NASA Robotic Lunar Exploration Program

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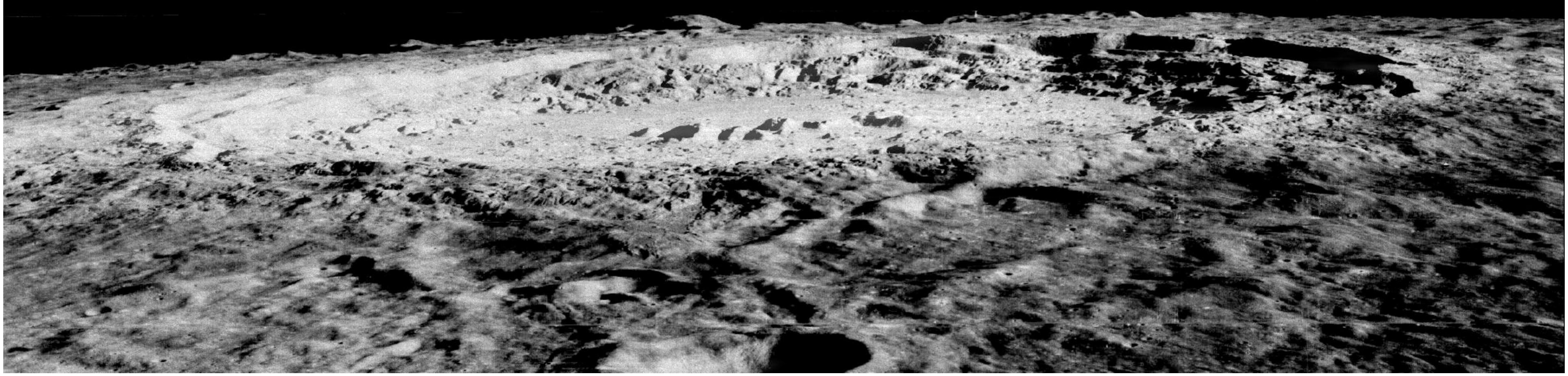
Robotic Lunar Exploration

"Starting no later than 2008, initiate a series of robotic missions to the Moon to prepare for and support future human exploration activities"

- Space Exploration Policy Directive, January 2004



Robotic Lunar Exploration Program (RLEP)

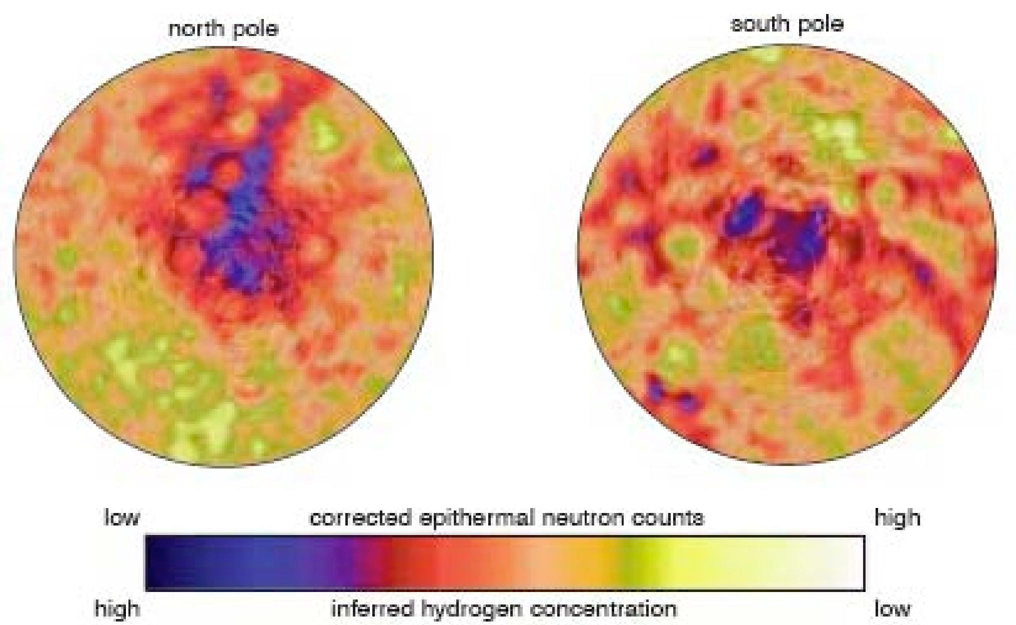
- **A program-level systems approach to robotic exploration of the Moon that will reduce cost and risk for human exploration missions as well as enhance their overall mission success**

