Galaxies & Extragalactic Astrophysics

Galaxies

1. Historical Introduction

1. Introduction

1.1 Notions

- Galaxy: gravitationally bound stellar system
- Considered as the fundamental contituent blocks of the Universe, although they are grouped in groups, clusters and other structures
- Formed by stars, gas and dark matter
- Observational characteristics: flux, luminosity, colour, metallicity, shape,….
- Galaxy morphologies: elliptical, lenticulars, spirals, irregulars, bared
- Active galaxies: seyfert I i II, liners, blazars, quasars
- Galaxy groups and clusters

1. Introduction

1.2 Galactic Astronomy history

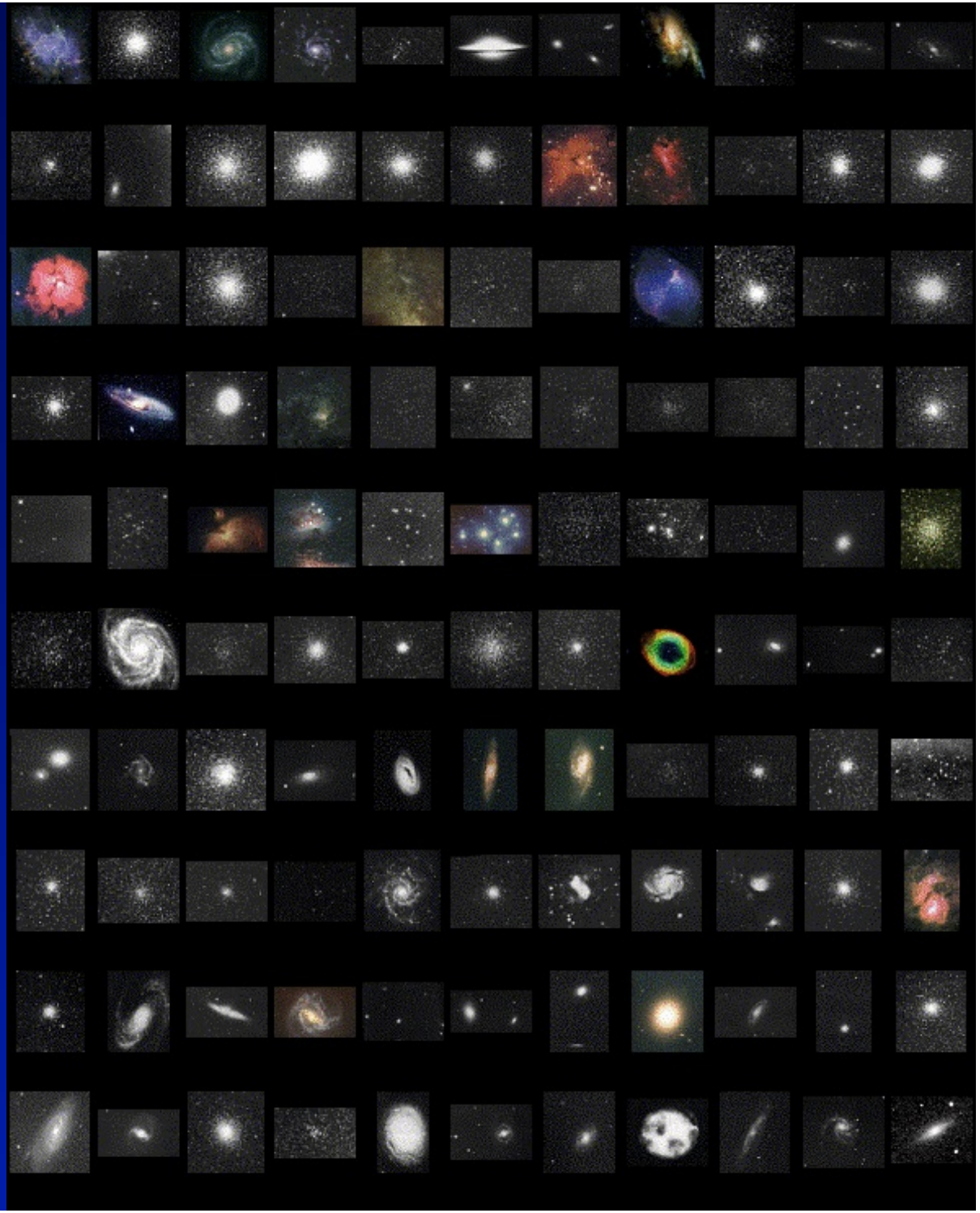
- Milky Way: Greeks: river of milk coming out of Hera's breast, Zeus' wife

