LECTURE 16:
ANDROMEDA AND THE MILKY WAY
I. WHAT ARE GALAXIES?

16.1 CEPHEID VARIABLES

Most stars have steady luminosity; they change only over millions or billions of years.

Some isolated stars vary periodically, in a repeating pattern. These variations are usually caused by pulsation.

Cepheid variables (a.k.a. Cepheids) are bright, variable stars, typically 1,000-10,000 times solar luminosity.

They have periods of a few days to a few weeks, and they vary in brightness by a factor of two or more.

By comparing pictures in a series, one can easily identify Cepheids, even from relatively far away.

Period-luminosity relation: more luminous Cepheids are bigger and have longer periods.
3 day period: 1,000 $L_\odot$
30 day period: 10,000 $L_\odot$

After measuring a Cepheid's period and apparent brightness, one can determine its distance from $f = L/4\pi d^2$.

16.2 THE MILKY WAY

The Greeks named the band of diffuse light that crosses the night sky the *Galaxy*, meaning Milky Way.

In 1609 Galileo, using the first astronomical telescope, determined that the Galaxy is made up of many stars, too faint to be seen individually with naked eye.

Galileo's new observational technology led him to a fundamental new discovery.

Herschel (1790's): counted stars in different directions. He assumed that all stars had the same *intrinsic* luminosity in order to gauge the size and shape of the Galaxy.

Kapteyn (1910 – 1920): a similar, though more sophisticated effort.
His conclusion: The Galaxy is a flattened, ellipsoidal distribution of stars, with an extent of about 10,000 parsecs (10 kiloparsecs, kpc). The sun is near the center.

16.3 SHAPLEY'S VIEW OF THE MILKY WAY

Harlow Shapley (1915 – 1920) challenged Kapteyn's model by examining the distribution of globular clusters on the sky.

This distribution is not highly flattened, but it is concentrated towards the constellation Sagittarius.

Shapley estimated distances to globular clusters using variable stars.

Shapley's conclusion: the sun is *not* at the center of the Galaxy but 15 kpc away.

He was eventually (1930) proven right, when it was convincingly demonstrated that absorbing dust in the plane of the Galaxy had prevented Kapteyn from seeing most of the stars.

Modern estimates put the sun about 8 kpc from the Galactic center, closer than Shapley thought.

16.4 SPIRAL NEBULAE

In addition to stars and star clusters, the sky contains nebulous, extended objects.

There are various kinds of diffuse gas nebulae, including planetary nebulae, supernova remnants, and star forming clouds. Their spectra show emission lines (bright emission at specific wavelengths).

18th century astronomers knew of these objects, and also of objects they called "white" nebulae — some of these had spiral structure and were called spiral nebulae. Their spectra show absorption lines, like the spectra of stars.

The Andromeda nebula, extending about 1 degree across the sky (twice the apparent diameter of the full moon), is the most dramatic example.

In the 1750's, Thomas Wright and Immanuel Kant suggested that these nebulae might be "island universes," stellar systems like the Galaxy.

However, many astronomers believed that spiral nebulae were gaseous objects in the Galaxy, much closer and much smaller than "island universes."

16.5 THE SHAPLEY-CURTIS DEBATE

By 1920, the nature of spiral nebulae had become one of the major questions in astronomy. The National Academy of Sciences organized a debate on the topic between Harlow Shapley and Heber Curtis.

Shapley defended the "conventional" view that spiral nebulae were objects in the Galaxy, *not* large, independent stellar systems. Among his arguments:

(1) An 1885 nova in Andromeda, when compared to other novae, implied a distance to Andromeda of 10 kpc, and a size much smaller than the Galaxy.

(2) A "proper rotation" of 0.02 arc-seconds/year had been measured in a different spiral nebula, M101. If M101 were at an enormous distance, this would imply a rotation velocity close to the speed of light.

(3) Spiral nebulae were rarely detected close to the plane of the Galaxy. This suggested that they are influenced by the Galaxy, avoiding the plane because of some (previously unknown) repulsive force.

Curtis defended the “island universe” hypothesis, that spiral nebulae are independent stellar systems like the Galaxy. Among his arguments:

(1) *Typical* novae in Andromeda, compared to other novae, implied a large distance and a size comparable to the Galaxy.

(2) Many edge-on spirals show a dark, obscuring belt in the middle of the disk. A similar belt in the Galaxy would explain why spiral nebulae aren’t seen near the plane.

(3) Doppler shifts imply that many spiral nebulae have large radial velocities, so they would probably escape from the Galaxy’s gravity.

16.6 HUBBLE SETTLES THE ISSUE

The fundamental difficulty in resolving the debate was the unknown distance to spiral nebulae.

In 1923, using photographs from a newly built 100-inch telescope, Edwin Hubble found Cepheid variables in the Andromeda nebula.

Their period and apparent brightness implied that Andromeda was at a large distance and was therefore itself a large system.

The “Andromeda nebula” is really the “Andromeda galaxy.”

“Spiral nebulae” are now called “spiral galaxies”; they are stellar systems comparable to the Galaxy.

Once again, new technology led to a fundamental new discovery.

16.7 SUMMARY

Cepheids are luminous, variable stars, and they exhibit a regular relation between period and luminosity. They are thus useful for measuring distances to far away stellar systems.

The Milky Way (a.k.a. the Galaxy), a band of diffuse light across the sky, was shown by Galileo to consist of many faint stars.

Nature of the Galaxy:
Kapteyn (star counts): sun roughly in center .
Shapley (globular clusters): sun many kpc from center.
A convincing demonstration of the presence obscuring dust eventually showed that Shapley was right.

Nature of spiral nebulae:
Curtis: “island universes” like the Galaxy.
Shapley: not.
Once Hubble discovered Cepheids in Andromeda, he used the period luminosity relation to show that Andromeda was at a large distance, and thus that Curtis was right.