Taking the Measure of our Solar System

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Douglas Adams…

BBC

Space is big

Really big

You just won't believe how vastly, hugely, mind-bogglingly big it is

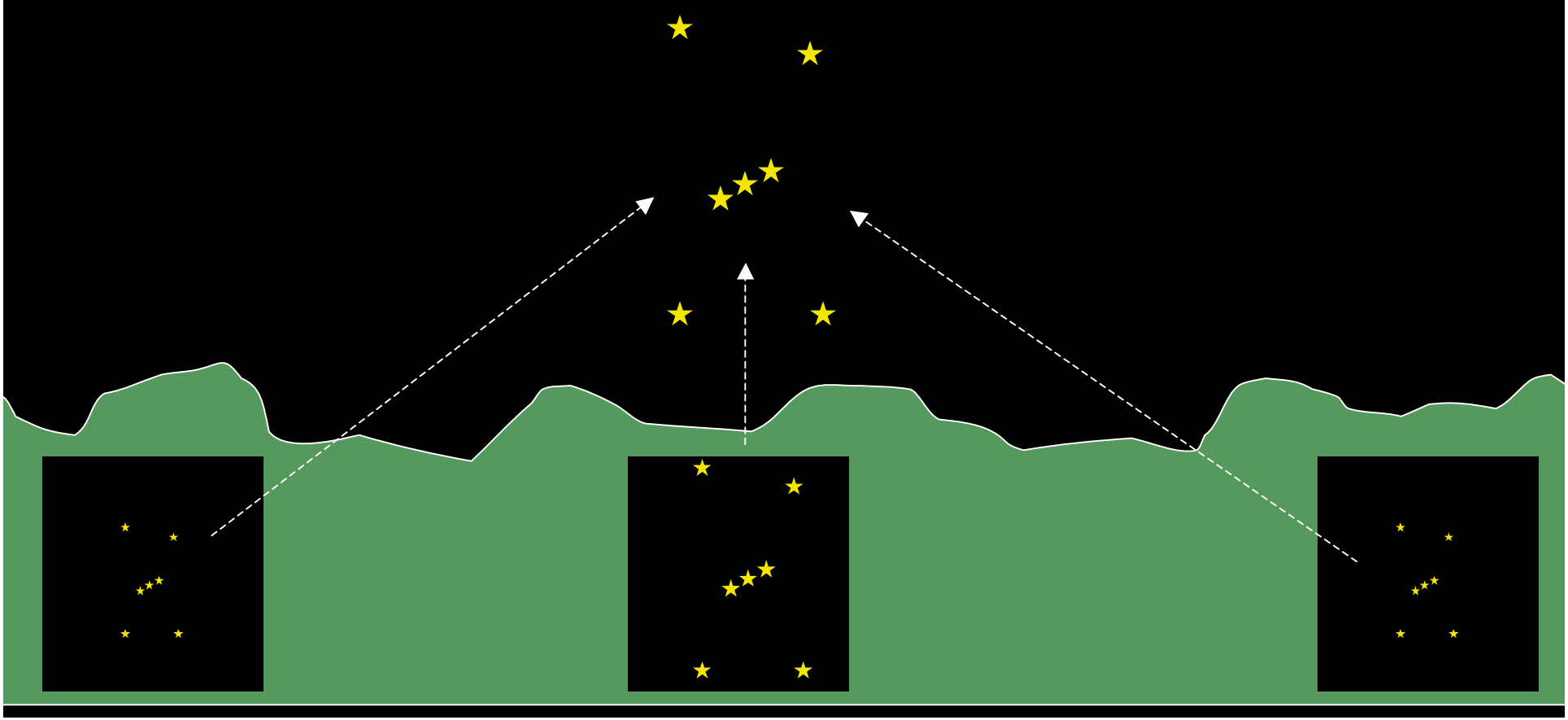
I mean, you may think it's a long way down the road to the chemist's*, but that's just peanuts to space….

*Pharmacist's

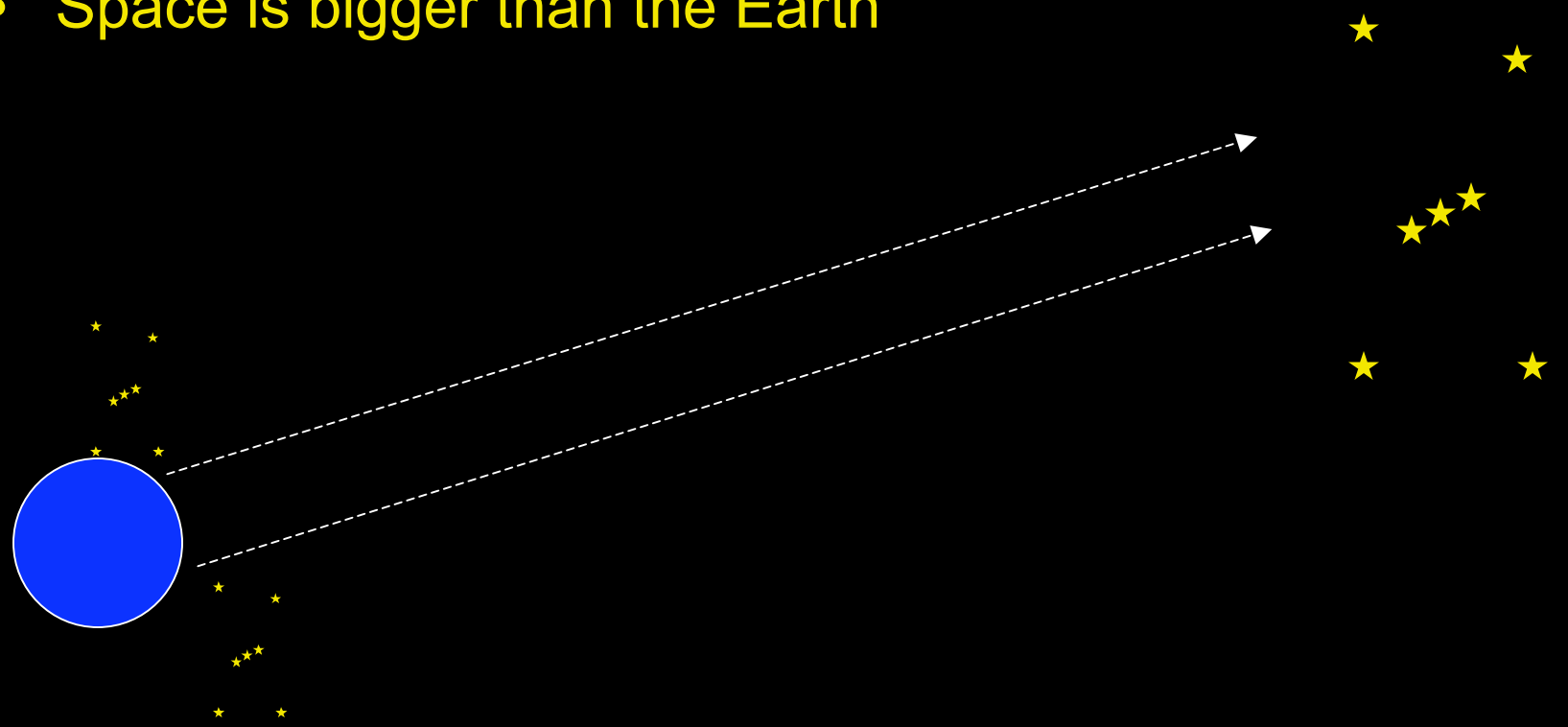
How Do We Know?

How Far Away is the Sky?

- You can't "stroll past" Orion



- Relative proportions of things in space are the same no matter where you are on the Earth
- Space is bigger than the Earth



So, How Big is the Earth?

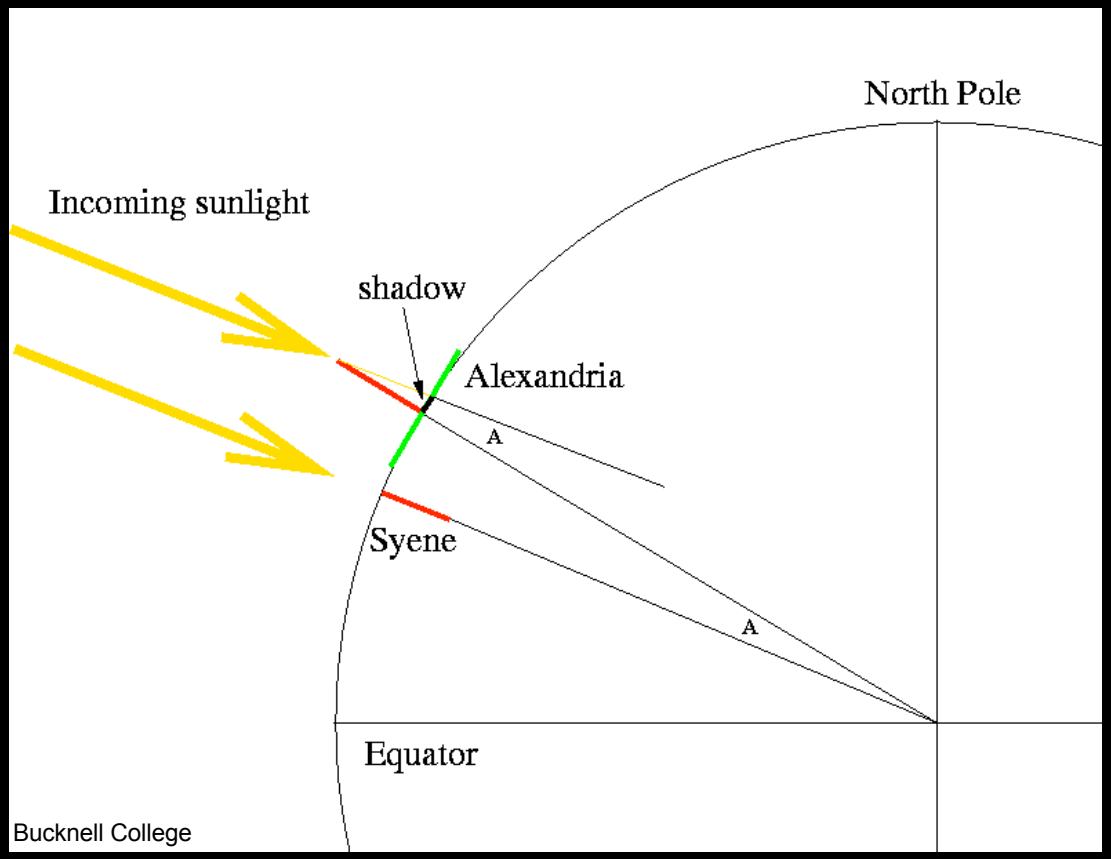
- Eratosthenes, ~240 B.C.

Michael Lahanas

How Big is the Earth?

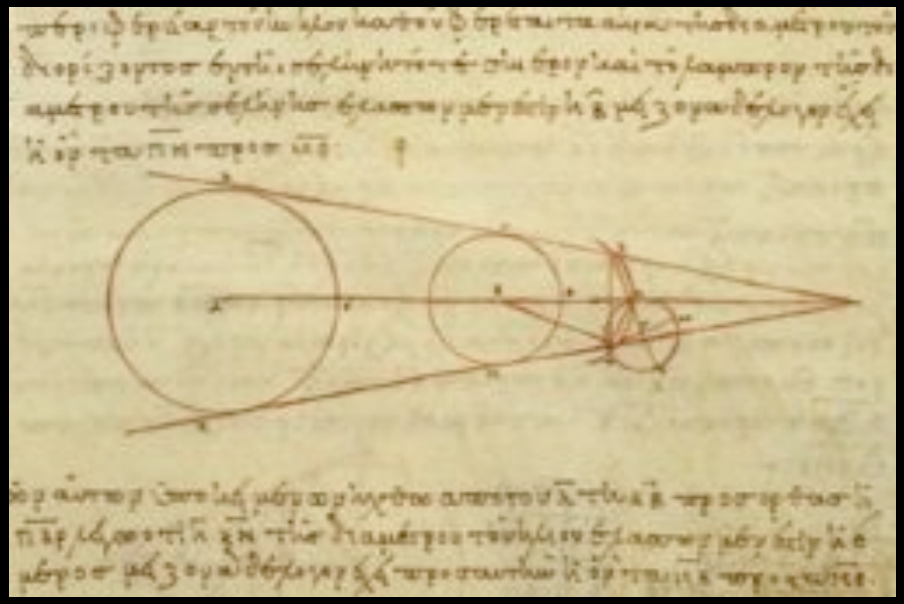
- Answer: Circumference is 252,000 stadia or ~29,000 miles (~16% too big)

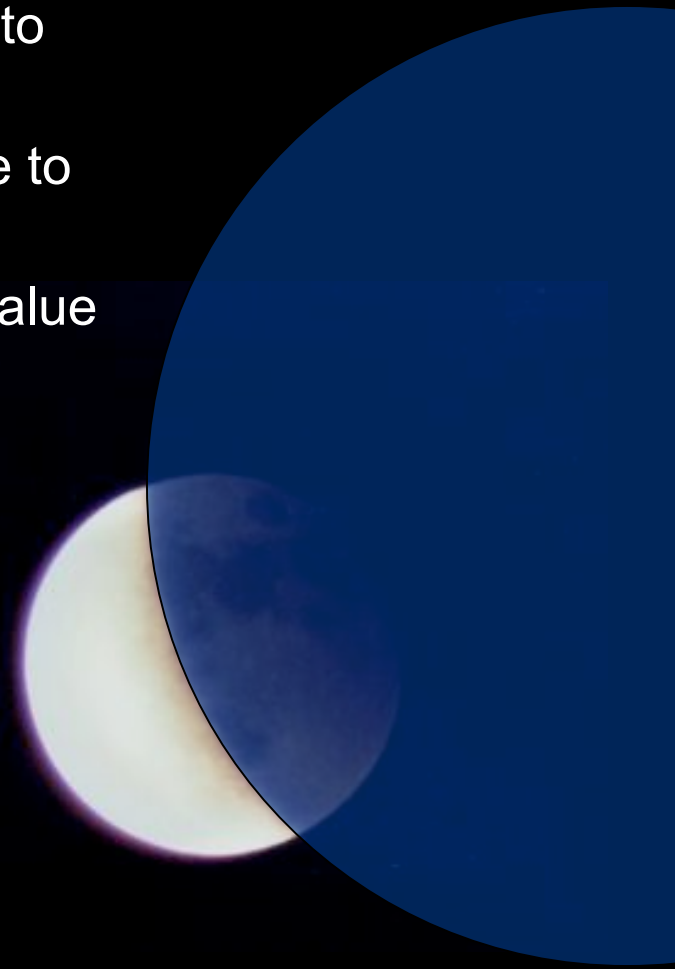
- Once we know the size of the Earth, we can start boot-strapping our way into the universe…



How Far is the Moon?

- Aristarchus, ~260 BC
- Earth's shadow on the Moon is curved
- Curvature gives the size of the moon relative to the earth
- Size of the moon in the sky gives the distance to the moon compared to the size of the Earth
- Hipparchus ~150 BC fixed some errors: got value within ~10% of the truth

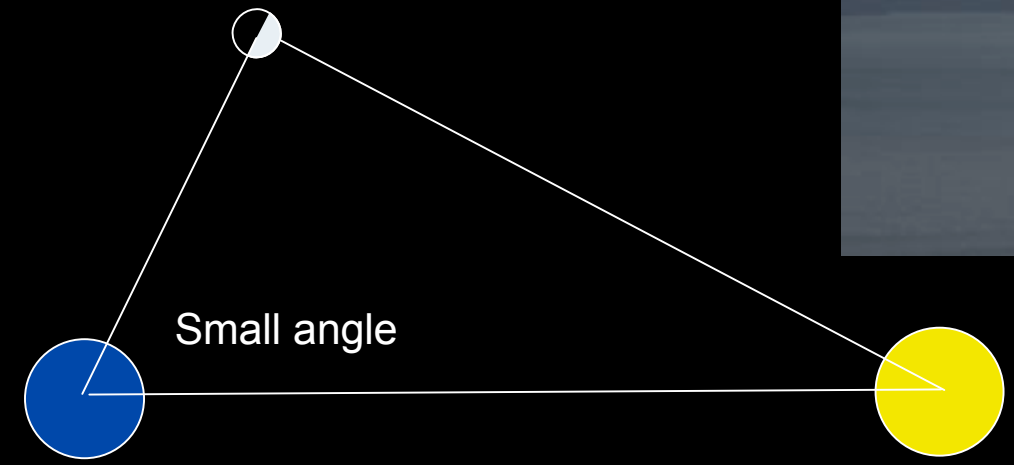


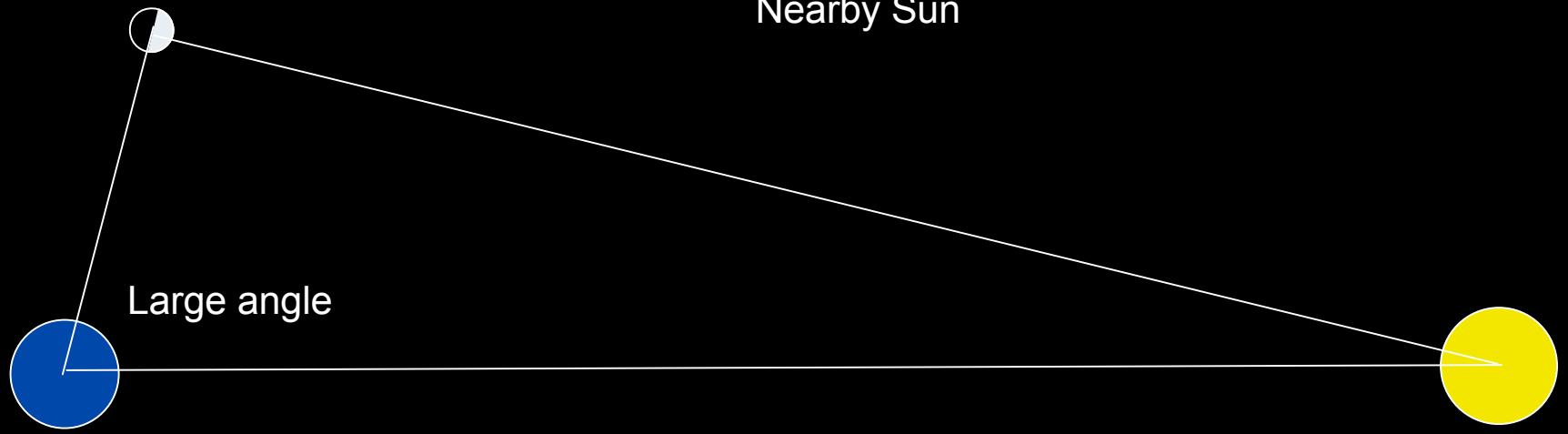


F. Ringwald, CSU Fresno

How Far is the Sun?

- Aristarchus ~260 B.C (again)
- Measured the angle between the half-moon and the sun



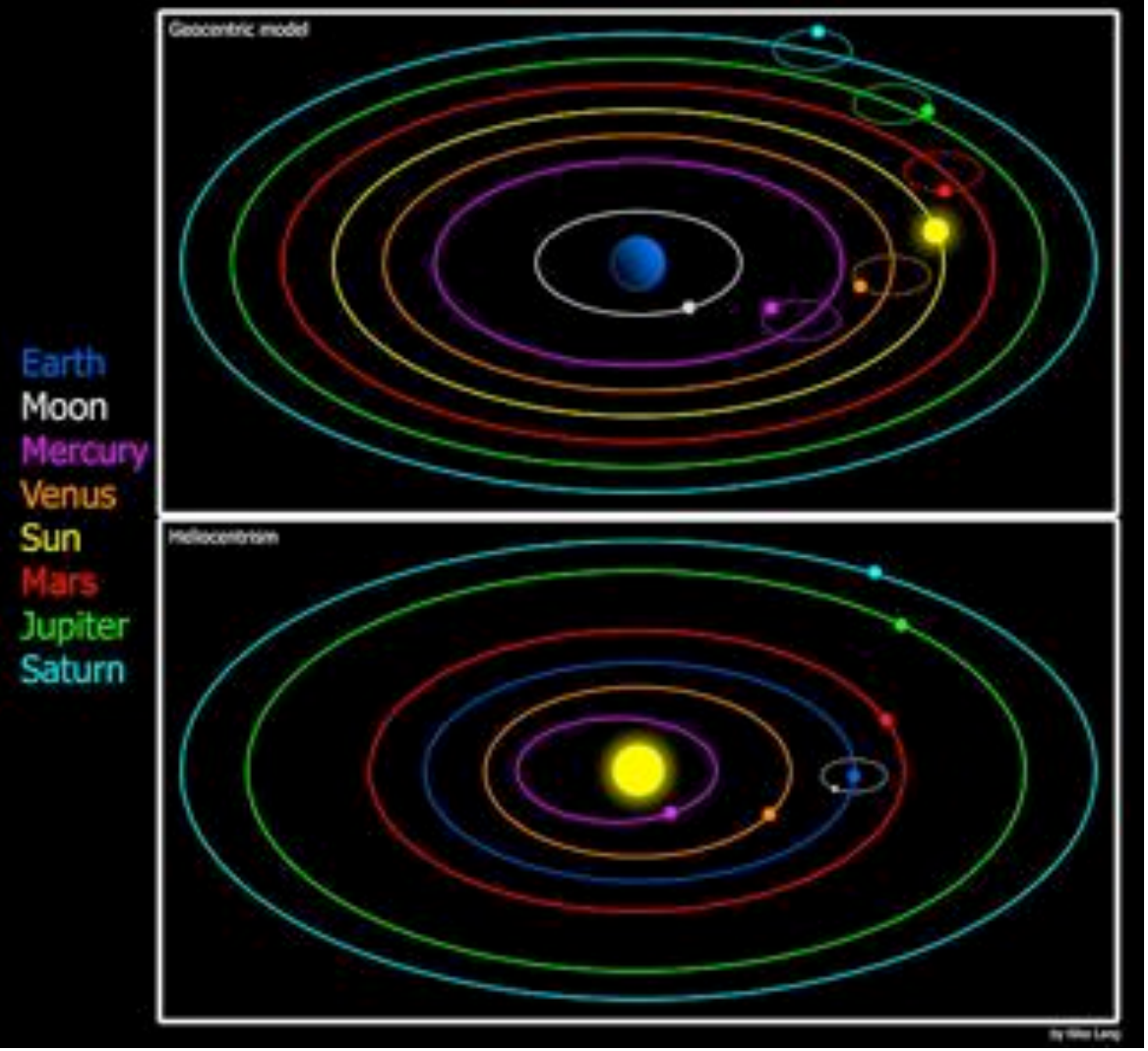


The Reality…

- Aristarchus estimated the sun was 19x further away than the moon
- Reality- 400x further away
- Nice try…

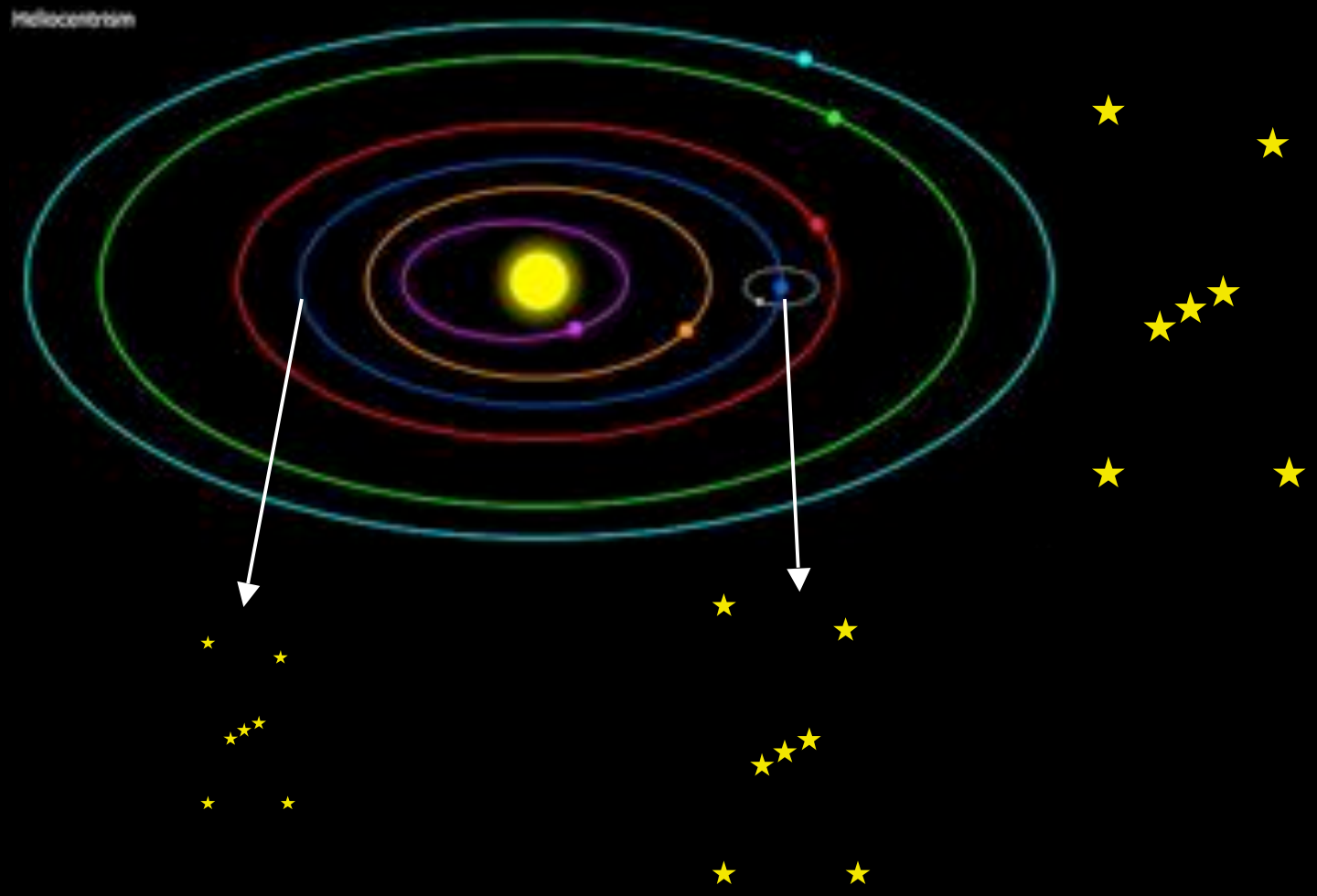
How Far are the Stars?

