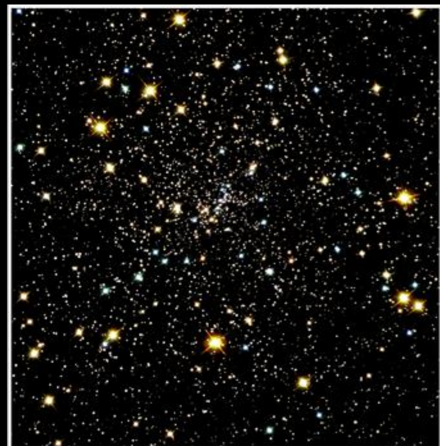
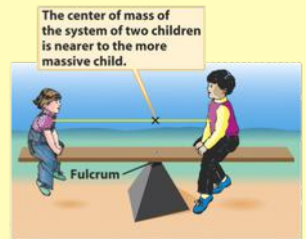
Stars

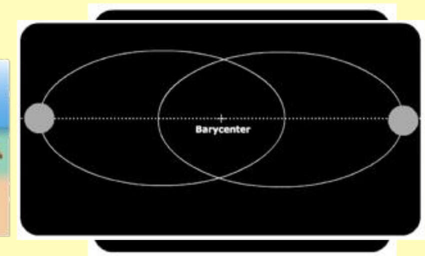


Center of Mass

- ***center of mass (barycenter)***: "point of balance"
- stars ***orbit*** about ***center of mass*** of the system



A "binary system" of two children

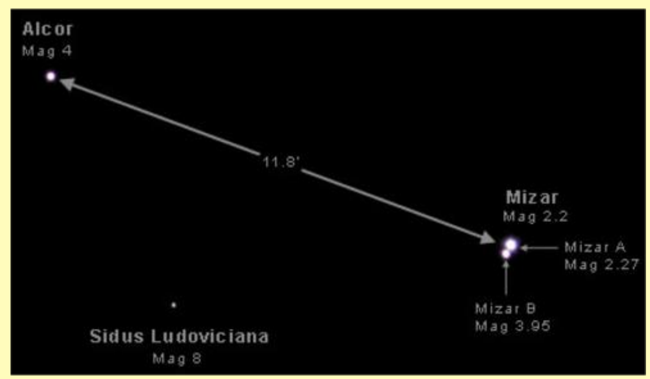


Stellar Groupings

- ***single stars***: *one star* forms out of ***solar nebula***
  (eg) *Sun*

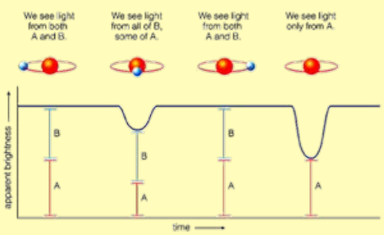
- ***binary stars***: *two stars* form out of ***solar nebula***
- both stars ***orbit*** about common ***center of mass***
  (eg) *Albireo*

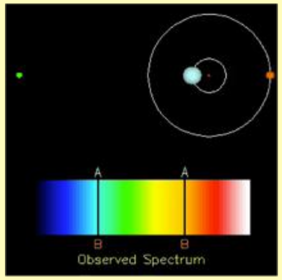
- ***optical binaries*** only *appear* to be ***binaries***
  (eg) *Mizar & Alcor in Big Dipper*



- ***visual binaries*** can be seen *visually (surprise!!)*
  (eg) Mizar A & Mizar B

• ***eclipsing binaries*** orbit so that one star *blocks* the other's light, affecting *overall brightness*

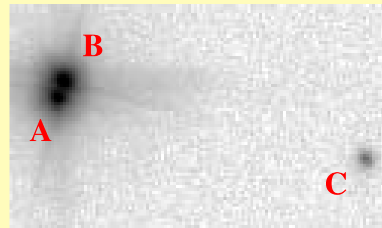




• ***spectroscopic binaries*** can ***only*** be split using *doppler shifts* in each stars' ***spectra***

