3RD SPACE EXPLORATION CONFERENCE & EXHIBIT

Lunar Architecture Update

Doug Cooke
Deputy Associate Administrator
Explorations Systems Division

Geoffrey Yoder
Director, Exploration Systems Mission Directorate Integration Office

Sandy Coleman
Space Enterprise Council – US Chamber of Commerce
Director, NASA Exploration Program, ATK Washington Operations

Dr. Scott Hensley
Lunar, JPL

February 28, 2008

Topics

• **Introduction** • **Contrast Dec 06 AIAA conference to now**	**Doug Cook**
• **Lunar Architecture update** – Constellation Lunar Study Status – Partnership Flexibility	**Geoff Yoder**
• **U.S. Chamber of Commerce Space Enterprise Council**	**Sandy Coleman**
• **Lunar Imaging from Goldstone**	**Scott Hensley**
• **Wrap up and Questions**	**Doug Cooke**

3RD SPACE EXPLORATION CONFERENCE & EXHIBIT

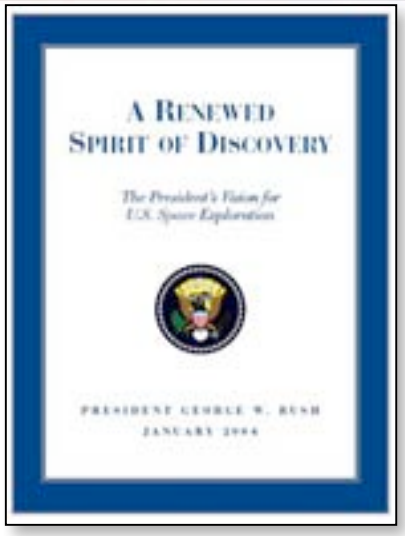
Introduction

Doug Cooke
Deputy Associate Administrator
NASA Exploration Systems Mission Directorate

February 28, 2008

US Policy for Space Exploration

Foundations for Exploration



NASA Authorization Act of 2005

The Administrator shall establish a program to develop a sustained human presence on the Moon, including a robust precursor program to promote exploration, science, commerce and U.S. preeminence in space, and as a stepping stone to future exploration of Mars and other destinations.

Global Exploration Strategy Themes

Human Civilization

Global Partnerships

Scientific Knowledge

Economic Expansion

Exploration Preparation

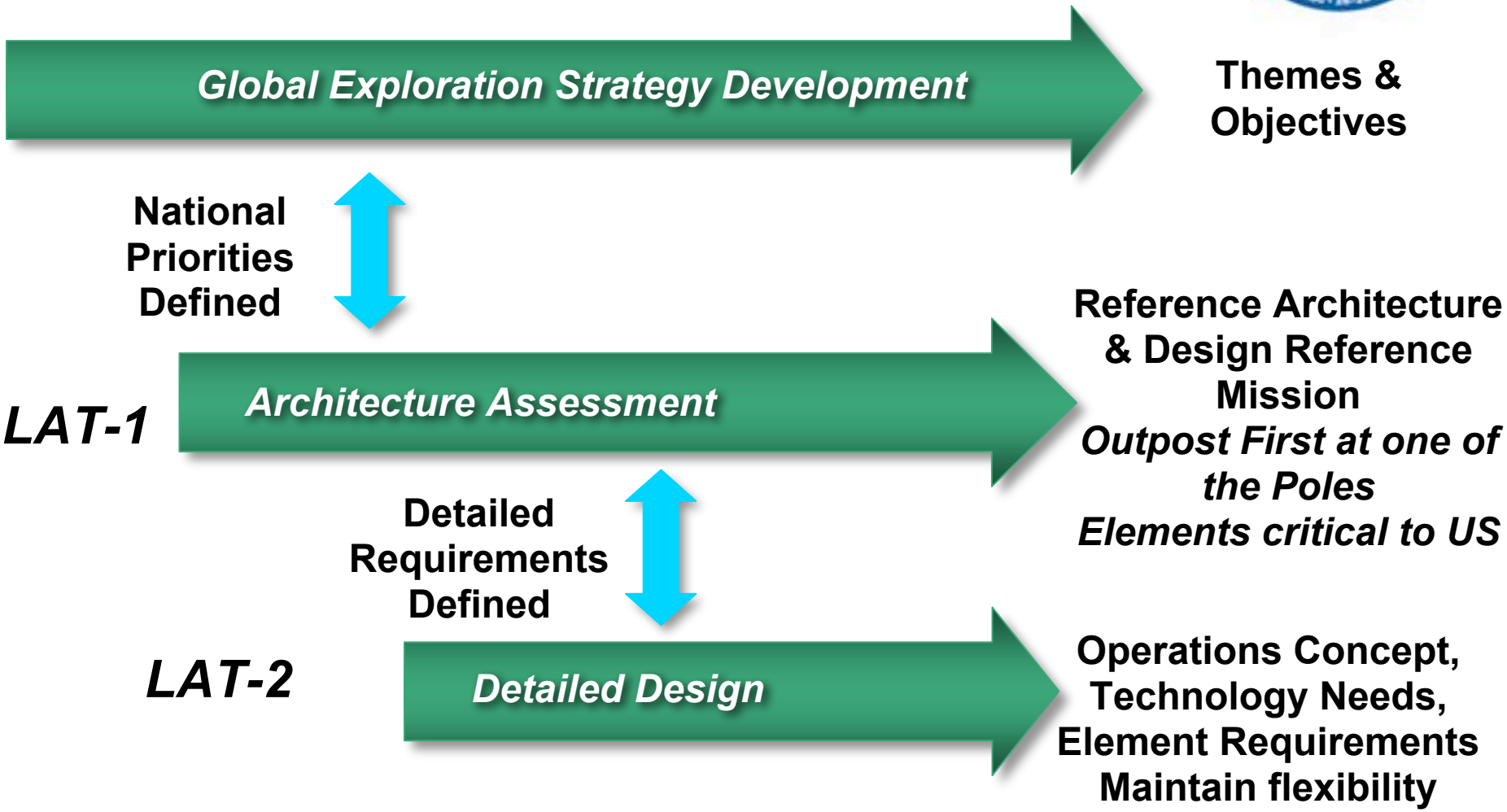
Public Engagement

Architecture Guidelines

In addition to supporting the basic goals and objectives of the US Space Policy, the Architecture must have the following:

- Programmatic Flexibility – Adaptable to changes in national priorities and budgets over several election cycles
- Participant Flexibility – Adaptable to changes in external participation and their priorities (Commercial or International Partners)
- Exploration Flexibility – Adaptable to changes in exploration priorities and methods

Architecture Development Driven By A Strategy



Summary of December 06 AIAA Briefing

Lunar Architecture Team Summary

- Human lunar missions will be used to build an outpost initially at a polar site
- Preserve the option for an outpost at other lunar locations
- Preserve the ability to fly human sorties and cargo missions with the human lander
- Initial power architecture will be solar with the potential for augmentation with nuclear power later
- The US will build the transportation infrastructure, initial communication & navigation infrastructure, and initial surface EVA capability
- Open Architecture: NASA will welcome parallel development and development of lunar surface infrastructure by international and commercial interests

Open Architecture: Infrastructure Open for Potential External Cooperation

- Lander and ascent vehicle
- EVA system
  - CEV and Initial Surface capability
  - Long duration surface suit
- Power
  - Basic power
  - Augmented
- Habitation
- Mobility
  - Basic rover
  - Pressurized rover
  - Other; mules, regolith moving, module unloading
- Navigation and Communication
  - Basic mission support
  - Augmented
  - High bandwidth
- ISRU
  - Characterization
  - Demos
  - Production

- Robotic Missions
  - LRO- Remote sensing and map development
  - Basic environmental data
  - Flight system validation (Descent and landing)
  - Lander
  - Small sats
  - Rovers
  - Instrumentation
  - Materials identification and characterization for ISRU
  - ISRU demonstration
  - ISRU Production
  - Parallel missions
- Logistics Resupply
- Specific Capabilities
  - Drills, scoops, sample handling, arms
  - Logistics rover
  - Instrumentation
  - Components
  - Sample return

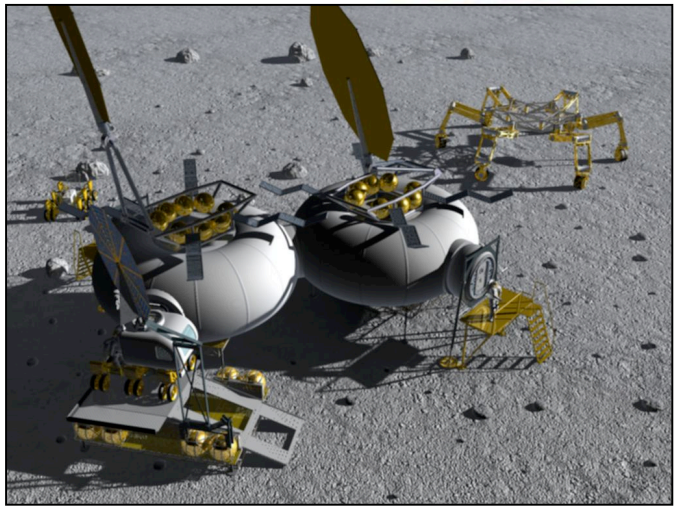
** US/NASA Developed hardware

Strategy for Second Phase of Architecture Studies

- Build on LAT 1 decisions, assessing a range of options
- Combine best features into a hybrid approach
- Attributes:
  - Enable lunar sustained presence early
  - Develop infrastructure while actively engaged in science and exploration
  - Ensure architecture supports broader range of Objectives
  - Support the establishment of Mars analog
  - Allow the earliest partnership opportunities for commerce and International Partners
  - Continuous and focused public engagement

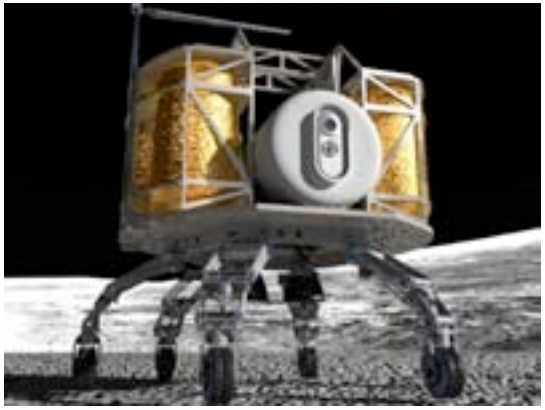
Hybrid Approach to Options

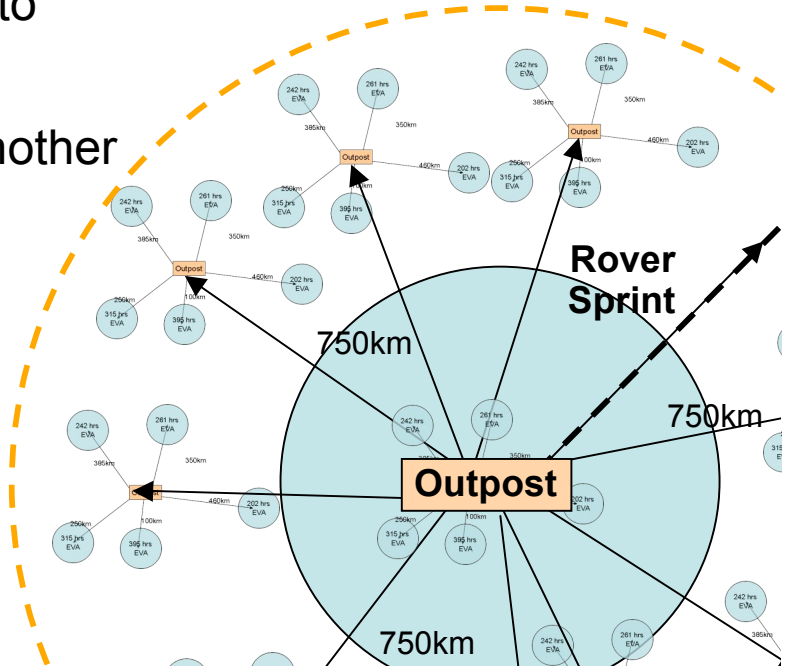
- Surface Architecture-
  - Worked as a system with the transportation architecture (Ares I&V, Orion, and Lander)
  - Ares V shroud expanded to 10M dia. for lander packaging
  - Cargo lander utilized to transport major components to the surface
  - Outpost built up from only 2 or 3 modular habitat elements; each pre-integrated with power, life support, communications, etc.
  - Mobility capability that utilizes the 'Leg-Wheel' concept for unloading, transportation and emplacement of elements
  - Early delivery of small, agile pressurized rover



Extended Surface Exploration

- **Wheel-on-leg surface carrier provides capability in addition to offloading and positioning surface elements:**
  - Provides capability for mobile habitat
  - Mobile habitat drives robotically to new interim Outpost
  - Crew drives separately in pressurized rover to extended sortie site.
  - Habitat can be sent to sites for a visit from another crew a de.





