Gravity Experiment in Waiting

RICHARD BENISH([1])

([1]) *Eugene, Oregon, USA, rjbenish@comcast.net*

Abstract. — In 1632 Galileo proposed an extremely simple gravity experiment that has yet to be carried out. Its essence is to determine what happens when a test mass is dropped into a hole through the center of a larger source mass. It is a common problem in first year physics courses. Using a modified Cavendish balance or an orbiting satellite, with modern technology the experiment could have been done decades ago. In a seemingly unrelated context, many modern theories in physics have been criticized for their lack of connection with empirical evidence. One of the critics, Jim Baggott, has expounded on the problem in a book and more recently in an article, *The Evidence Crisis*, posted to the weblog, *Scientia Salon*. Einstein's theory of gravity is widely regarded as being supported by empirical evidence throughout its accessible range, from the scale of millimeters to Astronomical Units. Not commonly realized, however, is that, with regard to gravity-induced motion, the evidence excludes the *insides* of material bodies over this whole range. Specifically, the gravitational interior solution has not been tested. It is thus argued that here too modern physics suffers an evidence crisis. In this case it pertains to the lack of evidence from what may be called the most ponderous half of the gravitational Universe, inside matter. This large gap in our empirical knowledge of gravity could be easily filled in by conducting Galileo's experiment. Why don't we?

PACS 04.80.Cc – Experimental tests of gravitational theories.

1. – Introduction

The motto of the Royal Society, *nullius in verba*, is a succinct declaration of the ideals of science. It means: "Take nobody's word for it." On the Royal Society's website it is stated that the motto

> . . . is an expression of the determination of Fellows to withstand domination of authority and to verify all statements by an appeal to facts determined by experiment. [1]

Jim Baggott's recent post to *Scientia Salon* [2] concerning the "crisis of evidence" in string theory and cosmology well characterizes the trend of diminishing respect for these ideals by modern theorists. Presently, we will discuss a less well known, but comparably troubling example of the same trend found in a particular case of gravitational physics.

A crucial difference between the circumstance described by Baggott and the present one is this: Baggott points out the failure of theorists to provide predictions by which theories can be tested. Whereas the failure to be discussed here concerns a prediction that is easily obtained in both Newton's and Einstein's theories, one that *could* fairly easily be tested, but nevertheless *remains untested*. It is thus an example in which scholars of gravity are routinely taught to *submit* to authority, to take the word of theorists, and to not trouble themselves with verifying such statements "by appeal to facts determined by experiment."

Ironically, the prediction pertains to a test that was proposed by the "Father of Modern Science" himself. 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]. [3]

A "pierced" body of matter that is much smaller than a planet would facilitate doing the experiment in an orbiting satellite or an Earth-based laboratory. [4]

This problem is often discussed in freshman physics courses. The standard answer is that the dropped object harmonically oscillates between the extremities of the hole. So common is the problem and so obvious is the "answer," that the fact of having no direct empirical support is routinely overlooked. The answer is assumed to be true on a basis quite like the "*theoretically confirmed theory*" approach that Baggott has cogently criticized as a manifestation of modern physics' "losing respect for evidence."

Newton and Einstein say the test object oscillates. It is therefore presumed to be needless to check the prediction against physical reality. In what follows I will present three lines of argument to expose this state of affairs as unacceptable and to provide incentive to actually carry out the experiment in question.

2. – Motivations

Reasons to conduct Galileo's experiment may be categorized as follows:

1. Basic scientific curiosity;

2. The reputation of gravity as a puzzling enigma; and

3. A clue suggesting that the standard prediction could be wrong.

It will be emphasized that, if the science of physics lived up to its ideals, then argument (1) should be *sufficient* motivation to do the experiment.

Argument (2) adds to the motivation because gravity's notoriety for being a mysterious oddball should naturally inspire a diligent and thorough investigation. In spite of many confirmations of the predictions of Newton and Einstein, the *essence* of gravity and its connection to the rest of physics remain profound unsolved puzzles. Such conundrums warrant the most prudent course of action whereby no stone is left unturned. This is an especially advisable strategy in the present case, because the stone before us is large; and it resides, metaphorically, smack dab in the middle of the garden of physics.

