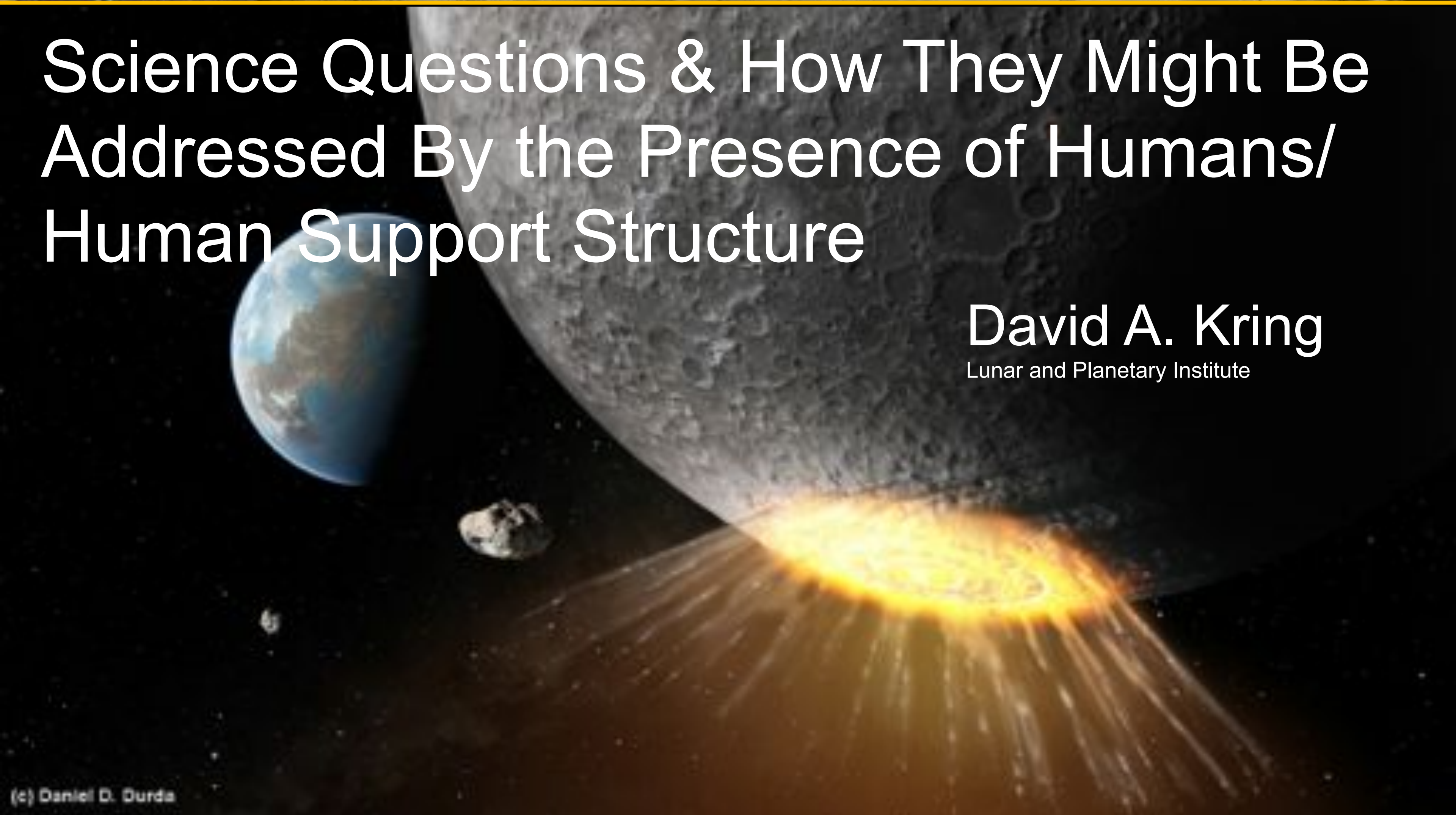
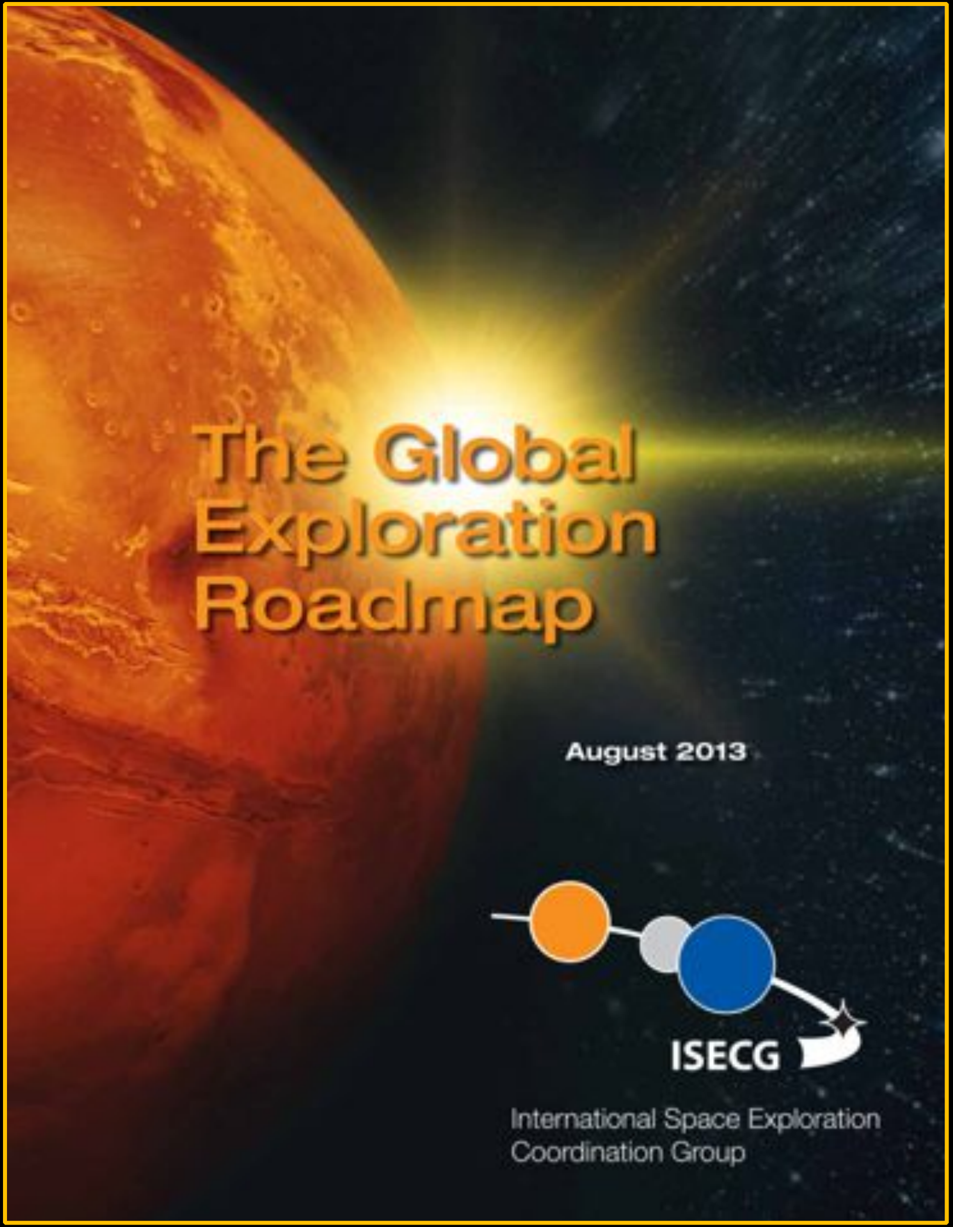
Science Questions & How They Might Be Addressed By the Presence of Humans/ Human Support Structure

David A. Kring
Lunar and Planetary Institute



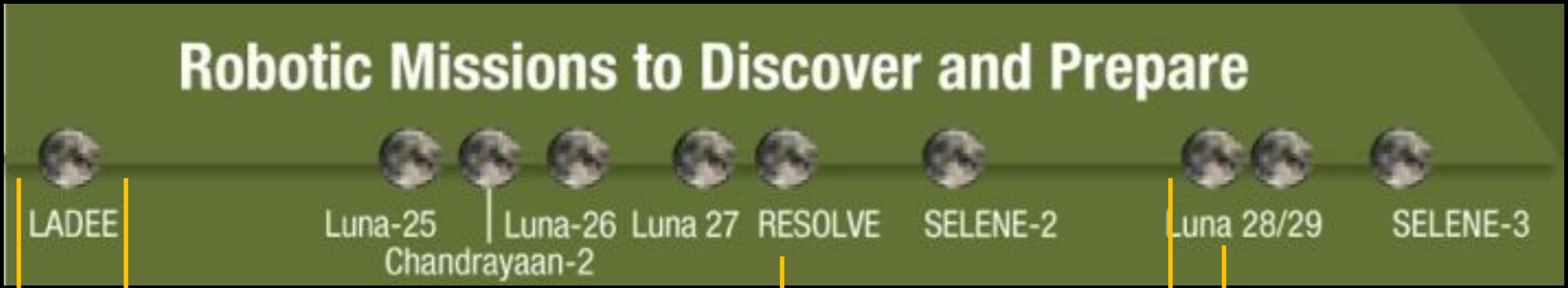


Roadmap for Human Exploration

- Outlines a plan that extends human exploration beyond low-Earth orbit (LEO)
- Includes multiple destinations (the Moon, asteroids, and eventually Mars)
- Highlights the need for a robotic program that
  - Serves as precursor explorers, then as
  - A parallel mission element partner,
  - Before we have a fully developed human exploration program

Elements of a Lunar Robotic Program

- It is essential that we restore the capability of lunar surface operations and
- Sample return



Chang'e 3
Lander and rover

Lunar Reconnaissance Orbiter
(current mission)

Now being implemented
as Resource Prospector

Lunar sample return
(~2020)

Chang'e 5
Lunar sample return
(prior to 2020)

Illustration from the GER (2013)

NASA's Resource Prospector Robotic Lunar Surface Element

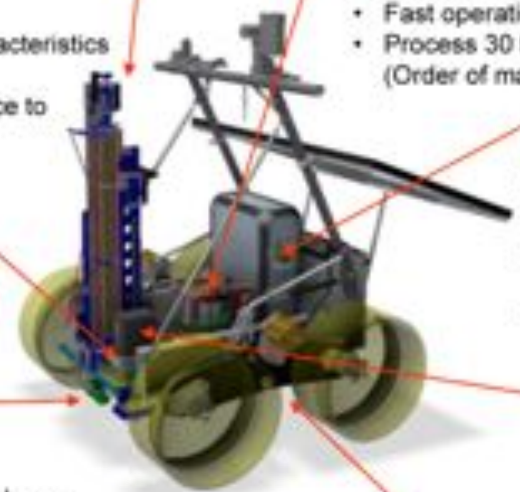
RESOLVE (Regolith & Environment Science and Oxygen and Lunar Volatile Extraction)

Sample Acquisition –
Auger/Core Drill [CSA provided]
- Complete core down to 1 m; Auger to 0.5 m
- Minimal/no volatile loss
- Low mass/power (<25 kg)
- Wide variation in regolith/rock/ice characteristics for penetration and sample collection
- Wide temperature variation from surface to depth (300K to <100K)

Sample Evaluation –
Near Infrared Spectrometer (NIR)
- Low mass/low power for flight
- Mineral characterization and ice/water detection before volatile processing
- Controlled illumination source

Resource Localization –
Neutron Spectrometer (NS)
- Low mass/low power for flight
- Water-equivalent hydrogen ≥ 0.5 wt% down to 1 meter depth at 0.1 m/s roving speed

RESOLVE Instrument Suite Specifications
- Nom. Mission Life = 10+ Cores, 12+ days
- Mass = 60-70 kg
- Dimensions = w/o rover: 68.5 x 112 x 1200 cm
- Ave. Power: 200 W



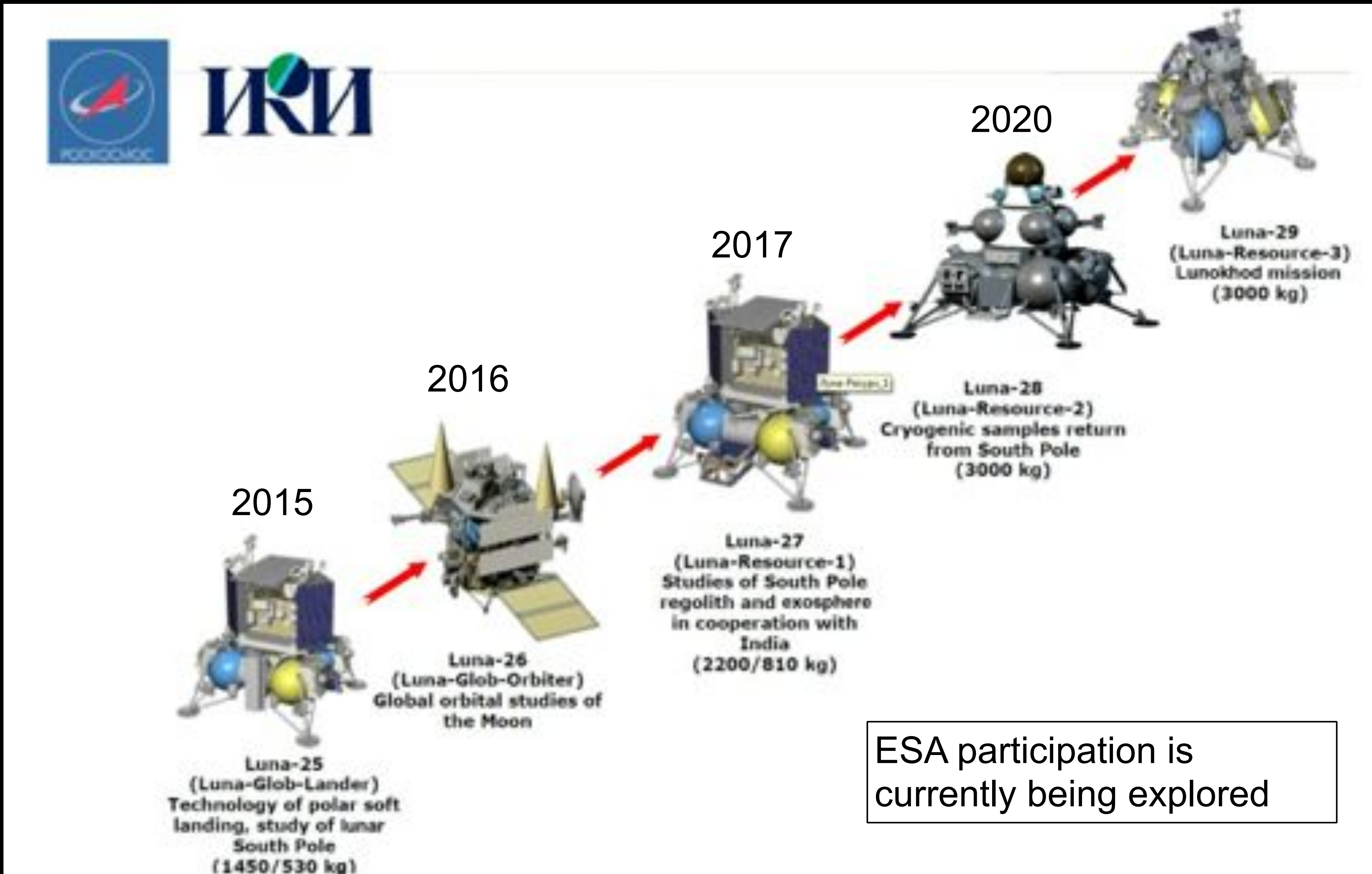
Volatile Content/Oxygen Extraction –
Oxygen & Volatile Extraction Node (OVEN)
- Temperature range of <100K to 900K
- 50 operations nominal
- Fast operations for short duration missions
- Process 30 to 60 gm of sample per operation (Order of magnitude greater than TEGA & SAM)

Volatile Content Evaluation –
Lunar Advanced Volatile Analysis (LAVA)
- Fast analysis, complete GC-MS analysis in under 2 minutes
- Measure water content of regolith at 0.5% (weight) or greater
- Characterize volatiles of interest below 70 AMU

Operation Control –
Flight Avionics [CSA/NASA]
- Space-rated microprocessor

Surface Mobility/Operation [CSA mobility platform]
Rover nicknamed "Artemis Jr."
- Low mass/large payload capability
- Driving and situation awareness, stereo-cameras
- Autonomous navigation using stereo-cameras and sensors
- NASA contributions likely for communications and thermal management

A Roscosmos-led Series of Robotic Lunar Surface Elements

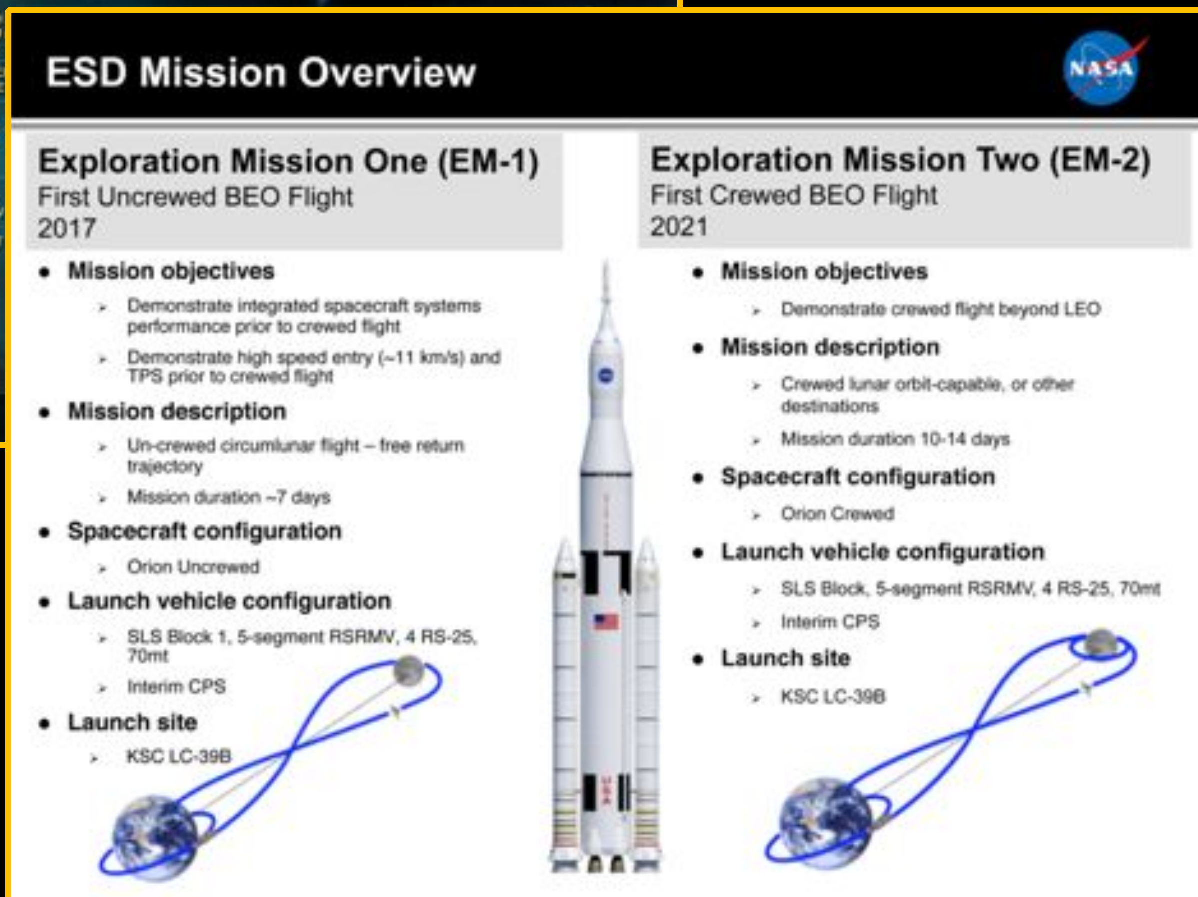


ESA participation is currently being explored

EXPLORATION – DEVELOPMENT OF ORION AND SLS VEHICLES

EFT-1 (December 2014)

