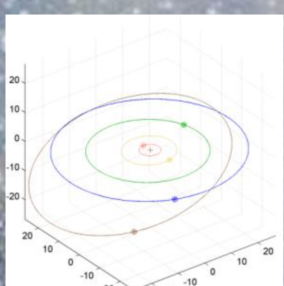
Cosmology

- **Age of the Universe**
  - Future?
  - The cosmic calendar
  - Age of the Earth
  - Red shift
- **Structure and evolution of stars**
- **Relativity**
  - Special Relativity
  - Ideas of General Relativity
    - Gravitational lensing
    - Precession of Mercury
- **Size of the Universe**
  - Measurement
    - Parallax
    - Luminosity
  - Earth
    Solar System
    Galaxy ...
- **Exotic case studies**
  - Neutron stars
  - Black holes, quasars
- **Gravity**
  - Newton/Kepler
  - Einstein
  - Computer Simulation
- **A human history of cosmology**
- **Planets & moons**
  - Detecting planets orbiting other stars
  - The Solar System
    - The Earth

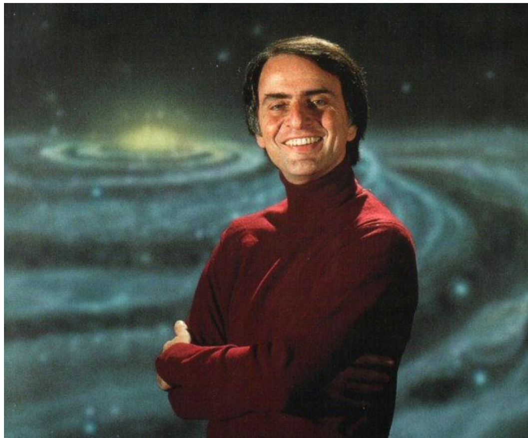


The Cosmos is all that is or ever was or ever will be.

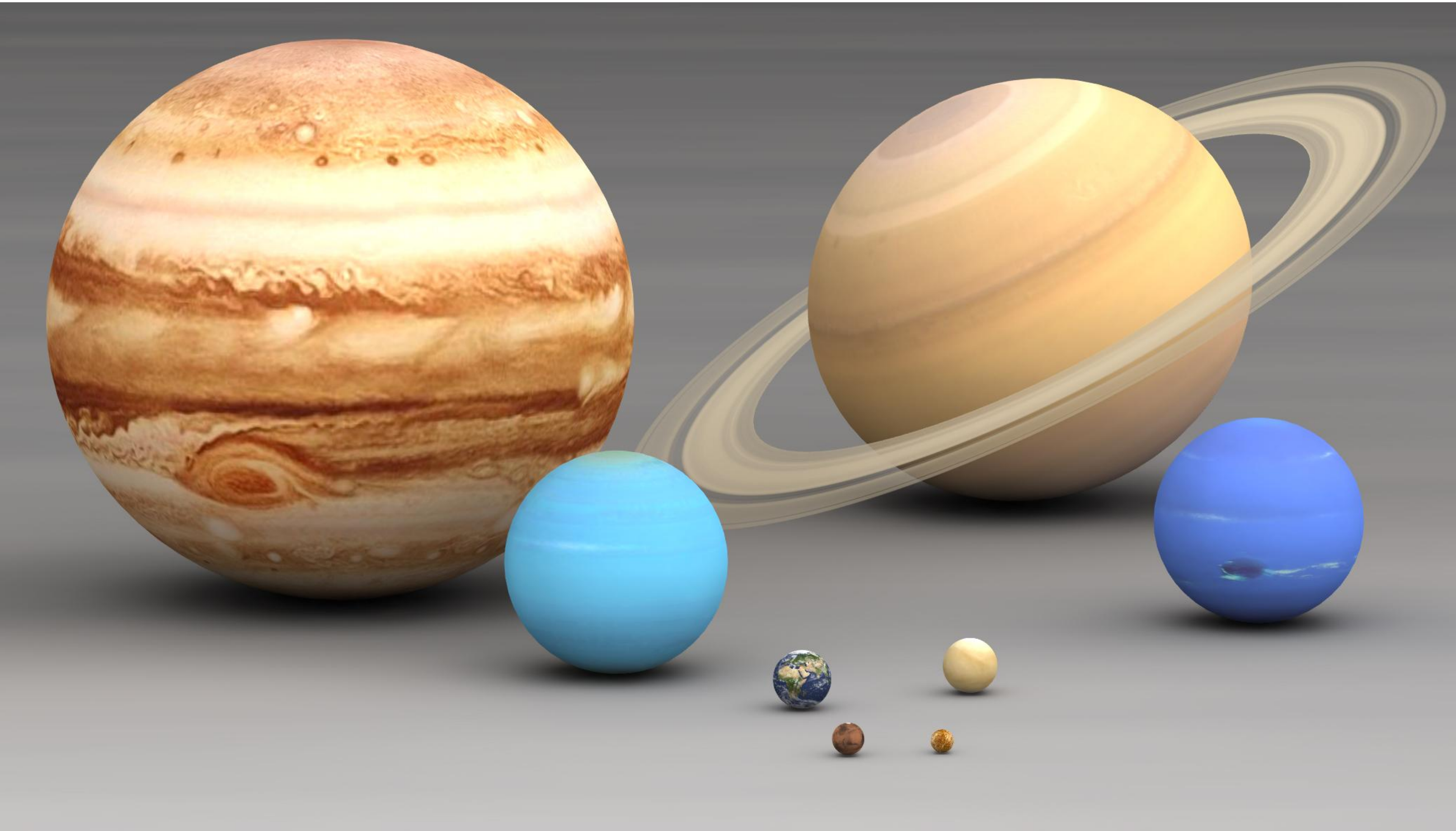
In the last few millennia we have made the most astonishing and unexpected discoveries about the Cosmos and our place within it, explorations that are exhilarating to consider. They remind us that humans have evolved to wonder, that understanding is a joy, that knowledge is prerequisite to survival.

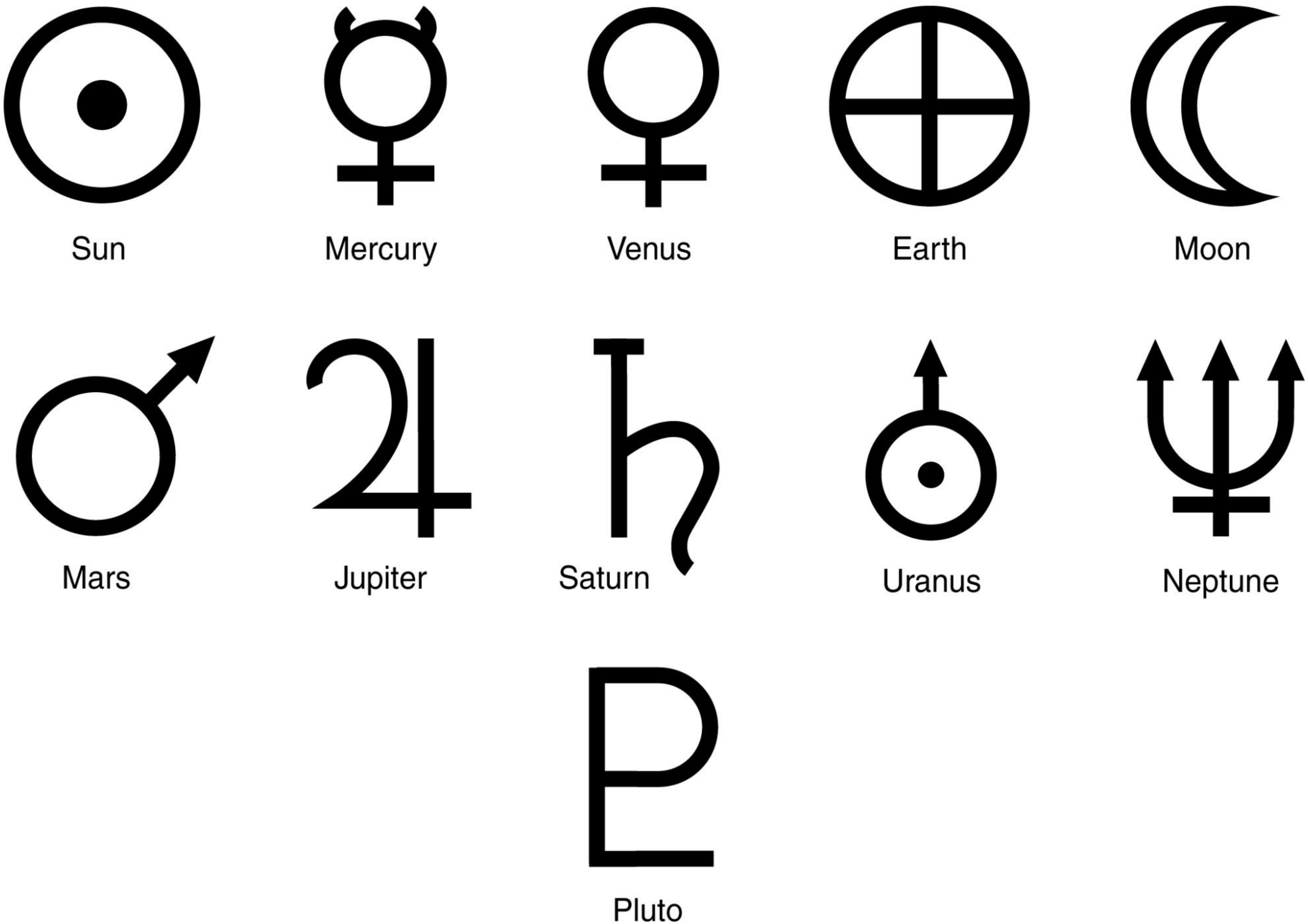
I believe our future depends on how well we know this Cosmos in which we float like a mote of dust in the morning sky.