Multiple Stars

• *larger groups* may also form from ***solar nebula***
(eg) Polaris
(eg) Castor *(in Gemini) is a visual trinary, &* ***each star*** is a *spectroscopic binary!*



Clusters of Stars

• ***open cluster****: loosely bound* stars
• stars ~ *same age*
(eg) *Pleiades, 100 My, 365 ly away*
• over 1000 stars

• ***globular cluster****:* stars *tightly bound*
• *very old* ("metal" **poor**)
• orbit *center of galaxy*
(eg) *M2 (Aquarius)*
• 13 Gy, 50,000 ly away
• 150,000 stars, 175 ly across

M15 (Pegasus)

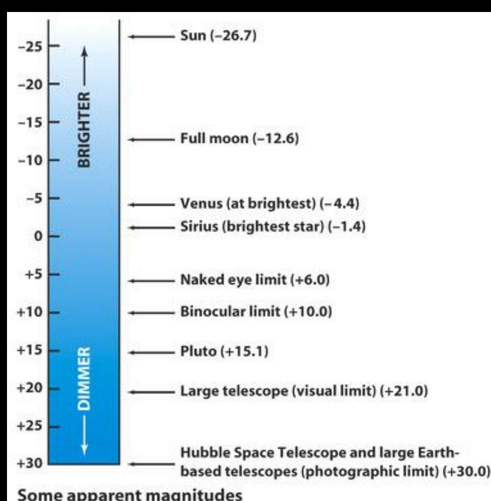
CLICKER: *Classify the images using(a) single star (b) binary (c) open cluster (d) globular cluster*

Stellar Magnitudes

- originated by ***Hipparchus***, ~200 BCE
- based on *naked eye brightness*
- *brightest stars* were "*magnitude 1*", then 2, …. 6
- *refined* so *5 magnitudes = 100*x *brightness*
- thus *each magnitude* step is ~ *2.5*x *brightness*

(eg) a *mag 1* star is 100x **brighter** than a *mag 6* star

(eg) a *mag 3* star is 2.5x **dimmer** than a *mag 2* star



Some apparent magnitudes

Q: *Why* might a star appear *bright* to us on Earth?

- ***apparent magnitude*** (**m**)*:*
how bright a star *looks from Earth*
- ***absolute magnitude*** (**M**)*:*
how bright a star *would look* **if** it were located *10 parsecs from the Earth*

(eg) Sun: m = -26.7; M = +4.8

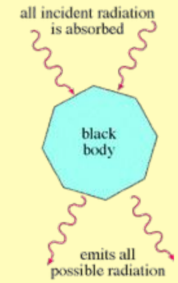
CLICKER: *A star has m = +6.7; M = +1.2. Is it **(a)** closer or **(b)** further than 10 parsecs away?*

- since star appears **dimmer** from Earth (+6.7) than it would if *at 10 parsecs* (+1.2) it must be **further**

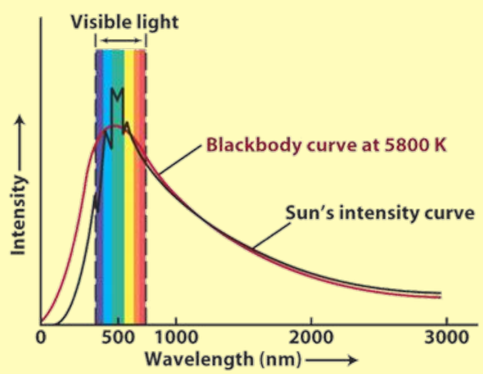
Colours of Stars

Blackbody Radiation

- "***blackbody***": absorb & emit at ***all*** wavelengths
- ***planets*** & ***stars*** are *approximately blackbodies*
- as a "***blackbody***", stars emit *at every wavelength*, but ***not*** at equal intensities
- star's ***spectrum*** has a *peak* at some *specific wavelength*



