Observational Astronomy - Lecture 6
Solar System I - The Planets

Craig Lage

New York University - Department of Physics

craig.lage@nyu.edu

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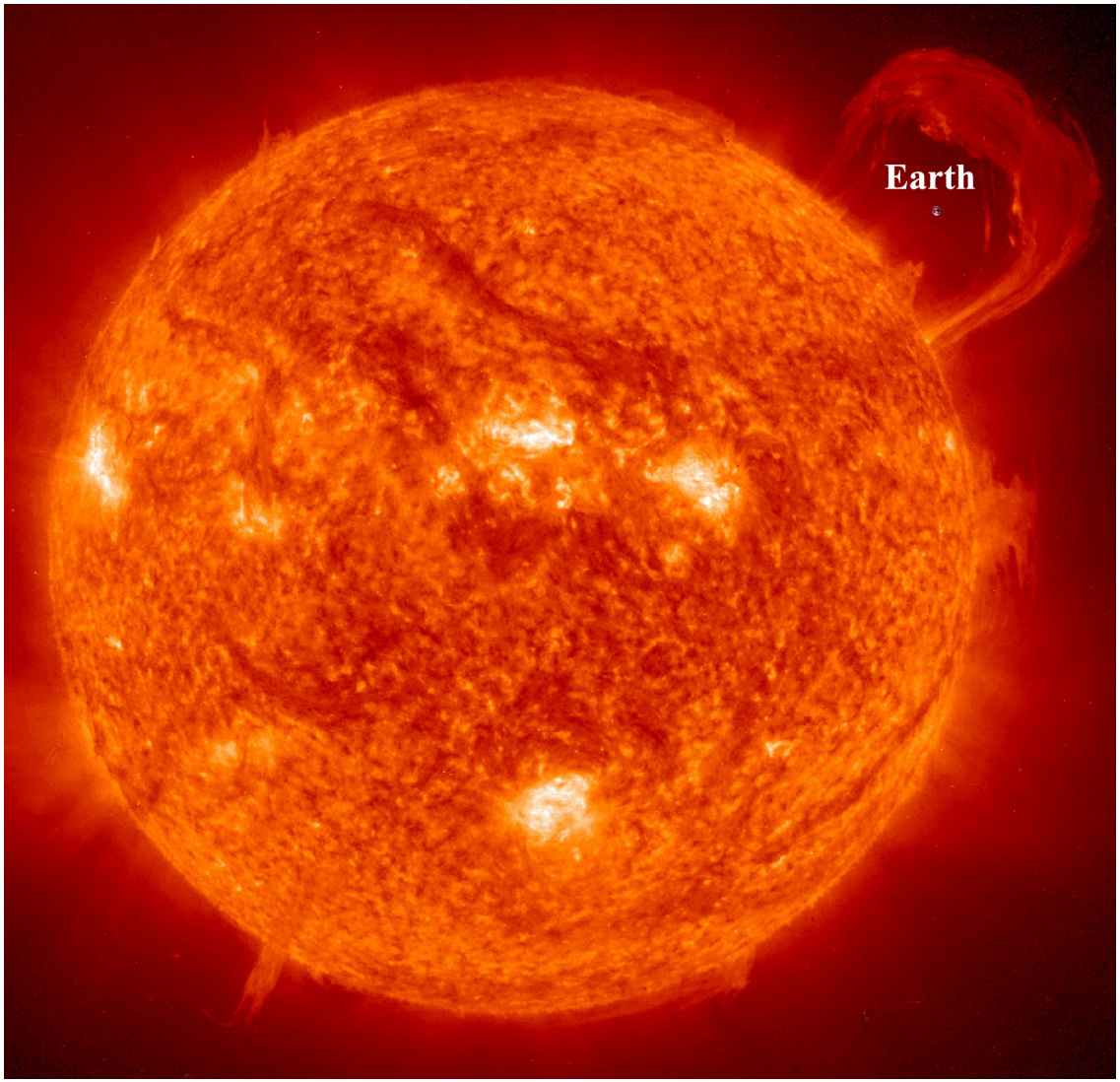
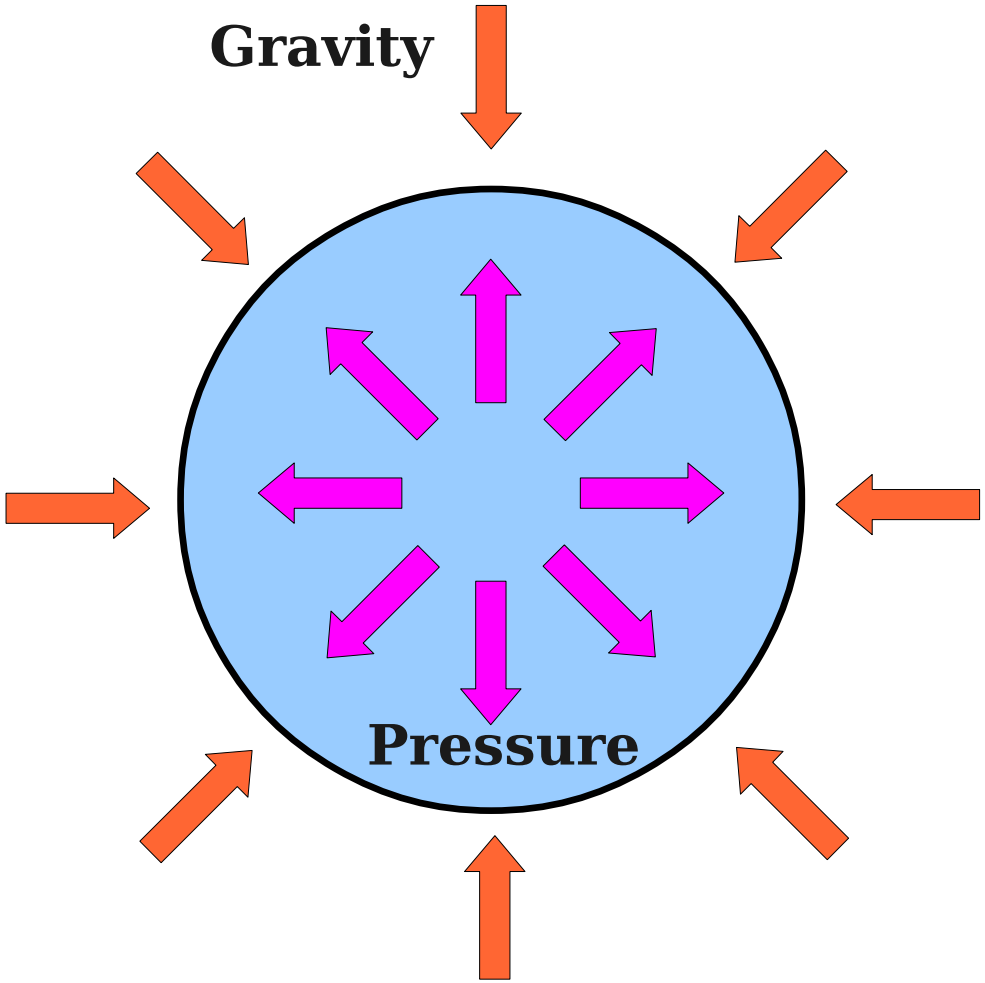
The Sun and the Earth



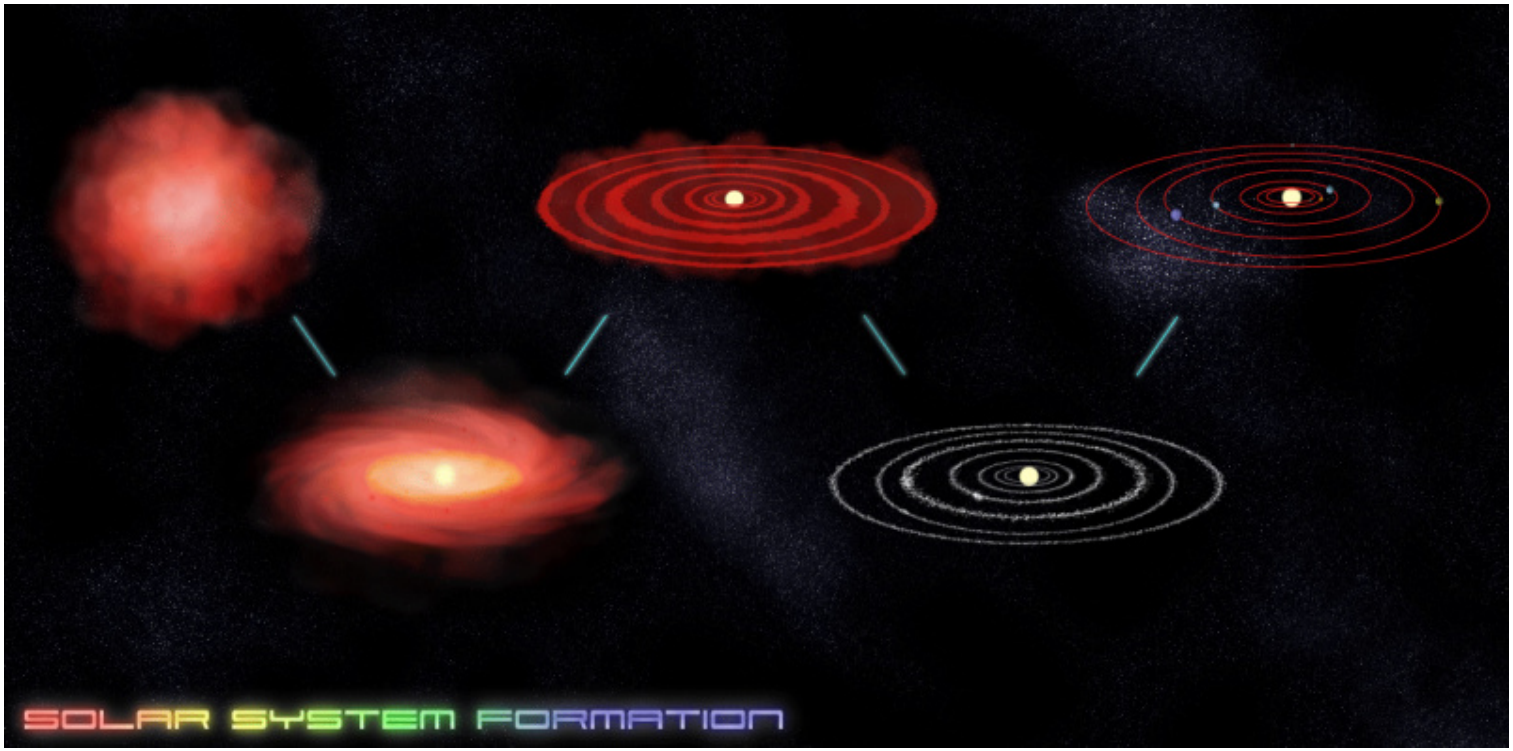
The Sun is 23,000 times larger in radius and 330 million times more massive than the Earth.

Hydrostatic Equilibrium



Planets and stars are in *Hydrostatic Equilibrium*, with the outward pressure balancing the inward pull of gravity.

