

Stars, Galaxies & the Universe Announcements

- HW#6 – due Friday by 5 pm!

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1

Stars, Galaxies & the Universe Lecture Outline

1. Formation of Planets/Solar System
2. Stellar Evolution – why? how?
 - energy generation in stars
 - hydrostatic equilibrium & degenerate gas
 - H-R diagrams for stellar clusters
 - changes in the H-R diagram
3. H-R diagram: Main sequence

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2

Protostar Formation

A dense gas clump breaks off from molecular cloud and collapses. Angular momentum turns the irregular clump into a rotating disk.

The central region is denser and forms into a protostar; the nebular disk forms slower to become a planetary system. Infalling matter increases the size of the protostar by a factor of 100.

Infall is stopped when the protostar begins thermonuclear fusion and produces a strong stellar wind.

How do we know this is true?

Can we ever catch a star in the process of forming?

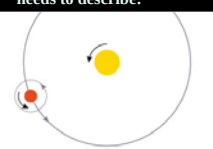
- massive: no
- solar type: yes!

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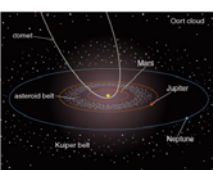
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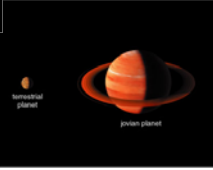
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A theory for formation of the Solar System needs to describe:



1. Large bodies in the solar system have orderly motions.
All planets and most satellites have nearly circular orbits going in the same direction in nearly the same plane. The Sun and most of the planets rotate in this same direction as well.





2. The first eight planets fall into two major categories: small, rocky terrestrial planets near the Sun and large, hydrogen-rich jovian planets farther out. The jovian planets have many moons and rings made of rock and ice.



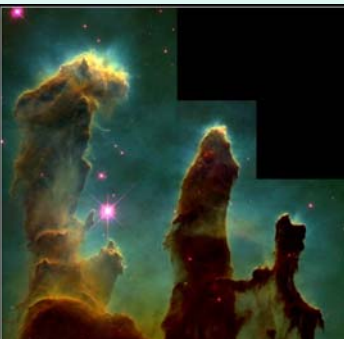
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Asteroids are concentrated in the asteroid belt, and comets populate the regions known as the Kuiper belt and the Oort cloud.

Large, notable exceptions to these general trends stand out, such as planets with unusual axial tilt or surprisingly large moons, and moons with unusual orbits.

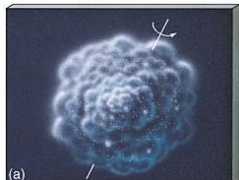
The Birth of the Solar System

- the Solar System Started as a cloud of Hydrogen, Helium → Sun
- universe by nature is 98% H, He
- 2% of the universe is composed of "heavier" than H, He
- common elements in that 2%:
carbon oxygen
nitrogen neon silicon
magnesium sulfur iron

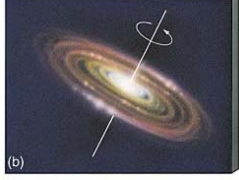


Gaseous Pillars • M16
PRC95-44a • ST Scd OPO • November 2, 1995
J. Hester and P. Scowen (AZ State Univ.), NASA

HST • WFPC2



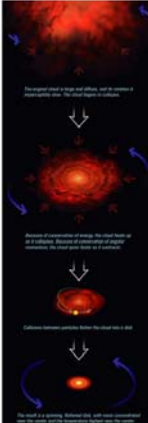
(a)



(b)

The collapse of an interstellar gas cloud:

- Heating**
(temperature increases during collapse; gravitational potential)
- Spinning**
(cloud spins faster as it collapses – angular momentum)
- Flattening**
(random motions become more orderly; i.e. material orbits in a flat disk)



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Leftover rocky planets – Asteroids – convene in the “Asteroid Belt”

