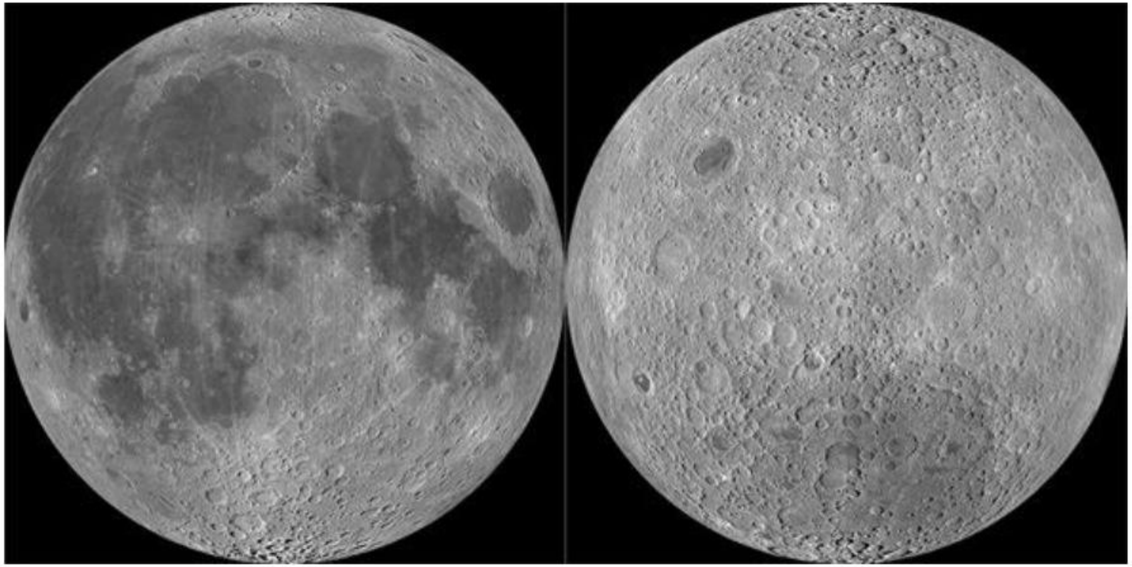
Luna: Earth's Moon

Syzygy Asymptote / Dr. William F. Wall*

Researcher at Instituto Nacional de Astrofísica, Óptica, y Electrónica, Tonantzintla, Puebla, México

ge Millimeter Telescope Alfonso Serrano, Jul



The side of the Moon facing the Earth (left) is very different than the side facing away (right). Why?

Photo by NASA/GSFC/Arizona State University

VFW, Cypress Falls Park, May 2018

*Observational astronomer specializing in molecular clouds in nearby galaxies.

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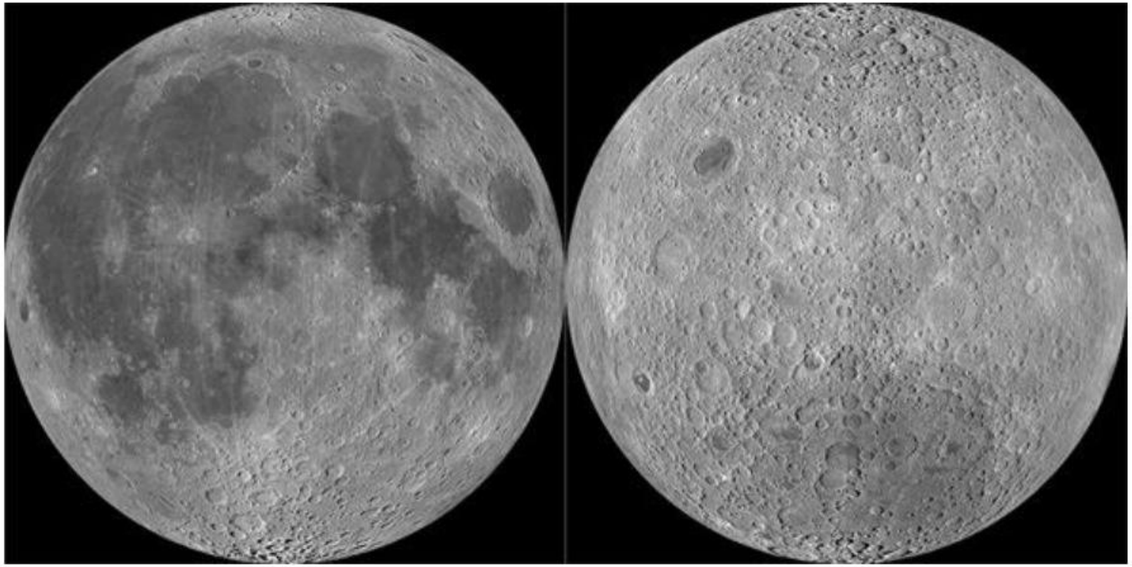

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Outline

- Motivation
- Lunar Basics
- Formation and Structure
- Moon's Orbit about Earth
- Missions to the Moon
- Future of Humanity and the Moon.

This image was taken on November 4th, 2017 at 4:19 am in Titusville, Florida. It shows the International Space Station (with a crew of six currently onboard) transiting the full "Beaver Moon." As the ISS orbits Earth at 17,500mph, or roughly five miles *per second*, the transit lasted just 0.90 seconds.

So I decided to build a restaurant on the moon.
The food is great and all but there's no atmosphere.

How does the man in the moon cut his hair? (From 9yo ch
Eclipse it.

Motivations:

Why is the Moon Interesting?

Motivations:

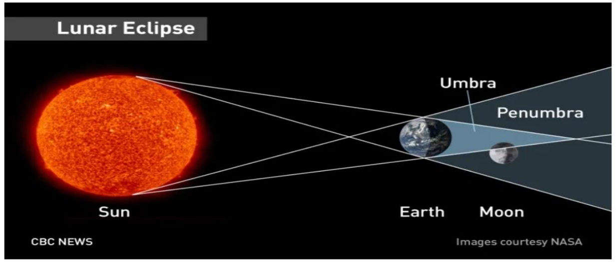
Why is the Moon Interesting?

1) Seasons, tides, eclipses (solar and lunar), occultations, navigation.

2) A base for exploration, for scientific experiments, for settlements.

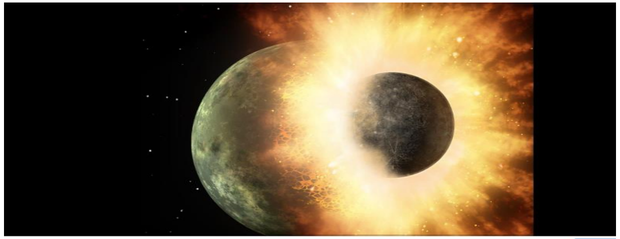
3) To understand the formation and structure of the Earth better. Understand the past and future of the Earth.

4) Inspiration: scientific, explorational, romantic, literary, artistic, religious.



Lunar eclipses occur as the moon passes through Earth's shadow. It can pass through the outer, fainter shadow, called the penumbra. When it passes into the umbra, we can get either a partial or total lunar eclipse, depending on how much of the moon crosses into it. (CBC)

https://sputniknews.com/science/201812011070300348-russia-moon-bas



Artist's depiction of a collision between two planetary bodies. Such an impact between Earth and a Mars-sized object likely formed the Moon.

NASA/JPL-Caltech - http://www.nasa.gov/multimedia/imagegallery/image_feature_1454.html

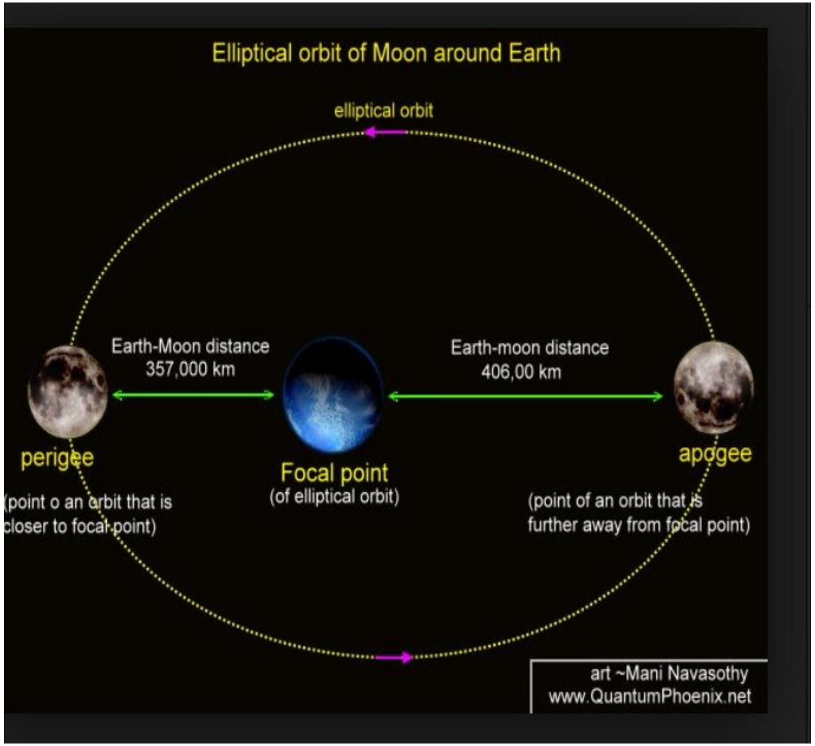
This artist's concept shows a celestial body about the size of our moon slamming at great speed into a body the size of Mercury. NASA's Spitzer Space Telescope found evidence that a high-speed collision of this sort occurred a few thousand years ago around a young star, called HD 172555, still in the early stages of planet formation. The star is about 100 light-years from Earth.

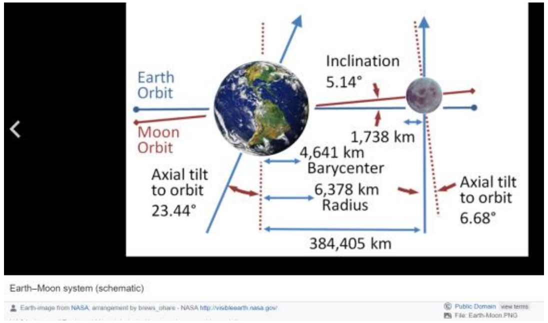
Public Domain
File: Artist's concept of collision at HD 172555.jpg
Created: 26 August 2009

Lunar Basics:

Orbital characteristics

- Perigee 357000 km
Apogee 405400 km
- Semi-major axis 384399 km
- Eccentricity   0.0549
- Orbital period 27.321661 d (sidereal – relative to distant stars)

