LECTURE 18: SPIRAL GALAXIES AND DARK CORONAS

18.1 SPIRAL GALAXIES

Andromeda and the Milky Way are examples of spiral galaxies.

All spiral galaxies have a disk, with light enhanced along spiral arms.

Most also have spheroids, although in some galaxies they are rather small.

The inner part of the spheroid, where it merges with the disk, is often called the *bulge*. The outer part is often called the *stellar halo*. The stellar population of the bulge is intermediate between that of the disk and the halo.

Because the disk rotates, the spectra of stars or gas in the disk of a spiral galaxy show that one side is redshifted (moving away from us) and the other is blueshifted (moving towards us), relative to the average motion of the whole galaxy.

18.2 MEASURING MASS FROM ROTATION

If an object is held in a circular orbit by gravity, we can determine the mass required to keep it in that orbit provided we know its speed and orbital radius.

We apply this method to planets to determine the mass of the sun.

We apply it to binary stars to determine the masses of the stars.

We can also apply it to stars or gas clouds in a galaxy disk. A star is held in orbit by the mass *interior* to it (closer to the center of the galaxy), so this technique measures the mass of the galaxy inside the radius of the star's orbit.

IMPORTANT EQUATIONS

6: THE MASS – ROTATION SPEED EQUATION

In symbols:

$$M_{\rm int}(R) = \frac{V_{\rm rot}^2 R}{G}.$$

$M_{\rm int}(R)$ = mass interior to radius R [solar masses]
$V_{\rm rot}$ = rotation velocity [km/s]
R = radius (distance from center of galaxy) [kiloparsecs]
G = Newton's gravitational constant

In words: The mass interior to a radius R in a disk galaxy is equal to the square of the rotation speed at this radius multiplied by the radius and divided by Newton's gravitational constant.

Comments:

This equation can be derived from Newton's law of gravity and law of motion. A similar equation can be used to describe the solar system or other gravitating systems with circular rotation.

Examples:

(1) Two galaxies are the same radius, but one of them is four times more massive than the other. How much higher is its rotation speed?

Since $M \propto V_{\rm rot}^2$ when the radius is the same, the more massive galaxy has double the rotation speed.

(2) When I was in graduate school, I used a radio telescope in New Mexico to observe hydrogen gas in a galaxy called UGC 12591, which is the most rapidly rotating spiral galaxy known. My observations detected gas with a rotation speed of 465 km/s at a distance of 20 kpc from the center of the galaxy, and by plugging these numbers (and the value of G) into the equation, I could tell that the inner 20 kpc of the galaxy contained a mass of 1 trillion solar masses. My observations also detected gas 36 kpc from the center, and it also had a rotation speed of 465 km/s. How much mass is contained in the inner 36 kpc of UGC 12591?

Since the rotation speed at 20 kpc and 36 kpc is the same but the radius at 36 kpc is 36/20=1.8 times bigger, there must be 1.8 trillion solar masses in the inner 36 kpc.

18.3 ROTATION CURVES

We can use Doppler shifts to measure the rotation speed at different locations in a disk galaxy.

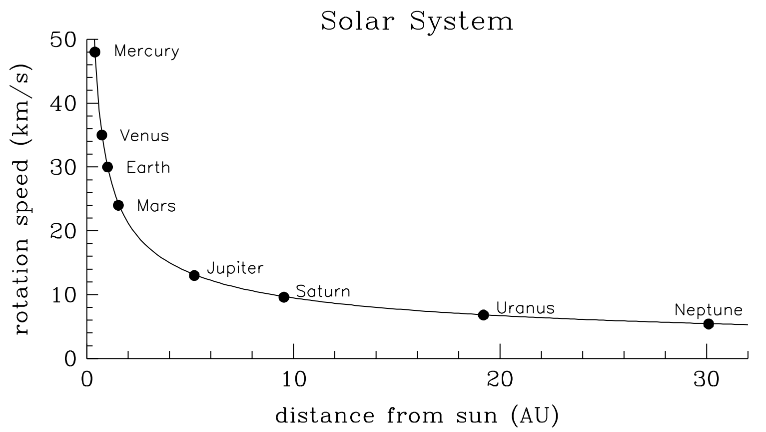
A plot of rotation speed against radius (distance from the galaxy's center) is called a *rotation curve*.

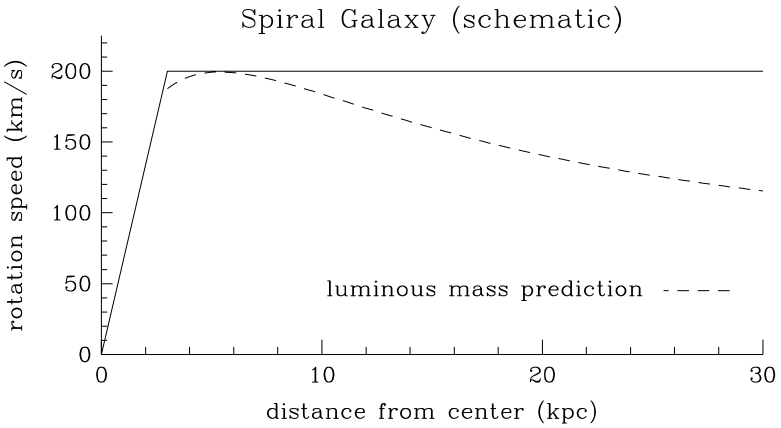
Recall: period $= 2\pi \times$ radius/speed.

In the solar system we find a falling rotation curve – speed falls as radius increases, and periods get longer.

In a typical spiral galaxy we observe:

- center: rising rotation curve – speed rises with radius, and periods stay roughly constant.
- outside center: flat rotation curve – speed stays the same as radius increases, and periods get longer.





18.4 DARK MATTER IN SPIRAL GALAXIES

Most of a typical galaxy's light is in the inner 10 kpc.

If a galaxy's stars provided all of its mass, we would expect the rotation curve to drop outside this radius.

But the rotation speed stays constant $\Longrightarrow$ more mass is needed to hold the galaxy together.

Flat rotation curves imply that spiral galaxies have extended *dark coronas* (a.k.a. *dark halos*) of unseen matter.

18.5 SPIRAL ARMS

Through most of the disk, stars and gas on the inside overtake stars and gas on the outside $\Longrightarrow$ irregularities naturally get stretched into spiral patterns.

Hypothesis 1: "material arms"

A spiral arm is made up of the same stars and gas over time.

This hypothesis fails, because such an arm would wind up too tightly over many rotation periods.

Hypothesis 2: “density waves”

Stars and gas slow down as they move through the spiral arm, because of its enhanced gravity.

The arm is produced by a crowding of stars and gas, like a traffic jam.

Hypothesis 2 seems to work, though the details remain a subject of active research.

Star formation occurs mainly in spiral arms, where the gas is crowded together, so the young, blue stars display the strongest spiral patterns.

18.6 SUMMARY

The rotation of a spiral galaxy's disk can be measured using Doppler shifts. From the rotation speed at a given radius, one can infer the interior mass using $M_{\rm int}(R) = V_{\rm rot}^2 R/G$.

In a typical spiral galaxy, the light is concentrated towards the center, but the rotation curve remains flat out to large radii. This implies that spiral galaxies are held together by the gravity of extended dark coronas.

Spiral arms are caused by crowding of stars and gas clouds as they pass through. Their appearance is enhanced by active star formation.