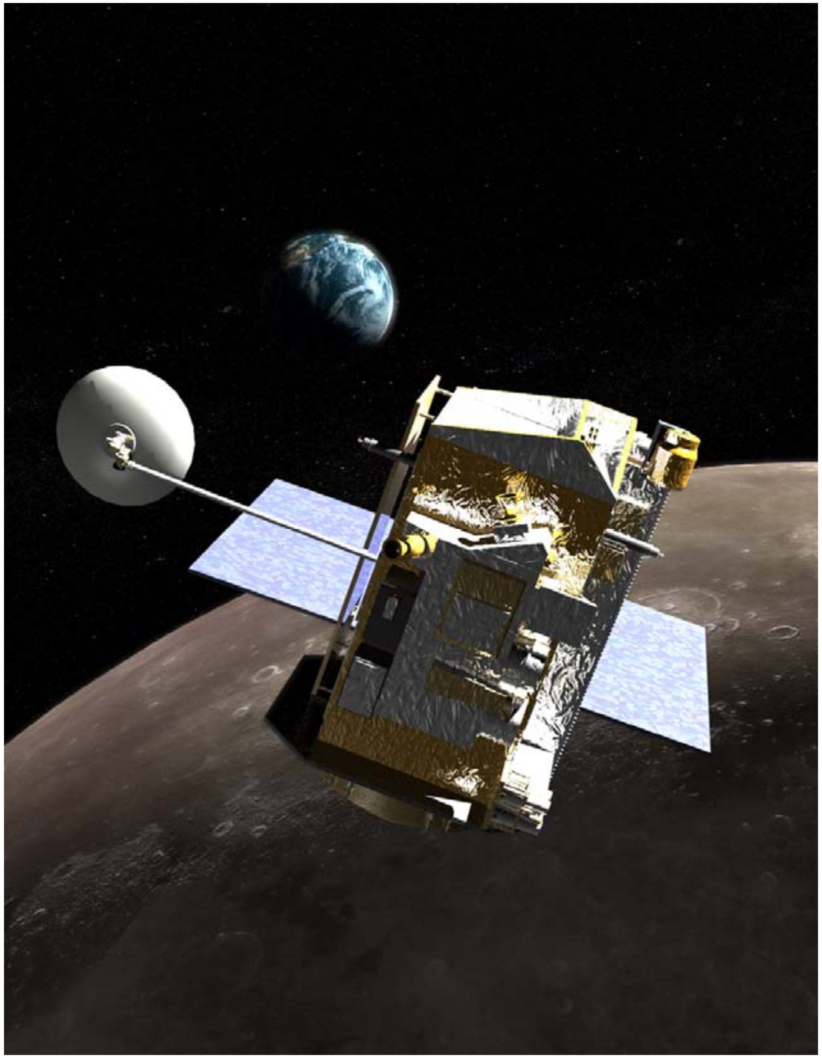
Lunar Reconnaissance Orbiter Spacecraft & Objectives



Craig Tooley – LRO Project Manager
NASA Goddard Space Flight Center
craig.r.tooley@nasa.gov
http://lunar.gsfc.nasa.gov/
301.286.1158

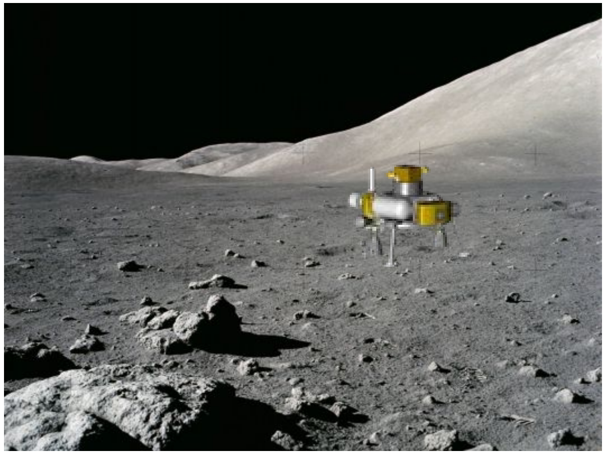
2006 AIAA-Houston
Annual Technical Symposium
May 19, 2006

Lunar Exploration Robotic Precursor Missions

***"Starting no later than 2008, initiate a series of robotic missions to the Moon to prepare for and support future human exploration activities"*, NPSD-31**

- Provide early information for human missions
  - Key knowledge needed for human safety and mission success
  - Infrastructure elements for eventual human benefit
  - Results will guide human exploration

- Resolve many unknowns are at the North and South Poles
  - Knowledge of the environment – temperatures, lighting, etc.
  - Resources/deposits – composition and physical nature
  - Terrain and surface properties - dust characterization
  - Support infrastructure – navigation/communication, beacons

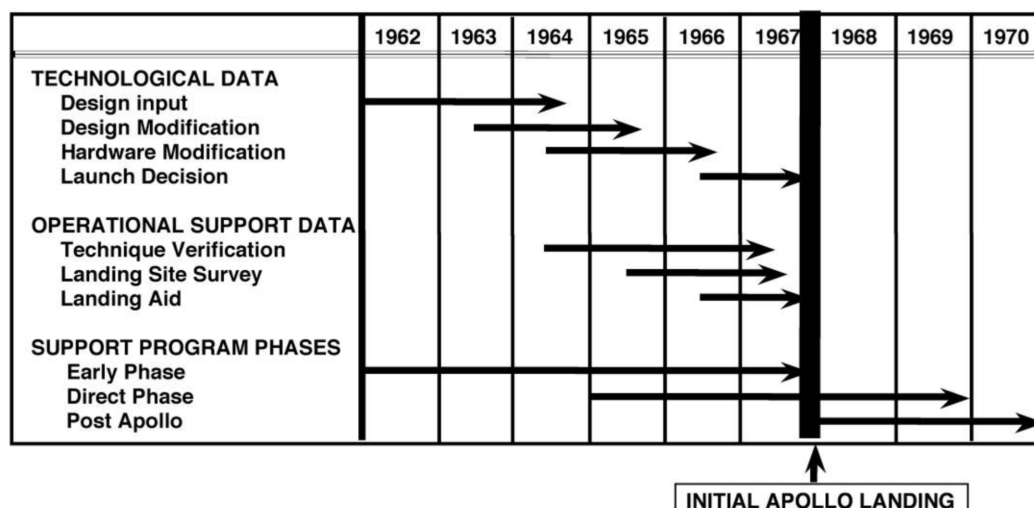


- Make exploration more capable and sustainable
  - Surface systems
  - Operations
  - Science community

LRO Follows in the Footsteps of the Apollo Robotic Precursors

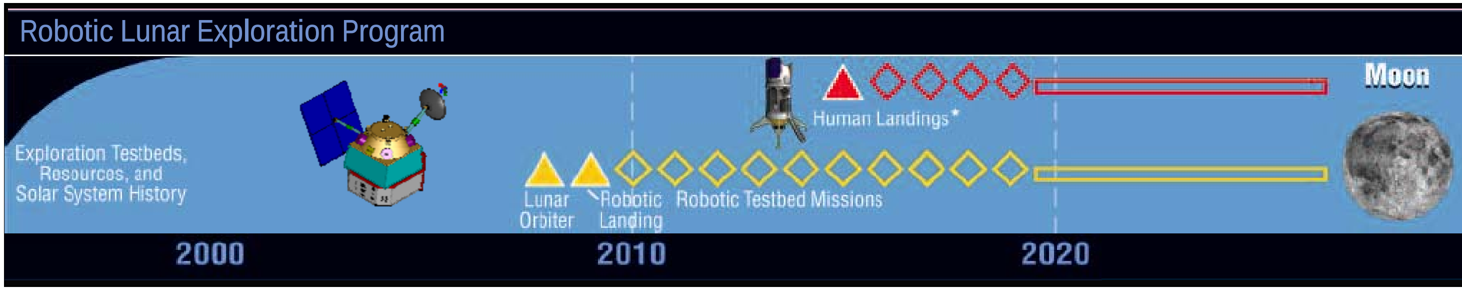
- Apollo had three (Ranger, Lunar Orbiter and Surveyor) robotic exploration programs with 21 precursor missions from 1961-68
  1. Lunar Orbiters provided medium & high resolution imagery (1-2m resolution) which was acquired to support selection of Apollo and Surveyor landing sites.
  2. Surveyor Landers made environmental measurements including surface physical characteristics.
  3. Ranger hard landers took the first close-up photos of the lunar surface
- Exploration needs the above information to go to new sites AND resource data to enable sustainable exploration.

