The Moon:
Our natural satellite

Galilean Nights

United Nations Educational, Scientific and Cultural Organization

International Astronomical Union

THE UNIVERSE YOURS TO DISCOVER

INTERNATIONAL YEAR OF ASTRONOMY 2009

Sister Moon

The Moon is a familiar sight to us all. Since time immemorial, people have wondered about its true nature.

To celebrate the International Year of Astronomy 2009, let's look at our satellite, its origin, nature, and evolution as a physical body, and its multifaceted influence on our lives.

A lunar calendar

Humans are instinctively drawn to **naturally recurring patterns**, as their predictability seem to fulfil a deeply felt longing for **logic** and **order** within our chaotic and ever-changing universe.

Away from the equator, the length of the day **varies throughout the year**, the beginning of seasons are not clearly definable, and astronomical processions are complex to follow. But for primitive people, the Moon displayed a relatively *simple recurring cycle* from a **New** to a **Full Moon**.

The Jewish lunar calendar

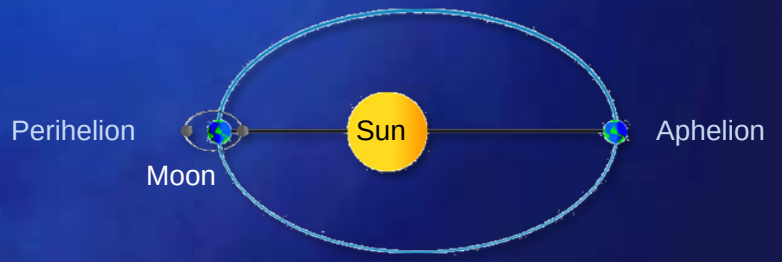
It comes as little surprise that most early calendars were based on **lunar phases**.

Out of phase… phases

Unfortunately, the orbital period of the Earth around the Sun, or the length of the **astronomical year** (365.24 days), does not relate to **the lunar year** (354.37 days), or 12 lunar months of 29.53 days.

So every few years the lunar calendar has to be **readjusted**, usually adding an extra 13th month, to coincide with the solar year.

This is why the lunar calendar is only kept nowadays for **folkloristic** (e.g. astrology) or **religious** (e.g. the Islamic calendar or Hijri) recurrences.



The ancients and the Moon…

Even early humans must have noticed that the surface of the Moon, unlike the Sun, is **not uniform**, being characterised by both **bright** and **dark** areas.

The moon god **LAH** from Egypt,

Late Period, after 600 BC.

The British Museum

People have often projected imaginary symbolic shapes on the lunar surface: for instance in eastern traditions (from China to Korea), the dark areas on the Moon's nearside depict a pounding **Jade Rabbit**. Many other civilisations saw the outline of a **face** instead.

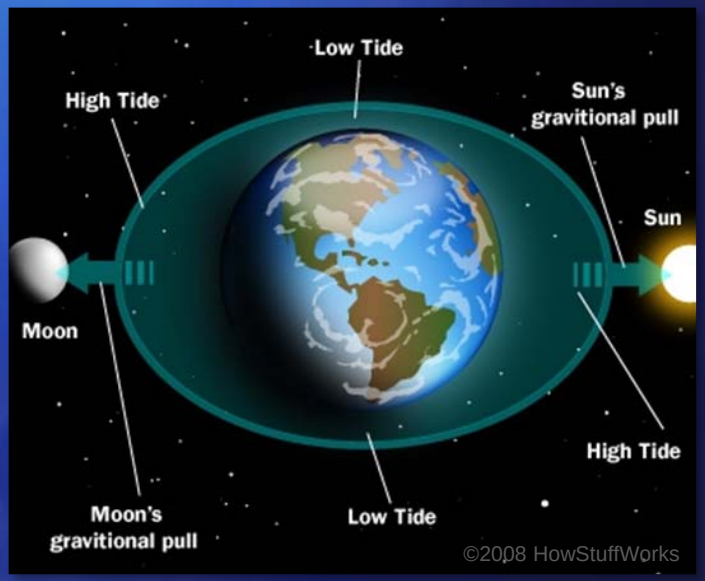
In ancient times all sorts of religious, mystical, and magical manifestations were often associated with our satellite. **All** were eventually proved to be mere **random associations** with, at the time, inexplicable phenomena.

