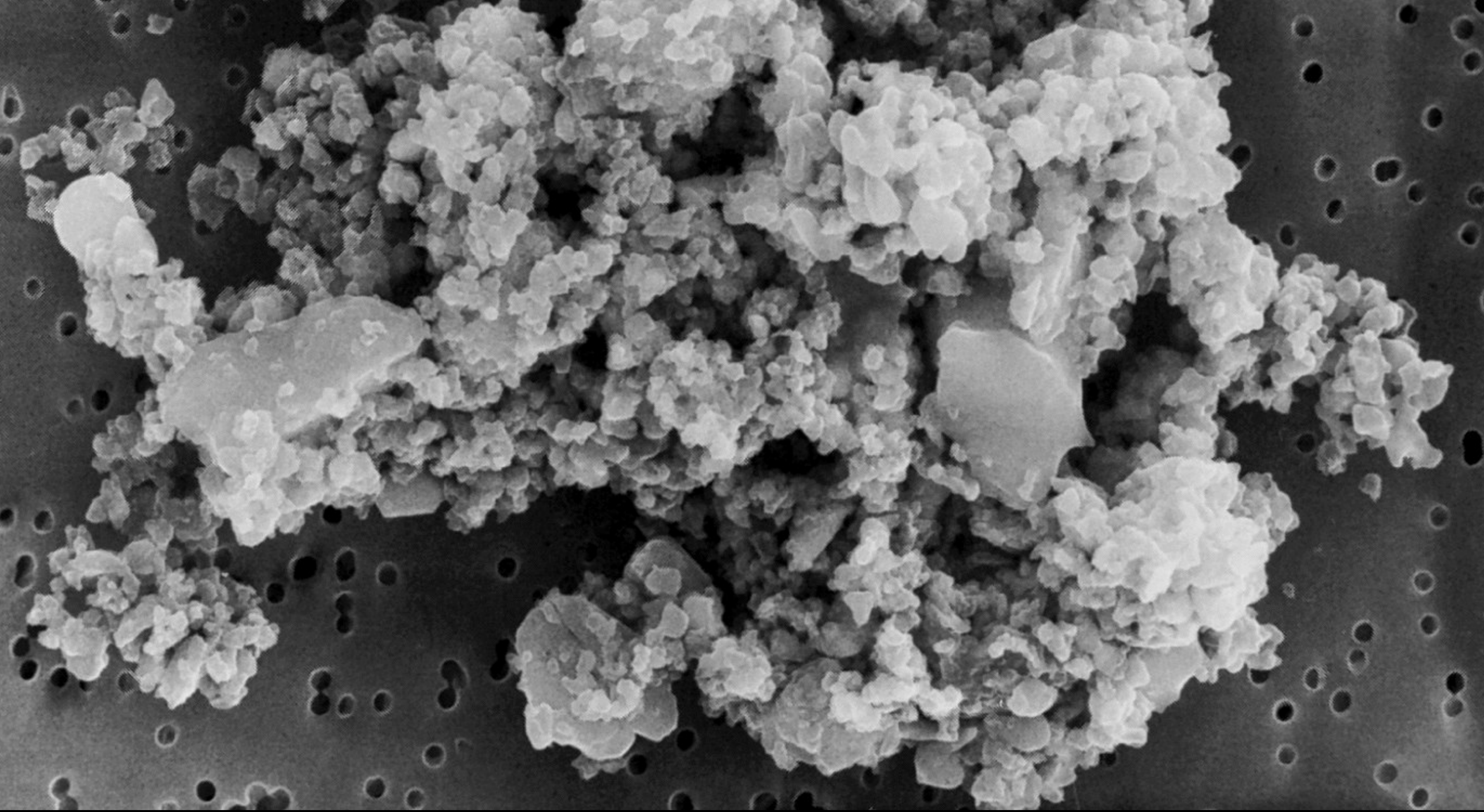


Comparative Planetology II: The Origin of Our Solar System

Chapter Eight

Introduction To Modern Astronomy I

Introducing Astronomy
(chap. 1-6)

Planets and Moons
(chap. 7-17)

Ch7: Comparative Planetology I

Ch8: Comparative Planetology II

Ch9: The Living Earth
Ch10: Our Barren Moon
Ch11: Sun-Scorched Mercury
Ch12: Cloud-covered Venus
Ch13: Red Planet Mars
Ch14: Jupiter and Saturn
Ch15: Satellites of Jup. & Saturn
Ch16: Outer World
Ch17: Vagabonds of Solar System

Guiding Questions

1. What must be included in a viable theory of the origin of the solar system?
2. Why are some elements (like gold) quite rare, while others (like carbon) are more common?
3. How do we know the age of the solar system?
4. How do astronomers think the solar system formed?
5. Did all of the planets form in the same way?
6. Are there planets orbiting other stars? How do astronomers search for other planets?