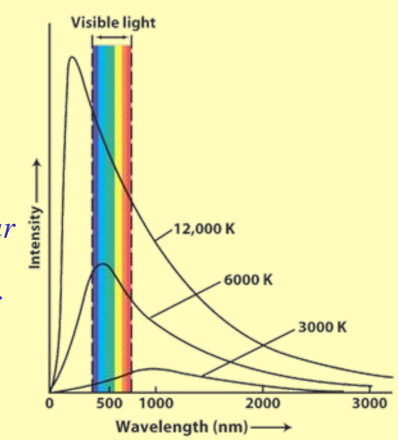
- *shape* of ***spectrum*** & position of *peak* depend ***only*** on *surface temperature* of the ***blackbody***



- ***peak*** is where star **emits** *most intensely*

- as *temperature* changes, *location of peak & **intensity** of **spectrum** changes*

CLICKER: *What colour would a star with a **surface temperature** of 3000 K appear to be?*
(a) blue (b) yellow
(c) green (d) red



Wien's Law

• ***peak*** *wavelength* of ***blackbody emission*** is dependent on ***temperature*** *of object*

$$\lambda_{max} = \frac{.0029}{T}$$

• λ_{max} has units of ***meters, m***
• T has units of ***Kelvin, K***

• holds for ***any*** object which is ~ a ***blackbody***

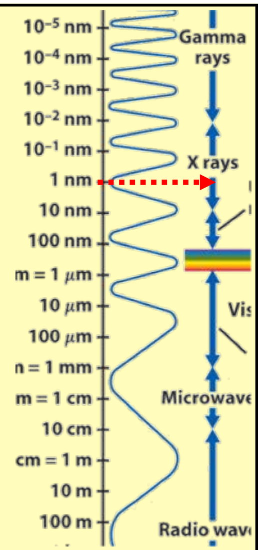
Infrared Emission

(eg) What is λ_{max} for a temperature of 3 million K?

• from ***Wien's Law***:

$$\lambda_{max} = \frac{.0029}{3\text{x}10^6 \text{ K}} = 1\text{x}10^{-9} \text{ m} = 1 \text{ nm}$$

Q: *We observe X-rays emitted from Sun's* ***corona***. *What does this imply about the* ***corona****?*



Stefan-Boltzmann Law

• ***energy flux*** measures *how fast* ***energy*** is *emitted* from **1 m²** surface of a ***blackbody***

• ***energy flux (F)***: *energy per second per m²*
• depends ***only*** on *surface temperature to 4th power*

$$F = \sigma T^4$$

• F has units of ***watts per square meter, W/m²***
• T has units of ***Kelvin, K***
• σ is constant with value of ***5.67x10⁻⁸ W/m²•K⁴***

Luminosity

- ***luminosity*** is ***total energy emitted per second***:

$$L = F \times \text{area}$$

- ***L*** has units of ***watts, W***
- ***absolute magnitude*** is *related* to ***luminosity***

Q: Do two stars with ***same F*** but ***different sizes*** emit the ***same total energy***? Can objects with ***different F*** 's emit the ***same total energy***?

CLICKER: *L* if Sun had ***same size*** but ***twice as hot…*** ?
(a) *unchanged* (b) 2x (c) 4x (d) 8x (e) 16x

Spectral Classes of Stars

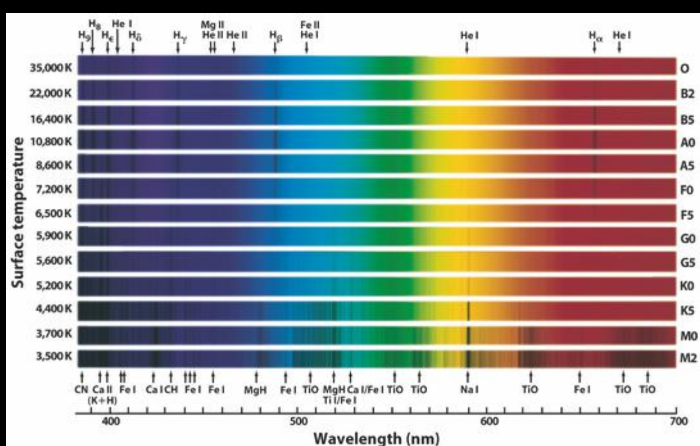
- late 1800's/early 1900's, ***Harvard College Obs.***
- *women* sorted & classified ***thousands*** of ***spectra***

- stars ***classified*** via ***spectra*** into ***spectral classes***

- *blue* stars *hottest*
- ***spectra*** contain emissions from *ionized elements*

- *red* stars *coolest*
- ***spectra*** contain *molecular lines*

Spectra of Stars



- ***spectral classes*** are (*hot to cold*):

O B A F G K M

- *mnemonic*: **Oh, Be A Fine (Girl/Guy), Kiss Me**

Q: Why are they *not* in alphabetical order?

