Space Geodesy and Space Science

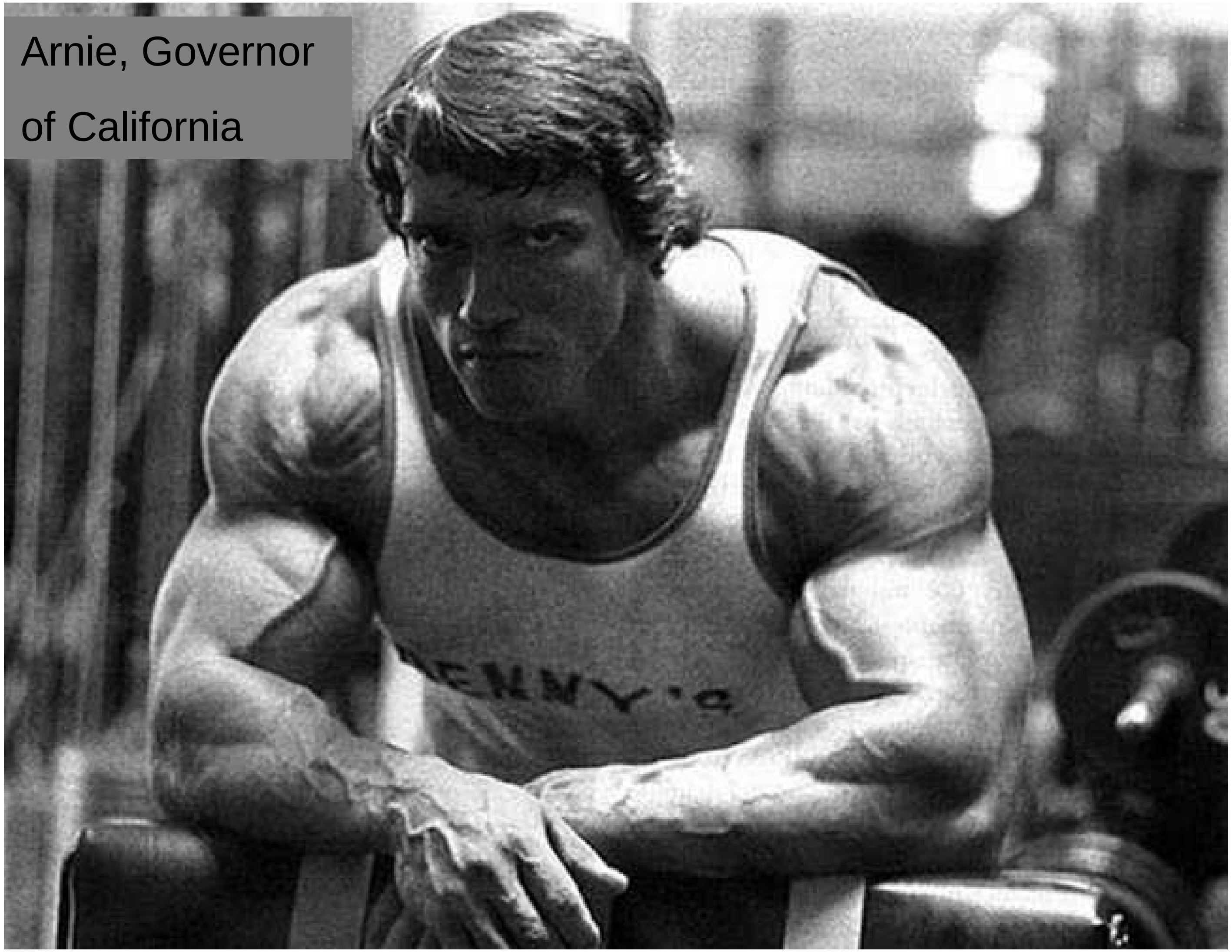
Ludwig Combrinck
HartRAO

3rd Space Geodesy Workshop
16 March 2009
Matjiesfontein

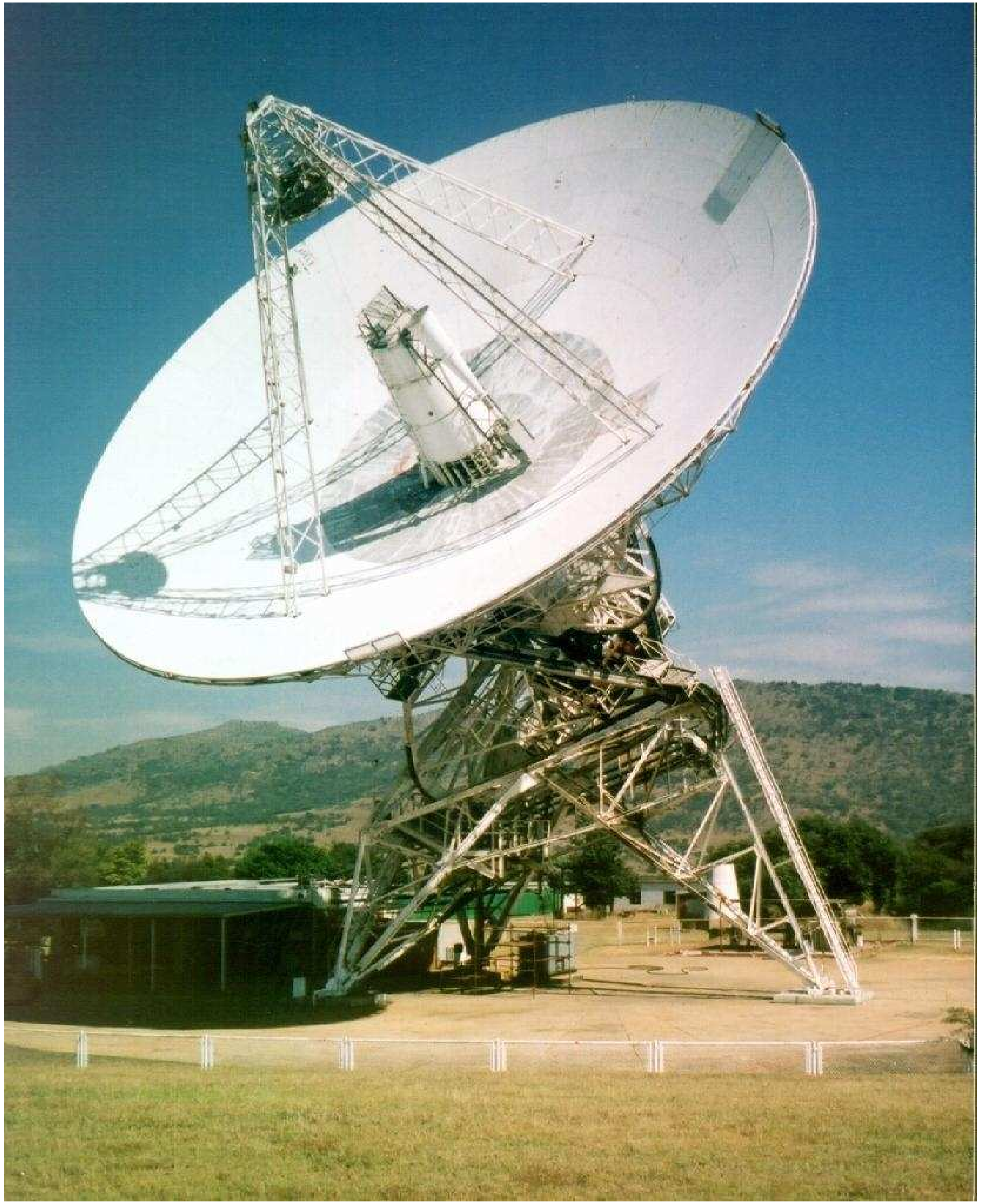
DST’s Concept of Space Science

- SA Space Agency, commercial applications, CSIR Satellite Applications Centre, space legislation and international protocols
- Where do we fit in?

In the USA, the politics and support for science are a bit different than in SA… Similar in Europe, Galileo etc. we have to find a niche and play a role where our size and capacity can be meaningful…..and grow through participation



Arnie, Governor of California



26 meter radio astronomy telescope used
for geodetic Very Long Baseline Interferometry (VLBI)

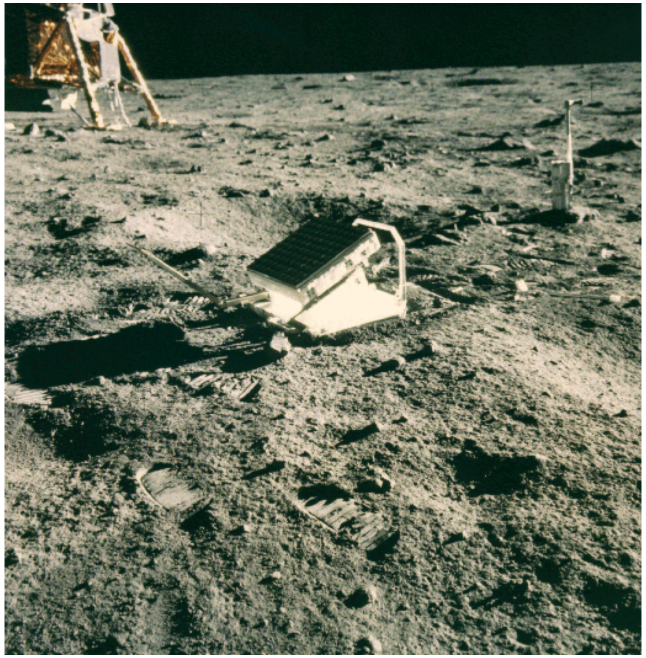
This telescope is used in a global network of similar telescopes, and observing quasars as ‘beacons’ can determine earth rotation, orientation of Earth’s axis and maintains the Celestial Reference Frame.

Satellite Laser Ranging (SLR), used for precise orbit determination, gravity field models,Tests of General Relativity

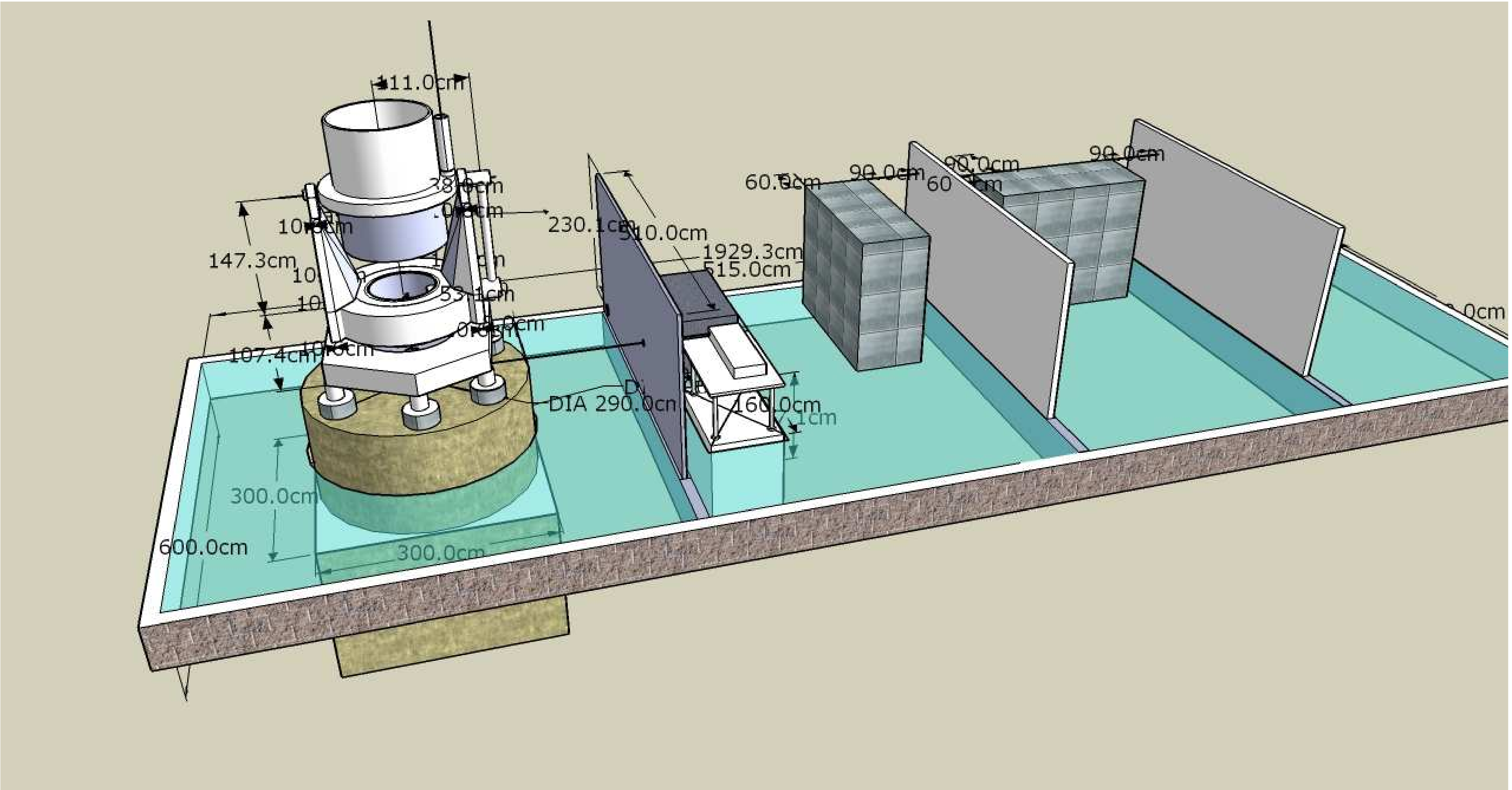
Lunar Laser Ranging (LLR)

The Space Geodesy Programme at HartRAO will develop a Lunar Laser Ranger in collaboration with France, NASA and local partners (CGS, CSIR, UNISA, UP) ….more partners sought (i.e are you interested?)

