Scale of the Universe – The "Great Debate"

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HET 602

22nd November 2001

Introduction

At the start of the twentieth century our knowledge of the universe was far more limited than it is today. The size and structure of our universe had been a topic of discussion for many years. The sky surveys of William Herschel (1738-1822) hinted at a structure. In the early twentieth century, Jacobus Kapteyn (1851-1922) made use of photographic images of 454 875 stars in the southern skies to demonstrate a disc-shaped universe. By 1920 state-of-the-art thinking and research had settled on a disc-shaped galaxy of stars approximately 30 000 light-years[1] (lyr) across and 5 000 lyr thick with the Earth at a nearly central position.

In 1920 two astronomers were invited to make presentations at the U.S. National Academy of Sciences addressing the issue of the scale of the universe. They were Harlow Shapley (1885-1972), a promising astronomer with several notable pieces of work to his credit, and Heber Curtis (1872-1942) a more established researcher with a solid reputation.

Debate

Following the presentations each participant published a paper [Sha21, Cur21] putting their case and addressing the other's arguments.

Both parties were happy to agree that:

- the galaxy had a flattened disc-like structure,
- uniformity of stellar characteristics across the universe could be assumed,
- the effect of dust and gas in the space between stars was not significant, and
- the 100 or so known globular clusters[2] (GCs) were part of the galactic structure although external to the main disc. They also agreed that the relative distances to these clusters were essentially correct.

[1] A convenient measure of stellar distances is the distance traveled by light in one year, approximately 9.5 trillion kilometres.

In their arguments both astronomers would adopt elements of the status quo and discard others. Shapley maintained the concept that the galaxy and attendant GCs was the universe but challenged the size of the galaxy asserting that it was ten-fold larger: 300 000 lyr. Curtis, on the other hand, would argue that the galaxy was in the order of 30 000 lyr across but that the universe extended far beyond the galaxy to encompass so-called 'island universes'.

The assumption of uniformity throughout the universe was relied on heavily in support of both viewpoints. Shapley, using data from stars in the GC Messier 13 (M13), equated the luminosity of samples of blue, giant and variable stars with samples from star clusters in the solar neighbourhood. He reasoned that their apparent brightness[3] was congruous with a distance of 36 000 lyr and not 3 600 lyr. Curtis used an average luminosity figure for giant stars near the Sun, whether in clusters or not, to counter Shapley's argument. His average brightness was sixteen times smaller than Shapley's, decreasing the distance by a factor of four to 9 000 lyr. The smaller figure was more palatable to Curtis' position.

The wide range of variation in stellar characteristics lead Curtis to argue that only aggregate data from large samples should be used. Having determined the characteristics of an average star from a sample of 500 nearby stars, Curtis applied that to an average assessment of M13. Assuming the M13 and galactic average stars to be equal then the apparent brightness of M13 would be commensurate with a distance in the region of 10 000 lyr. Curtis reasoned that if M13 were indeed four or more times further distant then it must contain a large proportion of giant stars to appear as bright as it does. This would make GCs abnormally abundant in giants compared to galactic stars.

Shapley made one observation that Curtis didn't challenge in his paper. Radial velocity measurements of GCs gave values in the region of 150 km/sec and higher and, given the usual assumption of a random distribution of proper motions, transverse motion should be present. At 3 600 lyr this motion should be measurable, and well above the limits of precision, but not at 36 000 lyr. There were no measurable transverse motions amongst the GCs lending weight to Shapley's position.

Curtis' greatest disagreement was with the validity of using Cepheid variable stars as distance measuring devices. Shapley had used the newly discovered Cepheid period-luminosity relationship to show that the larger galaxy was a better fit to the data. The method and small sample (11) of galactic Cepheids used to calibrate the distance had large potential error values. Curtis was reluctant to accept a measurement device with such large uncertainties involved and discounted this evidence accordingly.

Curtis considered the many thousands of visible spiral nebulae as extragalactic on the basis of the nature of their light emissions, their distinctly non galaxy-centric distribution, and their very large radial velocities. Further, some spirals were being resolved into individual stars and novae had been seen amongst them. Curtis asserted that the spirals were galaxies of comparable size to our own on the basis of uniformity, 500 000 or more lyr distant, and that

[2] Globular clusters are dense, spherical associations of between 10 000 and 1 000 000 stars with a radius of between 10 and 500 lyr.

[3] Apparent or observed brightness drops with the square of distance. The observed brightness of an object is one hundredth as great if the object is moved ten times further away from the observer.

the appearance of spiral novae was consistent with such a distance. However, recent measurements of the rotational velocity of spiral nebulae coupled with the large distances, required a rotational velocity that was a significant portion of the speed of light. Shapley found this unacceptable and concluded that the spiral nebulae were galactic phenomenon and not a substantial element in the scale of the universe.

Having defended his distance estimate for M13, Shapley then argued that apparently fainter and smaller GCs, assuming equivalent actual size to M13, are more distant. He put the furthest of these at nearly 300 000 lyr and concluded that the galaxy, of which the GCs are a subordinate part, is a similar size. Coupled with Shapley's earlier study of the distribution of GCs the galactic centre was some 50 000 lyr away in the direction of the constellation Saggitarius.

Right and Wrong?

This was a debate in which the parties were neither entirely right nor wrong. Both astronomers put forward logical and convincing arguments based on the same evidential base. The debate highlights that there is often considerable scope for interpretation of leading-edge results. For each argument there seemed to be an opposite argument using the same theory.

Differing interpretation affected the areas of agreement. Shapley's arguments were partly based on similarity between stars in nearby and distant clusters. Curtis, on the other hand, interpreted uniformity as requiring the same overall distribution of all types of stars. Globular clusters have been since shown to have a distribution of characteristics quite different from the run-of-the-mill galactic sample.

Shapley was correct in his assessment of the location of the galactic centre and the relative distances to the GCs but not in the absolute distances. He was, however, incorrect in his dismissal of spiral nebulae as issues peripheral to the scale of the universe.

Curtis' opposition to the use of Cepheid variables was partly justified by the discovery that some of the variables identified in GCs were not Cepheids but a similar, inherently dimmer, RR Lyrae type variable. In a touch of irony, Edwin Hubble used Cepheids to determine the distance to the Andromeda Galaxy thereby settling the debate about spiral nebulae in Curtis' favour.

On the assumption that interstellar dust was not significant both Curtis and Shapley were mistaken. Dust limits visibility in the galactic plane and shortens estimates of depth based on star density. Dust in inter-galactic space makes stars dimmer than their distance would dictate leading Shapley to overestimate.

Overall, the presentations and associated papers were an excellent catalyst and focal point for much of the research to follow.

References

[Cur21] Heber D. Curtis. The Scale of the Universe, Part II. *Bulletin of the National Research Council*, 2(11):194, May 1921.

[Sha21] Harlow Shapley. The Scale of the Universe, Part I. *Bulletin of the National Research Council*, 2(11):171, May 1921.