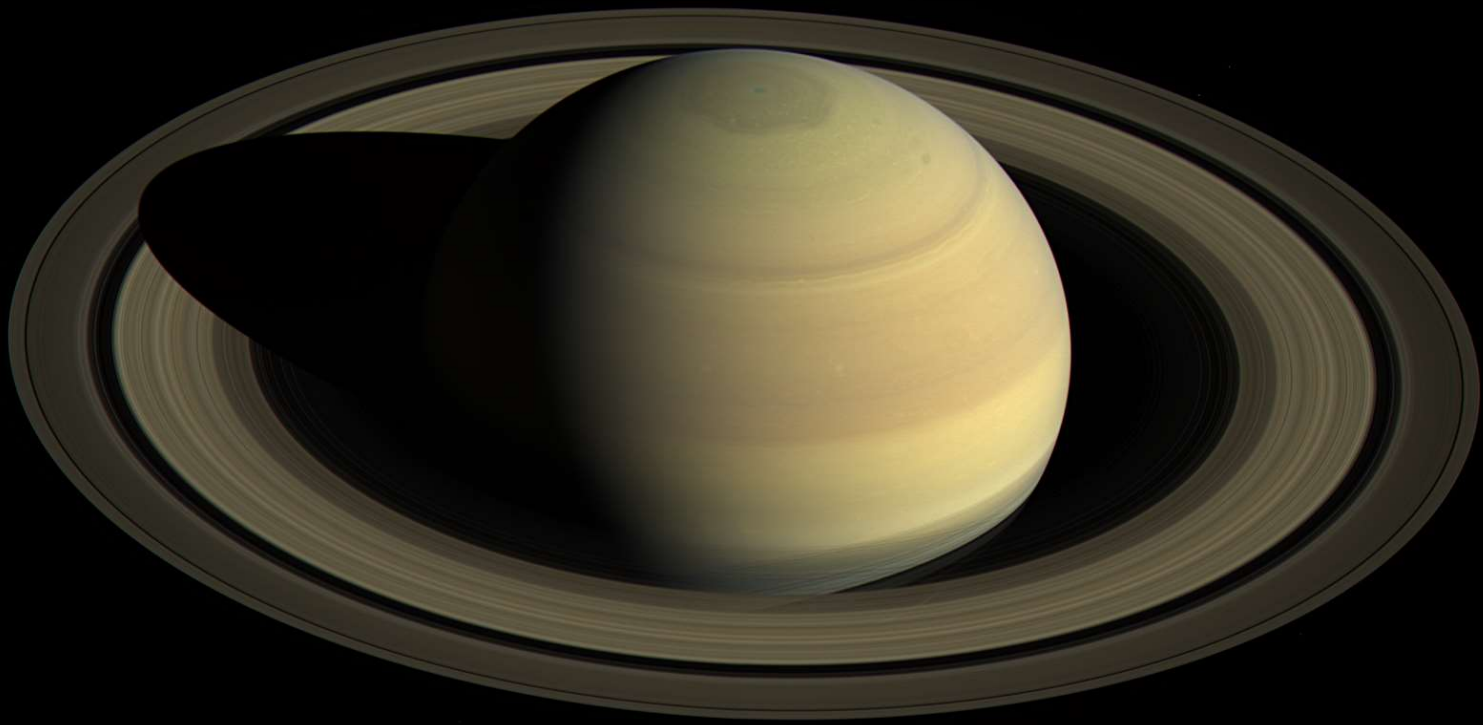
AST 2002
Introduction to Astronomy



A Few Quick Things…

Mary Hinkle, Graduate Teaching Assistant:

Office Hours: Mon 1:30-3:30pm. PSB 316 (this week only)

May not be there this week… is heading out of town

My office hours: Mon 3:30-4:30pm. PSB 308 (this week only) – Will be an exam make-up time…

… I cannot answer exam questions today!

Tue 3-4 pm. PSB 308

First Mid-term was last week… Friday 9th February.

Next Knights Under the Stars Event – Thur 22nd Feb 7-8:30pm

How did the Exam go?

A. It was too easy…
B. It was too hard…
C. I think the difficulty was about right…
D. There was not enough time.

What we have covered so far…

Part I – Developing Perspective

- **Chapter 1:** A Modern View of the Universe
- **Chapter 2:** Discovering the Universe for Yourself
- **Chapter 3:** The Science of Astronomy

Part II – Key Concepts of Astronomy

- **Chapter 4:** Making Sense of the Universe: Understanding Motion, Energy, and Gravity
- **Chapter 5:** Light: The Cosmic Messenger

What's up next?

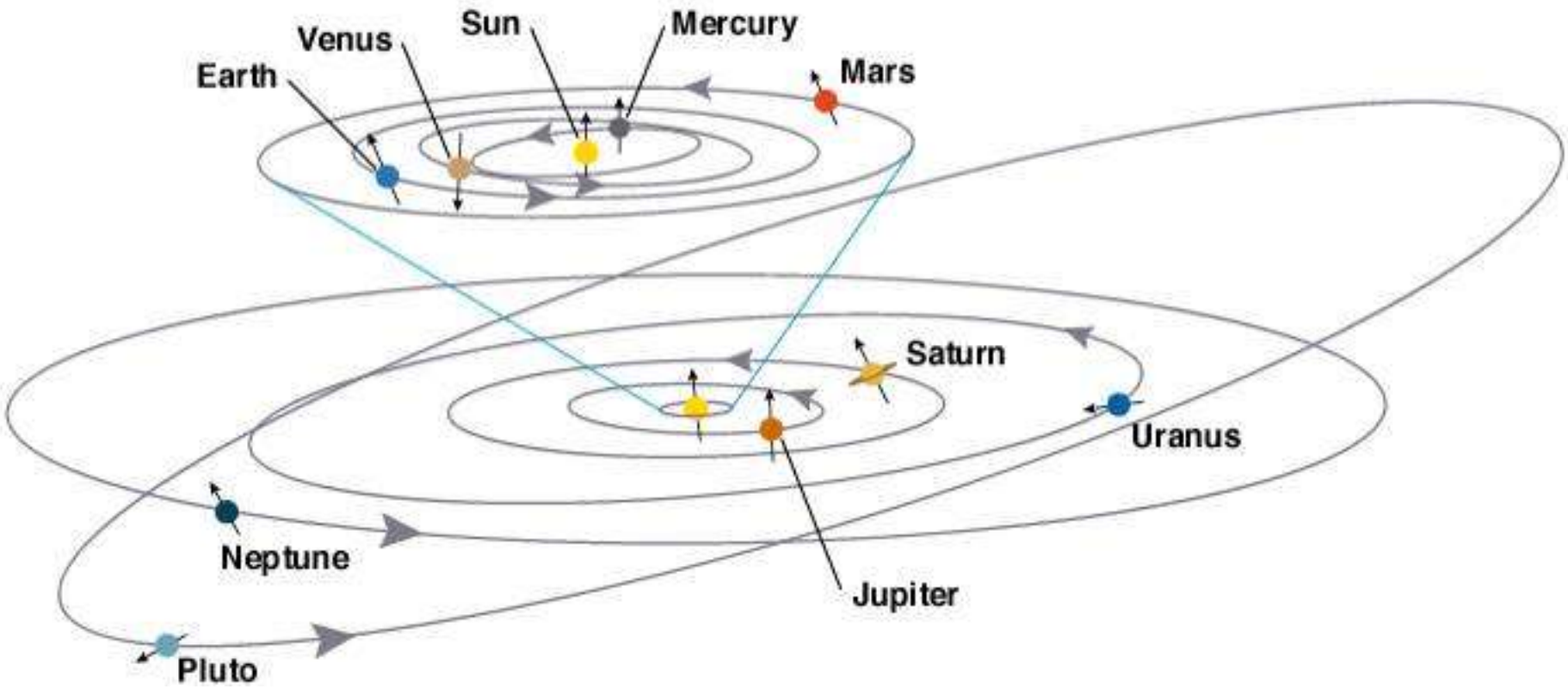
Part III – Learning from other Worlds

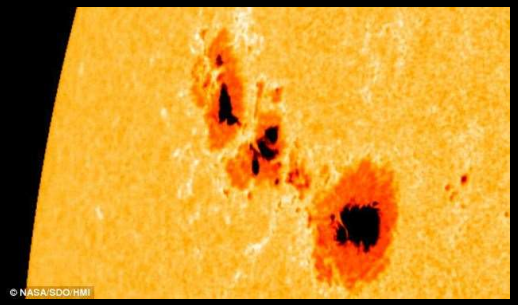
- **Chapter 6:** Formation of the Solar System
  - **Today:** Tour of the Solar System… Nebula Hypothesis
- **Chapter 7:** Earth and the Terrestrial Worlds
- **Chapter 8:** Jovian Planet Systems
- **Chapter 9:** Asteroids, Comets, and Dwarf Planets: Their Nature, Orbits and Impacts.

