Laboratory Test of a Class of Gravity Models

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Ideas for explaining the mechanism of gravity involving the expansion of matter have been proposed several times since the 1890's. Due to their radical nature and other reasons, these ideas have not gotten much attention. An experiment is proposed whose result would unequivocally either falsify the matter expansion hypothesis or support it. Analyses of star cluster velocity dispersions suggest that some support already exists.

Keywords: gravitation, expansion hypothesis, Cavendish balance, interior solution, star cluster, velocity dispersion

1. Introduction.

In response to a model of gravitation that was proposed by a contemporary, [1] in 1898 Arthur Schuster was inspired to write:

> *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?* [2]

In §2 we will briefly mention ideas similar to Schuster's that have appeared in more recent times. In §3 it is acknowledged that simplistic expansion models are untenable and a more sophisticated alternative is briefly outlined. Schuster's question, "How are we to prove…" can be answered by performing the experiment described in §4. A more feasible, laboratory version of the experiment is described in §5. In §6 it is pointed out that, in principle, the answer the experiment would directly provide is already indirectly available to us in the kinematics of astronomical cluster systems. In §7 we summarize and conclude.

2. Expansion models in the literature.

Arthur Schuster, quoted above, was a well-respected physicist and has the renowned distinction of being the first to correctly explain the mechanism of a radiometer. In the interest of keeping his reputation intact, I suppose, the title of the *Letter to Nature* containing the above comment was "A Holiday Dream." The only other instance, to my knowledge, of a gravity-as-expansion of matter idea being published in a peer reviewed journal is the paper by C. Cahen, titled: *"The Proportional Expansion of Each and Every Celestial Body as the Cause of Gravitation,"* [3] More common are self-published books (Robertson, [4] Carter, [5] McCutcheon, [6]) or internet physics forums and weblogs: (Markov, [7] Hodson, [8] Fischer, [9] Copple, [10] Spork, [11]) and probably others. For completeness, I'll mention that the cartoonist, Scott Adams, has also had occasion to dream up this explanation of gravity. [12]

But is it science? At least one lucid and purportedly conclusive critique of the concept may also be found on the internet. [13]

Although the critique pays the idea enough respect to gather evidence against it, I don't believe its conclusion is as certain as it is claimed to be. In the interest of leaving absolutely no doubt as to the viability of the expansion idea, I would suggest probing a domain of physical reality that has been largely overlooked. In the books of both Carter and McCutcheon this domain's potential as a testing ground for falsifying (or supporting) their respective models is mentioned, namely, the *insides* of gravitating bodies. To seek to witness the trajectories of test objects moving inside massive bodies is most certainly within the purview of science.

3. Accelerometers, clocks, spacetime curvature and space dimensions.

> *The notion of analogy is deeper than the notion of formulae.—J. R. Oppenheimer* [14]

Before pointing out how the interiors of massive bodies provide the perfect testing ground for expansion models, a little more background is in order. One of Einstein's most important analogies is the Equivalence Principle (EP). Most of the authors cited above appeal to the EP in defense of (or as the basis of) their expansion models. A simple consequence of the EP, often mentioned even in mainstream texts, is that our experience at Earth's surface is as though the ground were accelerating upward. (This explains why all bodies fall with the same acceleration, etc.) If, as a working hypothesis, one omits the "as though" and supposes this idea contains more truth than the idea of gravity as a force of attraction, the implication is that the Earth as a whole is expanding.

Objections immediately arise. For example, if expansion of matter is the cause of gravity, how then does one explain the variation of the acceleration due to gravity, *g*, at different radial distances from a given body and on bodies with different sizes and masses? Or how does one explain 360° orbits? The critique cited above [13] expounds on these objections, and the model that is set up is convincingly shot down. The simplistic idea of matter expanding into a pre-existing three-dimensional Euclidean space is not tenable. With some added sophistication, however, a more defensible model may be conceived.

