Stars, Galaxies & the Universe Announcements

- **HW#6 – due Friday by 5 pm!**
- **Nearly half way through HWs and Read Quizzes**
  - **Make sure you are getting your points**
- **In-class Quizzes #4, #5, #6 – grades in ICON tonight**
- **Labs meet regularly this week**
  - **spectroscopy or the solar lab**

Stars, Galaxies & the Universe Lecture Outline

1. Space Weather
   - Solar Wind
   - Van Allen Belts/Aurorae

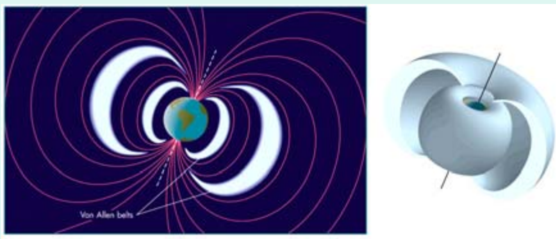
2. Formation of Stars & Planets

Solar Wind:

a not very dense flow of particles from Solar Corona into space
moves past Earth ~4 days after it leaves Sun

Van Allen Belts protect Earth from highly-charged (energetic) Solar particles!

- discovered by Dr. James Van Allen in 1958
- first flight of a U.S. Earth-orbiting satellite
- Van Allen insisted that Geiger counter be on board to count particle detections (found VA Belts!!)



A Cross-sectional view of the Van Allen belts

B Cutaway view showing that the belts are actually shells

October 4th 1957 - 50th anniversary - first artificial satellite orbits the Earth!

IGY - International Geophysical Year (July 1957-December 1958)

The US program included investigations of aurora and airglow, cosmic rays, geomagnetism, glaciology, gravity, the ionosphere, determinations of longitude and latitude, meteorology, oceanography, seismology, solar activity, and the upper atmosphere.

Sputnik

The world's first artificial satellite
- size of a beach ball (22.8 inches diameter)
- weighed 83.6 kg (183.9 lbs) (US effort ~4 lbs)
- took 98 minutes to orbit the Earth, h=900 km

Changed way people thought about the world
- fear of on-board nuclear weapons
- increased US space effort
- November 3rd, 1957 Sputnik 2 launched with first on-board passenger (Laika, a dog!)
- Sputnik 2 was ~1000 lbs, orbited for 200 days!

"All the News That's Fit to Print"

The New York Times. LATE CITY EDITION

SOVIET FIRES EARTH SATELLITE INTO SPACE; IT IS CIRCLING THE GLOBE AT 18,000 M. P. H.; SPHERE TRACKED IN 4 CROSSINGS OVER U. S.

HOFFA IS ELECTED TEAMSTERS HEAD; WARNS OF BATTLE

COURSE RECORDED

560 MILES HIGH

Device Is 8 Times Heavier Than One Planned by U.S.

ARGENTINA TAKES EMERGENCY STEPS

SATELLITE SIGNAL BROADCAST HERE

January 31st 1958: Launch of Explorer 1

After Sputnik, US effort was increased
- charge was to get an artificial satellite up! 84 days later, Explorer 1 launched
- scientific instruments built by Dr. Van Allen, rest designed by Pickering

Explorer-I was placed in an orbit with a perigee of 224 miles and an apogee of 1,575 miles having a period of 114.9 minutes. Weight was 30.66 lbs (18.35 lbs instrumentation)

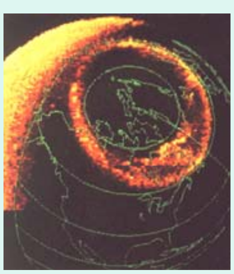
Instrumentation built to detect cosmic rays
-highly-energetic charged particles (90% protons, 9% alpha particles & 1% electrons)
- where do they come from?
Once in orbit, Explorer 1 detected fewer cosmic rays Than predicted
-Van Allen's theory that there Were "belts" trapping the Cosmic rays in them

Van Allen's Early Experiments: Rockoons

Rockoon - hybrid instrument: Rocket and balloon
The rockoon was a solid fuel rocket that, rather than being immediately lit while on the ground, was first carried into the upper atmosphere a gas-filled balloon, and then separated from the balloon when it had reached its maximum height and automatically ignited.