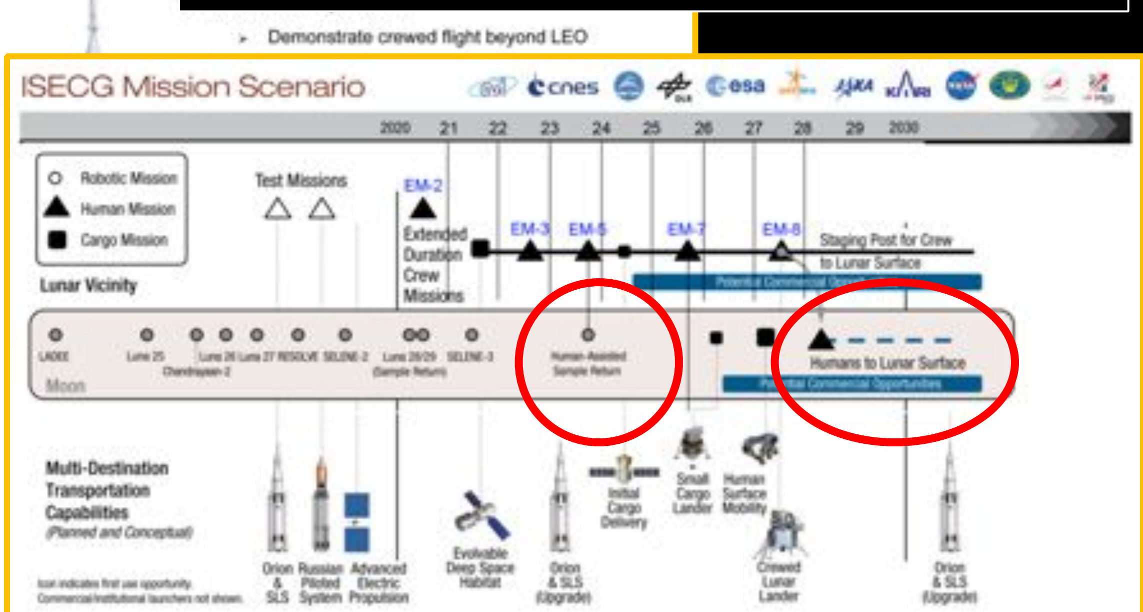
EXPLORATION – DEVELOPMENT OF ORION AND SLS VEHICLES



EFT-1 (December 2014)

EM-1 and EM-2 (2017 and 2021)

EXPLORATION – DEVELOPMENT OF ORION AND SLS VEHICLES



EFT-1 (December 2014)

EM-1 and EM-2 (2017 and 2021)

And, within the framework of the Global Exploration Roadmap:

- Human-assisted sample return
- Humans to the lunar surface

NASA Human Spaceflight Architecture Team (M. Lupisella and M. R. Bobskill , 2012)

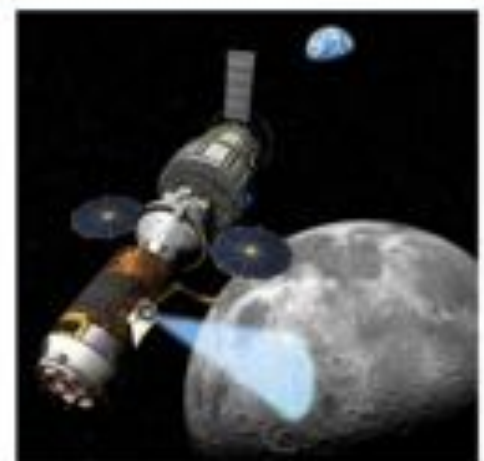
Preliminary

Mission Summary

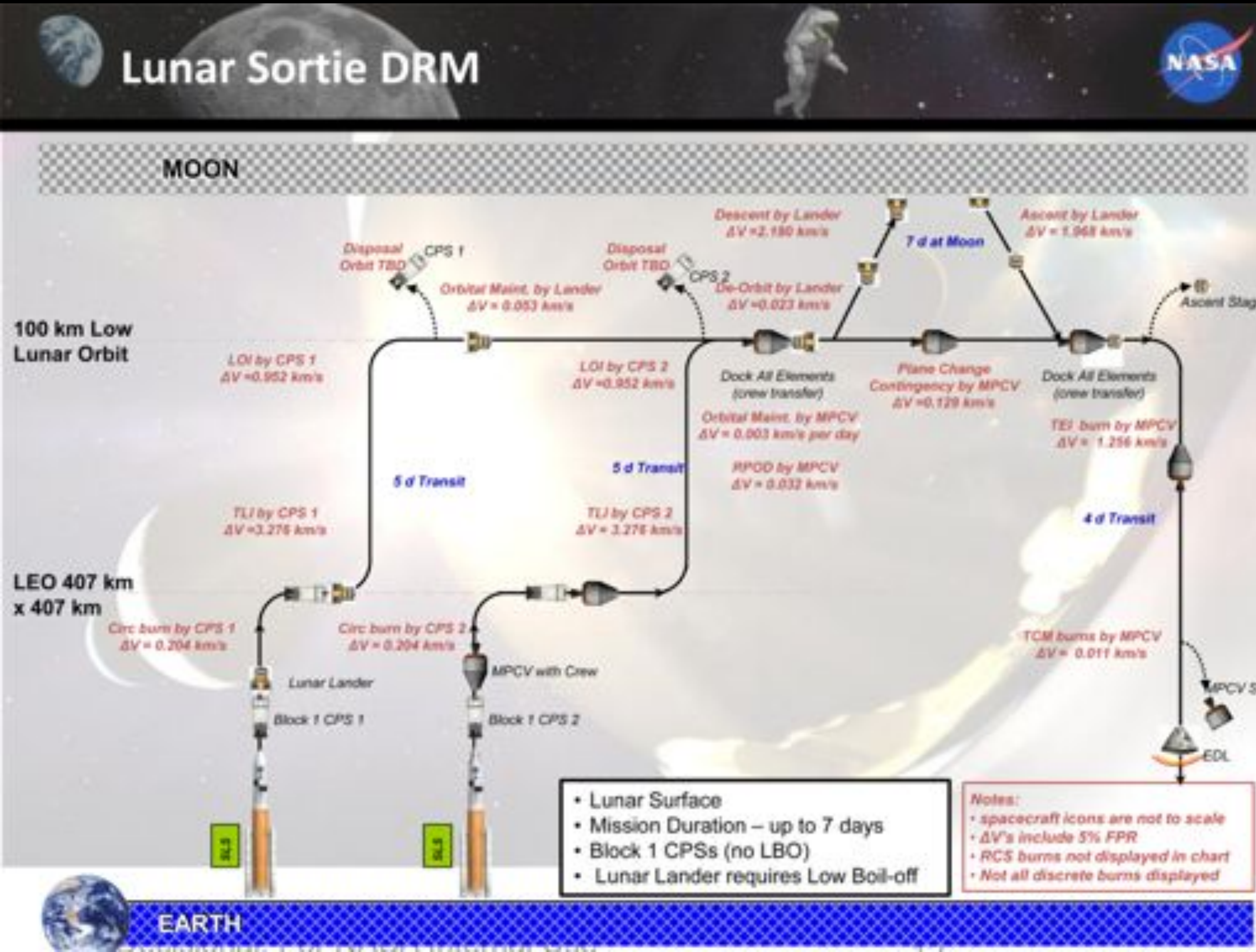
- Crew visits Deep Space Facility (DSF) located @ E-M Lagrange point. Crew tests & demonstrates future exploration systems & operations, controlling assets on the lunar surface, performing lunar surface observations, and other deep space science tasks. DSF could be derivative of ETM and moved between E-M L1 & L2 points and be visited multiple times.
- Uses ETM and MPCV (first MPCV/SLS mission beyond test flights) for crew pressurized volume
- First crew arrives for first DSF mission, later crews bring further infrastructure, stay for longer durations
- Station-keeping (with ACS, RCS?)
- NEA stack assembly in situ?

Mission Benefits

- Develop habitation capabilities & reduce risk for future exploration missions
- Enhance lunar & space science: e.g., survey farside, control robots on surface, perform surface assembly (e.g. farside radio telescope)
- Perform exploration research & technology ops: crew+robot autonomous ops, long delay comm, advanced EVA systems, measurements (e.g., radiation shielding)
- Demonstrate deep space assembly
- ETM serves as foothold in deep space



NASA Human Spaceflight Architecture Team (Connolly et al. , 2012)
Lunar Destination Activities

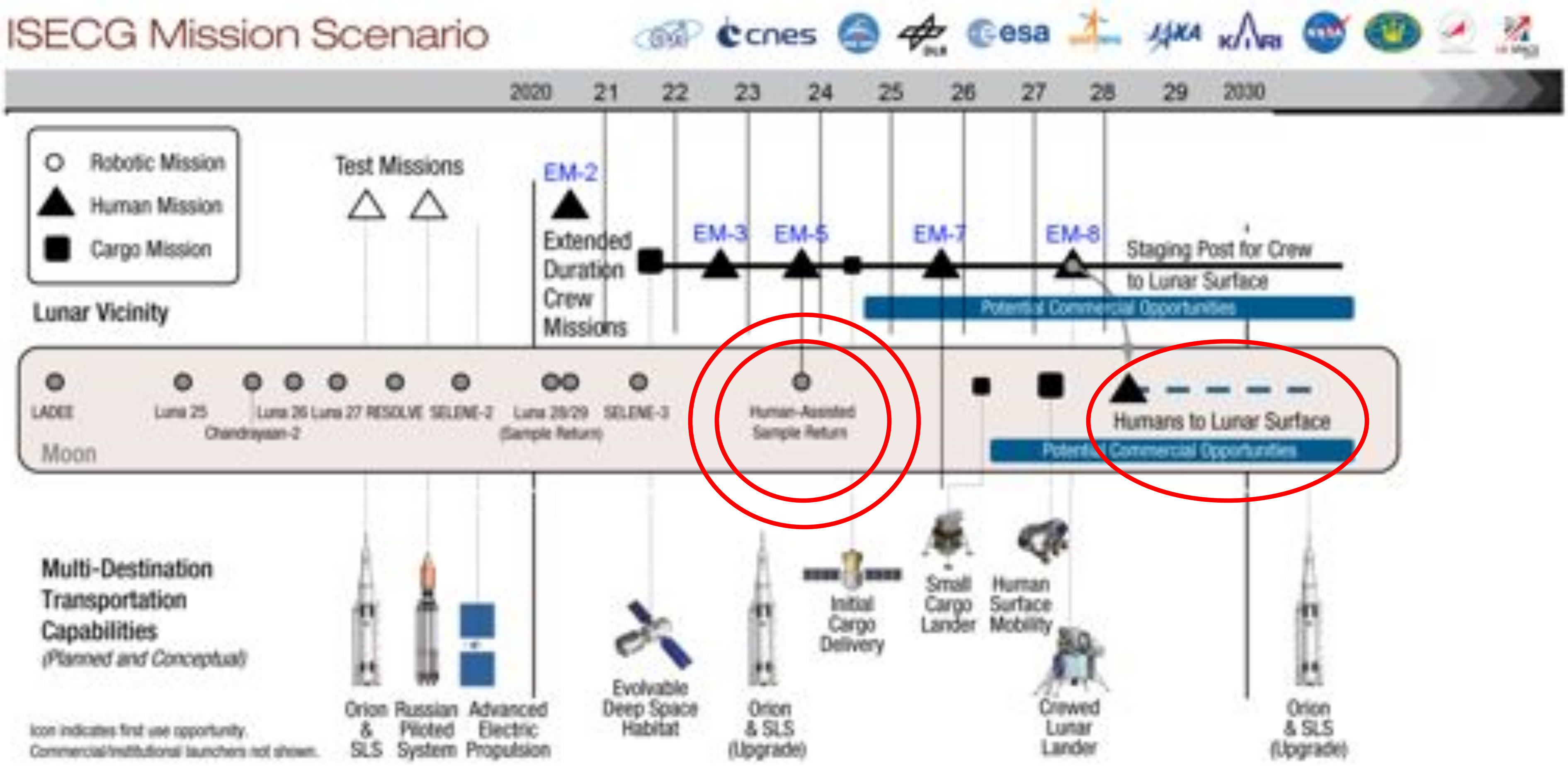


The Missing Element

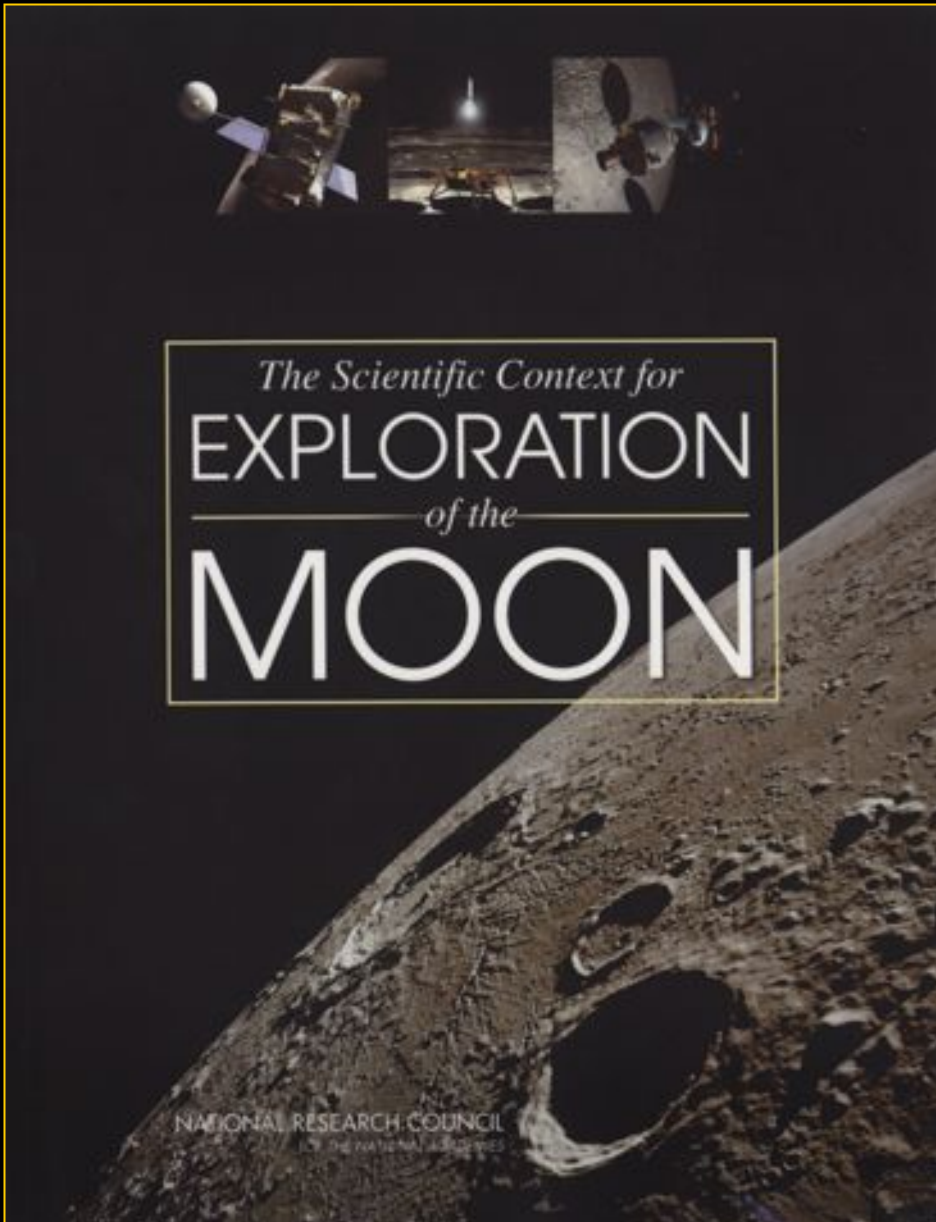
- Human-rated lunar lander (European concept pictured)
- Until this capability is developed, we will be limited to missions with crew in cis-lunar space and robotic lunar surface components

