Cosmic Chemistry: Planetary Diversity

Solar Nebula Supermarket

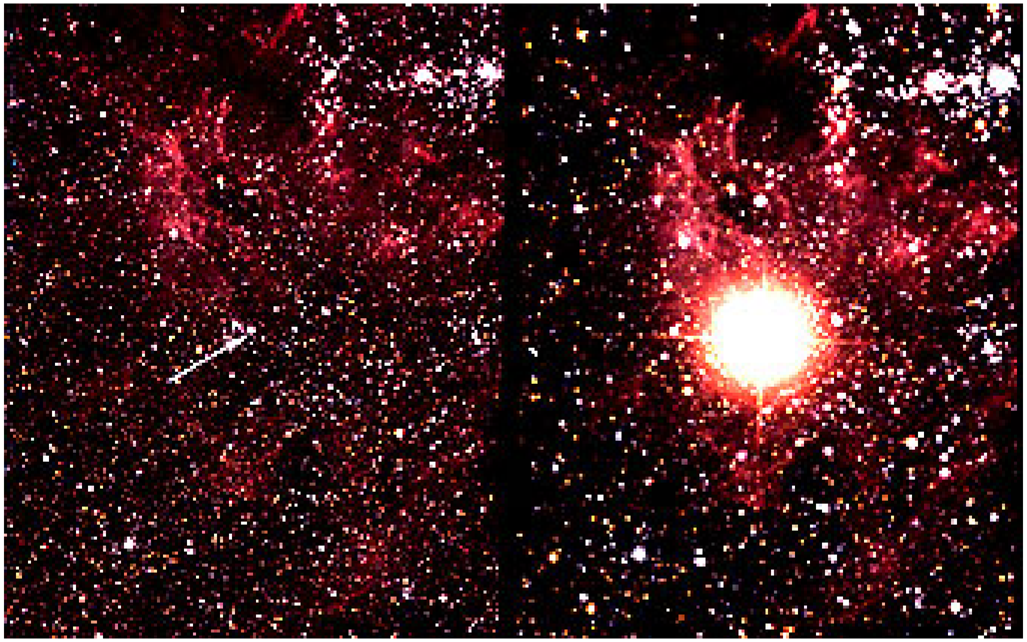
Student Text Supplement

NASA

Most cosmologists believe that the universe was created about 15 billion years ago with the “Big Bang,” a cosmic explosion resulting in an expanding cloud of hydrogen and helium.

Mutual gravitational attractions among hydrogen and helium nuclei at high concentrations led to the formation of the first generation of stars. When enough material had fallen into a new star, the pressure and temperature at its center was great enough to initiate nuclear fusion.

Star Formation in Eagle Nebula *NASA*



NASA

The structure and properties of these stars changed as their nuclear fuels were depleted. Their cores began to contract rapidly, causing dramatic increases in temperature.