As TIME reported in 1959, Van Allen's Rockoons could not be fired in Iowa for fear that the spent rockets would strike an Iowan or his house. So Van Allen convinced the U.S. Coast Guard to let him fire his rockoons from the icebreaker *Eastwind* that was bound for Greenland. The first balloon rose properly to 70,000 ft., but the rocket hanging under it did not fire. The second Rockoon behaved in the same maddening way. On the theory that extreme cold at high altitude might have stopped the clockwork supposed to ignite the rockets, Van Allen heated cans of orange juice, snuggled them into the third Rockoon's gondola, and wrapped the whole business in insulation. The rocket fired."

Auroral Phenomena



→ Sometimes magnetosphere gets overloaded with charged particles

→ Solar wind electrons precipitate into polar regions, ionizing nitrogen and oxygen atoms

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University of Iowa Space Physics Research

- group led by Dr. Craig Kletzing in U Iowa's Physics & Astronomy Dept.
- study of particles in auroral regions, magnetic fields, energetics of this region
- build/design detectors and instruments here in Van Allen Hall
- launch the spacecraft into the auroral regions from northern Alaska at night

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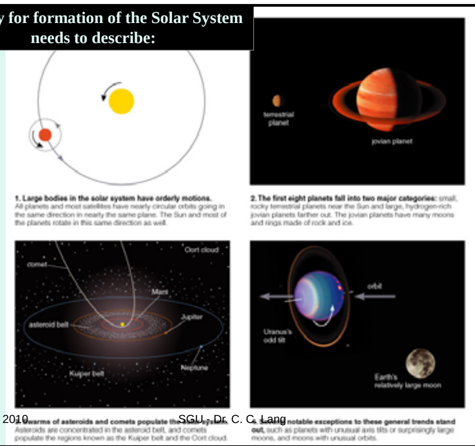
How do stars form?

How did our Solar System (including the planets) form?

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



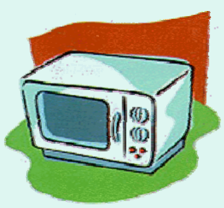
Interstellar Medium: stuff between stars

- stars are just one component of the universe
- "interstellar medium" (ISM) is material between them

Where is the birthplace ("Stellar Nursery") of stars?

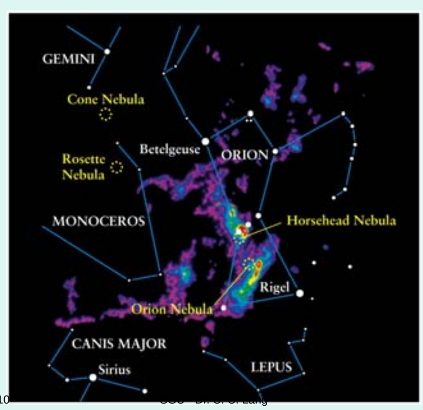
LARGE regions of dark nebulae (dust, molecular hydrogen) are known as GIANT MOLECULAR clouds!

- **very cold molecular hydrogen ~10 K**
- **as much as a million solar masses of material**
- **10-100's of light years across and deep**



Hydrogen Molecules
rotate and vibrate

These rotations/vibrations correspond to MICROWAVES (short radio waves)



Interstellar DUST – keeps our Galaxy dark!

- only 40% of light from a star 3000 ly away is seen by us

the other 60% is absorbed by dust

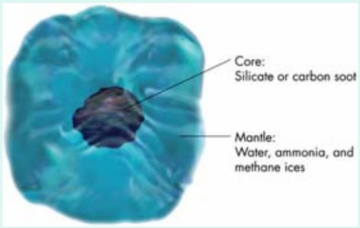
- only 16% of light from a star 15,000 ly away is seen by us!

→ *"Interstellar Extinction"*

Properties of Dark Nebulae

- concentrations of cold hydrogen and microscopic *dust* particles
- how cold? ~10-100 K (hydrogen is a molecule)
- the main observed property of a dark nebula **is that it is dark – it absorbs surrounding radiation**

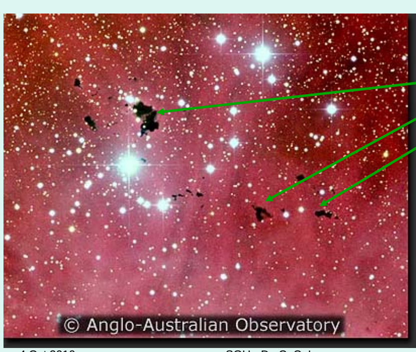
What does an interstellar "dust grain" look like?
- an artists' conception:



→ SIZES of DUST GRAINS: variety
- typically in the range of visible light ~500 nm across

Interstellar extinction prevents us from seeing starlight from inner parts of our Galaxy!