Summary

- **Builds on architecture decisions presented at December 2006 Exploration Conference**
- **Utilizes the robust transportation system provided by Ares 1 and Ares 5**
- **Open architecture facilitates different modular functions and operations**
- **Early exploration**
  - Reduced assembly through pre-integrated habitats
- **Modular mobile habitation**
  - Facilitates “super sortie” mobility for 100’s km distances from the outpost
  - Facilitates greater lunar access to capture exploration and science objectives beyond LAT1 results
- **Early small pressurized rover**
  - Augments EVA operations by allowing astronauts to explore in shirt sleeve environment using EVA judiciously

3RD SPACE EXPLORATION CONFERENCE & EXHIBIT

Lunar Architecture update

Constellation Lunar Study Status
Partnership Flexibility

Geoffrey Yoder

Director, Exploration Systems Mission Directorate
Integration Office

Topics

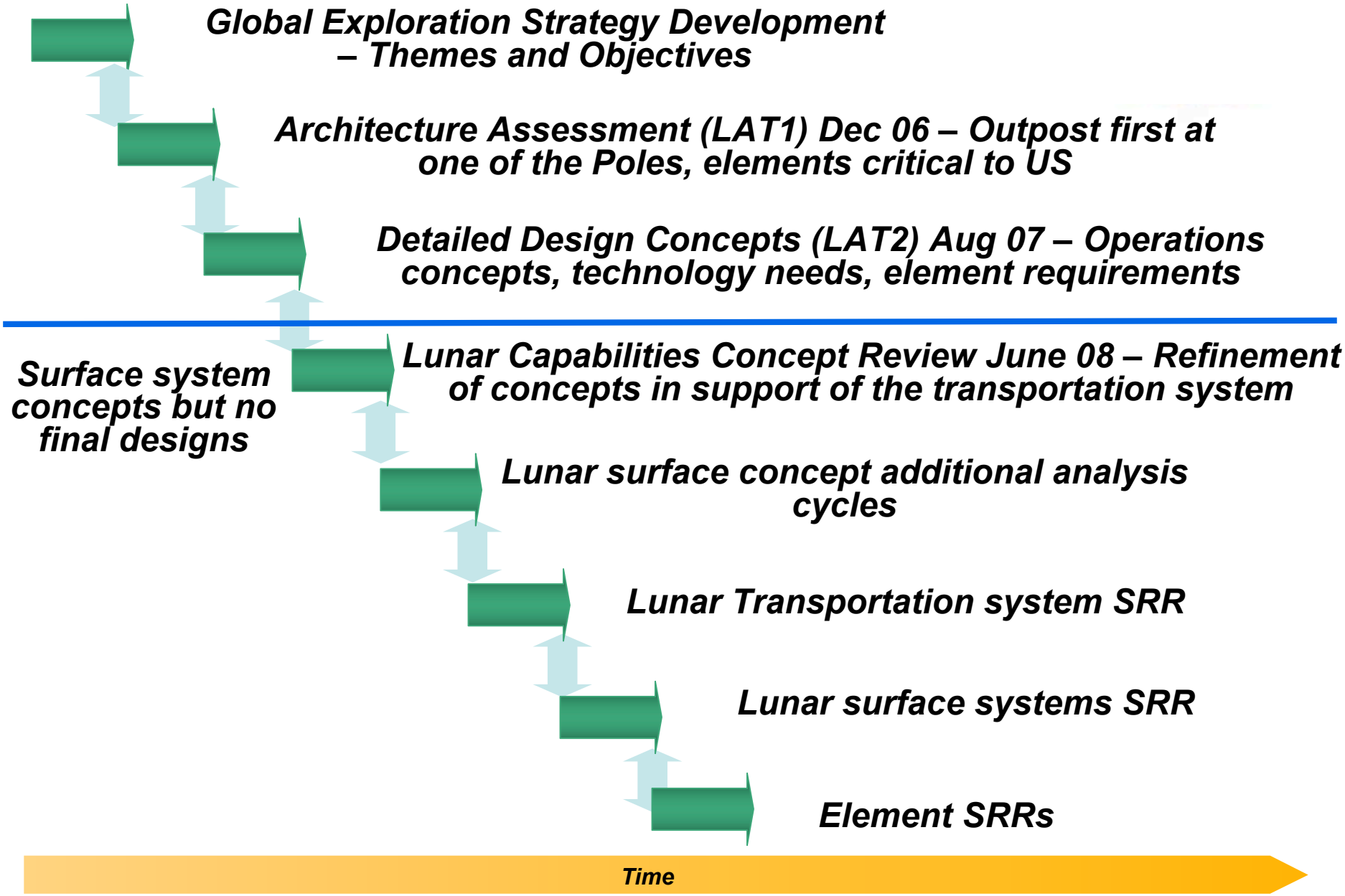
Status of CxLunar

Pressurized Rover features

Participant Flexibility

Architecture Driven By A Strategy

Where We Have Been and Next Steps

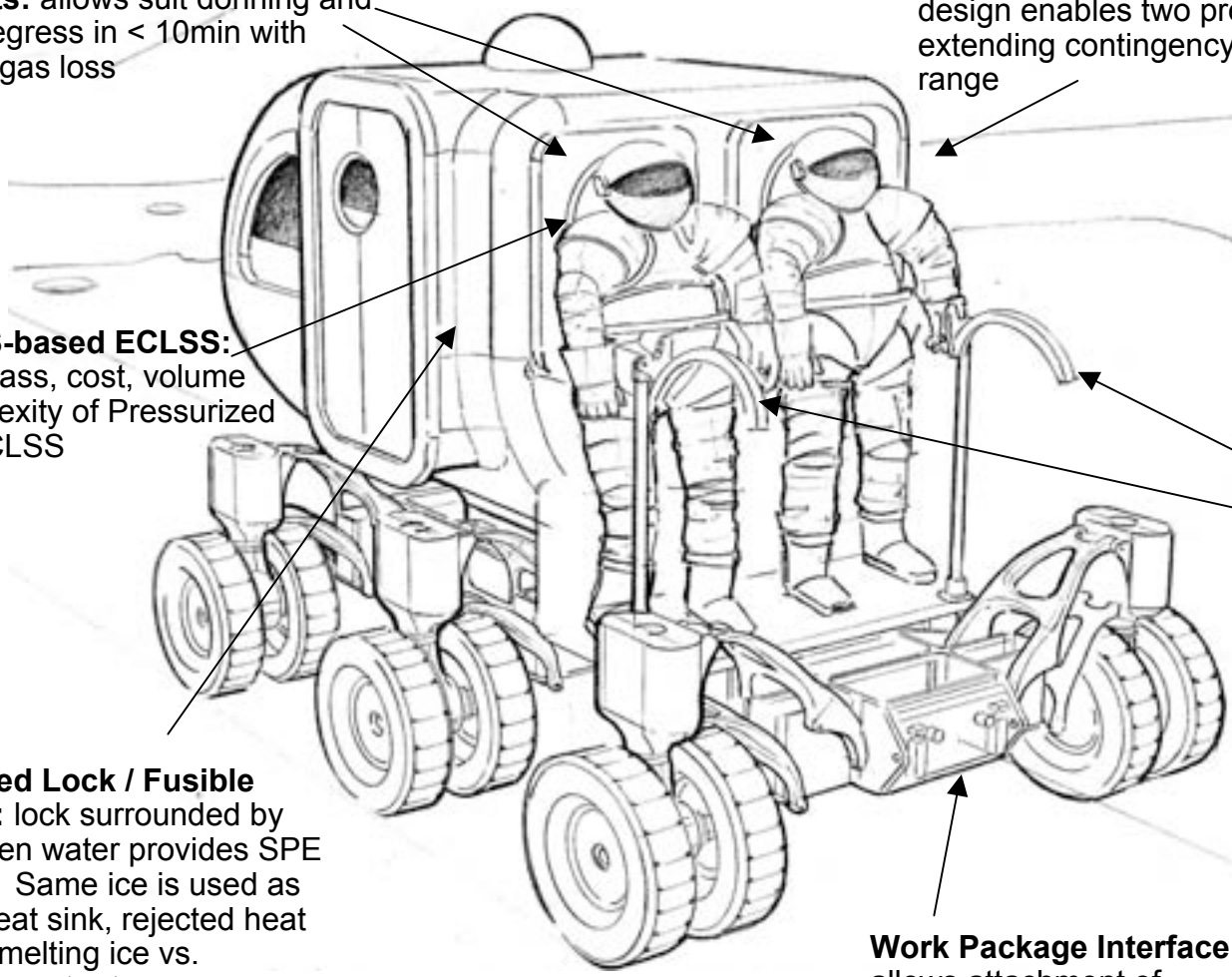


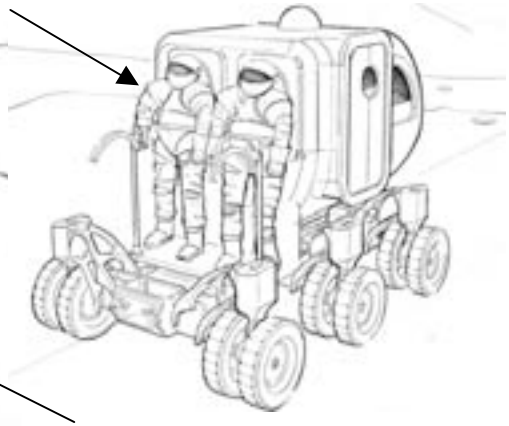
Small Pressurized Rover Design Features

(Slide 1 of 2)

Suitports: allows suit donning and vehicle egress in < 10min with minimal gas loss

Two Pressurized Rovers: low mass, low volume design enables two pressurized vehicles, greatly extending contingency return (and thus exploration) range



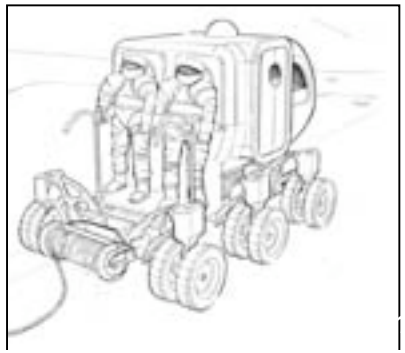


Suit PLSS-based ECLSS: reduces mass, cost, volume and complexity of Pressurized Rovers ECLSS

Chariot-Style Aft Driving Station: enables crew to drive rover while EVA, also part of suitport alignment

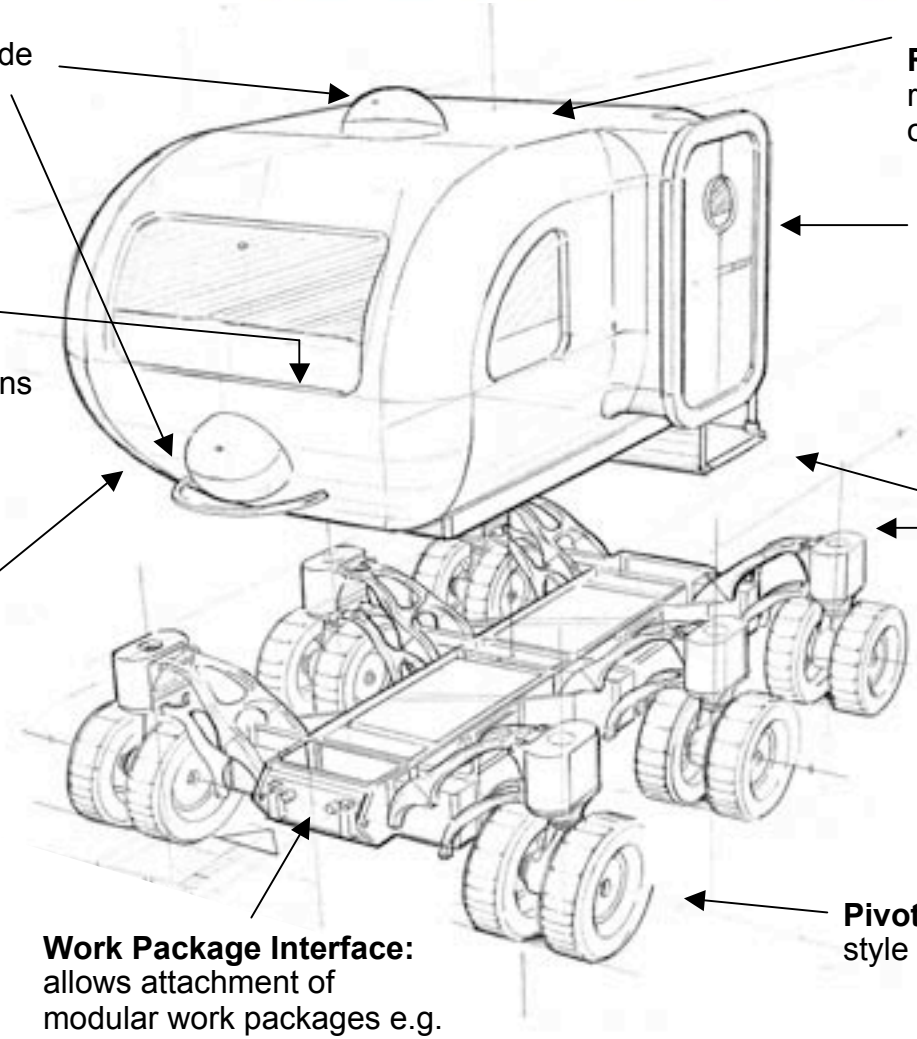
Ice-shielded Lock / Fusible Heat Sink: lock surrounded by 2.5cm frozen water provides SPE protection. Same ice is used as a fusible heat sink, rejected heat energy by melting ice vs. evaporating water to vacuum.

Work Package Interface: allows attachment of modular work packages e.g. winch, cable reel, backhoe,



Small Pressurized Rover Design Features

(Slide 2 of 2)



Dome windows: provide visibility as good, or better than, EVA suit visibility

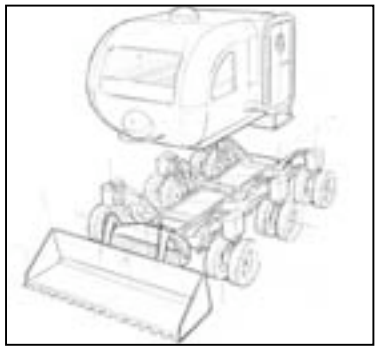
Radiator on Roof: allows refreezing of fusible heat sink water on extended sorties

Docking Hatch: allows pressurized crew transfer from Rover-to-Habitat, Rover-to-Ascent Module and/or Rover-to-Rover

Exercise ergometer (inside): allows crew to exercise during translations

Modular Design: pressurized module is transported using Mobility Chassis. Pressurized module and chassis may be delivered on separate landers or pre-integrated on same lander.

