Let's Study the "MOON"

October 2014

Let's Study the Moon

What to know・・・

- ***Characteristic features of the Moon***
- ***Origin and evolution of the Moon***
- ***Scientific results from "KAGUYA"***

What to feel・・・

- ***Interests of lunar exploration***
- ***Dreams for the future lunar development***

1. Characteristic Features of the Moon

- Size of the Moon and Earth, and distance between them
- Motion of the Moon and its appearance from the ground
- Environment of the Moon
- Man's landing on the Moon

- *Let's compare the size of the Moon with that of the Earth.*
- *What is the distance between the Moon and the Earth?*

Moon and Earth（Size and Distance）

Size and Location

Distance on average :384,000km（nearly 30 times of the earth diameter）
Nearest distance :357,000km（called as “Super Moon”, observed in July, August, and September this year (2014)）

1

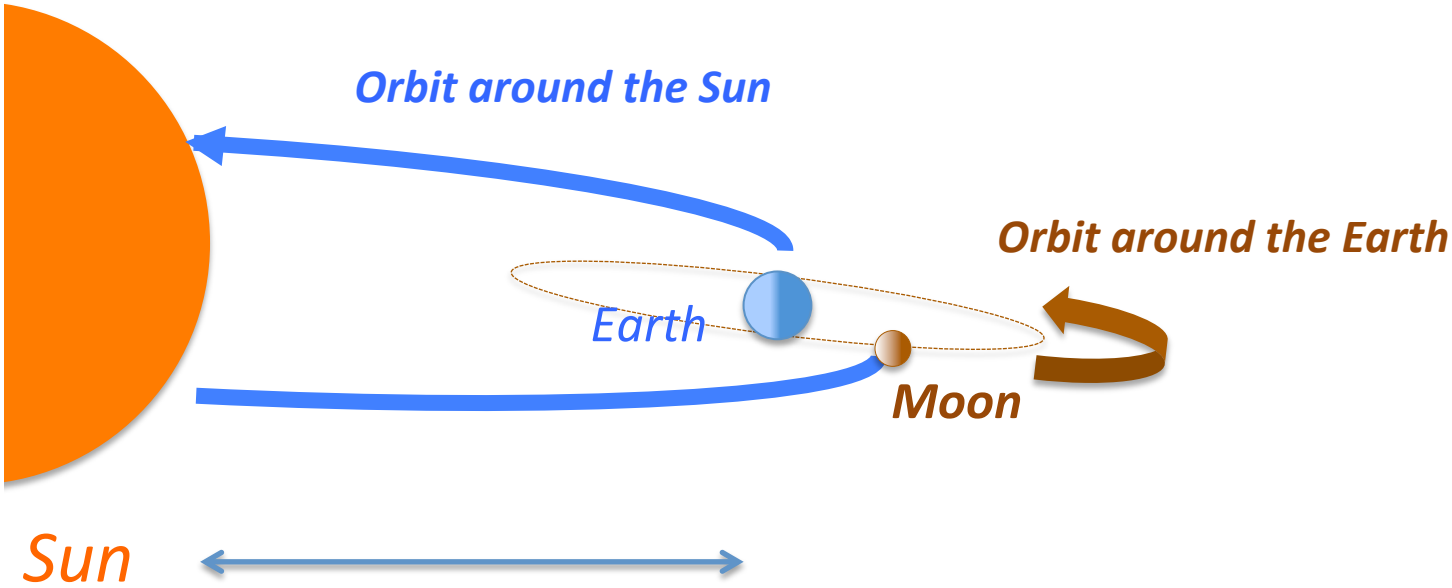
Moon

4

Earth

- *Orbital Motion of the Moon and Earth*
- *View of the Moon from Ground*

Motion of the Moon, Earth, and Sun



The Sun is 400 times as far away as the Moon from the Earth.

The Moon goes round the Earth once a month (orbital revolution)

➡*During one revolution of the Moon, the Earth rotates nearly 27 times.*

➡*Moon's day and night are each half a month long.*

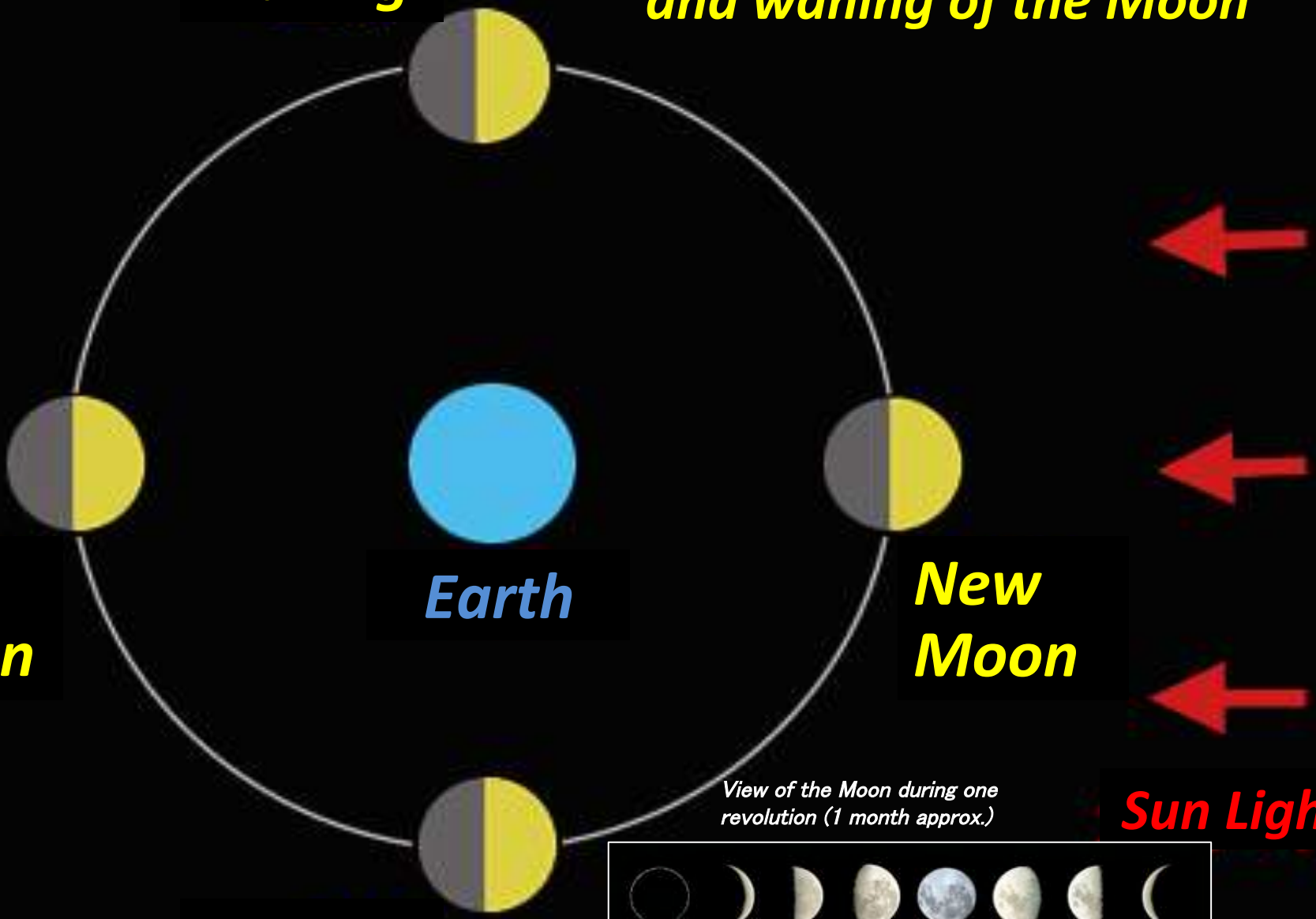
Waxing and Waning of the Moon

If you observe the Moon every night, you will see the waxing and waning of the Moon, as shown below. Can you explain why?

Waxing and waning of the Moon during one month

Does the Moon itself change its shape every night ?
Or, ????

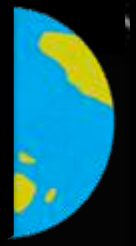
Mechanism for waxing and waning of the Moon

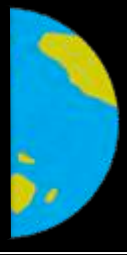


View of the Moon during one revolution (1 month approx.)

Similarly, we can see the waxing and waning of the Earth if we go out of the Earth.

The left half of the Earth is missing.