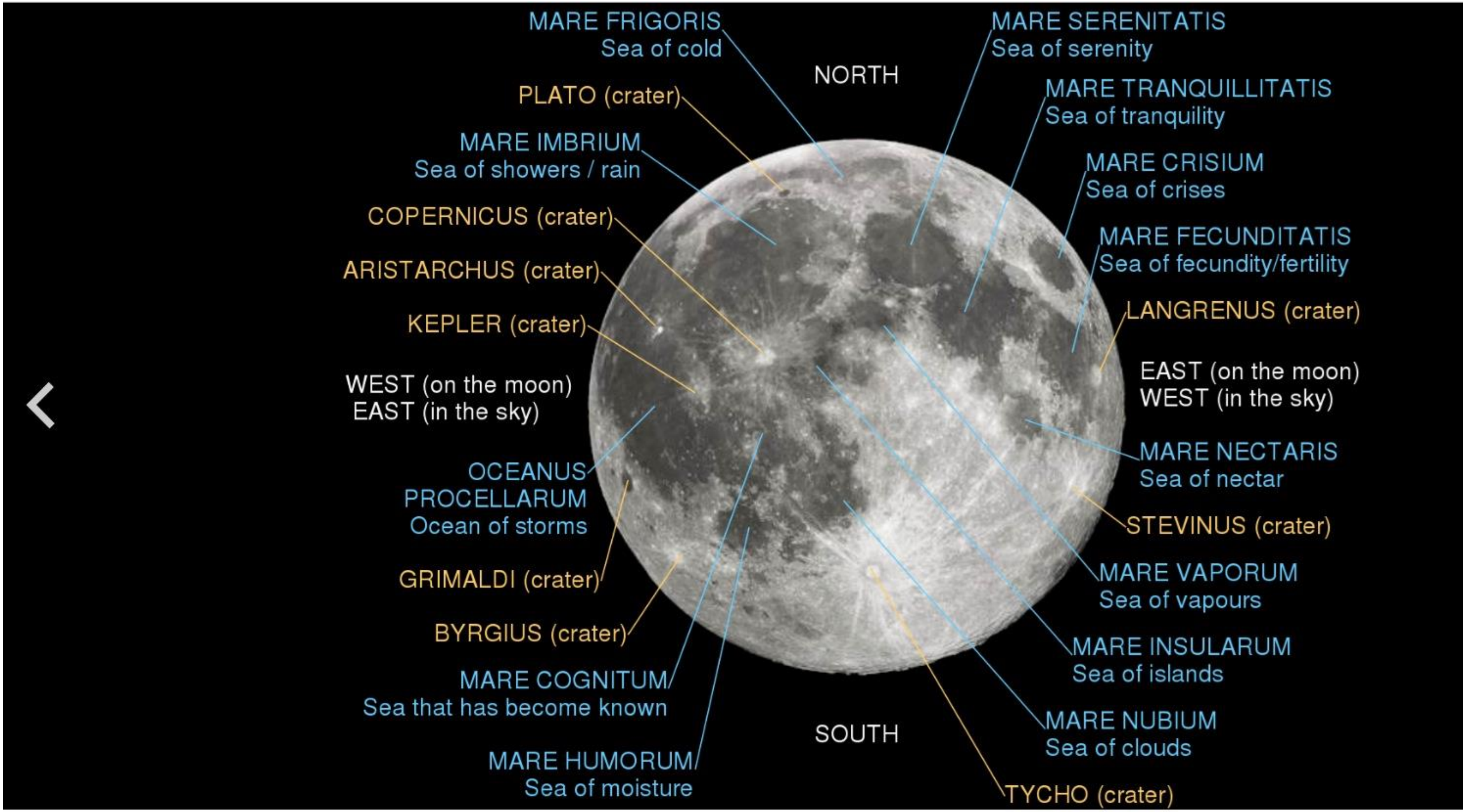




Physical characterist

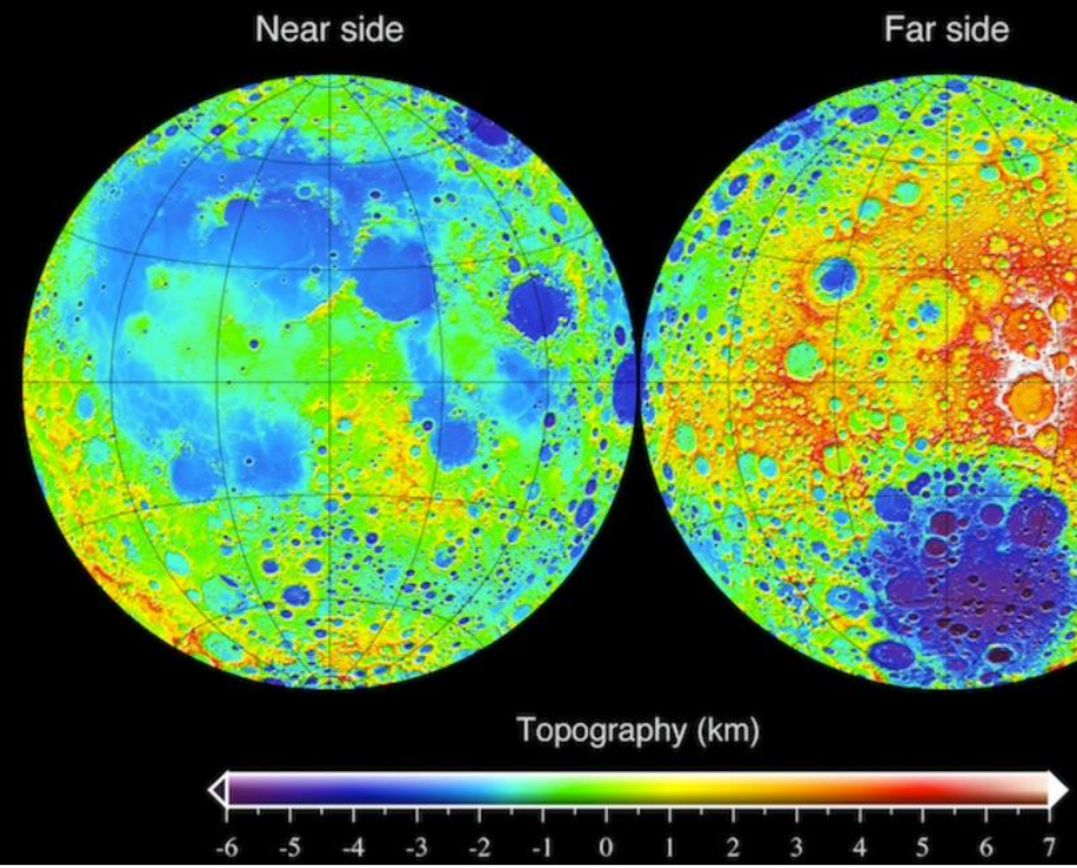
- Mean radius 1737.1 km (0.27
- Flattening 0.0012
- Mass 7.342×10^{22} kg (0.01
- Mean density 3.344 g/cm^3 or 0.606 × Earth
- Surface gravity 1.62 m/s^2 (0.1654 g)
- Escape velocity 2.38 km/s
- Sidereal rotation period 27.321661 d

Lunar Formation and Structure:



Lunar nearside with major maria and craters labeled

Peter Freiman Cmglee Background photograph by Gregory H. Revera - Remake of File:FullMoon2010.jpg Bitmap from File:FullMoon2010.jpg



Topography of the Moon

Mark A. Wieczorek - Own work

The topography of the Moon referenced to a sphere with a radius of 1737.4 kilometers. Data were obtained from the Lunar Orbiter Laser Altimeter (LOLA) that was flown on the mission Lunar Reconnaissance Orbiter (LRO). The color coded topography is displayed in two Lambert equal area images projected on the near and far side hemispheres.

File: MoonTopoLOLA.png
Created: 7 August 2010

Formation

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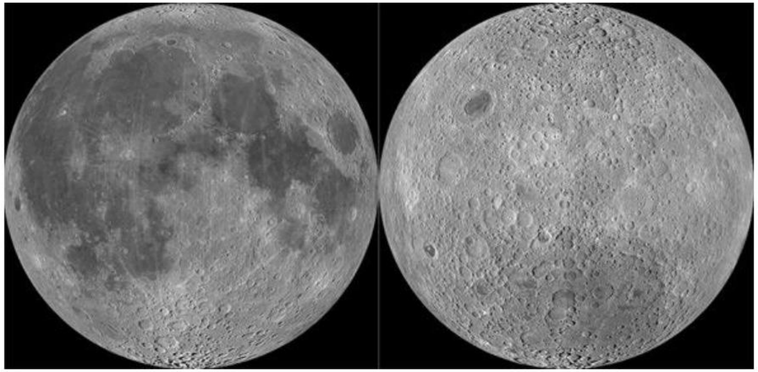


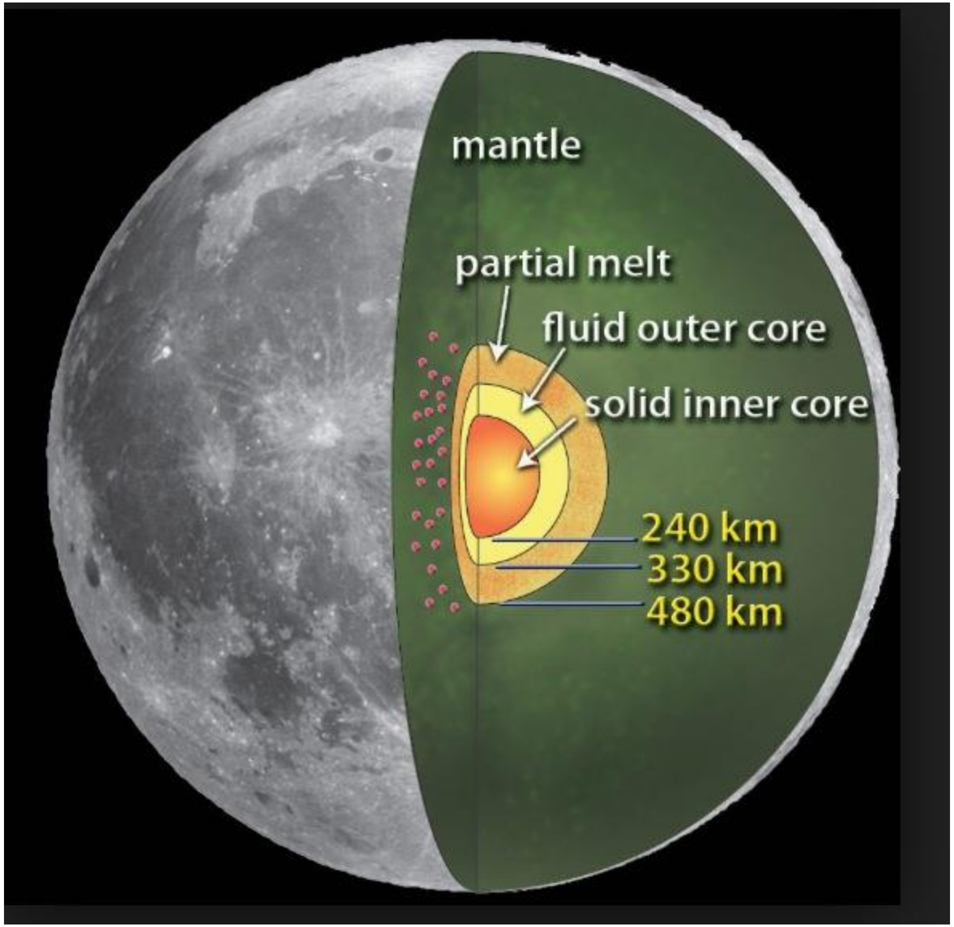
The side of the Moon facing the Earth (left) is very different than the side facing away (right). Why?