Developing the Human Exploration Elements

- NASA's SLS and Orion vehicles
- ESA service module

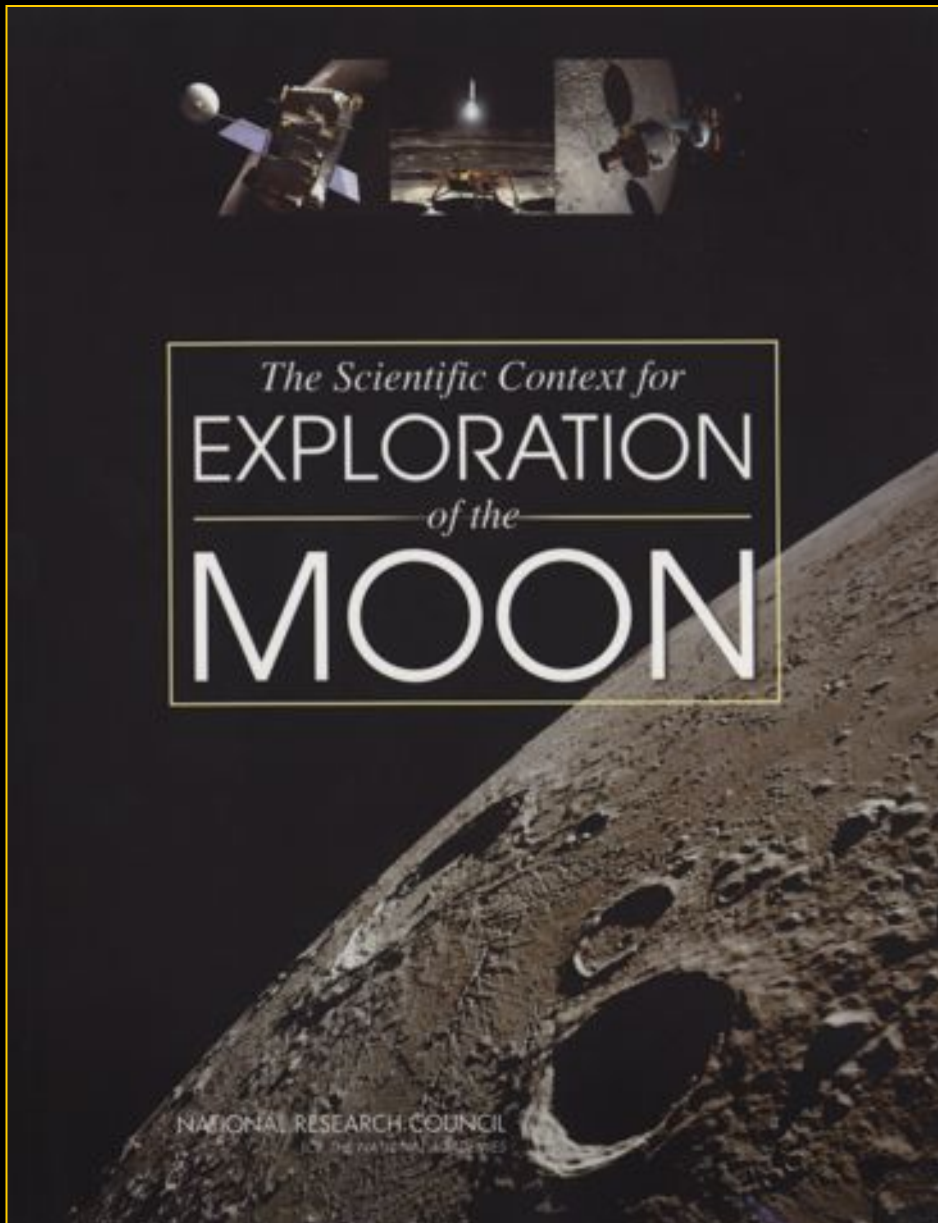


Detail of illustration from the GER (2013) with small modifications



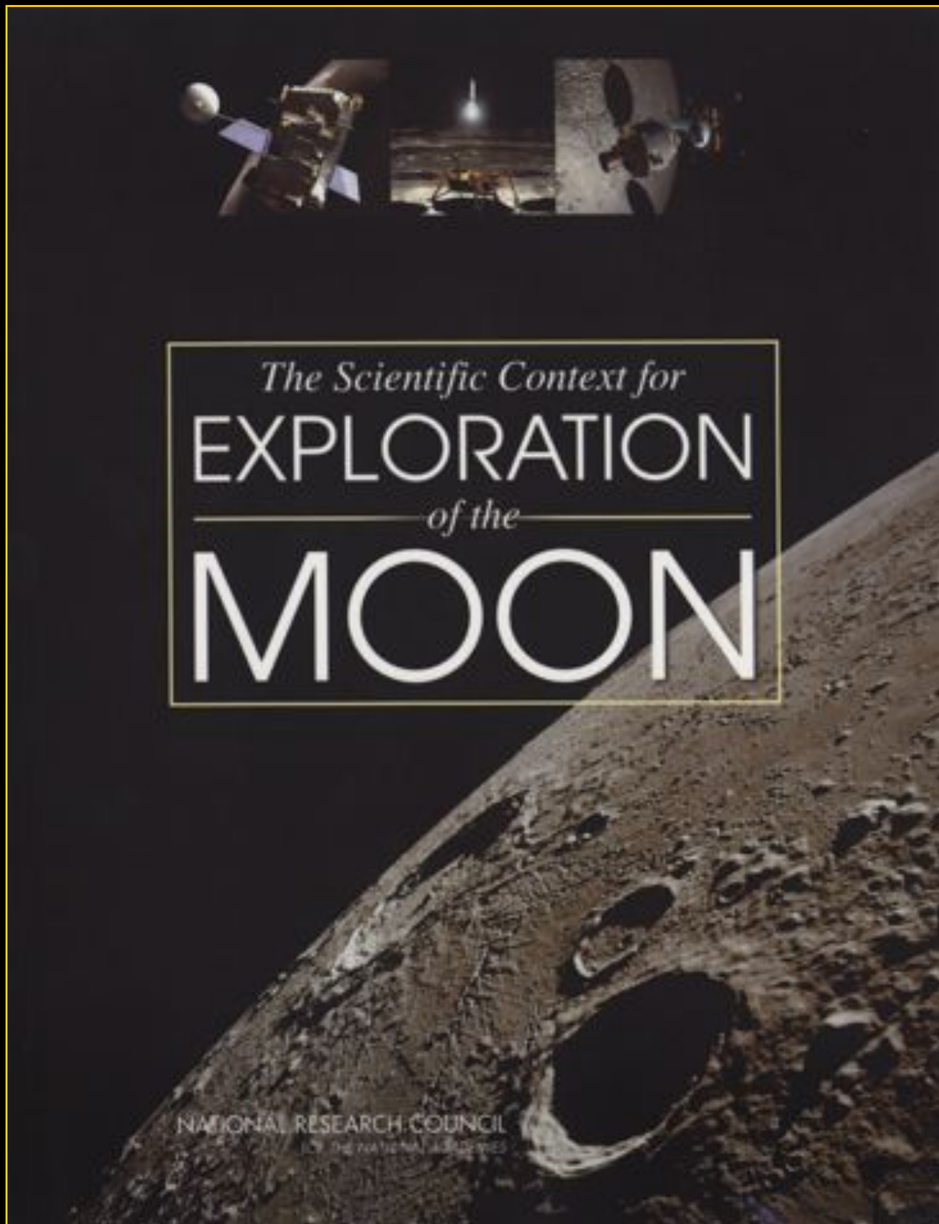
In 2007,

- The National Research Council published a report called *The Scientific Context for Exploration of the Moon*, which provided NASA with scientific guidance for an enhanced exploration program that would provide global access to the lunar surface through an integrated robotic and human architecture.
- The report outlined 3 major hypotheses, identified 8 science concepts, and, within those concepts, it
- Identified 35 specific investigations
- Importantly, the report also prioritized those investigations



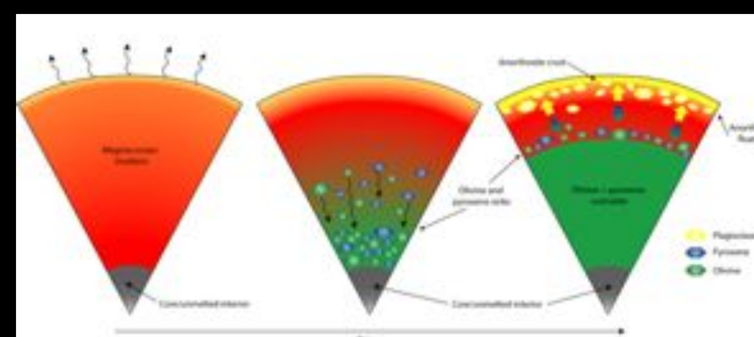
The “BIG” ideas to be explored:

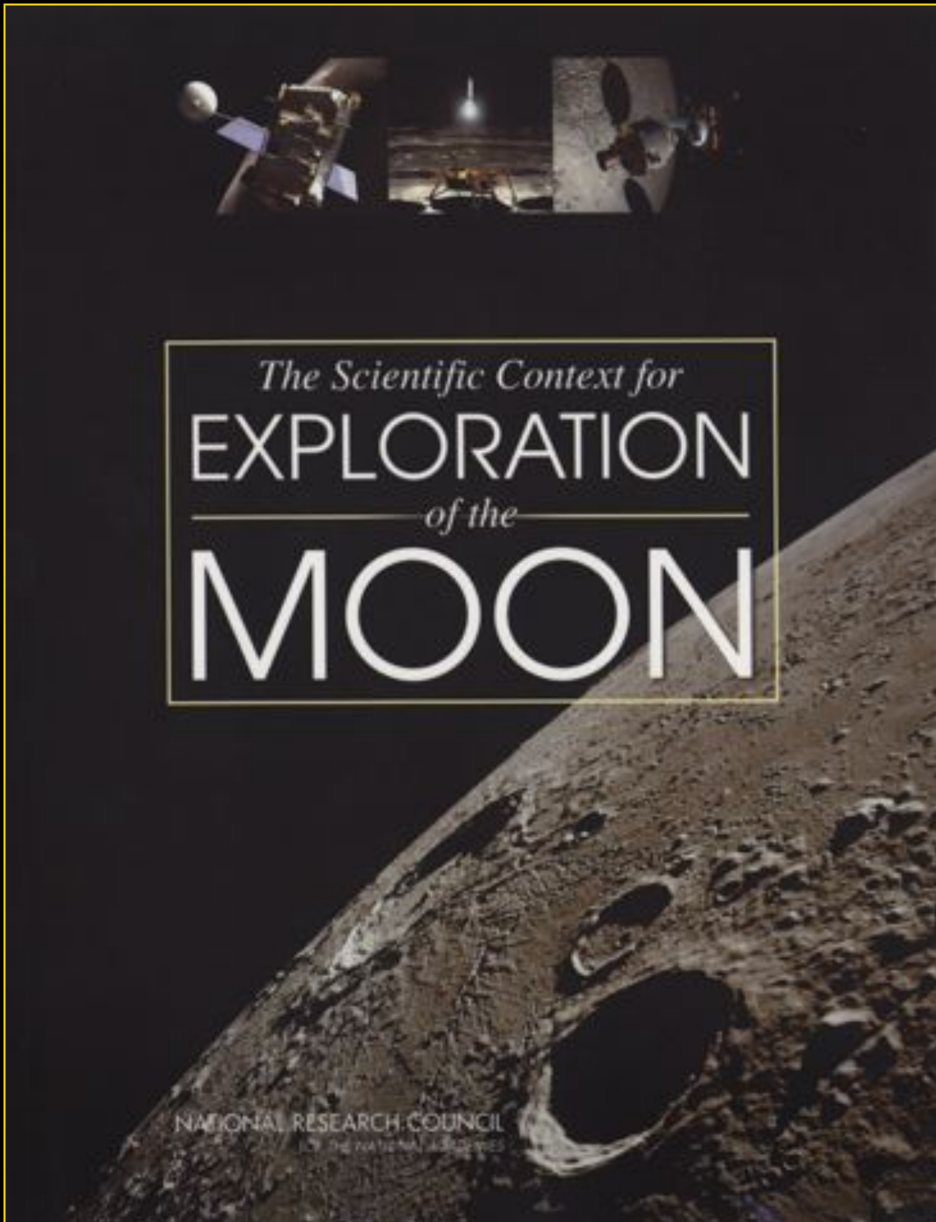
- Giant impact hypothesis for the origin of the Moon



The "BIG" ideas to be explored:

- Giant impact hypothesis for the origin of the Moon
- Lunar magma ocean hypothesis and fundamental principles of planetary differentiation

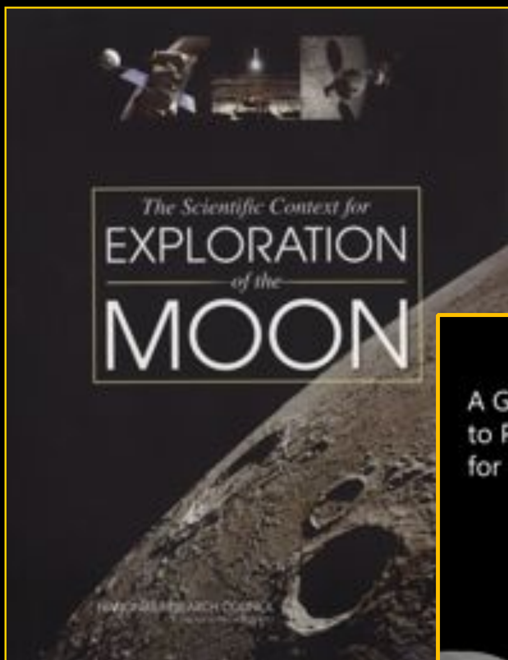




The “BIG” ideas to be explored:

- Giant impact hypothesis for the origin of the Moon
- Lunar magma ocean hypothesis and fundamental principles of planetary differentiation
- Lunar cataclysm and inner solar system cataclysm hypotheses

Where on the Moon can these objectives be addressed?



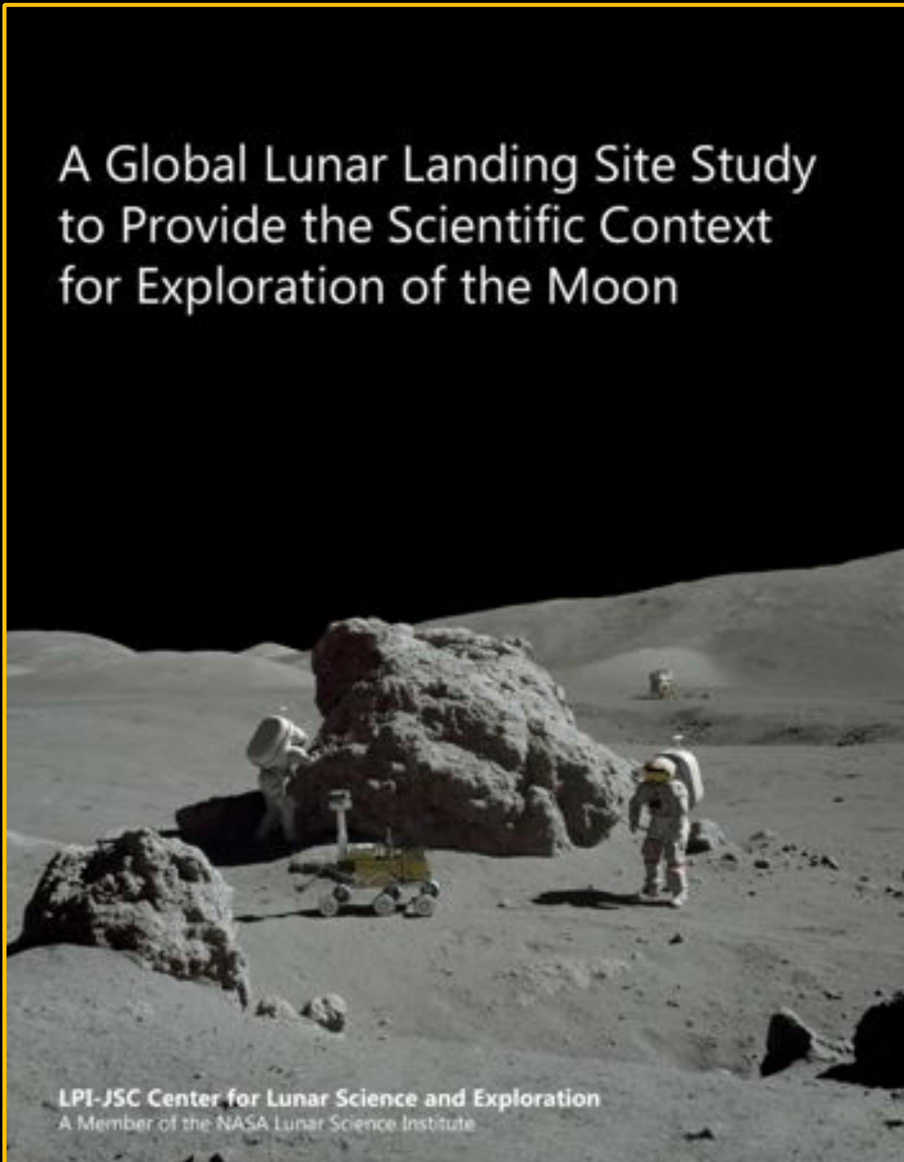
Input

Output

Guided, in part, by the 2007 National Research Council report called *The Scientific Context for Exploration of the Moon*,

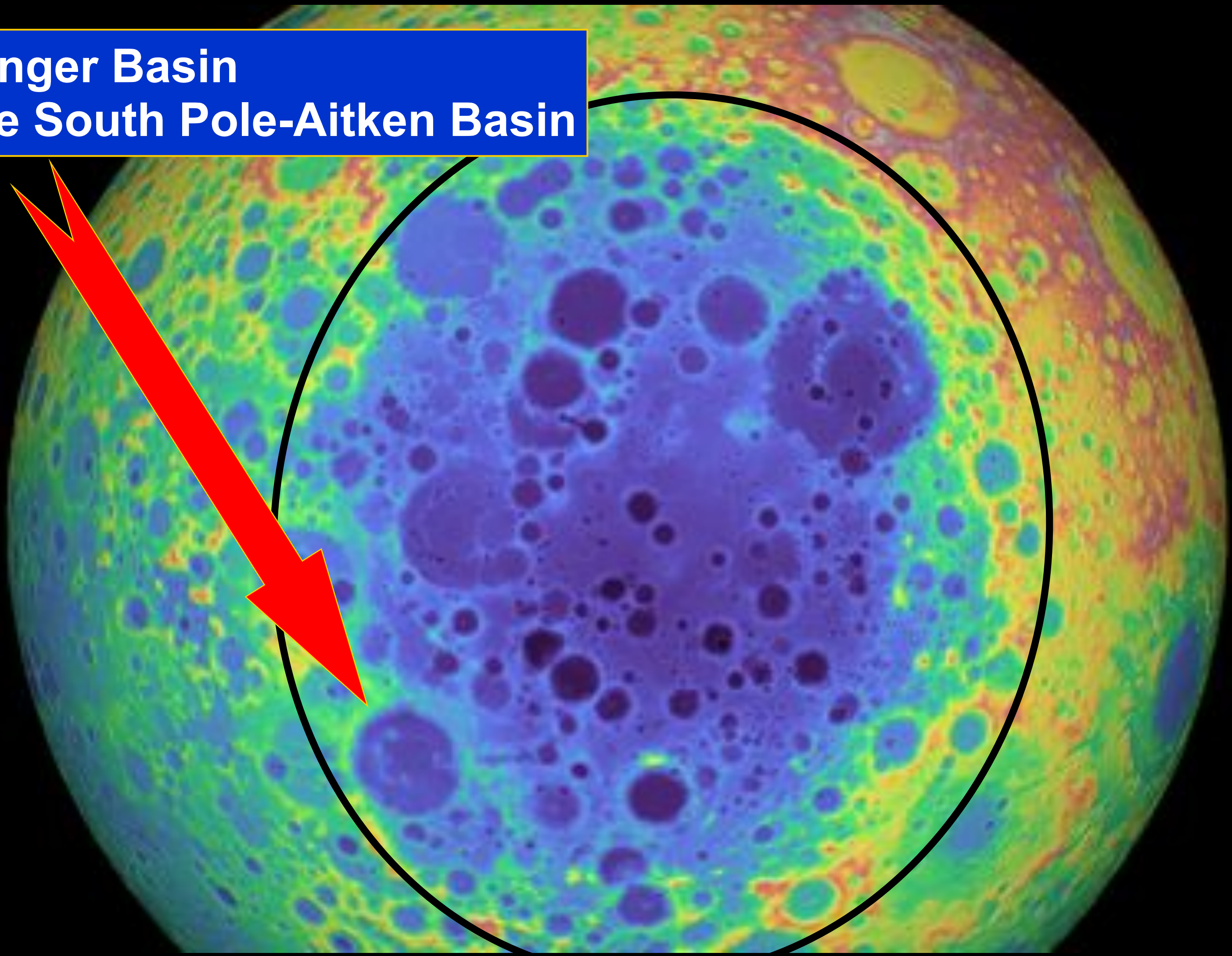
We conducted a six-year series of summer studies to identify suitable landing sites on the Moon.

Stacking maps of the locations where each investigation could be addressed, we identified sites where a particularly large range of objectives could be addressed at th same time.



