Astronomy 210

Section 1– MWF 1500-1550

134 Astronomy Building

This Class (Lecture 26):

Debris/ Birth of the Solar System

2nd Hour Exam
This Friday!

Next Class:

Birth of the Solar System II

Outline

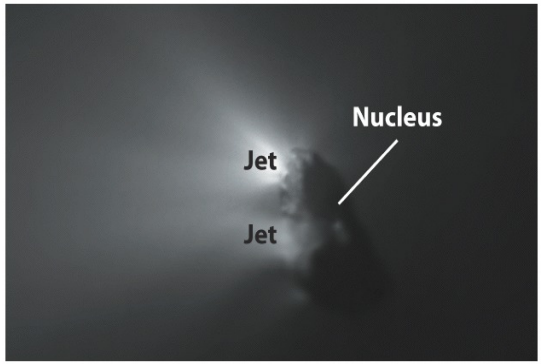
- Comets– You Dirty Iceball
- Asteroids– Spacecraft hazard?
- Meteroids– watch your head
- Mommy, where did the Solar System come from?

Comets

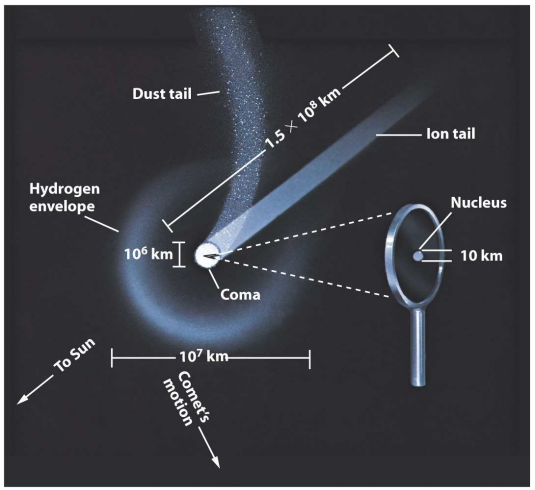
- Apparitions that appear like ghostly fireballs frozen in the sky
- In ancient times, the appearance of a comet was often considered a harbinger of doom
- Ironically, life on Earth may have been impossible without them
- Also comets and meteoroids are the oldest original solar system material! Left over building materials.

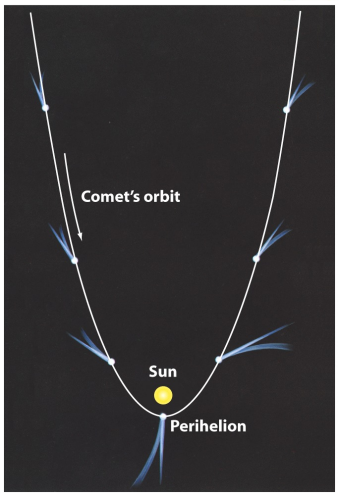
What is a Comet?

- Dirty icebergs in space
  - 10-50 km across
- Composed mostly of water ice (but also CO_2 and CH_4), with some solid dust, rock & metal
  - Dark surfaces!
- Very elliptical orbits ⇒ varying r implies varying T
- When one approaches the Sun, sunlight sublimates ice into vapor.



Comets

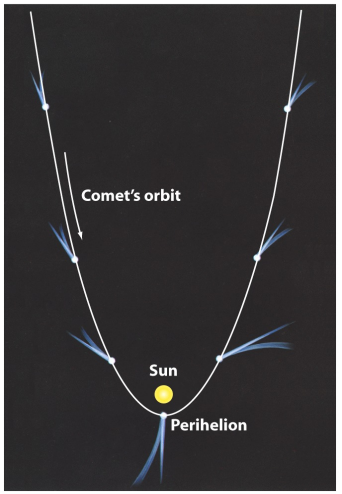




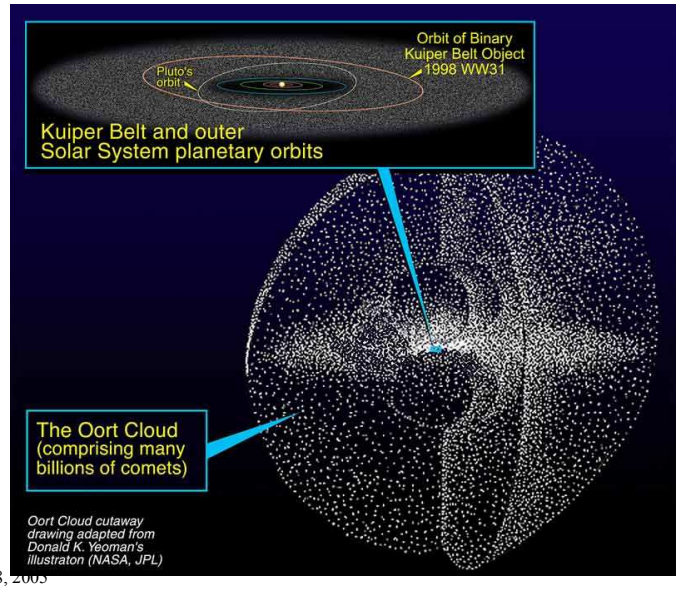
Changing r implies a change in T

Comets

- Coma
  - Sunlight evaporates comet surface
  - Forms a cloud of gas & dust around the nucleus
- Tails
  - Gas is ionized by the sun's UV light
  - Gas & dust pushed away by the solar wind



Where Do Comets Lurk?