Mid-Term #2

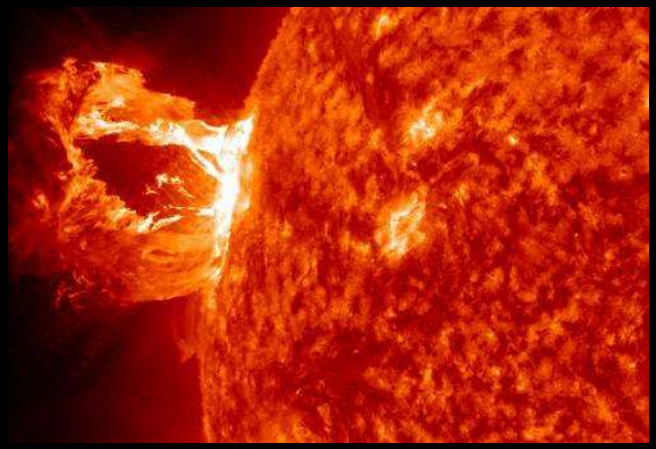
Chapter 10: Other Planetary Systems: The New Science of Distant Worlds

A Brief Tour of the Solar System



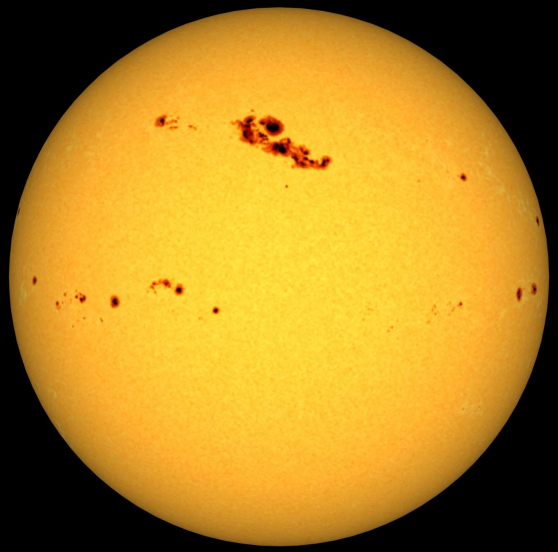


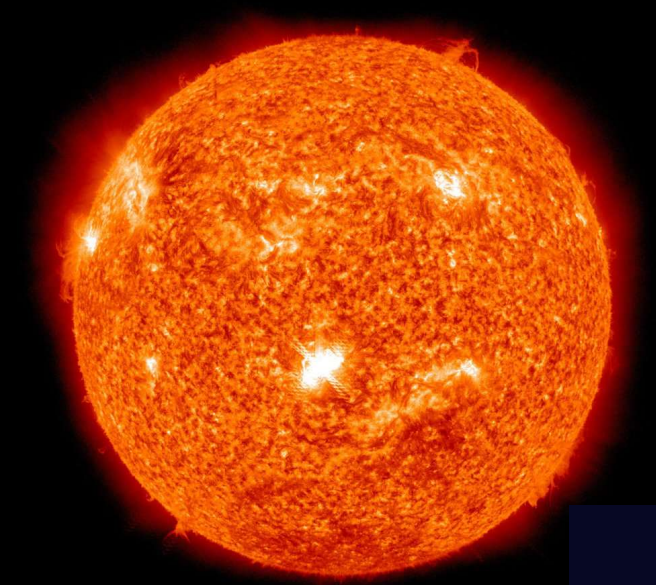
Sunspots



The Sun

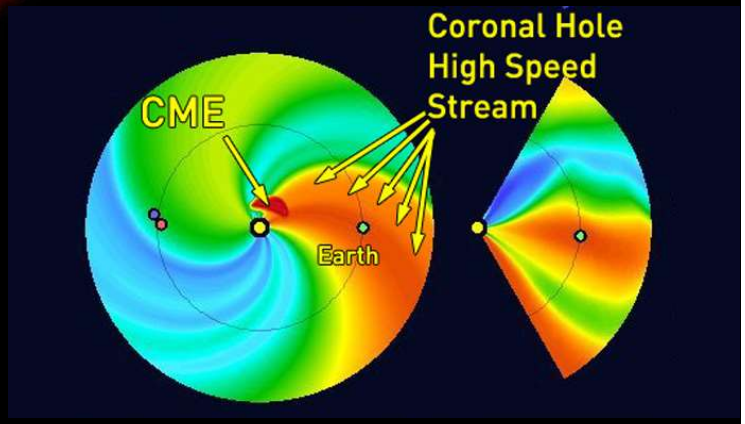
- 99.8% of Solar System Mass
  ~333,000 M_{Earth}
  108 x R_{Earth}
- Made of mostly of H/He
- Converts ~ 4 million tons of mass into energy each second
  $(e = mc^2)$
- Density ~ 1.41 g cm^{-3}
- Age ~ 5 billion years
- Activity – Solar Wind

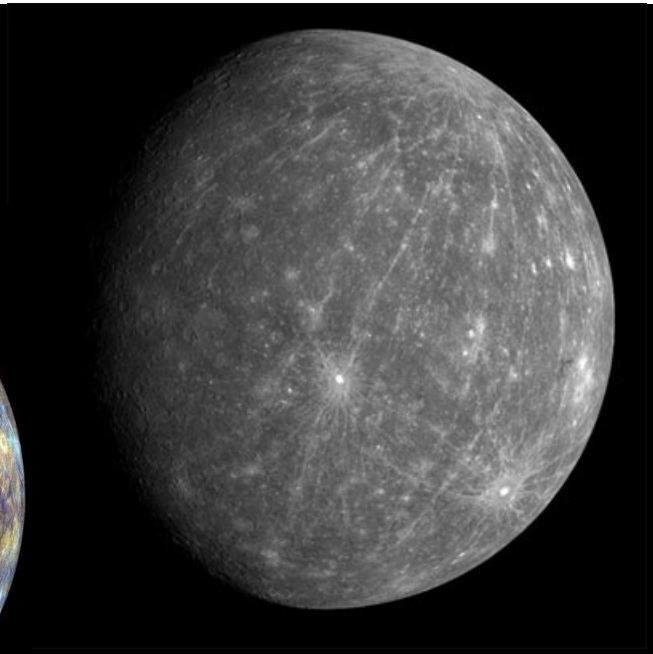


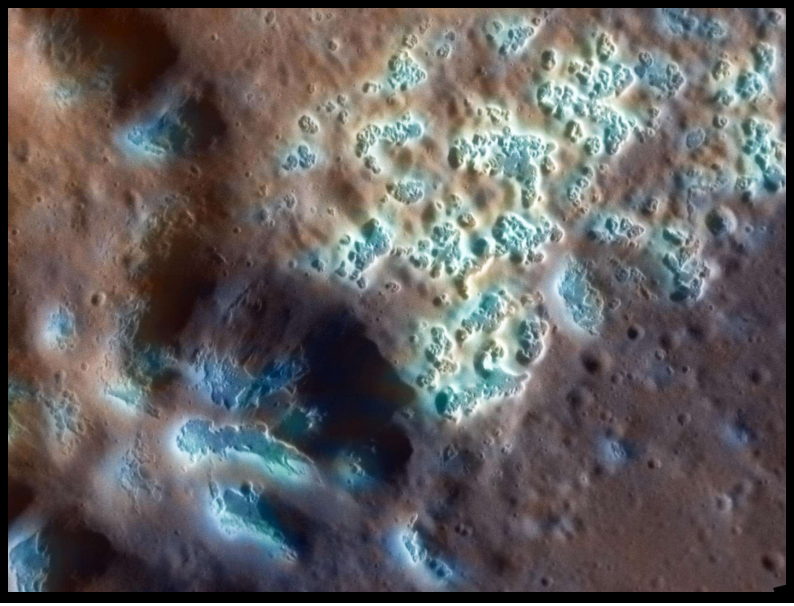


Flares

Solar Dynamics Observatory (SDO) captured an X1.2 class solar flare, peaking on May 15, 2013





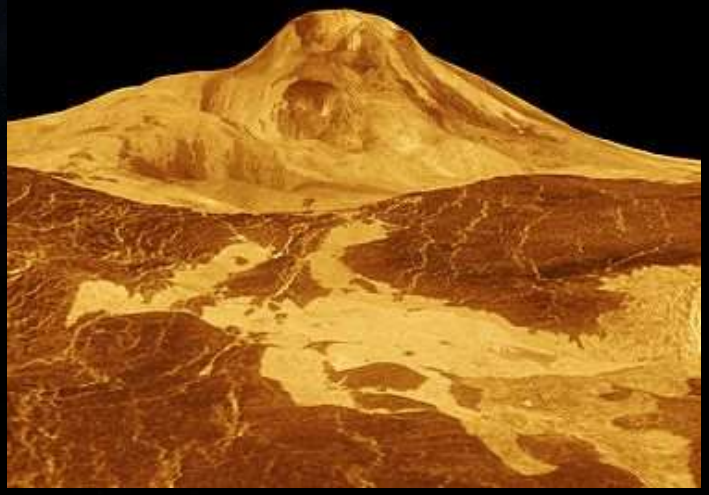


Mercury

~0.055 M_{Earth}
0.38 R_{Earth}

- Distance: 0.39 AU
- Composition:
  Rocks & Metals
- Density ~ 5.43 g cm^{-3}
- Daytime T ~ 700 K
- Nighttime T ~ 100 K
- Moons: 0
- Has permanently shadowed craters
- Large Iron Core (80%)
- Planetary shrinking
- Hollows Material (left)

- Orbital period: 88 days
- Rotational period on axis = 59 days
- Sunrise to sunset is 176 days



