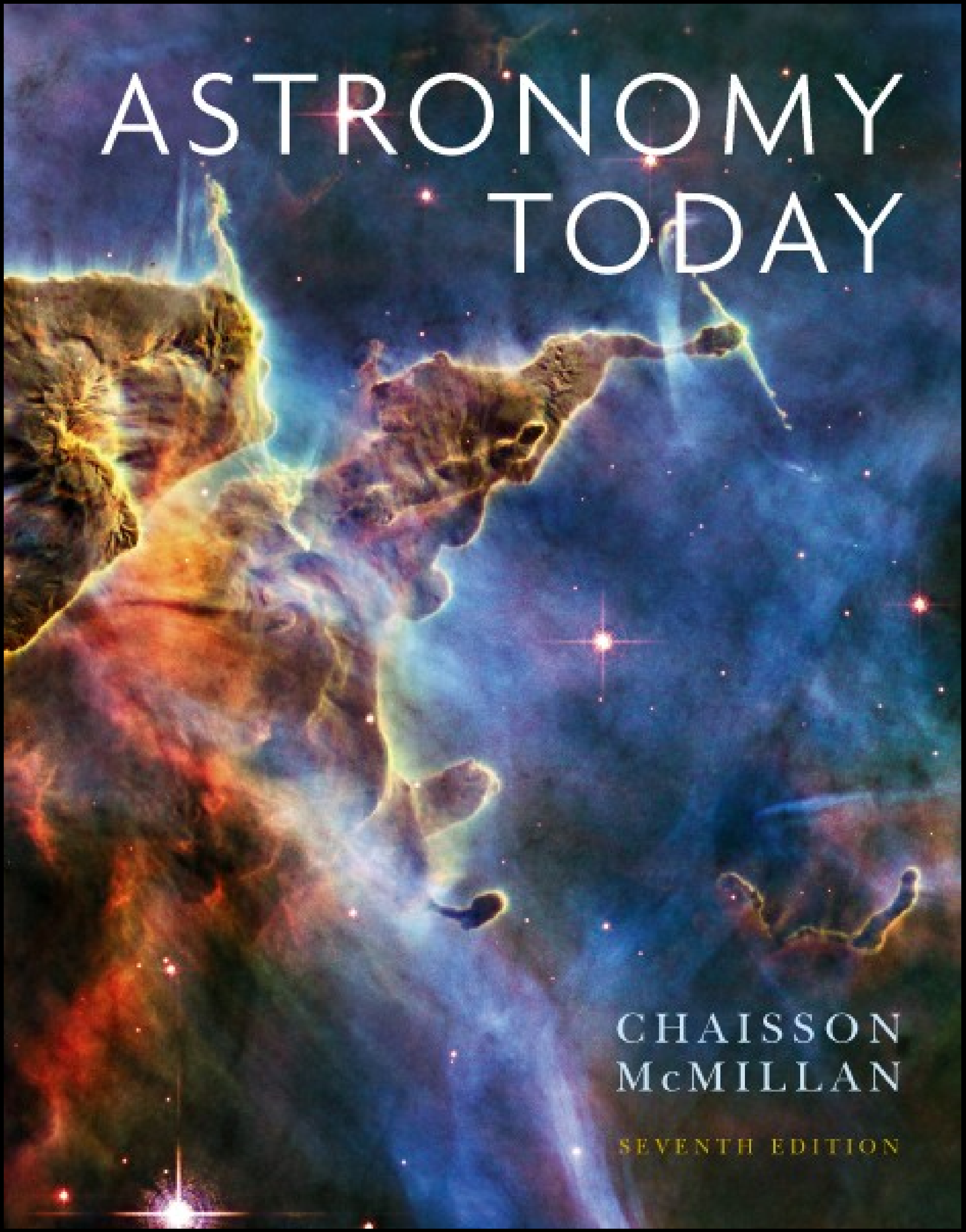


Lecture Outlines

Chapter 6

Astronomy Today

7th Edition

Chaisson/McMillan

Chapter 6
The Solar System

Units of Chapter 6

Units of Chapter 6 (cont.)

6.6 Spacecraft Exploration of the Solar System

Gravitational “Slingshots”

6.7 How Did the Solar System Form?

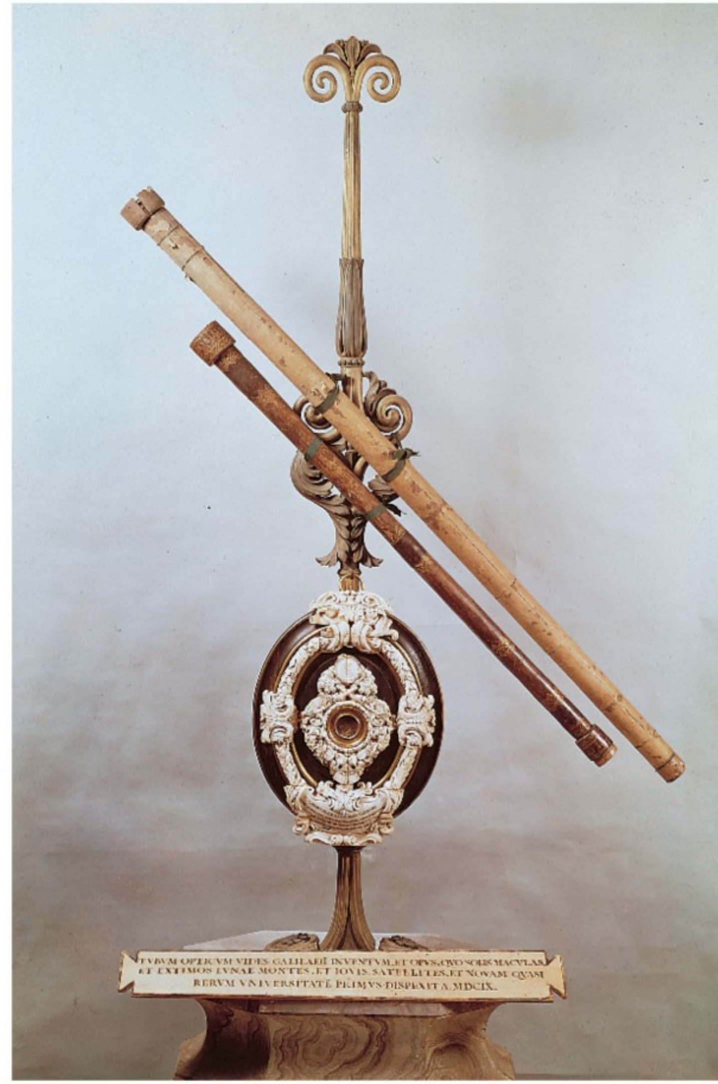
Angular Momentum

6.1 An Inventory of the Solar System

Early astronomers knew of the stars, the 7 *luminaries,* comets, and meteors.

The Copernican Revolution gave us the correct ordering and spacing of the planets (in AU).
The telescope led to measuring:

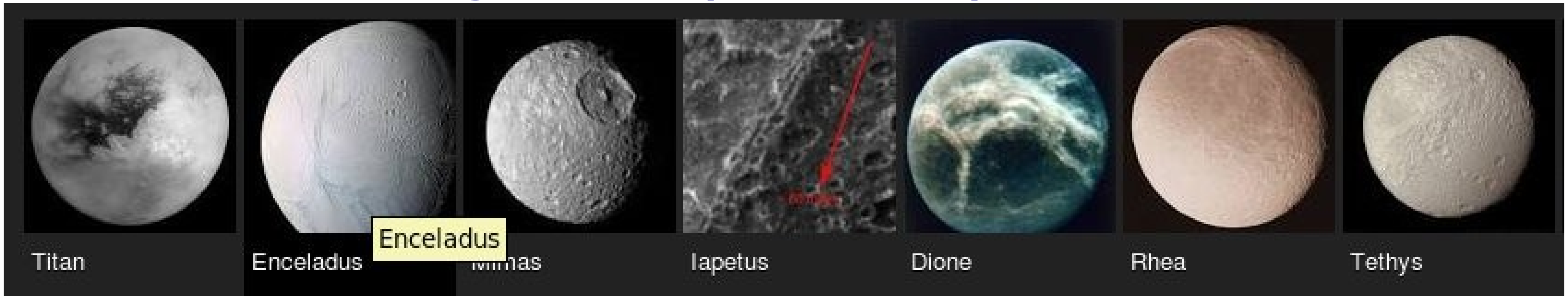
- **the size of AU**
- **stellar parallax**
- **aberration of starlight**
- **and lots of new objects ...**



6.1 An Inventory of the Solar System

Now known:

- **Stars: 1**
- **Planets: 8 (added Uranus and Neptune)**
- **Moons: 166 (2011) → 205 (2021, around planets only)**
- **Asteroids: 8 bigger than 300 km, 10^6 over 1 km.**
- **Kuiper Belt Objects: 100 bigger than 300 km**
- **+ many small asteroids, KBOs, comets, and meteoroids (<100m).**
- **"Dwarf Planets: Ceres + >3 big KBOs, Pluto**
- **Interplanetary: dust (zodiacal), solar wind**



6.2 Measuring the Planets

TABLE 6.1 Properties of Some Solar System Objects

Object	Orbital Semimajor Axis (AU)	Orbital Period (Earth Years)	Mass (Earth Masses)	Radius (Earth Radii)	Number of Known Satellites	Rotation Period * (days)	Average Density (kg/m^3)	(g/cm^3)
Mercury	0.39	0.24	0.055	0.38	0	59	5400	5.4
Venus	0.72	0.62	0.82	0.95	0	–243	5200	5.2
Earth	1.0	1.0	1.0	1.0	1	1.0	5500	5.5
Moon	—	—	0.012	0.27	—	27.3	3300	3.3
Mars	1.52	1.9	0.11	0.53	2	1.0	3900	3.9
Ceres (asteroid)	2.8	4.7	0.00015	0.073	0	0.38	2700	2.7
Jupiter	5.2	11.9	318	11.2	63 79 (2019)	0.41	1300	1.3
Saturn	9.5	29.4	95	9.5	56 82 (2019)	0.44	700	0.7
Uranus	19.2	84	15	4.0	27	–0.72	1300	1.3
Neptune	30.1	164	17	3.9	13 14 (2019)	0.67	1600	1.6
Pluto (Kuiper belt object)	39.5	248	0.002	0.2	3 5 (2019)	–6.4	2100	2.1
Hale-Bopp (comet)	180	2400	1.0×10^{-9}	0.004	—	0.47	100	0.1
Sun	—	—	332,000	109	—	25.8	1400	1.4

**A negative rotation period indicates retrograde (backward) rotation relative to the sense in which all planets orbit the Sun.*