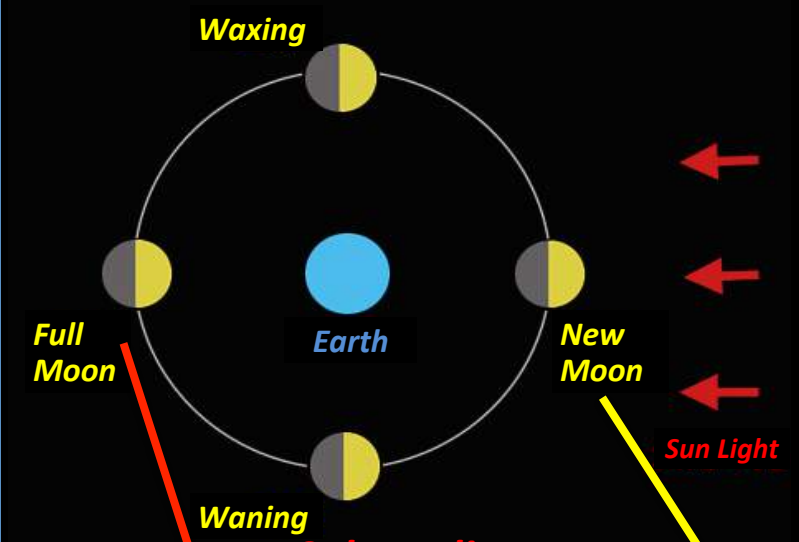




Spacecraft

Sun Light

Solar and Lunar eclipses



Solar eclipse occurs when the Sun, Moon, and Earth are in line. In Japan, on Oct. 8 this year(2014), and on April 4, 2015 next time .

Lunar eclipse occurs when the Sun, Earth, and Moon are in line. In Japan, on May 21, 2012 last time, and on March 9, 2016 next time.

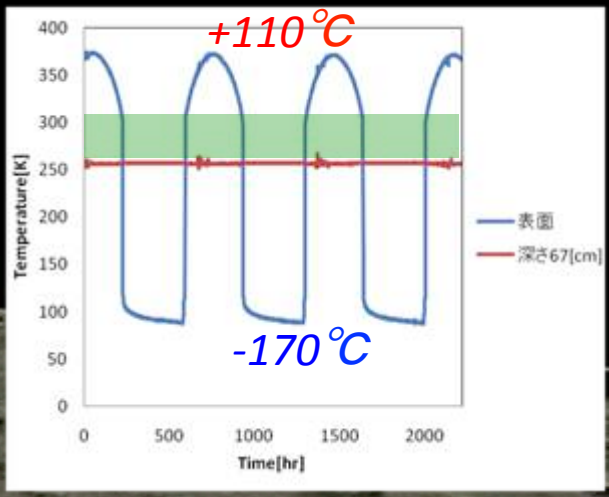
Lunar Eclipse : Moon in the shadow of Earth

Solar Eclipse : Earth in the shadow of Moon

Now, let's look at the lunar environment (terrain, temperature, and gravity).

Lunar Environment

No air and no water, completely different from the Earth.



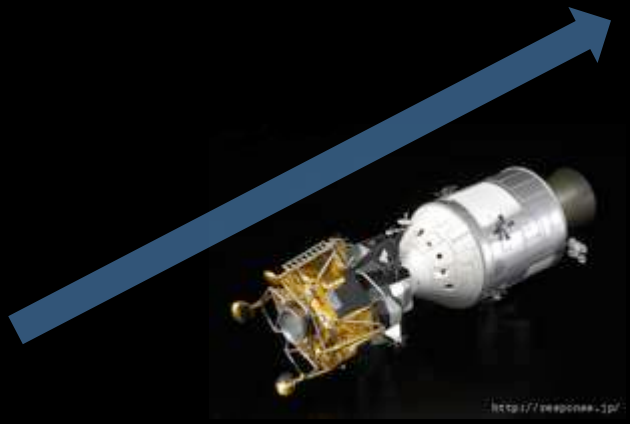
Temperature is +110℃ during day time, and -170 during night time. "Green" shows the temperature range of the Earth in °K.

The gravity of the Moon is 1/6 of the Earth. Jumping astronauts on the Moon.

A lot of explorers, nearly 100, have visited the Moon.

The Moon is the only celestial body that humans have landed on.

How to get the Moon ?



It takes about 1 week to get there by spacecraft.

Lunar Exploration

Human beings (American astronaut) first landed on the Moon in 1969.

In the Apollo program, 12 astronauts explored the surface of the Moon. As a result, Lunar science greatly advanced

After the Apollo program, the lunar exploration re-started in 1990's. Japan, U.S., Europe, China, and India have sent their explorers to the Moon. Among them, "KAGUYA", Japanese Lunar Explorer launched in 2007, was the most sophisticated mission and a lot of scientific data were obtained.

2. Mysteries of the Moon

- The Moon is the most familiar and the most well– studied celestial body.
- However, there are a lot of mysteries about the Moon.
- What are the mysteries still left unsolved？

The Biggest Mystery: Origin of the Moon

Before thinking about it, let's look at the birth of the solar system 4.6 billion years ago.

Molecular cloud (a stellar nursery) → *Accretion to protosun and small planets* → *Accretion to larger planets*

Sun's Family

Sun

Planets (totally 8)

Mercury Venus Earth Mars Jupiter Saturn Uranus Neptune

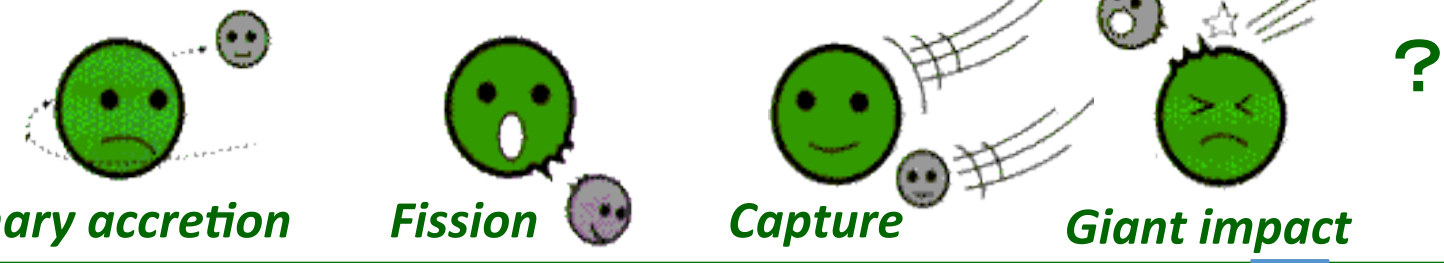
These planets have their own satellites, similarly to the Moon of the Earth.

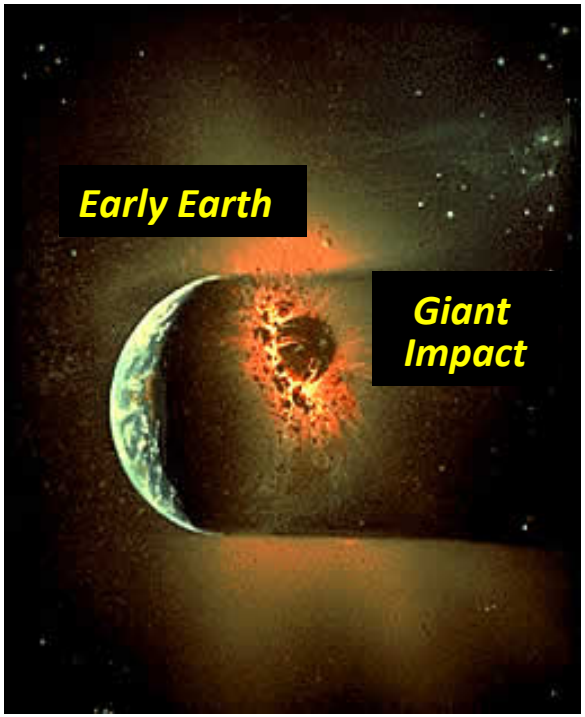
Asteroid

Comet

Analyzing the lunar stones that Apollo astronauts brought back, the Moon and the Earth were born almost at the same time, 4.6 billion years ago. There must have been some relation in the origin of the Moon to the very early Earth. … Now, what's the relation ?

4 Major hypotheses





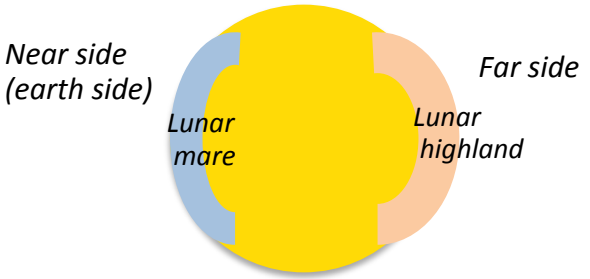
video

Giant impact is the most widely-believed hypothesis, but true?

A Mars-sized body impacted the early Earth?

Not only the mystery in the origin, but also there are several important mysteries in the evolution of the Moon.

