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Early Edition

Age of the Universe: *Infinite*

Size of the Universe: *300,000 Light Years*

SUN'S GRAVITY BENDS STARLIGHT— EINSTEIN'S THEORY **Triumphs**

Sir Joseph Thompson said, "One of the greatest...of achievements in the history of human thought" was a new prediction Dr. Albert Einstein made. This prediction was proven true during the total eclipse of the Sun on May 29, 1919. His prediction was that light bends around large, massive objects like the Sun. However, what makes the prediction different from other predictions is that Einstein said the light bends around objects twice as much as what Sir Isaac Newton said it should two hundred years ago.

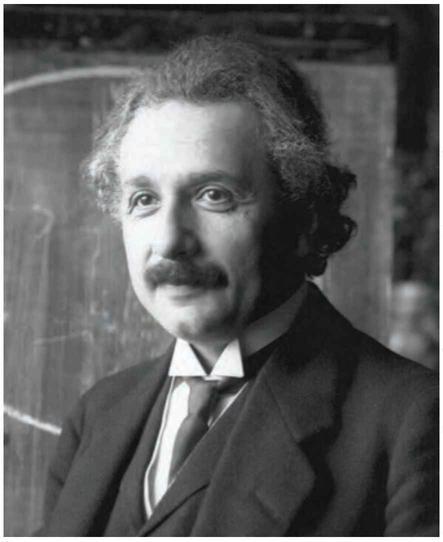

IMAGE CREDIT: FERDINAND SCHMUTZER, VIA WIKIMEDIA COMMONS

Albert Einstein

Sir Joseph made this announcement at a meeting of both the Royal Society and the Royal Astronomical Society in London on November 6, 1919. A large number of astronomers and physicists were at the meeting. Everyone was very excited, and they all agreed that observations made during the eclipse proved Dr. Einstein's prediction to be correct. Dr. Albert Einstein is a Professor of Physics at the University of Berlin and also the Director of Kaiser Wilhelm Physical Institute in Germany.

The Prediction

Two hundred years ago, Sir Isaac Newton explained how gravity works in his book, *Optics*. Newton said if a ray of light from a distant star passes by the edge of a large or massive object, then the ray of light should be bent by the gravity of that object. Newton thought gravity was a force that pulled things toward an object. The more mass an object has, the stronger its pull would be. The object with the largest mass near the Earth is the Sun. Based on Newton's ideas, light from a distant star shining just at the edge of the Sun would be bent a very small amount by the Sun's gravity. Einstein said that the change in the light's position could be measured by taking photographs of the star when its light is passing close to the Sun, then photographed again later in the year when the distant star's light is not passing close to the Sun. These photographs must be taken very carefully and very precisely.

Dr. Einstein's General Theory of Relativity explains that "gravity" and "inertia" are the same. The "force" of gravity pressing you down on a chair is the same force you feel when the automobile you are riding in quickly slows down, and you keep moving forward. Dr. Einstein says gravity, like inertia, does not pull an object (this is different than what Newton said). Instead, anything in space that has mass will warp and curve both space and time around the object. Dr. Einstein also says that the amount of curvature is directly related to the mass of the object. The more mass an object has, the stronger the curve around the object. This curvature of space is what curves the path of light coming from a distant star.
As stated earlier, Dr. Einstein's highly mathematical prediction was that the Sun's gravity should

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bend starlight twice as much as Newton's earlier calculations said it should.

May's Solar Eclipse

Dr. Einstein published his prediction in Germany four years ago, in 1915, during the Great War between England and Germany. During that time, a Dutch astronomer smuggled a copy of Dr. Einstein's research paper out of Europe and into England. Once the paper was safe in England, Arthur Stanley Eddington, the Plumarian professor of Astronomy and Experimental Philosophy at Cambridge University, read Einstein's prediction. Eddington's position at Cambridge University is the same one Newton held when he came up with his Theory of Gravity.

Other astronomers had read earlier versions of Einstein's research and already tried to test his predictions during total solar eclipses in 1912 and 1914. However, they were not successful in their attempts due to cloudy weather in 1912 and the start of the Great War in 1914. When astronomers studied the conditions of the upcoming 1919 eclipse, it seemed that the Sun would be in a good position, right in the middle of a group of bright stars. Also, the Sun's light would be totally blocked by the Moon for more than five minutes, which would give photographers enough time to take pictures of the Sun and the stars at the same time.

