer. A simple calculation gives the mathematical result, but obviously not the physical one. The actual experiment has never been done. In such matters the only authority whose testimony holds any weight is that of Nature. But in this case, she patiently waits to be summoned. Until that happens we cannot rightly say we know whether the textbook answer is correct, or not. In our attempt to act as diligent scientists, we do not let this oversight pass. We question, if it is really so, then why don't we prove it?

With a flexible mind, one can see both the proverbial vase and the proverbial facial profiles; both the proverbial duck and the proverbial rabbit. Being ever-cognizant of the empirical facts, we construct a new portrait of physical reality that, of necessity, *accommodates* most of the old impressions, but is ultimately distinguishable from them. Far from being merely a new interpretation of established knowledge, the SGM proposes that much of that knowledge is demonstrably wrong. Galileo proposed the needed demonstration almost 400 years ago. If the reader's curiosity has been kindled as to the result of this experiment—which would unequivocally decide the issue—if the scholars of gravity would please refrain from pretending to know the result before the experiment is actually carried out, then we are off to a good start.

2. – Accelerometers and Clocks; Empirical Foundation

2˙1. *Extreme Strategy*. – Physical facts are often most clearly revealed in the extremes. Physicists are well-served by empirically observing these extremes when possible and by otherwise deducing what exactly are the extremes, i.e., what are the baselines and the limits. This uncontroversial strategy partly explains why modern physicists invest so heavily in the extreme case of smashing the tiniest bits of matter into one another with high energies, to analyze the results of these violent collisions. One of the extreme consequences predicted by General Relativity (GR) is inherently impossible to observe, yet receives a similar level of mental investment. Known as a *black hole*, this extreme arises because the theory allows the undesirable possibility of dividing by zero.

Another extreme that, by contrast, is physically quite accessible, has nevertheless remained empirically unexplored. We have lots of data concerning gravity-induced motion of objects near and over the surfaces of larger gravitating bodies, [3, 4] but no data at all concerning gravity-induced motion near the *centers* of gravitating bodies. The zone near $r = 0$, where r represents the body's radius, is thus a reachable extreme that remains unreached. This fact is especially interesting for the Space Generation Model of gravity (SGM) because, as noted above, it is where the model can be most convincingly tested. It is obviously impractical to drill a hole through the Earth. Using smaller bodies, however, the experiment is quite feasible in an Earthbased laboratory or in an orbiting satellite. [5, 6]

My first priority is to generate interest in probing this inner space, to find out the result of Galileo's experiment. Until that happens, my second priority—and the main purpose of this essay—is to explain why many experiments that have already been done (far beyond the extreme $r = 0$) reveal GR and the SGM to be in nearly exact agreement. Considerable attention will also be given to the historical and philosophical roots of our concepts of matter, space, time, gravity, and the Universe. Establishing this broad context is necessary because the SGM poses a challenge to much of the standard wisdom concerning these core foundations.

2˙2. *Preliminary Case: Massive Bodies, Accelerometers and Clocks*. – The stakes are clearly high. To establish the new model as a viable contender, we pay due respect to the subject's roots and the rules of the game. Of necessity this involves casting a wide and deep net. Before doing so, however, a brief preview concerning a physical example from our current understanding of gravitational fields is in order. For this defines the stage upon which the drama of humanity's quest to figure out the physical Universe is played. It defines the kinds of questions that need to be asked and answered. Happily, the stage is very familiar: a large spherical body, such as the Earth. One of the tricks, as the history of science testifies, is to be alert to ways that familiarity may give false impressions. Taking nothing for granted, we thus ask for empirical evidence to back up every claim of knowledge. However abstract our exploration may sometimes get, we seek to maintain a firm connection to the concrete world of experience, which is where we must ultimately begin and end.

To better understand both GR and the SGM, and to see how they differ, it is helpful to conceive of gravitational fields with concretely visualizable imagery. Consider the weak-field case such as applies to the Sun, Earth, or even to laboratory-sized spheres of matter. As is typically done, in what follows we will consider such fields in relative isolation because including additional bodies of comparable mass needlessly complicates the picture. Our idealized field is well-characterized by the readings of accelerometers and the rates of clocks fixed to the source mass, as shown in Figure 1. Both accelerometer readings and clock rates vary with distance in a well-defined way. An accelerometer placed on Earth's surface gives a reading $g \approx 9.8$ m s^{-2}. Over the surface, as on the towers in Figure 1, the readings diminish with distance according to the inverse-square law.

The predictions of GR and the SGM for the readings given by these accelerometers and the rates of these clocks are in almost exact agreement. The differences are much

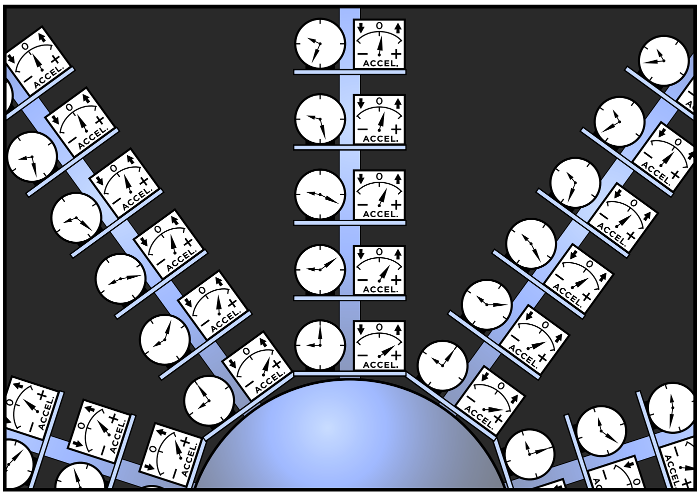

Fig. 1. – Basic motion-sensing devices: Exterior behavior. Accelerometers and clocks arrayed outside the surface of a gravitating body. In the weak-field approximation GR and the SGM agree on the behavior of both devices. Accelerometer readings are a maximum near the surface. Clock rates are a minimum near the surface. Clocks are shown with different *times*; but this is to be understood as also indicating different ticking rates, i.e., *frequencies*.

too small to measure. The models sharply diverge, however, for two different (weak-field) extensions of this picture. One of these extensions (inside matter) corresponds to a drastic deviation even with respect to Newton's theory of gravity. It thus pertains to the gross motion of material bodies. Whereas the other extension (both inside and outside matter) corresponds to empirically more subtle—known as *relativistic*—effects involving the motion of light and clocks.

Considering these in turn, suppose a diameter length hole (as suggested by Figure 2) is dug through the body so as to extend the array of instruments to the center. The SGM again nearly exactly agrees with GR concerning the accelerometer readings, but deviates from GR concerning clock rates. GR predicts that clock rates will continue to decrease toward the center (being a minimum at $r = 0$); whereas the SGM predicts that clock rates increase toward the center (being a *maximum* at $r = 0$). This difference in clock rate predictions inside matter is especially pronounced for strong fields, as seen in Figure 3. It is also evident for the weakest field case, as seen in the top curve in each graph. For added clarity, these top curves have been merged and rescaled in Figure 4. A body small enough so that its center could be accessed would exhibit rate differences between clocks at the center and surface that are much too small to be directly measured.

Small as such relativistic consequences may be for weak fields, it is well known that the rate of a stationary clock in a gravitational field correlates directly with the maximum *speed* that the field can produce at the location of the clock. This is supposed to be true for both exterior and interior fields. Therefore, the difference in predictions concerning clock rates inside matter—though not *directly* measurable as a clock rate difference—can be *indirectly* measured by observing the gross motion (i.e., observing the speed) of matter in the field near $r = 0$. This observation is possible as a laboratory experiment (e.g., using a modified Cavendish balance). Inside matter the small relativistic effect thus corresponds to a large Newtonian effect that is observable even to

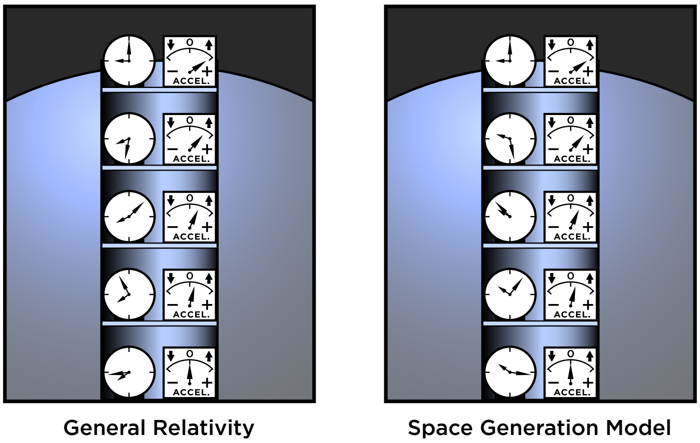

Fig. 2. – Basic motion-sensing devices: Interior behavior. Accelerometers and clocks arrayed between the surface and center of a gravitating body. In the weak-field approximation GR and the SGM agree on the accelerometer readings, but they disagree on the clock rates. GR says clocks get slower going inward, with a *minimum* at the center. Whereas the SGM says clock rates get faster going inward, with a *maximum* at the center. As in Figure 1, clock times are also indicative of frequency. We have no unequivocal evidence indicating which model is closer to the truth. Conducting the experiment proposed by Galileo nearly four centuries ago would fill this gap in our empirical knowledge of gravity.

the naked eye. Such an experiment, in fact, is exactly the same in principle as the one proposed by Galileo.

The graph in Figure 5 shows the dramatic difference in predictions as between Newton and GR on one hand, and the SGM on the other. The standard prediction is that the test object oscillates with simple harmonic motion. The SGM prediction is that the test object never passes the center. In the Newtonian context the difference corresponds to the question whether gravity is really a force of attraction or not. In the general relativistic context the difference corresponds to whether a gravitational field is *static* or not; whether the rates of clocks vary due to some mysterious geometrical effect or due to their *motion*.

The near agreement in clock rate predictions outside matter means that for the *gross motion* of small bodies *over* the surfaces of massive bodies like the Earth and Sun the SGM differs only indiscernibly from GR. Predictions differ, however, for the rates of falling clocks and the propagation of light. These differences will be illustrated for the extreme case involving the radial—i.e., up-down—motion of clocks and light signals.

Before specifying the differences, note first another important point of agreement. This is not just an approximate agreement, but one that is *exact* as between Newton, GR and the SGM. If our falling test object is an accelerometer, then according to all three models, the reading it gives will always be *zero*. Falling in a gravitational field always results in a zero accelerometer reading. By contrast, being firmly attached to a non-rotating gravitating body (anywhere except at its center) always results in a *non-zero* accelerometer reading. Empirical evidence in support of these predictions is quite common. In some profoundly empirical sense, *falling objects evidently do not accelerate, whereas objects attached to gravitating bodies do accelerate*. This is what our motion-sensing devices are telling us. The SGM prediction for the result of Galileo's experiment is

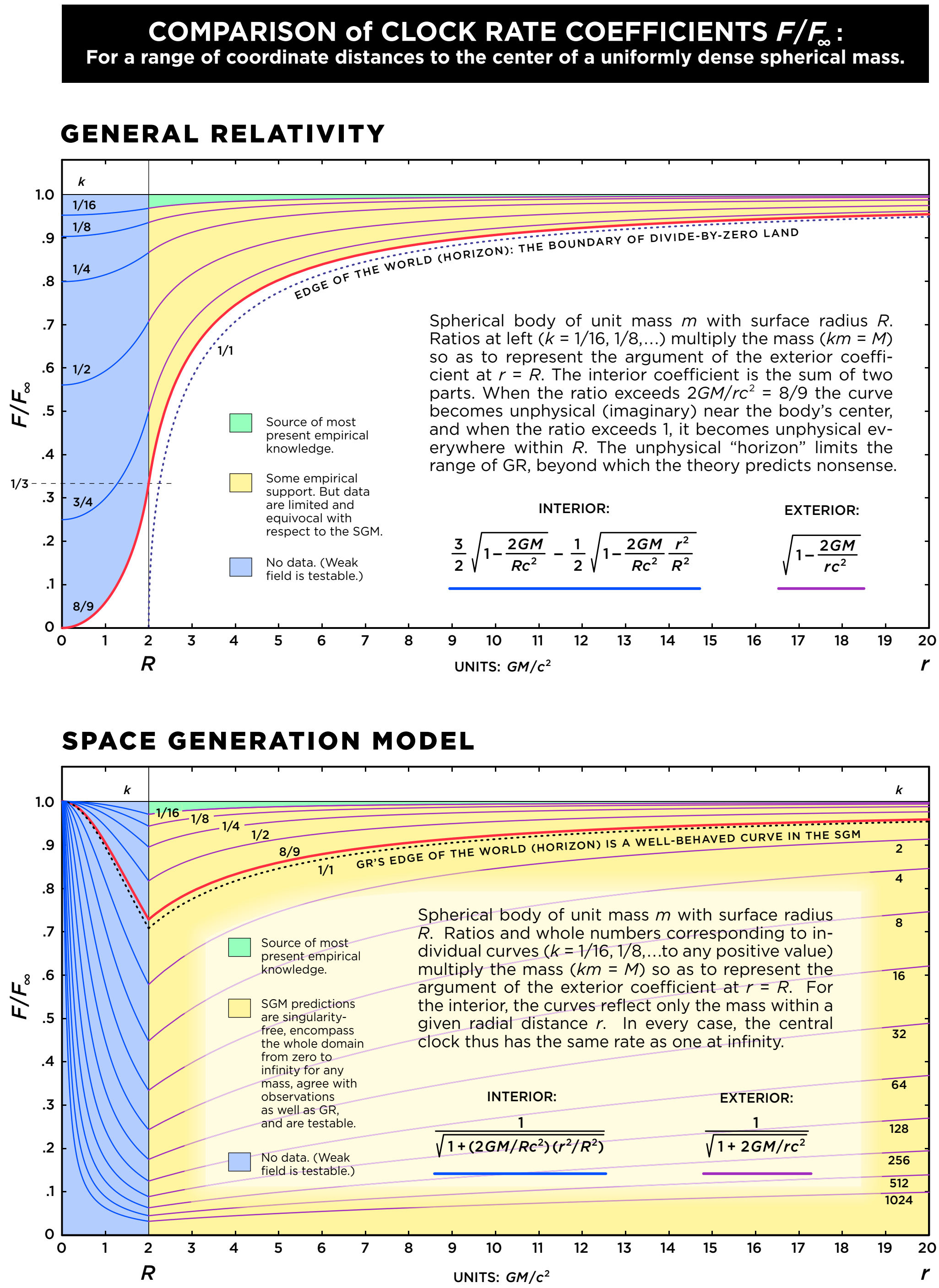

Fig. 3. – Clock rate comparison. Top: Singularity-ridden GR predicts that clocks stop and densities become infinite when $M/r \geq c^2/2G$. Bottom: Well-behaved SGM accommodates all non-negative M/r ratios. G is Newton's constant and c is the light speed constant. Mathematical expressions will be explained later.

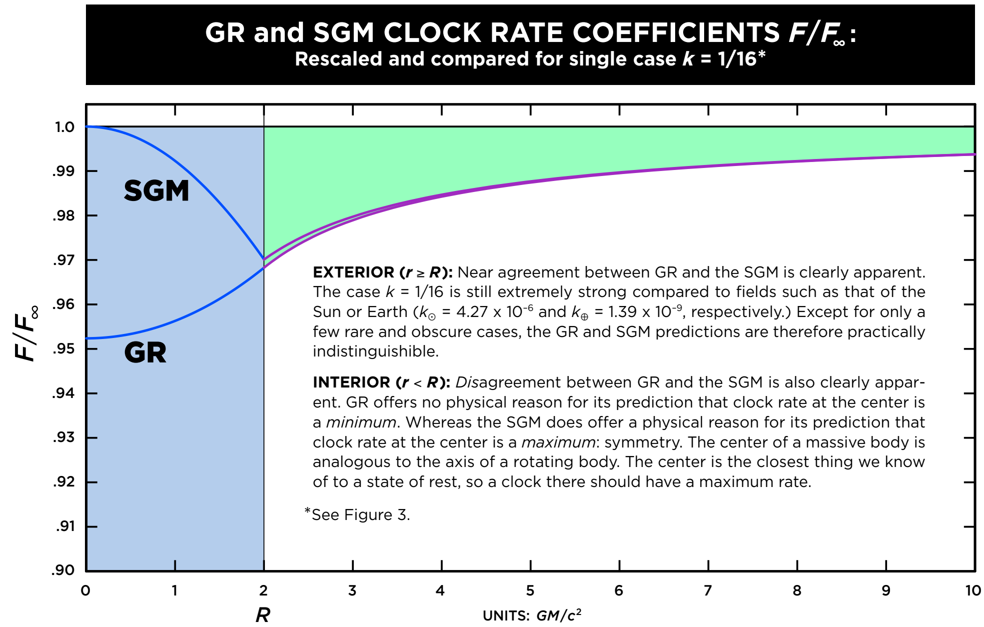

Fig. 4. – Clock rate comparison for the smallest M/r ratio from Figure 3 (i.e., $2GM/Rc^2 = 1/16$). Curves are rescaled to emphasize near agreement for the exterior and stark disagreement for the interior.

based on the assumption that clocks and accelerometers tell the truth about their state of motion.

2˙3. *Rotation Analogy: First Look.* – We now return to the disagreements between GR and the SGM that are considerably more difficult to measure than by simply observing the readout of an accelerometer or watching a small body fall through the center of a larger one. According to GR, in the neighborhood of a given point, the radial motion of clocks and the radial propagation of light is essentially up-down *symmetrical* with regard to the effect on the clock's rate and the speed of the light's propagation. Specifically, at the given point—in addition to the effect due to its location—the rate of a clock is supposed to depend only on its speed, not at all on direction. And the speed of light is supposed to be entirely independent of direction. These predictions follow from the idea that the source mass and its gravitational field are utterly static things. The assumption of staticness is more commonly expressed in terms of the isotropy of space and local Lorentz invariance. Symmetry, isotropy and staticness are three conceptions of the physical world (thought to be applicable with respect to isolated bodies like the Earth and Sun) that underlie Einstein's theories. On the basis of clock and accelerometer readings, and other arguments to be adduced below, we suspect these foundational ideas to be vulnerable and in need of testing and possible replacement.

A logical alternative comes to light by contemplating the *physical reason* for the location dependence on the rates of clocks, as suggested by Figure 1, and as suggested by a well known analogy. First contemplated by Einstein in the course of building GR, the analogy is visually represented by the juxtaposition shown in Figure 6, and symbolically represented by comparison of analogous quantities, as shown in Table 1. If

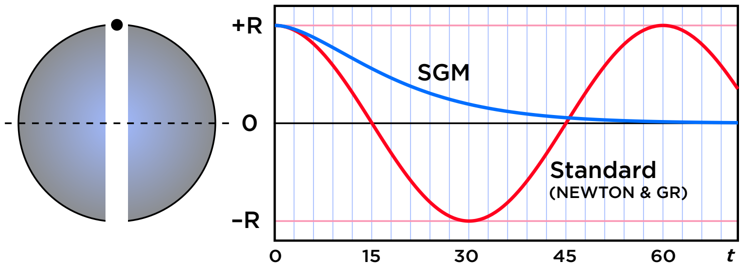

Fig. 5. – Schematic of Galileo's experiment with graph of competing predictions. The standard textbook answer is that the test object executes simple harmonic motion (red curve). But in none of the many textbooks, papers, and classrooms where this prediction is given do we ever find *empirical evidence* to back it up. Even without a competing model, therefore, carrying out the experiment is scientifically expedient. All the more so since the SGM predicts a drastically different result (blue curve). The 60 minute oscillation period corresponds to a sphere whose density is about that of lead.

r is the radial distance and ω is the angular velocity, then the rates of rotating clocks depend on the square of the rotation speed, i.e., $(r\omega)^2$. Similarly, the acceleration (as measured by accelerometers) depends on the radius and the square of the angular velocity, $a = r\omega^2$. The rotation speed $r\omega$ is thus analogous to the corresponding speed in gravitational fields, $\sqrt{2GM/r}$, and the rotational acceleration $r\omega^2$ is analogous to the gravitational acceleration GM/r^2, where, as in Figure 3, G is Newton's constant, M is the body's mass and r is the radial distance to the body's center.

PHENOMENON	VELOCITY	ACCELERATION
Rotation	$r\omega$	$r\omega^2$
Gravitation	$\sqrt{2GM/r}$	GM/r^2

TABLE 1

Einstein assumed that gravitating bodies are static things, so he used the analogy to assert (contrary to common sense) that it is therefore also reasonable to regard rotating bodies as static things; that rotating observers can rightfully claim to be "at rest." [7,8] The similarity that aided development of GR is that, in both cases, rod lengths and clock rates are diminished, which indicates the failure of Euclidean geometry. Einstein thus used the analogy to deduce the existence of curved spacetime.

We accept this latter facet of the analogy because it is supported by empirical evidence. But we question Einstein's assumption that it is reasonable to deny the absolute physical reality of rotational *motion*. Instead, the analogy makes more sense when turned around. Which means we assume that the physical reality of rotational velocity and acceleration, $r\omega$ and $r\omega^2$ indicates a corresponding physical reality to gravitational velocity and acceleration $\sqrt{2GM/r}$, and GM/r^2. These quantities refer not to the velocities and accelerations of falling bodies, but to the gravitating body and its surrounding space. The rotating body is really moving; by analogy a gravitating body is therefore

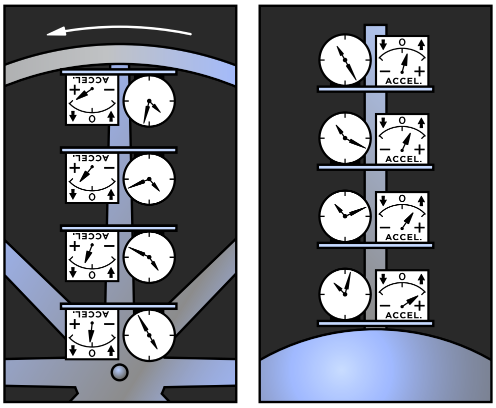

Fig. 6. – Rotation analogy. Both rotating and gravitating bodies exhibit the identical effects of distance-dependent non-zero accelerometer readings, variations of clock rates, and changes in length standards (by the same magnitude that clock rates change). In the rotating system Euclidean geometry fails. (The circumference no longer equals $2\pi r$.) Corresponding effects are also found in the gravitating system. This implies the preference for non-Euclidean geometry; i.e., *spacetime curvature*. Since the *effects* are the same, we reasonably deduce that the *causes* are the same. Contrary to Einstein's unintuitive assertions that rotational motion is *not real* and that rotating observers should regard themselves as being *at rest*, [7,8] the SGM adopts the much simpler deduction that in both cases, *spacetime curvature is caused by motion*. Gravitating bodies are not static; they undergo stationary motion.

also really moving. It is not *just* by analogy that we come to this idea. It is what our motion-sensing devices are telling us. In both cases the *cause* of spacetime curvature is *motion*.

Pursuing this idea further, we arrive at a most asymmetrical picture of radial motion—whether of light or clocks—in gravitational fields. Analogy with rotation illustrates the meaning of this. Given a large initial rotation speed, suppose the body to which it applies is given a positive boost. This increase in tangential speed causes the rates of clocks on the body to slow down more than they were slowed by the original rotation speed. If the body receives a negative boost that slows down or stops the rotation speed, the rates of clocks on the body will be correspondingly increased. The gravitation-rotation analogy correlates the positive rotation boost with upward motion in a gravitational field and the negative rotation boost with downward motion in a gravitational field. The increase in clock rate corresponding to a negative rotation boost suggests that radially falling in a gravitational field also results in increased clock rates. The picture is grossly asymmetrical. Thus, in a gravitational field *moving upward is much different from moving downward*. The rates of clocks and the propagation of light are both affected by the resulting velocity sum (positive or negative boost).

Already highlighted or implied in the above discussion are a number of fundamental and empirically consequential differences between GR and the SGM. By simply accepting that rotating bodies are really moving and regarding the same *effects* found in gravitational fields to have the same *cause*, we are led to a radically different conception of physical reality. It is therefore essential to establish that existing empirical evidence that seems to support GR [3, 4] supports the SGM just as well.

2.4. *Looking Backward and Forward*. – Most of these issues were addressed in a much shorter earlier version of this essay. [9] The present, extended and amplified revision is warranted primarily because of a crucial development that strengthens the SGM's plausibility in at least two key ways: 1) The original version gave the metric coefficient from GR, i.e., $(1 - 2GM/rc^2)$, a new interpretation that was applied only to weak-field cases; strong-field issues were not discussed. The strong field consequences are now given a robust treatment (§XX) with a physically well-motivated new coefficient $(1 + 2GM/rc^2)^{-1}$, that maintains the same agreement with observation for weak-field cases, but without the possibility of becoming negative or dividing by zero. The singularities that plague GR are thus absent in the updated SGM. And 2) This modification is of fundamental significance, as it appeals directly to the role of the limiting speed of light. The absence of singularities in the SGM corresponds to the analogous case of rotation. Material bodies cannot rotate at the speed of light ($r\omega < c$) because doing so would violate the limit. We simply adapt the same limit for the *gravitational speed* of material bodies. Application of this idea to a class of problems in astrophysics then facilitates an extension of SGM cosmology, whose cogency is thereby enhanced. SGM cosmology exhibits firm and direct connections to atomic physics. These connections will be explored in due course, thus fulfilling our goal of addressing the physical world's and the model's most important extremes.

To clarify the role of the speed of light in the SGM we compare it with the corresponding role in Einstein's Special and General Theories of Relativity. We consider a number of the empirical successes of Einstein's theories, and explain the point of view from which they arise. But we are critical of the metaphysical underpinnings. Experiments are proposed by which newly suggested underpinnings can be tested. Our investigation is thus unlike many criticisms of relativity that merely offer unconventional *interpretations* of the facts, without predicting anything that is new and testable. It is also unlike the work of those who deign to "extend" relativity in some subtle way that lends itself to testing very small effects near the limits of our ability to measure. Rather, what is proposed in what follows is readily testable in gross and dramatic fashion; and if the SGM prevails, a major paradigm shift will follow. A careful examination of the foundations and an exposition of the new model sufficient to establish its agreement with known empirical evidence is therefore clearly in order.

Even if the SGM ultimately proves to be incorrect, it is, of course, always prudent to re-check one's foundations. All the more so, as recent developments in physics—or lack thereof—have motivated many harsh critiques of its present state. [10-13] Among the responses to this trend, this worry that things are not adding up, is that of the experimentalist, Eric Adelberger, who suspects that "we are missing something huge in physics." [14] Perhaps a new way of looking will facilitate seeing, in the foundations of physics, the huge missing thing, as it may be "hiding in plain view." Perhaps the crucial missing thing is a simple (albeit radical) shift in perspective. In this spirit, we thus question several basic assumptions—not only those of Einstein, but of his predecessors and his successors.

2.5. *Rotation Again*. – As we have already begun to see, one of the most fertile testing grounds for our critique is the phenomenon of *rotation*. This is true because we have a vast store of empirical support for the arguments to be given, and because of how clearly this brings out the relevant issues. Considering once again Einstein's appeal to rotation, note how he characterized its connection to his general principle of relativity (and thus to gravity):

> The treatment of the uniformly rotating rigid body seems to me to be of great importance on account of an extension of the relativity principle to uniformly rotating systems along analogous lines of thought to those that I tried to carry out for uniformly accelerated translation. [15]

John Stachel has called Einstein's treatment the "'Missing Link' in the History of General Relativity" because it inspired Einstein to conceive of non-Euclidean (curved) spacetime. From the present perspective we surmise that Einstein only got it part right. He correctly deduced spacetime curvature, but because of his insistence on the staticness of matter, he failed to see that he was looking right at the cause of spacetime curvature: stationary motion.

In 1936 Einstein wrote: "[GR does not] consider how the central mass produces this gravitational field." [16] This failure of GR perpetuates the same failure suffered by Newton's theory of gravity, i.e., ignorance of its cause. Humanity's failure to understand gravity's mechanism is one of the reasons physicists (such as Jayant Narlikar) sometimes admit: "It would be no exaggeration to say that, although gravitation was the first of the fundamental laws of physics to be discovered, it continues to be the most mysterious one." [17] Suggesting that it is possible to remove or at least diminish our ignorance by conducting the right experiments, Robert H. Dicke observes:

> Serious lack of observational data... keeps one from drawing a clear portrait of gravitation... There is little reason for complacency regarding gravity. It may well be the most fundamental and least understood of the interactions. [18]

For other comments to the same effect, see References [19-23]. Echoing Dicke's supposition as to the *fundamentality* of gravity are the many similar admissions of ignorance or confusion regarding the essential nature of the elements of physics: *matter*, *time* and *space*. Few would argue that a deeper understanding of gravity—especially an understanding of its causal mechanism—would facilitate significant advances in solving these persistent puzzles. An SGM-supporting result of Galileo's experiment would thus have consequences reaching far beyond itself.

As Einstein and many others have often pointed out, GR is based on certain preconceptions (principles) with regard to *symmetry* and other abstract mathematical considerations. Whereas the interpretation put forth here is based on more concretely physical considerations: i.e., the readings of accelerometers, the rates of clocks, and the physical experience of motion. A recurrent source of confusion in the literature of gravity, as suggested in Figure 7, is that general relativists regard *non-zero* accelerometer readings as indicating *either* the presence or absence of acceleration, depending on their mathematical purpose. The same kind of equivocation is found with regard to zero readings. Falling bodies, e.g., accelerometers giving *zero* readings are regarded as *either* accelerating or not, depending on the mathematical purpose. A falling accelerometer is most commonly regarded as accelerating downward in spite of its zero reading; but sometimes such a trajectory is regarded as uniform (geodesic) motion *because of* the zero reading. The surface of a gravitating body is sometimes thought of as being in a state of upward acceleration—because of non-zero accelerometer readings—even as the more usual approach is based on our visual impression that the surface, the body as a whole, and the surrounding field are utterly static things. Strangely enough, according to standard physics—specifically, the general principle of relativity—that which accelerates is also static or at rest.

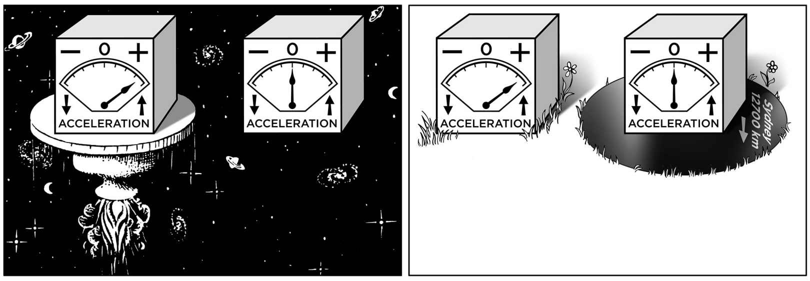

Fig. 7. – Left: It is widely understood that an accelerometer in outer space that is being accelerated gives a positive reading. If the accelerometer is not accelerating because it is not rotating and has no source of propulsion, then it gives a zero reading. Right: In the Newtonian framework, this logic is discarded when a large massive body is nearby because now one is supposed to imagine the existence of a mysterious force of attraction. The large body is presumed to be at rest, so the accelerometer giving the positive reading is presumed to be *not* accelerating. Whereas the accelerometer dropped into the hole, whose reading is zero, is presumed to be accelerating. In the general relativistic framework, the terms *acceleration* and *rest* are variably applied to any one of these accelerometers, depending on one's mathematical purpose. Having an abundance of mathematical options, to the general relativist, is a much higher priority than figuring out what's really going on, physically.

The standard language is starkly contradictory. The idea of spacetime curvature is sometimes invoked to reconcile the contradiction; such arguments may appear to be mathematically consistent, but one's physical intuition remains unsatisified. Something seems deeply wrong. The fact of having only incomplete empirical data exacerbates the impression. Doing Galileo's experiment would complete the picture and settle the matter.

From the SGM perspective the prevailing contradictory terminology is intolerable. Instead of scrambling acceleration with rest and staticness and obscuring the picture with curvature, we regard non-zero accelerometer readings as consistently reliable indicators of acceleration, and zero readings as correspondingly reliable indicators of its absence. If the SGM's prediction for Galileo's experiment proves true, we will have learned that non-zero accelerometer readings never indicate a state of rest, nor the condition of staticness because no such condition exists: everything moves all the time. It is this perpetual motion that *causes* spacetime curvature. All of the conclusions and predictions to follow trace back to this patently empirical foundation provided by our key motion-sensing devices: accelerometers and clocks.

3. – Roots of the Prevailing Conceptions of Physical Reality

> *[In ancient times] observing had never been regarded as particularly important. Noble concepts of the mind were rated much higher.* — GUY MURCHIE [24]

> *The theoretical scientist is compelled in an increasing degree to be guided by purely mathematical formal considerations in his search for a theory, because the physical experience of the experimenter cannot lead him up to the region of highest abstraction.* — ALBERT EINSTEIN [25]

3˙1. *Introduction*. – Without pretending any rigor with respect to the sciences of psychology or sociology, experience gives me the impression that the preferences among physicists for particular theories and methods of promulgating them, roughly correspond to a range of personality types which may be characterized in terms of other occupations. Toward one end of the spectrum we find types that reflect the activities of judges, lawyers, politicians, priests, performers, mathematicians, and marketers. In other words, those who are concerned with abiding by, investing in, or inventing and promoting morally comforting or entertaining stories and systems of abstract rules. Toward the other end we find types that reflect the activities of car mechanics, investigative journalists, police detectives and curious children. In other words, those with a passion to figure out *what is really going on*. ([1])

If the stories told by priests are really true, then why is that? How do we know? If they are not true, then why do so many people believe them? Is it possible to discover the story behind the story, to expose the deeper truth of the matter? For all the illumination they have surely provided, Einstein's theories of relativity are known also to have generated lots of confusion. Disagreements as to their "proper" understanding and deeper implications yet remain *among physicists* (which leaves the general public, as a result, even more confused). With the intent of dispelling some of this confusion, we emphatically refuse to be satisfied with explanations that are couched in terms of abstract principles. We will endeavor instead to ask the kinds of questions that are conducive to figuring out what is really going on.

3˙2. *From the Ancient Greeks to Kepler and Galileo.* – It is worthwhile to begin with a brief sketch of the roots of physics. This history is checkered with representatives from the whole range of personality types, whose extremes were mentioned above. In addition to their many lofty untested ideas, the Ancient Greeks also engaged in concrete empirical pursuits such as, for example, those of Eratosthenes' measurement of Earth's diameter and Archimedes' explorations into buoyancy. Much as modern physicists have seemed to enjoy being released (by the blessing of Einstein) from the "experience of the experimenter," empirical evidence still does sometimes play a role in directing and deciding which "high abstractions" are the most meaningful and fruitful ones. And just about all physicists, including Einstein, now and then at least pay lip service to the empirical ideals of science.

With this in mind, let's go back to consider—so as to set the stage for more modern developments—a few of the basic conceptions of space, time, and matter that have prevailed for large stretches of human history. One of the longest reigning ideas is the Ptolemaic concept that Earth lies at rest at the center of the Universe. Even as Copernicus' idea that the Earth and other planets actually orbit the Sun seemed to agree better with the observational facts, and was certainly simpler from the point of view of the Sun, in his day the evidence did not yet constitute proof. In his day, to seriously suggest

([1]) An analysis of the shortcomings of contemporary theoretical physics by Lee Smolin echoes the existence of a similar kind of dichotomy of personalities. Smolin observes among theoretical physicists the preponderance of "craftspeople" who are good at solving math problems, but do not possess the rarer quality of perceptive insight and instinct for asking the right questions, the qualtiy exhibited by "seers." Because seers are much less common, Smolin laments: "We are horribly stuck and we need real seers, and badly." [26] Real seeing can happen only when one does not pretend to know what will be seen before looking. Real seeing requires being able to tell the difference between abstraction and reality, and to maintain the sense that reality is more important—a sense that seems to have atrophied in many physicists. Maybe this is why they are so "horribly stuck."

ideas that conflicted with Biblical scripture was to put one's life at risk. Leaving that story to be told elsewhere, we simply acknowledge that Copernicus bravely succeeded in planting the seed of a basically correct new idea. It was a big step in the right direction. A snag in the progression toward truth, even for Copernicus, however, was the persistent inherited idea that planetary motion was based on *circles*.

Founded largely on the meticulous observational data of Tycho Brahe, Johannes Kepler's deduction that the orbits are actually *ellipses*, with the Sun at one focus, once again raised the level of enlightenment, and paved the way for Copernicus' ultimate vindication and Newton's grand synthesis. Note that Kepler well exemplifies the *mixture* of personality types found in most people and in most physicists. He was steeped in mysticism and held deep prejudices about mathematical meaning and beauty. Yet his respect for the "experience of the experimenter," i.e., Brahe's and his own observational data, led him along a path that tended to contradict some of his own cherished preconceptions.

Substantially strengthening the case even before Newton got into the act, were Galileo's contributions, including his telescopic observations of the phases of Venus, Jupiter's moons, and Earth-based observations of falling bodies. Of similarly lasting import were Galileo's arguments concerning the *relativity of motion*. A famous example used by Galileo was that of a ship moving uniformly along the shore. From within a closed windowless cabin, observers cannot tell whether they are moving or not. From this it could be deduced that it is as true to say the shore moves as it is to say the ship moves. It was the *ideas* discussed by Galileo, and not his exact words, that have resulted in their being characterized as *Galilean relativity* or *Galilean invariance*. The example of the ship cabin was later echoed by Einstein with his famous railway carriage scenarios—about which, more later. As will be discussed more fully below, Newton formalized and in many ways extended Galileo's observations. Galileo's relativity of uniform motion was subsumed under Newton's first law of motion (also known as the *law* or *principle of inertia*).

Before going further, an important guiding principle that has so far only been implied ought to be made explicit: the idea of *simplicity*. It is understandable why, due to their primitive experiences and visual impressions, the ancients conceived the Earth to be at rest at the center of the Universe. Based on these same visual impressions, bodies of matter found on Earth and Earth itself were regarded as essentially static chunks of stuff. These ideas are *simple* and seem to accord well with the facts as they were understood at the time. Observations of the heavens were also interpreted in the simplest terms. A reasonable first impression is that heavenly bodies go around the Earth in perfect circles. When it was noticed that the planets wander with respect to the stars, the simplest interpretation seemed to be that their motion was a *combination* of various circles. A system of circle-based motion that included mathematical elements known as epicycles, deferrants, and equants was devised around 140 A. D. by the Greek astronomer Ptolemy. His scheme enabled fairly accurate predictions which maintained the idea that the Sun and the planets all revolve around the fixed Earth.

Almost 1500 years later, the fixed Earth hypothesis persisted in the attempts by Tycho Brahe to reconcile it with his impressive advances in observational accuracy. This was after the heliocentric hypothesis of Copernicus had been known for about 50 years. Brahe modified the Ptolemeic system only by assuming that the other planets revolve around the Sun and the whole entourage travels in a circle around the Earth. Simple as it seemed to be at the outset, the circle-based "cosmology" prevailing in the early 17th century was beginning to look rather grotesque, because Brahe's observational improvements indicated that Ptolemy's initial level of circular paraphernalia were not sufficient. Additional layers of epicycles were needed. Given this morass of growing complexity, it is easy to appreciate the impact of Kepler's meticulous analysis of Brahe's and his own data, from which he derived his laws of planetary motion (ca 1619). The first law is that the shape of a cyclical orbit is not a jumble of circles, but an ellipse, the conic section with a *pair* of foci, one of whose locations is the Sun. A higher order of simplicity turned out to be the ticket.

Returning to the question of linear (uniform) motion, Galileo's research dispelled the views of Aristotle that had prevailed for centuries. Aristotle argued that even uniform motion required some kind of agent to keep things moving. Galileo deduced that no agent is required for constant linear motion. Though still problematic in some ways, Galileo's new idea is surely one of the simplest possibilities: that between two bodies that move uniformly with respect to each other, it is seemingly impossible to decide which of the two is "really" moving, or how the motions of both of them should be reckoned with respect to a third "unmoving" body, or a somehow more fundamental frame of reference.

How was motion to be conceived if not *relative* to other bodies? Could there be one other body, perhaps as an overarching composite body, that includes what appears to be "empty space" between separated chunks of matter, whose function as reference frame should for some reason be *preferred*? If such a "body" could be identified, would that make it—and thereby motion with respect to it—in some sense absolute instead of relative?([2]) Such questions, in the coming decades and centuries, came forcefully to the fore. Galileo and Kepler are rightly recognized as pioneers, who, by drawing attention to various questions about motion, both local and astronomical, deeply inspired further developments.

3˙3. *From Newton's Synthesis to Mach's Critique*. – As is well known, the next major advance is the work of Isaac Newton, whose system of mechanics and theory of gravity still dominate modern thought. As noted above, Galileo's conception of uniform motion was now recast as Newton's first law of motion, also known as the law of inertia:

> Every body continues in its state of rest or of uniform motion in a right line, unless it is compelled to change that state by forces impressed upon it. [28]

Also well known is that Newton supposed the need to frame the various motions in a backdrop of *absolute space* and *absolute time*. Many volumes have been filled with critiques and analyses of the Newtonian world view. Right off the bat it was controversial for being at odds with, for example, the views of Rene Descartes, whose contrasting conception was that space is a kind of extension of matter and not the sterile, passive, disconnected backdrop that Newton proposed.

Another famous conflict arose between the advocate for Newtonianism, Samuel Clarke (who was a friend of Newton) and Gottfried W. von Leibniz, the German math-

([2]) Understandably, it did not occur to Galileo that the positions of the "fixed stars"—much less an all-pervading universal heat bath, known as the cosmic background radiation, CBR [27] might suffice as a reference frame with respect to which motion is not merely relative, but does indeed acquire some degree of "absoluteness." This remark anticipates the discovery of the wave nature of light, developments in electromagnetic theory and much later observations in cosmology. We will consolidate the questions it evokes in §21 – §XX. Elements of that discussion and additional related questions need to be introduced beforehand.

ematician and philosopher. A small sampling of the flavor of their dialog is summarily captured in an introduction to the Clarke-Leibniz correspondence by H. G. Alexander:

> Leibniz says, the Newtonians believe that there can be space with no bodies in it. If space is a property [as the Newtonians also claim] then like all properties it is a property of something. But if space were devoid of bodies, then aside from space there is nothing of which it is a property, and this is absurd. [29]

In the 300 years since this dialog took place, many other philosophers have chimed in. It is important to realize that the core issues have not yet been resolved.

For a variety of reasons it is interesting that Newton appealed to two experiments to defend his view, and that both experiments involve *rotation*. The first one—which Newton actually performed—involves the rotation of a suspended bucket of water by allowing the twisted rope from which the bucket hangs, to untwist. The observations concern the gradual communication of the motion of the bucket itself to the water it contains, the resulting shape of the surface of the water and the relationship between these things, as they change, to surrounding space. The second one is a thought experiment involving two massive globes tethered together by a cord. The idea is to suppose the globes to be rotating around their common center of mass, first "in an [essentially empty] immense vacuum," and then in a space such as ours, having a distribution of "fixed stars." By correlating the tension on the cord with the circular motion of the globes, Newton implied that this enabled deducing the globes' "true" *translational* motion, i.e., their motion with respect to absolute space.

