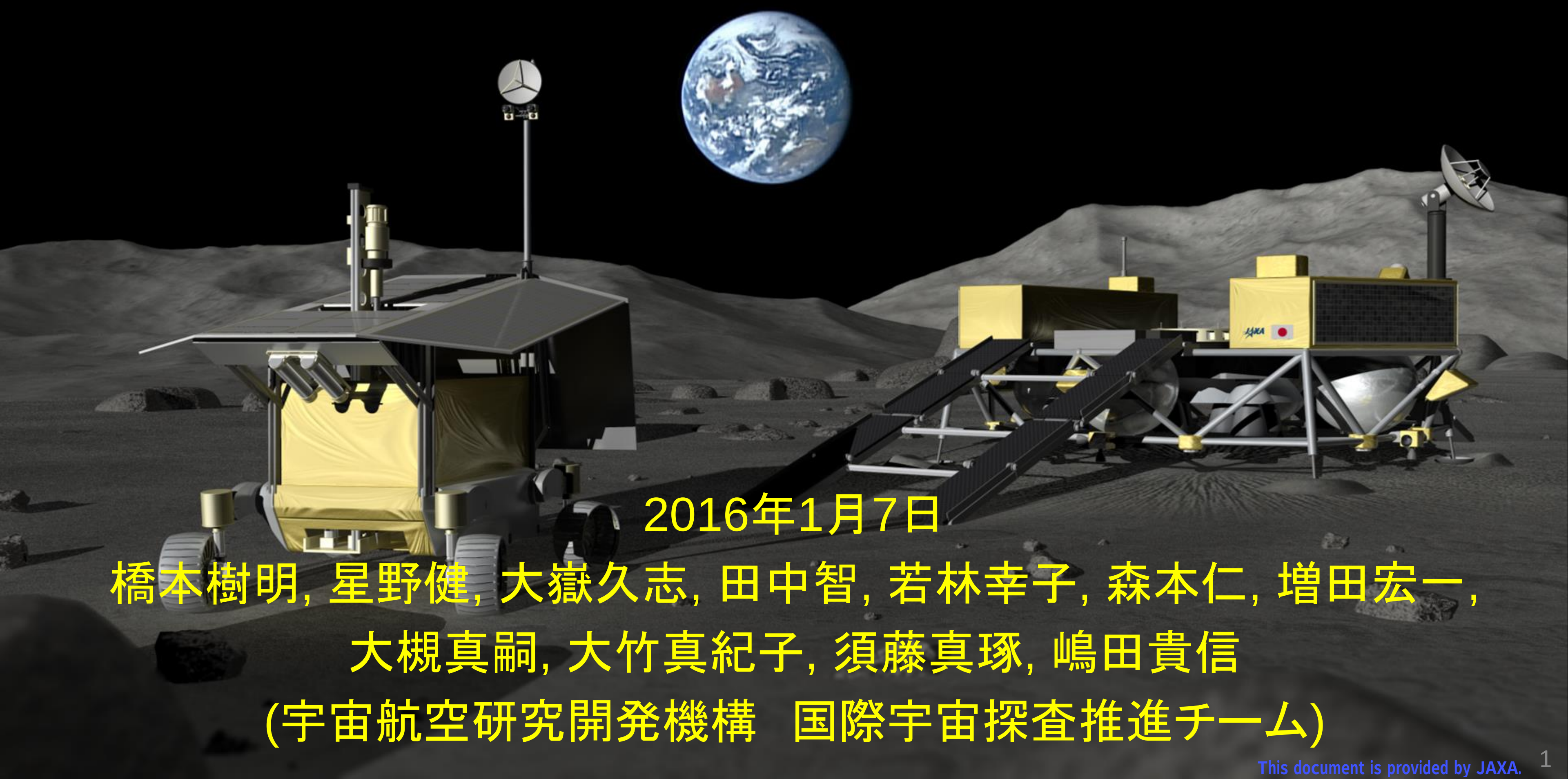
月極域探査ミッション の検討状況



2016年1月7日

橋本樹明, 星野健, 大嶽久志, 田中智, 若林幸子, 森本仁, 増田宏一,
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Study status of Lunar polar Exploration Mission

January 7 2016

Tatsuaki Hashimoto, Takeshi Hoshino , Hisashi Otake, Satoshi Tanaka
Sachiko Wakabayashi, Hitoshi Morimoto , Koich Masuda, Masatsugu Otsuki
Makiko Ohtake, Masataku Suto, Takanobu Shimada
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Contents

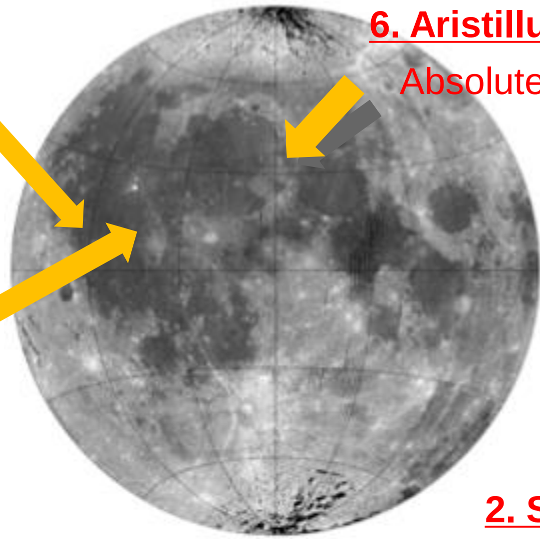
- Objectives of Moon exploration
- History of SELENE-2 study
- Study of Lunar polar exploration mission
- Spacecraft design
- Summary

Why do we go toward moon?

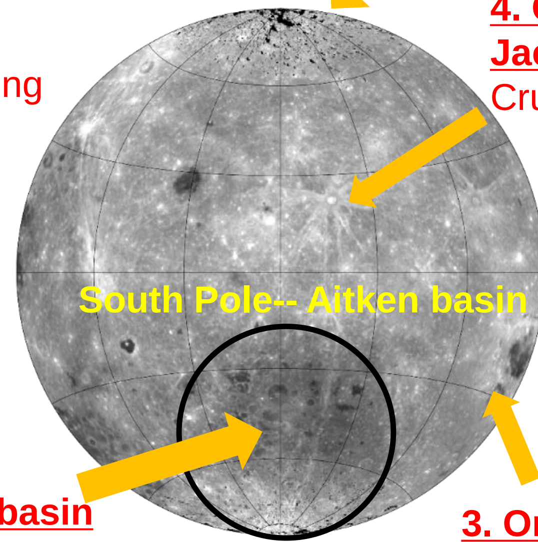
- Scientific interest and knowledge for future exploration
  - Detailed and subsurface geological observation
  - Geophysical observation to know internal structure
  - Volatile investigation
  - Moon surface environment (terrain, solar illumination, dust, radiation, soil mechanics)
- Technology demonstration
  - Safe and accurate landing
  - Surface mobility
  - Night survival
  - Return to earth (sample and return)
- Political, Outreach, Education
  - Contribute to international human moon exploration
  - HDTV, etc

Candidates of landing site

Near side



Far side



7. Skylights
Lava tube
Future moon habitat
Geology
Utilization

6. Aristillus
Absolute dating
Geology

5. Aristarchus crater
Heat source elements
Geology

1. Pole

4. Central hill of Jackson crater
Crust material
Geology

8. Far side
Low frequency radio astronomy
Utilization

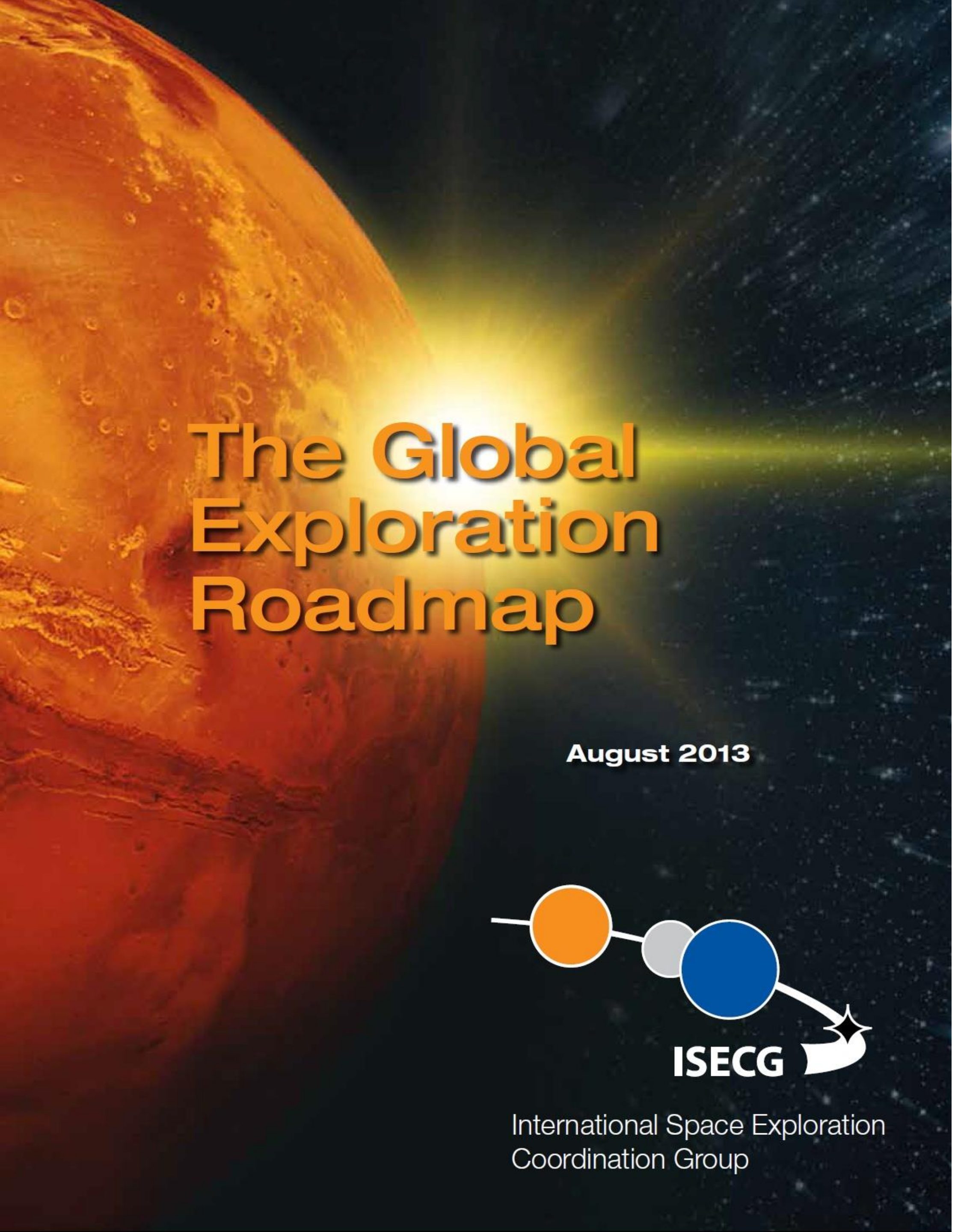
3. Orientale basin
Crust material
Geology

