Planetary Exploration 2061

STEP 3 : Synthesis Workshop

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Relevant Technologies and Validation Assumptions for ISRU

Michel Blanc,
[1]IRAP，OMP, France
[2]JEWEL, DFH, CAST, China
michel.blanc@irap.omp.eu

LinLi Guo
JEWEL, DFH, CAST, China
guolinli@spacechina.com

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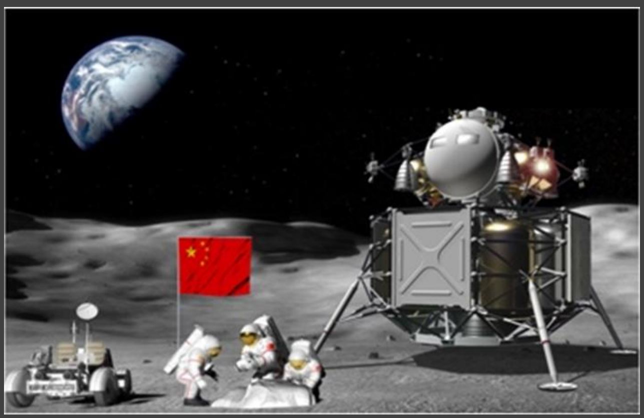
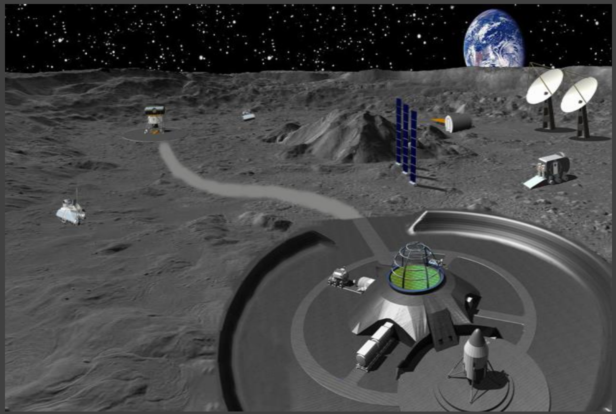
1 The Value of ISRU Technology

How to make humans multi-planet species?



Manned lunar Landing
(2024~ 2030)



Manned lunar base
(2030~2040)

Manned Mars Landing and
Mars Base
(after 2040~2050)
Image credit: NASA

The most important goal of ISRU is to provide the consumables support for human long-term survival and work on the lunar or Mars.

For Mars, ISRU is more important than lunar. but It is more practical to verify ISRU technology on the Moon base.

How can ISRU benefit for Moon or Mars base ?

Based on the size of the base and the technical difficulty of ISRU, we believe that:

◆ For Pre-Outpost

— Resources determination ;
— Proof of concept of ISRU capabilities and link to commercialization ;
— Site characterization, …

◆ For Early Moon Outpost

— Initial ISRU capabilities ;
— Crew scale oxygen production, storage & transfer；
— Crew scale water production, storage& transfer； (making hydrogen available?)
— In-situ fabrication and repair ;(3D printer for making shield for base?)
— Other capabilities: Excavation, site preparation, …