Models of Solar System Origins: Scientific Methods

- Any model of solar system origins must explain the present-day Sun and planets

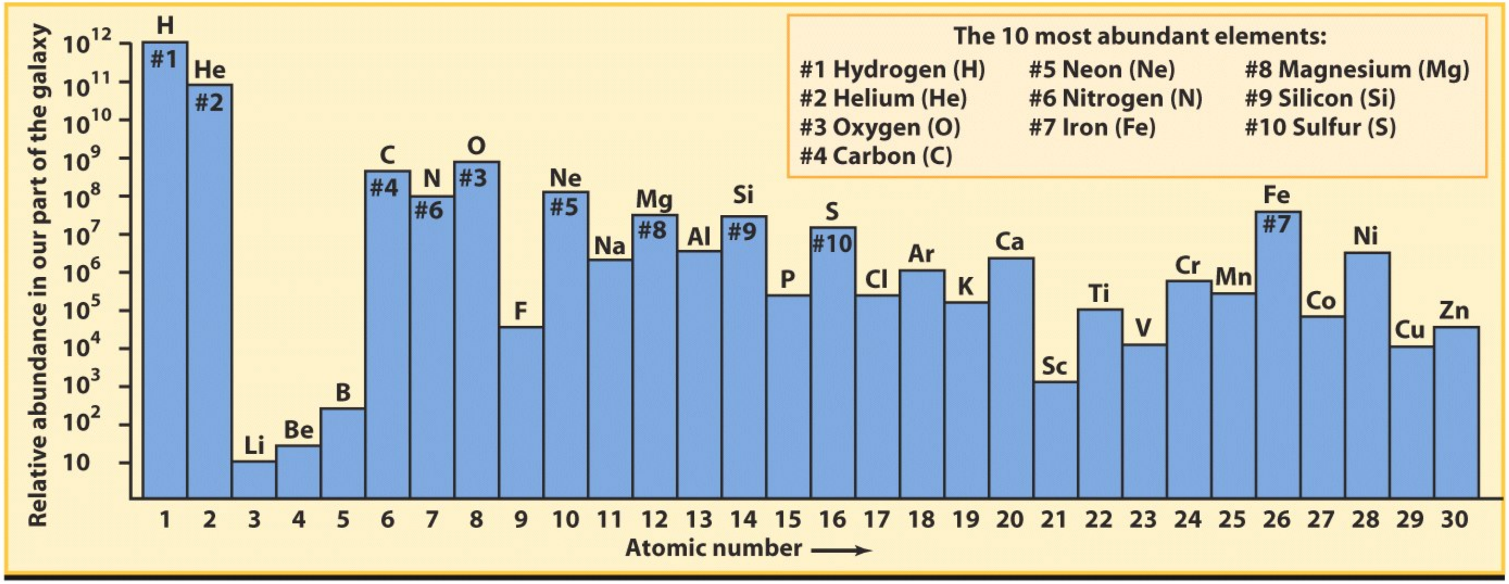
1. The terrestrial planets, which are composed primarily of rocky substances, are relatively small, while the Jovian planets, which are composed primarily of hydrogen and helium, are relatively large

2. All of the planets orbit the Sun in the same direction, and all of their orbits are in nearly the same plane

3. The terrestrial planets orbit close to the Sun, while the Jovian planets orbit far from the Sun

Abundances of Chemical Elements

- Hydrogen makes up nearly three-quarters of the combined mass of the Sun and planets
- Helium makes up nearly one-quarters of the mass
- Hydrogen and Helium together accounts for about 98% of mass in the solar system
- All other chemical elements, combined, make up the remaining 2%,e.g., oxygen, carbon, nitrogen, Iron, silicon

