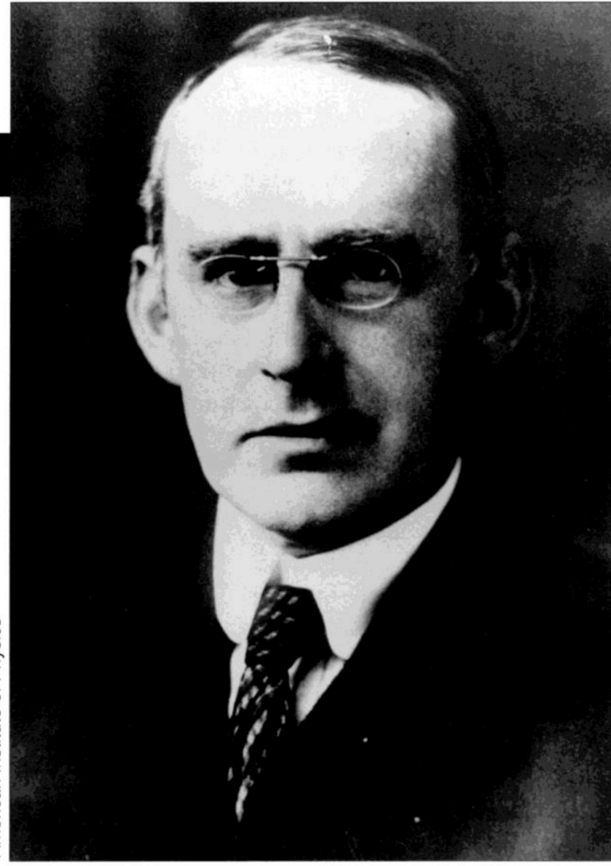
Bruce Medalist Profiles

Arthur Stanley Eddington: The Nineteenth Bruce Medalist

Joseph S. Tenn
Sonoma State University



American Institute of Physics

Arthur Stanley Eddington
28 December 1882 - 22 November 1944
1924 Bruce Medalist

Arthur Stanley Eddington dominated theoretical astrophysics in the early decades of this century, and his influence continues. Just since 1988, astronomers have published at least twenty papers with titles containing his name, with references to Eddington luminosities, Eddington limits, Eddington approximations, Eddington ratios, Eddington winds, and the Eddington-Lemaître model of the universe. A compendium of the most important papers in astronomy and astrophysics from 1900 to 1975 includes six by Eddington and no more than four by any other individual. He was also an outstanding expositor of scientific discovery. Six of his 13 books are still in print, nearly half a century after his death.

Eddington was not quite 41 when the ASP board of directors voted unanimously to award him the Bruce medal, an honor nearly always reserved for those much older.

His mother and sister, who devoted their lives to keeping house for him (his father died when he was two; he never married) called him Stanley. Everyone else called him Eddington or Professor Eddington until he was knighted and became Sir Arthur. He was a religious man who regularly attended and quietly kept the books for his Quaker meeting; a mystic whose incomprehensible later writings did much to damage his reputation; a philosopher of science who has inspired more than a dozen books, most of them denouncing his views; and a conscientious administrator and teacher.

Eddington conducted research in four broad areas: stellar motions, relativity and cosmology, stellar structure and evolution, and "fundamental theory."

From childhood it was evident that he was brilliant, especially in mathematics, and that the stars fascinated him. He won scholarships to the University of Manchester, where he studied physics, and then to Cambridge, where a half century later he was still the only student to have taken first place on the legendary mathematical tripos exam in his second year (most take it in the third). In 1906 he accepted an offer from Astronomer Royal William Christie to become Chief Assistant at the Royal Observatory, Greenwich.

