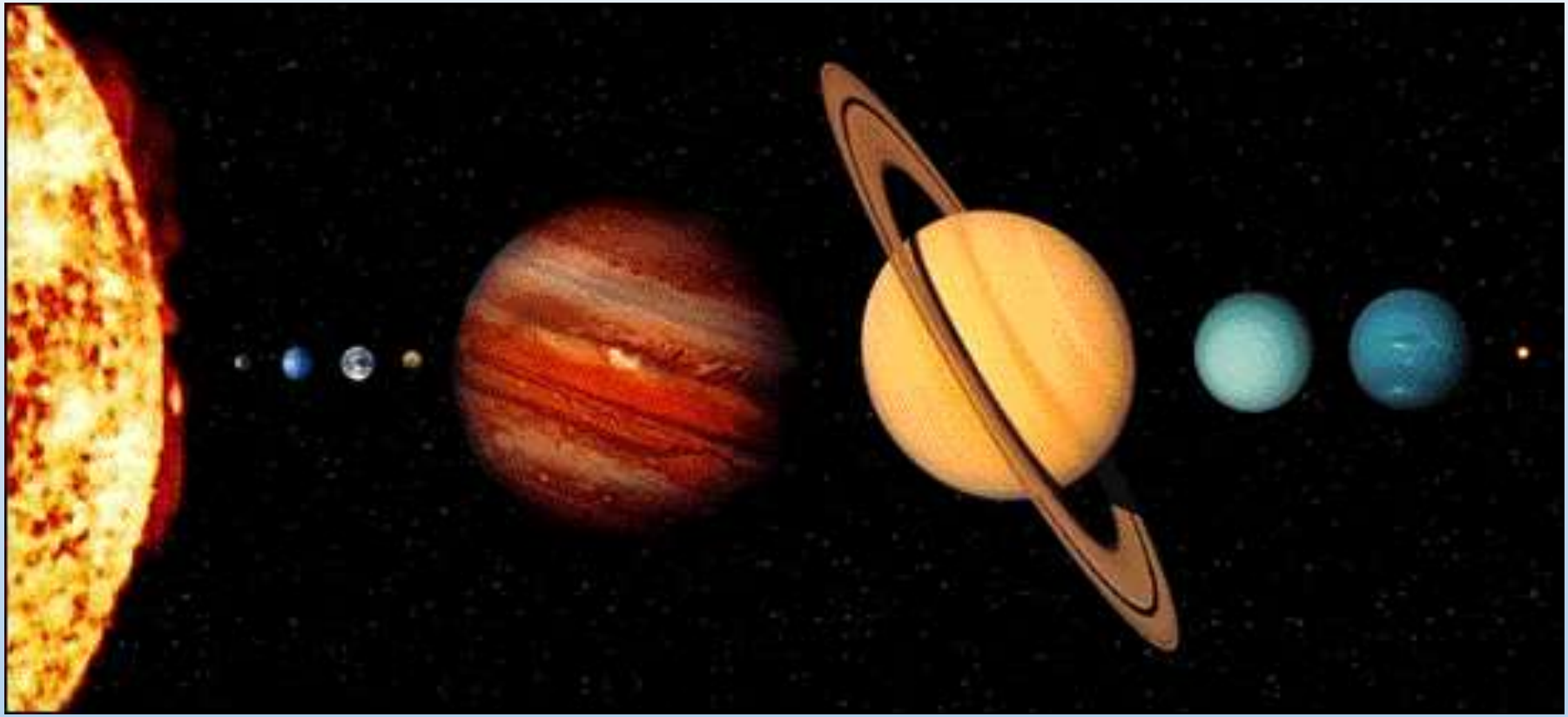
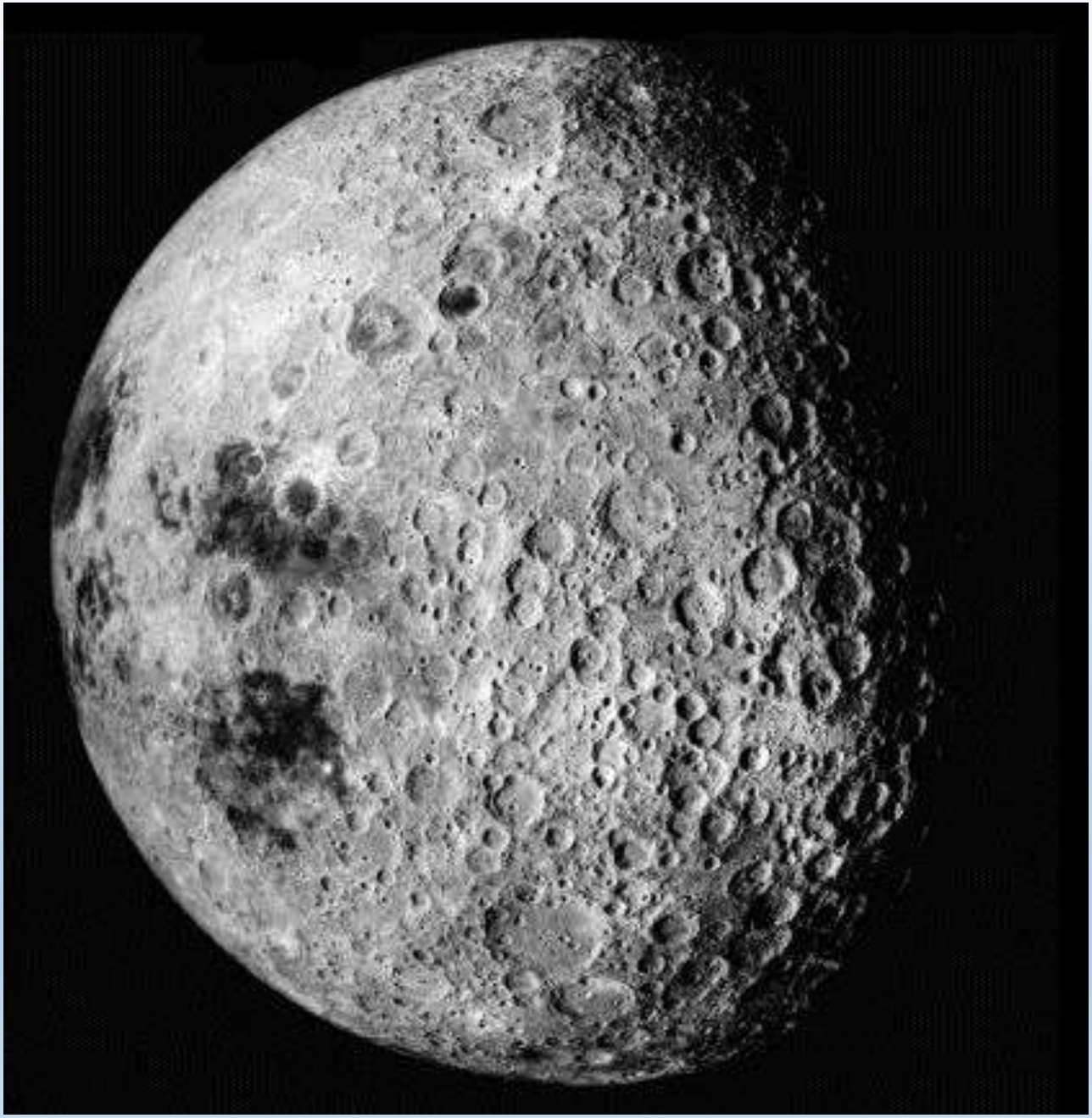
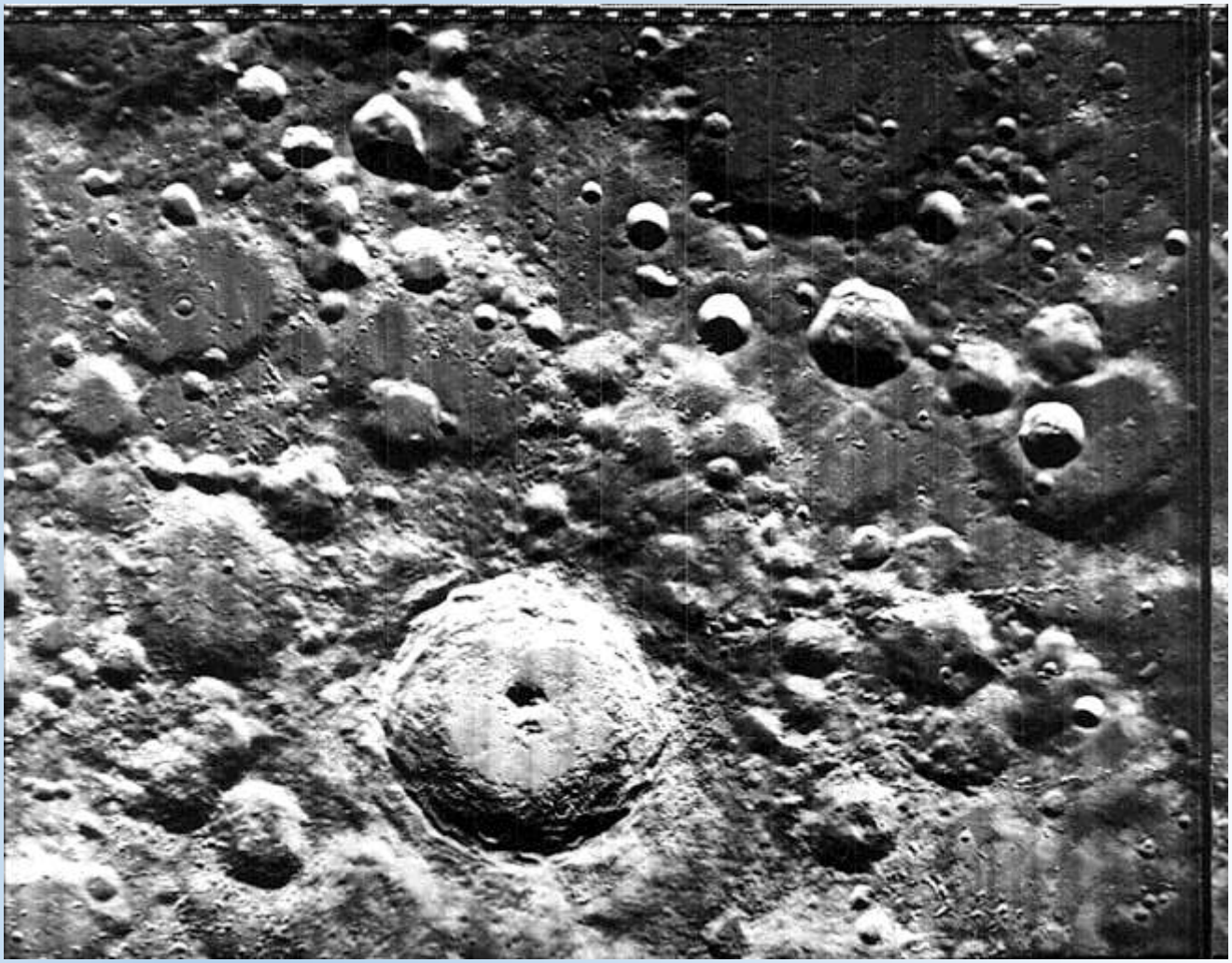
Moon Bases – Plans and Hopes

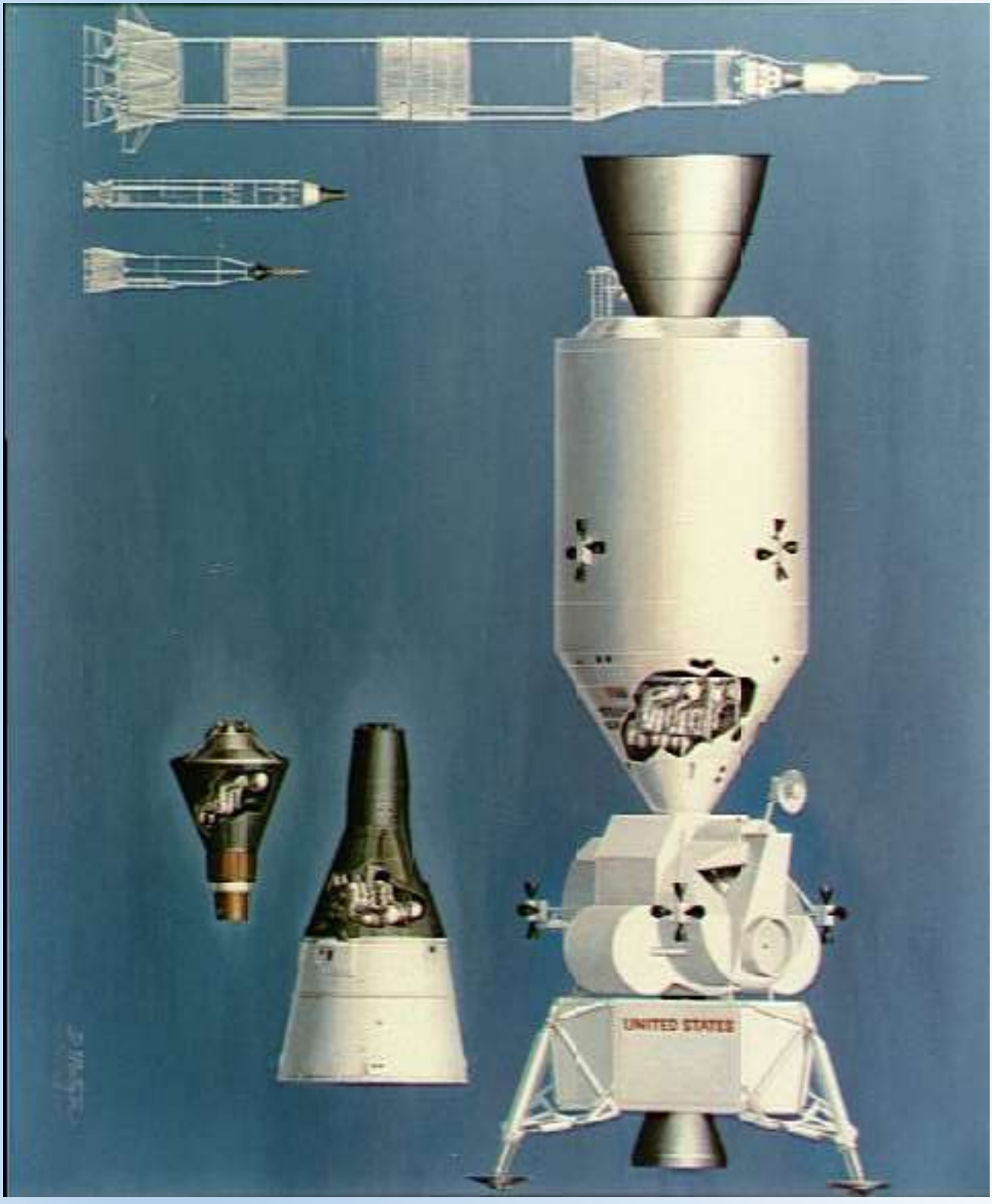
Presentation to
American Institute of Chemical Engineers (AIChE)
Independence, OH

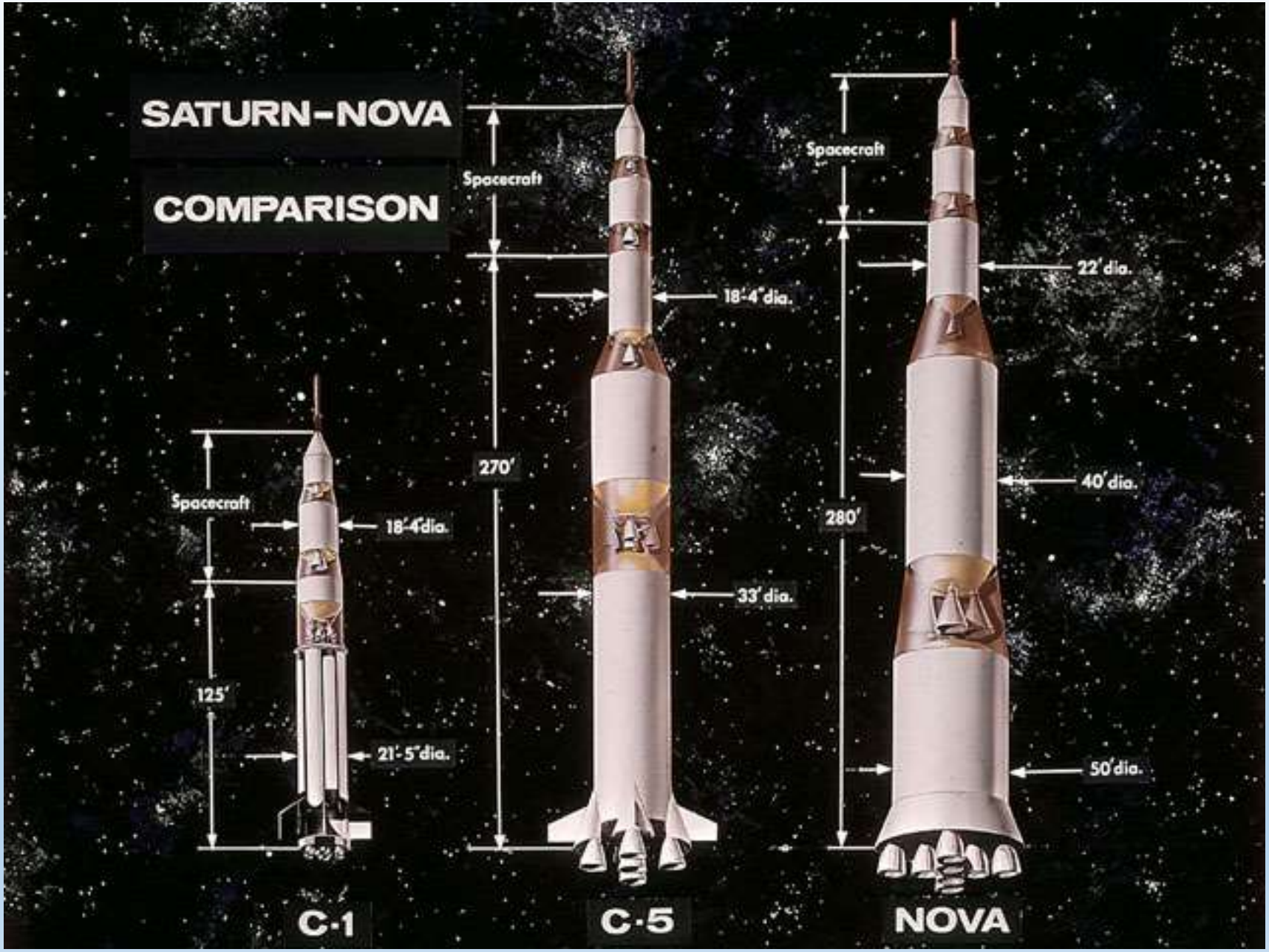
Bryan Palaszewski
NASA John H. Glenn Research Center
Cleveland, OH, 44135
March 19, 2019



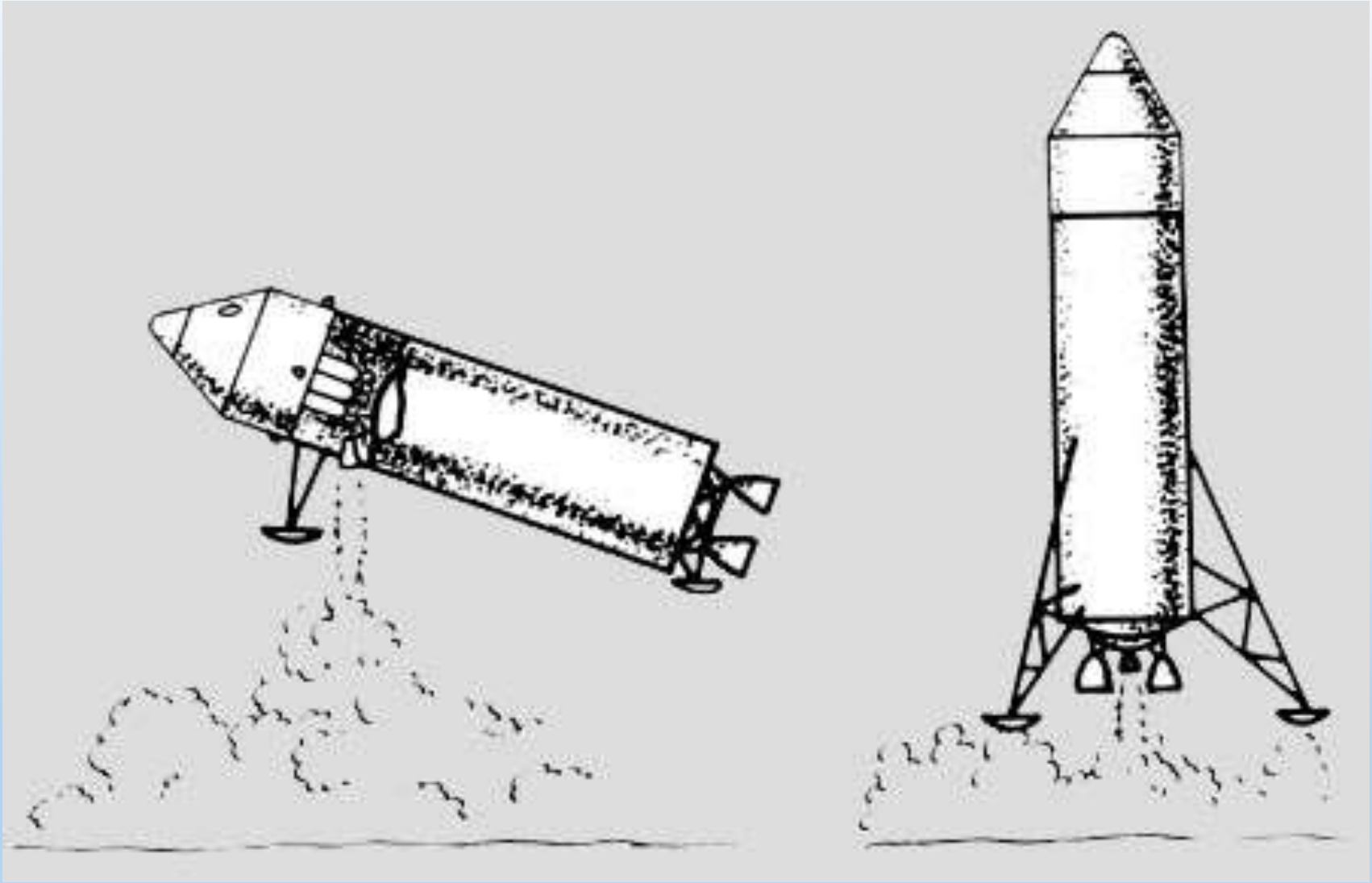


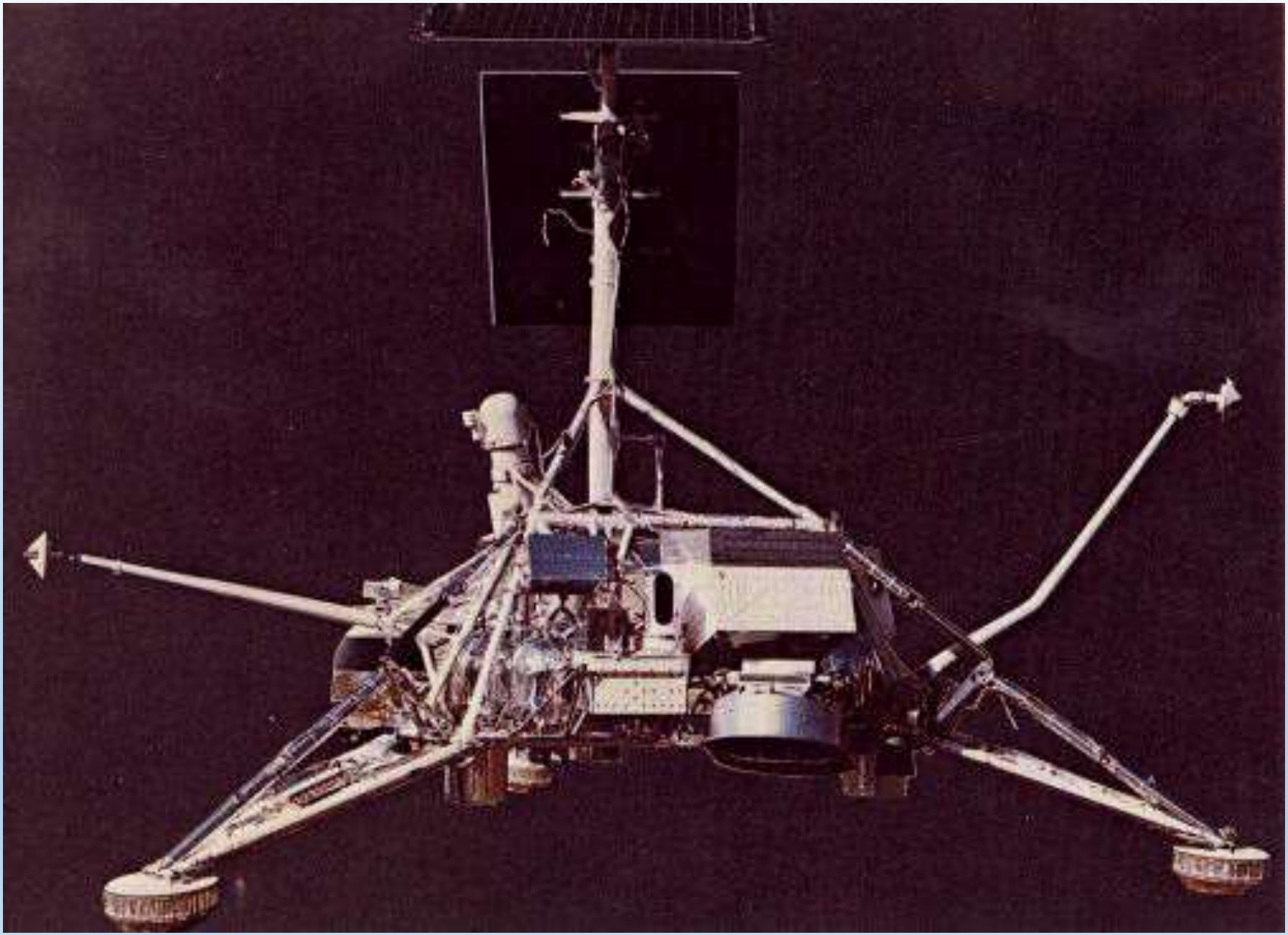


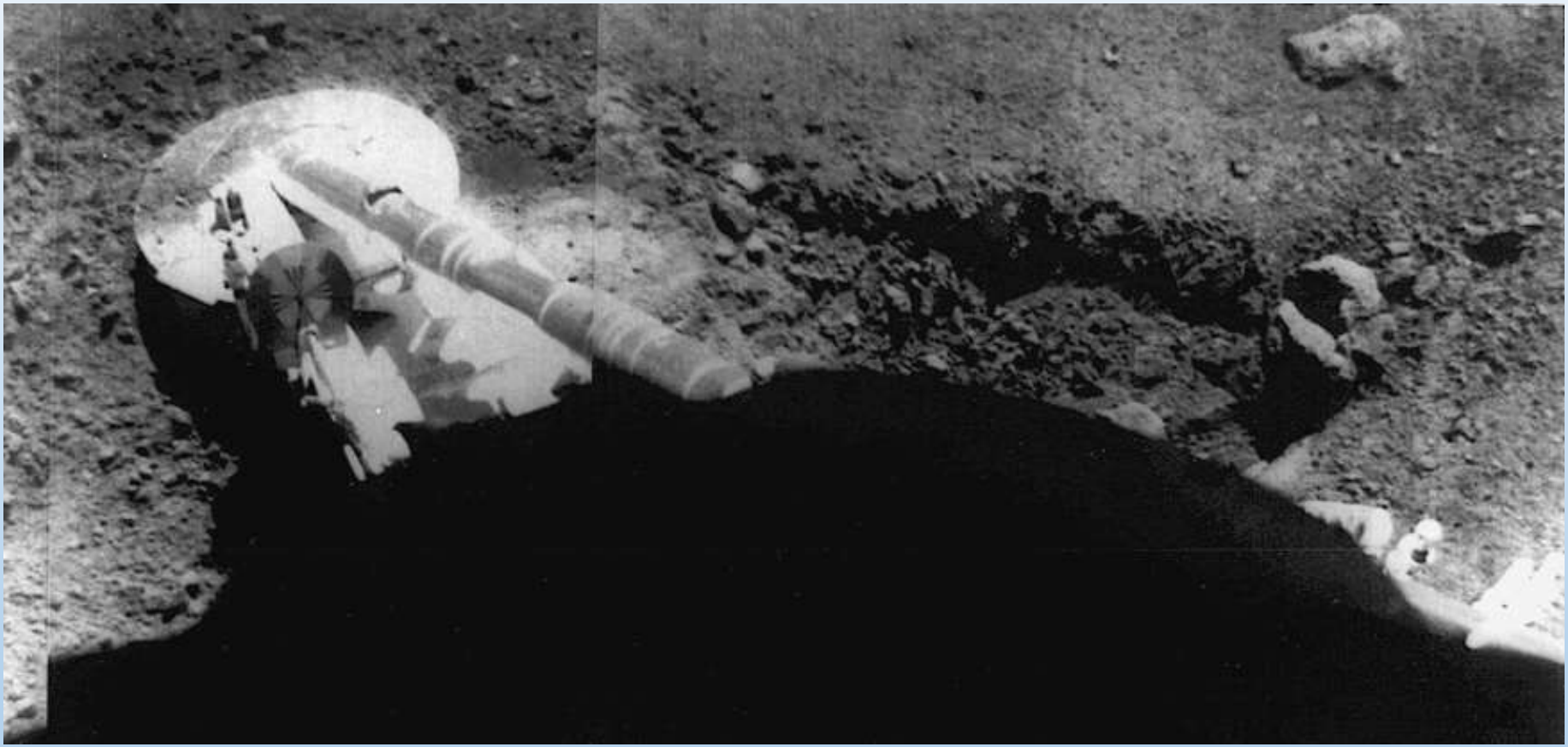

UNITED STATES

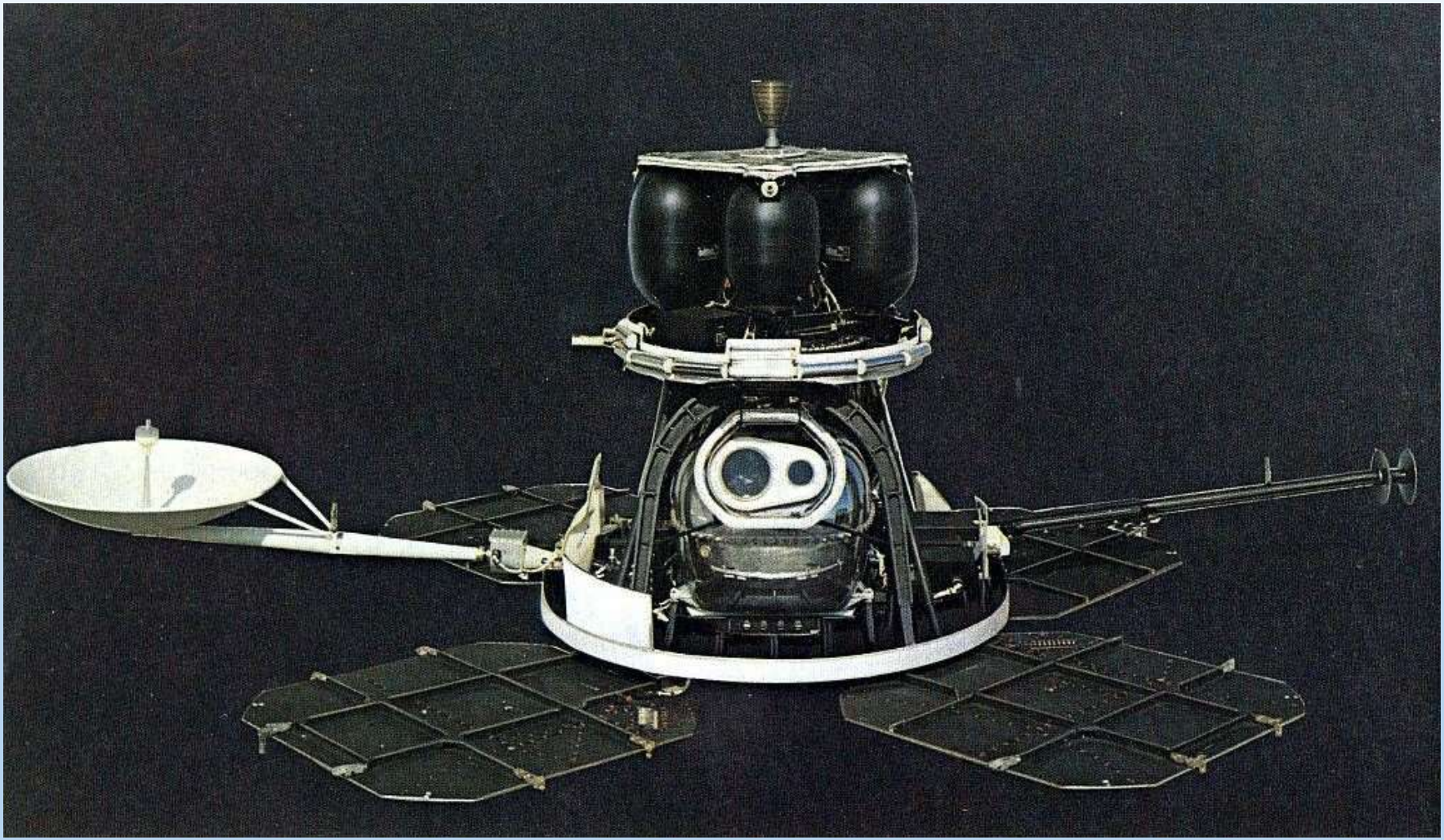

SATURN-NOVA
COMPARISON
Spacecraft
18'-4" dia.
270'
33' dia.
Spacecraft
22' dia.
280'
40' dia.
50' dia.
Spacecraft
18'-4" dia.
125'
21'-5" dia.
C-1
C-5
NOVA

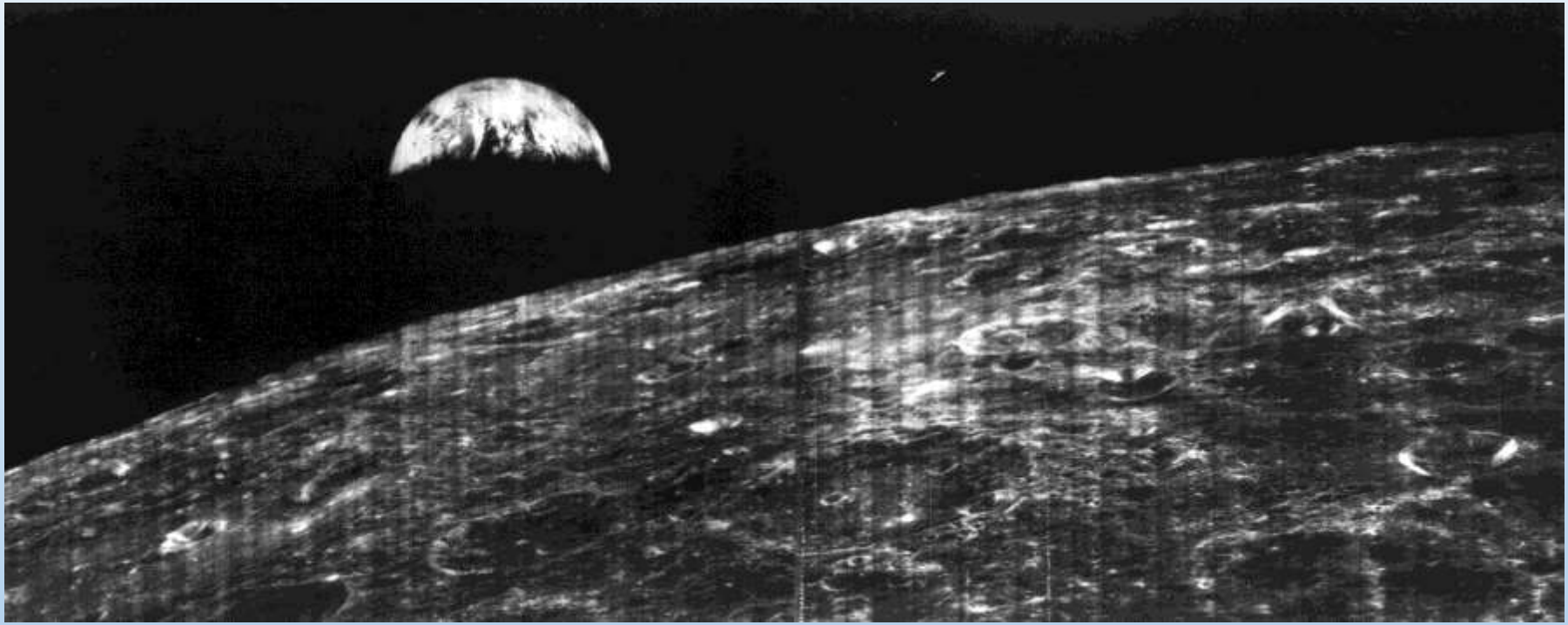
MODULAR NOVA CONCEPT

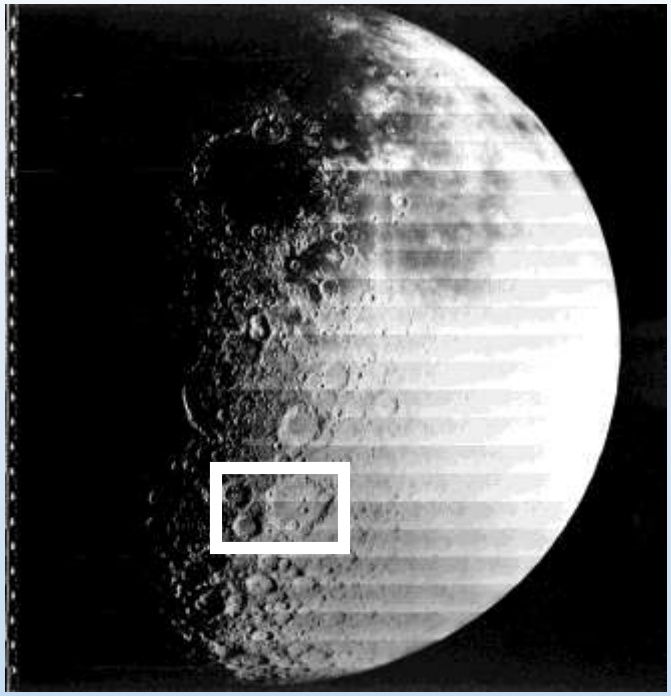












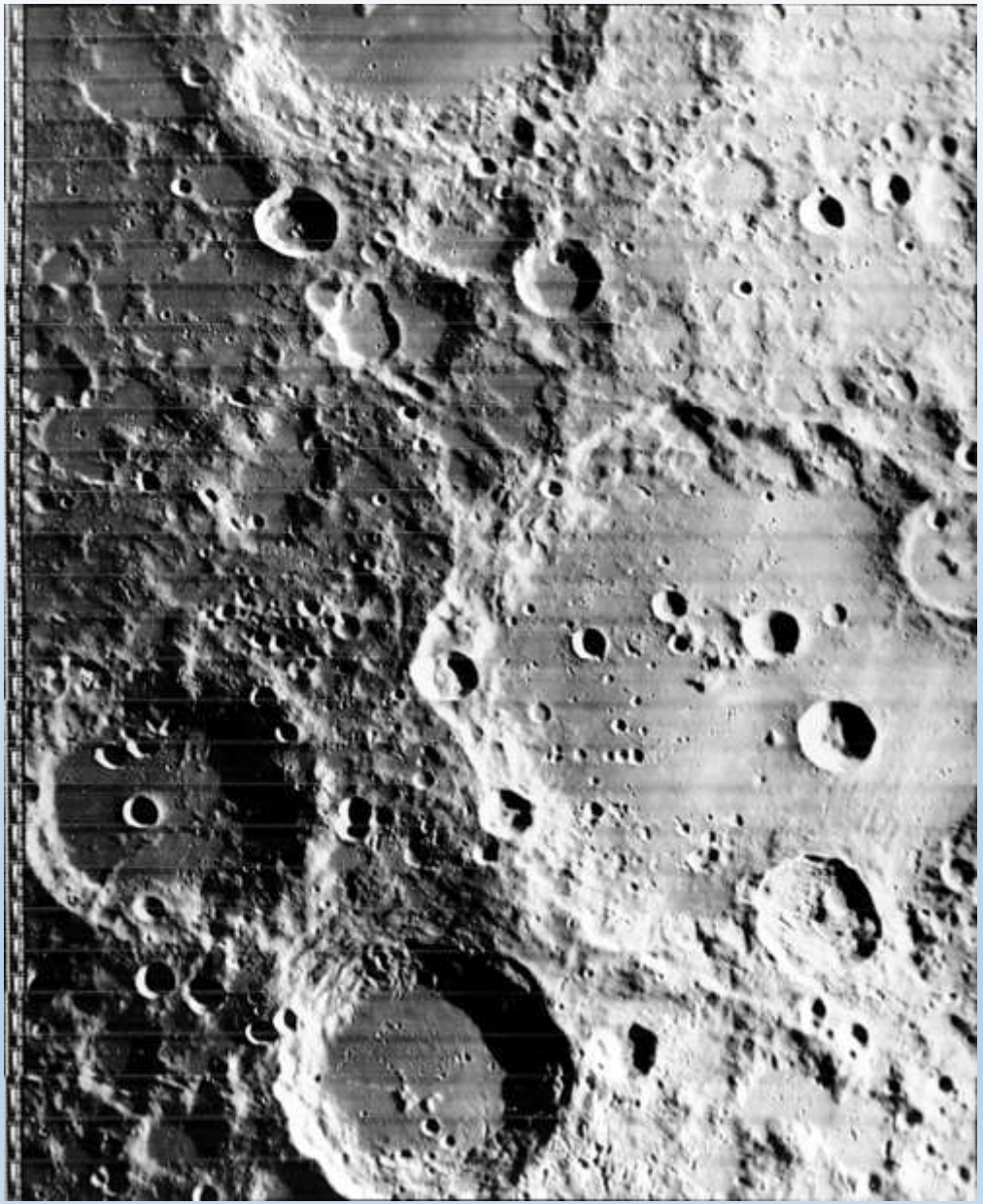
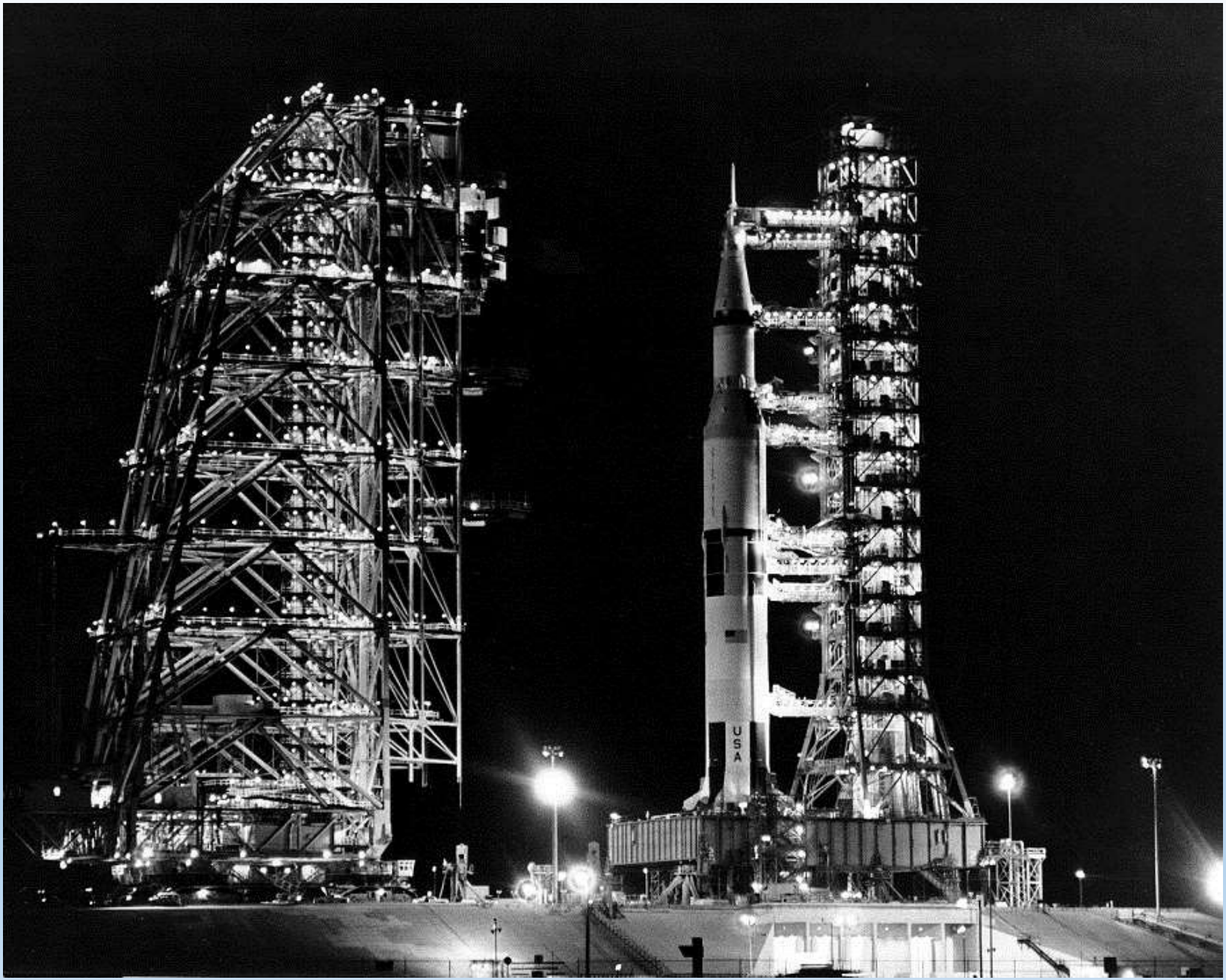
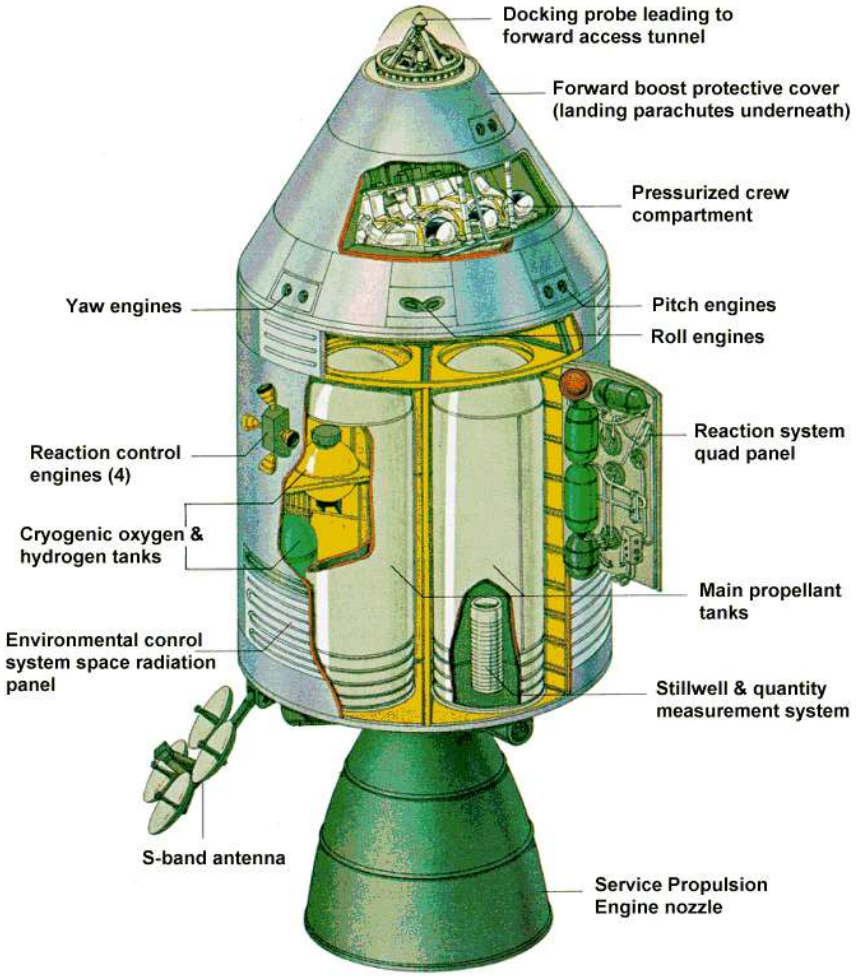


