THE SPIRAL QUANDARY

The Great Debate of 1920 and the Second Astronomical Revolution

Word count: 2379

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INTRODUCTION: THE GREAT DEBATE

What is our place in the universe? It's one of the questions humanity has been pondering for the last thousand years, in one form or another. In an astronomical sense, we can give an answer with some amount of confidence, but we couldn't always answer with such certainty. In the early 20th century, astronomers didn't have the precision we have today. This was before corrective optics, before computer-controlled telescope mounts, before the first satellite. Prevailing wisdom placed the Sun at the centre of the Milky Way galaxy, and nothing outside our galaxy at all. [1]

Not everyone agreed with the prevailing wisdom. Heber Curtis was directly opposed to it. He'd spent most of his career studying photographs of nebulae, particularly what were at the time known as spiral nebulae. He firmly believed that these objects were not nebulae at all, but entirely separate galaxies from our own, calling them 'island universes'. [1] When an invitation came in 1920 for him to debate the topic in the next meeting of the National Academy of Science, he accepted, eager to present his views to a large audience. [1]

His debate partner, Harlow Shapely, was less eager. Shapely, like many physicists, was not an experienced public speaker. He had been working on his own theories. He thought the Milky Way was much larger than the accepted figure of 10,000 light years (ly), and that the Sun was not at its centre. He accepted the invitation, hoping his own theories would disprove the idea that spiral nebulae were not part of the vast Milky Way. [1]

The event came to be known as the Great Debate. It took place in the Smithsonian Museum of Natural History, on the 23rd of April, 1920. [1]

Shapely spoke first. He outlined his new theories on the Milky Way's size and the Sun's position. He mapped out the galaxy through estimated positions of globular clusters. This method produced a diameter an order of magnitude larger than anything previously assumed. If his theories were true, and the spiral nebulae were similar sizes, they must be unimaginable distances away. He trumpeted observations that showed rotation in M101, the Pinwheel Galaxy. This would be impossible to observe if the spiral nebulae were as large as the Milky Way. [2]

Curtis followed. He pointed out similarities in spectra of light produced by the spiral nebulae and those of star clusters. These similarities existed both in the form of the spectra, and the positions of absorption lines. The evidence suggested that the spirals were similar to star clusters, groups of stars, not diffuse gas like nebulae. The high frequency of nova events in spirals was additional evidence that they contained more stars than any cluster. Finally, he pointed to evidence that the Milky Way, too, had a spiral structure. [2] [3]

The audience of the time named Curtis as the winner of the debate. However, how well the two astronomers spoke onstage says little about the validity of their theories. In order to truly find out who was right, solid evidence needed to be provided. Here, astronomers ran into a problem. To tell whether the spirals were inside the Milky Way, the distance to them had to be measured. But how do you measure the distance to objects that are so far away they can barely be seen?

SECTION 1: LEAVITT'S LAW

To find true distances to the perplexing spirals, astronomers needed a way to quantify distance. This is exceptionally difficult without any reference points, and without any idea of how large or how bright the object being observed is.

Imagine, if you will, looking out to sea on a dark night. Two ships are on the horizon, two sets of lights. One set is brighter than the other, but you've dropped your glasses, and can't tell anything else about the ships. Which one is closer?

The easy answer, that the brighter ship must be closer, isn't always right. If the brighter ship had a more powerful lamp than the dimmer ship, it could be further away. The luminosity of a star depends on several factors, including its age, its size, and its composition. Many of these factors are almost impossible to infer without first knowing the distance the star is from the observer. There is a rough correlation between a star's temperature and its luminosity, but there are several classes of star which do not obey this pattern. Red giant stars, for example, are cool, but luminous due to their large surface area.