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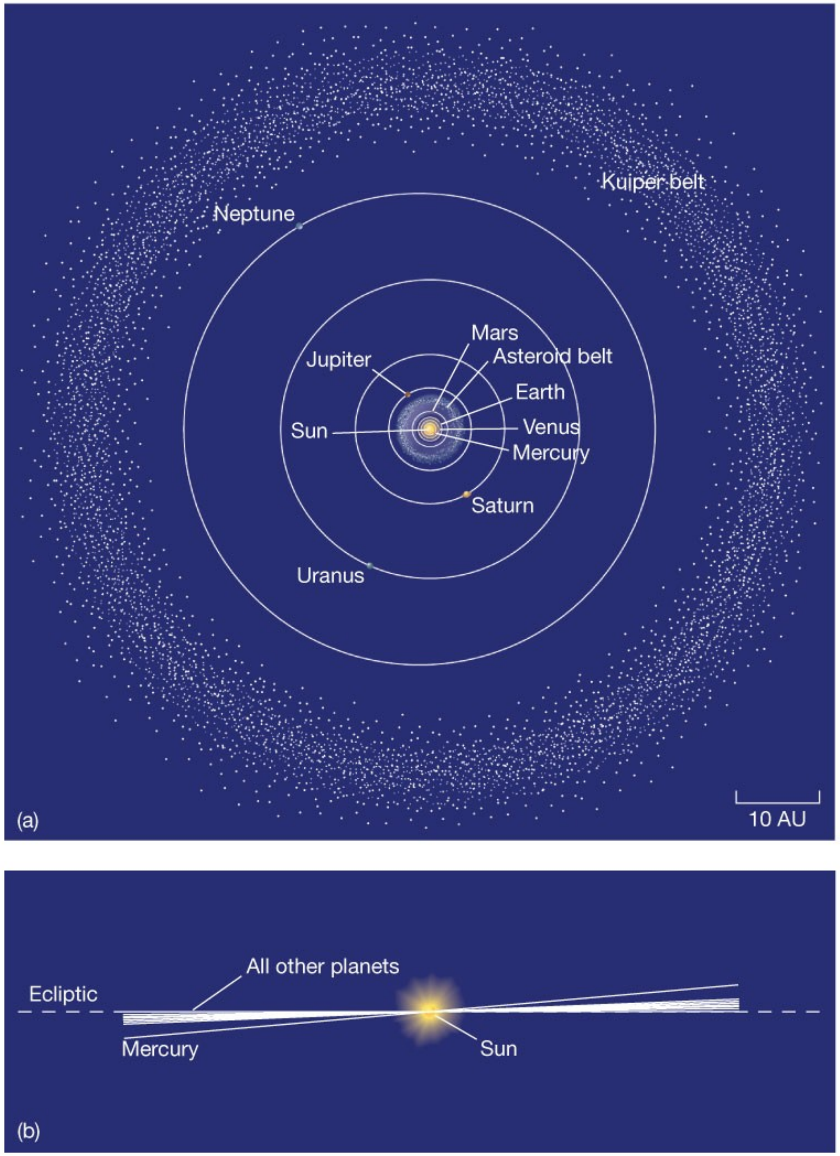
6.2 Measuring the Planets

- **Orbital period** found from synodic period
- **Distance from Sun** from Kepler’s 3rd law
- **Radius** known from angular size and distance
- **Masses** from Newton’s laws / Kepler's laws
- **Rotation period** by watching surface features
- **Density** can be calculated knowing radius and mass
- ***Uncompressed density***: the density of a planet if gravity were not compressing it

6.3 The Overall Layout of the Solar System

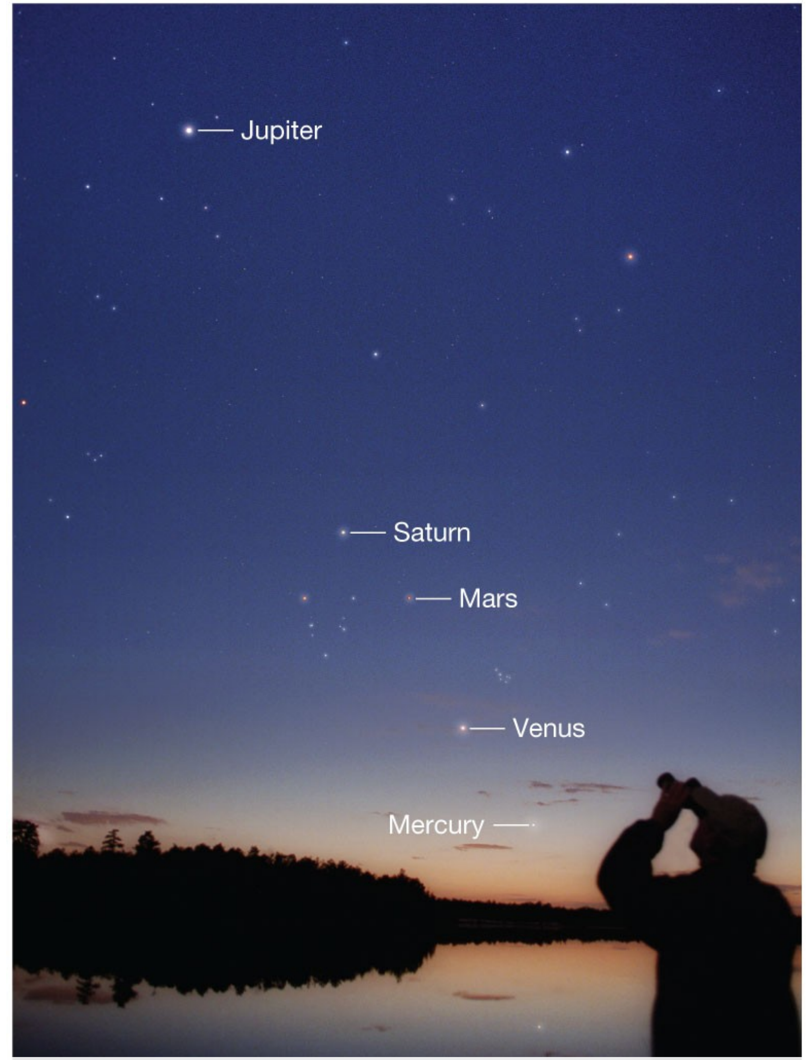
All orbits but Mercury's are close to the same plane



6.3 The Overall Layout of the Solar System

Because the planet's orbits are close to being in a plane, it is possible for them to appear in a straight line as viewed from Earth.

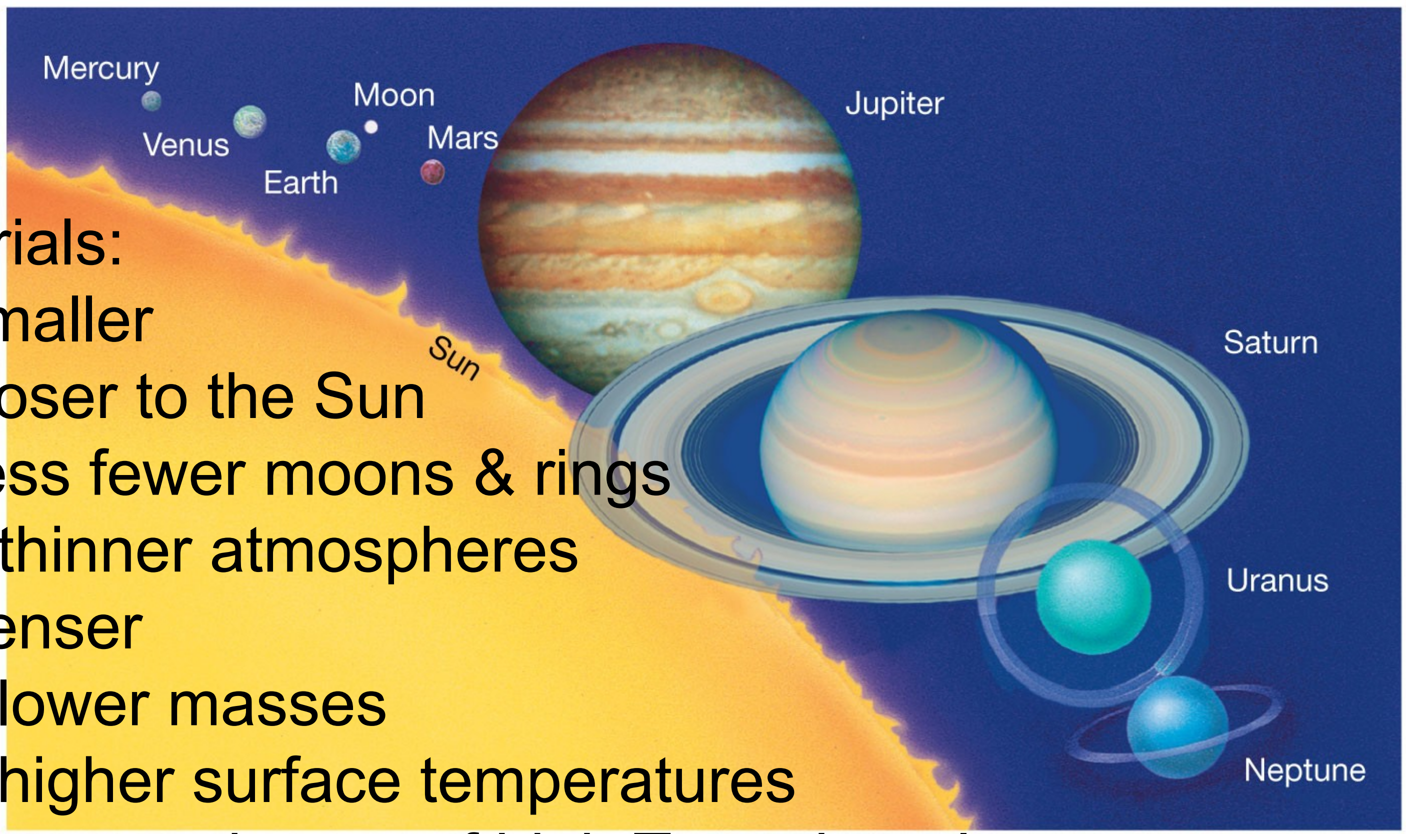
(Photograph was taken in April 2002.)



*A 1974 book, "The Jupiter Effect", predicted end-of-world destruction in 1982 due to a similar alignment.

6.4 Terrestrial and Jovian Planets

In this picture of the eight planets and the Sun, some of the differences between the four terrestrial and four Jovian planets are clear.



Terrestrials:

- Are smaller
- Are closer to the Sun
- Possess fewer moons & rings
- Have thinner atmospheres
- Are denser
- Have lower masses
- Have higher surface temperatures
- Are composed more of high T_{melt} minerals

6.4 Terrestrial and Jovian Planets

Differences *among* the terrestrial planets:

- **All have atmospheres, but they are very different; surface conditions vary as well**
- **Only Earth has oxygen in its atmosphere, liquid water on its surface, and life**
- **Earth and Mars spin at about the same rate; Mercury and Venus rotate much more slowly, Venus also rotates retrograde**
- **Only Earth and Mars have moons**
- **Only Earth and Mercury have magnetic fields**

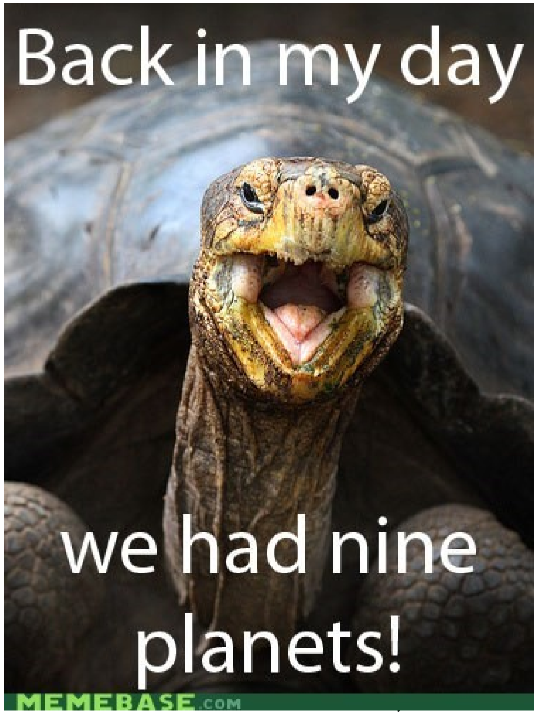
6.4 Terrestrial and Jovian Planets

Pluto was always the oddball.

