feature article

A fifth force farce

Lawrence M. Krauss

A decade before Alan Sokal's famous hoax was published in *Social Text*, a thinly veiled spoof was submitted to *Physical Review Letters*. But in that case the editors gave as good as they got.

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When I was a young assistant professor at Yale University in 1986, a great deal of interest was aroused by a paper that had appeared in *Physical Review Letters* (E. Fischbach et al., *Phys. Rev. Lett.* **56**, 3, 1986). The paper argued that a reanalysis of data from the famous Eötvös experiment provided evidence for a force that violated the equivalence principle—the equivalence between inertial and gravitational mass. While many people were skeptical of that result, I reacted with surprise to the notion that the paper had survived the refereeing process, which at the time had very strict self-imposed requirements of general interest, importance, and validity.

Having written papers using data from ongoing experiments, I was acutely aware of how difficult and dangerous it is for someone not involved in an experiment to select anomalous data for significance, even if the experiment is contemporaneous, much less almost a century old. I decided to respond by writing a spoof piece and submitting it to *PRL* and then seeing what would happen. Writing the piece was great fun, and I got several good lines from colleagues.

That's not to say the paper by Fischbach and colleagues wasn't a serious analysis. It was, pointing out that the Newtonian gravity theory had not been tested at scales of tens to hundreds of meters. And it led to a number of experiments to perform such tests. Indeed, with the recent interest in modifications to Newtonian gravity due to large extra dimensions, experiments testing the classic theory are still under way.

About a week after I submitted the spoof, when I had heard nothing, my department chair and friend, Tom Appelquist, suddenly got very worried that *PRL* might actually publish it! Something much better happened, however. In a response that forever raised my opinion about the editorial process at *PRL*, I got back six referee "reports," clearly done in-house but typed on different typewriters—in the words of editor George Basbas, "one [report] for each force." The reports were a brilliant and self-effacing parody on *PRL*'s reputation for using its three requirements to make it difficult for reasonable papers to get published there and also on the common experience of getting referees' reports that are inconsistent with each other but nevertheless come to the same conclusions.

I had sent out the paper using the normal preprint mailing methods, and it got some notoriety in the community. Indeed, I first got to know Murray Gell-Mann because he remembered my name from the preprint when we first met. Numerous people have asked over the years what happened to the paper. So, as a tribute to *PRL* on its 50th anniversary, here it is, essentially unchanged.

On Evidence for a Third Force in the Two New Sciences: A Reanalysis of Experiments by Galilei and Salviati

Abstract: We have carefully reexamined the experiments described by Salviati on the acceleration of objects at the Earth's surface and find evidence for the existence of a new force. An archival search indicates that this result is supported by earlier work of Aristotle.

Submitted to: *Physical Review Letters*
(and the *New York Times*)

It is commonly assumed that the work of Galileo Galilei and collaborators[1] established the basis for the Newtonian theory of universal gravitation, later refined by Einstein. However, we note here that a careful examination of their published results indicates a potential anomaly, which could represent evidence for a new self-coupling resulting in a velocity-dependent force for baryonic matter. Confirmation of this result could help explain earlier anomalous results reported by Aristotle.[2] It is possible that other anomalous results[3,4,5] may also be explained in terms of this new effect.

In the absence of relativistic effects, and other external nongravitational perturbations, Einstein's theory predicts a coupling of the form

$$V(r) = -G_N m_1 m_2 / r \tag{1}$$

between two masses $m_{1,2}$. Here G_N is Newton's constant, and r is the distance separating the objects in question.

The experiments of Salviati et al. are reported to have involved in one instance observation of acceleration at the Earth's surface over a distance of 12 cubits.[1] Based on information obtained by us,[6] we estimate this to be approximately 8 meters. The experiments were performed using "a very round polished bronze ball" of undetermined alloy content and size, and a wooden channel, lined with parchment. Since no lubrication was reported, we may assume a coefficient of kinetic friction in the region 0.07–0.1. We will also assume a drag coefficient of 8×10^{-5} Ns/m, appropriate for a ball of radius 1 m in air at room temperature.

The results of interest involved observation of distances traversed in consecutive time

Roland von Eötvös (1848–1919) used a torsion balance to accurately measure the equivalence between gravitational and inertial mass to one part in 10^8.

intervals as the bronze ball rolled down the wooden channel. As reported by Salviati[1] the ratios of these distances were given by the ratio of consecutive odd integers. It was also reported that no two measurements disagreed by more than 1/10 of a pulse beat and that each set of measurements was performed 100 times. From this, assuming a standard pulse rate of 90 beats per minute based on an exhaustive analysis of medical records from that time,[7] we therefore expect a timing accuracy of about 6×10^{-3} seconds. For small inclinations, the time required to traverse one tenth of the distance along the wooden ramp could be in excess of 6 seconds. Thus the expected accuracy of the Galilei results is one part in 10^{-4}.