Professor Eddington decided to lead a group to the island of Principe, near the coast of Africa, where the eclipse could be photographed. He also convinced Sir Frank Dyson, the Director of the Royal Observatory to send another group to a different location. This would increase their chances of success, reducing the chance that clouds would block the

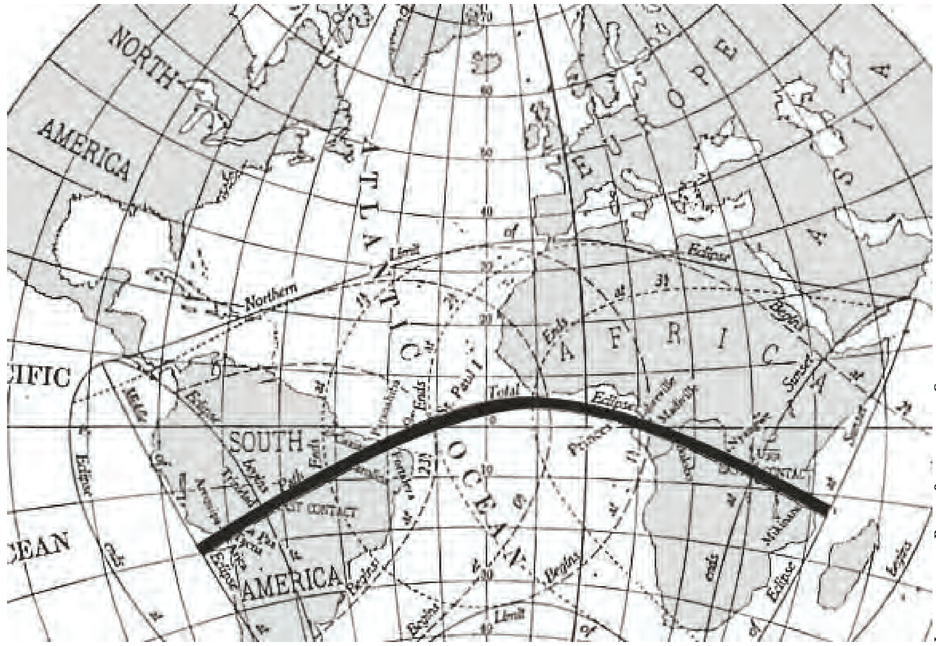

IMAGE CREDIT: ROYAL OBSERVATORY GREENWICH

Map showing the path of the moon's shadow during May's eclipse, stretching from South America to Africa.

eclipse. Sir Frank Dyson agreed, and sent Dr. Andrew Crommelin and his group to northern Brazil to view and photograph the eclipse.

As long as the weather was clear at one of the two places on the day of the eclipse, it would be possible to take pictures. They needed to take pictures of the totally eclipsed Sun along with some of the bright stars that appeared close to the Sun.

Results Discussed

Later, at the meeting in London in November, Sir Frank Dyson described the work of the two groups. The reason for the meeting was to decide if Einstein's prediction was correct. They wanted to see if the light coming from the stars was bent (deflected) by the Sun as the stars' light passed by the Sun. Sir Frank said that if the Sun did bend the light, the stars would seem farther away from the Sun than they actually were. The group also had to figure out how far out of position the stars would be on the photographic plates.

The group from the Royal Observatory, led by Dr. Crommelin, arrived in Brazil in June of 1919 in time to get ready for the eclipse and to photograph groups of stars in the sky. Early on the day of the eclipse, they were nervous because it was cloudy. But later on the clouds cleared and the group's observations were made with almost complete success. The group stayed in Brazil until July so they could also take pictures of the same group of stars during a time when their light did not pass by the Sun. By July, the Sun had moved away from this group of stars. Once they took the second set of photographs, they returned to Greenwich, England, where each photographic plate was carefully measured two times each.

The other group from Cambridge University arrived on the island of Principe on April 23, 1919. But there were problems on the island with clouds. "We soon realized that the prospects of a clear sky at the end of May were not very good," said Professor Eddington. At the beginning of the eclipse,

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the sky was completely cloudy. About half an hour before the complete eclipse, or "totality," the group was able to catch glimpses of the Sun through the clouds. They took photographs just as they had planned, but only two out of the 16 photographic plates showed enough stars to measure. Unlike the group from the Royal Observatory who stayed until July to take a second set of photographs, the Cambridge University group was not able to stay on Principe Island to take a second set of photographs to compare the first photos to.