- If the Earth is at the center of the Universe, can't tell
- But what if the Sun is at the center (Aristarchus again)…



How Far are the Stars?

- Must be very far away

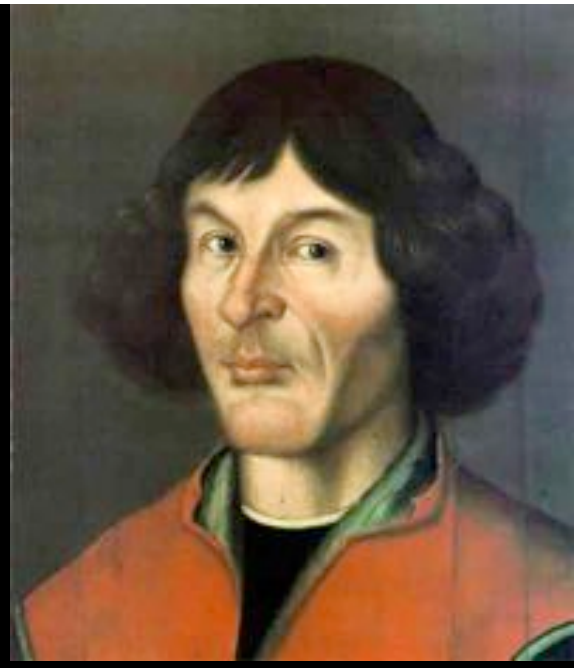


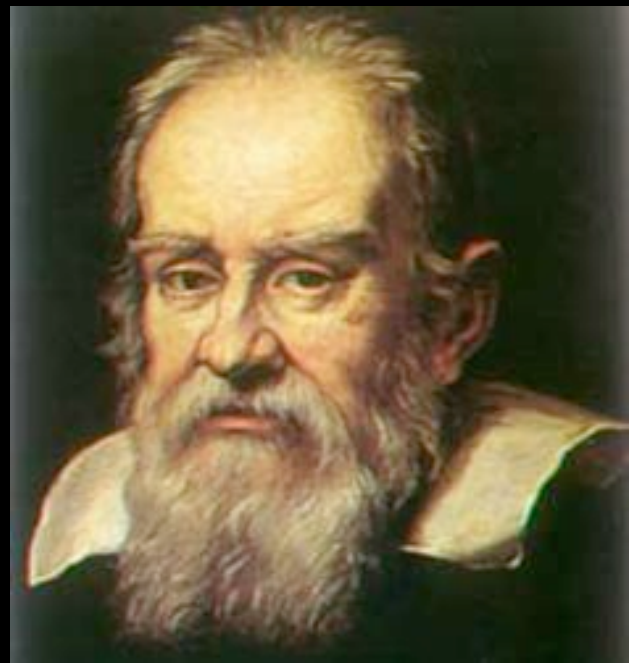
- Earth orbits the sun another 1800 times before anyone else figures out that’s what it is doing

Finally…

- Early 1500s: Copernicus becomes the second person in history (after Aristarchus) to realize that he inhabits a planet orbiting the sun

- 1610: Galileo proves this by inventing the astronomical telescope



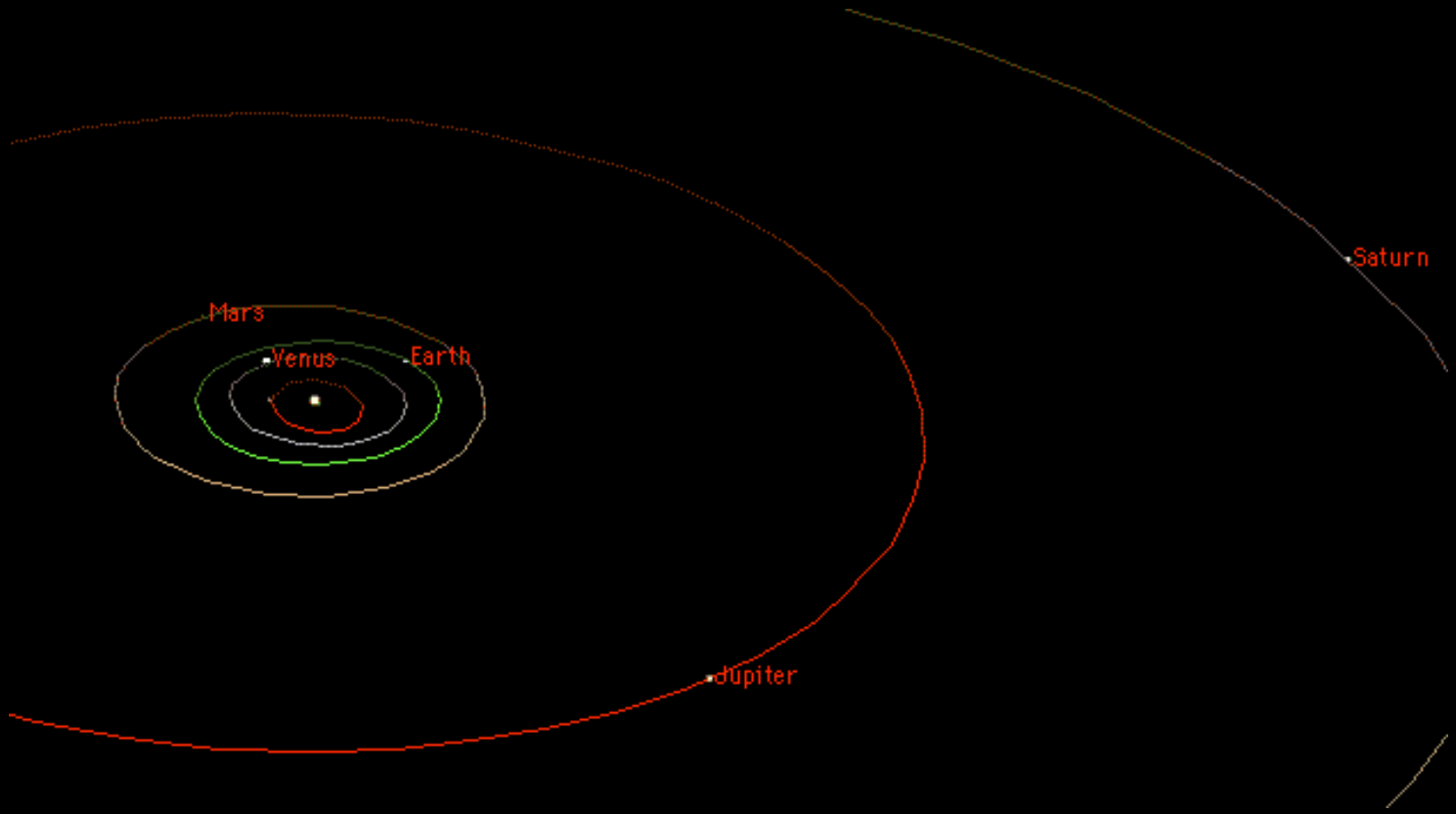


- ~1620: Kepler determines that all planets (including the Earth) travel according to mathematical laws
  - The distance of a planet from the sun determines its orbital period, which we can measure

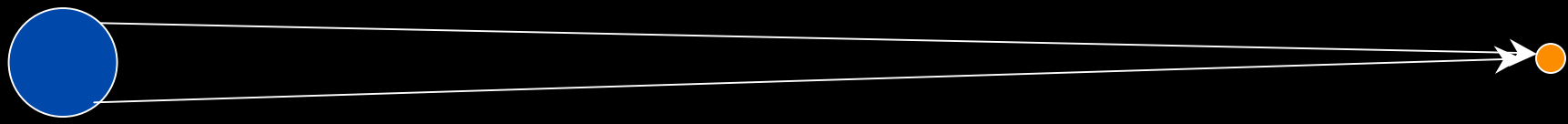
- 1660s: Newton explains it all with his theory of gravity

Finally…

- Result: a scale model of the solar system
- But we don’t know the scale!



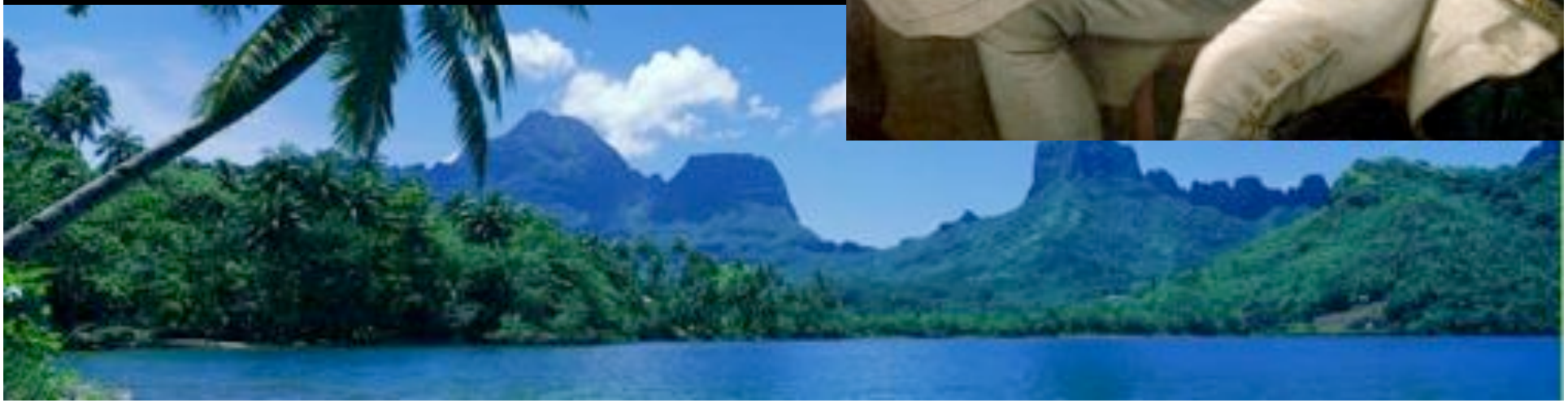
How Far is the Sun? (part 2)



- Measure the angle to a planet from two places on the Earth at the same time
  - Gives the distance to the planet
  - Once have distance to one planet, we have the distance to all of them (and the Sun…), thanks to Kepler
- One way: measure the time when a planet passes in front of the Sun, from two different places

Transits of Venus

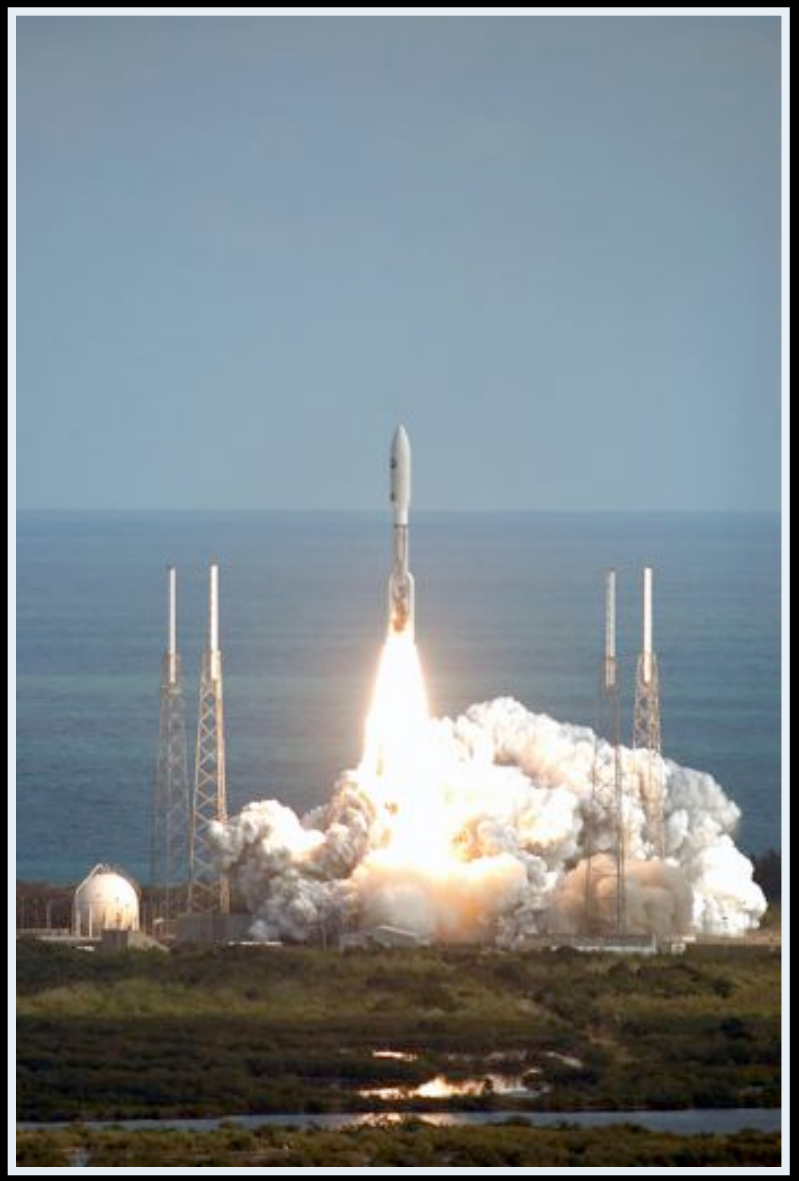
- 1761, 1769
- Heroic efforts to observe these
- Captain Cook in Tahiti
  - Measured the distance to the sun to within 10%



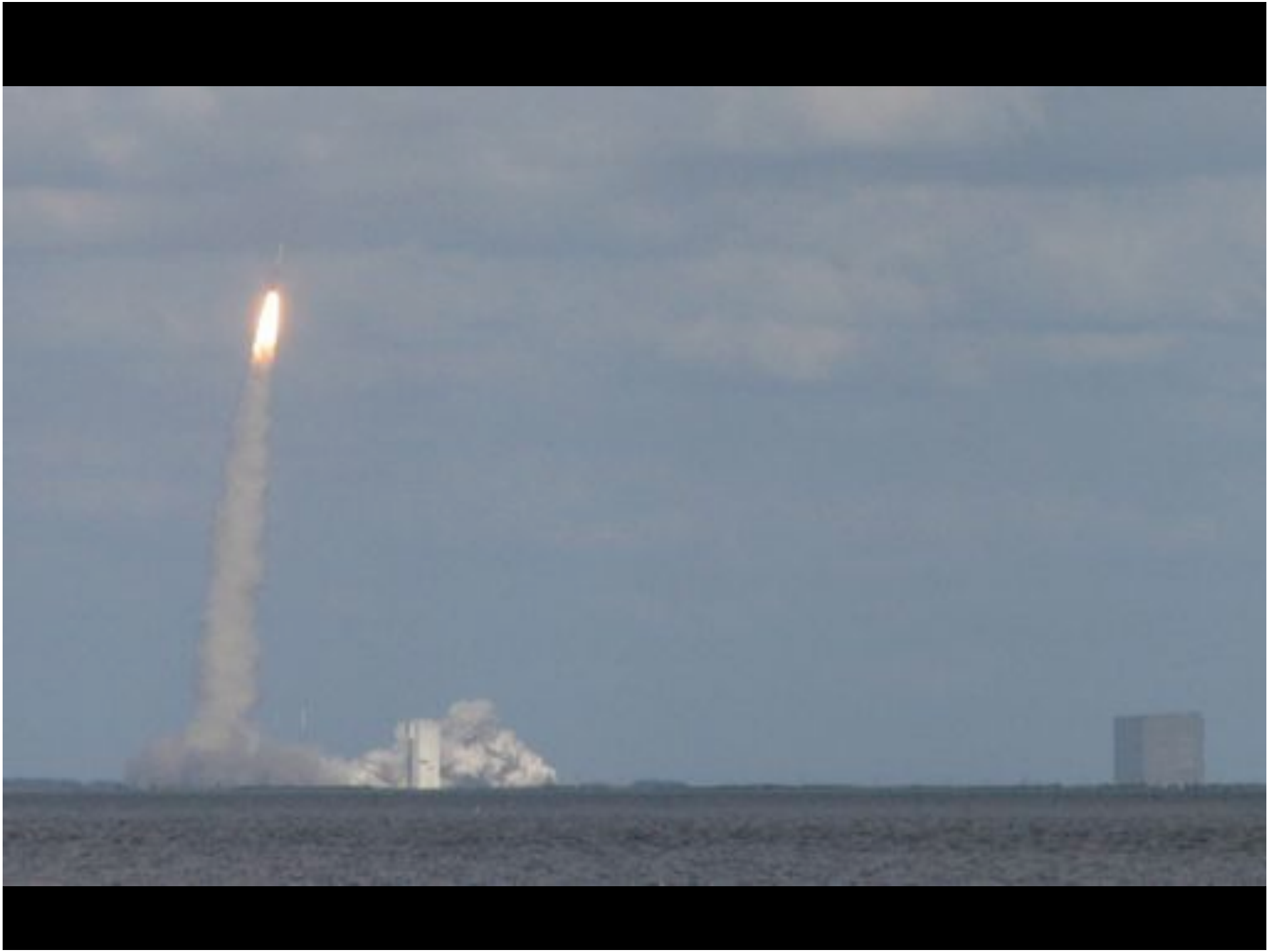
So Now We Know…

• Diameter of the Earth	8000 miles
• 30x further to the Moon	250,000 miles
• 400x further to the Sun	93,000,000 miles
• 40x further to Pluto	2,790,000,000 miles
• 10,000x further to the nearest star	26,000,000,000,000 miles
• 3,000,000,000x further to the edge of the obervable Universe	300,000,000,000,000,000,000,000 miles

