Astronomy 122

<u>This Class (Lecture 15):</u>

Stellar Evolution:
The Main Sequence

Midterm on Thursday!

Last week for Nightlabs

<u>Next Class:</u>

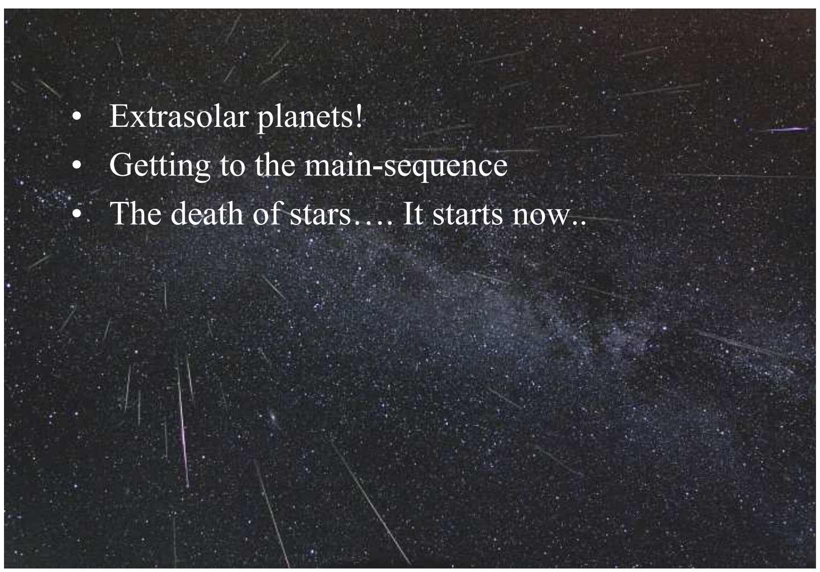
Stellar Evolution:
Post-Main Sequence

Music: *For Science* – They Might Be Giants

Midterm

- 1 hour exam in this classroom
- Will cover material up to and including star formation
- Approximately 25 multiple choice and 6 short answer.
- Exam will have 105 points graded out of 100 (i.e. extra credit)
- You may bring normal-sized sheet with notes on each side.

Outline



What Are We Looking For?

General Predictions of our Star Formation Theory

- ☺ Are interstellar dust clouds common? ***Yes!***
- ☺ Do young stars have disks? ***Yes!***
- ? Are the smaller planets near the star?
- ? Are massive planets farther away?

Test of Exoplanets

Planets around other stars

= extrasolar planets = ***"exoplanets"***

Would our solar system nebula formation theory account for other solar systems around other stars?

Finding Planets

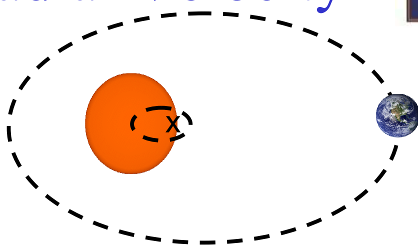
1. Radial Velocity: Stars will wobble.
2. Astrometry: See the stars move.
3. Transit Method: Occultation.
4. Optical Detection: Direct.

Arguable 2 extrasolar planets have been detected directly in the IR. Remember that planets in our Solar System seem bright because they reflect light from the Sun in the visible.

Star Wobble: Radial Velocity

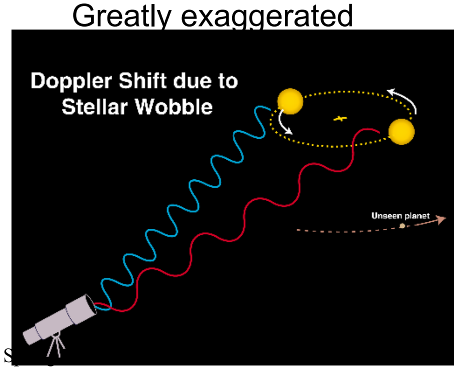
Newton's 3rd Law:

- *Both* planet *and star* move
- Both orbits fixed around the "center of gravity"