Very difficult project, sub cm distance measurement to the Moon, General Relativity, tests, Satellite tracking, only station in southern Hemisphere. Telescope to be refurbished and equipped at the CGS premises at Donkerhoek, final installation at new Space Geodesy observatory located at Matjiesfontein.



Started conceptual design of system, many alternatives, have to consider longevity and maintenance of complete system, not only the electronics, software and mechanics, but also some new innovative ideas will be sought



But not only observations using Earthbound telescopes, or photography from lunar orbiters, also RADAR observations

First radar signal bounced off the Moon Sept 1945 using 32 dipole array (US signal corps) ….could be used as passive relay for comms

The 70-meter antenna at the Goldstone complex in California.

Goldstone = 75 meter resolution

Arecibo (1000 ft), 20 meter resolution

Radar images, today are very impressive

During 2006, JPL scientists targeted the moon's south polar region using Goldstone's 70-meter radar dish. The antenna, three-quarters the size of a football field, sent a 500-kilowatt strong, 90-minute long radar stream 380 000 km to the Moon. Signals were reflected back to two of Goldstone's 34-meter antennas on Earth.

As wonderful as they are, however, these radar images will pale in comparison to next-generation photos from NASA's Lunar Reconnaissance Orbiter. The spacecraft is scheduled for launch in November 2008 and its camera will beam back pictures of the Moon with details as small as 1 meter.

The Lunar Reconnaissance Orbiter is the first mission in NASA's Vision for Space Exploration, a plan to return to the moon and then to travel to Mars and beyond. LRO has the objectives of finding safe landing sites, locate potential resources, characterize the radiation environment, and demonstrate new technology.

A Bold Vision for Space Exploration, Authorized by Congress

- Complete the International Space Station
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- Return to the Moon no later than 2020
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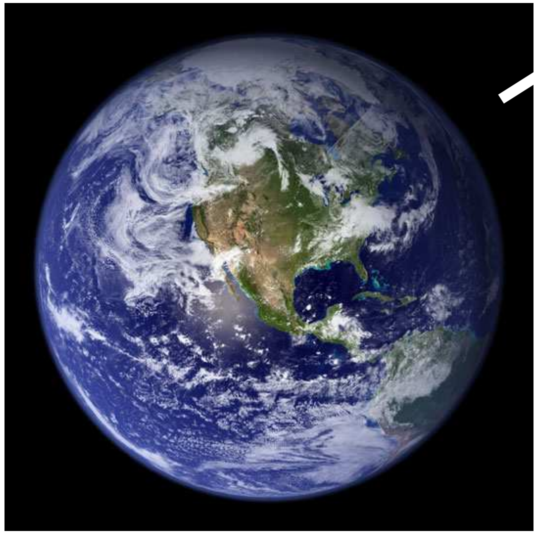
NASA Authorization Act of 2005

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.

Human Exploration of the Moon and Mars



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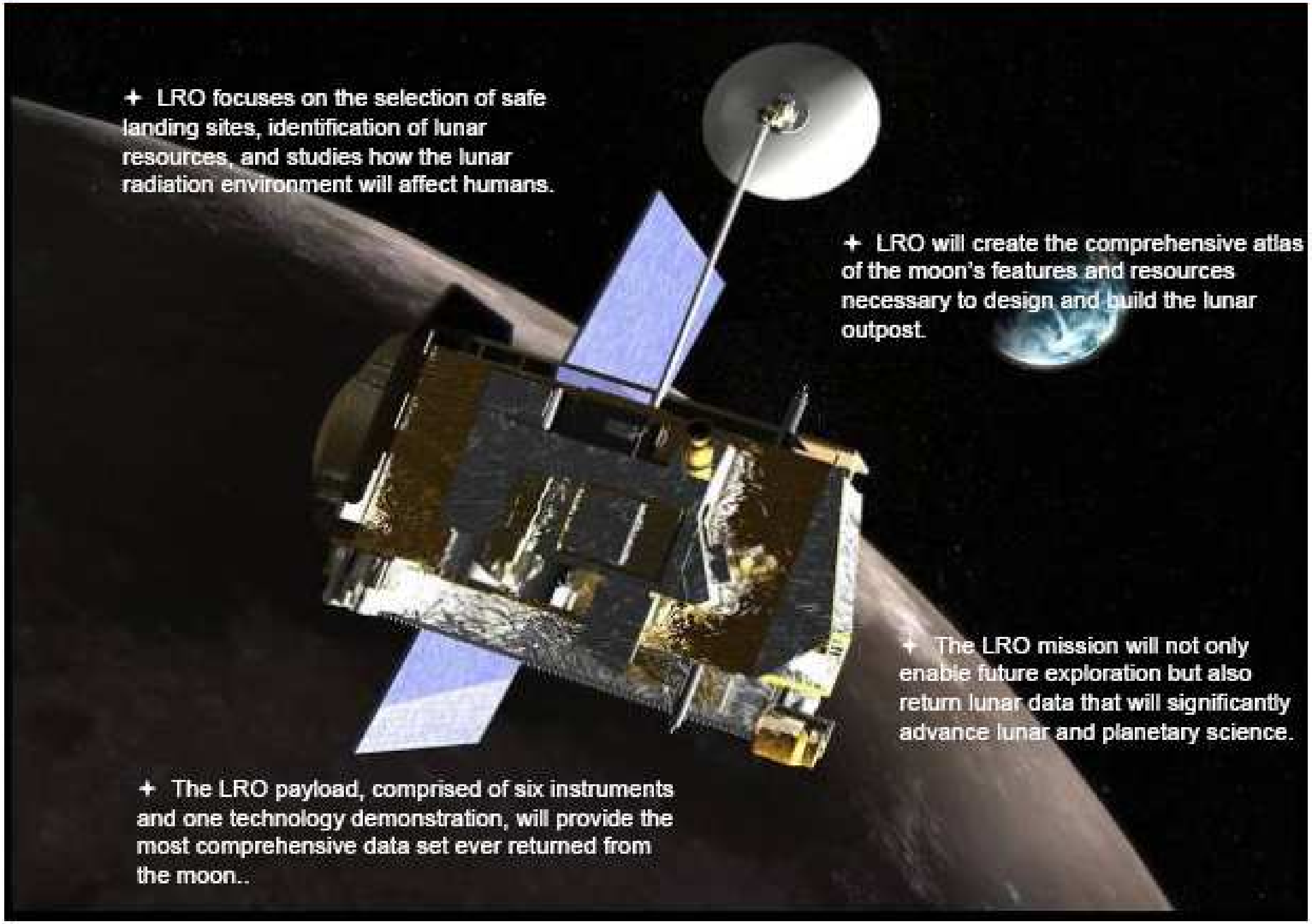

The Space Geodesy programme at HartRAO will participate in the LRO Mission by ranging to it with the SLR

Lunar Reconnaissance Orbiter (LRO) – Laser Ranging (LR) Overview

LRO is requesting ILRS support for one-way laser ranging

- Transmit 532 nm laser pulses at =< 28Hz to LRO
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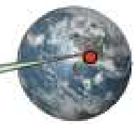
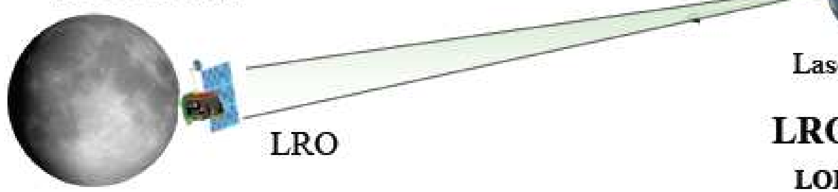
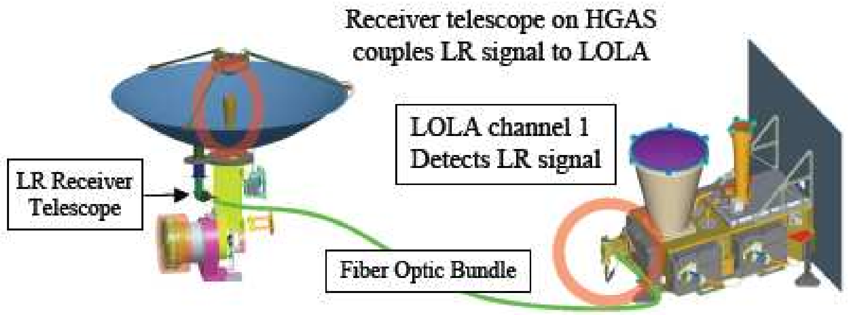




Laser Station



LRO Mission Includes:

LOLA, laser altimeter

LROC, camera

LAMP, Lyman alpha telescope

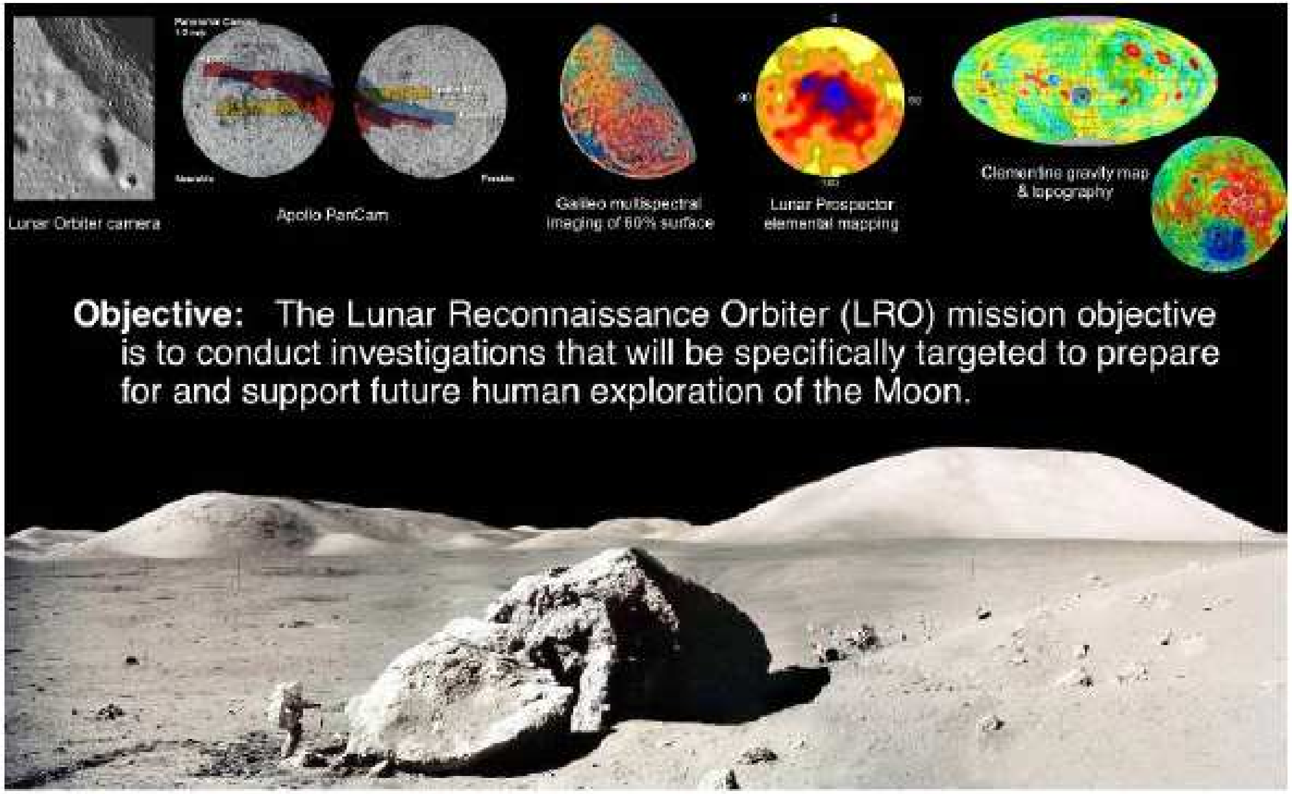
LEND, neutron detector

DIVINER, thermal radiometer

CRATER, cosmic ray detector

mini-RF, radar tech demo

Lunar Reconnaissance Orbiter
Mission Objectives



Locate Potential Resources
Hydrogen/water at the lunar poles
Continuous solar energy
Mineralogy