Now imagine that you turn to look along the coast and see two lighthouses. You know that all lighthouses along this coast have the same bulbs, so you immediately recognise that the brighter lighthouse must be closer to you. In this case, there is no doubt. If you know that the two are the same brightness, you know their relative distances. But, again, not all stars have the same brightness. And, in order to quantify the distances involved, a benchmark is needed, for example a lighthouse you know is a mile away. From there, it is simple to work out the distances to the other lighthouses. [4]

In 1912, Henrietta Swan-Leavitt (Fig. 1) worked as a 'computer' at Harvard College Observatory. [5] Her main field of study were variable stars in the Small Magellanic Cloud. [5] She spent each day analysing photographic plates, recording variations in the intensity and time period of nearly two thousand variable stars. [5] Whilst embroiled in this tedious work, she noticed something.

Fig. 1: Henrietta Swan-Leavitt sitting at her desk, writing. Image Source: American Institute of Physics, Emilio Segrè Visual Archives

The Small Magellanic Cloud isn't close enough to the Earth for parallax measurements to be taken of stars within it, but Leavitt assumed that all the stars within it were similar distances away from Earth. [6] In our analogy, this is as if there were an island out at sea, with many boats docked at its harbour. Though the true distance away is unknown, comparisons between them can be made. Plotting these relative luminosities against the time period of 25 Cepheid variables, Leavitt found a classic logarithmic plot. She took her results to her supervisor, Edward Pickering, and they were published under his name in 1912, with a short note that the content of the paper was entirely

Leavitt's work.[6] The relation between period and luminosity for Cepheid variable stars began to be known as Leavitt's Law. [5]

Leavitt's Law enabled the true luminosity of any Cepheid variable star to be calculated simply by observing its period. This allowed astronomers to tell the distance to any object they could resolve stars in - as long as one of those stars was a Cepheid variable.

Of course, all this was known to Shapely and Curtis, as they debated the true nature of spirals. Curtis used Cepheid variables in globular clusters as one of his main points of evidence that the Milky Way was larger than anyone had thought. But no astronomer had found a Cepheid variable inside one of the spiral nebulae.

At least, not yet.

SECTION 2: HUBBLE'S NOVA

Mount Wilson Observatory was the home of the largest telescope in the world in 1917 to 1949.[7] It was, and still is, situated just outside the city of Pasadena, California. [7] The jewel in its crown was the Hooker Telescope, a 100-inch reflector. [7] Recently, the light pollution of this huge city has made it impossible for the observatories nocturnal observations to continue, but to this day it continues as a hub of solar research and observations. [7] Fig. 2 shows the sheer scale of the Hooker telescope, as well as Edwin Hubble looking through its eyepiece.

Fig. 2: Edwin Hubble operating the Hooker Telescope.
Image Source: http://time.com/ 3586145/edwin-hubble-photo-of-a-genius-at-work/

Edwin Hubble started working at the observatory in 1919, when he was 30.[8] He started working on the Hooker Telescope in 1923, making observations of M31, the largest spiral in the sky. We know it as Andromeda, the closest galaxy to the Milky Way, doomed to collide with us in 4.5 billion years.[9] One night, after taking a 45-minute exposure of Andromeda, he sat down to mark the photographic plate of his observation, comparing to an earlier example in order to make obvious any new sources of light. [8] The plate, shown in Fig. 3, told a different story to any before it.

Hubble labelled several new sources of light as N, standing for nova. Nova are fairly common, bright bursts of light as a star dies. But, on comparison with earlier plates, Hubble noticed that this particular source of light had appeared before in another observation. Novae do not repeat. The only explanation for a repeating source was a variable star. Hubble relabelled the source as a variable, adding an exclamation point. [8]