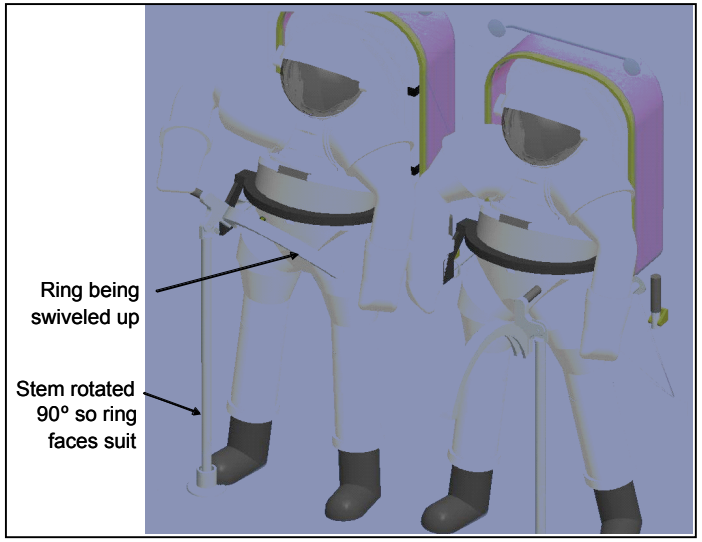
Cantilevered cockpit: Mobility Chassis does not obstruct visibility

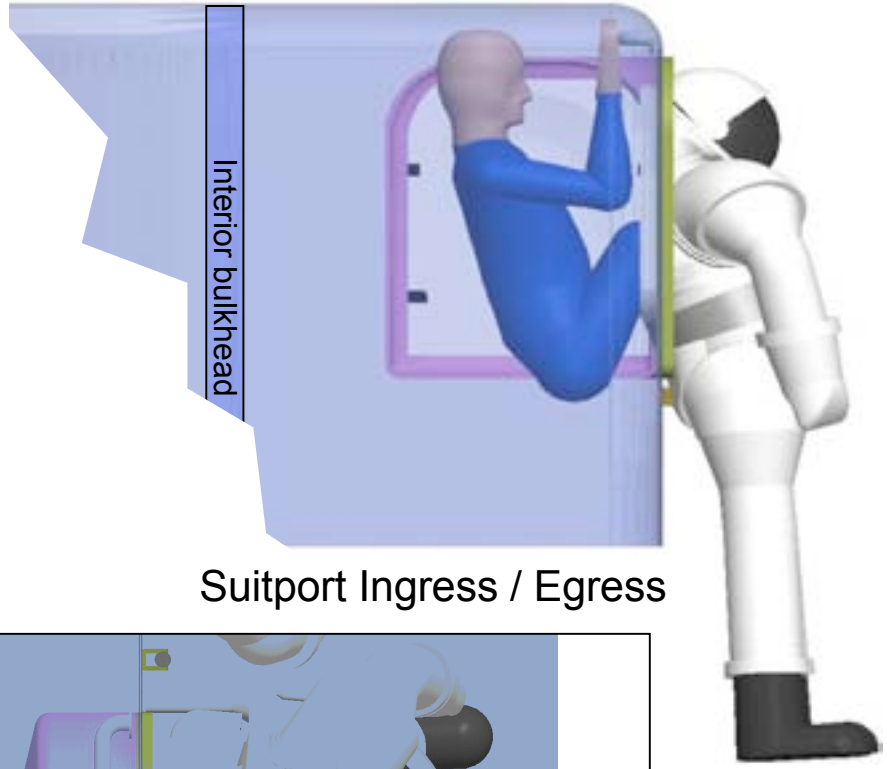


Pivoting Wheels: enables crab-style driving for docking

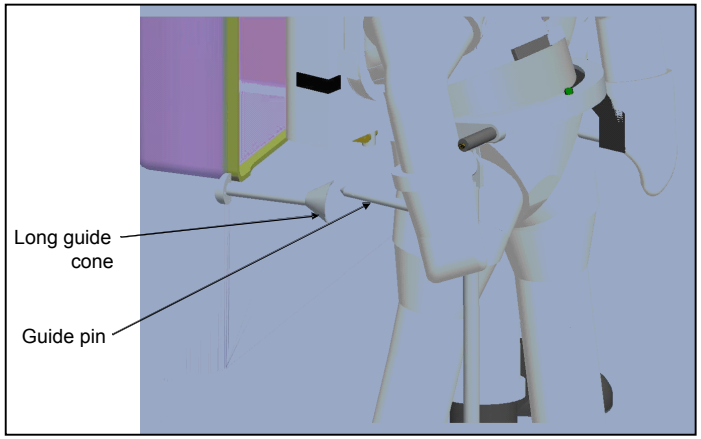
Work Package Interface: allows attachment of modular work packages e.g. winch, cable reel, backhoe, crane

Suit Alignment Guides and Suitport Ingress/Egress

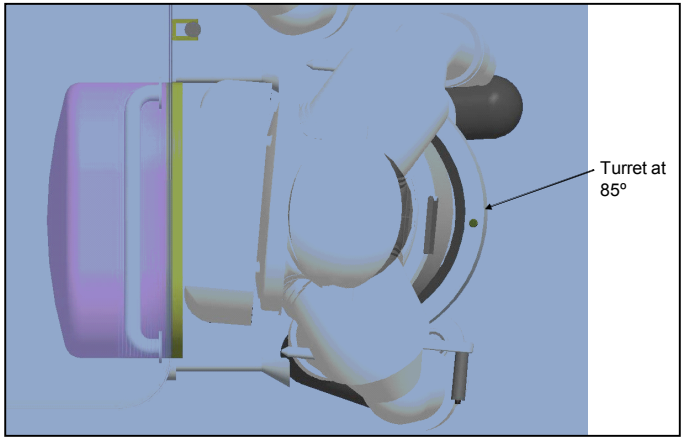




Suitport Ingress / Egress

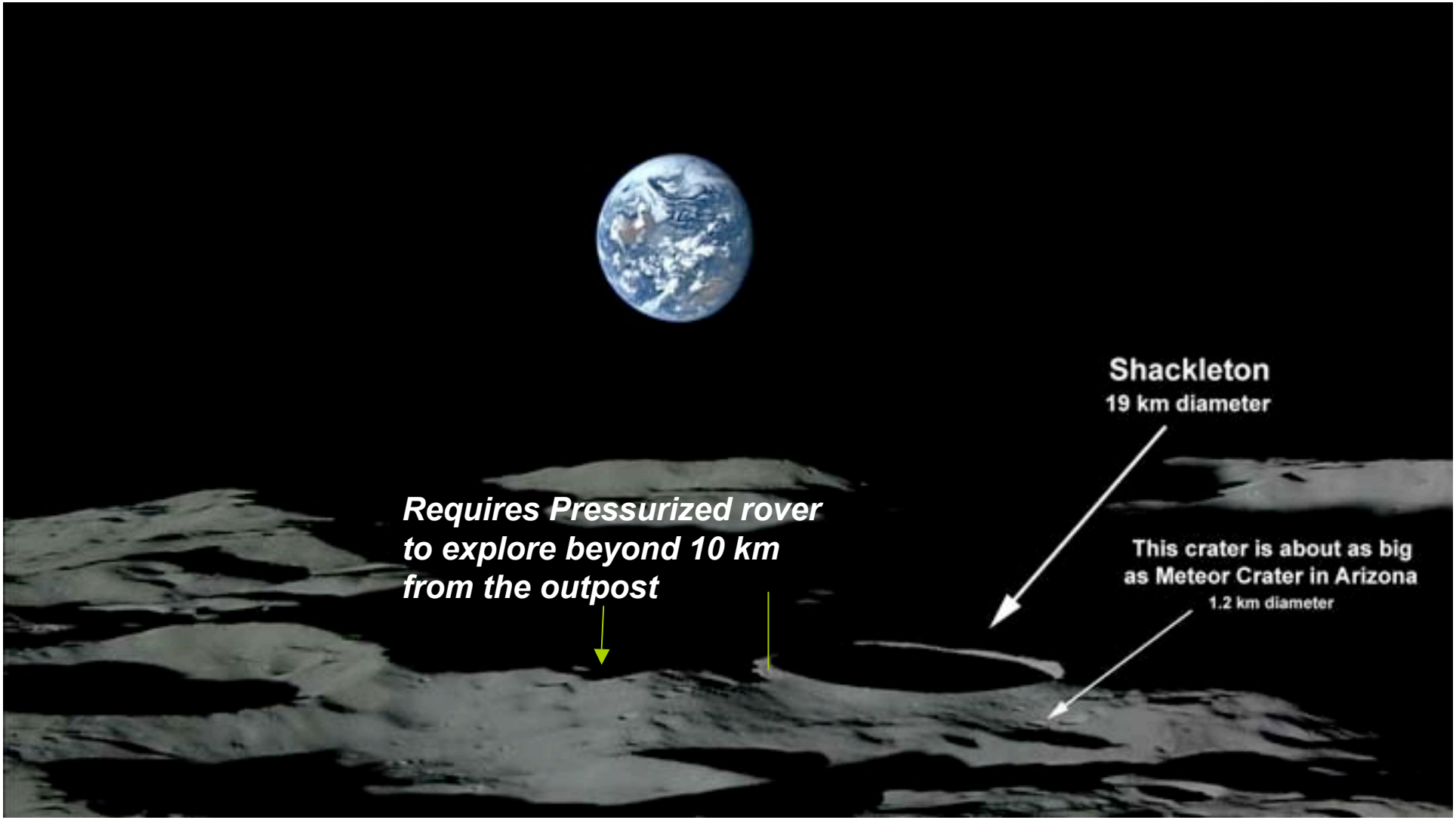


Suit Alignment Guides



Why is a Pressurized Rover Necessary?

Kaguya Satellite - Lunar South Pole Image



Architecture Guidelines

- **In addition to supporting the basic goals and objectives of the US Space Policy, the Architecture must have the following:**
  - Programmatic Flexibility – The Architecture must be able to adapt to changes in national priorities and budgets over several election cycles
  - Participant Flexibility – The Architecture must be able to adapt to changes in external participation (Commercial or International Partner) and changes to their priorities
  - Exploration Flexibility – The Architecture must be able to adapt to changes in exploration priorities and changes in exploration methods

Participant Flexibility

Since the announcement of the U.S. Space Exploration Policy in 2004, global interest in science and exploration of the Moon has steadily increased

- **A multi-pronged approach in communicating the Exploration Policy and pursuing opportunities for cooperation**
  - Sponsored workshops and conferences in the US, and have participated in conferences overseas
  - Engaged the US Chamber of Commerce
  - Initiated multilateral dialogue with representatives of 13 science and space agencies around the world under the banner of the Global Exploration Strategy
  - Employed specific bi-lateral strategies on a country by country basis based on a particular partner's capability and interests

- **Rationale**
  - Robust capabilities and redundant systems are key factors in a successful exploration program
  - Affordable exploration program that accomplishes as many goals as possible as early as possible is a program with active participation from international and commercial partners

Open Architecture
The Pieces of a Greater Mission

Human Missions to the Moon

US/NASA Developed initial capabilities

- Launch Vehicle Architecture
- Lunar Lander: ascent vehicle, descent vehicle, basic habitation
- Initial EVA system for CEV and an Initial Surface Suit
- Basic Navigation and Communication

Open for Cooperation

Systems and Capabilities Envisioned for <u>an Outpost including Outpost enabled sorties</u>

- Long duration surface suit
- Advanced, long-duration Habitation
- Augmented Power Systems
- Basic, unpressurized rover
- Pressurized rover
- Logistics rover
- Augmented, high bandwidth satellite communication/navigation
- Logistics Resupply
- ISRU Production

Time

Participant Flexibility Strategy

- **Welcome parallel capabilities while seeking "open architecture" contributions**
- **Continue success of the Global Exploration Strategy through multilateral engagement in International Space Exploration Coordination Group (ISECG)**
- **Continue success of US Chamber of Commerce engagement**
- **Build on long-standing bilateral relationships while seeking new relationships when opportunities and conditions permit**

Summary of Multilateral Activities to Date

- **Following announcement of the Exploration Policy, NASA began to engage nations on a bilateral and multilateral basis to explain progress in implementing the Vision and to discuss potential partnerships**

- **In April 2006, NASA initiated multilateral discussions aimed at developing a globally coordinated strategy for exploration – the Global Exploration Strategy**
  - Australia, Canada, China, the European Space Agency, France, Germany, Great Britain, India, Italy, Japan, Russia, the Republic of Korea and Ukraine

- **In May 2007, 14 space agencies released the results of 12 months of intensive discussion: "The Global Exploration Strategy – The Framework for Coordination"**

- **In November 2007, established the International Space Exploration Coordination Group (ISECG)**

Summary of Bilateral Accomplishments to Date

- **European Space Agency (ESA)**
  - In May 2007, NASA initiated a dialogue with ESA's exploration architecture team
  - NASA presented results of Lunar Architecture Team Phase 2 study to ESA's exploration architecture team at ESTEC September 26-27
  - In January 2008, NASA and ESA have initiated a four-month "comparative architecture assessment" to outline potential collaborative scenarios utilizing respective human/robotic exploration capabilities
- **United Kingdom (BNSC)**
  - Administrator signed April 2007 joint statement with UK Department of Trade and Industry to establish joint study of potential lunar cooperation. Study results to be released soon
- **Germany (DLR)**
  - NASA Administrator/DLR Chairman signed a February 2007 joint statement expressing desire to discuss areas of exploration cooperation

Selected ESA Key Capabilities for Comparison

- Lunar logistics system;
- Crew transportation system;
- Human surface support and habitation;
- Orbital infrastructures in cis-lunar space;
- Communication/navigation systems.

Note: further definition and development of these capabilities is subject to decision at the next ESA Council meeting at ministerial-level the end this year.