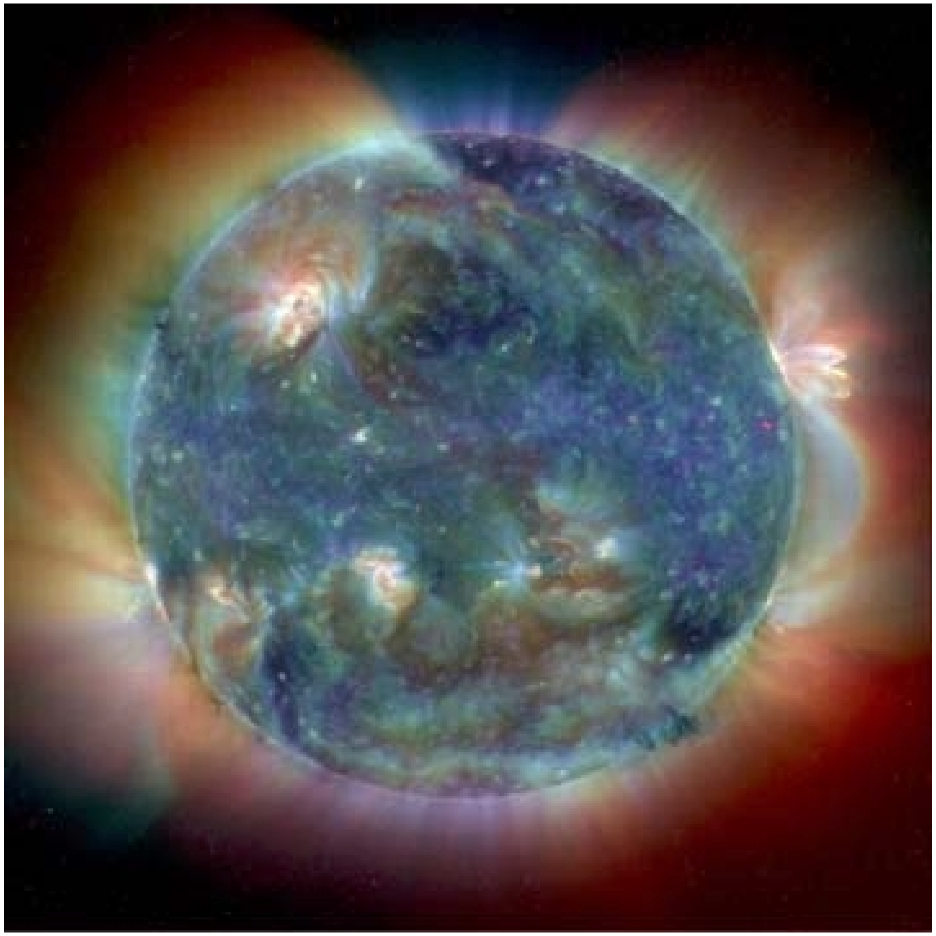
Supernova 1987A Rings *NASA*

Massive, aging, unstable stars became supernovas. They either exploded violently, creating even heavier elements very rapidly and spewing them into space, or they released the nuclear material from their interior zones to the surface. There it was released into space when the outer layers were blown off.

Some of these heavy elements condensed to form small solid grains out of which new stars were formed. This process occurred over and over. Each generation of stars contained higher abundances of heavy elements than the previous generation. These stars formed the building blocks of planets.

Orion Nebula *NASA*

Solar Nebula Supermarket

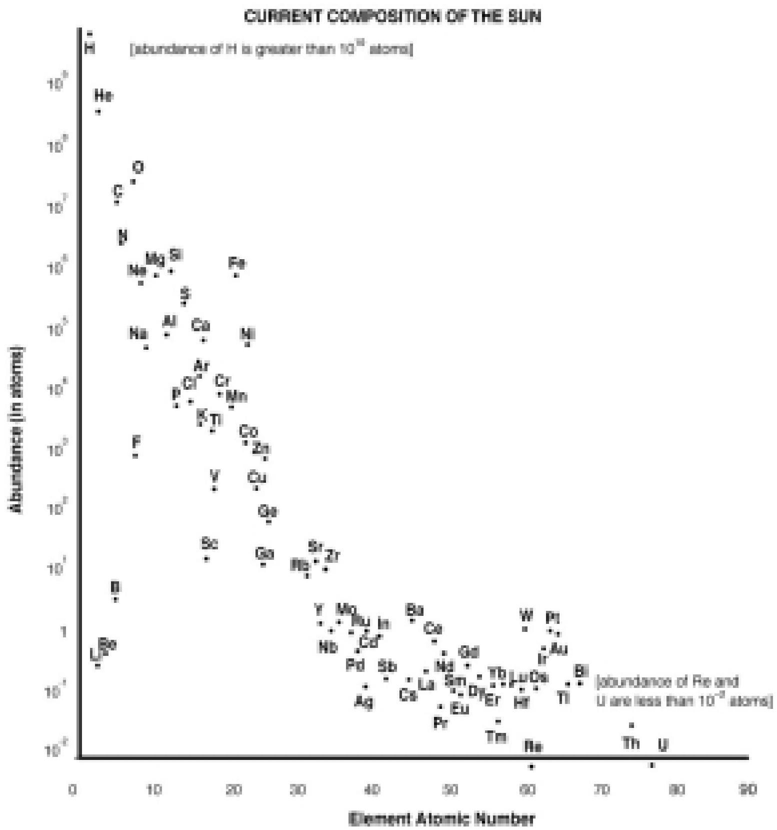


Composite of three images taken from the SOHO observatory *NASA*

Our sun was created about 4.6 billion years ago from a cloud of interstellar dust, ice crystals, and gas. This cloud, which contained most of the elements of the periodic table, contained material accumulated from several generations of supernovas. They collapsed to form the nebula from which the sun and the solar system planets were formed.

