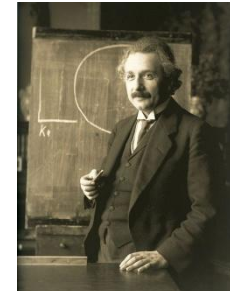
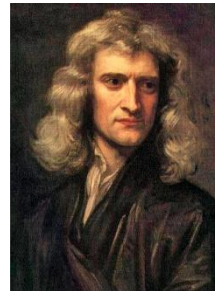




A human history of Cosmology

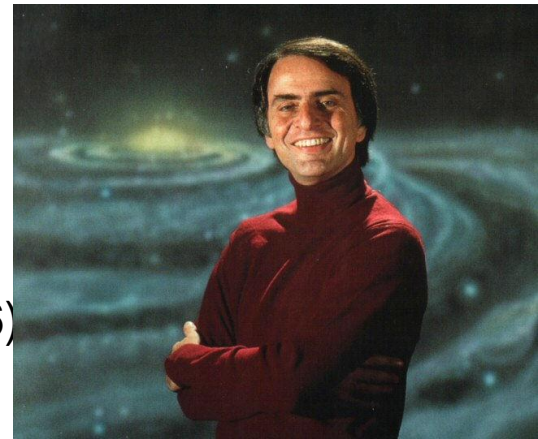


The Cosmos is all that is or ever was or ever will be.

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



20,000 BC



Ishango Bone
Africa

5,000 BC



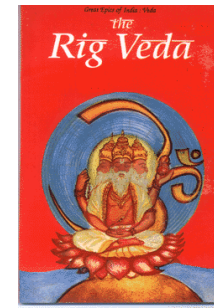
Megalithic structures

3000 BC



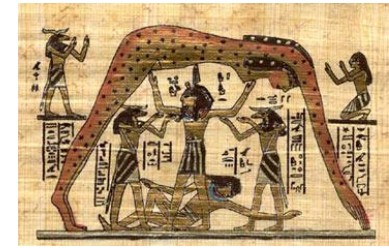
Babylonian

2000 BC



Hindu Rig Veda

3000 - 300 BC



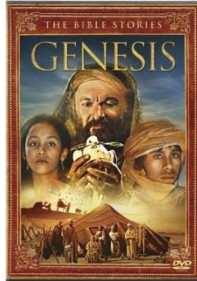
Ancient Egypt

520BC



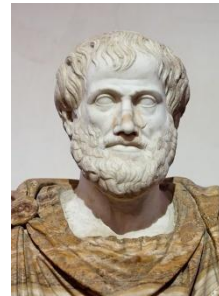
Jainism

500BC



Old Testament

384-322BC



Aristotle

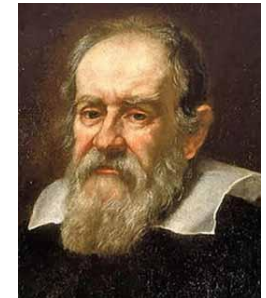
Aristarchus

200AD



Ptolemy

1564-1642



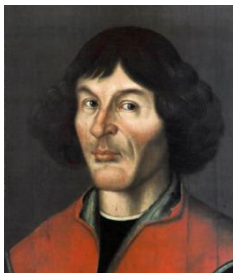
Galileo

500AD



Aryabhata

1473-1543



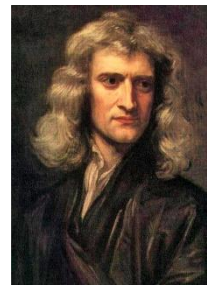
Copernicus

1571-1630



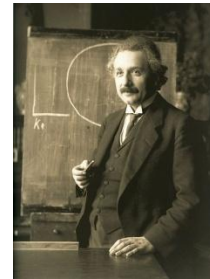
Kepler

1642-1727



Newton

1879-1955



Einstein

1894-1966



Lemaitre



Hawking

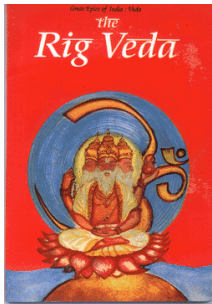


The **Ishango Bone** was certainly a rudimentary form of tally-counting.

It is conjectured that it might be a six month lunar calendar...



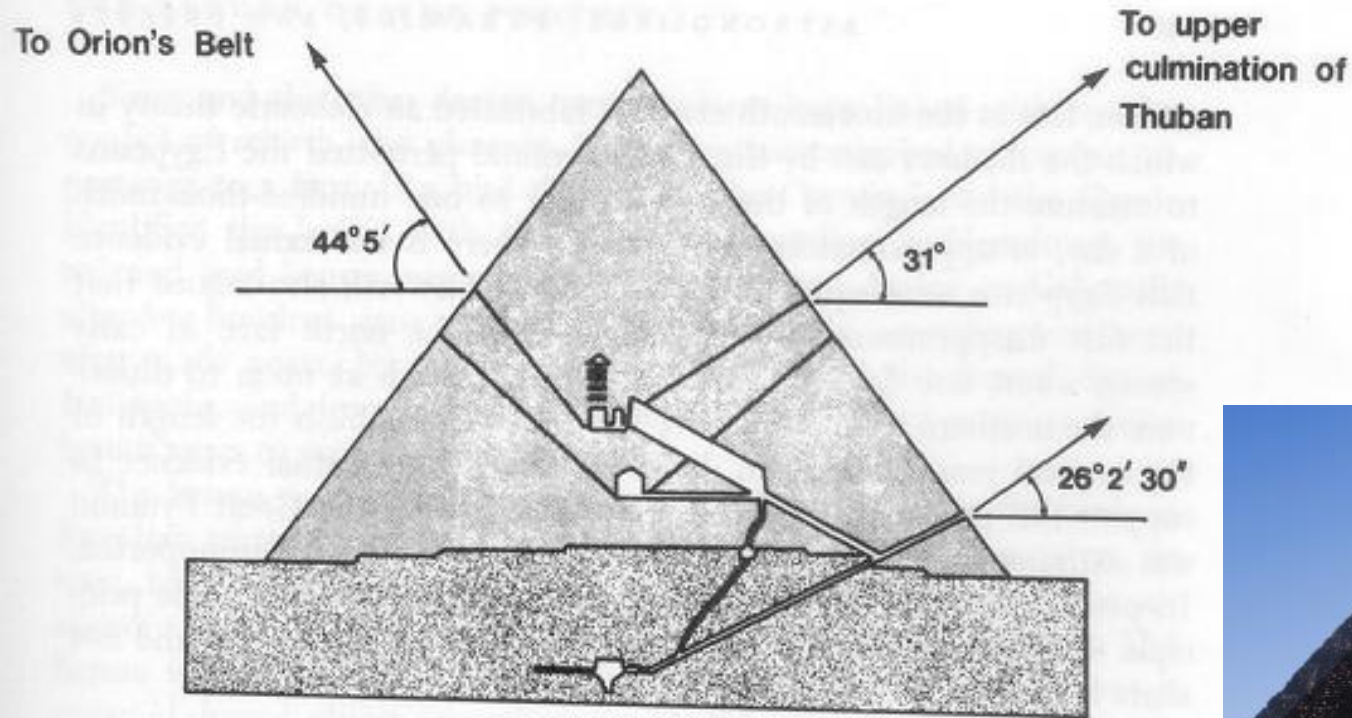
The **Babylonians** believed in a flat Earth floating in “the waters of chaos”. Although it is uncertain how coherent their cosmological understanding was, *they did record astronomical phenomenon* such as a star catalogue and eclipses, and had a notion of a planet possibly distinct from other stellar bodies.



The ancient Hindu **Rig Veda** text postulates the Universe has a lifetime of 8 million years. There are an infinite number of Universes in ‘existence’. Existence itself renews after a cycle of 311 trillion years!



The **Ancient Egyptians** believed the flat Earth god **Geb** was overarched by the air god **Shu** and then the sky God **Nut**. During the day the sun god **Ra** would traverse the underside of Nut before moving through the mysterious realm of *Duat*, before being ‘reborn’ from Nut the following day. It is not clear where Duat was located, but this was the region associated with death and rebirth. Beyond the shy and in the Underworld was **Nu** (chaos).