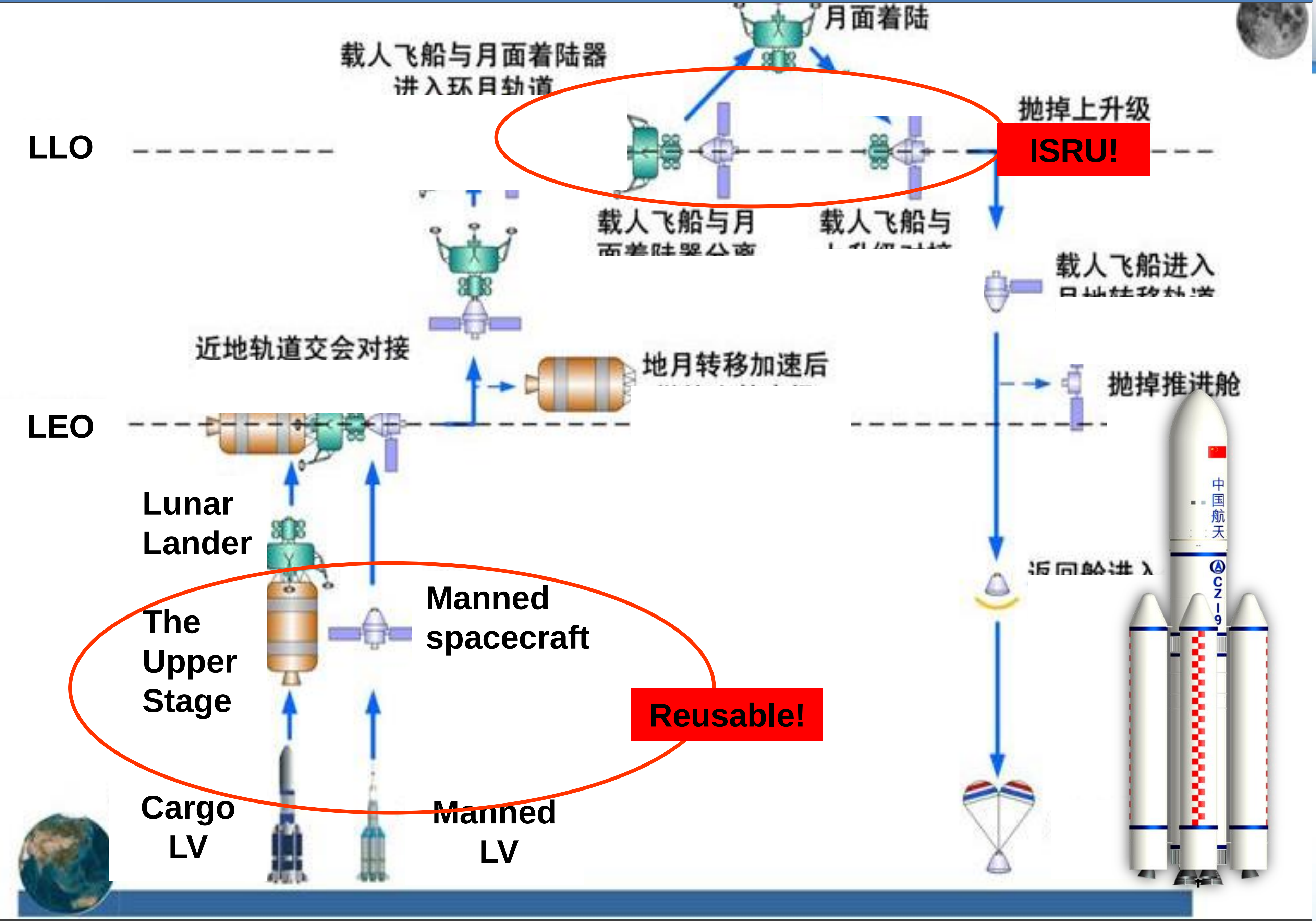
◆ For Mid-Term Moon or Mars Base

— Propellant production for Lander ;(LOX/LH, LOX/liquid methane?)
— Consumables for habitation and pressurize drover ;
— Construction and fabrication demonstrations ;
— Disassembly and utilization of obsolete spacecraft equipment demonstrations,…

◆ For Long-Term Moon or Mars Base

— In-situ manufacturing and assembly ;
— Habitat construction ; (Glass products made from lunar soil?)
— In-situ life support ;
— Power generation for Moon and Mars,…

How can ISRU benefit for Flight Mode?



ISRU Technique Process

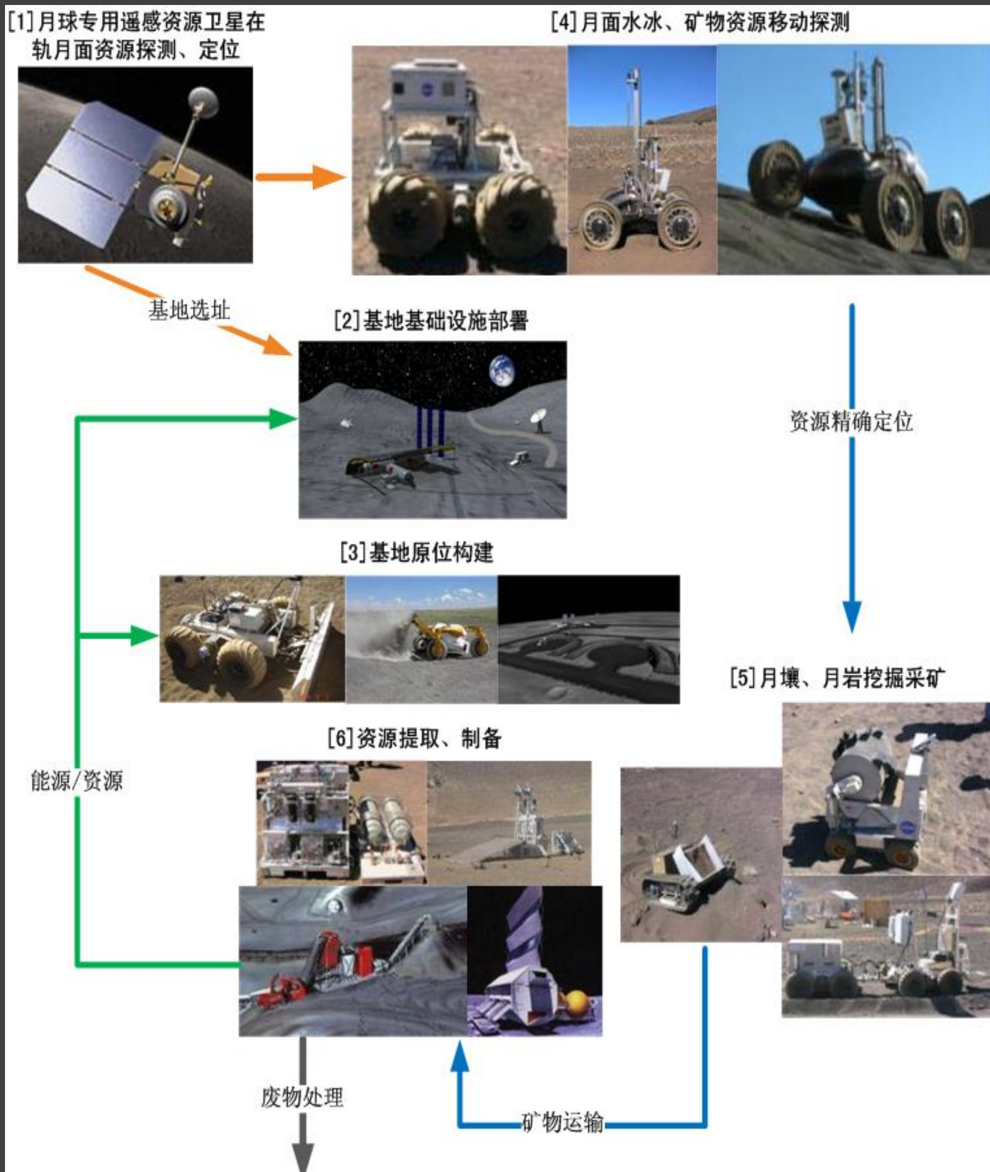


Image credit: NASA /ESA

① Resource Prospector

- swarm microsatellites, cube satellites, constellations
- swarm rovers in situ, mapping

② Deployment and construction of infrastructure

- Sustainable Power, GNC, communication
- Deployment Sampling device
- Deployment Habitant

③ Sampling , separation and manufacture

- Material handling sampling and separation
- Surface manufacturing with In-Situ Resources
- 3D printer