2. SPA basin
(Schlesinger basin, Bhabha crater, etc.)
Lower crust and Mantle material
Geology

1. Pole
Volatile including water
Human base candidate
Environment
Utilization
Geology

0. Global
Not depending on particular place
Geophysics
Environment

Geology	Suitable for Geological observation to know surface material composition. Sample and Return are required for detailed observation.
Geophysics	Suitable for Geophysical observation such as seismometer to know interior structure.
Environment	Suitable for surface environment measurement and resource investigation.
Utilization	Suitable for human base, astronomical observatory, or moon hotel.



The Global Exploration Roadmap

August 2013

ISECG

International Space Exploration Coordination Group

Italy

France

Canada

Germany

European Space Agency

India

Japan

Republic of Korea

United States

Ukraine

Russia

United Kingdom

SKG summarized by ISECG (Moon)

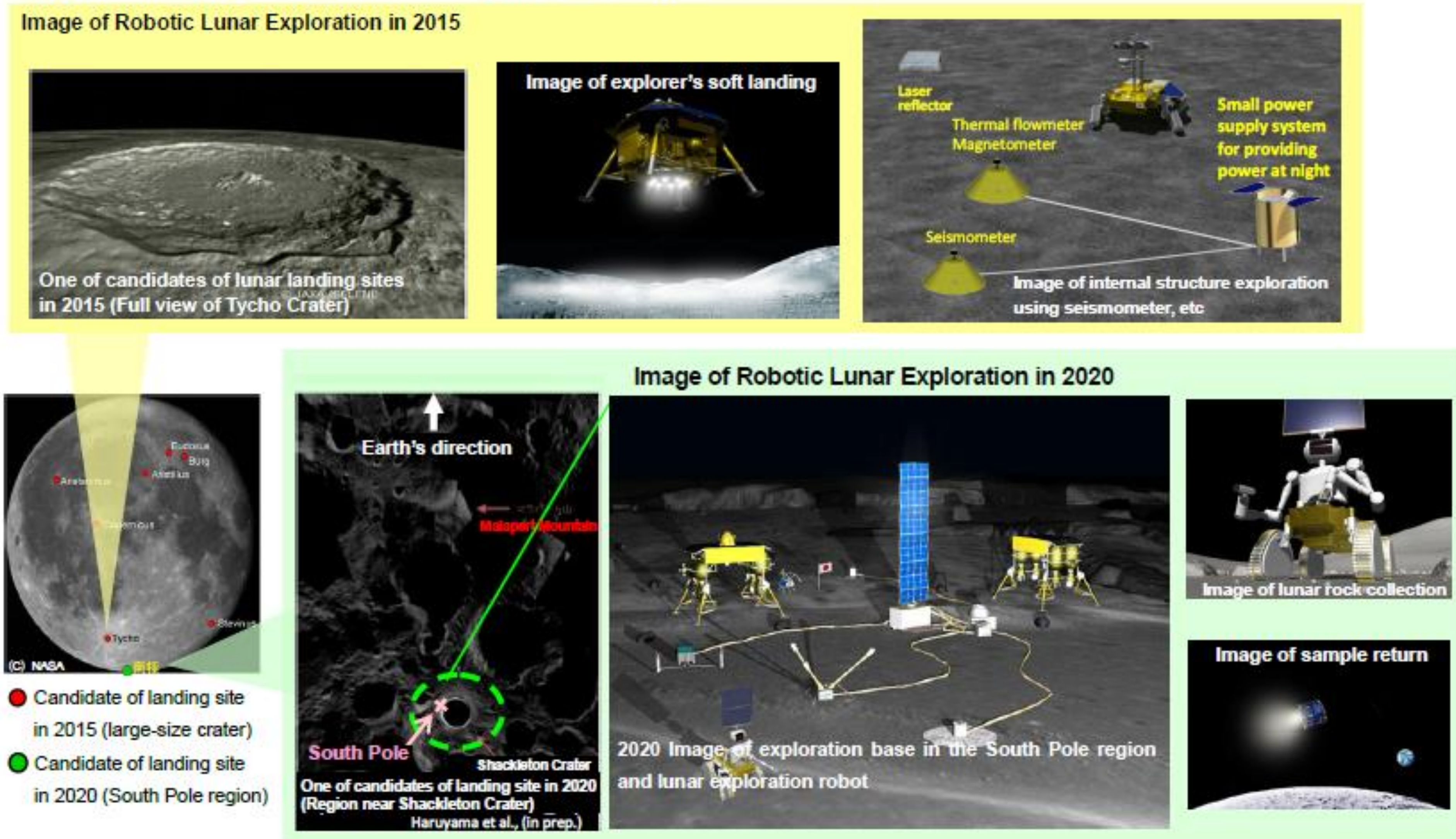
- Strategic Knowledge Gap (SKG), that is, knowledge to reduce the risk of human exploration, is summarized in Global Exploration Roadmap (GER) ver.2.

Knowledge domain	Description and Priority	Required mission or ground activity
Resource potential	Solar illumination mapping	Already enough data
	Regolith volatiles from Apollo samples	Ground activity
	Regolith volatiles an organics in mare and highlands.	Robotic mission, Sample return
	Lunar cold trap volatiles (water, etc.) distributed within permanently shadowed area.	Robotic mission, Sample return
	Resource prospecting in pyroclastic, dark mantle deposits, etc.	Robotic mission, Sample return
Environment and effects	Radiation at the lunar surface	Robotic mission
	Toxicity of lunar dust	Robotic mission, Sample return, Ground activity
	Micrometeoroid environment	Robotic mission
Live and work on lunar surface	Geodetic Grid and Navigation	Already enough data
	Surface Trafficability	Robotic mission, Ground activity
	Dust & Blast Ejecta:	Robotic mission, Ground activity
	Plasma Environment & Charging	Robotic mission
	Lunar Mass Concentrations and Distributions	Already enough data

History of mission study (1/3)

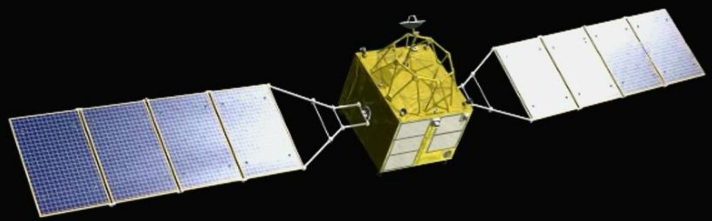
- JAXA has been studying a moon landing mission “SELENE-2” since 2007. The mission objectives of SELENE-2 were lunar science (Geology, Geophysics, and surface environment measurement) and technology demonstration (precise landing, surface mobility, and night survival) for planetary surface exploration. Therefore, landing site candidates of SELENE-2 were in low or middle latitude of the moon.
- One-year study of Japanese lunar exploration strategy at government started in August, 2009. The final report was issued in June 2010. The report says that the first lander is to be launched in 2015, though it also says that the timing of implementation should be considered responding to budgeting status.

Supplemental Figure 1 Image of Robotic Lunar Exploration



(Image materials: courtesy of JAXA)

Candidate payloads on SELENE-2



Instrument candidates on Orbiter

- Electro-magnetic Sounder : LEMS
- Radio source for VLBI : VLBI
- Lunar dust monitor : LDM
- Low frequency radio astronomy : LLFAST
- Radiation monitor : PRMD-Ⅲ
- High definition TV : HDTV

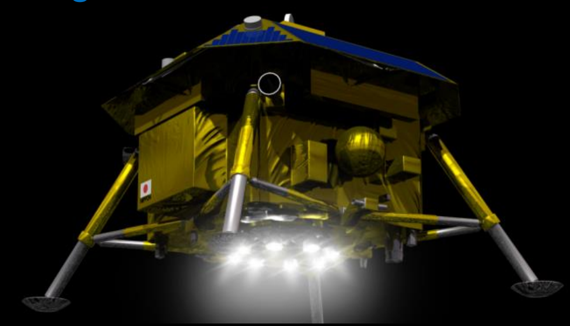
Instrument candidates on Rover

- Multi-band camera : LMUCS
- Macro spectral camera : LUMI
- Science integrated package : R-SIP
- Gamma-ray and neutron spectrometer : GNS
- Active X-ray spectrometer : AXS
- Laser-induced breakdown spectrometer : LIBS
- High definition TV : HDTV