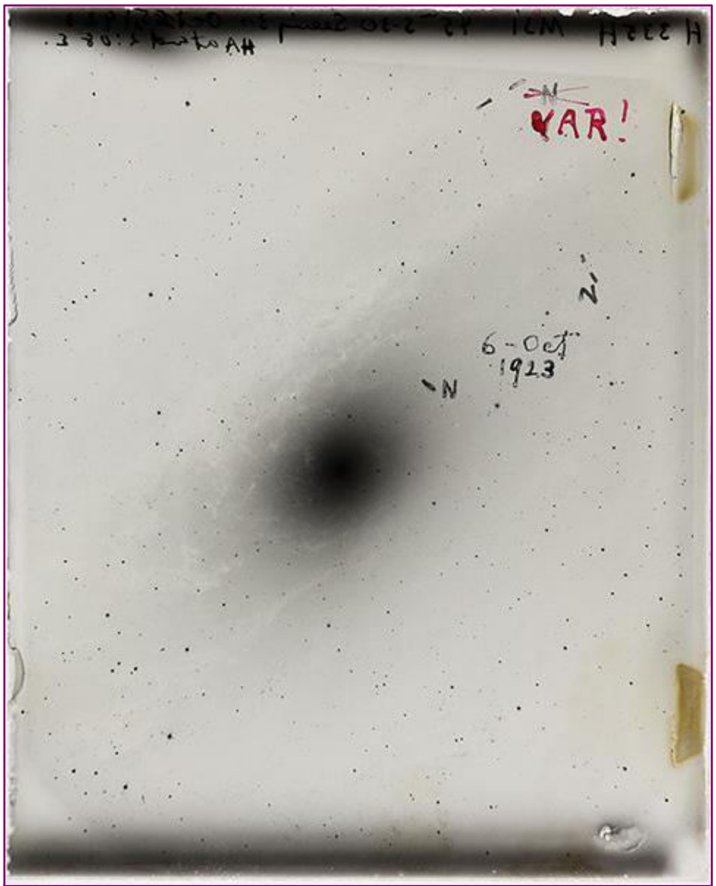

Fig. 3: Photographic plate showing M31, annotated by Edwin Hubble. Image Source: http://nautil.us/issue/32/space/these-astronomical-glass-plates-made-history

This variable, now known as V1, is the first Cepheid variable star to be discovered outside our galaxy. Like most Cepheid variables, its light curve has a characteristic, unusual shape. An example light curve, for Delta Cephei, is shown in Fig.4. This was the first Cepheid Variable discovered, and gave the type of star their name. [10]

This characteristic shape is due to the mechanism driving the Cepheid's variation in luminosity. This process, known as the Eddington valve or kappa-mechanism, is based on a star's radiative opacity. This quantity measures how much light a substance absorbs, and is different for different materials. Stone, for example, has a much higher radiative opacity than glass. Materials with a high radiative opacity will absorb most of the light that travels through them, and will heat up. [11] [12]

In the outer layers of a Cepheid variable star, material properties of helium cause a feedback loop between the temperature of the outer layers and their radiative opacity. If a layer's temperature rises, it becomes more opaque, which causes it's temperature to rise more. The layer starts to block light from escaping the star, becoming more and more opaque. Pressure builds up under the layer, until the pressure overcomes the layers weight, and it shoots outward, to the cooler surface layers of the star. The layer's temperature drops, as does its opacity. Light can escape the star once more, and does with vigour. The pressure holding the layer outward also fades, and the layer begins to fall in towards the hot core of the star under its own weight. This causes the layer to heat up, and the cycle to start once more. This cycle of contraction, heating, expansion, and cooling causes the star's luminosity to periodically grow and shrink. [11] [12]

