



Cosmic Times: '
Astronomy History and Science '
for the Classroom '

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May 28, 2009 '
Project ASTRO Site Leaders '

Cosmic Times '

- * Curriculum support materials that trace our changing understanding of the expanding Universe over the past century
- * Includes:
 - * 6 posters resembling newspaper front pages '
 - * 2 newsletter versions for ' each poster, one at a differentiated reading level '
 - * 4-5 lesson plans for each poster exploring fundamental science, social ' context, and reading skills '



You will receive a DVD containing all of these materials at the end of this workshop

The year is 1919... '

- * What's going on?
- * What's going on in science?
- * What is your view of the Universe?

* Infinite

* Unchanging/static

* Ageless '

Enter Einstein'

✳ What is Gravity?

✳ Gravity is curved space-time.

✳ Gravity bends light.

✳ Amount of deflection differs from Newton's prediction.

➤ 1919 Solar Eclipse verified Einstein's prediction.

Age of the Universe:
Infinite

COSMIC TIMES

1919

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 he felt 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 advanced by Sir Isaac Newton in his classic work which came into common use, rays of light from a distant star just grazing across the edge of a massive object, like the sun, are bent by its gravitational field. Newton thought of gravity as a force that pulls things toward an object, the nearer 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. In fact, this angle is very small, about equivalent to a human hair at 75 feet, but it is actually measured on today's astronomical photographs taken independently in various countries.

Dr. Einstein's general theory of relativity, however, conceived of gravitation as indistinguishable from inertia. The "bend" of gravity was both pressing and stretching a star's rays as they passed, not both when pulled toward an astronomical object as Newton thought.

According to Dr. Einstein, gravity, like its earth-born pull, instead, a mass "wags" or curves space-time around the object. The amount of curvature is proportional to the amount of mass. The curvature of space-time 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 multiplied by astronomers and physicists as one of the crucial tests in determining the validity of 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 last Great War between England and Germany. That a total Dutch astronomer sought a copy of Dr. Einstein's published paper through war-torn Europe in England. There it was used by Professor Arthur Stanley Eddington, Peruvian Professor of Astronomy and Experimental Philosophy at Cambridge University—the same chair and university where Newton presented his great theory of gravity.

Although astronomers who had read earlier unpublished drafts of Einstein's paper tried to buy his prediction during the total solar eclipses of 1912 and 1914, they were foiled by clouds and by the onset of the Great War. It was only the conditions of the 1919 solar eclipse showed that the Sun would be very favorably placed among a group of bright stars at that time. Moreover, the Sun's light would be totally blocked by the Moon for over five minutes even "why a Total Solar Eclipse?", allowing both

act as arranged but east of the 14 plates taken, only two showed in many at five stars each. Prof. Eddington was also unable to stop several men from taking photographs of the eclipse in the field.

Frank explained in detail the apparatus, both exposures had employed, the way the photographic plates were mounted back at the Greenwich Observatory, the corrections that had to be made for various disturbing factors, and the methods by which comparison between the several and corrected plates 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 amount of deflection predicted by his theory was in close accord with the theoretical amount predicted by Dr. Einstein, as opposed to half that amount, the amount that would follow if the prediction 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 theory."

"For the full effect that has been obtained, we must assume that gravity bends the star light 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 is equally behind the Sun as seen from Earth will be deflected—bent toward the Sun—by the Sun's gravity. The amount of deflection would make the star look slightly far from the edge of the Sun than it really is.

Dr. Einstein's theory of relativity, however, predicts that the amount of 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 seconds).

The apparent position of stars close to the Sun is thus shifted twice more than that of stars farther away.

The more stars around the Sun during a solar eclipse, and the more photographic exposures can be taken, the more accurately the differences between Dr. Einstein's prediction 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 stars near stars are visible in the sky along with the Sun in during a total solar eclipse, when the Moon blocks most of the Sun's blinding light. And it is unusual good fortune, the total solar eclipse of 1919 took place just on May 29.

The solar eclipse of the solar eclipse of May 29, 1919, occurred at the distance of the maximum distance from the Earth to the Sun. The Sun's rays were at their longest, and the Moon's rays were at their shortest. The Sun's rays were at their longest, and the Moon's rays were at their shortest. The Sun's rays were at their longest, and the Moon's rays were at their shortest.

The Royal Observatory party arrived in Brazil all in simple time to prepare for the eclipse and photograph nearby fields. The day of the eclipse opened cloudy but cleared later, and the observations were made with almost complete success. The observers stayed in Brazil until they were able to see the field in the night sky at an altitude of the eclipse spot and under ideal conditions. The photographic plates were measured at Greenwich immediately by the observers' return, each plate being measured twice over.

The Cambridge University party arrived on Prince on April 23. The island is about 10 miles long and 4 miles wide. It was well situated for the purpose of a clear sky at the end of May were to be observed. The sky was completely cloudy at the beginning of the observers' return, each plate being measured twice over.

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MIT. WILSON ASTRONOMER ESTIMATES MILKY WAY TEN TIMES BIGGER THAN THOUGHT
But Dismisses Suggestion that Spiral Nebulae are Other "Island Universes"

The Milky Way is a "colossal" (also-shocking) galaxy of stars 100 times bigger than astronomers had previously conceived, according to M. Wilson astronomer Dr. Harlow Shapley. Moreover, he claims, the Sun exists nearer to its edge than its center. But the discovery of the hypothesis of other universes that scores of spiral galaxies in the story between an other galaxies, "island universes," that resemble the Milky Way.

In his two de three series of papers following 1918 and 1919, the profile Dr. Shapley examines other recent astronomical work in attaching detail, as well as presenting the results of his own astronomical photography using the 26-inch reflector of the Mount Wilson Observatory in southern California. His particular subject of interest is galactic star clusters—so-called "open" clusters of hundreds of stars that have long period astronomical because of their peculiar positions in only certain parts of the sky. When Dr. Shapley began his study in 1914, galactic clusters were known by the time he completed his work in 1918 he had added another 17 to the list.

In addition to preparing the exact position of each galactic cluster in the sky, he also prepared star light spectra to determine their motions, specifically whether they were approaching the Sun or receding from it from their data. Dr. Shapley sought to calculate the gravitation of stars 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 galactic clusters from the Sun using the novel method of Cepheid variables proposed by Miss Hertzsprung at Harvard Observatory. He also looked for irregularly shaped clusters of stars, the so-called "spiral galaxies," as well as other individual stars and pairs of objects.

After four years of diligent study, often assisted by his aid, Martin B. Shapley, Dr. Shapley has published a number of interesting conclusions.

Dr. Shapley has concluded that "our galactic universe" appears as a single, continuous, all-comprehending unit, the extent and form of which seems to be indicated throughout the dimensions of the widely extended assemblage of globular clusters. "The center of our disk-shaped nebular system," he states from the Earth were twenty thousand parsecs—more than 60,000 light-years—"in the direction of the constellation Sagittarius," Dr. Shapley continued.

His conclusions in the field of generally accepted astronomical wisdom: "Until last year or so, most students of our profession 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 position of globular clusters in the neighborhood of globular clusters of the actual distance 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 100 times the distance between our star and the nearest star."

"This new conception greatly substantiates the interpretation of spiral nebulae organizations of a comparatively recent date from their data," Dr. Shapley said, because such a size would imply that the spiral nebulae are distant galaxies, not "island universes" as they were called.

"For example," he pointed out, "if any light-year of 10 parsecs of an angle measured that an actual distance directly comparable with that of the galactic system, its distance must be greater than 100,000 light-years." Similarly, the star-galaxy proper motions suggested by the careful observational measurements of recent astronomers "would indicate opposing velocities in space."

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

EXPANDING OR CONTRACTING? Einstein's Theory of Relativity Must Decide One or the Other

Einstein Says Neither

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

But what 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, or there is a general explosion. Or they are contracting, or they were all collapsing upon one another.

But Dr. Einstein, a devotee of the book *God is Dead* by the Danish philosopher Soren Kierkegaard from 1843, followed that God is dead, which is the same thing, all the universe is impossible. "Dr. Einstein was troubled by the concept of a universe that was not immovable or unchangeable."

"We can add to the list of the field equations—for the time being—a unknown universal constant," Dr. Einstein said, explaining the quantity by denigrating by the Greek letter lambda, and calls it "cosmological constant." He explains, "such a term has no identity, the proposed universal constant determines the average density of the universe that can remain in equilibrium."

According to Dr. Einstein, a beautiful immovable universe, the presumably spherical universe would be neither expanding nor contracting.

In Their Own Words

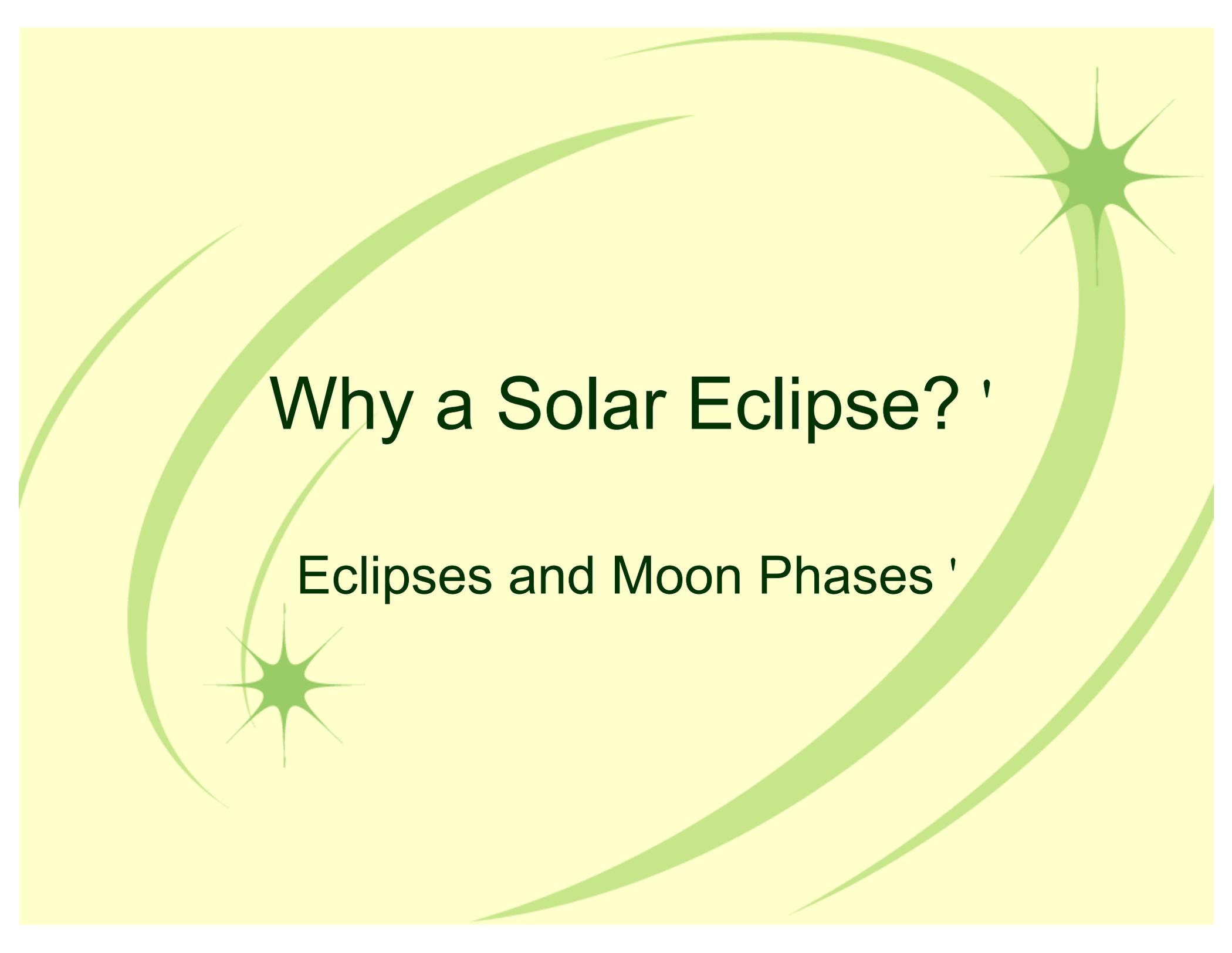
Periods of 25 Variable Stars in the Small Magellanic Cloud - Miss Hester in London

Dr. Hester's observations of the Small Magellanic Cloud (SMC) have revealed a group of 25 variable stars. The stars are of various types, including Cepheids and RR Lyrae stars. The observations were made using a 10-inch telescope at the Royal Observatory, Greenwich. The results show that the stars are distributed throughout the cloud, and that their periods are in good agreement with theoretical predictions.

The Relation of the System of Stars to the Spiral Nebulae - G. P. Starr

Dr. Starr's work on the relation of the system of stars to the spiral nebulae has shown that the stars are distributed throughout the nebulae. The observations were made using a 10-inch telescope at the Royal Observatory, Greenwich. The results show that the stars are distributed throughout the nebulae, and that their periods are in good agreement with theoretical predictions.

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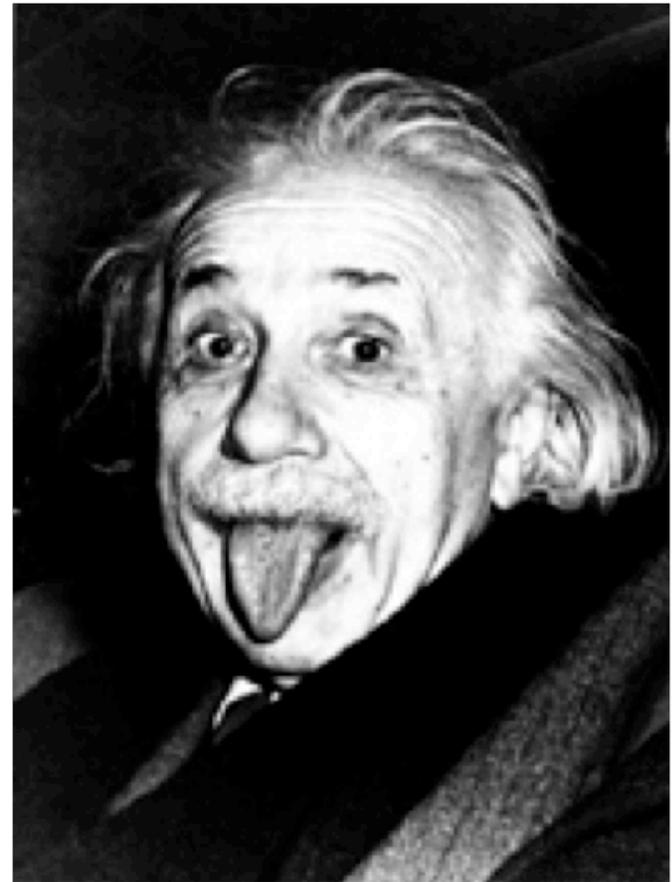


Why a Solar Eclipse? '

Eclipses and Moon Phases '

Unchanging Universe? '

- * Einstein's theory implies universe is not static - it's expanding or contracting.
- * Einstein was troubled by a non-static Universe.
- * Cosmological Constant keeps the Universe static.



1919 Lessons

- * Einstein and His Times

- * Should Einstein be 1919's "Man of the Year" ?

- * Two Versions of Gravity

- * Compare Newton's & Einstein's gravity

- * Einstein's Gravity

- * Create a model of Einstein's gravity

Other 1919 Stories!

Age of the Universe:
Infinite

COSMIC TIMES

Size of the Universe:
200,000 Light Years

1919

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 larger 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, conceived 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, then 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 favorably 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



Here 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 observed 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 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.

The Cambridge University party arrived on Principe on April 23. The island is about 10 miles long by 4 miles wide. "We soon realized 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 ex-

actly as arranged, but out of the 16 plates 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 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."

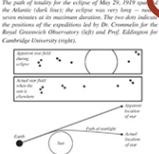
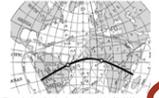
WHY A TOTAL SOLAR ECLIPSE?

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 seconds). The apparent positions of stars closer to the Sun's limb would be deflected 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. There, a cluster of stars so bright they are clearly visible to the naked eye is visible.

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 annual good fortune, the total solar eclipse of 1919 took place right on May 29.



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 believed, according to Mt. Wilson astronomer, Dr. Harlow Shapley. 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 twelve-volume series of papers throughout 1918 and 1919, the profile 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 aided by his wife Martha B. Shapley, Dr. Shapley has published a number of astonishing conclusions.

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 would be contracting, as if they were all collapsing upon one another.

But Dr. Einstein, a devotee of the book *Etica* by Dutch philosopher Spinoza, quoted from memory Corollary 2 of Proposition 20: "It follows that God is immutable, or which is the same thing, 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.

Dr. Shapley has concluded that "our galaxy" universe appears as a single, enormous, all-pervading unit, the entire cosmos of which we are a part. He estimates that the Milky Way is 100,000 light-years in diameter, and that the radius of 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 enhances 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 motion 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."

In Their Own Words

Periods of 25 Variable Stars in the Small Magellanic Cloud - Miss Henrietta Leavitt
The stars in the Small Magellanic Cloud, a satellite galaxy to our own, have been observed for a long time. There is a group of 25 variable stars in the Small Magellanic Cloud, and the brightness of the variables and their periods: the brighter variables have the longer periods.

Spectroscopic Observations of Spiral Nebulae - H. Shapley
The average radial velocity of spiral nebulae is +400 kilometers per second. But a considerable jump is noticed from the average of the stars in the line of sight. Positive radial velocity means an object is moving, while negative radial velocity means an object is approaching. As well as the average velocity of the spirals is about 25 times the average radial velocity.

The Relation of the System of Stars to the Spiral Nebulae - G. F. Paddock
The spiral nebulae are a group of stars in a comparatively small region of space, and are seen as a line of sight from the Earth. They are a group of stars in a comparatively small region of space, and are seen as a line of sight from the Earth. They are a group of stars in a comparatively small region of space, and are seen as a line of sight from the Earth. They are a group of stars in a comparatively small region of space, and are seen as a line of sight from the Earth.

How Far Away are “Spiral ‘ Nebulae”?’

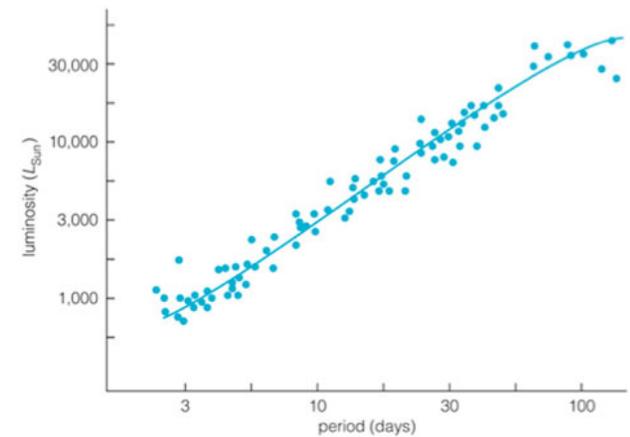
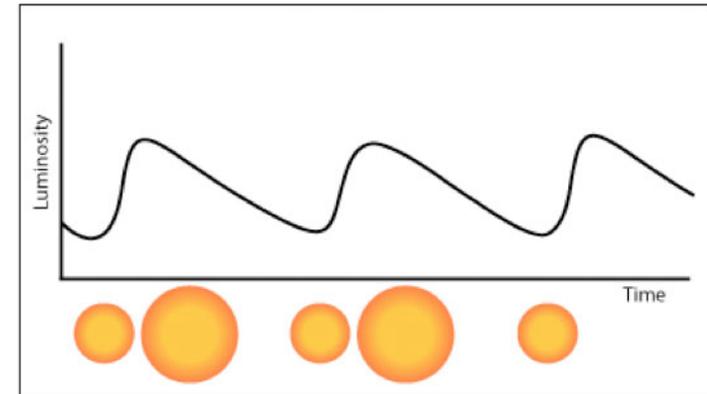
- * In 1920, astronomers ‘ pondered the distance to the “spiral nebulae.” ‘
 - * Recall article on Shapley in 1919 ‘
- * Harlow Shapley and Heber Curtis debated whether they were within our own Galaxy or outside our Galaxy
- * Shapely won the debate with his arguments for the spiral nebulae being part of the Galaxy.