The Great Pyramid of Giza

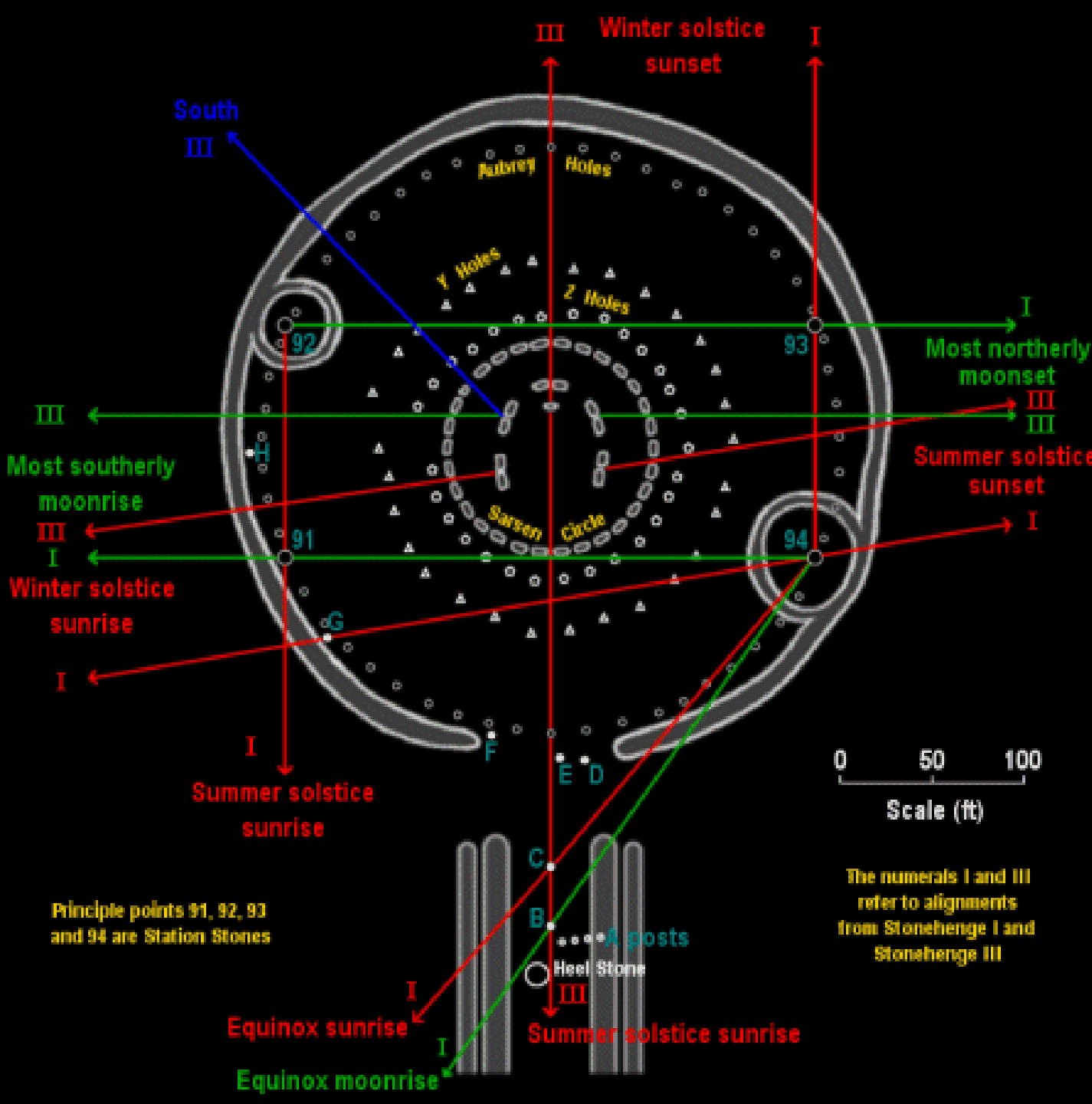


The **Great Pyramid of Giza** has many mysterious design features (specifically the angle of shafts connecting the Pharaoh burial chamber to the outside world). It is thought that the Egyptians believed the soul of the Pharaoh would be transported via these shafts to particular star constellations, which were associated with the rebirth cycle of the Gods



Megalithic structures such as **Stonehenge** were designed to align with positions of the Sun and Moon at special times of year.

e.g. at the dawn of the Summer Solstice (longest day) the sun rises above the Heel stone.



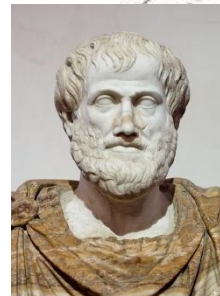
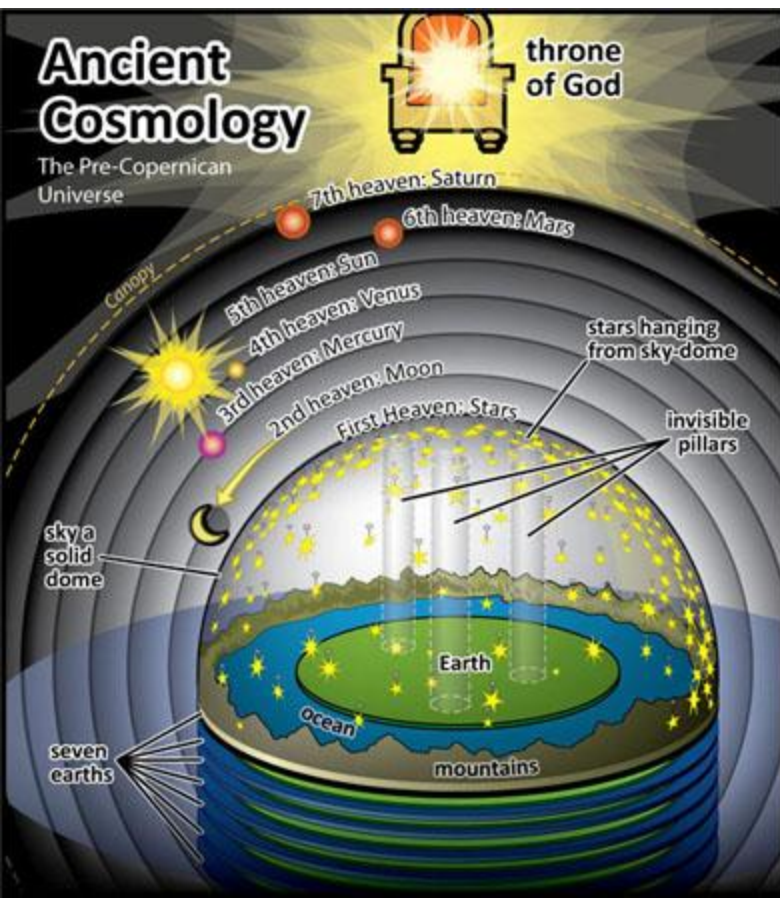
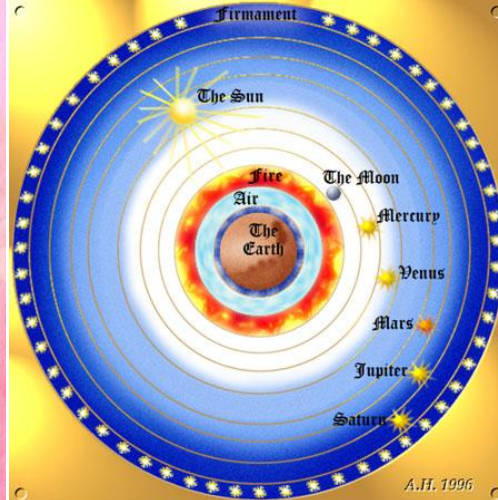


The earliest recorded astronomical observation is the **Nebra sky disk** from northern Europe dating approximately 1,600 BC.

