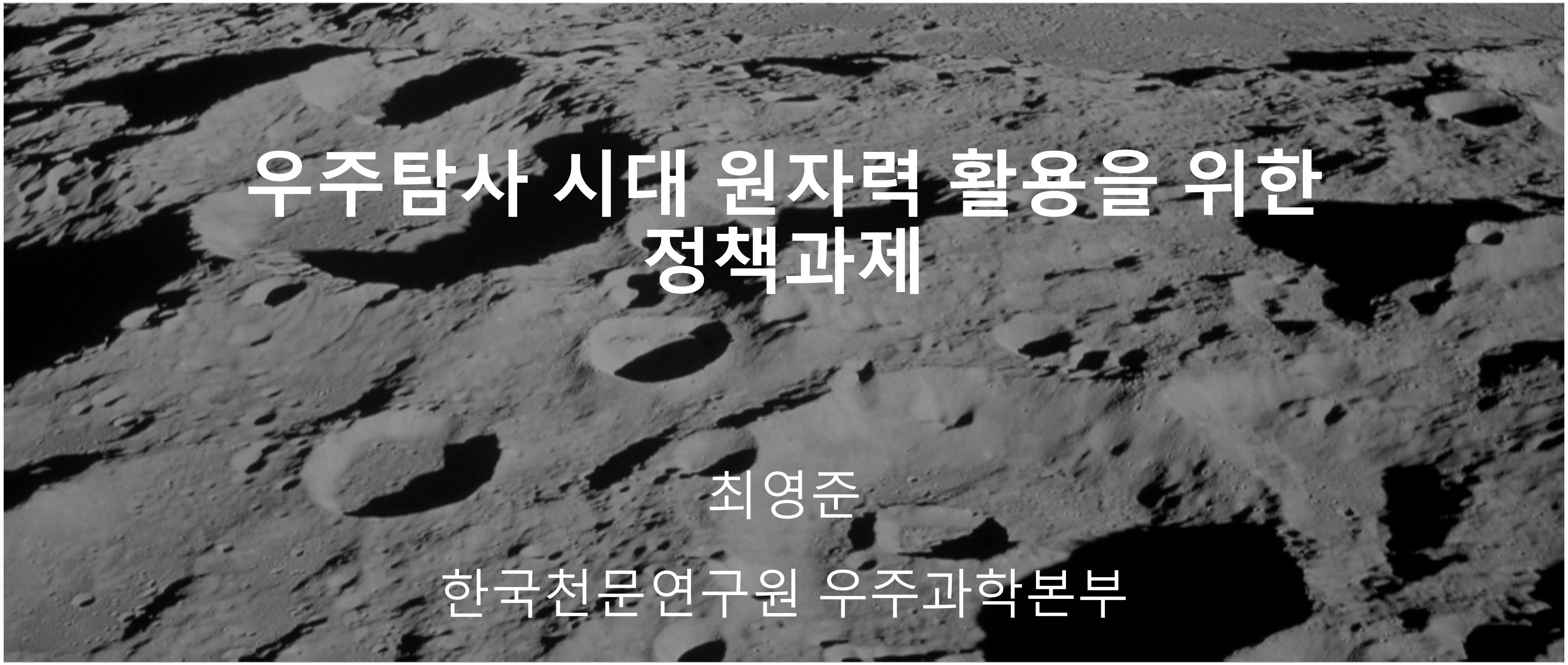


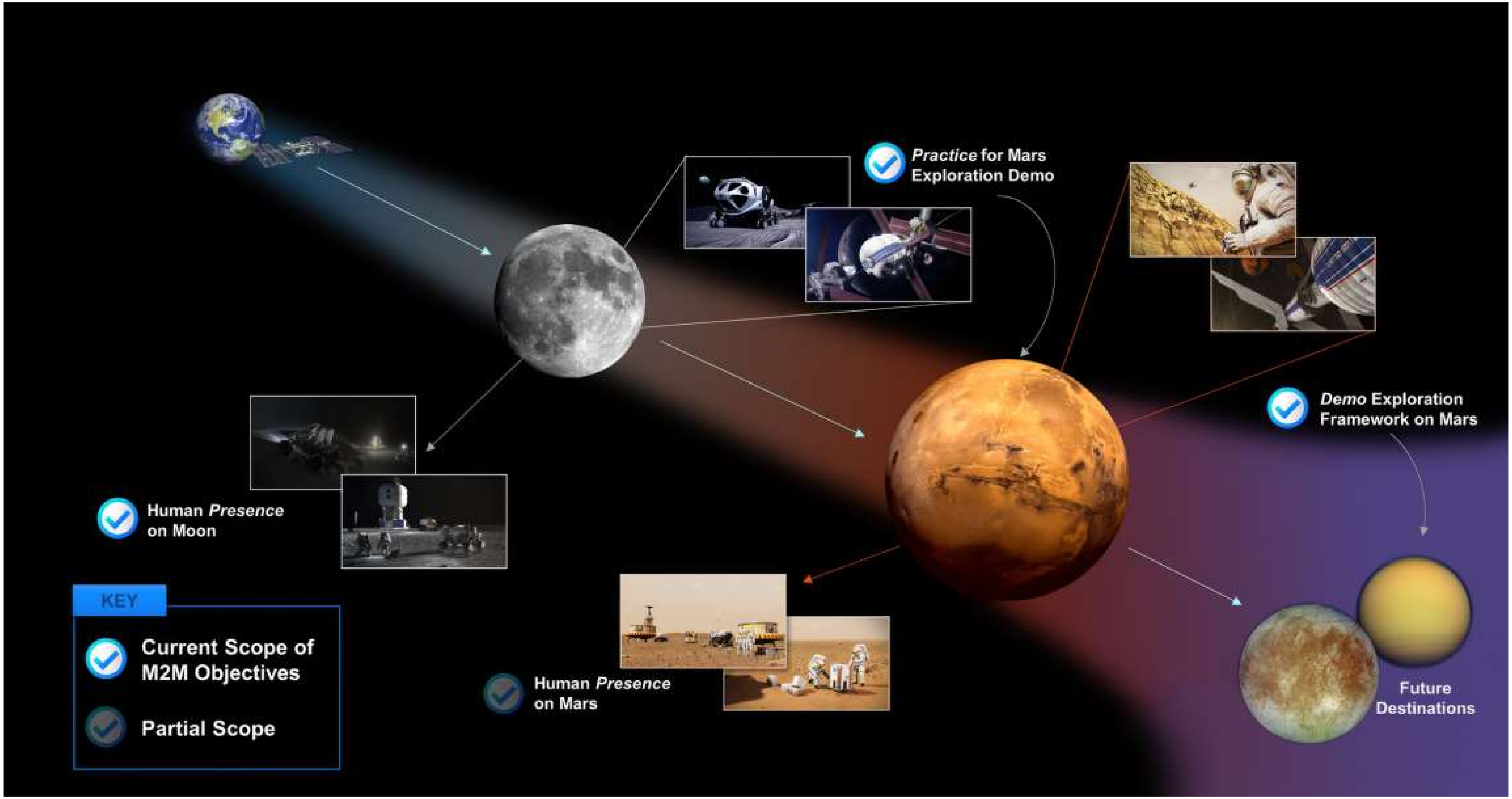
우주탐사 시대 원자력 활용을 위한 정책과제

최영준

한국천문연구원 우주과학본부

한국천문연구원
Korea Astronomy & Space Science Institute

NASA Moon-to-Mars

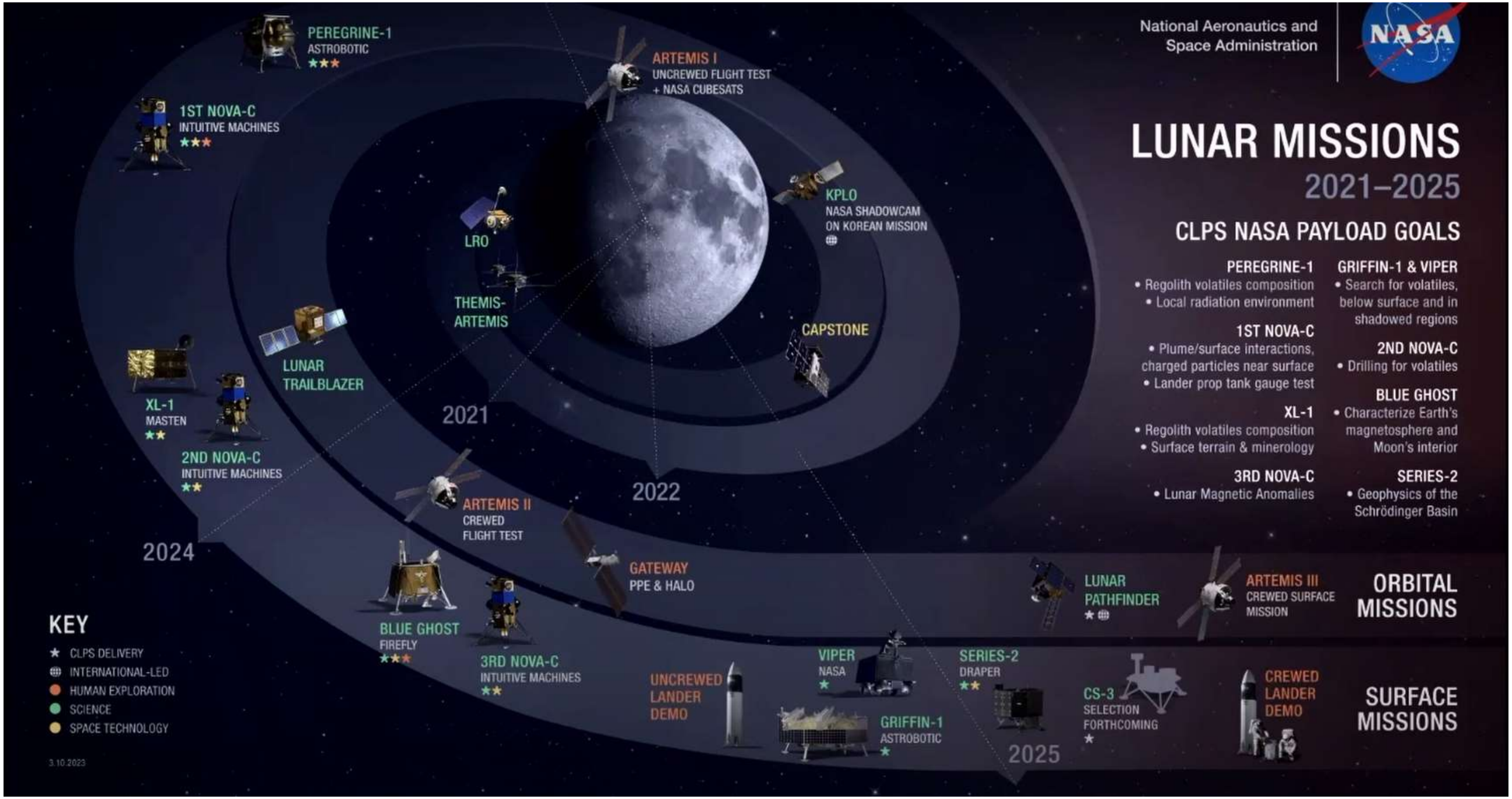


NASA M2M Strategy and Objectives

국가전략기술

우주항공·해양	▸ 대형 다단연소사이클 엔진
	▸ 우주관측·센싱
	▸ 달착륙·표면탐사
	▸ 첨단 항공가스터빈 엔진·부품
	▸ 해양자원탐사

NASA Lunar Missions



NASA Lunar Surface Science Workshop

Danuri (Korea Pathfinder Lunar Orbiter; KPLO)

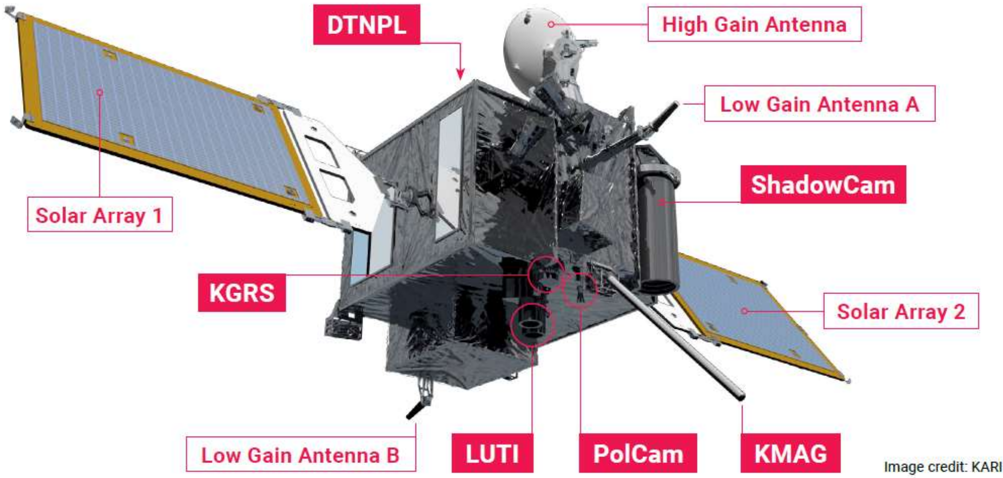


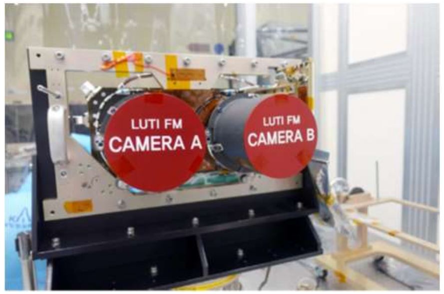