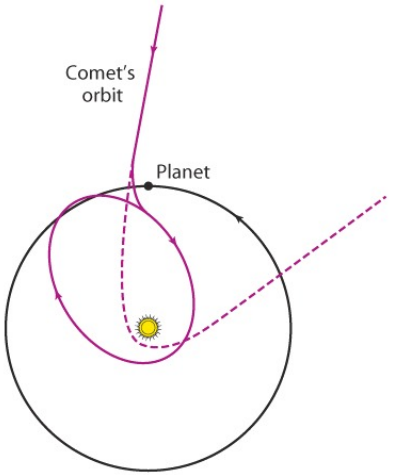


Where Do Comets Lurk?

- The vast majority live far out in the Solar System, beyond the planets
- Short period comets: Kuiper Belt (aka trans-Neptunian)
  - Orbital periods of hundreds of years
  - Around and beyond the orbit of Pluto (30-500 AU), probably formed there.
  - Now about 240ish the size of 10% Pluto
- Long-period comets: Oort Cloud
  - Edge of Sun's gravitational influence
  - Out to 50,000 AU
  - Periods > 10^5 yrs
  - Probably did not form there. Ejected bodies by Jovians.

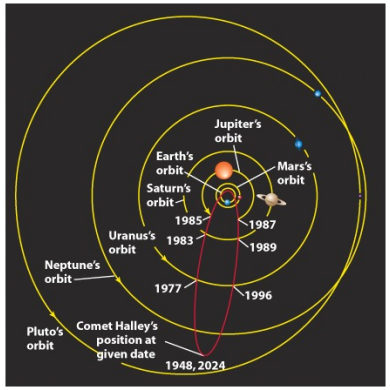
Falling Into the Solar System

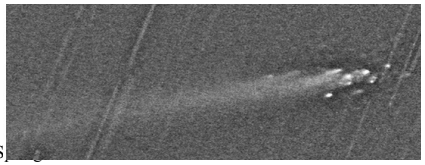
- Occasionally, comet orbits get "perturbed" by passing stars
- They fall into the inner Solar System on highly elliptical orbits
- Interactions with planets can shorten their orbits



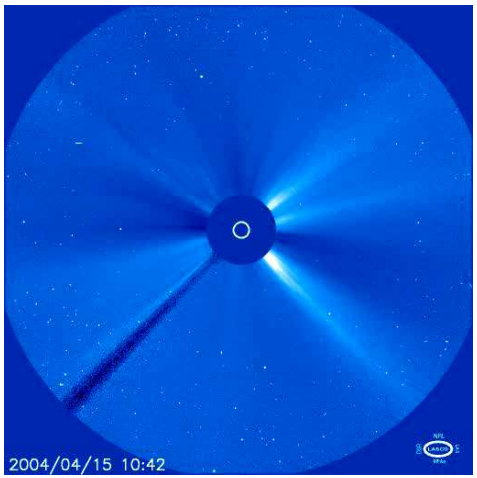
Life & Death of a Comet

- Even comets on shortened orbits live mostly in the outer solar system
- Every orbit, they lose 1% of their masses to solar evaporation
  - Halley's Comet will only last about 5600 more years
- When they become too small, they break apart

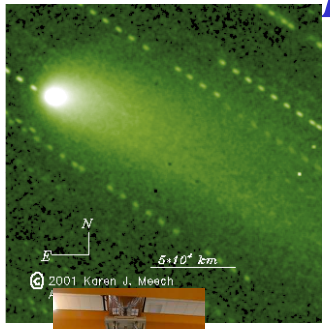




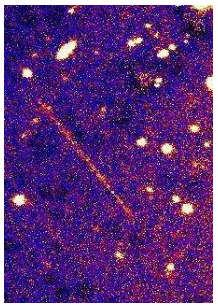
Life & Death of a Comet



Deep Impact



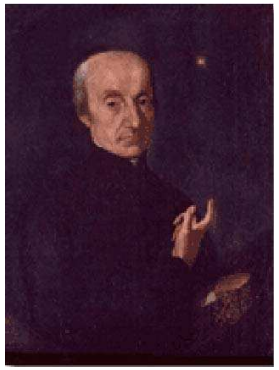
Deep Impact



http://realserver1.jpl.nasa.gov:8080/ramgen/Video-NASA1st-Pesrson-Yeomans-AVC2005-016.rm

