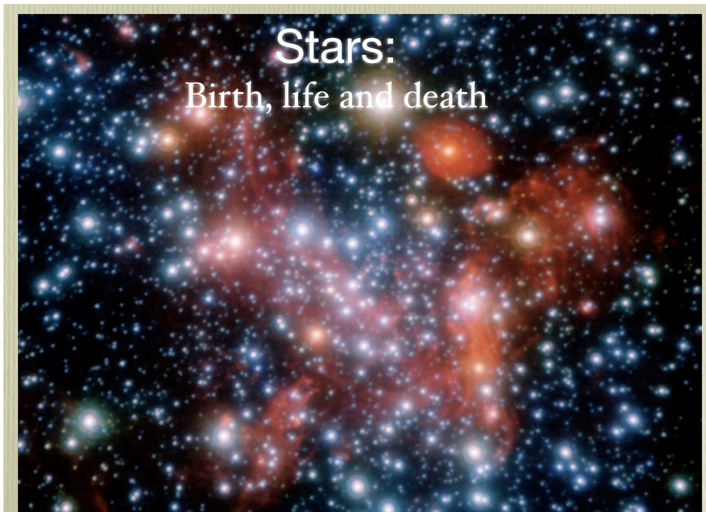


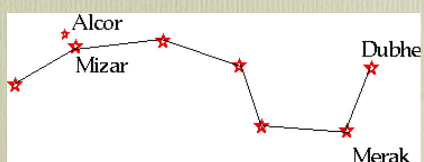
We have always divided the sky up into "patterns" or constellations

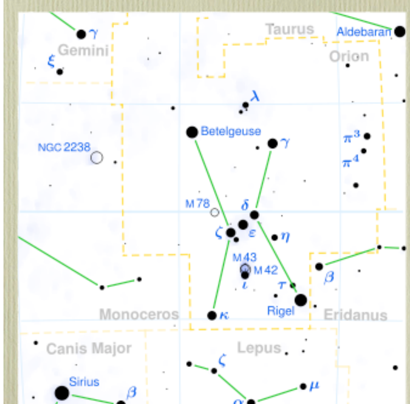
- But remember: The stars that make up Orion are random lights in the sky

They do not represent a mythic figure!

A long preamble...how do we name the stars?

- The brightest stars have names that derive from (usually) Arabic: e.g. Ursa Major

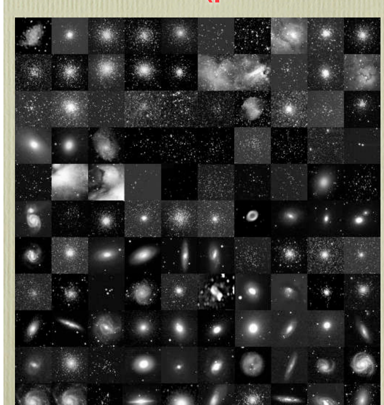




- Subsequently stars named with Greek letters, in order of brightness
- α-Orionis = Betelgeuse
- β-Orionis = Rigel
- (Unfortunately, Rigel is brighter than Betelgeuse, since it is much hotter & radiates mainly in UV!
- so system refers to visual brightness only.)

- Now we mostly use catalogs: the best known is

Messier (pr Messié)



- A catalog of objects that aren't comets
- M1 = Crab nebula
- M3 = Globular cluster
- M31 = Andromeda galaxy
- M45 = Pleiades cluster
- M51 = Spiral galaxy
- M57 = Ring nebula

Credit: P. Gitto

Now most objects are referred to by catalogue numbers:

e.g. BD + 59° 1915 is 1915[th] star classified in Bonner Durchmesterung

New General Catalog has ~ 10000 galaxies

so NGC 224 = M31

So what's the system?

- There is NO system for naming objects in the heavens
the same object can have several names!
e.g Sirius (Dog Star) is also

α Canis Majoris
α CMa
9 Canis Majoris
9 CMa
HD 48915,
HR 2491
BD −16Â°1591
GCTP 1577.00 A/B,
GJ 244 A/B
LHS 219
ADS 5423
LTT 2638
HIP 32349

Brightness/Magnitude

- Easiest observation about stars is that some are brighter than others.
- Hipparchus defined brightest to be of first magnitude, down to the dimmest of sixth magnitude.
- A first mag. star turns out to be 100 x brighter than a 5th mag.

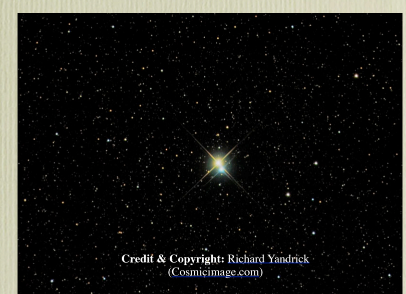
This seems backwards (it is!)

- a twentieth magnitude star is .00000000001 times as bright as a first magnitude star *(sigh!)*.
- Need to have negative magnitude stars which are brighter than positive magnitude stars *(double sigh!)*
- Finally we have close dim stars (like Sirius) which are much brighter than distant bright stars (like Rigel) *(triple sigh!)*
- We'll take brightness and distance as a given, and worry about absolute numbers only.

