The Nebular Hypothesis & Protoplanets

- The Sun forms from a collapsing cloud of <u>cold</u> interstellar gas and dust.
  ... with a time scale of ~ 5 Myr
- The material forms a proto-Sun surrounded by a <u>cool</u> gas and dust disk.
  ... which flattened by rotational forces
- Small particles form and grow in the disc by <u>collisional</u> <u>accretion</u>.
  ... and are bound by chemical forces
- Larger bodies (<u>planetesimals</u>) accrete rapidly with the aid of gravity.
  ... and with collisional heating a by-product
- Planetesimals grow by accretion of gas, dust, and other planetesimals
  ... gradually clearing the disk of much of the remaining material.
  ... and maintained in molten or gaseous states by collisional heating
- The remaining molten or gaseous objects are <u>protoplanets</u>.
  ... with some surfaces cooling and solidifying as accretion slows
  ... with gaseous atmospheres dissipating at a decreasing rate
- The protoplanets evolve with time to become the present-day planets.
  ... with cooling and differentiation of planetary cores
  ... with chemical separation and atmospheres
  ... with subsequent atmospheric evolution

Note: Satellites are formed by accretion in disks about protoplanets, acquired by later capture, or result from collisions.

The Nebular Hypothesis: Details

- The Nebular/Protoplanetary hypothesis satisfactorily explains the overall orbital properties of solar system objects.

- The "physics and chemistry" of the processes is reasonably well understood.

- It provides mechanisms (cooling, condensation, accretion) for the formation of the secondary bodies (planets, asteroids, comets, etc.)

- It accounts for the basic orbital characteristics of the solar system

- It explains the principal physical differences (size, mass, composition) between the Terrestrial and Jovian planets and the smaller bodies.

CURRENT STATUS:

- Very great explanatory and predictive power*. Eminently testable.
- No fundamental issues or problems outstanding.
- Is a successful model for star formation as well as stellar systems.
  (Stars are now known and observed to form from cool interstellar clouds.)
- No viable competing model has been forthcoming.

* e.g., explaining the differences between Jovian and Terrestrial planets.

Some Cosmic Chemistry

Hydrogen and Helium atoms account for almost all of the ordinary matter in the present-day universe:

Hydrogen (H) atoms constitute 92.1% of all atoms
Helium (He) atoms constitute 7.8 % of all atoms.
(which amounts to just under 99.9% of the total)

Most of the remaining 0.1% of atoms are represented by just four elements:

Carbon (C) at 0.030%
Nitrogen (N) at 0.008%
Oxygen (O) at 0.061%
and Neon (Ne) at 0.008%
(which together are about 1,000 times rarer than hydrogen and helium atoms)

All of the remaining 86 naturally-occurring elements together account for less than 0.01% (one ten-thousandth) of the total. This tiny fraction is itself dominated by just five elements:

Iron (Fe) at 0.004%
Silicon (Si) at 0.003%
Magnesium (Mg) at 0.002%
Sulfur (S) at 0.001%
and Argon (Ar) at 0.0006%

The abundances of the elements within the solar system are about the same.

Cosmic Chemistry: Atoms and Molecules

Some atoms (Helium, Argon, ...) will be found only as single atoms, others can be found in molecules. On the basis of atomic abundances we expect the most common molecule (by far) to be the hydrogen molecule:

H_2

Next in abundance we expect : **H_2O, CH_4, NH_3**

Next: **O_2, N_2, CO, CO_2, NO, N_2O, and C_x**

Next: **FeO, Fe_2O_3, SiO_2, SiC, MgO, SO_2, H_2S, and Fe_x**

The expected physical state of these molecules under plausible conditions of temperature and pressure in a collapsing gas cloud are as follows:

Gaseous	Volatile/Icy	Refractory/Solid
H, H_2	H_2O	C_x
He, Ne	CH_4	FeO, Fe_2O_3
O_2, N_2	NH_3	SiO_2
CO	CO_2	SiC
SO_2	•	MgO
H_2S	•	Fe_x
•	•	•
•	•	•

Cosmic Chemistry: Rock, Ice, and Gas

Explanations, Predictions & Expectations

• The first <u>solids</u> to form will be largely composed of the ice forms of water, methane, ammonia, and carbon dioxide
- simply because of the abundances of these materials.

• Their spatial properties now reflect the dimensions of the proto-solar cloud.
- and the many gravitational interactions they experienced.

• The first planetesimals will be of similar composition. The survivors of this population are likely to be found in the outer extremes of the present-day solar system. (Comets; the smaller KBOs and TNOs)

• The protoplanets formed from these planetesimals will be largely gaseous bodies. The more massive will be able to retain their materials against evaporation. (The Jovian Planets; the outer ice planets)

• In the warmer inner regions of the system only refractory materials survive as solids. The scarcity of these materials implies the formation of relatively low mass protoplanets which evolve as initially liquid bodies which cool toward solidity. (The Terrestrial Planets; the Asteroids)

Details: Subsequent Planetary Evolution

Ice Bodies: **Volatile solids in a cold environment.**

- **The Ice Planets & Trans-Neptunian Objects:** **Pluto, Eris, ...**
- **Icy Satellites of the Jovian Planets and of Ice Planets**
- **Comets and comet nuclei**
  - **Small bodies incapable of retaining gaseous atmospheres**
  - **Dirty Snowballs and Rocky Cores?** (Density differentiation by “settling”)

