Age of the Universe:

Infinite

COSMIC TIMES

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Size of the Universe:

300,000 Light Years

SUN'S GRAVITY BENDS STARLIGHT

Einstein's Theory Triumphs

"One of the greatest—perhaps the greatest—of achievements in the history of human thought" was what Sir Joseph Thomson, President of the Royal Society of London, called Dr. Albert Einstein's prediction, which was apparently verified during the total eclipse of the Sun May 29 last.

Sir Joseph made his pronouncement during a discussion of the results from observations of the solar eclipse at a joint meeting of the Royal Society and the Royal Astronomical Society in London on Thursday evening, November 6, before a large attendance of astronomers and physicists. The excitement in the air was almost palpable as it seemed generally accepted that the observations were decisive in verifying the prediction of Dr. Einstein, Professor of Physics at the University of Berlin and Director of the Kaiser Wilhelm Physical Institute.

The prediction

According to the gravitational principles enunciated by Sir Isaac Newton in his classic work *Optics* some two centuries ago, a ray of light from a distant star just grazing across the edge of a massive object should be bent by an amount that depends on the object's mass and thus its gravitational field. Newton thought of gravity as a force that pulls things toward an object: the bigger the object, the stronger the pull.

The most massive object in the vicinity of the Earth is the Sun. So according to Newtonian principles, a light ray from a distant star grazing the edge of the Sun should be attracted or bent by the Sun's gravity by an amount equal to 0.87 seconds of arc. To be sure, that angle is very small, about equivalent to a human hair at 75 feet; but it is actually measurable on today's astronomical photographic plates if adequate care is taken.

Dr. Einstein's general theory of relativity, however, conceives of gravitation as indistinguishable from inertia. The "force" of gravity one feels pressing one down into a chair is the same as the "force" one feels when pulled forward in an automobile when the driver brakes.

According to Dr. Einstein, gravity, like inertia, doesn't pull. Instead, a mass warps or curves space and time surrounding the object. The amount of curvature is proportional to the amount of mass. The curvature of space then curves the paths taken by rays of light.

Dr. Einstein's theory, which is highly mathematical, predicts that the curvature of space around the Sun should bend starlight by twice as much as Newton's theory predicts: 1.75 seconds of arc. Thus, Dr. Einstein predicts that a ray of light from a distant star, grazing the edge of the Sun on its way to the Earth, would suffer twice the deflection predicted by Newtonian principles.

The amount by which starlight is deflected by the Sun is thus regarded by astronomers and physicists as one of the crucial tests in determining the validity of the Dr. Einstein's Theory of Relativity versus Newtonian physics.

May's solar eclipse

Dr. Einstein made his prediction in a paper published in 1916, in the middle of the late Great War between England and Germany. But a neutral Dutch astronomer smuggled a copy of Dr. Einstein's published paper through war-torn Europe to England. There it was read by Professor Arthur Stanley Eddington, Plumian Professor of Astronomy and Experimental Philosophy at Cambridge University—the same chair and university where Newton pioneered his great theory of gravity.

Although astronomers who had read earlier unpublished drafts of Einstein's paper tried to test his prediction during the total solar eclipses of 1912 and 1914, they were foiled by clouds and by the start of the Great War. But a study of the conditions of the 1919 solar eclipse showed that the Sun would be very favourably placed amongst a group of bright stars at that time. Moreover, the Sun's light would be totally blocked by the Moon for over five minutes (see "Why a Total Solar Eclipse?"), allowing both

Herr Einstein in Berlin

the Sun and the stars to be photographed at the same time.

Prof. Eddington himself decided to lead an expedition to the island of Principe, in the Gulf of Guinea close to the coast of West Africa, near the end of the path of totality (see map). He also convinced the Astronomer Royal—Sir Frank Dyson, Director of the Royal Observatory, Greenwich—to send another expedition elsewhere, to minimize the chances of clouds interfering with the observations. Led by Dr. Andrew Crommelin from the Royal Observatory, it set up instruments at Sobral in northern Brazil, near the beginning of the path of totality.

At each of these places, if the weather were propitious on the day of the eclipse, it would be possible to take during totality a set of photographs of the obscured Sun along with a number of bright stars which happened to be in the vicinity.

Results discussed

At the joint meeting, Sir Frank described the work of the two expeditions. Their purpose was to ascertain whether the light from these stars as it passed by the Sun came as directly toward the Earth as if the Sun were not there, or if there was a deflection due to the Sun's presence. "The effect of the predicted gravitational bending of the ray of light is to throw the apparent position of the star away from the Sun," said Sir Frank. If a deflection were to occur, measurements would be made of how far the stars would appear on the photographic plates from their theoretical positions.

The Royal Observatory party arrived in Brazil in ample time to prepare for the eclipse and photograph stellar fields. The day of the eclipse opened cloudy but cleared later, and the observations were carried out with almost complete success. The observers stayed on in Brazil until July to secure the star field in the night sky at the altitude of the eclipse epoch and under identical instrumental conditions. The photographic plates were measured at Greenwich immediately after the observers' return, each plate being measured twice over.