It is on the inner edge of the Kuiper Belt. a=39 AU.

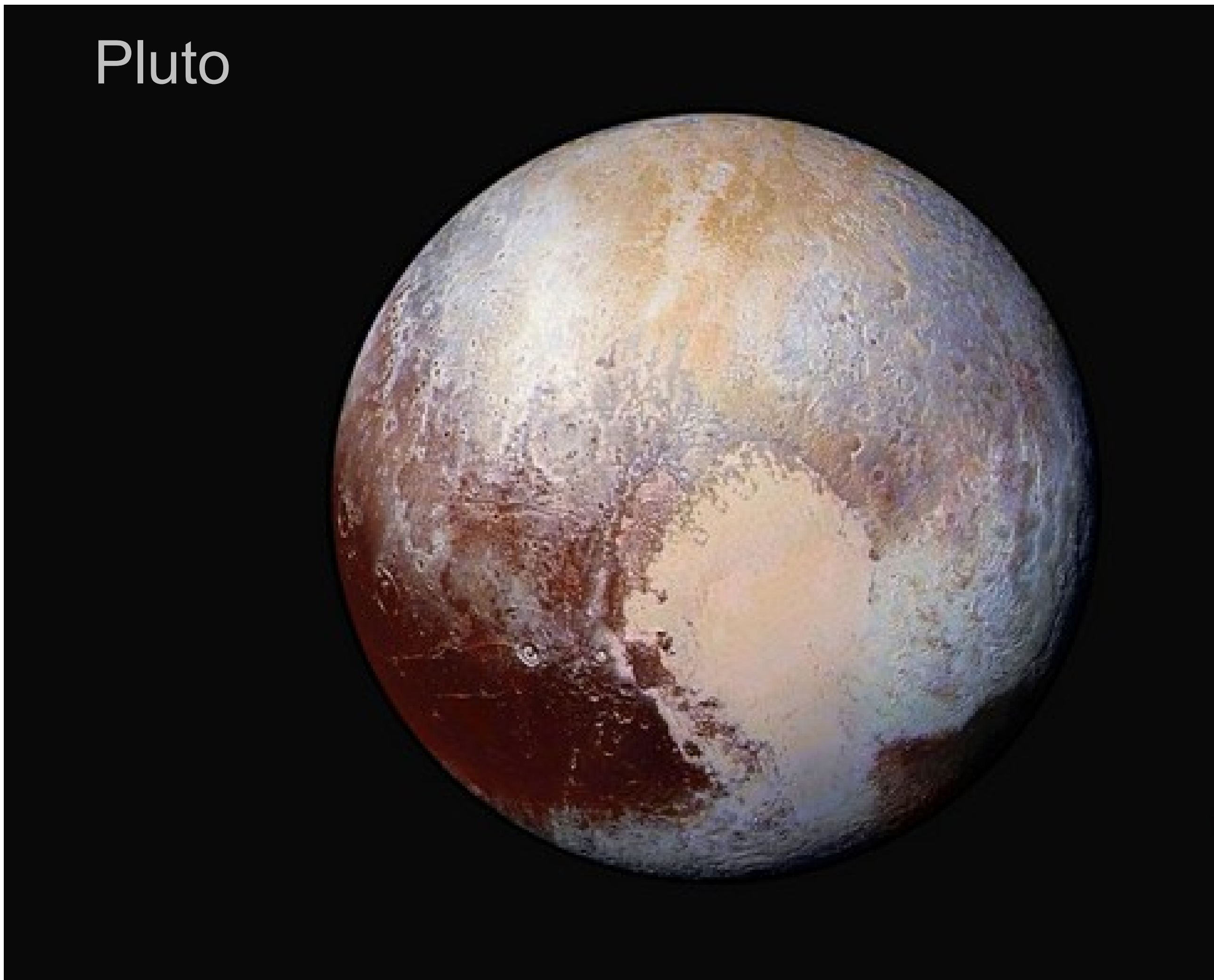
Trans-neptunian objects found (Quauar, Makemake, Sedna) of nearly the same size.

Then, Eris was found, even bigger than Pluto and has Moon (Dysnomia).



6.4 Terrestrial and Jovian Planets

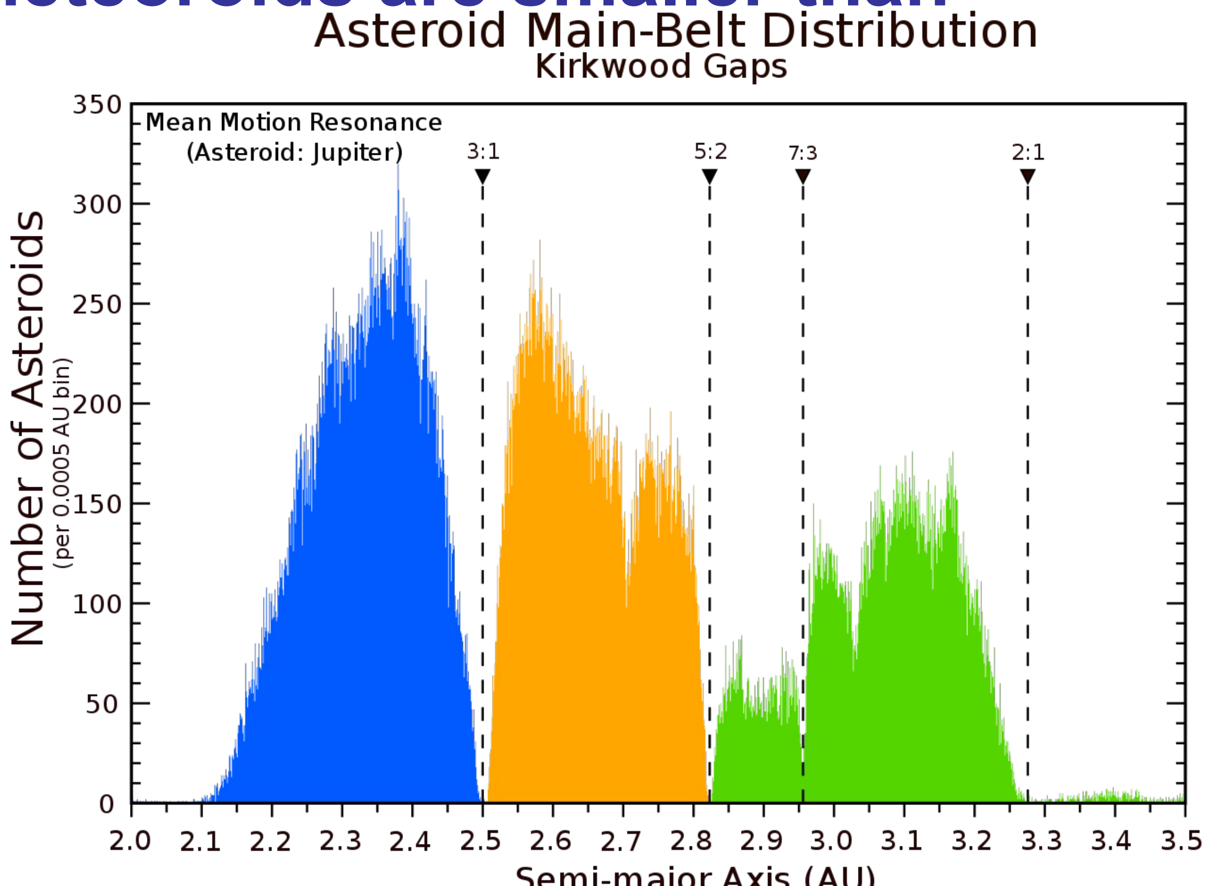
Pluto was visited by New Horizons on July 14, 2015. It is bigger than Eris after all! Has 5 moons!



6.5 Interplanetary Matter

Asteroids and meteoroids have rocky composition. (Meteoroids are smaller than 100 m.)

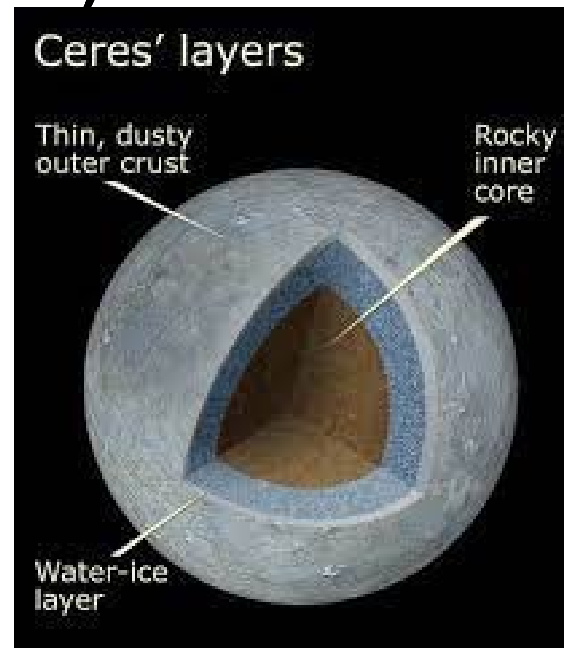
Most asteroids 2<a<3.5 AU.



NEA = Near Earth Asteroids (also PHA) pose danger.

6.5 Interplanetary Matter

<u>Asteroids!</u> Biggest asteroid (Ceres[†]) is spherical and *differentiated*.



Most are potato shaped.

Ex) Asteroid Eros is 34 km long*

(a)

Visited by Dawn in 2018. *Visited by NEAR in 2001.

6.5 Interplanetary Matter

Comets are "dirty snowballs"

Comet Hale-Bopp

Had biggest nucleus (37 mi).

Visible to eye in 1997.

Period ~ 2530 years.