Belief in some lunar-related phenomena persists even **today**, as in astrology, menstrual cycle rhythms, mood swings, and baby gender bias. People are still described as "**lunatics**", from the word lunar, if displaying unusual behaviour.

Back to the real world

But the Moon *does have* a real physical impact on our lives, for instance through its gravity pull (*tidal cycles*) and, especially on a full Moon, its *reflected* nocturnal illumination.

Full Moon moonlight



Some aspects of **animal life** are also governed by the monthly lunar cycle, such as when eggs hatch in many species including tortoises and butterflies, or guiding bird migrations.

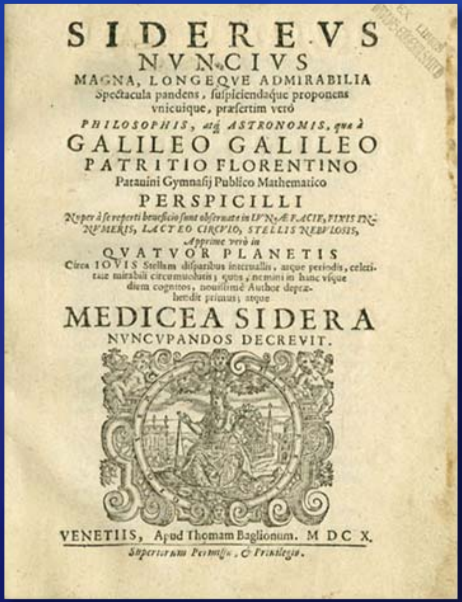
Galileo Galilei

The astronomical (orbital) understanding of the Moon was already advanced centuries **before** the Birth of Christ; indeed, there is evidence that at least the **Greeks**, **Chinese**, and several **South American** civilisations could already forecast lunar and solar eclipses with a high degree of accuracy.

Annular solar eclipse

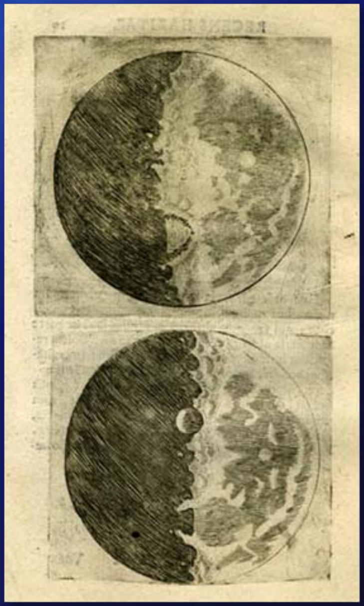
Lunar eclipse

But for the physical planetary study of this celestial body we really need to wait until the development of observational astronomy, starting with Galileo Galilei's first lunar studies in the year 1609, outlined in his book **Sidereus Nuncius**.



SIDEREVS
NVNCIVS
MAGNA, LONGEQVE ADMIRABILIA
Spectacula pandens, suspiciendaque proponens
vnicuique, præsertim verò
PHILOSOPHIS, atq; ASTRONOMIS, quæ à
GALILEO GALILEO
PATRITIO FLORENTINO
Patauini Gymnasij Publico Mathematico
PERSPICILLI
Nuper à se reperti beneficio sunt obseruata in LVNÆ FACIE, FIXIS INNVMERIS, LACTEO CIRCVLO, STELLIS NEBVLOSIS,
Apprime verò in
QVATVOR PLANETIS
Circa IOVIS Stellam disparibus interuallis, atque periodis, celeritate mirabili circumuolutis; quos, nemini in hanc vsque diem cognitos, nouissimè Author depræhendit primus; atque
MEDICEA SIDERA
NVNCVPANDOS DECREVIT.

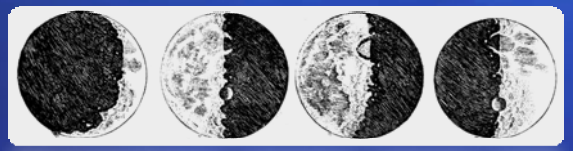
VENETIIS, Apud Thomam Baglionum. M DC X.
Superiorum Permissu, & Priuilegio.