Image credit: KARI

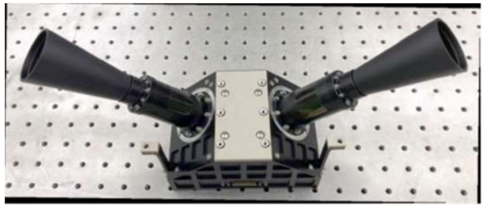
Launch

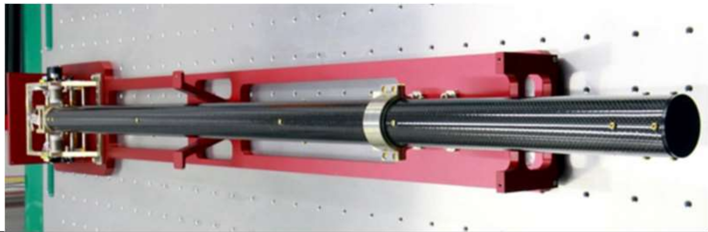
Time: Thursday, August 4, 2022 at 7:08 p.m. EST (23:08 UTC)
Location: Space Launch Complex 40 (SLC-40), Cape Canaveral

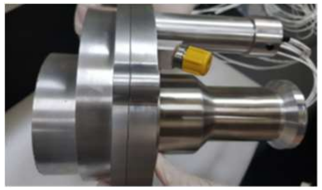
Satellite

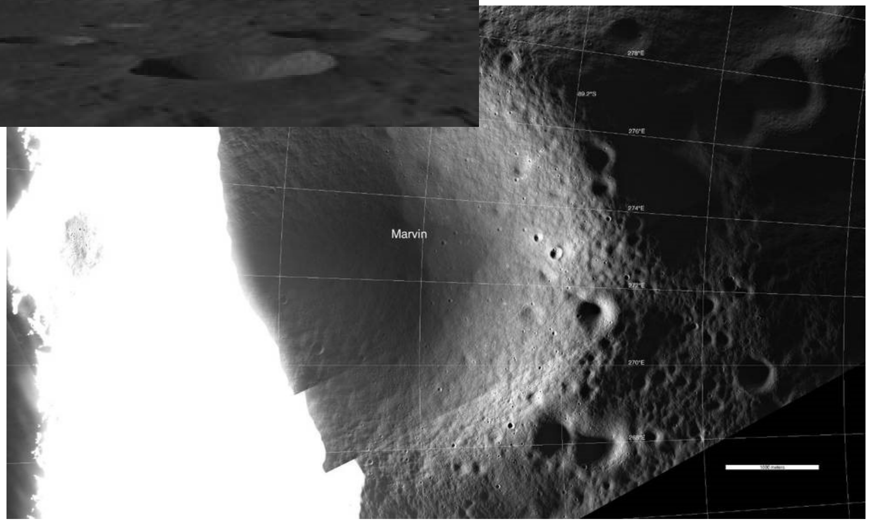
Weight: 678 kg (1495 lb)
Communications: S-band Uplink/Downlink, X-band Downlink
Electrical: Orbit-averaged 760W power generation
Dimensions: 3.18 x 6.3 x 2.67 meters (10.4 x 20.6 x 8.75 feet)
Mission Length: One year primary mission

