



# Status Briefing of LRO Pre-Selection Formulation Efforts

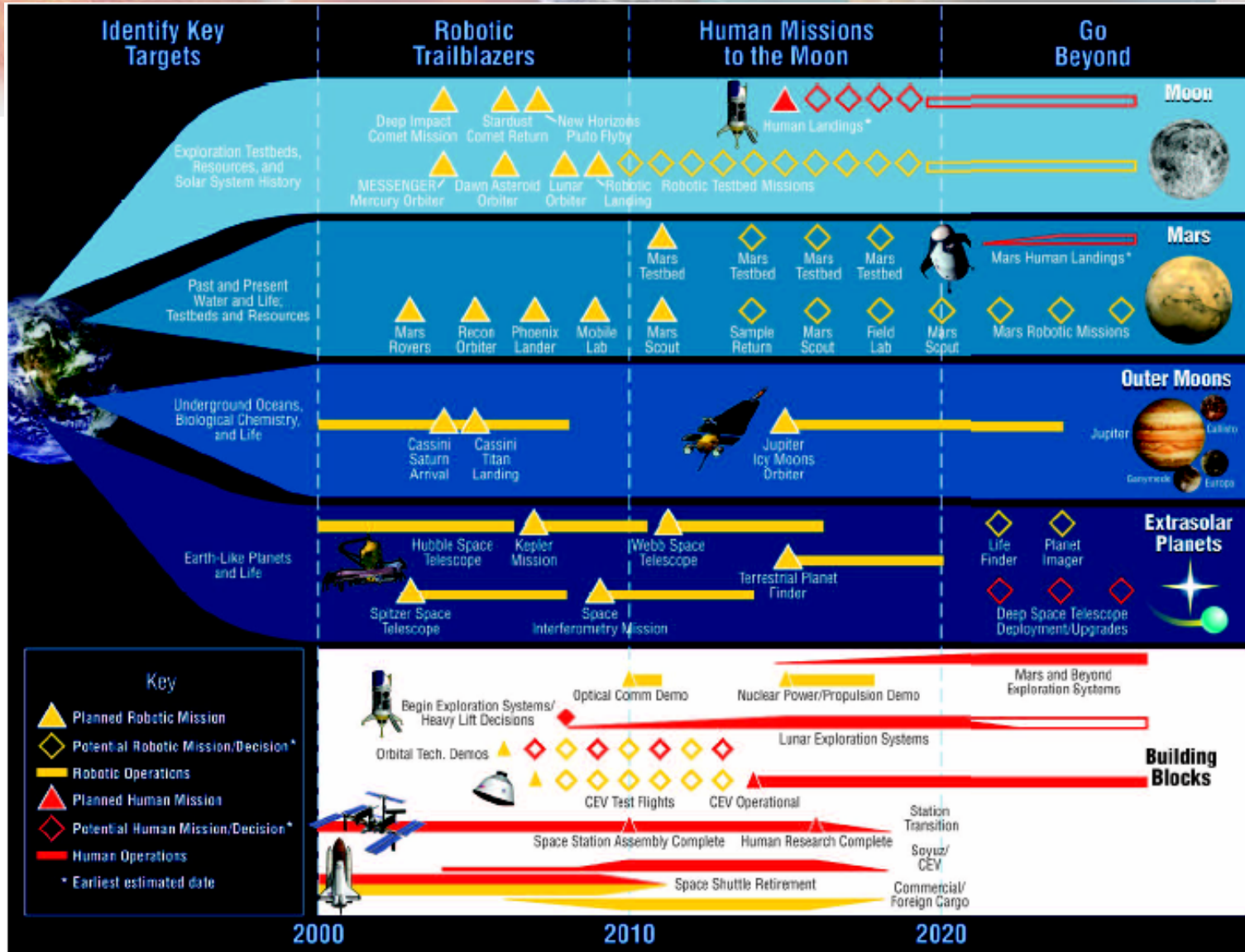
GSFC RLEP Office, Code 430

James Watzin - RLE Program Manager  
Craig Tooley - LRO Project Manager

December 22, 2004

<http://lunar.gsfc.nasa.gov>

# The Vision for Space Exploration



# The Role of LRO

- The Vision for Space Exploration outlined a robust robotics program beginning with a 2008 Lunar Reconnaissance Orbiter mission
- The Vision for Space Exploration outlined broad areas of content for the robotics program

## Site Selection:

- Develop detailed terrain and hazard maps at landing site scales
- Characterize radiation, dust, thermal, and partial gravity environment
- Identify potential water/ice resources and validate with ground truth measurements

## Life Sciences:

- Demonstrate radiation shielding capabilities for human systems
- Characterize lunar environment and its biological impacts

## Resources:

- Characterize lunar regolith for resource assessment
- Demonstration of ISRU package for water/ice
- Demonstration of oxygen extraction

