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EINSTEIN AND ASTRONOMY *

The problem which set Albert Einstein on the road to fame was the problem of the want of harmony between pure and applied mathematics.

It was a problem of which the seed had been sown twenty-three hundred years ago by Plato. Plato was responsible for the distinction between pure and applied mathematics. To Plato, mathematics was a vision of eternal truths; it was pure, so pure that he decried its use as a mere tool to solve crass, earthy, mechanical problems.

With the renaissance of Plato, it became a fetish for mathematicians at the universities to protest that they were pure mathematicians, and to disdain to investigate the possible use of the results of their investigations.

Einstein was born into a world in which there were mathematicians going their way not caring whether their results would be of any use to any man at any time, and in which physicists were experimenting and astronomers observing, and both just saying: "These are the facts." Meanwhile, the number of unexplained facts was growing, as was also the number of mathematical theories which seemed to have no connection with real life.

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Such was the state of affairs, as Einstein saw it, after he had completed his studies at the Polytechnic School at Zurich, and had gone to work as a clerk to earn his living.

The discontinuity between the knowledge of mathematics and the knowledge of physicists and astronomers was as a nightmare to Einstein's tidy mind. He was haunted with the desire to bring mathematics and the physical sciences into better accord.

With his simple and clear mind he pondered on the result of the Michelson-Morley experiment - it meant nothing if it did not mean that the velocity of light was constant.

As a clerk, he had time to think. Quietly, his daring and precise mind went into action. Courageously, he followed his reasonings to their logical conclusions.

The mere rejection of the accepted mathematical concept of time, considered as a function independent of coordinate systems, led to his Special Theory of Relativity. His Special Theory offered an explanation of the null findings of the Michelson-Morley experiment, but it also led to the conclusion that mass and energy are equivalent. The conclusion was inevitable. The soundness of his reasonings convinced the world, and the revolution in science was on.

The influence of Einstein's Special Theory on Astronomy was due to the use of the New Physics in Astronomy. The influence of Einstein on Physics is to be treated in a paper by Dr. Archibald, therefore, I must pass over the influence of the Special Theory on Astronomy.

By propounding his Special Theory, Einstein had set himself another problem. His Special Theory was successful only where gravitational forces could be ignored. Newton's gravitational law could not be brought into line with the Special Theory.

Since the Newtonian law was founded on the Galilean law of equal accelerations for falling bodies, Einstein started to wonder about the validity of Galileo's law. It was at this point that his child-like sense of wonder came to his aid. He wondered if there could be another world in which feathers, when let drop, would fall with a thud, and in which elephants would float in the breeze. It occurred to him that the trouble with Newton's law was the Euclidean space which it postulated.

Made bold by his success with relative time, Einstein, with a daring now known as characteristic, abandoned Euclidean space. He assumed a Riemannian space of four dimensions, and accepted Minkowski's concept of space-time, as the fundament of our concepts of space and time. Thus the General Theory of Relativity was born. Einstein formulated his ideas in the language of the absolute differential calculus. He began their physical application by identifying the "points" of Riemannian space-time with events, so that a Riemannian space-time became a map of events. He continued to the deduction of ten gravitational equations from which, given the energy-tensor of a material system, the coefficients of the appropriate Riemannian space-time, in the immediate neighborhood of the event, could be determined.

The General Theory was looked upon as an ingenious mathematical formalism until blessed by astronomers. The first to make practical application of the theory was Karl Schwarzschild, Director of the Potsdam Observatory. Schwarzschild applied it to the computation of Mercury's orbit, and found that it gave answers more in accord with observations than did the Newtonian gravitational theory.

The perihelion of a planet, due to the perturbations of its neighbours, hasa slow progressive motion. For some time, astronomers had known that Mercury's perihelion was progressing faster than it should according to Newton's law. The astronomers kept the news of Mercury's bad behaviour more or less within ~~the~~ family circles until they were able to announce that it was behaving according to Einstein's theory. The announcement was made that experimental verification of Einstein's General Theory had been found, and the imagination of astronomers was fired.

It was during the First World War that Einstein published his General Theory and that Schwarschild tested it. Due to Eddington, it was well received in England, and in England there were astronomers eagerly waiting for the end of the war to put it to another test. They wished to test the theory that light passing close to the sun should be bent more than Newton's gravitation theory would allow.

As soon as the war was over, two English expeditions were planned to observe the next total eclipse of the sun - that of May 1919. One expedition (with Eddington) set out for the Island of Principe, off the west coast of Africa, and the other for Brazil. They photographed stars seen close to the sun while it was eclipsed. If light coming from a star was bent when passing close to the sun, then a star when seen close to the sun in the sky should seem to be displaced from the position in which it was seen when the sun was not close by. During the eclipse of 1919, the stars seen close to the sun undoubtedly seemed to be displaced, and the observed displacement was too large to be accounted for by Newtonian theory. It was not far from the amount predicted by relativity. This result was taken as confirming Einstein's theory.

