Total Lunar Eclipse & Mars Opposition

Dr. Leonid Zotov

Host:

Good evening ladies and gentlemen. This is English Geo-Science Café, session 24. It's a great pleasure for us to introduce our guest who is going to talk about "Total Lunar Eclipse & Mars Opposition". We are honored and delighted to have Dr. Leonid Zotov with us today. Dr. Leonid Zotov is a visiting scientist from Russia. His research field includes but not limited to Earth`s Rotation, climate change and the relation between them. He has published more than 50 articles and conference proceedings and more than 100 talks at conferences and seminars. He is now an Associate Professor at National Research University Higher School of Economics, Institute of Electronics and Mathematics, and senior scientific researcher at Sternberg Astronomical Institute of Lomonosov Moscow State University (MSU). He is a member of Wuhan University Discipline Innovative Engineering Plan of Modern Geodesy and Geodynamics (grant No. B17033).

The whole session is divided into two parts. On the first part Dr. Leonid Zotov will present his talk and later on, we have a question and answer session. Ladies and gentleman, let's welcome, Dr. Leonid Zotov.

Dr. Leonid Zotov

I am happy to see so many people here this evening to listen to my talk. Since childhood, I am interested in astronomy and selected it as my profession. Today, I will tell about a special event, which will happen at night of 27-28 July at 1:15-7:28 CST (17:15-23:28 UTC), simultaneously the longest lunar eclipse of the century and the Mars opposition; such an event, only happens on the same day once within 2500 years.

Fig.1. Dr. Leonid Zotov, on a moment of his informative presentation. (photo by Xu Lei)

My whole presentation is divided into ten parts as follows.

1. Old stories about the moon in China & Europe;
2. The Lunar landscape & the origin of the Moon;
3. The Phases of the Moon, Lunar periods, & Lunar Libration
4. Lunar Eclipse & Total Lunar Eclipse of 27th July, 2018;
5. Moon Orbit Inclination & its 18.6 Years Precession;
6. The Philosophical idea of space exploration (Early Age);
7. Future Moon Exploration;
8. Oppositions of Mars and 27th July, 2018 event;
9. Martian Topography; and
10. NASA`s Journey to Mars: Curiosity rover & Insight Mission.

1. Old stories about the moon in China & Europe:

At the beginning of this lecture, I would like to show some of the ancient images. Each image represents a story about the moon from China and Europe. Fig.2 (1) shows what can be seen on the moon without a telescope. As we know, different cultures found different images or symbols in the moon. As examples well-known Chinese rabbit, frog,and the god and goddess of the moon, are shown in Fig.1 (2). The well-known rabbit at a Shanghai Buddhist temple is shown in Fig.1 (3), if you visit and climb the stairs of the Jingan temple you will see images of sun and moon. Inside the image of the sun, you can see the symbol of the bird and inside the moon - this famous rabbit. In Shanghai museum, you will find the famous full-moon painting by the well-renowned painter Li Yi from Ming dynasty in Fig.1 (4).

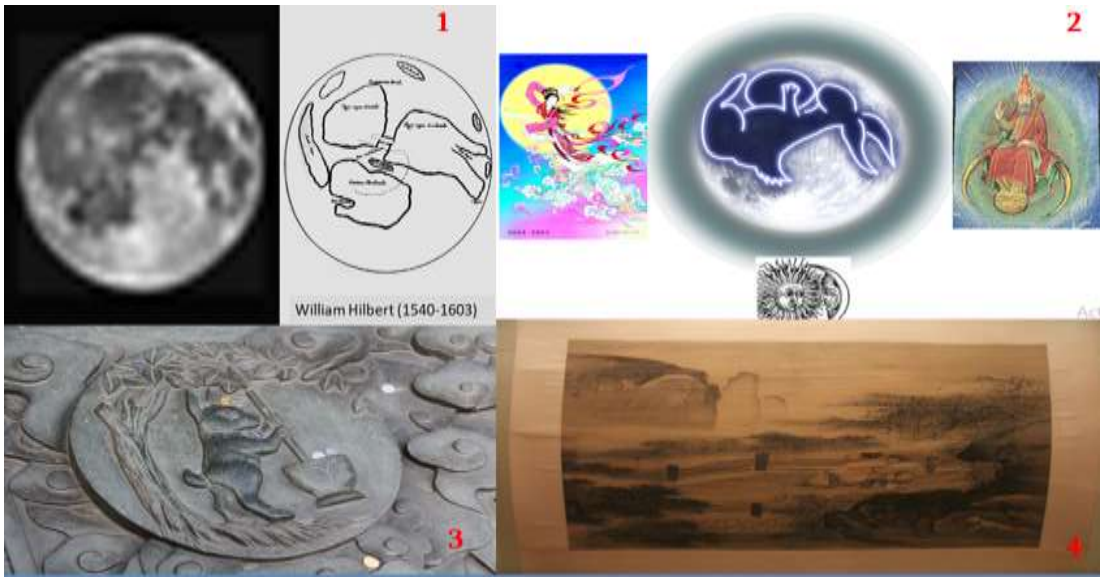

Fig.2. An existing story about the moon in China.

If we look back to Europe, there was a goddess of the moon called Selene, shown in Fig.3 (1). She is the daughter of the Titans Hyperion and Theia, and sister of the sun-god Helios, and

Eos, goddess of the dawn. She drives her moon chariot across the heavens and wears a moon shaped golden crown on her head. Interesting story of Selene and Endymion is shown in Fig.3 (2) together with the famous painting called Apollo and the nine Muses by French painter Gustav Moro, painted in 1882.

One of the greatest paintings, Mona Lisa painted by Leonardo Da Vinci shown in Fig.3 (3) describes, how the people at that time thought the moon landscape looks like. Without a telescope, developed by Galileo later, people expected lots of water on the moon and if you see deeply in the painting of mysterious Mona Lisa, you can see water, fog and unclear mountains inside the picture. Galileo made his first observation of the moon in 1609 through his telescope and discovered no water on the moon, but rather that it is full of rigid solid surfaces as shown in Fig.3 (4). In his book "Starry Messenger" (1609) Galileo noted that, "From observations of these spots repeated many times, I have been led to the opinion and conviction that the surface of the Moon is not smooth, uniform and precisely spherical as a great number of philosophers believe it to be. It is uneven, rough, and full of cavities and prominences, being not unlike the face of the Earth."

The satellites of Jupiter were observed by Galileo in January-March 1610, Fig.3 (5). The four largest moons of Jupiter called lo, Europa, Ganymede, and Callisto are now known as Galilean satellites. In the painting "Observation of Jupiter" by Donato Creti made for the Pope's collection in Vatican, you can see three Galilean moons (generally 4) moving around the Jupiter. Today if there is no cloud and Jupiter is on the sky, they can also be seen nearby just through a pair of binoculars.

Fig.3. An existing stories about the moon in Eupore.

2. The Lunar landscape & the origin of the Moon:

As the moon was observed through telescopes, many craters were found on its surface, some of them are shown in Fig.4 (1). The most prominent craters among all the lunar craters are Copernicus and Tycho. The Italian Catholic priest Giovanni Battista Riccioli (1598-1671) named most of the lunar features he observed on the moon from Asinelli tower in Bologna (博洛尼亚).

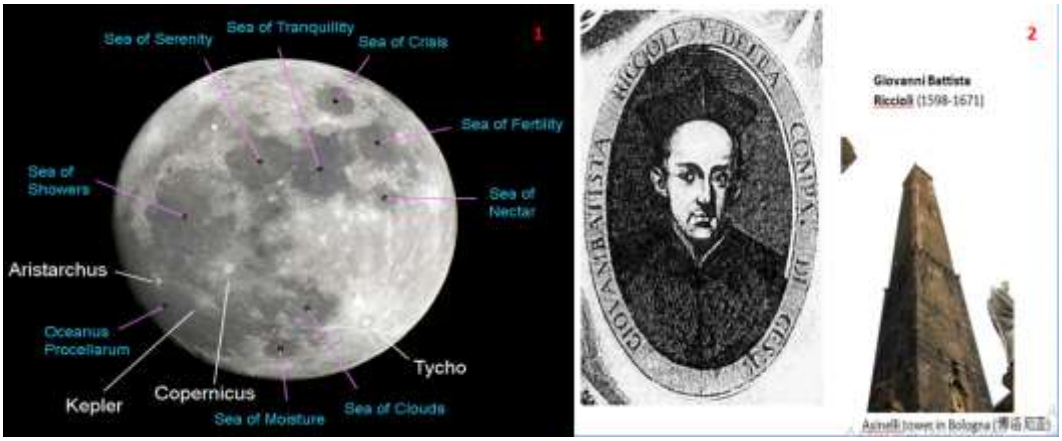

Fig.4: **Giovanni Battista Riccioli** (1598-1671) named all 13 lunar craters.

