Rainer Weiss

PROFESSOR of PHYSICS • NOBEL LAUREATE (2017)

Massachusetts Institute of Technology • LIGO

Email Correspondence

January 9 – April 1, 2017

PREFACE

On two separate occasions (one in 2015, one in 2017) Weiss replied to my queries about doing Galileo's Small Low-Energy Non-Collider experiment. In the second instance no mention was made of the first. In both instances—more explicitly in the first—Weiss expressed his familiarity with the idea, as it arose in his early days as a professor at MIT. A Small Low-Energy Non-Collider was to function as the mechanical heart of an experimental proposal (Masters Thesis) by one of his graduate students. The motivation was then drastically different from mine. As per the usual, Weiss and his student *presumed* that a pair of massive bodies—one large, with a hole through its center and one small, to be dropped into the hole—would function as an "oscillator," i.e., a gravitational *clock*. And as per the usual, the plans were left unfulfilled.

Echoing an ironically common theme in my respondents' replies, Weiss refers to the idea of actually doing Galileo's experiment as "fun." For no good reason, Weiss and the others deny themselves this fun.

To put Weiss' comments in better perspective, consider that the most basic gravitational effects associated with, say, a uniformly dense sphere—the typical textbook case—are two: *Force* = mass × acceleration (where the acceleration is commonly measured with an accelerometer); and *Speed* (where the meters/second are measured by visual monitoring). These are typically regarded as *Newtonian* effects, as they are predicted with great (though not perfect) accuracy by Newton's theory of gravity.

With the advent of Einstein's even more accurate theory, General Relativity (GR), subtle effects on space and time have often come to the fore. The effect of *spatial* curvature is tiny and usually extremely difficult, if not impossible, to measure. Whereas the effect of *temporal* curvature has, since the 1960s become directly measurable in some important cases, and clearly bears on the matter at hand because of the theoretical link between Newton's theory and Einstein's theory.

That link is called the gravitational *potential*, which is a mathematical thing having the dimensions of velocity squared. As such, it correlates directly with the degree to which clocks are slowed by gravity. As the square-root of the potential, speed is thus also correlated with time dilation (rates of clocks).

Measurements so far obtained—almost entirely in *exterior* gravitational fields, i.e., the regions of space *over* the surfaces of gravitating bodies, like our sphere—show the magnitudes of all three effects increasing together as the surface of the sphere is approached from a further distance: Acceleration increases, speed increases and gravity's effect on clock rates increases. These are empirical facts.

Because of its *relationship* to temporal curvature, spatial curvature is important to consider—even though its measurable effects are small. Note first that its physical reality has been firmly established by carefully measured effects in the Solar System. The curvature of *space*, as distinct from the curvature of time, reveals itself in the advance of the perihelion of Mercury, light-bending around the Sun and Shapiro's *Time Delay* test, as predicted by GR.

One of the things that makes GR's prediction of spatial curvature especially curious is that its relationship to temporal curvature *changes* inside matter. Outside matter (over the surface) the coefficient of spatial curvature $(1-2GM/rc^2)^{-1}$ is everywhere the *reciprocal* of temporal curvature $(1-2GM/rc^2)$.

But *inside* matter GR predicts that the magnitude of these effects abruptly diverges from the pattern established outside matter. Zero curvature corresponds to coefficients that = 1. The maximum deviation for the *spatial* coefficient occurs at the *surface* (similar to *acceleration*, which is also a maximum at the surfsace). Whereas the maximum deviation for the *temporal* coefficient is supposed to occur at the *center*. Spatial curvature is zero at $r = \infty$ and at $r = 0$. Whereas temporal curvature is supposed to be zero only at infinity, and exhibits an extremum at the center of massive bodies.

