REVIEW

Gravity before Einstein and Schwinger before gravity[1]

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Abstract: Julian Schwinger was a child prodigy, and Albert Einstein distinctly not; Schwinger had something like 73 graduate students, and Einstein very few. But both thought that gravity was important. They were not, of course, the first, nor is the disagreement on how one should think about gravity, which was highlighted at the June 2012 meeting of the American Astronomical Society, the first such dispute. Explored here are several views of what gravity is supposed to do: action at a distance versus luminiferous ether, universal gravitation versus action only on solids, finite versus infinite propagation speed, and whether the exponent in the $1/r^2$ law is precisely two, or two plus a smidgeon (a suggestion by Simon Newcomb among others). Second, an attempt is made to describe Julian Schwinger's early work and how it might have prefigured his "source theory," beginning with his unpublished 1934 paper "on the interaction of several electrons," through his days at Berkeley with Oppenheimer, Gerjuoy, and others, to the application of nuclear physics ideas to radar, and of radar engineering techniques to nuclear physics. Those who believe that good jobs are difficult to come by now might want to contemplate the couple of years Schwinger spent teaching introductory physics at Purdue before moving on to the Radiation Laboratory in 1942.

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Résumé : Julian Schwinger était un enfant prodige, Albert Einstein ne l'était pas ; Schwinger a eu 73 étudiants gradués et Einstein très peu. Cependant, les deux pensaient que la gravité était importante. Ils n'étaient évidemment pas les premiers. Le désaccord sur la façon de penser la gravité qui a été souligné à la réunion de juin 2012 de l'American Astronomical Society n'était pas une première non plus. Nous explorons ici plusieurs vues de ce que la gravité est supposée faire : action à distance vs éther, gravitation universelle vs agissant seulement sur les solides, vitesse de propagation finie vs infinie et est-ce que l'exposant dans $1/r^2$ est précisément deux ou deux plus un chouia (une suggestion de Simon Newcomb parmi d'autres). Ensuite, nous essayons de décrire les premiers travaux de Julian Schwinger et comment ils peuvent avoir influencé sa théorie des sources, commençant avec son papier non publié de 1934 sur les interactions entre plusieurs électrons, en passant par ses travaux avec Oppenheimer, Gerjuoy et d'autres, à l'application d'idées de physique nucléaire au radar et des techniques d'ingénierie du radar à la physique nucléaire. Ceux qui croient que maintenant les bonnes positions sont difficiles à trouver pourraient examiner les deux années que Schwinger a passé à Purdue à enseigner les rudiments de la physique avant de rejoindre le *Radiation Laboratory* à MIT en 1942. [Traduit par la Rédaction]

1. Introduction: what constitutes a "viable" theory of gravity?

The answer to the question posed here depends very much on what one believes is the problem in need of solution. For generations the problem was "what holds up the sky?" at least until the time of Descartes. Then it was "what holds down the sky?" and, as Newtonian mechanics and gravity gradually triumphed, ideas occasionally had to be stretched rather far (as in the hypothesized planets Vulcan, Nemesis, and Planet X), but when Ole Roemer said you need a finite speed of light to preserve Kepler's laws, he was quite right.

Next came "what is the relationship between the distribution of mass–energy in space and time and the geometry of that space–time?" It was recognized that this was the question only after Einstein had provided an answer in the form of his general theory of relativity. So, is there now a new problem posed by evidence for dark matter, the Pioneer effect, or some other anomaly that must be resolved by a new theory? Not in the author's universe. But "source theory" appeared in the 12 February 2012 issue of *New Scientist* in connection with the Casimir effect. The latter is an unexpected attraction between two closely spaced capacitor plates in the absence of net charges. It can be attributed to vacuum field energy or something classically calculable, and perhaps other entities.

2. What holds up the sky?

If you go outdoors and drop something and then look up, that is a perfectly reasonable question to ask. If my wine glass and its contents fall down, why does the sky not fall to a central earth? Various early cultures had some interesting answers, including a few where the universe was expanding, long before Hubble. Many of them are described by Leeming and Leeming [1], others (with references) by Trimble et al. [2].

The prettiest pictures belong to the Ancient Egyptian cosmos, where the air god Shu stood on the earth god Geb and held up the sky goddess Nuit (holding her in some embarrassing places in some versions). The sky was sufficiently material and held up firmly enough that the sun god Ra could sail his boat across it (and then underneath the earth at night). Babylonian (Enlil et al.), Hittite (Serri and Hurri), and early Hebrew (four pillars of the earth) models were rather similar. The Norse case had a single supporting axis, the tree Yggdrasil.

