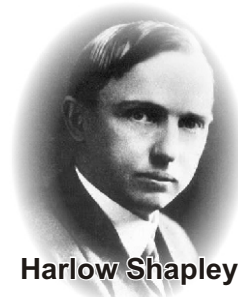




# The Great Debate

## Just How Big is the Universe?



Harlow Shapley

On April 26, 1920, Harlow Shapley – an astronomer from Mount Wilson Observatory in Pasadena, California – took the podium at the annual meeting of the National Academy of Sciences in Washington, D.C. The Academy selected him to argue against the existence of external galaxies, also called 'island universes.' Looking into the crowd of respected scientists from many disciplines, Shapley realized he had no ammo to directly shoot down the idea. What he did have, however, was a great deal of evidence for his own idea that the Milky Way was ten times bigger than anyone had ever imagined.

This 'Big Galaxy,' as he called it, filled up the universe. Judging his evidence for an enormous Milky Way credible, Shapley could then tack on the implication that nothing existed outside its boundaries, not even island universes. Shapley was inexperienced at the lecture podium but knew that many scientists unfamiliar with astronomy filled the hall. He thus crafted an understandable twenty-page speech to get his point across, not even bringing up the word 'light-year' until page seven. His opponent, Heber D. Curtis, an experienced orator from the Lick Observatory near San Jose, California, watched from the audience. Curtis followed with a technical and dense speech arguing for the existence of island universes. Many scientists declared him the 'victor' of the day by default for the mere fact that he gave an appropriate talk. Such was the so-called "Great Debate," and since Curtis won the day, later generations of scientists looked back at this meeting to be the day external galaxies won official acceptance.

Despite the immortalization of the Shapley-Curtis debate, it was never really a debate to begin with. Here's what Curtis thought would go on:

I agree with [astronomer George Ellery Hale] that it should not be made a formal "debate", but I am sure that we could be just as good friends if we did go at each other "hammer and tongs". . . . A good friendly "scrap" is an excellent thing once in a while; sort of clears up the atmosphere. It might be far more interesting both for us and our jury, to shake hands, metaphorically speaking, at the beginning and conclusion of our talks, but use our shillelaghs in the interim to the best of our ability.

The lore of the "Great Debate" began a year after the real event, in 1921, when the Academy published its proceedings. Neglecting to mention that their edition didn't contain the original transcripts, the Academy published

new papers that Shapley and Curtis had extensively reworked to seem like a point-counterpoint argument. Except for those few who actually attended the proceedings, most who learned of the debate read the published proceedings. Most received the impression that a true debate occurred, and ended with Curtis' victorious speech.



**Although possibly entertaining, formal debates are not the best method of working out scientific conclusions. In formal debates, too often theatrics, personalities and stage presence win over substance. Moreover, formal debates limit participation, evidence and interpretation in ways that the informal ongoing dialogue in scientific circles does not. Finally, acceptance or rejection of scientific ideas is determined over time by the scientific community.**

Looking back, both Shapley and Curtis had well-founded arguments. The Milky Way was indeed much larger than anybody had ever imagined, and galaxies did indeed exist outside it. The clinching evidence for island universes, however, wouldn't arrive until 1924 with the work of Edwin Hubble, after whom the Hubble Space Telescope was named. This story looks at how astronomers concluded that island universes were real, and that the Milky Way was just one of many, many galaxies in the sky.

While the Great Debate might have been over-hyped, it nonetheless encapsulated a very pressing question. Was the Milky Way the only galaxy in the universe, or were there many more like it? The question was difficult to answer because so many details come into play. As you read, note what questions drive astronomers, move ideas forward, and become points of controversy.

**1) Scientists and textbooks frequently speak about the history of science as though successful ideas had been self-evident upon their emergence, yet few ideas have ever been as obvious as textbooks often state. What are some reasons that might account for why scientific knowledge often takes years or decades to become well established?**

The story begins in the late 1700s. Using ever-improving telescopes, skywatchers viewed planets, comets, asteroids, stars – and an unidentified class of fuzzy objects called nebulae. Meaning 'cloud' in Latin, early astronomers saw nebulae as immense blotches of light against a background of pin-point sized stars. Some astronomers speculated that nebulae comprised many stars, while others proposed some kind of mysterious luminous matter. By the 1840s, Lord Rosse of Ireland used his giant telescopes to discern individual stars within nebulae, but over in Scotland John P. Nichol swore that the clouds were some sort of luminous fluid. As telescopes improved throughout the 1800s and revealed more detail of the nebulae, they were further classified into 'spirals' and 'globular clusters' based on their appearance. Yet the fundamental challenge posed by nebulae was to determine whether they were comprised of star-like material or an entirely unknown substance.