Comet Bernardinelli-Bernstein

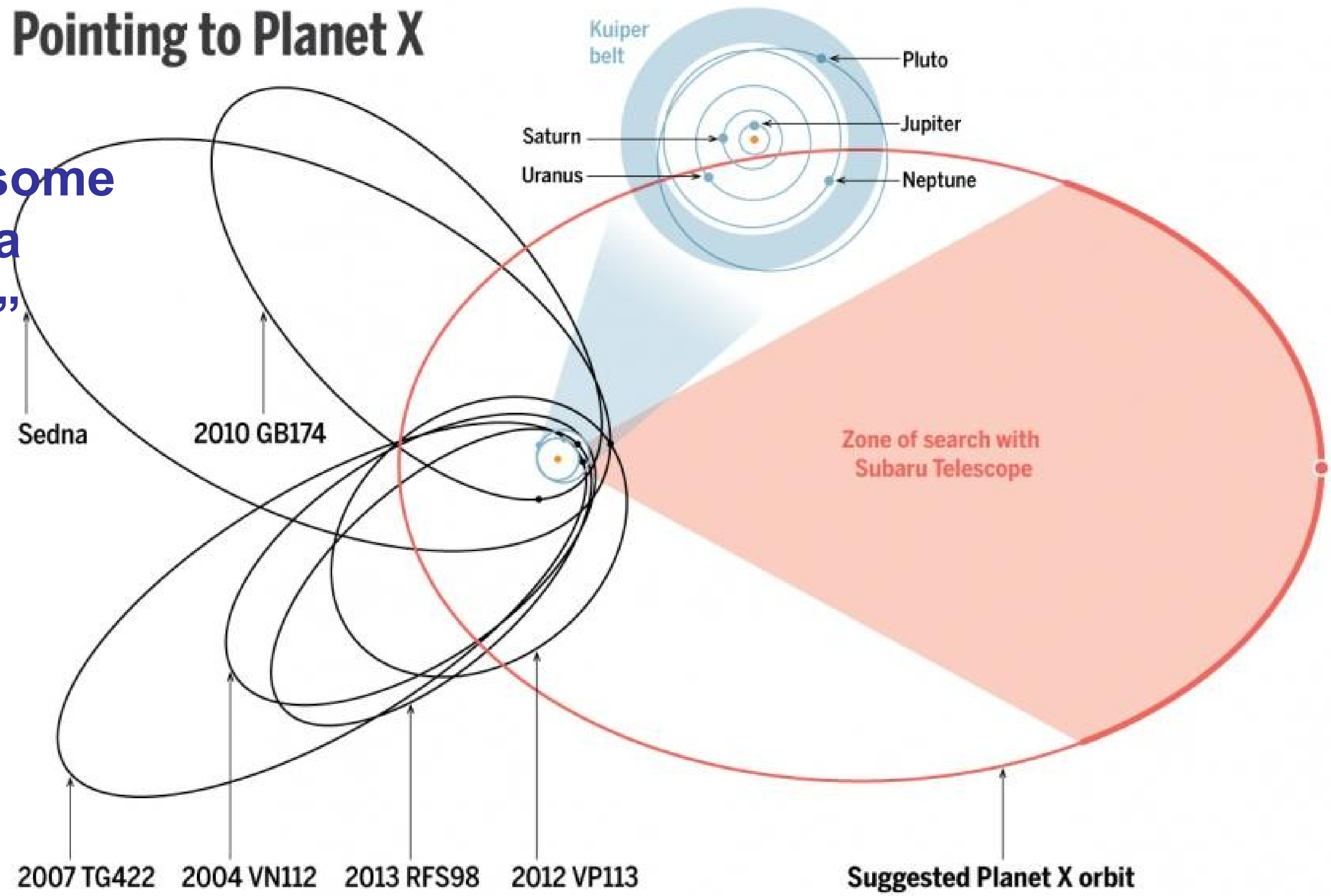
Is now the largest known at 60-120 miles. Will be closest (~11 AU) in 2031.

(b)

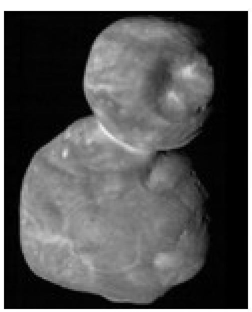
6.5 Interplanetary Matter

Kuiper Belt Objects are beyond Neptune.

Orbits of some suggests a "Planet X."

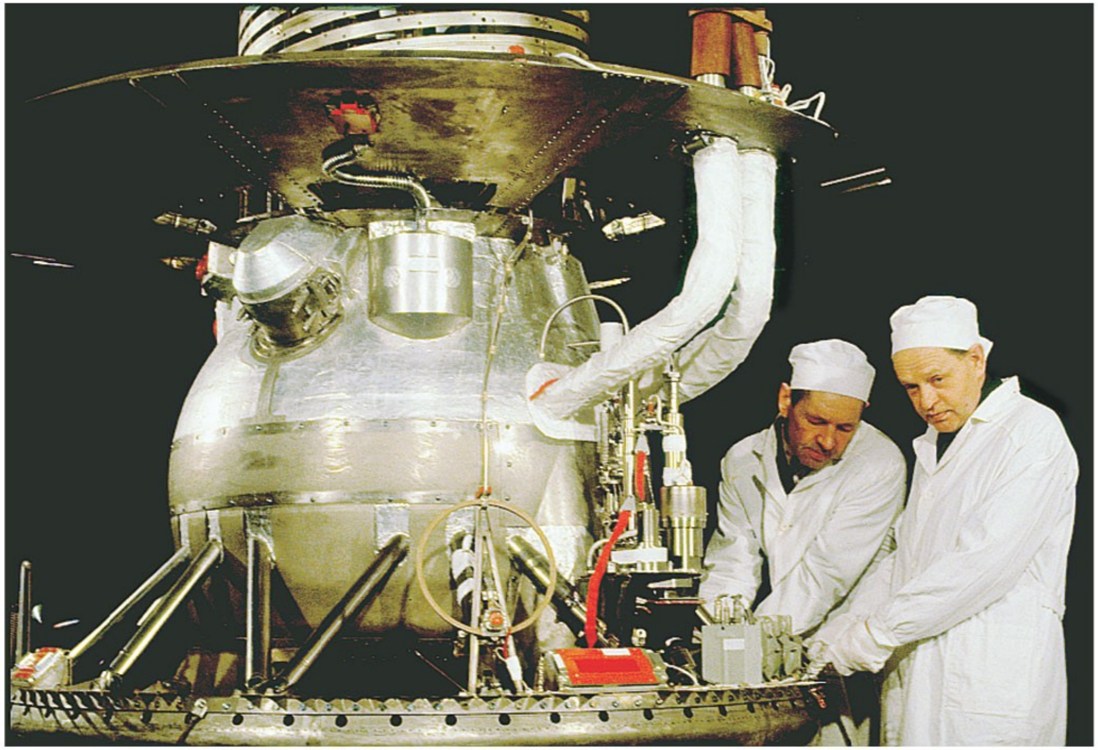


"Arrokoth"



6.6 Spacecraft Exploration of the Solar System

Soviet *Venera* probes landed on Venus from 1970 to 1978



6.6 Spacecraft Exploration of the Solar System

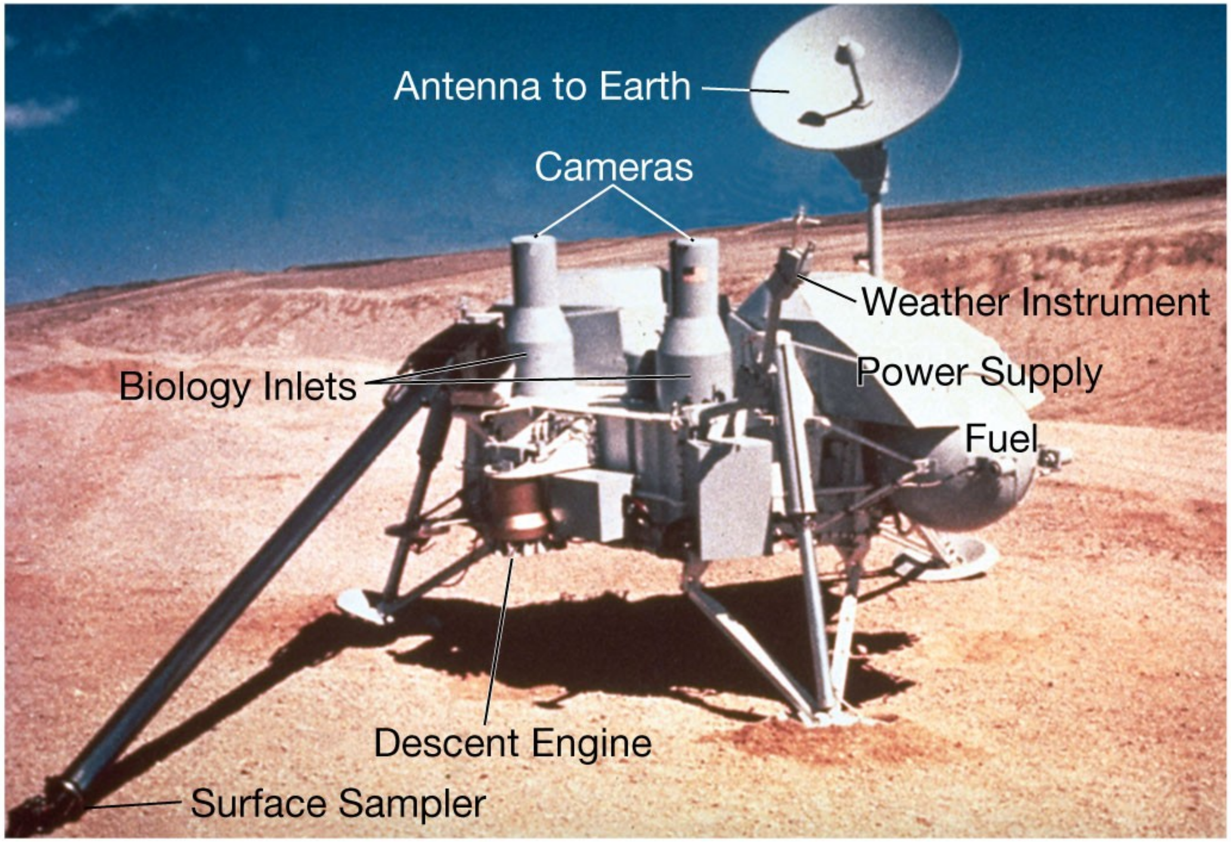
The most recent Venus expedition from the United States was the *Magellan* orbiter, 1990–1994.

ESAs latest: *Venus Express*, 2005-2015.

