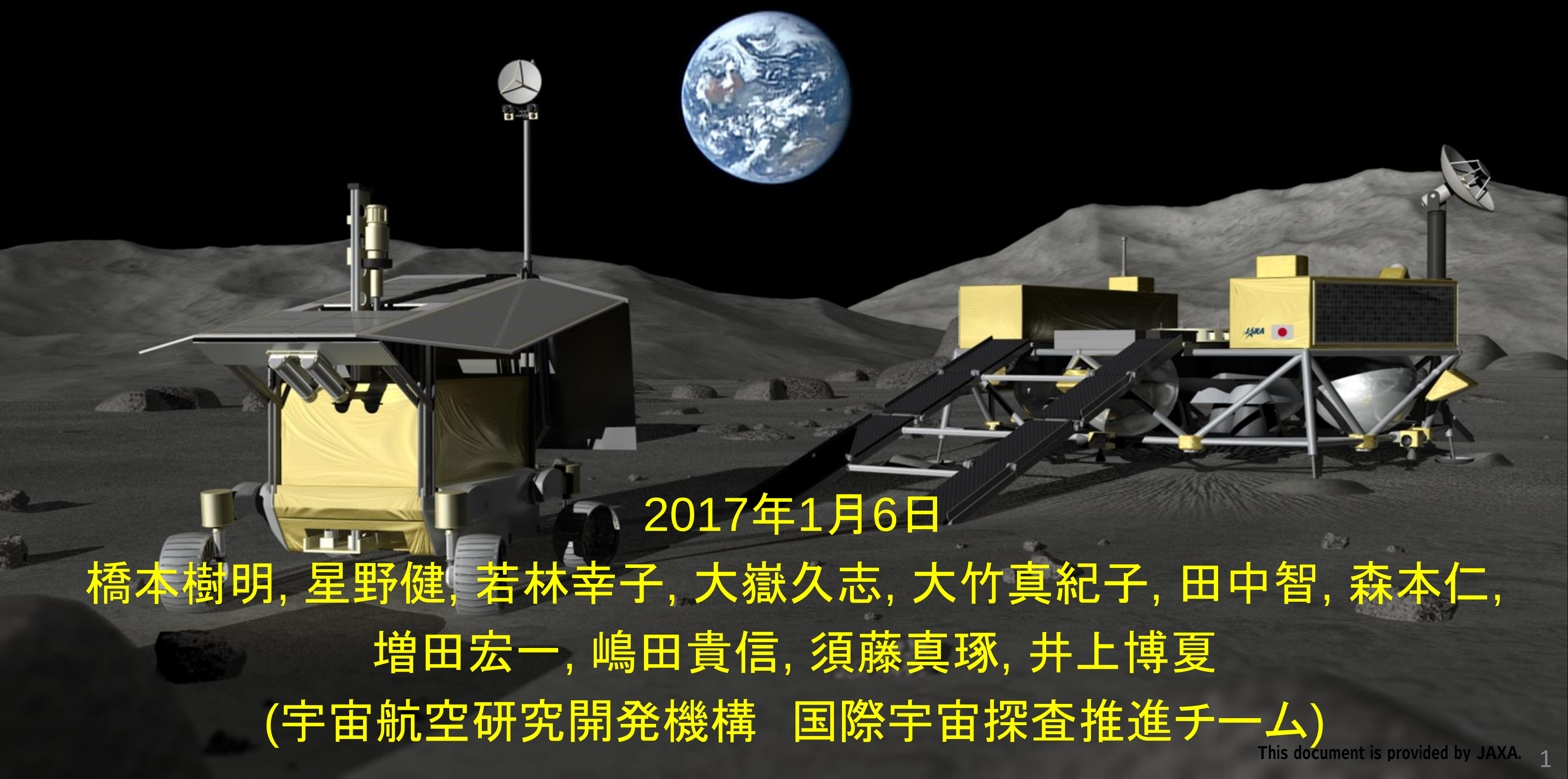
月極域探査ミッション
仮称SELENE-R



2017年1月6日

橋本樹明, 星野健, 若林幸子, 大嶽久志, 大竹真紀子, 田中智, 森本仁,
増田宏一, 嶋田貴信, 須藤真琢, 井上博夏
(宇宙航空研究開発機構　国際宇宙探査推進チーム)

Lunar polar Exploration Mission

January 6 2017

Tatsuaki Hashimoto, Takeshi Hoshino, Sachiko Wakabayashi, Hisashi Otake,
Makiko Ohtake, Satoshi Tanaka, Hitoshi Morimoto , Koich Masuda,
Takanobu Shimada, Masataku Sutoh, Hiroka Inoue
(Japan Aerospace Exploration Agency)

Contents

Contents

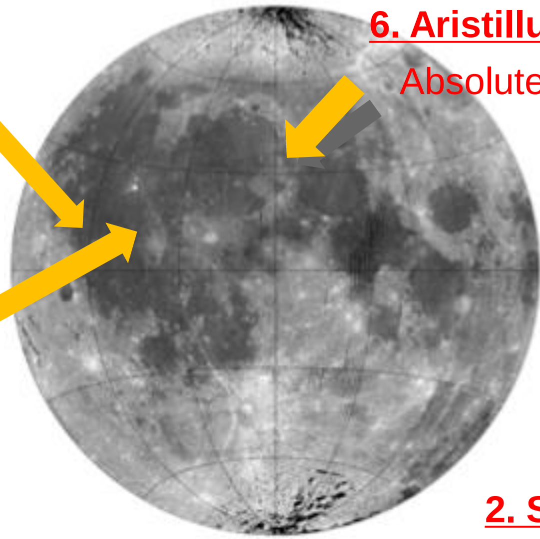
Why do we go toward moon?

- 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

7. Skylights
Lava tube
Future moon habitat
Geology
Utilization

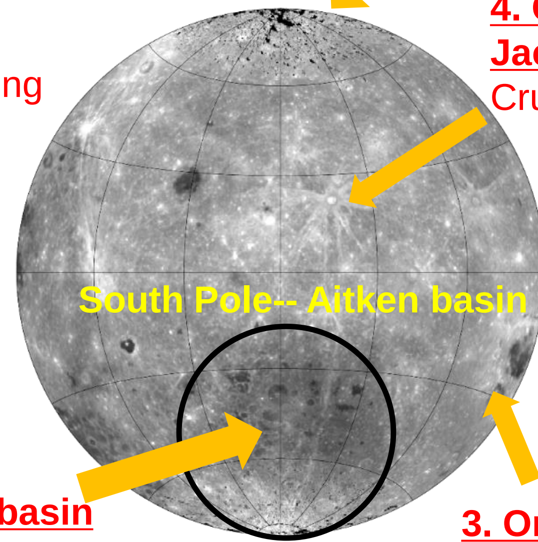
Near side



6. Aristillus
Absolute dating
Geology

5. Aristarchus crater
Heat source elements
Geology

Far side



1. Pole

4. Central hill of Jackson crater
Crust material
Geology

8. Far side
Low frequency radio astronomy
Utilization

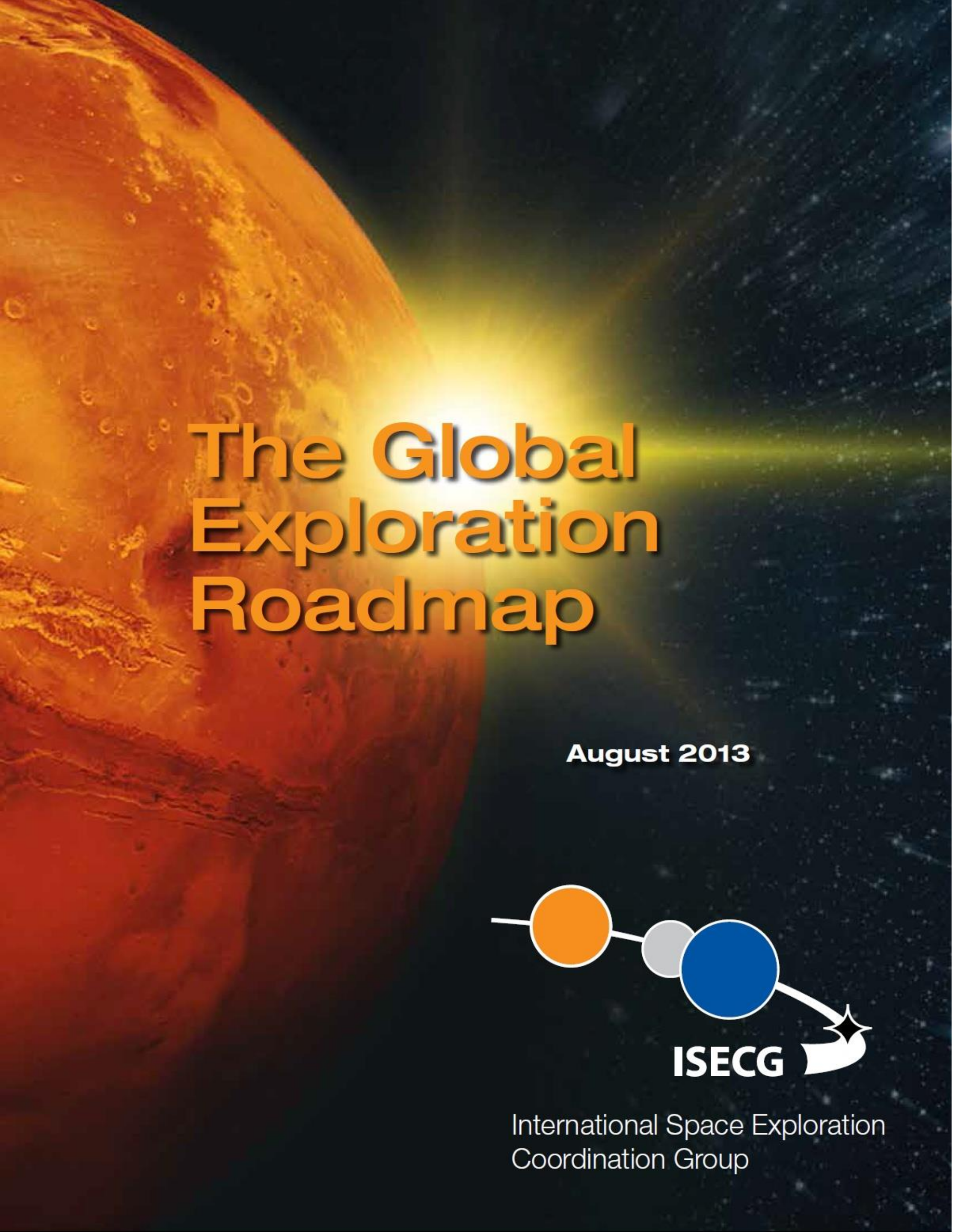
3. Orientale basin
Crust material
Geology

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

Common Goals and Objectives

The Global Exploration Roadmap is driven by a set of goals and supporting objectives that reflect commonality while respecting each individual agency's priorities. They demonstrate the rich potential for exploration of each of the target destinations, delivering benefits to people on Earth. The definitions listed below remain largely unchanged and demonstrate the synergy between science and human exploration goals and objectives.

ISS Commander Chris Hadfield communicates the significance of research activities on board the station.

Manufacturing has begun on the JAXA's Hayabusa2 flight article that is scheduled to launch in 2014.

Robo-Ops is an example of how planetary surface exploration challenges engage the minds of students around the world.

ESA's Mars Express image of the Reull Vallis region of Mars, showing a river-like structure that stretches for almost 1,500 km and is believed to have been formed long ago by running water.

Develop Exploration Technologies and Capabilities
Develop the knowledge, capabilities, and infrastructure required to live and work at destinations beyond low-Earth orbit through development and testing of advanced technologies, reliable systems, and efficient operations concepts in an off-Earth environment.

Engage the Public in Exploration
Provide opportunities for the public to engage interactively in space exploration.

Enhance Earth Safety
Enhance the safety of planet Earth by contributing to collaborative pursuit of planetary defense and orbital debris management mechanisms.

Extend Human Presence
Explore a variety of destinations beyond low-Earth orbit with a focus on continually increasing the number of individuals that can be supported at these destinations, the duration of time that individuals can remain at these destinations, and the level of self-sufficiency.

Perform Science to Enable Human Exploration
Reduce the risks and increase the productivity of future missions in our solar system, characterizing the effect of the space environment on human health and exploration systems.

Perform Space, Earth, and Applied Science
Engage in science investigations of, and from, solar system destinations and conduct applied research in the unique environment at solar system destinations.

Search for Life
Determine if life is or was present outside of Earth and understand the environments that support or supported it.

Stimulate Economic Expansion
Support or encourage provision of technology, systems, hardware, and services from commercial entities and create new markets based on space activities that will return economic, technological, and quality-of-life benefits to all humankind.