Photo by NASA/GSFC/Arizona State University

- The prevailing hypothesis is that the Earth–Moon system formed after an impact of a Mars-sized body (named Theia) with the proto-Earth (giant impact). The impact blasted material into Earth's orbit and then the material accreted and formed the Moon.
- The Moon's far side has a crust

Structure

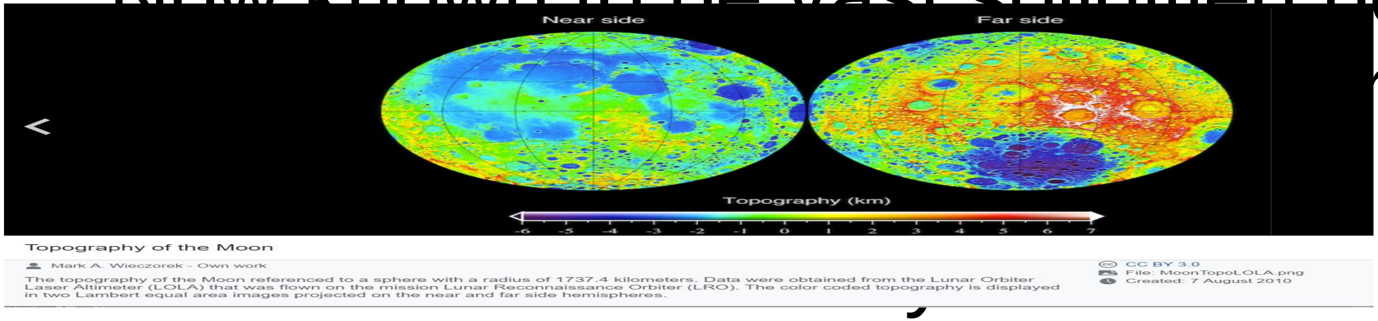
- The Moon is a differentiated body. It has a geochemically distinct crust, mantle, and core.
  - solid iron-rich inner core with a radius possibly as small as 240 kilometres (150 mi) and a
  - fluid outer core of liquid iron with a radius of



nasa.gov

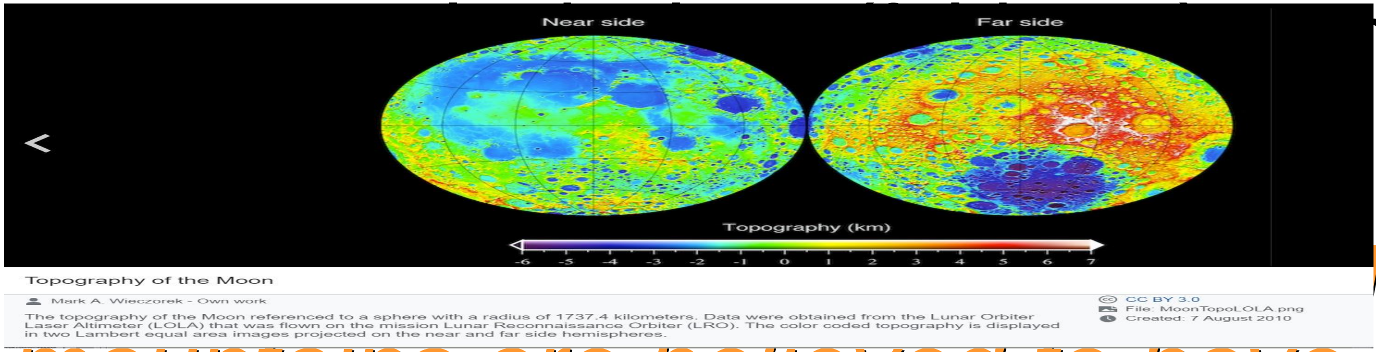
Volcanic Surface Features

- Lunar mare
  - The dark and relatively featureless lunar plains, clearly seen with the naked eye, are called maria (Latin for "seas"; singular mare), as they were once believed to be filled with water;
    - Now known to be vast solidified pools of ... rrestrial ... ron and



Volcanic Surface Features

- Lunar Highlands
  - The lighter-coloured regions of the Moon are called terrae, or more commonly highlands, because they are higher than most maria.
  - They have been radiometrically dated to having formed 4.4 billion years ago, and may … ulates of



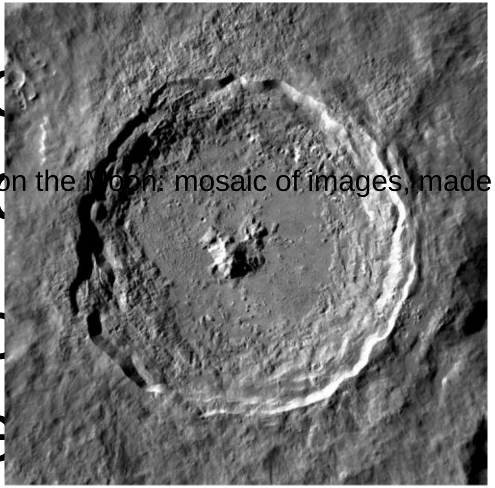
  - … r

mountains are believed to have formed

Impact Craters

- Craters formed when asteroids and comets collide with the lunar surface.

- Roughly 300,000 c than 1 km (0.6 mi) on the Moon's near si

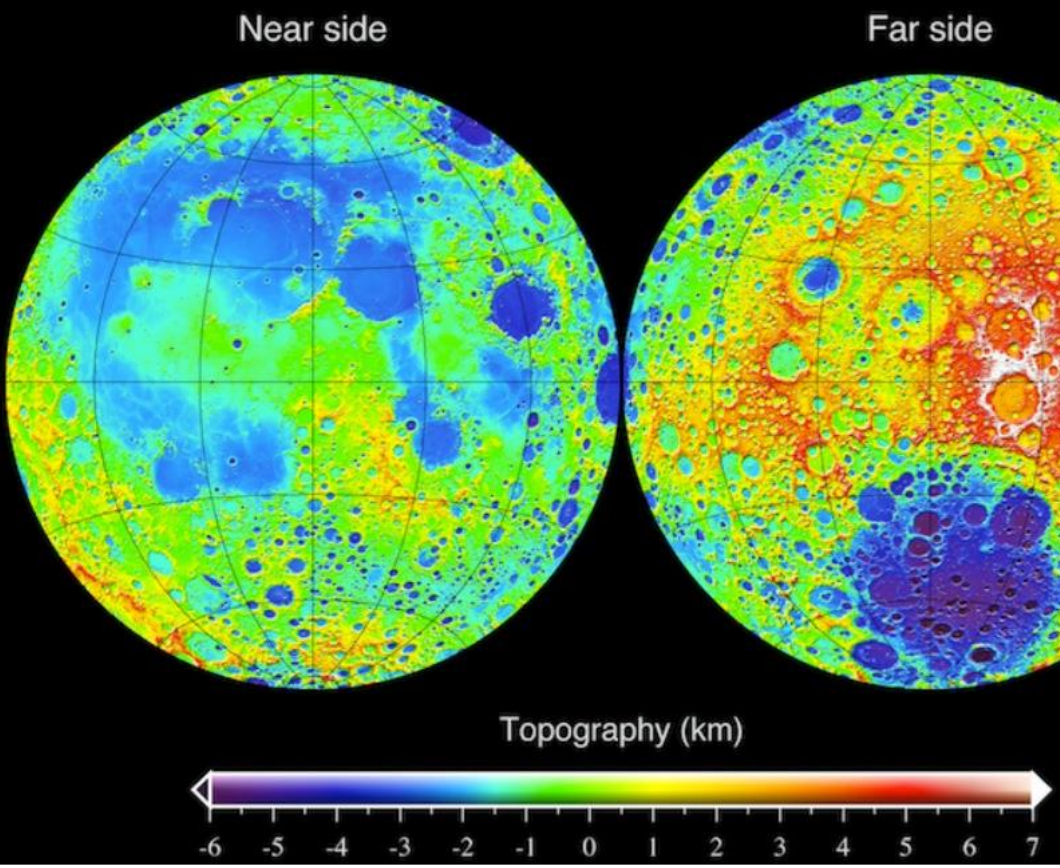


Tycho crater on the Moon: mosaic of images, made by Lunar Reconnaissance Orbiter (Wide Angle Camera). Width of th

- The lunar geologic based on the most prominent impact e ing Nectaris, Imbrium, and Orientale

- The lack of an atmosphere, weather and recent geological processes mean that many of these craters are well-preserved.

  – structures characterized by multiple rings of uplifted material, between hundreds and



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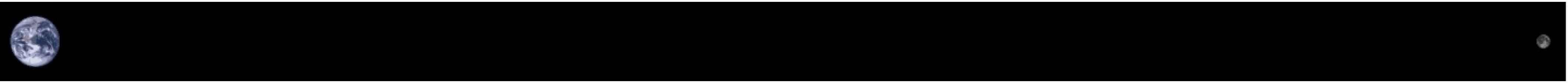
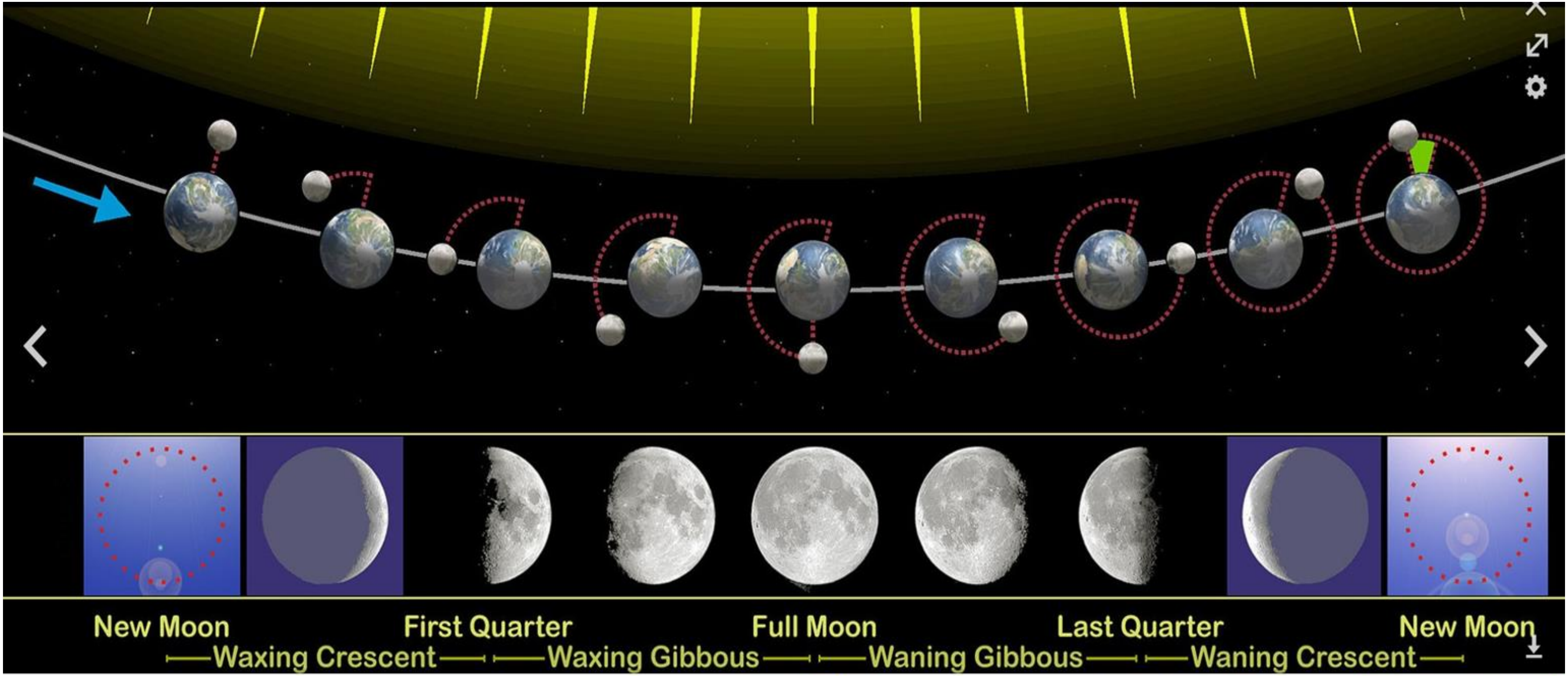
Moon's Orbit about Earth:



Scale model of the Earth–Moon system: Sizes and distances are to scale.