The Cambridge University party arrived on Principe on April 23. The island is about 10 miles long by 4 miles wide. "We soon realised that the prospects of a clear sky at the end of May were not very good," recounted Prof. Eddington. The sky was completely cloudy at the beginning of the eclipse, but about half an hour before totality they caught glimpses of the Sun's crescent through the clouds. They took photographs exactly as arranged, but out of the 16 plates taken, only two showed as many as five stars each. Prof. Eddington was also unable to stay several more months to take check-photographs of the star field.

Sir Frank explained in detail the apparatus both expeditions had employed, the way the photographic plates were measured back at the Greenwich Observatory, the corrections that had to be made for various disturbing factors, and the methods by which comparison between the theoretical and observed positions had been made. He convinced the meeting that the results were definite and conclusive, and that deflection did take place. He also asserted that the measurements showed that the extent of the deflection was in close accord with the theoretical amount predicted by Dr. Einstein, as opposed to half of that amount, the amount that would follow if the principles of Newton were correct.

"After a careful study of the plates I am prepared to say that there can be no doubt that they confirm Einstein's prediction," Sir Frank declared. "A very definite result has been obtained that light is deflected in accordance with Einstein's law of gravitation."

"For the full effect that has been obtained, we must assume that gravity obeys the new law proposed by Einstein," added Prof. Eddington. "This is one of the most crucial tests between Newton's law and the proposed new law."

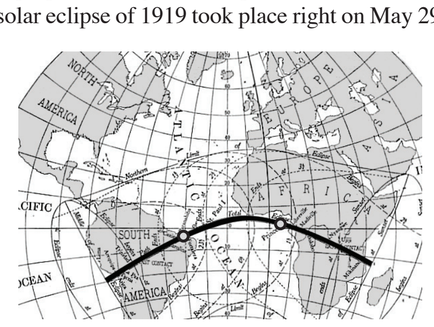
WHY A TOTAL SOLAR ECLIPSE?

According to predictions by both Sir Isaac Newton and Dr. Albert Einstein, a ray of light from a star nearly behind the Sun (as seen from Earth) will be deflected—bent toward the Sun—as it passes by the limb (edge) of the Sun. Such a deflection would make the star look slightly farther away from the edge of the Sun than it really is.

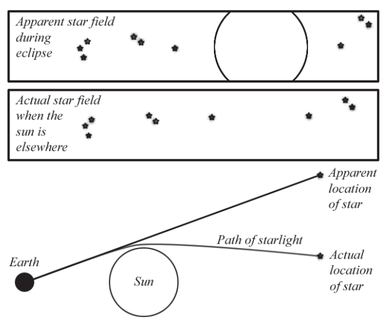
Dr. Einstein's theory of relativity, however, predicts that the amount of the deflection should be double that predicted by Newtonian mechanics. The maximum shift, for a star whose ray of light just grazes the limb of the Sun, would be 1.75 seconds of arc, twice the amount Newton predicted (0.87 arcsecond). The apparent positions of stars closer to the Sun's limb would be shifted more than those of stars farther away.

The more stars around the Sun during a solar eclipse, and the more photographs astronomers can take, then the more accurately the differences between Dr. Einstein's predictions and Sir Isaac's could be measured. Each year on May 29, as the Earth revolves around the Sun, the Sun appears to pass in front of the Hyades in Taurus, a cluster of stars so bright they are clearly visible to the naked eye in winter.

The only time stars are visible in the sky along with the Sun is during a total solar eclipse, when the Moon blocks most of the Sun's blinding light. And by unusual good fortune, the total solar eclipse of 1919 took place right on May 29.



The path of totality for the eclipse of May 29, 1919 spanned the Atlantic (dark line); the eclipse was very long — nearly seven minutes at its maximum duration. The two dots indicate the positions of the expeditions led by Dr. Crommelin for the Royal Greenwich Observatory (left) and Prof. Eddington for Cambridge University (right).



MT. WILSON ASTRONOMER ESTIMATES MILKY WAY TEN TIMES BIGGER THAN THOUGHT

But Disputes Suggestions that Spiral Nebulae are Other "Island Universes"

The Milky Way is a "discoidal" (disc-shaped) galaxy of stars 10 times bigger than astronomers had previously conceived, according to Mt. Wilson astronomer, Dr. Harlow Shapley. Moreover, he claims, the Sun exists nearer to its edge than to its center. But he disputes the hypotheses of other astronomers that scores of spiral nebulae seen in the starry heavens are other galaxies, or "island universes", that resemble the Milky Way.

In his tour-de-force series of papers throughout 1918 and 1919, the prolific Dr. Shapley examines other recent astronomical work in astonishing detail, as well as presenting the results of his own astronomical photography using the 60-inch reflector of the Mount Wilson Observatory in southern California. His particular subject of interest is globular star clusters—nearly spherical clusters of hundreds of stars that have long puzzled astronomers because of their peculiar positions in only certain parts of the sky. When Dr. Shapley began his study in 1914, 69 globular clusters were known; by the time he completed his work in 1918, he had added another 17 to the list.