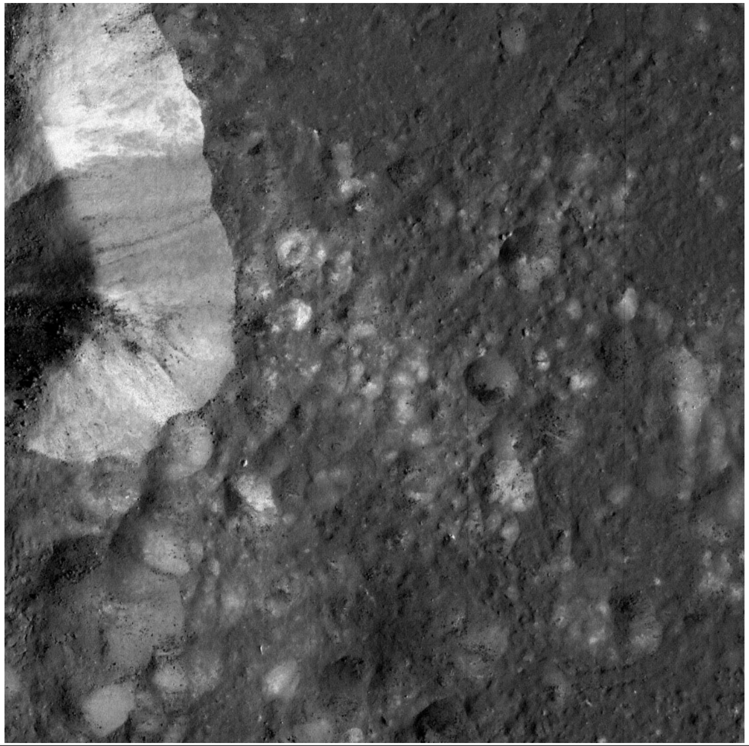









Marvin

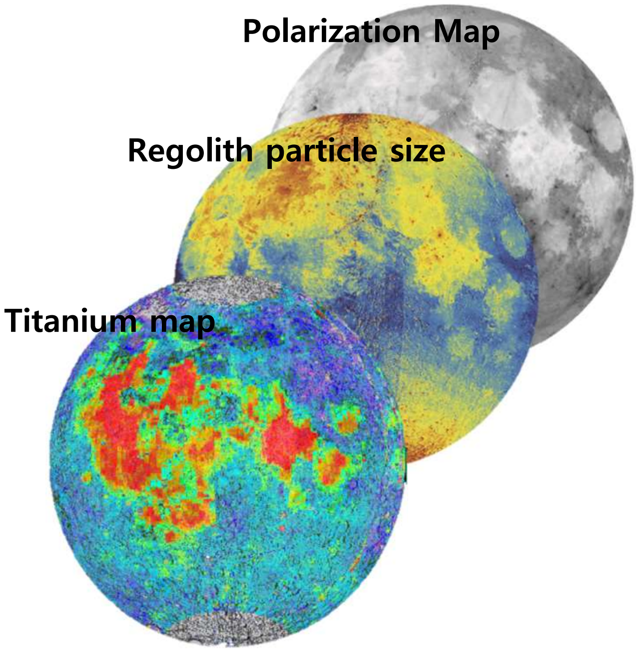


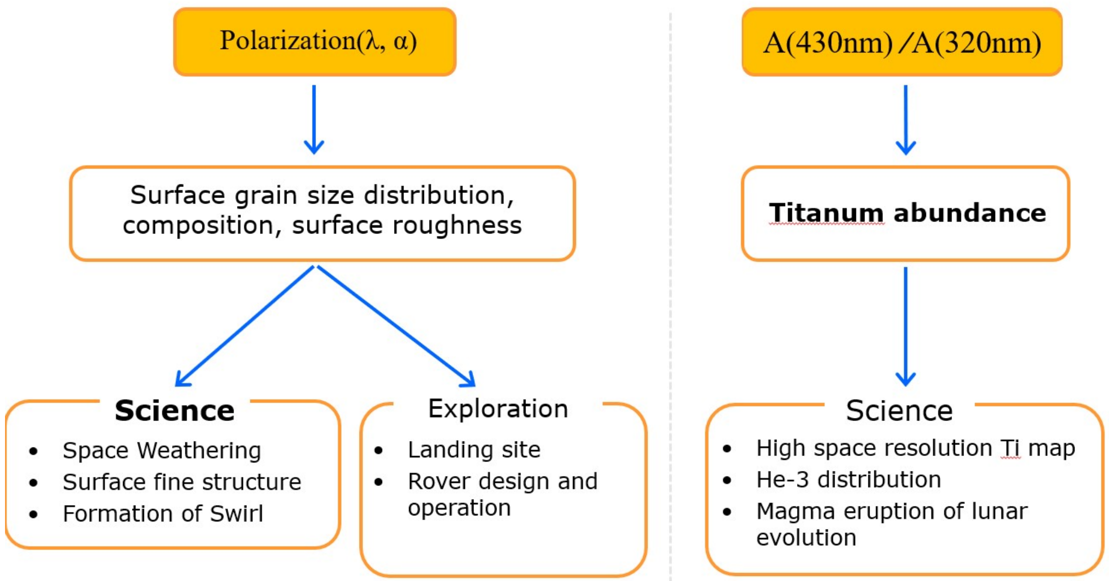
PolCam/KPLO

▣ **Understanding space weathering process on the surface of airless bodies**

- **Bands: 320(no polarization), 430(0, 60, 120), 750(0, 90) nm**
- **Mass: 3 kg**
- **Power: 15W (standby: ~ 8W)**
- **Spatial resolution: 70m**

경희대학교
KYUNG HEE UNIVERSITY

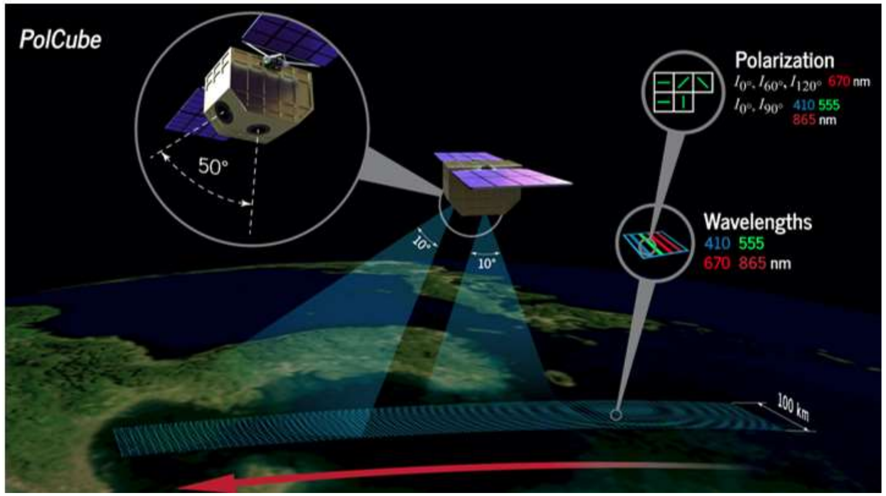




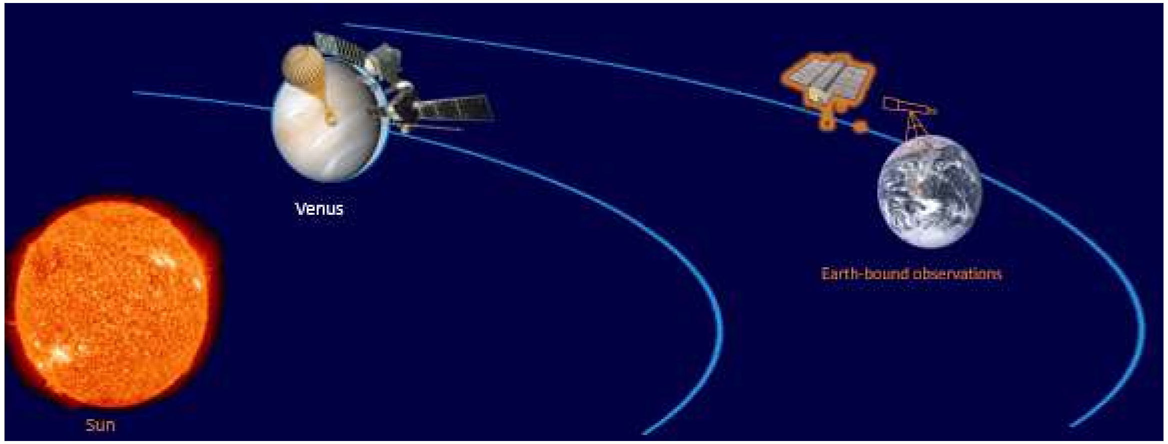
PolCube & CLOVE

The PolCube CubeSat Polarimeter Mission: A Collaboration between NASA and Korea Astronomy and Space Science Institute (KASI)