The monthly changes in the angle between the direction of sunlight and view from Earth, and the phases of the Moon that result, as viewed from the Northern Hemisphere. The Earth–Moon distance is not to scale.

More details

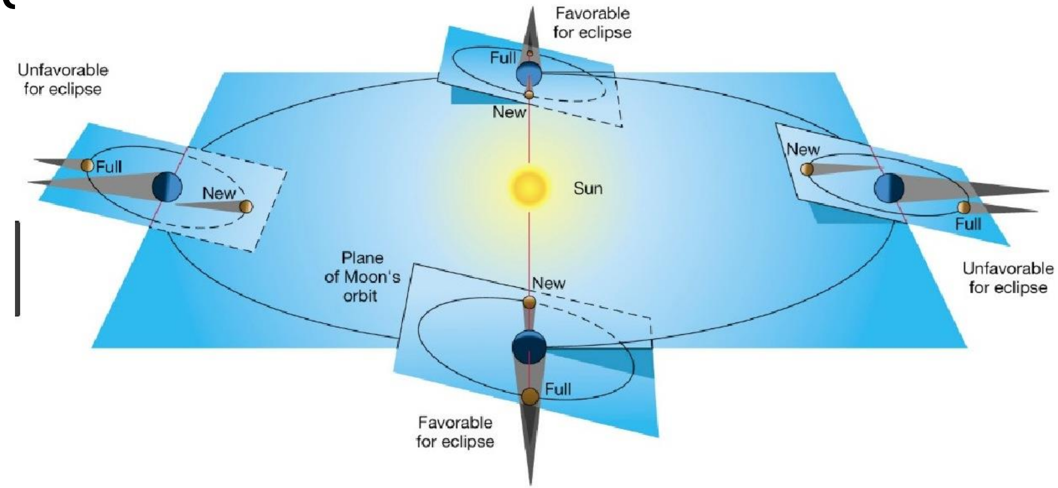
Orion 8 - Own work

The relation of the phases of the Moon with its revolution around Earth. The sizes of Earth and Moon, and their distance you see here are far from real. On this image the following are also depicted: the synchronous rotation of the Moon, the motion of the Earth around the common center of mass, the difference between the sidereal and synodical month (green mark), the Earth's axial tilt. (NOTE: the precise moment of a New Moon take place in daylight when you can see only the bright Sun.)

File: Moon phases en.jpg
Created: 2010-08-19ddd

Eclipses

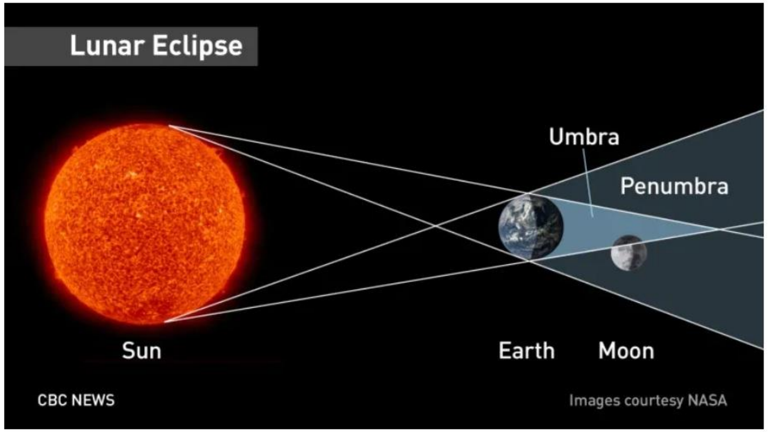
- Eclipse shadows always have an umbra and penumbra because the sun is not a point source. An observer standing in the penumbra would see part of the sun.



https://astronomy.stackexchange.com/questions/11728/supermoon-lunar-eclipse

- From the figure above, it's obvious that lunar or solar eclipses cannot occur every month, because the Moon's orbital plane around the Earth is inclined to the ecliptic (the Earth's orbit around the sun). Only when the a New Moon or Full Moon occurs in the

Eclipses

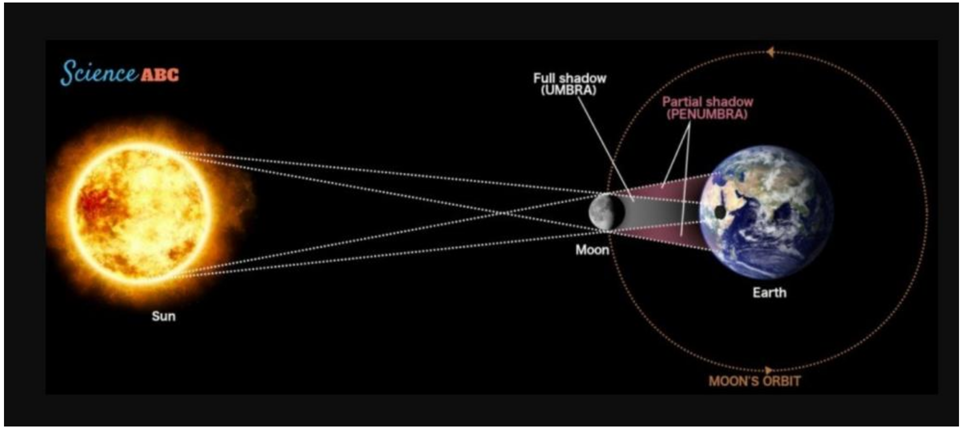


Lunar eclipses occur as the moon passes through Earth's shadow. It can pass through the outer, fainter shadow, called the penumbra. When it passes into the umbra, we can get either a partial or total lunar eclipse, depending on how much of the moon crosses into it. (CBC)

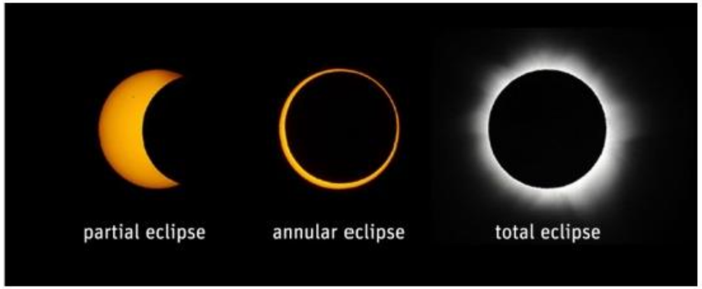
Lunar eclipses occur from 2 to 5 times per year although they're not a

During total lunar eclipses, the Moon is bathed in a dark red light, du

A lunar observer during a total lunar eclipse would see a bright red ri



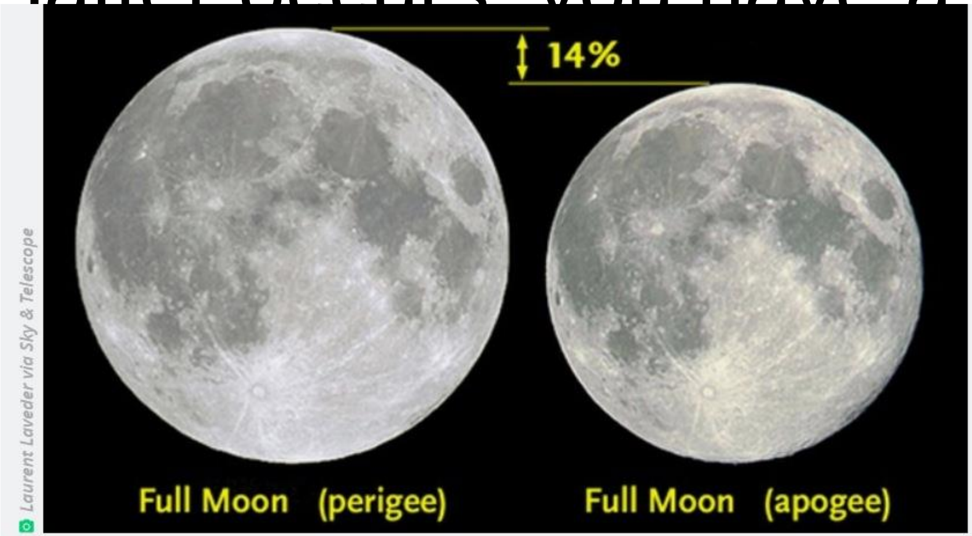
Solar eclipses occur roughly 2-3 times per year (though not neces



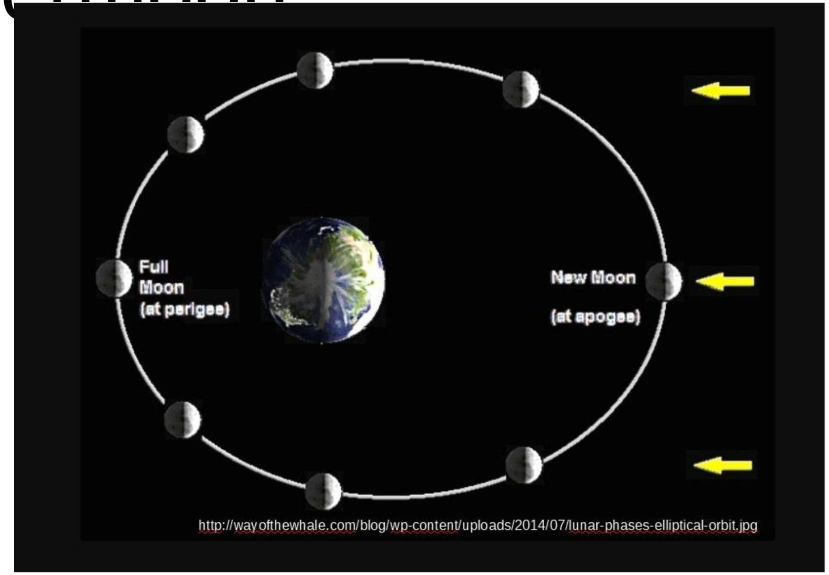
http://www.exploratorium.edu/files/eclipse/hybrid/2013/

SUPERMOON!!

- Major axis of Moon’s orbit seldom aligns with Earth-Sun direction. When it does, you can have a full Moon at apogee or at perigee. When the latter occurs, you have a supermoon

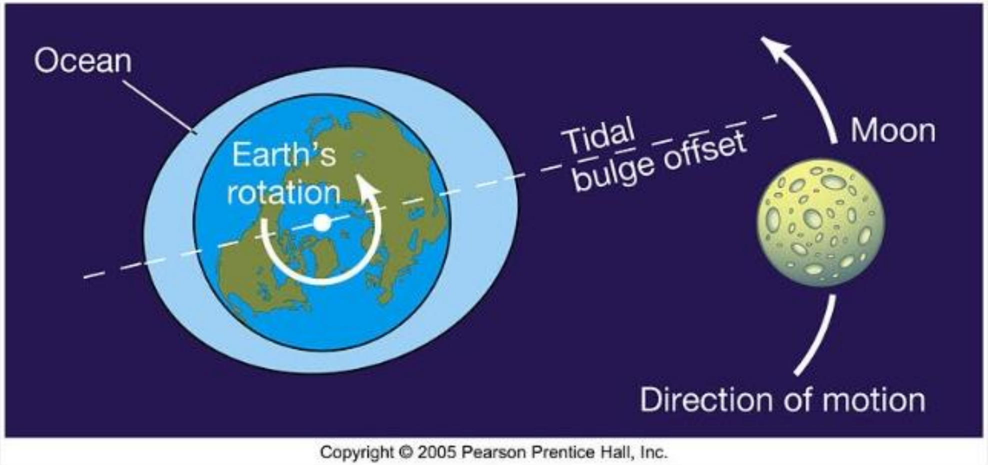


A comparison of a "normal" Moon and a Supermoon.