Two of the critiques (among many) of Newton's analysis are pertinent here, as the first, by George Berkeley, has sometimes been characterized as "anticipating" Ernst Mach and Einstein, and the second, by Mach himself, because his views were an inspiration to Einstein in the early development of GR. Berkeley earned his "anticipator" status by pointing out that, though it may well make sense to refer the rotation in Newton's experiments to the fixed stars, it does not make sense to refer it to absolute space. [30]

In Mach's critique of Newton's interpretation of his experiments, the fixed stars are referred to not only as a kind of fundamental reference frame but, insofar as they constitute an enormous distribution of mass, as also possibly having some kind of *dynamical* influence on local phenomena. Einstein approvingly regarded Mach's arguments as indicating that the very *origin of inertia* could be attributed to "a kind of interaction" with distant masses.

Einstein was also inspired by Mach's arguments concerning the *relativity* of *all* motion. This is by contrast with the relativity of only uniform motion, which we will address more fully in §21. The combination of these latter arguments with those concerning the origin of inertia, Einstein referred to as *Mach's Principle*. Einstein had hoped that his theory of gravity would satisfy this principle by showing that the cosmic matter distribution determines the local inertial behavior of massive bodies. Due partly to the vagueness about these ideas in Mach's own work, Einstein evidently felt he could formulate "the principle" as he saw fit. His initial (1912) understanding of it was stated as:

> The hypothesis that the whole inertia of any material point is an effect of the presence of all other masses, depending on a kind of interaction with them. [31]

The original vagueness of the principle and the fact that Einstein did not consistently stick to the above "hypothesis," but reformulated it a few times into the early 1920s, explains why Mach's Principle in the modern literature has come to have a notoriously ambiguous meaning. Physicists, philosophers, and mathematicians continue debating the proper definition and significance of "Mach's Principle." The unresolved state of this debate is exemplified by the *Index* of 21 different formulations of the principle in a 1995 symposium volume devoted to the subject. [32]

Curiously, for all the debate over the validity of Newton's absolute space and time, it has played virtually no role in the erstwhile success of Newton's mathematical theories of mechanics and gravity. Similarly, for all the debate over Mach's Principle (among others) it has played virtually no role in the erstwhile success of Einstein's mathematical theory of gravity (GR). We'll find this to be a recurring theme in physics: *the mathematical consistency and predictive success of a given physical theory may be of only little help in understanding its conceptual, intuitive, and ultimately, physical meaning*.

For what follows it is important to consider in some depth one more "Machian" characteristic that Einstein had hoped GR would fulfill. We thereby set up the context to show how the SGM provides a more satisfactory basis from which to fulfill it. *The very existence of space* should, Einstein argued, depend on the gravitational behavior of matter. Einstein wanted to show—and initially thought that he could—that without matter there would be no space. Note also that this idea is reminiscent of the critiques of Leibniz and the theories of Descartes, that matter and space are extensions, or at least inextricable *properties*, of each other. In the end, Einstein and his followers have had to concede that GR does not satisfy this variant (or aspect) of Mach's Principle. Recalling the ancient preconception that material bodies are to be regarded as essentially static, discontinuous chunks of stuff, and that in the context of gravity, they continue to be so regarded, this failure to establish for space a dependence on matter is hardly surprising. Nor will this be the only instance where we find the prevailing primal idea that matter is "made of" discontinuous "building blocks" acting as an impediment to discovery, an obstacle to a coherent conception of the physical world.

4. – *Hypothesis non Fingo:* From Mach's Critique to a Variety of Clues to the SGM

> *The general theory of relativity is a satisfying system only if it shows that the physical qualities of space are **completely** determined by matter alone. Therefore... no space-time continuum is possible without matter that generates it.* — ALBERT EINSTEIN [33]

4˙1. *The Real Nature of Gravitation*. – The importance to Einstein in fulfilling the Mach-inspired idea quoted above is reflected by the fact that, in a 1918 paper *On the Foundations of the General Theory of Relativity*, Einstein listed Mach's Principle as among the "three fundamental aspects" upon which the theory is based: "c. Mach's Principle. The *G*-field is completely determined by the masses of the bodies." [34] One of the ironic twists of Einstein and his theories is that this "basis" did not hold up as such. Perhaps also ironic is that the SGM perspective facilitates seeing not only the fate of matter-space interdependence *in the context of GR* as inevitably doomed, but seeing also a new physical rationale by which the idea makes a lot more sense.

The Machian problem can be clarified by putting it in the earlier context of the *cause* of Newtonian gravity. We illustrate this with a basic image borne of experience. Imagine a large and small body of matter in deep space, initially separated by an auxiliary

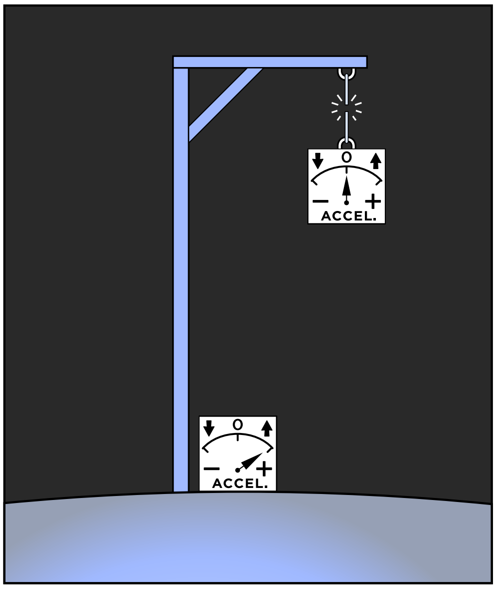

Fig. 8. – Basic falling picture. What causes tension on the string? When it is cut, why does the accelerometer suddenly read zero? Why does the accelerometer attached to the large body give a positive reading? Sometimes it is admitted that the answers to these questions are unknown. Sometimes it is pretended that the answers *are* known. Sometimes they are shrugged off as being *metaphysical* questions. If we want clear and unequivocal answers, the only authority worthy of our trust is *Nature*.

structure with a suspended string that prevents the small body from falling. (See Figure 8.) When the string is cut the distance between the two bodies decreases. Why? What makes it happen? Neither verbalized *things*: gravity, potential, attractive force, gravitons, spacetime curvature, nor *abstract mathematics*: Newton's force law, Einstein's field equations, answer the question. We seek to understand, conceptually, what actually *happens* to make the distance decrease. (The SGM-based answer is given in Appendix A.)

Newton repeatedly pleaded ignorance about this question. In his *Principia* he wrote: "Hitherto we have explained the phenomena of the heavens and of our sea by the power of gravity, but have not yet assigned the cause of this power." More famously—because of its final clause—Newton added, "hitherto I have not been able to discover the cause of those properties of gravity from phenomena, and I frame no hypothesis." [35] In the revised modern translation of the *Principia*, Cajori provides more background on this passage, writing that the expression *hypothesis non fingo* ("I frame no hypothesis") was "used by [Newton] in connection with a public statement relating to *that special, that difficult and subtle subject, the real nature of gravitation, which was mysterious then and has remained so to our day.*" (Ref. [35], p. 671; Emphasis added.)

It is well known that Newton's stance of framing no hypothesis was his public stance only. In unpublished writing and correspondence he did venture to speculate on the "real nature of gravitation." But his speculations (involving "ethers" of variable subtility, fineness and grossness) did not ring true. They did not help, and ultimately, Newton resigned himself to mysticism, to the idea

> ...that God in the Beginning form'd Matter in solid, massy, hard, impenetrable, moveable Particles... [endowed with] certain active principles, such as that of Gravity. [36]

By contrast, though we can find one occasion (1936) on which Einstein stated explicitly that his theory "[does not] consider how the central mass produces the gravitational field," [16] I have found no record of any indication that Einstein further contemplated the problem (nor even a second instance of his mentioning it). Much easier to find are Einstein's assertions as to having provided "The Solution of the Problem of Gravitation," and his assessments as to the solution's "excellent beauty." (Ref. [8], pp. 100, 102.)

We thus get the impression that Einstein was so satisfied with his mathematical theory that he never troubled himself to ponder the *real nature of gravitation*, to figure out the underlying physical mechanism that explains *why* many of GR's predictions seem to agree so well with observations. To Einstein, evidently, the "problem of gravitation" was merely a math problem, and he solved it. A commonly encountered product of this view is the statement that *gravitation is geometry*. Gravity is an abstraction, whose understanding has come to mean being conversant with Riemannian geometry. Einstein's lack of concern for gravity's underlying physical mechanism has thus set a precedent that prevails to this day, notwithstanding a few scattered grumbles such as Dicke's that we ought not to be *complacent* about the *persistent enigma of gravitation*. [18]

4˙2. *Outline of Clues*. – On the positive side, I think, was Einstein's desire (unfulfilled though it was) to have a theory whereby space and matter are *unified* in the sense that the existence of one (space) is utterly dependent on the existence of the other (matter). From the SGM point of view, we see an abundance of clues, clues that actually support Einstein's desire (which is a clue unto itself), but not in the way he imagined. In most cases, they are the same clues, or perhaps seemingly mundane facts, that physicists are already familiar with. The negative assessments presented so far (and more to come) as to the unhappy state of physics or its failure to solve certain problems, serve to show that the pieces of the puzzle, the clues, are not being assembled properly. They do not fall gracefully into place; they do not reveal a coherent picture, but appear strained, crooked, fragmented or incomplete. Seeing the pieces thus scattered about helps to appreciate the difference when they are finally seen to align and cohere.

Using the same clues to which we all have access, the SGM frames a new hypothesis by which the pieces nicely mesh, a cogent new hypothesis framed so that it accommodates what is truly known, and whose fate rests on a probe into the unknown (Galileo's experiment). To see this involves momentarily suspending all attempts to force the pieces into place by standard methods. It involves shaking a variety of preconceptions, such as, for example, the energy conservation law and the $(3+1)$-dimensionality of spacetime. It involves reassessing the meaning and significance of Einstein's Equivalence Principle and the so called *origin of inertia*.

In the following six sections (§5 – §10) we come to inspect these clues with the underlying assumption that accelerometers and clocks tell the truth about their state of motion. I intend to show that things will then begin to fit, and we will have a basis for answering the questions posed in conjunction with Figure 8. We will then also have a basis upon which to extend the emerging ideas and seek out new clues in the realms of cosmology and atomic physics, as we do in §11 – §20.

5. – Dimensions of *G*; Generation of Space

> [NEWTON'S] RULES OF REASONING IN PHILOSOPHY
>
> RULE I: *We are to admit no more causes of natural things than such as are both true and sufficient to explain their appearances.*
>
> To this purpose the philosophers say that Nature does nothing in vain, and more is in vain when less will serve; for Nature is pleased with simplicity, and affects not the pomp of superfluous causes.
>
> RULE II: *Therefore to the same natural effects we must, as far as possible, assign the same causes.* [37]

It has already been suggested that Einstein was looking right at, but failed to see the cause of spacetime curvature in the context of his rotation analogy. In the opening quote of the previous section we find another intimation of pregnant truth that Einstein did not see as such, and so ultimately rejected (or ignored). Einstein wrote: "No spacetime continuum is possible without matter that generates it." The word *generates* is conspicuous for being a *verb* that is suggestive of some kind of positive *action*. It implies something matter must *do* to create (generate) the "spacetime continuum."

But the most famous solution of Einstein's field equations, the Schwarzschild exterior solution—which is used to represent gravity around the Earth or Sun—is an utterly static thing. It just sits there, conserving itself. There is no causal connection between the material body and the surrounding space. One simply accepts the static geometry of the thing as existing for no known physical reason. This Einstein admits, so his readers are left to wonder: *How does* matter generate the spacetime continuum?

The clue has been apparent since long before Einstein. If length, mass, and time are represented by L, M, and T, respectively, then Newton's gravitational constant G has dimensions

$$G \to \frac{L^3}{MT^2} \,. \tag{1}$$

We have a volume in the numerator, a squared time in the denominator, which suggests acceleration, and a mass in the denominator, which suggests that multiplying by mass leaves a quantity involving the other elements. Altogether, G may thus be expressed as an *acceleration of volume per mass*.

This is not necessarily inconsistent with thinking of gravity as a force of attraction, provided that the effect is regarded as negative (toward the origin). The gravitational force, $F = GMm/r^2$ is supposedly "felt" by falling bodies (the M and m in the equation). But no such "feeling" is ever *experienced*. Physicists often speak of the *pull* or the *tug* of gravity. The only time a pull or tug is actually felt is when a structure connected to a gravitating body allows suspending another body from above. (See Figure 9.) For example, an apple hanging from a branch feels the tug of gravity, but the tug is demonstrably upward, not downward.

We see the difference between an upward pull and an upward push on the water balloons in Figure 9. *Downward* pulls or pushes are nowhere to be seen. The middle, falling balloon is spherical precisely because it feels neither a push nor a pull. This is not surprising. The primary effect of a gravitational force is expected when gravitating bodies are in contact with each other not when there is no contact.

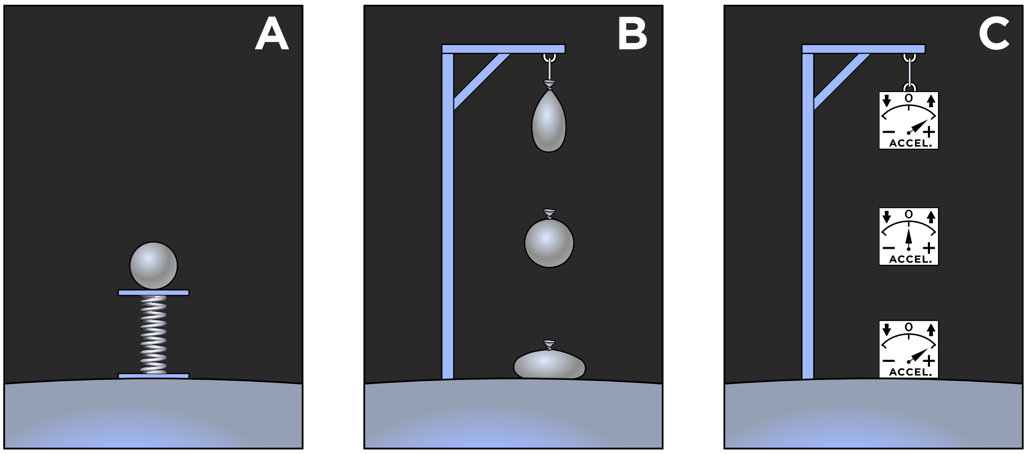

Fig. 9. – Basic spring balances and accelerometers. Both instruments can be regarded as motion sensing devices that operate by the same principle, i.e., degree of deformation of a deformable body of matter. **A.** The degree of spring compression can be calibrated to give either the weight of the steel ball or its acceleration. **B.** Deviation from sphericity of the water balloon indicates deviation from zero acceleration. Clearly visible is the significance of *one-sidedness* in the measurement: push from below (compression) or pull from above (tension). **C.** The internal mechanism (deformable component) of an accelerometer is typically insulated from unwanted disruption by an enclosure. Though somewhat more difficult to implement, a pivot system with counterweights is preferable to and often used instead of springs or membranes.

The alleged negativity of gravitational force and gravitational energy has sometimes been characterized by the expression, *gravity sucks*. In some ways this is a more revealing characterization than what we see by considering one small body juxtposed with a second larger gravitating body. The latter circumstance indicates a *line* of interaction. Whereas the former indicates the *volumetric* character of gravity. We will see this even more clearly later in the context of cosmology. Presently, it suffices to see that, if gravity represents negative energy, then the acceleration of volume per mass means space is being sucked out of the Universe by matter. And as usual, space and matter are utterly discontinuous from each other. Space is sucked away, but matter just sits there.

Even this pre-relativistic picture contains more action than what is allowed by the static Schwarzschild solution. Far from *generating* spacetime, matter, in Einstein's view of gravity has no active interaction with space at all. Nothing moves. If this seems like an exaggeration, consider the relativistic perspective as explained in the highly acclaimed book by Robert Geroch, *General Relativity from A to B*:

> There is no dynamics within spacetime itself: nothing ever moves therein; nothing happens; nothing changes... [Rather, this] ongoing state of affairs is represented, past, present, and future, by a single, unmoving spacetime. [38]

A reasonable response to this "state of affairs," I think, is that it indicates a serious inadequacy of the relativistic perspective, an inadequacy that ought to be fixed. Instead, it is commonly presented and accepted as a profound reflection of some deeper truth about the Universe (especially with regard to the nature of *time*).

Be that as it may, we now understand, at least, that when a test object is inserted into the field and is seen to move, there is no explanation for it. A commonly encountered pseudo explanation is that "matter tells spacetime how to curve and spacetime tells matter how to move." [39] How this "telling" is accomplished is completely unknown. How exactly are the orders carried out? As far as I know, the authorities of gravity consistently avoid asking this question. Why is that?

By contrast, in the SGM the acceleration and velocity derived from G are *positive* quantities that clearly indicate a causal matter-space interaction. Matter generates the spacetime continuum in the most direct possible manner. Gravity is not an abstraction; it is not geometry. Gravity is *the process whereby matter creates space*. By symbolizing acceleration of volume per mass, Newton's constant indicates the rate at which space is created by a given quantity of matter.

Another fact—somewhat less directly involving the dimensions of G, but related directly to Newton's quoted *Rules of Reasoning*—suggests something amiss in the standard view. If, as Geroch states, "nothing happens or changes" in spacetime—if gravity is just geometry, then how are we to conceive the usual idea of *cause and effect* (as expressed, for example, in Newton's Rules I and II) as applying to gravity? This seems especially puzzling even if we allow things to "happen," because according to GR, gravitational effects are commonly regarded as being caused by the curvature of spacetime, and the curvature of spacetime is typically, as near Earth, very tiny. What makes this puzzling is the mathematical *order* of what are the causes and what are the effects. It is most common in relativistic physics that a grossly perceptible phenomenon (momentum, for example) is well approximated mathematically by terms of first order. Whereas more subtle effects that typically coexist with the gross effects are represented by higher order terms (e.g., squares). Are the separately conceivable first and second order effects like chickens and eggs, or is there a logical preference as to which comes first?

The tininess of spacetime curvature can be seen in terms of the coefficients in GR's exterior Schwarzschild solution, which is displayed here for reference:

$$ds^2 = c^2dt^2\left[1 - \frac{2GM}{rc^2}\right] - dr^2\left[1 - \frac{2GM}{rc^2}\right]^{-1} - r^2(d\theta^2 - sin^2\theta d\phi^2)\,. \tag{2}$$

Perceptible gravitational effects may be found when the bracketed coefficients deviate from unity. (In the case of Earth the deviation is about 1.4×10^{-9}.) The arguments of these coefficients are typically small, squared quantities ($2GM/rc^2$), where ($2GM/r$) is a squared velocity. The velocities are often not explicitly shown; they are normalized by making G and c equal to one, so as to give the length $L = GM/c^2$. This leaves the argument appearing as a ratio of lengths, $2L/r$. We thus have a static geometrical object, characterized by a second order velocity ratio or first order length ratio, that *somehow* causes first order accelerations and velocities. Theoretically (i.e., mathematically) this is possible, of course. Strictly speaking, one could also say that first and second order quantities necessarily *go with* each other, perhaps more so than one *causing* the other.

The case of rotation suggests otherwise. On a rotating body the tangential lengths of rods and the rates of clocks deviate from those of a rod and a clock located at the unmoving axis by a quantity of second order (velocity squared). Now which statement makes more sense, to say that the shortened rods and slowed clocks cause the body to rotate, or that the rotation of the body causes rods to be shortened and clocks to slow down? Surely the latter makes more sense. The grossly evident first order speed is the cause of the barely perceptible second order effects on rods and clocks. Why should it be any different for gravity?

If we deny such a causal relationship, if we accept only that the phenomena go with one another, or that the second order quantities cause the first order effects, then we remain stuck with regard to Einstein's failure to explain how matter generates the spacetime continuum. But if we accept the more intuitive relationship: *speed causes rods to be shortened and clocks to slow down*, then we are not stuck. We have a plausible idea, a potent clue, that seemingly answers at least one question and leads to a variety of others, that we continue now to explore.

6. – Dimensions of Space and Spacetime Curvature

> *Once a theoretical idea is acquired, one does well to hold fast to it until it leads to an untenable conclusion.* — ALBERT EINSTEIN [40]

> *Analogy is surely the dominant idea in the history of the concept of dimensions.* — THOMAS F. BANCHOFF [41]

> *The notion of analogy is deeper than the notion of formulae... You start thinking by the use of analogy. Analogy is not the criterion of truth; it is an instrument of creation, and the sign of the effort of human minds to cope with something novel, something fresh, something unexpected.* — ROBERT OPPENHEIMER [42]

6˙1. *Introduction to Higher Dimensions*. – In physics the term *dimension* may refer either to the elemental L, T, M breakdown of a physical quantity or to the geometrical directions in space or spacetime. As it turns out, the latter sense of the word—our present concern—is also subject to a range of meanings often depending on whether a particular *size* is attributed to a particular dimension. This has come to be the case in most (but not all) discussions of hyper-dimensional modern physics. In these cases, only the first three spatial dimensions are assumed to be of infinite size; whereas those beyond the third are usually regarded as being *compactified*—usually into some extremely small circular loop.

For convenience, let's say those hyper-dimensionalists who attach importance to dimensions of reduced size belong to the "school" of compactification. This is to distinguish them from another school whose members scarcely, if at all, refer to compactification, but consider hyper-dimensional reality from a more geometrical perspective wherein each dimension is (at least implicitly) sizeless. Let's say these latter hyper-dimensionalists belong to the school of *geometry.* The literature on higher dimensions is vast. So I will mention only one other school, this one being considerably smaller than the first two. Roughly speaking, they are the general relativists, Paul Wesson, some of his colleagues in their "5D Space-Time-Matter Consortium," and others who have proposed a variety of ways to add a fifth coordinate to the usual $(3+1)$-dimensional coordinatization of relativity. [43] (Note: In the notation just used—which is very common—the first number in parenthess refers to spatial dimension, and the added 1 refers to the time coordinate.)

Examples of members of the compactification school are Edward Witten [44], Nima Arkani-Hamed, *et al* [45], Lisa Randall [46], and Brian Greene [47]. Examples of members of the geometry school are Thomas Banchoff [41], Rudy Rucker [48], Charles Hinton [49], and Richard Swinburne [50].

These various schools of hyper-dimensionality are mentioned here to establish a context for and contrast with the approach based on the SGM. Readers interested in more detailed histories and accounts of the resurgence of hyper-dimensionality in modern theories are referred to books by Paul Halpern: *The Great Beyond* [51] or Lawrence Krauss: *Hiding in the Mirror*. [52] The existence of this range of approaches indicates, among other things, that many others have taken the idea of extra dimensions seriously. Reasons for this vary, even as none of them exhibit any factual connection to physical reality. It also implies a kind of *versatility* to the idea. Extra dimensions have been invoked to solve or mitigate a variety of different problems. Yet, to repeat, there is no unequivocal evidence of the reality of any dimension beyond the first $(3 + 1)$. The result of Galileo's experiment, if the SGM's prediction is confirmed, would provide such empirical evidence.

One of the reasons for compactification relates at least indirectly to gravity, as we will see momentarily in graphic terms. The geometers' treatment of the fourth spatial dimension comes with its own rather different graphical representation, which relates more closely to the SGM approach.

6˙2. *Why Compactify?* – A compactified fifth spacetime dimension was first proposed by Theodor Kaluza in 1921 as a way to incorporate electromagnetism directly into GR. Einstein was initially very impressed with the idea, and intermittently worked on it himself with various colleagues through 1943. In 1926 Oskar Klein began a series of contributions to the subject that more explicitly involved quantum theory. For these authors' pioneereing work, physical theories involving more than $(3 + 1)$ dimensions are often referred to as *Kaluza-Klein theories*.

The standard argument for why the extra dimension needs to be tiny has often been discussed in terms of gravity's inverse-square law. These discussions all assume that gravity is some kind of *attractive force* whose magnitude diminishes with distance from its source as it spreads out in space. In three-dimensional space the attraction diminishes according to the inverse-square law. But if there were one more infinitely large dimension—so the story goes—gravity would spread itself out (become "diluted") more rapidly and diminish according to an inverse-*cube* law. If the fourth spatial dimension were much smaller than the sizes of bodies with respect to which gravitational influences have been measured, then the idea is supposedly still viable up to that size. In other words, even though the inverse-square law would fail at separation distances smaller than the compactified fourth spatial dimension's size, if measurements below that size are too hard to make, then nobody would ever notice. Compactification is invoked to assure that the extra dimension remains invisible, within known limits. Recent impressively meticulous experiments have put the limit at about 0.1mm. [53]

Other reasons for the smallness of extra dimensions derive from *superstring theory*, which typically requires vastly smaller sizes. Particles called gravitons, in the guise of loopy strings, are supposed to propagate through not just one but at least 6 tiny extra dimensions, while other forces are confined to $(3 + 1)$-dimensional mathematical "branes." The standard visually aided explanation for compactification begins with a one-dimensional line. The idea is that, upon closer inspection, we would see that the line is actually a *tube*, such that every point of the line is associated with a "one-dimensional circle." (See Figures 10 and 11.)

Among the reasons for which this approach seems to me contrived and misguided, is that a "one-dimensional circle" actually encompasses two dimensions, when the interior of the tube is accounted for. A more important reason is one that pertains also to the uncompactified inverse-cube law argument. It's that, however many dimensions

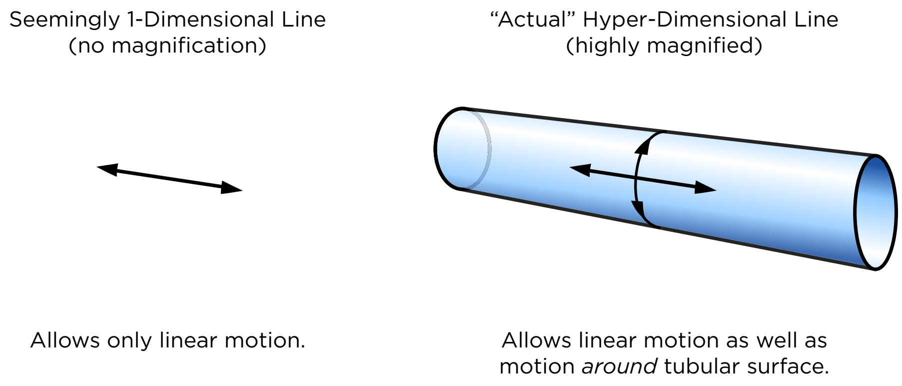

Fig. 10. – Kaluza-Klein-inspired conception of extra spatial dimension. The idea that a *line* in three-dimensional space is actually a tiny *tube* in four-dimensional space evokes various questions, such as: What scale of magnification is needed to make the extra dimension visible or physically relevant? I.e., how *big* is the extra dimension? What is the significance of the *volume* enclosed within a compactified tube? Does it really make sense that a spatial dimension should have a particular size?

there may be, and whatever their size may be, their purpose in this approach is only to serve as a kind of passive conduit for gravitons, strings, and other "force-mediating" thingons. The purpose is, in effect, to merely widen the stage across which something, some hypothetical thing in some unknown way causes discontinuously separated bodies of matter to be attracted to one another. Because of these unknowns, compactification of the extra dimensions does not diminish, it *compounds* and *complicates* the mystery of gravity. Because of the generally abstract character of these hypotheses, and the difficulty or impossibility of testing them, they are clearly very far removed from physical experience. Nobody has ever come close to explaining what the array of dimensions in Figure 11, for example, has to do with the flattening of our undersides or the slowing of clocks. To my knowledge, no one has even tried. These ideas resemble Ptolemy's jumble of circles, except for their typical failure to make any sensible predictions about the physical world. Finally, in spite of enormous efforts by thousands of physicists over several decades of time, this approach has remained unfruitful. I suspect it will remain unfruitful, so we'll consider it no further.

6˙3. *Geometrical Hyper-dimensionality*.

> In terms of dimensions, the line is extension and the birth of time. — ARTHUR YOUNG [54]

Popular interest in extra dimensions predates GR. For example, *Scientific American* sponsored an essay contest on the subject in 1909, which attracted 245 entries. As explained by the 1st prize-winning author, [55] the idea traces back to the 19th century researches of Bernhard Riemann and others on the limitations of Euclidean geometry. By questioning Euclid's fifth postulate (concerning parallelity), they came to invent geometries in which this postulate was not upheld. These inventions came to be known as non-Euclidean geometries. Although hyper-dimensional and non-Euclidean geome-

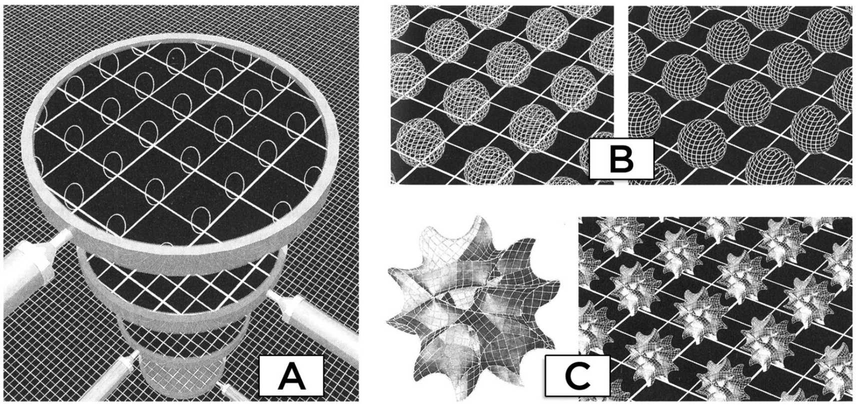

Fig. 11. – Compactified dimensions, as explained by Brian Greene. A) "Kaluza-Klein proposal is that on very small scales, space has an extra circular dimension tacked on to each familiar point." B) "Close-up of a universe with the three usual dimensions, represented by the grid, and (left) two curled-up dimensions, in the form of hollow spheres, and (right) three curled-up dimensions in the form of solid balls." C) "(Left) One example of a Calabi-Yau [even higher-dimensional] shape. (Right) A highly magnified portion of space with additional dimensions in the form of a tiny Calabi-Yau shape." [47] Images taken from Brian Greene's *The Fabric of the Cosmos*, without permission.

tries share this common origin, they do not necessarily go together. It is possible to conceive of higher-dimensional "spaces" that obey all of Euclid's postulates; and it is possible to conceive of non-Euclidean geometries that are confined to one dimension lower than the higher dimension in which they may be embedded. A common example of the latter case is the treatment of a spherical surface as a two, rather than a three-dimensional object. Hyper-dimensionality thus may or may not be regarded as relevant to a given problem in curved space (or spacetime). Perhaps the most important example in which curvature is deemed to exist without a corresponding higher dimension is the standard treatment of GR. This is the gist of the remark by Rudolf v. B. Rucker, in his Introduction to the work of Charles Hinton:

> It is certainly true that the most natural way of presenting Einstein's theory of gravitation entails viewing our space as a curved hypersurface in some higher-dimensional space. But General Relativity does not seem to demand any hyperthickness to the space of our world. [56]

This lack of "hyperthickness" will be explained from the SGM point of view as being due to the *staticness* of GR. We will argue that extension into the fourth spatial dimension is a natural consequence of associating the curvature with *motion*. Having the belief that GR is correct throughout the low-energy regime of our experience, workers in the field have failed to see or take this crucial step. The Schwarzschild solution, even though completely static, nevertheless seems to work. Relativists may therefore resign themselves, as Rucker has, to noticing an *implication* of higher dimensionality, without seeing how to make good use of it. The work of Wesson, *et al* supposes the higher dimension to have some reality, some "hyperthickness," but it is much too subtle. None of their many proposals pertain to any observable effects within reach of practical experience. Most importantly, they do not think to look inside matter to conduct the needed experiment (of Galileo) to make sure their assumption of GR's correctness is true.

The relationship between hyper-dimensionality, curvature, and motion will be the main focus of the remainder of this section. First let's add to our context by acknowledging some prior work. Much of the literature on hyper-dimensionality has a fantasy or science fiction-like character. Near the end of the 19th century and into the mid 20th, extra dimensions were often adopted by "mystics" and "spiritualists." Even serious science writers have inferred by analogy some rather fantastic things about the possible existence of a physical fourth spatial dimension. Carl Sagan, for example, wrote that:

> If a fourth-dimensional creature existed it could, in our three-dimensional universe, appear and dematerialize at will, change shape remarkably, pluck us out of locked rooms and make us appear from nowhere. It could also turn us inside out. [57]

Though it is not hard to understand the *mathematical* reasoning by which Sagan reaches these conclusions—even independent of the fact that no such things have ever been observed—there is no good *physical* reason to believe them. Since we too will be appealing to an analogy similar to that of Sagan and many others, it is important to keep our bearings with regard to the difference between abstraction and reality, so that we do not take the analogy too far.

Let us assess the tenability of Sagan's logic. His claims are based on a common story (e.g., *Flatland* [58], *Sphereland* [59]) of imaginary creatures who inhabit a flat two-dimensional surface or the surface of a sphere. Let's call them Twoworlders. Here's the idea: If we can figure out what the perceptual experience of a Twoworlder would be—especially with respect to Twoworld's relationship to Threeworld, which humans inhabit, then by analogy, we can figure out what the human perceptual experience would be with respect to our relationship to *Four*world. Of the analogies alluded to by Banchoff in our opening quote (p. 23) perhaps most prevalent is the one that supposes some truth to be found in the relationship: 3D is to 4D as 2D is to 3D.

According to the story, a Twoworlder can be "plucked" out of her surface by a god-like Threeworlder. Higher-dimensional beings are conceived as having superior powers due to their access to a dimension of space that the Twoworlders supposedly do not have access to. This makes for an entertaining story from which some of the hoped-for insight can indeed be gotten. But I hasten to point out that it is ultimately (obviously) *impossible*, and in some ways quite misleading.

Disregarding such objections for the moment, according to the story, the powerful Threeworlder can, if he wants to, flip the hapless plucked Twoworlder over (as a mirror image) and plop her back into her surface anywhere he pleases. For example, he can put her into an area that had previously seemed to be securely walled off. Similarly, a one-time prisoner of the walled off area can be plucked off the surface by the liberating Threeworlder and put back into the surrounding open space. Threeworlders are also supposed to be able to intersect the surface of Twoworld anywhere they please, so as to "appear and dematerialize at will." Sagan's description is an exact analogy of the corresponding experiences as expected for one higher dimension. For example, two-dimensional *flipping over* is exactly analogous to three-dimensional *turning inside out*.

What makes this scenario logically untenable is that *physically, there is no such thing as a two-dimensional surface*. Points, lines, and surfaces are all just mathematical abstractions, not concrete physical things. As a geometrical abstraction it makes some sense to say that a solid sphere and a plane can intersect each other. One can then imagine the intersecting circle as a "spot" in Twoword. If the sphere is free to move through the plane, its initial appearance will be as a (tangent) point that grows to a circle of maximum size when half-way through, and diminishes again to a point just before "disappearing." But in physical reality, interpenetration of three-dimensional objects through flat surfaces clearly never happens because it's impossible.

This becomes more obvious by considering the microscopic reality of anything we might think of as a "surface." It is fuzzy and spread out in three, not just two dimensions. But even if it looks "solid" and perfectly smooth, the surface—as with any of its "parts"—is not "pluckable"; it cannot be physically *extracted* from a three-dimensional object, because "it" is not there to begin with. Nor can a line be plucked out of a surface, nor a point out of a line. However flat or filamentary or tiny any such extracted thing may be, it is still at least three-dimensional—or else it is not physically real. Since Sagan and others have put such scenarios in the context of human experience, as though they could be true, it is important to point out these reasons why they are not possible, even in principle. The map will *never be* the territory. Imagination is a marvelous thing, but in the game of science it is important to distinguish between abstraction and reality, and to maintain the sense that reality is more important.

6˙4. *Physical Hyper-Dimensionality.*

> We must find the fourth dimension, if it exists, in a purely experimental way. . . If the fourth dimension exists, one of two things is possible. Either we ourselves possess the fourth dimension, i.e. are beings of four dimensions, or we possess only three dimensions and in that case do not exist at all. — PETER D. OUSPENSKY [60]

The arguments above suggest a basic physical principle that I think we can safely assume to be true: *Any physical sub-unit of a physical continuum such as our Universe, has the same dimensionality as the whole Universe*. That is, it is not possible to physically extract one dimension out of the others. The idea of doing so is sometimes mathematically possible and useful, but it is always just an abstraction. If this is true (we have no evidence to the contrary) then it is obviously a big mistake to confuse any resulting mathematical construction with reality. It is erroneous to assume that mathematical consequences involving extra dimensions—no matter how legitimate they are mathematically—actually correspond to physical reality. By this assumption the dimensionality of a "realistic" Twoworlder is exactly as high as ours. Note that this is exactly the point made by Ouspensky in the quote above. We are not as gods to lower-dimensional creatures; and we are not at the mercy of any physically real Fourworlder, because if Fourworlders exist, we are them. And if we are them, we must find out, as Ouspensky also states, "in a purely experimental way."

This raises the question, is $(3 + 1)$-dimensionality *sufficient* to insure physicality? If the world is actually $(4 + 1)$-dimensional, then by analogy the answer is *no*. Something is still missing. Even $(3 + 1)$-dimensionality is still just abstract geometry, not physical reality. Allowing *time* is a step in the right direction. But to be physical there must also be *matter*, whose behavior implies, by making spacetime curve, that one more spatial dimension is also needed. It would appear, therefore, that if we are to go beyond abstract mathematics, the two senses of the word dimension must be merged; in some sense they need each other. The physical elements of space, time, and matter seem to require at least three spatial dimensions and vice versa: Volumetric space seems to require time, matter, and perhaps a *fourth* spatial dimension, in order to exist at all.

Bearing this possibility in mind, let us now build up a "hierarchy" of dimensions to see if we can reconstruct the inter-dimensional analogy, being careful, on one hand, to not to take it too far; and on the other hand, to take it further than it has been

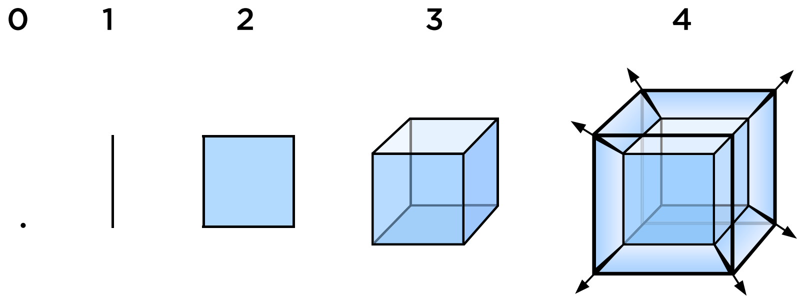

Fig. 12. – Basic geometrical build-up of spatial dimensions. Time is at least implied because the point needs to *move* to generate a line. What does this imply with respect to the transition from step 3 to step 4? What does it imply with respect to gravity?

taken before, by appropriately *mixing* physical properties with geometrical properties, as needed. Initially we'll run through our hierarchy quickly, and then go back to make explicit some things that were initially only implicit.

An abstract mathematical point has zero dimension. But as soon as it begins to move it traces out a one-dimensional line. If the line moves perpendicular to itself it sweeps out a two-dimensional surface (plane). If the plane moves perpendicular to itself, it sweeps out a three-dimensional volume. Compactificationalists and most others concerned with the physical application of higher dimensions would stop here—at step 3 in Figure 12—except perhaps to suggest that the line we started with (and presumably all subsequently generated lines) should be *microscopically* branched out, as per Figure 11. Whereas the geometrical hyper-dimensionalists frequently portray the next, fourth step as a hypercube (aka a *tesseract*). See Figure 13.

This highly suggestive figure has been called a "head-on view" or a "shadow" of an *actual* four-dimensional hypercube. As a mere snapshot from our seemingly $(3+1)$-dimensional perspective, it is important to realize that such images are no better than *hints*, which do not suffice to fully visualize the fourth spatial dimension. Before expounding on this visualizability problem and on what we may or may not infer from this image, let's first go back to our dimensional build-up. This time we'll emphasize the fact that a geometrical object of a given dimensionality may imply the next higher dimension, depending on whether or not it is *curved*.

As before, the movement of a *point* traces out a *line* that represents entrance into the first dimension. *Even if it curves*, the line itself remains a one-dimensional object. But from a higher-dimensional perspective we can see that the figure of a curved, seemingly one-dimensional line extends also into the second dimension. In order to curve the line needs another dimension, represented by a planar *surface*, to curve into. Similarly, a surface remains a two-dimensional object even if it curves. But from a higher-dimensional perspective we see that the figure of a curved surface extends into the third dimension. The third dimension is needed so that the surface has a *volume* to curve into. Acknowledging the inclusion of time, we can say that, by curving, a $(1+1)$-dimensional line implies the existence of a $(2+1)$-dimensional surface. By curving, a $(2+1)$-dimensional surface implies the existence of a $(3+1)$-dimensional volume.

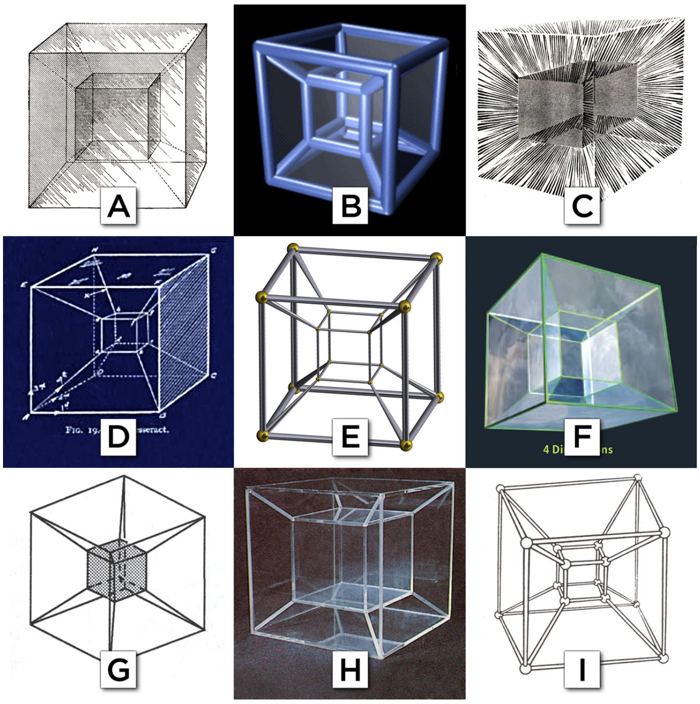

Fig. 13. – Hypercube (tesseract) gallery: A) Claude Bragdon [61]; B) Wikipedia [62]; C) Martin Gardner [63]; D) Alexender Horne [64]; E) Victor Schlegel [62]; F) Jan Ambjørn, *et al* [65]; G) Clifford Pickover [66]; H) Carl Sagan [57]; I) Rudy Rucker [67]. The geometer Thomas Banchoff has described a tesseract as a *head-on view* or *central projection* of a four-dimensional cube. Motivated entirely by geometrical, as opposed to physical considerations, these images are all supposed to represent an "extra" spatial dimension, which is just as *static* as the first three. I.e., there is no explicit, or even implicit relationship to matter, time, or gravity. Whereas in the SGM, the relationships are such that no space at all would exist were it not that matter is perpetually generating space by moving, with the unfolding of time, into (or outfrom) the fourth spatial dimension.