探査技術と能力の開発
先進技術、高信頼システム、および地球環境外での効率的な運用方法の開発・ 試験を通じて、地球低軌道以遠の探査目的地で活動するために必要な知識、技術、およびインフラを開発する。

一般市民の探査への参加
一般市民が双方向的に宇宙探査に参加する機会を提供する。

地球の安全性の向上
地球への小惑星衝突と軌道上の宇宙ゴミに関する国際協力による管理システムを構築し、地球の安全性を向上させる。

人類の存在領域の拡大
地球低軌道以遠の様々な目的地の探査を行いながら飛行士の人数を増やし、滞在期間を延長し、自立レベルを強化する。

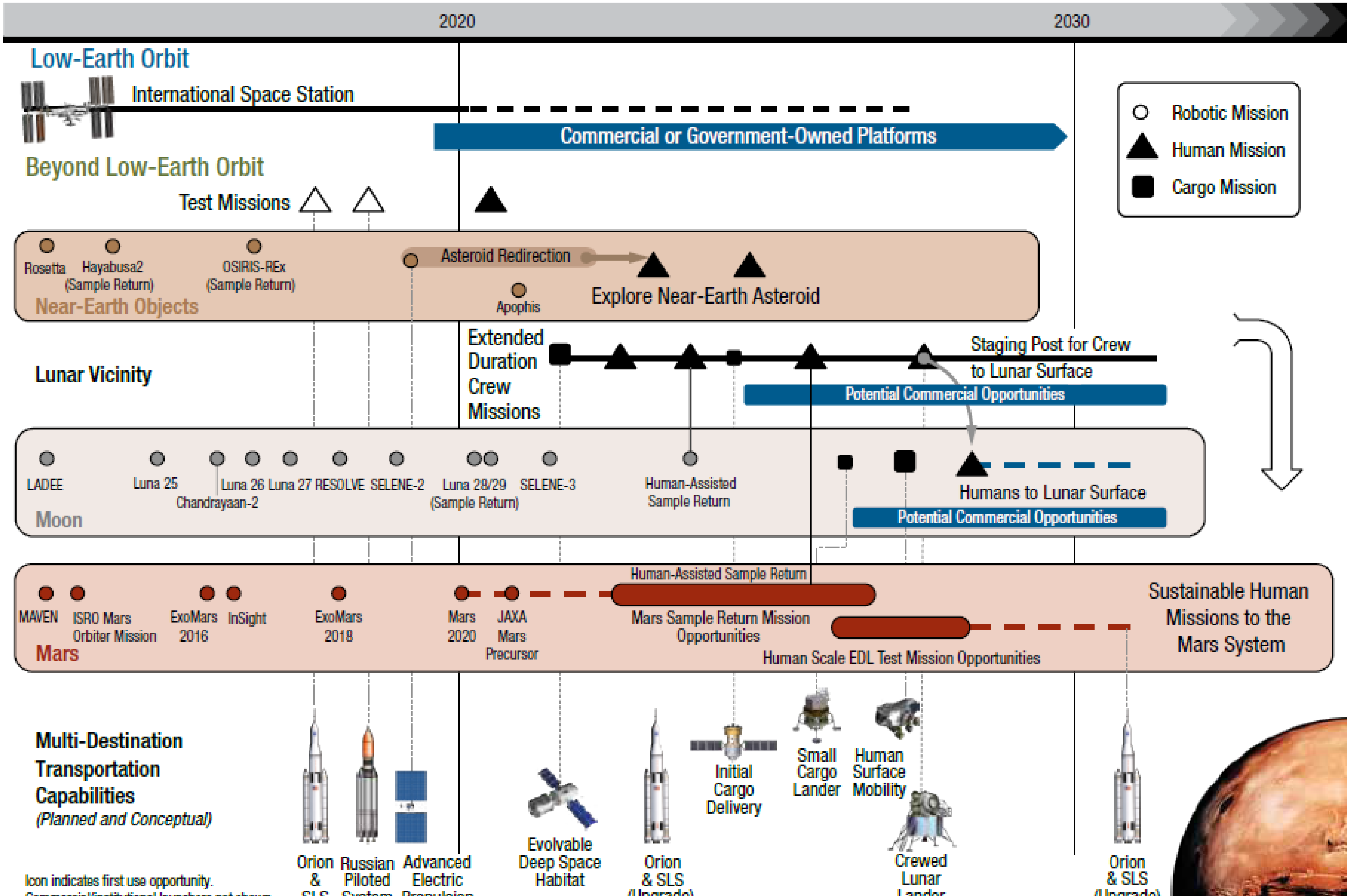
有人探査を可能にする科学の研究
宇宙環境が人の健康や探査機に及ぼす影響を明らかにして、太陽系における将来の探査ミッションのリスクを軽減し、効率を向上させる。

宇宙科学、地球科学、および応用科学の研究
太陽系の様々な目的地での科学調査を行うとともに、その目的地に固有な環境での応用研究を実施する。

生命の探索
地球外生命が存在するか、または存在していたかを判断し、それらの生命を維持し、または維持していた環境を把握する。

経済拡大への刺激
民間企業からの技術、システム、ハードウェア、およびサービスの提供を支援または奨励することで、宇宙活動に基づいた新規市場を創出することになる。この活動により、経済、技術、および生活の質に関する利益を人々に還元する。

Outline of GER#2



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

ISECG
International Space Exploration Coordination Group

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-R
	Lunar cold trap volatiles (water, etc.) distributed within permanently shadowed area.	Robotic mission, Sample return	SELENE-R
	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-R
	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-R
	Dust & Blast Ejecta:	Robotic mission, Ground activity	SELENE-R
	Plasma Environment & Charging	Robotic mission	Future mission
	Lunar Mass Concentrations and Distributions	Already enough data	Kaguya (SELENE)

