Biographical Encyclopedia of Astronomers

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Eddington, Arthur Stanley

Born Kendal, (Cumbria), England, 28 December 1882

Died Cambridge, England, 22 November 1944

English theoretical astrophysicist Arthur Stanley Eddington is most widely remembered for coordinating the 1919 solar eclipse expeditions that provided confirming evidence for the gravitational deflection of light predicted by Albert Einstein's general theory of relativity. He also formulated the modern theory of Cepheid and other pulsationally varying stars, wrote down the equations that describe how radiation moves through stellar material, and was a pioneer in attributing stellar energy sources to "subatomic" (nuclear) processes and in recognizing that interstellar gas pervades the Milky Way Galaxy

Eddington was born to Sarah Ann Shout Eddington and Arthur Henry Eddington, a Quaker schoolmaster and the descendant of four generations of Somerset Quakers. After his father's early death, Arthur Stanley was educated at home and in small schools in Weston. His love of and talent for mathematics was soon evident, and he won many contests and prizes. At the age of 16, he won a scholarship to Owens College, Manchester, where he studied physics and mathematics with Arthur Schuster and Horace Lamb. At Manchester, Eddington lived at Dalton Hall, where he came under the lasting influence of the Quaker mathematician J. W. Graham.

Eddington was always dependent on financial support, and a Natural Sciences Scholarship allowed him to enter Trinity College, Cambridge, in 1902. There he was coached by the famous mathematician Robert Herman and became the first second-year student to earn a place as senior wrangler on the tripos He received his BA from Cambridge in 1905 and his MA in 1909. After teaching briefly at Trinity College, Eddington became chief assistant at the Royal Observatory, Greenwich, from 1906 to 1913. In 1913, he was appointed to a fellowship at Trinity College, Cambridge, and awarded the Plumian Professorship of Astronomy and Experimental Philosophy and the directorship of the Cambridge Observatory, positions he held until his death. The best known of Eddington's students there were the theoretical astrophysicist Subrahmanyan Chandrasekhar and the historian and philosopher Clive Kilmister. He advised Cecilia Payne-Gaposchkin, who had been a Cambridge undergraduate, to pursue graduate studies in the United States.

Eddington's early work concerned the motions of stars through space, based primarily on proper motion data. His 1914 book, *Stellar Movements and the Structure of the Universe*, placed the Sun very near the center of the stellar system (then called the Universe, now called the Galaxy) and endorsed Jacobus Kapteyn's two-stream hypothesis, in which the motions were described by two intermingling streams of stars moving in different directions relative to the Sun. The description given by Karl Schwarzschild in terms of velocity ellipsoids turned out to be more useful. Both were incomplete descriptions of the effects of a differentially rotating galactic disk, a nonrotating halo, and a solar position far from the center

In Cambridge, Eddington turned his attention to the interior structure of stars, how energy was transported from the center to the photosphere, and what the sources of that energy might be. Robert Emden had formulated the mathematics of stars in which energy was carried by convection, and Schwarzschild had begun considering the effects of radiation shortly before his death in 1916. Eddington's standard model, begun in 1916, was a completely radiative star,

and he concluded that the most common kind of stars, like the Sun, were those where the pressure due to the hot gas and the pressure due to radiation were equal. He, like most contemporaries, thought that stellar composition must be similar to that of the Earth, with lots of silicon, oxygen, and iron.

During this period, Eddington (1) correctly described the variable brightness of Cepheids as being due to inward and outward pulsation of the stars, driven by ionization and recombination of gas just beneath their visible surfaces; (2) coined the term "main sequence" to describe the locus of the majority of stars in a Hertzsprung-Russell diagram and the word "bolometry" to describe measuring the brightness of stars at all wavelengths; (3) derived for the first time the relationship between luminosity and mass ($L \ M^3$) for fully radiative stars, which agrees with observations and does not depend on the nature of the energy sources; (4) endorsed the suggestion from James Jeans, with whom he otherwise had rather little in common, that the gas in stars would be completely ionized, so that perhaps the atoms could be crammed together much closer than they are on Earth; and (5) suggested an approximation to the structure of stellar atmospheres (the Milne-Eddington approximation) in which the particles that produce the continuum ("rainbow") and those that produce the absorption lines are completely mixed. The opposite, with the absorption layer on top, is the Schuster-Schwarzschild approximation, due to his former teacher and German contemporary.