- Galileo first to observe the Milky Way with a telescope in 1610. He discovers that it is formed by a huge number of stars. It is a stellar system and not a fluid

Kant in the middle of the XVIII century compares the Milky Way system to the solar system and argues that the gravitational force acts equally as in between the Sun and planets and thus the Milky Way has to present a disk structure if there is rotation to avoid the gravitational collapse. As the dimensions are large the stellar movements are indiscernible to us. Besides he suggested that the nebulae that we observe on the sky were “islands universes”

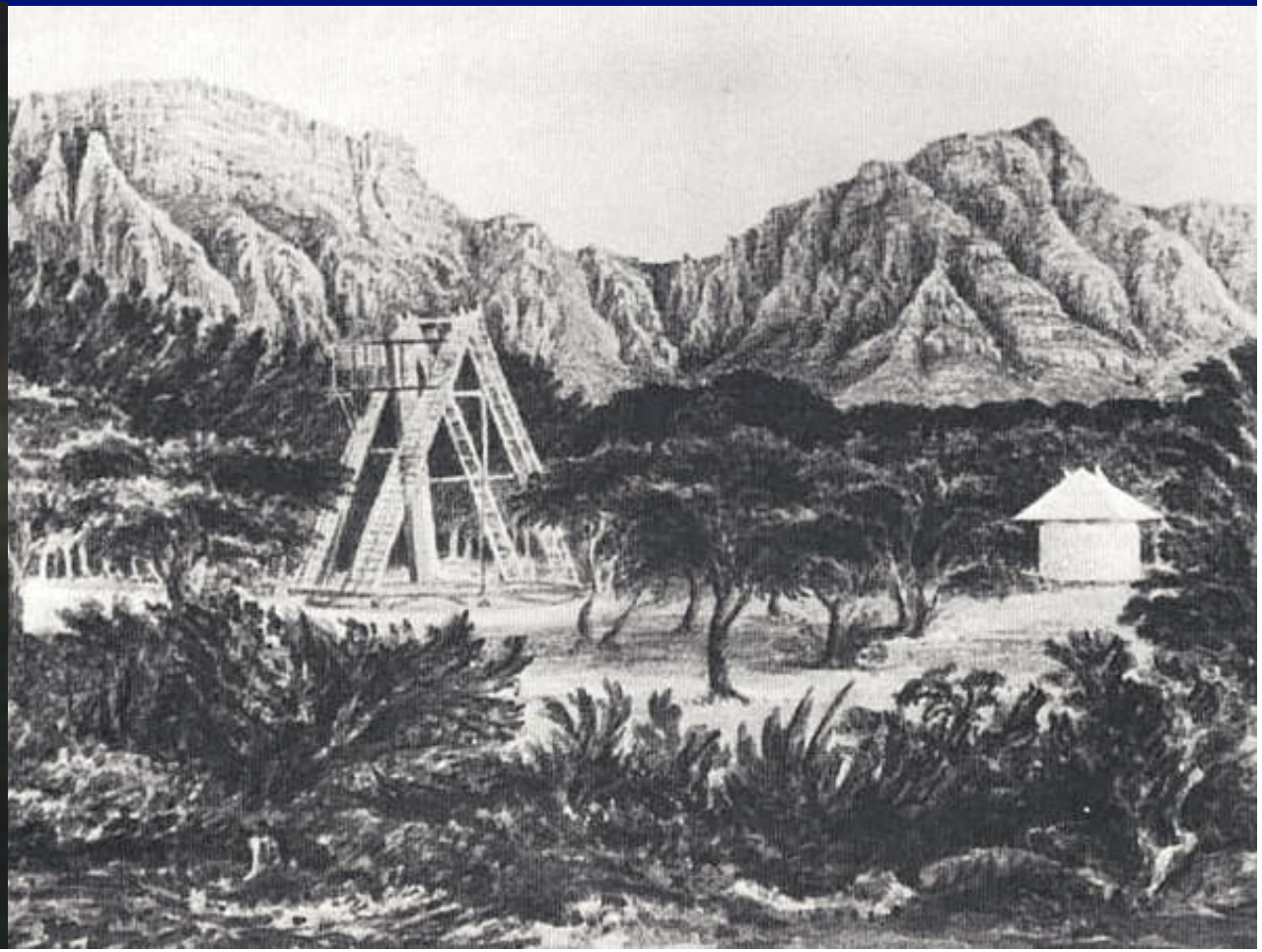
Nebulae

Messier at the end of the XVII century catalogued 109 nebulae not to confuse them with comets