1. ***There are big differences between the near side and far side. Why ? and How ?***



Difference of the geographical features between the far side and near side,

2. ***Was there a magma ocean in its early phase? If there was, what scale, local or global?***

Magma ocean

3. ***How the topographic and geological features were formed?***

Various types of landforms

In the first half of this lesson, we have studied:

- *features of the Moon*
- *mysteries of the Moon*

In the latter half of this lesson,

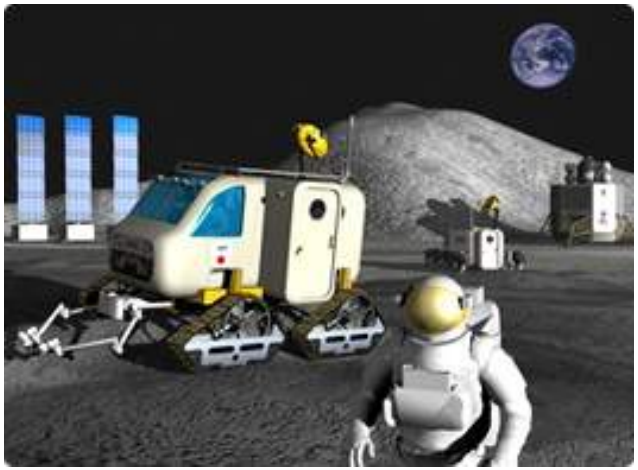
- *we will study the Lunar Explorer "KAGUYA" project and its scientific achievements.*

3. Lunar Exploration by "KAGUYA" "

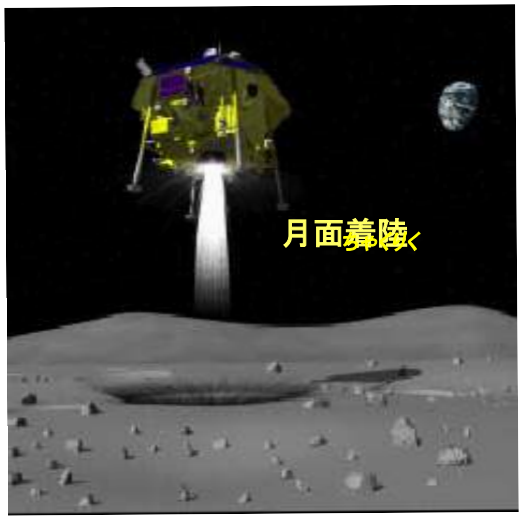
- In order to reveal the mysteries of the Moon, Japanese lunar explorer "KAGUYA" was sent to the Moon in 2007.
- We will overview the "KAGUYA" project and study new outcomes from the "KAGUYA" observation.

"KAGUYA" Mission Objectives

1. ***To study the origin and evolution of the Moon.***
2. ***To get information for manned lunar activities in the near future.***
3. ***To acquire the technologies (lunar orbit insertion, orbit control, and controlled hard landing at a designated point) for the next-step lunar exploration.***



Manned lunar activities in the future



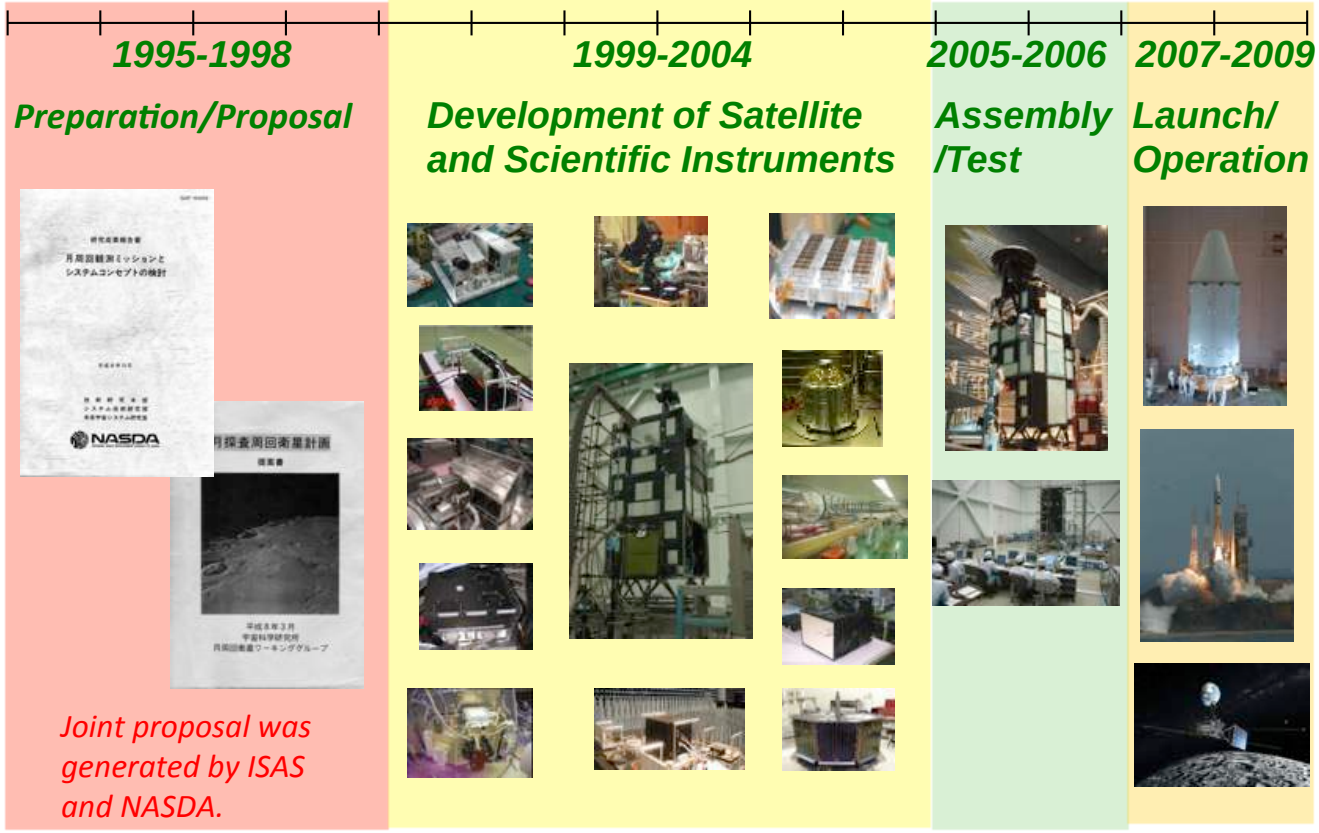
Technologies for the next-step lunar exploration

Lunar Explorer “KAGUYA”

Size : 2.1x2.1x4.8m
(about the same size of minibus)
Configuration: Main satellite and two sub-satellites
Weight: 3 tons in approx.

History of "KAGUYA"

It took 14 years from the proposal to the end of the mission. Many Japanese and foreign scientist are still working for "KAGUYA" data analysis.



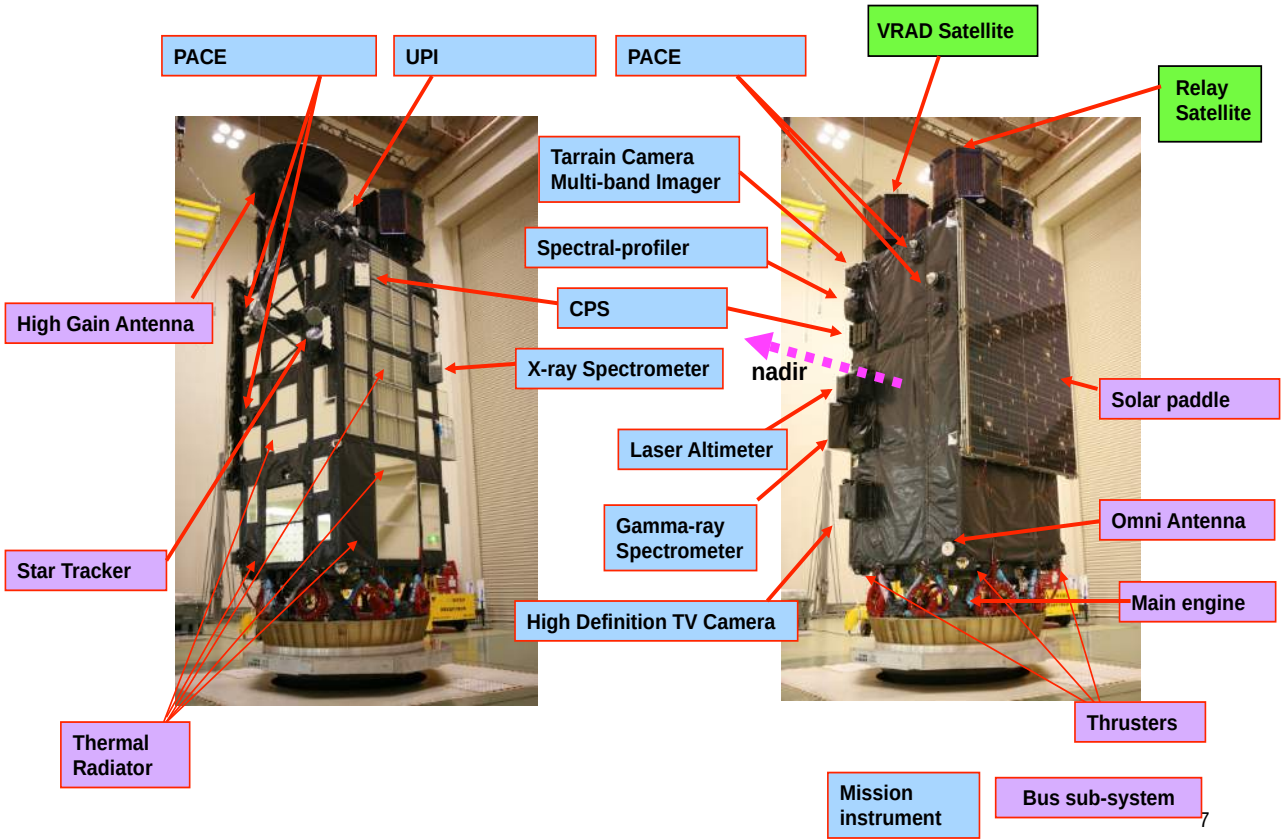
International Competition and Collaboration

- "KAGUYA" (Japan) (2885kg) — Launch: September 2007
- Chang'e 1 (China) (2350kg) — Launch: October 2007
- Chandrayaan-1 (India) (1050kg) — Launch: April 2008
- LRO (U.S.) (1000kg) — Launch: June 2009

Onboard Scientific Instruments

Surface materials and composition・・・4 instruments
Topographical and geological structure ・・・3 instruments
Gravity field・・・2 instruments
Environment (including magnetic field)・・・5 instruments
High-density TV・・・1 instrument

More than 200 researchers participated in development and operation of the scientific instruments.