Lunar Orbiter ETU in Smithsonian Air & Space Museum, Washington DC



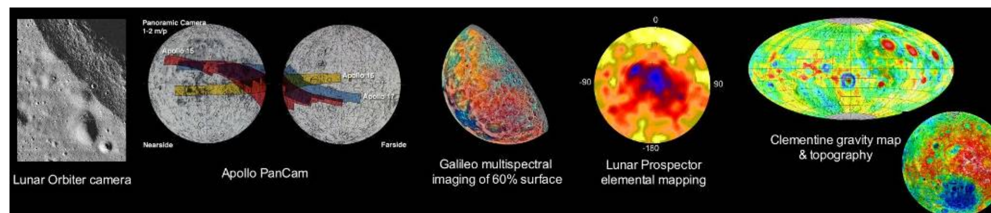
2008 Lunar Reconnaissance Orbiter (LRO)

First Step in the Robotic Lunar Exploration Program



LRO Objectives

- **Characterization of the lunar radiation environment, biological impacts, and potential mitigation. Key aspects of this objective include determining the global radiation environment, investigating the capabilities of potential shielding materials, and validating deep space radiation prototype hardware and software.**
- **Develop a high resolution global, three dimensional geodetic grid of the Moon and provide the topography necessary for selecting future landing sites.**
- **Assess in detail the resources and environments of the Moon's polar regions.**
- **High spatial resolution assessment of the Moon's surface addressing elemental composition, mineralogy, and Regolith characteristics**



Objective: The Lunar Reconnaissance Orbiter (LRO) mission objective is to conduct investigations that will be specifically targeted to prepare for and support future human exploration of the Moon.

LRO Project Implementing Organizations

NASA HQ ESMD
Level 1 Requirements

↓

NASA ARC RLEP
Program Management

↓

GSFC LRO Project
Mission Management
Spacecraft Bus
Ground Data System

KSC
Launch Services

Federal Space Agency of Russia/ Russian Institute for Space Research
LEND

Southwest Research Institute
LAMP

Arizona State University/MSSS
LROC

UCLA/JPL
Diviner

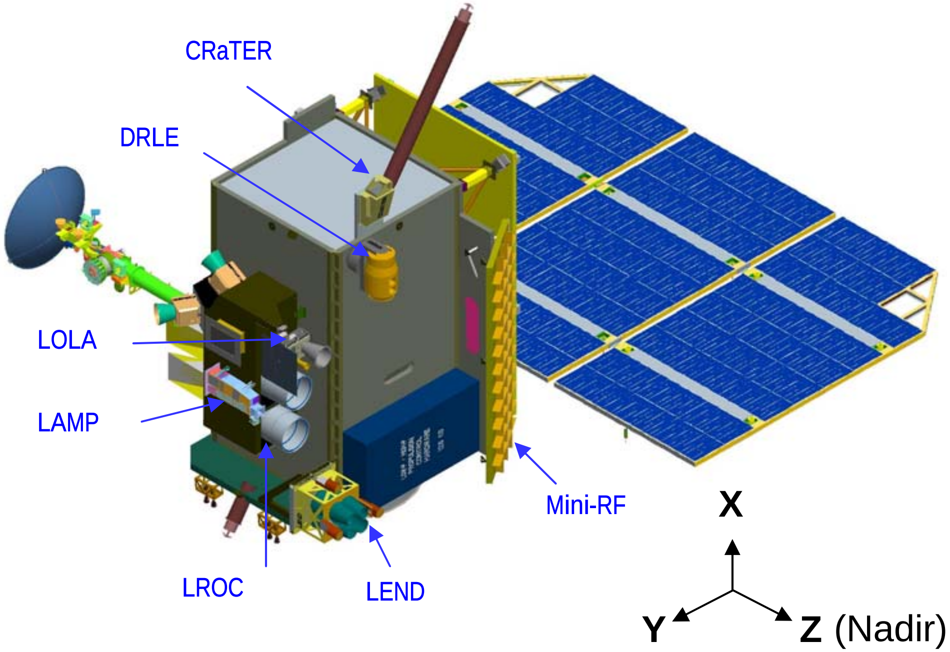
Boston University/MIT
CRaTER

Naval Air Warfare Command/SOMD
Mini-RF

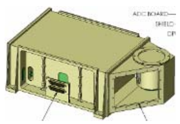
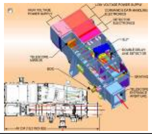
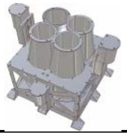
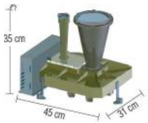
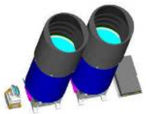
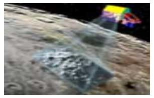
GSFC
LOLA

LRO Mission Overview

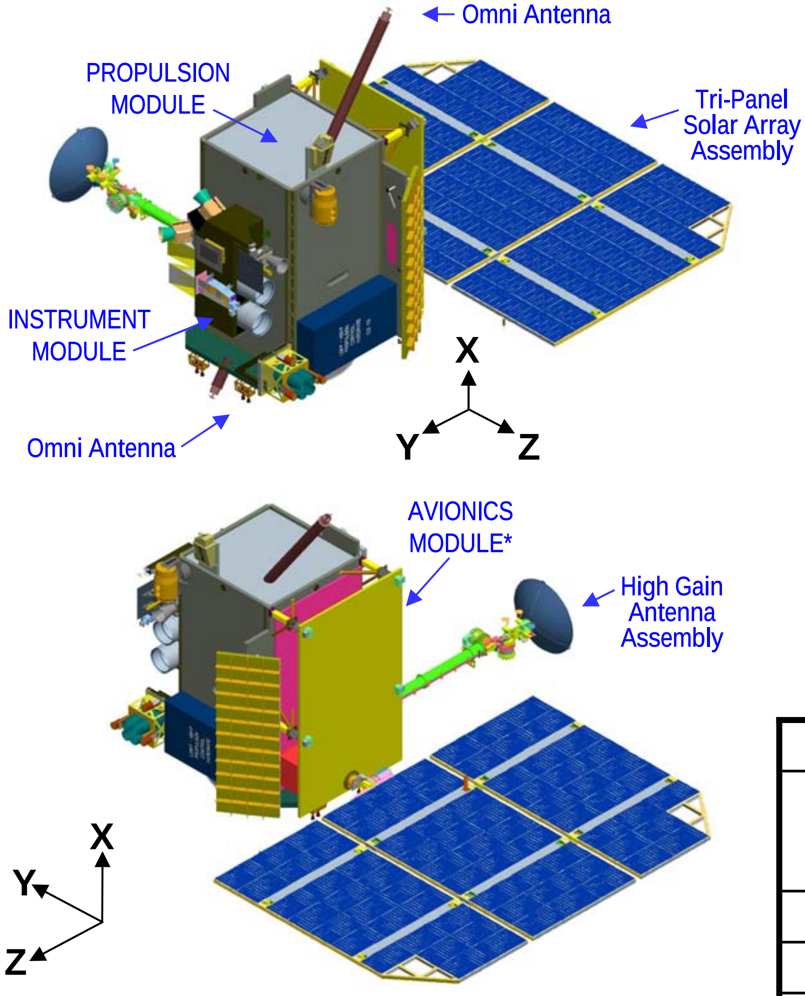
- Launch in late 2008 on a EELV into a direct insertion trajectory to the moon.
- On-board propulsion system used to capture at the moon, insert into and maintain 50 km mean altitude circular polar reconnaissance orbit.
- 1 year mission with extended mission options.
- Orbiter is a 3-axis stabilized, 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.



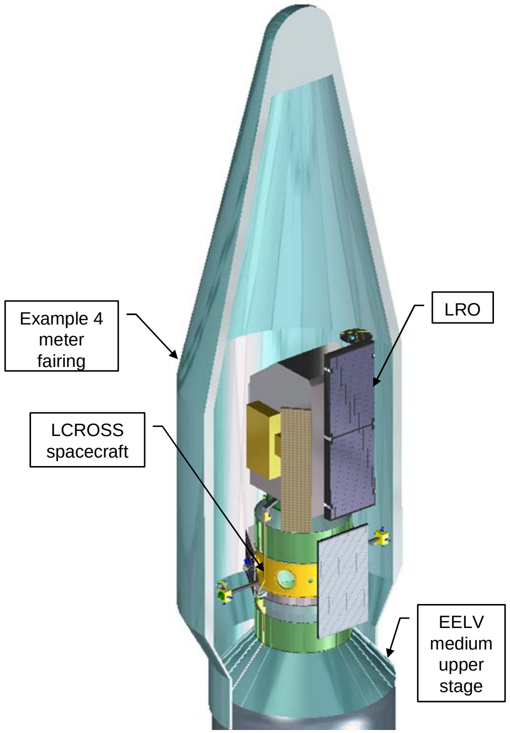
LRO Instrument Suite is a Robust Response to Exploration Requirements

INSTRUMENT	Key Data Products	Exploration Benefits	Science Benefits
CRaTER Cosmic Ray Telescope for the Effects of Radiation 	Lunar and deep space radiation environment and tissue equivalent plastic response to radiation	Safe, lighter weight space vehicles. Radiation environment for human presence at the Moon and journeys to Mars and beyond.	Radiation boundary conditions for biological response . Map radiation reflected from lunar surface
DLRE Diviner Lunar Radiometer Experiment 	500 m scale maps of surface temperature, albedo, rock abundance, and ice stability	Measures thermal environment in permanent shadow and permanent light, ice depth map	
LAMP Lyman Alpha Mapping Project 	Maps of frosts and landforms in permanently shadowed regions (PSRs).	Locate potential water-ice on the surface, image shadowed areas, and map potential landing areas in PSRs	Source, history, migration and deposition of polar volatiles
LEND Lunar Exploration Neutron Detector 	Maps of hydrogen in upper 1 m of Moon at 10 km scales, neutron albedo	Locate potential water-ice in lunar soil or concentrations of implanted hydrogen	
LOLA Lunar Orbiter Laser Altimeter 	~25 m scale polar topography at < 10 cm vertical, global topography, surface slopes and roughness	Identify safe landing sites, image shadowed regions, map potential surface ice, improve gravity field model	Global topography and gravity for interior structure and geological evolution
LROC Lunar Reconnaissance Orbiter Camera 	1000's of 50cm/pixel images, and entire Moon at 100m in UV, Visible. Illumination conditions of the poles.	Surface landing hazards and some resource identification including locations of near constant solar illumination	Tectonic, impact and volcanic processes, resource evaluation, and crustal evolution
Mini-RF *Technology Demonstration* 	X and S-band radar imaging and interferometry	Demonstrate new lightweight SAR and communication technologies, locate potential water-ice	Source, history, deposition of polar volatiles

