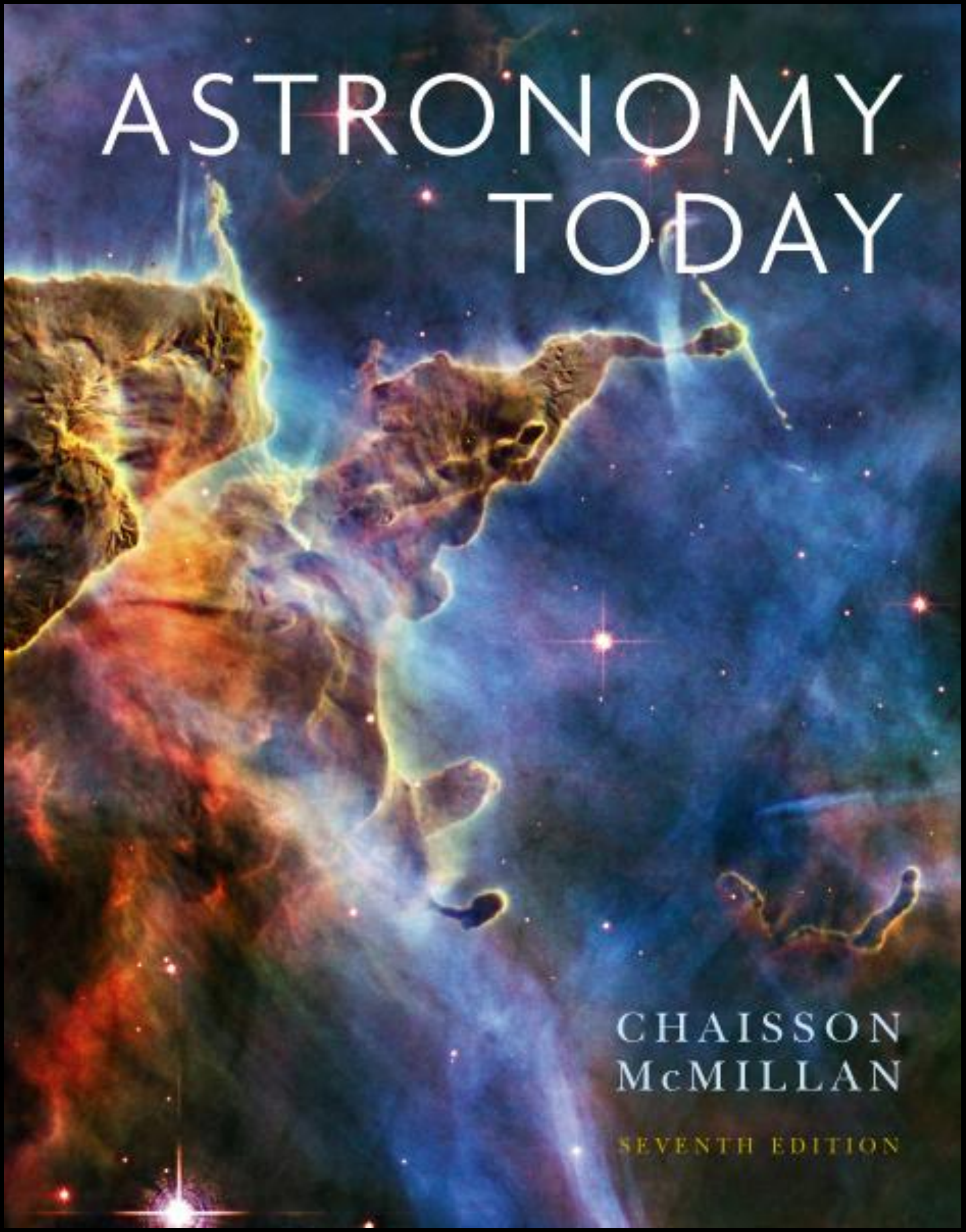


Lecture Outlines

Chapter 15

Astronomy Today

7th Edition

Chaisson/McMillan

Chapter 15
The Formation of Planetary Systems

© 2011 Pearson Education, Inc.

Units of Chapter 15

15.1 Modeling Planet Formation

Any model must explain

1. Planets are relatively isolated in space
2. Planetary orbits are nearly circular
3. Planetary orbits all lie in (nearly) the same plane
4. Direction of orbital motion is the same as direction of Sun's rotation
5. Direction of most planets' rotation is also the same as the Sun's

15.1 Modeling Planet Formation (cont.)

6. Most moons' orbits are also in the same sense
7. Solar system is highly differentiated
8. Asteroids are very old, and not like either inner or outer planets
9. Kuiper belt, asteroid-sized icy bodies beyond the orbit of Neptune
10. Oort cloud is similar to Kuiper belt in composition, but farther out and with random orbits

15.1 Modeling Planet Formation

Solar system is evidently not a random assemblage, but has a single origin.

Planetary condensation theory, first discussed in Chapter 6, seems to work well.

Lots of room for variation; there are also irregularities (Uranus's axial tilt, Venus's retrograde rotation, etc.) that must be allowed for by the model.

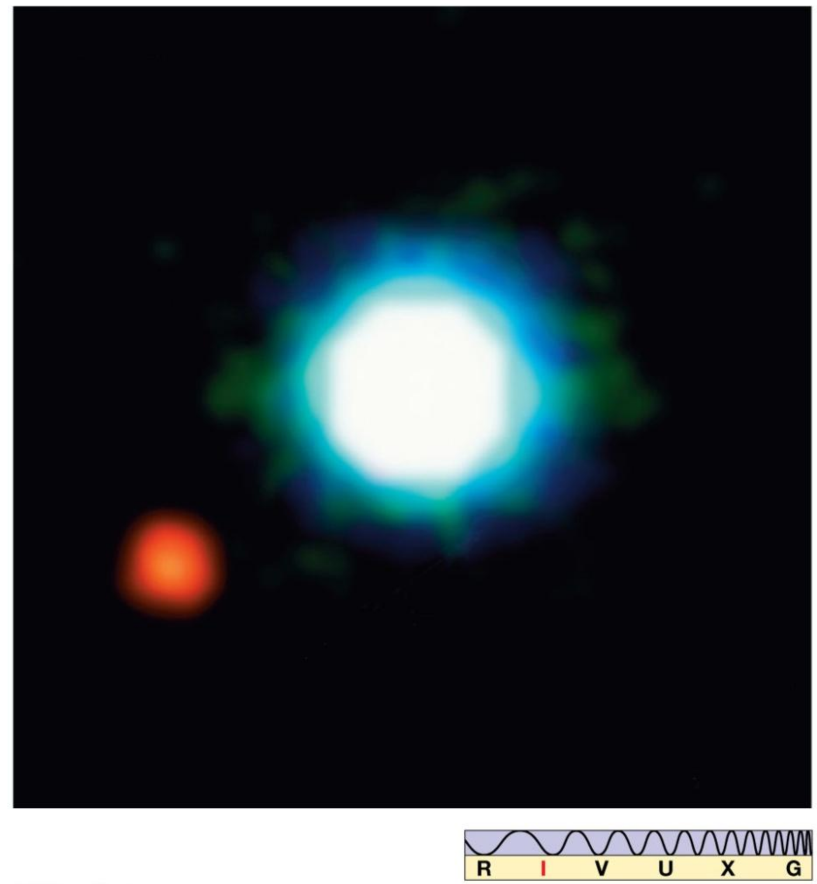
15.1 Modeling Planet Formation

Review of condensation theory:

• Large interstellar cloud of gas and dust starts to contract, heating as it does so

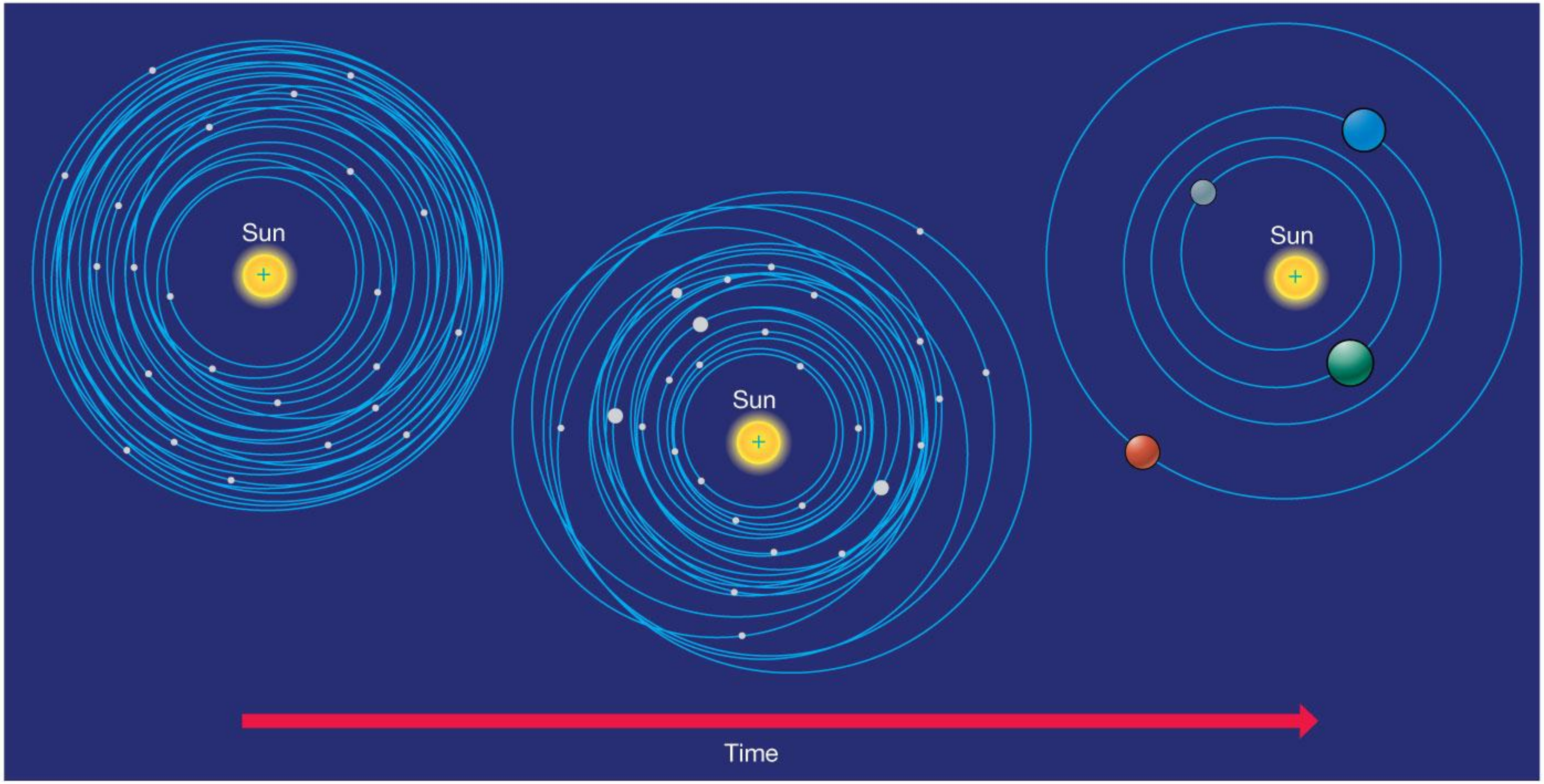
• Sun forms in center; dust provides condensation nuclei, around which planets form

• As planets grow, they sweep up smaller debris near them



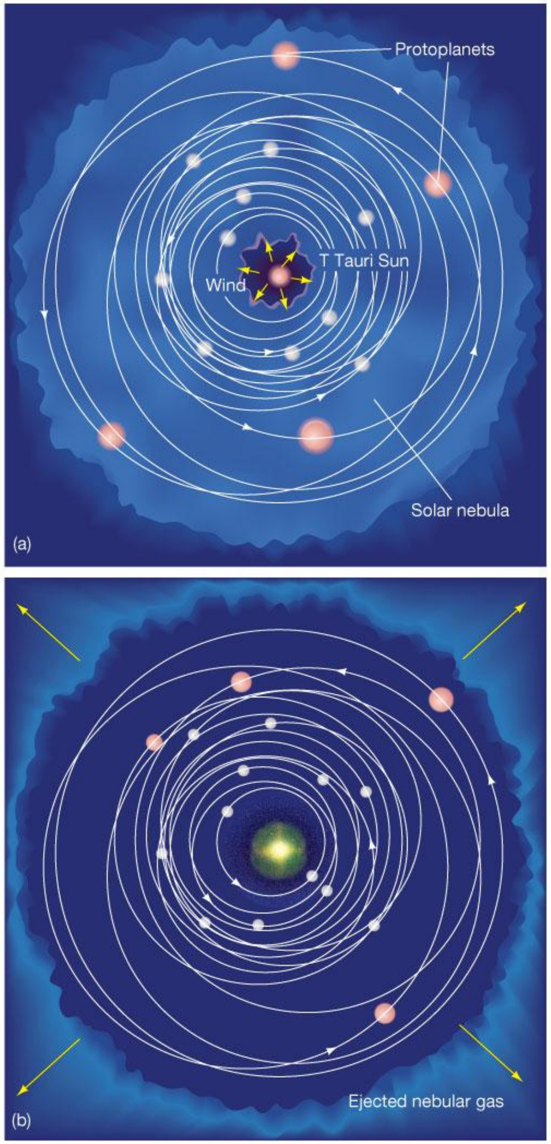
15.2 Terrestrial and Jovian Planets

Terrestrial (rocky) planets formed near Sun, due to high temperature—nothing else could condense there.



