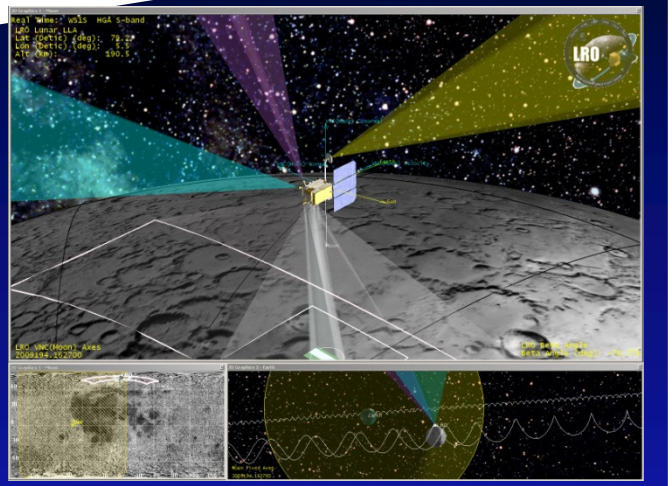
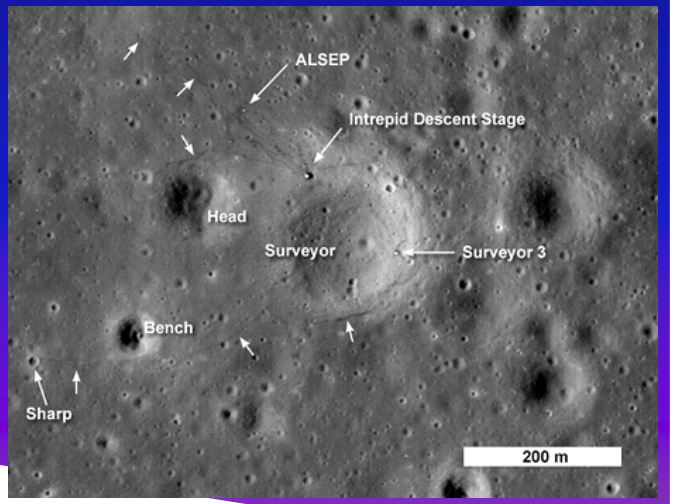
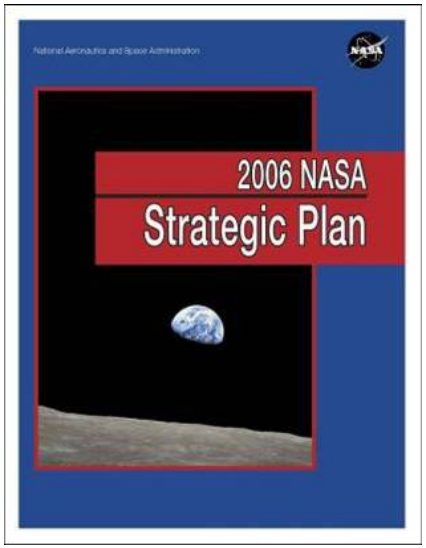
Lunar Reconnaissance Orbiter Mission Update

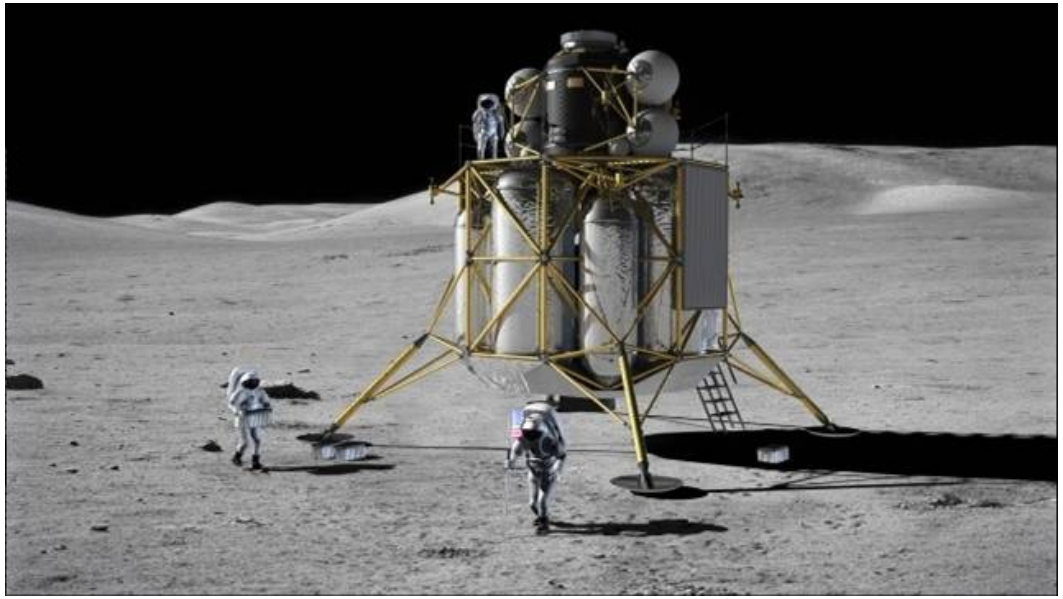




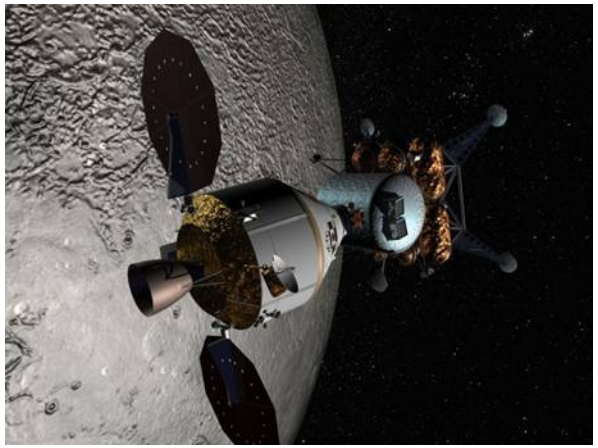
AAS Symposium, *Looking Ahead: The Next Chapter in Space*
Wernher von Braun Memorial Symposium, October 20-21, 2009

LRO Driving Objective

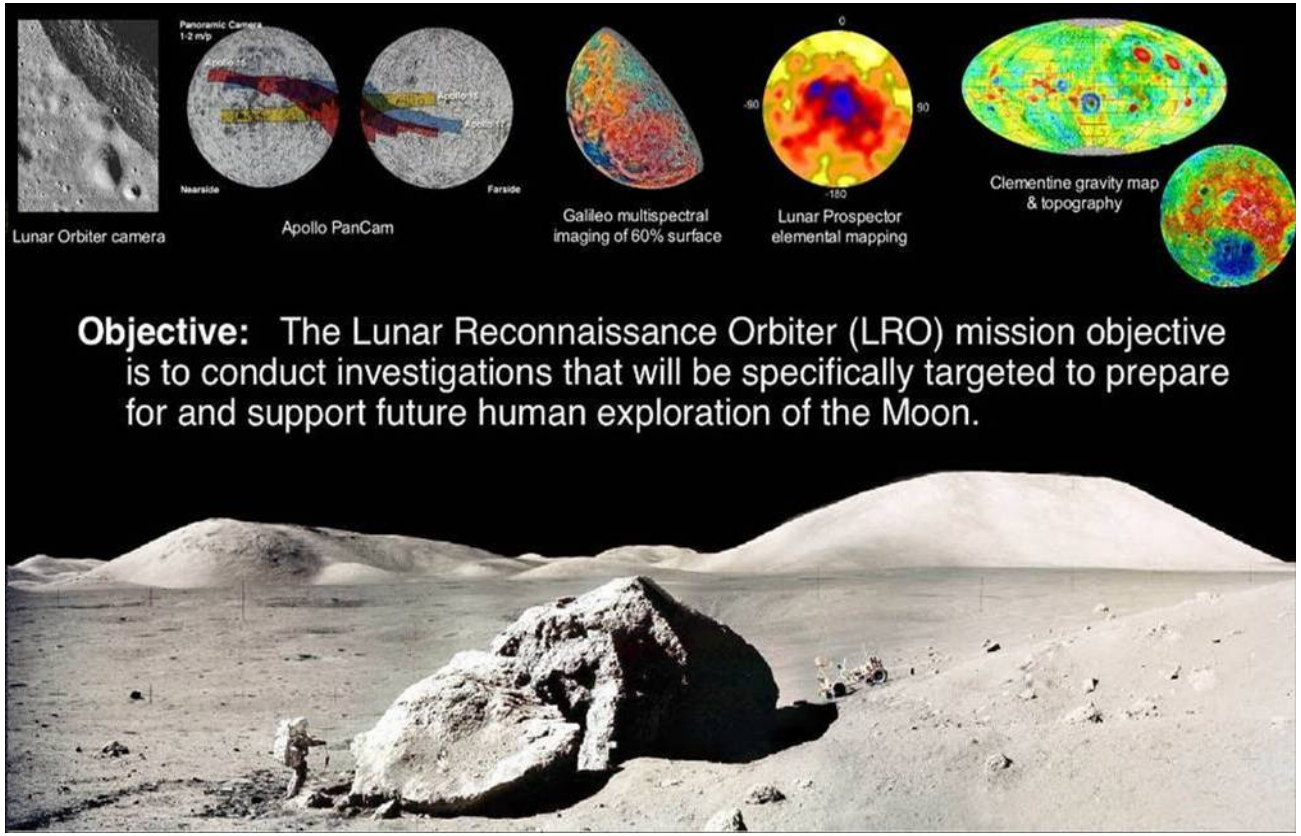




- **Strategic Goal 6: Establish a lunar return program having the maximum possible utility for later missions to Mars and other destinations.**
  - 6.1. By 2008, launch a Lunar Reconnaissance Orbiter (LRO) that will provide information about potential human exploration sites.
- NASA moved LRO launch to June 2009 to accommodate both other national launch priorities and problems with missions ahead of LRO in the launch manifest



