12.002 Physics and Chemistry of the Earth and Terrestrial Planets
Fall 2008

Solar System Formation

How do we think the solar system formed. Conditions and observations?

➔ Sun formed out of collapse of giant molecular cloud.

Observations of molecular clouds 1 – 10 million M_{Sun},10 – 30 K

Pressure = few thousand molecules/cm^3. Astronomical observations show that their compositions are indistinguishable from the Sun and bulk solar system.

Molecular clouds are made primarily of gas (H, He) and a little dust.

Why don't giant molecular clouds just collapse quickly? Several forces oppose self-gravity:

-ordinary gas pressure

-magnetic field (exerts pressure, do not like to move in and out of conductors- Frozen Flux Theorem). Shrinking cloud increases magnetic intensity inside, which increases magnetic pressure.

-Rotation: centripetal force

-Turbulence

Then why do molecular clouds collapse?

1. Passage through a spiral arm (density waves in Milky Way travel at .5 speed of galactic rotation)
2. Supernovae (direct evidence of a supernovae – radioactive nuclides – made during nucleosynthesis of supernovae – preserved inside grains, enriched in short lived nuclides)

Cloud loses gravitational energy as it collapses. Some of this is converted into heat. This heat is then radiated away. This predicts that clouds should be bright in the infrared and we should be able to see them before stellar fusion even begins.

➔ They appear as infrared emission in excess of that from central star.

Wien Displacement Law

λ_{max} [meters] = $2.9 \times 10^{-3}/T$

Planck – Radiation Law gives brightness of a radiating body

$$B_\nu(T) = \frac{2h\nu^3}{c^2} \frac{1}{e^{\frac{h\nu}{kT}-1}}$$

The bigger the temperature the more intense the radiation, with peak wavelength of emission shifting to higher frequency. Lower temperature means lower flux➔ colder objects are harder to detect.

Detection of this “infrared excess” in T Tauri stars provided some of the first evidence for formation of planetary systems. Infrared excess persists for only first several million years of stellar life.

Relic of net angular moment of cloud (spinning = centripetal force). Emmanuel Swedenborg, Immanuel Kant, 18th centur → planetary nebular should be discs.

After a few million years, the sun turns on, blasts away the dust (radiation pressure via solar wind). This may be the reason why we have terrestrial planets in the inner solar system, and gas giants in the outer solar system. However, nearly all detected extrasolar planets are gas giants located very close to the star (although major observation bias in favor of this).

Lewis Condensation sequences. What is the sequence of crystallization from the gas? Predicts first phases are rich in Ca, Al.

CAIs – calcium aluminum inclusions—oldest known solar system solids. Condensed straight from gas. As the solar system cools, the inner solar system stays hot (never gets below 150 K), but outer solar system is cooler.

Blackbody equilibrium temperature at 2-3 AU today = 150 K (the asteroid belt)

“The Frost Line” divides rocky planets from giant planets.