Cepheid Variables '

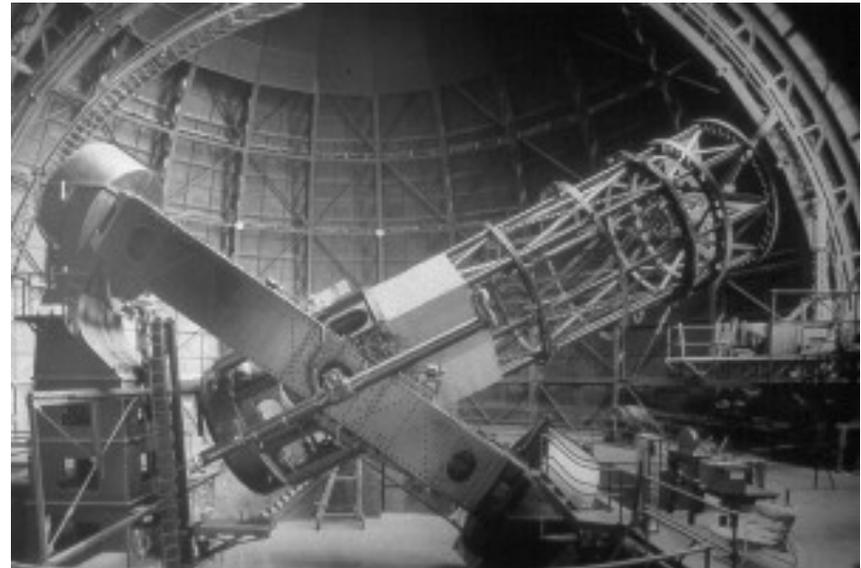
- * Henrietta Leavitt observed pattern in the variability of Cepheids - a brighter star had a longer period
- * By measuring the observed luminosity, and knowing intrinsic luminosity we can determine distance

$$L_o \propto L_i / r^2$$



Using the Standard Candle

- * Hubble used the 100" ' Telescope at Mt Wilson - the first to provide the aperture and resolution to resolve the stars in ' Andromeda '
- * Using the Cepheids, he determined distance to Andromeda to be 900,000 ' LY* '
- * That distance is too far to ' lie within the Milky Way '

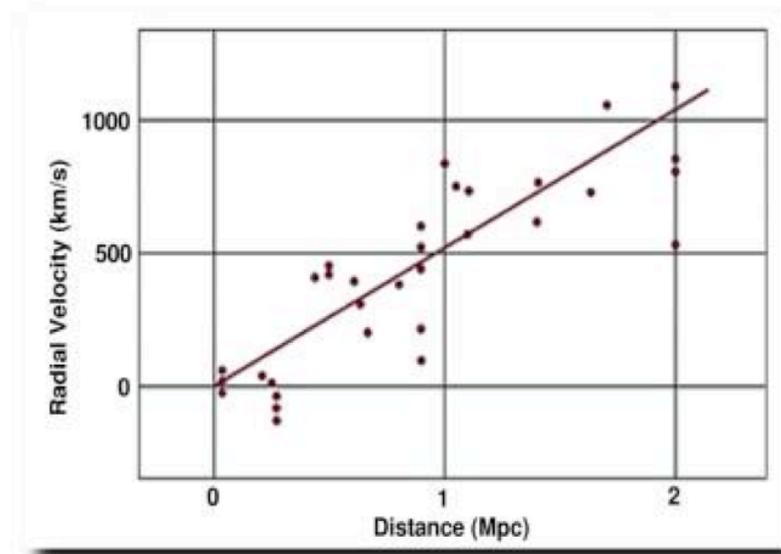


Despite winning the debate, Shapely was wrong! Spiral Nebulae lie outside the Milky Way

* actual dist. is 2.8 million LY

But Wait, There's more ... '

- * Vesto Slipher showed the “nebulae” were red-shifted.
 - * I.e. moving very fast away from us.
- * Hubble put together the redshifts with their distances.



Hubbles' Original Data

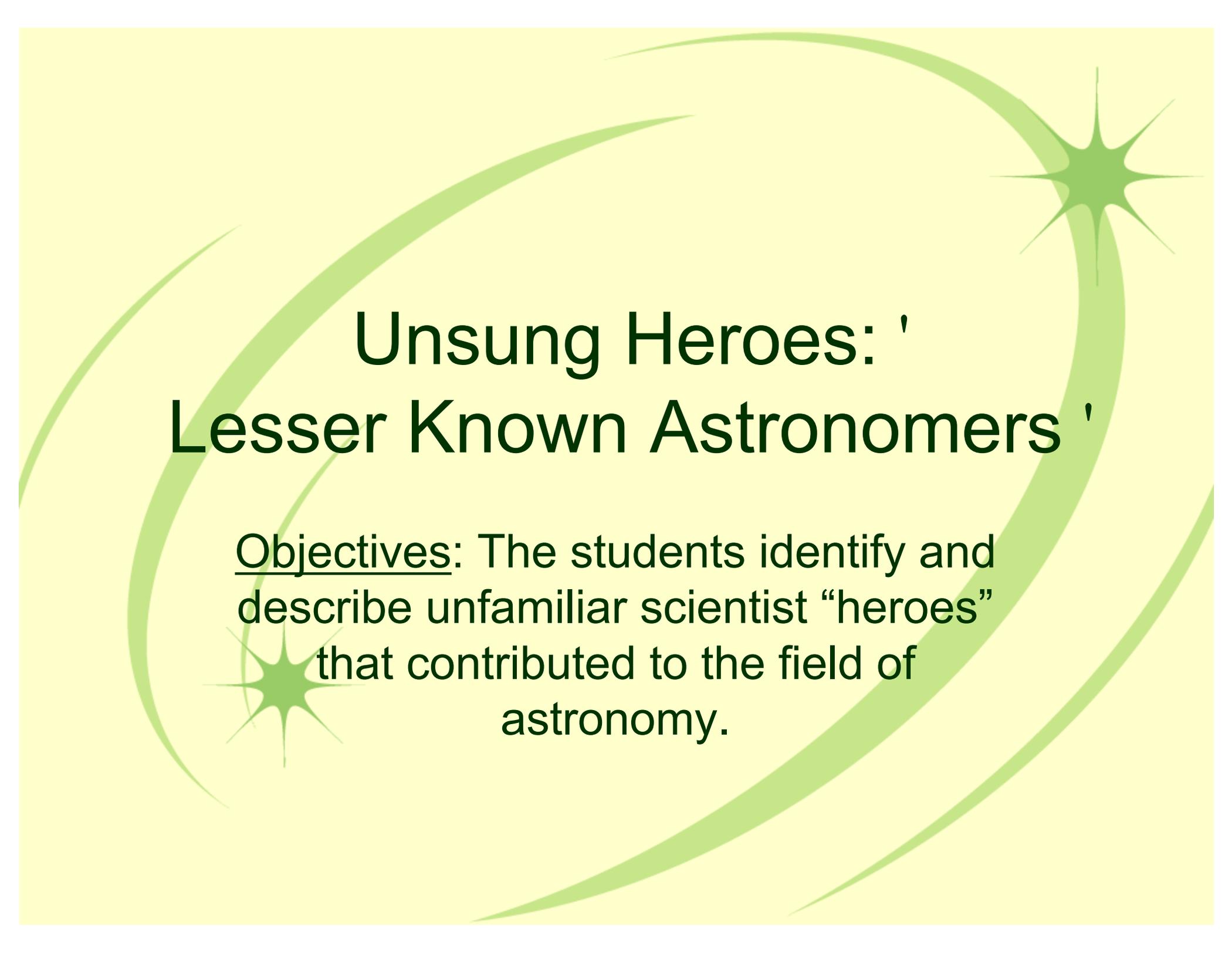
Universe is expanding!

“Cosmological Redshift”

- * “Doppler” redshift would require the galaxies themselves to be moving at very high speeds.
- * Friedmann (1922) and Lemaître (1927) abandoned Einstein’s static universe, and showed that space-time could expand.
 - * Then wavelength of light would stretch in response to space-time’s stretching.



Scientists Game'



Unsung Heroes: ' Lesser Known Astronomers'

Objectives: The students identify and describe unfamiliar scientist “heroes” that contributed to the field of astronomy.

1929 Lessons

- * Discovering the Milky Way
 - * Students study the Cepheid P-L relation '
- * Just How Far is that Star?
 - * Determining distances using apparent and absolute brightnesses
- * Cosmic CSI
 - * Elemental Composition through Spectra '
- * Determining the Universe
 - * Students reproduce Hubble's Law

Other 1920s Stories'

Age of the Universe:
2 Billion Years

COSMIC TIMES

1929

Size of the Universe:
280 Million Light Years

Andromeda Nebula Lies Outside Milky Way Galaxy

Spiral Nebulae are indeed "Island Universes"



Dr. Edwin Hubble found that the Andromeda nebula is the most distant object known and is not part of the Milky Way Galaxy.

Astronomer Edwin Powell Hubble, of the Mount Wilson Observatory of the Carnegie Institution at Pasadena, California, has solved the mystery of the spiral nebulae, the great heavenly objects that appear as hazy pin-wheels in the sky. He has determined that these objects are much more distant than previously thought and therefore are galaxies themselves, rather than part of our own Milky Way Galaxy. In the process, Dr. Hubble was also able to determine the distance to the spiral Andromeda nebula.

Hubble's observations vindicate the views of Dr. Heber Curtis expressed in the "Great Debate" with Dr. Harlow Shapley at the 1920 National Academy of Sciences (see "Great Debate Resolved" article). Curtis maintained that bright diffuse nebulae are relatively close to Earth and are part of the Milky Way, while spiral nebulae are at great distances and not part of the Milky Way.

On December 30, 1924, Hubble announced that he had taken photographic plates of a few bright spiral nebulae with Mount Wilson's Hooker telescope, the largest reflecting telescope in the world. According to Hubble, "The 100-inch reflector partially resolved a few of the nearest, neighboring nebulae into swarms of stars."

Hubble estimates the Andromeda Nebula is as large, and holds as much matter, as the Milky Way. It may contain some three to four thousand million stars that produce one billion times the light of the Sun.

Photographic plate images revealed not only individual stars within the nebulae, but that some of the stars changed in brightness over time. Known as Cepheid variable stars, these stars were the key to determining distances to the nebulae. The intrinsic luminosity, or actual brightness, of the Cepheids in the nebulae Hubble studied was known. Since the same star will appear dimmer the more distant it is, the apparent magnitude of these stars is a clear indicator of the distance to their host nebulae.

Hubble's work builds upon earlier observations by Miss Henrietta Swan Leavitt of the Harvard College Observatory and by Shapley of the Mount Wilson Observatory.

In 1912, Miss Leavitt was the first to recognize the importance of Cepheid variables. They are giant stars, often visible from great distances, and each varies in brightness over time. Cepheids are named after the first such star of its type found: Delta Cephei in the constellation Cepheus. While counting their number, as captured on photographic plates, of the small cloud of Magellanic, Miss Leavitt noticed that the Cepheids had periods, or repeating cycles,

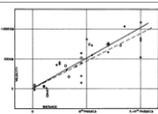
Universe is Expanding

"Red Shift" is Proof of Einstein's General Theory

Using the 100-inch Hooker Telescope at Mount Wilson Observatory, Dr. Edwin Powell Hubble has studied a variety of spiral nebulae and established that they are moving away from us at a rapid pace—strong evidence of an expanding universe. He has further determined that the speed of motion increases with greater distance.

Hubble and his colleague Milton Haman measured the radial velocities and distances of twenty-four of these nebulae. Because they are moving so quickly, their light waves are stretched out. This shifts their energy signals—as we detect them—toward the red end of the electromagnetic spectrum, a phenomenon known as "redshift." The team noticed that dimmer, more distant objects have a larger redshift than objects closer to Earth. As reported in a recent paper, Hubble's measurements led him to a useful velocity-distance relationship: redshifts increase in direct proportion to their distance from us.

Hubble's initial analysis reveals that for every million parsecs of distance, the velocity of the spiral nebulae increases by approximately 300 miles per second, where one parsec is equal to 1.26 light years. He determined distances to the nebulae using Cepheid variables, stars with



Hubble's research led to this diagram, showing the general correlation between how far away a galaxy is and the speed it is moving away from us.

a known luminosity, or "standard candles." He concluded that the most distant objects are speeding away from us at perhaps thousands of miles per second.

Hubble's recent discoveries reveal that the volume of space itself is expanding. Spiral nebulae appear to be moving away from each other at a rate that increases with distance, but these nebulae aren't just moving. They are being pulled along as the fabric of space-time expands.

Hubble's findings build on the work of Dr. Vesto Slipher of Lowell Observatory in Flagstaff, Arizona, who in 1912 became the first to record the electromagnetic spectra of a spiral nebula. Of the more than fifty spectra Slipher subsequently gathered, all but a few were measurably redshifted, and therefore are moving away from us. His studies, however, led him to a conclusion that velocities for the nebulae might be closer to a mere 600 miles per second.

"Great Debate" Resolved

Dr. Hubble's discovery settles the "Great Debate" over the size of our own Milky Way Galaxy and the distance to, and nature of, spiral nebulae.

Since 1920, the National Academy of Sciences in Washington, D.C., the debate focused on the opposing views of astronomer Dr. Harlow Shapley of the Mount Wilson Observatory and Dr. Heber D. Curtis at the University of California's Lick Observatory.

Shapley's studies had led him to a concept of the Milky Way as an enormous galaxy of stars some 300,000 light years across, much larger than most previous estimates. His model also held that the Solar System is far from the galaxy's center and that all nebulae, including spiral nebulae, are within the confines of the Milky Way.

Citing photographic surveys done at the Lick Observatory, Curtis put forth his idea that spiral nebulae were "island universes," distant star systems similar to the Milky Way and not outlying components of it. He also believed the Milky Way was less than 30,000 light years in diameter and 8,000 light years in thickness.

Hubble's recent observations vindicate Curtis' views. While bright, diffuse nebulae are at relatively close distances and part of the Milky Way, spiral nebulae are separate systems at great distances from it. He estimates that the spiral Andromeda Nebula is as large and holds as much matter as the Milky Way. However, Hubble's findings also support Shapley's general view of the Milky Way's size, with the Solar System located far from its center.

Shapley's work had increased the size of the universe by about ten times, but Hubble's recent discoveries have multiplied it by at least another ten. Shapley achieved a historical progression, from belief in a small universe with man at its center, to a larger one with Earth further from the center. "The significance of man and the Earth... has diminished with advancing knowledge of the physical world."

Classifying Nebulae

For over a thousand years, astronomers have speculated on the nature and evolution of nebulae, faint clouds of gas and dust. There have been insufficient observations to allow a classification of nebulae based on their features or qualities.

Dr. Hubble, during his studies of the spiral nebulae, proposed a system to classify all nebulae, both inside and outside the Milky Way. He sorted them into three basic categories: elliptical, spiral, and irregular. These, in turn, were further subdivided according to shape (elliptical to elongated ellipses, for example) and structure (barry to distinct spiral arms, barred spirals, etc.).

Hubble's schema shows a sequence of evolutionary change but was "based primarily on the structural forms of photographic classification which should be entirely independent of theoretical considerations." Future astronomical studies and evidence will be the test for this new classification system.



The Minds Atop Mount Wilson

The next year, Hubble returned to the United States. He was completed in 1917, his intelligence and curiosity were soon no longer his. He was promoted to night assistant on the 60-inch telescope.

Working under the observatory's director, Dr. George Ellery Hale, Hubble became an expert observer. Dr. Hale recognized his abilities and appointed him to the observatory's scientific staff in 1918. Haman soon became an expert at measuring the redshifts of distant nebulae and chief assistant and collaborator to Dr. Hubble.

In Their Own Words

...beyond the last frontier... actually know family... about it is absolutely that astronomy of them would be nearly unable to comprehend their significance." —Edwin Hubble — 1927

"...encompass the outlook may change and new methods may shed our knowledge and belief of today, or even turn into remote history. Soon we may look far

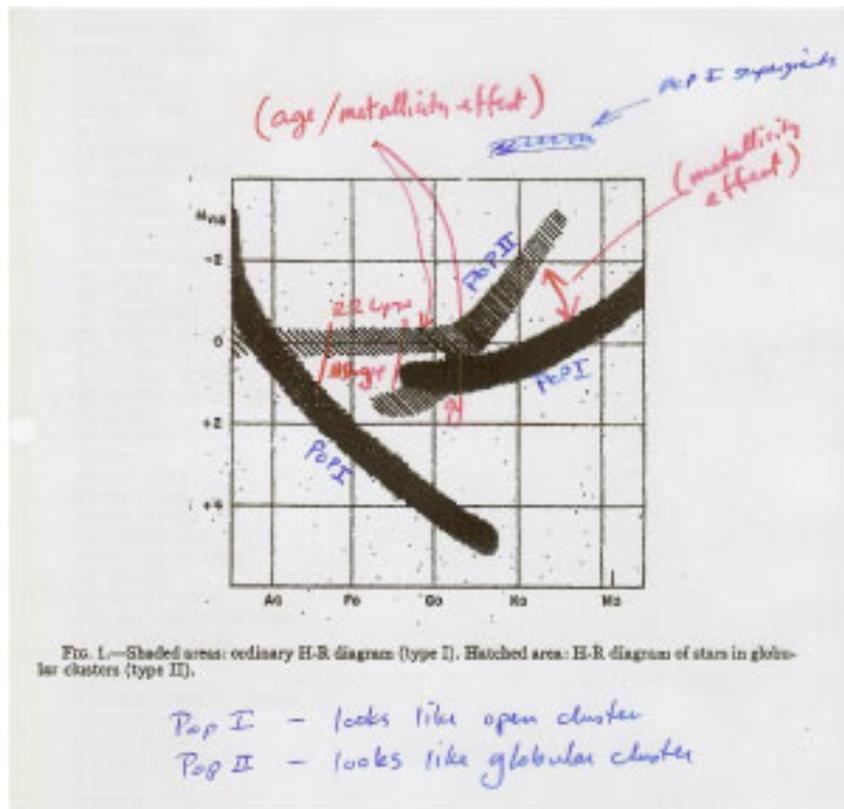
Former Formula-Team Driver and Junior Helps Discover Expanding Universe

Milton LaSalle Haman was born in Eagle Lake, Minnesota in 1901, but moved to California with his family as a child. Having excelled in the eighth grade, Haman received no formal training as an astronomer. In fact, his career at Mount Wilson began as a multi-team driver for the park trains that carried large components of the telescope and its building to the top of Mount Wilson during the observatory's construction.

Problem with the Cepheids?

- * Hubble studied globular clusters in Andromeda and M 33 in the early 1930s
 - * Equivalence principle says that similar objects found in different parts of the Universe should be similar
 - * But ... Globular clusters of Andromeda were showing peak luminosities that were 1.5 magnitudes dimmer than those in the Milky Way
 - * Either equivalence principle not applicable, or distance scale was wrong
 - * Then M 33 showed globular clusters that were dimmer still than Andromeda
 - * Problem with the distance scale!

Two Populations!



- * In 1944, Walter Baade imaged Andromeda in greater detail than previous studies
- * Found definitive evidence of two stellar populations
- * Therefore - two types of Cepheids with different Period-Luminosity relationships.

Universe Doubled in Size

★ An error in the calibration of the Cepheid period-luminosity relationship led to an under-calculation of the distances to most objects...by half!

Age of the Universe:
6 Billion Years

COSMIC TIMES

1955

Size of the Universe:
4 Billion Light Years

'Yardsticks' in Neighbor Galaxy Double Universe's Size

The universe is twice as large as we thought it was, Caltech astronomer Walter Baade, who has now employed the giant 100-inch glass reflecting telescope at Mount Palomar to confirm the scale of the universe.

Baade's discovery has not come from simply finding more stars in space, of course. To properly divine the distance of stars and the scale of the universe first he had to discover that Nature has created more than one kind of stellar yardstick, if you will. Until a few years ago, there was just one cosmic yardstick known to astronomers, and it was being used incorrectly. Gladly enough, it took the wartime blackout in Los Angeles to begin getting things straight.

That first universal yardstick was discovered toward the turn of the century. It is a type of pulsating variable star called a Cepheid. Harlow Shapley of the Harvard Observatory was surveying the Magellanic Clouds, those junior galaxies outside of the Milky Way, when she noticed that brighter Cepheids pulsated slower than dimmer Cepheids. This was intriguing, since for all practical purposes stars in the Magellanic Clouds can be considered the same distance from Earth. It suggested that those Cepheids were offering up a handy relationship between their rate of pulsation and luminosity and therefore distance.

If, for example, an astronomer observes a fast-pulsating Cepheid in our own Milky Way galaxy which appears dim from Earth, he can use Miss Lavoisier's brightness-pulsation relationship to surmise that the star is actually very bright, just very distant. Likewise, a slowly pulsating Cepheid which appears bright at our sky is probably a relatively dim star that only appears bright because it's closer.

The same relationship seemed to hold with Cepheids found in other star clusters, in our own Galaxy, as was discovered by astronomer Simon Bailey. Finally, astronomer Harlow Shapley standardized the yardstick so he could map the distance of both far-period and slow-period Cepheids both inside and outside globular clusters in the Milky Way.