Snorre Stamnes, Beth Brumbaugh, Vianni Ricano Cadenas, Matthew Brown



Long-Term monitoring Venus w/IBS



NASA CLPS (Commercial Lunar Payload Services)

NASA		CLPS Provider
• Payloads (PRISM, Int'l cont. ~30%)	+	• Spacecraft/lander/rover • launch • Cruise, landing • Operation/communications, data return

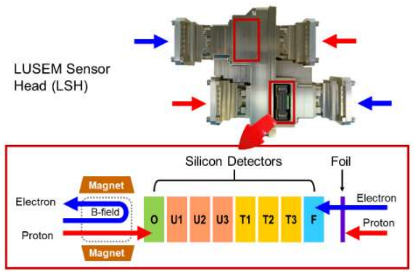
□ **Government-funded project (2020 ~ 2027) based on KASI-NASA Exploration Science Working Group Charter (May 2019)**

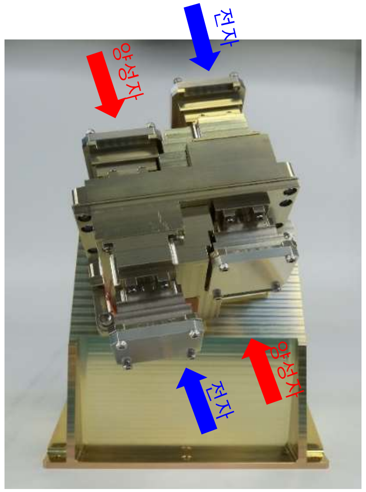
□ KASI will provide four science instruments to NASA CLPS program

LUSEM (Lunar Surface Environment Monitor)

□ Objectives

- ○ To measure high energy charged particle
- ○ To understand the space weathering process
- ○ To understand the interaction between the lunar surface and geomagnetical field





□ Key features

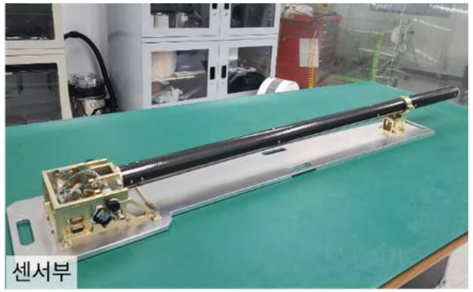
- ○ Electrons, protons
- ○ Both deep space and lunar surface sides
- ○ Wider energy range than Apollo
  Electron: 50 KeV ~ 3.8 MeV
  Proton: 50 KeV ~ 22.5 MeV

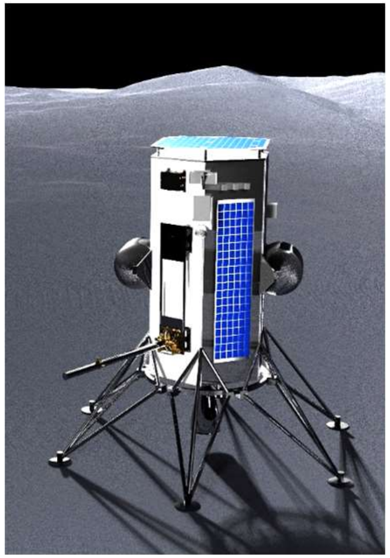
Specifications	LSH	IDPU
FoV	20° cone	-
Dimension (w/o MLI)	~168 x 175.7 x 230.8 ㎣	~291.0 x 308.0 x 131.7 ㎣
Mass	< 1.87 kg	< 7.53 kg
Op. Temperature	-24℃ ~ +80℃	-40℃ ~ +80℃
Power	7 W (heater)	13.79 W(op), 18 W (heater)

LSMAG (Lunar Surface Magnetometer)

□ Objectives

- ○ To measure the temporal variation of magnetic field strength and direction
- ○ To understand Paleo magnetic field by magnetic anomaly measurement
- ○ To understand the lunar surface environment





□ Key features

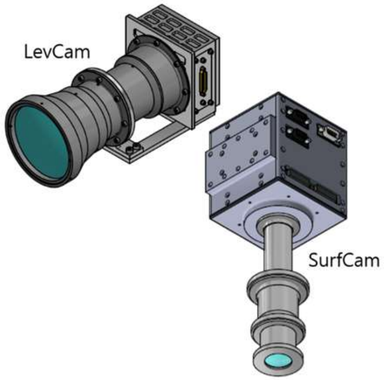
- ○ **Two MAG sensors and Accelometer →** small scale variation of magnetic field
- ○ Boom deploy after landing
- ○ Integrated study with other magnetometers on the lunar surface by CLPS

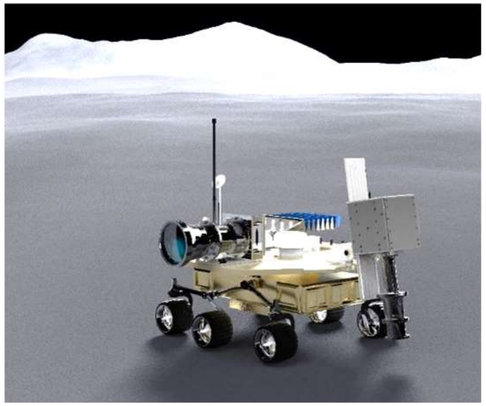
Specifications	Sensor (MAG unit)	Electronics (FCE unit)
FoV	± 2000 nT (<0.2 nT resolution)	
Dimension	1320 x 120 x 165 ㎣	152 x 155 x 79 ㎣
Mass	< 7 kg	
Op. Temerature	-55℃ ~ +70℃	-20℃ ~ +50℃
Power	< 6 W	

GrainCams (3-D Surface Grain Camera)

□ Objectives

- ○ To measure the micron-scale structure of the lunar surface
- ○ To measure the dust particle lofted/levitated by electrostatic force





□ Key Features

- ○ **SurfCam** Surface micron-scale structure camera
  LevCam Lofted/levitated particle camera
- ○ Lightfield camera technology
- ○ Self-lighting
- ○ Dust removal mechanism
- ○ Pristine surface far from landing site by rover
- ○ Temporal observation during lunar dusk

Specifications	SurfCam	LevCam
FoV	8.96° × 6.49°	7.45° × 5.96°
Dimension	~125 × 125 × 300 ㎣	~125 × 125 × 260 ㎣
Mass	< 4.1 kg	< 4.7 kg
Op. Temperature	-20℃ ~ +60℃	-20℃ ~ +60℃
Power	12 W	10 W

LVRAD (Lunar Vehicle Radiation Detector)

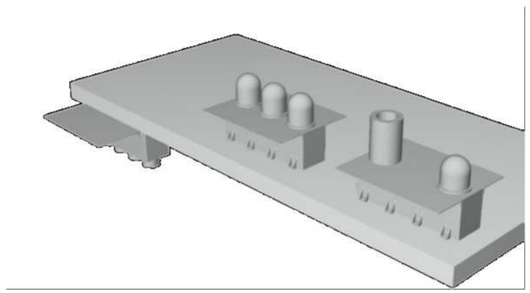
□ Objectives

- To understand the radiation environment on the lunar surface
- To understand the impact on humans of radiation exposure
- To estimate water existence below the lunar surface