Lunar Logistic System

Objectives

- Demonstrate soft precision landing (500m)
- Transport robotic elements to lunar surface from LTO
- Deliver cargo to Lunar surface

Launcher AR5 ESC-B

Main Functions

- Safely land on moon surface, any location, a net P/L mass of 1750 kg
- Deploy the P/L on surface
- Provide resources to the P/L (power, comm‘s etc)
- Operative life: ~ 15 days

Interfaces

- Ariane 5 launcher
- Payload
- Surface infrastructures
- Comm/nav

Timeframe

- First demo mission: 2016/17 with reduced payload capability
- Full capability: 2021
- Key decision points: 2011

Limitation/ Needs

- Refinement of requirements for lunar logistics services
- Propulsion technology

Lunar Logistic Lander

European Mission Scenarios

Mass 200 kg

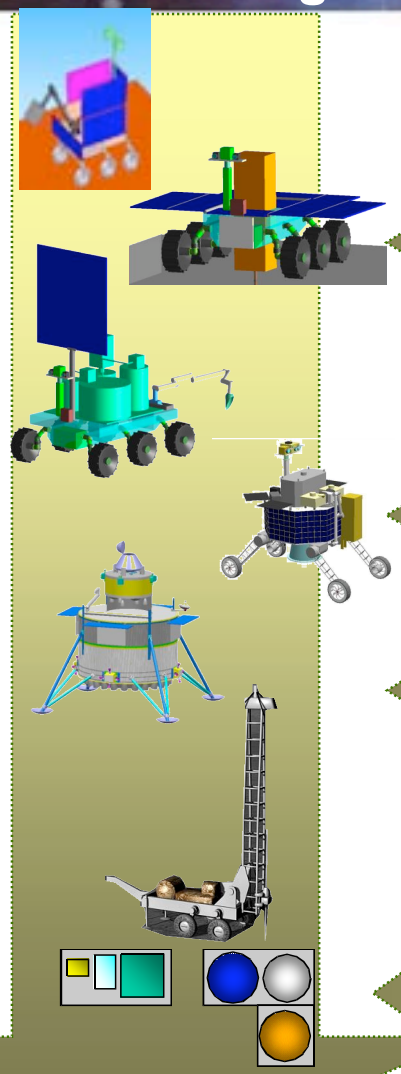
Potential payloads identified

Exploration rover
Robotic surface mobility and in-situ analysis

ISRU demonstration
Extraction and production of oxygen

Sample Return vehicle
Bring back a 1kg sample to Earth

Very deep driller
Mobility and very deep drilling capability (100 m)



Potential payloads identified

Deep driller rover
Mobility and deep drilling capability (10 m)

Exploration Hopper
Extended robotic surface mobility and sample collection capability

Low frequency radio astronomy
LOFAR telescope deployment

Logistics for pressurized rover
Deliver logistics of the pressurized rover

1,500 kg

Commercial Participation

- US Chamber of Commerce
  - Engaged the US Chamber of Commerce
    - Actively engage US companies through a single focal point
    - Provides US industry expertise on a level playing field
  - Performing Architecture element standards evaluation
    - Described in following presentation by Sandy Coleman

3RD SPACE EXPLORATION CONFERENCE & EXHIBIT

U.S. Chamber of Commerce Space Enterprise Council

Sandy Coleman
Director, NASA Exploration Program
ATK Washington Operations

February 28, 2008

Who Are We?

- Founded in 2000 out of a joint NASA/DOD conference focusing on commercial space

- Now focus on all aspects of the space industry
  - Commercial
  - Civil
  - National Security

- Affiliated with the U.S. Chamber of Commerce
  - USCC represents 3 million businesses and 1,500 Chambers of Commerce
  - SEC can tap into the USCC's wide swath of resources

SEC Relationship with NASA's ESMD

- For the past two years, the Council has hosted NASA Lunar Exploration Architecture workshops
- Output from these workshops has been directly incorporated into NASA's Lunar Architecture Plan
- Council agreed to work with NASA on Lunar Standards
  - To identify where standards would be of value
  - Candidate sources of those standards

SEC Relationship with NASA's ESMD

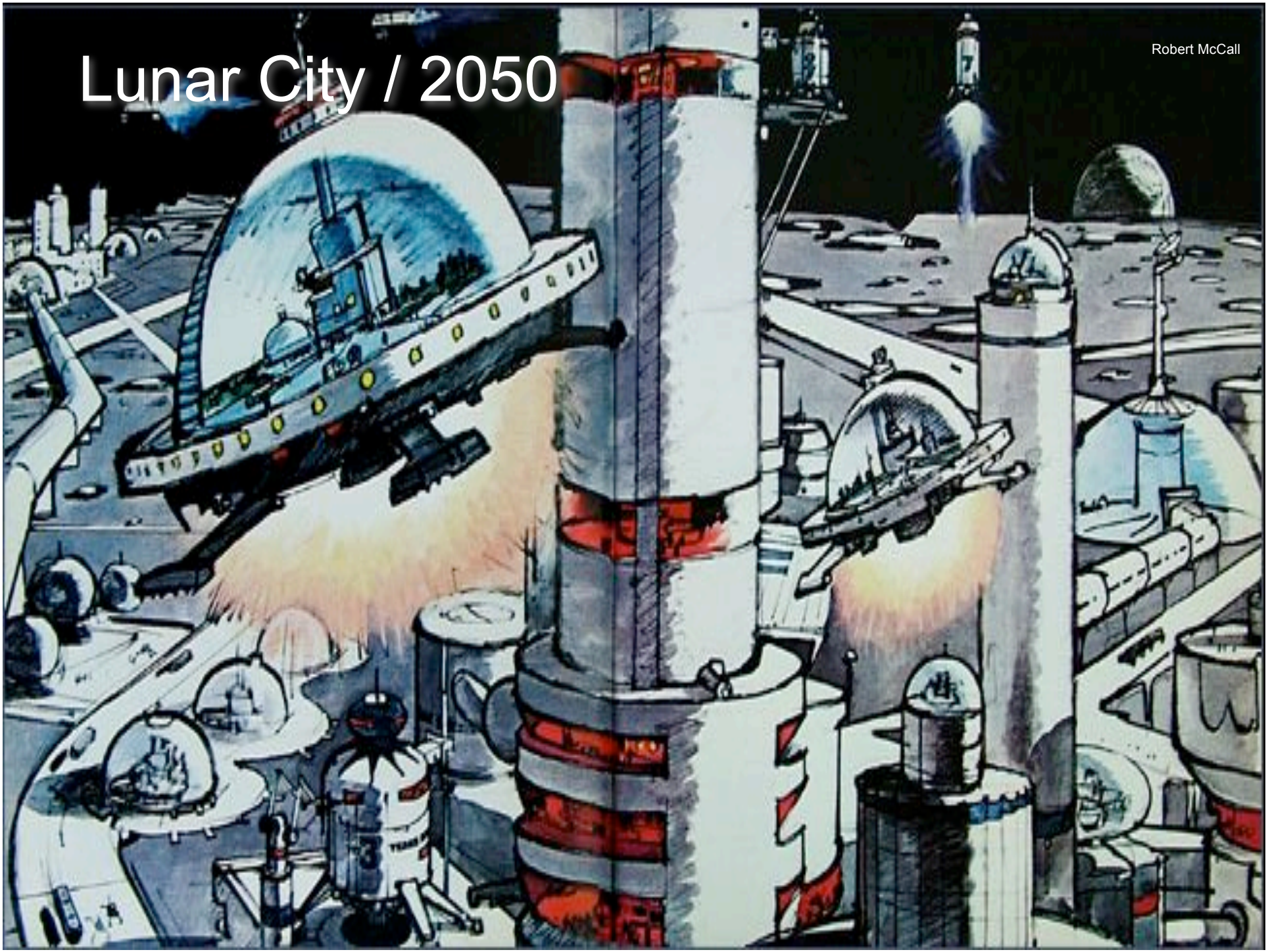
Scope and Focus of Effort

- Focus on commercial standards that assist ESMD in areas that have long term applicability to the lunar architecture
- Enabling Commercial Off The Shelf (COTS) type solutions are of particular interest
- Identify what would be best served by U.S. vs International standards

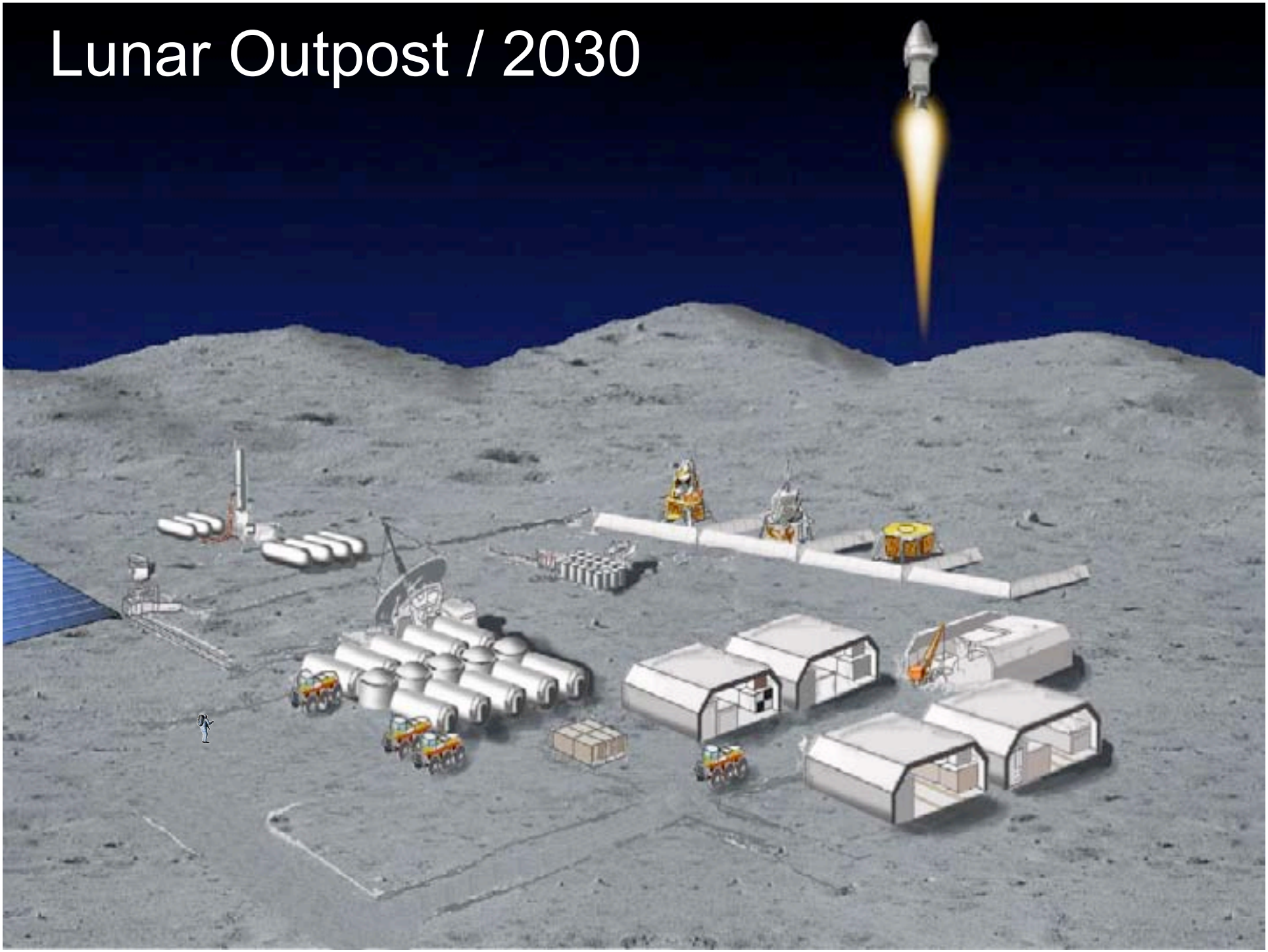
Space Transportation Working Group

- ATK
- The Boeing Company
- Honeywell
- Lockheed Martin
- Northrop Grumman
- Orbital
- Raytheon
- United Space Alliance

We encourage wide industry participation


Lunar City / 2050
Robert McCall

Lunar Outpost / 2030



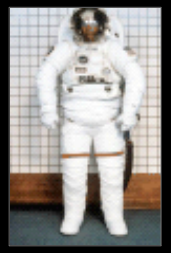
Lunar Surface Elements vs Functions

Interface Functional Needs	NASA Lunar Surface Element										
	Long Duration Surface Suit	Living Habitat	Work Habitat	Health Habitat	Power Systems	Surface Transportation & Handling Systems	Communication & Navigation	Logistics Resupply	ISRU Production	Emergency Egress Systems	Surface Construction & Maintenance
Pressurized mechanical interfaces (docking ports, airlocks/suitlocks, interconnects/couplings)	x	x	x	x		x		x	x	x	x
Unpressurized mechanical interfaces (attachments/adapters, connectors, grapples, plugs and sockets, handles, hard/lift/hoist points)	x	x	x	x	x	x		x	x	x	x
Atmosphere/Environmental (pressure, temperature, composition, humidity, trace gases and contaminants, ionization, radiation shielding & hardening, environmental monitoring)	x	x	x	x	x	x	x	x		x	
Water (purity, sterility, sterilization approach, electric conductivity, ion balance, isotope composition, trace minerals)	x	x	x	x		x		x	x	x	
Power (voltage, AC/DC, frequency, stability/tolerances)	x	x	x	x	x	x	x	x	x	x	x
Communications protocol (formats, bandwidth, frequencies, waveforms, encryption, clock speed and timing accuracy)	x	x	x	x		x	x			x	
Diet (water content/food dehydration, storage temperature, nutrient content, composition, caloric value, vitamins, minerals)	x	x	x	x		x		x			
Reactants and working media (fuels/propellants, lubricants, CO2 removal agents, detergents and cleaners, disinfectants, cooling fluids, catalysts)	x	x	x	x	x	x		x	x		
Materials (mechanical/chemical/electrical properties, outgassing characteristics, UV resistance, radiation resistance and penetrability)	x	x	x	x	x	x		x	x	x	x
Anthropometry (size ranges, weight ranges, metabolic rates, reaction times, cognitive capabilities and perception, vision, hearing, reach, strength)	x	x	x	x	x	x	x	x	x		x
Waste Management & Recycling (human, non-human, planetary protection)		x	x	x	x	x		x			x

Long Duration Surface Suit

INTERFACE STANDARDS

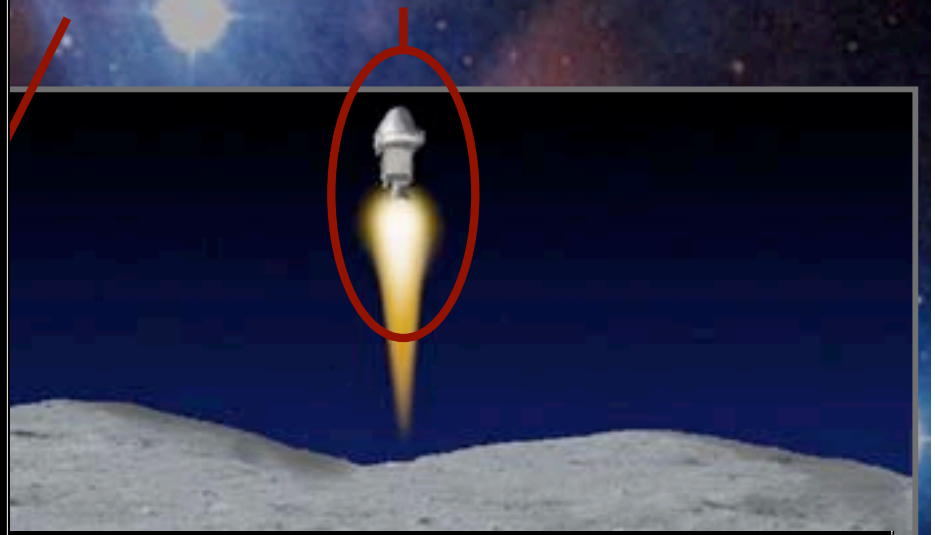
- Mechanical Interfaces
- Atmosphere/Environmental
- Water
- Power
- Communications Protocol
- Diet
- Reactants/Working Media
- Materials
- Human Factors



Will the power and life support modules of the US Surface Suit be inter -changeable with International Partner suits?

