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Home Edition

Age of the Universe: Infinite

Size of the Universe: 300,000 Light Years

SUN'S GRAVITY BENDS STARLIGHT
Einstein's Theory **Triumphs**

According to Sir Joseph Thompson, "the greatest achievement in the history of human thought" was a prediction made by Dr. Albert Einstein. Dr. Einstein's prediction was proven true during the total eclipse of the Sun on May 29, 1919.

Herr Einstein in Berlin

Sir Joseph made this pronouncement at a joint meeting of the Royal Society and the Royal Astronomical Society in London on November 6, 1919. In the audience were a large number of astronomers and physicists. The excitement in the meeting was quite obvious, and everyone agreed that the observations made during the eclipse did prove Dr. Einstein's prediction. Dr. Einstein is a Professor of Physics at the University of Berlin and Director of the Kaiser Wilhelm Physical Institute.

The Prediction

Two centuries ago Sir Isaac Newton explained how gravity works in his book *Optics*. According to Newton, if a ray of light from a distant star passes by the edge of a massive object, the ray should be bent by the gravity of that object. The most massive object near Earth is the Sun. According to Newton's principles, a light ray from a distant star would be bent only a very small amount by the Sun's gravity, but that change in position can be measured by taking photographs of the star when its light is passing close to the Sun and later in the year when its light is not passing close to the Sun. The photographs must be taken with great care and precision.

Newton thought of gravity as a force that pulls things toward an object; the more massive the object, the stronger the pull.

In his General Theory of Relativity, Dr. Einstein explains that gravity and inertia are the same. The "force" of gravity pressing you down in a chair is the same force you feel when the automobile you are in quickly slows down, and you continue to move forward. Dr. Einstein says gravity, like inertia, doesn't pull. Instead, anything in space that has mass will warp or curve space and time around it. Think of a pillow as space. If you place a heavy (massive) object on the pillow, the pillow will curve around the object. Dr. Einstein says the amount of the curvature

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relates directly to the mass of the object. This curvature of space is what curves the path of the ray of light from a distant star.

Dr. Einstein's theory, which is highly mathematical, predicts that the curvature of space caused by the Sun's mass should bend starlight twice as much as Newton's principles predicted it should.

The amount by which starlight is bent by the Sun's mass is considered by astronomers and physicists to be the most important test of Dr. Einstein's Theory of Relativity.

May's Solar Eclipse

Dr. Einstein published his prediction in Germany in 1915 during the Great War between England and Germany. A Dutch astronomer smuggled a copy of Dr. Einstein's paper out of war-torn Europe into England where it was read by Arthur Stanley Eddington, Plumian Professor of Astronomy and Experimental Philosophy at Cambridge University. This was the same position Newton held when he developed his theory of gravity.

Other astronomers had read earlier versions of Einstein's paper and tried to test his prediction during total solar eclipses in 1912 and 1914. They were not successful in their attempts due to cloudy weather and the start of the Great War. When astronomers studied the conditions of the 1919 eclipse, it appeared the Sun would be well placed in a group of bright stars. Also, the Sun's light would be totally blocked by the Moon for over five minutes which would allow enough time for the Sun and the stars to be photographed at the same time.

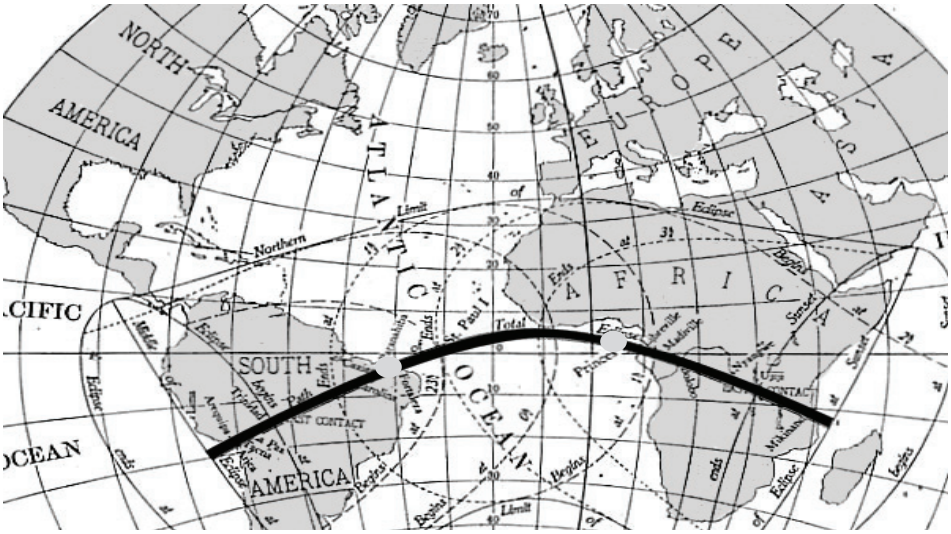
Professor Eddington decided to lead a group to the island of Principe near the western coast of Africa where the eclipse could be photographed. He also convinced Sir Frank Dyson, Director of the Royal Observatory, to send another group to a different location to reduce the chance that clouds might block the eclipse at both locations and prevent photographing the Sun. This other group, led by Dr. Andrew Crommelin from the Royal Observatory, traveled to northern Brazil to view the eclipse.

