Lecture

Solar Nebula and Condensation

Objectives

• Solar nebula: dense cloud, protoSun, protoplanetary disc, solar wind
• Condensation: molecular substances, ionic substances, condensation sequence, refractory elements, volatile elements, condensation of water into ice at 5 AU

Notes

• ***From Big Bang to solar nebula***
According to a widely accepted view, the Universe started with a Big Bang about 13 Ga ago. Clumps of material then formed into galaxies. Our galaxy, the Milky Way, contains 10^{11} stars and interstellar medium (the material between stars). Dense clouds are relatively common in the Milky Way. They are characterized by a low temperature (typically 10 K), a high density (by the standards of interstellar medium), and a rich collection of molecules. Once a dense cloud reaches the critical mass (known as Jeans mass), it can contract under the gravitational force (gravitational collapse) and initiate a star-formation process.

The trigger for gravitational collapse is uncertain. Ideas include a nearby supernova explosion, interaction between dense clouds, and passage of the cloud through a spiral arm of the galaxy.

Current models of Solar System formation are based on the nebula hypothesis. Solar nebula is the hypothetical rotating cloud of gas and dust within which the Sun and other constituents of the Solar System formed.

Solar System formation is a highly dynamic process, involving material falling in and flowing out, accumulating and breaking up, heating and cooling.

Some key stages of Solar System formation have been recognized:
1, As the solar nebula flattens, it gives rise to a protoSun and protoplanetary disc (also known as circumstellar disc, a disc of gas and dust around a star from which planets may form);
2, ProtoSun grows (solar accretion, accumulation of material onto the protoSun), accompanied by solar wind (a stream of high-speed charged particles, mainly protons and electrons, that spreads out from the Sun and carries traces of the Sun's magnetic field) in the form of bipolar outflows;
3, Upon the completion of solar accretion, protoSun becomes a T Tauri star (a newly formed star that has not yet achieved high enough internal temperature to initiate hydrogen burning), with solar wind in the form of outflows in all directions;
    Planetary accretion begins;
4, T Tauri winds remove residual nebula gas;
    Planetary accretion in the inner Solar System ends;
    Giant planets sweep up the remnant nebula gas.

Evidence for the model has been obtained from the Hubble Space Telescope images of dusty circumstellar discs around young stars, images of bipolar outflow taken by a radio astronomy technique, and observations of star wobble due to the presence of nearby planets (e.g. hot jupiters).

• ***Condensation***
Condensation is the formation of liquid droplet or solid particles by cooling of gas. The Solar Nebula contains molecular substances and ionic substances. Molecular substances have discrete

molecules (atoms or groups of atoms which are capable of independent existence). Examples of molecular substances include water, methane, and ammonia. Ionic substances are composed partly or wholly of charged species (anions, cations). For example, common salt (NaCl) is an ionic substance composed of Na^+ cations and Cl^- anions.

Molecular substances tend to be volatile (with low melting or boiling temperature). Under low pressure in the Solar Nebula, gases of molecular substances condense directly into solid grains. Ionic substances tend to be refractory (with high melting or boiling temperature). In the Solar Nebula, condensation of ionic substance usually occurs before the molecular substances.

The order in which solids would form out of an initially hot, gaseous solar nebula upon cooling is known as the condensation sequence. CAIs (calcium-aluminum-rich inclusions) found in carbonaceous chondrites are composed of highly refractory minerals. The mineralogy of the inclusions matches very well with what is predicted to form at high temperatures in the condensation sequence.

In most types of chondrites, volatile elements are depleted relative to Solar System abundances. Such depletion can be explained by incomplete condensation of a hot Solar Nebula, which separate gaseous volatile elements from the early condensates of refractory elements.

Note that near 5 AU from the Sun, the temperature was low enough for water to condense. Condensation of water increases the relative proportion of dust and may have facilitated the formation of giant planets.