15.2 Terrestrial and Jovian Planets

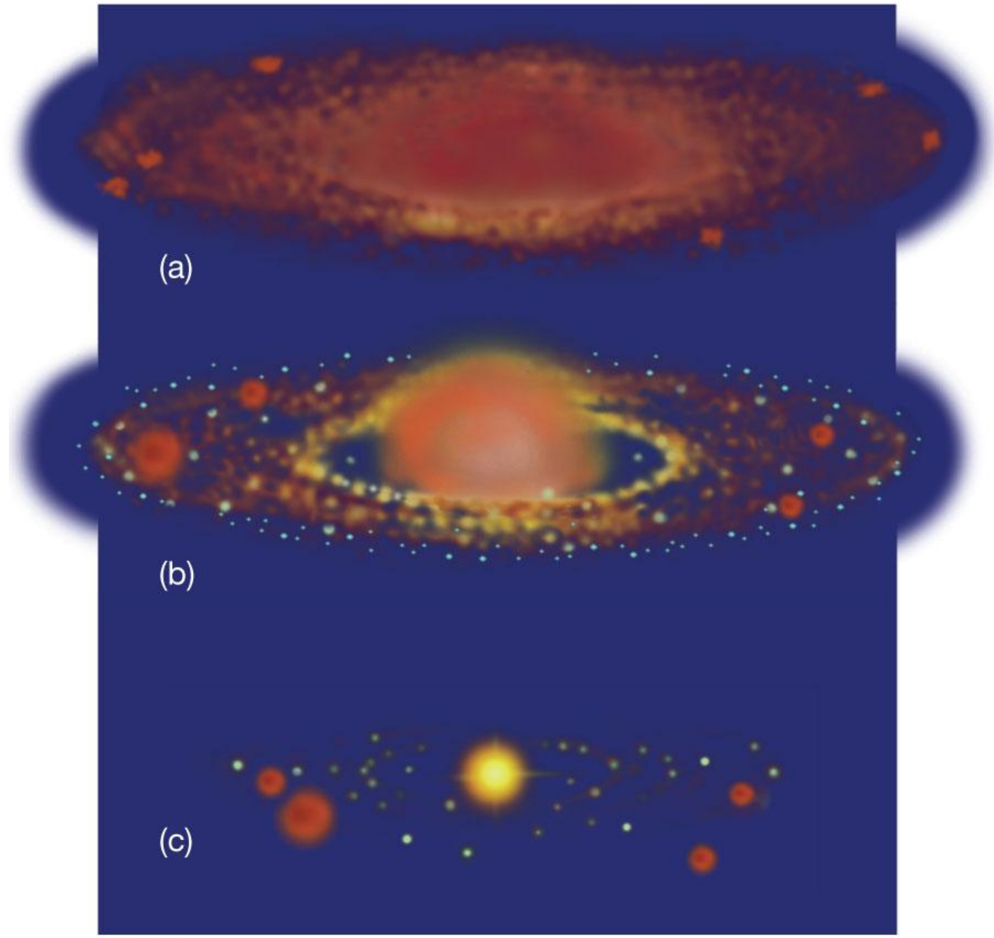
T Tauri stars are in a highly active phase of their evolution and have strong solar winds. These winds sweep away the gas disk, leaving the planetesimals and gas giants.



15.2 Terrestrial and Jovian Planets

Jovian planets:

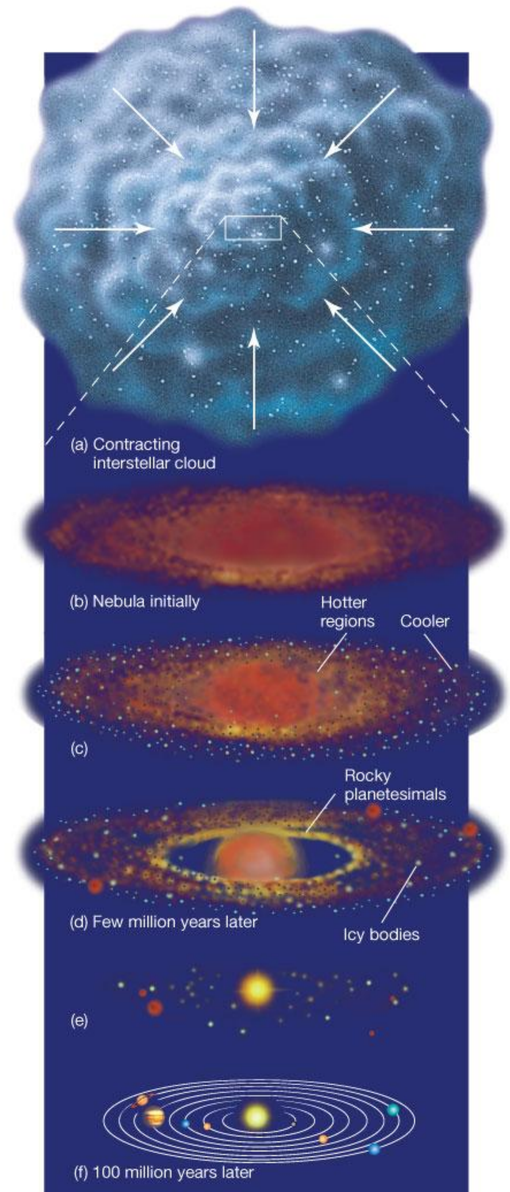
- Once they were large enough, may have captured gas from the contracting nebula
- Or may not have formed from accretion at all, but directly from instabilities in the outer, cool regions of the nebula



15.2 Terrestrial and Jovian Planets

Detailed information about the cores of jovian planets should help us distinguish between the two possibilities.

Also possible: The jovian planets may have formed farther from the Sun and "migrated" inward.