TIDES-
Differential Gravitational Force

- Force of gravity falls off with distance ($1/r^2$), which means the near side of one body is pulled more strongly by its orbiting partner than its far side (e.g., Moon on Earth and vice versa). This pulls both bodies into egg-like shapes.



The Earth is stretched slightly by the lunar tidal force. But the Earth turns, and it and the oceans don't snap back into shape instantly, so there's always a little extra mass leading the Moon. The pull of this extra mass speeds up the Moon in its orbit and slows the turning of the Earth.

TIDES-
Differential Gravitational Force

- Tidal Locking: Only one lunar face is towards us on the Earth. Remember that the Moon is pulled into an egg-shape by tidal forces.
  - If the Moon were rotating with respect to the Earth-Moon line, the egg-shaped bulging would move around throughout the Moon's interior, thereby generating heat because of internal friction.
    - That heat dissipated the Moon's rotational kinetic energy, resulting in its current tidally locked state.
  - Roll a rubber ball around between your hands. Flatten the ball while doing so. The ball heats up as internal friction dissipates the kinetic energy from your hands.

The Moon Stabilizes the Earth's Rotational Axis

- The Moon is in a stable orbit and pulls on the Earth's equatorial bulge, thereby keeping the Earth's rotational axis from wandering too far during its usual precession. (Like having a spinning top that is extra wide – it's more stable.)
  - This keeps the obliquity of the ecliptic confined to a narrow range ($22.1 – 24.5^{O}$), minimizing seasonal extremes in climate.
  - Earth is more suitable for life than it would be otherwise.

Easter

(Gregorian Calendar)

- Easter is the *first* Sunday after the *first* full Moon that occurs on, or after, the March equinox – between 2… …eeus, "*Astronomi*… …nethod for computing … …ar.

Divide	by	Quotient	Remainder
the year x	19	—	a
the year x	100	b	c
b	4	d	e
$b + 8$	25	f	—
$b - f + 1$	3	g	—
$19a + b - d - g + 15$	30	—	h
c	4	i	k
$32 + 2e + 2i - h - k$	7	—	l
$a + 11h + 22l$	451	m	—
$h + l - 7m + 114$	31	n	p

Then n = number of the month (3 = March, 4 = April),
$p + 1$ = day of that month upon which Easter Sunday falls.

Missions to the Moon:

Spacecraft	Launch date[1]	Carrier rocket[2]	Operator	Mission type	Outcome
Pioneer 0 (Able I)[3]	17 August 1958	Thor DM-18 Able I[3]	USAF	Orbiter	Launch failure
	First attempted launch beyond Earth orbit; failed to orbit due to turbopump gearbox malfunction resulting in first stage explosion.[3] Reached apogee of 16 kilometres (9.9 mi).[4]				
Luna E-1 No.1	23 September 1958	Luna	OKB-1	Impactor	Launch failure
	Failed to orbit; rocket disintegrated due to excessive vibration.[3][5]				
Pioneer 1 (Able II)[3]	11 October 1958	Thor DM-18 Able I[3]	NASA	Orbiter	Launch failure
	Failed to orbit; premature second stage cutoff due to accelerometer failure. Later known as Pioneer 1.[3] Reached apogee of 113,800 kilometres (70,700 mi).[6]				
Luna E-1 No.2	11 October 1958	Luna	OKB-1	Impactor	Launch failure
	Failed to orbit; carrier rocket exploded due to excessive vibration.[3][5]				
Pioneer 2 (Able III)	8 November 1958	Thor DM-18 Able I	NASA	Orbiter	Launch failure
	Failed to orbit; premature second stage cutoff due to erroneous command by ground controllers; third stage failed to ignite due to broken electrical connection.[3] Reached apogee of 1,550 kilometres (960 mi).[7]				
Luna E-1 No.3	4 December 1958	Luna	OKB-1	Impactor	Launch failure
	Failed to orbit; seal failure in hydrogen peroxide pump cooling system resulted in core stage underperformance.[3][5]				
Pioneer 3	6 December 1958	Juno II	NASA	Flyby	Launch failure
	Failed to orbit; premature first stage cutoff.[3] Reached apogee of 102,360 kilometres (63,600 mi).[8]				
Mechta (E-1 No.4)	2 January 1959	Luna	OKB-1	Impactor	Launch failure
	Carrier rocket guidance problem resulted in failure to impact Moon, flew past in a heliocentric orbit, later known as Luna 1.[9] Closest approach 5,995 kilometres (3,725 mi) on 4 January.[10]				
Pioneer 4	3 March 1959	Juno II	NASA	Flyby	Partial failure
	Second stage overperformance resulted in flyby at greater altitude than expected, out of instrument range, with 58,983 kilometres (36,650 mi) of distance.[9] Closest approach at 22:25 UTC on 4 March. First U.S. spacecraft to leave Earth orbit.[11]				
E-1A No.1	18 June 1959	Luna	OKB-1	Impactor	Launch failure
	Failed to orbit; guidance system malfunction.[9]				
Luna 2 (E-1A No.2)	12 September 1959	Luna	OKB-1	Impactor	Successful
	Successful impact at 21:02 on 14 September 1959. **First spacecraft to reach lunar surface**.[12]				
Luna 3 (E-2A No.1)	4 October 1959	Luna	OKB-1	Flyby	Successful
	Returned **first images of the far side of the Moon**.[13]				
Pioneer P-3 Able IVB	26 November 1959	Atlas-D Able	NASA	Orbiter	Launch failure
	Failed to orbit;[14] payload fairing disintegrated due to design fault.[9]				
Luna E-3 No.1	15 April 1960	Luna	OKB-1	Flyby	Launch failure
	Failed to orbit; premature third stage cutoff.[15]				
Luna E-3 No.2	16 April 1960	Luna	OKB-1	Flyby	Launch failure
	Failed to orbit; rocket disintegrated ten seconds after launch.[15]				
Pioneer P-30 (Able VA)	25 September 1960	Atlas-D Able	NASA	Orbiter	Launch failure
	Failed to orbit; second stage oxidiser system malfunction resulting in premature cutoff.[16][15]				
Pioneer P-31 (Able VB)	15 December 1960	Atlas-D Able	NASA	Orbiter	Launch failure

Spacecraft	Launch date[1]	Carrier rocket[2]	Operator	Mission type	Outcome
	Failed to orbit, exploded 68 seconds after launch, at an altitude of 12.2 kilometres (7.6 mi). Second stage ignited while first stage was still attached and burning.[17][15]				
Ranger 3 (P-34)	26 January 1962	Atlas LV-3 Agena-B	NASA	Impactor	Spacecraft failure
	Partial launch failure due to guidance problem; attempt to correct using spacecraft's engine resulted in it missing the Moon by 36,793 kilometres (22,862 mi).[18][19]				
Ranger 4 (P-35)	23 April 1962	Atlas LV-3 Agena-B	NASA	Impactor	Spacecraft failure
	Failed to deploy solar panels, ran out of power ten hours after launch; incidental impact on the far side of the Moon on 26 April.[18][20]				
Ranger 5 (P-36)	18 October 1962	Atlas LV-3 Agena-B	NASA	Impactor	Spacecraft failure
	Solar panels erroneously disengaged from power system, failed 8¾ hours after launch when batteries were depleted.[18] Missed the Moon as course correction was not completed.[21]				
Luna E-6 No.2	4 January 1963	Molniya-L	OKB-1	Lander	Launch failure
	Failed to depart Low Earth orbit;[22] guidance system power failure prevented upper stage ignition.[23]				
Luna E-6 No.3	3 February 1963	Molniya-L	OKB-1	Lander	Launch failure
	Failed to orbit; guidance failure.[23]				
Luna 4 (E-6 No.4)	2 April 1963	Molniya-L	OKB-1	Lander	Spacecraft failure
	Failed to perform mid-course correction,[23] remained in high Earth orbit until given escape velocity by orbital perturbation.[24]				
Ranger 6 (P-54)	30 January 1964	Atlas LV-3 Agena-B	NASA	Impactor	Spacecraft failure
	Impacted on 2 February 1964, failed to return images due to power system failure.[25][26]				
Luna E-6 No.6	21 March 1964	Molniya-M	OKB-1	Lander	Launch failure
	Failed to orbit; third stage underperformed due to oxidiser valve failure.[25]				
Luna E-6 No.5	20 April 1964	Molniya-M	OKB-1	Lander	Launch failure
	Failed to orbit; power failure caused by broken connection resulted in premature third stage cutoff.[25]				
Ranger 7	28 July 1964	Atlas LV-3 Agena-B	NASA	Impactor	Successful
	Impacted on 30 July 1964 at 13:25:48 UTC.[27]				
Ranger 8	17 February 1965	Atlas LV-3 Agena-B	NASA	Impactor	Successful
	Impacted on 20 February 1965 at 09:57:37 UTC.[28][29]				
Kosmos 60 (E-6 No.9)	12 March 1965	Molniya-L	Lavochkin	Lander	Launch failure
	Upper stage failed to restart due to guidance system short-circuit,[28] Failed to depart low Earth orbit.[30]				
Ranger 9	21 March 1965	Atlas LV-3 Agena-B	NASA	Impactor	Successful
	Impacted on 24 March 1965 at 14:08:20 UTC.[28][31]				
Luna E-6 No.8	10 April 1965	Molniya-L	Lavochkin	Lander	Launch failure
	Third stage failed to ignite due to loss of oxidiser pressure, failed to orbit.[28]				
Luna 5 (E-6 No.10)	9 May 1965	Molniya-M	Lavochkin	Lander	Spacecraft failure
	Loss of control after gyroscope malfunction,[28] failed to decelerate for landing and impacted the Moon at 19:10 UTC on 12 May 1965.[32]				