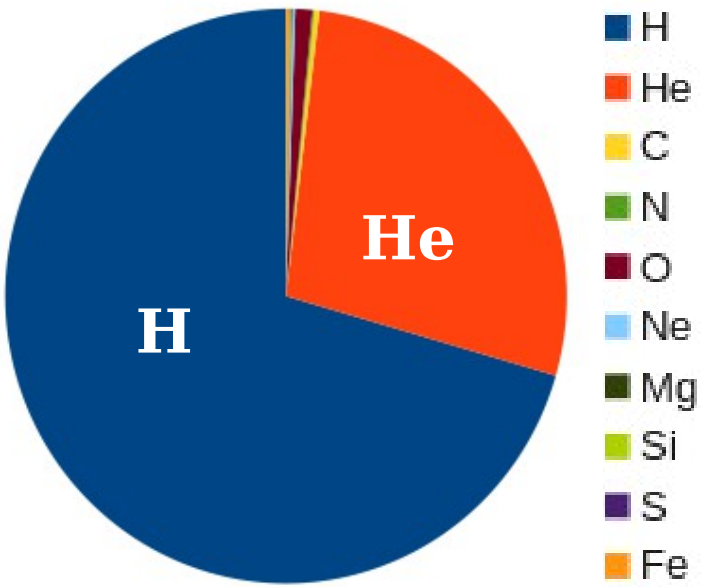
Solar System Formation



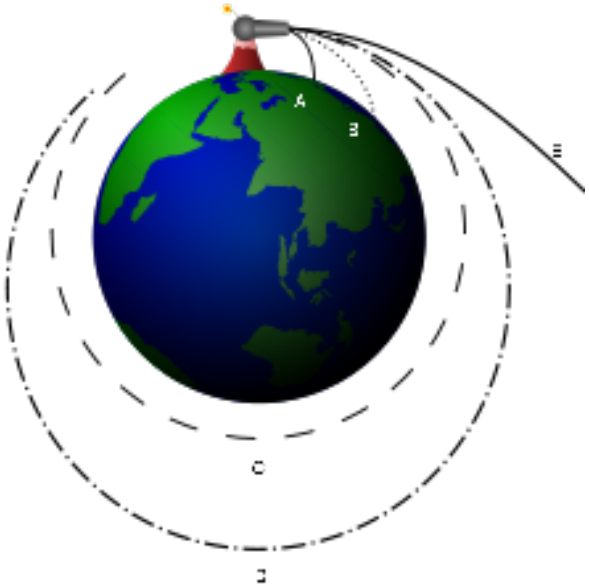
- Gravity pulls a cloud of gas into a spherical proto-star.
- Most of the matter collapses into the central star.
- Some of the remaining matter forms a proto-planetary disk.
- Matter in the disk clumps up into planetesimals, then into larger planets.
- Radiation pressure from the star "blows away" most of the remaining gas that has not coalesced into planets.

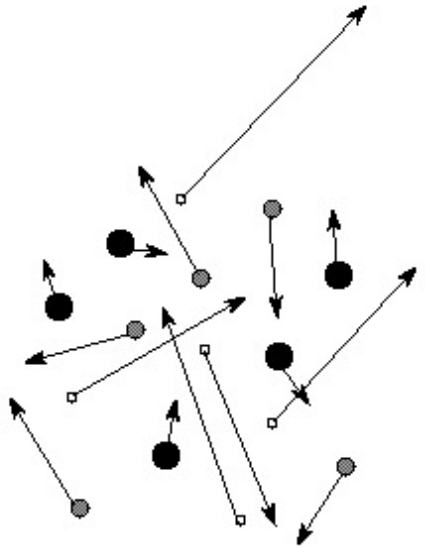
The Composition of the Solar Nebula

Element	Mass fraction
H	70.54%
He	27.56%
C	0.31%
N	0.11%
O	0.96%
Ne	0.17%
Mg	0.06%
Si	0.07%
S	0.04%
Fe	0.18%



Escape Velocity and Molecular Speeds





Higher Temperature:
- faster ***average*** speeds
- heavy gas molecules move slower than lighter gas molecules

$$V_{Escape} = \sqrt{\frac{2GM_{Planet}}{R}}$$

$$V_{Gas} \propto \sqrt{\frac{T}{m_{Gas}}}$$

Hotter gas molecules move faster
Heavier gas molecules move slower.

Gravity and Escape Velocity

Planet	Mass (Me)	Radius (Re)	Gravity (g)	Vescape (km/sec)	Temp (K)	VH2 (km/sec)	VHe (km/sec)	VO2 (km/sec)	VN2 (km/sec)	VCO2 (km/sec)
Mercury	0.055	0.38	0.38	4.4	600	22.3	15.8	5.6	6.0	4.8
Venus	0.82	0.95	0.91	10.4	500	20.3	14.4	5.1	5.4	4.3
Earth	1.00	1.00	1.00	11.2	350	17.0	12.0	4.3	4.5	3.6
Moon	0.012	0.27	0.16	2.4	350	17.0	12.0	4.3	4.5	3.6
Mars	0.11	0.53	0.38	5.1	250	14.4	10.2	3.6	3.8	3.1
Ceres	0.0002	0.076	0.03	0.51	200	12.9	9.1	3.2	3.4	2.7
Jupiter	317.7	11.21	2.53	59.6	165	11.7	8.3	2.9	3.1	2.5
Saturn	95.3	9.45	1.07	35.6	135	10.6	7.5	2.6	2.8	2.3
Titan	0.022	0.40	0.13	2.6	90	8.6	6.1	2.2	2.3	1.8

$$\text{Surface Gravity} \quad g = \frac{GM}{r^2}$$

$$\text{Escape Velocity} \quad v = \sqrt{\frac{2GM}{r}}$$

Example 1 - Mercury

Planet	Mass (Me)	Radius (Re)	Gravity (g)	Vescape (km/sec)	Temp (K)	VH2 (km/sec)	VHe (km/sec)	VO2 (km/sec)	VN2 (km/sec)	VCO2 (km/sec)
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Titan	0.022	0.40	0.13	2.6	90	8.6	6.1	2.2	2.3	1.8

Mercury's gravity is not enough to hold any gases, so it is an airless body.

Example 2 - Earth

Planet	Mass (Me)	Radius (Re)	Gravity (g)	Vescape (km/sec)	Temp (K)	VH2 (km/sec)	VHe (km/sec)	VO2 (km/sec)	VN2 (km/sec)	VCO2 (km/sec)
Mercury	0.055	0.38	0.38	4.4	600	22.3	15.8	5.6	6.0	4.8
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Titan	0.022	0.40	0.13	2.6	90	8.6	6.1	2.2	2.3	1.8

The Earth can hold heavier gases, but not Hydrogen and Helium.

Example 3 - Moon

Planet	Mass (Me)	Radius (Re)	Gravity (g)	Vescape (km/sec)	Temp (K)	VH2 (km/sec)	VHe (km/sec)	VO2 (km/sec)	VN2 (km/sec)	VCO2 (km/sec)
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Saturn	95.3	9.45	1.07	35.6	135	10.6	7.5	2.6	2.8	2.3
Titan	0.022	0.40	0.13	2.6	90	8.6	6.1	2.2	2.3	1.8

The moon's gravity is not enough to hold any gases, so it is an airless body.

Example 4 - Mars

Planet	Mass (Me)	Radius (Re)	Gravity (g)	Vescape (km/sec)	Temp (K)	VH2 (km/sec)	VHe (km/sec)	VO2 (km/sec)	VN2 (km/sec)	VCO2 (km/sec)
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Titan	0.022	0.40	0.13	2.6	90	8.6	6.1	2.2	2.3	1.8

Mars just manages to hold on to some heavier gases.

Example 5 - Jupiter

Planet	Mass (Me)	Radius (Re)	Gravity (g)	Vescape (km/sec)	Temp (K)	VH2 (km/sec)	VHe (km/sec)	VO2 (km/sec)	VN2 (km/sec)	VCO2 (km/sec)
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Saturn	95.3	9.45	1.07	35.6	135	10.6	7.5	2.6	2.8	2.3
Titan	0.022	0.40	0.13	2.6	90	8.6	6.1	2.2	2.3	1.8

Jupiter's gravity is enough to hold all gases.

Example 6 - Titan

Planet	Mass (Me)	Radius (Re)	Gravity (g)	Vescape (km/sec)	Temp (K)	VH2 (km/sec)	VHe (km/sec)	VO2 (km/sec)	VN2 (km/sec)	VCO2 (km/sec)
Mercury	0.055	0.38	0.38	4.4	600	22.3	15.8	5.6	6.0	4.8
Venus	0.82	0.95	0.91	10.4	500	20.3	14.4	5.1	5.4	4.3
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Mars	0.11	0.53	0.38	5.1	250	14.4	10.2	3.6	3.8	3.1
Ceres	0.0002	0.076	0.03	0.51	200	12.9	9.1	3.2	3.4	2.7
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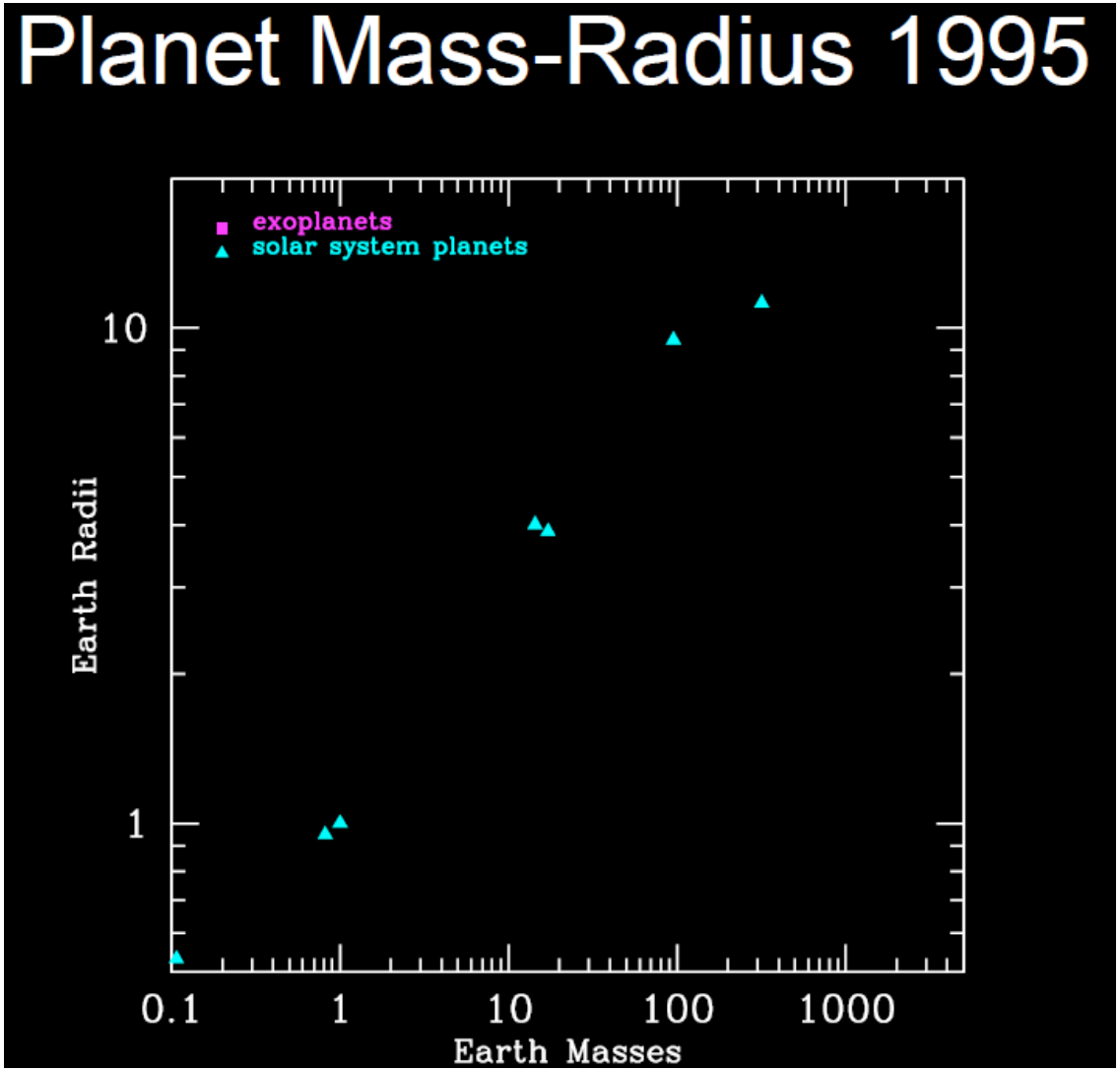
Titan	0.022	0.40	0.13	2.6	90	8.6	6.1	2.2	2.3	1.8