④ Transfer and Storage

- Storage of cryogenic liquids
- ZBO
- VLVT spacecraft

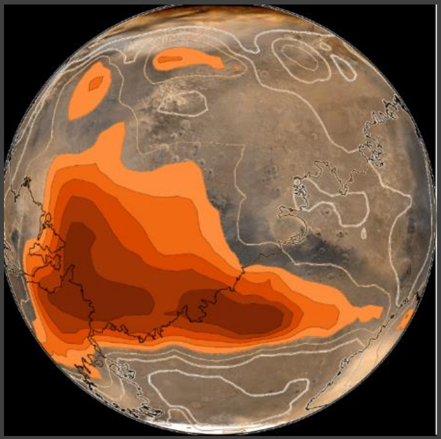
⑤ Waste disposal and recycling

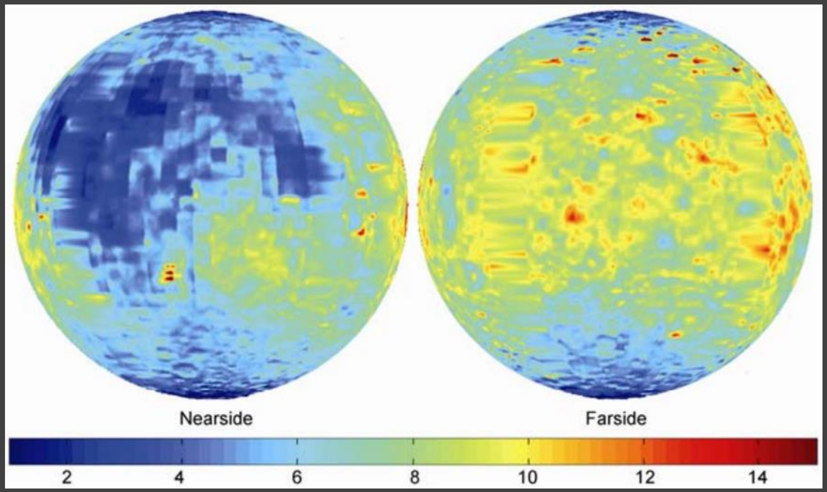
- Recycling of lunar or Mars resource
- Environment Protection

2. The Relevant Technologies of ISRU

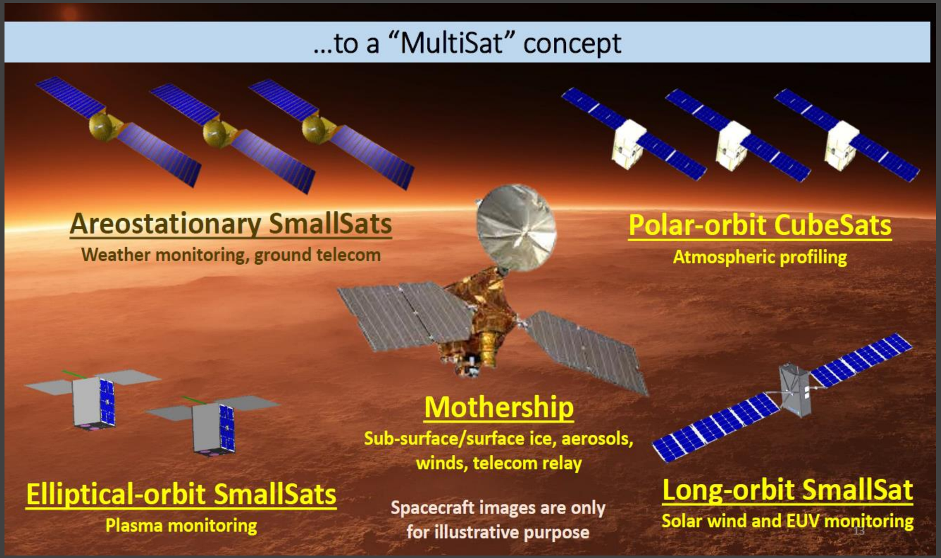
① Resource Prospector(RP): Exploration of Lunar or Mars Resources

- ✓ The three-dimensional mapping of the lunar or Mars resources is completed by using Mult-microsatellites or their constellations, and the resource maps that can be further developed and utilized are drawn.
- ✓ From an Aerostationary Smallsat Concept to a “multi-sats” concept





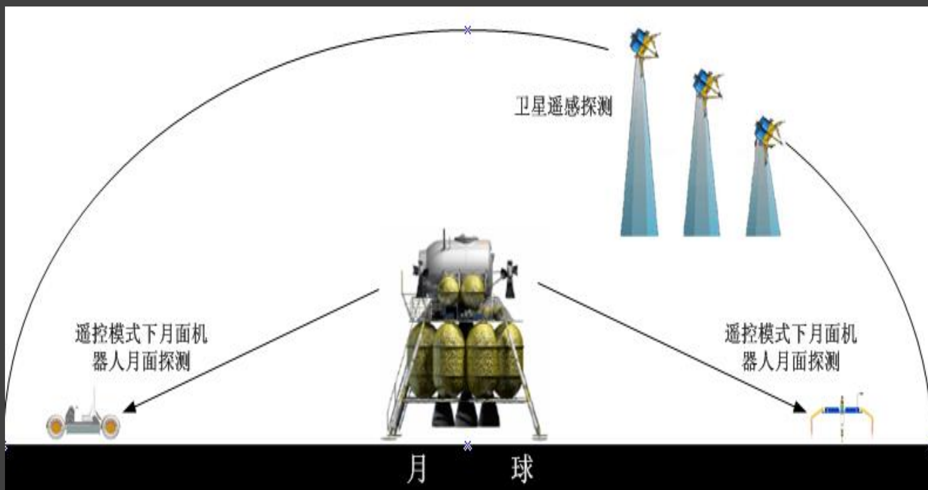
The total lunar soil thickness was obtained according to the inversion interpolation of CE-1 microwave datas.



From icubsat 8th, Monitoring Mars’ Atmospheric Dynamic, L.Montabone, USA

① Resource Prospector(RP): Exploration of Lunar or Mars Resources

Do We have sufficient data to support long-term landing site selection?