Safe Landing Sites
High resolution imagery
Global geodetic grid
Topography
Rock abundances

Space Environment
Energetic particles
Neutrons

Orbiter Instrumentation

LROC/WAC: Wide-Angle Camera

- Global Imagery
- Lighting
- Resources

Day Side
Autonomous

LROC/NACs: Narrow-Angle Cameras

- Targeted Imagery
- Hazards
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Day Side
Timeline Driven

LOLA: Lunar Orbiter Laser Altimeter

- Topography
- Slopes
- Roughness

Full Orbit
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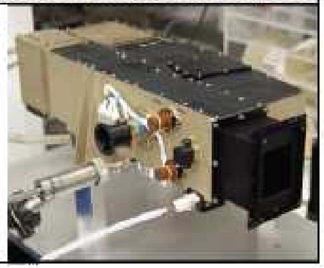

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- Tech Demonstration
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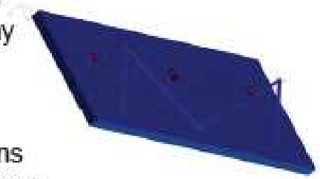

Polar Regions
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LEND: Lunar Explr. Neutron Detector

- Neutron Albedo
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CRaTER: Cosmic Ray Telescope…

- Radiation Spectra
- Tissue Effects

Full Orbit
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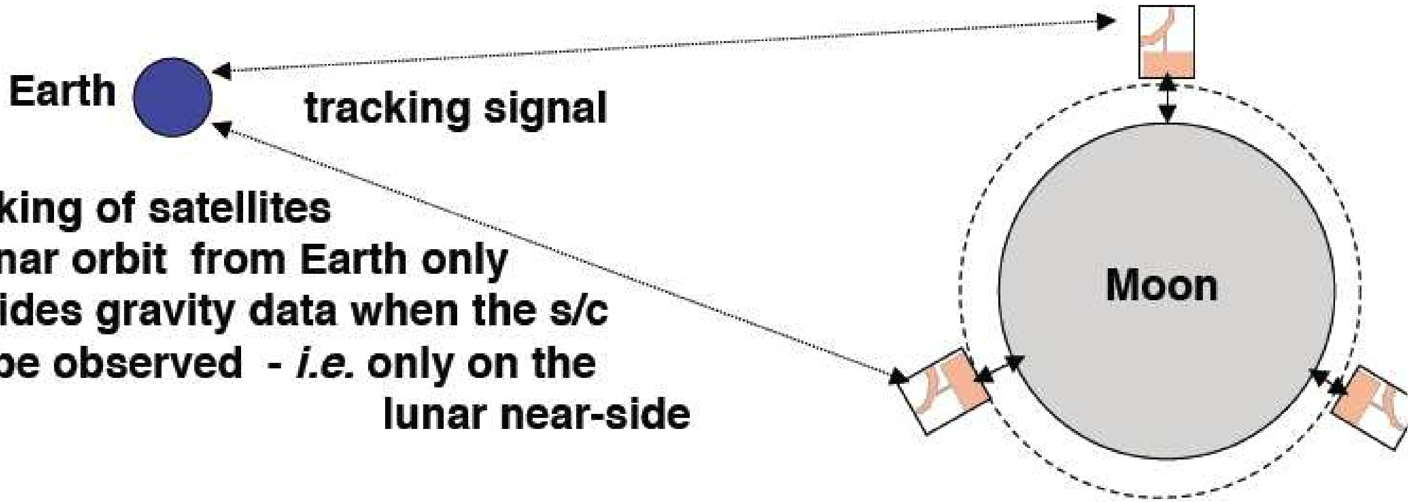
LRT: Laser Ranging Telescope

- Topography
- Gravity

LRGS LOS
Autonomous

Improving the Lunar Gravity Field



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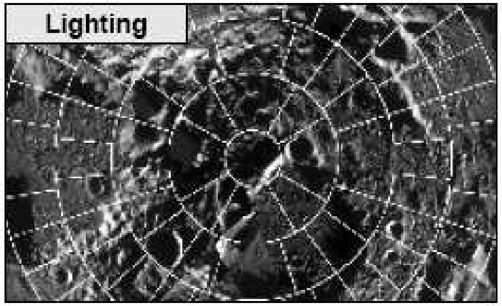
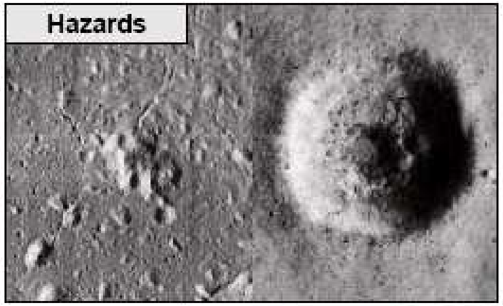
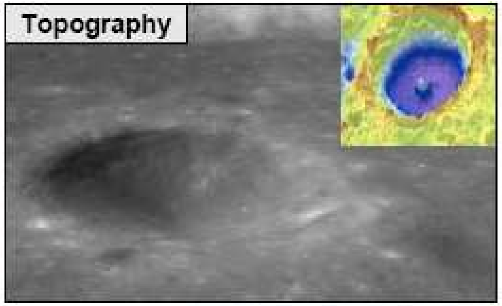
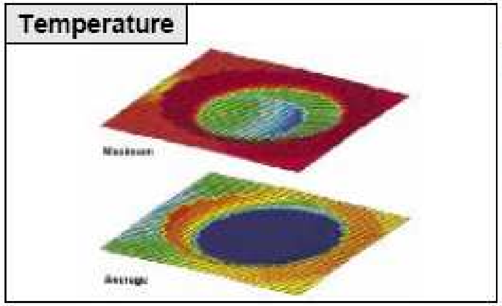
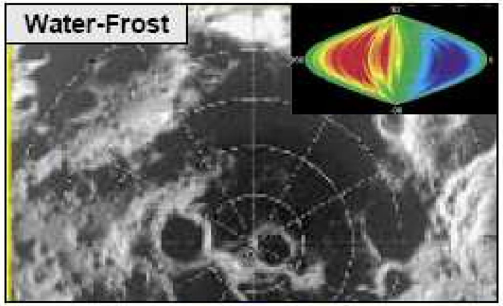
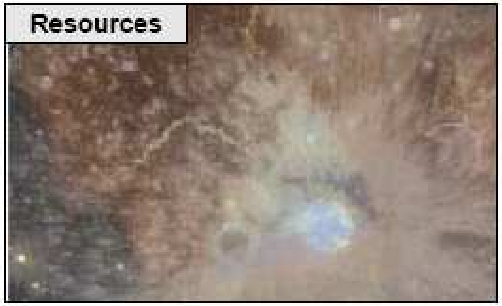