Let`s look at Copernicus and Tycho Craters. In 1842, there was no photography developed yet. So, J Hershel painted the Copernicus crater, observing it through a telescope as shown in Fig.5 (1). If you observe the painting carefully, you will see there were many rigid mountains around the crater. The diameter of the crater is about 93 km; it was formed about 800 million years ago. Fig.5 (2) shows the formation of any impact crater.

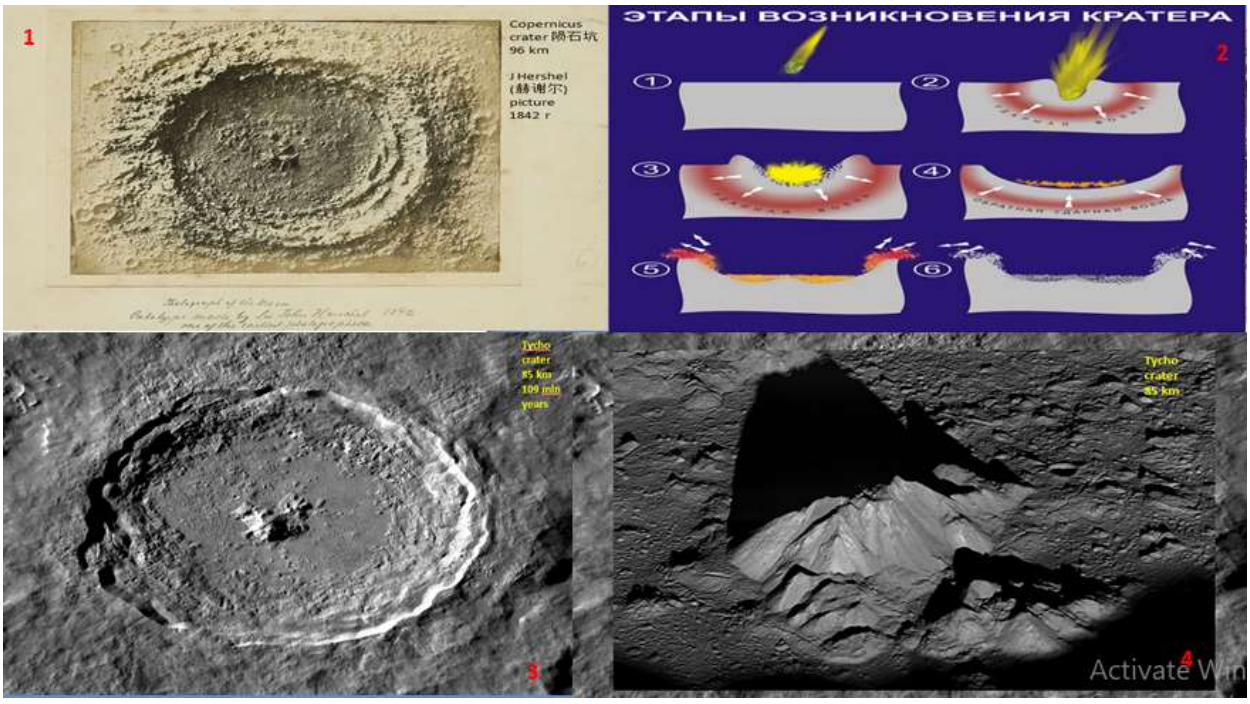

Fig.5. Copernicus and Tycho Crater, two of the most prominent Lunar craters.

If an impact is large and the energy of an event high, a central mound might form, similar to those of the Tycho crater shown in Fig.5 (3). The diameter of the crater is about 85 km it was formed about 109 million years ago. Recently, scientists found a big stone on top of the Tycho crater central mound, as shown in Fig.5(4). Nobody knows how that stone came to be there. Now I want to talk about the origin of the Moon.

According to contemporary theory, about 5 billion years ago, a Mars-sized body called Theia collided with the Earth, making a debris ring that eventually collected into a single natural satellite, the moon, as shown in Fig.6. There are however, a number of variations on this giant-impact hypothesis, as well as alternate explanations, with ongoing research into how the Moon was formed, its chemical content, shape, and density. Other proposed scenarios include captured body, fission, Earth and Moon formed together (condensation theory), planetesimal collisions (formed from asteroid-like bodies), and collision theories.
The standard giant-impact hypothesis suggests that collision also resulted in the 23.5° tilted axis of the earth, thus causing the seasons. The Moon's oxygen isotopic ratios seem to be essentially identical to Earth's. Oxygen isotopic ratios, which may be measured very

precisely, yield a unique and distinct signature for each solar system body. If the Theia had been a separate proto-planet, it probably would have had a different oxygen isotopic signature from Earth, as would the ejected mixed material. Also, the Moon's titanium isotope ratio (50Ti/47Ti) appears so close to the Earth's (within 4 ppm) that little if any of the colliding body's mass could likely have been part of the Moon. But, the lunar density is less than the earth's and it lacks volatilities, which probably evaporated during the impact.

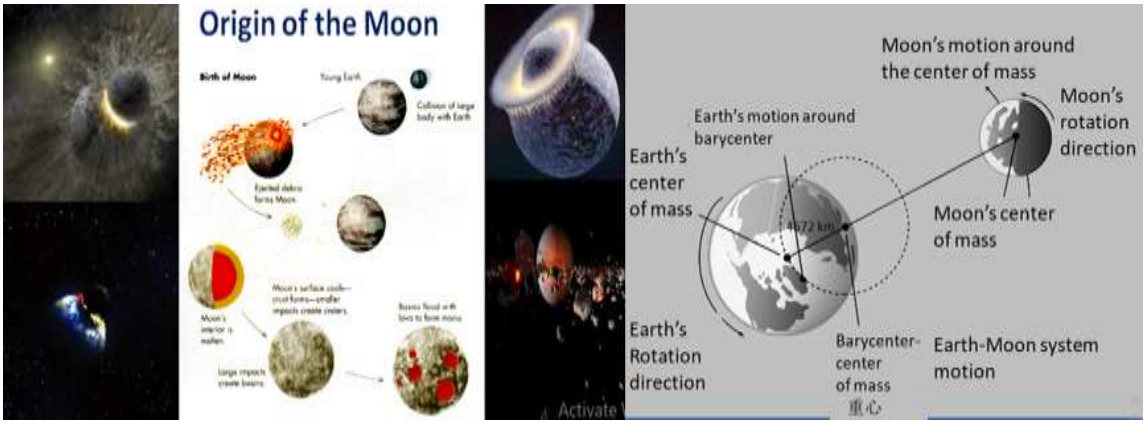

Fig.6. Origin of the Moon

3. The Phases of the Moon, Lunar periods, & Lunar Libration:

The phases of the Moon change the look of the Moon from Earth during the synodic month. As the Moon orbits around the Earth, the half of the Moon that faces the Sun will be lit up. The different shapes of the lit portion of the Moon that can be seen from Earth are known as phases of the Moon. The phase is a ratio of the lit part of the moon's diameter to the whole diameter, it changes from 0 (new moon) to 1 (fool moon) and as shown in Fig.7 (1). Each phase repeats itself every 29.5 days. The same half of the Moon always faces the Earth, but it is wrong to say that the opposite side of the moon is always dark.