**Many people wrongly think that production of useful technology is the goal of science. While technologies are often based on scientific understanding, *basic science* is solely concerned with furthering our understanding of the natural world – knowledge for knowledge sake. Yet, science and technology are intricately tied together. New technologies (such as improved telescopes) can increase scientists' ability to make careful observations that might possibly lead to new understandings. And new understandings of the natural world often lead to technological advances that could not have been predicted.**

In 1864, William Huggins attached a spectroscope to his telescope and aimed it at a nebula. In brief, a spectroscope is used to measure the emission spectrum from an incandescent object. Using a spectroscope, astronomers can tell the elemental makeup of celestial objects because each element has a unique spectrum line. Although he was later shown to be mistaken, Huggins wrote the following of his initial observations and thinking.

[I had a feeling] of excited suspense, mingled with a degree of awe, with which, after a few moments of hesitation, I put my eye to the spectroscope. Was I not about to look into a secret place of creation?

I looked into the spectroscope. No spectrum such as I expected! A single bright line only! At first I suspect some displacement of the prism, and that I was looking at a reflection of the illuminated slit from one of its faces. This thought was scarcely more than momentary; then the true interpretation flashed upon me. The light of the nebula was monochromatic, and so, unlike any other light I had yet subjected to prismatic examination, could not be extended out to form a complete spectrum...

The riddle of the nebulae was solved. The answer, which had come to us in the light itself, read: Not an aggregation of stars, but a luminous gas. Stars after the order of our own sun, and of the brighter stars, would give a different spectrum; the light off this nebula had clearly been emitted by a luminous gas.

**2) Huggins, within the same passage, notes that data must be interpreted and speaks as though the answer to the riddle was self-evident. In the excitement of discussing their ideas, scientists often leave out important aspects of how they arrived at their conclusions. Scientists must struggle to make meaning of data, interpreting new evidence in light of what they know about the natural world. If conclusions were truly self-evident, doing science would be straightforward and boring with little creativity needed. How does this story thus far illustrate the need for creativity and inventiveness when doing science?**

Other astronomers argued that nebulae were made of stars based on an 1885 "nova" in the Andromeda Nebula. At the time, no astronomer thought that stars could explode. The word "nova" means "new star" in Latin, and they thought these bright objects to be stellar newborns. Then in 1898, the German astronomer Julius Scheiner used a spectroscope pointed toward the Andromeda



*Andromeda Nebula, as photographed in 1889 by Isaac Roberts*

Nebula. His observations of the nebula had a similar spectrum to the sun. Considering the visual evidence and the spectroscopic evidence combined, most astronomers then worked with the idea that nebulae were composed of stars.





**Observations can be affected by what one thinks is true about nature. As seen above, scientists in the 1880s could make out the Andromeda Nebula pretty well, but not until thirty years later would they think it was an external galaxy.**

Many argued that nebulae weren't just composed of stars, but actually in the process of forming stars. Following the 1885 nova, astronomers looked more closely at the spiral nebulae. By 1900, over 100,000 nebulae had been detected. These twisted, whirlpool-like objects seemed as if they would condense into stars or planetary systems over time. If nebulae were just proto-stars, then no need existed to think of them as being outside the Milky Way. They could just be the seeds of stars within the Milky Way.

Other astronomers continued to think that nebulae were truly 'island universes' – great collections of stars that reside outside our own galaxy. To determine if nebulae were within our galaxy or external, astronomers focused on the distances to the nebulae. The size of the Milky Way played an important factor in determining the distance to nebulae. For example, astronomer F.W. Very assumed that the Milky Way and the Andromeda Nebula were of a similar size. He arbitrarily assigned each to have a diameter of 120 light-years. By comparing their brightness he concluded the two were about 3800 light-years apart. Most astronomers, however, felt that the Milky Way was far larger than 120 light-years – an accepted consensus around 1910 was about 30,000 light-years in diameter. Efforts continued to determine the sizes of nebulae. The German astronomer, Max Wolf, concluded that most were about 1,000 light-years in diameter. By the beginning of the twentieth century most accepted that nebulae were made of stars, and the question then turned into the location of these nebulae.