Leftover Jovian planets – Comets– convene in the “Kuiper Belt” and “Oort Cloud”

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Evolution of the Solar Nebula

The solar nebula's composition was similar to the present-day Sun's composition:

- 98% hydrogen and helium
- 1.4% hydrogen “compounds (water, methane, ammonia)
- < 0.6% other (“heavies”)

Near Sun (closer than Mercury’s orbit): too hot for anything to condense ($T > 1600\text{ K}$)

Mercury’s orbit: cool enough for metals to condense (not hydrogen compounds)

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Examples	Typical Condensation Temperature	Relative Abundance (by mass)
Hydrogen and Helium Gas hydrogen, helium in nebula	do not condense	98%
Hydrogen Compounds water (H_2O) methane (CH_4) ammonia (NH_3)	$< 130\text{ K}$	1.4%
Rock various minerals	500–1,300 K	0.4%
Metals iron, nickel, aluminum	1,000–1,600 K	0.2%

8

Within the frost line, rocks and metals condense, hydrogen compounds stay gaseous.

Beyond the frost line, hydrogen compounds, rocks, and metals condense.

frost line:

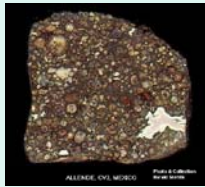
Seeds: metal, rock

Seeds: ices, metals and rock → more solids!

Within the solar nebula, 98% of the material is hydrogen and helium gas that doesn't condense anywhere.

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Evidence for Condensation of the Solar Nebula

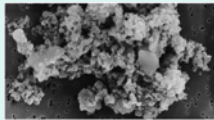


Meteorites!

- The C (or carbonaceous) chondrites contain water-bearing minerals and carbon compounds including a variety of organic molecules such as amino acids.

- Carbonaceous chondrites are the most primitive meteorites—primitive in a chemical way.

- For example, the CI group of carbonaceous chondrites are closest in composition to the photosphere (visible surface) of the Sun.



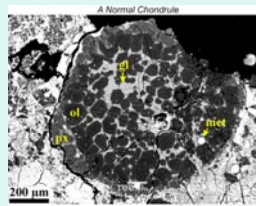
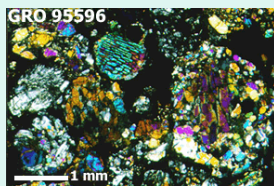
Rock/dust/ice particles
sizes: few mm – km's

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10

Evidence for Condensation of the Solar Nebula



Materials present which would have condensed
During the collapse of the solar nebula:

Most of the grains are olivine crystals (black, labeled ol).

They are surrounded by a glass (grey, labeled gl). Pyroxene (px) and droplets of metallic iron (white, labeled met) are also visible.

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11

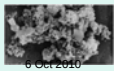
How does that “debris” form into terrestrial planets?

- “collisions” between microscopic solid particles
- because a collision depends on speed, the collisions were gentle because speeds of particles very similar

- mass not great enough to have strong gravitational encounters
- instead, particles “stuck” together through electrostatic forces

- gravity then takes over by gravitational encounters

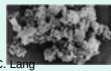
- planetesimals form (proto-planets of size ~100s km in size (largest))
- form (accrete) in a few million years!
- further growth into planets was difficult; orbits were altered, then collisions were more powerful and destructive



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12



Simulation of Solar Nebula Collapsing, Planets forming
 Note: inner part of disk gets "cleared out" - in part due to the solar wind from recently-formed Sun

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Dr. Michael Resner



A planetary system forming (NASA)

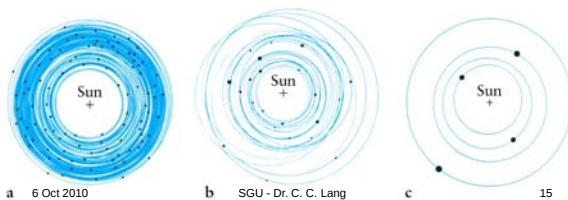
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14

How does that "debris" form into terrestrial planets?