LRO Orbiter Configuration Overview

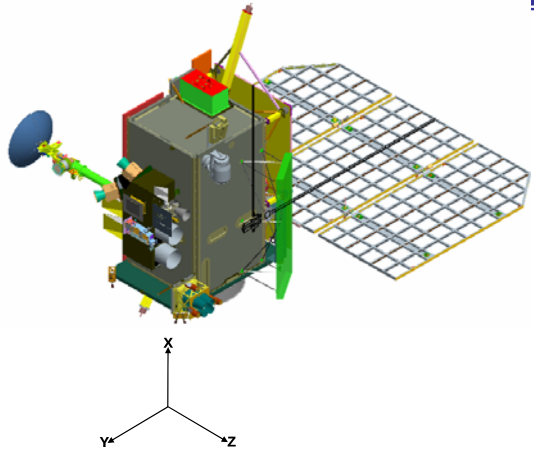


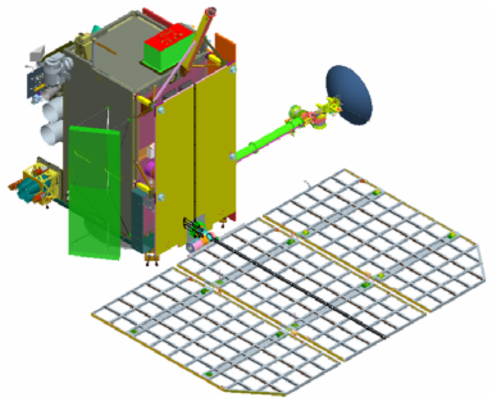
*(Some close-out covers removed for clarity)

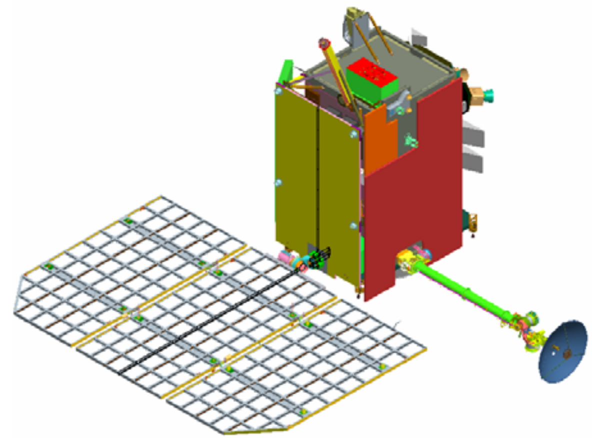


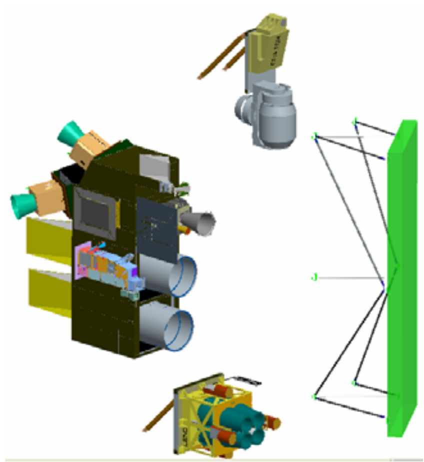
LRO Orbiter Characteristics		
Mass (CBE)	1706 kg	Dry: 809 kg Fuel: 897 kg (1326 m/sec)
Orbit Average Bus Power	681 W	
Data Volume, Max Downlink rate	572 Gb/day, 100Mb/sec	
Pointing Accuracy, Knowledge	60, 30 arc-sec	

LRO Modular Construction

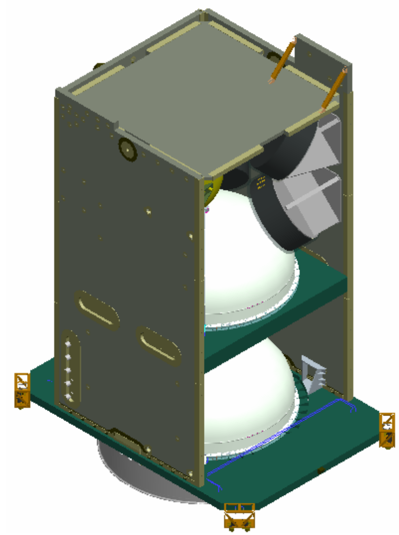




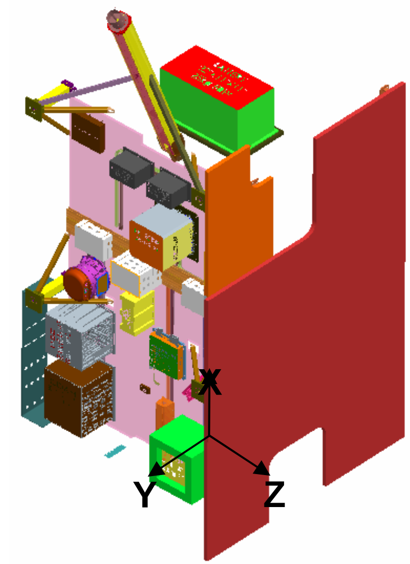




Instruments & Optical Bench



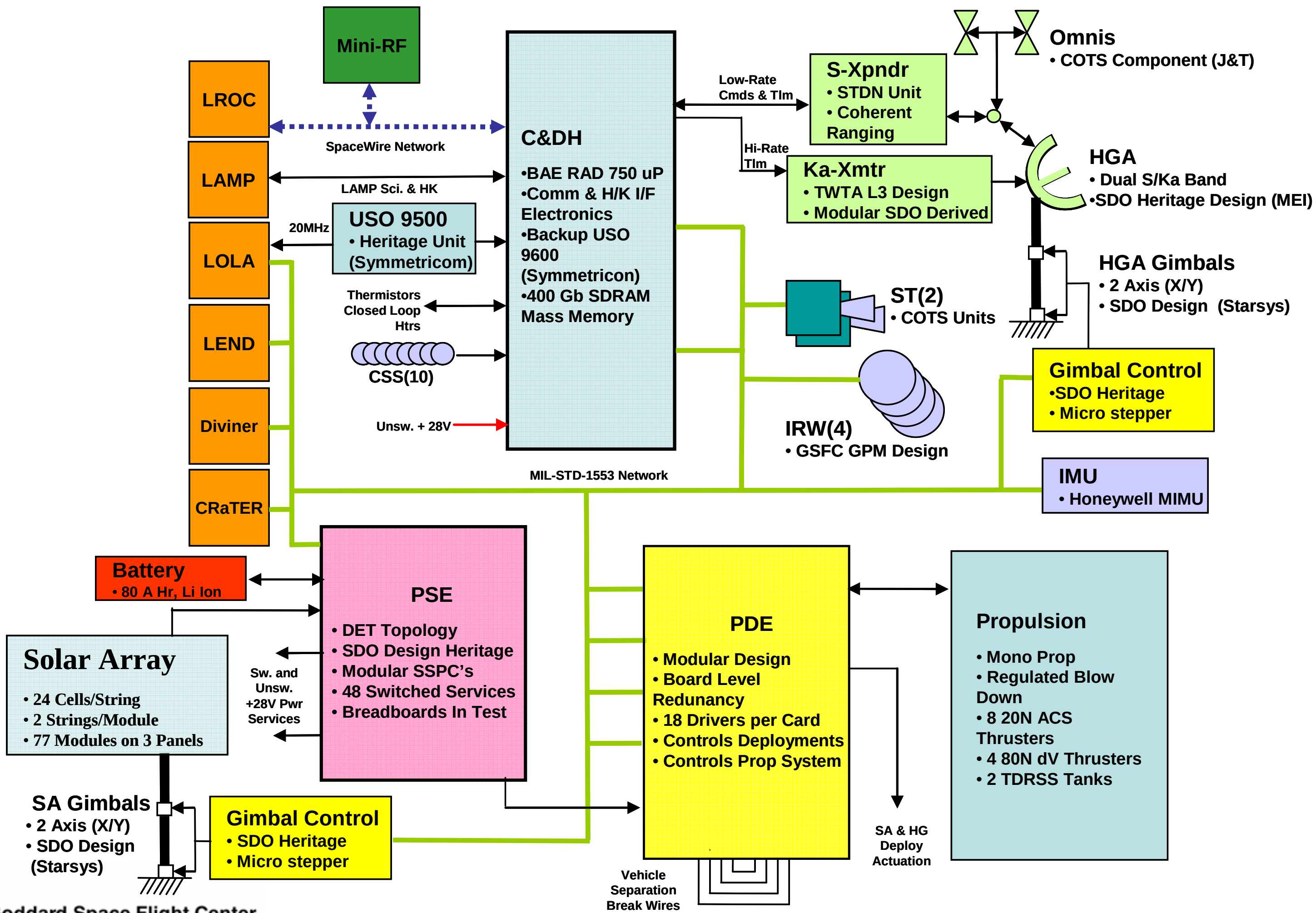
Propulsion Module
(Primary Structure w/Propellant Tanks and Reaction Wheels Visible)