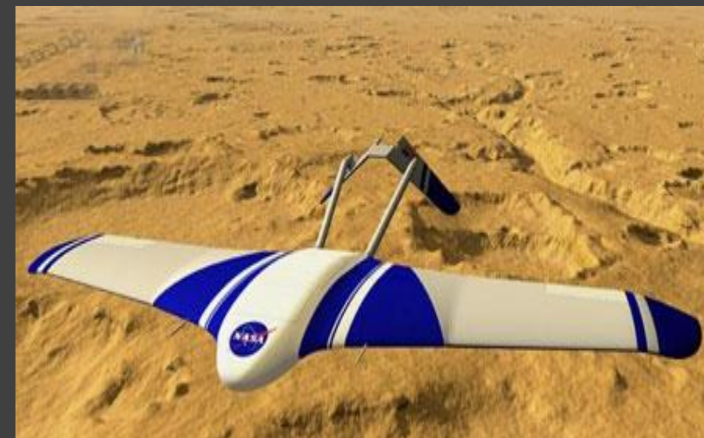


Image credit: NASA

- **Lunar exploration robotic**： For exploration and evaluation of lunar resources
- **Airplane in Mars**： Especial for exploration and evaluation of Mars resources
- **Another:**
  - ✧ Resource assessment;
  - ✧ Resource lifetime;
  - ✧ Site Selection and management;
  - ✧ Transportation line convenience.

(2) Deployment and Construction of Infrastructure

- ◆ **Sustainable Power, GNC, communication**
- ◆ **Deployment Sampling ,separation ,transfer storage device**
  - ✧ Excavator /Drilling machine
  - ✧ Heavy-duty lunar rover : used for encapsulation and transportation of surface mining resources
  - ✧ Resource separation and extraction equipment : for the preparation of water, oxygen, hydrogen and other resources
  - ✧ Packaged storage device : Used for product storage
- ◆ **Emplacement Habitant infrastructure**
  - ✧ living module, experiment module
  - ✧ Manned lunar surface transfer vehicle
  - ✧ 3D printer for radiation shield
  - ✧ Landing area clearing, surface hardening

Image credit: ESA

(3) Sampling , Separation and Manufacture

◆ Consumable Production (In-Situ Oxygen, Water, Fuel)

✧ O2 Production from Regolith

✓ Oxygen extraction from regolith processing (low risk/low efficiency to high risk/high efficiency)

✓ Solar concentrators and regolith thermal management

✓ Dust insensitive sealing

✓ Water, carbon dioxide, and gas processing and separation subsystems

✓ Resource location and ‘mine’ planning for process control vs resource obtained

✧ In-Situ Water Production

✧ In-Situ Methane Production

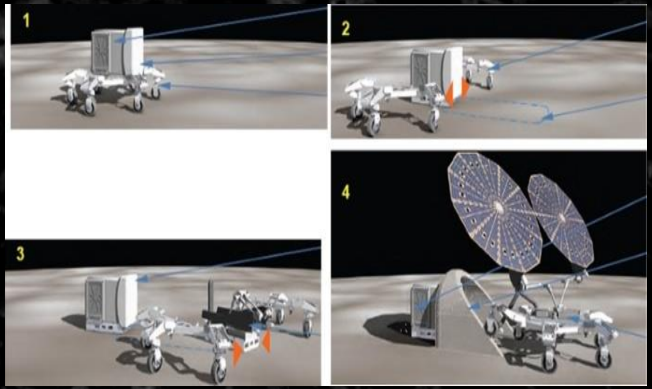


Image credit: NASA

(4) Transport and Storage of production

◆ **Excavation and Material Transport**

✧ End-effectors for excavation, material transport, and surface manipulation for large and small surface mobility platforms

✧ Dust insensitive mechanisms

✧ Understanding of lunar regolith characteristics and behavior in 1/6-g

✧ Comparative testing of concepts anchored to lunar regolith characteristics

◆ **Cryogenic Fluid Management**

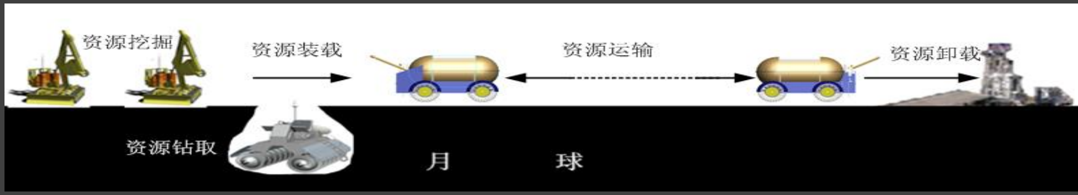
✧ Oxygen (and possibly methane) liquefaction and storage

✧ Oxygen disconnects

✧ Hydrogen (H_2) scavenging with ISRU

◆ **Autonomous Control and Failure Recovery**

✧ Navigation and control software for long-term simplistic operation of excavation for O_2 production;Oxygen production plant automation and control



(5) Waste disposal and recycling

◆ In-Situ Lunar Resources

'Natural' Lunar Resources:

✧ Regolith, minerals, metals, volatiles, and water/ice

✧ Sunlight, vacuum, thermal gradients/cold sinks

◆ Discarded Materials

✧ descent stage fuel residual scavenging, tanks, material, etc. after landing

✧ Crew trash and waste (after Life Support processing is complete)