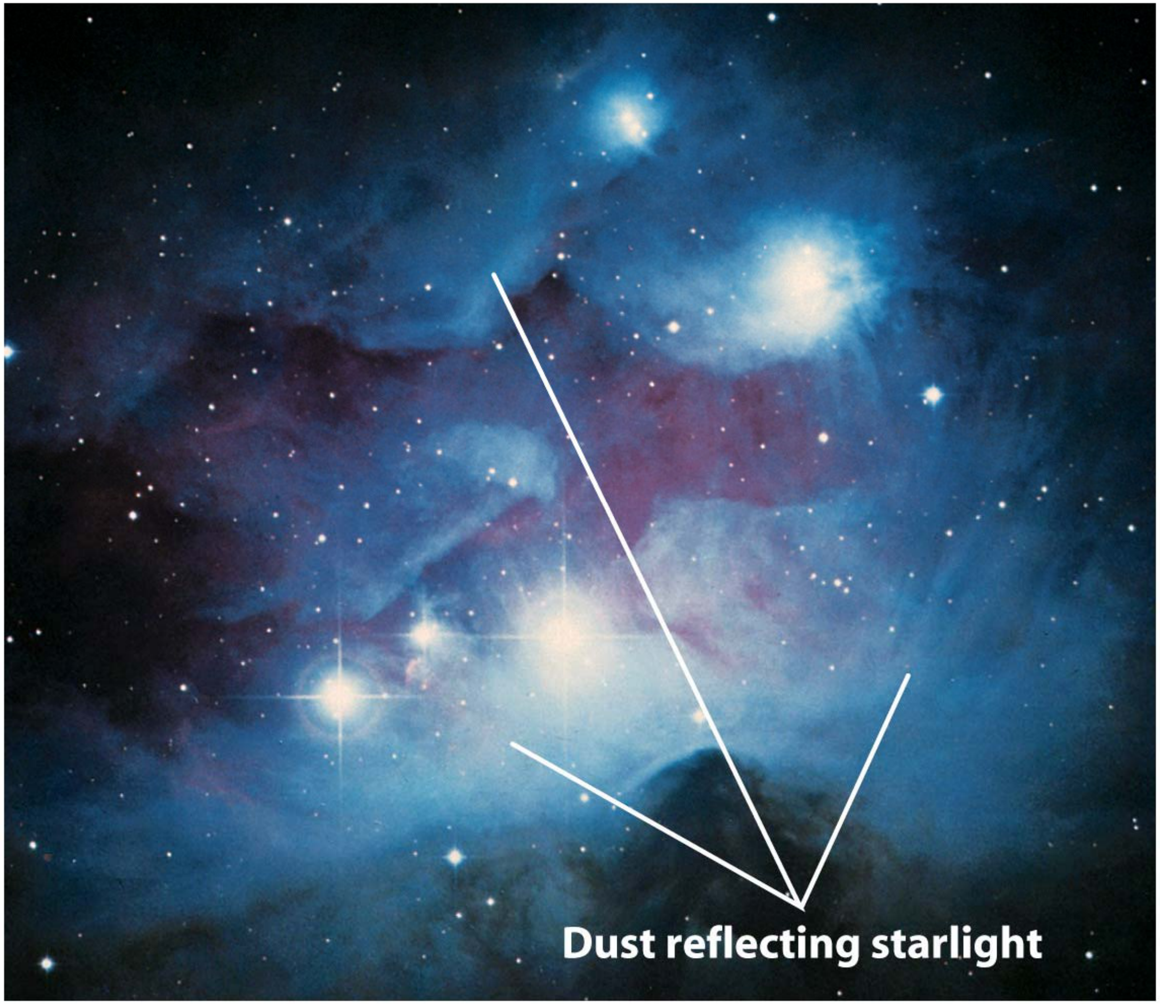


Abundances of Chemical Elements

- The dominance of hydrogen and helium is the same as in other stars and galaxies, throughout the universe
- **Hydrogen and helium atoms are produced in the Big Bang,** which created the universe 13.7 billion years ago.
- **All heavier elements were manufactured by stars later**.
  - Thermal-nuclear fusion reaction in the interior of stars
  - Violent explosions, so called supernovae that make the end of massive stars
- As stars die, they eject material containing heavy elements into the **interstellar medium**
- New stars form from the interstellar medium with enriched heavy elements
- Solar system contains “recycled” material from dead stars

Abundances of Chemical Elements

- The **interstellar medium is** a tenuous collection of gas and dust that pervades the spaces between the stars



Solar System’s Age

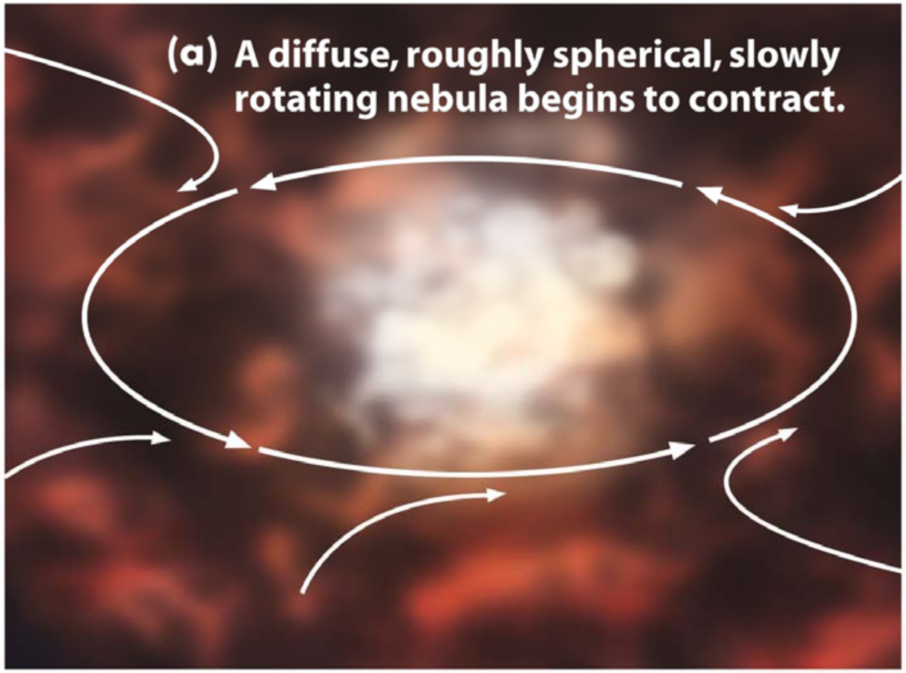
- The solar system is believed to be about **4.56 billion years old**
- Radioactive age-dating is used to determine the ages of rocks
  - Radioactive elements decay into other elements or isotopes
  - The decay rate, measured in half life, is constant for radioactive element.
    - e.g., Carbon 14: 5730 years;
    - e.g., Rubidium 87: 47 billions year
  - By measuring the numbers of the radioactive elements and the newly-created elements by the decay, one can calculate the age

Solar System’s Age

- All Meteorites show nearly the *same* age, about 4.56 billion years.
  - Meteorites are the oldest rocks found anywhere in the solar system
  - They are the bits of meteoroids that survive passing through the Earth’s atmosphere and land on our planet’s surface
- On the Earth, some rocks are as old as 4 billions years, but most rocks are hundreds of millions of years old.
- Moon rocks are about 4.5 billion years old