Surface Transportation

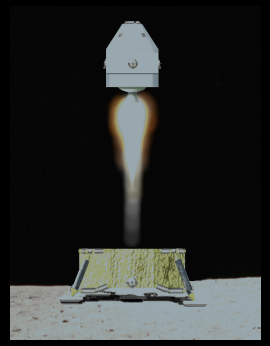
Emergency Egress

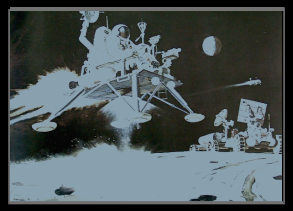


Emergency Egress Systems

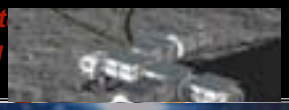
INTERFACE STANDARDS

- Mechanical Interfaces
- Atmosphere/Environmental
- Water
- Power
- Communications Protocol
- Materials





Would water standards for emergency sit
same as those utilized for the living



Surface Suit

Work Habitat

Living Habitat

Health Hab

Sample of Standard Evaluation Living Habitat

Interface Functional Needs	H-M-L
Pressurized mechanical interfaces (docking ports, airlocks/suitlocks, interconnects/couplings)	
Unpressurized mechanical interfaces (attachments/adapters, connectors, grapples, plugs and sockets, handles, hard/lift/hoist points)	
Atmosphere/Environmental (pressure, temperature, composition, humidity, trace gases and contaminants, ionization, radiation shielding & hardening,	
Water (purity, sterility, sterilization approach, electric conductivity, ion balance, isotope composition, trace minerals)	
Power (voltage, AC/DC, frequency, stability/tolerances)	
Communications protocol (formats, bandwidth, frequencies, waveforms, encryption, clock speed and timing accuracy)	
Diet (water content/food dehydration, storage temperature, nutrient content, composition, caloric value, vitamins, minerals)	
Reactants and working media (fuels/propellants, lubricants, CO_2 removal agents, detergents and cleaners, disinfectants, cooling fluids, catalysts)	
Materials (mechanical/chemical/electrical properties, outgassing characteristics, UV resistance, radiation resistance and penetrability)	
Anthropometry (size ranges, weight ranges, metabolic rates, reaction times, cognitive capabilities and	
Waste Management & Recycling (human, non-human, planetary protection)	

Lowest

Lowest Applicability

Likely to exist when needed

Pressurized mechanical I/F Unpressurized mechanical I/F	Waste Managemet / Recycling	
Atomsphere / Environmental Materials	Reactants / Working Media	
Power Communication Protocol	Water Anthropometry	Diet

Highest

Highest Applicability

Applicable to ESMD International Partner Long Duration Needs

Status and Plans

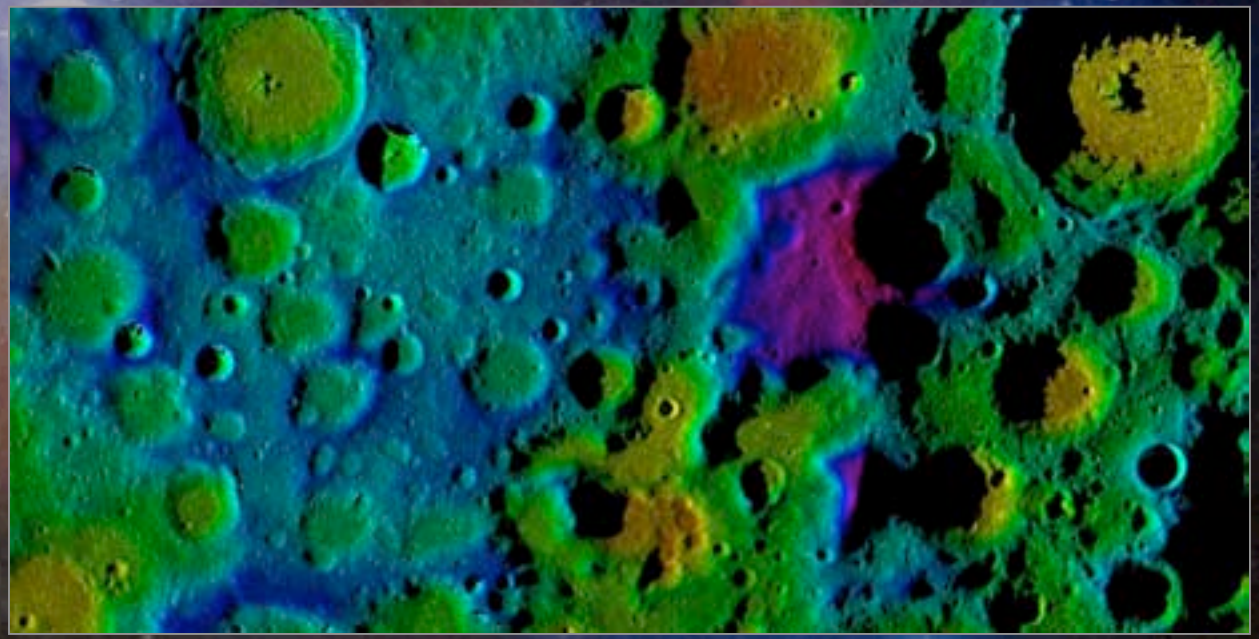
- **Evaluated all 11 architectural elements for value of standards and when needed**
- **Next step is to identify candidate sources to develop the standards**
- **Hosting a Lunar Architecture Workshop on April 1, 2008 at the Chamber with NASA participation**
- **SEC/Industry results to ESMD in May 2008**
- **This is the first step for industry involvement in the Lunar Architecture structure – encourage wide industry participation**

3RD SPACE EXPLORATION CONFERENCE & EXHIBIT

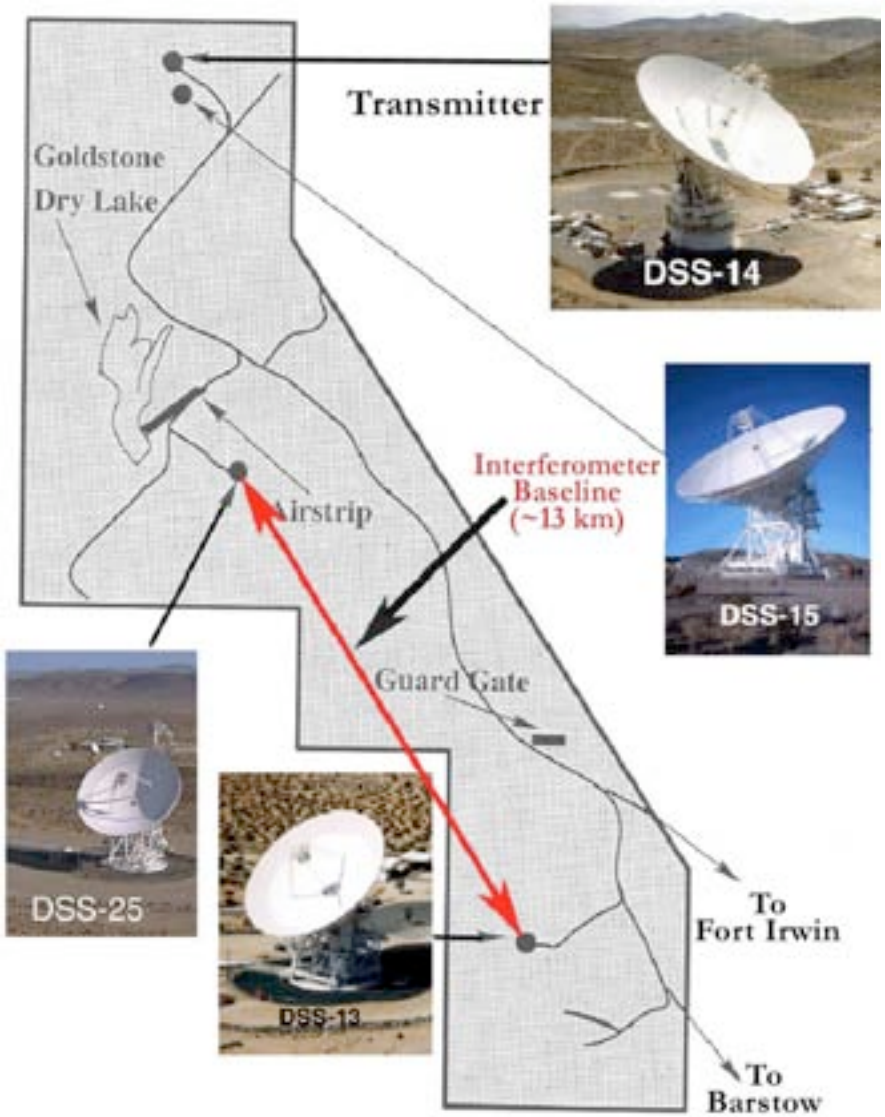
Goldstone Solar System Radar Lunar Polar Topography

Dr Scott Hensley

February 28, 2008



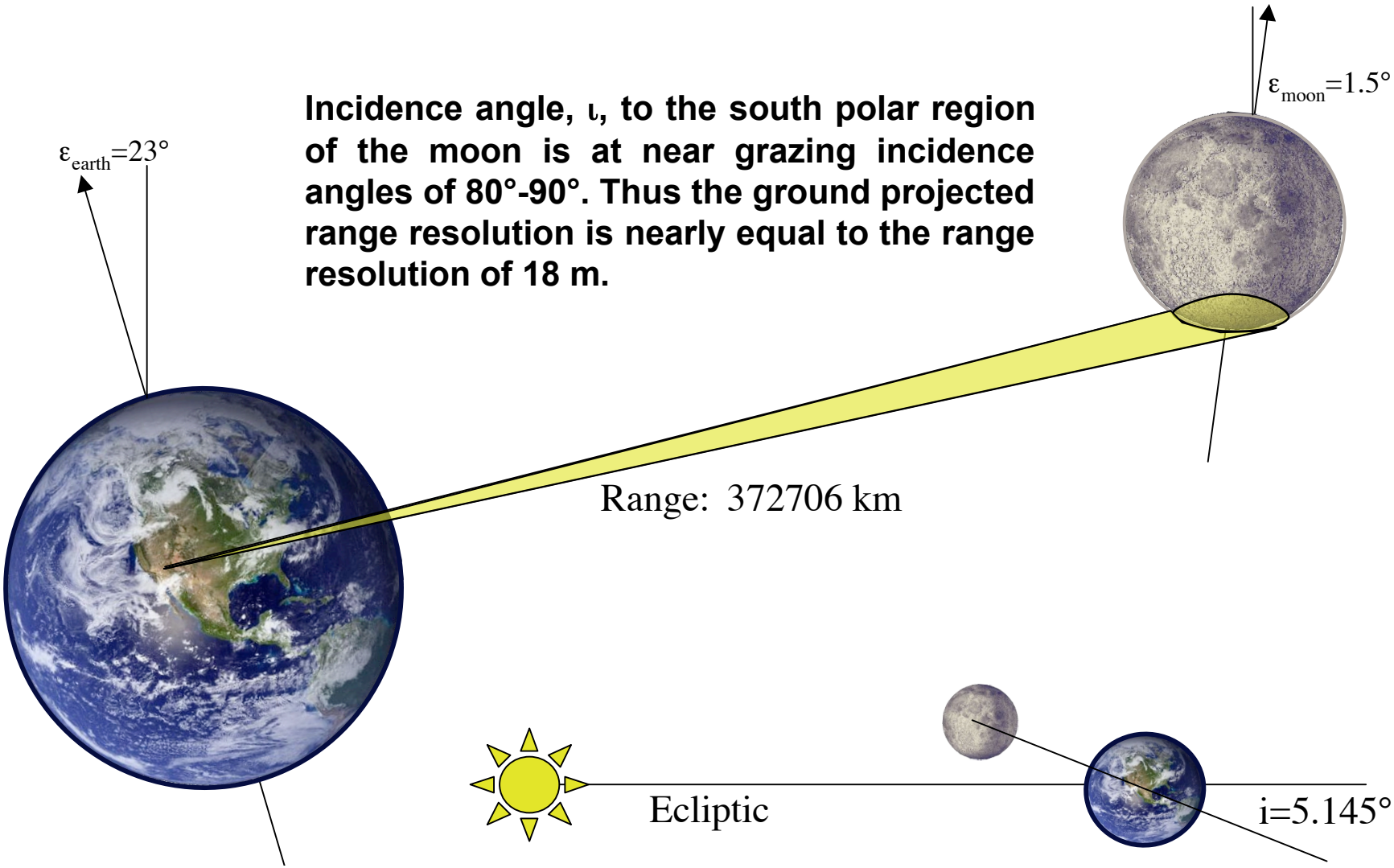
The Goldstone Solar System Radar (GSSR)



- **A unique NASA facility for high-resolution ranging and imaging of planetary and small-body targets**
  - One transmitting, multiple receiving antennas for interferometry
  - 500 kW X-band transmitter
  - Very sensitive maser receiver
- **Provides a wide variety of information**
  - Simultaneous, co-registered radar image and topography - even in Lunar unlit areas
  - Surface characteristics, structure and composition
  - Orbits, rotations, spin axis
- **Leverages DSN assets for radar Mission support and radar science**
  - Deep Space Network (DSN) primary function is communication and nav for space missions beyond low Earth orbit

GSSR Lunar Imaging Geometry

Incidence angle, ι, to the south polar region of the moon is at near grazing incidence angles of 80°-90°. Thus the ground projected range resolution is nearly equal to the range resolution of 18 m.