The assumption of “uniformity in nature,” comes into play here. The assumption claims that processes and like-objects are uniform throughout nature, regardless of location. We've already seen this at work in spectroscopy. That is, because the spectrum of nebulae was similar to that of our own sun, we then infer that they must be made of similar stars. All stars like the sun, then, should be of similar brightness and move around at similar rates. Since nebulae generally looked alike and moved in similar fashions, astronomers could then use the philosophical idea of Occam's Razor (when more than one explanation may account for data, the simplest explanation tends to be best) and uniformity to lump all nebulae into 'external' or 'internal' categories. Either they were star clusters connected to the Milky Way (i.e., internal) or galaxies unto themselves (i.e., external). Many wondered, however, if it was right to assume all nebulae the same.



**Science, much like other ways of knowing, must make certain assumptions from which it works. While we cannot be absolutely certain that natural processes are uniform throughout the universe, that assumption has been fundamental to understanding the natural world.**

Measuring the velocity of nebulae began in earnest in 1909 and continued through the next decade. At the Lowell Observatory in Flagstaff, Arizona, Vesto Slipher measured radial velocities of nebulae. Radial velocities are the rates of movement of an object directly toward or away from the observer. The Doppler Effect is the basis on which the velocity is determined. When Slipher aimed his spectrograph at an oncoming object, its spectrum would be shifted toward the blue end; with a receding object, the spectrum would be shifted toward the red. This is where the words “redshift” and “blueshift” come from. The Doppler Effect is demonstrated by the sound waves produced by the siren of a passing police cruiser – as the cruiser approaches, the sound becomes higher pitched because the frequency of the sound waves increases. As the cruiser passes by, the frequency decreases due to the movement of the cruiser, and the sound becomes lower pitched. With light spectrums, an object moving away from an observer shifts toward the longer wavelengths (red), and objects moving toward an observer shift to the shorter wavelengths (blue). Slipher measured the Andromeda Nebula to be moving toward the Milky Way at a rate of 300 kilometers per second.

This measurement became crucial to the island universe debate. In 1911, William Wallace Campbell of the Lick Observatory determined a correlation between the age of stars and their velocities – the older the star, the higher its velocity. Campbell reasoned that if nebulae were forming stars, then they would have speeds similar to nearby young stars, 10 km/s. With the Andromeda Nebula clocking in at 300 km/s, however – the fastest measured object recorded at the time – it seemed unlikely to be a proto-star. Campbell politely instructed Slipher to redo his work, for such a great velocity must have surely been an error. Slipher continued his work for the better part of a decade, showing repeatedly that the nebulae moved faster than stars. With speeds so unlike those found in the Milky Way, Slipher's observations strengthened the evidence that the Andromeda Nebula was indeed an island universe.



**In 1911, Campbell had a hunch that the nebulae might be island universes, but hadn't firmly made up his mind. In asking Slipher to recheck his work, Campbell demonstrated great integrity. Eight years later, Campbell ended up the early front-runner to argue for island universes in the Great Debate. His colleague Curtis beat him out solely on the fact that he had published more material on the subject.**

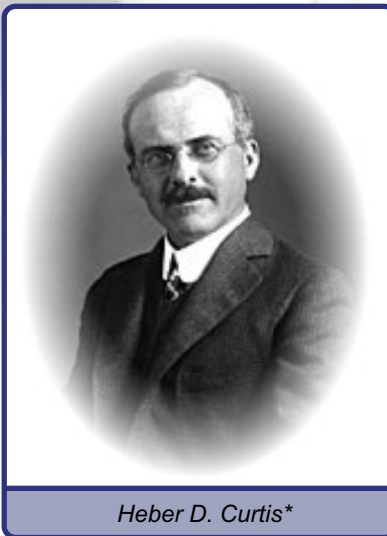
Evidence opposing the idea of island universes appeared in 1915. The Dutch astronomer Adriaan van Maanen, working at Mount Wilson with Shapley, had set upon measuring the internal rotational motions of nebula M101. By selecting and comparing numerous points on photographic plates taken over many years, he determined that M101 must have a rotational period of 85,000 years. A world-renowned stickler for detail, his colleagues trusted him with hardly a question.