Development and Test

"KAGUYA" was the largest lunar explorer after the Apollo program.

KAGUYA systems test

Test configuration

Integration into the nose fairing of H Ⅱ rocket just before launch

"KAGUYA" launch on September 14, 2007

Launch

Sep.14

Orbit Insertion

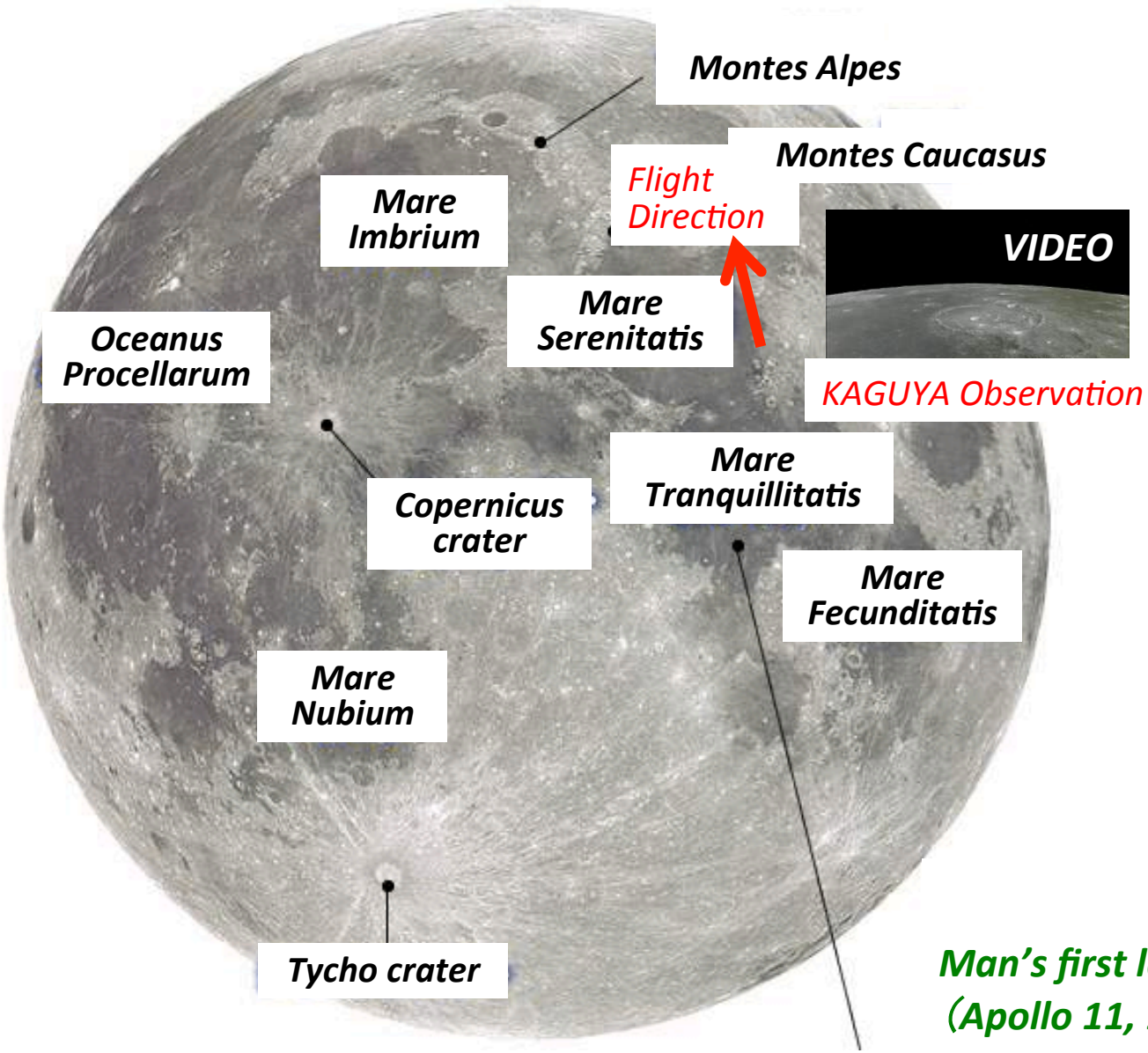
Oct.5

Oct.19

Failure case

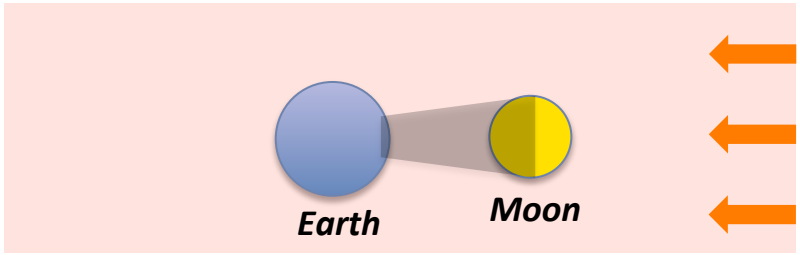
Lunar orbit insertion: most critical and nervous “20 minutes”

View of Lunar Surface from "KAGUYA" (at 100 km height)



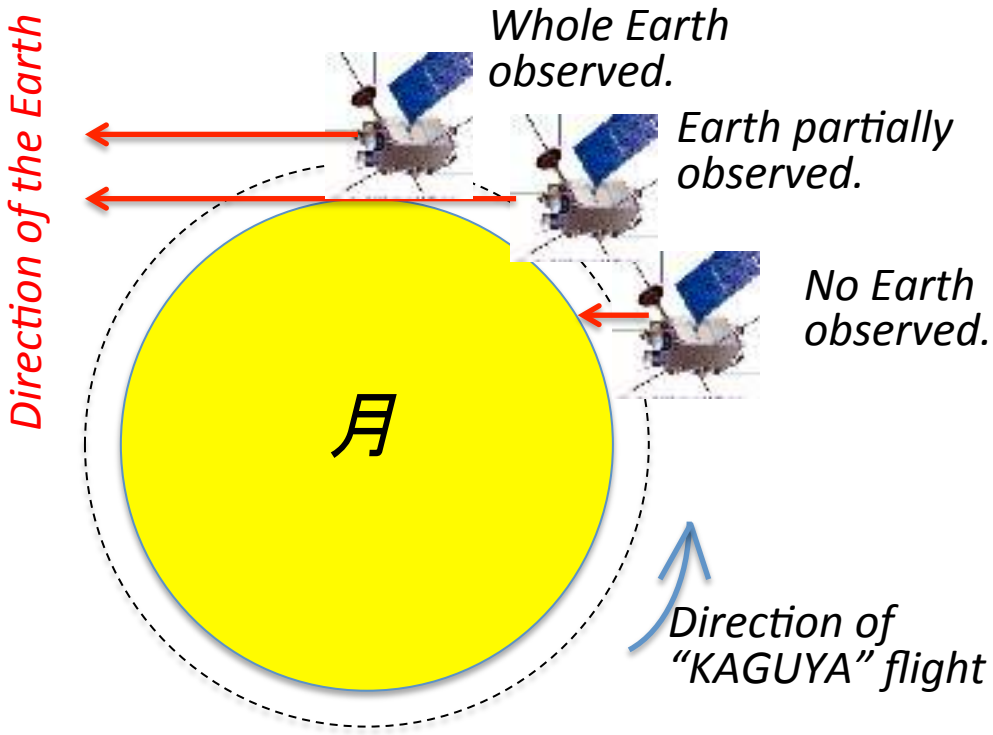
“KAGUYA” observed “Solar Eclipse”. Why possible ?

Solar eclipse on the Earth



Solar eclipse observed from ”KAGUYA”

“KAGUYA” observed “Earth Rise”. Why possible ?

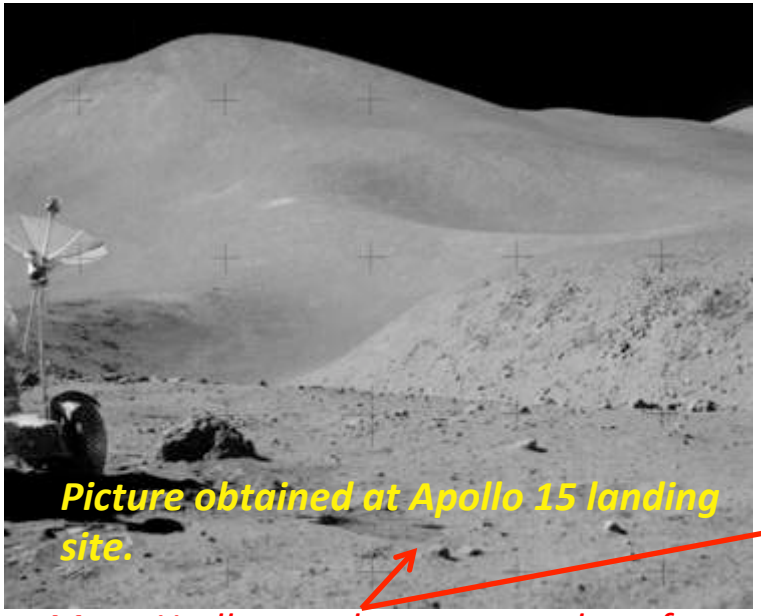


Rise of Full Earth

Earth rise can not be seen from the Moon surface. It can be seen only from spacecraft orbiting the Moon.

