The Curtis-Shapley Debate: Refining Galactic Models and Our Place in the Universe

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Introduction

The beginning of the 20th century saw discoveries and advances in astronomical techniques that allowed greater precision in measurement and in photographic resolution of faint objects than ever before. As these data started to emerge they allowed estimation of the size and structure of our Galaxy, and they prompted a reassessment of the nature of some galactic objects. However, gaps, errors, and uncertainty in the data and theories still lead to inconsistencies and controversy. The Curtis-Shapley debate of 1920 was an important reference point in the evolution of two interrelated theories, on the size and structure of our Galaxy and the possible existence of other galaxies like our own. As is often the case with emerging scientific theory, both of the presented viewpoints contained a mixture of correct and incorrect interpretation and conclusions, and both of the proponents are now regarded as having made important contributions to our understanding of the structure of the universe.

The *Great* Debate

While there was a specific event promoted as a debate, the term "*Great* Debate" is often used to refer to the various schools of thought on the general structure of the universe in the 1900-1920 era.

Theories formed around three questions: the nature, structure, and size of our Galaxy, whether the Galaxy was the Universe or only part of it, and the nature of spiral nebulae. Key observations of interest to this debate were: the non-uniform distribution of stars, the asymmetric distribution of globular clusters, the motion and speed of various classes of observed objects, the apparent lack of spiral nebulae in the plane of the Galaxy, and the occasional appearance of novae in the spiral nebulae.

The prevailing model for the size of the galaxy, developed by Kapteyn [1913], was of a disk-shaped system 10 Kiloparsecs[1] in diameter [Struve and Zebergs, 1962]. Immanuel Kant [1755] proposed a Universe consisting of many disk-shaped structures, one of which was our Galaxy [WeissteinWeb], and photographic studies of spiral nebulae were lending support to this model. Curtis supported this Island Universe model, while Nemiroff and Bonnell [NasaWeb] describe Shapley's position as "one final assault on this idea".

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1 Distances in referenced literature use a mixture of Light Years and Parsecs. I have converted all distances to Parsecs for this paper.

The *Actual* Debate

The actual Curtis-Shapley debate at the 1920 meeting of the National Academy of Science was not a formal debate, but rather presentations of two different viewpoints, followed by comments from the audience. Hoskin [1976] suggests this format was the result of lobbying by Shapley, who wished to avoid confrontation and controversy in the event. (He was being considered for a senior role at the Harvard observatory, and members of the selection committee were in the audience.)

The presentations were not in direct opposition, but focused on different topics that were somewhat contradictory, and they were presented at very different levels of detail. Shapley read a very general, "popularized" speech on the size of the Galaxy, and then Curtis gave a presentation with slides that rebutted some of Shapley's data and then focused on the nature of spiral nebulae.

The published title of the debate, "The Scale of the Universe", allowed this misalignment of topics. Shapley believed the Galaxy *was* the Universe; so discussing the size of the Galaxy was appropriate. Curtis believed there were numerous galaxies in the Universe, so was arguing for a vast universe of unknown size. The "transcripts" that were published following the event [NRC, 1921] were not, in fact, transcripts, but more refined papers.

Points of View

Although Curtis represented the growing view that the spiral nebulae were island universes, and Shapley opposed this view, Shapley presented first, so it is easier to compare their presentations in that order.

Shapley's argument was based on determining the distance to the globular clusters (GCs), then using these distances to determine the size and shape of the Galaxy. Using M13 as an example, he derived the distances to the GCs using several methods: parallax, relative magnitude of type-B stars, apparent sizes, and Cepheid variables. Although his use of Cepheid variables was novel, and contested by Curtis, Shapley stated that the data derived from B stars was sufficient even without the support of the Cepheid data. To use Cepheids as measures, Shapley calibrated the period-luminosity relationship discovered by Leavitt [Pickering, 1912] to distance using parallax and proper motion measurements.

Shapley argued that the GCs should be evenly clustered around the centre of the Galaxy, and that the direction in which we see them congregate must be the direction of the centre. His distances suggested the centre to be about 20 kiloparsecs from our Sun, in the direction of Sagittarius. He also argued that the GCs were located around the outer periphery of the Galaxy, so the distance to the furthest of them sized the Galaxy, to a diameter of approximately 100 kiloparsecs.

Finally, Shapley commented on the spiral nebulae. He argued that, if they were separate galaxies, they should be similar in size to ours, but to achieve their apparent size they would have to be at great distances. He said these distances were impossible because novae observed in the nebulae would then have to be of unimaginable luminosity, and because rotational speeds of the nebulae (recently measured by Van

Maanen [1916]) would have to be unreasonably high. He also pointed out our Galaxy has a much lower surface brightness than the spiral nebulae, so it did not seem reasonable to assume they were the same type of object. Shapley's alternate explanation for the spiral nebulae was that they were gaseous, outside but associated with our galaxy, and being driven away by some kind of repulsive force, possibly light pressure. Novae in spiral nebulae might be caused when a moving nebula "ran over" a star, causing it to explode.