The significance of this rotational period requires understanding Shapley's size of the Milky Way. Shapley had been a supporter of the island universe idea until he determined the Milky Way to be 300,000 light-years in diameter (10x larger than the consensus estimate). He concluded this by measuring distances to globular clusters. These clusters had been estimated to be about 500 light-years in diameter, which Shapley then calculated to be anywhere from 20,000 to 200,000 light-years distant using a technique that will be discussed later. Such a 'big galaxy' had enough room to hold every observable object, and then applying van Maanen's rotational motions gave him all the reason he needed to turn against island universes.



**The accepted diameter of the Milky Way has changed over time. Starting at 120 light years, then 30,000 light years, and finally 300,000 light years, the accepted measurement continued to grow. Scientific ideas are, by nature, tentative and open to revision. Most consider this to be a great strength of scientific knowledge. Improved technology, new observations, new approaches, and new ways of thinking can each cause scientists to reconsider prior ideas.**

If nebulae really were island universes, they would have similar sizes to the Milky Way. Taking a low-end estimate, Shapley plugged in a diameter of 100,000 light-years for M101; its circumference (multiplied by 3.14) was then around 300,000 light-years. If van Maanen was right, which nobody doubted he was, then M101 would be rotating 300,000 light-years in 85,000 years. That would be over three times the speed of light! To Shapley, in this evidence was all the confirmation he needed. To promote nebulae to the size of galaxies was to break the speed of light, a task which Albert Einstein had just recently shown to be impossible. Based on this seemingly flawless logic, Shapley and van Maanen became the most vocal opponents of island universes.



Heber D. Curtis\*

Now was time for the infamous 1920 debate. At first, Curtis didn't really want to participate, but his numerous publications associated his name tightly with island universes. Shapley, meanwhile, had his mind elsewhere. Focused on securing the Directorship at the Harvard College Observatory, all he wanted to do was avoid being humiliated by the more experienced Curtis. Knowing he had no evidence directly opposing island universes, Shapley instead drew up an understandable talk on his Big Galaxy model, which, if true, provided argument against the existence of island universes. The audience mildly accepted Shapley's non-technical talk. Curtis, completely flabbergasted, went ahead with his technical speech. Shortly after, he wrote to his family, "Debate went off fine in Washington, and I have been assured that I came out considerably in front." Shapley remembered many years later, "Now, I would know how to dodge things a little better. . . . As I remember it, I read my paper and Curtis presented his paper, probably not reading much because he was an articulate person and was not scared." The attendees in Washington knew the result of the debate to be no-contest, but to the faculty back home in the California observatories, the episode was a battle of giants. The validity of island universes, however, had been far from established.

**3) Debates are not the last word on a subject. They're more often intended to share information among colleagues, and optimally to convince associates of the strength of one's work. How does scientists' need to convince others of the meaning of observations illustrate that data doesn't show or tell scientists what to think?**

By 1920 much accumulated data existed for and against island universes. However, the evidence for each side was less than ideal. For island universe advocates, they could argue that nebulae moved far faster than stars. For Big Galaxy advocates, they could argue that collected evidence showed island universes to be physically impossible. The key to solving the island universe debate lay with Cepheid variable stars.

By the early twentieth century, it had been known that many stars varied in respect to their luminosity. Cepheid variables were a class of variables that had a very notable relationship between the period of their variability and their absolute luminosity. This relationship was demonstrated in 1912 after much research and calibration by Henrietta

\*Photo courtesy of the Astronomical Society of the Pacific



Leavitt of the Harvard College Observatory. The relationship was quite predictable, and because the absolute luminosity was known, these stars could be used as 'standard candles' to determine distance. In 1918, Shapley further studied these stars and began using them as yardsticks to measure distances to globular clusters.