Maat Mons

Venus

$0.95\ M_{Earth}$
$0.82\ R_{Earth}$

- Distance: 0.72 AU
- Composition:
  Rocks & Metals
- Density ~ 5.24 g cm^{-3}
- Surface T ~ 740 K
  Runaway greenhouse effect
- Moons: 0
- One of the least studied terrestrial planets…
- Orbital period 225 days
- Rotational period: 243 days
- **Venus slowly rotates clockwise…**

Venera 13, 1982

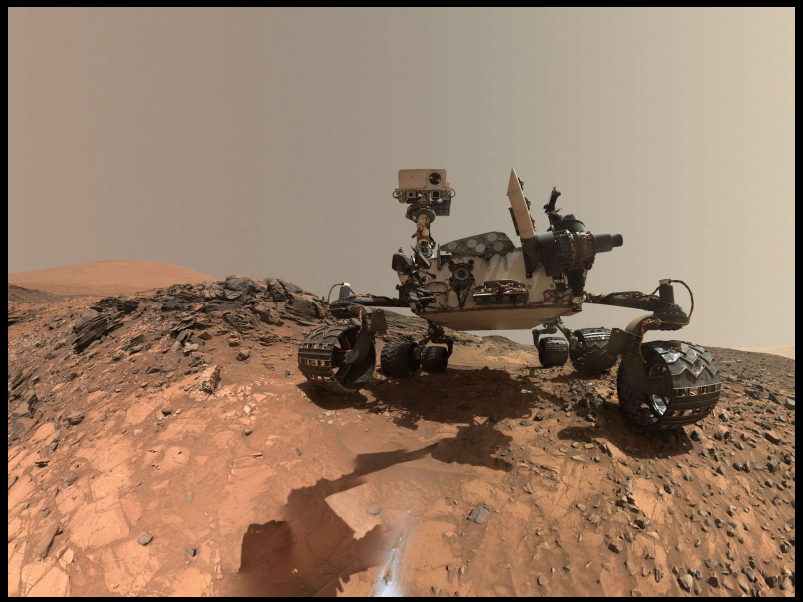
Earth

1.00 M_{Earth}
1.00 R_{Earth}

- Distance: 1.00 AU
- Composition:
  Rocks & Metals
- Density ~ 5.52 g cm^{-3}
- Surface T ~ 290 K
- **Moons: 1 (too large)**
- Orbital period: 365 days
- Rotational period: 24 hrs
- **The only planet with liquid water on the surface… and life**

Phobos
size 20 x 28 km

Deimos
size 12 x 16 km

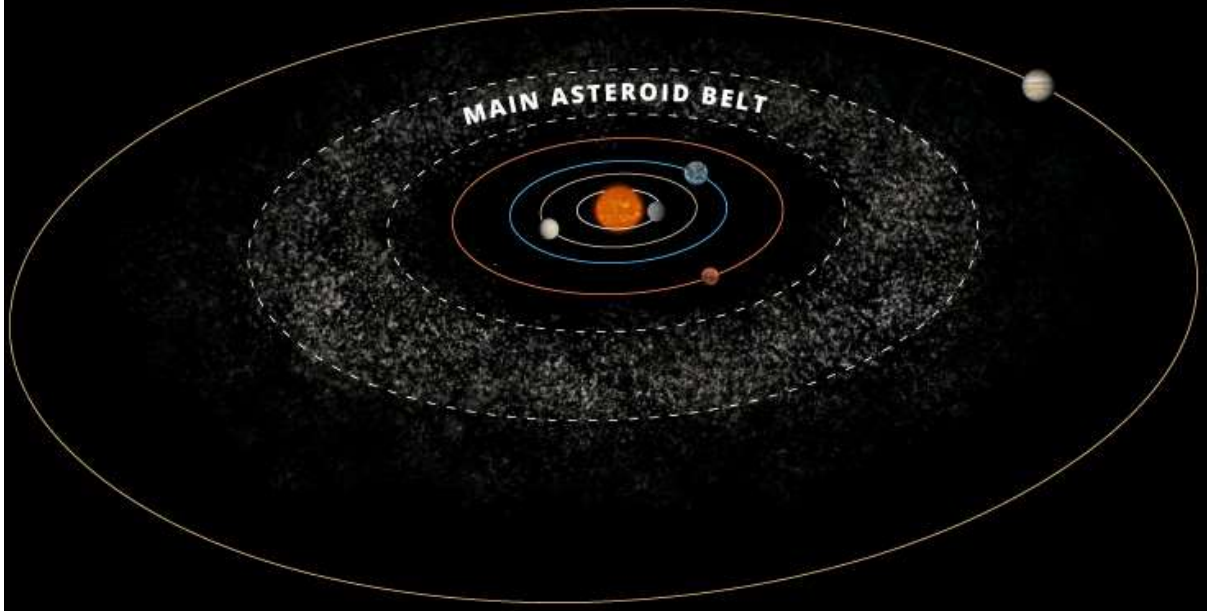


Mars

0.11 M_{Earth}
0.53 R_{Earth}

- Distance: 1.52 AU
- Composition:
  Rocks & Metals
- Density ~ 3.93 g cm^{-3}
- Surface T ~ 220 K
- Moons: 2 (*v. small - capture*)
- Orbital period: 687 days
- Rotational period: 24 hrs 40 min

The Asteroid Belt



~4% mass of the Moon

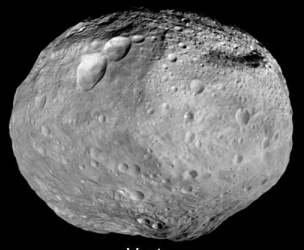
- Distance: 2.0-3.3 AU
- Composition:
  Rocks & Metals, some volatiles
- > 150 million > 100m

Distances between them are huge! (thousands of km)

Carbonaceous C-type asteroids may have formed outside Saturn or Jupiter

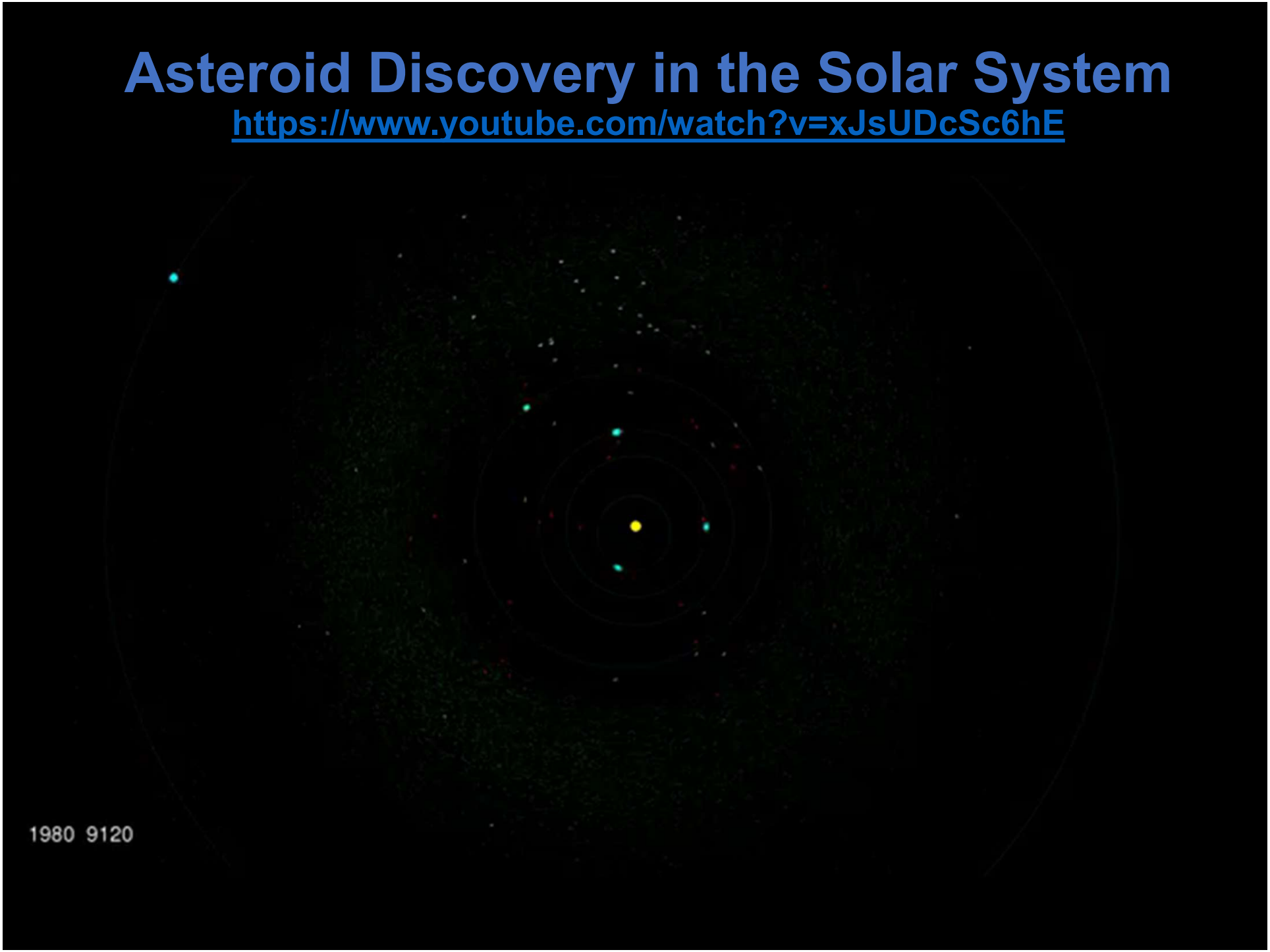
Stony S-types were scattered from rocky planet forming region