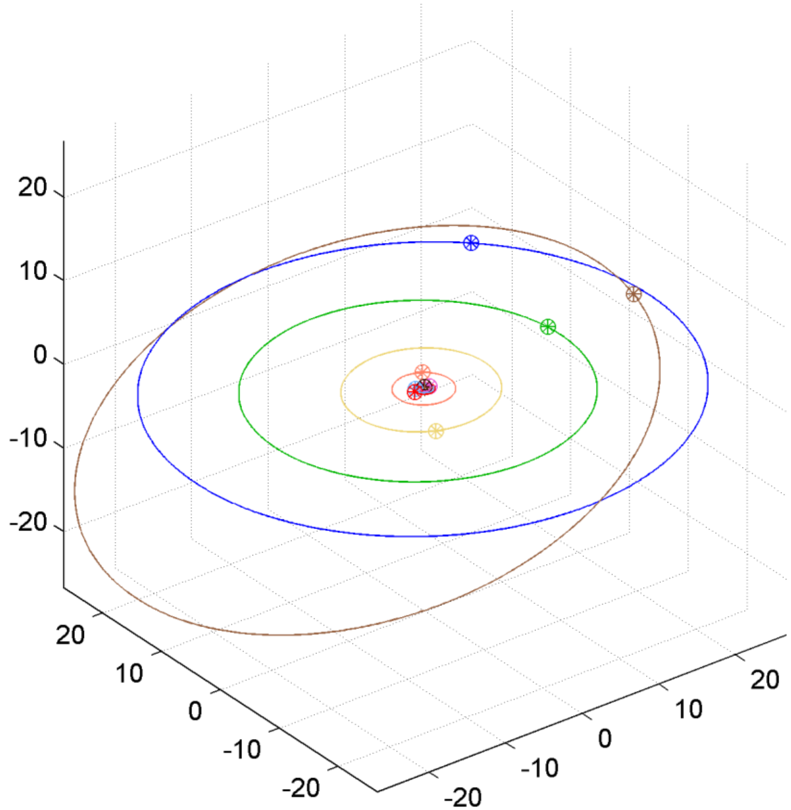
Carl Sagan (1934-1996)
Cosmos pp20

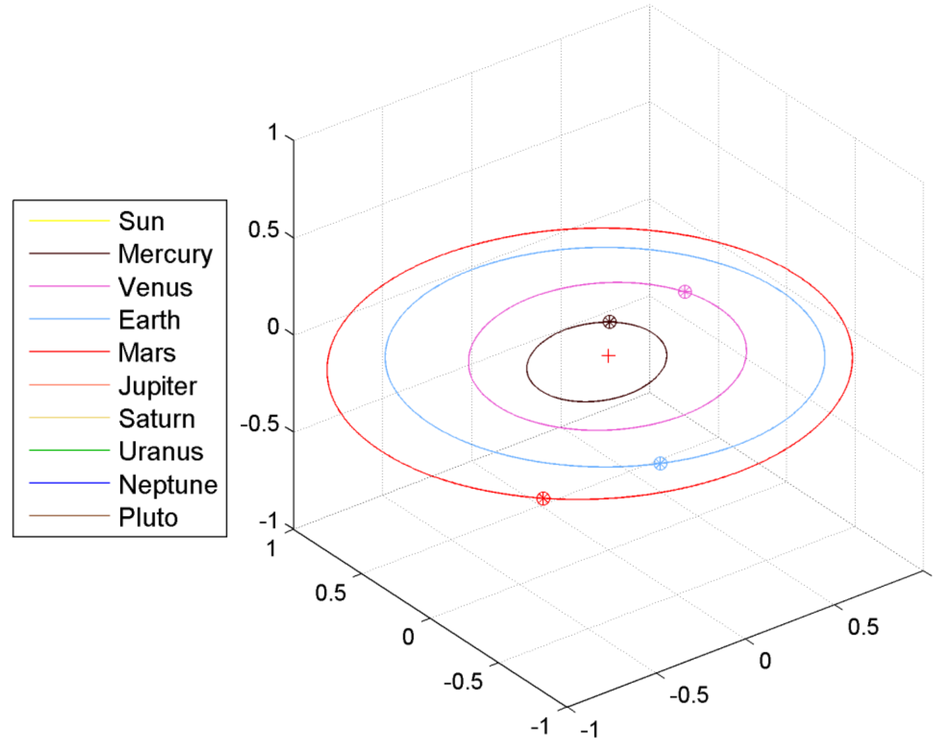


The Solar System



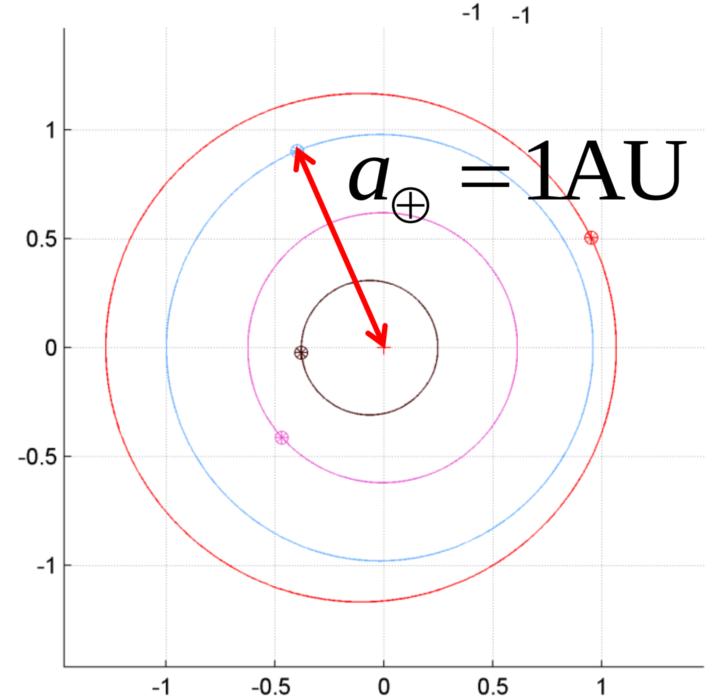

Sun
Mercury
Venus
Earth
Moon
Mars
Jupiter
Saturn
Uranus
Neptune
Pluto

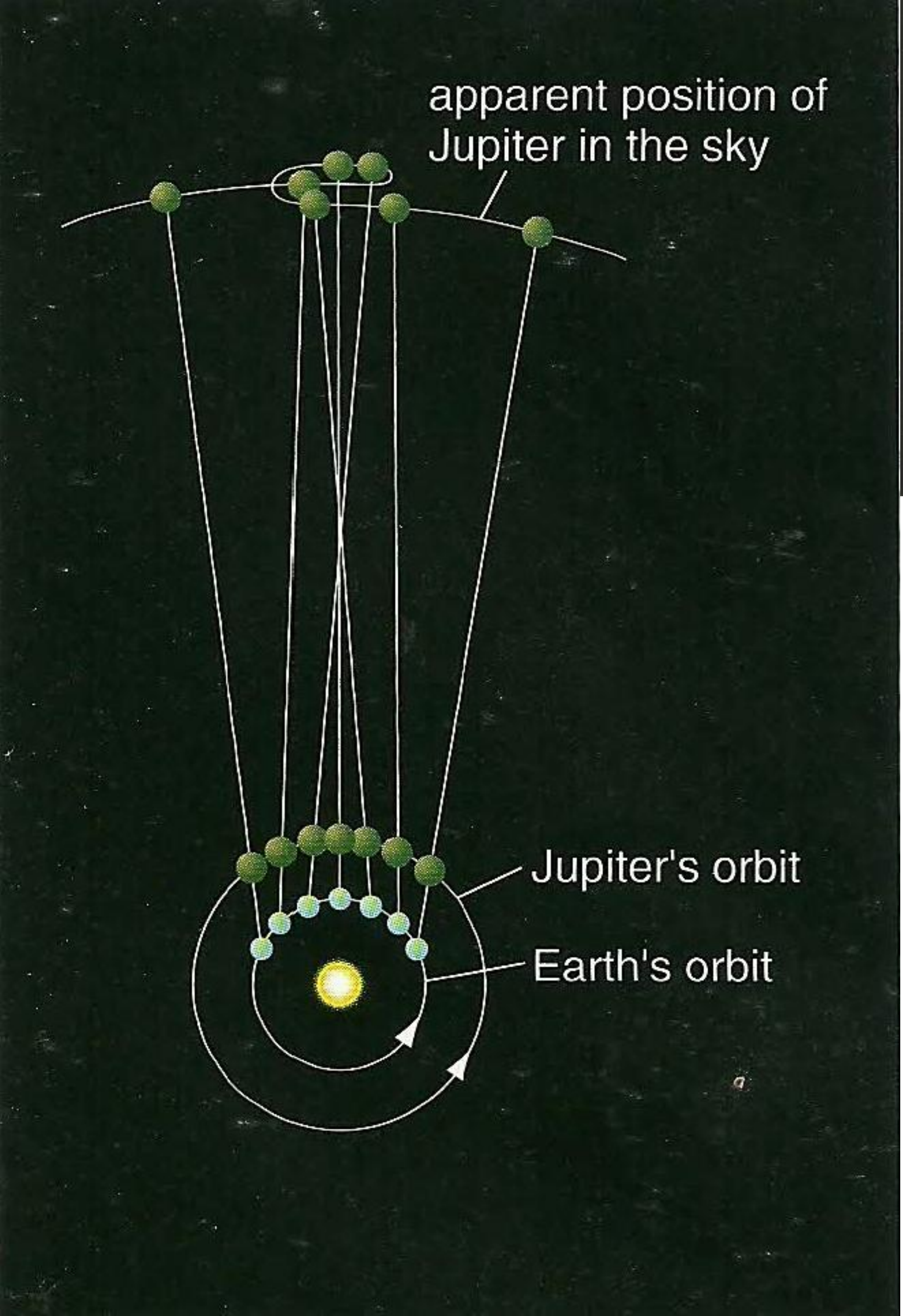


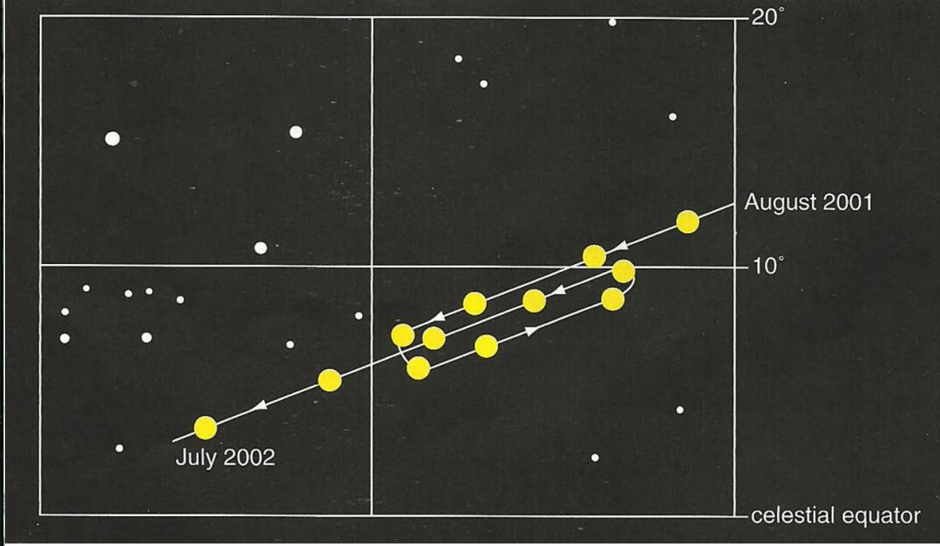


Scale in astronomical units AU

$$1\text{AU} = 1.496 \times 10^{11}\,\text{m}$$

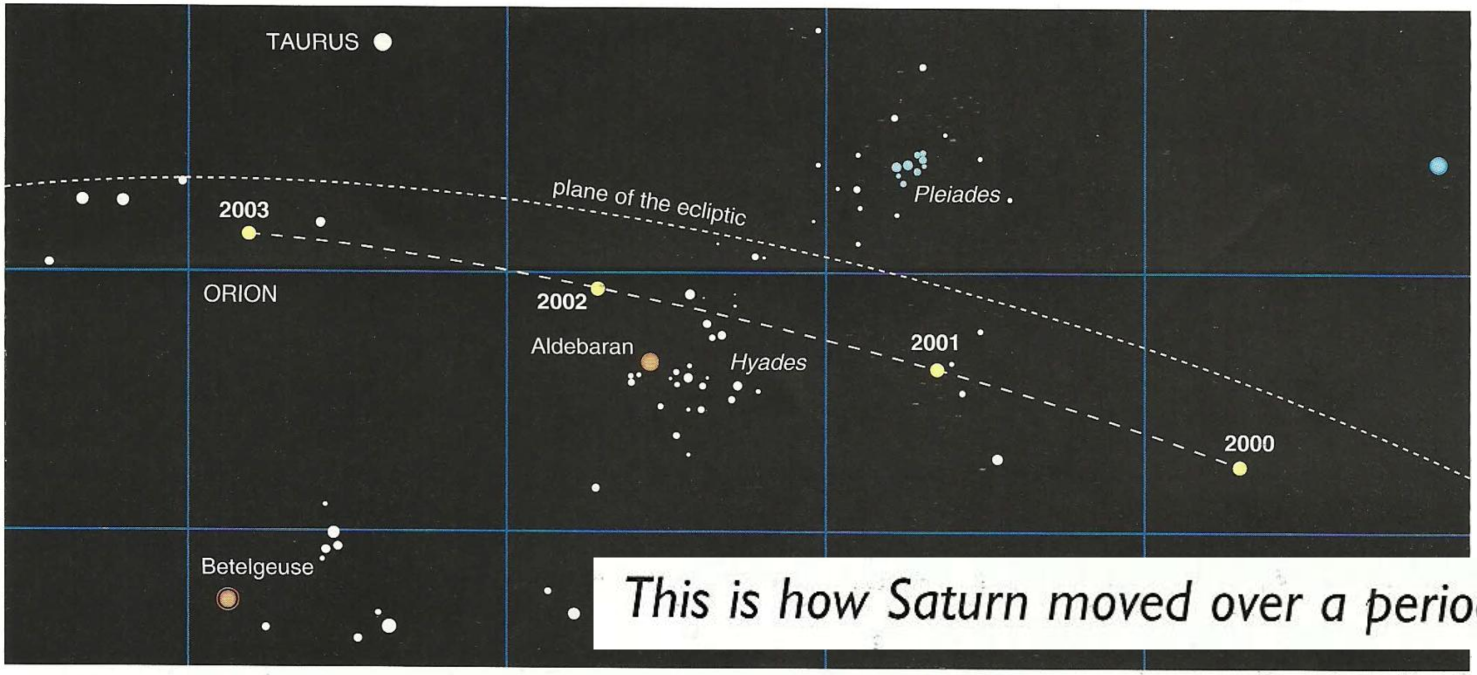




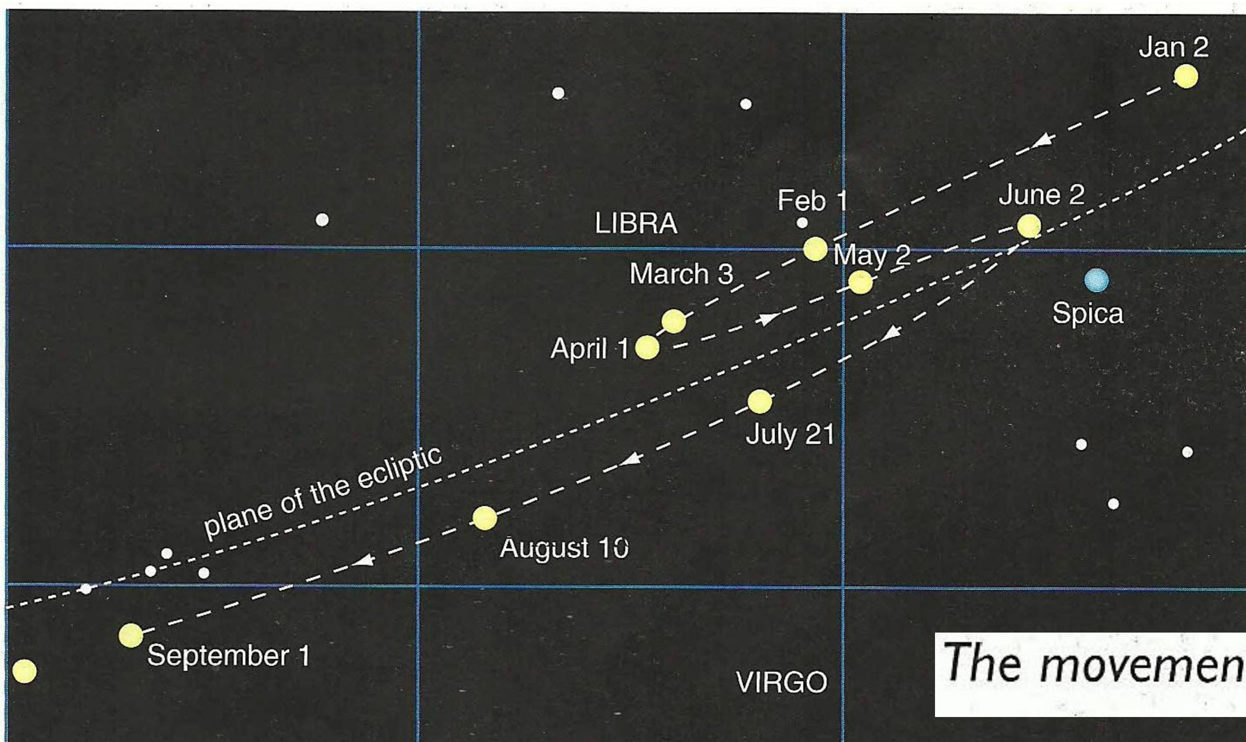


Since the Earth is also orbiting the Sun the positions of the planets as observed from Earth appear to make complex motions across the sky as viewed over any nights.

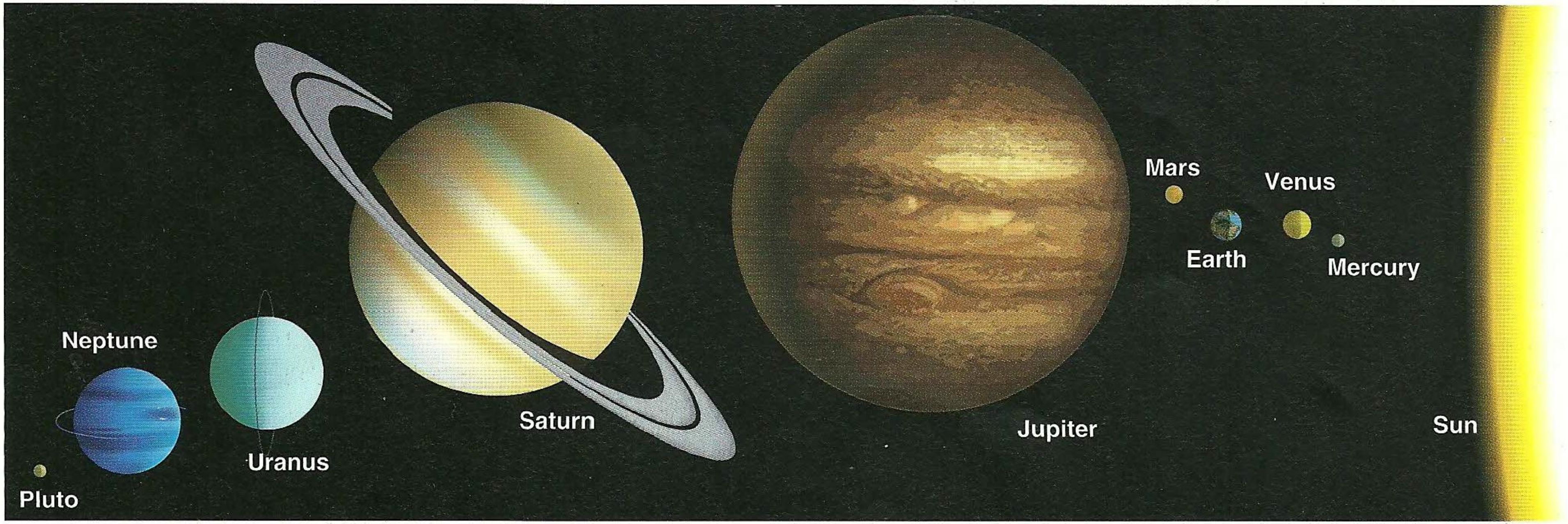
This is why a heliocentric model is *much easier to understand* than one based upon a fixed Earth (geocentric)



This is how Saturn moved over a period of 4 years



The movement of Mars during 1999



Planet	*Diameter of planet*	*Average distance of planet from the Sun*	*Time taken to go round the Sun*	*Number of moons*	*Average temperature on sunny side*
Mercury	4900 km	58 million km	88 days	0	350°C
Venus	12 000 km	108 million km	225 days	0	480°C
Earth	12 800 km	150 million km	365¼ days	1	20°C
Mars	6800 km	228 million km	687 days	2	0°C
Jupiter	143 000 km	780 million km	12 years	14	−150°C
Saturn	120 000 km	1430 million km	29 years	24	−190°C
Uranus	52 000 km	2800 million km	84 years	15	−220°C
Neptune	49 000 km	4500 million km	165 years	3	−240°C
Pluto	3000 km	5900 million km	248 years	1	−240°C

