Air and Space this Week

Item of the Week

SIR ARTHUR STANLEY EDDINGTON AND THE SOLAR ECLIPSE OF 1919

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Newtonian Mechanics held sway for over two centuries, and they are still more than adequate for most physical situations, but the first decades of the Twentieth Century saw the rise of Albert Einstein and his Theories of Relativity. This Item is about another of those rare "called shots' in Science, where a bold and perhaps unexpected prediction turns out to be true. Recall the impact of the prediction that Jupiter's moon, Io, would be volcanically active, proved a week later with data from the fly-by of Voyager 1*. Einstein's theories explained one vexing problems of planetary motion, and they also led to a bold prediction, one that was tested not long after it was made, with spectacular results.*

"Oh leave the Wise our measures to collate
One thing at least is certain, LIGHT has WEIGHT,
One thing is certain, and the rest debate –
Light-rays, when near the Sun, DO NOT GO STRAIGHT!"

Arthur S. Eddington, with apologies to Omar Khayyam

ARTHUR STANLEY EDDINGTON

Arthur Eddington was born on December 28, 1882, in what is now Cumbria, England. His father, who was the headmaster of the local Quaker school, died two years later in the 1884 typhoid epidemic. His mother raised young Stanley and his sister by herself. His prowess as a student served him well, earning scholarships to go the next educational level he could not otherwise afford on three separate occasions. Professorial recommendations earned him a position at the Royal Observatory at Greenwich. By January, 1906, he was the chief assistant to the Astronomer Royal.

Eddington's career progressed rapidly. He became the Director of the Cambridge Observatory in 1913 and was elected a Fellow of the Royal Society in 1914. He made important contributions in two divisions of astronomy: astrometry, the use of precise positional measurements for orbital mechanics and other things, and astrophysics, particularly the properties of stellar interiors.

After the 1919 eclipse and its aftermath, described below, Eddington continued his studies in astrophysics and wrote a number of books, ranging from scientific research textbooks to philosophical tracts, to explanatory books aimed at the general public. He was knighted in 1930 for his eclipse work, and won many other prestigious awards. A lunar crater and an asteroid are named after him; he even had a proposed satellite mission, ESA's counterpart to *Kepler*, named for him, but it was cancelled in 2003.

ASTROPHYSICAL KNOWLEDGE CIRCA 1915

The rate of scientific advancement in astronomy and astrophysics during the period 1900-1920 was phenomenal. The recent "Great Debate" Item of the Week about spiral nebulae also gets at the state of scientific growth occurring at this same time (here). Einstein's breakthroughs of a decade earlier were a part of it, as were the results of his work published in 1911, when he showed that a strong gravity field will deflect a light ray passing close by. Newton's work allowed for that, too, but deflection calculated under Newtonian formulae was small than that predicted under Relativity.

The present state of astronomical equipment capabilities in this era did not allow the observation of stars close in the sky to the Sun, let alone make the accurate measurements needed to determine whether Newton or Einstein was correct. Einstein realized that during a total solar eclipse, where the Moon would block the Sun's light for us, fainter stars near the Sun could be seen well enough to show any deflection present, and recommended that expeditions be mounted to upcoming eclipse sites.

AN EXPLANATION AND A PREDICTION

Newtonian mechanics allowed the astronomers of a century ago to understand the motion of all of the bodies of the Solar System. Except for one small thing – Mercury.

Mercury's orbit is more elliptical than that of the other planets. It's still pretty circular, but its ellipticity was well-known before Eddington came on the scene. In addition, the long axis of Mercury's orbit was not fixed in Space, rather it precessed slowly, but measurably. Newtonian mechanics could explain the ellipticity, but not the precession.

Einstein analyzed Mercury's orbit using his Relativistic model, and showed in 1915 that the observed precession is exactly what his model predicts.

The problem was, the observation was around well before the evidence for it was acquired. There was no "called shot" here. The work was still of value, but it was insufficiently extraordinary to move many away from tried-and-(almost)true Newtonianism.

Einstein's 1911 and earlier papers not only could explain Mercury's orbit, they also offered up an observational test to determine if straight Newtonianism or this new Relativity was more correct. Observations of the starfield around the Sun during an eclipse compared with the same starfield with the Sun not present could/should allow the determination of the deflection.

This would be the penultimate example of Understanding Things from the Study of a Thing in Front of Another Thing to advance several disciplines of Science!

Chasing an eclipse with the astronomical equipment of the time was no small undertaking, and there were a number of potential eclipses and observing sites in the decade following the 1911 paper, but logistical difficulties and political unrest precluded sending expeditions to the eclipses of 1912 and 1914. And then The Great War intervened.

International travel to faraway places to observe eclipses became impossible for the duration. Most scientific communications/collaborations were blocked. But Eddington was by then the Secretary of the Royal Astronomical Society, and had connections with a colleague in Holland who managed to get a copy of the 1915 paper to him, the only one of Einstein's papers that made it to Brittian during the War. Eddington read the paper, followed the analysis, and became an Einstein believer.

Eddington used some of the forced down time to plan an eclipse observing expedition that could make the necessary measurements regarding gravity deflection. He looked ahead to upcoming total solar eclipses, and found that the total solar eclipse of May 25, 1919, would be an ideal candidate for study, and that the date was far enough in the future for the then-present state of war and unrest would likely be over. The eclipse would occur near the Hyades star cluster (the "V" of the face of Taurus), which would mean that there would be a lot of stars to use for the deflection measurements. Further, the eclipse would occur near lunar perigee, making the eclipse longer than usual (over five minutes), giving more time to make observations. The eclipse spanned the Atlantic, starting in west of South America and ending east of southern Africa.