Differences in composition indicate different origin, rather than planet being destroyed by a collision; planets difficult to form due to resonances with Jupiter *(Kirkwood gaps)*



Asteroid Discovery in the Solar System

https://www.youtube.com/watch?v=xJsUDcSc6hE

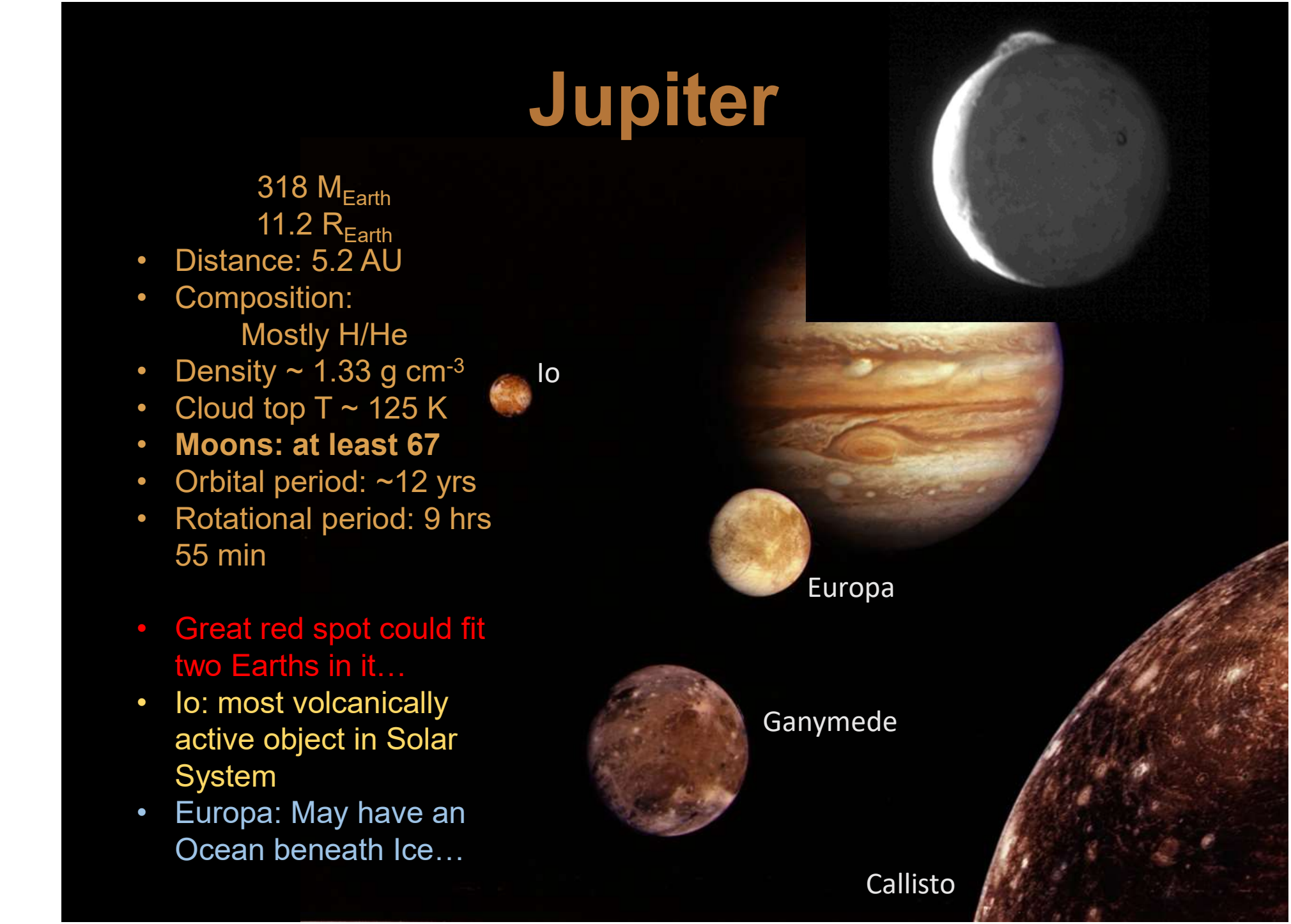


Jupiter

318 M_{Earth}
11.2 R_{Earth}

- Distance: 5.2 AU
- Composition:
  Mostly H/He
- Density ~ 1.33 g cm^{-3}
- Cloud top T ~ 125 K
- **Moons: at least 67**
- Orbital period: ~12 yrs
- Rotational period: 9 hrs 55 min

- Great red spot could fit two Earths in it…
- Io: most volcanically active object in Solar System
- Europa: May have an Ocean beneath Ice…



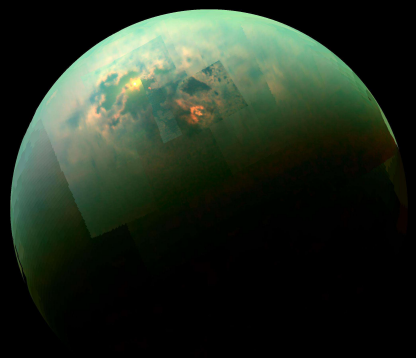
Saturn

95.2 M_{Earth}
9.4 R_{Earth}

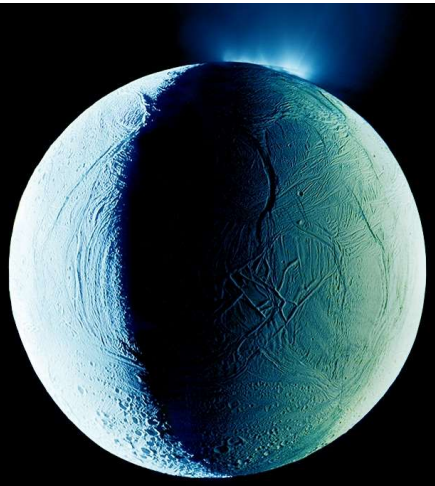
- Distance: 9.54 AU
- Composition:
  Mostly H/He
- Density ~ 0.70 g cm^{-3}
  Would "float on water"
- Cloud top T ~ 95 K
- **Moons: at least 62**
- Orbital period: ~29.4 yrs
- Rotational period: 10 hrs 42 min

- **Titan:** lakes of methane and ethane. 1.5 atm.

- **Enceladus:** Has plumes indicating sub-surface ocean and hydrothermal activity…



Titan



Enceladus

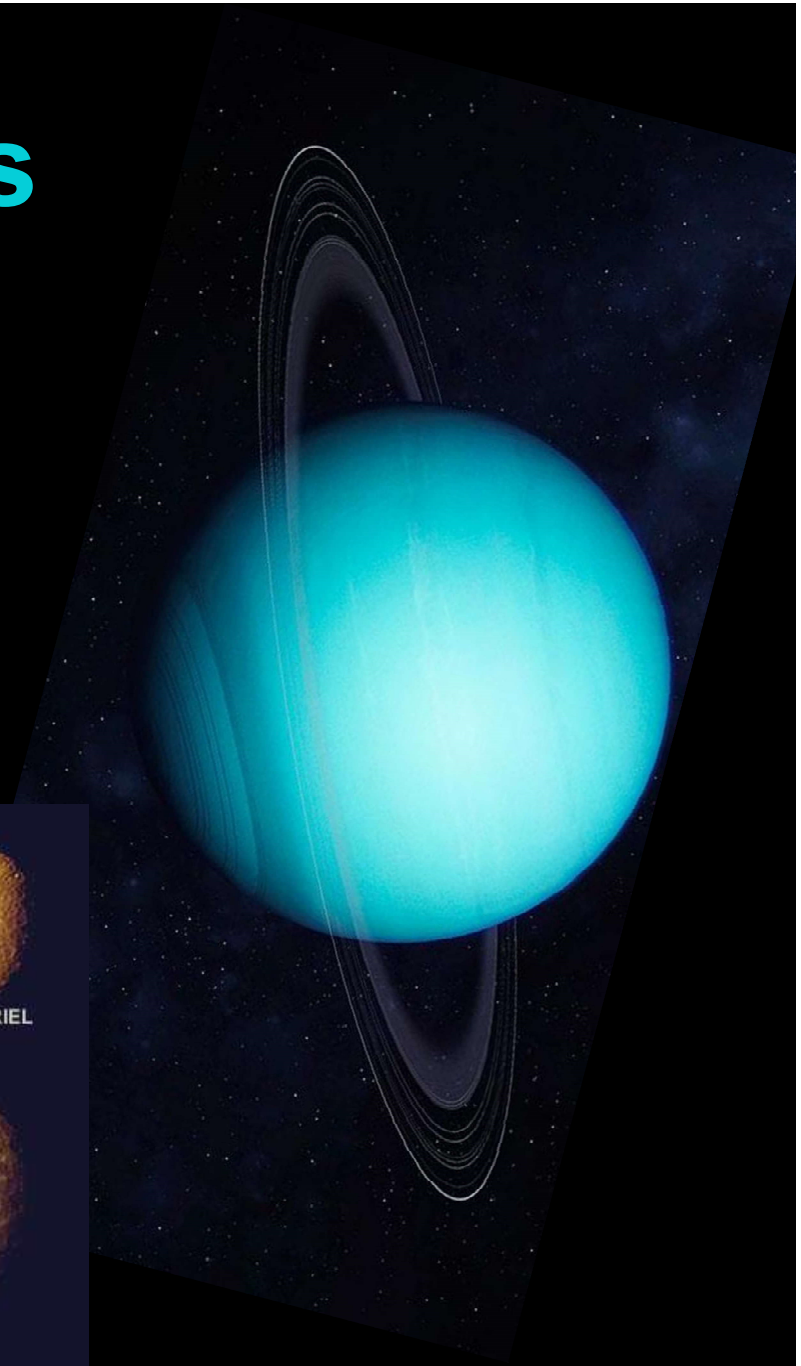
Rings: 280,000 km across, 1 km thick
micron to house-sized ices