- **First mission launch in 2008, to be followed by a series of missions to prepare for the human landings**
  - 2008 Lunar Reconnaissance Orbiter
  - 2009-2011 Robotic Lunar Landed Mission or Orbiter or combination
  - Future Robotic Lunar Testbeds / Orbiters

- **Requirements / Objectives for these missions determined by Exploration Systems Mission Directorate, in cooperation with the Science Mission Directorate**
  - Draft Robotic Lunar Exploration Program requirements were generated 9/2004
    - LRO mission requirements complete
    - Second mission requirements still in work
  - Lunar Exploration Analysis Group (LEAG) recently suggested additional requirements and priorities which will be incorporated into new revision of requirements document

RLEP Measurement Objectives

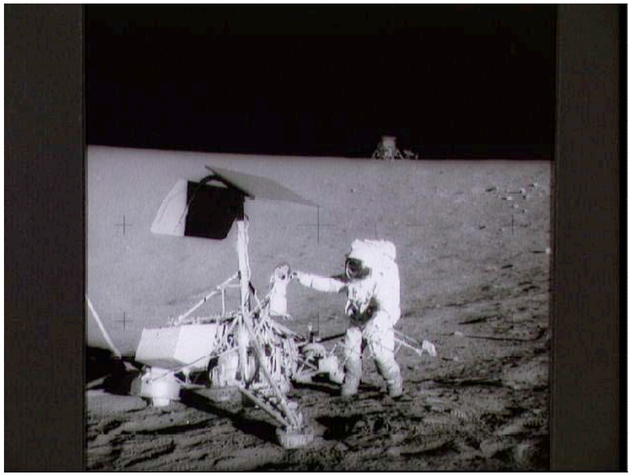
- Acquisition of a high spatial resolution, 3-dimensional, global geodetic grid for the Moon suitable for analysis at landing site scales
- Characterization of the lunar environment and its biological impacts (including radiation, dust, thermal, and partial gravity)
- Landing site imaging at landform as well as landing hazard relevant scales
- Characterization of lunar regolith for resource assessment
- Identification of possible water ice resources on/within the lunar surface through orbital and in-situ ground truth measurements



Hydrogen concentrations in the lunar polar regions measured by Lunar Prospector

RLEP
Technology and Infrastructure Objectives

- Demonstration of precision landing on the lunar surface
- Demonstration of shielding capabilities, as well as prototype hardware and software for monitoring/mitigating space environment effects on humans
- Demonstration of ISRU package for water ice, if any is found on the lunar surface, and/or demonstration of oxygen extraction from lunar regolith
- Demonstrate thermal and power technologies
- Demonstration of partial gravity effects on multi-phase flow systems
- Establishment of communications infrastructure for use by future robotic and human missions



RLEP Objectives Summary
(notional timeline)

2008	2015 - 2020

Prepare for Safe Landing / Mission and Select Sites

- Acquisition of a high spatial resolution, 3-dimensional, global geodetic grid for the Moon
- Characterization of the lunar environment and its biological impacts
- Landing site imaging at landform as well as landing hazard relevant scales
- Characterization of the lunar environment and its biological impacts (including radiation, dust, thermal, and partial gravity)

Prepare for Resource Utilization

- Characterization of lunar regolith for resource use
- Identification of possible water ice resources

Mature Technologies

- Demonstration of precision landing, power and thermal technologies
- Demonstration of shielding capabilities, as well as prototype hardware and software for monitoring/mitigating space environment effects on humans
- Demonstration of ISRU package for water ice and/or demonstration of oxygen extraction from lunar regolith
- Demonstration of partial gravity effects on multi-phase flow systems