Photo Number IV-130-H3

Feature Name: Clavius
Feature Latitude: 58.8°S
Feature Longitude: 14.1°W
Size: 245 km
Sun Angle: 81.3°
Spacecraft Altitude: 3574.83 km
Medium Photo Center Latitude: 65.02°S
Medium Photo Center Longitude: 25.85°W


USA

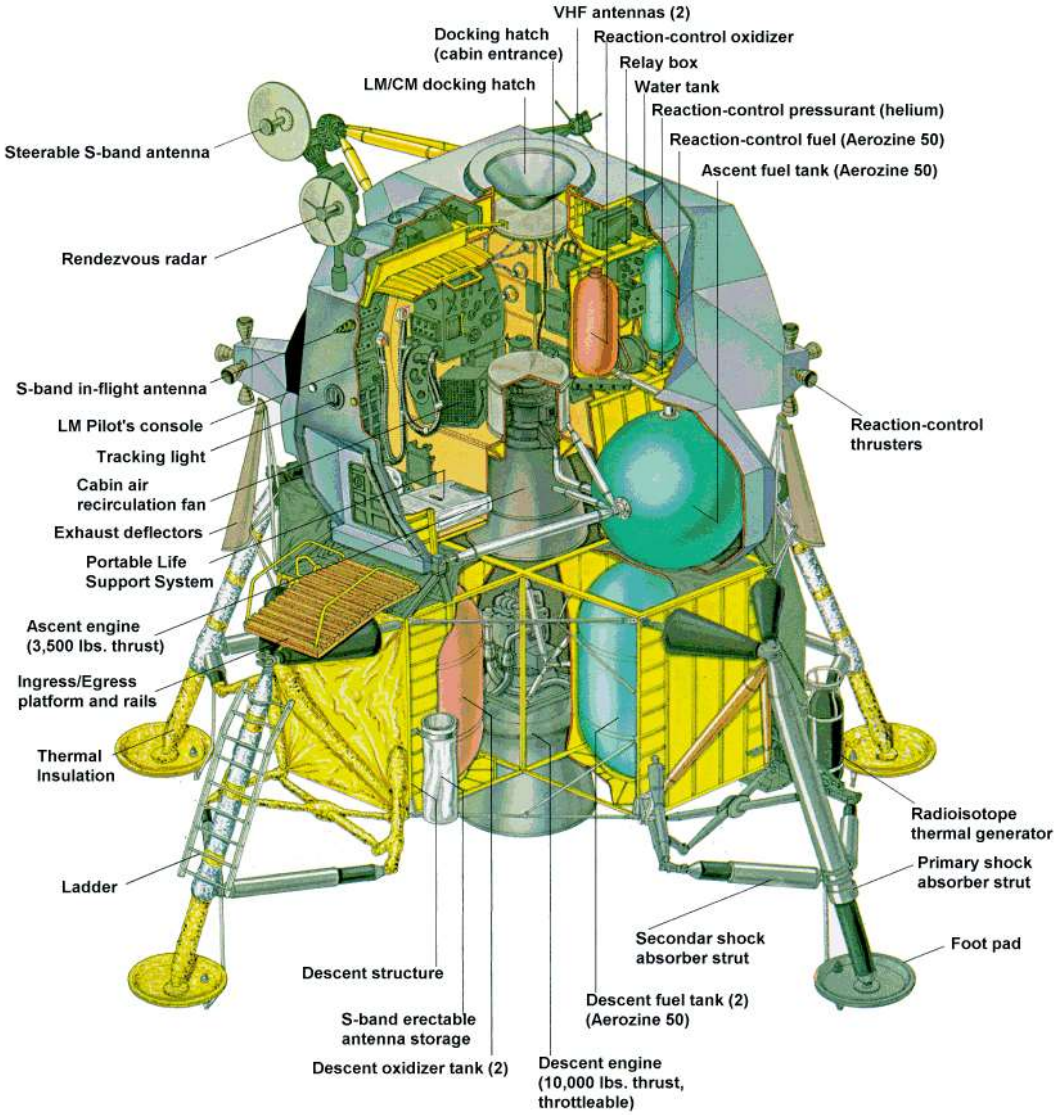
Apollo Command and Service Modules



Apollo CSM Facts

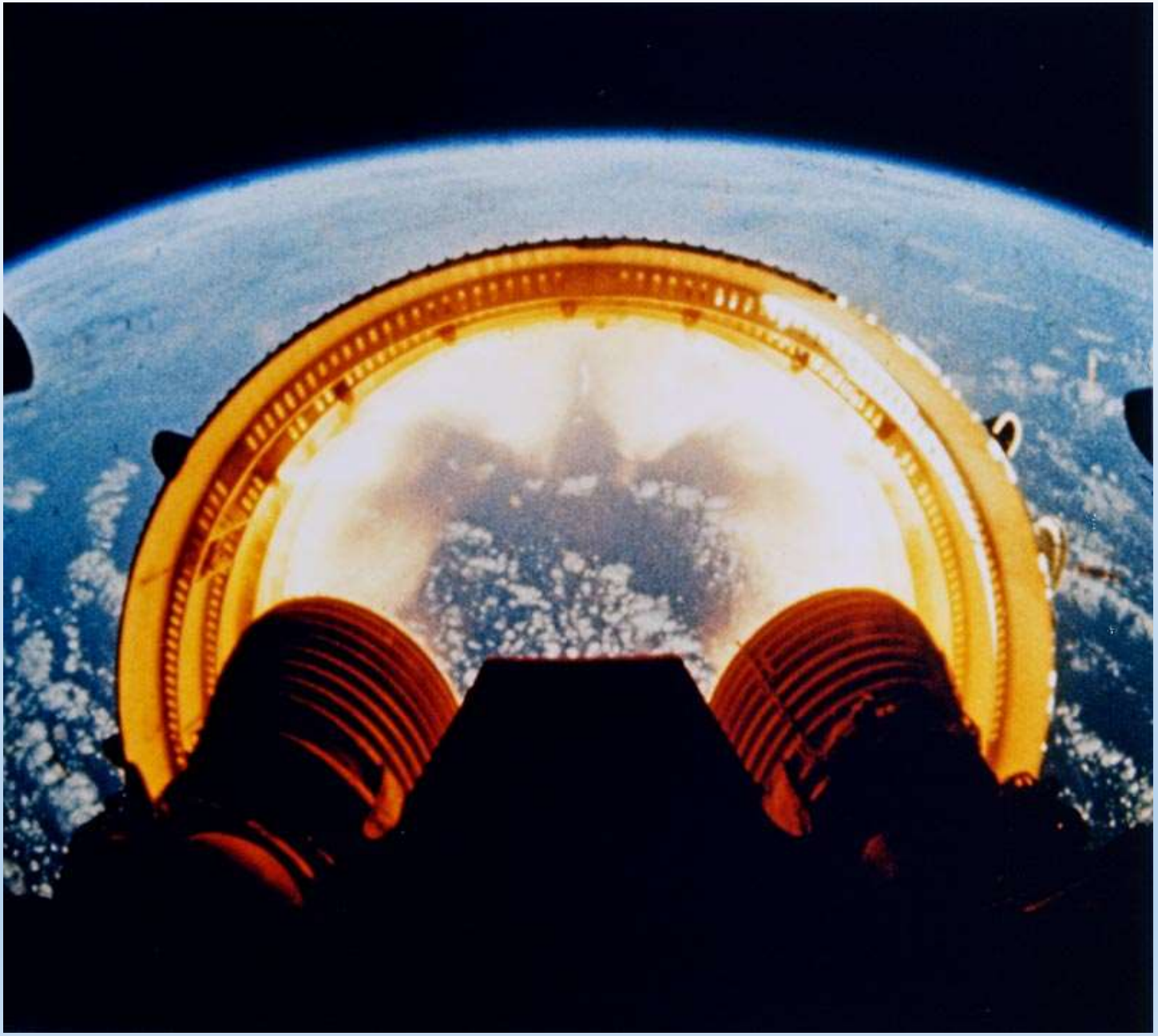
The Apollo Command Module was 10.6 ft. tall and 12.8 ft. at its maximum diameter, and typically weighed 13,090 lbs. with astronauts. The Service Module was 24.3 ft. tall and 12.8 ft. in diameter and weighed 54,074 lbs.. The Service Propulsion System engine delivered a thrust of 20,500 lbs..

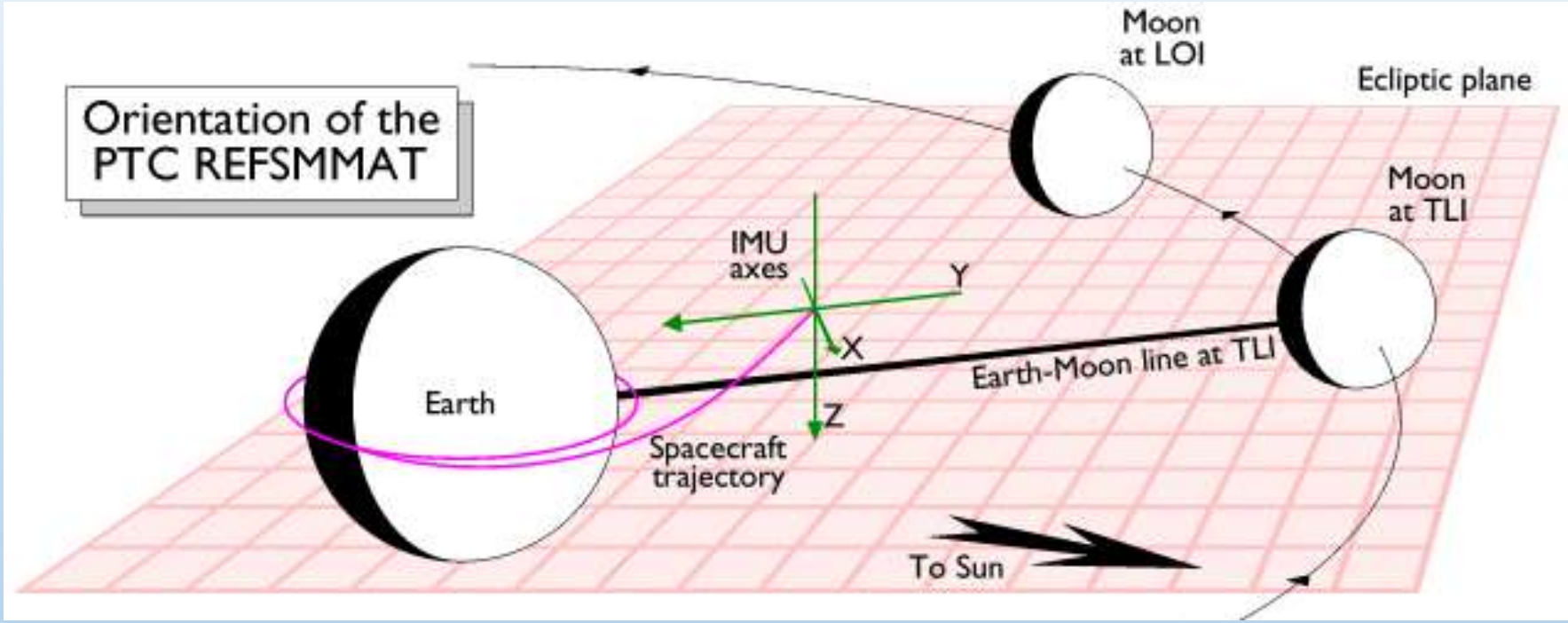
Apollo Lunar Module

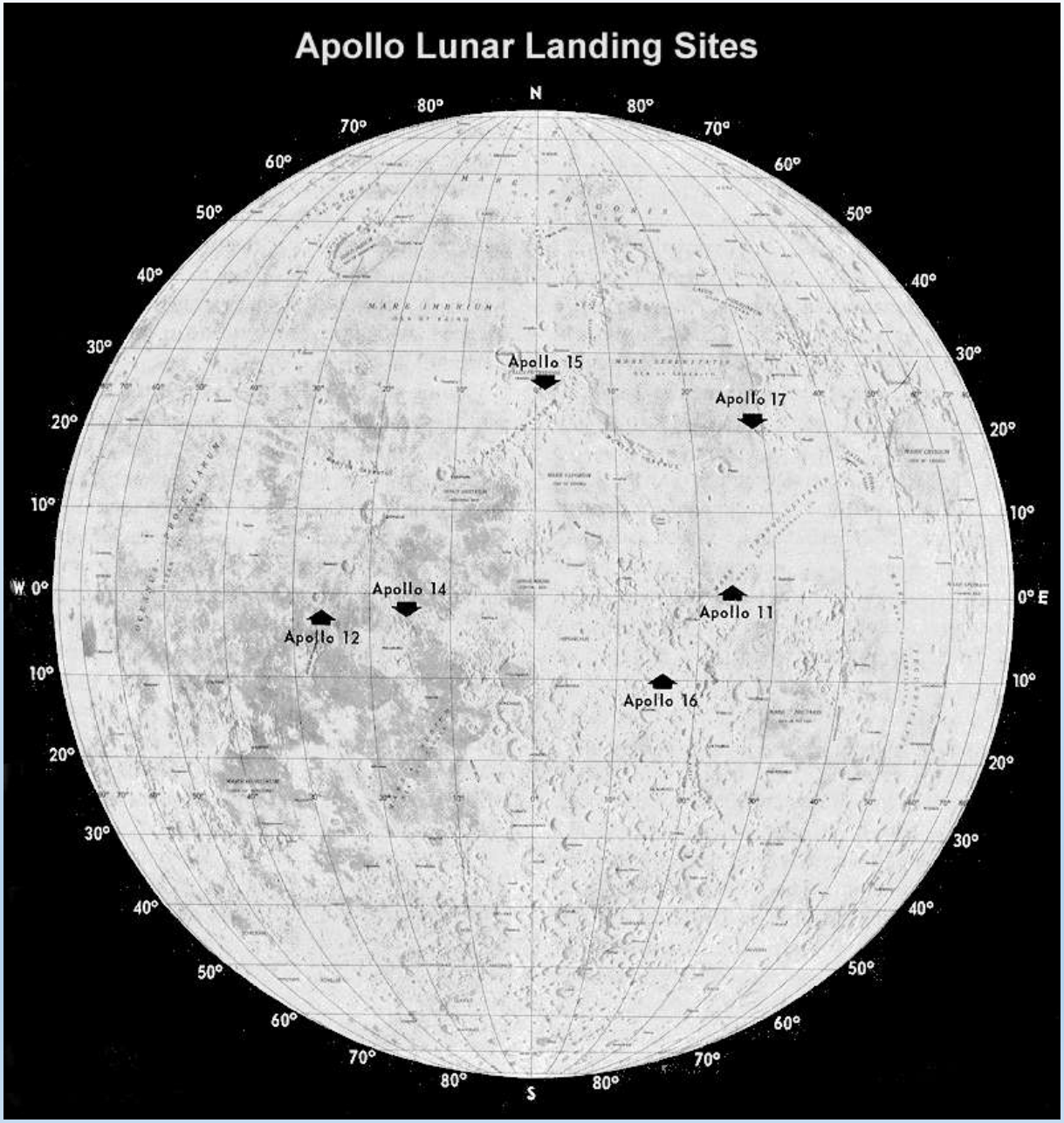


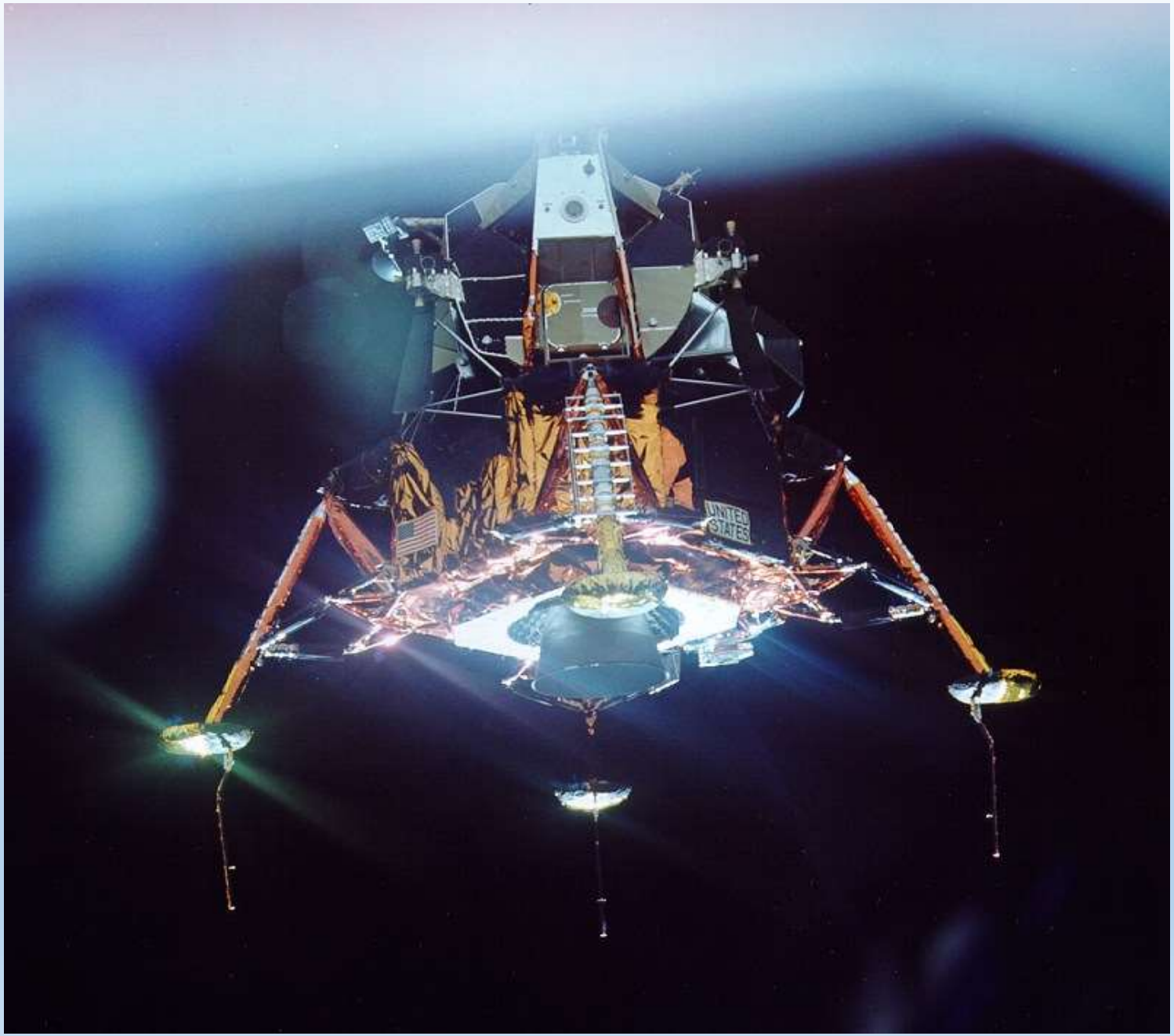
The lunar module was 23 ft. tall and had a launch weight of 33,205 lbs.
(The Apollo 17 J-Series lunar module weighed 36,244 lbs.)

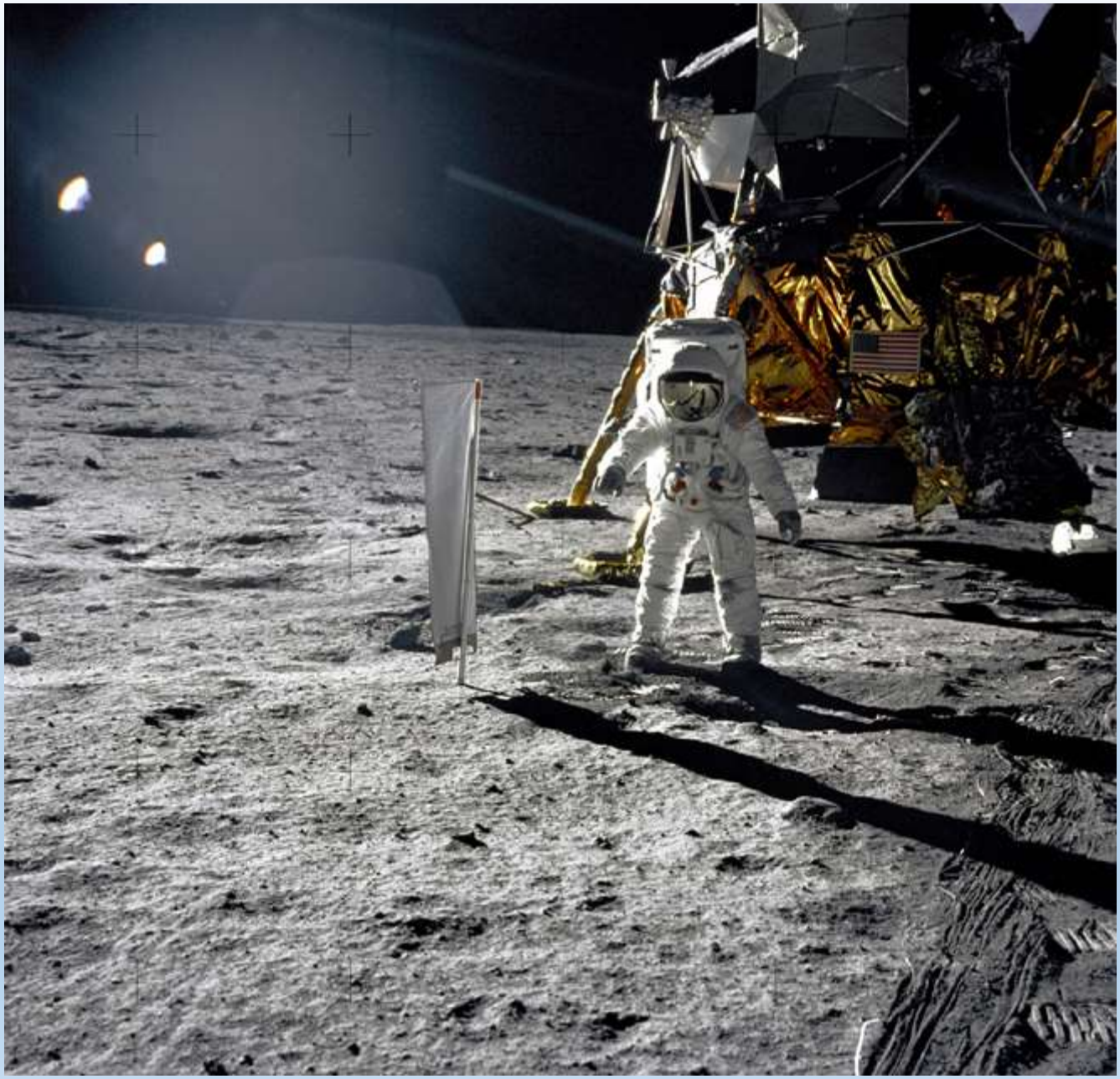

NASA
APO
KC-702-014

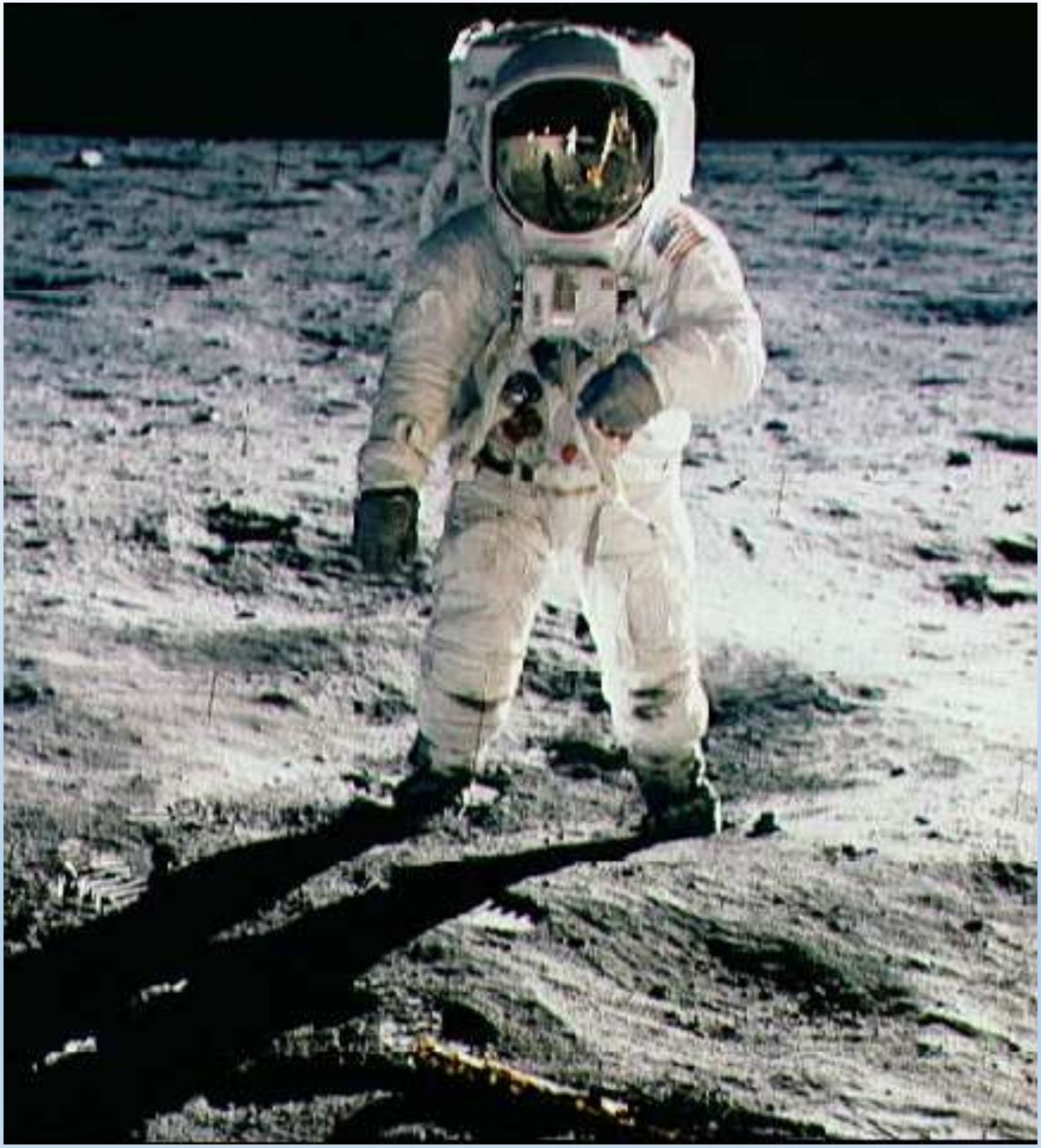


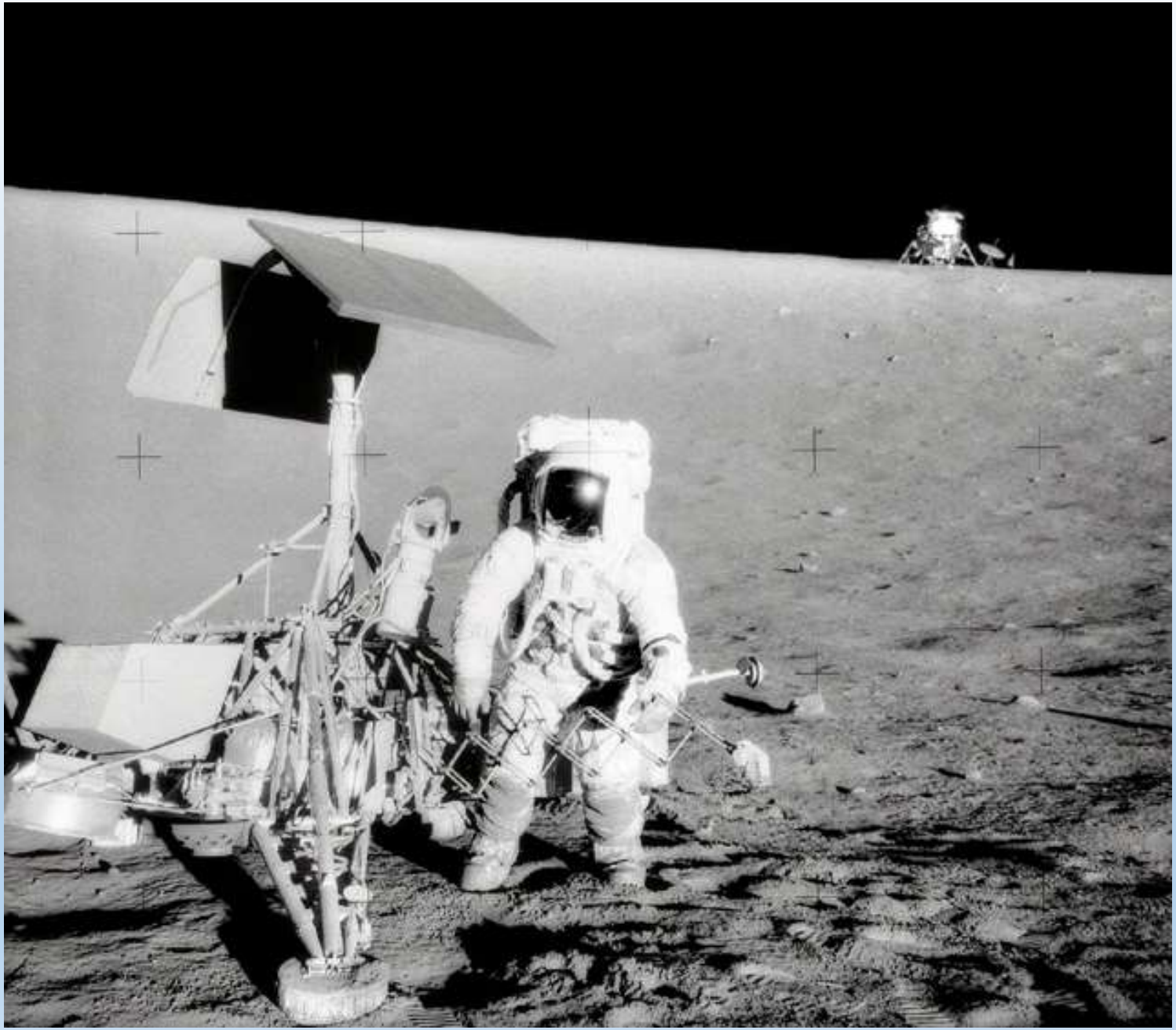

Orientation of the PTC REFSMMAT
Moon at LOI
Ecliptic plane
Moon at TLI
IMU axes
Y
X
Z
Earth
Earth-Moon line at TLI
Spacecraft trajectory
To Sun

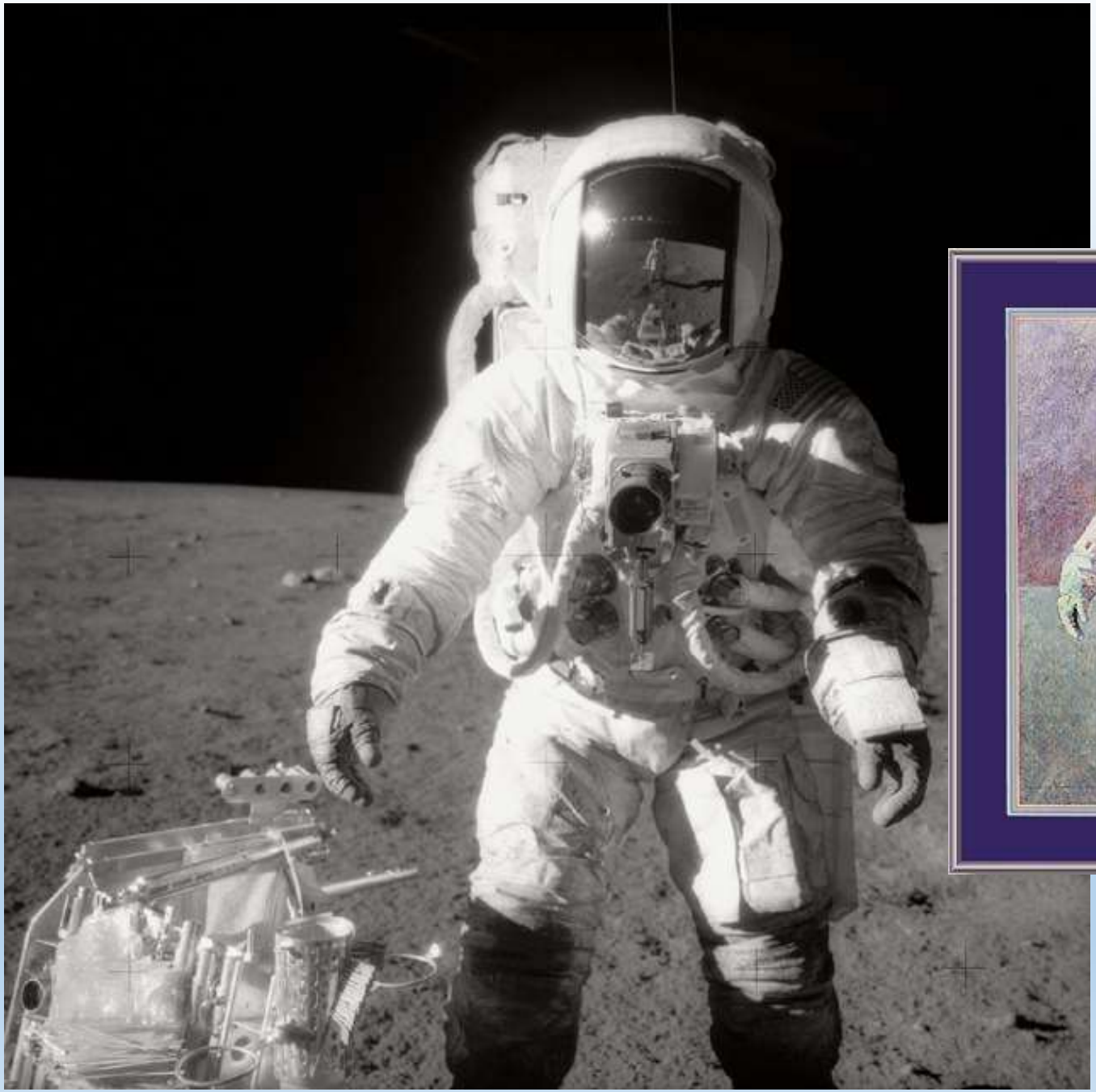

Apollo Lunar Landing Sites
N
S
W 0°
0° E
Apollo 15
Apollo 17
Apollo 14
Apollo 12
Apollo 11
Apollo 16


UNITED
STATES

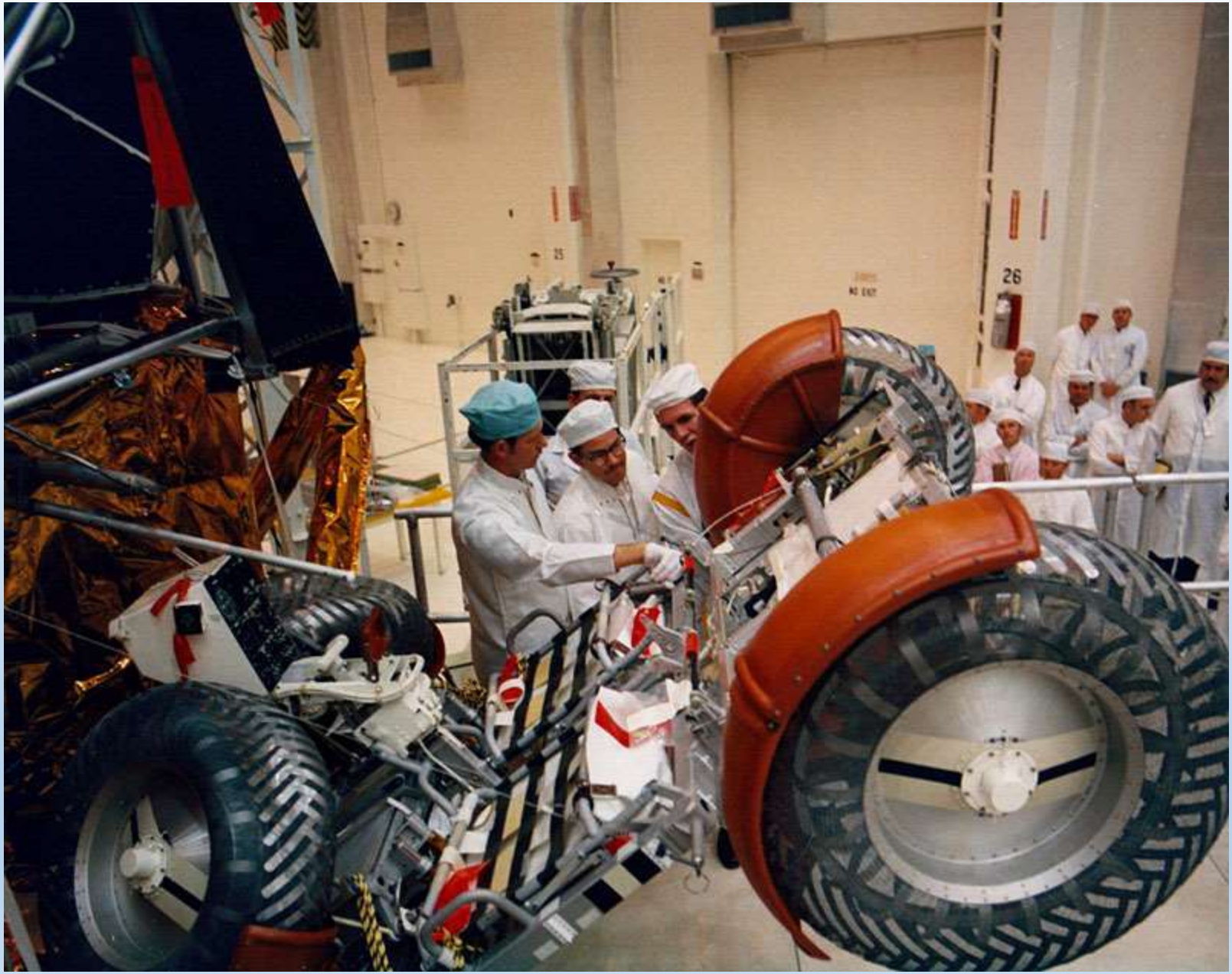


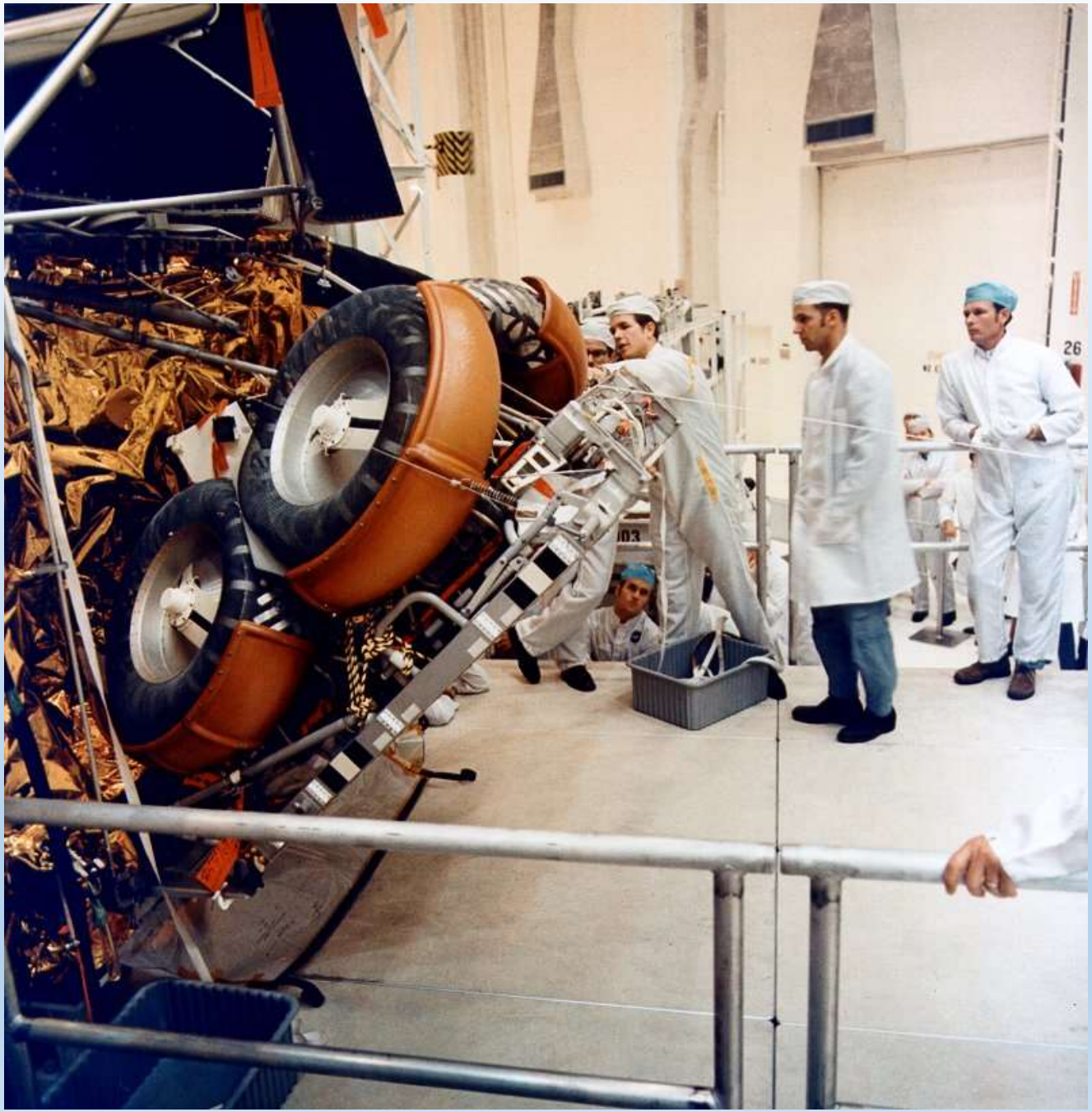


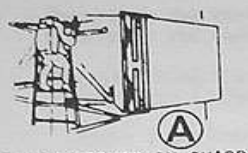





UNITED
STATES

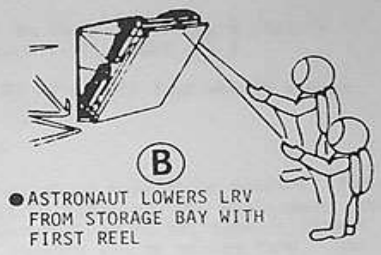

26





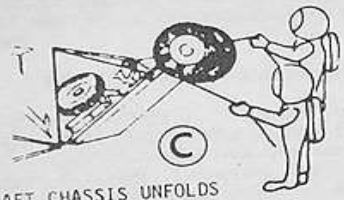
A

- LRV STOWED IN QUADRANT
- ASTRONAUT REMOVES INSULATION BLANKET, OPERATING TAPES
- ASTRONAUT REMOTELY INITIATES AND EXECUTES DEPLOYMENT