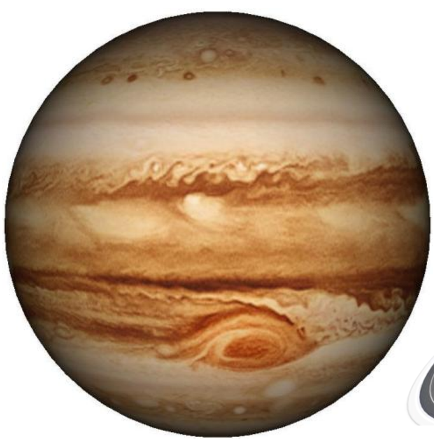
Object	$M/M_\oplus$	a /AU	$R/R_\oplus$	T_{rot} / days	P /Yr
Sun	332,837	-	109.123	-	-
Mercury	0.055	0.387	0.383	58.646	0.241
Venus†	0.815	0.723	0.949	243.018	0.615
Earth	1.000	1.000	1.000	0.997	1.000
Mars	0.107	1.523	0.533	1.026	1.881
Jupiter	317.85	5.202	11.209	0.413	11.861
Saturn	95.159	9.576	9.449	0.444	29.628
Uranus†	14.500	19.293	4.007	0.718	84.747
Neptune	17.204	30.246	3.883	0.671	166.344
Pluto†	0.003	39.509	0.187	6.387	248.348

Venus, Uranus and Pluto rotate clockwise about their internal axis
All other planets rotate anti-clockwise

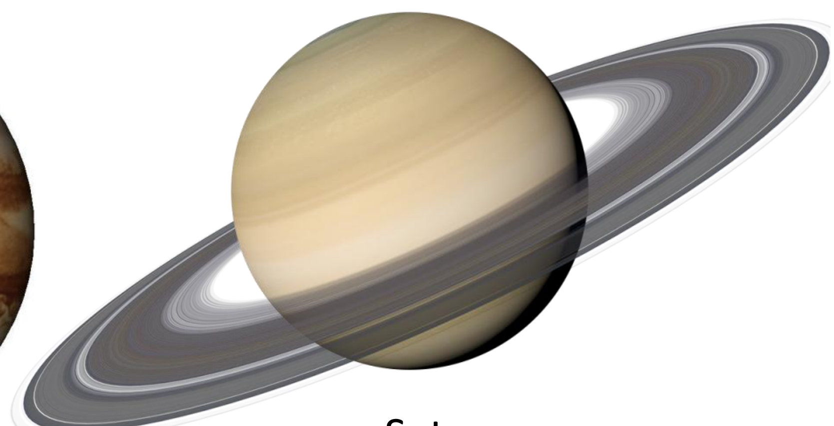
Earth parameters

$$M_\oplus = 5.972\times10^{24}\,\text{kg}$$

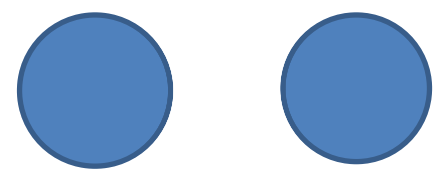
$$R_\oplus = 6.371\times10^{6}\,\text{m}$$



Jupiter



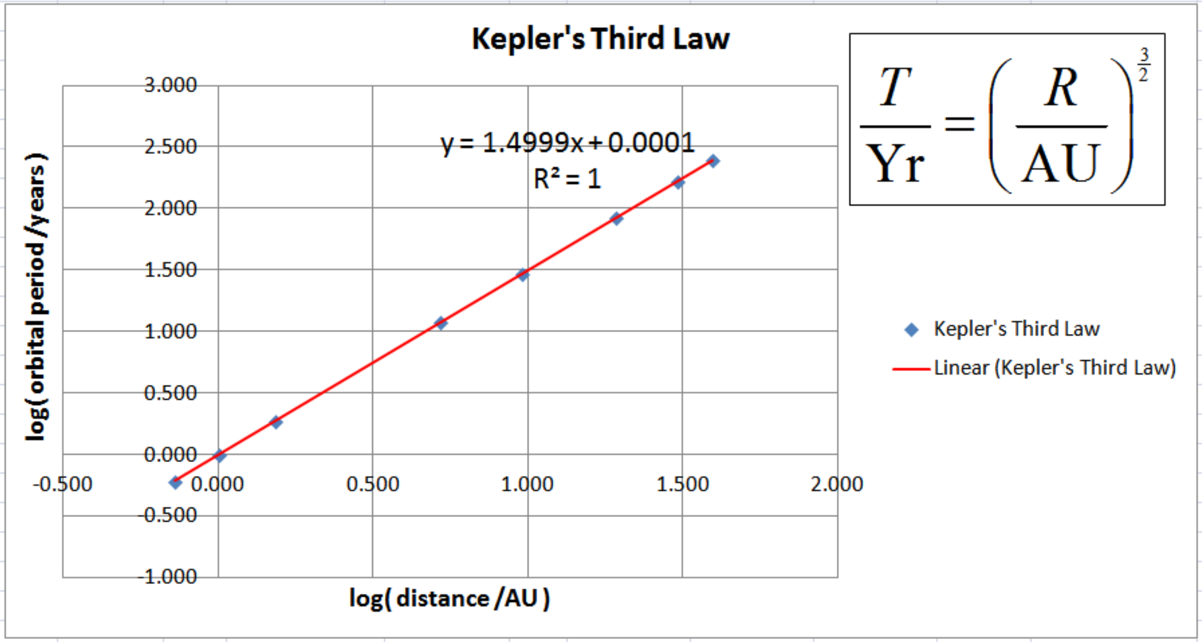
Saturn



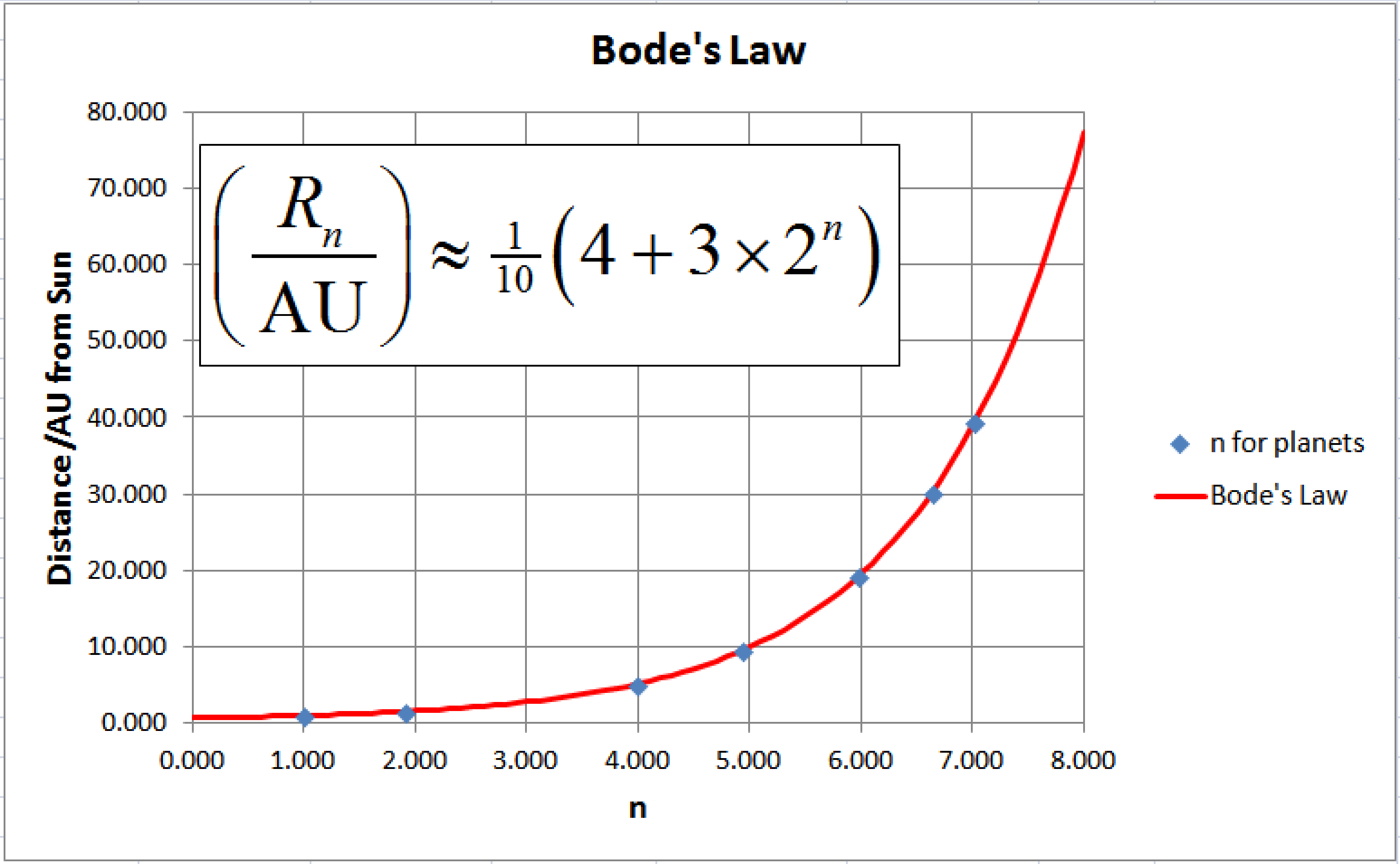
Uranus

Neptune

Object	Mass in Earth masses	Distance from Sun in AU	Radius in Earth radii	Rotational period /days	Orbital period /years	Gravitational field (in terms of g = 9.81 ms^-2)
Mercury	0.055	0.387	0.38	58.65	0.24	0.37
Venus	0.815	0.723	0.95	243.02	0.62	0.90
Earth	1.000	1.000	1.00	1.00	1.00	1.00
Mars	0.107	1.523	0.53	1.03	1.88	0.38
Jupiter	317.85	5.20	11.21	0.41	11.86	2.53
Saturn	95.16	9.58	9.45	0.44	29.63	1.07
Uranus	14.50	19.29	4.01	0.72	84.75	0.90
Neptune	17.20	30.25	3.88	0.67	166.34	1.14
Pluto	0.00	39.51	0.19	6.39	248.35	0.09
Sun	332,837	-	109.12	-	-	27.95



$$\frac{T}{\mathrm{Yr}} = \left(\frac{R}{\mathrm{AU}}\right)^{\frac{3}{2}}$$



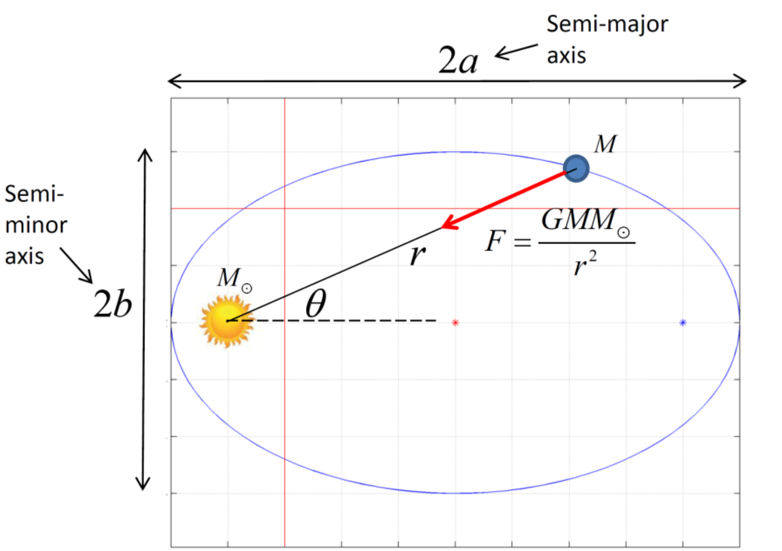
Bode's Law
$$\left(\frac{R_n}{\text{AU}}\right) \approx \frac{1}{10}\left(4 + 3 \times 2^n\right)$$
Distance /AU from Sun
80.000
70.000
60.000
50.000
40.000
30.000
20.000
10.000
0.000
0.000
1.000
2.000
3.000
4.000
5.000
6.000
7.000
8.000
n
n for planets
Bode's Law

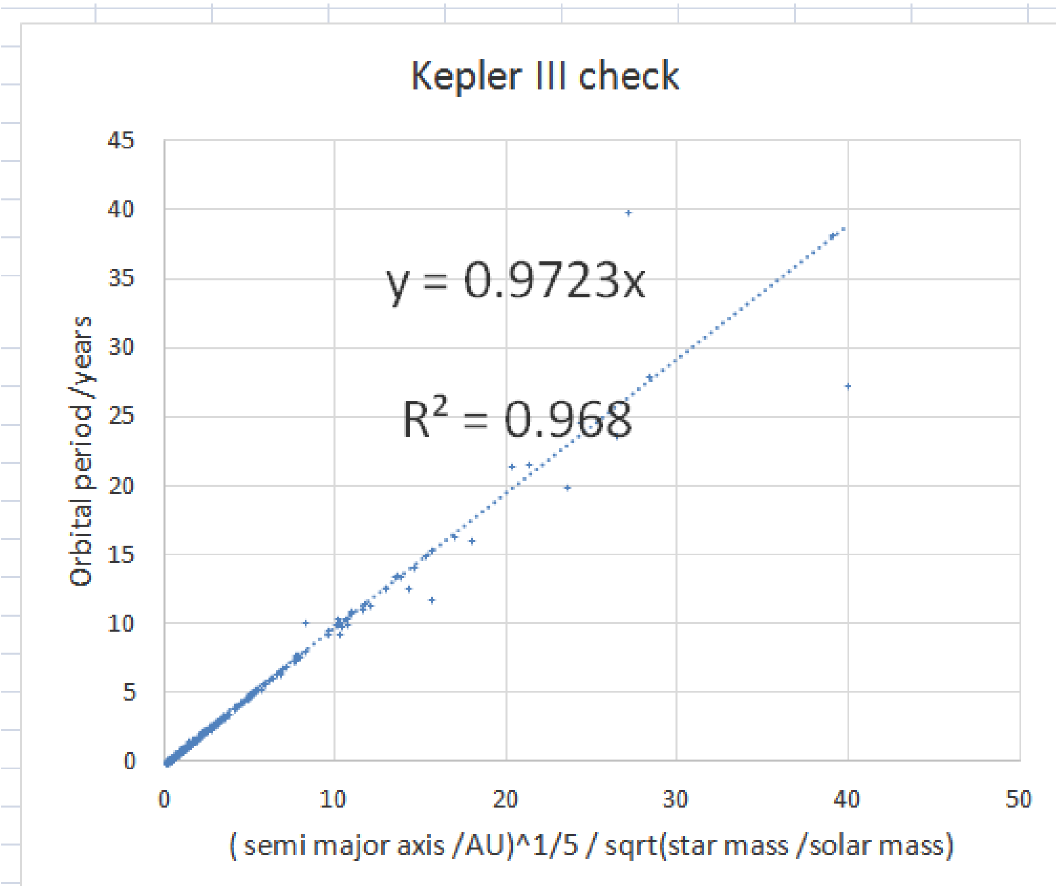
Msun /kg	1.989E+30
Mjupiter /kg	1.898E+27