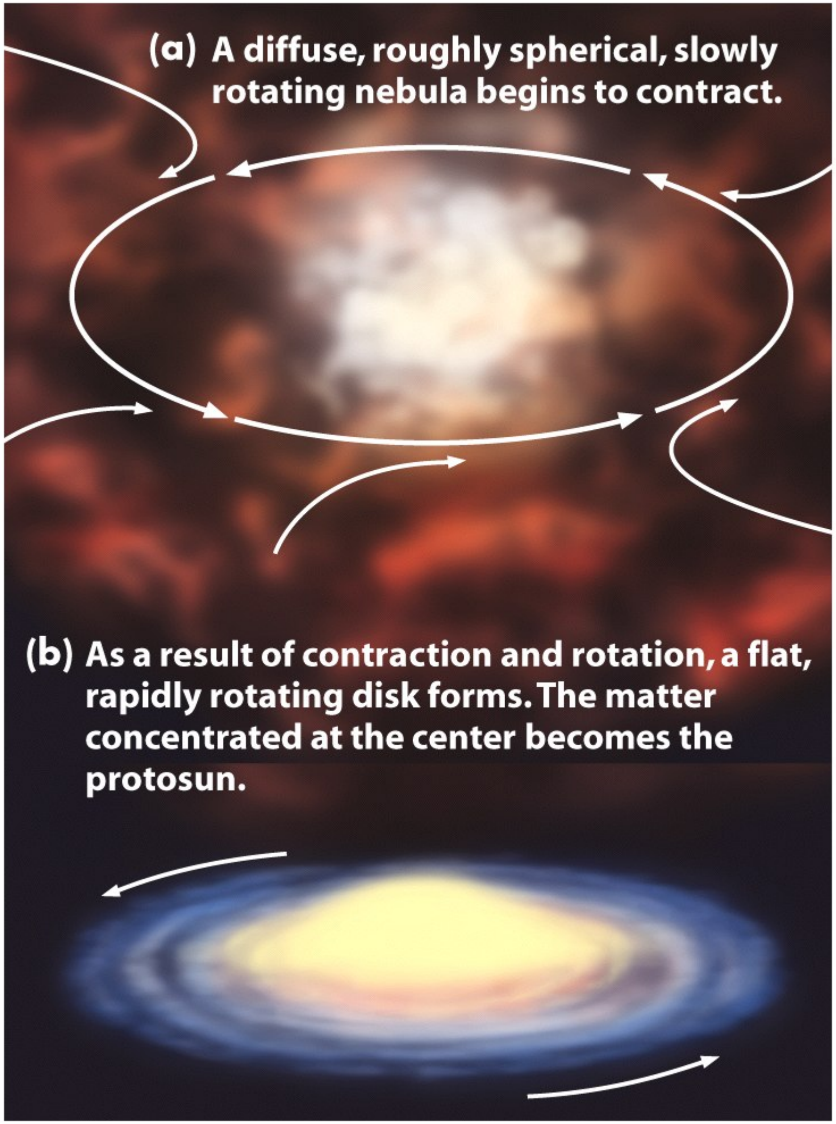
Solar Nebula Hypothesis

- The Sun and planets formed from a common **solar nebula**.
- **Solar nebula** is a **vast, rotating cloud of gas and dust** in the interplanetary space
- The most successful model of the origin of the solar system is called the nebular hypothesis



Solar Nebula Hypothesis

- The nebula began to contract about 4.56 billion years ago, because of its own gravity
- As it contracted, the greatest concentration occurred at the center of the nebula, forming a relatively dense region called the **protonsun**
- As it contracted, the cloud flattens and spins more rapidly around its rotation axis, forming the **disk**



(a) A diffuse, roughly spherical, slowly rotating nebula begins to contract.

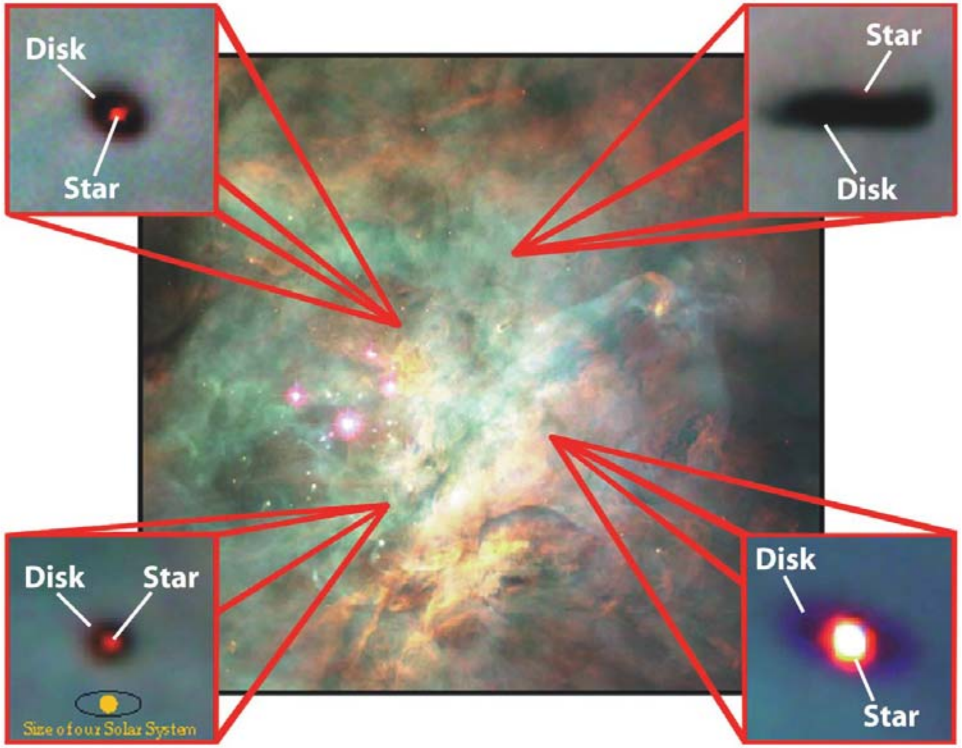
(b) As a result of contraction and rotation, a flat, rapidly rotating disk forms. The matter concentrated at the center becomes the protosun.

Solar Nebula Hypothesis

- As protosun continued to contract and become denser, its temperature also increased, because the gravitational energy is converted into the thermal energy
- After about 10 million years since the nebula first began to contract, the center of the protosun reached a temperature of a few million kelvin.
- At this temperature, nuclear reactions were ignited, converting hydrogen into helium. A true star was born at this moment.
- Nuclear reactions continue to the present day in the interior of the Sun.