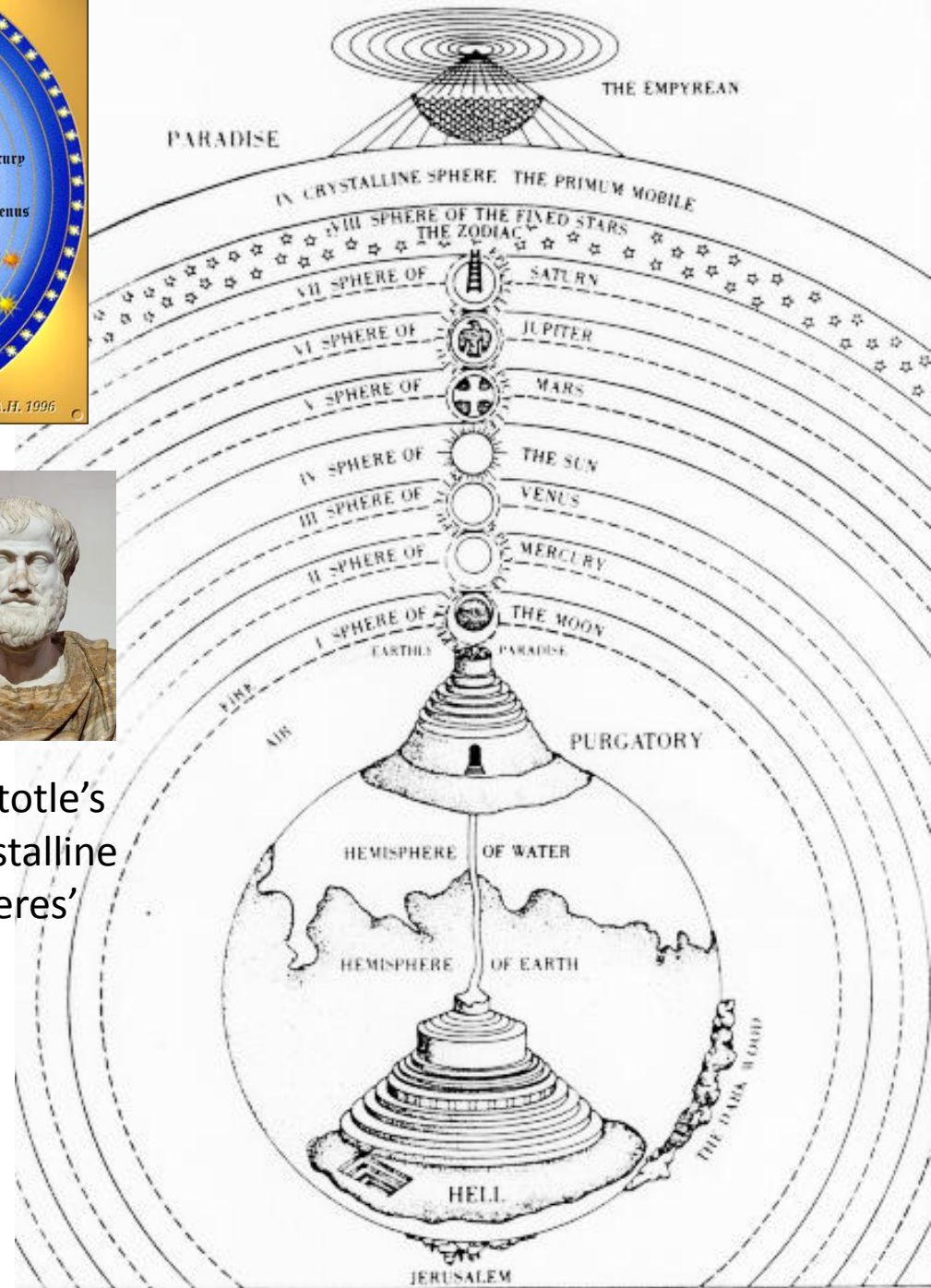
This 30 cm bronze disk depicts the Sun, a lunar crescent and stars (including the *Pleiades* star cluster).



Ancient mankind sought to explain natural phenomenon via the deeds of Gods and other supernatural beings. Beasts, heroes and more prosaic objects (e.g. a plough) were superimposed upon the pattern of stars in the Cosmos via the imagination of our ancestors. These constellations are of course in motion within the Milky way galaxy, so are not fixed!

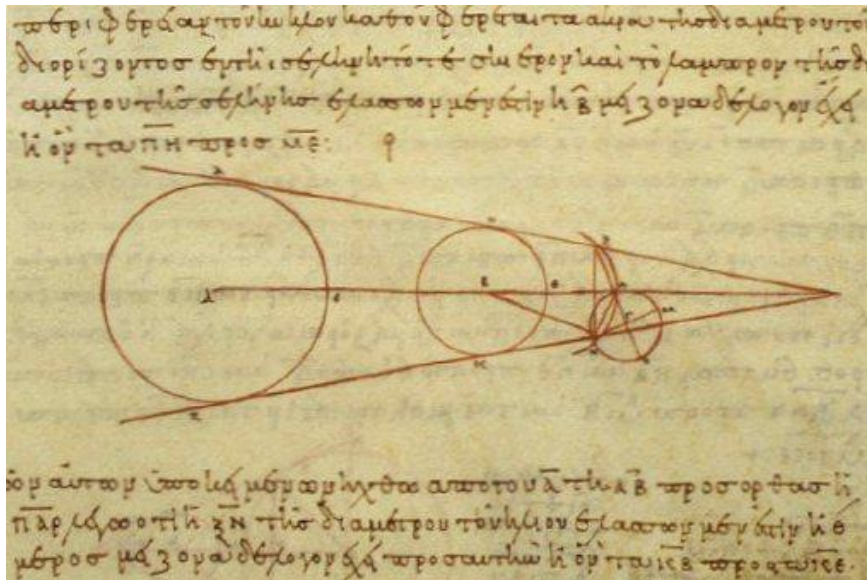


Aristotle's
'crystalline
spheres'



Note **Aristarchus of Samos** (310-230BC) proposed many modern ideas such as that the planets rotated about an internal axis, and in turn orbited the Sun. In other words a heliocentric model.

Sadly the Western world had to wait over 1700 years for this view to be shown to be correct!



Aristarchus's 3rd-century BC calculations on the relative sizes of (from left) the Sun, Earth and Moon. *From a 10th-century AD Greek copy*

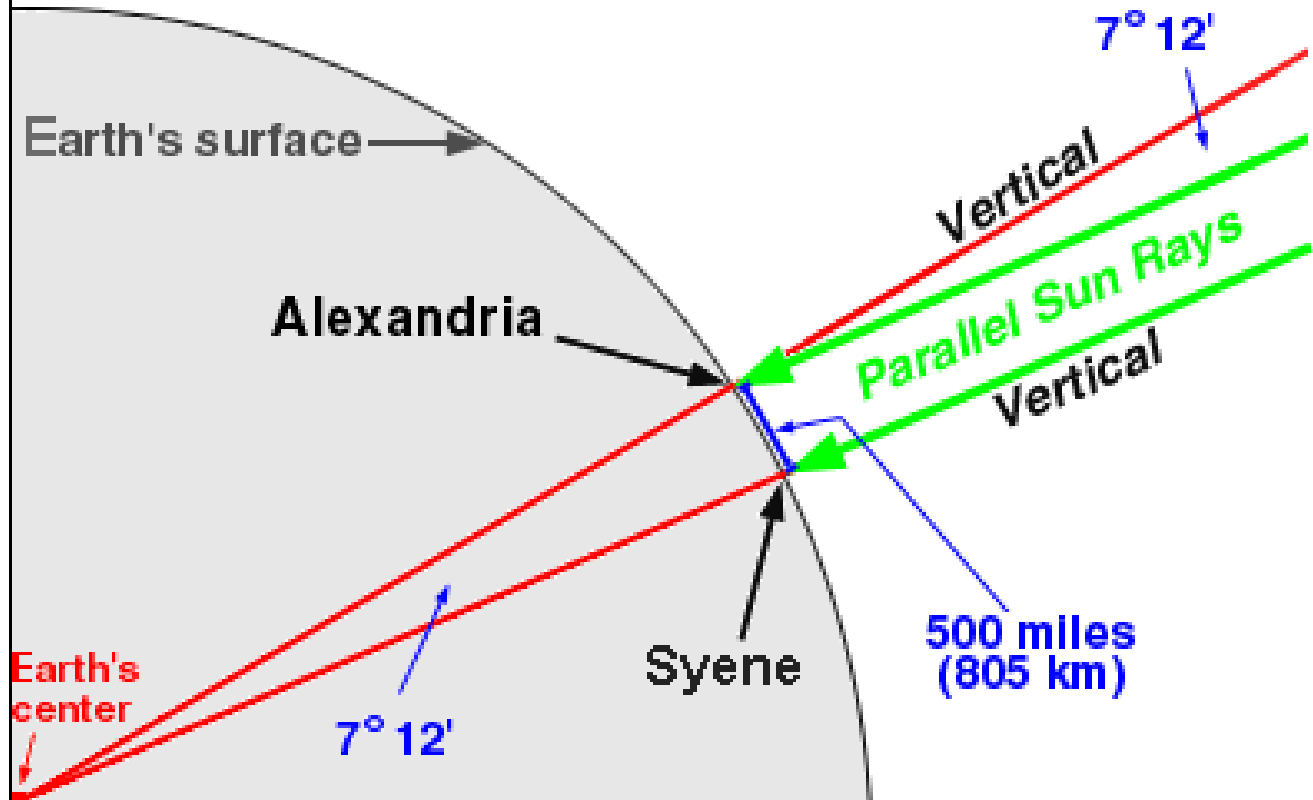
Aryabhata

(499AD)

also proposed a heliocentric system, and also elliptical orbits.



IF
 $7^{\circ} 12' = 1/50$ of a circle
THEN
 $50 \times 500 = 25,000$ miles
or
 $50 \times 805 = 40,250$ km



Eratosthenes (276-194 BC) calculated the radius of the Earth by measuring the arc length between (wells!) where the sun's rays are vertical and inclined to a known angle.