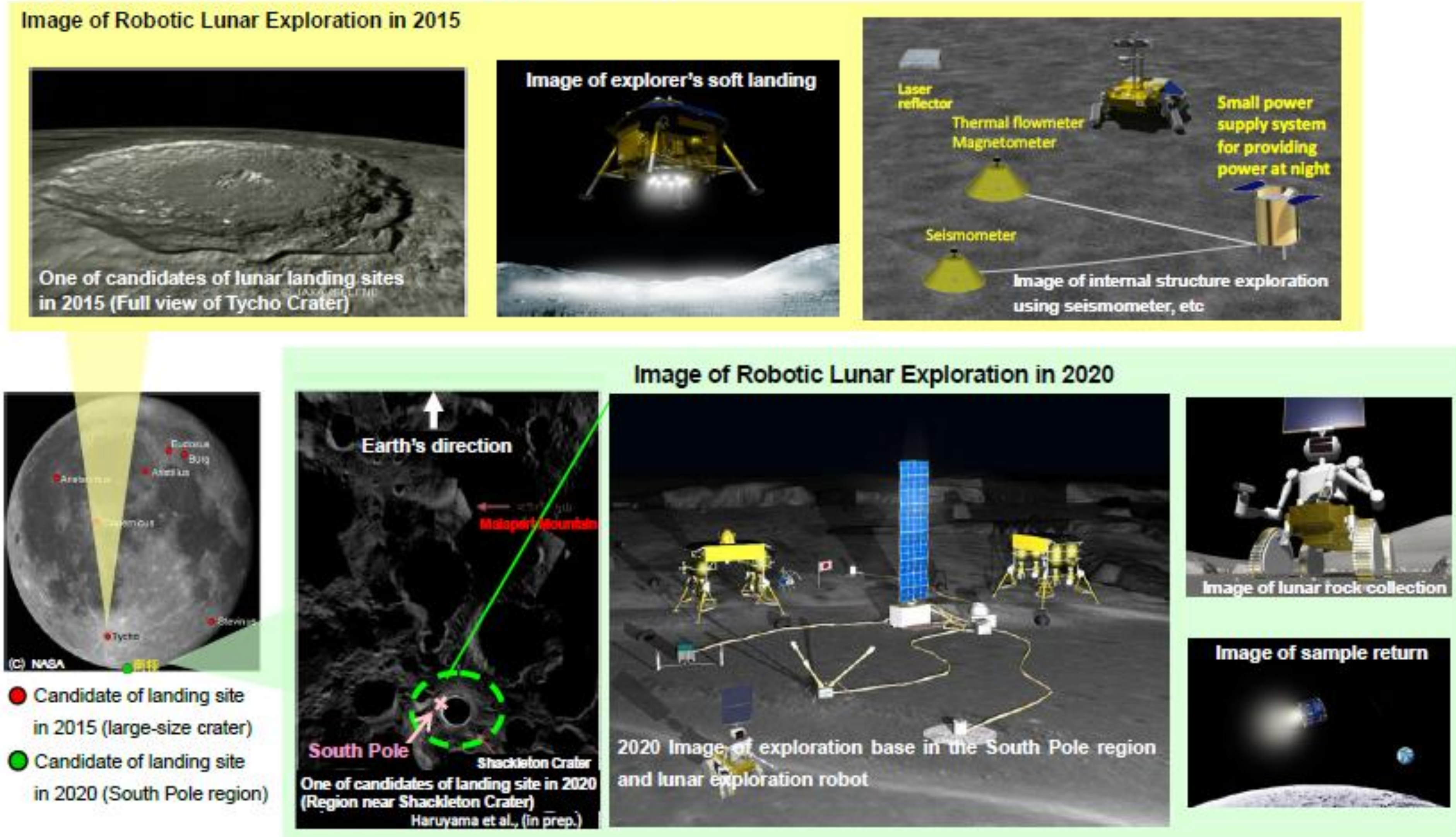
我が国の月探査戦略

～世界をリードするロボット月探査と有人宇宙活動への技術基盤構築～

平成22年7月29日

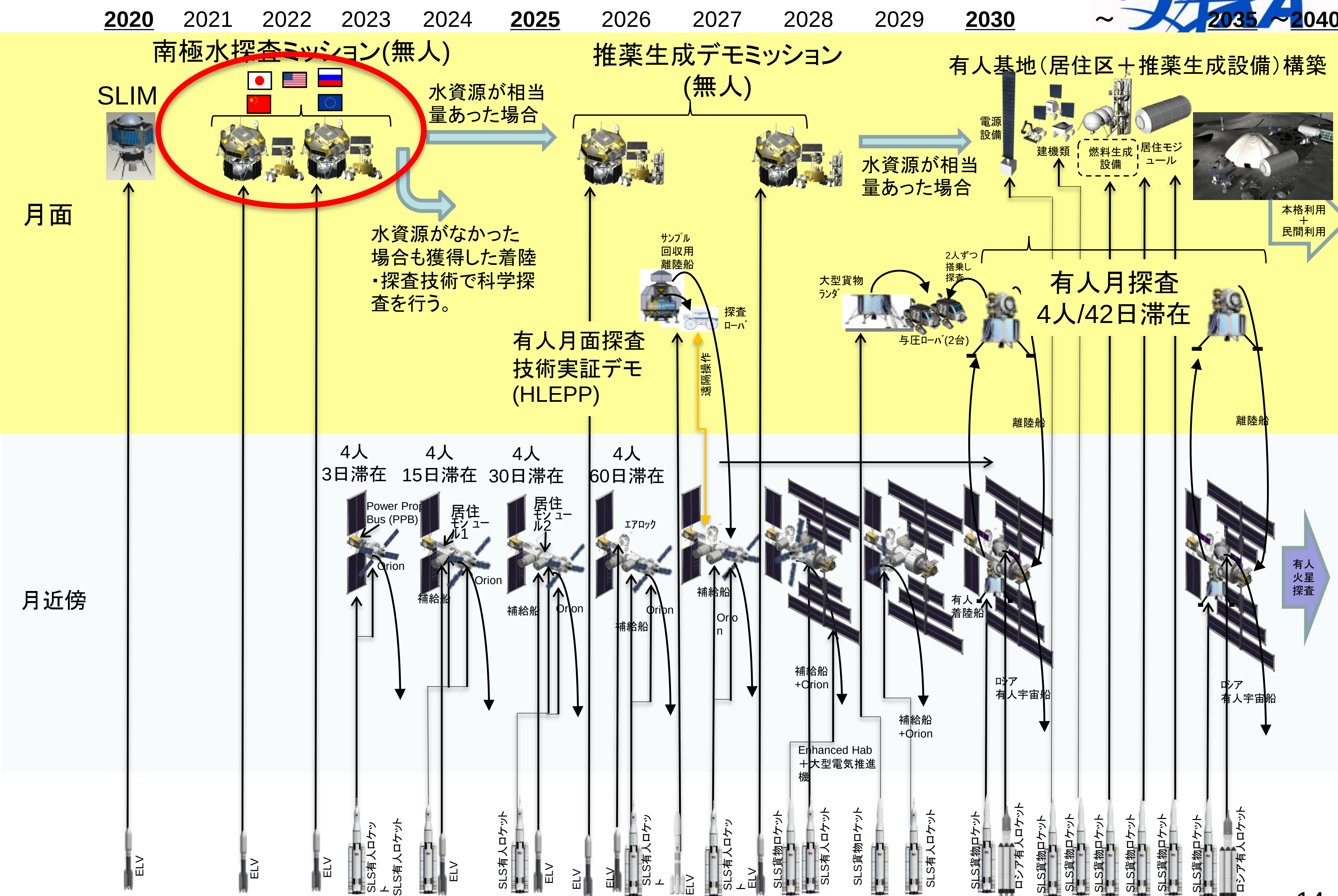
月探査に関する懇談会

Supplemental Figure 1 Image of Robotic Lunar Exploration

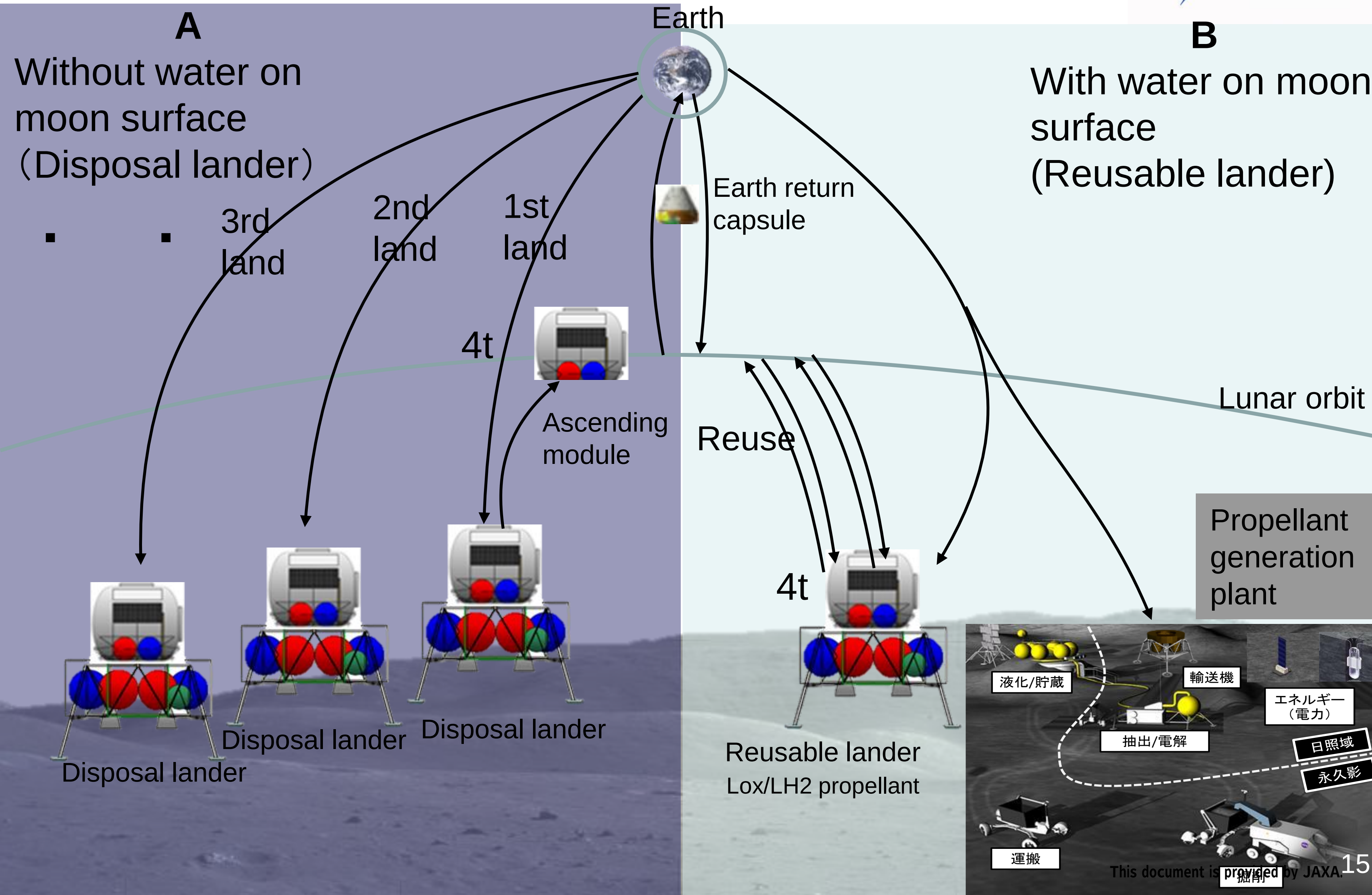


(Image materials: courtesy of JAXA)

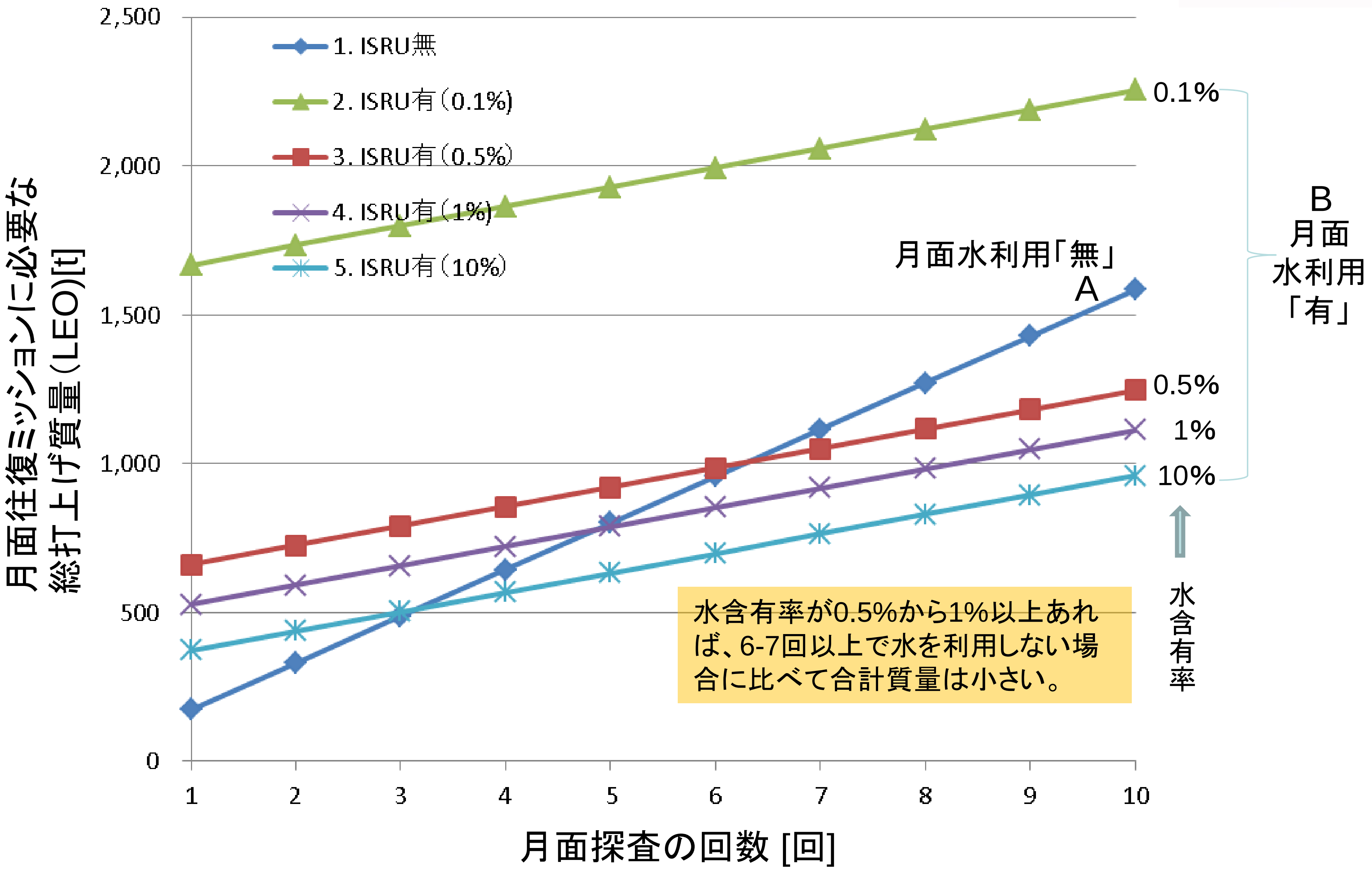
探査推進チームとしての月探査全体シナリオ(案)



Effect of usage of moon surface water for propellant（LOX/LH2)



Effect of usage of moon surface water for propellant（LOX/LH2)



Contents

- Objectives of Moon exploration
- Study of Lunar polar exploration mission
- Spacecraft design
- Technology development
- 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

International volatile exploration study

- 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 SELENE-2 team started the conceptual study to adapt the spacecraft configuration to the RP requirements.
- Lunar volatile exploration is studied not only by NASA but also ISECG including Roscosmos, ESA, DLR, JAXA, and KARI.
- Since Japanese budgetary environment for exploration is severe, NASA is currently considering collaboration with another international partner. Therefore, JAXA thinks about Japanese own spacecraft, though possibility of international collaboration is still considered.

SELENE/RP collaboration Mission

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

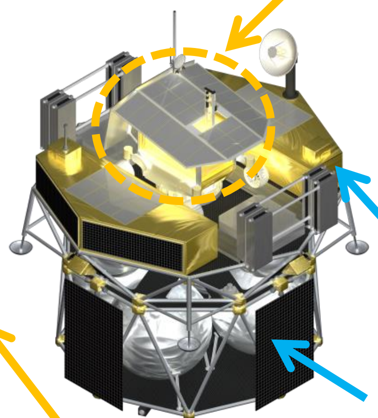
Rover (NASA)

- 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



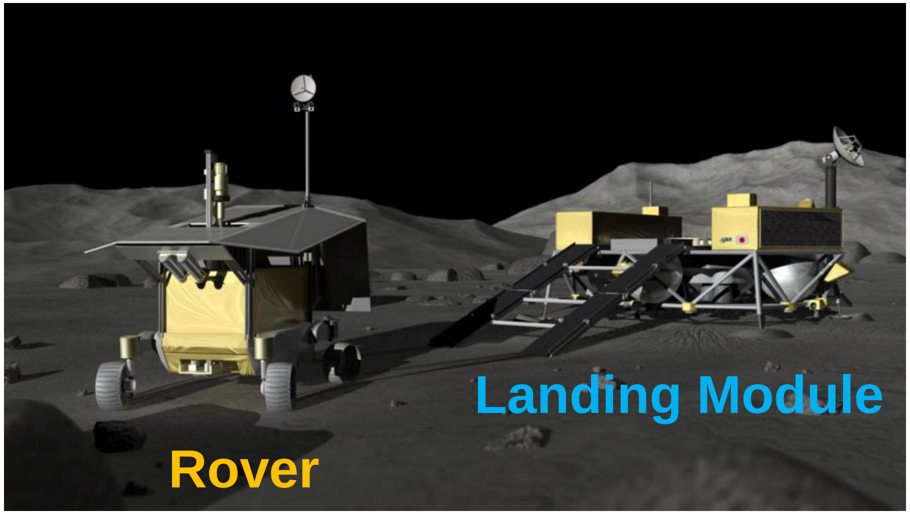
Landing Module (JAXA)

Propulsion Module (JAXA)

Launch Vehicle (NASA)

Launch vehicle selection depends on the payloads.