Cosmic Chemistry: Planetary Diversity

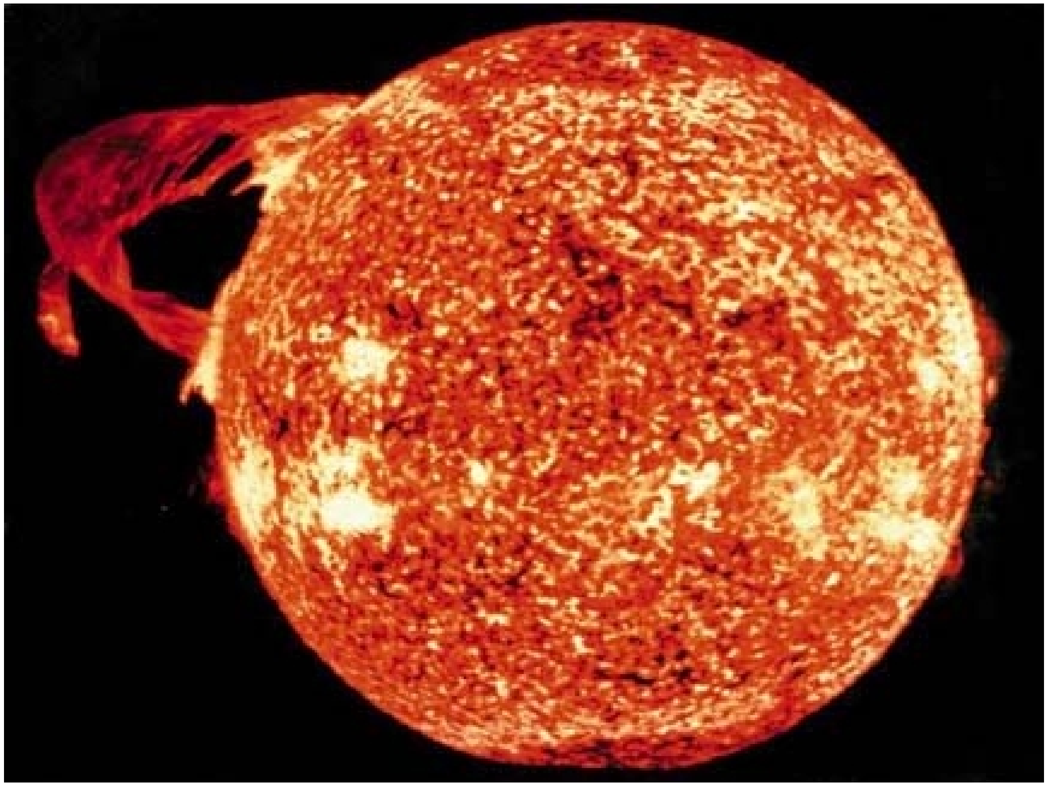
Solar Nebula Supermarket



(Figure 1)

The concentration of these elements decreases rapidly as their atomic numbers increase. Hydrogen is our sun's only fuel source, so the heavier elements must have been inherited from an earlier generation of stars.

Most of the theories of the origin and development of the solar system depend on knowing the original composition of the material from which the sun and planets were formed. How can current data from our sun help reconstruct the composition of the solar system's elemental composition 4.6 billion years ago?



Element	Constituents of Cool Primordial Nebula (percent by mass)
Hydrogen (H_2)	74%
Helium (He)	24%

Hydrogen and helium are thought to be the most prevalent elements in the primordial gas.

Condensed Solids	Constituents of Cool Primordial Nebula (percent by mass)
Water (H_20)	.95
Methane (CH_4)	.5
Ammonia (NH_3)	.05

The remaining two percent of elements in the original solar nebula included carbon, nitrogen, and oxygen.

Solar Nebula Supermarket

Condensed Solids	Constituents of Cool Primordial Nebula (percent by mass)
Water (H_20)	.95
Methane (CH_4)	.5
Ammonia (NH_3)	.05
Rock	.5