LRO Mission Objectives



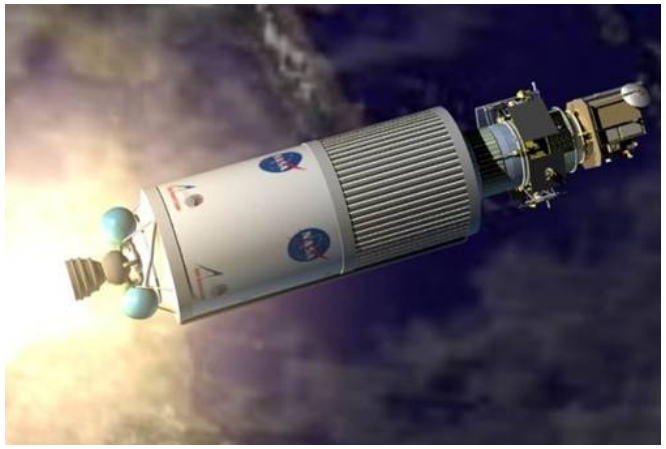
Locate Potential Resources
- Hydrogen/water at the lunar poles
- Continuous solar energy
- Mineralogy

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

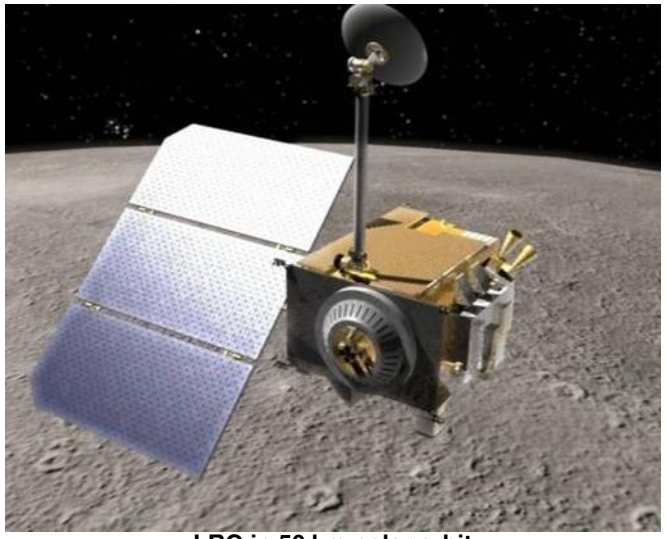
Space Environment
- Energetic particles
- Neutrons

LRO Mission Overview

- Launched June 18, 2009 on a Atlas V into a direct insertion trajectory to the Moon. Co-manifested with LCROSS lunar impact mission.
- On-board propulsion system used to capture at the Moon, insert into and maintain 50 km mean altitude circular polar reconnaissance orbit.
- 1 year exploration mission with planned 2 year extended science mission.
- Orbiter is a 3-axis stabilized, nadir pointed spacecraft designed to operate continuously during the primary mission.
- Investigation data products delivered to Planetary Data Systems (PDS) within 6 months of primary mission completion.



LRO & LCROSS on Atlas-Centaur Upper Stage



LRO in 50 km polar orbit

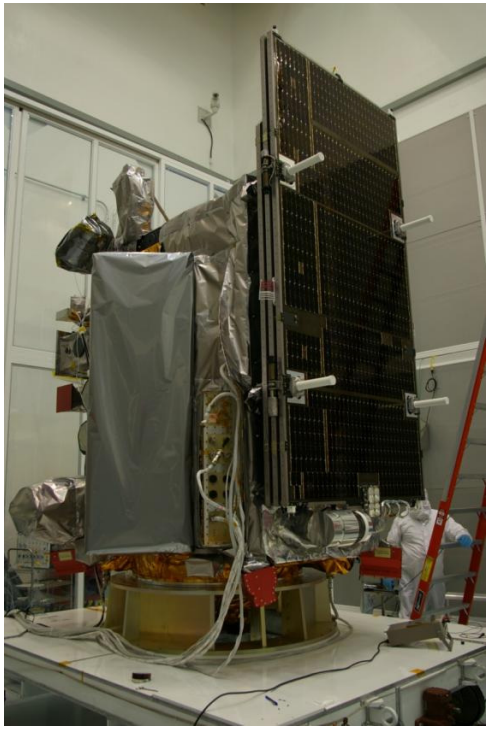
LRO Mission – Background & Chronology

- **The LRO mission was initiated in May 2004 at GSFC under the direction of NASA Code S.**
  - *Anticipated to be Discovery mission class in scope to be launched in 2008*
  - *Assigned as an in-house GSFC development in response to the accelerated schedule*
  - *Competitive AO to solicit high heritage instruments released in late June 2004.*
  - *Class C risk classification (per NPR8705.4/NPR7120.5D) established consistent with cost, mass, and schedule constraints. Select tailoring of some aspects to B levels per GSFC practice. Single String Design Accepted.*

- **LRO Chronology**

– ***ORDT convened and made recommendations to NASA about LRO objectives***	***- March 2004***
– ***Instruments selected (competitive AO)***	***- December 2004***
– ***Funding released to Project (ATP)***	***- February 2005***
– ***Program moved from NASA SMD to ESMD***	***- February 2005***
– ***Mini-RF added to LRO***	***-April 2005***
– ***SRR***	***-July 2005***
– ***LRO moved to and redesigned for EELV instead of Delta II***	***- December 2005***
– ***PDR***	***- February 2006***
– ***LCROSS ATP***	***- April 2006***
– ***Confirmation***	***- May 2006***
– ***CDR***	***- November 2006***
– ***I&T Starts***	***- January 2008***
– ***LPRP directs LRO to plan for March 2009 instead of December 2008 launch***	***- July 2008***
– ***PSR***	***- February 2009***
– ***FOR***	***- March 2009***
– ***MRR***	***- April 2009***
– ***Launch***	***- June 18,2009***
– ***Commissioning orbit (30x199km) established about the Moon***	***- June 27, 2009***
– ***Commissioning completed & primary mission begun***	***- Sept. 16, 2009***

The Lunar Reconnaissance Orbiter Mission Begins



LRO in Launch Configuration at KSC/Astrotech

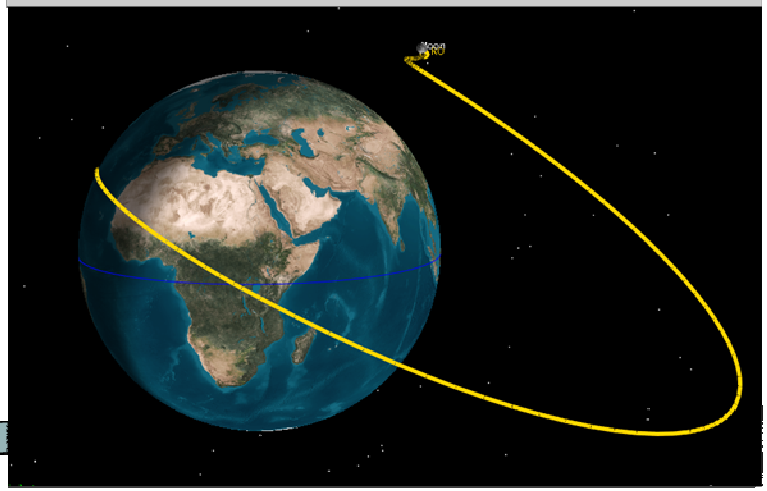
LRO Encapsulation in Atlas V Faring

LRO Mission Operations Center (MOC) GSFC just prior to LOI-1

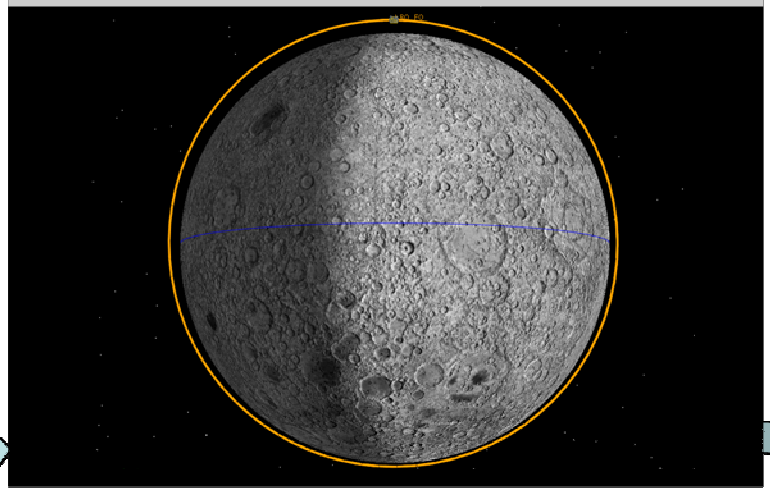
LRO/LCROSS Atlas V Launch on June 18, 2009