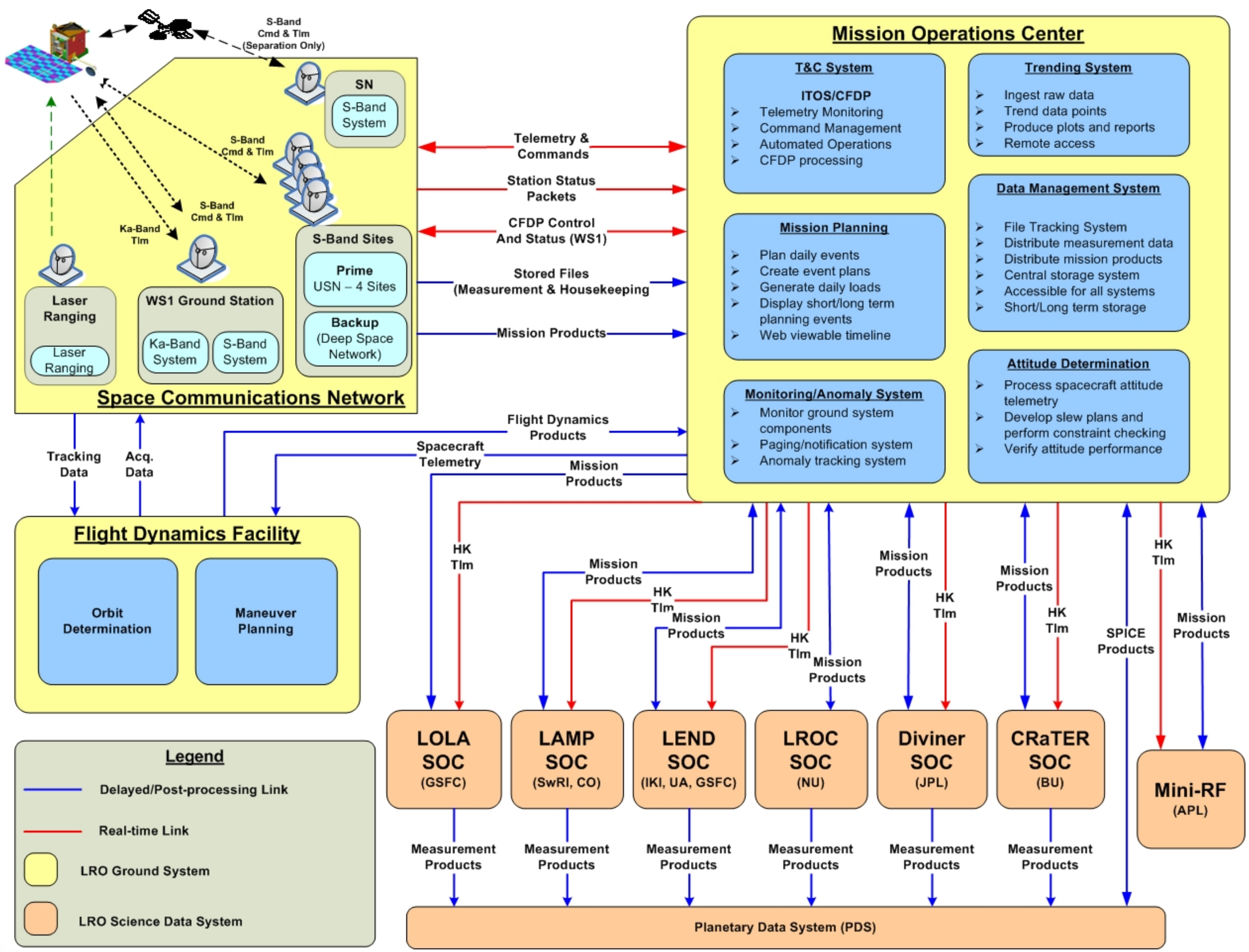
Avionics Module
(Avionics, Isothermal Panel, & Radiator)

LRO Orbiter System Architecture

- Spacecraft architecture emphasizes modularity through the use of standard interfaces
- Subsystems leverage prior GSFC designs