Instrument candidates on Lander

- Observation onboard lander -

- Multi-band panoramic camera : ALIS
- High definition TV : HDTV



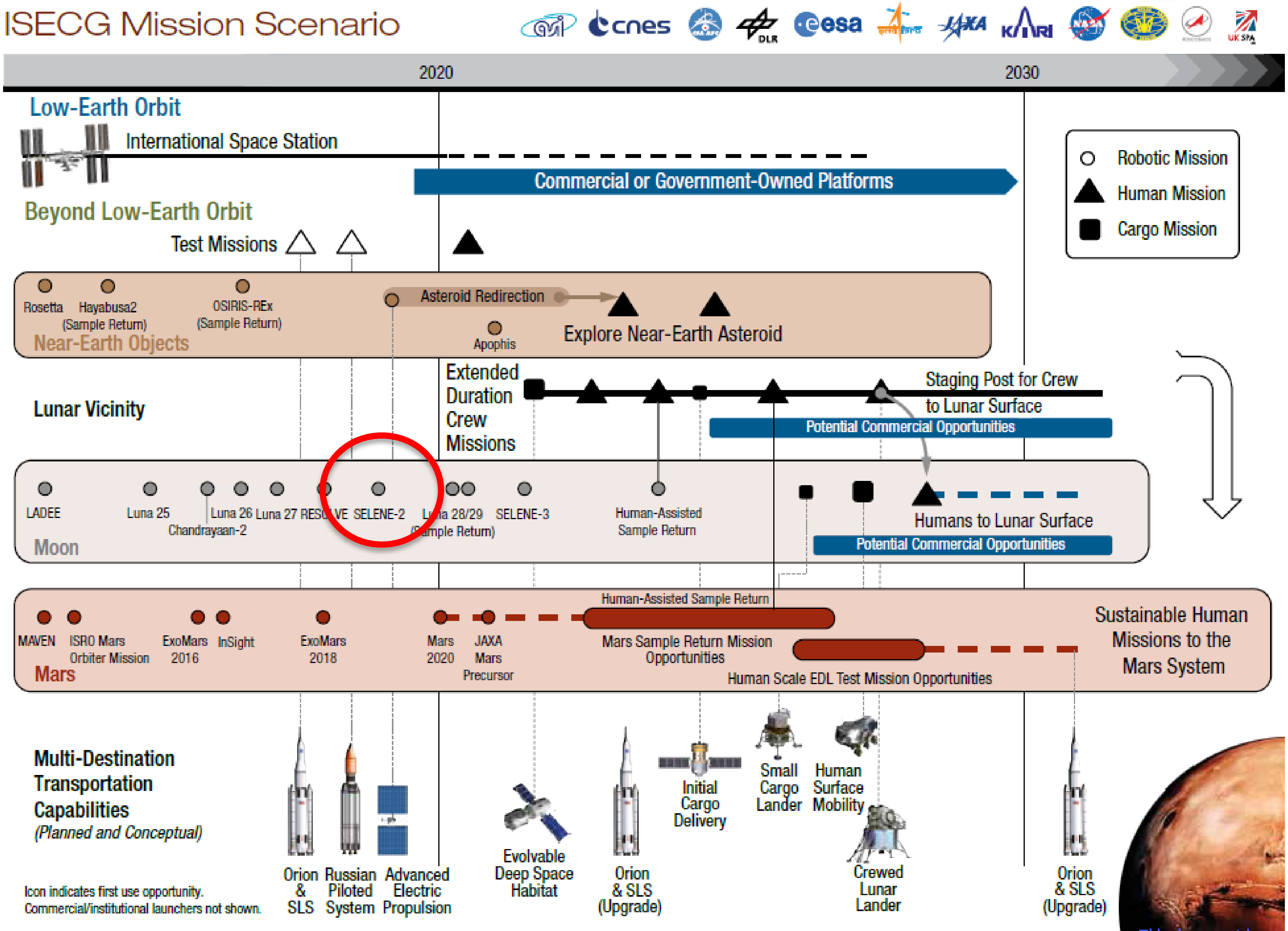
- Observation on lunar surface -

- Broadband seismometer : LBBS
- Heat flow probe : HFP
- Electro-magnetic sounder : LEMS
- Radio source for VLBI : VLBI
- Laser reflector for lunar ranging : LLR
- Soil mechanics measurement : LSM

Why do we go toward moon?

- Scientific interest and knowledge for future exploration
  - Detailed and subsurface geological observation
  - Geophysical observation to know internal structure
  - Volatile investigation
  - Moon surface environment (terrain, solar illumination, dust, radiation, soil mechanics)
- Technology demonstration
  - Safe and accurate landing
  - Surface mobility
  - Night survival
  - Return to earth (sample and return)
- Political, Outreach, Education
  - Contribute to international human moon exploration
  - HDTV, etc

Global Exploration Roadmap 2



History of mission study (2/3)

- Recently, Cis-lunar and moon surface exploration are considered in the world. JAXA started to think about the importance of lunar volatile investigation in order to think about exploration strategy. Polar region became a landing site candidate of high priority.
- In fact, depending on water ice existence, exploration architecture of human Moon mission and human Mars mission will be changed.

SKG summarized by ISECG (Moon)

(*) This column is added by JAXA

Knowledge domain	Description and Priority	Required mission or ground activity	Japanese mission (*)
Resource potential	Solar illumination mapping	Already enough data	Kaguya (SELENE)
	Regolith volatiles from Apollo samples	Ground activity	NA
	Regolith volatiles an organics in mare and highlands.	Robotic mission, Sample return	SELENE/RP
	Lunar cold trap volatiles (water, etc.) distributed within permanently shadowed area.	Robotic mission, Sample return	SELENE/RP
	Resource prospecting in pyroclastic, dark mantle deposits, etc.	Robotic mission, Sample return	Future mission
Environment and effects	Radiation at the lunar surface	Robotic mission	SELENE/RP
	Toxicity of lunar dust	Robotic mission, Sample return, Ground activity	Future mission
	Micrometeoroid environment	Robotic mission	Future mission
Live and work on lunar surface	Geodetic Grid and Navigation	Already enough data	Kaguya (SELENE)
	Surface Trafficability	Robotic mission, Ground activity	SELENE/RP
	Dust & Blast Ejecta:	Robotic mission, Ground activity	SELENE/RP
	Plasma Environment & Charging	Robotic mission	Future mission
	Lunar Mass Concentrations and Distributions	Already enough data	Kaguya (SELENE)

Collaboration with NASA RP

- NASA RP (Resource Prospector) mission plans to find water ice on the moon surface and mine it. RP investigates volatiles such as hydrogen, oxygen and water.
- JAXA started the feasibility study of the collaboration with RP since 2013. The joint study between JAXA and NASA has been continuing under Letter of Agreement.
- The SELENE-2 team started the conceptual study to adapt the spacecraft configuration to the RP requirements.
- JAXA is currently one of candidate organizations to provide a lander to RP mission. NASA also thinks about collaborations with other international partners and industries.

SELENE/RP collaboration Mission

- Spacecraft mass : 5000 kg (Wet)
- Surface payload: 340 kg
- Launch target : 2020 (TBD)

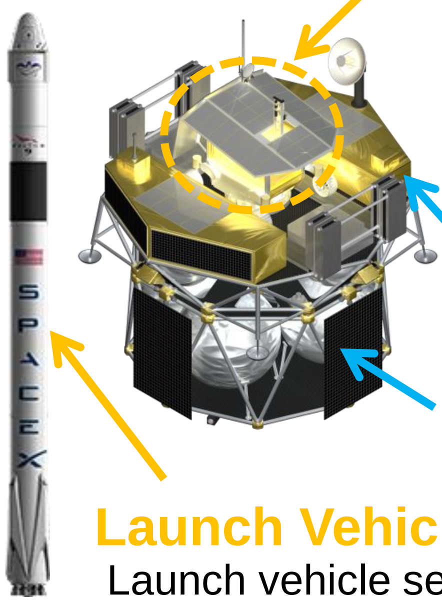
Rover (NASA)

- Near Infrared Spectrometer
- Neutron Spectrometer
- Oxygen & Volatile Extraction Node
- Lunar Advanced Volatile Analysis
- Isotope Measurement of Volatile

Volatile observation in Polar region

- Radiation monitor
- Seismometer
- Heat flow measurement
- Spectro-microscope camera
- Active X-ray spectrometer

Other instruments candidates



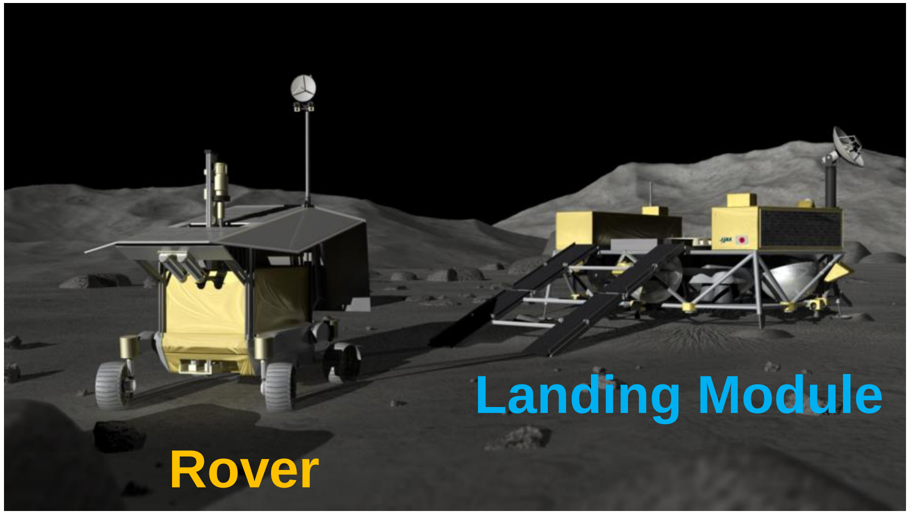
Landing Module (JAXA)

Propulsion Module (JAXA)

Launch Vehicle (NASA)

Launch vehicle selection depends on the payloads.