◆ Waste disposal and recycling

✧ Biodegradation treatment

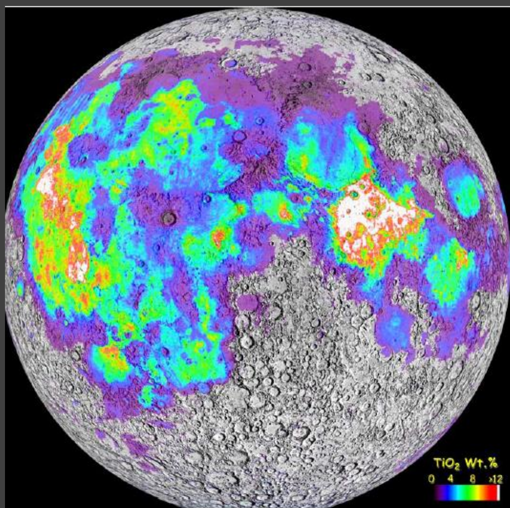
◆ Environment Protection

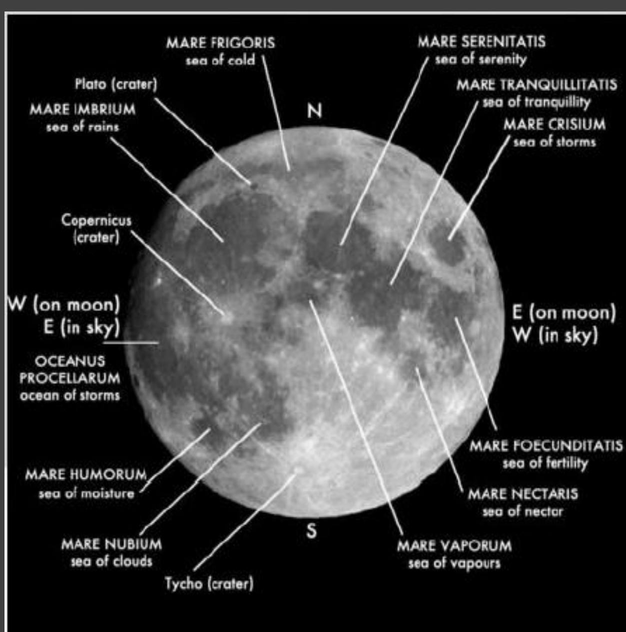
✧ sanitary landfill

We cannot allow the moon or Mars to be polluted like the earth!

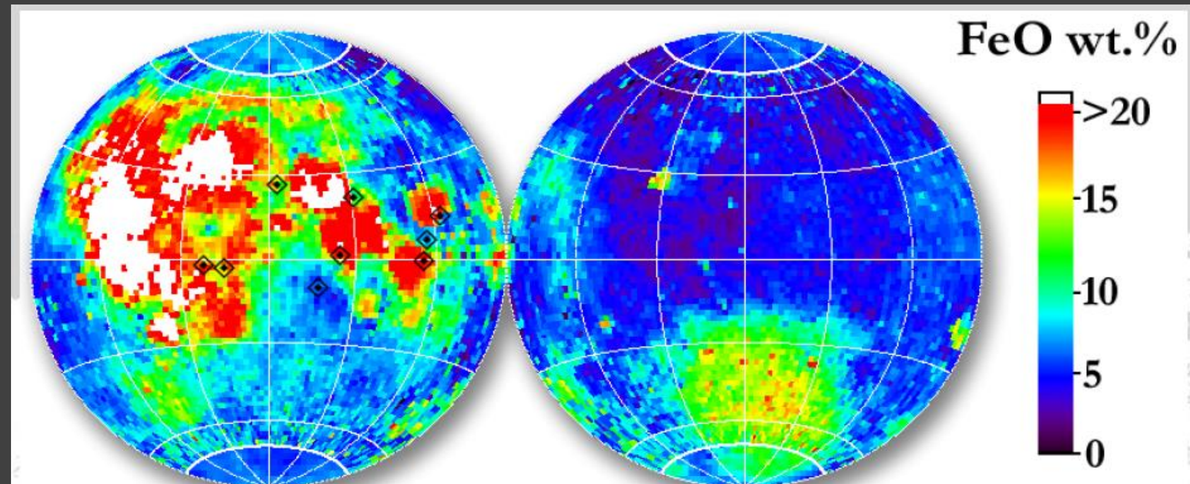
3. Tentative Idea of Technical Verification

Lunar resources: TiO2





Lunar resources: FeO



Regolith geographical distribution & availability

Mineral	Mare	Highlands	Resources
Plagioclase	10-40%	70-95%	Al, Na, Ca, Si, O_2
Ilmenite	2-20%		Fe, Ti, O_2
Olivine	0-20%		Mg, Fe, Si, O_2

- ✓ oxygen (about 45% by weight)
- ✓ silicon (about 21 %)
- ✓ iron (6 to 15%)
- ✓ aluminum (5 to 13%)
- ✓ calcium (8 to 10%)
- ✓ magnesium (about 5%)
- ✓ titanium (up to 6%).

Lunar Regolith

Place	Mineral	Composition
Mare	Ilmenite	$FeTiO_3$
	Pyroxene	$(Fe,Mg)SiO_3$
	Olivine	$(Fe,Mg)_2SiO_4$
	Anorthite	$CaAl_2Si_2O_8$
Highland	Anorthite	$CaAl_2Si_2O_8$

3. Tentative Idea of Technical Verification

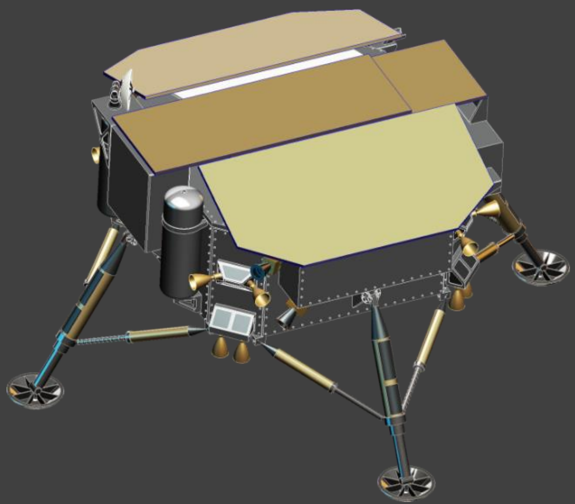
Verification Goals: To explore the scientific mechanism of oxygen production based on lunar soil and the feasibility of in-situ oxygen production on lunar surface.

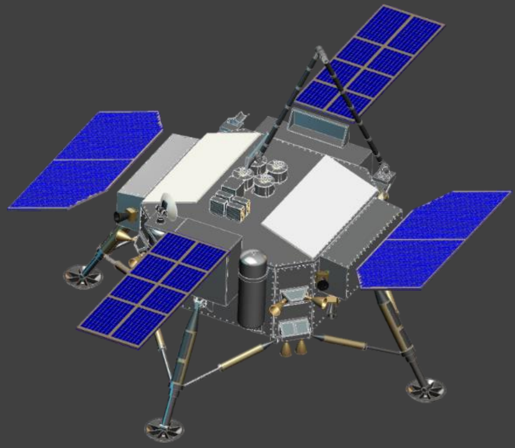
- Breakthrough in the Critical technology of oxygen in situ manufacturing based on lunar soil in lunar environment;

- Carry out flight verification and Test oxygen production efficiency.(The expected 16%);

- Solve high efficiency reaction chamber heating technology, high reliability oxygen separation technology and efficient energy supply technology, obtain first-hand measured data；

- Provide scientific and technical support for further human exploration of the lunar and even Mars.

