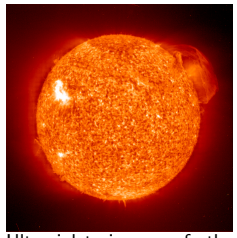
A Tour of the Human Orrery

"Space isn't remote at all. It's only an hour's drive away if your car could go straight upwards."

Fred Hoyle[1]

The Sun

The Sun, a vast sphere of mostly hydrogen and helium 1.4 million kilometres in diameter, lies at the centre of the solar system. Every second, nuclear reactions in its core — the source of the Sun's heat — convert more than 600 million tonnes of hydrogen into helium, turning more than 4 million tonnes of mass into energy through Einstein's famous equation $E = mc^2$. Nearly 750 times more massive than the nine planets combined, its gravitational pull binds the solar system like the arms of a carousel. All life on Earth depends on the Sun for energy; even Earth's fossil fuels represent a store of solar energy from the distant past.



Ultraviolet image of the Sun, showing a huge eruptive prominence and active regions. Courtesy SOHO (ESA and NASA).

The Sun is around five billion years old and its supply of hydrogen will last for another five billion years. Once this fuel is exhausted, the star will expand and cool, swallowing the inner planets as it becomes a 'red giant'. Look at the Sun tile and imagine the central yellow image of the Sun expanding to fill the whole inner solar system up to the orbit of Mars.

After a further billion years, the Sun will finally contract to become a 'white dwarf', a tiny, dying star 200,000 times denser than the Earth but only slightly larger in volume. Its diameter on the Orrery would be less than one tenth of a millimetre!

Terrestrial Planets

Mercury is the god of Travel and Commerce in Roman mythology, and also the Messenger. Orbiting the Sun every 88 days, it is easy to see why Mercury's fleeting passage is associated with The Winged Messenger. The Greeks gave it two names: Apollo for its appearance as a morning star, to the right of the Sun as they saw it; Hermes as an evening star, to the left.

Mercury is the closest planet to the Sun, a scorched, rocky world with a diameter of 4,879 km, just 38% that of the Earth. The surface temperature, averaging $170\,^{\circ}$C, ranges from a daytime high of about $430\,^{\circ}$C down to $-180\,^{\circ}$C on the night side.

[1] 1915–2001. English astronomer. Crafoord Prize 1997.

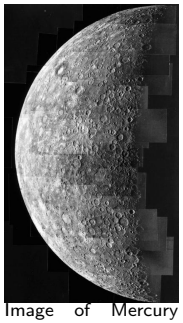


Image of Mercury (NASA and NSSDC).

The Mariner 10 image, taken during the spacecraft's approach to the planet on 1974 March 29, shows a heavily cratered terrain. Mercury rotates once every 58.65 Earth days, exactly 2/3 of its period of revolution about the Sun, and has only a very thin, transient atmosphere, mainly composed of oxygen, sodium, hydrogen and helium. This is removed from the planet by the heat of the Sun, and replenished by the solar wind and impacts of high-energy particles and meteoroids on the planetary surface. Mercury has no known satellites.

On the Human Orrery, as you follow Mercury's eleven tiles numerically, you travel two full revolutions before returning to its zero tile. With this arrangement, the accuracy of Mercury's position is maintained to within a tile spacing for approximately 520 revolutions, or about 125 years.

Venus, the second planet from the Sun, is the Roman goddess of love and beauty. It can be the brightest object in the sky except for the Sun and Moon. In some respects Venus is similar to Earth: its mass is 80% that of Earth, the diameter (12,104 km) is nearly the same, and the orbit is the closest of any planet to a circle with an eccentricity less than 1%. However, Venus has no known moon and rotates on its axis just once every 243 Earth days, almost the same as the Venusian year (224.7 days), and in the *opposite* direction to its orbital motion. As a result, the Venusian day lasts $116\frac{3}{4}$ Earth days, and the Sun rises in the west!