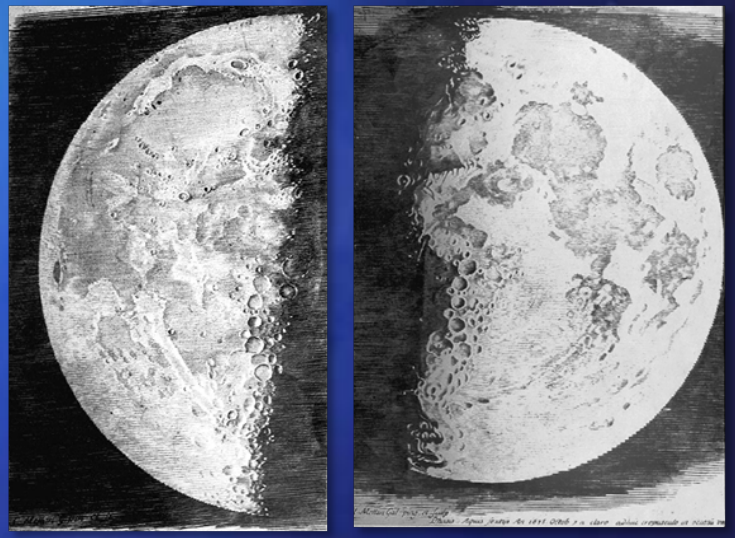


Terra et mare, land & sea

To the early telescopic observers, the lunar surface must have appeared as **alien**, **mysterious**, and difficult to compare and relate to known terrestrial landscapes. The bright rugged and elevated terrains were baptised with the Latin names **Terræ** (lands), and the dark, smooth, and uniform surfaces **Maria** (seas).

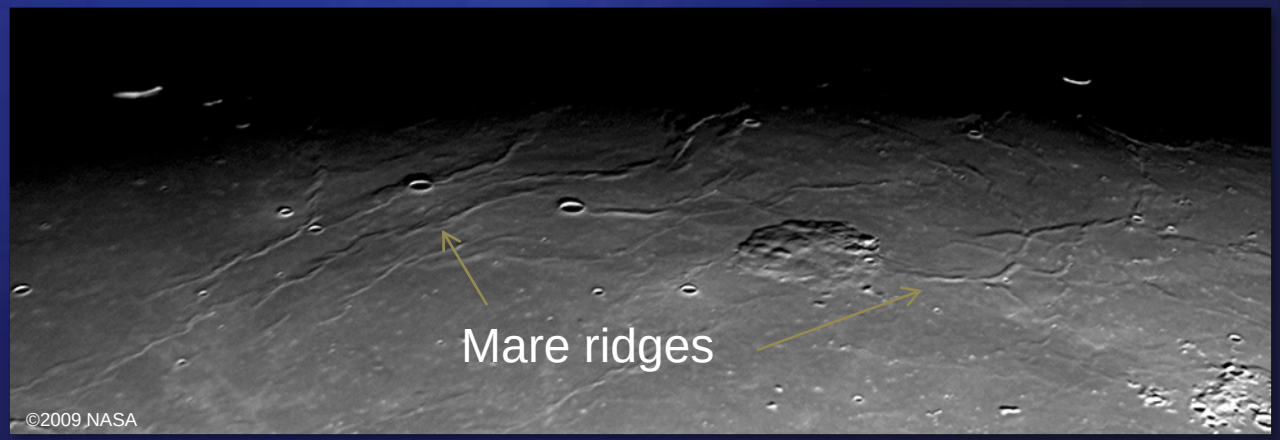
Galileo's sketches of the Moon





1634 Claude Mellan's Moon engravings

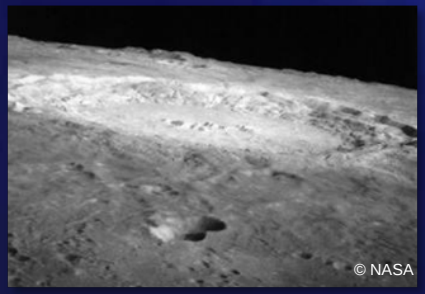
On closer inspection, the maria appeared to display characteristics similar to **liquid bodies**: they occupy mostly low elevation basins; "pools" or ""lakes" of presumably similar materials could also be spotted within terrae; they appear to embay and penetrate "coastal" landforms creating promontories and lagoons; "islands" could also be identified.



