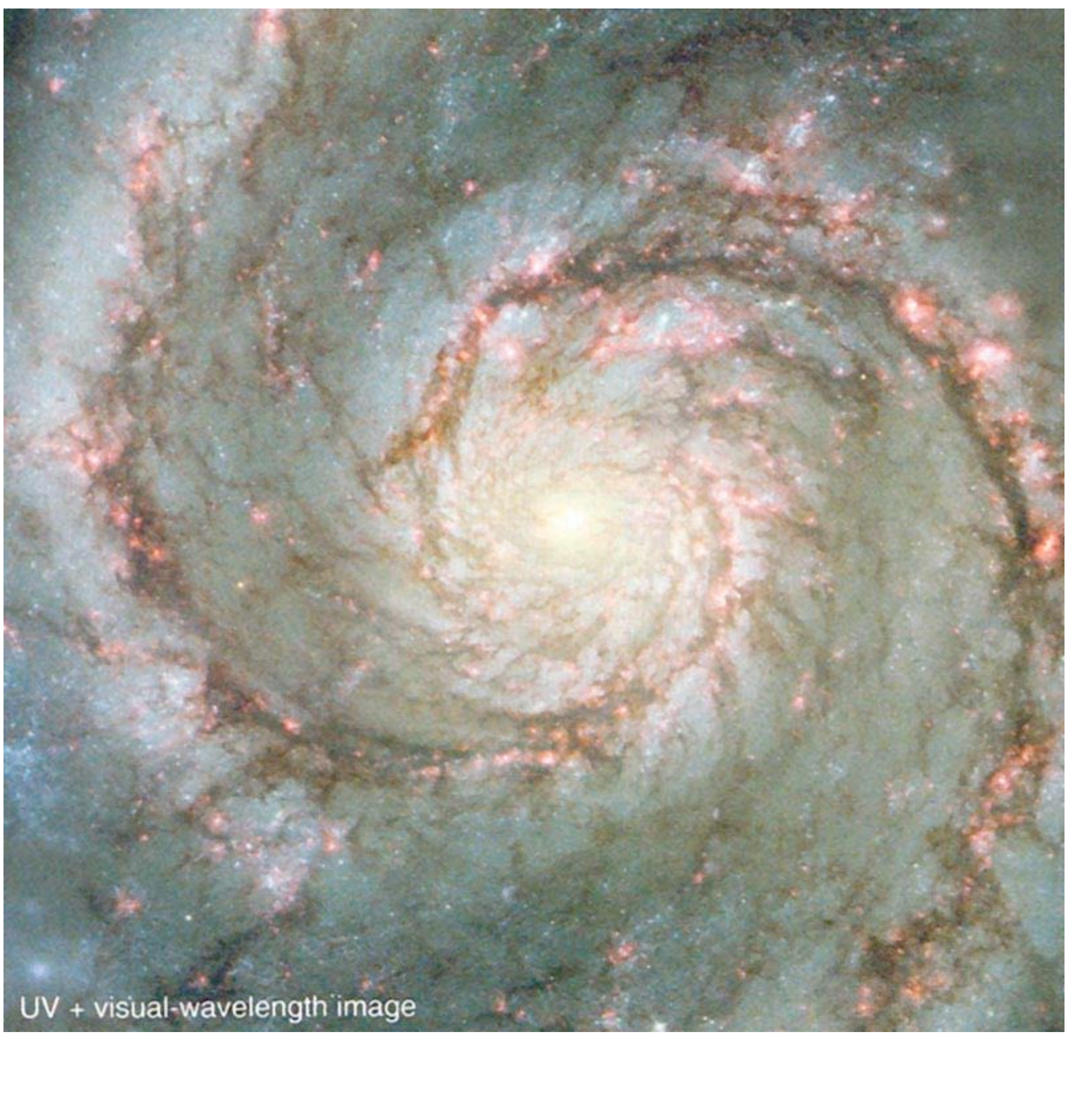
Notes on Ch. 23 ~~and 24~~.