Launch configuration



Lunar surface configuration

Interest on (South) Pole

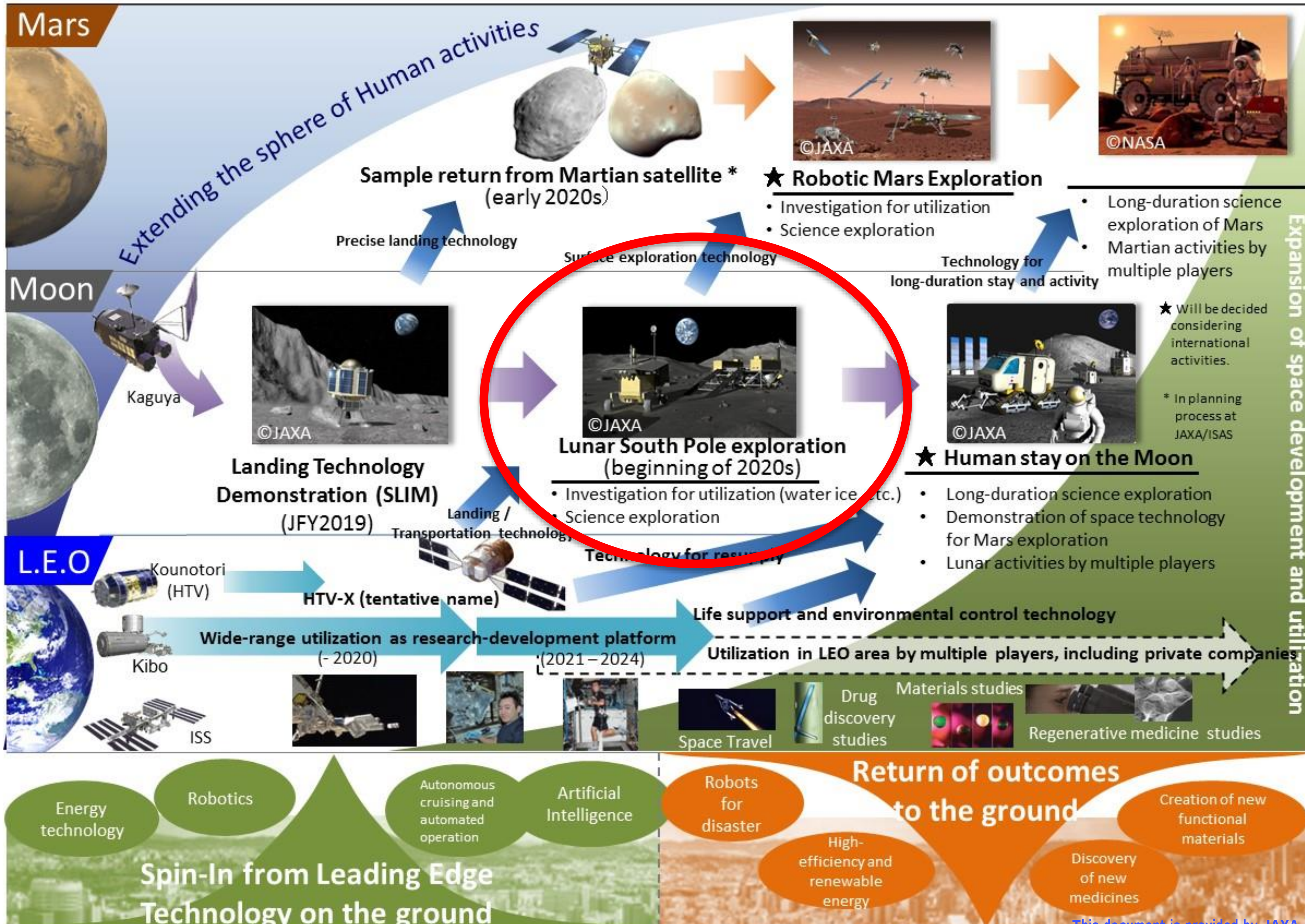
- Scientific interest and knowledge for future exploration
  - Geology : Ejecta from SPA basin
  - Geophysics : Long-term sunshine (solar energy)
  - Volatile : Permanent shadow or low temperature region
  - Environment (terrain, solar illumination, dust, radiation, soil mechanics)
- Technology demonstration
  - Safe and accurate landing to very limited area
  - Surface mobility for volatile exploration
  - Night survival for large-scale observation base
  - Sample and return of volatile, etc
- Political, Outreach, Education
  - Candidate site of the international moon outpost
  - Fantastic movie from polar region

History of mission study (3/3)

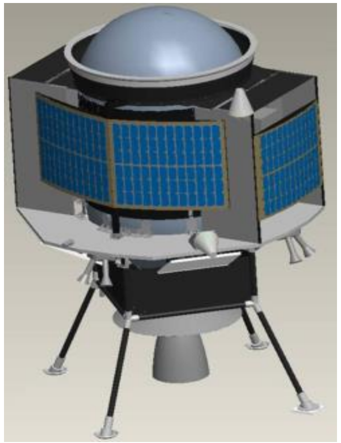
- In 2011, we had a large earthquake. The budget of the government was limited.
- SLIM was selected as a candidate of the next small scientific spacecraft. It can demonstrate precise and safe landing technology.
- We have been waiting for budget approval for seven years, but finally we had to give up our original mission concepts. Phase-A study of SELENE-2 has canceled in March, 2015.
- We started Phase-0 study of SELENE/RP collaboration mission. A lunar polar lander was shown in the second Report of MEXT's ISS-Space Exploration Sub-Committee.

Japan's approaches to international space exploration

(Second Report of MEXT's ISS-Space Exploration Sub-Committee/ English translation by JAXA)



SLIM(Smart Lander for Investigation Moon)



- SLIM is a mission to demonstrate the technology for pin-point soft landing on lunar or planetary surface.
- Planned to be launched in Fy 2019.

- Technology demonstration with Small Spacecraft:

（Landing on the point where we want to explore!)

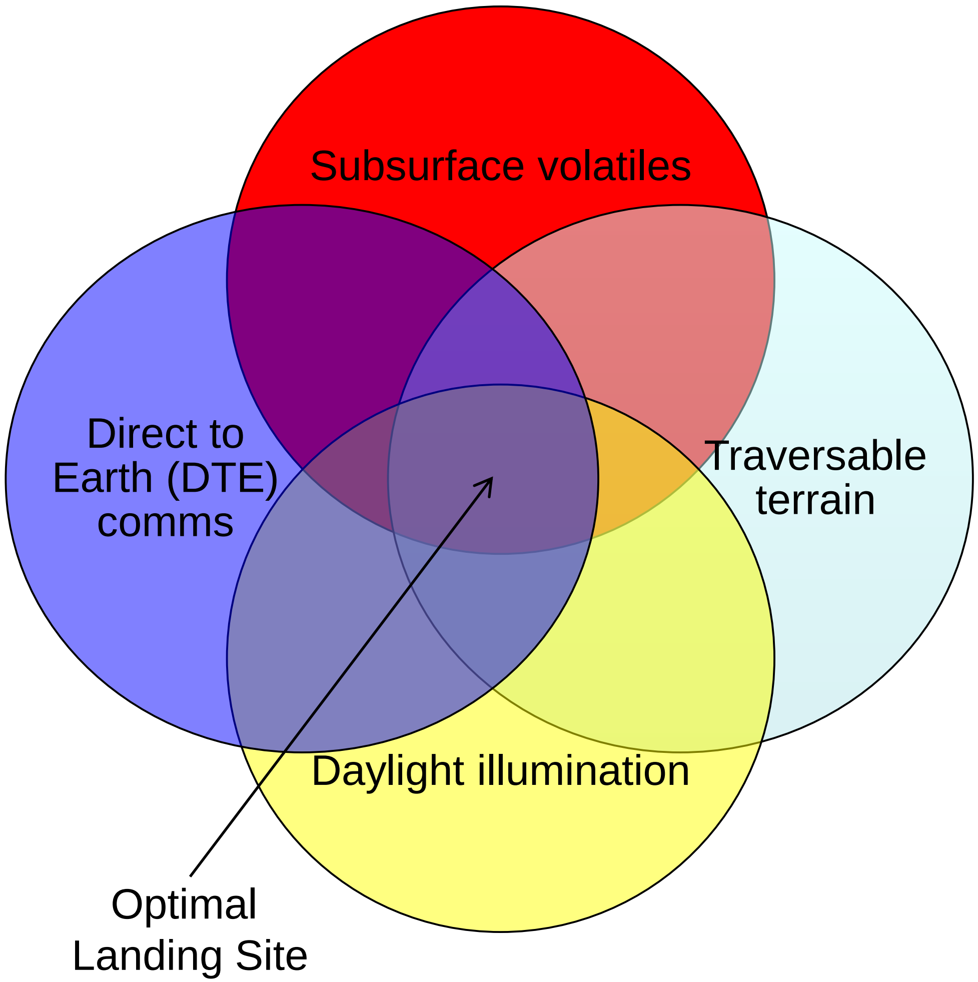
  - Image-based Navigation utilizing Lunar Terrain
  - Autonomous Obstacle Detection
  - Robust Pin-point Guidance
  - Landing Shock Absorber
  - High-performance Propulsion
  - Exploration using Tiny Rovers (option)
- Enable frequent trials of lunar/planetary surface exploration technology
- Precursor of future full-scale lunar or planetary missions

Why do we go toward moon?

- Scientific interest and knowledge for future exploration
  - Detailed and subsurface geological observation
  - Geophysical observation to know internal structure
  - Volatile investigation
  - Moon surface environment (terrain, solar illumination, dust, radiation, soil mechanics)
- Technology demonstration
  - Safe and accurate landing
  - Surface mobility / Deployment of surface instruments
  - Night survival
  - Return to earth (sample and return)
- Political, Outreach, Education
  - Contribute to international human moon exploration
  - HDTV, etc

Site Selection Criteria

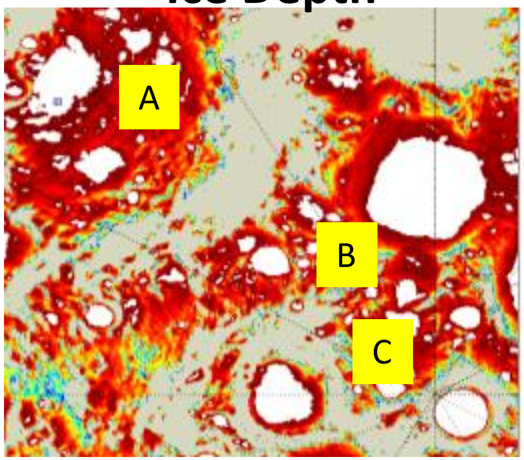
- Likely subsurface volatiles
  - Sustained low subsurface temperatures conducive to volatile retention
  - Orbital neutron spectrometer hydrogen signature
- Sufficient daylight illumination
  - More than 4 Earth days of solar power for rover operations
  - Clement surface temperature for rover survival
- Suitable for Direct to Earth (DTE) communication
  - DSN stations clear the horizon
- Traversable terrain
  - Slopes < 10 deg
  - Limited density of rocks