Argument (3) appeals to an analogy that Einstein used to build his theory of gravity, General Relativity. The space-time curvature produced by gravitating matter, Einstein argued, is analogous to the effects on rods and clocks caused by a body undergoing *uniform rotation*. The historian of physics, John Stachel has called Einstein's use of the analogy between rotation and gravitation "The 'Missing Link' in the History of General Relativity" because of how it guided Einstein to appreciate the need for non-Euclidean geometry. [5]

An illustration of how Euclidean geometry fails in the case of a rotating circular disk is that its circumference no longer equals $2\pi r$. This is due to the shortening of tangentially oriented rods. As we will see, the effect of rotational motion on the *rates of clocks*—and the analogous effect in the case of gravity—plays an even greater role in connecting the two phenomena. Our third argument involves a simple application of the analogy to the inside of a body of gravitating matter. This will be done in due course of considering each of the arguments in a little more detail, as follows.

3. – Basic Human Curiosity; The Ideals of Science

The literature is rightly replete with nods, winks, and full-fledged salutes to the ideals of science. To the Royal Society's motto that we started with, let's add a few more examples. The astronomer, Bradley Schaefer stated simply that, "Science advances by exploring unexplored regions and by performing critical tests of standard wisdom." [6] The zoologist, Harry Greene wrote: "The best thing about being a scientist is when you realize that you've just seen something that no one else has seen before." [7]

Doing Galileo's experiment would represent exploration of an unexplored region, performance of a critical test of standard wisdom, and the act of witnessing something that no one has seen before. How much more motivation do we need?

A possible counterargument is that Newton's and Einstein's theories have proven themselves so well in so many cases that we have *no reason to question* their predictions for this case. By this reasoning all motivation to do the experiment quickly evaporates. The well known physicist, Herman Bondi has provided a statement of the ideals of physics that urges against settling for this *theoretically confirmed theory* approach, even in the present case. Bondi's advice primarily concerns the practice whereby a theory's predictions are regarded as confirmed when the "test" that they undergo is done only by mental *extrapolation*:

> 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. [8]

Conclusions borne of observations of gravitational behavior from the surface upward are only *assumed*, by extrapolation, to apply just as well from the surface downward, to the center. Bondi's advice thus clearly applies to Galileo's experiment. We must not be satisfied with "self-evidence" based on extrapolation. If possible, Nature itself must be probed to discover whether or not the extrapolation is valid. This takes us to our second argument.

4. – The Persistent Mystery of Gravity

We'll begin by citing a few authorities who have testified to the accuracy of the title of this section. The cosmologist J. Narlikar has written: "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." [9] Suggesting that it should be possible to at least reduce some of gravity's mysteriousness by conducting the right experiments, the well known physicist, 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. [10]

The kinds of experiments that have been performed since Dicke wrote this (in 1959) have evidently failed to put much of a dent in our ignorance, as modern theorists sometimes exhibit an air of near desperation and frustration at gravity's continued impenetrability. In an article that contemplates the possible need to rethink one of the foundations of General Relativity, known as the Equivalence Principle, Elias Okon has recently written:

> 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. [11]

Given this state of confusion—especially given the prominent role of gravity as one of its causes—a worthwhile strategy for getting out of it is surely to double-check everything we think we already know. Upon such double-checking, we find that the *first* check of gravity-induced motion inside matter has never occurred. *Oops*, we missed a spot! This is simply illustrated in the graph in Figure 1.

If the scale of this graph, i.e., the surface radius, $r = R$, were that of Earth, then a short (practically invisible) curve segment could be drawn from R inward. This would correspond to dropping an object into a deep mine shaft, whose bottom is, however, still unacceptably close to the surface.

I should mention another kind of gravity experiment that has also been conducted inside matter. Laboratory measurements using *static* methods have confirmed the inverse-square law of gravity. [12] Crucially missing in all cases studied so far is the observation of radial motion of a test object *through the center* of a source mass. This is the essence of Galileo's experiment. In summary, the data pertaining to gravity-induced motion inside material bodies, as provided by the current state of physics (as shown on our graph) amounts to one big question mark.

Extrapolation from the outside to the inside would be justified by proof that the result of Galileo's experiment confirms the standard prediction. All attempts to procure such a result are hereby encouraged. The question yet remains, if not the standard prediction, then what else might we expect to happen? This takes us to our third argument.

5. – Standard Prediction: A Spark of Doubt?

To appreciate this argument an important difference in character as between Newton's and Einstein's predictions needs to be considered. Newton's prediction is based on the idea that gravity is a force of attraction that pulls on the falling test object. Whereas Einstein's prediction is based on the idea of *spacetime curvature*. The General Relativity prediction is not about a pulling force; it is about how the *rates of clocks* are supposed to vary inside matter.