- each subdivided into range 0-9 ("*hot to cold*")
(eg) A8 hotter than A9; A9 hotter than F0

- Sun is classified as **G2**; Sirius A is **A1**

CLICKER: *Why do the hottest spectral types (O and B stars) show so few absorption lines?*

(a) these stars have used up most of their elements
(b) these stars are old & formed before heavy elements were available
(c) O & B stars only produce continuous spectra
(d) most atoms in these stars are ionized and do not readily absorb photons

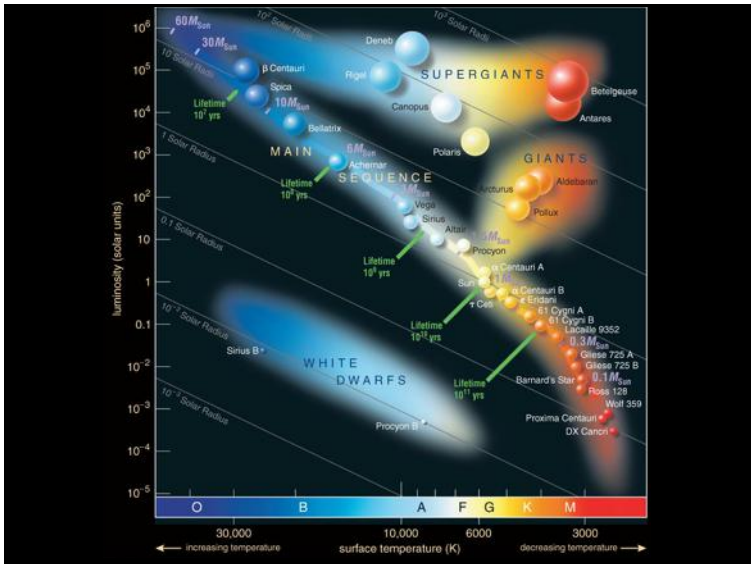
H-R Diagrams

- ***Hertzsprung*** & ***Russell*** (early 1900's)
- plotted ***luminosity*** vs ***surface temperature*** of stars

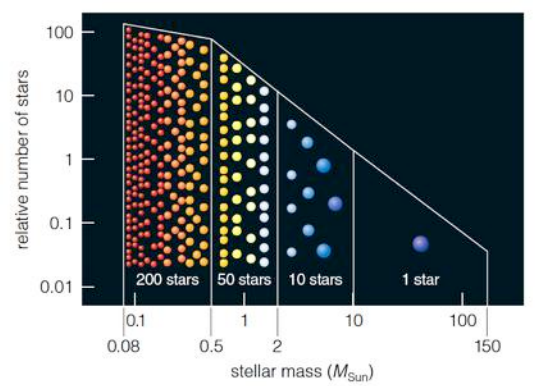
- result ***not*** random!
- *relationship* between ***luminosity*** & ***surface T***