- Star's period? Place your bets…
  - Same as planet

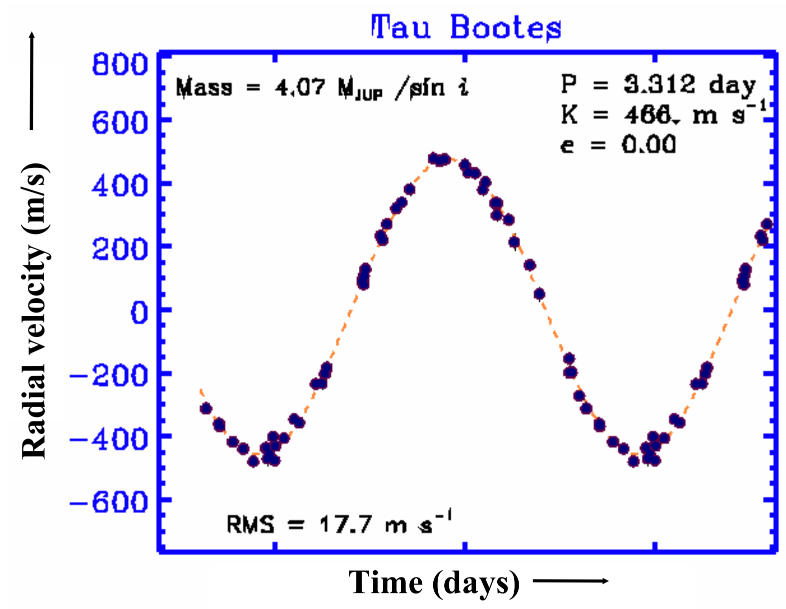
Greatly exaggerated



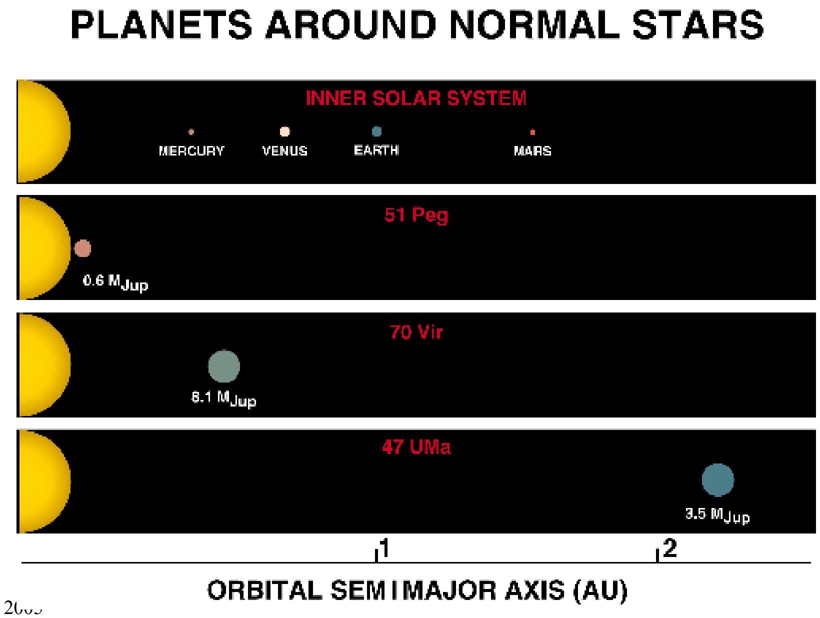
- Star movement too small to see
  - Moves in small, tight circle
  - But "wobble" in star speed detected!

http://www.howstuffworks.com/planet-hunting2.htm

Radial Velocity Shifts: Planets around other Stars?

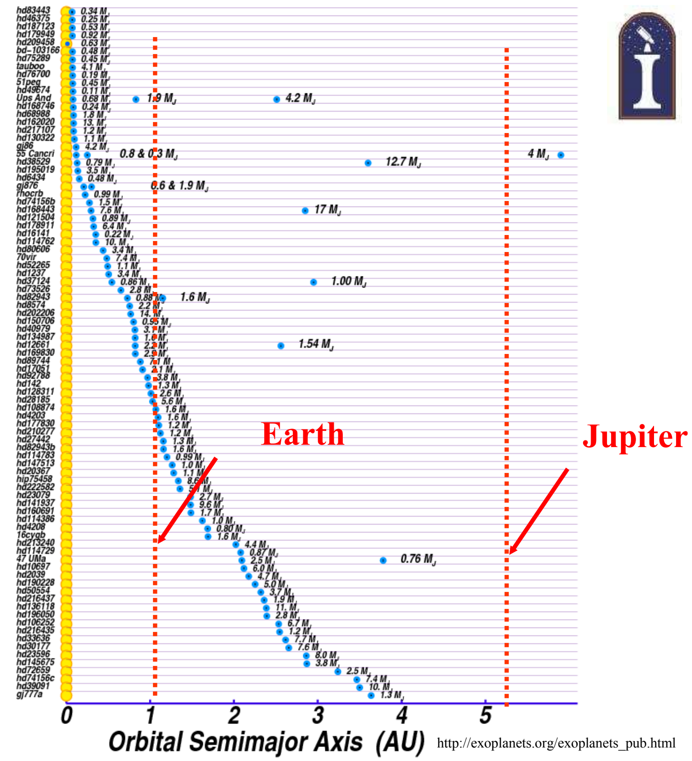


Early Discovery-- 1996



Hear all about it.

As of Jan, there are at least 155 planets around nearby stars.

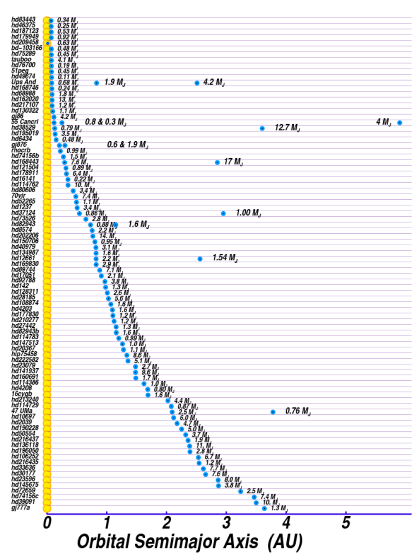


http://exoplanets.org/exoplanets_pub.html

Exoplanets: Results to Date

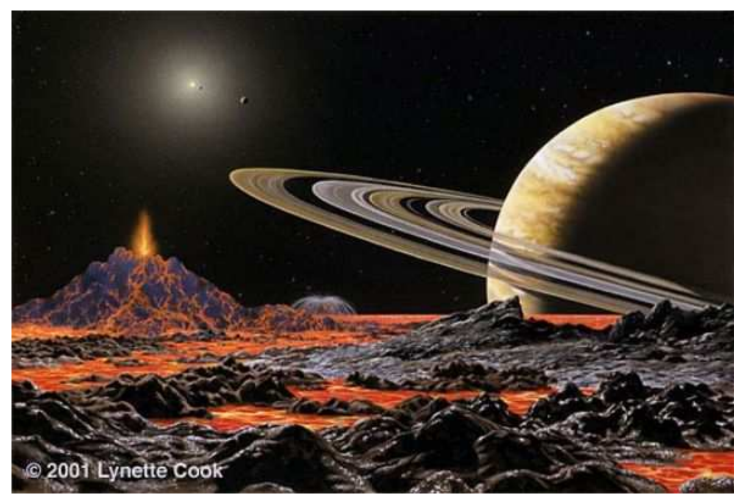
Over 155 planets detected so far
- More than 15 times the number in our Solar System!

