Reception of General Relativity

There are several curious features about the solar eclipse observations that in 1919 confirmed General Relativity and brought widespread popular recognition to Einstein. For example,

- *English* astronomers confirmed a *German* theory in the period immediately following World War I, when feelings were still high.
- The English physicists in any case had never been especially enthusiastic about special relativity.
- The observations made during the eclipse were not unambiguous.

Let us look at each of these points in more detail. World War I had been, as you probably know, an enormously destructive war. And it had been unexpectedly so—when the war began in August 1914, both sides expected a quick and decisive victory. To oversimplify a bit, neither side had realized the technological changes in war brought about by the machine gun and early 20th century artillery. Charges by massed infantry formations in the face of barbed wire, machine guns, and artillery were notably unsuccessful! But it took years, and enormous casualties on both sides, to bring this point home. (For further reading: Three books that I have found helpful are Barbara Tuchman, *The Guns of August* and *The Proud Tower*, and John Keegan, *The Face of Battle*.)

Consequently, feeling against Germany and Germans was very high in England. The English scientists had reacted strongly to the German intellectuals' "Manifesto to the Civilized World," which strongly defended Germany's involvement in the war. Even in the early 1920s, there was concern for Einstein's safety when he gave a public lecture in London. Einstein himself noted in the 20s that English newspapers referred to him as a "Swiss Jew," while German papers called him "a distinguished German scientist." Einstein speculated that if the theory had not been confirmed, the nomenclature might have been reversed!

Moreover, English physicists had been reluctant to accept Einstein's 1905 special relativity theory. English tradition, stemming from James Clerk Maxwell and Lord Kelvin, had strongly supported the notion of a mechanical aether. These mechanical models hung on much longer in England than on the continent. Here is a description of one of Kelvin's models for the aether:

> Suppose, for example, that a structure is formed of spheres, each sphere being the center of the tetrahedron formed by its four nearest neighbors. Let each sphere be joined to caps at their ends so as to slide freely on the sphere. Such a structure would, for small deformation, behave like an incompressible perfect fluid. Now attach to each bar a pair of gyroscopically mounted flywheels, rotating with equal and opposite angular velocities, and having their axes in the line of the bar; a bar thus

equipped will require a couple [that is, a torque] to hold it at rest in any position inclined to its original position, and the structure as a whole will possesses a kind of quasi-elasticity ... (Whittaker, vol I, p 145)

Here are a few British reactions from early in the 20th century to special relativity: First, from a 1911 meeting of the British Association for the Advancement of Science:

> Dr. C. V. Burton, after expressing his satisfaction that no one had confessed a disbelief in the aether, urged the importance of the search for residual phenomena [that is, phenomena that might show the existence of the aether] not falling within the electromagnetic scheme. Conceivably gravitation is such a phenomenon. There is the further question of whether neighboring electrically neutral masses exert forces upon one another in virtue of their motion through the aether. (quoted in Goldberg, p 233)

Here is another British physicist, A. McAuly, in a 1910 article titled titled "Spontaneous Generation of Electrons in an Elastic Solid Aether":

> Sir Oliver Lodge [a prominent British physicist] seems to strike the correct note when he ... calls upon us to explain everything in the world by pushing and pulling, or indeed, by pushing and not pulling.... The now familiar perfect fluid is alone left from which to extract our bricks and straw wherewith to build the world as it appears. (quoted in Goldberg, p 234)

Finally, here is Sir Oliver himself:

> If anyone tries to picture clearly ... the action of one body on another without any medium of communication [that is, the aether] whatever, he must fail. A medium is instinctively looked for in most cases; and if not in all, as in falling weight or magnetic attraction, it is only because custom had made us stupidly callous to the real nature of these forces.

or again,

> Touch seems to be a purely material sensation, the result of direct contact with matter. It is indeed what we call 'contact.' But when we come to analyze touch, we learn that atoms are never in contact. They approach each other within an infinitesimal distance; but there is always a cushion, what may be called a repulsive force between them—a cushion of ether. Hence even our apparently most material sense is dependent on this omnipresent medium on which alone we can directly act, and through which all our information comes. It is the primary instrument of the

> Mind, the vehicle of Soul, the habitation of Spirit. Truly it may be called the garment of God. (both quotations taken from Goldberg, pp 223ff.)