- ***main sequence:*** **curved line;** holds *90%* stars

- stars ***move*** on ***H-R diagram*** *over their lifetime*

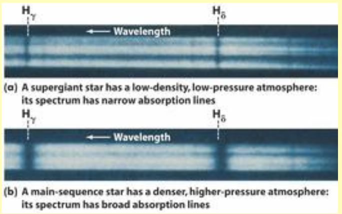


Stellar Demographics



Luminosity Classes

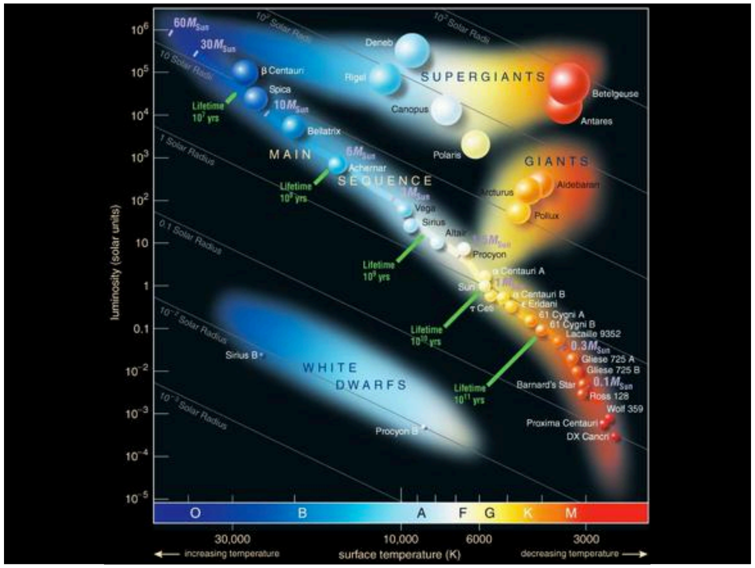
- a *G star* could be in one of *several stages*
- *extended classification* based on *details* of spectra



Class	Description
I	Supergiants
II	Bright giants
III	Giants
IV	Subgiants
V	Main sequence

- *white dwarves* denoted by "*wd*"

(eg) Sun is a ***G2V*** star; ***Betelgeuse*** is a ***M1I*** star



CLICKER: *In a random sample stars, you would expect most to belong to which group?*

(a) main sequence
(b) giants
(c) super giants
(d) white dwarfs

CLICKER: *The most common type of star is a…*

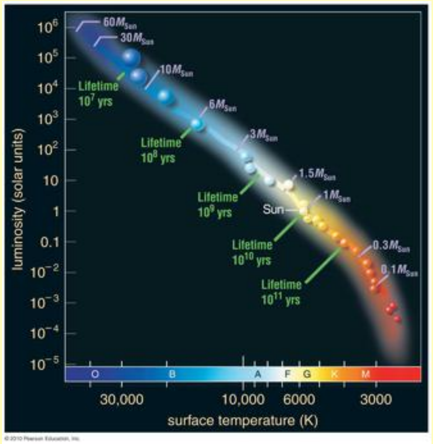
(a) red dwarf star
(b) yellow (Sun-like) star
(c) blue-white high mass star
(d) blue super-massive star

Lifetimes of Stars

- *larger* stars have *shorter* lifetimes

Q: *Why?*

- *hotter cores* so *"burn" H faster*

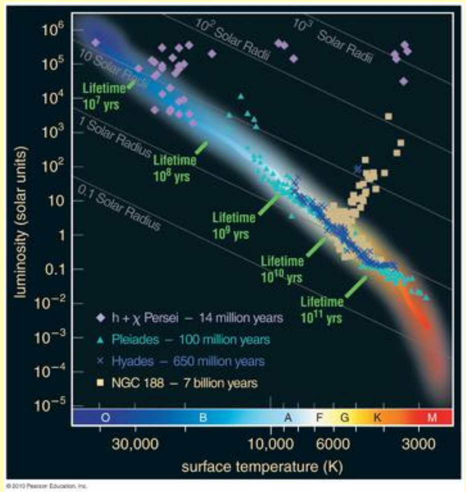


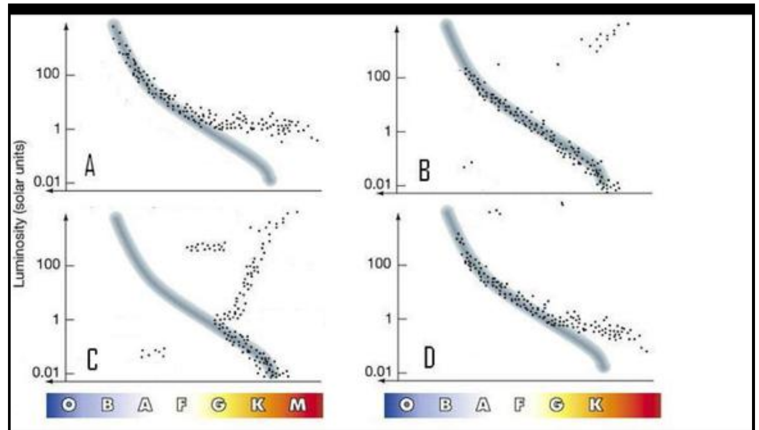
- lifetimes of single stars can be *determined theoretically* by location on the *H-R diagram*

