

# Lecture 26: The Realm of the Nebulae: The Milky Way and Andromeda

Readings: Sections 25-1, 26-1, and 26-2

## Key Ideas:

The Milky Way is our Galaxy

We see it as a diffuse band of light crossing the sky

Milky Way consists of many faint stars

The Nature of the Milky Way

**Question:** What is the size and shape of the Milky Way and what is the position of the Sun?

**Problem:** Measuring distances and the absorption by dust

**Answer:** The Milky Way is a disk galaxy with a radius of 15 kpc. The Sun is about 8 kpc from the center.

The Nature of the “Spiral Nebulae”

**Question:** Are the spiral nebulae part of the Milky Way or are they separate galaxies?

**Problem:** Measuring distances to the nebulae compared to the size of the Milky Way

**Answer:** Andromeda and the other spiral nebulae are separate galaxies. The Milky Way is one of many galaxies.

## The Milky Way

Diffuse band of light crossing the night sky

All cultures have named it (visible in both the Northern and Southern Sky)

Celestial River

Celestial Road or Path

Our names are derived from Greek and Latin

Greek *Galaxias kuklos* = “Milky Band”

Latin *Via Lactea* = “Road of Milk”

## “The Starry Messenger”

1610: Galileo observed the Milky Way with his new telescope.

Published his findings in his pamphlet *Siderius Nuncius* (The Starry Messenger).

## A Theory of the Heavens

Immanuel Kant (1755):

Also made no observations of his own

Model:

Lens-shaped disk of stars rotating about its center

No particular special location for the Sun

Other “nebulae” are distant, rotating “Milky Ways” like our own

## The Herschels’ Star Gauges

William & Caroline Herschel (1785):

Counted stars along 683 lines of sight using their 48-inch telescope

Assumed all stars are the same luminosity, so relative brightness gives relative distance

Assumed that they could see all the way to the edges of the system

Model:

Flattened Milky Way (“grindstone”)

Sun is located very near the center

See Figure 25-2 for Herschels’ Map of the Galaxy

## The Kapteyn Universe

Jacobus Kapetyn (1901 through 1922):

Used photographic star counts

Estimated distances statistically based on parallaxes & proper motions of nearby stars.

Neglected interstellar absorption of starlight (assumes fainter stars are just farther away)

Model:

Flattened disk 15 kpc across & 3 kpc thick

The Sun is located slightly off center

## Harlow Shapley (1915 through 1921)

Astronomer at Harvard

Noticed two facts about Globular Clusters

1. Uniformly distributed above and below the Milky Way on the sky

2. Concentrated in the sky toward Sagittarius

Observations:

1. Globular cluster distances from RR Lyrae stars (“standard candles”, see next section)
2. Used these distances to map the globular cluster distribution in space

## Shapley’s Globular Cluster Distribution from Shapley 1918

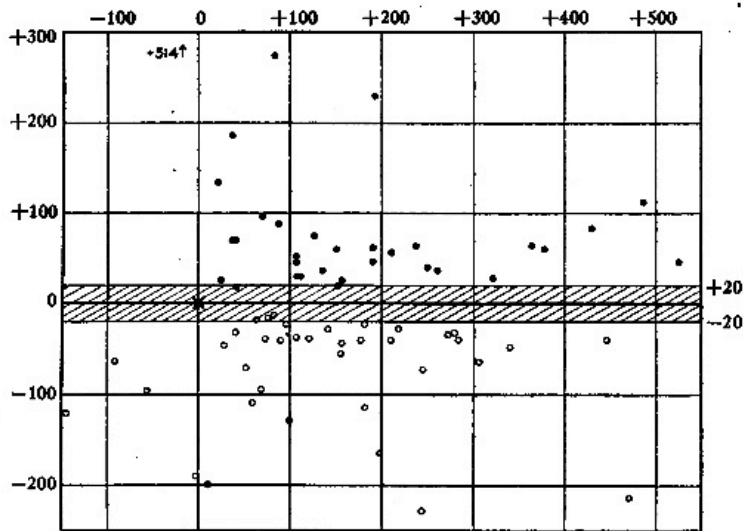


FIG. 3. PROJECTION OF THE POSITIONS OF GLOBULAR CLUSTERS ON A PLANE PERPENDICULAR TO THE GALAXY

## The Greater Milky Way

Shapley’s Results :

Globular clusters form a subsystem centered on the Milky Way

The Sun is 16 kpc from the MW center

MW is a flattened disk ~ 100 kpc across

Right basic result, but too big

Shapley ignored interstellar absorption

Caused him to overestimate the distances

## The Problem of Absorption

Absorption of Starlight

Interstellar space is filled with gas and dust

Dust absorbs/scatters light, making distant objects look fainter (and redder)