Mission Trajectory / Orbits Overview

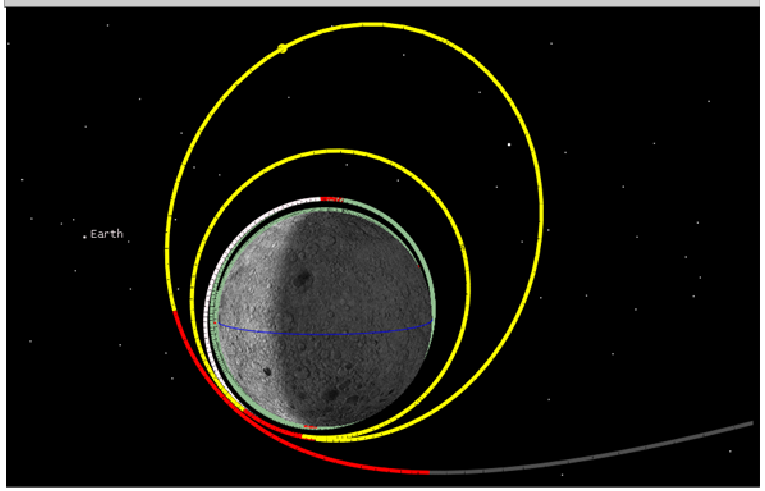
Minimum Energy Lunar Transfer: 4-5 days



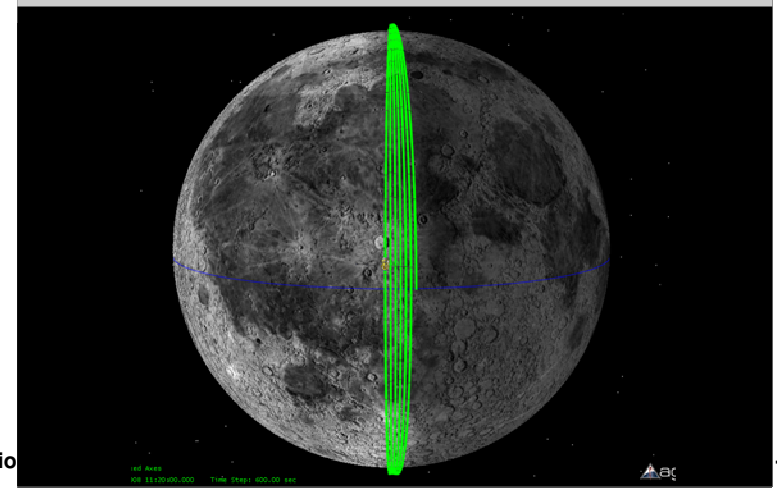
30 x 216 km Quasi-frozen Orbit: up to 60 days



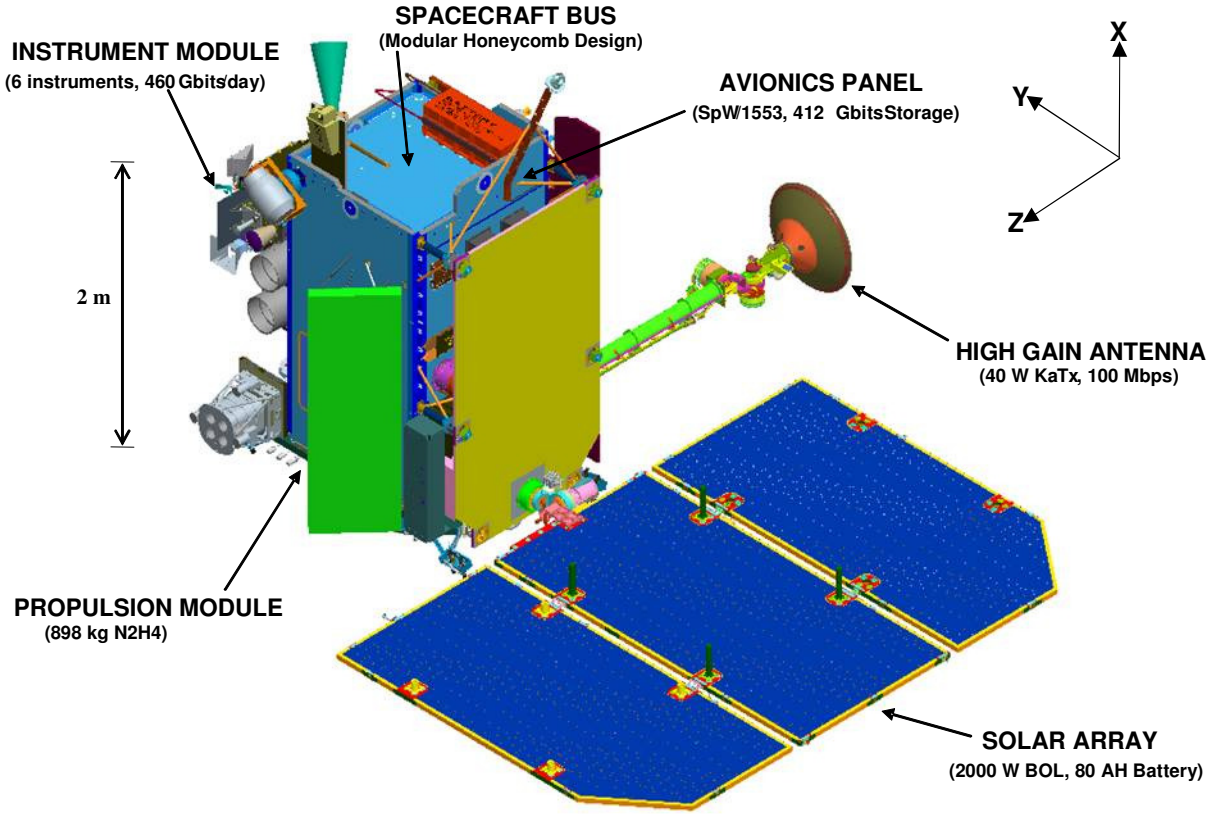
Lunar Orbit Insertion Sequence (4): 4-6 days



50 km Polar Mapping Orbit: at least 1 year



The LRO Spacecraft



LRO Orbiter Characteristics		
Mass (CBE)	1916 kg	Dry: 1018 kg, Fuel: 898 kg (1313 m/sec)
Orbit Average Bus Power	647 W @ Beta 0	
Data Volume, Max Downlink rate	461 Gb/day, 100Mb/sec	
Pointing Accuracy, Knowledge	60, 30 arc-sec	

Space Communications Network Assets Employed for LRO Mission Operations

DSN
(Early Mission & Emergencies)

S-Band
&
KA-Band

S-Band Telemetry
S-Band Telecommand

S-BAND EXTERNAL GROUND NETWORK

VPN

White Sands (18M)
(WS1 & SDO2)

Telemetry Files
UTDF Files
Weather Data Files

Real-Time TCP/IP Sockets
- Telemetry
- Telecommand
- Equipment Status

Mission Planning
Real-Time
Non Real-Time
USN NMC

SOC

LRO MOC

Flight Dynamics Facility

Schedule Request

Ephemeris Track File

WOTIS

Ephemeris Track File

UTDF Tracking Files

LRO Spacecraft & Operations Status

- Atlas V launch was nearly perfect with very little tip-off and TLI error.

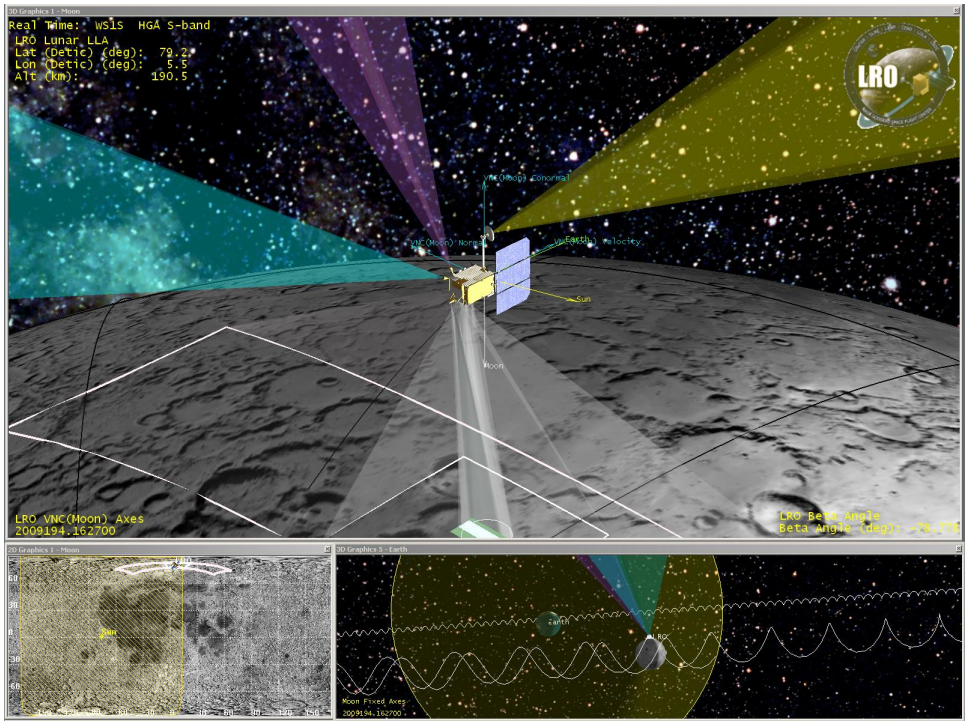
- Initial Acquisition through Lunar Orbit Insertion (LOI) completed flawlessly.
  - Propulsion System performed perfectly
  - LRO arrived in Lunar Orbit with 147 m/s worth of extra ▽V above 65 m/s budgeted for extended mission and contingencies.

- Commissioning Phase Completed (9/15/2009)
  - Gyro Calibrations
  - High Gain Antenna Calibrations
  - Safing Tables and RTSs Updated
  - Minor changes to ACS Controller gains/limits
  - One-way Laser Ranging Operating
  - Calibration of Instruments
  - ***All spacecraft subsystems and instrument operating nominally and meeting or exceeding specifications***

- One year Exploration mapping mission has begun !

- LRO supported LCROSS Impact Event with observations of ejecta plume.

- 2 year science mission planned after completion of 1 year primary Exploration mission.



Screen snap from real-time STK display in LRO MOC. Driven by real-time spacecraft telemetry and on-board ephemeris.