- By measuring the wobble variation:
  - With time, gives the planet distance: Kepler's 3rd law
  - The orbital speed of the star gives masses: the bigger the wobble amplitude, the heavier the planet
- At least 13 are multi-planet systems



Other Planets, Other Stars

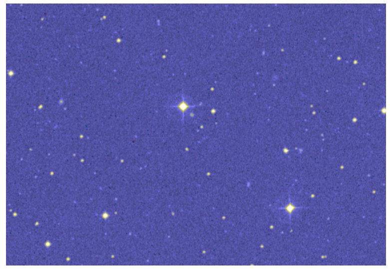
47 Ursae Majoris System– 51 light years away (near the Big Dipper). 13 years of data has shown 2 planets– 1 Jupiter like and 1 Saturn like.

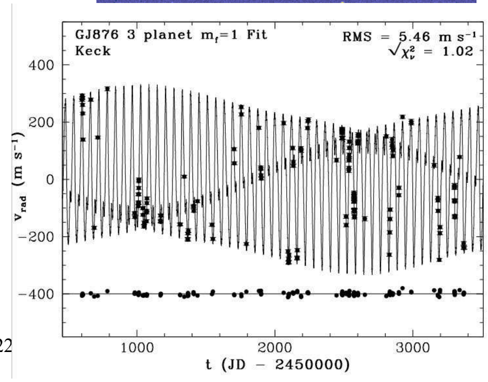


Wow! Among the most similar to our own system

The Lowest Mass to Date

GJ 876 – a Red Dwarf that is 15 light years away (in Aquarius). Has three planets! 2 Jupiter-like and one that is 6-8 Earth masses! But all are inside 1 AU!





The Lowest Mass to Date

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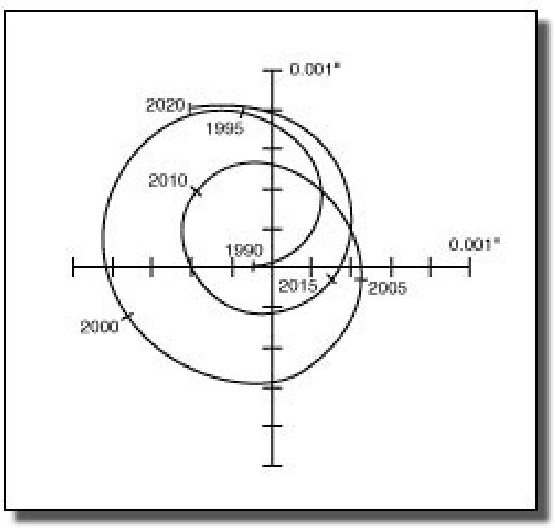
The Sun's Wobble

Astrometric displacement of the Sun due to Jupiter (and other planets) as at it would be observed from 10 parsecs, or about 33 light-years.

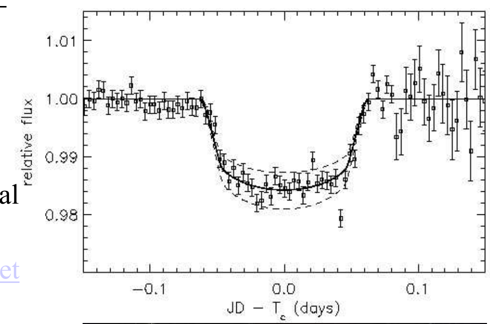
If we could observe this, we could derive the planetary systems– also called astrometry.

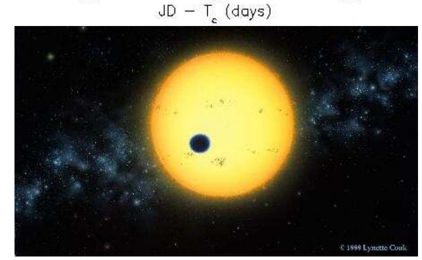


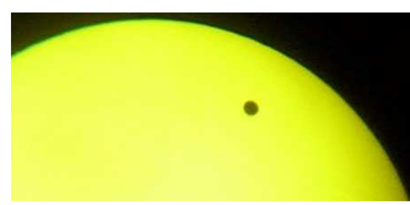
http://planetquest.jpl.nasa.gov/Keck/astro_tech.html

Transits

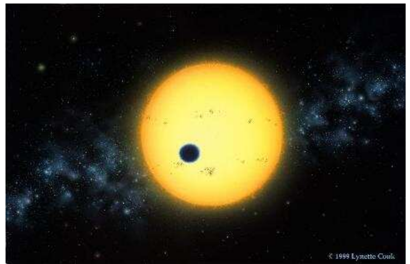
- The planet passes in front of the star– like Venus in 2004.
- Can find planet radius
- Best chance of finding Earth-like planets
- Requires the extrasolar planet's orbital plane to be pointed at Earth
- http://www.howstuffworks.com/planet-hunting2.htm