Binaries

- many stars are in multiple star systems: about 40% in pairs
- This is Albireo: orbital period of 75000 years

If a star is a binary, very easy to estimate mass



Stars: some numbers

- Mass: will refer to mass of sun as $M_\odot$
- so Earth has a mass of ~one millionth $M_\odot$
- Jupiter ~ $M_\odot$ /1000
- Smallest stars (brown dwarfs) ~ $M_\odot$ /100
- Largest "normal" stars ~ 20 $M_\odot$
- Maybe R136a1 ~ 300$M_\odot$, but any star this size loses material very fast

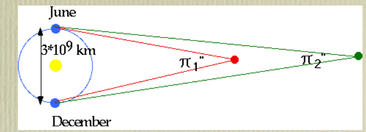
Mass governs how a star works

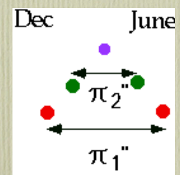
- If M ~ $M_\odot$, ⇒ star like the sun
- If M ~ $M_\odot$ /10 ⇒ red dwarf
- If M ~ $M_\odot$ /100 ⇒ Smallest stars (brown dwarfs)
- If M ~ 20 $M_\odot$ ⇒ Supergiant (like Rigel or Betelgeuse)

Stars: some numbers

- Radius: sun is ~ 1000000 km
- Time: One million years (1 Myr) is fairly short

- To find distance, can use "parallax"
- Position of star will vary over year





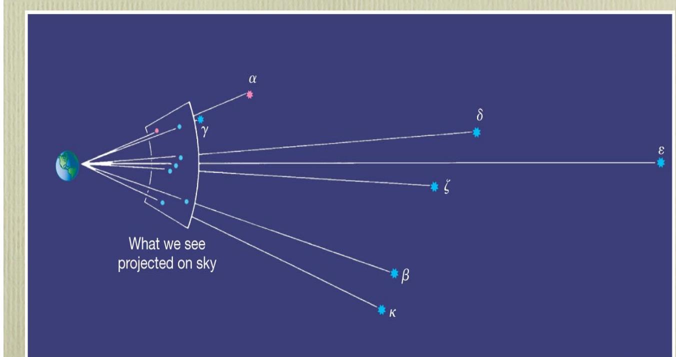
one second of arc (dime at 10 km)=> distance of one parsec

- Takes us out to 100 parsecs (400 light years)

Stars: some numbers

- Distance: light year is distance traveled by light in 1 yr
- Astronomers usually use the "parsec": 1 pc ~ 4 ly (thirty trillion km).
- Closest star (α Centauri) is at a distance of ~1.3 pc. Sirius is at about 5 pc.

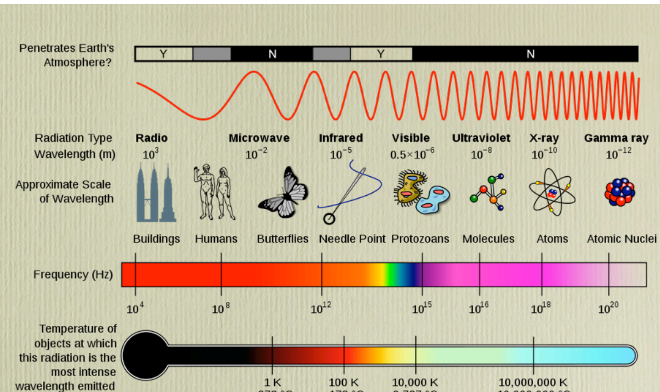
- Note that if we see a 3-D view of Orion, the picture changes totally!



Pearson publishing

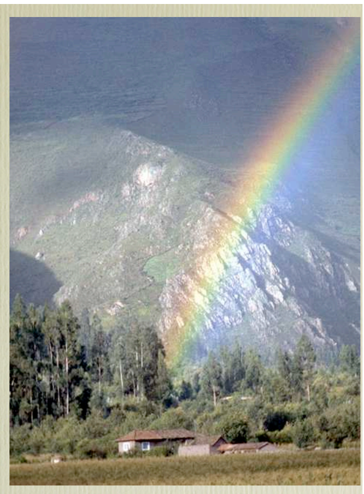
And the most important thing we learn is from barbecues

- What's hot and what's not: roughly
- red is 800°C
- orange is 1500°C
- yellow is 2000°C
- blue is 15000°C
- X-rays are 1 million °C

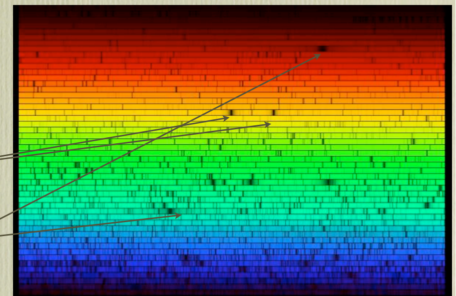


So we need to analyse the light from stars

- Start by splitting up the light



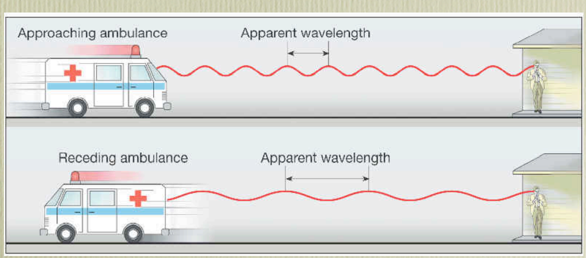
- We can look at the light from the sun
- Each line is corresponds to a particular element
  - e.g sodium
  - and hydrogen



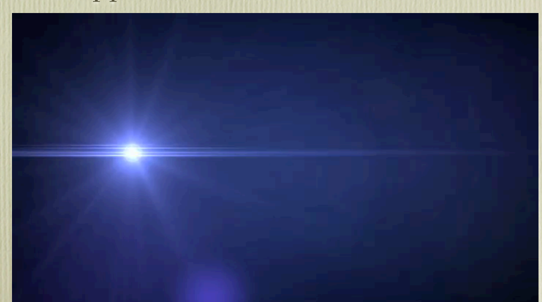
- So we can look at the hydrogen in the sun

Doppler shift

- Can measure how fast something is moving by looking at the light



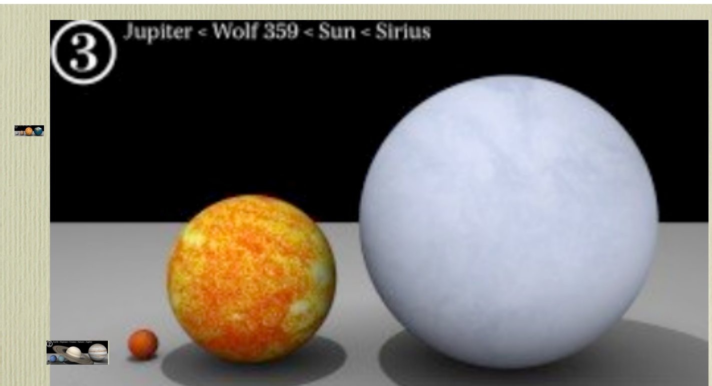
- Blue shift: something moving towards us (and appears hotter)
- Red shift: something moving away from us (and appears cooler)