## Technology Maturation:

- Demonstrate precision landing
- Demonstrate prototype h/w and s/w for monitoring/mitigating space environment effects on humans

## Infrastructure Emplacement:

- Communication systems
- Navigation systems

- LRO will make a substantial impact in many areas

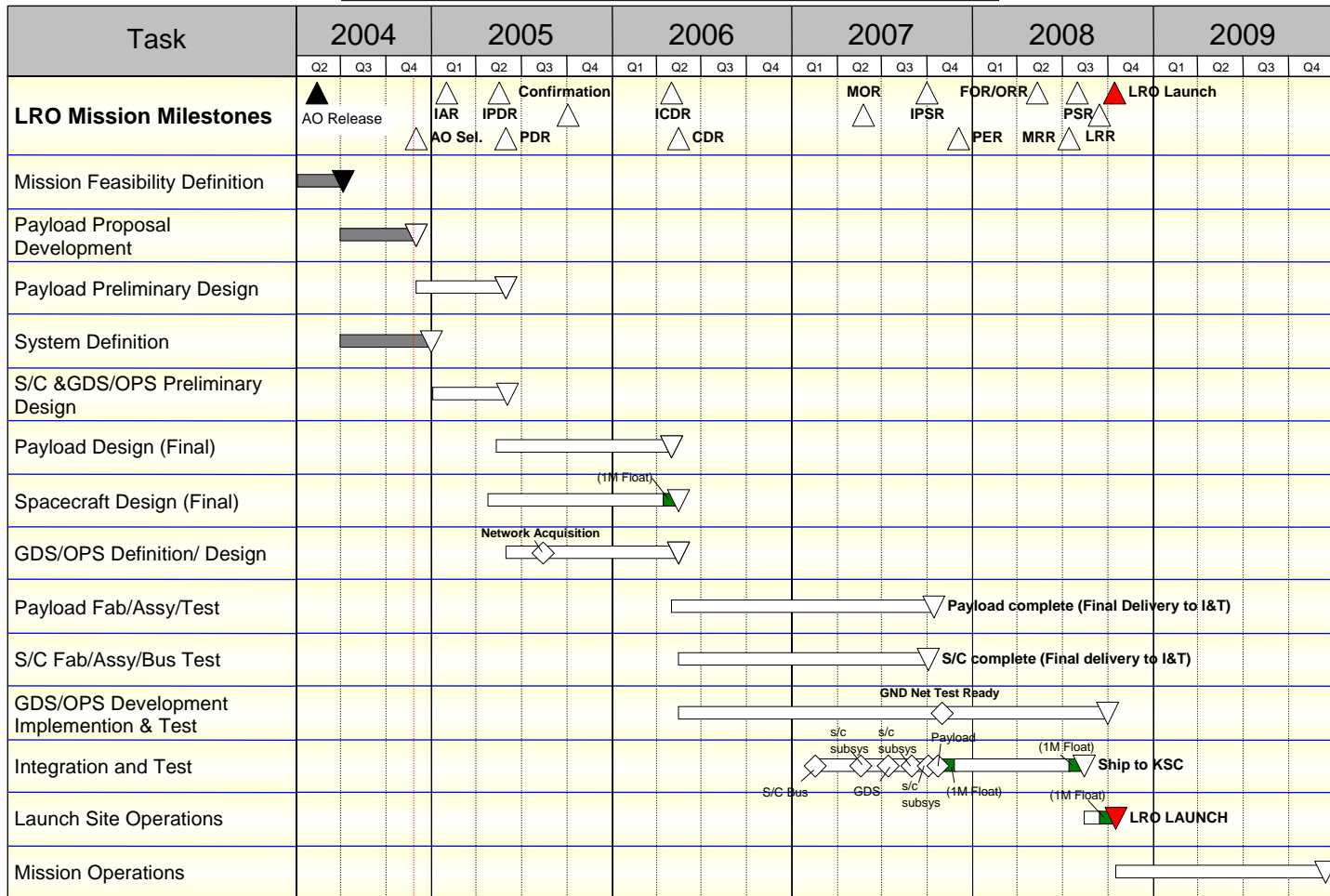
# LRO Schedule

“...Starting no later than 2008, initiate a series of robotic missions to the moon to prepare for and support future human exploration activities.”