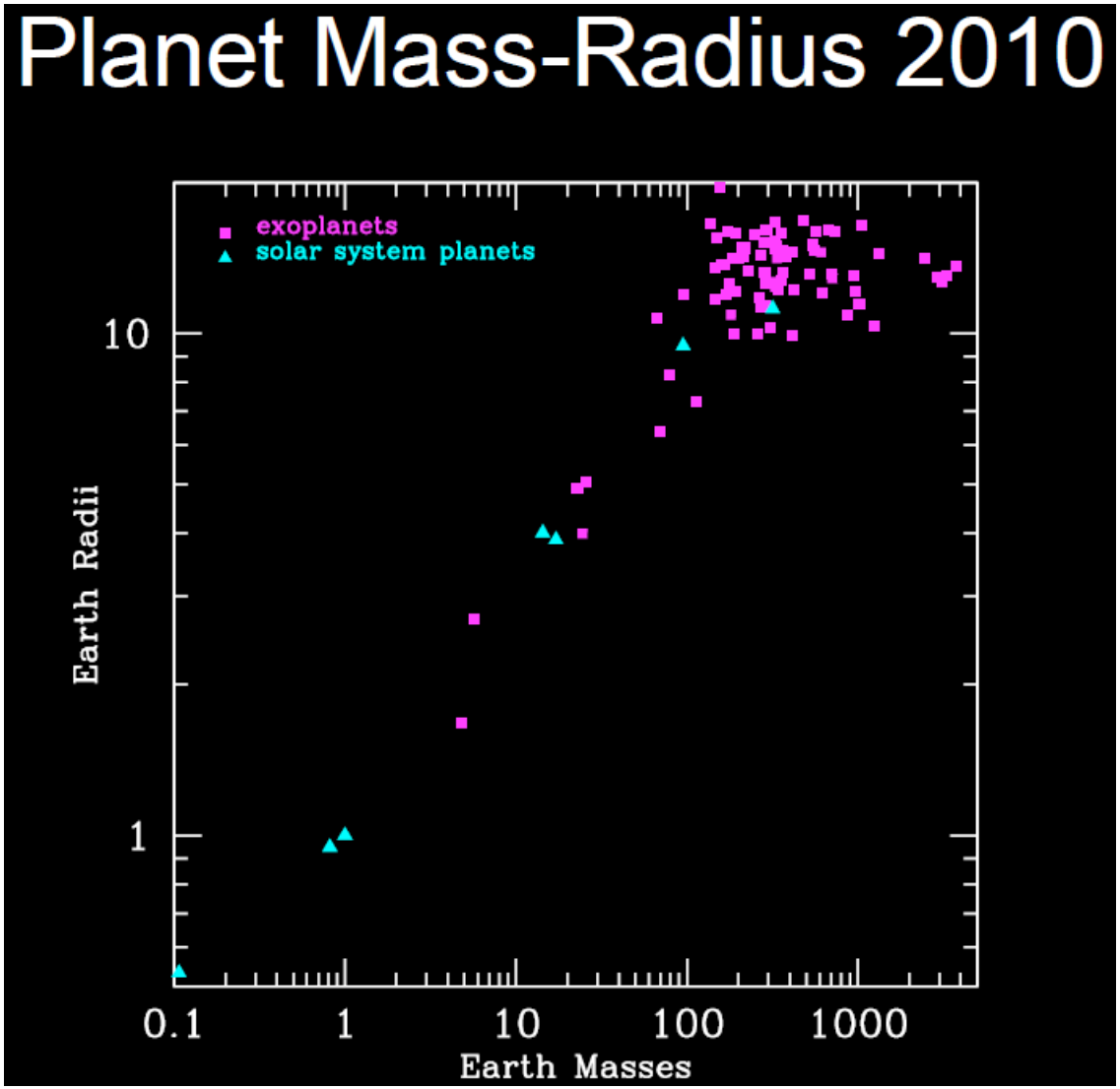
Even though Titan's gravity is weak, it has an atmosphere because it is so cold.

Mass vs Radius Relation - 1995



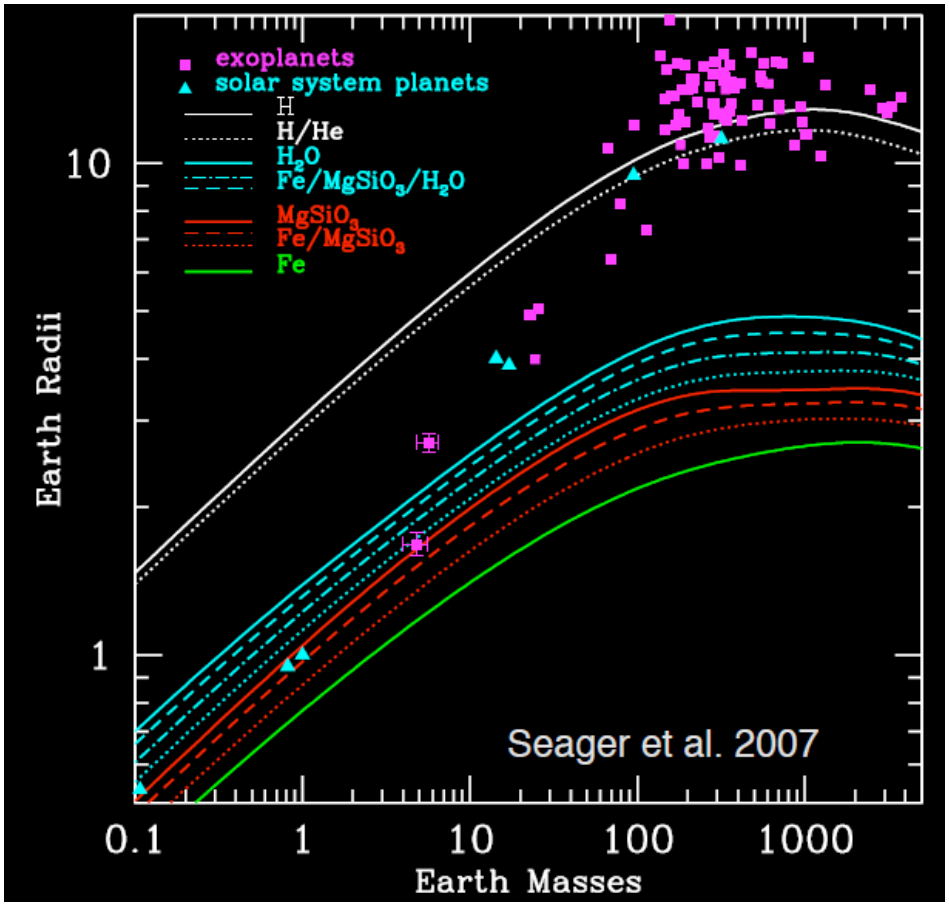
In 1995, only the Solar System planets were known.

Mass vs Radius Relation - 2010



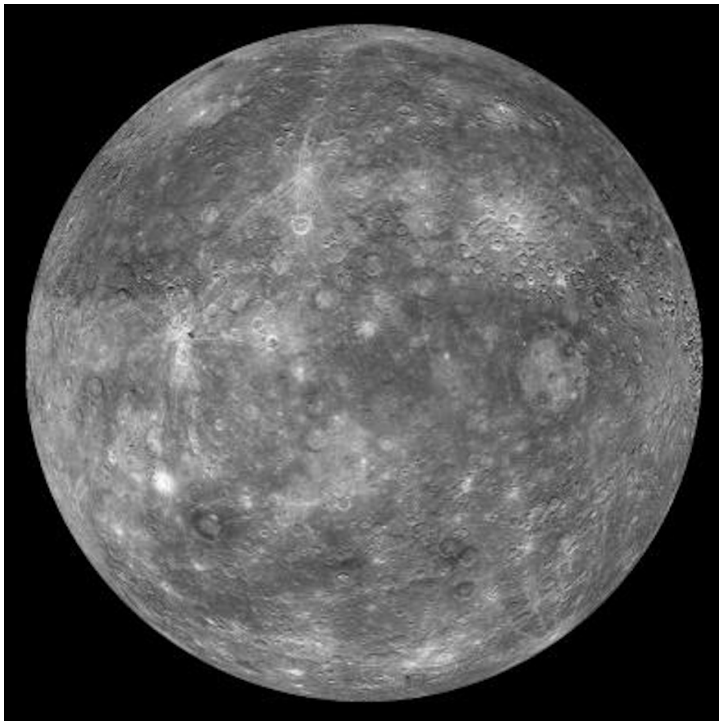
By 2010, we had added many planets around other stars.

Mass vs Radius Relation - Composition



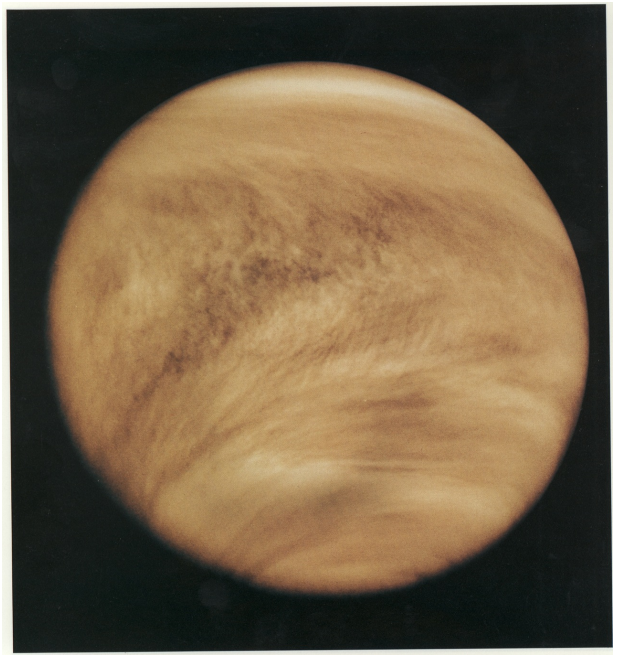
- Smaller planets (like Earth) are rocky.
- Larger planets (like Jupiter) are “gas giants”.
- Intermediate size (like Neptune) are often called “ice giants”.

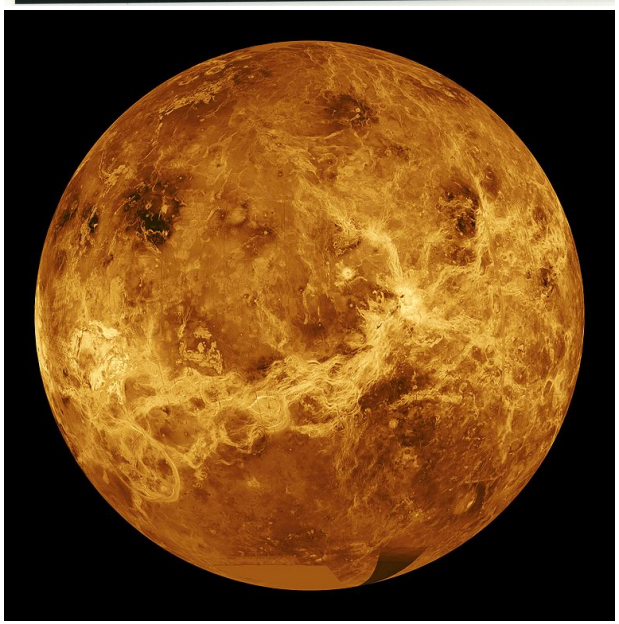
Mercury



Mass	3.3×10^{23} kg
Mass	0.055 $\mathrm{M}_{\oplus}$
Radius	2440 km
Radius	0.147 $\mathrm{R}_{\oplus}$
Gravity	0.38 g
SM axis	0.39 AU
Orbital Period	88.0 days
Rotation Period	58.6 days
Temperature	-190C to +430 C