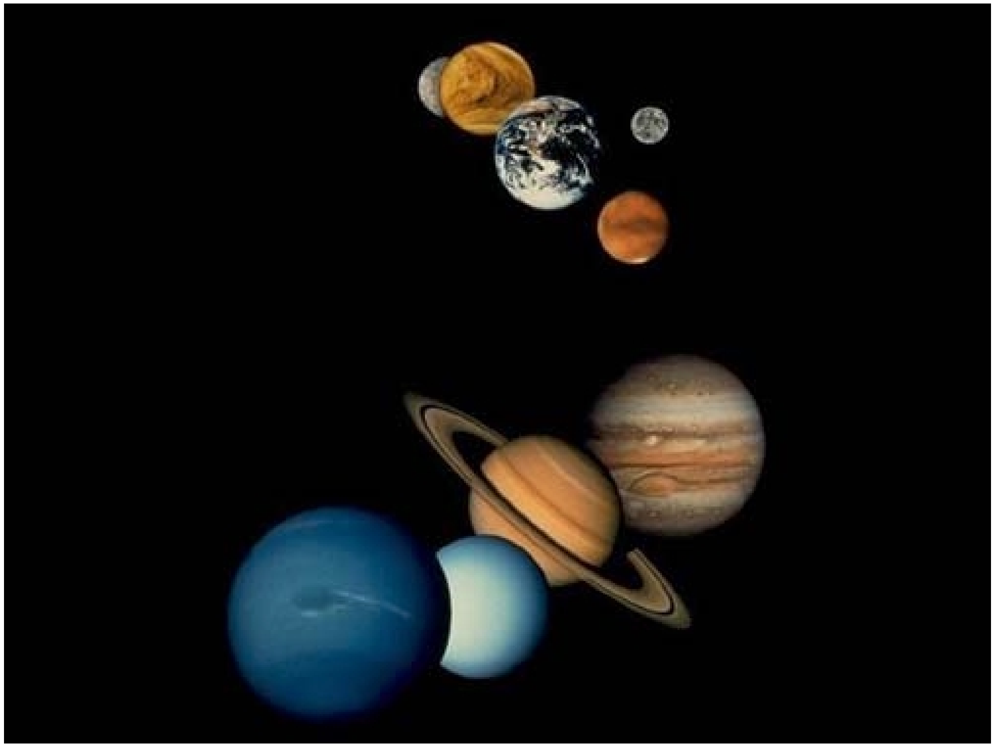
About one-fourth of the condensed material contained metals and silicate “rock.”

Current Abundance of Chemical Elements Observed in the Sun			
Element	**Current Abundance (percent of atoms**	**Constituents of Cool Primordial Nebula (percent by mass)**	
Hydrogen	92.1	Hydrogen	74
Helium	7.8	Helium	24
Oxygen	.061		
Carbon	.030	**Condensed Solids**	
Nitrogen	.0084	Water	.95
Neon	.0076	Methane	.5
Iron	.0037	Rock	.5
Silicon	.0031	Ammonia	.05
Magnesium	.0024		
Aluminum	.00026		
Sulfur	.0015		
Potassium	.000012		
Calcium	.00019		
Titanium	.0000074		
Chromium	.000042		
Manganese	.000029		
Nickel	.00015		

Starbirth in Galaxy NGC 1080 *NASA*

The solar nebula is considered the transition state between the remains of the sun's stellar ancestors and our new sun and its planets.

As it rotated, the cloud flattened until it was shaped like a very large compact disk, about 10^{10} kilometers in diameter—the distance of the sun to Pluto—with a density of 1000 g cm^{-3}.



NASA

Every planet in our solar system appears to have a different elemental and molecular composition. Planetary scientists have explained these differences using many theories, models, and assumptions about the evolution of the solar system.