The actual circumference of the Earth at the equator is 40,008 km

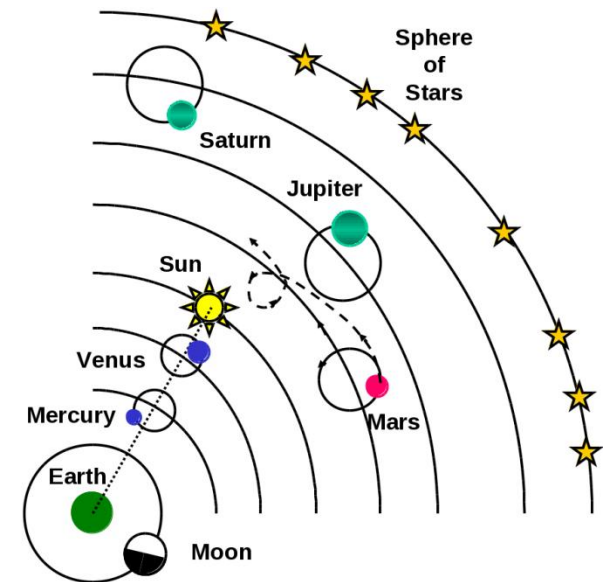
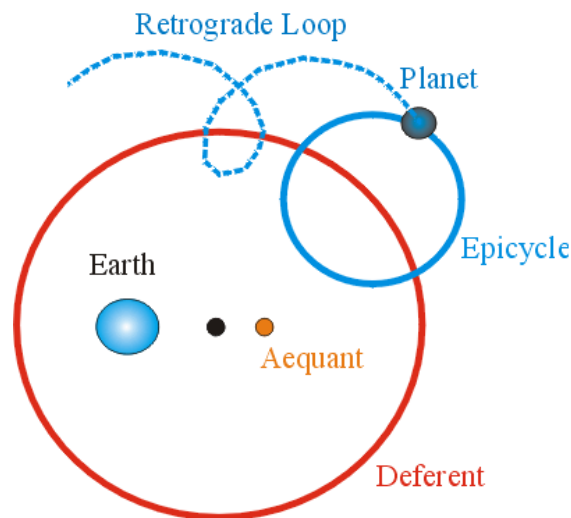
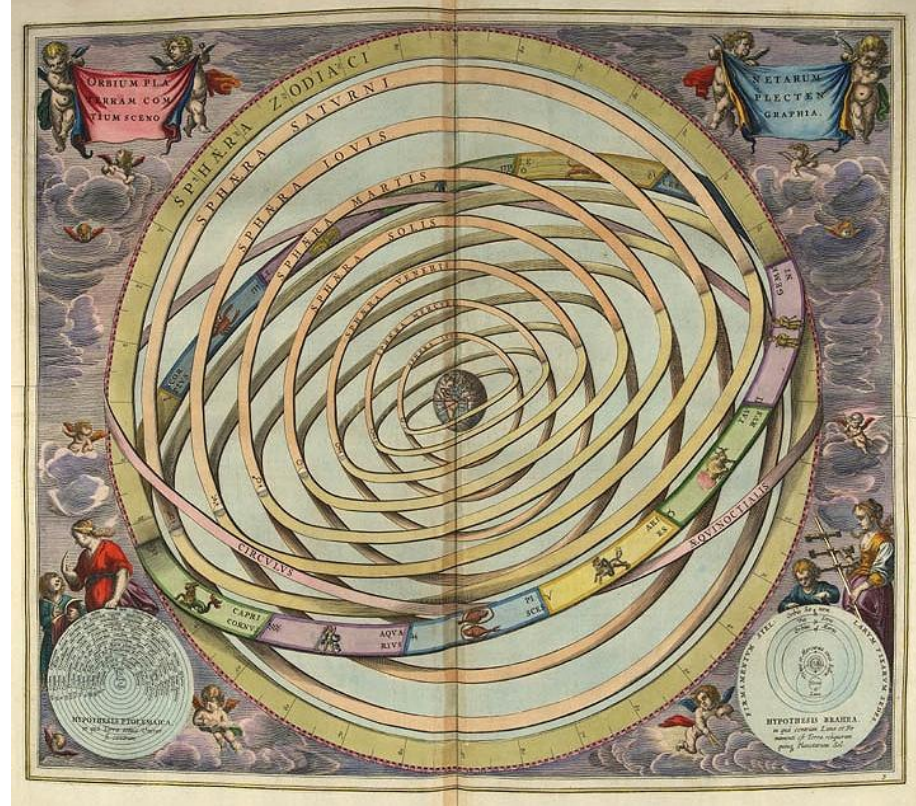


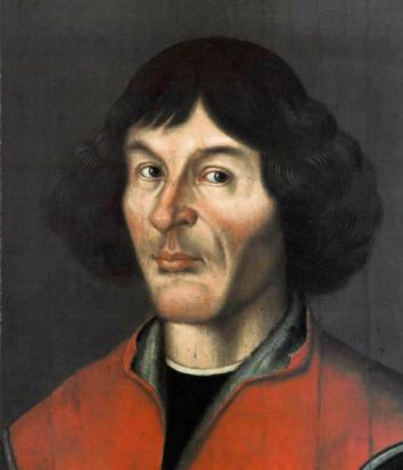
Ptolemy

(AD 90-168)

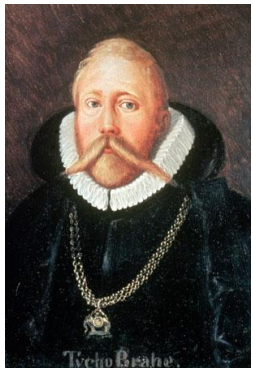
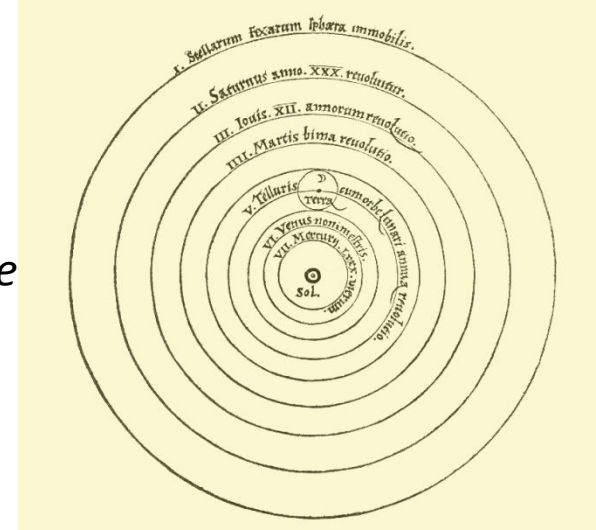
published a sophisticated system for predicting the motion of the sun and planets in the *Almagest* and *Planetary Hypotheses*.

His model was Earth-centric (*geocentric*) so he had to postulate complex 'epicycles' to explain the retrograde motion of planets such as Mars



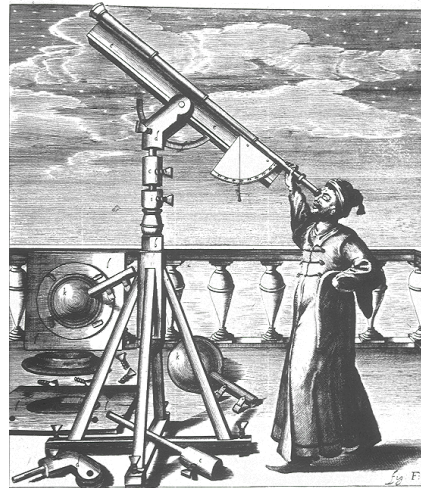


Nicolaus Copernicus (1473 – 1543) was a Renaissance mathematician and astronomer who formulated a model of the universe that placed the Sun rather than the Earth at its centre. He published this model in his book *De revolutionibus orbium coelestium* (On the Revolutions of the Celestial Spheres) just before his death in 1543

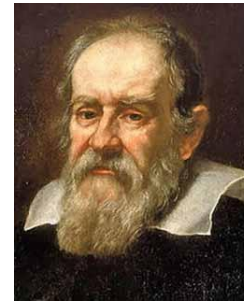


Tycho Brahe
1546-1601

Accurate
observations of
planetary
orbits

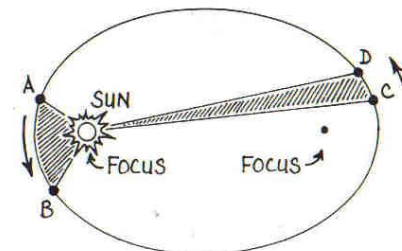


Development
of telescopes

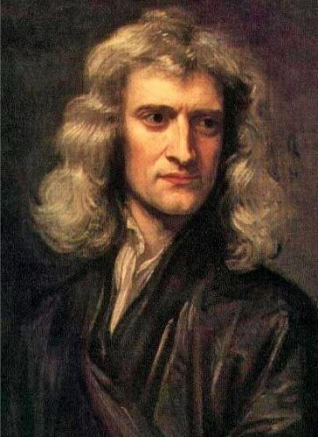


Galileo
1564-1642

Kepler's First Law
Planets have
elliptical orbits,
with the Sun at
one focus.