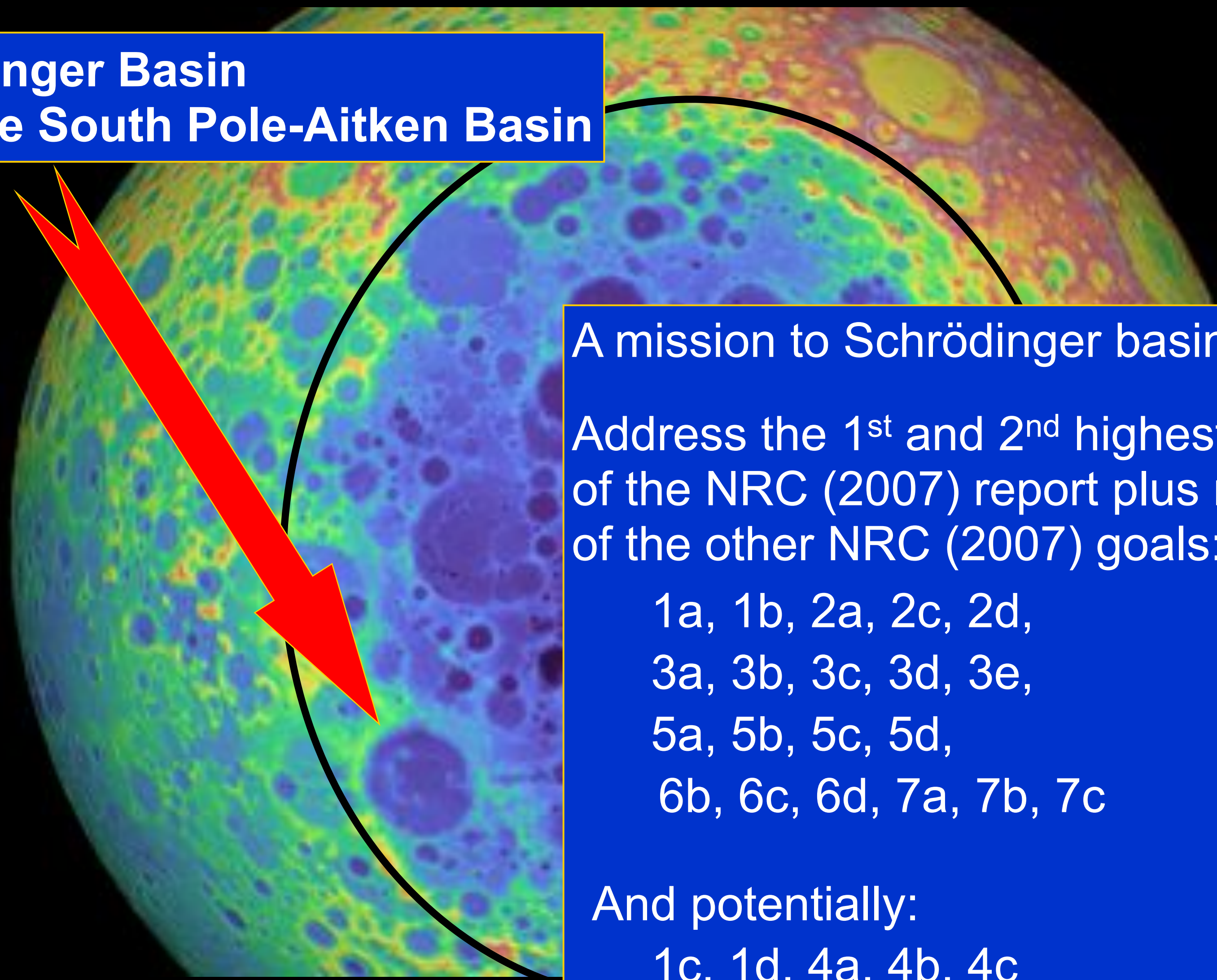
Some highlights

- Schrödinger basin on the lunar far side, within the South Pole-Aitken basin, is the location where the largest range of objectives can be addressed.
- For studies of polar volatiles, Amundsen crater may be a better target than Shackleton crater.
- Most of the NRC (2007) objectives can be addressed within the South Pole-Aitken basin on the lunar far side,
- But to truly resolve all of the NRC (2007) objectives, global access to the Moon is required



SPA Image: LRO-LOLA/NASA GSFC SVS

Schrödinger Basin
w/i the South Pole-Aitken Basin



A mission to Schrödinger basin can:

Address the 1st and 2nd highest priorities of the NRC (2007) report plus many more of the other NRC (2007) goals:

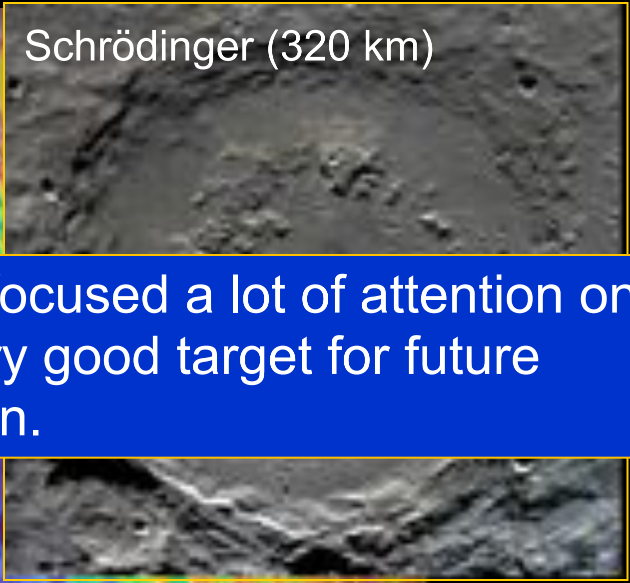
1a, 1b, 2a, 2c, 2d,
3a, 3b, 3c, 3d, 3e,
5a, 5b, 5c, 5d,
6b, 6c, 6d, 7a, 7b, 7c

And potentially:

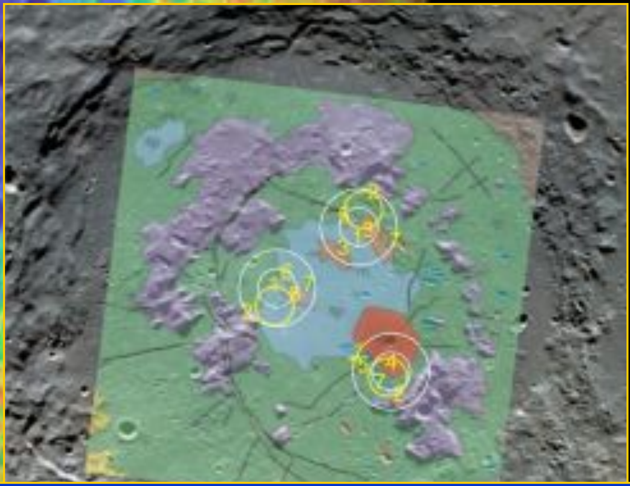
1c, 1d, 4a, 4b, 4c

Background SPA image: LRO-LOLA/NASA GSFC SVS

**Schrödinger Basin
w/i the South Pole-Aitken Basin**



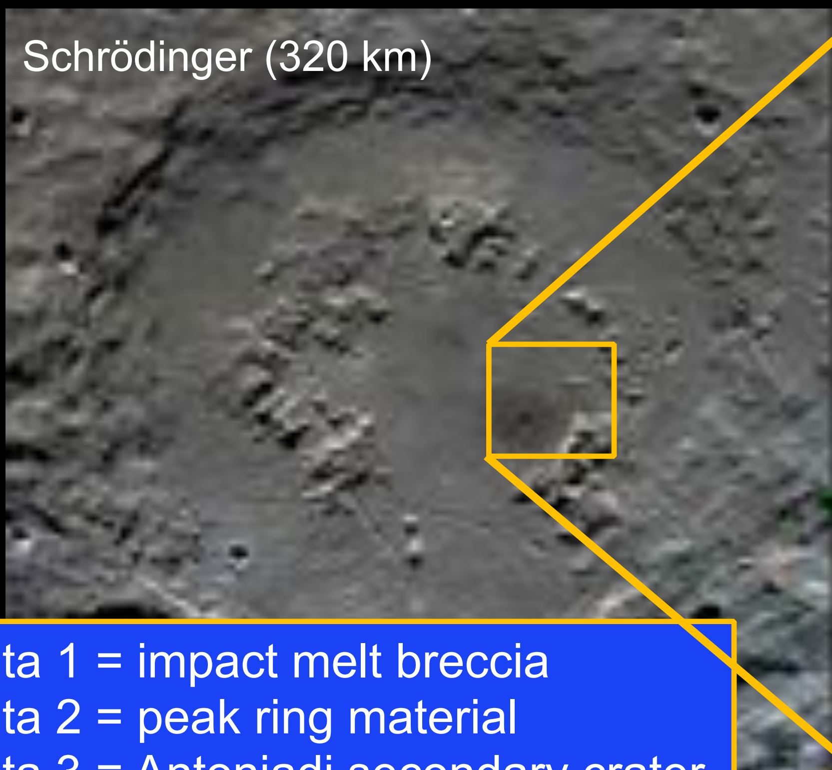
For those reasons, we have focused a lot of attention on Schrödinger basin. It is a very good target for future robotic and human exploration.

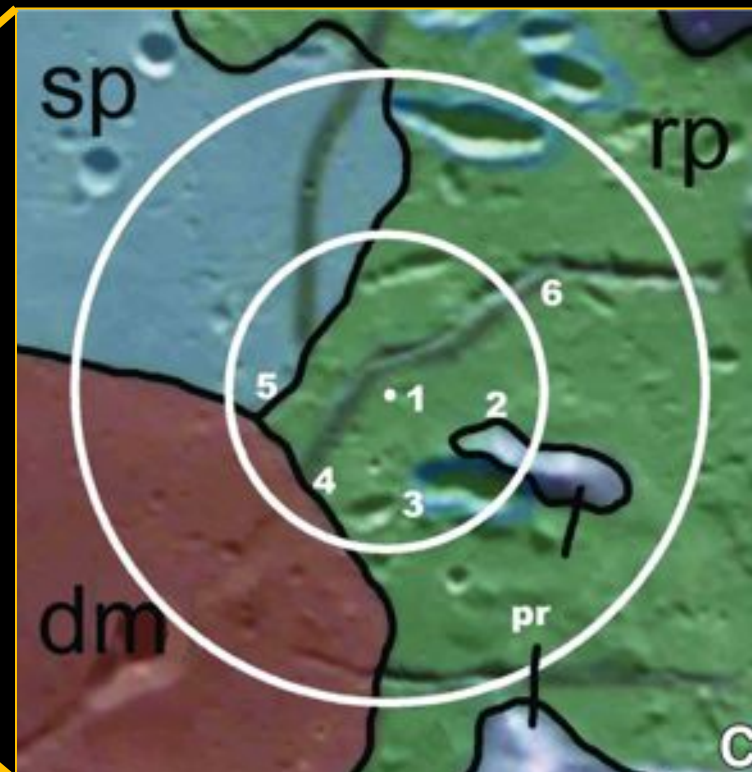


**Landing Site Study
O'Sullivan et al. (GSA SP 477, 2011)
See also Bunte et al. (GSA SP 483, 2011)**

Background SPA image: LRO-LOLA/NASA GSFC SVS

Schrödinger Basin
within South Pole-Aitken Basin





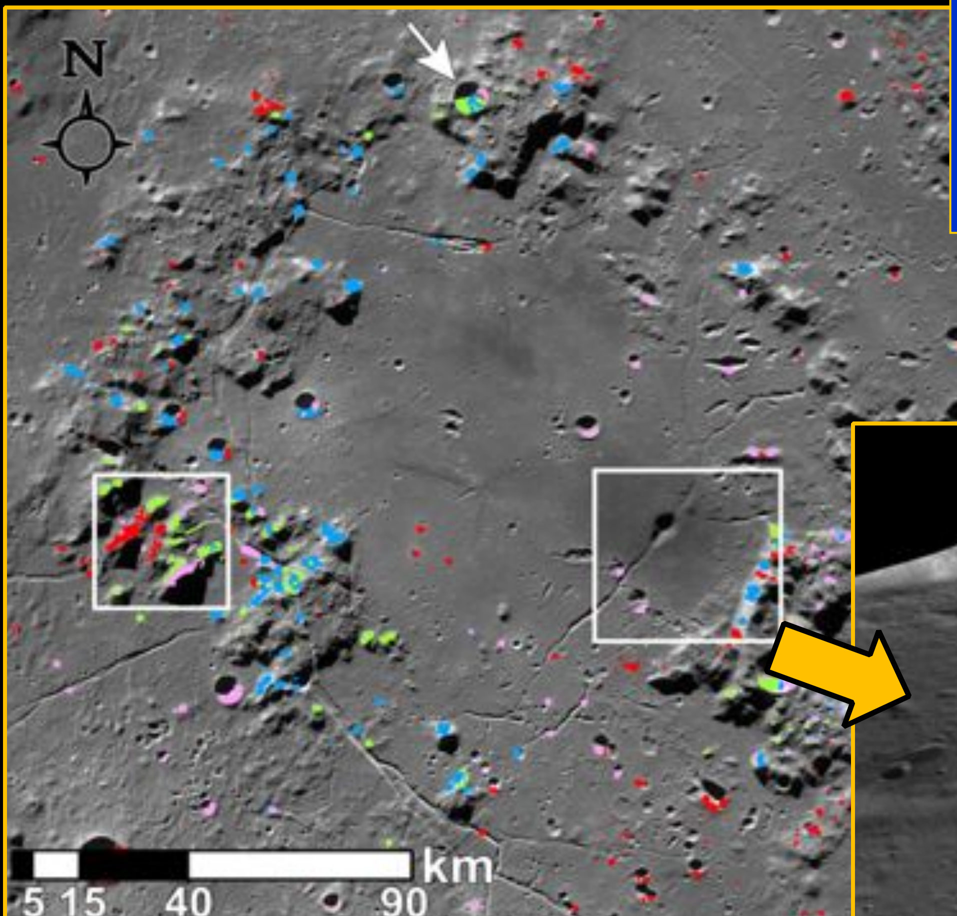
O'Sullivan et al. (2011)

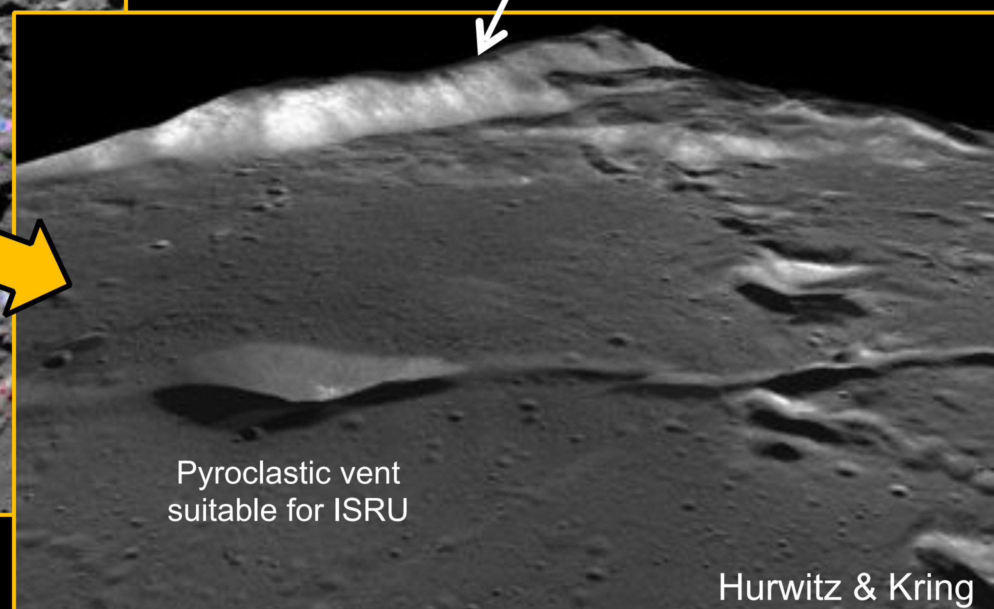
- Sta 1 = impact melt breccia
- Sta 2 = peak ring material
- Sta 3 = Antoniadi secondary crater
- Sta 4 = pyroclastic deposit
- Sta 5 = central melt sheet
- Sta 6 = deep fracture

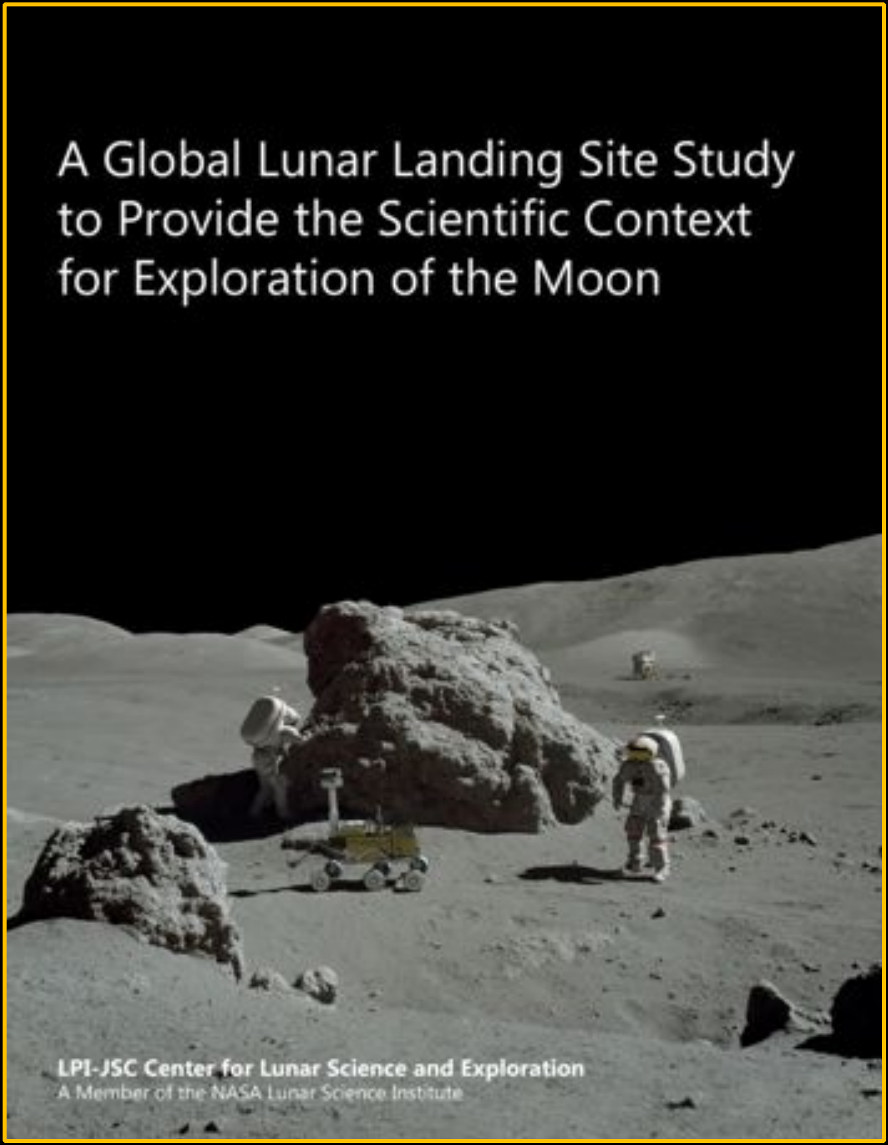
Schrödinger Basin
w/i the South Pole-Aitken Basin

Detailed studies by:
Kramer, Kring, Nahm, & Pieters (Icarus 2013)
Kumar et al. (JGR 2013)
Chandnani et al. (LPSC 2013)

Using M[3] data, LOLA data, and LROC data.