Examples of LRO Instrument Performance during Commissioning Phase

DIVINER South Polar Brightness Temperature Map

DLRE: Diviner Lunar Radiometer Exp.

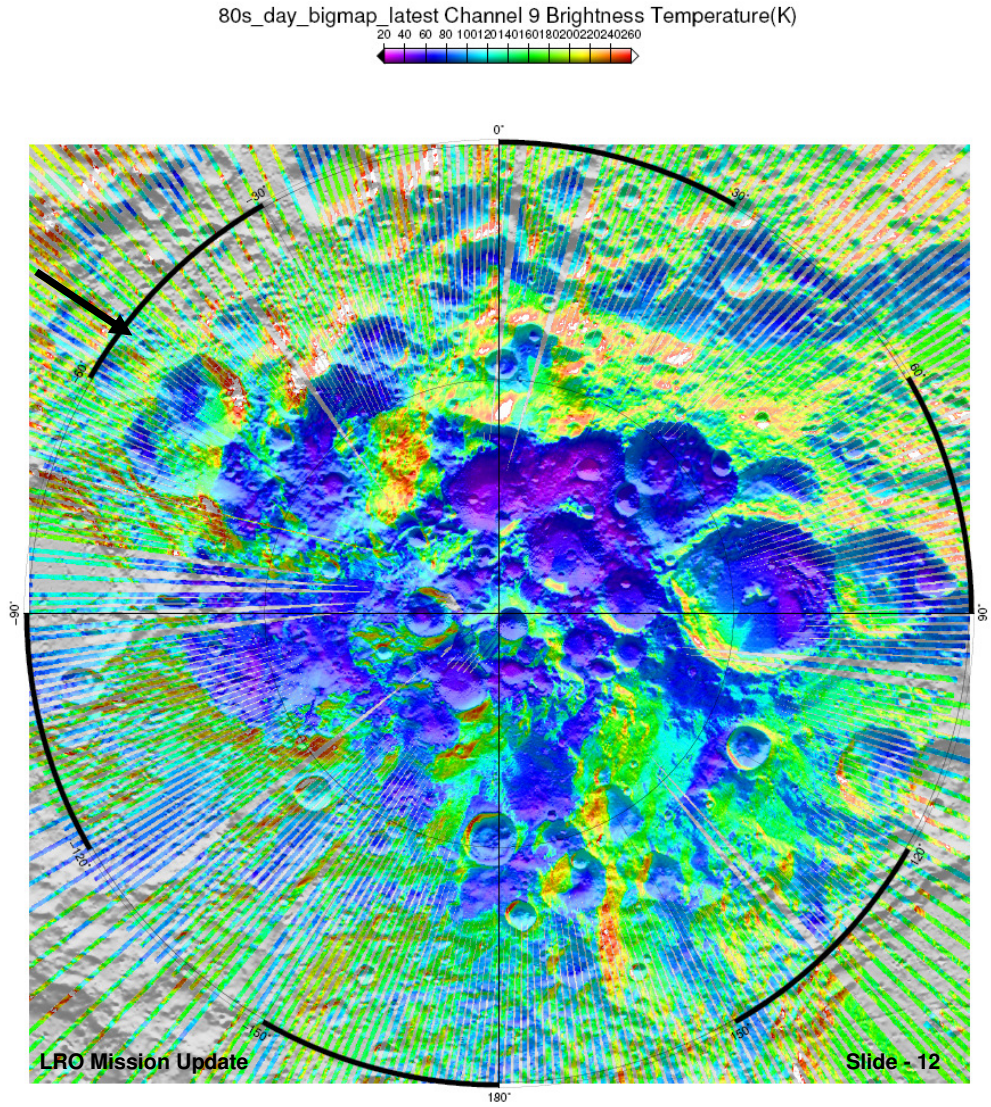
- Temperature
- Lighting
- Hazards
- Resources

Full Orbit
Autonomous

Diviner Daytime Map Channel 9 Brightness Temperatures Of South Polar Region (100-400 micron wavelength)

The map was acquired over a 27.5 day period from 27.5 days from July 17 – Aug 14, 2009

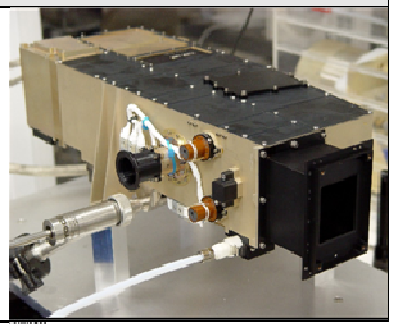
Local time decreases counterclockwise from ~17 hrs at Lon=-55E to ~15 hrs



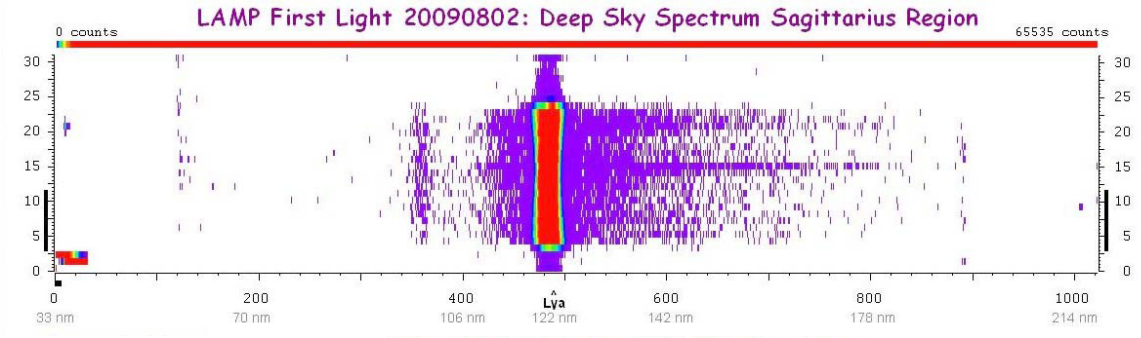
LAMP Commissioning Results

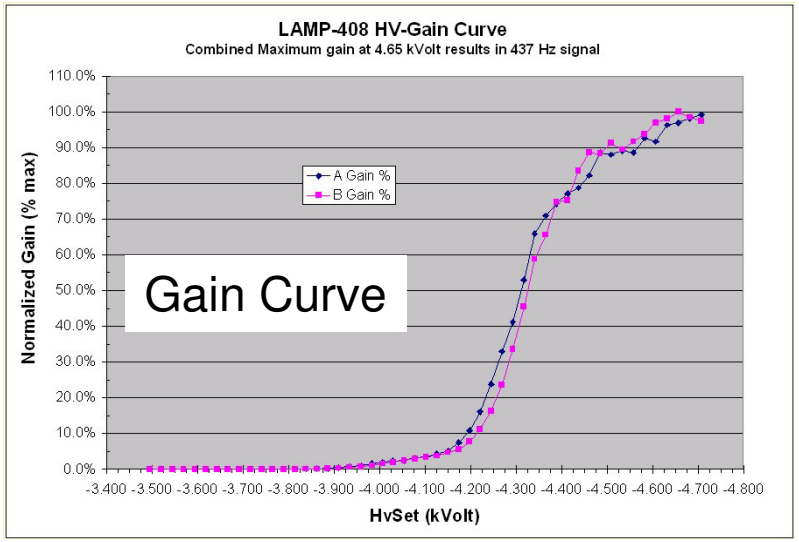
LAMP: Lyman-Alpha Mapping Project

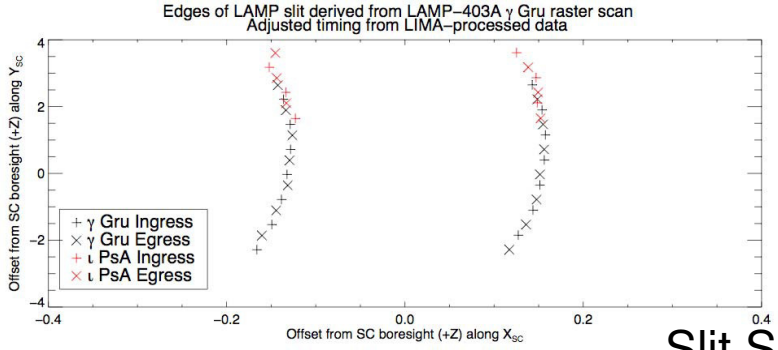
- Water-Frost
- PSR Maps



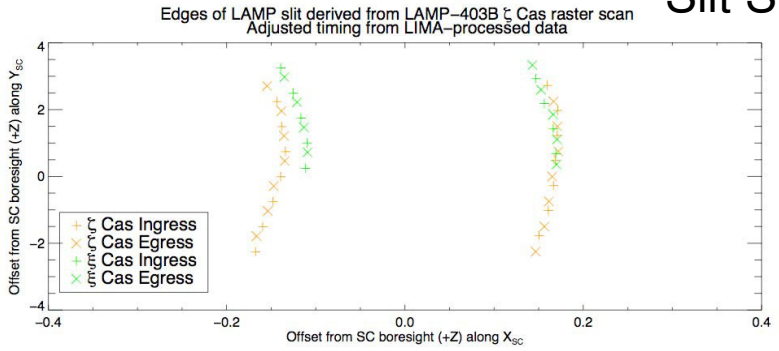
Night Side Autonomous







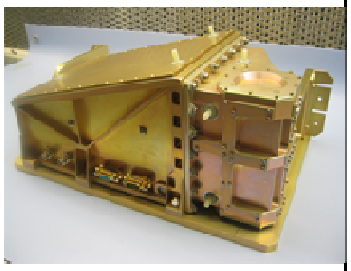
Slit Shape



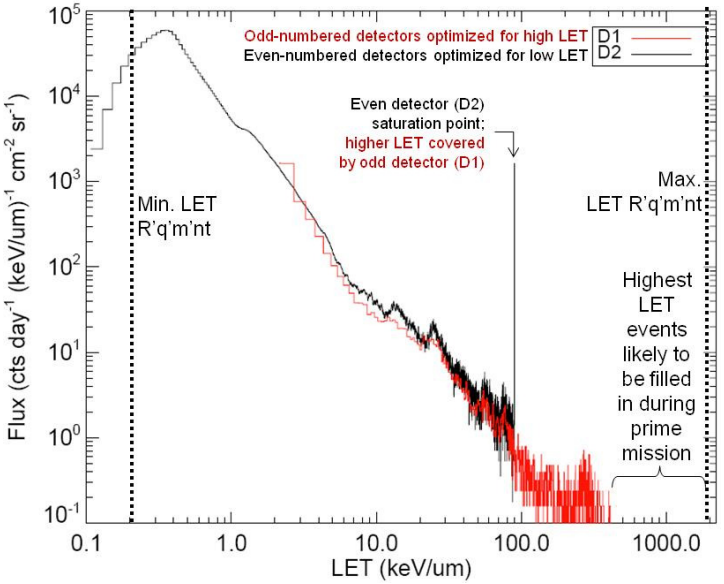
CRaTER Commissioning Performance: LET Spectra & Correlation to Models