Venus



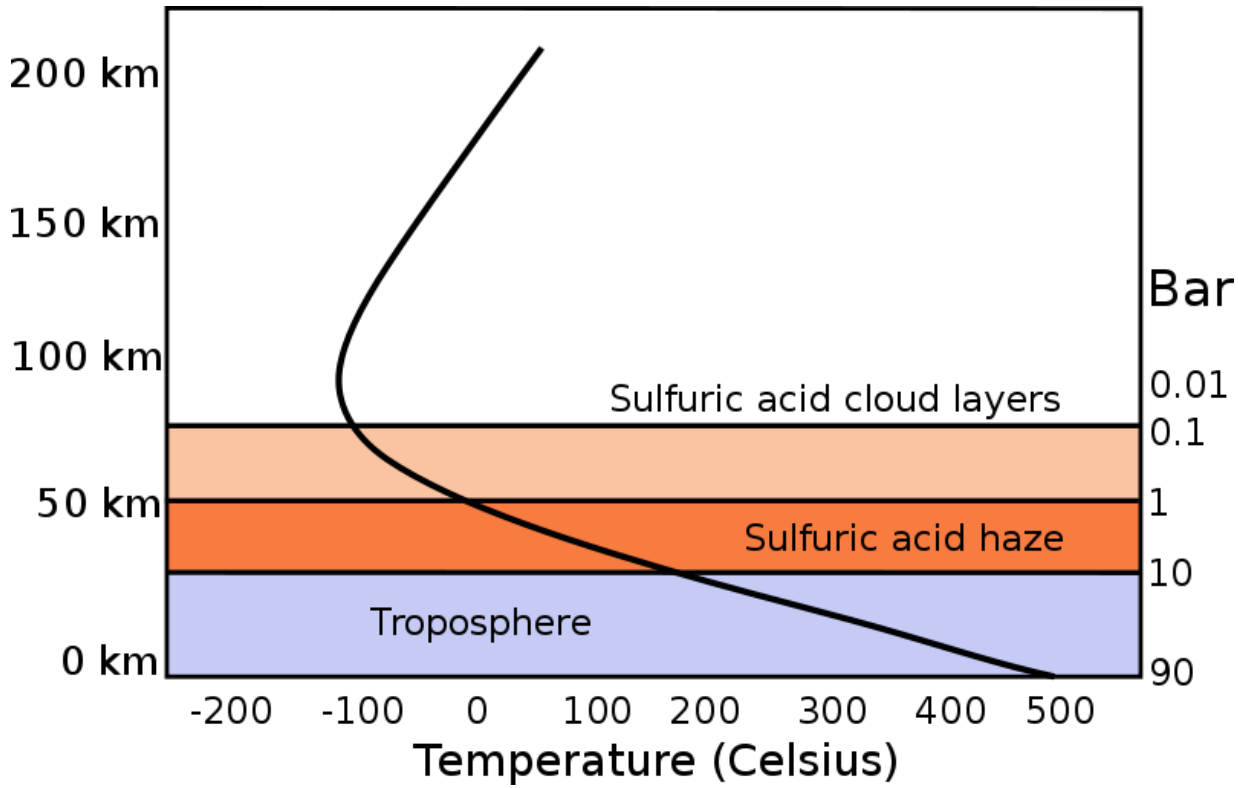


Mass	4.9×10^{24} kg
Mass	0.81 $\mathrm{M}_{\oplus}$
Radius	6052 km
Radius	0.95 $\mathrm{R}_{\oplus}$
Gravity	0.90 g
SM axis	0.72 AU
Orbital Period	224.7 days
Rotation Period	-243 days
Temperature	+460 C

The Surface of Venus

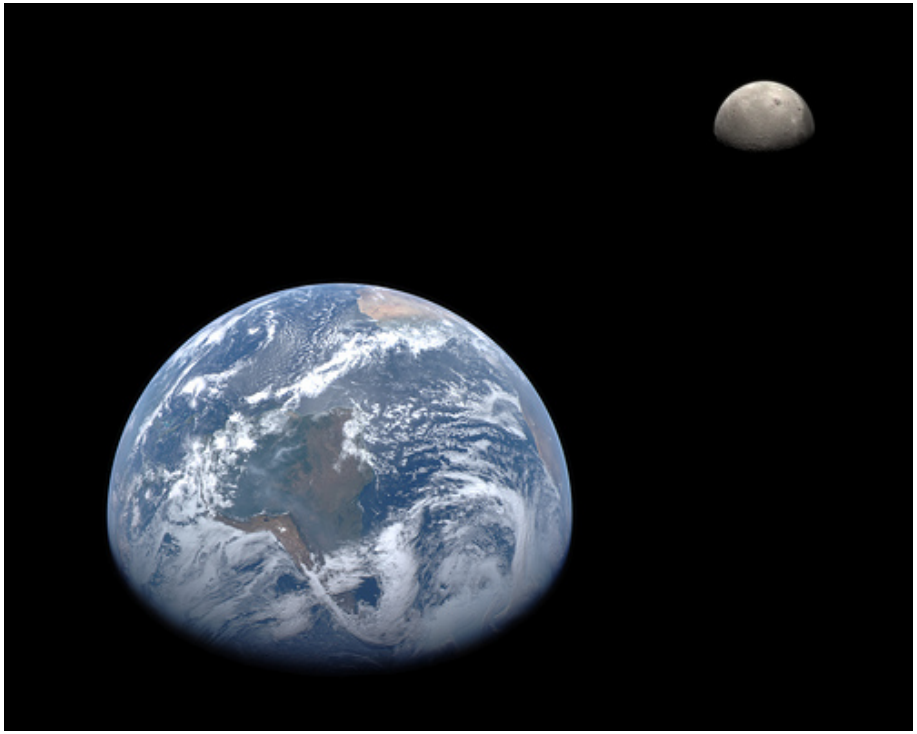
Taken from the Soviet Venera 13 spacecraft in 1982.
The spacecraft survived on the surface for 2 hours.

Colonizing Venus



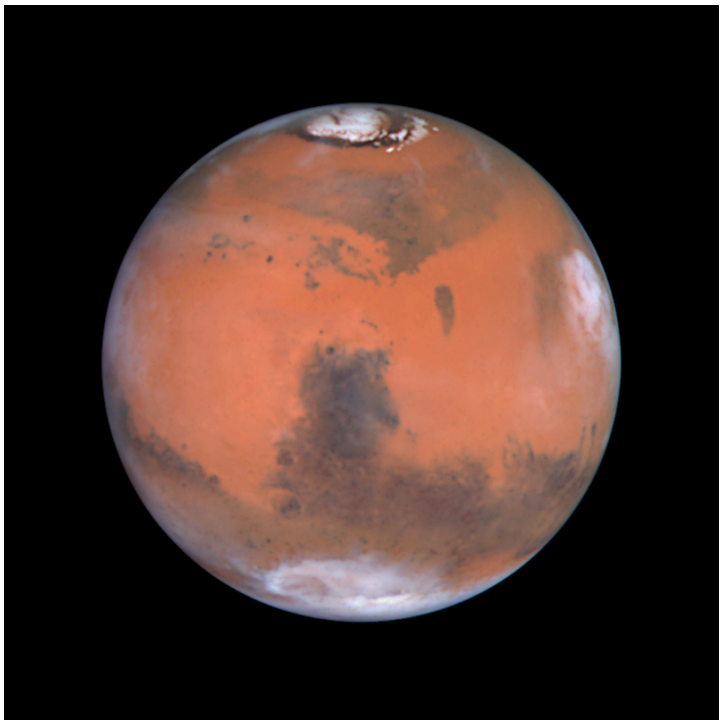
While Venus seems inhospitable at first glance, Geoffrey Landis of NASA has pointed out that at an altitude of 50 km, the temperature, pressure and gravity are all near Earth normal. Floating cities in the atmosphere of Venus have been proposed.

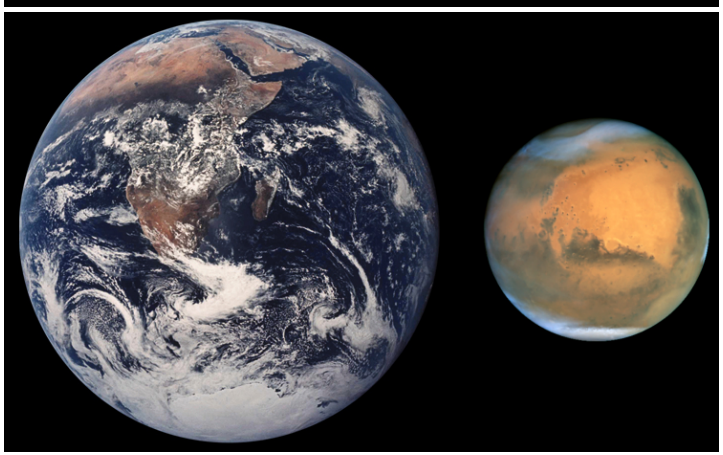
Earth



Mass	6.0×10^{24} kg
Mass	1.00 $\mathrm{M}_{\oplus}$
Radius	6378 km
Radius	1.00 $\mathrm{R}_{\oplus}$
Gravity	1.00 g
SM axis	1.00 AU
Orbital Period	365.25 days
Rotation Period	$23^{\mathrm{h}}56^{\mathrm{m}}$
Temperature	15 C

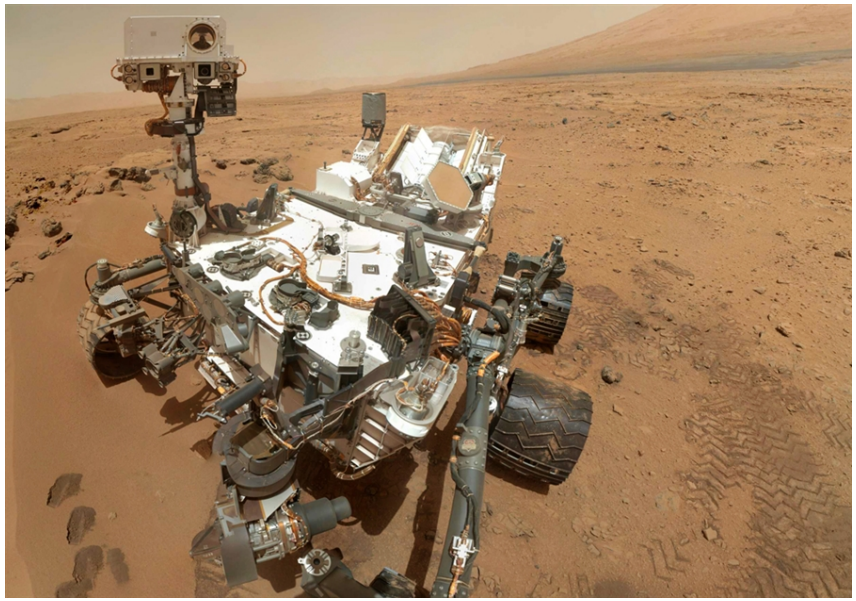
Mars

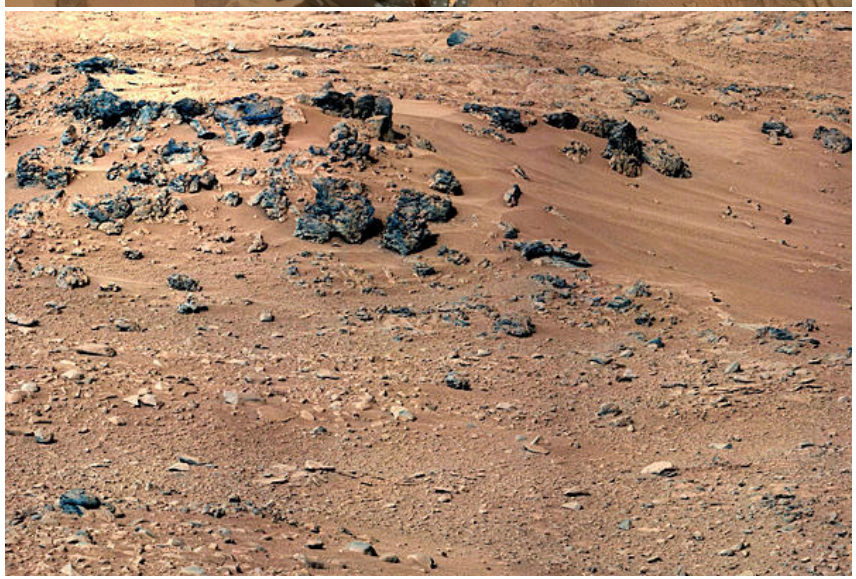




Mass	6.4×10^{23} kg
Mass	0.11 $\mathrm{M}_{\oplus}$
Radius	3396 km
Radius	0.53 $\mathrm{R}_{\oplus}$
Gravity	0.38 g
SM axis	1.52 AU
Orbital Period	1.88 years
Rotation Period	$24^{\mathrm{h}}37^{\mathrm{m}}$
Temperature	-60C