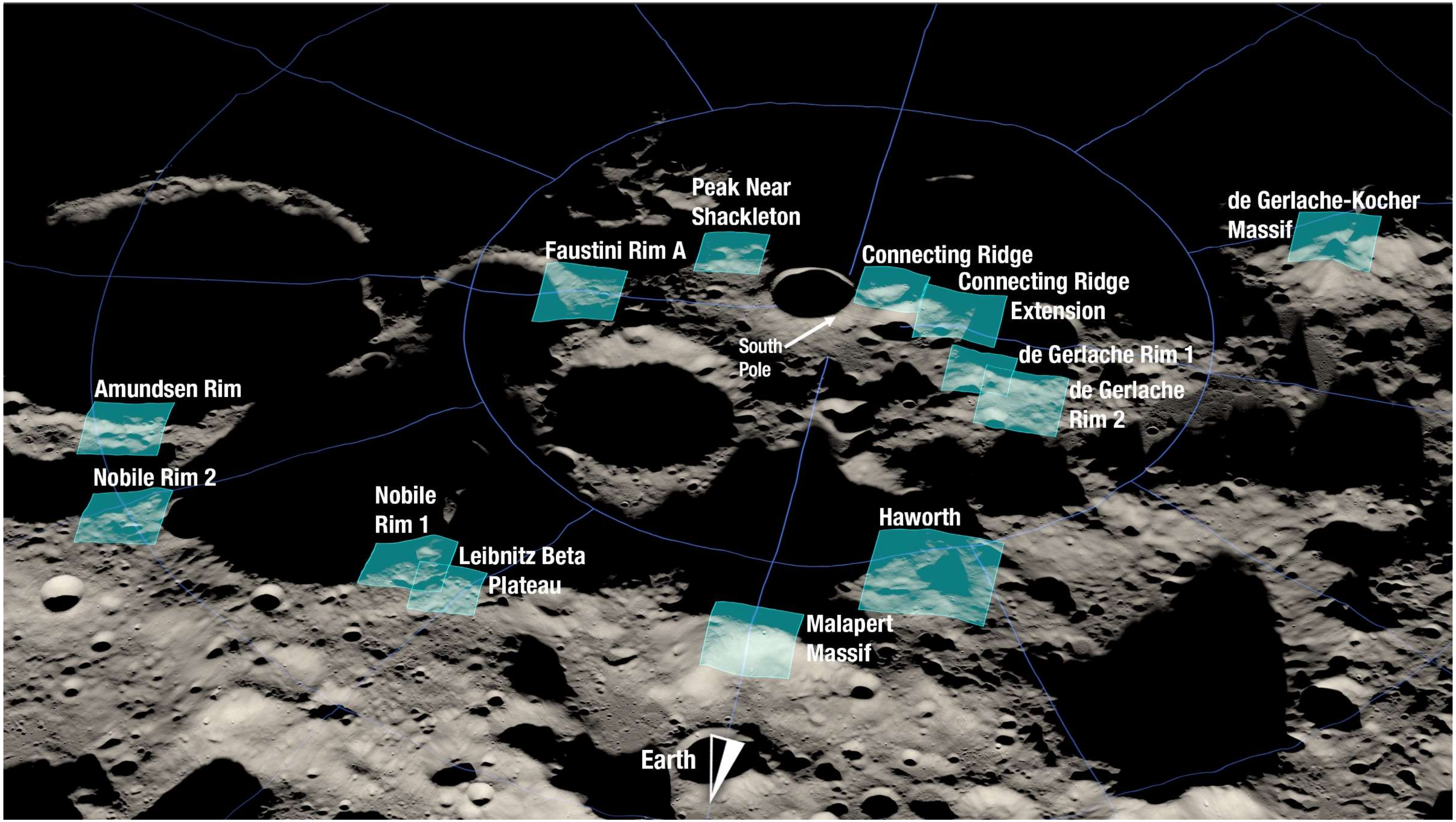
□ Key Features

- **PDS:** Particle Dosimeter and Spectrometer
- **TED:** Tissue Equivalent Dosimeter
- **NS-F:** Fast Neutron Spectrometer
  NS-E: Epithermal Neutron Spectrometer

Specifications	PDS + TED	NS-F	NS-E
Direction	Omni-direction		Lunar surface
Dimension	(each) 80 x 300 x 200 ㎣ x 3 modules		
Mass	(each) < 2.8 kg x 3 modules		
Op. Temperature	0℃ ~ +30℃		
Power	< 8.6 W + 25 W(heater)	< 11.5 W + 25 W(heater)	< 9.1 W + 25 W(heater)