Landing site candidates for RESOLVE

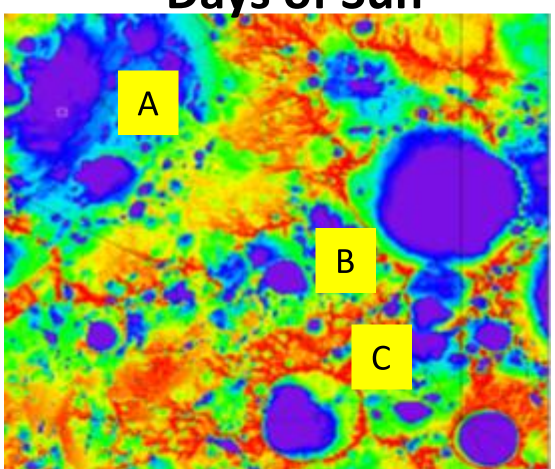
Combined Site Analysis

Ice Depth

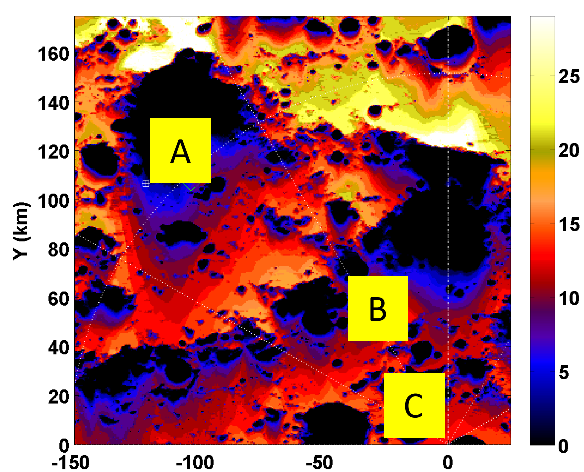


Site:	A	B	C
Shallow “Frost Line”	<0.1 m	<0.2 m	<0.1 m
Slopes	<10°	<15°	<10°
Neutron Depletion	4.5 cps	4.7 cps	4.9 cps
Temporary Sun*	4 days	2-4 days	5-7 d
Comm Line of Sight*	8 days	17 days	17 days
* may not coincide			

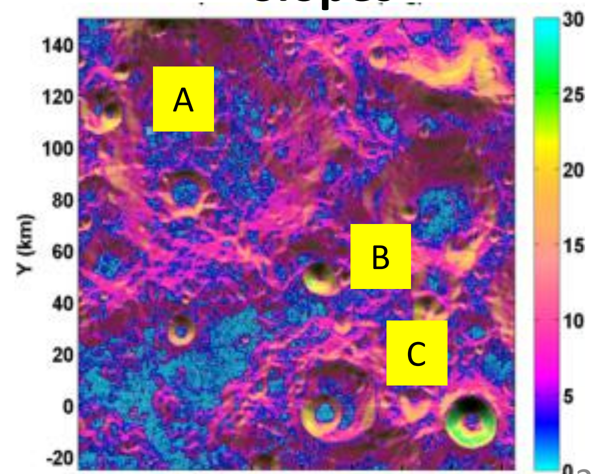
Days of Sun



DTE comm.



Slopes

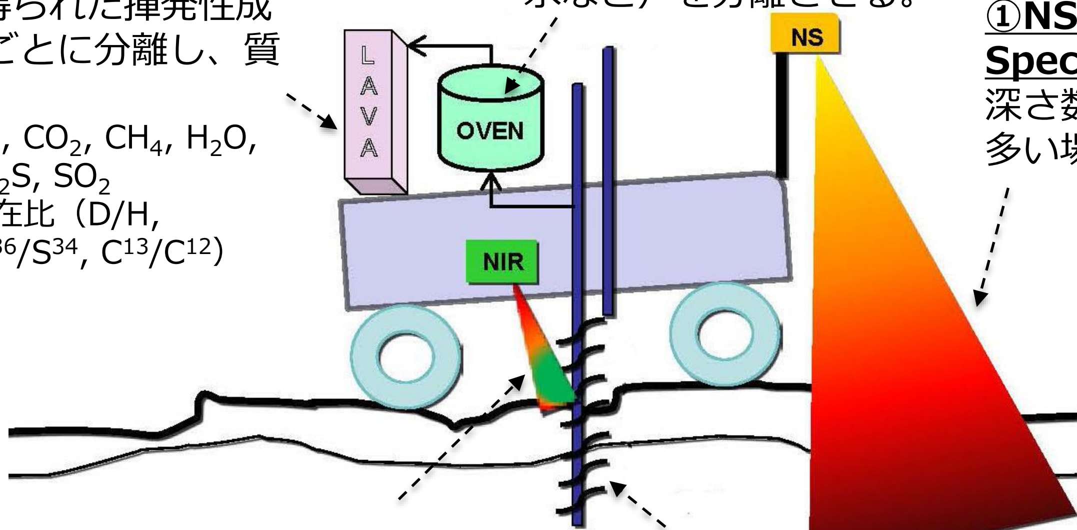


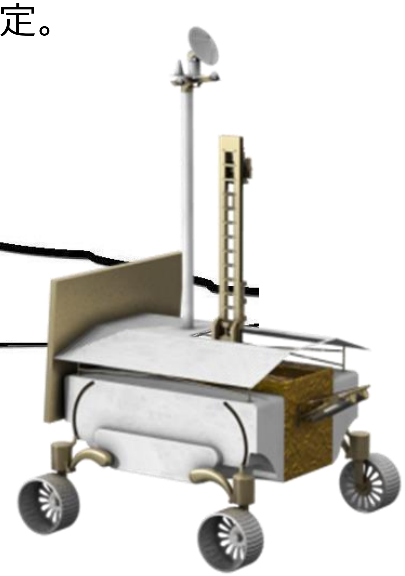
Volatile exploration

⑤LAVA（Lunar Advanced Volatile Analysis）により、OVENで得られた揮発性成分を分子量ごとに分離し、質量を測定。
- H_2, He, CO, CO_2, CH_4, H_2O, N_2, NH_3, H_2S, SO_2
- 同位体の存在比（D/H, O^{18}/O^{16}, S^{36}/S^{34}, C^{13}/C^{12}）

④Oven（Oxygen & Volatile Extraction Node）により、ドリルで掘り起こされたレゴリスを150～900℃に加熱して揮発性成分（水氷など）を分離させる。