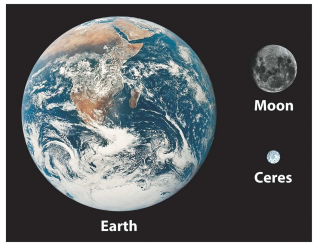
Discovery of the Asteroids

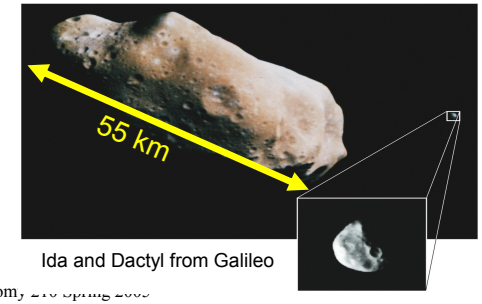
- In 1801, Giuseppe Piazzi noticed an uncharted "star" that shifted position among the stars over several nights
- Could it be another planet?
  - Its orbit was between Mars and Jupiter
  - Very dim, so it must be small
  - Too small to be a planet
- It was an *asteroid,* a "minor planet"



Asteroids

- Small sizes
  - Largest – Ceres: 940 km across
  - Only 3 more than 300 km
  - About 240 bigger than 100 km
  - Millions under 1 km
- Composition
  - Rocks (silicates) and iron/nickel

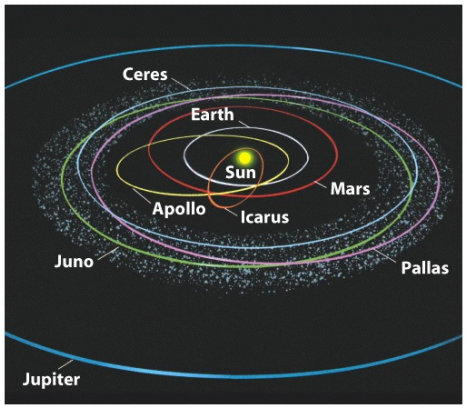




Ida and Dactyl from Galileo

The Asteroid Belt

- Most asteroids are found between 2 to 3.5 AU
  - Between Mars & Jupiter
  - Region is called the **Asteroid Belt**
  - Nearly circular orbits



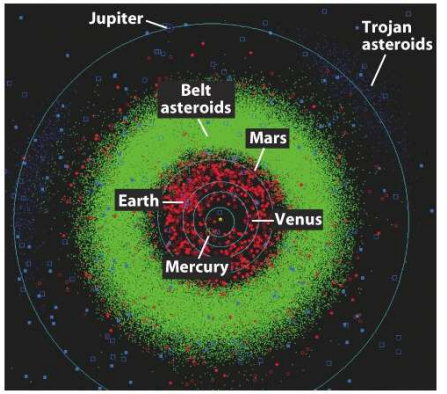
The possibility of successfully navigating an asteroid field…

- Actually, NASA has sent many space probes into and through the Asteroid Belt
- Unlike in Star Wars, the Asteroid Belt is not that crowded
- Average separation between sizable asteroids is 10 million km!

Destroyed… by the Empire

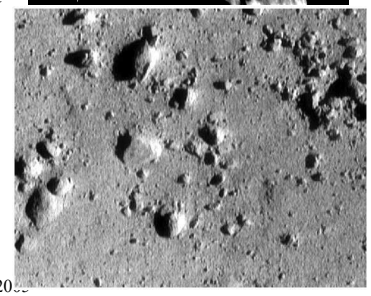
- Are the asteroids a destroyed planet? **No**
  - Combined, the asteroids have a mass about 0.1% that of the Earth
  - Less than 10% that of our Moon
- The asteroids might be a *failed* planet
  - Jupiter's gravity kept the asteroids from coalescing into a planet
  - Jupiter probably ejected many asteroids from the Solar System

Apollos and Trojans



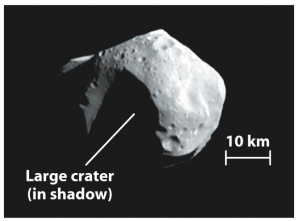
- Some asteroids are on orbits that cross Earth's orbit
  - Called *Apollo asteroids*
  - At least 1690 are known
  - In 1972, one skipped off the Earth's atmosphere
- Other asteroids share Jupiter's orbit!
  - Called *Trojan asteroids*
  - Lead and trail Jupiter around the Sun

Landing on Eros



- In 2001, NASA landed a spacecraft on the asteroid Eros
- Heavily cratered surface
- Boulders buried in the regolith
- Ancient – 4.6 billion years old

Asteroids - Early Solar System Leftovers



- The asteroids were too small to have much internal heat
  - No differentiation
  - No geologic activity
  - The same as when they formed 4.6 billion years ago
- Fossils of the early solar system!

