Age of the Universe:

2 Billion Years

Cosmic Times

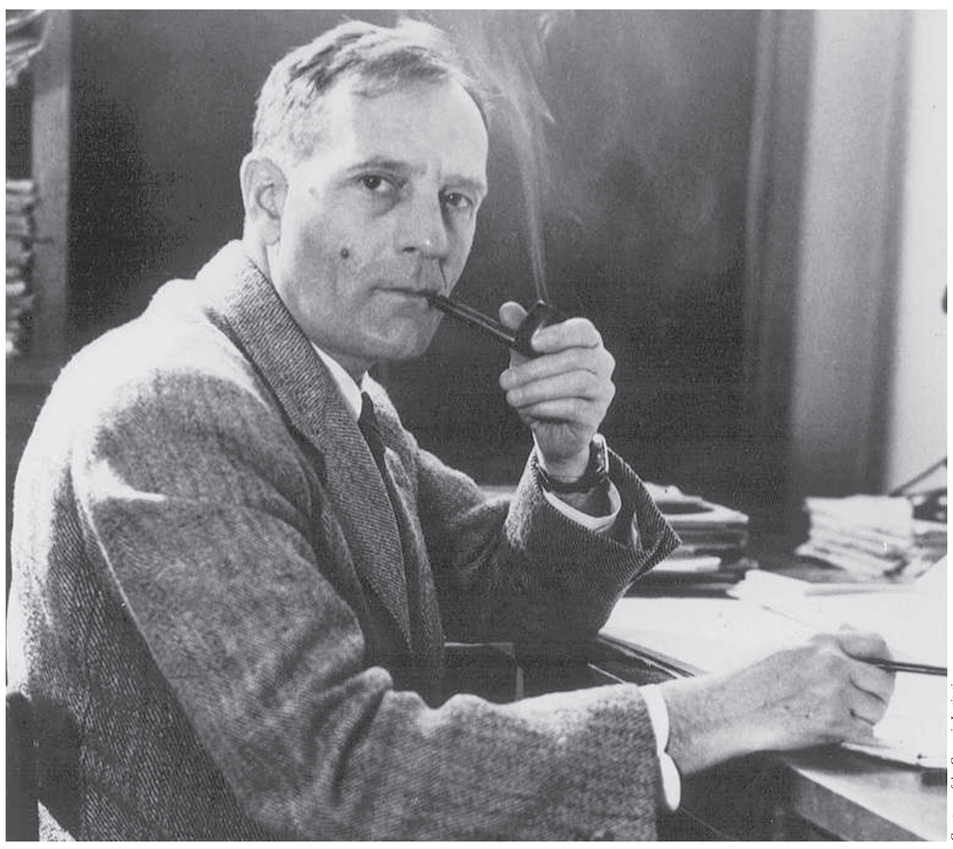
1929

Size of the Universe:

280 Million Light Years

Andromeda Nebula Lies Outside Milky Way Galaxy

Spiral Nebulae are indeed "Island Universes"



Courtesy of the Carnegie Institution

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 Magellan, Miss Leavitt noticed that the Cepheids had periods, or repeating cycles, directly related to their average brightness: the longer the period, the brighter the star. The Small Magellanic Cloud (SMC) is a massive aggregate of stars visible in the southern hemisphere, and since all of these stars were in the SMC, they were at roughly the same distance from the Earth. Each Cepheid's intrinsic brightness was directly related to its period.

Soon after Miss Leavitt's discovery, Shapley began systematically searching for Cepheids in globular clusters in the Milky Way galaxy, globes of tens of thousands of densely-packed stars. He used the period-luminosity relationship to determine the distance to more than 230 globular clusters. On the assumption that Cepheids in distant globular clusters obey the same physics as nearby Cepheids, he found that the most distant clusters reside some 200,000 light years away.

By studying the periods of the Cepheids in the Andromeda Nebula (M31), Hubble was able to determine each variable's intrinsic brightness, its absolute magnitude. He then made observations of the apparent magnitude of every one. Once he knew the difference between how bright a star appeared and how bright it actually was, he was able to calculate its distance from the Earth. He found Andromeda to be 900,000 light years away – the most distant object known to date.

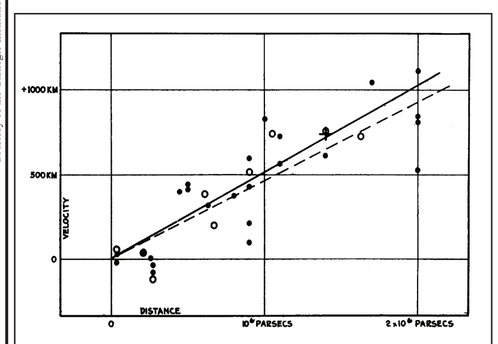
Universe is Expanding

"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 Humason 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 3.26 light years. He determined distances to the nebulae using Cepheid variables, stars with 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 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.

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 M. 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 forty 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.

Although Hubble's work presents a tremendous breakthrough in our understanding of the universe, one big question remains. How far out into the universe does his model hold? The 100-inch telescope can resolve Cepheids in only the nearest nebulae. In nebulae where Cepheids are barely visible, Hubble has identified the most luminous individual stars, some 50 to 100 times brighter than the Cepheids. He uses these luminous stars as standard candles for more distant objects.