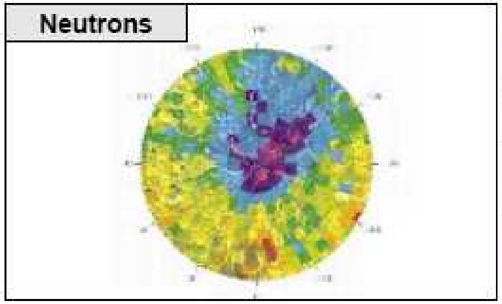


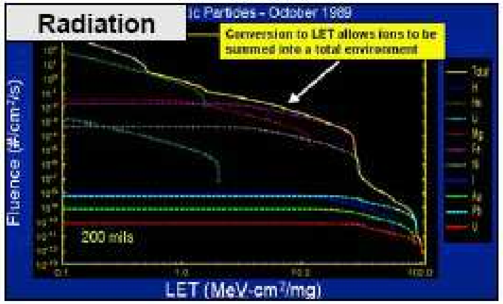


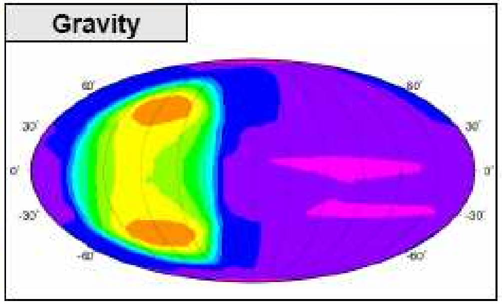


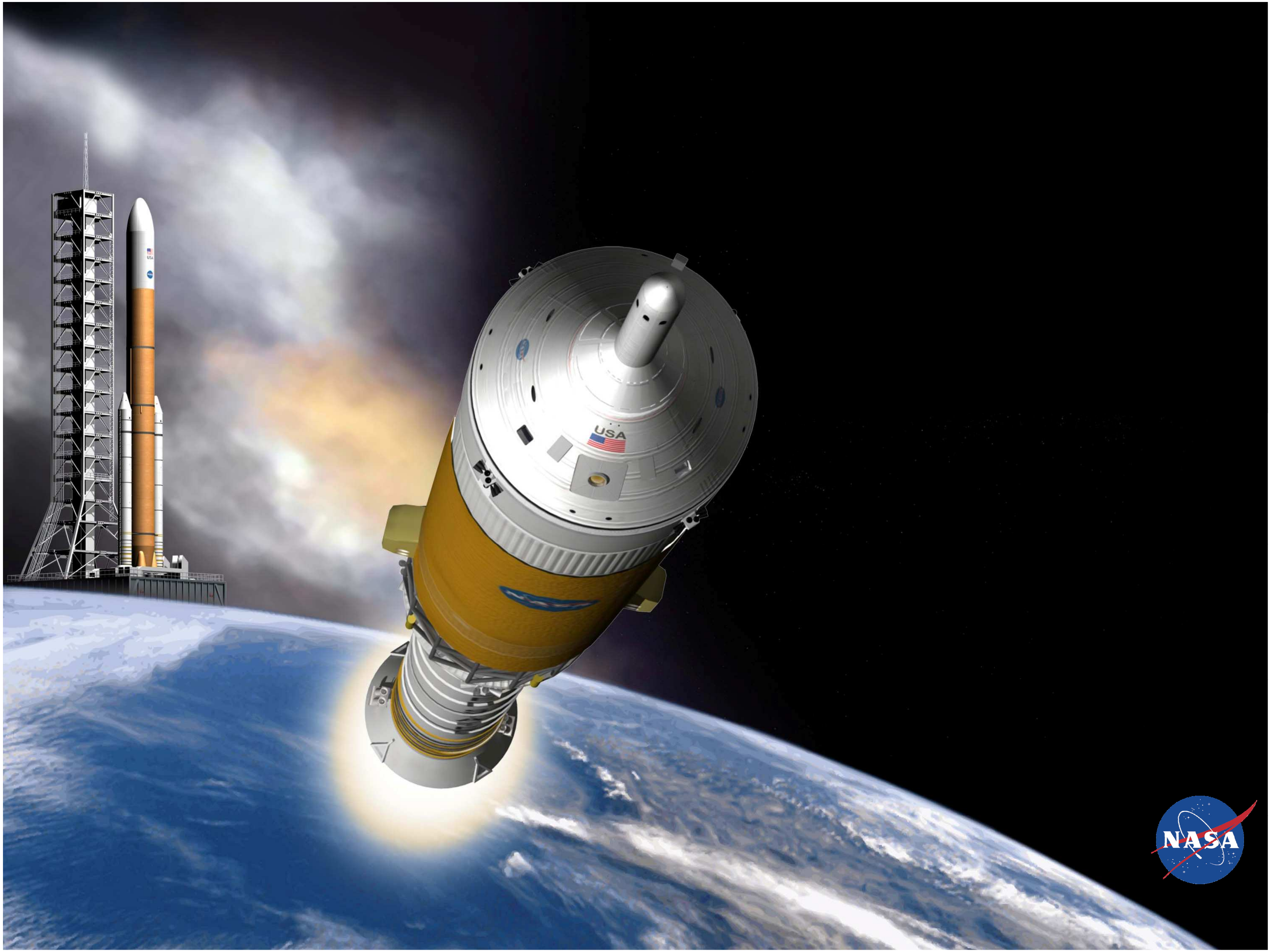


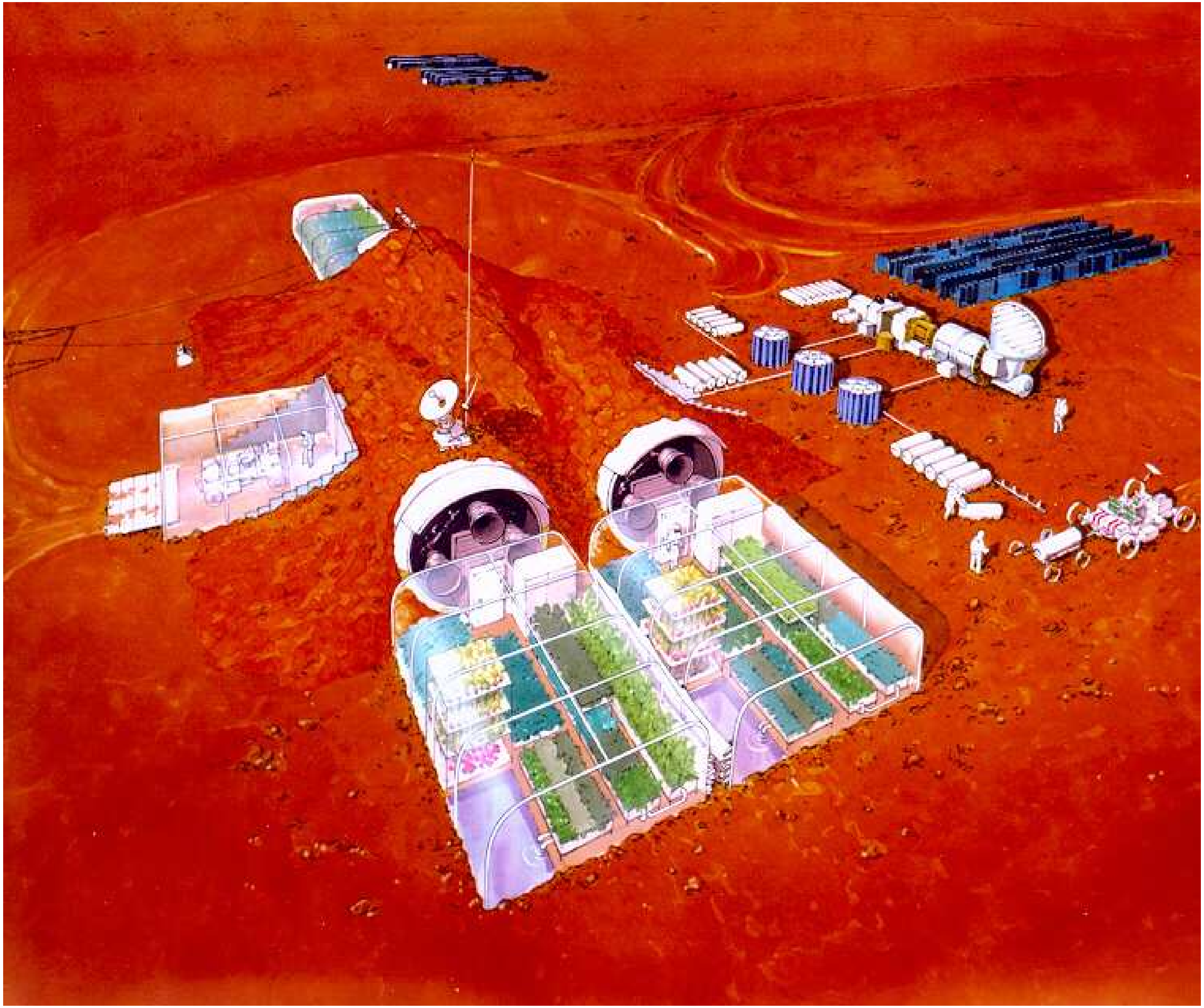






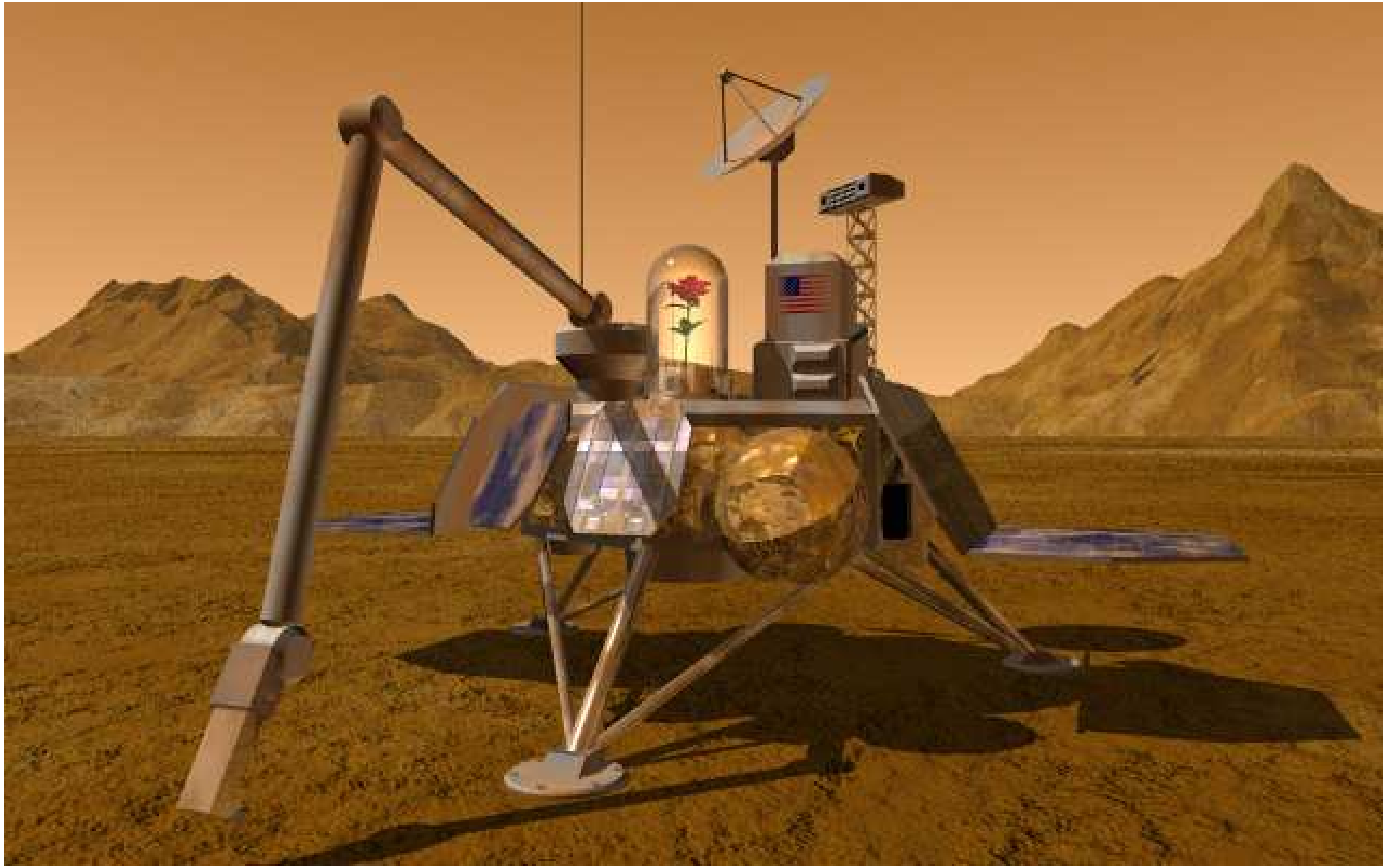



USA
NASA



Near-term missions

Using the martian soil and atmosphere for a plant growth module



Back to the Moon…is it just a USA venture?

No…Italy, Japan, India, China, all have plans

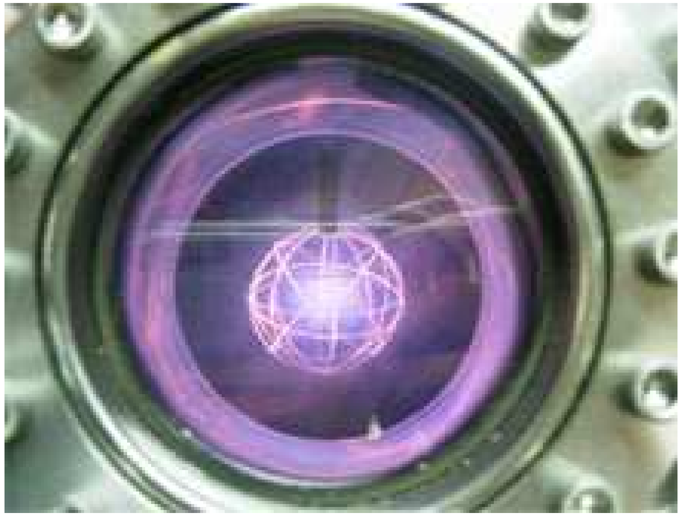
And they certainly intend to mine the Moon

In this artist's rendering, released by the Japan Aerospace Exploration Agency, a piloted spacecraft heads out from Earth toward the moon in the year 2025.

...and they all certainly intend to mine the Moon, and use the Moon as a test bed for Mars Exploration (and colonisation)

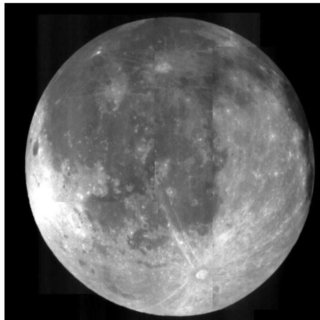
USA permanent Moon base by 2024
Russia by 2015-2020

One reason for much of the interest appears to be plans to mine Helium3, (embedded in the upper layer of regolith by the solar wind over billions of years) purportedly an ideal fuel for fusion reactors but almost unavailable on Earth--from the Moon's surface.



He3 fusion reactor

Finish!