Meteors

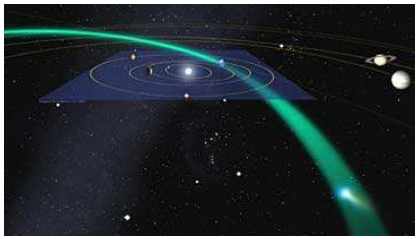
- When you see a "shooting star", that is a **meteor**
  - A piece of solar system debris (a **meteoroid**) interacting with our atmosphere
- Most "burn up" or disintegrate in the upper atmosphere, but some do survive fall
  - These are **meteorites**
- Composition: rock, some metals

Meteor Showers

- Meteors hit Earth all the time
- In the early morning, you can typically see about 3 per hour
- Several times a year, the rate increases
  - Maybe more than a meteor per minute
  - Called **meteor showers**
- Seem to originate from a single point in the sky

Meteor Showers

- When a comet enters the inner Solar System, it leaves a trail of dust
- When Earth passes through this dust, we get a meteor shower
- Meteor showers don't typically produce meteorites
  - Its all dust, not rocks



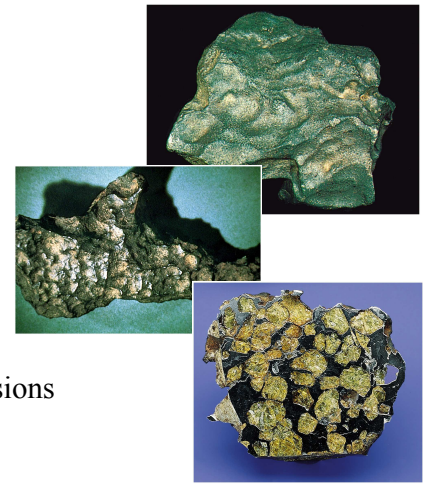
Prominent Yearly Meteor Showers

Shower	Date of maximum intensity	Typical hourly rate	Constellation
Quadrantids	January 3	40	Boötes
Lyrids	April 22	15	Lyra
Eta Aquarids	May 4	20	Aquarius
Delta Aquarids	July 30	20	Aquarius
Perseids	August 12	80	Perseus
Orionids	October 21	20	Orion
Taurids	November 4	15	Taurus
Leonids	November 16	15	Leo Major
Geminids	December 13	50	Gemini
Ursids	December 22	15	Ursa Minor

Peekskill Fireball (October 9, 1992)

Types of Meteorites

- 94% of meteorites are **stony**
  - Made of silicates, hard to distinguish from Earth rocks
- 5% are **irons**
  - Iron-nickel crystals
- 1% **stony-irons**
  - Silicates with iron inclusions



Meteorites are Ancient

- Meteorites are the oldest objects in the Solar System
- Remnants of the Solar System's formation
- The oldest are carbonaceous chondrites (a type of stone)
  - Abundant in carbon and water
  - Contain amino acids - building blocks of life!
  - 4.56 billion years old
- Some have diamonds produced by interstellar shock waves!

Carbonaceous chondrite

Meteorite Observing

- The UofI has a small meteorite collection in the Natural History Building
- Activities:
  - Count the numbers of each type of meteorite, compare to the fractions that exist in space
  - Why do we know when most of the stony meteorites fell, but not the iron ones?
  - Visit a web-site, learn about how to identify meteorites
- Extra Credit Report: Due April 8th, worth 1/3 a homework.

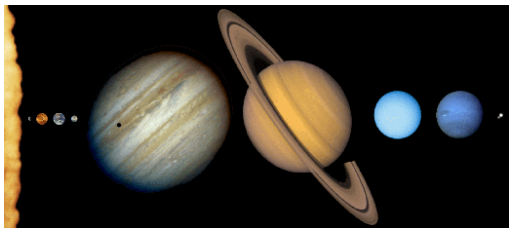
What is the origin of the Solar System?

- Explain present-day Solar System data.
- Predict results of new Solar System data.
- Should explain and predict data from other stars!

What are clues to solar system origins?