4. Scientific Achievements from "KAGUYA" Observation

Precise Three-dimensional Topographical Map



Picture obtained at Apollo 15 landing site.

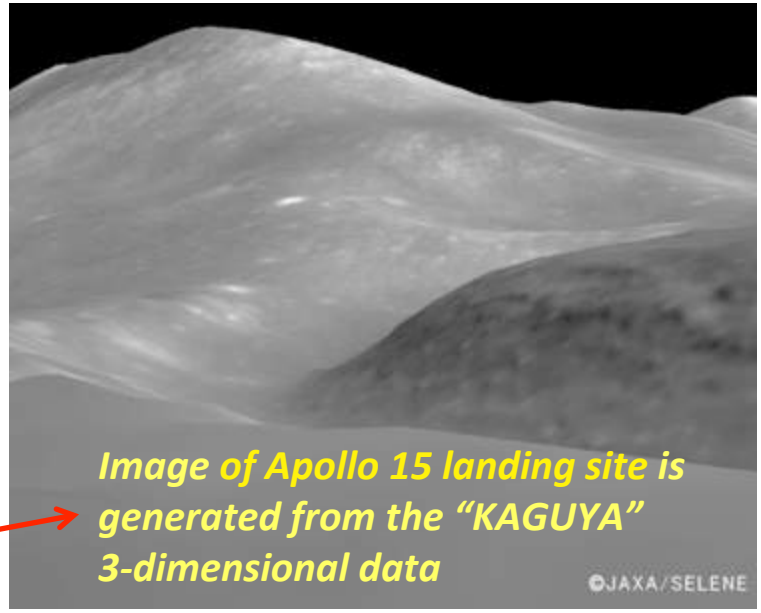
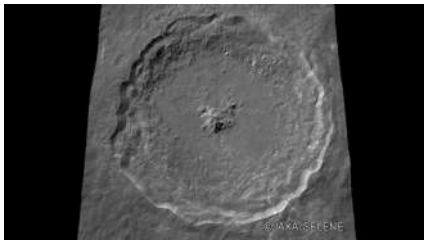


Image of Apollo 15 landing site is generated from the "KAGUYA" 3-dimensional data

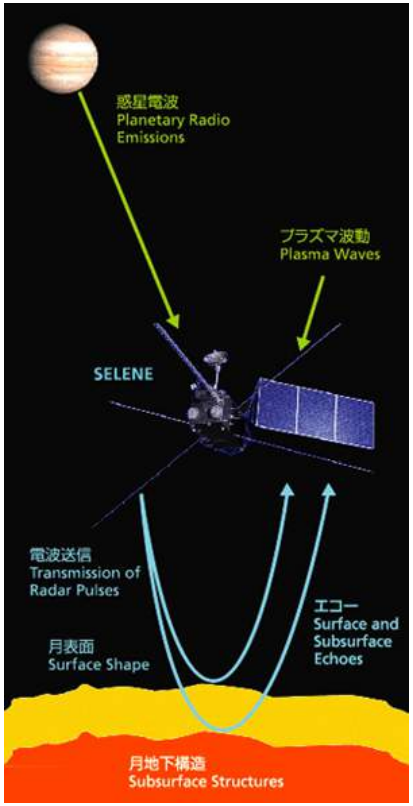
Mons Hadley on the eastern edge of Mare Imbrium

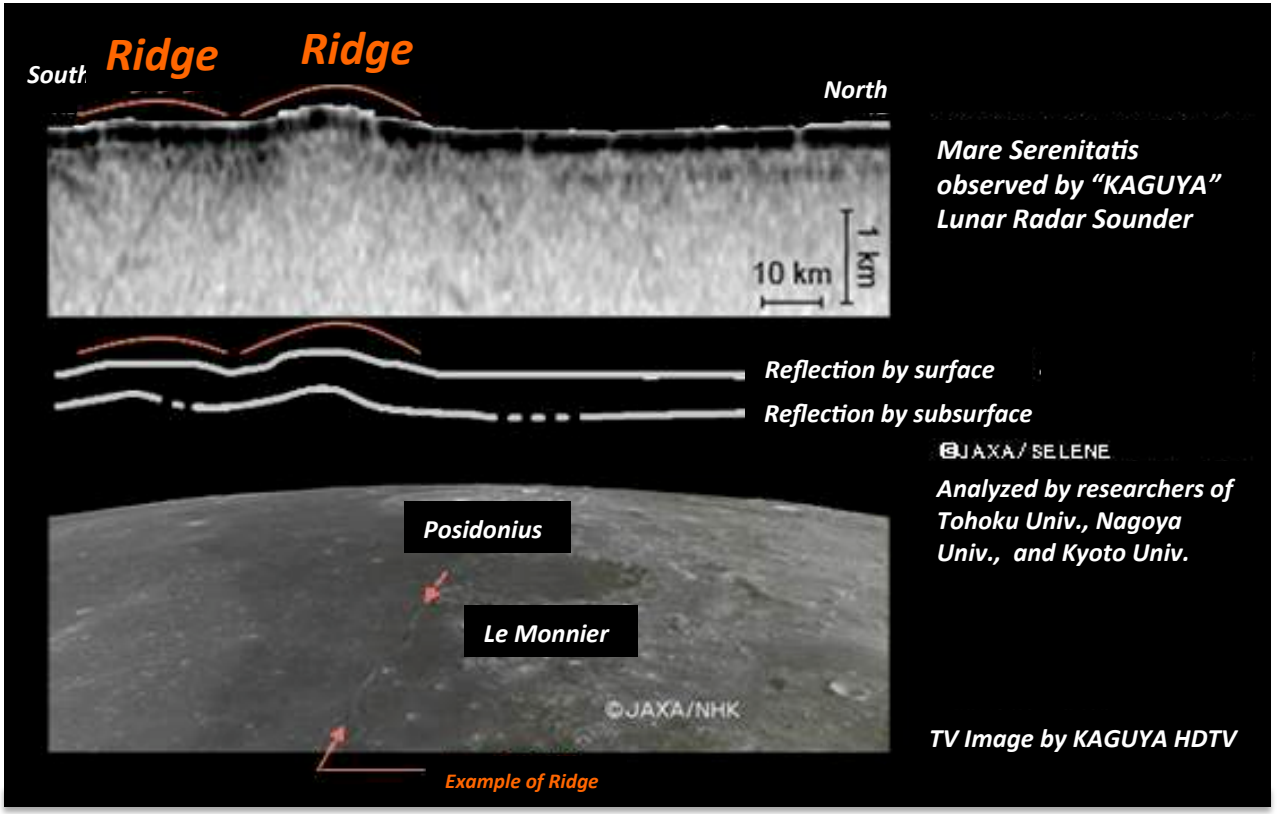


Video

Tycho crater, 85km in diameter with central peaks up to 1.6 km above the floor, is a relatively young crater formed about 110 million years ago. Since it is one of the places of interest on the Moon, sightseeing flights will be planned in future. You can enjoy the simulated experience well in advance using the three-dimensional KAGUYA data (JAXA/ISAS KAGUYA Gallery).