The Milky Way Galaxy (ch. 23)

[Exceptions: We won't discuss sec. 23.7 (Galactic Center) in class, but read it if interested—there will be no questions from this section on the exam.]
~~→ These notes also cover Chapter 24, Nearby Galaxies.~~

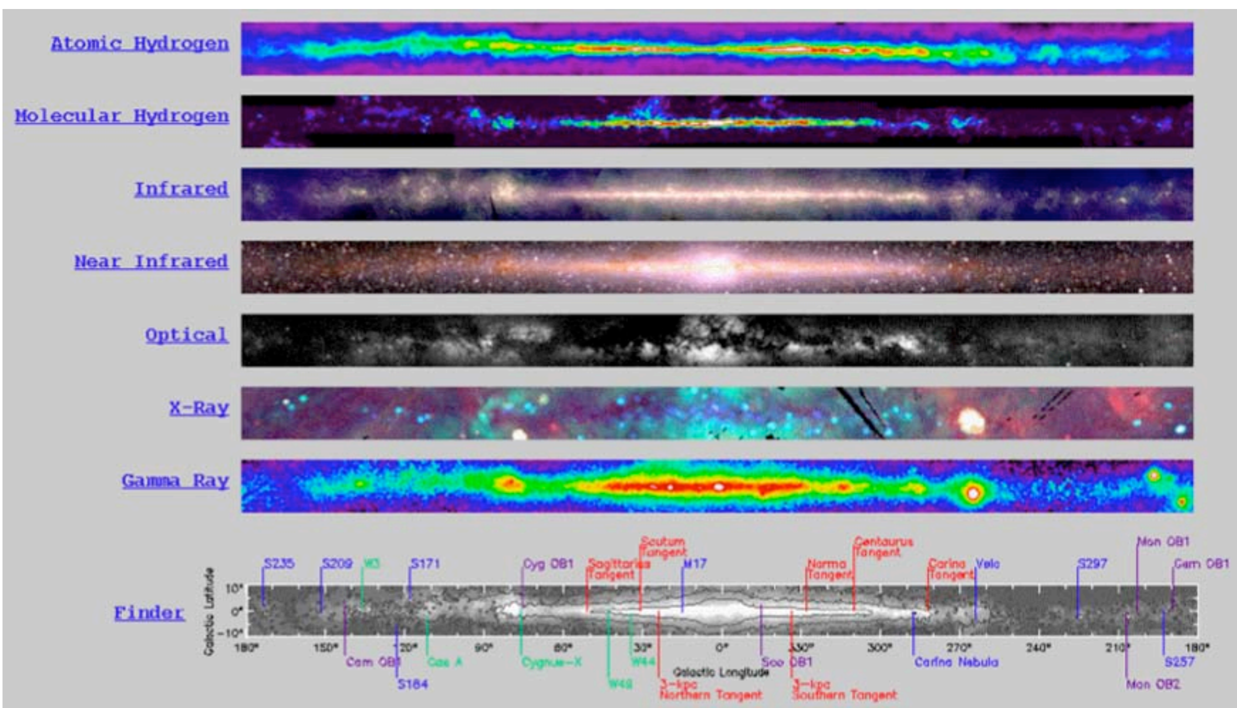
In following lecture outline, numbers refer to the Figure numbers in your textbook.

A basic theme in this chapter is how it was gradually discovered that our Galaxy is not the whole universe, but that instead, if we could view it from the outside, our Galaxy would look something like:



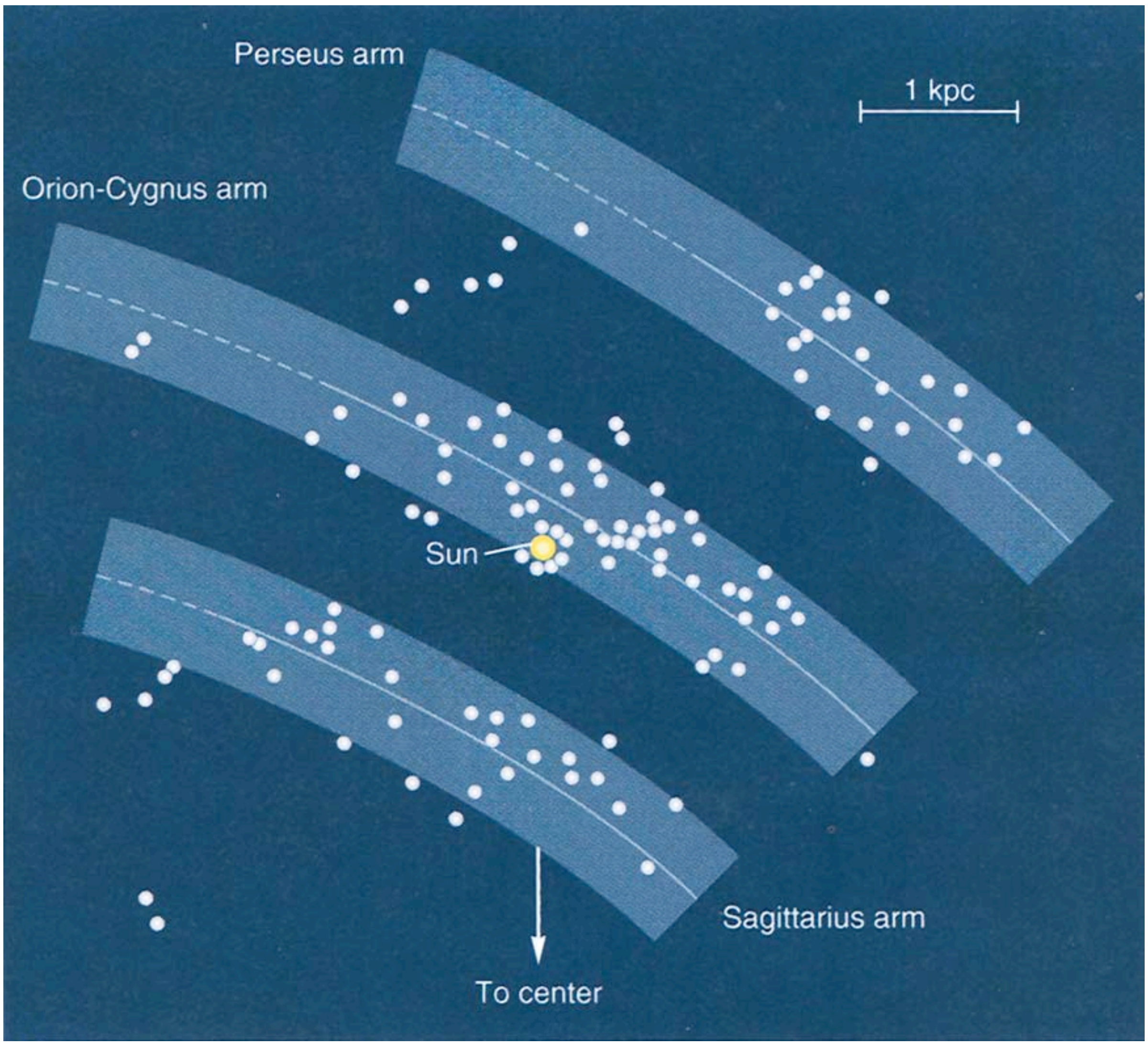
Think about the problem of getting a characterization of the nature of the surface of the earth while standing within a forest. In the Galaxy case the trees are dust grains, preventing us from seeing outside our local neighborhood (at visible wavelengths or smaller). But even using light of longer wavelengths, there is a big problem: how do we get accurate distances to the objects too distant to use trigonometric, or even spectroscopic, parallaxes?

One thing we can tell by just looking at the pattern of stars and gas in the sky: our Galaxy must be **flat**. Look at the images of the sky at different wavelengths (similar to an image in your book):



But how do we know that this disk doesn't extend for a thousand, or a billion, parsecs?

What about applying **spectroscopic parallax** (remember?) to all the O and B stars we can see (think: why use these stars?). Here is a schematic of the result:



In hindsight, we interpret this as seeing parts of the spiral arms of our galaxy, but until around 1950-1960 the calibration wasn't good enough to see this, and even when we could, there are still these important questions:

- How far does this disk extend? Is it round, elongated, … ?
- Is our Galaxy made of bands in a disk, or is there more? What is the shape of the distribution of the young and old stars?
- Our there other galaxies like ours?

Answers to these questions require distances using the next "standard candle": variable (pulsating) stars.

Finding our position in the Milky Way (MW)—Counting stars in different directions very misleading (23.4). Instead the breakthrough came from using RR Lyrae stars to get the distances to globular clusters (23.9).

There are two kinds of variable stars (their apparent brightness varies periodically because they are *pulsating*) that are used as "standard candles" for distance estimates:

a. RR Lyrae stars—all have similar light curves, periods 0.5 to 1 day (23.5), and *all have approximately the same luminosity!* (Think about how handy this is—see 23.6.).