Uranus

14.5 M_{Earth}
4.0 R_{Earth}

- Distance: 19.2 AU
- Composition:
  H/He, hydrogen compounds
- Density ~ 1.32 g cm^{-3}
- Cloud top T ~ 60 K
- **Moons: at least 27**
- Orbital period: ~84 yrs
- Rotational period: 17 hrs 14 min

- **On its side…**



Neptune

17.1 M_{Earth}
3.9 R_{Earth}

- Distance: 30.1 AU
- Composition:
  H/He, hydrogen compounds
- Density ~ 1.64 g cm^{-3}
- Cloud top T ~ 60 K
- **Moons: at least 14**
- Orbital period: ~165 yrs
- Rotational period: 16 hrs 6 min

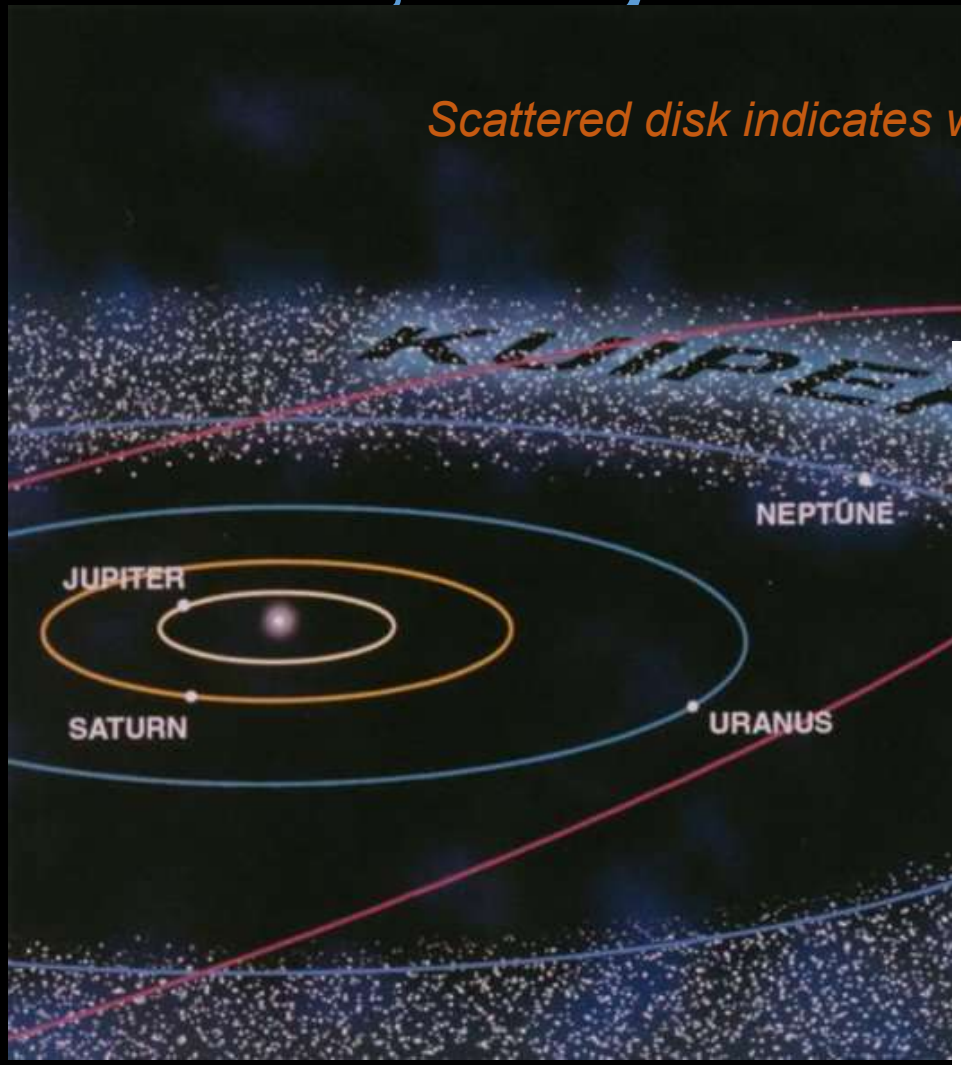
- **Triton: Retrograde Orbit, May be a captured Kuiper Belt Object, Similar to Pluto. Has active cryovolcanism…**

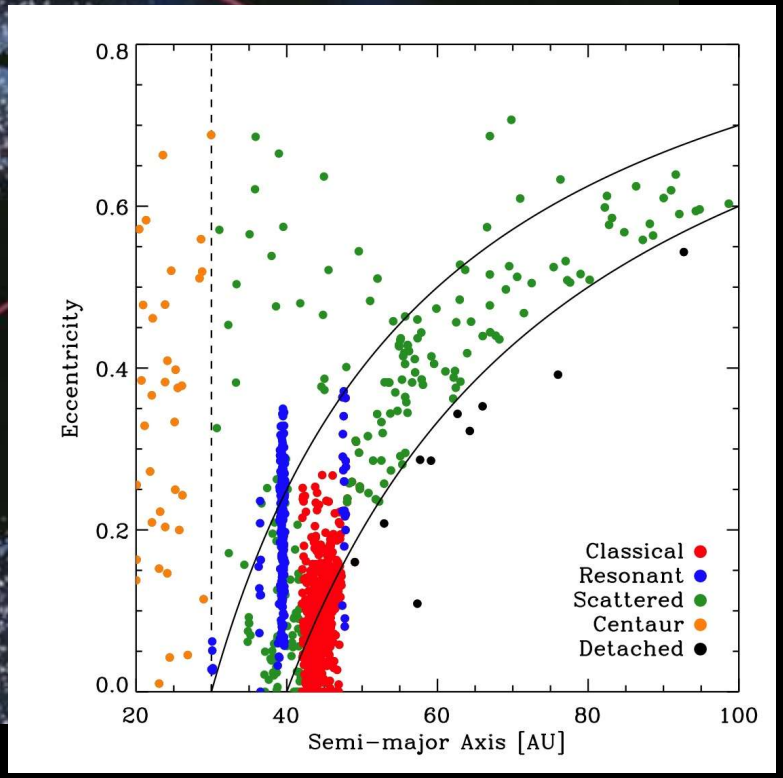
Triton

The Kuiper Belt

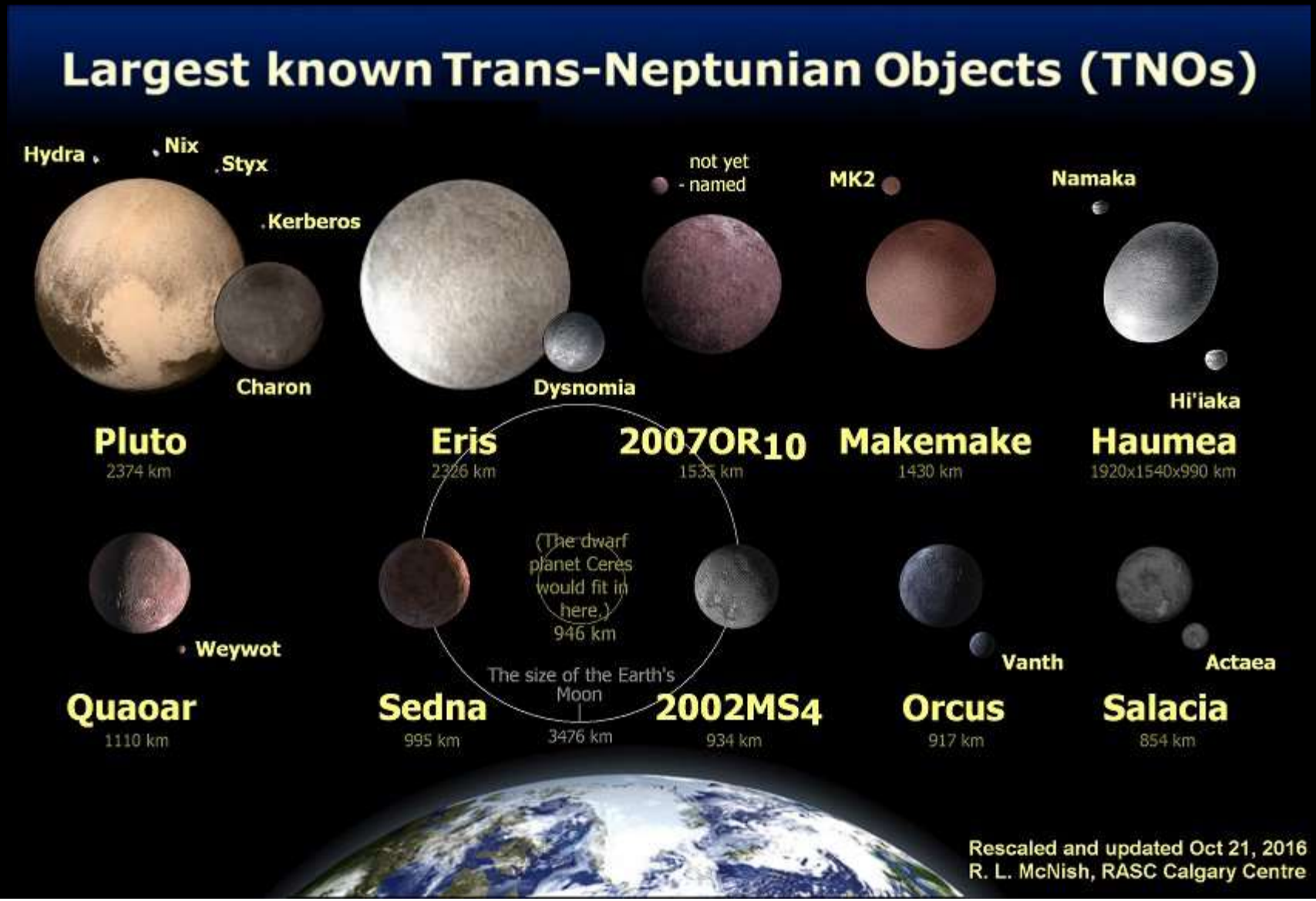
over 100,000 icy bodies > 100 km in size