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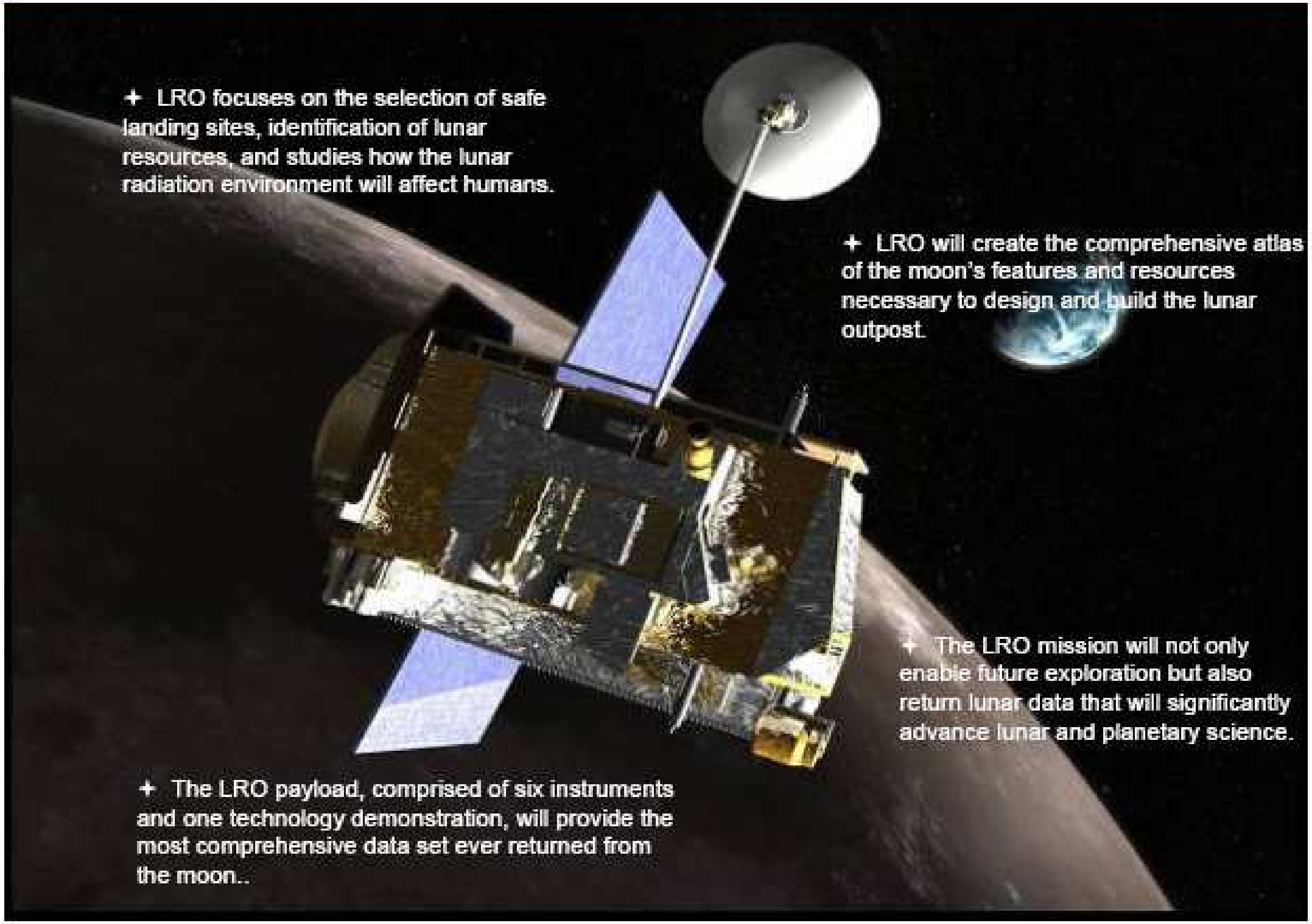

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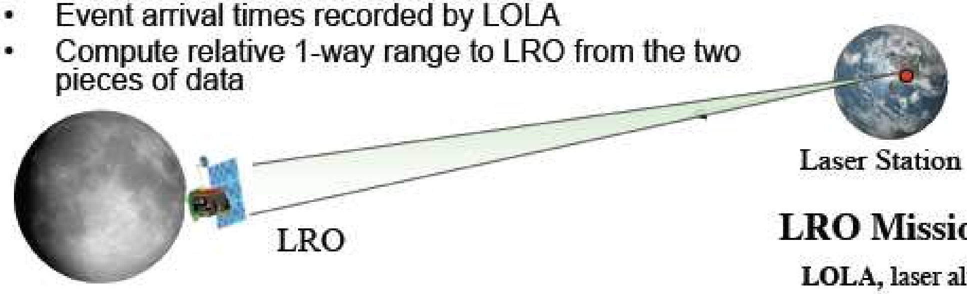

LRO Mission Includes:

- **LOLA**, laser altimeter
- **LROC**, camera
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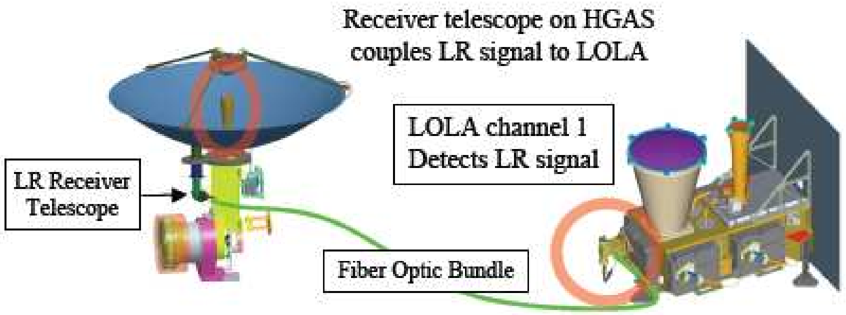
- **mini-RF**, radar tech demo

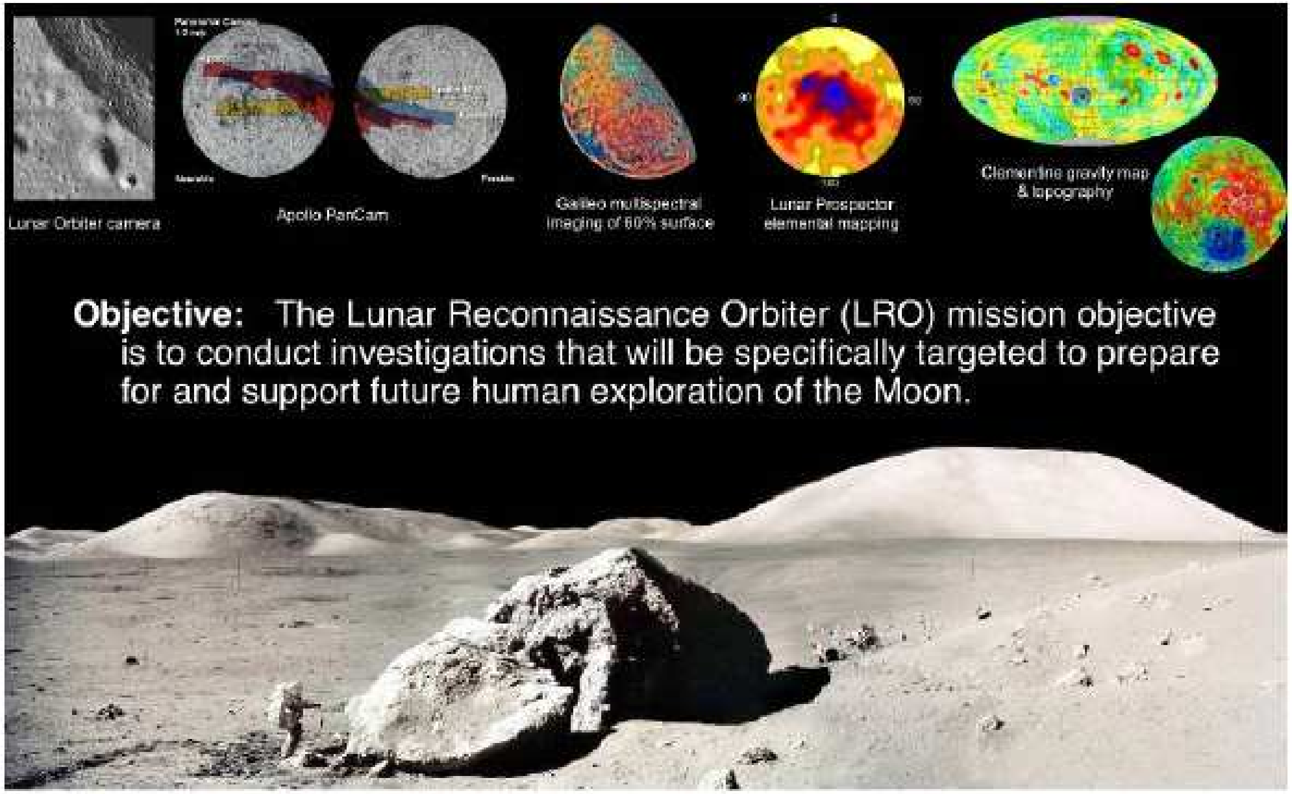


Laser Ranging Overview

- LR will support the precision orbit determination process that will, in conjunction with S-band tracking and LOLA altimetry, enable improved positioning of LRO and improvements to the lunar gravity field model.
  - 25 to 50 meter positioning of LRO in horizontal position over both lunar near and far side
  - Improve instrument targeting

- LR will provide 1-way range measurements between earth station(s) and LRO to better than 10cm precision.
  - SLR2000 transmits laser pulses at 532.2 nm synchronized to the LOLA instrument operating cycle of 28 Hz.
  - Participating ILRS stations transmit asynchronously (eg MLRS at 10 Hz).
  - LOLA detects the LR signals and transmits this information and receive energies in the LOLA telemetry packet for "real-time" feedback to stations.
  - LOLA SOC generates range data from ground station fire times and LOLA receive events.

Lunar Reconnaissance Orbiter
Mission Objectives



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Continuous solar energy
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Safe Landing Sites
High resolution imagery
Global geodetic grid
Topography
Rock abundances

Space Environment
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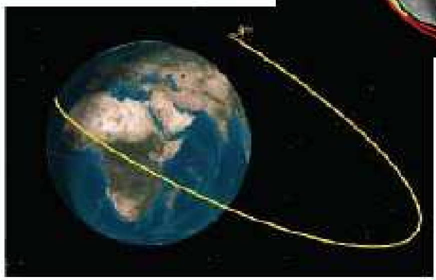
Neutrons

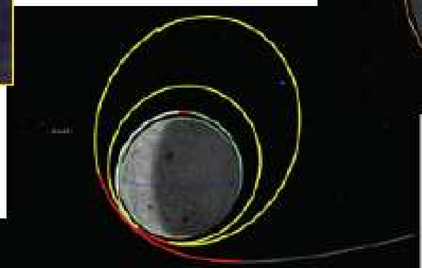
LRO Mission Overview

Launch: October 28, 2008

Minimum Energy
Lunar Transfer ~ 4 Days



Lunar Orbit Insertion
Sequence, 4-6 Days

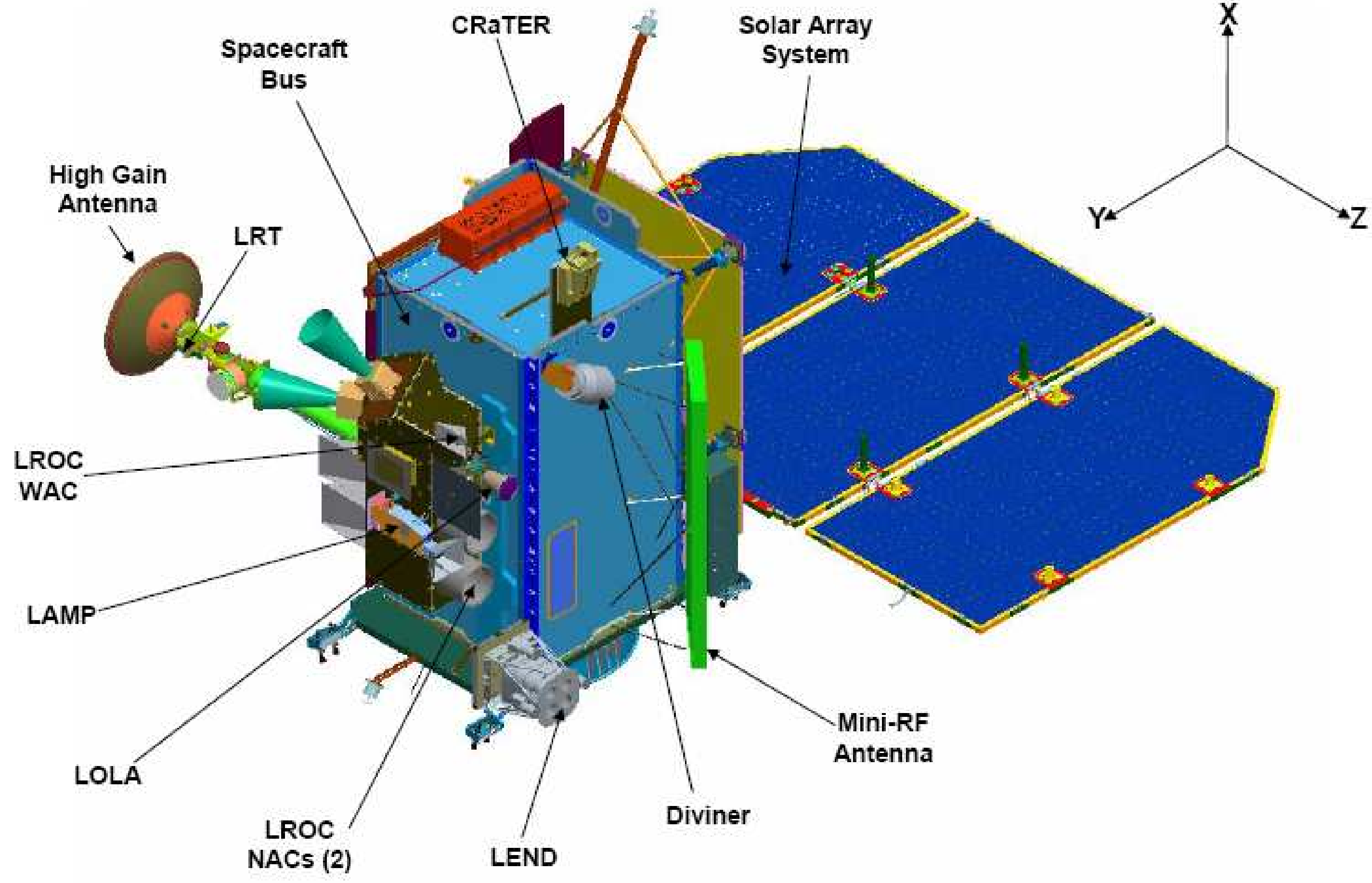


Commissioning Phase,
30 x 216 km Altitude
Quasi-Frozen Orbit,
Up to 60 Days

Polar Mapping Phase,
50 km Altitude Circular Orbit,
At least 1 Year

Nominal End of Mission: February 2010

LRO Spacecraft



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- Global Imagery
- Lighting
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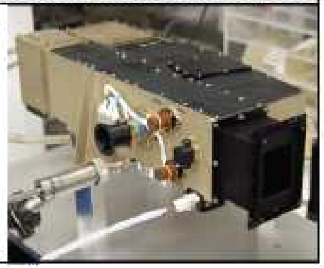