"That a period-luminosity relation was established which covered the whole range of the Cepheid variation and which was accepted as the period-luminosity relation for the next 30 years," recalled Baade in a speech at a recent annual assembly of the Astronomical Society of the Pacific.

Unfortunately, Shapley's yardstick had flaws, as the famous astronomer Edwin Hubble began to discover more than 20 years ago. Doctor Hubble began studying the straight line between globular clusters and the Andromeda nebula, a sister galaxy of the Milky Way, in 1911. For some reason those clusters were being more dimly - 1.5 magnitudes dimmer - than their counterparts here in the Milky Way. This mismatch must either the globular clusters in Andromeda are basically different animals than those in our own Milky Way, or Andromeda must be further than originally calculated.

Origin of Everything: Hot Bang or Ageless Universe?

It's difficult to imagine a deeper mystery than the one being addressed recently at the meeting of the National Academy of Sciences in Pasadena, California. Is the universe eternal or does it have a beginning, middle and end?

The case for an ageless, steady-state universe which forever looks much as it does today was presented at the conference by astrophysicist Jose L. Greenstein and physicist William A. Fowler of the California Institute of Technology. The steady state theory rivals the "evolutionary" theory of the universe which calls on an initial burst of hot particles exploding and cooling down and making all of the universe's hydrogen and perhaps helium on our left swoop. Both theories explain - in entirely different ways - the inescapable fact that the universe is expanding. This cosmic expansion was first detected in 1914, when American astronomer Vesto Slipher surveyed some galaxies and noticed the light from most of them was "red-shifted." This is essentially the broadening and reddening of the visible light waves caused by the retreat of the galaxies. It's the electromagnetic equivalent of how the wall of a retreating locomotive drops in tone as it passes by a train watcher's ear.

In the steady-state theory the expansion comes from the continuous bubbling up of the new basic elements, hydrogen, from empty space as a sea of one particle every cubic meter every 100,000 years or so. The hydrogen eventually gathers and condenses into stars which, through nuclear fusions in their cores, manufacture all the heavier elements. As stars age and die, they disperse the heavier elements and other gaseous gas, giving rise to new stars with rocky planets around them - like our own Solar System. As evidence of that process, Greenstein and Fowler referred to the heavy-element-making red giant stars which can be seen today in our Galaxy.

An important aspect of the steady-state is that it's anything but static, as the champion of this theory British cosmologist Fred Hoyle, likes to point out. Hoyle compares the deathless universe to a river. It may appear unchanging, but there is plenty of movement and change in the surface. So, as he notes the old river song, you can never step into the same universe twice.

Then, on the other hand, there is the somewhat less "evolutionary" theory of Robert Oppenheimer and his colleagues Ralph Alpher and Richard Herman. These scientists call the explosion and decay of a hot ball of neutrons as the birth of the universe to create all the hydrogen and some helium. These elements freeze out as the blast expanded and cooled. The first stars were made of only these two original elements and found them into new, heavier elements. These, then, were dispersed throughout the galaxy as the first stars died, and led to the first firm mixture of elements seen in stars now.

This evolutionary theory also accounts for the retreating galaxies: They are still in flight from the power of the initial blast. There must be other direct evidence of the blast as well. Alpher and Herman have predicted that some firm residual heat from that initial explosion may still be glowing dimly in the form of stretched-out light waves called "microwaves" just a few degrees above absolute zero. As yet, however, no one has devised a way to detect this theoretical remnant heat.

More conceivable evidence for the evolutionary universe comes from Edwin Hubble's 1929 measurements of the velocities of galaxies beyond our own, which built on Slipher's earlier discoveries. Hubble found that the more distant a galaxy is, and therefore the closer in time to the original explosion, the faster they appear to be moving away from us. This is exactly what would be expected if there was an ancient blast that started all our things being blown down ever since.

The downside to an evolutionary universe, of course, is that it doesn't end happily. There's no limitless fount of hydrogen on the steady state theory. The universe has finite resources. It might expand forever as all the stars burn out and the universe cools down to a vast, frigid stellar graveyard. Or the gravity of all matter might eventually pull everything back together

Death of a Genius

The world has just lost its greatest scientific mind. Albert Einstein died in his sleep on April 18th from complications of a long-ago bladder infection. He was 76. There is no doubt that this marvellous, white-haired, pipe-smoking professor passed deeper into the mire of the universe than any other man. In his death he leaves a void few - such as Newton, Copernicus, Aristotle and Pythagoras - as a giant in science whose genius changed the course of history.

The astronomical beginning of tributes to the German-born scientist began to come by his place in history. President Eisenhower said "No other man contributed so much to the vast expansion of 20th century knowledge." Mike Sharpe, the Prime Minister of Great Britain, said "The world has lost its foremost genius." There were even eulogies behind the Iron Curtain. Parvati described him as "A great transformer of natural science."

The true nature of Einstein's achievements are better known to his colleagues and scientific peers, who will labor to understand, use and apply his theories. There is his revolutionary re-thinking of light as not just waves but particles. There is his theory of special relativity, which set speed limit within the universe at that of light. Or his most famous equation $E = mc^2$, which divided the wall between matter and energy. Finally, we have his space-time-bending theory of gravitation. Taken together, Einstein's ideas are the basis of all modern physics.

For the non-physicist, however, Einstein's genius is a gift, but largely a mystery. The man on the street knows that such things as television and the hydrogen bomb are the results of his work, but exactly grasp how it is so. We are, it seems, rather like the nurse in Einstein's described, who failed to grasp the great man's final work, unless in German. She did not speak German. Most of us do not speak physics. Instead, we sense the importance of the man indirectly and gaze like children at a parade, in his life and his genius passes before us.

Radio 'Ear' on the Universe Being Built

The NRA will perhaps the 218-foot parabolic aerial antenna, also at Jodrell Bank. That pioneering aerial was tall poles and was used to reflect and concentrate radio waves to a single point. Through the current set up allows astronomers some leeway - they can tilt the 156-foot high central receiver pole somewhat to cover a wide range of sky - it rests heavily on the opening of Earth in its orbit to change its view of the heavens.

Despite that limitation, the eight-year-old parabolic aerial antenna has led to some important discoveries which more than made the case for building the Mark II, according to its designer Dr. Bernard Lovell of the University of Manchester. Among the most startling discoveries was that there are radio emissions coming from the Great Andromeda Nebula and that the brightest radio center in the night sky is from a little nebula in the constellation Cassiopeia.

It's a Star! It's a Nova! It's Super-Nova!

There's more than one sort of "new" star in the heavens, say astronomers. The evidence has been building for decades that some - those stars which light up suddenly to great brightness, then fade away - actually come in at least two distinct classes. On one hand there are pulsations, Clark Kerr, like nova and on the other there are truly Super-Novae.

The first clue that there were super-novae lurking among the stars came 35 years ago by the re- discovery of ancient astronomer Hipparchus. Using medieval star maps, he discovered that one of his stars had become as bright as he had observed in 1345 in the Andromeda Galaxy actually must have been about one hundred times more luminous than any nova recently observed in our own Milky Way Galaxy.

Forteen years later, in 1914, physicist Walter Baade and Fritz Zwicky coined the term "super-nova" when they suggested those were not just brighter than normal nova, but were one or two million times, even in its given galaxy. The most recent super-novae in our own galaxy, they speculated, were those recorded by German astronomer Johannes Kepler in 1604 and another by Danish astronomer Tycho Brahe in 1572.

A new wrinkle in the matter was added in 1941 by astronomer Rudolph Minkowski. He split the light from 14 distant galactic super-novae into their component colors and found that nine of these spectrums contained no helium lines for hydrogen (Type I) and five did (Type II). The possible reason for this, speculative British cosmologist Fred Hoyle, is that in the superlative violence of their death throes, the giant stars that become super-novae might be capable of fusing hydrogen and helium to forge heavier elements like carbon and iron. They then, they say, not only Super, but have like Stars of Steel.

The telescope that captured the scale of the cosmic Mount Palomar's 100-inch Hale Telescope was completed in 1948.

As chance would have it, the solution came during the wartime blackouts of 1943 in California. Doctor Baade took advantage of the darkened skies and the power of the 100-inch Hooker telescope at the Mount Wilson Observatory near Los Angeles to re-examine Andromeda's globular clusters. Using special red-sensitive photographic plates Dr. Baade discovered two populations of stars: redder, fainter "Type II" stars near Andromeda's center and in the outlying halo the same arrangement as in the Milky Way and bluer, brighter "Type I" variable stars located in the outer spiral arms as well as in abundance in the Magellanic Clouds. So, Dr. Baade realized that there must be two populations of Cepheids - those Type I Cepheids more common in the disk of a galaxy and those Type II Cepheids more common in the globular clusters.

Each type of Cepheid, it turns out, has a different way of encoding its actual brightness into its pulsing light. It is as if the recurring ticks of one type of Cepheid was measured in feet, i.e., a good old American yardstick, and the other was in inches. The problem was Shapley had treated them both as regular French yardsticks.

[Unintentionally] Shapley took a fatal step when he linked the cluster-type variables to the type I Cepheids through the type II Cepheids in globular clusters and that in reality were not dealing with two different period-luminosity relations," explained Dr. Baade.

Recently at Mount Palomar, Baade and his computer assistant Heorata Sorenson confirmed that both types of Cepheids are very different and not animals. After re-calculating his measurements, Dr. Baade started his paper in 1952 at the Rome meeting of the International Astronomical Union by announcing that Andromeda was not 800,000 light-years away, as Hubble thought, but 1.8 million light-years distant. Likewise, with the two measuring sticks sorted out, the universe was now known in 1950 to be two billion light-years across.

Fred Hoyle and William Fowler in Fowler's office in Los Angeles, California.

Hoyle Scoffs at "Big Bang" Universe Theory

British cosmologist Fred Hoyle has thrown down the gauntlet with regard to where and when all the universe's elements were created. In a recent radio broadcast he pointed a rival theory, championed by Christian-born American physicist George Gamow, labeling it a ridiculous "big bang."

Gamow's Evolutionary Theory of the universe calls on an initial state of super-hot nuclear fusions of basic particles to create all the hydrogen in the cosmos in one explosive moment. The same blast then caused space to expand. The expansion function that "big bang" is observed by astronomers today throughout cosmos.

Hoyle is having none of it. "It is an irrational process that cannot be described in scientific terms... [and] challenged by an appeal to observation," he has written regarding Gamow's theory.

For one thing, the "big bang" requires something before the explosion. No one knows that that might be. If on the other hand, the universe is created and stars are always being made and forever making heavier elements, as Hoyle suggests, there is no need for an initial explosion. Recent advances in nuclear physics seem to back Hoyle's "steady state" view of the universe on the presence and temperatures inside stars to manufacture all the heavy elements seen in the cosmos today.

Albert Einstein in 1930.

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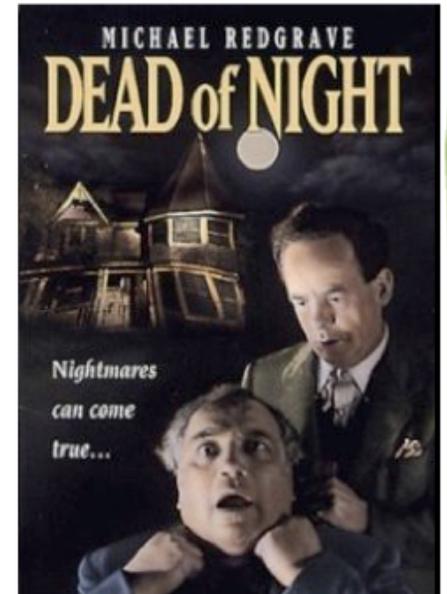
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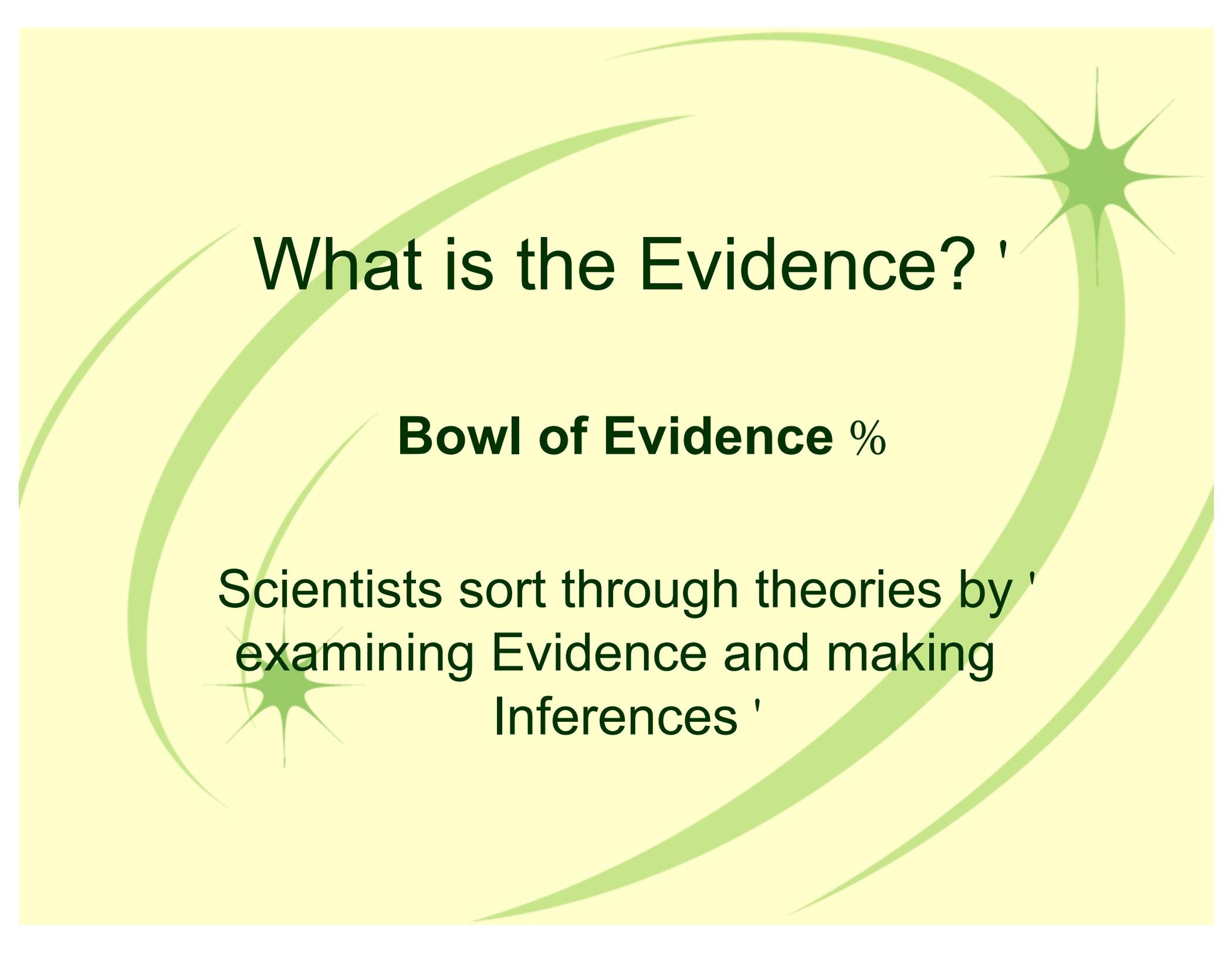
Steady State Universe '

- * Fred Hoyle, Hermann Bondi and Thomas Gold see the movie *The Dead of Night*, in which the end of the story circles back to its beginning.
 - * Unchanging situations need not be static
 - * New matter can be created spontaneously as the universe expands (a few hundred atoms per year per galaxy)
 - * Expansion of universe and creation of new matter balanced via a negative energy. '
 - * The universe is constant in its overall density '



Evolutionary Universe

- * Starting from earlier work, George Gamow & Ralph Alpher worked out the conditions in the early universe
 - * Universe is expanding from a state of high density and pressure.
 - * Hydrogen & Helium were formed as universe cooled.
 - * There should be left over a background radiation with a temperature of ~ 5 Kelvin
 - * Hoyle scoffed at this theory and coined the term “Big Bang”



What is the Evidence? '

Bowl of Evidence %

Scientists sort through theories by '
examining Evidence and making
Inferences '

Steady State vs. Big Bang '

- * Resolution of Steady State vs Big Bang won't come until the mid-to-late 1960s.
- * But as a competing theory, the Steady State provides the impetus to make observations to test the theories.

1955 Lessons '

- * Cosmic Jeopardy!
- * Big Bang Science Fiction
- * Discovering Yardsticks are Metersticks
 - * An illustration of the recalibration of the Cepheid distance scale
- * Hubble's Law Mis-calibration Extension
 - * Revisit the 1929 lesson

Otter 1950s Stories'

Age of the Universe:
6 Billion Years

1955

COSMIC TIMES

Size of the Universe:
4 Billion Light Years

'Yardsticks' in Neighbor Galaxy Double Universe's Size

The universe is twice as large as we thought says Caltech astronomer Walter Baade, who has now employed the giant 200-inch glass reflecting telescope at Mount Palomar to confirm the scale of the cosmos.

Baade's discovery has come from simply reading mile markers in space, of course. To precisely divine the distance of stars and the scale of the universe first he had to discover that Nature has created more than one kind of mile marker, or yardstick, if you will. Until a few years ago, there was just one cosmic yardstick known to astronomers, and it was being used inaccurately. Oddly enough, it took the wartime blackouts in Los Angeles to begin setting things straight.

The first universal yardstick was discovered around the turn of the century. It is a type of pulsating, variable star called a Cepheid. Henrietta S. Leavitt of the Harvard Observatory was surveying the Magellanic Clouds, those junior galaxies outside of the Milky Way, when she noticed that brighter Cepheids pulsed slower than dimmer Cepheids. This was intriguing, since for all practical purposes the stars in the Magellanic Clouds can be considered the same distance from Earth. It suggested that those Cepheids were offering up a handy relationship between their rest (not just apparent) luminosity and their pulsation rate.

If, for example, an astronomer observes a fast-pulsating Cepheid in our own Milky Way galaxy which appears dim from Earth, he can use Miss Leavitt's brightness-pulsation relationship to surmise that the star is actually very bright, just very distant. Likewise, a slowly pulsing Cepheid which appears bright in our sky is probably a relatively dim star that only appears bright because it's close.

The same relationship seemed to hold with Cepheids found in dense star clusters in our own Galaxy, as was discovered by astronomer Helen Babcock. Finally, astronomer Harlow Shapley standardized the yardstick so he could map the distance of our fast-pulsing and slow-pulsing Cepheids both inside and outside globular clusters in the Milky Way.

"Thus a period-luminosity relation was established which covered the whole range of the Cepheid variation and which was accepted as the period-luminosity relation for the next 30 years," recalled Baade in a speech at a recent annual conference of the Astronomical Society of the Pacific.

Unfortunately, Shapley's yardstick had flaws, as the famous astronomer Edwin Hubble began to discover more than 20 years ago. Doctor Hubble began studying the starlight from globular clusters in the Andromeda nebula, a sister galaxy of the Milky Way, in 1913. For some reason those clusters were burning more dimly - 1.5 magnitudes dimmer - than their counterparts here in the Milky Way. This mismatch meant either the globular clusters in Andromeda are basically different animals than those in our own Milky Way, or Andromeda must be further than originally calculated.



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Each type of Cepheid, it turns out, has a different way of encoding its actual brightness into its pulsing light. It was as if the measuring stick for one type of Cepheid was measured in feet, i.e., a good old terrestrial yardstick, and the other was in cubits. The problem was Shapley had treated them both as regular 36-inch yardsticks.

[I]t just now truly Shapley had made a final step when he linked the cluster-type variables to the type I Cepheids through the type II Cepheids in globular clusters and that in reality were dealing with two different period-luminosity relations," explained Dr. Baade.

Recently at Mount Palomar, Baade and his computer assistant Horatio Swope confirmed that both types of Cepheids are very different stellar animals. After recalibrating his measuring sticks, Dr. Baade started his paper in 1952 before a meeting of the International Astronomical Union by announcing that Andromeda was only 800,000 light-years away, as Hubble thought, but 1.8 million light-years distant. Likewise, with the two measuring sticks sorted out, the universe we knew in 1920 to be two billion light-years wide has now doubled to five billion light-years across.

This evolutionary theory also accounts for the retreating galaxies. They are all still in flight from the power of the initial blast. There may be other direct evidence of the blast as well. Albert Einstein has predicted that some of the initial heat from that initial explosion will still be glowing dimly in the form of stretched-out waves called "microwaves" at a few degrees above absolute zero. As yet, however, no one has devised a way to detect this theoretical remnant heat.