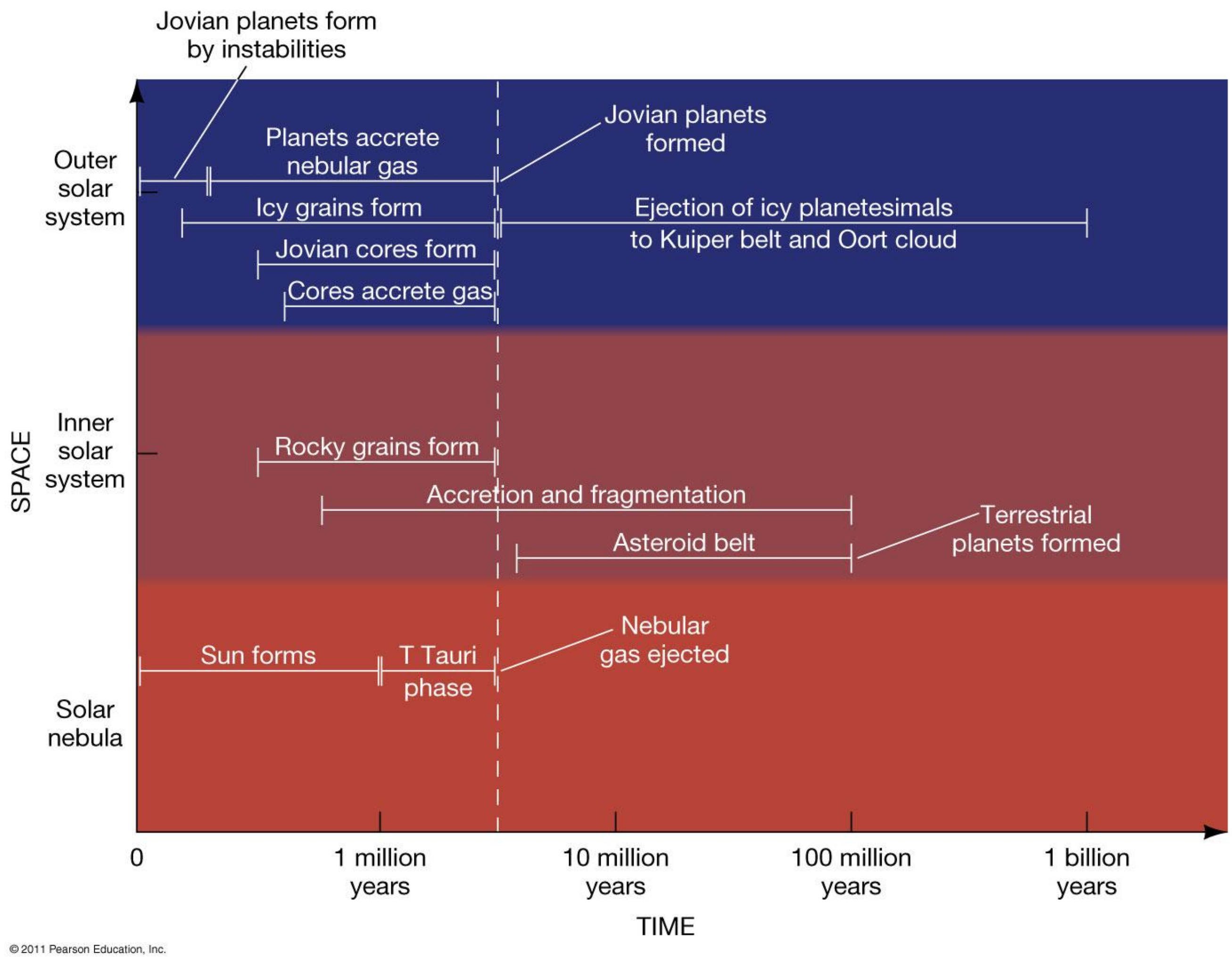
15.3 Interplanetary Debris

Asteroid belt:

- Orbits mostly between Mars and Jupiter
- Jupiter's gravity kept them from condensing into a planet, or accreting onto an existing one
- Fragments left over from the initial formation of the solar system

15.3 Interplanetary Debris

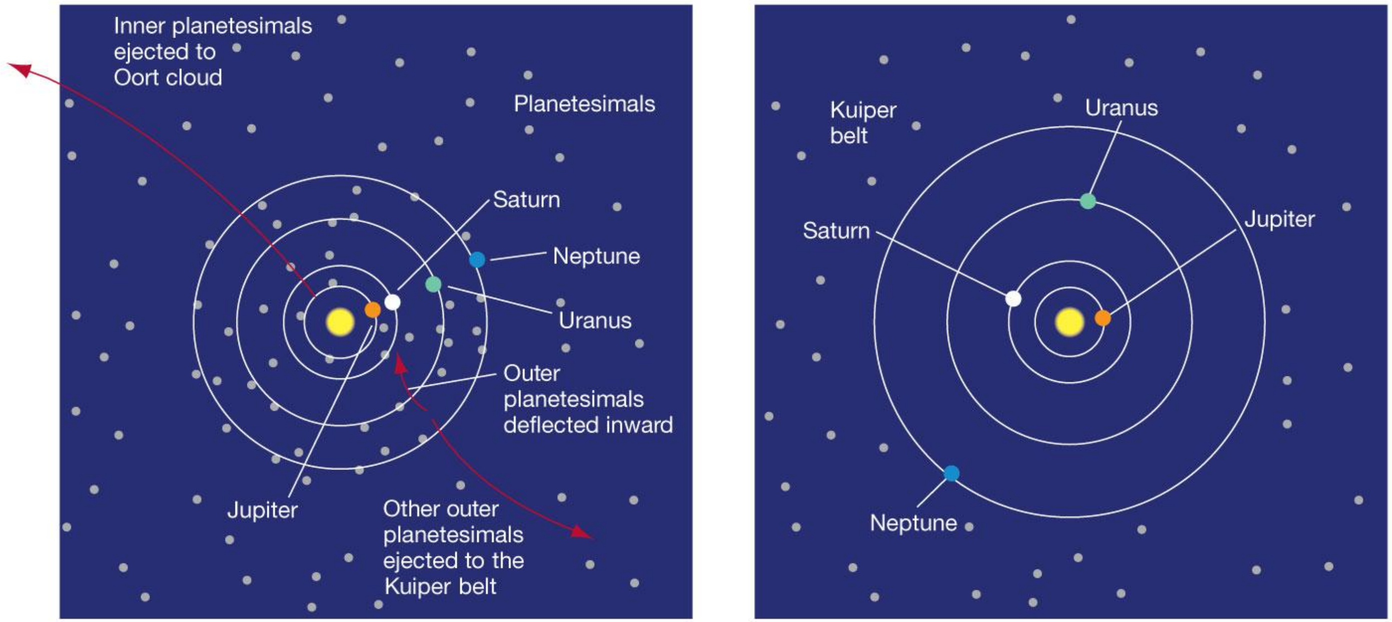
General timeline of solar system formation



15.3 Interplanetary Debris

Icy planetesimals far from the Sun were ejected into distant orbits by gravitational interaction with the jovian planets, into the Kuiper belt and the Oort cloud.

Some were left with extremely eccentric orbits and appear in the inner solar system as comets.



(a) (b)

15.3 Interplanetary Debris

Kuiper belt objects have been detected from Earth; a few are as large as, or larger than, Pluto, and their composition appears similar.

About 1/3 of all Kuiper belt objects (including Pluto) have orbits that are in a 3:2 resonance with Neptune; such objects are called "plutinos."

15.4 Solar System Regularities and Irregularities

Condensation theory covers the 10 points mentioned at the beginning.

What about the exceptions?

1. Mercury’s large metallic core may be the result of a collision between two planetesimals, where much of the mantle was lost.