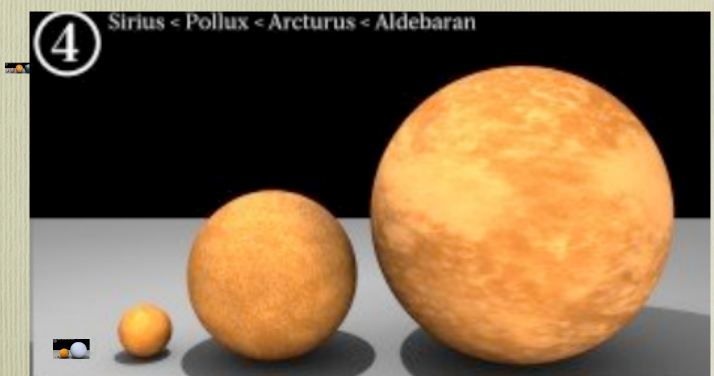


Combining all of these

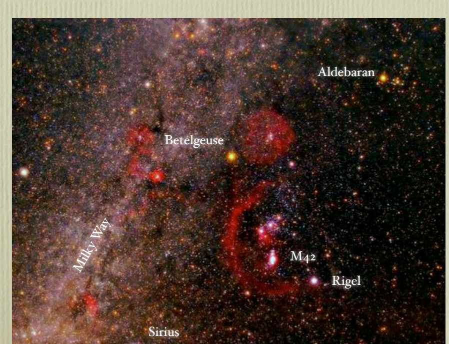
1. Temperature (easy)
2. Constituents (easy: eat your heart out, Augustus Comte)
3. Distance (out to 100 pc)
4. Luminosity (given 1. and 3.)
5. Radius (given 1. and 4.)
6. Mass (if it's a binary)
7. Speed relative to us

Star-Sizes





- We can see all this around Orion
- Sirius; fairly dim star that is very close
- Rigel: blue supergiant: would be 1000 times brighter than Sirius if it were at the same distance



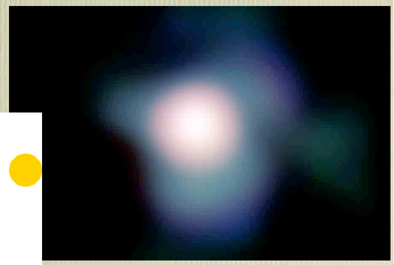
Note red glow is hot hydrogen gas

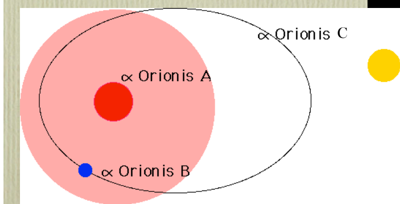
Betelgeuse: red supergiant:

10000 times larger than the sun

Orbits of Mercury, Venus, Earth and Mars would be inside it!

In fact it may be 3 stars!

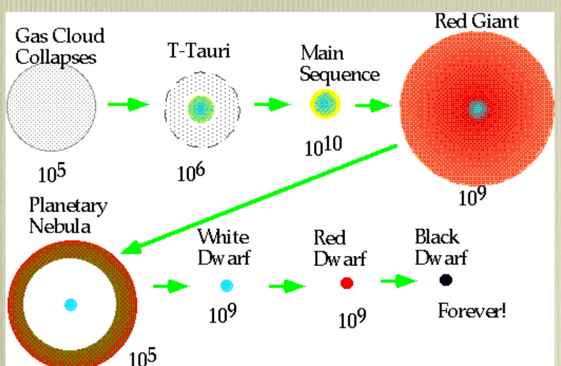




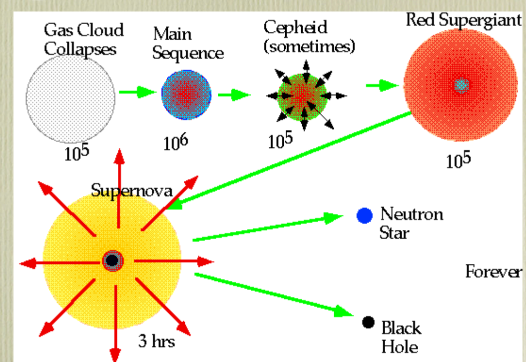
Stellar evolution once over lightly:

- Stars are born, mature and grow old.
- We call this stellar evolution, which is stupid, since we don't talk about the evolution of a baby into an adult.
- Also note: **ALL** stars go through **ALL** the stages.
- We don't (usually) see them change because a human lifetime is so short compared to stellar

Small stars (like the sun)
Times are approximate in years.



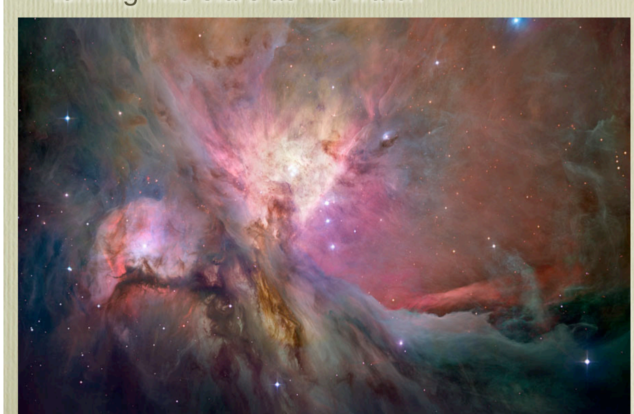
Big stars work much faster:



Live fast, Die Young!