Nebulae classification

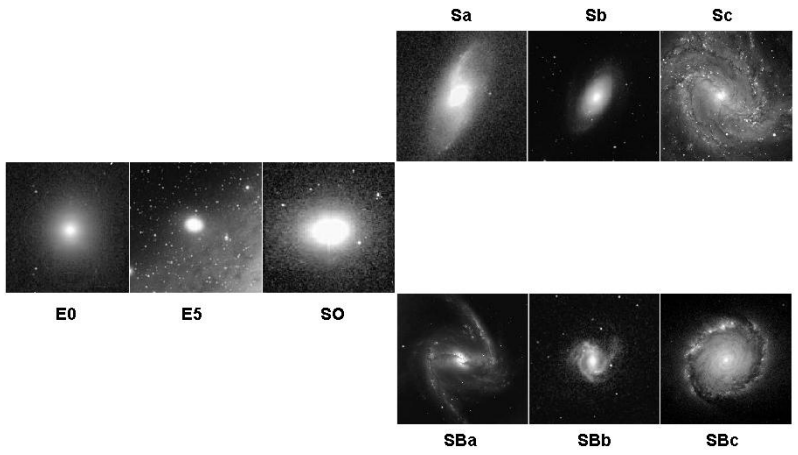
The Herschels catalogued around 5000 nebulae on the whole sky and resolved some of them into stars and others in rings (planeraty nebulae). They realized the distinction between gaseous unresolved nebulae and resolved nebulae