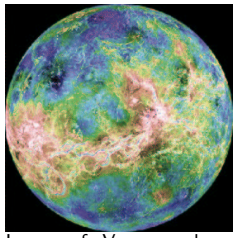


Image of Venus, colour-coded to represent elevation (NASA/JPL-Caltech).

The thick, highly reflective atmosphere of Venus is mainly composed of carbon dioxide (96.5%) and nitrogen (3.5%). The resulting 'greenhouse effect' is similar to that on Earth but much stronger, making Venus the hottest of all the planets, with an average temperature of approximately $465\,^{\circ}$C. The layers of clouds, many kilometres thick, completely obscure our visible view of the surface. After 23 revolutions of the Orrery, take a 'leap stop', i.e. stand still for one turn, to compensate for the leap error.

Earth is the largest of the terrestrial planets, rotating once on its axis every 23 hours 56 minutes. It is unique in being the only planet with conditions suitable for liquid water (71% of its surface is covered by water, 64% by open oceans), and the only one currently known to harbour living organisms.

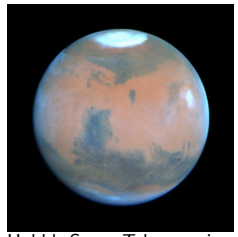
With its near-circular orbit, average temperature around $15\,^{\circ}$C, plentiful water supply and atmosphere largely composed of nitrogen (78%) and oxygen (21%), and small amounts of argon, carbon dioxide and water vapour, Earth seems uniquely placed to support life. The atmosphere warms the planet by trapping and reflecting sunlight, whilst shielding land life from harmful high-energy solar radiation. It interacts with the land and oceans to produce the familiar weather patterns that give us clouds, winds and rain — and occasionally clear skies!

Earth, the Blue Planet, 1972 July 12 (NASA and NSSDC).

The Earth's crust varies in thickness, being thinner under the oceans and thicker under the continents. The inner core and crust are solid, whereas the outer core and mantle layers are ductile or semi-fluid. With an average density 5.5 times that of water, slightly more than that of the planet Mercury, Earth has the highest density of any planet in the solar system.

Earth is also unusual in having a Moon with a diameter (3,476 km) a substantial fraction of its own size (12,756 km). The Moon revolves around the Earth every 27.32 days, although the lunar month (close to $29\frac{1}{2}$ days) is two days longer owing to motion of the Earth-Moon system around the Sun. On the Human Orrery, take a leap step every 6 revolutions to maintain accuracy.

Mars, the fourth planet from the Sun, is the natural next step for human space exploration, especially since the discovery of water ice near its surface. Mars is also the Roman God of War, probably receiving this name for its blood-red, rusty tint, caused by iron oxide dust on its surface. The red colour does not indicate a hot world; instead, Mars has a cold, rarefied atmosphere and is plagued by dust storms. Like Venus, the atmosphere is mainly composed of carbon dioxide (95.3%) and nitrogen (2.7%), as well as some argon (1.6%) and oxygen; but, unlike Venus, there is no 'greenhouse effect': the average surface temperature is $-63\,^{\circ}$C. The planet rotates on its axis once every 24 hours 37 minutes, and revolves around the Sun every 687 days.



Hubble Space Telescope image of Mars, 1995 February 25 (NASA and NSSDC).

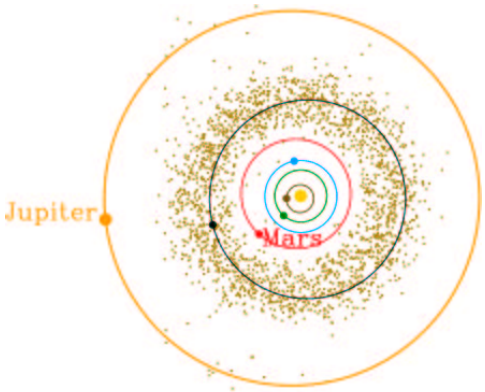
With a diameter of 6,794 km, about half that of Earth, the surface area is about the same as the land area of Earth. Mars has seasons similar to Earth, and permanent polar ice caps mainly composed of solid carbon dioxide, or 'dry ice'. Mars also has the solar system's tallest mountain, Olympus Mons (25 km high, nearly 550 km across), and two small moons: Phobos and Deimos.