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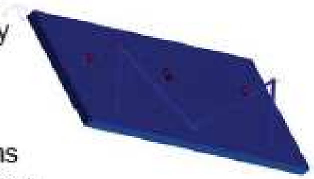

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- Radiation Spectra
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LRT: Laser Ranging Telescope

- Topography
- Gravity

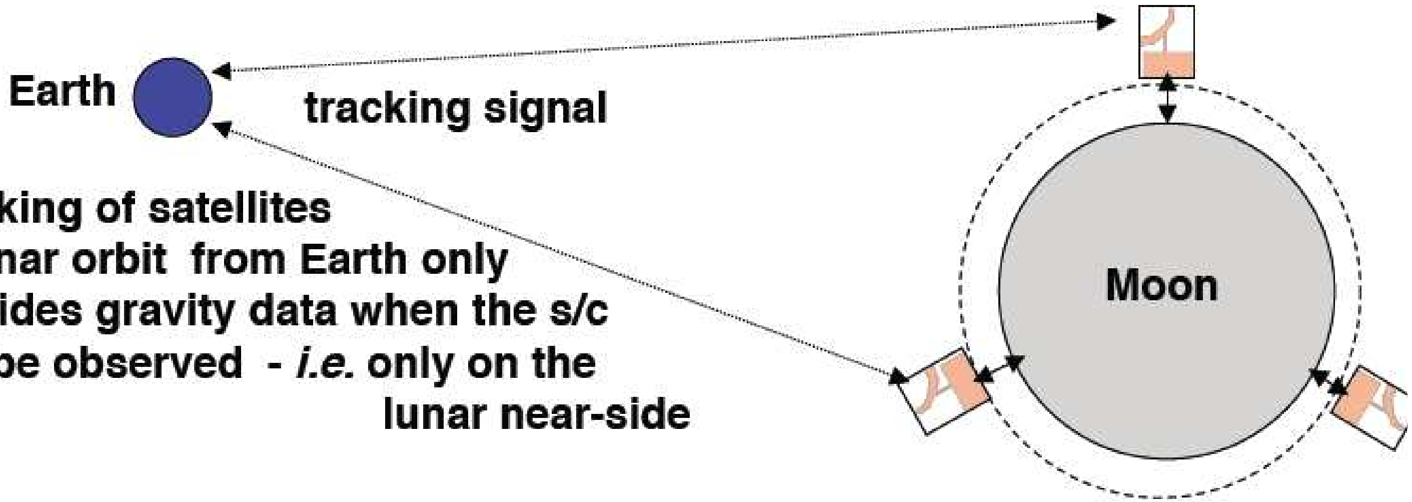
LRGS LOS
Autonomous

Required Science Measurements by LR

LR measurements will:

- Provide relative range measurements to LRO spacecraft at <10-cm precision, at 1 Hz.
- Maintain range stability to ±1 m over 1 hour.
- in conjunction with the S-band data and the LOLA altimeter data, allow the orbit of the LRO spacecraft to be determined within 50 m along track, 50 m across track, and 1 m radial.
- improve the targeting of LROC by improving the prediction of the LRO orbit.
- allow every LROC pixel coordinate to be known to 50 meters and all LRO data co-registered at the 50-m horizontal level.
- improved knowledge of the lunar gravity model to enable visiting a particular location to within ~50 m.

Improving the Lunar Gravity Field



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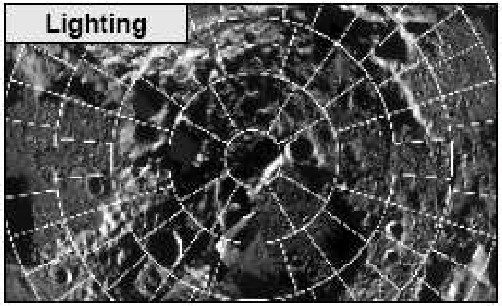
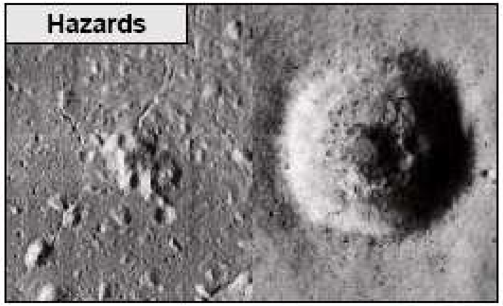
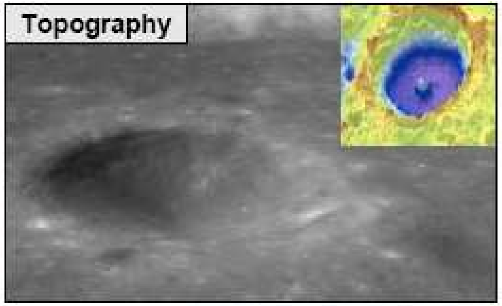
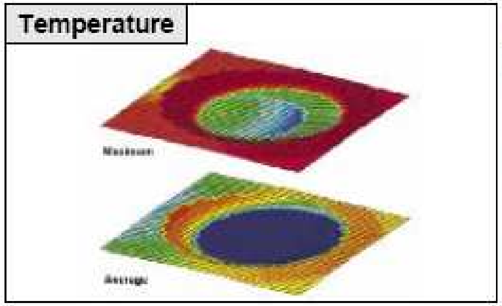
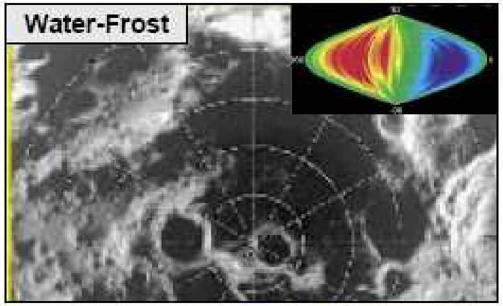
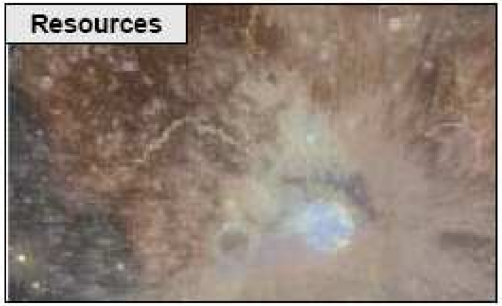


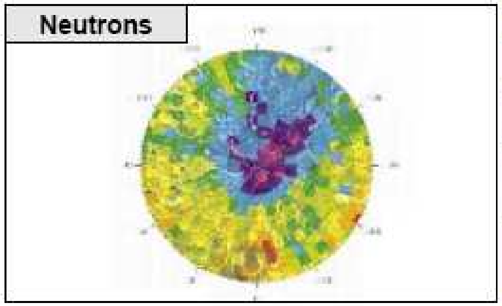


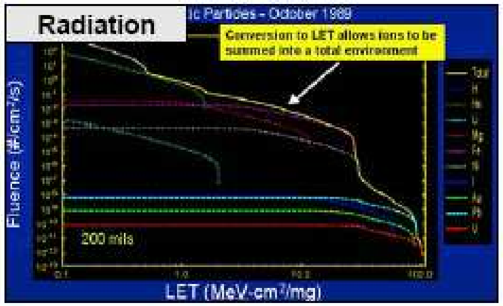


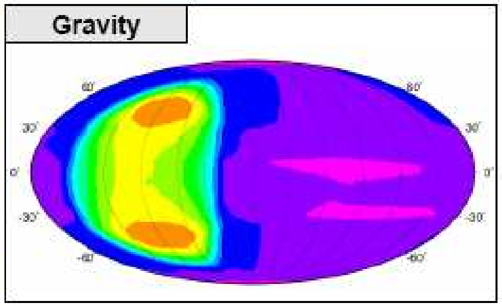












Configuration changes needed to Moblas-6

Picosecond event timer, to be integrated into sysytem

Ground System Requirements

- Deliver between 1 and 10 femtoJoules per sq.cm of signal to the receiver aperture. For SLR2000 (55 microrad laser divergence) → 30mJ per pulse.

- Wavelength must be 532.2 +- 0.15 nm. LRO filter throughput will be 50% at 532.05 and 532.35 nm (many ILRS stations fall within this wavelength region).

- Laser pulsewidth =< 8ns (onboard system bandwidth is ~6ns).

- Maintain the transmitted pulse time stamp accuracy to within 100 ns of UTC.

- Measure the relative laser time of fire to better than 200 ps (1 sigma) shot-to-shot over a 10 sec period. Laser fire time must be recorded to <100 psec resolution.

- Deliver laser pulses into the LOLA earth window at least once per second. Laser fire rate cannot exceed 28 Hz because it will affect LOLA threshold!

- Shot to shot measurement of the output laser energy is desired.

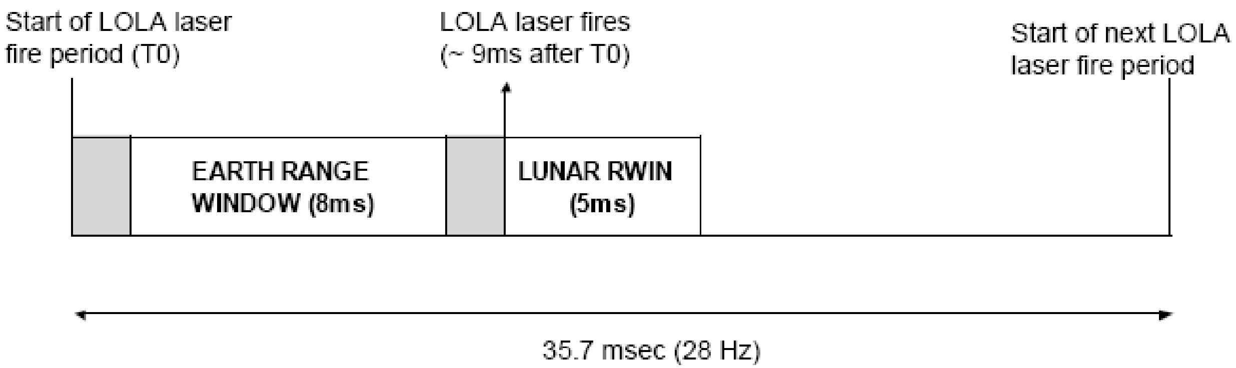
- Data should be delivered to CDDIS in new CRD format daily (or faster).

One LOLA Detector does both earth and lunar

- Two range windows in one detector: fixed 8 msec earth and up to 5 msec lunar.

- Range to LRO changes ~ 5-10 ms over an hour's visibility.

- Need to either synchronize the ground laser fires to LOLA to ensure pulses land in every Earth Window, or fire asynchronously to LOLA (eg 10Hz).



Getting Pulses into the LOLA Earth Window

➢ **Method #1 (SLR2000): synchronize to LOLA**

-Must compensate for range changes (5-10 msec per hour).