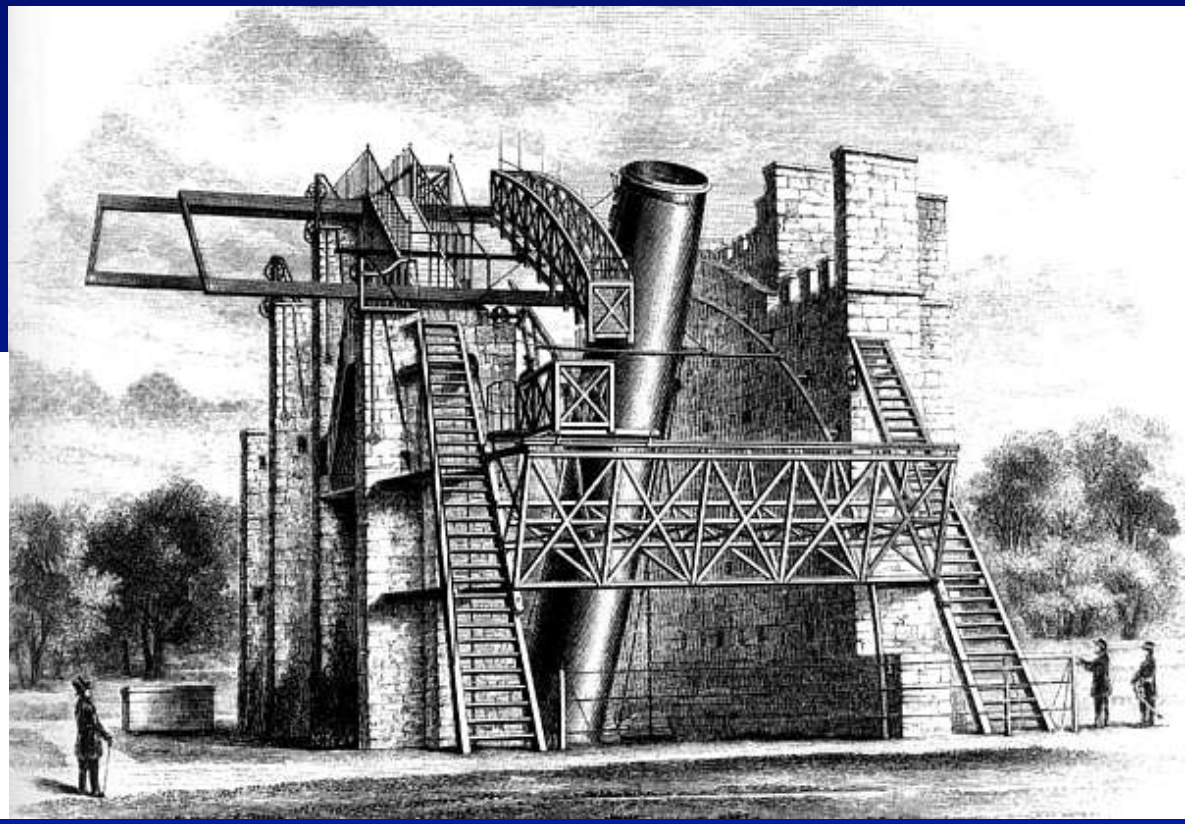


Nebulae classification

Dreyer (1888) published a compilation of 7840 nebulae in the New General Catalogue (NGC). Later, he augmented the catalogue with 5086 new nebulae with the Index Catalogue (IC)

Parsons in the XIX century could distinguish between elliptical and spiral nebulae

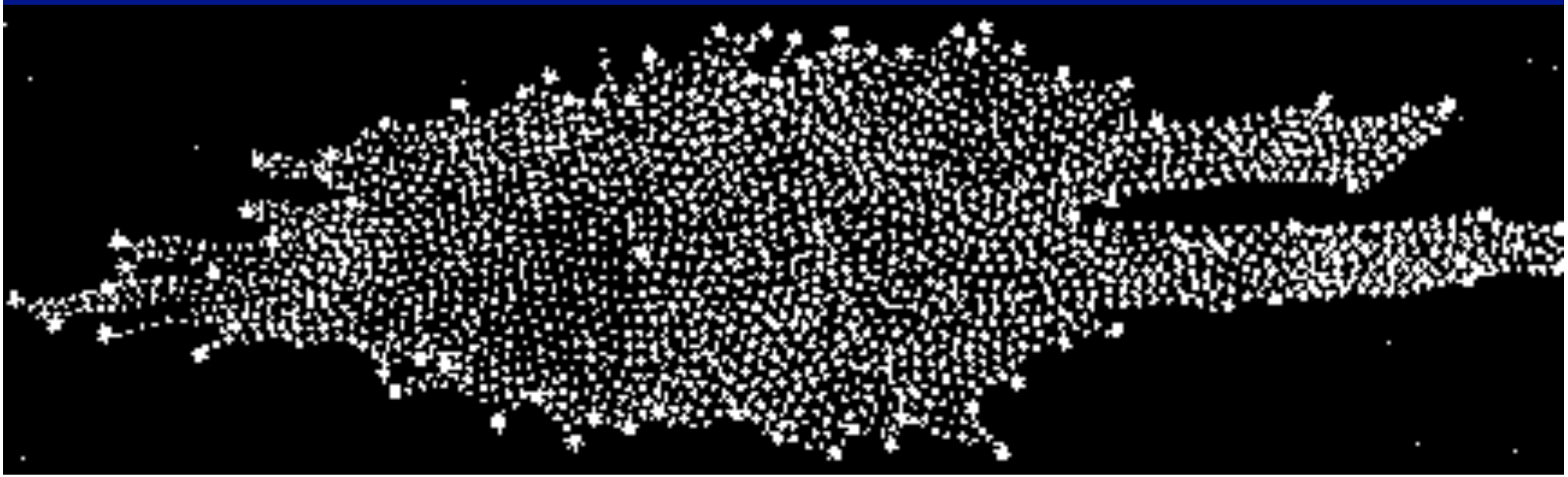




The introduction of photography at the end of the XIX century revolutionized the astronomical world