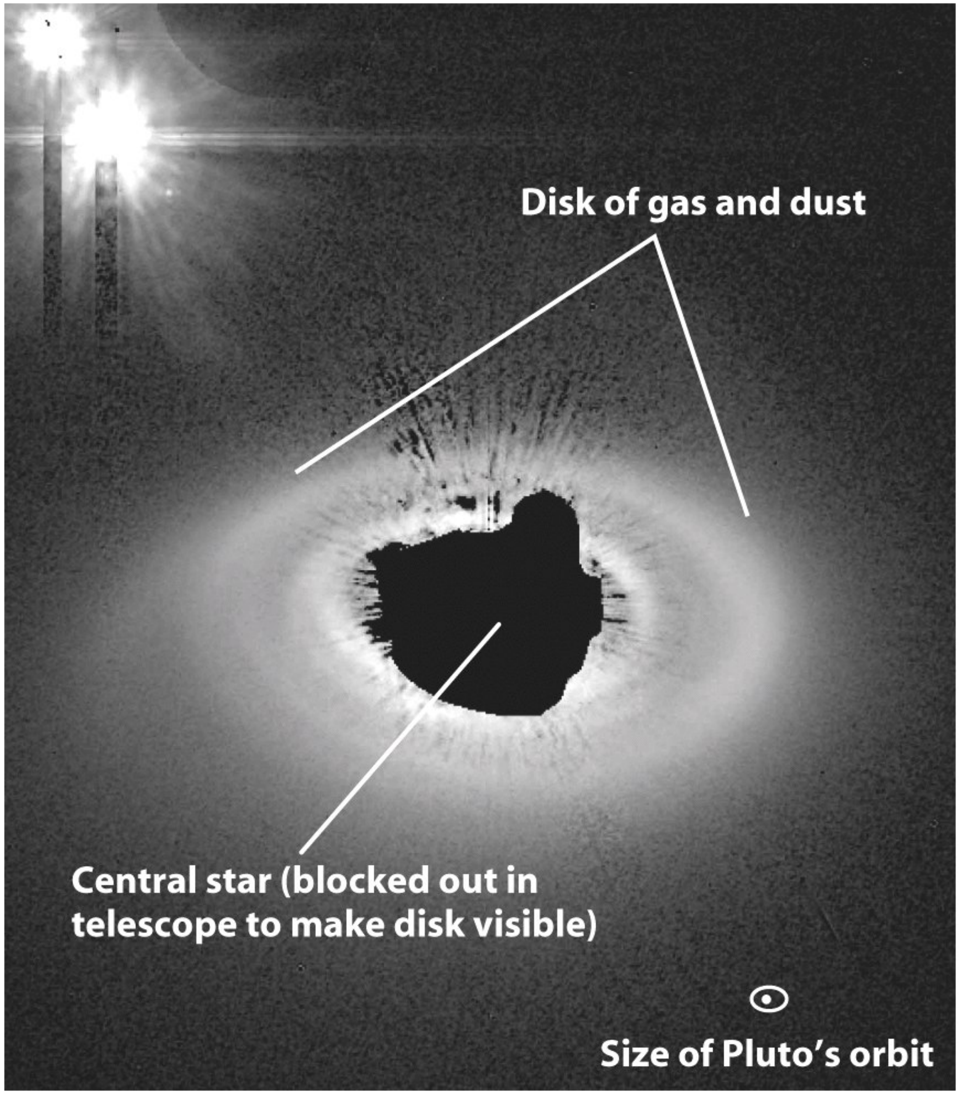
Solar Nebula Hypothesis

- **Protoplanetary disk,** the disk of material surrounding the protosun or protostars, are believed to give birth to the planets
- The flattened disk is an effect of the rotation of the nebula.
- The centrifugal force of the rotation slows down the material on the plane perpendicular to the rotational axis fall toward the center
- But the centrifugal force has no effect on the contraction along the rotational axis



Formation of Planets

- The protoplanetary disk is composed by gas and dust.
- A substance is in the sate of either solid or gas, but not in liquid, if the pressure is sufficiently low

