# W H E N THE EARTH HAD TWO MOONS 

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## A SHORT LIST OF PLANETS AND MOONS

There are at least nine planets in the solar system (depending on who's counting) and they have almost two hundred known moons (natural satellites). Below are some of the most interesting and important ones. ${ }^{1}$ Because some of the moons are oddly shaped, and the fast-rotating planets are oblate, what's given is the average diameter. Orbital distances of planets are in AU, where 1 AU is the Earth's average distance from the Sun, 149.6 million kilometers. The orbital distances of satellites are given in units of their planetary radius.

## MERCURY

Distance from Sun: 0.39 AU
Diameter: $4,878 \mathrm{~km}$
Mass: $3.301 \times 10^{23} \mathrm{~kg}$
Orbital period around the Sun: 0.24
years / 88 days
Spin period: 58.6 days

## VENUS

Distance from Sun: 0.72 AU
Diameter: $12,104 \mathrm{~km}$
Mass: $4.867 \times 10^{24} \mathrm{~kg}$
Orbital period around the Sun: 0.62
years / 226 days
Spin period: 243 days (retrograde)

EARTH
Distance from Sun: 1 AU (defined)
Diameter: $12,742 \mathrm{~km}$
Mass: $5.972 \times 10^{24} \mathrm{~kg}$

Orbital period around the Sun: 1 year / 365.26 days

Spin period: 23.93 hours (sidereal day)

## Moon

Distance from planet: 60.3 Earth radii Diameter: $3,474 \mathrm{~km}$
Mass: $7.35 \times 10^{22} \mathrm{~kg}$
Orbital period around Earth: 27.3 days (sidereal month)

MARS
Distance from Sun: 1.52 AU
Diameter: $6,779 \mathrm{~km}$
Mass: $6.417 \times 10^{23} \mathrm{~kg}$
Orbital period around the Sun: 1.88
years
Spin period: 24.6 hours

## Phobos

Distance from planet: 2.8 Mars radii
Diameter: 22 km

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Mass: $10.8 \times 10^{15} \mathrm{~kg}$
Orbital period around Mars: 7.7 hours

## Deimos

Distance from planet: 7.0 Mars radii
Diameter: 12 km
Mass: $1.48 \times 10^{15} \mathrm{~kg}$
Orbital period around Mars: 30.3 hours

## JUPITER

Distance from Sun: 5.2 AU
Diameter: $139,822 \mathrm{~km}$
Mass: $1.898 \times 10^{27} \mathrm{~kg}$
Orbital period around the Sun: 11.86 years
Spin period: 9.9 hours

## lo

Distance from planet: 6.03 Jupiter radii
Diameter: $3,643 \mathrm{~km}$
Mass: $8.93 \times 10^{22} \mathrm{~kg}$
Orbital period around Jupiter: 1.8 days

## Europa

Distance from planet: 9.59 Jupiter radii
Diameter: $3,130 \mathrm{~km}$
Mass: $4.79 \times 10^{15} \mathrm{~kg}$
Orbital period around Jupiter: 3.6 days

## Ganymede

Distance from planet: 15.30 Jupiter radii
Diameter: $5,268 \mathrm{~km}$
Mass: $1.48 \times 10^{23} \mathrm{~kg}$
Orbital period around Jupiter: 7.2 days

## Callisto

Distance from planet: 26.93 Jupiter radii
Diameter: $4,806 \mathrm{~km}$

Mass: $1.08 \times 10^{23} \mathrm{~kg}$
Orbital period around Jupiter: 16.7 days

## SATURN

Distance from Sun: 9.6 AU
Diameter: $116,464 \mathrm{~km}$
Mass: $5.683 \times 10^{26} \mathrm{~kg}$
Orbital period around the Sun: 29.44
years
Spin period: 10.7 hours

## Mimas

Distance from planet: 3.18 Saturn radii
Diameter: 398 km
Mass: $3.75 \times 10^{19} \mathrm{~kg}$
Orbital period around Saturn: 0.942 days

## Enceladus

Distance from planet: 4.09 Saturn radii
Diameter: 504 km
Mass: $1.08 \times 10^{20} \mathrm{~kg}$
Orbital period around Saturn: 1.37 days

## Tethys

Distance from planet: 5.06 Saturn radii
Diameter: $1,072 \mathrm{~km}$
Mass: $6.17 \times 10^{20} \mathrm{~kg}$
Orbital period around Saturn: 1.89 days