- planets begin to form when disk is ~200 AU across
- smaller bodies attracted (and stuck to) larger ones
 - eventually forming the planets!
- simulation: 100 "planetesimals" → 30 million years
 → 22 proto-planets 79 Myr → 11 proto-planets



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c 15

Saturn's Moons - Mouse Over a Moon to Learn More
 Enceladus, Tethys, Dione, Rhea, Titan, Hyperion, Iapetus, Mimas, Phobos, Deimos, Mars, Venus, Earth, Jupiter, Saturn, Uranus, Neptune, Pluto, Haumea, Makemake, Eris

Jupiter and its rings

Jupiter and its 4 Galilean moons

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The Solar Nebula – formation of the Giant planets

- Giant planets (Jupiter, Saturn) – a different story
- more solid material because hydrogen compounds are ice
- they do have rocky cores, but they attract more material
- they attract large reservoirs of H, He gas from solar nebula
- they form a spinning, flattened “disk” of gas around them
- out of which their many moons form (ice-rich)

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17

New Extrasolar Planets

Two groups of astronomers have taken the first widely accepted pictures of planets orbiting other stars.

HR 8799

Solar System

FOMALHAUT

One group used the Gemini and Keck telescopes on Mauna Kea in Hawaii to record three planets circling the star HR 8799, 130 light-years away. The group used adaptive optics, in which the telescope mirrors are warped several times a second, and software filtering to compensate for atmospheric turbulence and glare from the star.

Another group used the Hubble Space Telescope to spot a planet orbiting the bright star Fomalhaut, 25 light-years away. Using a mask called a coronagraph to block the star's direct light (above, in black), the team was able to take detailed images of Fomalhaut's huge dust ring in 2004 and again in 2006. One bright spot inside the ring had moved slightly — a massive planet.

HR 8799

FOMALHAUT

Planet Fomalhaut b

Dust ring

10-second image

Processed image with starlight glare removed

Processed images combined over 1 hour

Composite image from 2004 and 2006

Location in 2004

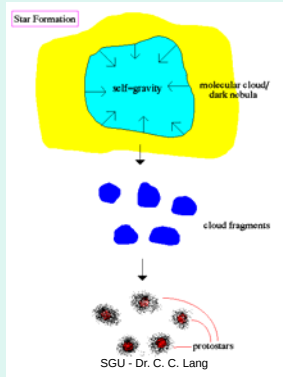
Location in 2006

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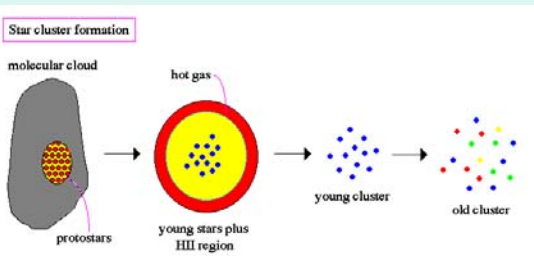
The story of star formation



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19

The story of how stars form in the Galaxy



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20

How are stars fundamentally different from each other?

1. How do different stars compare to the Sun?

Mass of the Sun: 2×10^{30} kg = 1 "solar mass"

Luminosity of the Sun: 4×10^{26} W = 1 "solar luminosity"

2. What can we measure from stars?

Distance (1)

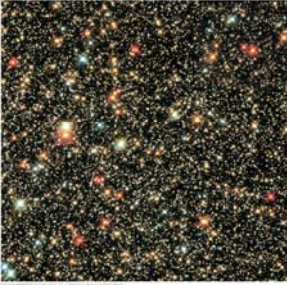
Luminosity (1)

Temperature (2)

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What color are most of the bright stars in this cluster?

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How are stars fundamentally different from each other?