Stars form in very dense regions



"Bok globules"

masses:
1-1000
solar masses

sizes:
few light years

How does a star form?

1. Coldest, darkest part of a cloud/nebula collapses

Gravity inwards (due to mass of gas/dust)
balanced by
Pressure outwards

Pressure: combination of DENSITY and TEMPERATURE of dust/gas

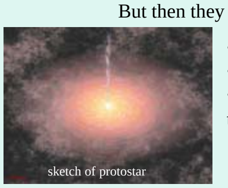
density: quite high in dark nebulae (10^4-10^9 cm^{-3})
temperature: VERY LOW – only ~10 K

→ GRAVITY wins and the dark nebula collapses

embedded collapsing objects

2. Protostars

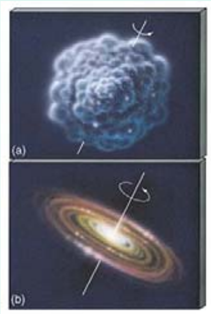
- protostars result from collapse of cloud core
- gravitational energy from collapse -> thermal energy
  -At first, radiate strongly in the infrared band
  But then they become "opaque" to infrared light


sketch of protostar

- object heats up as it can't lose energy
- interior gets hotter – up to 15 million K
- eventually, the collapse halts and the object begins to resemble a star
- collapse takes ~10 million years

for a Sun-like star, that is only 1/10th of its lifetime

Cloud cores are rotating!



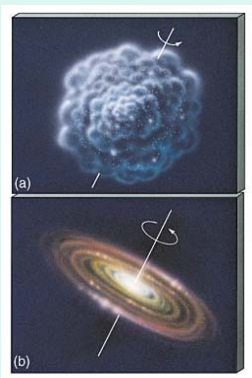
- collapsing cloud does not form spherical object

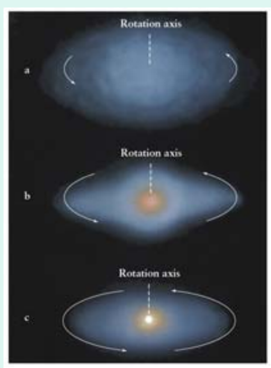
1. central SPHERE "protostar"
2. surrounding DISK

- protostar & disk system

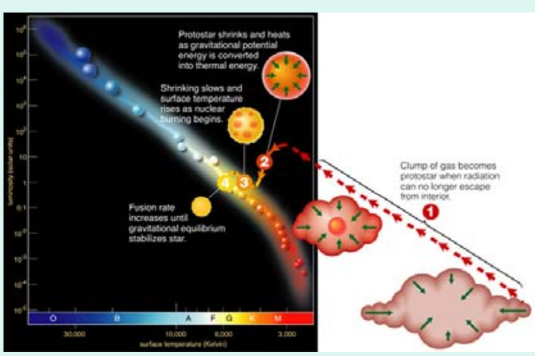
-smaller than original cloud core
-bigger than the final star

