Stars, Galaxies & the Universe
Announcements

- **HW#6 – due Friday by 5 pm!**

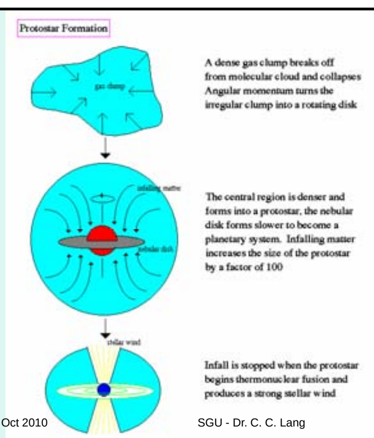
Stars, Galaxies & the Universe
Lecture Outline

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

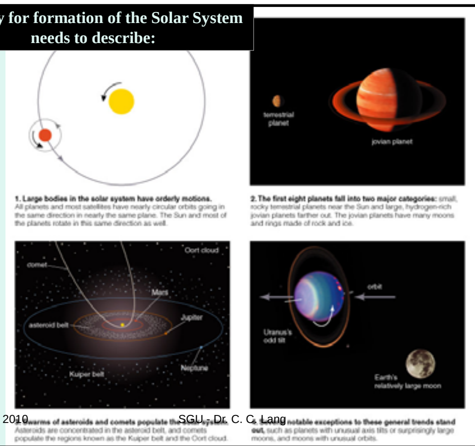


How do we know this is true?

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

- massive: no
- solar type: yes!

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



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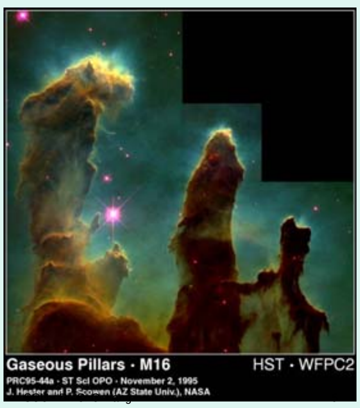
The Birth of the Solar System

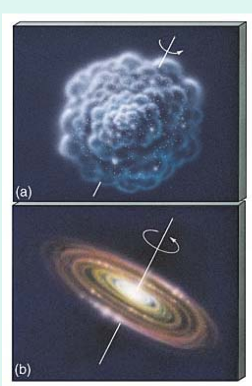
• the Solar System Started as a cloud of Hydrogen, Helium → Sun

• 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



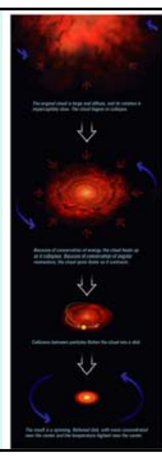


The collapse of an interstellar gas cloud:

-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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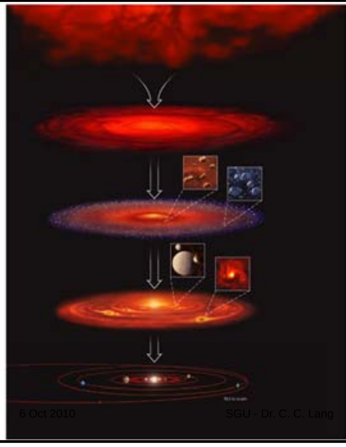


Leftover rocky planets – Asteroids – convene in the “Asteroid Belt”

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

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”)

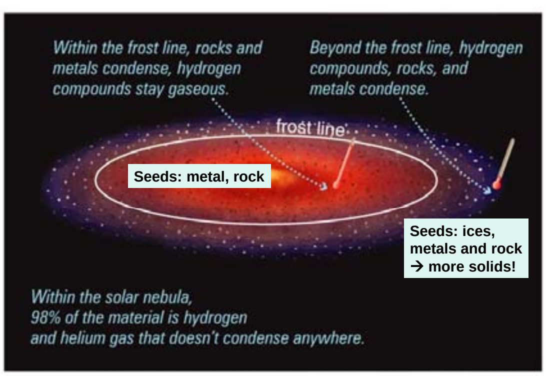
Near Sun (closer than Mercury’s orbit): too hot for anything to condense (T> 1600 K)

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

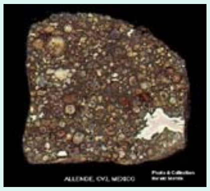
Table 8.1 Materials in the Solar Nebula

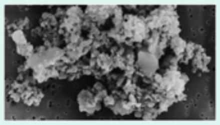
A summary of the four types of materials present in the solar nebula. The squares represent the relative proportions of each type (by mass).