During the meeting, Sir Frank explained how they made observations, the equipment they used, and how the photographic plates were measured back at the Greenwich Observatory. He also talked about how the star positions during the eclipse compared to their positions two months later, when their light did not pass by the Sun. The audience at the meeting was convinced that the results of the experiment were definite and did show that the Sun's gravity bent the stars' light. He also said that the amount of bending, or deflection, of the light was very close to what Dr. Einstein predicted, and almost twice as much as what Newton's calculations predicted it would be.

The results proved Einstein's predictions. "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. He also said that the results were definite that the bending of light matched Dr. Einstein's law of gravitation. Professor Eddington added that, "we must assume that gravity obeys the new law proposed by Einstein." ♦

Why a Total Solar Eclipse?

Both Sir Isaac Newton and Dr. Albert Einstein predicted that a ray of light from a star passing very close to the edge of the Sun (as seen from Earth) will be bent, or deflected. A bend in the star's light would make the star look slightly farther away from the edge of the Sun than it really is.

Dr. Einstein's Theory of Relativity predicts that the amount of deflection should be twice as much as the amount of deflection Newton predicted.

The astromers would get better accuracy of their measurements the more stars there were near the Sun in the sky during the eclipse. They would also get better results the more pictures they could take during the eclipse. This would give them better accuracy when comparing Dr. Einstein's predictions to Newton's predictions. Each year, on May 29th, as the Earth revolves around the Sun, the Sun appears to pass in front of a cluster of stars in the constellation Taurus. The cluster of stars, called Hyades, is so bright that they are clearly visible without a telescope during the winter in the night sky.

The only way this star cluster could be viewed on May 29th would be if the Sun was totally eclipsed and its light was blocked. On May 29, 1919, a total eclipse happened, which allowed Dr. Einstein's prediction to be accurately tested.♦

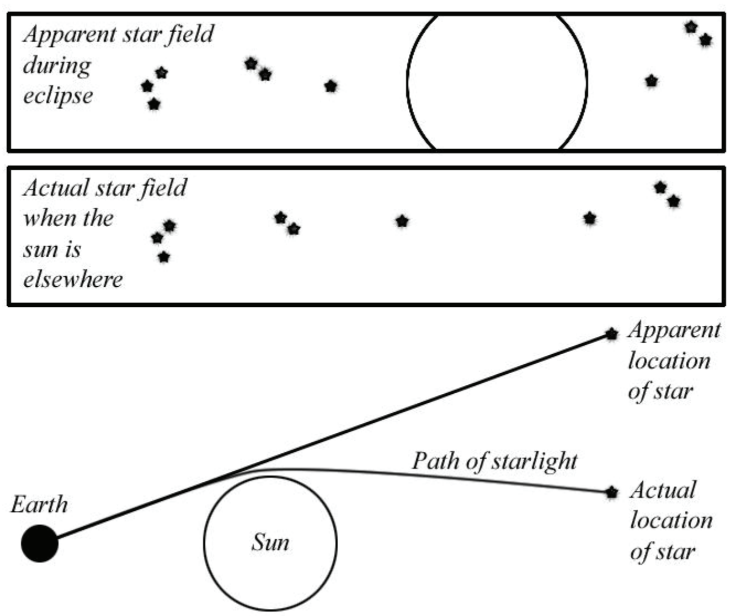

IMAGE CREDIT: NASA'S COSMIC TIMES

Top: The apparent positions of the stars during the eclipse when their light is bent around the Sun. Middle: The positions of the stars when their light is not bent around the Sun. Bottom: The actual path of the light as is bends near the Sun and reaches Earth, and the apparent position of that star as a result of its light bending around the Sun.

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 disc-shaped, or "discoidal," galaxy of stars ten times bigger than astronomers once thought, says Mt. Wilson astronomer Dr. Harlow Shapley. He also says the Sun is closer to the edge of the disc than the center. However, he disagrees with the hypotheses of other astronomers who claim that dozens of other spiral nebulae seen in the skies are other galaxies, or "island universes" that are similar to the Milky Way.