Now we'll look at all of these stages in detail

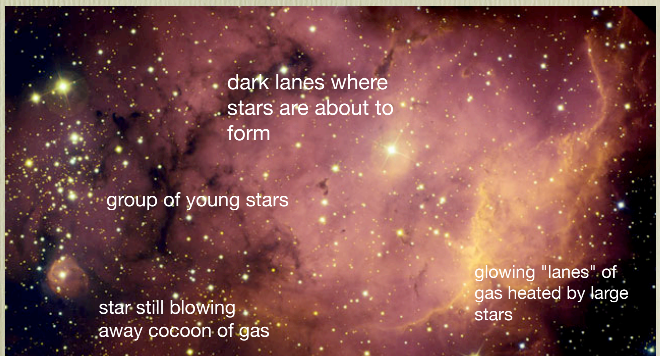
- M42 (Orion's sword) is a vast cloud of gas
- turning into stars as we watch



Star Nurseries

- Eagle Nebula (M16)
- Cluster of stars just formed in centre of dark shell of dust and gas

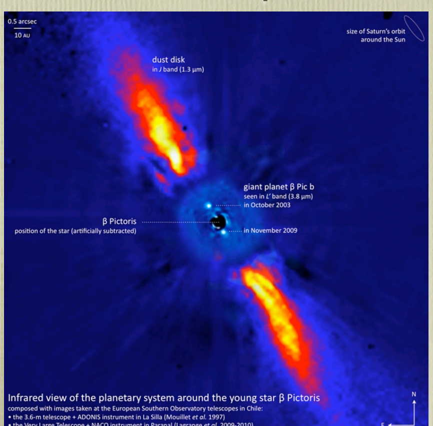
Star Birth: Stars are born from vast clouds of gas and dust



The Eagle's EGGs:

- Evaporating Gaseous Globules (EGGs).
- Very dense parts of the Eagle nebula form new stars which promptly blow away the surrounding dust and illuminate the columns

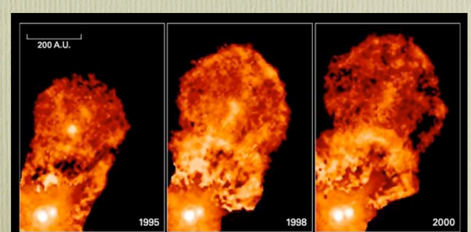
β-Pictoris



- A young star still surrounded by dust
- But it's had time to form at least one giant planet

Teenagers

- XZ Tauri consists of 2 very young unstable stars, separated by about Sun-Pluto distance, emitting vast cloud of gas
- (pictures taken over 5 years)



How do stars "work"?

This is the stellar structure problem

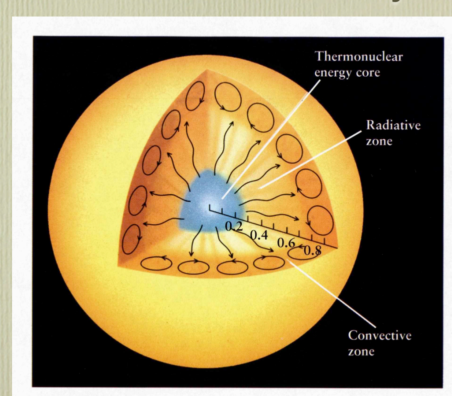
Hadyja HBV (BR) (Don El Chall Harley FHP) 16 March 2002 In foal to *Magic Dream CAHR - foal date 3/2/2011

Hadyja embodies the definitive traits of a Brazil mare - big, bold, grey mare and still enchantingly feminine with a proportional harmonious design and enrapturing charisma.

Her sire, Don El Chall, world renowned for their superior type, noble elegance, perfectly balanced three-dimensional proportion

and stellar structure.

But seriously



A rather small set of equations governs a star

$$\frac{dL}{dr} = 4\pi r^2 \rho(r)\varepsilon(r,T)$$

$$\frac{dm}{dr} = 4\pi r^2 \rho(r)$$

$$\frac{dT}{dr} = -\frac{3\kappa(r)\rho(r)L(r)}{64\pi\sigma r^2 T^3}$$

$$\varepsilon(r) = a\left(\frac{T}{T_0}\right)^4$$

$$P = \frac{k\rho T}{\mu m_H}$$

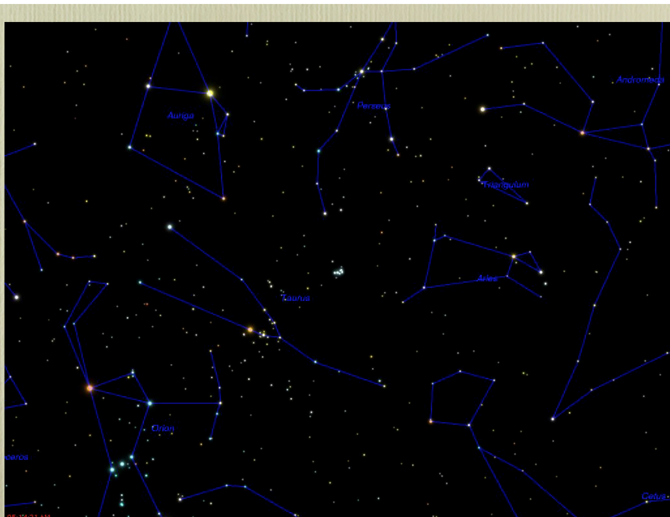
$$\kappa(r) = \frac{CZ(1+X)\rho(r)}{T^{7/2}}$$

$$\frac{dP}{dr} = -\frac{Gm(r)\rho(r)}{r^2}$$

Note that stars are much simpler than (e.g..) human beings: on the other hand we still need a computer to solve for one!