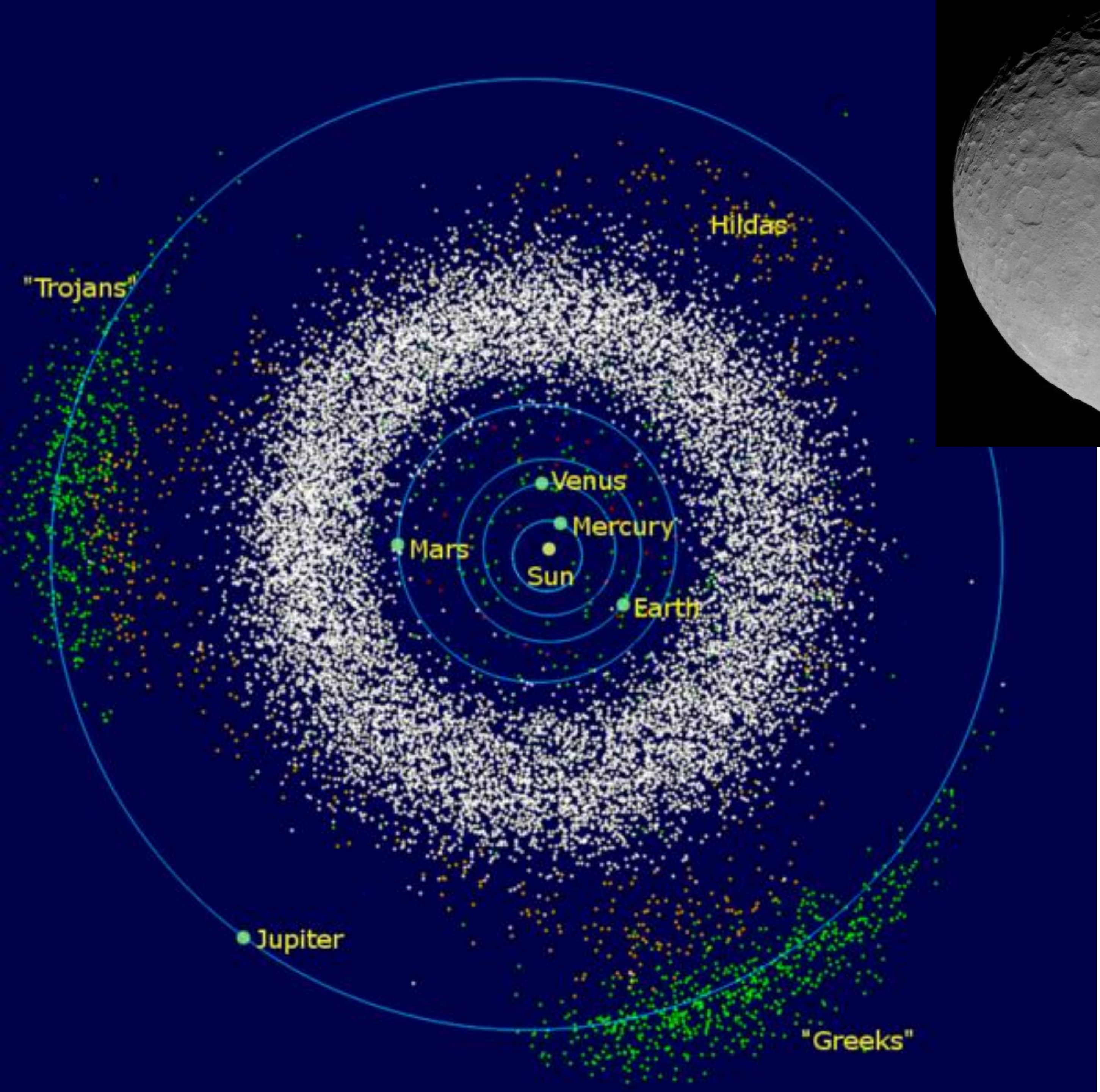
Star mass /solar mass	orbital_period /days	Period /years	Exoplanet	Star	Exoplanet mass / mass	Exoplanet mass /solar	semi_major_axis	(a/AU)^1.5 /sqrt(M/Msol)
4.5	471.6	1.291170431	HD 13189 b	HD 13189	14	0.013359477	1.85	1.186182017
2.7	326.03	0.892621492	11 Com b	11 Com	19.4	0.018512418	1.29	0.891666978
2.7	594.9	1.628747433	eps Tau b	eps Tau	7.6	0.007252288	1.93	1.631751729
2.4	1455	3.983572895	HD 14067 b	HD 14067	7.8	0.007443137	3.4	4.046809443
2.4	157.57	0.431403149	HD 100655 b	HD 100655	1.7	0.001622222	0.76	0.42767589
2.3	359.9	0.985352498	HD 17092 b	HD 17092	4.6	0.004389542	1.29	0.966096809
2.25	579.8	1.587405886	sig Per b	sig Per	6.5	0.006202614	1.8	1.609968944
2.17	835.477	2.287411362	HD 110014 b	HD 110014	11.09	0.010582614	2.14	2.12515589
2.1	184.2	0.504312115	HIP 105854 b	HIP 105854	8.2	0.007824837	0.81	0.503057793
2.0687	288.822	0.79075154	Kepler-34(AB) b	Kepler-34(AB)	0.219928893	0.000209867	1.0896	0.790773095

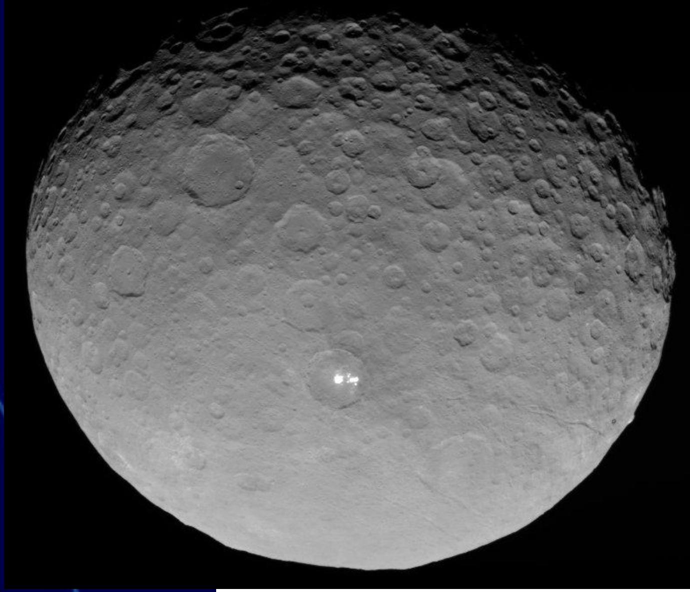
Kepler III works for *Exoplanets* too!

$$\left(\frac{T}{\mathrm{Yr}}\right) = \frac{1}{\sqrt{M/M_\odot}}\left(\frac{a}{\mathrm{AU}}\right)^{\frac{3}{2}}$$





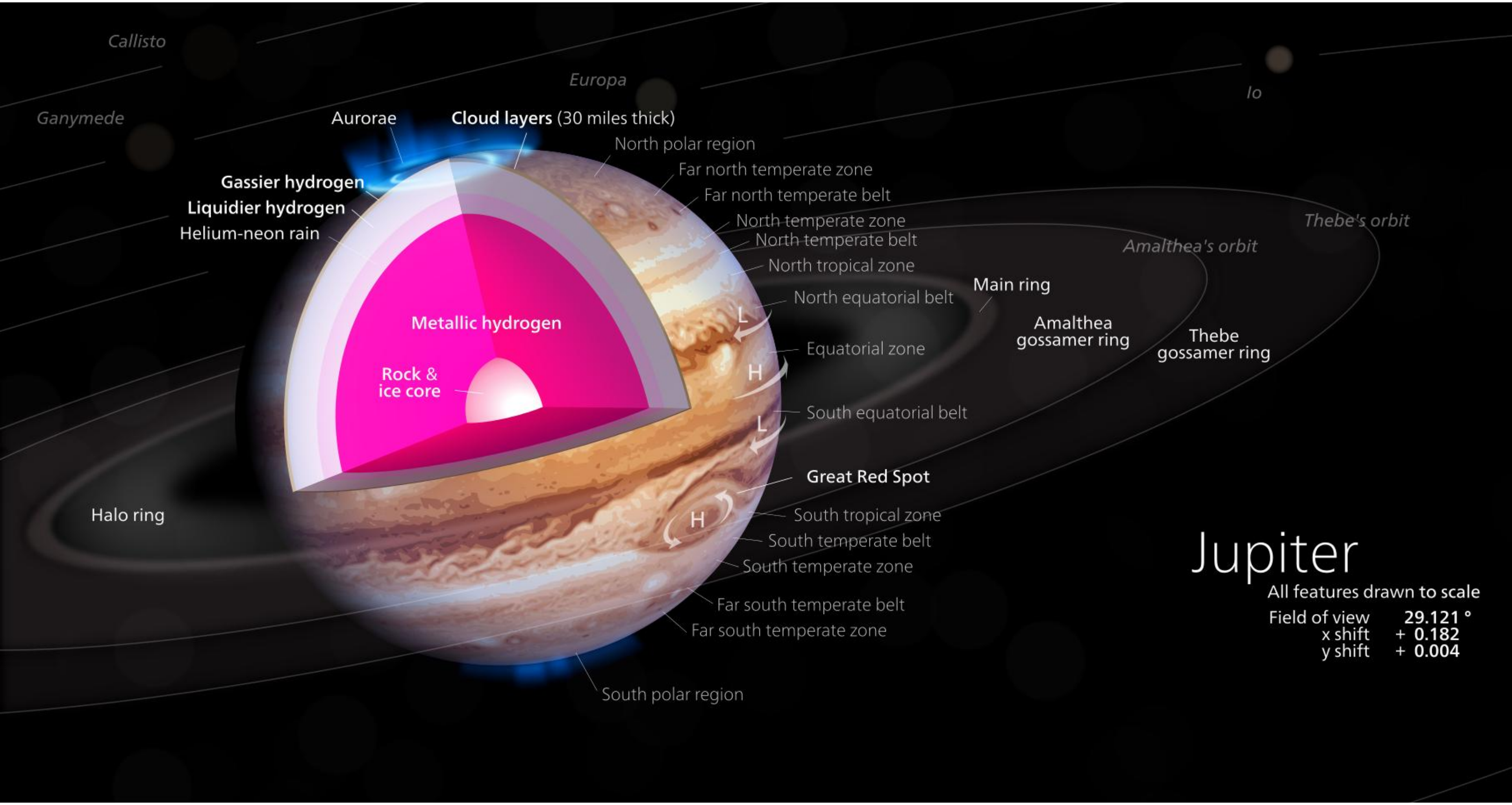


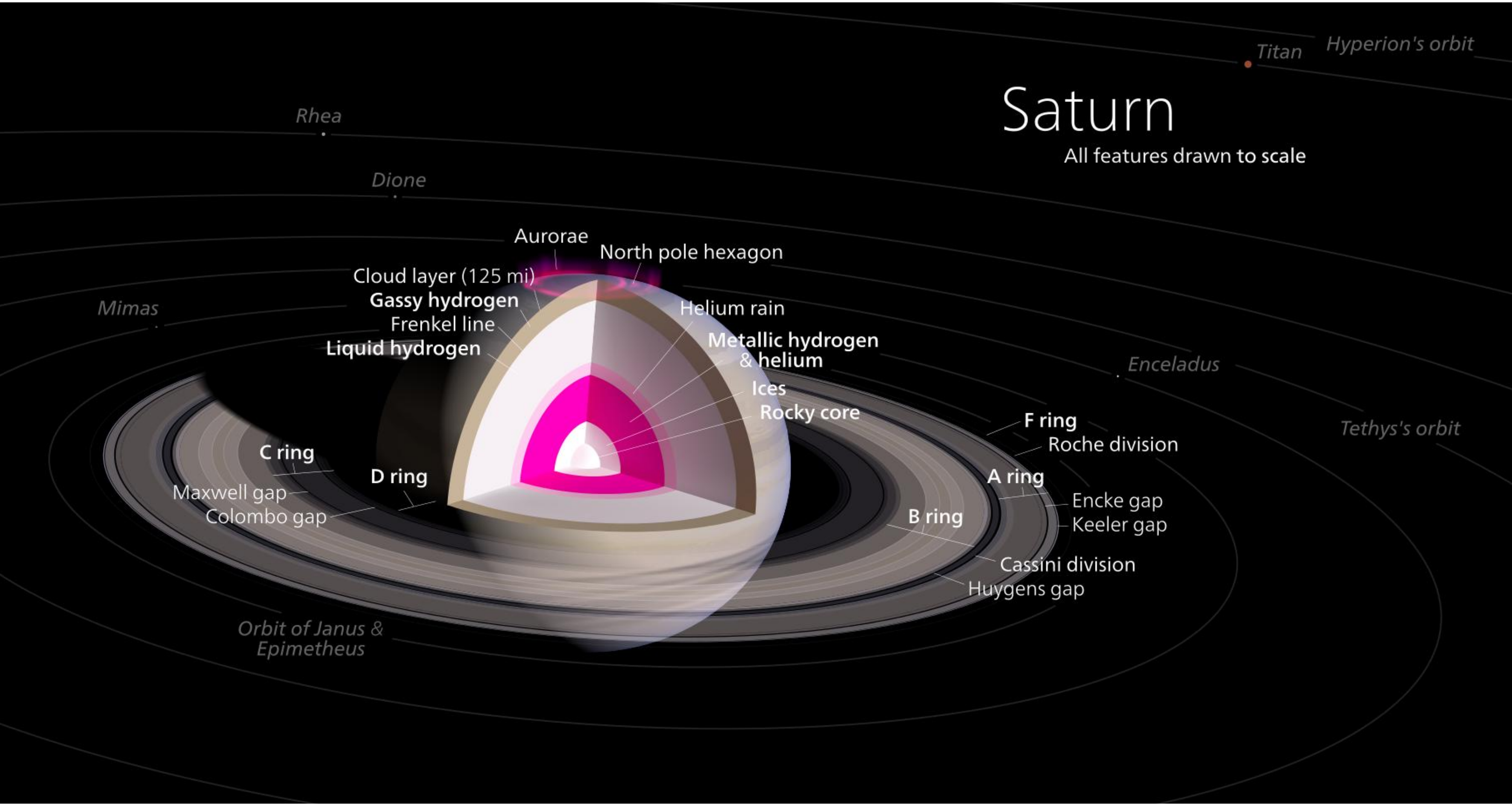


Dwarf planet **Ceres** within the *Asteroid belt*

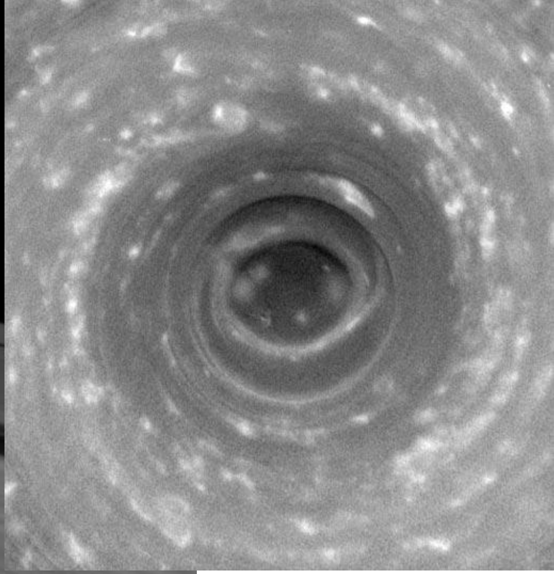
Radius
476 km

Mass
0.00015 Earths
(9.43 x 10^{20} kg)