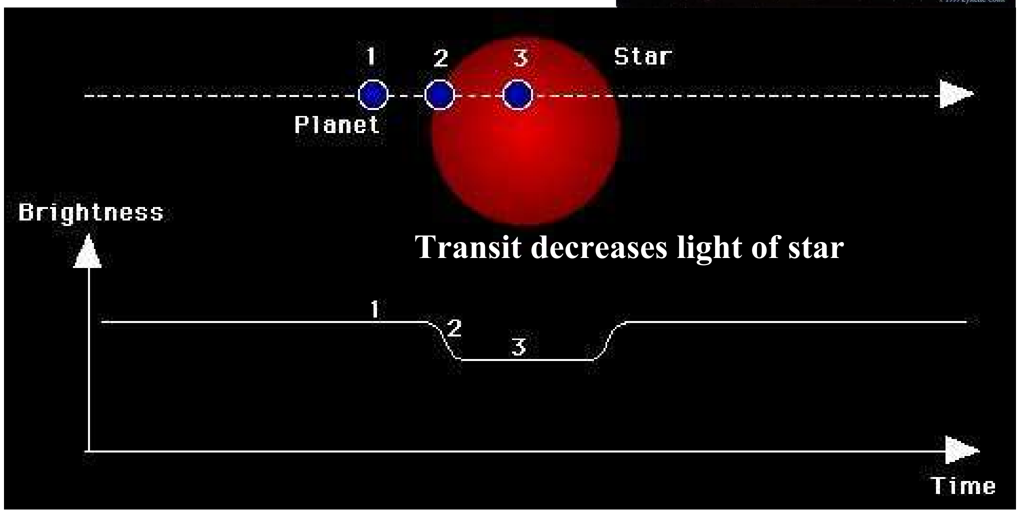






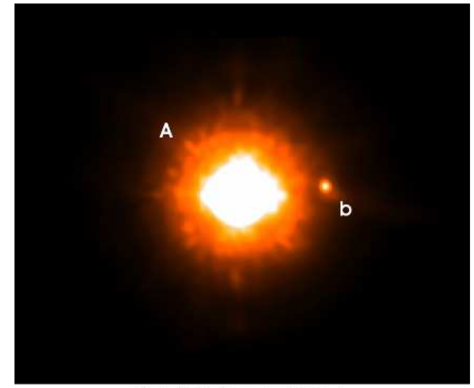
Planet Transits





Direct Detection?

- The race is on to directly image a planet in the IR, it is still difficult to determine the stellar mass.
- Best example so far is an adaptive optic image from April, so planet or brown dwarf?

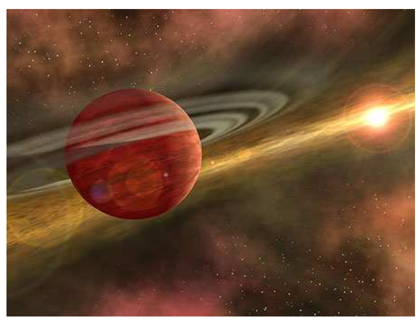


The Sub-Stellar Companion to GQ Lupi (NACO/VLT)

Results to Date

No surprise

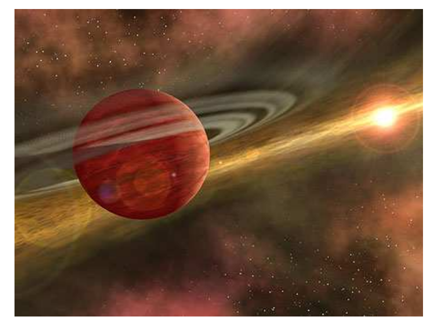
- ✓ New planets are massive
- ✓ Why? Big planets make a big wobble
- ✓ If not massive, we could not have found them
- ✓ About 3-5% of all stars have some type of planet.



Results to Date

Big surprises

- ? Some periods of only *a few days!*
- ? Most planets are very near their stars!
- ? τ Bootes' planet is 3.6 times Jupiter's mass, but it's orbit smaller than Mercury's!
- ? If a Jupiter-like planet formed close in, perhaps that prevents terrestrial planets from forming.



What Are We Looking For?

General Predictions of Solar Nebula Theory

☺ Are interstellar dust clouds common? ***Yes!***

☺ Do young stars have disks? ***Yes!***

? Are the smaller planets near the star?

Not the ones found so far! Haven't found smaller planets yet!

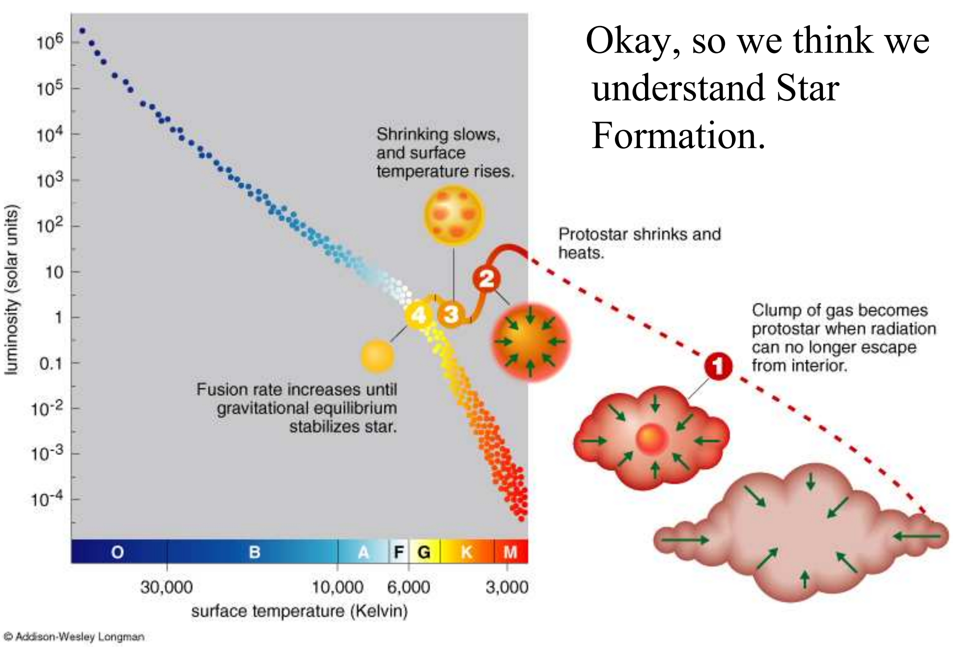
? Are massive planets farther away?