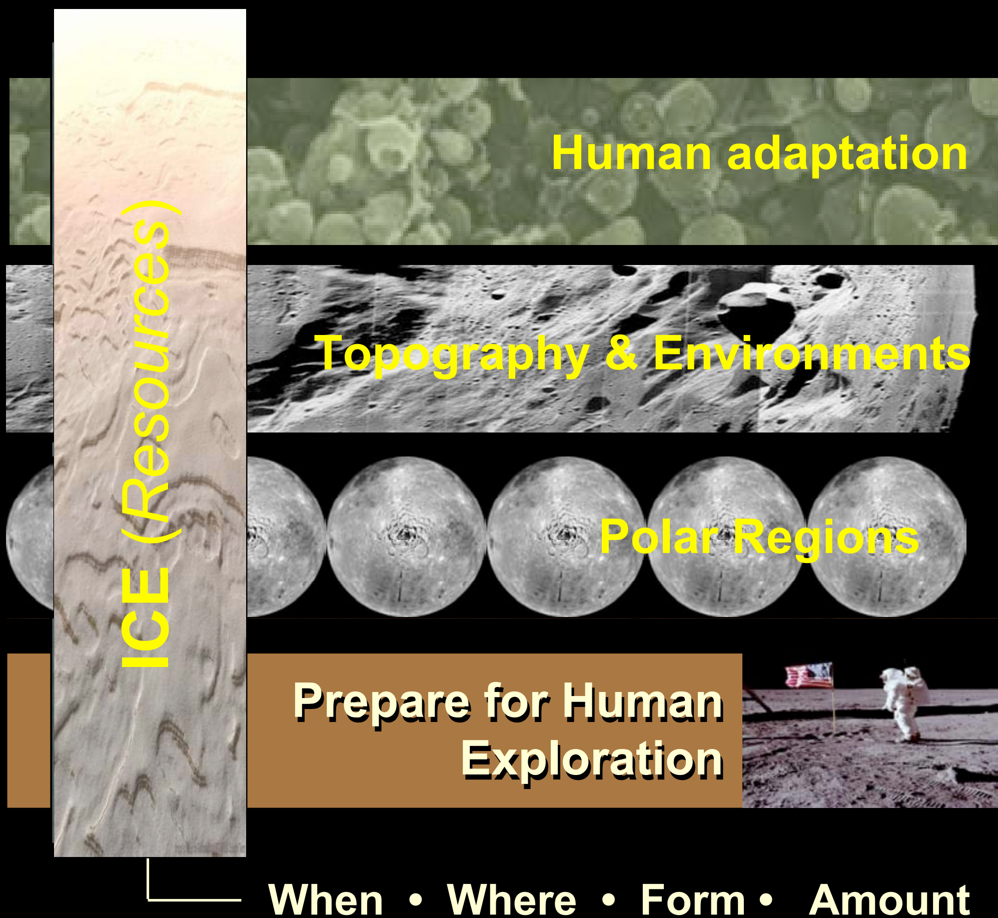
Emplace Infrastructure Support

- Establishment of communications infrastructure
- Potential emplacement of power infrastructure

RLEP Status and Plans

- **Lunar Reconnaissance Orbiter (LRO) instruments have been selected**
  - Instrument kick-off meeting was held 1/13 - 15 with all Principal Investigators
  - LRO development is fully underway at Goddard Space Flight Center
- **Architectural Trade Studies underway to aid in determining scope and frequency of missions from 2008 through 2015 - 2020 (first human landing)**
  - Pathways approach for post-LRO missions with flexibility to incorporate recent data (I.e. water ice discovery), science findings, and technology developments into architecture
  - February/March Objectives and Requirements Definition team (ORDT) planned to convene for Mission #2 definition
- **Lunar Exploration Analysis Group (LEAG) first meeting completed**
  - First meeting of LEAG was held 1/10 - 12. Next meeting planned for summer.
  - High priority tasks were assigned to Special Action Teams to complete prior to next meeting
- **RLEP requirements update planned for February 2005 to incorporate CE&R contractor, NASA center, and LEAG inputs**

2008 Lunar Reconnaissance Orbiter Measurement Objectives



Project Objectives

Biological adaptation to lunar environment *(radiation, gravitation, dust…)*

Understand the current state and evolution of the volatiles (ice) and other resources in context

Develop an understanding of the MOON in support of human exploration *(hazards, topography, navigation, environs)*