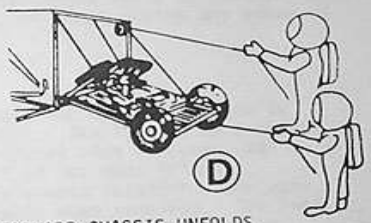
B

- ASTRONAUT LOWERS LRV FROM STORAGE BAY WITH FIRST REEL



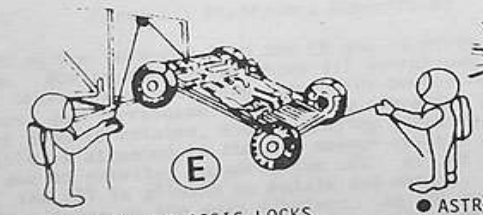
C

- AFT CHASSIS UNFOLDS
- REAR WHEELS UNFOLD
- AFT CHASSIS LOCKS IN POSITION



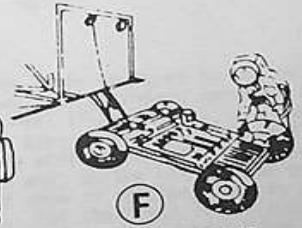
D

- FORWARD CHASSIS UNFOLDS
- FRONT WHEELS UNFOLD



E

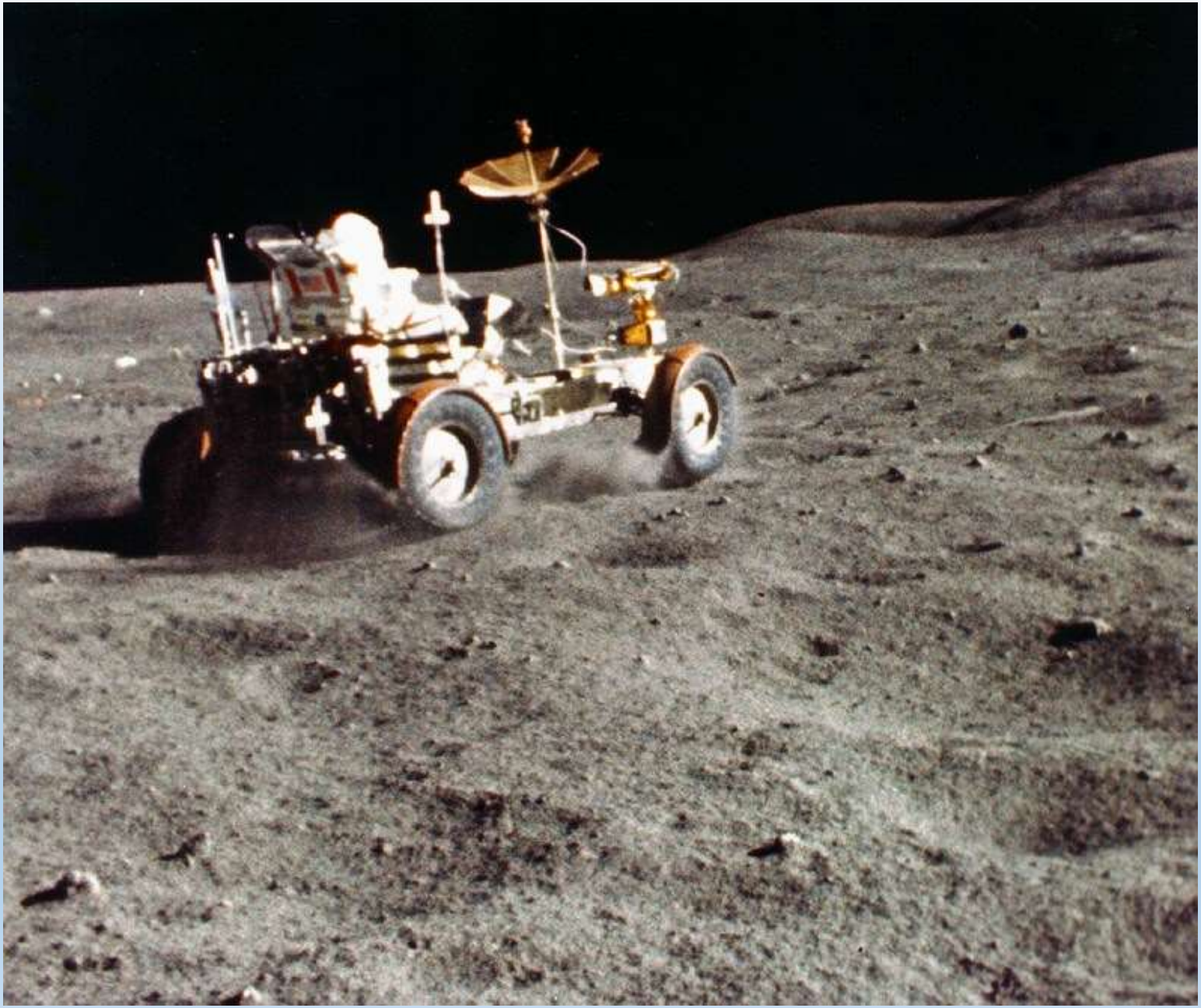
- FORWARD CHASSIS LOCKS IN POSITION. ASTRONAUT LOWERS LRV TO SURFACE WITH SECOND LEVEL

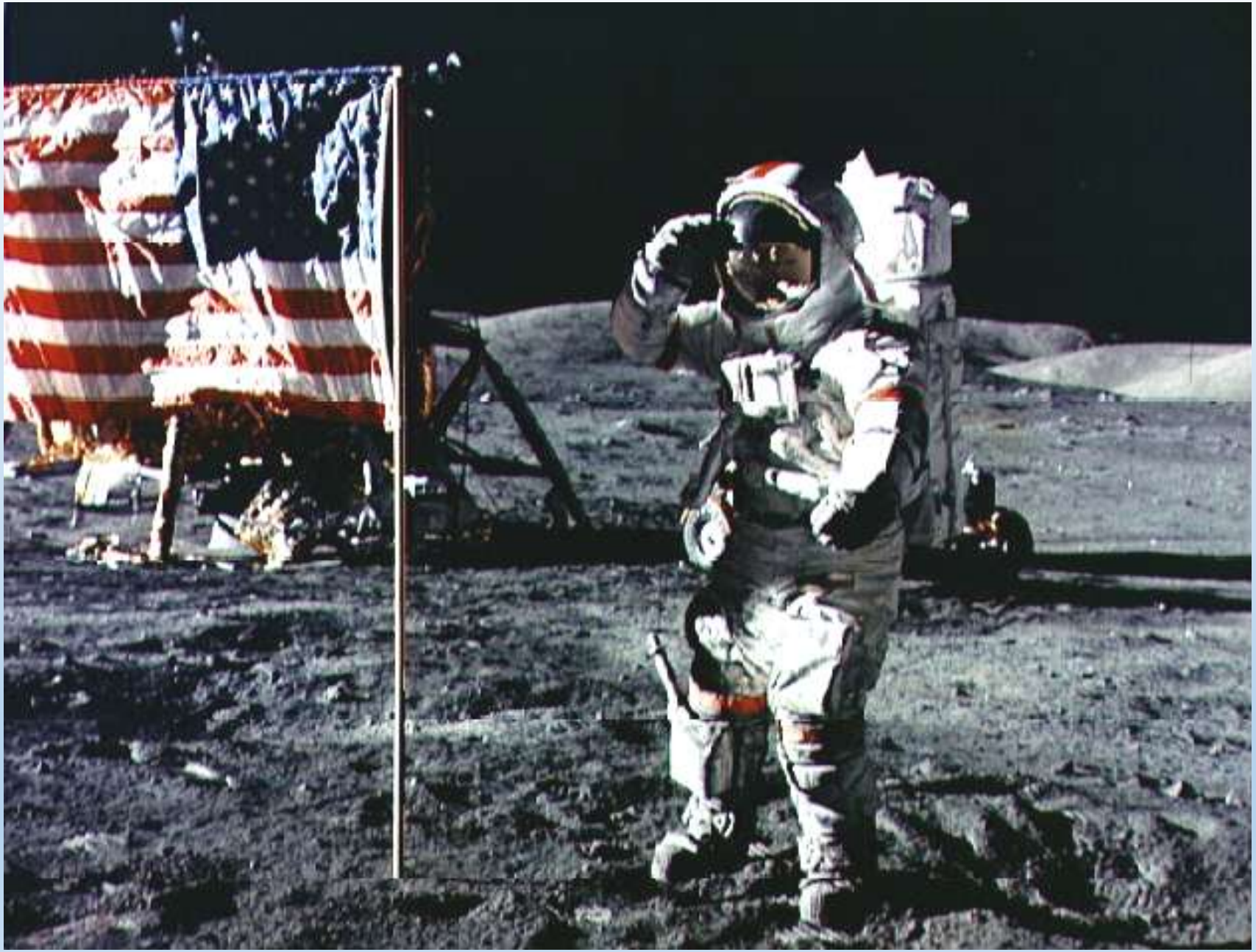


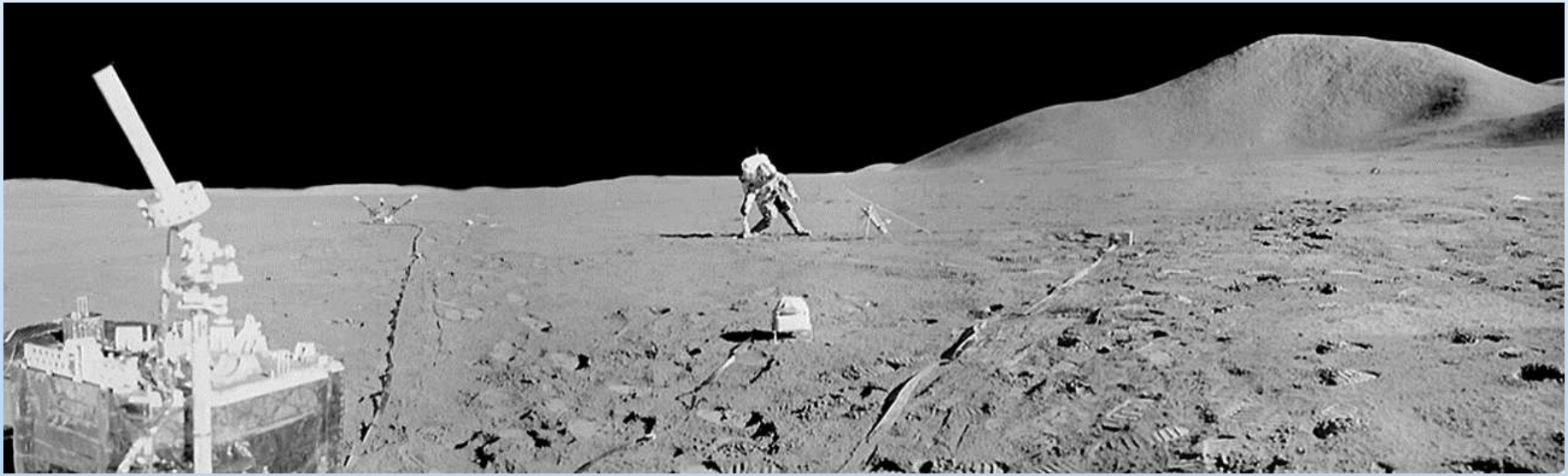
F

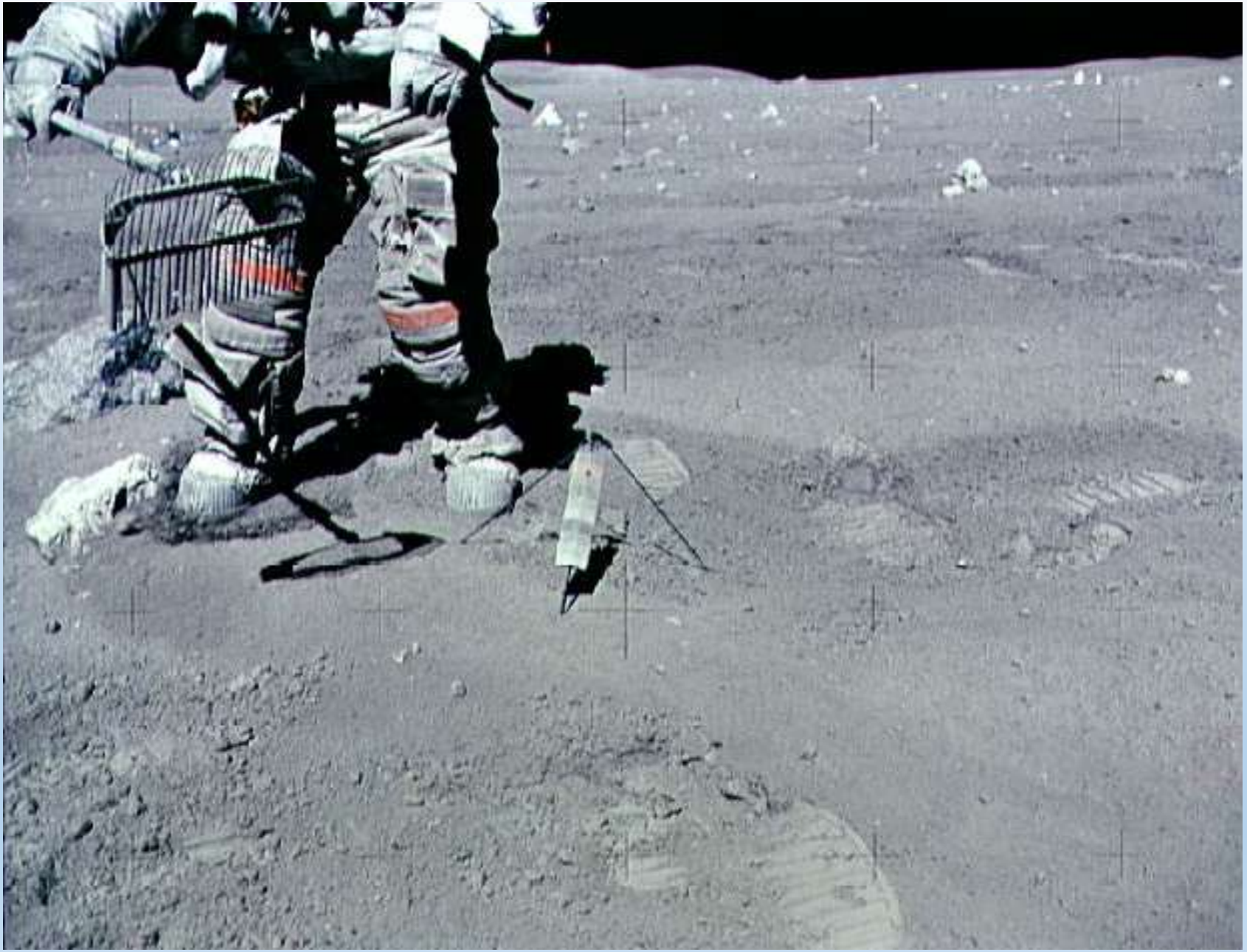
- ASTRONAUT DISCONNECTS SSE
- ASTRONAUT UNFOLDS SEATS, FOOTRESTS, (FINAL STOP)

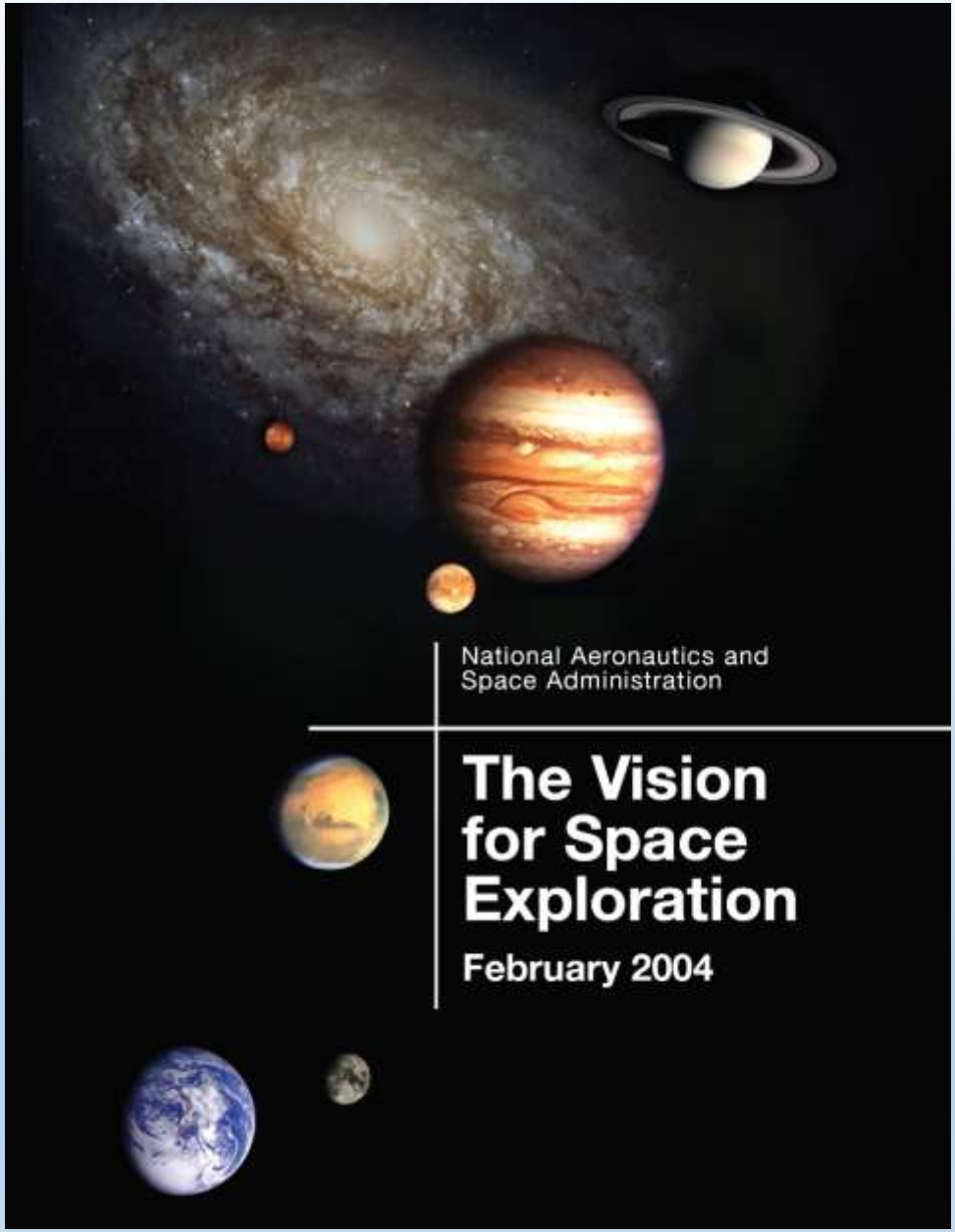
FIGURE 1-39 LRV DEPLOYMENT SEQUENCE

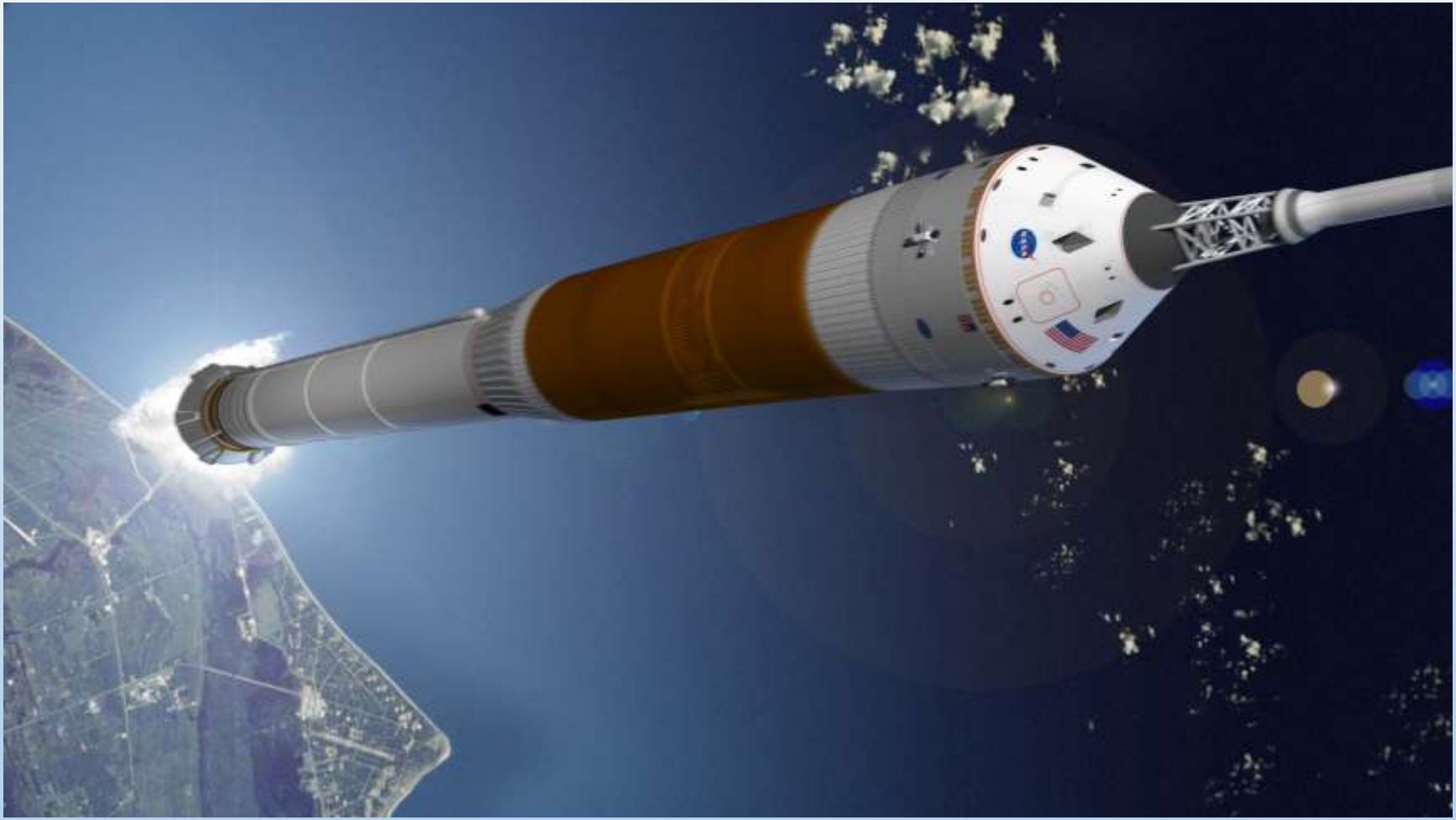


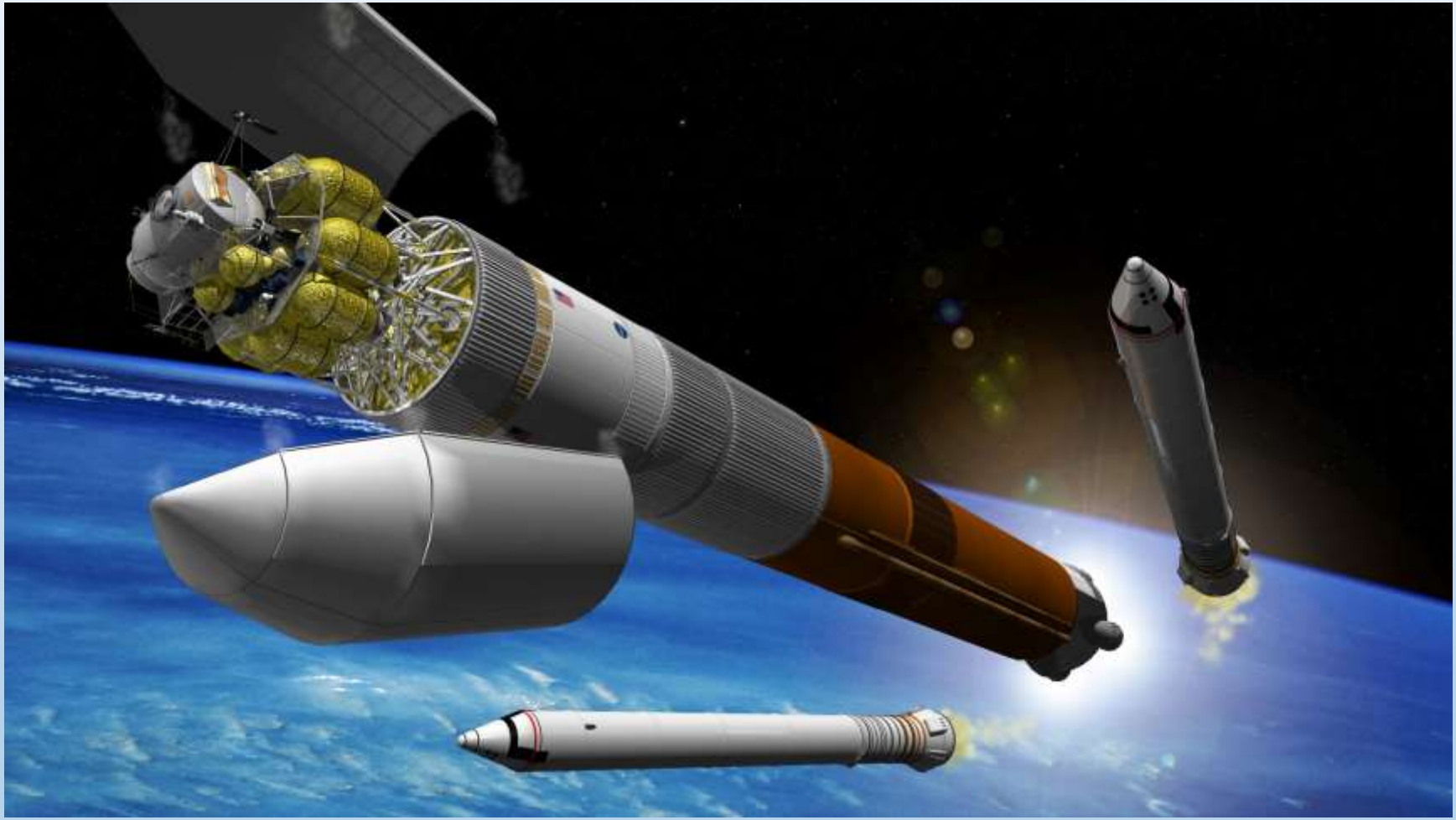


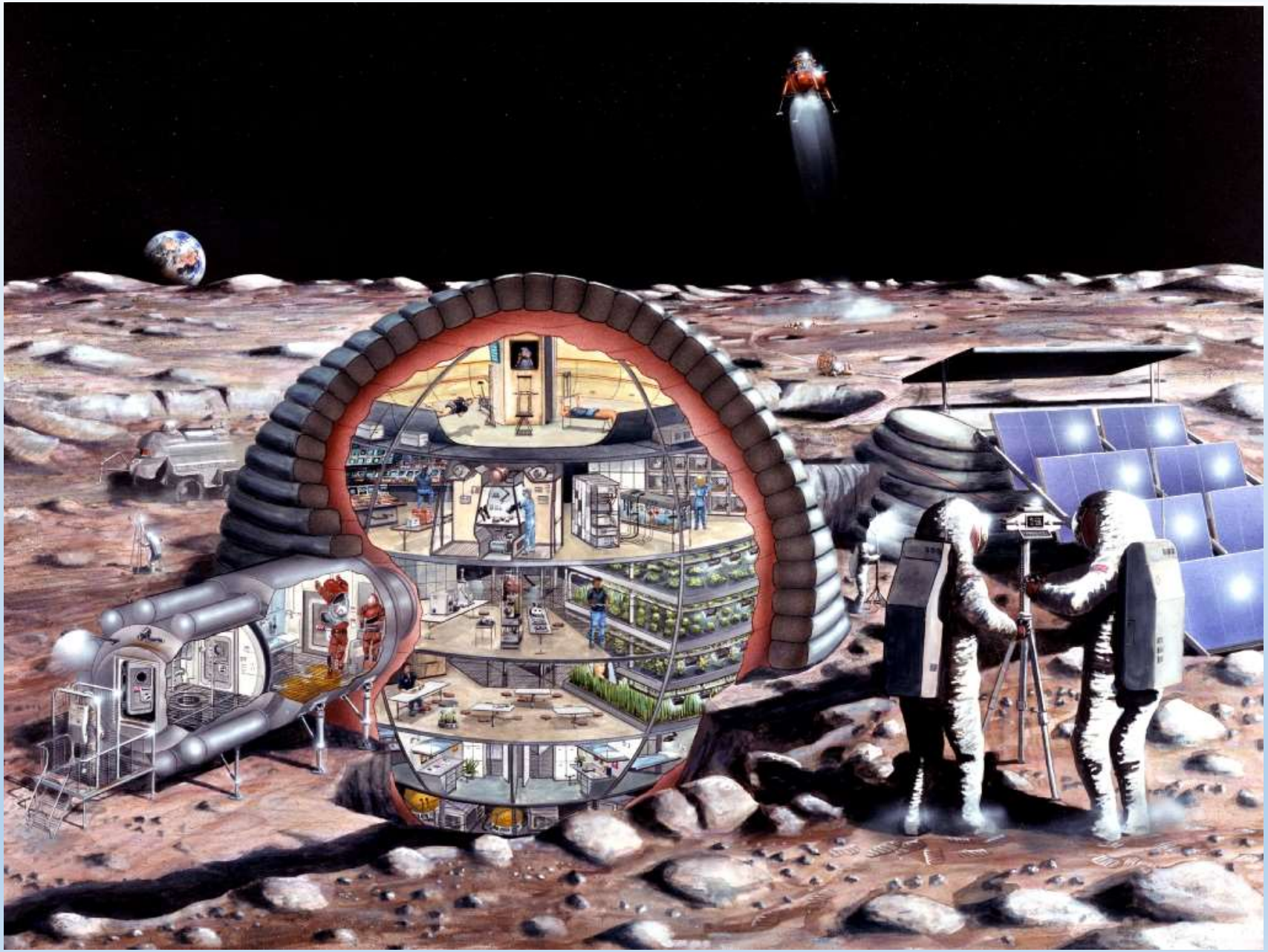





National Aeronautics and
Space Administration
The Vision
for Space
Exploration
February 2004

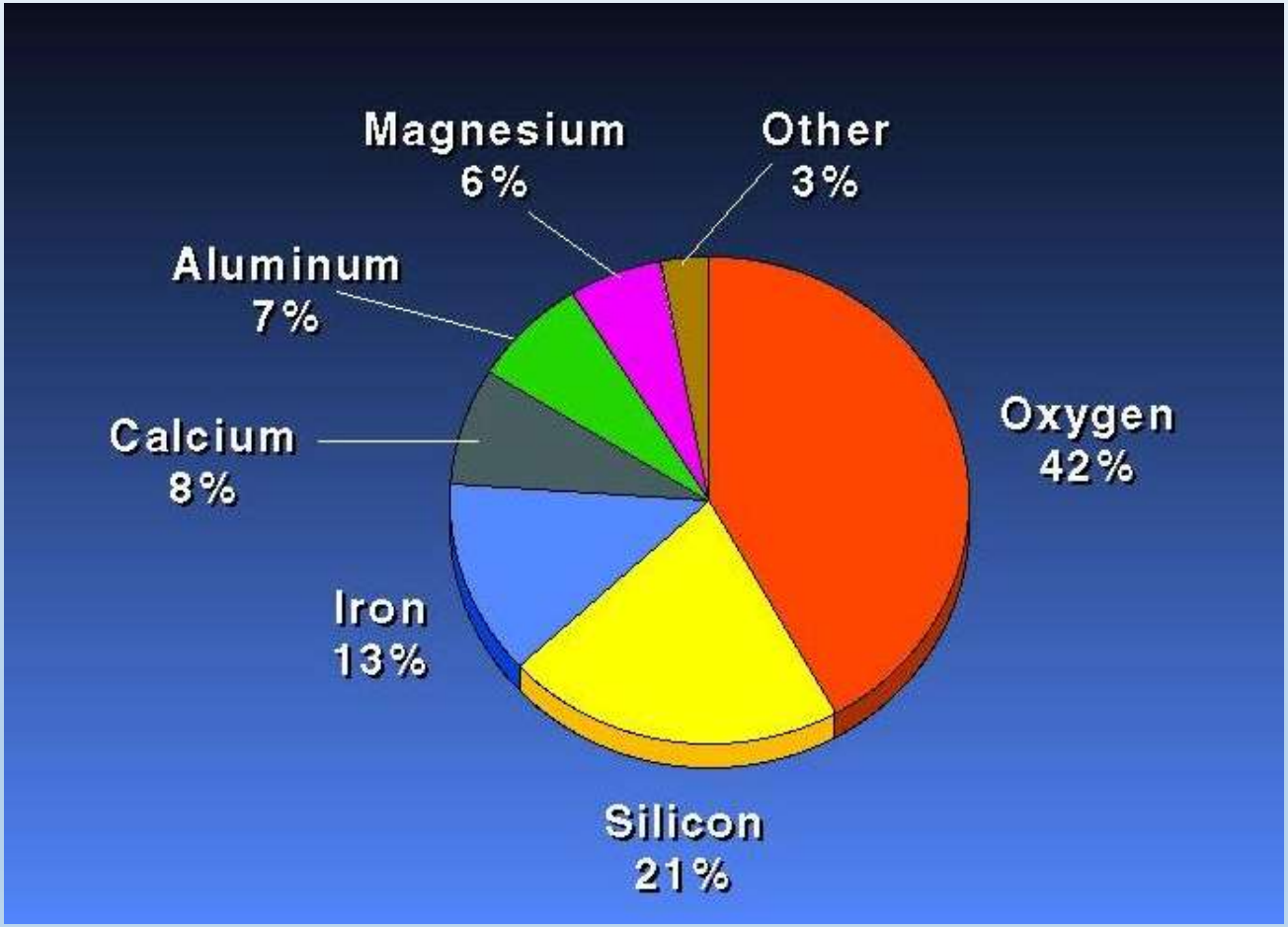


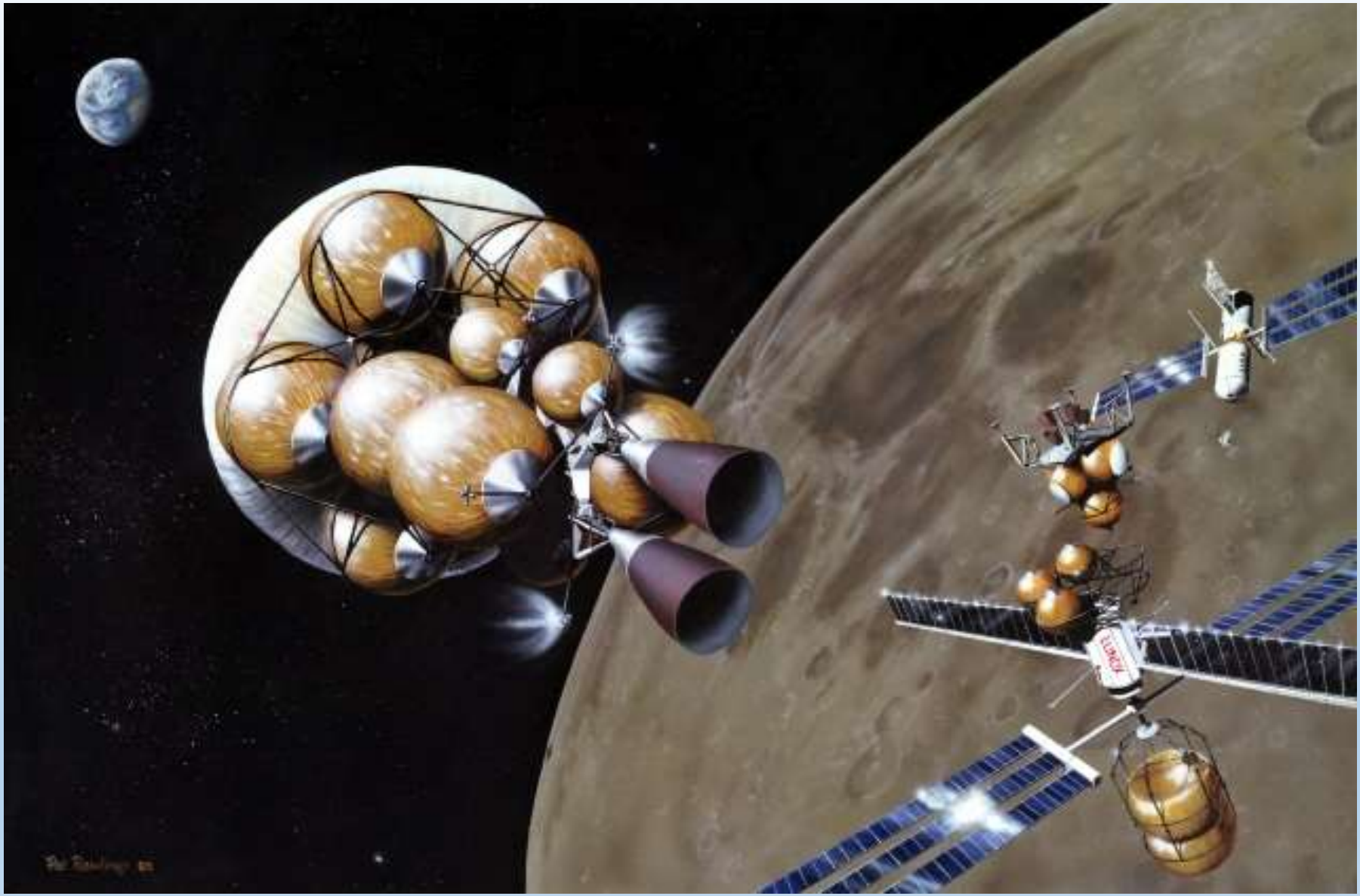


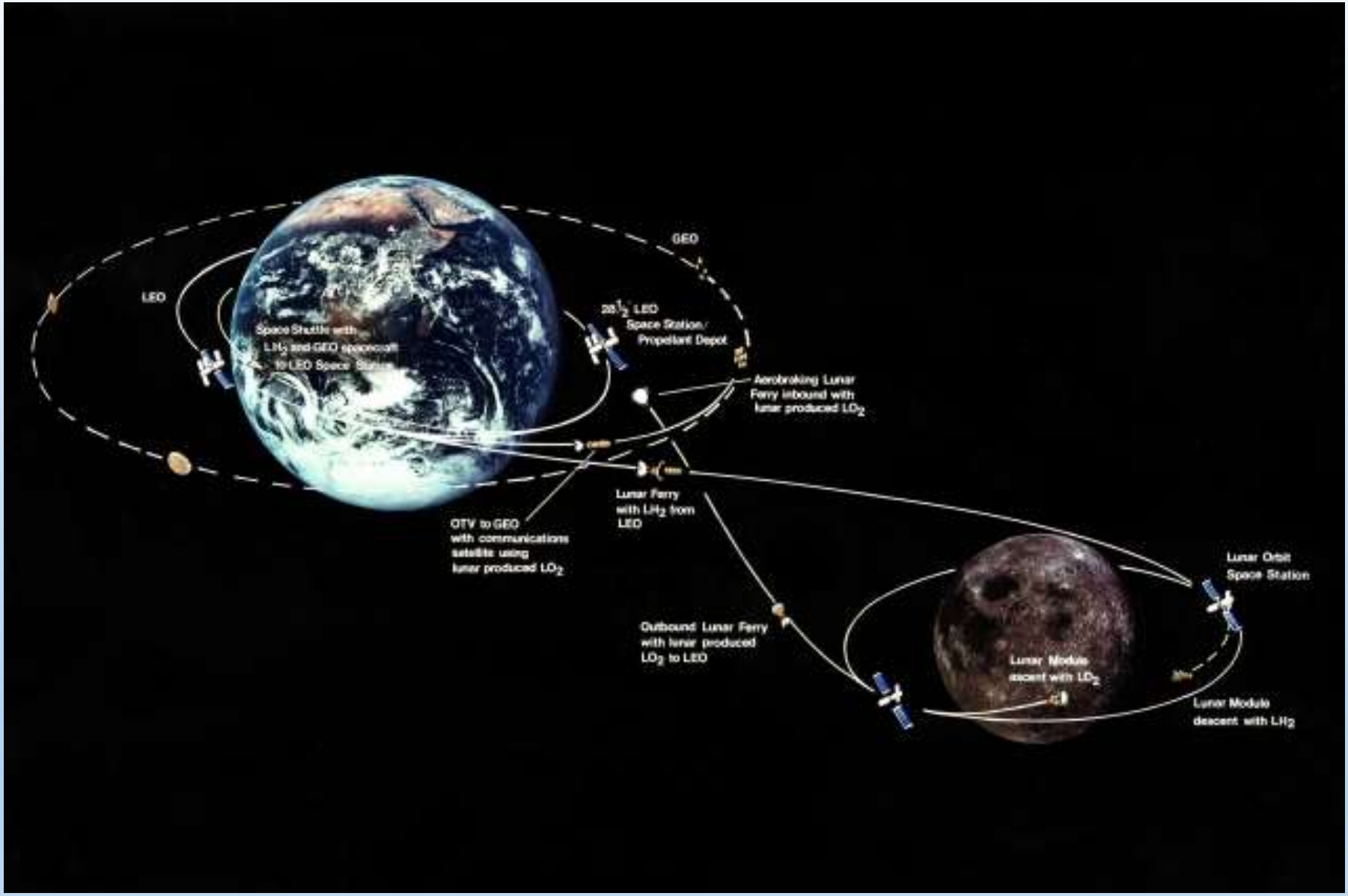



NASA

Lunar Regolith Composition



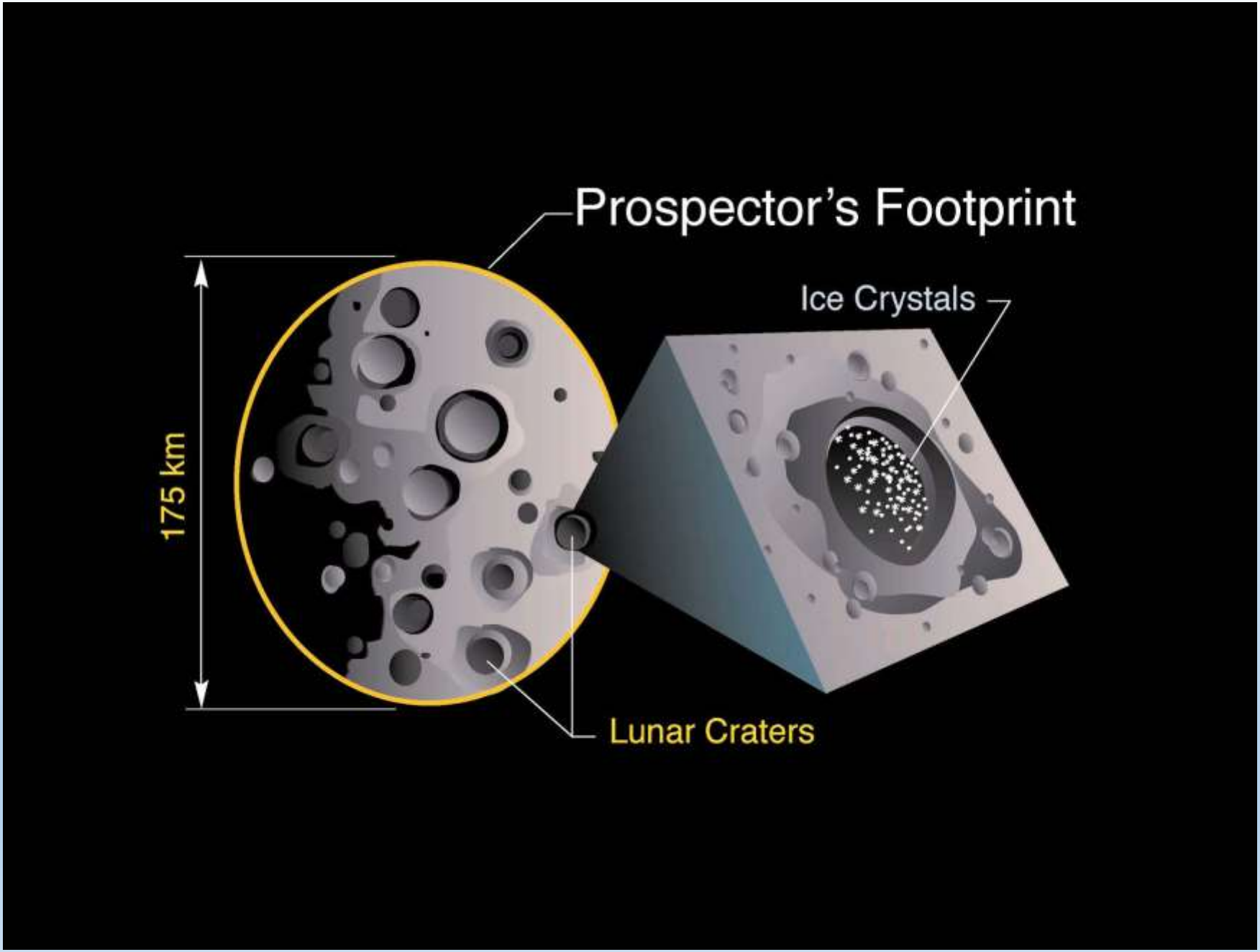



GEO
LEO
28½° LEO
Space Station/
Propellant Depot
Aerobraking Lunar
Ferry inbound with
lunar produced LO_2
Lunar Ferry
with LH_2 from
LEO
OTV to GEO
with communications
satellite using
lunar produced LO_2
Lunar Orbit
Space Station
Outbound Lunar Ferry
with lunar produced
LO_2 to LEO
Lunar Module
ascent with LO_2
Lunar Module
descent with LH_2