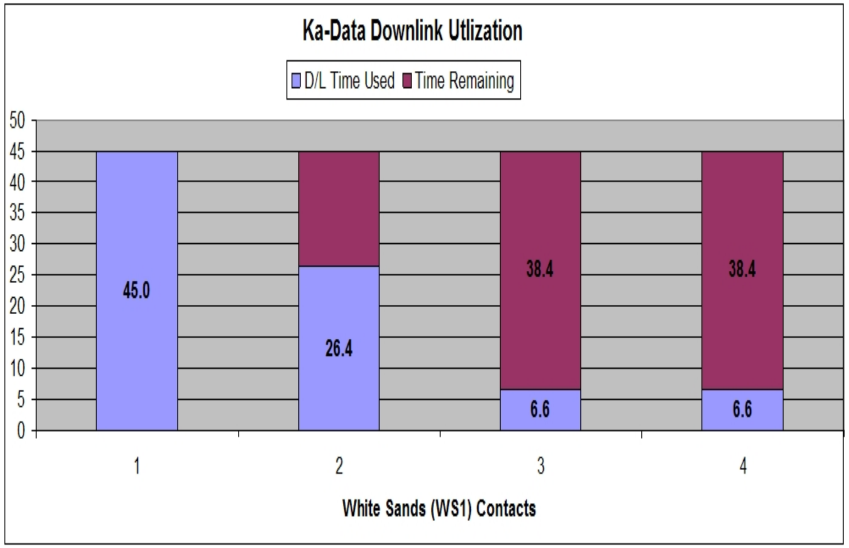


LRO Ground Segment Overview



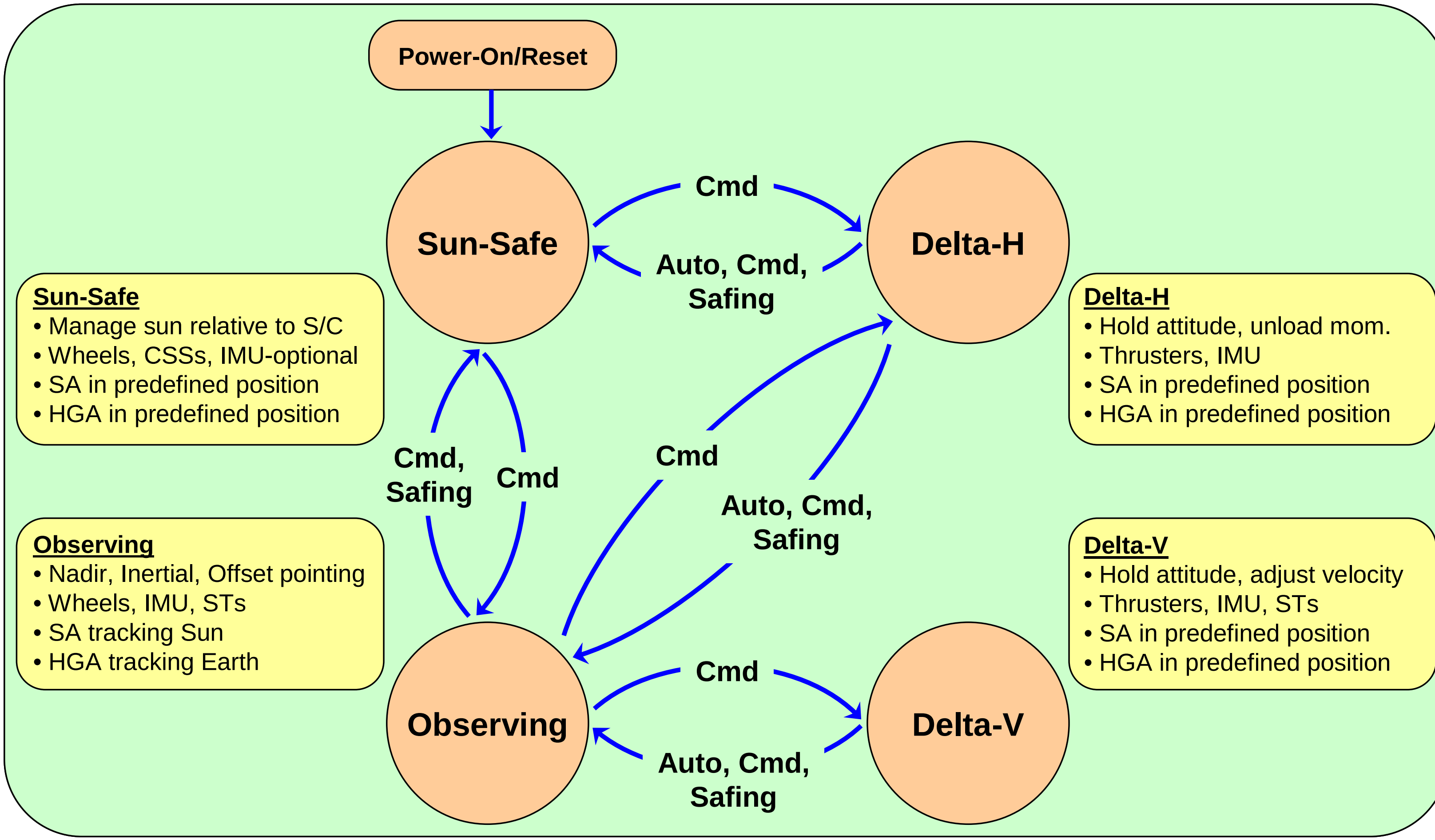
LRO Data Volume and Downlink Margin

LRO Daily Data Estimates				
Data Source	Data Volume per Orbit (Mbits)	Data Volume per Day (Gbits)	Files per Orbit	Files per Day
Spacecraft HK	216.96	2.76	27.1	345.6
CRaTER	609.09	7.76	1.0	13.1
Diviner	274.24	3.49	34.3	459.0
LAMP	73.77	0.94	1.7	22.2
LEND	20.52	0.26	2.6	33.2
LOLA	110.11	1.40	13.8	234.1
LROC NAC	30,317.42	386.35	24.0	305.8
LROC WAC	3,204.43	40.84	3.0	38.2
Totals:	34,826.54	443.81	107.42	1,451.29

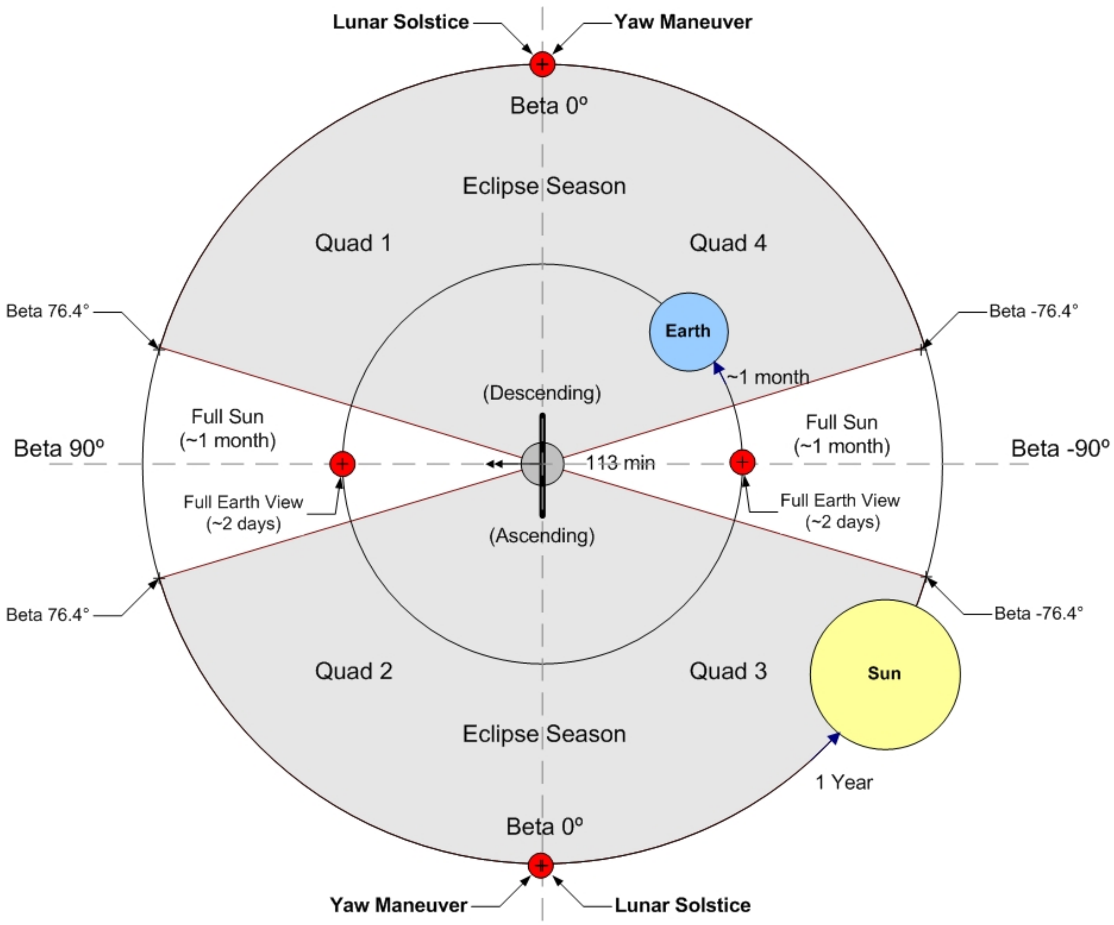


- Maximum daily data volume: ~450 Gbits
- Data stored in files within the spacecraft recorder
- Ka Downlink Utilization: ~47%
- S/C recorder provides ~1.3 days worth of storage (data volume dependant)

LRO Control Modes Overview



The Moon-Centered LRO Universe



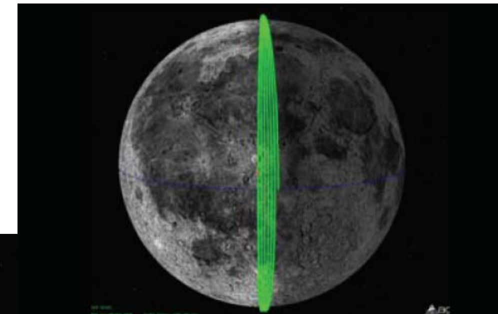
- Twice a month, LRO's orbit will be in full view of the Earth for roughly 2 days.
- Twice a month, LRO will perform a momentum management maneuver while the ground has complete coverage.
- Once a month, LRO will perform a station-keeping (SK) maneuver while the ground has complete coverage.
- Twice 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 maximum 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 Mission Timeline Summary

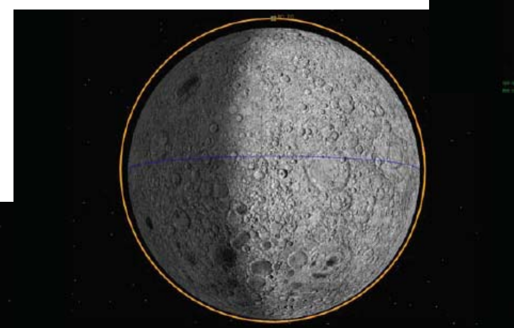
Phase	Entry	Exit	Duration	Objectives
Pre-Launch	Start of LV Count-down Sequence	LV Lift-off	~1 Day	• Configure Orbiter into Launch Mode • Short Spacecraft Checkout
Launch	LV Lift-off	Payload Separation	~90 Minutes	• Achieve Trans-Lunar Trajectory
Early Cruise	Payload Separation	Observing Mode	~6 Hours	• Sun Acquisition and Ground Acquisition • Deployments • Initial MCC Planning
Mid Cruise	Observing Mode	Completion of MCC	~1 Day	• Propulsion Checks • Final MCC Planning • Execution of MCC Burn within L+24 hrs
Late Cruise	Completion of MCC	Start of LOI Sequence	~3-4 Days	• LEND/CRaTER Early Turn-On Activities • Spacecraft Functional Checkout • LOI Planning
Lunar Orbit Acquisition	Start of LOI Sequence	Commissioning Orbit	~4-6 Days	• Perform Lunar Orbit Capture Maneuver • Achieve 30x216 km Commissioning Orbit
Commissioning	Commissioning Orbit	Mission Orbit	Up to 60 Days	• Spacecraft Checkout and Calibrations • Instruments Checkout and Calibrations • Mission Orbit Adjustment
Nominal Mission	Mission Orbit	After 1-Year Nominal Operations	1-Year	• Routine Operations • Non-Routine Operations • Data Product Generation
Extended Mission	After 1-Year Nominal Operations	Impact	Up to 4 Additional Years	• Goals to be Determined • Impact Prediction/Activities
End-of-Mission	Impact	Completion of Closeout Activities	N/A	• Finalize Mission Operations/Activities

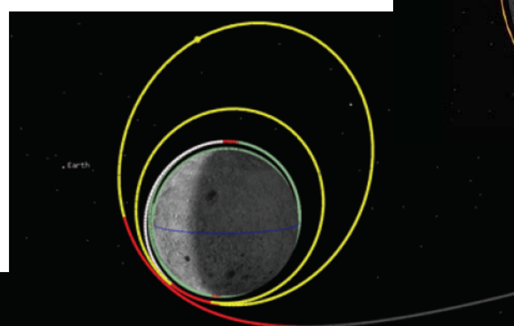
LRO Transfer Trajectory & Lunar Orbit Acquisition