More accessible evidence for the evolutionary universe comes from Edwin Hubble's 1929 measurements of the velocities of galaxies beyond our own, which built on Hubble's earlier discoveries. Hubble found that the more distant a galaxy is, and therefore the closer in time to the original explosion, the faster it appears to be moving away from us. This is exactly what you'd expect if there was an initial blast that started it all and things have been slowing down ever since.

The discovery is an evolutionary universe, of course, is that it doesn't end happily. There's no last luncheon for all hydrogen atoms and state theory. The universe has finite resources. So it might expand forever as all the stars burn out and the universe cools down to a vast frigid nuclear graveyard. Or the gravity of all matter might eventually pull everything back together

Death of a Genius

again in a gigantic collapse that rebounds and starts the universe all over - the endlessly exploding and collapsing universe described by the late Caltech physicist Richard Feynman. Which theory will prevail? Only more research with bigger and better telescopes will tell.

Origin of Everything: Hot Bang or Ageless Universe?

It's difficult to imagine a deeper mystery than the one being addressed recently at the meeting of the National Academy of Sciences in Pasadena, California: Is the universe eternal or does it have a beginning, middle and an end?

The case for an ageless, steady-state universe which forever looks much as it does today was presented at the conference by astrophysicist Jesse L. Greenstein and physicist William A. Fowler of the California Institute of Technology. The steady state theory rivals the "evolutionary" theory of the universe which calls on an initial burst of fire, the big bang, exploding at the dawn of time and making all the universe's hydrogen and perhaps helium on one fell swoop.

Both theories explain - in entirely different ways - the inescapable fact that the universe is expanding. This cosmic expansion was first detected in 1914, when American astronomer Vesto Melvin Slipher surveyed some galaxies and noticed the light from most of them was "red-shifted." This is essentially the broadening and reddening of the visible light waves caused by the retreat of the galaxies. It's the electromagnetic equivalent of how the wail of a retreating locomotive drops in tone, as it passes by a train watcher's ear.

In the steady-state theory the expansion comes from the continuous bubbling up of the most basic element, hydrogen, from empty space at a rate of one particle every cubic meter every 300,000 years or so. This hydrogen eventually gathers and condenses into stars which, through nuclear fusions in their cores, manufacture all the heavier elements. As stars age and die, they disperse the heavier elements around the galaxies, giving rise to new stars with rocky planets around them - like our own Solar System. As evidence of that process, Greenstein and Fowler referred to the heavy-element-making red giant stars which can be seen today in our Galaxy.

An important aspect of the steady-state is that it's anything but static, as the champions of this theory. British cosmologist Fred Hoyle, likes to point out. Hoyle compares the countless universe to a river, in that it's always changing, but there is plenty of movement and change under the surface. So, to borrow the old river saying, you can never step into the same universe twice.

Then, on the other hand, there is the somewhat less sexy "evolutionary" theory of Russian-born American physicist George Gamow and his colleagues Ralph Alpher and Robert Herman. These scientists call on the explosion and decay of a hot ball of neutrinos at the birth of the universe to create all the hydrogen and some helium. These elements froze out as the blast expanded and cooled. The first stars were made of only these original elements and fused them into new, heavier elements. And then, were dispersed through the galaxies as the first stars died, and led to the less pure mixtures of elements seen in stars now.

Hoyle Scoffs at "Big Bang" Universe Theory

British cosmologist Fred Hoyle has thrown down the gauntlet with regard to where and when all the universe's elements were created. In a recent radio broadcast he pummed a rival theory, championed by Ukrainian-born American physicist George Gamow, labeling it a ridiculous "big bang."

Gamow's "Evolutionary Theory of the universe calls on an initial stew of super-hot nuclear fusions of basic particles to create all the hydrogen in the cosmos in one explosive moment. The same heat then caused space to expand. The ongoing expansion from that "big bang" is observed by astronomers today throughout cosmos.

Hoyle is having none of it. "It is an irritating process that cannot be described in scientific terms - [yet] challenged by an appeal to observation," he has written regarding Gamow's theory.

For one thing, the "big bang" requires something before the explosion. "No one knows what that might be. If on the other hand, the universe is eternal and stars are always being created and forever making heavier elements," Hoyle suggests, there is no need for an initial explosion. Recent advances in nuclear physics seem to back Hoyle's "steady state" view, calling on the pressures and temperatures inside stars to manufacture all the heavy elements seen in the cosmos today.

Size of the Universe:

4 Billion Light Years

Radio 'Ear' on the Universe Being Built

thought to be coming from hydrogen.

The MKI will replace the 216-foot parabolic aerial antenna, also at Jodrell Bank. That pioneering metal ear tall poles and wire mesh that pointed toward the cosmos and radio waves to a single point. Though the center set up allows astronomers some leeway - they can tilt the 196-foot-high central receiver pole somewhat to cover a little more sky - it relies heavily on the shape of Earth's surface as it reflects change in view of the heavens.

Despite that limitation, the eight-year-old parabolic aerial antenna has found that some important discoveries which more than made the effort for building the Mark I, according to its designer Dr. Bernard Lovell of the University of Manchester. Among the most startling discoveries was that there are radio emitters coming from the Great Andromeda Nebula astronomer to explore the entire sky for radio transmissions - something they cannot do today. It will also be able to investigate the recently discovered 14204 Megabertz radio emissions



Albert Einstein in 1950.

The world has just lost its greatest scientific mind. Albert Einstein died in his sleep on April 18th from complications of a lingering gall bladder infection. He was 76. There is no doubt that this rumpled, white-haired, pipe-smoking professor peered deeper into the nature of the universe than any other man. It death he joins a select few - such as Newton, Copernicus, Archimedes and Pythagoras - as a giant in science whose genius changed the course of history.

The immediate outpouring of tributes to the German-born scientist began to convey his place in history. President Eisenhower said "No other man contributed so much to the vast expansion of 20th century knowledge." Moshe Sharett, the Prime Minister of Israel observed "The world has lost its foremost genius." There were even eulogies behind the Iron Curtain. Pravda described him as "A great transformer of natural science."

The true nature of Einstein's achievements are better known to his colleagues and scientific progeny, who still labor to understand, test and apply his theories. There is his revolutionary rethinking of light as not just waves but particles. Then his theory of special relativity, which set speed limit within the universe at that of light. Or his most famous equation $E = mc^2$, which dissolved the wall between matter and energy. Finally, we have his space-time bending theory of gravitation. Taken together, Einstein's ideas are the basis of all modern physics.

For the non-physicist, however, Einstein's genius is a given, but largely a mystery. The man on the street knows that such things as television and the hydrogen bomb are the results of his work, but we scarcely grasp how it is so. We see it, it seems, rather like the name at Einstein's deathbed, who failed to grasp the great man's final words, uttered in German. She did not speak German. Most of us do not speak physics. Instead, we sense the importance of the man in individual and state alike children at a parade, as his name is called out in the crowd.

It's a Star! It's a Nova! It's Super-Nova!

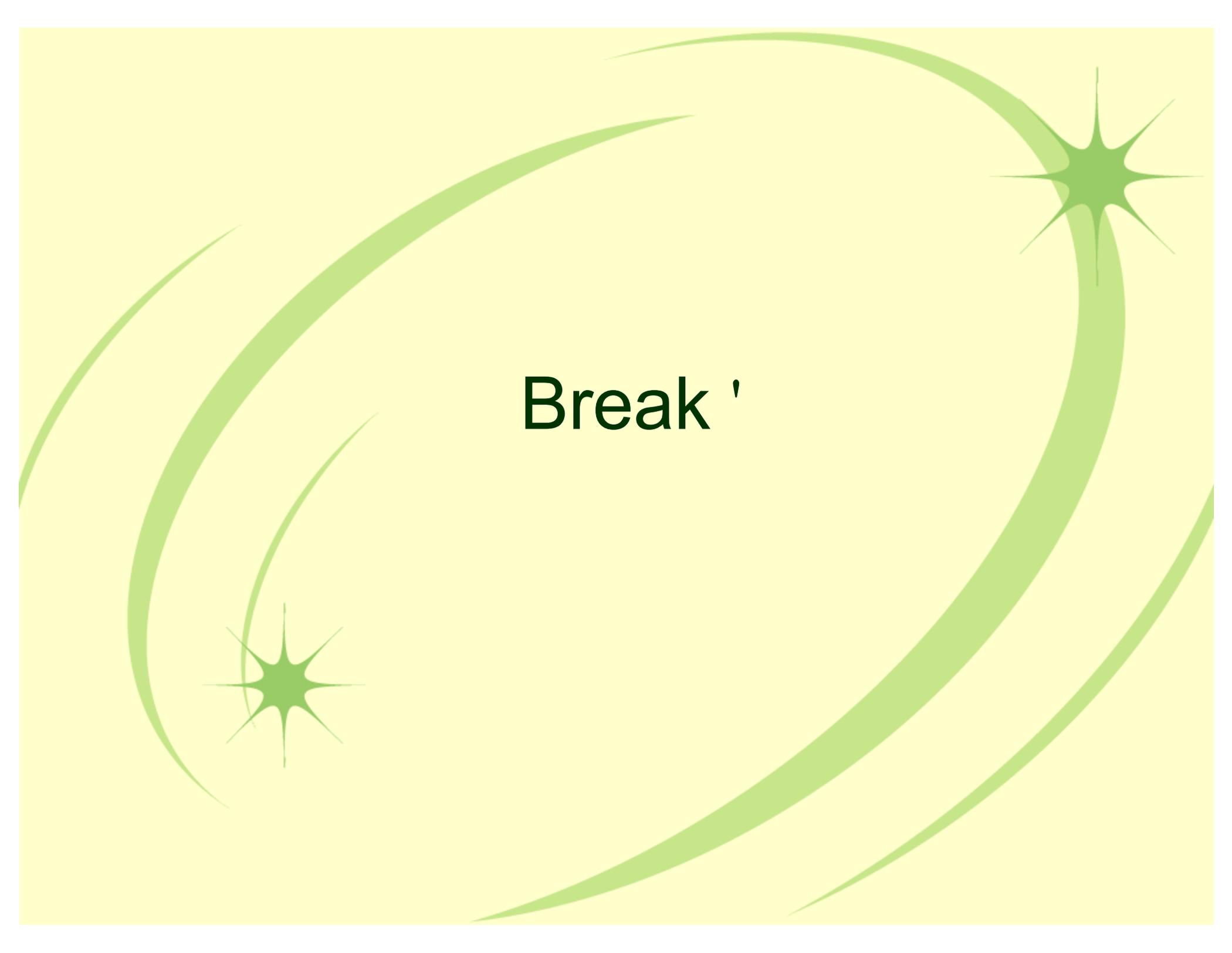
building for decades that three super-novae recently to great brightness, that they actually come in at least two distinct classes. One hand there are pulsars, Clark Kerr like novae and on the other there are truly Super-Novae.

The first clue that there were super-novae lurking among the stars came 35 years ago by the recently deceased astronomer Edwin Hubble. Using his revolutionary method for measuring celestial distances, he calculated that a nova observed in 1885 in the Andromeda Galaxy actually must have been about one hundred times more luminous than any nova recently observed in our own Milky Way Galaxy.

Forteen years later, in 1914, physicists Walter Baade and Fritz Zwicky coined the term "super-nova," when they suggested these were not only far brighter than normal nova, but rare, once-in-a-millennium events in any given galaxy. The most recent super-nova in our own galaxy, they speculated, were those recorded by German astronomer Johannes Kepler in 1604, and another by Danish astronomer Tycho Brahe in 1572.

A new wrinkle in the matter was introduced in 1941 by astronomer Rudolph Minkowski. He split the light from 14 distant galactic super-novae into their component colors and found that nine of the spectra contained no telltale lines for hydrogen (Type I) and the Freid (Type II). The possible reason for this, speculated British cosmologist Fred Hoyle, is that in the superlative violence of their death throes, the giant stars that become super-novae might be capable of fusing hydrogen and helium to forge heavier elements like carbon and iron. They are, then, truly, not only "super," but bona fide Stars of Steel.

26

The background is a light yellow-green color. It features several thick, curved green lines that sweep across the frame. Two starburst shapes, composed of multiple thin green lines radiating from a central point, are positioned on the left and right sides of the image.

Break '

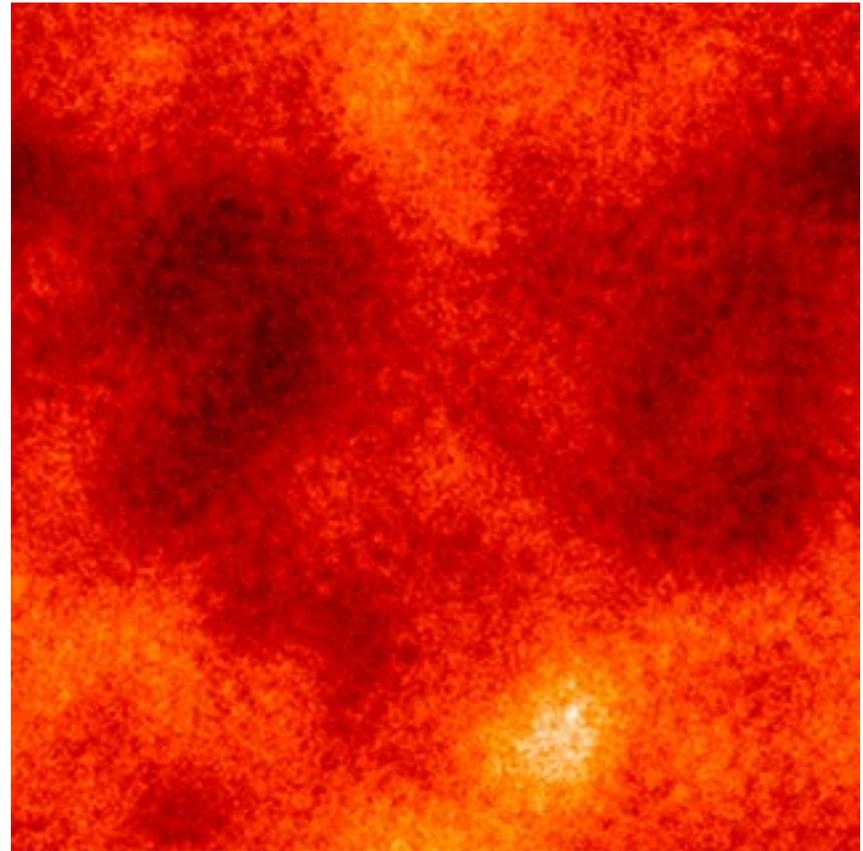
How Cosmic Times ' Came to Be '



- * BE Teacher Focus Group (March 2005) '
- * Idea developed by HEASARC E/PO team '
- * Survey of Cosmologists
- * Trudy Bell sketched out each of the articles '
- * PA teachers developed lessons.

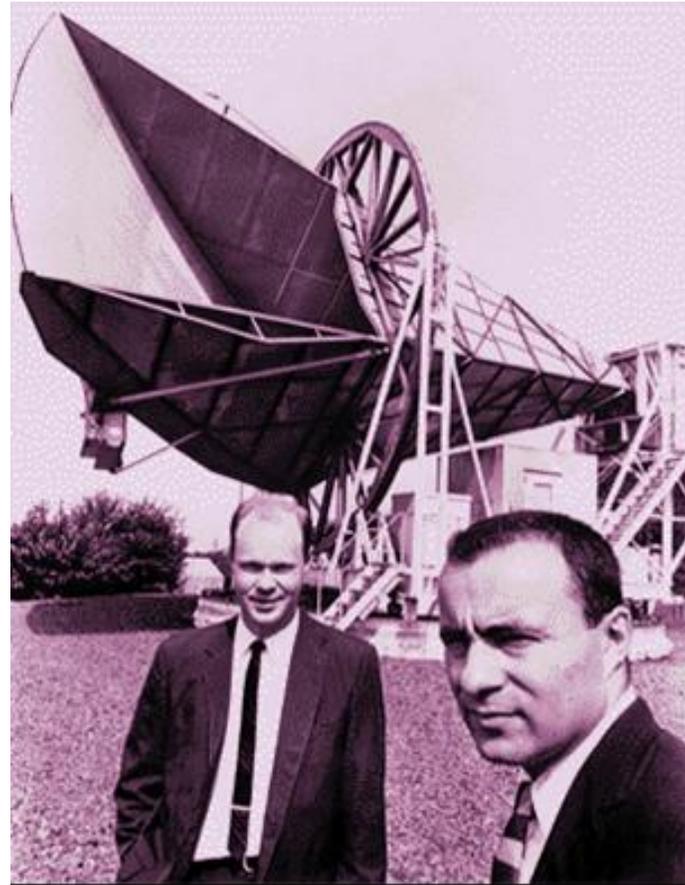
Breaking the Stalemate

- * A hot “bang” should leave left-over heat. '
- * Where to look in the ' EM spectrum? '
- * Many looked. Some concluded it would be ' too faint to detect. '
- * Without both the data ' and the theory, the dots could not be connected. '



In 1965, Enter Dumb Luck* '

- * Penzias and Wilson were making radio observations of the Milky Way.
- * Left with mysterious 3 K residual noise in their detector.
- * Peebles and Dicke (Princeton) had just calculated an estimate for the temperature of the residual background in the microwave region.



* Not to imply that the researchers were dumb – quite the opposite, in fact! '

In 1965, Enter Dumb Luck

- ✦ The CMB predicted by Big Bang theory. 'Steady State theory has no such prediction. 'The signal peaks in the microwave, so is called 'the Cosmic Microwave Background radiation, or CMB for short. '

Age of the Universe:
10 - 25 Billion Years

COSMIC TIMES

1965

Size of the Universe:
25 Billion Light Years

MURMUR OF A BANG



Robert Wilson (left) and Arno Penzias stand in front of their horn reflector antenna in Holmdel, New Jersey. They discovered a radiation signal that matches that expected by theorists who proposed that the universe began with a hot explosion called the "big bang." This discovery was made by accident as they tried to track down the source of unwanted noise in their receiver.

Astronomers have identified a faint cosmic radio rumble as the distant roar of the universe's birth. The discovery not only provides the first observational evidence that the universe started with a "big bang," but it also has implications for how it might end.

The faint radio hiss comes in the form of 7.3-centimeter microwaves, which lie on the electromagnetic spectrum between radio waves and infrared light. The microwaves come from every direction in space, without regard to time of day or season. The background radiation signal matches that expected by some theorists who proposed that the universe began with a hot explosion of hydrogen about seven billion years ago and has been cooling ever since.

The discovery of what's being called "cosmic black body radiation," where the wavelength of radiation emitted is directly related to the temperature, was made more or less by accident by Arno Penzias and Robert Wilson of Bell Telephone Laboratories. The two were trying to track down the source of unwanted radio noise in the 20-foot horn reflector antenna at the Crawford Hill Laboratory in Holmdel, N.J. The "Holmdel horn" antenna was built to test telecommunications with the Echo satellite.

When the Holmdel horn was aimed at zenith, Penzias and Wilson found that it picked up the 7.3-centimeter microwave signal consistent with a temperature of 0.7 degrees Kelvin. That is to say, it corresponded to 6.7 degrees above the theoretical value of absolute zero, at which there is no thermal energy at all. After subtracting natural microwave energy emissions from Earth's atmosphere and energy losses in the antenna itself, Penzias and Wilson were left with an unexplained temperature of about 3.5 degrees Kelvin, give or take one degree, coming from empty space.

Luckily, just down the road some Princeton scientists had the solution. Astronomer Robert Dicke and his team were in the process of building a radio telescope that would be used to probe the whisper of the Big Bang. When they heard about Penzias' and Wilson's mystery microwave hiss, they knew it was their prey. After confering, the Bell Lab and Princeton teams announced the discovery in a pair of letters published in the July issue of *Astrophysical Journal*.

"The presence of thermal radiation remaining from the fireball is to be expected if we can trace the expansion of the universe back to a time when the temperature was of the order of a billion degrees Kelvin," wrote Dicke and his

Big Hiss Missed By Others

One of the biggest surprises from the recent discovery of the Big Bang's faded thunder is how many times others have missed it.

Last last year, Russians Andrei Doroshkevich and Igor Novikov published a study that calculated correctly that, if the Big Bang happened, the remnant heat would be between 1 and 10 degrees Kelvin. They even proposed searching for the signal in sky temperature measurements made by Edward Orn in 1961.

Ironically, Orn had gathered that data using the same Holmdel horn antenna used by Arno Penzias and Robert Wilson this year at Bell Laboratories to identify the 3.5 degree Kelvin background radiation of the Big Bang. But Orn found a 3.5 degree Kelvin noise that he assumed was coming from the antenna itself. The Bell Laboratories team has been able to say with far more confidence that the faint cosmic static truly came from space, because they had to weed out the antenna's own noise to arrive at their conclusion.