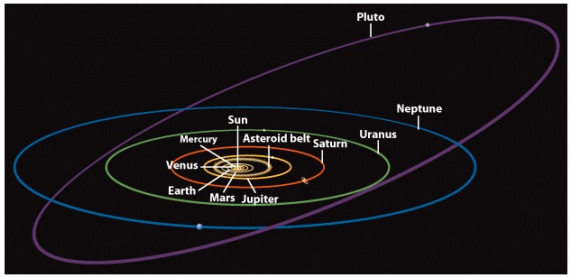
Some Facts of the Solar System

- Mass of solar system
  - 99.85% in the Sun (planets have 98% of ang. mom.)
  - Outer planets more massive than the inner ones
  - Jupiter is more than twice as massive as the rest of the planetary system combined!
- The inner planets are rocky and the outer planets are gaseous



Planetary Orbits

- Most of the motions in the Solar System are counter clockwise in a flat system (pancake-like)



  - There are some exceptions
  - Venus, Uranus, and Pluto rotate clockwise
  - Some moons orbit backwards

http://janus.astro.umd.edu/javadir/orbits/ssv.html

What is the Age of the Solar System?

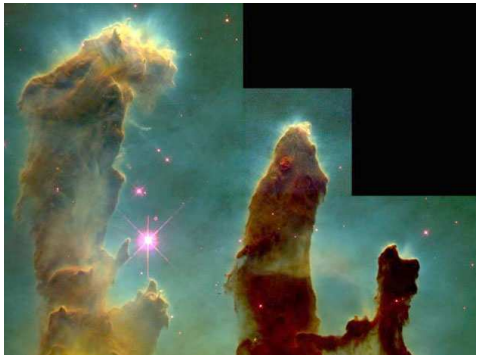
- Earth: oldest rocks are 4.4 billion yrs
- Moon: oldest rocks are 4.5 billion yrs
- Mars: oldest rocks are 4.5 billion yrs
- Meteorites: oldest are 4.6 billion yrs
- Sun: models estimate an age of 4.5 billion yrs

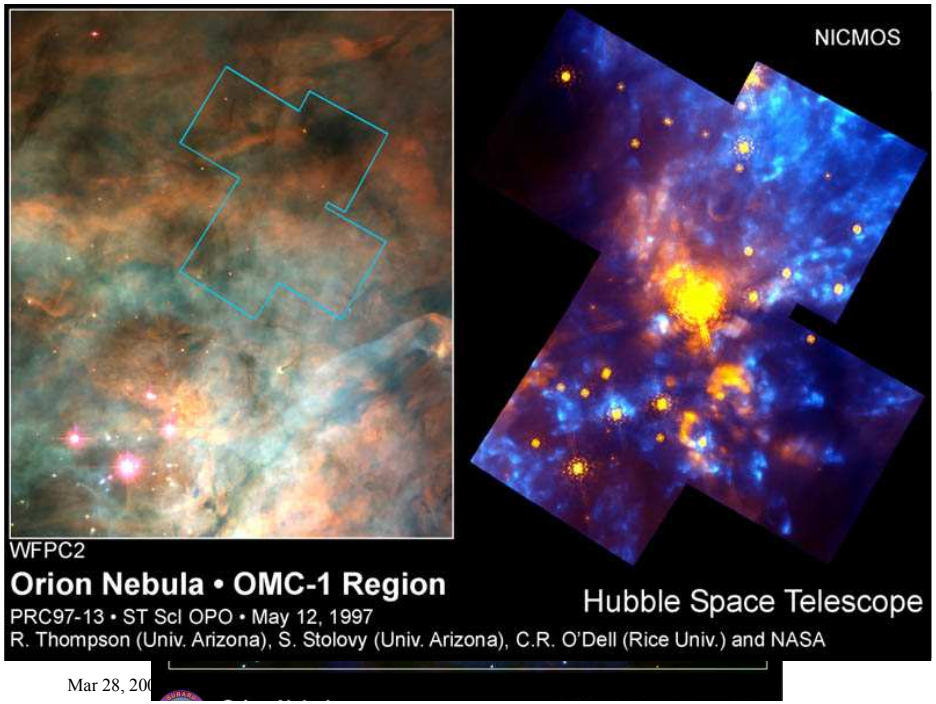
- **Age of Solar System is probably around 4.6 billion years old**

Solar Nebula Theory

- Proposed by Immanuel Kant (the philosopher)
- The solar system formed from a spinning cloud of gas, dust, and ice
  - Mostly hydrogen and helium
  - 4.6 billion years ago

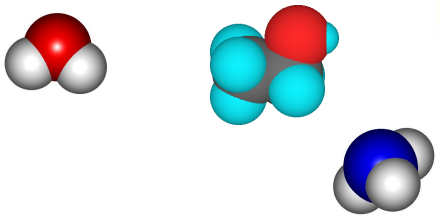
"*nebula*" = space cloud

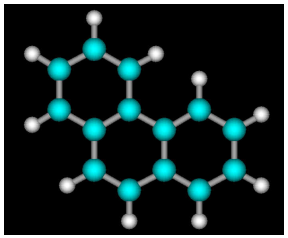




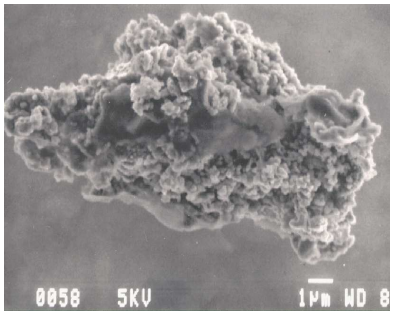
Other Things Besides Hydrogen in Molecular Clouds