Gas Bodies: **Volatile materials in a warm environment.**

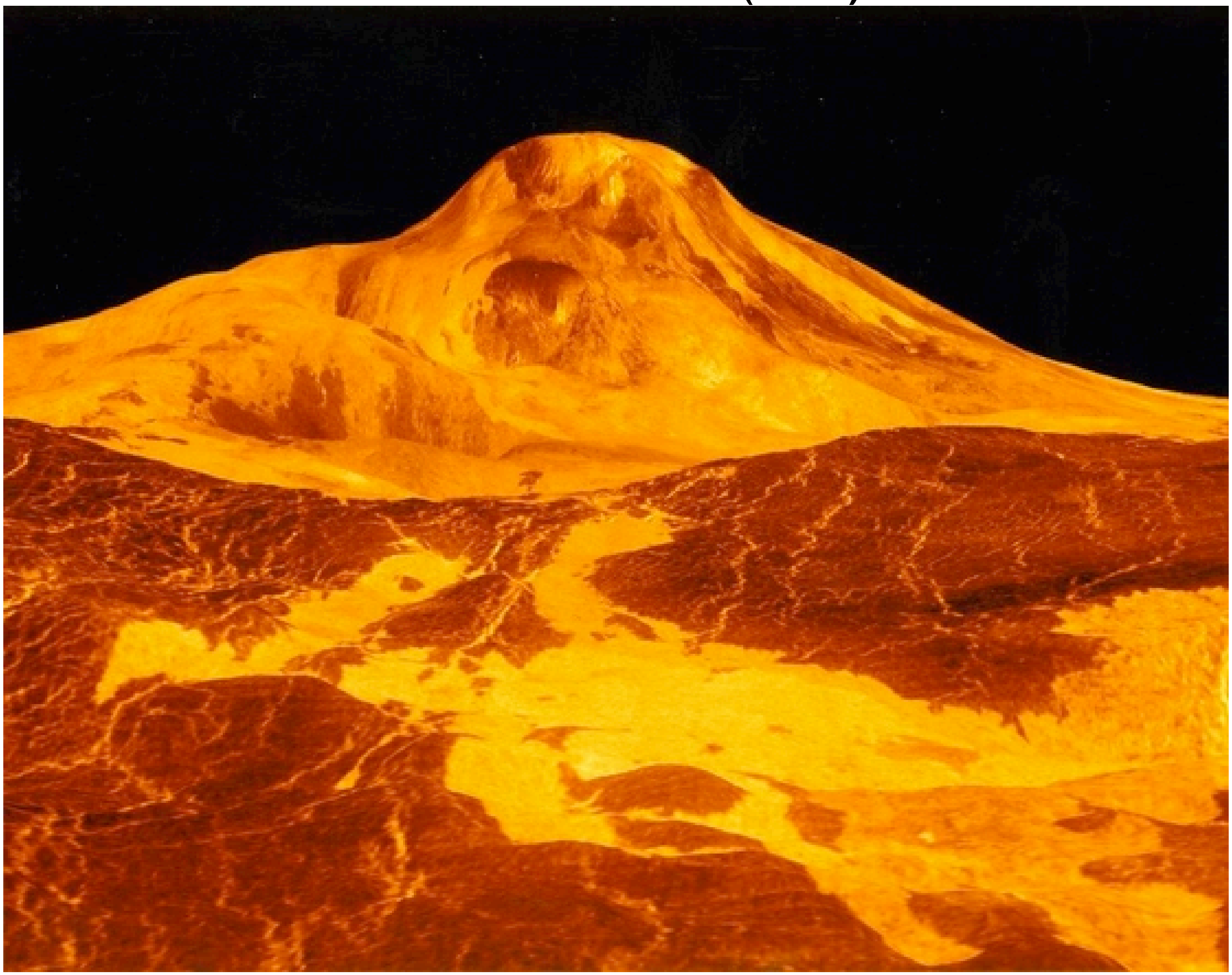
- **Jovian Planets:** **Jupiter, Saturn, Uranus, and Neptune**
  - **Internal eating by gravitational contraction**
  - **Atmospheric retention. Rotation, convection, and winds**
  - **Rocky and Icy Cores**

Rocky Bodies: **Refractories in a hot environment**

- **The Terrestrial Planets:** **Mercury, Venus, Earth, and Mars**
- **Asteroids & Rocky Satellites**
- **The Interplanetary Dust as Comet Debris?**
  - **Heating by impacts and Internal heating by Radioactive Decay**
  - **Planetary <u>Differentiation</u>**
  - **Mantle convection, continental drift and vulcanism**
  - **Outgassing: The Formation and Retention of Atmospheres**

Mars: Olympus Mons (24 km)

Venus: Maat Mons (8 km)



Planetary Atmospheres

Producing an Atmosphere

Infall of volatile materials: Comets?
Outgassing & Vulcanism

Retaining an Atmosphere

Temperature and Gravity
The Evaporation of Atmospheres

Evolving an Atmosphere

Atmospheric Chemistry
Vulcanism and the Atmospheres of Venus and Mars
(The Greenhouse Effect)

The Oddity of the Earth's Atmosphere

The primordial Terrestrial atmosphere: CH_4, H_2O, CO_2, NH_3.
Water, Carbon Dioxide, and temperature
$H_2O + CO_2 \rightarrow H_2CO_3$
Life, Photosynthesis, and Oxygenation
$6\ H_2O + 6\ CO_2 + h\nu \rightarrow C_6H_{12}O_6 + 6O_2$
(Water + Carbon Dioxide + Sunlight → Glucose + Oxygen)