There were two other near misses as well. Ten years ago Ennio Le Roni reported a background radiation of 3 degrees Kelvin, plus or minus 2 degrees, while studying the sky in the 31-centimeter radio wavelength at Paris' Nançay Radio Observatory. In 1957, Russian Tigran Shabatov nearly made the discovery, reporting that he measured a background temperature of 4 degrees Kelvin, give or take 3 degrees, while looking at a 3.2-centimeter wavelength of microwaves.

The missing piece in both Le Roni's and Shabatov's work was the connection of what they had seen to theoretical predictions from the Big Bang made as early as 1948. It was a matter of having the right data, without a theory to make sense of them. Penzias and Wilson would have fared no better had not their neighbors at Princeton helped them recognize the noise as the long-sought radiation.

Galaxies Still Misbehaving

Recent attempts to weigh galaxies still come up a bit short. Two spiral galaxies under study, NGC 3521 and NGC 972, have weighed in at 80 billion and 12 billion suns, respectively. The puzzle is why the amount of starlight from these galaxies doesn't add up to such huge amounts of matter.

The starlight measurements of the two galaxies are based on careful accounting of the galaxies' total luminosity, or magnitude, as recorded on photographic plates. It also takes into account the way the galaxies' stars are arranged from their centers to the edges.

The mass measurement is based on the same idea that long ago allowed astronomers to calculate the mass of the Sun (if a relatively small-mass object orbits a very large-mass object at a known speed, the larger object's mass can be determined mathematically). The same physics applies to stars orbiting a galaxy's center of gravity.

Since the motions of the extremely distant stars are not detectable through any telescope, researchers sampled fields of galaxies starlight from different parts of the galaxies and split the light into spectra—their rainbows of color. These spectra contain patterns of lines, representing different energies, that shift in proportion to the speed of the stars.

To make comparisons easier, astronomers blend luminosity and mass measurements into a single number called a mass-to-light ratio. Our Sun, for example, has a mass-to-light ratio of one "solar mass" divided by one solar luminosity, which equals 1. A ratio greater than 1 implies more mass than luminosity—which means that some mass isn't accounted for.

In the case of NGC 3521, measurements from the University of Texas' powerful 62-inch telescope at McDonald Observatory give it a mass-to-light ratio of 4 or greater. NGC 972 is a bit less worrisome, with a ratio of 1.2. These results were reported in recent issues of *Astrophysical Journal* by teams of researchers led by Margaret Burbidge of the University of California at

SUPERNOVAE LEAVE BEHIND COSMIC X-RAY GENERATORS

Two years after discovering that the universe is awash in X-rays, astronomers are starting to pinpoint discrete sources with greater accuracy—and none of which resemble your doctor's X-ray machine.

One source is the Crab nebula, the remnant of a supernova that exploded nearly 900 years ago. Another, designated 0809+51, is a faint, tantalizingly close to the size of another past supernova, SN 1604. In fact, the distribution of many sources in the galaxy mimics that of the known supernova remnants, suggesting that supernovae may leave behind X-ray generators. The exact cause of the X-ray radiation is still a mystery, but if 0809+51 is, indeed, indeed, indeed, originate from a supernova remnant, then a comparison of these two sources may peel back some of the mystery.

The feat of namingowing down these sources shows the power of modern astronomical X-ray instruments for rockets and then obtain enough observing time on them for sufficient measurements. Rockets are needed because X-rays cannot penetrate Earth's atmosphere. The atmosphere protects life from dangerous X-rays in space, but it also makes advancing the fledgling field of X-ray astronomy rather difficult and expensive.

The identification of these X-ray sources is the culmination of about three years of rocket flights searching for sources other than the Sun, which is weak in X-rays. The first rocket launch in 1962 used to previous five minutes in space to observe the Moon in X-rays. Riccardo Giacconi and his team at Princeton's Office of Engineering, Inc. expected to discover minerals fluorescing in X-rays as a result of being hit by heavy atomic particles from the Sun.

What they found instead was just unexpected and far more amazing. A seemingly uniform X-ray

QUASARS: Express Trains To Netherworlds

Astronomers have discovered a quasar racing towards the edge of the known universe at the unprecedented speed of 450 million miles per hour—two-thirds of the speed of light! This and other new-found quasars have more than just going for them, however. The fact that these strange objects are visible to us from these far distances means they must be fantastically bright.

For years, radio astronomers have seen quasi-stellar objects, or quasars, adding them to a growing list of unexplained "radio" sources all over the sky. In 1960, astronomers managed to match a quasar with an object seen by optical telescopes. But it was only two years ago that astronomers Jesse Greenstein and Martin Schmidt managed to determine the speed of one.

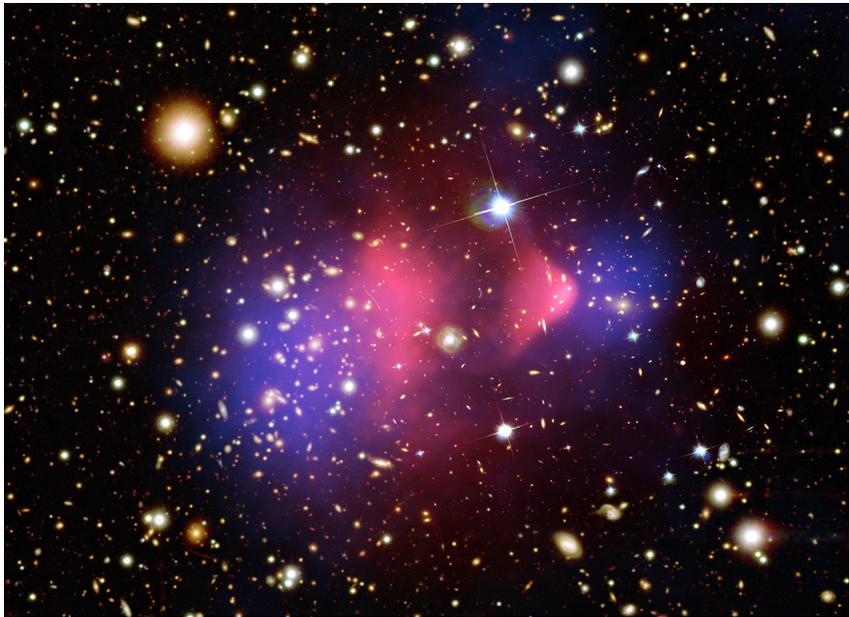
That was when Greenstein and Schmidt split the visible light from quasar 3C 273 into its spectrum of colors. What they found was jaw-dropping. The telltale pattern of spectral lines, which signify the presence of specific elements, were shifted dramatically to the red side of the spectrum, the optical equivalent of a train whistle's tone dropping as the train moves away. In the case of 3C 273, the redshift corresponded to an astonishing speed of 16 percent of the speed of light—more than 100 million miles per hour. The same technique was used by Schmidt and Caltech's Allan Sandage to check the latest record holder, dubbed quasar B50-1.

No one has yet explained what a quasar is, but Sandage reported, "We do know that [quasars] provide us with the long-sought keys to determine the size and shape of the universe."

Scientists are confident that at least one theory can be ruled out. Quasars are not coded messages from a super-civilization, as has been suggested by Russian astronomer Nikolai Kardashev. It is highly improbable that any civilization could broadcast messages with the power of 10,000 billion suns.

Any message from quasars may be from the universe itself. Astronomers at the 200-inch Mount Palomar telescope hope that, by measuring the distance to more quasars, they can catch a glimpse of some that started shining when the universe was just seven percent of its current age. Some of that light, perhaps 15 billion years old, is only now reaching Earth.

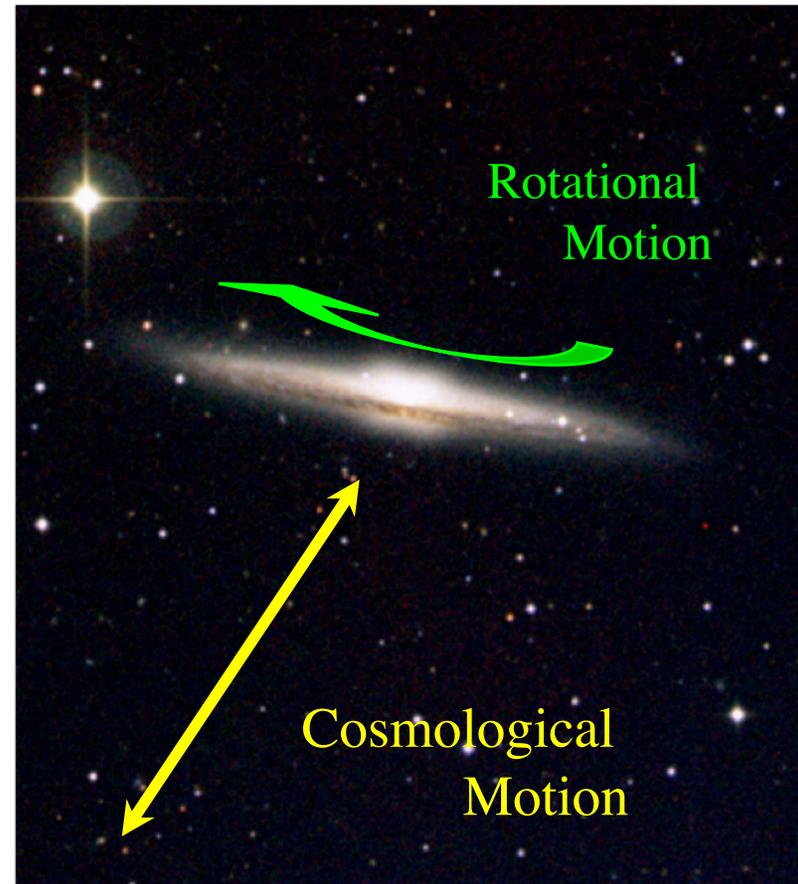
Galaxies still misbehaving



- * In the '60s, researchers ' start to “weigh” galaxies
- * They begin to find that there must be “unseen” matter to account for their observations
- * Not the first glimpse at unseen matter - Zwicky ran into trouble when he measured mass in clusters in the '30s

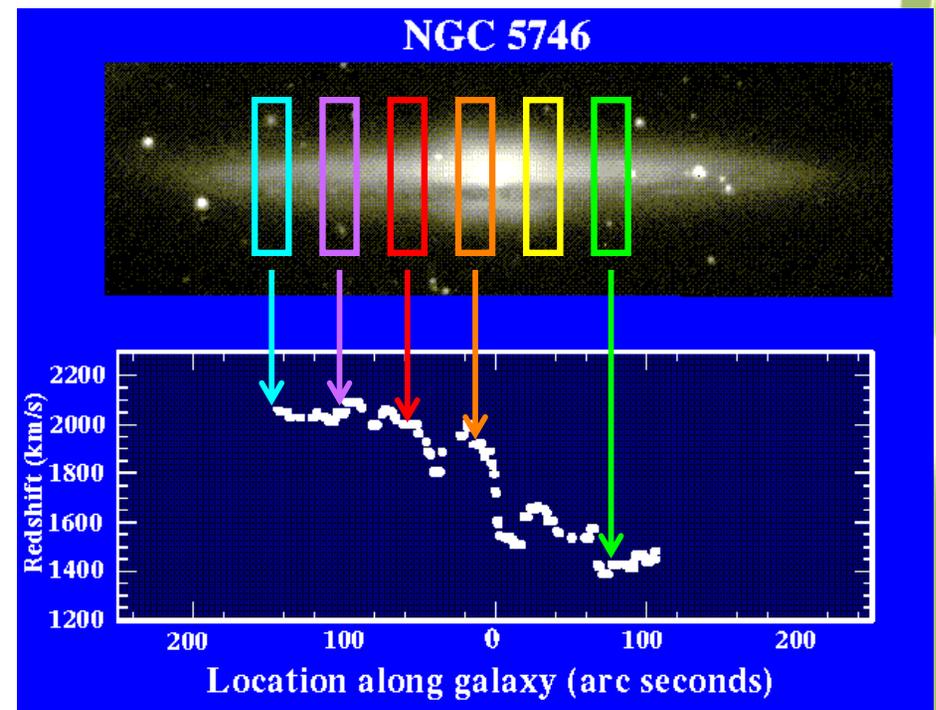
Galaxies still misbehaving '

- * Use redshift to map the rotation of a galaxy.
- * Here we are interested in the rotational redshift.



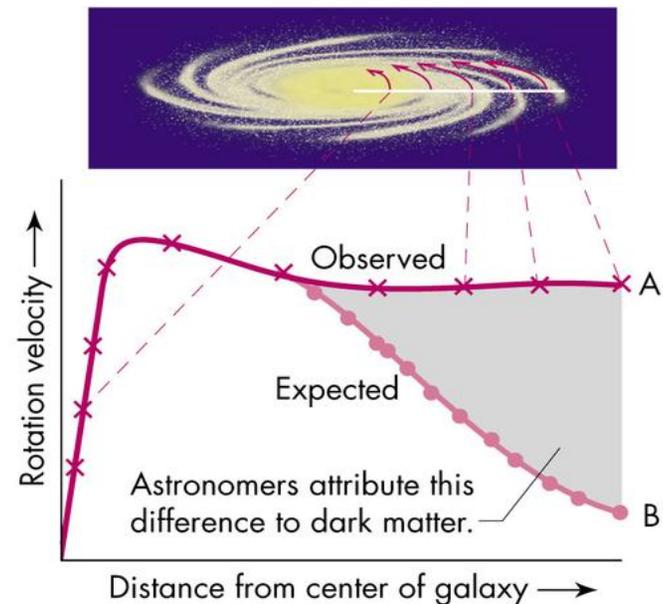
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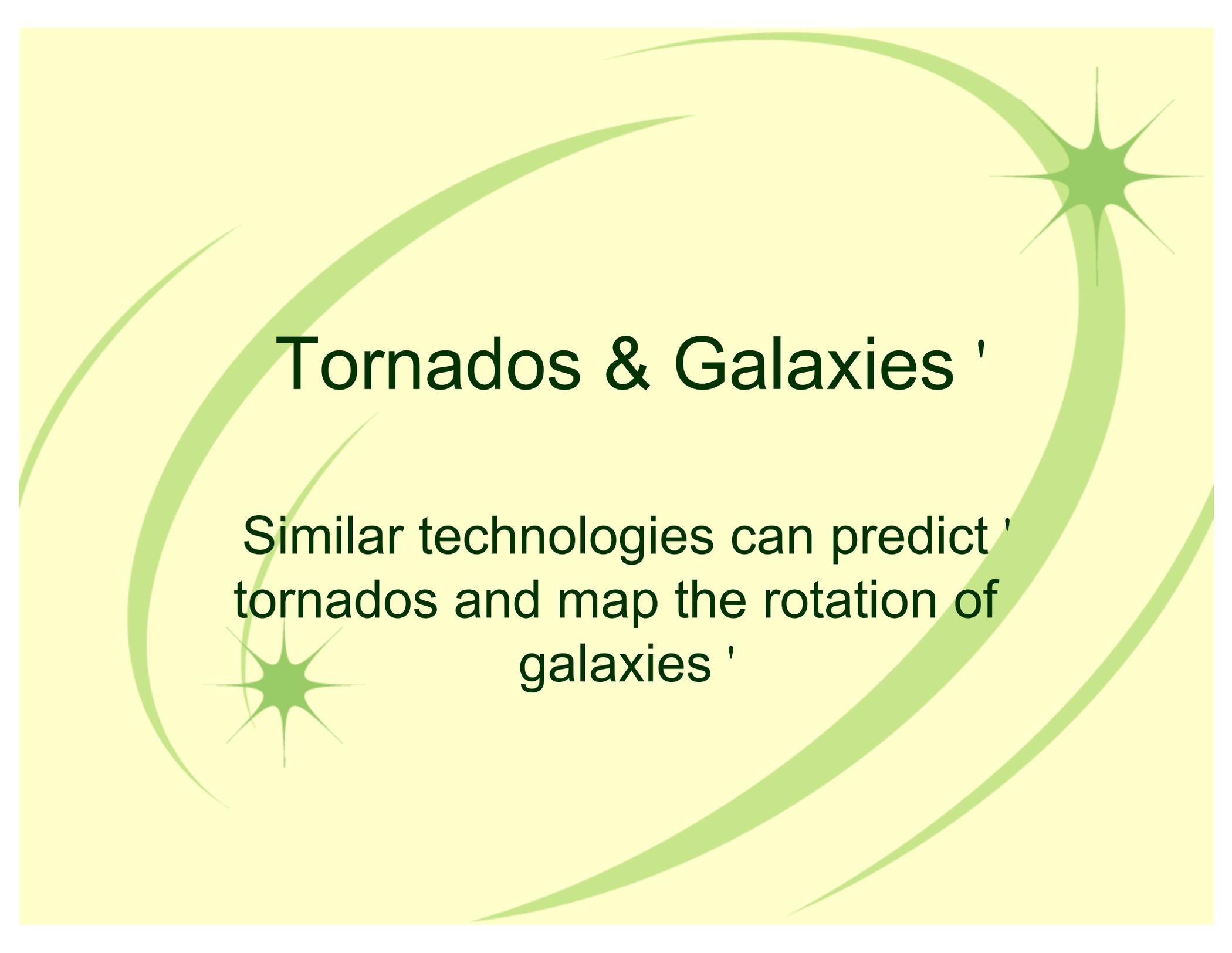
- * Use redshift to map the rotation of a galaxy. '
- * Here we are interested in ' the rotational redshift. '
- * Create a map by ' determining the redshift of ' several slices of the galaxy. '



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- * Create a map by determining the redshift of several slices of the galaxy. '
- * Compare the resulting rotation curve to that ' expected if all of the mass were visible as luminous ' matter ' '





Tornados & Galaxies '

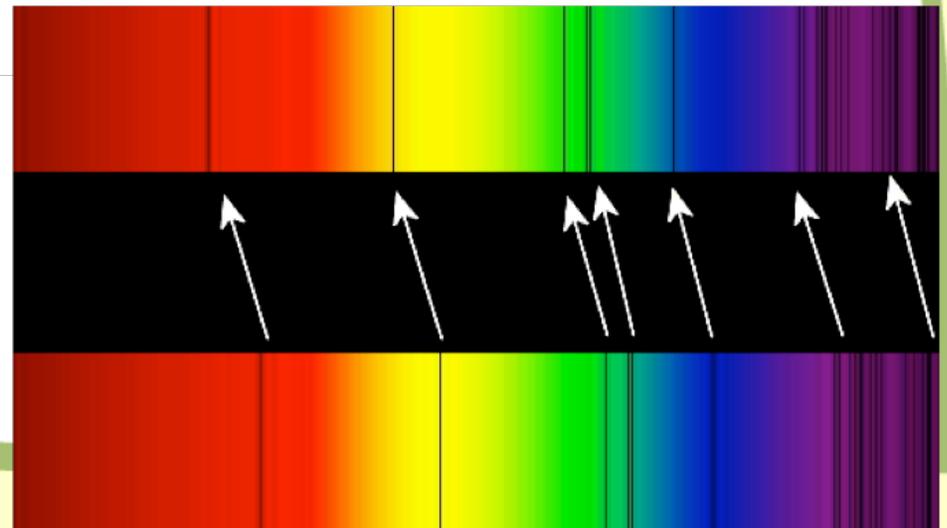
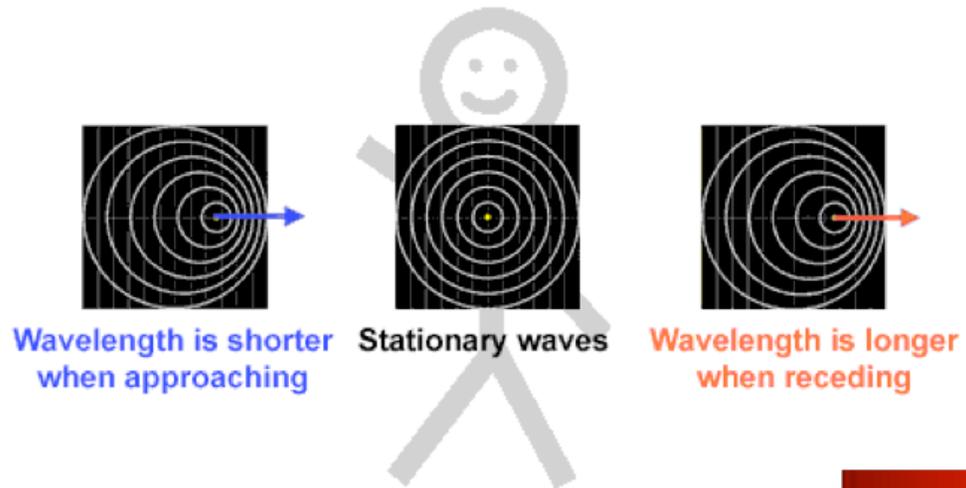
Similar technologies can predict '
tornados and map the rotation of
galaxies '