See Globe of Venus

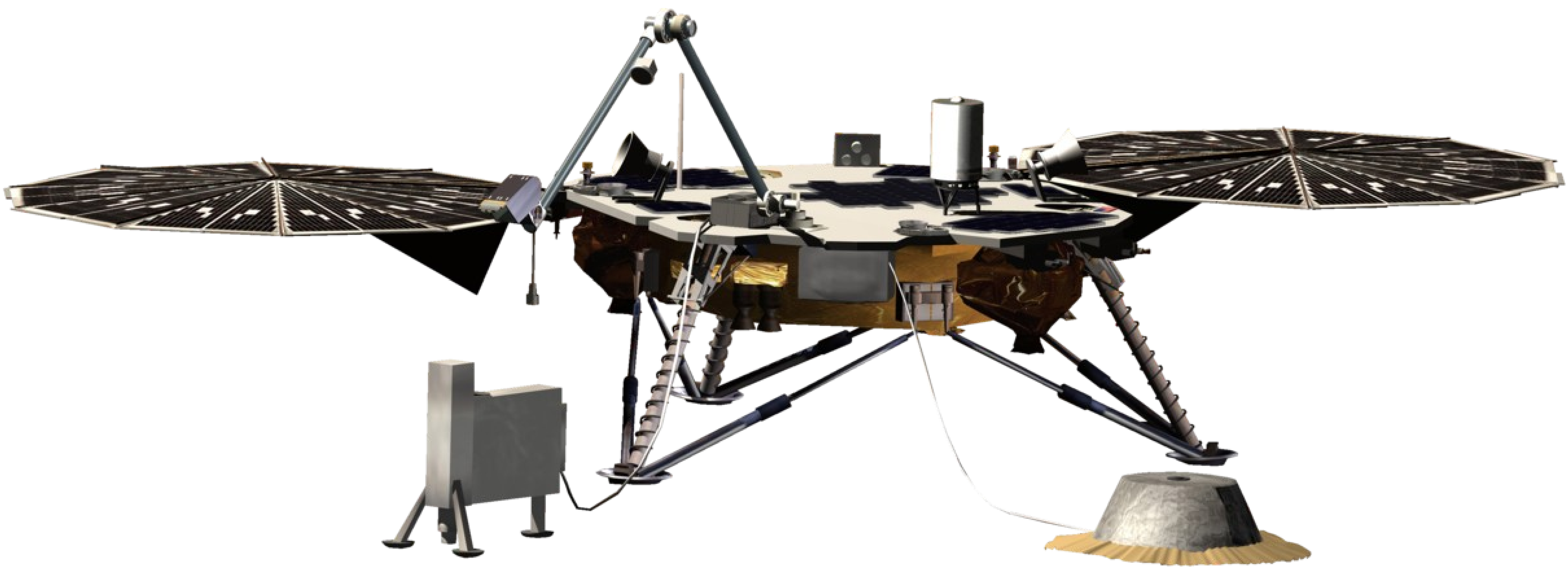
6.6 Spacecraft Exploration of the Solar System

Viking **landers arrived at Mars in 1976**



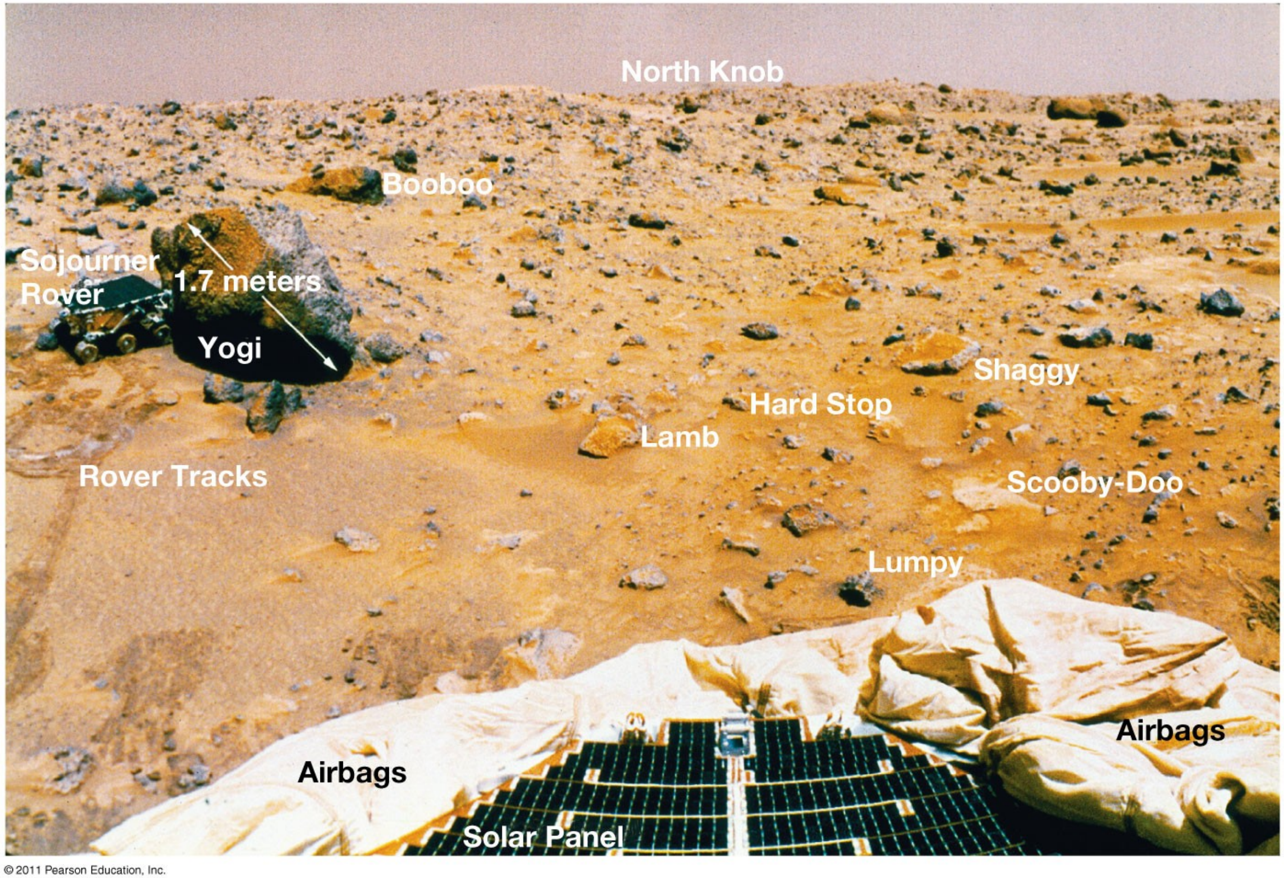
6.6 Spacecraft Exploration of the Solar System

InSight **lander landed on Mars in Nov. 2018. Has seismometer.**



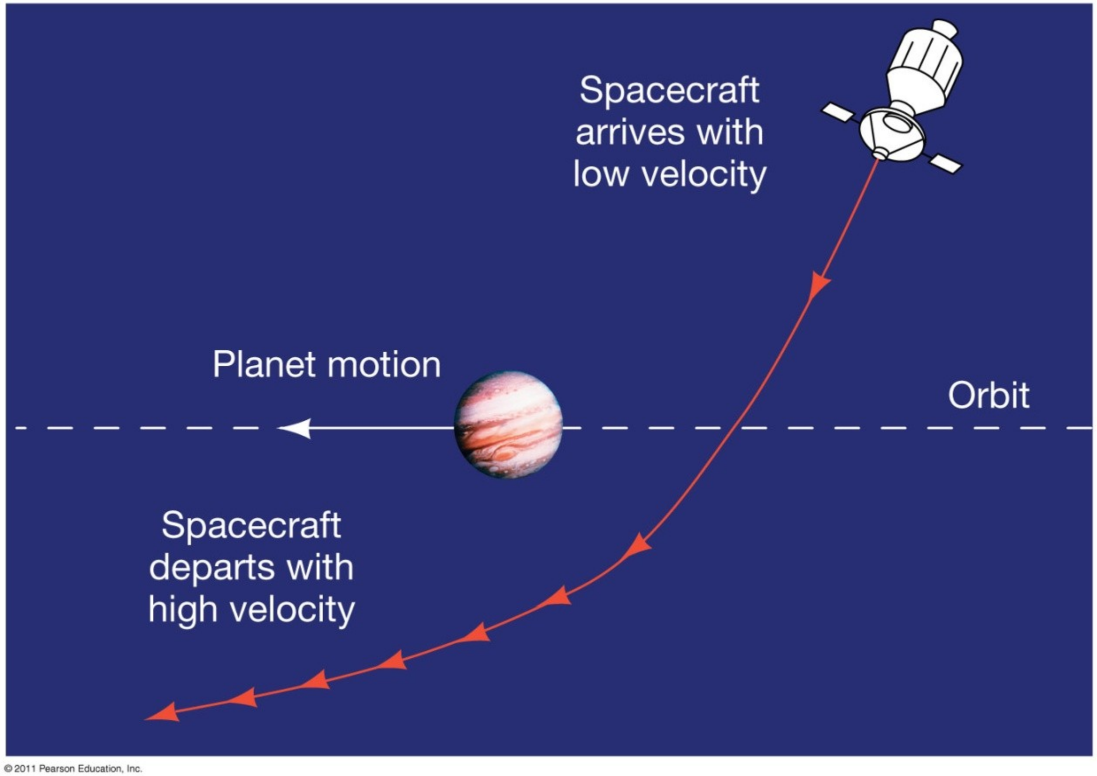
6.6 Spacecraft Exploration of the Solar System

Sojourner **rover was deployed on Mars in 1997**



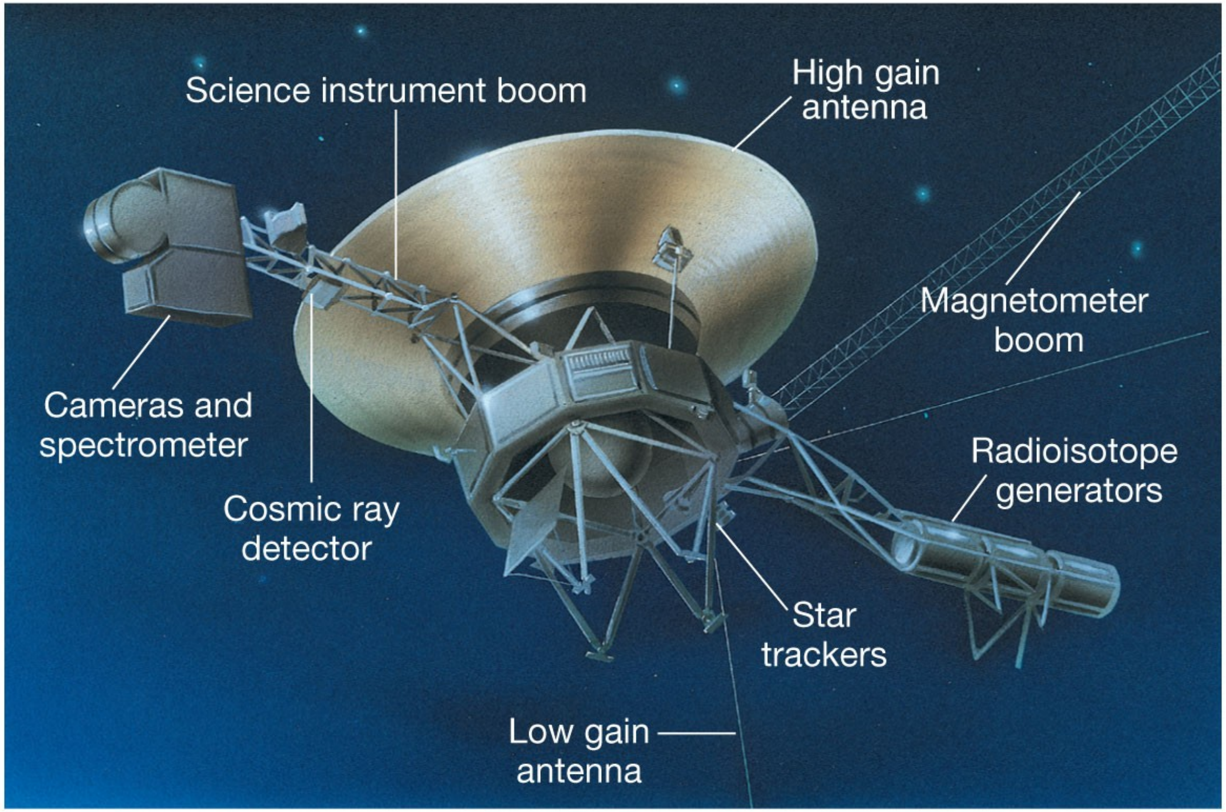
Discovery 6-1: Gravitational "Slingshots"