In a Chinese expanding universe, the god Phan-ku (or other spellings) grew 10 feet per day for 18 000 years to separate earth

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and sky. More serious Chinese cosmology was represented by an armillary sphere, originally built in 1435. A modern replica stands in Beijing and has the universe seemingly supported by dragons, though closer examination reveals that a tortoise is doing most of the work. Turtles (probably because they can get along with both earth and water) feature in a number of myths, such as for the surface of the earth, swimming in a bowl, supported by elephants, which stand on another turtle, and so forth. That last myth is normally associated with the Indian subcontinent, probably because bowls, turtles, and elephants are all to be found there.

The earth-centered structures associated with the names of Aristotle, Ptolemy, and so forth did not have supporting structures, but relied on aether or crystalline spheres for their stability. Reversion to walls holding up the sky occurred in the sixth century universe of Cosmas [3].

The transition from "holding up" to "holding down" was a gradual one. Somewhere around 1154 C.E. in Moriond, France (where cosmology conferences are held to this day!), a sage provided drawing, table, and text (in Latin coming from that of the Venerable Bede and his 701 *De Natura Kerum*, according to Lippitsch and Draxler [4]) that said, in translation, "Between earth and heaven seven stars are suspended...called wanderers... And although by a perpetual revolution of immense celerity they are raised and carried to the setting, they nevertheless are perceived to go in adverse motion, everyone by its pace, straying once higher, once lower because of the obliquity of the sign-bearer (i.e., the ecliptic). But hindered by the rays of the sun they become abnormal, or retrograde, or stationary." The model required no angelic host to rotate things from outside or hold them up from inside. Later versions, for instance in the 1493 Nuremberg Chronicle, did.

The last to "lay this old aside" was, I think, Rene Descartes, whose theory of gravity used whirlpools in the ether both to confine planets around the stars where they belonged and to keep the systems away from each other. In his 1636 version, our solar system is neither central nor larger than the others, which filled an infinite universe. In those last two respects, Descartes was more "modern" than many of his successors. And it must be confessed that ether had a very long afterlife, important to Crookes, Lodge, Huygens, Heaviside, Hooke, Euler, Newton (but only for optics, including dichroic lenses), Lorentz and Fitzgerald, Kelvin (who used it for practically everything), Stokes, Mendeleev, and, at the very last, a couple of semicranks, T.J.J. See, who used it to circularize the orbits of Jupiter and Saturn, and Dayton Miller, who repeated the Michelson–Morley experiment in the 1920s and got a positive result.

3. What holds down the sky?

Well, Isaac Newton's gravitation of course, although from around 1675 to the 1680s Newton supported a Descartesian vortex theory, with a downward-flowing gravity ether that pulled objects downward. *Principia* was completed in 1687 when he was already in his mid-forties, and many of the ideas and equations (including much of the calculus) either pre-dated him or were clarified considerably later by Europeans. By 1675, Ole Romer was sufficiently committed to the part of Newtonian gravitation that we call Kepler's laws that he was prepared to propose a finite speed of light (which he got roughly right) to account for eclipses of Io by Jupiter occurring too early or too late.

The Newtonian cosmos had some spectacular successes, some dismal failures, some odd outgrowths, and (as ever) some lingering defenders. To take the last first, Heber Doust Curtis (of the Curtis–Shapley debate) had, according to one of his last students, the late Ralph Baldwin, "not much use for that fellow Einstein" up to the time of his death in 1943. The weirdnesses championed by

scholars familiar to all of us included the conviction that gravity could act only on solid bodies, so that (thought William Herschel) the sun must be solid, with, perhaps, a cool, inhabited interior. Herschel's son John also held that view, and, in addition, supposed that the rings of Saturn were solid, could be stable only if eccentric, and, misled by his own ideas, said he had seen them to be noncircular. Bode's law (not a law, not originating from Bode, and not required by anything in Newton's ideas) led to what would have been a search for a planet between Mars and Jupiter (led by van Zach) if the project had not been scooped by Giuseppe Piazzi spotting Ceres on 1 January 1801.