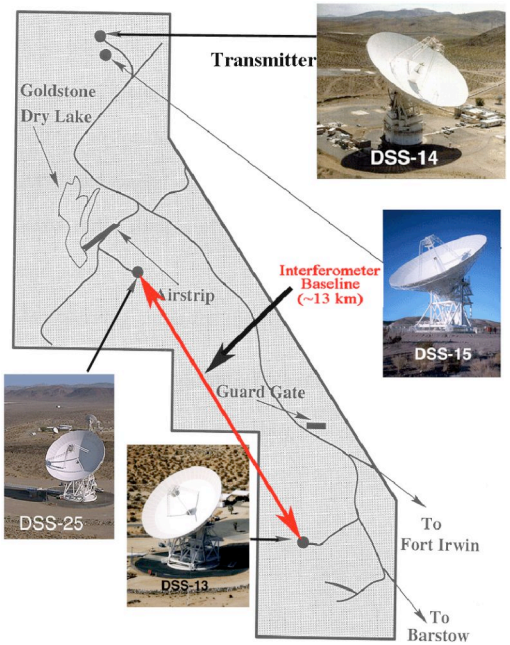


Previous Lunar Polar Measurements

Measurement Source	Date	Polar Coverage	Topography	Polar Topography	
				Spatial Resolution	Height Resolution
Lunar Orbiter 4	1967	Yes	No	No topography	
Apollo 15-17 Lidar & Radar	1971-1972	No	Yes	No polar data	
Clementine / Lidar	1994	No	Yes	No polar data	
Clementine / Stereo Imager	1994	Yes	Yes	1 km	1 km
Lunar Prospector	1998	No imaging	No	No topography	
GSSR	1997	Yes	Yes	150 m	50 m
Arecibo	2006	Yes	No	No topography	

Only Clementine & GSSR measured polar topography

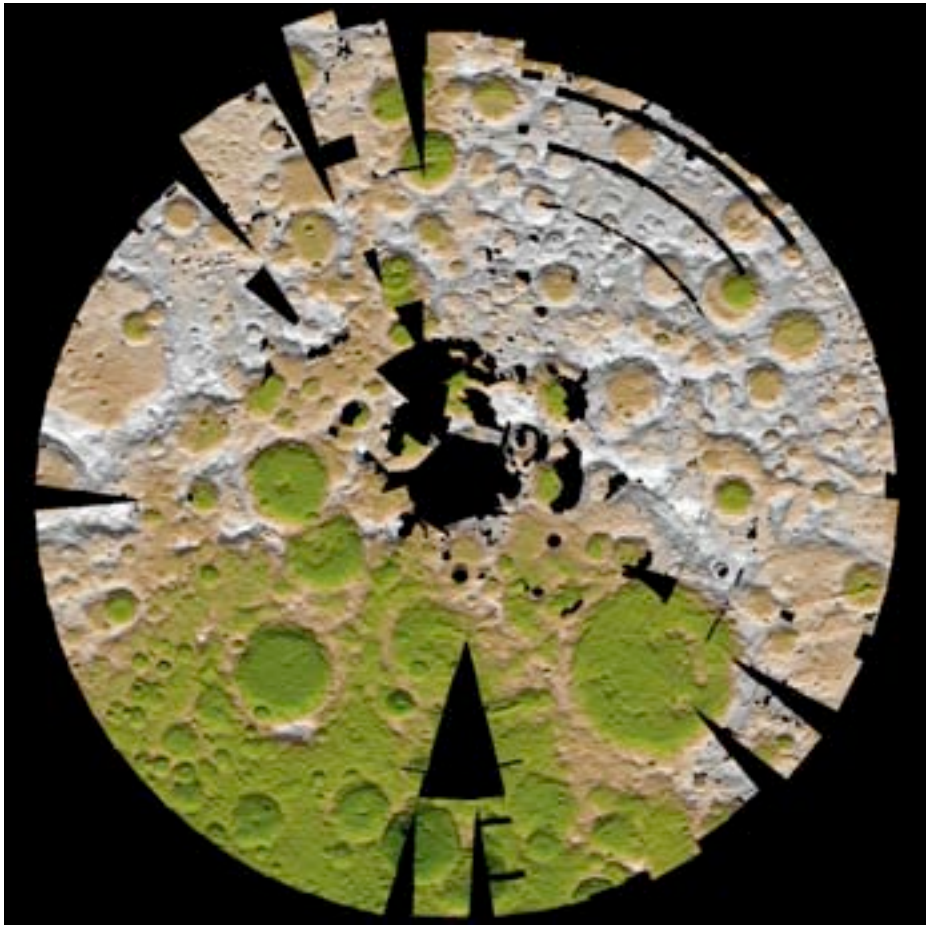
Data Acquisition



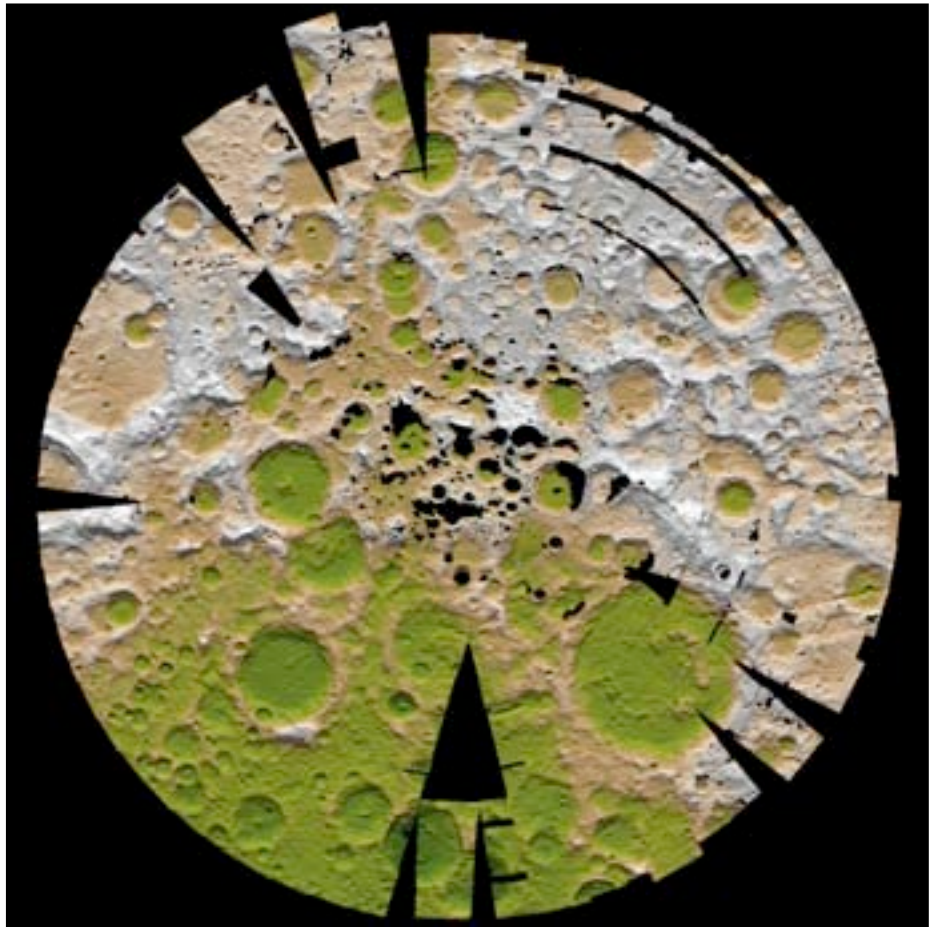
- Three ~90 min. acquisitions of Lunar South Pole data at optimum librations
- DEM processing to 40-m pixels, 5-m height accuracy complete
- Image processing to 20-m pixels nearly complete
- Being tested for planimetric, topographic accuracy against Unified Lunar Control Net, orbital photography