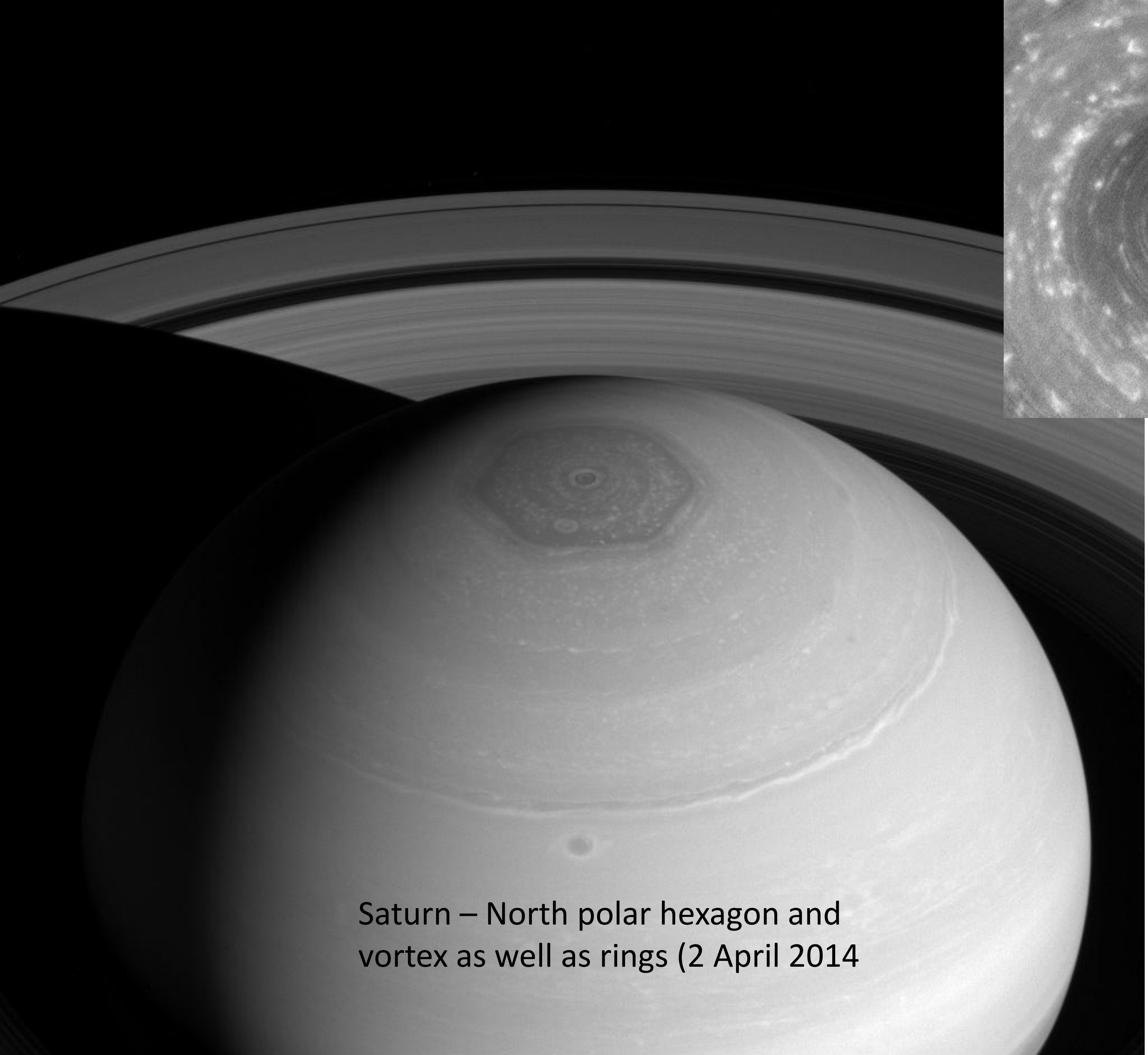

Callisto
Europa
Io
Ganymede
Aurorae
Cloud layers (30 miles thick)
North polar region
Far north temperate zone
Far north temperate belt
North temperate zone
North temperate belt
North tropical zone
North equatorial belt
Equatorial zone
South equatorial belt
Great Red Spot
South tropical zone
South temperate belt
South temperate zone
Far south temperate belt
Far south temperate zone
South polar region
Gassier hydrogen
Liquidier hydrogen
Helium-neon rain
Metallic hydrogen
Rock & ice core
Halo ring
Main ring
Amalthea gossamer ring
Thebe gossamer ring
Amalthea's orbit
Thebe's orbit
L
H
L
H
Jupiter
All features drawn to scale
Field of view 29.121 °
x shift + 0.182
y shift + 0.004



Saturn
All features drawn to scale
Titan
Hyperion's orbit
Rhea
Dione
Aurorae
North pole hexagon
Cloud layer (125 mi)
Gassy hydrogen
Frenkel line
Liquid hydrogen
Helium rain
Metallic hydrogen & helium
Ices
Rocky core
Mimas
Enceladus
Tethys's orbit
F ring
Roche division
A ring
Encke gap
Keeler gap
C ring
D ring
Maxwell gap
Colombo gap
B ring
Cassini division
Huygens gap
Orbit of Janus & Epimetheus

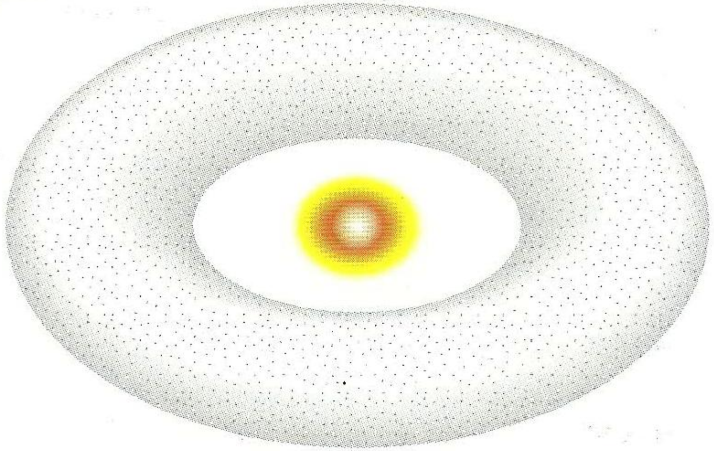


South Pole
Saturnian
‘hurricane’

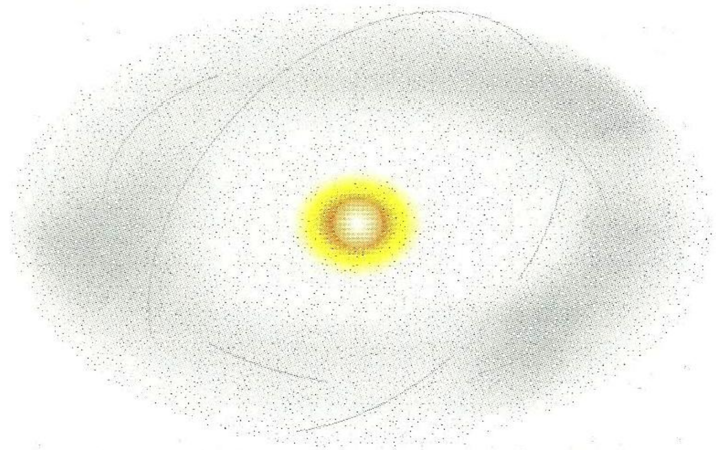


Saturn – North polar hexagon and
vortex as well as rings (2 April 2014

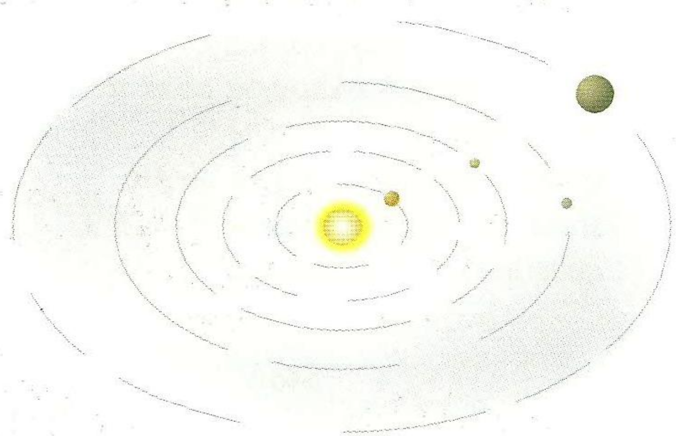
Formation of the solar system



1 4500 million years ago a shock wave, in a spiral arm of our galaxy, triggered the collapse of a gas cloud. This developed into a doughnut shape, which flattened out



2 Enough hydrogen gathered in the centre for fusion to start in the Sun. Solid particles began to strike each other and stick together

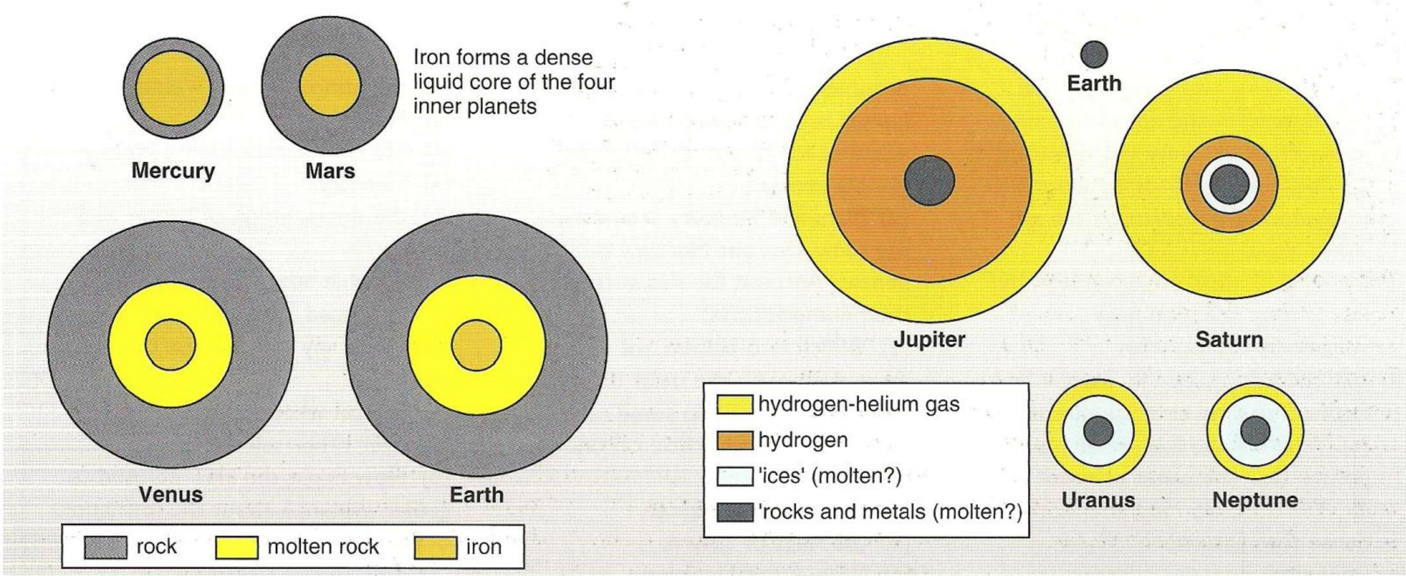


3 Eventually, as the small particles continued to coalesce, just a few large planets and moons were left. Most of the gas and dust in the solar system became attached to a planet, or was removed by a strong solar wind. After millions of years, the gravitational attraction between the planets tended to pull their orbits into the same plane.

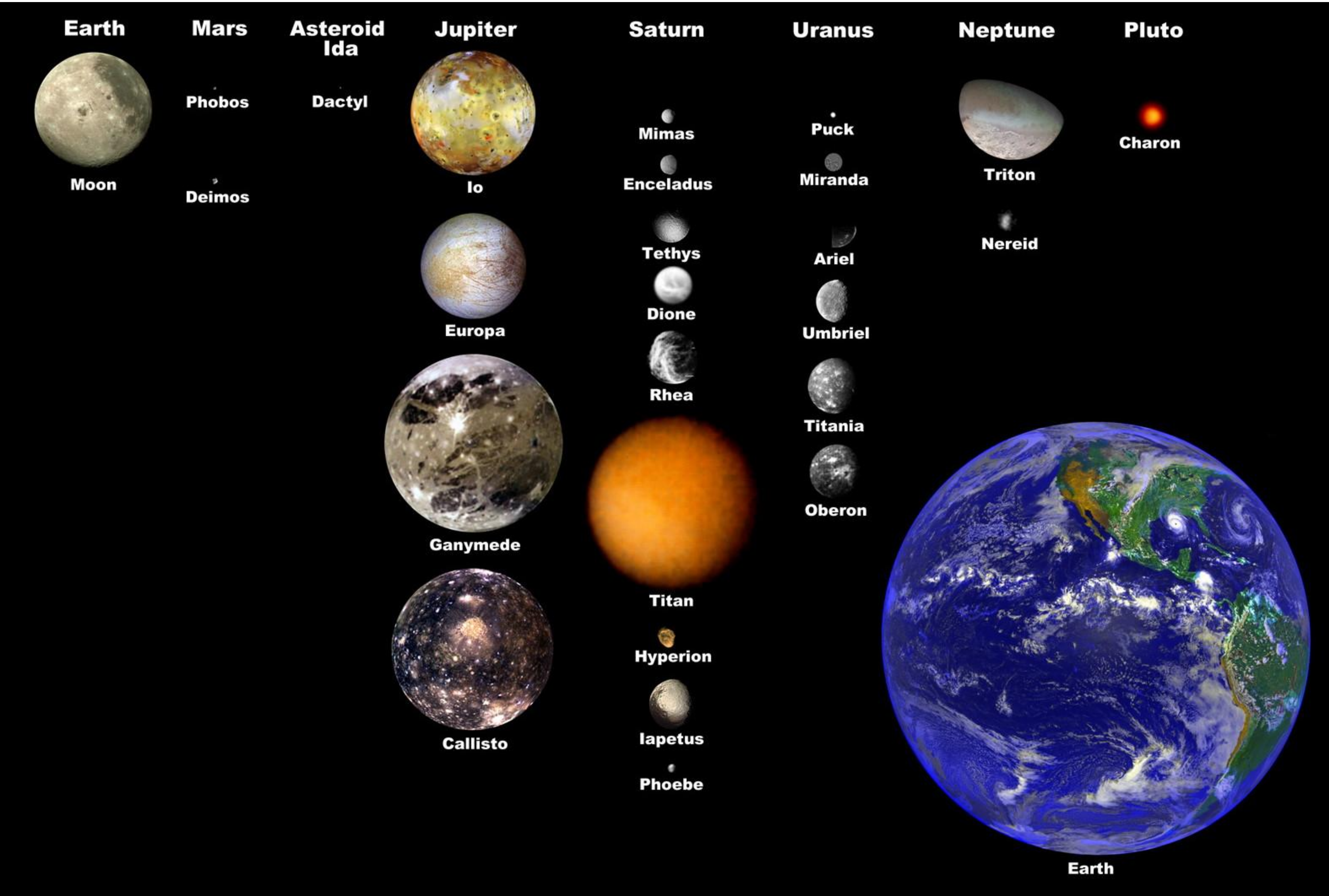
Planet	*Mass relative to Earth*	*Radius (Earth = 1)*	*Relative density (water = 1)*	*Distance from Sun in AU†*	*% Rocks*	*% Ice*	*% Gas*	*Main gases in atmosphere*
Mercury	0.06	0.38	5.4	0.39	nearly all	–	–	none
Venus	0.82	0.95	5.2	0.72	nearly all	–	some in atmosphere	CO_2
Earth	1	1	5.5	1	nearly all	water in oceans, ice at poles	some in atmosphere	N_2, O_2
Mars	0.11	0.53	3.9	1.5	nearly all	ice at poles	some in atmosphere	CO_2
Jupiter	318	11.2	1.3	5.2		10% rock/ice	90%	H_2, He
Saturn	95	9.4	0.7	9.5		30% rock/ice	70%	H_2, He
Uranus	14.6	4.1	1.2	19.1		70% rock/ice	30%	H_2, He, CH_4
Neptune	17.2	3.9	1.7	30.1		70% rock/ice	30%	H_2, He, CH_4
Pluto	0.1?	0.4?	?	39.4		mostly rock/ice	?	none?