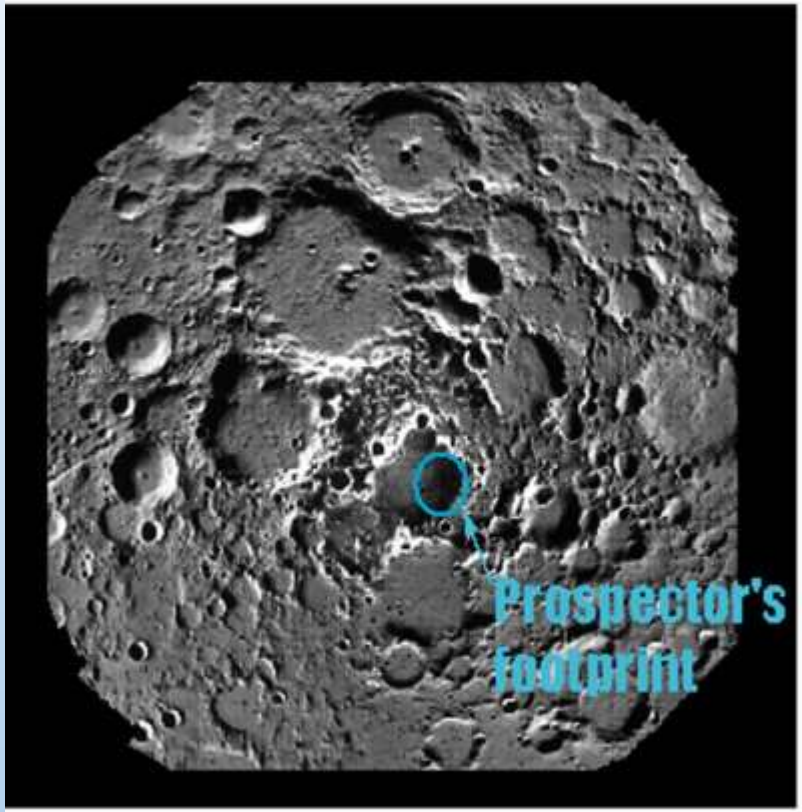
Candidate Lunar ISRU Products

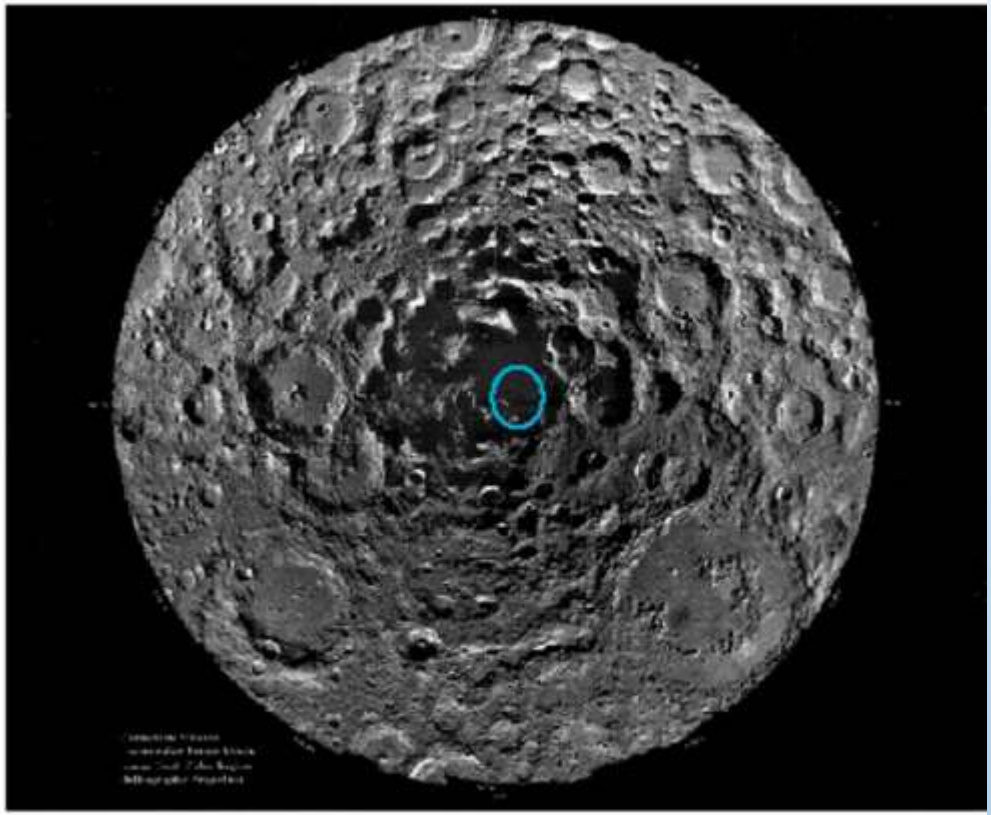
Volatile Resources
-Water (H and O2 for life support & propellant)
-Nitrogen and carbon gases (CH4 NH3)
-3He

Industrial / Manufacturing
-Sulfur (concrete)
-Soil for agriculture
-Basalt fiber
-Cast basalt
-Iron / Steel
-Aluminum
-Sintered Bricks (e.g. Pavers)
-Solar cells
-Transparent & opaque glass (including fiber)
-Shielding for L1 Gateway


Prospector's Footprint
Ice Crystals
175 km
Lunar Craters

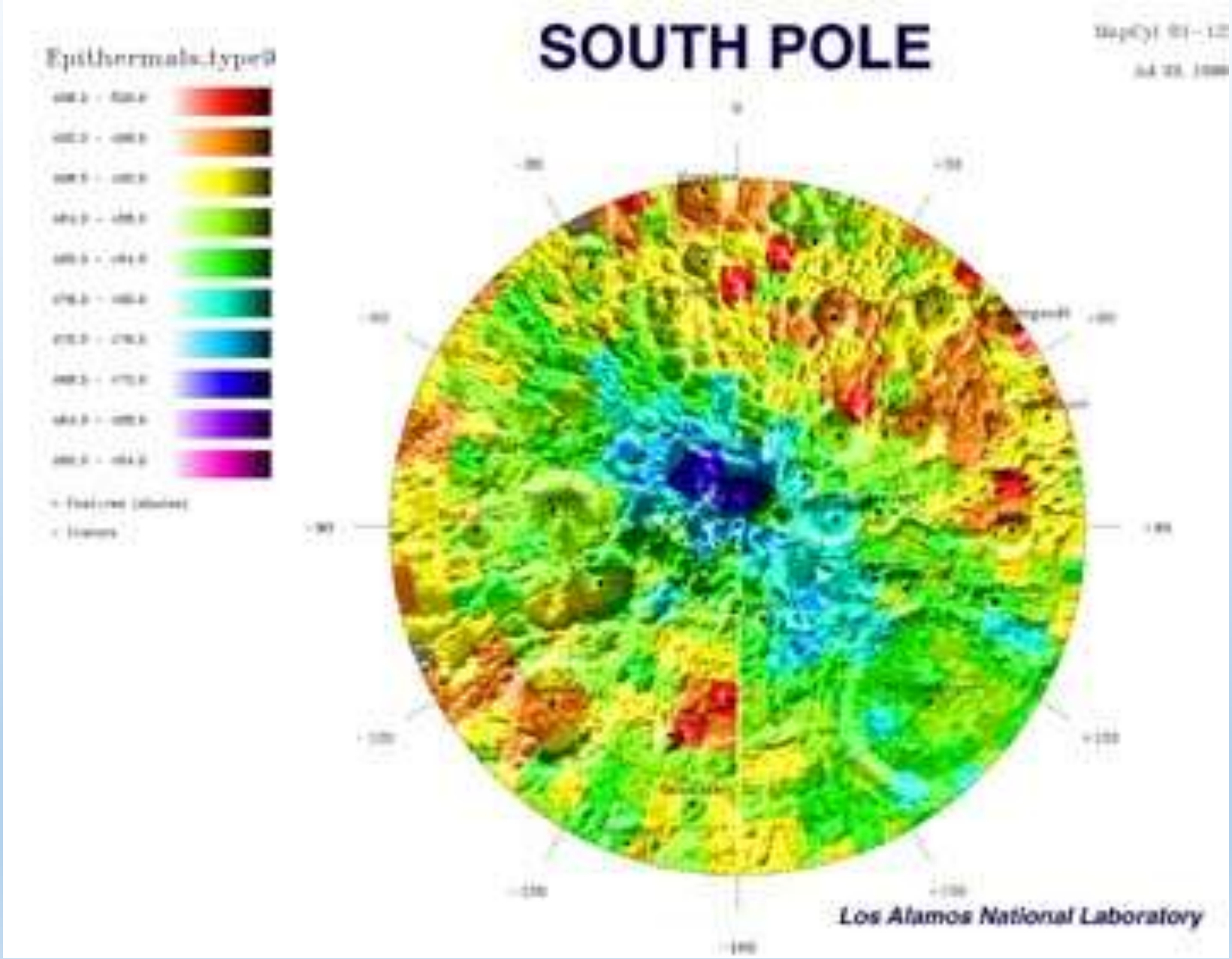
Mosaics of Lunar Poles

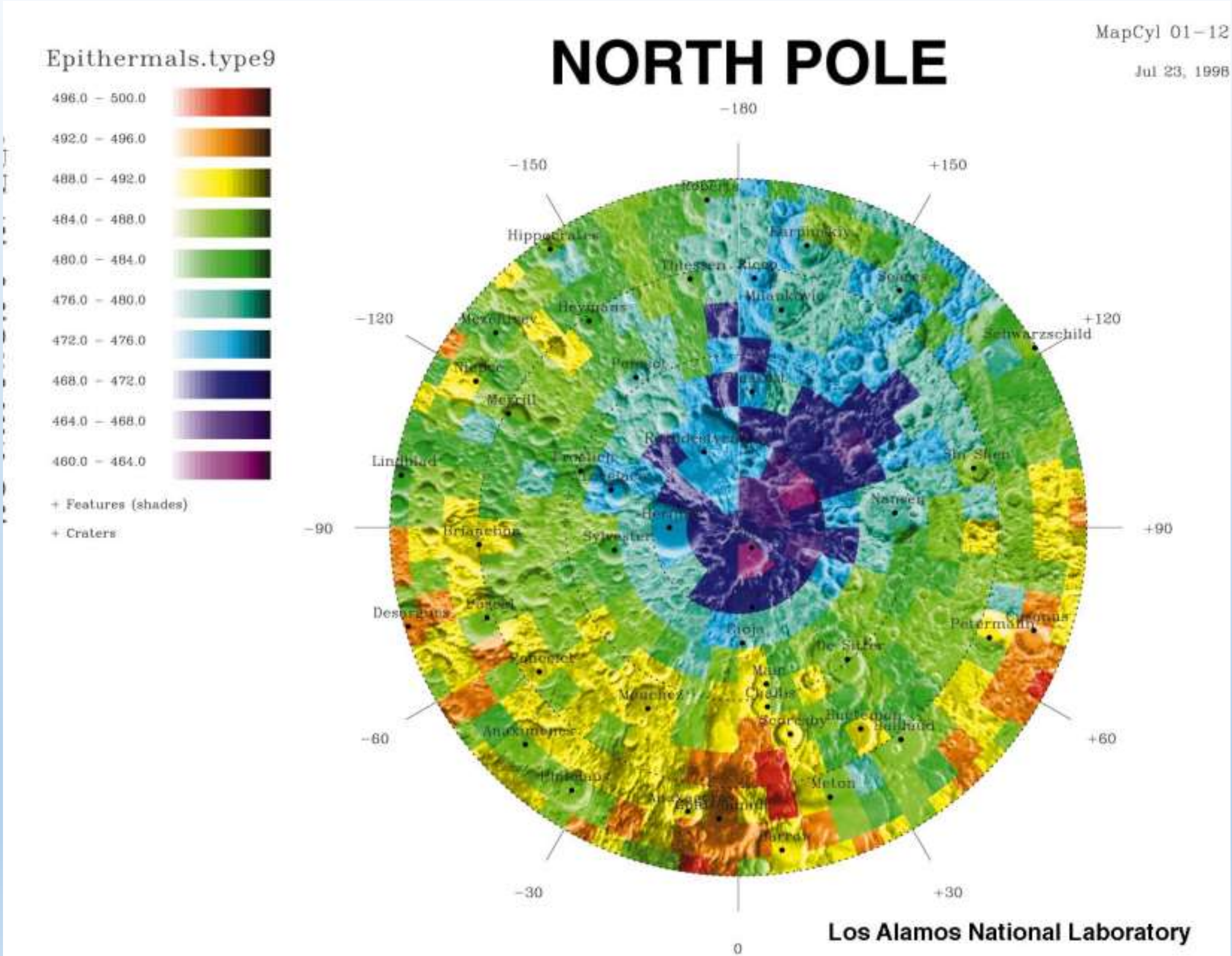


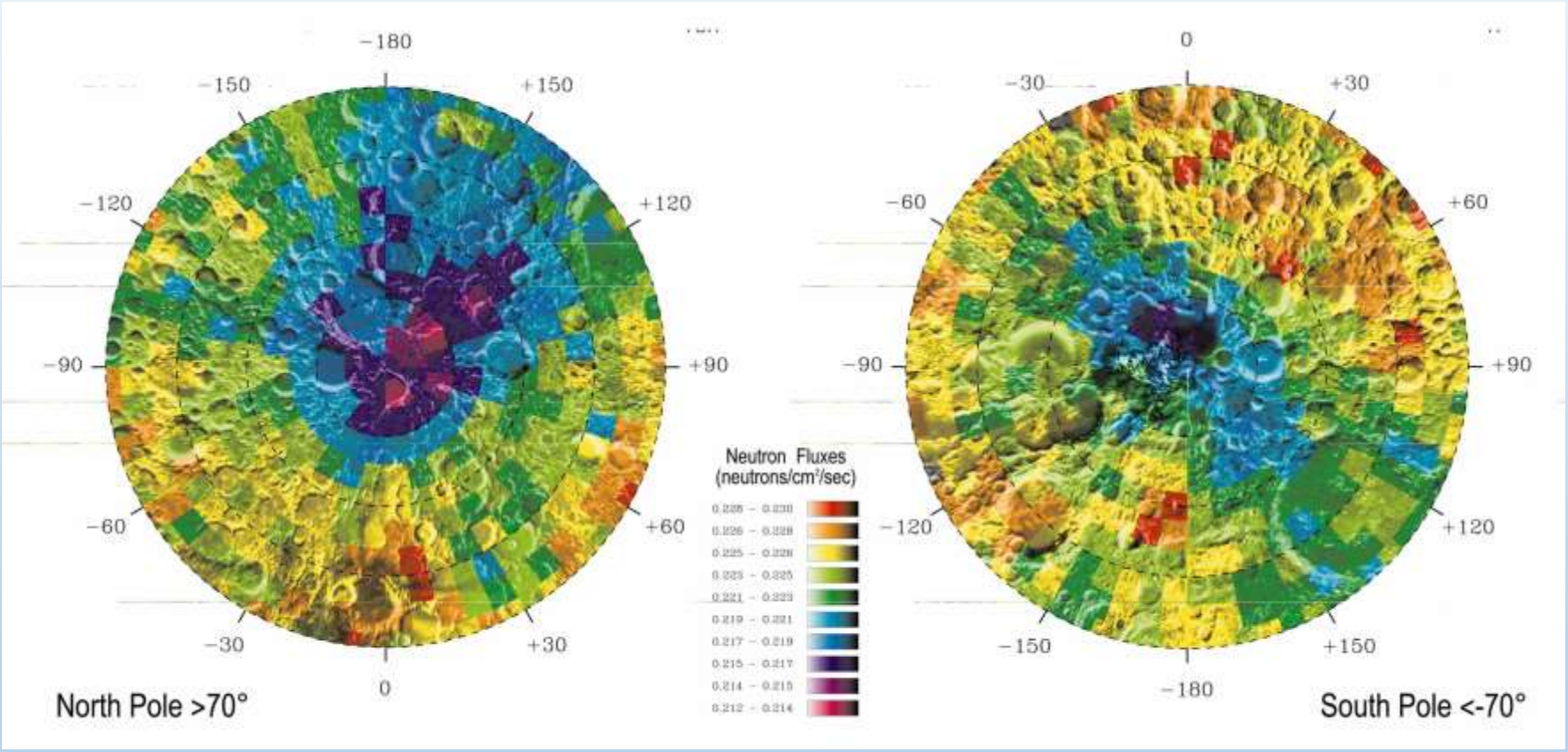


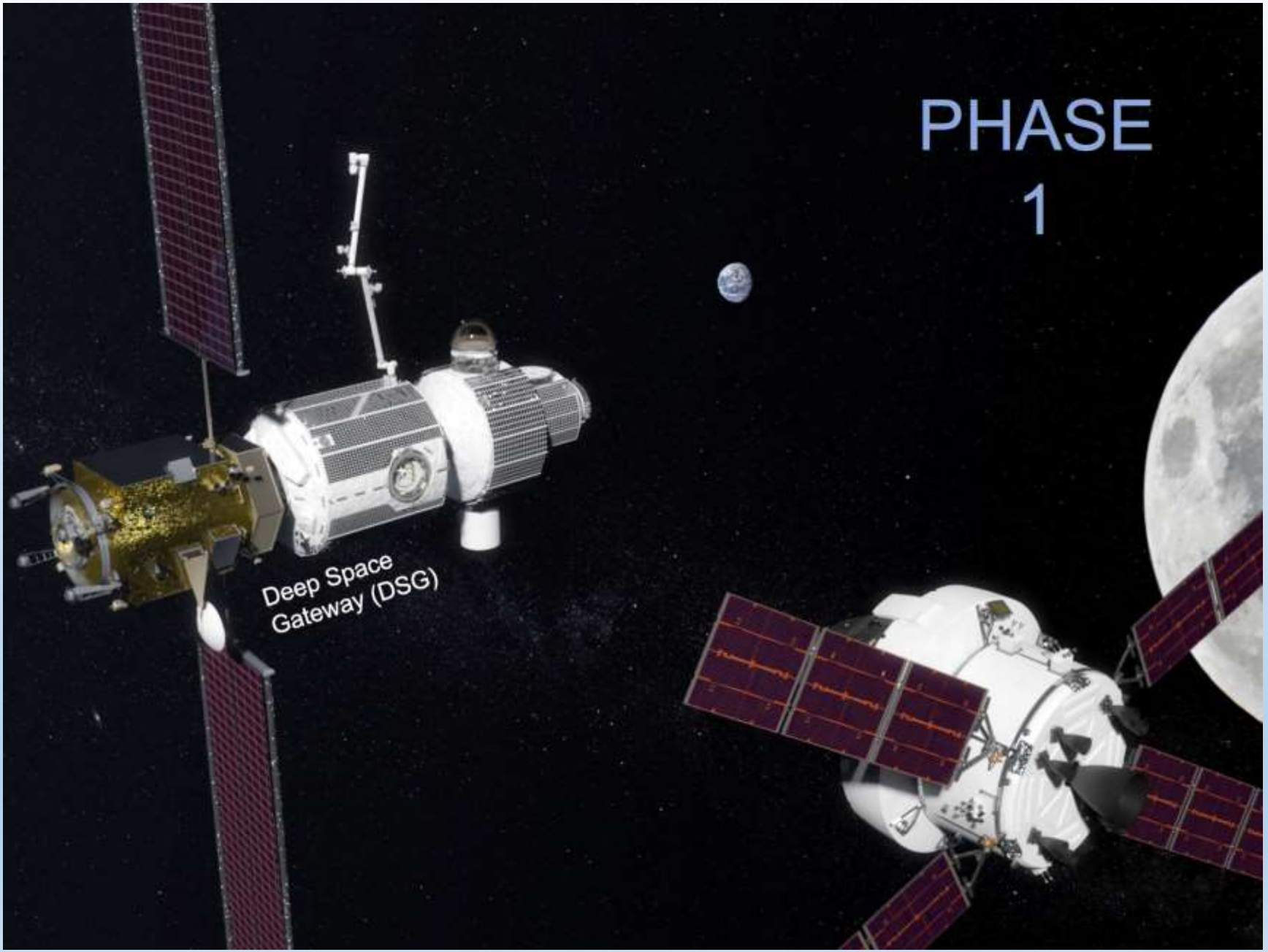
North Pole

South Pole


Epithermals.type9
SOUTH POLE
Los Alamos National Laboratory


Epithermals.type9
496.0 – 500.0
492.0 – 496.0
488.0 – 492.0
484.0 – 488.0
480.0 – 484.0
476.0 – 480.0
472.0 – 476.0
468.0 – 472.0
464.0 – 468.0
460.0 – 464.0
+ Features (shades)
+ Craters
NORTH POLE
MapCyl 01–12
Jul 23, 1998
–180
–150
+150
–120
+120
–90
+90
–60
+60
–30
+30
0
Schwarzschild
Heymans
Merrill
Brianchon
Sylvester
Petermann
De Sitter
Mouchez
Anaximenes
Meton
Los Alamos National Laboratory


−180
−150
+150
−120
+120
−90
+90
−60
+60
−30
+30
0
North Pole >70°
Neutron Fluxes
(neutrons/cm²/sec)
0.228 – 0.230
0.226 – 0.228
0.225 – 0.226
0.223 – 0.225
0.221 – 0.223
0.219 – 0.221
0.217 – 0.219
0.215 – 0.217
0.214 – 0.215
0.212 – 0.214
0
−30
+30
−60
+60
−90
+90
−120
+120
−150
+150
−180
South Pole <-70°


PHASE
1
Deep Space
Gateway (DSG)


THE VERGE
Designing a tiny home to orbit the Moon
SOURCE: LOCKHEED MARTIN
MORE VIDEOS
SUBSCRIBE
0:49 / 7:45
YouTube

Figure 26. The telerobotic command and control of robotic agents is a rapidly advancing field. Recent demonstrations from ISS suggest that this technology could be useful for lunar /Mars CC/SIS machine operations, circumventing the signal time delay associated with extraterrestrial surface operations management from Earth mission control and ground station networks.[Credit NASA GSFC 2012]

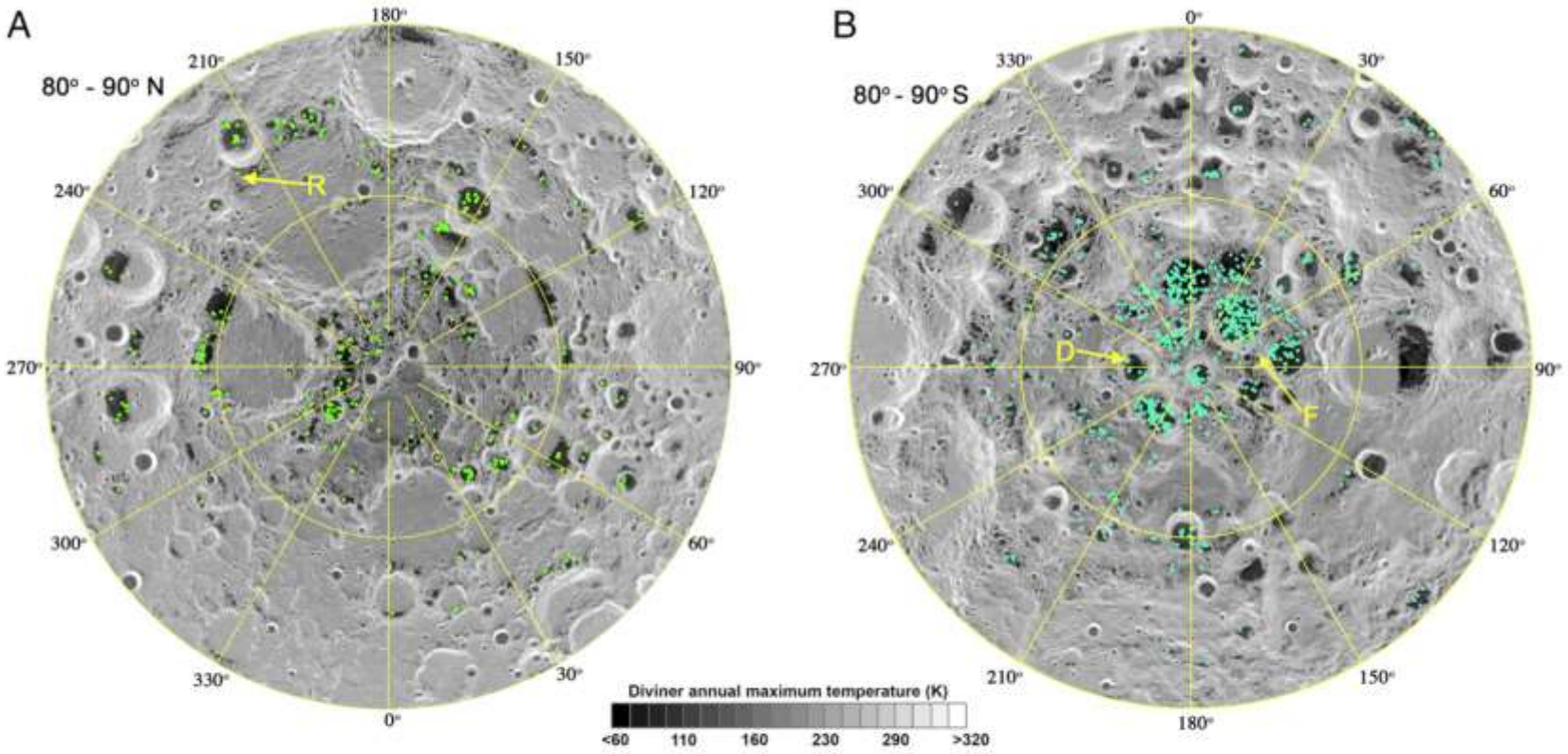
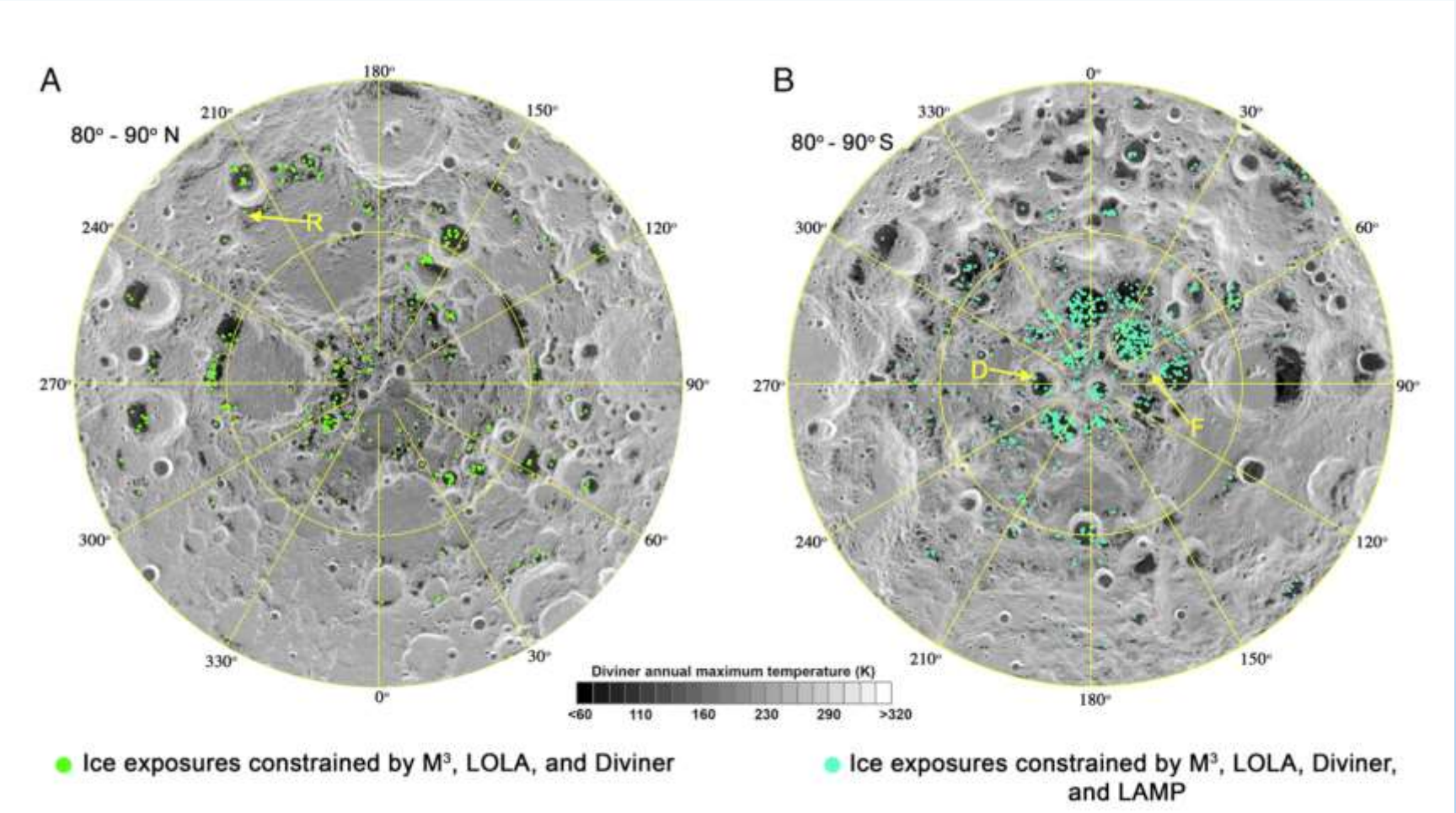
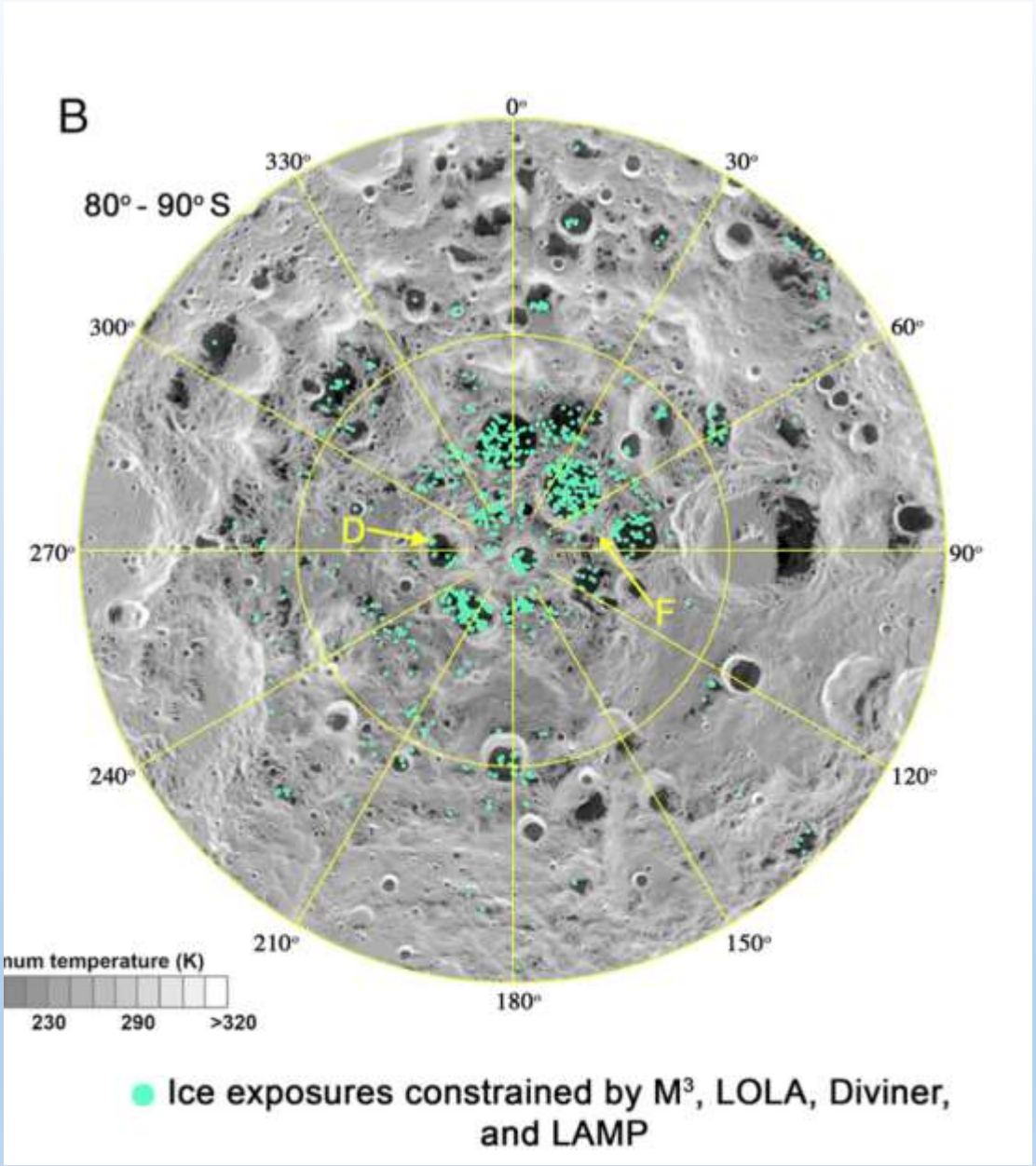


Fig. 4. Distribution of water-ice-bearing pixels (green and cyan dots) overlain on the Diviner annual maximum temperature for the (*A*) northern- and (*B*) southern polar regions. Ice detection results are further filtered by maximum temperature (<110 K), LOLA albedo (>0.35) (12), and LAMP off and on band ratio (>1.2, only applicable in the south) (13). Each dot represents an M (3) pixel, ~280 m × 280 m.

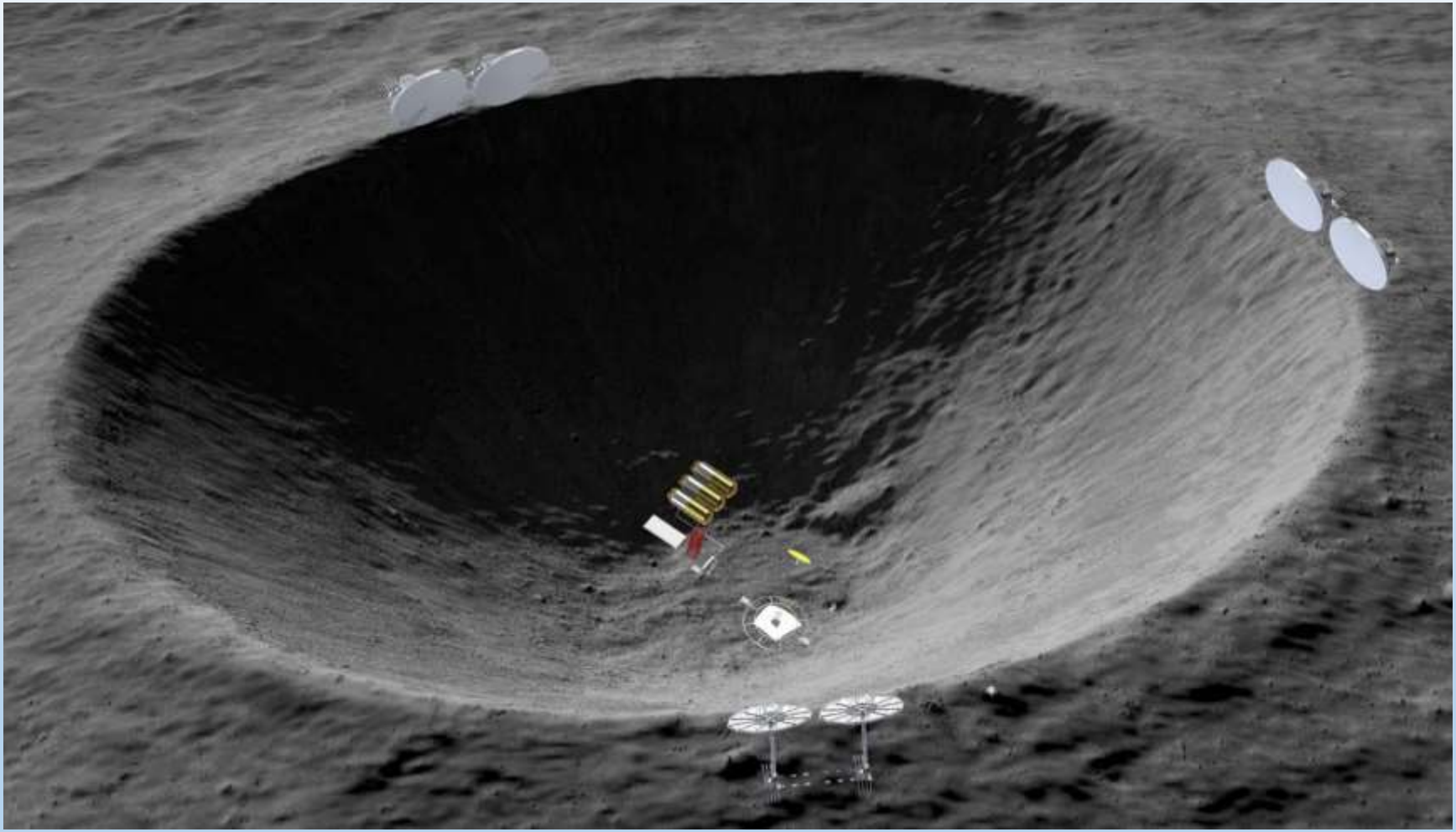
Li, et al., Direct evidence of surface exposed water ice in the lunar polar regions, PNAS, 2018, pnas.1802345115



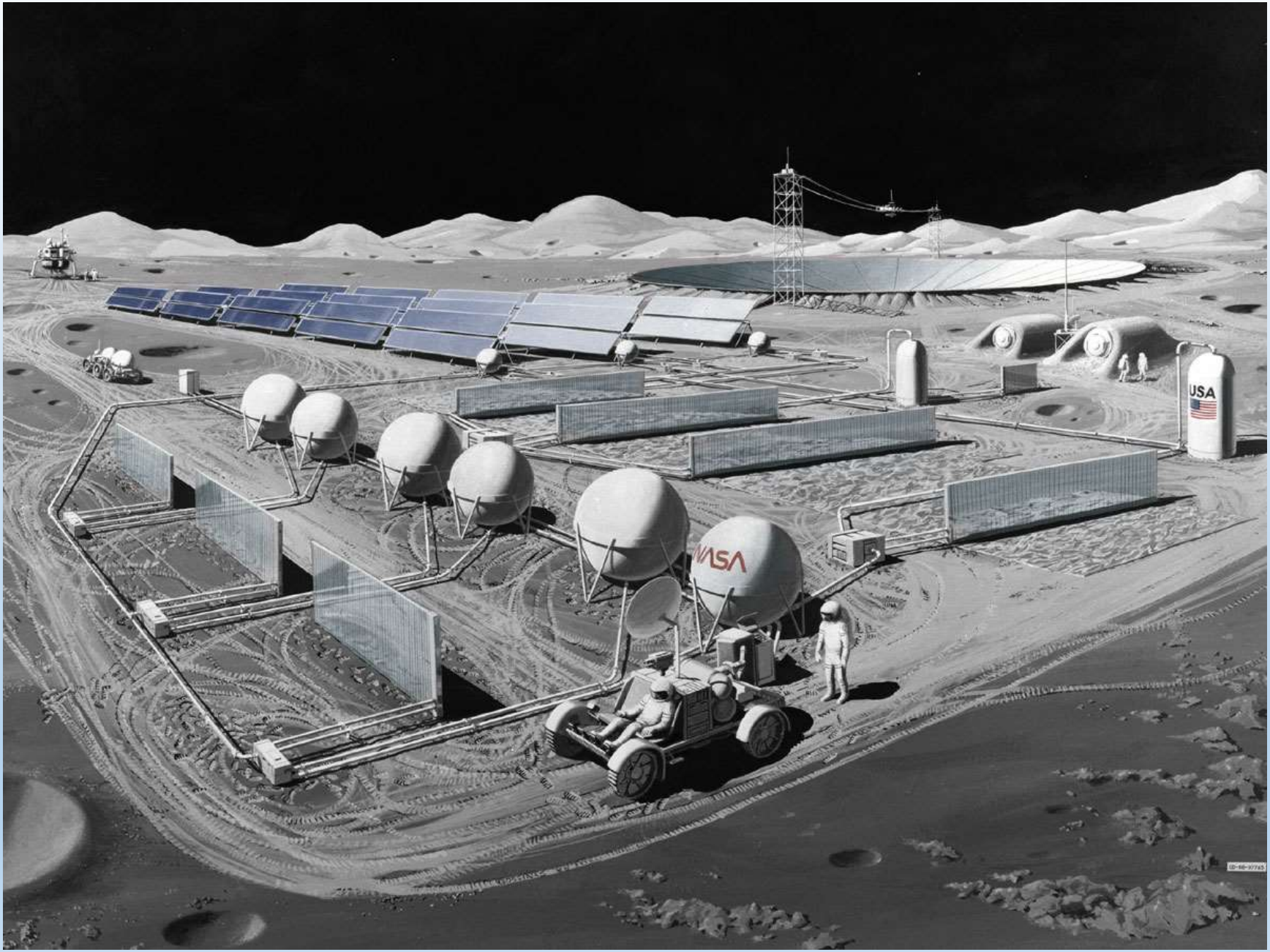
Li, et al., Direct evidence of surface exposed water ice in the lunar polar regions, PNAS, 2018, pnas.1802345115



Li, et al., Direct evidence of surface exposed water ice in the lunar polar regions, PNAS, 2018, pnas.1802345115



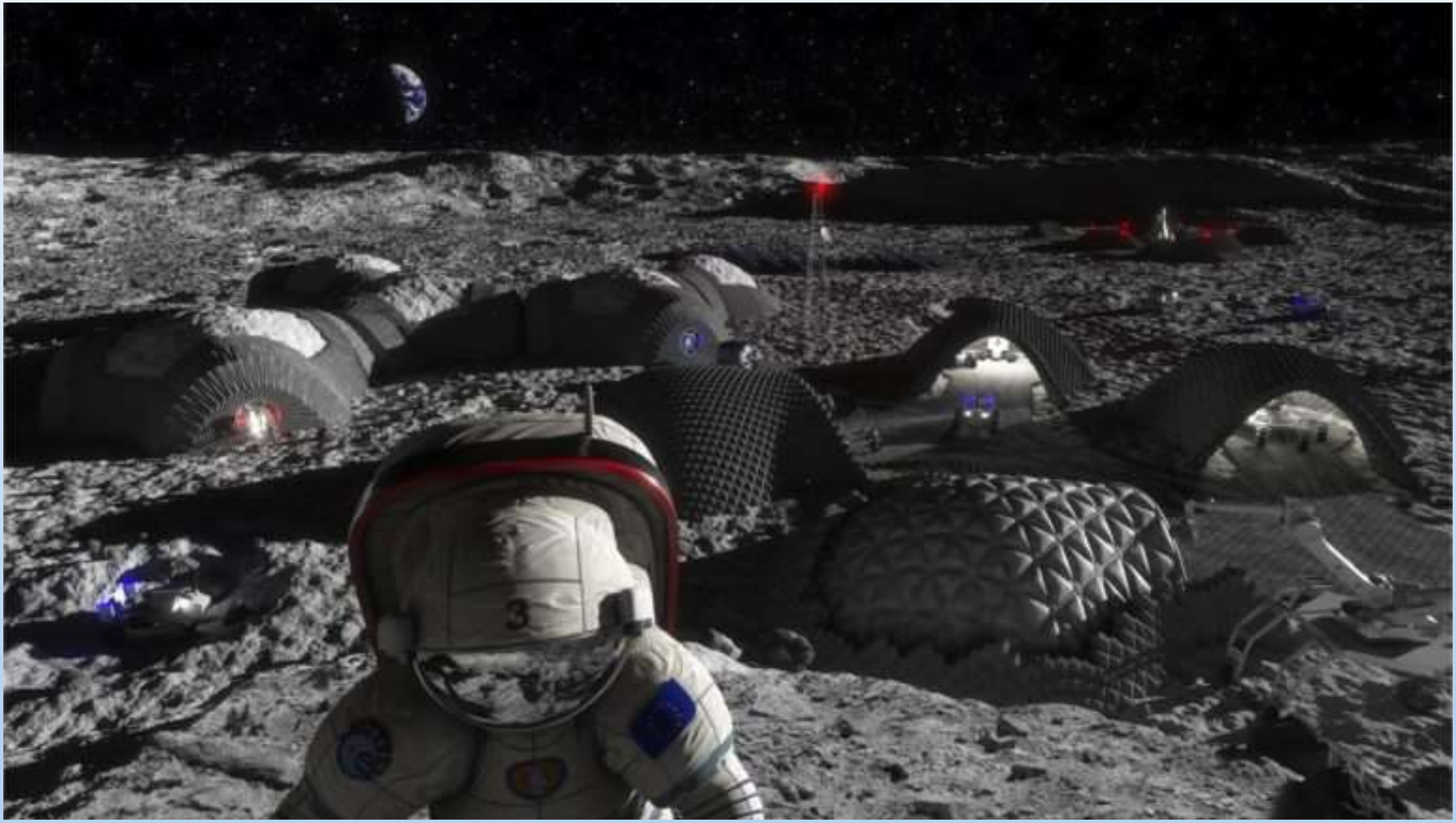
Colorado School of Mines / Dreyer, Williams, Sowers


USA
NASA

European Space Agency, ESA / Foster + Partners

Figure 2. A Contour Crafting robot is shown here printing a road in front of a parabolic hangar structure housing a lunar lander. In the background can be seen a plant intended for processing regolith that will be used in the construction process.