**LRO Mission Schedule**  
Supports 2008 LRD from The Vision for Space Exploration

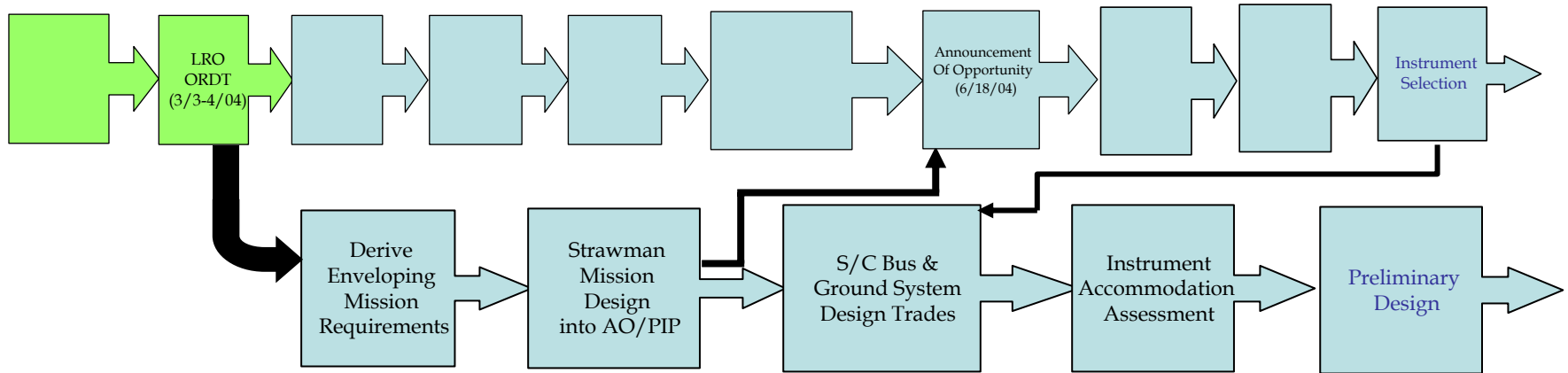
Ver. 0.2

11/23/04





# LRO Project Pre-Instrument Selection Activities



- Enveloping requirements derived from the ORDТ allowed PIP development for AO, mission planning and trade studies to begin.
- Spacecraft and GDS developers have been working trades and evolving designs from the onset, a benefit of in-house implementation.
- RLEP Requirements evolved from ORDТ and Mission Strawman, will be definitized and aligned when instruments are selected, and baselined at PDR.

# 2008 Lunar Reconnaissance Orbiter (LRO): First Step in the Robotic Lunar Exploration Program



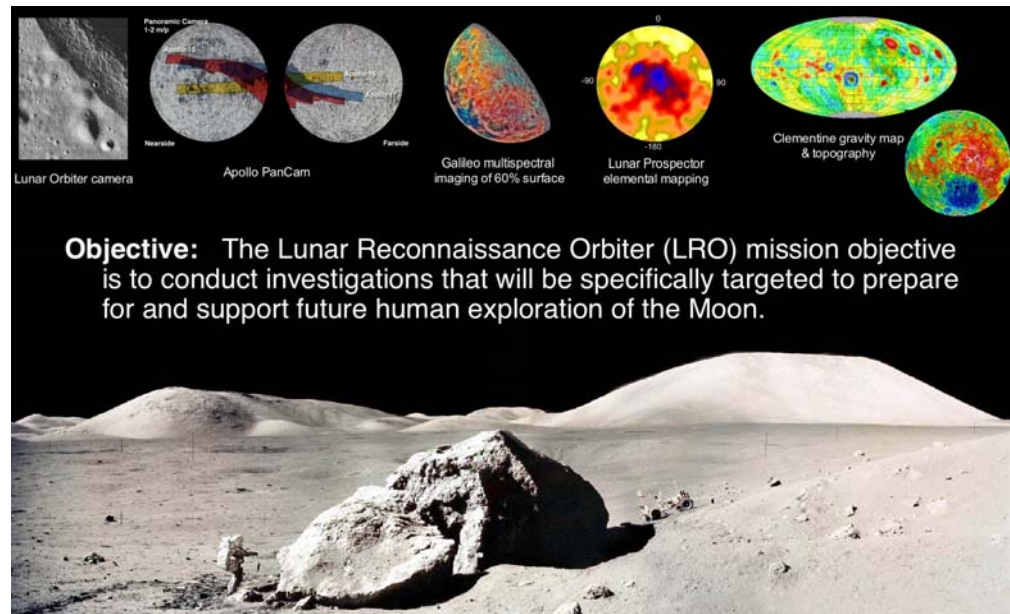
## Solicited Measurement Investigations

- Characterization and mitigation of lunar and deep space radiation environments and their impact on human-relatable biology
- Assessment of sub-meter scale features at potential landing sites
- High resolution global geodetic grid and topography
- Temperature mapping in polar shadowed regions
- Imaging of the lunar surface in permanently shadowed regions
- Identification of any appreciable near-surface water ice deposits in the polar cold traps
- High spatial resolution hydrogen mapping and assessment of ice
- Characterization of the changing surface illumination conditions in polar regions at time scales as short as hours