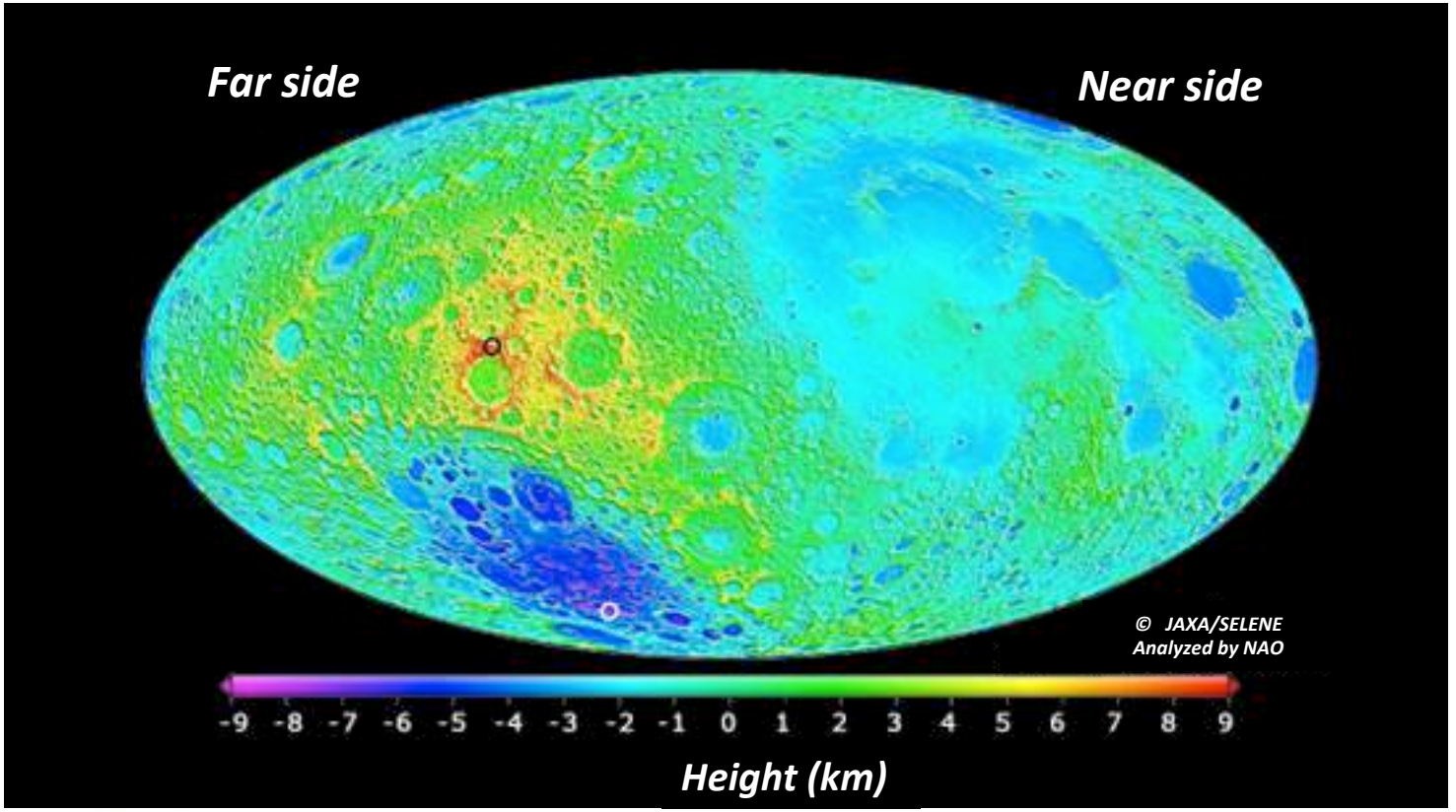
Observation of Sub-surface Structure

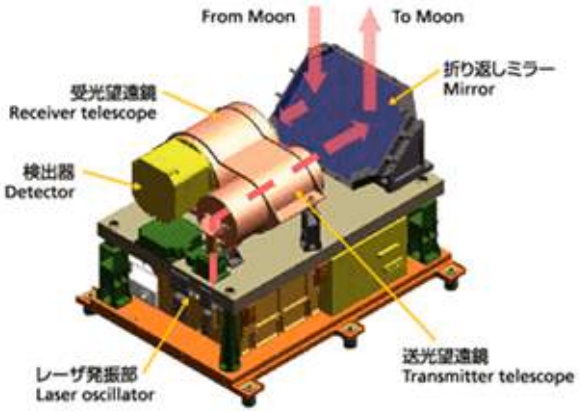




The sub-surface structure had been almost unknown. "KAGUYA" observed the underground structure up to 5 km from the surface, by transmitting radio waves to the Moon and by receiving the reflected signals from the sub-surface structure. The sub-surface structure shown above suggests that the "Ridges" of the Moon were formed by shrinking of the lunar surface as it was cooled.

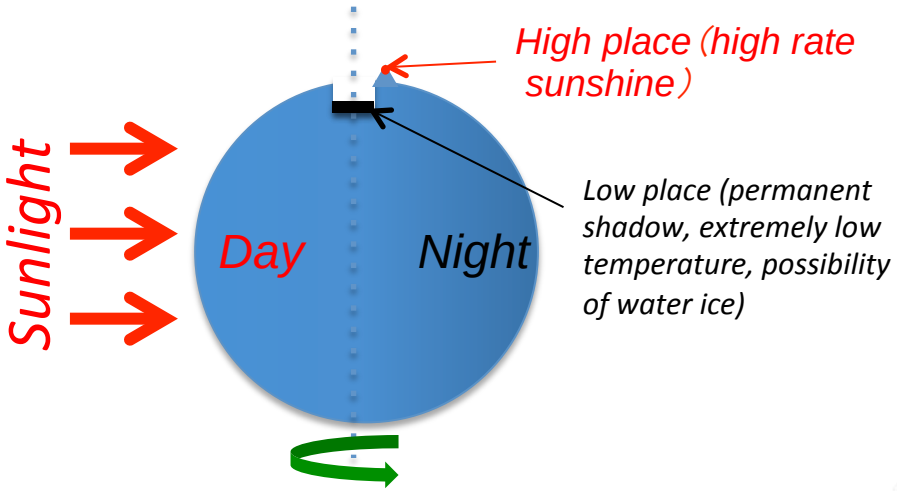
Precise Lunar Terrain Map



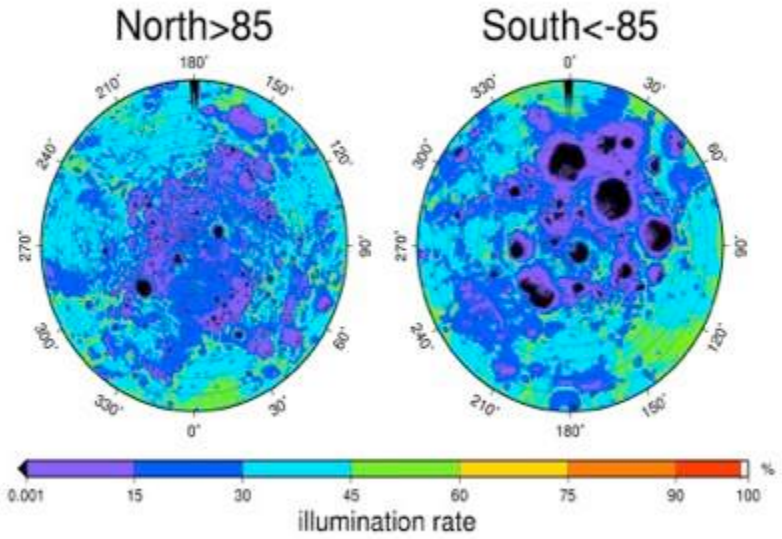


A very precise terrain map was obtained by "KAGUYA" Laser Altimeter. The difference between the highest and lowest points was found to be larger by 2 km approx. than the previously estimated value.

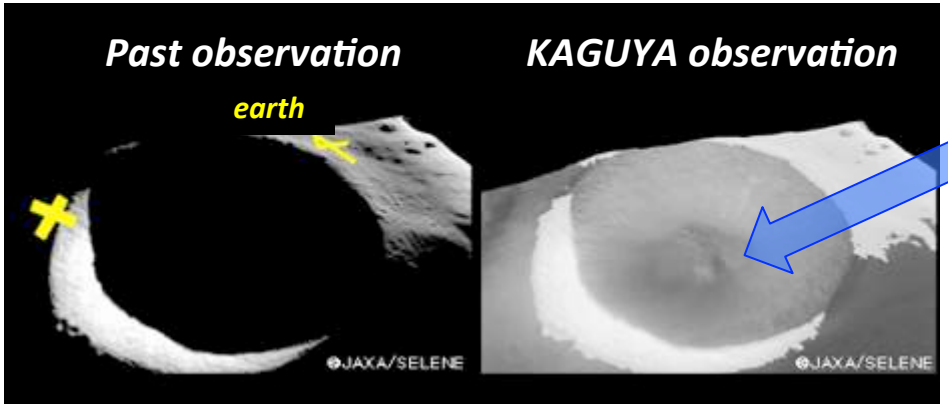
High Rate Sunshine Area and Permanent Shadow Area



Rotation axis almost perpendicular to the plane of the ecliptic

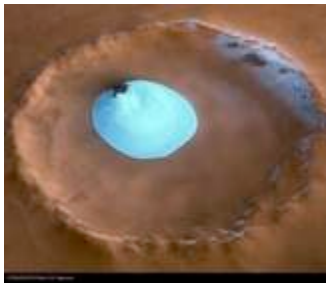


"KAGUYA" observation. "Black" shows "permanent shadow" area. The maximum sunshine rate is 89 % in the north polar region and 86 % in the south polar region. (Noda et al., GRL, 2008) .