If the weather was clear at either of these locations on the day of the eclipse, it would be possible to take a set of photographs of the totally eclipsed Sun along with a number of bright stars that appeared close to the Sun.

Results Discussed

At the joint meeting, Sir Frank described the work of these two groups. The purpose of the meeting was to decide if the light coming from these stars was bent (deflected) by the Sun as it passed by. According to Sir Frank, if the Sun did affect the light, it would make the stars appear farther from the Sun than they actually were. The group would also need to determine how far out of position the stars would appear on the photographic plates.

The Royal Observatory party arrived in Brazil in time to prepare for the eclipse and to photograph other star fields. It was cloudy early on the day of the eclipse but cleared later, and the observations were carried out with almost complete success. The observers remained in Brazil until July so they could photograph the same set of stars during the night sky, when their light did not pass by the Sun. Between May and July the Earth had moved in its orbit, which changed the position of these stars compared to the positions of the Earth and Sun. Waiting for the Earth to move in its orbit positioned these stars in the night sky once again. Once this second set of photographs was obtained, the observers immediately returned to Greenwich where each plate was



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).

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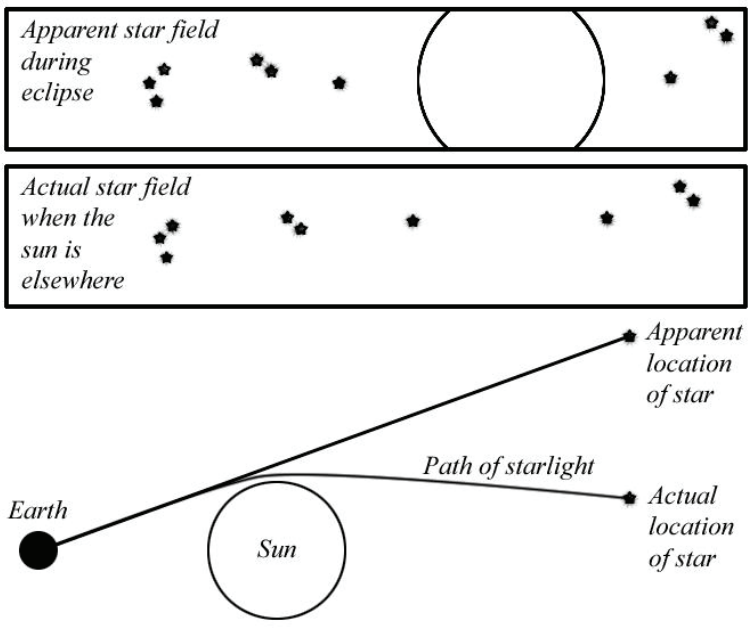
Why a **TOTAL** Solar Eclipse?

According to predictions by both Sir Isaac Newton and Dr. Albert Einstein, a ray of light from a star very close to the Sun (as seen from Earth) will be bent (deflected) as it passes by the 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 predicts that the amount of the deflection should be twice as great as the deflection Newton predicted.

Astronomers would get the best results the more stars around the Sun during a solar eclipse and the more photographs they took. This would provide greater accuracy in comparing Dr. Einstein's predictions to Newton's. Each year on May 29 as the Earth revolves around the Sun, the Sun appears to pass in front of a cluster of stars in the constellation of Taurus. This cluster of stars, called Hyades, is so bright that it is clearly visible in the night sky even without a telescope months later during the winter.

The only way this star cluster could be viewed on May 29 would be if the Sun were totally eclipsed and its light was blocked. On May 29, 1919 such an eclipse did occur, and this bit of good fortune allowed Dr. Einstein's prediction to be accurately tested. ♦



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 it bends near the Sun and reaches Earth, and the apparent position of that star as a result of its light bending around the Sun.

