Lecture 8

The Distance Ladder

Feb 25 2003
8:00 PM
BMPS 1420

This week's topics

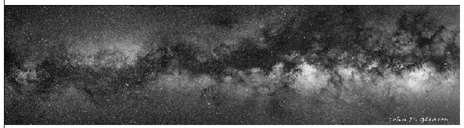
- The Milky Way
- Distance Ladder
- To the Roof?

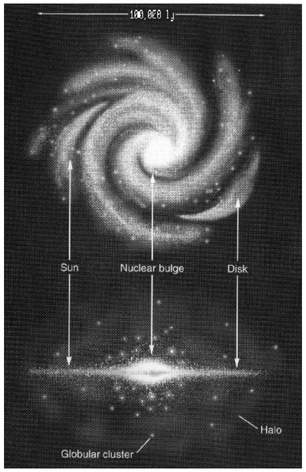
The Milky Way

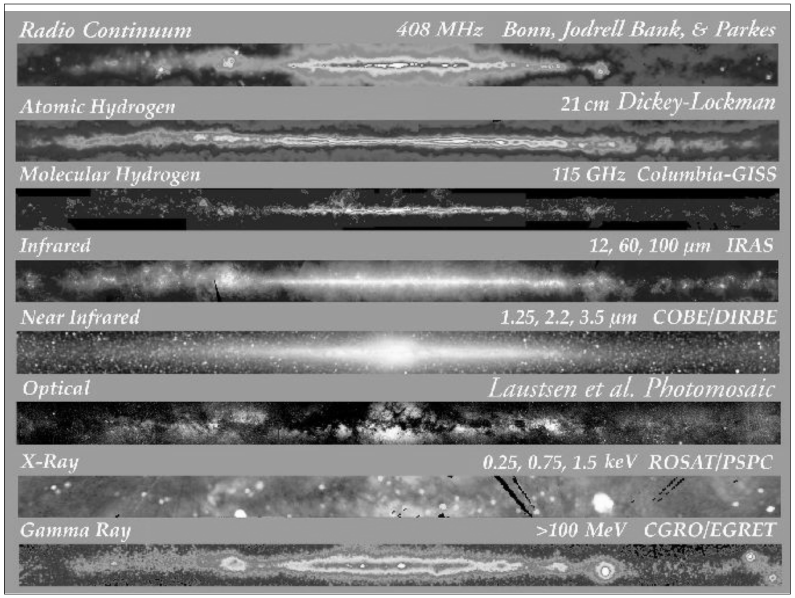
100,000 ly wide

Over 100 billion stars

Lots of dust and gas in the disk, as seen below



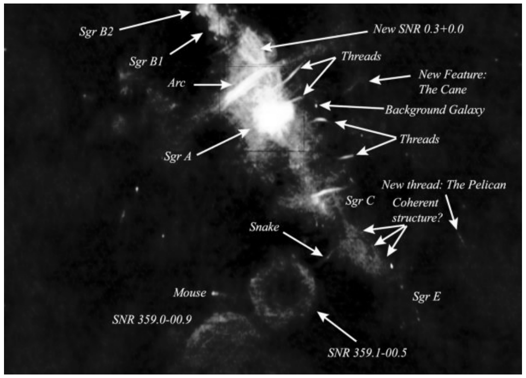




Center of the Milky Way

2000 ly on a side

Center is Sagittarius A radio source (actually 3 sources). Image was taken at 1 m wavelength at the Navel Research Laboratory.



Distance modulus

- Absolute magnitude is the magnitude that an object would appear to have if it were at a distance of 10 pc.
  - m - M = 5 log (d/10) (d is in parsecs)
    - m is apparent magnitude
    - M is absolute magnitude

Distance Ladder

- Most difficult problem in Astronomy (depends on who you ask)
  - Need accurate measurement of distance to tell absolute magnitude
    - m - M = 5 log (d/10) (d is in parsecs)
  - Also can be used to get actual size of objects
    - Measure angular size, find distance, know size

Methods for determining distance

- Direct Measurements
  - Parallax
  - Baade-Wesselink
- Indirect Measurements
  - Variable stars
    - Cepheids
    - RR Lyrae
  - Tully-Fisher
  - Standard Candles
    - SN
  - Hubble Flow

Parallax

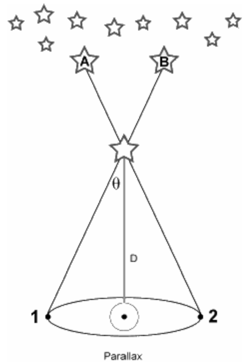
Direct measurement of distance using the awesome power of geometry (we told you in math class that you would need it...)

$$d = \frac{1}{p}$$

where p is the parallax angle (θ in the diagram on the right) and is measured in arcseconds

This distance is in parsecs. In fact, one parsec is defined as the distance to an object that has a parallax angle of one arcsecond.