Fills in Gaps in Solar Illumination Imagery

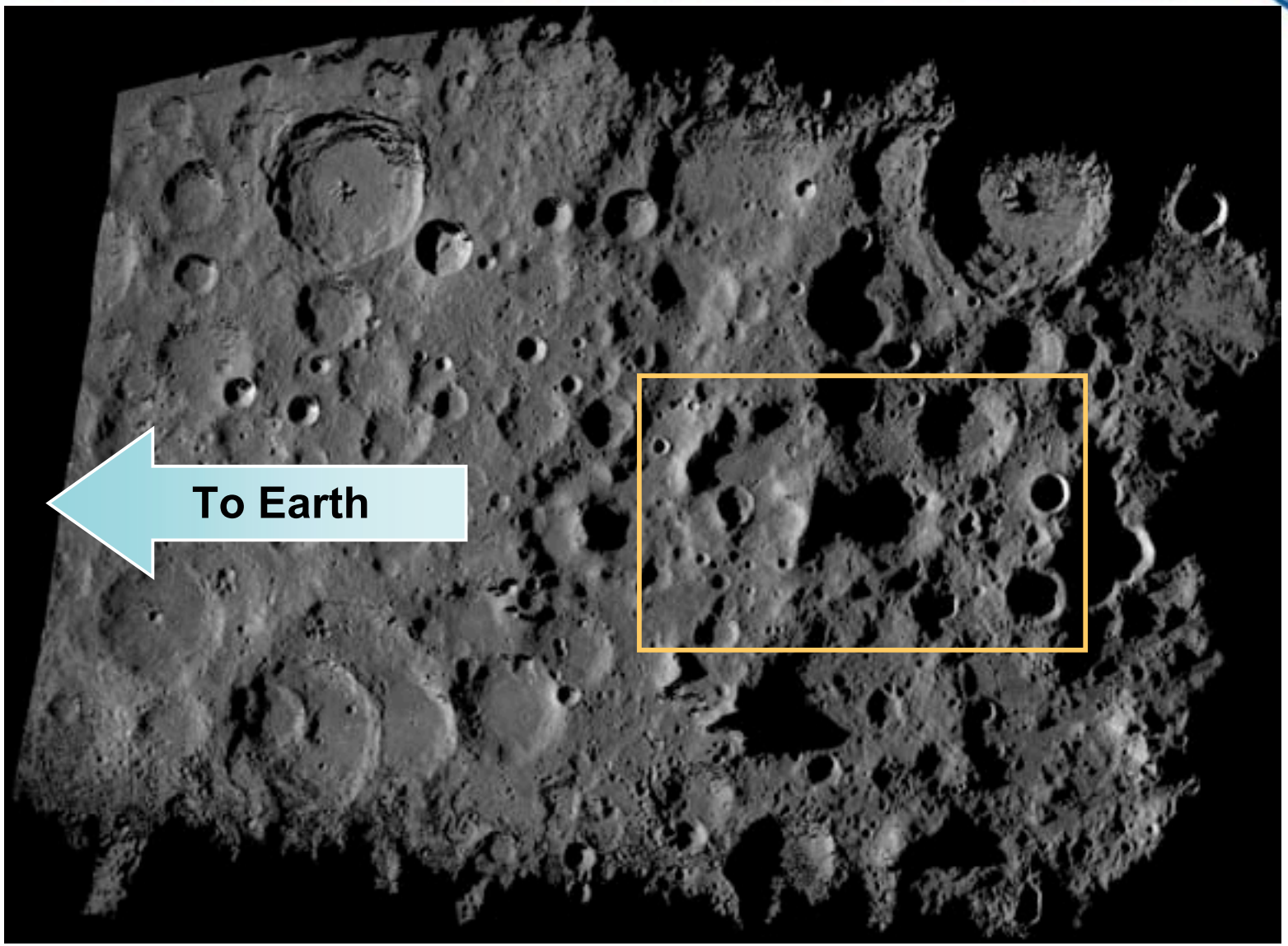
Clementine stereo topography

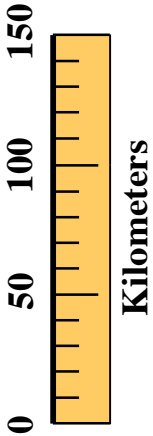


GSSR data overlay

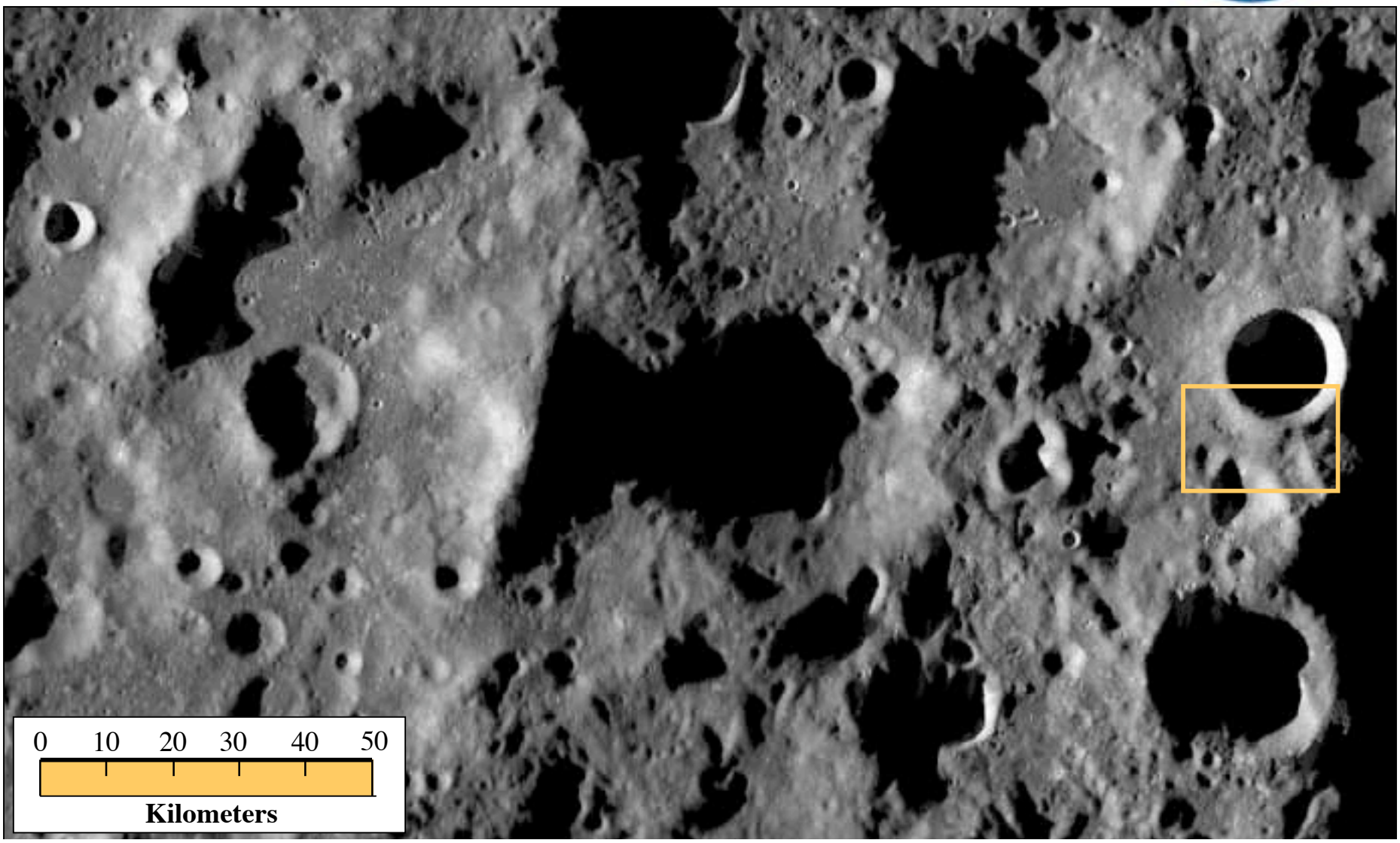


GSSR Image of South Pole Region

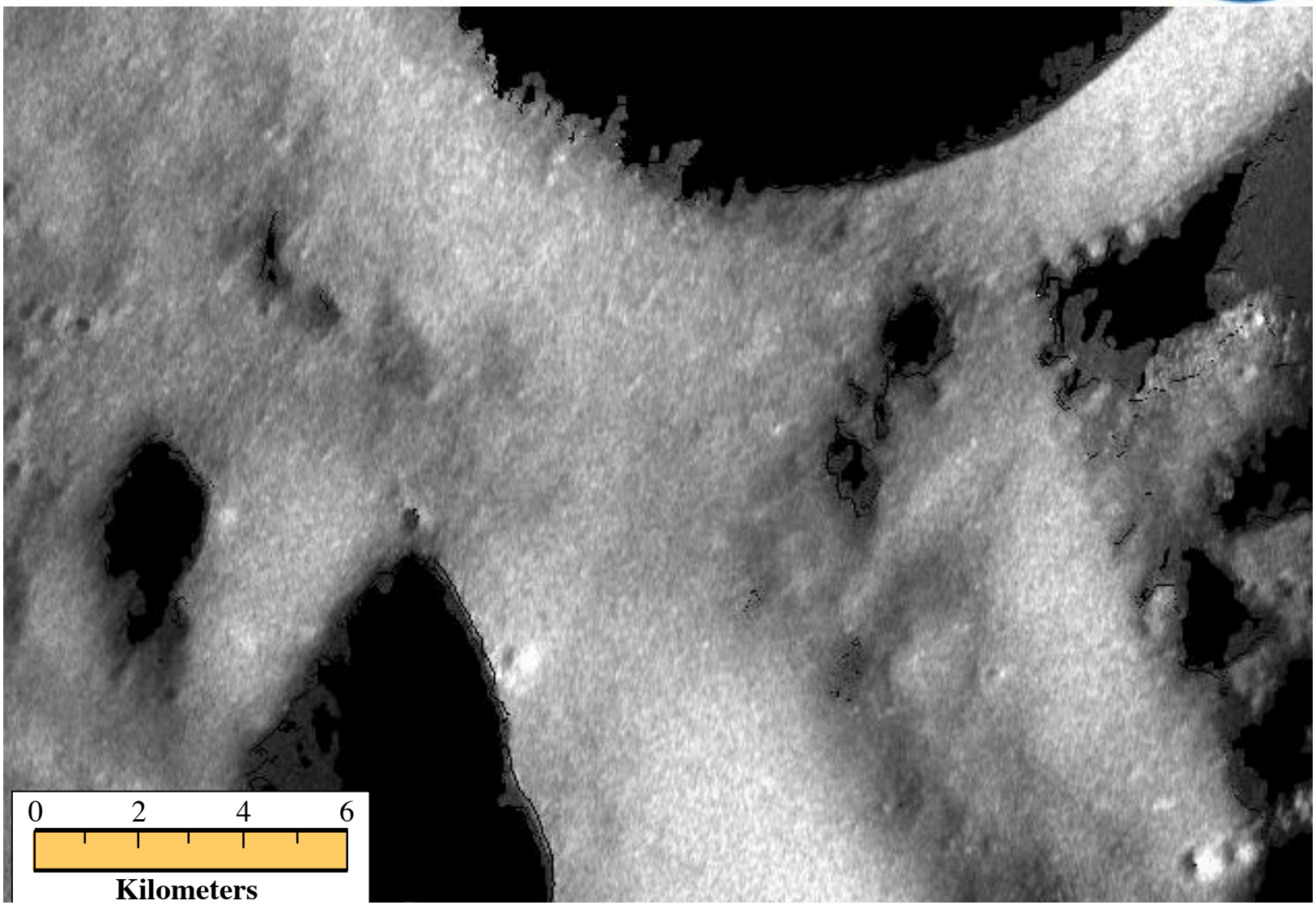




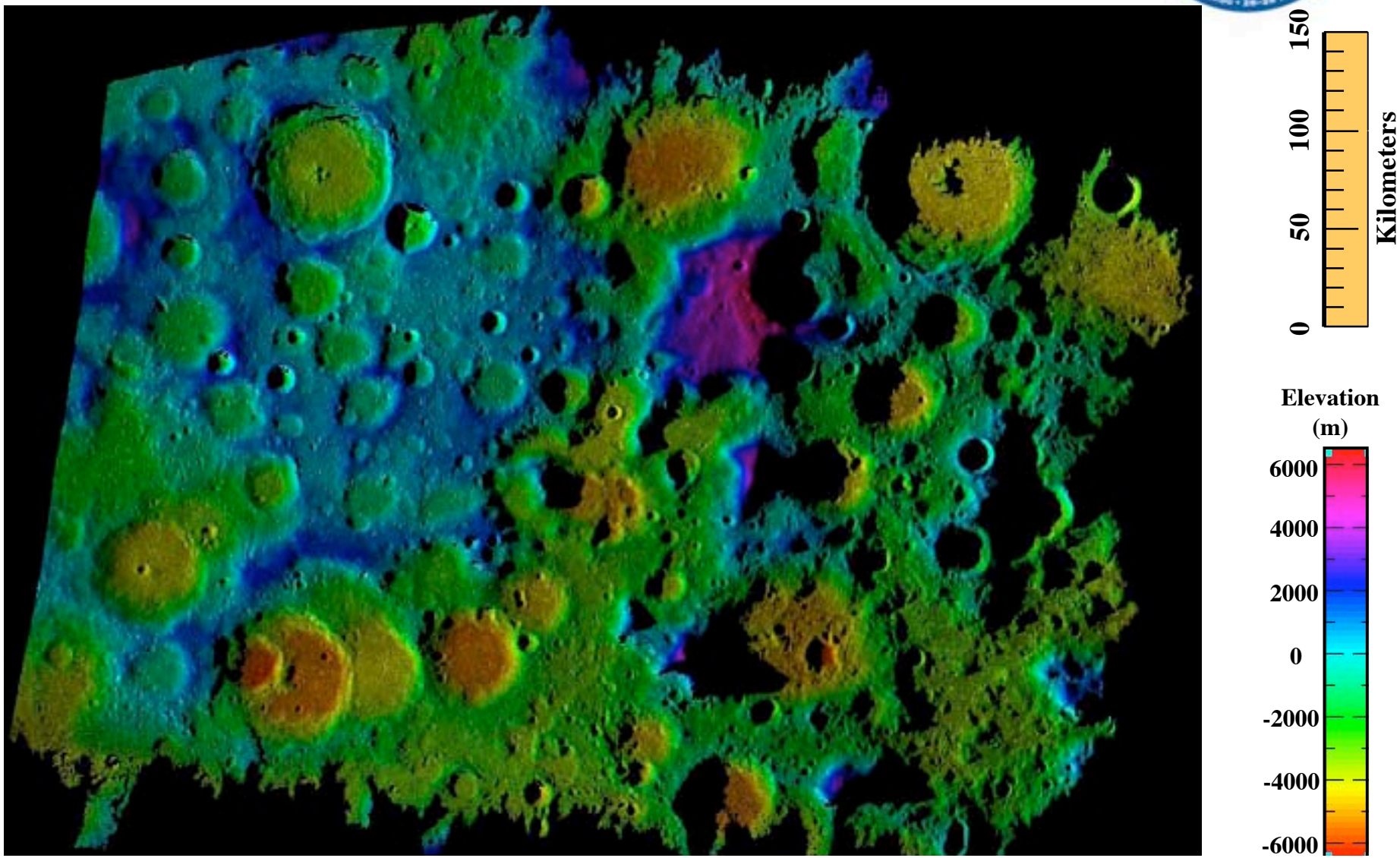
GSSR Image of South Pole Region



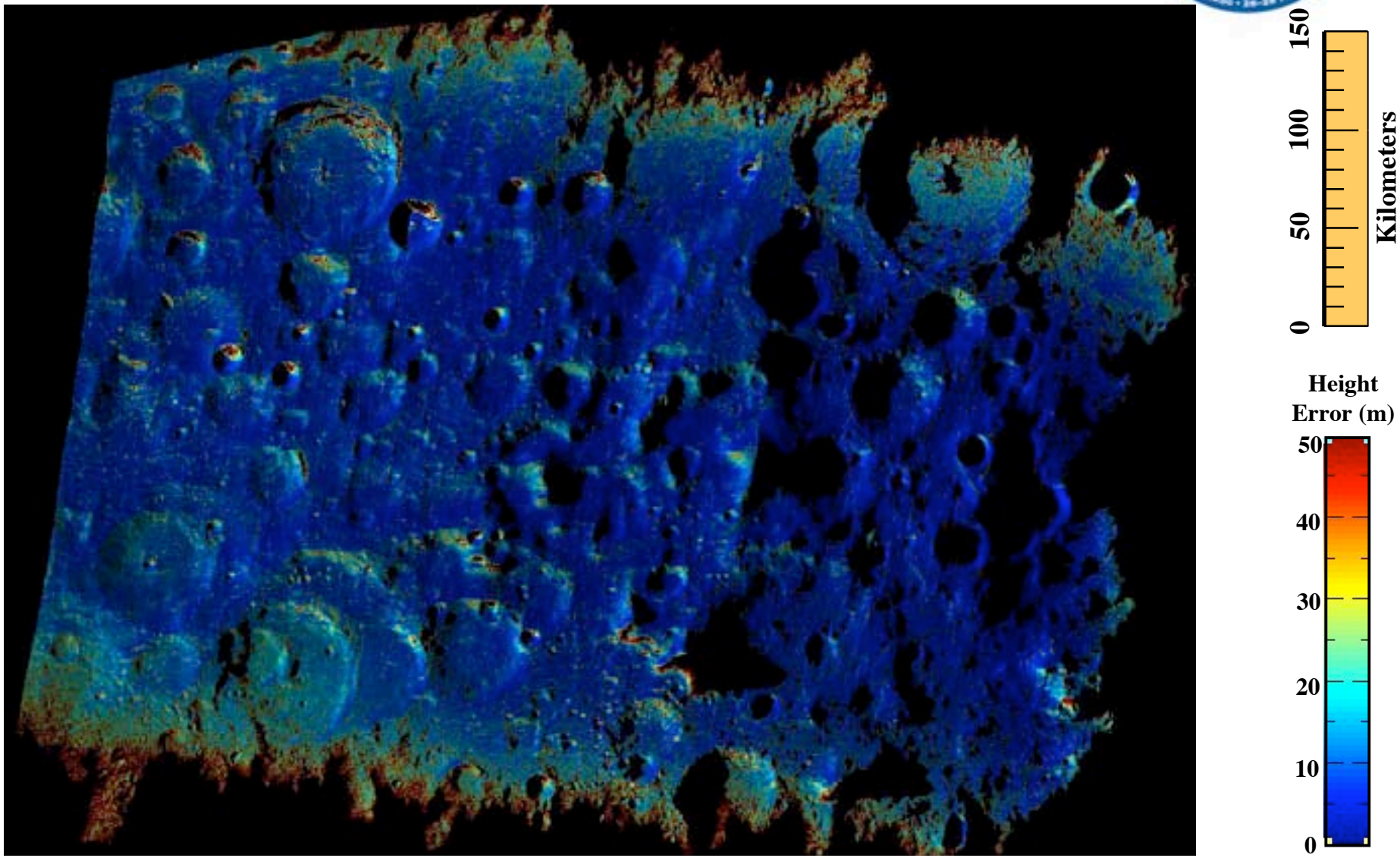
Enlargement of Shackleton Rim Area



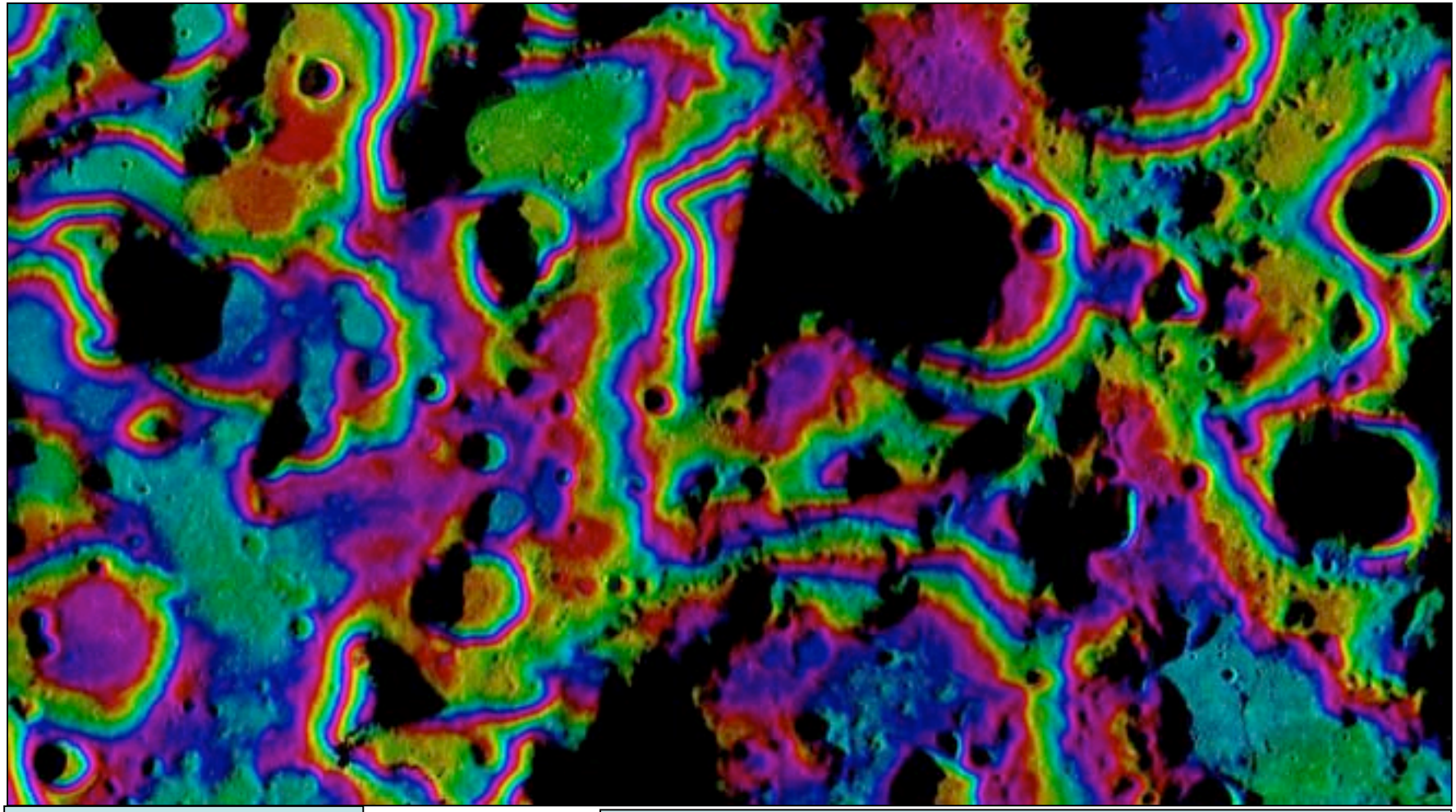
Digital Elevation Map of Lunar South Pole Region



Height Error Map