Gravitational phenomena could be described as a process of outward movement, I suggest, if the expansion is occurring in a curved space that has four, instead of just three, dimensions (plus one time dimension). The math obviously needs to be worked out; but the force of analogy suggests that it should be possible to do so. One of the conceptual bases of this model is a rotation analogy similar to Einstein's, in which he argued that the "space" of a uniformly rotating plane is curved because of its rotation. [15] Einstein had other occasions to make analogies between circumstances that patently involve motion and circumstances typically regarded as static. As with these other occasions, one of his motivations in the case of rotation was to give observers in the *moving* system justification for regarding themselves as being *at rest*. Presently, we regard Einstein's logic as backwards.

General Relativity's Schwarzschild solution epitomizes Einstein's static conception of gravity. The lengths of measuring rods and the rates of clocks are altered by a massive body's gravitational potential; the potential is quantitatively *represented* by these alterations. In the present scheme, changes of length and time standards and non-zero accelerometer readings represent not the *potential* to cause motion; they reflect the *existence* of motion. Accelerometers giving non-zero readings do so because they are absolutely accelerating. Ideal clocks whose rates vary with position indicate the existence of absolute velocity. Evidence for motion indicated by an array of accelerometers and clocks attached to a rotating body would be just as abundant as by a similar array of accelerometers and clocks attached to a large massive body. The instruments indicate that neither of these systems should be regarded as static. I am only suggesting that we begin to trust our instruments, to regard accelerometers and clocks as *consistently telling the truth* about their state of motion—even if this implies that we need to radically alter our conceptions of matter, space and time. *Stationary motion* is as much a property of a gravitating body as it is of a rotating body.

Although description of the rotating system can be accommodated with only three space dimensions, the stationary radial motion due to gravity would require one more space dimension. The idea of turning into (or out from) a higher space dimension is thus proposed as the key to developing a mathematical description of gravity as an expansion process, wherein the *stationary velocity* and *stationary acceleration* are now both directed radially outward. Spacetime curvature arises *because* of the expansion. The "expansion of matter" would then be more correctly conceived as a dynamic, locally inhomogeneous *projection* of both matter and space. The inhomogeneity is manifest as gravity. Spacetime curvature does not cause motion; *motion causes spacetime curvature*. Outward motion is the *essence* of matter. Gravity is the fourth dimension of space.

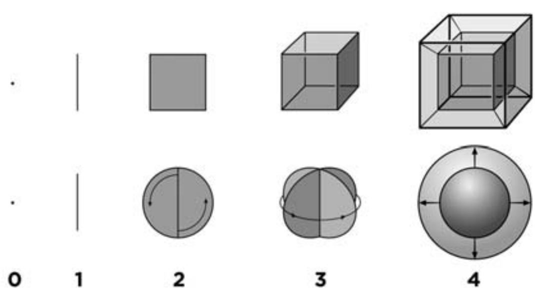

Figure 1. Hierarchy of dimensions: linear, rotational and omnidirectional projection.

4. To oscillate or not to oscillate?

Assuming then, that gravitational phenomena occurring near and beyond Earth's surface do not necessarily prove the expansion idea wrong, suppose we were able to probe deeply *within* Earth's surface. Even better, consider an idealized uniformly dense sphere with a hole through a diameter. Suppose the sphere is far removed from other large gravitating bodies in the vacuum of space. What happens when we drop a test object into the hole? Due to the simplicity of the answer based on Newton's theory of gravity, this problem is often found in elementary textbooks [16, 17, 18, 19] (and also higher level texts [20, 21]). If gravity is a force of attraction the object will harmonically oscillate in the hole. Whereas, if the expansion hypothesis is closer to the truth, the object will not pass the center because it has never been *forced* to move toward the center; *nothing pulls it inward* (zero accelerometer reading). Instead, as the large massive sphere expansively accelerates past it, the test object will at first appear to accelerate downward; it will reach an apparent maximum speed about 1/3 of the way down ($r \approx 2R/3$, where R is the sphere's surface radius), and then appear to decelerate as it asymptotically approaches the center. If we had empirical proof that the test object oscillates in the hole, the expansion hypothesis would have been falsified. Unfortunately, as B. DeWitt has pointed out, "the experiment you mention has never been done." [22]

Even if one doubts the likelihood that performing such an experiment would reveal "new physics," I believe it would be worthwhile to do. The texts that discuss the Newtonian prediction rarely (if ever) refer to it as such. Rather, it is typically presented as though the results were a known fact, even though no empirical evidence is ever given. The success of Newton's model gathered from evidence near and beyond the surfaces of large massive bodies (exterior solution) is implicitly regarded as sufficient to extrapolate from the surface inward. Doing the experiment would allow us to replace the extrapolation with an empirical fact.