①NS（Neutron Spectrometer）により、深さ数十cmの範囲で水氷が多い場所を推定。

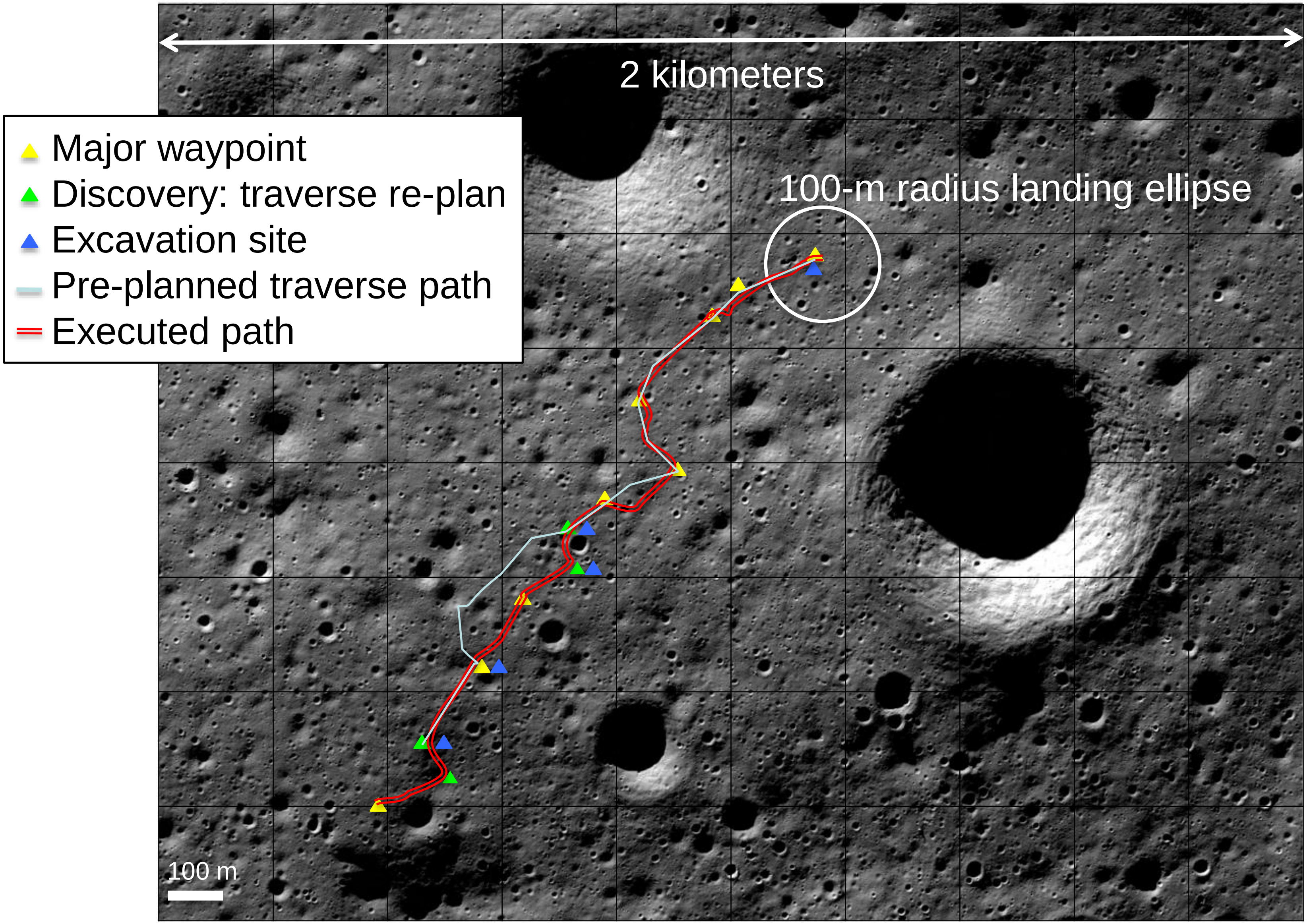




③NIR（Near Infrared Spectrometer）により、ドリルで掘り起こされたレゴリス中の水氷量の深さによる変化を測定。

②Drillにより、水氷が多いと推定される場所を深さ1mまで掘削。

RESOLVE Mission Options – Notional Traverse



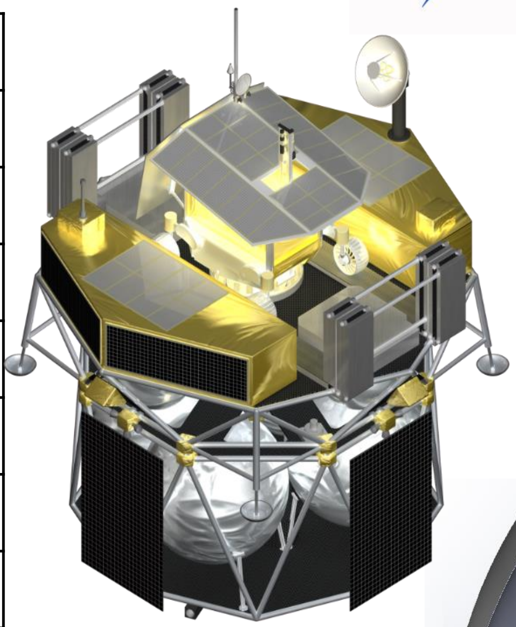
Requirements from RP

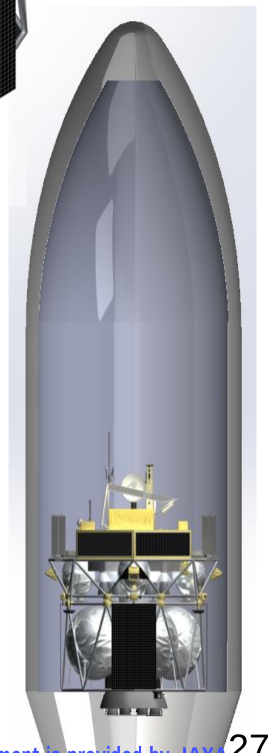
- The lander shall land on the lunar surface within a 100 meter radius of the pre-launch selected target location.
- The lander shall be capable of landing on slopes up to 15 degrees relative to lunar gravity.
- The lander shall carry the rover (about 300 kg) to the lunar surface and have rover egress mechanism such as a ramp.
- The lander shall be designed to withstand the shock and vibration environment and radiation environment.
- The lander shall provide electrical power and a communication antenna to the Rover and onboard instruments.
- The spacecraft shall have a total mass of no grater than 5,000 kg (in case of GTO launch)

Spacecraft configuration (tentative)

Propulsion Module	Bus system	478
	Fuel	2136
	Total	2614
Lander	Bus system	807
	Rover and instruments	309
	Option instruments	40
	Fuel	1229
	Total	2386
Total		5000

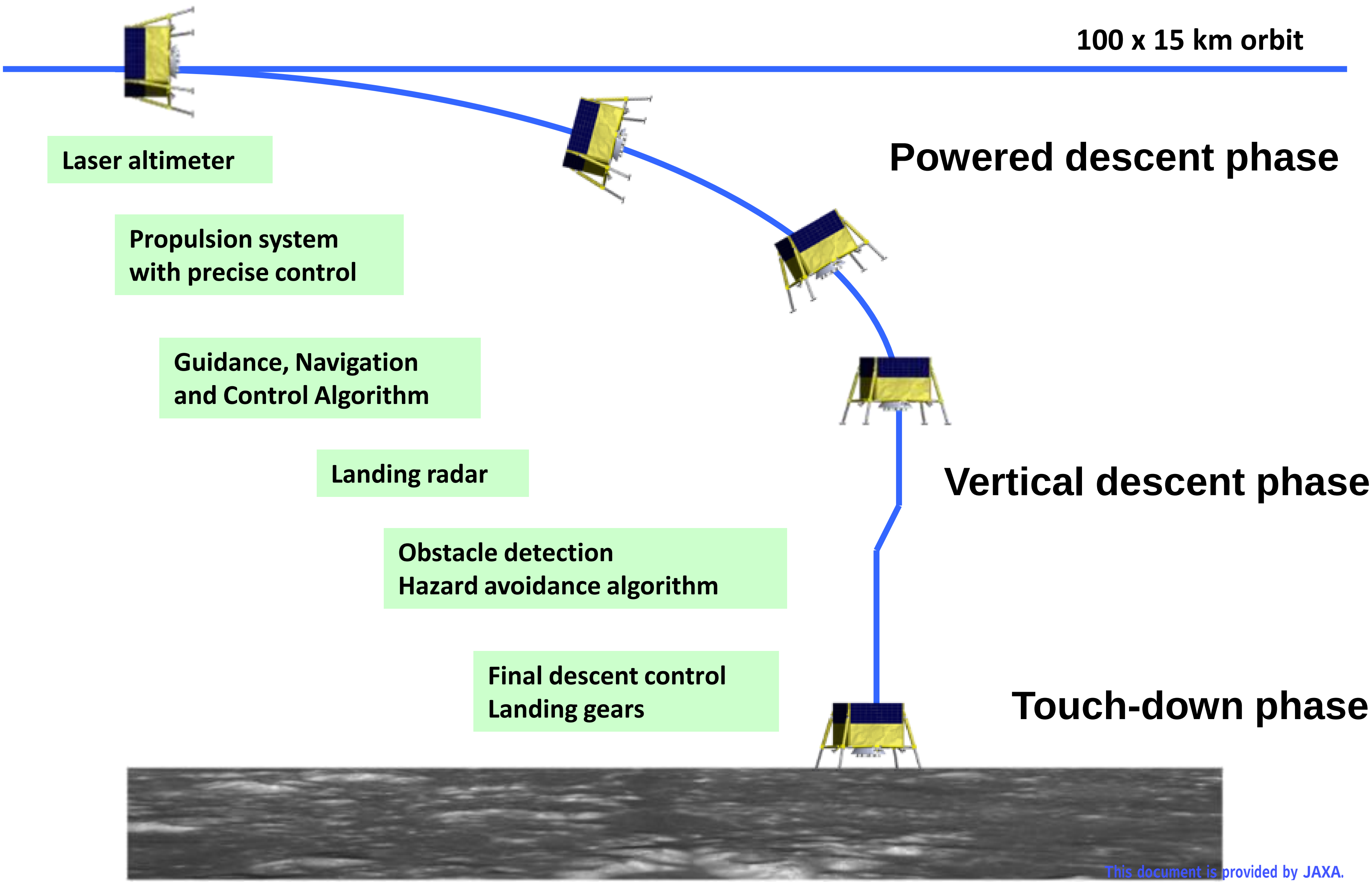
Unit : kg





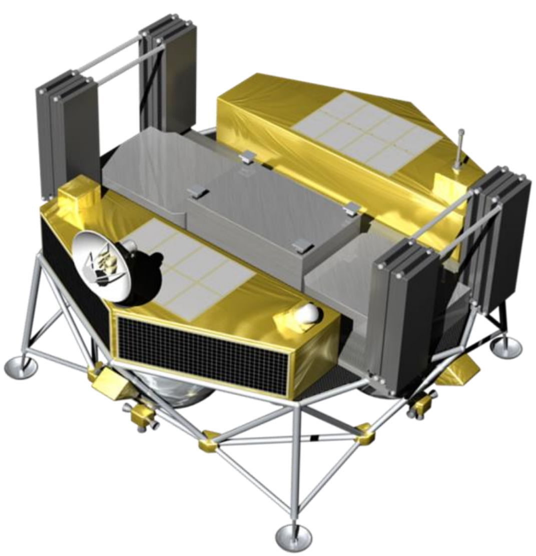
Compatible with Falcon 9 ver. 1.1

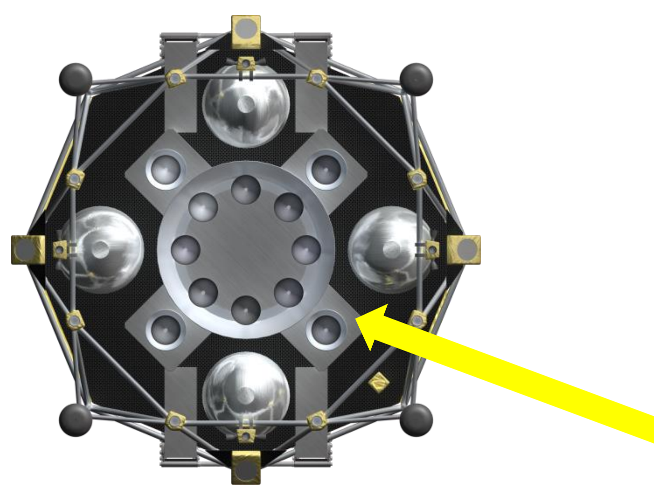
Landing technology



Propulsion system

- Large and accurate-controlled thrusters are required for the propulsion system of the lander.
- 12 of flight-proven 500 N thrusters are used for descent.
- Bipropellant (MON3, N2H4), Isp = 325 sec.
- Pulse firing tests are being conducted.



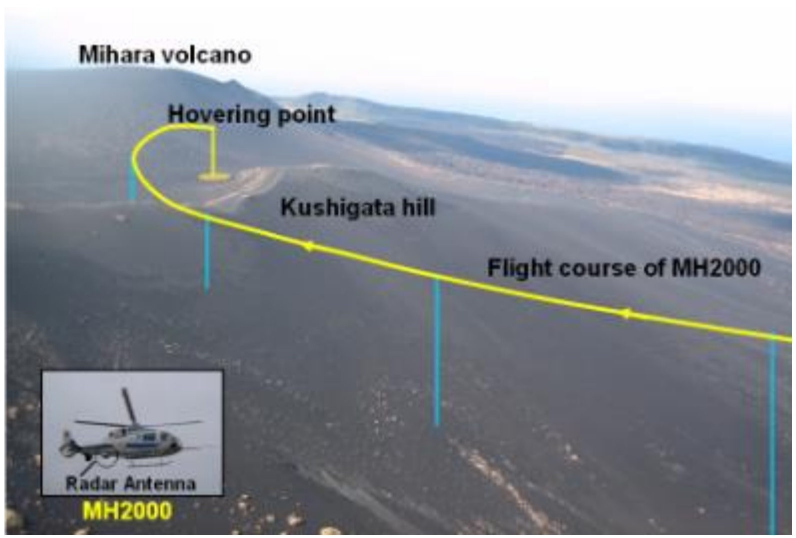


Laser altimeter and Landing Rader

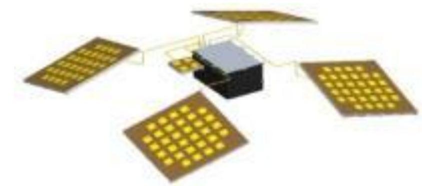
- For vertical descent phase of landing, precise speed and altitude measurements are required.
- JAXA has the heritage of laser altimeters.
  - LALT on Kaguya : 50km～150km
  - LIDAR on Hayabusa: 50m ～50km
- JAXA has been developing a landing radar with one beam altimeter and four beams of speed meter.
  - Altitude: 10m-3.5km (precision: 0.3m or 5%)
  - Velocity: 0～50m/s (precision: 0.3m/s or 5%)
- Landing Rader will be tested by SLIM project.