	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)	<150 K	1.4%
Rock	various minerals	500–1,300 K	0.4%
Metals	iron, nickel, aluminum	1,000–1,600 K	0.2%



Evidence for Condensation of the Solar Nebula





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

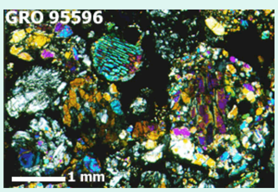
Meteorites!

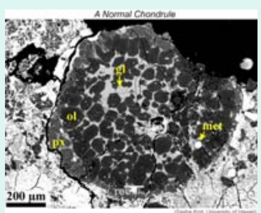
• The C (or carbonaceous) chondrites contain water-bearing minerals and carbon compounds including a variety of organic molecules such as amino acids.

• 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.

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.

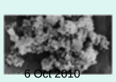
How does that "debris" form into terrestrial planets?

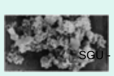
• "collisions" between microscopic solid particles
- because a collision depends on speed, the collisions were gentle because speeds of particles very similar

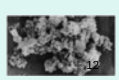
• mass not great enough to have strong gravitational encounters
• instead, particles "stuck" together through electrostatic forces

• 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







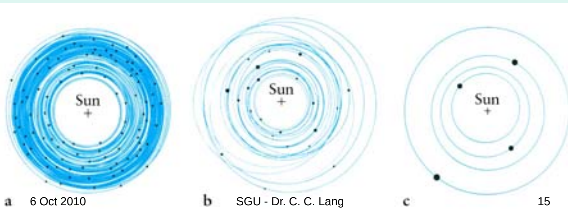
Simulation of Solar Nebula Collapsing, Planets forming
Note: inner part of disk gets “cleared out” - in part due to the solar wind from recently-formed Sun

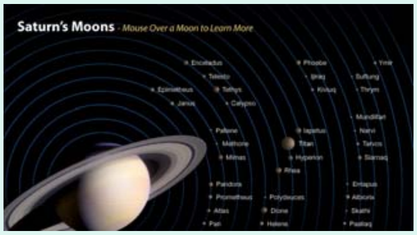
Dr. Michael Ressler

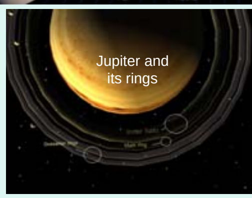
A plantary system forming (NASA)

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

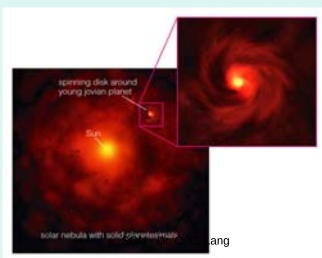


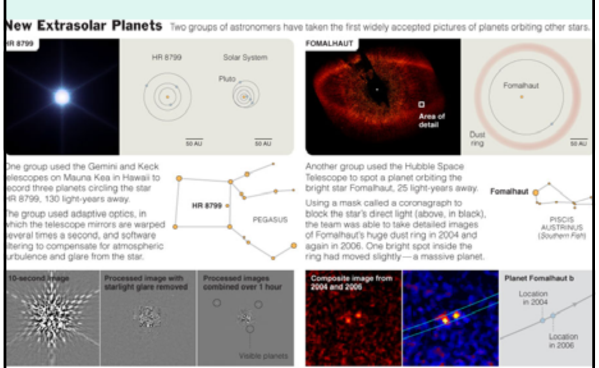




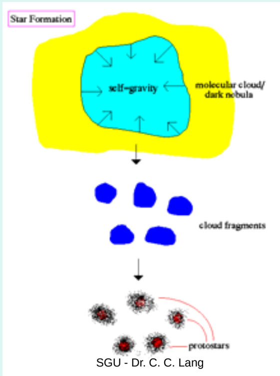
The Solar Nebula – formation of the Giant planets

- 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)

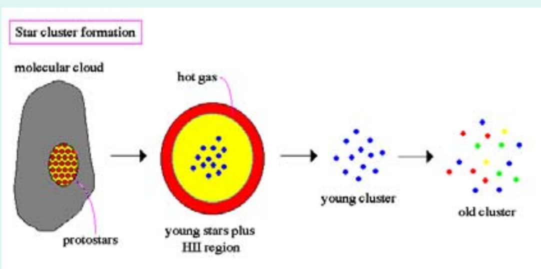




The story of star formation



The story of how stars form in the Galaxy



How are stars fundamentally different from each other?