Not most of the ones found so far!

Important Caveat

- Our current observations of extrasolar planets do **not** exclude planetary systems like our solar system
- Current instruments are most sensitive to large planets close to their stars
  - Big planet - big wobble
  - Close planet - fast wobble
- We only have a little over 10 years of data - 1 orbit's worth for Jupiter
- To find solar-type systems, we need more sensitive equipment

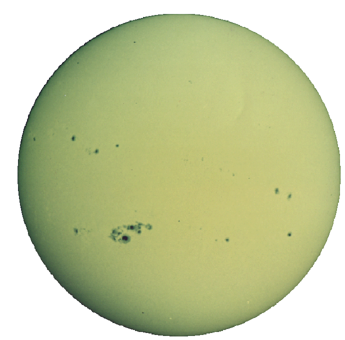
Back to Stars



Okay, so we think we understand Star Formation.

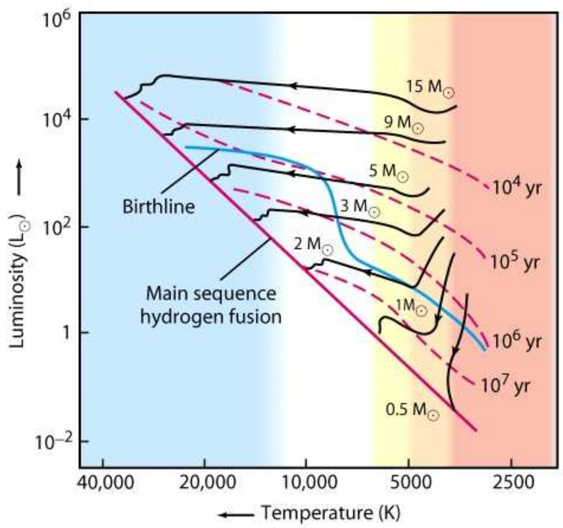
Becoming a Star

- When the temperature in the pre-main-sequence star's core reaches about 10 million K, hydrogen fusion starts
- Gravitational collapse stops, pressure from fusion in the core halts contraction
- Now a main sequence star!



More Mass = Rapid Aging

- More massive cores "age" faster
- Very massive protostars begin fusion before mass accretion stops!

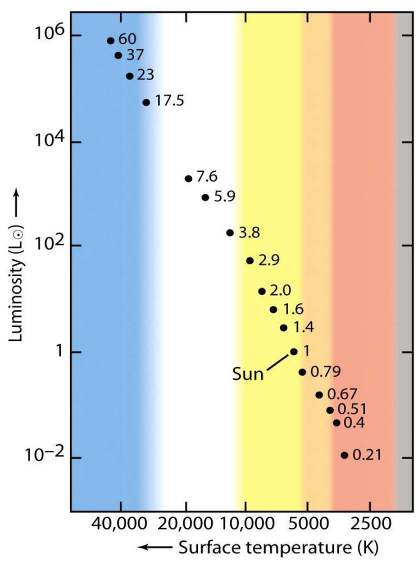


Important Questions

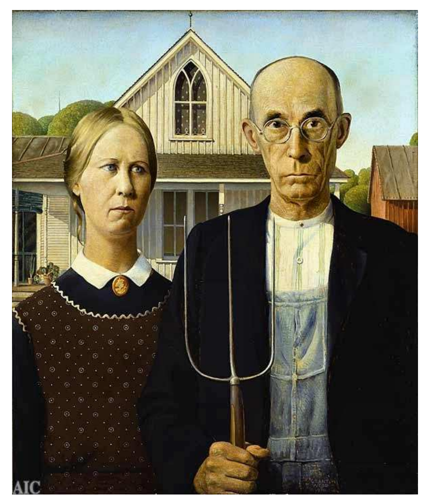
- A star remains stable and on the main sequence as long as it has hydrogen to fuse in the core…
- **How long will the fuel last?**
- **What happens when the fuel runs out?**

Main Sequence Lifetimes

- The mass-luminosity relation has a big effect on the lifespans of stars
  - Mass ⇒ amount of fuel available
  - Luminosity ⇒ rate at which fuel is being consumed
- Lifetime = t $\propto$ M/L $\propto M/M^{3.5} = 1/M^{2.5}$
- **High-mass stars have**