Dr. Shapley surprised astronomers last year and this year when he published a total of 26 scientific papers in several astronomical journals. In these papers, Dr. Shapley studied other recent astronomical research in amazing detail. He also published the results of his own astronomical photography using the 60-inch reflector telescope of the Mount Wilson Observatory in southern California. His favorite objects to study were globular star clusters, which are almost spherical groups of hundreds of stars. These clusters have puzzled astronomers for years because they are located in only certain places in the sky. In Dr. Shapley's study, he discovered 17 new globular star clusters.

Along with locating the exact position of each globular cluster in the sky, he also analyzed their light using a spectroscope to find out if they were moving towards the Sun or away from it. From these studies, he calculated the gravitational forces acting on these clusters. The gravitational forces would tell him if the clusters were revolving around a common center and where that common center was located. He also calculated the distances of the globular clusters from the Sun using Cepheid variable stars. Using Cepheid variable stars is a new method of measuring distance that was discovered by Miss Henrietta Leavitt of Harvard Observatory.

After years of careful research and study, often with the help of his wife Martha B. Shapley, Dr. Shapley published many surprising conclusions.

Dr. Shapley found that our galactic universe is a single, enormous unit, the size of which is shown by the widely scattered globular clusters. He also said that the center of our disc-shaped galaxy is more than 60,000 light years away in the direction of the constellation Sagittarius.

Dr. Shapley's findings are opposite from generally accepted astronomical findings. Until the last year or so most students of astronomy believed the Sun was near the center of the galaxy. They also believed that the radius of the galaxy was around 3,000 light years. Some astronomers thought the galaxy system might be as large as 10,000 to 20,000 light years across. But according to Dr. Shapley, the locations of the globular clusters show that the actual diameter of the galactic system is about 300,000 light years across. This is ten times larger than any other astronomer hypothesized.

Image credit: AIP Emilio Segre Visual Archives, Shapley Collection

Harlow Shapley

The new size of the galaxy made Dr. Shapley think that the other spiral nebulae could not possibly be other galaxies. If they were galaxies as large as the Milky Way, then it would mean that those spirals were unimaginable distances away in space. "For example," Dr. Shapley said, "if any bright spiral of 10 minute of arc in angular measure [0.17 degrees] has an actual diameter similar to the Milky Way, its distance must be greater than 100 million light years," and its measured speed would be very large.

Dr. Shapley concludes that the many observations all seem to be against 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, Dr. Albert Einstein and Dutch astronomer Willem de Sitter showed that Einstein's General Theory of Relativity could describe a highly simplified universe.

But, when the Theory of Relativity was used to look at the real universe and not just a model of the universe, there was a problem.

Dr. Einstein's model predicted that either space would be expanding, causing all of the stars to move apart from one another (as if from a huge explosion), or space would be contracting, making all of the stars move closer to one another. If space was contracting, or getting closer, this would finally cause all stars to collapse on one another.

But Dr. Einstein believed strongly in the book *Ethics*, by the Dutch philosopher Spinoza. A section from the book says, "It follows that God is immutable (not capable of being changed) or, which is the same thing, all His attributes are immutable." Dr. Einstein was troubled by the idea of a universe that could change.

Because Dr. Einstein did not feel comfortable with a changing universe, he allowed one side (the left side) of his "field equation" to be changed. He added a new universal constant, which determines the average density of the universe. This quantity, or amount, which is shown by the Greek letter lambda, is called the "cosmological constant."

According to Dr. Einstein's unchangeable universe, the universe, assumed to be shaped as a sphere, should not be expanding or contracting.♦

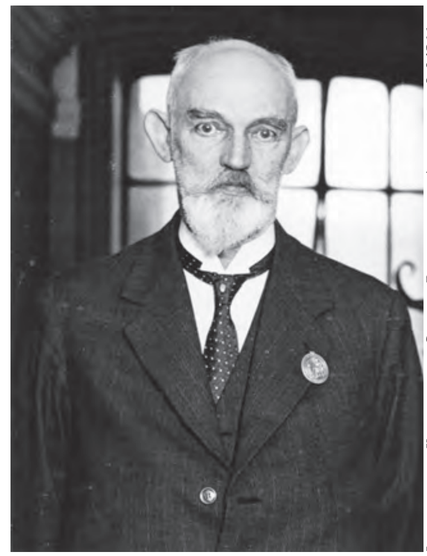

Image credit: University of Chicago Photographic Archive, apf6-04311, Special Collections Research Center, University of Chicago Library.

Willem de Sitter

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.♦