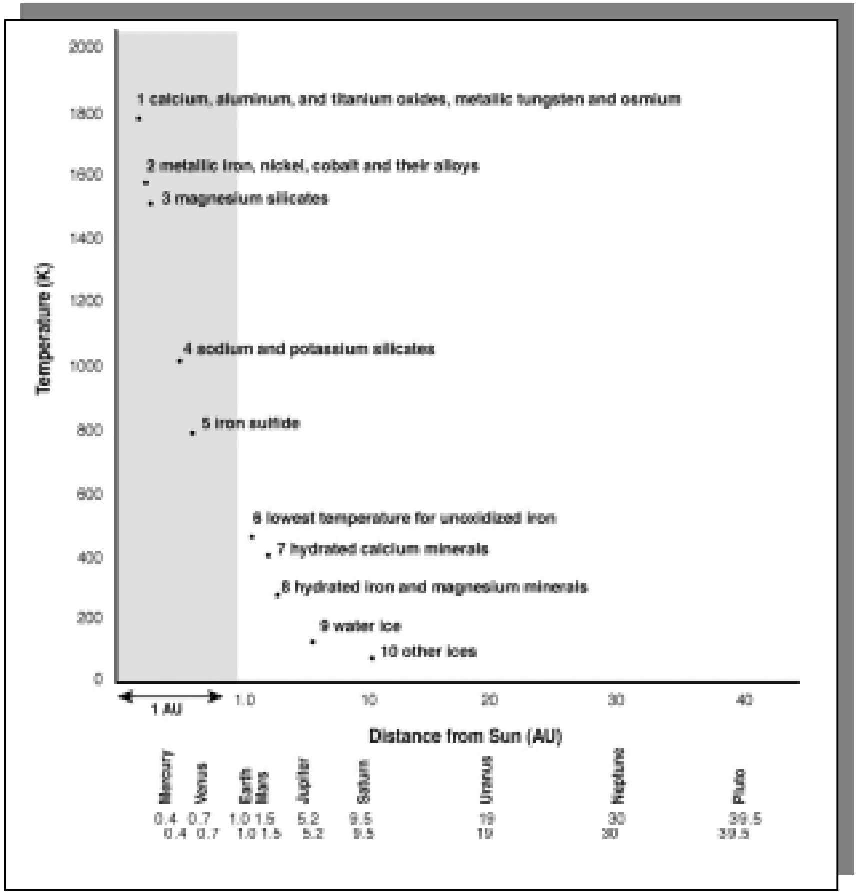
Cosmic Chemistry: Planetary Diversity

Solar Nebula Supermarket

According to the condensation theory, the heat produced by the contraction of the nebular cloud created temperatures of almost 2000 K and pressures of 10^{-2} atmospheres.

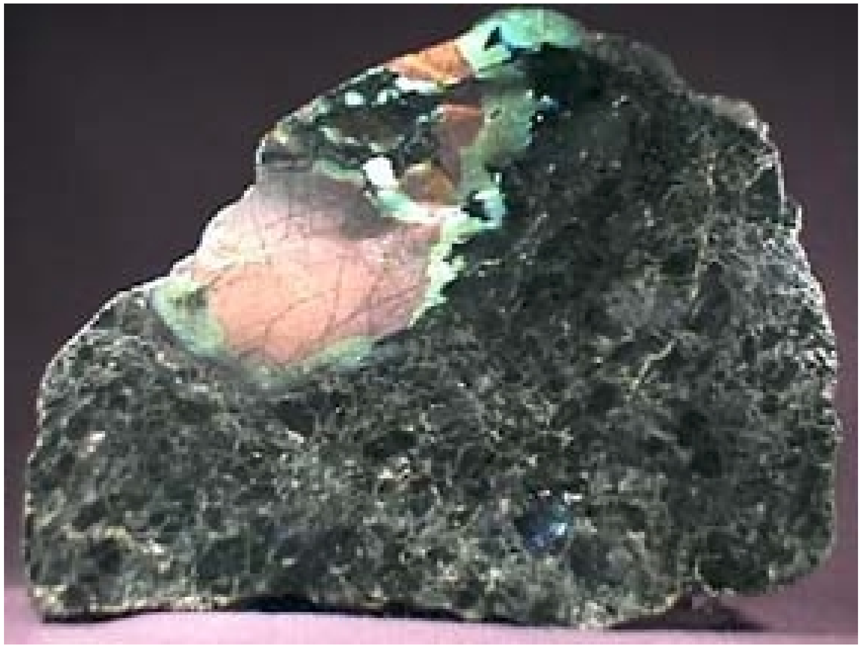
These conditions would lead to at least partial, if not complete, evaporation of the nebular solids.

Ring Nebula *NASA*



(Figure 2)

<u>Figure 2.</u> Temperature (K) and distance from sun (AU) at which major planetary constituents would condense from primordial solar nebula.