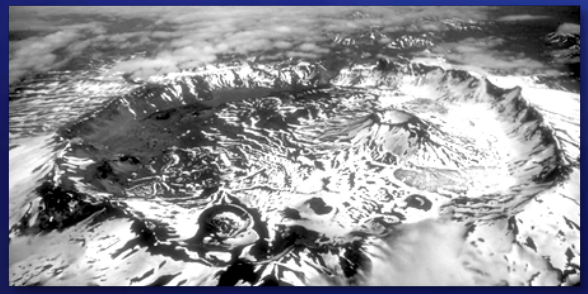
Ridges, flow fronts and craters

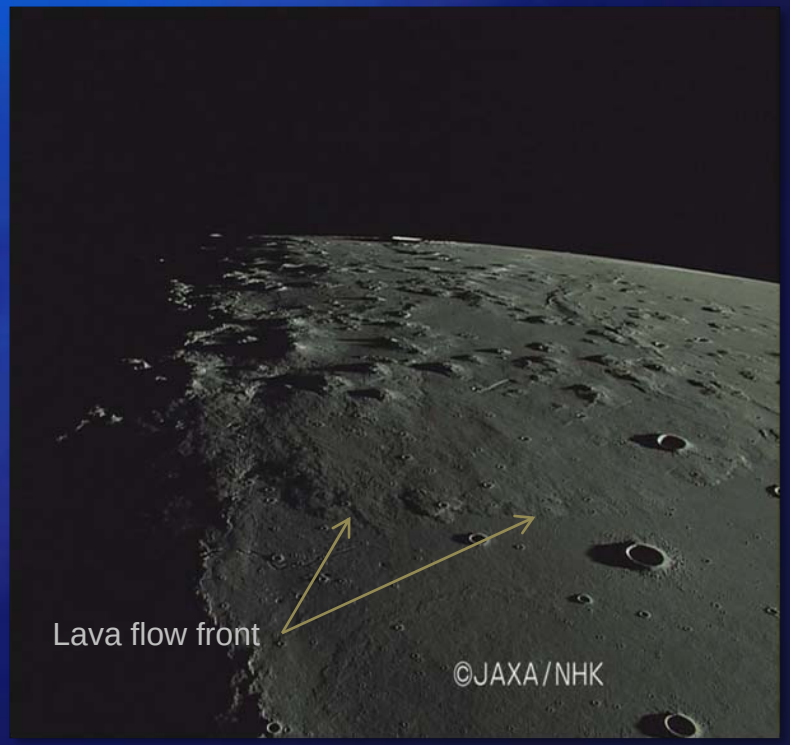
Further inspection even revealed the unmistakable outlines of massive "**sea waves**". The difference with our seas was that these ones **did not move**. The maria were very dark and static, like oceans frozen in time. They must once have moved and flowed, just like water or molten rock erupting from a volcano. Eventually, similarities with terrestrial igneous phenomena became apparent: they were observing solidified lava fields on a planetary scale.

Within a few years it had become clear that the lunar surface is saturated at all scales by **circular constructions** with seemingly raised rims.
On Earth at that time, the only natural circular morphologies known were those linked to **volcanic** phenomena. It was logical to presume those lunar features also to be the result of a continued and relentless eruptive phase.