In addition to pinpointing the exact position of each globular cluster in the sky, he also spread out their light into spectra to determine their motions, specifically whether they were approaching the Sun or receding from it. From these data, Dr. Shapley sought to calculate the gravitational forces on the clusters, to learn whether they were revolving around a common center, and if so, the location of that center. He also sought to determine the distances of the globular clusters from the Sun using the novel method of Cepheid variables pioneered by Miss Henrietta Leavitt of Harvard Observatory. He also looked at irregularly-shaped clusters of stars, the so-called "open clusters", as well as other individual stars and types of objects.

After four years of diligent study, often assisted by his wife Martha B. Shapley, Dr. Shapley has published a number of astonishing conclusions.

Dr. Shapley has concluded that "our galactic universe appears as a single, enormous, all-comprehending unit, the extent and form of which seem to be indicated through the dimensions of the widely extended assemblage of globular clusters." The center of our discoidal sidereal system "is distant from the Earth some twenty thousand parsecs"—more than 60,000 light-years—"in the direction of the constellation Sagittarius," Dr. Shapley continued.

His conclusions fly in the face of generally accepted astronomical wisdom. "Until the last year or so, most students of stellar problems believed rather vaguely that the Sun was not far from the center of the universe, and that the radius of the galactic system was of the order of 1,000 parsecs," he said (1,000 parsecs is more than 3,000 light-years). Some astronomers thought the galactic system might be as large as 10,000 to 20,000 light-years across. But according to Dr. Shapley, the positions of globular clusters in the arrangement of sidereal objects suggest "that the actual diameter of the galactic system is of the order of 100,000 parsecs", This is a staggering distance, larger than 300,000 light-years across, more than 10 times larger than any other astronomer had hypothesized.

"This newer conception greatly embarrasses the interpretation of spirals as stellar organizations of a size comparable to that of the Galaxy," Dr. Shapley said, because such a size would imply that the spirals were inconceivable distances away in space. "For example," he pointed out, "if any bright spiral of 10 minutes of arc in angular measure has an actual diameter directly comparable with that of the galactic system, its distance must be greater than a hundred million light-years.". Similarly, the average proper motions suggested by the careful observational measurements of several astronomers "would indicate appalling velocities in space."

In short, Dr. Shapley concludes, many observations "all seem definitely to oppose the "island universe" hypothesis of the spiral nebulae."

EXPANDING OR CONTRACTING?

Einstein's Theory Predicts Universe Must be Doing One or the Other

Einstein Says Neither

In 1917, Albert Einstein and the Dutch astronomer Willem de Sitter showed that Einstein's general theory of relativity could describe a highly simplified universe.

But when it was applied to the real universe full of stars, there was a difficulty.

Dr. Einstein's model predicted that either all the stars would be expanding or moving apart from one another, as if from a gigantic explosion. Or they had to be contracting, as if they were all collapsing upon one another.

But Dr. Einstein, a devotee of the book *Ethics* by Dutch philosopher Spinoza, quoted from memory Corollary 2 of Proposition 20: "It follows that God is immutable or, which is the same thing, all His attributes are immutable." Dr. Einstein was troubled by the concept of a universe that was not immutable or unchangeable.

"We can add, on the left side of the field equation—for the time being— an unknown universal constant," Dr. Einstein said, explaining the quantity he designates by the Greek letter lambda, and calls the "cosmological constant." He explains: "Not much harm is done thereby… the proposed new universal constant determines the average density of the universe that can remain in equilibrium."

According to Dr. Einstein's beautiful immutable universe, the presumably spherical universe would be neither expanding nor contracting.

In Their Own Words

Periods of 25 Variable Stars in the Small Magellanic Cloud - *Miss Henrietta Leavitt*

A remarkable relation between the brightness of the studied variables and the length of their periods has been noticed. There is a simple relation between the brightness of the variables and their periods: the brighter variables have the longer periods.

Spectroscopic Observations of Spiral Nebulae - *V. M. Slipher*

The average radial velocity of spiral nebulae is +400 km/sec. Radial velocity is the speed along an observer's line of sight; positive radial velocity means an object is receding, while negative radial velocity means an object is approaching. As well may be inferred, the average velocity of the spirals is about 25 times the average stellar velocity.

The Relation of the System of Stars to the Spiral Nebulae - *G. F. Paddock*

Endeavors have recently been made to present a comparative list of average radial or line-of-sight velocities of the several different kinds of objects in the sky, and to discuss the relation of the spiral nebulae to other objects. The average radial velocities of all except the spirals range in increasing magnitude from zero to fifty kilometers per second. But a considerable jump is noticed from the fifty kilometers to 400 kilometers for the average of the spirals. This suggests the question: Are the spirals dissociated from the star system? The average velocity is decisively positive, which means that they are receding not only from the observer or star system but from one another.