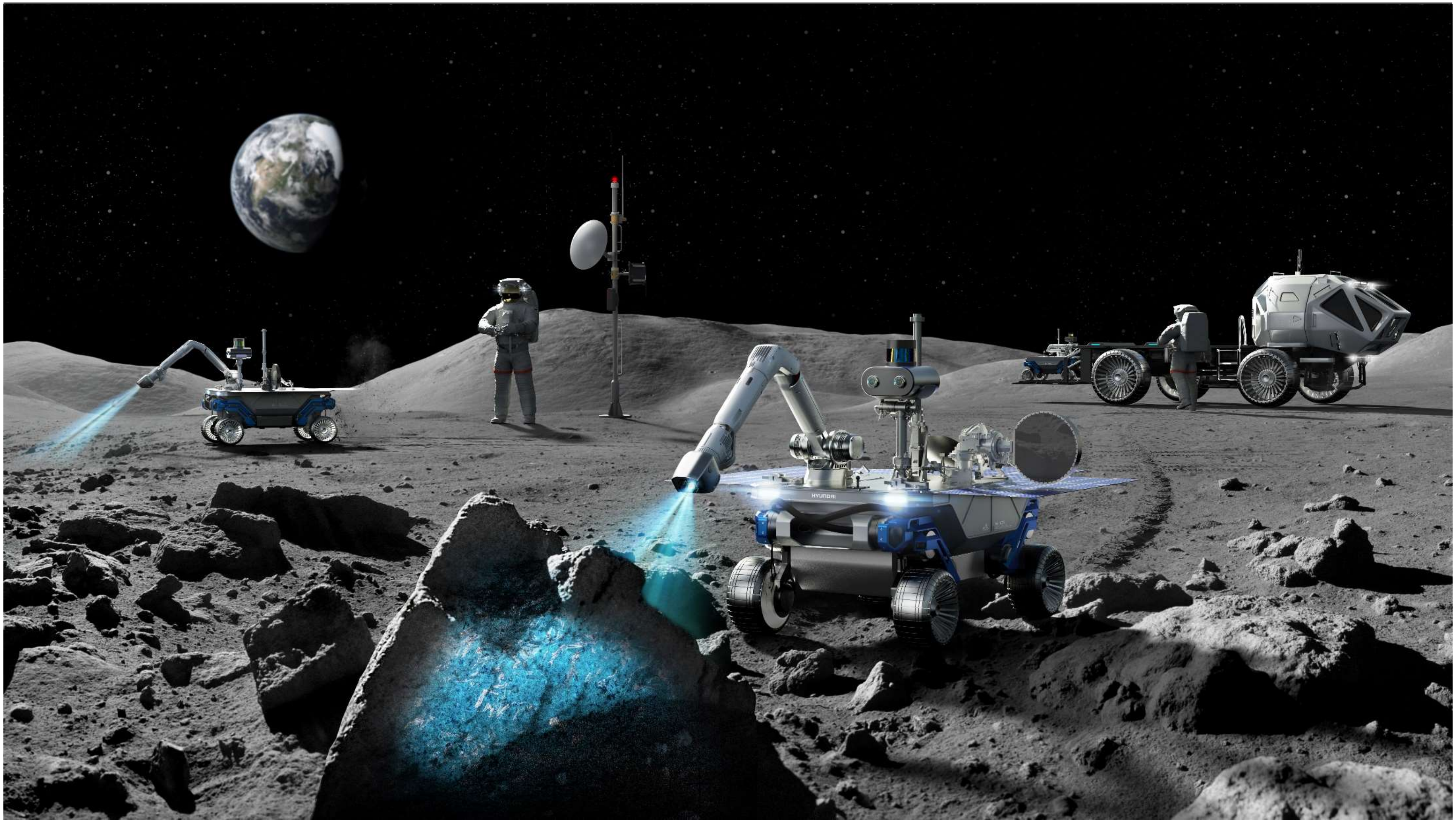


Artemis Landing Sites



NASA Lunar Surface Science Workshop

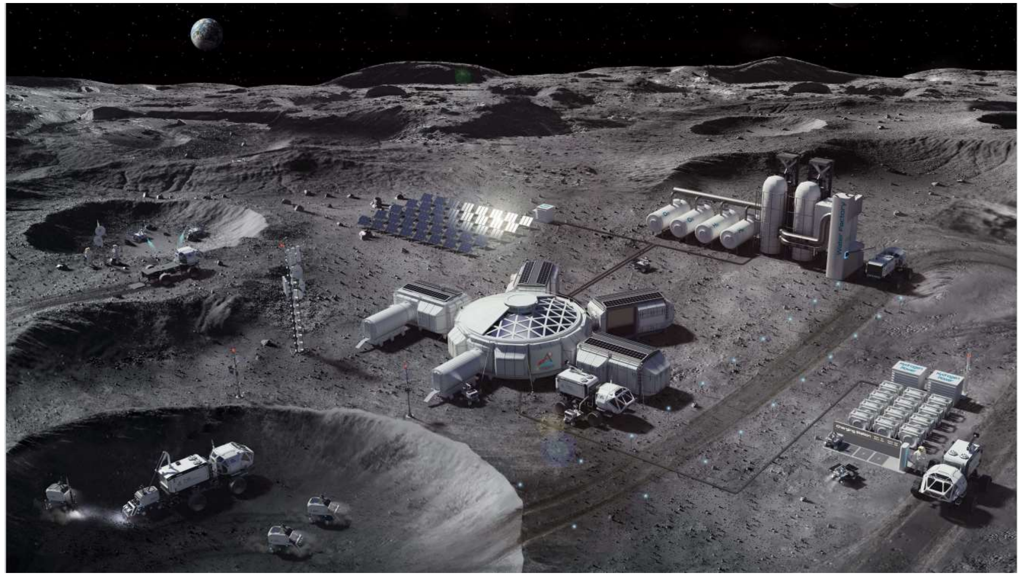
Lunar Surface Mobility



현대차그룹

Commercial Space Exploration

□ ISRU, Mobility/Robotics, Power Infrastructure(Nuclear, Fuel-cell, ...)

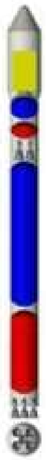


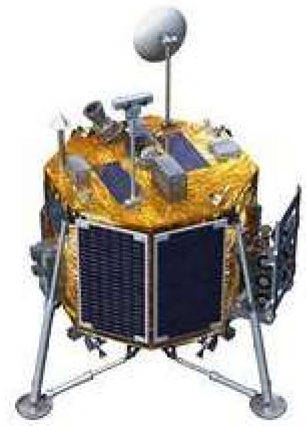
현대차그룹

Korean Lunar Lander

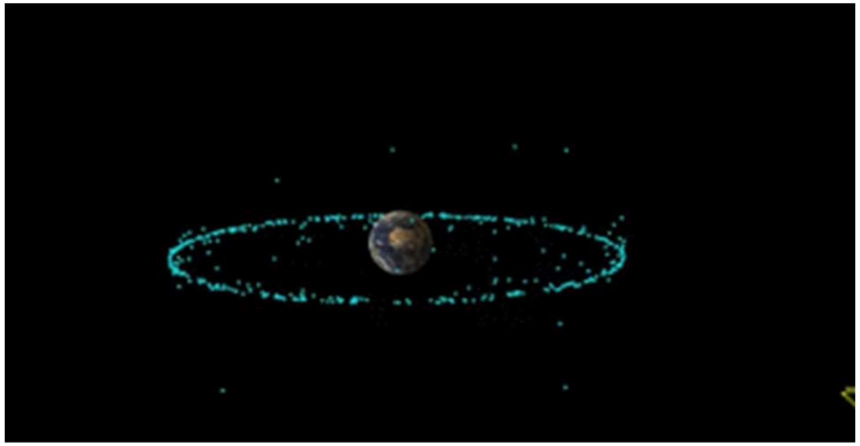
< 한국형발사체와 차세대 발사체 성능 비교 >

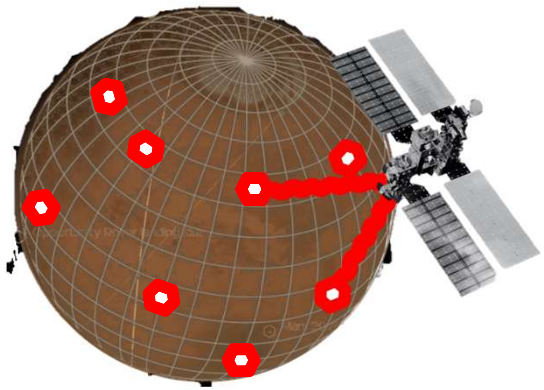
한국형발사체(KSLV-II)	발사 임무	차세대발사체(KSLV-III)
3.3톤	지구저궤도(LEO) 투입성능 고도 200 km (경사각 80도)	우주관광, 대형 화물수송 10.0톤
2.2톤	태양동기궤도(SSO) 투입성능 고도 500 km (경사각 98도)	다목적실용위성 등 7.0톤
0.1톤	달전이궤도(LTO) 투입성능 $C3 = -2\ km^2/s^2$	달탐사선/달착륙선, 우주자원탐사 1.8톤
0.0톤	화성전이궤도(MTO) 투입성능 $C3 = 10\ km^2/s^2$	행성/심우주 탐사, 소행성귀환 등 1.0톤





달착륙선 상상도/KARI

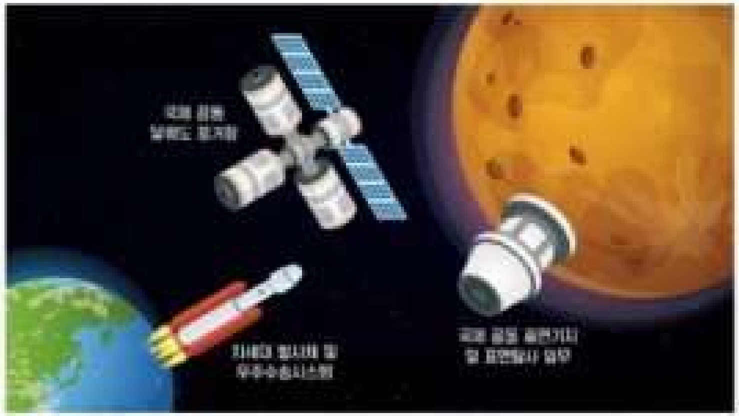




제 4차 우주개발진흥기본계획: 우주탐사

임무 1. 우주탐사 확대 : 담덕 계획

과학기술정보통신부



개요

인류의 우주 활동영역 확대에 따른 국제질서의 재편에 대응하여심우주 유/무인 활동을 주도적으로 추진할 핵심 역량 확보

핵심 목표 '32년까지 '달 착륙' ▶ '45년까지 '화성 착륙'

- (달화성 탐사) '32년 달착륙선, '35년 화성 궤도선, '45년 화성 착륙선
- (ISRU) ~'35년 달표면 기술 시연 ▶ '35년 ISRU기반 달기지 건설 시작

추진 전략 달화성 탐사의 독자적 역량 확보와 동시에 국제협력을 통한 ISRU 달 기지 건설 활동을 시작

- 발사체, 무인 궤도선, 착륙선, 운송선의 독자적 능력 확보
- 궤도정거장, 달·화성 표면 기지 등의 분야에서는 국제협력 강화
- ISRU 기초 기술을 확보하고 지상의 산업 역량 적극 활용
- 유인 우주 관련 선행 기술 확보 신속히 착수

아르테미스 계획

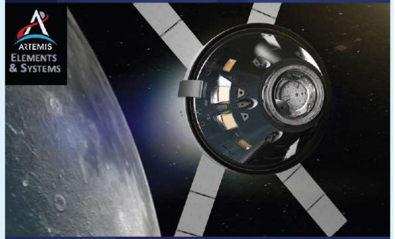
SPACE LAUNCH SYSTEM BLOCK 1

Key Components and Functions

- High payload mass and volume capability
- Ability to send Orion, crew, and cargo to the lunar vicinity on a single mission

The Space Launch System (SLS) is a powerful, advanced rocket for a new era of human exploration beyond Earth's orbit. SLS will launch astronauts aboard the Orion spacecraft. SLS is designed to safely send humans to deep space and can support a variety of complex missions.