Copernicus Crater, Moon


Aniakchak Caldera, Alaska

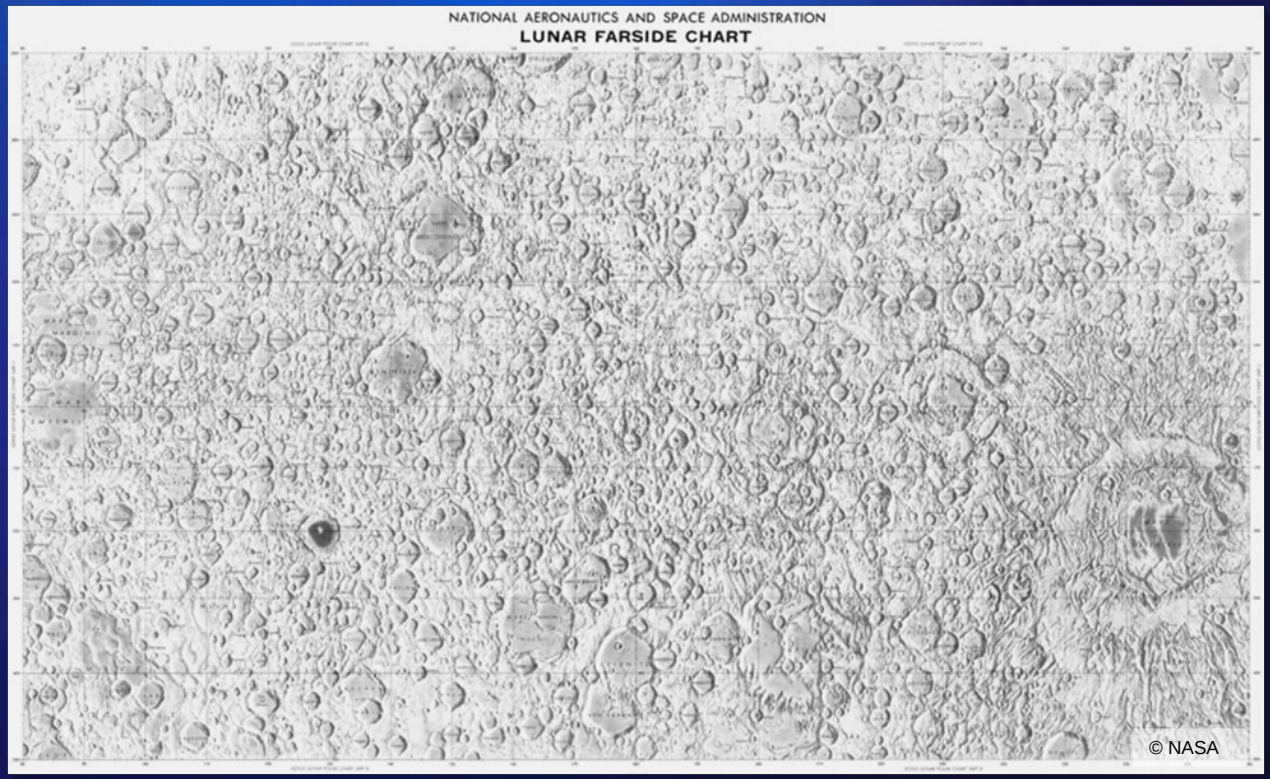


A violent past…

This assumption lasted well into the first half of the 20th century and only with analysis and observations from the Apollo and Luna missions did it become apparent that **volcanism**, or at least as we know it on Earth, played **a very minor role** in shaping the lunar surface.

Instead, the lunar surface bears witness of a **violent past** and **relentless bombardment** of interplanetary objects from the macroscale (meteors and comets) down to the microscale (micrometeorites, cosmic and solar particles), which continues to this day.

Lunar basalt from the Apollo 12 site.
Pitted by micrometeorite bombardment



Impact-saturated lunar farside

A few facts about the Moon

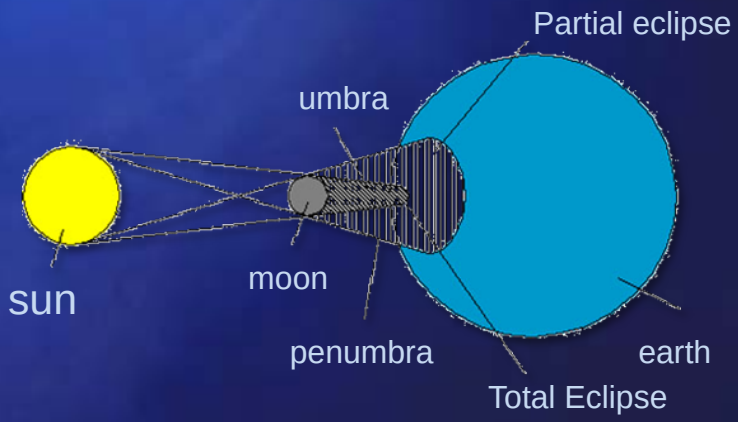
Average distance from Earth: 385,000 km (nearly **10 times** the circumference of the Earth)

Circumference: 10,921 km (around **four times** smaller than the Earth's)

Surface Gravity: 1.62 m/s^2 (**six times** weaker than on Earth)

Surface temperature at the equator: min. -173˚C; max. 117˚C.

The time it takes the Moon to complete a full rotation around its axis (a lunar day) is the **same** as it takes for a full orbit of the Earth; the result is that the Moon **always shows** the same side to the Earth.



Full solar eclipses are the result of an **extraordinary** celestial coincidence. The sizes of the Moon and the Sun **appear identical** when viewed from Earth, since the Sun's diameter is **400** times the Moon's diameter, and the Sun's distance from the Earth is also about **400** times the Moon's distance. During a New Moon only the outer layer of the Sun remains visible, the spectacular **corona**.