Launch configuration

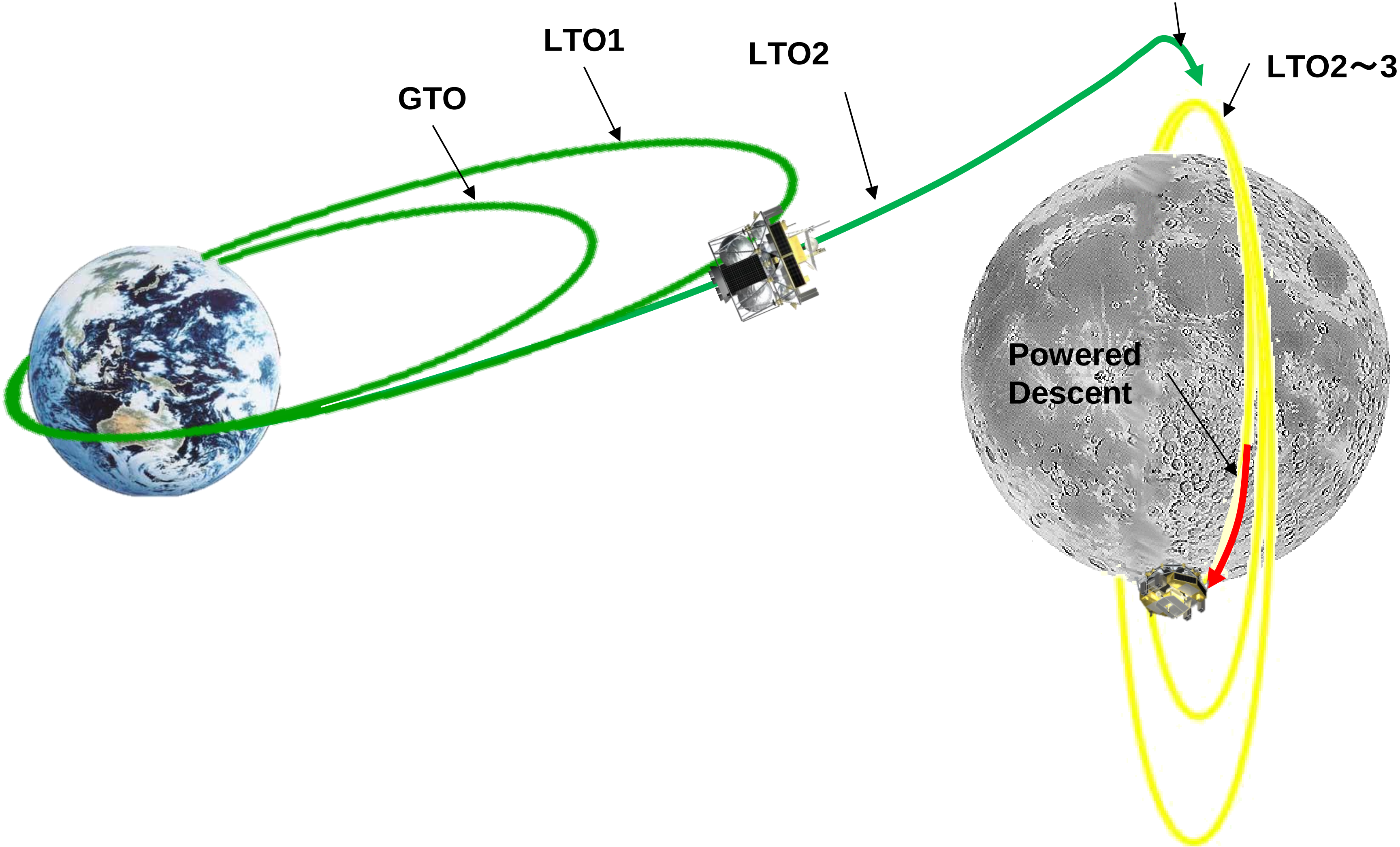


Lunar surface configuration

Contents

- Objectives of Moon exploration
- Study of Lunar polar exploration mission
- Spacecraft design
- Technology development
- Summary

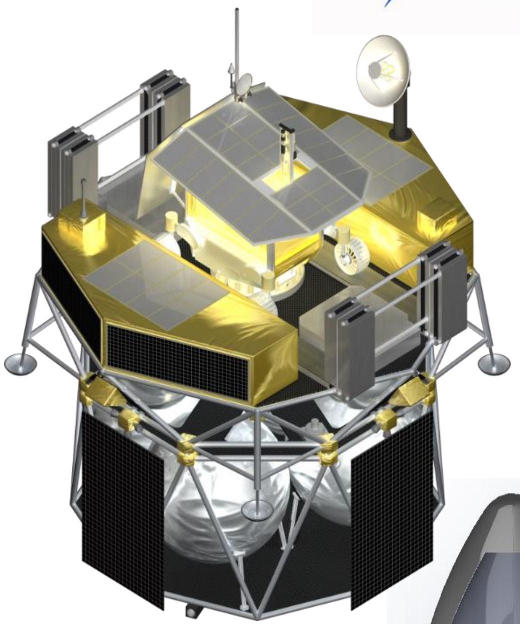
Trajectory


Lunar Orbit Insertion LOI1
LTO1
LTO2
GTO
LTO2～3
Powered
Descent

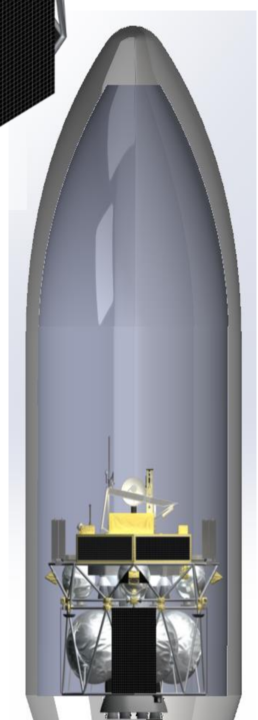
Spacecraft configuration (tentative)

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 H-II-A
or Falcon 9 ver. 1.1



SELENE/RP collaboration Mission

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

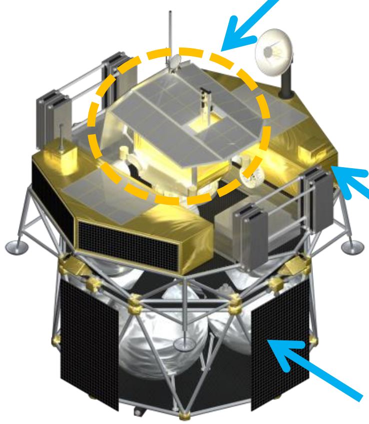
Rover

- Near Infrared Spectrometer
- Neutron Spectrometer
- Drill
- 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

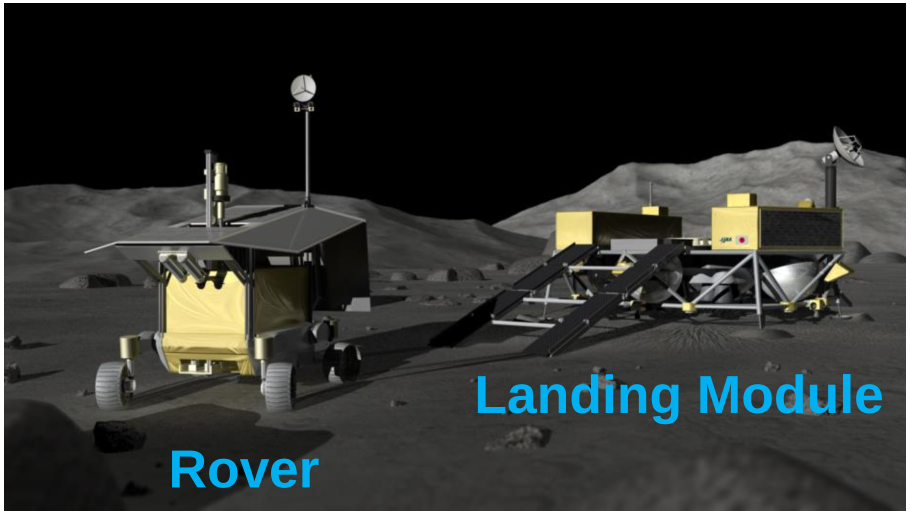
Other instruments candidates



Landing Module

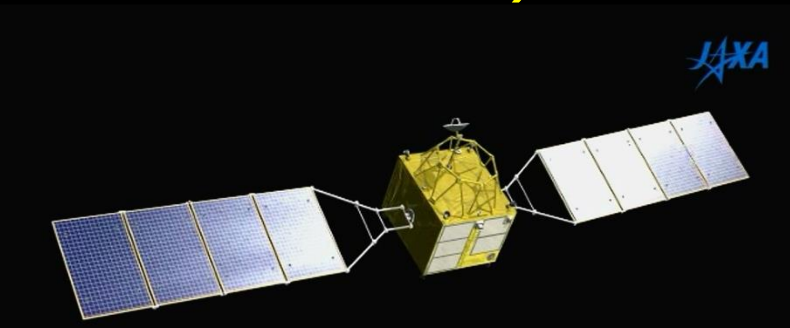
Propulsion Module

Launch configuration



Lunar surface configuration

(Reference) 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 -

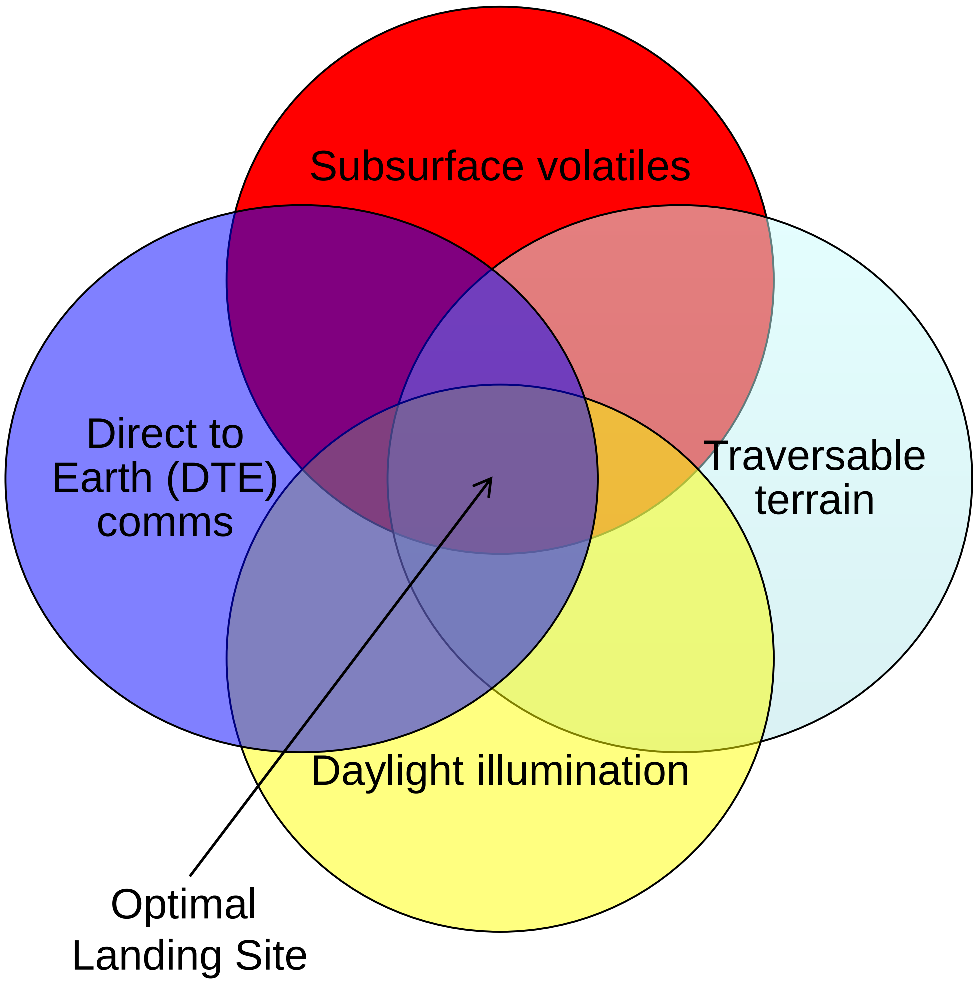
- Multi-band panoramic camera : ALIS
- High definition TV : HDTV