2. Two large bodies may have merged to form Venus.

3. Earth–Moon system may have formed after a collision.

15.4 Solar System Regularities and Irregularities (cont.)

4. Late collision may have caused Mars's north–south asymmetry and stripped most of its atmosphere.

5. Uranus's tilted axis may be the result of a glancing collision.

6. Miranda may have been almost destroyed in a collision.

7. Interactions between jovian protoplanets and planetesimals could be responsible for irregular moons.

8. Binary Kuiper belt objects (including the Pluto-Charon system) could have formed through collisions before ejection by interactions with the jovian planets.

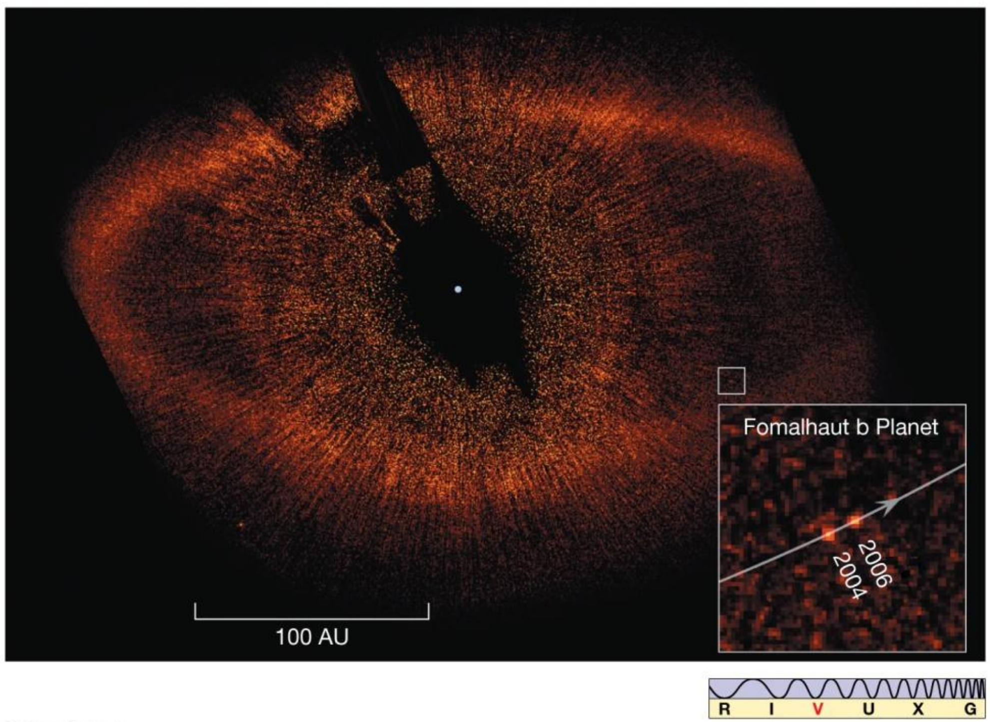
15.4 Solar System Regularities and Irregularities (cont.)

Many of these explanations have one thing in common—a catastrophic, or near-catastrophic, collision at a critical time during formation.

Normally, one does not like to explain things by calling on one-time events, but it is clear that the early solar system involved almost constant collisions. Some must have been exceptionally large.

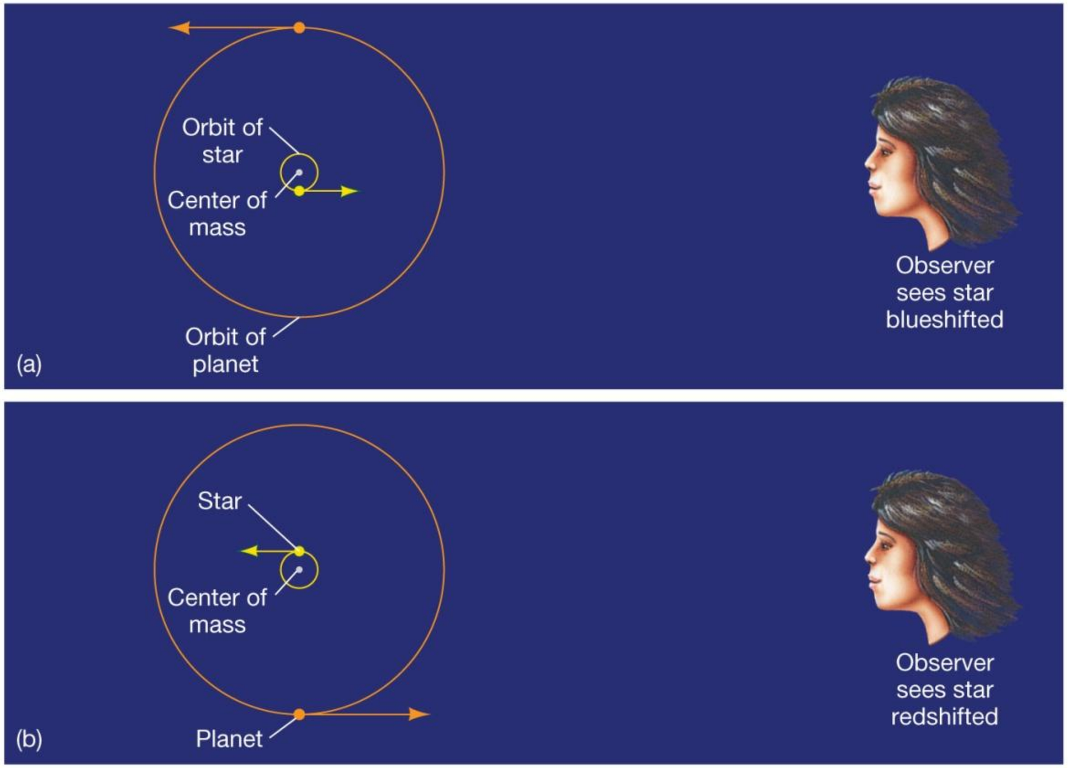
15.5 Searching for Extrasolar Planets

Most extrasolar planets have been discovered indirectly, through their gravitational or optical effects, and they cannot be seen directly due to the glare of their star. This is one exception; the planet orbits about 100 AU from its star, Fomalhaut.