If in 1919 British physicists were skeptical about special relativity, they did not know much about general relativity. The latter theory had appeared in German journals, which because of the war were hard to obtain in Britain and the United States. Moreover, the theory used the mathematics of “tensor analysis,” which most physicists did not know well, and which therefore seemed strange and mysterious to many of them. Here, for example, is H. D. Curtis, a prominent American astronomer, in a letter written in 1923:

> Just a few minutes ago I was called to the telephone to speak to Dayton C. Miller, of Cleveland, who is on his way to Montreal to speak on the Michelson & M. exp.: he says in the January Phil. Mag. [the British journal *Philosophical Magazine*] Larmour says Einstein's result [for the deflection of starlight by the sun] is twice as large as it should be. I have not seen the paper & suppose it will be involved and difficult to read, but I shall look into it to-morrow. ‘Who shall decide if doctors disagree?’ Almost daily I am called on to explain Einstein, and have to plead ignorance of the way in which the results are obtained. (quoted in Earman and Glymour, p 57)

It is thus at first sight a little surprising that British astronomers should have been inspired to test general relativity. That surprise is only intensified when one reflects on the difficulty in making those tests. One is looking for a very slight change in the apparent position of a star when its light passes close to the edge of the sun. Such observations can be made only during a total eclipse of the sun.

An eclipse of the sun is total only over a small and limited path. Such paths rarely intersect established observatories. Hence astronomers who want to observe a solar eclipse must pack up their telescopes and other apparatus and decamp to the location of the eclipse. The tribulations such expeditions can encounter may be seen in the attempts to observe the eclipse of 21 August 1914, for which the path of totality passed through southern Russia. An American team of astronomers from Lick observatory had packed up their equipment and gone to Russia to try to observe this eclipse. These expeditions were not easy to organize, and travel was of course by ship and rail. In the event, the weather was cloudy, and the expedition unsuccessful. Moreover, the outbreak of World War I made it necessary for the Lick team to ship their telescopes back by way of Vladivostok and Japan. Because of the war, it took over four years. There was another eclipse in August 1918 in this country—but the telescopes did not get back in time! The temper of the Lick team can be imagined!! Nevertheless, their difficulties pale in comparison to those of Erwin Freundlich, a German astronomer who also attempted to observe the 1914 eclipse in Russia. At the outbreak of the war his equipment was impounded, and he himself was arrested and held as an enemy alien. [1]

The English expeditions of 1919 were due to the efforts of two men: Sir Frank Watson Dyson, at that time Astronomer Royal of Britain; and Arthur Stanley Eddington, a young but nevertheless prominent theoretical physicist and astronomer at Cambridge University. Both men were Quakers, and Eddington was an active pacifist during World War I—a position that was unpopular and difficult to maintain to a degree hard to imagine today. Nor was Eddington shy about advocating it: When friends tried to arrange to exempt him from the military draft because of his scientific eminence, Eddington almost scotched the deal by declaring that he would in any case claim conscientious objector status if his deferral on scientific grounds were denied. It appears that only Dyson's intervention, and his promise that if deferred Eddington would undertake an "arduous scientific task" secured Eddington's deferment.[2]

Moreover, Eddington was one of the few astronomers in England who was both knowledgeable and enthusiastic about both the special and general theories. (He had learned about the general theory through friends in Holland, a neutral country, who were able to pass along to him copies of the German journals that were otherwise difficult to obtain in England during the war.) Moreover, at a time when many British scientists spoke of boycotting German science after the war, Eddington, the pacifist and Quaker, looked for ways to reconcile German and English scientists. Here are two quotations from Eddington—the first is from an obituary for the German astronomer Karl Schwarzchild, published in 1916—during the war:

> The war exacts its heavy toll of human life, and science is not spared. On our side we have not forgotten the loss of the physicist Moseley, at the threshold of a great career; now, from the enemy, comes news of the death of Schwarzchild in the prime of his powers. His end is a sad story of long suffering from a terrible illness contracted in the field, borne with great courage and patience. The world loses an astronomer of exceptional genius . . .