University of Southern California / Behrokh Khoshnevis, Anders Carlson, Madhu Thangavelu



LIQUIFER Systems Group, 2018 / René Waclavicek

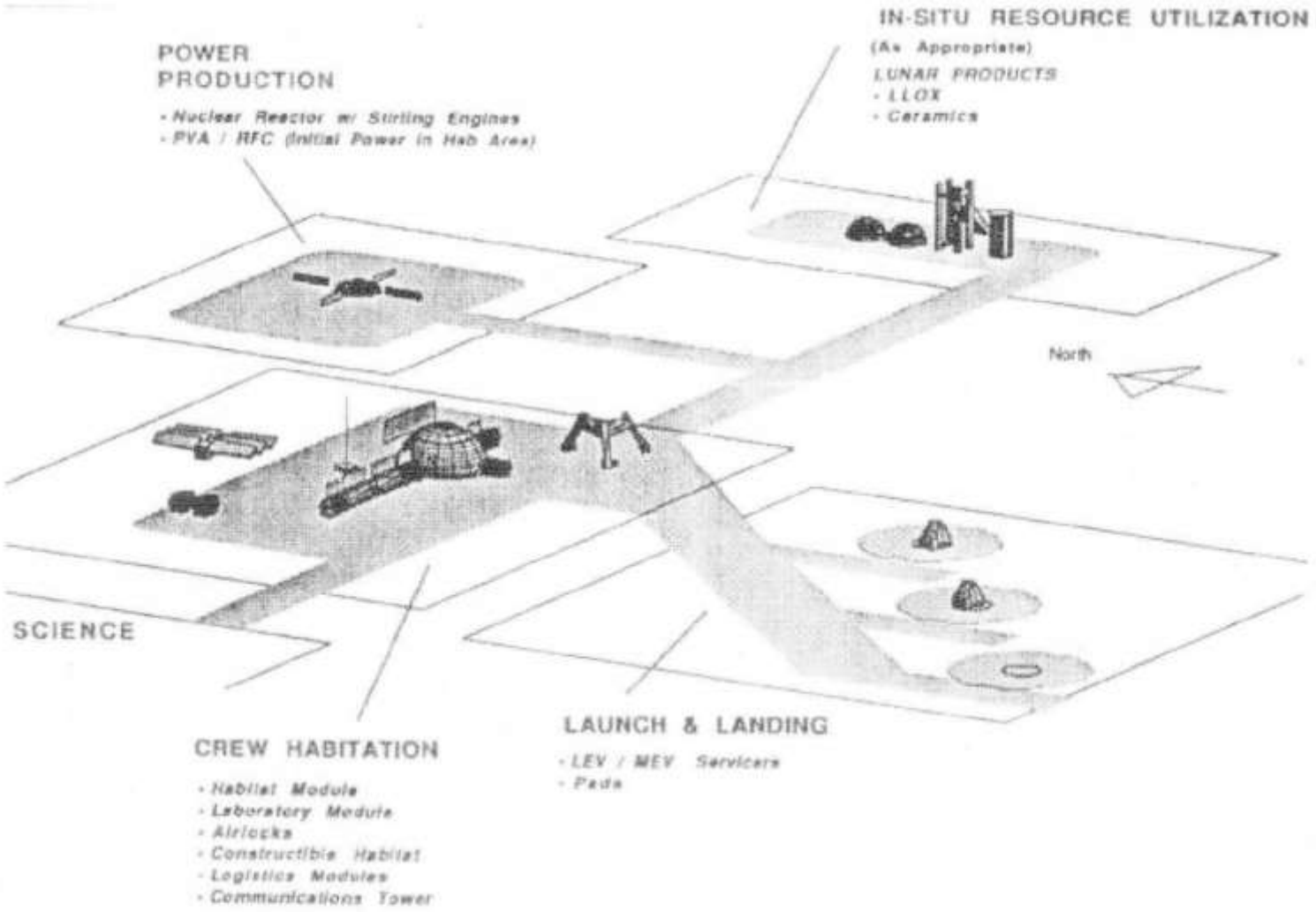
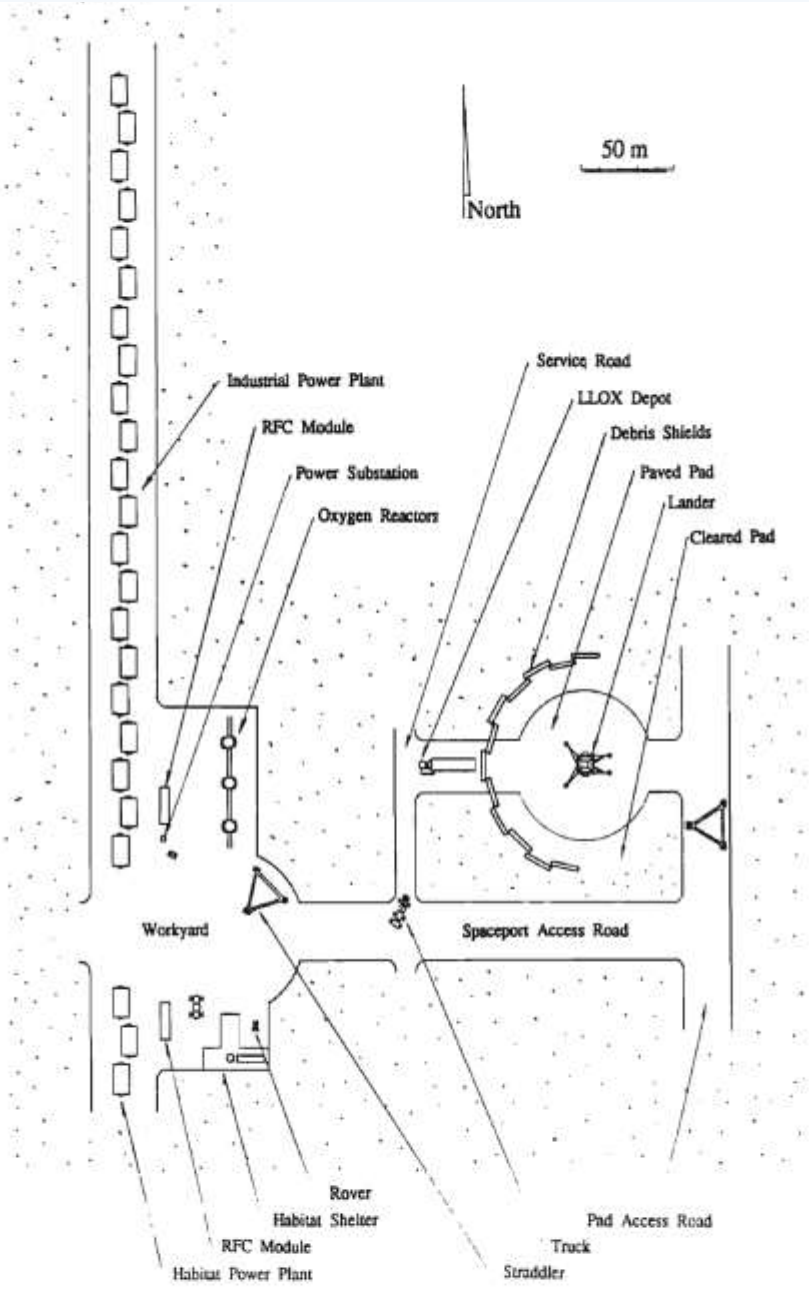


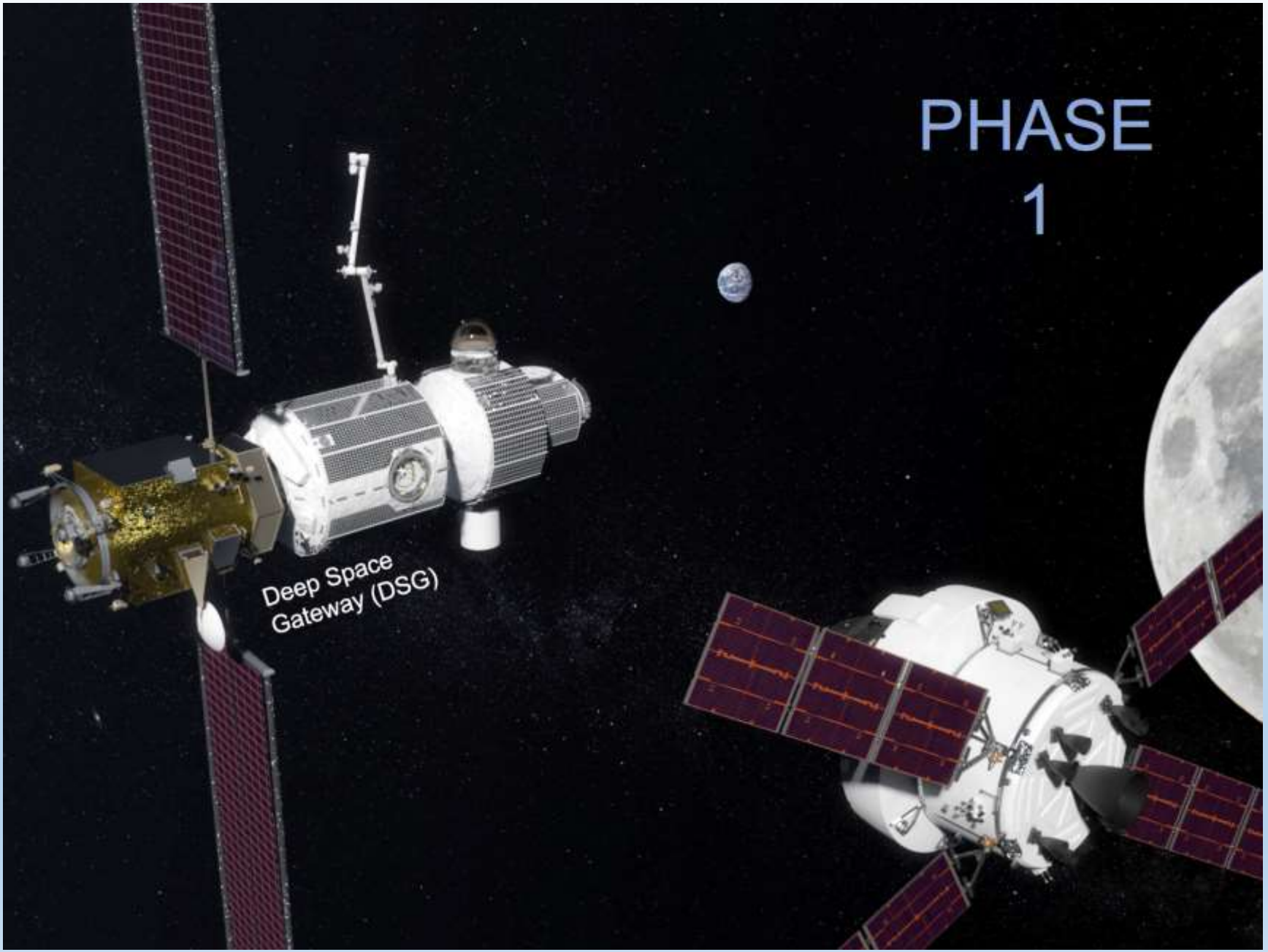
Figure 4. Architecture from the Space Exploration Initiative 90 Day Report [90 Day Report, NASA 1989]

Figure 23. Bird's eye view of the NASA SEI lunar base show the schematic layout of an early lunar base. [Credit NASA JSC Alred etal.,1989, O'Handley Orbitec NASA NIAC Report 2000]


50 m
North
Industrial Power Plant
RFC Module
Power Substation
Oxygen Reactors
Service Road
LLOX Depot
Debris Shields
Paved Pad
Lander
Cleared Pad
Workyard
Spaceport Access Road
Rover
Habitat Shelter
RFC Module
Habitat Power Plant
Pad Access Road
Truck
Straddler

Tourism - Marriott

With advanced propulsion, one must always look to the past and look to the future.


PHASE
1
Deep Space
Gateway (DSG)

Phase 1 Plan

Establishing deep-space leadership and preparing for Deep Space Transport development

		Deep Space Gateway Buildup			
EM-1	Europa Clipper	EM-2	EM-3	EM-4	EM-5
2018 - 2025					2026
SLS Block 1 Crew: 0	SLS Block 1B Cargo Europa Clipper (subject to approval)	SLS Block 1B Crew: 4 CMP Capability: 8-9T 40kW Power/Prop Bus	SLS Block 1B Crew: 4 CMP Capability: 10mT Habitation	SLS Block 1B Crew: 4 CMP Capability: 10mT Logistics	SLS Block 1B Crew: 4 CPL Capability: 10mT Airlock
Distant Retrograde Orbit (DRO) 26-40 days	Jupiter Direct	Multi-TLI Lunar Free Return 8-21 days	Near Rectilinear Halo Orbit (NRHO) 16-26 days	NRHO, w/ ability to translate to/from other cislunar orbits 26-42 days	NRHO, w/ ability to translate to/from other cislunar orbits 26-42 days
Gateway (blue) Configuration (Orion in grey)			Cislunar Support Flight	Cislunar Support Flight	

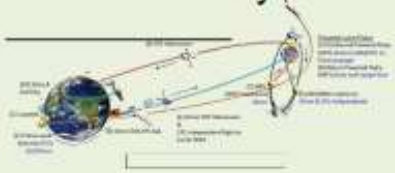
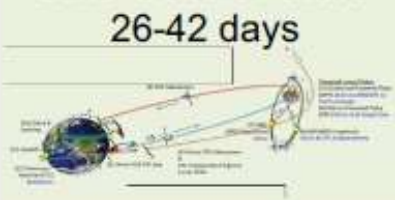
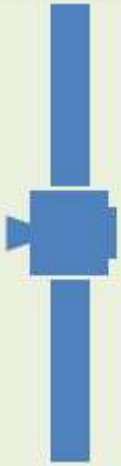
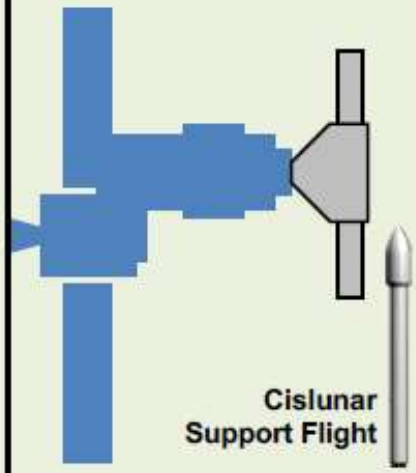
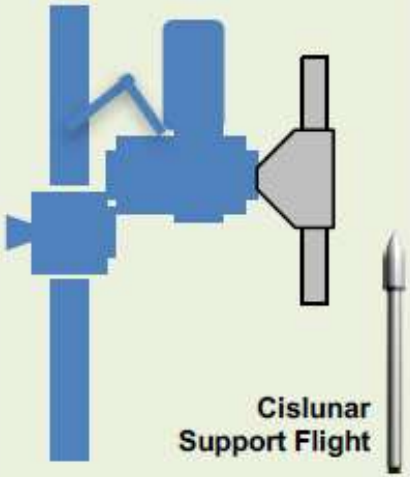
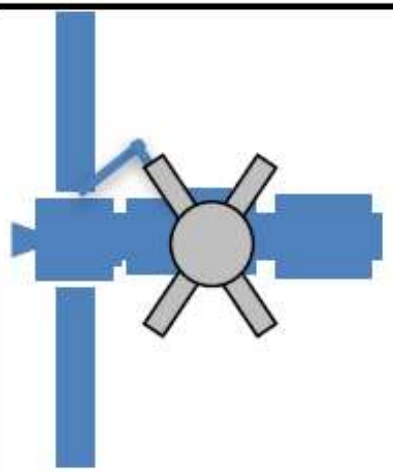
These essential Gateway elements can support multiple U.S. and international partner objectives in Phase 1 and beyond

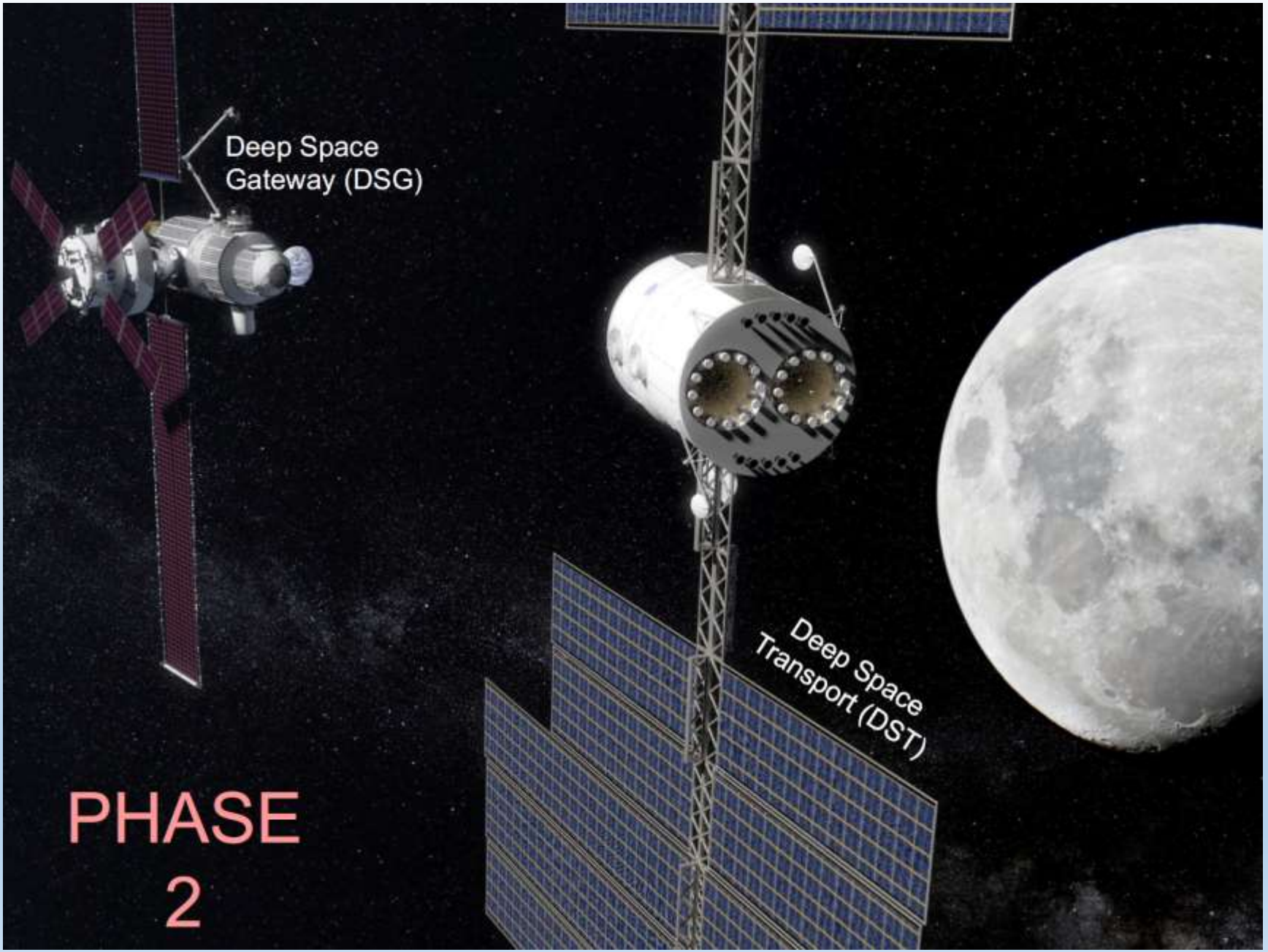
Known Parameters:

- Gateway to architecture supports Phase 2 and beyond activities
- International and U.S. commercial development of elements and systems
- Gateway will translate uncrewed between cislunar orbits
- Ability to support science objectives in cislunar space

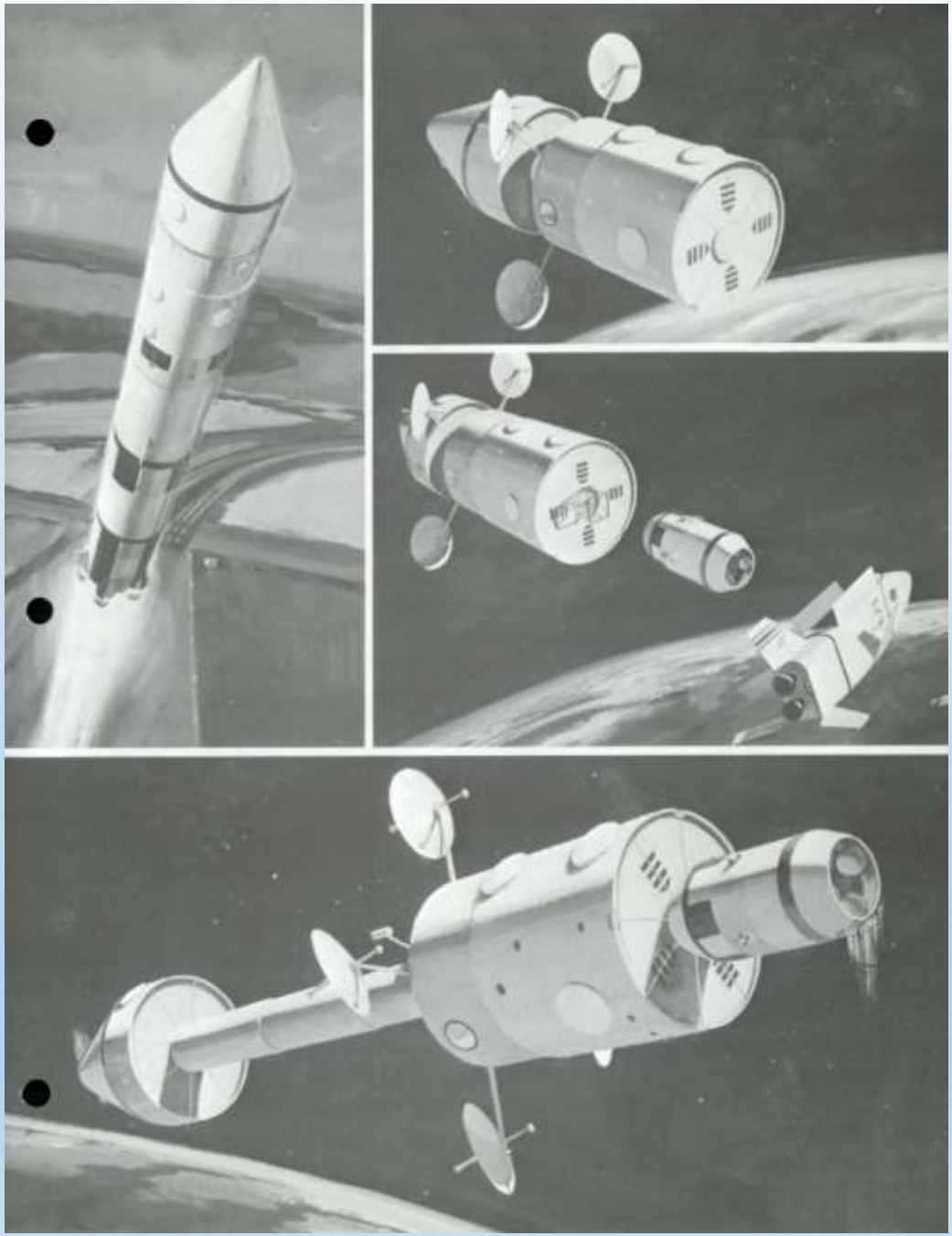
Open Opportunities:

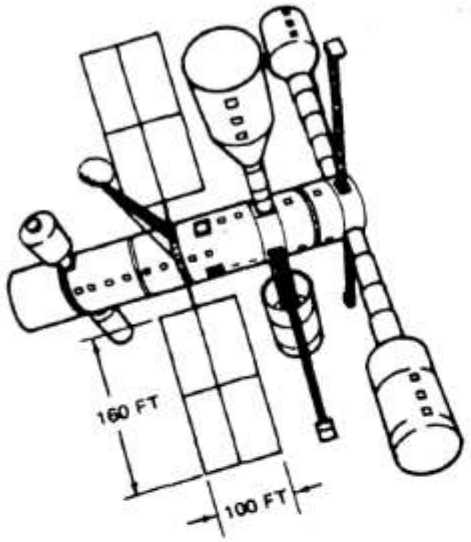
- Order of logistics flights and logistics providers
- Use of logistics modules for available volume
- Ability to support lunar surface missions

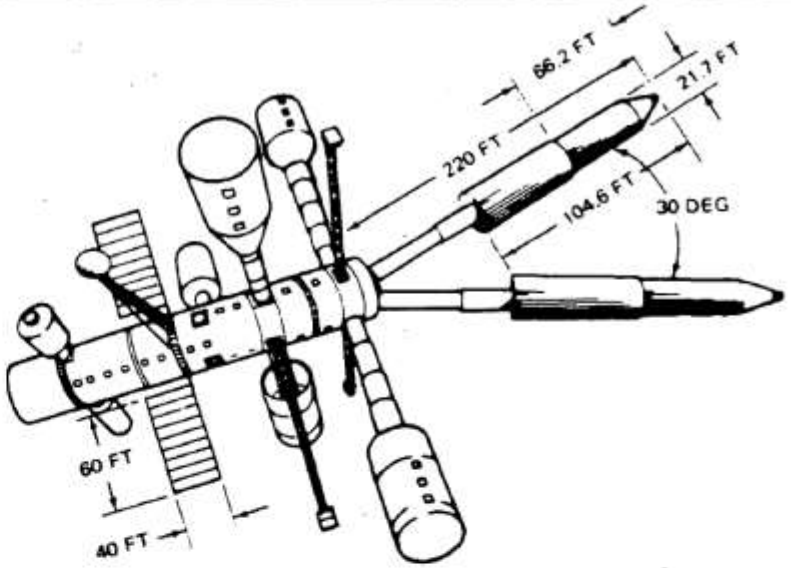
Multi-TLI Lunar Free Return 8-21 days	Near Rectilinear Halo Orbit (NRHO) 16-26 days	NRHO, w/ ability to translate to/from other cislunar orbits 26-42 days	NRHO, w/ ability to translate to/from other cislunar orbits 26-42 days
			
			


Deep Space
Gateway (DSG)
Deep Space
Transport (DST)
PHASE
2

At Saturn







REACTOR POWER

SOLAR ARRAY

100 kwe
30,000 FT^2
- ROLL-OUT
- RIGID
- SEMI-RIGID

POWER SOURCES

PRIMARY:
- REFERENCE U-ZrH REACTOR
- ADVANCED REFERENCE REACTOR
- MECURY RANKINE-CYCLE
- THERMOELECTRIC

POWER CONVERSION SYSTEMS
- BRAYTON-CYCLE
- MERCURY RANKINE-CYCLE
- ORGANIC RANKINE-CYCLE
- THERMOELECTRIC

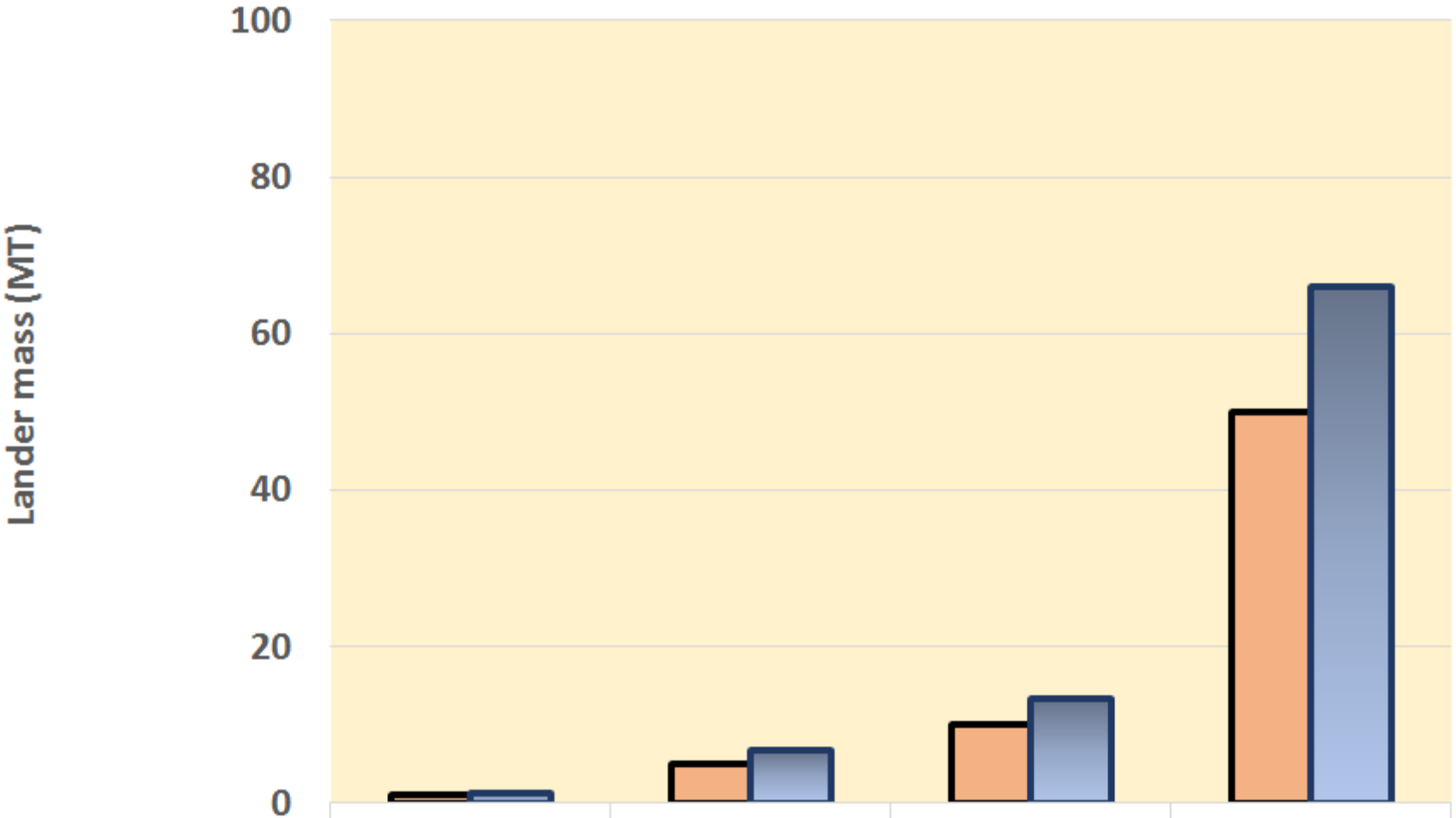
STANDBY/EMERGENCY:
- FAST REACTOR
- HIGH-TEMPERATURE BRAYTON-CYCLE
- IN-CORE THERMIONIC

RECOMMENDED

STANDBY/EMERGENCY:
SOLAR ARRAYS/PANELS
- SOLAR-ARRAY BACKUP

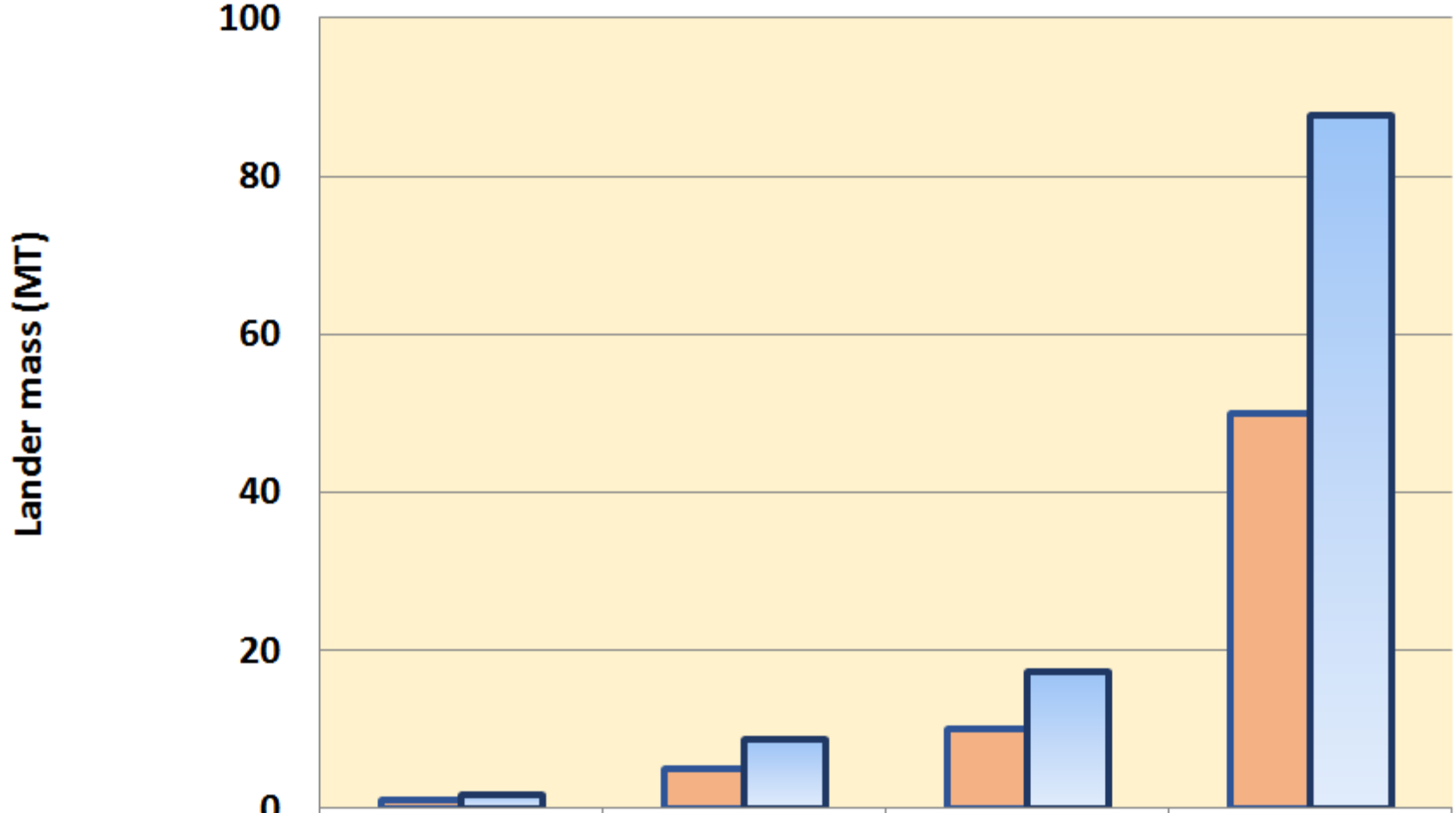
Figure 3-2. Candidate Electrical Power Subsystems

At Saturn: Enceladus Lander Mass (MT), Two-Way Flights, delta-V = 0.6 km/s , Isp = 480 s, M,tank = 0.4 M,p



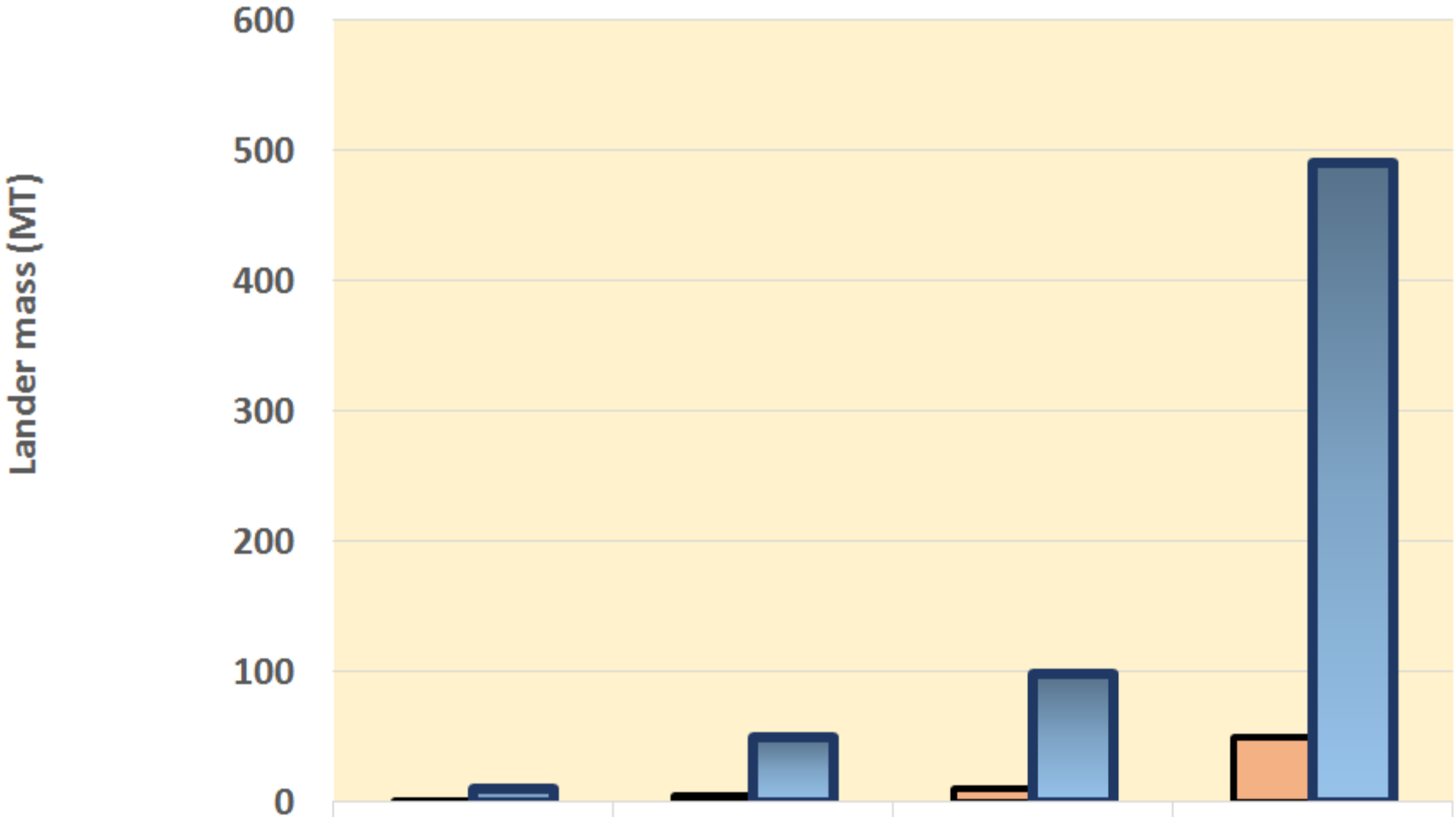
	1	2	3	4
Payload mass (MT)	1	5	10	50
Lander mass (MT)	1.3	6.6	13.2	66.1

At Saturn: Iapetus Lander Mass (MT), Two-Way Flights, delta-V = 1.40 km/s, Isp = 480 s, M,tank = 0.4 M,p



	1	2	3	4
Payload mass (MT)	1	5	10	50
Lander mass (MT)	1.7	8.6	17.2	87.8

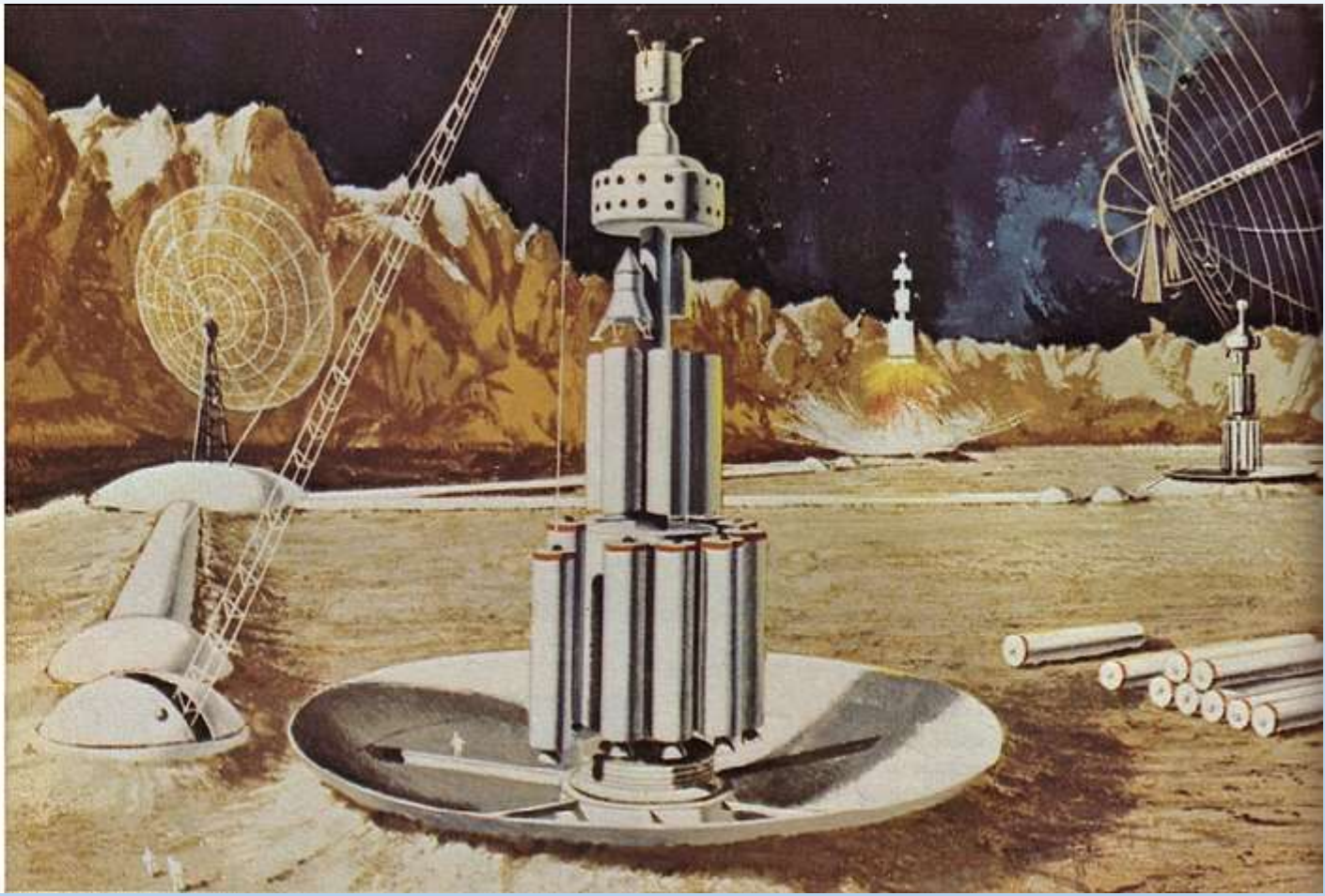
At Saturn: Titan Lander Mass (MT), Two-Way Flights, delta-V = 6.34 km/s , Isp = 480 s, M,tank = 0.2 M,p