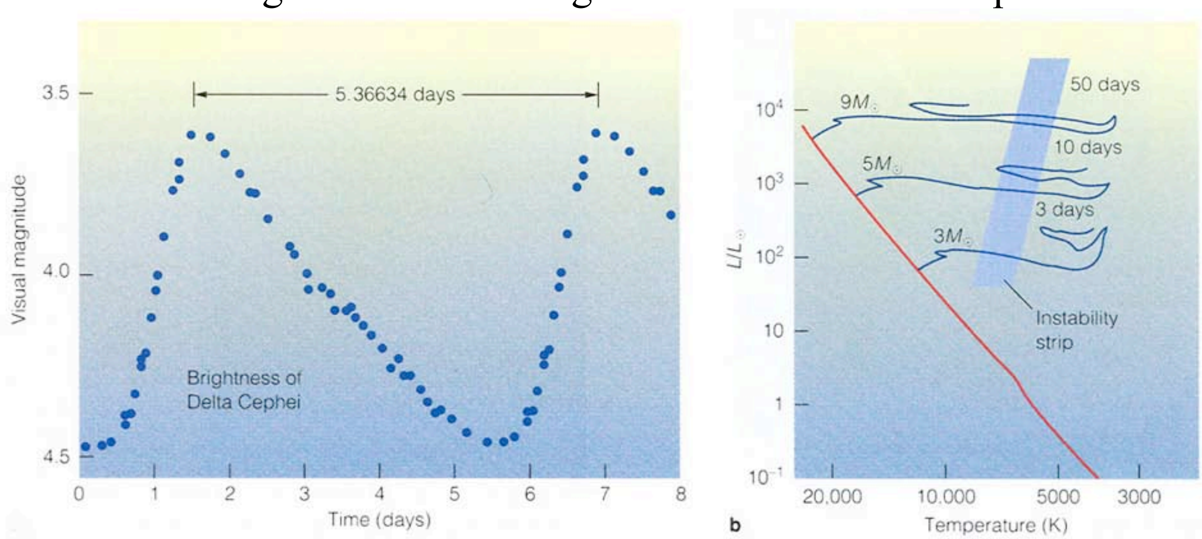
Only low-mass metal-poor stars become RR Lyrae stars, so these gave distances to globular clusters (think: old, metal-poor), showing that we weren't located at the center of our Galaxy, and that the Galaxy has a roughly spherical "halo." (23.9)

So we already have an answer to part of question 2 above: The oldest stars in our galaxy are distributed in space in a roughly spherical halo, consisting mostly of the globular clusters. ***This tells us that, since these stars are all old and metal-poor, our Galaxy probably began its life as a roughly spherical cloud, and later flattened into a disk.***

[Later we will see that there is a much more massive “dark matter” halo that is actually most of the mass of our Galaxy—yet we can’t see it and we don’t know what it is made of!]

b. <u>Cepheid variables</u>—periods 1-100 days; show very tight <u>period-luminosity relation</u> (23.7), which can be used to get their distances. Important because they are much brighter than RR Lyrae stars, so can get distances to the nearest galaxies using Cepheids.

These two methods form the next rung of the ladder of “standard candles” of distance indicators that we will eventually extend to map the structure of the whole universe. Make sure you understand the relation between needing distances to things in order to make a map!



Variable stars. (a) A graph of the brightness of the star δ Cephei versus time shows that it is varying in brightness with a period slightly more than 5 days. (b) The instability strip is a region of the H–R diagram in which stars become unstable and pulsate as variable stars. More massive stars evolve across the instability strip higher in the diagram, are larger, and have longer periods of pulsation.