We'll postpone taking the next step to consider some advice that we should stop right here. Up to this point, we are clearly still within the realm of experience; at least, our mathematical logic does not *contradict* our physical experience because we do not claim our abstractions to be physical. We have not jumped to any fantastic conclusions about extracting one dimension from the others. Where we have stopped corresponds dimensionally $(3+1)$, to the standard treatment of GR. Since GR also explicitly includes curvature—curvature that has been verified empirically—the pattern established above implies the existence of a fourth spatial dimension that the $(3+1)$-dimensional spacetime needs *to curve into*. If we do not allow another dimension—as general relativists would have it—then this curvature can be accounted for in terms of a purely *intrinsic* description of the space. In other words, because only three space dimensions and one time dimension are needed to locate all points in spacetime, the possibility of a higher dimension by which an *extrinsic* description could be given is deemed unnecessary or inadvisable. In their textbook on GR, Michael P. Hobson, *et al* clarify this point by first referring to the standard analogy of Twoworlders living on a surface:

> It is important to make a distinction ... between the *extrinsic* properties of the surface, which are dependent on how it is embedded into a higher-dimensional space, and properties that are intrinsic to the surface itself... Properties of the geometry that are accessible to the [lower-dimensional creature] are called *intrinsic*, whereas those that depend on the viewpoint of a higher-dimensional creature (who is able to see how the surface is shaped in the three-dimensional space) are called *extrinsic*. [68]

In the sociology of Twoworld we can imagine a dominant school of academics who insist that dimensions beyond $(2+1)$ are useless fantasy. Imposing this dimensional restriction on their fellow Twoworlders is supposedly justified because $(2+1)$ dimensions (i.e., latitude, longitude, and time) suffice to locate all points in their world. On this basis they implicitly suggest that it's a waste of time and energy to even consider a higher $(3+1)$-dimensional embedding space. Hobson, *et al* adopt the analogous stance in Threeworld:

> We may take our discussion one step further, dispense with the [higher]-dimensional space and embedding-related extrinsic geometry and consider the surfaces in isolation. *Intrinsic geometry is all that remains with any meaning.* For example, when we talk of the curvature of spacetime in general relativity, we must resist any temptation to think of spacetime as embedded in in any 'higher' space. *Any such embedding, whether or not it is physically realized, would be irrelevant to our discussion.* [68] [Emphasis added.]

One is struck by the rigidity of this advice. Fortunately, a somewhat less dogmatic spirit exists in the work of Wesson *et al*. Unfortunately, even this latter work deviates from established standards only in some rather subtle, virtually unobservable ways. The prevailing view remains that spacetime is curved, but supposedly all we need are $(3+1)$ dimensions to satisfactorily describe all things gravitational; $(4+1)$-dimensionality has no meaning or relevance, "whether or not it is physically realized."

Happily, our more radical approach has not yet exhausted all the insight to be gained from the Twoworld analogy. In the stories as commonly told, sphere-dwelling Twoworlders are able to deduce the curvature of their surface by empirical measurements. Even if the sphere is very large compared to the size of the occupants, cartographic expeditions can yield the fact that the interior angles of triangles laid out on the surface do not add up to 180°. This proves that the geometry of the surface is not Euclidean. Even so, Twoworld geometers who are satisfied with latitude and longitude may still insist that higher dimensions are unnecessary.

Now let's suppose that an expedition of Twoworld surveyors, whose plan was to travel as far as they could in one straight direction, returns to its starting point from the opposite direction. By traveling a perfectly "straight" line, spherical Twoworld can thus be *circumnavigated*. From this empirical evidence the extrinsic-minded Twoworld geometers establish a convincing case for the existence of a higher dimension. They argue that they have discovered a new direction, a direction besides latitude and longitude that their world curves into—that their world, indeed *curves back on itself* in a higher dimension. The Twoworld explorers call this direction *in-out*, which they *imagine* as existing perpendicular to their surface, even though they cannot directly see it.

As higher-dimensional creatures who are going along with the story, we salute the imaginative Twoworlders for their deduction. We can see that the $(3+1)$-dimensional deduction is correct, and imagine that on its basis, Twoworlders can continue to make other discoveries about their existence, about the fact that they are embedded in a higher dimensional space. A variety of things that had previously seemed magical or inexplicable—various influences impinging on their world from "above"—can now be explained in terms of the existence of a higher spatial dimension.

Impossible though Twoworld actually is, the analogy is nevertheless inspirational for its degree of coherence and applicability to our circumstance of living in a curved, seemingly $(3+1)$-dimensional world. Evidence of curvature in our world, as in theirs, should be taken as an indication that a higher spatial dimension is at least *possible*, and that the possibility ought to be explored further. If it pans out, it may lead to other unanticipated discoveries about our physical existence.

Especially noteworthy is the evidence that clinched the case on Twoworld, i.e., circumnavigation—traveling all the way *around* the continuum of their surface. The analogous circumstance for Threeworlders is clearly to probe our way *through* our volume, *through* the continuum of space we call home (or a scaled down version thereof). A thorough exploration of the Twoworlders' spherical *surface* revealed the existence of a new direction (in-out). By analogy, it is therefore reasonable to suspect that a comparably thorough exploration of the continuum of a spherical *volume* of matter, which is already known to exhibit spacetime curvature, might also exhibit a new direction beyond $(3+1)$ dimensions. Enormous efforts have been expended to explore *over* the surface of our spherical volume of matter. Is the analogy not beckoning us to at last explore *under* the surface, *inside* material bodies? Might not our inspection reveal the veritable engine that *generates* the curvature, the hyper-dimensional *motion* that explains *why* spherical planets form in the first place, and *why* spacetime is curved?

6˙5. *Motion* ***Through*** *Space vs. Motion* ***Of*** *Space*. – To wrap up our excursion into hyperdimensionality, we need to explore a fundamental consequence of the SGM that, for its unifying implications, is of potentially great importance. This will be made easier to grasp in what follows by further comparisons with GR and intermittent appeals to history. The idea comes into view by returning to the question of the minimum number of dimensions needed to assure that our construction is of physical, not just geometrical pedigree. If the world is $(3+1)$-dimensional, in accordance with the standard view of GR, then, as per Geroch's proclamation, "*nothing ever moves*." We cannot explain *why or how* spacetime curvature comes to be because, in effect, the foundational *principles* act as a restriction to further exploration. The question of what matter *does* to "generate the spacetime continuum," is not within the stated purview of the static, intrinsic geometry, within "*the* solution of the problem of gravitation," so it remains unasked. Feeling the urge to break out of this tiny box, having the strong desire to *explain* the real nature of gravitation, if possible, we infer that $(3+1)$-dimensionality is not sufficiently physical because it lacks a palpable cause of motion.

Bringing the rotation analogy back into the picture, we could perhaps envisage a rotating system as at least coming close to our requirement. Once set into a state of rotation, a body persists therein. The system would exhibit its motion by way of nonzero accelerometer readings, slowed clocks, and tangentially shortened rods. Beware again, however, of excessive abstraction. It is easy to draw circular arrows or write equations representing rotation. But the geometrical thing we've invented would surely *fly apart* as soon as it started to turn—were it not composed of *matter*. That property by which matter *coheres* to itself is imperative, as is the property by which *clocks tick*. These properties are closely related to each other. Evidently coherence (and clock ticking) must be achieved by some process whose action is directed from the inside out; i.e., a radially directed force. Furthermore, to persist as such without disintegration, the energy supply must evidently be inexhaustible. We will cover the rationale for this statement more fully in §13 – §20. For now it suffices to point out that, like rotation, the motion needed for coherence must be *stationary*; but unlike rotation, it cannot be tangential, and it cannot be merely motion *through* pre-existing space. Rather, according to the SGM, it must be the motion *of* space.

Let's step back to assess the meaning of this. The Universe is full of space. Like fish in water or birds in air, we usually don't notice. Our attention is drawn to things that *punctuate* space. Among the many properties of space—as discussed by Clarke, Liebniz, Mach, and countless other physicists and philosophers—is that the punctuating things (matter) rather easily move *through* space. Let's call this Spatial Property #1: *Space allows matter to move through it*. Importantly, space hardly resists until speeds approach c. And then (as always) it's not *uniform* motion that is resisted; it's *accelerated* motion.

We can identify, and need to expound on, three distinct kinds of accelerated motion. Two of them fall under the general category of motion *through* space: (1) *Linear acceleration*, as by rockets or muscles; and (2) *Rotational acceleration*, which is *stationary* when uniform. The third kind of acceleration is the most fundamental of the three, because it *provides* the space that makes (1) and (2) possible—that is: (3) *Gravitational acceleration*, which is produced only by matter. All three kinds of acceleration, as per the definition of acceleration, also result in a change in velocity. This is visually perceptible as such for (1) and (2), but is, in a sense, visually camouflaged for (3). Rocket propulsion is easily seen as changing the *linear speed* of motion through space. Rotational acceleration is easily seen as changing the *direction* of motion through space. Gravitational acceleration is commonly regarded as changing the speed of *falling* objects. But this is not a consistent explanation because, unlike our first two cases, the velocity change does not correspond to objects that yield non-zero accelerometer readings. By all accounts the pattern is disrupted. Gravitational acceleration is somehow exceptional.

Our new way of thinking is simply motivated by the logic that motion-sensing devices, accelerometers and clocks, are as truthful with regard to gravitational acceleration as they are with regard to rocket-propelled or rotational acceleration. It should be possible to conceive all three kinds of acceleration as *bona fide* acceleration only when accelerometers give non-zero readings. By introducing the idea of motion *of* space, as distinct from motion *through* space, in combination with a fourth dimension of space, we facilitate seeing change in gravitational velocity (acceleration) by reference to this fourth spatial dimension. Arrays of accelerometers exhibiting a range of *radial* acceleration remain coherent because the motion is *perpendicular* to our familiar $(3+1)$ spacetime dimensions. The hyper-dimensional account of non-uniform, yet stationary radial acceleration is thus analogous to ordinary rotational acceleration through space. Though not as easy to visualize, the perpendicular turning from $(3+1)$-dimensional spacetime to $(4+1)$-dimensional spacetime renders the changing velocity of gravitational acceleration consistent with acceleration due to rockets and rotation. Whether acceleration of space or through space, to qualify as acceleration means producing non-zero accelerometer readings. Devices to aid visualization of these ideas will be introduced as our exploration unfolds—especially in §9.

As suggested in §2 (pp. 9, 11 and Figure 6) what characterizes *stationary motion* is that an array of accelerometers and clocks indicate *constant* acceleration and *constantly* ticking at the same range of reduced frequencies. The constancy of clock rates indicates that for both kinds of stationary motion, the acceleration results in velocities whose *magnitudes* remain constant. Both systems can persist in these states indefinitely. That's why we call them stationary. In the case of rotation, the state can be completely neutralized, so it is sometimes regarded as *temporary*. Whereas, in the case of gravity, the state is subject only to reconfiguration, not neutralization. A ticking, gravitating body of matter (as with any of its component bodies) never stops generating space. Gravitational fields caused by matter are thus sometimes regarded as *permanent*.

In general, as in our experience on rotating, gravitating Earth, where we are often moving about the planet's surface, the acceleration we experience is a combination of the three types. They can be differentiated, one from the others, by empirical observations. Note that one solitary motion sensing device, e.g., an accelerometer, is not sufficient to make such a distinction. To disentangle motion through space from motion of space, an *array* of devices or a combination of different kinds of observations is needed.

Presently, our concern is to relate these kinds of motion to the dimensionality of space. The first two—at least seemingly—require only three dimensions of space. This is the identifying characteristic of motion through space: it is motion through what appears as pre-existing three dimensional space (as we often observe in our daily experience). By contrast, gravitational motion is more fundamental because it is identifiable as the $(4 + 1)$-dimensional process whereby *space is created*: generation of space by matter. Like rotation, this motion is stationary. What distinguishes it from stationary motion *through* space is that it is stationary in the *radial* direction (both acceleration and velocity). That's what makes it hyper-dimensional stationary motion *of* space. Matter is the only thing that makes this happen. If there were no matter, there'd be nothing to generate space, so there would not *be* any space.

Now let's consider the *electromagnetic properties* of space, as explored and conceived by Michael Faraday and as put into compact mathematical form by James C. Maxwell. These properties are diverse and wide-ranging, and we roughly refer to two of them as *coherence* and *clock ticking* (both of which, especially the latter, borrow somewhat from later developments in quantum theory). Though many other sub-properties may be identified, let's collect them all under one. That is, Spatial Property #2: *Everything electromagnetic*. As we recall, Property #1 comes with the qualifying characteristic of the limiting speed allowed by space, which exists *because of* its electromagnetic properties. Therefore Property #1 and Property #2 are not independent of each other. It is indeed arguable that virtually *all* properties of space are electromagnetic, especially if electromagnetism and gravity can be "unified."

It is well known that these electromagnetic properties have been comprehensively subsumed in both Hendrik A. Lorentz's *Theory of Electrons* and Einstein's *Special Theory of Relativity* (SR). It is also well known that, though these theories are empirically equivalent, Lorentz (being more in concert with Maxwell's views) conceived the space described thereby as having a *substantiality* that Einstein preferred to deny.

A few more historical remarks are in order before coming back to our questions of dimensionality. The *substantiality* of space was irrefutably established around 1800 when Young and Fresnel established the wave nature of light. All previously known instances of wave propagation indicated that, propagating as a wave requires a substantial *medium* such as solid, liquid, or gaseous bodies. The light medium, also known as the *ether*, was certainly unique for its evident *weightlessness*, but, by analogy, it was widely understood as being not the same thing as an utterly vacuous *nothingness*. Its properties, in fact, were eventually deduced as being those of a *rigid elastic fluid*.

It is important to realize that discovery of light's wave nature and its implied medium, had the profound implication of refuting Galilean relativity. It seemed, rather, that, just as solid, liquid, and gaseous bodies allowed finding a unique frame of reference with respect to which wave propagation was isotropic, the same should be true for the (presumed universal) light medium. Maxwell himself and most 19th century physicists regarded Maxwell's theory of electromagnetism as supporting the ether hypothesis. The ether was often regarded, in fact, as the embodiment of Newton's absolute space. Maxwell's theory is so broad in application that it also served as a preliminary basis for explaining the *coherence* of molecular matter by electric and magnetic forces. One of Maxwell's most famous results is his theory's prediction of the *finite speed* of light, which came to be recognized as a physical maximum (limit). In some contexts it becomes relevant also to contemplate the *stiffness* of space, whose high magnitude is widely acknowledged. Altogether, these various patently physical attributes bolster one's impression of the *substantiality* of space.

After attempts to find the Earth's speed though the ether failed to do so, and for other reasons, Einstein invented a theory (SR) according to which we would *never* find our speed through the ether. Einstein proposed, rather, that the ether should be regarded as non-existent. Lorentz disagreed. As noted above, Lorentz's theory made the same predictions as Einstein's. But Lorentz was never convinced by Einstein's arguments as to the ether's non-existence. Note that Einstein's interpretation corresponds to his cherished idea that all observers are entitled to think of themselves as being at rest. Whereas Lorentz's interpretation was that, though one's absolute speed through the ether was difficult (and maybe impossible) to discover, it was nevertheless physically real.

Given this history, it becomes clear that, by proposing that matter generates space, the SGM says that gravity and electromagnetism must be intimately related. The space produced by gravity includes the electromagnetic properties of the ether; a medium for light propagation and *continuity* with the forces (intermolecular and otherwise) of electricity and magnetism. A more mathematical basis for this "unification" will be presented in §12. A brief preview is presently in order. The analysis begins with the quantum theoretical equation from which it follows that all matter is clock-like. Combining this equation with a small number of simple SGM-based assumptions leads to a cosmological model that ultimately yields a definition of Newton's constant G. The definition involves five measured constants, from the realms of electromagnetism, nuclear, atomic, and cosmological physics. We find that G is proportional to the fundamental acceleration of volume per mass, $c^2 \mathrm{a}_0/m_\mathrm{e}$, where a_0 is the Bohr radius and m_e is the electron mass. The dimensionless coefficient is a ratio of saturation densities; one cosmological and the other nuclear, $8(\rho_\mu/\rho_\mathrm{N})$.

Neither in GR, nor in the whole rest of physics (until now, in the SGM) is there, nor has there ever been, any convincing way to relate G to the other constants. Finding that G is defined by these fundamental quantities, from nuclei to atoms to the cosmos, is strong support for the idea that the generation of space occurs essentially as described here; that gravity is indeed closely related to electromagnetism; that the space generated by matter is fully endowed with all known electromagnetic properties.

To a limited extent, GR accommodates electromagnetic properties. But it breaks down and ceases to accommodate them by treating gravitating bodies as static. The classic example is, in terms of GR's Schwarzschild solution, the case when the length $2GM/c^2$ equals the radial distance r, such that the temporal coefficient becomes zero and the spatial coefficient becomes infinite. When this happens (or soon thereafter) clocks stop ticking and light stops moving. This is a mathematical *black hole*. By contrast, in the SGM clocks never stop ticking and light never stops moving. *There are no black holes because gravitational stationary motion respects the electromagnetic speed limit.*

Returning to less extreme circumstances, we see more clearly now the connection between stationary motion and spacetime curvature. As suggested by Figure 6, the range of different speeds found on a body undergoing stationary motion causes clock rates (and rod lengths) to vary inhomogeneously; Euclidean geometry fails. In the case of gravity, the motion indicated by motion-sensing devices cannot be understood *as motion* if there are only $(3+1)$-dimensions of spacetime. If spacetime had been *proven* to be only $(3+1)$-dimensional, then it would not make sense to interpret the accelerometers in Figure 1 and 2 as telling the truth. For this would require the acceleration to be *through* space, which would mean the surface accelerometer would rise upward faster than the ones above it so as to overtake them, which is obvious nonsense. But in $(4+1)$-dimensional spacetime, even with a range of non-uniform radial accelerations, the system remains coherent. As the essential product and process of coherent matter, the fourth dimension of space is percieved not as a widening of the static stage of space, but *as gravity*, as the stationary acceleration (generation) *of* space.

This train of thought has exposed a variety of interdependencies (unifications). Because of the electromagnetic properties of space, to say that space depends on matter is to say that electromagnetism depends on gravity. They inextricably merge. Motion *through* space is made possible by the motion *of* space because motion of space is also the *creation* of space. Spacetime *curvature* is evidence that hyper-dimensional motion is taking place. Without this hyper-dimensional creation of curved spacetime, without gravity, there would be no space for anything to move *through*.

The deeper relationship between gravity and electromagnetism will be discussed later. For now it suffices to see the implication that the electromagnetic coherence of molecular matter goes with the electromagnetic properties of the "ether," with its limiting speed; and that this limiting speed is the reason non-uniform motion of space manifests itself as spacetime curvature. Empirical evidence and our analogies involving rotation and hyper-dimensionality evidently converge on the idea that we live in a *moving* $(4+1)$-dimensional space-*matter*-time continuum. This is what we get by simply remaining faithful to accelerometers. If we've come full circle more than once, it may be just as well. To sink in, new ideas require some repetition.

6˙6. *Hyper-dimensional Conclusions*. – In terms of static, geometrical hyper-dimensionality, a hypercube is an attempt to represent all four mutually perpendicular directions of space. In a strictly geometrical sense, each one is equivalent to the others. The visual apparatus of humans prohibits "seeing" all four dimensions at one time. But the image is also suggestive—with its nested cubes—of dimensional extension, not as a static pre-existing condition, but as a perpetually occurring *action* that clearly appears as some kind of *expansion*. The behavior of matter revealed by motion-sensing devices indicates a kind of perpetually nucleated structure of "hypercubical," bodies of matter such that locally, all directions are *not* equivalent. Instead we find a definite inhomogeneous *outwardness*.

This outwardness, this active perpendicular extension of all parts of three-dimensional space as a whole, cannot happen without matter, without electromagnetism, and it must not be regarded as expansion *through* pre-existing $(3+1)$-dimensional spacetime. Only on a cosmological scale does it make sense to regard the process as uniform. The local magnitude of the motion clearly depends on the distribution of matter, as we should expect in accordance with gravity's inverse-square law. The creation and distribution of space by matter is perhaps the most fundamental manifestation of this law.

The impression that matter is static has persisted for so long because we are immersed in and move along with the perpetual flow. The next two sections will provide more evidence that motion-sensing devices tell a deeper truth than that suggested by our primal visual impressions (of staticness). In §9 this evidence will be combined with our hyper-dimensional explorations to produce a graphic tool by which our visual sense regains some satisfaction. This will involve identifying a class of ideal but physically possible objects (*maximal geodesics*) that facilitate conceiving that we are always in motion. We will construct a visualizable model that helps to conceive motion as inhomogeneous while at the same time preserving material coherence. Helpful as such visual-conceptual tools may be, the most important—in fact essential—way to determine whether we are engaged only in far-out mental gymnastics or in deepening our understanding of the physical world, is to inspect the volumetric continuum through the center of a body of matter (Galileo's experiment).

Summarizing then, we see that the SGM treatment of higher dimensions bears very little resemblance to the stringbrane-graviton-inspired compactification scheme. The analogy with lower dimensional creatures helps to establish that *curvature in a given dimension indicates the existence of a higher dimension to curve into*. It illustrates the difference between the intrinsic and extrinsic perspectives. Without matter, without the electromagnetic properties of material coherence and a wave carrying medium, we have no physical reason to expect a point to move, nor a volume to exist. Empirical evidence suggests that the motion that causes spacetime curvature thereby brings space into existence at the same time. Our proposed mix of geometrical and physical dimensions thus implies that space, time, and matter are interdependent physical elements. They manifest themselves, via gravity, as the stationary motion of space, the generation of matter and space into or outfrom the fourth spatial dimension, without which none of the others would exist.

7. – Equivalence Principle: True or False?

> *Men occasionally stumble over the truth, but most of them pick themselves up and hurry off as if nothing ever happened.* — SIR WINSTON CHURCHILL [69]
>
> *The truth knocks on the door and you say, "Go away, I'm looking for the truth," and so it goes away. Puzzling.* — ROBERT M. PERSIG [70]
>
> *The illusion which exalts us is dearer to us than ten thousand truths.* — ALEKSANDR PUSHKIN [71]

Having not yet conducted Galileo's experiment, we do not yet know the truth of the dimensional analysis given above—whether $(3 + 1)$-dimensional spacetime is curved but static, or its curvature is due to its motion into a higher dimension. What is readily apparent, however, is that if the combination {stationary motion : spacetime curvature : $(4+1)$-dimensionality} corresponds to physical reality, then we will have fulfilled Einstein's Machian requirement that the "spacetime continuum is possible [only because of the] matter that generates it."

Turning now to another one of Einstein's three principles upon which GR is based, we will find once again that it makes more sense from the SGM perspective than it does within the context of GR. The same paper in which Einstein lists Mach's Principle as the third of his foundational principles, he lists the Equivalence Principle (EP) as the second: "Inertia and gravity are phenomena identical in nature." [72] Momentarily we will point out a couple things that make this statement, from the standard static perspective, too sweeping, too grandiose. First, however, let's consider another of Einstein's enunciations of the principle, wherein he mentions a patently valid empirical basis for it. In a 1940 *Science* article, Einstein wrote:

> The inertia and the weight of a body, in themselves two entirely distinct things, are measured by one and the same constant, the mass. From this correspondence follows that it is impossible to discover by experiment whether a given system of coordinates is accelerated, or whether its motion is straight and uniform and the observed effects are due to a gravitational field (this is the equivalence principle of the general relativity theory). [73]

Einstein's EP has sometimes been criticised by otherwise conventional physicists. The most poignant of these objections may be that of John L. Synge, who wrote:

> Does [the EP] mean that the effects of a gravitational field are indistinguishible from the effects of an observer's acceleration? If so it is false. In Einstein's theory, either there is a gravitational field or there is none... This is an absolute property... The Principle of Equivalence performed the essential office of midwife at the birth of general relativity... I suggest that the midwife be now buried with appropriate honours and the facts of absolute space-time faced. [74]

From the SGM perspective Synge's objections do not go far enough, but they do establish more evidence that a mathematical theory—which Synge has no objection to—may stand far apart from its conceptual "principled" foundation.

Before considering examples in support of Synge's claim that the EP is evidently "false" (if we take Einstein's statement of it to mean what it says), it is good to bear in mind that the equivalence of those two physical phenomena that Einstein claimed to be identical, is not known for a *fact* to be so. W. Klein and P. Mittelstaedt thus point out:

> The proportionality of inertial and gravitational mass is left unexplained, even in the general theory of relativity, wherein it appears as a hypothesis. [75]

It may well be a good guess that these two different manifestations of mass are equivalent. But if we don't know the physical reason *why* they are equivalent, then it is good to remember that it is still only a guess. We'll come back to this point in what follows.

Presently, let's consider the examples of support for Synge's objection. The quoted statement of the EP is consistent with Einstein's earlier claim of the right rotating observers have to regard themselves as being *at rest* in a gravitational field. Uniform rotation is an example of an accelerated coordinate system, so Einstein clearly intends to include it as falling under the dictates of his principle. The gist of Einstein's EP is that a static gravitational field can always be blamed for effects that hide the supposedly preferred alternative "reality" of one's actually being in a state of rest or uniform motion. Einstein could always convince himself that he was himself *at rest*. It is for this purpose that he invented the General *Principle* of Relativity.

If a rotating observer intends to regard his own motion as being "straight and uniform," as noted earlier, this requires him to regard the whole rest of the Universe as rotating around him. Though this was acceptable to Einstein, simple arguments put forth by Newton in response to essentially the same idea suggest that it was little more than common sense that motivated him to dismiss it as "too incongruous" and "yet more absurd." [76] We agree with Synge's implication that concocting such an absurd, incongruous "gravitational field" to explain rotation, is much less sensible than facing

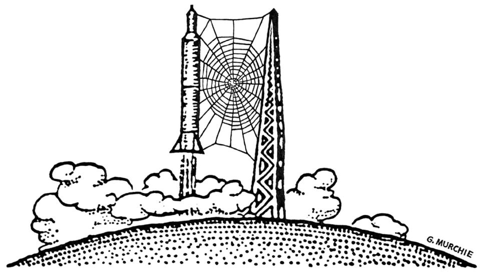

Fig. 14. – Einstein's Equivalence Principle has evoked a variety of statements to the effect that our experience of gravity on Earth is that "it is the ground which is accelerating upwards, as if powered by a million rockets." [77] The best way to find out whether this picturesque account of our experience contains any truth is to *ask Nature*—to probe the insides of material bodies. (Galileo's experiment.) Illustration from Guy Murchie's, *Music of the Spheres*. [78]

the fact of rotational absoluteness. Ironically, whatever truth may lie in the EP, it is put further from reach by some of Einstein's arguments for it.

The next example concerns rotation-free acceleration, as suggested by the rocket in Figure 14. It is not hard to imagine "discovering by experiment" whether the rocket is hovering over a large body like Earth or not. If Earth were not there, then the rocket would accelerate through the Universe. In this case onboard observers would experience ever more blueshifted light from sources in its direction of motion and ever more redshifted light from the opposite direction. Whereas, in the case that Earth is there, whether the rocket is burning fuel to hover, or is being supported by the launchpad below, the light from distant sources would not change. The acceleration does not have the effect of increasing the speed of the rocket through the Universe. This is just one of several ways to empirically distinguish whether the rocket is accelerating far from large gravitating bodies or immediately over one. In Einstein's words, it is one of various ways of "discover[ing] by experiment whether a given system of coordinates is accelerated, or whether its motion is straight and uniform and the observed effects are due to a gravitational field." It thus appears that Einstein is saying that the *obvious* is "impossible." By referring to the idea as a *principle*, Einstein is emphatic that we might just as well regard the motion of the blasting rocket and the gravitating (blasting?) planet as "straight and uniform," i.e., at rest; and that we cannot tell which is which.

Our main objection to Einstein's characterization of this circumstance is, as before, that he insists that both of them may be regarded as *static*. This is what identifying inertia with gravity means to Einstein. Since one case (gravity) is "obviously" static, and some of the effects of rocket propulsion are the same, a rocket hurtling through space must also be at rest. Einstein thus appeals to the EP to create a kind of staticness-acceleration *fog*. Within this fog we may have a clue as to the equal falling of all bodies, but we are left clueless as to how to conceive that gravity and inertia are "phenomena identical in nature." How is a body's resistance to acceleration the same thing as its gravitational attraction?

In the context of GR one searches in vain for a direct answer to this question. Much easier to find are instances of Einstein's waxing philosophical about the difference between "constructive" theories and "principle" theories. Being an example of a principle theory (with the EP as one of its principles) GR supposedly has the advantage of "logical perfection and security of [its] foundations." [79] When reading such advertisements it is good to remember that GR does not tell us "how the central mass produces the gravitational field." Einstein has no idea what physical process causes spacetime curvature. He claims the impossibility of distinguishing between two phenomena that are actually quite easy to distinguish (rocket or planet). So by what stretch of the imagination is such a scheme "logically perfect?" Are its foundations really "secure" if, when we look for them, we find such an abundance of fog and contradiction?

The main reason we do not find this kind of simple critique in the literature, I suppose, is the unarguable empirical success of the theory. Since the final product is so impressive, most physicists either excuse Einstein for his questionable marketing tactics or simply never discern them as such, and so pay no attention to them.

I think it is possible to clear away the fog of Einstein's EP, first of all, by disallowing any association between acceleration, on one hand, and rest and staticness on the other hand. This amounts to simply trusting accelerometers to tell the truth. The empirically supported part of the EP is thus retained: i.e., the equal falling of all bodies. It is explained not by the *relativity* of acceleration, but by the *absoluteness* of acceleration. That is, we propose to identify the mechanism that explains why it should always be true. Our second fog-clearing agent is to emphasize the gross *in*equivalence (as pointed out by Synge) between gravity, on one hand, and rotation or rocket-like propulsion, on the other hand. It is crucial to make this physical distinction because, according to the SGM, it represents the difference between the acceleration *of* space and acceleration *through* space.

Finally, a comment is in order as to why Einstein would maintain his stated stance on the EP when that aspect of it that was objected to by Synge seems so easy to refute. This subject has been widely discussed in the literature. The only semblance of a viable defense (that I still think is inadequate, however) has to do with qualifications that Einstein and others sometimes add to their statements of the principle. The qualifications assert that the EP is only *locally* valid. This is often taken to mean, for example, that observers are not allowed to look out of the windows of their laboratories (or rockets). However much this and other qualifications may add to the EP's plausibility, and however well supported the principle is by certain kinds of experiments, the issue that we take with it—which has never been adequately defended—is how *resistance to acceleration* (inertia) can be identical with *gravitational attraction*. Einstein said they are "identical in nature." How exactly is that?

8. – Gravity = Inertia: How Can it Be?

From the GR point of view, if "inertia and gravity are phenomena identical in nature," then how are we to understand that *resistance to acceleration* (the definition of inertia) is the same thing as *attraction between massive bodies* (the definition of gravity)? The most celebrated empirical fact that supports the EP is the equal falling of all bodies, regardless of weight or composition. As noted above, nobody has ever explained *why* this aspect of the principle rings true. In fact, according to some theories of quantum gravity it is expected that ultimately the principle is not true. If it were truly understood (and unequivocally demonstrated empirically) *why* all bodies fall the same way, then all theories that say they don't would be proved false. The existence of theories that violate this aspect of the EP is thus a strong indication of continued confusion. Sometimes this is even acknowledged, as it is in Elias Okon's paper, "On the Status of the Equivalence Principle in Quantum Gravity":

> It is the opinion of at least a sector of the fundamental theoretical physics community that such field is going through a period of profound confusion. The claim is that we are living in an era characterized by disagreement about the meaning and nature of basic concepts like time, space, matter and causality, resulting in the absence of a general coherent picture of the physical world. [80]

Okon's paper is a brief review of the situation. An example of a specific theory that violates the EP is the recent paper by Subir Ghosh. [81]

Curiously, the explanation as to how the inertia and the gravity of a material body can be conceived of, and even proven to be identical, is evidently within reach. Clues abound. From the SGM perspective, we regard the silver lining in the fog-shrouded literature on the EP as its many pronouncements that we suspect represent stumblings over the truth, just prior to its being told to go away. A few examples of that fleeting encounter are gathered below:

> If we insist on maintaining that we are [at rest], we have to *invent* this distinctly odd force [gravitational attraction] to explain what we observe about things falling...It looks as if there may be *some* sense in saying that the force of gravity is an illusion that arises because we deny being accelerated when we really are...The simplest interpretation of what we observe would be to say that *we* are accelerated. — SAM LILLEY [82]

> Einstein's view of gravity is that things don't fall; the floor comes up! That easily explains why heavy objects don't fall faster than light objects. But don't take it too literally, because if the floor is coming up in both New Orleans and Calcutta, the earth's diameter could not remain 8000 miles. — LEWIS C. EPSTEIN [83]

> Although the apple is regardable as accelerating downward, can one...could one possibly justify a claim that the earth is accelerating upward just as much...If the Earth's surface is accelerating upward all around the earth, the earth as a whole must be exploding. Which it obviously is not. — GUY MURCHIE [84]

> Einstein proposed something very bold. Gravity was nothing more than an accelerated frame of reference.
>
> But if gravity and accelerated motion were the same, then gravity was nothing but accelerated motion. Earth's surface was simply accelerating upward.
>
> Still one must ask how Earth's surface could be accelerating upward...if Earth itself is not getting bigger and bigger with time like a balloon. The only way the assertion could make sense is by considering spacetime to be curved. — J. RICHARD GOTT III [85]

Gott's final comment attempts to reconcile the contradictory concepts of staticness and acceleration by appealing to curvature. Allowing curvature does not, however, eliminate the contradiction. A non-zero accelerometer reading doesn't come with an explanation as to whether the surrounding space is curved or not. The device says only "I accelerate," or "I do not accelerate." It is up to the obsever to deduce from additional observations how much of the acceleration is due to motion through space and how much is due to motion of space (gravity). Volumetric spacetime curvature is produced only by gravitating matter, not by accelerating *through* space. In any case, curvature does not explain how a static body is also accelerating. Curvature does not resolve the contradiction because *in the context of GR there is no explanation of what happens to make spacetime curve*. Therefore, curvature doesn't lessen the mystery, it *adds* to it.

To the unknown of positive accelerometer readings produced by supposedly static matter we add the unknown of spacetime curvature produced by supposedly static matter. The sum is not *zero* unknowns; it is *two* unknowns. Perhaps *adding* unknowns is the wrong operation. If one of them is supposed to *depend* on the other, then the operation may be more like *multiplication* of two unknowns. The floor comes up. The floor is static. The floor is curved. The static curved floor comes up. Faced with these assertions, we have two choices: Either (1) we continue trying to convince ourselves that they are logically consistent with one another and it all "makes sense" now. Or (2) we realize that the word *static* does not belong here. We suspect he word *static* to be the source of confusion, because it arguably contradicts the physical facts.

Even though general relativists often say they do believe accelerometers, the overriding conception of staticness indicates that deep down, they really don't. The absolute spacetime that Synge thought needed to be faced was absolutely *static* (as in the Schwarzschild solution) not absolutely accelerating. General relativists don't resolve the contradiction, they pretend it doesn't exist. By trusting accelerometers, in the SGM we have no contradictions.

The possibility of conceiving a simple, intuitive way of seeing how the inertia and the gravity of a material body are the same thing requires denying staticness and believing accelerometers. The idea that follows bears also on another facet of Mach's Principle, often referred to as the *origin of inertia*. It also bears on the messy problem in modern physics of where particles "get" their mass. The problem is messy in standard physics because the source of mass is supposedly not the same for all forms of matter. Bearing in mind *Newton's Rules of Reasoning* (p. 20) and how simple the *effects* of mass are, the spirit of simplicity is not happy with the "pomp" of the standard model's multiplicity of superfluous causes.

Be that as it may, we now ask the simple question, "what must a body of matter *do* to manifest the properties of mass?" To avoid some complications that we will address later, let's neglect effects at orders higher than the first in $1/c$. By this restriction we enable seeing the first order manifestation of inertial and gravitational mass in pristine starkness.(3) As noted by Einstein, the properties of mass are twofold: resisting acceleration (inertia) and causing weight (gravity). If the inertia and gravity of a material body are the same thing, then what they do to manifest these properties must also be the same. If we don't know how matter generates the field (as in GR) then we cannot possibly know whether the mechanism of gravity is really identical to the mechanism of inertia. Though GR proposes the causes to be the same, it does not explain why or what they are. The SGM does.

The SGM explanation accounts for both inertial and gravitational properties in terms of the *generation of space*. Inertia is resistance to deviation from uniform motion; i.e., *resistance to linear acceleration*. Gravity (according to the SGM) is the accelerated generation of space; i.e., the *manifestation of volumetric acceleration*. To impart a given linear acceleration to a material body requires a force that is proportional to the rate at which the body generates space. A body's *resistance* to acceleration in one direction *through* space is the same thing as *acceleration itself* in every direction *of* space.

That's it. The cause of the gravity of a material body is also the cause of its inertia. There's no reason to expect this "origin of inertia" to be any different for any form of

(3) Inertial and gravitational mass become more complicated when subtle effects of gravitational *energy* and other forms of energy come into play. These complications will be discussed in §17.

matter. The origin of inertia is the origin of gravity. They both come from inside any body of matter. The equal falling of all bodies is explainable by the demonstrable truth of the idea that "the floor comes up." Galileo's experiment can provide the needed demonstration.

9. – Spacetime Graphs, Tubular Models, and Maximal Geodesics

Einstein's theories of relativity, both Special and General, are often presented with the aid of a graphic device known as a *spacetime diagram*. In the context of Special Relativity this is often referred to as a *Minkowski diagram*. Before we make use of a similar diagram, note that the particular path that we've taken in discussing the foundations of physics has left some chronological gaps. Though we've mentioned a few of the developments and concerns that led up to SR, we will postpone a more detailed account of its history and the theory itself, so that other concerns may be addressed first. Our path is thus a conscious choice: The problems of Newtonian space and Euclidean geometry sprung us nearly clear over Maxwell and SR to Mach's Principle and Einstein's theory of gravity. Later we'll return to fill the gaps.

Presently, let us bring in from this later discussion one of the devices used in SR to inspire a new graphic tool by which the hyper-dimensionality of the SGM can be visualized. These diagrams are used to track the temporal evolution of points (e.g., clock-bearing observers) on a graph whose vertical axis is *coordinate time* and whose horizontal axis is motion through space, which means motion in any direction through the Cartesian coordinate grid. It is common to find problems involving motion along only one spatial direction, such as the Cartesian coordinate x. The units are typically chosen so that a 45° angle corresponds to a light ray. (See Figure 15.)

In his marvelous book, *Relativity Visualized*, Lewis C. Epstein has modified the usual graph by making the vertical axis *proper time* instead of coordinate time. [86] As Epstein explains, and as shown in Figure 16, his graph is a 90° *projection* of the usual Minkowski

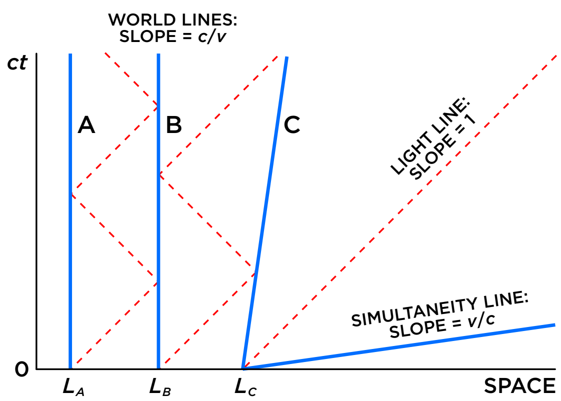

Fig. 15. – Basic Minkowski or spacetime diagram. Observers A and B are at rest with respect to each other and the coordinate origin. Their world lines indicate "travelling" only in time. They are exchanging light signals with each other as represented by the dashed diagonal (45°) lines. The world line of Observer C indicates moving away from A, B, and the origin in any direction of space. C is exchanging light signals with B. The significance of the simultaneity line of C will be discussed later.

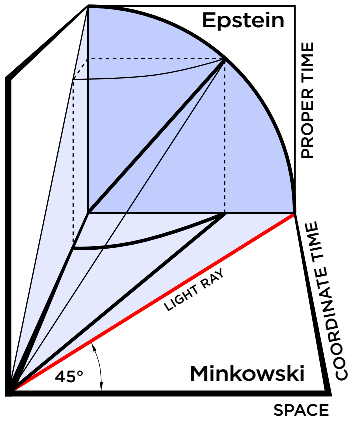

Fig. 16. – Epstein's space/proper time diagram is related to the more common Minkowski diagram as a 90° projection, as shown. Each version has its advantages, a few of which will be discussed in the text.

diagram, that puts light speed on its own axis instead of being a 45° line. Epstein's graph has the intuitively appealing feature that a circular arc from the origin of the diagram can be thought of as encompassing a range of speeds, like a speedometer, from zero (straight up) to the speed of light (horizontal). (See Figure 17.) The total speed can be vectorially decomposed into speed through space (horizontal) and speed through time (vertical).

One of the advantages of this diagram is that, by curling the time axis around itself

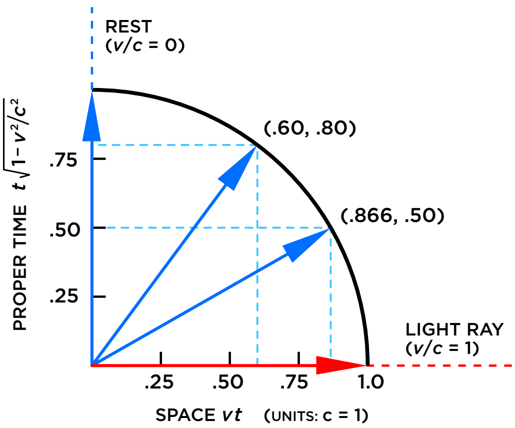

Fig. 17. – Space/proper time diagram, as per Epstein. Each blue arrow represents a different clock-bearing observer traveling at different speeds. Clearly illustrated is the Pythagorean relationship between spatial speed (component of motion along the horizontal axis) and proper time (component of motion up the vertical axis). Material bodies can never reach the speed of light, which means, among other things, that however slowly their clocks may tick, they never stop. Light, on the other hand (red arrow) does not travel through time at all, so is in a sense, timeless.