Russia's quest to the Moon

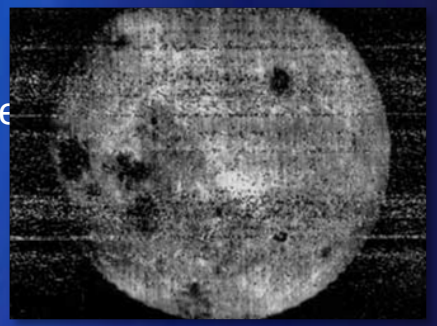
The exploration and 'conquest' of the Moon is commonly attributed to the Americans and their Apollo programme. Nevertheless, many consider the **Russians** to be the true pioneers of our satellite.

In 1959:

LUNA 1 first manmade object to escape the Earth's gravity and approach the

LUNA 2 first manmade object to impact on the Moon

LUNA 3 first photographs of the "far side" of the Moon



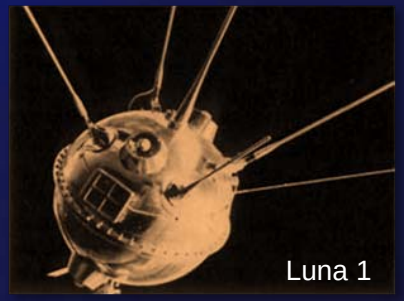
Indeed, no-one before 1959 knew what the hidden side of the Moon looked like. It was a surprise: few dark areas of note (maria), but a monotonous light-coloured surface scarred by countless impacts.

The Russians persevered through their exploration programme while the Americans were busy developing the most ambitious space programme ever: landing the first men on the Moon.

In 1966, the Russian programme continued:

LUNA 9 first successful **soft landing**

LUNA 10 first **lunar orbiting satellite** (followed by Luna 11 and 12)



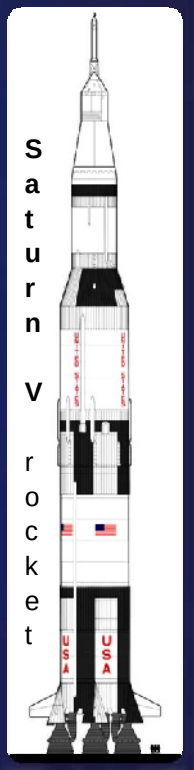
Luna 1

Here comes the cavalry…

But the Americans responded with a breathtaking performance including:

Apollo 8	first **manned lunar orbit**	1968
Apollo 11	first **man landing** on the Moon	1969
Apollo 14	first **colour images** of the Moon	1971 January
Apollo 15	first use of **lunar rover** (~28 km)	1971 July
Apollo 16	first mission to the **highlands**	1972
Apollo 17	first mission with a **scientist on board**	1972

This was also the last manned mission beyond low Earth orbit.

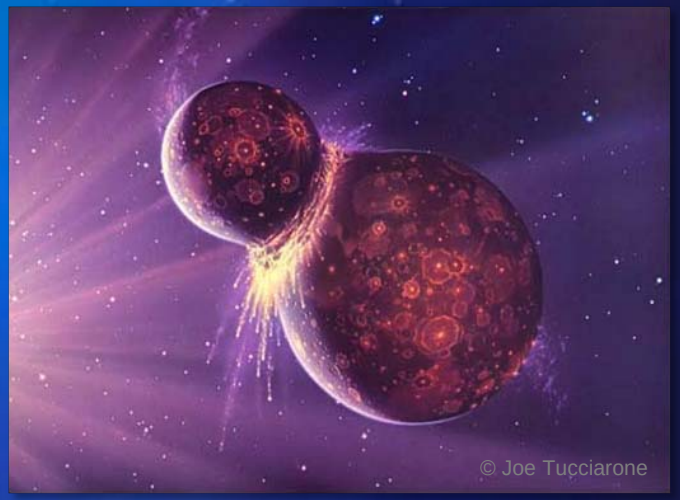


In total the Apollo missions returned **381.7 kg** of rocks and other surface materials.

It all started so many years ago…

So where did the Moon come from? Scientists think that around 4.45 billion years ago a large object about the size of Mars collided with the Earth. The material thrown out then reformed and became the Moon.