1. **How do different stars compare to the Sun?**

Mass of the Sun: 2 x 10^{30} kg = 1 “solar mass”

Luminosity of the Sun: 4 x 10^{26} W = 1 “solar luminosity”

2. **What can we measure from stars?**

Distance (1)

Luminosity (1)

Temperature (2)

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

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)

Studying the properties of a *cluster* of stars

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

Distance

Luminosity

Temperature

is like trying to find characteristics of a group of people

Height

Weight

Hair Color

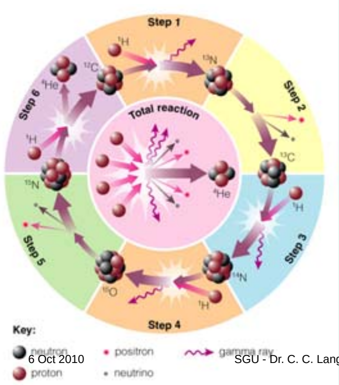
Carter family at the turn of the century (1900) in Kentucky

***Stellar Evolution* is the study of**

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

Why do stars evolve?

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}Carbon + **proton** = ^{13} Nitrogen + *gamma ray* (γ)

Step 2:
^{13}Nitrogen → ^{13}Carbon + ν + γ

Step 3:
^{13}Carbon + **proton** = ^{14} N + γ

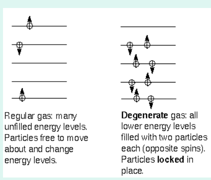
Step 4:
^{14} N + **proton** = ^{15}Oxygen + γ

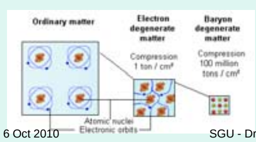
Step 5: ^{15}Oxygen → ν + positron + ^{15} Nitrogen

Step 6:
^{15}Nitrogen + **proton** = ^{4} He + ^{12}C

Gas in the core of the star (corpse) is under extreme pressures

• Degenerate gas





• common example:
- metals
- difficult to compress any further

Stellar Clusters : Many stars do not live alone

Globular Clusters:

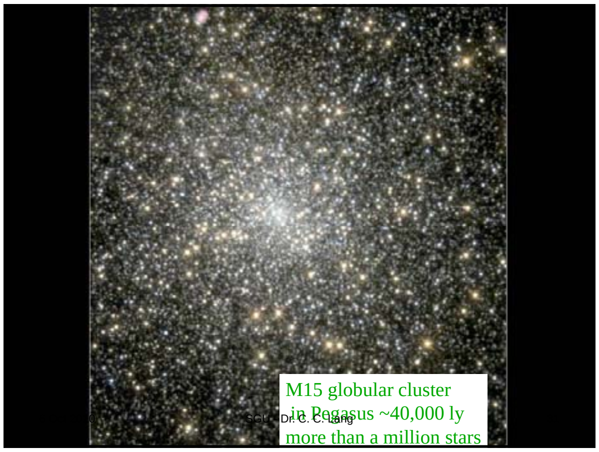
• stars gravitationally bound to the cluster

• 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



M15 globular cluster
in Pegasus ~40,000 ly
more than a million stars

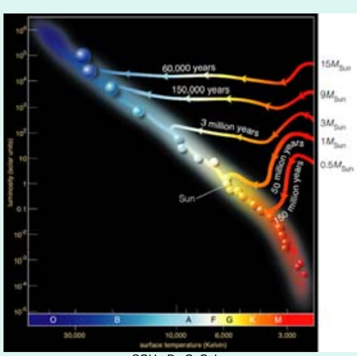
Stellar Clusters : Many stars do not live alone

"Open" Clusters:

"Pleiades or 7 sisters"

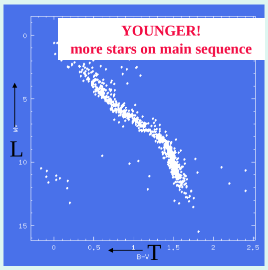
- related stars very loosely bound together
- usually drift apart over time
- only a few million years old (stars much more massive than Sun: 10-50 solar masses)
- after 100 million years, the cluster has disbanded – many stars will have gone "supernova"

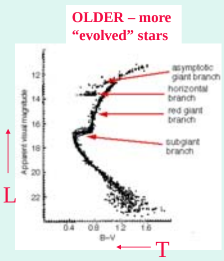
H-R diagram for Protostars with lifetimes of formation indicated