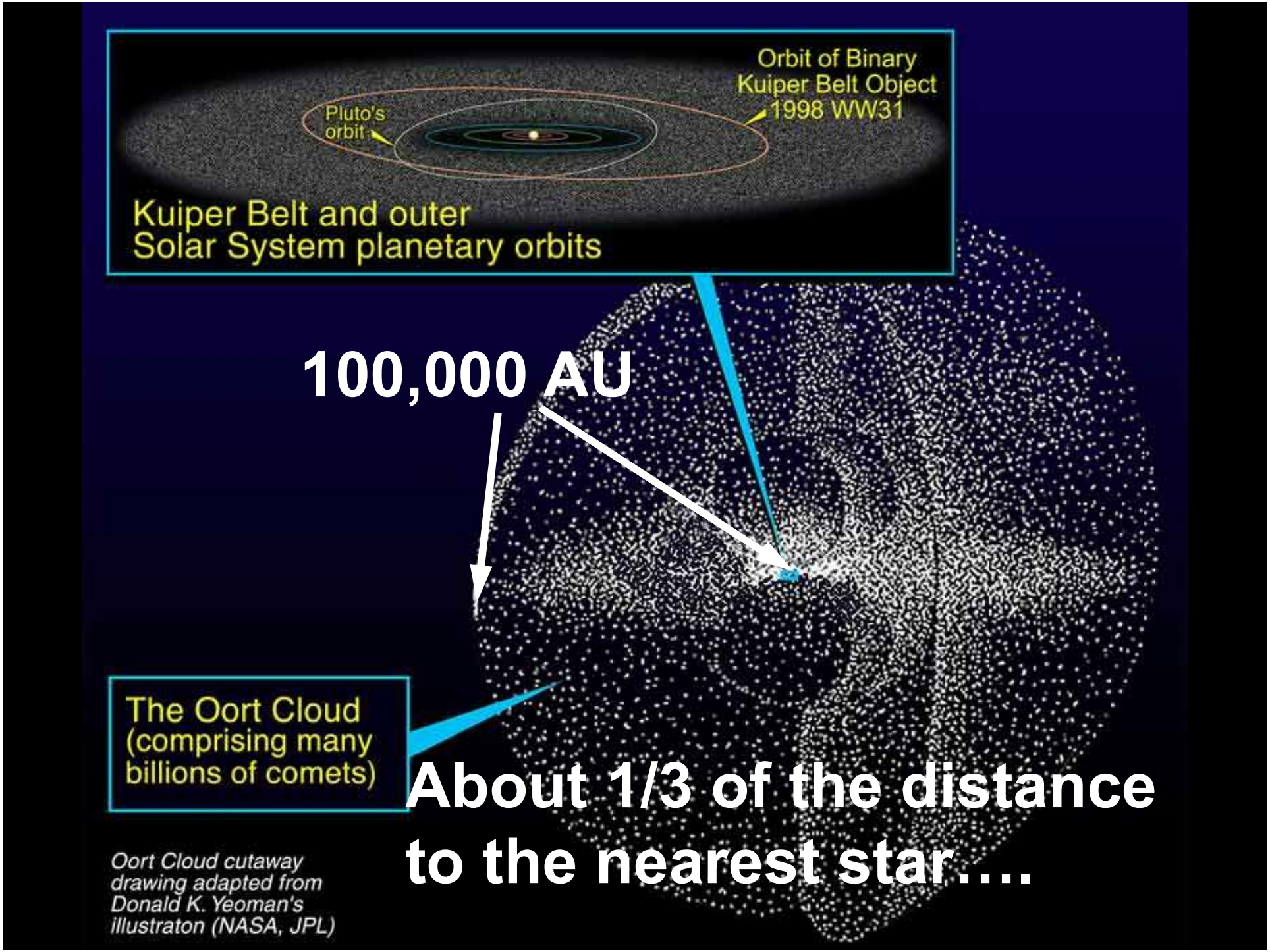
Scattered disk indicates were not formed in ecliptic plane



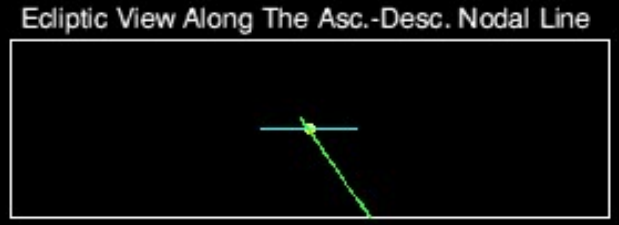


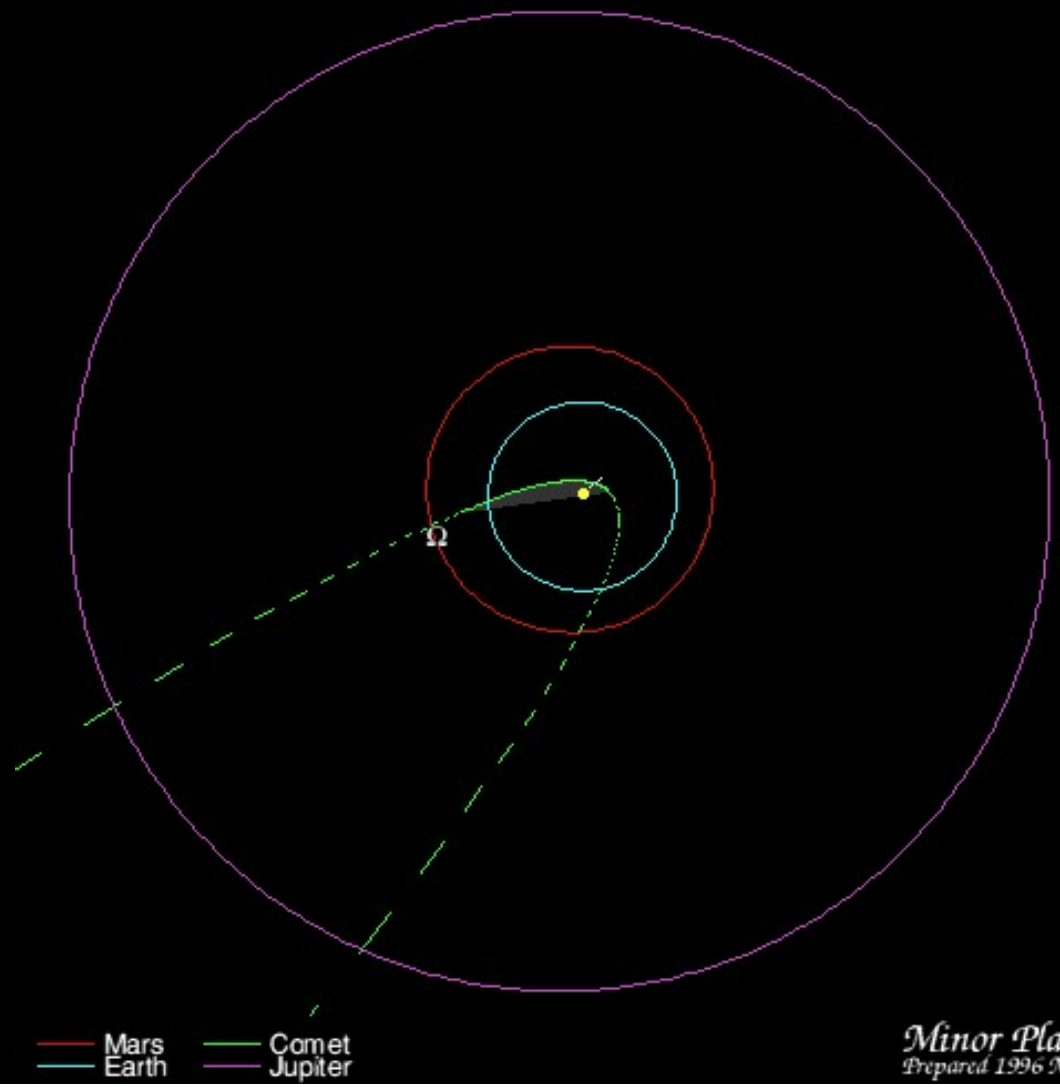
Kuiper Belt Objects and TNOs




Orbit of Binary
Kuiper Belt Object
1998 WW31
Pluto's
orbit
Kuiper Belt and outer
Solar System planetary orbits
100,000 AU
The Oort Cloud
(comprising many
billions of comets)
About 1/3 of the distance
to the nearest star….
Oort Cloud cutaway
drawing adapted from
Donald K. Yeoman's
illustraton (NASA, JPL)

C/1996 B2 (Hyakutake)





An Oort Cloud Comet….