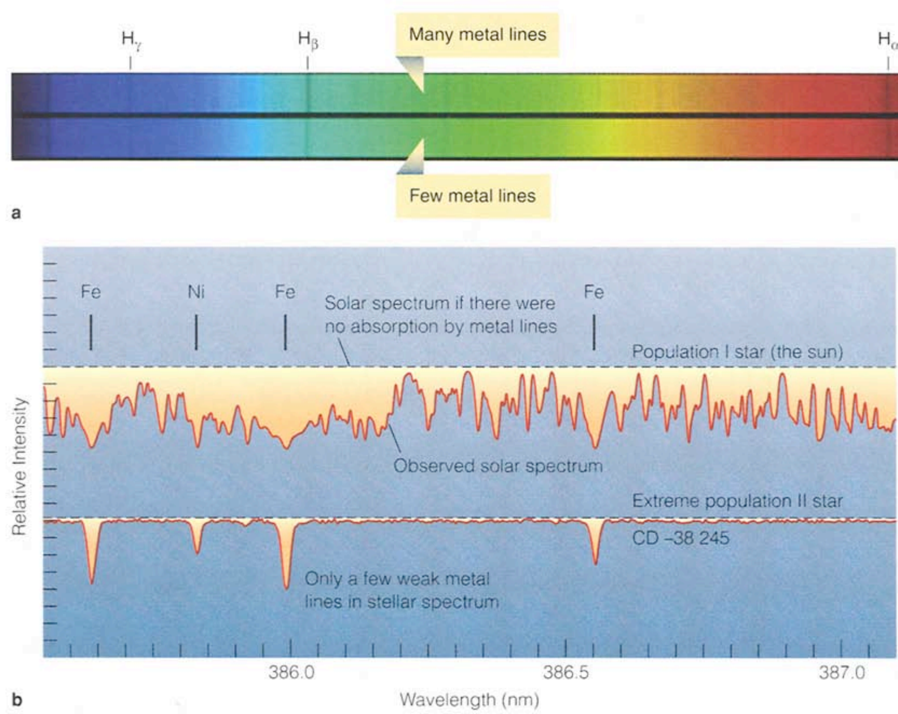
The above illustration shows a light curve for a Cepheid variable (left); this is all we need to measure in order to find that we are looking at a Cepheid. The H-R diagram on the right shows the “instability strip” where all the Cepheids are found—it turns out that the envelopes of stars in this band are unstable to radial pulsations.

Consider how lucky we are that there are pulsating stars that can be used to get distances. If not for these stars, we might not have discovered that there are other galaxies (e.g. our nearest neighbors, Large and Small Magellanic Clouds [LMC, SMC], and Andromeda) until much later in this decade.<u>hjhjhjh</u>

<u>Our galaxy's "stellar populations"</u>: Disk, halo, and bulge. Properties to discuss and understand (see also table 23.1):

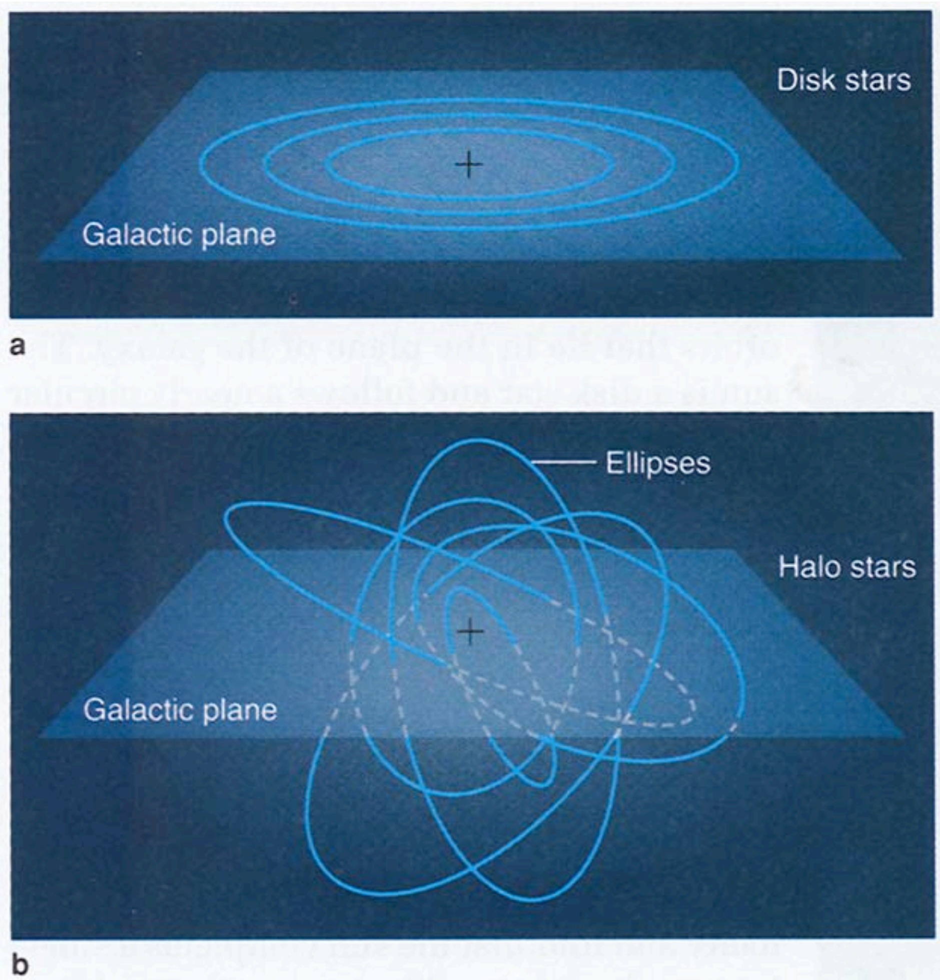
- Spatial distribution (23.10)
- Color
- Age
- Metal abundances
- Orbits (23.13)