Launch: October 31, 2008

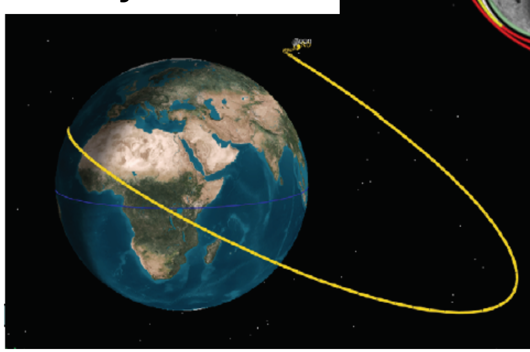


Lunar Orbit Insertion Sequence, 4 Maneuvers, 2-4 Days





Minimum Energy Lunar Transfer ~ 4 Days

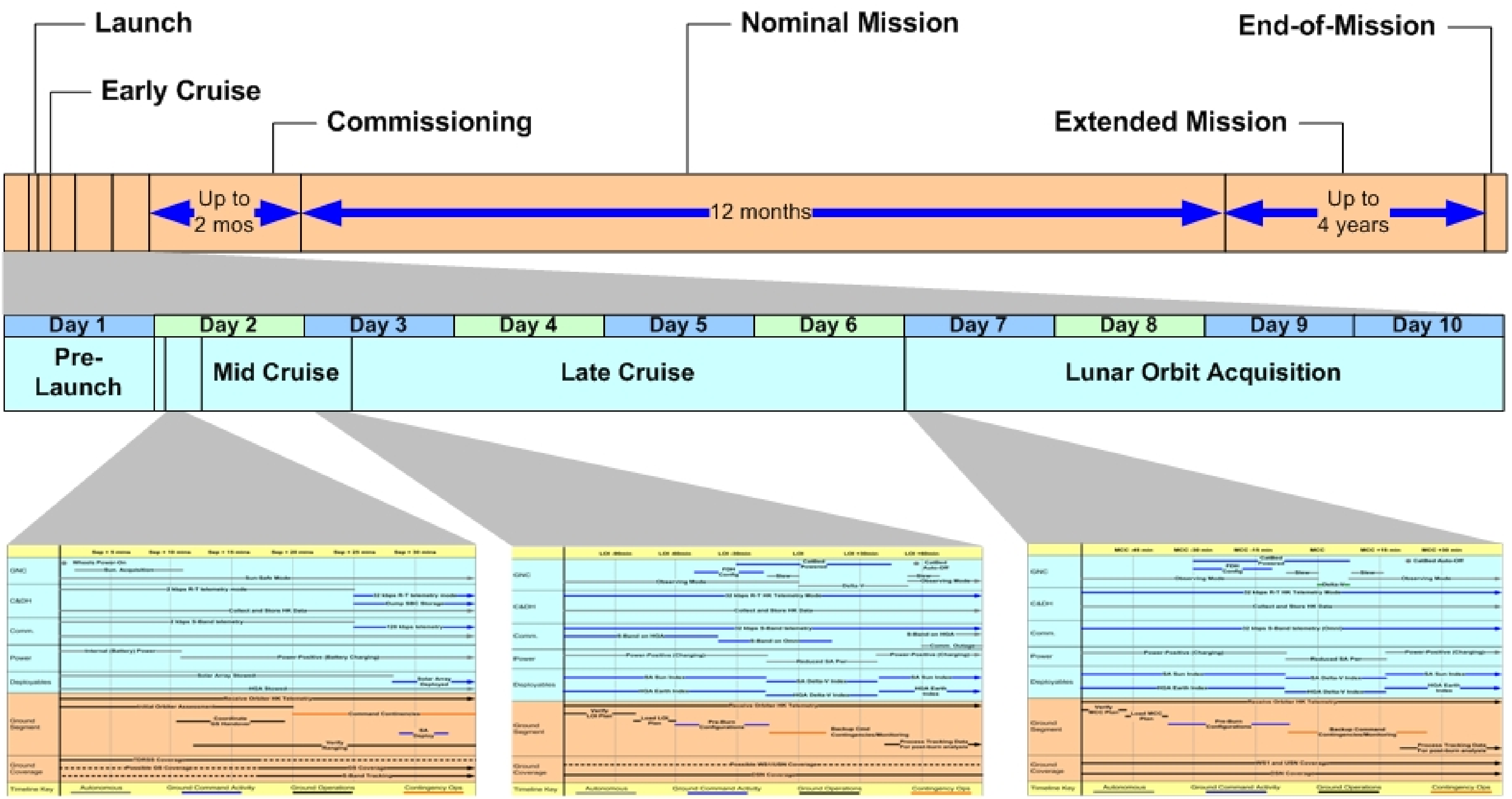


Commissioning Phase, 30 x 216 km Altitude Quasi-Frozen Orbit, Up to 60 Days

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

Nominal End of Mission: February 2010

LRO Mission Timeline

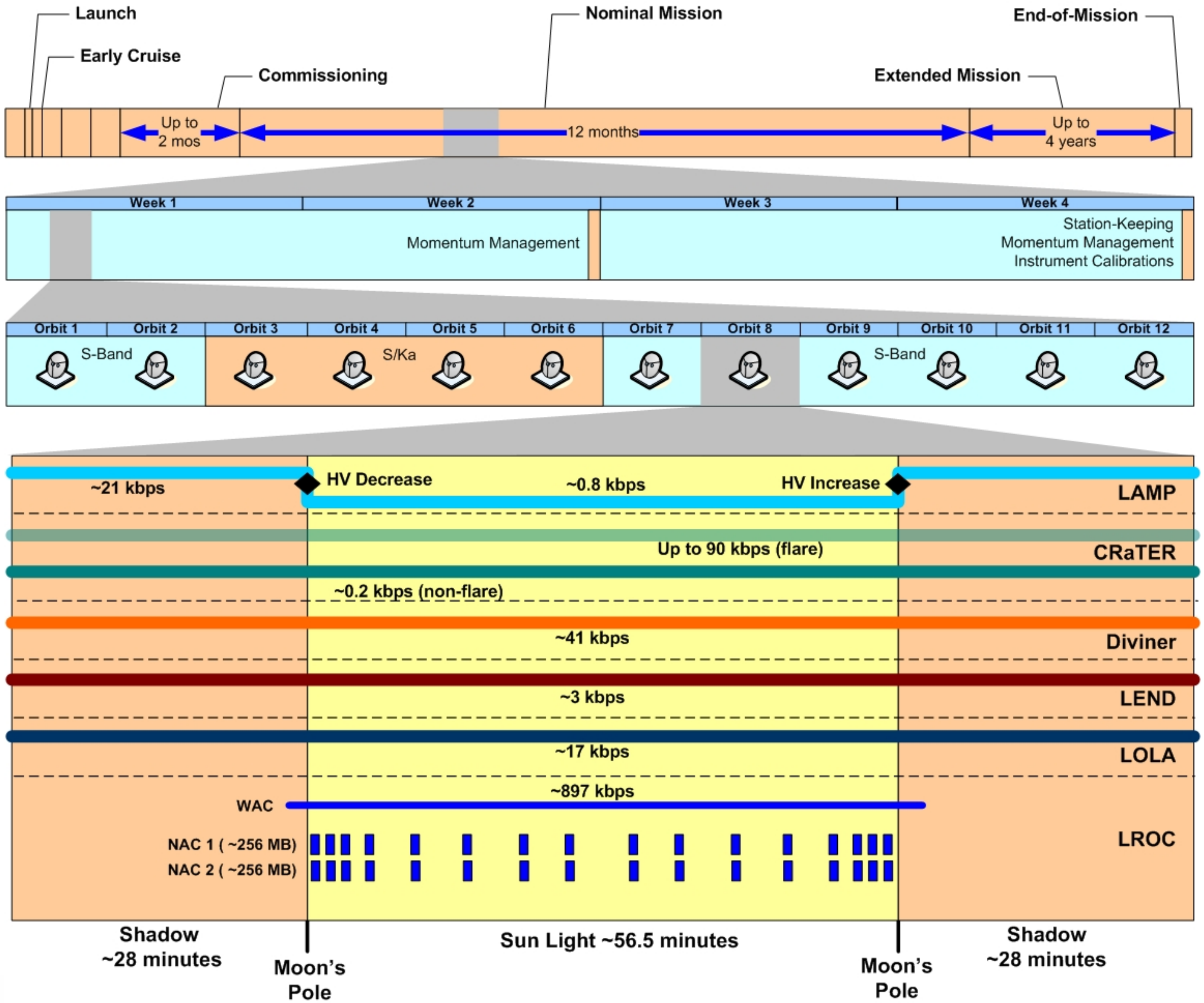


Initial Acq. Timeline

MCC Timeline

LOI – 1 Timeline

LRO Typical Nominal Orbit Operations



LRO Non-Routine Operations

Momentum Dumps
- Performed twice a month when Earth has full orbit view
- One orbit allocated for activity
- Resets system momentum state
- Burn duration on order of secs
- Orbiter holds nadir attitude
- Performed with MOC support

Station-Keeping
- Performed monthly when Earth has full orbit view
- One orbit allocated for activity
- Consists of two burn sequence
- Coordinated with momentum management activity
- Sequences are 27.4 days apart
- Performed with MOC support

Monthly Calibrations
- S/C and payload calibrations
- 3 orbits allocated for activities
- Subset of calibrations performed during initial commissioning
- Planning meetings held through-out month to refine sequence
- Involves orbiter slew maneuvers
- Performed with MOC support