Executive summary

- To start burning, core of star need to get to 13 million °C
- Stars "burn" hydrogen for most of their life, producing helium
- To "burn" helium (to carbon) star need to be much hotter (100 million °C): small stars can't make it
- Large stars can burn carbon but process is very inefficient
- All stars run out of fuel eventually



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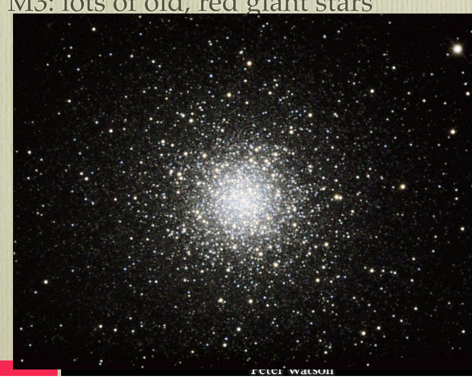
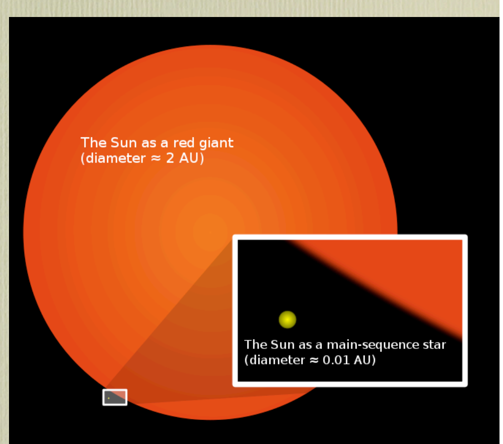
- Since all the stars in a cluster form at about the same time, we can see the evolution by looking at different clusters.
- This is M3: lots of old, red giant stars

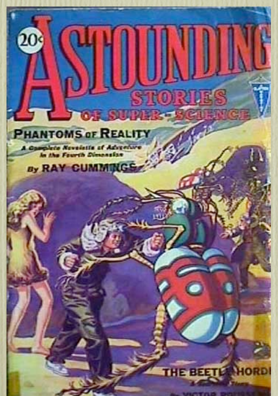


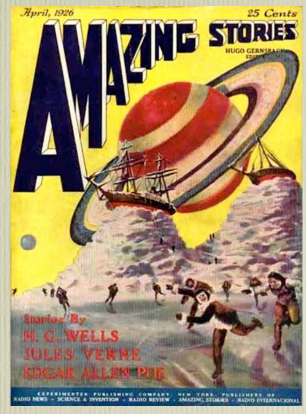
Adulthood is dull

- Don't we know it!
- Finally star will run low on fuel and expand
- Becomes red giant

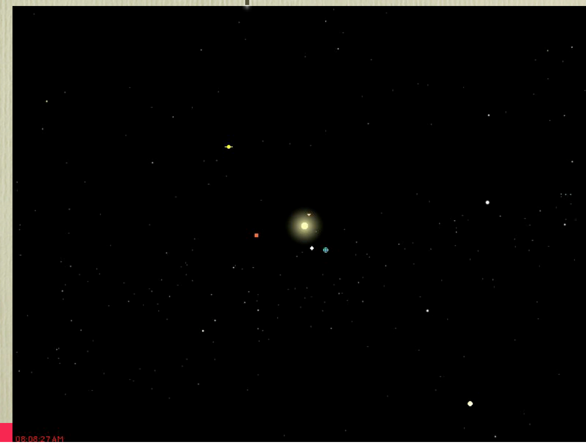


ET, phone home
Are we alone in the universe?



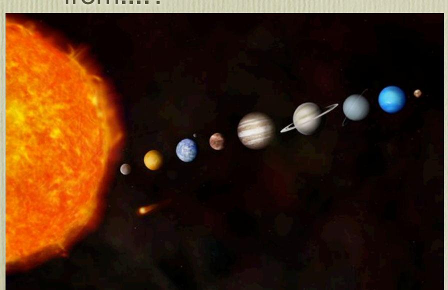


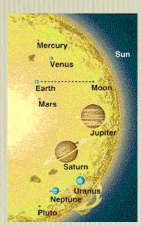
The solar system looks so simple



Cosmogony: Origins of the Solar System

- So where did the solar system come from....?



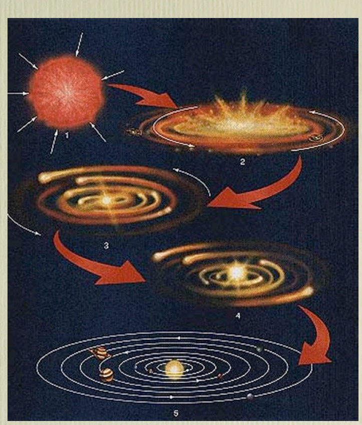


What we Thought we Knew (~1960)

- Age ~4.5 billion years
- All planets orbit in almost the same plane.
- Orbit shapes are nearly circular
- Most of mass the of solar system is in the sun.
- Inner planets are small and rocky (terrestrial)
- outer planets are large cold gas giants (jovian)
- moons are rocky and bare

Nebular Hypothesis.

- A rotating gas cloud, probably compressed by a nearby supernova shock wave, starts to collapse.
- The central part collapses to the sun.

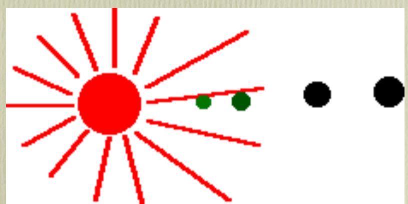


http://scienceclass.ning.com/

- The outer planets condense first.
- Gas and dust particles out of the plane collide more often and get forced into plane

- The orbits are circularized by collisions and tidal effects.

- Solar winds removes hydrogen and helium from the inner planets.
- Terrestrial planets form from the left over refractory materials.