## Dione

Distance from planet: 6.48 Saturn radii
Diameter: $1,125 \mathrm{~km}$
Mass: $1.10 \times 10^{21} \mathrm{~kg}$
Orbital period around Saturn: 2.74 days

## Rhea

Distance from planet: 9.05 Saturn radii

Diameter: $1,528 \mathrm{~km}$
Mass: $2.31 \times 10^{21} \mathrm{~kg}$
Orbital period around Saturn: 4.52 days

## Titan

Distance from planet: 21.0 Saturn radii
Diameter: 5,150 km
Mass: $1.34 \times 10^{23} \mathrm{~kg}$
Orbital period around Saturn: 15.9 days

## Hyperion

Distance from planet: 25.7 Saturn radii
Diameter: 270 km
Mass: $1.08 \times 10^{19} \mathrm{~kg}$
Orbital period around Saturn: 21.3 days

## lapetus

Distance from planet: 61.1 Saturn radii
Diameter: $1,469 \mathrm{~km}$
Mass: $1.81 \times 10^{21} \mathrm{~kg}$
Orbital period around Saturn: 79.3 days

## URANUS

Distance from Sun: 19.2 AU
Diameter: $51,26 \mathrm{~km}$
Mass: $8.681 \times 10^{25} \mathrm{~kg}$
Orbital period around the Sun: 84.02 years
Spin period: 17.2 hours (retrograde)

## Miranda

Distance from planet: 5.08 Uranus radii
Diameter: 472 km
Mass: $6.59 \times 10^{19} \mathrm{~kg}$
Orbital period around Uranus: 1.41 days

## Ariel

Distance from planet: 7.47 Uranus radii

Diameter: $1,160 \mathrm{~km}$
Mass: $1.3 \times 10^{21} \mathrm{~kg}$
Orbital period around Uranus: 2.52
days

## Umbriel

Distance from planet: 10.4 Uranus radii
Diameter: $1,170 \mathrm{~km}$
Mass: $1.17 \times 10^{21} \mathrm{~kg}$
Orbital period around Uranus: 4.14 days

## Titania

Distance from planet: 17.1 Uranus radii
Diameter: $1,577 \mathrm{~km}$
Mass: $3.53 \times 10^{21} \mathrm{~kg}$
Orbital period around Uranus: 8.71 days

## Oberon

Distance from planet: 22.8 Uranus radii
Diameter: $1,523 \mathrm{~km}$
Mass: $3.03 \times 10^{21} \mathrm{~kg}$
Orbital period around Uranus: 13.5 days

## NEPTUNE

Distance from Sun: 30.0 AU
Diameter: $49,244 \mathrm{~km}$
Mass: $1.024 \times 10^{26} \mathrm{~kg}$
Orbital period around the Sun: 165 years
Spin period: 16.11 hours

## Proteus

Distance from planet: 3.77 Neptune radii
Diameter: 420 km
Mass: $4.4 \times 10^{19} \mathrm{~kg}$
Orbital period around Neptune: 1.1 days

## Triton

Distance from planet: 14.4 Neptune radii

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Diameter: $1,682 \mathrm{~km}$
Mass: $2.14 \times 10^{22} \mathrm{~kg}$
Orbital period around Neptune: 5.9 days

## Nereid

Distance from planet: 224 Neptune radii
Diameter: 340 km
Mass: $3.09 \times 10^{19} \mathrm{~kg}$
Orbital period around Neptune: 360 days

## PLUTO

Distance from Sun: 39.5 AU
Diameter: $2,377 \mathrm{~km}$
Mass: $1.303 \times 10^{22} \mathrm{~kg}$
Orbital period around the Sun: 248 years
Spin period: 6.39 days (retrograde)

## Charon

Distance from planet: 16.5 Pluto radii
Diameter: $1,212 \mathrm{~km}$
Mass: $1.55 \times 10^{21} \mathrm{~kg}$
Orbital period around Pluto: 6.39
days

## Nix

Distance from Pluto-Charon barycenter: 41 Pluto radii
Diameter: 74 km
Mass: $4.5 \times 10^{16} \mathrm{~kg}$

Orbital period around Pluto-Charon: 24.9 days

## Hydra

Distance from Pluto-Charon
barycenter: 54.5 Pluto radii
Diameter: 38 km
Mass: $4.8 \times 10^{16} \mathrm{~kg}$
Orbital period around Pluto-Charon: 38 days