Table 1

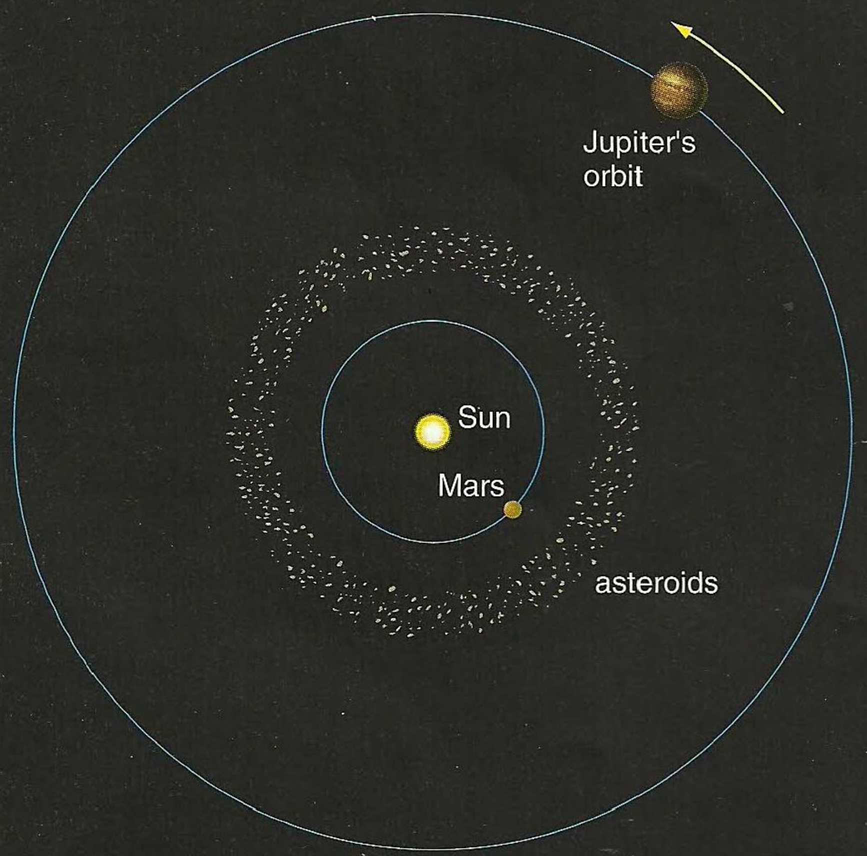
† 1 Astronomical Unit of AU is the average Earth–Sun distance.
O_2 oxygen, N_2 nitrogen, CH_4 methane, CO_2 carbon dioxide.

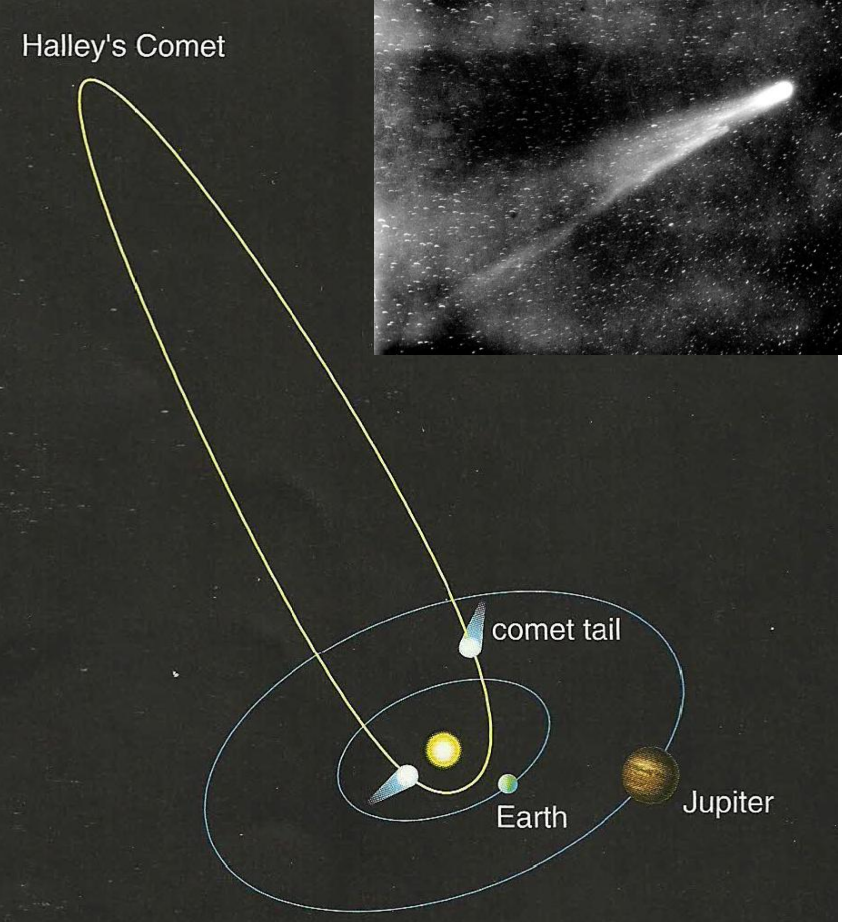


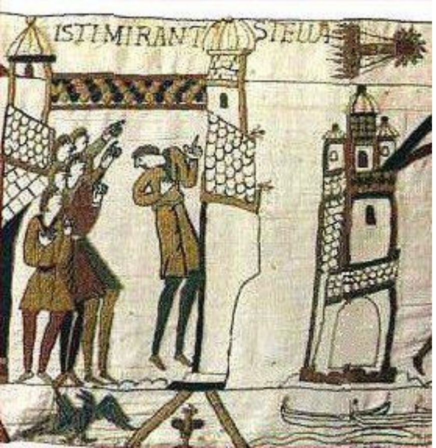
Moons



Earth
Mars
Asteroid Ida
Jupiter
Saturn
Uranus
Neptune
Pluto
Moon
Phobos
Deimos
Dactyl
Io
Europa
Ganymede
Callisto
Mimas
Enceladus
Tethys
Dione
Rhea
Titan
Hyperion
Iapetus
Phoebe
Puck
Miranda
Ariel
Umbriel
Titania
Oberon
Triton
Nereid
Charon
Earth


Jupiter's
orbit
Sun
Mars
asteroids

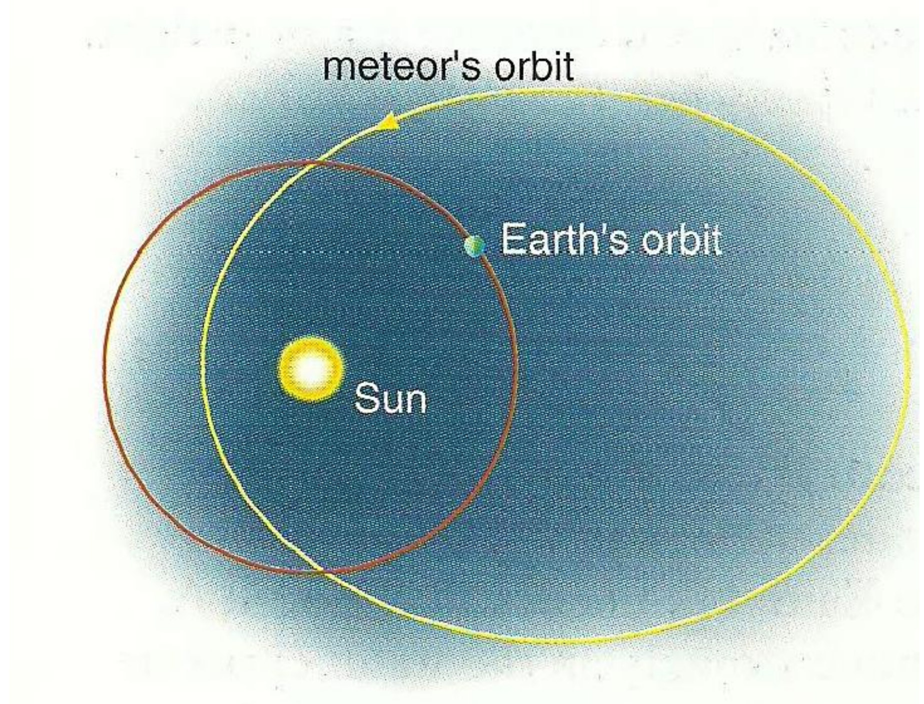

Halley's Comet
comet tail
Earth
Jupiter

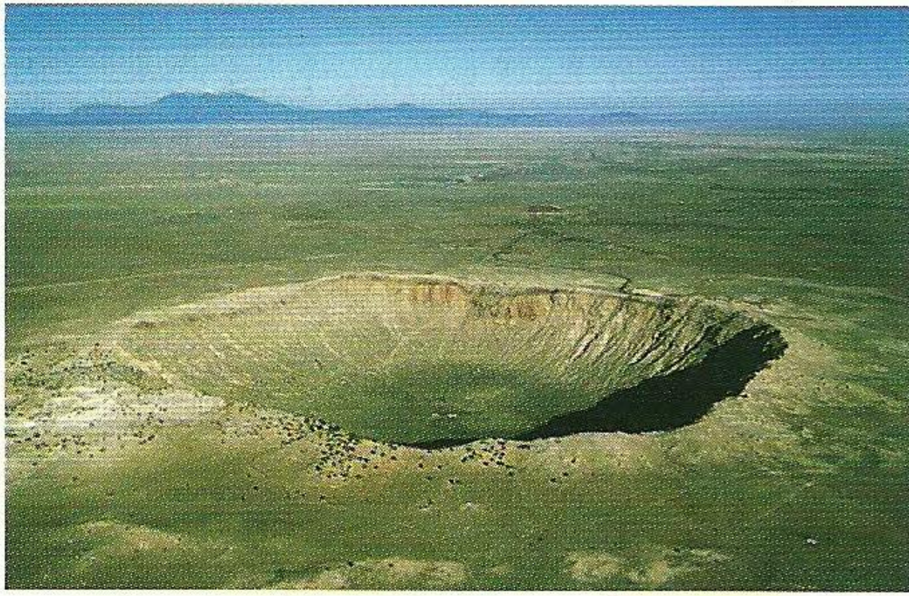

ISTIMIRANT


Hale Bop 1997


1577

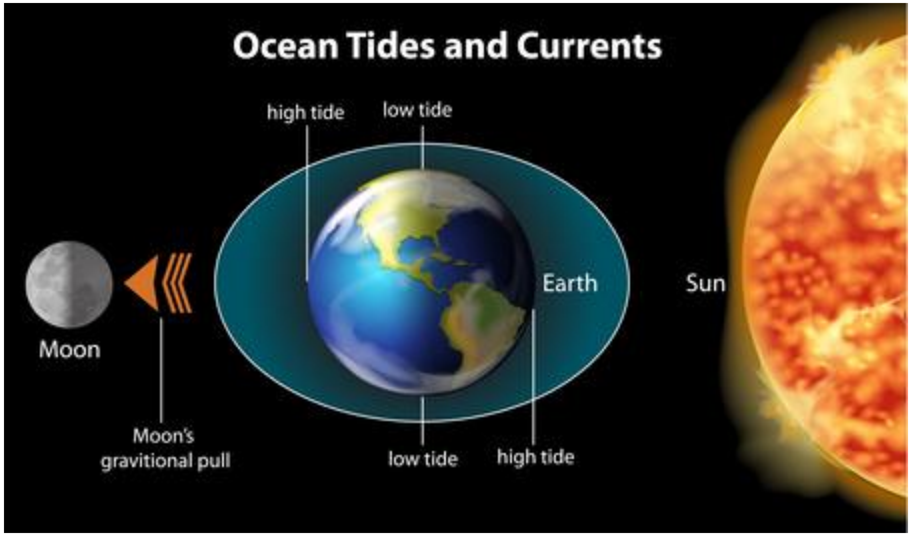
Comet 67P/Churyumov–Gerasimenko photographed from the Rosetta mission 2014