- Molecules (e.g.)
  - Carbon monoxide (CO)
  - Water (H_2O)
  - Ammonia (NH_3)
  - Formaldehyde (H_2CO)
  - Glycine (NH_2CH_2COOH)?
  - Ethyl alcohol (CH_3CH_2OH)
  - Acetic Acid (CH_3COOH)
  - Urea [$(NH_2)_2CO$]
- Dust particles
  - Silicates, sometimes ice-coated
  - Soot molecules





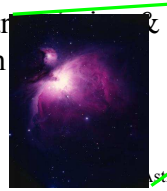
Polycyclic aromatic hydrocarbons (PAH)

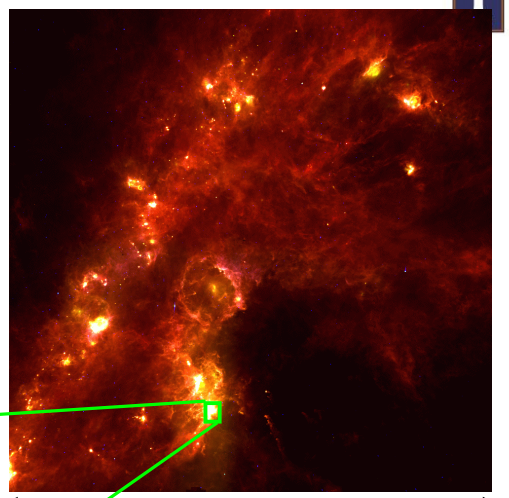


Dust particle (interplanetary)

Giant Molecular Clouds

- Cool: < 100 K
- Dense: $10^2 - 10^5$ H_2 molecules/cm^3 (still less dense than our best vacuum)
- Huge: 30 – 300 lyrs across, $10^5 - 10^6$ solar masses
- CO molecular & dust emission structure

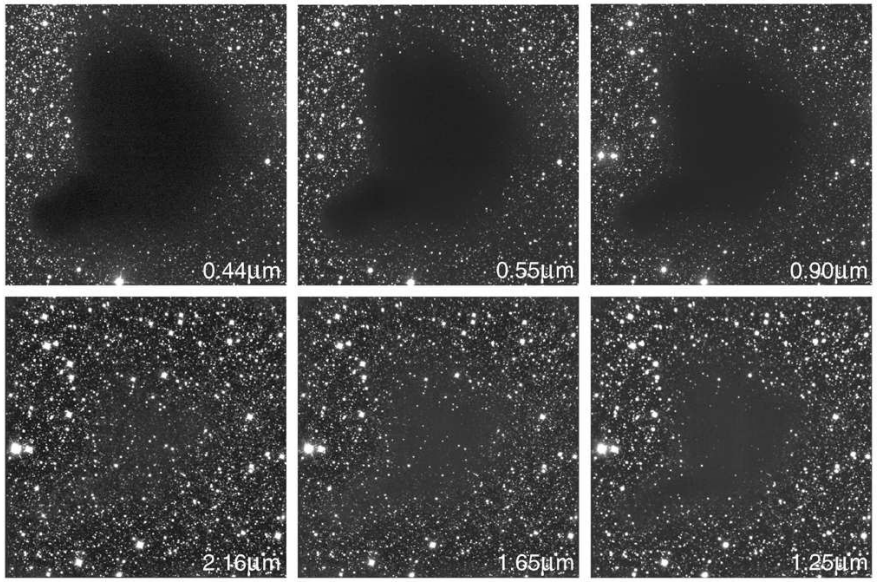




Infrared image from *IRAS*

Interstellar Clouds

http://www.seds.org/messier/more/oricloud.html



The Dark Cloud B68 at Different Wavelengths (NTT + SOFI)

ESO PR Photo 29b/99 (2 July 1999)

Solar Nebula Theory

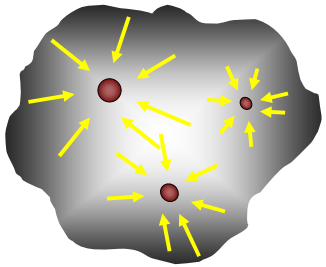
- In these clouds are small clumps that become gravitationally unstable
- The gas and dust has mass (thus gravity)
- Gravity pulls it toward the center – contracts!

- **Question:** What do you think happens?