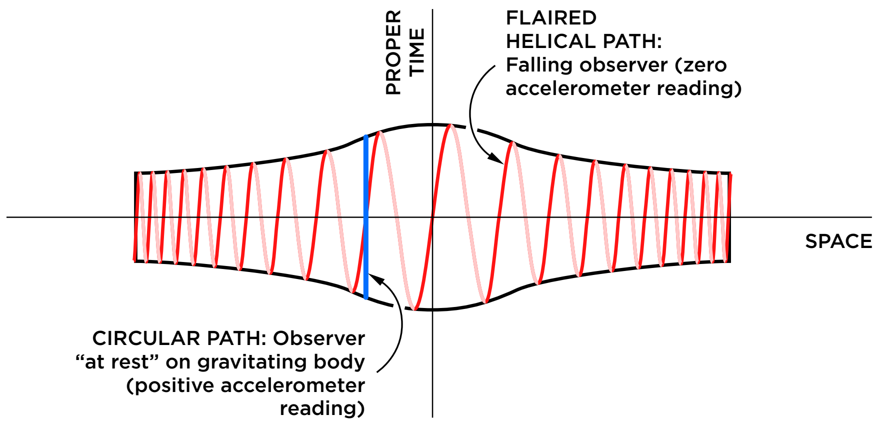

Fig. 18. – Epstein space/proper time gravity tube diagram. The horizontal component of the helical path represents motion through space; i.e., radial falling. The circumferential component of the helical path represents motion through time. The greater the projected pitch angle of the helix onto the central axis, the greater the spatial speed and the slower the clock rate (smaller proper time per given coordinate time). Such diagrams are understood as extensions of the limited, flat space/proper time diagram of Figure 17 into regions where spacetime is curved. They may accurately and insightfully represent the falling motion and corresponding clock rate according to GR. Key consequences of the model have not, however, been tested: especially *inside* matter.

we get a tubular diagram that can be used to represent motion near a gravitating body. Starting with the absence of any large gravitating bodies—i.e., *flat* spacetime—the diagram for a given observer would be an essentially perfect cylindrical tube. To prevent repetitive loops in time, the tube should be thought of as a multitude of infinitesimally separated layers. The observer's path up the diagram, for increasing values of time would be either a circle, which represents zero speed through space, or a helix of increasing pitch, for increasing speeds. For material bodies this speed never reaches the speed of light. Only light itself travels exclusively on the spatial axis—which means it does not travel through time at all. This latter fact will be instrumental in later discussions of cosmology and other things.

The mass of a planet or star affects the tube by giving it a circular bulge that gradually flares back to a nearly perfect cylinder at great distances from the mass. What used to be a virtually circular motion around the tube (for an observer at rest) because of gravity, now becomes a helix of gradually increasing pitch as it approaches the massive bulge. This is shown in Figure 18. Similar models have also been devised by Rickard M. Johnsson. [87] An accelerometer attached to the massive body, as represented by a circular cross-section of the tube, is regarded as being "at rest"; it gives a positive reading. Whereas an accelerometer falling in the field is represented by the line drawn around the tube (geodesic); it gives a zero reading. GR-based tubular diagrams reflect the staticness of gravitational fields by not moving. For no known reason (beyond the assumption that time advances) falling observers move along the tubes' surfaces.

The SGM adaptation of the idea is shown in Figure 19. The key difference is that the motion is represented not as falling bodies around the surface of a static tube—as motion *through* pre-existing space; but as the stationary motion *of* the tube—as motion *of* newly generated space. This is accomplished by regarding the tube as turning with respect to the radial axis. The vertical axis units and the shape of the tube are not the same as in the GR version. The shape is *somewhat* different for the exterior field, and *drastically* different for the interior. Rotational motion of the tube's outer contour (graph profile) represents the maximum speed that the central gravitating body can produce at any given radial distance.

The following ideas apply to both weak and strong fields, but the given quantities

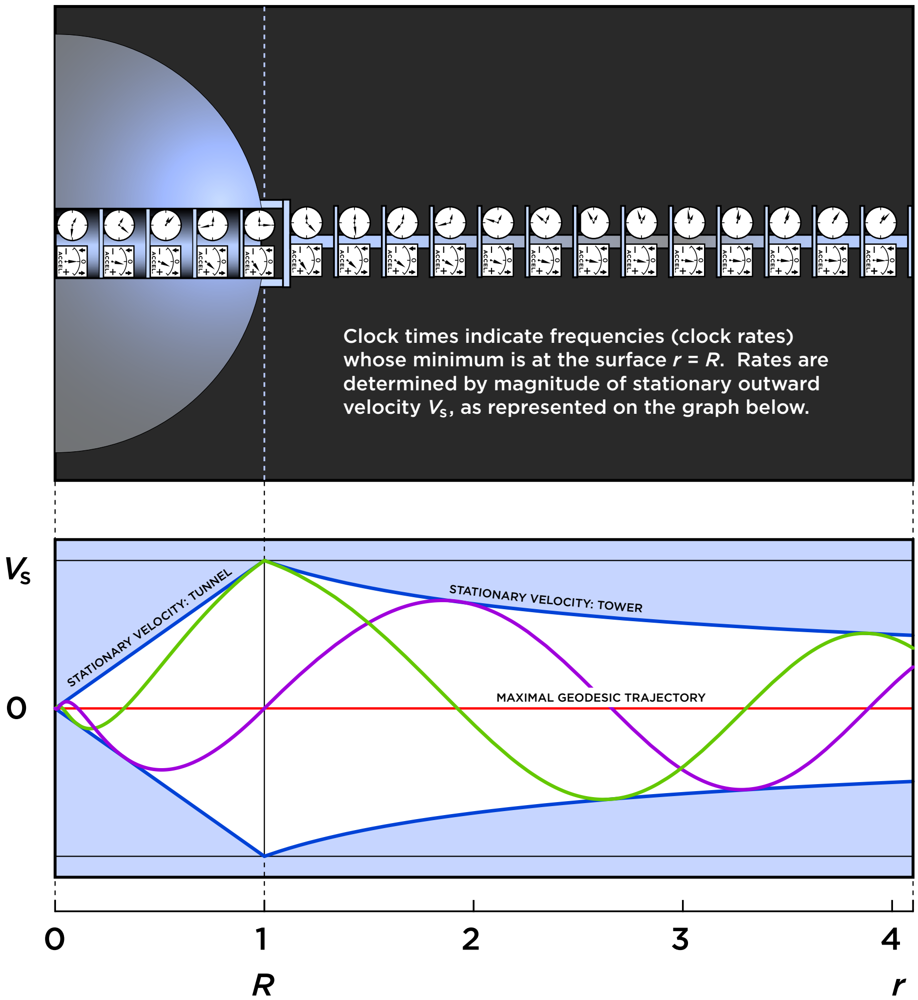

Fig. 19. – SGM tubular model of hyper-dimensional radial stationary motion. Top: Physical circumstance represented in graph below; i.e., a gravitating body and an imaginary tower attached to its surface. Bottom: V_S–axis represents stationary outward velocity; i.e., the stationary motion *of* space—into or outfrom a fourth spatial dimension. Cross-section is to be regarded as rotation of the graph around the r-axis. Helices drawn on the tube at 45° to the axis facilitate visualizing the falling motion of maximal geodesics. (See text.)

will be the approximation for weak fields. From our discussion of the rotation analogy, we recall that this speed outside the body is given by $V_{\text{EX}} = \sqrt{2GM/r}$. If the spherical body is of uniform density then the speed decreases linearly to zero at the center, i.e., $V_{\text{IN}} = (r/R)\sqrt{2GM/R}$, where R is the surface radius $r = R$. Whether inside or outside, when referring generically to *stationary outward velocity*, it will be denoted V_{S}. Recall that these velocities are empirically verifiable *as* velocities by their observed effect on the rates of stationary clocks. The relationship between curvature and dimensionality suggests that the velocities indicate the stationary motion *of* space.

To make the idea more concrete, imagine one of the towers from Figure 1 extending many bodily diameters into space—or all the way "to infinity." The idea is shown at the top of Figure 19. Clocks attached to the tower are slowed down according to the magnitude of V_{S}, as we recall from Figures 3 and 4. The equation for the clock rate as a function of radius is

$$f(r) = \frac{f_0}{\sqrt{1 + \frac{V_{\text{S}}^2}{c^2}}} = \frac{f_0}{\sqrt{1 + \frac{2GM}{rc^2}}}, \tag{3}$$

where f_0 is the rate of a clock at infinity. By the rotation analogy, and our literal interpretation of motion-sensing devices, it follows that clocks at infinity, at the axis, or *falling from* infinity all have the same maximum rate. These states all correspond to a kind of inhomogeneous "preferred frame"; all of its members are on trajectories that we will call *maximal geodesics*.

NOTE: The argument of the coefficient in Equation 3 is $1/\sqrt{1 + 2GM/rc^2}$ instead of $\sqrt{1 - 2GM/rc^2}$ for reasons that will be explained later. For now, note that a closer resemblance to the standard form can be obtained by use of the equality

$$1/\sqrt{1 + \frac{2GM}{rc^2}} = \sqrt{1 - \frac{2GM}{(r + 2GM/c^2)c^2}} = \sqrt{1 - \frac{2GM}{(2GM + rc^2)}}. \tag{4}$$

The difference arises because in the SGM the argument of the coefficient reflects the need to obey the speed limit c. When the argument is subtracted from unity, the quantity within the square root in the right side expressions can never become zero, which means clocks never stop ticking.

The outer envelope of our spinning graph represents a state of being fixed to the tower (or tunnel for $r < R$). A state of zero velocity (maximal geodesic) corresponds to any location on the radial axis. Even though objects falling from infinity appear to have a (negative) speed toward the massive body's center, bear in mind that the whole purpose of the diagram is to represent positive, outward motion as being consistent with our visual impression that falling objects seem to fall "downward." What's actually happening—what the diagram helps to visualize—is that the tube's rotation represents outward motion of the tunneled mass and tower. The graphic image coheres and appears stationary just as our experience on Earth. Thinking of the tube's rotation as being motion into or outfrom the fourth dimension of space facilitates perceiving the difference between *stationary* and *static*. Our experience on Earth is not static, it's stationary. Downward radial falling appears to be toward the origin, but it is more accurate to think of this as the motion of space past the falling objects, than as the falling objects moving through space.

This description bears on our answer to the questions posed in connection with Figure 8. (See Appendix A.) If one is not yet completely satisfied with the description or the graph, it may help to empathize with our mythical Twoworlders. We are like them insofar as they never get to *directly see* the higher dimension they are embedded in; i.e., to see their surface as a three-dimensional sphere. But they *deduce* and *imagine* its existence as such by exploring the surface's geometrical properties.

We have a decided advantage over our lower dimensional colleagues because our world is endowed with matter, and because of the resulting logical association between hyper-dimensionality and *motion*. To see this more clearly, suppose our large massive body is "pierced with hole through its center." Suppose a small rocket is "hovering" at one end of the hole. If the rocket engine is suddenly turned off, then by what magic could it possibly reach the opposite side? According to the SGM getting to the other side cannot happen by mere radial falling because nothing ever forces the rocket downward. A source of propulsion would be needed. If the unpropelled fall does not get the test object farther than the center, then we can know that there is no such thing as gravitational attraction; that instead, the source mass is perpetually generating space into or outfrom a higher dimension.

A maximal geodesic is like a rocket that starts from rest at infinity but whose engine is *never* turned on. Its accelerometer reading *never* deviates from zero. Since a maximal geodesic accelerometer gives a perpetually zero reading, corresponding to perpetually *zero speed*, it follows that maximal geodesic clocks also have maximum rates. Whereas accelerometers attached to the tower give constant positive readings and clocks on the tower are all slowed by their absolute velocity with respect to the maximal geodesics. As will be discussed in more detail in §21 – §XX, maximum clock rates also correspond to a state wherein light propagates isotropically at the speed c. Whereas the absolute velocity indicated by the tower clocks means that light propagation with respect to the tower is *an*isotropic (slower upward, faster downward). Note that this approach follows closely the analogy with rotation. Maximal geodesics are analogous to the rotation axis.

Having covered the basic logic of maximal geodesics, note that our tubular graph can be easily scaled to tie the inverse-square law into the picture. When the helices on the envelope of the tube are drawn so that their projected angle onto the horizontal axis is everywhere $45°$, then spinning the tube results in a speed of any helix-axis intersection being equal to the rotational speed of the envelope. This means that if we follow one such intersection (think of a point that seems to move along the length of a spinning barber pole) as it moves along the axis, its apparent radial speed changes constantly according to the inverse-square law.

Our graph represents the most important extreme case of radial falling. Similar figures can be drawn to represent falling from finite distances to the center. Note that when the intersection point crosses the surface $r = R$ (from outside to inside) the acceleration is no longer toward the center, but toward the *surface*. This may *appear* as a repulsion from the center. But it is important to realize that there is neither repulsion nor attraction. There is only generation of space. Consider again falling from the surface, as suggested by the above example of the initially hovering rocket. The hovering rocket's initial state is not that of zero velocity but of the stationary outward velocity of the surface. In terms of the graph in Figure 19, such a trajectory would start at the outer envelope, which it rapidly peels away from. An apparent maximum downward speed is reached about $1/3$ of the way in; and then the falling object asymptotically approaches the origin. The object thus approaches the maximal geodesic trajectory near the center. In the more conventional manner of graphing motion, the trajectory of this fall from the surface has been shown in Figure 5 (p. 8).

Consider again the dual purpose of the vertical axis. It represents not only the stationary outward velocity of points of our extended tower, it also represents the extension of $(3 + 1)$-dimensional space into the higher space of $(4 + 1)$ dimensions. Ideally speaking, all bodies of matter everywhere in the Universe would be represented by a similar kind of diagram, where the spin rate is determined by the Hubble constant (which is related to G and other constants, as we'll see later). To include strong-field behavior, a comprehensive version of the graph would represent the speed c as an unreachable limit.

Consider the case of rotation such as we experience or witness everyday. This is motion *through* pre-existing space; if the rotation is uniform, it is stationary motion through space. Thanks to the coherence of matter, we can easily see how parts of a seemingly rigid body can have a range of different *tangential* speeds and (radial) accelerations without flying apart. With the aid of our diagram, gravitational stationary motion can be similarly conceived. The inhomogeneous *radial* velocities and accelerations of a seemingly rigid body can now be seen as possible without disintegration because the motion is into the fourth spatial dimension. We now conceive the underside-flattening motion that we experience every day as a kind of "rotation" from $(3 + 1)$-dimensional spacetime into $(4 + 1)$-dimensional spacetime, as the motion not through but *of* space. Accelerometers and clocks reveal a wide range of accelerations and velocities due to gravity. In terms of our diagram, every gravitating body is nevertheless spinning at the same hyper-dimensional rotation rate, whose range and local magnitudes of the absolute radial speed V_S depend on the density distribution of matter.

10. – Energy Conservation: First Look

> The principle question I am left with myself is: Have we perhaps been unable to formulate the prime illuminating question? — JAN H. OORT [88]

What has been described above is in dramatic conflict with the idea of the conservation of energy. But the only place where a dramatic conflict is predicted to be found *empirically* is near the centers of gravitating bodies (Galileo's experiment). Perhaps the most important way of seeing this is in terms of spacetime curvature. This essay began with a discussion about how closely the SGM comes to matching the predictions of GR, especially with regard to clock rates outside matter. It is well known that the deviation of the coefficients of radial distance r and time t from unity in the Schwarzschild solution correspond, for weak fields, to the predictions of Newtonian gravity; and that the coefficient for the time coordinate is by far the more dominant one with regard to observable effects. Small deviations from temporal flatness correspond to readily perceptible gravitational motions. Since the SGM's predictions for spacetime curvature agree so closely with GR for exterior fields, the various behaviors in Newtonian gravity in which energy seems to be conserved are thus also predicted by the SGM.

Referring back to Figures 3 and 4, we see the dramatic disagreement between GR and the SGM (for weak fields) only *inside* matter. This is where we are sorely in need of empirical data. In the coming sections much will be said about how Quantum Theory provides many hints not only that energy may not be conserved, but that the Universe of both matter and space appear to be endowed with an *infinite* reservoir of energy. This is exactly what must be the case if a seemingly "resting" accelerometer on the surface of a gravitating body is to perpetually give the same positive reading.

The perpetual increase of energy appears to manifest itself in an observable way only in the context of gravity. Energy conservation has rightly earned its revered status in the context of thermodynamics, electromagnetism, Newtonian mechanics and elementary particle theory. All of these fields of study have evolved without any investigation into gravity-induced motions inside matter.

Furthermore, we have already seen that the foundational assumption of the SGM, i.e., trust in the readings of motion-sensing devices, has facilitated the plausible reinstatement of that facet of Mach's Principle involving the interdependence of matter and space. It has facilitated a much more lucid explanation for the identification of the inertia and the gravity of material bodies (EP). And it explains the mechanism by which "matter generates the spacetime continuum." That is, it explains what matter *does* to cause the curvature of spacetime. It does this by making a concrete connection between the curvature and the dimensionality of spacetime.

For all these reasons, we may see the SGM's violation of energy conservation as a possibly very good thing, because it may ultimately turn out that Nature does not conserve energy. Far from it (perhaps); Nature's energy may be an endless fountain whose perpetual flow is what so reliably provides our inertia and flattens our undersides. On that note, we turn now to see how the emerging Space Generation Model fosters a new perspective on the Universe as a whole.

11. – Cosmological Theories, Ideas, and Observations

> What is gravity?... What is inertia?... Is our much-exalted axiom of the constancy of mass an illusion based on the limited experience of our immediate surroundings?... How are we to prove that what we call matter is not an endless stream, constantly renewing itself and pushing forward the boundaries of our universe? [89] — ARTHUR SCHUSTER, 1898

> To my mind there must be, at the bottom of it all, not an equation, but an utterly simple idea. And to me that idea, when we finally discover it, will be so compelling, so inevitable, so beautiful, that we will say to one another, how could it have been otherwise? [90] — JOHN ARCHIBALD WHEELER

By jumping from Newton to Mach's Principle, we have mostly skipped over some key developments involving electromagnetism and SR. Important as it is to fill these gaps, we will postpone doing so yet again in favor of an exploration of cosmological questions. When these questions involve particular features of electromagnetism and atomic physics, we will get a partial preview of some of these issues as they arise from here through §19. The logic of following through on the big picture issues raised by Cartesian, Newtonian, Machian, and Einsteinian views of space shall here precede the various problems and concepts of spacetime arising in the context of SR.

The ideas proposed in the preceding sections clearly have the potential to upturn a vast expanse of fundamental physics. It is inevitable that such a drastic change in gravitational model will entail a correspondingly drastic change in cosmological model and relationship to the atomic constituents of matter. It is appropriate, therefore, to roughly round out this big picture as follows.

11˙1. *Why No Cosmic Catastrophe?* – The big picture of gravity, of course, is the whole Universe. This is where it becomes easiest to see, among other things, the dimensions of Newton's constant as "acceleration of volume per mass." Even if not commonly expressed as such, this is the gross and simple effect of gravity even according to standard ideas. In the context of both Newton's and Einstein's theories of gravity, it was recognized early on that, with nothing to counteract the action of gravity, its effect on a cosmic scale would be to *eliminate* all the space between material bodies. In the standard conception of gravity Newton's constant thus represents an accelerated *reduction* of space per mass. General relativists sometimes like to deny that gravity is an attractive force, appealing instead to the more sophisticated interpretation of spacetime curvature. But in the cosmological context we see that even if "properly" regarded as manifestation of curved spacetime, gravity is still supposed to *suck*, in the Newtonian sense of reducing the distances—and therefore volumes—between all mass centers. Mathematically this corresponds to the acceleration due to gravity being *negative* and so too its potential energy.

Serious application of gravity theories to the Universe as a whole came into common practice well after 1900, when astronomical observations were beginning to reveal the vastness of our Galaxy and beyond. Therefore it was not until GR had become the leading theory of gravity that Einstein finally proposed a way to "prevent" what had seemed to be an inevitable gravitational collapse. It was a *mathematical* fix; the addition of a space-creating force to Einstein's field equations that would counteract gravity over cosmological distances. Einstein's proposed fix turned out to be unstable, but other theorists soon proposed a variety of other options, all based on Einstein's field equations, a few of which seemed to have more promise of matching observations.

11˙2. *Basics of the deSitter Solution*. – One of these other solutions, by the Dutch astronomer, Willem deSitter in 1917 [91] played a role in Einstein's struggles with Mach's Principle. It was the first cosmological solution that predicted a redshift-distance relation. The increase in redshift with distance means light from distant sources is shifted to ever lower frequencies with ever greater distance. This is customarily assumed to be due to the recession of galaxies, i.e., the expansion of the *space* of the Universe, excluding matter. What is supposed to expand is only the space *between* gravitationally unbound systems, i.e., *intergalactic* space. Curiously, deSitter's model was supposedly empty of galaxies or any other material bodies. The model contained nothing that caused any *attraction*. It was assumed—without much thought—that matter invariably causes gravitational attraction (space-elimination) so the absence of attraction corresponds to absence of matter. Einstein and deSitter engaged in a lively correspondence over this solution because it was argued by deSitter as representing an example that allowed the possibility of inertia, even without matter. Specifically, it indicated that a *single* material body in an otherwise empty Universe would possess inertia. Einstein didn't like this because it violated his views about Mach's Principle.

Two other noteworthy features of deSitter's solution are: (1) The rates of clocks increase with time; i.e., the more that time passes, the more quickly it passes. Far distant clocks would appear to be ticking slow because in the time that light takes to reach an observer, clocks near the observer would be ticking faster than they were when the light was emitted. More commonly this was explained without reference to implications for *local* clock behavior, but simply in terms of the redshift. It was and sometimes still is referred to as the *deSitter effect.* [92-95] The effect would only be observable on vast distance scales, just barely (if at all) accessible by the telescopes in operation at that time.

To reiterate, if sufficiently large distances were probed, we would see a lower frequency than we'd see in an identical nearby source because light from the distant source was emitted earlier in time, when it was ticking slower. Curiously, deSitter's model leaves a variety of its features open to interpretation, so the exact form of its redshift-distance law, for example, has been given at least eight different ways. [94]

With this variability in mind, we turn to the next noteworthy feature, which has been described as: (2) The manifestation of a kind of *stationary expansion*. One of the foremost cosmologists of the mid 20th century, H. P. Robertson (with co-author, T. W. Noonan) called deSitter's solution "the only non-static stationary model," because "the fundamental world-lines expand away from each other but they also present the same appearance at any cosmic time." [96] *Non-static but stationary.* This description could also be given (as it has been [97-99]) to a *rotating* body. It is good to take notice of every instance of analogous characteristics, as between gravity and rotation; here is one on a cosmic scale. This instance is especially noteworthy because it indicates motion *of* space rather than motion *through* space. We would not directly see it, but infer it from the redshift. The solution was originally shown to be conducive to a $(4+1)$-dimensional representation, which (from the earlier sections on hyper-dimentionality) we might expect of a model that predicts perpetual radial motion that is not directly observable as such. As every mathematician knows, the only kind of expansion that always looks the same, from the infinite past to the infinite future, is an *exponential* expansion, and so it is with deSitter space.

11˙3. *Big Bang, "Steady State," and Fragmentary Chunks of Static Stuff*.

> Singularities. . . are intolerable from the point of view of classical field theory because a singular region represents a break-down of the postulated laws of nature. . . A theory [such as GR] that involves singularities and involves them unavoidably, moreover, carries within itself the seeds of its own destruction. — PETER G. BERGMANN (Long-time assistant to Albert Einstein) [100]

I've described some of the details of deSitter's solution because they are quite similar to some expectations based on the SGM. The model serves as a convenient basis for comparison. Other models that more accurately reflect the preconceptions of 20th century astronomers ultimately won out over the deSitter model. The main preconception, once again, is the idea that chunks of matter are essentially static, and that they attract other bodies of matter across space. In this context we see most clearly the entrenched notion of discontinuity between matter and space.

Consider A. Zee's GR-based account of how it all started: Going backward in time, we eventually arrive at "the spacetime singularity at which space disappears. . . known as the Big Bang. . . No space!. . . The Big Bang is actually the creation of space: from no space to space." [101] The "early" creation of space, the lawless birth of the Universe, corresponds, essentially, to the "freezing" and fragmentation of energy into particulate matter. Once begun, once elementary units of matter begin to fragment out of the miraculous primordial egg, their average number per volume steadily decreases. Space increases; matter does not. The stage of this alleged process currently underway is that the space between *galaxies* expands while the gravitating matter does not; matter remains divorced from the global expansion.

Since its inception, modern cosmology has largely been a story of the battle between the Big Bang-caused expansion of space and matter's "attempt" to pull it back and slow it down. Via gravity, matter is engaged in the perpetual process of "trying" to eliminate

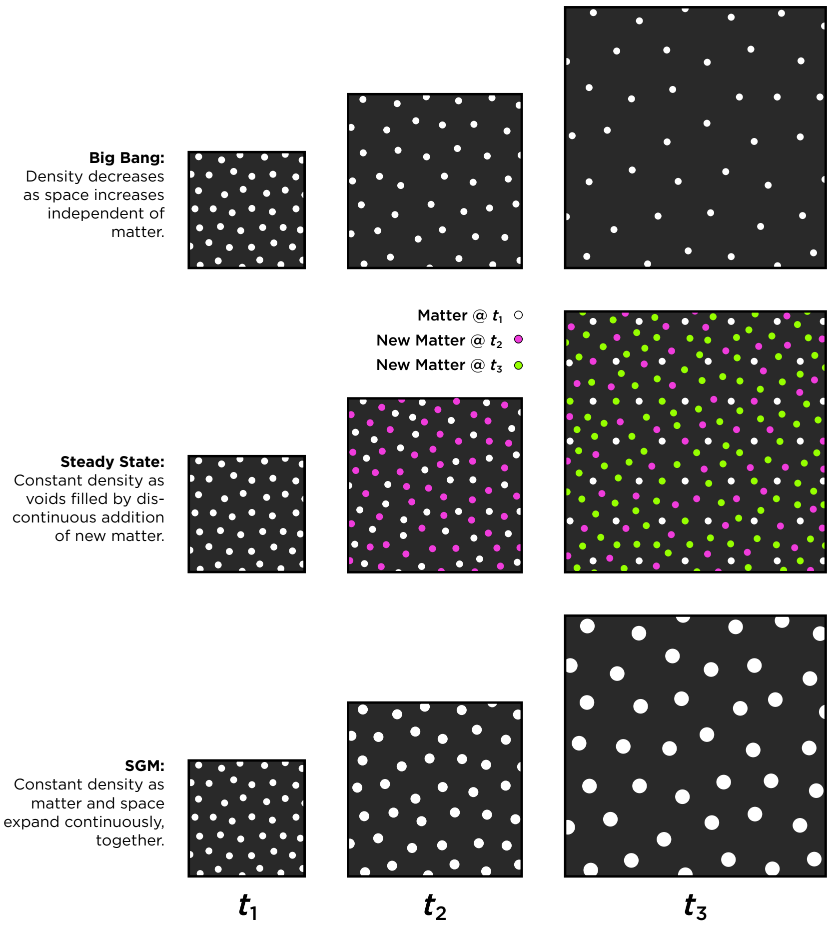

Fig. 20. – Basic cosmological ideas: Big Bang and "Steady State" feature stark discontinuities and independence as between matter and space. SGM features perpetual matter-space continuousness and interdependence.

the space given to us by the Big Bang. Through most of the 20th century, observational evidence has suggested that the average cosmic density of matter is insufficient to neutralize the Big Bang and *reverse* the expansion. But it seemed to be sufficient to at least keep slowing it down. Then, in 1998 and ever since, evidence has seemed to suggest that space itself is causing its own expansion to *accelerate*. The fate of the Universe and everything in it is to ever more rapidly approach zero temperature—to fizzle and die.

Commonly presented as the strongest evidence for the correctness of this view is the redshift-distance relation. The redshift is almost unanimously regarded as the result of a kind of *recession velocity*. This can be visualized as a pattern of motion of galaxies away from one another that perpetually widens the distance between them, as shown at the top of Figure 20. Because of the tremendous force of the Big Bang (and in more recent times, supposedly, because of "dark energy") space is supposed to keep opening up—being created only between gravitationally unbound galaxies.

Though the changing clock rate interpretation of the deSitter effect has been mostly forgotten, deSitter's solution has played a role in a few other contexts. The most recent ones are the earliest and latest stages of *inflationary* cosmology. DeSitter's solution was also adopted in the Steady State models that received some serious attention from the late 1940s through the mid 1960s. [102,103] The authors of these cosmologies appealed to the deSitter model for its having "world lines [that] expand away from each other [while] they also present the same appearance at any cosmic time." The Universe could persist like this forever without a hot beginning or a cold ending. But they also presumed to know that gravity is an attraction and that the recession-velocity interpretation of the redshift was basically correct. Therefore, they had to posit the "spontaneous generation of matter" *out of the voids of space* to maintain a constant density. This is shown in the middle panels of Figure 20. The result is a most fragmented, discontinuous view of matter and space.

With these contrasting models in view then—one by which density steadily, even *acceleratingly* diminishes, and one by which density is maintained by the magical appearance of new chunks of stuff—we can more readily appreciate the basics of SGM cosmology.

11˙4. *Qualitative Description of SGM Cosmology and Cracks in the Standard Model.* – As noted above, the characteristic (described by Robertson and Noonan) of expanding while preserving appearances over time indicates that the expansion is exponential (think of a logarithmic spiral). Another way of characterizing exponential expansion is that it means the whole increases with a rate that increases in proportion to how much there is at any given time. Everything is getting bigger and bigger faster and faster all the time.

This suggests a solution resembling deSitter's, except that we now see it as being not empty (for its lack of attraction) but quite full. One of the differences between the straight deSitter solution and the SGM is that the former is *uniform* throughout. The behavior that it attributes to seemingly empty space strongly resembles the behavior that the SGM attributes to matter: continually increasing and moving outward. The key difference, therefore, lies in the *inhomogeneity*. On local scales neither space nor matter are homogeneous. The space of the Universe is generated by its infinitude of localized, concentrated *sources*. Matter (via gravity) is not working against the expansion; matter is the *cause* of it.

The SGM conception is shown graphically in the bottom panels of Figure 20, which as a whole reveals the contrast with both the Big Bang and Steady State conceptions. Density continually decreases according to the Big Bang and it is maintained as a constant in Steady State models by the discontinuous appearance of new chunks of stuff. This ad hoc manner of conceiving the so-called *spontaneous generation of matter* is probably the most objectionable feature of the model. In their defense, Steady State cosmologists would sometimes present their idea of matter creation at all cosmic times as being more reasonable than the Big Bang idea whereby all matter in the Universe suddenly appears at the birth of the Universe. [104] Curiously missing in the mainstream literature are objections to *any* invocation of discontinuous popping into existence of new chunks of matter—whether by a succession of lots of little pops or by one sudden Bang. Nor is there mention of the (obvious?) alternative that the density is held constant by the creation of matter out of all material bodies that already exist.

We can put the idea in perspective by supposing the Earth's mass to be spread out over a volume that would make the ratio equal to the cosmic average density. This comes out to a sphere whose radius is about 10 light years (10^{17} meters). When the mass is spread out so thinly, the locally discernible *motion* caused by the expanse becomes extremely slow, because the radial distance is in the denominator of the motion equations. Nevertheless, the hyper-dimensional generation of space is always and everywhere the same for every unit of matter. The locally visible rapidity of space generation depends on how concentrated the sources are. On a cosmic scale it is not visible at all because we ourselves are totally immersed. It is impossible to disconnect ourselves and look at the process from the "outside." The imagined 10 light year sphere of Earth's mass would scarcely be identifiable as such for lack of contrast.

By supposing that the cosmic fluid is continuous as between matter and space, generation of *space* is virtually synonymous with generation of *matter*. The density remains constant and the expansion is exponential. This condition of maintaining constant density is sometimes referred to as *saturation* or *stability*. The SGM's cosmic fluid remains saturated as it expands and perpetually replenishes itself from the inside out. Spontaneous generation of matter in the SGM is thus not an *ad hoc* popping into existence of new particles or a new Universe. It is the same thing as the spontaneous generation of *volume*, which is the same thing as the gravity and inertia of all material bodies that already exist.

One of the most noteworthy consequences of the SGM cosmology is that it leads to a definition of Newton's constant, G by which it is shown to be simply related to other (electromagnetic and nuclear) constants. This has never been done before. In standard physics, G is completely unrelated to other constants; and few are those who look for a connection based, as the SGM is, on simple empirical facts. Yet it seems obvious that such a connection should exist. One of the determining factors in the SGM-derived value of G is a ratio between the energy density of the cosmic background of space, to the nuclear saturation density. If this factor were zero, there would be no gravity and so arguably no matter. The interdependence of matter and space is thus implied by this extreme contrast as between the low energy of seemingly empty intergalactic space and the high energy of atomic nuclei. Local inhomogeneities in the globally cosmic continuum are thus expected. It's as though localized bodies of matter ultimately *need* the vastness of intergalactic space, and vice versa.

According to the SGM the Universe never dies because it was never born; it extends infinitely into the past and future. In a more thorough treatment of the SGM cosmology, specific arguments in support of the Big Bang that claim evidence of "evolution" would need to be addressed. Standard cosmologists argue that observations of remote (high redshift) reaches of space are different from our local (low redshift) neighborhood. Though a full exposition of counter-arguments is beyond the scope of this essay, it will be noted that the literature is brimming with a wide variety of observations that conflict with their assumptions of evolution. Particularly puzzling within the Big Bang context are observations of things that would seem to require a lot more time than the alleged 13.7 billion year *age* of the Universe to come into existence.

Three of these things are worth mentioning: (1) The formation of galaxies. Huge quantities of a hypothetical substance known as *Cold Dark Matter* are needed to make possible the most common large scale ingredients of the Universe. The Big Bang is thus unabashedly propped up by gobs of magical stuff that is supposedly more than four times as plentiful as ordinary matter. Since there is no concrete evidence of this stuff, it would help to keep things in proper perspective if it were called *snark* matter, or *purple-winged horsie* matter. (2) At the center of most galaxies resides an enormous dark body of matter hypothesized to be a so-called supermassive black hole. Within the given time constraints, there is no convincing explanation for how such things could have come to exist, even if we allowed the discontinuous, lawless, singular behavior (division by zero) that is attributed to them. Whereas their existence is no problem at all in the SGM. They are dark, dense and extremely massive. But as we recall (p. 35) their clocks do not stop and they do not halt the motion of light, because the speed limit is always and everywhere respected. (3) Even more troublesome for the Big Bang theory is the existence of enormous voids, walls of galaxies and large scale streaming motions that cover huge expanses of the observable Universe. Again, there has simply not been enough time within the Big Bang context for these things to have taken form, unless one invokes a variety of dubious initial conditions, helping agents, and fudge factors.

Aside from formation problems, it is also true that lots of observations indicate that the high redshift reaches of the Universe are unexpectedly similar to low redshift reaches. It is worthwhile to provide enough detail to understand a particluar example. Astronomer Greg Bothun, who has studied the magnificent Ultra Deep Field images from the Hubble Telescope, includes on his website a disconcerting comment concerning the highest redshift objects whose angular sizes were expected to be larger. The expectation of large angular sizes for high redshift galaxies is a peculiar feature of Big Bang cosmologies. The theory predicts, for a galaxy of known absolute size, a *minimum* angular size. In other words, beyond a particular redshift ($z \approx 1.5$) the sizes of galaxies are supposed to appear to get *bigger*, not smaller. Very high redshift galaxies are, however, not seen to follow this pattern. Instead, they tend to obey the more intuitive SGM prediction that the farther away an object is, the smaller it appears.

With that theoretical background we can readily appreciate the implications of Bothun's remark: "The great preponderance of small angular size objects in this [Hubble Ultra Deep] field is challenging to understand." [105] Comments like this are very common. Yet belief in the Big Bang is not shaken because cosmologists keep finding ways to water down the challenge. They keep devising variations on the theme of cosmic evolution, dark matter, and dark energy by which they can "understand" just about any observation that defies a straightforward, *simple* Big Bang based explanation.

Note that a contingent of dissident astronomers exists. Each one has his or her own reasons for grumbling about the prevailing dogma of the Big Bang, usually including an alternative model of some kind. I think some of these grumbles and alternatives are misguided, but some of them are quite cogent, making the point, overall, that we have many reasons to be suspicious of the prevailing views. The reader is urged to seek out evidence and arguments from all corners of our vast store of data. Turning now to the task of building a mathematically more specific model based on the SGM, we presently bring in a few simple facts from the other extreme in size: atomic physics.

12. – Cosmology by the Numbers

> *The desire to explain the constants has been one of the driving forces to develop a complete unified description of nature, or "theory of everything." Physicists have hoped that such a theory would show that each of the constants of nature could have only one logically possible value. It would reveal an underlying order to the seeming arbitrariness of nature.* [106] — JOHN D. BARROW and JOHN K. WEBB

12˙1. *Redshift z.* – Long before the category of *Quantum Cosmology* appeared on the official website of physics archives, it was understood that, at some level, atomic physics and cosmology must be deeply related. The prevailing interest is almost entirely to do with the conditions near the alleged beginning, where it is acknowledged that GR breaks down and Quantum Theory (QT) is brought in for the rescue. [107] The particle smashing exploits of modern physicists are sometimes framed in the context of how close collision energies have approached the extreme conditions so many picoseconds after the Big Bang time, $t = 0$. Theoretical physicists focus on these extremes because this is where they hope to achieve "unification" of the forces, where they hope it is possible to "marry" GR and QT. "Unification of forces," to modern theorists, is thus not something they conceive as existing at the present time. Instead they conceive the present state of the world as irreversibly fragmented. Having an entirely different conception in mind, we are not concerned about standard theorists' preoccupation with notions of the ancient past—when gravitons, gluons and photons were supposed to be as one—except to point out that it continues to be as popular as it is unfruitful (extremely).

Our concern, rather, is more like that of the first physicists who speculated on a micro-macro connection, either on the basis of Steady State type cosmologies or on the basis of some well known, highly suggestive numerical "coincidences" between atomic constants and cosmological parameters. Among these numbers—as will be explained in the following—are extremely large force, length, and density ratios (on the order of 10^{40}) that seem to connect the scale of atoms to the scale of the Universe.

One of the first to suggest a connection (on both counts, steady state and numerical curiosities) was John Q. Stewart in 1931. [108] A noteworthy review of developments along this line of thought was written by E. J. Zimmerman in 1955. [109] We too expect a connection on both counts for the following reason. We are exploring the possibility that the Universe is infinitely old, that matter and space are ultimately a seamless continuum and that their exponential expansion arises *because it is generated by matter*. If these assumptions are true, then the numerical relationships pertaining to atomic matter and the forces found therein *must* be related—and presumably *simply* related—to the numerical relationships pertaining to the Universe as a whole. For nearly (though not entirely) the same reasons, Herman Bondi corroborates the basic argument:

> There are, however, a few numerical 'coincidences' arrived at by combining cosmical, 'ordinary size' and atomic measurements. These coincidences are very striking and few would deny their possible deep significance, but the precise nature of the connexion they indicate is not understood and is very mysterious.
>
> The likelihood of coincidences between numbers of the order of 10^{39} arising for no reason is so small that it is difficult to resist the conclusion that they represent the expression of a deep relation between the cosmos and microphysics, a relation the nature of which is not understood.
>
> In any case it is clear that the atomic structure of matter is a most important and significant characteristic of the physical world which any comprehensive theory of cosmology must ultimately explain. [110]

I would argue further that the connections implied by the SGM are so inevitable and would have to be so tight and simple, that if they were not found to be so, then this would be a strong argument against the SGM. The main reason for this argument is that the Universe we envision is of *infinite* age; perhaps more accurately, it is *ageless*. It is therefore reasonable to assume that the *state of organization* of the Universe should reflect the kind of "perfection" one might expect of a system that has had an infinite amount of time to optimize all its manifest physical relationships. Surely it is not farfetched, but rather obvious that any complex thing that is truly eternal, must exhibit an exquisitely perfect means of self-organization and self-perpetuation. We may also expect this perfection to be not hidden, but plainly evident, if only looked at correctly.

With that build-up, a little more history is in order before unfurling the details of the SGM cosmology. Those who have sought to devise a theory using the micro-macro connections referred to by Bondi—either as a mathematical basis or conceptual inspiration—are many. Among them we find, not long after Stewart, Paul A. M. Dirac, who called his model the *Large Numbers Hypothesis*. [111] Dirac intermittently worked on the model from the 1930s into the 1970s. Another renowned physicist, Robert H. Dicke [112] appealed to the numerical coincidences as a motivating factor in his attempts (mostly in the 1960s) to revive interest in Mach's Principle.

The cosmic-atomic connection that has probably received more attention than any other concerns a pair of force and length ratios, where three of the four numbers are known fairly accurately, but the fourth, the cosmic length R_C, only roughly. The force ratio is a comparison of the gravitational and electromagnetic forces between the proton (m_p) and electron (m_e) in a hydrogen atom, which may be expressed as

$$\frac{F_G}{F_E} = \frac{G m_p m_e}{e^2/4\pi\epsilon_0} \approx 4.4068 \times 10^{-40}\,. \tag{5}$$

where e is the elementary charge and ϵ_0 is the electric constant. Because both forces obey an inverse square law (falling off as $1/a_0^2$) the characteristic distance between proton and electron, known as the Bohr radius, a_0 cancels out of this equation. Notice that by having the smaller number in the numerator, the ratio we obtain is a small number instead of a large number. Either way, the idea is the same, of course. The curious thing is that when a_0 is compared to R_C a ratio of similar magnitude appears

$$\frac{F_G}{F_E} \approx \frac{a_0}{R_C}\,. \tag{6}$$

This implies that, just as a_0 is the scale length that characterizes the electric force in atoms, R_C is the scale length that characterizes gravity in the Universe; and that deeper connections may be found by following this trail. Insofar as rearrangements of simple algebraic equations can have the effect of seeing the same thing from a new angle, note that by cross multiplication we get an equally curious equation with dimensions of energy:

$$a_0 F_E \approx R_C F_G\,. \tag{7}$$

A characteristic feature of most hypotheses involving these numbers is that their potential significance is is scarcely ascertainable beyond *order of magnitude*. Uncertainties in measuring R_C (by a chain of assumptions) and in choosing a model that dictates what assumptions are to be made, explain why few have ventured to specify a more exact connection. In this regard the SGM is exceptional. Based on a small number of assumptions, SGM cosmology yields new expressions among the constants that are most sensibly regarded as being *exact*. To see this we need to begin with a basic idea from QT whose roots extend back at least to the transitional period before the theory fully blossomed. Bohr's theory of the atom, which regarded electrons as planet-like negative charges orbiting a Sun-like positive charge, had been born. But the wave nature of matter was still in the womb, so to speak. The crucial idea, as Einstein wrote in 1920, concerns the relationship between *clocks and matter*:

> Every system is to be considered as a "clock" which by virtue of internal laws and periodically occurring processes is endowed with a specific frequency, that is, e.g., an atom that can emit or absorb a certain spectral line. [113]

With the contributions of deBroglie, Schrodinger and others, to be made in the next few years, the wave nature of matter was eventually established and the frequency to which Einstein refers was given a more exact meaning. Specifically, an elementary particle "clock" has a proper frequency that is proportional to its rest mass

$$f_0 = \frac{m_0 c^2}{h}\,, \tag{8}$$

where h is Planck's constant. [114, 115]

Bearing Equation 8 in mind, we now jump to the cosmos, the SGM, and what it has in common with the deSitter solution. The exponential expansion that leaves the Universe "non-static" yet appearing always the same refers to a change in scale that is not directly visible to observers who participate in it (us), but may be imagined as observable if it were possible to disconnect ourselves from the perpetual cosmic flow. From this imaginary perspective, any given cosmological length r_0 changes according to the exponential law

$$r = r_0 \exp(\beta \Delta t)\,, \tag{9}$$

where β is yet to be determined and Δt can be thought of as an increment of cosmic time. A similar equation arises in the Steady State models referred to earlier. It is useful to consider the major difference in meaning. In the Steady State models this change in length is directly responsible for the redshift; i.e., it is still regarded as a kind of recession velocity. Whereas the change of length in the SGM is of significance not for any linear velocity, but because when cubed, it gives a change of *volume*, which in turn is proportional to the change in *mass*. By Equation 8 we thus expect the increased mass to correspond to an increased frequency. When r is cubed, so is the right side of Equation 9, so we get the volumetric relationship:

$$r^3 = r_0^3 \exp(3\beta \Delta t)\,, \tag{10}$$

Our assumption of ultimate matter-space continuousness and corresponding constant average cosmic density means that mass changes the same way as volume:

$$m = m_0 \exp(3\beta \Delta t)\,. \tag{11}$$

Finally, by Equation 8, the masses are interchangeable with frequencies:

$$f = f_0 \exp(3\beta \Delta t)\,. \tag{12}$$

Up to now our equations have referred to *increases* in length, volume, mass and frequency, as we predict for the *forward* direction of time. Looking far into space means looking *backward* in time, so the *reciprocal* of the exponent in Equation 12 will figure in our derivation of the redshift. The frequency of a source whose light emission takes the time Δt to reach us is thus: $f = f_0/\exp(3\beta\Delta t)$. Redshift z, is the difference between the frequency of a local source and an identical distant source, divided by the frequency of the distant source. In the end we get:

$$z = \frac{f_0 - f}{f} = \frac{f_0}{f} - 1 = \exp(3\beta\Delta t) - 1\,. \tag{13}$$

This is the SGM redshift law, in preliminary form.