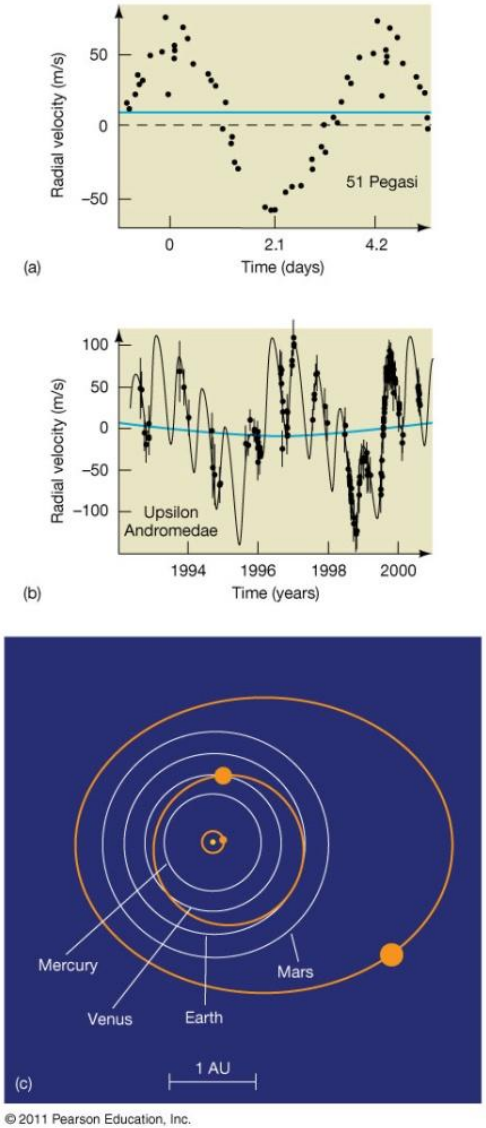
15.5 Searching for Extrasolar Planets

Planets around other stars can be detected if they are large enough to cause the star to "wobble" as the planet and star orbit around their common center of mass.



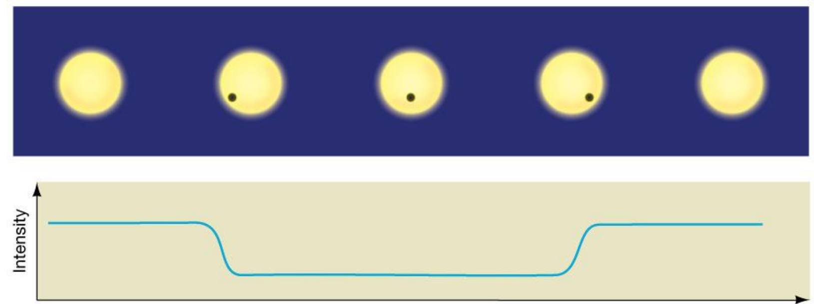
15.5 Searching for Extrasolar Planets

If the "wobble" is transverse to our line of sight, it can also be detected through the Doppler shift as the star's motion changes.

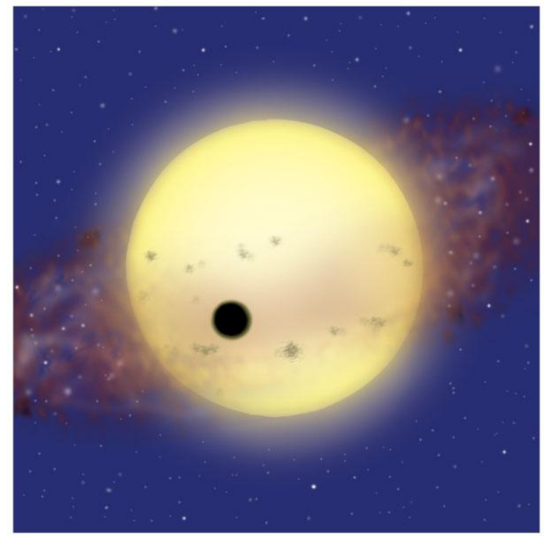


15.5 Searching for Extrasolar Planets

An extrasolar planet may also be detected if its orbit lies in the plane of the line of sight to us. The planet will then eclipse the star, and if the planet is large enough, some decrease in luminosity may be observed.



(a)


(b)

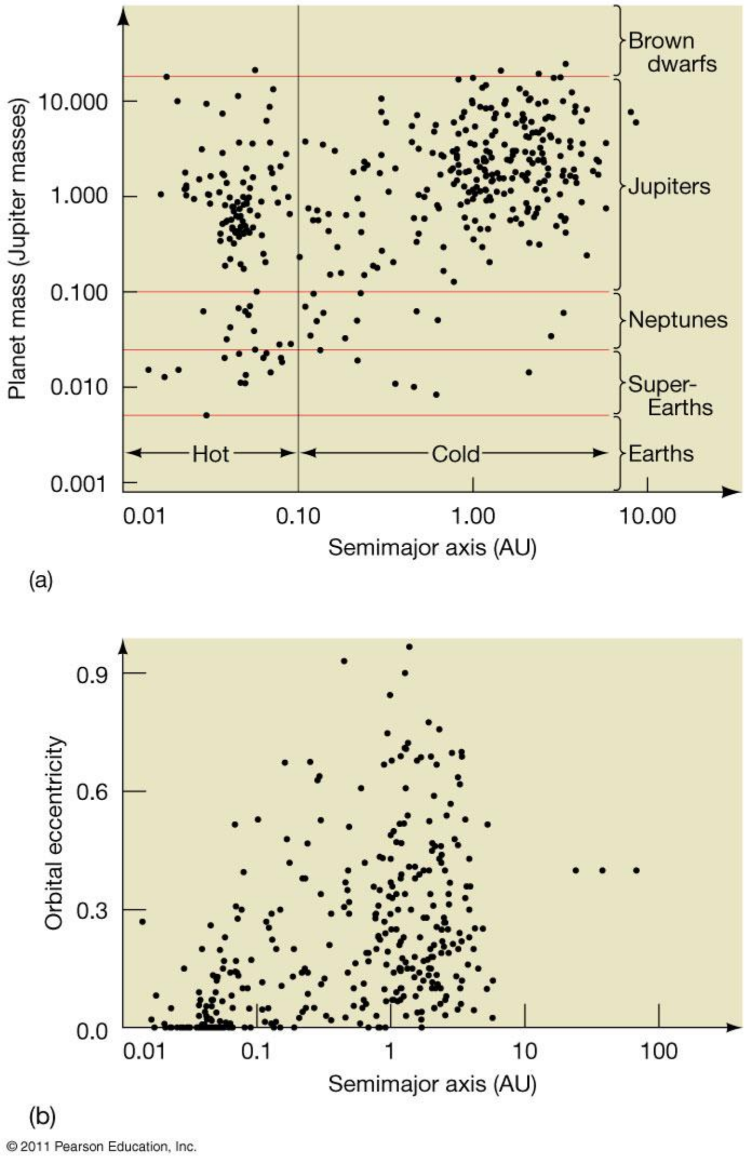
15.6 Properties of Exoplanets

More than 450 extrasolar planets have been discovered so far:

- Most have masses comparable to Jupiter’s
- Orbits are generally much smaller, and in some cases very much smaller, than the orbit of Jupiter
- Orbits have high eccentricity

