Cosmic distances

- Discussed earlier that the most direct way to measure the distance to a star or other astronomical object is to measure its *parallax* – the small shift in its position over a year caused by the movement of the Earth from one side of its orbit to the other.
- This is only accurate out to a few hundred parsecs at best. So how do we find out the distances to objects further away than that?
- There is an elaborate set of interlinking distance measures which is used to work out the scale of the universe - the *cosmic distance ladder*.

Expansion parallax

- Compare plane-of-sky expansion with line-of-sight (Doppler) velocity: the Crab Nebula is at a distance of 2000+-500 parsecs.

Expansion parallax

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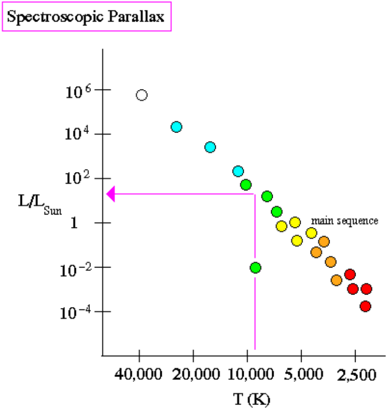
Spectroscopic parallax

- If we can work out the position of a star on the Hertzsprung-Russell diagram, we know its absolute magnitude, and therefore its distance.
- Temperature is easily determined, and therefore its luminosity can simply be read off from the diagram.
- This is known as *spectroscopic parallax*. It's not particularly accurate. And it's also not anything to do with parallax!

Spectroscopic parallax



the true brightness of a star can be found if the color is known by matching the star to the main sequence. Knowledge of the observed brightness plus the true brightness derives the distance to the star.

Main sequence fitting

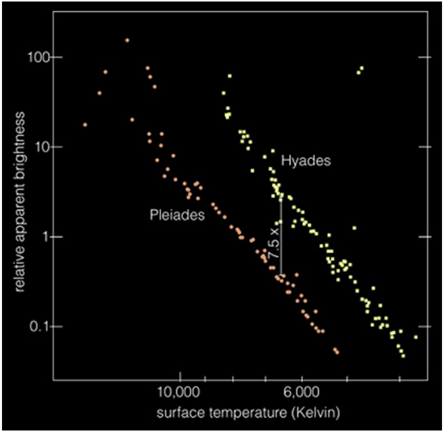
- More useful than the spectroscopic ‘parallax’ is *main sequence fitting*. If we observe a cluster of stars, and plot an HR diagram using apparent magnitude and temperature, we will see the main sequence.
- The distance to the cluster is then easily determined from the difference between the apparent magnitude of its main sequence, compared to the absolute magnitude of the standard main sequence.

Main sequence fitting

- Example: Pleiades and Hyades - two nearby well-known star clusters.
- On an HR diagram, we see that the main sequence of the Hyades is about 7.5$\times$ brighter than the main sequence of the Pleiades.

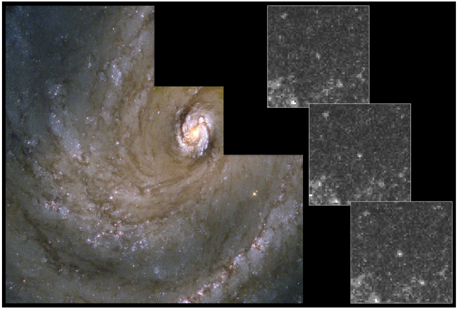
Main sequence fitting

- From the inverse square law, this means that the distance to the Pleiades is $\sqrt{7.5} = 2.7$ times the distance to the Hyades.



Standard candles

- As discussed earlier, many evolved stars go through phases where their brightness is variable. A very useful type of variable star is called a *cepheid variable*, named after δ Cephei, the first known example. The Pole Star is also a cepheid



Standard candles

- Cepheids brighten and fade extremely regularly over periods ranging from a few hours to a few weeks.
- They are are extremely useful because it turns out that their luminosity and period are tightly related – the longer the period, the brighter the Cepheid.
- The brightest cepheids are many thousands of times brighter than the Sun. This means they can be seen out to large distances – as far away as 60 million light years.