Johannes Kepler
1571-1630



Isaac Newton

(1642-1727) developed a mathematical model of Gravity which predicted the elliptical orbits proposed by Kepler

Force of gravity →

$$F = \frac{GMM_{\odot}}{r^2}$$

$$G = 6.67 \times 10^{-11} \text{ m}^3 \text{ kg}^{-1} \text{ s}^{-2}$$

Planet and Solar masses

$$r = \frac{a(1 - \varepsilon^2)}{1 + \varepsilon \cos \theta}$$

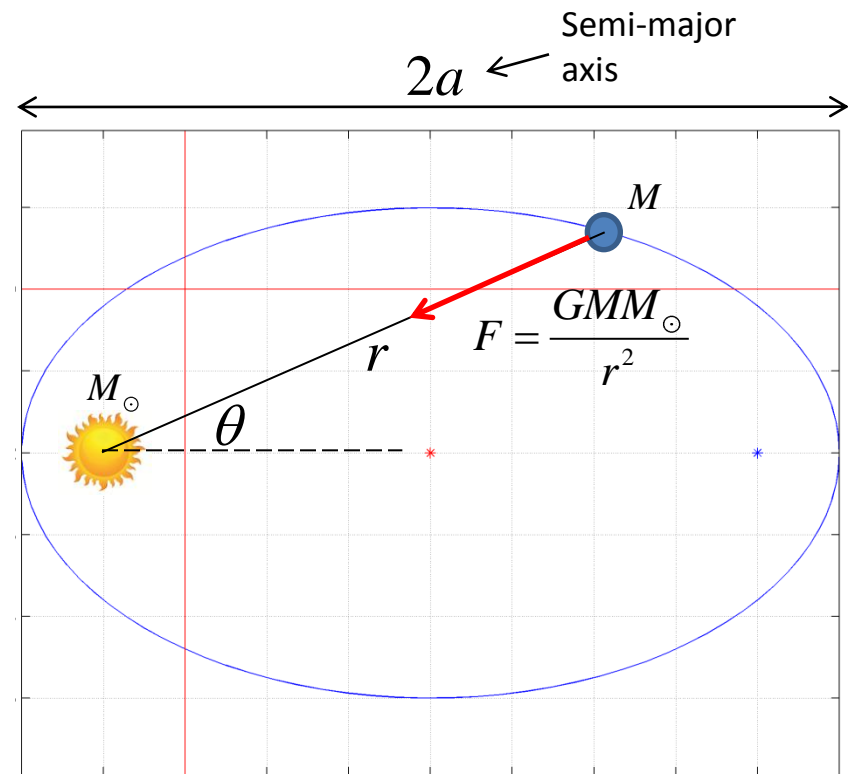
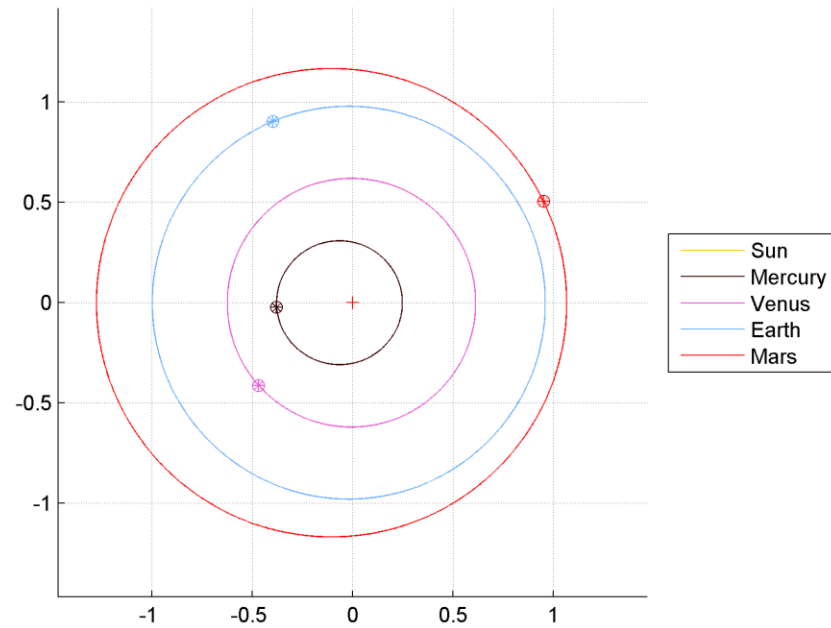
Polar equation of ellipse

$$\varepsilon = \sqrt{1 - \frac{b^2}{a^2}}$$

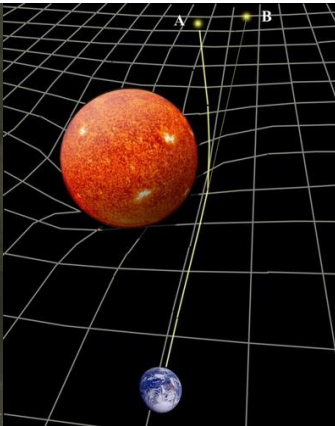
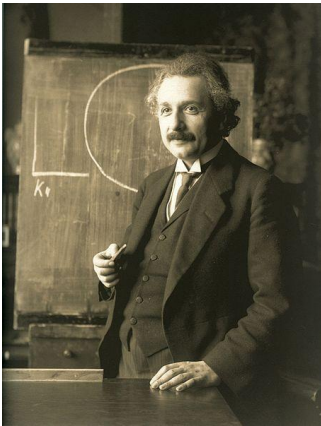
Eccentricity of ellipse

$$P^2 = \frac{4\pi^2}{G(M + M_{\odot})} a^3$$

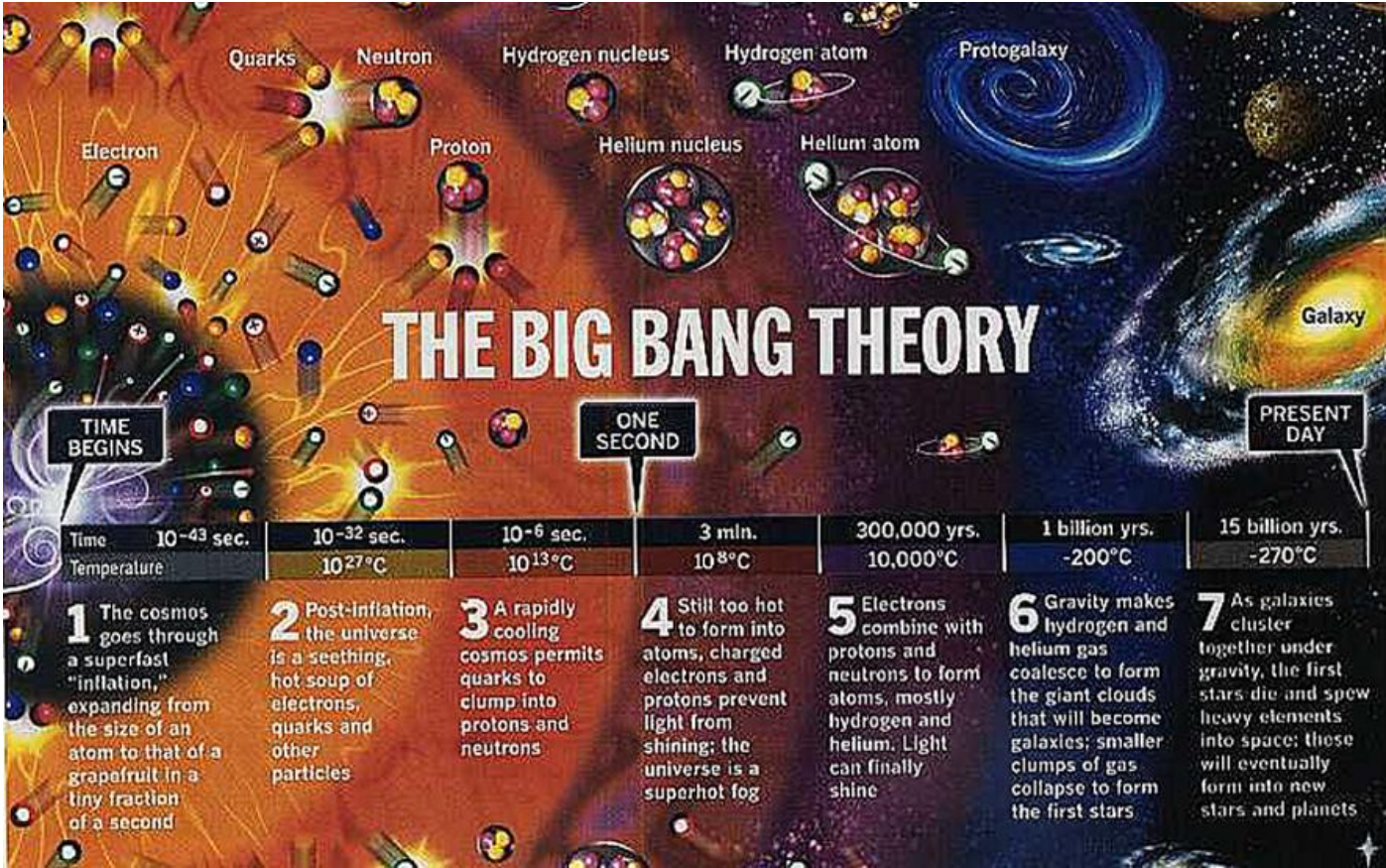
Orbital period P



Albert Einstein (1879-1955) proposed a radical new theory of gravity, General Relativity, in which both space & time ('*spacetime*') are *curved* by the presence of mass. This helped to explain *anomalies* in the Newtonian model such as the *precession of the orbit Mercury* and the amount that light is bent by massive objects (*Gravitational lensing*). Note General Relativity predicts the *same* planetary dynamics as Newton's model when gravity is fairly weak. i.e. Newton's model can be thought of as an *approximation*.