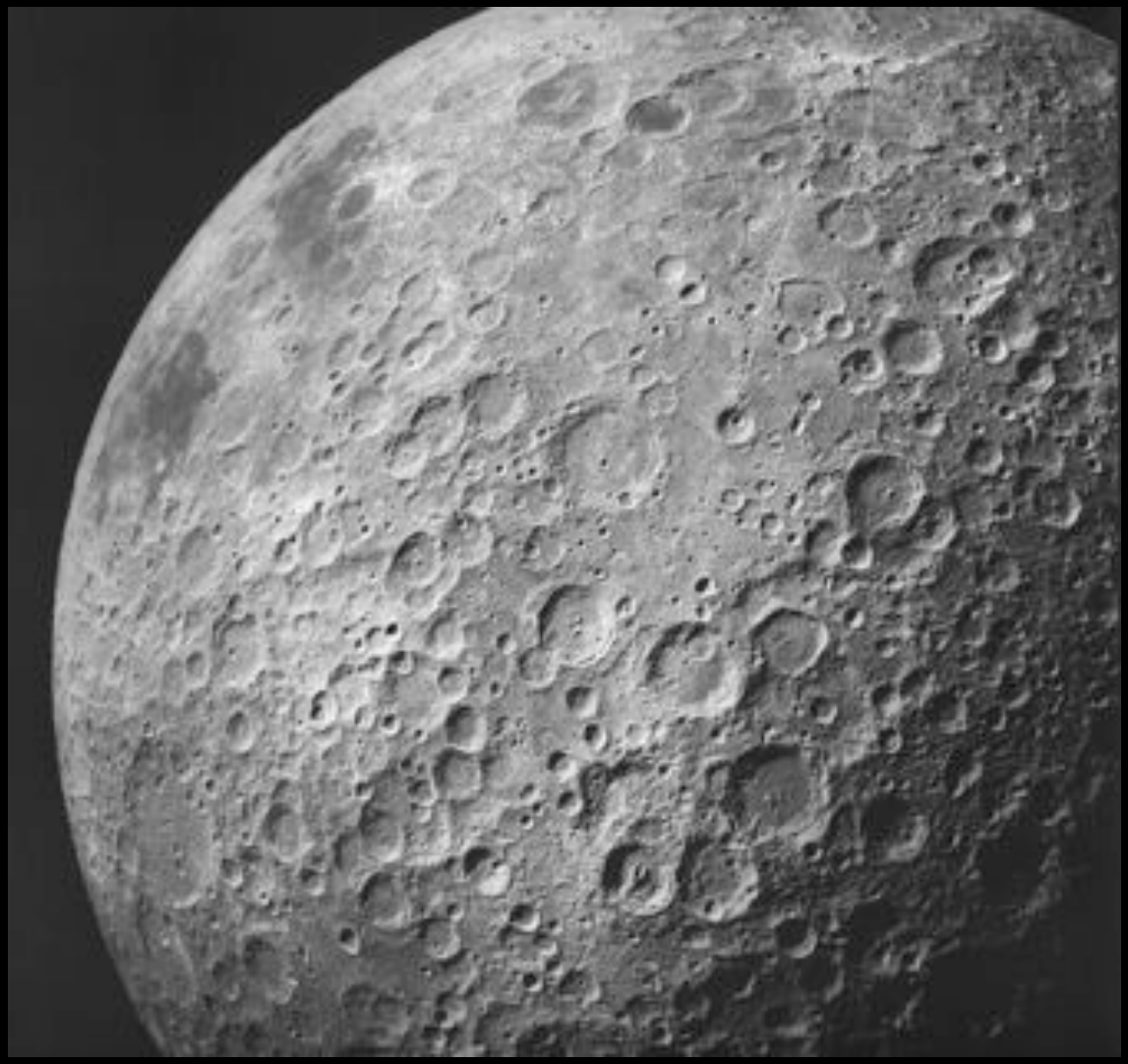
New Horizons to Pluto



- Launched January 19th 2006, 2pm



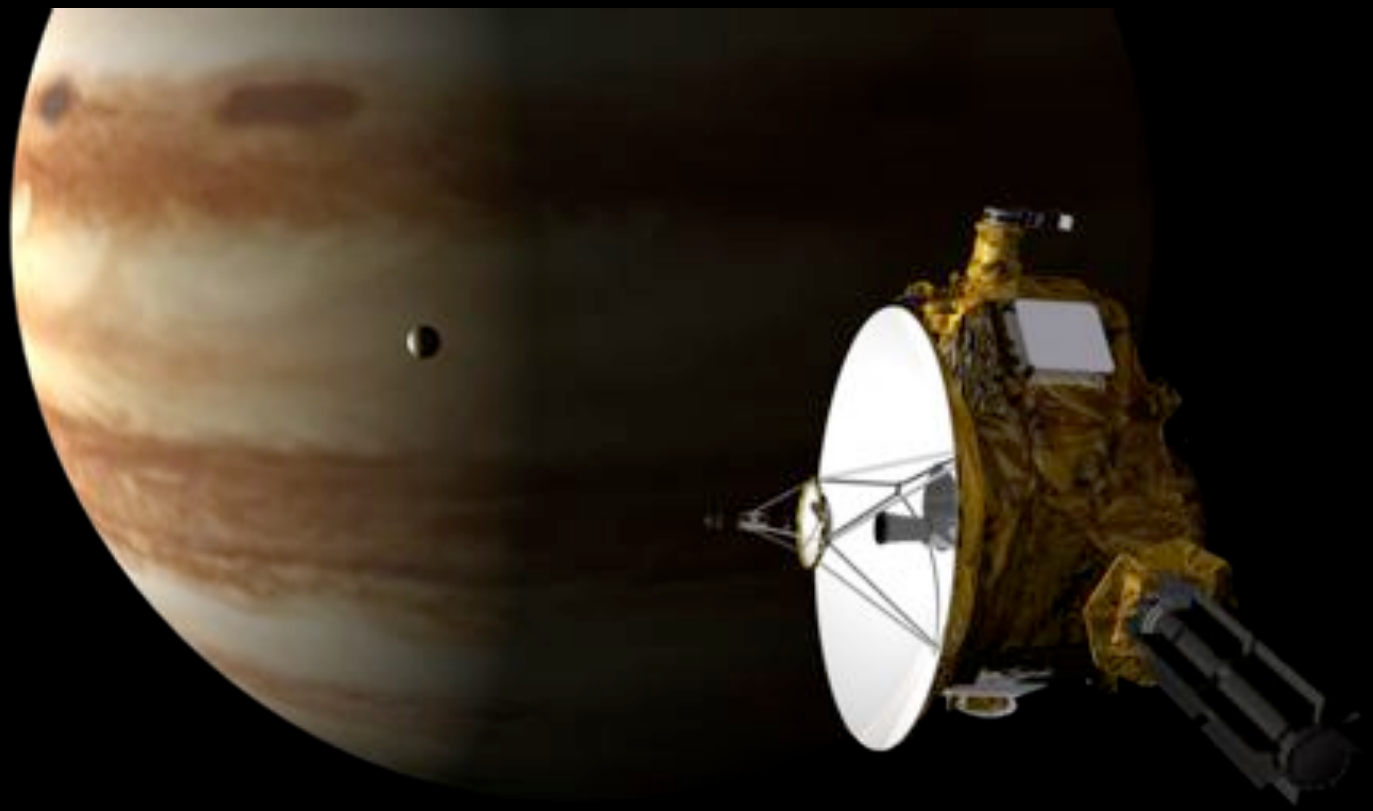
New Horizons to Pluto



- Passed the Moon's orbit at 11pm

New Horizons to Pluto

- Passed Jupiter February 28th 2007



New Horizons to Pluto

- Reaches Pluto on July 14th 2015

Another Way to Think about Scale

- If Pluto is 100 meters away…
- Earth is 0.2 millimeters diameter
- Moon is 6 millimeters away
- Sun is 22 miilimeters across (quarter-sized), 2.5 m from the Earth
- Jupiter is 2.2 millimeters across, 13 meters from the sun
- Nearest star is 600 miles away, e.g. in Minnesota

1930

Discovery of Pluto

1930

- Clyde Tombaugh

Feb. 18th 1930

- Small part of image 1

Feb. 18th 1930

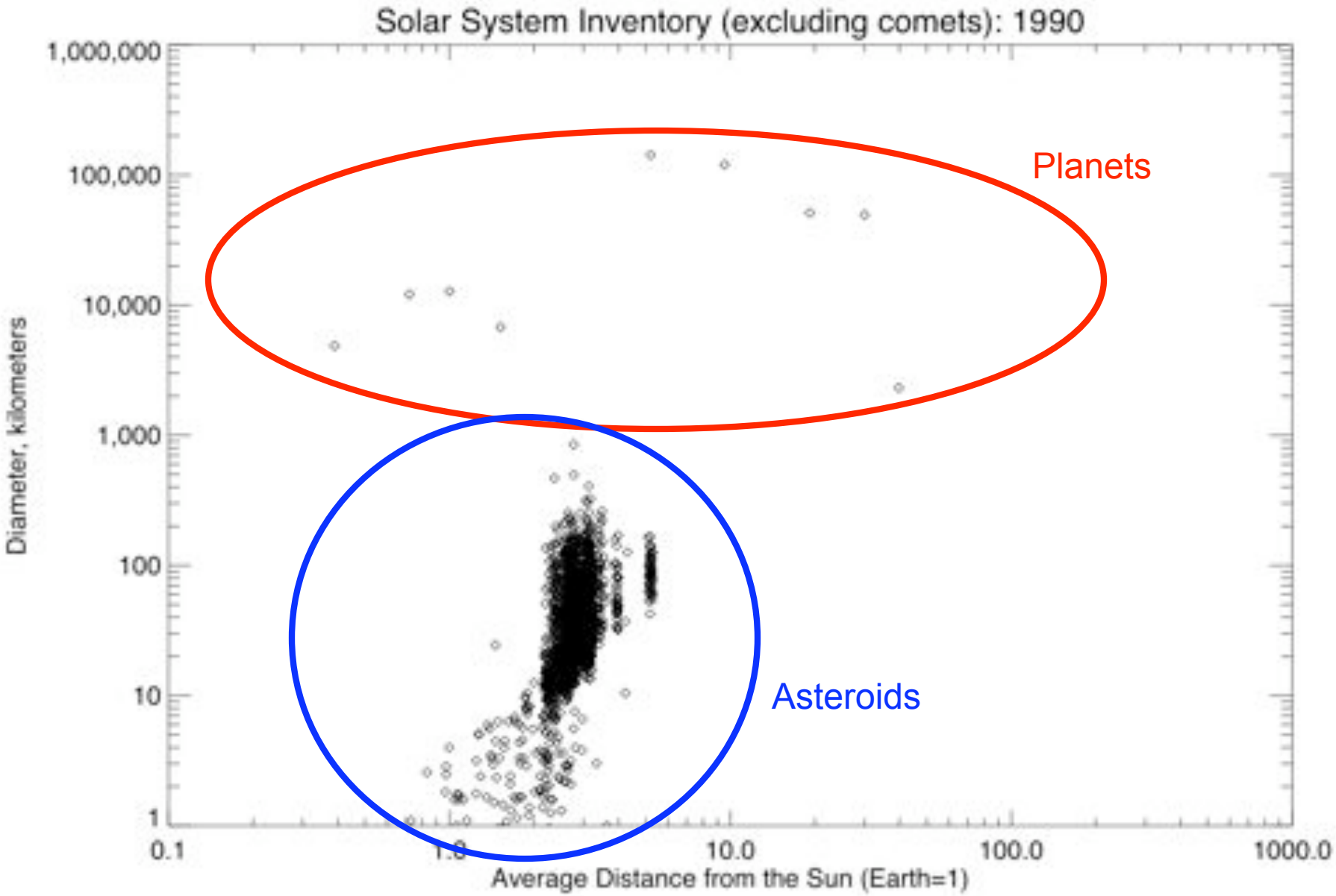
- Small part of image 2

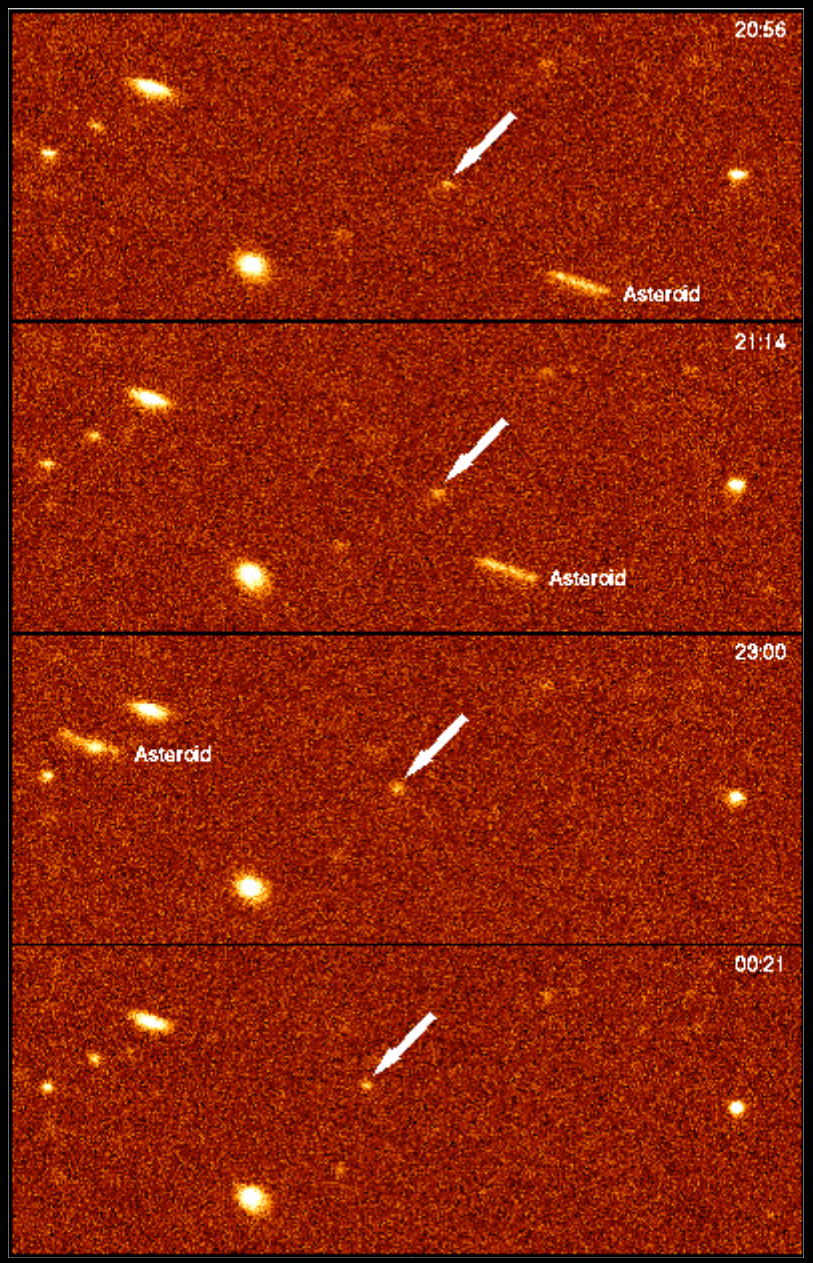
Feb. 18th 1930

- Small part of image 1

Feb. 18th 1930

- Small part of image 2


Solar System Inventory (excluding comets): 1990
1,000,000
100,000
10,000
1,000
100
10
1
Diameter, kilometers
Planets
Asteroids
0.1
1.0
10.0
100.0
1000.0
Average Distance from the Sun (Earth=1)

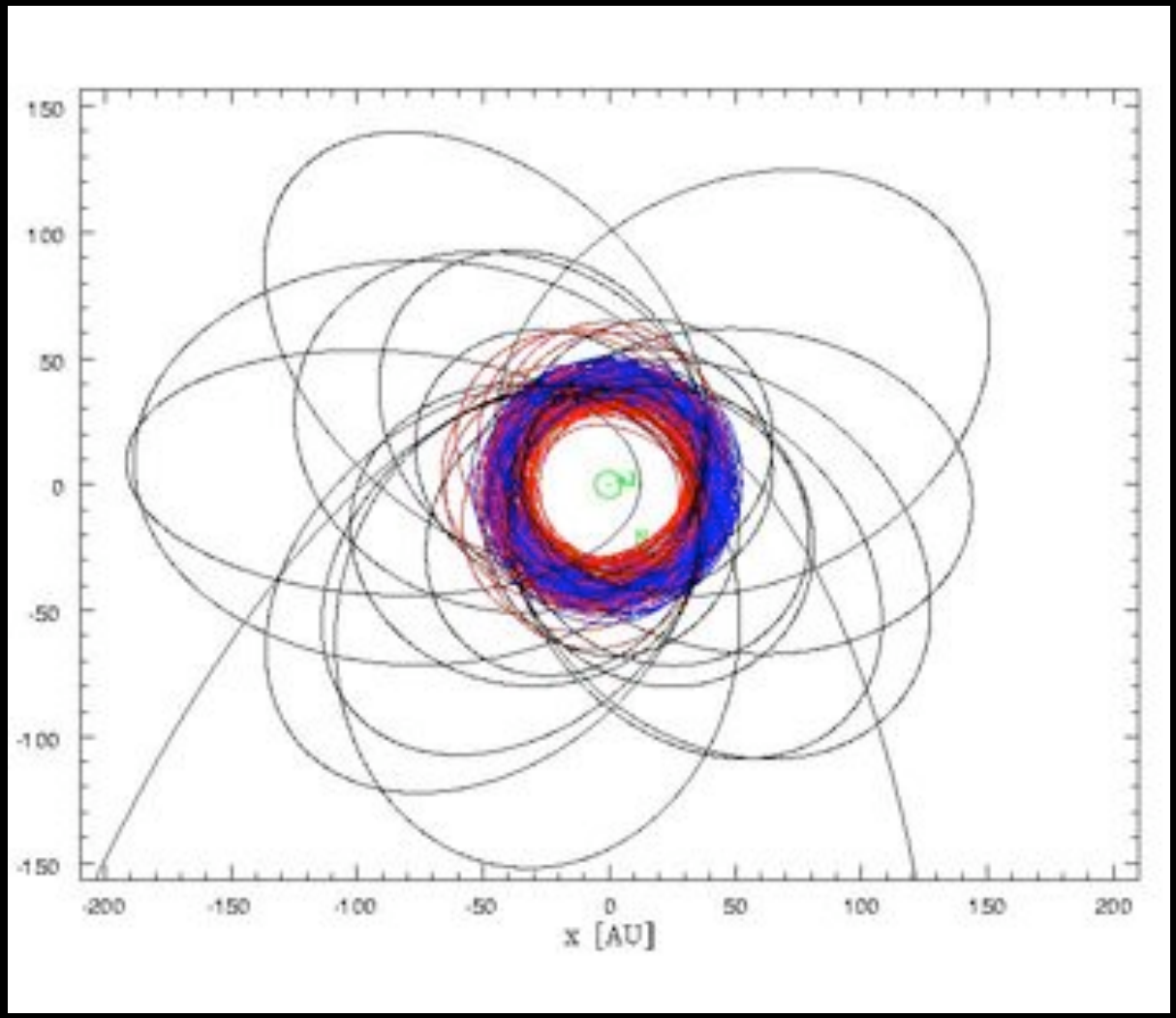


1992

Jane Luu, Dave Jewitt

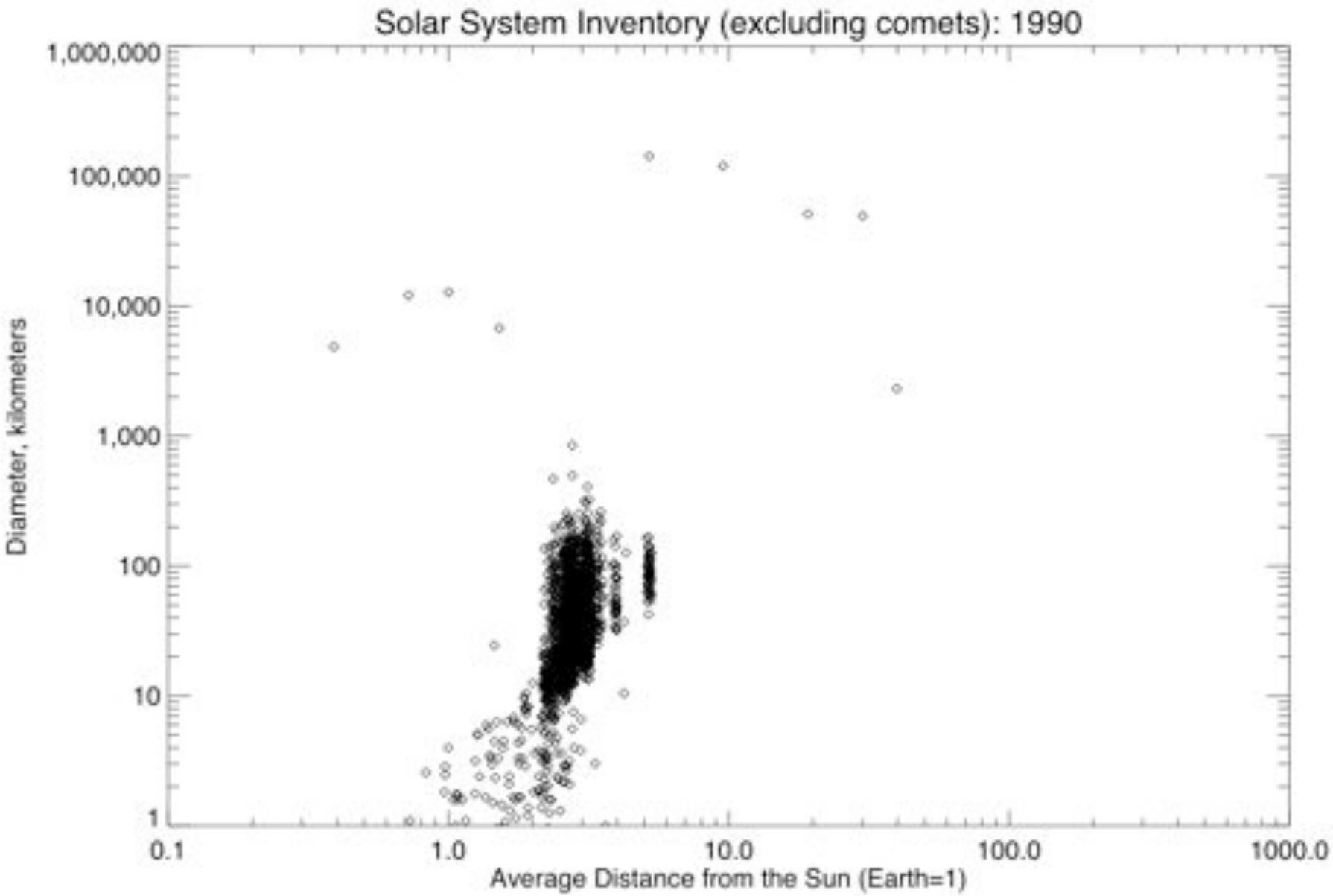
The Kuiper Belt!