5. Apparatus.

> *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.—Herman Bondi* [23]

Desirable as it is to test the oscillation prediction in the purity of empty space, for the moment at least, that is beyond our reach. It may nevertheless be possible to get the answer we seek in an Earth-based laboratory. A Cavendish-like balance, whose large masses are sculpted so as to permit motion of the arm and small masses through their centers could be built and operated in a modest laboratory (Figure 2). Besides having large masses with holes in them, the other crucial modification from the original Cavendish balance involves the arm support mechanism. The arm needs to be able to swing freely through a wide angular range ($\approx 20°$) without any particular equilibrium angle being singled out, or at least without being singled out too strongly. A fiber support whose restoring force increases with twist angle therefore will not work. Magnetic or fluid support systems are possible solutions.

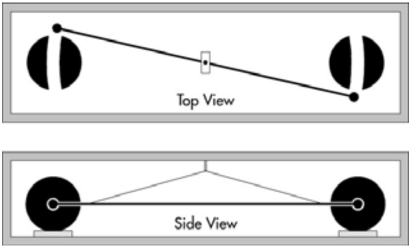

Figure 2. Schematic of modified Cavendish balance.

Perhaps the biggest challenge in building such an apparatus is minimizing torque-producing asymmetries in the suspension system. The neutrality of the arm must be established before putting the large masses in the enclosure. Only then would one be able to assure that when the large spheres were installed the movement of the arm is due primarily to their gravity. This assessment is borne of experience, as I have attempted to build such a device myself. I may still succeed in getting it to work. Presently, with the large spheres not yet installed, I find that unwanted systematic torques are only slightly greater than what would be produced by the gravitation of the large spheres. Evidently, success is less than an order of magnitude away.

6. Astrophysical evidence.

In response to my suggestion that a test object may not oscillate through a spherical mass in circumstances such as those described above, John A. Wheeler wrote back:

> *The best place to see a spherical distribution of mass with a hole through it is a star cluster. Spectroscopic observations show that individual stars oscillate right through it in the stated manner.* [24]

Actually, spectroscopic observations show nothing of the kind, as one may readily discover in any astronomy library. What such observations do show is the component of velocity of a star or galaxy along the line of sight. They are thus known as *line-of-sight* or *radial* velocities. Perpendicular to this velocity component, *angular velocities* can sometimes also be measured. Changes in a star's position on the plane of the sky are also known as *proper motions*. Evidence bearing on our question, "to oscillate or not to oscillate" may be gleaned by comparing the results of these two measurement methods applied to one cluster. An explanation for why this is so and a brief description of the astronomer's task are thus in order.

With one exception, the observations to be discussed are of the densely populated Globular Clusters (GC's). These are very old objects whose member velocities are typically supposed to be highly randomized. From the Newtonian perspective this means, ideally, that trajectories through the cluster's center are just as likely as circular orbits (with a corresponding distribution for the various orbital shapes in between). According to the expansion hypothesis, on the other hand, a perfectly radial stellar orbit will result in the star getting stuck at the center. To ensure long-term stability, therefore, stellar orbits would need to tend toward being circular. Otherwise, the cluster would collapse. The expansion hypothesis thus predicts that

> *Members of stable gravitationally bound cluster systems will possess substantially fewer near-radial orbits than near-circular orbits.*

This would be revealed observationally as proper motions being faster than line-of-sight velocities, especially near the center of the cluster.

The density distribution of most GC's resembles a power law $\rho \propto 1/r^n$, with $1.5 < n < 3.5$ (and a flattening near $r = 0$.) Therefore, at moderate to large distances from the cluster's center the circumstance approximates an exterior solution, in which case we assume Newtonian predictions and expansion hypothesis predictions are similar. Near the center, however, there should be an observable difference.