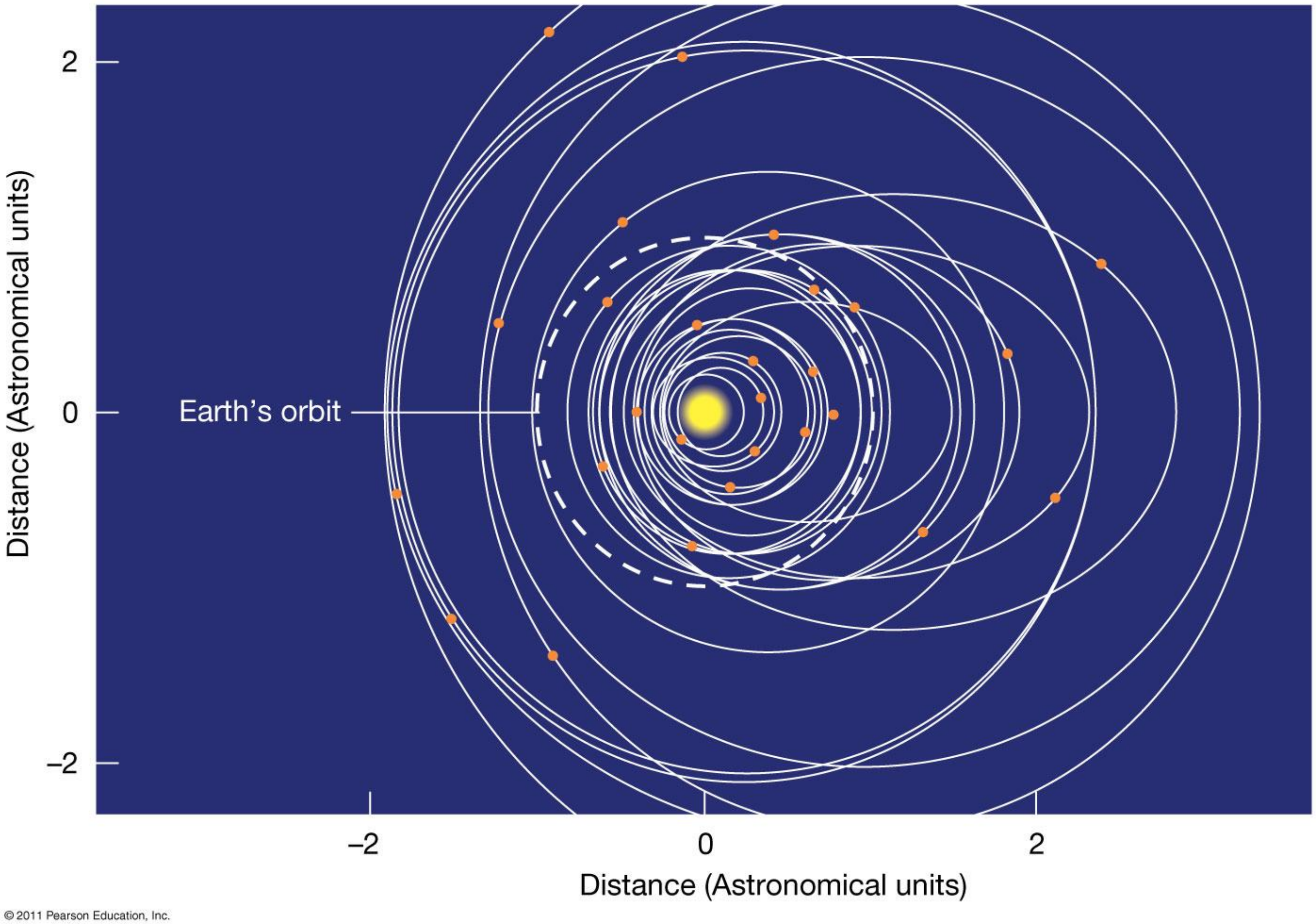
15.6 Properties of Exoplanets

This plot shows the mass, semimajor axis, and eccentricity for 400 extrasolar planets, with the mass ranges corresponding roughly to Jupiter, Neptune, and Earth included for comparison



15.6 Properties of Exoplanets

Orbits of 60 of the known extrasolar planets. Note that some of them are very close to their star:



15.6 Properties of Exoplanets

Planets orbiting within 0.1 AU of their stars are called "hot Jupiters"; they are not included in the previous figure but are numerous.

Stars with composition like our Sun are much more likely to have planets, showing that the "dusty disk" theory is plausible.

Some of these "planets" may actually be brown dwarfs, but probably not many.

15.7 Is Our Solar System Unusual?

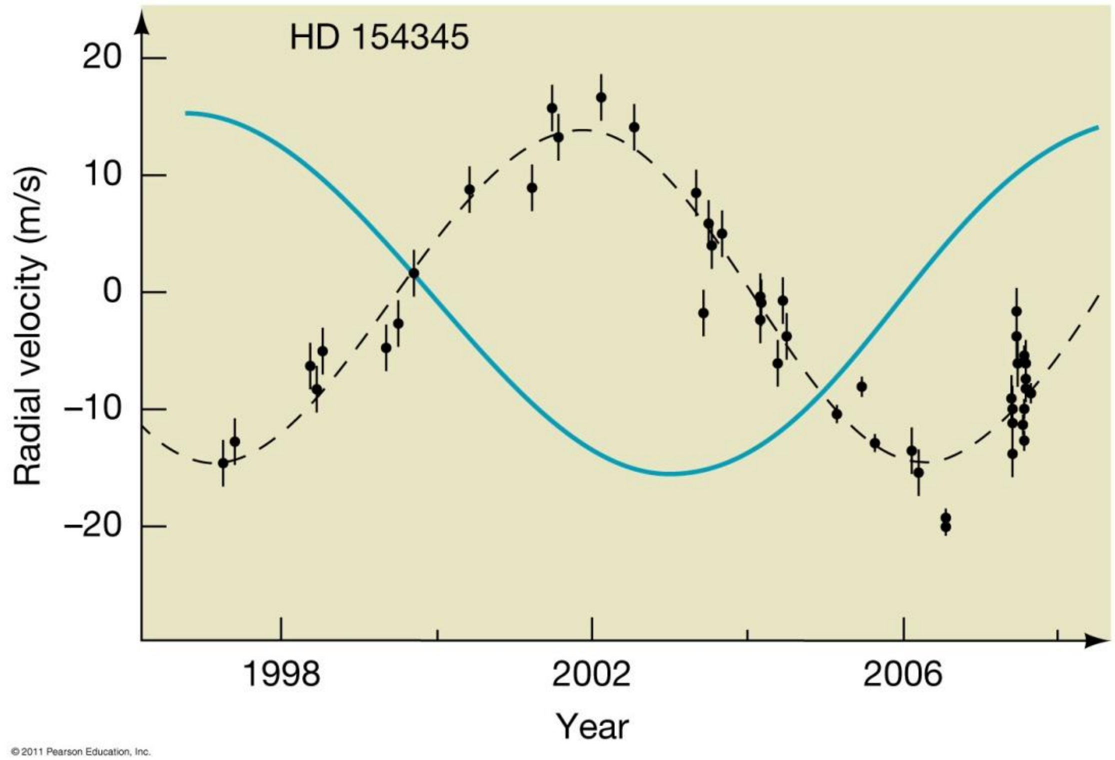
The other planetary systems discovered so far appear to be very different from our own.