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carefully measured two times.

The Cambridge University party arrived on Principe on April 23. "We soon realised that the prospects of a clear sky at the end of May were not very good," recalled 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 through the clouds. They took photographs exactly as arranged, but only two out of 16 plates taken showed enough stars to measure. Prof. Eddington was also not able to stay on Principe for several more months to take a second set of photographs for comparison.

Sir Frank explained in detail how the observations were made, the equipment used, and the way the photographic plates were measured back at the Greenwich Observatory. He also discussed how the observed star positions during the eclipse were compared to their positions two months later when their light did not pass near the Sun. He convinced the audience at the joint meeting that the results of the experiment were definite and conclusive, and that the Sun's gravity did deflect the light. He also stated that the amount of deflection was very close to what Dr. Einstein predicted and almost twice as much as Newton's principles predicted.

"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." Prof. Eddington added, "we must assume that gravity obeys the new law proposed by Einstein." ♦

10 Mt. Wilson Astronomer Estimates Milky Way **10 times Bigger** than Thought

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

The Milky Way is a "discoidal" (disk-shaped) galaxy of stars 10 times bigger than astronomers have previously thought, according to Mt. Wilson astronomer Dr. Harlow Shapley. He also claims the Sun is located closer to the edge of the disk than the center. However, he disagrees with the hypotheses of other astronomers that claim dozens of other spiral nebulae observed in the skies are other galaxies or "island universes" that resemble the Milky Way.

Dr. Shapley astonished astronomers last year and this year when he published a total of 26 scientific papers in several astronomical journals. In these papers, Dr. Shapley examined other recent astronomical work in amazing detail. He also published the results of his own astronomical photography using the 60-inch reflector of the Mount Wilson Observatory in southern California. His favorite subject of study was globular star clusters which are nearly spherical clusters of hundreds of stars. These clusters have puzzled astronomers for years, because they are located in peculiar positions in only certain parts of the sky. In his study, Dr. Shapley discovered 17 new globular star clusters.

In addition to pinpointing the exact position of each globular cluster in the sky, he also analyzed their light using a spectroscope to determine if they were approaching the Sun or moving away from it. From this analysis he calculated the gravitational forces acting on the clusters. He also tried to determine if they were revolving around any common center and where that common center was located. Furthermore, he calculated the distances of the globular clusters from the Sun using Cepheid variable stars. This new method of measuring distance was discovered by Miss Henrietta Leavitt of Harvard Observatory.

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

Dr. Shapley concluded that our galactic universe is a single, enormous unit, the size and form of which is shown by the widely scattered globular clusters. Dr. Shapley added that the center of our discoidal galaxy is more than 60,000 light- years away in the direction of the constellation Sagittarius.

His conclusions contradict generally accepted astronomical wisdom. Until last year, most astronomers believed that the Sun was near the center of our galaxy, and that the radius of the galaxy was about 3000 light years. Some astronomers thought the galactic system might be as large as 10,000 to 20,000 light-years across. According to Dr. Shapley, the positions of globular clusters in the galaxy indicate that the actual diameter of the galactic system is about 300,000 light-years across. This is more than 10 times larger than any other astronomer had hypothesized.

Harlow Shapley

Dr. Shapley said that this newer concept rules out the possibility that other spiral nebulae would be groups of stars of a size comparable to the Milky Way. Such a huge size would mean these spirals were inconceivable distances away in space. As an example, he pointed out that if a bright spiral of 10' (0.17° in angular measure) diameter has an actual diameter comparable to that of the Milky Way, its distance must be greater than 100 million light-years, and its measured rotational speed would exceed the speed of light.

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

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. ♦

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 problem.

Dr. Einstein's model predicted that either space would be expanding or contracting. If space were expanding, then all the stars would move apart from one another, as if from a gigantic explosion. If space were contracting, all the stars would ultimately collapse upon one another.

Dr. Einstein however, believed strongly in the book *Ethics* by the Dutch philosopher Spinoza. A passage from this book states, "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 concept of a universe that could change.

"For now, we can add on the left side of the field equation...an unknown universal constant," Dr. Einstein said. He explained that the quantity he designates by the Greek letter lambda is called the "cosmological constant." He goes on to explain, "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 unchangeable universe, the presumably spherical universe would be neither expanding or contracting. ♦

Frank Schlesinger and Willem de Sitter of Leiden Observatory inspecting the 30- inch mirror of the Loomis telescope, 1931.