For experiments of the type described by the authors, several other effective forces in addition to that described in equation (1) must be taken into account. These may not be conservative and therefore cannot be derived from a potential. Two that will interest us here are of this type, including a frictional force of the form $F = \mu F_N$, where F_N is the normal force of one object on another and μ the coefficient of kinetic friction, and the drag force $F = kv$, where k is the drag coefficient in air and v the velocity.

The first effect that could alter the result from the quoted one expected for a constant force is the fact that the actual gravitational potential over the length of the 8 meter channel is slowly varying, as given in (1). Expanding to first order in this length over the Earth's radius we find $\delta a/a \approx 3 \times 10^{-6}$ for the change in the acceleration from the top to the bottom of the channel. This is below the measurement accuracy derived earlier. Similarly, the frictional force, while non-negligible, is constant and hence, while it would change the absolute value of the measured acceleration due to gravity at the Earth's surface, it would not change the ratio of consecutive distances traversed in equal time intervals.

The drag force of air on the ball is however both relatively large, and time varying. For small inclinations we expect v_{final} in the range of 2–3 meters per second, implying a drag force in the range of 2×10^{-4} newtons. For inclinations of 10°–20°, the gravitational force is about 1 newton for a 1 kg ball. Thus the expected deviation in acceleration from top to bottom of the channel is about

$$\delta a/a \approx 2 \times 10^{-4}. \qquad (2)$$

This level is clearly above the quoted limits.

We interpret this result as suggestive of the presence of a new velocity-dependent force which operates on a distance scale of meters which can counteract the effects of the drag force described above. Such an intermediate-range force may in fact have escaped detection in experiments testing Newtonian gravity and its subsequent revisions, although it is not clear to us why the space shuttle is not affected upon reentry. This latter concern might justify a wide range of new experiments performable by NASA.[8]

Spurred on by this, we have made an exhaustive search of the literature to see if this effect has been previously measured. Such a force seems to have been measured earlier by Aristotle,[2] who observed a velocity dependent force resulting in changes in acceleration of order

$$\delta a/a \approx 1. \qquad (3)$$

The agreement between equations (2) and (3) is surprisingly good. Rare K-decay experiments are also suggestive.[9]

We have also discovered evidence in the work of Galilei and Salviati, and the earlier work of Aristotle, for variations in acceleration at the Earth's surface depending on composition of the material used. We do not consider this here, however, since the later results of Eötvös et al.[10] demonstrate convincingly with great accuracy that there is no such effect.

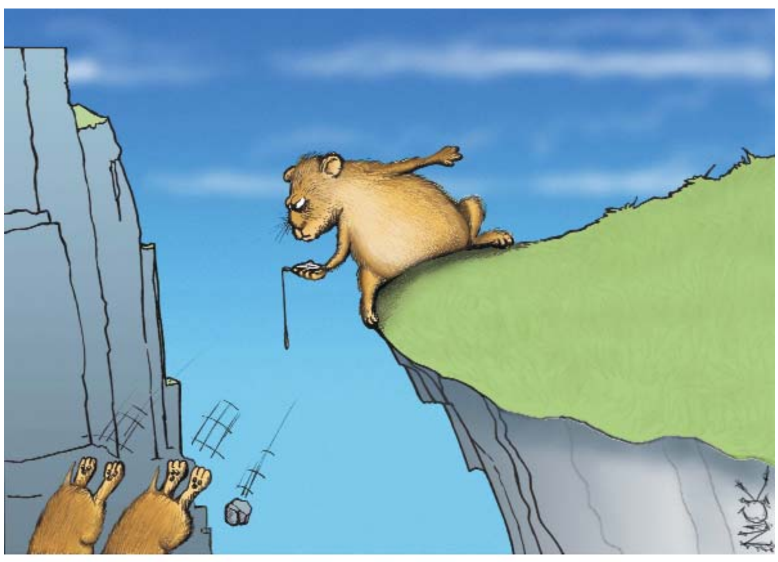
While a repeat of the experiments of Galilei et al. with better sensitivity may be possible with modern techniques, we have not performed such an experiment. While such an effort was being considered, recent results[11] led to it being abandoned. In the meantime, however, Monte-Carlo studies of this effect in a unified gauge field theory are being carried out by A. Chodos et al.[12] Also, R. Shankar[13] is presently reanalyzing several of Einstein's gedanken experiments. We are hopeful that in the near future some new results will appear.

Since this velocity-dependent force appears to have first appeared in the work of Galilei and Aristotle, we suggest that if our analysis is confirmed by later work, the force should be entitled the "third" force, since it was discovered before the strong and weak interactions, and after gravitation and magnetism. We personally find this possibility extremely exciting.

We are indebted to our colleagues at Yale University for their valuable suggestions and support and forebearance throughout this work, and particularly to Tom Appelquist, who occasionally seemed to agree with some of what is said here.