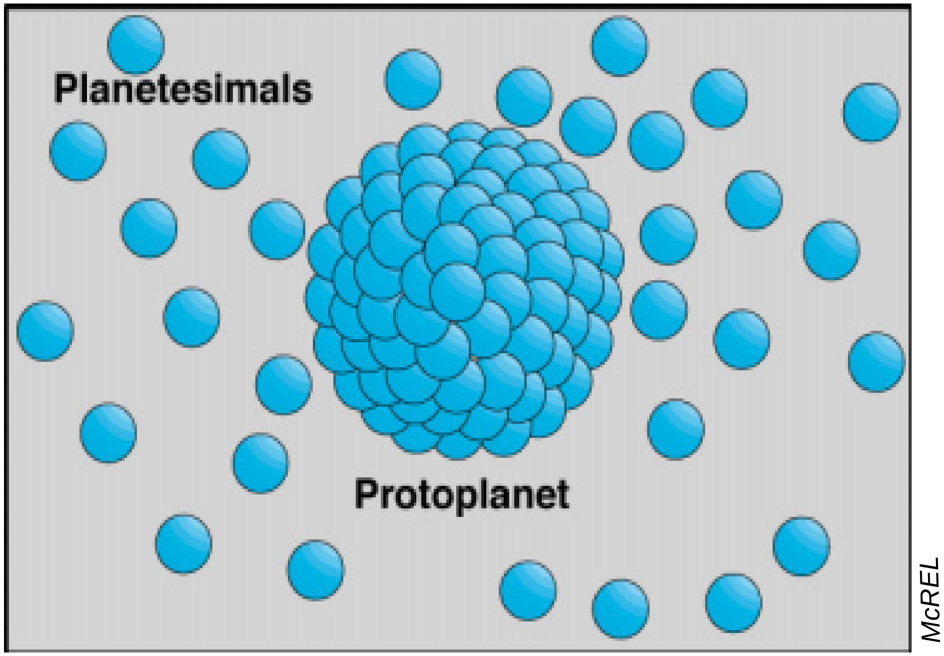


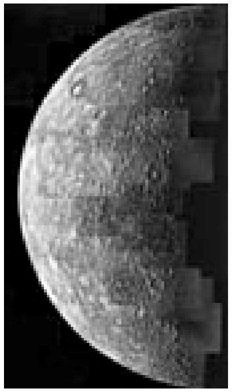
Feldspar *Terran Technologies, Inc.**

As the nebular cooling continued, feldspar materials—such as sodium and potassium silicates—formed. At even lower temperatures, mineral grains reacted with gases to form iron minerals. Next to form were hydrated minerals, followed by water, ice, and frozen methane and ammonia.

*Unless otherwise noted, all mineral descriptions and images, plus the related descriptions on this server are the property of Amethyst Galleries, Inc., and may not be copied for commercial purposes. Permission to copy descriptions and images is granted for personal and educational use only. All such copies must include this copyright notice and explicit references to the URL http://mineral.galleries.com/. All programs and data structures are Copyright © 1995, 1996, 1997, 1998 by Terran Technologies, Inc.. All rights reserved.

Over a period of 100 hundred years, solids migrated to the equatorial plane of the disc. Small grains started sticking together to form larger planetesimals and still larger protoplanets, which had diameters of several hundred kilometers, continued to form over an estimated period of 10^8 years. When the protoplanets stopped growing, most of the planetesimals had joined together to form the nine stable planets.




Mercury


Venus


Earth


Mars

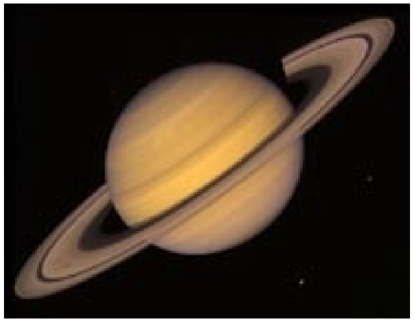
(Images courtesy of NASA)

Planetesimals made of rock from grains of dust probably were the first to be formed because they were made from components with higher freezing temperatures. According to the condensation theory, the four rocky planets—Mercury, Venus, Earth, and Mars—formed closest to the sun in this way.