The illustration below shows how the disk and halo stellar populations of our Galaxy are distinct in their spectra, with the halo stars having weaker spectral lines than disk stars of the same temperature (spectral type). Why would this be so??



(a) The difference between population I stars and population II stars is dramatic even to the eye. *(AURA/NOAO/NSF)* (b) Graphing such spectra, we find overlapping absorption lines of metals completely blanketing the solar spectrum. The lower spectrum is that of an extremely metal-poor star with only a few, weak metal lines of iron (Fe) and nickel (Ni). This population II star contains about 10,000 times less metals than the sun. *(Adapted from an ESO illustration)*

The following illustration shows the different orbital characteristics of disk and halo stars.



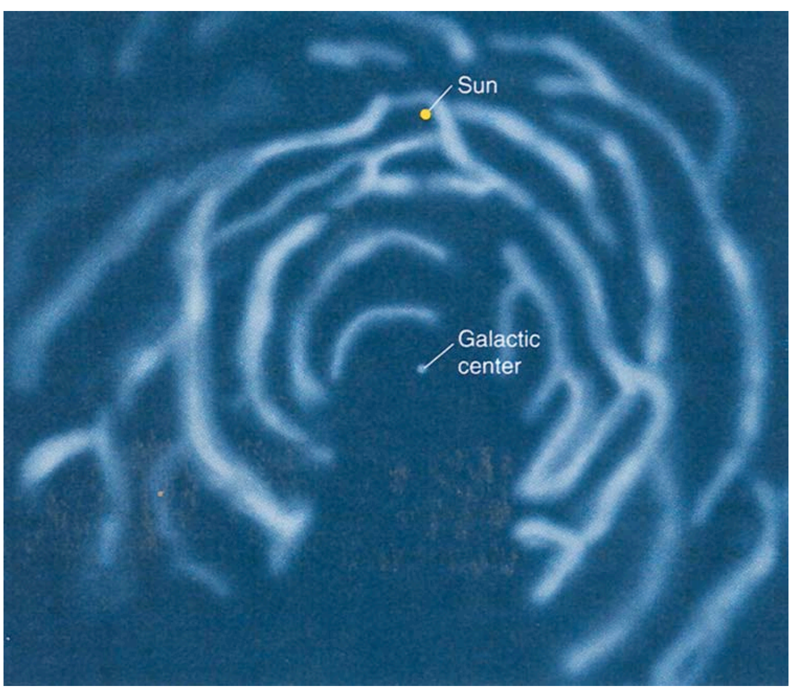
(a) Stars in the galactic disk have nearly circular orbits that lie in the plane of the galaxy. (b) Stars in the halo have randomly oriented, elliptical orbits.

These population characteristics suggest a consistent picture for the formation and evolution of our galaxy (Fig.23.14)—halo forms first in nearly spherical shape, rest of gas collapsed to disk which has formed stars continuously since that time. (Think about how above properties suggest this.)

More recently it was discovered that our Galaxy has a weak but detectable bar structure in the bulge. This rotating bar is important, because it keeps things "stirred up" through its gravity, and might even drive density waves (see below).

<u>Mapping the disk</u>—can't use stars except nearby (why?); must use radio HI and CO spectral lines for more distant regions. Result from radial velocities and distances: <u>differential galactic rotation</u> (23.12). Inner parts rotating faster than outer parts (at least at our distance from the center—see below). Note that this is just for the disk—the halo stars are moving differently (see 23.13).

Here is an illustrative HI map of our Galaxy.