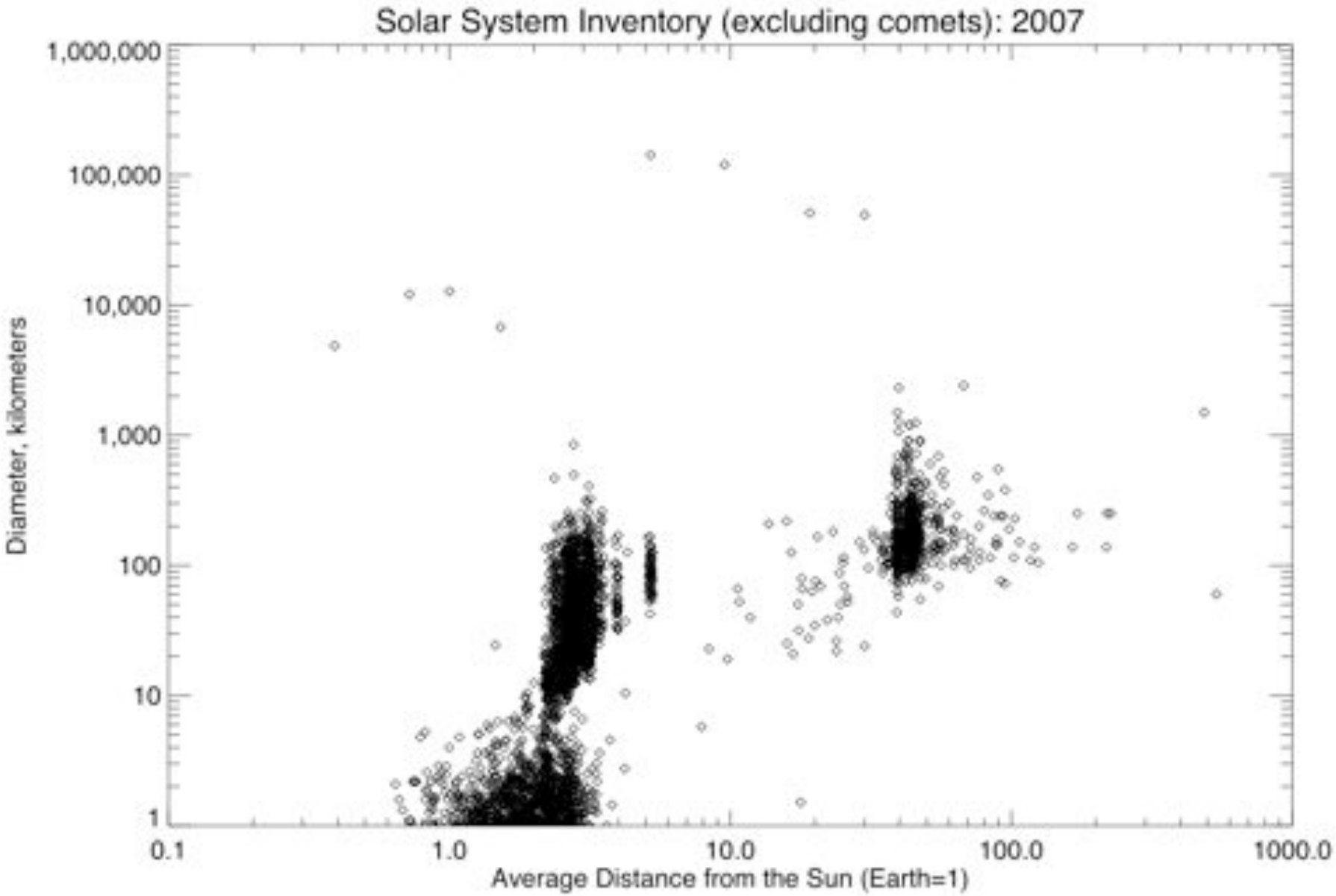
1992 onwards



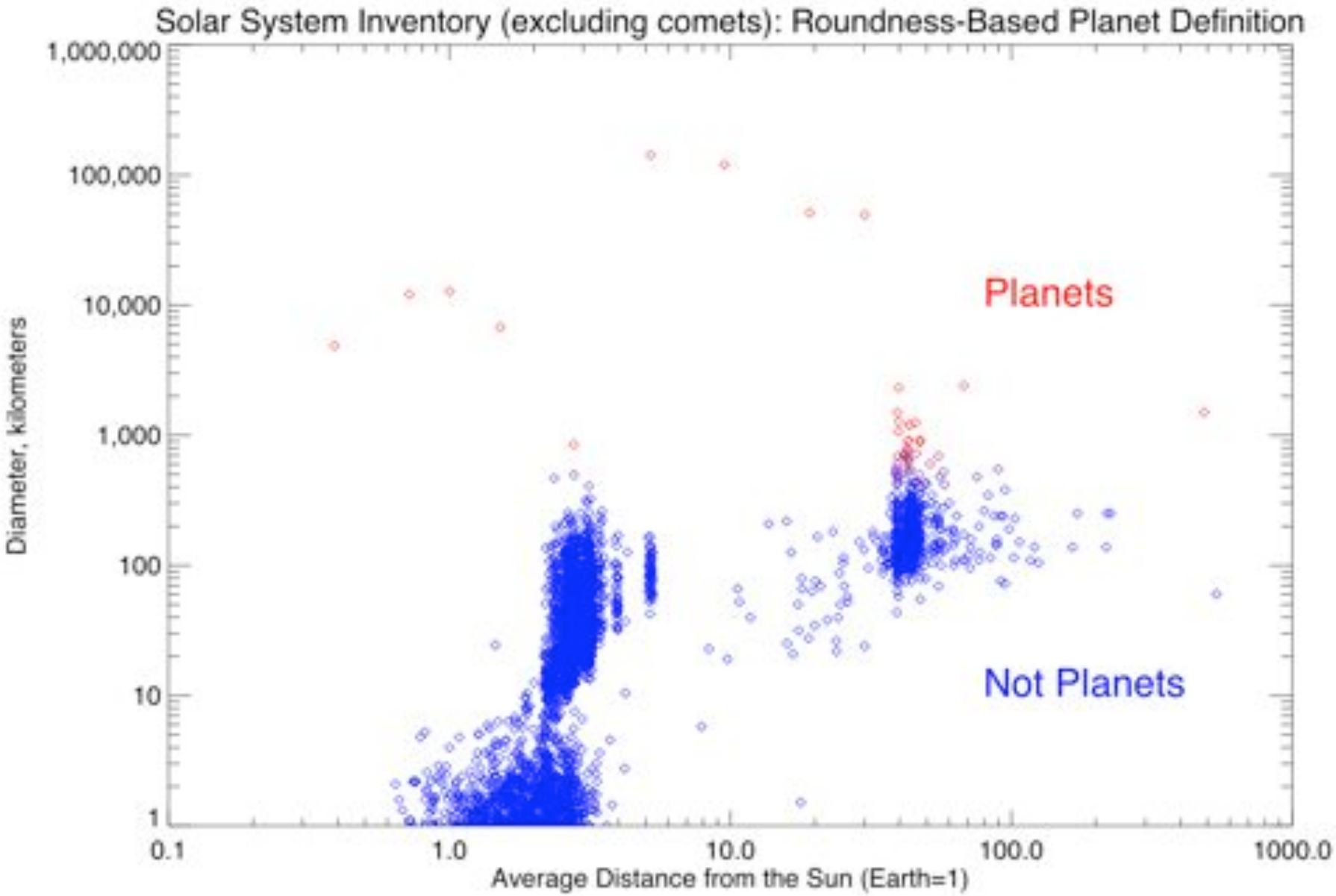
~1000 Kuiper Belt Objects found. 100,000 to go…

More Pluto-Sized Objects

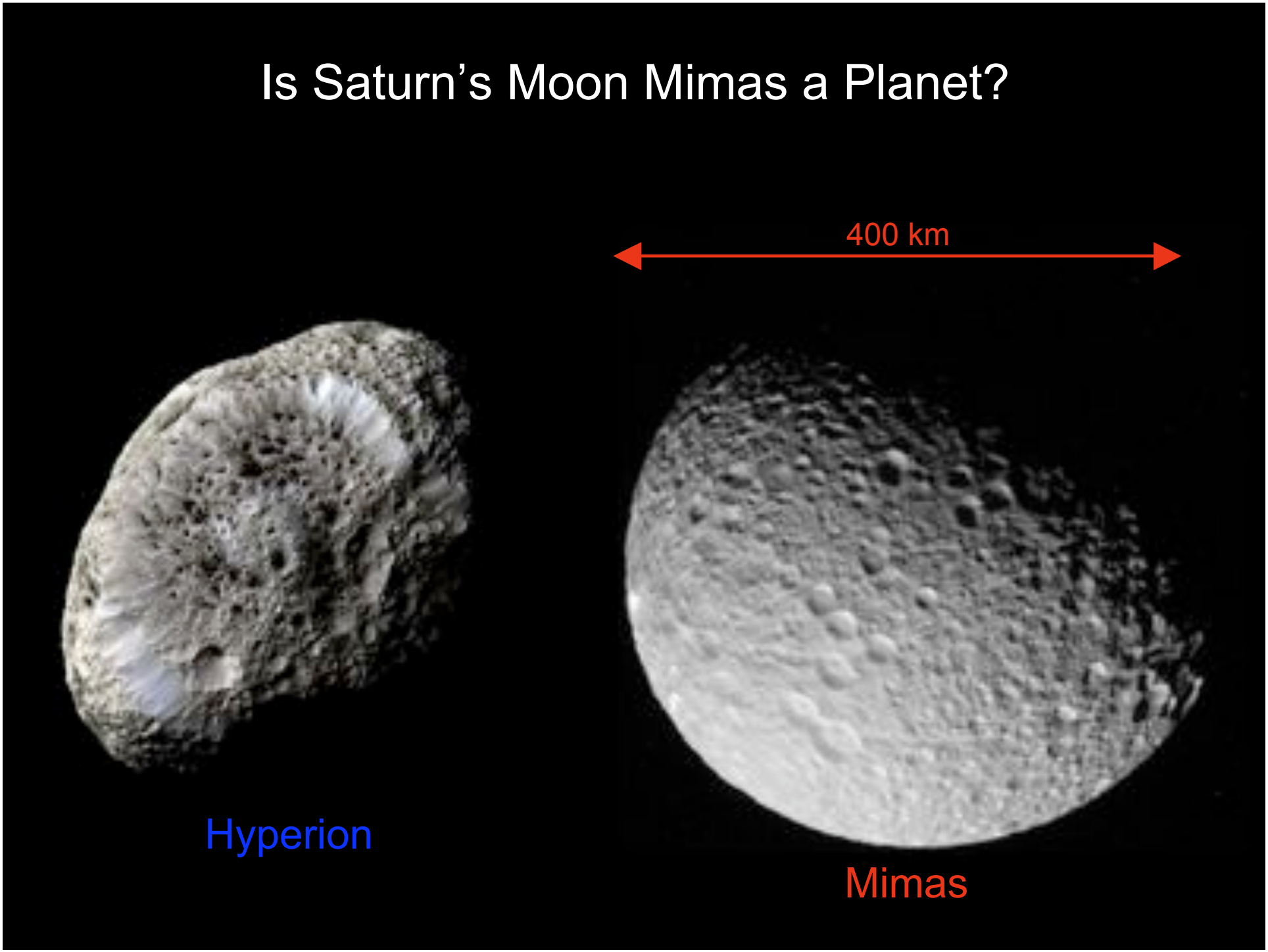

Solar System Inventory (excluding comets): 1990
1,000,000
100,000
10,000
1,000
100
10
1
Diameter, kilometers
0.1
1.0
10.0
100.0
1000.0
Average Distance from the Sun (Earth=1)

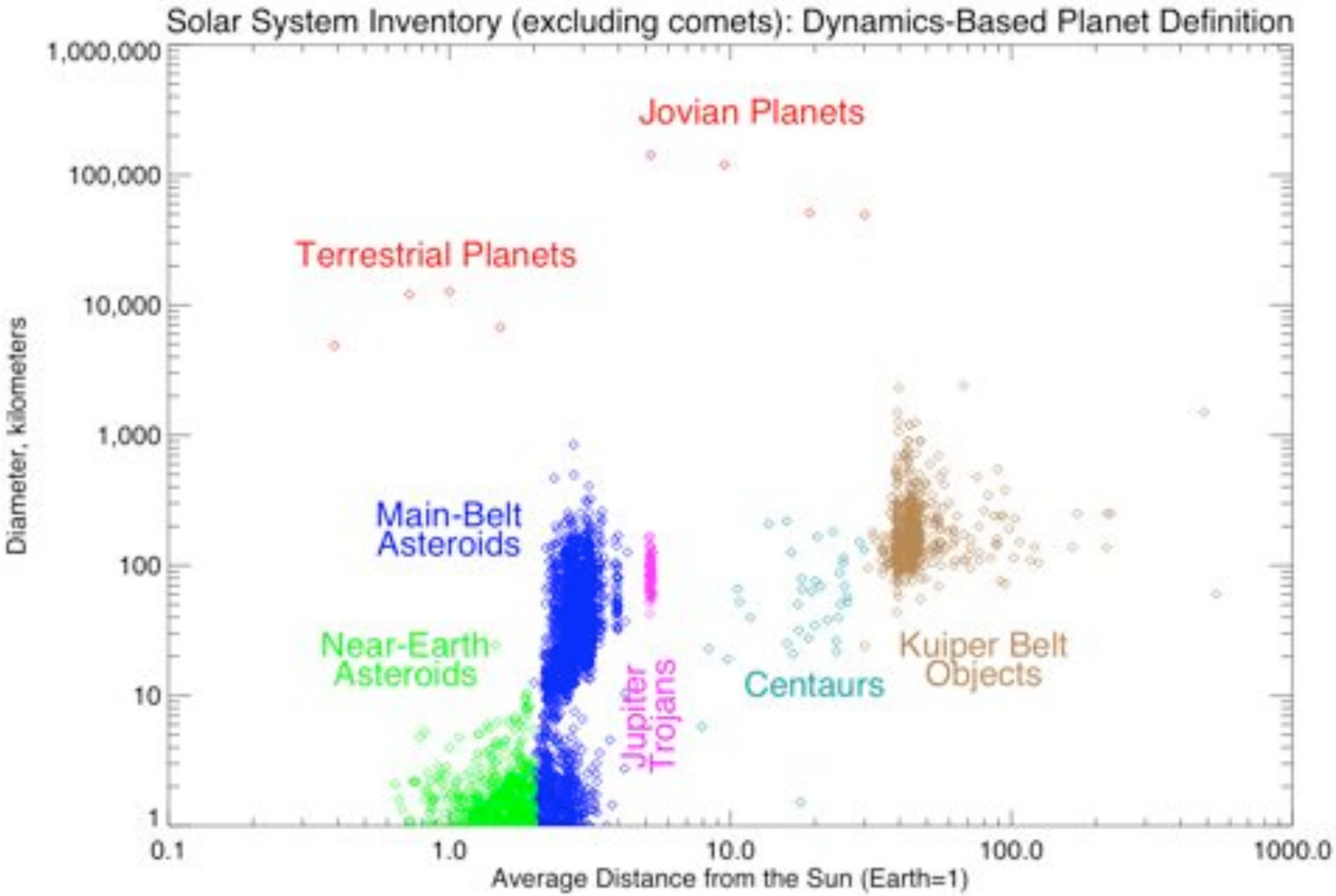

Solar System Inventory (excluding comets): 2007
1,000,000
100,000
10,000
1,000
100
10
1
Diameter, kilometers
0.1
1.0
10.0
100.0
1000.0
Average Distance from the Sun (Earth=1)

Maybe it's a Planet if it's Large Enough to be Spherical?


Solar System Inventory (excluding comets): Roundness-Based Planet Definition
1,000,000
100,000
10,000
1,000
100
10
1
Diameter, kilometers
Planets
Not Planets
0.1
1.0
10.0
100.0
1000.0
Average Distance from the Sun (Earth=1)

Is Saturn's Moon Mimas a Planet?

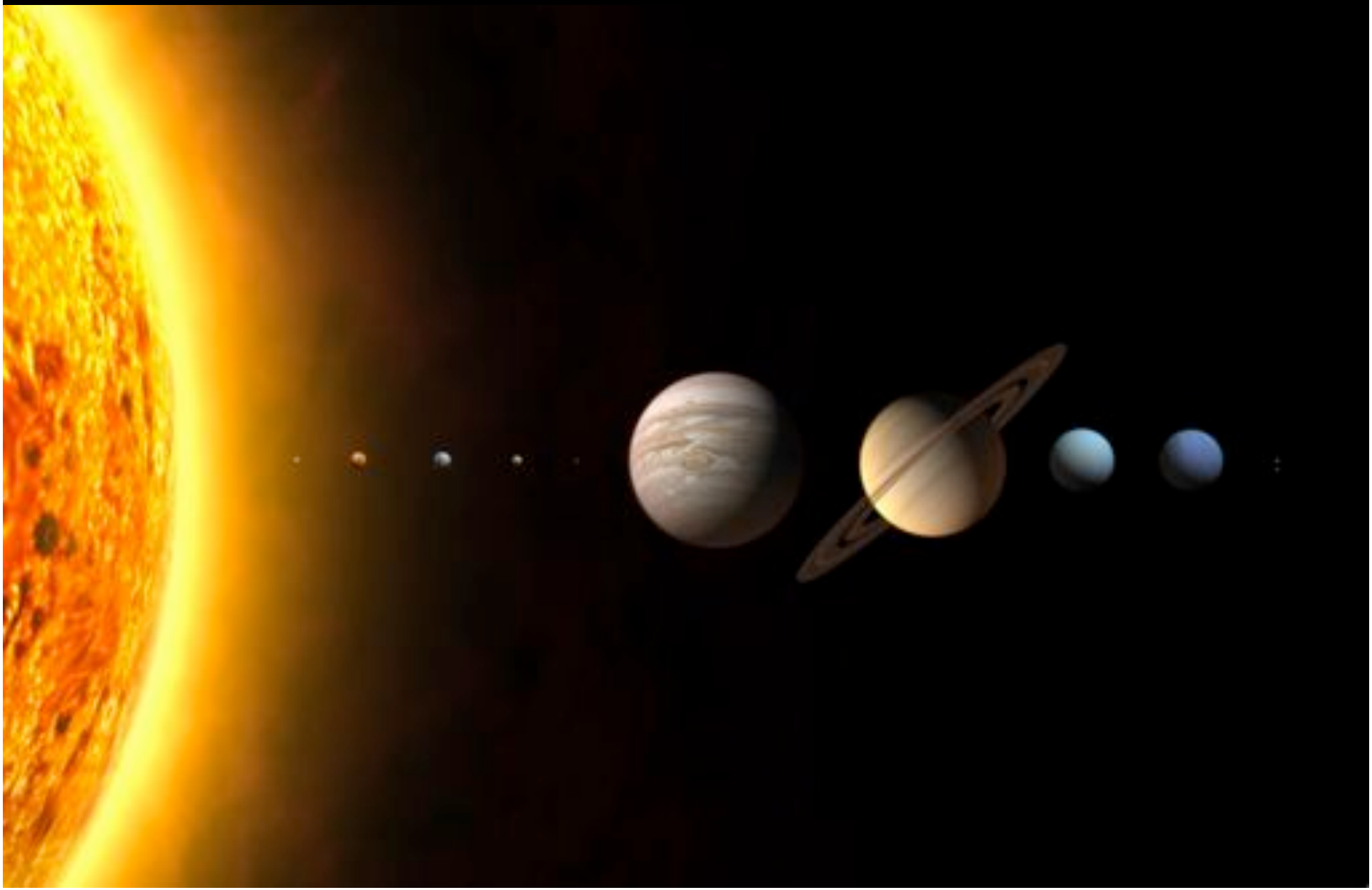


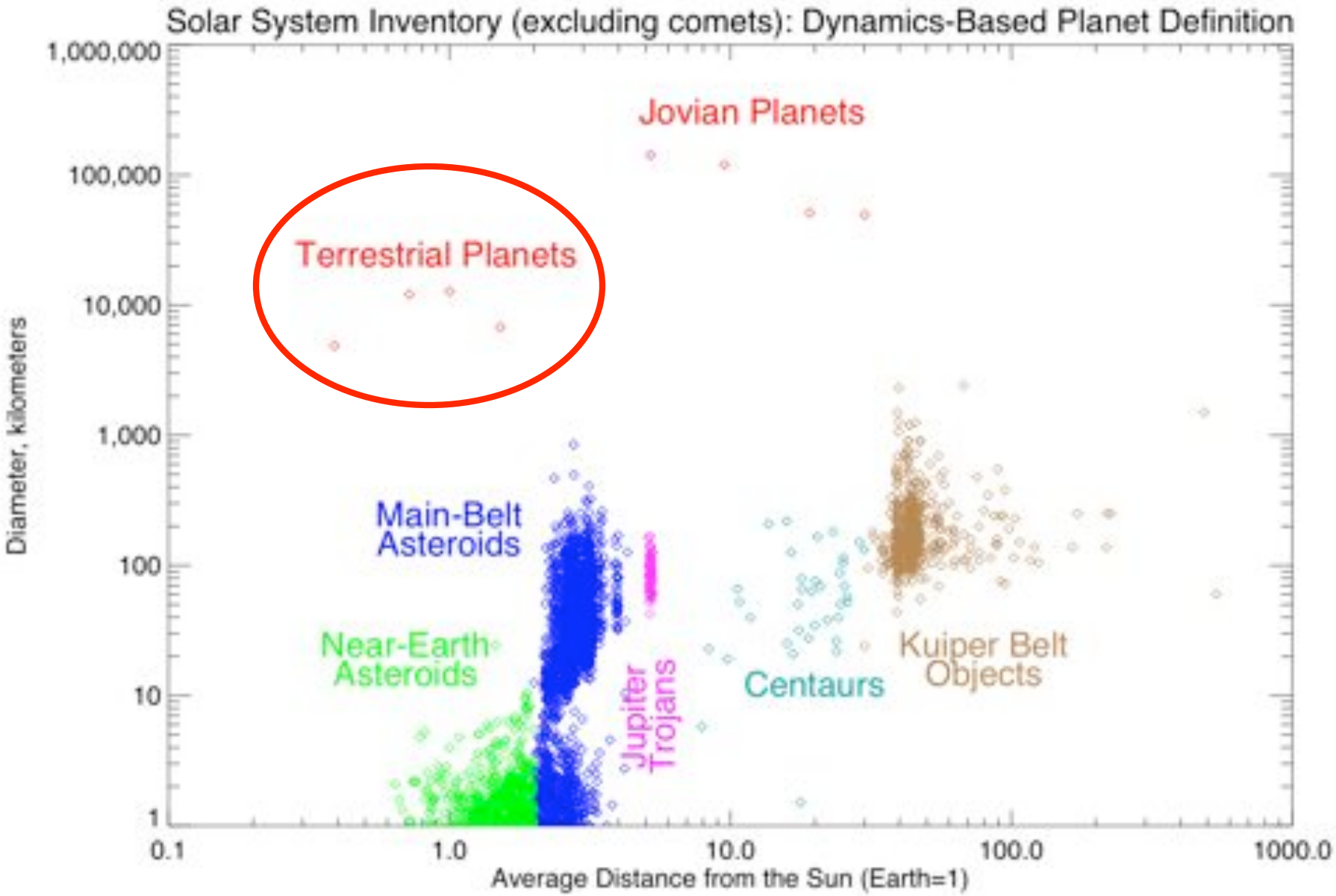

Solar System Inventory (excluding comets): Dynamics-Based Planet Definition
Diameter, kilometers
1,000,000
100,000
10,000
1,000
100
10
1
0.1
1.0
10.0
100.0
1000.0
Average Distance from the Sun (Earth=1)
Jovian Planets
Terrestrial Planets
Main-Belt Asteroids
Near-Earth Asteroids
Jupiter Trojans
Centaurs
Kuiper Belt Objects

What's Out There?