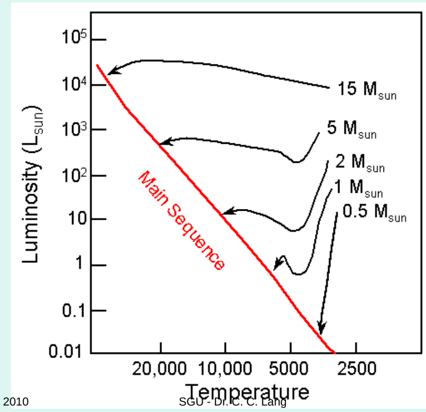
100-1000 AU's across

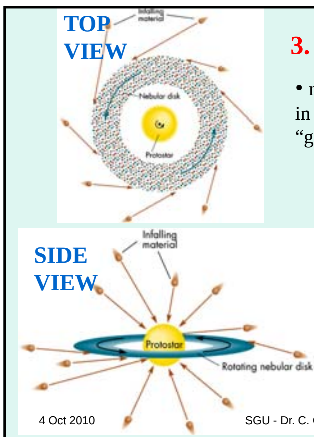




Resulting shape: sphere at center, with flattened disk surrounding it

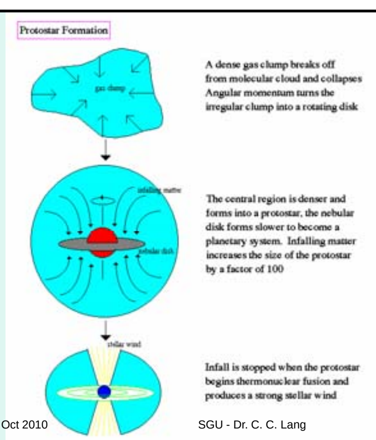






3. Disk builds up the star

- material from the cloud falls in to a central object (gravity=heat) "gravitational collapse"
- eventually, enough matter accretes to begin nuclear fusion – a STAR is born!
- some material accumulates into a DISK around protostar

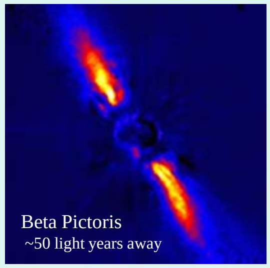


How do we know this is true?

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

- massive: no
- solar type: yes!

Observations of disks around protostars:



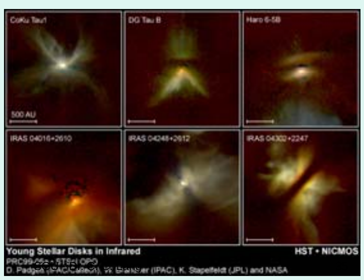
AB Aurigae
~470 ly away
disk ~ 3000 AU
star is 2-4 million yrs. old

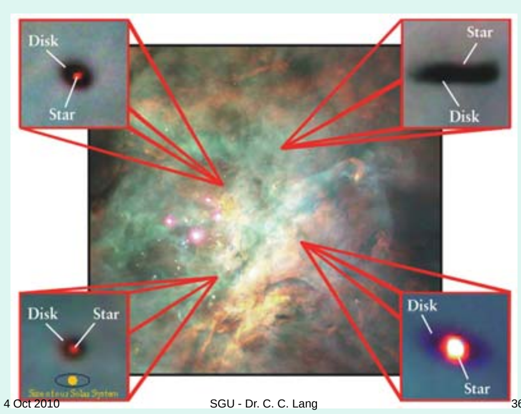
Observational evidence: "Protostars" and their DISKS

- protostar emits energy in the infrared but also has a disk of colder material
- disk can block the infrared light

Hubble images – the line shows 500 AU in size!

These are 1000 AU across





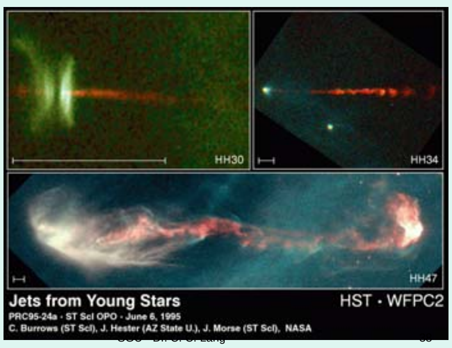
Protostars also have observable JETS

- protostars also LOSE mass as they are forming
- high powered JETS of material shoot out from protostar
  -extend for hundreds of AU