Gravitational "slingshots" can change direction of spacecraft, and also accelerate it



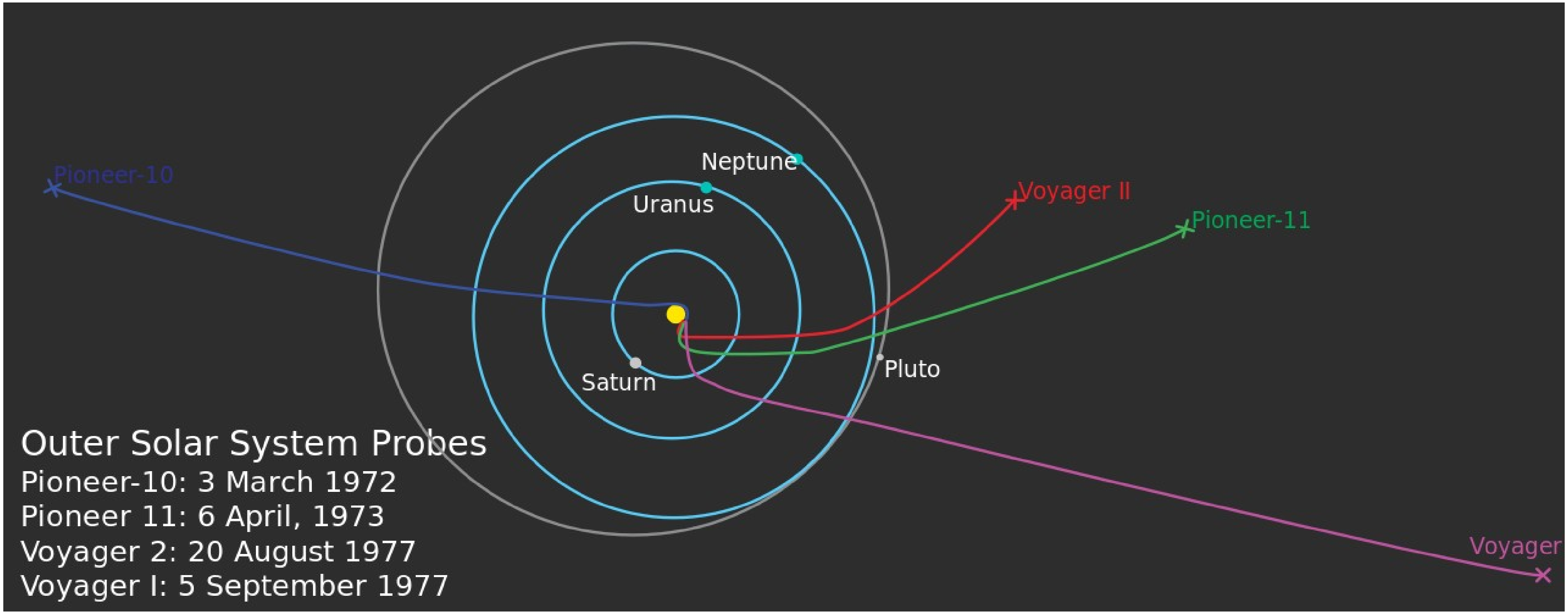
6.6 Spacecraft Exploration of the Solar System

Pioneer **and** ***Voyager*** **flew through through asteroid belt on way to outer solar system. This is** ***Voyager.***



6.6 Spacecraft Exploration of the Solar System

***Pioneer* and *Voyager* launch dates and trajectories. Only 5 craft have reached escape velocity from the solar system!**



6.6 Spacecraft Exploration of the Solar System

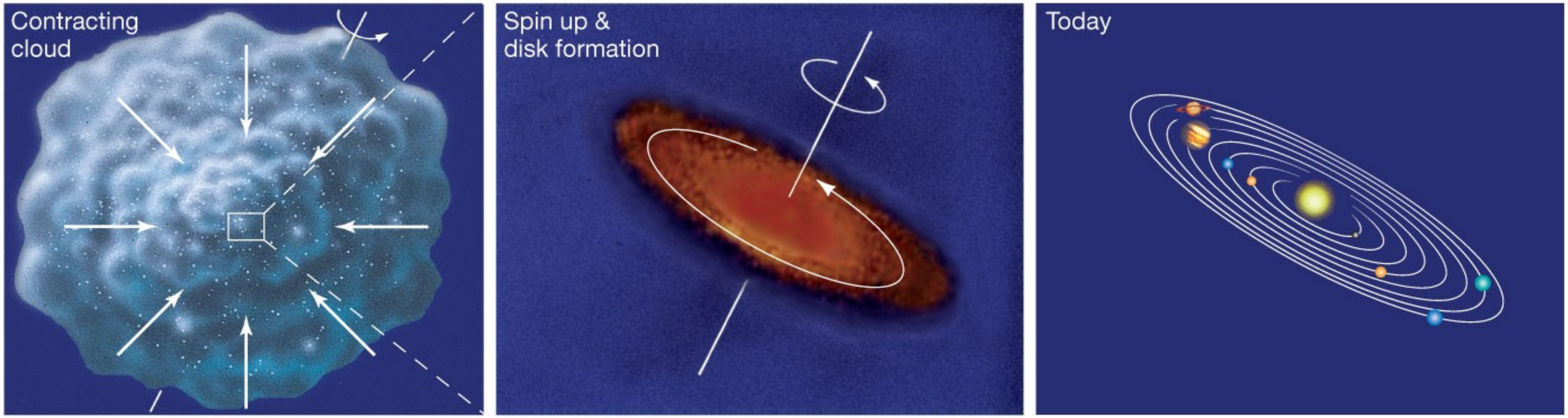
Cassini-Huygens **mission arrived at Saturn in 2004.**

It has returned many spectacular images.

6.7 How Did the Solar System Form?

Nebular theory:

Cloud of gas and dust contracts due to gravity.
Contracts more easily along spin axis – forms disk.
Conservation of angular momentum means it spins faster and faster as it contracts.

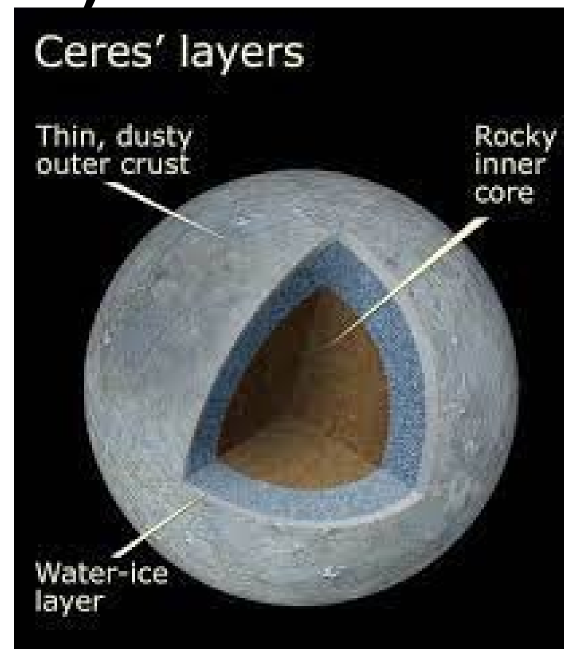


(a) (b) (c)

Planets form out of disk.

6.5 Interplanetary Matter

<u>Asteroids!</u> Biggest asteroid (Ceres†) is spherical and *differentiated*.



Most are potato shaped.