- Four terrestrial planets
- Four Jovian planets
- Asteroids in stable orbits
- Asteroids in unstable orbits (e.g. near-Earth asteroids)
- Kuiper Belt Objects in stable orbits
- Kuiper Belt Objects in unstable orbits (Centaurs, comets)

The Planets Themselves, To Scale

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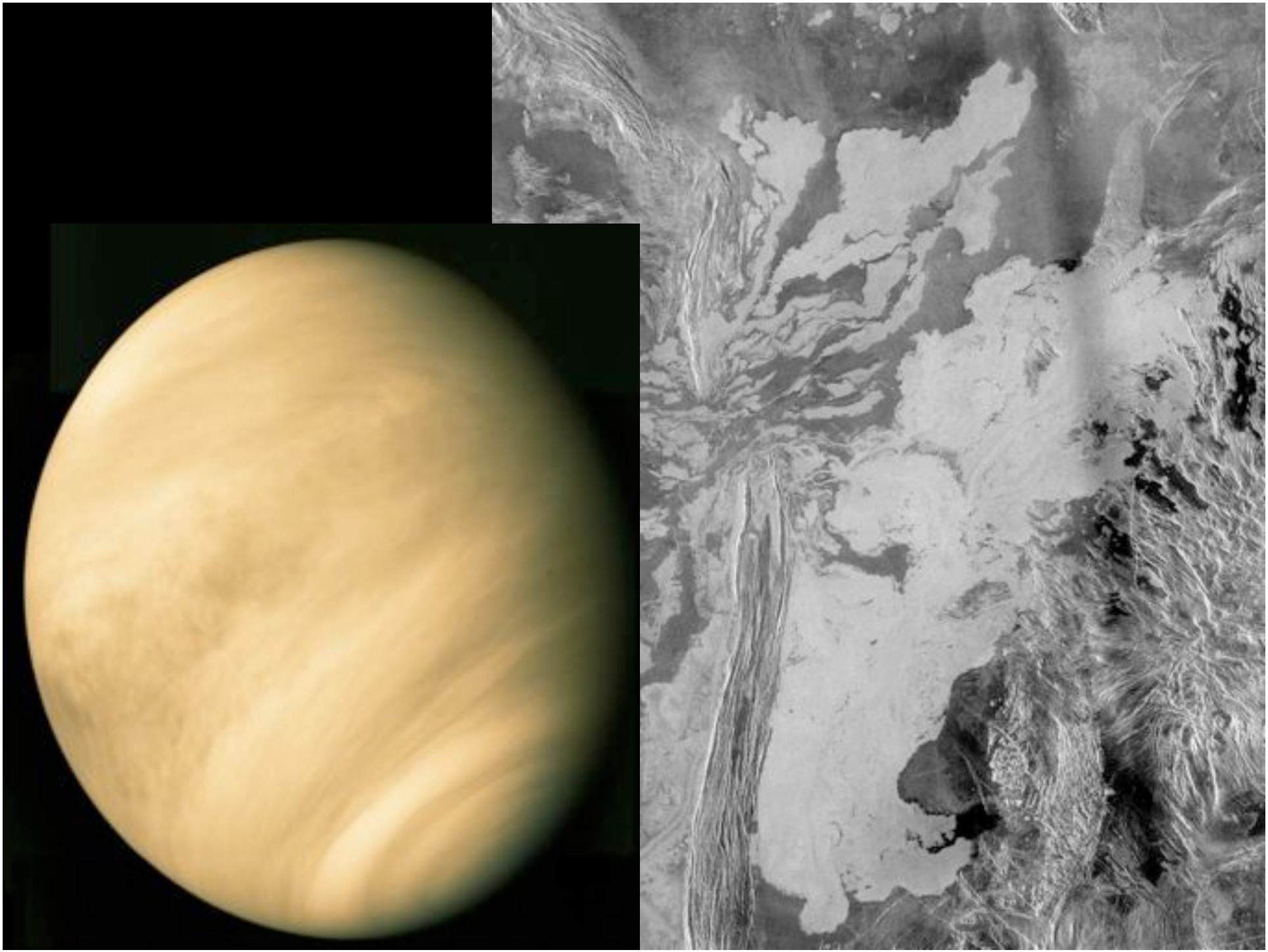
0.1
1.0
10.0
100.0
1000.0
Average Distance from the Sun (Earth=1)

Terrestrial Planets

- Too close to the Sun to accumulate much ice or gas: small and rocky
- Only three moons between them

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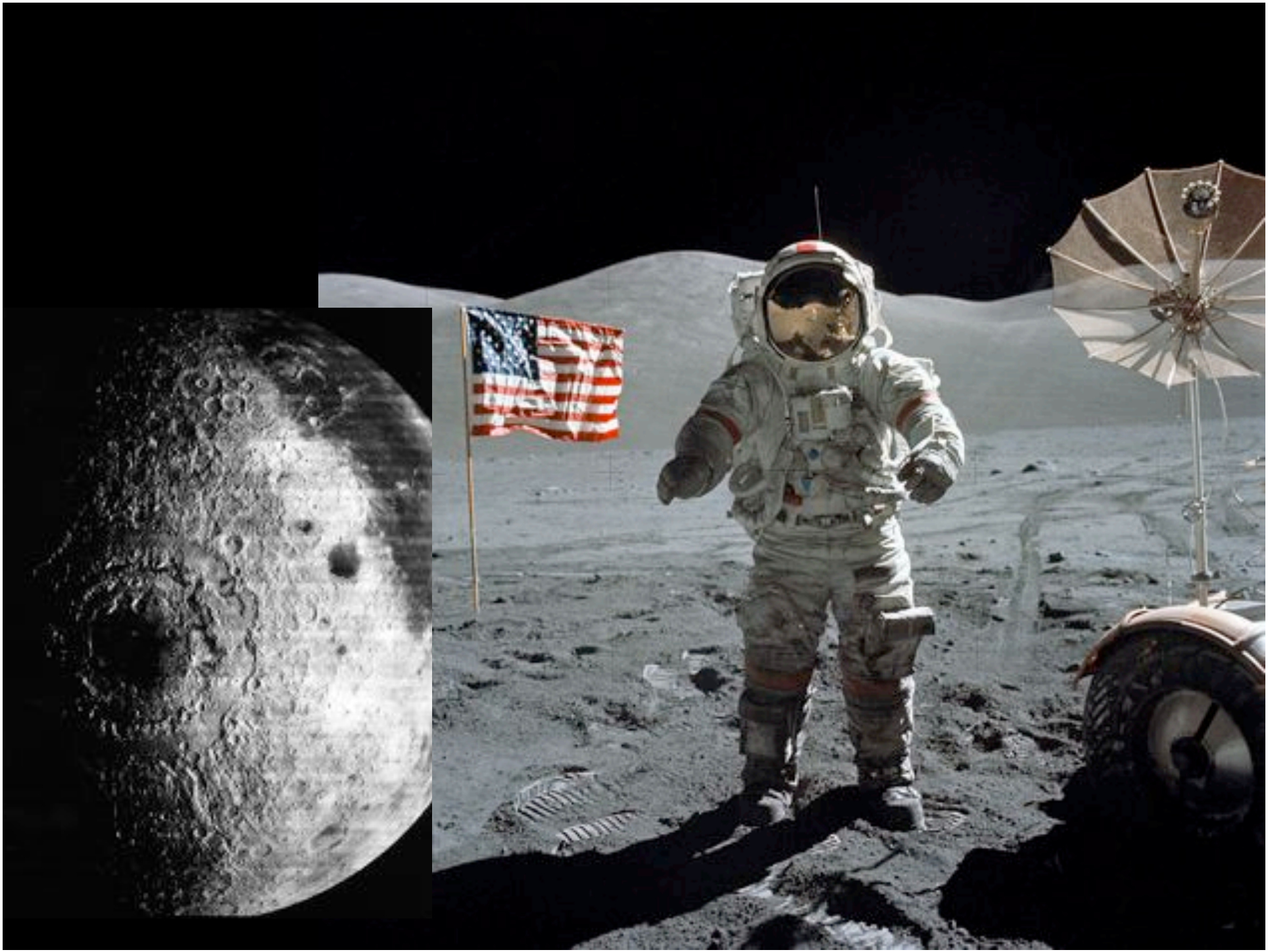