Why do the predictions for the "metric coefficients" exhibit this curious divergence? Why should they not relate to each other the same way (reciprocally) both outside and inside matter? The theoretical answer is that it is a *consequence of Einstein's field equations*. But *there is no intuitive, physical answer*. That spatial curvature should go to zero at the center is probably more intuitive because of the correlation with acceleration, which also goes to zero. The effects cancel "by symmetry." The question thus becomes: Why does *temporal* curvature not go to zero? Why does the temporal coefficient supposedly exhibit *maximum* deviation from unity at the center? Why do clock rates drop to a minimum at the center? What causes that? Nobody knows.

The general relativistic prediction for *temporal curvature* is directly correlated with the prediction for the Newtonian potential. And the *potential* is directly related to the standard prediction for the gravitational oscillator (i.e., the harmonic oscillation prediction for Galileo's experiment). Therefore, doing Galileo's experiment would not only be a direct test of Newton's theory where it has not yet been tested, it would also provide very convincing (though somewhat less direct) evidence for the temporal curvature prediction of Einstein's theory.

These issues are all clearly discussed in the papers that I sent to Weiss (especially *Gravitational Clock…*). Yet Weiss sees fit to conclude that Galileo's experiment—i.e., the idea of building and operating a Small Low-Energy Non-Collider—is *obsolete*. He writes: "the gravitational clock has passed its time." Really? The thing has never even been born. A gravitatioinal clock has not yet sounded a single tic. But Weiss says it has *"passed its time."*

This assessment flies in the face of Bradley Schaefer's characterization of progress in science, which is echoed abundantly with many variations throughout the literature of physics: ***"Science advances by exploring unexplored regions and by performing critical tests of standard wisdom."*** My papers and my plea to Weiss humbly suggest that we explore the unexplored gravitational interiors and test the standard prediction ("wisdom") to see if it holds up when compared directly with Nature.

If Weiss had cited some evidence that the standard oscillation prediction has been directly verified, then and only then, would it be justifiable to claim the experiment to have "passed its time." He seems to be entirely uninterested in such data, as he stoicly admits only to having missed out the "fun" of gathering it. Sadly, Weiss chooses to turn his back on the unknown, *pretending* instead that he already knows it full well. By re-trampling the path of dogmatic authority, Weiss slams the door in my face. More tragically, he slams the door in the face of the spirit of humble inquiry.

No fun in that.

weiss@LIGO.MIT.EDU, 10/28/15 5:10 PM -0800, Galileo's Gravity Experiment 1

To: weiss@LIGO.MIT.EDU
From: Richard J Benish <rjbenish@comcast.net>
Subject: Galileo's Gravity Experiment
Attachments: <Galileo's-Belated-Experiment.pdf:> <Mr-Natural-Says-LR.pdf>

Dear Professor Weiss,

The attached paper argues that until we do Galileo's experiment, we cannot be certain whether or not an important stone in gravitational physics has been left unturned.

Among the fundamental principles that would be tested by doing the experiment are time-reversal invariance and energy conservation.

I hope you have some interest in filling this large gap in our empirical knowledge of gravity.

Thank you for your good work.

Sincerely,

Richard Benish

Rai Weiss, 10/29/15 9:56 AM -0700, Re: Galileo's Gravity Experiment 2

Date: Thu, 29 Oct 2015 12:56:24 –0400 (EDT)
From: Rai Weiss <weiss@ligo.mit.edu>
To: Richard J Benish <rjbenish@comcast.net>
Subject: Re: Galileo's Gravity Experiment

> Richard,
>
> What you are describing was the subject of a Physics Master's Thesis at MIT in 1968. The reference is:
>
> *The Feasibility of a Gravitational Clock to Test the General Theory of Relativity*, Michael Gordon Blitch, MS Thesis, 1968.
>
> The idea was to look for changes of G, the Newtonian gravitational constant, as a function of the time. The notion of G changing in time came from Dirac and then was adopted by Pascual Jordan and Robert Dicke in the middle 1960s when experimental tests of gravitation became part of general physics. The concept for the gravitational oscillator is exactly what you call the Galileo second test. The idea was to * launch a satellite with a large round ball of highly homogeneous material which had a diametric hole bored in it. A small ball was placed in the hole and if the gravity gradients in space and the electrostatic charging could be well enough controlled, the ball would exert sinusoidal oscillations in the diamateric hole. The period of the oscillations is given by
>
> ```
>                   3*pi
> period  =  SQRT{------}
>                   G*rho
> ```
>
> where rho is the density of the large ball with hole bored in it. With a density say of 4 gms/cm^3, the oscillation period of the ball in the hole is 90 minutes. We went so far as to propose this to NASA but at the time NASA was not interested. It could probably be done now as a free flyer experiment. Unfortunately, the space station has too large gravitational gradients. A tricky bit for