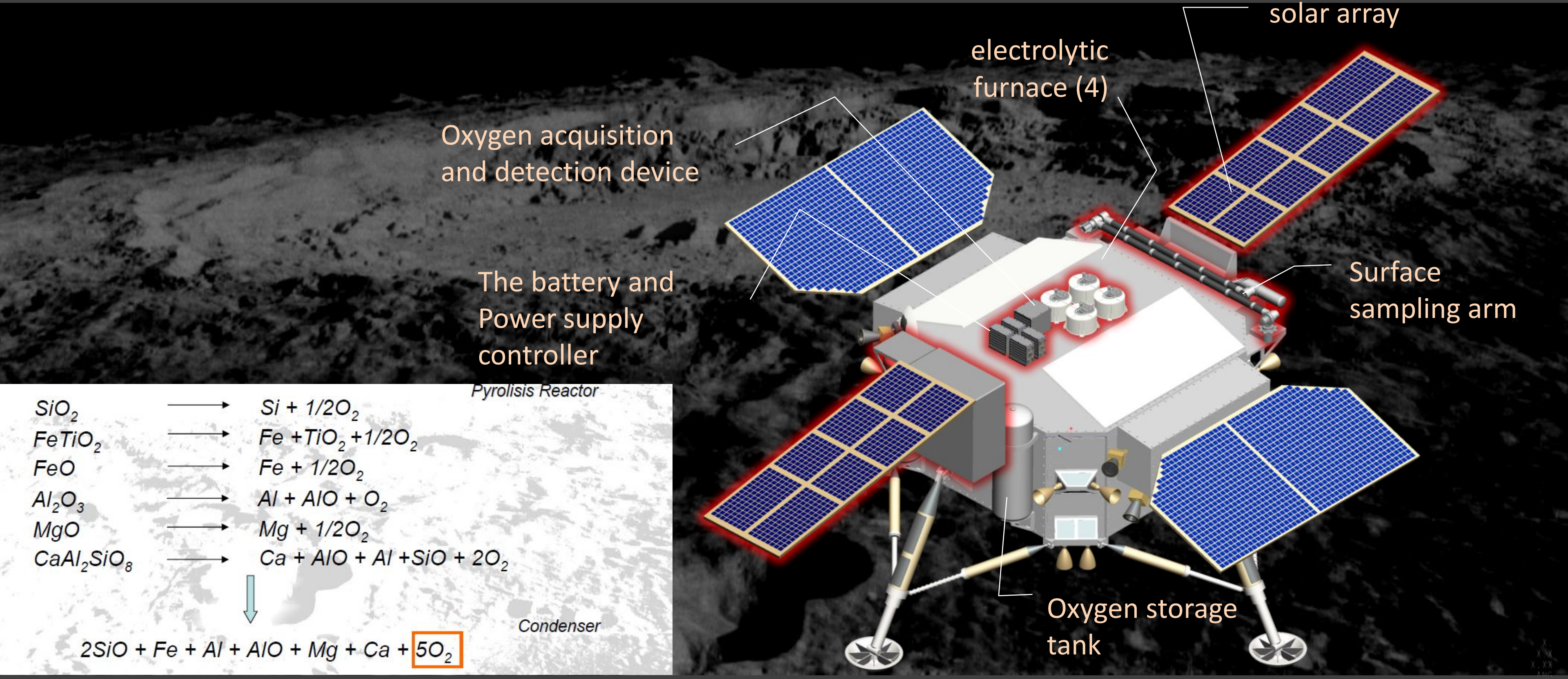




Based on Small Lunar Lander Platfor

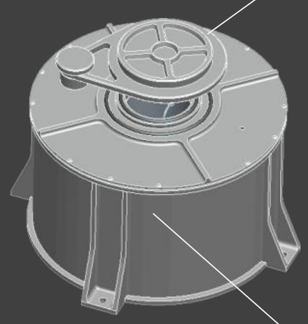
Lunar oxygen generating verification vehicle

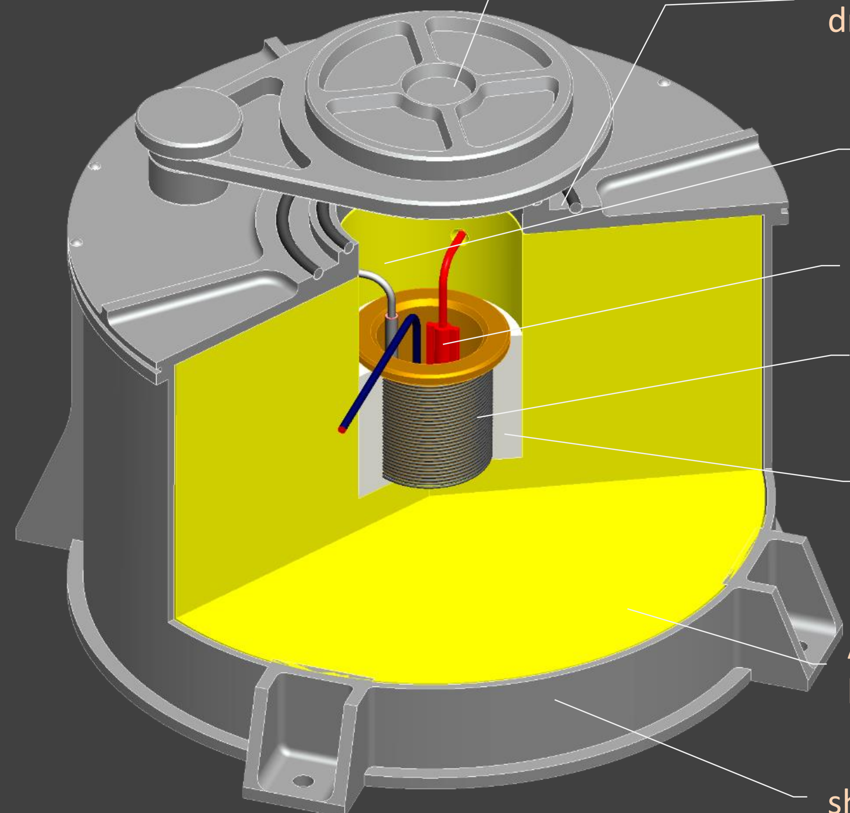
- Based on small lunar lander, mass<300kg;
- Four high temperature electrolytic furnaces are placed in the center of Lander;
- Add a robotic arm, a surface sampling device, to collect lunar soil and separate it;
- A pair of solar array, Improve the efficiency of power generation on the lunar surface;
- Increase the heat area of the cooling plate;
- Add a set of gas composition detection equipment.