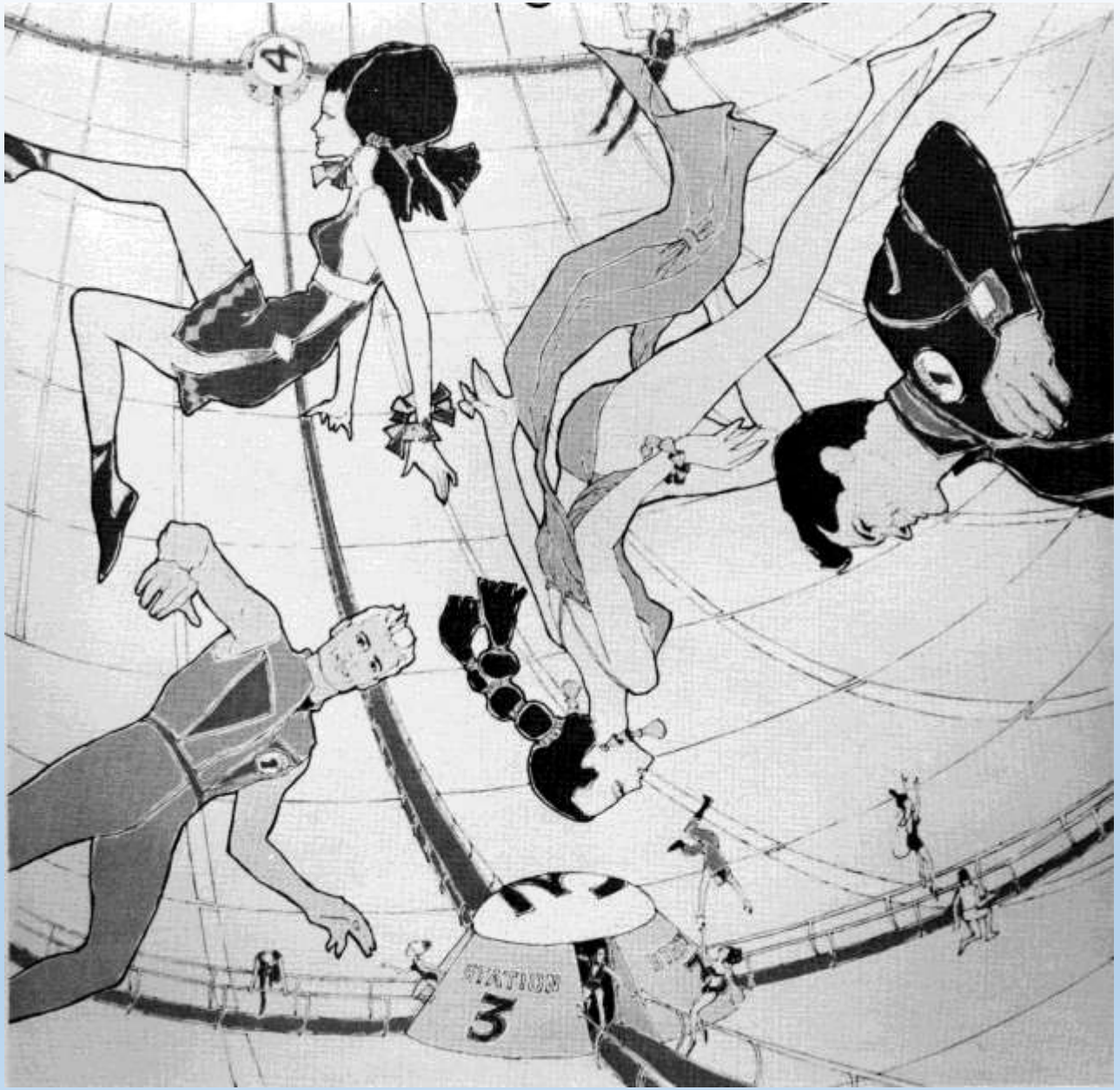


	1	2	3	4
Payload mass (MT)	1	5	10	50
Lander mass (MT)	9.8	49.0	98.0	490.2

Krafft Ehricke, Selenopolis


USA
UNITED STATES
SX-SSC
USA



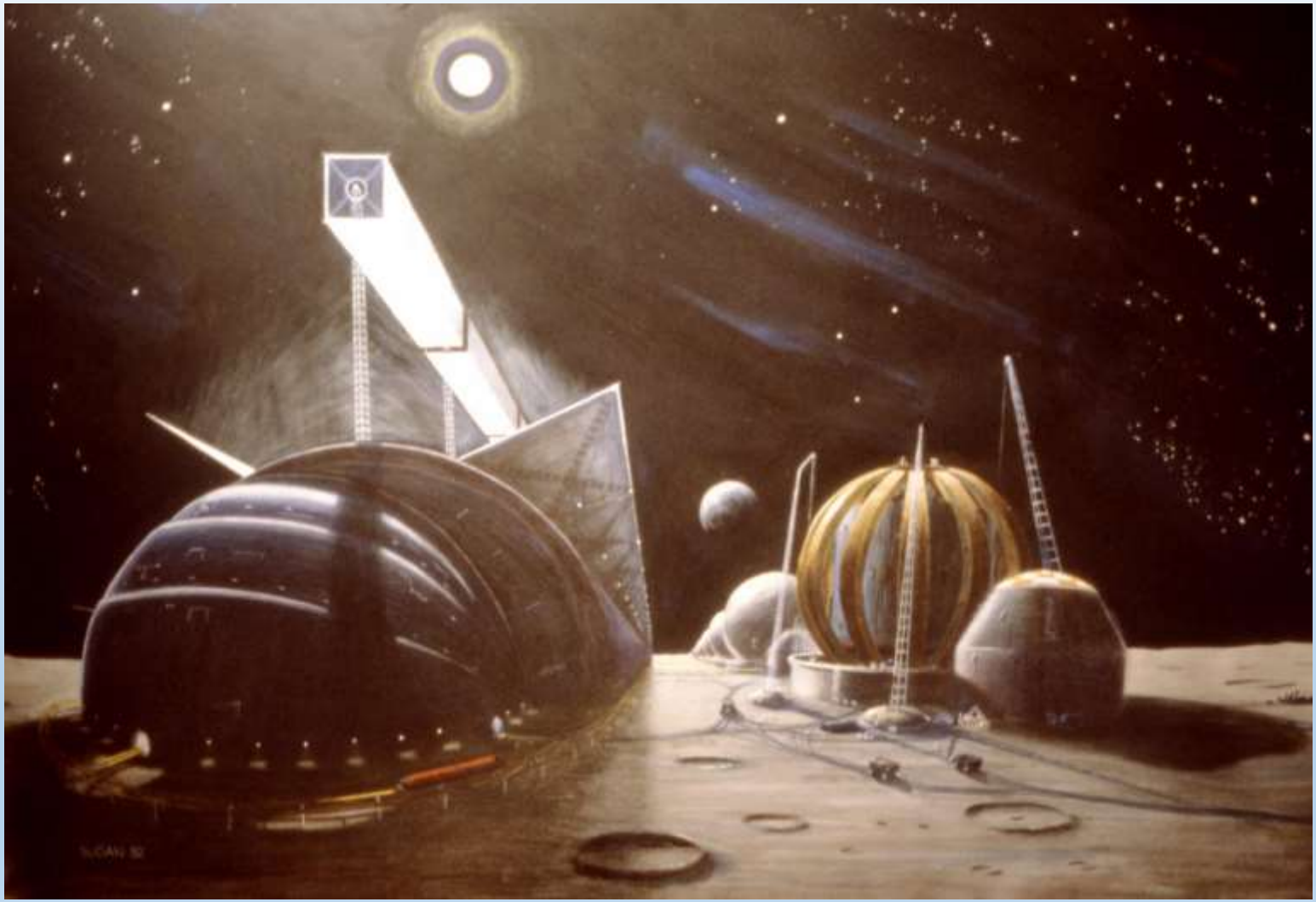

4
STATION
3

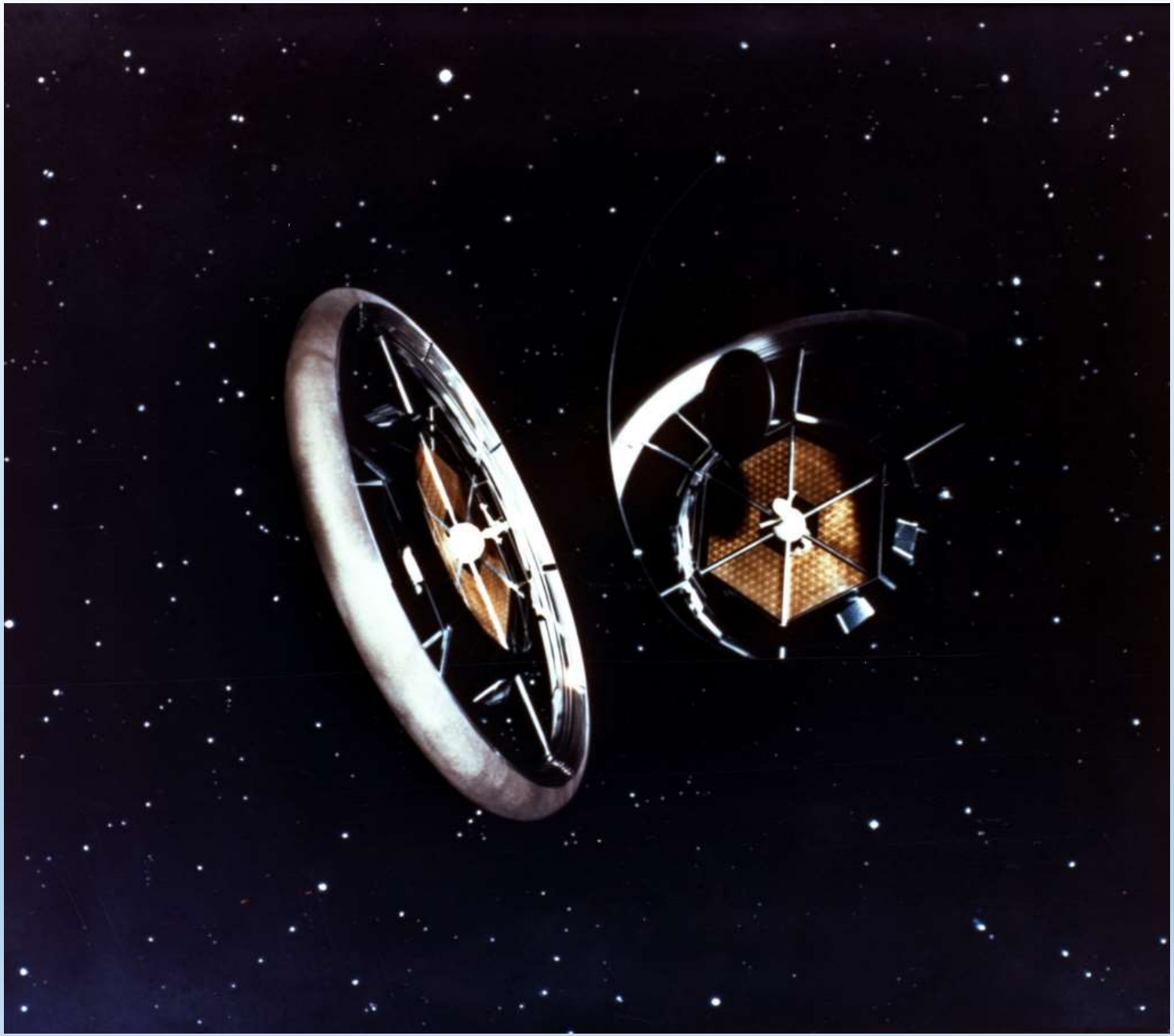

STAFF

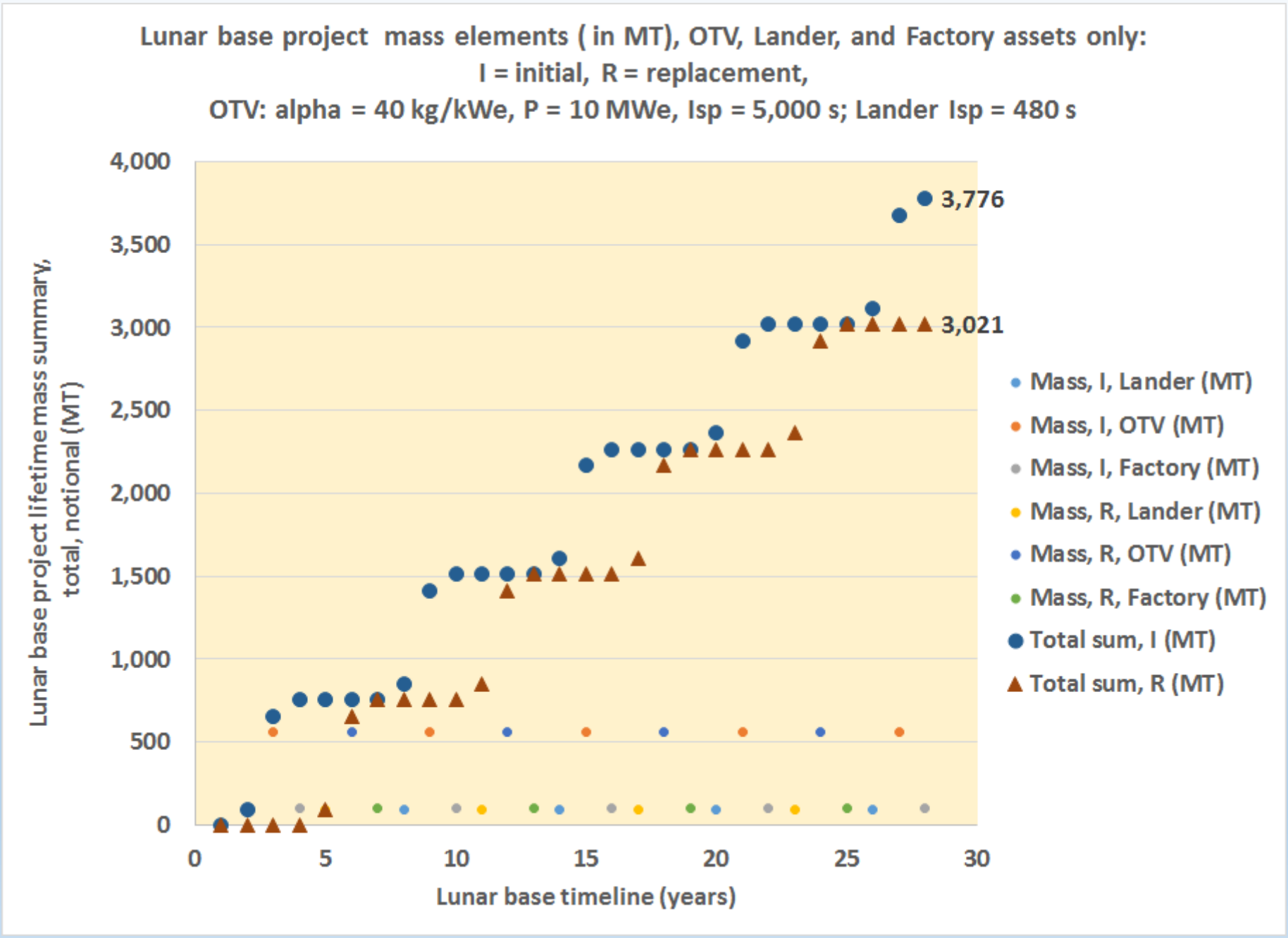
Vorschlag

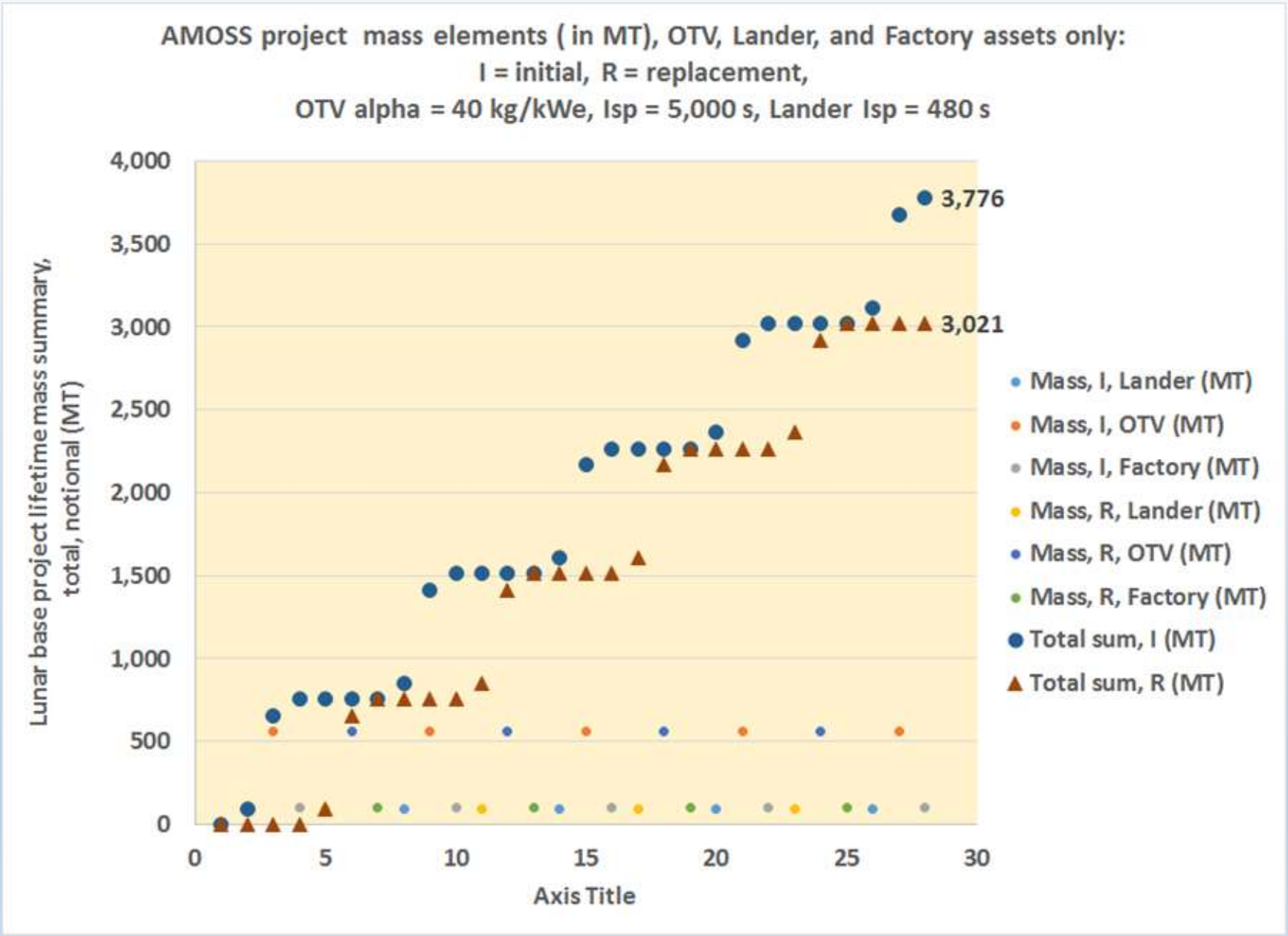
zur Verwirklichung des Baues

moderner Raketen in China

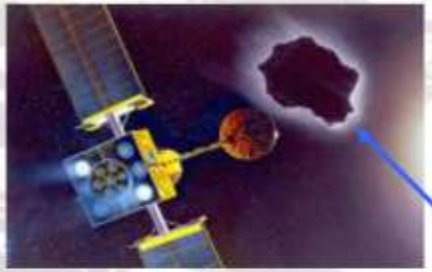


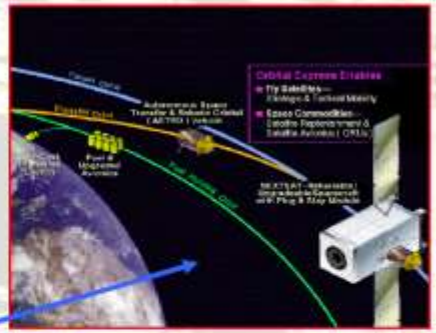



Lunar base project mass elements (in MT), OTV, Lander, and Factory assets only:
I = initial, R = replacement,
OTV: alpha = 40 kg/kWe, P = 10 MWe, Isp = 5,000 s; Lander Isp = 480 s
Lunar base project lifetime mass summary, total, notional (MT)
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
0
5
10
15
20
25
30
Lunar base timeline (years)
3,776
3,021
Mass, I, Lander (MT)
Mass, I, OTV (MT)
Mass, I, Factory (MT)
Mass, R, Lander (MT)
Mass, R, OTV (MT)
Mass, R, Factory (MT)
Total sum, I (MT)
Total sum, R (MT)

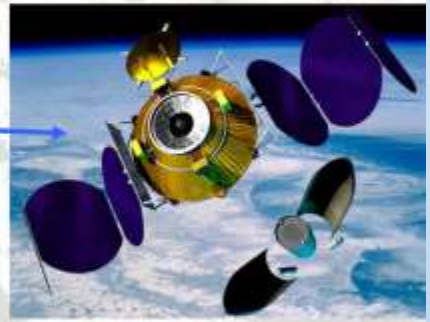

AMOSS project mass elements (in MT), OTV, Lander, and Factory assets only:
I = initial, R = replacement,
OTV alpha = 40 kg/kWe, Isp = 5,000 s, Lander Isp = 480 s
Lunar base project lifetime mass summary, total, notional (MT)
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
0
5
10
15
20
25
30
Axis Title
3,776
3,021
Mass, I, Lander (MT)
Mass, I, OTV (MT)
Mass, I, Factory (MT)
Mass, R, Lander (MT)
Mass, R, OTV (MT)
Mass, R, Factory (MT)
Total sum, I (MT)
Total sum, R (MT)

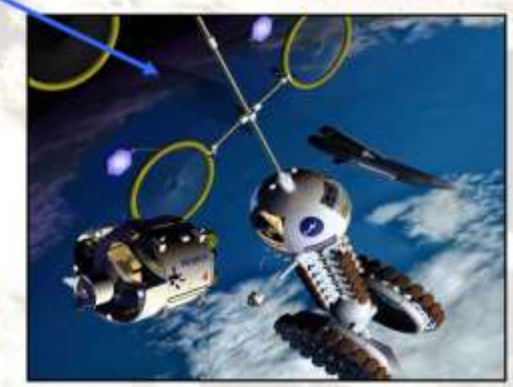
The Emerging Cislunar Marketplace





NASA-Science
Military Missions
Debris Management
Satellite Servicing & Refueling
International Space Station
Human Exploration
Space Solar Power
Self-Sustaining Colonies





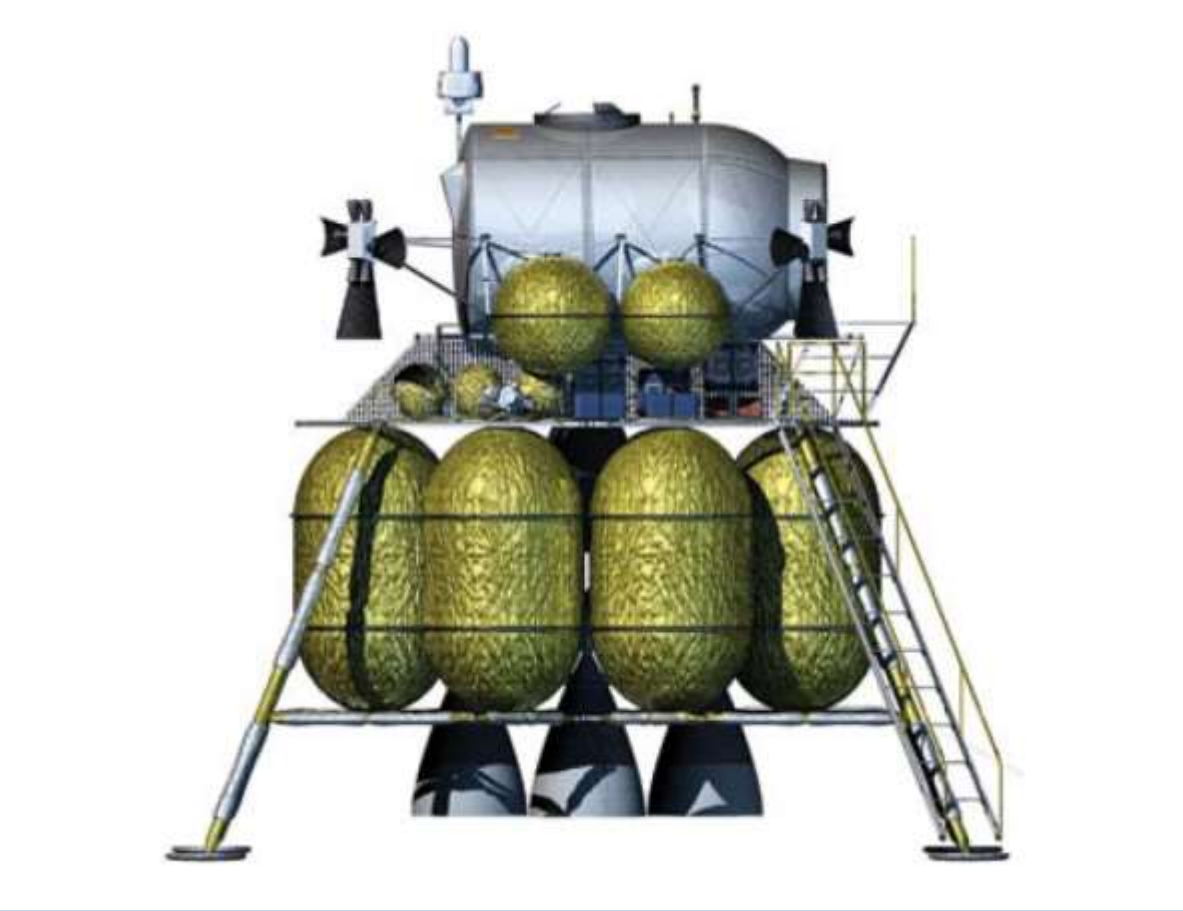
Brad R. Blair, NewSpace Analytics, *2017 LEAG Annual Meeting*

Candidate Lunar ISRU Products

Volatile Resources
-Water (H and O2 for life support & propellant)
-Nitrogen and carbon gases (CH4 NH3)
-3He

Industrial / Manufacturing
-Sulfur (concrete)
-Soil for agriculture
-Basalt fiber
-Cast basalt
-Iron / Steel
-Aluminum
-Sintered Bricks (e.g. Pavers)
-Solar cells
-Transparent & opaque glass (including fiber)
-Shielding for L1 Gateway

Lunar Surface Access Module (LSAM)



Notional Schedule of Lunar Surface Activities

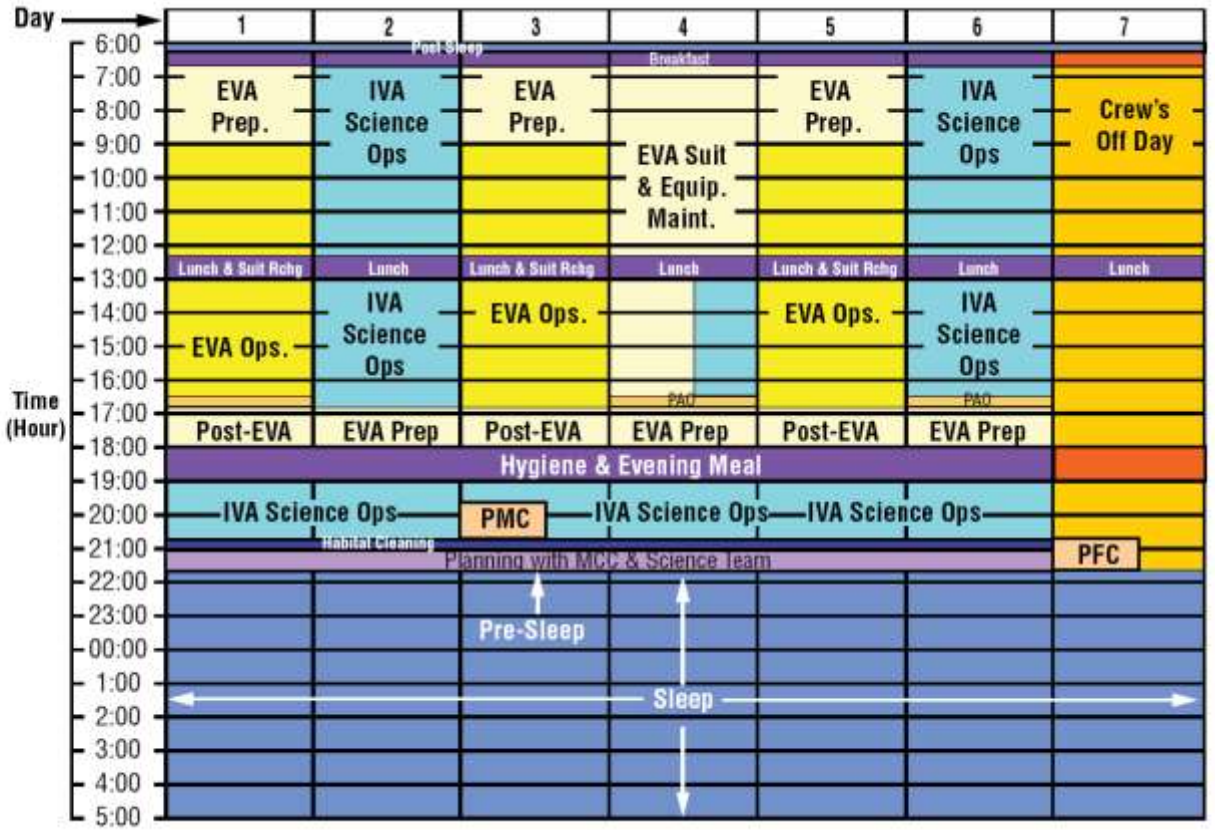
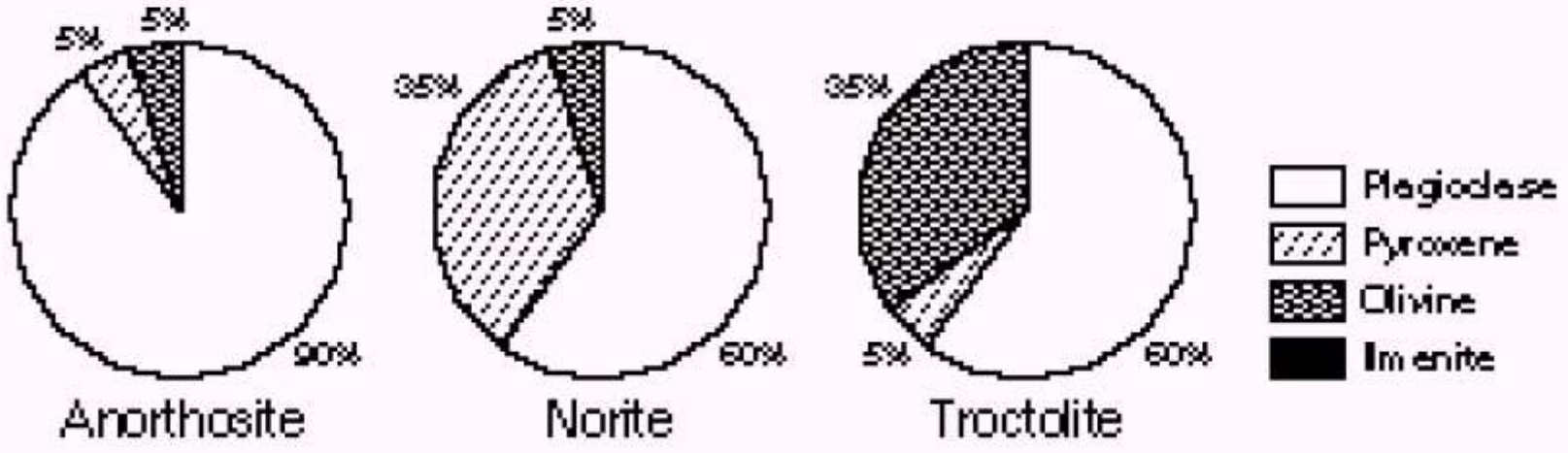


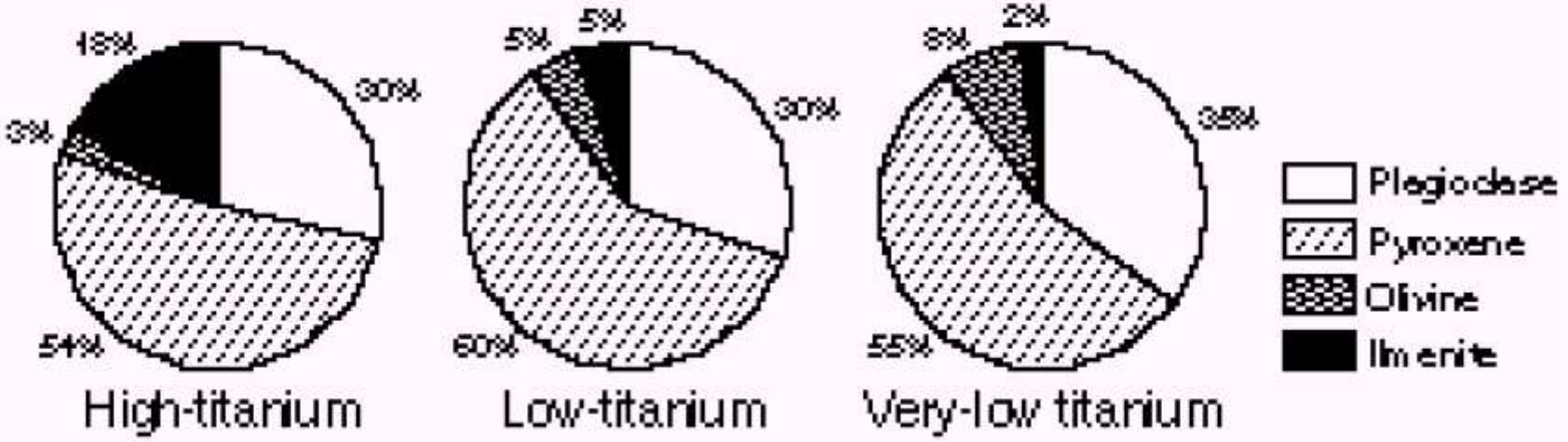
Figure 4-57. Notional Schedule for a Typical Week at a Lunar Outpost

Apollo 15 Imbrium Basin Impact Melt

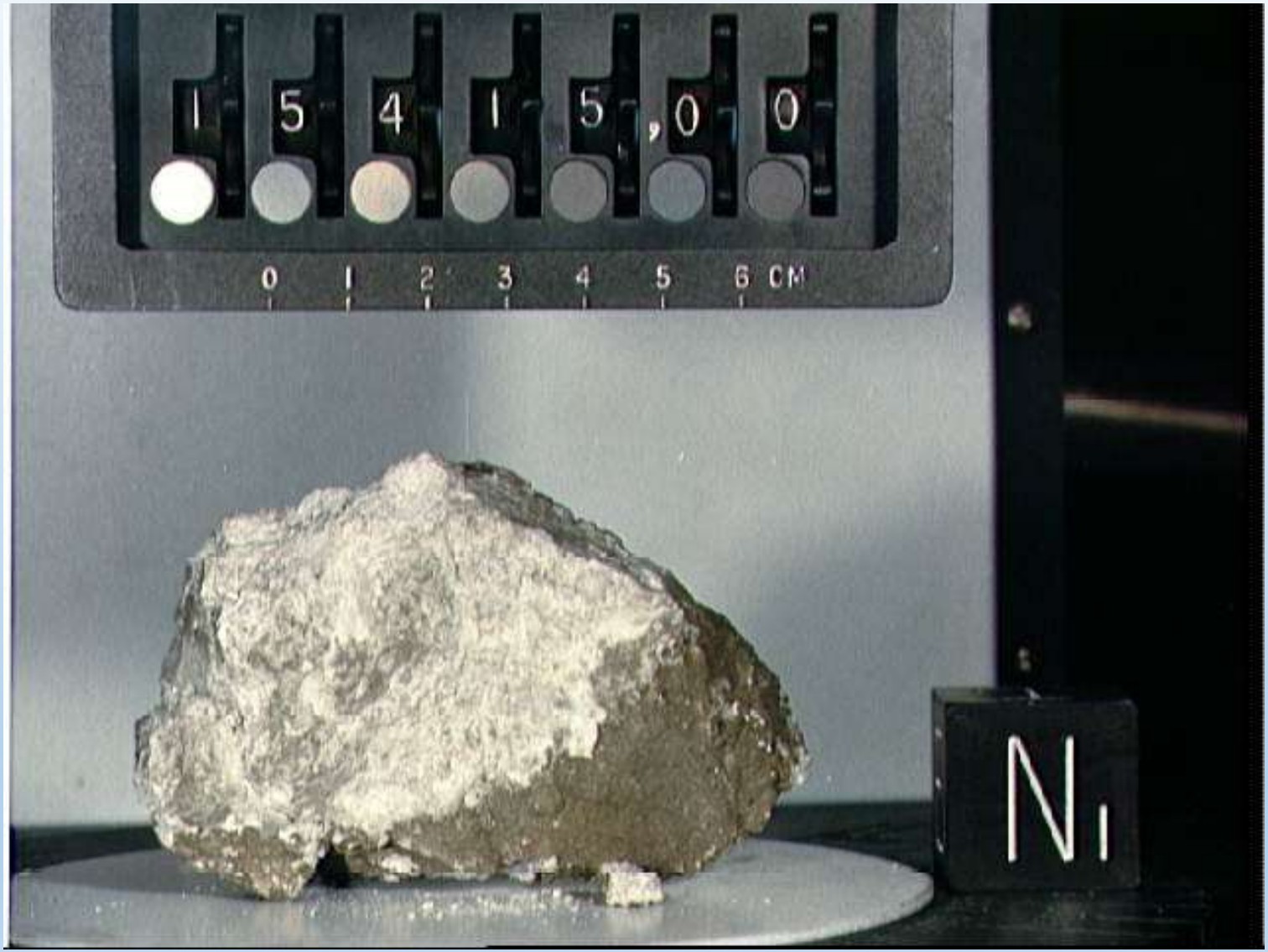
Mineral abundances in highland rocks



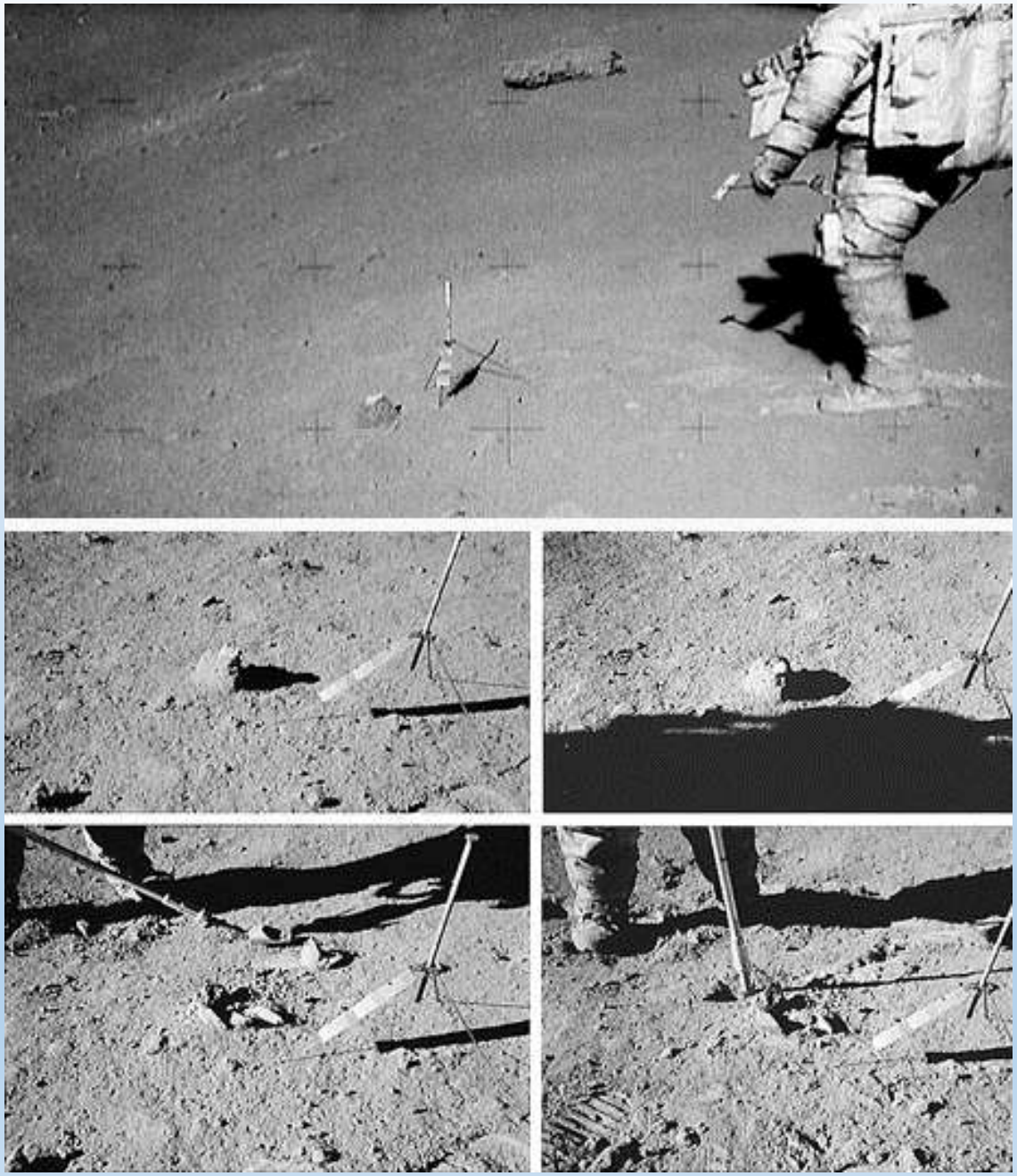
Mineral abundances in mare basalts



Apollo 15 “Genesis Rock”