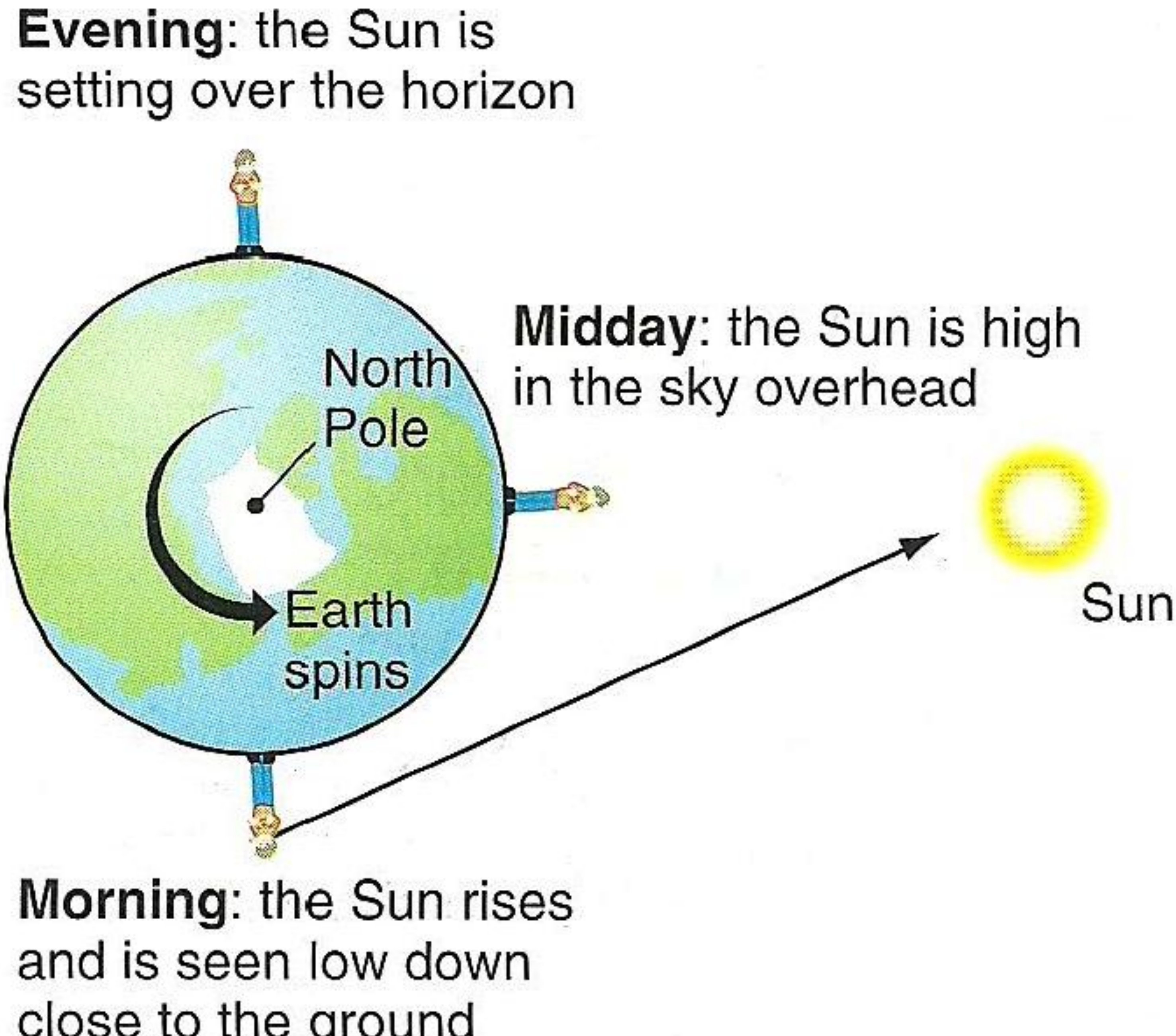




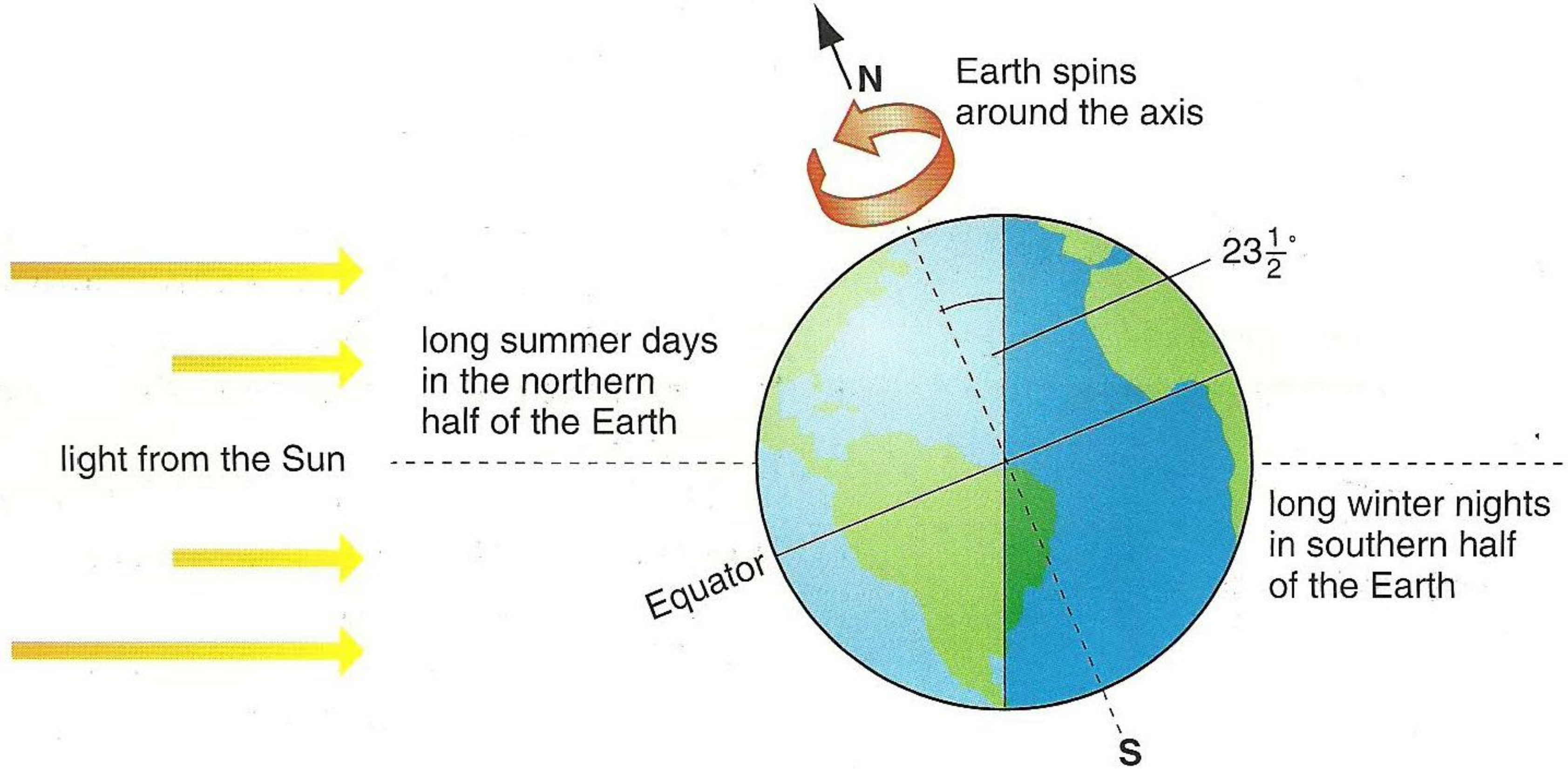
This crater in the Arizona desert is thought to have been formed by a meteor impact about 20 000 years ago. It is 200 m deep and 800 m wide.

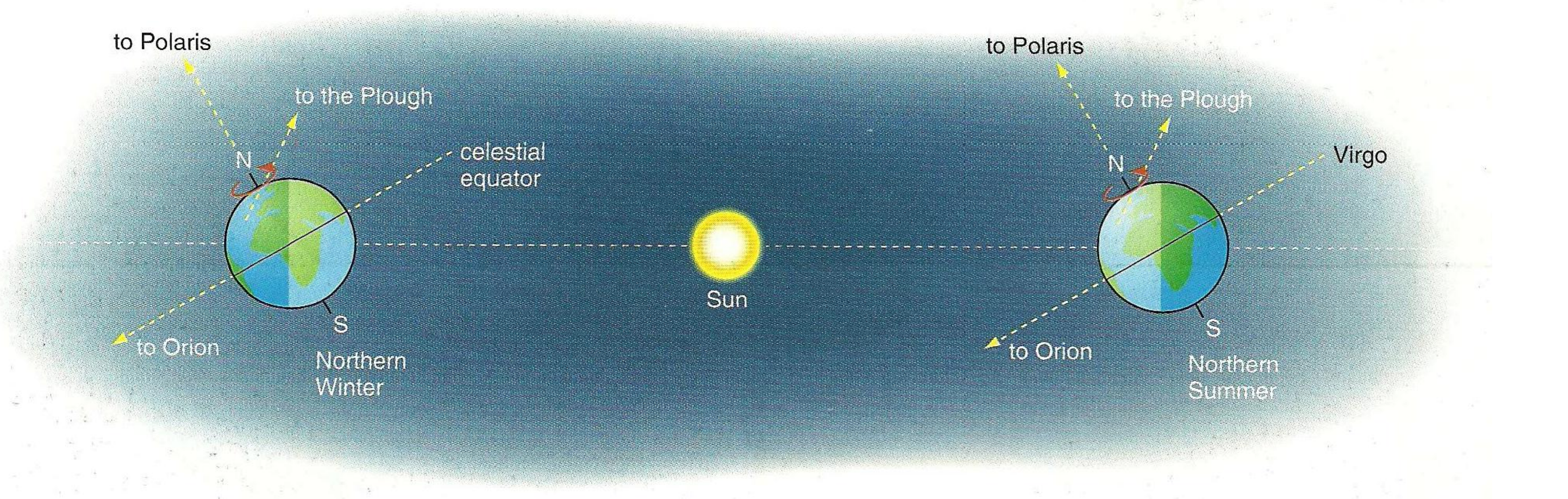
Earth seasons & tides

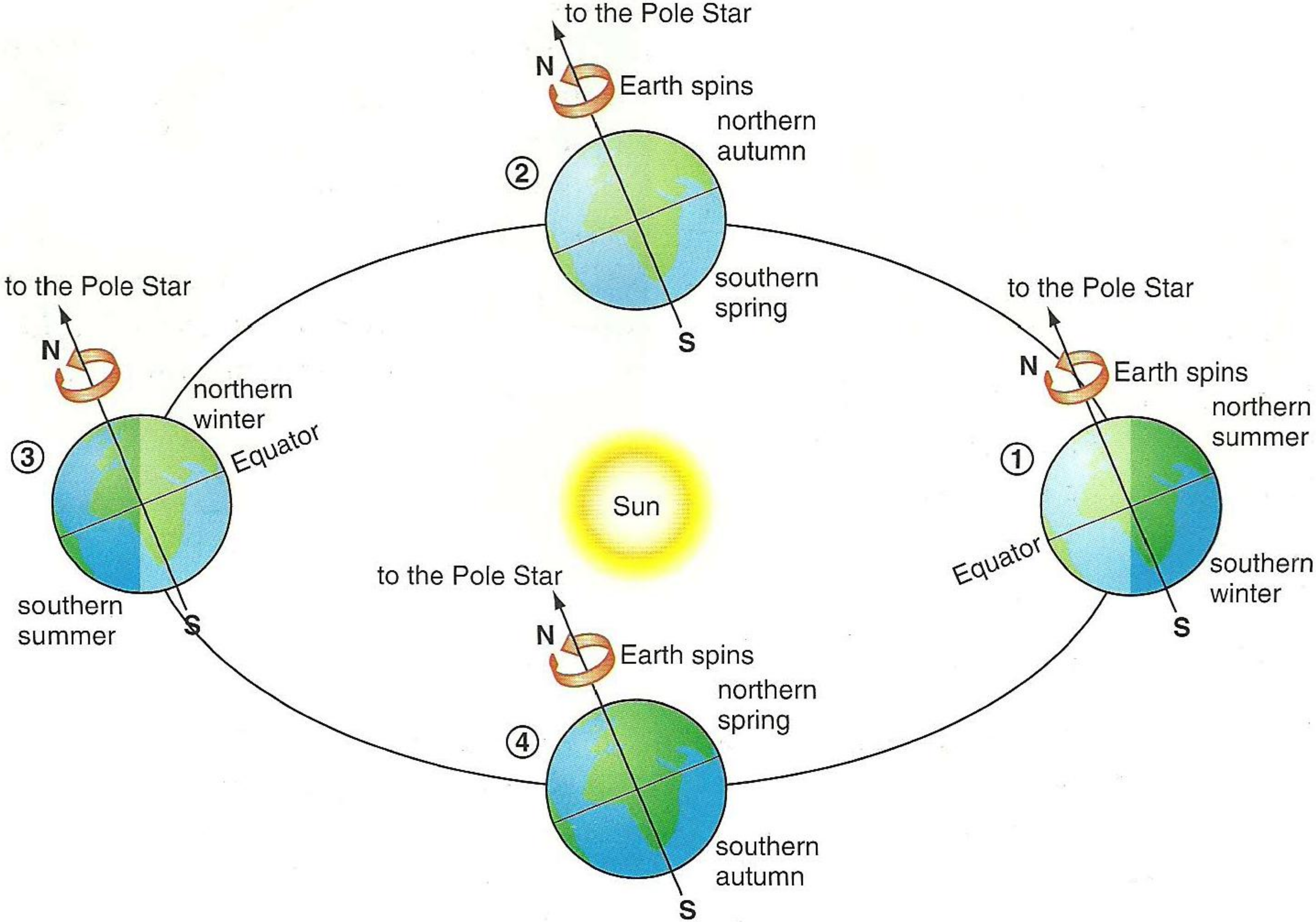




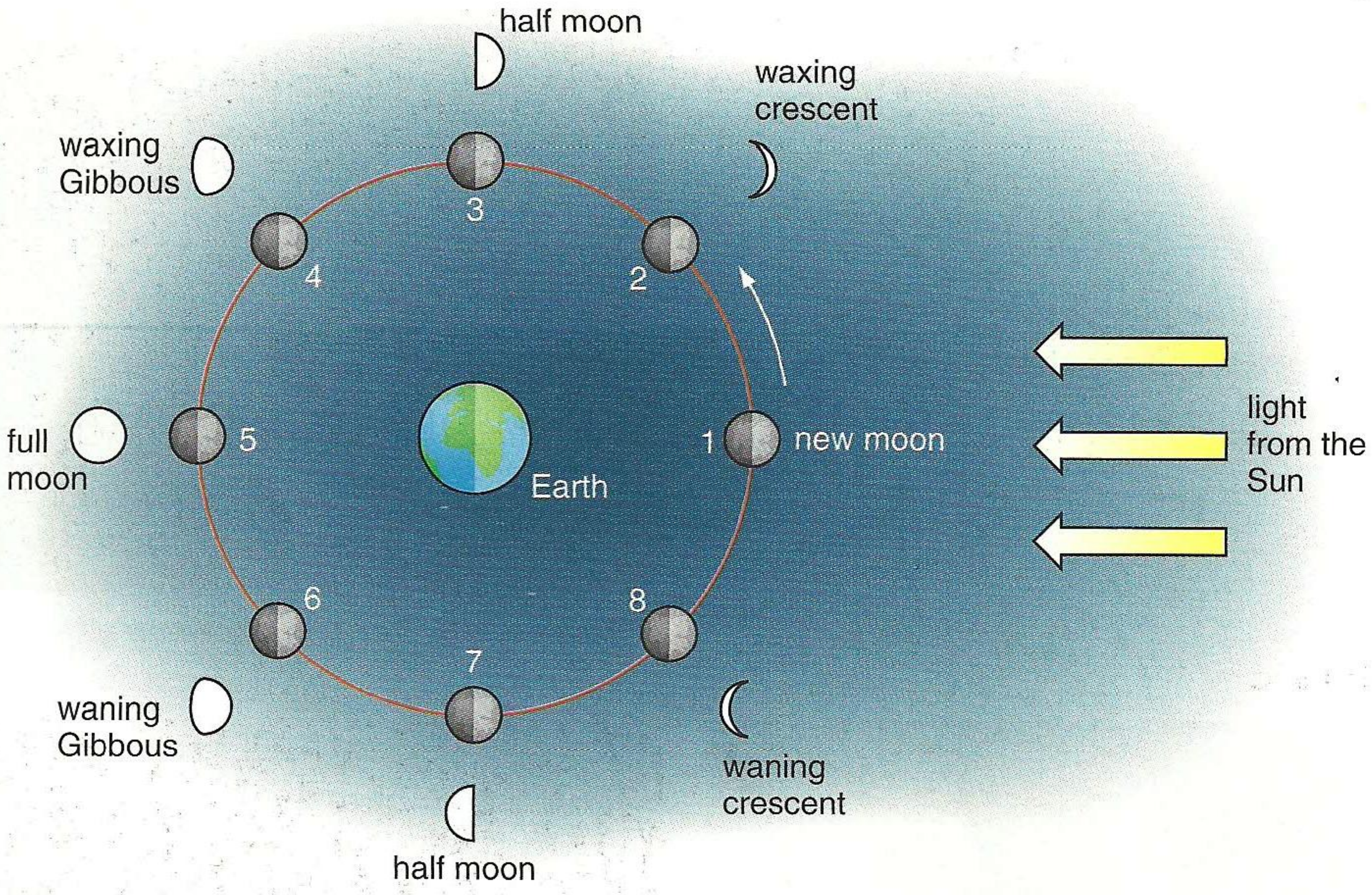
Evening: the Sun is setting over the horizon
Midday: the Sun is high in the sky overhead
North Pole
Earth spins
Sun
Morning: the Sun rises and is seen low down close to the ground