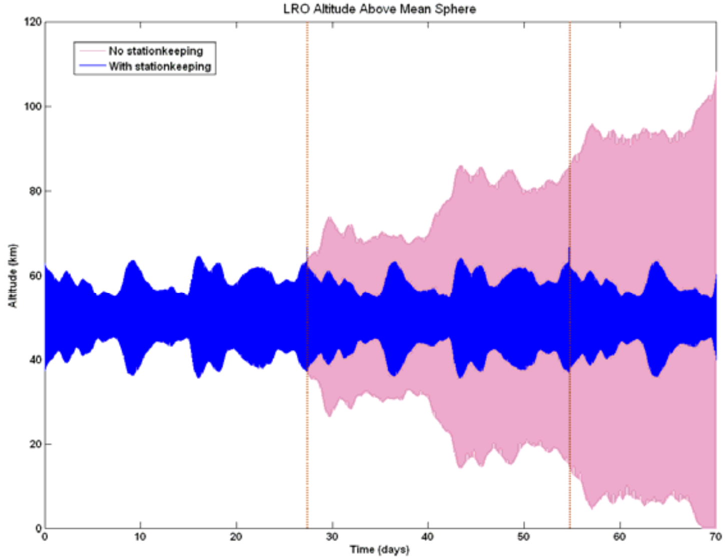
Mini-RF Operations
- Minimum of 1 data collection opportunity each month
- Incorporated into monthly calibration activities
- Sequence timeline generated by Mini-RF POC
- Mini-RF ops constraints will be documented in the Mission Flight Rules and Constraints document

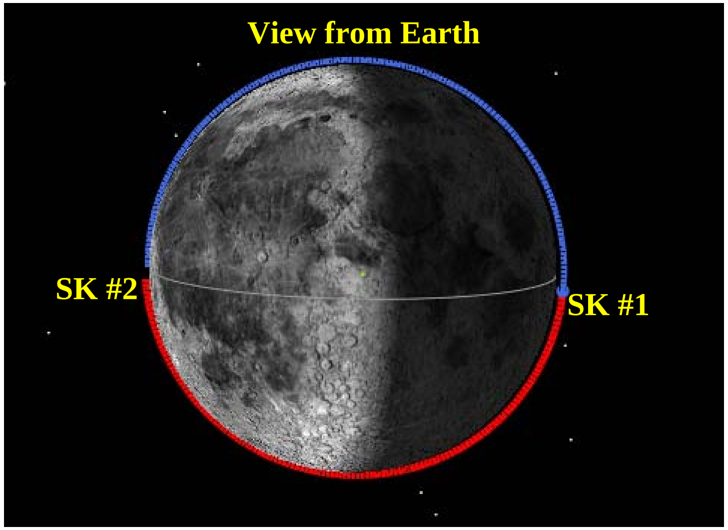
Yaw Maneuvers
- Performed every 6 months
- One orbit allocated for activity
- Takes approximately 15 minutes
- Consists of 180° yaw maneuver
- Thermal and power are main drivers governing execution
- Payload will remain operational
- Performed with MOC support

Lunar Eclipses
- 2 to 4 occurrences per year
- 2009 lunar eclipses pose no threat to orbiter health and safety
- Baseline calls for low power state
- Design maturation and on-orbit performance will dictate measures

Station-Keeping

- Station-keeping is done monthly
  - Fixed schedule, but robust to delays
- Strategy
  - Altitude controlled to within ±15 km
  - Maneuvers are done when lunar longitude of ascending node is 270 deg
  - 12-month SK cost (ΔV) is 150 m/sec
- Repeatable Station-keeping cycle
  - Phase and altitude plots are same every sidereal period (27.4 days)
  - 2-burn sequence; 66 minutes apart
  - Costs (ΔV) are the same each month



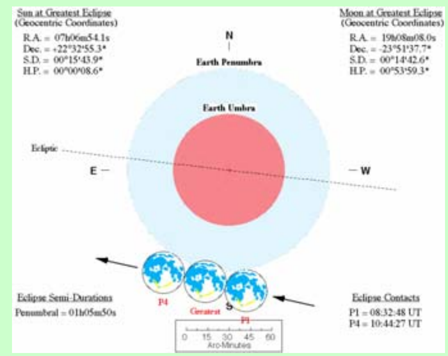


Lunar Eclipses

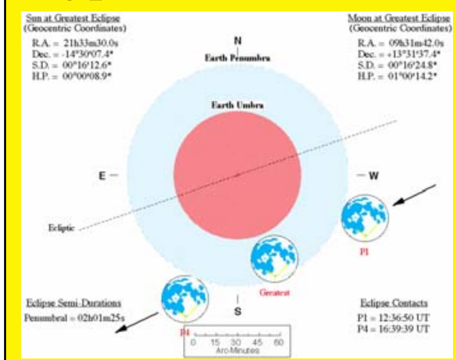
- Lunar eclipses drive LRO worst case design

Lunar Eclipses: 2009-2013		
Date	**Type**	**Time**
2009 Feb 09	**(2)** Penumbral	–
2009 Jul 07	**(1)** Penumbral	–
2009 Aug 06	**(1)** Penumbral	–
2009 Dec 31	**(2)** Partial	1:02
2010 Jun 26	**(3)** Partial	2:44
2010 Dec 21	**(4)** Total	3:29
2011 Jun 15	**(4)** Total	3:40
2011 Dec 10	**(4)** Total	3:33
2012 Jun 04	**(3)** Partial	2:08
2012 Nov 28	**(2)** Penumbral	–
2013 Apr 25	**(2)** Partial	0:32
2013 May 25	**(1)** Penumbral	–
2013 Oct 18	**(2)** Penumbral	–