Stellar Lifestyles



Low-mass stars

Massive stars

Life Fast, Die Young

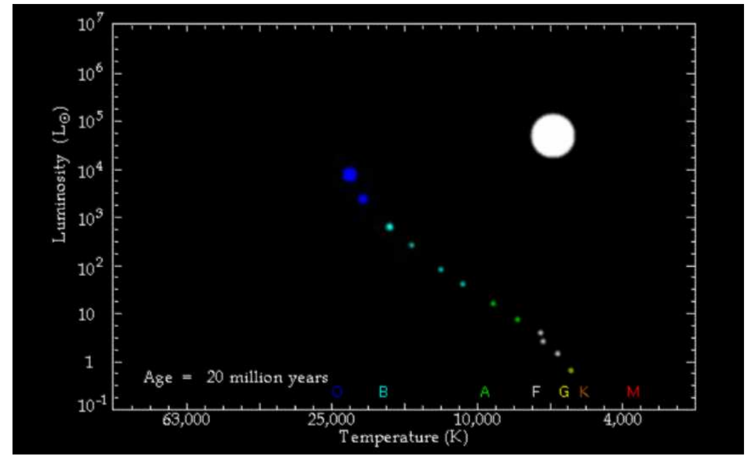
- High-mass stars: "gas guzzlers"
  - Very bright
  - Live short lives, millions of years
- Low-mass stars: "fuel efficient"
  - Dim
  - Long-lived, tens to hundreds of billions of years

table 21-1 Approximate Main-Sequence Lifetimes

Mass ($M_\odot$)	Surface temperature (K)	Spectral class	Luminosity ($L_\odot$)	Main-sequence lifetime (10^6 years)
25	35,000	O	80,000	4
15	30,000	B	10,000	15
3	11,000	A	60	800
1.5	7000	F	5	4500
1.0	6000	G	1	12,000
0.75	5000	K	0.5	25,000
0.50	4000	M	0.03	700,000

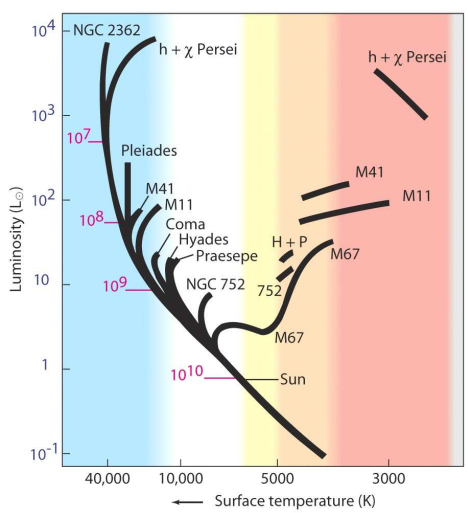
The main-sequence lifetimes were estimated using the relationship $t \propto 1/M^{2.5}$ (see Box 21-2).

Main Sequence Lifetimes

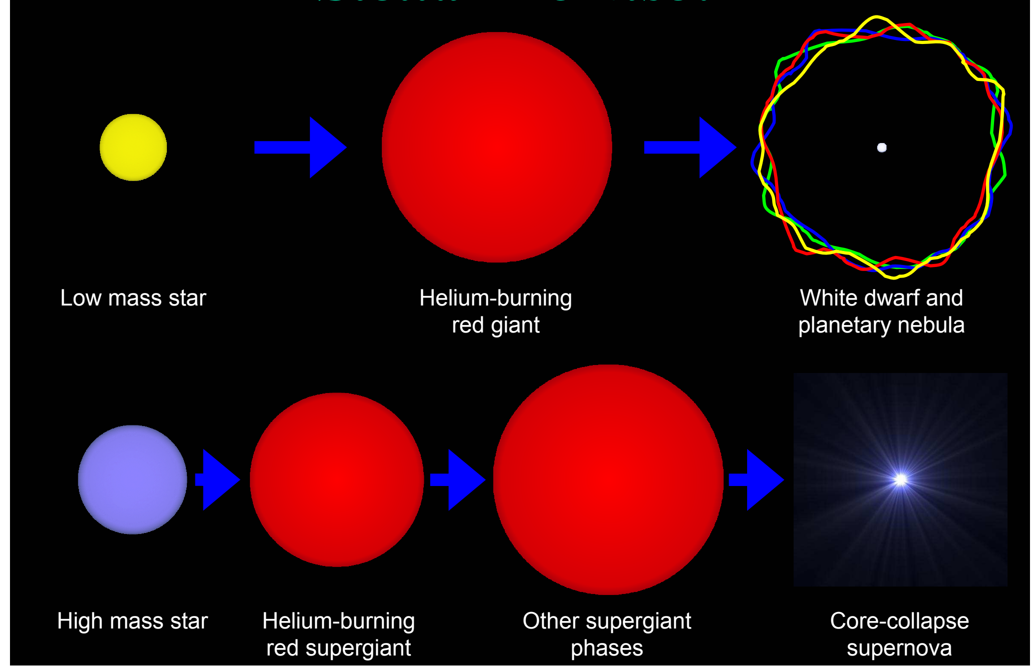


Guess The Cluster's Age!

- We can estimate the age of a cluster from its main sequence stars
  - Massive stars age faster than low mass stars
  - The cluster can't be any older than its most massive stars' main sequence lifetimes
  - We call the point where a cluster's main sequence ends the *main sequence turnoff*



Stellar Demise!

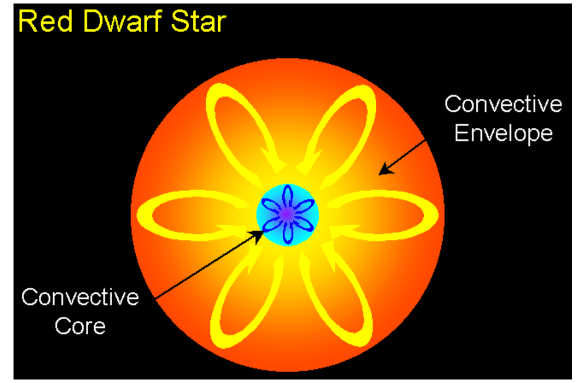


The Evolution of Stars

- A star's evolution depends on its mass
- We will look at the evolution of three general types of stars
  - Red dwarf stars (less than 0.4 M_{Sun})
  - Low mass stars (0.4-8 M_{Sun})
  - High mass stars (more than 8 M_{Sun})
- We can track the evolution of a star on the H-R diagram
  - From main sequence to giant/supergiant and to its final demise