Tornados & Galaxies '

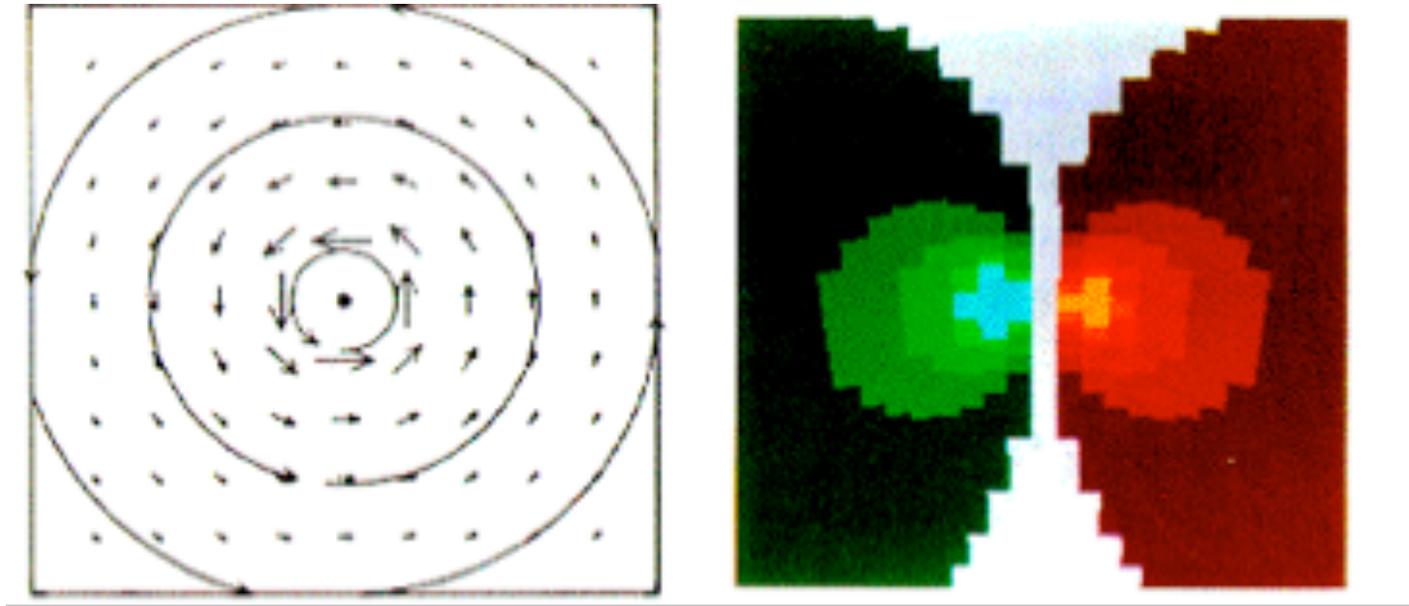


Tornado image from Florencia Guedes on Flickr

Doppler shift '



Doppler mapping '



1965 Lessons

- * Reading Strategies
 - * Can be applied to any of the articles
- * What's the Matter?
 - * Modeling dark matter through hidden densities
- * Cosmic Microwave Background
 - * Illustrating the nature of the CMB '

Other 1965 Stories

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MURMUR OF A BANG

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In the case of NGC 3521, measurements from the University of Texas' powerful 32.8-inch telescope at McDonald Observatory give it a mass-to-light ratio of 4 or greater. NGC 972 is less worrisome, with a ratio of 1.2. These results were reported in recent issues of *Astrophysical Journal* and *Astronomical Journal* by Margaret Burbridge of the University of Cambridge.

QUASARS: Express Trains To Netherworlds

Astronomers have discovered a quasar racing across the edge of the known universe at 99.999 percent of the speed of light. This and other new-found quasars have more than speed for them, however. The fact that these objects are visible to us from these far distances means they must be fantastically bright.

For radio astronomers have seen a growing list of unexplained "loud" radio sources all over the sky. In 1960, astronomers managed to match a quasar with an object seen by optical telescopes. But it was only two years ago that astronomers Josee Greenstein and Maarten Schmidt managed to determine the speed of one.

That was when Greenstein and Schmidt split the visible light from quasar 3C 273 into its spectrum of colors. What they found was jaw-dropping. The telltale pattern of spectral lines, which signify the presence of specific elements, were shifted dramatically to the blue side of the spectrum, the optical equivalent of a train whistle's tone dropping as the train moves away. In the case of 3C 273, the redshift corresponded to an astonishing speed of 16 percent of the speed of light—more than 100 million miles per hour. The same technique was used by Schmidt and Greenstein's Adam Riess to clock the latest record holder, dubbed quasar BSO-1.

No one has yet explained what a quasar is, but Sandage reported, "We do know that [quasars] provide us with the long-sought keys to determine the size and shape of the universe."

Scientists are confident that at least one theory can be ruled out. Quasars are not cooled messages from a super-civilization, as has been suggested by Russian astronomer Nikolai Kardashev. It is highly improbable that any civilization could broadcast messages with the power of 10,000 billion suns.

Any message from quasars may be from the remote future. Astronomers at the 200-inch Mount Palomar telescope hope that, by measuring the distance to more quasars, they can catch sight of some that started shining when the universe was just seven percent of its current age. Some of that light, perhaps 15 billion years old, is only now reaching Earth.

SUPERNOVAE LEAVE BEHIND COSMIC X-RAY GENERATORS

After discovering that the universe is crisscrossed by X-ray sources, astronomers are now hunting for the sources with greater accuracy—and some of which resemble your doctor's X-ray machine.

One source is the Crab nebula, the remnant of a supernova that exploded nearly 900 years ago in the constellation of Ophiuchus. XR-1, first spotted by looking close to the site of another past supernova, SN 1054, in 1964, is the distribution of X-ray sources in the galaxy mimics that of the known supernova remnant, suggesting that supernovae may leave behind X-ray generators. The exact cause of the X-ray radiation is still a mystery, but if Ophiuchus XR-1 does indeed originate from a supernova remnant, then a comparison of these two sources may peel back some of the mystery.

The feat of naming down these sources should not be underestimated. Scientists have developed improvements to astronomical X-ray instruments for rockets and then obtain enough observing time on them for sufficient measurements. Rockets are needed because X-rays cannot penetrate Earth's atmosphere. The atmosphere protects life from dangerous X-rays in space, but it also makes advancing the fledgling field of X-ray astronomy rather difficult and expensive.

The identification of these X-ray sources is the culmination of about three years of rocket flights searching for sources other than the Sun, which is weak in X-rays. The first rocket launch in 1962 used its precious five minutes in space to observe the Moon's X-rays. Rocket scientist and his team at American Science and Engineering, Inc. expected to discover minerals fluorescing in X-rays as a result of being hit by heavy atomic particles from the Sun.

What they found instead was unexpected and far more amazing. A seemingly uniform X-ray

An Archer, rocket launched from Wallops Island, Virginia. This is similar to those used in recent discovery of cosmic X-ray sources such as Scorpius XR-1 and recently the Crab nebula and Ophiuchus XR-1.



41

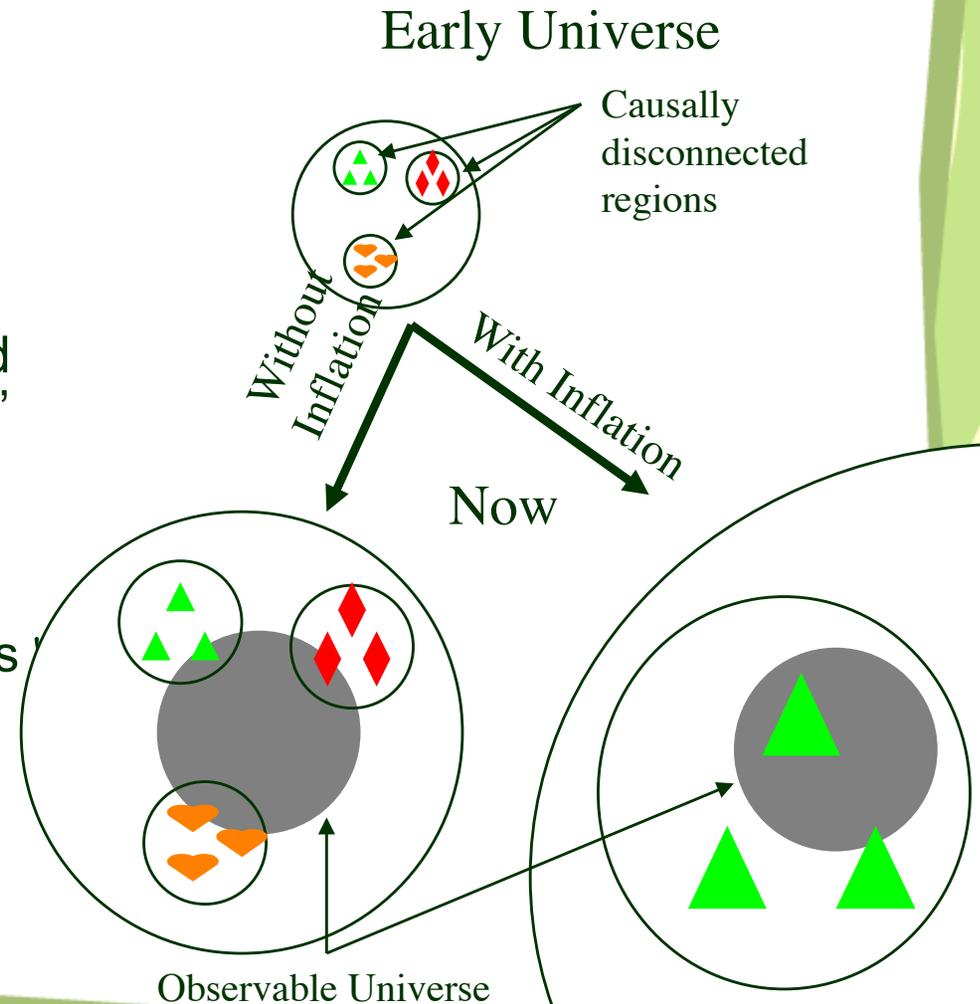
Trouble in the Early Universe '

- * By the 1970s, three serious problems ' were emerging with Big Bang Theory '
 - * Horizon problem - disparate regions of the Universe should not have been able to “talk”, and yet they look nearly homogeneous.
 - * Flatness problem - the Universe is too flat!
 - * Magnetic Monopoles - where are they?

Inflation to the rescue

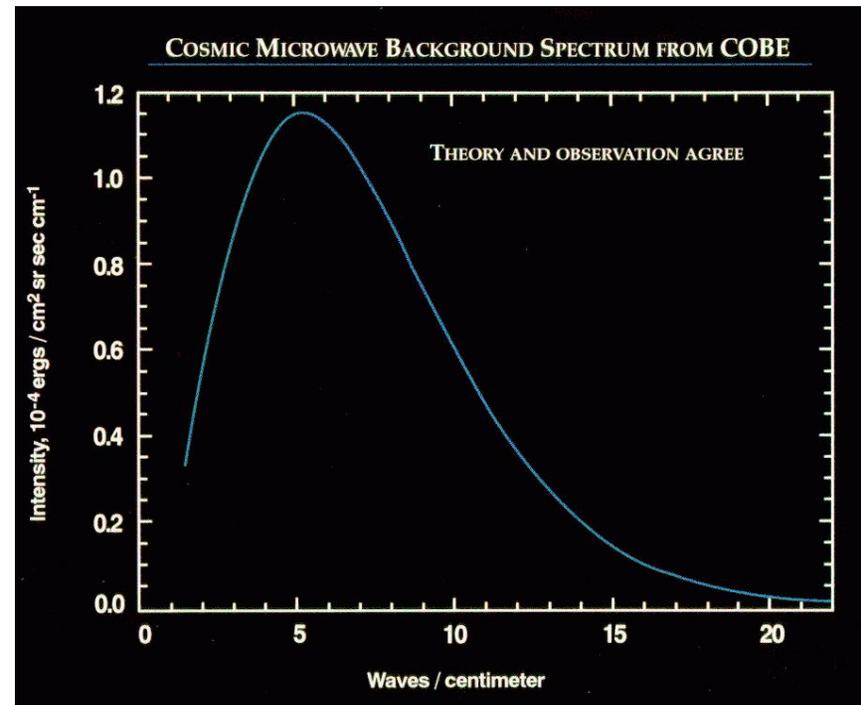
* Inflation Theory (early '80s) takes care of these issues)

- * The Universe we see all started in a small, "causally-connected" region
- * This region underwent an exponential expansion '
- * The detailed mechanism for this expansion is not currently understood '
- * However, inflationary theory makes predictions that have been shown to be correct '



Perfect Black Body! ' But, where are the lumps? '

- * The Cosmic Background Explorer is launched in 1989 to examine the CMB in finer detail '
- * The first result was the ' spectrum of the CMB '
- * Which was a **perfect** black body (the error bars are contained in the line thickness!) '
- * Almost too perfect!



Astronomers hold their breath ' for two years...

- * Some “lumps” are needed in the CMB to act as seeds of the structure we see in the Universe today - galaxy clusters, galaxies, stars, everything
- * If the lumps were not detected by the limit of COBE’s abilities, the Big Bang and Inflationary theories would all be in trouble

At Last, a Lumpy Universe

✦ NASA's COBE mission finds "lumps" in the CMB!

✦ These "lumps" are tiny, consisting of changes on the order of 1 part in 10^5 .

✦ But they are enough to produce the structure we see.

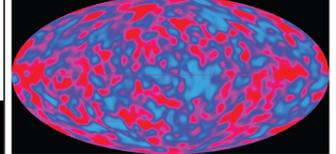
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What did the newborn universe look like? In 1965, scientists peered into the distance with a radio telescope, and discovered a microwave background that was rather plain and featureless. Today's technology has drawn a more detailed picture of this cosmic microwave background, telling us there's a lot more to the story... and providing further evidence of the Big Bang.

Scientists have now confirmed the existence of these very slight... but now clearly measurable... energy differences. Smoot and his team created an all-sky map of these microwave variations, illustrating for the first time these anisotropies, or "lumps," in the oldest light in the universe. The COBE data shows the abundance from the very early universe, only 300,000 years after the Big Bang. The current age of the universe is estimated at 12 to 20 billion years.

COBE excited scientists three years ago with data that exactly matched what they had expected from a Big Bang universe. COBE measured the spectrum of light from the CMB and found that it was, as predicted, in the form of a perfect blackbody curve. These data were collected by COBE on an instrument designed by John Mather of NASA's Goddard Space Flight Center, who also headed the COBE project.

With the addition of the latest findings, the eight-decade-old Big Bang theory, with the addition of inflation, is now firmly the lead model for how the universe began. Other models either cannot account for COBE's results or must undertake some difficult and unattractive corrections to do so.

The lumps in the map do not correlate with anything particular in the night sky today, but they are of distinct importance, say the researchers. If the theory was perfectly uniform, according to them, we could not exist! So while the greatest variations in the CMB are only a few tenths of one part in 100,000, they are sufficient to ultimately lead to the current structures in the universe.

Princeton astrophysicist David Spergel observed at the meeting, "It's the most important discovery in cosmology in the past 20 years."

Dark Matter Hunt Heats Up

The mystery of dark matter just deepened with a new report of about 20 trillion suns-worth of the invisible, unexplained stuff hanging out in a small cluster of galaxies.

The vast mass of dark matter was found using the ROSAT X-ray satellite. ROSAT detected a gigantic cloud of very hot gas in a very unexpected place: the seemingly empty space between two galaxies. This cloud is a surprise because its great heat - detected from its radiation of X-rays - should have made the gas quickly dissipate.

The existence of the hot gas cloud can only be explained by the existence of a gravitational force to hold it in place. Only dark matter could do the job without being seen, explains Richard Mushotzky of NASA's Goddard Space Flight Center.

What's more, the hot gas requires an amazing 30 times more dark matter than visible matter in the cluster to achieve this, says Mushotzky. The normal matter ROSAT observed is just a small fraction of what's really there.

If that sort of dark matter ratio holds true throughout the cosmos, dark matter could determine the fate of the universe. Its gravity could be enough to someday reverse the direction of matter and energy flung out by the Big Bang and pull the universe back together into a "Big Crunch," say some researchers.

An earlier case for the existence of dark matter was that made by astronomer Vera Rubin in 1970. She studied the rotation rate of stars in the Andromeda galaxy and found that it just didn't make sense. The stars in the disc farther from the galactic center were rotating more slowly than those closer in, as models predicted they should.

Pulsar Gravitational Waves Win Nobel Prize

This year's Nobel Prize in Physics was awarded for the amazing discovery of the first evidence, albeit indirect, for the existence of gravitational waves.

In 1974, Princeton University astronomers Russell A. Hulse and Joseph H. Taylor located PSR 1513-16, which is a special type of superdense neutron star called a pulsar. This pulsar emits a radio pulse every 59 milliseconds as it rotates on its axis. It is locked in a dizzying eight-hour orbit with another star, which is likely to be another neutron star.

Four years later, after some careful timing measurements of the pulsar, they found that two stars are spinning closer to each other by about three millimeters per orbit. That could only happen if something was pulling energy out of the system. But what was it?

Einstein's theory of general relativity provides the answer. It predicts that two massive objects tearing around in a strong gravitational field radiate gravitational waves out into space. This extracts energy from their orbits, and causes them to drift in closer to each other. The 8-hour orbit should be 75 microseconds shorter every year.

After 18 years of refinement, Taylor has honed down the timing of PSR 1513-16's orbital periods to within 1/3 percent of general relativity predictions - strong confirmation of the existence of the gravitational waves predicted by Einstein.

The pulsars won't be colliding any time soon. Although each neutron star is 7 miles in diameter and 1.4 times the mass of the Sun, they are still about a million miles apart. At their present rate, it will take 300 million years for the stars to merge.

Fool-Proofing Galactic 'Candles'

The "standard candle" used for measuring the distance to other galaxies just got a much-needed upgrade.

For years, the bright supernovae created by the deaths of white dwarf stars in binary systems, known as Type Ia supernovae, have been a standard candle. Wherever they occurred, they were believed to have roughly the same intrinsic brightness. So scientists used them to calculate the distance to the galaxies in which they occur. But recent research has revealed a way to greatly improve the accuracy of these calculations.

In the 1940s, astronomers realized supernovae came in two flavors: some (later called Type I) did not show any evidence of containing hydrogen, while others (denoted Type II) did. The lack of hydrogen means that the star has used up the basic fuel that drives nuclear reactions in stars. Type II's were found to result from the death of a single, massive star. In the 1980s, however, it became clear that some Type I's also come from the death of a massive star. The remaining Type I's, now called Type Ia, were found instead to result from the collapse of a white dwarf star in a binary star system.

In a binary system, a white dwarf can gain mass from its companion star. With sufficient mass gained from the companion, the white dwarf reaches a critical mass at which nothing

Inflation in the Universe

The Big Bang theory has a problem, say scientists. It can't go from a tiny ball of energy to the universe we see today without some help in an adjustment called inflation.

Astronomers observe that the overall temperature of the cosmic microwave background (CMB) is nearly smooth and uniform. The temperature can become uniform only if distant regions can interact and exchange energy. The fastest interactions occur at the speed of light. However, at the time the CMB radiation was emitted, two regions that are far apart in the sky today would have been separated by more than the light travel distance in the young universe. So why is the CMB temperature so nearly uniform?

Inflation theory explains this by stating that shortly after the Big Bang, the universe underwent a very rapid expansion in a very short amount of time. This expansion gave the size of the universe by a factor of 10^{26} in about 10^{-32} seconds. This region, only in contact with each other as now in the Big Bang era of the universe. The overall uniformity of the background temperature expanded with inflation. Particle physicists think that inflation might be a natural by-product of the transition in which the grand unified force separated into the strong nuclear

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can counteract the inward crush of gravity of the star on itself. The white dwarf collapses and explodes as a Type Ia supernova.

Since all Type Ia's are created by the explosion of a white dwarf star as it exceeds a critical mass, astronomers believed they should all have the same intrinsic brightness, and be useful as a measuring stick to distant galaxies. In addition, Type Ia's may be visible at distances greater than the Cepheid variable stars, identified as standard candles in 1912 by Henrietta Leavitt.

But a target not at all Type Ia's are equal either. A large sampling of supernovae has revealed that the pattern of brightening and fading over days - known as a light curve - varies a great deal. Astronomer Mark Phillips at the Cerro Tololo Interamerican Observatory in Chile found that the infrared light curves of some brighter Type Ia's fade more slowly over the first 15 days than do those of dimmer ones.