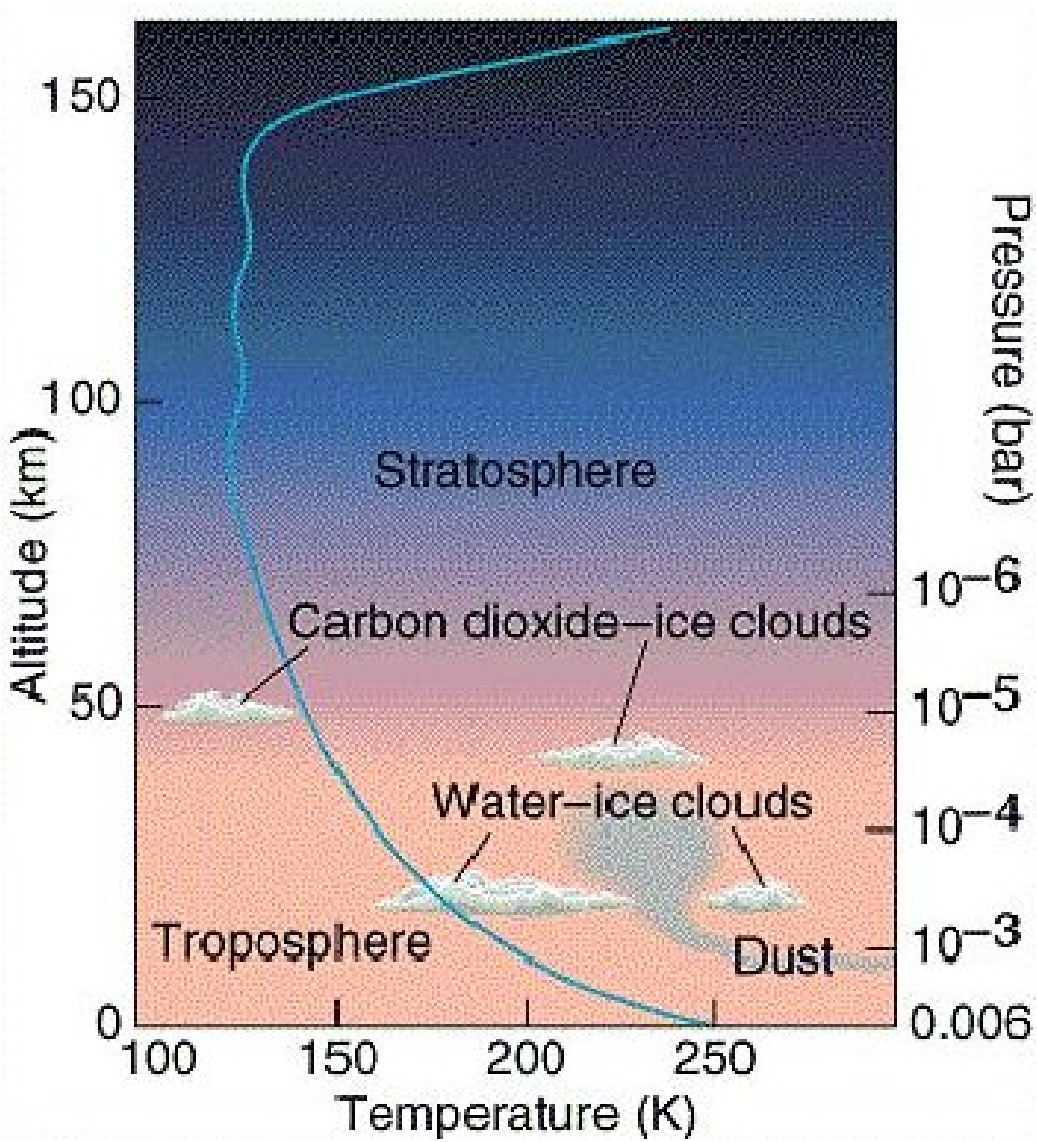
The Surface of Mars





Taken from the Curiosity rover.

Mars Atmosphere

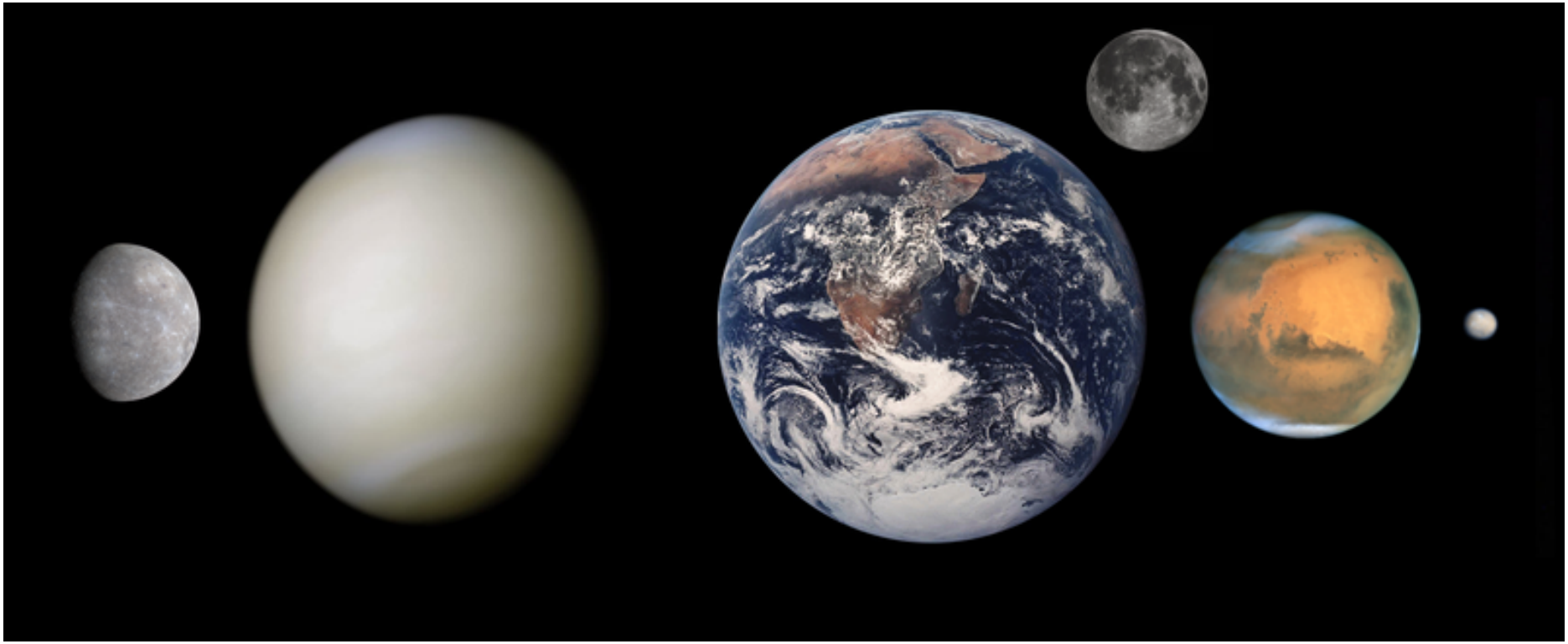


The atmospheric pressure on Mars is less than 1% of that of the Earth.

Colonizing Mars

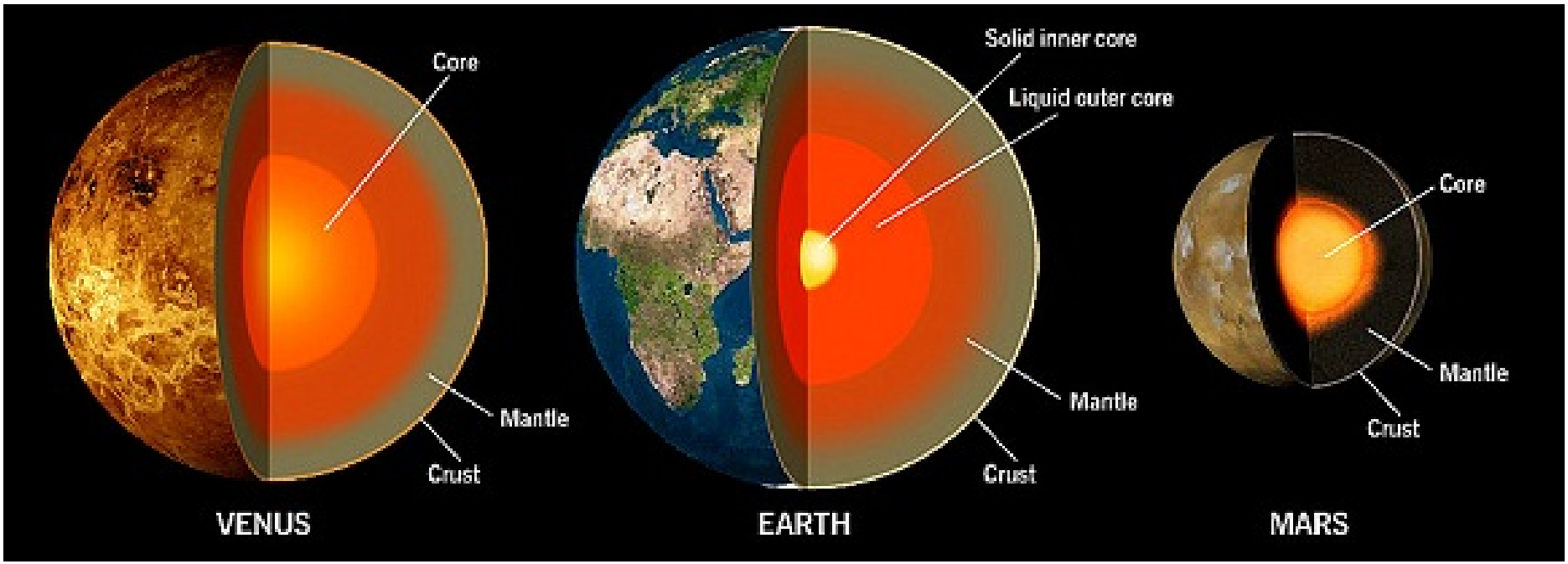
Artist's conception of proposed Mars One colony.

Rocky Planets Compared



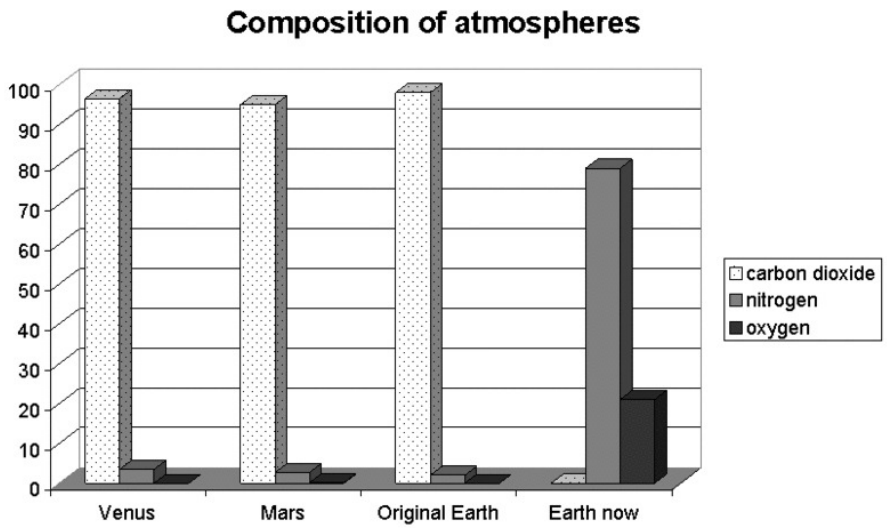
Mercury, Venus, Earth, Moon, Mars, Ceres

Rocky Planet Interiors

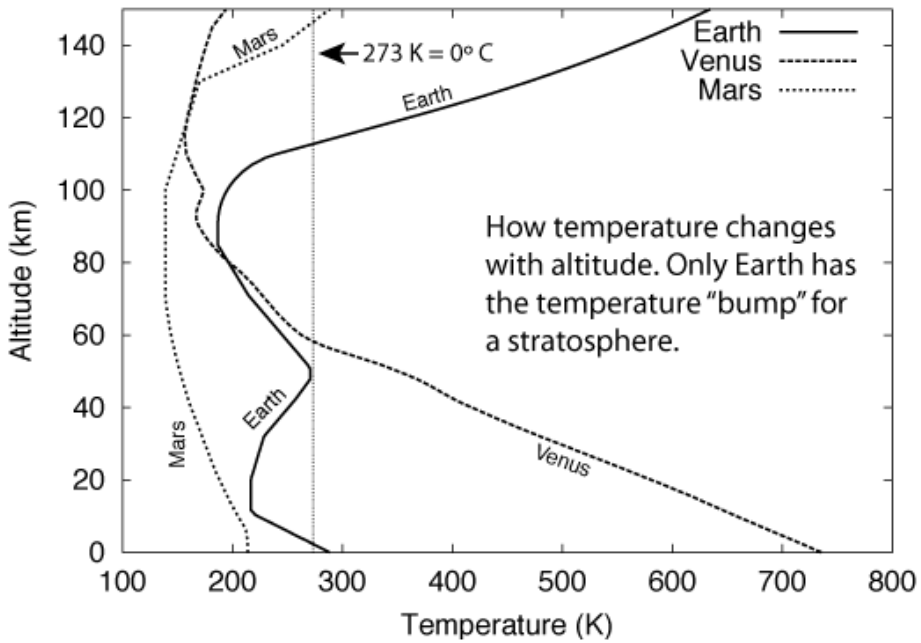


Possible structure of the Terrestrial Planets.