During World War I, Eddington became embroiled in controversy within the British astronomical and scientific communities. Many astronomers, chief among them Herbert Turner, argued that scientific relations with all of the Central Powers should be permanently terminated due to their conduct in the war. Eddington, a Quaker pacifist, struggled to keep wartime bitterness out of astronomy. He repeatedly called for British scientists to preserve their prewar friendships and collegiality with German scientists. Eddington's pacifism caused severe difficulties during the war, especially when he was called up for conscription in 1918. He claimed conscientious objector status, a position recognized by the law, if somewhat despised by the public. However, the conscription board refused to grant such status since he had previously held a deferment for his astronomical work; the government would not allow him to be both a scientist and a Quaker. Only the timely intervention of the Astronomer Royal and other high-profile figures kept Eddington out of prison

During the war, Eddington was Secretary of the Royal Astronomical Society (RAS), which meant he was the first to receive a series of letters and papers from Wilhelm de Sitter regarding Einstein's theory of general relativity. Eddington was fortunate, being one of the few scientists able to understand the mathematics of relativity, and also one of the few interested in pursuing a theory developed by a German physicist. He quickly became the chief supporter and expositor of relativity in Britain. Eddington and Astronomer Royal Frank Dyson (one of the few other internationalists in the RAS) organized the 1919 expedition to make the first empirical test of Einstein's theory: the measurement of the deflection of light by the Sun's gravitational field. In fact, it was Dyson's argument for the indispensability of Eddington's expertise in this test that allowed him to escape imprisonment during the war

The eclipse expedition to Principe in Africa and Sobral in Brazil was held up as a complete success, and Eddington embarked on a campaign to popularize relativity and the expedition as landmarks both in scientific development and in international scientific relations. In recent years, Eddington has been accused of having manipulated the data from the expedition to favor Einstein, but there is no evidence that this was the case. During the 1920s and 1930s, Eddington gave innumerable lectures, interviews, and radio broadcasts on relativity (in addition to his textbook *Mathematical Theory of Relativity*), and later, on quantum mechanics. Many of these were compiled into books, including *Nature of the Physical World* and *New Pathways in*

Science. They were immensely popular with the public, not only because of Eddington's clear exposition, but also for his willingness to discuss the philosophical and religious implications of the new physics He argued for a deeply rooted philosophical harmony between scientific investigation and religious mysticism, and also that the positivist nature of modern physics (i.e., relativity and quantum physics) provided new room for personal religious experience. Unlike many other spiritual scientists, Eddington rejected the idea that science could provide proof of religious propositions. His popular writings made him, quite literally, a household name in Great Britain between the world wars.

In addition to receiving popular acclaim, Eddington also received most of the traditional professional accolades, including more than a dozen honorary doctorates, memberships, and medals of the Royal Society (London), the RAS (which he served as president and which later named one of its medals for him), the United States National Academy of Sciences, and the Astronomical Society of the Pacific.

By the time of the 1926 publication of his ^, Eddington had taken definite stands on a number of other issues One was the basic source of stellar energy, which he attributed to processes concentrated at the centers of stars that would change one element into another. This allows for stellar lifetimes much longer than the gravitational contraction timescale of William Thomson and Hermann Helmholtz, but much shorter than the 10^{12}–10^{13} years advocated by Jeans on dynamical grounds, which would have required the complete annihilation of stellar matter. He also applied general relativity to white dwarf stars, predicting that they should exhibit a gravitational redshift (reported the following year, 1925, by Walter Adams). On the other hand, Eddington accepted Ralph Fowler's 1926 suggestion that white dwarfs would be fully degenerate, but rejected the later conclusion of his student Chandrasekhar that there was an upper limit to the possible masses of these stars. Eddington's dispute with Chandrasekhar was not based on racism, as is sometimes claimed, but rather on straightforward disagreements about how best to combine relativity with quantum mechanics.

Eddington was also involved in applying general relativity to expanding universe models. He supported Georges Lematre's 1927 work, but rejected the idea of a discontinuous "Big Bang" beginning to the Universe. His own work in cosmology focused on the role of the cosmological constant, which most scientists had rejected as superflows.

From about 1900 to 1930, the astronomical community was divided over whether diffuse material was pervasive in interstellar space, whether it might absorb significant amounts of light, and whether accretion from diffuse material might significantly augment the masses and brightnesses of stars. Eddington correctly interpreted observations by John Plaskett as meaning that at least calcium and sodium were pervasive, although he did not think such material would result in significant absorption or accretion

particles in the observable universe, of the fine structure constant. Toward the end of his life, Eddington attempted his own unification of general relativity and quantum mechanics in the posthumously published *Fundamental Theory*. He provided what were intended as calculations from first principles of the total number of particles in atomic physics and other basic properties of nature. Few of his colleagues attempted, or were able, to follow the arguments, some of which were heavily philosophical.

Matthew Stanley and *Virginia Trimble*

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