We determine β and Δt by connecting them to the observational parameter that relates a distant light source to its redshift, often referred to as Hubble's constant, H_0. Note that in standard cosmology H_0 is not a constant; it is supposed to change. R_C is also supposed to change with the discontinuous cosmic expansion. In fact, R_C as we've referred to it so far (Equations 6 and 7) is better known as the *Hubble radius* (or Hubble length) which is defined as

$$R_H = \frac{c}{H_0}\,. \tag{14}$$

The Big Bang-based near-distance approximation for the redshift law is sometimes given as $z = H_0\Delta t$, where Δt is the time between emission and reception of a light ray, r_0/c and $H_0 = c/R_H$. Combining expressions yields:

$$z \approx \frac{r_0}{R_H}\,, \qquad r_0 \ll R_H\,. \tag{15}$$

The exponent in Equation 13 suggests that the SGM should have a similar near-distance approximation. It is also true in the SGM that $\Delta t = r_0/c$. But if $\beta = c/R$, then this R must be three times bigger than R_H. In other words, the relationship between H_0 and the Hubble radius and the SGM cosmic radius is

$$H_0 = \frac{c}{R_H} = \frac{3c}{R_{SGM}}\,. \tag{16}$$

Therefore, our $\beta = H_0 = 3c/R_{SGM}$. The 3 remains in the exponent and in the near distance approximation because the redshift depends on the change in mass or volume, both of which change as the third power of the change in linear scale. Let us then reinstate R_C and reserve it to indicate the SGM's cosmic radius. This yields the SGM near-distance approximation for the redshift:

$$z \approx \frac{3r_0}{R_C}\,, \qquad r_0 \ll R_C\,. \tag{17}$$

The SGM redshift-distance law thus becomes:

$$z = \exp(3r_0/R_C) - 1 \ , \qquad 0 \le r_0 < \infty \, . \tag{18}$$

12˙2. *Mass Density Parameter* Ω_M. – Our next task is to consider another key cosmological parameter—another one that *changes* in standard cosmology, but is constant in the SGM. It is known as the *density parameter* Ω_0. Once again it is useful to appeal to comparison with standard cosmology to arrive at the SGM's value for Ω_0.

The method of comparison is easiest to see in terms of cosmological ideas as they prevailed before 1998, when observations seemed to indicate the presence of *dark energy*. Before that happened, it was supposed by most cosmologists that the value of Ω_0 was due only to the average matter density of the Universe. The complication introduced by the 1998 (and subsequent) observations will be discussed later. Suffice it to say for now that Ω_0 represents a total average density, two of whose terms are Ω_M and Ω_Λ. For the sake of simplicity, we presently assume that $\Omega_\Lambda = 0$, so that only Ω_M contributes to the total.

The idea behind Ω_0 is this: If it were up to gravity to stop the expansion caused by the Big Bang, then there is a critical density at which this would almost exactly (asymptotically) happen. The density parameter is defined as the ratio between a measured or hypothesized density ρ_M and the critical density such that $\rho_M/\rho_{CRIT} = \Omega_M$. The case of almost completely halting the Big Bang expansion (in the far distant future) means

$$\frac{\rho_M}{\rho_{CRIT}} = \Omega_M = 1 \, . \tag{19}$$

This case ($\Omega_0 = \Omega_M = 1$) corresponds to a so called *flat* Universe. The critical density is related to other parameters as follows:

$$\rho_{CRIT} = \frac{3H_0^2}{8\pi G} = \frac{3c^2}{8\pi G R_H^2} \, . \tag{20}$$

To find the SGM density parameter Ω_{SGM} so as to compare it with observations, we need to express the constant cosmic average density predicted by the SGM (ρ_C) in terms of the critical density, such as those in Equation 20.

Doing this requires backtracking a bit to introduce another assumption—one that many others have made, especially in the context of Mach's Principle-inspired cosmologies. Just as the Bohr radius a_0 is regarded as the scale length that characterizes atomic physics, we expect a corresponding scale length that characterizes gravitational (cosmological) physics. It has often been assumed that the most reasonable definition of a cosmic radius would be

$$R_C = \frac{GM_C}{c^2} \qquad \text{or} \qquad \frac{GM_C}{R_C c^2} = 1 \, , \tag{21}$$

where M_C is the mass contained within a sphere of radius R_C. The needed definition of density can now be found because the mass is given in terms of the other cosmic constants: $M_{\rm C} = R_{\rm C}\, c^2/G$. Density, of course, is a mass per volume ratio, which, from the above relationships follows as

$$\rho_{\rm C} = \frac{M_{\rm C}}{V_{\rm C}} = \frac{R_{\rm C} c^2/G}{\frac{4}{3}\pi R_{\rm C}^3} = \frac{3c^2}{4\pi G R_{\rm C}^2}\,, \tag{22}$$

where $\rho_{\rm C}$ denotes the SGM's cosmic average mass density. The similarity with Equation 20 is readily apparent. Comparing them gives the ratio of density predicted by the SGM to the standard critical density. If the length $R_{\rm C}$ were equal to the Hubble radius, we would have

$$\Omega_{\rm M} = \frac{\rho}{\rho_{\rm CRIT}} = 2.0\,. \tag{23}$$

This clearly conflicts with the theoretical preference for flat model Universes (in which $\Omega_{\rm M} = 1$, not 2). More importanly, it conflicts with observational evidence that $\Omega_{\rm M}$ must be subtantially even less than 1. For these and other reasons, such Machian cosmologies lost their appeal 30 or 40 years ago.

Our factor of 3 greater cosmic radius ($R_{\rm C} = 3R_{\rm H}$) increases the denominator by a factor of 9, so the ratio as a whole yields the SGM density parameter:

$$\Omega_{\rm SGM} = \frac{\rho_{\rm C}}{\rho_{\rm CRIT}} = \frac{2}{9} \approx 0.2222\,. \tag{24}$$

The value $2/9$ compares quite favorably with observations. Though it is difficult to measure very precisely, many different methods yield error margins within which Equation 24 comfortably lies. In a 2004 review article on these efforts, the cosmologist P. J. E. Peebles [116] provides a table of 13 different methods used in recent astronomical investigations to conclude that they converge as

$$0.15 \leq \Omega_{\rm M} \leq 0.30\,. \tag{25}$$

The SGM value lies pretty close to the middle of this range. The error margin is still unimpressively wide, however, so let's now take the steps that allow comparing parameters whose values are more accurately known. We'll work our way to the Hubble constant because this will allow giving a numerical value to $R_{\rm C}$, so that we can come back to reassess the ratios given in Equation 6.

12˙3. *Fine Structure Constant* $\alpha \approx 1/137$.

> All good theoretical physicists put this number up on their wall and worry about it.
> — RICHARD FEYNMAN [117]

So far we've established a density ratio, and a length ratio, both of which are arguably meaningful, but suffer by being theoretical rather than observational quantities. Connecting to physical reality requires bringing at least one empirically measured cosmological quantity into the scheme. As it turns out, we have access to a measured density whose accuracy is widely acclaimed. Even if its reported accuracy is slightly exaggerated—as some suspect—measurements of the cosmic background temperature (and corresponding energy density) by the COBE mission in the early 1990s are most impressive. After years of adjusting results from repeated re-analyses of the data,([4]) the final COBE result was reported as $T_{\text{COBE}} = 2.725 \pm .001$ K.

A key fact in thermodynamic physics is that a so-called black body temperature, such as that of the cosmic background radiation (CBR) corresponds to a definite *energy density*. By virtue of Einstein's famous equation $E = mc^2$, the energy density may then be expressed as an "equivalent" *mass density* (by simply dividing by c^2). To make use of this, we now introduce an assumption based on the idea that atomic physics is directly related to cosmic physics. This involves another mysterious ratio near the heart of fundamental physics: the mass of a proton compared to the mass of an electron, which is $m_{\text{p}}/m_{\text{e}} \approx 1836.15$. Concerning the physical role of protons and electrons in atoms, we may say this: Electrons are by far the more ethereal of the two. Electron clouds surround the comparatively tiny and extremely dense proton (and neutron)-populated nuclei. Furthermore, the interplay between protons and electrons is the source of virtually all light in the Universe. Evidently, the ratio $m_{\text{p}}/m_{\text{e}}$ plays a significant role in maintaining a kind of dynamical stability within atoms. We suspect that it plays an analogous role on the scale of the cosmos.

In combination with its much heavier, positively charged nucleus, a negatively charged electron in a hydrogen atom (and atoms in general) functions as a kind of switch or gateway to light. Therefore, I surmise by analogy, that the ratio comparing the matter density of the Universe to the mass-equivalent of the cosmic radiation density should be similar to $m_{\text{p}}/m_{\text{e}}$. If not exactly this ratio, then one with a small rational coefficient is a reasonable guess. Subsequent exploration of this hypothesis strongly implied that the coefficient is 2. Let's call the mass equivalent of the CBR ρ_μ to distinguish it from the average density in material form, ρ_{C}. Converting from a temperature to a mass density involves multiplying by the radiation density constant, $a \approx 7.56577 \times 10^{-16}\,\text{J m}^{-3}\text{K}^{-4}$ and the fourth power of the temperature, then dividing by c^2; i.e., $\mu = aT^4$ and $\rho_\mu = \mu/c^2$. Our assumption thus corresponds to

$$\frac{\rho_\mu}{\rho_{\text{C}}} = \frac{1}{2}\frac{m_{\text{e}}}{m_{\text{p}}}\,. \tag{26}$$

This relation leads to a variety of other surprisingly simple, suggestive expressions and a prediction for Hubble's constant that is in agreement with many observations. Note that Equation 26 and the expressions to follow are accurate only if the actual temperature of the CBR is $T_{\text{C}} \approx 2.713$ K instead of $T_{\text{COBE}} \approx 2.725$ K. The close agreement between these temperatures justifies assuming, at least tentatively, that the connections implied by adopting the lower value are physically meaningful.

The next step in getting a number for H_0 is to calculate the matter density based on the above assumption:

([4]) Because of this unusually protracted period of analysis, with several intermittently published preliminary results, P. M. Robitaille [118] has questioned whether the final results are as accurate as claimed. Unfortunately, there have not been any comparable follow-up missions to recheck COBE's absolute temperature measurement. Later satellite missions were all designed to measure *fluctuations* in the temperature across the sky, but not the absolute value of the temperature itself. COBE was unique for having this function, and for performing it so well.

$$\rho_{\text{C}} = 2\left(\frac{m_{\text{p}}}{m_{\text{e}}}\right)\rho_\mu \approx 3672.3\,\rho_\mu \approx 1.675\times10^{-27}\,\text{kg m}^{-3}\,. \tag{27}$$

Then we equate it with the density arrived at in our critical density comparison (Equation 22):

$$\rho_{\text{C}} = \frac{3c^2}{4\pi G R_{\text{C}}^2}\,. \tag{28}$$

Rearranging to find R_{C}, we get

$$R_{\text{C}} = \sqrt{\frac{3c^2}{4\pi G\rho_{\text{C}}}} \approx 4.380\times10^{26}\,\text{m}\,. \tag{29}$$

Using this value for R_{C} in Equation 6 or 7 yields

$$\frac{\mathrm{a}_0}{R_{\text{C}}}\frac{F_{\text{E}}}{F_{\text{G}}} \approx 274\,. \tag{30}$$

The curious thing about this result is that 274 is very nearly two times (the inverse of) another prevalent ratio in quantum theory known as the *fine structure constant*:

$$\alpha = \frac{h}{2\pi\,m_{\text{e}}\,c\,\mathrm{a}_0} \approx \frac{1}{137}\,. \tag{31}$$

From this we can rearrange Equation 30 to get

$$\frac{\alpha}{2}\frac{\mathrm{a}_0}{R_{\text{C}}}\frac{F_{\text{E}}}{F_{\text{G}}} = 1 \qquad \text{or} \qquad \alpha\,\mathrm{a}_0 F_{\text{E}} = 2R_{\text{C}}F_{\text{G}}\,. \tag{32}$$

That we should pursue all conceivable implications of Equation 32 is suggested by comments such as the following by Richard Feynman concerning the ubiquity and mysteriousness of α:

> [The meaning of α] has been a mystery ever since it was discovered more than [eighty] years ago, and all good theoretical physicists put this number up on their wall and worry about it... It's one of the *greatest* damn mysteries of physics; a *magic number* that comes to us with no understanding by man. [117]

The importance of α in atomic physics will be discussed in more detail in §13, §18 and §20. Either by accident or because it is physically meaningful, the magic number has popped up in relation to the *scale* of the cosmos, which strongly implies a connection to the *scale* of the atom; which strongly implies a connection between atomic and cosmic *forces*, i.e., between electromagnetism and gravity.

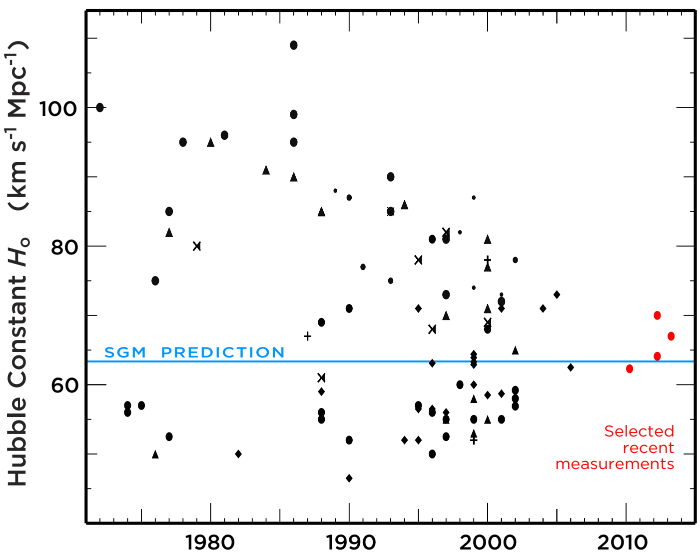

Fig. 21. – Hubble constant measurements in the last few decades. Original graph and black data points are from a 2006 review paper. [119] Without pretending to be exhaustive, red points are more or less typical of recent measurements.

12·4. *Hubble Constant* H_{SGM}. – Taking stock before proceeding to further revelations, note that our exploration so far has uncovered an evident relationship between at least three famously mysterious ratios: F_G/F_E, m_p/m_e, and $\alpha = h/2\pi c m_e a_0$.

From Equation 16 the SGM Hubble constant is given as $H_0 = 3c/R_C$. Now that we have a number for R_C, we can assign the constant a number: $H_0 = 3c/R_C \approx 2.0532 \times 10^{-18}\,\mathrm{s}^{-1}$. Converting this into the customary cosmological units of kilometers per second per megaparsec (Mpc) means multiplying by 1 Mpc ($\approx 3.0857 \times 10^{22}$ m) and dividing by 1000 to convert meters to kilometers. This yields

$$H_{\mathrm{SGM}} \approx 63.356 \text{ km s}^{-1}\,\mathrm{Mpc}^{-1}\,. \tag{33}$$

Note that Hubble's constant is often expressed as a ratio $h_0 = H_0/100$ km s^{-1} Mpc^{-1}. For the SGM we thus have $h_{\mathrm{SGM}} \approx .634$. Before comparing the SGM's prediction with measurements, we should briefly consider some history. The struggle to determine a reliable value for H_0 began soon after evidence for some kind of redshift-distance relation began to look convincing in the late 1920s and early 1930s. The first few guesses, including Hubble's own, were anywhere from 4–13 times too large. In the ensuing decades the value kept coming down. In the 1960s and 1970s there was a kind of battle, with proponents for $h_0 \approx .50$ on one side and for $h_0 \approx 1.00$ on the other. Observational improvements narrowed the field in the 1980s through the early 2000s, as seen in Figure 21. [119]

Perhaps as a lingering remnant of the earlier "battle," to this day we still find measurements made by different observers whose error margins do not overlap, or maybe overlap just barely. One contingent of observers keep finding values $h_0 \approx$ low .70s with ever shrinking error margins. This has become the dominant group, even though a less well publicized group persists at finding values in the low .60s. The current *Wikipedia* entry (as of this writing) [120] cites a well-publicized 2013 measurement by the Planck satellite whose result is $h_0 \approx .67$. Not mentioned by *Wikipedia* is a 2013 symposium volume, one of whose primary subjects is the value of Hubble's constant. The papers in the book include a review given by the proponents of the $h_0 \approx .70$ contingent; and also a review given by Tammann and Reindl [121] who have maintained for many years that a value in the low .60s is closer to the truth. The latter review was also a tribute to of one of the authors' recently deceased colleagues, the distinguished Allan Sandage. The paper closes by stating with approval that "Sandage's last published [2010] value of the Hubble constant is $H_0 = 62.3$ km s^{-1} Mpc^{-1}." And they report their new measurement of $H_0 = 64.1 \pm 2.4$ km s^{-1} Mpc^{-1}. All of the recent measurements mentioned above are easily visualized in their place in Figure 21. Happily, the astronomical community is commited to keep measuring with ever-improving technology. On that note, we are also happy with the empirical status of our prediction, so we move on to the next connection.

12˙5. *Nuclear Saturation Density* $\rho_{\rm N}$, *and Newton's Constant* G. – If our arrival at this juncture has not been due to the fortuitous (or misleading?) alignment of random facts, but we are actually on the right track, then it is reasonable to suppose connections to be forthcoming if we extend our exploration to the even deeper domain of nuclear matter. In atomic nuclei, for all but the lightest atoms, we find a nearly constant density, known as the *nuclear saturation density* $\rho_{\rm N}$. Though agreed to be nearly constant, reported values of $\rho_{\rm N}$ unfortunately vary by more than the error in the CBR energy density measurement. Specifically, cited values vary by about 6%. Nevertheless, it is curious that error bars are often neglected and values are sometimes given that seem to align quite evocatively with the rest of our scheme. A commonly stated value is $\rho_{\rm N} \approx 0.17 m_{\rm p}/10^{-45}\,{\rm m}^3 \approx 2.843 \times 10^{17}\,{\rm kg\;m}^{-3}$. Given this value for the nuclear saturation density and the value for the cosmic average density given by Equation 27, we connect back to our force ratio to get

$$\frac{F_{\rm E}}{F_{\rm G}} \approx \frac{\alpha^2}{4}\frac{\rho_{\rm N}}{\rho_{\rm C}}\,. \tag{34}$$

The left side of Equation 34 is larger than the right by $\approx$ .0041. Once again it seems not unreasonable to assume that this equation should be exact.

Here's the payoff. The most (potentially) meaningful result of our exploration is that it leads to an expression—an extremely simple expression—by which Newton's constant is related to other key constants of physics:

$$G = 8\left(\frac{\rho_\mu}{\rho_{\rm N}}\cdot\frac{c^2 {\rm a}_0}{m_{\rm e}}\right) = 8\left(\frac{\mu}{\rho_{\rm N}}\cdot\frac{{\rm a}_0}{m_{\rm e}}\right)\,. \tag{35}$$

The trail by which we've arrived at Equation 35 contrasts very sharply with the haphazard wanderings and repeated parameter adjustments of standard physics and cosmology. For all the research on quantum cosmology and quantum gravity that appeal to the physically dubious Planck scale of enormous Big Bang-like energies; for all the talk of "marrying" QT with GR by invoking holographic gravitons, stringbranes, and other fanciful concoctions, none of it has shed any light on how G connects to any other attribute of matter, electromagnetism, or nuclear physics. Fortunately, the desirability of finding such a connection is sometimes mentioned. It is understood to be desirable because establishing such a connection would be tantamount to a big step in *unifying* the forces of Nature. Since most efforts at unification are focused on the fanciful distractions mentioned above, statements of the problem put explicitly in terms of connecting the constants are rare. I'll quote two examples that I've found in which this approach is stated and a third where the possibility is implied but then curiously shrugged off as inconsequential.

Sisterna and Vucetich write:

> In spite of many attempts at unification with other fundamental interactions, gravitation remains in isolation and its only parameter, the Newtonian gravitational constant G, is still unrelated to the other fundamental constants. [122]

Our comparatively blasé authority, A. H. Cook writes:

> The relevance of G to the rest of physics is slight. The other principle constants of physics form an interconnected set and a good knowledge of their values has consequences in both fundamental theory. . . and in practical measurement of high precision. . . Almost no such requirements or implications apply to knowledge of the value of G. It is, so far as is known or postulated. . . independent of all the other constants. [123]

By contrast, our most compelling reflection is given by I. J. R. Aitchison:

> Could the dimensions of Newton's gravitational constant be explained. . . by a theory of gravity characterized by a fundamental mass (or length) and a dimensionless strength? Could we then unify all the forces?. . . Something new is needed. [124]

Notice that our first expression (Equation 35, including the factor c^2) fulfills all three ideas in Aitchison's prescription: The fundamental *mass* is that of the electron. The fundamental *length* is the Bohr radius. When the ratio of these two constants is multiplied by the light constant squared we get an elementary acceleration of volume per mass. Finally, the *dimensionless strength* is the ratio between the extremities of known, commonly occurring physical densities. As we might reasonably expect, every regime of the Universe is thus represented in our interconnected set of constants: nuclei, the cosmic background, atomic matter, and radiation by light.

All of these quantities have been measured, leaving us with an expression that is at least very nearly true, whether by accident or because it is a potent clue, a conspicuous and explicit invitation to yet deeper physical truths. It seems rather obvious that G must be related to the rest of the constants *somehow*. What else could it be? Why shouldn't this be it?

Standard approaches to unification are unlikely to involve the CBR, because it is presumed to be not a constant. The standard hypothesis is that the temperature of the Universe always changes. In the most unrealistic extreme, its initial value at $t = 0$ was infinite. Being fully aware that this is unrealistic, quantum cosmologists scoot ever so slightly forward from this so-called Planck era, and surmise that at a "Planck time," $t_\text{P} \approx 10^{-42}$ sec *after* $t = 0$, the Universe had something close to the "Planck temperature," $T_\text{P} \approx 10^{32}$ K. Thenceforth it approaches zero forever. Its *present* value therefore has no fundamental significance.

What has no fundamental significance, from the SGM point of view, is the contrived system of *Planck units*. None of them have ever been shown to have *any* connection to physical reality, making their role at the fantasy birth of the Universe, all the more far-fetched. It seems to me that quantum cosmologists will not figure out how to *meaningfully* interconnect their set of constants with G until they ask and figure out what matter *does* to produce gravity. This question leads to a cosmology in which the Universe had no primeval state. Most importantly, it leads to a *test* of cosmological import that could be done in a relatively modest Earth-based laboratory.

Physicists celebrate what they perceive as the success of GR because its exterior solution has passed a variety of tests. By combining GR's cosmological solution with standard ideas about particulate matter (inflation) modern cosmologists have extended the theory to the Universe beyond. Meanwhile, the *interior* solution remains untested. This is no small oversight. The interior solution represents the most ponderable half of the gravitational Universe. Until we have inspected that half, which is right under our feet, right under our noses, we clearly run the risk of barking up a lot of wrong trees if our *assumed* understanding of the interior turns out to be wrong.

Presently we pursue our hunch that accelerometer readings are to be trusted. This leads in turn to the idea that the insides of material bodies—from nuclei to planets and galaxies—are as perpetually running engines that prop up themselves and the Universe, by simultaneously generating ever more matter and ever more space. Our path thus connects the small and the near to the large and the far in a comprehensive new way. Matter, space, and time are now seen as the continuous and interdependent physical elements of the Universe, whose unification is manifest as gravity and inertia. We are therefore delighted, but not surprised to find a connection between G and the temperature of the CBR, the nuclear saturation density and the rest. Altogether, it is strongly implied that questions of cosmic significance would be among those answered by the results of Galileo's experiment.

13. – Cosmological Connections to Local and Atomic Physics

> *Slight not what's near through aiming at what's far.* — EURIPIDES (455 BC) [125]

> *[Our visual impressions do] not answer the question: what moves? The usual definition that it is **matter** which moves is not very helpful since we can hardly say that we know exactly what matter is.* — ROBERT B. LINDSAY *and* HENRY MARGENAU [126]

13˙1. *Loose Ends*. – Before continuing with our cosmological implications, let's reorient ourselves and reassert our strategy. Modern physicists are generally very good at thinking mathematically. The persistence of various deep problems in fundamental physics therefore indicates the likelihood that these problems are *not mathematical*. If they were mathematical, they'd have been solved long ago. This very point was made even by Dirac, who is well known for his reverence for mathematics and for stressing the importance of seeking beauty in one's equations. Seeing the limitations of this strategy for solving the fundamental problems of physics, Dirac said: "It is quite possible that they will require wholly new ideas. In fact it's pretty certain they will; otherwise they would already have been thought up." [127] Echoing back to Smolin's comment about the dire need for "seers" in physics, this remark makes it evident that physics is stuck because crucial *conceptual* problems have not been solved. Ironically, not having even roughly the right idea, being nowhere near the right track compounds the problem of finding it. It does not help that physicists often exhibit a great deal of *confidence* in the soundness of their conceptual foundation; e.g., fixation on symmetry, conservation laws, and the correctness of Einstein's relativity theories. These things they clutch, because it's all they "know." From our present perspective these foundations appear unreliable. We are eager to question and to let go of them if they fail the test (of Galileo).

Stripped to its essentials, our strategy for understanding physical reality is simply to be alert to the most meaningful *distinctions*, that we may perceive the most fundamental *relationships*. We have thus tried to emphasize both the contrasts and the similiarities between standard and SGM-based conceptions of space, time, matter and gravity. Although physicists who concern themselves with foundational issues sometimes state their suspicions that a substantial revision of current ideas may be needed to break out of a long period of stagnation, few if any would anticipate the kind of shakeup that is implied by the SGM. Therefore, it would hardly be possible to palatably convey what the SGM even is except by repeated, sometimes negative, references to the standard picture, and sometimes to alternatives that have been proposed but did not bear fruit.

To augment the coherence of the new model, in what follows we will extend the emerging constellations on our sky of thought to several concepts borne of the standard picture that, I will argue, make more sense or can be understood more clearly from the SGM perspective. These include the following questions or ideas:

1. Matter–light dichotomy
2. Energy conservation puzzles; energy location puzzles
3. Mach's Principle-inspired cosmic interconnections
4. Cosmological constant problem; dark energy (vacuum) problem
5. Stability of matter problem; infinite self-energy problem

Most of these issues arise in the context of QT and in the relationship between QT and the rest of physics. It's not just that these subjects cohere (or dissolve) more reasonably or convincingly from the SGM perspective. Each one also bears on what may seem to be the strongest objection to the SGM. *Energy conservation* is often referred to as one of, if not "the most sacred law of physics." [128-131] Even allowing that the law has not been (and therefore should be) tested inside matter does not facilitate seeing how the result of Galileo's experiment should be expected to violate the law. *How can it be* that matter and space keep increasing as the SGM predicts? *How can it be* that this perpetual increase is the essence of gravity, in flagrant violation of the energy conservation law? Each one of the topics above will contribute some evidence which comes together to support the SGM's thesis that energy in the Universe is perpetually increasing. The discussion will show, furthermore, that in spite of the SGM's radical novelty, its description of Nature harmonizes with a wide range of ideas that fit only with a degree of discord, if at all, within the standard scheme from which they arose.

13˙2. *Clock-like Matter; Timeless Light; Conservation of Energy.*

> There are no sacred cows in physics. Laws of physics such as conservation of energy, or whatever, are made to be tested. — SHELDON LEE GLASHOW [132]

> Time keeps on slippin', slippin', slippin', into the future (tick, toc, tick). — STEVE MILLER BAND [133]

The difference between matter and light has played a crucial role in our cosmological model without much explanation. Both matter and light are forms of *energy*, which, under certain circumstances are known to be convertible from one to the other. For example, an atom (matter) in a so-called excited state, is likely to emit some light, by which process the atom's energy will be lowered. The emitted light carries some of the once-localized energy off into space. Before emitting the light the atom actually weighed more than after the emission because the total energy (atom after emission + emitted light) stays the same. According to our cosmological model, however, if the light's energy is measured only after traveling a cosmological distance, then the energy sum would not be the same; the light will appear to have lost energy, as revealed by its redshift.

A few cosmologists over the decades have proposed explaining the redshift as being due to a so-called *tired light* effect. Somehow during the course of its transit, according to their hypothesis, the light's energy diminishes. As explained above, the SGM posits not a decrease in the light's energy, but an increase in the energy (mass) of all surrounding atoms while the light was en route. The increased energy of the surrounding atoms corresponds to an increase in the rates of their clocks. The question naturally arises, if all cosmic proportions stay the same, if the energy of *matter* is supposed to increase with cosmic time, then why not also the energy of *light*? In a nutshell, the answer is that matter is clock-like, but light is not; light is, in a sense, timeless.

A more comprehensive answer is in order. Let's begin by considering a few humbling facts about the prevailing understanding of energy. This will take us to a brief digression concerning the difficult challenge of living up to the ideals of science. In his renowned *Lectures on Physics*, R. P. Feynman (*et al*) admits that, "It is important to realize that in physics today we have no knowledge of what energy *is*. . . We do not understand the conservation of energy." [134] Feynman's discussion is centered around *gravitational* energy, which he concludes is conserved. Although he duly insists that "it is always necessary to check. . . experimentally," Feynman is satisfied with results found only *over* the surface of a gravitating body. He fails to realize that he (and everyone else) has thereby left what may be the most important part of the gravitational Universe—*below* the surface, inside matter—*un*checked. His conclusion is thus premature because it is unwittingly based on a large unjustified extrapolation.

382 years ago Galileo proposed a way to check this particular extrapolation—by dropping a test object ("cannon ball") into a hole through the center of a larger massive sphere. As noted earlier, this problem is common fare in introductory physics courses and textbooks. However good it was of Feynman to admit that "we don't understand energy conservation," he commits the same oversight as the rest of his peers by tacitly pretending that he knows what happens inside matter. If he had seen fit to look ("check") instead of just guess, we might have long ago learned something new about "what energy is." The *faux pas* of Feynman and the whole community of physicists, flies in the face of the following advice of Herman Bondi:

> It is a dangerous habit of the human mind to generalize and to extrapolate without noticing that it is doing so. The physicist should therefore attempt to counter this habit by unceasing vigilance in order to detect any such extrapolation. Most of the great advances in physics have been concerned with showing up the fallacy of such extrapolations, which were supposed to be so self-evident that they were not considered hypotheses. These extrapolations constitute a far greater danger to the progress of physics than so-called speculation. [135]

This remark stands as a succinct declaration of the ideals of science, as does Feynman's above remark about "checking experimentally," and Glashows opening quote about the perpetual vulnerability of *all* of the laws of physics. Lip service to ideals is common and easy; living by them is rare and hard. This digression serves as a partial answer to those readers who may wonder why—in spite of its great potential importance—Galileo's experiment has not yet been carried out.

From issues of human fallibility, let's now return to physics. In a discussion about how energy-matter convertibility complicates our understanding of energy, matter, and its presumed conservation in the context of GR, Roger Penrose begins by asking: "What indeed is matter?" His point is that the best answers given by current theory—whether QT is included or not—come up short:

> The energy—and therefore the mass—of a gravitational field is a slippery eel indeed, and refuses to be pinned down in any clear location. Nevertheless it must be taken seriously. It is certainly there, and has to be taken into account in order that the concept of mass can be conserved overall.
>
> Even before we need consider the mysterious effects of quantum theory, our theories of physics tell us that there is something very odd and counter-intuitive about the nature of matter. We cannot at all draw a clear dividing line between what we call 'matter' or 'substance' and what we call 'empty space'—supposedly, the voids entirely free of matter of any kind. Matter and space are not totally separate types of entity. Actual substance need not be clearly localized in space. These are hints that our treasured intuitive views as to the nature of physical reality are less close to the truth than one would have thought. The nebulous and non-local additional features that the quantum theory injects into our picture of the world greatly strengthen this conclusion, but such conclusions must already be drawn on the basis of classical theory. We must expect, also, that future theory will provide us with yet further shocks to our cherished intuitions. [136]

Astute readers will connect this ambiguity in the location of gravitational energy with the ambiguity manifest by the Equivalence Principle, i.e., the mixing of staticness with acceleration. It is also compounded by the assumption that gravitational energy is a *negative* quantity. If it were possible to distinguish one state of motion from another—e.g., by consulting accelerometers and clocks, and consistently regarding what these motion-sensing devices are telling us about the difference between what accelerates and what does not, between what has an absolute velocity and what does not, and what portion of the measurements refer to motion *through* space compared to the portion of motion *of* space—this ambiguity would be eliminated. But eliminating the ambiguity comes at the "cost" of violating energy conservation. Penrose and his fellow physicists do not think of this as an option, so they keep slipping and sliding like their elusive eel. We will return to these issues in later sections.

Inspiring or disconcerting as Penrose's remarks may be with regard to gravitational energy, their connection to our concern over the matter-energy/light-energy dichotomy is indirect. Addressing the latter concern more directly then, we begin by asking: How can it be that one is "clock-like" and the other not? Let us appeal to the thoughts of another well respected physicist. On the basis of Quantum Theory, SR, and observational evidence, David Bohm describes matter and light as different forms of *movement*:

> The transformation of "matter" into energy is just a change from one form of movement (inwardly, reflecting, to-and-fro) into another form (e.g., outward displacement through space).

> If rest mass [matter] is "inner" movement, taking place even when an object is visibly at rest on a certain level, it follows that something without "rest mass" has no such inner movement, and that all its movement is outward, in the sense that it is involved in displacement through space. So light. . . may be regarded as something that does not have the possibility of being "at rest" on any given level, by virtue of cancellation of inner reflecting movments, because it does not possess any inner movments. As a result it can exist only in the form of "outward movement." [137]

This description suggests the satisfying idea—connecting back to the deBroglie frequency relation (Equation 8) that launched our cosmological excursion—that these "inwardly reflecting to-and-fro movements" are as the *ticking* that makes matter clock-like. This is in contrast with the absence of such movements that make light correspondingly timeless. As the speed of a moving clock approaches the speed of light, its ticking rate decreases. In the limit of the speed of light itself (which is not reachable by matter) the ticking rate becomes zero. It has thus been said that "time stands still for the photon."

It is then not much of a stretch to build on Bohm's description by conceiving matter as being, in a sense closed, knotted, locked (engaged) energy; whereas light is open, untied, unlocked (disengaged) energy.([5]) According to the SGM, the matter-light dichotomy is manifest not only by virtue of matter's being clock-like, but by its being *hooked up* to (engaged with) the whole clockwork Universe. This may sound a little more poetic than scientific, but we will offer at least three arguments or echoes of support.

The first supporting argument is simply the SGM's expression for Newton's constant,

$$G = 8\left(\frac{\rho_\mu}{\rho_{\mathrm{N}}}\cdot\frac{c^2 a_0}{m_{\mathrm{e}}}\right). \tag{36}$$

The presence of the CBR radiation density constant in this equation means that even local gravitational effects somehow depend on the magnitude of the background temperature. If the temperature were zero, there would be no gravity because there'd be no Universe. We will see below that, even from the standard view, matter in the Universe is undergoing such vigorous internal to-and-fro movements that we have reason to be amazed that everything nevertheless hangs together with a great deal of order. In fact, within the context of quantum field theory, the stability of matter has still not been adequately explained. The SGM suggests a connection by which the vigorous motions within matter extend, of necessity throughout space (in a well-timed orderly way) because they are ultimately continuous with each other. Equation 36, our definition of G, must either be a meaningless coincidence or a profound truth. If the latter, as we suppose, then it strongly implies confirmation of Barrow and Webb's stated hope of "show[ing] that each of the constants of nature could have only one logically possible

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([5]) It is important to maintain perspective by never forgetting how *very much* energy is contained in a small "inwardly reflecting" package of matter. *One gram* of matter, when converted to energy, corresponds to the amount of energy released in the explosion of an atomic bomb. In less destructive terms, it's the amount of energy generated in about 18 hours by the Hoover Dam. It's the amount of energy involved in heaving a 10 meter thick $\times$ one square kilometer slab of steel 10 meters upward against gravity. *One gram*—all this energy is "tied up" and ticking away inside every single gram of matter. Amazing fact.

value." [106] It strongly implies that space and matter are exquisitely coordinated *in time*, from intra-nuclear ticking to intergalactic redshifts.

Our second "echo" of support for the idea of a temporal/cosmic "hookup" is found in a curious argument in defense of the Big Bang theory by the philosopher of science, Adolph Grünbaum. At issue is the question of the creation of the matter of the Universe; it bears both on our present concern for the clock-like nature of matter as well as on the issue of energy conservation. Grünbaum argues that the Big Bang theory does not have the problem that is sometimes claimed of it; that it is a "pseudo-problem." To make his case he sets up a historical idea (proposed by Descartes) as a straw man:

> The question of creation is just as ill-posed in the context of the recent rival physical cosmologies as was the following sort of problem, which agitated philosophers until the middle of the 18th century: Why do ordinary material objects (e.g., tables) not simply vanish into nothingness?... There were thinkers until at least the 18th century ... who took this question very seriously.
>
> [Grünbaum quotes Descartes' answer:] "It is as a matter of fact perfectly clear and evident to all who consider with attention the nature of time, that, in order to be conserved in each moment in which it endures, a substance has need of the same power and action as would be necessary to produce and create it anew, supposing it did not yet exist." [138]

To Grünbaum, Descartes' idea is so weak and so much like that of the modern authors he argues against, that by showing the fallacy of the former he presumes to show the fallacy of the latter. Admittedly, Descartes does eventually appeal to the hand of "God," which is surely inadmissible. But before doing so (or at least by considering only the passage quoted above) I'd say his argument contains at least a kernel of truth. From the SGM perspective, in fact, we see fit to turn the whole discussion around by siding with Descartes!

By considering "with attention the nature of time," Descartes hits on an idea that sounds curiously similar to exponential expansion. To maintain itself, i.e., to give the impression of being "conserved," exponential expansion needs an ever increasing "power and action" operating *in time*—always in proportion to how much already exists at a given time. If this process were to *stop*, if time stopped, then all accelerometers would suddenly read zero. Tables, and everything else would indeed vanish, because matter and space would lose the most fundamental properties that characterize them. Forward motion in time is absolutely essential, by the SGM, to cause non-zero accelerometer readings, to exhibit inertia, to generate space, and to generate the medium through which light propagates.

Clearly, however, it is not just *time* that facilitates the stable existence of things, it is also *timing*. Without some kind of cosmically coordinated *regulation* of the power and action by which matter and space manifest themselves, chaos would ensue. With the SGM in view, we infer from Descartes' remark, that the forward direction, i.e., the *perpetual increase* of time, is related to the importance of *timing*, both of which are essential to insure the stable persistence of tables, chairs, and everything else.

In anticipation of our next subsection on the cosmological constant problem, and to clarify an important point bearing on the present discussion, another remark on the role of energy conservation in GR is in order. A prevalent (but not universal) way to interpret energy conservation in the context of general relativistic cosmology is that globally, energy is *not* conserved. Sean Carroll has adopted this interpretation and gives his reasons for doing so on his blog. [139] Especially when augmented by the "dark energy" that is supposed to be accelerating it, the Big Bang-like expansion of the Universe entails a perpetual increase in energy because the speeds of the mutually receding galaxies keep increasing.

We get a rough idea how this works by considering the galaxies within, say, a cosmic radius, at two points in cosmic time. At the later time, both cosmic radius and the alleged recession speed between any two galaxies will have increased. Therefore, the energy associated with this set of galaxies has increased and will keep increasing (approaching exponentially) as what is propelling them is the ever-increasing vacuum energy in the ever-increasing volume of space. The *source* of the energy increase in this picture is seemingly empty space that acts discontinuously from matter (like magic). When accounted for this way, the energy change is not locally measurable because it is spread out too thinly. The whole thing is supposed to happen without affecting any accelerometers anywhere. Global physics is not related to local physics.

Is it not more reasonable to suppose that the large scale *global* effects are the *result* of the sum-total of physically measurable *local* effects? In both cases (accelerating Big Bang and SGM) energy increases. But in the second case we can account for all of it without magic. By seeing the essence of matter as its highly localized outward motion, the otherwise "slippery eel" of gravitational energy would transform into concretely graspable (clock and accelerometer-measurable) hyper-dimensional motion. Global increase of energy would then correspond to the sum of all the local energy increases.

Coming curiously close to this picture is our next supporting argument for the idea of a comprehensive *clockwork* Universe; i.e., some of the work of Robert H. Dicke. Dicke was well known both for his experimental and theoretical research into gravity and cosmology. [140] His cosmological theory possesses a similar function as what we've called a temporal cosmic *hookup*, but he refers to it as a *scalar field*. Mach's Principle was a motivating factor in Dicke's theory. One of the key assumptions Dicke made in his attempt to satisfy Mach's Principle was the same as our Equation 21:

$$R_{\mathrm{C}} = \frac{GM_{\mathrm{C}}}{c^2} \qquad \text{or} \qquad \frac{GM_{\mathrm{C}}}{R_{\mathrm{C}}c^2} = 1\,, \tag{37}$$

Many authors have regarded this equation as being of fundamental cosmological significance. But, as we have seen above, by the prevailing ideas about gravity and the alleged recession of the galaxies, Dicke's R_{C} is not constant. The cosmic radius increases so that to keep the equation true, authors such as Dicke, Dirac, and others have suggested that the value of Newton's constant changes with time. Observational evidence does not support this hypothesis. Another possibility that Dicke was bold enough to suggest is that, even if G were constant, the equation could be satisfied if M_{C} increased along with R_{C}. The idea is that for all the mass within the cosmic radius to change, the masses of individual bodies must also increase to make it so. It should be emphasized that Dicke still believed gravity to be an attraction and cosmic redshifts to be due to a velocity of recession. Yet he conceived this equation to have a meaning that ostensibly resembles our own:

> [If] the gravitational constant is fixed... [Equation 37 could mean that] the masses of the particles would adjust themselves appropriately, in such a way as to give M/R the appropriate value.
>
> It is as though the Universe is a giant servosystem, continuously and automatically adjusting particle masses to the value appropriate to the feedback condition $GM_{\mathrm{C}}/R_{\mathrm{C}}c^2 = 1$. [140]

As mentioned above, Dicke imagines this "feedback condition" as being effected by a new *scalar field*. It is beyond the scope of this essay to speculate as to the detailed machinery by which such coordination comes about. But a pattern is clearly emerging, I think, with enough physical and mathematical facts and ideas to establish that it might plausibly be so. We have global non-conservation of energy (Carroll) and we have a *globally coordinated* increase of all particle masses (Dicke). With these ideas on the table, standard physicists were one step away from the SGM, which is to associate the global energy and local mass increases with each other, and with that which flattens our undersides.