The second quotation is from an article published in 1916, again in the midst of the war:

> It is not any personal attitude of the German scientists that presents a difficulty, but the feeling that they are involved in the general condemnation of their nation. But the indictment of a nation takes an entirely different aspect when applied to the individuals composing it. Fortunately, most of us know fairly intimately some of the men with whom, it is suggested, we can no longer associate. Think, not of a symbolic German, but of your former friend, Prof. X., for instance—call him Hun, pirate, baby-killer, and try to work up a little fury. The attempt breaks

[1] See Earman & Glymour.

[2] Earman & Glymour, p 72

> down ludicrously. No doubt, he is a most ardent supporter of his fatherland, passionately convinced of the righteousness of its cause. Call this wrong-headed, if you will, but surely not morally debased. Far be it from me to deny his individual responsibility for his country's share in the evil that has befallen. The worship of force, love of empire, a narrow patriotism, and the perversion of science have brought the world to disaster. But how can we expect him to look at these things with our eyes—to see his country as we see it; with us even the attempt to view the conduct of our government from the German's standpoint is discouraged as harmful to the state. (Both quotations are taken from Earman and Glymour, pp 82ff.)

Thus, both Eddington's scientific interests and his political and religious convictions led him to support, and indeed to organize and lead, the British expeditions to observe the eclipse of 1919. There were in fact two expeditions, one, led by Eddington himself, to Principe, an island off the coast of West Africa, and the other to Sobral in Brazil.

The measurements are made by taking two sets of photographic plates, one set during the eclipse, and the other set at some time at least a month or two earlier or later. The two sets of plates are then compared, and one looks for the very small shifts in apparent positions for stars passing close to the edge of the sun during an eclipse. The deflection predicted by Einstein is small—$1.75''$ of arc for a star passing by the edge of the sun. Consequently, the analysis is tricky and subject to many corrections and experimental errors.

At Principe, the heat of the sun distorted the telescope frame and caused the plates to go out of focus, so the analysis was even trickier than usual. The reported result was a deflection of

$$1.61'' \pm\ 0.30''.$$

A modern reanalysis of the same plates yields

$$1.61'' \pm\ 0.44''$$

The Sobral group (which had two telescopes) also had its problems—one telescope mirror suffered from distortion, and its clock drive (the instrument that keeps the telescope pointed at the sun) malfunctioned. This group reported two sets of results, one for each telescope:

$$1.98'' \pm\ 0.12'' \text{ and } 0.86'' \text{ (no error cited)}$$

A modern reanalysis yields

$$1.98'' \pm\ 0.18'' \text{ and } 0.86''\ \pm\ 0.48''$$

Remember that Einstein had predicted a deflection of $1.75''$. Pause for a moment here and reflect on how well you think the observations and the theory agree.

Here is Sir Frank Dyson, reporting on these results at a meeting of the Royal Society in November 1919:

> After a careful study of the plates I am prepared to say that there can be no doubt that they confirm Einstein's prediction. A very definite result has been obtained that light is deflected in accordance with Einstein's law of gravitation. (quoted in Earman and Glymour, p 76)

There have been, one might add, many observations of much greater accuracy made since 1919. (The earliest were carried out by the Lick Observatory team in the Western Australian desert in an eclipse in 1922—persistence sometimes pays off!) It is nevertheless interesting to reflect on the initial evidence and the reaction to it.

References

Stanley Goldberg, *Understanding Relativity: Origin and Impact of a Scientific Revolution*. Birkhäuser 1984.

John Earman and Clark Glymour, "Relativity and eclipses: The British eclipse expeditions of 1919 and their predecessors," in *Historical Studies in the Physical Sciences* **11** (1980), 49–85.

Sir Edmund Whittaker, *A History of the Theories of Aether & Electricity* (Thomas Nelson and Sons, second edition, 1951)