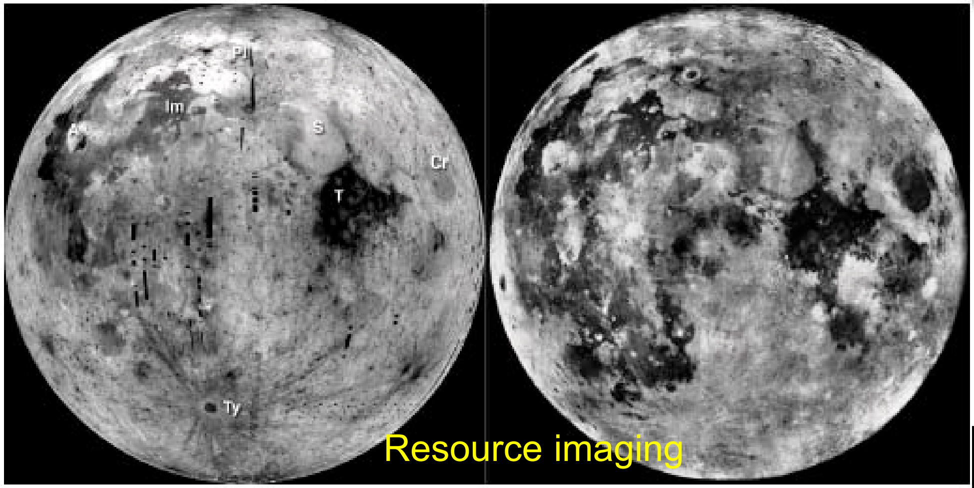
Selected LRO Measurement Investigations

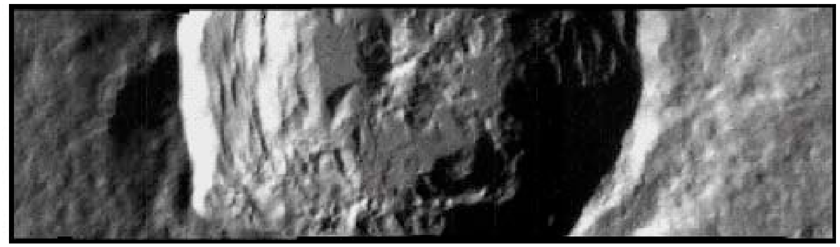
Instrument	Type	PI, Institution	Attributes
LOLA	5 beam Lidar Altimeter	Dave Smith, PI NASA/Goddard	Global geodetic topography Polar topography, roughness, reflectivity
LROC	Very High Resolution Imaging	Mark Robinson, PI Northwestern University	Targeted Imaging of landing sites (< m) Polar illumination (per orbit)
LEND	Collimated Neutron Spectrometer	Igor Mitrifanov, PI Space Research Institute *Russia*	Global H mapping at 5-20km scales Polar H (ice?) at 5 km and Global neutron albedo > 10 MeV
Diviner	Imaging IR Radiometer	David Paige, PI UCLA	Global Temperature mapping 300m scale IR mapping (ice, rocks)
LAMP	Far UV spectrometer	Alan Stern,PI SWRI	Global far UV mapping at km scale Polar far UV imaging at < 1 km (frost)
CRaTeR	Cosmic ray telescope and dosimeter	Harlan Spence, PI Boston University	Tissue equivalent Plastic (TEP) GCR response of TEP to radiation

LRO Payload Instruments

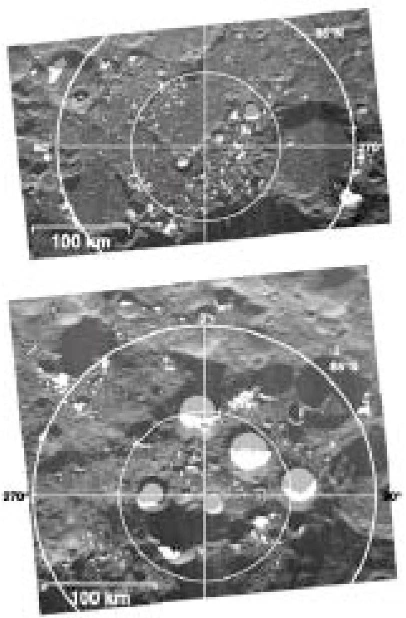
- **Lunar Orbiter Laser Altimeter (LOLA) Measurement Investigation**
  - Principal investigator Dr. David E. Smith, NASA Goddard Space Flight Center (GSFC), Greenbelt, MD. LOLA will determine the global topography of the lunar surface at high resolution, measure landing site slopes and search for polar ices in shadowed regions.
- **Lunar Reconnaissance Orbiter Camera (LROC)**
  - Principal investigator Dr. Mark Robinson, Northwestern University, Evanston, IL. LROC will acquire targeted images of the lunar surface capable of resolving small-scale features that could be landing site hazards, as well as wide-angle images at multiple wavelengths of the lunar poles to document changing illumination conditions and potential resources.
- **Lunar Exploration Neutron Detector (LEND)**
  - Principal investigator Dr. Igor Mitrofanov, Institute for Space Research, and Federal Space Agency, Moscow, Russia. LEND will map the flux of neutrons from the lunar surface to search for evidence of water ice and provide measurements of the space radiation environment which can be useful for future human exploration.
- **Diviner Lunar Radiometer Experiment**
  - Principal investigator Professor David Paige, UCLA, Los Angeles, CA. Diviner will map the temperature of the entire lunar surface at 300 meter horizontal scales to identify cold-traps and potential ice deposits.
- **Lyman-Alpha Mapping Project (LAMP)**
  - Principal investigator Dr. Alan Stern, Southwest Research Institute, Boulder, CO. LAMP will observe the entire lunar surface in the far ultraviolet. LAMP will search for surface ices and frosts in the polar regions and provide images of permanently shadowed regions illuminated only by starlight.
- **Cosmic Ray Telescope for the Effects of Radiation (CRaTER)**
  - Principal investigator Professor Harlan Spence, Boston University, Boston, MA. CRaTER will investigate the effect of galactic cosmic rays on tissue-equivalent plastics as a constraint on models of biological response to background space radiation.