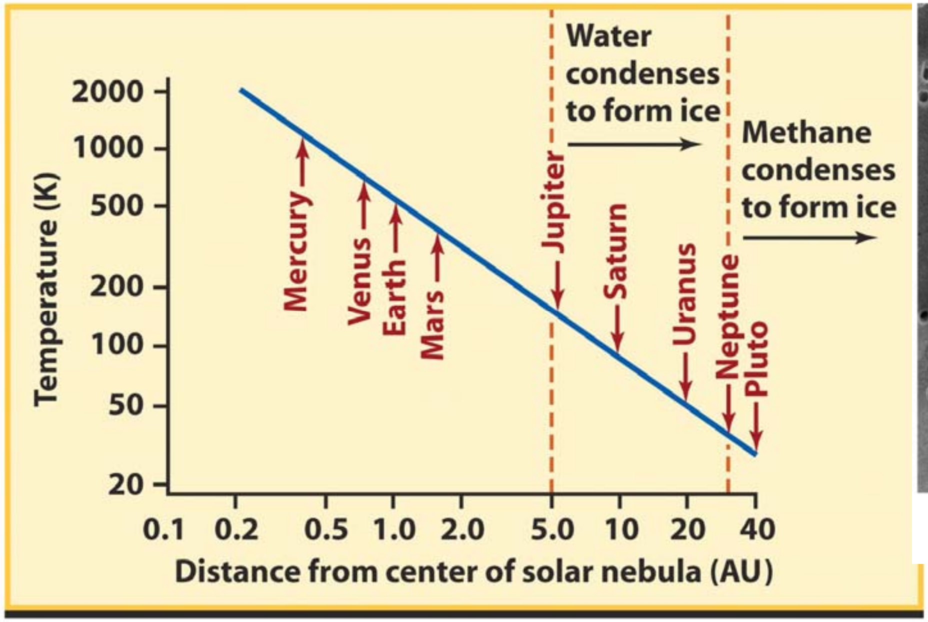


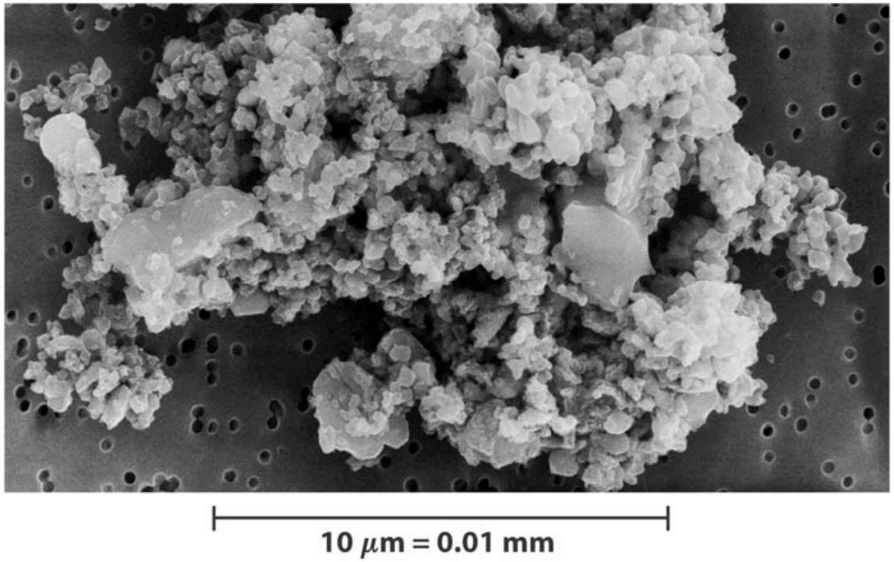
Formation of Planets

- **Condensation temperature** determines whether a certain substance is a solid or a gas.
    - Above the condensation temperature, gas state
    - Below the condensation temperature, solid sate
- Hydrogen and Helium: always in gas state, because concentration temperatures close to absolute zero
- Substance such as **water (H_2O), methane (CH_4) and ammonia (NH_3)** have low concentration temperature, ranging from 100 K to 300 K
    - Their solid state is called **ice particle**
- Rock-forming substances have concentration temperatures from 1300 K to 1600 K
    - The solid state is often in the form of **dust grain**

Formation of Planets

- In the nebula, temperature decreases with increasing distance from the center of the nebula
- In the inner region, only heavy elements and their oxygen compounds remain solid, e.g., iron, silicon, magnesium, sulfur. They form dust grains.
- In the outer region, ice particles were able to survive.

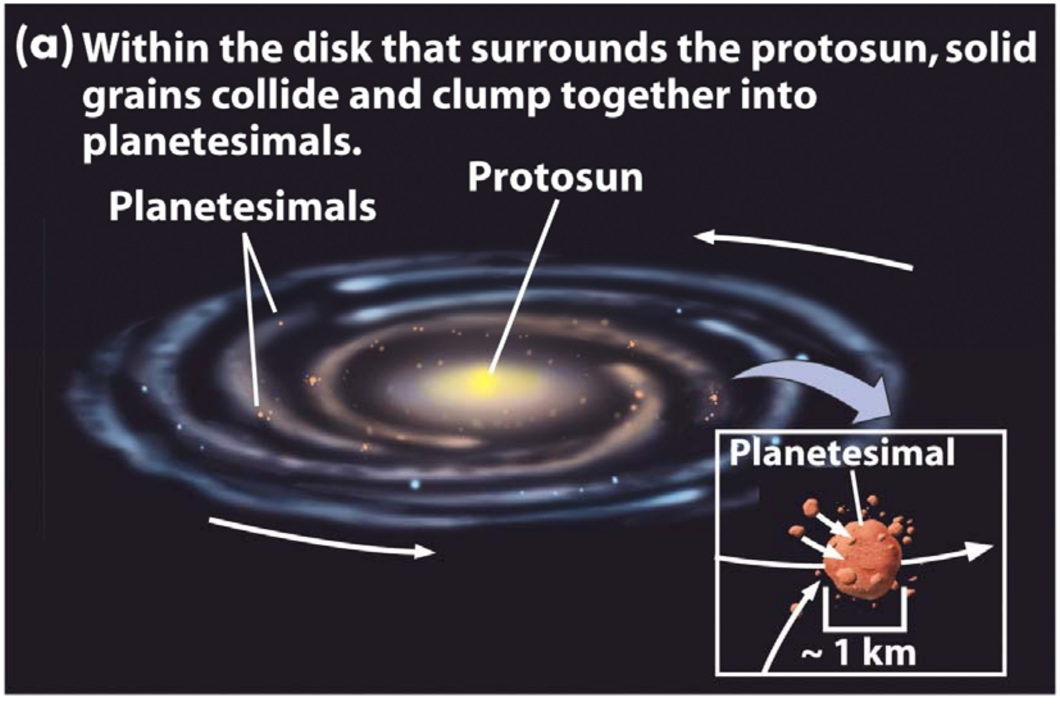




Dust grain

Formation of Planets

- In the inner region, the collisions between neighboring dust grains formed small chunks of solid material
- **Planetesimals**: over a few million years, these small chucks coalesced into roughly a billion asteroid-like objects called planetesimals
- **Planetesimals** have a typical diameter of a kilometer or so