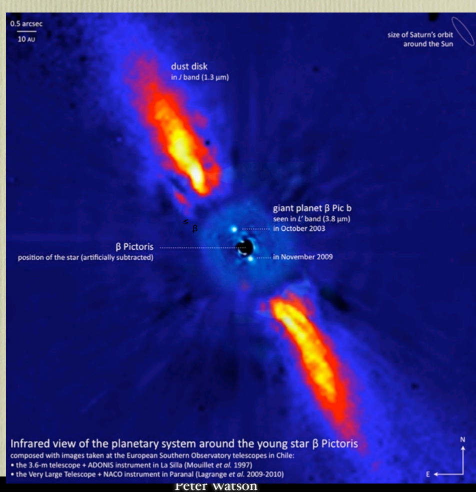


Exoplanets: other solar systems

- first found around 51 Pegasi in 1995: 5 times as big as Jupiter

If we are lucky, we can see them directly

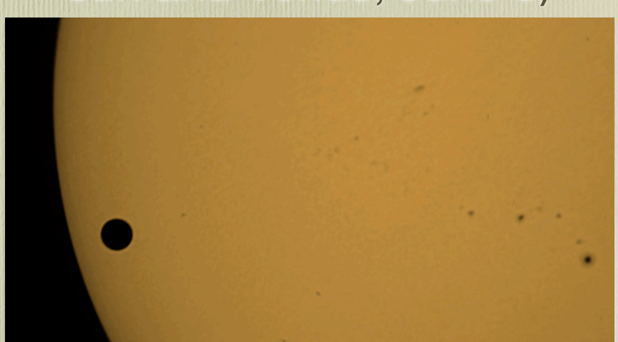
- e.g β-Pictoris
- Young star
- dust clouds
- giant planet



Now we are seeing lots of other solar systems

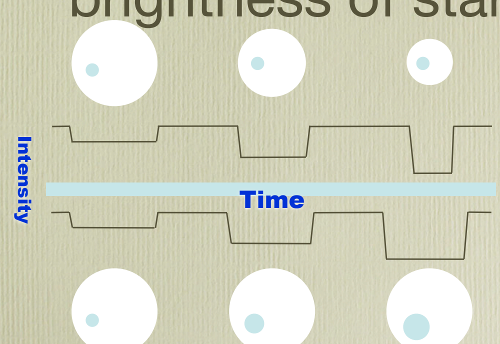
- Many methods & collaborations
- Most look for tiny fluctuations in stellar brightness due to “eclipses”
- Amateurs (AXA)
- Ground-based telescopes
- CoRoT & Kepler space telescopes

Like this! (except this is our sun and Venus, June 5)



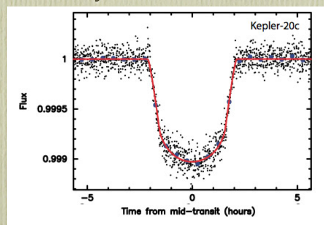
Picture by Etienne Rollin

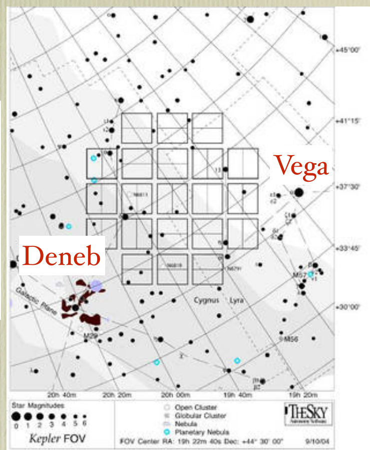
Regular tiny dips in brightness of star



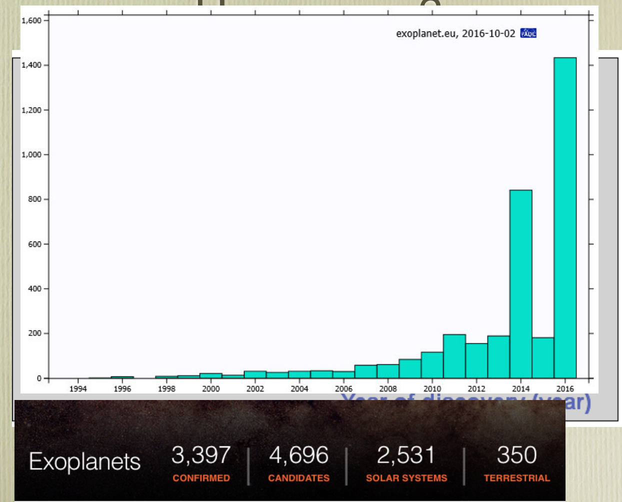
Kepler

- observes 150000 stars every 30 mins.

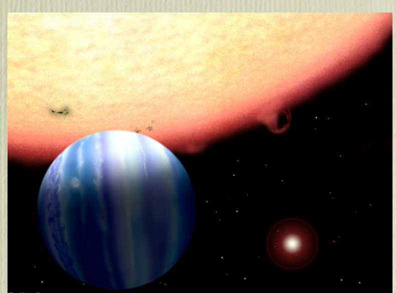




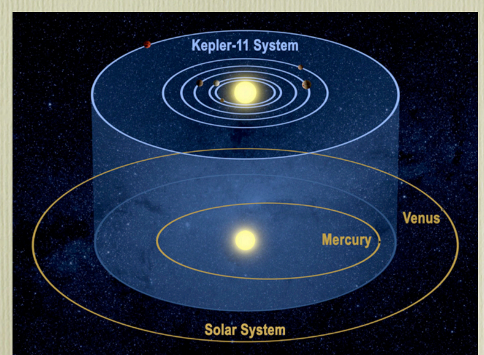
- Note 0.1 % change
- 4 hours
- symmetrical shape

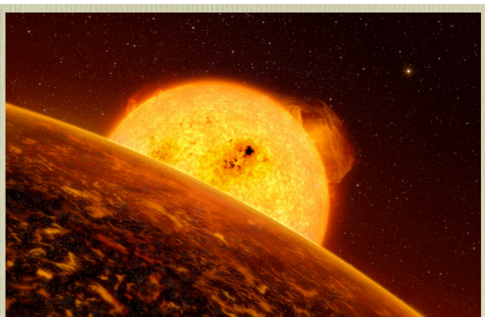


- Orbit has to be aligned with earth
- Need to see several transits
- Does best with large planets, close to star
- "hot jupiters"