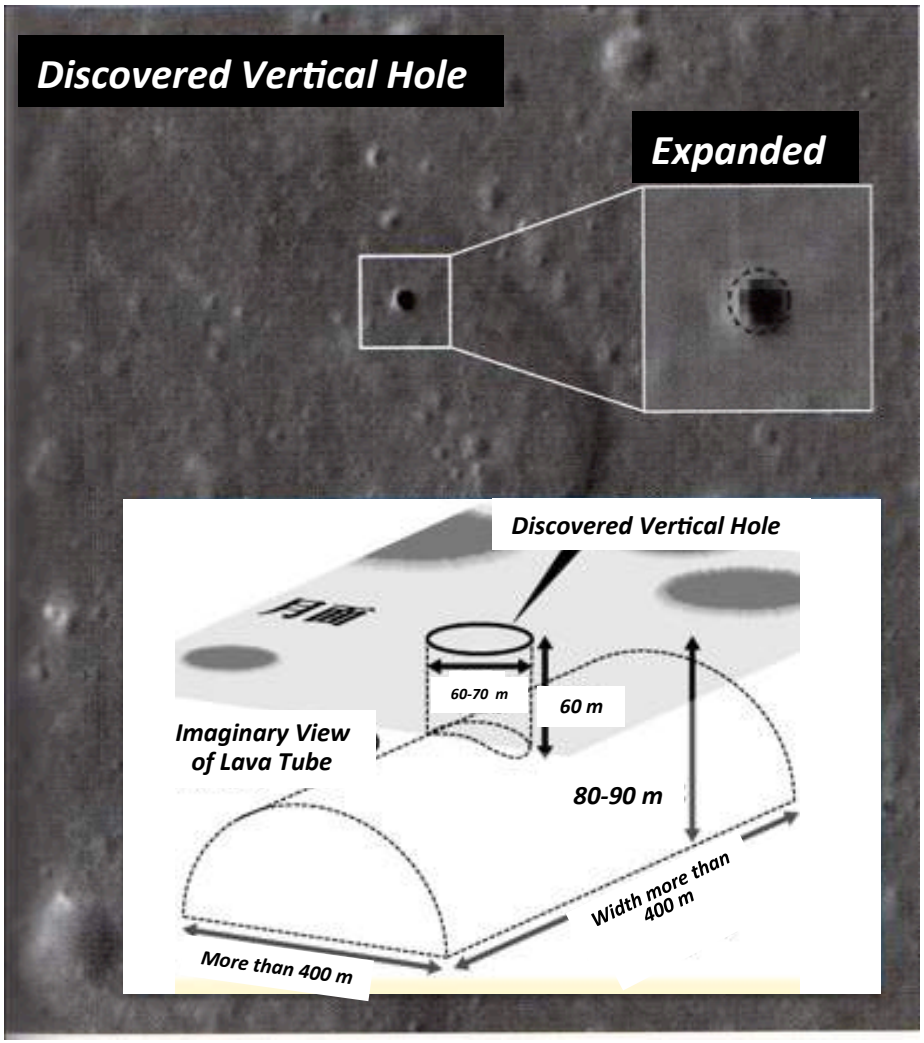
Shackleton crater near the south pole, one of the candidates of the lunar base.

The Inside of the Shackleton crater observed by Terrain Camera. There was no block of water ice exposed inside the crater, rather different from the case of Mars. The amount of water ice is assumed to be several % maximum if any (Haruyama et al., Science, 2008).

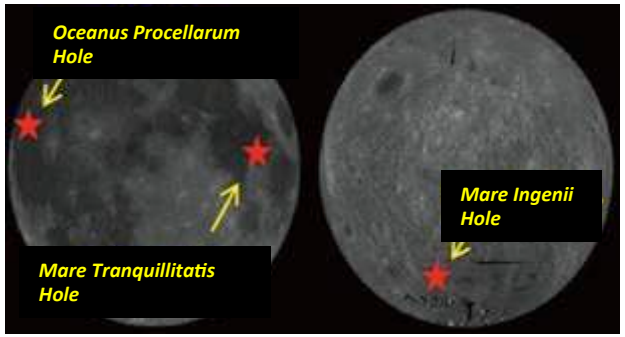


Water ice observed by Mars Express (2005)

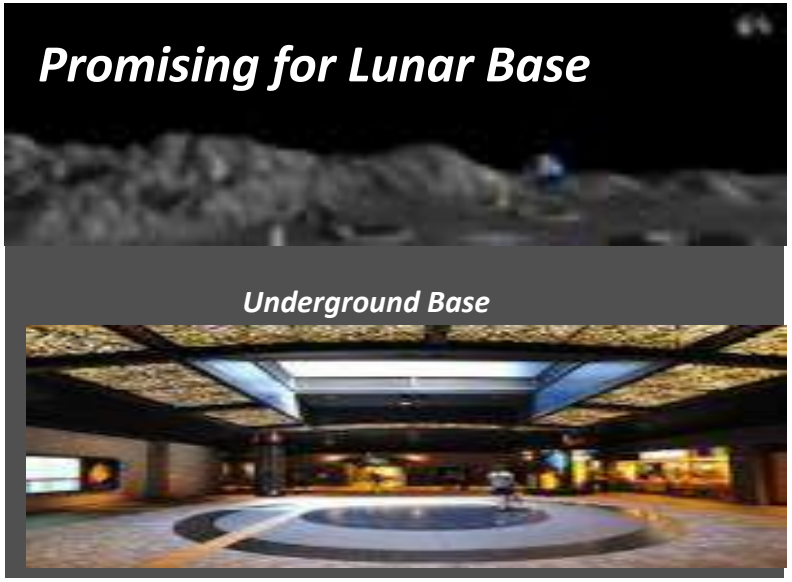
Vertical Hole and a Possible Lava Tube



Vertical hole (approx. 70 m diameter) and Lava Tube (approx. 370 m size) (Haruyama et al., GRL, 2009)

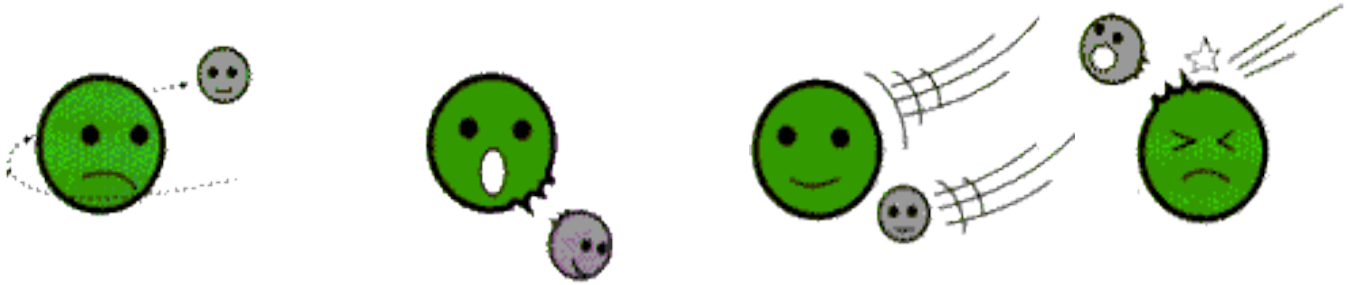


3 Vertical holes discovered by "KAGUYA"



Temperature :-20℃ constant (Surface: -170～+110℃)
Radiation :same level as the earth surface, approx. 1 mSv/year (at 5 m below the surface) (100-500 mSv/year at the surface)
Protected from meteorite impacts

“KAGUYA” Contribution to “Origin of the Moon”



	Binary accretion	Fission	Capture	Giant impact
Mechanically feasible?	△	○	△	◎
Global-scale magma ocean?				
Material similarity?				
Core size?				

Studied by “KAGUYA” so far.

1. *Under analysis. A certain conclusion will be obtained.*
2. *Under analysis. Some conclusion will be obtained. But, will be finally confirmed by another mission to study the internal structure.*
3. *Evidence obtained.*

1	2	3
Source Material	*Internal Structure*	*Global-scale Magma Ocean*

3 major keys to conclude the origin of the Moon.

Not final conclusion yet, but we are getting closer and closer.

"KAGUYA" Contribution to "Evolution of the Moon"

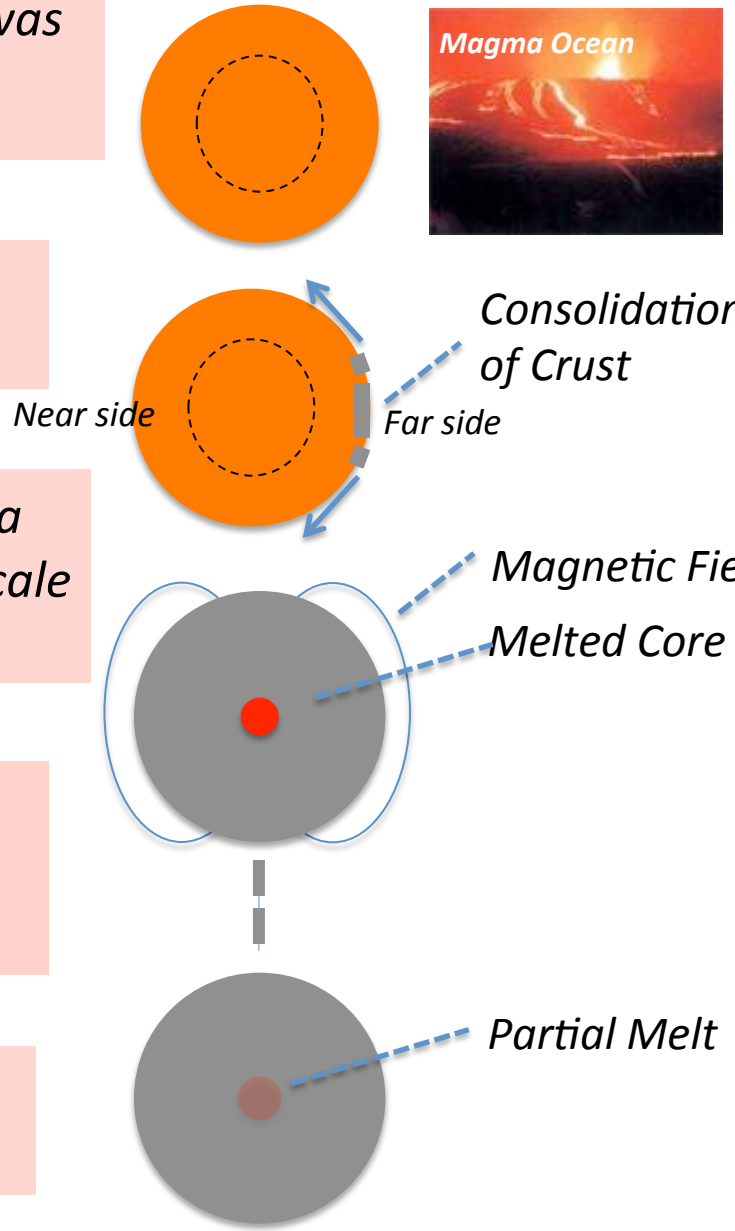
When the Moon was born, the temperature was so high that the surface was globally melted (global-scale magma ocean).