The successes are well known: first, the prediction of the planet Neptune from irregularities in the motion of Uranus. That was actually only possible because Uranus had just recently passed Neptune at the time the former was discovered. Credit was divided among Leverier, Adams, and Galle as historians see fit. Discredit can be distributed among Airy, Challis, and whoever snitched the Neptune papers from the Royal Greenwich Observatory in the 1960s. Tobias Mayer, whose 1756 prediscovery observation of the position of Uranus facilitated the recognition of irregular motion, also lives on the credit side. To the same 1840s time frame belong the calculations and observations by Bessel that led him to say that both αCMa and αCMi (Sirius and Procyon) must have dark companions of about their own masses. Indeed they do.

Much more recently, some invisible shepherd satellites for the rings of Saturn and some invisible shepherd planets for gaps in the rings around young stars have been invoked. At least some are surely correct, so that the method constitutes something like the 13th way of searching for exoplanets!

Lastly we have the failures. The most recent are claims for a planet X or Nemesis to account for various events in the outer solar system affecting the orbits of comets and such. Before that came Pluto, formerly counted among the successes, but its mass is far too small to produce the perturbations on the orbit of Neptune that led to the Lowell Observatory search by Clyde Tombaugh.

And there is the item readers have been waiting for, the non-Newtonian advance of the perihelion of Mercury found by U.J.J. Le Verrier, who by 1859 doubted that the cause could be an undiscovered intra-Mercurial planet, yet led a solar eclipse expedition to look for it in 1860. No, they did not confirm previous claims of sightings of Vulcan, either in transit or during solar eclipses. Alternative explanations included a ring of asteroids very close to the Sun and an oblate Sun (revived in the 1960s by Robert Dicke who by then was looking for evidence of non-Einsteinian gravity). Simon Newcomb, suggesting a law of gravity that deviated slightly from $1/r^2$, came closer to the truth than a few die-hards campaigning for ether drag. In 1894, Asaph Hall, Newcomb's successor as director of the U.S. Naval Observatory, presented an actual formula relating the precession constant for Mercury to the power of r (different from −2) in the expression for gravitational force [5].

4. Some aspects of Julian Seymour Schwinger

The Anchorage meeting-in-a-meeting session of the AAS included a talk by Schwinger expert Kimball Milton, which he decided not to write up. Much of his expertise is, however, captured by Mehra and Milton [6], and additional lore appears in Schweber [7]. The author knew Schwinger only rather slightly, during his late years at UCLA, so most of this section is derived from the knowledge of others, particularly Ed Gerguoy[2] [8] to whom special thanks is expressed.

Schwinger was born in New York City on 12 February 1918. He attended Townsend Harris High School and the City College of New York (for one year) before going on to receive a B.A. in physics

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[2]E. Gerjuoy. Personal communication. 2013.

in 1936 and a Ph.D. from Columbia in 1939, working with I.I. Rabi, He went on to join Oppenheimer's group at the University of California, Berkeley, but opted to join the Radiation Laboratory during World War II, rather than the Oppenheimer-led Manhattan Project at Los Alamos. After the war, he taught introductory physics at Purdue for about a year before moving on to Harvard for the largest part of his research career.

Among Schwinger's early collaborators were Edward Teller, Lloyd Motz, and Ed Gerguoy, who taught him to play pool. Schwinger was notoriously a night worker, and he courted and married a woman he found so attractive that he was willing to face the day as early as 3 p.m. to see her. His 70-some Ph.D. students included four future Nobel Prize winners (three in physics, one in chemistry) and, on the relativity side, Bryce DeWitt and Gordon Baym. His curious schedule meant that most saw him only rather rarely. The total number of Ph.D. students is not quite a record; mathematical physicist Elliott Montroll had about 100 (and he and his wife Shirley had 10 biological children). Schwinger shared the 1965 physics Nobel Prize with Shinichiro Tomonaga and Richard Feynman. He moved on to UCLA in 1972 and died in Los Angeles on 16 July 1994.

Schwinger's intellectual activities were linked in unexpected ways. His war work on radar led to a fondness for Green's functions, which he applied to his version of quantum field theory and to first-order corrections to the magnetic moment of the electron in quantum electrodynamics. For reasons that have never entirely been explained, late in life he developed an interest in cold fusion and sonoluminescence. His colleagues' lack of enthusiasm for these led to his resignation from membership in the American Physical Society, in contrast to Feynman's resignation, chosen as the only way he could find to stop receiving *Physics Today*, which nevertheless produced a special issue in his honor after his death.

Eponyms featuring Schwinger include an S function, S model, S effect, S-Dyson equations, S quantum action principle, Rarita-S action, Lippmann-S equation, S parameterization, and S limit. None seem to be as well known as Feynman diagrams. The author does not know how Schwinger referred to any of the "S items." Feynman himself referred to Feynman diagrams as "the diagrams."