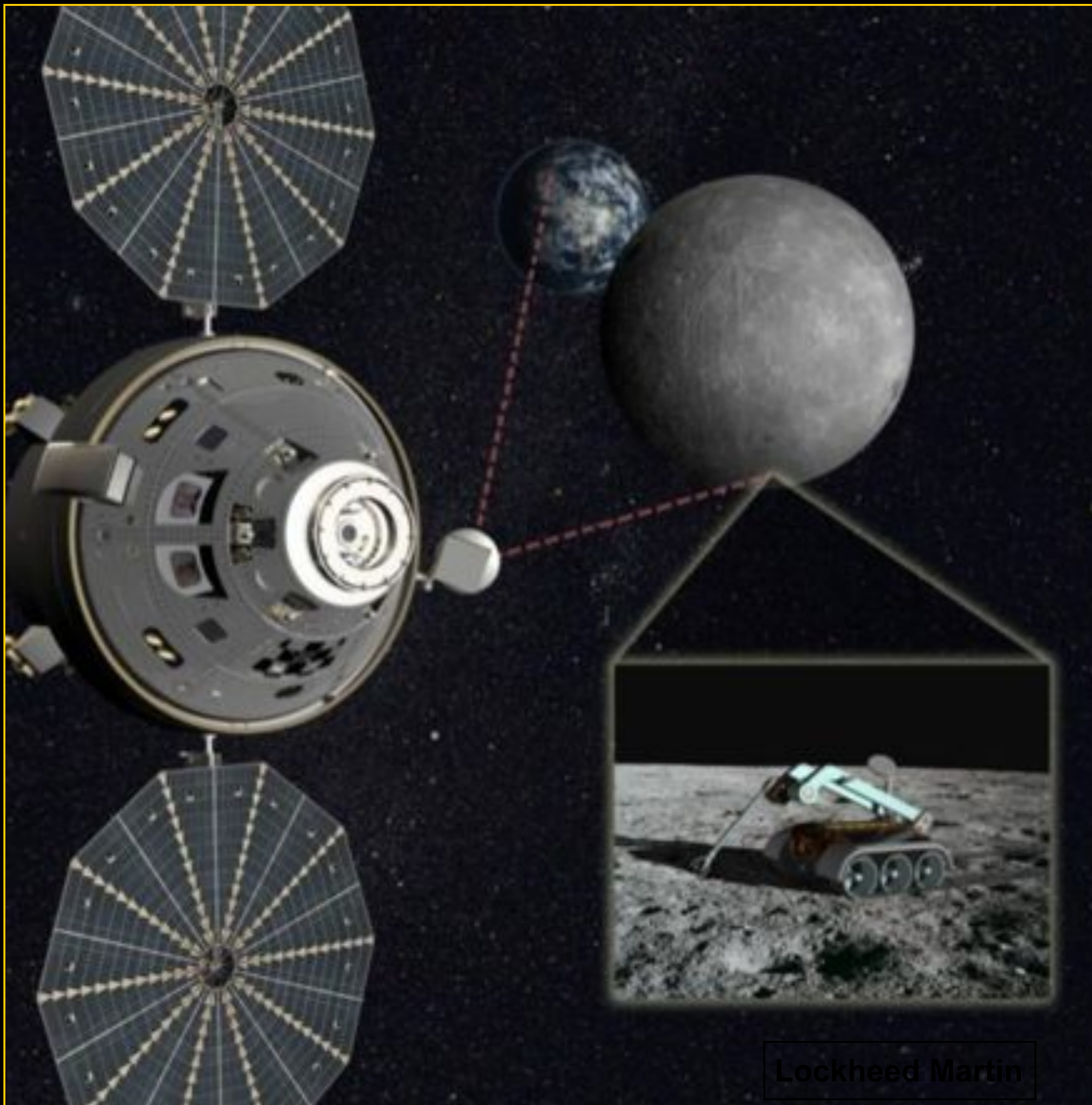






Experience suggests

- **The best results would be obtained by a trained crew on the lunar surface**
- **If crew cannot be delivered to the lunar surface, then significant progress can be made robotically or with an integrated robotic and human architecture (e.g., deploying crew to Earth-Moon L2 above the lunar far side in Orion)**



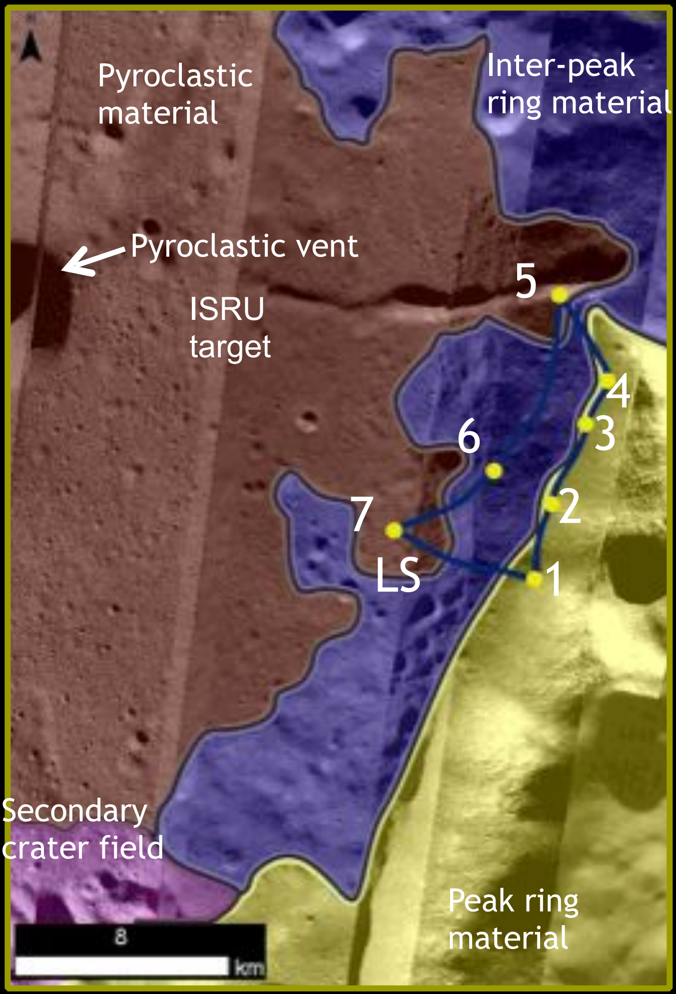
Re-examining the details:

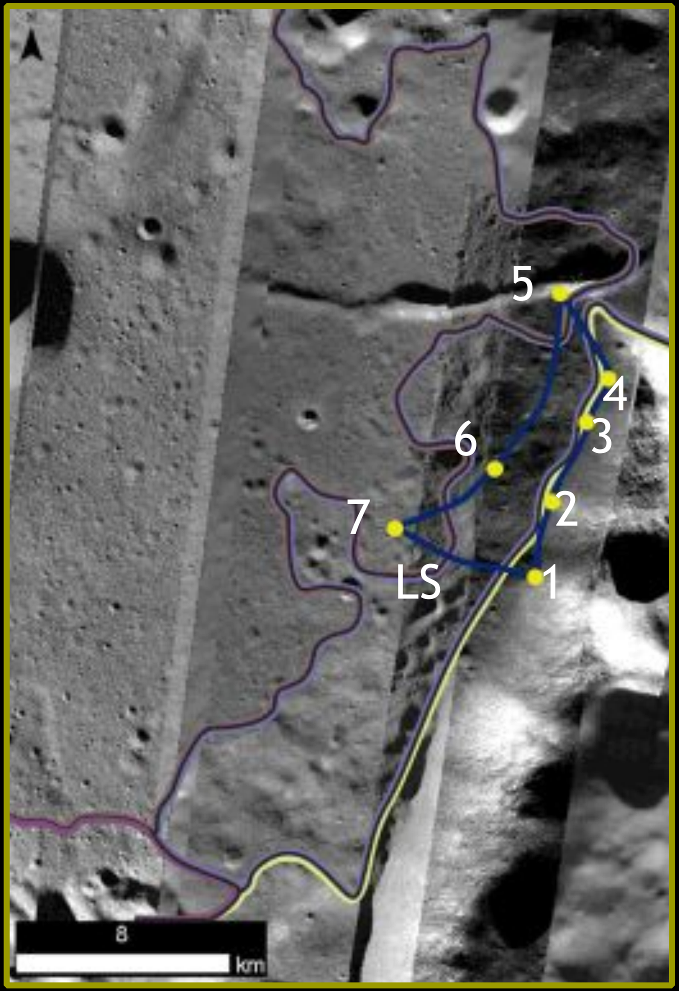
- Our previous landing site study of **Schrödinger Basin** assumed crew were landing.

- In an integrated robotic and human exploration program that is consistent with the multi-agency **Global Exploration Roadmap**, we re-evaluated the landing site and stations for a robotic surface asset.

Burns, Kring, Norris, Hopkins, Lazio, & Kasper (2013)

EXAMPLE ROBOTIC TRAVERSE (SITE C)





SITE C
28.8 km, 1 km/hr
13.5 days (total traverse time)

Addresses NRC (2007) priority:
Station 1: 2, 3, 7
Station 2: 2, 3, 7
Station 3: 2, 3, 7
Station 4: 2, 3, 7
Station 5: 2, 3, 5, 7
Station 6: 1, 3, 6, 7
Station 7: 3, 5, 6, 7

Plus ISRU studies in the vicinity of the pyroclastic vent

Gullickson et al. (2014)

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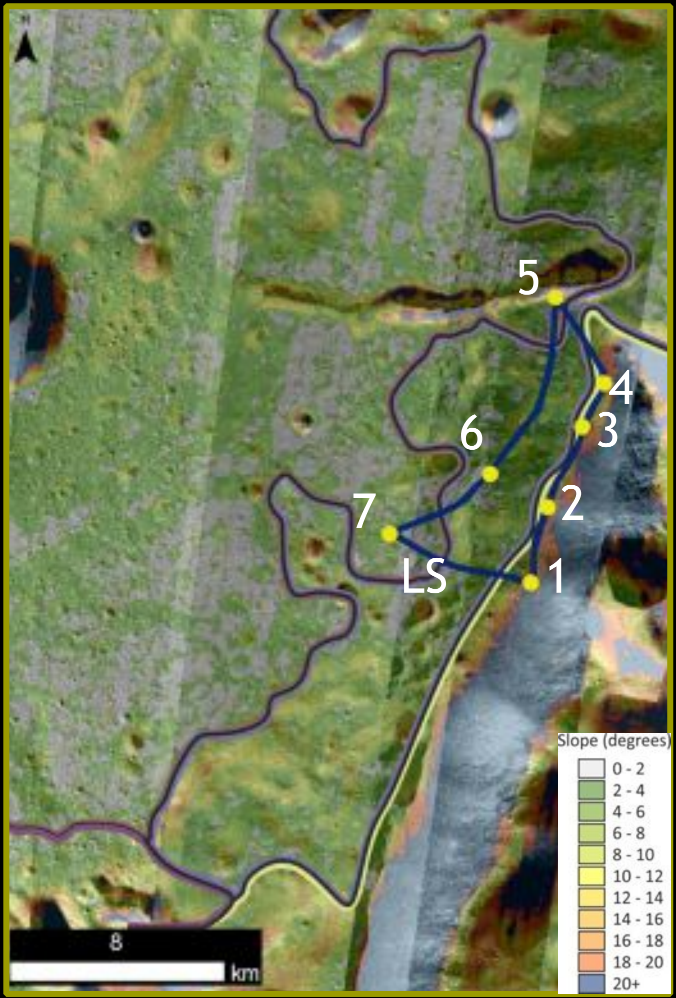

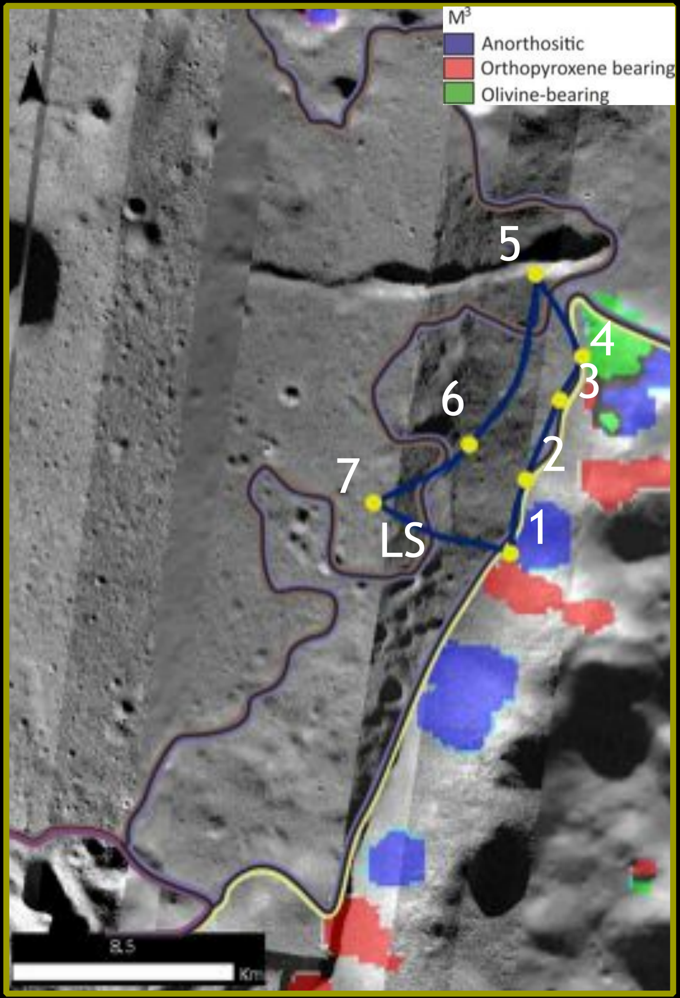

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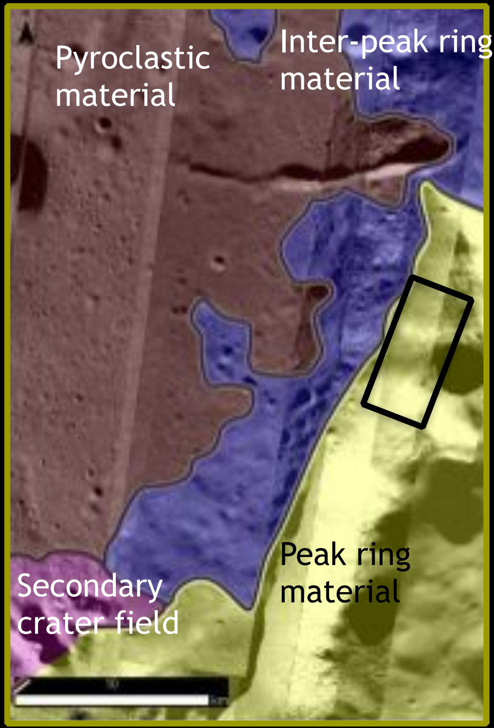
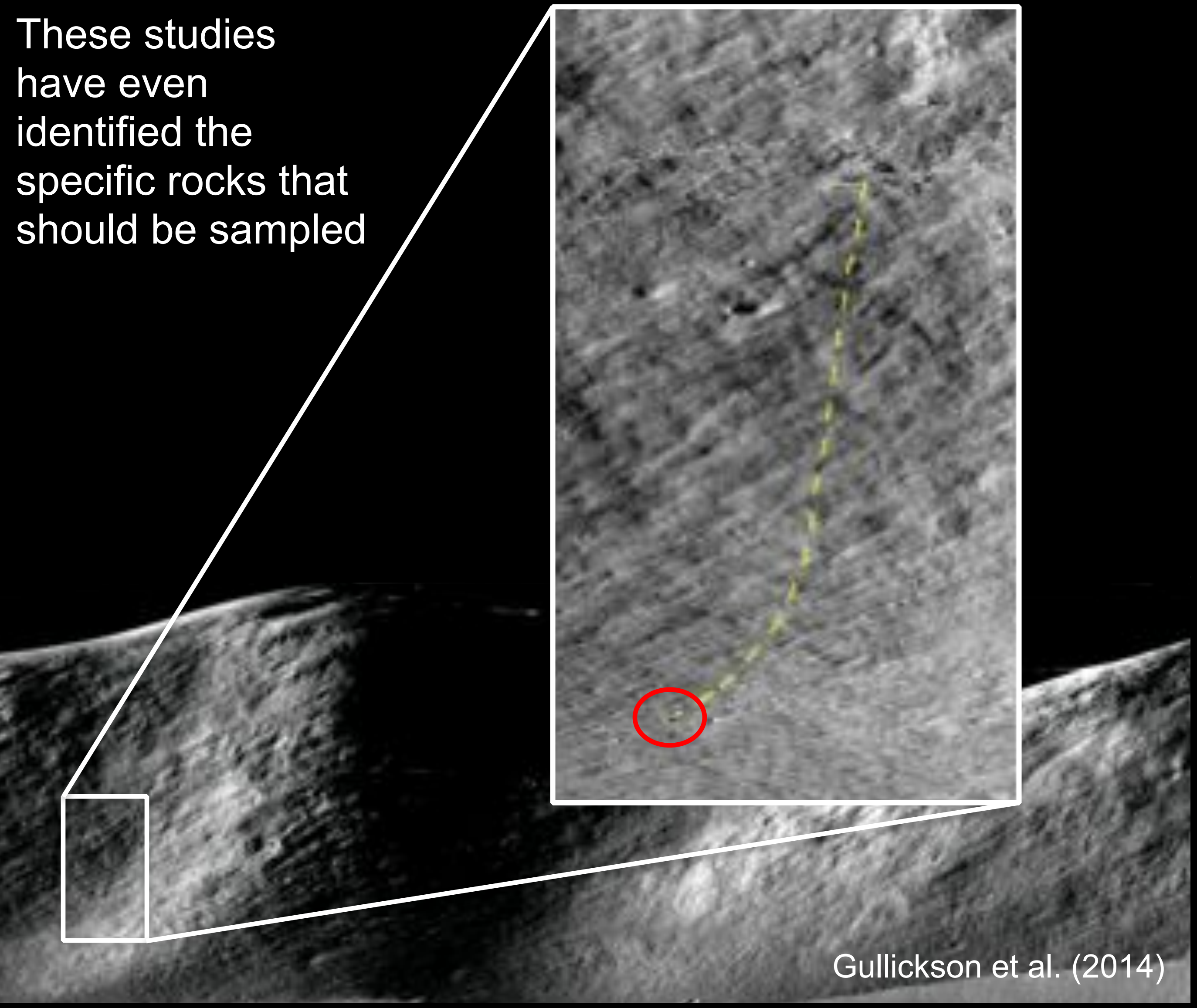


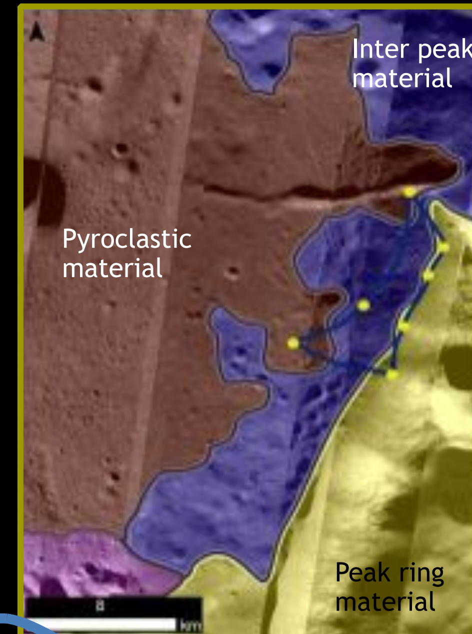
These studies have even identified the specific rocks that should be sampled



EXAMPLE ROBOTIC TRAVERSE (SITE C)

SITE C
28.8 km, 1 km/hr
13.5 days

Average slope: 6.1°
Maximum slope: 15.8°



Gullickson et al. (2014)

ILLUMINATION –SITE C

- Mission planned 2021
- Optimum period of sunlight = 6th August 2021 – 19th August 2021

Potts et al. (2014)

ILLUMINATION –SITE C

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- Optimum period of sunlight = 6th August 2021 – 19th August 2021

Potts et al. (2014)

ILLUMINATION –SITE C

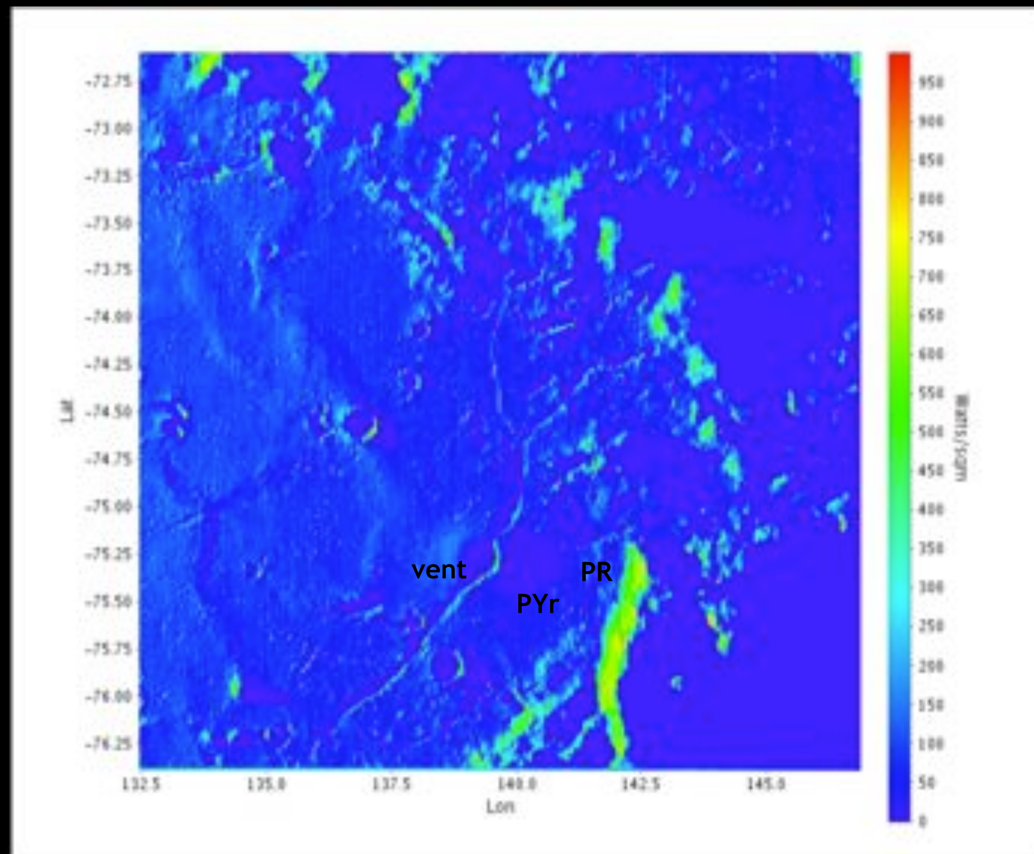
- Mission planned 2021
- Optimum period of sunlight = 6th August 2021 – 19th August 2021