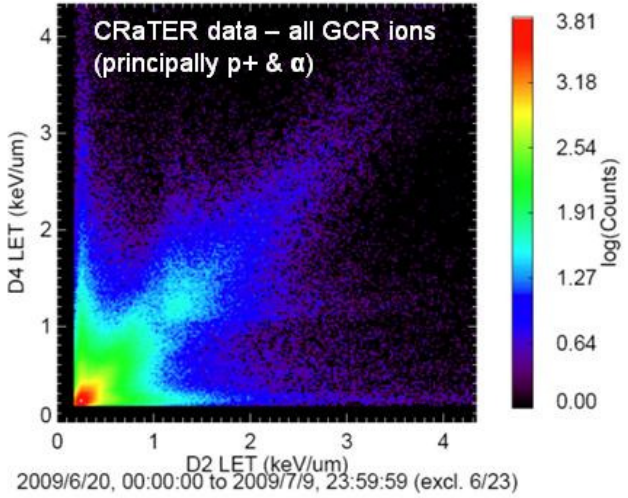
CRaTER: Cosmic Ray Telescope…

- Radiation Spectra
- Tissue Effects

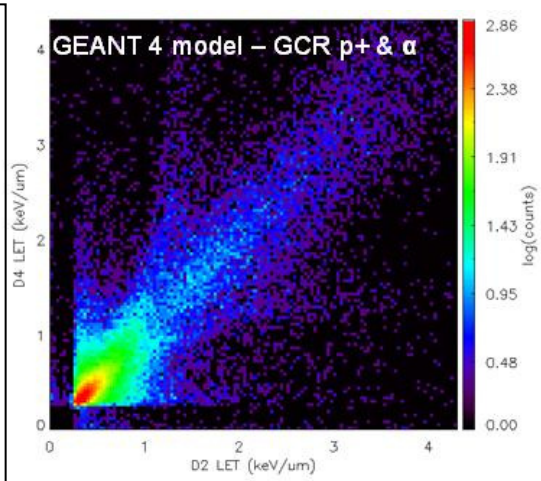


Full Orbit Autonomous





- Two dimensional flux histogram from ~19 days of flight showing LET spectra in both D2 (horizontal axis) and D4 (vertical axis) which is in the center of the telescope (TEP on either side)
- GCR proton signature seen in both D2 and D4 at low LET; GCR α's (and heavy ions) seen at higher LET
- Geant4 models using current GCR flux affirm CRaTER in-flight performance

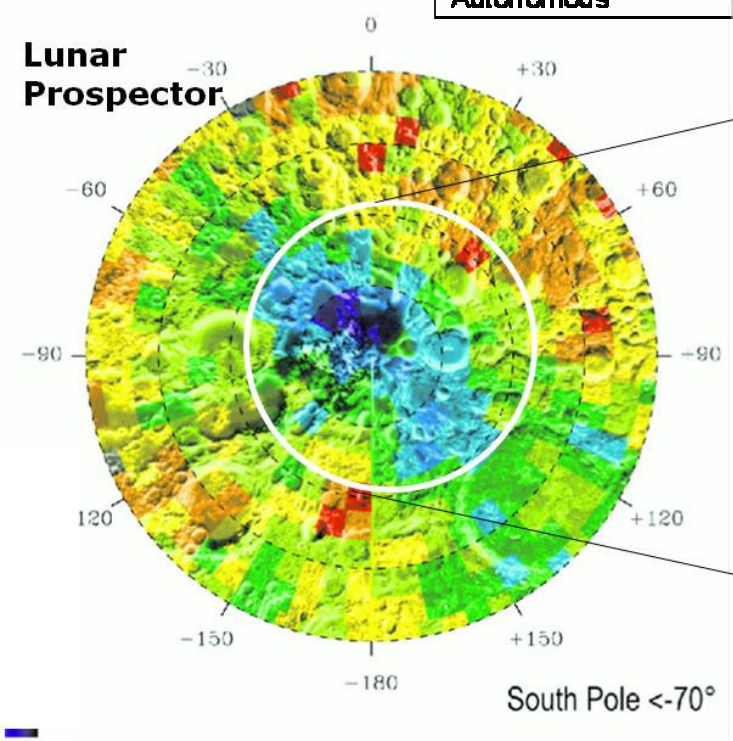


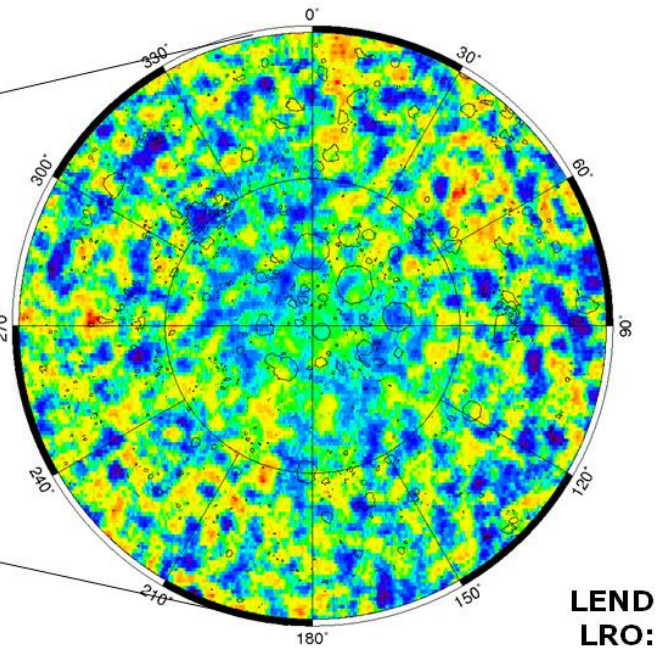
LEND – Preliminary Mapping of Hydrogen Abundance