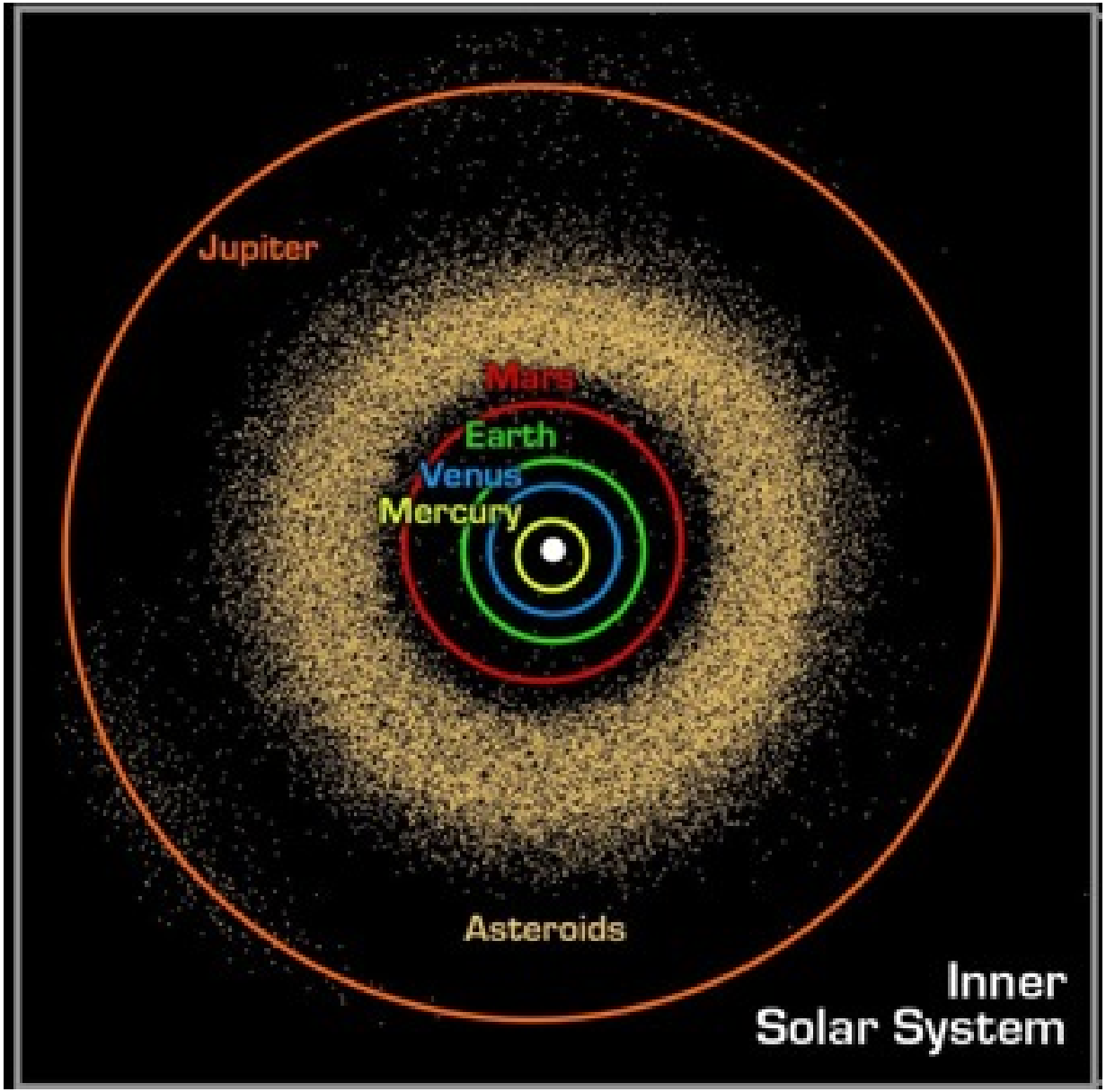
Terrestrial Planet Atmospheres



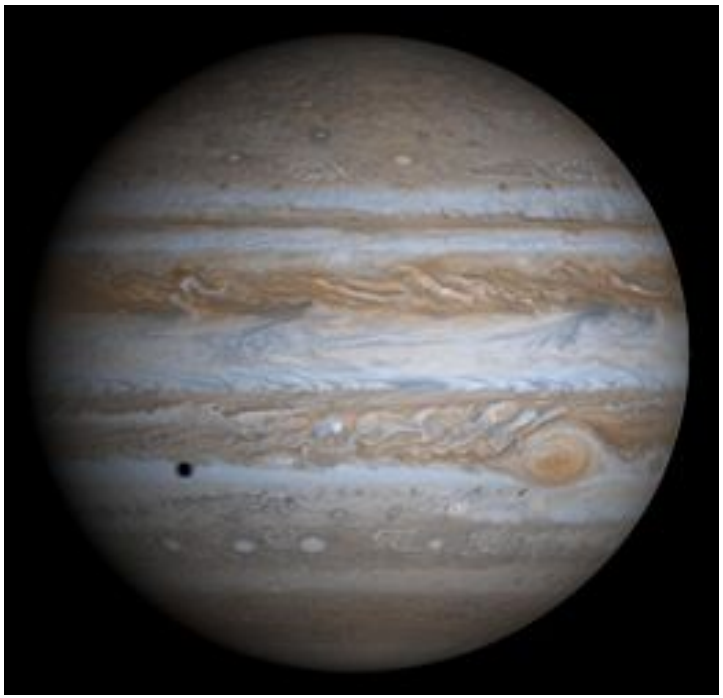
Life has dramatically changed the composition of Earth's atmosphere.