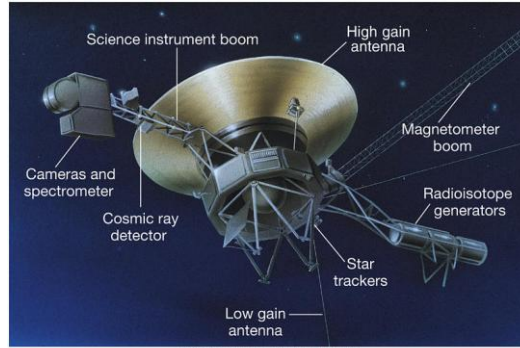


George Lemaitre (1894-1966) proposed what is now termed the **Big Bang theory** of the Universe i.e. an expansion from a *singularity*

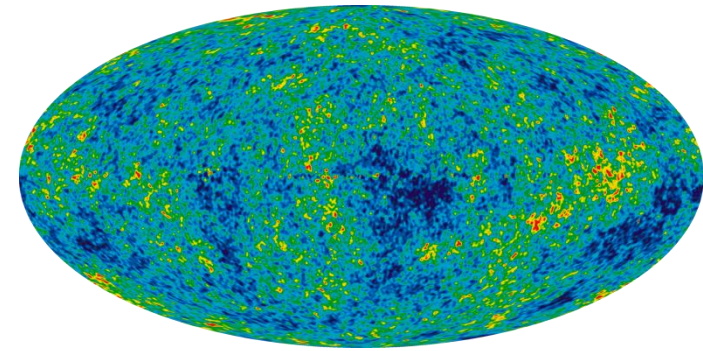




Missions to
comets, Mars



Voyager exploration
of the solar system



Measurement of the
Cosmic Microwave
Background Radiation

Modern cosmology & astronomy

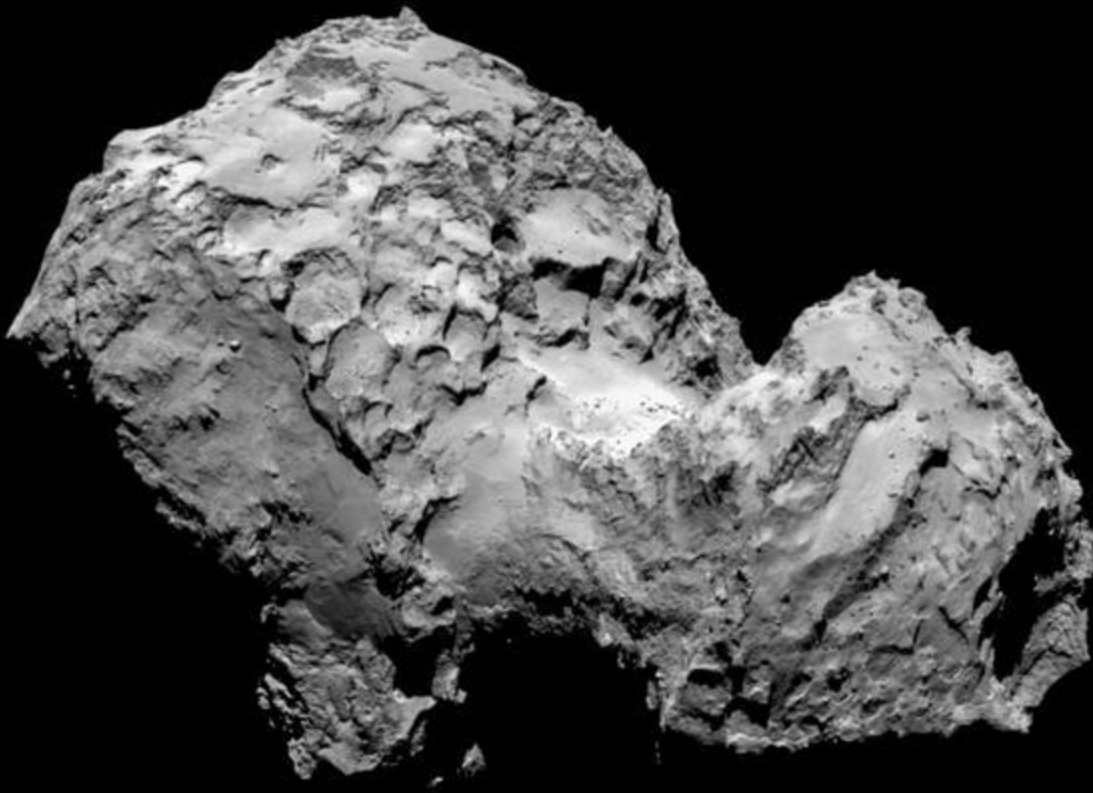
Space telescopes
such as Hubble

Exotic new theories: dark
matter, superstrings



Radio astronomy

The Rosetta Mission



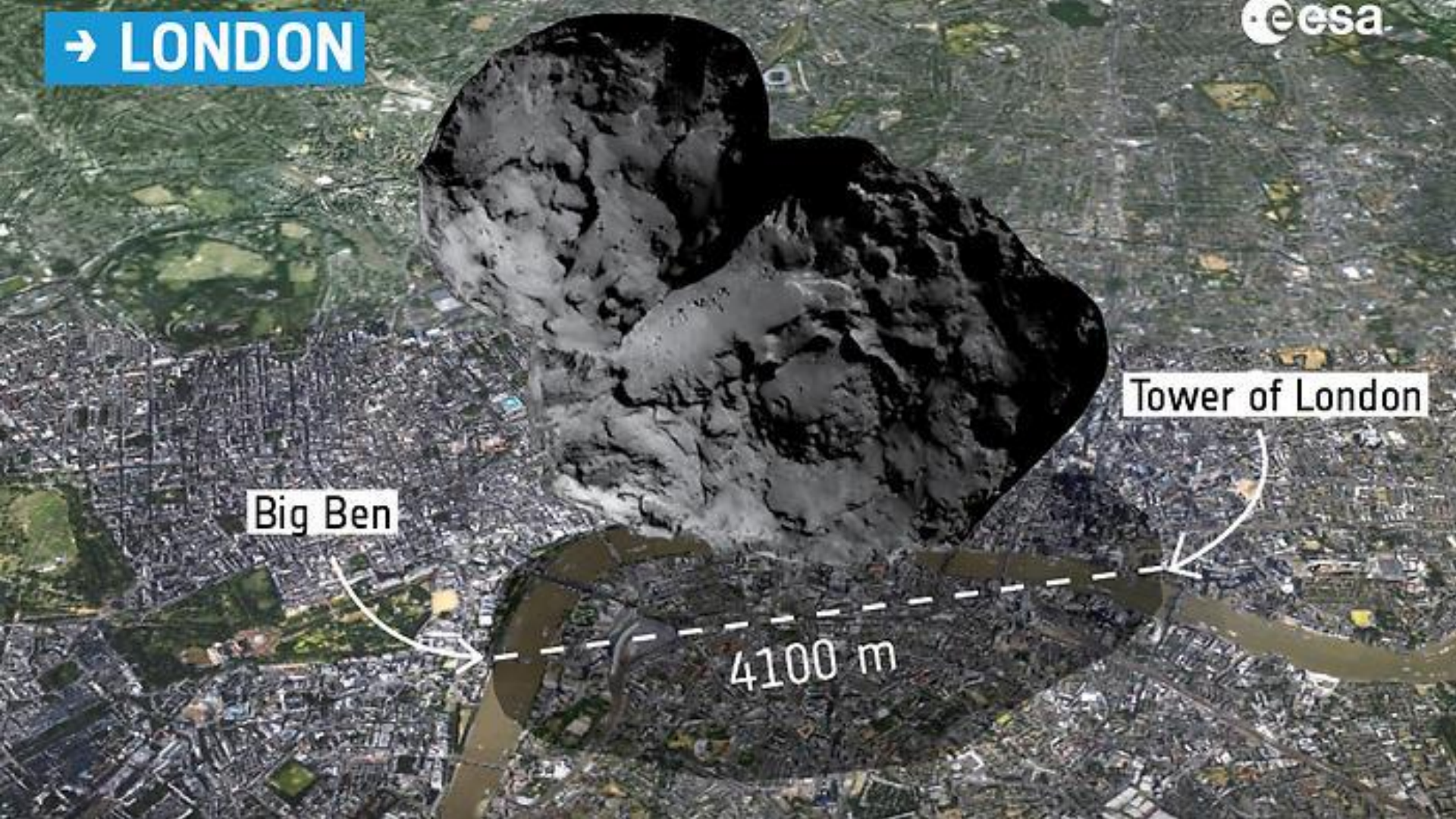
ESA/Rosetta/MPS for OSIRIS Team MPS/UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA