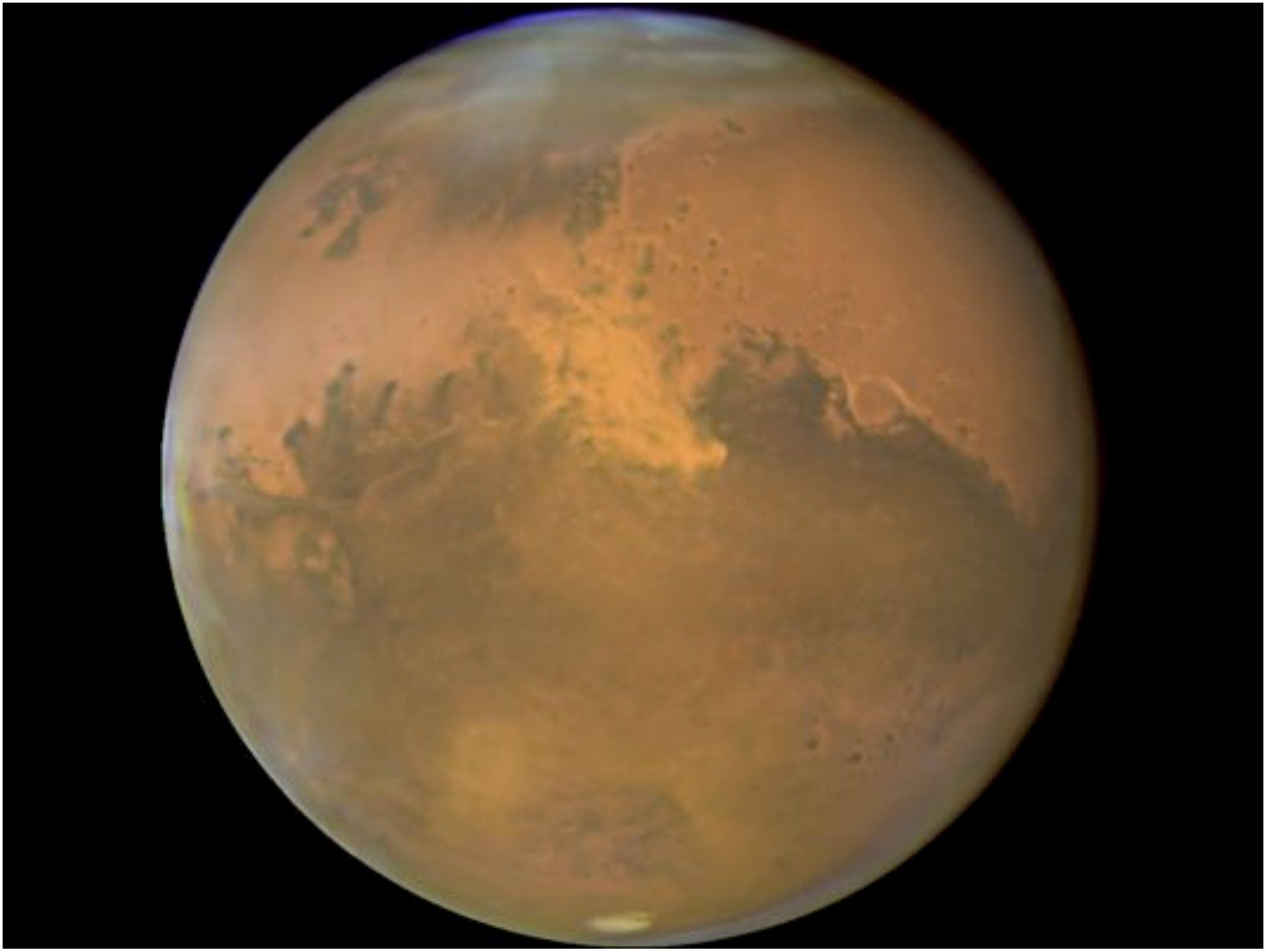

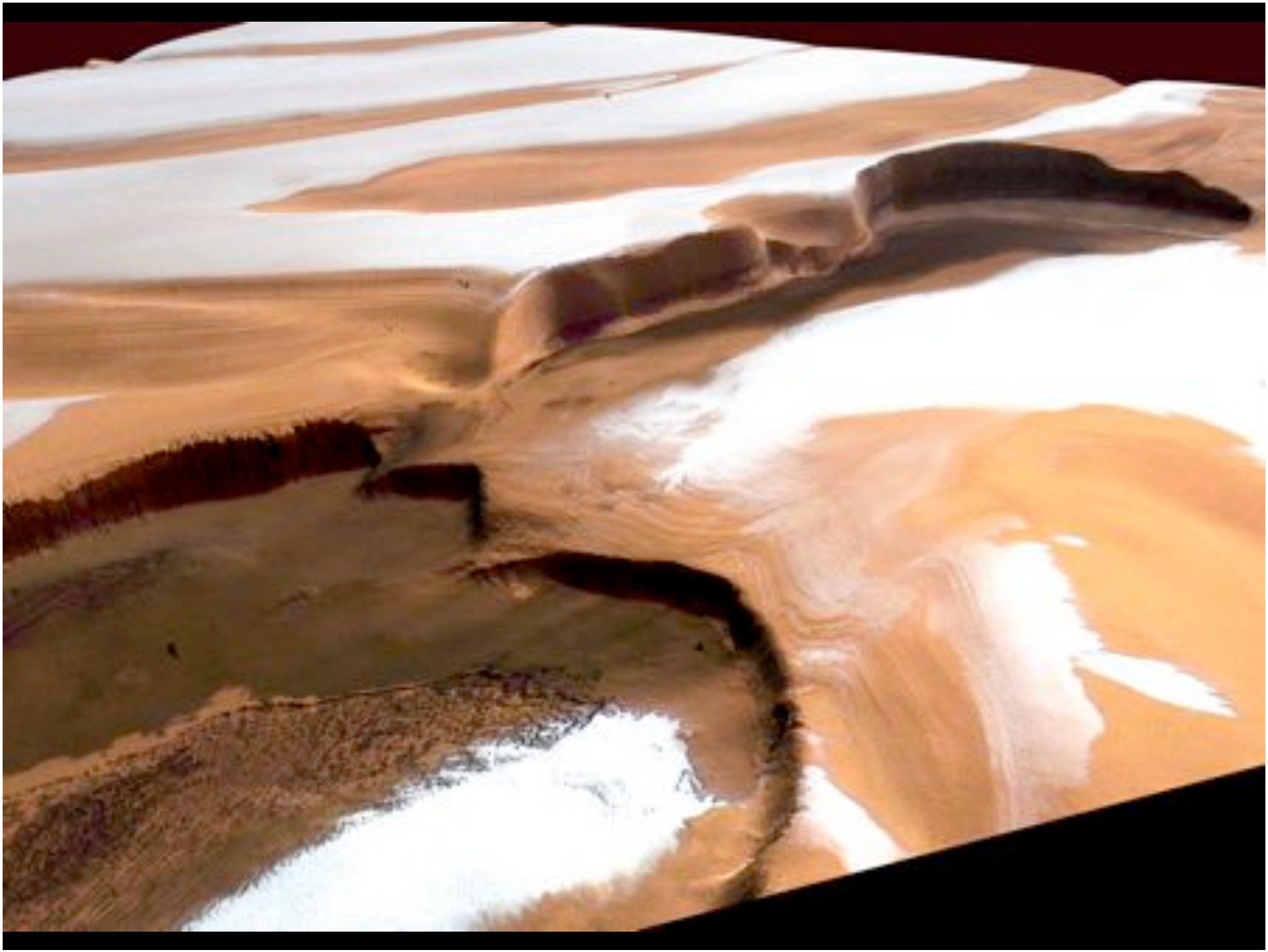

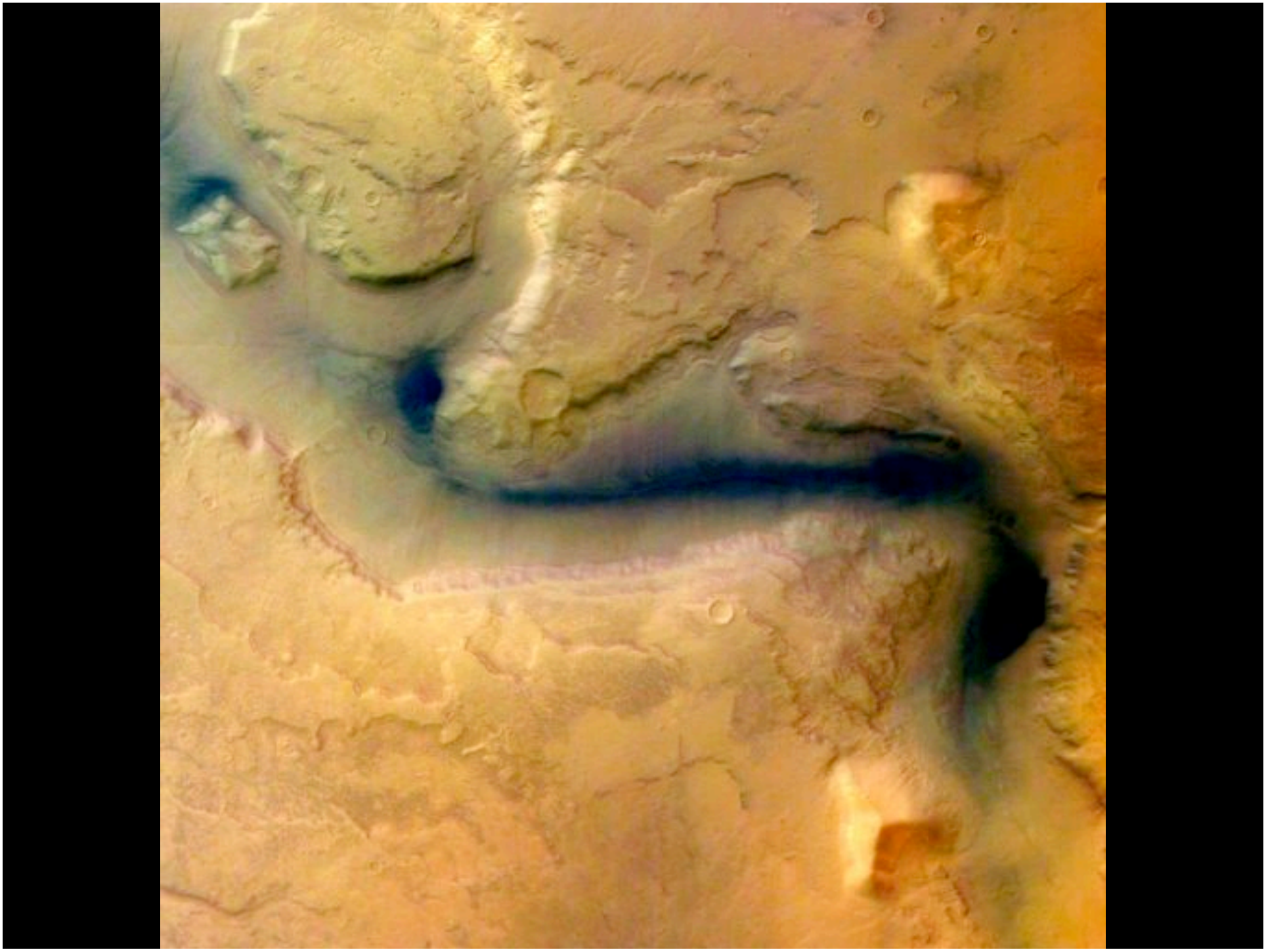

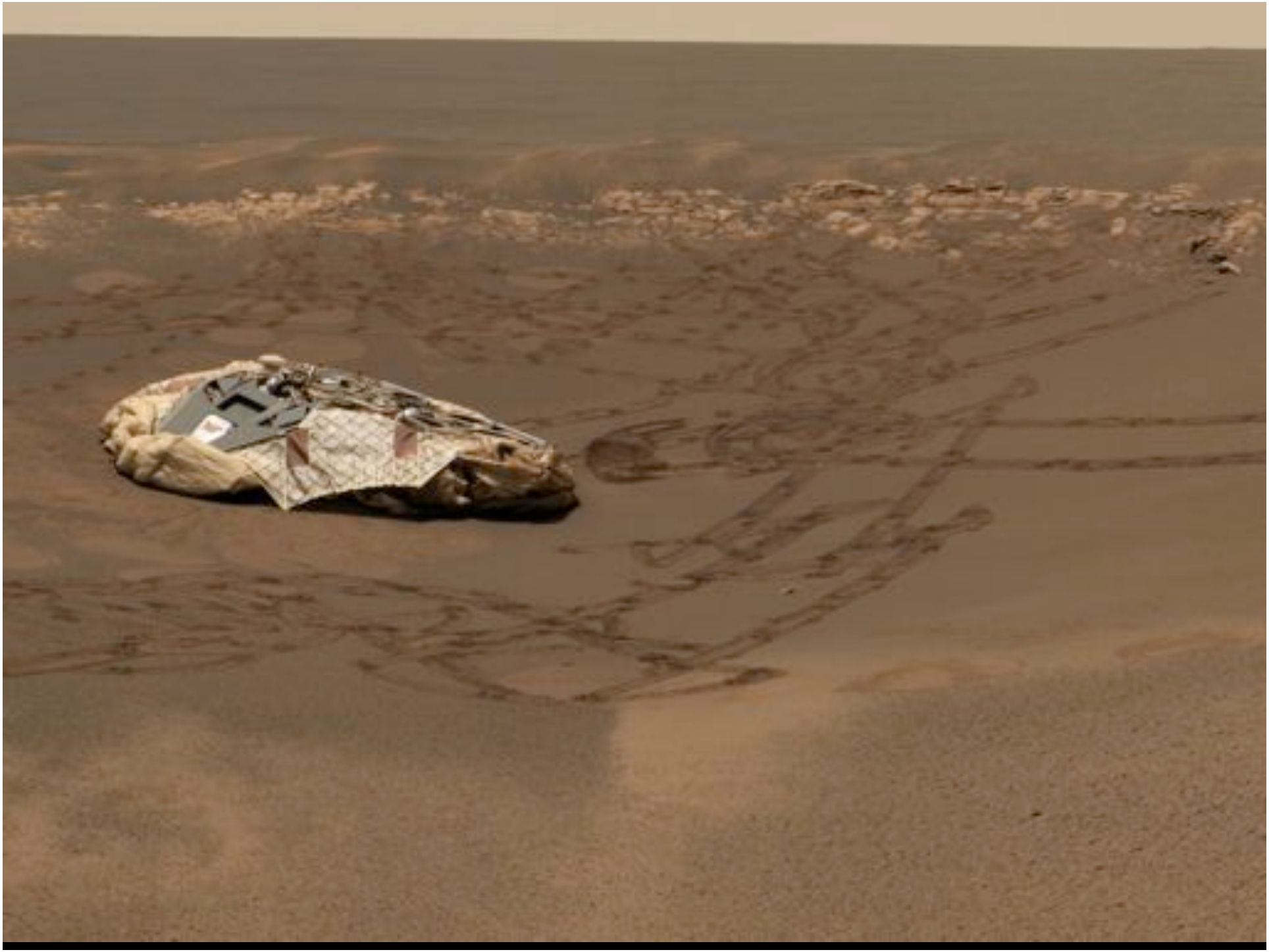

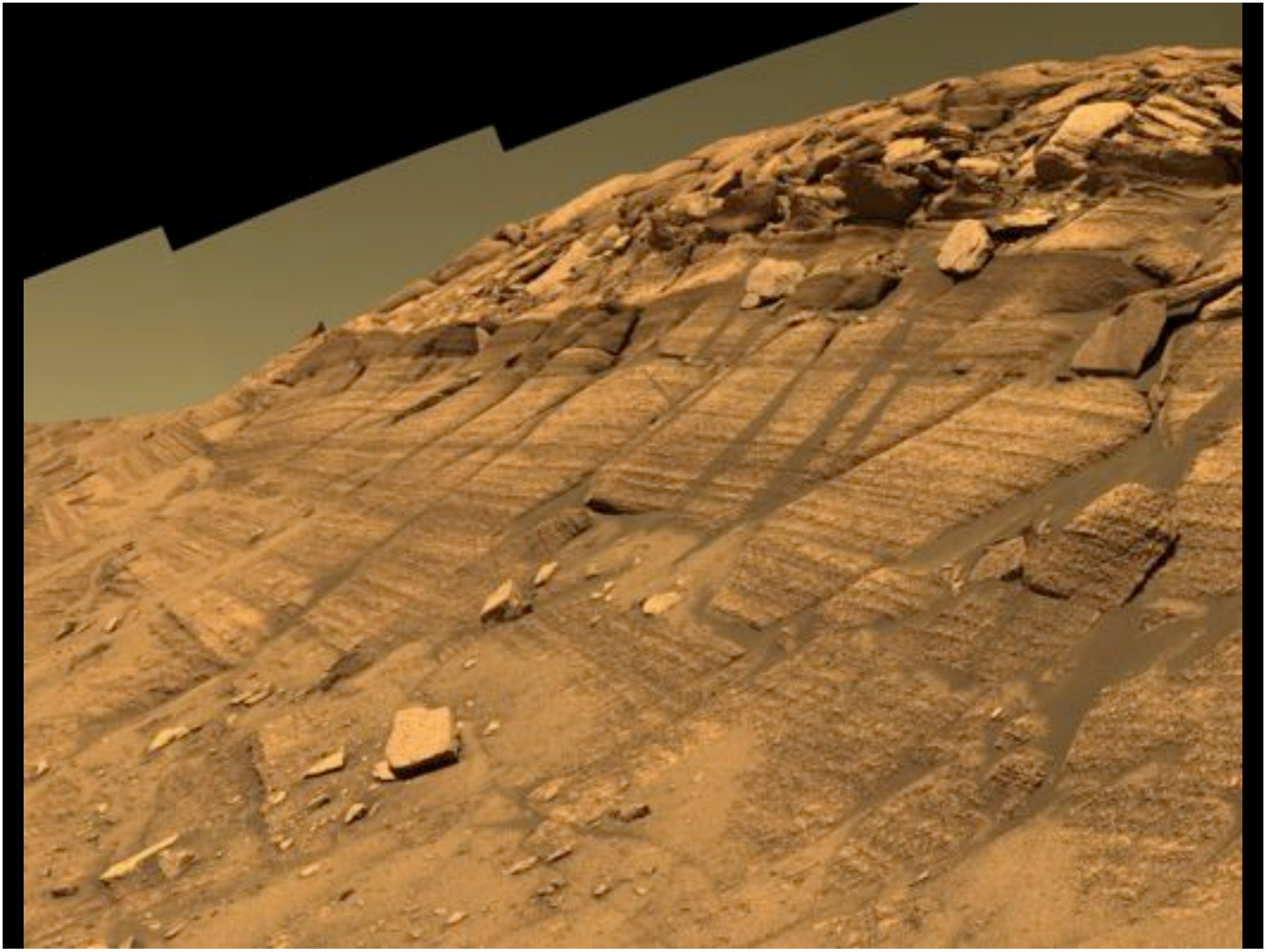

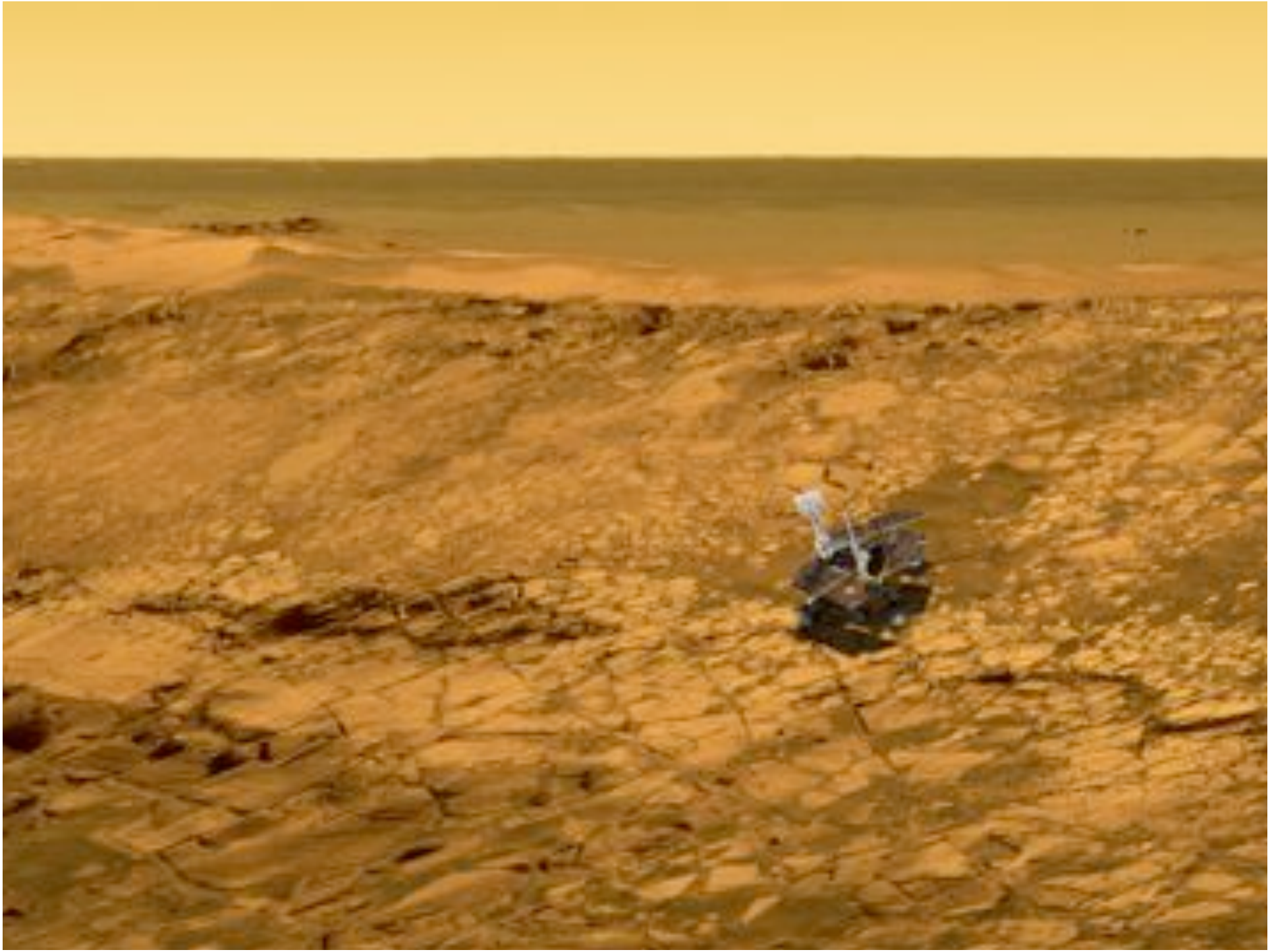

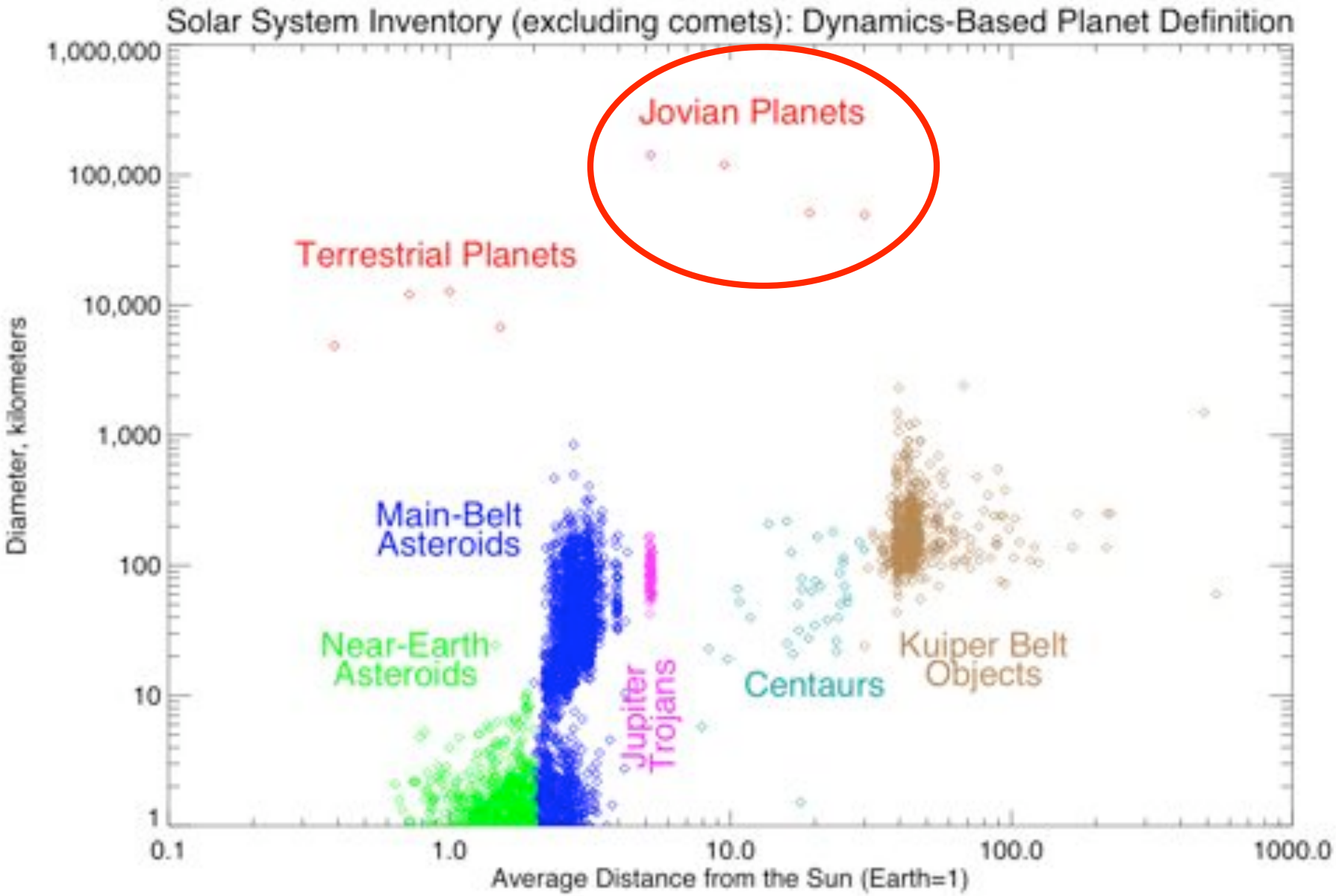
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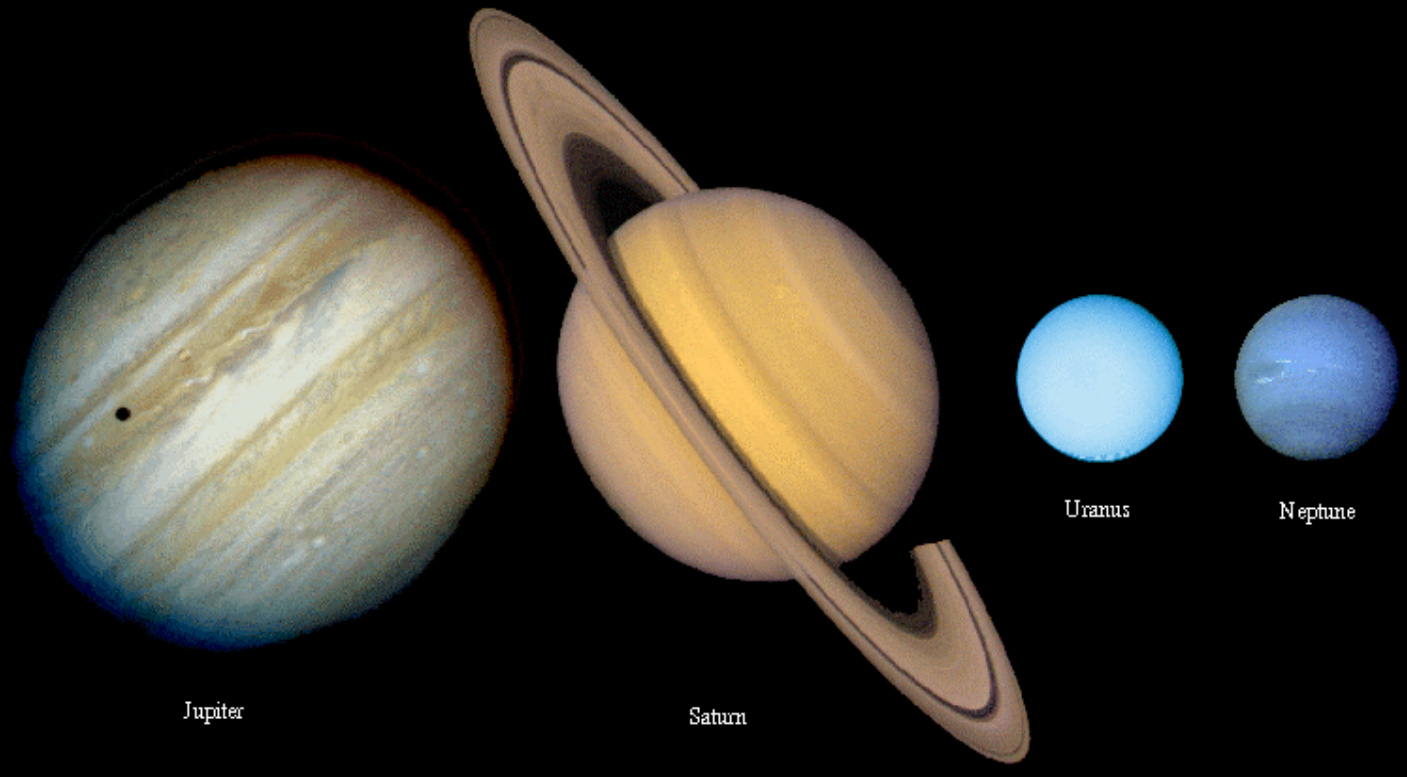
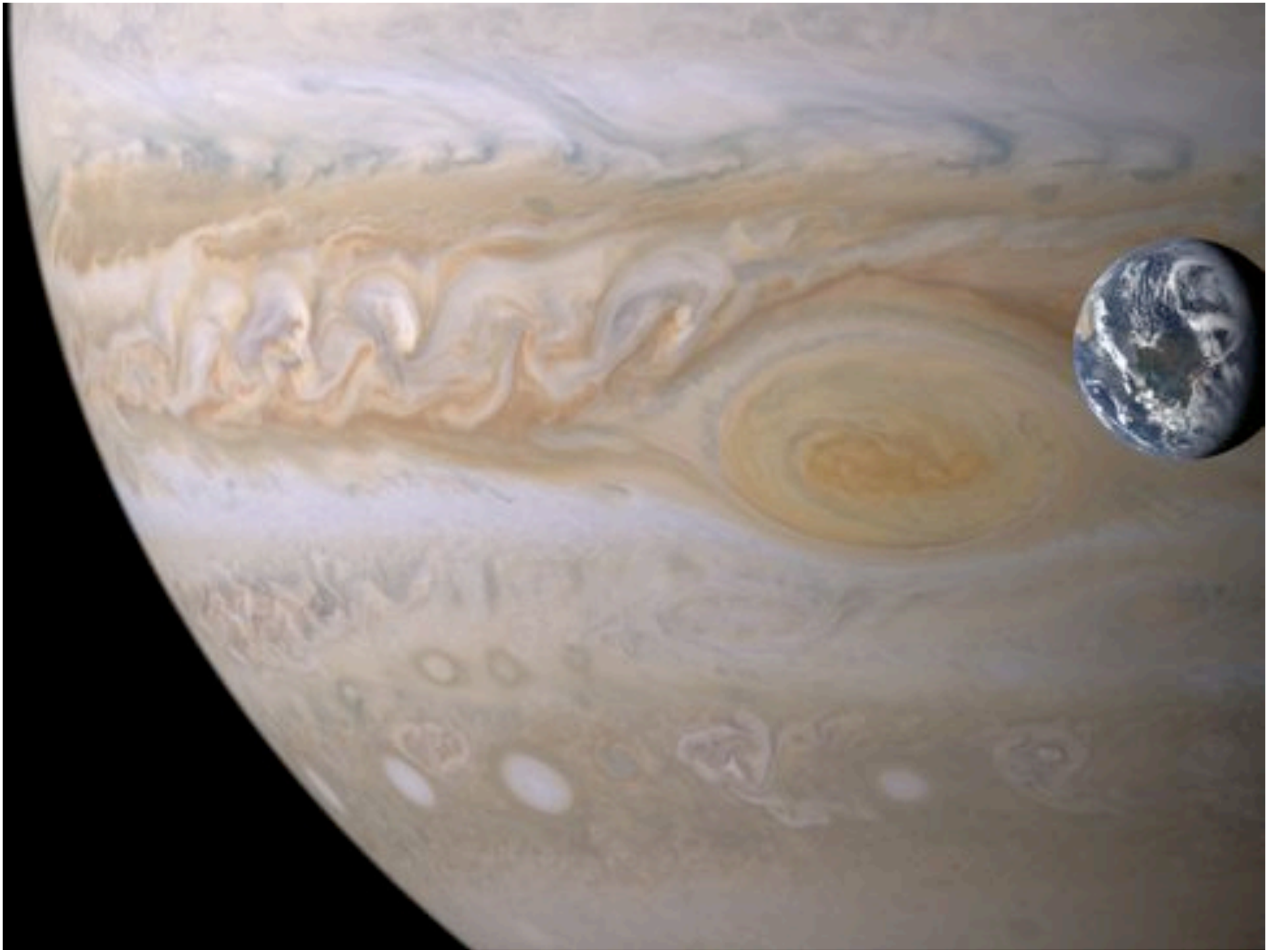
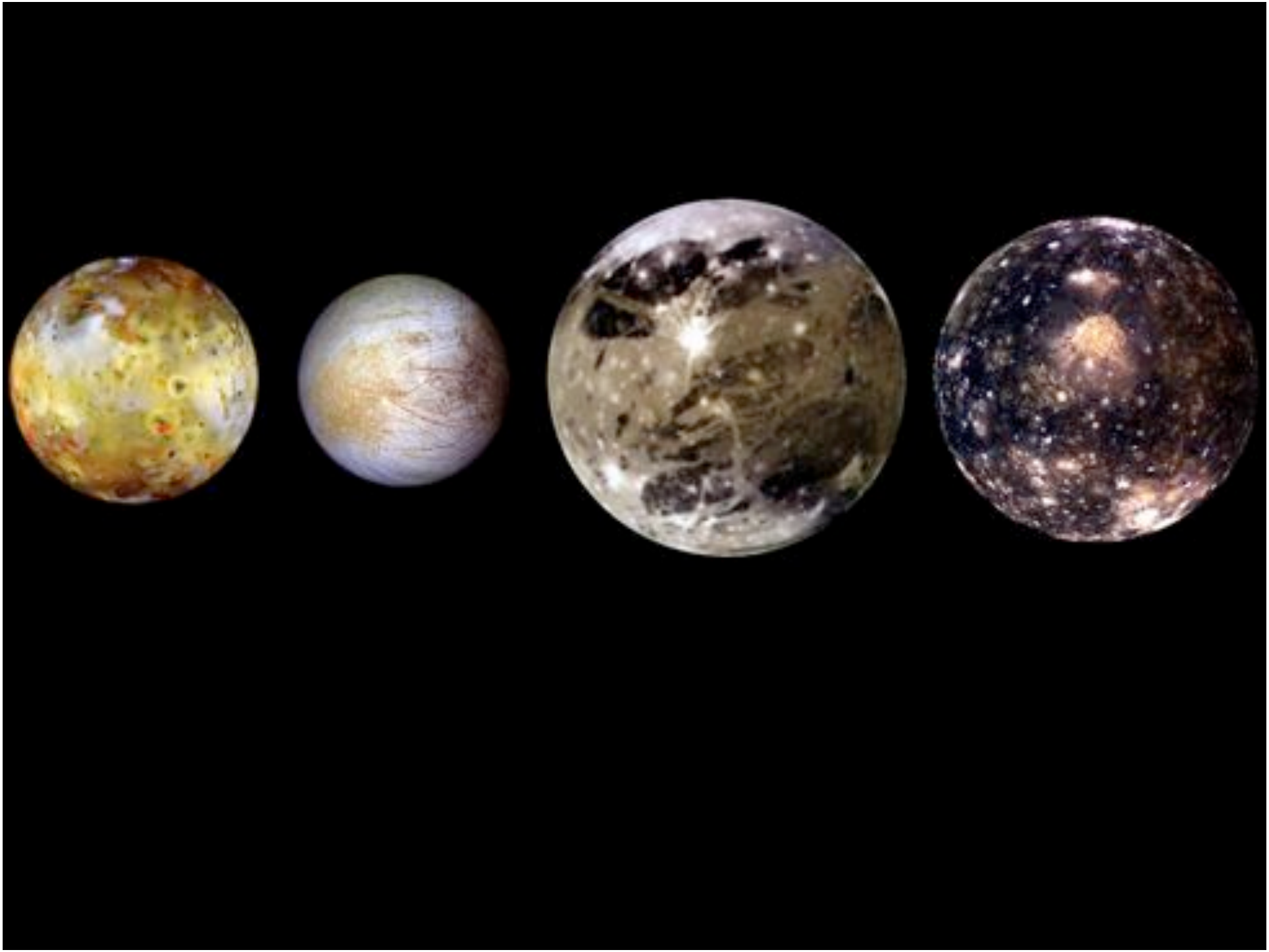