Our time line is very short compared to the time taken for a star to traverse an appreciable distance through the cluster it resides in. Therefore the kinematic pattern within the cluster can only be deduced from the statistics of the instantaneous radial velocities or the very short proper motion arcs of many stars. Proper motion measurements are especially dependent on high-resolution telescopes and archival observational data—the latter being needed to enable comparison of at least two different positions on the plane of the sky from which to deduce a velocity. This is still, however, just an *angular* velocity. To convert it to a *linear* velocity requires an estimate of the cluster's distance. Radial velocities, on the other hand, are straightforward deductions from the Doppler effect and so do not depend on distance. In either case, the velocities in an appropriate selection bin are squared and averaged; such a data set is known as a *velocity dispersion* (radial or proper motion).

Astronomers have developed several independent methods for measuring distances (e.g., based on *standard candles* or *main sequence fitting*). If these distance measurements were perfectly reliable and the velocities of stars in the cluster are randomized, then if the given distance were used to convert the angular velocities to linear velocities the result would be that the proper motion velocity dispersions would match the radial velocity dispersions. As it turns out, they rarely match. Proper motion velocity dispersions are generally higher. The greater proper motion velocities are regarded as casting some degree of doubt on the original distance measurement. Astronomers routinely adjust the distance to make the two different velocity dispersions equal. This procedure is called an *astrometric (kinematic or dynamical) distance measurement.*

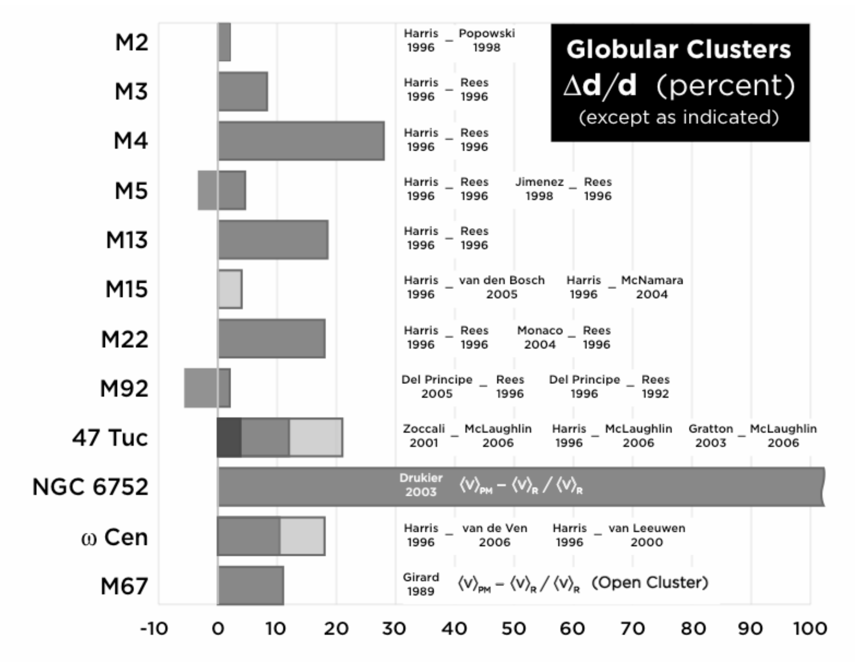

Figure 3. Distance and velocity dispersion discrepancies. Percent greater than zero indicates non-astrometric distance greater than astrometric distance or proper motion velocity greater than radial velocity. Sources are: Harris, [25] Rees, [26] Popowski, [27] Jimenez, [28] van den Bosch, [29] McNamara, [30] Monaco, [31] Del Principe, [32] Rees, [33] Zoccali, [34] McLaughlin, [35] Gratton, [36] Drukier, [37] van de Ven, [38] van Leeuwen, [39] Girard, [40].

The data compiled in Figure 3 clearly show that proper motion velocities are inclined to be greater than radial velocities. A few cases are of marginal significance. For two of these, M5 and M92, the author (Rees 1996) gave large error margins and pointed out the need for more and better data. The same author suggested that the results for M4 and M22 "seem particularly solid."