Potts et al. (2014)

SOLAR IRRADIANCE – SITE C

- Mission planned 2021
- Optimum period of sunlight = 6th August 2021 – 19th August 2021

Incidence sunlight (i.e., sunlight power on surface)



Potts et al. (2014)

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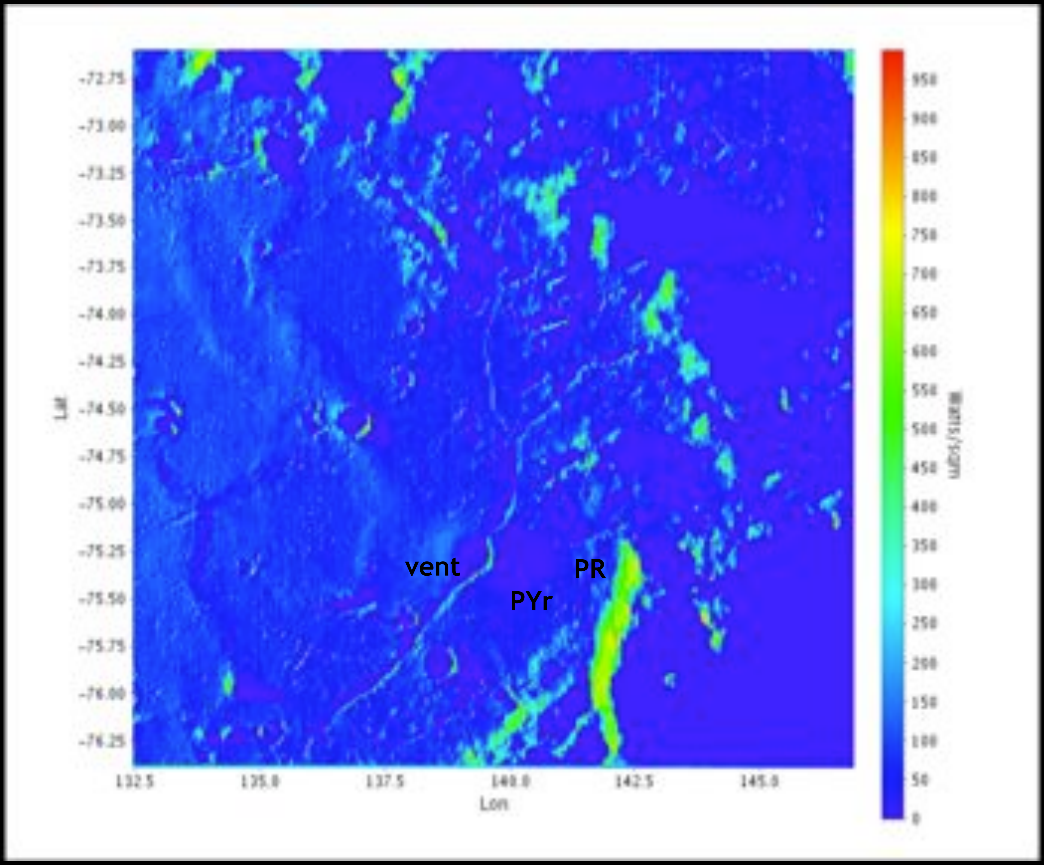

Potts et al. (2014)

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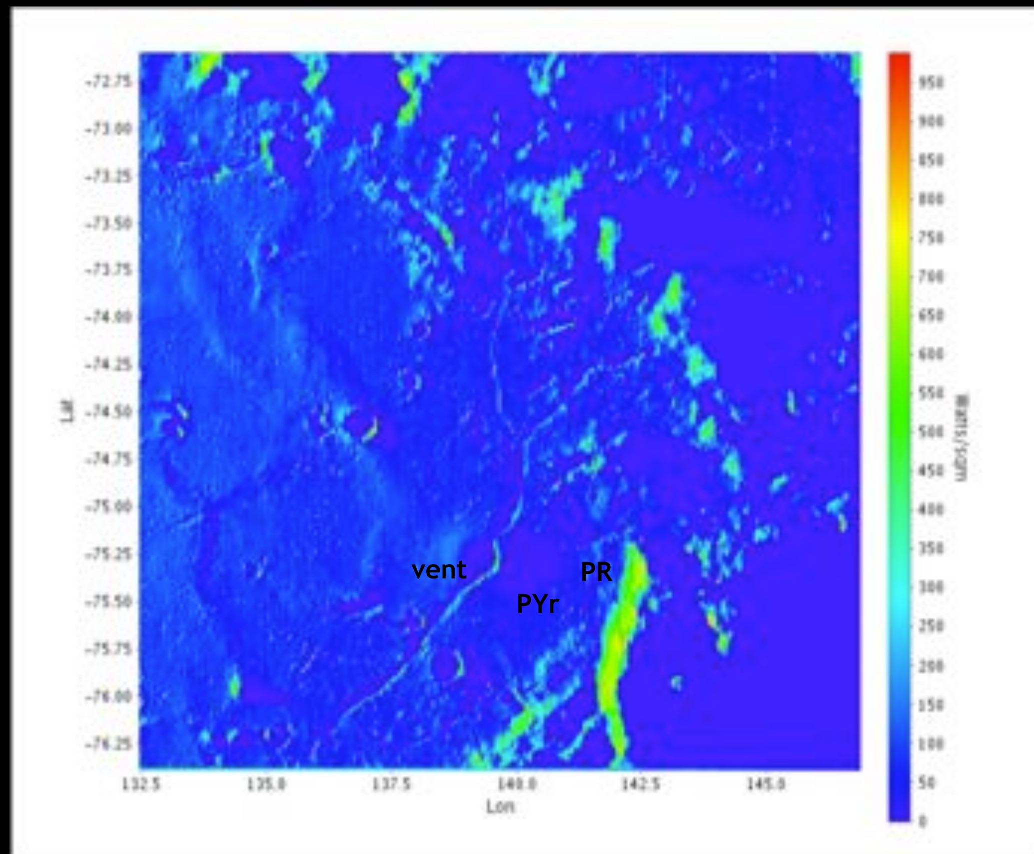
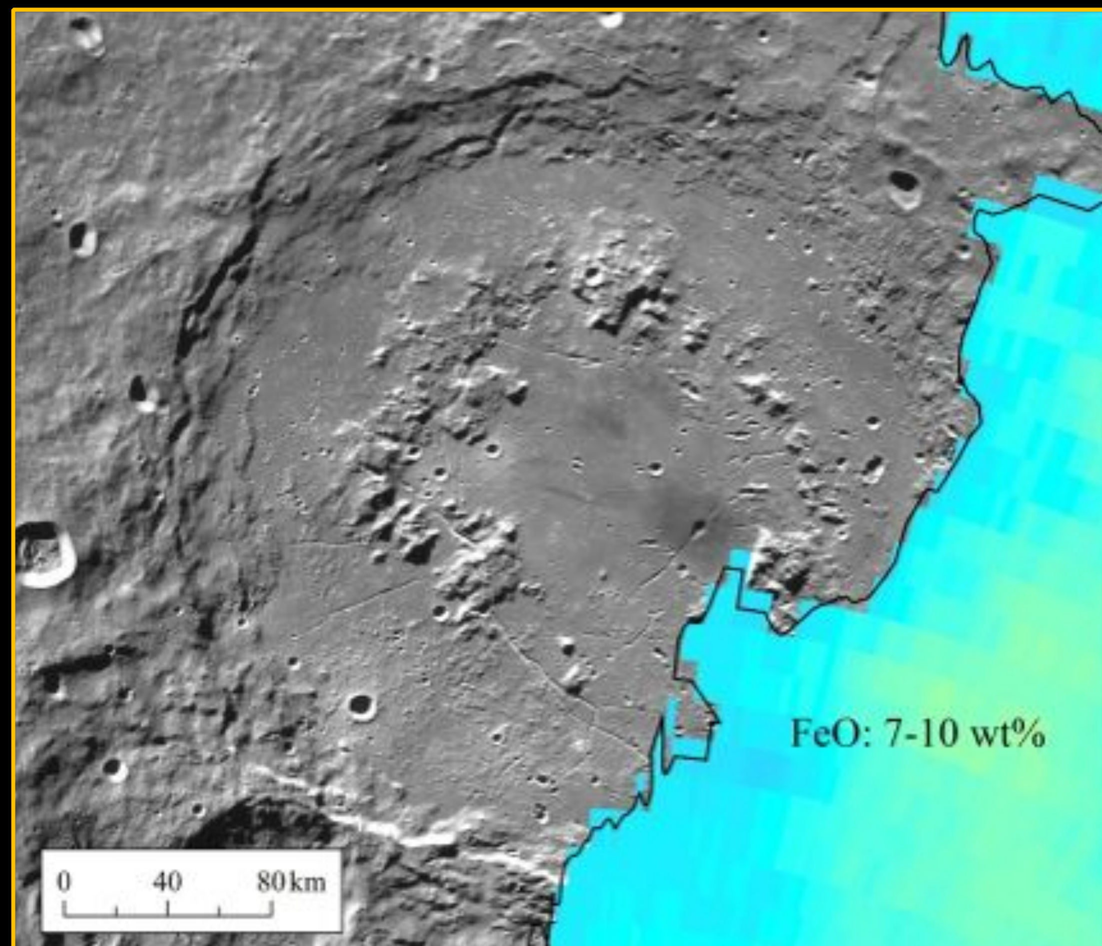


Potts et al. (2014)

POTENTIAL SCHRÖDINGER & SPA IMPACT MELT DEPOSITS

- Iron anomaly that has been used to define regions with SPA melt extends into the Schrodinger basin

- Within that region, look for low-Ca pyroxene exposures, which can reflect crystallized SPA melt



Hurwitz & Kring (2014)

POTENTIAL SCHRÖDINGER & SPA IMPACT MELT DEPOSITS

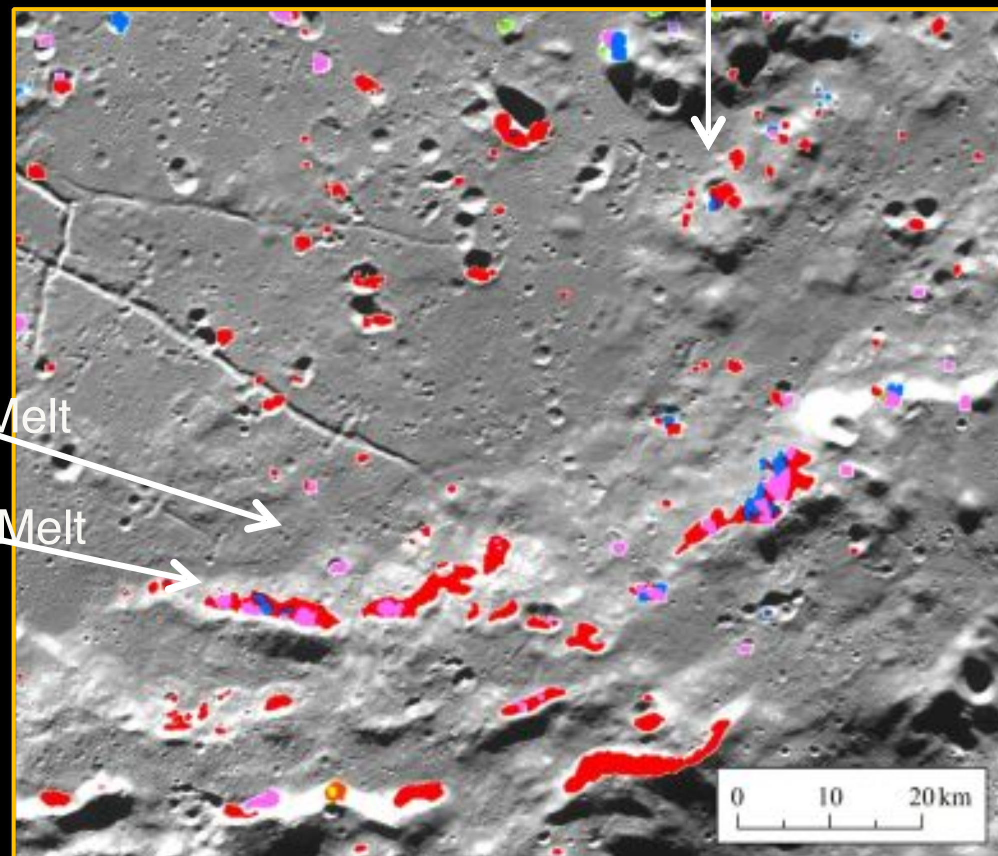
- Basin walls more likely to host SPA melt
  - Possible exposures of SPA melt
  - Slumped terraces, fallen rocks

- Possible Mission
  - Sample candidate SPA impact melt
  - Compare with Schrödinger melt

Candidate SPA Impact M

Schrödinger Impact Melt

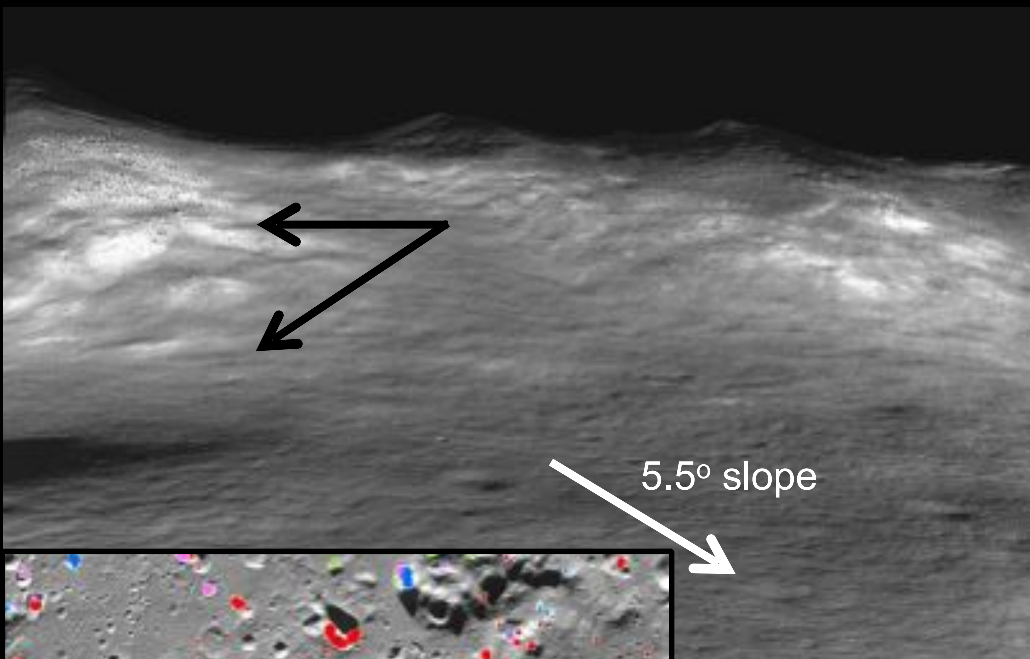
Candidate SPA Impact Melt

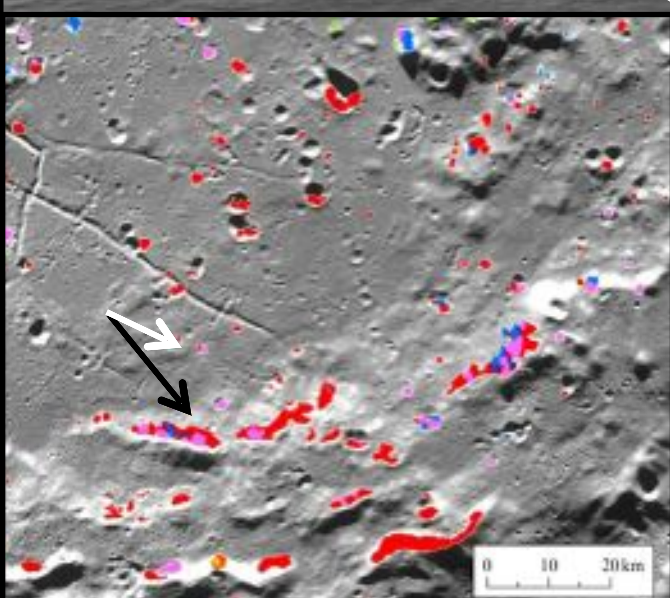


Hurwitz & Kring (2014)

Low-Ca pyroxenes: red and pink
Anorthosite (blue)
Olivine (green)
(Kramer et al. 2013)

POTENTIAL SCHRÖDINGER & SPA IMPACT MELT DEPOSITS

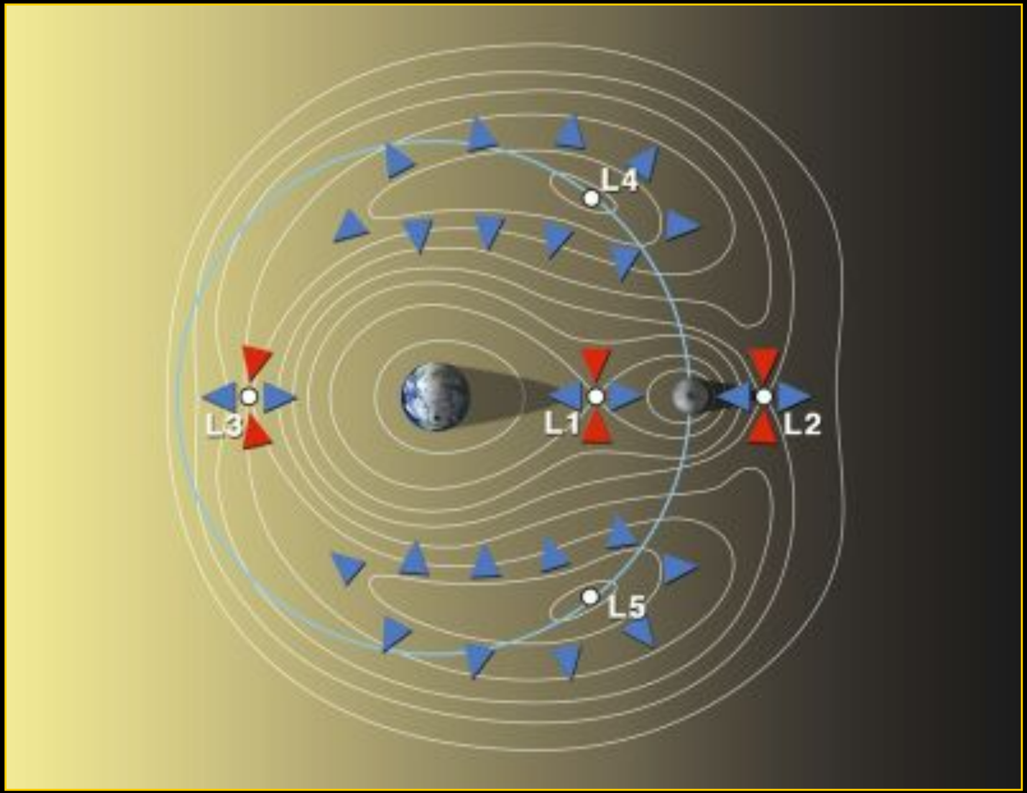




- Basin walls more likely to host SPA melt
  - Possible exposures of SPA melt
  - Slumped terraces, fallen rocks
- Possible Mission
  - Sample candidate SPA impact melt
  - Compare with Schrödinger melt
    - 15–18 km away on plains floor
    - Slope from plains to lower rocks: 5.5º