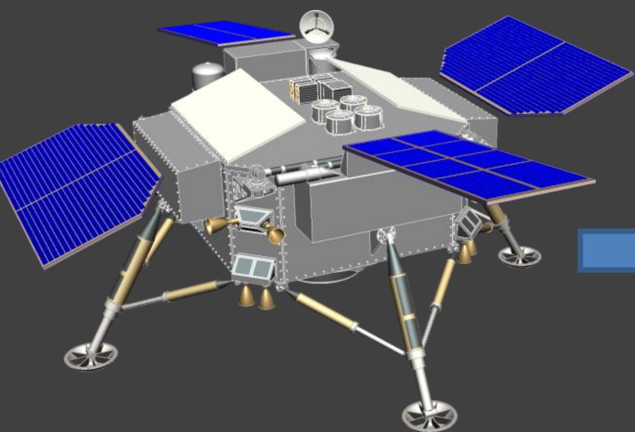
Core equipment: high temperature electrolytic furnace

- Effective heating zone：Φ40mm×50mm（100g lunar regolith）
- Oxygen production per unit： 10g（5.8L@1atm， 50% current efficiency）
- Maximum heating temperature： 2000℃
- Heating power： 500W
- Heating up time: ≯2h
- Electrolysis power: 10W
- Weight per unit≯10kg

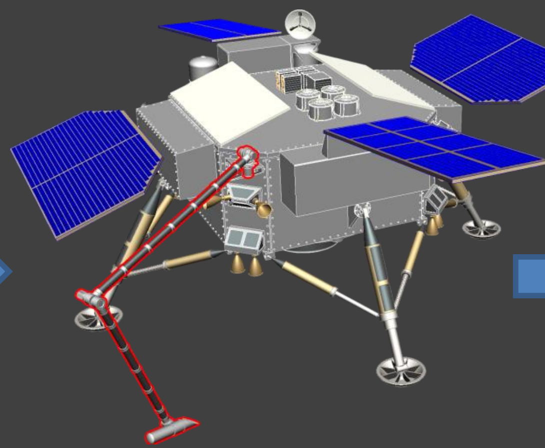




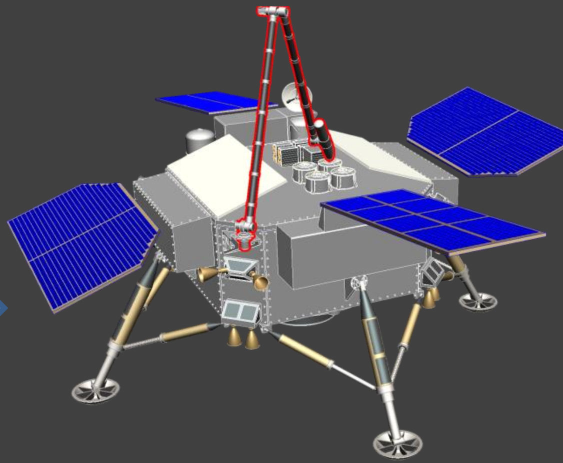
Lunar surface oxygen production process



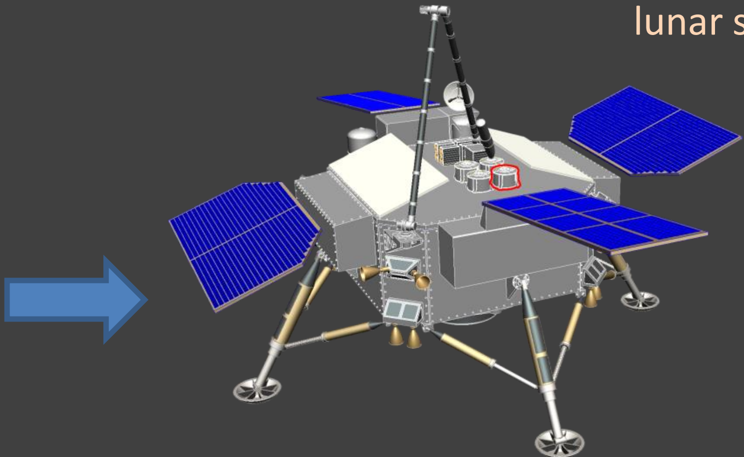
① Deploy solar array， and cooling plate, equipment ready



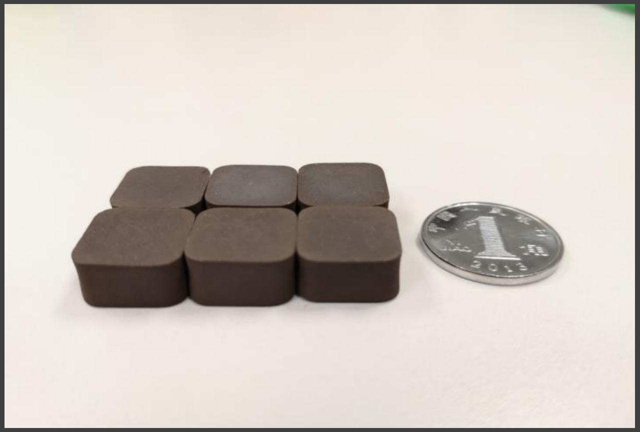
②Deploy robotic arm，sampling regolith on lunar surface