Selection effect biases sample toward massive planets orbiting close to parent star; lower-mass planets cannot be detected this way.

15.7 Is Our Solar System Unusual?

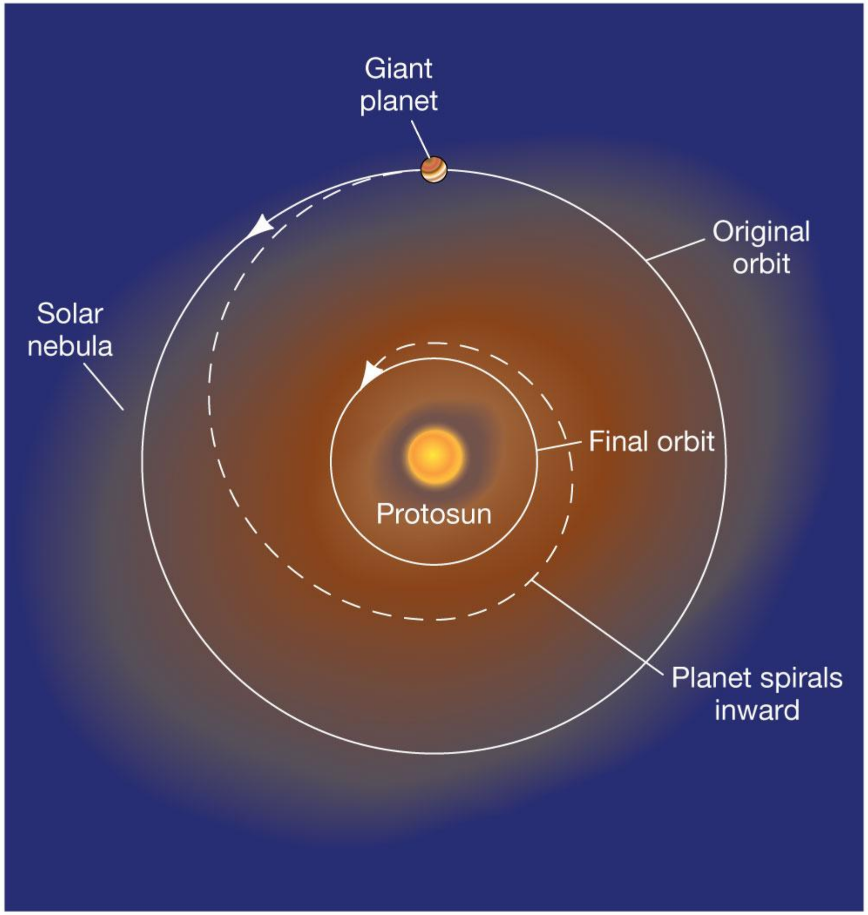
Recently, more Jupiter-like planets have been found; this one has almost the mass of Jupiter and an orbital period of 9.1 years.

The blue line is the same curve for Jupiter.



15.7 Is Our Solar System Unusual?

Current theories include the possibility that Jupiter-like planets could migrate inward, through friction with the solar nebula



15.7 Is Our Solar System Unusual?

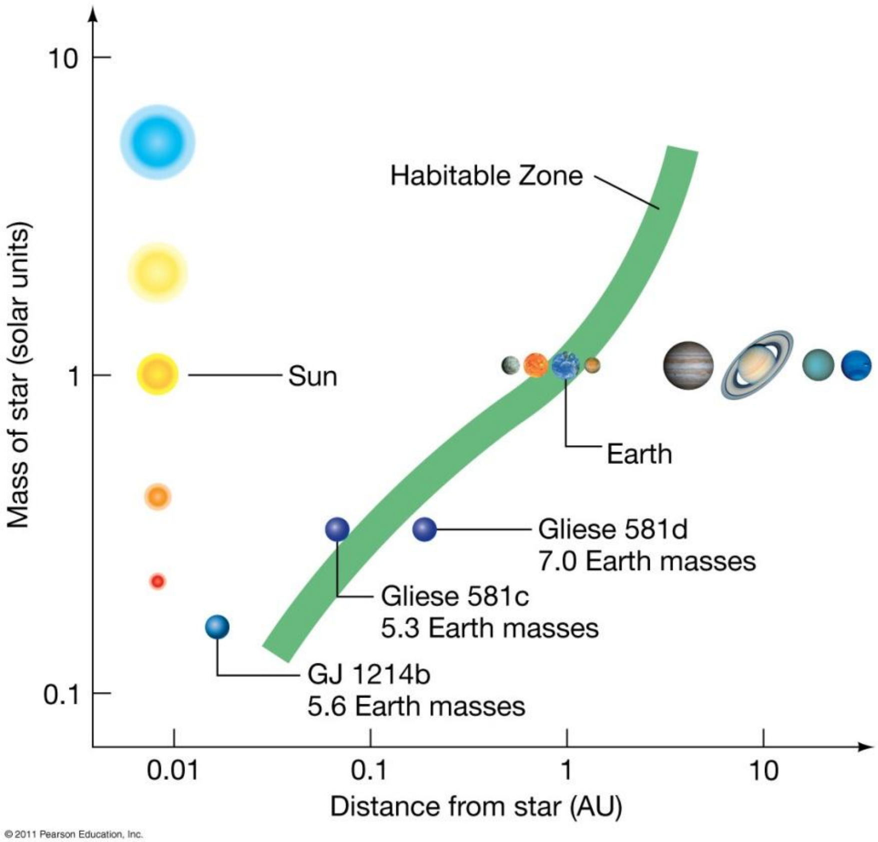
A method of detecting Earth-like planets is much desired but will not be available for some time.

The most promising detection method involves looking for changes in a star's brightness as a planet transits across it.

Until we can observe such planets, we will not be able to draw conclusions about the uniqueness of our own system.

15.7 Is Our Solar System Unusual?

This figure shows the size of the habitable zone – where there is a possibility of liquid water being present – as a function of the mass of the parent star.



Summary of Chapter 15

- The solar system is orderly, not random; need formation theory that explains this.
- Condensation theory is the current favorite—large cloud of interstellar gas and dust starts to collapse, the Sun forms at the center, and dust particles act as accretion nuclei to form the planets.
- Rocky planets would form close to the Sun; outer planets contain materials that would vaporize or escape at higher temperatures.
- Jovian planets may have formed directly from instabilities in the cloud.
- Asteroids never condensed into a larger object.

Summary of Chapter 15 (cont.)

• Leftover planetesimals were ejected from the main solar system and are now in the Kuiper belt and the Oort cloud. Some occasionally enter the inner solar system as comets.

• Collisions probably explain oddities of planets and moons.

• Over 450 extrasolar planets have been observed; most are massive and orbit very close to their star. This is probably the result of selection bias.

• Further conclusions cannot be drawn until it is possible to detect terrestrial planets.