Red Dwarf Stars

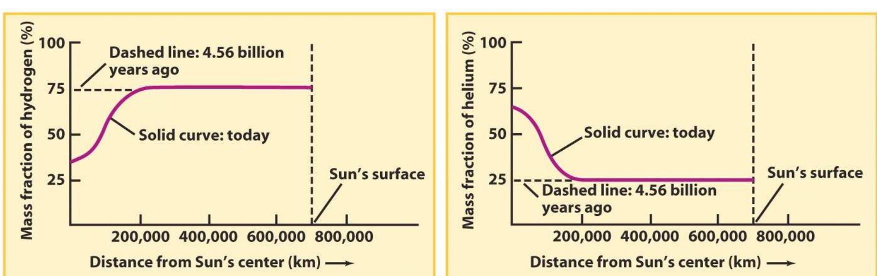
- 0.08 M_{Sun} < Mass < 0.4 M_{sun}
- Fully convective interior
- The star turns all of its hydrogen to helium, then all fusion will stop
- Live hundreds of billions to trillions of years
- The Universe is only about 14 billion years old, so none of these stars have yet made it to the end of their life



http://www-astronomy.mps.ohio-state.edu/~pogge/Ast162/Unit2/RedDwarf.gif

Low-Mass Stars (Sun-like)

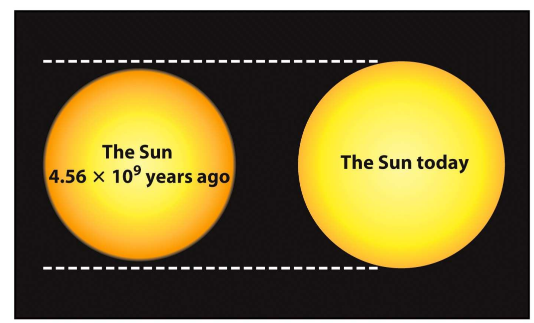
- On the main sequence for ~10 billion years.
- The core is where fusion occurs- H $\Rightarrow$ He
- Eventually, runs out of hydrogen.



(a) Hydrogen in the Sun's interior **(b) Helium in the Sun's interior**

Life of a Low Mass (Solar) Star

- Most of its life is spent in the happy pursuit of burning H $\Rightarrow$ He
- With time, L and T evolve gradually in response
- The Sun is now 40% brighter and 6% bigger than zero age MS.



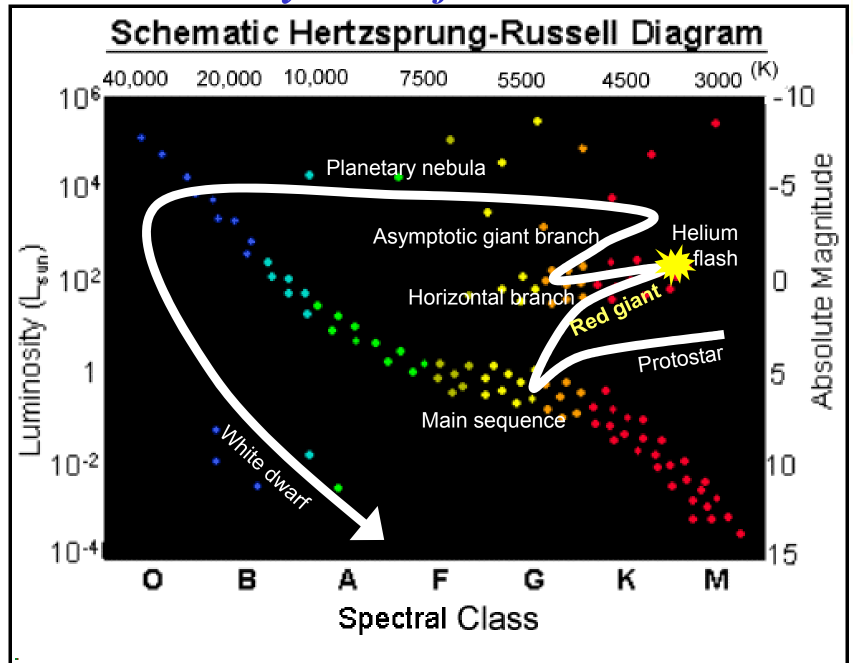
http://wings.avkids.com/Book/Myth/Images/ocean_sun.gif