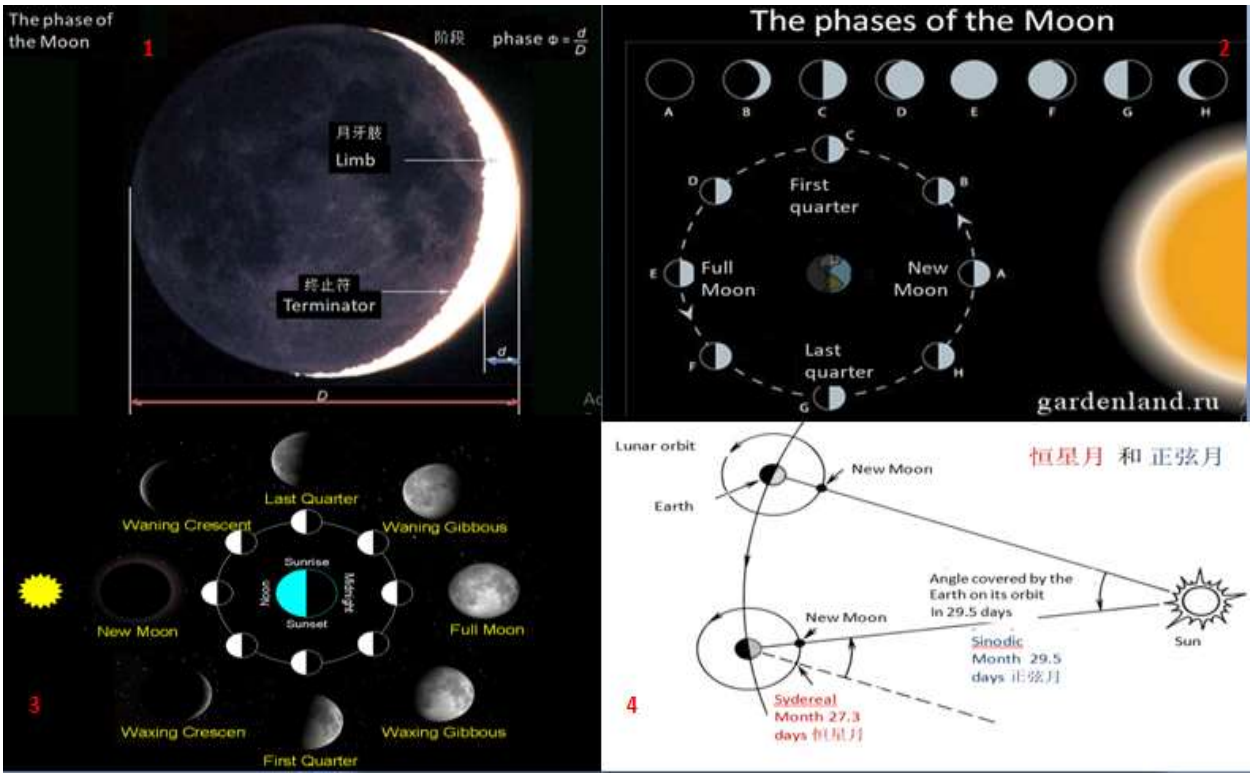

Fig.7. The Different Phases of the Moon & Lunar periods

According to Fig.7 (2 and 3) we can see the eight phases that the Moon goes through. The new moon phase occurs when the Moon is directly between the Earth and Sun. A solar eclipse can only happen during a new moon. A waxing crescent moon is when the Moon looks like crescent and the crescent increases ("waxes") in size from one day to the next. This phase is usually only seen in the west after sunset. The first quarter moon (or a half moon) is when half of the lit portion of the Moon is visible after the waxing crescent phase. It comes a week after new moon. A waxing gibbous moon occurs when more than half of the lit portion of the Moon can be seen and the shape increases ("waxes") in size from one day to the next. The waxing gibbous phase occurs between the first quarter and full moon phases. A full moon occurs when we can see the entire lit portion of the Moon. The full moon phase occurs when the Moon is on the opposite side of the Earth from the Sun, called opposition. A lunar eclipse can only happen during a full moon. However, this phase is not the best for moon observations through the telescope, since the shadows of the mountains are small with little contrast. A waning gibbous moon occurs when more than half of the lit portion of the Moon can be seen and the shape decreases ("wanes") in size from one day to the next. The waning gibbous phase occurs between the full moon and third quarter phases. The last quarter moon (or a half moon) is when half of the lit portion of the Moon is visible after the waning gibbous phase. A waning crescent moon is when the Moon looks like the crescent and the crescent decreases ("wanes") in size from one day to the next. An old moon is a moon with only a tiny bit of it seen in the corner, about to turn into a new moon.

Now, let's talk about lunar periods. There are two well-known lunar periods called Lunar Sidereal & Synodic Periods as shown in Fig.7 (4). The **Lunar Sidereal Period** is the time it takes the Moon to complete one orbit around the Earth with respect to the stars, also called

the “Sidereal Month”. The Moon's Sidereal period is 27.3 days. The Sidereal Period of the moon is measured by watching its motions against the background stars. The **Lunar Synodic Period** is the time between successive New Moons, also called the "Synodic Month". Moon's Synodic period is 29.5 days. This is the month used in Lunar Calendars. There are many other periods, related to the complicated motions of the moon, such as Draconic, Animalistic months, etc.

Lunar libration causes slight changes in the Moon's view from the Earth, due to the inclination of the moon’s axis and changes in the orbital velocity according to the second Kepler’s law. Libration allows us to observe 59% of the lunar surface. Libration is accompanied by the changes of the moon’s disk size, since the physical distance of the Moon to the Earth changes because of its elliptical orbit around the Earth.

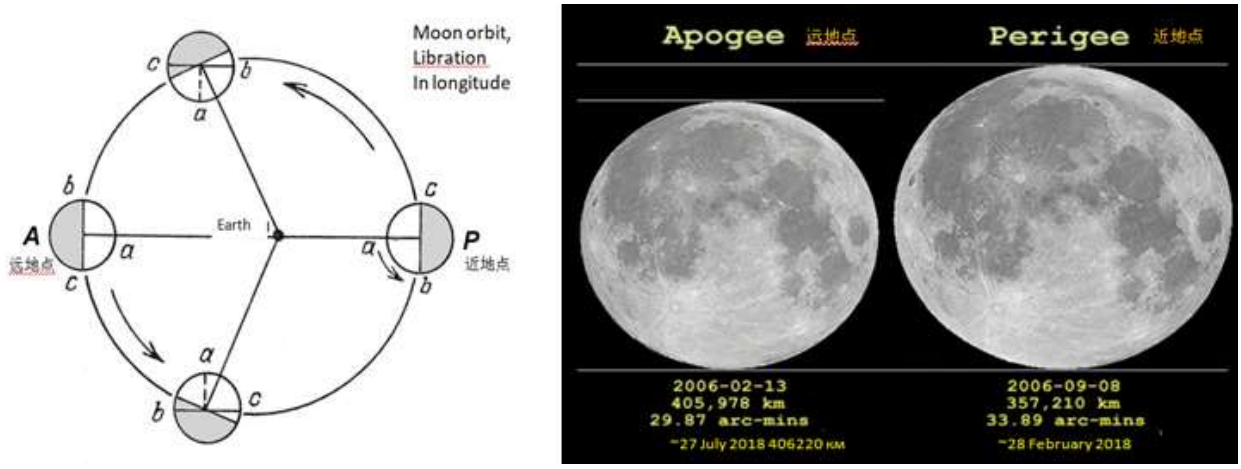

Fig.8. Lunar orbit, apogee & perigee.

Apogee and perigee refer to the closest and the farthest orbital points. **Apogee** is the farthest point from the earth. **Perigee** is the closest point to the earth and it is in this stage that the moon appears larger as shown in Fig.8. Full moon in perigee, called the Big Moon, happens every 412 days.

4. Lunar Eclipse & Total Lunar Eclipse of 27th July. 2018:

A lunar eclipse occurs when the Moon passes directly into the Earth’s shadow. This occurs only when the Sun, Earth, and Moon are exactly in a line or closely aligned, with Earth between the other two bodies. A lunar eclipse can occur only on the night of a full moon. The type and length of a lunar eclipse depend on the Moon's proximity to either node of its orbit.