1. Introduction 1.3 Milky Way Models

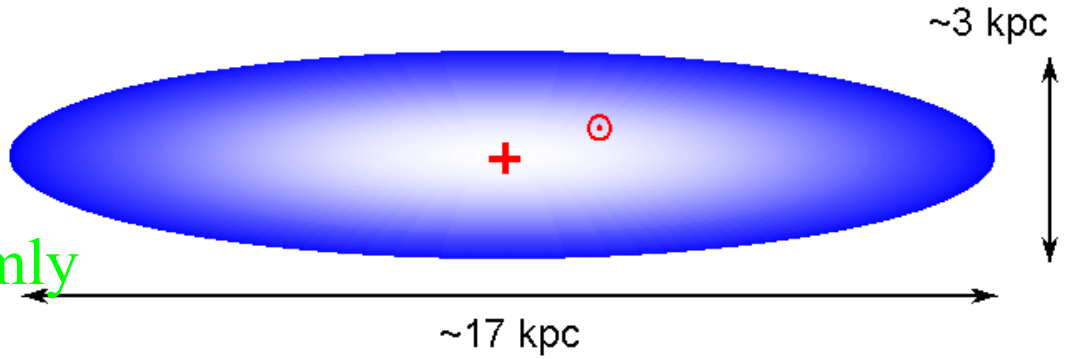
Herschel (1785) carried out the first attempts to measure the structure of the Milky Way. He measured the magnitudes of numerous stars in many zones. Then, he assumed that the stars had all the same luminosity, that they were distributed uniformly across the Milky Way and that all stars could be seen. He deduced that the Sun was at the centre of the distribution of stars, that was flat and had a size five times larger in the plane than in the perpendicular direction. But, he could not estimate the absolute size of the Galaxy as he did not know the luminosity of the stars



Kapteyn at the beginning of the XX century lead an observational effort to determine the structure of the Milky Way using photographic plates. He measured magnitudes, proper motions and stellar spectra in 200 regions and thus he obtained a tri-dimensional map of the Galaxy.

In "Kapteyn's Universe" (published at the beginning of the 1920s) the Sun was located almost at the centre of a flattened spheroidal distribution that was five times larger in the plane than perpendicular to it. Kapteyn demonstrated that the stellar density was falling uniformly with the distance to the centre.

Kapteyn Model (1922)



kpc = kiloparsec = 1000 pc

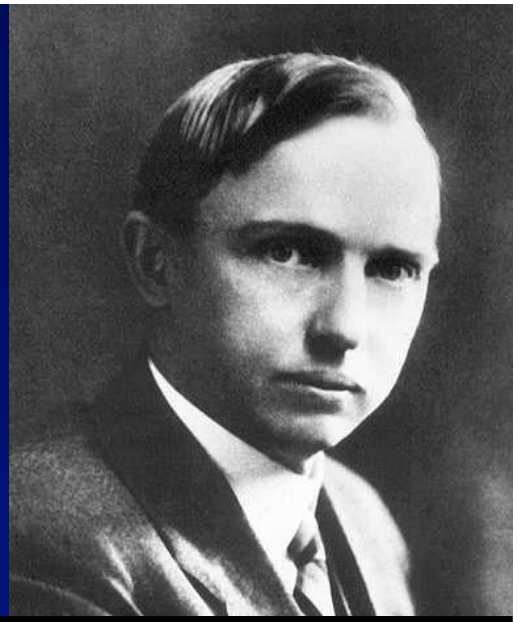
1. Introduction

1.3 Milky Way Models

- Kapteyn's system was "heliocentric".
- Interstellar absorption could make a non-central location seem like a central one. Studying the stellar colours Kapteyn concluded that Rayleigh scattering was a negligible effect.
- Trumpler in 1930, studying open clusters, concluded that the interstellar absorption was indeed important and rejected the conclusions of Kapteyn
- Nowadays we know that interstellar absorption is due to dust and not Rayleigh scattering

1.3 Milky Way Models

Shapley at the end of the 1910s carried out a detailed study of globular clusters. These are distributed across the sky and not only in the galactic plane. Shapley demonstrated that their distribution was not uniform and that they were concentrated in the Sagittarius region. Shapley argued that the globular clusters distribution, that were very massive, had to be an important component of the galaxy.and thus the centre of their distribution had to coincide with the galactic centre. Shapley estimated the distances to these clusters and that way he concluded that the Sun was 15 kpc away from the Milky Way centre.