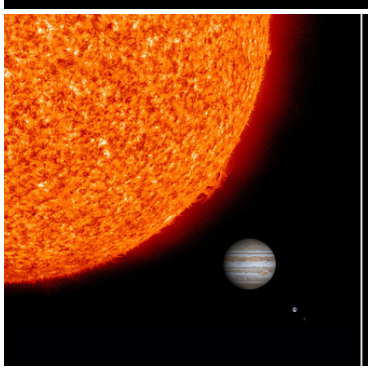


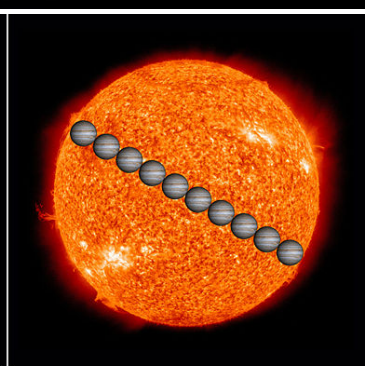
The Inner Solar System



Jupiter

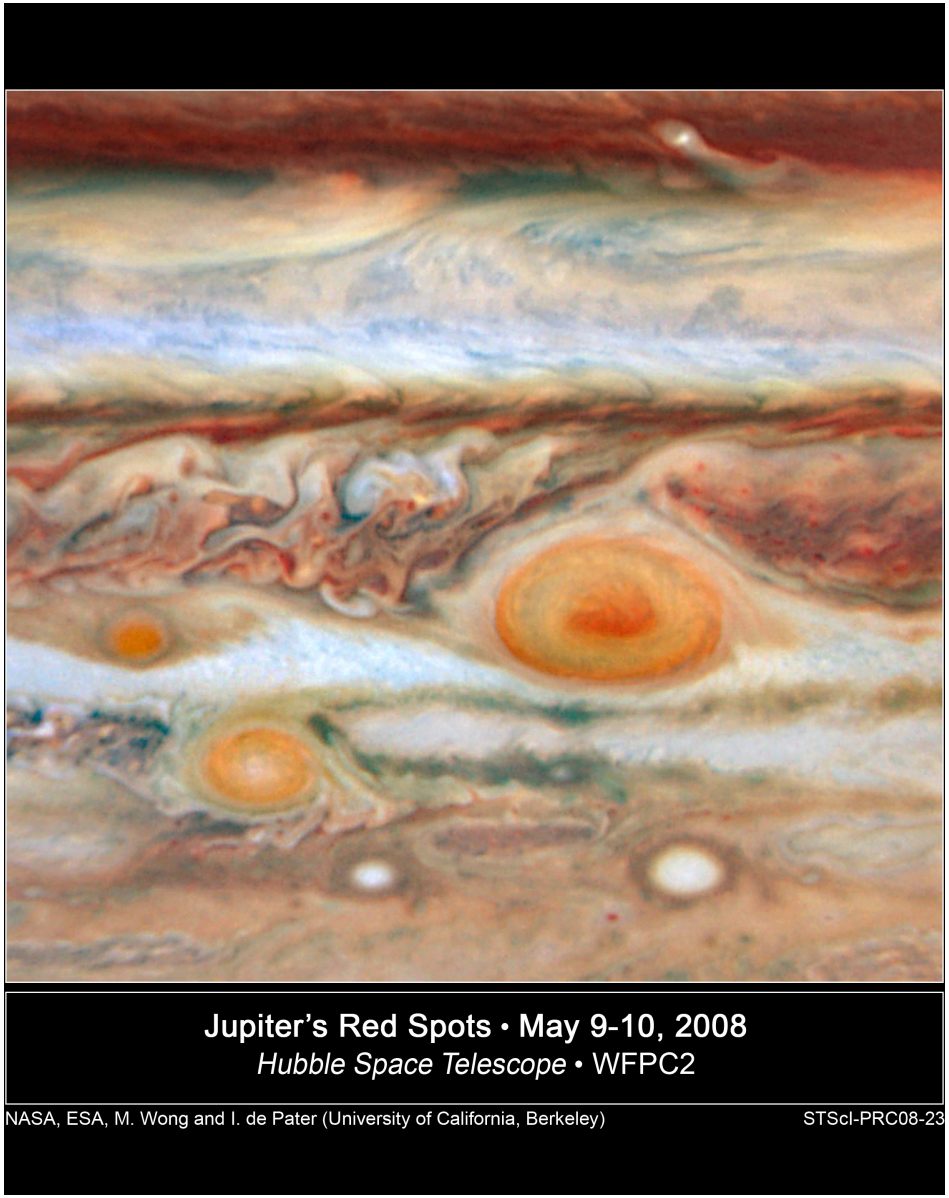






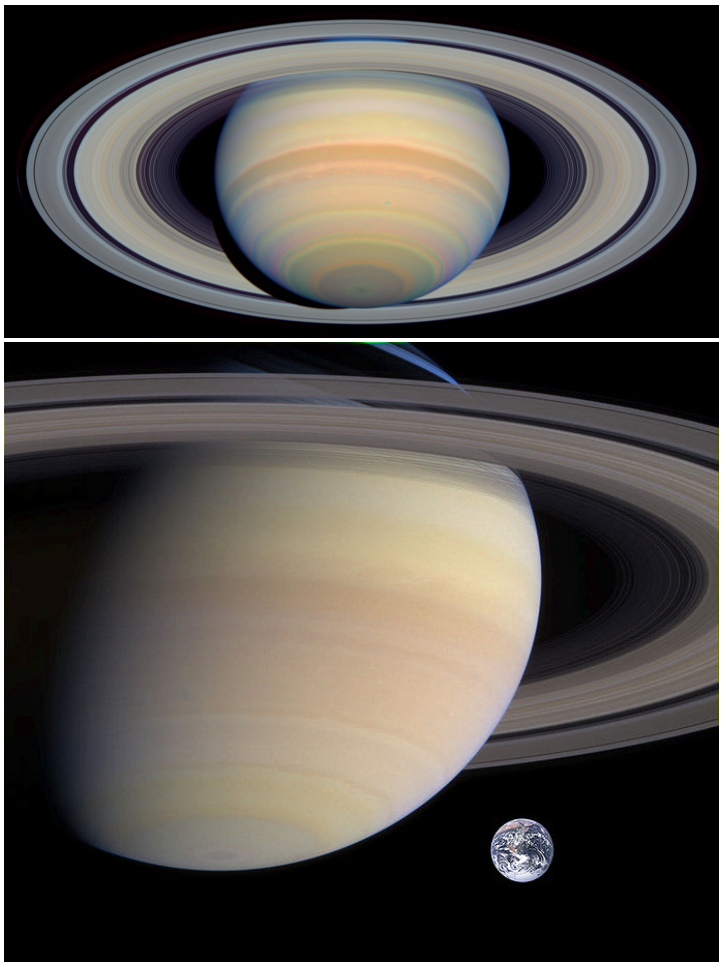
Mass	1.9×10^{27} kg
Mass	317.8 $\mathrm{M}_{\oplus}$
Radius	71,492 km
Radius	11.2 $\mathrm{R}_{\oplus}$
Gravity	2.53 g
SM axis	5.2 AU
Orbital Period	11.9 years
Rotation Period	$9^{\mathrm{h}}55^{\mathrm{m}}$
Temperature	-100C

Jupiter's Great Red Spot



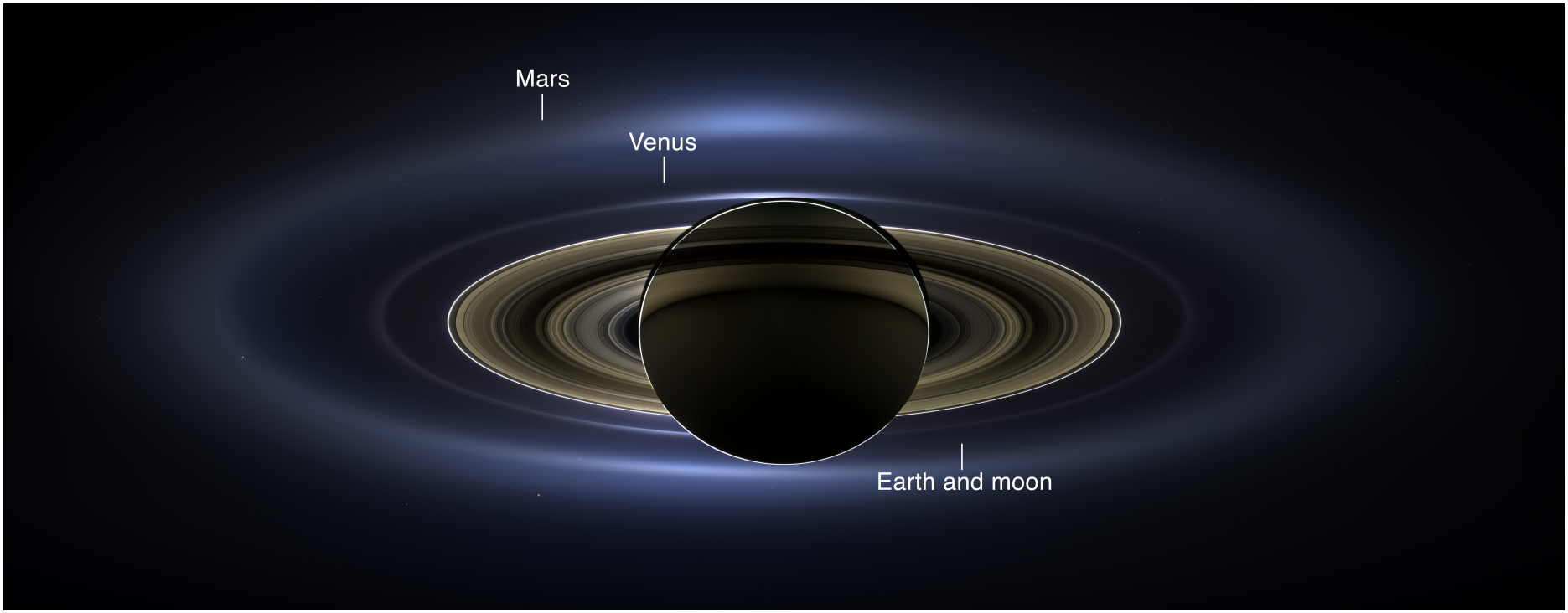
This is an immense storm similar to terrestrial hurricanes.

Saturn

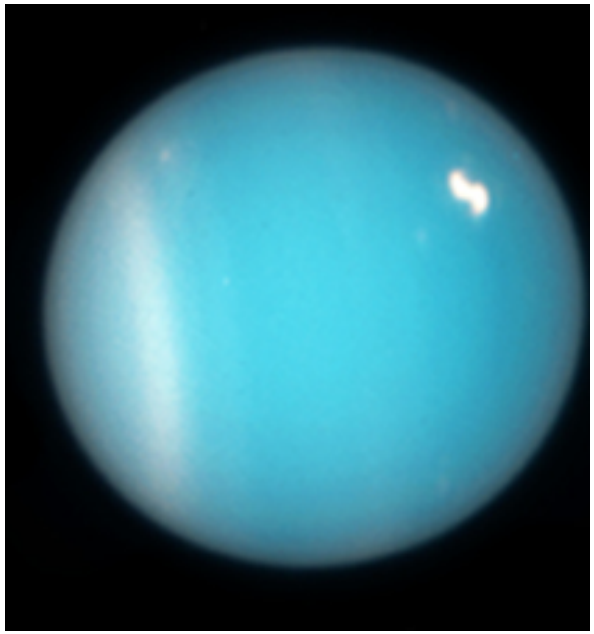


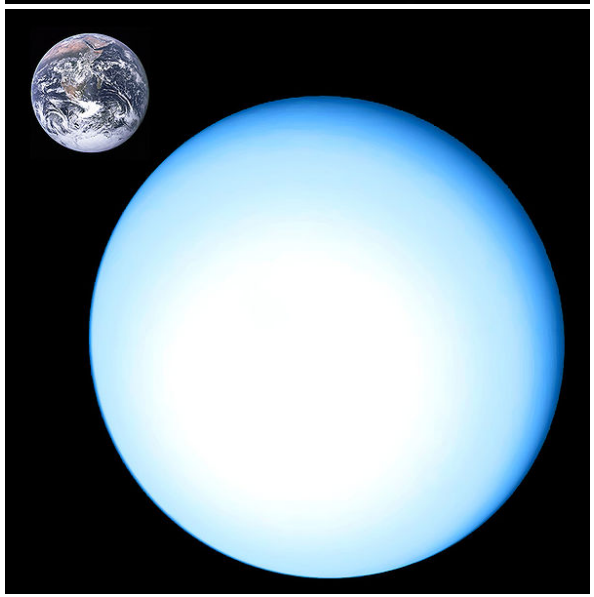
Mass	5.7×10^{26} kg
Mass	95.1 $\mathrm{M}_{\oplus}$
Radius	60,268 km
Radius	9.45 $\mathrm{R}_{\oplus}$
Gravity	1.06 g
SM axis	9.58 AU
Orbital Period	29.5 years
Rotation Period	$10^{\mathrm{h}}34^{\mathrm{m}}$
Temperature	-140C

Saturn from “Behind”



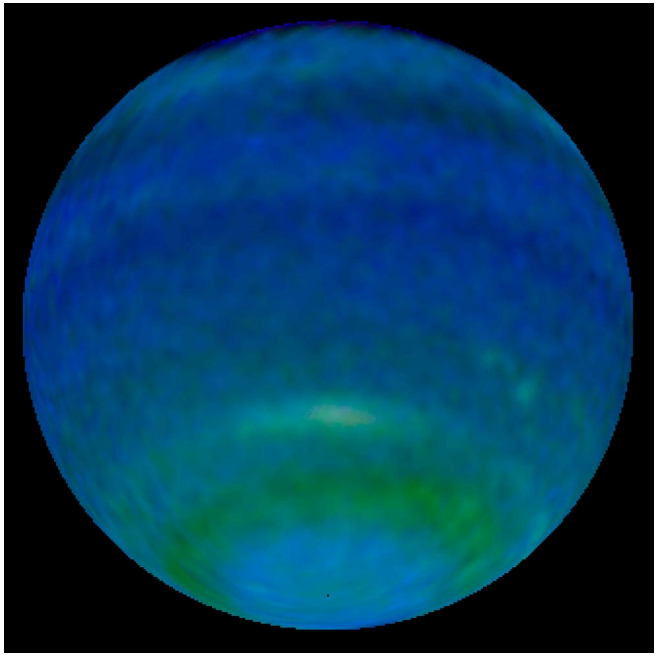
Uranus

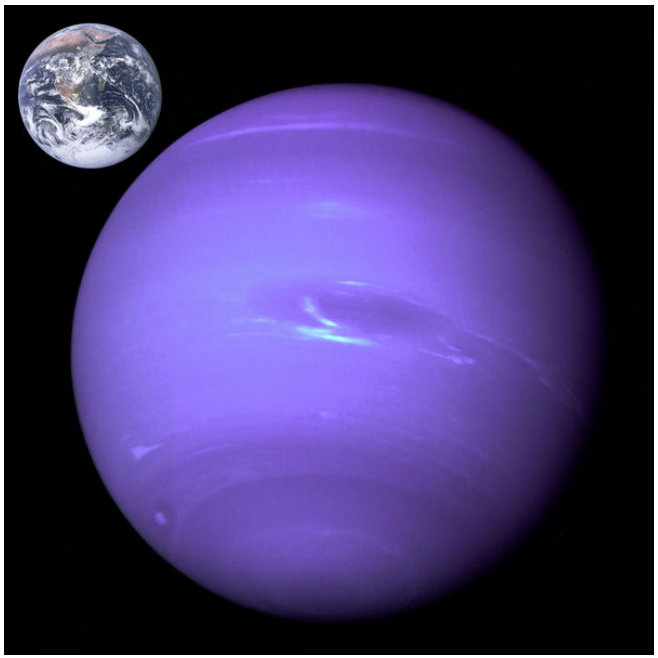




Mass	8.7×10^{25} kg
Mass	14.5 $\mathrm{M}_{\oplus}$
Radius	25,559 km
Radius	4.0 $\mathrm{R}_{\oplus}$
Gravity	0.89 g
SM axis	19.23 AU
Orbital Period	84.32 years
Rotation Period	$17^{\mathrm{h}}14^{\mathrm{m}}$
Temperature	-200C