Giant impact hypothesis



Are the Moon and the Earth made of the same materials?

The answer is roughly **yes: silicates** are the predominant minerals in both bodies but there are many differences too. For instance the Moon is highly depleted in **volatiles** (from H_2O to potassium), and it is enriched in **iron** in comparison to the Earth.

The post-impact accretion of the Moon

Helpless, if not for the Earth…

Owing to its **weak gravity pull**, the Moon lacks a gaseous atmosphere and the pressure is far too low to allow liquids to exist on its surface. Furthermore, the whole planet has been "**dead**" for billions of years, with no tectonic phenomena or sizable eruptions in the last billion years.

Indeed, this is what makes the Moon so fascinating to scientists. It represents a nearly perfect planetary laboratory, a "**geo-recorder**" placed at a convenient distance from the Earth and left to the mercy of the space elements. It has only been modified only by external factors such as impacts and radiation, and is devoid of any surface modifying factors including **water**, an **atmosphere**, a **biosphere**, or **active tectonics**…

A battered surface…

The lunar surface represents a unique opportunity for us to access a record of planet **Earth**, right back to its time of formation and its travel through time and space. Indeed, some lunar samples have been dated back **to around 4.5 billion years** ago, close to the time of the formation of the Earth/Moon system, a record nearly **completely obliterated** on our planetary surface.

As important as the composition of the Moon is, its **impact record** is also fundamental in helping to understand the dynamic evolution of the whole Solar System, including the role that major impacts had on our planet in regard to **extinction events** and **climate changes**.

On Earth, we find little evidence of past impacts. This is because our planet is still "**alive**" and the crust is continuously recycled by the elements and life, but more importantly by **plate tectonics**. The fractured uppermost layer of the Earth is distorted (e.g. mountain folds), created (e.g. oceanic ridges), and destroyed (e.g. plate subduction). This means that the record of ancient impacts is **obliterated**.

The early years – crustal formation

The most accepted model of lunar evolution goes something like this...

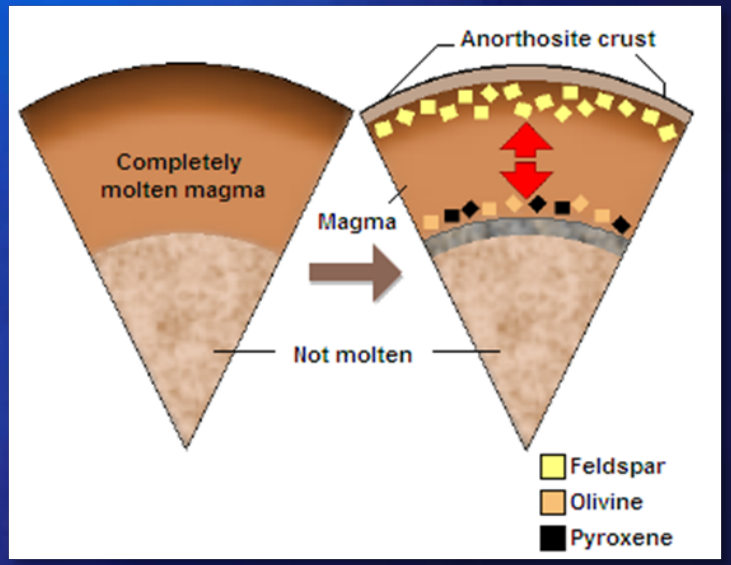
•The young Moon's outer layer was completely molten: a planet-wide **magma ocean**.

•As the magma cooled and crystallised, the "**lighter crystals**" tended to concentrate towards the surface while the "**denser crystals**" slowly sunk.

•The Moon, at the early stages of this process, must have looked **strikingly bright**, thanks to its alumino-silicate rich surface rocks.

•At depth, the accumulated heavier crystals underwent a process of partial melting and some of this liquid found its way to the surface.

•Radioactive materials at depth continued the process of heating, with more liquid magma moving to the surface.



Fractionation of lunar crust

The Past and the Future…

By around 2.6 billion years ago the lunar interior had cooled to the point and depth that **did not allow** magmas to reach the surface. The lunar surface had reached "*adulthood*".

In contrast, the **Earth** was still very much alive and ever-changing. There are few places where we can find rocks dating back to the Late Archean and most are heavily modified.