1,000,000
100,000
10,000
1,000
100
10
1
0.1
1.0
10.0
100.0
1000.0
Average Distance from the Sun (Earth=1)

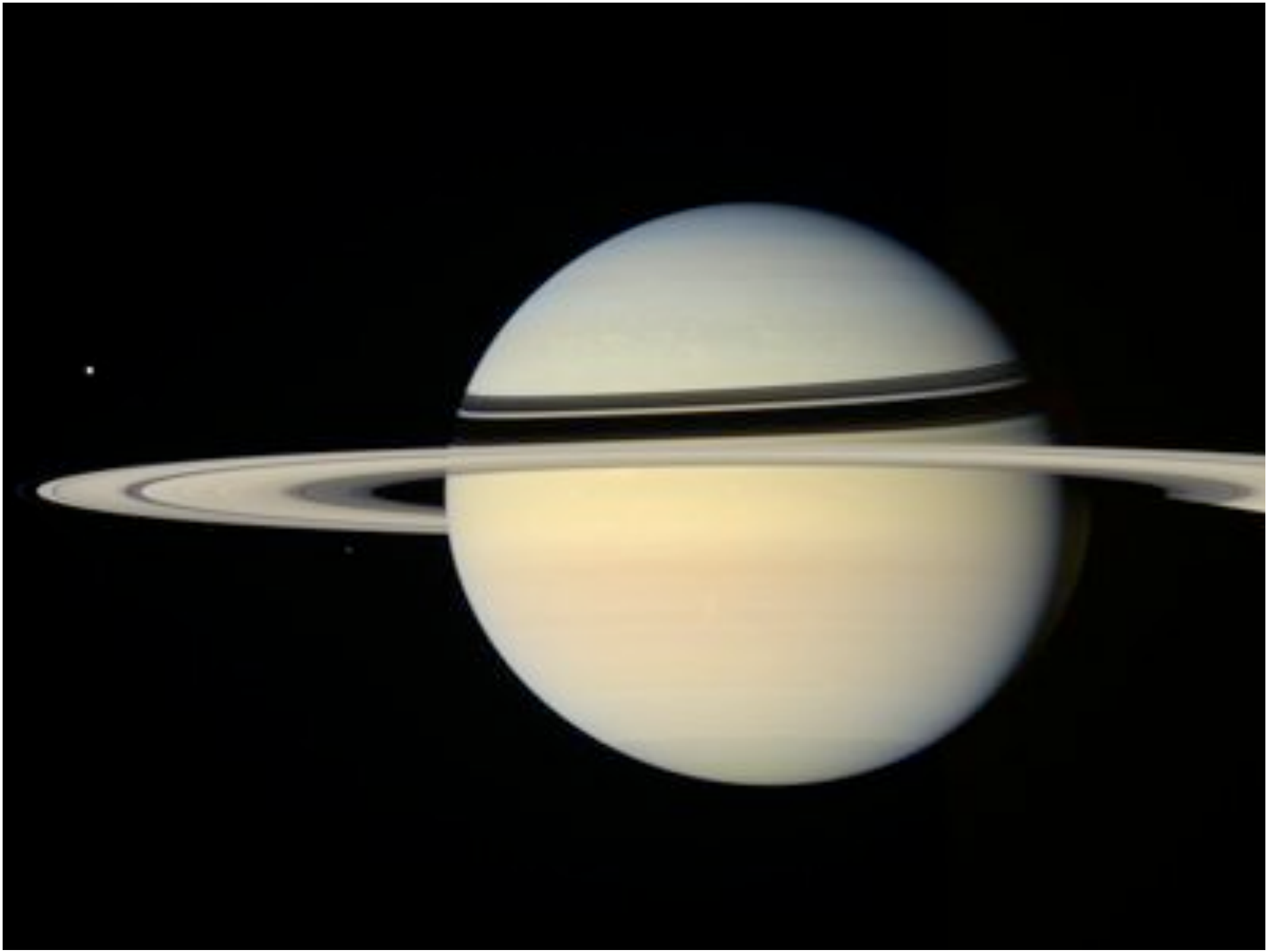
Jovian Planets

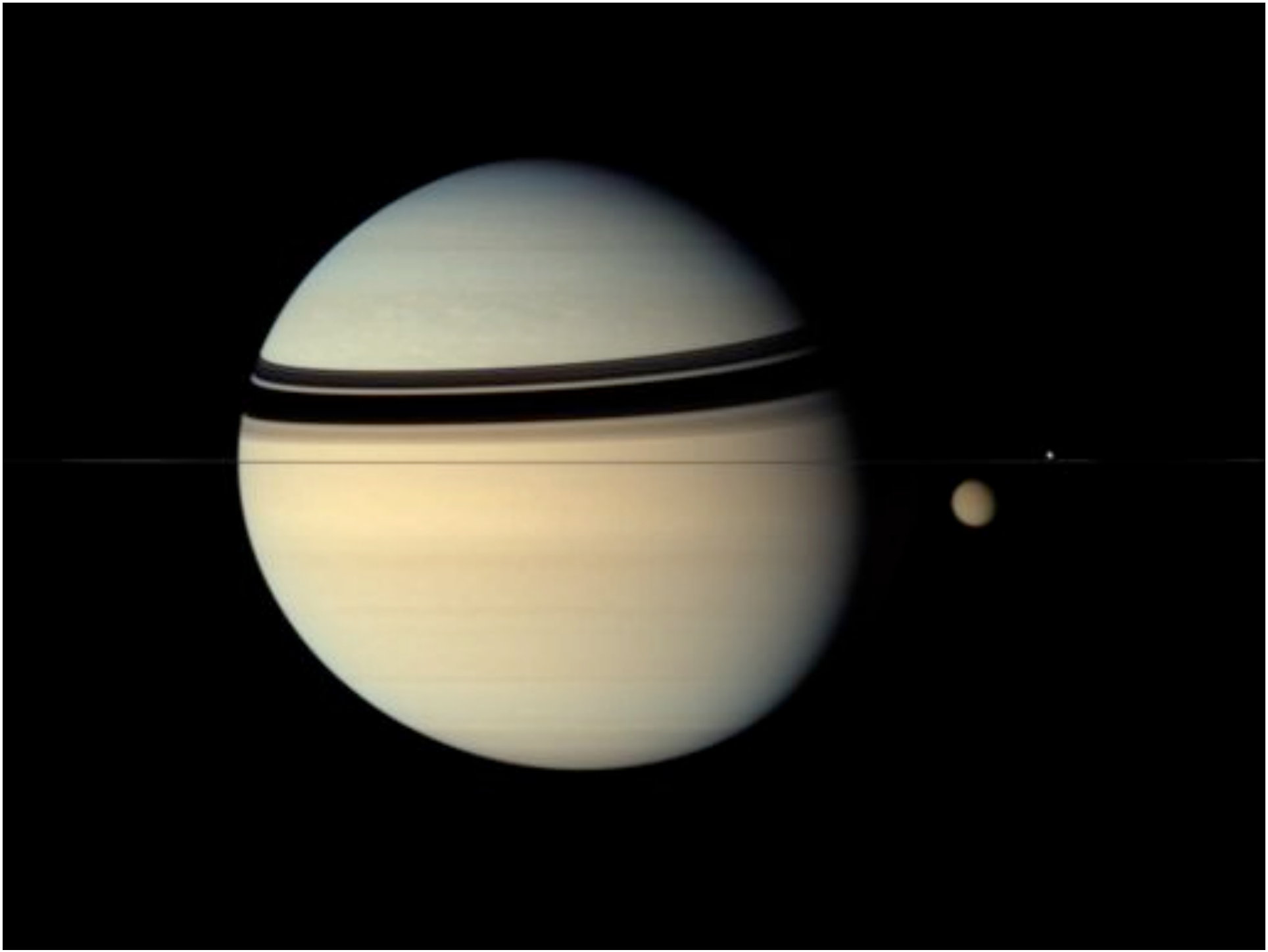
- 99.5% of the mass in the solar system
- Formed beyond the “snow line”- cold enough for growing planets to incorporate ice, made them big enough to pull in gas as well
  - Rock and ice, surrounded by massive hydrogen envelopes
  - Large retinues of satellites and rings