Spacecraft	Launch date[1]	Carrier rocket[2]	Operator	Mission type	Outcome
Luna 6 (E-6 No.7)	8 June 1965	Molniya-M	Lavochkin	Lander	Spacecraft failure
	Engine failed to shut down after performing mid-course correction manoeuvre,[28] flew past the Moon in a heliocentric orbit.[33]				
Zond 3 (3MV-4 No.3)	18 July 1965	Molniya	Lavochkin	Flyby	Successful
	Flew past the Moon on 20 July 1965 at a distance of 9,200 kilometres (5,700 mi).[34] Conducted technology demonstration for future planetary missions.[28]				
Luna 7 (E-6 No.11)	4 October 1965	Molniya	Lavochkin	Lander	Spacecraft failure
	Attitude control failure shortly before landing prevented controlled descent; impacted the lunar surface 22:08:24 UTC on 7 October 1965.[28][35]				
Luna 8 (E-6 No.12)	3 December 1965	Molniya	Lavochkin	Lander	Spacecraft failure
	Landing airbag punctured, resulting in loss of attitude control shortly before planned touchdown,[28] impacted Moon on 6 December 1965 at 21:51:30 UTC.[36]				
Luna 9 (E-6 No.13)	31 January 1966	Molniya-M	Lavochkin	Lander	Successful
	First spacecraft to land successfully on the Moon. Touchdown on 3 February 1966 at 18:45:30 UTC.[37] Returned data until 6 February at 22:55 UTC.[38]				
Kosmos 111 (E-6S No.204)	1 March 1966	Molniya-M	Lavochkin	Orbiter	Launch failure
	Upper stage lost attitude control and failed to ignite;[38] spacecraft never left low Earth orbit.[39]				
Luna 10 (E-6S No.206)	31 March 1966	Molniya-M	Lavochkin	Orbiter	Successful
	Entered orbit at 18:44 UTC on 3 April 1966, becoming the **first spacecraft to orbit the Moon**.[40] Continued to return data until 30 May.[38]				
Surveyor 1	30 May 1966	Atlas LV-3C Centaur-D	NASA	Lander	Successful
	Landed in Oceanus Procellarum on 2 June 1966 at 06:17:36 UTC.[38] Returned data until loss of power on 13 July.[41]				
Explorer 33 (AIMP-D)	1 July 1966	Delta E1	NASA	Orbiter	Launch failure
	Magnetospheric probe; rocket imparted greater velocity than had been planned, leaving spacecraft unable to enter orbit.[38] Repurposed for Earth orbit mission which was completed successfully.[42]				
Lunar Orbiter 1	10 August 1966	Atlas SLV-3 Agena-D	NASA	Orbiter	Partial failure
	Orbital insertion at around 15:36 UTC on 14 August. Deorbited early due to lack of fuel and to avoid communications interference with the next mission, impacted the Moon at 13:30 UTC on 29 October 1966.[43]				
Luna 11 (E-6LF No.101)	21 August 1966	Molniya-M	Lavochkin	Orbiter	Partial failure[a]
	Entered orbit on 28 August 1966. Failed to return images; other instruments operated correctly.[38] Conducted gamma ray and X-ray observations to study the composition of the Moon, investigated the lunar gravitational field, the presence of meteorites in the lunar environment and the radiation environment at the Moon. Ceased operations on 1 October 1966 after power was depleted.[44]				
Surveyor 2	20 September 1966	Atlas LV-3C Centaur-D	NASA	Lander	Spacecraft failure
	One thruster failed to ignite during mid-course correction manoeuvre resulting in loss of control.[38] Impacted the Moon at 03:18 UTC on 23 September 1966.[45]				
Luna 12 (E-6LF No.102)	22 October 1966	Molniya-M	Lavochkin	Orbiter	Successful

Spacecraft	Launch date[1]	Carrier rocket[2]	Operator	Mission type	Outcome
	Entered orbit on 25 October 1966 and returned data until 19 January 1967.[46] Completed photography mission intended for Luna 11.[38]				
Lunar Orbiter 2	6 November 1966	Atlas SLV-3 Agena-D	NASA	Orbiter	Successful
	Entered orbit at about 19:51 UTC on 10 November 1966 to begin photographic mapping mission. Impacted on the far side of the lunar surface following deorbit burn on 11 October 1967 at end of mission.[47]				
Luna 13 (E-6M No.205)	21 December 1966	Molniya-M	Lavochkin	Lander	Successful
	Successfully landed in Oceanus Procellarum at 18:01 UTC on 24 December 1966.[38] Returned images from the surface and studied the lunar soil.[48] Operated until depletion of power at 06:31 UTC on 28 December.[38]				
Lunar Orbiter 3	5 February 1967	Atlas SLV-3 Agena-D	NASA	Orbiter	Successful
	Entered orbit at 21:54 UTC on 8 February 1967. Deorbited at end of mission and impacted the Moon on 9 October 1967.[49]				
Surveyor 3	17 April 1967	Atlas LV-3C Centaur-D	NASA	Lander	Successful
	Landed at 00:04 UTC on 20 April 1967 and operated until 3 May.[50][51] Visited by Apollo 12 astronauts in 1969, with some parts removed for return to Earth.[52]				
Lunar Orbiter 4	4 May 1967	Atlas SLV-3 Agena-D	NASA	Orbiter	Successful
	Entered orbit at 21:54 UTC on 8 May 1967, operated until 17 July. Decayed from orbit, with lunar impact occurring on 6 October 1967.[50][53]				
Surveyor 4	14 July 1967	Atlas LV-3C Centaur-D	NASA	Lander	Spacecraft failure
	Contact with spacecraft lost at 02:03 UTC on 17 July, two and a half minutes before scheduled landing.[50] NASA determined that the spacecraft may have exploded, otherwise it impacted the Moon.[54]				
Explorer 35 (AIMP-E)	19 July 1967	Delta E1	NASA	Orbiter	Successful
	Magnetospheric probe, studying the Moon and interplanetary space. Deactivated on 27 June 1973.[55] Presumed to have impacted the Moon during the 1970s.[56]				
Lunar Orbiter 5	1 August 1967	Atlas SLV-3 Agena-D	NASA	Orbiter	Successful
	Final mission in the Lunar Orbiter series, entered selenocentric orbit on 5 August at 16:48 UTC and conducted a photographic survey until 18 August. Deorbited and impacted the Moon on 31 January 1968.[57]				
Surveyor 5	8 September 1967	Atlas SLV-3C Centaur-D	NASA	Lander	Successful
	Landed in *Mare Tranquillitatis* at 00:46:44 UTC on 11 September. Last signals received at 04:30 UTC on 17 December 1967.[58]				
Soyuz 7K-L1 No.4L	27 September 1967	Proton-K/D	Lavochkin	Flyby	Launch failure
	Technology demonstration for planned manned missions. Failed to reach orbit after a blocked propellant line caused one of the first stage engines to not ignite.[50]				
Surveyor 6	7 November 1967	Atlas SLV-3C Centaur-D	NASA	Lander	Successful
	Landed in *Sinus Medii* at 01:01:04 UTC on 10 November.[50] Made brief flight from lunar surface at 10:32 UTC on 17 November, followed by second landing after travelling 2.4 metres (7 ft 10 in). Last contact at 19:14 UTC on 14 December.[59]				
Soyuz 7K-L1 No.5L	22 November 1967	Proton-K/D	Lavochkin	Flyby	Launch failure
	Technology demonstration for planned manned missions; unable to achieve orbit after second stage engine failed to ignite.[50]				
Surveyor 7	7 January 1968	Atlas SLV-3C Centaur-D	NASA	Lander	Successful
	Final Surveyor mission.[60] Landed 29 kilometres (18 mi) from *Tycho* crater at 01:05:36 UTC on 10 January. Operated until 21 February 1968.[61]				

Spacecraft	Launch date[1]	Carrier rocket[2]	Operator	Mission type	Outcome
Luna E-6LS No.112	7 February 1968	Molniya-M	Lavochkin	Orbiter	Launch failure
	Failed to orbit after third stage ran out of fuel.[61]				
Luna 14 (E-6LS No.113)	7 April 1968	Molniya-M	Lavochkin	Orbiter	Successful
	Tested communications for proposed manned missions and studied the mass concentration of the Moon. Entered orbit on 10 April at 19:25 UTC.[62]				
Soyuz 7K-L1 No.7L	22 April 1968	Proton-K/D	Lavochkin	Flyby	Launch failure
	Technology demonstration for planned manned missions. Failed to orbit after second stage engine incorrectly commanded to shut down. Spacecraft was recovered using its prototype launch escape system.[61]				
Zond 5 (7K-L1 No.9L)	14 September 1968	Proton-K/D	Lavochkin	Flyby, circled	Successful
	Two tortoises and other life forms on board a technology demonstration for planned manned missions. Made a closest approach of 1,950 kilometres (1,150 mi) on 18 September, and circled the Moon before returning to Earth. Landed in the Indian Ocean on 21 September at 16:08 UTC, becoming the first Lunar spacecraft to be recovered successfully and carried the **first Earth life to travel to and around the Moon**.[63]				
Zond 6 (7K-L1 No.12L)	10 November 1968	Proton-K/D	Lavochkin	Flyby	Spacecraft failure
	Technology demonstration for planned manned missions. Flyby occurred on 14 November, with a closest approach of 2,420 kilometres (1,500 mi).[64] Reentered Earth's atmosphere on 17 November; however, recovery was unsuccessful after parachutes were prematurely jettisoned.[61]				
Apollo 8	21 December 1968	Saturn V	NASA	Manned orbiter	Successful
	First manned mission to the Moon; entered orbit around the Moon with four-minute burn beginning at 09:59:52 UTC on 24 December. Completed ten orbits of the Moon before returning to Earth with an engine burn at 06:10:16 UTC on 25 December. Landed in the Pacific Ocean at 15:51 UTC on 27 December.[65]				
Soyuz 7K-L1 No.13L	20 January 1969	Proton-K/D	Lavochkin	Flyby	Launch failure
	Technology demonstration for planned manned missions. Failed to orbit after one of the four second stage engines shut down prematurely. Third stage engine also shut down prematurely. The spacecraft was recovered using its launch escape system.[66]				
Luna E-8 No.201	19 February 1969	Proton-K/D	Lavochkin	Lander/rover	Launch failure
	First launch of the Lunokhod rover. Launch vehicle disintegrated 51 seconds after launch and exploded.[66]				
Soyuz 7K-L1S No.3	21 February 1969	N1	OKB-1	Orbiter	Launch failure
	First launch of N1 rocket; intended to orbit the Moon and return to Earth. First stage prematurely shut down 70 seconds after launch; launch vehicle crashed 50 kilometres (31 mi) from launch site. Spacecraft landed some 35 kilometres (22 mi) from the launch pad after successfully using its launch escape system.[66]				
Apollo 10	18 May 1969	Saturn V	NASA	Manned orbiter	Successful
	Dress rehearsal for Apollo 11. Lunar Module with two astronauts on board descended to a distance of 14.326 kilometres (8.902 mi) above the lunar surface.[67]				
Luna E-8-5 No.402	14 June 1969	Proton-K/D	Lavochkin	Sample return	Launch failure
	Intended to land on the Moon and return lunar soil sample. Did not reach Earth orbit after fourth stage failed to ignite.[66]				
Soyuz 7K-L1S No.5	3 July 1969	N1	OKB-1	Orbiter	Launch failure