Life was taking its first, insecure steps in a still relatively violent and dynamic environment. But the Moon from now on stands still, watching…

Heavily metamorphosed Archean rocks in North America

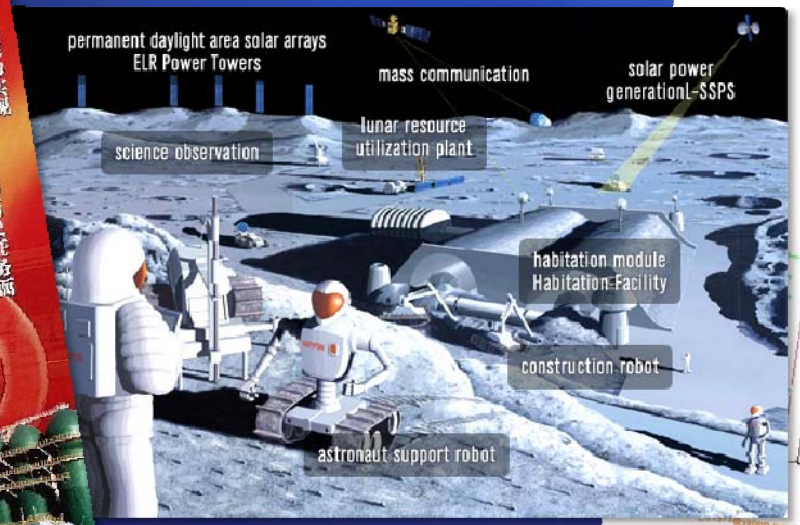

One of many scenarios of possible lunar settlements

If we already know so much about the Moon, why are we still spending vast amounts of money to send instruments around our satellite? And why are we planning to **send people back** to its surface?

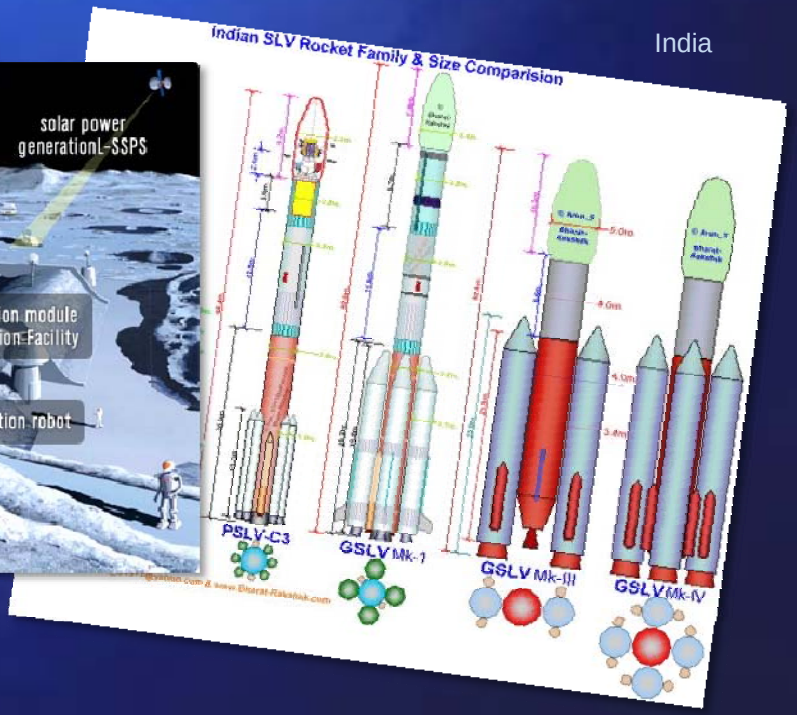
Why, the Moon, again?

As ever, mankind is motivated by an insatiable lust for knowledge and also power.
Emerging world powers are sending and planning new missions to the Moon, in part to pursue scientific goals but also for political prestige and economic stimulus. And the leading countries don't like to be left behind…

China



Japan



India

A few outstanding geological questions:

How does a magma ocean work?

What was the early thermal evolution of the Moon?

Are the Apollo measurements representative of the entire Moon, or only small areas around the landing sites?

What role did early volcanism play?

What is the composition and structure of the lunar mantle?

Was the Moon really created from a giant impact?

Roberto Bugiolacchi (Max-Planck Institute for Solar System Research, Germany) - Galilean Nights Task Group

Galilean Nights is a Cornerstone Project of the IYA2009
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