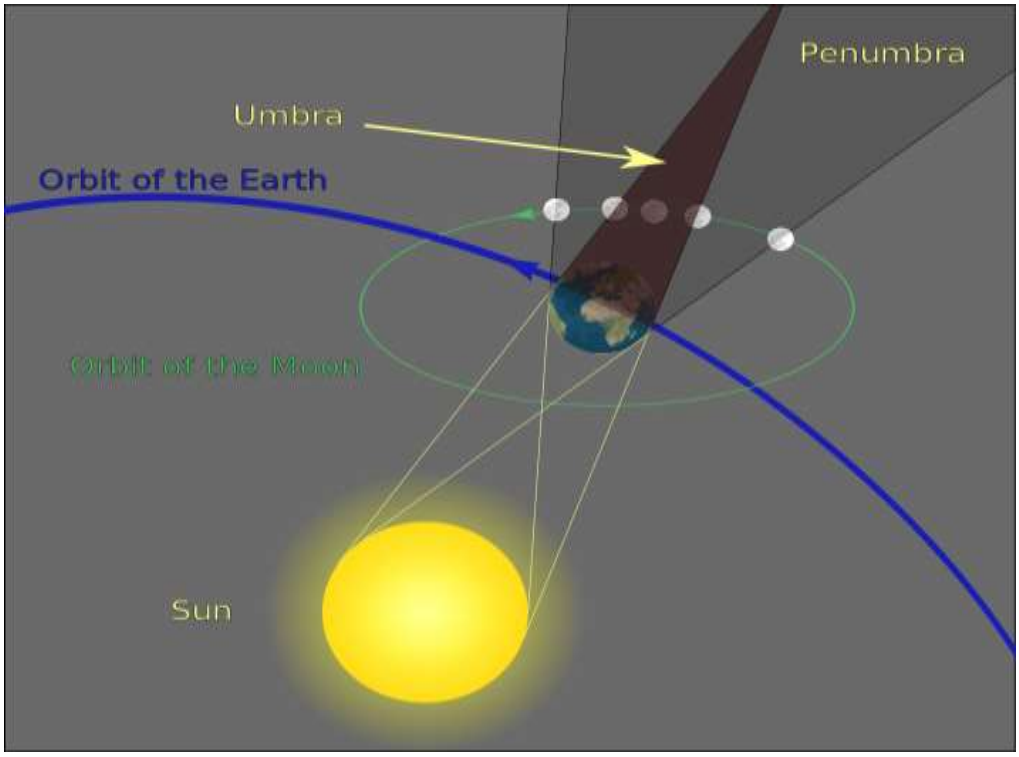

Fig.9. Geometry of a Lunar Eclipse.

The Earth's shadow can be divided into two distinctive parts: the umbra and penumbra as shown in Fig.9. Earth totally occludes direct solar radiation within the umbra, the central region of the shadow. The planet only partially blocks direct sunlight within the penumbra, the outer portion of the shadow. The Earth umbra at the moon distance is about 363,000 km in diameter (for the closest position of the Moon), the Sun's diameter appears about one-quarter of Earth's in the lunar sky, thus the lunar eclipse lasts several hours, needed for the moon to pass the Earth's shadow.

There is a common question as to why the moon became red during the lunar eclipse? Ancient Chinese peoples believed that the dog of god eats the moon. However, scientifically when the solar light first entered the atmosphere, it is bent (refracted) toward the Earth's surface. As when you observe a sunset, it is red, solar light when it exists on the other side of Earth is red, since it has passed a large layer of atmosphere. This bending sends the reddish light onto the moon during a lunar eclipse. In another way, a moon may look red during a lunar eclipse because sunlight filtered and refracted by the Earth's atmosphere reaches the moon.

Now let us talk about the total lunar eclipse that will happen next Friday night. The Blood Moon will appear in the night sky on July 27, as the moon enters the Earth's darkest shadow on the night side, which will be the first central lunar eclipse since 15 June 2011. Interestingly, at the time of a total moon eclipse, the Moon will appear smaller than normal

(a phenomenon sometimes called a micro-moon), because this event will take place at a time when the Moon is in apogee (the farthest point in its orbit). The total eclipse will last for 103 minutes, making it the longest lunar eclipse of the 21st century. The Moon will remain at least partially in Earth's shadow for four hours. The 27th July lunar eclipse coincides with Mars being at the closest position to the earth. A lunar eclipse by itself is not very rare event for example, previous total lunar eclipse happened on January 31 2018. However, such a concurrence, when both lunar eclipse and Mars opposition happens on the same day can be observed only once in 2500 years. It means that people living in the times of Confucius and Lao Zi could have witnessed this event the last time it occurred.

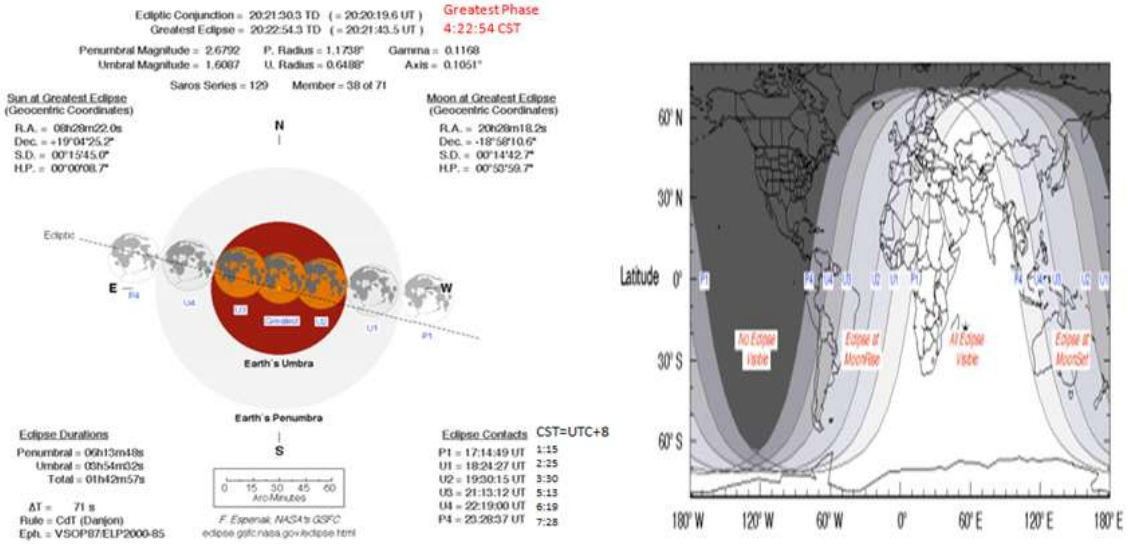

Fig.10. Total Lunar Eclipse of 27th July, 2018 at a glance

The eclipse of 27th July will be completely visible over the Eastern Africa, Southern Africa, Southern Asia, and Central Asia, seen rising over South America, Western Africa, and Europe, and setting over Eastern Asia, and Australia as shown in Fig.10. From China we can see the P1, U1, and U2 eclipse contacts as shown in above figure, but we can't observe the last few phases of the total lunar eclipses from China due to the moonset that will happen at 5:15 according to Beijing time as shown in Fig.11.

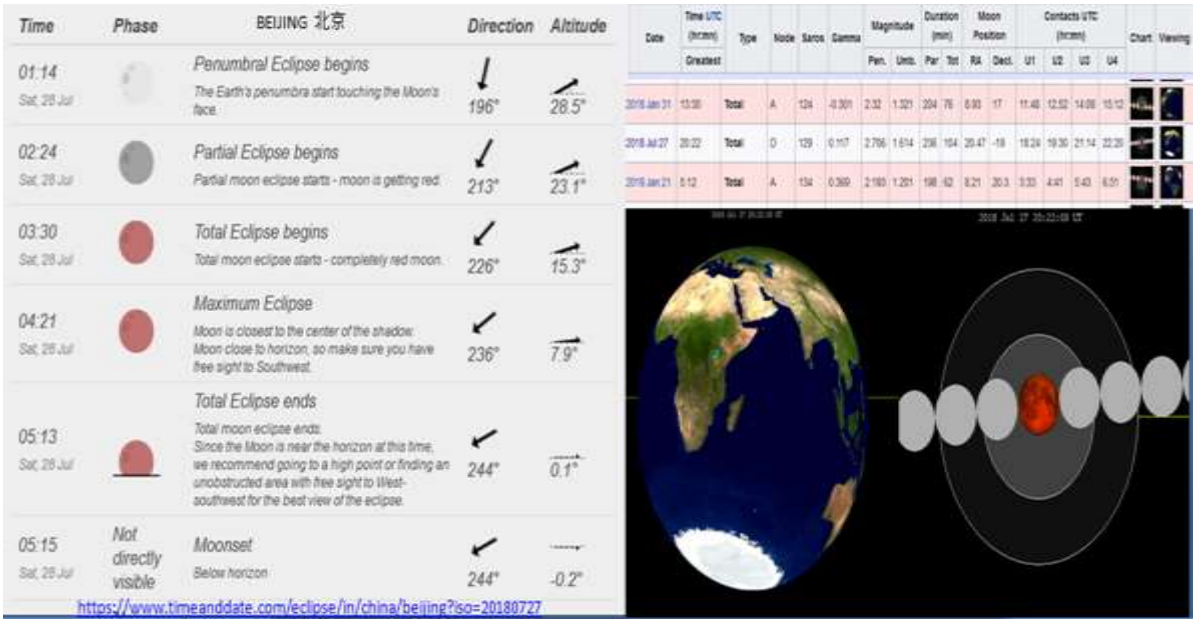

Fig.11. Visibility of Total Lunar Eclipse of 27th July. 2018 from Beijing, China.