ORION CREW VEHICLE



Key Components and Functions

- Habitable & stowage volume
- ECLSS
- Crew quarters
- Independent Guidance, Navigation, and Control (GN&C)
- Independent communication system
- Independent power generation
- Independent thermal control

The Orion spacecraft is designed to be launched on the Space Launch System (SLS) and is capable of carrying and sustaining a crew of four for 21 days (with on-board consumables) or longer (when docked to a habitation system that allows Orion systems to be powered down).

COMMERCIAL LUNAR PAYLOAD SERVICES

Key Components and Functions

- End-to-end payload delivery services
- Small to medium payloads, initially up to ~500 kg
- Delivery of science instruments and technology demonstration payloads on and at the Moon

The Commercial Lunar Payload Services (CLPS) provides commercial delivery services for small and medium payloads to the lunar surface. By engaging American companies to deliver key science and technology payloads, CLPS is crucial to NASA's strategic goal of catalyzing lunar economic growth. CLPS is leading America's return to the lunar surface and is an important predecessor to the eventual return of humans to the lunar surface in 2024.

VOLATILES INVESTIGATING POLAR EXPLORATION ROVER

Key Components and Functions

- Carries the Neutron Spectrometer System (NSS), Near-Infrared Volatiles Spectrometer System (NRVSS), Mass Spectrometer Observing Lunar Operations (MSolo), and the TRIDENT drill
- Driving distance of 10s of km
- Survives the lunar night for 100-day mission duration

Planned for delivery to the lunar surface in 2023 and about the size of a golf cart, the Volatiles Investigating Polar Exploration Rover (VIPER) will roam several miles, using its four science instruments —including a 1-meter drill—to sample various soil environments. VIPER will collect about 100 days of data that will be used to inform the first global water resource maps of the Moon.

EXPLORATION GROUND SYSTEMS

Key Components and Functions

- SLS Launch Pad 39B
- Crawler-transporter
- Vehicle Assembly Building
- Mobile Launcher
- Landing pads
- Landing runway

EGS was established to develop and operate the systems and facilities necessary to process and launch government and commercial rockets and spacecraft during assembly, transport, and launch and return of rocket stages or return of winged spacecraft to landing sites.

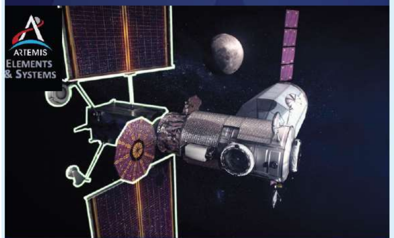
DEEP SPACE NETWORK

Key Components and Functions

- Upgraded to provide 100 Mbps downlink, 20 Mbps uplink
- 2 antennas upgraded at each DSN complex: Goldstone, Canberra, and Madrid
- Services compatible with international partner ground stations

Upgrades to the Deep Space Network's (DSN) 34-meter subnet will provide continuous high-rate command and telemetry services to the Gateway, Human Landing System, and other Artemis space systems. These new services are required to support human operations at the Moon and to return high volumes of scientific data from payloads planned for the Gateway and the Lunar surface. The Deep Space Network upgrades are critical to meeting the nation's challenge to land humans on the Moon by 2024 and following human exploration of Mars.

POWER AND PROPULSION ELEMENT

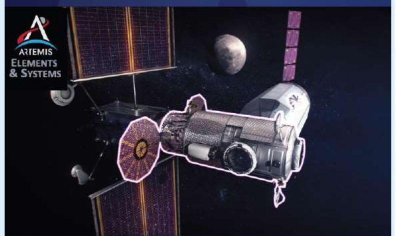


Key Components and Functions

- High-gain communications with Earth, space-element to space-element communication, and lunar surface relay
- Command and control capability
- Provides translation delta velocity (ΔV) with 12.5 kW electric propulsion
- Maintains attitude via non-propulsive (e.g., momentum wheels) and propulsive (e.g., thrusters) control
- Generates 60 kW+ power
- Transfers power to the Gateway elements
- Thermal control
- Accommodations for science and technology demonstration payloads

The Power and Propulsion Element (PPE) will be integrated with the HALO and launched to lunar Near Rectilinear Halo Orbit.

HABITATION AND LOGISTICS OUTPOST



Key Components and Functions

- Habitable and stowage volume
- ECLSS pressure control system, inter-modular ventilation
- Distributed Integrated Modular Avionics (DIMA) architecture
- Power pass-through for other Gateway elements
- Thermal control
- Provide communications with visiting vehicle and lunar surface
- Support external robotics & payloads via LPGFs and SORIs

The Habitation and Logistics Outpost (HALO) will be integrated with the PPE and launched on a commercial vehicle to the Near Rectilinear Halo Orbit. The HALO provides radial and axial IDSS compatible docking ports for visiting vehicles.

아르테미스 계획

DEEP SPACE LOGISTICS

Key Components and Functions

- Independent guidance, navigation, and control
- Independent communication system
- Independent power generation and thermal control
- Cargo resupply and trash disposal
- Up to 5,000 kg of pressurized payload/cargo mass
- From 1,000 to 2,600 kg of unpressurized payload/cargo mass
- Stowage volume

Gateway Logistics Services deliver cargo, science experiments, and supplies to the Gateway, such as sample collection materials and other items the crew may need on the Gateway and during their expeditions on the lunar surface. They also provide stowage volume while attached to Gateway and trash disposal upon departure.

EXPLORATION EXTRAVEHICULAR ACTIVITY SYSTEM

Key Components and Functions

- High mobility pressure garment
- Portable Life Support System with motherboard-style packaging
- Integrated communications and informatics systems
- Common system servicing and geology tools
- Vehicle interface systems and equipment

The destination-agnostic Exploration Extravehicular Activity System (xEVA) is built for both Moonwalks and spacewalks and is designed for upgrades as technologies advance and missions evolve. The vehicle interface systems and equipment feature a common design but can be customized to fit into multiple elements of the Artemis campaign. xEVA is designed for a long service life and leverages systems from ISS testing for most planned servicing tasks.

LUNAR GROUND STATIONS

Key Components and Functions

- Global network of 18-meter class antennas
- Services compatible with DSN's 34-meter subnet
- Additional capacity for Artemis systems
- Potential for commercialization

Lunar Ground Stations (LGS) will create a global network of 18-meter class antennas critical to meeting future demand for communication and tracking services created by sustained Lunar exploration. Additional capacity is required to service Artemis robotic and support elements such as CLPS, LSSMS, GLS, and LunaNet. Migrating traffic from the DSN's 34-meter subnet to the new LGS will preserve DSN capacity for NASA's planetary science missions and human exploration of Mars. NASA will pursue opportunities for commercial entities to provide LGS service.

LUNANET

Key Components and Functions

- Networked communication services
- Lunar PNT services
- Science and alert services
- Architected to accommodate NASA, commercial, and international partner assets
- Inclusive of lunar relay, lunar surface, and Earth assets
- Mars forward architecture

LunaNet is envisioned as a framework of standards, protocols, and interfaces to support a scalable communications and navigation network for NASA and other partners in cis-Lunar space. LunaNet will provide the basis for seamless robotic, science, and human operations by providing networked communication, PNT, science, and alert services. The LunaNet architecture is scalable to meet immediate mission needs at the Lunar south pole and Lunar far side and to provide global Lunar coverage as demand grows.

HUMAN LANDING SYSTEM

Key Components and Functions

- Habitable volume
- Power generation
- Energy storage
- Propulsion (chemical)
- Thermal control
- Avionics
- Communications
- GN&C
- ECLSS, tanks and consumables
- EVA equipment/ accommodations

The Human Landing System will be the final vehicle that the crew board for the descent to the lunar surface. After surface expeditions, the crew will return to the HLS for ascent back to lunar orbit before the return trip home to Earth. Early HLS are expected to provide surface access for two crew, with later, more sustainable HLS accommodating four crew on the surface.