For seven years, the last two of them under Frank Dyson, Eddington was an observational astronomer. It is possible that checking the positions of 12,000 stars for a catalog helped him to achieve a better understanding than that of most theorists of the possibilities and limitations of observation. He employed new data to attack the problem of what was then called interchangeably "the system of stars" or "the universe." His research on stellar motions culminated in the important book, *Stellar Movements and the Structure of the Universe.* He extended J.C. Kapteyn's model of two "star streams" and supported the idea that the spiral nebulae are external systems of stars:

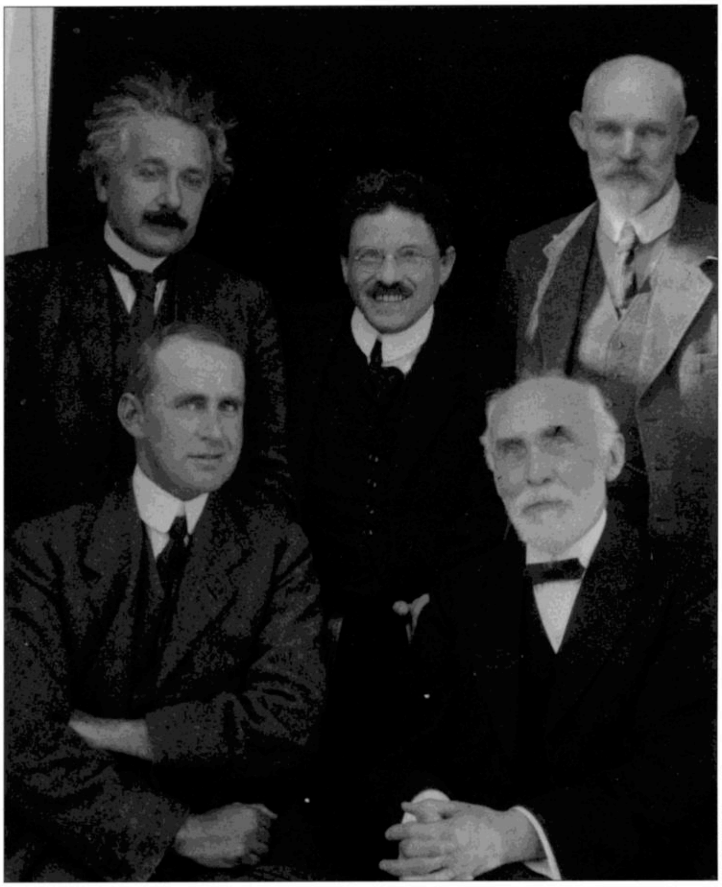
> If confirmed the hypothesis opens up to our imagination a truly magnificent vista of system beyond system...in which the great stellar system of hundreds of millions of stars (our galaxy)...would be an insignificant unit.

In 1913 Eddington returned to Cambridge as Plumian Professor of Astronomy, and the following year he became director of the Cambridge Observatory as well. He continued work on the motions of stars, including that of the Sun with respect to the stellar system, dynamics of star clusters, and even motions of comets, but soon he was immersed in two other fields as well.

During World War I Eddington received copies of Albert Einstein's papers on the general theory of relativity from Willem de Sitter in Holland. Eddington was captivated by the theory and quickly became its principal proponent in the English-speaking world. He wrote both technical and popular books to explain the new physics to scientists and the educated public. We have already seen [in the article on Dyson in the Mar/Apr 1993 issue of *Mercury]* Eddington's leadership, along with that of Dyson, in preparing the 1919 eclipse expedition which demonstrated that light is deflected by gravity. Afterward, physicists had to accept that the strange new theory of Einstein describes the universe better than the familiar laws of Isaac Newton.

Relativity led to cosmology, and Eddington vied with Einstein, de Sitter, the Belgian priest George Lemaître, and others in constructing and refuting models of the universe. Eddington's own cosmological models have not survived the test of observations, but much of his work on stellar structure has. In 1916, when he began trying to understand the physics of the pulsating stars known as Cepheid variables, there were really no models of stars and only a few very simple models of ideal gas balls held together by gravity. Today, stars, excepting only those just forming and those which have undergone catastrophic collapse, are considered fairly well understood, and few astronomers study them, one of the legacies of Eddington and the work he inspired.

In a long series of papers, and in the highly influential book, *The Internal Constitution of the Stars,* he applied contemporary discoveries in atomic physics to stellar interiors. He came along at the right time: his colleagues at Cambridge included Ernest Rutherford, who had discovered the atomic nucleus, and P.A.M. Dirac, the founder of relativistic quantum mechanics.