By sorting the dim, fast-fading supernovae from the bright, slow-fading ones, Phillips arrived at a luminosity-distance relation. It allows calculation of a correction factor for supernovae that are dimmer than the standard Type Ia supernovae. Astronomers can adjust the distance accordingly, and increase the accuracy of the distance measurements.

Pancake or Oatmeal Universe - What's for Breakfast?

Over its lifetime, the universe started out smooth, but has grown lumpy.

The COBE results present what has been called an isotropic, or smooth, early universe - with measured variations in the cosmic microwave background radiation of only 1 part in 100,000. You might say that, at that time, the universe was like the surface of a pancake: smooth as a glance, with differences in texture seen only under close inspection.

The universe today is more like a bowl of oatmeal, with real "lumps" and clumps of mat-

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ter and energy. Objects from planets and stars to galaxies and galaxy clusters are classed as lumpy. Nonetheless, overall the universe is much smoother than was predicted by the original Big Bang. This problem has been solved by inflation.

While the early universe was extremely smooth compared to today, those minuscule lumps in it were vital. Through the action of gravity, they led to the much bigger lumps we see today, the ones that make our very existence possible.

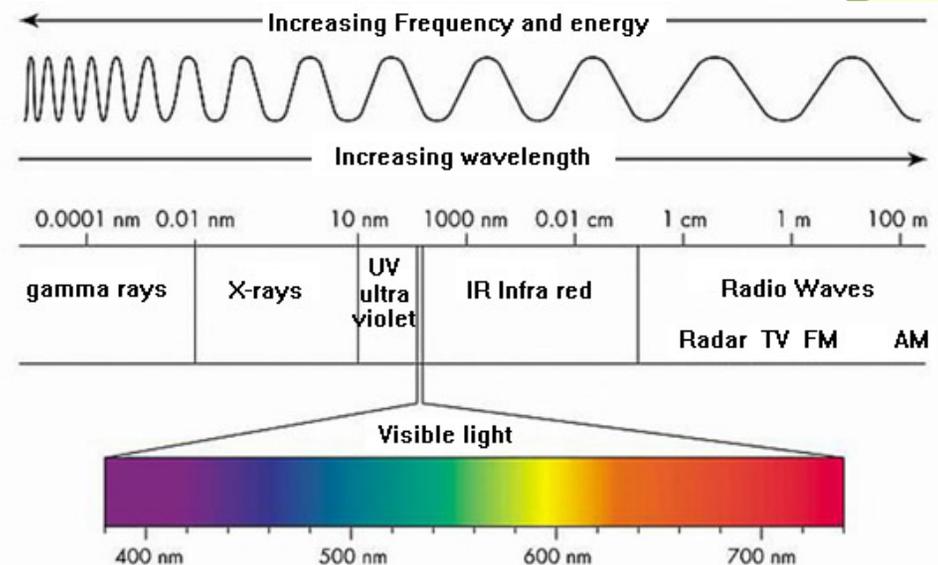
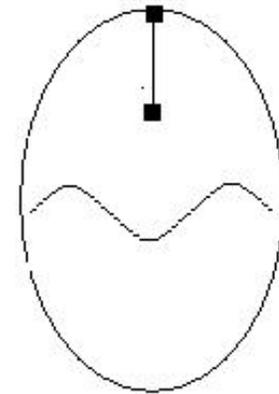
COBE's map of the sky, showing minute fluctuations in the cosmic microwave background, demonstrates that 30 maps show the background radiation 300,000 years after the Big Bang (NASA image)

It is a mystery why the cluster is populated exclusively by the ROSAT satellite in the region in this group of galaxies. The presence of the gas provides evidence for the existence of dark matter (NASA image)

Russell A. Hulse and Joseph H. Taylor, both of Princeton University, shared the 1993 Nobel Prize in Physics for their discovery of pulsars of gravitation waves, confirming the predictions by Einstein in 1916.

Let's Explore the CMB'

- * Take balloon and draw a line connecting two dots and a wavy line, as pictured
- * The “dots” represent galaxies.
- * The “wave” represents the wavelength of light emitted in the Big Bang.

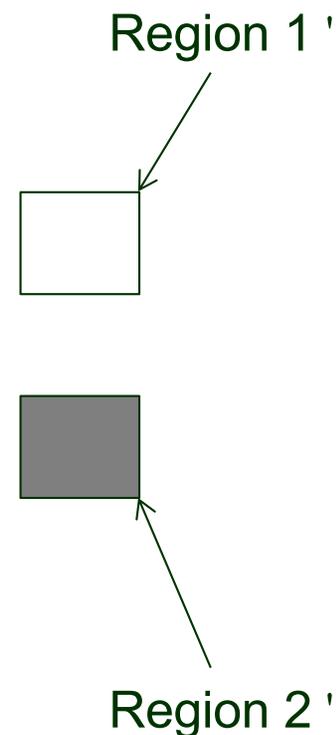


Characteristics of the CMB?

- * We've seen that the CMB is
 - * isotropic – observed in all directions
 - * smooth – similar in all directions
- * What does our Universe look like ' today? '
 - * Lumpy/structured, not smooth!
 - * Problem!! We need *some* lumpiness – some “anisotropies”

Explore CMB Anisotropy '

- * Go back to your balloon, turn it to the other side and draw two regions.
- * Imagine that gray is one temperature, pink (or balloon color) another temperature.



Supernovae as Standard Candles? '

- * Minkowski (1941) identifies two types of SN '
- * In late 60's, early 70's - Type I recognized as implosion of a white dwarf, and became candidates as standard candles.
- * 1985 - distinction arises between Type Ia and Ib based on spectral properties. Ia's ' continue to be candidates for std candles. '
- * 1992 - Phillips provides a correction which makes Ia's more robust as std candles.

1993 Lessons '

- * Raisin Bread Universe

 - * Cosmology in the kitchen!

- * Gravitational Waves

 - * Construct a Grav. Wave Demonstrator '

- * Melting Ice

 - * Carefully designed experiments can yield unexpected results

- * Dark Matter NASA Conference

Other 1993 Stories'

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After inflation, the expansion of the universe continued, but at a slower rate. As space expanded, the universe cooled and matter formed. Within the first second after the Big Bang, quarks, neutrinos, and electrons appeared, then protons and neutrons.

Inflation makes another remarkable prediction: how stars and galaxies formed in the universe. Since our cosmic neighborhood would have been microscopic in size prior to inflation, quantum fluctuations in the density of matter in this region would be stretched by inflation to astronomical proportions. After inflation, these fluctuations would be faint in contrast, but over time, the slightly over-dense regions would attract neighboring matter through the action of gravity. This would initiate the gradual process of galaxy formation. This inflation simultaneously explains why the CMB is so nearly, but not exactly, uniform and ultimately how we came to be.

Scientists are now more satisfied that with the addition of inflation, the Big Bang describes the universe we live in.

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COBE's map of the sky showing minor fluctuations in the cosmic microwave background. Astronomers estimate that this map shows the background radiation 300,000 years after the Big Bang (NASA image)

What did the newborn universe look like? In 1965, scientists peered into the distance with a radio telescope, and discovered a microwave background that was rather plain and featureless. Today's technology has drawn a more detailed picture of this cosmic microwave background, telling us there's a lot more to the story—and providing further evidence of the Big Bang.

"If you're religious, it's like looking at God," said George Smoot, an astrophysicist at the University of California, Berkeley and leader of the research team that unveiled the discovery. He was addressing a room packed with scientists at a meeting of the American Physical Society.

According to the Big Bang theory, the universe expanded from an unbearably small and dense ball of energy, distributing hot radiation—and space itself—uniformly in all directions. As the universe expanded and cooled, this hot ball of energy produced freshly minted particles, first in the form of quarks and electrons, then protons and neutrons, which combined to make the nuclei of hydrogen and helium. Over time, gravity gathered the denser clumps of gas into the familiar galaxies, stars, and planets of the modern universe. All the while, the radiation that was emitted in all directions by that early hot gas gradually shifted into the microwave energy range as the universe expanded. We see this radiation today as a cosmic microwave background (CMB).

Data from the 1960s did not show deviations in the CMB energy across the entire sky; however, in 1967, astrophysicists Martin Rees and Dennis Sciama predicted such deviations. The subtlety of the variations—just 10 millionths of a degree—made them extremely hard to detect until NASA's Cosmic Background Explorer satellite (COBE) was launched in 1990.

Dark Matter Hunt Heats Up

The mystery of dark matter just deepened with a new view of about 20 trillion suns-worth of the invisible, unexplained stuff hiding out in a small cluster of galaxies.

The vast store of dark matter surrounding the ROSAT X-ray satellite, ROSAT detected a gigantic cloud of very hot gas in a very unexpected place: the seemingly empty space between two galaxies. This cloud is a surprise because its great heat—detected from its radiation of X-rays—should have made the gas quickly disperse.

The existence of the hot gas cloud can only be explained by the existence of a gravitational force to hold it in place. Only dark matter could do the job without being seen, explains Richard Mushotzky of NASA's Goddard Space Flight Center.

What's more, the hot gas requires an amazing 30 times more dark matter than visible matter in the cluster to achieve this, says Mushotzky. The normal matter ROSAT observed is just a small fraction of what's really there.

If that sort of dark matter ratio holds true throughout the cosmos, dark matter could determine the fate of the universe. Its gravity could be enough to slow down or reverse the direction of matter and energy flung out by the Big Bang and pull the universe back together into a "Big Crunch," say some researchers.

An earlier case for the existence of dark matter was that made by astronomer Vera Rubin in 1970. She studied the rotation rate of stars in the Andromeda galaxy and found that it just didn't make sense. The stars in the disc farther from the galactic center were not rotating more slowly than those closer in, as models predicted they should.

Inflation in the Universe

The Big Bang theory has a problem, say scientists. It can't go from a tiny ball of energy to the universe we see today without some help: an adjustment called inflation.

Astronomers observe that the overall temperature of the cosmic microwave background (CMB) is nearly smooth and uniform. The temperature can become uniform only if distant regions can interact and exchange energy. The fastest interactions occur at the speed of light. However, at the time the CMB radiation was emitted, two regions that are far apart on the sky today would have been separated by more than the light travel distance in the young universe. So why is the CMB temperature so nearly uniform?

Inflation theory explains this by stating that shortly after the Big Bang, the universe underwent a very rapid expansion in a very short amount of time. This expansion grew the size of the universe by a factor of 10²⁶ in about 10⁻³² seconds. Thus, regions once in contact with each other are now in far flung regions of the universe. The overall uniformity of the background temperature expanded with inflation. Particle physicists think that inflation might be a natural byproduct of the transition in which the grand unified force separated into the strong nuclear force and the electro-weak force. If so, it would have occurred 10⁻³² sec after the Big Bang when the universe was 10²⁶ kelvins.

After inflation, the expansion of the universe continued, but at a slower rate. As space expanded, the universe cooled and matter formed. Within the first second after the Big Bang, quarks, neutrinos, and electrons appeared, then protons and neutrons.

Inflation makes another remarkable prediction: how stars and galaxies formed in the universe. Since our cosmic neighborhood would have been microscopic in size prior to inflation, quantum fluctuations in the density of matter in this region would be stretched by inflation to astronomical proportions. After inflation, these fluctuations would be faint in contrast, but over time, the slightly over-dense regions would attract neighboring matter through the action of gravity. This would initiate the gradual process of galaxy formation. This inflation simultaneously explains why the CMB is so nearly, but not exactly, uniform and ultimately how we came to be.

Scientists are now more satisfied that with the addition of inflation, the Big Bang describes the universe we live in.

Pancake or Oatmeal Universe – What's for Breakfast?

Over its lifetime, the universe started out smooth but has grown lumpy.

The COBE results present what's been called an isotropic, or smooth, early universe—meaning variations in the cosmic microwave background radiation of only 1 part in 100,000. Few might say that, at that time, the universe was like the surface of a pancake: smooth as a glass, with differences in texture seen only under closer inspection.

The universe today is more like a bowl of oatmeal, with real "lumps" and clumps of matter and energy. Objects from planets and stars to galaxies and galaxy clusters are easily detectable. Nonetheless, overall the universe is much smoother than was predicted by the original Big Bang. This problem has been solved by inflation.

While the early universe was extremely smooth compared to today, those minuscule lumps in it were vital. Through the action of gravity, they led to the much bigger lumps we see today, the ones that make our very existence possible.

David A. Hulse and Joseph H. Taylor, both of Princeton University, were awarded the Nobel Prize for their discovery of evidence of gravitational waves, confirming the prediction by Einstein in 1916.

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Cosmology's End? '

- * By the mid-90s, cosmologists thought that they had only to “fill in the details”.
- * Remaining questions:
 - * Will the expansion continue forever, or will Universe eventually collapse back on itself?
 - * What is the mass-density of the Universe (which would answer the above)?

Cosmology's End?

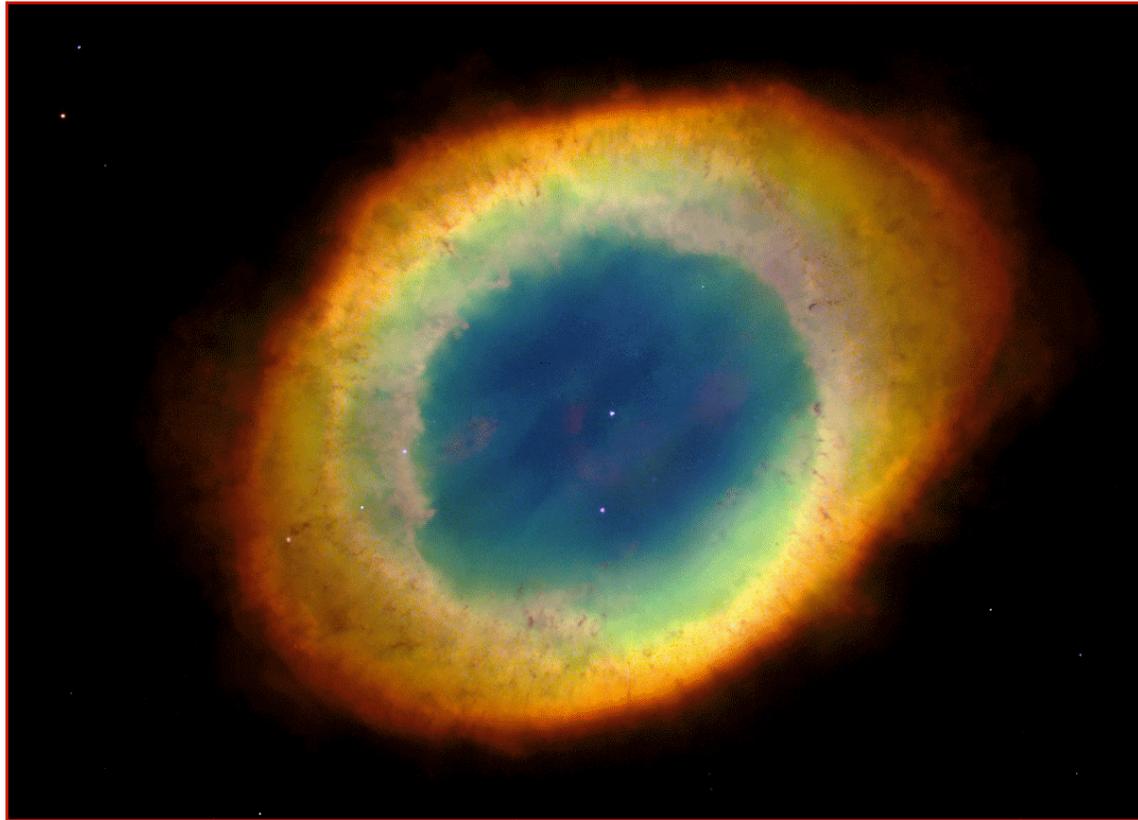
- * Things may not be what they seem.
- * When we see odd behavior, we look more carefully at what's going on.

Not the End '

In 1997 ...

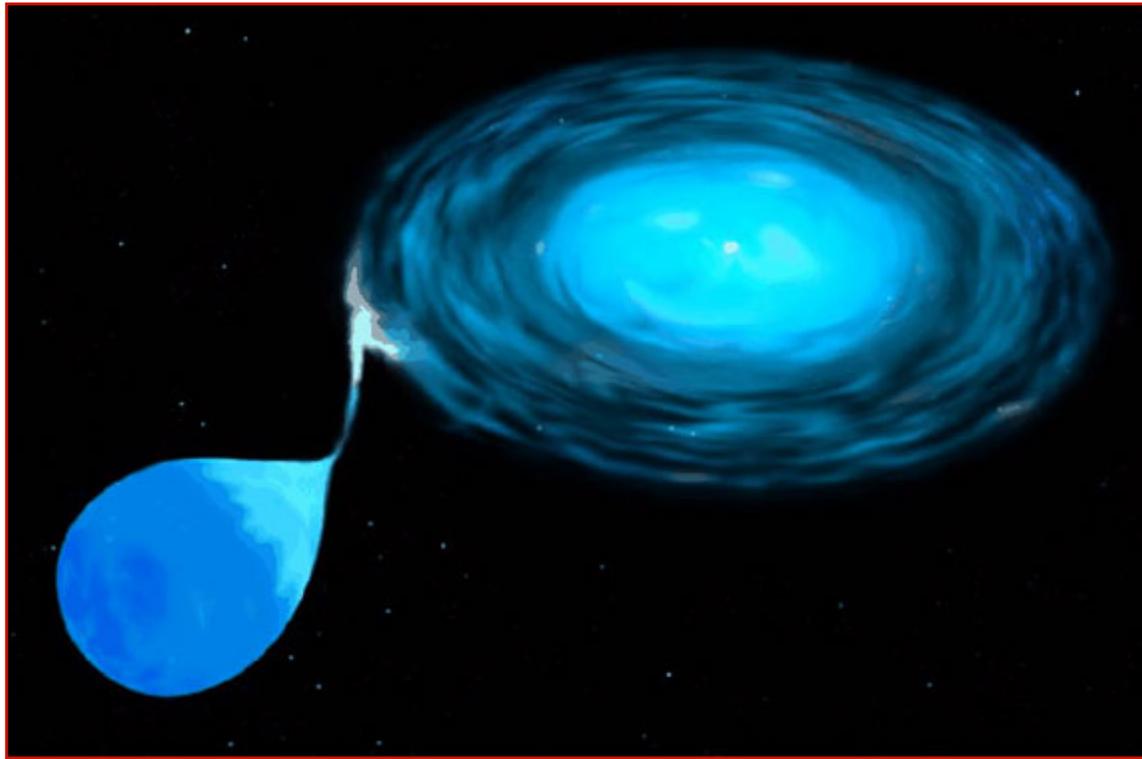
- * Recall, we were looking to “fill in the details” of the Universe’s expansion. '
- * Given that gravity is the longest-reaching force according to physics, the expansion of the Universe should be slowing down...

1. Create a White Dwarf



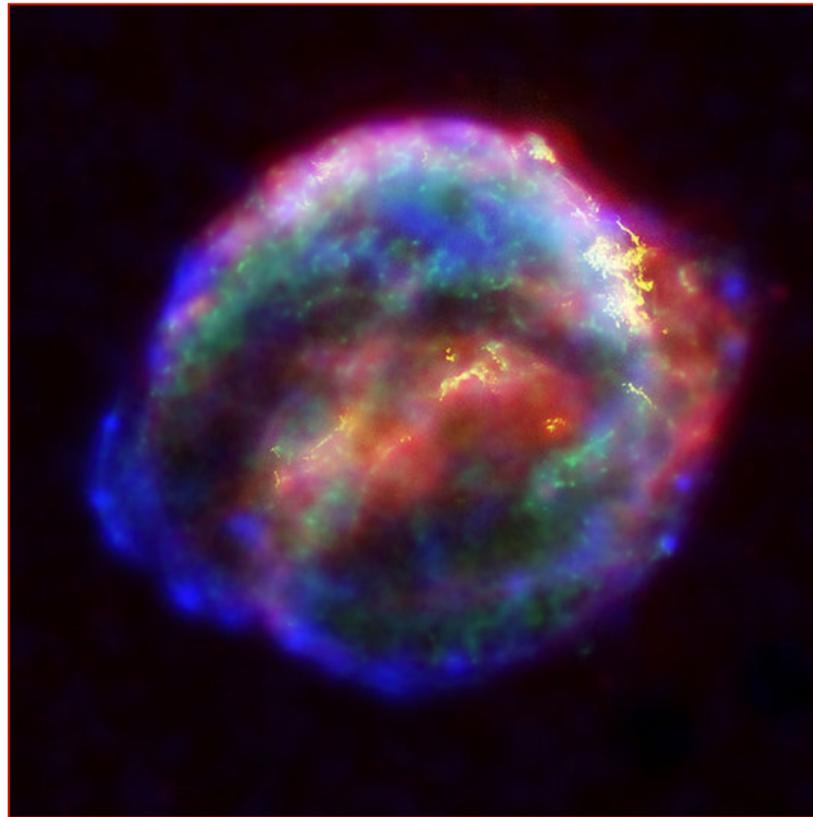
A dying star becomes a white dwarf.