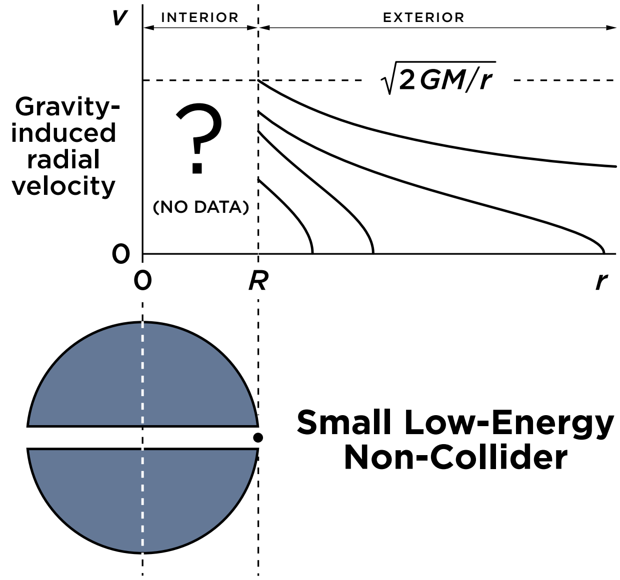

Fig. 1. – Empirical evidence gathered from above the surfaces of large gravitating bodies of matter like the Earth or Sun allow plotting the curves for the exterior region as shown. Whereas below the surface, inside matter, we have no data. *Static* experiments have been conducted inside matter to confirm gravity's inverse-square law. But such measurements do not necessarily indicate the *motion* of test objects through the centers of larger bodies. Galileo's experiment would allow completing the curves to the center; it would allow filling in the missing data.

A classic prediction of General Relativity is that clock rates vary continuously with distance from the center of a gravitating body. Clock rates everywhere correlate with the maximum speed that can be produced by the field at the location of a given clock. This has been abundantly confirmed for clocks over Earth's surface. It is reasonable to expect continuous clock rate variation also below the surface. The *sign* of the variation, however, is unknown. General Relativity predicts that going inward, clocks keep getting slower. A clock at the center is the slowest one; its rate is supposed to be a *minimum*.

This evokes the obvious question: *Why* is the rate of a clock at the center a minimum? What causes that? Nobody knows. Einstein himself admitted that General Relativity "[does not] consider how the central mass produces the gravitational field." [13] Nobody since has ever explained what exactly matter *does* to make spacetime curve. We have not yet discovered the mechanism of gravity. It is therefore advisable to look for clues by observing the *motion* that the field is supposed to produce. Short of doing the experiment, a clue or two may also be found in the rotation analogy.

Because of their tangential speed, the rates of clocks on a rotating body are reduced according to Einstein's time dilation formula. (This has also been abundantly confirmed by experiment.) The outer *periphery* of the body, where it has the greatest speed, is where the rates of clocks are a *minimum*. Whereas, the center of the body, the *axis*, is where the speed is zero; this corresponds to where the rate of a clock is a *maximum*.

What is the most straightforward way to relate these facts concerning rotation to gravity? An at least seemingly reasonable interpretation is that the analogy extends to the center, in the sense that the rate of a clock at the center of a gravitating body—as in the case of a rotating body—is also a maximum, not a minimum. This suggests that, going inward, clock rates get faster, not slower. If this were true, it would have a dramatic effect on the result of Galileo's experiment. It would mean that the standard harmonic oscillation prediction is not correct.

Gravitationally savvy readers may at this point think to put forth various reasons why, in spite of the "naïve" reasonableness of this analogy, the rate of the central clock *must* be a minimum. I am aware of these reasons, but hasten to point out that inside matter is exactly where the empirical validity of these reasons has never been tested. We have come once again to merely *theoretically confirmed theory*. If the rate of a central clock *must* be a minimum—because that's what General Relativity predicts or because it is "required" by some other sacrosanct principles of physics—then *must* we not do our best to check this prediction and such principles *by experiment*? Should we not finally look in that large place where we have not yet looked?