The phenomenon of the bending of light rays received great publicity, and captured the popular imagination. The name of Einstein became household. The minds of astronomers, however, were sobered when photographs taken at later eclipses did not afford convincing evidence. Comfort was taken from the fact that on these later occasions the stars observed were not particularly well situated.

The seeming displacement of stars near the sun remains a major problem for eclipse expeditions. In June of this year 1955, the sun was eclipsed while in the constellation of the Bull, rich in stars. Months ahead of time, the English, with bull-dog perseverance, prepared to settle, once and for all, the question of the amount of displacement in the position of a star when seen close to the sun. Their hopes were high that they would justify Einstein while yet he lived. They picked a team of British and Singhalese astronomers; they acquired the services of German technicians, and the use of a telescope, well suited to their purpose, and with the added value that it was designed and destined for the Potsdam observatory. In the midst of their preparations Einstein died. Their expedition became a sacred mission. They went to Ceylon and set up their equipment. The day of the eclipse dawned, and the sun rose and shone. Then, a large, black, cruel cloud loomed in sight. Slowly and surely and unrelentlessly it moved across the sky, and covered the sun. The astronomers stood by their instruments in silence with their eyes upon their watches, until the stoic British leader announced: "The eclipse is over; we have missed it;" and the technicians, fellow-countrymen of Einstein, sat down and wept.

Astronomers are not unduly perturbed by the failure to adduce, at the time of a solar eclipse, more evidence for relativity. The question of that little star, which we call the sun, distant from us a mere eight light-minutes, is a trivial matter. It would be parochial to centre all our interest in it. There are vaster fields in which there is evidence that relativity is allied with nature.

General relativity leads to the conclusion that spectral lines due to the emission of energy in an intense gravitational field should be displaced towards the red end of the spectrum. As lines are also displaced by the radial velocity of a star, it would not be possible to measure the Einstein displacement, or relativity red-shift, if there were not stars of enormous density, whose motion, in the line of sight, was otherwise known. Providentially there are stars of enormous density, known as White Dwarfs. Some of these White Dwarfs travel with companions, who are not White Dwarfs. The best known White Dwarf is that which travels with the bright star Sirius. As early as 1923, Eddington suggested that the spectrum of this White Dwarf should be investigated. Adams of Mount Wilson did so, and was able to announce that it showed a red shift which the spectrum of Sirius did not. Since then the spectra of many White Dwarfs in binary system have been studied. Their spectra show relativity red shifts, which are functions of their surface gravity, and in good accord with Einstein's theory.

The contribution of Einstein which has stirred up most continuous speculation in astronomical circles is his model of the universe, with its so-called "curved space." To apply his general theory of relativity to the general structure of the universe, Einstein had to make assumptions. He assumed that the universe consisted of galazies, that the galaxies already observed were typical, and that their distribution was uniform. He was well aware of the fact that he had made assumptions. He could afford to sit back while controversy raged. He had started discussions on an elevated level. He had raised the minds of many men, and set many minds in motion.

To the minds of astronomers, a Euclidean space with ever-receding galaxies is unsatisfactory. But, on the other hand, the uniform distribution of individual galaxies seems to be contrary to fact. Fortunately, there has come to light in recent years a fact that helps dissipate the dilemna. It is the fact that galaxies can be grouped in "clusters," which are uniformly distributed. Not only that, but the possibility of a crucial test has emerged. If it is the large-scale groups which are uniformly distributed, the smaller ones, according to the principles of General Relativity, should deviate from uniformity in their distribution. To find out if they do, counts of very faint galaxies must be made, and their velocity of recession determined. The work is going on apace, but may need a better instrument than a 200-in telescope to complete it. There is need to detect not only deviation from uniformity, but the nature of deviation. The nature of the deviation will indicate whether the galaxies behave as though in a space that is hyperbolic and infinite, or as though in one that is spherical and finite.

Modern theories as to the structure of the universe began with the publication of Einstein's paper: "Cosmological Considerations in General Relativity." When Einstein wrote this paper, in 1917, the universe, which he knew, was a million light years in extent. Urged by his considerations, astronomers have pushed the frontiers of their universe to 2,000 million light years, and talk of 100 million galaxies, with an average mass for each, of 100 thousand million times that of our sun. It is a universe of enormous masses in rapid motion, in which relativity can be tested on the grand scale. It is a universe of which the shape is conceived as dependent on the masses and the motions of the galaxies. It is a universe which has grown under the influence of Einstein.

Meanwhile, Albert Einstein grew. He started his career with child-like wondering, wondering how mathematics could be reconciled with the motions of the stars. And he ended in rapturous amazement at the harmony of the laws of nature.

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