Gravity follows the inverse square law, so closer = stronger. Once it falls in a little, it gets pulled in more.

RUNAWAY GRAVITY!

Cloud Contraction



Interlude: Angular Momentum

Spinning or orbiting objects in closed system have angular momentum.

Angular momentum is a single, *constant* number: =*conserved*!

Keep same dist. to axis → velocity same

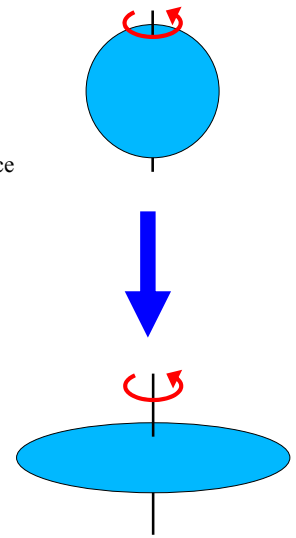
Move closer to axis → speed up!

Recall Kepler 2nd law – really due to angular momentum!

When Doves Cry and Stars Form

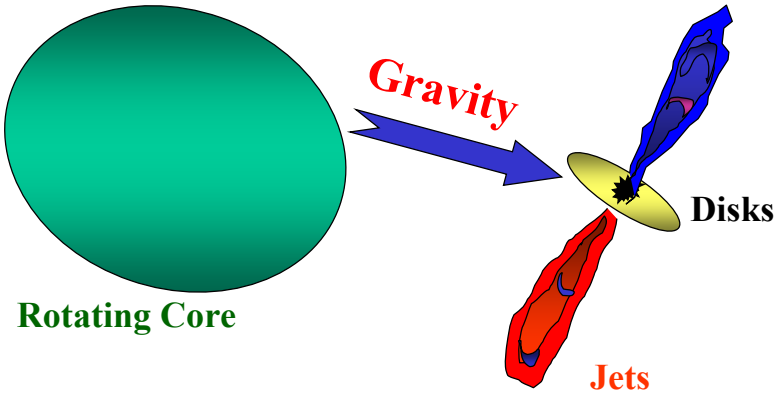
Solar nebula competition:
Gravity vs Angular Momentum

- If fall perpendicular to spin axis
  speed up → resistance centrifugal force
- If fall parallel to spin axis then
  same speed, so no resistance
  → form ***protoplanetary disk***
  - Origin of ecliptic!
  - Organizes orbits in same direction
  - Organizes spins along initial spin axis