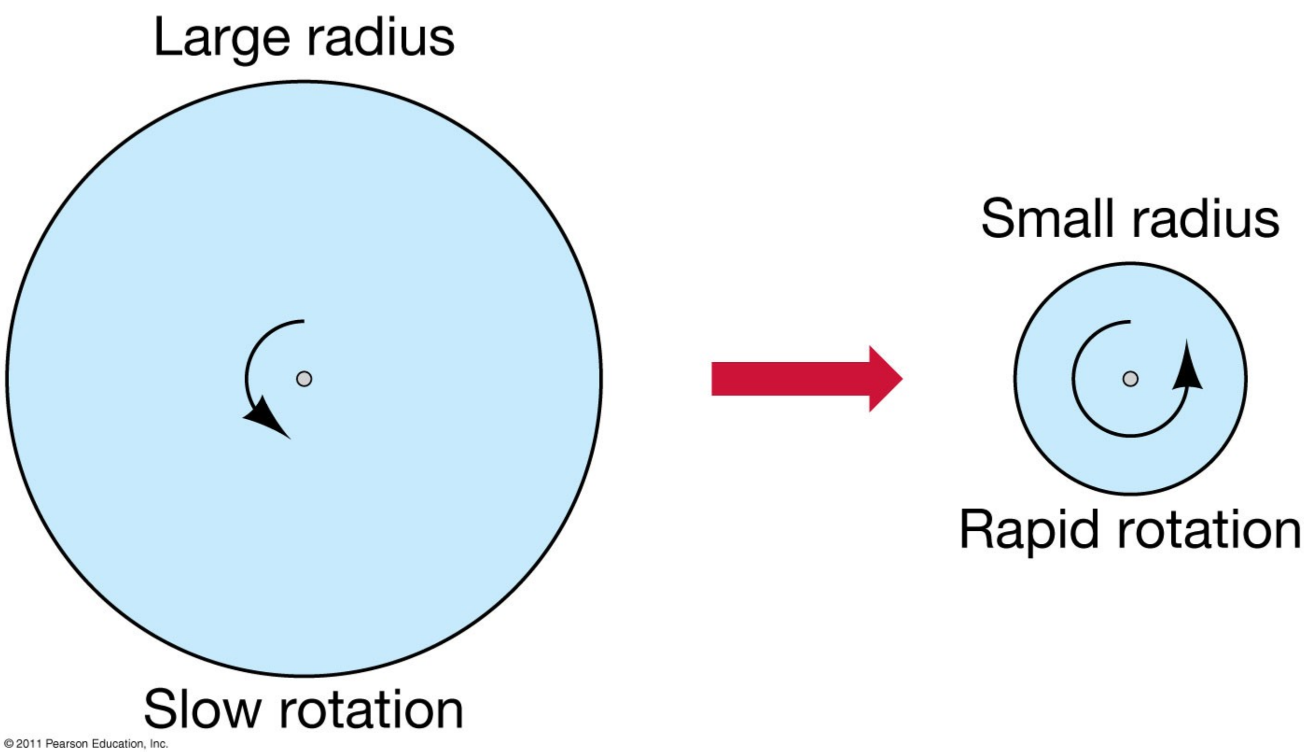
Ex) Asteroid Eros is 34 km long*

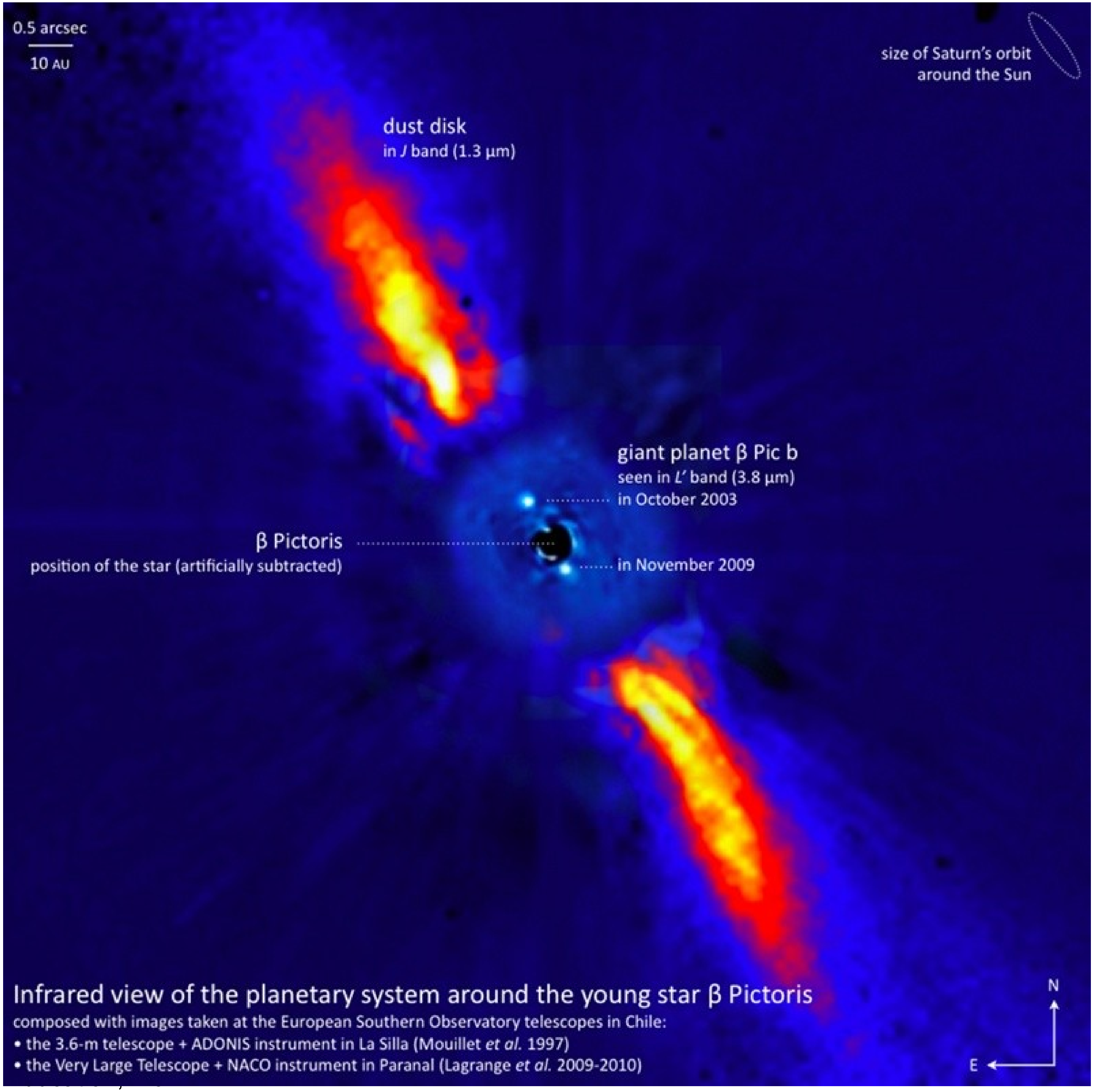
(a)

†Visited by Dawn in 2015-18. *Visited by NEAR in 2001.

More Precisely 6-1: Angular Momentum

Conservation of angular momentum says that product of radius and rotation rate must be constant. $L \sim MR^2 \omega$ **(where** ω **= spin rate)**



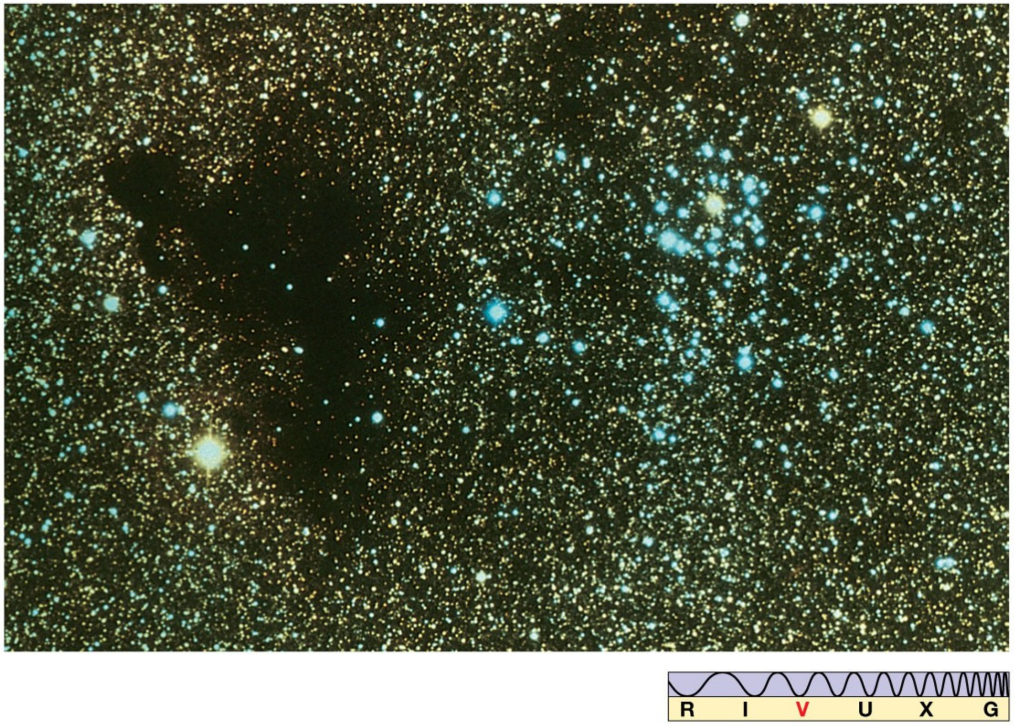

0.5 arcsec
10 AU
size of Saturn's orbit around the Sun
dust disk
in J band (1.3 µm)
giant planet β Pic b
seen in L′ band (3.8 µm)
in October 2003
β Pictoris
position of the star (artificially subtracted)
in November 2009
Infrared view of the planetary system around the young star β Pictoris
composed with images taken at the European Southern Observatory telescopes in Chile:
• the 3.6-m telescope + ADONIS instrument in La Silla (Mouillet et al. 1997)
• the Very Large Telescope + NACO instrument in Paranal (Lagrange et al. 2009-2010)
N
E

6.7 How Did the Solar System Form?

Dust is important ingredient in the solar nebula.

1) It allows nebula to cool and contract.

2) It provides nuclei for condensation and accretion onto small chunks.

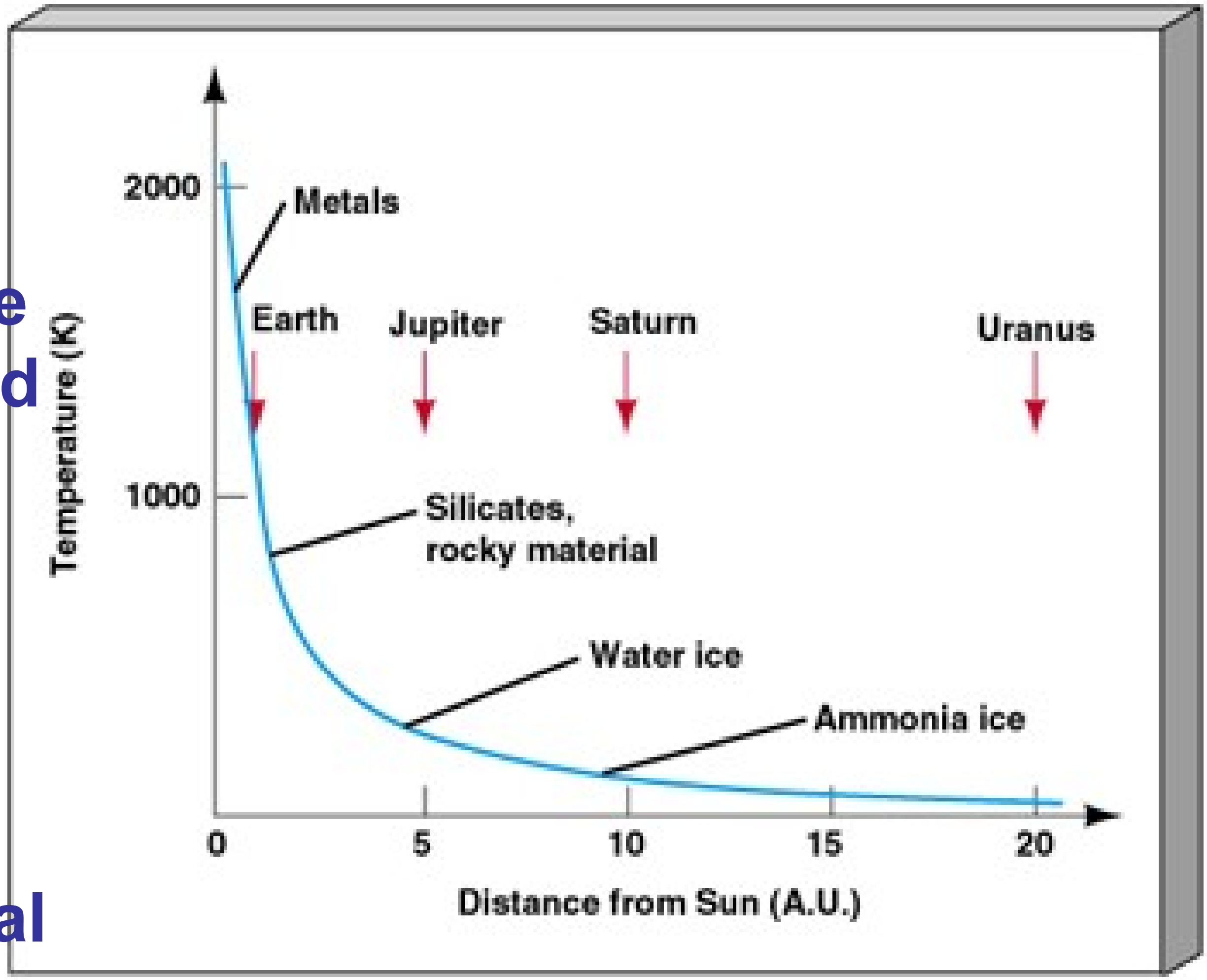


Dust can be seen in inter-stellar clouds as shown here.