In Greek Mythology, Phobos and Deimos were the sons of Ares (Mars) and Aphrodite (Venus). Phobos rises in the west (like many artificial satellites of the Earth), moves rapidly across the sky and sets in the east, usually twice a day. The outer satellite, Deimos, is one of the smallest moons in the solar system, just 16 km long and similar in size to the nucleus of Halley's comet.

As you travel round the Human Orrery, take a leap step every 16 revolutions to maintain accuracy.

Asteroid Belt

The main asteroid belt lies between the orbits of Mars and Jupiter. The first — and largest — main-belt object to be discovered was the asteroid, or minor planet, *(1) Ceres*. Ceres is roughly spherical, with an average diameter of 950 km. It was discovered by the Italian astronomer Giuseppe Piazzi on the first day of the nineteenth century, 1801 January 1, whilst searching for a supposed 'missing' planet predicted in this region by the 18th century German astronomers Johann D. Titius and Johann E. Bode.



The orbit of Ceres and location of the main asteroid belt between Mars and Jupiter. The image also shows Near-Earth Asteroids and the so-called 'Trojans', 60° ahead of and behind Jupiter.

In Roman mythology Ceres was an Earth goddess and the patron of agriculture, especially fruit and grain. With a mass of 8.7×10^{20} kg, it comprises more than one third the estimated mass (2.3×10^{21} kg) of all the main-belt asteroids in the solar system. There are some indications that its surface may have a thin, perhaps transient, atmosphere and frost.

'Leap stops' must be taken into account for Ceres' orbit too, so once every 50 revolutions stand still for one step — if you get that far...

Gas Giants

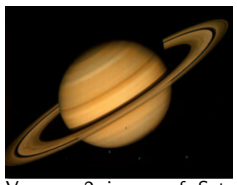
Jupiter is the largest planet in the solar system, with an equatorial diameter of 143,000 km and nearly 318 times the mass of the Earth. Aptly named after the king of the Roman gods and with 63 currently known moons, Jupiter is the undisputed head of the planetary system. The gas giants, Jupiter and Saturn, have exceptionally short rotation periods (both close to 10 hours), and are dominated by thick, outer atmospheres composed mostly of hydrogen and helium with small quantities of methane and ammonia, and clouds of mainly ammonia and water ice. The deep interiors are largely liquid hydrogen under immense pressure.

In 1610, soon after the invention of the telescope, Galileo discovered Jupiter's four principal moons: Io, Europa, Ganymede and Callisto, and recorded their periodic motions around Jupiter. The so-called 'Galilean' satellites are almost large enough to be considered as planets in their own right. Galileo's discovery of a centre of motion distinct from the Earth — and of what almost appeared to be a 'mini' solar system — provided a compelling argument for the new heliocentric, or Sun-centred, theory.

Voyager 1 image of Jupiter and Ganymede (NASA and NSSDC).

Jupiter's visible atmosphere has an average temperature varying from roughly -160 to $-110\,^{\circ}$C, increasing with depth. Despite such low temperatures, the atmosphere is extremely active, containing broad belts of rotating gas and innumerable 'storms'. The most famous of these — Jupiter's Great Red Spot — covers an area larger than the Earth and has been visible for centuries. Its discovery is usually attributed to Giovanni D. Cassini or Robert Hooke in the 17th century. To maintain accuracy, take a 'leap stop' every 13 revolutions.