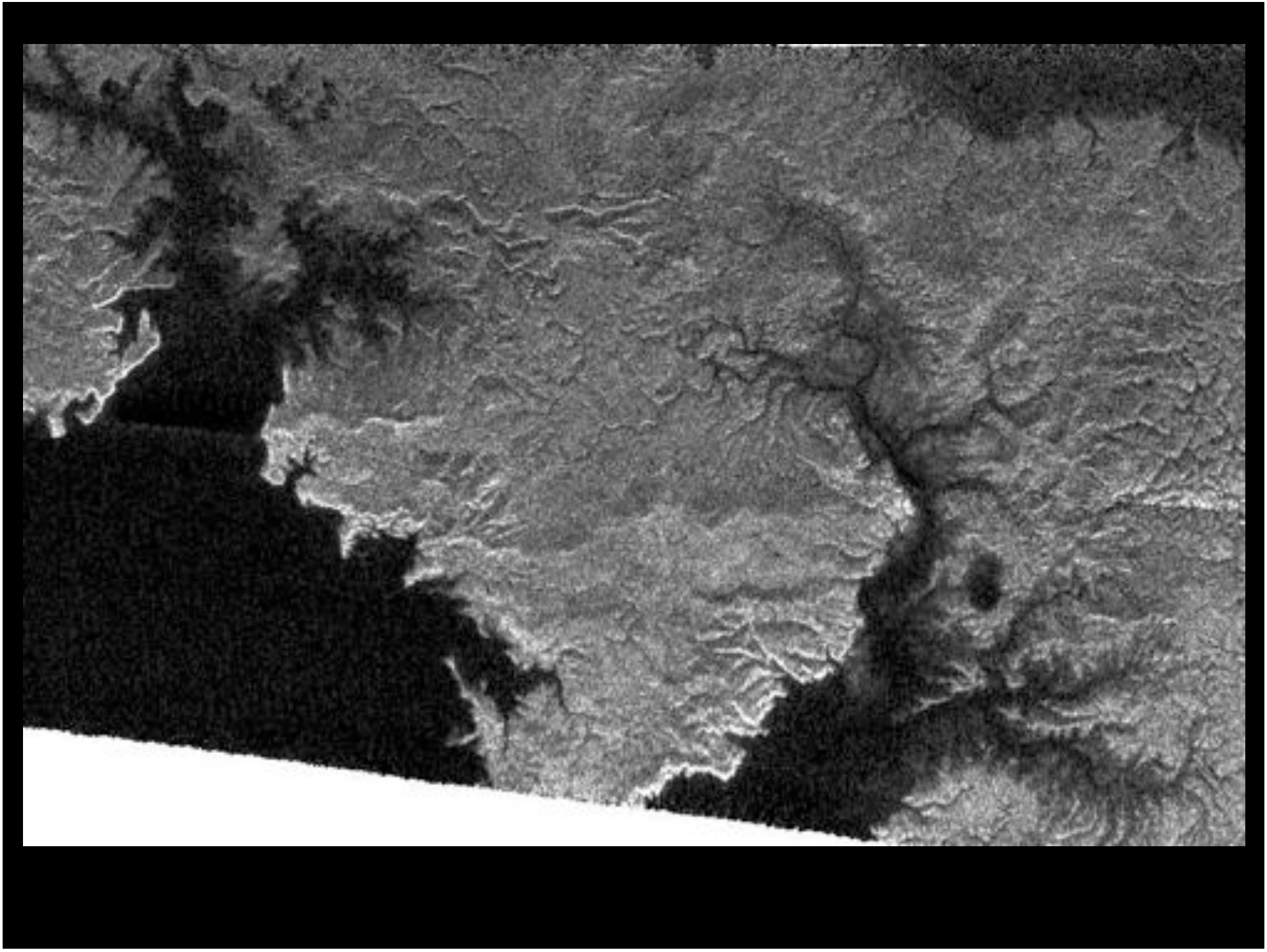


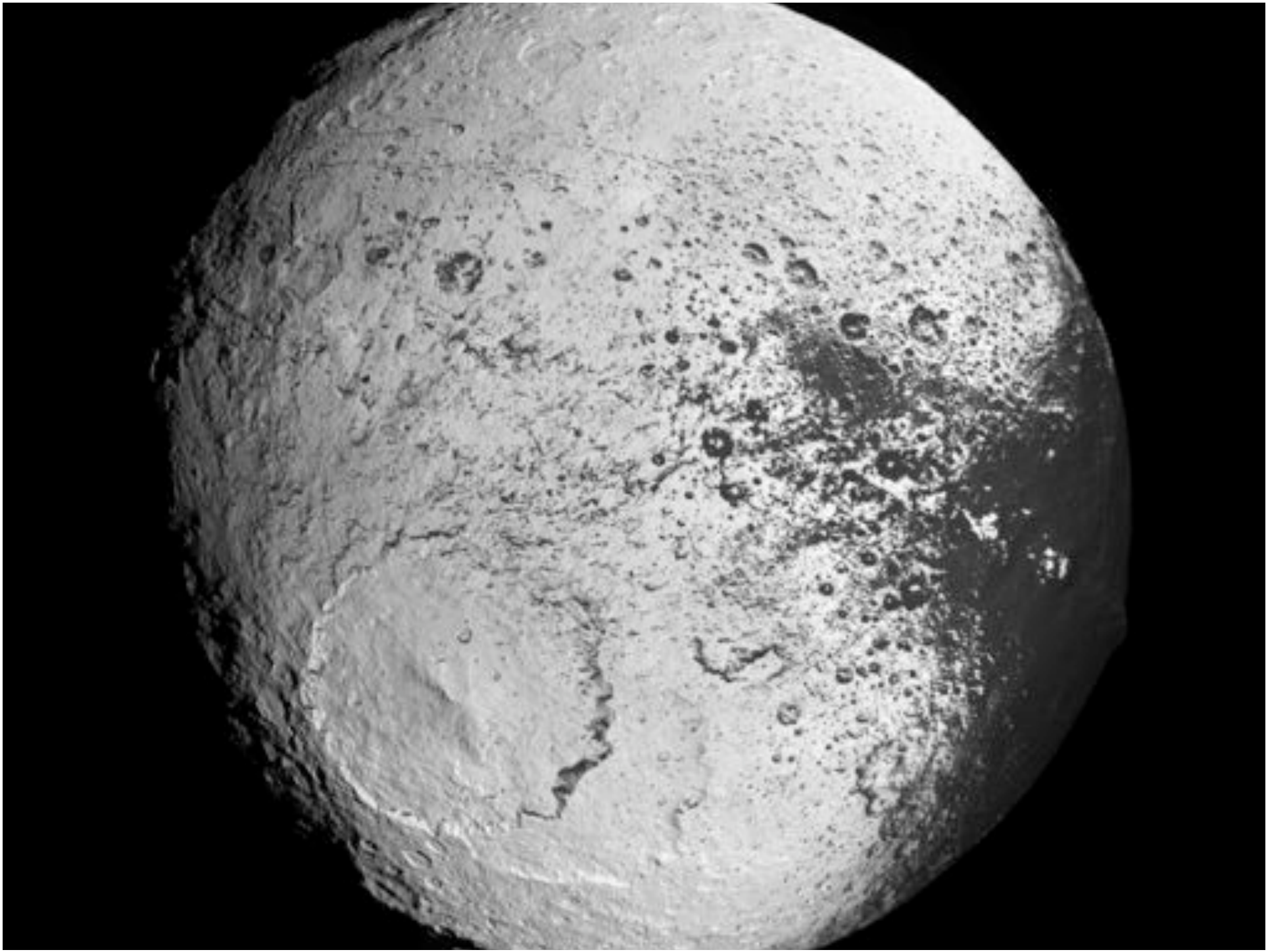


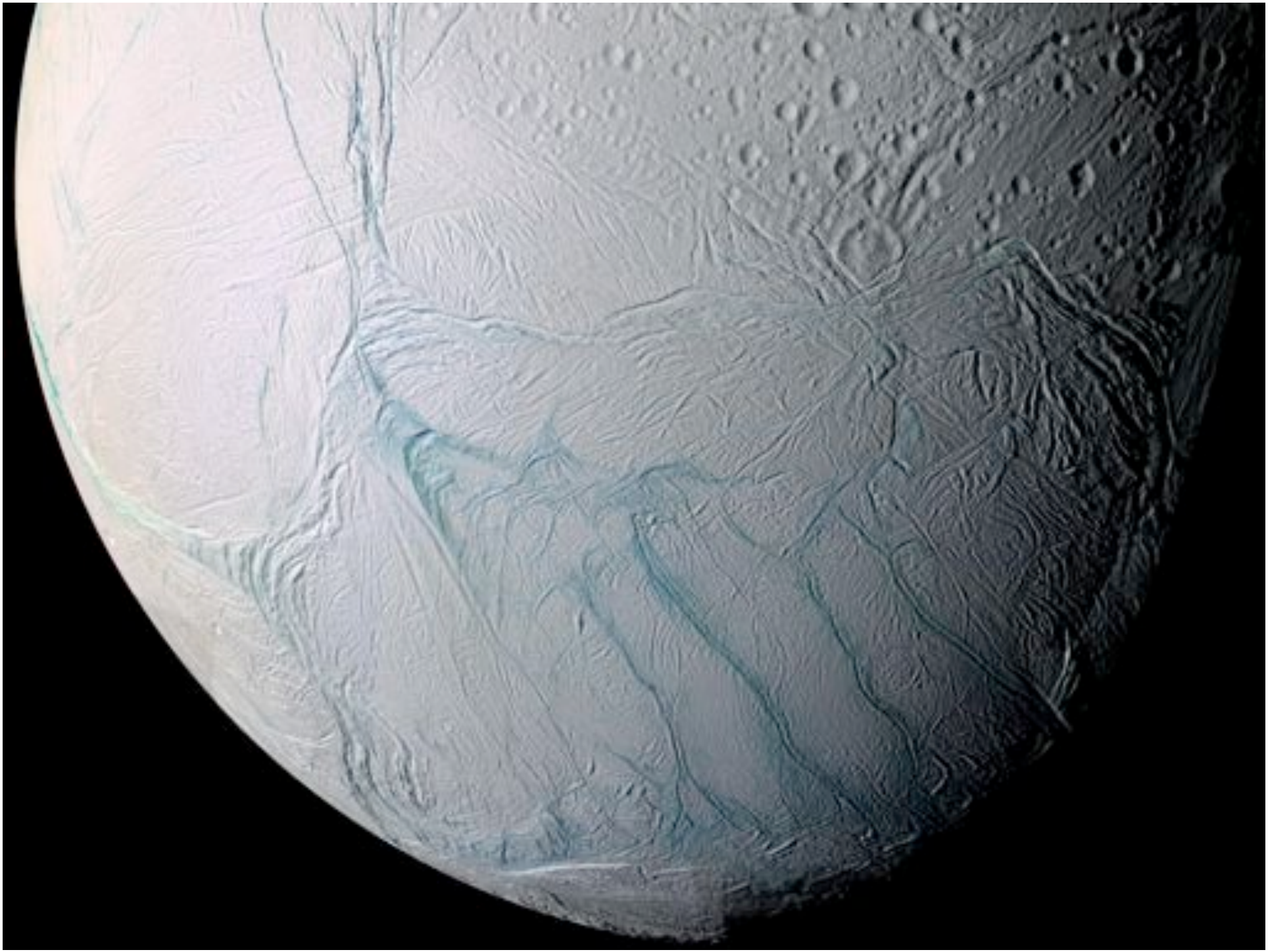


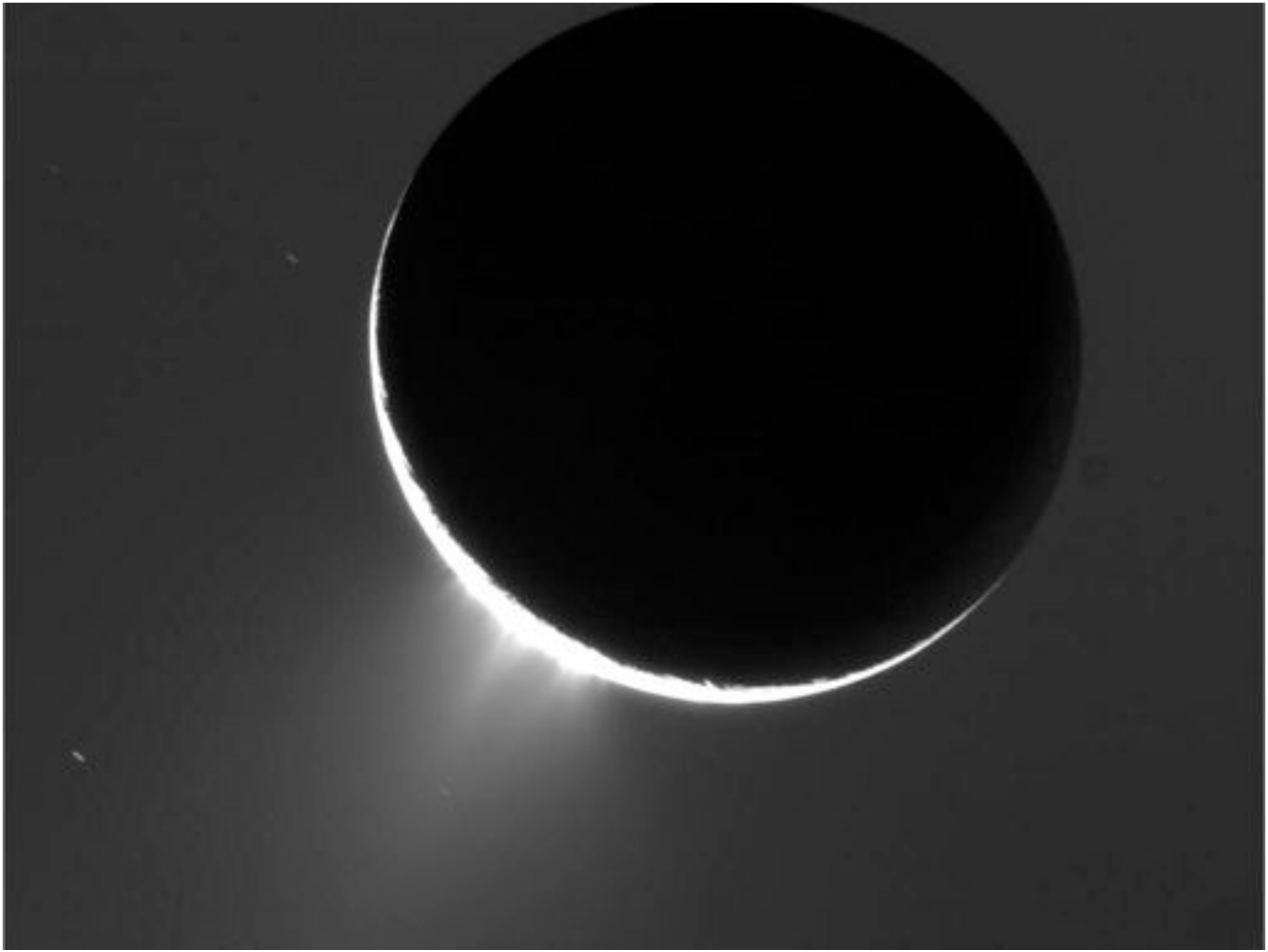




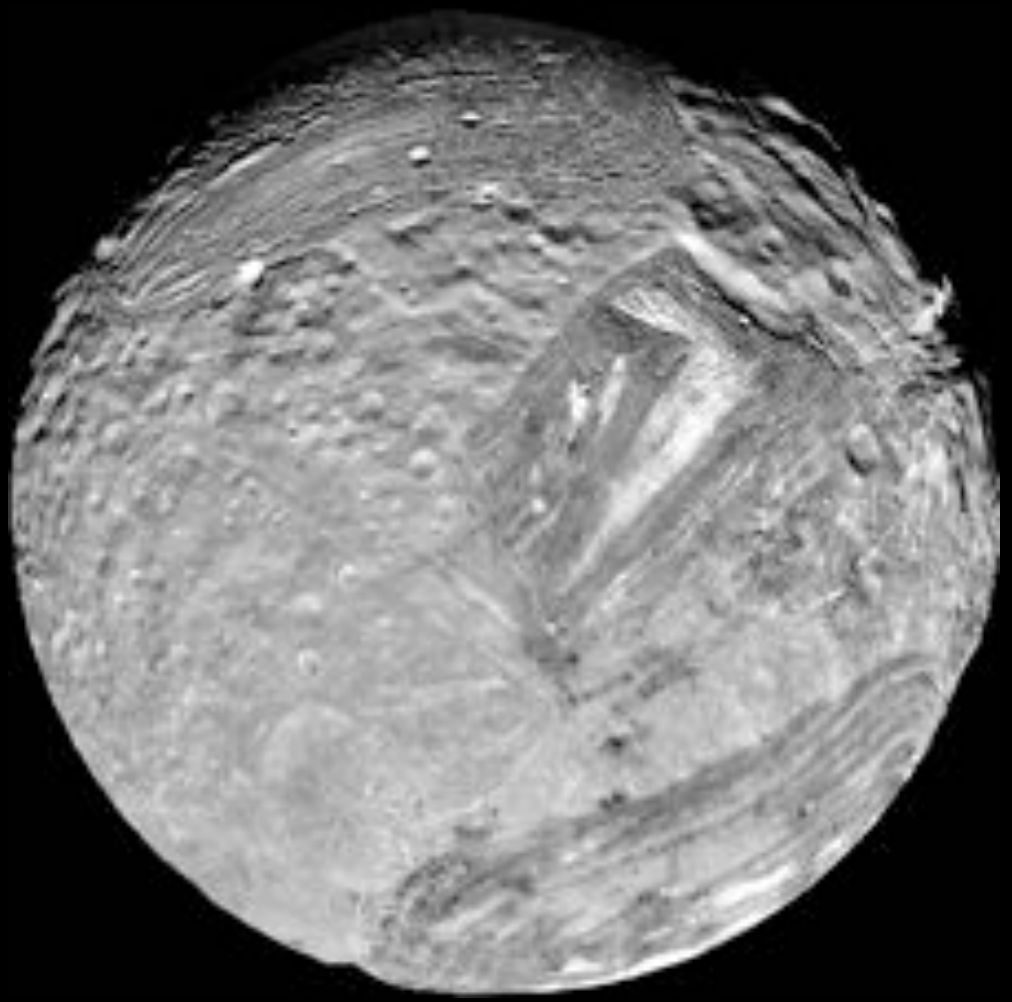


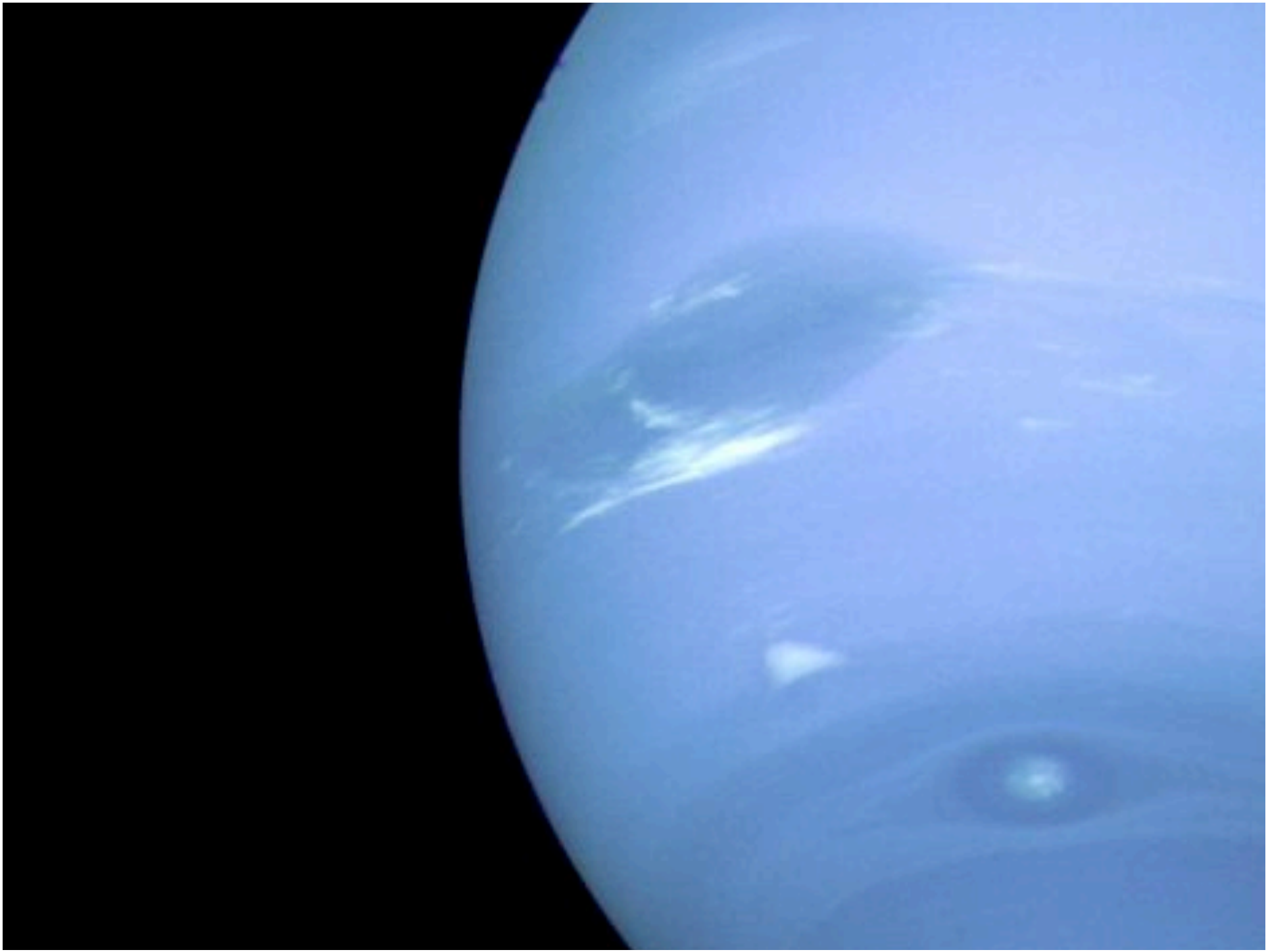


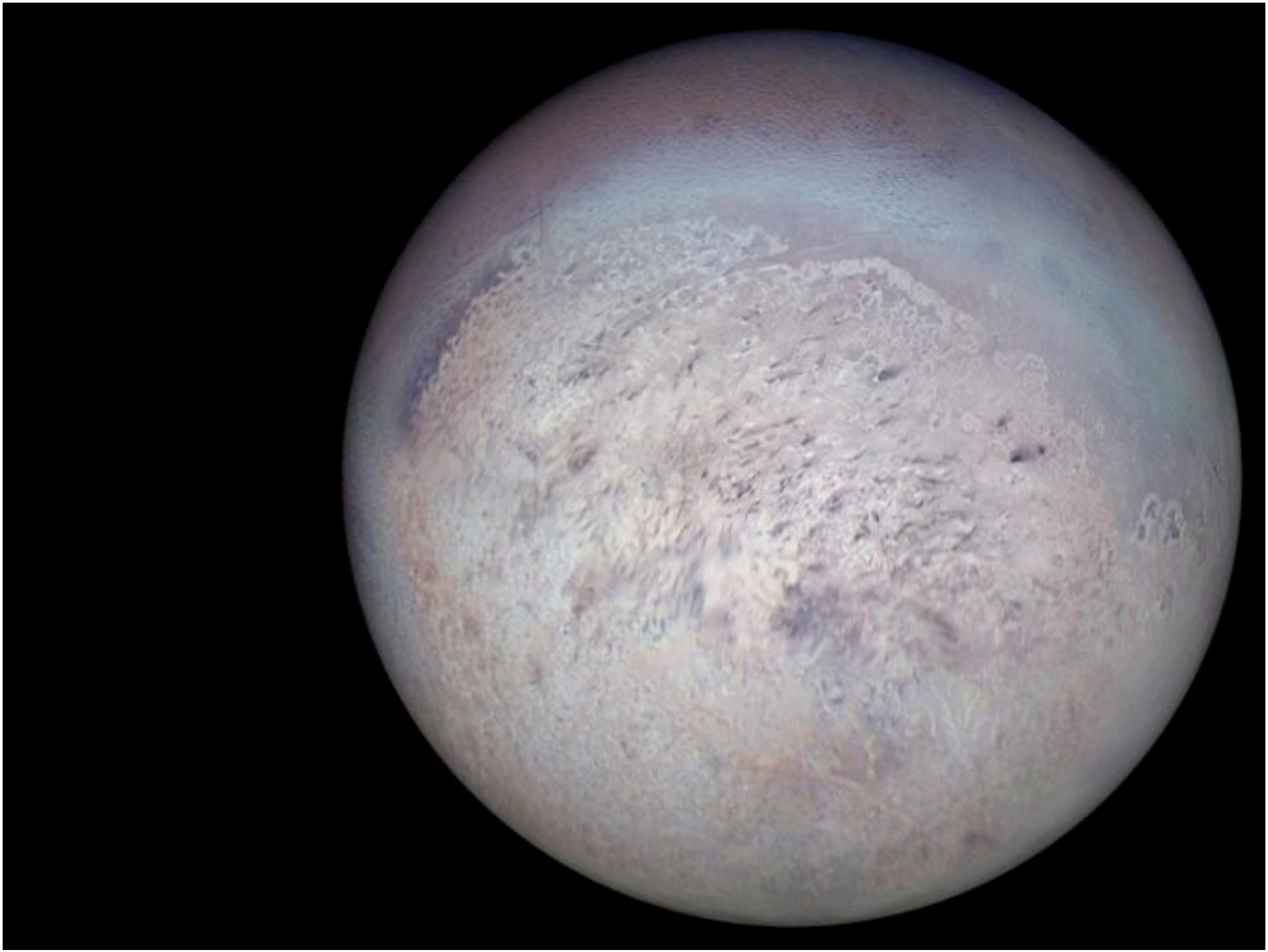


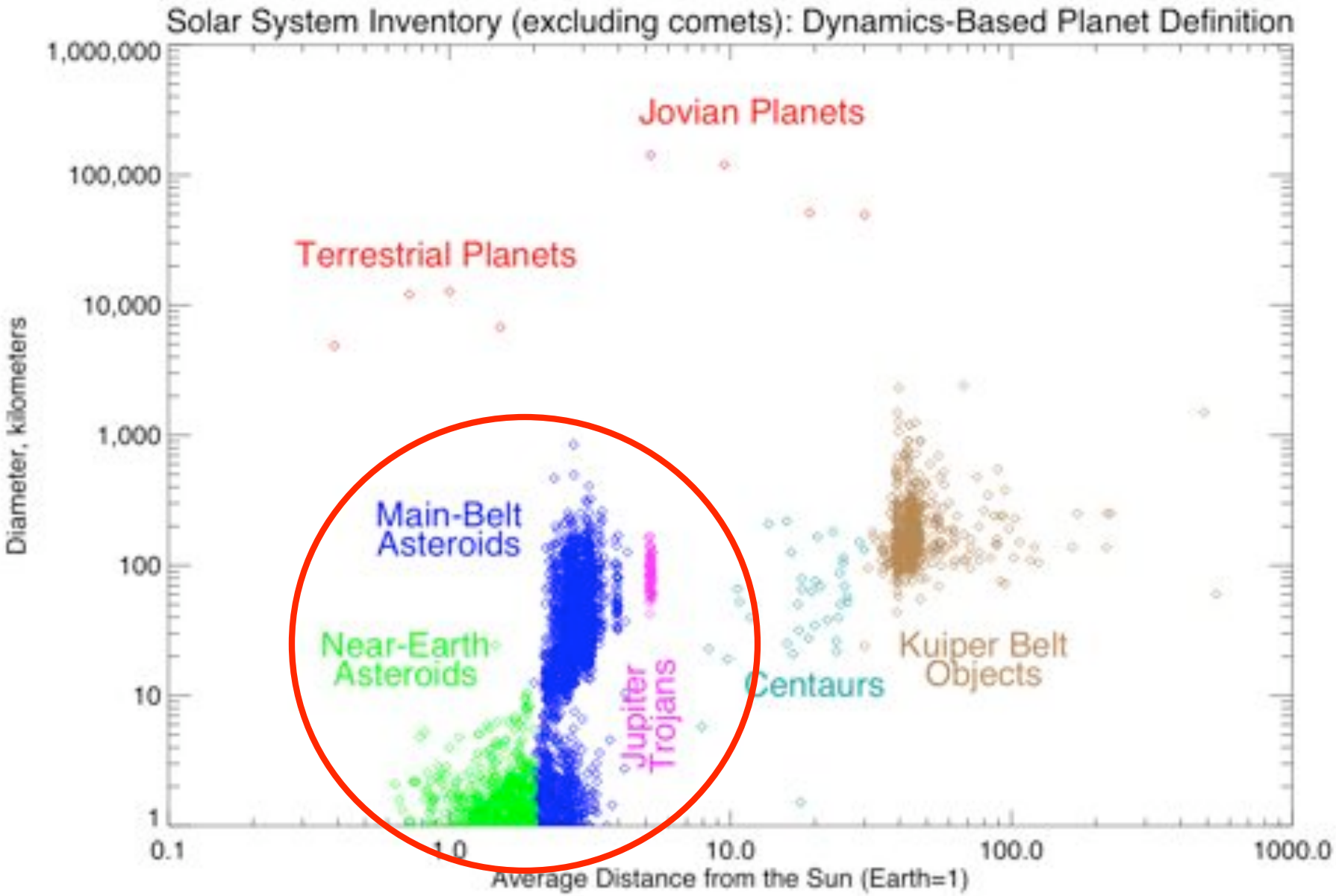


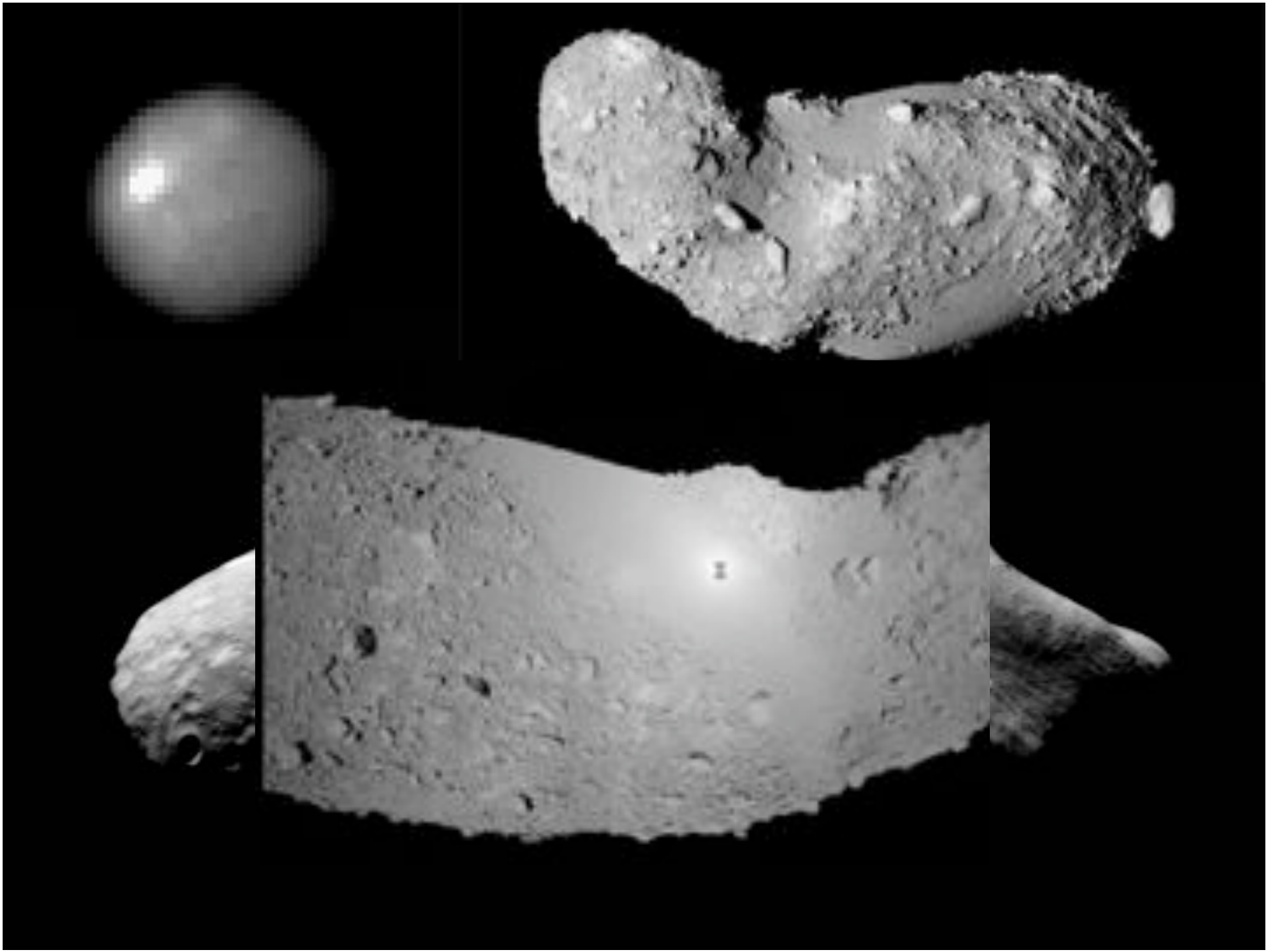
Uranus and Miranda

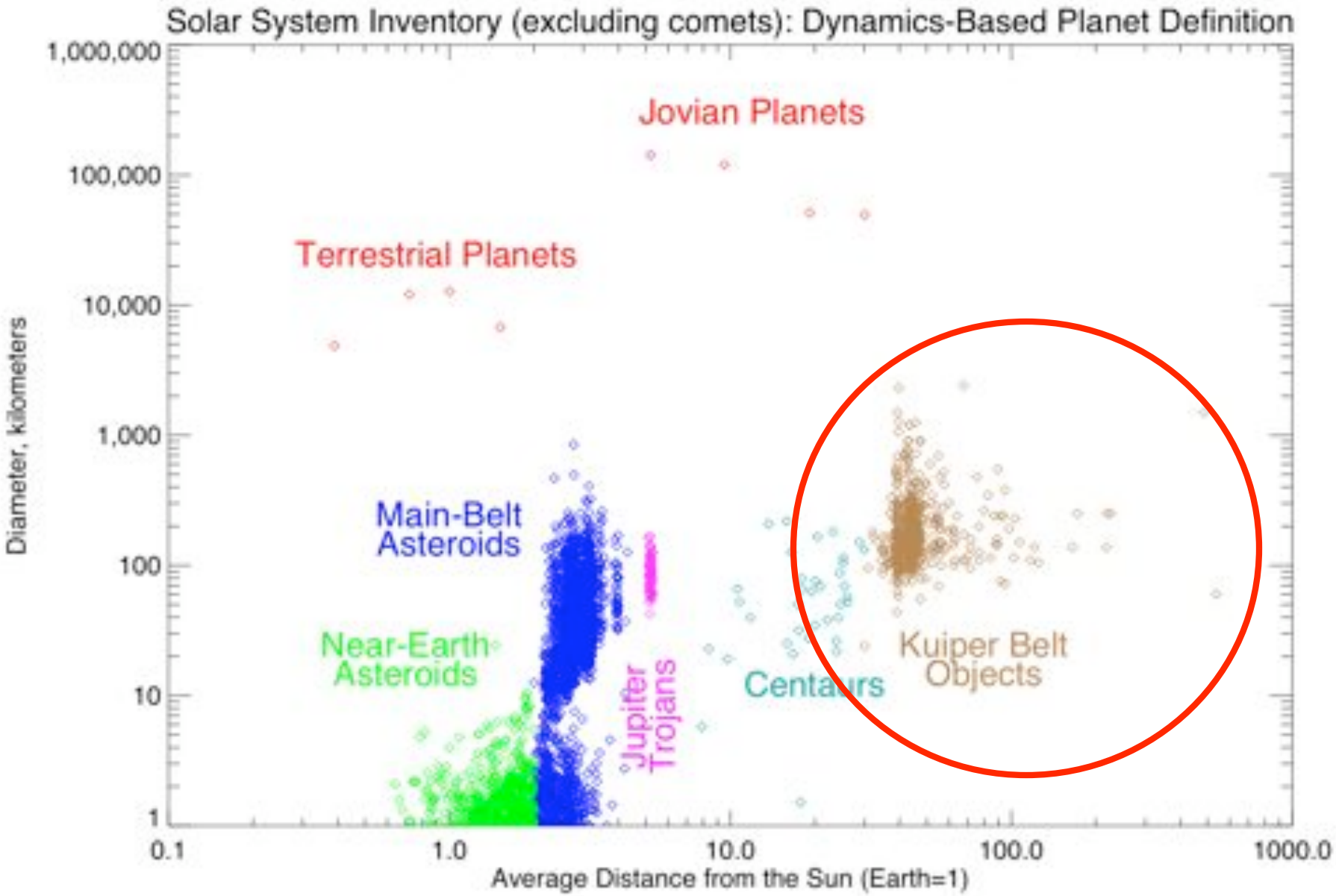







Solar System Inventory (excluding comets): Dynamics-Based Planet Definition
Diameter, kilometers
1,000,000
100,000
10,000
1,000
100
10
1
0.1
1.0
10.0
100.0
1000.0
Average Distance from the Sun (Earth=1)
Jovian Planets
Terrestrial Planets
Main-Belt Asteroids
Near-Earth Asteroids
Jupiter Trojans
Centaurs
Kuiper Belt Objects




Solar System Inventory (excluding comets): Dynamics-Based Planet Definition
Diameter, kilometers
1,000,000
100,000
10,000
1,000
100
10
1
0.1
1.0
10.0
100.0
1000.0
Average Distance from the Sun (Earth=1)
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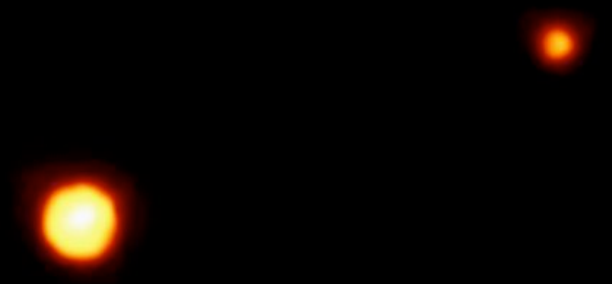

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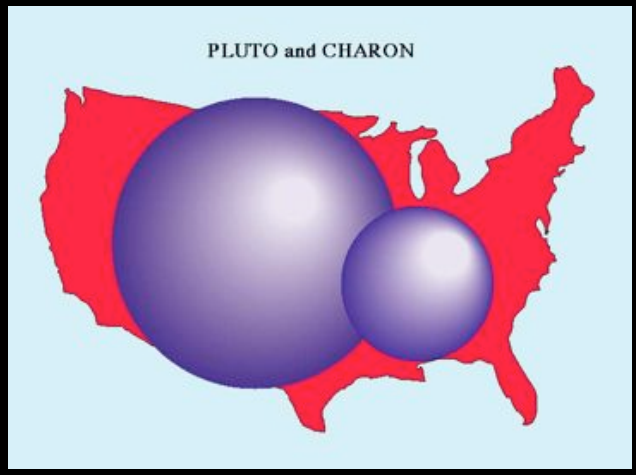
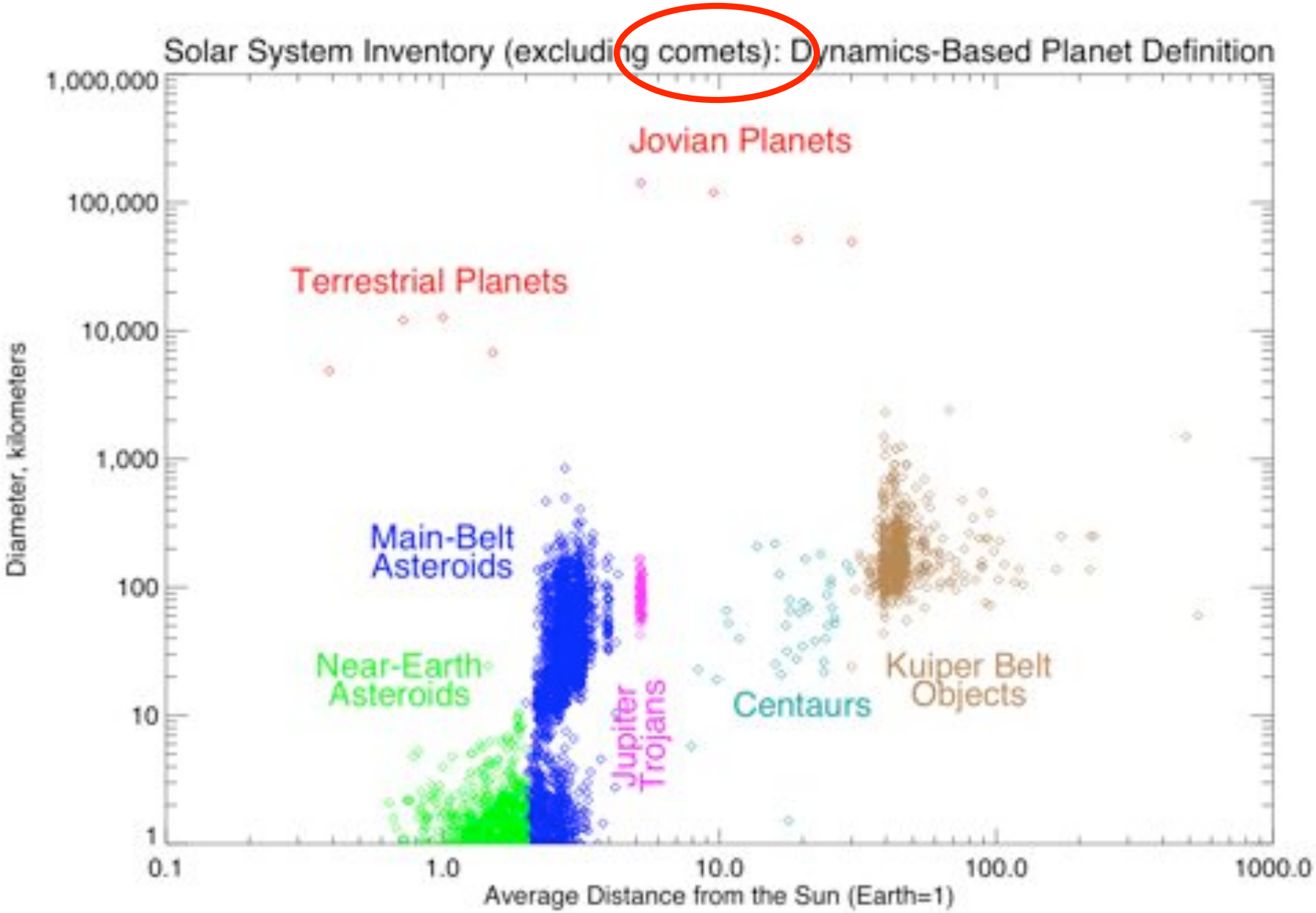

PLUTO and CHARON


Solar System Inventory (excluding comets): Dynamics-Based Planet Definition
Jovian Planets
Terrestrial Planets
Main-Belt Asteroids
Near-Earth Asteroids
Jupiter Trojans
Centaurs
Kuiper Belt Objects
Diameter, kilometers
1,000,000
100,000
10,000
1,000
100
10
1
0.1
1.0
10.0
100.0
1000.0
Average Distance from the Sun (Earth=1)