Distance – measure star position 6 months apart
figure out the parallax angle

Luminosity – measure “flux”, know distance
use INVERSE SQUARE law to solve for
the star’s intrinsic energy (Luminosity)

Temperature –

1. Wien’s Law (look at wavelength of peak intensity)
2. Measure the spectrum, categorize by spectral class (get the temperature from the classes)

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Studying the properties of a *cluster* of stars



Distance

Luminosity

Temperature

Quintuplet cluster located in the
center of the Milky Way (HST/IR)

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is like trying to find characteristics of a group of people



Height

Weight

Hair Color

Carter family at the turn of the century (1900) in Kentucky

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Stellar Evolution is the study of

- how stars are born
- how stars live their “lives”
- how stars end their lives



2005/09/28 17:28



2005/09/28 18:10



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Why do stars evolve?

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Fusion proceeds using a different reaction

The C-N-O Cycle
 → C, N, O although in small amounts, can act like catalysts

Step 1:
 $^{12}\text{C} + \text{proton} = ^{13}\text{N} + \text{gamma ray } (\gamma)$

Step 2:
 $^{13}\text{N} \rightarrow ^{13}\text{C} + v + \gamma$

Step 3:
 $^{13}\text{C} + \text{proton} = ^{14}\text{N} + \gamma$

Step 4:
 $^{14}\text{N} + \text{proton} = ^{15}\text{O} + \gamma$

Step 5: $^{15}\text{O} \rightarrow v + \text{positron} + ^{15}\text{N}$

Step 6:
 $^{15}\text{N} + \text{proton} = ^4\text{He} + ^{12}\text{C}$

Key:
 neutron, 6 Oct 2010, positron, gamma ray, proton, neutrino
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Gas in the core of the star (corpe) is under extreme pressures

- Degenerate gas

Regular gas: many unfilled energy levels. Particles free to move about and change energy levels.

Degenerate gas: all lower energy levels filled with two particles each (opposite spins). Particles locked in place.

Ordinary matter	Electron degenerate matter	Baryon degenerate matter
Atomic nuclei Electronic orbits	Compression 1 ton / cm ²	Compression 100 million tons / cm ²

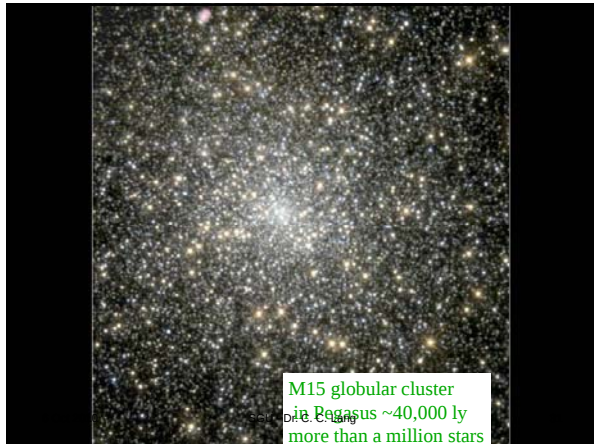
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Stellar Clusters : Many stars do not live alone

Globular Clusters:

- stars gravitationally bound to the cluster
- as many as 1 million stars – usually 50,000 – 500,000
- may be 15 billion years old (less massive than the Sun)
- much lower in “heavy elements” formed early in the universe
- Our Galaxy has ~200 globular clusters

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Stellar Clusters : Many stars do not live alone

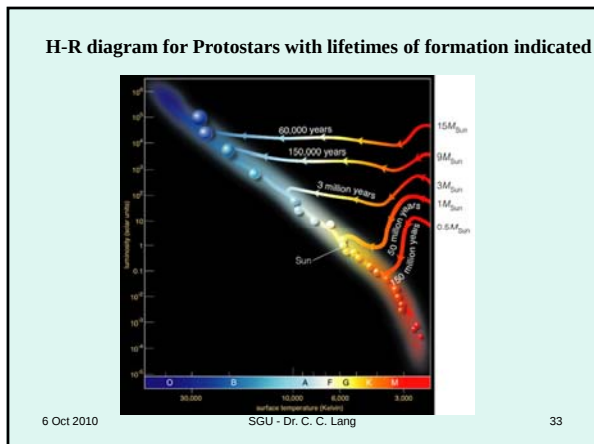
“Open” Clusters:

- related stars very loosely bound together
- usually drift apart over time
- only a few million years old (stars much more massive than Sun: 10-50 solar masses)
- after 100 million years, the cluster has disbanded – many stars will have gone “supernova”

“Pleiades or 7 sisters”

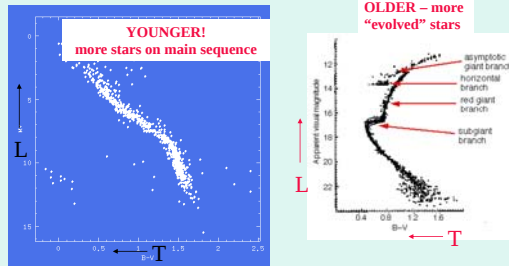


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Stellar Clusters : Open vs. Globular -- AGES

you can learn about the “age” of a cluster by looking at the H-R diagrams



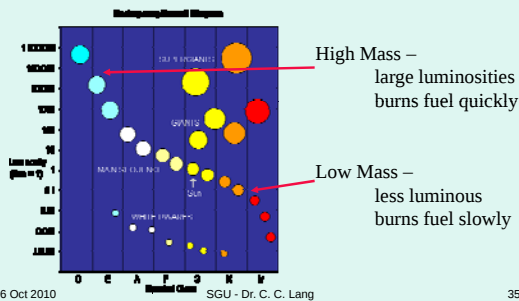
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34

Main Sequence

- Fusing $H \rightarrow He$ in core
- Star “leaves” the main sequence when $H \rightarrow He$ fusion stops



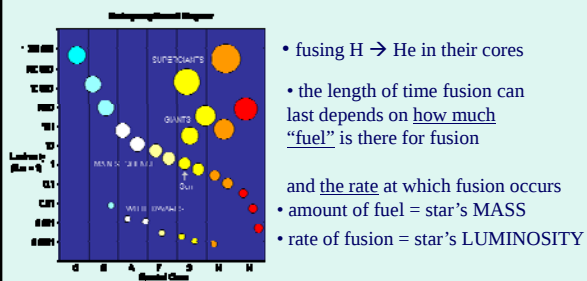
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35

The Hertzsprung-Russell Diagram (H-R Diagram)

Properties of stars on the Main-Sequence



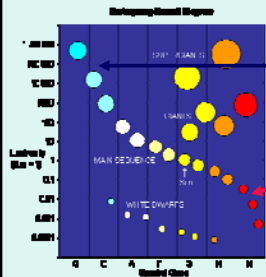
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36

The Hertzsprung-Russell Diagram (H-R Diagram)

Properties of stars ON the Main-Sequence



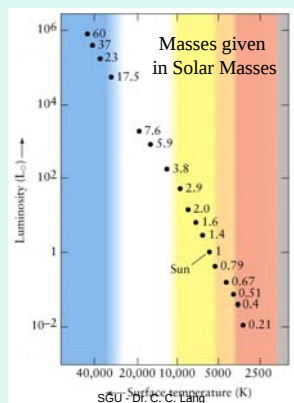
The LUMINOUS stars
are more massive
5 to 50 times solar mass

The DIMMER stars
are less massive
0.1 – 1 times solar mass

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37



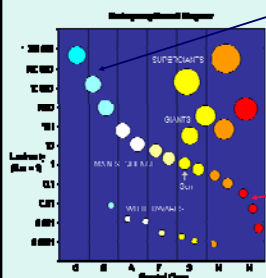
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38

The Hertzsprung-Russell Diagram (H-R Diagram)