KAGUYA LALT

HAYABUSA LIDAR



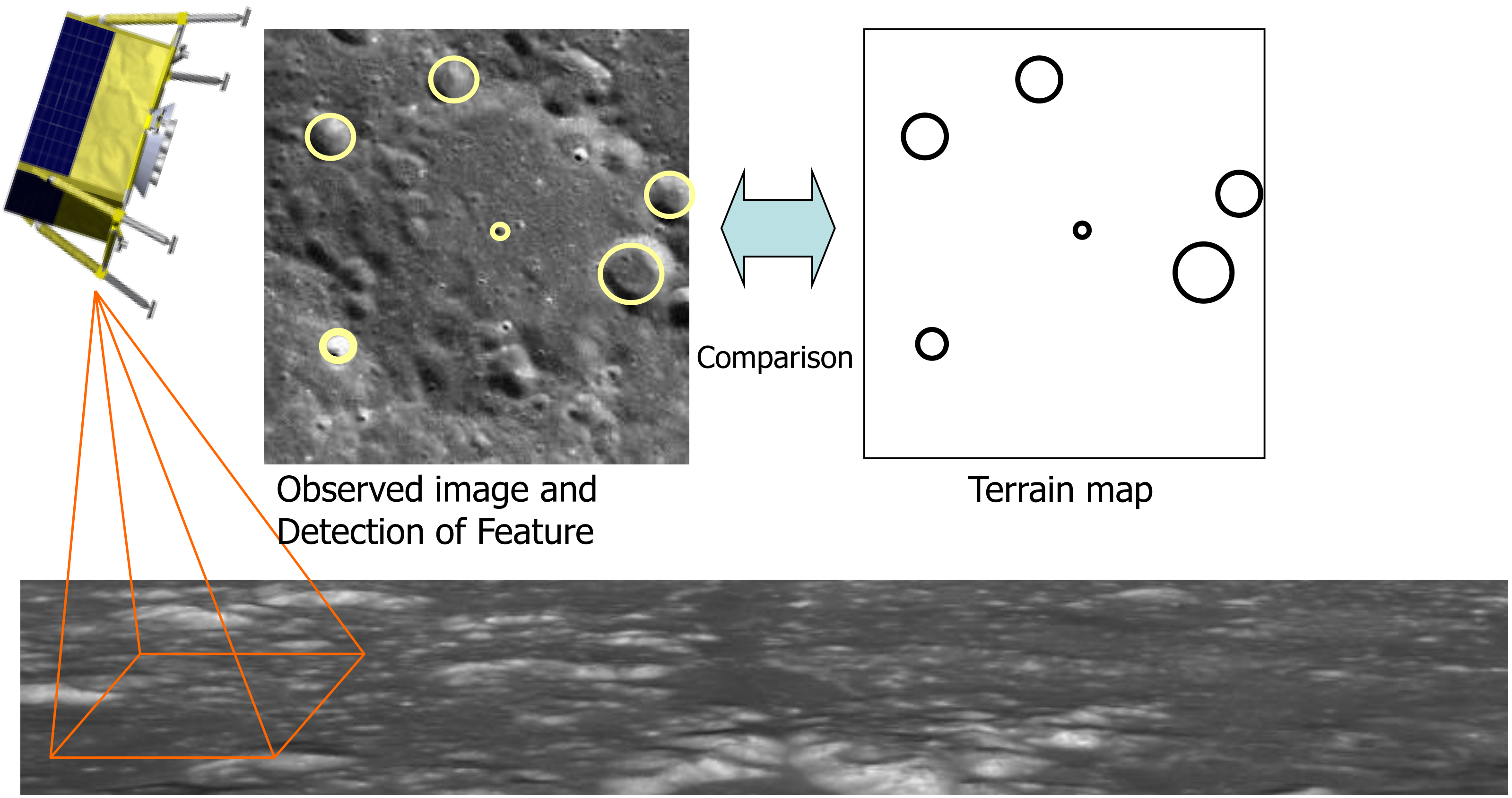
Field tests of landing radar using helicopter



Type	Pulse Doppler Radar 4 beams for velocity 1 beam for altitude
Altitude	10m～3.5km
Velocity	10m～3.0km 0～50m/s

Landmark optical navigation

- Landmark navigation is planed to be used for accurate pin-point landing.
- The navigation algorithm is now under study. Similar ground-based method was demonstrated while Hayabusa landing navigation.
- The landmark navigation will be tested by SLIM project.



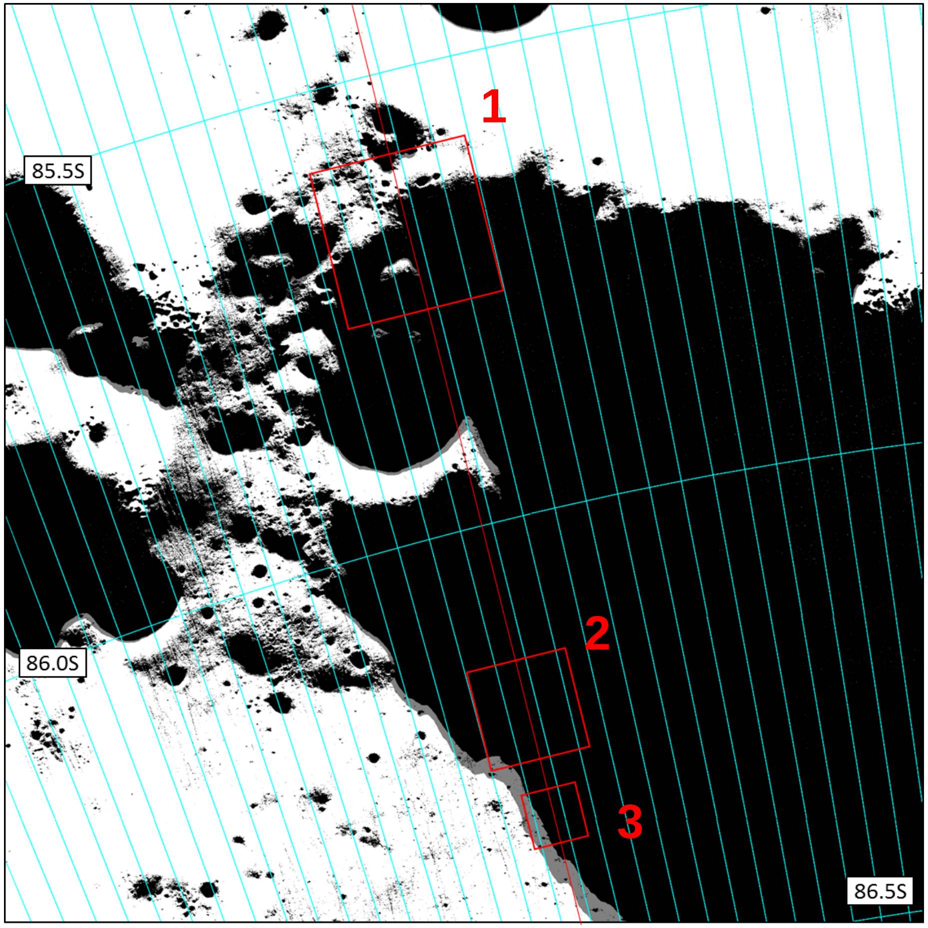
Simulated images for the landmark navigation

Landing to North Haworth (86.33S, 14.19W)

2020/04/08 00:00:00

Optical landmark Nav. timing (TBD)

0. Start powered descent (15 km)
1. Waypoint (9.8 km)
2. Waypoint (5.9 km)
3. End powered descent (3.5 km)

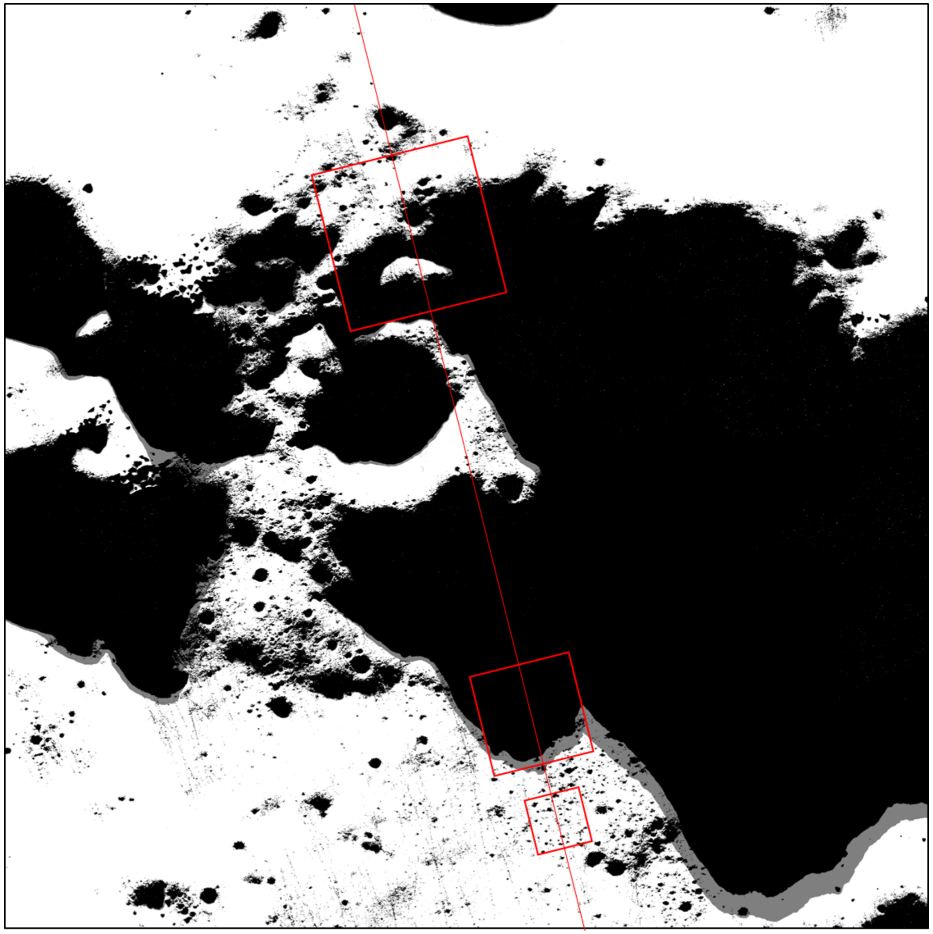


Landing site is dark.