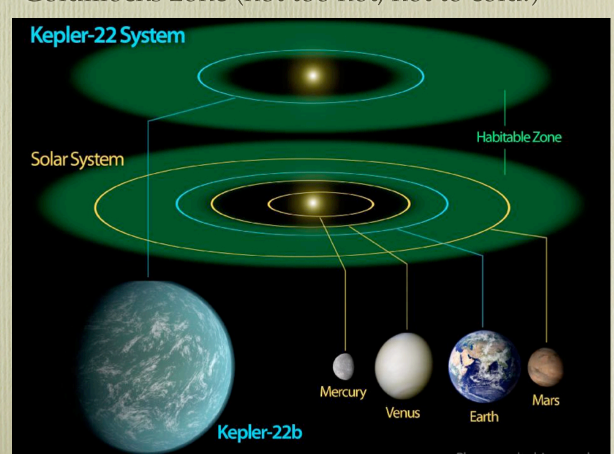
Kepler 11 has at least 6 planets





- CoRoT-7b
- mass ~ five Earth, radius~ 1.7 Earth
- year lasts ~20 hours
- FAR too hot (1500°)

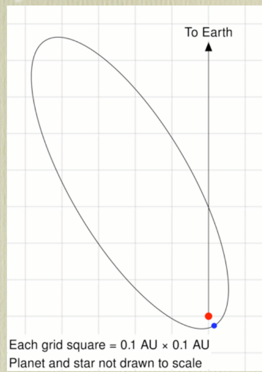
- Kepler 22b: first earth-sized planet in Goldlilocks zone (not too hot, not to cold!)



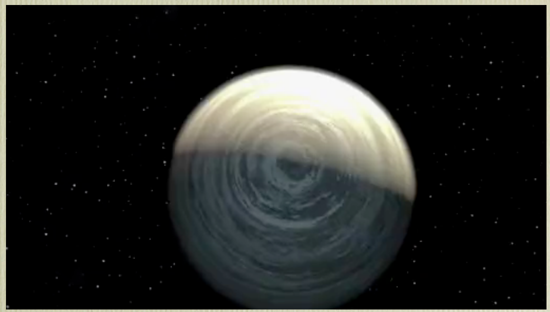
So planetary systems are common: do they look like ours?

Not really

- Lot of stars have hot Jupiters
- Some don’t know they should be in circular orbits!
- HD80606b goes from 500°C to 1200°C in 6 hours
- Lots go backwards

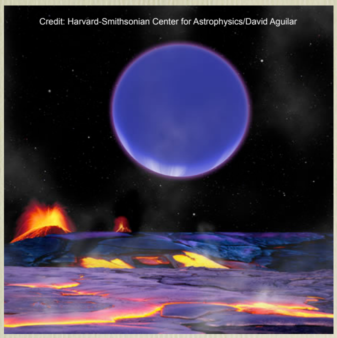


- Planets in orbit round binary (double-star) systems: Kepler 16b



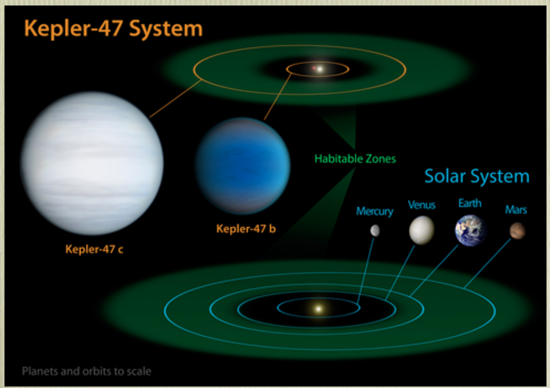
Kepler 36

- ~Earth sized planet + ~Neptune sized planet
- Every 97 days approach to ~1.5 million km



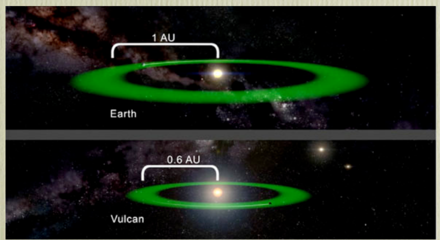
Kepler-47

- First Binary Star 2-Planet System



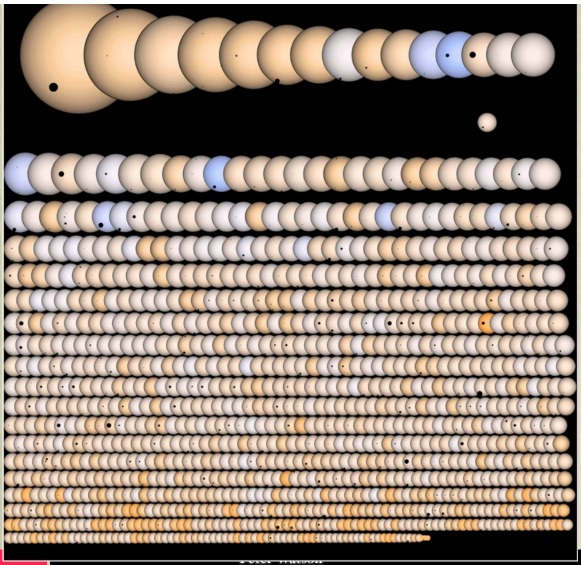
On the other hand ...