LEND: Lunar Explr. Neutron Detector

- Neutron Albedo
- Hydrogen Maps

Full Orbit
Autonomous





LEND
LRO:
19 km resolution

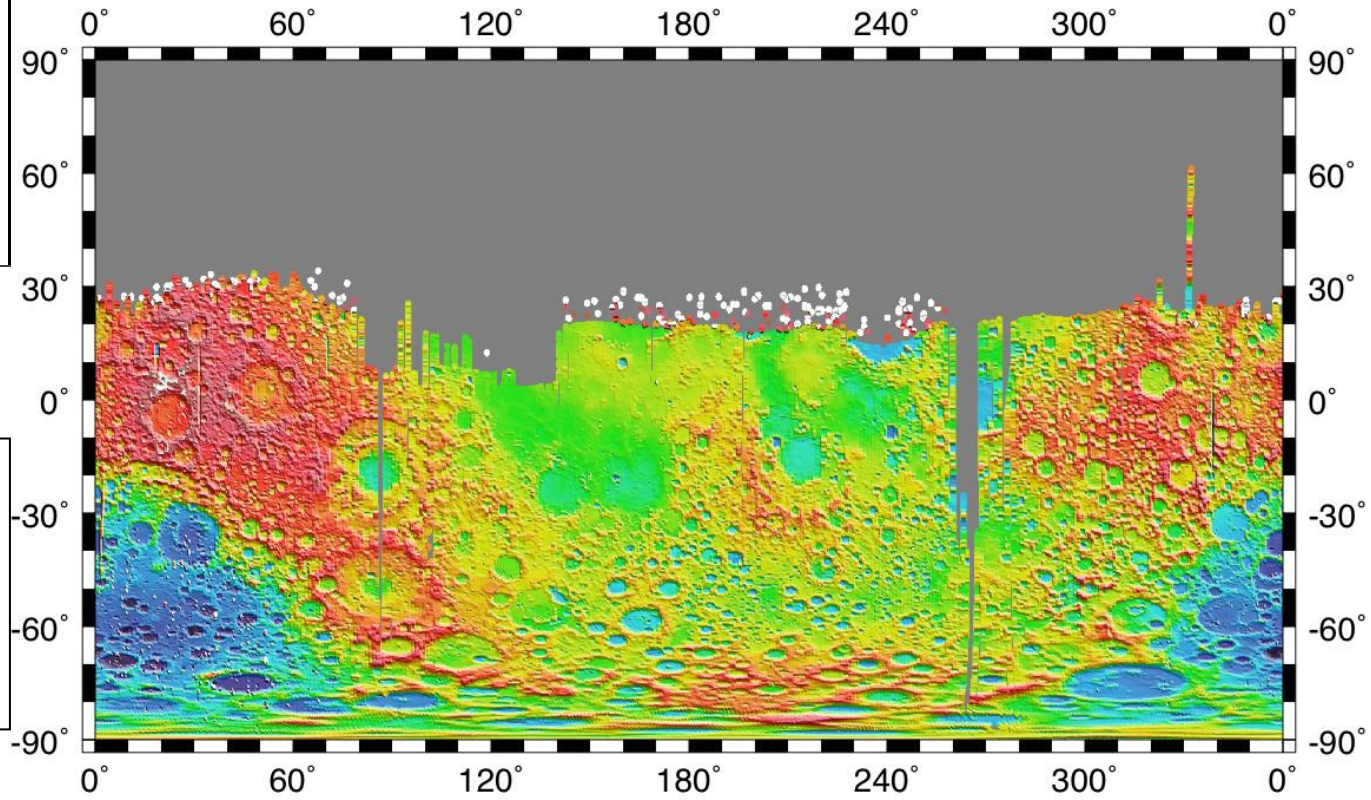
South Pole <-80°

LOLA Instrument Performance: Topography

LOLA: Lunar Orbiter Laser Altimeter

- Topography
- Slopes
- Roughness

Full Orbit
Autonomous



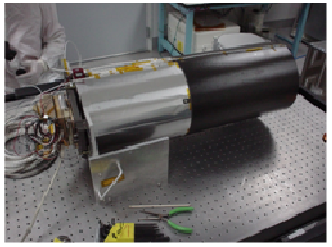
- Approximately 80 million LOLA altimetry measurements used to develop this image.

- Data acquired between July 11 and Aug 12.

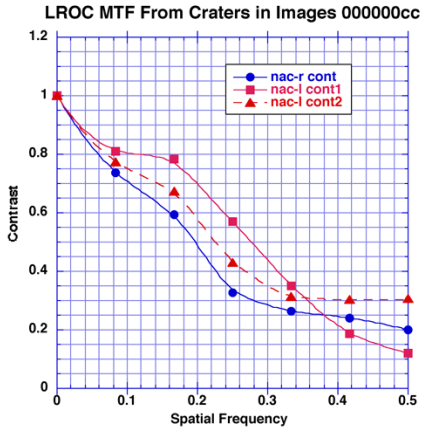
LROC Lunar Images

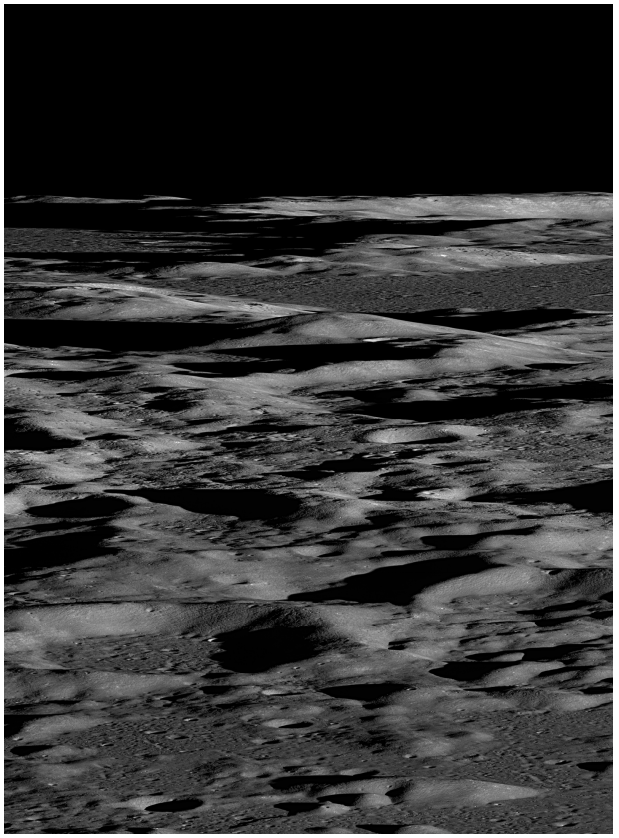
LROC/NACs: Narrow-Angle Cameras

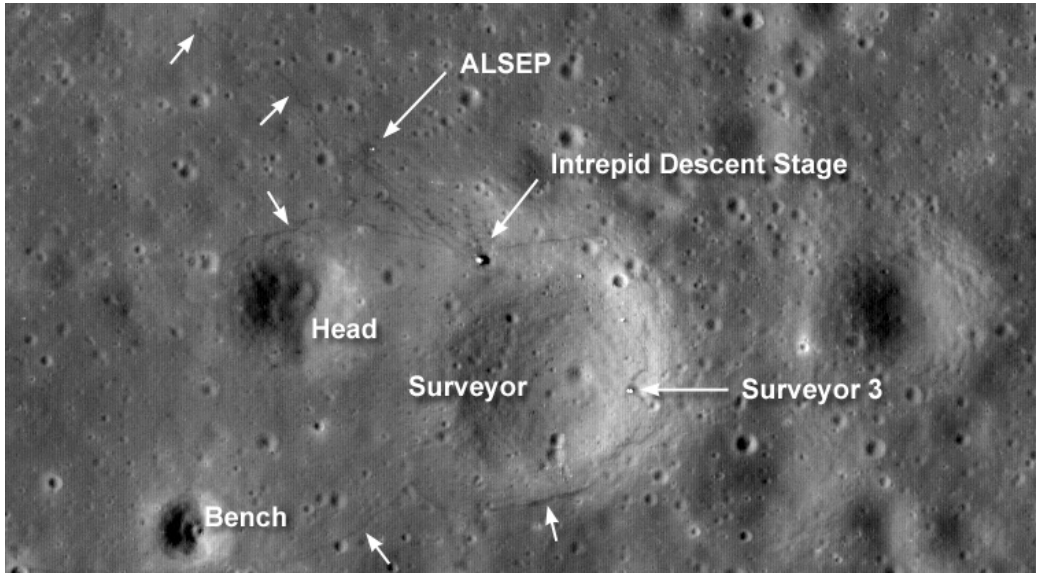
- Targeted Imagery
- Hazards
- Topography



Day Side
Timeline Driven







Apollo 14 site, 1 m/pixel

Example Lunar Limb observation (center of mosaic of NAC R (top) and L (bottom), 75° north looking east from 73°E

Mini RF S-band Mosaic of South Pole

Mini-RF: Synthetic Aperture Radar

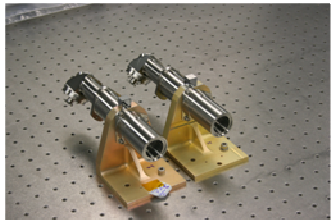
- Tech Demonstration
- Resources
- Topography

Polar Regions
Timeline Driven

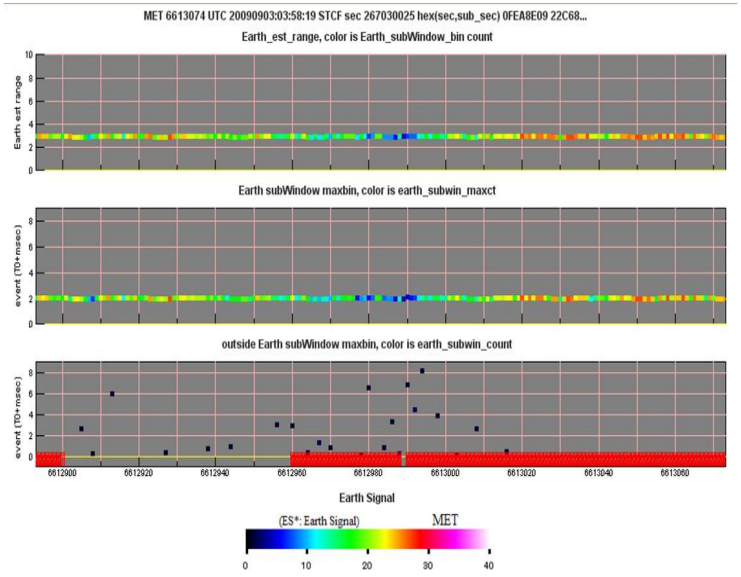
Goddard Geophysical and Astronomical Observatory (Laser Ranging to LRO)

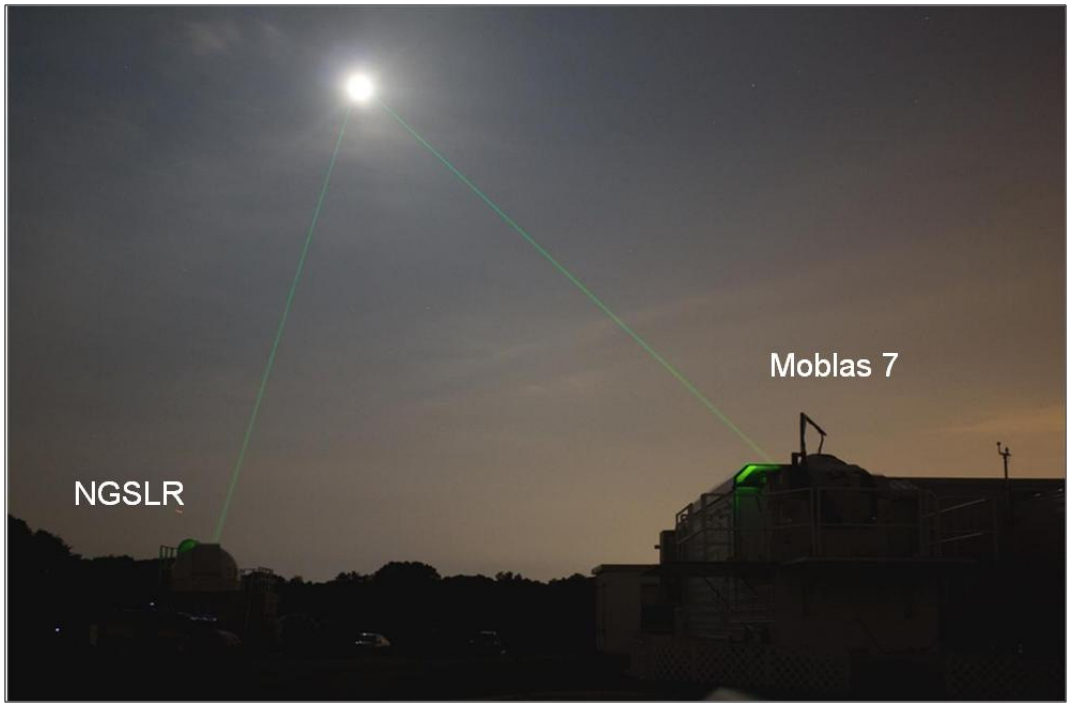
LR: Laser Ranging

- Topography
- Gravity



GSFC LOS
Autonomous





3 minutes of LR observations. TOP Chart: Red indicates 28/s, green 15 to 20/s. Short loss of signal usually due to clouds at the tracking station.