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* I have never called this experiment "Galileo's second test." I usually refer to it simply as "Galileo's experiment"—the one whose apparatus is a Small Low-Energy Non-Collider, as in the essay sent to Weiss.

> the experiment is that although the small ball is stable for diametric motions (bounded by sinusoidal oscillations), it drifts and becomes unstable for motions perpendicular to the bored diameter. A servo system which does not exert radial forces is needed to stabilize the motion (stop the small ball from hitting the walls of the hole). Nowadays one would do this with lasers and the radiation pressure of light. With more cleverness one could try to make the system operate on Earth using a diamagnetic superconducting suspension. The difficulty will be to reduce the magnetic forces along the diametric hole to a level where the Newtonian gravitational force of the large ball dominates.
>
> I think the gravitational clock has passed its time. We now know that G changes fractionally less than 10^−12/year from the lunar ranging experiments. I don't agree with you that the Galileo second test is necessary to believe in General Relativity or even Newton. There is such good evidence that the gravitational theory we have works. This does not say that building a gravitational oscillator would be a waste. It would be fun but it is not needed to prove that we understand weak field gravitation.

Rai Weiss, 10/29/15 11:56 AM -0700, Re: Galileo's Gravity Experiment 3

To: Rai Weiss <weiss@ligo.mit.edu>
From: Richard J Benish <rjbenish@comcast.net>
Subject: Re: Galileo's Gravity Experiment
Attachments: <SLENC as Clock Smalley 1975.pdf> <Rethinking Einstein's Rotation Analogy.pdf>
<Maximum Force Nov 17 2011.pdf> <Max Force Annotation.pdf>

> > Dear Professor Weiss,
> >
> > Many thanks for your thoughtful reply.
> >
> > It is a pleasure to receive your insightful details on the early space-based G-measurement proposals. I've attached a copy of a 1975 review by Larry Smalley, which includes your name on the "Distribution" list (p. 37). What I have called a Small Low-Energy Non-Collider is indeed the same thing as what Smalley refers to as a "Gravitational Clock."
> >
> > The technical difficulties you raise (among others) certainly make finding any changes in G—or even measuring G itself to any impressive degree of precision—quite challenging. Suppose, however, that we are not interested in fine-tuning our knowledge of G, but simply want to demonstrate the predicted oscillatory behavior as a first approximation.
> >
> > This should be quite doable in a satellite experiment, or even as an Earth-based laboratory experiment. The apparatus builder, George Herold (at TeachSpin in Buffalo, NY) contemplated constructing such a device (modified Cavendish balance) for this purpose, just because nobody has done it yet.
> >
> > I understand that the abundance of evidence in support of Newton's and Einstein's theories of gravity gives one great confidence that any further weak-field tests will yield similar support. Yet we've never witnessed gravity-induced radial motion through the center of a source mass. Is this not a rather large physical domain to leave unobserved? Is this not an invitation to explore?
> >
> > I've attached another paper (Rethinking Einstein's Rotation Analogy) which proposes a perspective from which doing Galileo's experiment becomes a matter of course. A reference is provided therein to a third