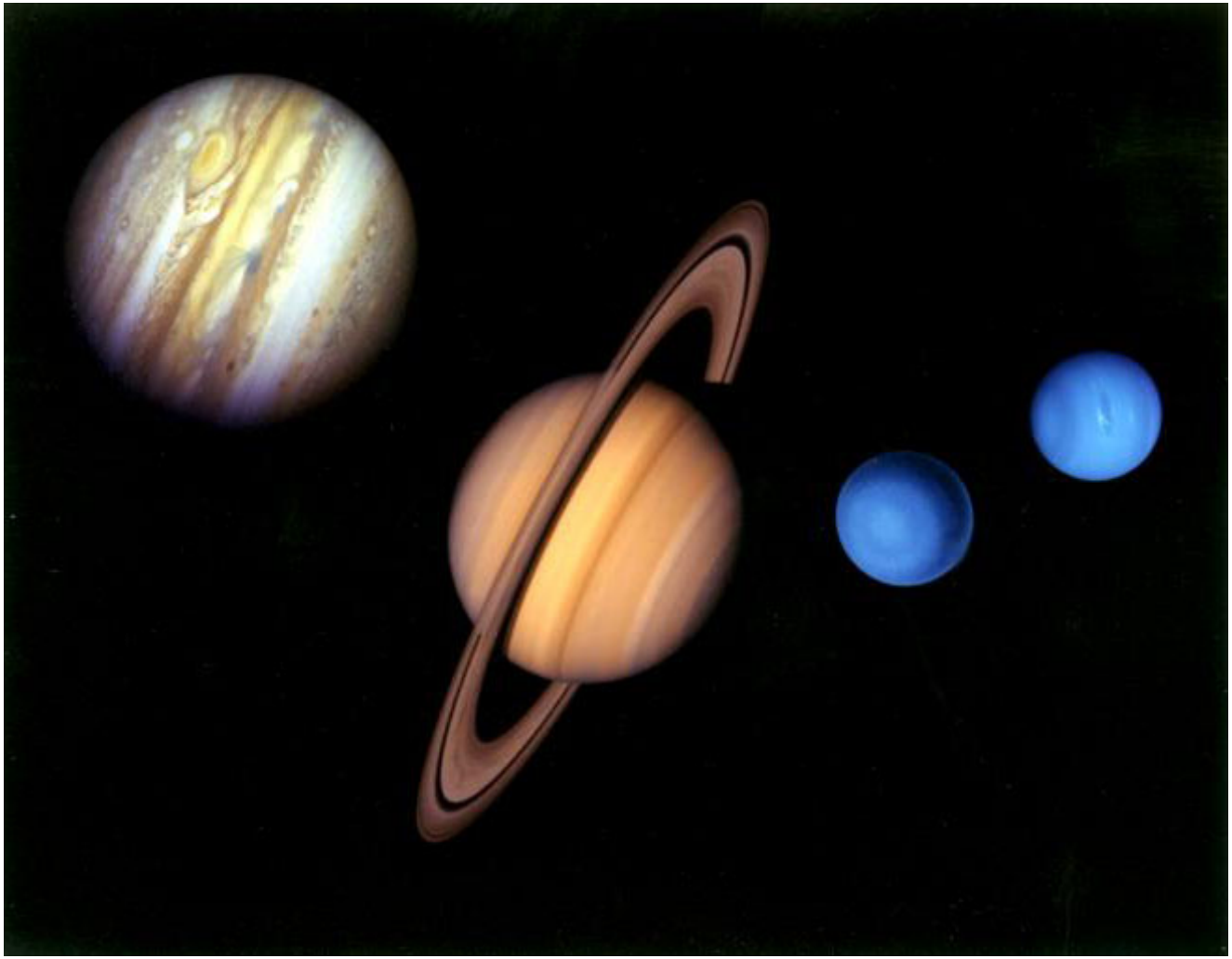
Neptune





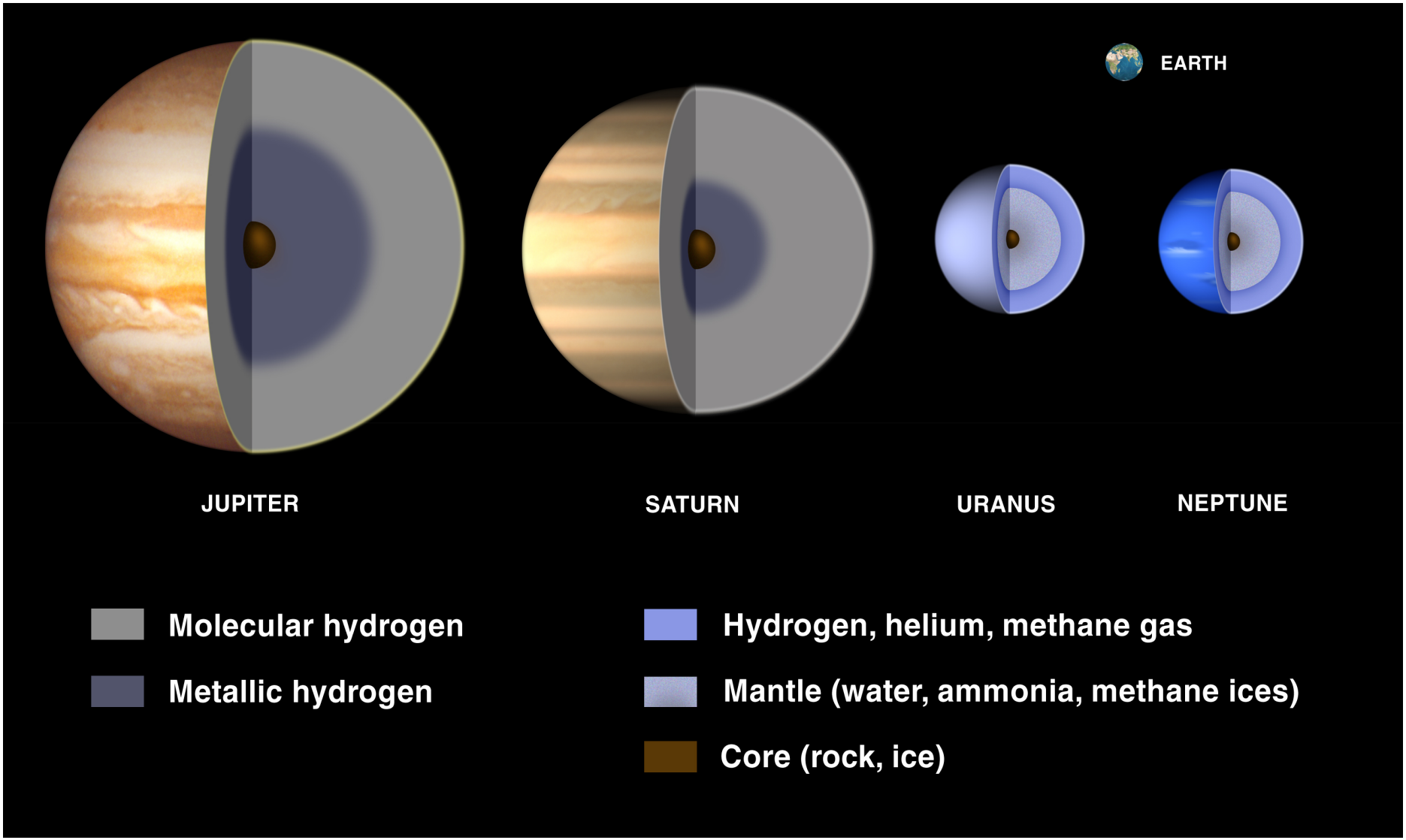
Mass	1.0×10^{26} kg
Mass	17.1 $\mathrm{M}_{\oplus}$
Radius	24,764 km
Radius	3.88 $\mathrm{R}_{\oplus}$
Gravity	1.14 g
SM axis	30.1 AU
Orbital Period	164.8 years
Rotation Period	$16^{\mathrm{h}}6^{\mathrm{m}}$
Temperature	-200C

Gas Giants Compared



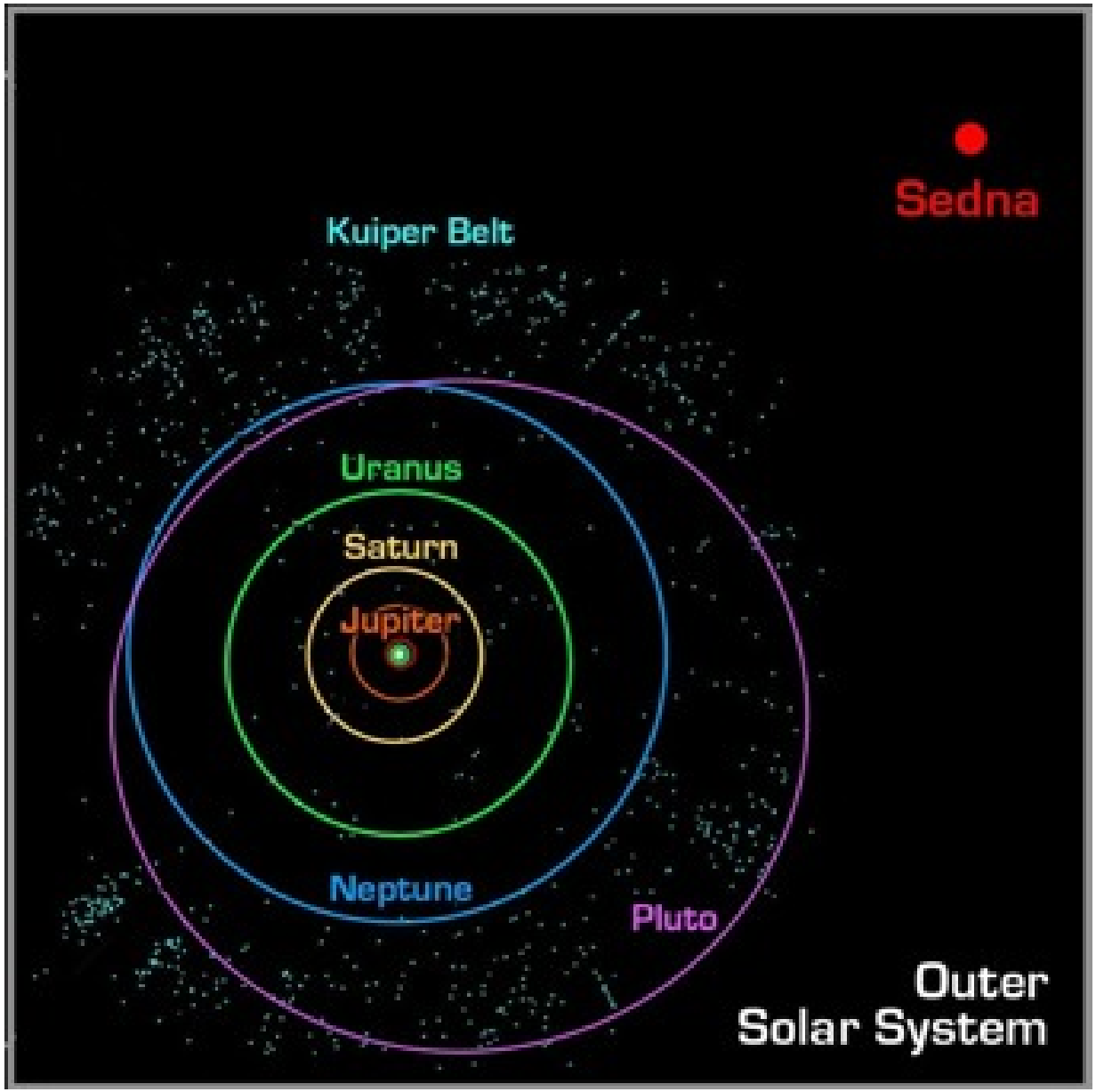
Jupiter, Saturn, Uranus, Neptune

Gas Giant Interiors



Possible structure of the Gas Giants

The Outer Solar System



Summary

1. Planets (and stars) are in hydrostatic equilibrium, with outward pressure balancing the inward force of gravity.
2. The planets were formed from "left-over" material from a gas cloud which collapsed to form the sun.
3. Most of the matter in the universe is hydrogen and helium.
4. There are two types (alternatively three types) of planets in the solar system.
   - Rocky planets, also called terrestrial planets.
   - Gas giants.
     - The gas giants, like Jupiter and Saturn, have enough gravity to hold hydrogen and helium, so they are much larger.
     - Some astronomers distinguish Uranus and Neptune as a third type known as "Ice Giants".