Yale University

Five pioneer "relativists" in 1923. From left to right, they are Albert Einstein, Eddington, Paul Ehrenfest, H.A. Lorentz, and Willem de Sitter.

In 1916, he attempted to explain Cepheid variable stars as stellar engines. This was shortly after Ejnar Hertzsprung and Henry Norris Russell independently showed that nearly all stars could be divided into two classes, giants (or red giants) and dwarfs (main sequence stars; the two or three white dwarfs known did not fit in). The giants are so big that their average densities are very low. They were expected to behave like ideal gases which are easily compressed. The dwarfs, on the other hand, have average densities as great as that of terrestrial liquids and solids, and were thought to be as difficult to compress as water or iron.

Eddington decided that it isn't just gas pressure which keeps a star from collapsing under gravity; radiation pressure is also important. Karl Schwarzschild had used radiation pressure to model a star's atmosphere, but Eddington was the first to use it in a stellar interior. This led him to the study of *opacity,* the absorption or scattering of radiation by a gas, which provided the necessary "valve." He discovered that a star of a given mass cannot exceed a certain luminosity, now called the Eddington limit, or radiation pressure will blow the star apart. He constructed stellar models with very high temperatures, and presumably high energy generation, at their centers, and with radiation pressure providing much of the support against gravitational collapse. With some simple assumptions, he obtained the important mass-luminosity relation: the luminosities of stars made of ideal gases should be roughly proportional to the cubes of their masses.

Sure enough, the bloated red giants like Betelgeuse, with average densities less than a thousandth that of air, obeyed the mass-luminosity relation. But much to Eddington's surprise, so did main sequences stars like the Sun, which is slightly denser than water. This demolished the widely-held belief that red giants evolve into main sequence dwarfs. Eddington soon realized that matter at the high temperatures which must prevail in stellar interiors is ionized, as was suggested by his rival, James Jeans. With the electrons removed from the nuclei, stars denser than platinum are as compressible as the air in a balloon.

Eddington was convinced that the stars must shine as a result of the liberation of "subatomic" energy. (The word "nuclear" had not yet entered physics.) In 1920 another Cambridge colleague, F.W. Aston, invented the mass spectrometer and showed that a helium atom is less massive than four hydrogen atoms, and Eddington (and Jean Perrin in France) suggested the fusion of hydrogen into helium as the source of stellar energy. In his presidential address in 1920, he told the British Association that it was time to abandon gravitational contraction as the source of a star's energy, a source long known to be too puny to keep the Sun shining for more than a few tens of millions of years. He went on:

> A star is drawing on some vast reservoir of energy by means unknown to us. This reservoir can scarcely be other than the sub-atomic energy which, it is known, exists abundantly in all matter; we sometimes dream that man will one day learn how to release it and use it for his service. The store is well-nigh inexhaustible, if only it could be tapped.

He showed that even if the stars are only five percent hydrogen, there would be enough energy available to keep them shining for billions of years. He also pointed out that

> if, indeed, the sub-atomic energy in the stars is being freely used to maintain their great furnaces, it seems to bring a little nearer to fulfilment our dream of controlling this latent power for the well-being of the human race—or for its suicide.

Later it became clear that the Sun is composed mostly of hydrogen. Complete stellar models remained unattainable, however, until after the neutron was discovered in 1932 (also at Cambridge!), and the specific nuclear reactions that power the stars became known at the end of the 1930s.

By then Eddington had moved on to metaphysics. He had become convinced that he could discover the laws of nature by thought, without much need of experiment or observation. He decided that the pure number $hc/2\pi e^2$, where h is Planck's constant, c is the speed of light, and e is the charge on the electron, must be exactly 137, a number that was then within the uncertainties of the experimental value. He invented a theory as to why this should be so, and opened a chapter of one of his later books with, "I believe there are 157···296 protons in the universe, and the same number of electrons." He presented all eighty digits; he had calculated the number, which is 136×2^{256}, on a trans-Atlantic voyage.

