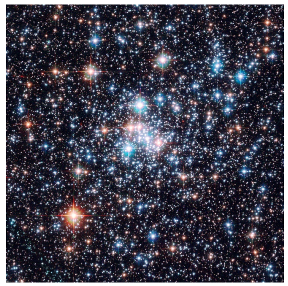
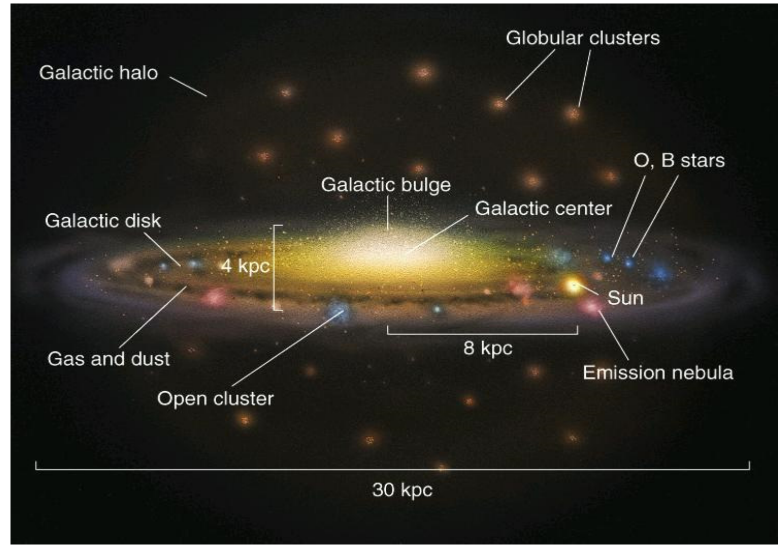
Star clusters (back to Sec 19.4)

- Groups of 100’s to ~a million of stars formed together
- Stars in a cluster
  - Are all at same distance (easy to compare e.g. luminosities)
  - All have the same age
  - All have the same chemical composition (not so important for us)
  - Have a wide range of stellar masses
- A cluster provides a snapshot of what stars of different masses look like, at the same age and distance



“Open” and “Globular” Clusters in the Milky Way



Open clusters

- Open clusters (galactic clusters) contain 100’s-1000’s of stars, not very centrally concentrated.
- The clusters are confined to disk of the Galaxy.
- Stars are young. Open clusters generally disperse with time.

M11 the “Wild Duck” open cluster.

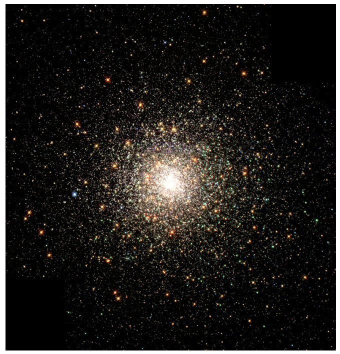
H and Chi Persei

M35 and NGC 2158 in Gemini

Globular clusters

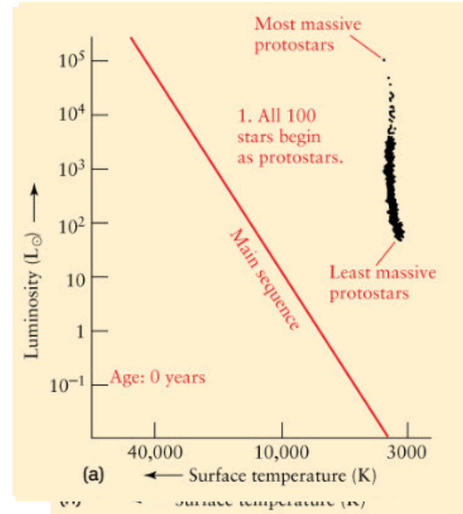
- Globular clusters contain 10^5 to 10^6 stars, centrally concentrated.
- Found in the halo of the galaxy.
- The stars are old.
- Provide an important, lower limit to the age of the Universe.