LUNAR TERRAIN VEHICLE

Key Components and Functions

- Limited power generation
- Energy storage
- Avionics
- Communications
- EVA / crew accommodations (2 crew)
- Payload stowage volume
- Tele-operated science accommodations

The Lunar Terrain Vehicle (LTV) is the surface transportation system for the 2024 human lunar return. Significantly extends the range of crew excursions, enabling more science, resource prospecting, and exploration. The LTV also can be tele-operated to perform science during the non-crewed lunar periods and transport small deployable assets to desirable locations.

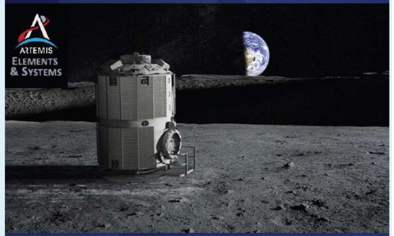
HABITABLE MOBILITY PLATFORM

Key Components and Functions

- Habitable volume
- ECLSS
- Avionics
- Communication
- Power generation and storage
- EVA suit accommodation

The Habitable Mobility Platform (HMP) will vastly expand the range of possible excursions and enable new science, resource prospecting, and exploration. The HMP will be used for analogs of Mars surface activities on the Moon to reduce risk and optimize operations concepts. The lunar HMP will be greatly leveraged for the Mars HMP.

FOUNDATION SURFACE HABITAT

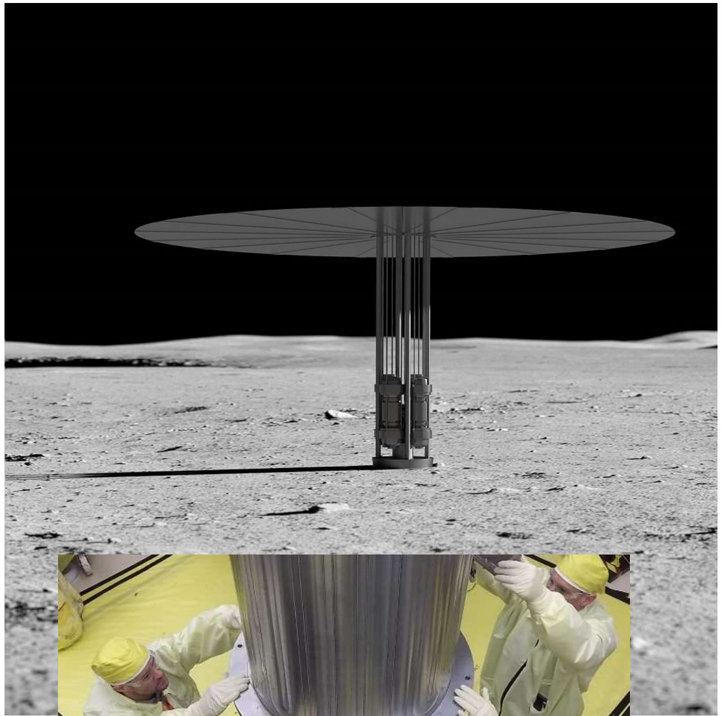


Key Components and Functions

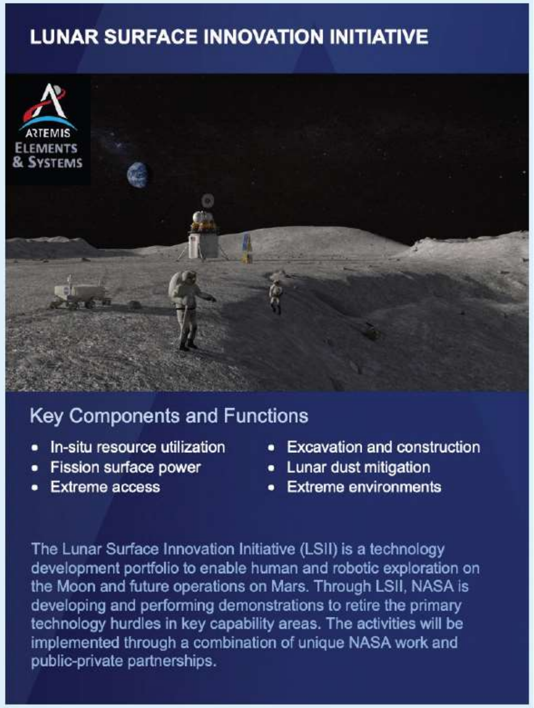
- Habitable and stowage volume
- ECLSS
- Power pass-through for other elements
- Thermal control
- Provide communications with surface elements and Gateway
- Support external robotics & payloads
- EVA suit compatibility or airlock

The Foundation Surface Habitat (FSH) will provide a continuous, long-term outpost for crew to visit for up to 60 days. Delivered through commercial / international partnerships, the FSH will provide the support necessary for extended human occupation.

아르테미스 계획



LUNAR/MARS SURFACE POWER
ARTEMIS ELEMENTS & SYSTEMS
Key Components and Functions
• Surface architecture depends on power capability delivered with landers
• Power level dependent on propellant type and transfer strategy
• Lunar and Mars commonality assessment desired
To support sustainable operations through the lunar night and empower human exploration of Mars, NASA is developing a modular nuclear fission power source up to 10 kW. Near-term demonstration on the lunar surface can provide reliable power to human landers, habitats, and ISRU systems continuously through eclipse periods and provide a proving ground to extend the capability as a power source that will enable Mars exploration.



LUNAR SURFACE INNOVATION INITIATIVE
ARTEMIS ELEMENTS & SYSTEMS
Key Components and Functions
• In-situ resource utilization
• Fission surface power
• Extreme access
• Excavation and construction
• Lunar dust mitigation
• Extreme environments
The Lunar Surface Innovation Initiative (LSII) is a technology development portfolio to enable human and robotic exploration on the Moon and future operations on Mars. Through LSII, NASA is developing and performing demonstrations to retire the primary technology hurdles in key capability areas. The activities will be implemented through a combination of unique NASA work and public-private partnerships.

Utilities in Moon and Mars Era

Lunar Infrastructure (LI) Goal: Create an interoperable global lunar utilization infrastructure where U.S. industry and international partners can maintain continuous robotic and human presence on the lunar surface for a robust lunar economy without NASA as the sole user, while accomplishing science objectives and testing for Mars.

LI-1[L]:	Develop an incremental lunar power generation and distribution system that is evolvable to support continuous robotic/human operation and is capable of scaling to global power utilization and industrial power levels.
LI-2[L]:	Develop a lunar surface, orbital, and Moon-to-Earth communications architecture capable of scaling to support long term science, exploration, and industrial needs.
LI-3[L]:	Develop a lunar position, navigation and timing architecture capable of scaling to support long term science, exploration, and industrial needs.
LI-4[L]:	Demonstrate advanced manufacturing and autonomous construction capabilities in support of continuous human lunar presence and a robust lunar economy.
LI-5[L]:	Demonstrate precision landing capabilities in support of continuous human lunar presence and a robust lunar economy.
LI-6[L]:	Demonstrate local, regional, and global surface transportation and mobility capabilities in support of continuous human lunar presence and a robust lunar economy.
LI-7[L]:	Demonstrate industrial scale ISRU capabilities in support of continuous human lunar presence and a robust lunar economy.
LI-8[L]:	Demonstrate technologies supporting cislunar orbital/surface depots, construction and manufacturing maximizing the use of in-situ resources, and support systems needed for continuous human/robotic presence.
LI-9[L]:	Develop environmental monitoring, situational awareness, and early warning capabilities to support a resilient, continuous human/robotic lunar presence.

Mars Infrastructure (MI) Goal: Create essential infrastructure to support initial human Mars exploration campaign.

MI-1[M]:	Develop Mars surface power sufficient for an initial human Mars exploration campaign.
MI-2[M]:	Develop Mars surface, orbital, and Mars-to-Earth communications to support an initial human Mars exploration campaign.
MI-3[M]:	Develop Mars position, navigation and timing capabilities to support an initial human Mars exploration campaign.
MI-4[M]:	Demonstrate Mars ISRU capabilities to support an initial human Mars exploration campaign.

Summary

□ 국가적으로 달-화성 탐사를 위한 장기적인 인프라에 투자할 필요

- ○ Nuclear fission power (Kilopower)

□ 우리 달착륙선용 RTG 또는 RHU 적극 활용

□ (기타)우주용 반도체 시험을 위한 제반 시험시설