- 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

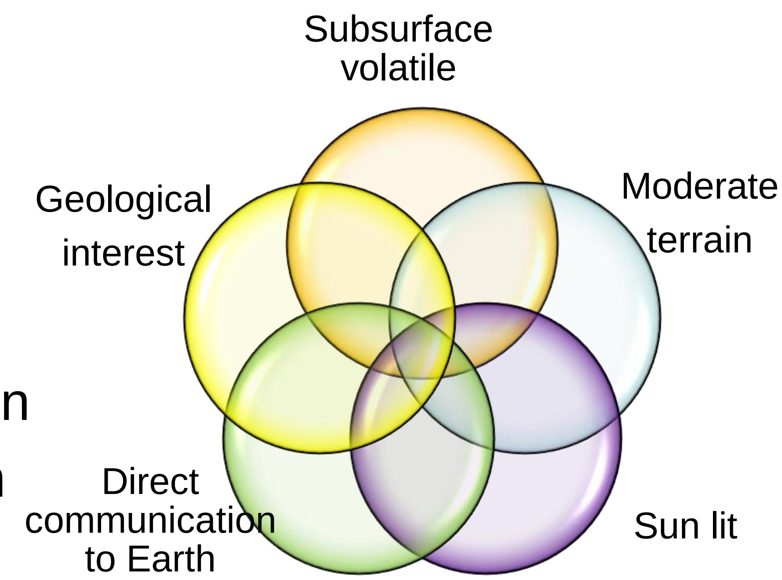
Site Selection Criteria for RP

- 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



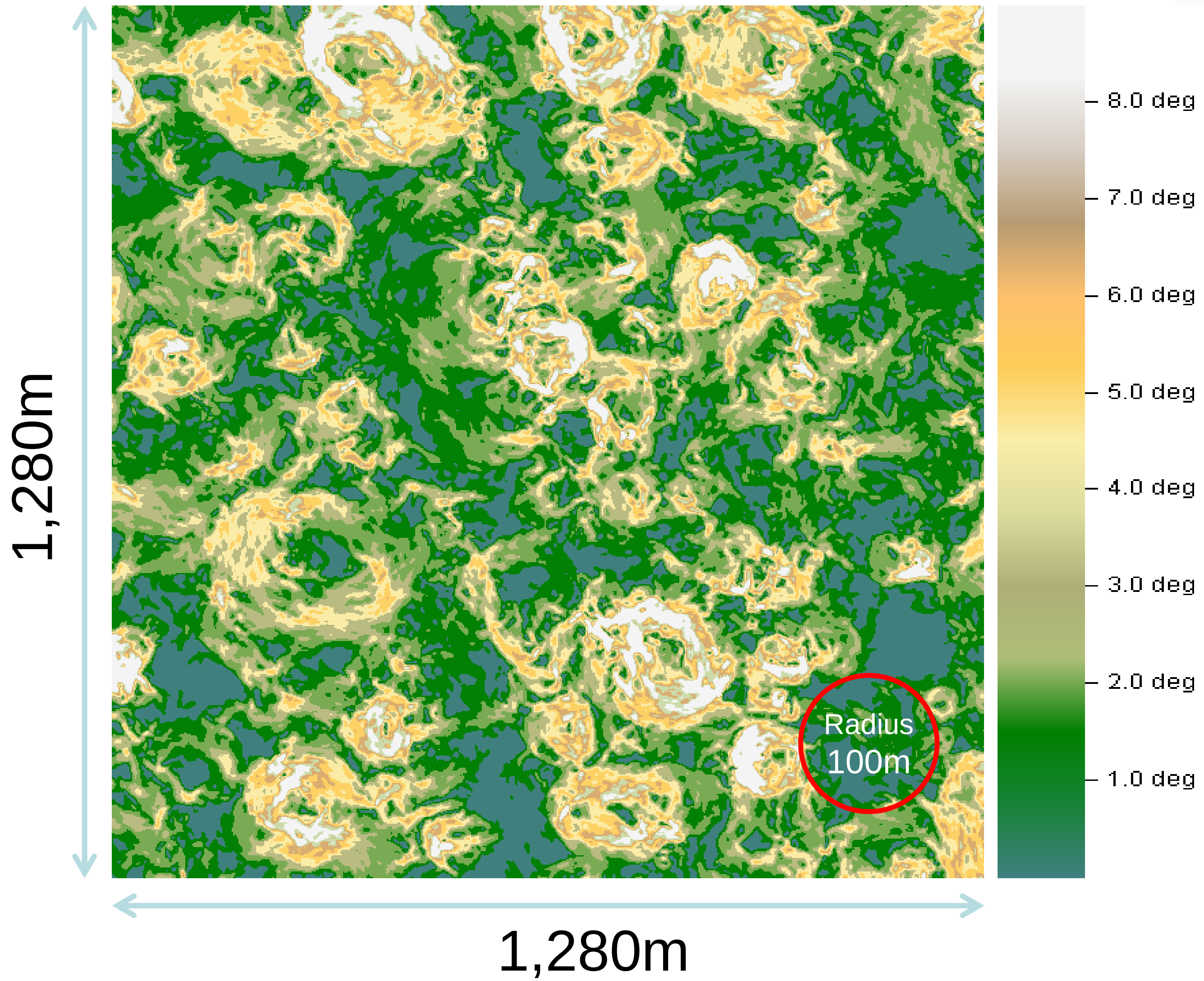
Site Selection Criteria for SELENE-R

- For volatile investigation
  - Existence of Subsurface volatile
  - Sunlit at least several days for rover activity
  - Direct communication to Earth
  - Limited obstacles, slope < 10 deg
- For geological and geophysical observation
  - Geological interest such as ejecta from South Pole Atkin basin
  - Sunlit for several month for long time observation



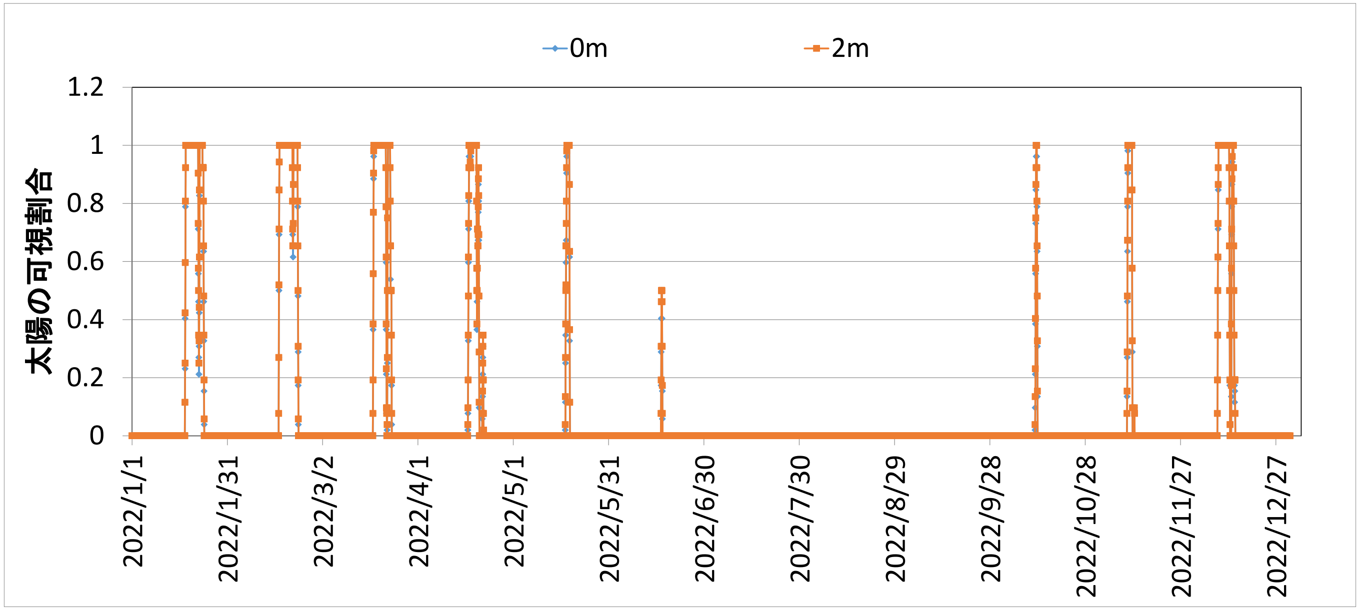
Area which meets those conditions is very limited.
Only a few hundred meters diameter area.

Landing site selection: Slope

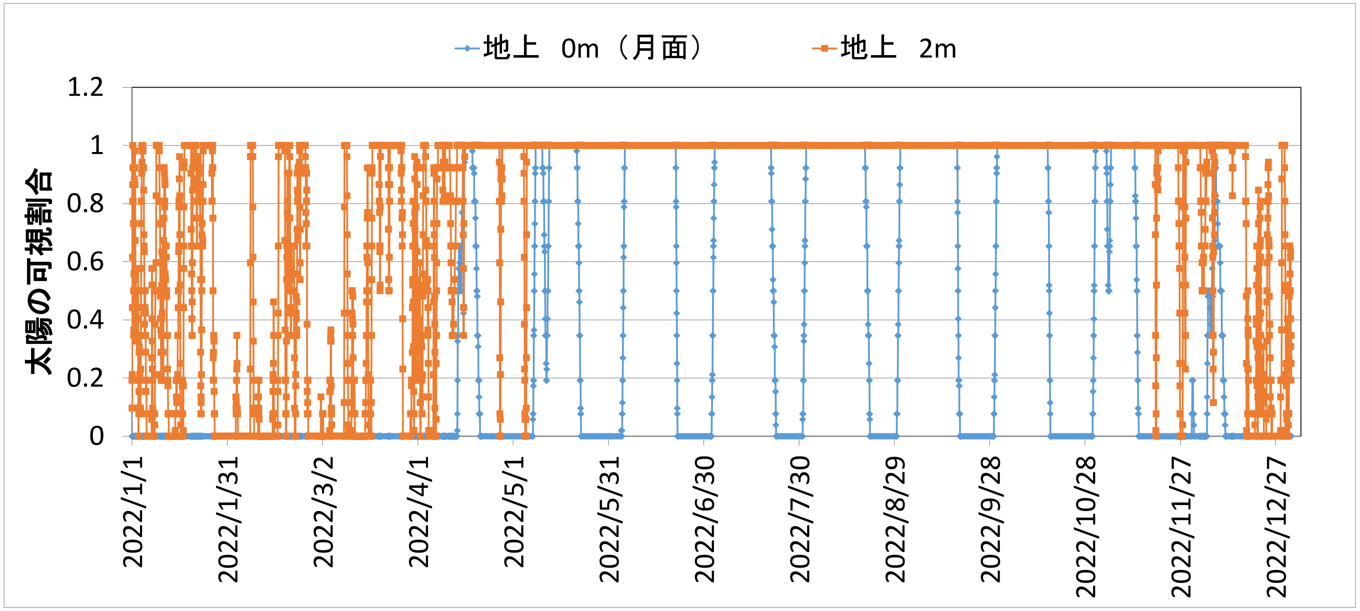


Slope map

Landing site selection: Solar illumination



2022 South pole
(Shorter sunshine)

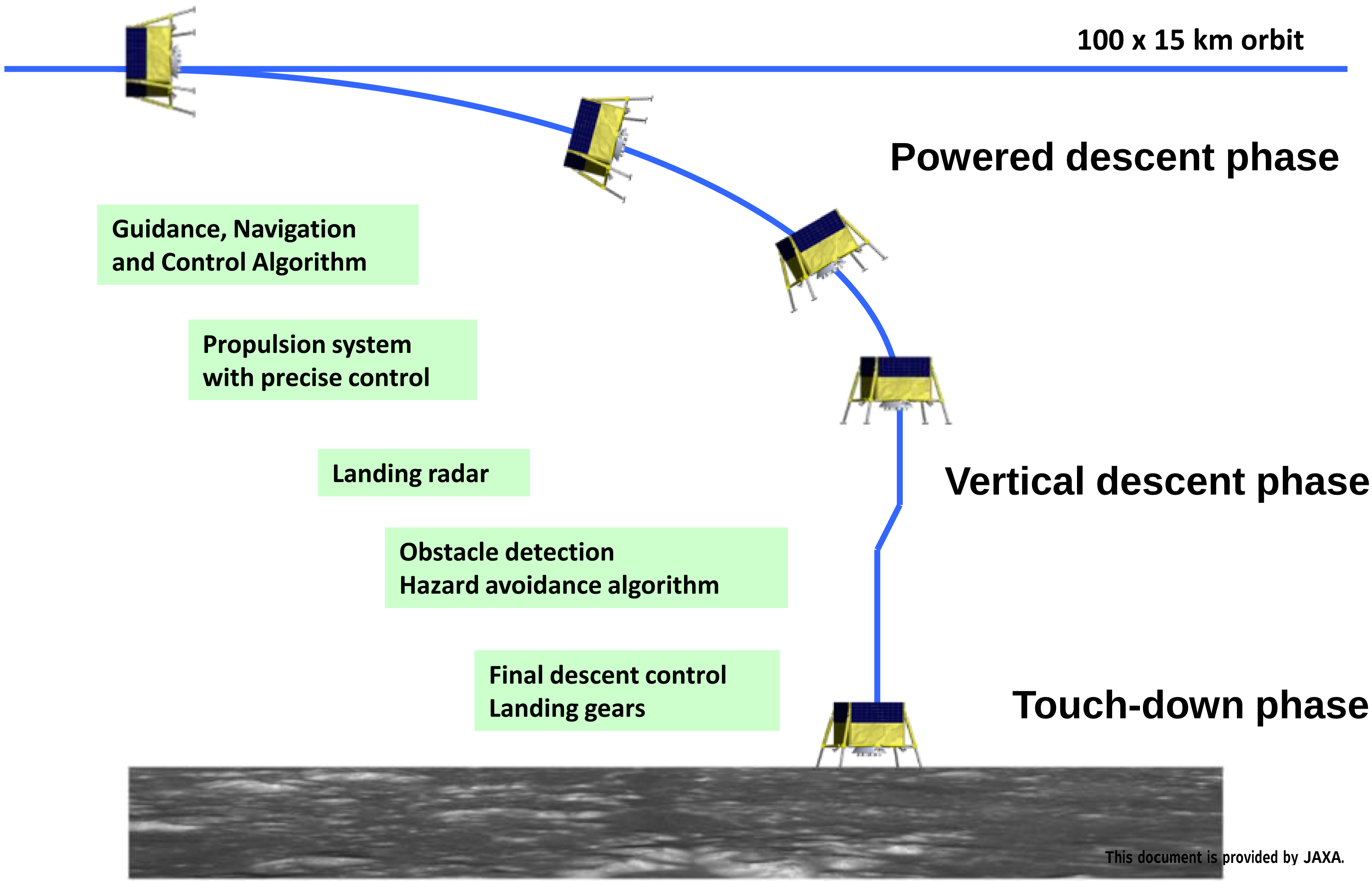


2022年 North pole
(Longer sunshine)

Contents

- Objectives of Moon exploration
- Study of Lunar polar exploration mission
- Spacecraft design
- Technology development
- Summary