The work of Dicke and the rest of the exposition above at least brings to our attention the remarkable fact that tables, atoms, planets, etc., do cohere and maintain their integrity, their inertia, their gravity and their surrounding space over vast stretches of time and space. As we will see momentarily, the existence of some kind of profound coordination ("giant servosystem") is implied by certain basic facts of electromagnetism and quantum theory.

13˙3. *Cosmological Constant Problem.*

> The universe says to the quantum field theorist, "I am doing just fine, thank you, but something is wrong with your understanding of the vacuum energy, or your understanding of how the gravitational field responds to the vacuum energy."
>
> A distinguished colleague said to me recently, "The cosmological constant paradox is more than a paradox; it's a profound public humiliation of theoretical physicists." [141] — ANTHONY ZEE

Through decades of rigorous training, physicists have been trained to not see that there are some things they've been trained not to see. One of these things is the possibility that gravity has nothing to do with attraction between bodies. In other words, the *definition* of gravity is wrong, because it is based on the illusion of static chunks of stuff. Through a fantastic maze of carefully crafted *laws* and abstract *principles*, unconsciously designed to maintain this illusion, they have come to a *humiliating paradox* that promises not to evaporate until the initial misconceptions concerning gravity and matter are corrected. This is the assessment borne of the SGM perspective.

The cosmological constant Λ, was born in 1917. It played a few bit parts in cosmology through the middle of the 20th century. In the late 1960s Zel'dovich framed its possible connection to atomic physics more comprehensively than the few scattered previous attempts to do so. To the effect that Zel'dovich's work thus represents a kind of milestone for Λ, Peebles and Ratra explain that

> The modern era begins with the paper by Zel'dovich (1967) that convinced the community to consider the possible connection between the vacuum energy density of quantum physics and Einstein's cosmological constant. [142]

Though having gained some respectability due to the work of Zel'dovich, the cosmological constant's appearances in the following three decades were still relatively minor, till its big break in 1998. The reason for the big break and the corresponding cosmological implications will be discussed below. First, however, we will address the reasons for its association with atomic physics. (For a more thorough chronology of these developments, the Peebles and Ratra paper cited above is to be recommended.)

Up to now I have loosely referred to "atomic physics" as meaning Quantum Theory. For what follows it will be good to tighten our nomenclature. It has sometimes been explained that the somewhat loose term *Quantum Theory* encompasses specific theories sharing the basic feature that the unfolding of events can be presented on a graph having time as one axis and space as the other axis. Sean Carroll points out that this is "true for classical mechanics as put together by Newton, or for general relativity, or for quantum mechanics, all the way up to quantum field theory and the Standard Model of particle physics." [143]

Carroll's list should arguably include SR between Newtonian mechanics and GR. In any case, its main benefit for us is in suggesting a hierarchical order amongst closely related atomic theories. The most basic, Quantum Mechanics, is typically understood to mean the non-relativistic theory of light and matter—which means including the wave nature of matter without including effects due to the limiting speed of light. Nor does it include phenomena besides electromagnetic ones, originating from atomic nuclei. Quantum Field Theory (QFT) is the generic name for atomic theories that include relativistic effects and nuclear phenomena. The Standard Model (SM) of particles and fields is regarded as a particular instance of a quantum field theory. The SM is often seen as encompassing at least two sub-instances of QFT, known as Quantum Electrodynamics (QED) and Quantum Chromodynamics (QCD). QED refers to the fully relativized and quantized theory of electromagnetism. QCD refers to the relativistic, quantized theory of the "strong force" in atomic nuclei. Within the SM, the nuclear "weak" force is typically thought of as being merged with QED, resulting in a somewhat more comprehensive form of QED known as "electroweak" theory. Having spelled out these distinctions, I will still refer generically to atomic physics as Quantum Theory (QT), unless there is a compelling need to pick out a specific theory.

For many good reasons the SM is widely regarded as one of, or perhaps *the* most successful theory in the history of physics. Our concern is not the successes but the huge or paradoxical loose ends and enigmas it has spawned. The word *huge*, as it turns out, actually understates the most notorious loose end: the *cosmological constant problem*.

The most general form of Einstein's gravitational field equations includes a constant that represents the behavior of space, independent of matter. If this constant, Λ is negative, it represents an augmentation of the space-*eliminating* effect of attractive gravity. Whereas if Λ is positive, it represents the opposite: a space-*creating* effect, sometimes characterized as a repulsive force. QT also predicts the existence of a space-creating repulsive force that is similarly independent of matter. With the hope of unifying GR with QT, theorists have sometimes considered associating these so-called vacuum energies with each other. Einstein's theory does not specify a sign or magnitude for Λ, leaving them to be determined by observation. Whereas QT does predict both a sign and a magnitude for its vacuum energy. What makes the cosmological constant a *paradoxical problem* is the difference between its predicted magnitude based on QT and observation. The "humiliating" discrepancy is often quoted as being on the order of 10^{120}.

The effect that Λ has on two separated bodies of matter (e.g., galaxies) is supposed to depend only on spatial distance. This means that within a given fixed volume the repulsion is always the same. But since distances and volumes are supposed to be increasing overall, the "repulsion" between two widely separated bodies keeps increasing. As the effect of attractive gravity keeps diminishing by the increasing dilution of the Universe, the repulsive (space-creating) effect ever more closely approaches that of a deSitter-like exponential expansion. Since 1998, when astronomers claimed to observe long-distance repulsive effects in the cosmos, Λ has sometimes been referred to as *dark energy*. Speculations have been proposed that the measured effect is due to something other than Λ, something whose effect would vary in time or space, unlike what we've described above. But the cosmological constant is widely regarded as the most likely candidate.

A more detailed discussion about the possible connection between Λ (borne of GR) and QT will be given later, after we've learned more about QT itself. As a preview, it is worthwhile to point out here that, according to QT, the repulsive energy of the vacuum is supposed to be *infinite*. That's the answer given by the strictest interpretation of the theory. Since we do not readily see an infinitely energetic repulsion going on around us, it has been assumed that the predicted effect should somehow get cancelled by some other effect that has escaped notice. It has also been assumed that the infinities predicted by QT are due to its being a somehow incomplete "effective" theory that will be replaced or subsumed in the future by a more comprehensive, more mathematically sound theory wherein QT's infinite answers are replaced by finite answers. It is often anticipated that, in this more comprehensive theory, physical quantities derived from the so-called Planck-scale will play a major role. It is commonly guessed that in this still elusive theory, a Plank scale *cut-off* should be applied to calculations involving the vacuum energy. If this is a correct guess, it would bring the disparity down from infinity to only 10^{120} times greater than what is suggested by observations.

It is important to note that the astronomical evidence is indirect and that its standard interpretation involves a chain of assumptions that the SGM does not agree with. We'll come back to that. Regardless of the standard interpretation's validity, the fact remains that QT predicts an effect that appears to be in gross conflict with experience. This is what motivated the remark by Zee's colleague—quoted above—that "the cosmological constant paradox is more than a paradox; it's a profound public humiliation of theoretical physicists." Zee himself calls the disparity in magnitude "the mother of all discrepancies." [144] Nobel Prize winner Frank Wilczek has written, "We do not understand the disparity. In my opinion it is the biggest and worst gap in our current understanding of the physical world." [145] And Nobel Prize winner Stephen Weinberg has been quoted as saying the problem is like "a bone in the throat." [146]

It has sometimes been pointed out that 10^{120} can be considered an exaggeration because other accounting procedures yield smaller ratios. Even the smallest of these is still *many orders of magnitude* away from what physicists expect to see in the real world. The cosmologist Sean Carroll thus concedes that "Our guess was not very good. . . This is the discrepancy that makes the cosmological constant problem such a glaring embarrassment." [147]

Many factors bear on the problem, from atomic to cosmological physics. A few of them will be discussed in the following sections. In what remains of this section, we present the primary astronomical data involving the observed brightness of distant supernovas. In Figure 22, the earliest observations correspond to the data points from near the middle toward the low redshift end of the curve. Since 1998, lots of other observations have contributed to the plot. Four different theoretical curves are also shown. Plots like this are known as *Hubble diagrams*, which relate redshift with luminous magnitude. [148, 149] In astronomy, *magnitude* is a measure of brightness on a logarithmic scale in which larger numbers indicate dimmer light sources. It was expected that the data would more closely match the lower (black) curve. Based on the observational data, a so-called "concordance" model—sometimes referred to as the Lambda Cold Dark Matter (Λ-CDM) model—was built to accommodate it (red curve). It is readily apparent, however that the SGM prediction (blue curve) agrees nearly as well.

The possibility of comparing observational data to theoretical curves depends on the existence of astronomical objects that can be regarded as standard candles. That a Type Ia supernova constitutes a pretty good approximation to a standard candle has

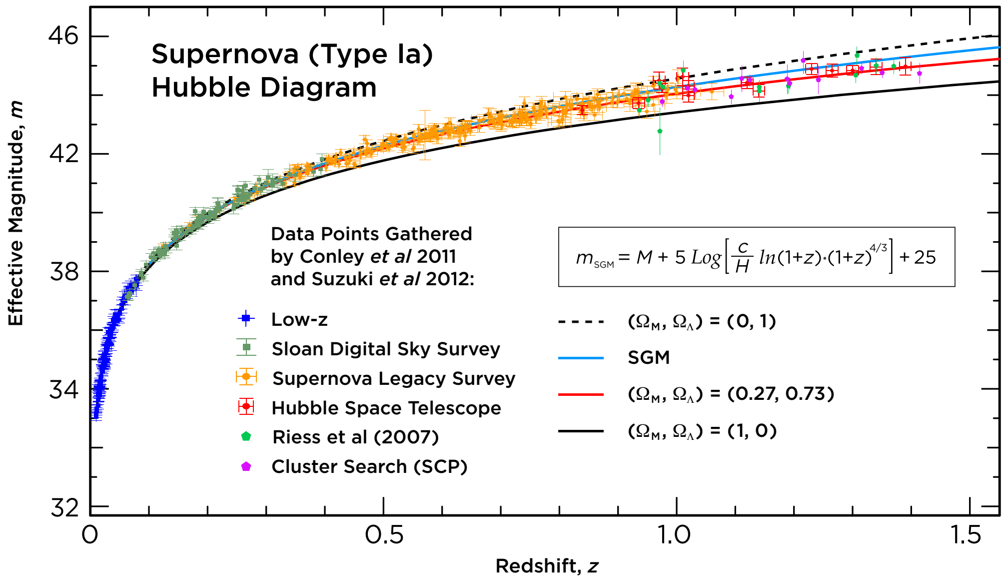

Fig. 22. – Redshift-Magnitude (Hubble) Diagram for Type 1a Supernovae. Data are from various sources. Upper and lower curves indicate extremes of Λ and matter-dominated Big Bang models, respectively. Red curve is "concordance" Λ-CDM model with common distribution of Λ and matter. Blue curve is SGM prediction. Equation for SGM curve is shown; derivation will be given elsewhere. Scatter at high-z end of curve suggests that more data would be desirable.

been claimed on the basis of empirical regularities in the flare-up and subsequent fading of these stupendous objects. Attempts have been made to construct Hubble diagrams based on another class of objects, known as Gamma Ray Bursts (GRB). Since these objects are so much brighter than supernovas, such diagrams substantially extend the redshift range. Unfortunately, GRBs are much less like standard candles. A variety of arguments have nevertheless been proposed by which they can be calibrated to serve the same purpose. [150, 151] The result of this is shown in Figure 23. Scatter at the high-z end once again indicates the need for more data. And once again the SGM curve appears to be a pretty good fit to the given data.

Derivation of the SGM equation for the Hubble diagram is beyond the scope of this essay. We will, however provide more qualitative justification for it. We will find that the SGM prediction connects back to our earlier discussion of the matter-light dichotomy, energy conservation and the Equivalence Principle. This will make more sense after giving a brief synopsis of QT and its history. What we find in the end is that the SGM provides a viable and testable model according to which $\Lambda = 0$ and dark energy is not needed, because the whole effect is due to gravitating matter; not a mysterious repulsive force or discontinuous creation of space between static chunks of stuff.

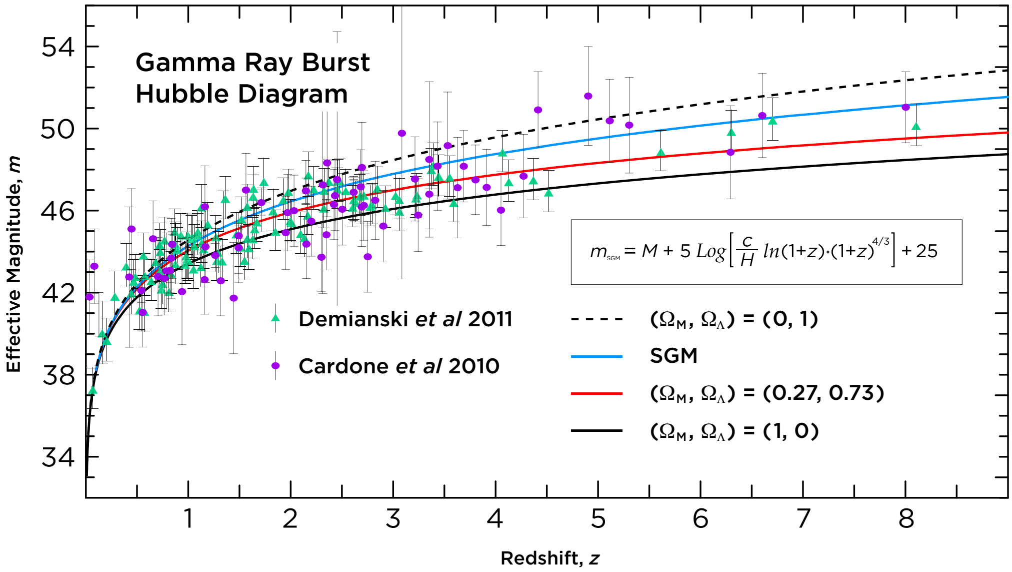

Fig. 23. – Redshift-Magnitude (Hubble) Diagram for Gamma Ray Bursts. Data are from the indicated sources. Upper and lower curves indicate extremes of Λ and matter-dominated Big Bang models, respectively. Red curve is "concordance" Λ-CDM model with common distribution of Λ and matter. Blue curve is SGM prediction. Equation for SGM curve is shown; derivation will be given elsewhere. Scatter in data is expected because GRBs are less like standard candles than Type 1a supernovae. Much more data and a better understanding of GRBs are needed.

14. – Roots of Quantum Theory

> *The modern physicist is forced to admit, with some embarrassment, that although he can formulate a powerful and beautiful mathematical theory of atomic and molecular behavior, he cannot be sure he knows exactly what the theory means.* — WILLIAM H. CROPPER [152]

14·1. *Ubiquity of Perpetual Motion*. – However perplexed they may be about the idea—borne of a chain of questionable assumptions and indirect evidence, that seemingly *empty* space accelerates its own expansion, exclusive of matter—physicists have nevertheless come to *accept it*. By contrast, everyday we see and feel *direct concrete evidence* that we and everything around us *accelerates*. Yet physicists emphatically *do not* accept it. They do not even consider it because to do so would be to violate their ancient preconceptions of staticness, symmetry, and (local) energy conservation. They seemingly *refuse* to draw a line of connection between the "dot" of positive accelerometer readings and the "dot" of cosmological redshifts. Why are they not *tantalized* by the temptation to do so? They just don't see it.

An insightful observation by one of the founders and long-time critic of QT, Erwin Schrödinger, helps to explain this. The more recent author, William Cropper, introduces Schrödinger's work as being exceptionally eloquent and humanistic:

> To the conceits that physics was non-existent before Newton and that the concepts of quantum physics are unique and new [Schrödinger] answered, "...quantum theory dates 24 centuries further back to Leucippus and Democritus. They invented the first discontinuity—isolated atoms in empty space." And "...physical science in its present form...is the direct offspring, the uninterrupted continuation of ancient science." [152]

The actions of modern physicists can be seen as simply to uphold this long tradition. We must nevertheless ask whether there are any *scientific* reasons for clinging to staticness and discontinuity. Does anything physicists may know about the nature of matter, from theory or experiment, prove by contradiction that our new conception of gravity—as a process of vigorous outward movement of matter and space—must be wrong? In other words, beyond our ancient visual impressions, do we have any definitive theoretical reason to continue treating bodies of matter, in the gravitational context, as discontinuous chunks of stuff?

The answer is a most definite, NO. Not only is there no disproof of the idea, there are many reasons to infer that the intense and ubiquitous motions taking place inside matter are *likely* to be manifest also in the context of gravity. We have already encountered some indications of this in the internal to-and-fro clock-like movement of atomic matter, as described by Einstein, Bohm, and the connection via deBroglie's relation (Equation 8) to a deSitter-like *non-static stationary expansion*. Let's now add some details so that the numerical relationships we've uncovered between the atomic and cosmic realms acquire more physical meaning.

14˙2. *Thermodynamic-Electromagnetic Background*. – The birth of QT was the result of attempts to reconcile some theoretical reasons to expect matter to be grossly unstable with the observable fact of its stability. Near the end of the 19th century Maxwell's theory of electromagnetism had been established and physicists were busily engaged in exploring its consequences. Thermodynamics was also beginning to mature as a science. The confluence of these new sciences, where matter, light and heat come together, was an area of intense study. It forced contemplation of the microscopic structure of matter, which most physicists believed was atomic, i.e., made up of tiny discrete units of the elements in Mendeleev's awe-inspiring table. When combined with Newtonian mechanics, Maxwell's theory worked beautifully (for most purposes) to describe the bulk behavior of the relationship between *charged* or *magnetized* bodies of matter and light. But this combination ran into contradictions in all attempts to extend the picture to the physics of atoms.

Given the level of theoretical and technological development achieved by turn of the (20th) century physicists and engineers, it is quite remarkable that they pieced their clues pertaining to the realm of atoms together as well as and in so short a time as they did. A few of these clues are as follows. Maxwell's electromagnetic theory predicted that oscillating electric charges would emit or absorb radiation (light). This was demonstrated for the first time by Hertz in 1888. In the context of thermodynamics, specifically in the behavior of gases as they were used in the function of heat engines, the atomic hypothesis was successfully applied. Maxwell made major contributions here too, having derived statistical relations representing the distribution of velocities of gas molecules under a range of different circumstances. The velocities were related to the temperature of the gases and the temperature was related to their energy.

At this time the nuclear character of atoms was unknown, though speculations to that effect were soon to emerge, based on the following facts. Thompson had measured the mass of an electron in 1897, the masses of various atoms and molecules had been roughly determined, and (pivotally) the team of experimentalists led by Rutherford were soon (1911) to probe the centers of atoms in gold foils with beams of alpha particles (helium nuclei that were discovered to be spontaneously emitted from radioactive metals). It was possible to deduce from the scattering pattern of the alpha particles that the objects they collided with must be highly concentrated.

Before the first successful model of a nuclear atom could be devised—i.e., a model that related the mechanical properties of its components with their light-emitting and absorbing properties (as it was by Bohr in 1913)—another fundamental and unexpected property of atoms needed to be discovered first. This happened as a result of attempts to understand a puzzle concerning heat and light that persisted as an empirical conflict with theoretical laws that rang true in other contexts.

14˙3. *Planck's Constant*. – The problem was the phenomenon of *cavity radiation*, also known as *blackbody radiation*. The first of these terms derives from the fact that this kind of radiation, which exhibits a characteristic spectral signature, was most commonly seen or created in furnaces or other small heated enclosures where the temperature of the interior of the cavity was maintained in equilibrium with the temperature of the walls. Research on gas thermodynamics by Maxwell and others was applied to the problem. Advances on Maxwell's work by Boltzman concerning the *statistical* breakdown of the molecular motion, and the connection between energy and the new concept of entropy, were all brought to bear on the puzzle. The crucial difference between the analyses involving gas behavior in piston cylinders and cavity radiation is the *radiation*; we are now concerned with the *glow* of the walls.

States of equilibrium were certainly achievable, as had been firmly established by empirical evidence. But the *theories* of thermodynamics and electrodynamics led to the prediction that equilibrium could *not* be achieved! Even without a detailed conception of atomic structure, a seemingly valid approximation was to regard atomic sources and receptors of radiation as a collection of generic linear "oscillators," analogous to masses suspended from springs. Another, in some ways superior, analogy is that of a metal bar that is set into vibration by a percussive blow. It wasn't so much the crudeness of such analogies that explained the theoretical failure; it was, rather, the assumption that radiation could be emitted (or absorbed) *continuously* from (by) the oscillators. Because of its rigorous prediction that the system of oscillators should skyrocket into extremely high vibration frequencies, the failed classical analysis is often referred to as the *ultraviolet catastrophe*.

The catastrophe can be explained in terms of our generic oscillators, as above, or as is often done, in terms of a somewhat more sophisticated image of the nuclear atom. In both cases the problem is that there is no reason to expect a *ground state*, a "bottom" below which the system cannot descend. Instead, the classical picture was of a kind of endless cascade, in which the generic oscillators of electric charge would result in a continual emission of radiation, causing the oscillator's frequency to get higher and higher as energy was lost. The problem can also be expressed as the fact that classically, energy is a function of the *amplitude* of the oscillation; whereas quantum mechanically energy is a function of its *frequency*. By the corresponding nuclear atom picture, an electron in orbit around the nucleus would similarly radiate energy continually, until final collapse into the nucleus. This loss in energy by the continual emission of light was a rigorous prediction of Maxwell's electromagnetic theory. Atoms were thus predicted to be grossly unstable.

Being intimately familiar with the various theoretical and empirical facts, Max Planck, with his keen physical and mathematical insight, found a big step toward the solution in 1900. One of the solution's keys was recognizing that atomic oscillators are not free to emit or absorb light across a continuous spectrum, but only in stepped or *quantized* amounts:

$$E \approx nhf\,, \tag{38}$$

where f is oscillator frequency, h is the fundamental constant, newly derived by Planck, and n is an integer known as the vibrational quantum number. The quantum number n is related to the size of the oscillator or its enclosure, such as a furnace cavity or an atom. When the principle of quantizing the allowable energy increments is applied to the blackbody problem, the result is an equation, derived by Planck, whose graph beautifully matches observations. The peak exhibited for a given temperature becomes progressively higher and more dominated by higher frequencies as the temperature increases. The key success is that the empirical peak is represented by the equation; with respect to frequency the energy distribution rises from near zero on one side and comes back down to near zero on the other side of the peak. There are no catastrophes, just well-behaved oscillators or non-collapsing atoms.

We've just recounted the basic success story, often told, about the birth of QT. To more fully appreciate its significance and it potential relationship with gravity, we need to go further. The ubiquity of Planck's constant h—sometimes referred to as the quantum of action—in the later development of the theory, is especially worthwhile to consider. The constant first emerged in the context of quantization of *light*, but its perhaps even more radical significance, as proposed later by deBroglie, is as an indicator of the *wave nature of matter*. We will have more to say about that in what follows. Presently, note that even in its first appearance, h functions as a kind of *threshold defining regulator*. It is this function in preventing the ultraviolet catastrophe that Boorse and Motz allude to by writing: "Precisely because the roles of the high-energy oscillators are practically eliminated in blackbody radiation by the quantum of action does Planck's theory give the correct spectral distribution of blackbody radiation." Capturing the essence of what was to come, they continue:

> The full significance of the quantum of action h is only now apparent when we see that it appears in all atomic, nuclear, and high energy processes. The presence of h in Planck's formula distinguishes it from the classical radiation formula and we find in general that all quantum formulae are characterized by the presence of this constant.
>
> From all that we know today, it is clear that the variegated structure of the atom [is] possible because h is finite. Thus if h were zero, atoms as we know them could not exist and such things as organic chemistry and life itself would disappear. [153]

A central tenet of the theory that highlights the role of h, is known as *Heisenberg's uncertainty principle*. This principle is prominent in discussions about the stability of atoms and the energy of the quantum vacuum. It relates so-called *conjugate variables*, whose products can approach Planck's constant from above, but never be smaller. One such pair of variables relates momentum and position:

$$h \lesssim \Delta p \cdot \Delta x\,, \tag{39}$$

and another pair relates energy and time:

$$h \lesssim \Delta E \cdot \Delta t\,. \tag{40}$$

These are called uncertainty relations because the more exact our information is about one of the different Δ-quantities, the less can be known about its conjugate. Note that "less knowledge" corresponds to a bigger difference Δ. For example, if Δx is known with near exactitude, i.e., the difference is small, then the range of possible momenta must be very wide. The product of the variables must always be larger than h. This is often explained as being a consequence of the wavelike nature of particles. For its implicit role in the SGM conception of gravity, we will return to the time-energy uncertainty relation later. First, however, a few of the persistently troubling features of QT should be introduced.

15. – Stability of Matter 1: No Catastrophic Collapse; Zero-Point Energy

> *The most glaring characteristic of the vacuum state is that its energy is infinite... The zero point energy of the vacuum is infinite in* any *finite volume.* — PETER W. MILONNI [154]

Another consequence of the wavelike nature of particles is the description of a hydrogen atom as a nucleus (proton) surrounded by an electron cloud. (See Figure 24.) Before the wave-like cloud electron was conceived, the much less fuzzy nuclear atomic model of Bohr depicted the motion of light and tiny electrons around the much heavier nucleus. In both cases the question arises as to why the negatively charged electron does not collapse onto the positively charged nucleus. As already mentioned, h plays a role, but how are we to understand it conceptually? According to Maxwell's theory, if the electron is conceived as moving around the nucleus in a closed orbit, the acceleration is supposed to cause emission of light, loss of energy and ultimate collapse. The problem Planck started with may be thus described in these more clearly defined terms (not just assumed generic "oscillators," but empirically confirmed protons and electrons).

The lowest energy level of a hydrogen atom is called its *ground state*. The patterns shown in Figure 24 all represent so-called excited states. In each case the electron could (and sometimes does) transition from the excited state to the ground state. When this happens a quantum of light is emitted, a quantum whose energy equals the difference between states. If the ground state were depicted in Figure 24 it would look like just a fuzzy spot, which engulfs the central nucleus. In this case the one-electron cloud is supposed to have no tangential orbital motion, but only radial motion toward and away from the nucleus. If the particles were concentrated in points, this would result in nearly immediate collapse, because the electric force would become enormous as the separation distance shrinks. Even within the context of quantum theory the full answer as to why collapse does not happen remains to be found. Calling the lowest energy level of an atom a ground state obviously does not explain *why* its energy could not be lower still. One of the ostensible explanations for atomic stability that is often given is that the uncertainty in momentum-position entails deviations from perfectly radial motion that somehow props up the atomic electron. Such reasoning is the rationale for this description given by P. C. W. Davies:

> To confine a particle near to the nucleus induces a large uncertainty in its momentum which means that it is likely to be moving very fast. When the electron is sufficiently close to the nucleus the energy associated with this motion offsets the electric energy gained by drawing closer to the attracting nucleus... Crudely speaking... [the electron] is prevented from falling on to the nucleus solely by the quantum uncertainty energy... which buoys it up against the electric attraction. [155]

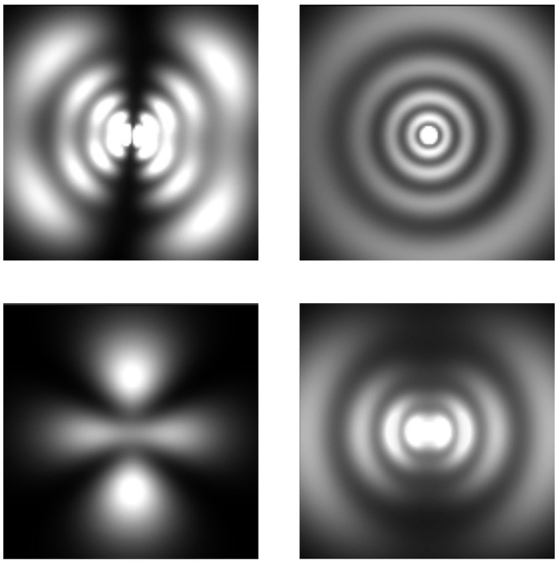

Fig. 24. – Excited states of a hydrogen atom described by the Schrodinger equation. Each image represents the density pattern of *one* electron. From these images it becomes fairly obvious that the idea of one tiny chunk of stuff orbiting a nucleus is not tenable. It's impossible to create these patterns by any reasonable "time-lapse" image of a curvilinear path of one tiny chunk of stuff.

This explanation still leaves unanswered the evident contradiction with Maxwell's prediction that an oscillating charge should emit radiation. The ground state still involves intense in/out electronic oscillations. Maxwell would have expected light emission. QT says there is none. It is not uncommon to find "explanations" having the character of "it cannot happen because it does not happen," or vice versa. The truth is, we don't know.

An alternative way of conceiving the problem is in terms of the *zero-point energy* of the field. Empty space (vacuum) is supposed to provide a repulsion that props up the electron. The underlying idea for this approach arose a few years after Planck introduced his quantum hypothesis and constant h. In 1911 Planck realized that Equation 38 is not quite correct. Planck deduced the need to suppose that, for every mode of oscillation, n, there must be, for every real material oscillator, an additional, usually unobservable *zero-point* vibrational energy $\frac{1}{2}hf$.

Based on this updated equation and on some further developments by Einstein in 1913, Nernst proposed in 1916 that the zero point-energy applies to not just the oscillators but to all of space. The updated equation 38 thus becomes

$$E \approx (n + \frac{1}{2})\, hf\,. \tag{41}$$

Although the theoretical validity of Equation 41 is universally accepted as following from the basic principles of QT, its interpretation is the subject of some controversy. The controversy is primarily due to two things: (1) The fact that, when summed for every mode of oscillation, the result is infinite. And (2) The challenge of proving experimentally that the equation is valid, i.e., providing empirical evidence that the zero-point energy is physically "real." Those who advocate for its "reality" cite a wide range of observations or theoretical predictions. For example, the Lamb shift in atomic hydrogen; the Casimir effect; spontaneous emission of radiation; the unfreezability of helium; and the prediction that a heat bath with a thermal spectrum is caused by linear acceleration through the vacuum (Davies-Unruh effect).

Those who question the reality of the zero-point energy have provided alternative explanations for some of the effects listed above, and yet it is widely agreed that QED cannot be properly formulated without the zero-point energy. Therefore, regardless of such alternatives, it is widely recognized that a definite problem exists with regard to the seemingly inevitable gravitational effects of the vacuum, which would have profound cosmological consequences according to GR. Before shifting our focus back to cosmology, let's continue our exploration in the quantum realm.

Not unlike the function of Λ, the zero-point energy represents a repulsive (space-creating) force that seemingly emanates from virtually everywhere. This ceaseless activity of the vacuum is sometimes referred to as *vacuum fluctuations* and has been described as a kind of "effervescent bubbling" or "jiggling" of empty space. We sometimes find descriptions that refer to swarms of *virtual photons*, where photons are thought of as quantized units of light. One of the key differences between a *real* photon and a *virtual* photon is that the former are represented by *transverse* waves, whereas the latter are represented by *longitudinal* waves. Real photons travel any distance and carry real measurable energy. Whereas virtual photons are confined to travel only within the limits of the time-energy uncertainty relation, and their energy is not directly measurable. It is sometimes warned that the term *virtual particle* is a misnomer; that the fluctuations bear no resemblance to "real" particles.

With that caveat in mind, we can nevertheless make some sense of the idea because longitudinal waves are, basically, *compression* waves. Transverse waves wiggle side to side (perpendicular to the direction of motion). Whereas compression waves are as *radial* pulsations. Every real particle is envisioned as being surrounded by a field of these virtual radial pulsations, effectively asserting its persistent extension in space. The vacuum field that surrounds real particles is said to be *polarized*, as the radially stratified virtual particles divide in pairs of opposing charges that effectively layer the field with alternations of (+)-(−) charge shells. But what could this mean for virtual particles that are supposed to exist everywhere, even very far from any real particles? Evidently it means *outward*. The ultimate effect is supposed to be *repulsion* (creation of space) which evidently means *outward* from anywhere and everywhere.

A single real photon is directly measurable, but a single virtual photon is not. As characterized by the phenomena listed above, however, the collective *swarm* of virtual particles seems to indirectly produce measurable effects. The unfreezability of helium, for example, is in contrast to the behavior of hydrogen near absolute zero temperature. Hydrogen can freeze to a solid state at a low enough temperature, because of its particular electron configuration. But the electron configuration of helium hinders solidification. Near absolute zero, freezing would be possible were it not for the zero-point energy, which keeps helium "jiggling" in the liquid state no matter how cold it gets. In any case, being neither individually persistent nor directly observable, being longitudinal, not transverse (and for other reasons) vacuum fluctuations are counted up, not as whole quanta, but as $\frac{1}{2}n$ quanta each, for every possible *mode* or *state*. B. K. Ridley describes the scene:

> Vacuum fluctuations of the photon field jiggle energy-rich electrons in atoms and induce them to emit light 'spontaneously.'...On average, each fluctuation amounts to having half a quantum of energy in every possible dynamic state.
>
> We cannot absorb or eliminate the half a photon associated with the field. That energy we call the zero-point energy...It cannot be touched. We cannot tap it to provide a source of power. It must always be there. The horror is that if we add up the zero-point energy of all the wavelengths we get an infinite amount. Very embarrassing. Every quantum field that operates in a vacuum has an infinite amount of energy in its fluctuations even before we begin to add energy in the form of real particles. [156]

Within the context of QT alone (i.e., excluding gravity) the infinite energy of the vacuum causes fewer problems than one might imagine, because for empirical purposes, all that matters are energy *differences*. The total absolute value is not observable. This has sometimes been explained in terms of a familiar analogy. The stability of a (well-sealed) house located at the bottom of Earth's atmosphere can be attributed to the nearly equal pressure that exists both inside and outside the house. If the exterior pressure were removed, the house would explode. If the interior pressure were removed, it would collapse. Both catastrophes would be due to the extreme pressure *difference*. The quantum vacuum is very nearly uniform and unshieldable, so, in effect, it props itself up by disallowing any large "bubbles" or voids where the magnitude of its differences would be big enough to easily observe. The analogy clearly lends support to the Maxwell-Lorentz conception of the *substantiality* of space (ether). These are obviously not the properties of *nothing*.

Not unlike confirmation of the condition of thermodynamic equilibrium by Planck and his pre-1900 colleagues, everyday experience confirms the stability of matter. Planck's theoretical solution and the subsequent development of QT have come a long way toward mollifying concerns about the ultraviolet catastrophe. An in-depth investigation reveals, however, that the account is not yet satisfactory. We are often given the impression, as by Davies above, that QT adequately accounts for the observed stability of matter. But this turns out to be not rigorously the case. A well known expert on the subject, Elliot Lieb thus writes: "[The] uncertainty principle...gives only a heuristic explanation of the power of quantum mechanics to prevent collapse." [157] Missing from the usual treatment is a proper account of the quantized vacuum electromagnetic field, as Lieb continues:

> The quantized field cannot be avoided because it is needed for a correct description of atomic radiation, the laser, etc.
>
> The quantized electromagnetic field greatly complicates the stability of matter question....At present such a complete theory does not exist, but a theory *must* exist because matter exists...It should not be necessary to have recourse to quantum chromodynamics (QCD) or some other high energy theory to explain ordinary matter.
>
> If low energy physics (atomic and condensed matter physics) is not explainable by a self-consistent...theory on its own level one can speak of an *epistemological crisis*.
>
> Some readers might say that QED is in good shape. After all, it accurately predicts the outcome of some very high precision experiments...But the theory does not really work well when faced with the problem...of understanding...the stable low energy world in which we spend our everyday lives. [157] [Emphasis added.]

The popular account that electrons in their atoms are prevented from collapsing by either a "quantum uncertainty buoyancy" or the gurgling repulsion of the vacuum is thus only part of the story. That these issues are discussed with an evident tone of puzzlment, dissatisfaction and incompleteness causes one to marvel at how much has nevertheless been accomplished. We'll have even more to marvel at after pursuing the other side of the stability puzzle: Why everything doesn't *blow up*—to which we now turn.

16. – Stability of Matter 2: No Catastrophic Explosions; Renormalized Infinities

> *The quantum theory of radiation predicted that a free electron should have an infinite mass... For an electron bound in a hydrogen atom, an infinite energy also occurs.* — WILLIS E. LAMB, JR. [158]

Another account of the circumstances referred to in our opening quote has been anthropomorphized by B. K. Ridley, as that, "The electron would like to explode, but something holds it together and there it sits full of pent up energy... What holds the repelling bits of negative charge together?" [156] As is also true of the collapse problem, the problem of infinitely energetic disintegration existed before the advent of QT. It is due to the simple fact that every tiny bit of an *electric charge* distributed in space acts to repel all other nearby bits of the same sign ($+$ or $-$). The smaller one visualizes an electron to be, the more intense the effect. In the late 19th and early 20th centuries Poincaré invoked a hypothetical force to keep electrons together. Insofar as the problem did not change even after the advent of QT, the QT "solution" is ultimately analogous to the classical solution. But not everyone is happy with it.

When the repulsive bits of an electron acting on itself are added up, whether classically or in QT, the answer is an *infinite self-energy*. The QT counterpart for the Poincaré forces that prevent self-explosion from happening is called *renormalization*. The idea is not so much an invocation of hypothetical forces as it is a *mathematical trick*. When applied to classical theory the need to invoke containment forces disappears, just as in QT. This has been done with respect to the classical Lorentz theory of the electron, as F. Rohrlich explains:

> A surface charge on a sphere would "fly apart" unless held together by some attractive forces. No such forces, however, appear in a purely electromagnetic theory.
>
> The electromagnetic stresses are not compensated and the electron is not stable. Poincaré simply postulated attractive forces corresponding to stresses which would exactly balance these and establish equilibrium.
>
> The renormalized classical electron is *stable*, just as in renormalized quantum electrodynamics.
>
> It remains to explain why, after renormalization the electron no longer "flies apart," since no attractive forces have been introduced. How can renormalization play the same role as the Poincaré "glue" played previously?
>
> This seems indeed to be a baffling situation. But what makes the electron unstable in the first place? It is the (repulsive) Coulomb force of one part acting on another part of the charge... [The renormalization scheme] permits a separation of the field of the electron into a part which acts on other charges and a part which acts on itself. The latter part is removed from the theory by renormalization. No part of the renormalized electron can act on another part of it, very much within the spirit of regarding the electron as "elementary." [159]

The primary motivation for renormalization is to get rid of the infinities to facilitate calculations of otherwise testable phenomena; i.e., to yield *finite* quantities for phenomena where finite quantities are reasonably expected. It is widely recognized that the program is a resounding success. It yielded three Nobel Prizes, for example. But serious concerns (that were more common a few decades ago than they have now become) were expressed in dramatic terms. In spite of the success of renormalization, Banesh Hoffmann would write, "the infinities are still there, lurking and snarling, tamed but unvanquished." [160]

Echoing this and other persistent problems, Boorse and Motz conclude their 1850-page compendium of essays, *World of the Atom*, stating:

> What is perhaps the most fundamental and simplest question of all still remains unanswered: What is the structure of the electron and why does it have its observed properties? Although the quantum electrodynamics has given us a way of calculating the interaction of the electron with the electromagnetic field to an amazing accuracy, it has done so at the expense of denying us any insight into the origin of the mass or the electric charge of the electron. The values for these quantities are to be accepted as preordained; they are shrouded in the mystery of renormalization—a scheme that relieves us of the mathematical burden of having to work with infinities, but burdens us with a deep sense of incompleteness. [161]

Dirac was another dissenter. He regarded renormalization as "just a stop-gap procedure." In response to a question posed by an interviewer, Dirac continued:

> There must be some fundamental change in our ideas…When you get a number turning out to be infinite when it ought to be finite, you should admit that there is something wrong with your equation, and not hope that you can get a good theory just by doctoring up that number." [127]

Richard Feynman was one of the Nobel Prize-winning inventors of the scheme, and one of its harshest critics. He called renormalization a "shell game," a "dippy process," and "hocus-pocus." Providing more substance to his insults, Feynman continues, "I suspect that renormalization is not mathematically legitimate. What is certain is that we do not have a good mathematical way to describe the theory of quantum electrodynamics." [162]

Considering Lieb's comment to the same effect, we see that experts agree: These fundamental problems of stability and explosively infinite self-energy have never been solved. Rather than persist at trying to resolve these old problems, in the last 30 years or so physicists have mostly gotten used to incomplete stability arguments and renormalization. They have mostly adopted the idea that QED is an "effective theory" that is excused for its seemingly unphysical features, because it is expected that a more complete, more physically justifiable and mathematically legitimate theory should eventually replace it.

Until the replacement theory comes along, renormalization is to be accepted as being legitimate enough (for government work). This is the prevailing view. Heavy-weight critics like Dirac and Feynman may have all died, but we sometimes still find some authorities who question it. By approvingly repeating a quote from Max Born—who anticipated and took exception to the prevailing trend—Kevin Brown implicitly also stands as exceptional. [163] In 1955 Born wrote of the classical attempts to deal with the electron's infinite self-energy:

> Today all these efforts appear rather wasted; quantum theory has shifted the point of view, and at present the tendency is to circumvent the problem of self-energy rather than to solve it. But one day it will return to the center of the scene. [164]

Should we not check the center of a body of matter (Galileo's experiment) for a clue to see whether that day has perhaps arrived?

17. – Rethinking Stability Problems; Matter-Light Dichotomy

> PETER G. BERGMANN: *I am afraid you have played with the energy concept in too naïve a fashion.*
>
> RICHARD FEYNMAN: *I understand that I have. I say things in this way in order to give the qualitative idea that the energy concept is the cause of the trouble. It is possible to use imprecise reasoning to get ideas.* [165]

The above dialog took place in 1963 at a Cornell University round-table meeting attended by 22 distinguished scientists concerning the *Nature of Time*. This and the following three sections have been written in the spirit of Feynman's response. They have been written under the assumption that the patterns revealed in the SGM cosmology are not an accident. I suspect that we are onto something important; we are at the stage of *brainstorming* what it could all mean. We shall thus engage in a dot-connecting session that may at times be "imprecise," yet nevertheless helps, I think, to see what we'd end up with if it turns out that Galileo's experiment supports the SGM, and perhaps even to see that this is the result we should expect.