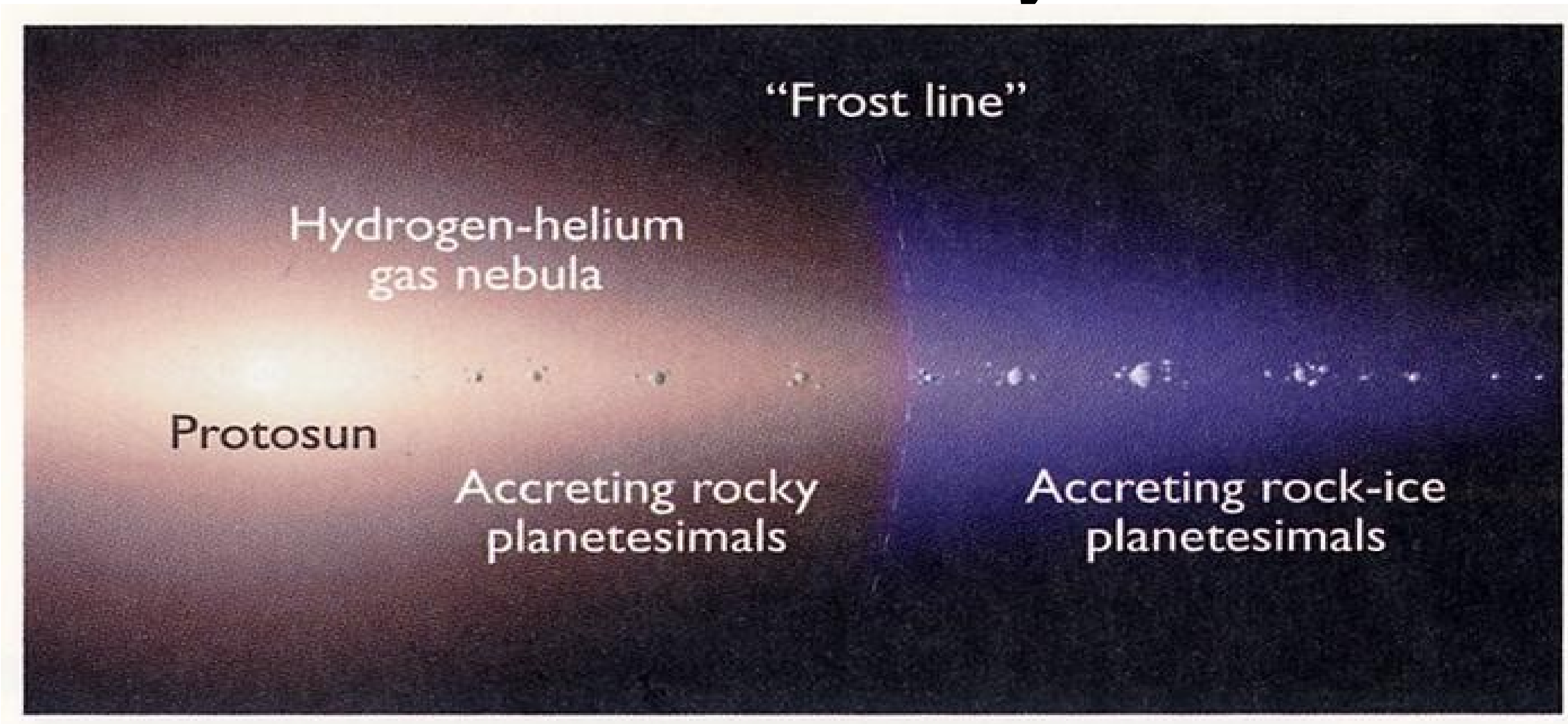
6.7 How Did the Solar System Form?

The *condensation sequence* is the way the composition of the dust grains in the solar nebula changed with distance from the Sun.

High melting point materials close to Sun, high and low melting point material far from Sun.



6.7 How Did the Solar System Form?



Once planets got big enough, they could gravitationally capture H and He gas from solar nebula.

6.7 How Did the Solar System Form?

Hierarchical formation terms

Interstellar grains < 1 micrometer

Protoplanetary disk grains >~ 1 micrometer

Aggregates, fractal aggregates

Pebbles

pebble+gas swarms

Planetesimals

Protoplanets

Processes

Bonds,
Molecular forces

“Static cling”,
Stickiness

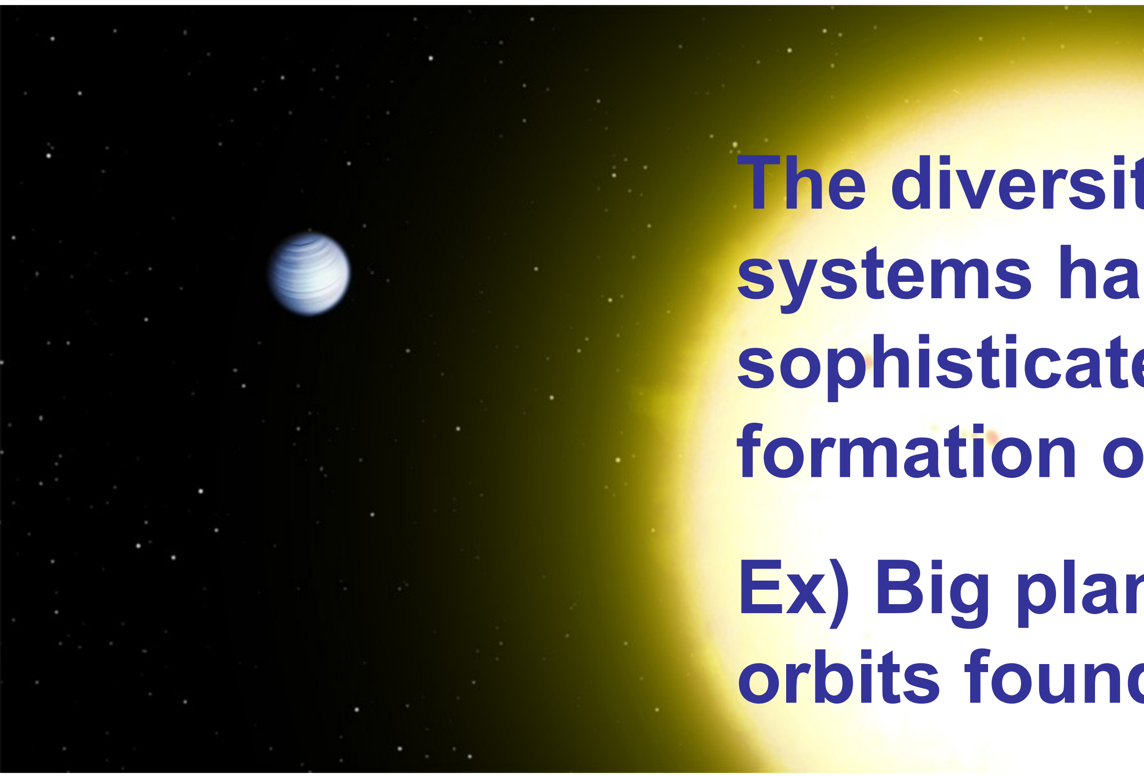
Slow collisions,
Fast collisions

Gravity + collisions
+ accretion of gas

6.7 How did the Solar System Form?

More than 3826 extrasolar planets have been confirmed! (4717 Kepler candidates)*

51 Pegasi, the first exoplanet discovered.
Artists conception, from *Wikipedia.*



The diversity of these new systems has required more sophisticated theories for the formation of planet systems.

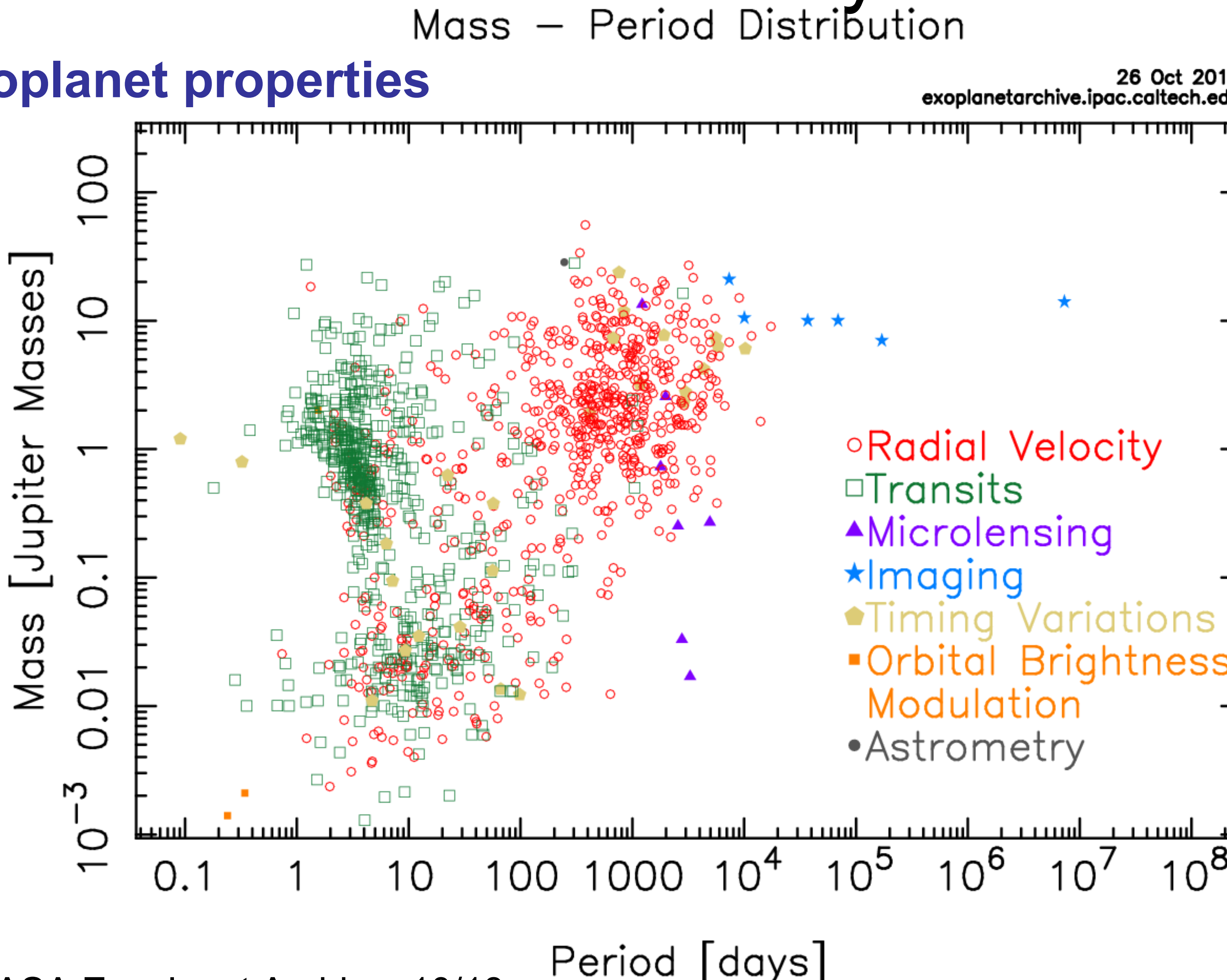
Ex) Big planets with eccentric orbits found.

Ex) Unusually low densities

 *NASA Exoplanet Archive, 10/18

6.7 How did the Solar System Form?

Exoplanet properties



 *NASA Exoplanet Archive, 10/18

Summary of Chapter 6

- **Solar system consists of Sun and everything orbiting it**
- **Asteroids are rocky, and most orbit between orbits of Mars and Jupiter**
- **Comets are icy and are believed to have formed early in the solar system's life**
- **Major planets orbit Sun in same sense, and all but Venus rotate in that sense as well**
- **Planetary orbits lie almost in the same plane**

Summary of Chapter 6 (cont.)

- **Four inner planets—terrestrial planets—are rocky, small, and dense**
- **Four outer planets—jovian planets—are gaseous and large**
- **Nebular theory of solar system formation: cloud of gas and dust gradually collapsed under its own gravity, spinning faster as it shrank**
- **Condensation theory says dust grains acted as condensation nuclei, beginning formation of larger objects**