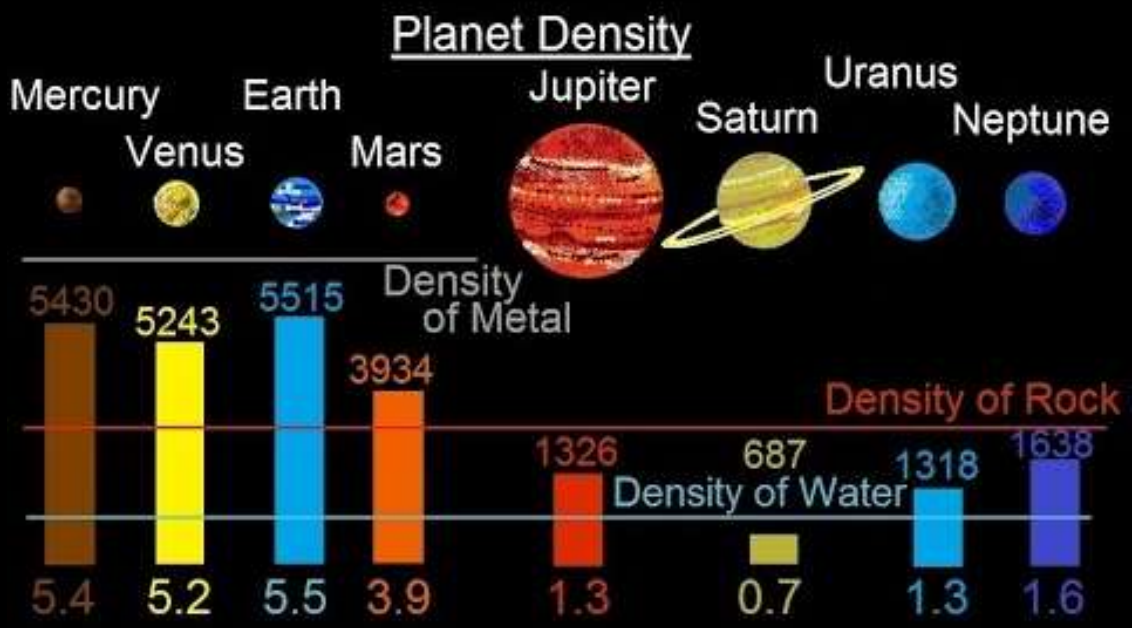
Perihelion: 0.23 AU

Eccentricity: 0.999735

Inclination: 145.88°

Nice Model of Planetary Migration

https://www.youtube.com/watch?v=6LzQfR-T5_A



Trends

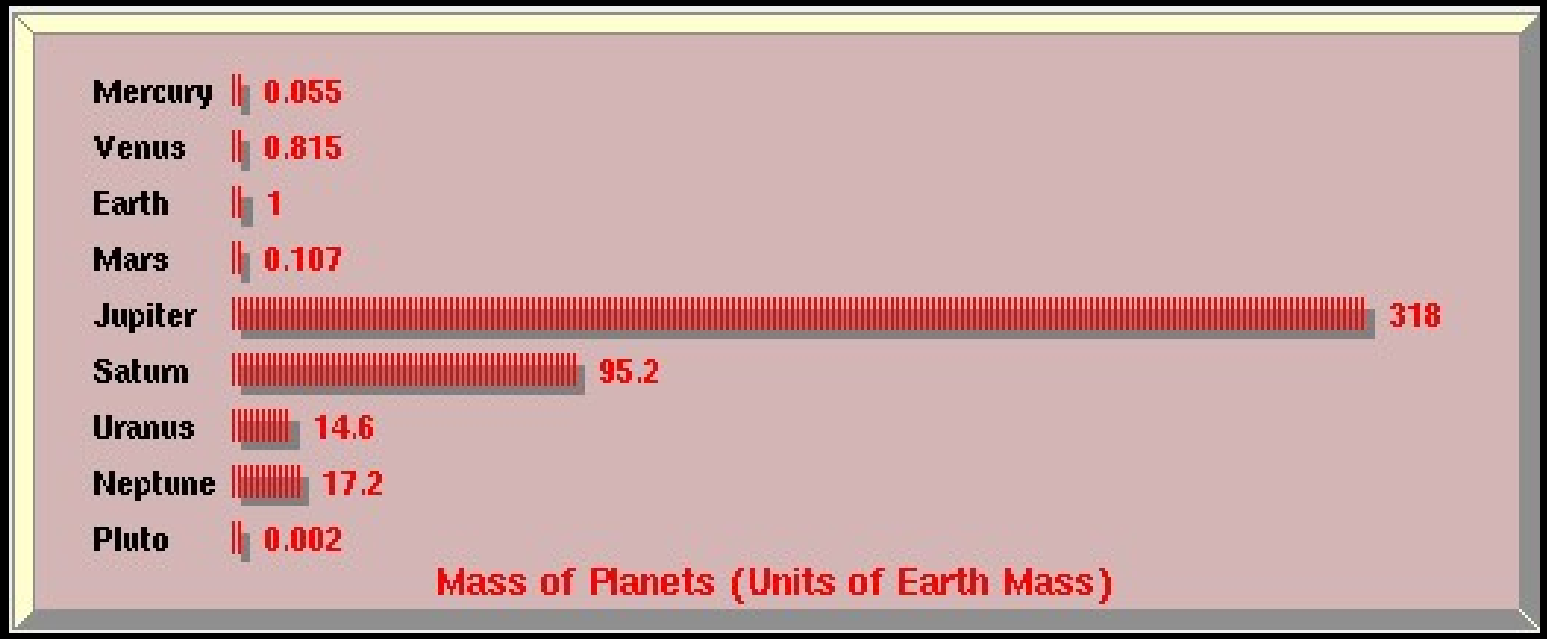
Density = mass/volume

(g/cm^3) = (g/ml) = (kg/dm^3) = (kg/l) - *bottom values*

(if in kg/m^3 it is 1000x larger number) – *top values*

Terrestrial planets are small (low mass) and dense

Jovian planets are large and mostly gaseous



Planetary Trends

- **Planets fall into two main categories:**
  - **Terrestrial (i.e. Earth-like)**
  - **Jovian (*i.e.* Jupiter-like or gaseous)**

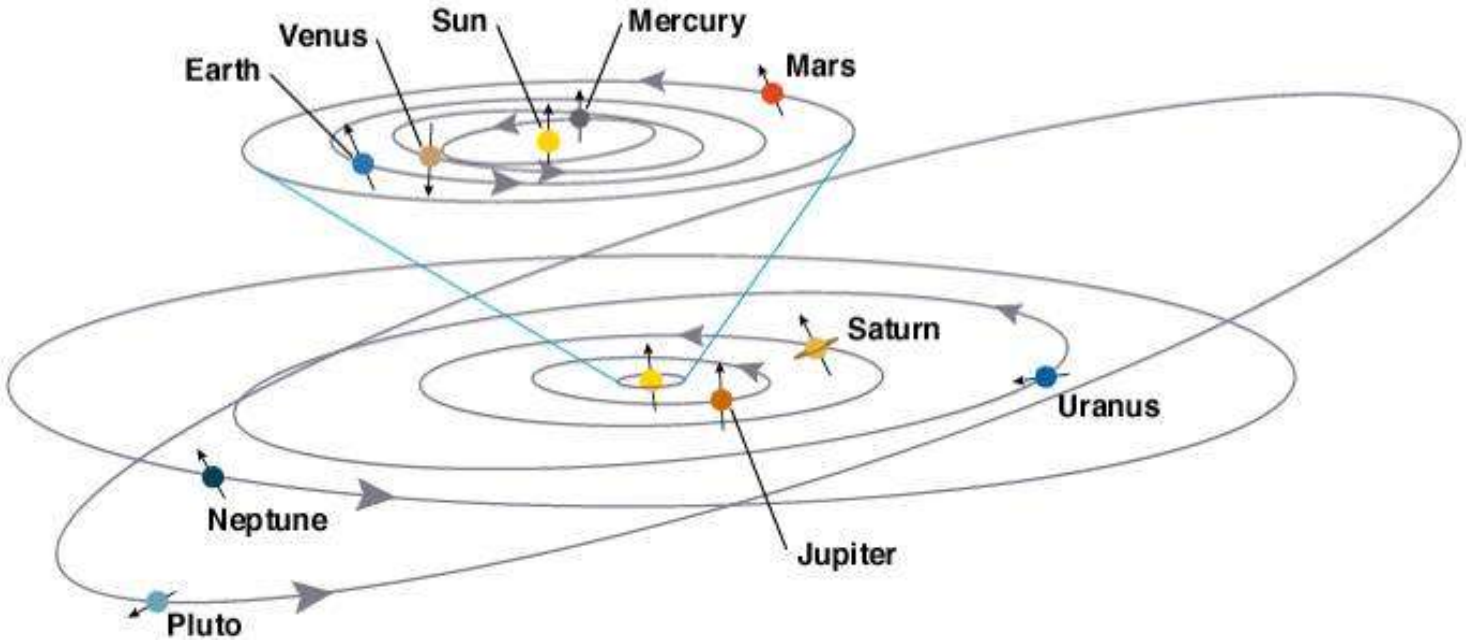
Planet	Mass (Earth Masses)	Radius (Earth Radii)	Density gm/cm^3
Mercury	0.055	0.38	5.5
Venus	0.815	0.95	5.2
Earth	1.000	1.00	5.5
Mars	0.107	0.53	3.9
Jupiter	318	10.8	1.4
Saturn	95	9.0	0.7
Uranus	14.5	3.93	1.3
Neptune	17.2	3.87	1.6
Pluto	0.002	0.178	2.1