17·1. *Simple Connection Between QT and the SGM.* – This essay is intentionally sprinkled with head-scratching comments from establishment physicists that paint a picture of modern physics that, in spite of its many successes, appears clunky, fragmented and plagued by some vital unfinished business. Our most successful theory of atomic physics predicts that both matter and vacuum are endowed with infinite energy. Such predictions are impossible to reconcile with the prevailing notions—borne of our ancient visual impressions—of staticness and energy conservation. Methods have been developed to regard some tiny fraction of vacuum energy as that which prevents collapse, allows spontaneous emission of light, and accounts for a variety of other subtle quantum effects. Methods have been developed to maintain the *appearance* of containment so electrons don't fly apart, so their masses can be reckoned as being finite and constant.

In light of this unsatisfactory "stop gap" picture, another possibility presents itself. A possibility that has not been fully (if at all) explored is that the calculated infinities are important clues to a reality that is yet to be perceived. We begin to see this by considering the following ideas of Erwin Schrödinger. Although one of its most illustrious founders, Schrödinger was also one of the most vociferous critics of the dominant interpretation of QT. In one of his last published papers he questions the energy conservation law with regard to the time-energy uncertainty relation: $h \lesssim \Delta t \cdot \Delta E$:

> The said uncertainty relation is usually taken to mean that in principle an infinite time is required for finding out the exact value of the energy. It is difficult to see how "after" doing so we should still manage to ascertain that the value we have found does not change with time.
>
> The detailed validity of the conservation law... is the point under discussion that I do not take for granted. [166]

Consider a common application of the time-energy uncertainty relation. The idea is often used to describe electrons as *excitations* in their *fields*. In this view electrons themselves are regarded as concentrations of electromagnetic energy that are surrounded by "virtual photons," whose emission and reabsorption happen so quickly that the change of energy could be very large. The emission phase corresponds to an increase in energy; reabsorption corresponds to return to energy balance. This momentary increase of energy—because it is supposedly illegal—is sometimes referred to as a kind of sneaky *borrowing* (or embezzling) that gets *paid back* before the withdrawal (theft) can be discovered. As implied by Schrödinger, a time interval, or a succession of time intervals, for all we know, may elapse before the withdrawal is entirely paid back. In other words, maybe it never is entirely paid back. Upon every jiggle, every fluctuation, the total energy may well actually increase. For all we know, this is happening systematically all over the Universe. A small "excess" energy allowed by quantum theory, if happening everywhere in the same proportion, would be microscopically unobservable, but would be observable on a larger scale by its *gravitational* effect.

One of the most coveted, unfound holy grails of physics is a *quantum theory of gravity*. The standard approach involves *gravitons* and many other things that the SGM does without. Presently, it is suggested that the quantization of gravity is not about particles that "mediate" an attractive force; it is about these tiny intermittent increases in energy emanating from all quantized bits of matter. If we grant the plausibility of the SGM for the various reasons presented earlier, then there must also be a physical connection to QT. Combining the suggestion of Schrödinger with hyper-dimensional stationary motion, with Dicke's "giant servosystem feedback condition," and with the other ideas presented above, leads to this simple quantum gravity idea, whose validity would be at least indirectly tested by doing Galileo's experiment. (See Appendix A.)

17˙2. *To Gravitate or Not to Gravitate: Matter-Light Dichotomy, Gravitational Energy, Three Kinds of Mass, and the Cosmological Constant, Revisited.*

> Nothing is so firmly believed as that which we least know. — MICHEL DE MONTAIGNE [**?**]

Seeing more clearly now the reasonableness of the idea that the perpetual propulsion of matter and space—the stationary hyper-dimensional motion that is gravity—is "fueled" by matter itself, without violation of any laws *known* to be true, let us consider another novel consequence of the SGM. We've laid the groundwork to facilitate seeing the SGM's resolution to the cosmological constant problem without yet spelling it out. It is now time to do so. In standard physics the problem exists because the vacuum energy in the form of electromagnetic fluctuations (virtual photons, etc.) is supposed to gravitate. If it did in fact gravitate as it is supposed to according to QT's prediction of its energy density, the Universe would be an endless cataclysmic process of everything rapidly blowing itself to undifferentiated smithereens. (Something like that.) Since this is obviously not the case, it is worthwhile to consider the SGM alternative, according to which we do not deny the virtual vacuum its energy, but neither do we expect it to gravitate. The only thing that gravitates is real clock-like matter.

A clarification of what we mean by *gravitate* is in order. Sufficient clarity can only be achieved by broadening our context to include the standard concept of gravitational *binding* energy and by relating and comparing this concept to three different roles played by mass. We need to relate these roles (masses) to the phenomena by which they are measured: gravitation (motion of space); and inertia (motion through space) as by rockets or rotation. Any thorough exposition of gravity includes mention of the functional difference between *active* gravitational mass, *passive* gravitational mass, and *inertial* mass—at least for the distinct roles they play in Newtonian gravity.

Inertial mass, as discussed in §9, is the property of matter by which it resists linear acceleration. Passive gravitational mass is the property of matter by which bodies *respond* to the gravity of another (typically larger) massive body. Insofar as these two masses exhibit exactly the same resistance and response with respect to a force-delivering rocket or a planet, they are identical. Inertial mass and passive gravitational mass are the same. This is true in Newtonian gravity (by coincidence); in GR (by hypothesis); and in the SGM (as we've begun to see, by *explanation*). Our third kind of mass, active gravitational mass is that property of matter by which a body *produces* a gravitational field; by which it causes spacetime curvature. It is this latter process that we mean by *gravitate*.

The connection to the concept of gravitational binding energy, though often calculated on the basis of Newtonian physics, is most clearly seen in the context of GR, where it is sometimes referred to as a *mass-defect*. Application of Einstein's famous equation, $E = mc^2$, combined with the presumed negativity of gravitational energy, has the consequence that the component parts of a gravitating body weigh more (as a sum) when they are widely separated than when the same components are weighed after being concentrated into one large body. The difference is the energy (or the mass-equivalent thereof) that it would take to move the component parts away from their concentrated configuration to their widely separated configuration.

Our above discussion evokes the question, does this mass-energy reduction refer to inertial mass, active gravitational mass, or both? According to GR it is both. Whereas according to the SGM, it refers to active gravitational mass; inertial mass would actually increase. Before explaining why the SGM assessment may seem to be more complicated, note first that in 1922 Einstein also conceived that, when once-scattered masses were brought into close proximity inertial mass should increase. Einstein stated this Mach-inspired idea as follows: "1. The inertia of a body must increase when ponderable masses are piled up in its neighborhood." [**?**] Einstein's discussion did not address the question of how this inertial mass increase relates to active gravitational mass, or how to reconcile it with the binding energy calculation that straightforwardly predicts a mass-energy decrease.

In modern texts Einstein's assertion is rarely mentioned. An insightful and presently more relevant point is that the mass-defect can also be thought of as being due to the reduction of the *volume* of gravitating bodies due to the contraction of radial lengths, i.e., *spatial curvature*. [169,170] This is especially noteworthy for the SGM because in our model the degree of spatial curvature (whose variation is responsible for the variation in volume) is everywhere the same as the degree of *temporal* curvature. Rods are shortened by the same factor by which clocks are slowed. Although this is true of GR for *exterior* fields, it is *not* true for the *interior* of material bodies. In other words, according to GR the coefficients for spatial and temporal curvature diverge from each other inside matter.

In the weak field approximation the *spatial* curvature inside massive bodies predicted by GR is the same as that predicted by the SGM. Therefore, the energy (and mass-equivalent) differences agree. But this agreement pertains only to active gravitational mass. Since the spatial curvature is the same as the temporal curvature in the SGM, contrary to GR, we get the added intuitive idea that the change in active gravitational mass corresponds directly to change in *clock rate*. The mass components of a gravitating body produce less gravity by the same factor that the clock rates of the components are reduced. And both reductions correspond to the reduction of the *volume* of the concentrated components due to the shortening of radial lengths.

The full significance of this is brought out by comparison with a well-supported effect on bodies that move *through* space. It is widely understood that, when material bodies move through space, their energies and so their total masses *increase* by the *inverse* of the factor by which their clocks slow down, which is also the inverse of the factor by which rods contract.

This is one of the higher-order effects that we postponed addressing back in §9, in connection with the EP. It is reasonable to suppose that the increase in inertial mass due to motion applies to both motion *through* space and motion *of* space. This can be intuitively understood as follows. Thinking of matter (recalling Bohm, pp. 71–72) as tied packages of internally reflecting energy, if this motion is regarded as a kind of internal wave motion taking place at the speed of light, then the reflecting waves get bunched up in the direction of motion of the gross body and spread out in the opposite direction—similar to a Doppler effect. This will be discussed in more detail in §2X. For now it suffices to understand that the bunching up in one direction more than makes up for the spreading out in the other direction, such that the total number of waves at any one time is $1/\sqrt{1-v^2/c^2}$ greater than it would be if the gross body were "at rest." This factor represents the coefficient of the total inertial mass-energy.

Clocks, however, will have slowed down by the inverse of this factor. This is the factor by which, in the case of a gravitating body, the active gravitational mass decreases. We thus find again that gravity is a *temporal* process whose magnitude is affected (at order $1/c^2$) by the rates of clocks of material bodies. Within and beyond a gravitating body the radial compression is manifest as *spatial curvature* because it permeates all volumetric space. Whereas length contraction as caused by inertial motion (through space) does not directly involve spatial curvature. In both cases (motion of space and through space) when matter is conceived as the internally reflecting clock-like process discussed above, we can see how this adds to inertial mass, while at the same time *reduces* active gravitational mass. The generation of space is slowed down by the same factor by which clock rates are reduced. The general conclusion is that active gravitational mass and inertial mass are affected by motion (energy) inversely to each other; i.e., by factors, $1/\sqrt{1+2GM/rc^2}$, $\sqrt{1-v^2/c^2}$, $\sqrt{1-(r\omega)^2/c^2}$, and their inverses, respectively.

However interesting this account is theoretically, it is important to realize how difficult it would be to measure the gravitational effects empirically. The inertial effects have been most famously confirmed by particle collision experiments. But these have no bearing on any change in the gravity produced by (active gravitational mass of) the particles involved, because such effects are much too small to measure. Even for much larger, seemingly more practical bodies of matter, the fraction of binding energy (mass-defect) to the total energy of a gravitating body is extremely small. Aside from the effect's smallness, compounding the difficulty of such measurements is the need to either have two identical bodies—one as a control and one that is susceptible to the causal agent. Or the possibility of turning the causal agent (of sufficient magnitude) off and on (switch). Neither of these conditions are easily obtained or accomplished.

To further understand why the SGM proposes that the quantum vacuum does not gravitate, let's consider a detailed example which more completely illustrates why the inertial mass of a body, when it is hot or moving through space, will be greater than its active gravitational mass. Suppose we have an idealized *furnace*, within whose thick and insulated walls resides a high temperature heat bath. As a control, suppose we have another identical furnace, composed of exactly the same number of component masses, but whose temperature, both inside and out, remains zero. Imagine that these furnaces are to be released to fall with respect to a much larger collection of component masses, e.g., a planet. (Something like Figure 8.) According to both GR and the SGM, both furnaces will fall exactly the same way. (Equality of inertial mass and passive gravitational mass.) Also, according to both GR and the SGM, given a sensitive enough balance, before falling, the hot furnace will be found to weigh slightly more than the cold furnace. Aside from the extremely tiny effects due to gravitational energy described above, the only thing contributing to the weight of the cold furnace is its active gravitational mass. (First order generation of space.) Whereas, contributing to the weight of the hot furnace are its active gravitational mass plus the mass-equivalent of the heat-energy. The inertial mass of the hot furnace therefore exceeds its active gravitational mass. GR disagrees with this conclusion. GR says the mass-equivalent of the heat-energy adds into the active gravitational mass the same way it adds into the inertial/passive gravitational mass. We defend the SGM conclusion as follows.

Suppose that the planet has a large inner cavity. For our initial experiment the planet was cold. But now we want to run the experiment again after adding a heat bath to the planet's cavity—without changing the number of component masses. We add only a large number of photons (electromagnetic radiation). The question is, will the added heat make an accelerometer on the surface give a higher reading? Will the small furnaces fall faster than they did when the whole planet was cold? Let's pose the question a little differently: *What would it take* for the accelerometer readings to increase? Newton and GR say the light would have to add to the planet's gravitational *attraction*. Whereas the SGM says that the planet would have to *generate space* at a faster rate. This means that the light waves (or photons)—whose presence inside the cavity is the only thing different from the cold planet—would have to generate space in the same way as an "equivalent" amount of matter. Is that possible? The short answer is *no*, it's not possible because energy (especially light) and matter are *not*, for all purposes, *equivalent*.

Matter is clock-like; light is not. This is crucial. Neither a light wave nor a photon has an internal clock by which to regulate the rate of space generation (or however gravity is produced). Matter generates space by virtue of its being clock-like. Whereas light is oblivious of time. Recalling Bohm, the phenomena are to be contrasted by the interior to-and-fro reflecting movement of matter, and the *only outward* movement of light. Matter generates space. Light—and by extension, other forms of energy besides matter—does not generate space. Light propagates as a vibration *through* space, but it does not *create* space (gravitate). It does not add to the spacetime curvature produced by clock-like matter. The logic of this is not hard to grasp. If it is true, then it should apply just as well to the quantum vacuum energy. The electromagnetic vacuum plays a vital role for light, but it is a product of matter, not a product of itself.

This consequence of the SGM and its implications for the cosmological constant problem becomes yet easier to see by comparison with some ideas brewing at the avant garde of quantum gravity theories. A strategy that also appeals to matterless vs. matter-like attributes has been suggested by the Dutch physicist S. J. B. Nobbenhuis as a possible solution to the cosmological constant problem:

> Gravitons couple universally to all kinds of energy. . . If gravity were not mediated by an exactly massless state, this universality would be avoided. One might hope that vacuum energy would then decouple from gravity, thereby eliminating its gravitational relevance and thus eliminating the cosmological constant problem. [171]

The distinction between active and passive gravitational mass does not explicitly enter into Nobbenhuis' idea. Rather, he considers the "decoupling" as applicable in a variety of extra-dimensional, massive graviton schemes that violate the Equivalence Principle. In other words, the decoupling he has in mind would cause variously composed (or heated?) bodies *to fall differently* from other bodies. His solution to the cosmological constant problem would therefore come at the high cost of violating a well-supported prediction of GR with which the SGM is in agreement. The similarity between Nobbenhuis' hypothesis and the SGM is that the energy of the vacuum is conceived as having no active gravitational effect; it does not contribute to the generation of curved spacetime, as it would if it were energy in the form of *matter*.

Consider what it means, from the standard point of view, for light to possess active gravitational mass. In terms of Nobbenhuis' graviton-based thinking, it means that a light wave (photons) emit and absorb gravitons. Light is already traveling at the speed of light. In this state of motion, light emits and absorbs, i.e., *exchanges* gravitons with all other matter and with all other light; it is supposed to exchange gravitons that are supposed to also travel at the speed of light. Graviton-exchange supposedly causes attraction between the involved bodies, between the involved waves or photons. This completely unintuitive idea seems highly doubtful, especially as no one has ever explained what gravitons *do* to cause attraction.

If one doubts the existence of gravitons and abides by a purely geometrical conception of gravity, a serious problem still remains. The idea that matter is clock-like and light is timeless comes from *standard* physics. The SGM merely agrees, because it makes sense and it is consistent with empirical observations. It seems like a sensible enough premise to build upon. We simply combine this premise with the fact that somehow matter must *generate* the spacetime continuum (to use Einstein's expression). Insofar as generating implies a process unfolding in time, it follows that that which is supposed to do the generating should be capable of (susceptible to) *temporal regulation*.

Einstein's own theory of relativity tells us that light simply does not qualify. Light travels through space; not through time. Matter ages; light does not. I dare say, *the underpinning of GR whereby light is supposed to have active gravitational mass is contradicted by the deeper underpinning whereby light does not keep time.* The contradiction gets overlooked because the gravitational field is assumed to be static. Under this assumption, all forms of energy gravitate, not just by passively responding to gravity, but by acting as *geometrical* "sources." But how does a "source" *act* as a *source* if it never *physically does* anything? Even if the central mass is densely filled with randomly reflecting high-energy light, the general relativistic picture is still completely static. Paying no mind to light's timelessness, general relativists add it up as though it were matter. Should we be surprised that they have a humiliating paradox to deal with?

The idea that an active gravitational "coupling" is produced both by matter and by energy is routinely taken for granted without empirical support. It is taken for granted because GR seems to be so well supported otherwise and because of how very difficult it would be to measure it. As noted above, such a measurement is rendered nearly out of reach by the problem of creating or finding a control sample, and/or a switch.

The above discussion has the important consequence of showing how the SGM has no need for the cosmological constant. Instead, we conceive the infinite energies of the vacuum and of unrenormalized particles as indicators of an endless reservoir that unfolds a little bit at a time into all the forms that we know and love. In light of this possibility, we are struck by the extremity of the puzzlement and near despair of the authorities in search of a solution.

The tiny acceleration of spatial expansion seemingly indicated by the supernova observations is by itself "completely perplexing." Being compounded by QT's implication that it is too small by 120 orders of magnitude, it evokes remarks such as that of S. Carroll, who concedes: "We are faced with a problem, a puzzle and a scandal." The stakes are clearly high, as Carroll continues:

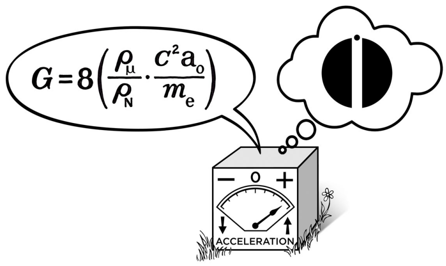

Fig. 25. – Grandest Challenge: "A theoretical model well motivated by fundamental physics that makes specific enough predictions to be falsified." Does this anthropomorphized accelerometer deliver a simple enough formula? Does it otherwise step up to the challenge?

> The fact that this behavior is so puzzling is a sign that there is something fundamental we don't understand. We don't even know whether our misunderstanding originates with gravity as described by general relativity, with some source of dynamical or constant dark energy, or with the structure of the universe on large scales. Regardless of what the answer is, we seem poised to discover something profound about how the universe works. [147]

In his groping, Carroll expresses the desirability of the kind of clue that the SGM readily provides:

> What we would really like is a simple formula that predicts the cosmological constant once and for all as a function of other measured constants of nature. We don't have that yet, but we're trying. [172]

The reader will perceive the irony of Carroll's plea for a formula for Λ—a tiny, obscure mathematical appendage—when G itself, the veritable *heart* of gravity, is left unquestioned. Carroll's plea is echoed by a similar call to action that ties even more directly into the thesis of this essay. The review article by Joshua A. Frieman, *et al* concludes with a two-pronged appeal:

> The grandest challenge of all is a deeper understanding of the cause of cosmic acceleration. What is called for is... [a] theoretical model that [is] well motivated by fundamental physics and that make[s] specific enough predictions to be falsified. [173]

Figure 25 displays the simple formula that Carroll should perhaps have asked for, and that generally captures the SGM's response to Frieman, *et al's* challenge.

18. – Deeper meaning of h and α; Cosmic Everything Chart

> *The number 137 is the dominant factor for all natural phenomena.* — MAX BORN [174]

18˙1. *Nature's PIN Code*. – Our concern with stability problems began by asking whether established physics provides any reason to be certain (or to believe at all) that material bodies are static chunks of stuff, such that their energy is conserved. I hope it has now become apparent that the opposite is more likely to be true. Staticness appears ever more as an illusion. Fundamental physics provides compelling reasons to conceive the existence of a vast reservoir of infinite energy, which "regulates" itself so that we see and experience only seemingly finite amounts (differences) at a time.

To facilitate appreciation for the graph which charts this vast reservoir, to be presented in the next subsection (and for its own sake) let us consider the broader context of the ubiquitous constants h and α, and their relationship to each other. In more ways than one, the Universe as a whole evokes the feeling that some things are so vast or so unique as to make analogies and metaphors appear almost futile. Almost. More analogies and metaphors will be forthcoming.

Consider first that the importance of dimensionless ratios in physics is a recurring theme in the literature. The simplest reason is that they eliminate the physical *units* that have only conventional significance. A more general (perhaps equivalent) reason is that they communicate *proportions*. Dimensionless ratios serve as immediate comparisons of *scale*. Nevertheless, as I have repeatedly emphasized with regard to Newton's constant, the dimensions of a physical constant can be rich with implications. Bearing in mind the incremental energy increase idea of "quantum gravity" mentioned above, let's consider what h and α may have to do with it.

Since its inception by Planck, the constant h that bears his name has represented a kind of "regulatory" function in the step-wise unfurling of this energy, as suggested by John D. Barrow's following description:

> When h is set equal to zero we are ignoring the quantum nature of the Universe, through which energies can only take on particular values, like steps on a ladder. The size of the steps between rungs are fixed by h. If h were zero there would be no gaps and the energy of an atom could change by any value, no matter how small. [175]

This suggests that the "function" of h is something like a microscopic ratchet and pawl, or clock escapement system. Everything keeps turning, but in small steps. If the steps were not built in, the "device" (Universe) would rapidly fly apart, out of control. For there to be a Universe without ultraviolet or any other catastrophe, h cannot be zero. The finite value of h represents a sort of intermittent governing valve that "quantizes" energy so that the whole reservoir does not let loose all at once, neither to collapse, nor explode, but to persist as an infinite symphony of relatively stable, harmonious structures.

The dimensions of h are often stated as being those of *action*: momentum $\times$ length, in the direction of motion. It is sometimes also pointed out that these are also the dimensions of angular momentum:

$$h \to \frac{ML^2}{T}\,, \tag{42}$$

which can be loosely thought of as the *turning* of matter; i.e., momentum in the direction of motion *around an axis*. This latter interpretation is more conducive to the image of clock-like matter consisting of internal cyclical movements; i.e., the *ticking* of matter. Time, frequency and energy are "coordinated" by h. Its dimensions function as a conversion factor: Multiplying h by frequency gives an energy. Multipying the inverse $1/h$ by the energy mc^2 gives a frequency (e.g., deBroglie's relation—Equation 8; the basis of SGM cosmology). And dividing by the atomic and electromagnetic constants ($m_e\, a_0\, c$) gives the fine structure constant

(43) $$\alpha = \frac{h}{2\pi\, m_e\, a_0\, c}\,.$$

And thus we return to our dimensionless "dominant factor for all natural phenomena." Note that our definition of α as the ratio $h/2\pi\, m_e\, a_0\, c$, though true, is uncommon. More often, α is expressed as a ratio that explicitly includes electric constants, as in the middle expression here:

(44) $$\alpha = \frac{e^2}{2\,\epsilon_0\, h\, c} = \frac{h}{2\pi\, m_e\, a_0\, c}\,.$$

That both expressions are equal serves to confirm Cook's assessment (p. 67) that the atomic constants form an interconnected set. The appearance of h in both expressions—in the first case in the denominator, and in the second case in the numerator—underscores its ubiquity. Since electric charge e (or e^2/ϵ_0) defies easy visualization, the middle expression is less intuitive than the one on the right, which is a ratio of angular momenta. Planck's constant is ≈ 137 times smaller than the angular momentum pertaining to the atomic constants in the denominator. That's one way to look at it.

It is sometimes pointed out that the fine-structure constant seems to be finely tuned, in the sense that small deviations from its observed value would have dramatic consequences. Barrow and Webb write:

> If α had a different value all sorts of vital features of the world around us would change. If the value were lower, the density of solid atomic matter would fall (in proportion to α^3), molecular bonds would break at lower temperatures (α^2), and the number of stable elements in the periodic table could increase ($1/\alpha$). If α were too big, small atomic nuclei would not exist because the electrical repulsion of their protons would overwhelm the strong nuclear force binding them together. A value as big as 0.1 would blow apart carbon.
>
> A shift of just 4 percent in α would alter the energy levels in the nucleus of carbon to such an extent that the production of this element by stars would shut down. [106]

The significance of the various *powers* of α as applying to particular kinds of electromagnetic phenomena suggests the kind of scaling relationships alluded to earlier, and lends itself to the following analogy. It may be of some benefit to first mention a few possibilities that occurred to me in the course of trying to find an appropriate analogy to express the ubiquity of α. Is it like a *musical key* that the Universe is tuned to? Or perhaps a kind of *currency*? Maybe a color palette or a language? Remember that for the SGM, we propose to have found α—through gravity—on the scale of the whole cosmos. Thinking the above ideas to be too limiting with respect to scale, images of fractals came to mind. Then it occurred to me that the golden ratio, $\phi = (\sqrt{5}+1)/2 \approx 1.6180339\ldots$ has a variety of things to recommend it.

It is well known that, among its other fascinating properties, this (other) magical number can be found in all things with five-fold symmetry: a five-pointed star, a pentagon, etc. Linear and planar relationships are covered by first and second orders of ϕ. A higher order of ϕ recurrence is found in (among other things) an icosahedron. Icosahedral symmetry emerges in a variety of biological structures (e.g., radiolaria and viruses). Perhaps most famously, it is the basis for the geodesic domes of Buckminster

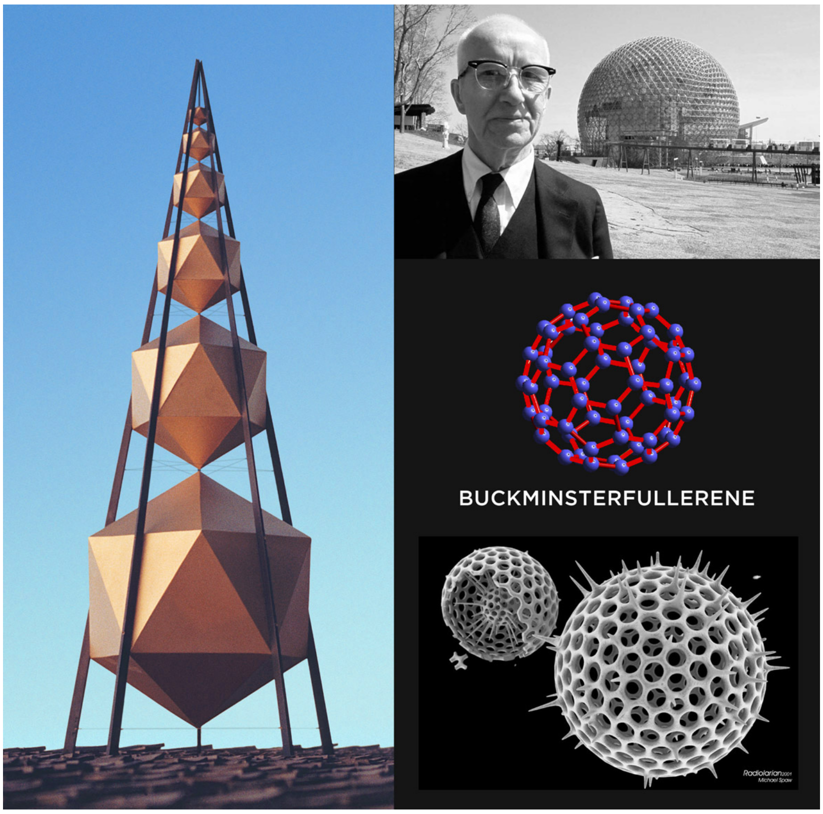

Fig. 26. – Golden analogy? Known since antiquity, the golden ratio is another dimensionless number besides α that is ubiquitous in Nature. It is present in five-fold symmetrical planar figures and volumetric structures with icosahedral symmetry, such as radiolaria, carbon molecules and geodesic domes. Exactitude is essential for the "perfection" of five-pointed stars and icosahedral structures. Is exactitude also essential for the gravitational-electromagnetic function of α?

Fuller. As shown in Figure 26, a "tree" of nested icosahedra, whose linear sizes increase in the proportion of ϕ, is also suggestive of exponential expansion. (The *nesting angle* of the tree is $\arcsin[1/\phi^3]$). It may also be significant that Fuller was adamant that the "coordinate system" upon which his domes were based was "preferred" by Nature over the "blockheaded" Cartesian system.

What makes the golden ratio seem appropriate for our analogy is that it represents and is embodied by a system of geometric structures whose proportions are everywhere "dominated" by one and the same number. If ϕ corresponds to α, then h would correspond, perhaps, to the 60° turning of one icosahedral edge to an adjacent one. Or perhaps to the spinning of a whole Buckyball. Local physical transformations are quantifiable as dimensioned constants, which operate within a "coordinate system" whose manifestations at different scales are represented by powers of dimensionless numbers, analogous to α.

It is conceivable that manifestations of ϕ could be found at yet larger scales and yet higher orders of physical/geometrical reality. Because of its known role in electromagnetism, the fine structure constant may be even more likely to reveal itself at larger scales and higher orders. If the space generated by matter via gravity has the various electromagnetic properties that we surmise it does, based on the SGM, then we expect α, i.e., $\approx 1/137$, and various powers thereof, to be observably manifest on the scale of the Universe.

There are many ways to express the consequences of making α smaller or larger than it is. Essentially, making α smaller would *dampen* the interaction between matter and light; atoms would be less likely to either emit or absorb light. And nuclei would be more tightly packed and more difficult to disrupt. Whereas making α larger would increase light-matter interactions, making matter more unstable. In the extreme, if α were equal to 1, there would remain little if any difference between light and matter.

What remains to be established is whether even small adjustments are possible or "allowed." In the case of the golden ratio, there is no room for adjustment. If the number ϕ is changed, then we do not get a symmetrical star, icosahedron or Buckyball. Integrity, coherence, and stability evidently depend on exactitude. I suspect this also to be true for α, c, G, h, and the others. But it is not yet exactly clear how to show that this is so, if it is.

18˙2. *Cosmic Everything Chart*.

> The coupling energy between atom and ether [represented by the fine structure constant] is of the greatest importance for the appearance of the physical world and our method to describe it... The fact however that α has just its value [$\approx$] $1/137$ is certainly no chance but itself a law of nature. It is clear that the explanation of this number must be the central problem of natural philosophy. — MAX BORN [174]

In 2005, when Barrow and Webb's article was published, they were looking for (and thought they had found) evidence that α was slowly changing with time. In the ensuing years the corroboration they had hoped for was not forthcoming. The constants appear rather, to be just that. As far as we know, each constant plays a role in the composition—in both the functional and aesthetic sense—of the Universe. Frank Close portrays the fine structure constant's role as follows:

> As photons and electrons come together, merge, and separate in cosmic terpsichore, Quantum Electrodynmics encodes the likelihood of their interaction in a number known as "alpha." Alpha sets the scale of nature—the size of atoms and all things made of them, the intensity and colors of light, the strength of magnetism, and the metabolic rate of life itself. It controls everything that we see... In 137, apparently, science had found nature's PIN code. [176]

Close refers to the α-coded dance as *cosmic* terpsichore. Appealing as the idea may be, this must be seen as an exaggeration in the context of standard cosmology. Otherwise, should we not expect the number 137 to appear in *large-scale* cosmic relationships? Barrow, Webb and others have reported on observations of spectral evidence from distant galaxies that the value of α has not changed over cosmic times. Starlight contains evidence of alpha's constancy. From a vast distance astronomers thus observe the microscopic components of matter. They don't think to look for *large-scale* manifestations of α, however, because they do not regard the Universe as a coherent system. On the contrary, they explicitly assume the Universe is fragmented and flying apart. What we have found challenges that assumption.

SGM cosmology comes much closer to satisfying Close's characterization of the cosmic ubiquity of α. This becomes easier to see by reference to a Chart that plots the masses of all known bodies with respect to their densities. The Chart is shown in Figure 27. Since the chart contains contains a lot of small print that is hard to read on a regular size page, it has been made available as a single pdf file. [177] The overall pattern is nevertheless evident enough. A few key features and facts about this Chart will now be considered.

Immediately apparent is that, by virtue of its logarithmic scales, the Chart spans over 80 orders of magnitude of mass and over 70 orders of magnitude of density. The mass component of every data point—variously colored diamonds, red stars, and black crosses—has been gotten from the standard literature. The exact values of the densities for the CBR mass-equivalent, cosmic average, and nuclear staturation density, may be slightly different than indicated (as discussed above). The only controversial (non-standard) feature of the Chart's data points is the placement of some of them above the Schwarzschild horizon line. In this regard I hasten to mention that the GR-based alternative to where I've placed these points is either (1) to place them at infinite density, which is how the mass should become concentrated, according to GR, very briefly after falling inside the "horizon." Or (2) to place them *on* the Schwarzschild horizon line (as shown by black crosses). This is where the points would go if it made sense to regard the horizon as the outer *surface* of the mass contained therein. It is well known that such physical surfaces are not allowed in GR. That's why the text on the Chart calls the crosses "geometric indicators of infinitely dense nonsense." I will comment further on this later.

Let's first work our way from the left (low mass) end of the Chart to the right. Though masses of elementary particles are often quite accurately measured, densities have only a theoretical significance because such objects have no known *surface* radii. It is therefore common to refer to the "size" of a particle by either its Compton wavelength, $\lambda = h/mc$, or its "barred" Compton wavelength, which is 2π smaller. With regard to the electron, it has sometimes been advantageous to think of its size as being yet smaller than the barred Compton wavelength, down to its so-called *classical radius*. Arguably the most physically meaningful size in atomic physics is the Bohr radius—the characteristic distance from the nucleus to the first electron orbital in a ground state hydrogen atom. Notice that the barred Compton wavelength and classical radius of the electron relate to the Bohr radius in multiples of α and α^2, respectively.

Two other instances of α worthy of mention are that (1) In the Bohr model of the hydrogen atom, the speed of the ground state electron orbital is αc. And (2) The strength of the nuclear "strong" force is $1/\alpha \approx 137$ times greater than the force of electromagnetism.

Also prominently evident in the Chart is the long stretch of objects of nearly the same density—the domain of our experience, i.e., the domain of molecular matter, from Buckyballs to planets and some stars. In terms of scientific investigation, toward one end of this stretch we find *chemistry* and toward the other end we find the spectral analysis of *starlight*. In both of these fields h and α play a dominant role. The sizes of the objects all along this stretch are those of various things found as either cosmic dust, or as sub-components of planets or solar systems. What holds these objects together are intermolecular electromagnetic forces. When enough of these objects, or the mass-equivalent of enough of these objects, gather in a small enough volume, the force of gravity begins to dominate. It is not an accident that this stretch of data points splits and branches in opposite directions exactly because of gravity.

Along one direction of the branch we find the more diffused (lower density) sources,

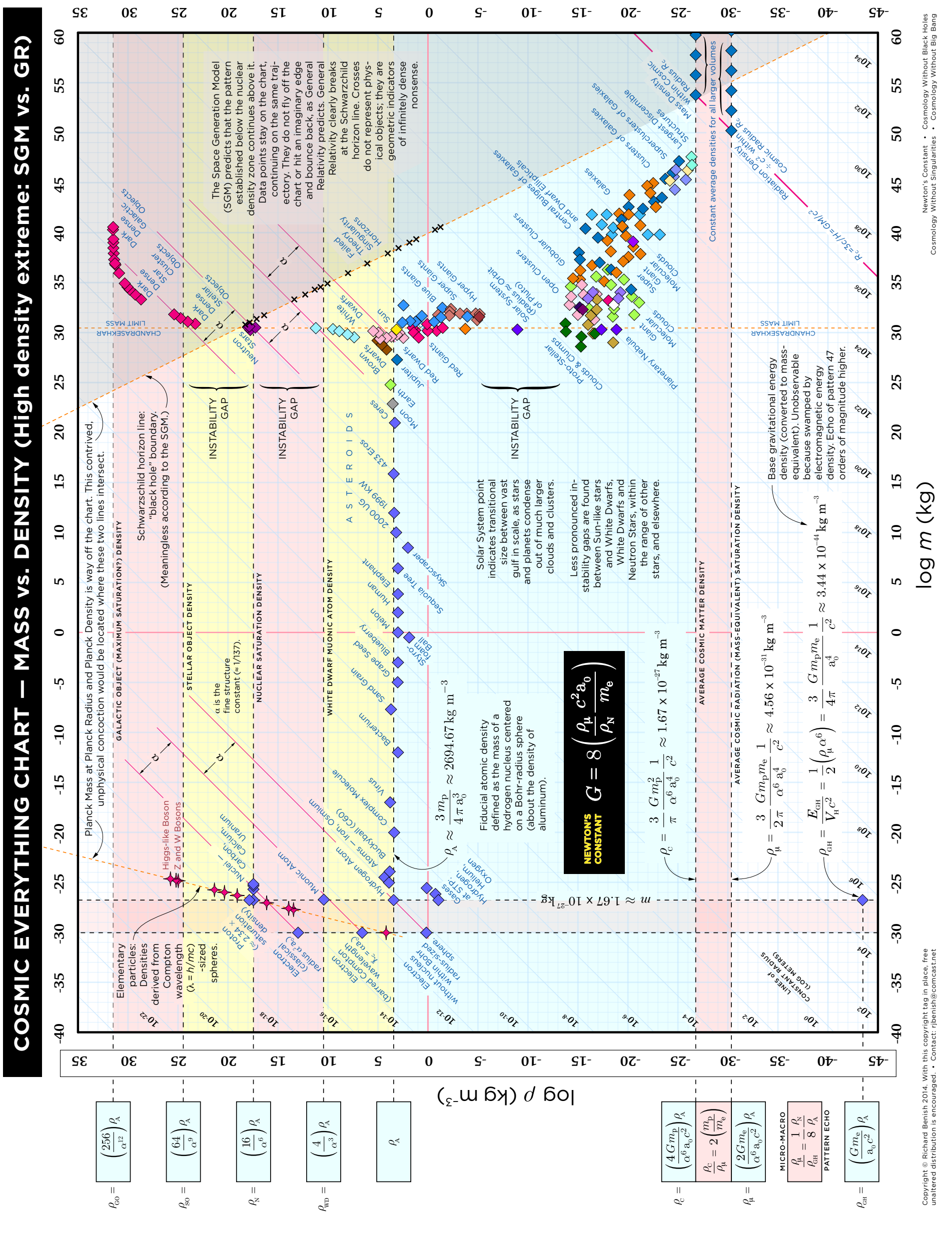

Fig. 27. – Cosmic Everything Chart. With respect to logarithmic scales spanning over 80 orders of magnitude of mass and over 70 orders of magnitude of density, this chart represents essentially all known bodies of matter in the Universe, including the Universe itself. A variety of essential cosmic relationships become immediately evident: the broad span of atomic matter, which branches toward increasing and decreasing density at the mass of stars; the Chandrasekhar limit mass; some curious ratios involving the fine structure constant; and the artificial, unnatural appearance of the Schwarzschild horizon line. Also displayed is a simple expression that defines Newton's constant G in terms of two key densities and three fundamental atomic constants.

which may condense to form stars. The lower limit in this direction is the maximally diffused system, which is the whole Universe. Along the other direction we find objects that have condensed into stars or more massive objects. Notice the prominent vertical line, which represents a limiting mass. Many old stars of about the same mass as the Sun, or younger, initially more massive stars that have shed most of their mass in supernova explosions, collapse to form White Dwarf stars, as shown near or on this line. In 1930 the astronomer Chandrasekhar predicted the limit mass of a White Dwarf to be about 1.4 times the mass of the Sun. The most distinctive thing about White Dwarfs and this limit mass (in terms of our Chart) is that it represents a curiously long stretch over which mass is nearly constant, but size actually decreases, so that density dramatically increases. This is where gravity overwhelms the electromagnetic force in atoms, crushing electrons down to a particular minimum, as dictated by a cornerstone of QT known as the *Pauli Exclusion Principle*.

The change in size, can be understood by referring back to the left end of the Chart. The space occupied by an electron in an uncrushed atom is close to the size of a hydrogen atom. When the linear size is reduced to the Compton wavelength, the volume collapses by the inverse cube of that length. As mentioned above the length involved here is α times the Bohr radius. If all the electrons in a star of the Sun's mass were to shrink by this amount, the result would be a White Dwarf about the size of Earth or the Moon. The size of a normal star is dictated by its degree of incompressibility due to being composed of atomic or molecular matter, combined with the random high speed motion of its gases. White Dwarfs, by contrast, are supported by the phenomenon corresponding to the collapsed state described above, known as *electron degeneracy pressure*.

Notice that, in terms of our Chart, White Dwarfs are found to have a short *range* of masses and densities. Unlike the particle end of the Chart, whose data points are occupied in solitude (as it were) the complexity created by large numbers of particles typically causes every data point to have lots of near neighbors, often, as seen, along one axis or one general direction. Under certain circumstances—especially when the mass exceeds the Chandrsekhar limit, electron degeneracy pressure no longer suffices to support the star. The gravitational force here becomes so strong as to further crush the degenerate electrons, forcing them to merge with protons. These oppositely charged particles pair up and transform into even smaller *neutrons*. This can happen even when the star masses are somewhat smaller than the limit. In any case, when circumstances are conducive to this transformation, the star goes through a phase of extreme instability before finally collapsing into a veritable ball of neutrons known as a *Neutron Star*. The jump down in size and jump up in density are very nearly another factor of α and $1/\alpha^3$, respectively.

Significant as this α-jumping may be, we need now to confront the wall that suddenly appears across our trajectory, known as the Schwarzschild horizon. Careful inspection of the small cluster of Neutron Stars indicates that their density can somewhat exceed nuclear saturation density before hitting the wall. In the context of relativistic astrophysics, which regards GR as rigorously reliable, this zone is extremely sensitive to catastrophic collapse. To understand this it is helpful to recall Bergmann's remark about the seeds of its own destruction being carried within any theory that involves singularities. [100] (§11.3, p. 52) This remark was in response to work by Hawking and Penrose, who proved mathematically that GR inevitably involves singularities under conditions similar to Neutron Stars. The problem is that the GR-based *equations of state* used by astrophysicists indicate that the *centers* of Neutron stars are dangerously close to the condition in which clocks stop ticking and light stops moving. In other words, they are a hair's breadth away from becoming *black holes*. Enormous efforts have been expended to keep mathematical models of Neutron Stars on the real world side of the dreaded horizon. Clearly the theorists don't have much room to work with. The precipitous horizon is only a tick or two away. If its mass increases only slightly, a Neutron Star near the edge inevitably meets its doom. GR is extremely fragile in this regard. It completely breaks, in fact, all along the line shown on the Chart.

In addition to the physical arguments causing us to suspect that such horizons and the singularities they contain are only needless abstractions, a simple *aesthetic* argument may also be offered. The Chart has revealed to us a variety of patterns, one of which is the steady climb in density near the Chandrasekhar limit mass, as caused by gravity. There is nothing in the data, nor in the arrangement of the other points to suggest the existence of a wall or a sharp corner; it is a purely *mental* thing. The most sensible, and aesthetically pleasing manner, I think, of extending the trajectory beyond White Dwarfs and Neutron Stars, is to continue along a smooth curve. Note that this aesthetic judgment is informed by the assumption that Nature abides by its electromagnetic speed limit, one of whose corollaries is to not let its material clocks stop ticking. By these considerations we deduce that the curve should look about as indicated by the red diamond data points.

By contrast, it seems entirely unpleasing, aesthetically, to suppose that the trajectory suddenly stops to bounce back at an unnaturally acute angle. The path of points becomes uglier still if they are conceived as jumping off the graph to escape the physical Universe to infinite, divide-by-zero land. These latter behaviors reflect the unphysical relativistic approach. As mentioned at the outset, the masses of the compact objects along this part of the Chart have been fairly accurately measured. Their densities are actually unknown. But if we simply suppose that they remain on the Chart, then it is not unreasonable to suppose that the pattern continues similar to the SGM-motivated guess, as shown.