Cosmic Chemistry: Planetary Diversity

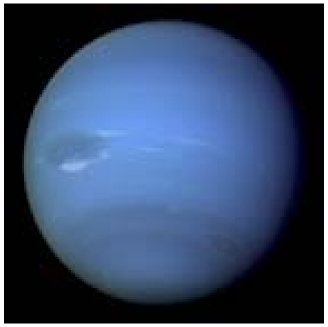
Solar Nebula Supermarket

Jupiter



Saturn

Uranus



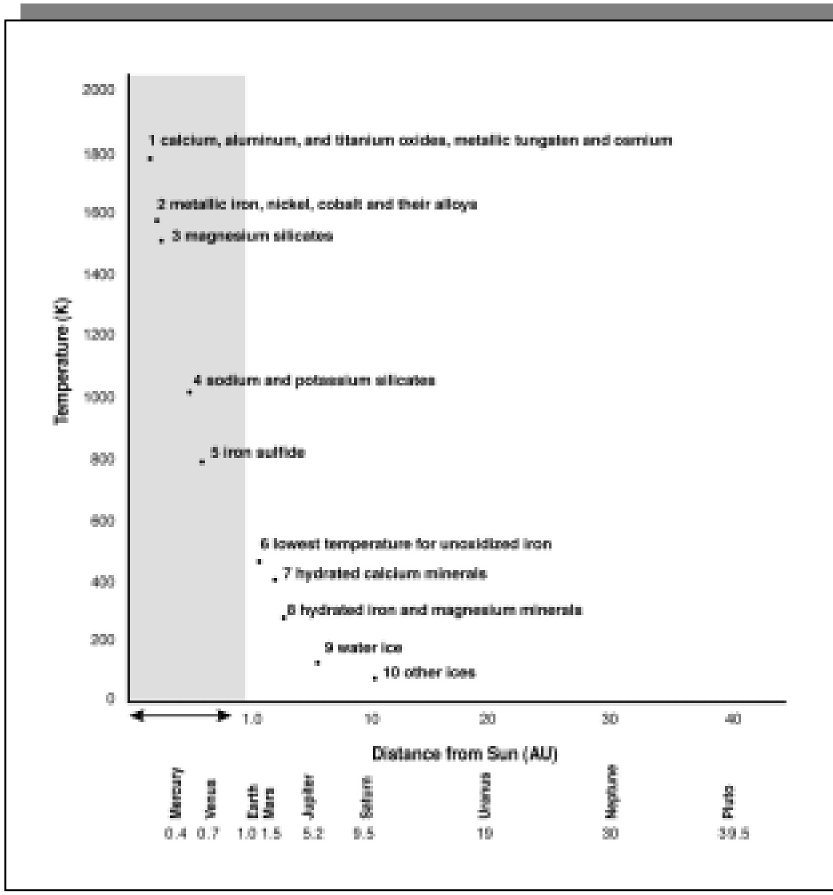
Neptune

(Images courtesy of NASA)

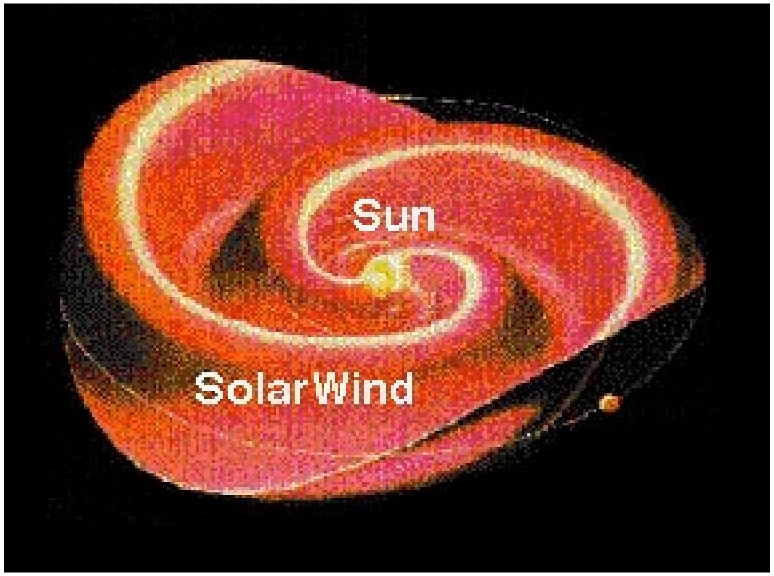
Where the giant planets were forming further from the sun, the temperature of the outer solar system was between 100 to 200 K. Rocks and metals in the planetesimals gave the giant planets their rocky cores, but there probably were larger numbers of ice crystals present in the portion of the nebula forming these protoplanets. As they grew sufficiently large, they attracted large amounts of hydrogen and helium gas from their surroundings.

Cosmic Chemistry: Planetary Diversity

Solar Nebula Supermarket



If the condensation theory has any validity, each planet should reflect the composition of solid particles present in the solar nebula corresponding to its distance from the sun. Planets should become less metallic and possess more ice as one goes farther from the sun. The mineral composition of rocks also should vary predictably among the planets.



It is theorized that the solar wind of the still immature sun had an intensity of approximately 10^8 times what it is today, so it could have acted as a solar whisk broom, sweeping away particles smaller than a few centimeters in size.