Spiral structure – These maps show evidence for spiral arms (although these can be seen more clearly in other galaxies, e.g. 23.3). How can spiral structure persist? If they were material structures, differential rotation would wind them up very tightly (23.17).

Two theories-- probably both processes contribute:

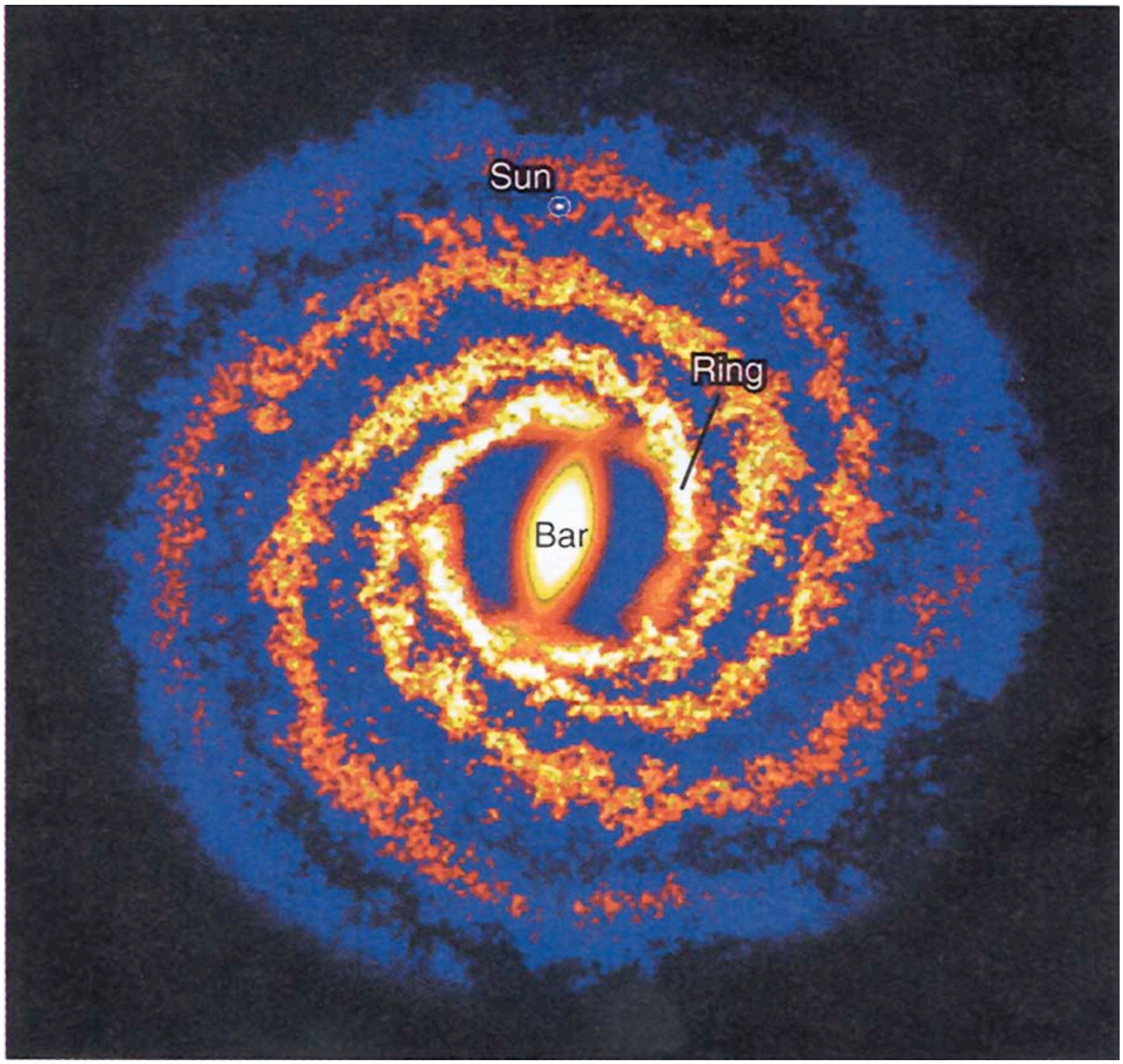
a. Spiral density waves—spirals are only wave patterns moving through the disk. (Think of sound waves—the gas itself doesn't move from one place to another.) Gas passing through wave is slowed down and compressed, get enhanced star formation (23.18 and Discovery 23-2).

b. Self-propagating star formation---Star formation at one location causes explosions that compress the gas some distance away, causing more star formation, and the process repeats, spreading through the galaxy. Makes spiral pattern in differentially rotating disk. (23.19)

The origin and maintainance of the spiral is only a problem for a), not b). But a plausible answer for (a) is: waves are "excited" by gravitational interactions with galactic neighbors, or by a "bar" within the bulge of our Galaxy and others (see picture on next page).