Examples of what LRO will do…

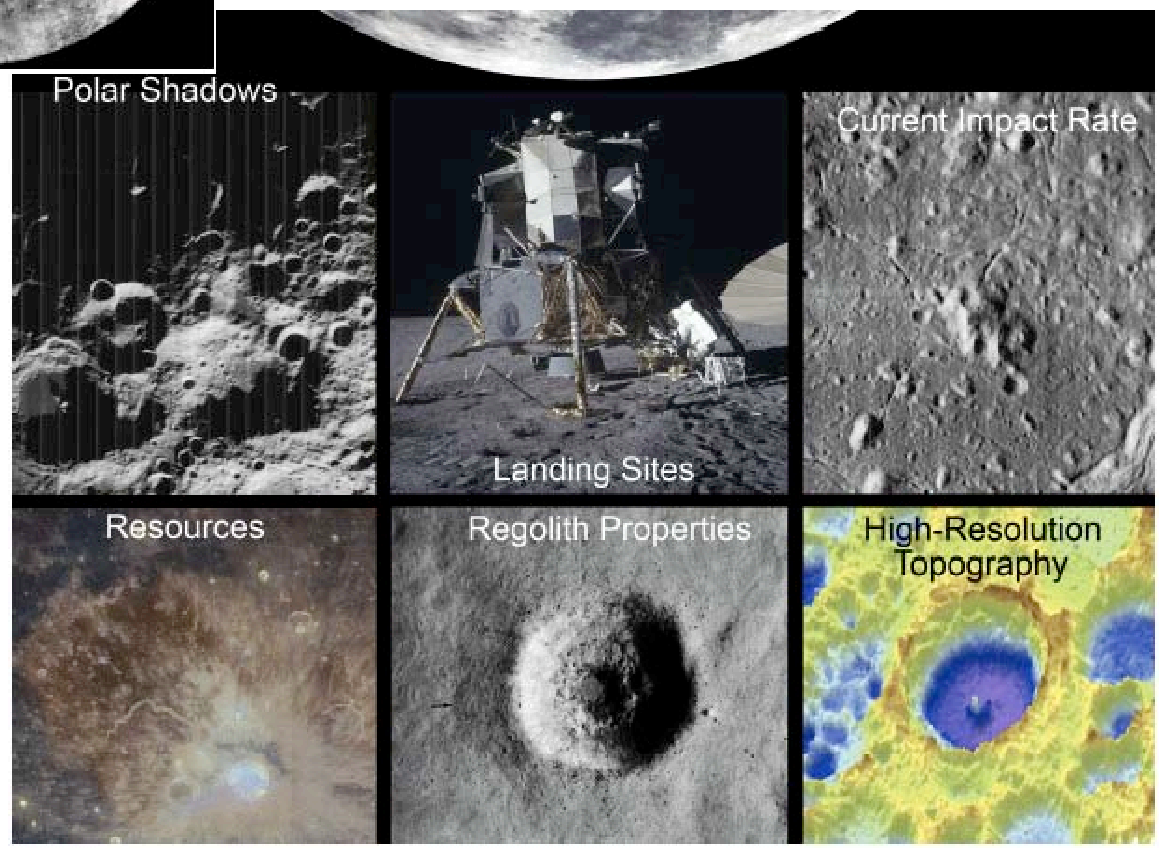




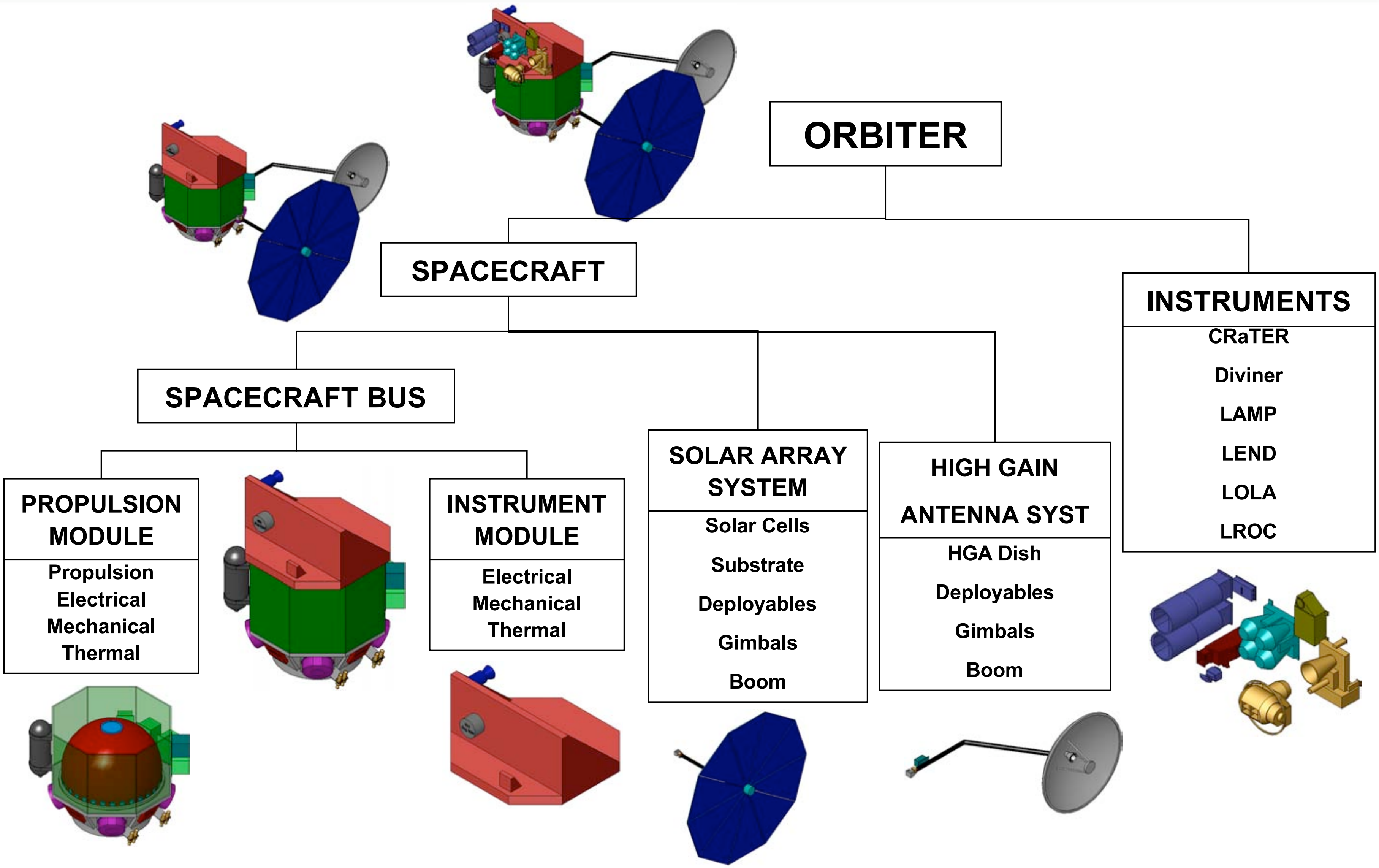
Temperature mapping



Polar Topography/shadow mapping

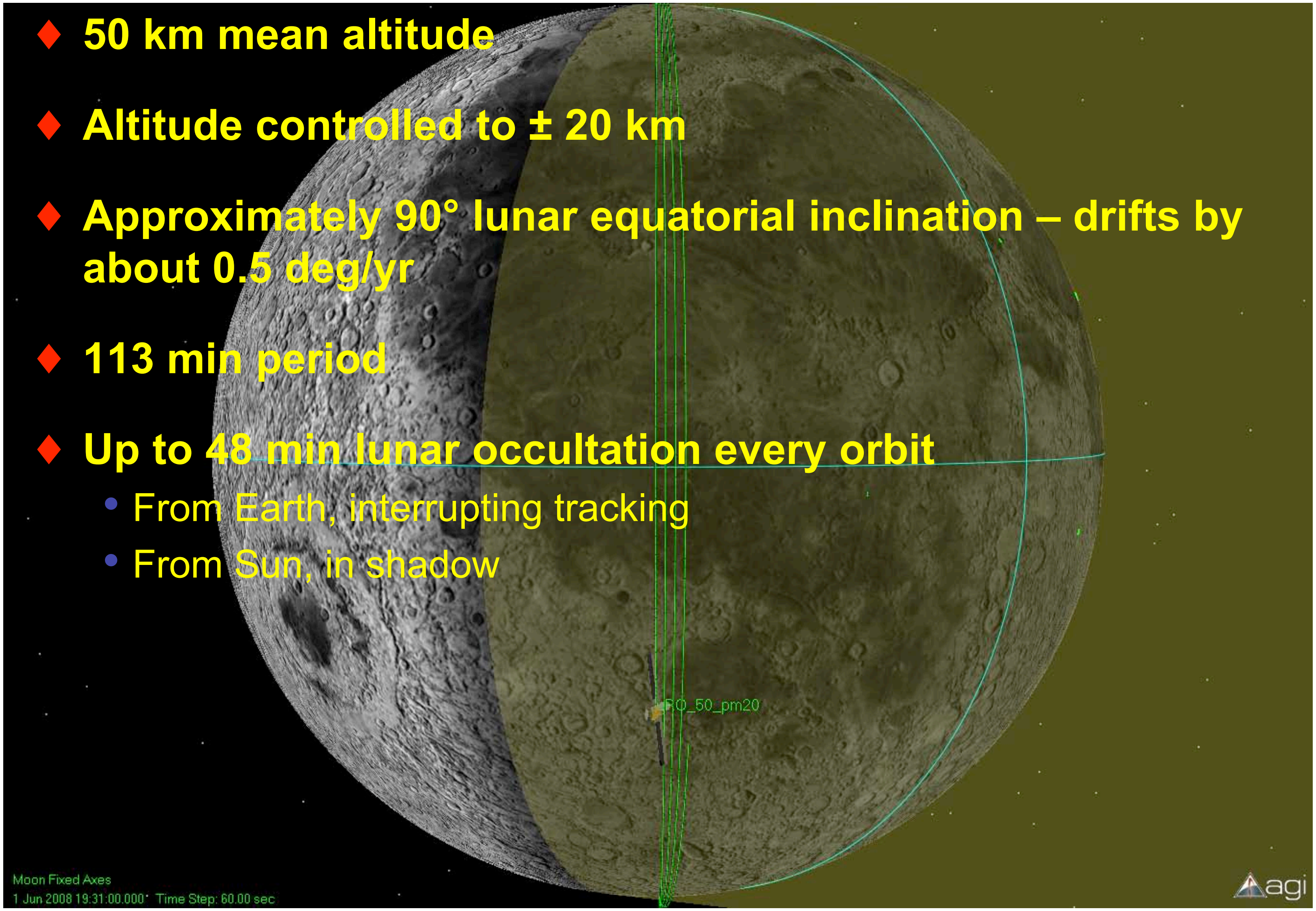


LRO Mission Elements

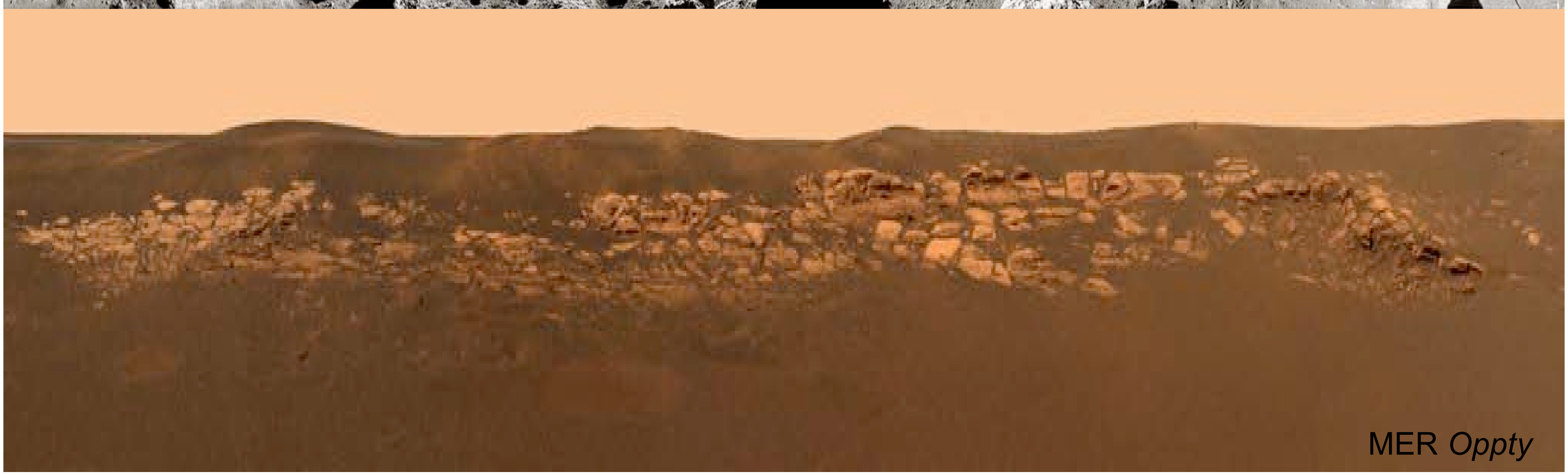


LRO Mission Orbit

- 50 km mean altitude
- Altitude controlled to ± 20 km
- Approximately 90° lunar equatorial inclination – drifts by about 0.5 deg/yr
- 113 min period
- Up to 48 min lunar occultation every orbit
  - From Earth, interrupting tracking
  - From Sun, in shadow



Reqt's for LRO *(from NASA ORDT, and ESMD RLEP Reqt's 9/04)*	*2008 NASA LRO* [50km orbit, 1 yr+]	**SELENE** [JAXA: Japan, 2008 