12 November 2014, the probe *Philae* achieved the first-ever soft landing on a comet **67P/Churyumov–Gerasimenko**



→ LONDON

esa



Comet **67P/Churyumov-Gerasimenko**

Experiments: X-ray spectrometer measures elemental composition of comet's surface, radiowaves probe internal structure of nucleus, six micro-cameras take panoramic pictures

Solar panels

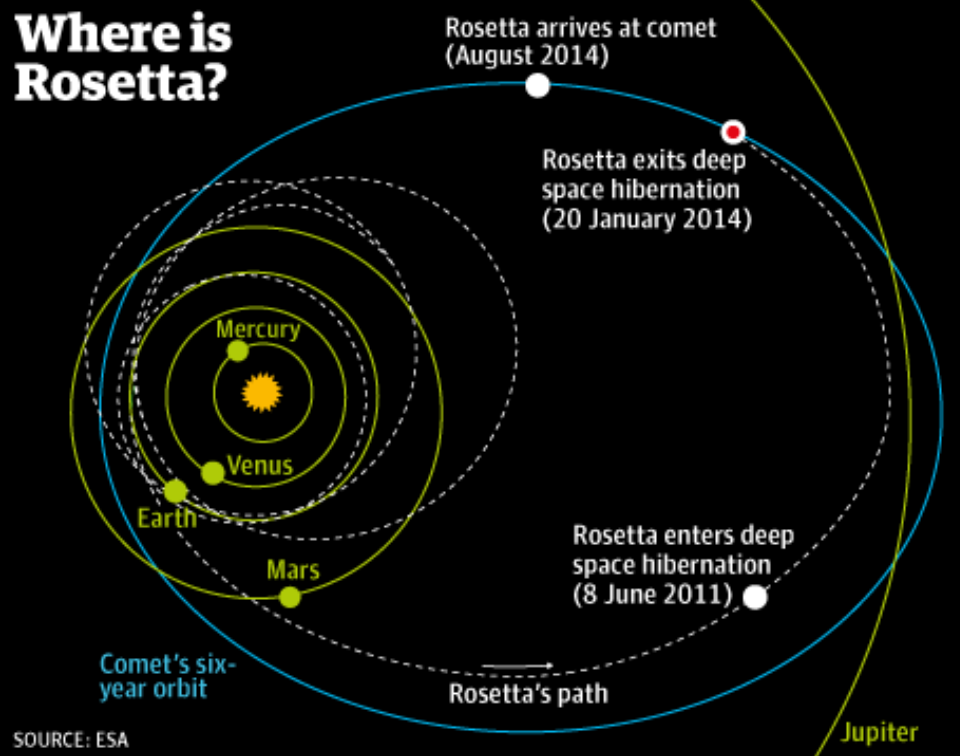
Gas analysers:
Identify complex organic molecules and isotopic ratios of light elements

Sampling system: Drill will probe 20cm into surface, collect samples and deposit them in different ovens or deliver them for microscope inspection

Anchor: Harpoon fired from craft will anchor lander to ground and also contains sensors to measure the density and thermal properties of the surface

Philae landing craft

Where is Rosetta?



MISSION MILESTONES

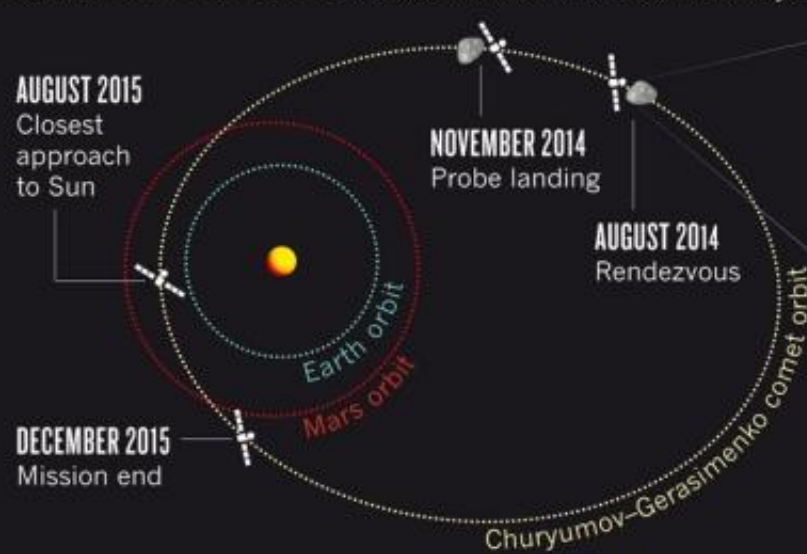
The Rosetta spacecraft is gearing up for its close encounter with a comet this year.

AUGUST 2015
Closest approach to Sun

NOVEMBER 2014
Probe landing

AUGUST 2014
Rendezvous

DECEMBER 2015
Mission end



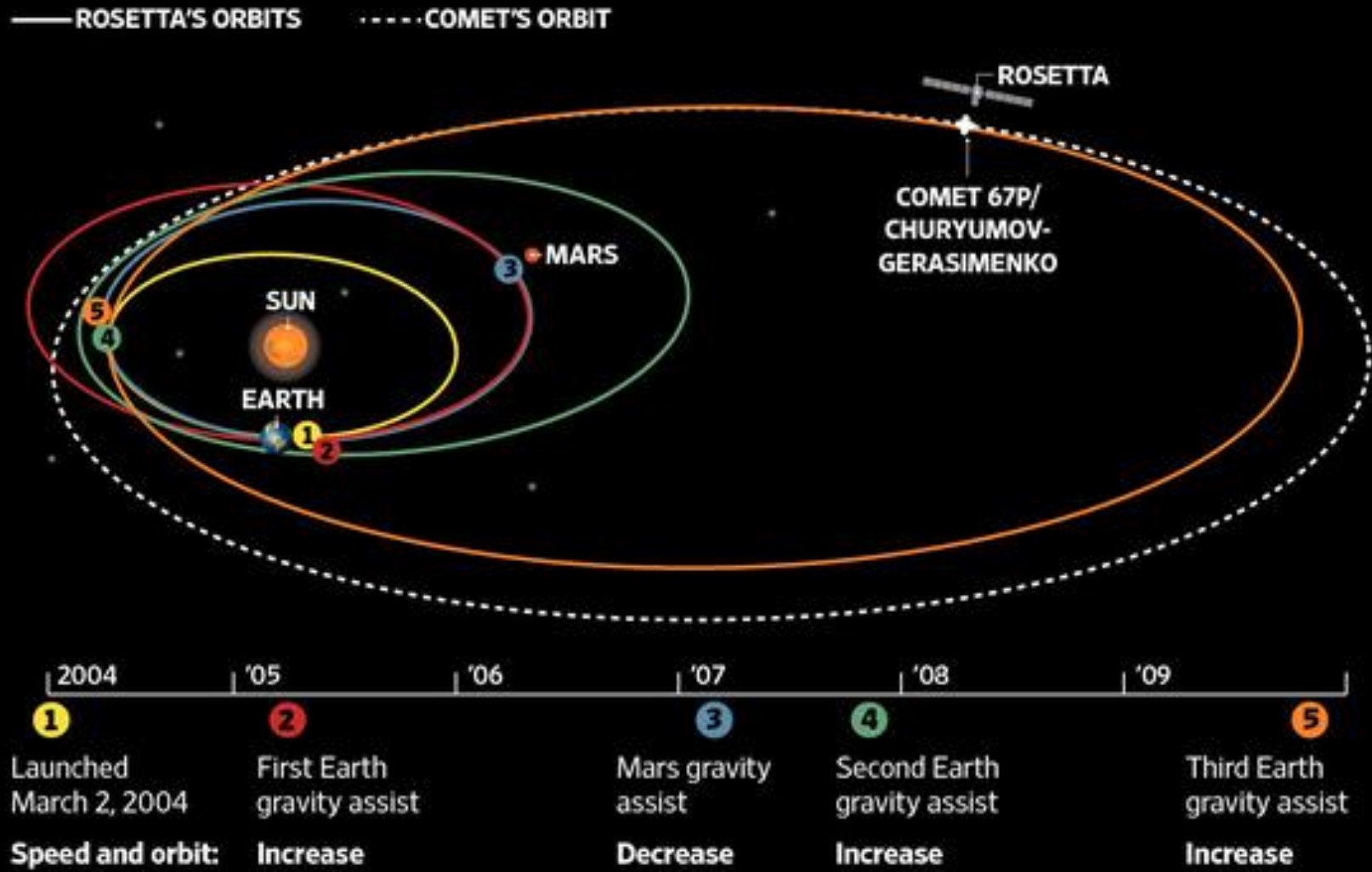
Comet Churyumov-Gerasimenko is about 4.5 kilometres long and 3.4 km high, more than four times the height of Dubai's Burj Khalifa, the world's tallest building.