Curtis began by rebutting Shapley's key points. He disputed his distances to the GCs on several grounds. First, he was unconvinced that Cepheids were reliable distance indicators, or that Shapley had calibrated them accurately. He argued the calibration was done with a small amount of data, and that half of the distances used were based on proper motion measurements where the measured values were of the same order as the probable error of the measurement, and thus unreliable. (He used this same argument on the inaccuracy of the proper motion data to dispute Van Maanen's measured rotational speed of the nebulae.) He also argued that the distances measured by relative magnitude of type B stars assumed a greater proportion of giant stars in the GCs than we see in other regions, and that this was unreasonable. Finally, he showed that Shapley's proposed collision mechanism for novae in spiral nebulae would predict a frequency of novae far different from what we actually observe.

Curtis supported and expanded Kapteyn's model of a disk-shaped Galaxy, with a diameter of 9 kiloparsecs and thickness of 1.5, and containing about 1 Billion stars. The stars were not uniformly distributed, and he indicated there was some evidence of a spiral structure. He placed the sun near the centre of the Galaxy.

Most of Curtis' presentation focused on the spiral nebulae. He categorized all known objects into five classes: stars, globular clusters, gaseous nebulae, planetary nebulae, and spiral nebulae. Spiral nebulae stood out as different from the other classes in several ways: their appearance only above and below the galactic poles, and their much higher velocities (1200 Km/S compared to 10-300 for the other objects). He noted the spiral nebulae had the same spectra as globular clusters, and spectra similar to the integrated spectra of stars in our Galaxy, so this suggested they were stellar in nature. On the other hand, if the spirals were not stellar then they must be gaseous, and we had no explanation for their spectra. Finally, by assuming that novae are similar everywhere, he used relative magnitudes of novae observed in spiral nebulae to estimate their distances, and then used these distances and the nebulae's apparent sizes to estimate their actual sizes. The results were similar to the size of our Galaxy, and consistent with Kapteyn's model.

Commenting on the "zone of exclusion" where no spiral nebulae are observed in the plane of our Galaxy, Curtis noted that some other spirals appear to be surrounded by a band of obscuring matter and hypothesized that our Galaxy may have a similar band, obscuring our view of distant nebulae in the plane of the disk.

Resolution

Each of the participants was right on some profoundly important point and wrong on some other. On the actual topic of the discussion – Scale of the Universe – both were wrong, by about equal amounts, on the size of our Galaxy. Curtis was more correct in that the island universe theory makes the Universe much larger than the Galaxy.

Shapley sized the Galaxy too large, but correctly argued the Sun is far from its centre. Many have assigned great importance to this victory, as maturing our sense of our non-central role in the universe [Nemiroff and Bonnell, NasaWeb]. Shapley was wrong in his explanation of the spiral nebulae. Some of his arguments were based on Van Maanen's proper motion data, later found to be inaccurate, and many of his counterarguments against the island universe theory were flawed. For example, Russell had already published results indicating light pressure could not be responsible for the recession of the spirals when Shapley suggested it as an explanation [Trimble, 1995].

Curtis sized the Galaxy too small, and incorrectly placed the Sun near its centre. However, he was correct that spiral nebulae are galaxies similar to our own, at vast distances. Although he was incorrect in discounting Cepheids as reliable distance measures, his concerns on the quality of the calibration data were valid and, in the case of the proper motion data, correct. Personally, I find Curtis' position on island universes more important and profound than the size of our Galaxy, and I feel his desire for consistency of observations, and his analysis of data quality and measurement error to better exemplify the scientific process.

Neither participant correctly allowed for the effects of the light absorption by interstellar matter. Shapley specifically discounted this point, while Curtis thought it occurred only in bands surrounding galaxies. Absorption is now known to be important, and to account for some of the discrepancies in their observations.

The debate was generally considered resolved when Hubble detected Cepheid Variables in M31 and M33 and used them to estimated distances to these nebulae of 1 million light years (300 kiloparsecs) [Struve and Zebergs, 1962]. Shapley then readily admitted the nebulae must be external to our galaxy.

Current Knowledge

We now know that the spiral nebulae are, indeed, one of the three major forms of galaxies. They are at varying remote distances, number in the billions, and each contain billions of stars. Our own Galaxy is a typical member of this class, with diameter of approximately 50 kiloparsecs, and containing approximately 10^{11} stars. Our Sun is located approximately 8 kiloparsecs from the centre, in one of the spiral arms.

We now also understand some of the discrepancies that troubled Shapley's and Curtis' analysis. Cepheids are accurate distance measures, but there are two major types, and they differ in luminosity by about 1.5 magnitudes. Likewise, there are two types of Novae. Supernovae, unknown to Curtis and Shapley, are the "unimaginably bright" novae that Shapley said were necessary to explain remote galaxies.

Conclusion

The Shapley-Curtis debate reflected the evolution of prevailing views of galactic structure at the beginning of the 20th century. Both participants made profound contributions to our understanding of galactic-scale phenomena, and our current model of the galaxy and the universe is based on both of their theories. It is equally instructive that the nature of scientific advance allowed each participant to interpret available data in greatly different ways, and to draw incorrect conclusions that they were still able to reconcile with their overall theories.

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