LOLA topography: 2x vertical exaggeration

A SCIENCE PERSPECTIVE ABOUT HUMAN AND ROBOTIC EXPLORATION



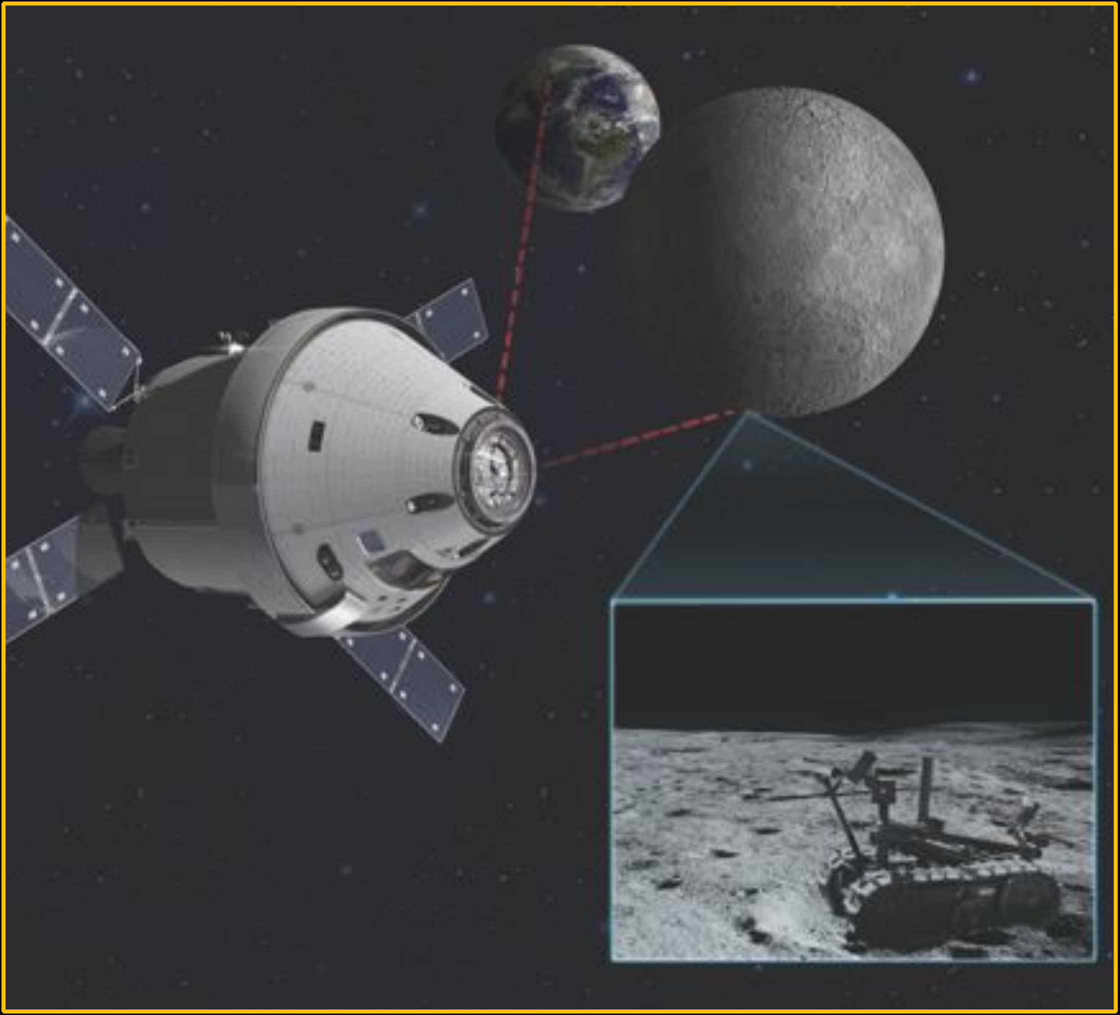
Burns, Kring, Norris, Hopkins, Lazio, & Kasper (2013)

An option we have been exploring

Earth-Moon L2 Mission:

- **L2 located 60,000 km above the lunar surface**
- **Orion launched and maneuvered into a halo orbit around L2**
- **The mission can also be conducted using the DRO architecture**

PREPARING FOR HUMAN ASSISTED SAMPLE RETURN (PER THE GER)

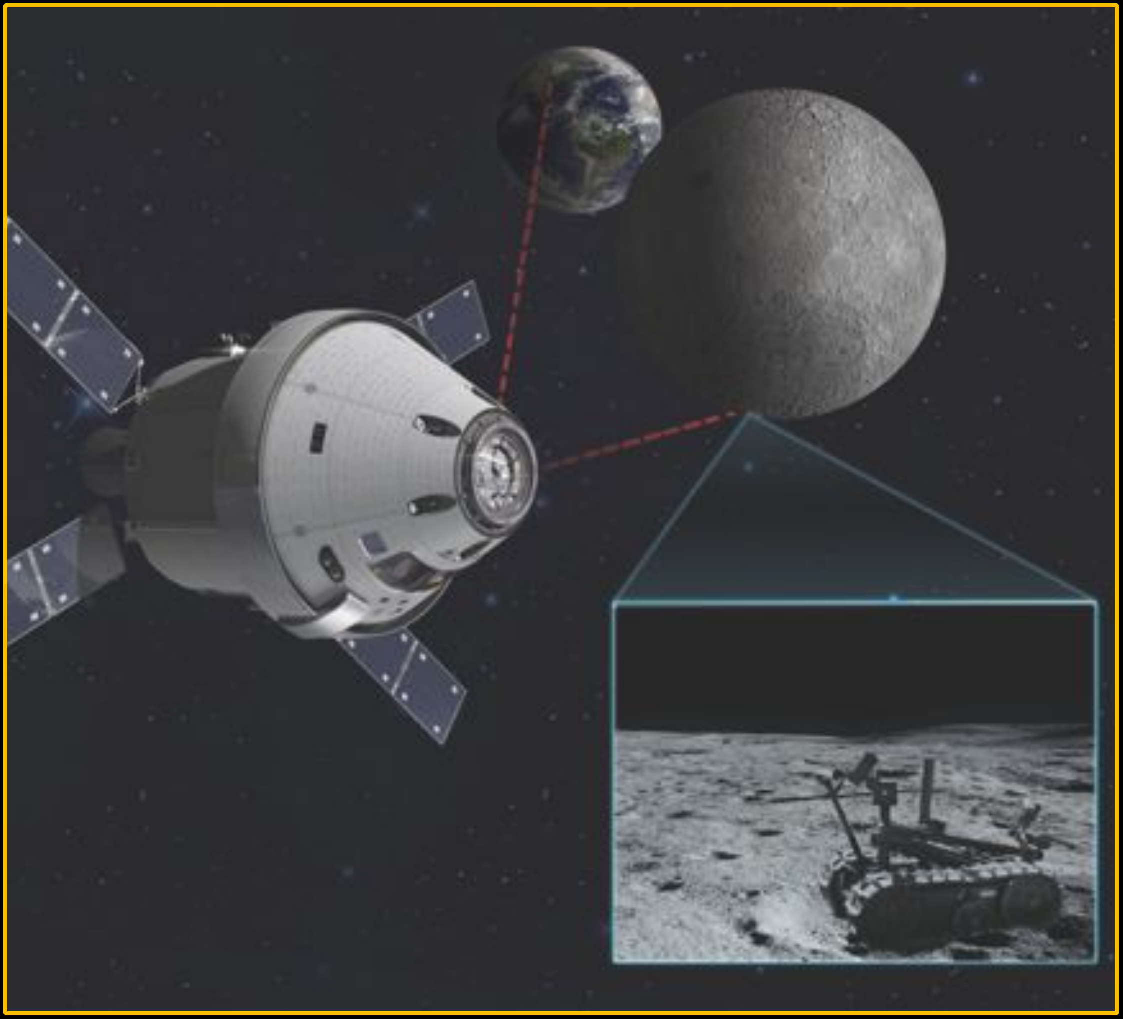


Burns, Kring, Norris, Hopkins, Lazio, & Kasper (2013)

Exploration risk reduction:

- **Demonstrate Orion in deep space and high speed Earth-entry**
- **30 to 35 day mission into trans-lunar space**
- **Crew will travel 15% farther than Apollo and spend 3 times longer in deep space**
- **Practice tele-operation of rovers**

PREPARING FOR HUMAN ASSISTED SAMPLE RETURN (PER THE GER)

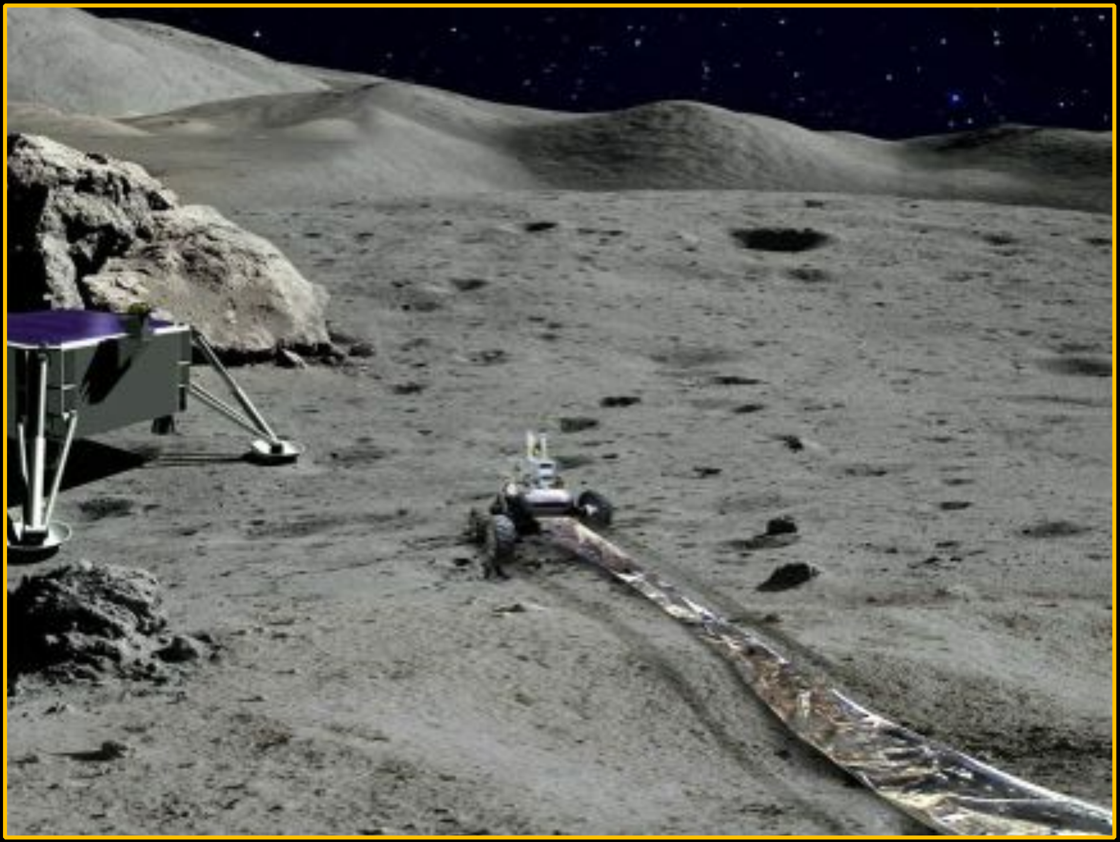


Burns, Kring, Norris, Hopkins, Lazio, & Kasper (2013)

Science objectives:

- **Land and explore a region within SPA (for example, Schrödinger Basin)**
- **Geologic measurements will be made.**
- **A sample will be collected and returned to Earth.**
- **An astrophysical system will be deployed.**

Status: Integrated science and engineering studies continue.



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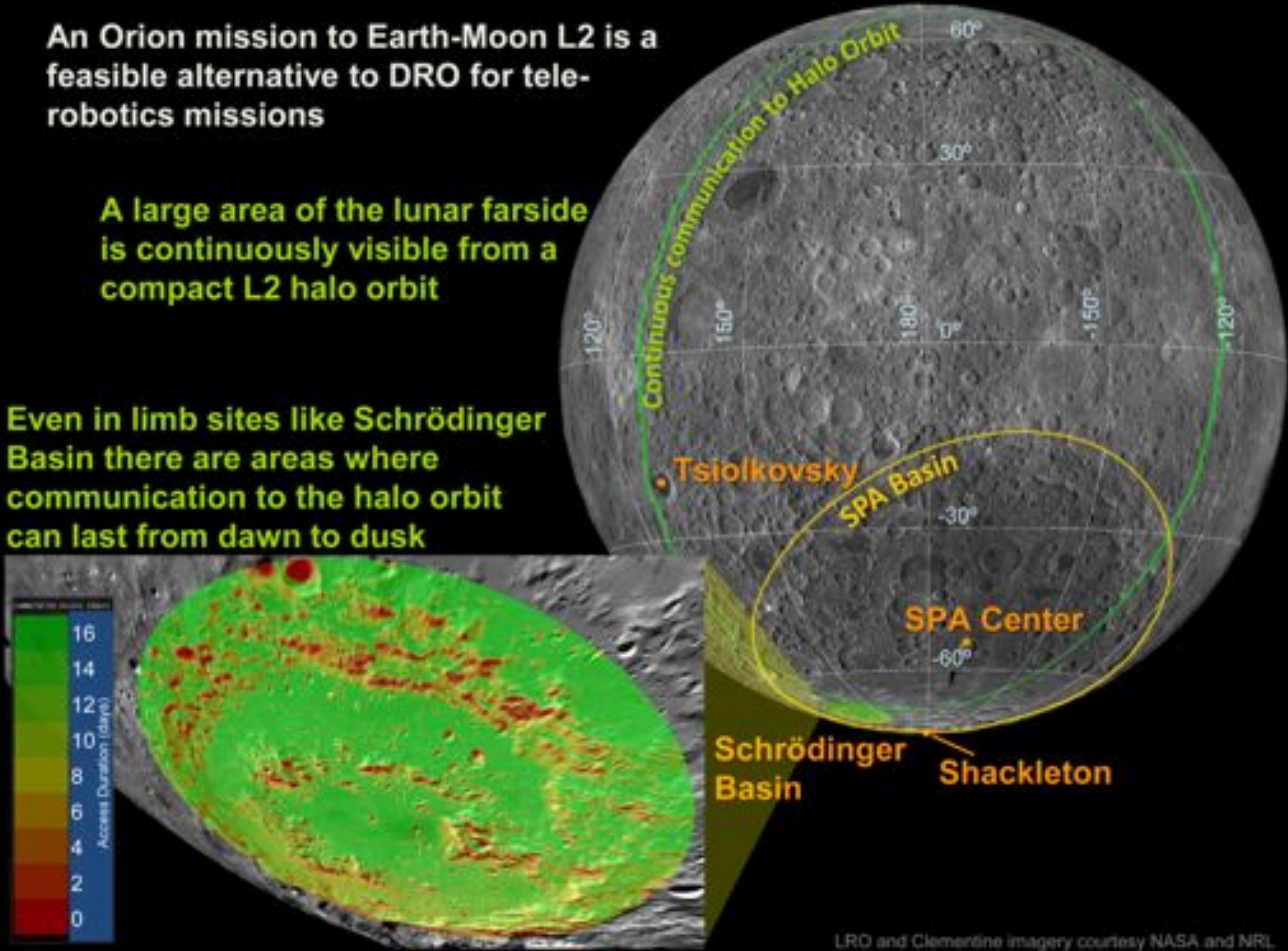
COMMUNICATION COVERAGE FROM A HALO ORBIT ABOUT EM-L2

Lockheed Martin (courtesy of Josh Hopkins)

An Orion mission to Earth-Moon L2 is a feasible alternative to DRO for tele-robotics missions

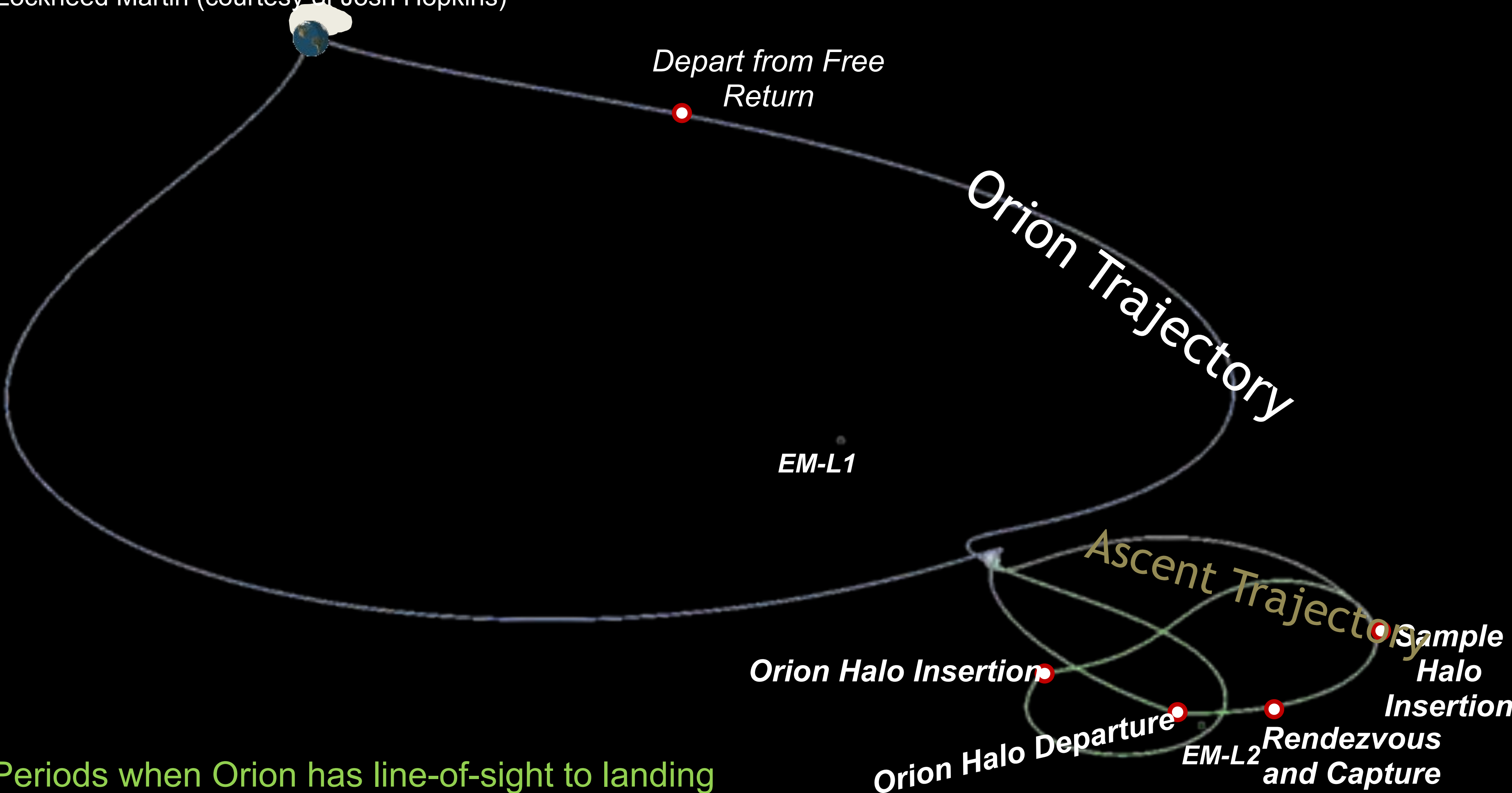
A large area of the lunar farside is continuously visible from a compact L2 halo orbit

Even in limb sites like Schrödinger Basin there are areas where communication to the halo orbit can last from dawn to dusk



TRAJECTORY FOR SAMPLE CAPTURE IN EARTH-MOON L2

Lockheed Martin (courtesy of Josh Hopkins)