1. Introduction

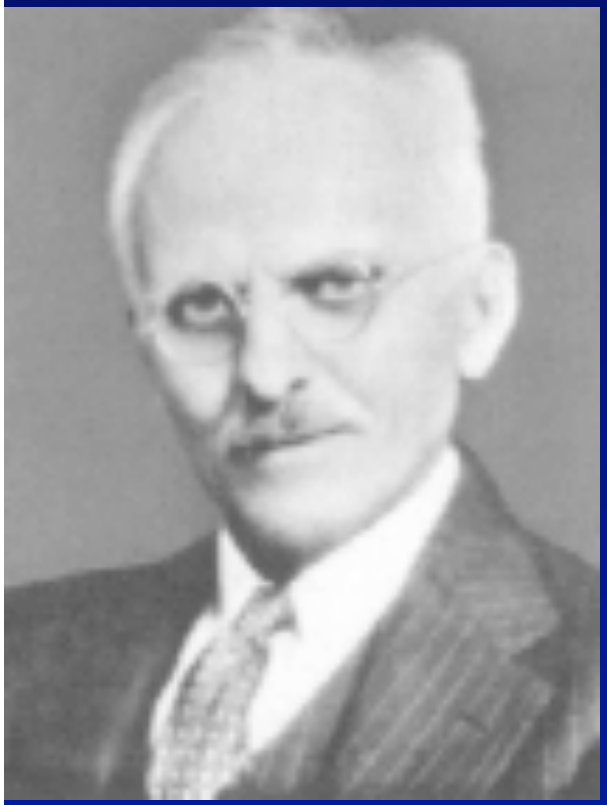
1.4 Spiral nebulae

- Shapley's vision of the Milky Way influenced his interpretation of the what the spiral nebulae were. As the Milky Way was large, if the "islands universes" had the same size as the Milky Way, as they presented very small angular sizes, they had to be at extremely large distances. These distances were unthinkable and therefore thay had to have a galactic origin.

- On the other hand, other astronomers believed in Kapteyn's model and thought that these nebulae were like the Milky Way at extremely large distances.

El Great Debate

Nebulae: galactic or extragalac?



Curtis

In April 1920 Hale organized a debate (known as the "Great Debate") between Curtis and Shapley at the National Academy of Sciences to elucidate whether nebulae were galactic or extragalactic, that is, if the Universe was formed just by our galaxy or if it was much larger

Shapley

1. Introduction

1.4 Spiral Nebulae

- Curtis criticized the measurement of the distances to the globular cluster carried out by Shapley using cepheids. Erroneously, he assumed that the most luminous stars were like the local stars and thus he obtained shorter distances.

- Curtis argued that the angular distances of the nebulae were very different and that if they were of a similar size then the distance ratio between the closest one and the furthest away one was more than a factor of a thousand and therefore they could not fit in the Milky Way.

1. Introduction

1.4 Spiral Nebulae

- Curtis also argued that there had been “many” novae in M31 and therefore this could not be a coincidence and they had to be associated to M31. These novae were much fainter than those observed in the Milky Way. Assuming that they were of the same luminosity, he calculated that the distance to M31 was 100 kpc. At that distance, the angular size of M31 corresponded to 3 kpc, similar to the Milky Way size in Kapteyn’s model.

1. Introduction

1.4 Spiral Nebulae

- The nebulae spectra also supported the hypothesis of differentiated stellar systems outside the Milky Way. The inferred velocities were larger than those of Milky Way stars. As the nebulae did not move on the sky, it was very unlikely that they belonged to the Milky Way. It seemed most likely that they were very far and therefore one could not measure their proper motions perpendicular to the line of sight. But, there was no explanation why all of them had receding velocities.

- Curtis also argued that the exclusion zone (there were no spiral nebulae at the galactic plane) was due to the Milky Way having absorbing material in its plane as it was seen in other nebulae. This absorbing material had to be in a ring at long distances not to invalidate Kapteyn's conclusions.