M10



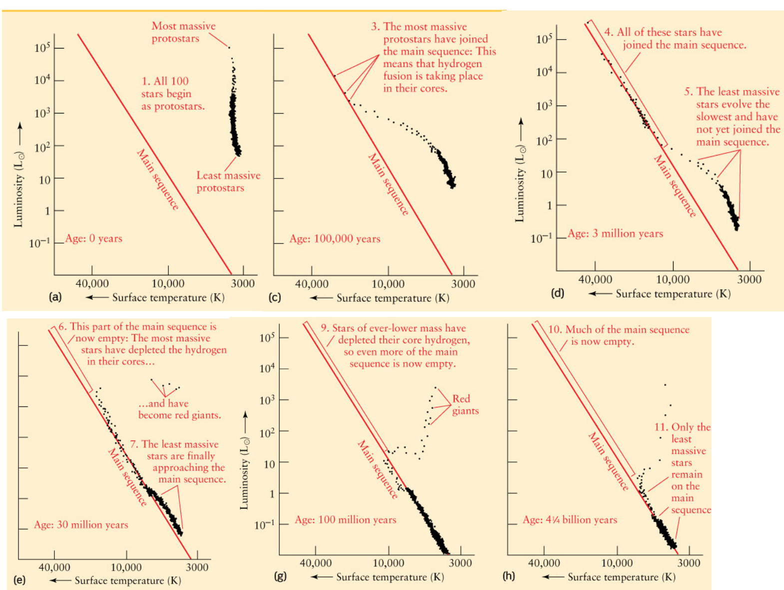
M80

Theoretical tracks (up to Red Giant phase):

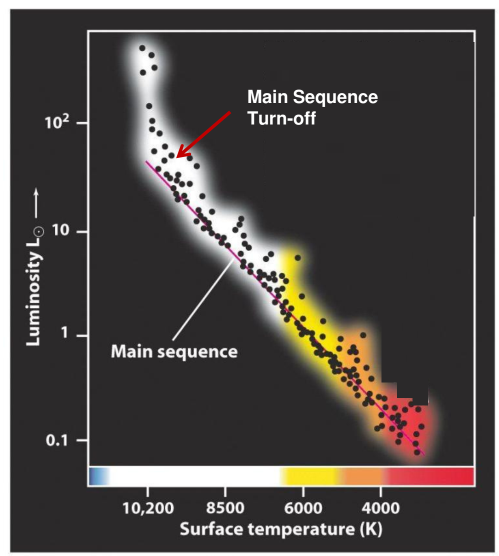


(Theoretical tracks not stacked on top of each other):

If distance not known, and incident flux plotted, will shapes change?



Comparison of theory and observations

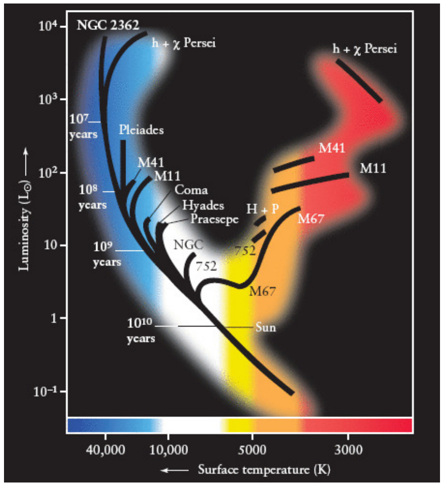


An H-R diagram of the stars in the Pleiades

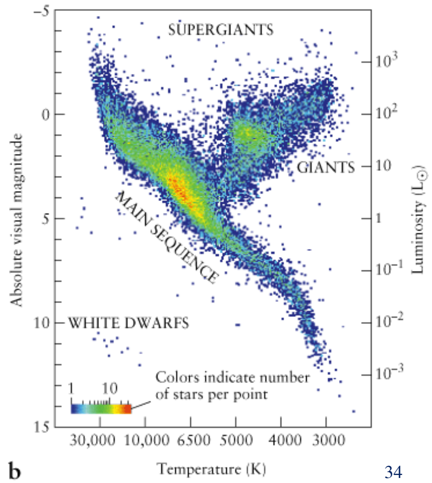
Get <u>age</u> from color of stars just leaving Main Sequence (MS Turn-off point).