6. – Conclusion

Einstein's theory of gravity is rightly celebrated for its many successes by comparison with Newton's theory. General Relativity is often claimed to have been thoroughly tested from 0.0001 to 10^{13} meters, i.e., from the scale of a grain of sand to the Solar System. Now we see that this is an exaggeration because, with regard to gravity-induced motion, neither Einstein's nor Newton's theory has been tested *inside* any of the source masses studied so far. By this revelation we see, furthermore, that the trend toward putting theoretical evidence on a par with empirical evidence has been with us since long before the advent of String Theory or Multiverse Cosmology. In fact, it has been with us since at least as long as Galileo's experiment has been technologically feasible.

The origin of humanity's inclination to believe—whether by extrapolation, by appeal to abstract theory, or due to fear of the unknown—is beyond the scope of this article. It may nevertheless be said that the inclination surely existed during the time of Michael Faraday. Note that Faraday was a *bona fide* member of the Royal Society. If empirical evidence had been unanimously appreciated in Faraday's time—to the extent as stated in the Society's motto—there would have been no need for his impassioned plea:

> It is absolutely necessary that we should learn to doubt the conditions we assume, and acknowledge we are uncertain . . . In the pursuit of physical science, the imagination should be taught to present the subject investigated in all possible and even in impossible views; to search for analogies of likeness and (if I may say so) of opposition—inverse or contrasted analogies; to present the fundamental idea in every form, proportion, and condition; to clothe it with suppositions and probabilities—that all cases may pass in review, and be touched, if needful by the Ithuriel spear of experiment. [14]

The admirable attitude reflected here echoes and compliments the expressions of the ideals of science quoted earlier. May these ideals soon be re-established and assiduously lived up to in the continuing evolution of physics. What better way to invigorate a renewed appreciation for empirical evidence than by satisfying the spirit of Galileo, by finally carrying out the experiment that he proposed nearly 400 years ago?

REFERENCES

[1] THE ROYAL SOCIETY: 'History.' < https://royalsociety.org/about-us/history/ >. Accessed July 1, 2014.

[2] JIM BAGGOTT: *Scientia Salon*, 'The Evidence Crisis.' < http://scientiasalon.wordpress.com /2014/06/09/the-evidence-crisis/ >. Accessed July 1, 2014.

[3] GALILEO GALILEI: *Dialogue Concerning the Two Chief World Systems—Ptolemaic & Copernican, Second Edition*. Translated by DRAKE, S. (University of California Press, Berkeley, 1967) pp. 22, 227, 236.

[4] RICHARD J. BENISH: 'Missing Measurements of Weak-Field Gravity.' *Progress in Physics*, **1** (2011) p. 40.

[5] JOHN STACHEL: 'The Rigidly Rotating Disk as the Missing Link in the History of General Relativity.' *Einstein and the History of General Relativity*. Eds. DON HOWARD and JOHN STACHEL (Birkhauser, Boston, 1989) pp. 48–62.

[6] BRADLEY SCHAEFER: 'The Hubble Diagram to Redshift >6 from 69 Gamma-Ray Bursts.' *Astrophysical Journal*, **660** (2007) p. 16.

[7] HARRY GREENE: 'How the Serpent Shed its Skin.' *New Scientist* (1 May 2004) p. 49.

[8] HERMAN BONDI: *Cosmology*. (Cambridge University Press, Cambridge, 1952) pp. 6–7.

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

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

[11] ELIAS OKON: 'On the Status of the Equivalence Principle in Quantum Gravity.' < http://jamesowenweatherall.com/SCPPRG/OkonElias2009QEP.pdf > Accessed July 1, 2014.

[12] R. E. SPERO, J. K. HOSKINS, R. NEWMAN, J. PELLAM, and J. SCHULTZ: 'Test of the Gravitational Inverse-Square Law at Laboratory Distances.' *Physical Review Letters*, **44** (1980) pp. 1645–1648.

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

[14] MICHAEL FARADAY: *Experimental Researches in Chemistry and Physics*. (Taylor, London, 1859) p. 480. Quoted in BERKSON, W.: *Fields of Force*. (John Wiley and Sons, New York, 1974) p. 57. In the final words of this passage, the allusion to "Ithuriel" was inspired by a verse in John Milton's epic poem, *Paradise Lost*. Ithuriel is a spear-wielding angel. As Eve lies sleeping, the Devil is whispering devilish things in her ear. At least temporarily saving the day, "Ithuriel with his Spear Touch'd lightly; for no falsehood can endure Touch of Celestial temper, but returns of force to its own likeness." Ordinarily, I'm not a big fan of Biblical allegories. But this one, as employed by Michael Faraday, is spot on.