Properties of stars on the Main-Sequence



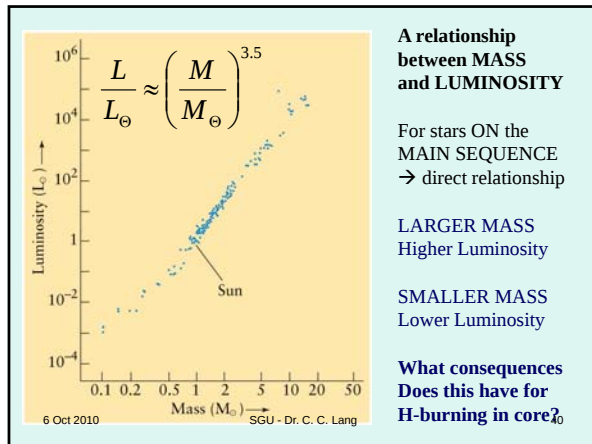
The more massive stars
have MORE FUEL
but also more LUMINOSITY
→ They fuse H → He faster!

The LESS LUMINOUS stars
have less fuel but they fuse
H → He more slowly

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39

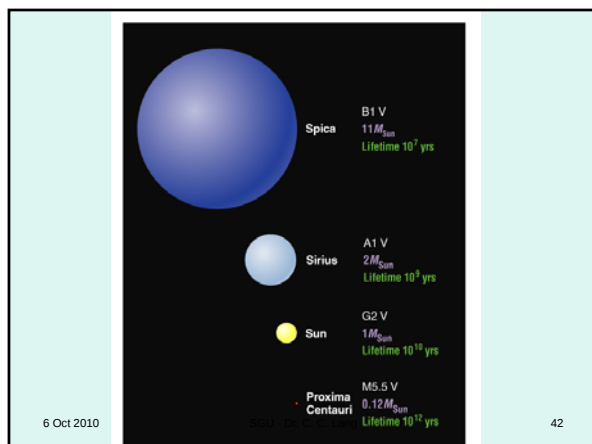


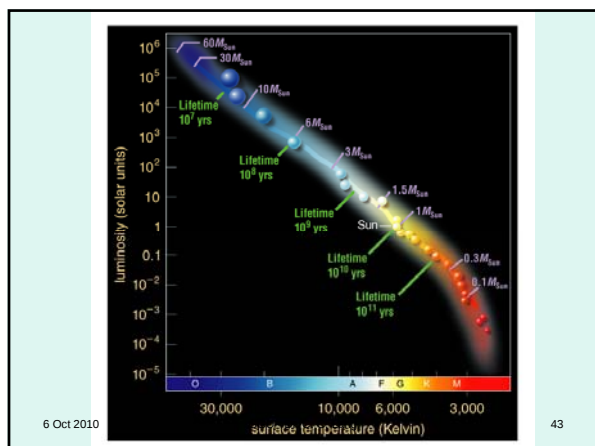
Mass-Lifetime relation

- The lifetime of a star (on the main sequence) is longer if more fuel is available and shorter if that fuel is burned more rapidly
- The available fuel is (roughly) proportional to the mass of the star
- From the main sequence, we know that luminosity is much higher for higher masses
- We conclude that higher mass stars live shorter lives

$$t \propto \frac{M}{L} \propto \frac{M}{M^{3.5}} = \frac{1}{M^{2.5}}$$

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43

A ten solar mass star has about ten times the sun's supply of nuclear energy. Its luminosity is 3000 times that of the sun. How does the lifetime of the star compare with that of the sun?

1. 10 times as long
2. the same
3. 1/300 as long
4. 1/3000 as long

$$t \propto \frac{M}{L} \propto \frac{10}{3000} = \frac{1}{300}$$

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44

Mass-Lifetime relation for M-S stars

Mass/mass of Sun	Lifetime (years)	
60	400,000	
10	30,000,000	30 million
3	600,000,000	600 million
1	10,000,000,000	10 billion
0.3	200,000,000,000	200 billion
0.1	3,000,000,000,000	3 trillion!

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45