Spacecraft	Launch date[1]	Carrier rocket[2]	Operator	Mission type	Outcome
	Intended to orbit the Moon and return to Earth. All first stage engines shut down 10 seconds after launch; launch vehicle crashed and exploded on the launch pad. Spacecraft landed safely 2 kilometres (1.2 mi) from the launch site after using launch escape sequence.[66]				
Luna 15 (E-8-5 No.401)	13 July 1969	Proton-K/D	Lavochkin	Sample return	Spacecraft failure
	Reached lunar orbit at 10:00 UTC on 17 July. Descent retro-rocket burn started at 15:47 UTC on 21 July. Contact lost 3 minutes after de-orbit burn; probably crashed on the Moon.[66]				
Apollo 11	16 July 1969	Saturn V	NASA	Manned orbiter/lander	Successful
	First manned landing on the Moon. The Apollo Lunar Module (LM) *Eagle* landed at 20:17 UTC on 20 July 1969.				
Zond 7 (7K-L1 No.11L)	7 August 1969	Proton-K/D	Lavochkin	Flyby	Successful
	Technology demonstration for planned manned missions. Lunar flyby on 10 August, with a closest approach of 1,200 kilometres (750 mi); returned to Earth and landed in Kazakhstan at 18:13 UTC on 14 August.[66]				
Kosmos 300 (E-8-5 No.403)	23 September 1969	Proton-K/D	Lavochkin	Sample return	Launch failure
	Third attempt at lunar sample return. After reaching low Earth orbit, the fourth stage engine failed to fire for trans-lunar injection due to oxidiser leak. Spacecraft re-entered Earth's atmosphere about 4 days after launch.[66]				
Kosmos 305 (E-8-5 No.404)	22 October 1969	Proton-K/D	Lavochkin	Sample return	Launch failure
	Fourth attempt at lunar sample return. After reaching low Earth orbit, the fourth stage engine failed to fire for trans-lunar injection due to control system malfunction. Spacecraft re-entered Earth's atmosphere within one orbit after launch.[66]				
Apollo 12	14 November 1969	Saturn V	NASA	Manned orbiter/lander	Successful
	Second manned lunar landing.				
Luna E-8-5 No.405	6 February 1970	Proton-K/D	Lavochkin	Sample return	Launch failure
	Failed to orbit.				
Apollo 13	11 April 1970	Saturn V	NASA	Manned orbiter/lander	Spacecraft failure
	Lunar landing aborted following Service Module oxygen tank explosion enroute to the Moon; flew past the Moon (free-return trajectory) and returned the crew safely to Earth.				
Luna 16 (E-8-5 No.406)	12 September 1970	Proton-K/D	Lavochkin	Sample return	Successful
Zond 8 (7K-L1 No.14L)	20 October 1970	Proton-K/D	Lavochkin	Flyby	Successful
	Technology demonstration for planned manned missions; returned to Earth successfully.				
Luna 17 (E-8 No.203)	10 November 1970	Proton-K/D	Lavochkin	Lander/rover	Successful
	Deployed Lunokhod 1.				
Apollo 14	31 January 1971	Saturn V	NASA	Manned Orbiter/Lander	Successful
	Third manned lunar landing.				
Apollo 15	26 July 1971	Saturn V	NASA	Manned orbiter/lander/rover	Successful

Spacecraft	Launch date[1]	Carrier rocket[2]	Operator	Mission type	Outcome
	Fourth manned lunar landing.				
PFS-1	26 July 1971	Saturn V	NASA	Orbiter	Successful
	Deployed from Apollo 15.				
Luna 18 (E-8-5 No.407)	2 September 1971	Proton-K/D	Lavochkin	Sample return	Spacecraft failure
	Failed during descent to lunar surface.				
Luna 19 (E-8LS No.202)	28 September 1971	Proton-K/D	Lavochkin	Orbiter	Successful
Luna 20 (E-8-5 No.408)	14 February 1972	Proton-K/D	Lavochkin	Sample return	Successful
Apollo 16	16 April 1972	Saturn V	NASA	Manned orbiter/lander/rover	Successful
	Fifth manned lunar landing.				
PFS-2	16 April 1972	Saturn V	NASA	Orbiter	Successful
	Deployed from Apollo 16.				
Soyuz 7K-LOK No.1	3 July 1972	N1	OKB-1	Orbiter	Launch failure
	Failed to orbit; intended to orbit the Moon and return to Earth.				
Apollo 17	7 December 1972	Saturn V	NASA	Manned orbiter/lander/rover	Successful
	Sixth and last manned lunar landing.				
Luna 21 (E-8 No.204)	8 January 1973	Proton-K/D	Lavochkin	Lander/rover	Successful
	Deployed Lunokhod 2.				
Explorer 49 (RAE-B)	10 June 1973	Delta 1913	NASA	Orbiter	Successful
	Radio astronomy spacecraft, operated in selenocentric orbit to avoid interference from terrestrial radio sources.				
Mariner 10 (RAE-B)	3 November 1973	Delta 1913	NASA	Flyby	Successful
	Interplanetary spacecraft, mapped lunar north pole to test cameras.				
Luna 22 (E-8LS No.206)	29 May 1974	Proton-K/D	Lavochkin	Orbiter	Successful
Luna 23 (E-8-5M No.410)	28 October 1974	Proton-K/D	Lavochkin	Sample return	Spacecraft failure
	Tipped over upon landing.				
Luna E-8-5M No.412	16 October 1975	Proton-K/D	Lavochkin	Sample return	Launch failure
	Failed to orbit.				
Luna 24 (E-8-5M No.413)	9 August 1976	Proton-K/D	Lavochkin	Sample return	Successful
	Final mission of the Luna programme. Entered orbit on 11 August 1976 and landed in Mare Crisium at 16:36 UTC on 18 August. Sample capsule launched at 05:25 UTC on 19 August and recovered 96½ hours later.[68] Returned 170.1 grams (6.00 oz) of lunar regolith.[69]				
ISEE-3 (ICE/Explorer 59)	12 August 1978	Delta 2914	NASA	Gravity assist	Successful
	Five flybys in 1982 and 1983 en route to comet 21P/Giacobini–Zinner.				

Spacecraft	Launch date[1]	Carrier rocket[2]	Operator	Mission type	Outcome
Hiten (MUSES-A)	24 January 1990	Mu-3S-II	ISAS	Flyby/Orbiter	Successful
	Designed for flyby, placed into selenocentric orbit during extended mission after failure of Hagoromo. Deorbited and impacted in USGS quadrangle LQ27 on 10 April 1993.[70]				
Hagoromo	24 January 1990	Mu-3S-II	https://en.wikipedia.org/wiki/Selenocentric_orbit		
	Deployed from Hiten. Communications failure; entered selenocentric orbit but returned no data.				
Geotail	24 July 1992	Delta II 6925	ISAS/NASA	Gravity assist	Successful
	Series of flybys to regulate high Earth orbit.				
WIND	1 November 1994	Delta II 7925-10	NASA	Gravity assist	Successful
	Made two flybys on 1 December 1994 and 27 December 1994 to reach the Earth–Sun L1 Lagrangian point.				
Clementine (DSPSE)	25 January 1994	Titan II (23)G Star-37FM	USAF/NASA	Orbiter	Successful
	Completed Lunar objectives successfully; failed following departure from selenocentric orbit.				
HGS-1	24 December 1997	Proton-K/DM3	Hughes	Gravity assist	N/A
	Communications satellite; made two flybys in May and June 1998 en route to geosynchronous orbit after delivery into wrong orbit.				
Lunar Prospector (Discovery 3)	7 January 1998	Athena II	NASA	Orbiter	Successful
Nozomi (PLANET-B)	3 July 1998	M-V	ISAS	Gravity assist	Spacecraft failure
	Two flybys en route to Mars.				
WMAP	30 June 2001	Delta II 7425-10	NASA	Gravity assist	Successful
	Flyby on 30 July 2001 to reach the Earth–Sun L2 Lagrangian point.				
SMART-1	27 September 2003	Ariane 5G	ESA	Orbiter	Successful
	Impacted moon in USGS quadrangle LQ26 at end of mission on 3 September 2006.				
STEREO A	25 October 2006	Delta II 7925-10L	NASA	Gravity assist	Successful
	Flyby on 15 December 2006 to enter a heliocentric orbit.				
STEREO B	25 October 2006	Delta II 7925-10L	NASA	Gravity assist	Successful
	Made two flybys on 15 December 2006 and 21 January 2007 to enter a heliocentric orbit.				
ARTEMIS P1	17 February 2007	Delta II 7925	NASA	Orbiter	Operational
	THEMIS spacecraft moved to selenocentric orbit for extended mission; entered orbit July 2011.				
ARTEMIS P2	17 February 2007	Delta II 7925	NASA	Orbiter	Operational
	THEMIS spacecraft moved to selenocentric orbit for extended mission; entered orbit July 2011.				
SELENE (Kaguya)	14 September 2007	H-IIA 2022	JAXA	Orbiter	Successful
	Impacted the Moon in USGS quadrangle LQ30 at end of mission on 10 June 2009.[71]				
Okina (RSAT)	14 September 2007	H-IIA 2022	JAXA	Orbiter	Successful
	Deployed from Kaguya, decayed and impacted Moon in USGS quadrangle LQ08 on 12 February 2009 after end of mission.				
Ouna (VRAD)	14 September 2007	H-IIA 2022	JAXA	Orbiter	Successful
	Deployed from Kaguya, completed operations on 29 June 2009[72] but remains in selenocentric orbit.				
Chang'e 1	24 October 2007	Long March 3A	CNSA	Orbiter	Successful

Spacecraft	Launch date[1]	Carrier rocket[2]	Operator	Mission type	Outcome
	Impacted Moon in USGS quadrangle LQ21 on 1 March 2009, at end of mission.				
Chandrayaan-1	21 October 2008	PSLV-XL	ISRO	Orbiter	Mostly successful
	Succeeded through mission, terminated the mission in 2009, remains in selenocentric orbit; discovered water on Moon.[73]				
Moon Impact Probe	21 October 2008	PSLV-XL	ISRO	Impactor	Successful
	Deployed from Chandrayaan-1, impacted Moon in USGS quadrangle LQ30 on 14 November 2008.				
Lunar Reconnaissance Orbiter	18 June 2009	Atlas V 401	NASA	Orbiter	Operational
LCROSS	18 June 2009	Atlas V 401	NASA	Impactor	Successful
	Observed impact of Centaur upper stage that launched it and LRO, then impacted itself. Impacts in USGS quadrangle LQ30.				
Chang'e 2	1 October 2010	Long March 3C	CNSA	Orbiter	Successful
	Following completion of six month Lunar mission, departed selenocentric orbit for Earth–Sun L2 Lagrangian point;[74] subsequently flew by asteroid 4179 Toutatis.[75]				
Ebb (GRAIL-A)	10 September 2011[76][77]	Delta II 7920H	NASA	Orbiter[78]	Successful
	Part of the Gravity Recovery and Interior Laboratory,[78] impacted the Moon in USGS quadrangle LQ01 on 17 December 2012 at end of mission.[79]				
Flow (GRAIL-B)	10 September 2011[76][77]	Delta II 7920H	NASA	Orbiter[78]	Successful
	Part of the Gravity Recovery and Interior Laboratory,[78] impacted the Moon in USGS quadrangle LQ01 on 17 December 2012 at end of mission.[79]				
LADEE	7 September 2013	Minotaur V	NASA	Orbiter	Successful
	Mission ended on 18 April 2014, when the spacecraft's controllers intentionally crashed LADEE into the far side of the Moon.				
Chang'e 3	1 December 2013	Long March 3B	CNSA	Lander	Operational
	Entered orbit on 6 December 2013 with landing at 13:12 UTC on 14 December.				
Yutu	1 December 2013	Long March 3B	CNSA	Rover	Mostly successful
	Deployed from the Chang'e 3 lander, which landed on the Moon.				
Chang'e 5-T1	23 October 2014	Long March 3C	CNSA	Flyby	Operational
	Demonstration of re-entry capsule for Chang'e 5 sample-return mission at lunar return velocity.				
Manfred Memorial Moon Mission	23 October 2014	Long March 3C	LuxSpace	Flyby	Successful
	Attached to third stage of CZ-3C used to launch Chang'e 5-T1.				
TESS	18 April 2018	Falcon 9 Full Thrust	NASA	Gravity assist	Successful
	Flyby on 17 May 2018 to designated high Earth orbit.[80]				
Queqiao	21 May 2018	Long March 4C	CNSA	Gravity assist / L_2 orbit	Operational
	Entered designated Earth–Moon L_2 orbit on June 14 in preparation of Chang'e 4 far-side lunar lander in December 2018.				
Longjiang-1	21 May 2018	Long March 4C	CNSA	Orbiter	Spacecraft failure
	Launched on the same rocket as Queqiao and Longjiang-2 but it never entered Moon orbit.[81]				
Longjiang-2	21 May 2018	Long March 4C	CNSA	Orbiter	Operational

Spacecraft	Launch date[1]	Carrier rocket[2]	Operator	Mission type	Outcome
	Launched on the same rocket as Queqiao and Longjiang-1.				
Chang'e 4	7 December 2018	Long March 3B	CNSA	Lander/rover	Operational
	Landed 3 January 2019 and deployed the *Yutu-2* rover to explore a large basin on the far side of the Moon.[82][83]				
Beresheet	22 February 2019	Falcon 9	SpaceIL	Lander	Spacecraft failure
	First Israeli and first privately funded lunar lander mission. Technology demonstration. Instrumentation included a magnetometer and laser retroreflector.[84][85] Spacecraft crashed into the lunar surface after main engine failure during descent from lunar orbit phase.				

