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Galileo's Belated Gravity Experiment:
The Small Low-Energy Non-Collider

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Abstract. — Galileo proposed a simple gravity experiment that has yet to be performed. Suppose we drop a test mass into a hole through the center of a larger source mass. What happens? Using a modified Cavendish balance or an orbiting satellite, modern technology could have revealed the answer decades ago. General Relativity is widely regarded as being supported by empirical evidence throughout its accessible range. Not commonly realized is that, with regard to gravity-induced motion, this evidence excludes the *interior* regions of material bodies over this whole range. If only to fill this huge gap in our empirical knowledge of gravity, Galileo's experiment ought to be performed without further delay.

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1. – Introduction

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]. [1]

"Piercing" a body that is much smaller than a planet would facilitate doing the experiment in an orbiting satellite or an Earth-based laboratory. [2] The resulting apparatus may be called a *Small Low-Energy Non-Collider*. This classic physics 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 seemingly obvious is the answer, that the fact of having no direct empirical support is routinely overlooked. Newton and Einstein say the test object oscillates. Widely accepted principles such as energy conservation may also be appealed to in arguing that the test object *must* oscillate as predicted. Instead of accepting such authorities and principles as reasons to *not* do the experiment, I would argue that the experiment presents itself as an important *test* of these authorities and principles—in a physical regime where they have not yet been tested, *where we have not yet looked*.

Motivations 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.

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 inspire an especially thorough investigation. Argument (3) appeals to an analogy that Einstein used to build his theory of gravity, General Relativity (GR). 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. [3] Our third argument involves a simple application of the rotation analogy to the inside of a body of gravitating matter.

2. – The Ideals of Science

The literature is rightly replete with nods, winks, and full-fledged salutes to the ideals of science. The Royal Society's motto may be one of the most succinct expressions of these ideals: *Nullius in verba*. It means: "Take nobody's word for it." On their 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. [4]

In addition, the astronomer, Bradley Schaefer stated simply that, "Science advances by exploring unexplored regions and by performing critical tests of standard wisdom." [5] 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." [6] 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? If the well known successes of Newtonian gravity and GR were held up as counterarguments, to claim that doing Galileo's experiment is unnecessary, then the advice of Herman Bondi, negates such reasoning:

> 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. [7]

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. Taking Bondi's advice to heart means being dissatisfied with "self-evidence" based on extrapolation. If possible, Nature itself must be probed to discover whether or not the extrapolation is valid.

3. – The Persistent Mystery of Gravity

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." [8] 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 observed:

> 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. [9]

The kinds of experiments that have been performed since Dicke wrote this (in 1959) have failed to significantly reduce our ignorance, as modern theorists sometimes seem desperate and frustrated at gravity's continued impenetrability. For example, 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. [10]

Since gravity is the main cause of this confusion, a prudent strategy is to double-check everything we think we already know about gravity. An account of that which has been *assumed* to be known via extrapolation—by admitting it to be *un*known—is expressed graphically in Figure 1. An additional question thus also comes to light: If not agreement with the standard prediction, then what might we expect to happen instead?

4. – 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 GR prediction involves the way the *rates of clocks* vary inside matter.

In GR clock rates vary continuously such that they 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. GR predicts that the rate of a clock at the center is a minimum. *Why?* Nobody knows. Einstein himself admitted that GR "[does not] consider how the central mass produces the gravitational field." [11] Nobody since has ever explained

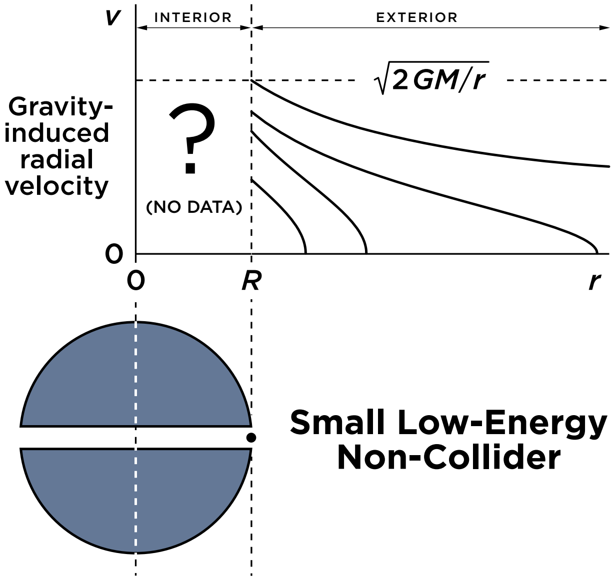

Fig. 1. – Empirical evidence gathered from above the surfaces of large bodies of matter like the Earth or Sun allow plotting the curves for the exterior region as shown. Whereas below the surface, inside matter, we have no data. Human beings have not yet witnessed the motion of test masses all the way to the center of a gravitating body. Galileo's experiment would allow completing the curves to the center; it would allow filling in the missing data.

what exactly matter *does* to make spacetime curve. Having not yet discovered gravity's mechanism, it is 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, clocks on a rotating body tick at slowed rates according to Einstein's time dilation formula. (This has also been abundantly confirmed by experiment.) The high-speed outer periphery of the body is where the rates of clocks are a minimum. Whereas, the zero-speed center of the body is where the rate of a clock is a maximum.

A seemingly straightforward way to relate these facts to gravity involves extending the analogy 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. If, going inward, clock rates get faster, not slower, this would have a dramatic effect on the result of Galileo's experiment. It would mean that the standard harmonic oscillation prediction is not correct.

Once again, energy conservation or other well-worn principles may be invoked to argue that, in spite of the ostensible reasonableness of this analogy, the rate of the central clock *must* be a minimum; the test object *must* oscillate. I would then hasten to reiterate that inside matter is exactly where the validity of these principles is unknown. An empirical test beckons.

5. – Conclusion

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. Celebration of their successes may therefore be premature. Ironically, only *faith and belief* stand in the way of the spirit of Galileo; only faith and belief inhibit admitting that *we really don’t know*, and therefore ought to support (or refute) the prediction for Galileo’s experiment by actually *doing* it.

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