## HAUMEA

Distance from Sun: 43 AU
Diameter: $1,436 \mathrm{~km}$
Mass: $4.0 \times 10^{21} \mathrm{~kg}$
Orbital period around the Sun: 284
years
Spin period: 3.9 hours

## Namaka

Distance from planet: 48.2 Haumea radii
Diameter: 170 km
Mass: $1.8 \times 10^{18} \mathrm{~kg}$
Orbital period around Haumea: 34.7 days

## Hi'iaka

Distance from planet: 60.7 Haumea radii
Diameter: 310 km
Mass: $1.8 \times 10^{19} \mathrm{~kg}$
Orbital period around Haumea: 49.1 days

## GLOSSARY

## absorption line

A feature in a spectrum, caused by the absorption of a particular wavelength of light by the presence of, for example, certain molecular bonds or electron orbital transitions. The depth of the absorption indicates the abundance of whatever species is present.

## accretion

Growth of discrete bodies by accumulation of mass from the planetary disk.

## achondritic

An asteroid or meteorite of evolved or once-melted composition.

## anorthosite

A cumulate rock made mostly of feldspar that comprises the highlands crust of the Moon.

## aphelion

The point in a planet's orbit when it is most distant from the Sun (compare perihelion).

## Apollo

The crewed space missions that brought twelve astronauts safely to the surface of the Moon and back. Also, a family of asteroids whose orbits come close to Earth.

## asteroid

A small rocky body originating in the terrestrial planetary region.

## astronomical unit (AU)

The average distance from the Earth to the Sun, 149.6 million kilometers.

## basalt

The most common terrestrial surface rock, made of solidified silicate lava.

## carbon cycle

In plate tectonics, the movement of carbon from the atmosphere, into the ocean, to the seafloor as carbonates, into the upper mantle, and back out of volcanic vents.

## chondritic

An asteroid or meteorite of composition undifferentiated from the condensable solid component of the original protoplanetary nebula (also solar composition).

## comet

A small, ice-rich planetary body orbiting the Sun, which originated far beyond the terrestrial planet region.

## cometesimal

An ice-dominated planetesimal.

## co-rotation radius

Orbital distance at which the period of the satellite orbiting the planet equals the rotation period of the planet.

## cryosphere

The exterior frozen solid shell of a water-rich planet or satellite.

## C-type

Dark reddish asteroids from the outer Main Belt, parent bodies of the carbonaceous chondrite meteorites.

## delta-v

The change in velocity required to get somewhere in the solar system; or, the amount of velocity change to a spacecraft that is attainable by a given rocket motor.

## density

The mass of something, per unit volume. Iron is almost three times as dense as rock, which is three times as dense as water.

## differentiation

The process by which a planet forms a core and mantle and other layers, usually by melting and segregating gravitationally.

## embryo

A planet that is rapidly growing and at risk for being accreted.

## extinct radionuclide

A radionuclide such as ${ }^{26} \mathrm{Al}$ or ${ }^{60} \mathrm{Fe}$ with a decay half-life shorter than the early evolution of the solar system, which may have been abundant but is now gone.

## gardening

The process by which small impacts overturn and reduce to powder the regolith on an asteroid.

## geometric series

A series of numbers where one is a constant factor times the preceding-e.g., 1, 3, 9, 27, ...

## grand tack

The theory that Jupiter originated where the Main Belt is today, at around 3 AU , then migrated in toward where Mars is today, at around 1.5 AU , and then when Saturn was formed, the pair of them migrated back out to their present locations at 5 and 10 AU .

## gravity assist

When a spacecraft makes use of a planet orbiting a star, or a massive satellite orbiting a planet, to speed up or slow down or otherwise modify its own orbit without any expenditure of fuel.

## half-life

The time for half the atoms to decay in a radioactive sample.

## hit-and-run collision

A common type of planetary collision in which the impactor and target are of comparable size and do great damage to each other (especially the smaller) during the event, but do not accrete.

## hydrocarbon

A compound made of C and H , e.g., methane $\left(\mathrm{CH}_{4}\right)$, and ethane $\left(\mathrm{C}_{2} \mathrm{H}_{6}\right)$, found in reducing conditions.

## ISRU

In Situ Resource Utilization, that is, using what's available for propulsion, life support, habitation, etc.