Then, the crust was formed from the far side to the near side.

In the initial stage of evolution, there existed a melted metal core which generated a large scale dipole magnetic field.

The cooling rate of the Moon's far side was slower than previously considered. Volcanic activities existed until more recently

There is a a low-viscosity layer at the core–mantle boundary, suggesting partial melting.



5. Lunar Exploration in Future

Lunar Exploration Plan Proposed by JAXA (as of 2014)

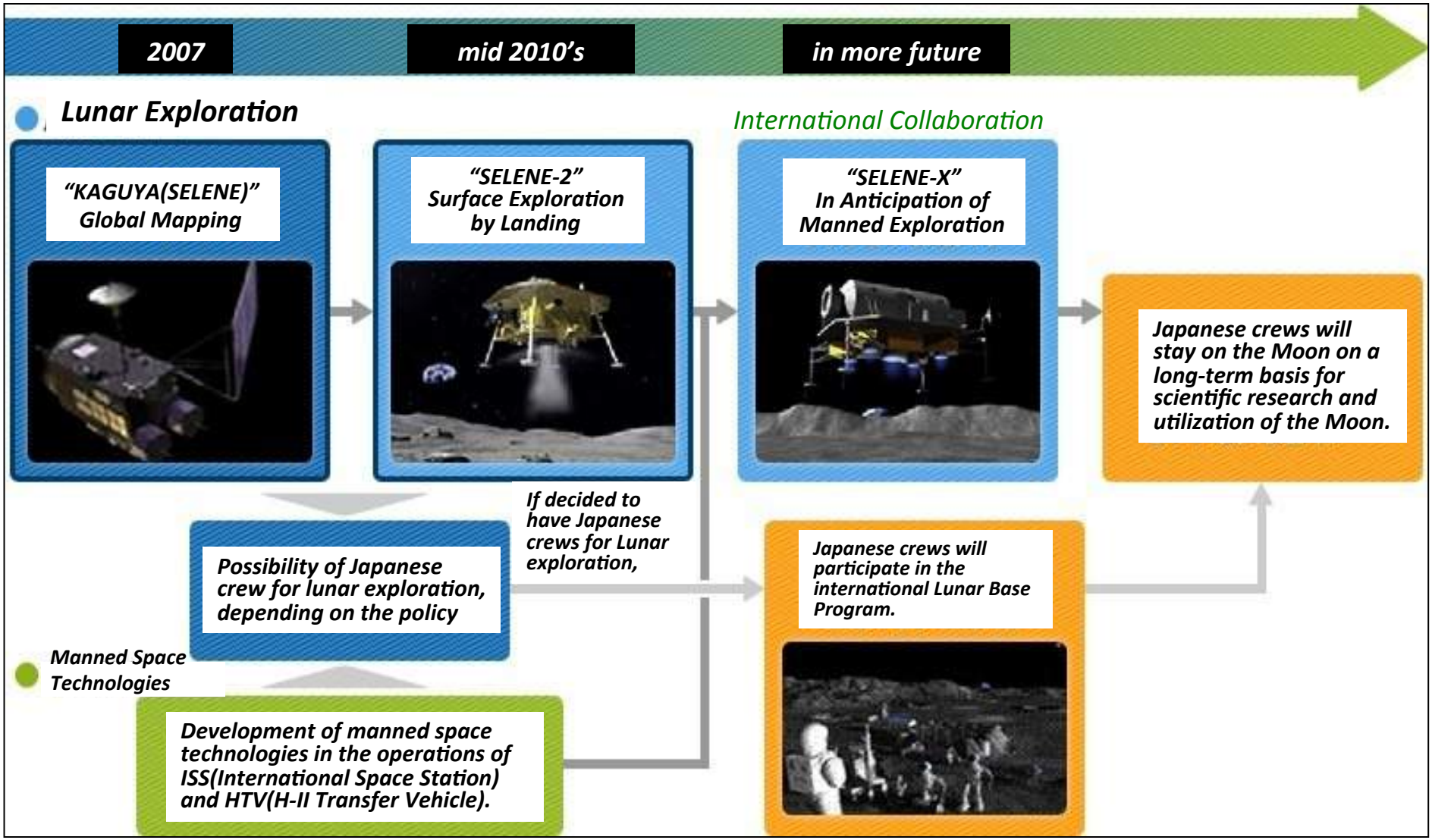
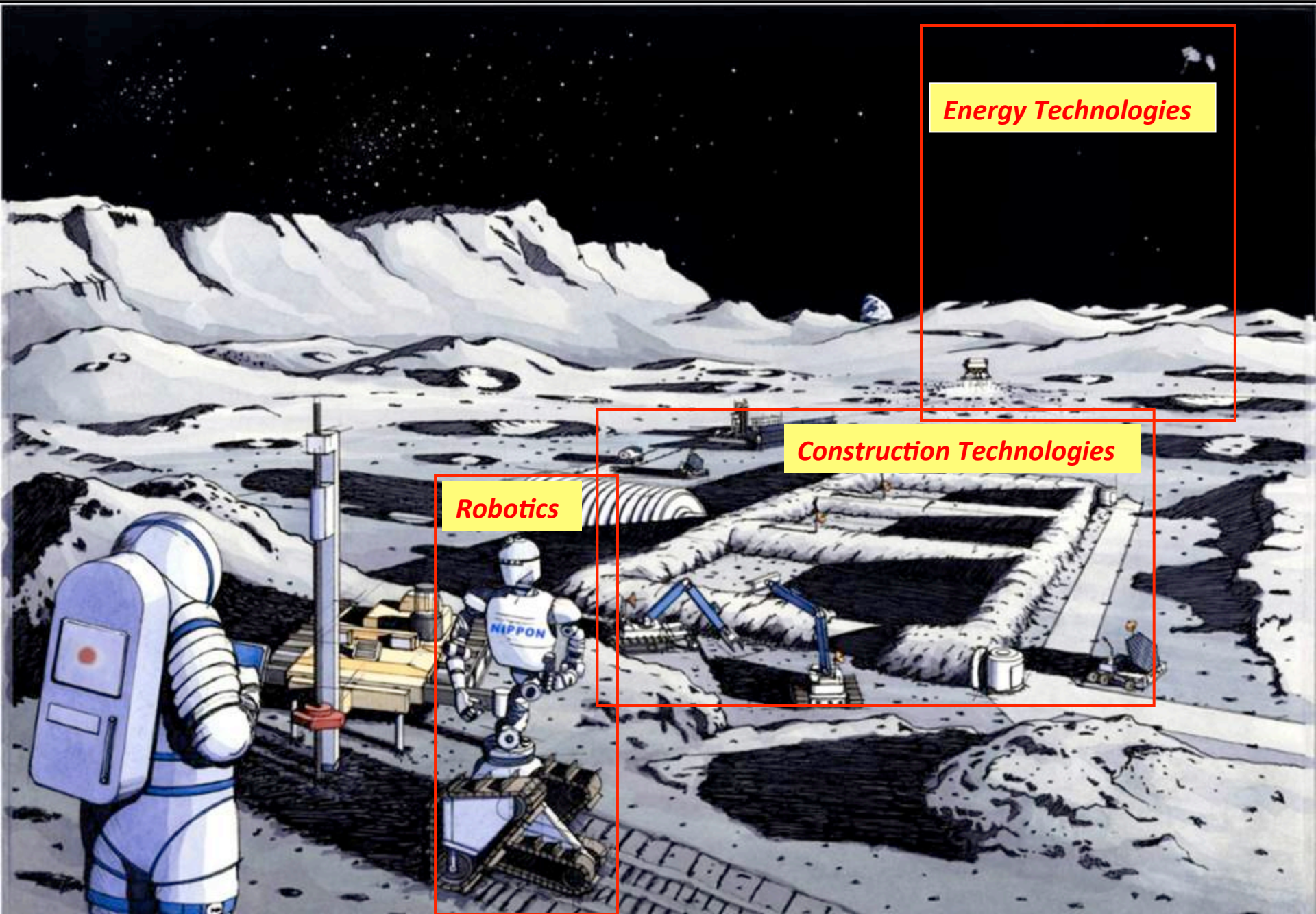


Image of Manned Lunar Base / Japanese Contribution



End of Today's Lesson

Can you understand more about the Moon ?