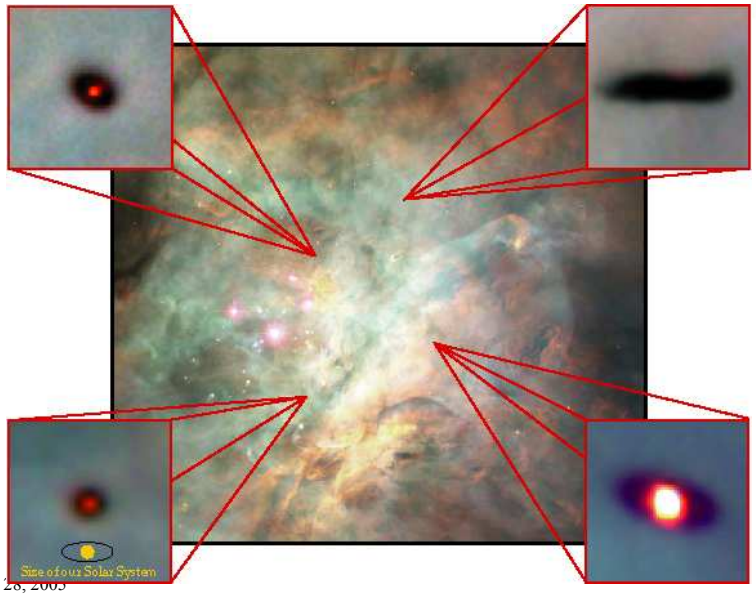
The Protostar Stage

Gravity, Spin, & Magnetic Fields

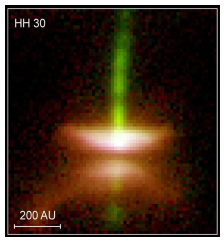


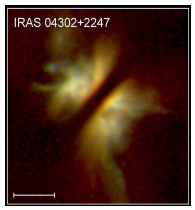
The Orion Nebula

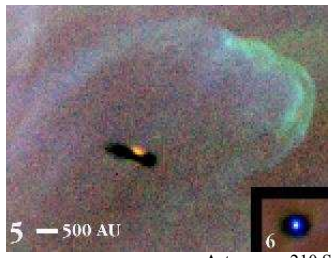
Disks around Young Stars are Common

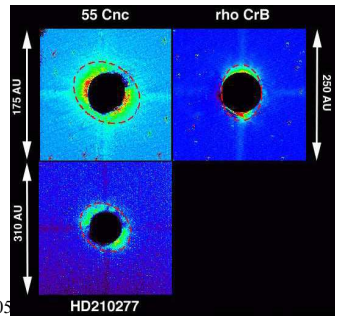


And Disks around Young Stars are Common



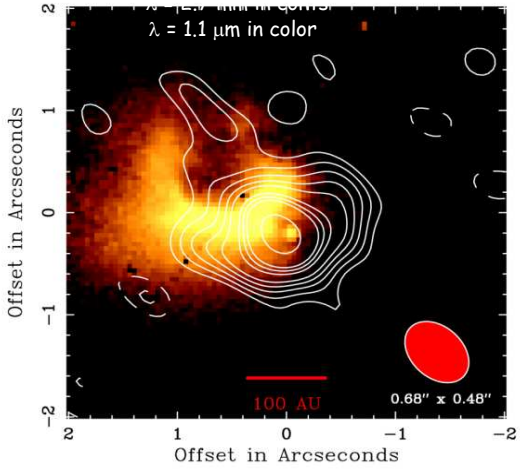






http://www.ifa.hawaii.edu/users/tokunaga/SSET/SSET.htm

The Circumstellar Disk of HL Tauri



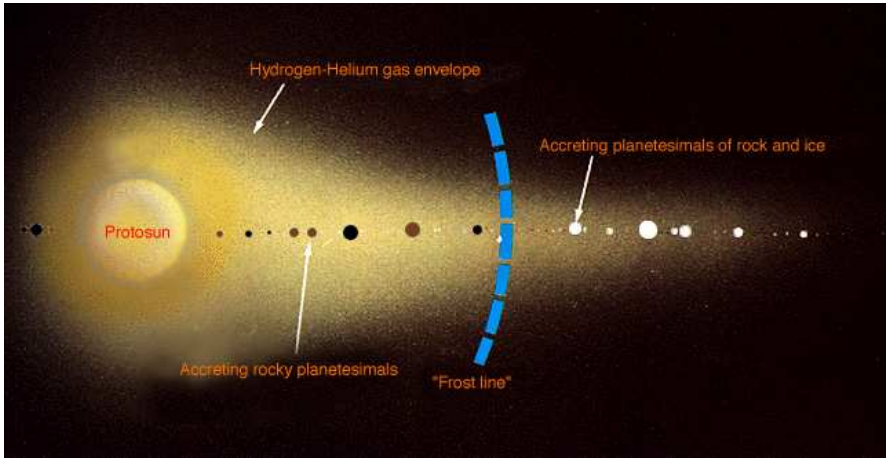
Formation of the Solar System 4.6 billion years ago

Planet Formation in the Disk

Heavy elements clump and then

1. *Dust grains* collide, stick, and form planetesimals– about 10^{12} of them, sort of like asteroids! All orbit in the same direction and in the same plane.
2. Gravity Effects: Big planetesimals attract the smaller planetesimals. So, fewer and fewer of large objects (100's). Collisions build-up inner planets and outer planet cores.
3. Collisions can also account for odd motions of Venus (backwards), Uranus (rotates on its side), and Pluto (high inclination of orbit). Proof of period of high collision evident on moon

Why are the Planets so Different?



Temperature is the key factor!

Why are the Planets so Different?

- Temperature is the key factor
- Inner Solar System: Hot
  - Light gasses (H, He) and "ices" vaporized
  - Blown out of the inner solar system by the solar wind
  - Only heavy elements (iron & rock) left
- Outer Solar System: Cold
  - Too cold to evaporate ices to space
  - Rock & ice "seeds" grew large enough to pull gasses (H, He) onto themselves

Heavy Bombardment

- There were billions of planetesimals in the early solar system
- Many collided with the young planets
  - Look at the Moon & Mercury!
  - Period of **heavy bombardment**
  - Lasted for about the first 800 million years of the Solar System
- Others were ejected from the solar system…

Earth's Water Source?

- There are two ideas on where Earth's water came from:
  - Released from within by volcanic vents
  - Brought to Earth by comets during the heavy bombardment

Fates of the Planetesimals

- Between Mars and Jupiter
  - Remain as the asteroids
- Near Jupiter & Saturn
  - Ejected from the solar system
- Near Uranus & Neptune
  - Ejected to the Oort Cloud
- Beyond Neptune
  - Remain in the Kuiper Belt

Results

- Most disk matter goes into the planets
- Asteroids and comets are left-over planetesimals
  - "Fossils" of solar system birth!
- The Solar System continues to evolve, but slower
  - Outer planets still contracting
  - Earth and Venus are still volcanically active
  - Impacts from left-over planetesimals continue

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?

? Are massive planets farther away?