③ Transfer lunar regolith and fill with furnace, then Sealing furnace cover

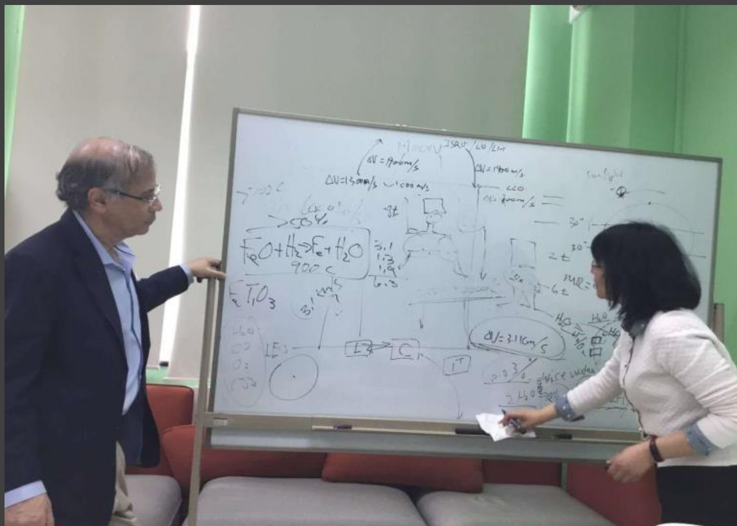


④ Makeing oxygen, separate and store gases

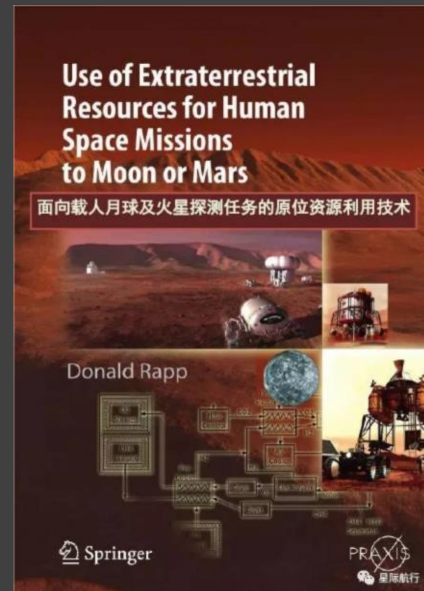


Analog mission and Felid testing

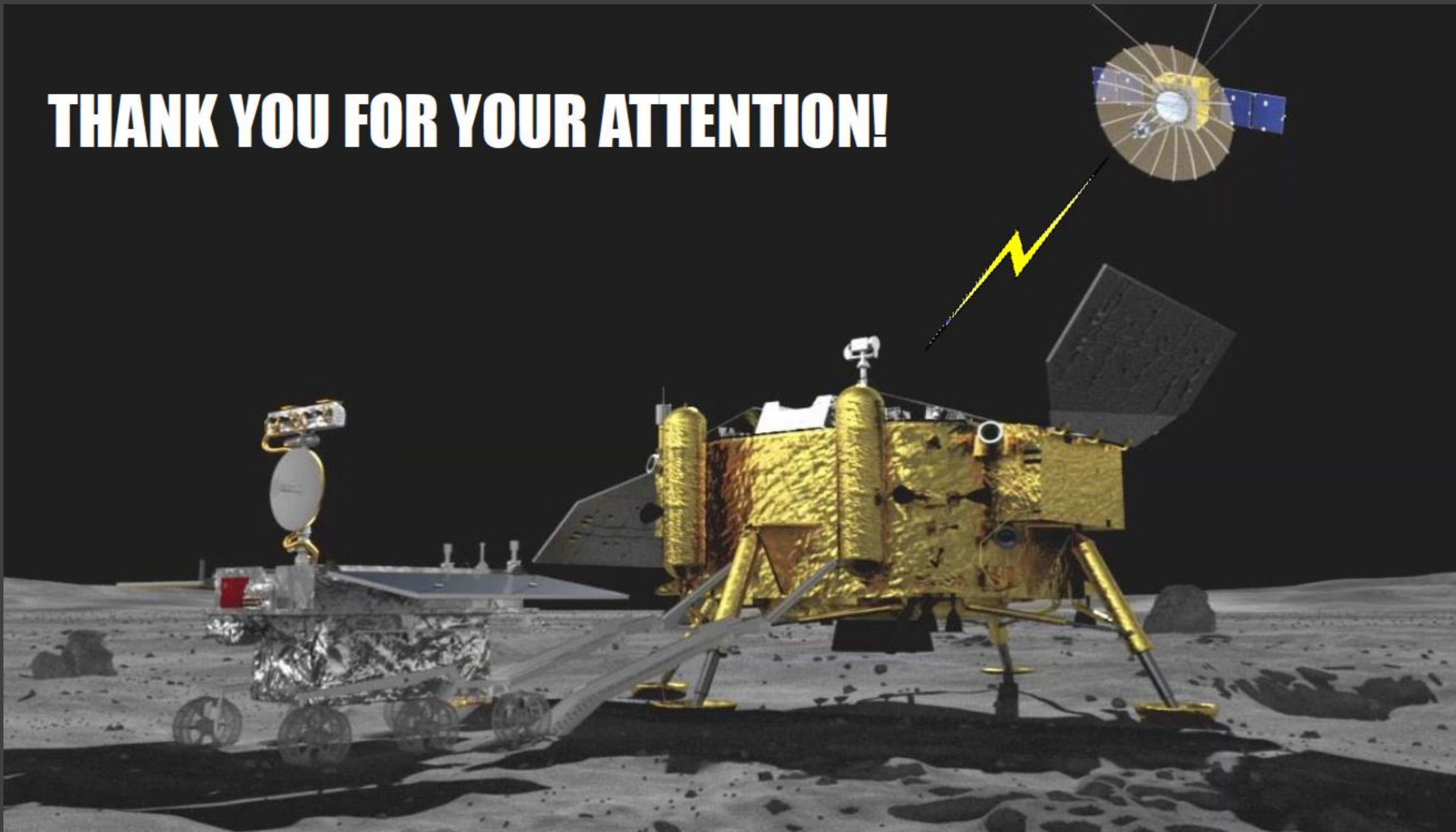
Communicate and Learn from International Counterparts



Discussion with the famous space Engineer of USA, Dr. Robert zubrin



We firmly believe: ISRU technologies will not only change the flight mode of human deep space exploration mission, but also change the life on lunar or mars base.



Corresponding Author: Linli Guo， guolinlidfh@spacechina.com