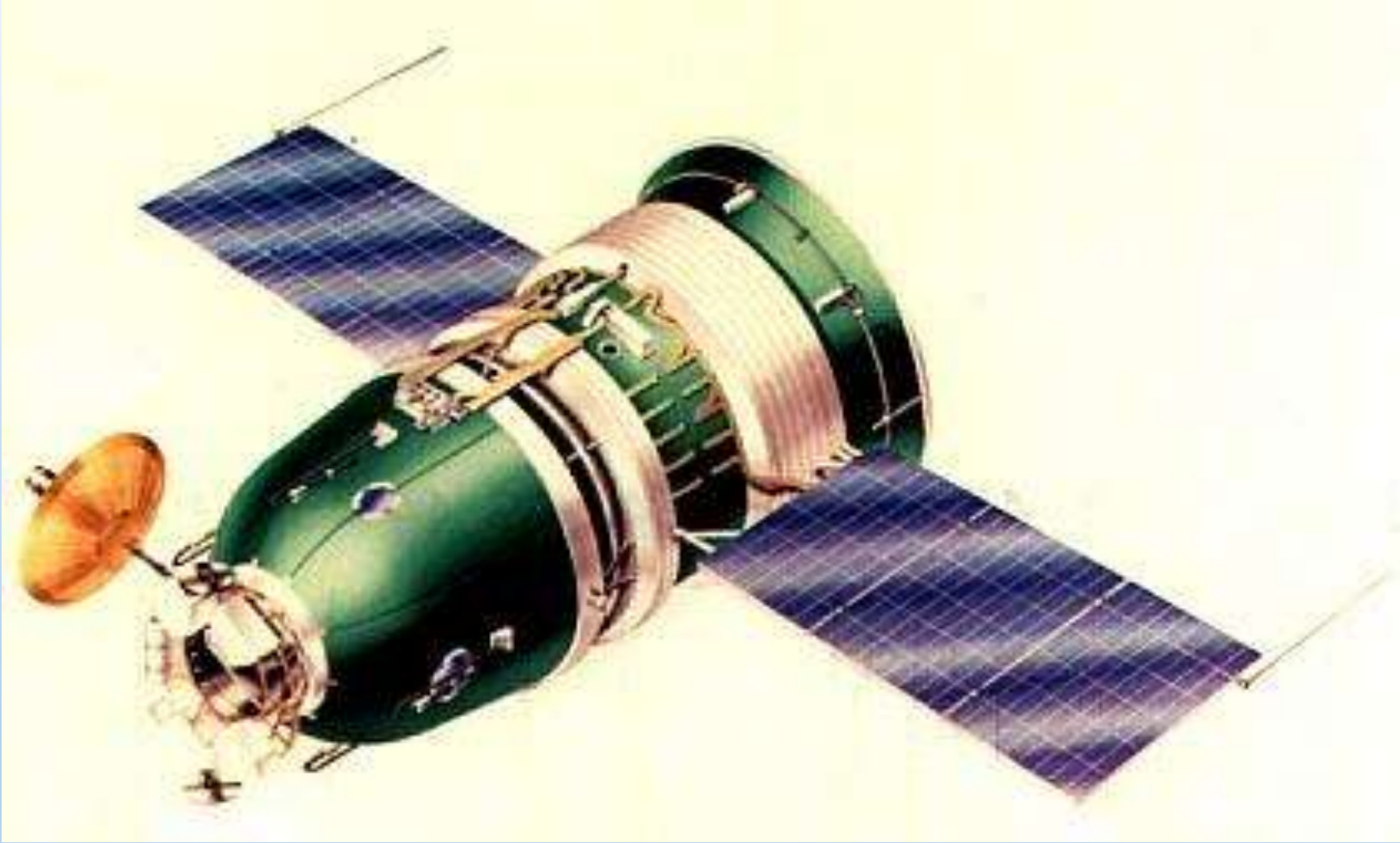


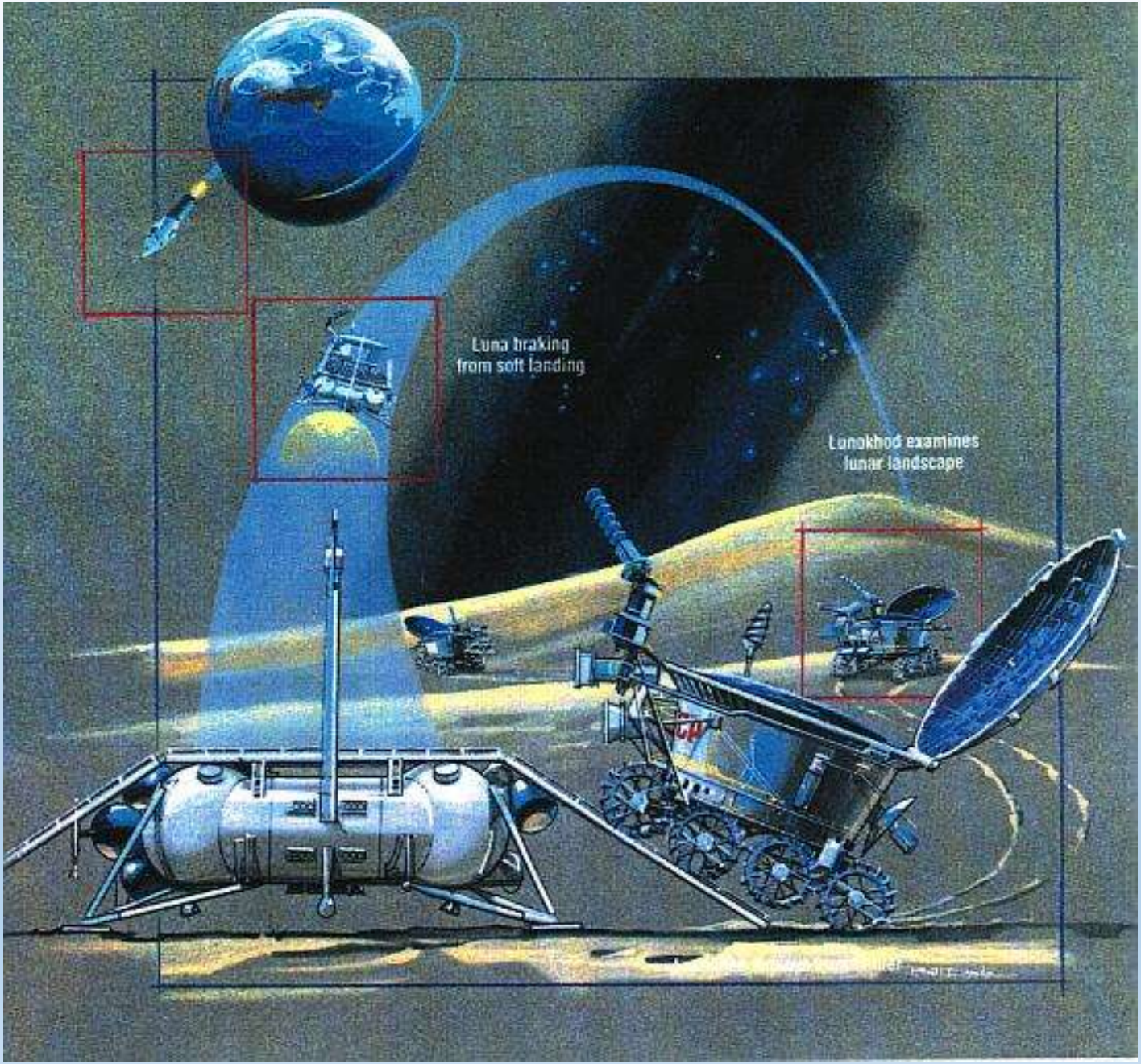
Apollo 15 Moon Rock Sampling

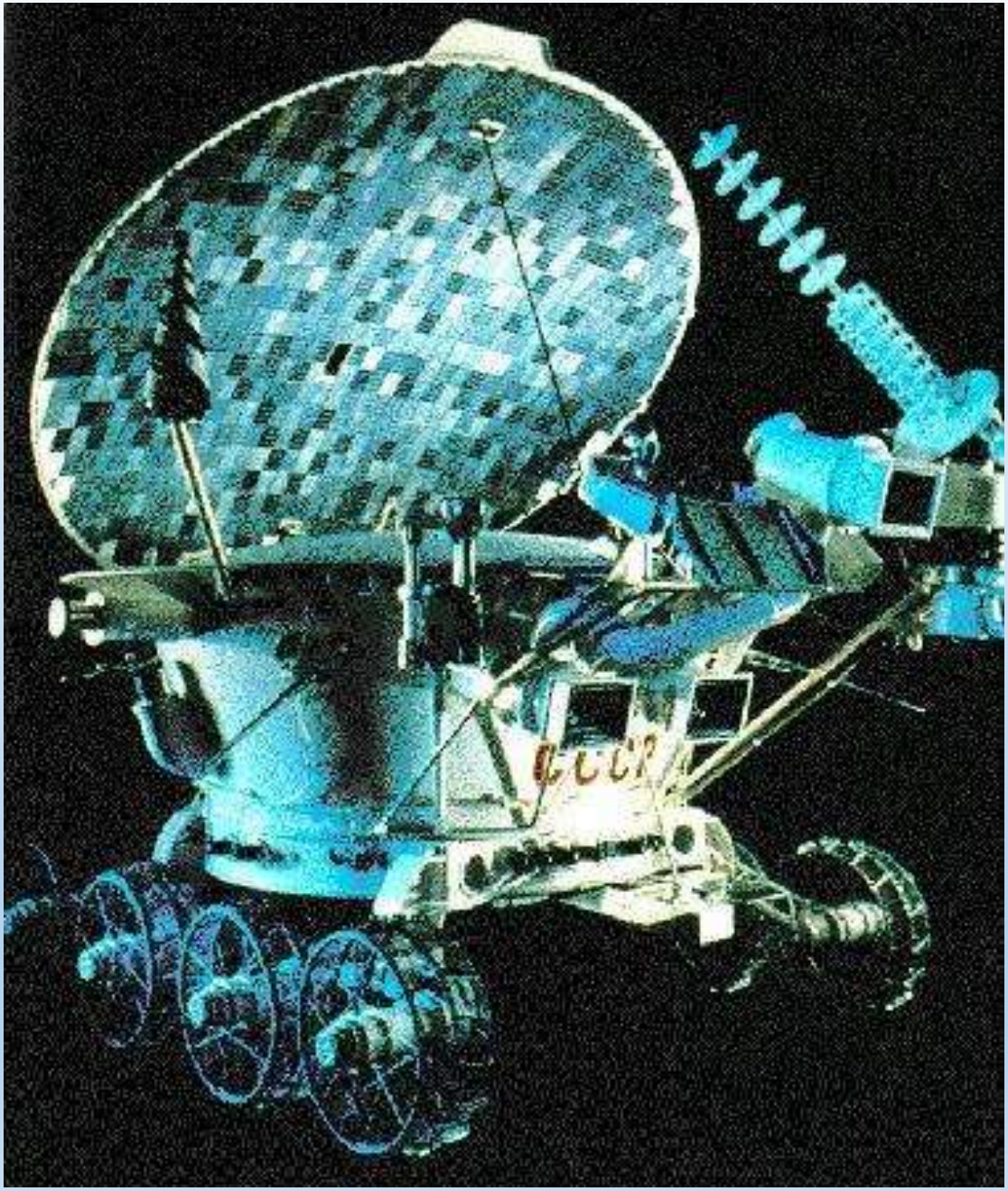


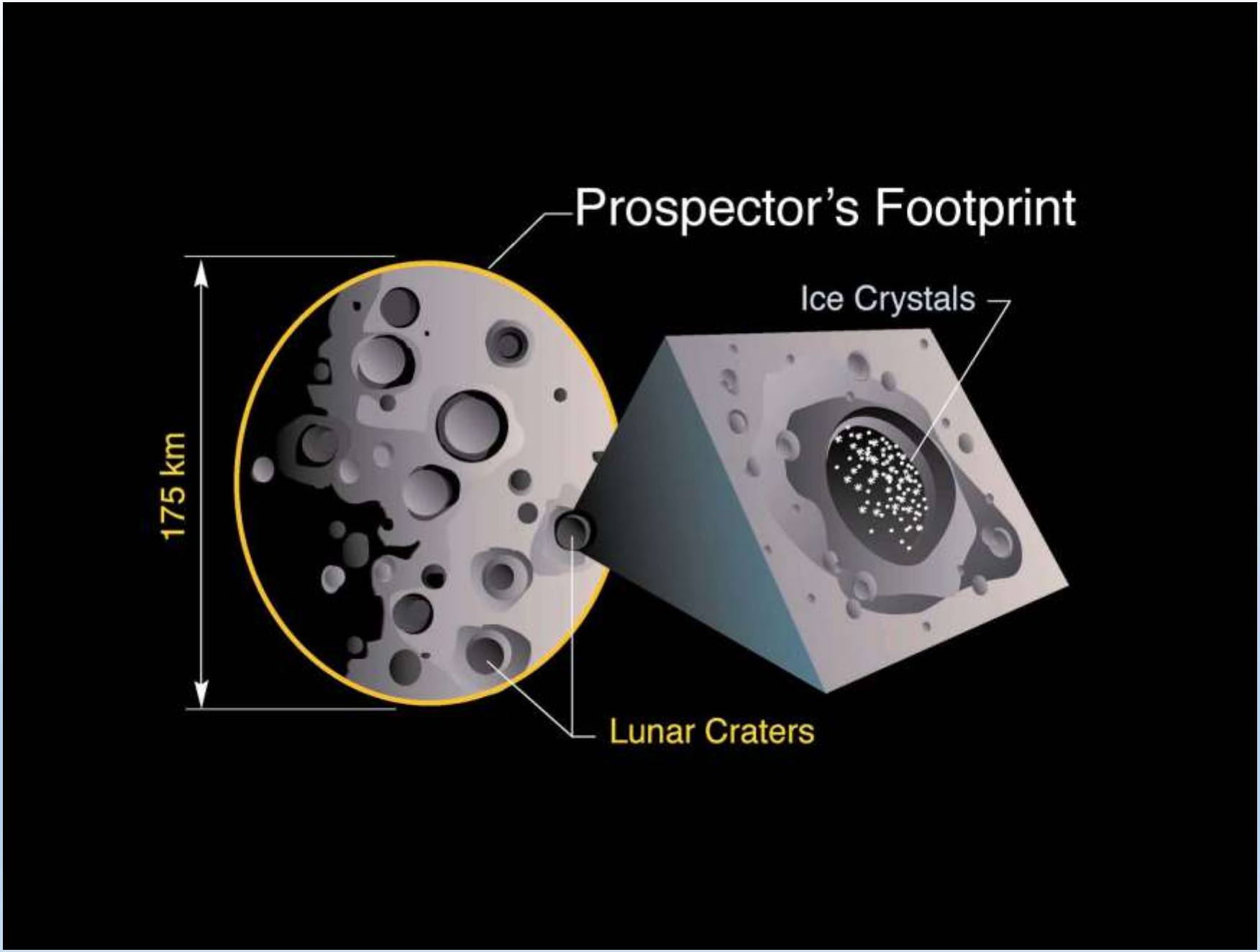
Apollo 16 Anorthosite

Apollo 17 Orange Glass in Soil

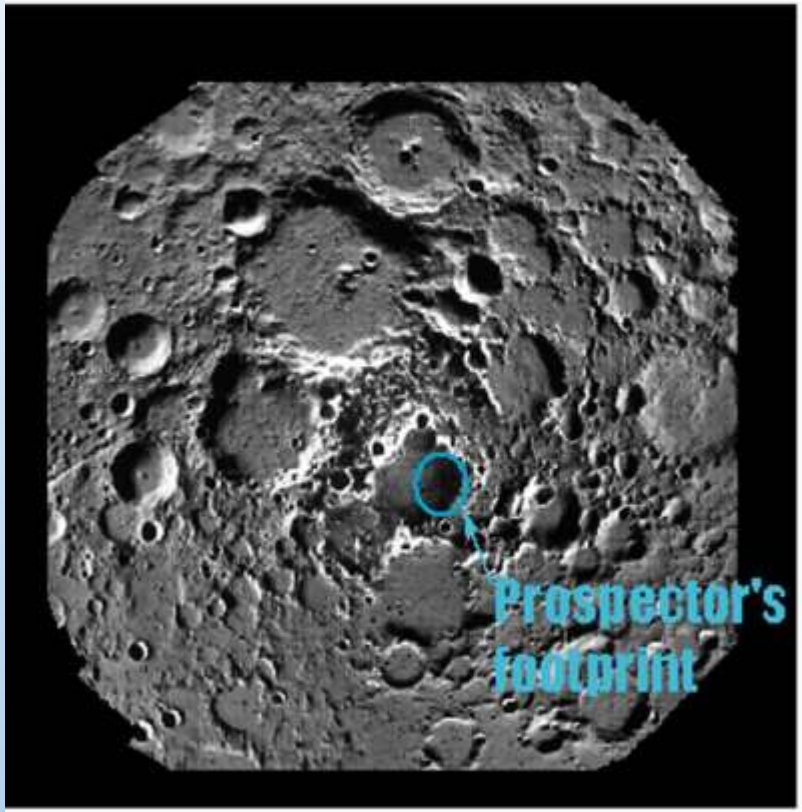


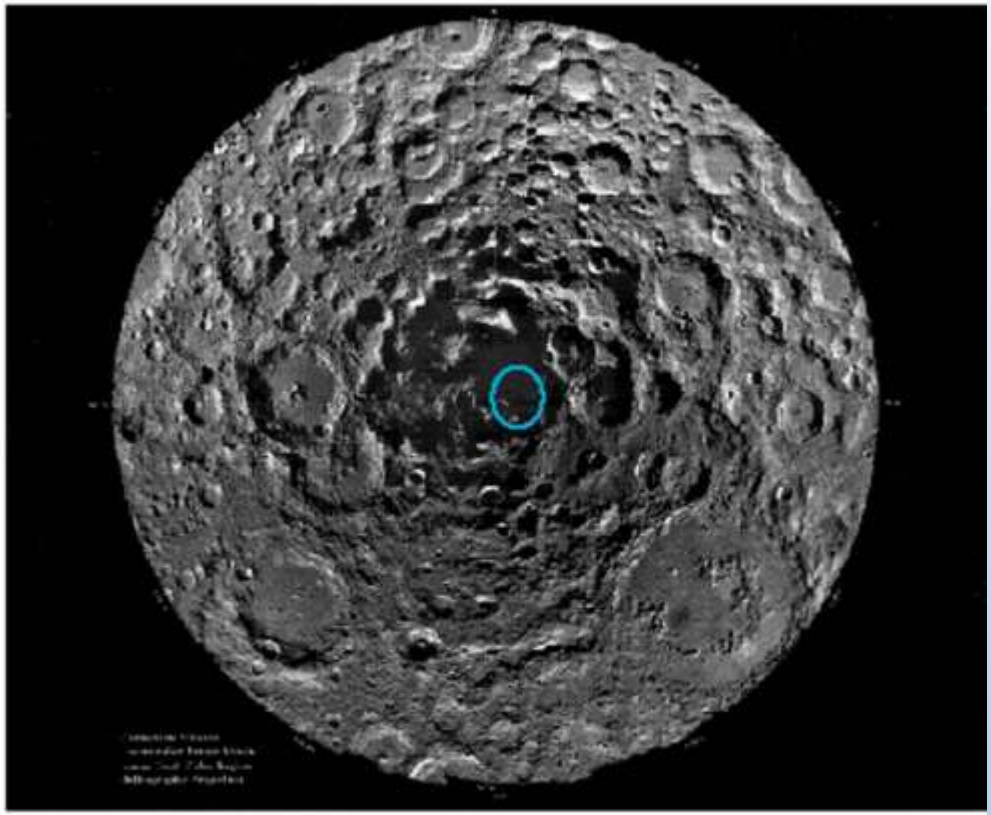

Luna braking
from soft landing
Lunokhod examines
lunar landscape


CCCP


Prospector's Footprint
Ice Crystals
175 km
Lunar Craters

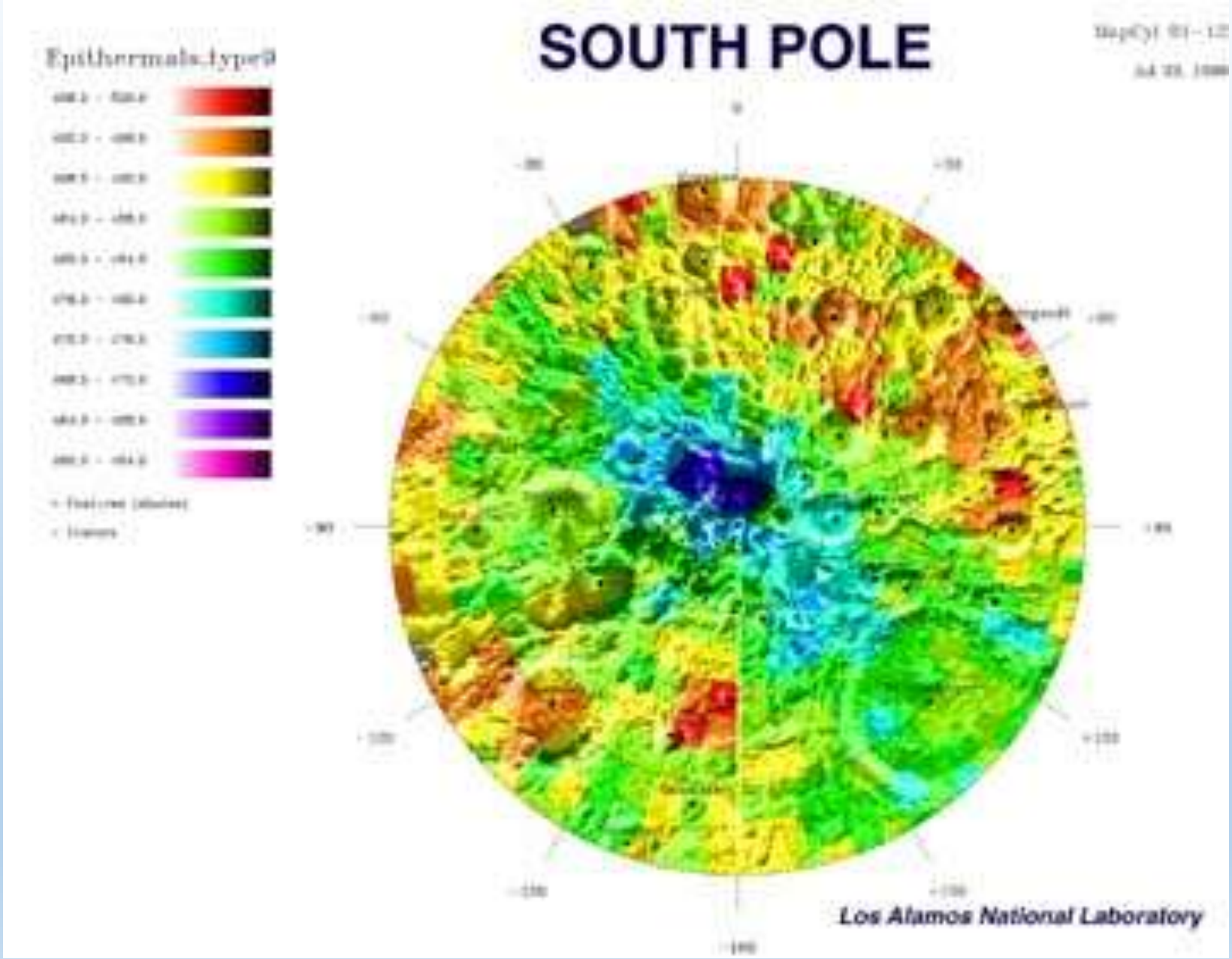
Mosaics of Lunar Poles

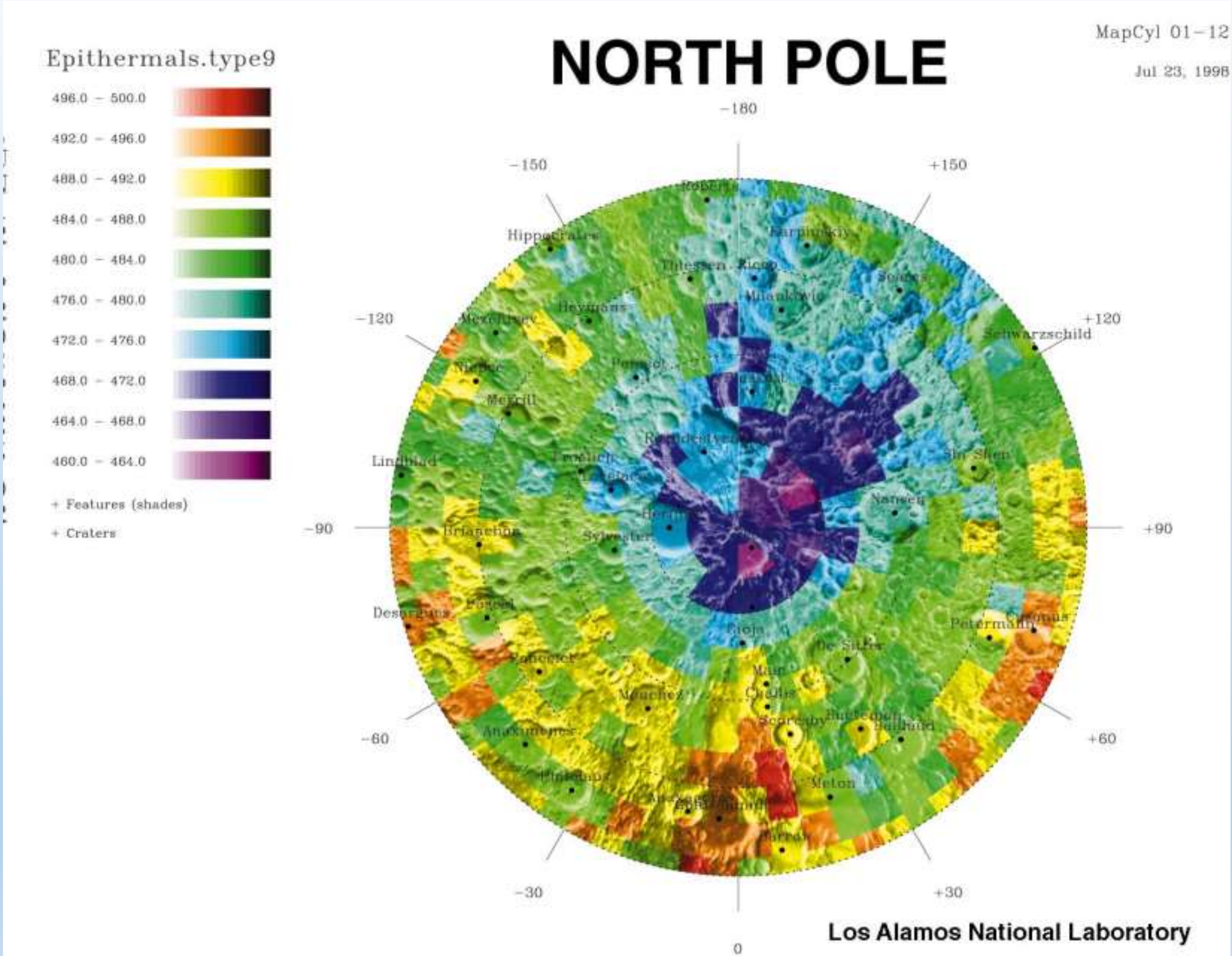




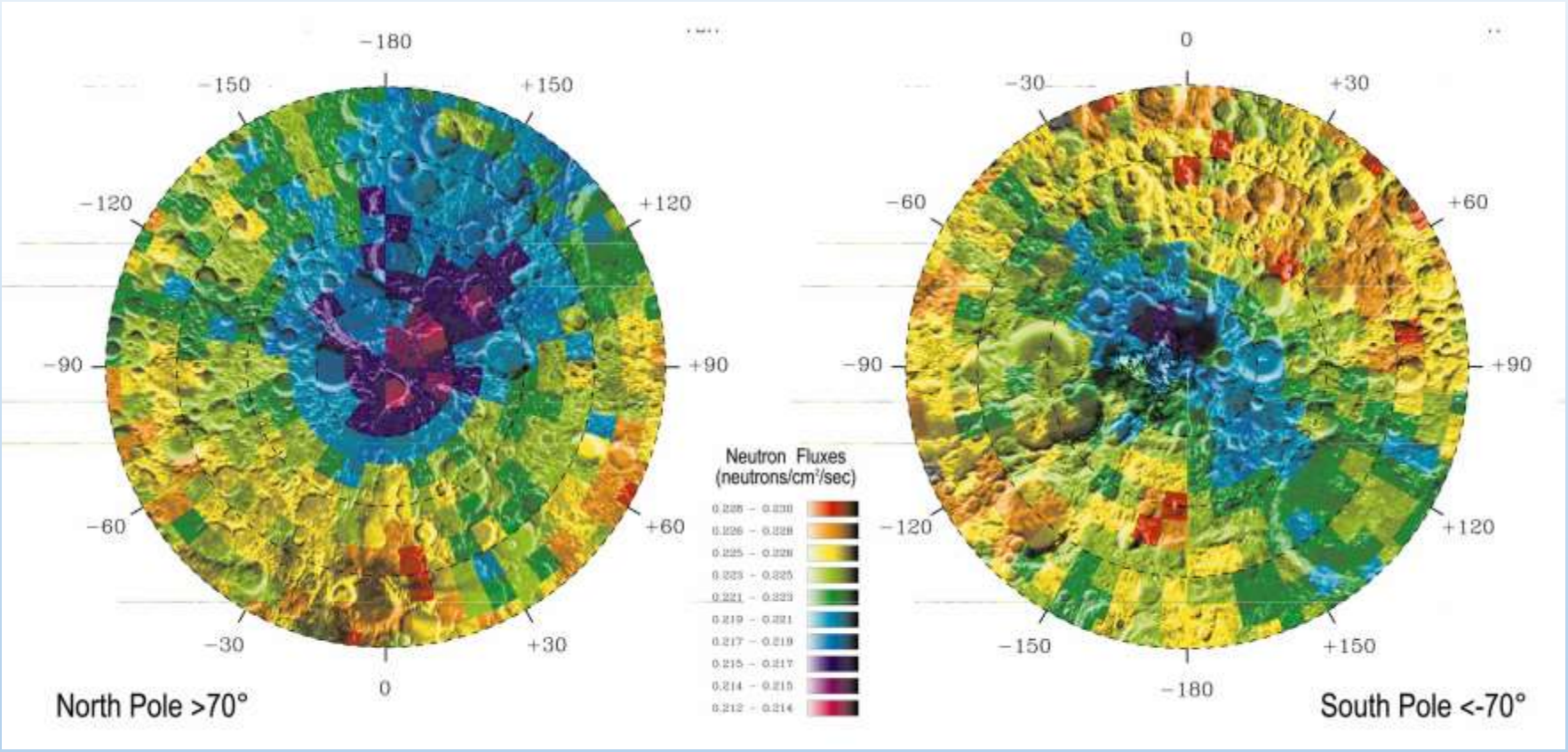
North Pole

South Pole


Epithermals.type9
SOUTH POLE
Los Alamos National Laboratory

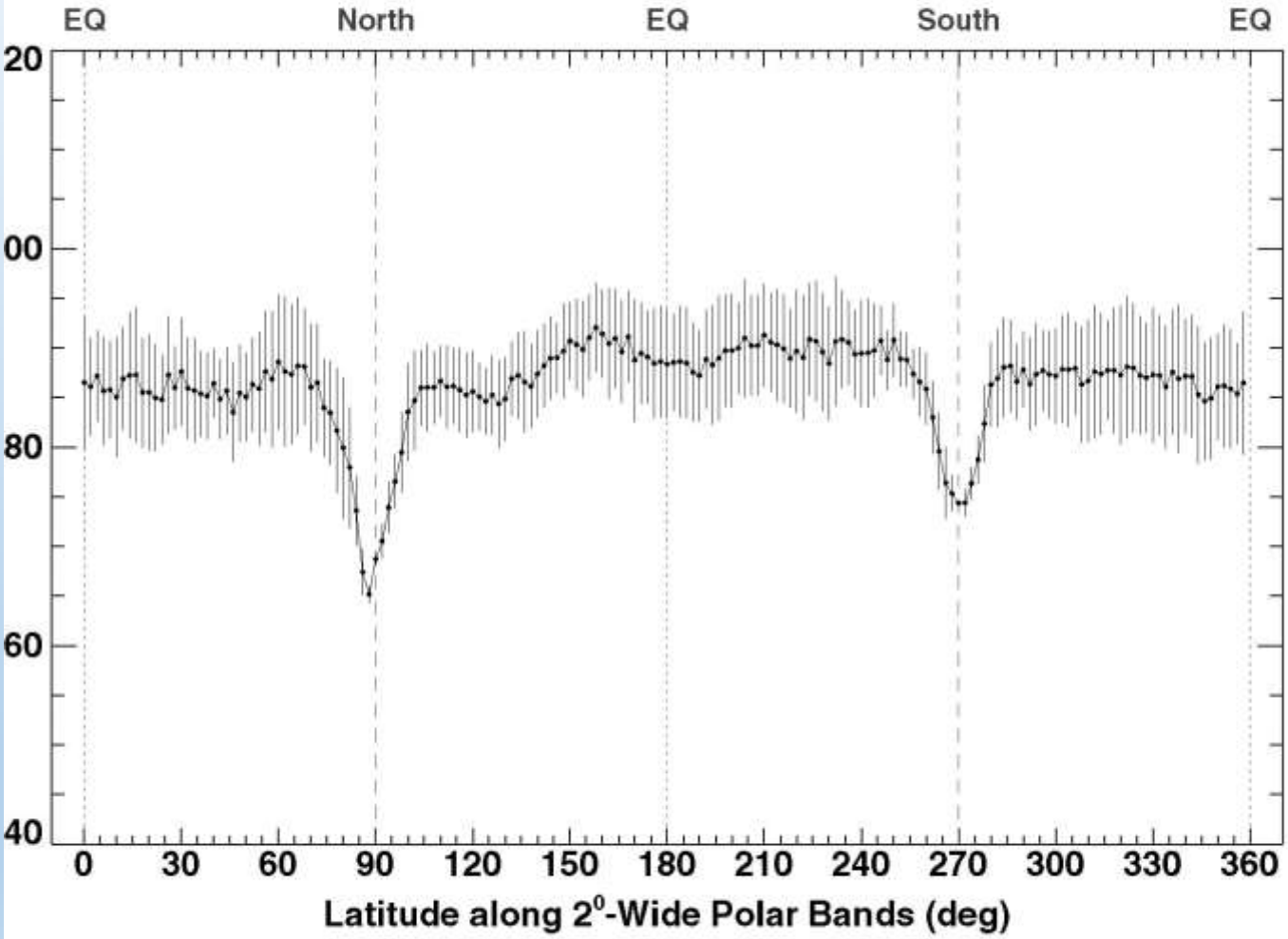


NORTH POLE
MapCyl 01−12
Jul 23, 1998
Epithermals.type9
496.0 − 500.0
492.0 − 496.0
488.0 − 492.0
484.0 − 488.0
480.0 − 484.0
476.0 − 480.0
472.0 − 476.0
468.0 − 472.0
464.0 − 468.0
460.0 − 464.0
+ Features (shades)
+ Craters
−180
−150
+150
−120
+120
−90
+90
−60
+60
−30
+30
0
Hippocrates
Heymans
Schwarzschild
Lindblad
Merrill
Nansen
Brianchon
Sylvester
Desargues
Pascal
Petermann
De Sitter
Anaximenes
Meton
Los Alamos National Laboratory


−180
−150
+150
−120
+120
−90
+90
−60
+60
−30
+30
0
North Pole >70°
Neutron Fluxes
(neutrons/cm²/sec)
0.228 – 0.230
0.226 – 0.228
0.225 – 0.226
0.223 – 0.225
0.221 – 0.223
0.219 – 0.221
0.217 – 0.219
0.215 – 0.217
0.214 – 0.215
0.212 – 0.214
0
−30
+30
−60
+60
−90
+90
−120
+120
−150
+150
−180
South Pole <-70°

Evidence of Polar Water Ice

Lunar Prospector

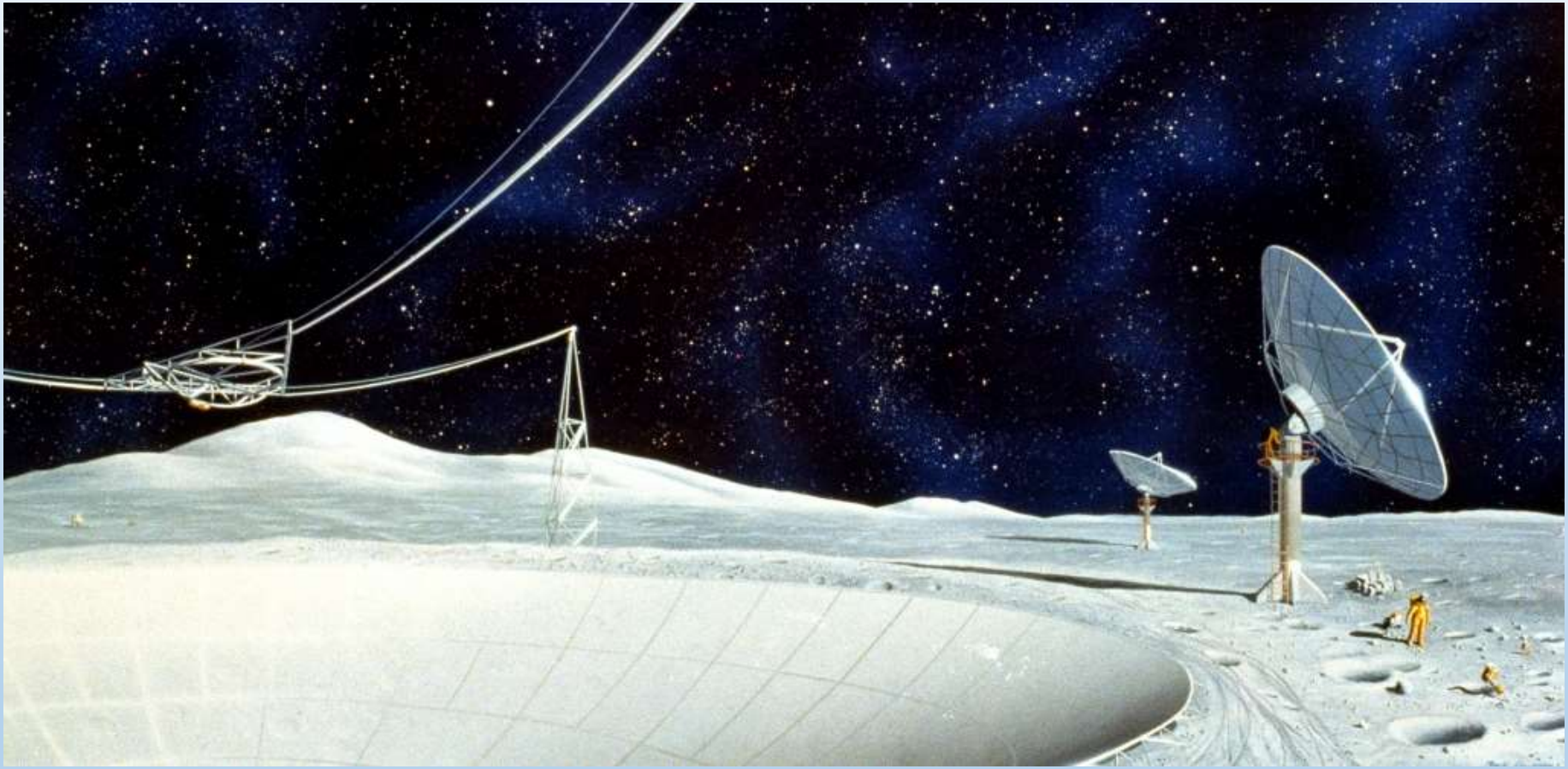


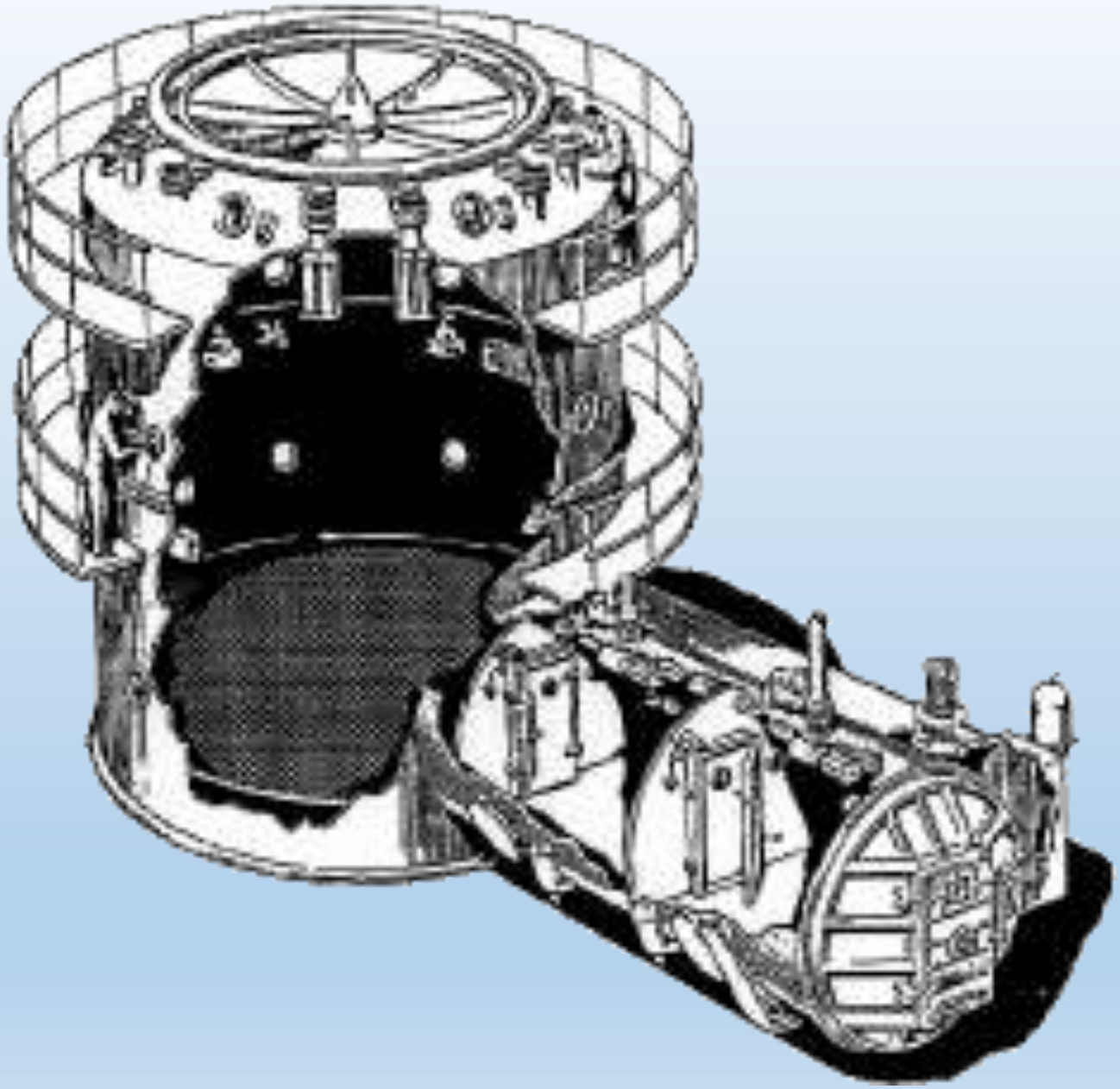
Los Alamos National Laboratory


Pat Rawlings


USA
NASA


TRANQUILITY SHORES
INDUSTRIAL PARK
LUNOX CORP.
EDC
He3 LTD.
LUNACOMM INC.
LUNOX

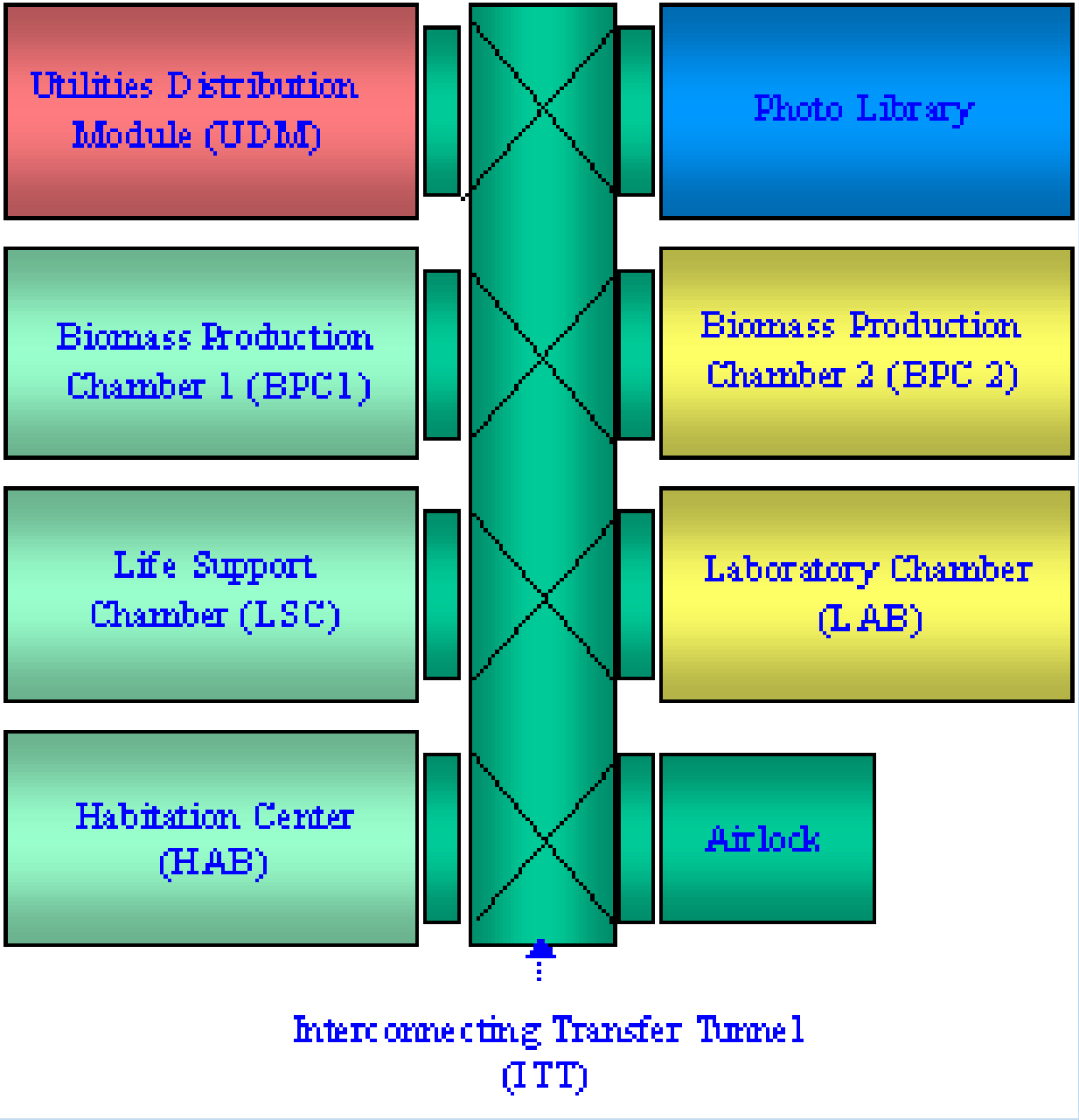




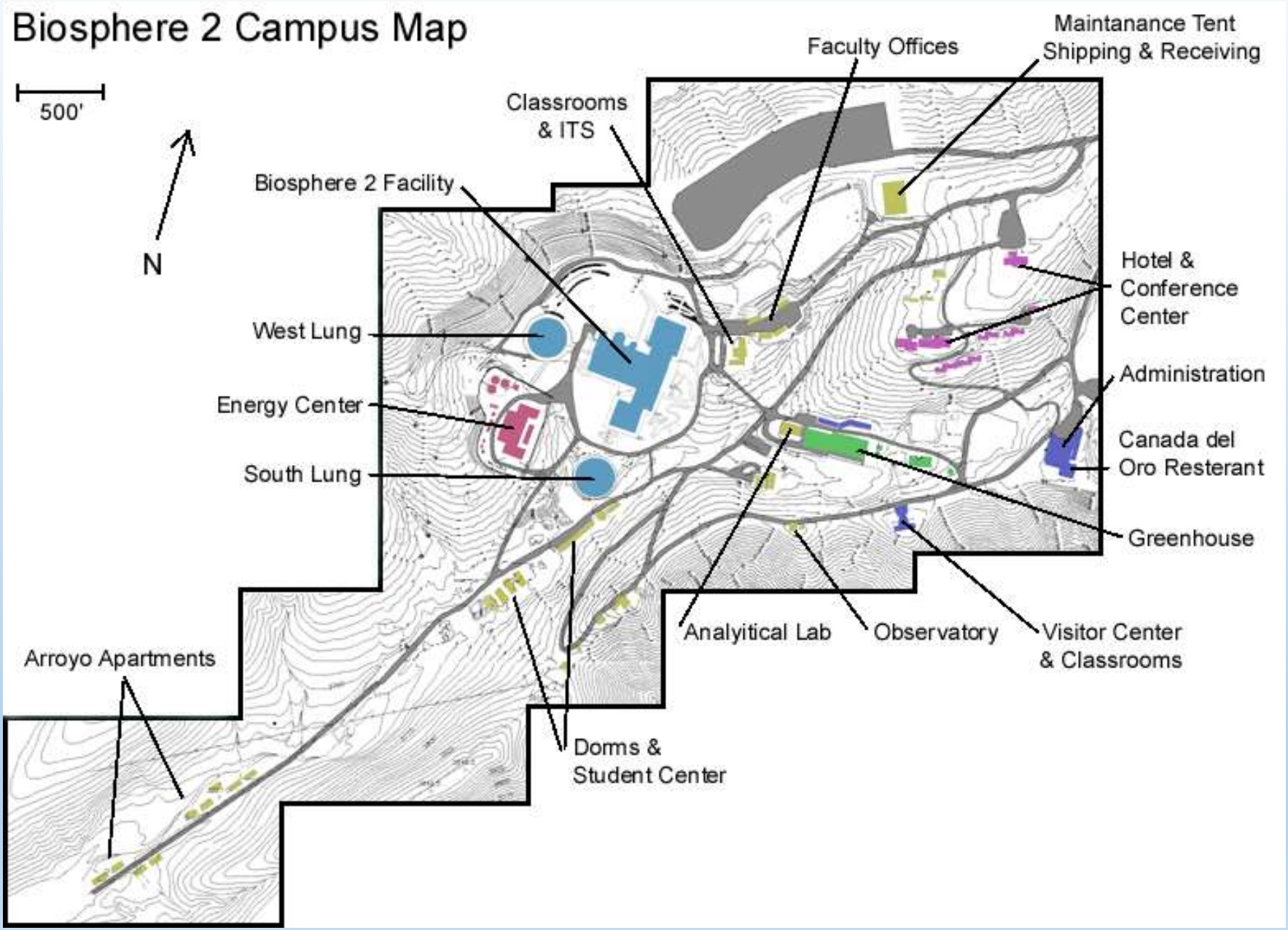

ROCKETS

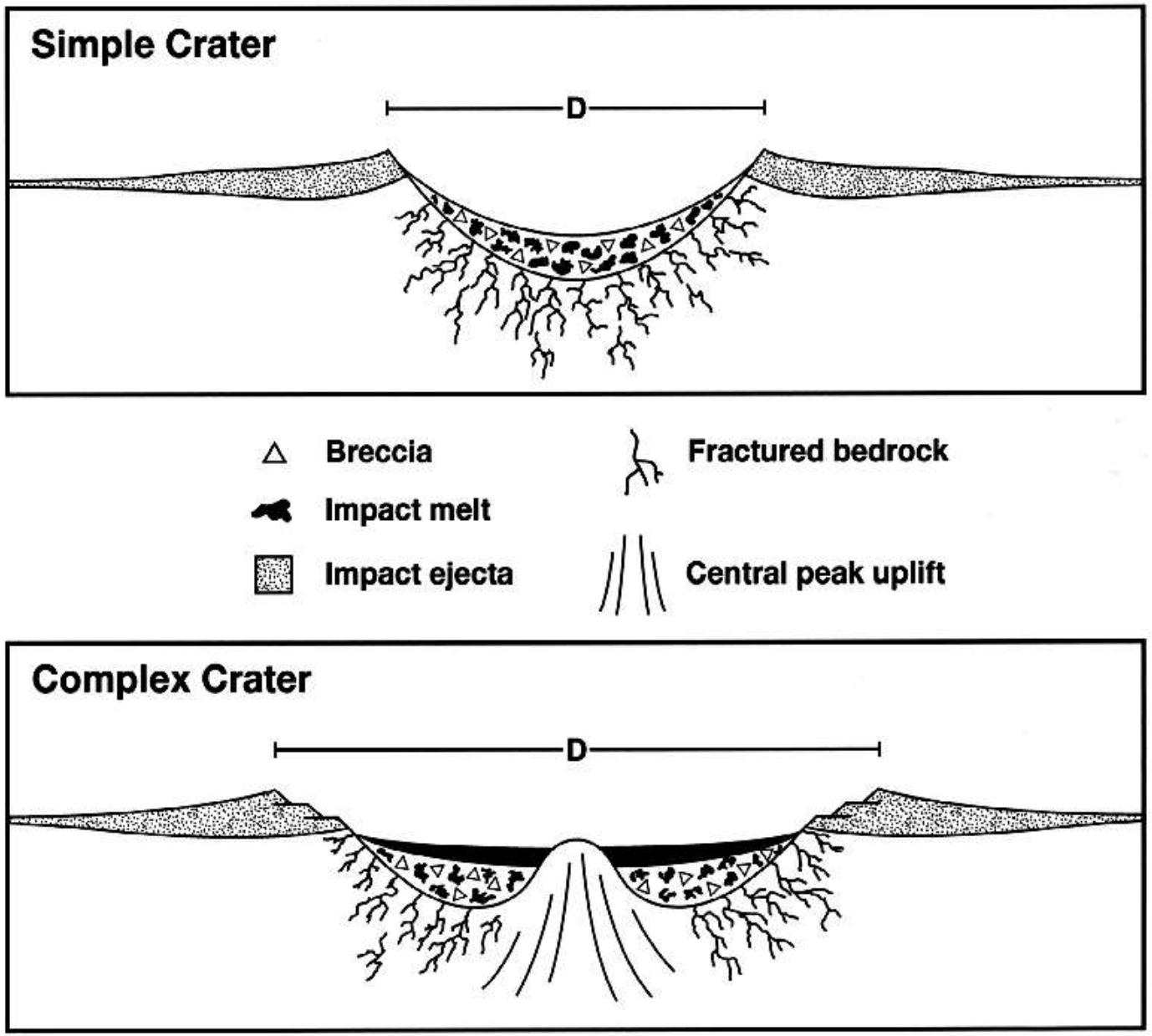

Quantum Devices Inc.