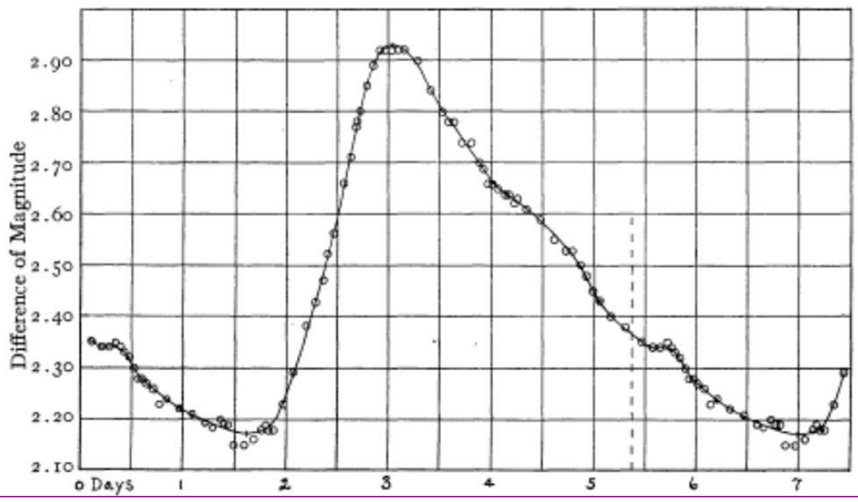

Fig. 4: The light curve of Delta Cephei. The y-axis shows the absolute magnitude of the star, while the the x-axis shows the number of days since the observation started. Image Source: Stebbins J. (1908), The light Curve of Delta Cephei, accessed through http://adsbit.harvard.edu //full/1908ApJ....27..188S/0000192.000.html

For larger, more luminous stars, each layer of the star is more massive, and so it's weight is larger. This means that it takes longer for enough pressure to build up inside the star to balance and overcome the layer's weight. This is the physics governing Leavitt's Law. [11] [12]

None of the reasoning behind the shape of this light curve was known to Hubble. But he knew Leavitt's Law, and from it calculated the stars luminosity. Comparing this with the apparent brightness of the star, he calculated, for the first time, the distance to Andromeda. [8] He found a value far greater than anyone had imagined. He began to collect evidence, using the sheer power of the Hooker telescope to search for more Cepheids in Andromeda. [8] He presented his findings at the meeting of the American Astronomical Society, on the 1st of January 1925.[8] By then, his findings were concrete: Spiral nebulae were near-impossible distances away, outside the confines of the Milky Way galaxy by any way of measuring. They were separate galaxies.

CONCLUSION: THE SECOND ASTRONOMICAL REVOLUTION

The Great Debate was settled. Spiral nebulae were not in fact nebulae, but galaxies, as big and as populated as our own. No one had thought to imagine that both Shapely and Curtis could be right, that spiral galaxies could be far enough away that their size, and size of our own galaxy, was large enough to align with Shapely's distance measurements.

The use of the word 'revolution' to mean a great change or uprising is said to have been popularised by Nicolaus Copernicus's book, *On the Revolutions of the Celestial Spheres.* [14] In this text, published in 1543, Corpernicus laid out a model of the Solar System with the Sun at its centre, opposing all the geocentric models that had preceded him. [14] This theory put all the observations previously made of the planets into a new, simpler context, explaining with one crucial revelation everything that had come before. [14] It was the spark that lit the Copernican Revolution, which built through Kepler's laws of planetary motion to culminate in Isaac Newton's theory of gravity, one of the foundations of classical mechanics.

If any scientific revolutionary were to have come out of the early 20th century, it would clearly be Albert Einstein. But we also owe our thanks to quieter revolutionaries. Parallels can clearly be drawn between the work of Copernicus, demoting the Earth from the centre of the universe to the third rock from the Sun, and the work of Curtis, Leavitt, and Hubble, demoting the Milky Way from filling the universe to simply existing within it.

We are in the midst of a second revolution. We've discovered a wealth of wonder that could never have been dreamt of by the star-studded audience of the Great Debate; quasars belching powerful radiation across the universe, supermassive black holes clawing stars into their maws, gaping voids of nothingness megaparsecs across. The study of galaxies has opened the door to discoveries like the accelerating expansion of the universe, the Big Bang, and the existence of elusive dark matter.

What is our place in the universe? We live on one planet of eight, orbiting one star of 250 billion, in one galaxy of 2 trillion. That's enough of an answer to satisfy me.

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