The next total lunar eclipse will happen on 21st January 2019 and the duration of the full eclipse will be one hour and two minutes, as shown in Fig.11.

5. Moon Orbit Inclination & its 18.6 Years Precession:

Now there is a common question why we can`t see an eclipse every month?

A detailed explanation is best considered in terms of the paths of the Sun and Moon on the celestial sphere, as shown in the Fig.12. It shows the abstract sphere of infinite diameter surrounding the Earth located at the center. The Earth is oriented so that its axis is vertical.

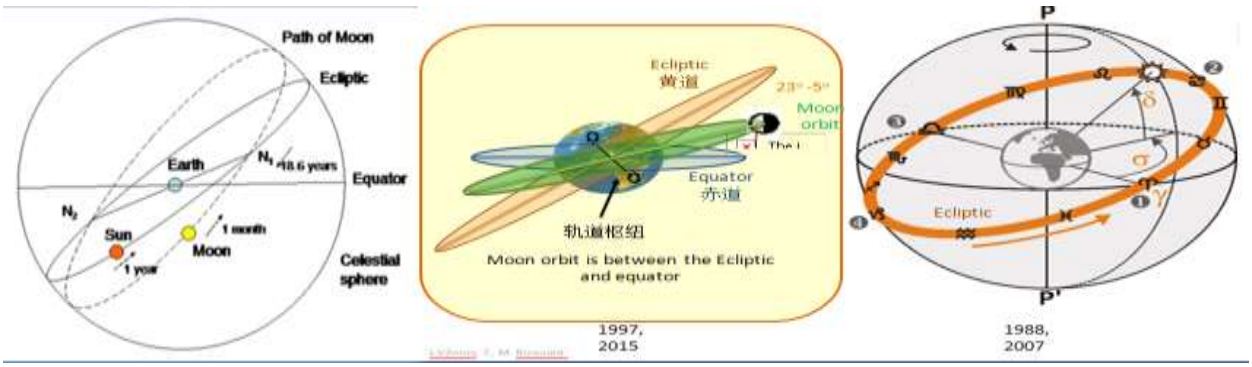

Fig.12. Apparent paths of the Sun and Moon on the celestial sphere.

The Sun is, by definition, always seen on the ecliptic (the Sun's apparent path across the sky) while Earth's equator is tilted at an angle of $e = 23.5°$ to the ecliptic plane.

The Moon's orbit around Earth depicted by the dotted line in Fig.12, is inclined at an angle of i = 5.14° relative to the ecliptic. The Moon completes one orbit around the Earth in 27.32166 days. The two points at which Moon crosses the ecliptic are known as its orbital nodes, shown as the ascending node "N1" and descending node,"N2". The line connecting them is known as the line of nodes; solar and lunar eclipses happen only near the nodes. Due to the gravitational torques, the moon orbit changes position, keeping a constant angle to the ecliptic plain. The crossing points, the nodes gradually move counter-clockwise along the ecliptic in a period of 18.59992 years due to this precision of the lunar orbit. Thus, similar eclipses happen over a Saros cycle of 18 years. The maximum declinations of the Moon in the sky also change over a nine-year period, since the angle between the equator and lunar orbit changes from $18.4^{o}=23.5^{o}-5.1^{o}$ (2015) to $28.6^{o}=23.5^{o}+5.1^{o}$ (2024) over that period of time.

6. The Philosophical ideas of space exploration (Early Age):

Now, let`s talk about one idea that motivated space research. Nikolay Fedorov (1829-1903) & Constantin Tsiolkovsky (1857-1953), are two Russian philosophers recognized as the founders of space research, seen in Fig.13. Their ideas moved space exploration, forward.

Fig.13. Nikolay Fedorov (1829-1903) & Constantin Tsiolkovsky (1857-1953)

As early as the 1860s, Nikolay Fedorov was proposing things like space travel and colonization. For Nikolay Fedorov, all matter contains particles of our disintegrated ancestors. Advanced science must find a way to restore whole persons from individual particles since some of these have dispersed beyond earth, and we must go into space to gather in the dispersed particles of our ancestors. Combining knowledge and action, science, religion, and art, everyone will join in the project. Everyone living will become a resurrector in practice, regardless of belief or unbelief. Sons and daughters will resurrect their parents, who in turn will resurrect their parents, and so all the way back to Adam and Eve. To those who worried about overpopulation and wondering where on earth we would put all those resurrected, Nikolay Fedorov answered: that's why we must colonize space, first of all, colonize the Moon.

Now, the space program is not to resurrect our ancestors and send them to Moon or Mars rather we must go to mars because in one billion years the sun will be 10 % warmer and everything on the earth will be destroyed. So, Mars is our future.

During the Lunokhod and Apollo missions several retro-reflectors were placed on the Moon to measure the distance between Earth and the Moon using laser ranging. The precision of such measurements are several millimeters now. Fig.14 display the photos from the Moon made during Apollo missions.

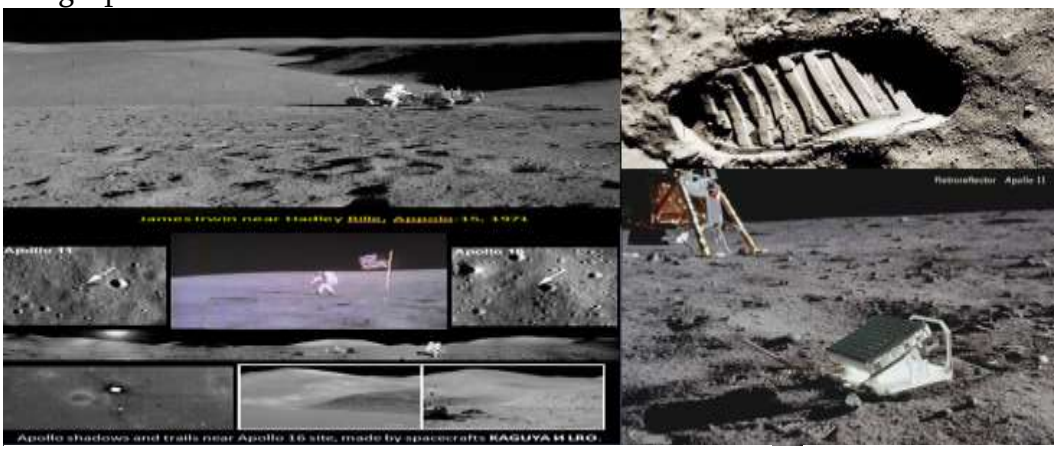

Fig.14. Apollo 15 mission, the eighth successful manned mission & the fourth to land on the Moon.

Lunar Reconnaissance Orbiter recently captured the shadows of the Apollo missions landing vehicles and rover traces on the moon. In Fig 15, you can see maps of the topography, gravity and magnetic field of the moon, obtained by LRO, GRAIL, Change and other satellites.