1 parsec (pc) = 3.2616 light years (ly)



Problems with parallax

- Difficult to measure such small angles
  - Need very accurate instruments
  - Recent satellites can measure to about 0.001"
- Only good for things nearby
  - As distance increases, parallax angle gets smaller
  - Good to about 1000 pc or so (1 kpc)
    - Our galaxy is about 30 kpc in size, so only good in solar "neighborhood".

Baade-Wesselink

Recall that for main sequence stars:

$L = 4 \pi R^2 \sigma T^4$

Or

$M_{bol} = -10 \log T_{eff} - 5 \log R + C$

This means that if we know a stars radius and can get the temperature (remember the color-magnitude diagram?) then we can calculate the absolute magnitude! Distance modulus does the rest of the work.

Great idea, but....

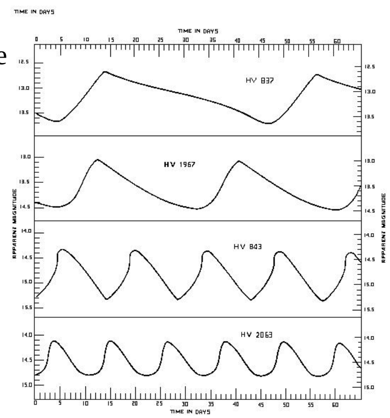
Problems with Baade-Wesselink

- How exactly do we find the radius of all of these stars?
  - There are crafty ways to do it with pulsating variable stars, but these rely on the assumption that the pulsation is radial and that we have a good understanding of the exact nature of the pulsation mechanism. These are not great assumptions.
  - We also assume that we can determine the temperature accurately from color. Also not quite true.

Variable stars

Class of objects that change brightness regularly. If we can find a relation between absolute magnitude and pulsation period, this would allow us to find distances to objects that were much further away.

This can be done for certain types of variables.



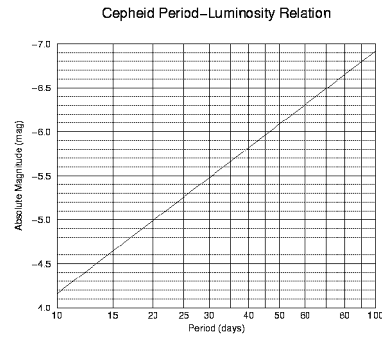
Cepheids

Classical (or Type I) Cepheids

$\langle M_v \rangle = -2.78 \log (p/10 \text{ days}) - 4.13$

Where p is the period in days and $\langle M_v \rangle$ is the average V band magnitude (need an average since it is a *variable* star...) We then use the distance modulus.

This is good to about 40 million pc (130 million ly)

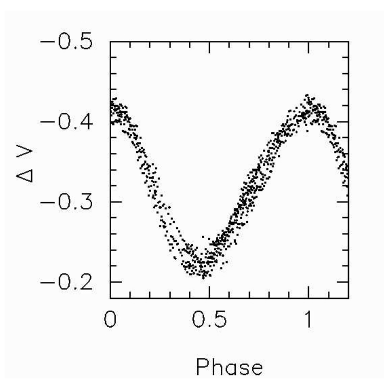


RR Lyrae

Similar to Cepheids, with a different relation.

RR Lyrae tend to be less massive than Cepheids. The lower mass means that they are on the whole older than Cepheids and have shorter periods (less than a day).

Good out to about 760,000 pc (2.5 million ly) or so. Really only good for Milky Way and nearby galaxies.



Tully-Fisher Relation

Relation between the maximum rotational velocity of a spiral galaxy and its absolute magnitude

$M = -10 \log V_{max} + \text{constant}$

It is an empirical relation, and the zero point (the constant) is different for different types of galaxies.

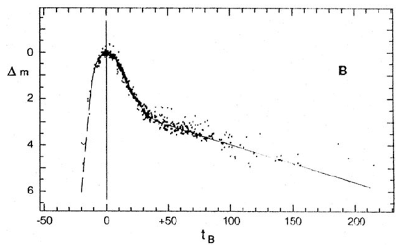
Similar relation for elliptical galaxies (Faber-Jackson relation).

It boils down to the idea that the greater the velocity of the objects in the galaxy, the greater the mass, the greater the mass the greater the amount of light.

Type Ia SN as Standard Candles

It is believed that type Ia Supernovae (catastrophic destruction of a white dwarf that was accreting mass from a red giant counterpart) all have nearly the same maximum brightness. If this is true then we can measure the apparent brightness of the maximum and get the distance.

With current technology we can see these out to about 1000 Mpc (~ 4 billion ly)



Hubble's Law

1929 Hubble found that most galaxies were moving away from us (seen as a redshift in the spectra). This was seen as proof of the Big Bang; the universe is expanding. This can be used as a distance estimator:

$$d = \frac{c\,z}{H_0}$$

Where H_0 is Hubble's constant. This constant is measured experimentally and there is some evidence that it is not constant in time. It is between 50 and 100 km/s/Mpc depending on who you ask. Current best estimate is around 70 km/s/Mpc.