Landing technology

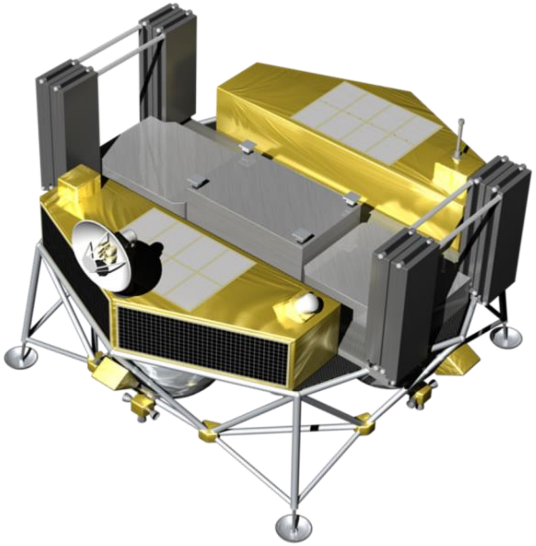


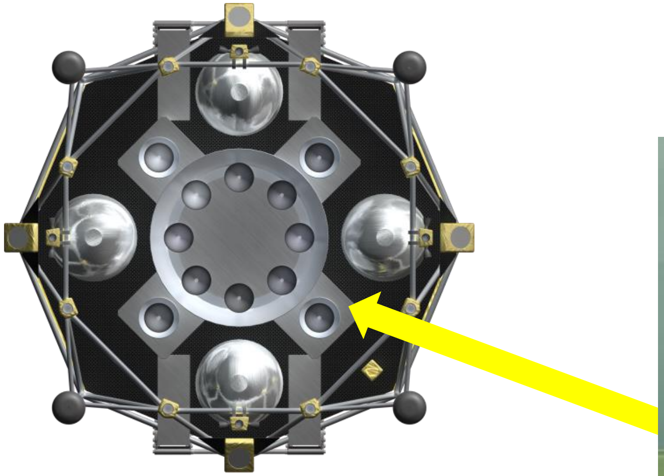
Landing technologies

	Heritage	Newly developed
Propulsion system	Experienced 500 N	10 or 12 clusters of 500 N thruster
GNC algorithm	Basically demonstrated by SLIM	Modification for polar lander
Landmark navigation	100 m accuracy	Modification for weak solar illumination
Landing radar	Developed and demonstrated by SLIM	N/A
Hazard avoidance	Developed and demonstrated by SLIM	Flash LIDAR?
Landing gear		Shock absorption plate?

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.



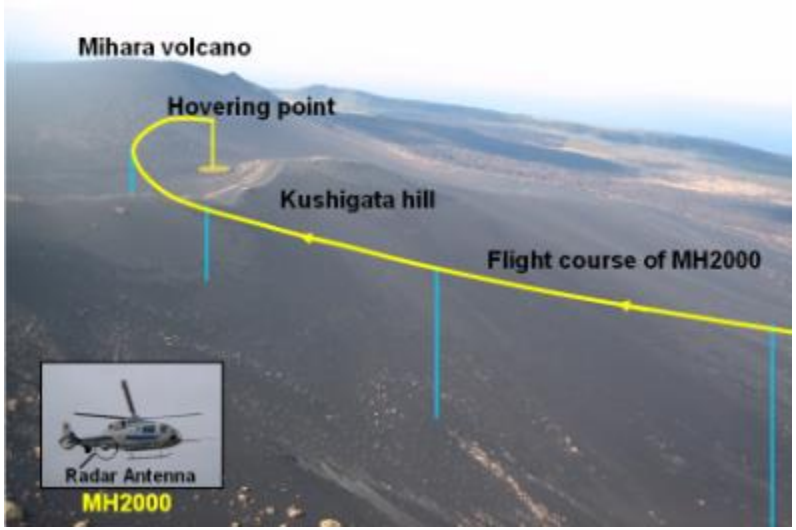


Laser altimeter and Landing Rader

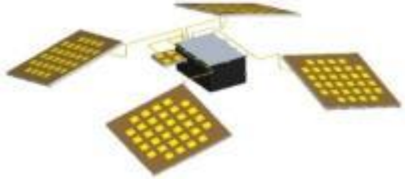
- For vertical descent phase of landing, precise speed and altitude measurements are required.
- JAXA has the heritage of laser altimeters.
  - LALT on Kaguya : 50km～150km
  - LIDAR on Hayabusa: 50m ～50km
- JAXA has been developing a landing radar with one beam altimeter and four beams of speed meter.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

KAGUYA LALT

HAYABUSA LIDAR



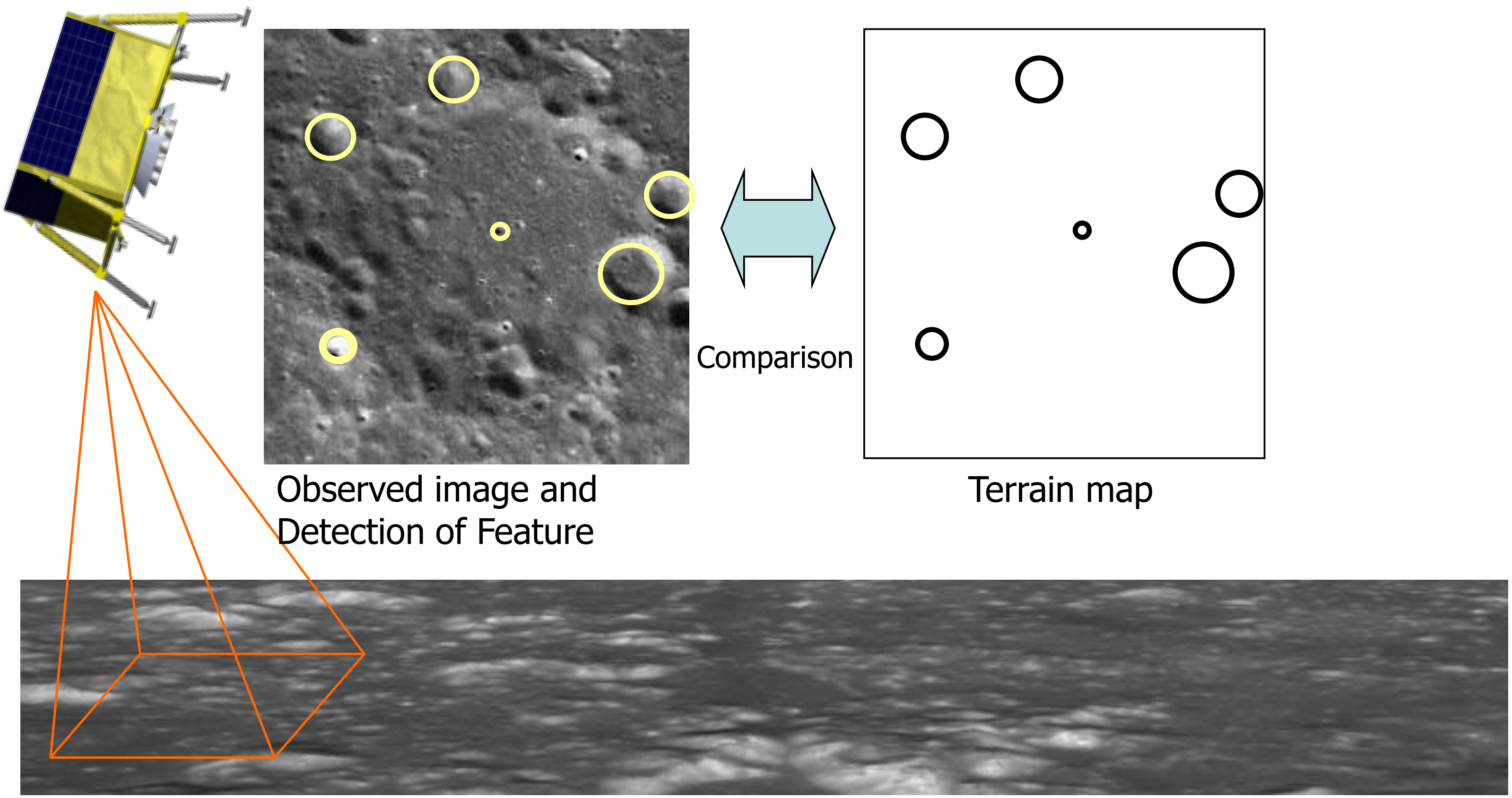
Field tests of landing radar using helicopter



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 demonstrated by SLIM project.



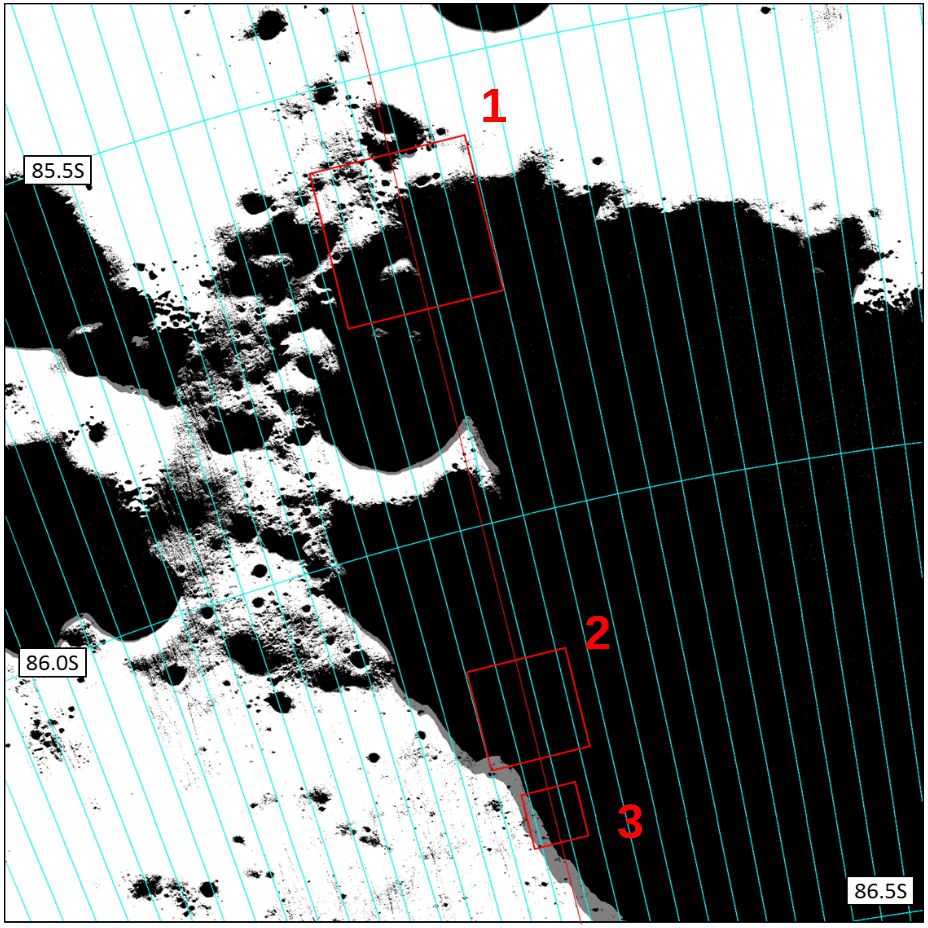
Simulated images for the landmark navigation

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)

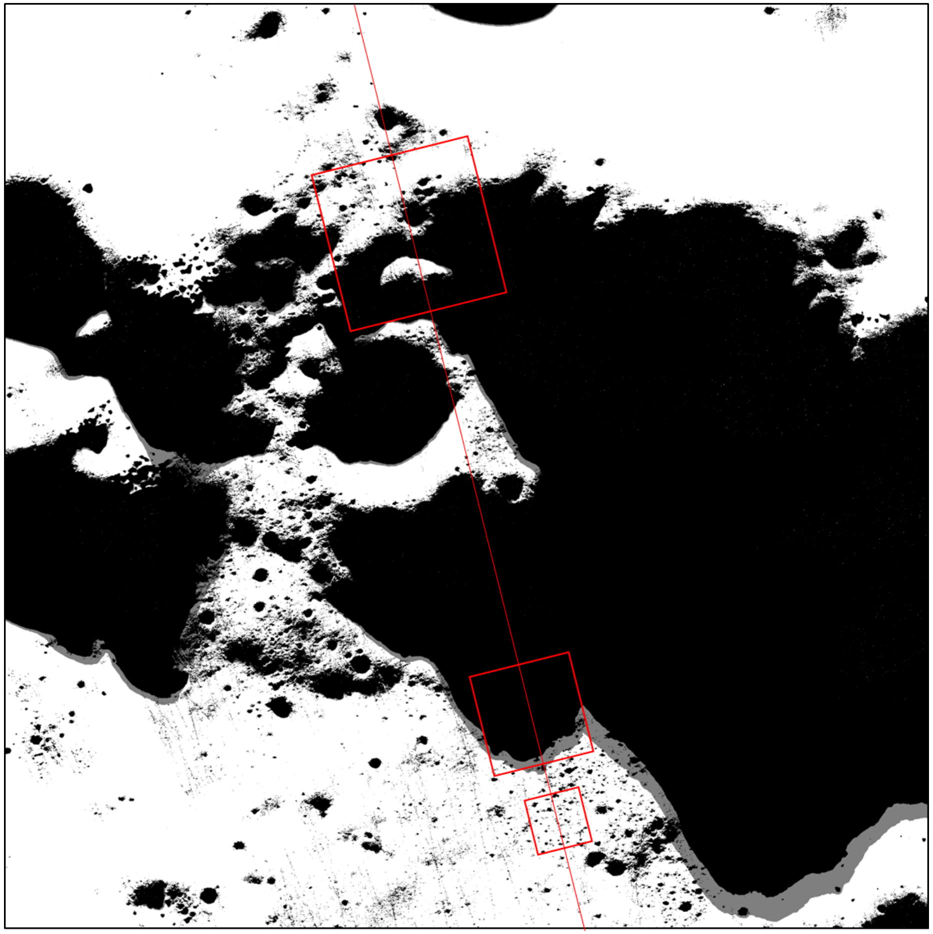


Landing site is dark.