20 Foot Chamber
1st Level Layout

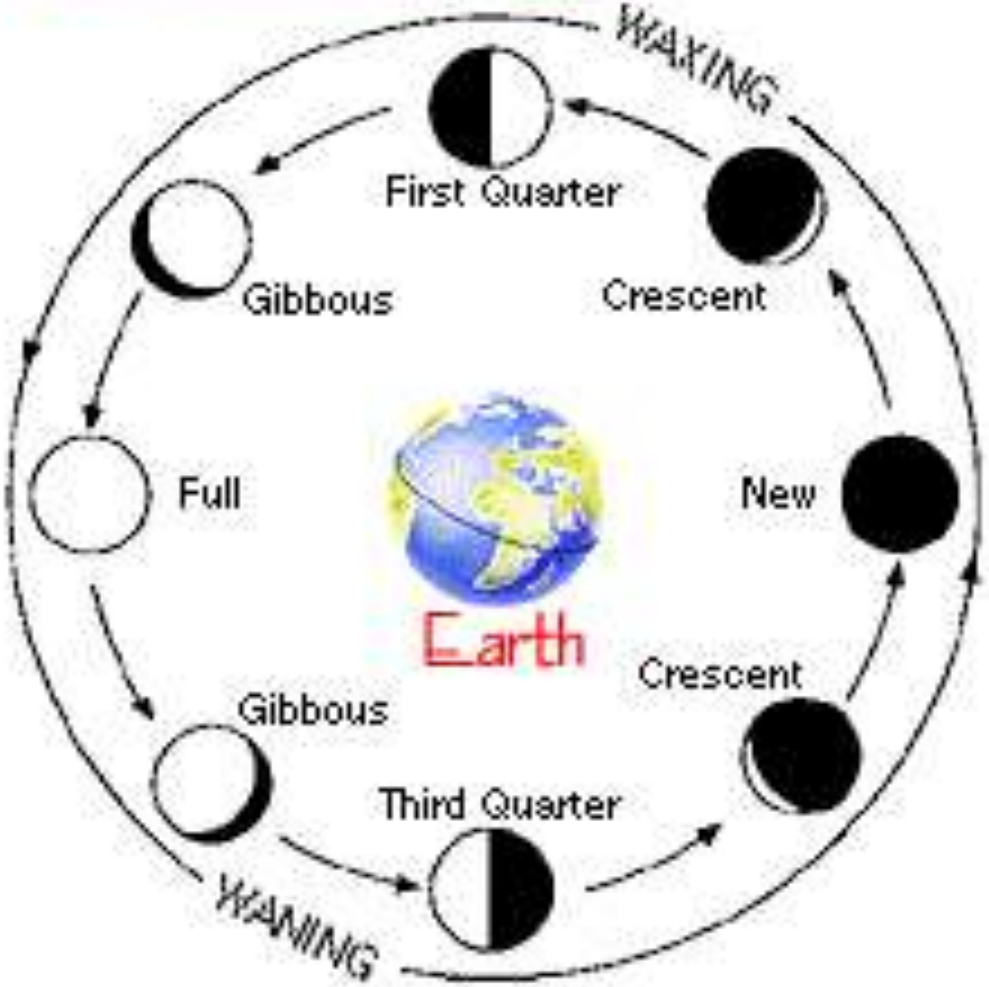

Utilities Distribution Module (UDM)
Photo Library
Biomass Production Chamber 1 (BPC1)
Biomass Production Chamber 2 (BPC 2)
Life Support Chamber (LSC)
Laboratory Chamber (LAB)
Habitation Center (HAB)
Airlock
Interconnecting Transfer Tunnel (ITT)

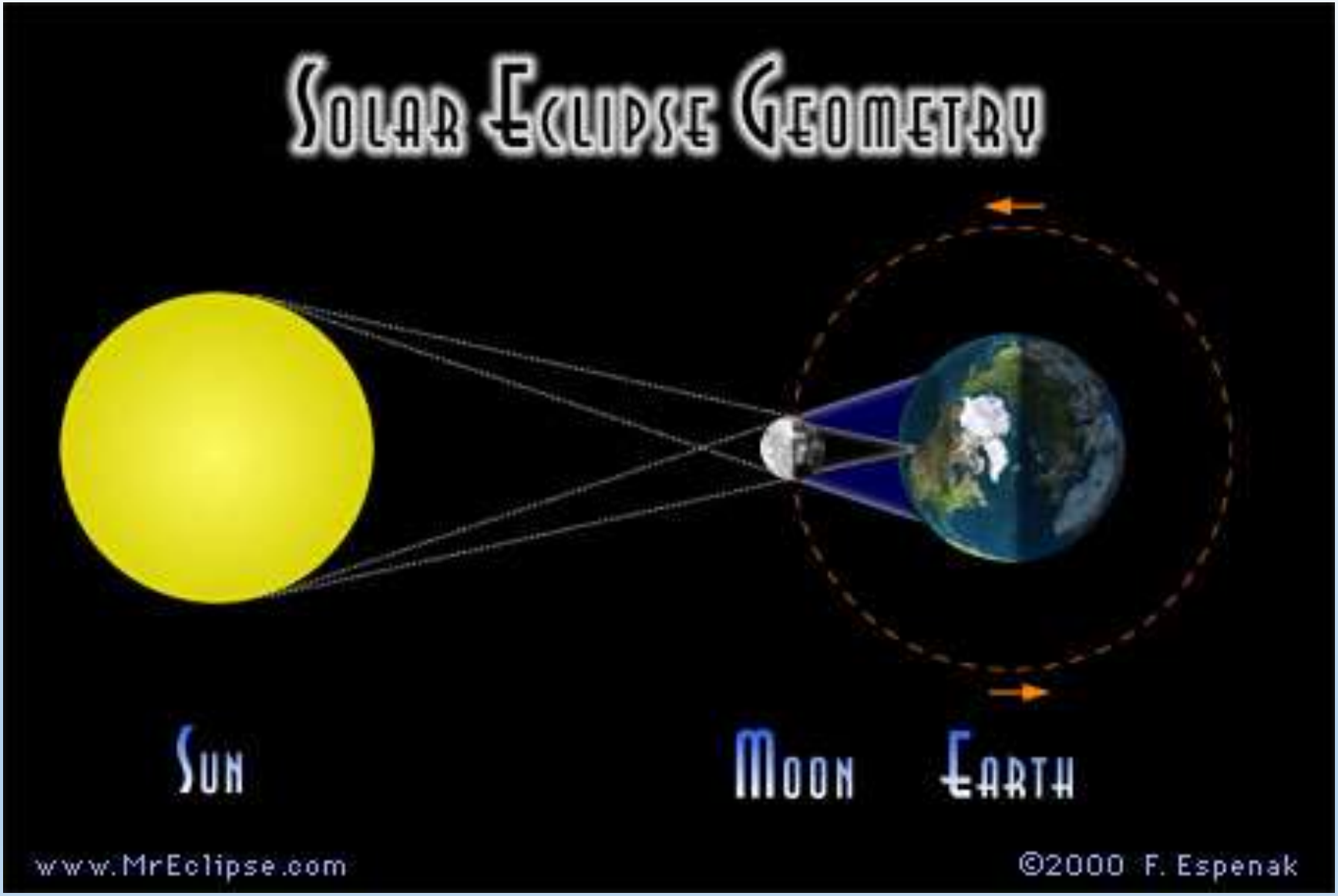

Agro-Forestry
Human Habitat
Savanna
Rainforest
Desert
Marsh
Ocean

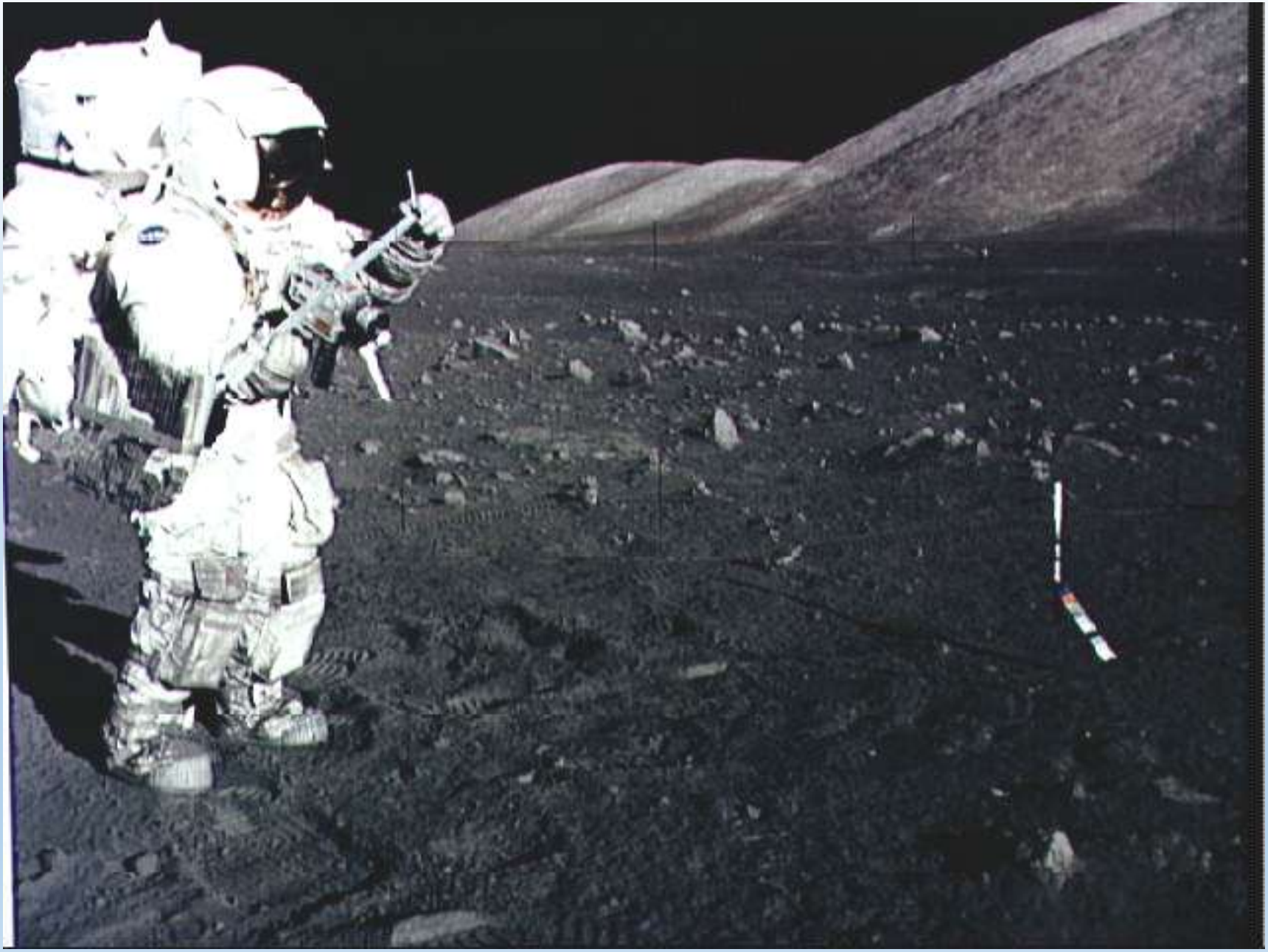

Biosphere 2 Campus Map
500'
N
Maintanance Tent
Shipping & Receiving
Faculty Offices
Classrooms
& ITS
Biosphere 2 Facility
Hotel &
Conference
Center
West Lung
Administration
Energy Center
Canada del
Oro Resterant
South Lung
Greenhouse
Analyitical Lab
Observatory
Visitor Center
& Classrooms
Arroyo Apartments
Dorms &
Student Center

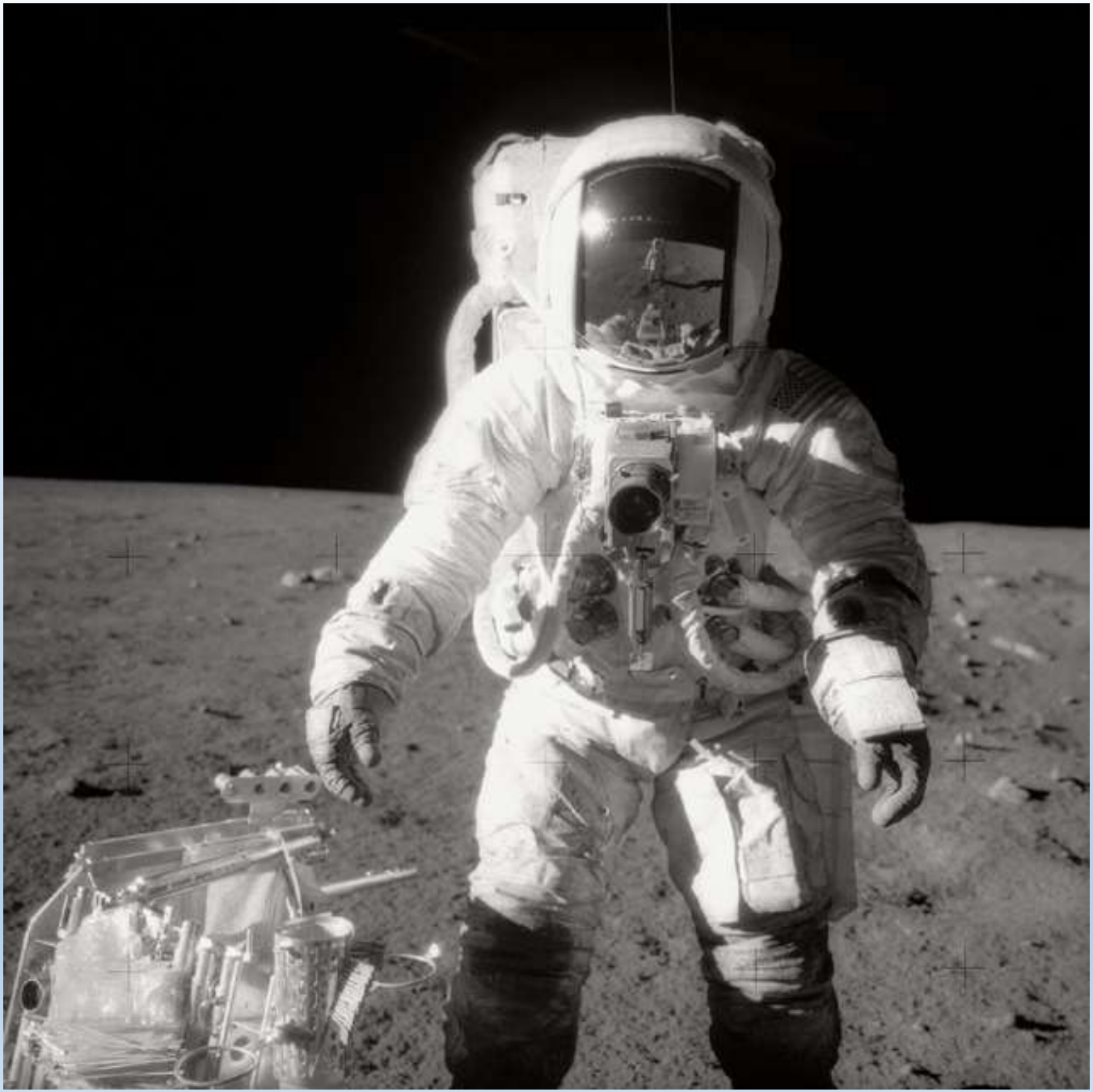

Simple Crater
D
Breccia
Impact melt
Impact ejecta
Fractured bedrock
Central peak uplift
Complex Crater
D

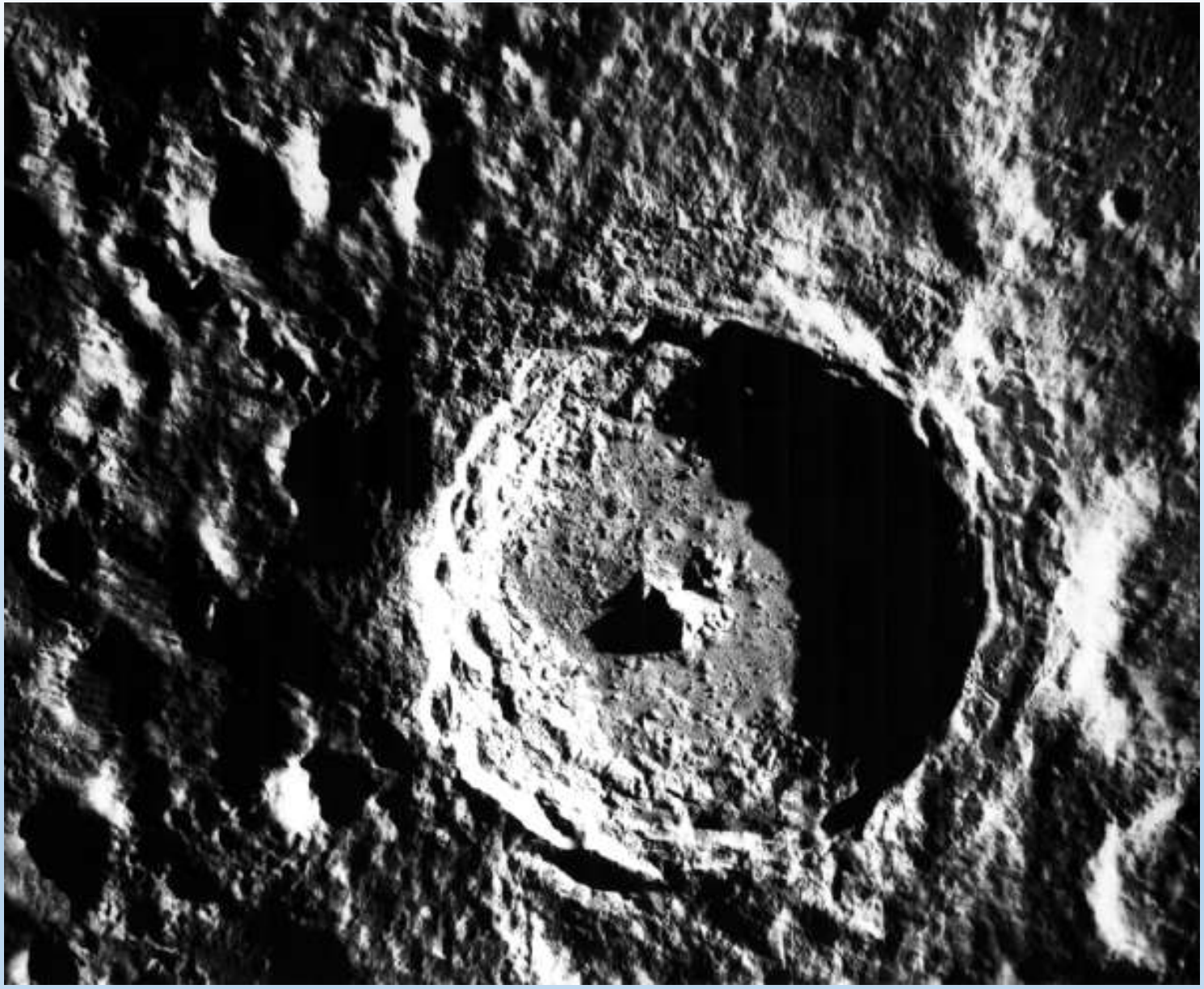
The Moon as seen from Earth

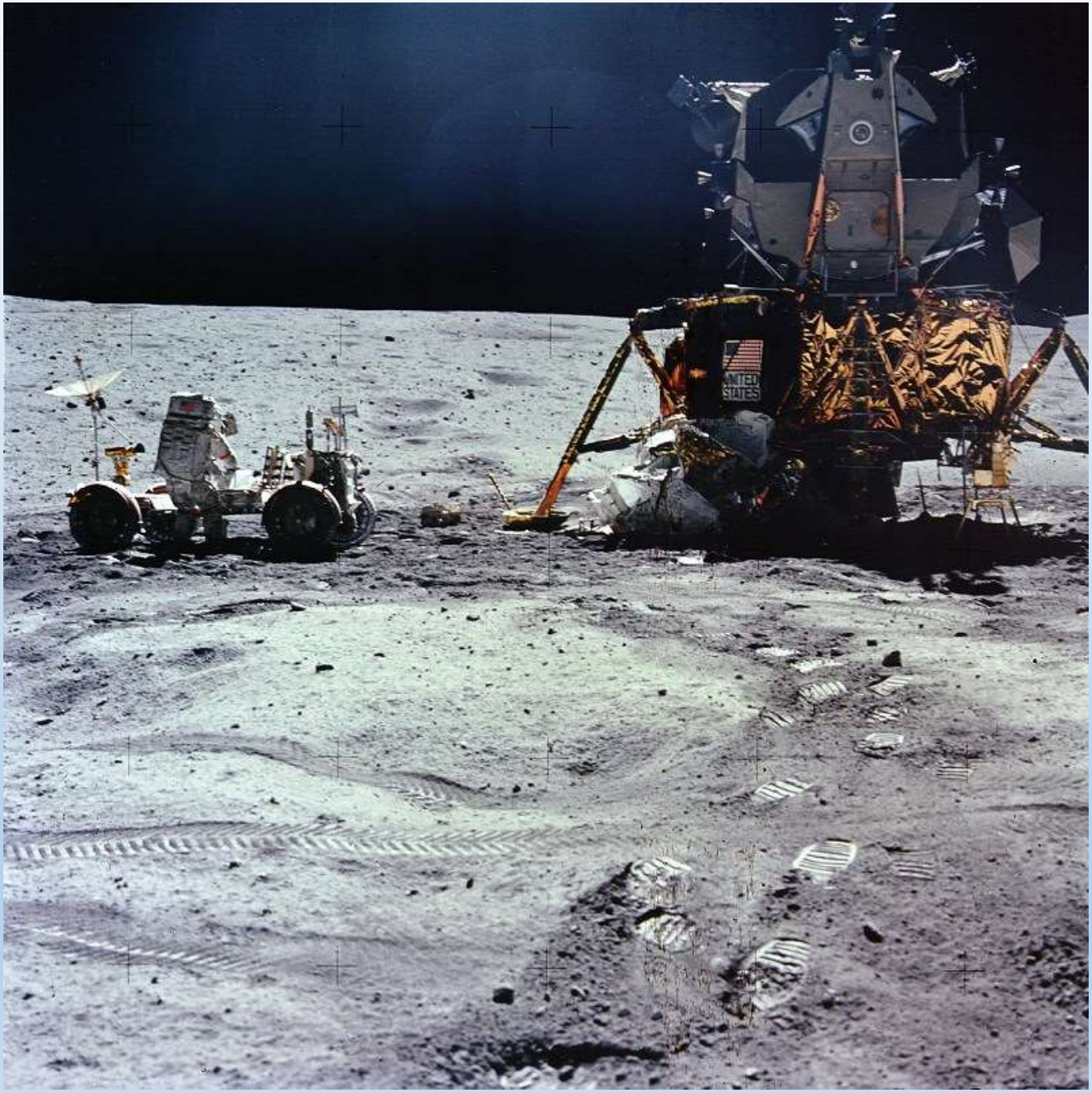


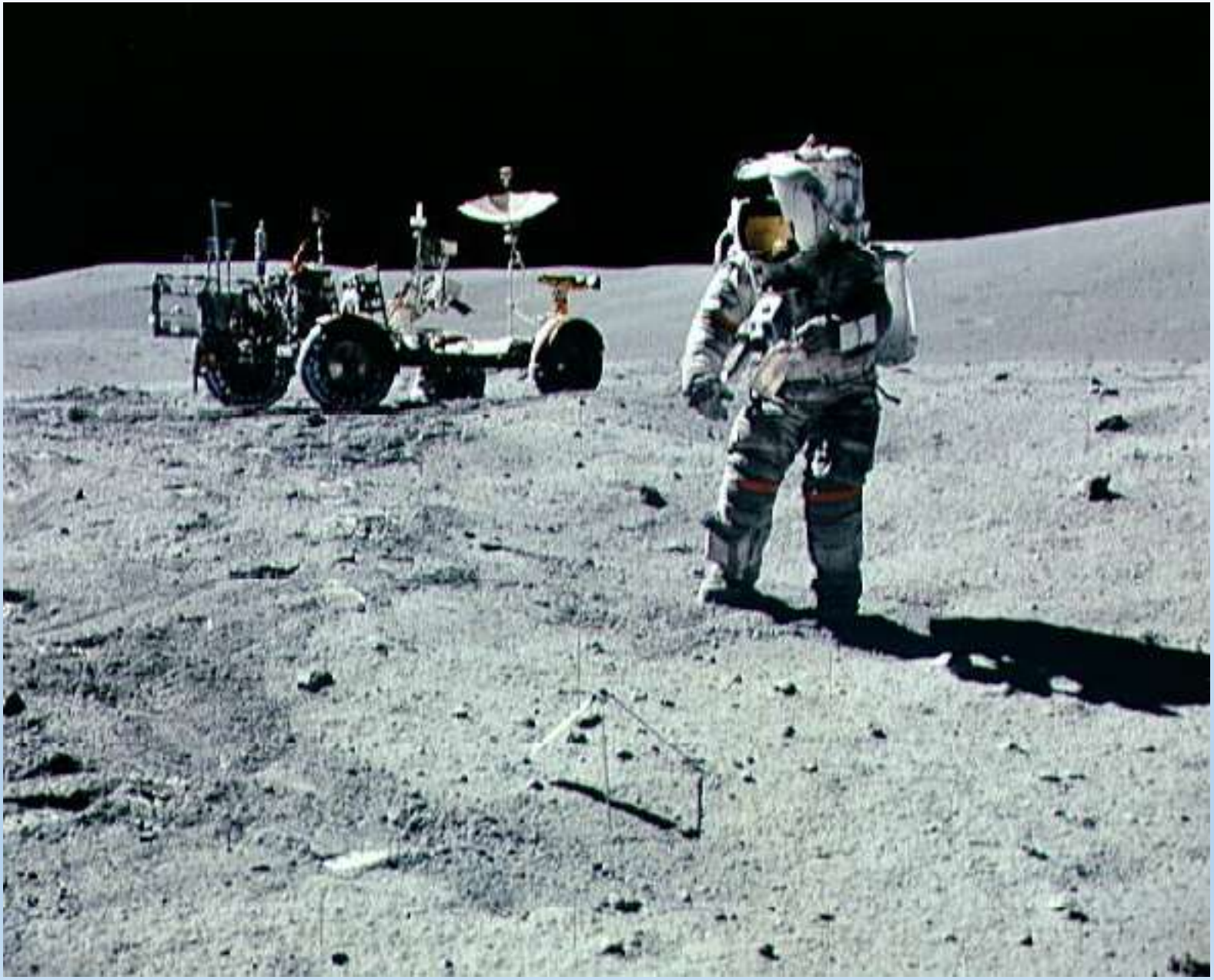

Solar Eclipse Geometry
Sun
Moon
Earth
www.MrEclipse.com
©2000 F. Espenak

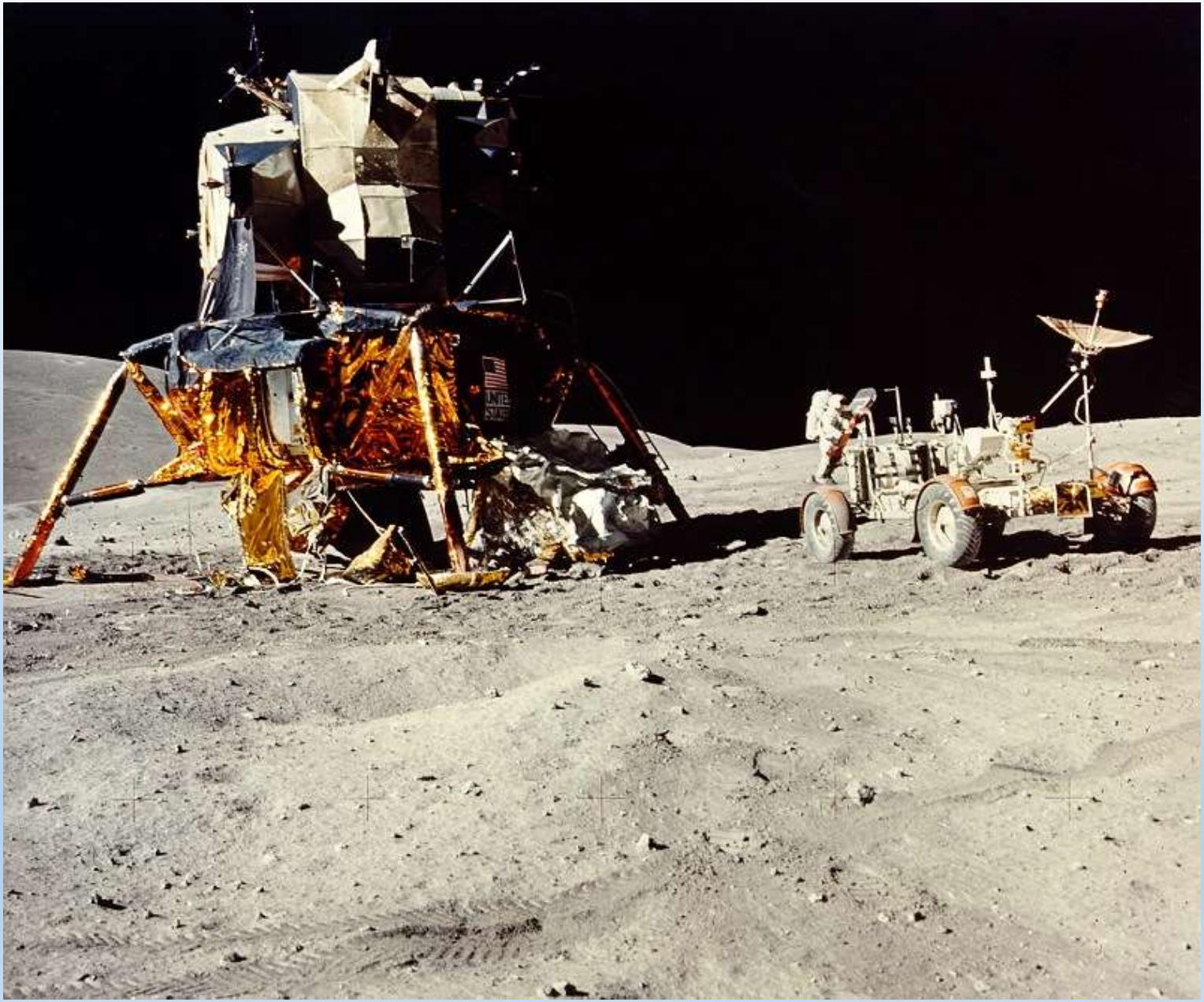


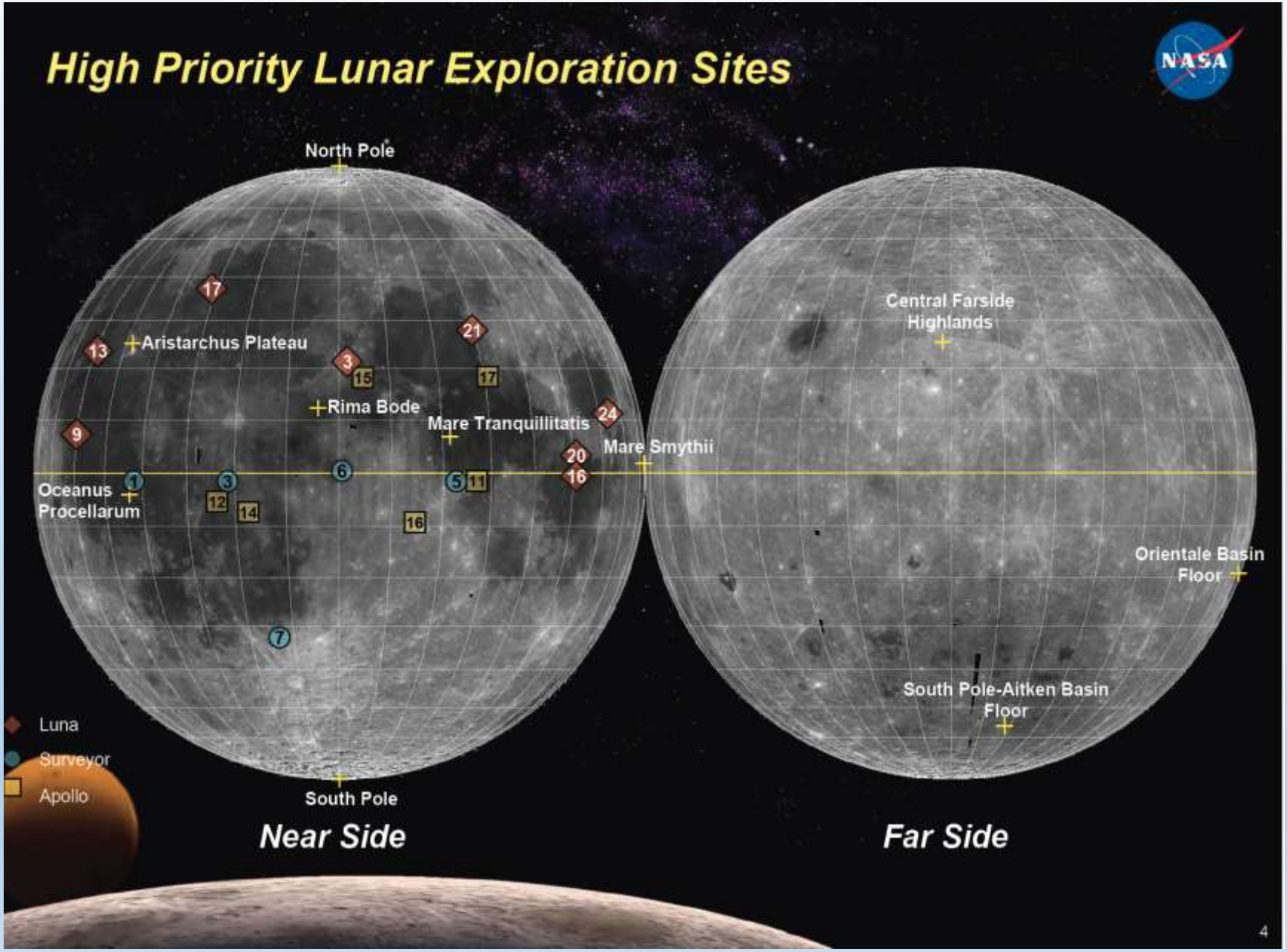


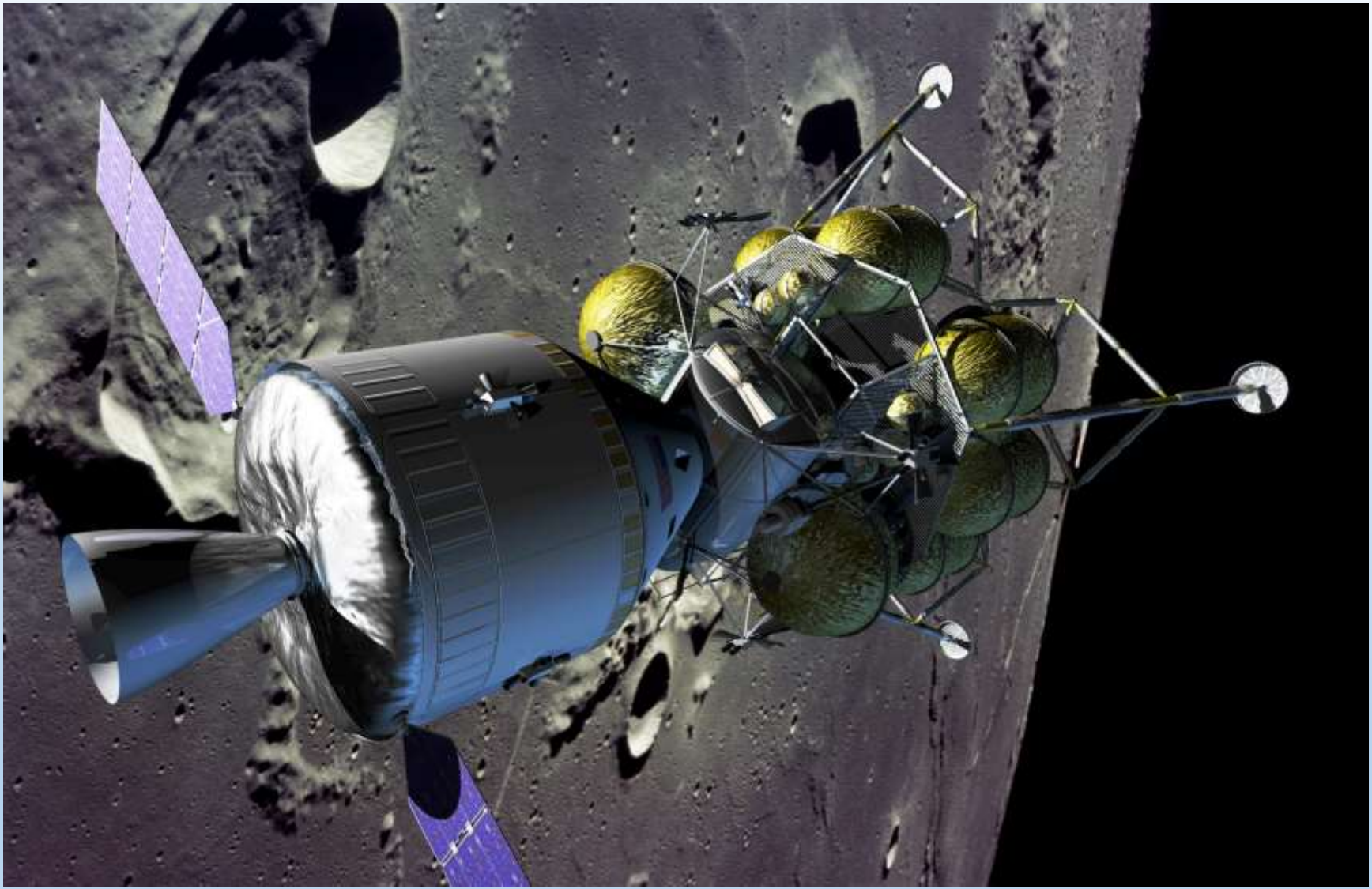


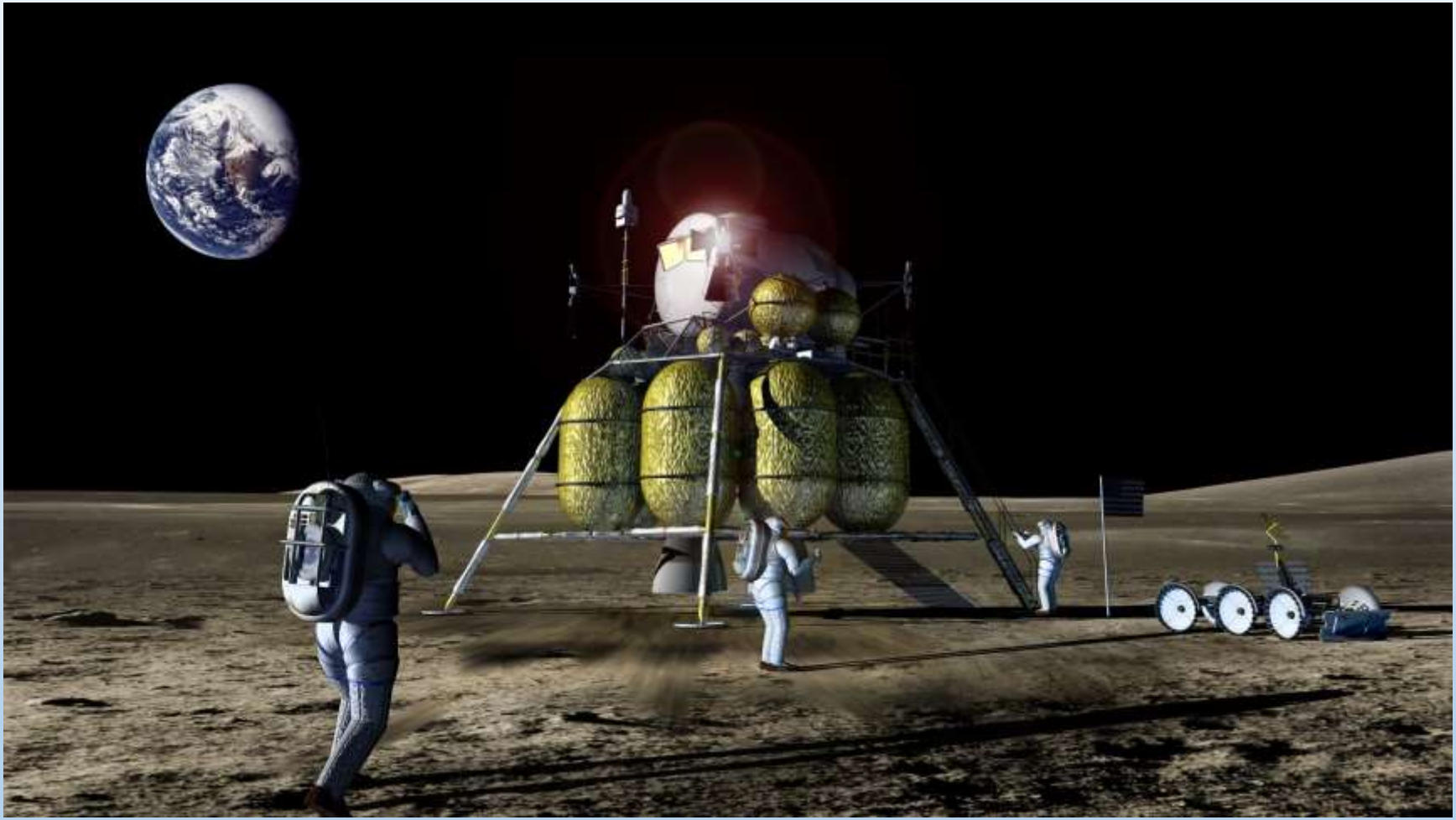

UNITED
STATES

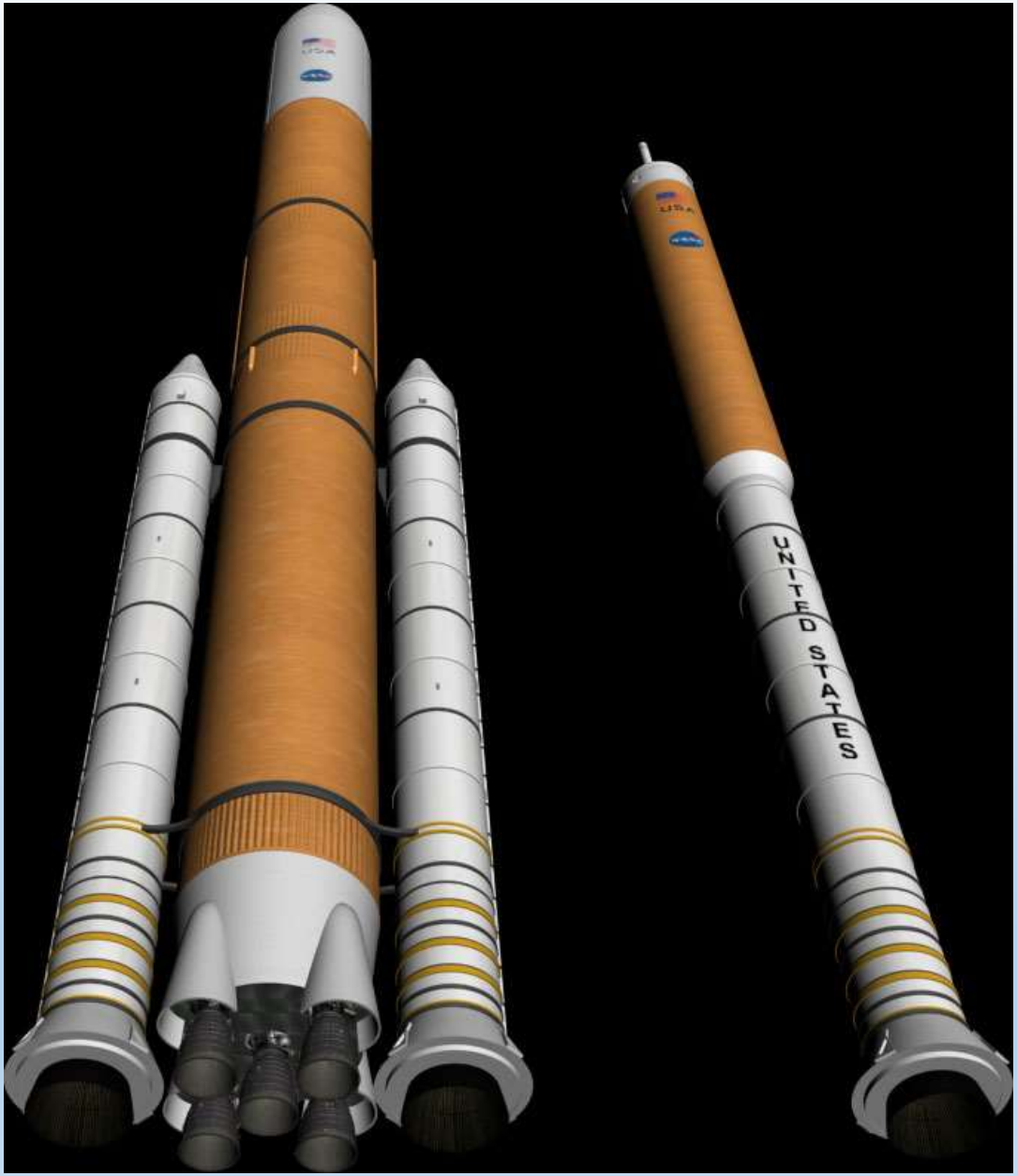





High Priority Lunar Exploration Sites
NASA
North Pole
Aristarchus Plateau
Rima Bode
Mare Tranquillitatis
Mare Smythii
Oceanus Procellarum
Central Farside Highlands
Orientale Basin Floor
South Pole-Aitken Basin Floor
South Pole
Near Side
Far Side
Luna
Surveyor
Apollo
4






UNITED STATES