- Maybe we need a planet called Vulcan.
- Star Trek puts it round the star 40-Eridani: quite sensible
- Green ring is “habitable zone”

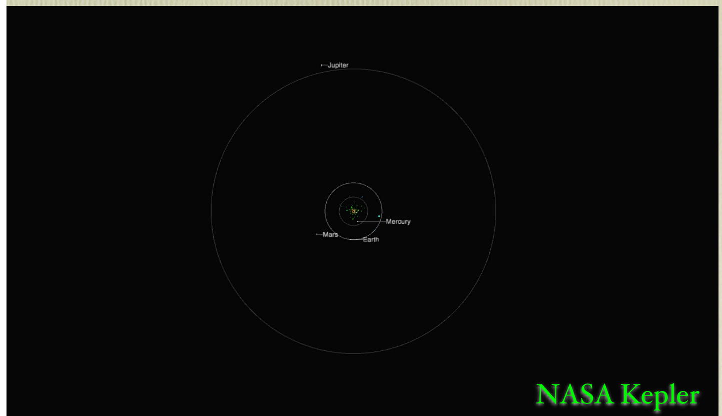


Kepler has found lots!

nearly 2300 confirmed and candidates



- This shows the all the confirmed ones to date



Conclusions

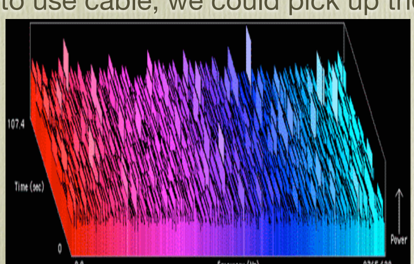
- Based on a very small # of stars and short observing time, it seems likely ALL stars have planets
- We haven't had time to observe orbits of longer than a year or so
- Maybe more than 100 billion planets in the Milky Way

So what does this do for alien life?

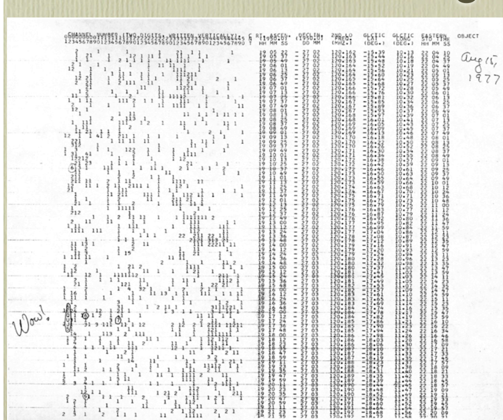
- **Where are they?**
- Enrico Fermi
- Systematized by the Drake equation
- BBC Future allows you to play with it

Search for Extraterrestrial Intelligence

- Vast amounts of data from Arecibo are never analysed
- If aliens are smart enough to communicate over large distances
- Too dumb to use cable, we could pick up their signals



The Wow signal



- 1977 from Big Ear observatory (Ohio)
- Very big signal, never repeated
- Before GUI's!

Where are they? Enrico Fermi

The Drake Equation

- How many advanced civilizations are there in our galaxy (50 billion stars)?
- R^* = (# of new stars born each year) = 10
- f = (fraction of stars with planets) = 100%
- N_e=(# of habitable planets/system) = 0.5
- f_{life} = (probability that life evolves) =100%
- f_{in} = (prob. that life develops intelligence) =5%

- f_c = (prob. that intelligent life can communicate across space) =5%
- L = (lifetime of intelligent civilization) =3500 yrs
- n = (# of times a civilization could re-develop) =1
- Total number of civilizations in our galaxy at the moment?
- 42!!!!!!!!!!!!
- Well, you decide which number I got wrong!

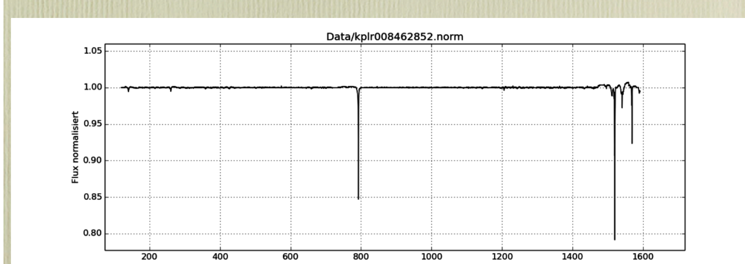
- There may be many planets that don't orbit stars
- A real αστήρ πλανήτης *(astēr planētēs)*, meaning "wandering star"
- Except we have defined planets to be in orbit round stars!


Free Floating Planet - [NASA/JPL-Caltech/R. Hurt]

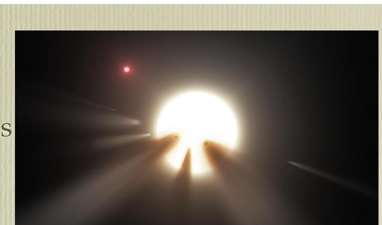
And then there's KIC 8462852

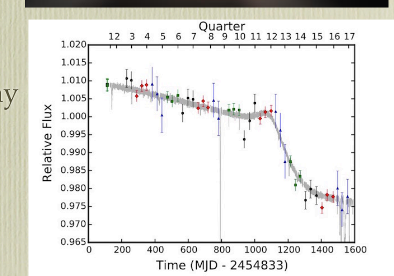
- aka as the WTF star (Where's The Flux)
- or Tabby's star

- Appears to be a perfectly normal star except that
- Sometimes it loses 22% of its output

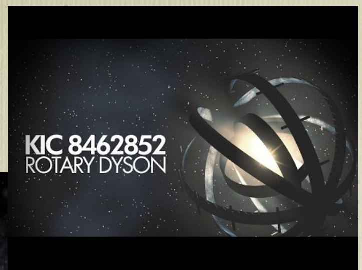


- A Jupiter-sized planet would cause a 1% drop in light on a regular basis
- Comets?
- But it's also been dimming slowly anyway





Or alien megastructure..



- If you want to play games with the data, try http://exoplanets.org/plot/
- http://exoplanet.eu/index.php
- Acknowledgements:
- Pictures by Steve Gilbert, NASA, ESA
- Tabby's star: https://www.ted.com/talks/tabetha_boyajian_the_most_mysterious_star

So what happens after?

- pulsars
- black holes
- gamma-ray bursters
- SS433
- Things that go beep and bang!