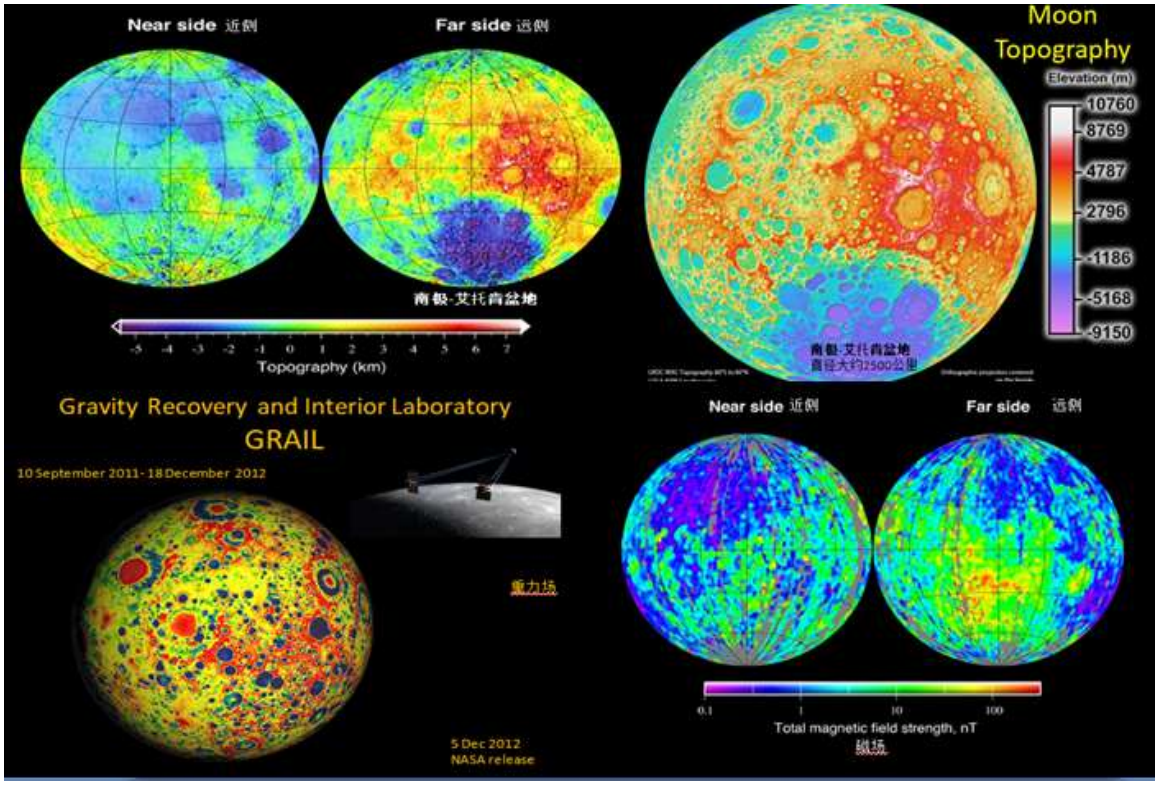

Fig.15. Topography of the Moon.

7. Future Moon Exploration:

The motives for moon exploration might be the mining of resources, placing observatories, building a moon orbital station as a base that people can use for travelling to Mars, some artist renderings are shown in Fig.16. A new phase of lunar exploration is starting now, 50 years after the Apollo moon landing.

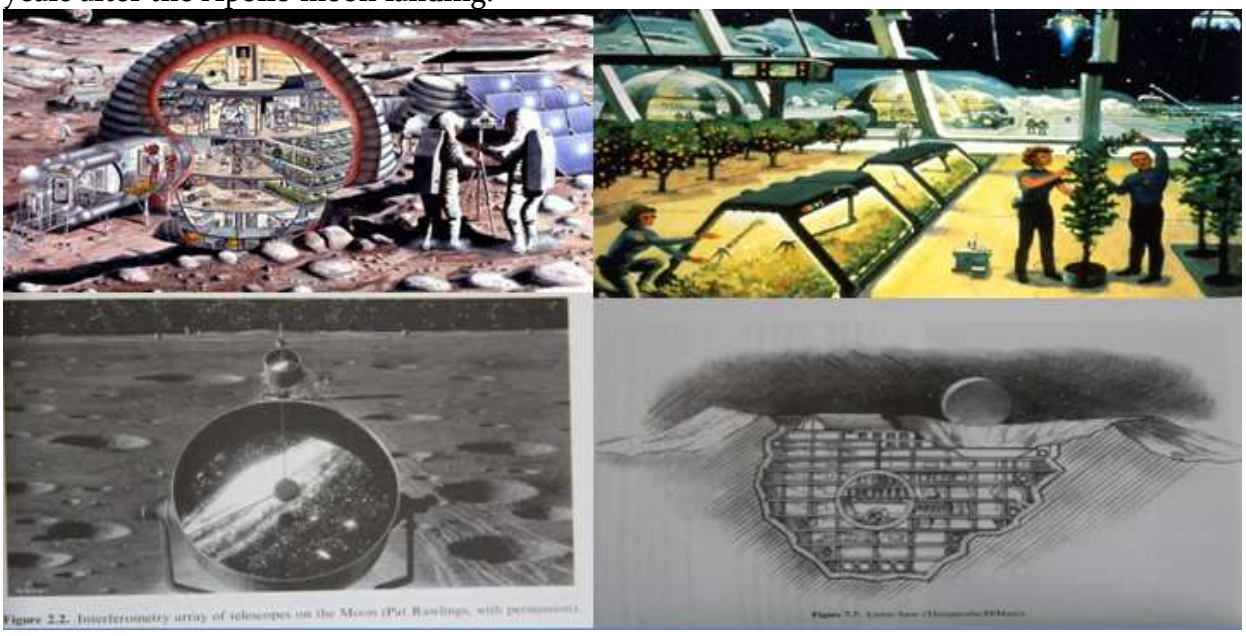

Fig.16. Lunar base projects.

8. Opposition of Mars and 27th July. 2018 event

Like all the planets in our solar system, Earth and Mars orbit the sun. However, Mars orbits the sun at a greater distance than Earth. The Earth (365.25 days) makes two trips around the sun in one Martian year (687 days), Fig.17. Due to these different orbital speeds, every two years or so, Earth passes between Mars and the sun. So sometimes, the two planets are on opposite sides of the sun, very far apart, and other times, Earth passes relatively close to Mars.

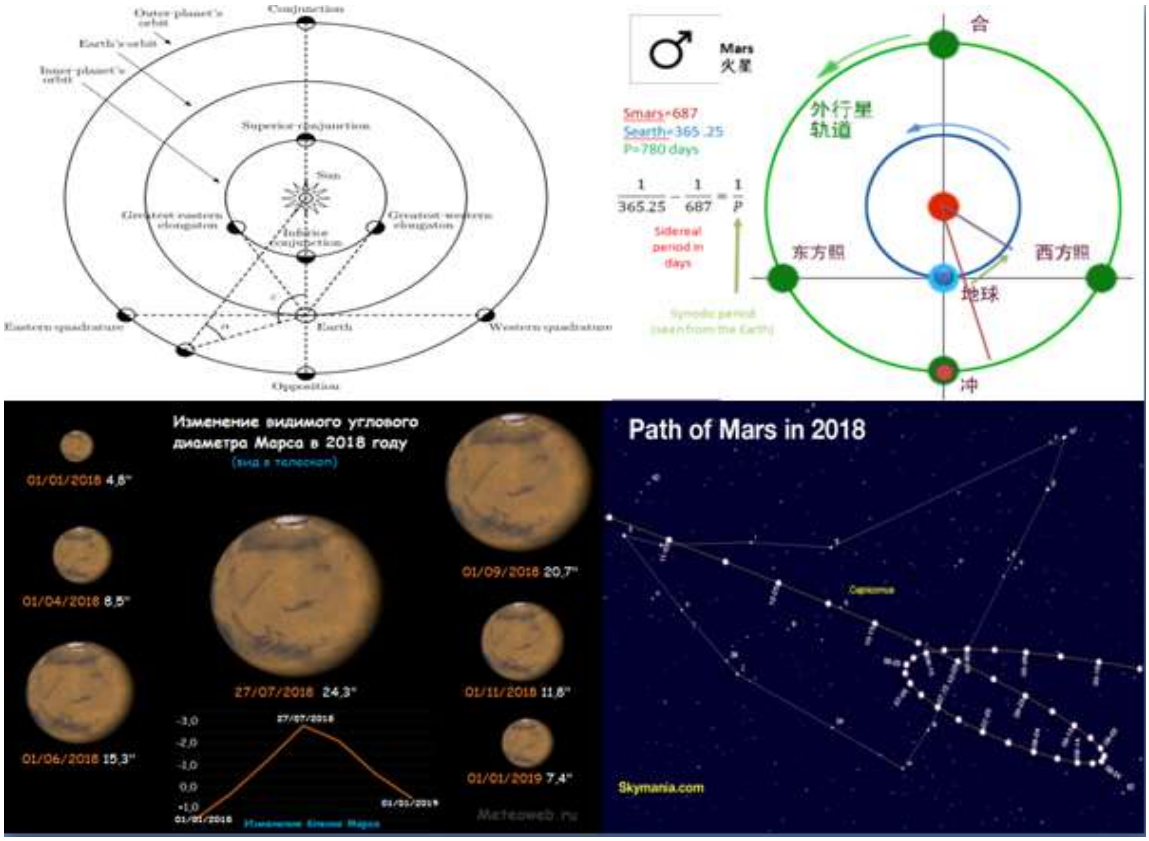

Fig.17. Mechanics behind Mars opposition

During opposition, Mars and the sun are on directly opposite sides of the Earth. The Mars is seen quite bright then. From the perspective of our spinning world, Mars rises in the east just as the sun sets in the west. Then, after staying up in the sky the entire night, Mars sets in the west just as the sun rises in the east. Since Mars and the sun appear on opposite sides of the sky, we say that Mars is in ***opposition***.