Contour Map



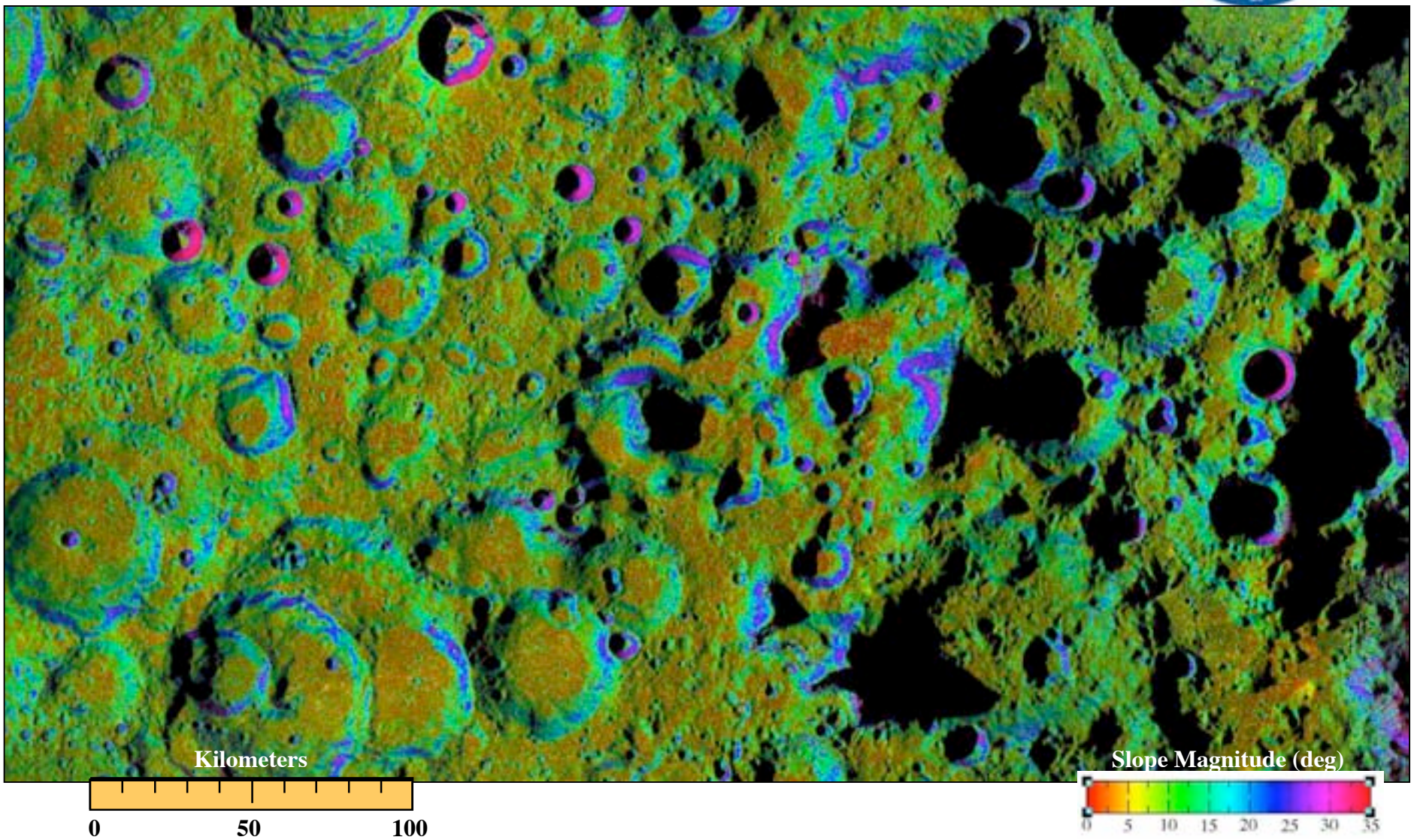
0 10 20 30 40 50

Kilometers

Contour lines: Each color cycle represents 2 km in elevation change

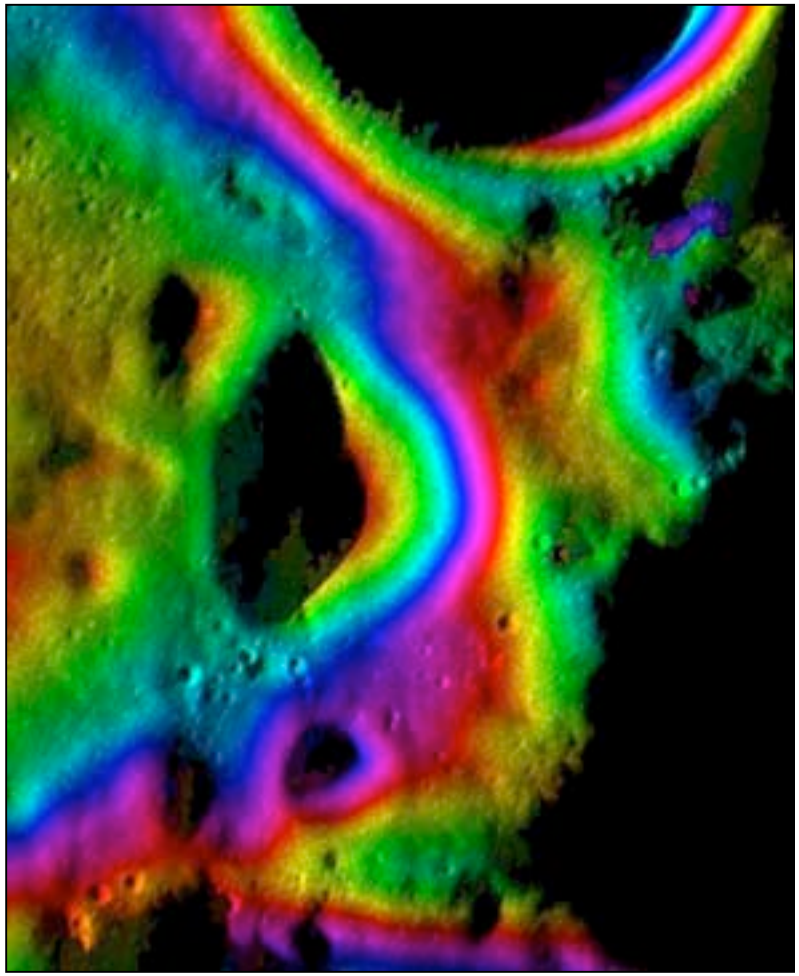
0 2 km 4 km

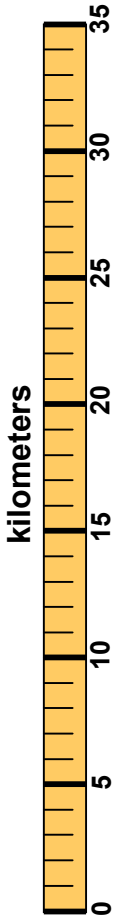
Slope Map



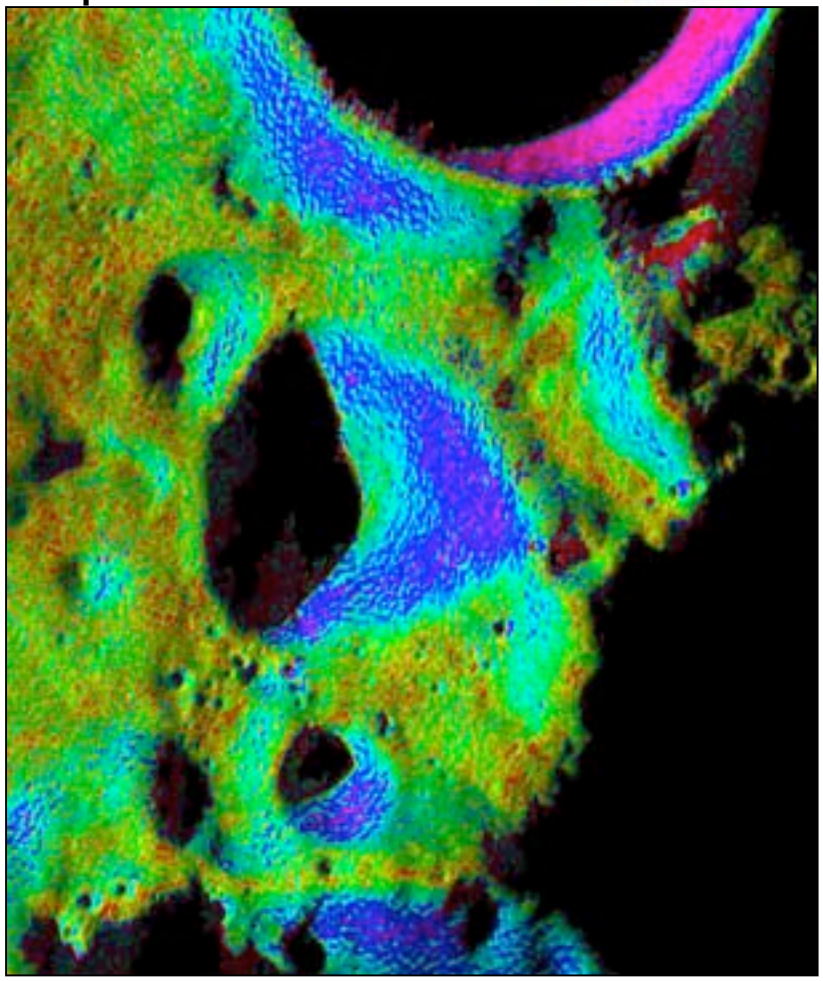
Shackleton Rim Area Detail

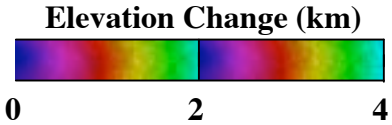
Elevation Contours

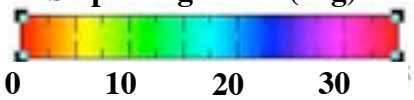




Slopes







3RD SPACE EXPLORATION
CONFERENCE & EXHIBIT
3RD SPACE EXPLORATION CONFERENCE
DENVER, COLORADO • 26-28 FEBRUARY 2008
Questions