But today's telescopes, and the stars they see, will only take Hubble so far. To measure even greater distances, astronomers will need a larger telescope and new types of standard candles.

One new instrument may hold the key. Last year the Rockefeller Foundation agreed to provide the six million dollars needed to fund the construction of a new observatory with a 200-inch telescope. When completed, this telescope will hold four times the light-gathering power of the instrument Hubble currently uses.

Einstein's General Theory Holds True

The past decade has been an exciting and challenging time in the development of scientific understanding of the universe, with theorists testing their ideas against the framework of Albert Einstein's 1916 theory of general relativity. The theory establishes the universe as three dimensions of space and one of time. It proposes that gravity curves the fabric of space-time and that the curvature controls the natural motions of bodies in space.

His theory also pointed to the expansion of the universe, but Dr. Einstein has rejected the idea. In 1917 he added a new term to his equations, the "cosmological constant," designed specifically to avoid the implication of an expanding universe. Hubble's recent observations dismiss the need for such a term, but while Einstein has examined the data and believes Hubble's paper to be sound, he is still not convinced.

In 1922, Soviet physicist Alexander Friedman developed his own solutions to the general relativity equations. He described two possibilities for the universe: either it was expanding or contracting, but it was not static.

Abbe George Lemaître, a Belgian-born Catholic priest and astronomer, released a paper in 1927 stating that a homogeneous universe of constant mass has to be expanding to account for the radial velocity of spiral nebulae. He described a possible universe that was expanding from its initial state as a single point. Lemaître believed that before this expansion began, the universe did not exist.

Hubble's discoveries answer many questions, but they also present a new direction for the future of cosmological studies.

"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.

Held on April 26, 1920 at the National Academy of Sciences in Washington, D.C., the debate focused on the opposing views of astronomers 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.

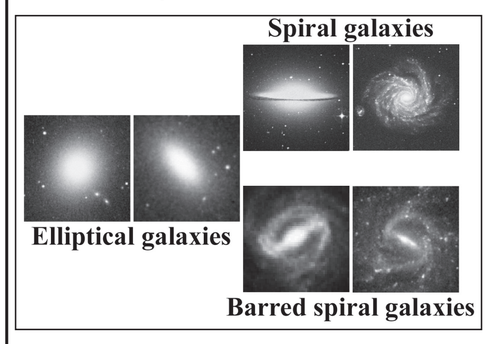
Shapley's work had increased the size of the universe by about ten times, but Hubble's recent discoveries have multiplied it by at least another ten. Shapley observed a historical progression, from belief in a small universe with man at its center, to a larger one with Earth further from the center: "The significance of man and the Earth…has dwindled 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 in the distant universe. However, until recently, 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 (spherical to elongated ellipses, for example) and structure (hazy 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

High above Pasadena, California in the San Gabriel Mountains, the astronomers at the Carnegie Institution's Mount Wilson Observatory are changing our view of the Universe. Who are these scientists?

Athlete-Scholar Unveils the Future of the Universe

Born in Marshfield, Missouri, in 1889, Edwin Powell Hubble's early life centered on athletics, primarily track and field events. At 6 foot 3 inches in height, he was quite successful, even setting an Illinois state record for the high jump.

At the University of Chicago, he focused on mathematics and astronomy, but his studies took a different direction when he attended Oxford University as a Rhodes Scholar. There he studied Roman law and Spanish but still made the time to compete in water polo and field events. He returned to the US in 1913 to teach high school physics and Spanish.

The next year, Hubble returned to the University of Chicago for a PhD, researching faint nebulae at the Yerkes Observatory. However, US entry into the Great War led him to rush through his dissertation and oral exam; he reported to the army three days later. Hubble served in France until the end of the war, when he returned to civilian life to take up a position that had been offered two years earlier – at the Mount Wilson Observatory.

Former Mule-Team Driver and Janitor Helps Discover Expanding Universe

Milton Lasalle Humason was born in Dodge Center, Minnesota in 1891, but moved to California with his family as a child. Having left school in the eighth grade, Humason received no formal training as an astronomer. In fact, his career at Mount Wilson began as a mule-team driver for the pack trains that carried large components of the telescope and its building to the top of Mount Wilson during the observatory's construction.

When the telescope was completed in 1917, Mr. Humason was hired as a janitor and electrician. His intelligence and curiosity were soon noticed, and it wasn't long before he was promoted to night assistant on the 60-inch telescope.

Working under the observatory's director, Dr. George Ellery Hale, Humason became an expert observer. Dr. Hale recognized his abilities and appointed him to the observatory's scientific staff in 1919. Humason soon became an expert at measuring the redshifts of distant nebulae and the chief assistant and collaborator to Dr. Hubble.

In Their Own Words

"New observations by Hubble…make it appear likely that the general structure of the Universe is not static." *– Albert Einstein – 1925*

"Tomorrow the outlook may change and new methods may dwarf our knowledge and beliefs of today, or convert them into remote history. Soon we may look far beyond the last frontier, now 140,000,000 light years away. We, or our successors, may actually know familiarly the farthest borders of this vast Universe and learn facts about it so astounding that astronomers of today would be nearly unable to comprehend their significance." *– Edwin Hubble – 1927*