One reason for his confidence was his success with stars. He had suggested that a physicist "on a cloud-bound planet, who has never heard tell of the stars, calculating the ratio of radiation pressure to gas pressure for a series of globes of gas of various sizes" would find that for masses much less than that of the Sun, gas pressure would be far greater than radiation pressure, while for masses much greater, the opposite would occur.

> Regarded as a tussle between matter and aether (gas pressure and radiation pressure) the contest is overwhelmingly one-sided except between [10^{33} and 10^{35} grams] where we may expect something to happen.
>
> What 'happens' is the stars.

The same "cocksureness" made him a tough antagonist in scientific debate. His disputes with James Jeans and Arthur Milne over the validity of stellar models at Royal Astronomical Society meetings became legendary. He was quoted in the published proceedings of one meeting as saying,

> Prof. Milne did not enter into detail as to why he arrives at results so widely different from my own; and my interest in the rest of the paper is dimmed because it would be absurd to pretend that I think there is the remotest chance of his being right.

His greatest error came when he ridiculed some results obtained by S. Chandrasekhar. The young man from India, who had recently completed his Ph.D. under one of Eddington's colleagues, had found by combining quantum mechanics and relativity that stars which have exhausted their energy sources cannot escape gravitational collapse if their masses are greater than about 1.4 times that of the Sun. "Chandra," of course, was right, but at the time, Eddington's harsh judgment and public ridicule contributed to Chandrasekhar's leaving Cambridge and going to the Yerkes Observatory, where he has since become an astrophysicist as acclaimed as Eddington.

Although he could be almost brutal in debate, Eddington bore no grudges, and he remained on friendly terms with his scientific rivals. In a letter to Herbert Dingle, a philosopher of science with whom he frequently disagreed, he wrote, "It has been my common experience through life that the most excellent people hold the most atrocious opinions."

Eddington wrote some of the finest prose ever used to explain science to the public, and he gave public lectures which were models of clarity. In his words,

> ...science is not just a catalogue of ascertained facts about the universe; it is a mode of progress, sometimes tortuous, sometimes uncertain. And our interest in science is not merely a desire to hear the latest facts added to the collection; we like to discuss our hopes and fears, probabilities and expectations. I have told the detective story so far as it has yet unrolled itself. I do not know whether we have reached the last chapter.

Many were inspired by this man they called "painfully shy." A number of today's senior astronomers started out reading his popular books. George McVittie, who found his teacher "distant, unapproachable, unintelligible," recalled many years later, "Well, I suppose [my interest in stellar structure] started, listening to Eddington in this course, though he proved to be, when lecturing to students, one of the most appalling lecturers, in the worst Cambridge style, unlike his public lectures which he prepared beforehand." His biographer, Allie Vibert Douglas, remembered her student days:

> In memory I see him in his classroom of Bene't Street. From my seat...I watch a master-mind at work. A slight man of average height, in academic gown, reserved almost to the point of shyness, he rarely looks at his class. His keen eyes look at or through the side wall as he half turns from the blackboard and seems to think aloud the significance of the tensors which he has just written on the board. The mathematical theory of relativity is developed *ab initio* before our eyes and the symbols are made to live and take on meaning. I see his face in profile and hear his low voice as he says as though in soliloquy: "The real three-dimensional world is obsolete, and must be replaced by the four-dimensional space-time with non-Euclidean properties... But the four-dimensional world is no mere illustration; it is the real world of physics, arrived at in the recognized way by which physics has always (rightly or wrongly) sought for reality." ■

Acknowledgements:

Eddington's letter to Dingle is quoted by permission of the archives of Imperial College of Science, Technology and Medicine, London. McVittie's statements are from an interview by David DeVorkin, 1978, American Institute of Physics. Douglas's reminiscence appeared in the University of Toronto Quarterly, 1945.

For Further Reading:

S. Chandrasekhar, *Eddington: The Most Distinguished Astrophysicist of His Time* (Cambridge Univ. Press, 1983). See also the author's centennial tribute to Eddington in *Mercury,* Nov/Dec 1982.