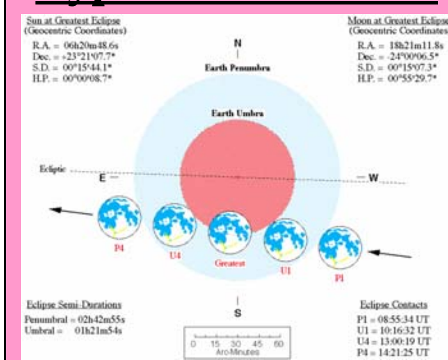
Type 1: 2009 Jul 07



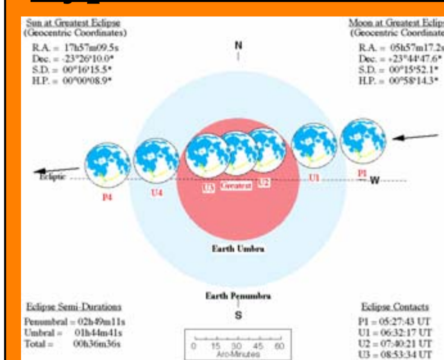
Type 2: 2009 Feb 09



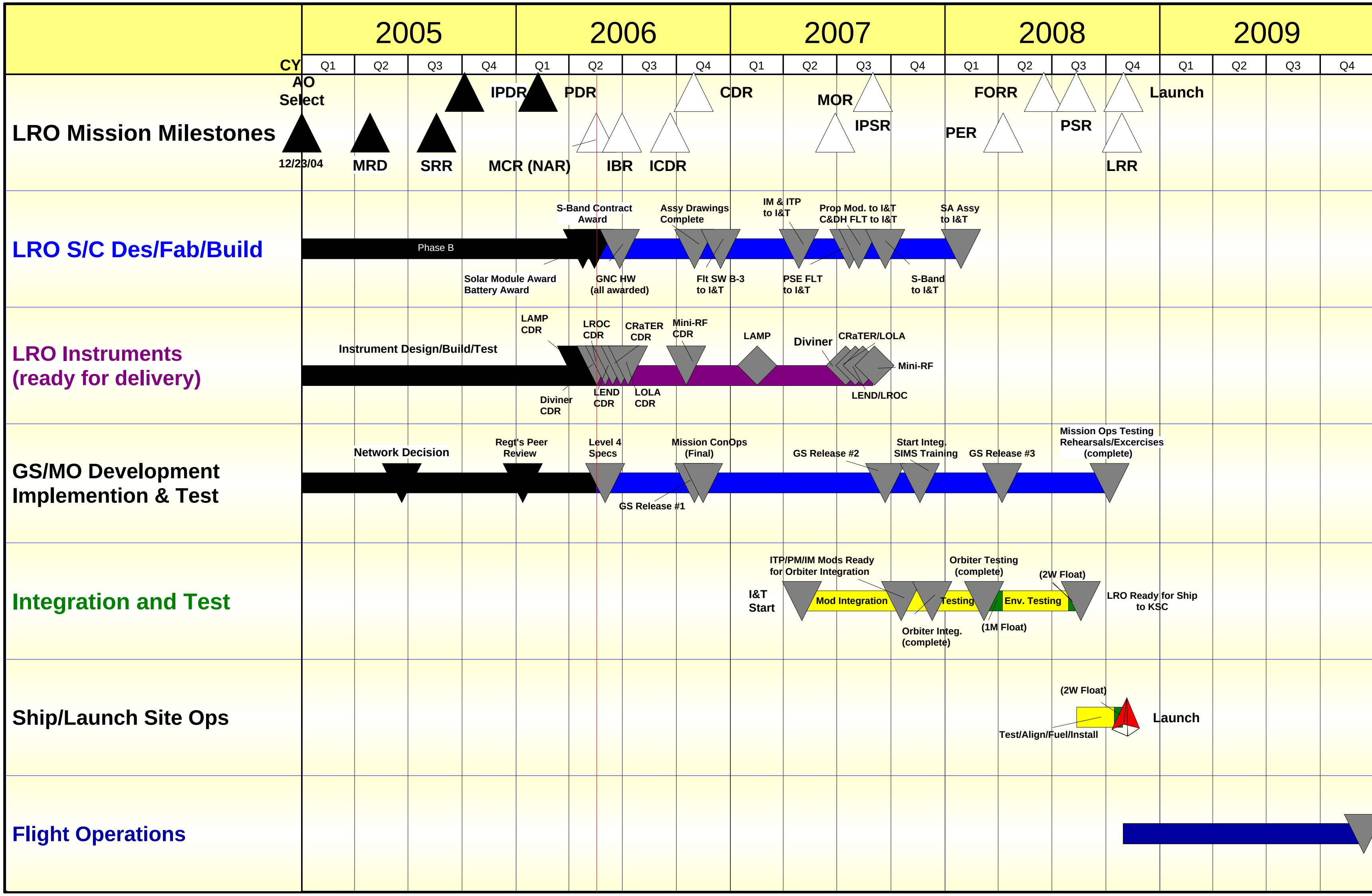
Type 3: 2010 Jun 26



Type 4: 2010 Dec 21



LRO Mission Schedule Overview

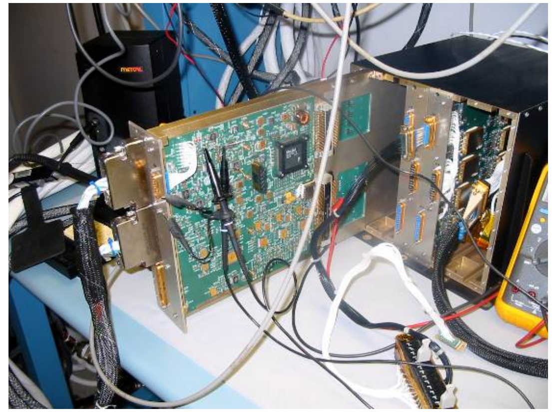


Implementation Schedule – Project Response

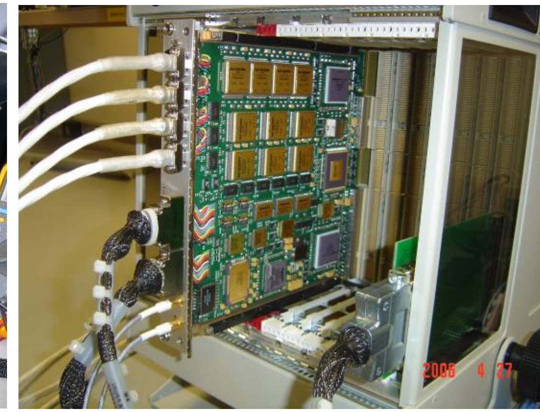
LRO Development Proceeding Rapidly

Avionics ETUs in Test at GSFC

Propulsion/Deployment Electronics

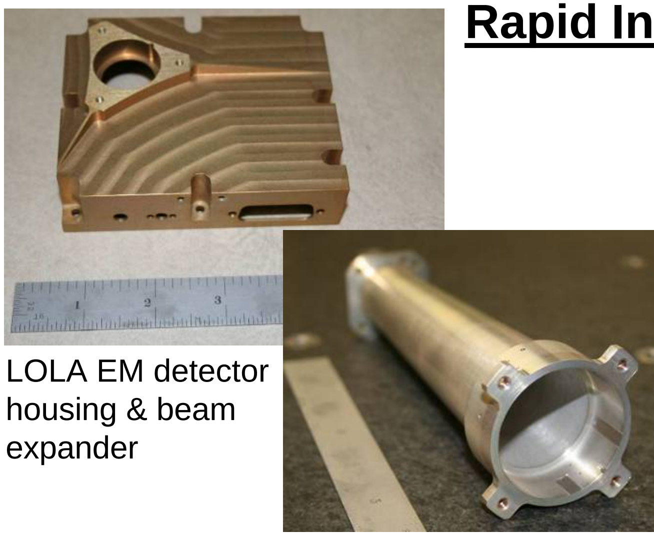


Power System Electronics

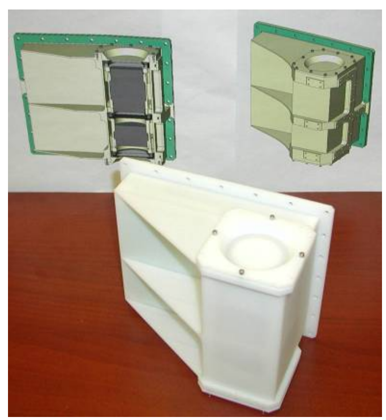


Single Board Computer

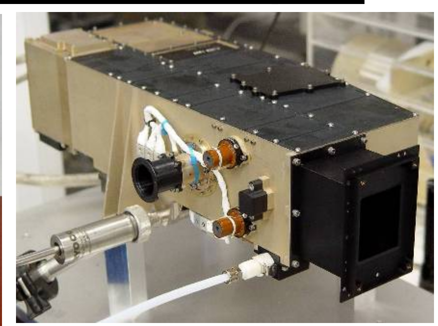
Rapid Instrument Development Examples



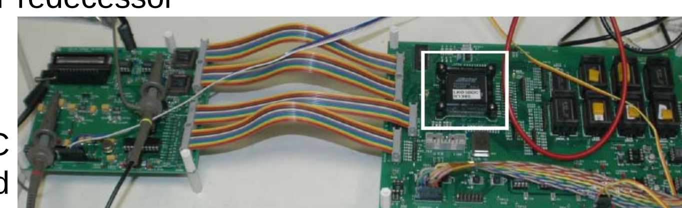
LOLA EM detector housing & beam expander



Rapid prototype model of CRaTER Telescope Assembly

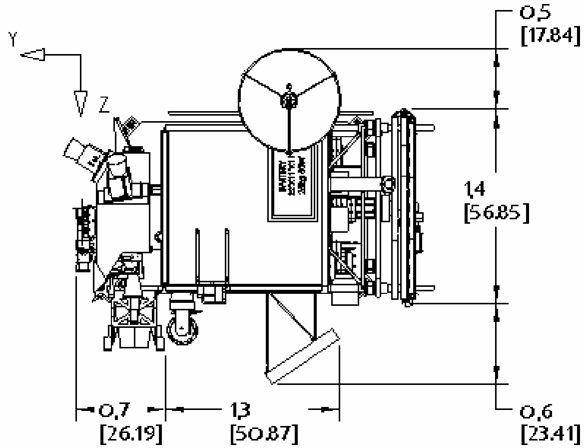


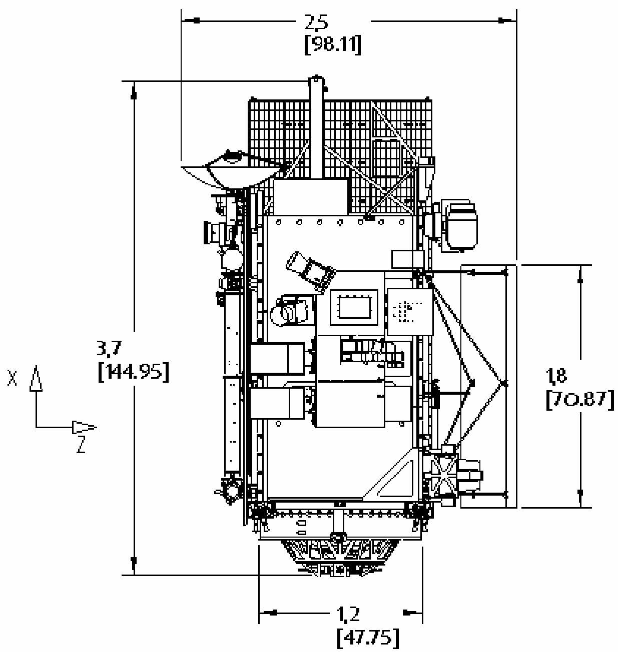
LAMP “Build to Print” Alice Predecessor

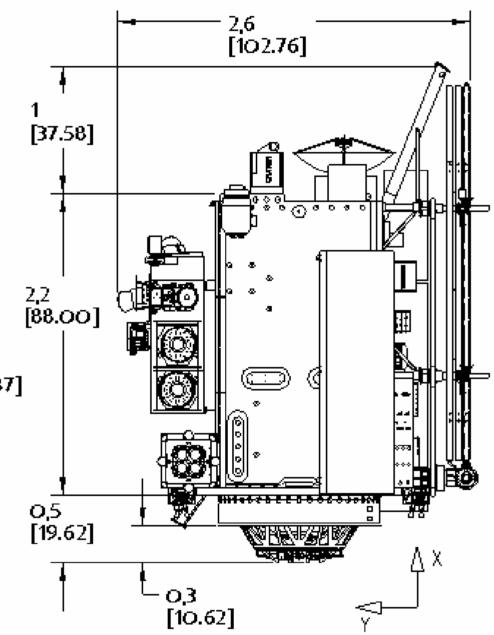


LROC NAC Breadboard

Dimensional Layouts (Stowed)







Dimensional Layouts (Deployed)