launch] [100km orbit, 1 yr]	**SMART-1** (ESA lunar 2005 orbiter) [250km periapsis]	**Chandrayaan** (ISRO 2007-2008 launch) [100+ km orbit]
Radiation Environment	Global assessment including neutrons, GCR (imaging NS, Rad Sensor)	**Highly limited overlap in some narrow energy ranges**	**Limited to some energy ranges**	**TBD**
Biological Adaptation	Biological responses to radiation (Rad Sensor)	**Not addressed**	**Not addressed**	**Not addressed**
Shielding materials *(test-beds)*	Shielding expt's with TEP (Rad Sensor)	**Not addressed**	**Not addressed**	**Not addressed**
Geodetic topography (global)	10's m x,y, with < 1m z precision, attn to poles (Lidar)	**1.6 km x, y at > 20 m vertical precision (RMS)**	**Not addressed**	**Not addressed**
H mapping to assess ice	Landform scale at 100 ppm (~5 km scale at poles) (imaging NS)	**160km scale via GRS (does not meet LRO goals)**	**Limited to 100's of km scale (H)**	**Some potential, but depends on contributed sensors**
T mapping cold traps (polar)	Landform scale at 3-5K (40-300K): ~300m scale (IR mapper)	**Not addressed**	**Not addressed**	**TBD**
Putative ice deposits at poles	~25-400m scales in shadows (Imager, Lidar, NS, etc)	**Not addressed in this mission (cf. GRS)**	**Not addressed**	**TBD *(contributed S-band SAR and Mineral mapping from US?)***
Sub-meter imaging for landing site assessment	Targeted, meter-scale feature detection, hazards (Imager, Lidar)	**Not addressed: best imaging is ~10m/pixel stereo, MS imaging (10+ VISNIR bands)**	**Not addressed (best imaging is 10-100 m/pixel)**	**Not addressed, but imaging (MS) will be included (10's m/pixel)**
Polar illumination	High time-rate polar imaging (Imagers)	**Partially addressed, but frequency TBD?**	**Limited**	**TBD**
OTHER	Potential UV, hyperspectral, or TBD	**Particles and Fields, Farside gravity, elemental chemistry**	**Particles and Fields, etc.**	**Likely (*contributed mineralogy mapping*?)**



LRO Initiates Exploration-driven robotic missions to the Moon: its new measurements will pave the way for Humans to the Moon (and later Mars)