Overestimate “luminosity distances”

Affects all maps of the Milky Way

Shapley & Kapteyn thought it was smaller than it really is  
Trumpler (1930) showed it was significant

## The Milky Way

A flattened disk of stars with a central bulge

Sun is ~8 kpc from the center (in the direction of the constellation Sagittarius)

~30 kpc in diameter and ~ 1 kpc thick

Galactic Center and much of the disk is obscured by dust in the plane of the Galaxy

## Spiral Nebulae

William Parsons, 3<sup>rd</sup> Earl of Rosse

Built a 72-inch telescope known as the “Parsonswon Leviathan” (c. 1845)

Discovered the “Spiral Nebulae”

Disks with a spiral pattern

Some edge-on disks with dark bands

Did not resolve them into stars

## Island Universe Hypothesis

Kant’s idea (1755) revived by Alexander von Humboldt (1845)

Spiral Nebulae are other Milky Ways (or *galaxies*) made of stars

Very *distant* and *external* to our Galaxy

### Big Picture:

The Milky Way is just one of many galaxies in a vast Universe of Milky Ways

## Nebular Hypothesis

Revival of a Solar System model of Pierre Simone Laplace (1796)

The Spiral Nebulae are swirling gas clouds

They are *nearby* and *internal* to our Milky Way

They might be forming solar systems

### Big Picture

The Milky Way *is* the Universe

## Some of the non-spiral nebulae are in the Galaxy

Nebula: from the Latin for mist, vapor, cloud

“Things that were fuzzy” were called nebula

Includes gas clouds in the Galaxy

- Supernova remnants

- Molecular/Ionized clouds

- Planetary nebulae

External galaxies: fuzzy because they are so far away.

## The Great Debate

The problem hinges on finding distances

- How big is the Milky Way

- How distant are the Spiral Nebulae?

### Island Universe Hypothesis

The Spiral Nebulae are more distant than the “edge” of our Galaxy and are as big as our Galaxy

### Nebular Hypothesis

The Spiral Nebulae are nearby and inside our Galaxy, and thus smaller than it.

## The Shapley-Curtis Debate

1920 Debate on *The Scale of the Universe*

Sponsor: National Academy of the Sciences

### Harlow Shapley

Defended his model for the Galaxy and the “conventional” Nebular Hypothesis

### Heber Curtis

Defended the Kapteyn Model and the “alternative” Island Universe Hypothesis

## The Battleground Questions:

What is the size of the Milky Way Galaxy?

- Kapteyn’s star counts vs. Shapley’s clusters

What is the distance to the Andromeda Nebula, the largest spiral nebula?

- Tried to estimate using “nova” outbursts

What are the motions of the Spiral Nebulae?

- Proper Rotation vs. Radial Velocities

## Shapley's Arguments

The Galaxy is 100 kpc across

The 1885 "nova" in the Andromeda Nebula gave it a luminosity distance of 10 kpc:

Smaller than 100 kpc for the Galaxy, hence it is internal to the Milky Way.

Van Maanen's "Proper Rotation" of M101

If very distant, it implies a rotation speed faster than the speed of light!

## Curtis' Arguments

Typical novae in Andromeda give it a distance of ~150 kpc:

Size is ~10 kpc, like Kapteyn's Milky Way, hence it is *external* to us

See dark obscuring bands in edge-on spirals

Like what we see in the Milky Way

Spirals have large radial velocities

They would escape from the Milky Way!

## The Outcome...

...was inconclusive

Shapley had better arguments, but in the end was wrong

Curtis was right, but his arguments were weak.

Issues preventing a conclusion

Nobody had a good distance to Andromeda

Nobody could reproduce van Maanen's proper rotation observations.

## Hubble Ends the Debate

Edwin Hubble (1923):

Using the new 100-inch telescope on Mt. Wilson in California

Found a Cepheid Variable in Andromeda

Shapley's P-L relationship gave a distance of 300 kpc

By 1925:

Hubble had measured 10 Cepheid variables

The Distance to Andromeda ~1000 kpc.

## The Realm of the *Galaxies*

We call the Milky Way "*The Galaxy*"

Spiral "Nebulae" are now called *Spiral Galaxies*

Stellar systems like the Milky Way

Typical sizes are 10s of kpc across  
Typical distances are Megaparsecs (Mpc)

The Universe suddenly became a much bigger place.