Star Formation

- Dense cores of molecular clouds collapse into hot plasma which eventually triggers nuclear reactions.
- Conversion of gravitational energy both heats the material and releases infrared radiation.
- Dense clumps form in protostellar disc that eventually themselves collapse into planets.
- Conservation of angular momentum requires spin rate to increase during collapse and disc formation.
- Emissions of protostar hidden by cooler infalling matter; eventually breaks out at poles (least resistance), producing jets.

- Sufficiently rapidly rotating collapses form double or multiple stars.
- Young star’s emissions sweep out gas and dust from planetary system.
Star Forming Regions

M42
C.R. O'Dell (Rice U.), NASA

NGC 604

M8

Lagoon Nebula Detail
HST • WFPC2
James Lattimer
Solar System Formation – History

- Georges Buffon suggested (1745) that the planets formed when a massive object (a comet, he thought) collided with the Sun and splashed out debris that coalesced into planets.
- Immanuel Kant proposed (1755) that the solar system formed from the gravitational collapse of an interstellar gas cloud.
- Pierre-Simon Laplace (1790) independently proposed Kant’s idea and suggested planets formed in successive rings of gas.
- Kant and Laplace idea is called the *nebular hypothesis*.
- Laplace’s ring idea was eventually replaced by condensation of solids into planetismals and gravitational accretion of solids and gases into planets.
- Modified nebular hypothesis agrees well with observations of compositions of different objects in the solar system.
- Chance close encounters are too rare.
- New observations of extra-solar planets are forcing modifications to explain surprising planetary orbits.
Solar System Formation – Major Stages

- Contraction: of a diffuse interstellar gas cloud due to gravity.
- Conservation of angular momentum: leads to increase in rotation rate and flattening. Thermodynamic laws result in heating as the central density rises.
- Condensation: Heavier elements condense into solid dust grains – metals and rocks (inner), ices like H$_2$O and CO$_2$ (outer).
- Accretion: Dust grains collide and stick.
- Continued accretion leads to formation of rocks; gravity helps form planetismals and planets. Gases retained on outer planets.
- Clearing: Solar heating repels gaseous matter that is not bound to planets. Most dust is incorporated into planets.
- Comets can be ejected far beyond planets by gravitational encounters with planets, which also causes planetary migrations. Asteroids are either material which never formed a planet (Jupiter’s influence?), or debris from collisions of planetismals.
As it contracts, the cloud heats, flattens, and spins faster, becoming a spinning disk of dust and gas. Large, diffuse interstellar gas cloud (solar nebula) contracts under gravity. Sun will be born in center. Planets will form in disk.

Warm temperatures allow only metal/rock "seeds" to condense in inner solar system.

Cold temperatures allow "seeds" to contain abundant ice in outer solar system.

Hydrogen and helium remain gaseous, but other materials can condense into solid "seeds" for building planets.

Terrestrial planets are built from metal and rock.

Solid "seeds" collide and stick together. Larger ones attract others with their gravity, growing bigger still.
Solid “seeds” collide and stick together. Larger ones attract others with their gravity, growing bigger still.

The seeds of jovian planets grow large enough to attract hydrogen and helium gas, making them into giant, mostly gaseous planets; moons form in disks of dust and gas that surround the planets.

Solar wind blows remaining gas into interstellar space.

Terrestrial planets remain in inner solar system.

Jovian planets remain in outer solar system.

"Leftovers" from the formation process become asteroids (metal/rock) and comets (mostly ice).

Not to scale
Remember that momentum is conserved in the absence of external forces. Likewise, angular momentum is conserved in the absence of external torques.

The skater begins spinning with her arms extended. But when she pulls in her arms, her rotational inertia goes down. Her angular momentum remains constant—so her angular velocity increases!

WOW!

“We’ve discovered a massive dust and gas cloud which is either the beginning of a new star, or just an awful lot of dust and gas.”

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**Materials in the Solar Nebula**

<table>
<thead>
<tr>
<th></th>
<th>Metals</th>
<th>Rocks</th>
<th>Hydrogen Compounds</th>
<th>Light Gases</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Examples</strong></td>
<td>iron, nickel,</td>
<td>silicates,</td>
<td>water (H₂O),</td>
<td>hydrogen, helium</td>
</tr>
<tr>
<td></td>
<td>aluminum</td>
<td></td>
<td>methane (CH₄),</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ammonia (NH₃)</td>
<td></td>
</tr>
<tr>
<td><strong>Typical Condensation Temperature</strong></td>
<td>1,000–1,600 K</td>
<td>500–1,300 K</td>
<td>&lt; 800 K</td>
<td>(do not condense in nebula)</td>
</tr>
<tr>
<td><strong>Relative Abundance (by mass)</strong></td>
<td>(0.2%)</td>
<td>(0.4%)</td>
<td>(1.4%)</td>
<td>(98%)</td>
</tr>
</tbody>
</table>

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**Centrifugal Force, n.**

The strong inward force experienced by a unit of currency clasped in the hand of a rotating Scotsman.
Planetismals Form

Inner disk heated by young Sun. Ices and gases cannot condense. Particles that condense here are mainly silicates and iron compounds. Mercury, Venus, Earth, Mars, Jupiter, Saturn.

Cold outer disk. Ices and gases condense here, as well as silicates and iron compounds.

Infalling dust

Bipolar outflow

X-wind

Key:
- interstellar dust
- nebula dust
- CAIs and refractory materials
- chondrules
- planetesimals

HH-30

www.astro.virginia.edu/class/skrutskie/ast121/notes/sscond.html

James Lattimer

AST 248, Lecture 5
Kuiper Belt

Green = Kuiper belt object
Orange = Scattered disc object or Centaur
Magenta = Trojan of Jupiter
Yellow = Trojan of Neptune

Eris

Charon
1,250 km

2003 UB_{313}
~ 2,600 km

Sedna
~ 1,600 km

Quaoar
~ 1,250 km

Pluto
2,250 km
Oort Cloud

The orange track represents a typical KBO orbit. Pluto’s orbit is represented by the yellow ring.

herschel.jpl.nasa.gov/solarSystem.shtml
Formation of the Earth

- Earth formed 4.5 Gyrs ago.
- From a small accumulation of gas and dust, it grew by accretion and bombardment of rocky material.
- Impacts and radioactive energy release kept the early Earth very hot and molten.
- A large impact about 4.4 Gyrs ago resulted in the formation of the Moon.

The moon is the largest natural satellite of the Earth; the other moons being Cruithne, asteroid 2003 YN107, 1998 UP1 and 2000 PH5.
• The peak “Late Heavy Bombardment” was from about 4.0-3.8 Gyrs ago.
• The Earth’s high temperature promoted differentiation, forming the core and mantle as heavier elements (Fe, Ni, Co, Mn and S) sank and lighter elements (Si, Mg and O) floated.
• The molten character of the Earth destroyed most traces, but some 4.4 Gyr-old zircons have survived.
• The Earth’s crust solidified and oceans formed about 4 Gyr ago.
• Life seems to have formed on the Earth about the same time.