2. Dump more mass onto it



The white dwarf strips gas from its stellar companion....

3. Until it explodes



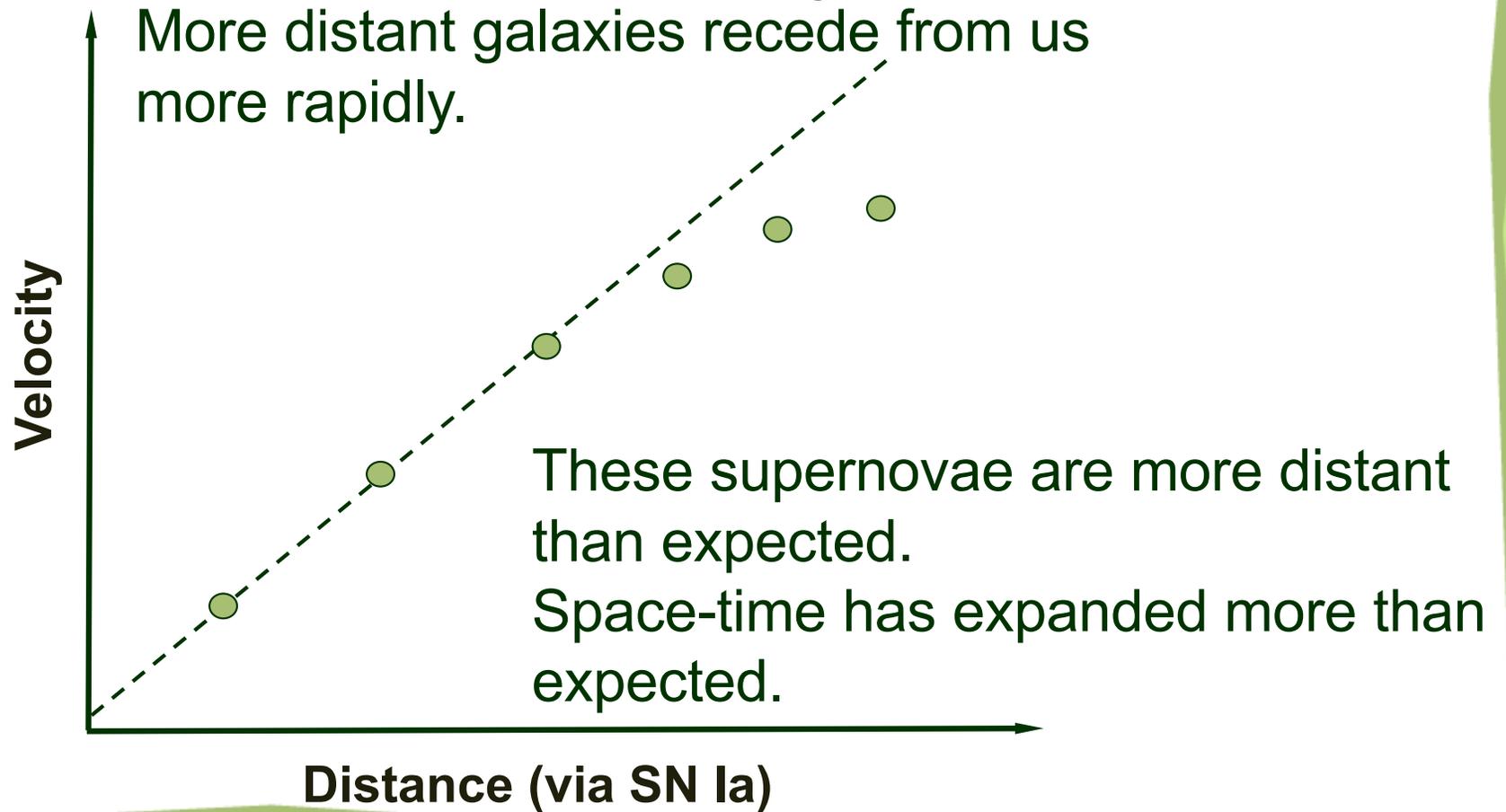
....and uses it to become a hydrogen bomb. Bang!

4. Observe in a distant galaxy

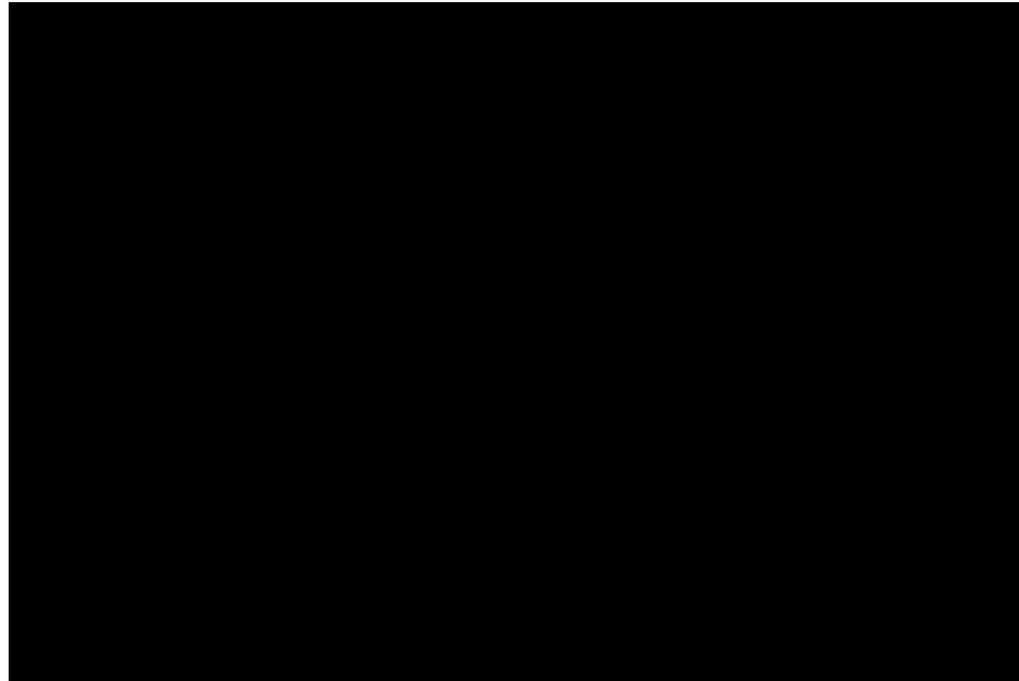


The explosion is as bright as an entire galaxy of stars....
.....and can be seen in galaxies across the universe.

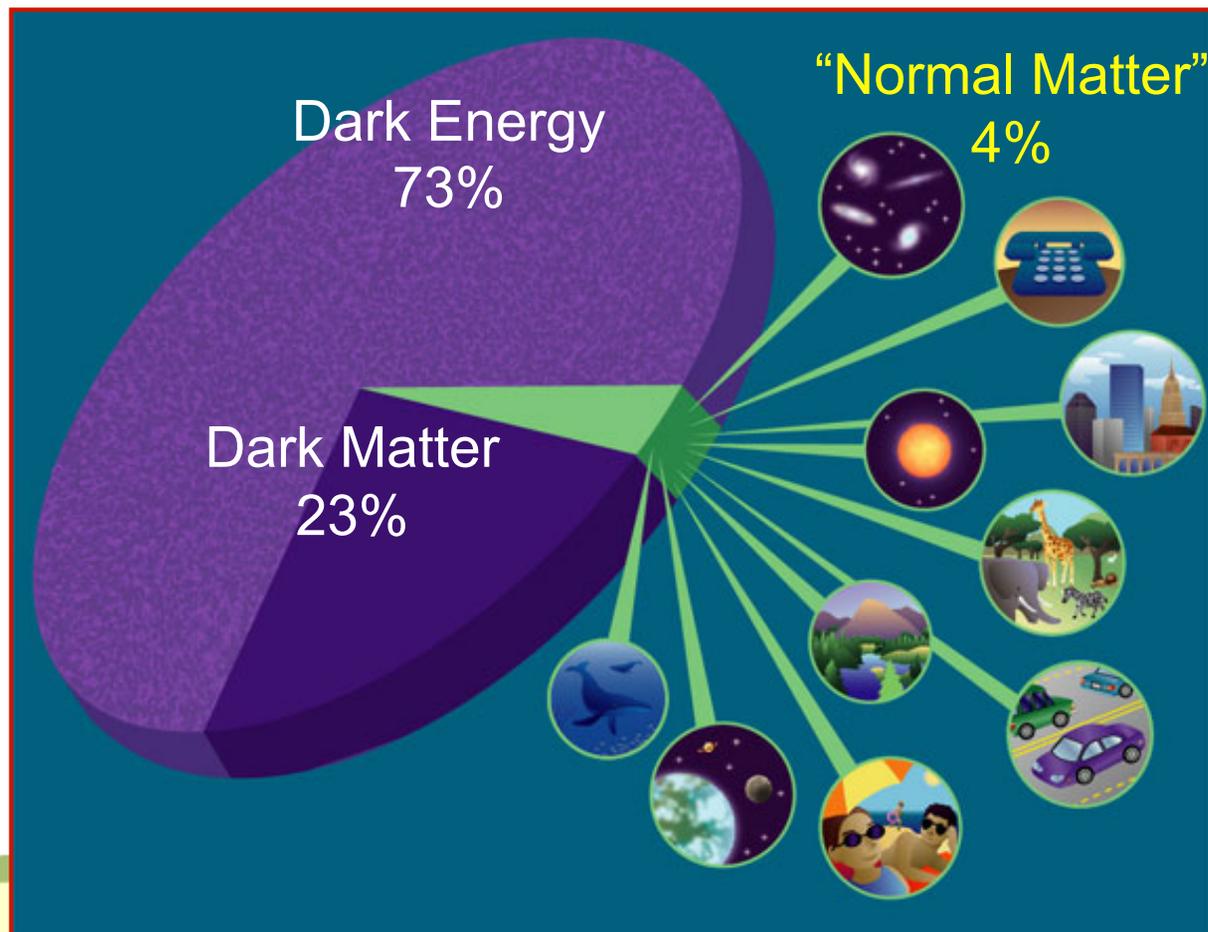
5. Compare its distance to its velocity



History of the Universe's Expansion



Dark Energy Comprises 73% of Universe



Century Timeline

Put together the Cosmic Times
timeline with events in:

- * Other Science
- * Arts/Entertainment/Culture
- * World History/Politics

Opportunities for cross-disciplinary collaboration

2006 Lessons

- * Measuring Dark Energy
 - * Use SN data to see evidence for Dark Energy
- * Tools of the Trade
 - * Satellites for investigating the cosmos
- * Cosmic Times 2019
 - * Students predict our state of knowledge and create their own CT edition

Other 2006 Stories

Age of the Universe:
13.7 Billion Years

COSMIC TIMES

Size of the Universe:
94 Billion Light Years

Faster Walk On The Dark Side

There is fresh evidence for the existence of dark energy, a peculiar entity that is hastening the expansion of the cosmos. Dark energy amazingly comprises almost three-quarters of the universe. It appears to be accelerating the distances between galaxies and working against gravity, but its nature is still unknown.

The new evidence is the discovery of an effect dark energy has on photons of light from the earliest universe. This ancient light began moving across the universe just 380,000 years after the Big Bang, and its initial energy has been shifted into the microwave part of the energy spectrum in the 13 billion years since. We see the light today as what scientists call the cosmic microwave background (CMB) radiation. The detection of an effect in the CMB called Integrated Sachs-Wolfe (ISW) confirms that dark energy had an additional influence on these photons.

ISW was named after Rainer Kurt Sachs and Arthur Michael Wolfe, who first described it in 1967. But its influence on the CMB was recently verified by an international collaboration of researchers: Stephen Dodel (Harvard College) and Robert Citlenden (University of Portsmouth), Charles Beemster (NASA) WMAP team, and a collaboration of astronomers from the Sloan Digital Sky Survey and the Institut d'Astrophysique de Paris.

Their conclusions result from efforts to pull together a treasure trove of data, on the large-scale structures of the universe and on light from the newborn universe. The data included observations from visible light, x-ray, radio and microwave telescopes.

Journey to Cosmos' Dark Heart

Here's how the ISW effect works: Gravity is a property of matter, so matter exerts "gravity wells" in space-time. More matter creates a deeper well. If there is no change in the depth of a well while a photon crosses it, the well has no effect on the photon's energy. But if dark energy stretches out deep wells of gravity into mere shallow dents, then CMB photons crossing the well will change their energy. The recent observations of these subtle changes in the CMB provides further evidence for the existence of dark energy.

This additional evidence is good news to astronomers who first detected a gravity-defying dark energy in 1998. At that time, two teams of astronomers were measuring the retreat of a collection of very distant Type Ia supernovae. These supernovae are created by the explosion of a white dwarf. The teams from the Supernova Cosmology Project at Lawrence Berkeley National Lab and the High-Z Supernova Search had intended to measure the rate at which the universe's expansion was slowing down. Instead, they found that the distance between Earth and these supernovae was growing, and at an increasingly faster rate. Starting about five billion years ago, some unexplained "dark" energy began to overwhelm the force of gravity and push galaxies apart.

The researchers chose to name it dark energy, not to be confused with dark matter, which is another confounding problem in cosmology.

As for that dark energy, it's, in anybody's guess right now. While there are at least a half dozen theories, none seem very close to an authoritative answer.

Seeds of Modern Universe

Scientists are probing the darkest mystery in the universe: dark energy. NASA and the US Department of Energy have selected three concept studies for consideration to become their Joint Dark Energy Mission (JDEM). JDEM is slated for launch as early as 2011.

JDEM's goal is to sharpen and double-check the distance measurements by Type Ia supernovae. This, in turn, should reveal critical clues to how fast the universe has expanded at different points in cosmic history.

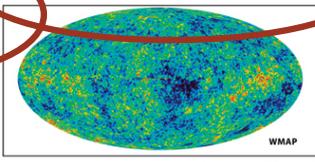
Type Ia's are considered a standard of comparison used to determine the distance to other astronomical objects. By observing a large number of these "standard candles" supernovae in galaxies far and near, researchers hope to find out just how quickly those galaxies are flying away from us.

The three proposed concepts are the Supernova Acceleration Probe (SNAP), the Advanced Dark Energy Physics Telescope (ADEPT), and the Dark Energy Space Telescope (Destiny). Each would look at the supernovae in a different way.

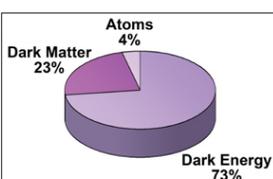
SNAP would use a 1.8-meter optical/infrared telescope with a CCD (charge-coupled device) light detector like those in digital cameras. But with a billion pixels, SNAP's detector beats any handheld camera by a factor of a thousand. SNAP would spot about 2,000 Type Ia supernovae each year over a wide range of distances—about 200 times more supernovae than are now detected each year.

ADEPT would use a 1.1-meter near-infrared telescope to locate 100 million galaxies and 1,000 Type Ia's. Its data would be compared with that of the minute temperature differences in the cosmic microwave background. The mission would reveal how well the earliest (most distant) galaxies match up with the earliest clump of matter, and how dark energy has altered the distribution since then.

Destiny would have a 1.65-meter near-infrared telescope, designed to detect 3,000 Type Ia supernovae over two years. It would spend an additional year surveying, in detail, 1,000 square-degrees of sky. This would give new readings on changes in the large-scale distribution of matter in the cosmos since the Big Bang. Both phases of Destiny's mission would improve on the sensitivity of similar ground-based observations by a factor of about 10.



A map of the temperature fluctuations in the Cosmic Microwave Background as measured by the Wilkinson Microwave Anisotropy Probe. The dark blue regions are only a few millionths of a degree cooler than the red regions. Astronomers analyzing these fluctuations have determined the percentages of matter and energy in the universe.



Atoms 4%
Dark Matter 23%
Dark Energy 73%

WMAP data reveals that the universe's contents include 4% atoms, the building blocks of stars and planets. Dark matter comprises 23% of the universe. This subtle difference from atoms is not what you'd expect. It has never been detected directly by its gravity. 73% of the universe is composed of "dark energy," which acts as a sort of anti-gravity. This energy, distinct from dark matter, is responsible for the present-day acceleration of the universal expansion.

Biggest Mystery: What is Dark Energy?

The further we look into the cosmos, the more puzzled we are. That's the experience of astronomers and astrophysicists now wrestling with the problem of dark energy. This unknown substance dominates the universe, yet is a profound mystery.

There are several theories being proposed to explain dark energy. So far, however, testing these ideas has been very hard to do. The key will be to create a new generation of scientific instruments to search deeper into the cosmos.

At the moment the only way to talk about dark energy is to say what we know it does. It creates more space, new space, pushing galaxies further apart and making the entire universe larger at an increasing clip. Some measurements of distant supernovae in the late 1990s showed us this startling phenomenon.

Ironically, there was one big hint that dark energy existed even before astronomers found evidence of it. None other than the great Albert Einstein had factored in an "anti-gravity" effect, which he called the "cosmological constant," into his theory of general relativity to make it work with the static universe that was observed in 1916. After Edwin Hubble discovered in 1929 that the universe was indeed expanding, Einstein and other physicists considered the cosmological constant an annoying fudge factor, without any connection to the real universe.

Later researchers proposed that the cosmological constant represents an underlying background energy. That energy might exert some kind of pressure on the cosmos. Unfortunately, the theory predicts that the energy ought to be 120 orders of magnitude stronger than dark energy appears to be.

Another strong contender for dark energy is something called quintessence. The word is the same as the ancient Greek term for a mysterious fifth element—"beyond earth, air, fire and water"—which acted in the Moon and stars. Unlike the cosmological constant, the modern theory of quintessence holds that it is some kind of energy field that pushes particles apart. It states that the energy is variable and that it can lessen in strength as it travels through space and time. This concept fits the data available, which suggests that dark energy has only been in the data set's view for about 5 billion years, so its effect is not constant.

Scientists need to learn much more about dark energy's impact on the universe to test their theories. The only way to do that, of course, is with more data from the heavens.

'First Light' Wins Nobel

Astrophysicists John Mather and George Smoot have been awarded the 2006 Nobel Prize in Physics. It was presented for their 1992 discovery about the cosmic microwave background radiation, the glowing remnant of the universe as we see it today.

According to the Nobel jury, "These measurements also marked the inception of cosmology as a precise science."

Using data from the space-based Cosmic Background Explorer (COBE), a team led by Mather and Smoot teased out the details of how the universe has cooled. They measured the spectrum of light from this background and found that it matched predictions from the Big Bang theory perfectly. They also found the very subtle variations across the sky in the CMB, which were the discovery of these tiny variations. It was difficult to account for the present structure of the universe, say cosmologists. Later experiments, however, have been able to measure the composition, they have been able to



Dr. John C. Mather and the Nobel laureate cosmologist, accepting his award from the King of Sweden.

Sorting Out the Dark Stuff

There's some good news and bad news about the cosmos. The bad news is that the normal matter that makes up stars, planets, Earth and Sun—and everything else we can detect—accounts for just 4 percent of the known universe! The good news is that our tiny little portion of the universe is beginning to get a handle on what makes up the rest of it.

The more abundant matter in the universe—dark matter—doesn't rule either. It makes up just 23 percent of the universe. This is far below the most prominent effort of all—dark energy, which is 73 percent of the universe. While both are mysterious, and both have been dubbed "dark" because they can't be directly sensed, they are very different beasts.

Dark matter is the universe's "missing mass." It does not appear to interact with normal matter, other than to tug with gravity. Dark matter was first proposed in the 1930s by astronomer who discovered that the amount of visible matter known to exist in galaxies wasn't enough to account for their measured gravitational effects. Dark matter is currently thought to be a kind of cold particle that interacts extremely weakly with both atoms and light.

Dark energy, on the other hand, is a stranger animal. It reveals itself only by flinging everything else apart. This peculiar energy is right now creating more space out of nothing and pushing everything in the universe farther apart at a faster rate. And that's good news too, if you like gravity.

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The year is 1919...

- * What's going on?
- * What's going on in science?
- * What is your view of the Universe?

* Infinite

* Unchanging/static

* Ageless

The year is 2009...

- * What's going on?
- * What's going on in science?
- * What is your view of the Universe?

* Finite

* Changing

* 13.7 Billion Years Old

Cosmic Times

<http://cosmictimes.gsfc.nasa.gov/>



Posters, Newsletters, Teacher Guide, Lessons