The topics on this page, theories of spiral structure, will *not* be on the next exam.

Another possibility, not mentioned in the book, is that the arms could be generated by the **bar** that is located in the central regions of the galaxy. Here is a simulated IR map of our galaxy showing the bar and the ring it definitely produces.



Mass of our Galaxy: Use rotational speeds of stars around galactic center to infer how much mass is inside of that orbit (23.20):

Total mass = (orbit size $)^3$/(period$)^2$

(This is just Kepler's 3rd law—be sure you understand how we are getting the Galaxy's mass by how fast stars are orbiting around within it.)

This use of orbital speeds is called the ***rotation curve*** of a galaxy (23.21). We expected speeds to decrease as you get further from center of galaxy (like planets in the solar system, so called "Keplerian rotation curve"). [Stop and think—why would orbital speeds decrease with increasing distance?]

Instead, the rotation curve outside a certain distance from the center becomes *flat* ⇒ stars moving faster than can be accounted for by the *observed* mass ⇒ **dark matter**, probably in the form of a halo.
Nobody knows what dark matter is, but a few possibilities have been ruled out.

Candidates for dark matter:

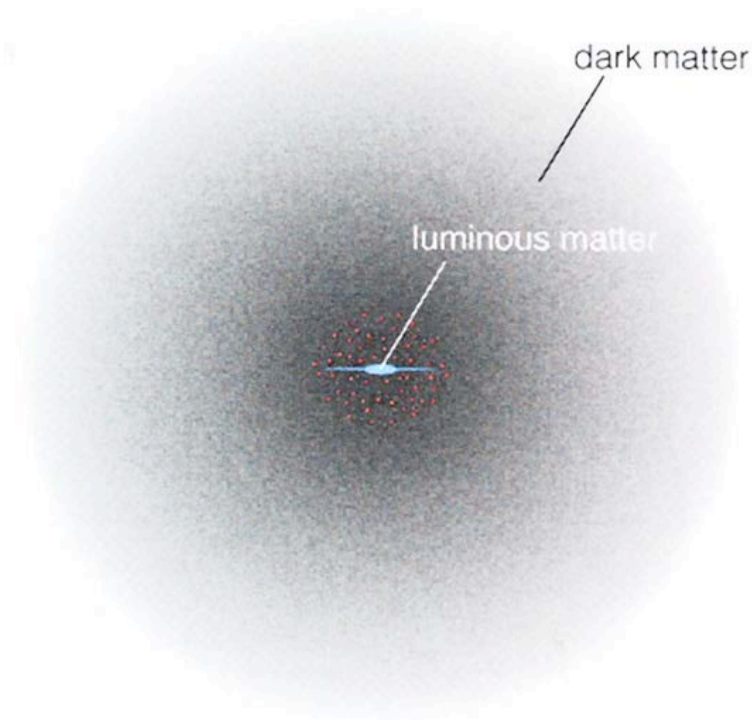
■ Faint red stars or brown dwarfs—can now rule this out. (p. 623).

■ Faint white dwarfs—can almost rule this out; gives less than about 10% of what is required (*not* half, as stated in the text).

■ Can test for these types of objects using gravitational lensing (Fig. 23.23). Must observe millions of stars every few days over a period of years, bcause the flickering should be very rare.

■ Exotic particles—some theories of particle physics predict there should exist a zoo of these massive particles, but we have no idea which ones could be the dark matter. But most astronomers think these "WIMPS" (weakly interacting massive particles, p. 624) are the most likely candidate.

Our galaxy: A disk and halo of light-emitting matter (disk, bulge, halo) within a ***dark matter halo,*** which is much larger than the disk or halo of stars.



The dark matter associated with a spiral galaxy like the Milky Way occupies a much larger volume than the galaxy's luminous matter. The radius of this dark-matter halo may be 10 times as large as the galaxy's halo of stars.