The Dusty Veil

Chris Williams
Student 1607421
HET 607

20th September 2003

Introduction

Step outside on any clear, dark night and you can clearly see the bright band that we call the Milky Way or the Galaxy. The hazy band and apparent concentration of stars in its general direction did not go unnoticed in the ancient world, with the 'celestial path' appearing in many myths. However, our knowledge of the nature of the Milky Way, its size, and structure are far more recent understandings. These understandings have evolved over approximately 500 years. Early galactic models were, unbeknown to their authors, severely limited by the seemingly insignificant factor of dust between the stars. This essay discusses the history of our understanding and the role dust played.

History

We first learnt that the the bright band in our sky was the merged glow of "a congeries of innumerable stars distributed in clusters" [1] after Galileo Galilei (1564-1642) trained his small telescope on the band. The band is strongly suggestive of a disc-like structure for the congregation of stars. Thomas Wright (1711-1786) and the philosopher Emmanuel Kant (1724-1804), writing in 1750 and 1755 respectively, expressed the ideas of the Galaxy's structure as a huge shell or disc of stars. While both models were theologically inspired they both provide essential characteristics consistent with observational evidence. The band corresponds to a view along the disc, while the regions away from the band are views out of the disc's plane. Kant also conjectured that the nebulae now being seen through telescopes were perhaps similar to the galaxy in which Earth resides. The concept that the Universe was larger than the Galaxy would not be confirmed until the twentieth century.

Sir William Herschel (1738-1822), a respected astronomer in the late 18th century, resolved to determine the position of Earth in the Galaxy through observation. His method relied on the assumption of roughly uniform star distribution and the ability of his equipment to see to the edge of the Galaxy. He divided the sky into 683 patches and counted the number of stars visible in each segment. More stars in a patch, he reasoned, should indicate a view through a greater depth of stars, while fewer stars indicated a shorter depth. The picture he derived for a circle on the sky is shown in Figure 1. The

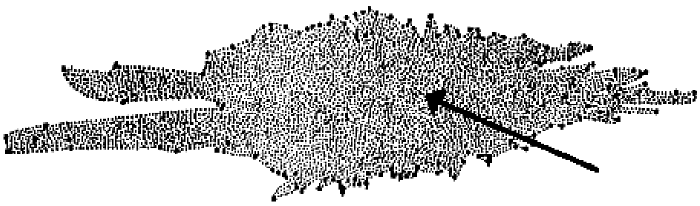

Figure 1: Herschel's galaxy based on "star gauges". Earth is indicated by the arrow. Adapted from [2]

model clearly places Earth near the centre of the galaxy. Herschel later abandoned this model because his new, larger telescope showed more stars than previously visible, and he became aware of more irregularity of star distribution. The model, however, lingered because there was little to replace it until the twentieth century.

Jacobus Kapteyn (1851-1922) took on the task of determining the shape and size of the Galaxy during the early 1900's. His method involved determining distances to galactic star clusters using statistical analysis of the motions and apparent brightness of the cluster stars. Kapteyn enlisted the help of many in gathering the necessary data. This approach determined the edge of the Galaxy to be approximately 30,000 light-years distant [3] and left the Earth in the centre of the Galaxy as in Herschel's model. Kapteyn made three conditions on the validity of this study, one of which was assumption that there is no light absorption in free space. Kapteyn expressed reservations about the validity of this assumption.

Using an alternate approach, Harlow Shapley (1885-1972), an astronomer at Mount Wilson Observatory, used the distance and distribution of globular clusters, very dense conglomerations of stars in orbit about our Galaxy, to derive a galactic size and shape. Shapley built on the pre-existing observation that globular clusters were overwhelmingly concentrated about a distant point in the direction of the constellation Sagittarius. If globular clusters indeed orbited the galaxy then the centre of the globular distribution must be an indicator of the centre of the Galaxy. By measuring distances to these clusters, building on work by Henrietta Leavitt (1868 - 1921) and some statistical assumptions, Shapley determined that the Galaxy's centre was on the order of 20000 parsecs (65000 light-years) distant and that Earth was some 3000 parsecs (9800 light-years) from the edge [4].

Shapley's approach to determining the galactic size had the distinct advantage of using very distant objects that, for the most part, were not near the galactic plane. If there were substantial scattering and absorbing material in the galaxy then the view to globular clusters would be minimally affected. The observations that globular clusters are not centrally distributed about Earth, and that few globular clusters are visible close to the galactic plane (a zone of avoidance) are of more importance than the absolute figure he derived for the size of the Galaxy. Astronomy now begins to see around the obscuring haze of the galaxy to gain a better picture of our place within it, and we're not in the centre.