Simulated images for the landmark navigation

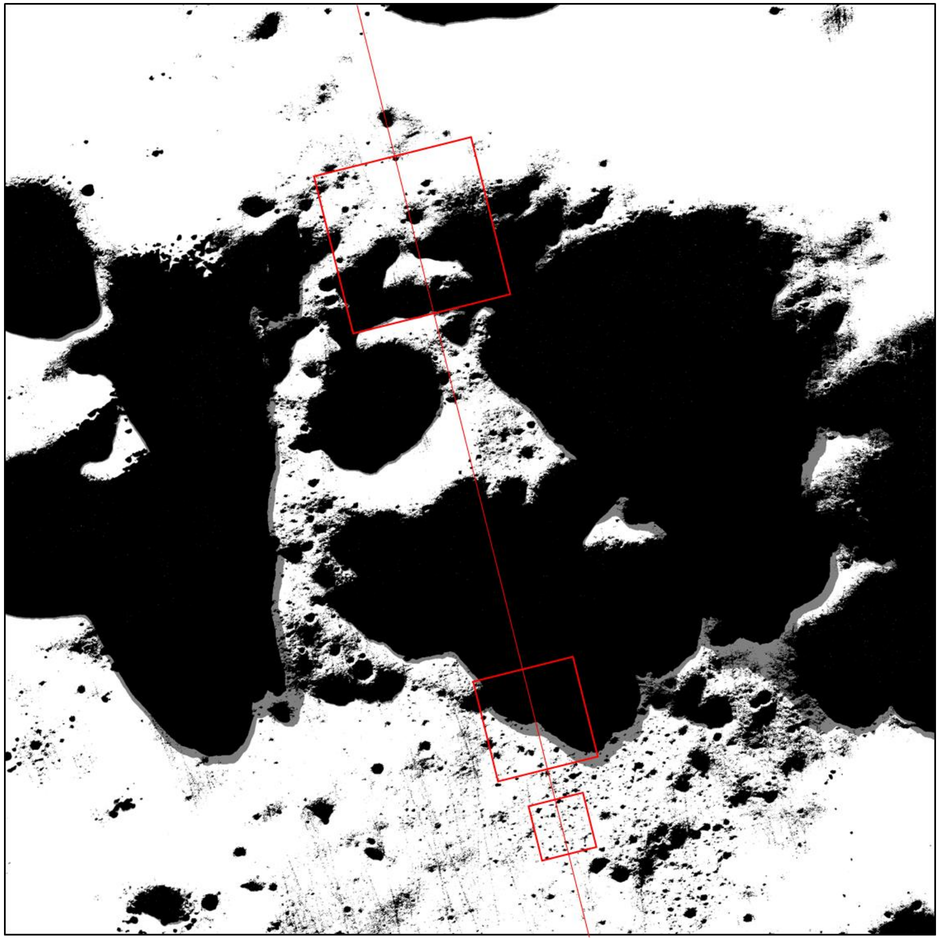
Landing to North Haworth (86.33S, 14.19W)

2020/04/09 00:00:00



Landing site is sunlit but optical nav. is difficult.

2020/04/10 00:00:00

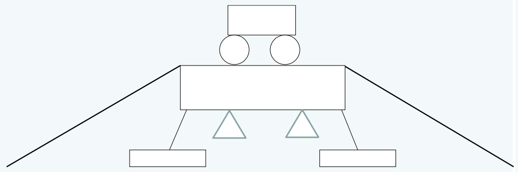
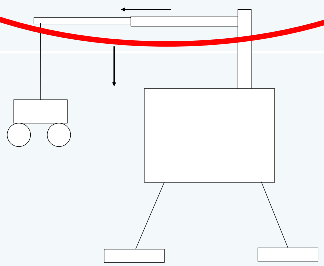
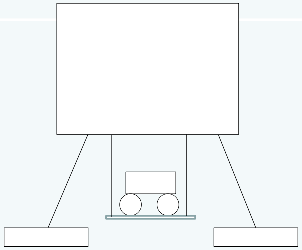
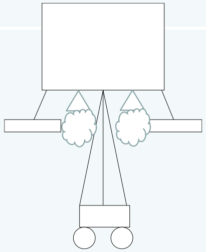


Optical nav. is OK.

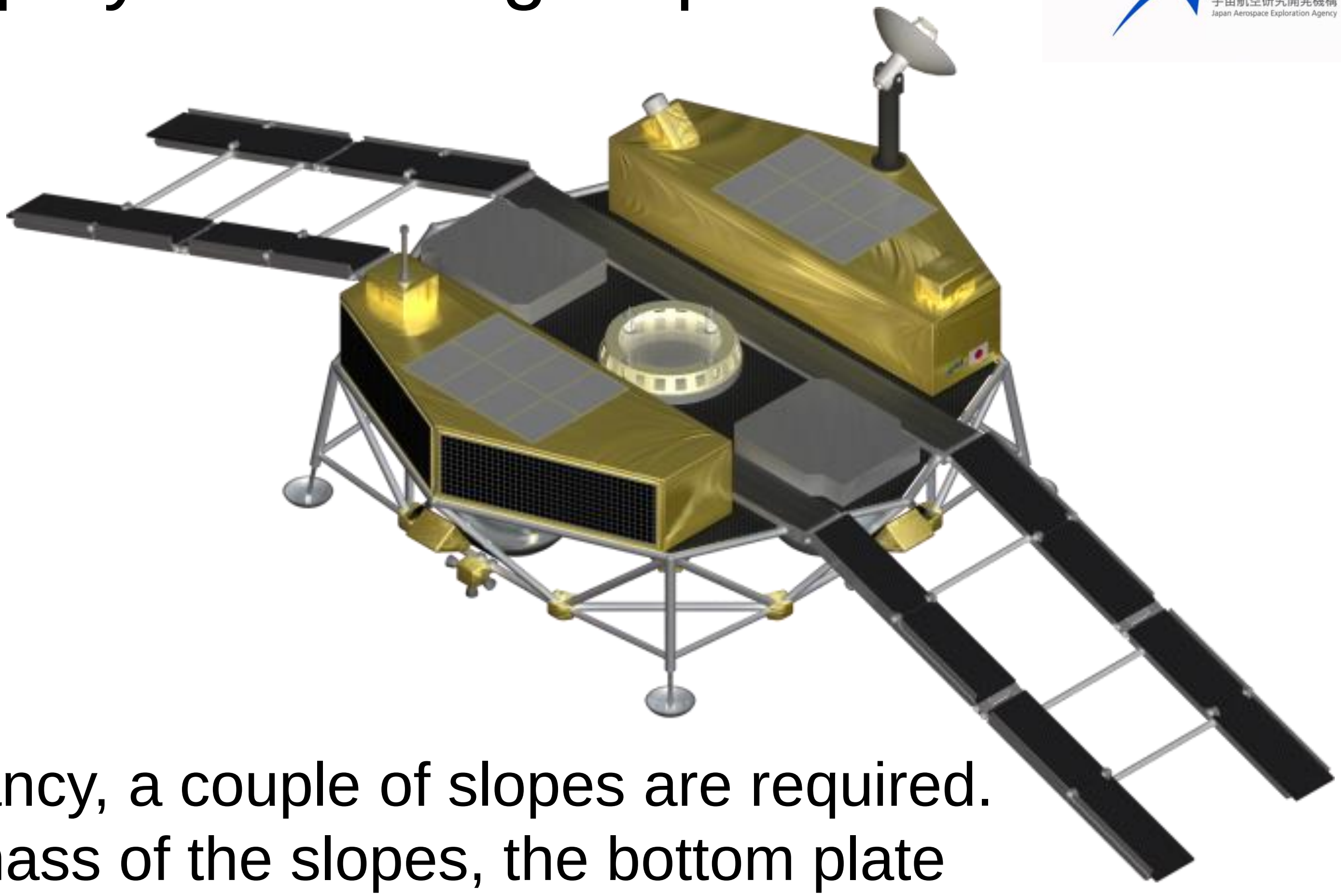
Surface exploration technologies

	Heritage	Newly developed
Payload deployment mechanism		Development of slope Low-floor lander
Exploration rover	SELENE-2 study	Light weight rover carrying heavy payload
Solar cell tower	Thin film solar cell	Deployment mechanism under gravity
High performance Li Ion battery	SELENE-2 study	
Wireless power transmission	SSPS study	Development of laser transmitter and receiver
Drill	SELENE-2 study	Light weight and for icy soil
Instruments	SELENE-2 study International partners	Most of instruments must be newly developed.

Rover deployment mechanism

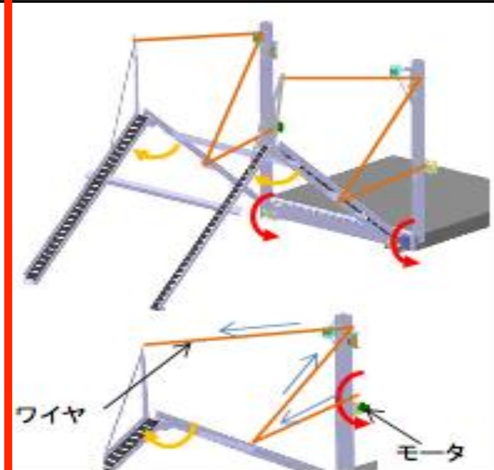
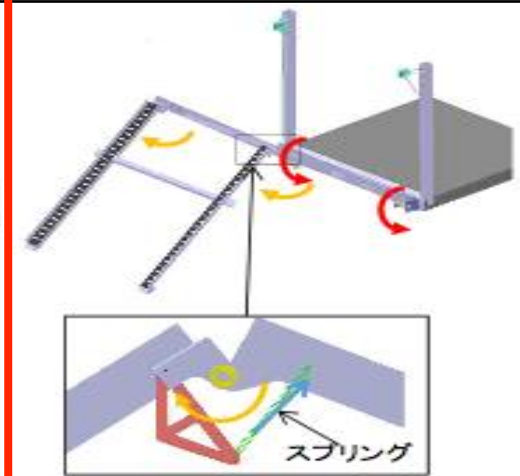
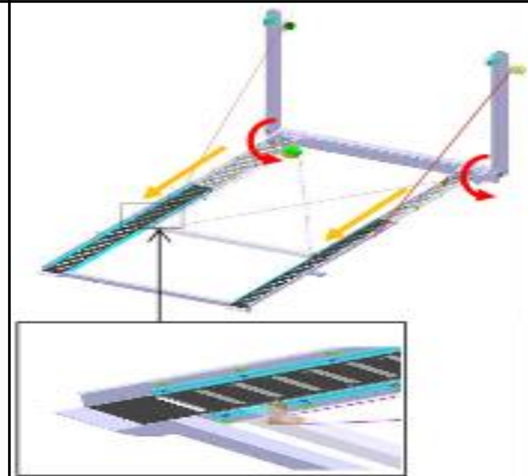
#	Deployment type	Schematic picture	Reachable area	Complexity	Mass
1	Slopes		Good	Good	Average (Good)
2	Top Crane		Good	Average	Average
3	Elevator		Poor	Good	Average
4	Skycrane		Excellent	Poor	Heavy