Closing Thoughts

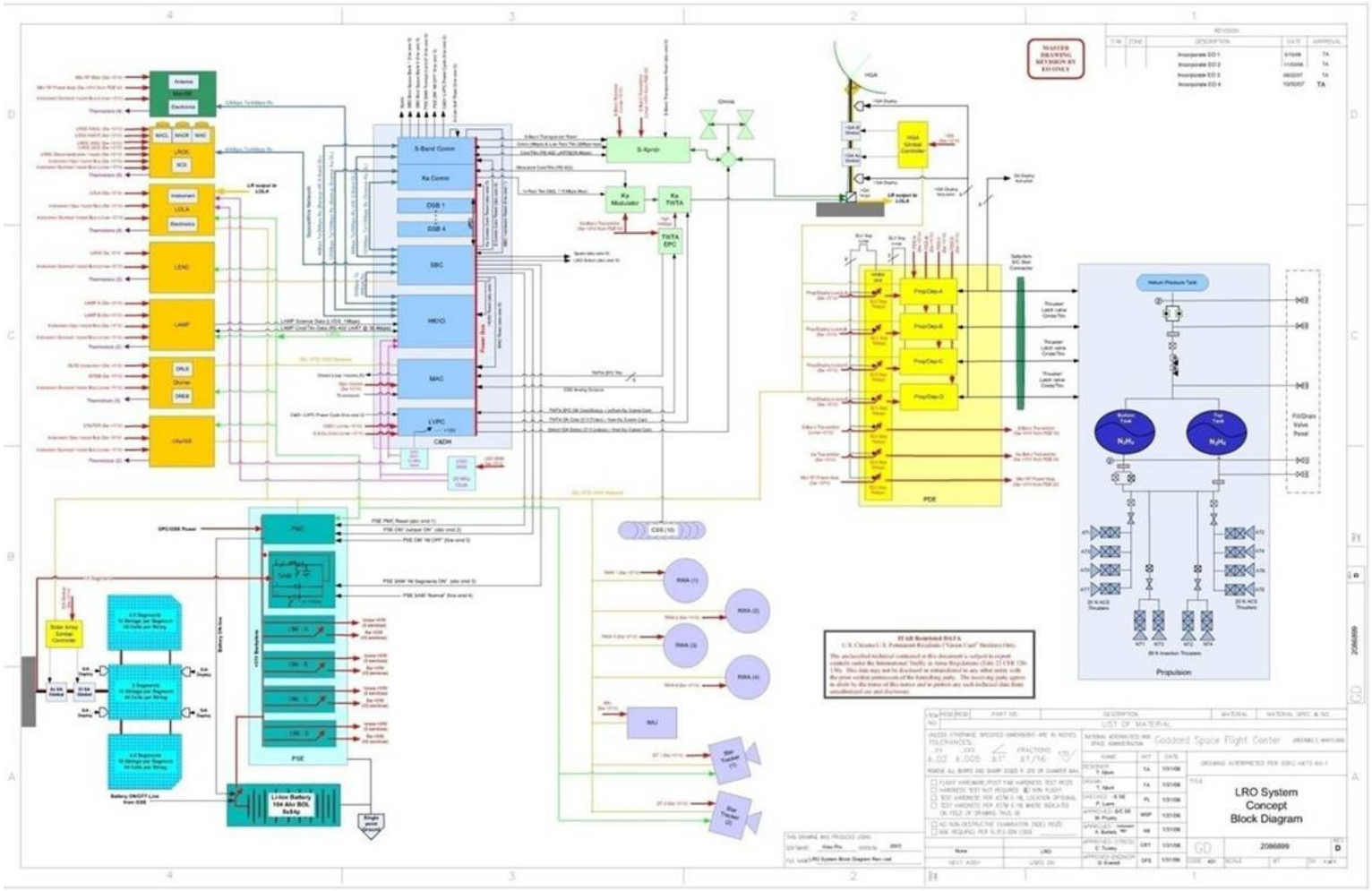
- The LRO mission was a programmatic success
  - *Completed on-budget at confirmed baseline cost (~$504M)*
    - Includes spacecraft, instruments, rocket, ground system, and 1 year of operations
  - *Completed on schedule*
    - LRO was ready to launch by the end of 2008, as planned and required, delay into 2009 was mandated by NASA and the DOD to allow other missions (which were late) to launch first.
  - *Mission is performing flawlessly thus far*
- The LRO-LCROSS Combined Mission was a Complete Success
  - *ESMD exploited an opportunity and ARC stepped up to the challenge with LCROSS*
  - *The LRO (GSFC) and LCROSS (ARC) Projects established a synergistic working relationship that permeated all levels of both projects .*
  - *The LPRP Program (MSFC) evolved into a high value-added organization that focused on the combined mission and its issues.*
  - *By the time we all reached the launch site the mindset was the success of the Mission (LRO+LCROSS)*

Reference Information

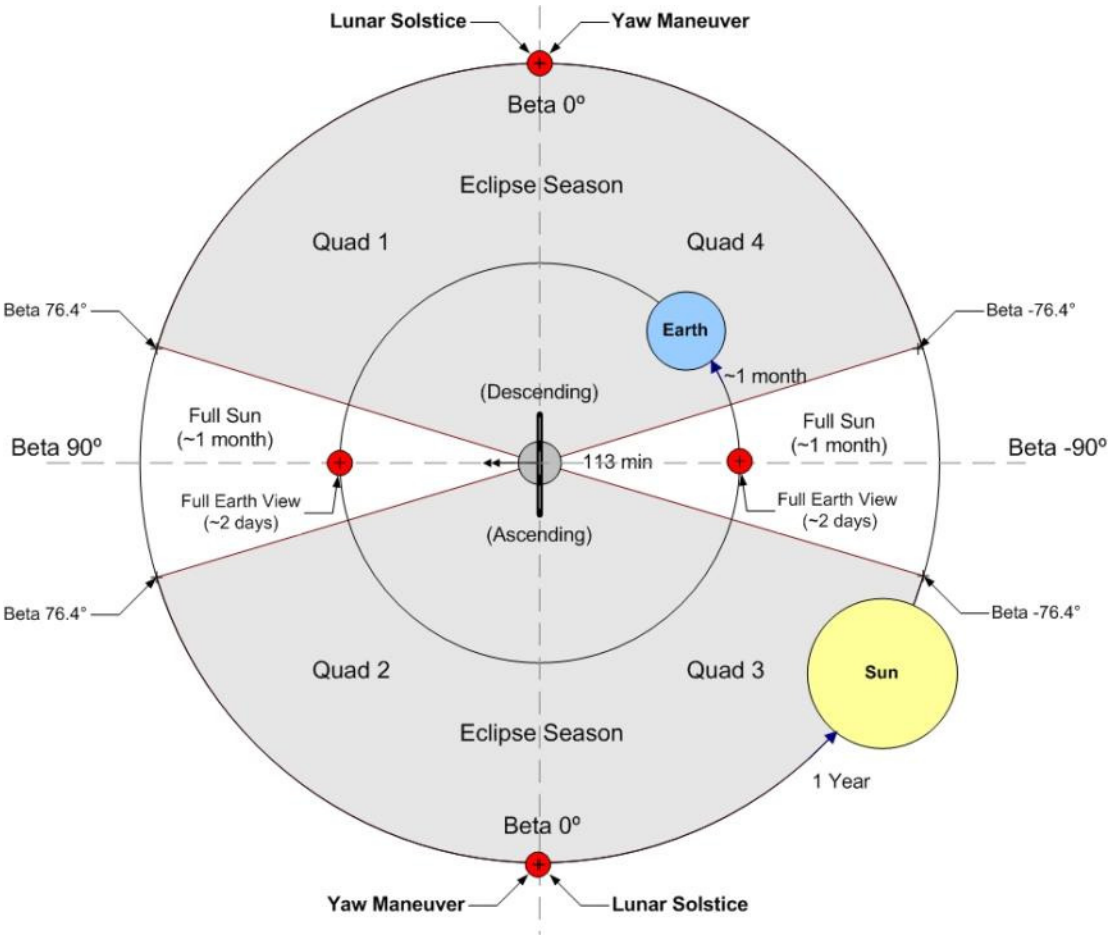
LRO Information Sources & Links

- Websites:
  - http://lroupdate.blogspot.com
  - http://www.nasa.gov/LRO
  - http://lunar.gsfc.nasa.gov/
  - http://lroc.sese.asu.edu