Kapteyn's suspicion about absorption was confirmed for the first time by Robert Trumpler (1886-1956) at the Lick Observatory (1930). Trumpler showed that galactic star clusters were systematically dimmer than distance alone could account for [5]. He further showed the behaviour of this dimming medium over a range of light wavelengths was consistent with absorption by particles of a size comparable to the wavelength of light, about a micrometre. This was the first quantitative evidence of an interstellar absorbing or scattering medium: a fine dust. Trumpler however, did not see dimming of light commensurate with the distance of Shapley's globular clusters and concluded that the absorbing medium is most likely confined to the galactic plane. Trumpler did find absorption though, and this leads to a downward revision of Shapley's distances. Further, while Shapley had concluded otherwise, the presence of dust in the galactic plane could explain the zone of avoidance he'd observed in the globular cluster distribution.

The twentieth century saw many technological advances that permitted determinations of the extent of our galaxy. Exploration of radiation in the infrared range, discovered by Herschel in the 18th century, became a possibility using ground and space-based telescopes. In the infrared range the feeble glow of very cold dust is detectable, confirming the presence of Trumpler's dusty haze heavily concentrated in the galactic disc. Infrared radiation also penetrates further through dust, allowing us to see stars in, and through, the inky voids in the optical sky. The dust that obscures optical, and to a lesser extent infrared, observations is nearly transparent to radio waves. Using modern radio astronomy we can "see" through the dense clouds obscuring the view toward or galaxy's centre. With this view the centre is revealed as a seething mass of activity that is utterly invisible to optical observers. By careful measurement of particular emissions, e.g that of neutral hydrogen atoms, and the way they vary with position radio astronomers have been able to determine the galaxy's bulk structures and rotational behaviour.

Our present understanding is of a disc-like galaxy (among a multitude) some 50000 kilo-parsecs (160000 light-years) in diameter, about 600 parsecs (2000 light-years) thick, with a central bulge of 2000 parsecs (6500 light-years) in diameter. The Earth is some 8000 parsecs (26000 light-years) for the central region. The bulge is completely obscured optical inspection by dust, but is discernible in the near infrared range.

Discussion

The work of Copernicus (1473-1543) and Kepler (1571-1630) in the 16th and 17th centuries had largely dispelled the notion of a central, immobile Earth about which the universe revolved. Nevertheless, as an extension from Earth-centred solar system views was the assumption that, whatever the form of the universe, the Earth, Sun, and planets were at the centre. When observational astronomy first tackled the problem of the structure of the Galaxy the conclusions were supportive of this assumption. It was not until the twentieth century that this notion was conclusively laid to rest by work like Shapley's and subsequent infrared and radio observations.

That early western astronomers did not account for the possibility of substantial loss of light en route from distant objects is not surprising. There are prominent dark patches in the Milky Way, e.g. the Coal Sack near the Southern Cross, but these were usually considered to be starless voids rather than obscured, star-filled regions. With optical instrumentation, limited data, and a long history of assuming the heavens to be perfect, there was no conflicting observation to hint at a different galactic structure. By the time of Kapteyn the suspicion that absorption and scattering were potentially significant was becoming more substantial. Unfortunately astronomers of the late nineteenth and early twentieth centuries had little concrete knowledge with which to quantify the problem.

Conclusion

The task of determining galactic structure is a difficult one, viewing the Galaxy from inside as we do. The early theories (Wright, Kant) and observation-based models (Herschel) confirmed the long-held belief of an Earth-centred universe. As scientific methods were brought to bear on the problem old notions were retired and the size and structure of the galaxy revised. The presence of substantial dust in the plane of the Galaxy, as confirmed by Trumpler, interferes with our ability to see significant portions of our galaxy and this has greatly affected our conclusions. Modern technology has allowed us to peer through the obscuring haze to get a better picture of the place we live.

References

[1] Galileo Galilei. *Sidereus Nuncius or the Sidereal Messenger*. University of Chicago Press, June 1989. Translated with introduction, conclusion, and notes by Albert van Helden.

[2] Michael Hoskin, editor. *The Cambridge Concise History of Astronomy*. Cambridge University Press, 1999.

[3] J. C. Kapteyn. Recent researches in the structure of the Universe. *The Observatory*, 31:346–348, September 1908.

[4] H. Shapley. Studies based on the colors and magnitudes in stellar clusters. XII. Remarks on the arrangement of the sidereal universe. *Astrophysical Journal*, 49:311–336, June 1919.

[5] R. J. Trumpler. Absorption of Light in the Galactic System. *Publications of the Astronomical Society of the Pacific*, 42:214–+, August 1930.