The sun, the Earth, and Mars will line up for a once-in-two-years treat called “Mars in opposition.” Every 15 or 17 years, a ***great opposition*** occurs within a few weeks of Mars' perihelion (the point in its orbit when it is closest to the sun). This is a chance to see the red planet in big, bright detail in the night sky.

The last time a great opposition of Mars happened was on August 27, 2003; the distance between the earth and Mars was 34.6 million miles as shown in Fig.18.
This summer, opposition will occur on July 27 2018, and Mars will reach its closest approach to Earth at the distance 58 million kilometers. The Red Planet will also be at its brightest (-2.8^{m}) since 2003 as shown in Fig.18, with angular diameter 24.3".

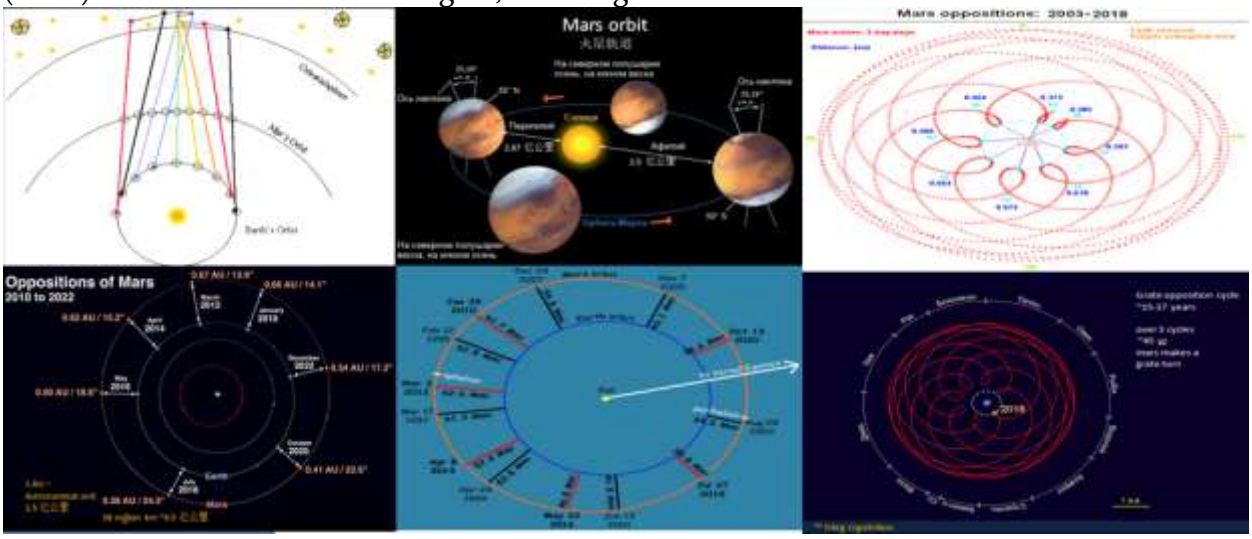

Fig.18. Opposition and great opposition cycle of mars

9. Martian Topography:

Let us make a small excursion to Mars. The temperature on the surface of Mars is quite low. The average temperature of Mars is -50 °C, varying from –153 °C in winter at the poles, up to +20 °C at equator at midday. It has an atmosphere, but the surface pressure (压力) on Mars is 160 times less than on Earth — 6.1 mbar. The axis of the mars is inclined by 25.2^{o} almost as the Earth's, and its day lasts 24 hours and 39 minutes.
Although Mars is a small planet, its radius is just a little over half of Earth's – we now know that it boasts scenery on a scale that makes Mount Everest and the Grand Canyon seem unimpressive by comparison.

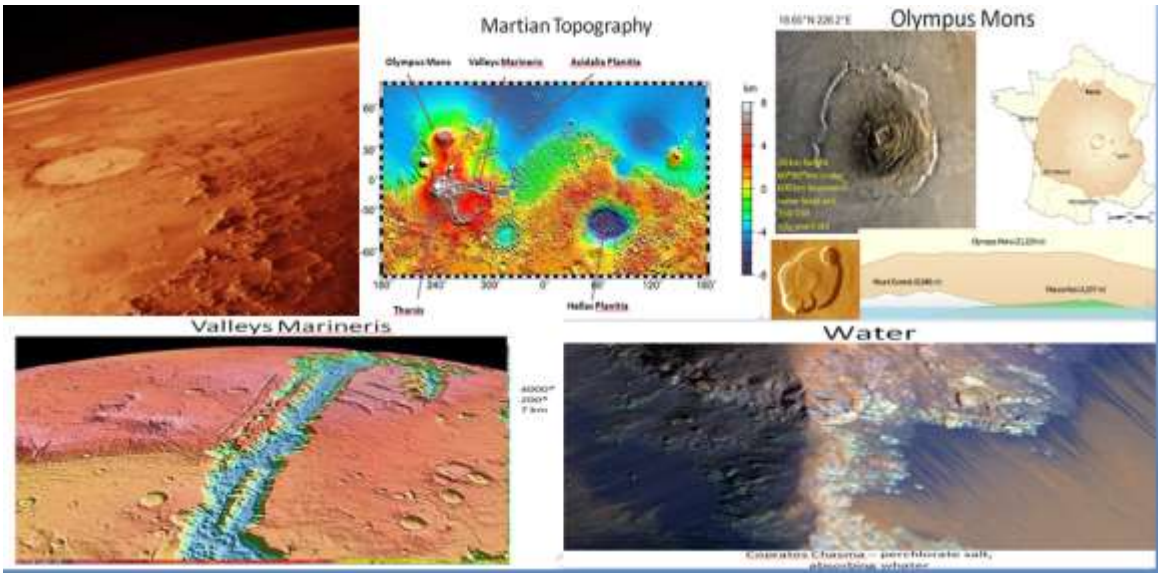

Fig.19. Topographic feature of Mars.

9.1 Olympus Mons (Mount Olympus):

Olympus Mons is a very large shield volcano on the planet Mars. By one measure, it has a height of nearly 26 km. Olympus Mons is about two and a half times Mount Everest's (8,848m) height above sea level as shown in Fig.19. It is the largest volcano on Mars, and has the second highest mountain in the Solar System (the highest is Rheasilvia on Vesta). It had been known to astronomers since the late 19th century as the albedo feature Nix Olympica (Latin for Olympic Snow). Its mountainous nature was suspected well before space probes confirmed its identity.

As a shield volcano, Olympus Mons resembles the largest volcanoes on Earth, making up the Hawaiian Islands. Nevertheless, its slope is smaller (5°) and area larger. The edifice is about 600 km (370 mi) wide. The volcano is located in Mars's western hemisphere at approximately 18.65°N 226.2°E.

On top it has six nested calderas (collapsed craters) forming an irregular depression 60 km (37 mi) × 80 km (50 mi) across and up to 3.2 km (2.0 mi) deep. Using geometric relationships of caldera dimensions from laboratory models, scientists have estimated that the magma chamber associated with the largest caldera on Olympus Mons lies at a depth of about 32 km (105,000 ft) below the caldera floor. Crater size-frequency distributions on the caldera floors indicate the calderas range in age from 350 Mya to about 150 Mya. Some regions probably formed within 100 million years of each other.