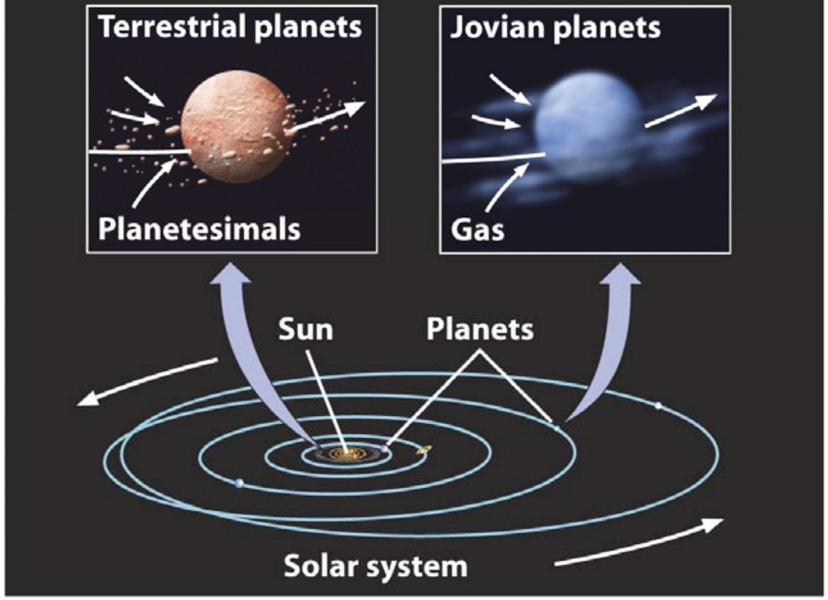


(a) Within the disk that surrounds the protosun, solid grains collide and clump together into planetesimals.

Formation of Planets

- **Protoplanets:** gravitational attraction between the planetesimals caused them to collide and accumulate into still-larger projects called protoplanets
- Protoplanets were roughly the size and mass of our Moon
- During the final stage, the **protoplanets collided to form the terrestrial planets**

(b) The terrestrial planets built up by collisions and by the accretion of planetesimals by gravitational attraction. The Jovian planets formed by gas accretion.



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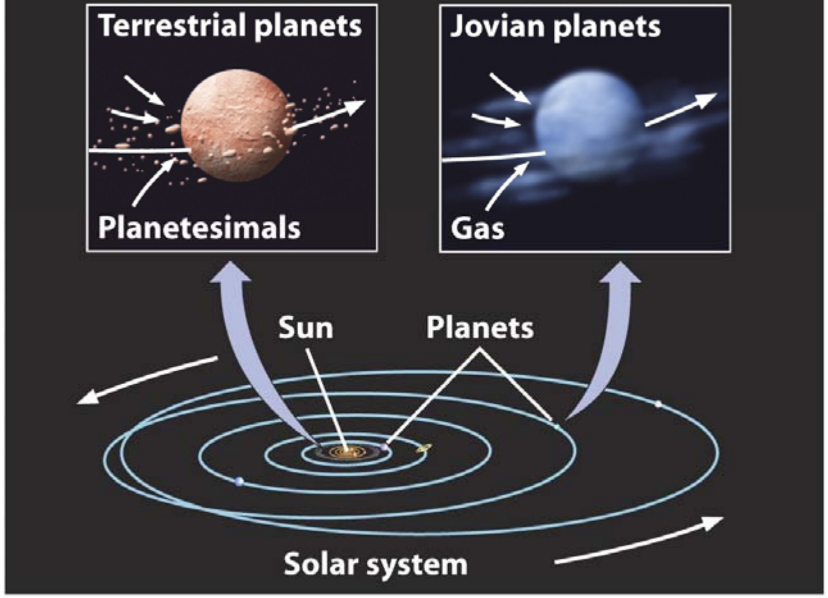
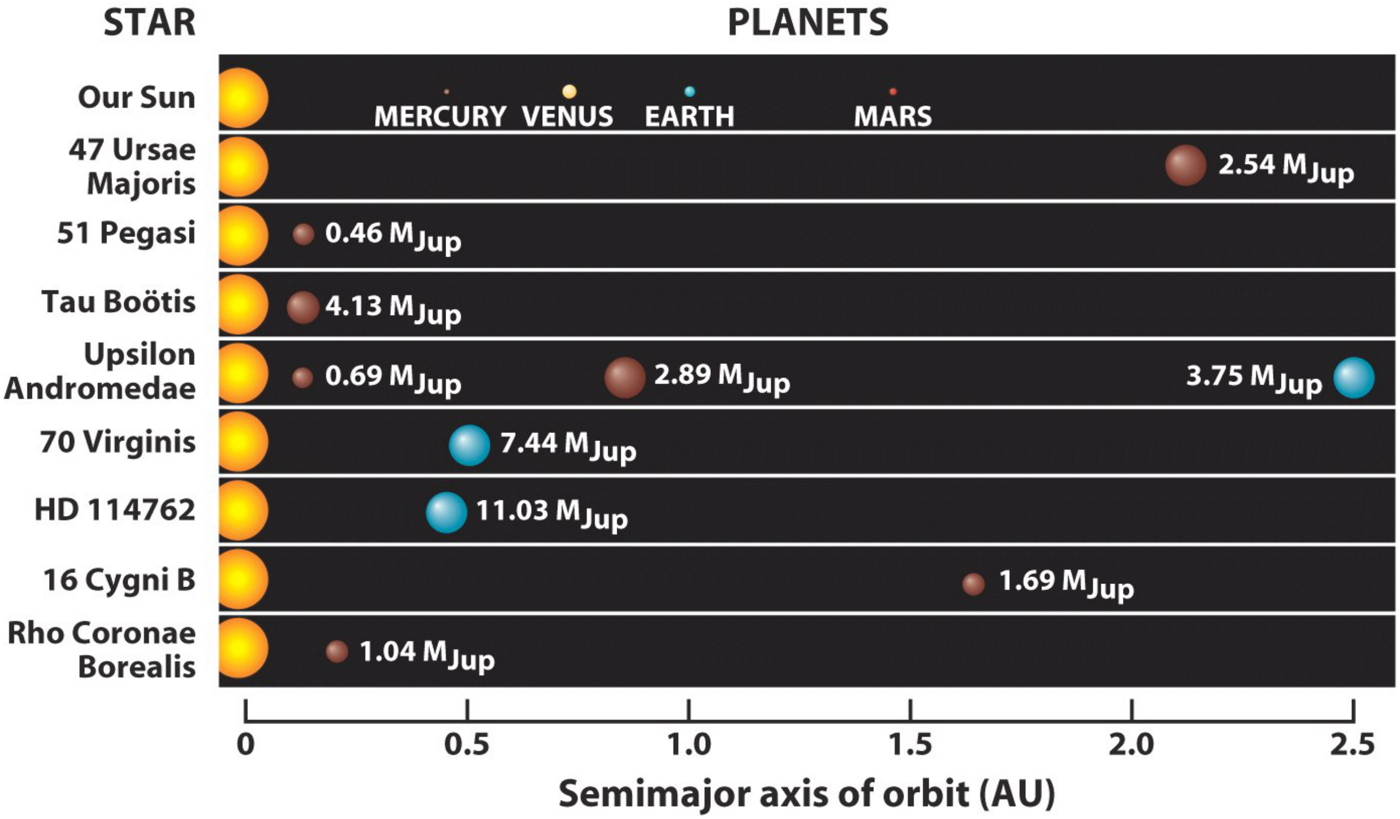