Stellar Clusters : Open vs. Globular -- AGES

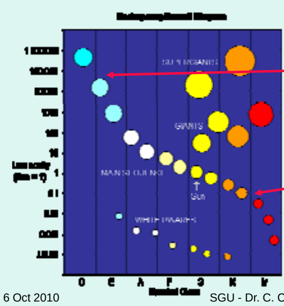
you can learn about the "age" of a cluster by looking at the H-R diagrams





Main Sequence

- Fusing H→ He in core
- Star "leaves" the main sequence when H→He fusion stops

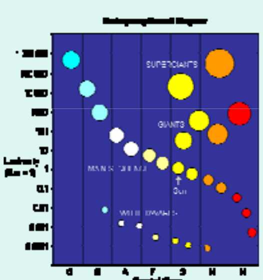


High Mass –
large luminosities
burns fuel quickly

Low Mass –
less luminous
burns fuel slowly

The Hertzsprung-Russell Diagram (H-R Diagram)

Properties of stars on the Main-Sequence



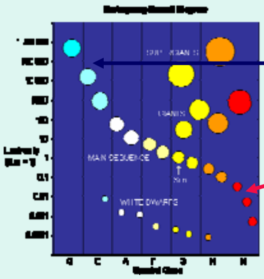
- fusing H → He in their cores
- the length of time fusion can last depends on how much "fuel" is there for fusion

and the rate at which fusion occurs

- amount of fuel = star's MASS
- rate of fusion = star's LUMINOSITY

The Hertzsprung-Russell Diagram (H-R Diagram)

Properties of stars ON the Main-Sequence

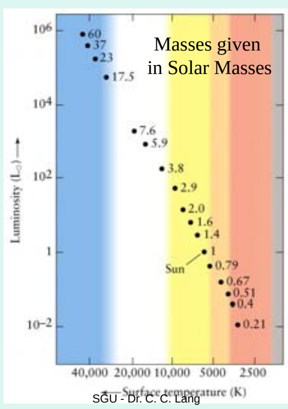


The LUMINOUS stars are more massive

5 to 50 times solar mass

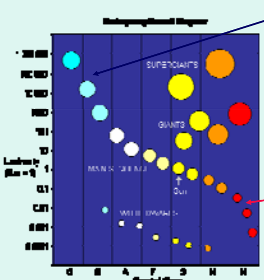
The DIMMER stars are less massive

0.1 – 1 times solar mass



The Hertzsprung-Russell Diagram (H-R Diagram)

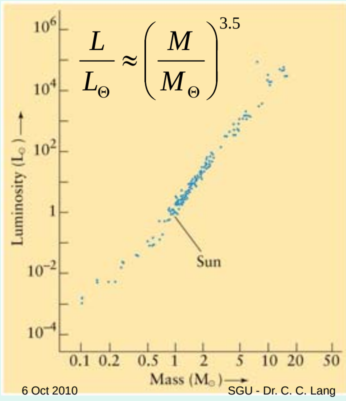
Properties of stars on the Main-Sequence



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



A relationship between MASS and LUMINOSITY

For stars ON the MAIN SEQUENCE
→ direct relationship

LARGER MASS
Higher Luminosity

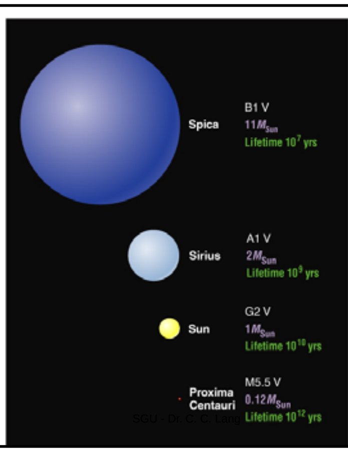
SMALLER MASS
Lower Luminosity

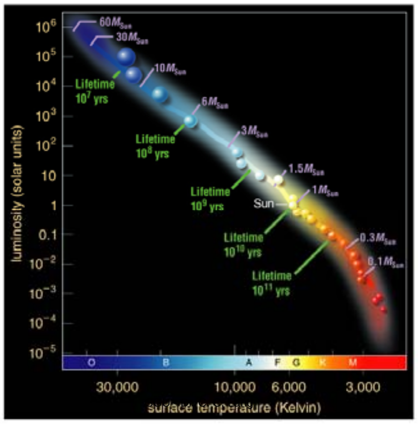
What consequences Does this have for H-burning in core?

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 known that luminosity is much higher for higher masses
- We conclude that higher mass star live shorter lives

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





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

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

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!