9.2 Valleys Marineris

Valles Marineris (Mariner Valley) is a vast canyon system that runs along the Martian equator just east of the high-elevated Tharsis region. Valles Marineris is 4000 km (2500 mi) long and reaches depths of up to 7 km (4 mi)! In contrast, the Grand Canyon in Arizona is about 800 km (500 mi) long and 1.6 km (1 mi) deep. In fact, the extent of Valles Marineris is as long as the United States and it spans about 20 percent (1/5) of the entire distance around Mars! The canyon extends from the Noctis Labyrinthus region in the west to the chaotic terrain in the east. Most researchers agree that Valles Marineris is a large tectonic "crack" in the Martian crust, forming as the planet cooled, affected by the rising crust in the Tharsis region to the west, and subsequently widened by erosional forces. However, near the eastern flanks of the rift, there appear to be some channels that may have been formed by water.

9.3 Water:

Since the conditions on Mars today do not permit liquid water on the surface, almost all water on Mars today exists as ice, though it also exists in small quantities as vapor in the atmosphere, and occasionally as low-volume liquid brines in shallow Martian soil. The only place where water ice is visible at the surface is at the north polar ice cap. Abundant water ice is also present beneath the permanent carbon dioxide ice cap at the Martian South pole and in the shallow subsurface at conditions that are more temperate. More than five million cubic kilometers of ice have been identified at or near the surface of modern Mars, enough to cover the whole planet with an ocean of 35 meters depth (115 ft). Some evidence of an annual water cycle on Mars were found recently, appearing as recurring slope lineae in the air where dissolved perchlorate salts capture water.

10. NASA`s Journey to Mars: Curiosity rover & Insight Mission

In Fig.20 we see NASA`s Curiosity rover walking on the Martian surface. The Curiosity mission is a part of Mars Science Laboratory project. This jeep-size rover was provided with a plutonium engine, landing on Mars in 2012. It will operate as long as it is scientifically viable. NASA officials expect this period to be up to 20 years.

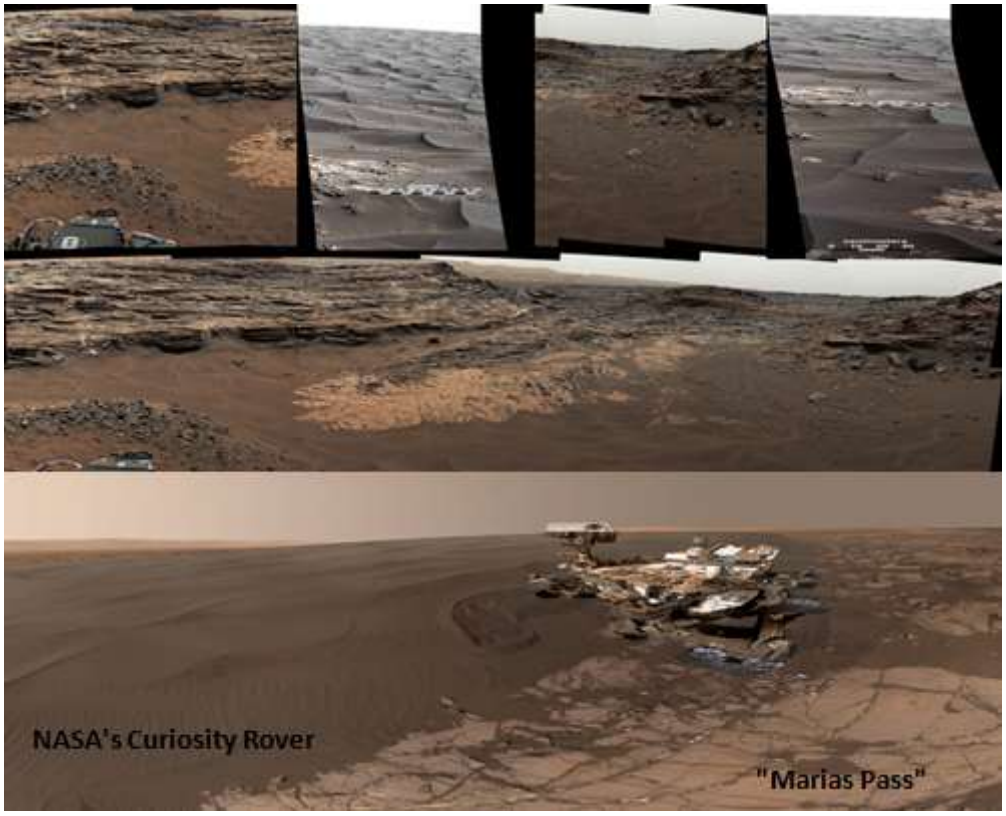

Fig.20. Curiosity ROVER, NASA`s Mars Science Laboratory mission (MSL)

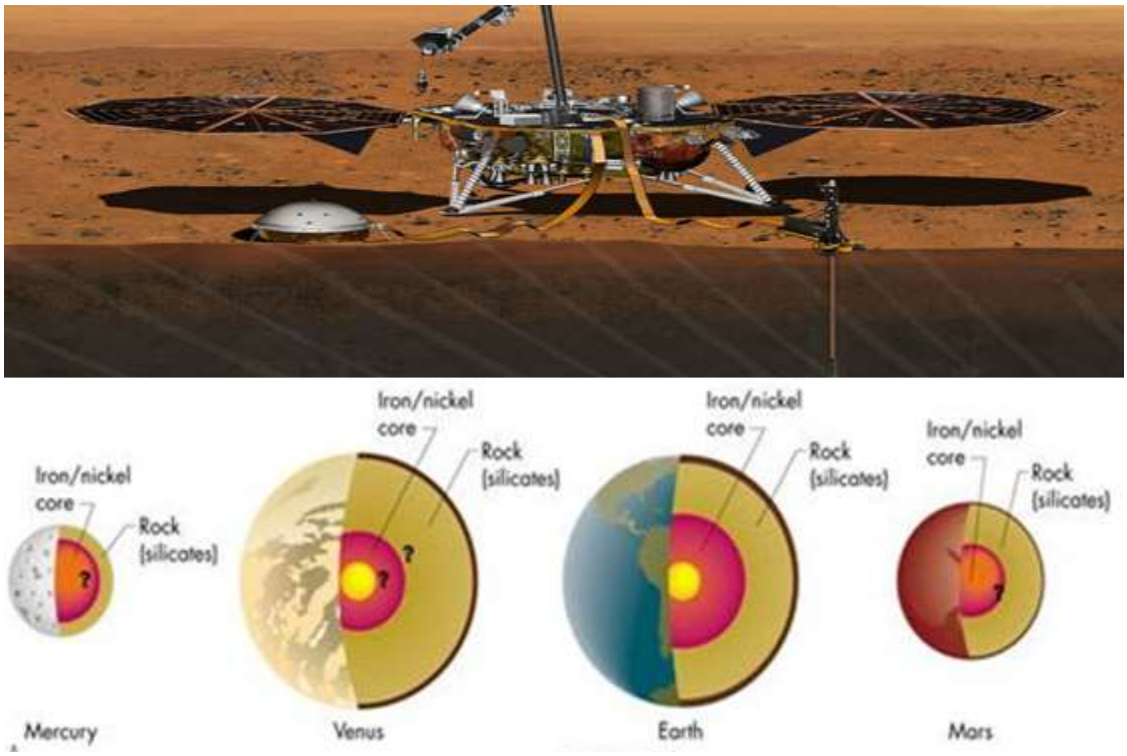

Fig.21. NASA`s Insight Mission

This year on May 5, 2018, NASA launched a new mission called the InSight Mission, which will arrive on Mars on November 26, 2018. The time of opposition is the best for the flight to Mars. The objectives of the InSight mission is to place a stationary lander equipped with a seismometer and heat transfer probe on the surface of Mars to give the Red Planet its first thorough checkup since it formed 4.5 billion years ago. It is the first outer space robotic explorer to study in-depth the "inner space" of Mars: its crust, mantle, and core. This mission will also allow tracking of the variations of the Martian rotation at centimeter precision, from its radio signals captured on orbit.

Researchers believes studying on Mars' interior structure will answers some key questions about the early formation of rocky planets in our inner solar system - Mercury, Venus, Earth, and Mars - more than 4 billion years ago, as well as rocky exoplanets as shown in Fig.21 InSight will also measure tectonic activity and meteorite impacts on Mars today. This mission is part of NASA`s discovery program for highly focused science missions that ask critical questions in solar system science.

Hope we will get new interesting information in the future and wish all of us to enjoy such a rare event, as Mars opposition together with lunar eclipse.
Thank you all for your attention.