Formation of Planets

- In the outer region, more solid materials were available to form planetesimals.
  - In addition to rocky dust grains, more abundant ice particles existed.
  - Planetesimals were made of a mixture of ices and rocky materials.
- In the outer region, protoplanets could have captured an envelope of gas as it continued to grow by accretion
  - this is called **core accretion model**
  - Gas atoms, hydrogen and helium, were moving relatively slowly and so easily captured by the gravity of the massive cores.
- The result was a huge planet with an enormously thick, hydrogen-rich envelope surrounding a rocky core with 5-10 times the mass of the Earth

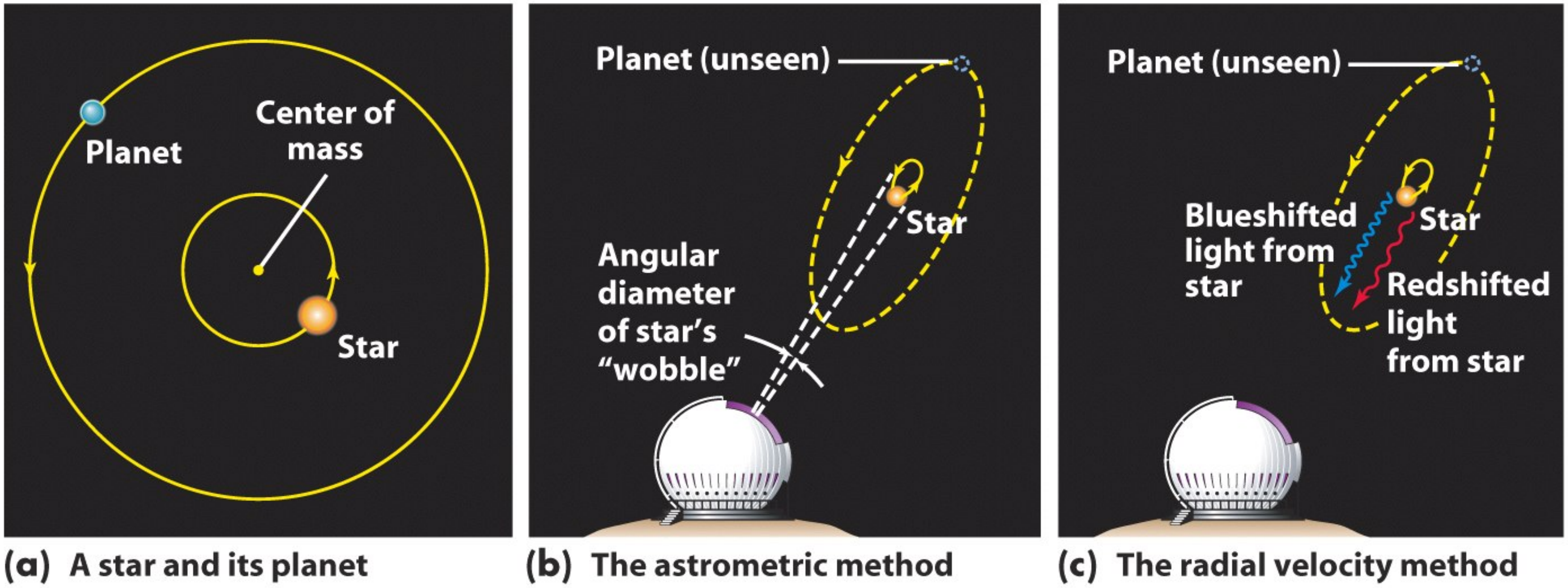
Finding Extrasolar Planets

- In 1995, first extrasolar planet was discovered by Michel Mayor and Didier Qieloz of Switzland
- As of Oct 22. 2006, 199 extrasolar planets have been found



Finding Extrasolar Planets

- Extrasolar planets can not be directly observed, because their reflected light is about 1 billion times dimmer than that of their parent stars
- Their presence is detected by the “wobble” of the stars
- The “wobble” motion of star is caused by the gravitational force of the planets
- The “wobble” motion can be detected using Doppler effect.



(a) A star and its planet (b) The astrometric method (c) The radial velocity method

Final Notes on Chap. 8

- 6 sections, all studied.
- Section 8-1 to 8-6 all covered in lect 08 on Oct. 23, 2006