Life of a Low Mass (Solar) Star

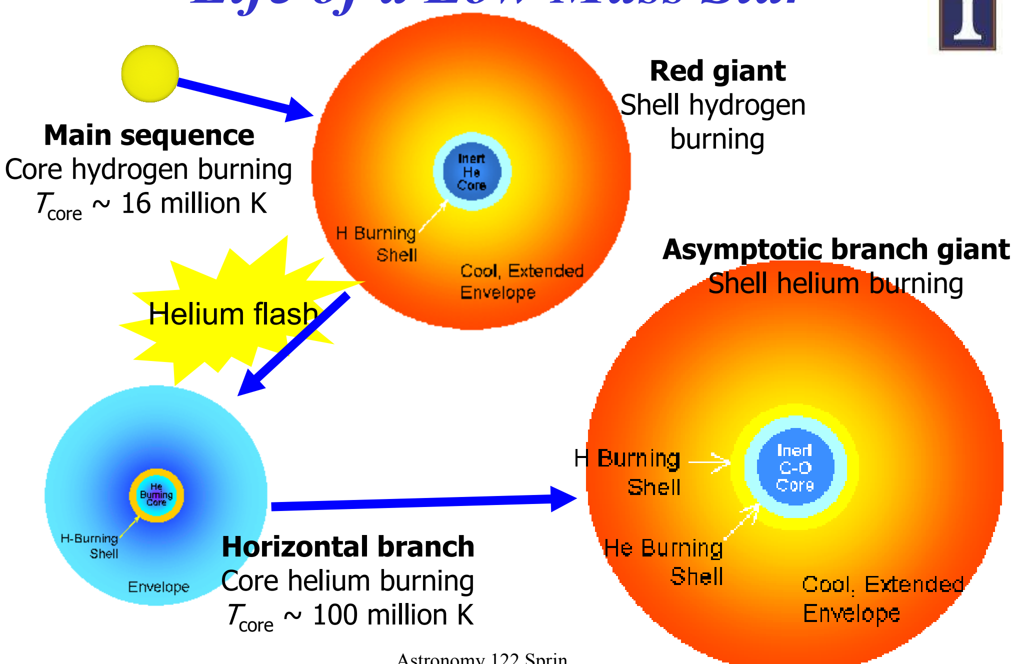
- At 10 Byr will be 2x as bright as now
- This alone will cause a Greenhouse effect on earth!
- But in fact, oceans boil⇒ runaway greenhouse when $L = 1.1L_{\odot}$, which happens in about 1 Byr. So this is when things may hit the fan, not in 5 Byr.
- Model dependent, but still….

http://wings.avkids.com/Book/Myth/Images/ocean_sun.gif

Evolutionary Path of a Solar-Mass Star

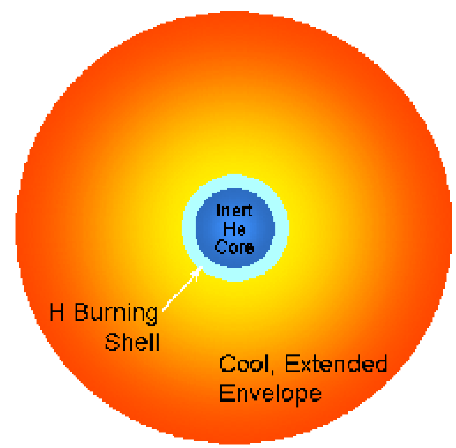


Life of a Low Mass Star



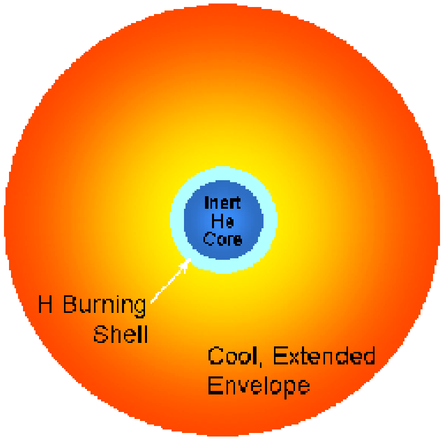
The Red Giant Phase

- When the hydrogen is gone in the core, fusion stops
- Core starts to contract under its own gravity
- This contracting heats the core, and hydrogen fusion starts in the shell around the core
- Energy is released, expands envelope ⇒ Lum increases!
- As the envelope expands, it cools – so it becomes a red giant



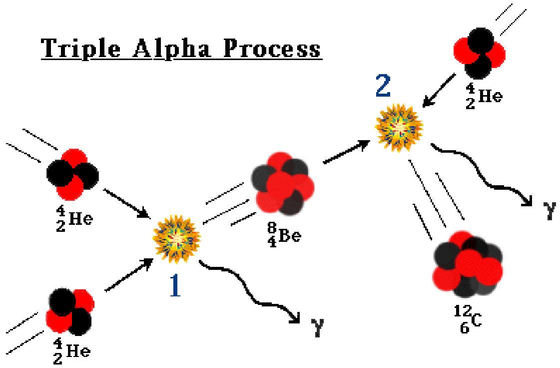
Contraction Junction

- In core, contraction increases density
- Degenerate core and H burning shell
- Core heats ⇒ He fusion ignites
- Helium Flash (few min)
- Note: explosion energy trapped in outer layers so don't see anything special from the outside



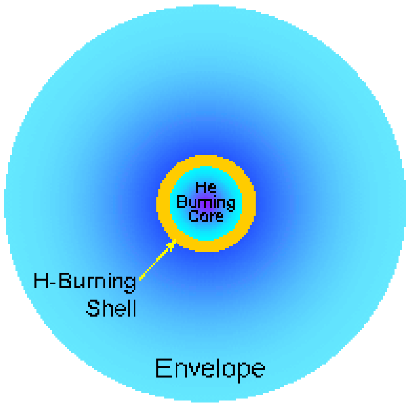
Helium Burning

- When the core of the star reaches 100 million degrees, it can start to fuse helium (the ash of hydrogen burning) into carbon
- Called the Triple-Alpha Process
  - Converts 3 heliums into one carbon + energy



The Horizontal Branch

- Helium burning stabilizes the core
- The outer envelope shrinks, heats up, and dims slightly
- But helium doesn't last very long as a fuel
  - Horizontal branch lifetime is only about 10% that of a star's main sequence lifetime
  - Our Sun will burn helium for about a billion years
  - Also He burning is unstable



Cepheid Variables

- Giants with more than 5 M_{Sun} enter periods of variability as they evolve
  - Become unstable
  - Start to pulsate at a regular pace
  - Pulsation makes them vary in brightness
- The period of pulsation is related to the star's absolute magnitude
  - Excellent way to measure distance!