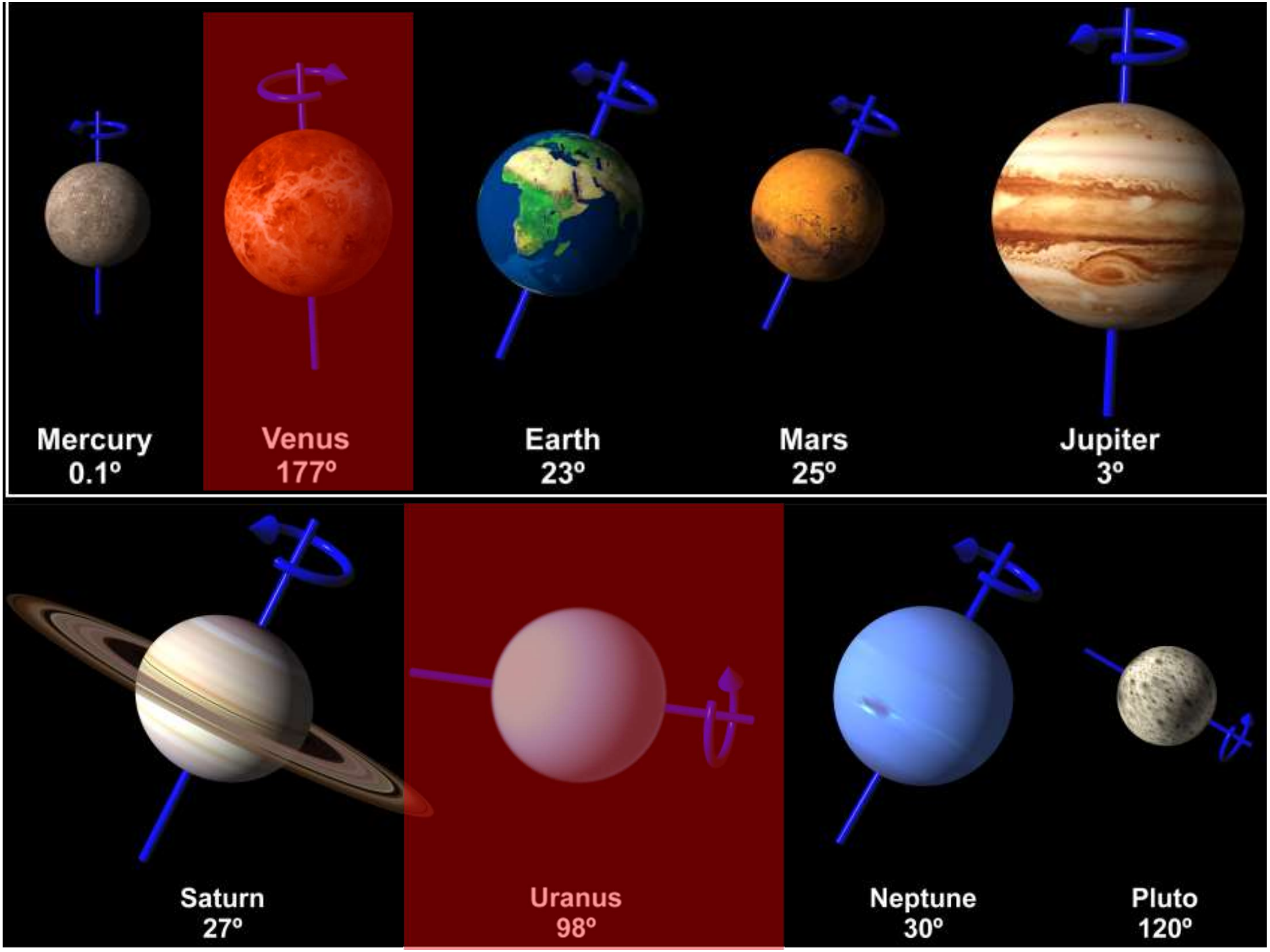
Terrestrial Planets	Jovian Planets
Smaller size and mass	Larger size and mass
Higher density (rocks, metals)	Lower density (light gases, hydrogen compounds)
Solid surface	No solid surface
Closer to the Sun (and closer together)	Farther from the Sun (and farther apart)
Warmer	Cooler
Few (if any) moons and no rings	Rings and many moons

The Layout of the Solar System

The bodies in the Solar System have orderly motions

- **the Sun rotates counterclockwise**
- **planets orbit counterclockwise in same plane**
  - **orbits are almost circular**
- **most moons orbit counterclockwise**




Mercury
0.1°
Venus
177°
Earth
23°
Mars
25°
Jupiter
3°
Saturn
27°
Uranus
98°
Neptune
30°
Pluto
120°

Our Explanation of Solar System Formation Must Explain:

Feature #1: Patterns of Motion Among Large Bodies

- All orbits are circular and in the ecliptic plane
- The suns rotation, planetary rotation, orbits of the planets and (most) satellites are counterclockwise (and in the same plane)

Feature #2: Two Types of Planets

- Terrestrial planets are close to the Sun, have low mass, but high density (rocks and metals)
- Jovian planets are far from the Sun, have high mass but low density (mostly gaseous)

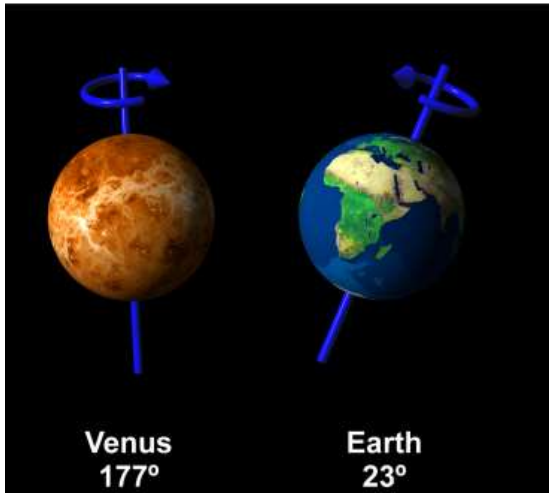
Feature #3: Asteroids and Comets

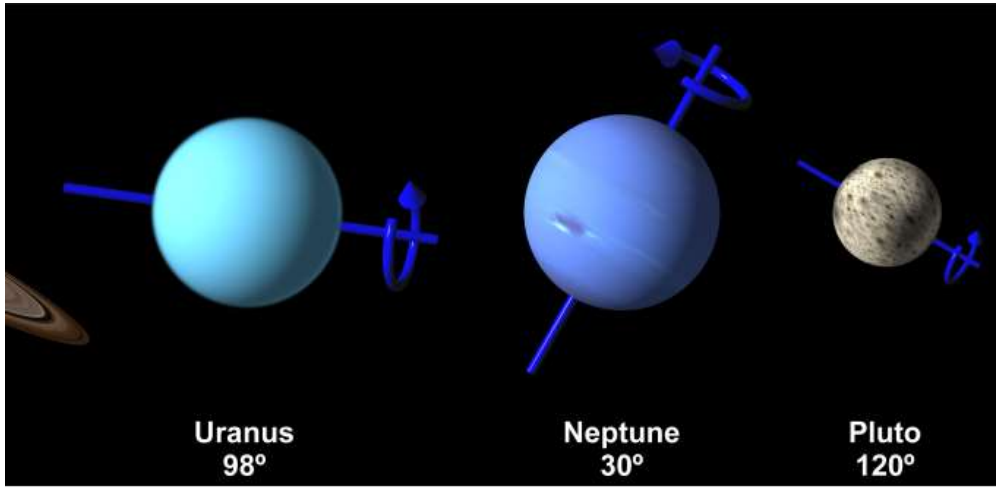
- Must be able to explain the formation of the asteroid belt, the Kuiper belt, and the Oort Cloud

Feature #4: Must be able to Explain Exceptions to the Rules…

A Few Exceptions to the Rules…

- **Both Uranus (& Pluto) are tilted on their sides.**
- **Venus rotates "backwards" (i.e. clockwise).**
- **Triton orbits Neptune "backwards."**
- **Earth is the only terrestrial planet with a relatively large moon.**





The Earth-Moon forming Impact

https://www.youtube.com/watch?v=xJsUDcSc6hE

End of Todays Lecture