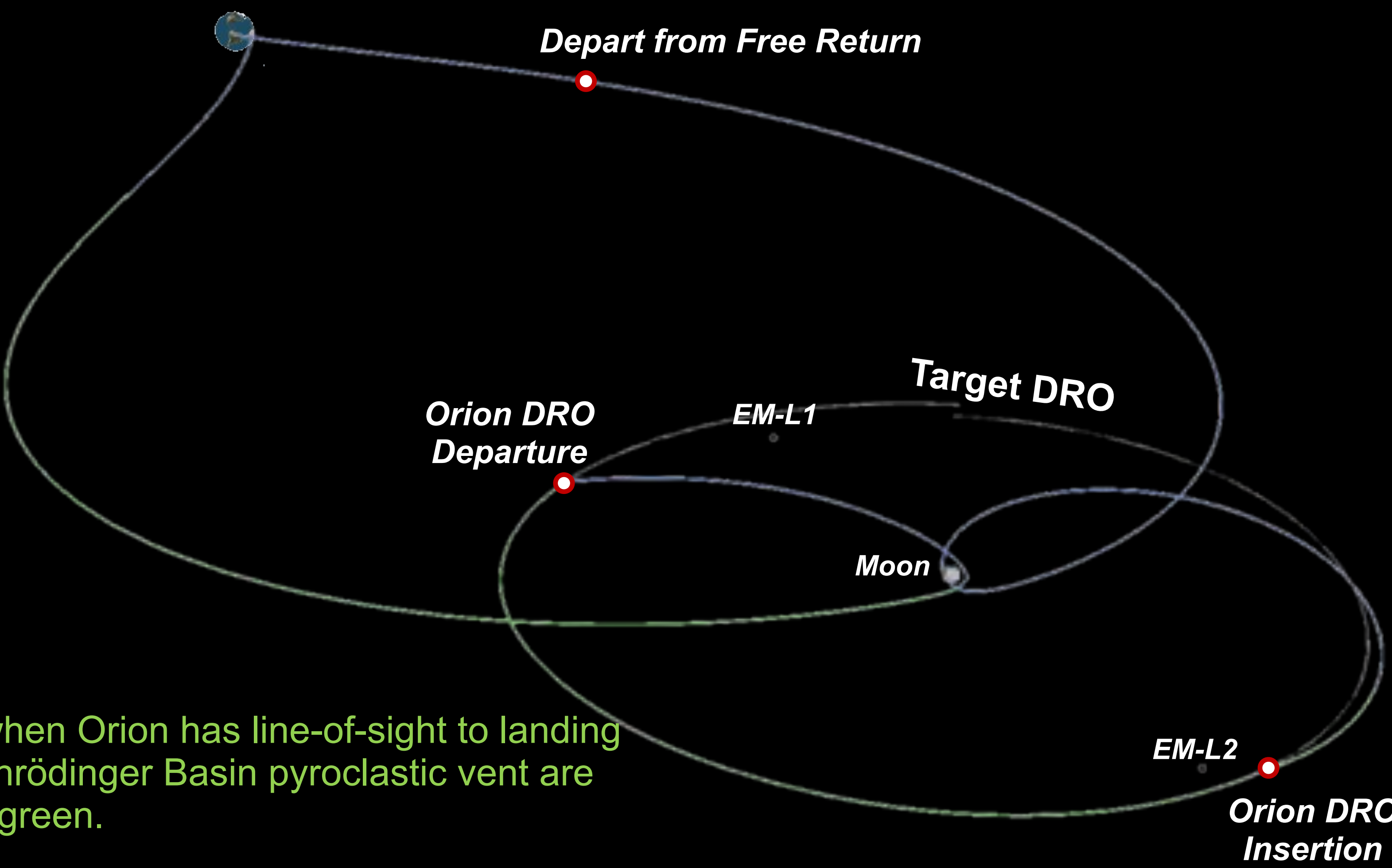


Periods when Orion has line-of-sight to landing site in the center of SPA Basin are shown in green.

Combined Trajectory by JPL

TRAJECTORY FOR TELEROBOTICS IN A DISTANT RETROGRADE ORBIT (DRO)

Lockheed Martin (courtesy of Josh Hopkins)

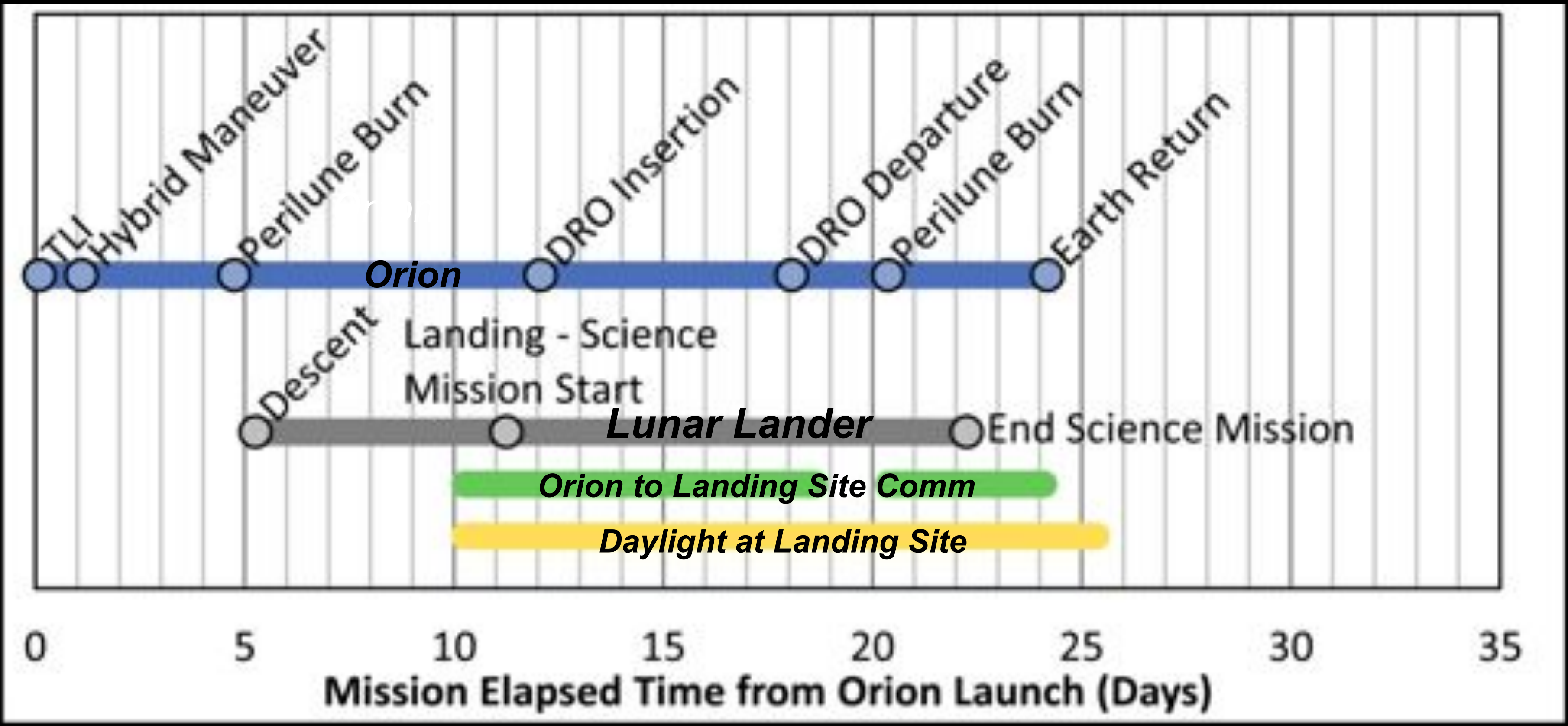


Periods when Orion has line-of-sight to landing site at Schrödinger Basin pyroclastic vent are shown in green.

Trajectory is compatible with Orion delta-V and duration capabilities

TIMELINE FOR DRO/SCHRÖDINGER BASIN MISSION

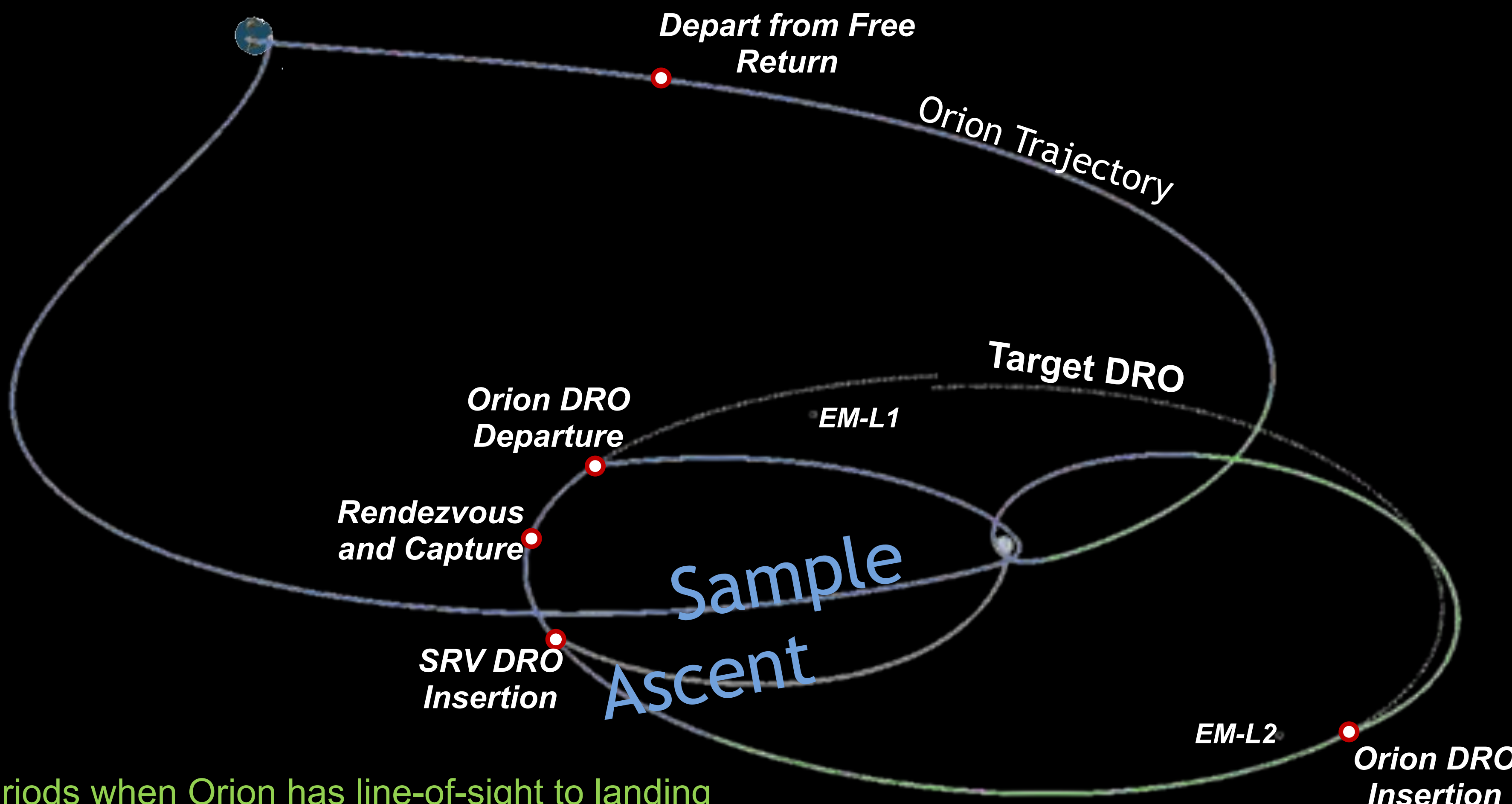
Lockheed Martin (courtesy of Josh Hopkins)



Telerobotic rover has 11 day operating duration with one telecom gap of ~1.5 days when Orion is not visible.

TRAJECTORY FOR SAMPLE CAPTURE IN DRO FROM SPA BASIN

Lockheed Martin (courtesy of Josh Hopkins)



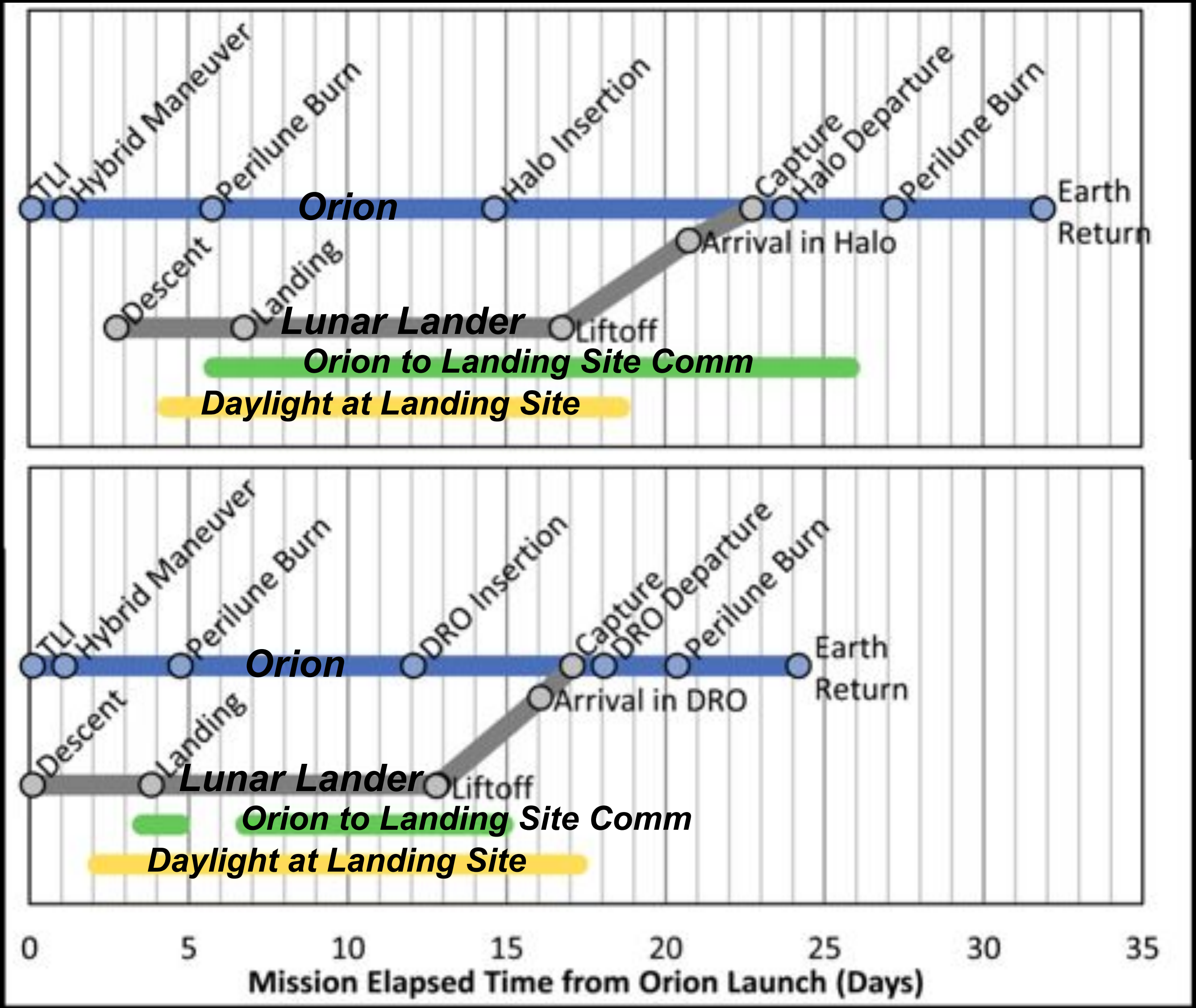
Periods when Orion has line-of-sight to landing site in the center of SPA Basin are shown in green.

SAMPLE CAPTURE MISSION TIMELINE COMPARISON

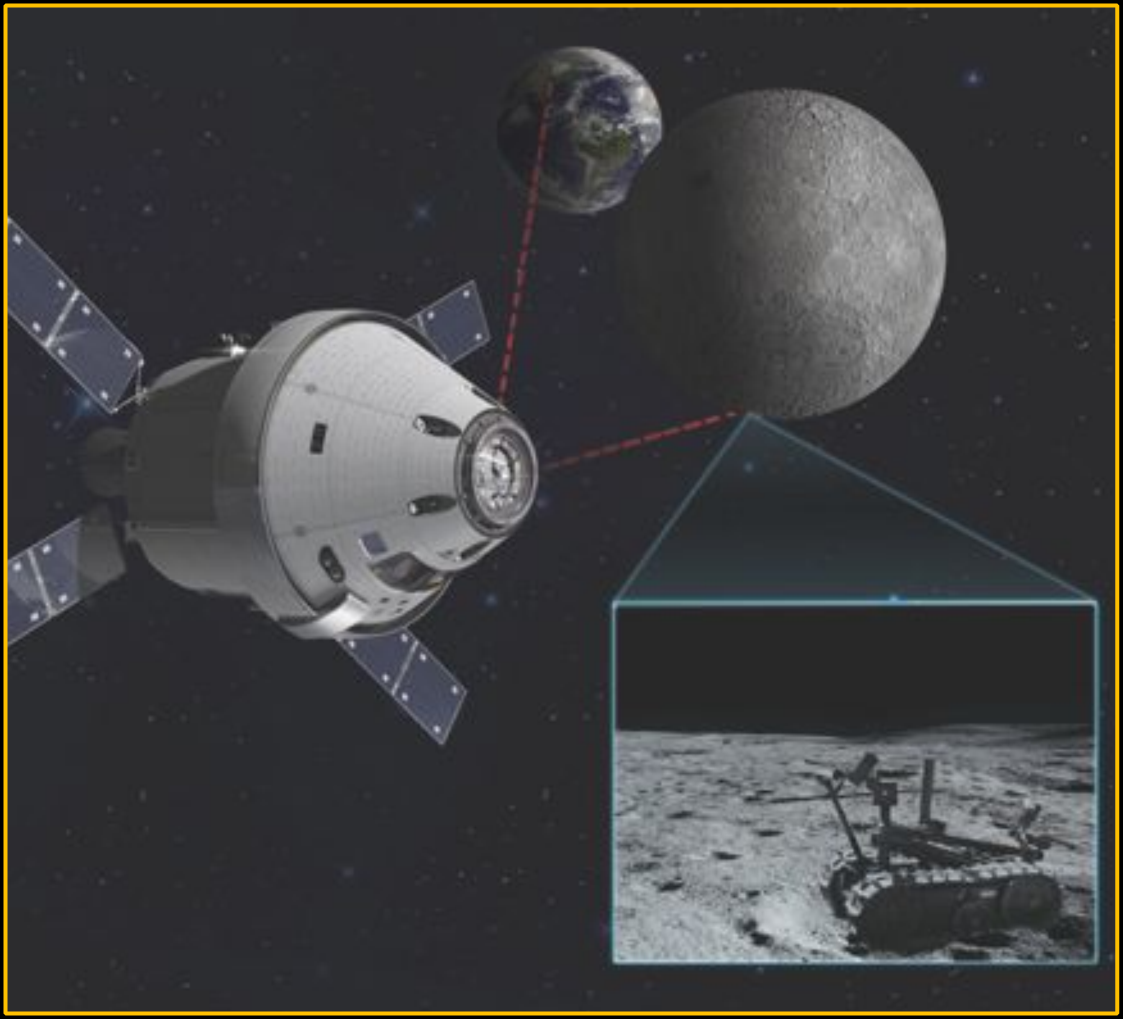
Lockheed Martin (courtesy of Josh Hopkins)

Sample Return Central SPA Basin to L2

Sample Return Central SPA Basin to DRO



PREPARING FOR HUMAN ASSISTED SAMPLE RETURN (PER THE GER)



Additional options:

- Deploy a communication satellite from Orion to support additional surface activity after crew returns to Earth

- If long-term station-keeping by crew is implemented in an L2 or distant retrograde orbit (DRO), then additional tele-ops can be conducted with the first rover and potentially other landed assets.

Conclusions

Schrödinger basin is one of the highest priority landing sites based on a global assessment of the NRC (2007) objectives

It can be used to test the

- Lunar Cataclysm Hypothesis
- Lunar Magma Ocean Hypothesis

It can provide ISRU resources

- Pyroclastic deposits
- & potentially volatile-rich deposits

The Moon is the best and most accessible place in the Solar System to answer fundamental planetary science questions.