Rover deployment using slopes

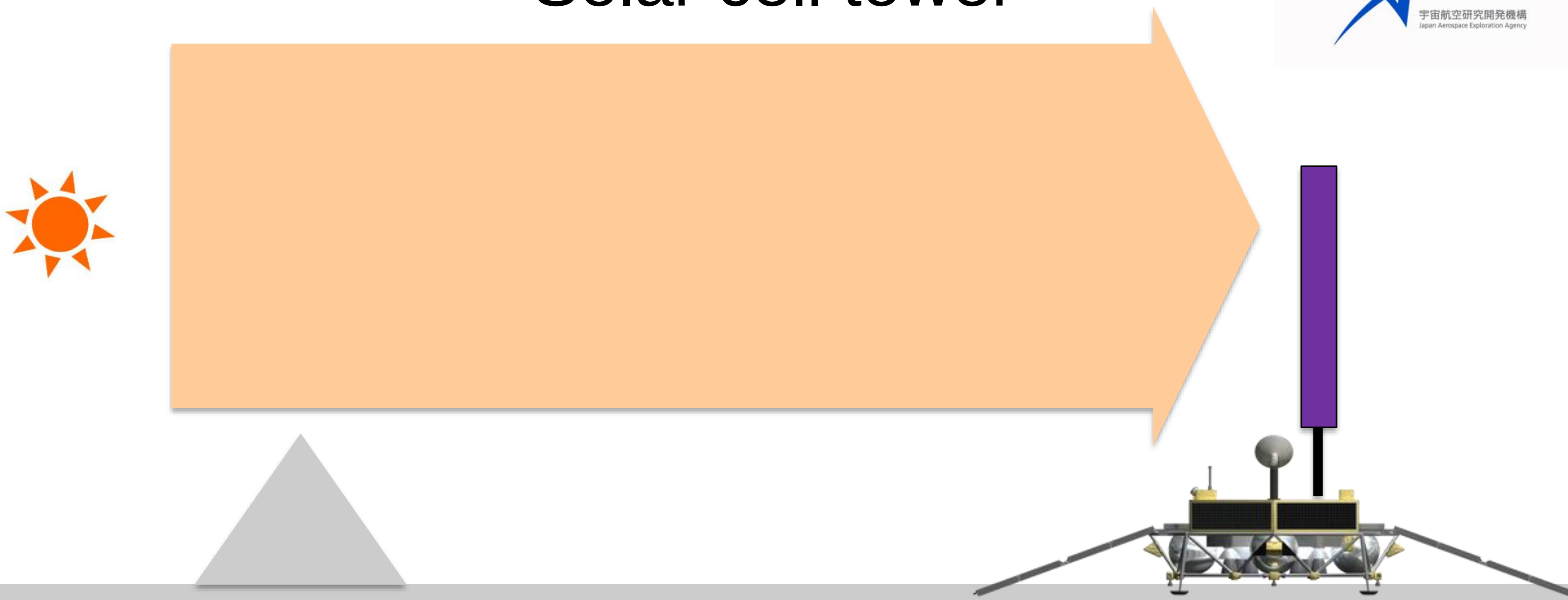


- For redundancy, a couple of slopes are required.
- To reduce mass of the slopes, the bottom plate should be placed as low as possible.
- Reliable and light weight mechanism should be studied.

Deployment mechanism tradeoff

	Wire controlled	Spring development	Sliding type
Concept			
mass	43 kg	60 kg	50 kg
Motor	4	0	6
Adaptability	Good	Poor	Very good
Simplicity	Good	Very good	Medium
Total	Good	Poor	Good

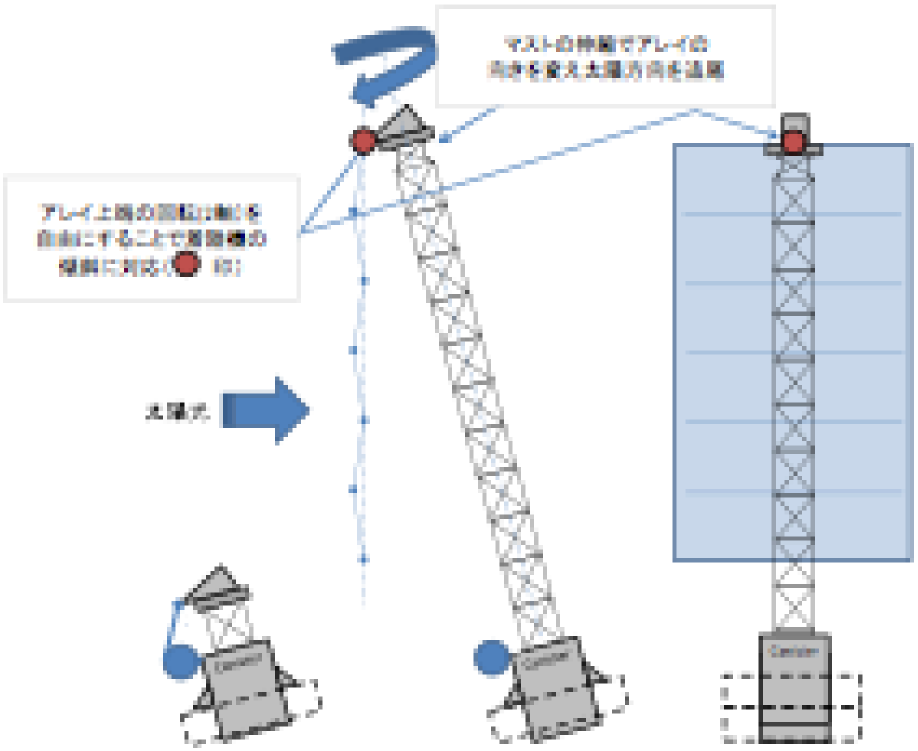
Solar cell tower



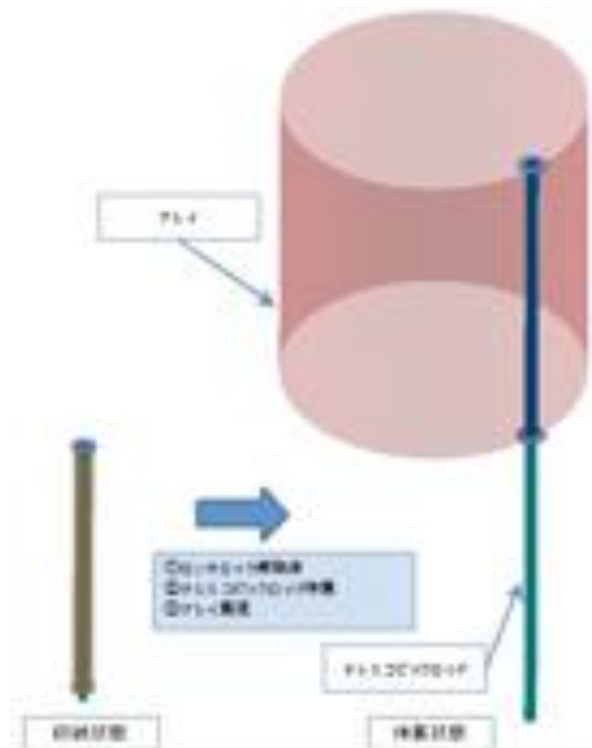
- At the polar region, solar illumination depends on local terrain. Sunlit at 2 or 5 meters level is much longer than the surface.
- Light weight deployable solar cell tower is required.

Extendable solar cell tower

A. Flat panel type
(need sun tracking)

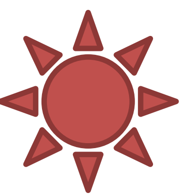


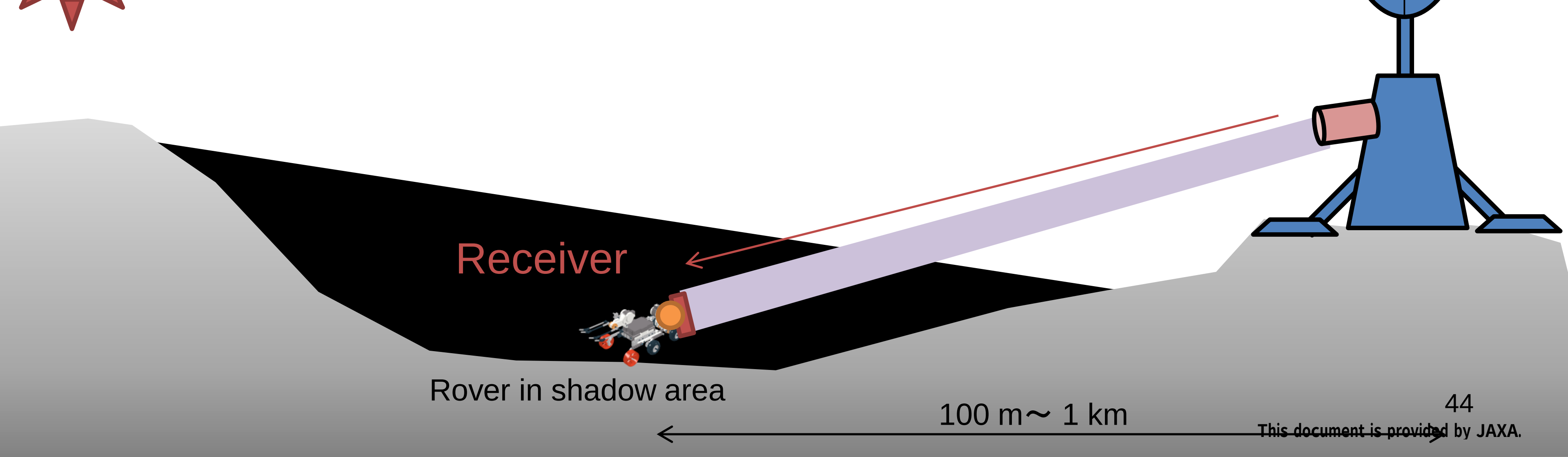
B. Cylindrical type



Laser power transmission

Transmission range	100 to 1000 m
Transmitter	Laser (800nm）
Diameter of Transmitter	Φ 100 mm class
Transmission power	10 to 100 W
Receiver	GaAs commonly used for Solar cell
Receiving power	More than 20W
Diameter of receiver	Φ300 mm class





Contents

- Objectives of Moon exploration
- Study of Lunar polar exploration mission
- Spacecraft design
- Technology development
- Summary

Summary

- JAXA thinks that the existence of lunar water ice affects exploration scenario. Therefore, measuring the existence of water ice on the surface is the top priority.
- Expanding landing technologies developed and demonstrated by SLIM, lunar polar mission is studied.

Reference (1/2)

- ISECG website: http://www.globalspaceexploration.org/
- ISECG Lunar Volatiles website: https://lunarvolatiles.nasa.gov/
- 月探査に関する懇談会：我が国の月探査戦略 http://www.kantei.go.jp/jp/singi/utyuu/tukitansa/100730houkokusho.pdf
- 文部科学省宇宙開発利用部会 国際宇宙ステーション・国際宇宙探査小委員会（第16回） 配付資料16-1, 第2次とりまとめ（案）, 2015/6/25, http://www.mext.go.jp/b_menu/shingi/gijyutu/gijyutu2/071/attach/1358968.h
- Resource Prospector Mission: http://www.nasa.gov/resource-prospector
- Tatsuaki Hashimoto, Takeshi Hoshino, Satoshi Tanaka, Masatsugu Otsuki, Hisashi Otake, Hitoshi Morimoto: Japanese moon lander SELENE-2 -Present status in 2009-, Acta Astronautica 68, pp1386-1391, 2011
- Tatsuaki Hashimoto, Takeshi Hoshino, Hisashi Otake, Satoshi Tanaka, Sachiko Wakabayashi, Hitoshi Morimoto, Koich Masuda, Makiko Ohtake, Masataku Sutoh, Takanobu Shimada: Japanese Lunar Polar Exploration Mission, 67th International Astronautical Congress, IAC-16-A3.2A.2, Guadalajara, Mexico, 2016
- 坂井 真一郎, 澤井 秀次郎, 福田 盛介, 櫛木 賢一, 佐藤 英一,上野 誠也, 鎌田 弘之, 北薗 幸一, 小島 広久,高玉 圭樹, 能見 公博, 樋口 丈浩,小型月着陸実証機「SLIM」プロジェクトの概要, 第60回宇宙科学技術連合講演会3C01, 函館, 2016

Reference (2/2)

- M. Nishiyama, H.Otake, T.Hoshino, T.Hashimoto, T.Watanabe, T.Tatsukawa, A.Oyama: SELECTION OF LANDING SITES FOR FUTURE LUNAR MISSIONS WITH MULTI-OBJECTIVE OPTIMIZATION, 46th Lunar and Planetary Science Coference, The Woodlands, Texas, March 16-20, 2015
- 西山万里、大嶽久志、星野健、橋本樹明、渡辺毅、立川智章、大山聖：月周回衛星「かぐや」のデータを用いた多目的最適化による月着陸最適候補地点の選定、宇宙科学情報解析論文誌、Vol.5、pp51-57、JAXA-RR-15-006、2016.3
- 嶋田貴信, 星野健, 若林幸子, 須藤真琢, 増田宏一, 橋本樹明, 坂本文信, 黒瀬豊敏, 久保田伸幸, 小野ゆかり, 前田修, 武内由成：月極域探査ミッション：機構系システム技術の検討状況、第60回宇宙科学技術連合講演会2C12、函館アリーナ、函館、2016年
- 須藤 真琢, 若林 幸子, 星野 健: 月極域探査ミッション：ローバの移動機構に関する検討, 第60回宇宙科学技術連合講演会2C11、函館アリーナ、函館、2016年
- 後藤大亮、鈴木拓明、大橋一夫、田中孝治、星野健、若林幸子、大嶽久志、田中智、宗正康、西城邦俊、橋本樹明：月面極域探査ミッションにおけるレーザーエネルギー伝送システムの有効性に係わる検討、第35回宇宙エネルギーシンポジウム、宇宙研、相模原、2016
- 若林 幸子, 星野 健: 月極域探査ミッション：月面掘削の実験的検討, 第60回宇宙科学技術連合講演会2C10、函館アリーナ、函館、2016年