> > paper (also attached) that defends this position with a bit more rigor (*Maximum Force…*).
> >
> > Using an argument similar to one used by Tangherlini, the latter paper shows that agreement with known evidence of space-time curvature OUTSIDE a gravitating body, need not mean that the corresponding INTERIOR solution would be that of GR.
> >
> > What does matter DO to make the rate of a clock at the center of a source mass a local minimum? Since we don't know the answer to this question, should we not probe the interior field in any way possible to gather evidence? Direct clock rate comparisons for this case are not possible. But indirect (and I think compelling) evidence would be gotten by conducting a kinematic (gravitational clock) test.
> >
> > Even if the (admittedly radical) ideas in the attached papers strike you as implausible, it remains that the test proposed by Galileo nearly 400 years ago has never been done. With respect to gravity-induced radial motion, the Schwarzschild interior solution has never been tested. Someday they will be. Why not now?
> >
> > Thanks again for your generous response.
> >
> > Sincerely,
> >
> > Richard Benish

End 2015 Correspondence

weiss@ligo.mit.edu, 5/30/17 11:38 AM -0700, Testing Gravity **1**

To: weiss@ligo.mit.edu
From: Richard J Benish <rjbenish@comcast.net>
Subject: Testing Gravity
Attachments: <Gravitational Clock Pt 1.pdf>

Dear Professor Weiss,

The attached paper concerns an elaborate and expensive gravity experiment that has been proposed recently, and a simpler, much less expensive experiment that I think should be performed first.

Please send feedback.

Thanks for your good work.

Sincerely,

Richard Benish

P S

Are you having any luck at corroborating LIGO data with simultaneous electromagnetic wave signals?

Thanks again.

RB

Rai Weiss, 6/15/17 9:03 PM -0700, Re: Testing Gravity **2**

Date: Fri, 16 Jun 2017 00:03:23 -0400 (EDT)
From: Rai Weiss <weiss@ligo.mit.edu>
To: Richard J Benish <rjbenish@comcast.net>
Subject: Re: Testing Gravity

> Richard,
>
> The idea of a self-contained gravitational oscillator has been thought about for years. The reason for making such a device was originally to test the strong principle of equivalence—that the laws of physics, even gravitation, are independent of the gravitational potential. Or simply that a reference frame freely falling anywhere, even near a strong source of gravity, would be equivalent to any other freely falling frame.
>
> The gravitational oscillator on Earth would be a test of the 1/r^2 character of gravitational force. Some of the experiments that have been done by the Adelberger group at the University of Washington with specially formed plates do this better than the sphere with a hole in in.
>
> You ask if there has been any identification of gravitational wave sources with electromagnetic counterparts. Up to now there have been no such identifications. The black hole binaries are more likely to have eaten any accretion disks around them which could be the sources of electromagnetic waves. Even so I hope people will keep looking as we are not so sure of this. The more likely source to have an electromagnetic counterpart is the neutron star binary which could well be a source of gamma rays.
>
> R W

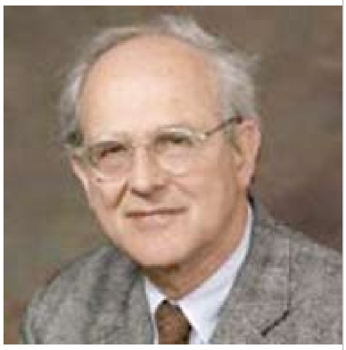
To: Rai Weiss <weiss@ligo.mit.edu>
From: Richard J Benish <rjbenish@comcast.net>
Subject: Re: Testing Gravity
Attachments:

> Dear Professor Weiss,
>
> Many thanks for your reply.
>
> I understand that various tests of the validity of the inverse-square law are regarded as sufficient reason to have no doubts as to the correctness of the standard prediction for the "self contained gravitational oscillator."
>
> Any yet nobody has ever seen nor built one.
>
> I sent my *Gravitational Clock* essay to all six authors of the *Deep Space* paper (attached last time) which proposed turning one on for the first time in the hinterlands of the Solar System.
>
> Virginia Trimble replied, asking if I had sent a copy to Michael Feldman, "the most enthusiastic member of our group." Before I replied that I had, Trimble more emphatically asked if I would "please" send Feldman a copy.
>
> No reply from Feldman.
>
> Should we be so sure there is no need to build a near-space proof-of-concept version of the experiment, or should we take the more cautious approach to, yes, build such a near-space version? Are we so sure the inverse-square law represents a force acting on the falling body? I would make the radical suggestion that we cannot really be sure of this before we actually witness this force yanking the falling object back and forth past the center.
>
> And then there is the General Relativity-inspired question, what exactly does matter DO to make the rates of clocks slow to a central minimum? Maybe this is not what happens at all: Another reason to try the experiment—the sooner the better, in my humble opinion.
>
> Congratulations on the latest LIGO observation.
>
> Cheers,
>
> Richard Benish

End 2017 Correspondence

MIT DEPARTMENT OF PHYSICS

Faculty



RAINER WEISS, SB '55, PHD '62
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2017 Nobel Laureate

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RELATED LINKS:

- LIGO MIT
- LIGO Group at MIT Kavli Institute for Astrophysics and Space Research
- MIT Libraries Open Access resources on LIGO & gravitational waves

Areas of Physics:

Experimental Atomic Physics, Atomic Clocks, Laser Physics, Experimental Gravitation, Millimeter and Sub - millimeter Astronomy, Cosmic Background Measurements

Research Interests

Writing this at 73 and having shed the august responsibilities of a full fledged faculty, it is natural to be retrospective rather than to look at prospects.

Currently working on the LIGO project, a joint Caltech and MIT effort, to observe gravitational waves and use them to study gravitation and astrophysics. My role now is to be the equivalent of a grad student. Very much enjoy this. Over the years have worked on cosmological studies with Robert Dicke and David Wilkinson at Princeton. Began physics in atomic beams with John King and Jerrold Zacharias at MIT. If you are really interested, you can read the standard stuff here [PDF].

Major Projects

Atomic Clock development
Balloon program to measure Cosmic Background Radiation,
Science Working Group Chairman, COBE satellite program,
Laser Interferometer Gravitational - Wave Observatory (LIGO)

Biographical Sketch

RAINER WEISS (NAS) is a Professor Emeritus at Massachusetts Institute of Technology (MIT). Previously Dr. Weiss served as an assistant physics professor at Tufts University and has been an adjunct professor at Louisiana State University since 2001. Dr. Weiss is known for his pioneering measurements of the spectrum of the cosmic microwave background radiation, his inventions of the monolithic silicon bolometer and the laser interferometer gravitational wave detector and his roles as a co-founder and an intellectual leader of both the COBE (microwave background) Project and the LIGO (gravitational-wave detection) Project. He has received numerous scientific and group achievement awards from NASA, an MIT excellence in teaching award, the John Simon Guggenheim Memorial Foundation Fellowship, the National Space Club Science Award, the Medaille de l'ADION Observatoire de Nice, the Gruber Cosmology Prize, and the Einstein Prize of the American Physical Society. Dr. Weiss is a fellow of the American Association for the Advancement of Science, the American Physical Society, The American Academy of Arts and Sciences; and he is a member of the American Astronomical Society, the New York Academy of Sciences, and Sigma Xi. He received his B.S. and Ph.D. in physics from MIT. Dr. Weiss is a member of the NAS and has served on nine NRC committees from 1986 to 2007 including the Committee on NASA Astrophysics Performance Assessment; the Panel on Particle, Nuclear, and Gravitational-wave Astrophysics; and the Task Group on Space Astronomy and Astrophysics.

Education

- 1955 - SB, Massachusetts Institute of Technology
- 1962 - PhD, Massachusetts Institute of Technology

Major Positions

- 1960-1961: Instructor of Physics, Tufts University
- 1961-1962: Assistant Professor of Physics, Tufts University
- 1962-1964: Research Associate in Physics, Princeton University
- 1964-1967: Assistant Professor of Physics, MIT
- 1967-1973: Associate Professor of Physics, MIT
- 1973-2001: Professor of Physics, MIT