• stars leave ***MS*** in ***decreasing size***, *large (hot) stars to small (cool) stars*

• "***turn off***" ***point***

• ***age*** of a ***cluster*** is determined by lifetime of *most recent stars* to *leave the MS*





CLICKER: *Which of the above is the OLDEST?*

CLICKER: *Which of the above is the YOUNGEST?*

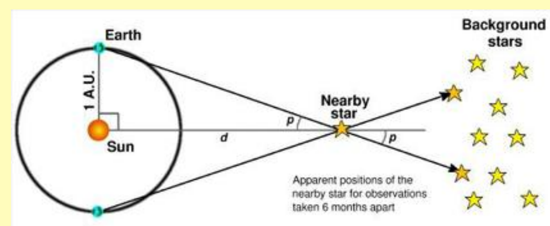
Distance Determination

• each method requires *different* ***info*** & applies over *different* ***distance ranges***

- ***stellar parallax***
- ***spectroscopic parallax***
- ***main sequence fitting***
- ***Cepheid variables***
- ***white dwarf supernovae***

Stellar Parallax

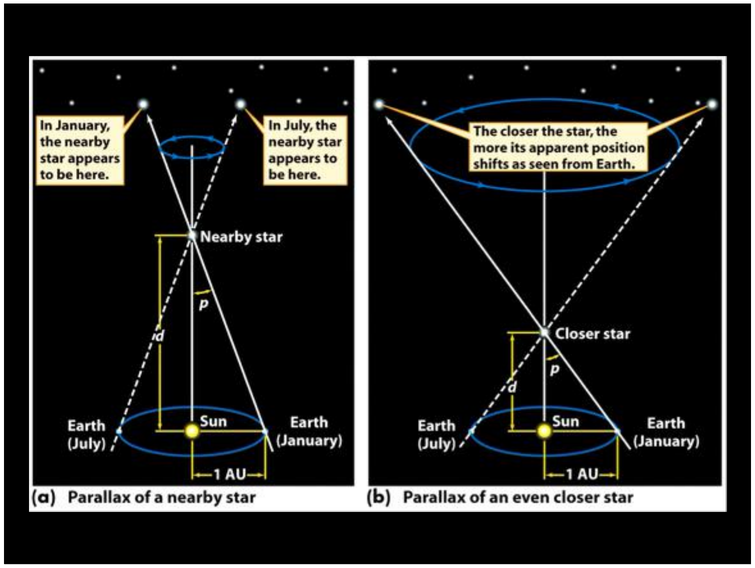
• *nearby stars* **appear** to *shift location* on sky when viewed from different locations



• ***size of apparent shift*** *indicates distance*

• *ancient Greeks* could ***not*** detect ***parallax***

• *human eye* can only **resolve** *angles > 1 arcmin*



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

- ***p***: ***parallax angle*** measured in ***arcseconds***
- ***d***: ***distance*** in ***parsecs***

- ***Hipparcos*** (1989), an ESA satellite, measured ***p*** for 100,000+ stars to ±0.001 *arcseconds*

(eg) *Proxima Centauri has the largest known parallax angle, 0.772″, so 1.3 pc (4.2 ly) away*

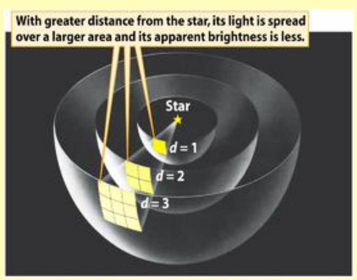
- ***parallax*** makes no assumptions ***BUT*** only useful to distances of *a few hundred parsecs (Why?)*