Simulated images for the landmark navigation

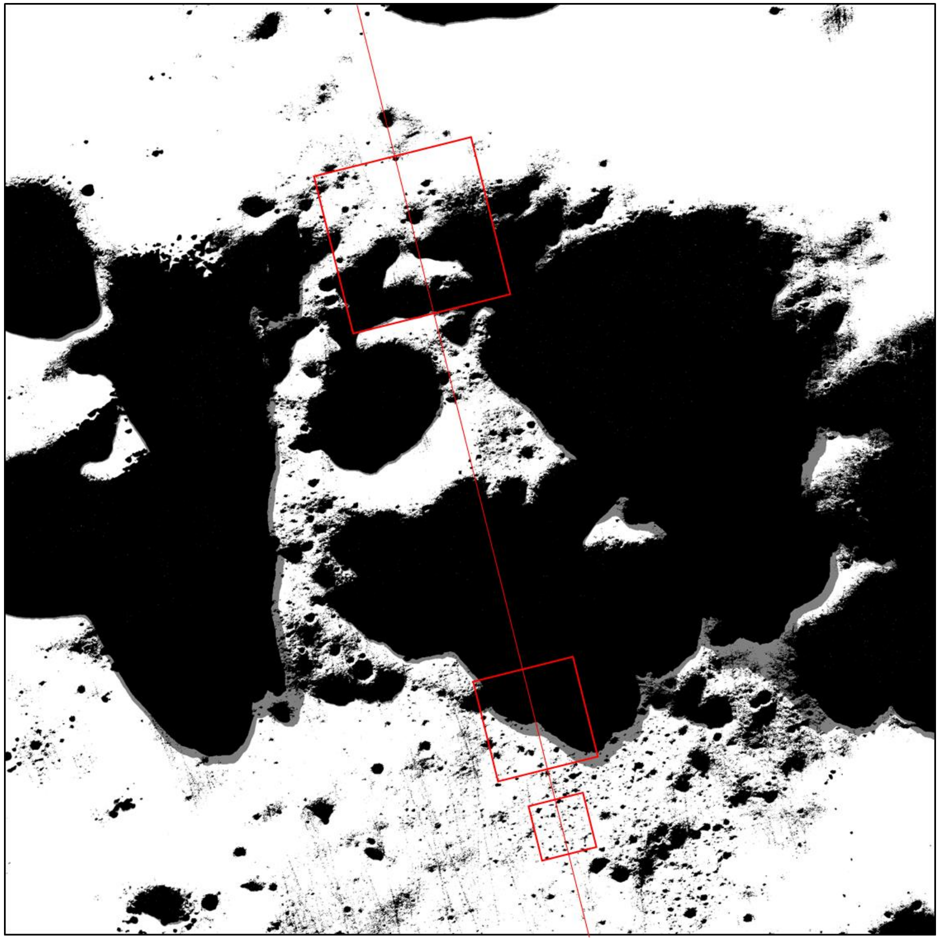
Landing to North Haworth (86.33S, 14.19W)

2020/04/09 00:00:00



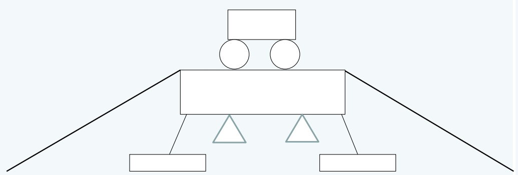
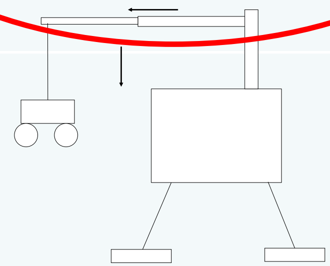
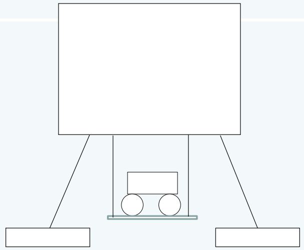
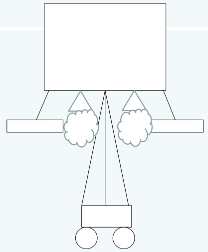
Landing site is sunlit but optical nav. is difficult.

2020/04/10 00:00:00

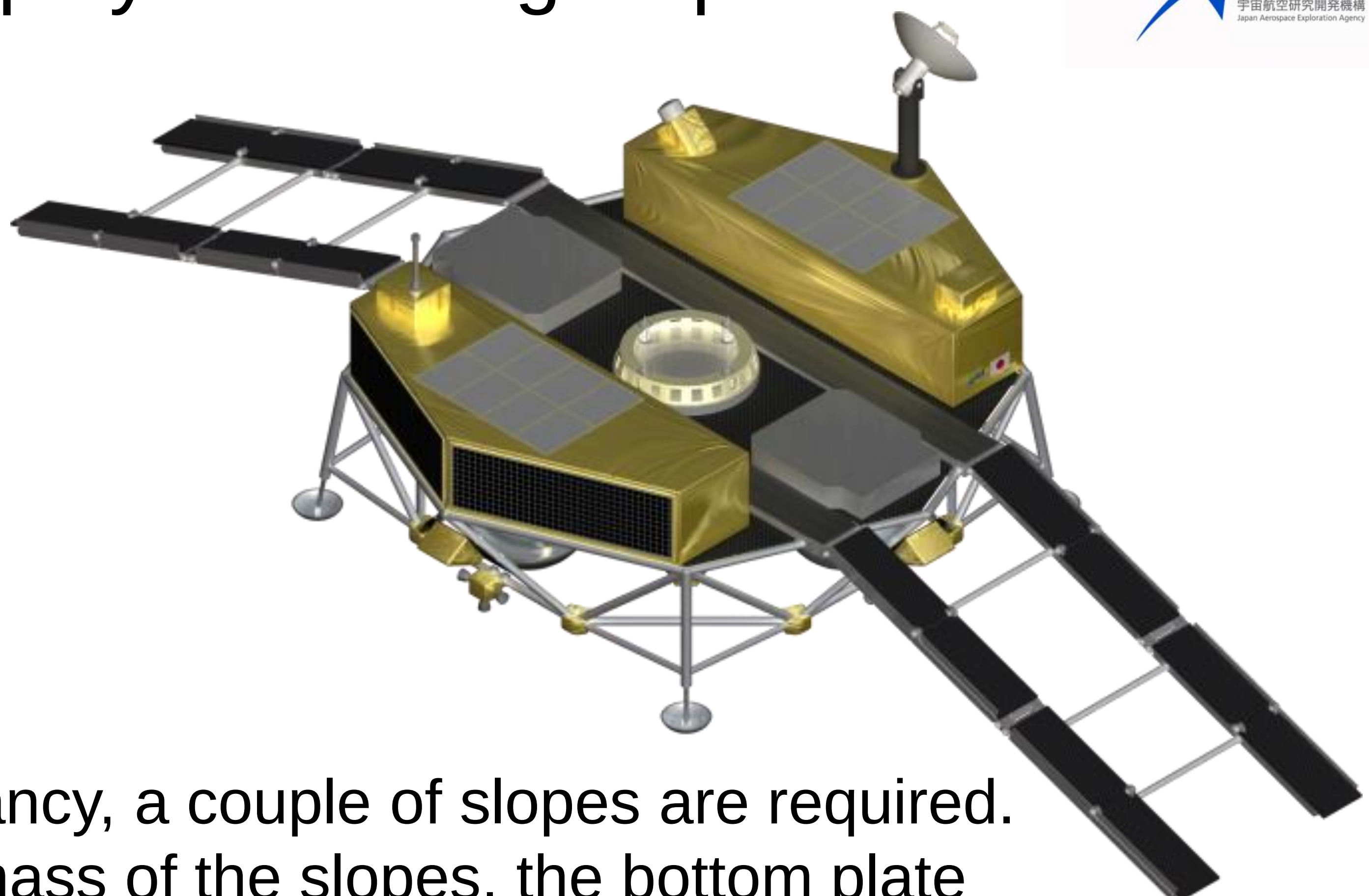


Optical nav. is OK.

Rover deployment mechanism

#	Deployment type	Schematic picture	Reachable area	Complexity	Mass
1	Slopes		Good	Good	Average (Good)
2	Top Crane		Good	Average	Average
3	Elevator		Poor	Good	Average
4	Skycrane		Excellent	Poor	Heavy

Rover deployment using slopes



- For redundancy, a couple of slopes are required.
- To reduce mass of the slopes, the bottom plate should be placed as low as possible.
- Reliable and light weight mechanism should be studied.

Solar cell tower

- At the polar region, solar illumination depends on local terrain. Sunlit at 2 or 5 meters level is much longer than the surface.
- Light weight deployable solar cell tower is required.

Summary

- JAXA is conducting the collaboration study with NASA RP. A solution which can carry 300 kg payload to the surface with some margin has obtained.
- However, to persuade Japanese community and the government, some additional instruments are also essential. We are now conducting further mass reduction study.
- Some new technologies should be developed for safe and precise landing. We have been conducting some experiments and analysis. We also plans to demonstrate the technologies with a small lander SLIM.

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