Eddington pitched his plan to his boss, the Astronomer Royal and Director of the Greenwich Observatory, Frank Watson Dyson. Dyson had considerable experience with using a solar eclipse to study the lower solar atmosphere, but he was not a supporter of Einstein's views. The notion of using the solar eclipse observations proposed by Eddington to resolve the issue completely resonated with him, and he quickly approved Eddington's idea. Dyson felt that observing sites at the east coast of South America and at Principe Island off the south-west coast of Africa would give the expedition redundancy to protect against bad weather. Eddington and Edwin Cottingham would lead the Principe group, astronomers Andrew Crommelin and Charles Davidson would lead the Brazil group, and Dyson would supervise from England. War hostilities ended in November, 1918. Dyson and everyone else involved had to move quickly in order to get the two expeditions prepared.

This time around, the observations are chasing the theoretical prediction (a "called shot" situation). If the observed deflection matched Einstein's prediction, then THAT would certainly get the attention of the astronomical community in a way the Mercury data could not.

THE TOTAL SOLAR ECLIPSE 1919

The Crommelin expedition chose their observing site in Sobral, Brazil, a town is about 50 miles inland from the coast. The expedition carried 14 large crates of equipment and supplies. Two weeks were required to ship everything to Para, in northern Brazil, then everything had to make an arduous trek to Sobral, taking almost two months total travel time. At least they had good weather at their site to make the necessary observations, even though clouds on the morning of eclipse day produced considerable anxiety.

Eddington's group faced fewer trials and travails getting to their observing site, arriving a month in advance. That gave them more than adequate time to set up and test equipment and otherwise prepare, but it also gave them an unpleasantly-hot environment that they had to endure for a month. Worse, a thunderstorm came in on eclipse day morning, and was waning but hadn't dissipated by the time the eclipse began. During the five-minute period of totality, the sky cleared enough for some useable photographs to be acquired.

Both groups hurried back to England after the eclipse, and Dyson and both teams eagerly analyzed the data they had acquired. It took several months of painstaking effort, on top of being tired from the travels, but in a few months, they were ready.

On November 6, 1919, Dyson, Eddington, and Crommelin announced their results to a joint meeting of the Royal Society and the Royal Astronomical Society. They showed that the deflections they measured were too large to be Newtonian, but matched well with the predictions from Einsteinian Relativity. The "Called Shot" of Einstein just got hit over the fence.

Einstein's ideas are difficult to wrap one's head around, and even though the eclipse results were quite dramatic, there was still a number of astronomers who did not accept the results immediately. Others, perhaps understanding Einstein's ideas more completely, were flabbergasted. For example, J.J. Thompson, a famous physicist credited with the discovery of the electron, recognized the importance of the eclipse data right away, and waxed enthusiastically about them. Others, not so much.

AFTERMATH

The professional astronomy community might not have been immediately impressed with Dyson, *et al.*'s observations, but the press certainly was. Major newspapers around the world put up very bold headlines about this being a Revolution in Science, Newton Overthrown, and other such. Most had no clue as to the overall significance of the observations and their effect on the grand scheme of things, but they did appreciate the boldness of both the prediction and the efforts made to test it.

Called shots delivered upon are remembered and revered a long time; called shots that miss are quickly forgotten. The confirmation of his bold predictions (and perhaps his improbable hair) made Einstein the public paragon of the Scientist. One important event may have been catalyzed by Einstein's reputation: the reaction of FDR to Einstein's letter suggesting the development of an atomic bomb.

CODA

The bending of starlight as it passes a star or other large mass was a novel concept a century ago, but nowadays it is an important astronomical tool. "Gravitational lensing" allows the detection and study things ranging from interstellar dark dwarfs to quasars to distant galaxies. **And now, astronomers are proposing to use the Sun's gravity as a giant telescope lens to actually image (crudely) the surfaces of exoplanets!** See more about that in the TWSftUoTtCBDftSoTiFoOT section below, and/or at: https://phys.org/news/2022-05-scientists-gravity-telescope-image-exoplanets.html.

Frank Dyson was the Astronomer Royal, and the lead author on the paper presented to the Royal Society and Royal Astronomical Society, yet today, it is Eddington who is mentioned most in the context of the 1919 eclipse results. There may have been a number of reasons why that is so, but I strongly suspect two reasons made Eddington more prominent today. The first is that he went on to make a number of other important discoveries after 1919, including showing that stars use hydrogen fusion for energy and he discovered the mass-luminosity relationship for stars. He didn't always get it right at first, notably thinking the calculations of Chandrasekhar showing the potential existence of black holes had not basis in reality, but he did help score an impressive called shot. The second reason is that, in addition to his scientific writings, he also was gifted in communications with non-specialists, and wrote several books on relativity for the public. He was also a gifted orator and popular lecturer, blending science, philosophy, and religion in harmony.

Eddington had been there and done that, but so had others, but Eddington could communicate better with the press and the public, so he got more recognition, and had more impact on the public, than his compatriots. ***A lesson for all of us in the science engagement effort!***

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Called Shots: A+StW Item of the Week (March 7, 2022), *The Thrill of Discovery, and the Agony of Defeat*,
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