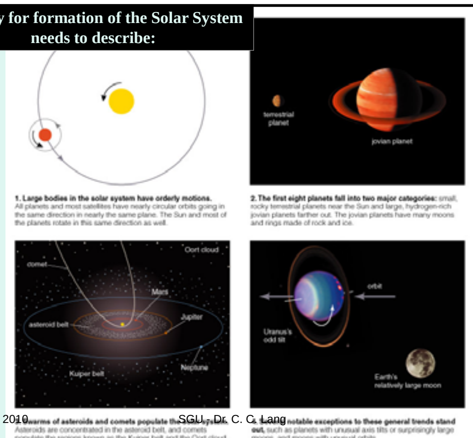
size of bar = 200 AU

Observational evidence: "Jets" from protostars

size of bar: 1000 AU in each picture



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



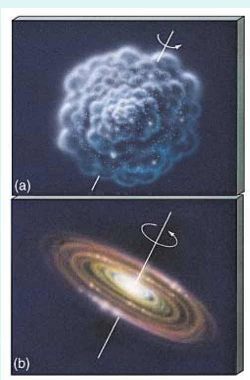
The Birth of the Solar System

• 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

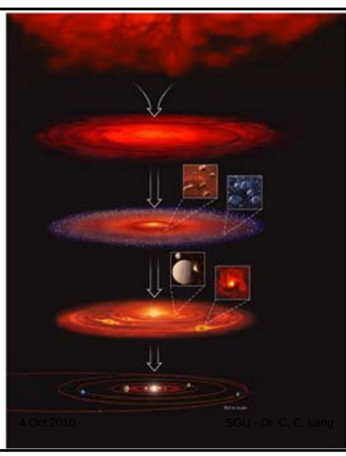


The collapse of an interstellar gas cloud:

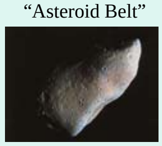
-Heating
(temperature increases during collapse; gravitational potential)

- Spinning
(cloud spins faster as it collapses – angular momentum)

-Flattening
(random motions become more orderly; i.e. material orbits in a flat disk)



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 Nebu

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")

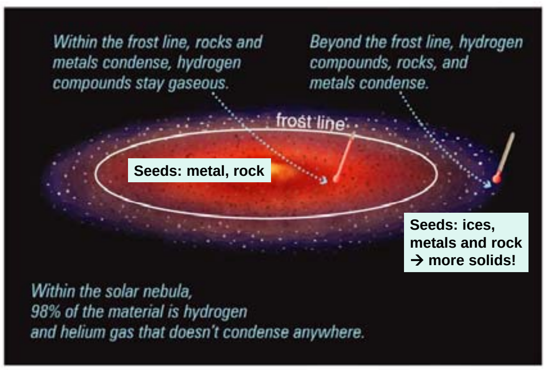
Near Sun (closer than Mercury's orbit): too hot for anything to condense (T> 1600 K)

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

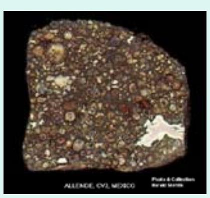
Table 8.1 Materials in the Solar Nebula

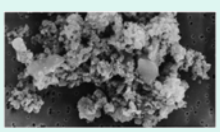
A summary of the four types of materials present in the solar nebula. The squares represent the relative proportions of each type (by mass).

	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



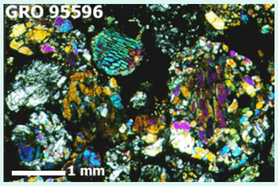


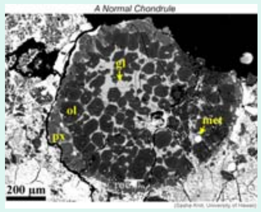
Rock/dust/ice particles
sizes: few mm – km's

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.

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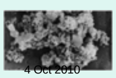
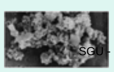
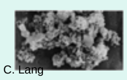
How does that "debris" form into terrestrial planets?

- "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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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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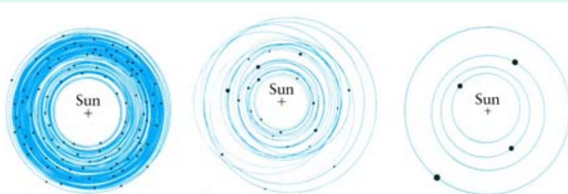
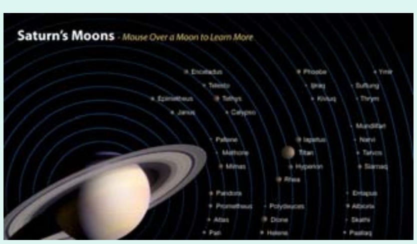
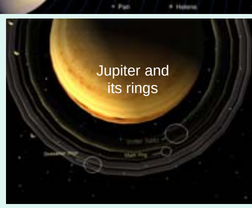
A plantary system forming (NASA)

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)