N
Earth spins
around the axis
$23\frac{1}{2}°$
long summer days
in the northern
half of the Earth
light from the Sun
long winter nights
in southern half
of the Earth
Equator
S

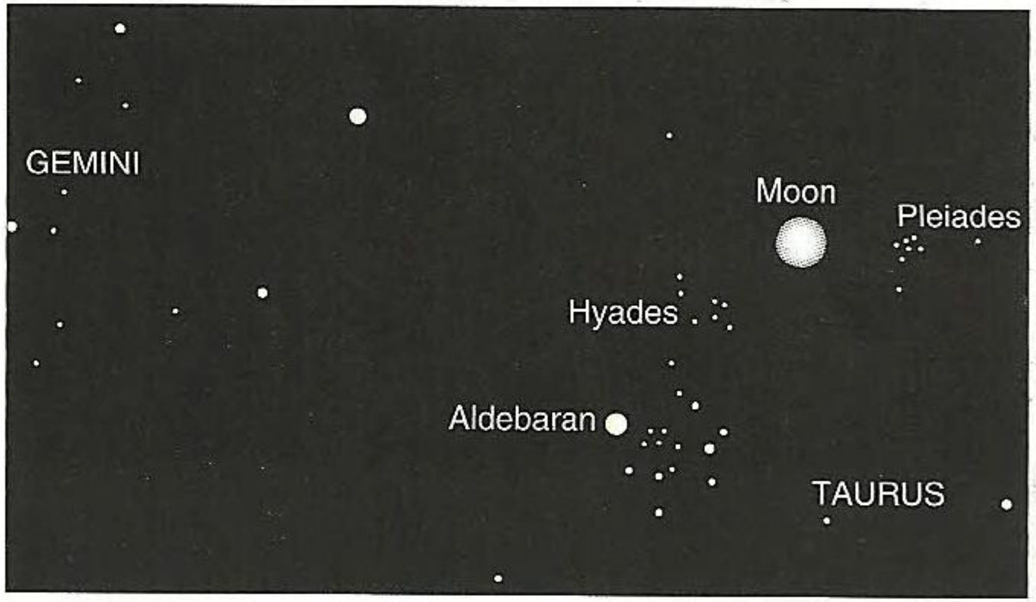

to Polaris
to the Plough
N
celestial
equator
to Orion
S
Northern
Winter
Sun
to Polaris
to the Plough
N
Virgo
to Orion
S
Northern
Summer



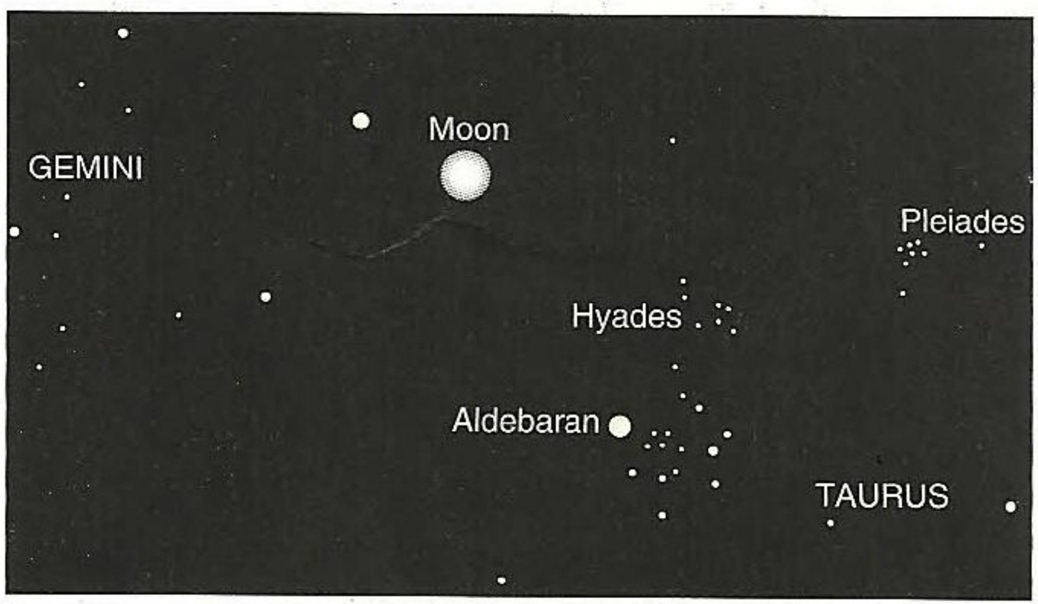
to the Pole Star
N
Earth spins
northern autumn
2
southern spring
S
to the Pole Star
N
northern winter
Equator
3
southern summer
S
to the Pole Star
N
Earth spins
northern summer
1
Equator
southern winter
S
Sun
to the Pole Star
N
Earth spins
northern spring
4
southern autumn
S

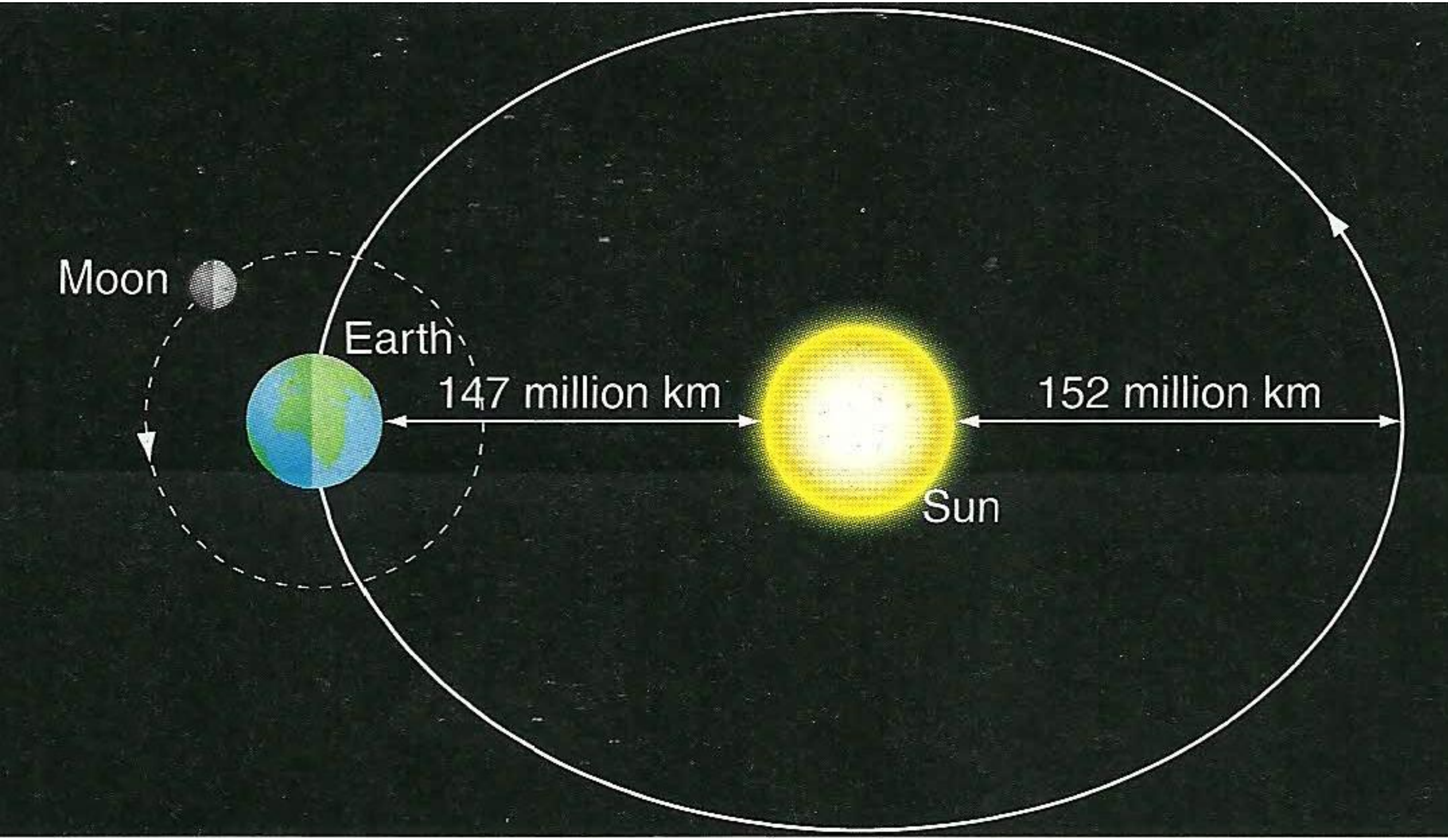


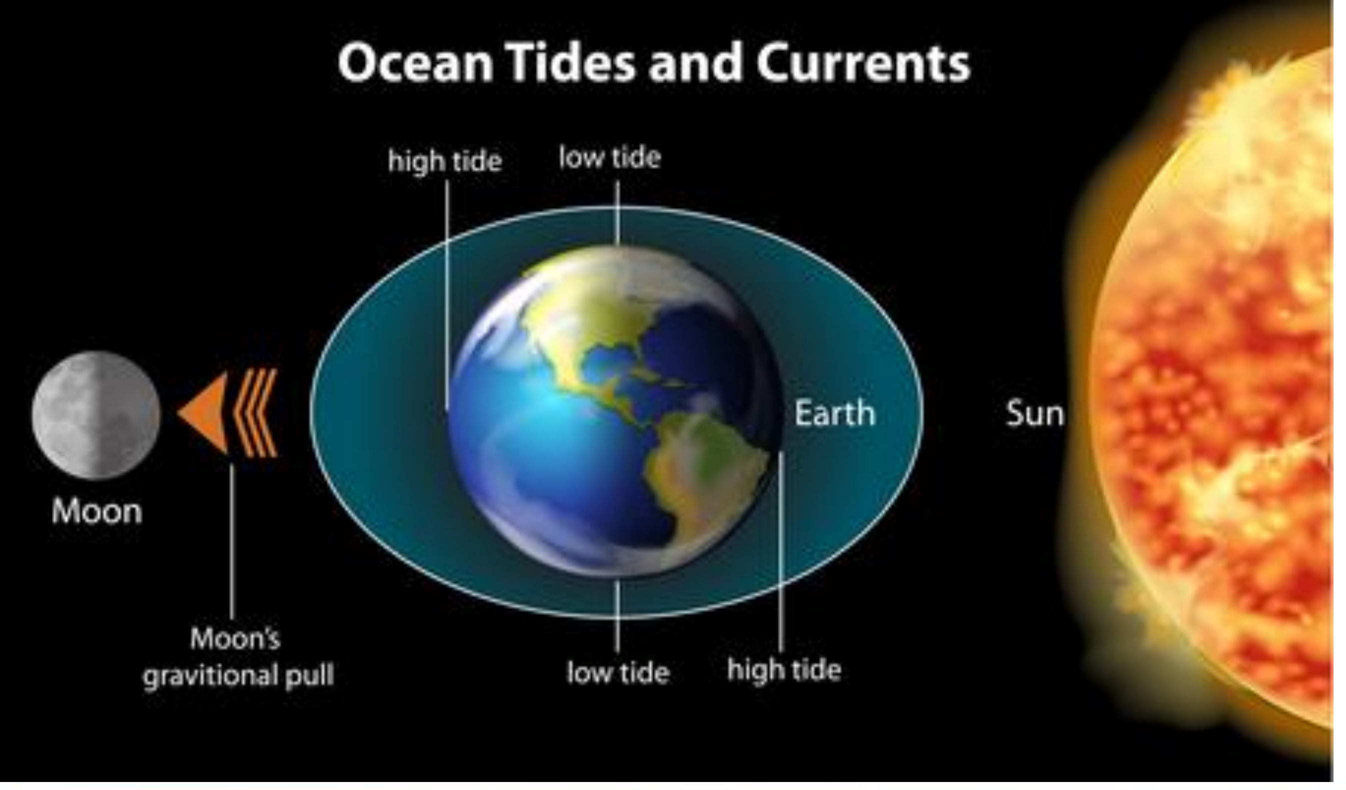
half moon
waxing
crescent
waxing
Gibbous
3
4
2
light
from the
Sun
full
moon
5
1
new moon
Earth
6
8
7
waning
Gibbous
waning
crescent
half moon

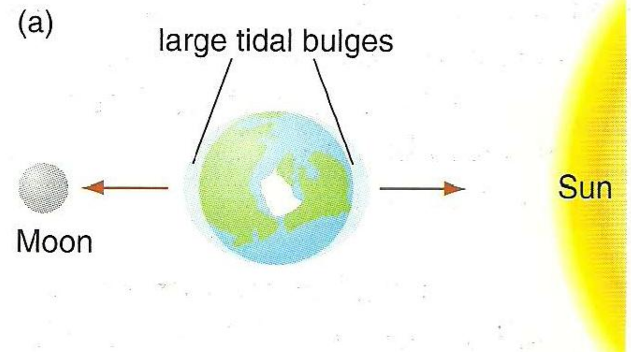


Change of position of the Moon against background constellations over the course of one day

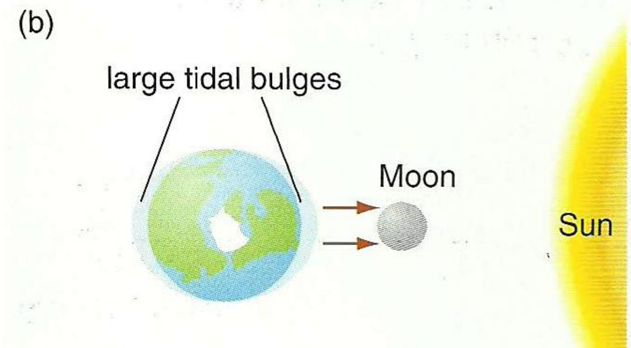



Moon
Earth
147 million km
152 million km
Sun

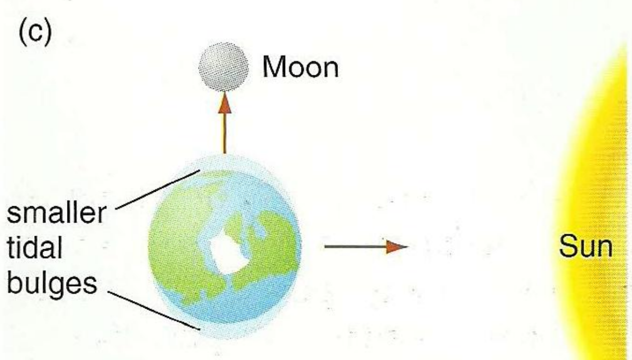

Ocean Tides and Currents
high tide
low tide
Earth
Sun
Moon
Moon's
gravitional pull
low tide
high tide



Spring Tide: Full Moon



Spring Tide: New Moon



Neap Tide

The gravitational pull of the Moon on the ocean causes our **tides**. We get two high tides a day. The Earth-Moon system rotates about a centre of gravity (or **barycentre**) at B (Figure 4). This is inside the Earth but not at its centre. At A, there is a high tide because the Moon pulls more strongly on the water closer to it. At C there is also a high tide. At C the Moon pulls the water less strongly. As the water rotates around B it piles up; this is because the Moon's pull is not strong enough to keep it in a smaller circular path.

The Sun also exerts a tidal pull on our seas, but about half as much as the Moon. Twice a month, the Sun and Moon line up to produce a large tidal pull. We then get **spring tides**. When the Sun and Moon pull at right-angles to each other, the high tides are smaller, These are called **neap tides** (Figure 5). Other factors, such as strong winds, also affect the height of tides.