Get <u>distance</u> by measuring stars' incident fluxes, plotting incident flux vs. T, recognizing MS. Know what their luminosities should be from theoretical MS.

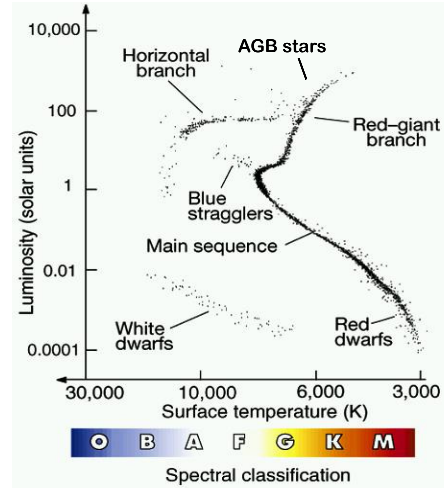
- The H-R diagrams of open clusters show range of MS turnoff points – range of ages.



H-R diagram for 21,000 of the brightest nearby stars from Hipparcos. Are these stars all the same age, like in a cluster?



Typical <u>globular </u>cluster H-R diagram. Note low turnoff point, many red giants and white dwarfs. Young or old?

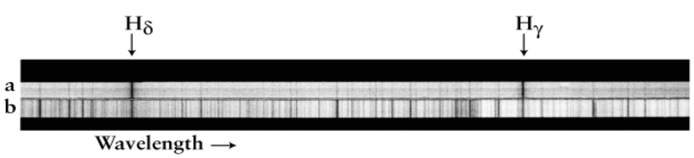


Also get <u>distance</u> from apparent brightness of Main Sequence or of Horizontal Branch.

Stellar populations

Two basic types of stars – a young class and an old class.

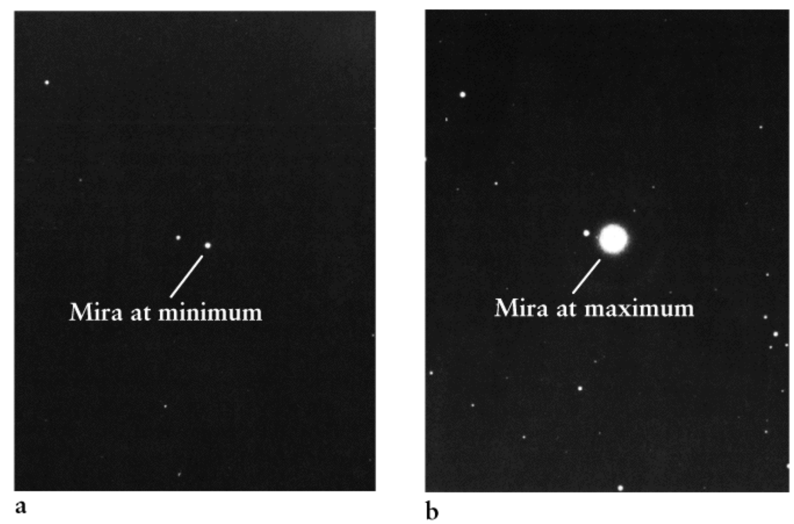
- *Population I* – young, in disk of galaxy, "metal-rich", including open clusters.
- *Population II* – old , in halo, "metal-poor", many in globular clusters.



A has low metallicity,
B has high metallicity.
Temperature same.

- Earlier stars formed out of "cleaner" gas (Pop II).
- Later generations formed out of gas which the first stars "polluted" with heavier elements ("metals") they created (Pop I). But they have a large range of metal content in spectra and thus ages.