Atomic and molecular density is surely well characterized by the fiducial value given on the graph. The given atomic density $\rho_{\rm A} = 3m_{\rm p}/4\pi {\rm a}_0^3$ is not only intuitively familiar and reasonable (about that of aluminum) it is calculated by the simple extreme of one proton (nucleus) within a Bohr radius-sized sphere. By its prominence on our Chart and for these simple theoretical reasons, if one were to pick out a *base density* for material objects found in the Universe, this is arguably the one.

The nuclear saturation density $\rho_{\rm N}$ is less familiar, but nearly as ubiquitous, and as sharply defined as $\rho_{\rm A}$. It is empirically found to be quite close to $\rho_{\rm N} = (16/\alpha^6)\rho_{\rm A}$. Even though White Dwarf densities vary over 3 or 4 orders of magnitude, they lie (logarithmically) nearly midway between atomic density and nuclear density. As noted above, their collapse from the size of normal stars involves an atomic shrinkage by a factor of α, corresponding to a density increase on the order of $1/\alpha^3$. It is therefore reasonable to represent this state by taking the square root of the coefficient that multiplies our base density to get the nuclear density, which is $\sqrt{16/\alpha^6} = 4/\alpha^3$ (White Dwarf density coefficient). Given the pattern from nuclear density downward, the coefficient just specified may reasonably be expected to serve as the defining factor for steps of ascending density. As shown by the horizontal bands and the labels at the left end of the Chart, this is in fact how the steps from Dark Dense Stellar Objects to Dark Dense Galactic Objects are laid out. Though suggestive and arguably reasonable, these conjectured density levels do not play a role in the model as a whole.

Let us then return to that which is considerably closer to the heart of the model and to empirically measured quantities. Density levels from nuclear saturation density and below are all at least very close to empirically measured values. The constants of which they are composed are typically even more accurately measured. Significantly, these densities all relate to each other by factors of α, and/or factors of $m_{\mathrm{p}}/m_{\mathrm{e}}$. Especially noteworthy is that the pair of extreme measured densities ρ_{N} and ρ_μ, combine to yield our definition of G. Simple algebra leads to expressions for G that transparently reveal its connection to h and α:

$$G = 8\left(\frac{\rho_\mu}{\rho_{\mathrm{N}}} \cdot \frac{c^2 \mathrm{a}_0}{m_{\mathrm{e}}}\right) = \frac{4}{\pi\alpha}\left(\frac{\rho_\mu}{\rho_{\mathrm{N}}} \cdot \frac{hc}{m_{\mathrm{e}}^2}\right) = \frac{1}{2}\alpha^3\left(\frac{\mathrm{a}_0}{R_{\mathrm{C}}} \cdot \frac{c^2 \mathrm{a}_0}{m_{\mathrm{p}}}\right). \tag{45}$$

Four noteworthy things about the latter expression in Equation 45 are as follows: (1) The dimensionless ratio now includes the SGM scale factor R_{C} (which makes the expression appear, in a sense, model-dependent). (2) The *acceleration of volume per mass* component includes another factor of a_0. (3) The fundamental mass is that of a proton instead of an electron. And (4) The cubed factor of α accentuates the *volumetric* character of G. This reminds us of the first appearance of α that we encountered in the force/scale-length equation $\alpha F_{\mathrm{E}} \mathrm{a}_0 = 2F_{\mathrm{G}} R_{\mathrm{C}}$. The relative ease by which we have found these relationships, their compatibility with both atomic and astrophysical observations, their simplicity, and the accelerometer and clock readings upon which they are based, all strongly suggest that α is writ large across the sky.

19. – Particles, Fields, and the Building-Block Mentality

> *The whole of physics for the last 30 years [since 1927] has been directed towards questions more or less exclusively evoked by doing abnormal things with matter rather than by simply observing its normal behavior.* — J. R. OPPENHEIMER [178]

In the clues that have played a role in building the SGM, notice that we've found none that indicate an edge as between matter and space. We've encountered references to particles in atoms and various theoretical atomic length scales. But the behavior of these atoms and their components is not fundamentally conducive to the Democritean idea of static chunks of stuff in the discontinuous void. Especially in view of the SGM, which seems to have revealed a close relationship between (cosmic) G and (atomic) α, it seems inevitable that the edgelessness of atoms extends all the way up to galaxies and intergalactic space. The idea that cosmic density remains constant corresponds to the idea that cosmic space is *saturated*, and will remain so forever. After a century of high level cosmological thinking by some of the world's most illustrious physicists and astronomers, failure to see this possibility, traces back, I believe, to an overly fragmented conception of atomic physics. The primal notion of static-sized chunks of stuff dies hard. Insofar as transcendence is facilitated by understanding one's present state, it is worthwhile to explore further evidence and a curious range of opinions about this persistent way of thinking.

It is sometimes reported that the size of an electron must be less than 10^{-18} m. It is often said that the electron cloud that surrounds an atom (as in Figure 24, p. 84) represents the "probability of finding the electron" at some point in the cloud. This is one of the many things that Schrödinger objected to in the standard interpretations of QT. He never tired of emphasizing that, in fact, we *never* find an electron at a definite place in an atom. Indirectly corroborating this view, Stephen Hawking wrote of our still unsuccessful attempts to understand QT:

> The unpredictable, random element comes in only when we try to interpret the wave in terms of the positions and velocities of particles. But maybe that is our mistake: maybe there are no positions and velocities, but only waves. [179]

We've all heard the cliché that "an atom is mostly empty space," which begs the question, what exactly does "mostly" mean? How much is space, how much is matter? The most common (layperson-intended) response is illustrated as some variant of the Bohr model, showing a Sun-like nucleus and planet-like electrons orbiting around it. Referring to this as the "cartoon version" of an atom, the physicist Matt Strassler attempts to make the picture more serious by shrinking the sizes of the bodies and putting them on a fuzzy backdrop. [180] On Strassler's blog where this discussion and these images are found, the name of the image file corresponding to our Figure 28 is "atom_real.png." Fortunately, Strassler admits that this figure "still isn't really accurate," but his reasoning is essentially that the *scale* is still off. He continues to refer to the outskirts of atoms being populated by "extremely tiny electrons." One gets the impression of a persistent clinging to the idea of static sized chunks of stuff.

Sizes of atomic nuclei, as Strassler points out, are more sharply defined. But even here we find fuzziness. Nuclear physicists refer to the transition zone between the inner nucleus and its exterior as the *skin*. The skin has a finite, though not especially *definite*, thickness, becoming denser (more matter-like) toward the interior and more tenuous (vacuum-like) away from the interior. Still, no edge. Even nuclei (protons and neutrons) defy the notion of crisply defined chunks of stuff.

In his book about the famous *Higgs boson*—the so-called *Particle at the End of the Universe* (aka the *God Particle*)—Sean Carroll acknowledges the persistent schism in prevailing conceptions of matter:

> Physics students for generations now have been confronted with the ominous-sounding question, "Is matter really made of particles or waves?" Often they get through years of education without quite grasping the answer. Here it is: Matter is really [made of] waves (quantum fields), but when we look at it carefully enough we see particles. [181]

The confusion that Carroll alludes to is due to the varying and shifting emphasis between particles and waves found within any given text and among various authorities. It is also due to the various meanings given to words like *look*, *carefully*, *see*, and most importantly, *particle*. Although the basis for Carroll's answer is essentially the same as that of other authorities (i.e., Quantum Field Theory) in the literature we find many instances that seem to defy Carroll's assertive answer. Recalling the comments from Cropper as to the lack of understanding of what QT *means*, [152] and from Lindsay and Margeneau as to our ignorance of what matter *is*, [126] we should not be surprised to find conflict.

More evidence of confusion is found in an observation by one of the fathers of inflationary cosmology, Alan Guth. In a *Discover* magazine article about the quantum vacuum, the author evokes a response from Guth that reinforces our impression:

> There seems to be a great chain of being that links vacuums, virtual particles, and "real" particles. There's no clear separation between space and what's in it…"What is a particle?" seems like a simple question. "But if you pose that to twelve different physicists," says MIT physicist Alan Guth, "you'll probably get twelve different answers." [182]

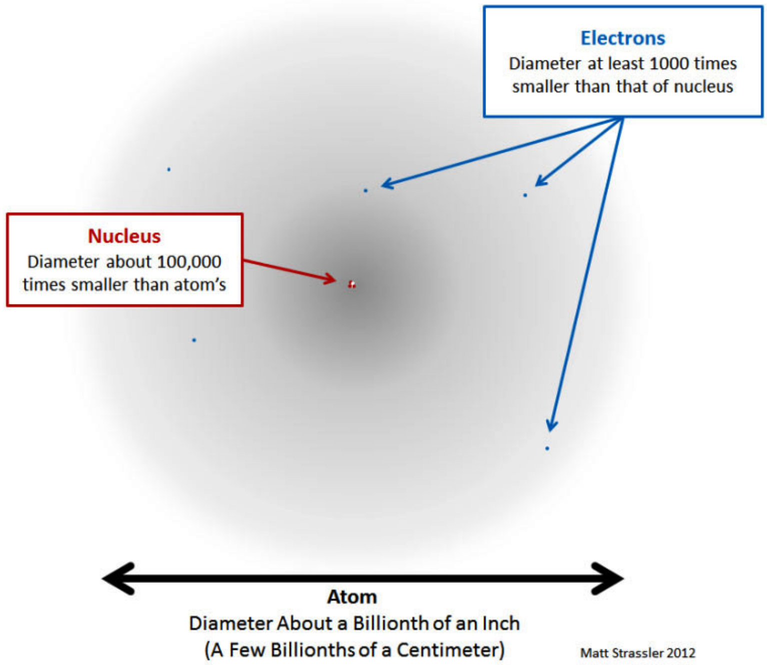

Fig. 28. – Democritean chunks of stuff. The electron size indicated here by Strassler is not deduced from experiments conducted in atoms; it is deduced from experiments in which electrons traveling at near the speed of light are made to collide with each other or with nuclei. Erwin Schrödinger criticized images like this because it makes no sense to think of tiny chunks of stuff as being responsible for the wave patterns as depicted in Figure 24. The faster a bundle of energy travels, the more *pointed* will be its effects. Taking the resulting pointiness as an indication of the sizes of the things involved in the collision, leads to contradictions with other experiments in which the energy absolutely must be spread out much wider than the sizes indicated here. Physics has yet to transcend its schizoid state of conflict over the wave-particle duality.

Carroll says matter is made of waves (fields). But the title of a book by the Columbia University Physicist, G. Feinberg [183] contains not only the same proverbial question, but a seemingly contradictory answer. (See Figure 29.)

Another example of a decidedly more "particlistic" interpretation of QFT is that of the Nobel Prize winning physicist, Martinus Veltman, who wrote:

> As we look at any object, at a table or our hands, it is curious to realize that all that is but a construction made of particles subject to forces, which from the modern point of view are nothing but the exchange of particles. [184]

Based on my experience, I'd say a thorough search of the literature will yield as many if not more instances of atomic reality (matter) characterized as being "made of" particles than as being "made of" fields or waves. I've presented these examples to provide a tangible context to a recent response to the schism in elementary physics by the philosopher-physicist, Meinard Kuhlmann, and the response borne of the SGM to the whole gamut of standard interpretations, including Kuhlmann's.

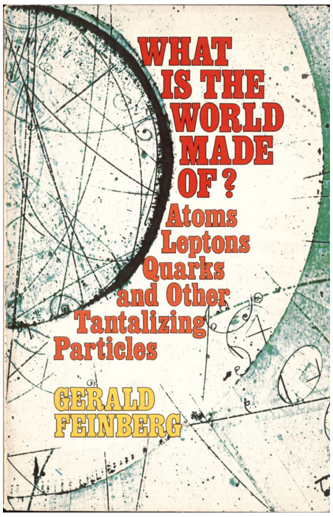

Fig. 29. – Endorsed by Einstein biographer, Jeremy Bernstein and Nobel Laureate, Stephen Weinberg, Feinberg's book celebrates the chunk-of-stuff based conception of the Universe.

The online version of Kuhlmann's recent *Scientific American* article addressing this issue frames it as a "Debate Whether the World is Made of Particles or Fields—or Something Else Entirely." The article explains the inadequacy not only of the extreme positions, but of any range of hybrid approaches to QFT that may prevail. Kuhlmann writes that, "Particle physics is a misnomer: despite the fact that physicists keep talking about particles, there are so such things." After describing those aspects of the contrasting *field* approach that "[makes] the theory very difficult to interpret, to translate into something physical you can imagine and manipulate in your mind," Kuhlmann concludes:

> The standard picture of elementary particles and mediating force fields is not a satisfactory ontology of the physical world. It is not at all clear what a particle or field even is. A common response is that particles and fields should be seen as complementary aspects of reality. But that characterization does not help, because neither of these conceptions works even in those cases where we are supposed to see one or the other aspect in purity. [185]

What Kuhlmann proposes as a replacement, he calls *ontic structural realism*. Basically, the idea is that particles and fields lose their significance in favor of the "structure" that supposedly ties everything together. This is supposed to be analogous to the network-like connections of the brain or the World Wide Web. Clearly this represents a kind of *giving up* on the idea of conceiving intuitive models of what's physically happening, and replacing them with a rather more abstract notion of reality. Since our attempts to make maps of the world have failed to demonstrate a consistent correspondence between one and the other, Kuhlmann seems to be recommending that we never mind the world itself and focus on the maps; the abstract "network" acquires greater meaning than the physical hubs of which it is composed. According to Kuhlmann, rather than consisting of particles and force fields, "The world may instead consist of bundles of properties, such as color and shape." Curiously, this harkens back to the Clarke-Liebniz correspondence, in which Liebniz dismissed the idea of properties without that which they are properties *of*, as absurd (p. 14).

From the SGM point of view this "debate" and Kuhlmann's proposed resolution are wholly inadequate and mostly irrelevant for a variety of reasons. First, is that it is just inconsequential *talk*. It's all about *interpretation* without any substantial difference by which a given interpretation should prevail due to *empirical evidence*. Second, and even more important, is that *none of the parties are asking a much more pertinent question*. Pretty much across the board, the stated concern of physicists is: What is the world *made of*? In the title of Kuhlmann's article, Feinberg's book, on the CERN website, the Fermilab website, in Carroll's book, Wilczek's book, Strassler's blog and countless other books and articles, the big question is: *What are the BUILDING BLOCKS of the Universe?*

Given the problems at hand, this is the wrong question. It's the wrong question—whether one imagines the answer to be particles, waves, fields, ontic structures or any other thing-like noun. With all due respect, we acknowledge that at times this has indeed been (and may again become) the right question, or certainly one of them. In the context of early chemisty and early atomic physics—before Mendeleev's table was complete or before the neutron was discovered—this was an excellent question. But it is not relevant, in my opinion, for the purpose of discovering what we presently need to know. The question is still relevant if one's concern is to sort out the debris left over from spectacularly energetic collisions between hurtling protons ("abnormal" behavior). But this activity will not help to understand the simple everyday experience of gravity or inertia. It will not help to understand *how matter behaves in its normal, undisturbed state*.

The possibility of shedding light on these questions by a simple probe of the inside of ordinary material bodies has not yet occurred to particle, gravitational, or cosmological physicists because they think they already know. They think it is obvious: gravitating matter is a static thing; it is *made of* essentially static things; it just sits there motionless, "conserving" itself. By drawing attention to the fact that we really do not know, by underscoring the huge gap in our empirical knowledge, and by proposing new predictions as to what we will find if we look, the SGM perspective emphatically asserts that the right question is not what is the world *made of*. The right question is: *What is the world **doing**?* The SGM suggests that the answer is given by the nearest accelerometer.

Even if the newly-released, feature-length movie produced by CERN were called *Field* Fever, or *Wave* Fever, instead of *Particle Fever*, it would still represent a fixation by the world's physicists on obscure and esoteric *building blocks*, rather than simple, universal, everyday *behavior*. To the modern physicist, the mystery of gravity evokes the word, *graviton*—the extraneous invented *thing* that supposedly "mediates" the gravitational force. A graviton is conceived as one of the world's building blocks. If the gravitational "field" is instead given primacy as that which may be *perturbed* or *fluctuated* to yield a graviton, swarms of gravitons, or the material bodies that supposedly emit them, and that they supposedly attract—this still doesn't help. It doesn't help because there's no reasonable way this scheme can be used to explain the simple fact, the normal behavior of non-zero accelerometer readings; i.e., the flattening of our undersides.

Whereas the concrete, inescapable *existence* of accelerometers and their non-zero readings is a strong clue that *what the Universe is **doing** is **accelerating***. Not just the space between galaxies, but the galaxies too, and every other atomic component of matter anywhere in the Universe. From this perspective the refusal to believe accelerometers appears as a symptom of the same malady by which we get the whole quagmire-stuck morass of field-particle, Planck scale, holographic string-brane, Big Bang, black hole, building-block thinking. Conducting Galileo's experiment could possibly put an end to

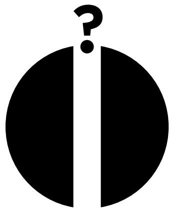

Fig. 30. – Small Low-Energy Non-Collider. What *happens*? What does matter *do*? (To oscillate or not to oscillate?)

this unfortunate state of affairs. The Large Hadron Collider and the big budget particlistic hoopla it has generated is a distraction, which obscures the fact that physics has yet to build the vastly simpler and perhaps vastly more enlightening *Small Low-Energy Non-Collider*. (See Figure 30.)

20. – Cosmic Metaphors

> *As scientists, what we really seem to do is engage in a form of art criticism: "my theory is prettier than yours."...I don't think that's something to be ashamed of. My personal view is that our esthetic sense is the only reliable guide we have.*
>
> *I feel that we are now, at this moment, going through a new period of epicycles in cosmology...We seem to be able to barely fit the data only with the aid of some rather convoluted mathematics...We have contrived to glue the various parts of our world view together to fit the data.*
>
> *There is no trick to fitting the data. What one has to be able to do is fit to the data elegantly.*
> — ARNO PENZIAS (Nobel Prize for discovering the CBR) [186]

It is ironic in the extreme that QT abounds with prominent clues that gravitating matter cannot possibly be *made of* static chunks of stuff. Rigorous application of their cherished theory tells of infinite self-energies of matter and infinite repulsions of the vacuum. These clues—as that of accelerometer readings—go unbelieved and unrecognized. That we should regard these clues as indicating a fundamental continuousness (expanding space, expanding matter) in the cosmic fluid is arguably supported by the ubiquity of Planck's constant h, the fine structure constant, α, and its recurring appearance in the relationships between regimes of cosmic size and density, as discussed above, and as represented on our Cosmic Everything Chart.

The half quantum-composed *vacuum* ($\frac{1}{2}hf$) was borne of investigations into the microscopic nature of whole quantum-composed *tangibly measurable light and matter* (hf). In the early days of atomic theory the composition of matter and energy was conceived as charged and polarized electric and magnetic fields (e^2, ϵ_0, $\mathbf{E}$, $\mathbf{B}$, etc.) and their excitations in the form of light. Before long this emerging set of interconnected physical constants grew to include h, α, the masses of the proton, neutron, electron, and others.

The infinite self-energy that an electron is calculated to have when it is allowed to "interact with itself" suggests that its "desire to explode" is real. The corresponding infinite energy of the vacuum is an indication that the explosive tendency of matter is held in check enough so that stability is maintained; but it is a stability created by a dynamic, α-controlled interplay at the fuzzy interface between matter and space. We find a manifest asymmetry in clock-like matter and timeless light that reflects the direction of time and the cosmic flow. With every tick matter replenishes itself and generates a proportional amount of new space. Whereas the energy of light, being timeless, perpetually fades by becoming ever more redshifted, the further it travels in cosmic space. One may perhaps look upon this fading of old light as simultaneously *inviting* the outwardness of matter and the Universe, to replenish itself from the inside out.

Evidently, there *must* be an imbalance, an asymmetry—or the process could not sustain itself. To avoid sterile static nothingness, one direction (collapse vs. explosion) must prevail, and since collapse would also leave us with nothing, we find instead *explosive growth*: a very finely controlled, rhythmical outward movement by which matter and space are perpetually generated, always in the same proportion. This is gravity.

Even with 5.97×10^{24} kg of matter beneath our feet, the acceleration and velocity due to Earth's gravity pales in comparison to the motion taking place within an atom. (Thus the cliché about the "weakness" of gravity.) But this is evidently what's left after the infinities of matter and vacuum almost exactly "cancel" each other. A graphic way of conceiving this is in terms of a cosmic machine—reminiscent of Dicke's "giant servo-system" and our earlier allusion to governing valves or a ratchet-pawl, escapement system. The idea is that the microcosm is populated with an infinitude of tiny, rapidly moving (ultra-high frequency) "gears." They represent the nuclear and electromagnetic forces. Collectively they turn the single huge (ultra low-frequency) gear of gravity. Or it could be conceived the other way around; each extreme implies the other.

Whichever way we suppose the driver-driven relationship to go, the metaphor serves well to illustrate the cohesiveness that spans the entire spectrum. Faraday's thoughts on the interdependence of Nature's forces are another way to capture the metaphor:

> I have long held an opinion, almost amounting to conviction. . . that the various forms under which the forms of matter are made manifest have one common origin: in other words, are so *directly related and naturally dependent* that they are convertible as it were into one another and possess equivalents of power in their action.
> — MICHAEL FARADAY [187] (Emphasis added.)

This is in contrast with the standard view according to which everything ultimately flies apart. Disintegration and absence of interdependence characterize the Standard Model, as seen in the following examples. It is not uncommon to hear physicists speak of "turning off" one or more of the "interactions" because they suppose the one or ones that are left on will continue to operate. The "interactions" are routinely thought of as being *independent* of one another. In our first example, Frank Wilczek writes, "Let's imagine that we could turn off the electric forces. There would still be gravitational attraction." [188] The same idea is conveyed in our second example by Sean Carroll's reference to the Standard Model of Particles as "explaining everything we experience in our daily lives (other than gravity, which is easy enough to tack on)." [189] The prevailing view represented by these not uncommon mental devices is that it makes sense to conceive that electromagnetism can be "turned off," without affecting gravity; or that gravity can be "tacked on" to the rest of physics, as an afterthought. Such ideas are exactly what the SGM says cannot be true. Stop one gear (interaction) and they all stop.

Further accentuating the standard fragmented view is their whole notion of what "unification" means. Physicists often speak of being in search of a "Grand Unified Theory," or "Theory of Everything." But the unification they envisage *does not pertain to the Universe as it is*, in its present state. It pertains to the conditions imagined to exist at the time of the Universe's alledged birth. Shortly thereafter, at about 10^{-42} seconds after the Big Bang, the fragmentation began. The separate interactions, each at its precisely calculated moment, supposedly "froze out" of the rapidly cooling primordial fireball. Soon thereafter, nuclei and then atoms similarly froze out of the blast. From then on matter has remained as statically conserved discontinuous chunks of stuff, while all discontinuous space keeps increasing around it. The standard model is fragmented in so many ways. It is reflected not only in the prevailing theories themselves, but in the sheer number of complicated variations they've come up with. In pursuit of "highest abstraction," physical reality, it seems, has been pretty much left behind. It's no wonder Penzias and others are unimpressed at how the prevailing models keep getting coddled and patched up, one epicycle after another.

Fragmentation also characterizes their high-profile experimental activities, which, as Oppenheimer has noted, are mostly about doing "abnormal things" to matter. This would be easier to justify if they would only finish the job of looking under their feet to see how matter behaves in its normal state. The experiment that Galileo proposed to check the normal, collision-free behavior of matter has been on the books for 382 years and counting. Meanwhile physicists have grown to be so proud of their theories and their store of empirical data that they routinely make claims such as the following:

> We already know the laws that govern the behavior of matter under all but the most extreme [high energy, high density] conditions. — STEPHEN HAWKING [190]

> General relativity [has] been tested thoroughly and work[s] excellently in [its] range of validity. . . on scales from 10^{-1} mm to at least 10^{14} cm, the size of the solar system. — S. J. B. NOBBENHUIS [191]

> When it comes to understanding the architecture of reality, the low-hanging fruit has been picked. — SEAN CARROLL [192]

Physicists have harvested warehouses full of knowledge about holographic black holes, Planck-scale string-branes, and fantastic mental things like that. They also have stores of data concerning real gravitational behavior, picked from branches as high as the Solar System. But they have *not one bit of data* concerning the fruit that hangs so low, they walk all over it every day: How does one ordinary body of matter fall, when unobstructed, with respect to the center of a larger ordinary body of matter? No data. Smothered by volumes of lip service, the spirit of Galileo has been left to starve. [193-195]

Let's return, then, to the more constructive story of the SGM. The machine metaphor introduced above also reinforces the need for constant proportionality and the need for temporal asymmetry. The "machine" only works in one direction. As the source of propulsion, matter, via gravity and inertia, is *monopolar*. Gravity's perpetual outwardness is the same thing as matter's perpetual increase, which goes only with the perpetual *forwardness* of time. It may help to conceive this (metaphorically) in conjunction with the ratcheted shape of the "gears," the direction in which they turn, the preponderance of matter vs. antimatter, and the left-handedness of biological life. The flattening of our undersides is a constant reminder that gravity works from the inside out. Time only increases because space and matter also only increase.

Our interconnected set of constants (representing various "machine" functions) extends from the electromagnetic nature of matter (e^2, ϵ_0, $\mathbf{E}$, $\mathbf{B}$, etc.) to quantum theory (h, α) to gravity (G) via nuclear physics ($\rho_{\rm N}$) and the Universe (ρ_μ). The problem of the stability of matter ties back into the cosmological context by the fact that stability is closely related to the idea of *saturation* (as in nuclear saturation density). By writing "matter is stable (or saturates)," Lieb clearly indicates the near synonymousness of the concepts. [196] Lieb's colleague, M. Loss, writes that "With the term 'stability of matter' we summarize the simple observation that all material objects are extended in space and occupy a volume that is proportional to the mass of the object." [197] This latter statement effectively equates stability with constant density. Atomic nuclei maintain a constant (nuclear saturation) density $\rho_{\rm N}$ some 47 orders of magnitude greater than the mass equivalent of the cosmic background radiation density ρ_μ. According to the SGM cosmology these are *both* to be regarded as saturation densities. The extremes are stable, so as to allow a wide variety of instabilities in between.

From all of the above we might reasonably *expect* the ratio of these extremes to play a role in defining Newton's constant:

$$G = 8\left(\frac{\rho_\mu}{\rho_{\rm N}} \cdot \frac{c^2 \mathrm{a}_0}{m_{\rm e}}\right). \tag{46}$$

We might reasonably expect that the less extreme ratio between the radiation density (mass-equivalent) and the average cosmic matter density $\rho_{\rm C}$ would be related to the electron to proton mass ratio:

$$\frac{\rho_\mu}{\rho_{\rm C}} = \frac{1}{2}\frac{m_{\rm e}}{m_{\rm p}} \approx \frac{1}{3672.305}. \tag{47}$$

If these relations are indeed true—as theoretical necessities and not "just" tantalizingly close approximations to empirical measurements—then we should expect to find further relationships that may not be so pivotal in building the frame of a cosmological model, but must exist nevertheless. Being especially interested in relationships that do not *depend* on the cosmological model, we consider one such gem before closing.

The gravitational energy in a ground state hydrogen atom can be expressed as

$$E_{\rm GH} = \frac{G\, m_{\rm p} m_{\rm e}}{\mathrm{a}_0}. \tag{48}$$

If we divide this energy by the atomic volume within the Bohr radius a_0, i.e., $V_H = (4\pi/3)\mathrm{a}_0^3$ we get the gravitational energy density. It turns out that this energy density is related to the energy density of the CBR as

$$\frac{E_{\rm GH}}{V_{\rm H}} = \frac{1}{2}\mu\,\alpha^6. \tag{49}$$

The exponent in the factor of α, i.e., 6, is not surprising, as third power increments correspond to whole power increments of the length a_0. (And there again is the ubiquitous factor $\frac{1}{2}$.)

This energy density is not directly measurable, but insofar as all the component quantities have in fact been measured, we can say it is indirectly measurable. More important, perhaps, is its potential theoretical significance. This comes to light by considering the mass density equivalent (which means dividing by c^2) as indicated on our

Cosmic Everything Chart, Figure 27. If we denote $\rho_{\mathrm{GH}} = E_{\mathrm{GH}}/V_{\mathrm{H}}c^2$, then we find a similar ratio as between atomic density and nuclear saturation density:

$$\frac{\rho_\mu}{\rho_{\mathrm{GH}}} = \frac{1}{8}\frac{\rho_{\mathrm{N}}}{\rho_{\mathrm{A}}} \qquad \text{or} \qquad \rho_{\mathrm{N}}\,\rho_{\mathrm{GH}} = 8\,\rho_\mu \rho_{\mathrm{A}}\,. \tag{50}$$

The pattern echoes. In gravity we find relationships pertaining to nuclei and atoms that reverberate up to the whole cosmos.

In 1955, before the CBR was discovered, when a few physicists were looking beyond the accumulation of data from particle smashing machines to the possibility of connecting the microcosm to the macrocosm, E. J. Zimmerman reflected on the still mysterious micro-macro numerical connections that were then known. His conclusions and speculations remain as true or enticing as they were when he wrote them:

> It is therefore plausible that the constants which we believe describe the cosmos are in some way related to the constants which we believe furnish an adequate microphysical basis for observable physical properties. . . The concepts of charge renormalization and of other vacuum polarization effects, the new "ether" theories of Dirac. . . and similar theories involving some kind of all-pervading background environment which is formally infinite or very large, are suggestive that a description of some large-scale structure may be necessary in a complete microphysical theory. It is an interesting speculation that at some future date this environment of elementary particle theory may be associated with an actual cosmological model of the universe. [109]

Such ideas all come together, as I have argued, when gravity is regarded as a process of outward hyper-dimensional motion and the generation of space.

We have compared the cohesiveness and stability of the pattern emerging above to a cosmic machine. Its proportions evidently must be just so. Though local deviations from the saturated ground state are commonplace, at the level of the whole cosmos, deviations simply cannot happen. It is not possible to throw a wrench in the works. The machine is not only finely tuned, it is infinitely durable and self-correcting. As such, a better metaphor readily suggests itself. Rather than conceive the Universe as a machine, it may be more accurate to conceive it as alive. The temperature of the background radiation may then be regarded as a body temperature. The ultimate function or purpose of the eternal "organism"—if one needs to be supposed—is to discover itself, to become aware of itself. We humans may think of ourselves as agents in this endless process.

However poetic (unscientific?) this metaphor may be, it is hard to resist. What we have found (scientifically) is a system of physical relationships by whose continuousness and dynamic persistence shows no sign of disintegration. Everything fits. Our interconnected set of constants implies that the terpsichore of matter and space, gravity and light, the interrelationships between G, c, h, α, and the rest, has always been and will always be dancing in simple harmony forever. Local components may assemble and disperse, live and die, but their collective effect is to perpetuate the eternal life of the whole cosmos. By conducting Galileo's simple experiment we can discover whether or not this model is "pretty" enough to be true.

Appendix A.

Acceleration and Falling Questions Evoked by Figure 8

Answers to the questions posed with regard to Figure 8 might have been given in the context of earlier discussions; for example in conjunction with the SGM tubular model of hyper-dimensional motion, or energy conservation violation by perpetual creation of space. To preserve the flow of those ideas where they arose, I've referred to this Appendix as the one place where a relatively complete and explicit answer is given.

Falling under gravity is not, as is often suggested, analogous to motion at the ends of a *spring*. Spring-induced motion causes non-zero accelerometer readings; falling in gravitational fields does not. For exterior circumstances, energy would appear to be conserved; but a probe of gravity *inside* matter, as in Galileo's experiment, would reveal a stark violation of the energy conservation law, because if the mechanism of gravity is the hyper-dimensional generation of space, then it is the source masses and their surrounding space that move ever outward; nothing ever pulls the probe downward. If gravity were an attractive, conservative force, then the probe would pass the center with a maximum speed and oscillate back and forth, while *feeling* no acceleration at all (zero accelerometer reading). But if the allowed microscopically intermittent energy increases add up to the creation and outward stationary motion of space, then passing the center would require that the probe be given a sufficient downward acceleration, an acceleration that would be revealed as such by an accelerometer.

If the real nature of gravity is hyper-dimensional motion of space, then the perpetual zero reading on the falling accelerometer indicates the following answer to the questions posed in connection with Figure 8. *What happens* when the support member of the accelerometer is cut is that the space that initially separated the accelerometer from the

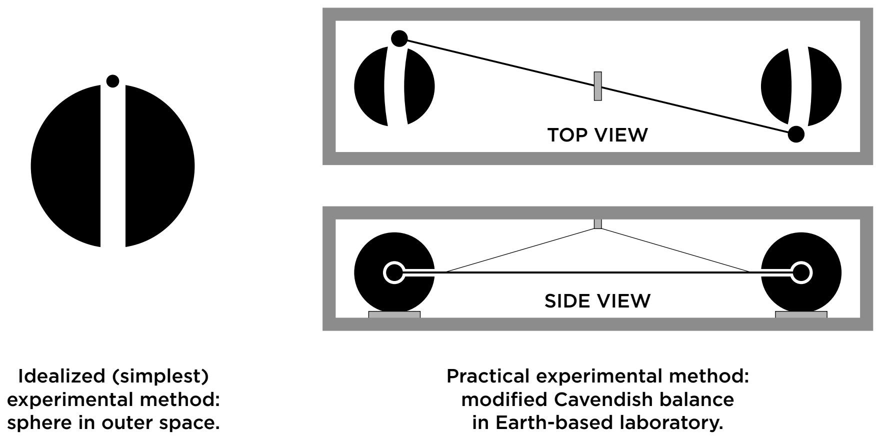

Fig. 31. – Small Low-Energy Non-Colliders; apparatus schematics. Left: The single source mass method, which resembles Galileo's original cannonball idea, could be done in an orbiting satellite. A small rotation would need to be given to the source mass so that the hole through its center would remain parallel to Earth's surface (Moon-like orbit). Right: A more practical method would be to use a modified Cavendish balance, whose support system poses the biggest challenge. A fluid or magnetic support would be needed so as to allow a full range of angular motion without any restoring force. The arced path deviates from the ideal, but suffices to at least roughly reveal the answer to the prime illuminating question: To oscillate or not to oscillate?

surface gets pushed upwardly past it. That's why it appears to fall "down." As long as the fall occurs over the surface the apparent acceleration will obey the inverse-square law (interpreted as a force of attraction). But, below the surface, as the amount of space-generating matter between the falling object and the center diminishes, so does the rate at which space gets pushed outwardly past it. This obviously goes to zero at the center. Inside matter the inverse-square law is still true with regard to accelerometer readings. But they do not necessarily correspond to the observable motion of falling objects.

An object released from the surface—whose initial velocity is absolutely upward (as indicated by clocks on the surface)—will thus reach a maximum apparent downward speed before asymptotically approaching the center, as shown in Figure 5. That's the SGM answer. To get *Nature's* answer we need to dig a hole under the falling accelerometer (or a hole through a laboratory sized source mass into which falls a smaller test mass) through the center. (See Figure 31.) Collision with the source mass needs to be prevented so we can see the motion all the way in. If what happens is that the intervening space gets pushed past the falling object and nothing ever pulls it downward, then Nature's answer agrees with the SGM's.

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Einstein wrote: "The following important argument speaks for the relativistic perspective. The centrifugal force that works on a body [that is part of a rotating system K'] under given conditions is determined by precisely the same natural constants [i.e., its mass] as the action of a gravitational field on the same body, in such a way, that *we have no means to differentiate a 'centrifugal field' from a gravitational field*. . . This quite substantiates the view that *we may regard the rotating system K' as at rest* and the centrifugal field as a gravitational field." [Emphasis added.]

[8] EINSTEIN, A.: *Relativity, the Special and General Theory*. (Crown, New York, 1961) p. 80.
A second example (in addition to Ref [7]) reinforces the point. In his book on SR and GR intended for lay readers Einstein discusses the observations made by an observer who is riding along with the rods and clocks attached to a rotating disk: "The observer on the disc may regard his disc as a reference-body which is "at rest"; on the basis of the general principle of relativity he is justified in doing this. The force acting on himself, and

in fact on all other bodies which are at rest relative to the disc, he regards as the effect of a gravitational field… This gravitational field is of a kind that would not be possible on Newton's theory of gravitation. But since the observer believes in the general theory of relativity, this does not disturb him."

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[16] EINSTEIN, A.: *Ideas and Opinions*. Crown, New York (1982) p. 310.

[17] NARLIKAR, J.: *Structure of the Universe*. (Oxford University Press, Oxford, 1978) p. 140.

[18] DICKE, R. H.: 'Gravitation—an Enigma.' *American Scientist*, 47 (1959) pp. 25–40.

[19] KOESTLER, A.: *The Watershed, A Biography of Johannes Kepler*. (Doubleday Anchor, New York, 1960) p. 154.
Koestler wrote: "Newton's concept of a 'gravitational force' has always lain as an undigested lump in the stomach of science; and Einstein's surgical operation, though easing the symptoms, has brought no real remedy."

[20] RIDLEY, B. K.: *Time, Space and Things, Second Edition*. (Cambridge University Press, Cambridge, 1984) pp. 99–100.
Ridley wrote: "Things in a force field start to move without anything visible pushing them. Pure magic, but we have talked ourselves into behaving as though such things are perfectly understandable… We think we understand. But, really, we do not. The invisible influences of gravitation and electromagnetic fields remain magic; describable, but nevertheless implacable, non-human, alien, magic. Potential energy is a measure of the strength of this magic."

[21] BREHME, R. W.: 'On Force and the Inertial Frame.' *Am. J. Phys.* **53** (10) (October 1985) p. 952.
Brehme wrote: "The nagging question remains: Why is it that in frames in which fixed clocks do not keep time at the same rate, free bodies spontaneously accelerate? We have no answers."

[22] MOOK, D. E. and VARGISH, T.: *Inside Relativity*. (Princeton University Press, Princeton, NJ, 1987) p. 149.
The authors wrote: "Einstein did not provide an answer to the question raised by Newton concerning the 'cause' of gravity… We will see after we have described Einstein's model for gravity that we are still left with a question of the sort 'how is it possible…?' just as with Newton's model."

[23] CLARK, S.: 'Warning Light.' *New Scientist* (4 January 2014) p. 31.
Clark wrote: "Although we don't see [spacetime's] ups and downs, we feel them as the force of gravity… There is just one nagging problem: no one knows what it is."

[24] MURCHIE, G.: *Music of the Spheres: The Material Universe—From Atom to Quasar, Simply Explained, Volume 1*. (Dover, New York, 1967) p. 69.

[25] EINSTEIN, A.: *Ideas and Opinions*. (Crown, New York, 1982) p. 282.

[26] SMOLIN, L.: *The Trouble With Physics*. (Houghton Mifflin, New York, 2006) p. 311.

[27] PEEBLES, P. J. E.: *Physical Cosmology*. (Princeton University Press, Princeton, NJ, 1993) p. 131ff. Discovery of the background radiation occurred in 1965. Since its peak energy is in the microwave band, it is sometimes referred to as the cosmic microwave background (CMB). Peebles is among those who refer to it as cosmic background radiation (CBR) which I prefer, so that is how it is denoted in this essay.

[28] NEWTON, I.: *Sir Isaac Newton's Mathematical Principles of Natural Philosophy and His System of the World, Volume I: The System of the World*. Translated into English by MOTTE, A., 1729. Revised translation by CAJORI, F.: (University of California Press, Berkeley, 1962) p. 13.

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[32] BARBOUR, J.: *Mach's Principle: From Newton's Bucket to Quantum Gravity*. Eds., BARBOUR, J. and PFISTER, H. (Birkhäuser, Boston, 1995) p. 530.

[33] EINSTEIN, A.: 'Critical Comment on a Solution of the Gravitational Field Equations Given by Mr. DeSitter.' Reprinted in *The Collected Papers of Albert Einstein, Volume 7, English Translation*. (Princeton University Press, Princeton, 2002) p. 38.
It is interesting that, having said that GR is "satisfying only if it shows that the physical qualities of space are *completely* determined by matter alone," it was subsequently shown that GR does not satisfy this condition. And yet Einstein never expressed any serious dissatisfaction with his theory. For example, he still referred to it as "THE Solution to the Problem of Gravitation," and claimed it to be of "excellent beauty." Was *Big Al an operator*, or what?

[34] EINSTEIN, A.: 'On the Foundations of the General Theory of Relativity.' Reprinted in *The Collected Papers of Albert Einstein, Volume 7, English Translation*. (Princeton University Press, Princeton, 2002) p. 33.

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This blog entry by the cosmologist, Carroll, is a critique of the work by two social scientists who have not lived up to Carroll's ostensible standards. A particular focus is the dubious

strategy of "thinking deeply" instead of devising empirical methods to support (or refute) one's theories. I contributed 5 of the 50 comments to the post, beginning with an echo of support for the idea that "Testing Your Theories" means testing by experiment. Then I hastened to point out that, in elementary academic physics, the interior falling experiment (referred to in this essay as Galileo's) is routinely "solved" by *thinking deeply*. Physicists including Carroll routinely accept this textbook "result," but do not see such acceptance as committing the same error as the one committed by the social scientists. Except for one comment of approval that appeared one morning and then vanished by that evening, my comments were ignored.
Note that, at the time of the initial posting, the blog was not Carroll's own, but was shared by 6 other physicists and astronomers under the auspices of *Discover Magazine*.

[194] BENISH, R.: Comments in weblog of STRASSLER, M.: 'No Comet, But Two Crescents.' <http://profmattstrassler.com/2013/12/06/no-comet-but-two-crescents/> Accessed June 3, 2014.
The comments that I contributed to this entry were motivated by the combined focus on Galileo and his observations of Venus, on one hand and on the other hand, by Strassler's recommendation to directly observe Nature: "Why learn from books what you can check for yourself?!?" My suggestion was to apply the same advice to another of Galileo's ideas: To conduct the interior falling cannonball experiment (Small Low-Energy Non-Collider). In this case, Strassler evidently has no interest in checking the book answer against direct observation of Nature. No human has *ever* checked Nature on this one. Strassler is evidently not likely to be the first. Except for another reader's comment concerning an entirely different kind of experiment, my comments were ignored.

[195] BENISH, R.: Comments in weblog of STRASSLER, M.: 'Did Hawking Say There Are No Black Holes?' <http://profmattstrassler.com/2014/01/30/did-hawking-say-there-are-no-black-holes/> Accessed June 3, 2014.
The comments that I contributed to this entry were motivated by the irony of so much attention being paid to *mathematical* "holes" in the context of gravitational *theory*, when we have not yet bothered to explore *real* holes in the context of *physical reality*. Except for a reply that entirely missed my clearly stated point (the importance of observing collision-free radial falling motion), my comments were ignored.

[196] LIEB, E.: 'The Stability of Matter.' *Reviews of Modern Physics*, **48**, (October 1976) p. 553.

[197] LOSS, M.: 'Stability of Matter.' <http://people.math.gatech.edu/~loss/papertalks/Nov14review.pdf> Accessed April 8, 2014.