3.4 km

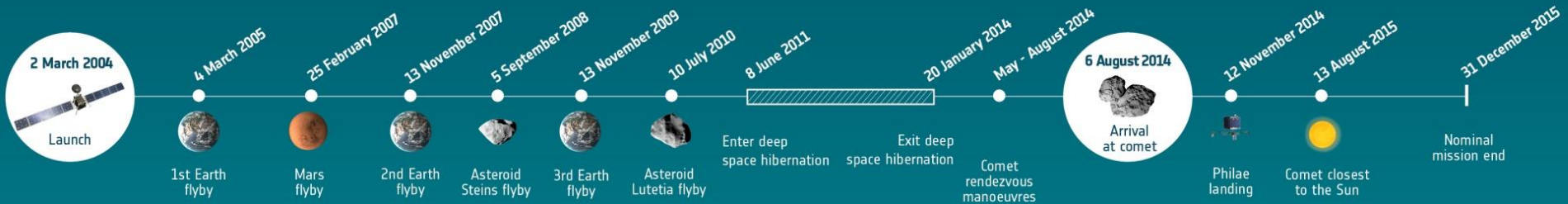
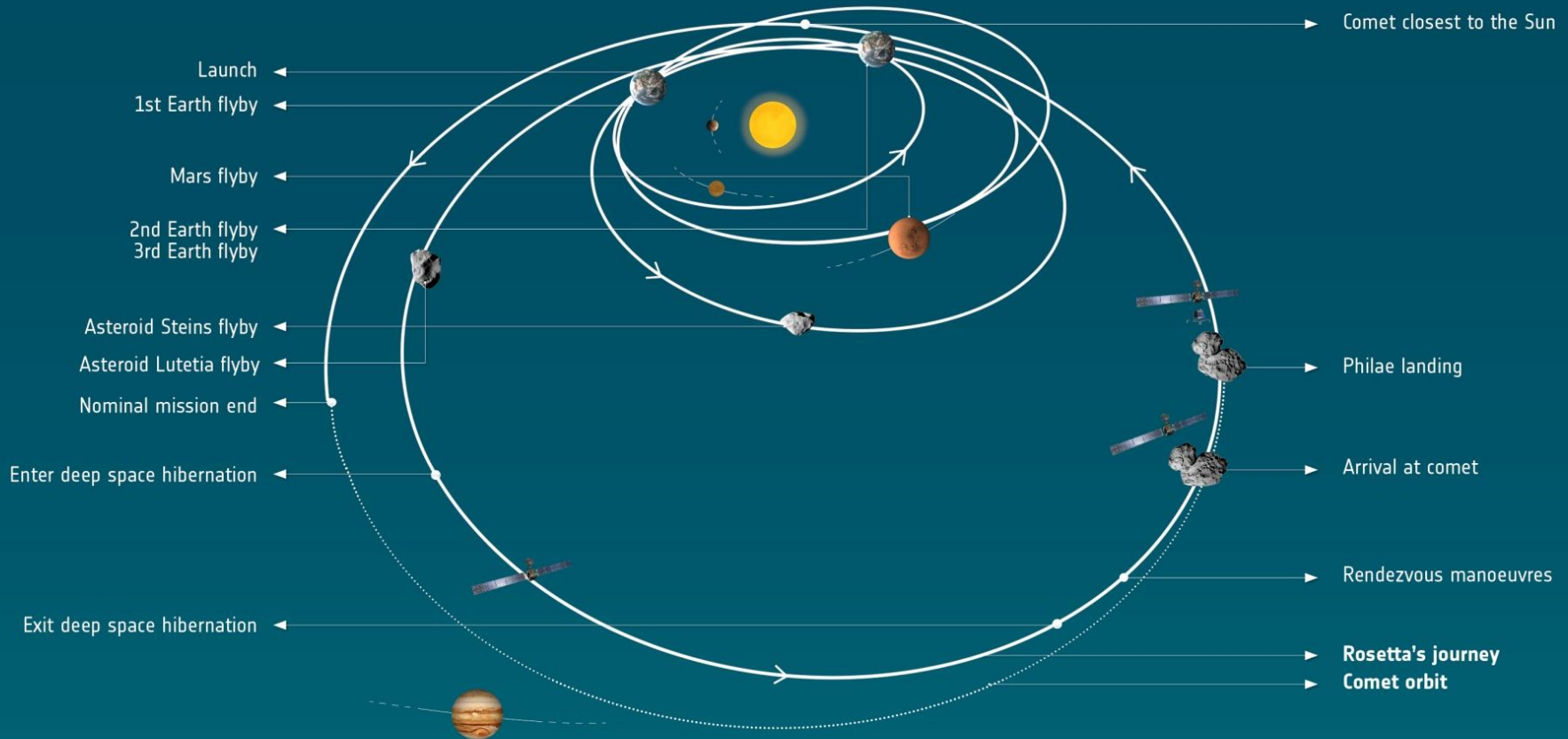
Burj Khalifa

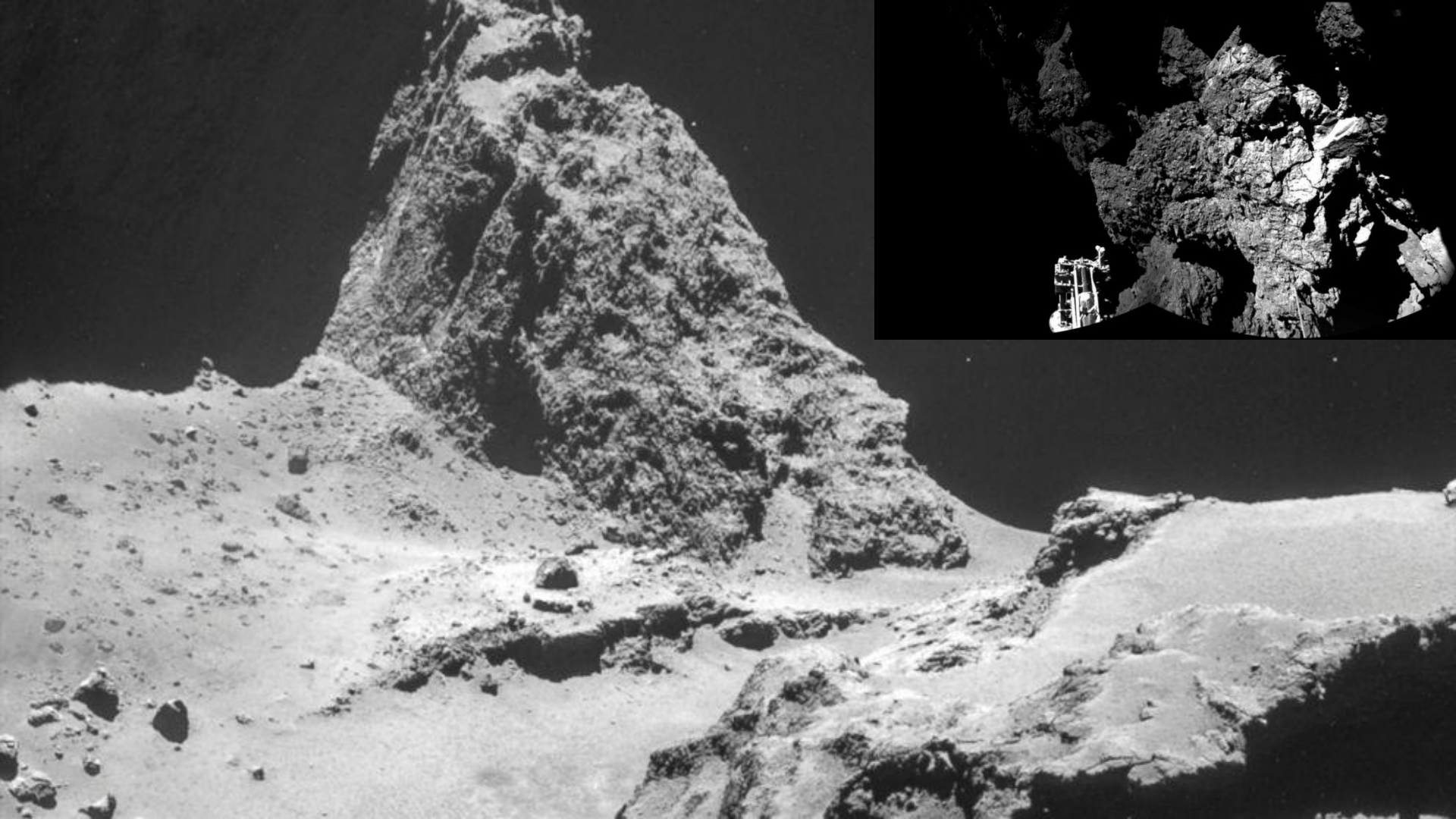
Space Boosters

When a spacecraft passes close to a planet or moon, the gravitational force changes its trajectory and speed. This 'gravity assist' allows the spacecraft, in its series of changing orbits, to travel farther with less fuel. Without it, many missions would be impossible.



→ ROSETTA'S JOURNEY





Images taken from *Philae* following landing on comet **67P/Churyumov-Gerasimenko**