5. Schwinger, gravity, and Einstein

The application of Schwinger's source theory to gravitation first appeared in a 1970 text [9] in which, among other things, he showed that his ideas could explain the four classic solar system tests of general relativity equally well.

His last discussion of the topic [10] won second prize in the 1976 competition for awards for essays on gravitation, given by the Gravity Research Foundation. He begins by saying:

> "It was Einstein's great ambition in his later years to construct a unified theory of gravitation and electromagnetism. In this he failed. The reason for that is quite clear once the problem is considered to be a physical one and not an exercise in pure mathematics. There is no known physical phenomenon in which the gravitational action of the electromagnetic field differs in any significant way from that of any other energy momentum bearing substance."

Kimball Milton, speaking at a session of the American Astronomical Society in Anchorage in June 2012, emphasized that Schwinger would have been appalled to think of himself in a role versus Einstein. Schwinger's 1985 popular book on Einstein [11] made no mention of source theory.

6. The three- and two-body problems

Schwinger's first paper [12], *On the Interaction of Several Electrons*, was never published, but exists in the UCLA special collections and is reproduced in Mehra and Milton [6]. There are no references, but the author speaks of using the quantum electrodynam-

ics of Dirac, Fock, and Podolsky on the first page, and of Møller's expression for the matrix element of the interaction between two electrons. Heisenberg and Lorentz also make brief appearances. Today, the names of Fock, Podolsky, and Møller are more readily associated with general relativity than with quantum mechanics, and Møller served a three-year term as President of the International Society on Gravitation and Relativity.

In the case of Fock, the association was not entirely a happy one. A short 1957 paper [13] presents his own harmonic coordinates as the best way to describe inhomogeneous space and suggests that Einstein's general covariance is needlessly complicated. And he turned off his hearing aid in the middle of at least one session of a meeting of what is now the International Society on General Relativity and Gravitation. He was also part of the Russian–Soviet delegation that walked out in the middle of another session of that conference, but that was a political statement rather than a scientific one.

The Gerjuoy and Schwinger paper [14] *On Tensor Forces and the Theory of Light Nuclei* showed that the properties of He^4 and He^3 were not the sum of a deuteron plus neutron or proton. The calculations were done with a hand-cranked Marchant–Monroe calculator, and, "when we disagreed, not once was I right, and I'm a pretty good physicist," says the senior author (who had known the junior author way back at CCNY).

The December 1965 Nobel Prize event in Stockholm would normally have been a three-body interaction. In fact, Tomonaga did not make the trip, having suffered an accident while celebrating the announcement of the prize. The Japanese ambassador accepted the prize for him.

Of course the three-body problem has no closed, analytic solutions, even in Newtonian mechanics and classical quantum mechanics, and in general relativity not even the two-body problem has an exact, closed solution. A new theory of gravity that admits such solutions could be very exciting.

The term "two-body problem" in the section title refers to the possibility of there being correlations between the way world-class scientists interact with their colleagues, especially students, and the way they interact with other sorts of people in their lives. In the end a division was made of eight outstanding theorists who had some role in relativity and quantum mechanics into prairie voles and mountain voles. Readers will probably have to look them up, because the editor is unlikely to allow a description here.

The bottom line is that there were only two clear prairie voles: Dirac, who had few students, and Schwinger, who had many. A wider net would have also caught Robert Dicke, with a moderate number of students, and Elliott Montroll, with very many.

The mountain voles included Einstein and Feynman, each with few students, but also Landau, Oppenheimer, Zeldovich, and Phil Morrison, each with many. Oppenheimer, for instance, guided 23 students through to physics Ph.D.s during his few years at Berkeley.

Their mountain vole status is based on first-hand information for three, second-hand for two, and only third-hand for Einstein.

7. A prejudiced conclusion

Viable theories of gravity in their times have included support structures, universal gravitation, and general relativity. There is nearly universal agreement that scientists must, some day, find a quantum theory of gravity or forever admit that some parts of the physical universe are unknowable (Freeman Dyson has taken that point of view at times). If Schwinger's source theory approach to quantum field theory was heading toward some sort of quantum gravity, he did not share the answer with us, although his late student Bryce DeWitt was one of the people most associated with the search for decades. The author's own view is that a new theory might alternatively be needed at the other end of size scales in

connection with some sort of multiverse. If so, perhaps the proper ancient analogy is "turtles all the way down."

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