-Knowledge of UTC to spacecraft MET will be good to < 3 msec.

-Start of LOLA fire interval (35.7 ms) is sychronized to MET.

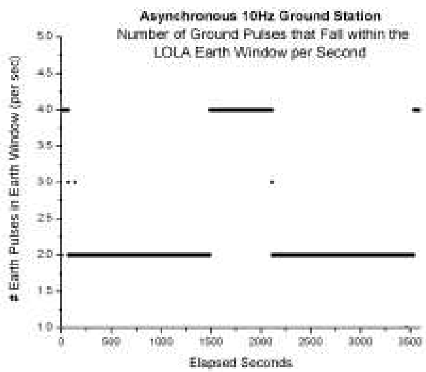
-LOLA earth window opens 1.0 msec after start of fire interval.

-LOLA earth window is open for 8 msec.

➢ **Method #2: run asynchronous to LOLA but at a fire rate that ensures at least one pulse per second into the earth window.**

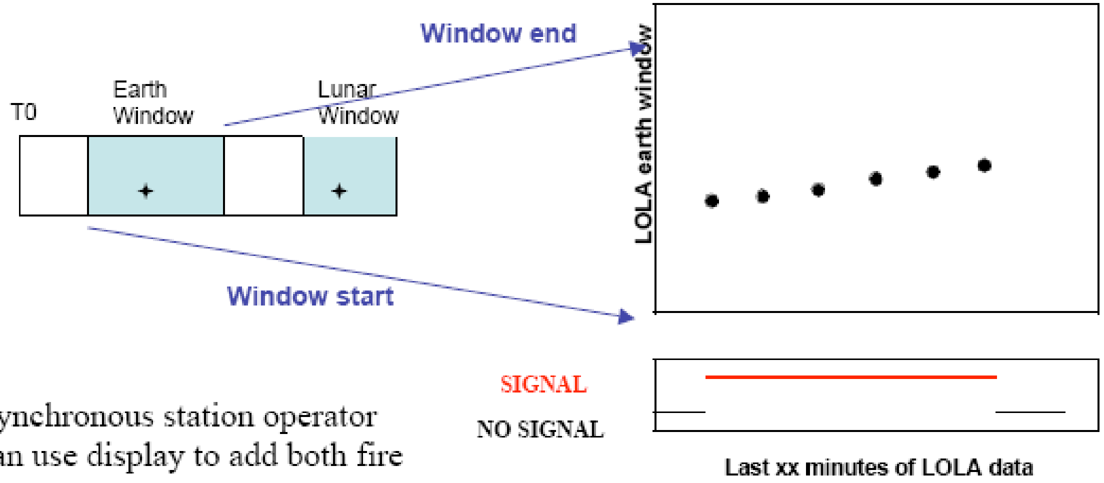
-Ground system fire rate of 10Hz ensures 2-4 pulses per second get into the earth window.

-No control of laser is needed.



Website Feedback from LOLA

- LOLA onboard algorithm determines if it sees earth pulses and if so it estimates the earth pulse event time.
- Each dot represents estimate over one second of time.
- If synchronous fire control is in the LOLA Earth Window the dots will form a straight line with small slope.
- Onboard algorithm will probably not be able to pick out asynchronous ground laser fires but LOLA SOC ground processing software can.
- Receive energies will also be sent down in real-time telemetry.



Synchronous station operator can use display to add both fire time bias to control laser fire.

Acknowledgements

LOLA investigation Team:

David E. Smith, PI

Maria T. Zuber, Dep PI

Co-I's: Oded Aharonson (Caltech); James W. Head (Brown);
Frank G. Lemoine (GSFC) Gregory A. Neumann (GSFC/MIT);
Mark Robinson (Northwestern)

LOLA Instrument Scientist

Xiaoli Sun (GSFC)

LOLA and LR Instrument Design:

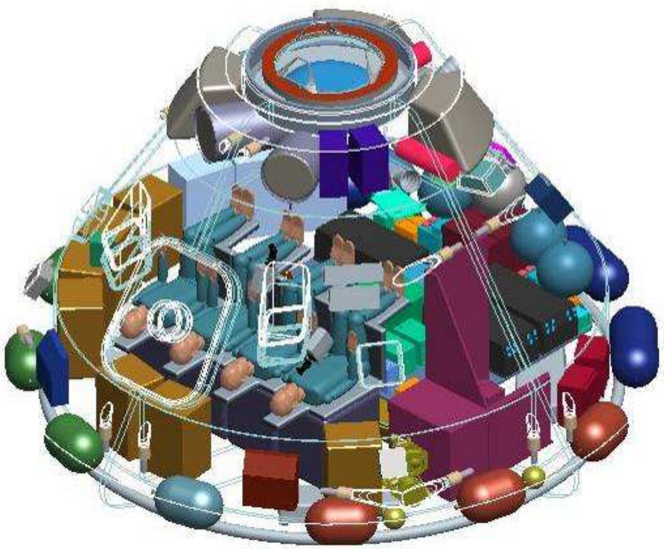
Jim Abshire, Xiaoli Sun, Jay Smith, John Cavanaugh, Luiz Ramos,
Danny Krebs, Jan McGarry, and many others

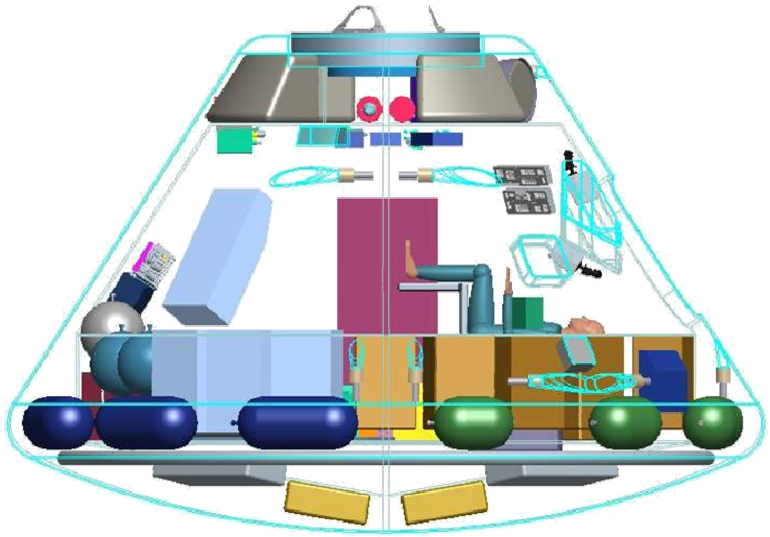
Slides from Mark Torrence, Jan McGarry presentation, ILRS workshop, Grasse 2007, Scott Greatorex,