Spectroscopic Parallax

- ***inverse square law (ISL):*** *light spreads out* & is *less concentrated (dimmer)* at greater ***distance***

DEMO: *flashlight*

- find distance with **ISL** by comparing ***apparent brightness*** (***observed***) & ***luminosity*** (***spectra/HR***)



$$b = \frac{L}{4\pi d^2}$$

- ***b***: ***apparent brightness*** in ***W/m²***
- ***L***: ***luminosity*** in ***W***
- ***d***: ***distance*** in ***meters***

- can be useful even at *very large distances*
- *b* determined by ***photometry***
- ***L*** determined from ***spectra & H-R diagram***
- ***L*** *limits* accuracy of distances to ~ *±10%*

Q: *Why is there error in determining **L** from **HR**?*

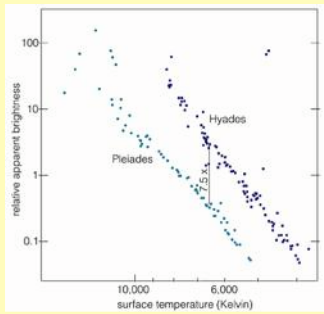
Main Sequence Fitting

• plot ***apparent magnitude*** *of main sequence stars* in a cluster & *compare* to brightness of a cluster of *known distance* ***(eg)*** *Hyades in Taurus @ 150 ly*

• *reduced uncertainty* compared to ***spectroscopic parallax*** from single stars

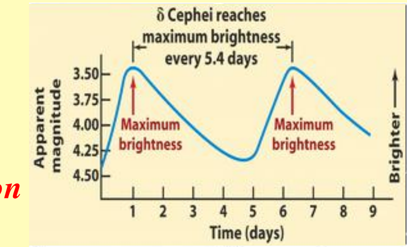
• $d \propto \sqrt{\text{ratio of brightness}}$

(eg) *Pleiades are 7.5 times dimmer, so ~2.8x further*



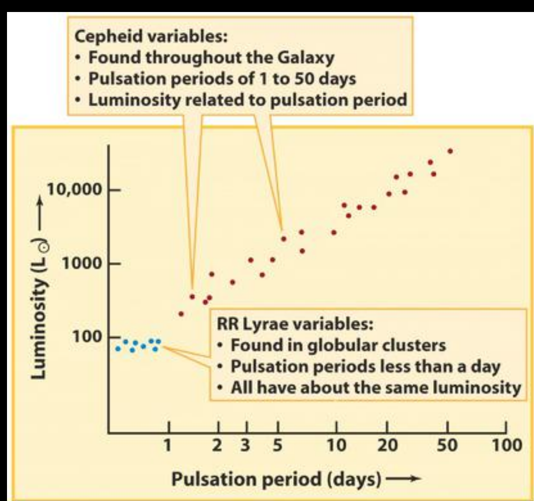
Cepheid Variables

• named for first such star found, *∂ Cephei*



• ***not*** *main-sequence*
• ***contraction/expansion*** of star's ***envelope***

• ***relationship*** between *pulsation period & L*
• *bright enough* to be visible up to 10^8 *ly*

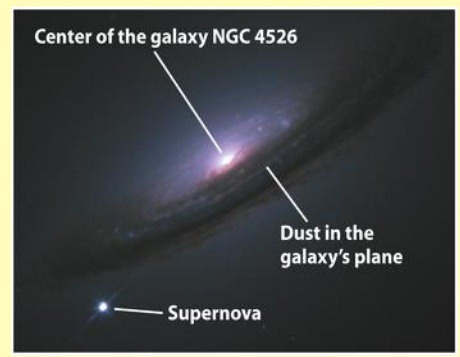


White Dwarf Supernovae

• aka ***Type Ia SN***

• adding mass to a ***white dwarf*** causes it to *detonate*

• up to 10^{10} L_{sun}
• *bright enough* to be seen @10^{10} *ly*



(eg) *Type Ia supernovae on the outskirts of a galaxy*