1. Introduction

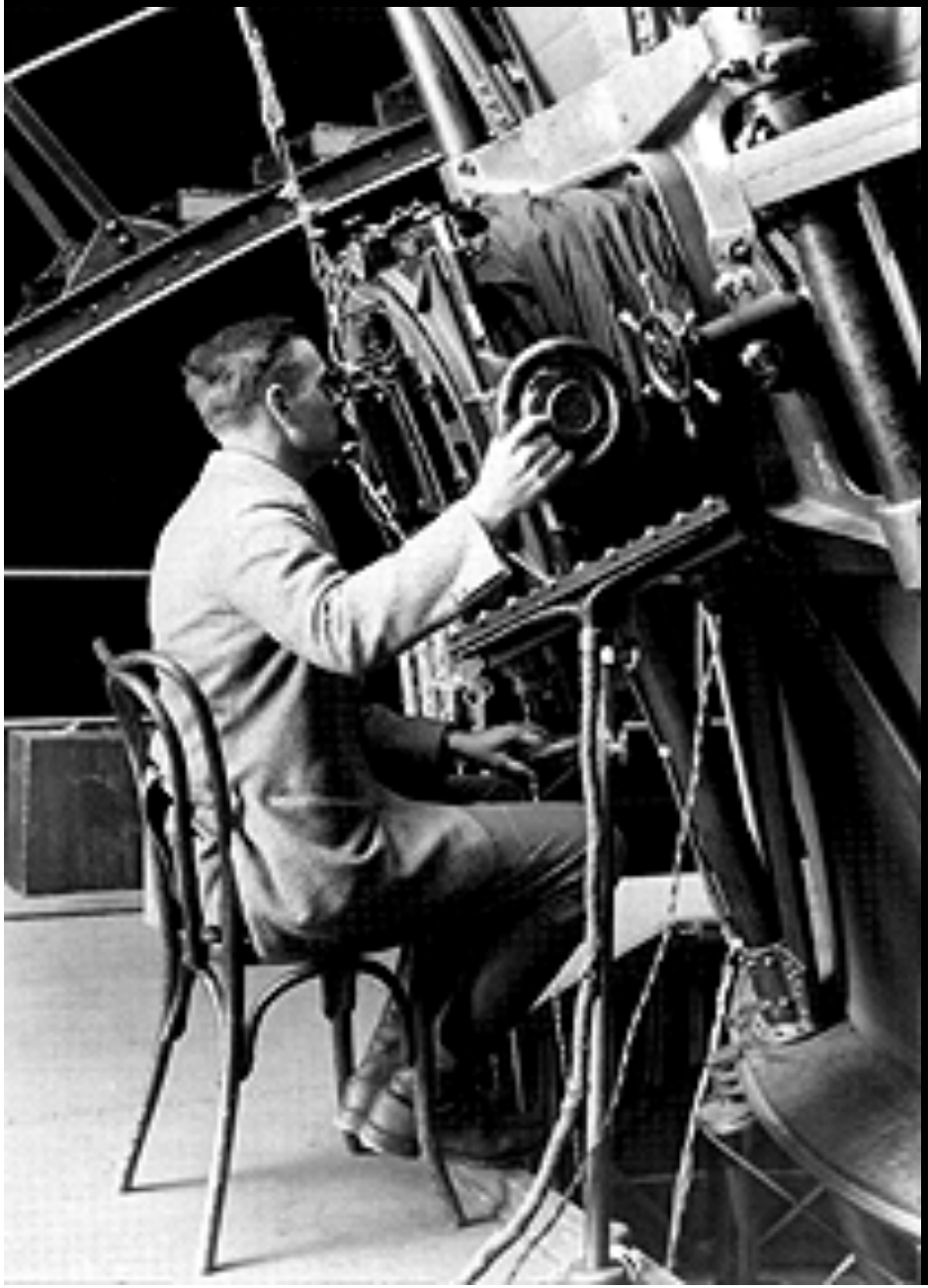
1.4 Spiral Nebulae

- Besides the size arguments, Shapley also argued that the Milky Way had different properties than the spiral nebulae: it had a faintest surface brightness and a redder colour than the nebulae.

- Another argument was that van Maanen in observations in the coming years measured that the spiral structure was rotating. If these nebulae had radii of 5 kpc, then the angular rotations measured would mean velocities larger than the speed of light.

- Years later, Lundmark showed that the measurements of van Maanen were wrong.

The Great Debate: The Answer



Hubble with the new 100 inch telescope at Mount Wilson could measure the distance to the nebulae and checked that they were very far and therefore they did not belong to our galaxy

1. Introduction

1.4 Spiral Nebulae

- Years later, Hubble solved the controversy using the 100 inch telescope at Mount Wilson.
- He resolved the spiral arms into stars. If these stars had the same luminosity than stars in the Milky Way, they had to be far away outside the Milky Way.
- Hubble later measured the distances using cepheid stars and demonstrated that M31 was outside our galaxy and it was a similar system at a distance of 300 kpc.