LRO System Block Diagram



The Moon-Centered Universe

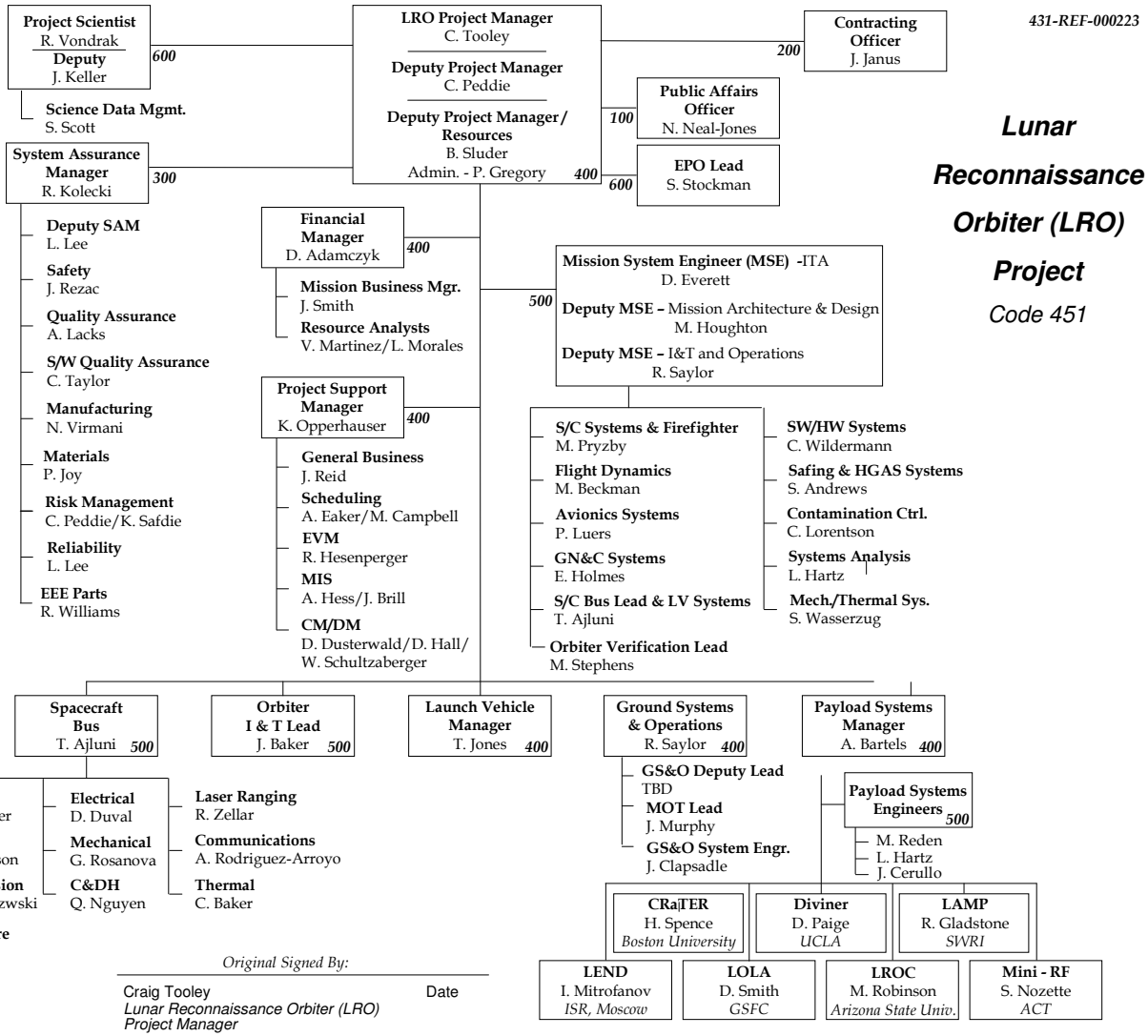


- Twice a month, LRO's orbit will be in full view of the Earth for roughly 2 days.
- Twice a month, LRO will perform a momentum management maneuver while the ground has complete coverage.
- Once a month, LRO will perform a station-keeping (SK) maneuver while the ground has complete coverage.
- Twice a year, LRO's orbit will be in full view of the Sun for roughly one month.
- During the eclipse season, LRO will have a max. lunar occultation of 48 minutes.
- LRO's orbit will be targeted such that lunar solstice occurs near maximum occultation.
- Twice a year, LRO will perform a 180° yaw maneuver.
- Twice a year, the Moon will pass through the Earth's shadow (Lunar Eclipse).

LRO Reserves & Margins at Launch

LRO Reserves & Margins at PSR				
Cost (reserve on Phase A-D cost-to-go)			15% (assumes funding for June 17 ILC)	
Cost (reserve on Phase E)			0% (as planned but residual A-D could be rolled over)	
Schedule days			12	
Technical Resource			Limit	CBE	Margin
Mass, Dry (kg)			1066.5	1018.4	4.7%
Power (W)			823	685	20.3%
RF Link - At Lunar Distance					
Uplink	HGA – S-Band	(WCS)	-	-	20.3 (dB)
	Omni – S-Band	(DSN)			15.9 (dB)
Downlink	HGA - S-Band	(WCS)	-	-	6.93 (dB)
		(USN)			4.64 – 7.44 (dB)
	HGA - Ka-Band	(WCS)			7.46 (dB)
RF Link – Worst Case (Tumble at Lunar Distance)					
Uplink	Omni – S-Band	(DSN)	-	-	15.9 (dB)
Data & Computational Margins					
Ka Downlink Utilization (min)			180	85.0	47%
Measurement Interruptions – Data Capture (Orbits)			234	80	193%
1553 Bus Utilization (kbits/sec)			300	193	35%
CPU (% utilization)			100%	29.6%	67%
EEPROM (Kb)			2048	983	23%
uP RAM (kB)			36864	18860	26%
PCI Bus (% utilization)			100%	21.8%	62%

LRO Project Organization at Phase C/D

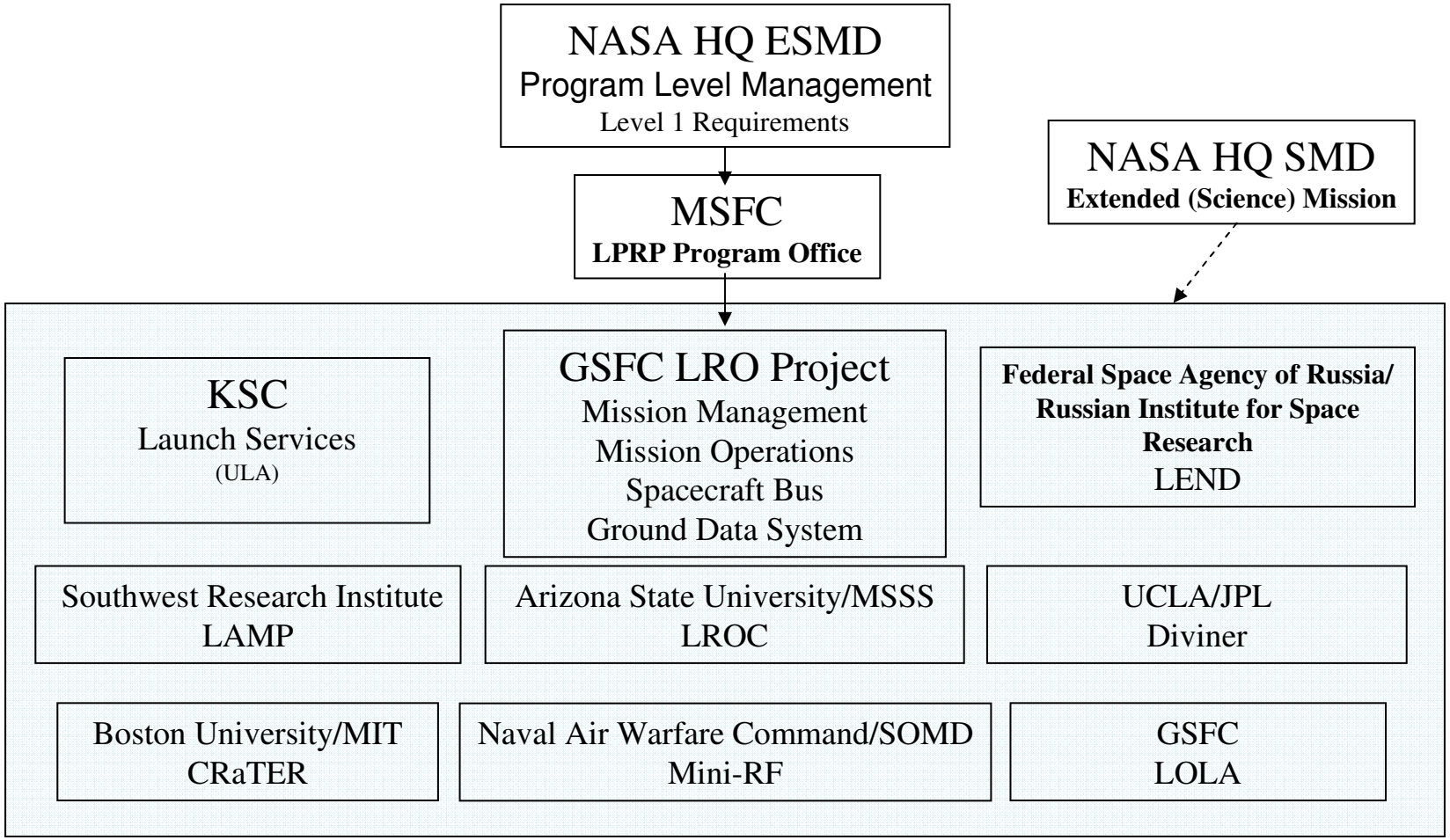


431-REF-000223

Lunar Reconnaissance Orbiter (LRO) Project

Code 451

LRO Mission Implementing Organizations



LRO Dimensional Layout (Deployed)