Launch configuration

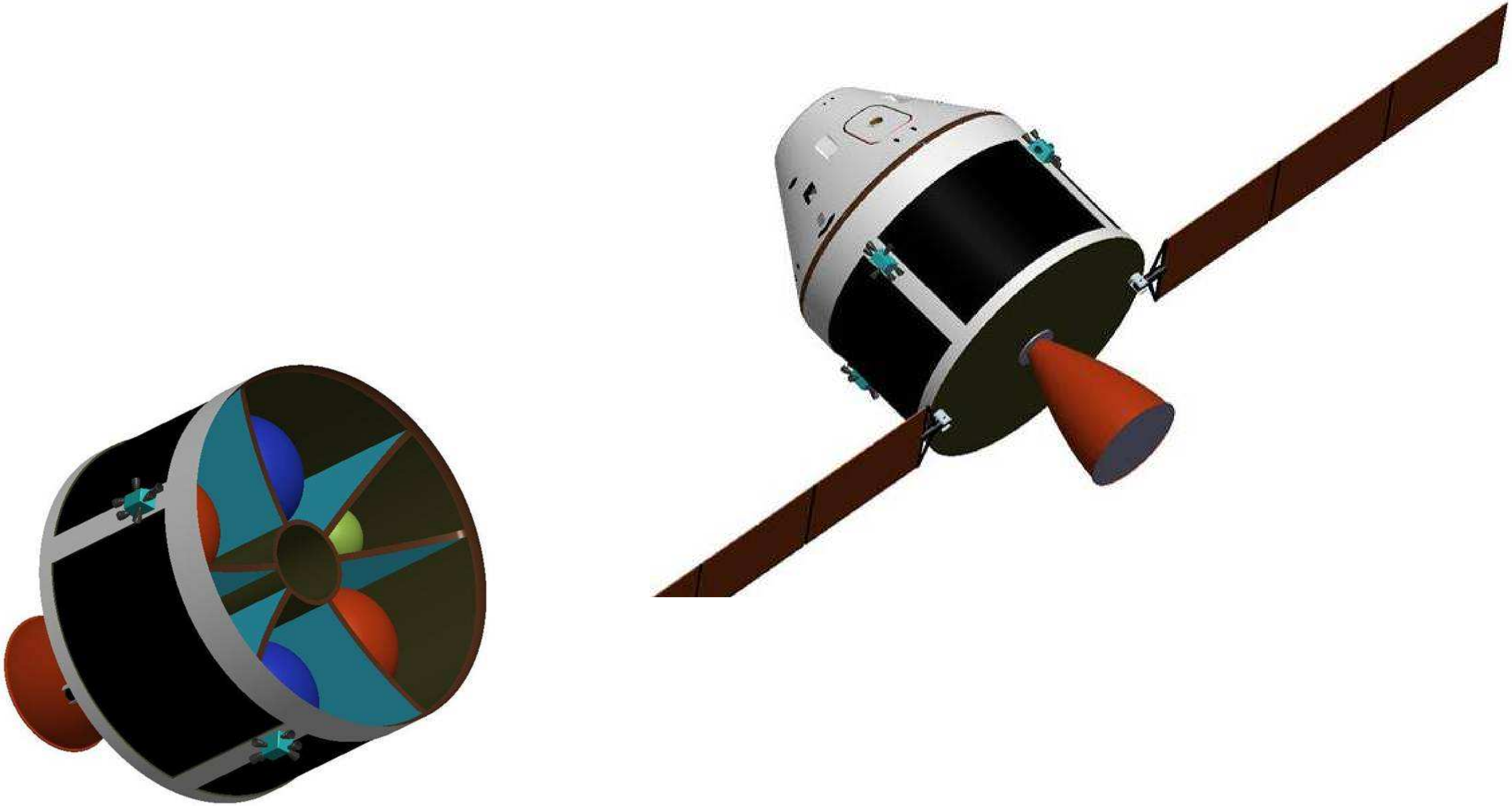

USA
NASA

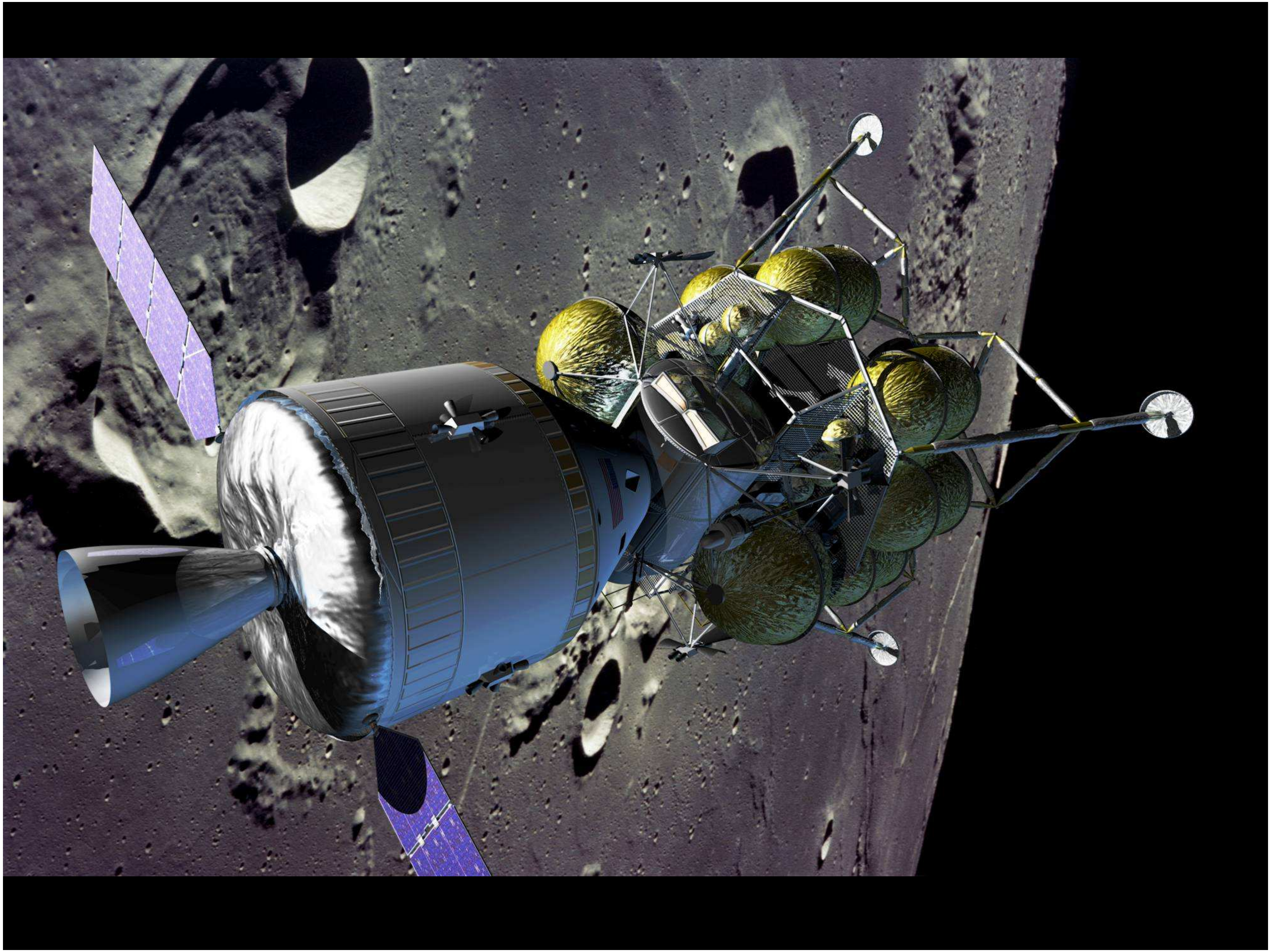
Crew Exploration Vehicle



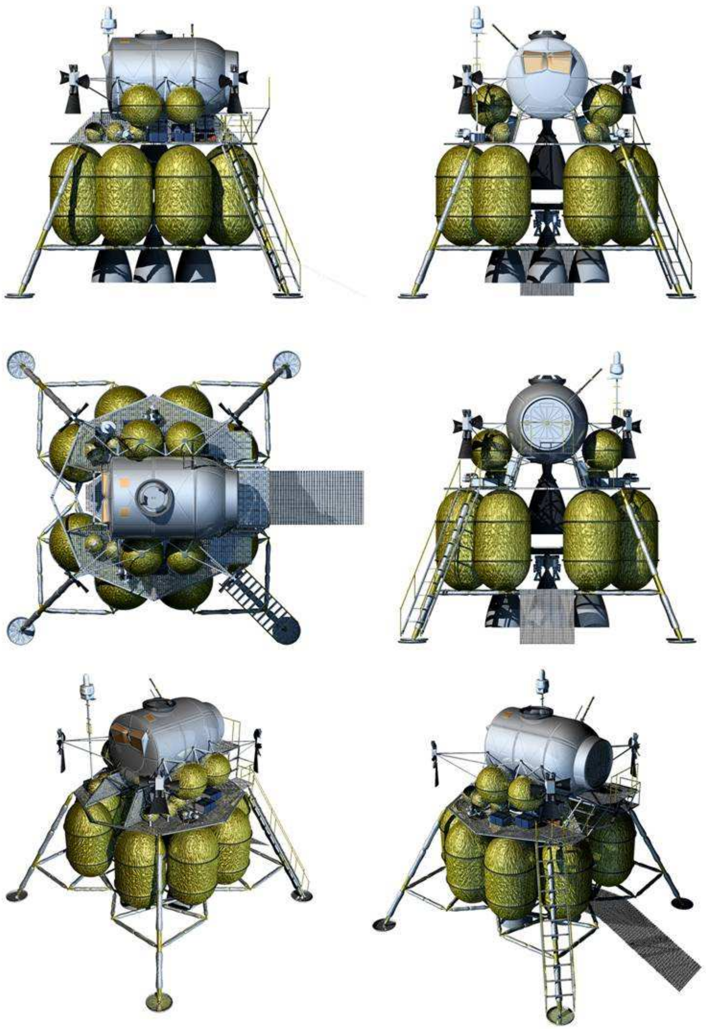


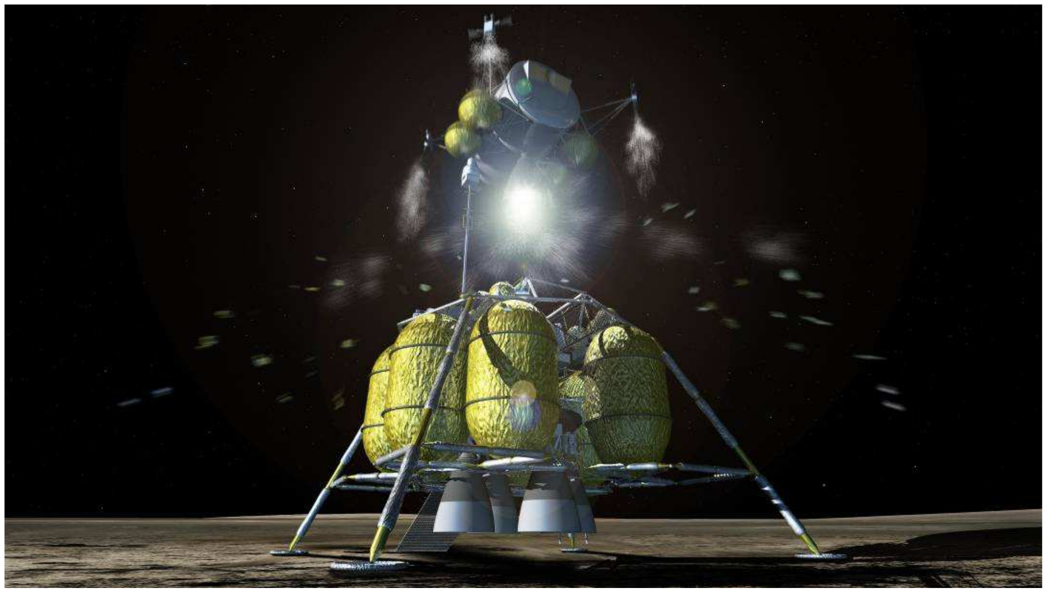
Service module carries the CEV to the Moon





Lunar Surface Module

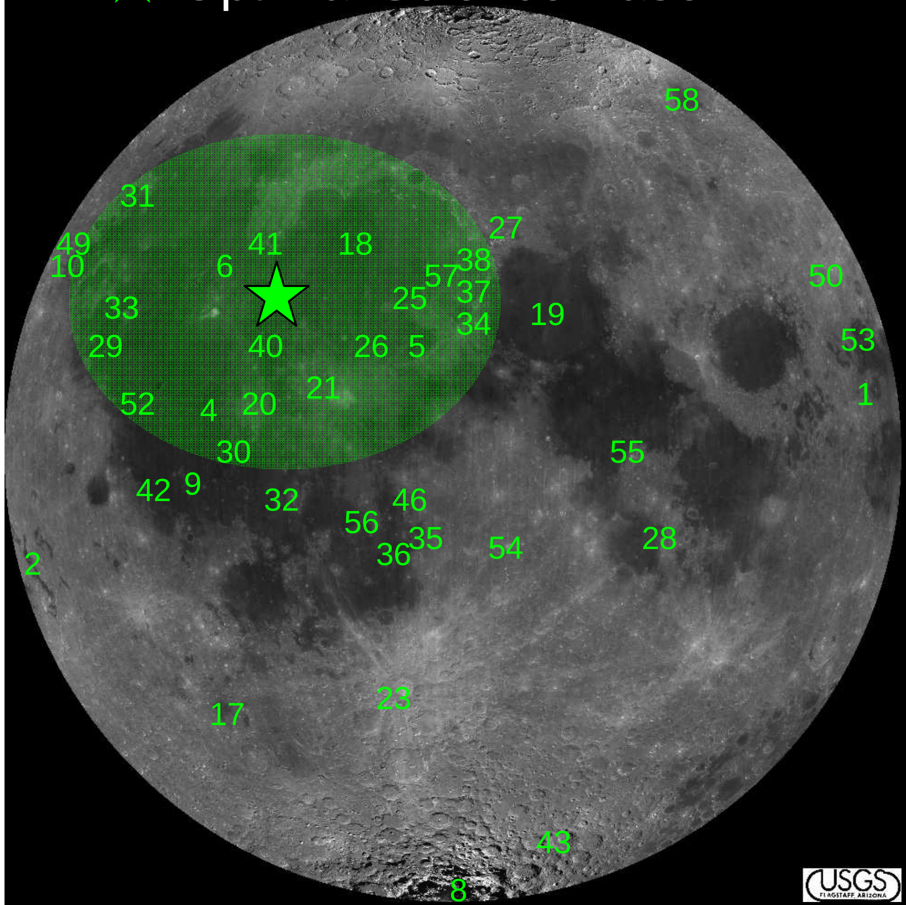




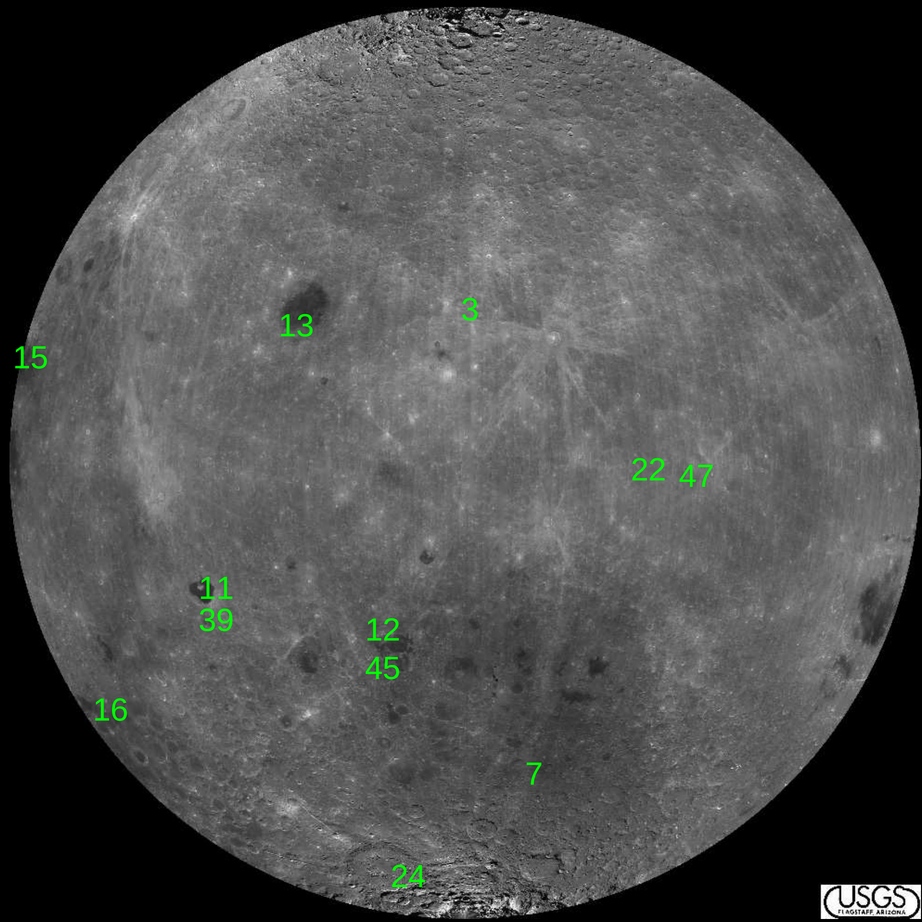
Site Selection for Moon

★ Optimal Science Base

* Numbers indicate sortie sites



Near-side



Far-side

Do it on the Moon first

- Partial gravity
- Radiation
- Planetary protection

Space Geodesy and Space Science

- We have to look at where space science is going, in order to participate, and be ready to participate
- Ionosphere, troposphere, solar activity, gravity models and missions, LRO type missions, LLR/SLR and applications, time transfers, high-rate LASER data transmissions over inter-planetary distances etc.
- Meet with Val Munsami April (HMO/HartRAO)