Here's how one could use a Cepheid variable to determine distance. First, begin with the following two definitions. The apparent magnitude is the brightness of a star as seen from earth (a standardized measurement). The absolute magnitude is the apparent magnitude as seen from 10 parsecs (about 30 light-years). Once these are optically measured, distance can be ascertained by this equation:

$$m - M = 5 \log r/10$$

Where  $m$  is apparent magnitude,  $M$  is absolute magnitude, and  $r$  is distance in parsecs. If, for example,  $m-M$  is 0, then  $r=10$  parsecs, because the logarithm of 0 is 1. If  $m-M=5$ , then  $r=100$ . From 1918 onwards, Shapley had been calculating the distances to globular clusters one by one, hoping to show that their distances all fit within the Milky Way galaxy.

Enter Edwin Hubble, whose work with Cepheid variables changed the landscape of astronomy. Born in 1889 and a student of math and astronomy at the University of Chicago, Hubble accepted a Rhodes Scholarship to Oxford and studied Roman and English law for a time. He served in World War I and then went on to get his doctorate in astronomy from the Yerkes Observatory. Upon graduating he joined the Mount Wilson Observatory and gained use of its new 100-inch telescope. Fresh out of school, Hubble had his eyes set on verifying the island universe model. He thought the required evidence could be gathered by locating a variable star within a nebula, which could be used to estimate the distance to the nebula. Frequently checking photographic plates, he realized in 1923 that he had stumbled upon a sight that no

astronomer had yet to notice - Cepheid variable stars in the Andromeda Nebula. He wrote to Shapley early in the next year:

You will be interested to hear that I have found a Cepheid variable in the Andromeda Nebula (M31). I have followed the nebula this season as closely as the weather permitted and in the last five months have netted nine novae and two variables...the distance comes out something over 300,000 parsecs...I have a feeling that more variables will be found by careful examination of long exposures. Altogether the next season should be a merry one and will be met with due form and ceremony.

For emphasis, 300,000 parsecs is over 900,000 light-years – over three times as large as Shapley's Big Galaxy. Shapley, in turn, remarked in his journal, "Here is the letter that has destroyed my universe."

**4) Oftentimes someone who is young in age or new to a field of study has new insight that revolutionizes scientific thinking. Why might this be the case?**

Hubble published his work in whole on January 1, 1925, and on that day the issue of external galaxies is said to have finally been put to rest. Faced with a catalog of evidence from Hubble and many other astronomers, a consensus emerged that large nebulae were indeed island universes – galaxies unto their own.



Edwin Hubble

**You may be wondering about the measurements van Maanen made earlier to determine the internal rotational motions of nebula M101. They turned out to be incorrect. This illustrates the need for caution in interpreting data from difficult observations and the need for multiple tests done by different groups.**

Hubble quietly continued his research on nebulae and by the end of the decade would come to one of the most remarkable conclusions in the history of astronomy: that the universe was expanding. In 1924, upon hearing of Hubble's results regarding the distance to the nebula, Curtis remarked,

There is a grandeur and majesty in the concept [of island universes] and an agreement with the general cosmical continuity expected on philosophical grounds, which is both inspiring and alluring. Few greater concepts

have ever been formed in the mind of thinking man than this one, namely that we, the microbic inhabitants of a minor satellite of one of the millions of suns which form our galaxy, may look out beyond its confines and behold other similar galaxies, tens of thousands of light-years in diameter, each composed, like ours, of a thousand million or more suns, and that, in so doing, we are penetrating the greater cosmos to distances of from half a million to a hundred million light years.

With sufficient evidence for the existence of external galaxies, a new wave of cosmology began, in which astronomers dutifully conjured up explanations of the universe's origins and its grand structure.



**Stories about the development of knowledge concerning the size of the universe might neatly use “the Great Debate” as the clincher for the existence of external galaxies. Yet, note how this story illustrates that (1) scientific ideas develop over time, and (2) scientists do not vote on what the natural world is like. Scientists do sometimes vote on what to call something or how to categorize it, but not how the natural world works. Much time (often decades) passes as scientific ideas emerge, develop and are eventually accepted or discarded.**



**The Great Debate: Just How Big is the Universe?** written by Blair Williams, Jerrid W. Kruse, Michael P. Clough, Matthew Stanley, & Charles Kerton

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