Variable stars as Distance Indicators

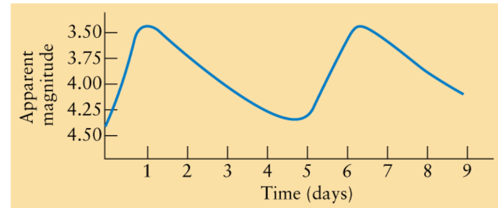


Some evolved stars vary in brightness. Mira variables are Long Period Variables: AGB stars varying in brightness by a factor of ~100 over a timescale of 100-700 days.

Short Period Variables – Cepheids and RR Lyraes

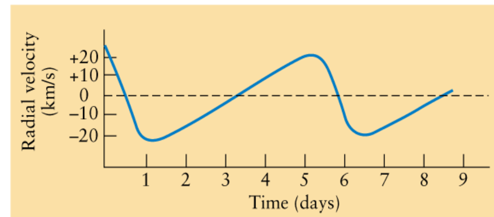
- They pulsate in radius. T also varies. Timescale days – weeks.
- This happens to some stars late in their evolution when their internal structure makes them unstable to pulsations – but we'll skip the physics.
- Cepheids are relatively massive, evolved, variable stars.
- RR Lyrae variable stars are Horizontal Branch stars.

How to study variable stars



a

We use light curves, which show the brightness (typically in some filter) versus time for the star.



b

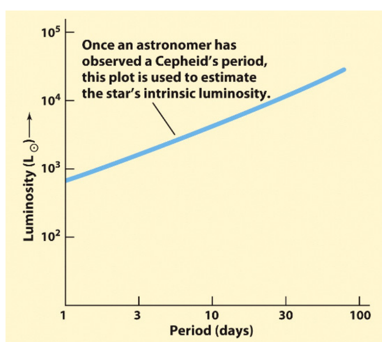
We can also look at the periodic change of other properties, such as the radial velocity, surface temperature, and size.

Distance indicators

- Variable stars like Cepheids, and RR Lyrae stars can be used as distance indicators. How?
- Cepheids exhibit a relation between their period and their (average) luminosity. Discovery goes back to Henrietta Leavitt (1912).

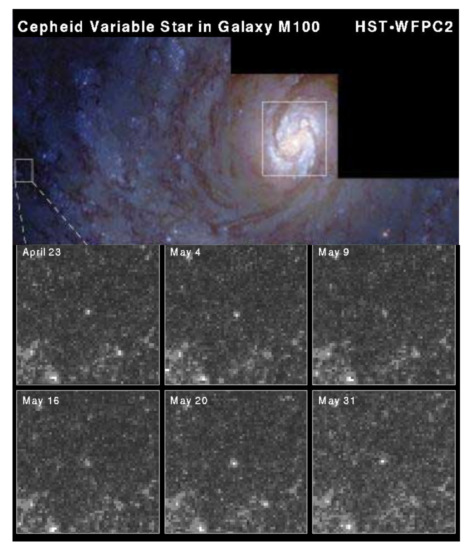
The mean period-luminosity (P/L) relationship for Cepheids.

=> Measure period, read off luminosity. Then with measured apparent brightness (incident flux) use inverse-square law to get distance. Usually done with a filter.



- The P/L relationship for RR Lyrae stars is trivial: all have *L* almost 100 L⊙

- Cepheids and RR Lyrae stars are giant and thus very luminous. We can see them as individual stars in other, nearby, galaxies.



Concepts in understanding stellar evolution

- Temperature increases with depth in a star.
- A nucleus with higher atomic number requires a higher temperature for fusion.
- Fusion provides pressure which supports core and star (shining is a “by-product”).
- When fusing of an element is complete, core not hot enough for fusion of next element: core contracts.
- As core contracts, heats up, as gravitational potential energy converted to heat.
- Core contracts until T high enough to fuse next element.
- When core inert and shrinking, layers above it contract, creating hot dense shell(s) where intense fusion happens, causing envelope to expand and star to become more luminous – even as core contracts.
- Expanding envelopes cool.