References

1. Galileo Galilei, *Dialogues Concerning the Two New Sciences*, 1638 (translated by H. Crew and A. de Salvio, Dover edition, 1914).
2. Aristotle, *Physics, The Works of Aristotle*, translated into English, vol. 2, W. D. Ross, ed., Oxford U. Press, New York, 1930.
3. UA1 Collaboration, see for example, G. Arnison et al., *Phys. Lett. B* **139**, 115 (1984).
4. GSI heavy ion collision data, see for example T. Cowen et al., *Phys. Rev. Lett.* **54**, 1761 (1985).
5. The zeta particle, reference unavailable at present time (Jan. 22, 1986, 8:30 AM).
6. Thanks to the intermediation of high-ranking officials from certain Italian banks, Vatican archival material was made available to us.
7. The actual analysis was limited due to exhaustion.
8. See L. Krauss, NASA grant proposal, to appear.
9. We are not sure at this time of exactly what.
10. R. Eötvös, D. Pékar, E. Fekete, *Ann. Phys. (Leipzig)* **68**, 11 (1922).
11. See Gramm and Rudman, *Congressional Record*.
12. See A. Chodos, J. Rabin, Yale Theory Preprint YPT 83-41 (April 1983), and other work.
13. To be unpublished. ■



Fluffy, the "Galileo of the Lemmings," with his stopwatch.

The response from *Physical Review Letters*:

Re: Manuscript No. LP3018

Dear Dr. Krauss:

Enclosed are six reports (one for each force) on your manuscript "Evidence for third force in the two new…". Although all advise publication (after some revision) the Editors, in their usual arbitrary and capricious manner, do not come to this conclusion. It is our sworn and solemn duty to guard zealously the selection of manuscripts that we allow to come before the eyes of our readers. We note that no referee finds that your manuscript satisfies all three criteria of PRL—validity, interest, and importance (the C, P, and T of our journal).

In addition, we feel that the general interest (and even novelty if you want to be arcane about it) no longer supports the discovery of new forces. Already five have been reported in the literature and we think the time has come to draw a halt to the unbridled publication of force discoveries.

If you could come up with a fractal force we might give further consideration. In the meantime we return the manuscript herewith and send our best wishes for publication of your nice discovery elsewhere.

Sincerely yours,

George Basbas,
Editor, Physical Review Letters

Report of referee A:

If this work were valid it certainly would be publishable on the grounds of its importance and general interest. However, I cannot agree with the author's force numbering system: The electromagnetic force cannot really be counted before this one because it is part of the electroweak force which was only recently discovered. The only fair thing to do is to count this a later force. It is not clear however exactly what number to assign it because with the unification of the electroweak force this one discovered by Krauss (or was it Aristotle?) is really the fourth force. Yet to call it number four will not do since this runs against the tradition of the four forces. Force #5 has already been discovered (Fishbach et al. of which the author is apparently unaware). It looks like this would have to be called number 6.

Moreover, the author's Ref. 1 is inaccurate. There is no such thing as "Dover edition, 1914." Dover first published this work in 1954. (It is true that the same translation was published by Macmillan in 1914, but the author's statement is misleading.) Such sloppy scholarship is, or should be, below the standards of PRL. If we cannot trust the author's most basic reference, what can we trust?

If the author can satisfactorily address this issue I would be willing to approve this for publication.

Report of referee B:

Although this work is valid and of general interest (we are all looking for new forces to bring to bear on the play of the universe) I can't see that it is so important as to merit the attention of the readers of PL. After all, if this force had any currency we would all know about it by now.

I nonetheless believe this work should be published on the grounds that it is novel, newsworthy and stimulating—this is the traditional standard and I still believe in it—even if it is not important (as the Editor now feels papers should be).

Report of referee C:

A PRL should be valid, important and of general interest. Although this sanguine work leaps the first two hurdles, it is hard to conclude that there will be much interest in this dusting-off of data. It will be good enough to let the iconoclastic aficionados see this rublished in one of their sacred volumes. If anything comes of it we will all be advised in due time.

In defense of the ms, however, I note that it reads crisply and is brief. It would do no harm to publish it and the author doubtless would be gratified. So, despite my reservations, I say publish.

Report of referee D:

This manuscript is valid (we could hardly expect less with eminent prior researchers such as Galileo and Aristotle). However, it is unlikely to be of interest to the readers, many of whom cannot even spell Galileo, let alone understand what he did. Further, it is surely unimportant. With a PRL publication on a fifth force recently, this one must be "whafnium." However, I don't think you have paid recent homage to Galileo and Aristotle. It is thus quite reasonable to publish this manuscript.

Report of referee E:

This manuscript is unusually interesting to read. It is a pity it is flawed scientifically. I thought every one knew Salviati et al. were joggers! A resting heartbeat of 90 beats per minute is simply absurd. With this flaw, and others I won't mention, I must also regard the manuscript as unimportant. Even so, it was so interesting to read that I would encourage publication.

Report of referee F:

This is potentially the most important manuscript I've ever seen. Unfortunately, close inspection reveals serious defects in analysis. Surely, the agreement between Eqs. (3) and (2) is not good. And there is no discussion of the rare K decay experiments! Only an expert could unravel these details and thus the manuscript would not be of broad interest. But it is so important that I would recommend publication anyway.