Future missions

There are several **future lunar missions** scheduled or proposed by various nations or organisations.

Funded and under development

Robotic

Country	Agency or company	Name	Launch due	Launch vehicle	Nature of mission
India	ISRO	Chandrayaan-2	Q3, 2019	GSLV Mk III	Lander, rover, in-situ analyses
USA	Moon Express	Lunar Scout	Q4, 2019[86]	Electron	Private lander technology demonstration; lander carries the International Lunar Observatory
China	CNSA	Chang'e 5	December 2019[87]	Long March 5	Sample-return
USA	NASA, ESA and CubeSat partners	EM-1	June 2020[88]	SLS Block 1	Primary: uncrewed test of Orion spacecraft in lunar flyby; secondary: 13 CubeSats[89][90]
USA	Astrobotic Technology	*Peregrine*	2020[91]	Atlas V	Private technology demonstrators: *Peregrine* lander and 3+ rovers: Andy, Hakuto, Unity
China	CNSA	Chang'e 6	2020[92]	Long March 5	Sample-return from the lunar south pole
Germany	PTScientists	ALINA[93]	Q1 2020[94]	Falcon 9	Private technology demonstration of lander and rover[95]
South Korea	KARI	Korea Pathfinder Lunar Orbiter (KPLO)	December 2020[96]	Falcon 9[97]	Orbiter, technology demonstrator.
Japan	JAXA	SLIM[98]	2021[99]	H-IIA 202	Pinpoint landing, roving[100][101][102]
Russia	Roscosmos	Luna 25	May 2021[103]	Soyuz-2.1b / Fregat-M	Lander will explore natural resources, part of Luna-Glob programme.
Russia	Roscosmos	Luna 26	2022[104]	Soyuz-2	Orbiter, part of Luna-Glob programme.
Japan	JAXA	DESTINY+	2022	Epsilon	Lunar flyby toward asteroid 3200 Phaethon[105]
Russia	Roscosmos	Luna 27	2023[106]	Soyuz[107]	Lander, part of Luna-Glob programme.

Crewed

Country	Agency or company	Name	Launch due	Launch vehicle	Nature of mission
USA	NASA	EM-2	June 2022[108]	SLS Block 1	Crewed test of the Orion spacecraft on a free-return trajectory around the Moon.
USA	SpaceX	DearMoon	2023[109]	BFR	Space tourism and art project; free-return trajectory and Earth re-entry of the BFR Starship.
USA	NASA	EM-3	2024[110]	SLS Block 1B	Deliver European System Providing Refuelling, Infrastructure and Telecommunications (ESPRIT), the U.S. Utilization Module, and an airlock to the Lunar Orbital Platform-Gateway (LOP-G).
Russia	Roscosmos	Federation spacecraft	2025[111]	Soyuz-5	Crewed lunar orbit

Proposed but full funding still unclear

Robotic

The following robotic space probe missions have been proposed:

Country	Name	Proposed launch	Nature of mission
Private	Synergy Moon	2019	Rover
Private	TeamIndus	2019[112]	Rover
Private	Nova-C	2021[113][114]	Commercial lunar lander
China	Chang'e 7	2023	South pole lander[115]
NASA	Lunar rover (unnamed)	2023	Polar rover to scout for water; mass: 300 kg - 500 kg [116]
Russia	Luna 28, Luna 29, Luna 30, Luna 31	2024-2026[103]	Technology development for prospecting water and other natural resources needed for a future lunar base; part of Luna-Glob program.
China	Chang'e 8	2026	South pole lander[115]
North Korea	*Moon Mission*[117]	2026 [118]	
USA	MoonRise	May compete in New Frontiers program NF5 selection in the late 2020s[119]	Sample return from South Pole–Aitken basin[120]
USA	BOLAS	TBD	Two tethered CubeSats on a very low lunar orbit.[121]

Crewed

Unmanned Lunar Landings

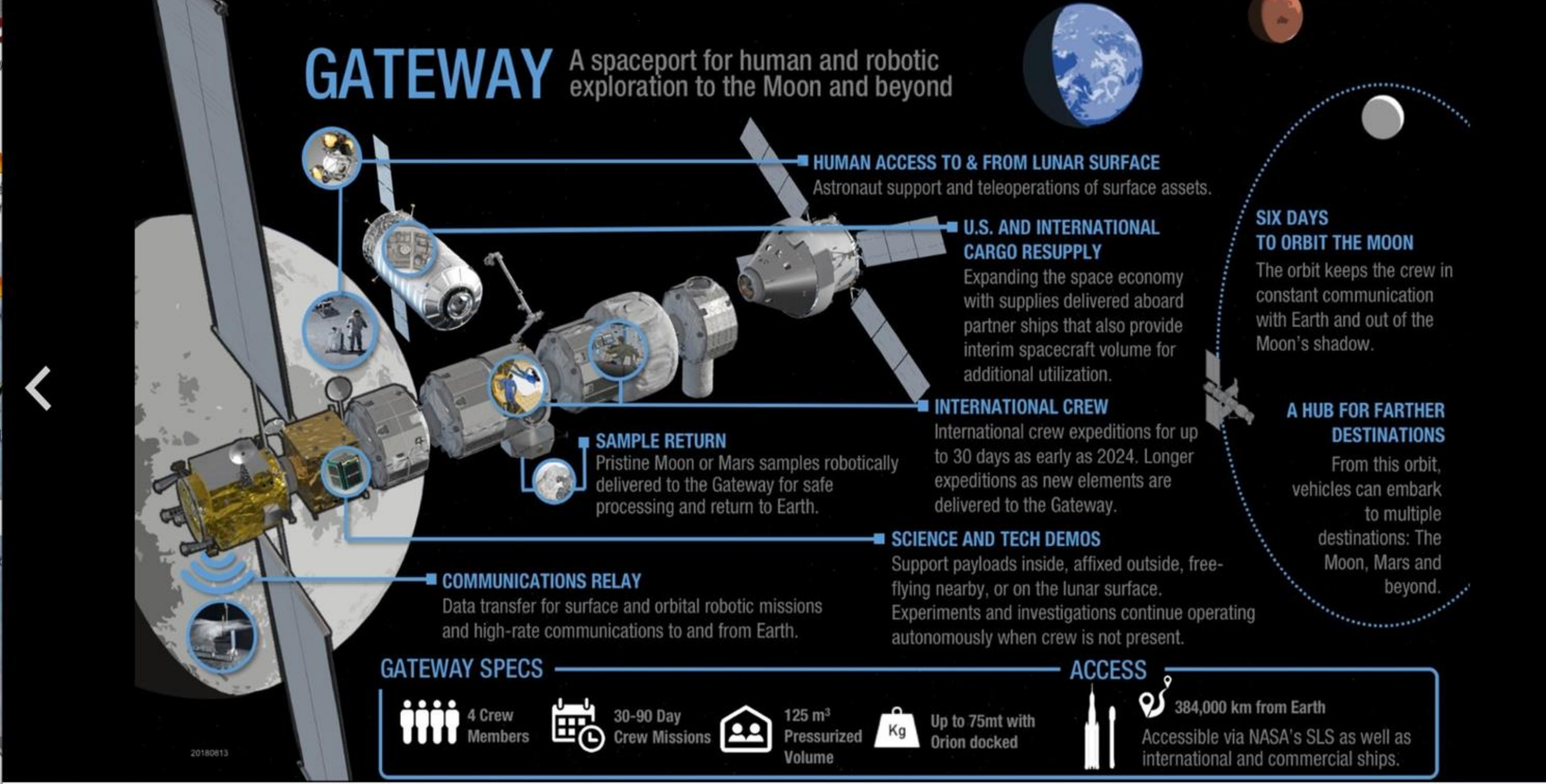
- After the unsuccessful attempt by the Luna 1 to land on the Moon in 1959, the Soviet Union performed the first hard (unpowered) Moon landing later that same year with the Luna 2 spacecraft, a feat the U.S. duplicated in 1962 with Ranger 4. Since then, twelve Soviet and U.S. spacecraft have used braking rockets to make soft landings and perform scientific operations on the lunar surface, between 1966 and 1976. In 1966 the USSR accomplished the first soft landings and took the first pictures from the lunar surface during the Luna

Manned Lunar Landings

- A total of twelve men have landed on the Moon. This was accomplished with two US pilot-astronauts flying a Lunar Module on each of six NASA missions across a 41-month period starting on 20 July 1969 UTC, with Neil Armstrong and Buzz Aldrin on Apollo 11, and ending on 14 December 1972 UTC with Gene Cernan and Jack Schmitt on Apollo 17. Cernan was the last to step off the lunar surface.

- All Apollo lunar missions had a third crew member

Future of Humanity and the Moon:



The Gateway advances NASA's goals of sustaining human space exploration and serves as a platform to further cislunar operations, lunar surface access and missions to Mars.

More details

NASA - https://pbs.twimg.com/media/Dln8ytJVsAAY5og.jpg:large https://www.nasa.gov/sites/default/files/atoms/files/cislunar-update-gerstenmaier-

Lunar Orbital Platform-Gateway

- The Lunar Orbital Platform-Gateway (LOP-G) is an American-led international project led by NASA proposed to create a lunar-orbit space station. It is intended to serve as a solar-powered communications hub, science laboratory, short-term habitation module, and holding area for rovers and other robots.[1]
- The science disciplines to be studied on the Gateway are expected to include planetary science, astrophysics, Earth observations, heliophysics

Colonizing and Industrializing the Moon

(see Isaac Arthur video: https://www.youtube.com/watch?v=bGcvv3683Os)

- Easy to build habitats because of low surface gravity.
  - Can cover craters or lava tubes with domes to create large city habitats.
- Plenty of metals like iron, aluminum, titanium for construction.
- Very easy to move resources to and from lunar surface because of low escape velocity

To the Moon:

- Art thou pale for weariness
- Of climbing heaven and gazing on the earth,
- Wandering companionless
- Among the stars that have a different birth,
- And ever changing, like a joyless eye
- That finds no object worth its constancy?

- \- Percy Bysshe Shelley

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