## KREEP

Acronym for potassium, rare-earth elements, and phosphorus, the residue of a primitive magma ocean that is concentrated in incompatible elements including uranium and thorium. Found in abundance on the lunar nearside, and rarely on the farside.

## low-Earth orbit (LEO)

The easiest orbits to attain, a few hundred kilometers above the atmosphere of Earth. This is where the International Space Station orbits.

## Main Belt

The debris disk between Mars and Jupiter where most asteroids are found. With a total of 5 percent the mass of the Moon, half of the Main Belt is contained in the four largest asteroids, Ceres, Vesta, Pallas, and Hygiea.

## mascon

A gravity anomaly (mass concentration) in the crust of the Moon or a planet, which can be caused by dense mantle rock flowing into the volume displaced by a large impact crater.

## meteorite

A fragment of planetary material that lands on Earth.

## meteoroid

A geologic mass in space that is smaller than an asteroid-that is, smaller than about 50 meters.

## near-Earth object (NEO)

An asteroid or comet that has perihelion distance inside 1.3 AU.

## oligarch

Any of the final planetary embryos after orderly growth, at the beginning of the late stage of giant impacts. Theia was an oligarch.

## olivine

The most common mineral in Earth's mantle, with a composition ranging from $\mathrm{Mg}_{2} \mathrm{SiO}_{4}$ to $\mathrm{Fe}_{2} \mathrm{SiO}_{4}$.

## orbital resonance

When two orbiting bodies are periodic. Usually we mean that the orbital periods are in a ratio of two small integers, but in a secular resonance the precessions of the orbits are synchronous.

## perihelion

The point in a planet's orbit when it is closest to the Sun. Earth's orbit is slightly eccentric, so on January 3 it is about 3 percent closer than at aphelion.

## photosynthesis

The formation of carbohydrates from carbon dioxide and a source of hydrogen in chlorophyllcontaining cells exposed to light.

## planetesimal

A primordial planetary body large enough to be gravitationally bound.

## primary accretion

The formation of the first macroscopic condensates in the nebula, from centimeterscale lumps to kilometer-scale planetesimals.

## protoplanetary nebula

The cloud of gas and dust from which the Sun and the solar system formed, sometimes called just "the nebula" or "the disk." Also, any such planet-forming region elsewhere in space.

## reduced

Conditions that preclude the formation of oxides, such as the hydrogen-rich conditions of the early nebula, or the atmospheres of the giant planets.

## regolith

Loose granular material on the surface of an airless body.

## resolution

The finest scale at which you can measure something in the data. A typical movie has a time resolution of $1 / 30$ of a second, for example; image resolution is typically a few pixels.

## rheology

How a material flows or deforms in response to a stress condition, and conversely, how stress builds up inside a body when it is deformed.

## Roche limit

The orbital distance inside of which an accreting satellite is always under some kind of surface shear stress that can pull it apart. Because satellites aren't liquids, the tidal disruption radius is closer than the Roche limit.
rubble pile
A geologic mass whose chief binding force is self-gravitation, but whose central pressure is far lower than the strength of rock. A rubble pile cannot hold on to its pieces if it is spun up to rapid rotation.

## scaling

A physics-based mathematical transformation allowing laboratory results to be extrapolated from one domain to another-e.g., to a much vaster scale, or to much longer time.

## small planetary body

A comet, asteroid, or small satellite; any geologic body where gravity is extremely low.

## solar pressure

The density of the linear momentum of the Sun's electromagnetic field, which applies a pressure that can be felt by small particles and spacecraft.

## space weathering

The process of surface reddening and darkening that occurs as minerals and metallic inclusions are exposed to the high-energy radioactive bombardment of space.

## S-type

The most common type of asteroid in near-Earth space; parent bodies of the ordinary chondrite meteorites.

## supernova

A massive star that has reached the end of the fusion process and undergoes core collapse and eruption.

## terrestrial planet

Any planetary body or satellite whose dominant processes are closely analogous to principal processes on Earth.

## tidal evolution

The migration of a satellite's orbit due to transfer of angular momentum from the planet's rotation to the satellite.

## triple point

The temperature and pressure where the standard phases of pure water coexist: liquid, vapor, and solid. With its atmosphere, Earth's surface environment is around the triple point.

## Trojan

A body that orbits at one of the stable Lagrange points, $L_{4}$ or $L_{5}$. Also known as a co-orbital.