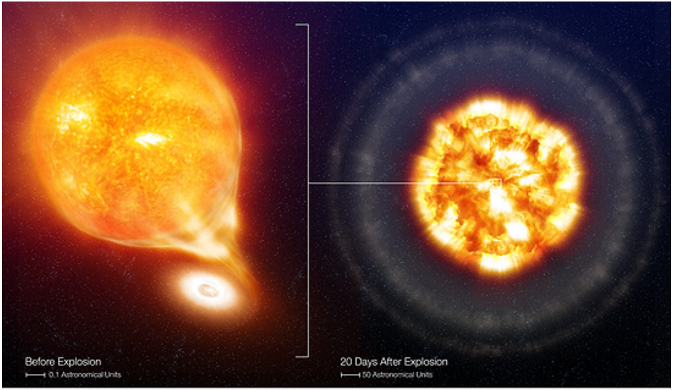
Cepheid variables

- Cepheids answered some major questions in astronomy: Shapley observed them in our galaxy and determined its size.
- Edwin Hubble observed cepheids in the Andromeda Galaxy, and thus showed that it was outside our own galaxy.
- One of the main aims of the Hubble Space Telescope was to observe cepheid variables in distant galaxies, to refine the cosmic distance scale.

Standard candles

- Cepheids are one of the most important of the *standard candles* – objects whose absolute magnitude is known and so whose distance can easily be found.
- Other examples of standard candles are:
  - RR Lyrae stars (similar to Cepheids but less luminous)
  - planetary nebulae
  - Type Ia supernovae
- We talked about core-collapse supernovae, which are the end result of the lives of very massive stars. These are also called Type II supernovae
- Type Ia supernovae result from binary system in which matter is flowing from a red giant onto a white dwarf.

Standard candles



SN 2006X, before and after the Type Ia Supernova Explosion
(Artist Impression)

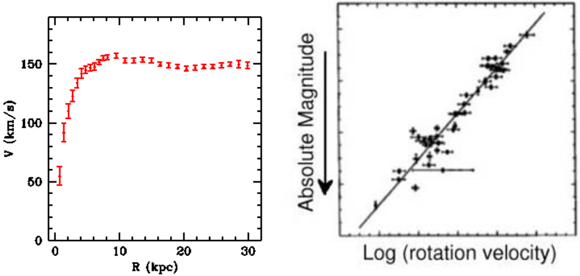
ESO Press Photo 31b/07 (12 July 2007)

Standard candles

- As it gets heavier, the temperature in the white dwarf rises. When the white dwarf reaches a critical mass, the temperature is high enough to trigger sudden explosive nuclear fusion, and the star explodes violently.

Greater distances

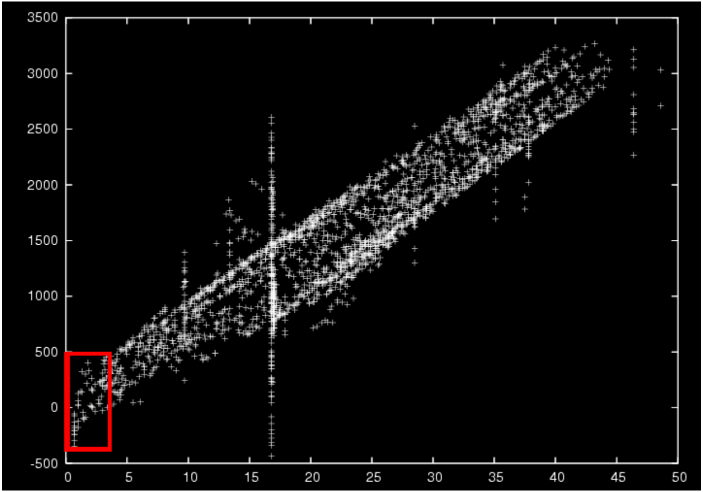
- Using all these distance measuring techniques, the distances to many relatively nearby galaxies have been found.
- It has been found that the *faster* the stars in a galaxy are orbiting the centre, the *brighter* the galaxy is. The relationship between rotation and luminosity is called the Tully-Fisher Relation



Hubble flow

- Edwin Hubble was the first to find (using cepheids) that all external galaxies (except the ones in the Local Group) are receding, and that the velocity of recession is proportional to the distance.
- $v = H_0 D$
- Ho is a constant, with units of km/s/Mpc, called the Hubble Constant. It is one of the most important numbers in astronomy.

Hubble flow


3500
3000
2500
2000
1500
1000
500
0
-500
0
5
10
15
20
25
30
35
40
45
50

Hubble flow

- Using all the distance indicators discussed eventually allows us to estimate the Hubble Constant. The generally accepted value is about 70 km/s/Mpc.
- Once it is known, then for very distant galaxies, measuring the redshift gives us an idea of the distance.

The distant universe

- Galaxies exist in clusters, clusters are members of super-clusters, super-clusters are members of filaments.
- Between the filaments - voids.