Saturn, the second largest planet in the solar system, has an equatorial diameter of 120,500 km, slightly less than that of Jupiter. With just 30% of Jupiter's mass, however, Saturn's average density is less than that of water; if you had a big enough bath tub, Saturn would float! In Roman mythology, Saturn is the god of agriculture. The NASA/ESA/ASI *Cassini-Huygens* spacecraft, launched to study Saturn's rings and moon systems, arrived at the planet on 2004 July 1, and will orbit Saturn for at least four years.

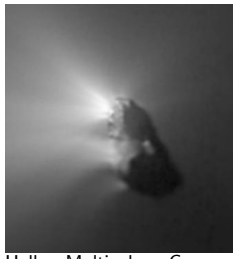


Voyager 2 image of Saturn, July 1981 (NASA and NSSDC).

Saturn is most famous for its distinctive ring system. For many years these rings seemed to be unique in the known solar system. However, faint rings were discovered around Uranus in 1977, and shortly thereafter also around Jupiter and Neptune. Saturn's rings look continuous, but are actually composed of innumerable small particles, each revolving on an independent orbit around the planet. The particles range in size from centimetres or less up to several metres. Despite their impressive appearance, they contain very little material; if all the rings were compressed into a single body it would be no more than 100 km across. Saturn has 35 currently known moons. After 4 revolutions of Saturn's orbit, stand still for one tile to correct the leap error.

Comets

Halley's Comet, now known as *1P/Halley*, the first of the *short-period* comets, has been observed since 240 BC on 30 successive apparitions. Perhaps its most famous appearance was that of 1066, when it appeared before the Battle of Hastings and was recorded on the Bayeux Tapestry. It is named after the English astronomer and mathematician Edmond Halley (1656–1742), who first calculated its orbit. Halley noticed that the bright comets of 1531, 1607, and 1682 had almost identical orbits, and — having accounted for the gravitational effects of Jupiter and Saturn — concluded that they were different appearances of the same comet, predicting its return in 1758. The comet was rediscovered, almost on schedule, by the German farmer and amateur astronomer, Johann Palitzsch, on Christmas Eve 1758.



Halley Multicolour Camera image of the nucleus of Comet Halley (ESA).

The nucleus of Halley's comet is ellipsoidal in shape, like a rugby ball, and measures approximately $16 \times 8 \times 8$ km. As shown on the Human Orrery, it most recently left the inner solar system in 1986, and will not return to perihelion until 2061. Note that Halley's orbit is retrograde (clockwise when viewed from above), inclined at 18 degrees to the ecliptic and, like almost all cometary orbits, highly eccentric.

Comet 2P/Encke was discovered by Pierre F.A. Méchain on 1786 January 17. However, Johann F. Encke was the first to suggest that the comet was the same as those seen in 1795, 1805, and 1819, and it was named Comet Encke in honour of his correct prediction of its return in 1822.

With an orbital period of 3.3 years, the shortest of all the known comets, Encke's comet has been seen at more returns than any other comet, marking its 59th observed perihelion passage in 2003. It follows an elliptical path around the Sun, taking it from just inside Jupiter's orbit at aphelion to a perihelion within the orbit of Mercury. Note that Encke's perihelion tile (2003 December 30) is not shown on the Human Orrery, as it lies underneath Mercury's 5th tile; also, both Halley's and Encke's comets spend less than half a year per revolution within the orbit of Mars. Other comets, the so-called 'long-period' comets (e.g. Comet Hale-Bopp), have orbital periods measured in thousands or millions of years, and are equally fleeting in their passages through the inner solar system.

Comet Hale-Bopp, 1997 March 28 (Mark Bailey).

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For more information, contact the authors by e-mail at meb@arm.ac.uk, or visit the Armagh Observatory web-site http://star.arm.ac.uk/.

Department of Culture, Arts and Leisure
www.dcalni.gov.uk

PPARC

Eleanor Nolan
Mark Purver
Armagh Observatory
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