The GC M15, indicating a small or zero discrepancy, is exceptional for a few reasons: its velocity dispersion curves are notably more complex than the others, and observations reveal a rapid rotation near its center. This cluster has long been suggested as having a "collapsed core," which some astronomers suspect harbors a black hole or a high concentration of dense dark objects, e. g., white dwarfs and neutron stars.

47 Tuc is a well-studied cluster whose distance has been estimated by various methods. Color variations in the bar indicate the resulting deviations for two of these methods. A fourth method has yielded near exact agreement with the middle value (12%) which represents both an average of all results and that gotten by the most focussed recent effort to get an astrometric measurement (McLaughlin 2006).

The largest GC in the Galaxy, ω Centauri, has also been extensively studied. One of these studies (the proper motion survey of van Leeuwen, et al, 2000) took decades to complete and yielded a report based on the measurement of nearly 10,000 stars. To the apparent consternation of some astronomers, the results implied a distance to the cluster that was deviant by ≈ 15%. This is represented by the faded part of the bar. A re-analysis has recently been published which, however, is still clearly deviant. (This deviation is reported as being somewhat smaller than what I have indicated due to an error in their basis for comparison. van de Ven, et al state this basis (5.0 kiloparsecs) as being the distance given by Harris (1996). But the distance actually given in Harris (1996) is 5.3 kpc, not 5.0 kpc.)

M67 is an *open cluster* whose velocity dispersions were not used explicitly for an astrometric distance measurement, but the results reinforce the pattern shown by the GC's.

Finally, we come to the most dramatic discrepancy of them all. Measurements of proper motion velocities in the globular cluster NCG 6752, especially near its center, came out as more than *double* (actually closer to 2.5 times) the radial velocities. The authors discussed at length the many difficulties involved in making such observations and in interpreting the results. It is relevant to quote their conclusion:

> *Our Hubble Space Telescope proper motions suggest that the velocity dispersion in the center of NGC 6752 is surprisingly large. At 12.5 km s^{-1} it is much larger than the measured dispersion along the line of sight. While there is some uncertainty in the distance to NGC 6752 it is certainly known to better than the factor of roughly two which would be required to bring the two measurements into agreement. …a most peculiar situation.* [36, 41]

Before commenting on this "peculiar situation," I'd like to point out that the data in Figure 3 are about all the radial vs proper motion comparisons we have. More, of course, are on the way. The GC NGC 6397, for example, is an object (among others) of an in-progress astrometric measurement project using the Hubble Telescope. Rees initially presented his measurement of this cluster in 1996, and it would have fallen in line with the pattern (15%–25%). But Rees noted reservations about his data, so I've excluded it from the chart.

Our alternative interpretation of these results is that the original (long) distance measurements are probably reliable. If the compared dispersions don't match, it indicates a deviation from Newtonian physics: a preponderance of near circular orbits, especially near the clusters' centers.

If these results had leaned the other way, if the radial velocities were consistently greater than the proper motions, then the expansion hypothesis would clearly have become very difficult to defend. The only out would involve denying the validity of these results. Even if the results were split down the middle the viability of the expansion hypothesis would have been seriously diminished. As it is, the data tends to support it. Due to the remoteness of these objects and the many uncertainties involved in the measurements, the strength of that support is difficult to assess. Clearly we need more data. The laboratory experiment seems the best bet.

7. Conclusion.

Objections to the idea that the mechanism of gravity involves some kind of expansion of matter may not be as ironclad as they are purported to be. The vast majority of evidence supporting Newton's and Einstein's theories of gravitation comes from observations near or beyond the surfaces of large gravitating bodies. The half of the observable world beneath our feet, in effect, has been left unexplored. To some extent, gravitational interior solutions are tested by observations of astronomical cluster systems. These objects are so large and remote, however, that their kinematic properties can be only indirectly deduced; the observations involve various complications and uncertainties. Still, it is a curious fact that the evidence lends support to the expansion hypothesis. Performing the proposed experiment is therefore recommended for at least two reasons: 1) The results may shed some light on these unexpected astronomical results. And 2) The results would fill in a large lacuna in our store of empirical knowledge of gravity.

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