## Mission Characteristics

- Primary mission of at least 1 year in circular polar mapping orbit (nominal 50km altitude) with various extended mission options
- ~100 kg of instrumentation mass

- LRO is the first mission of The Vision for Space Exploration



# LRO Development AO & PIP

- The PIP (companion to AO) was the project's 1st product, and contained the result of the early formulation and definition effort.
- *The PIP represents the synthesis of the enveloping mission requirement drawn from the ORDT process with the defined boundary conditions for the mission. For the project it constituted the initial baseline mission performance specification.*
- Key Elements:
  - Straw man mission scenario and spacecraft design
    - Mission profile & orbit characteristics
    - Payload accommodation definition (mass, power, data, thermal, etc)
  - Environment definitions & QA requirements
  - Mission operations concept
  - Management requirements (reporting, reviews, accountabilities)
  - Deliverables
  - Cost considerations

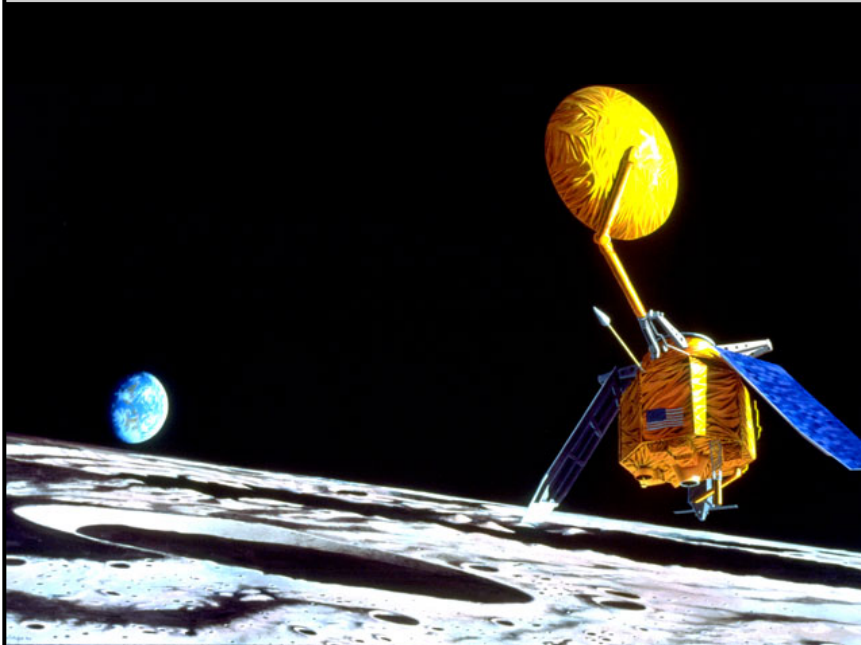
## LRO Development - PIP Strawman Orbiter

- One year primary mission in ~50 km polar orbit, possible extended mission in communication relay/south pole observing, low-maintenance orbit
- 100 kg/100W payload capacity
- 3-axis stabilized pointed platform (~ 60 arc-sec or better pointing)
- Articulated solar arrays and Li-Ion battery
- Spacecraft to provide thermal control services to payload elements if req'd
- Ka-band high rate downlink ( 100-300 Mbps, 900 Gb/day), S-band up/down low rate
- Command & Data Handling : MIL-STD-1553, RS 422, & High Speed Serial Service, PowerPC Architecture, 200-400 Gb SSR, CCSDS
- Mono or bi-prop propulsion (500-700 kg fuel)
- LRO Total Mass ~ 1000 kg/400 W
- Launched on Delta II Class ELV
- Centralized MOC operates mission and flows level 0 data to PI's, PI delivers high level data to PDS

# Flight Dynamics of the Moon

## Getting to the Moon is Hard

- High launch energy or high  $\Delta V$  from LEO
- Large braking maneuver or long transfer time
- No atmosphere for aerobraking/aerocapture
- Everything must be done propulsively
- Simpler, but more expensive (fuel = mass)



## Orbiting the Moon is Hard

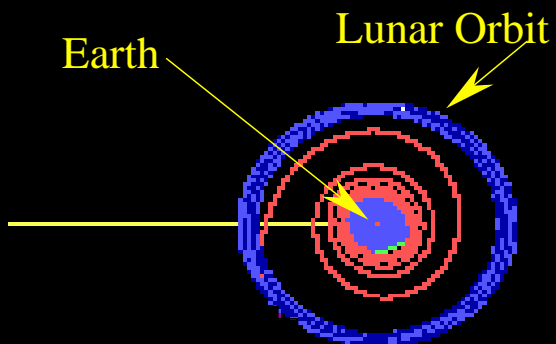
- Tight orbit control needed for best mapping
- Mass concentrations constantly perturb orbit
- No orbit precession possible (no  $J_2$  torque)
- Un-maintained orbit deteriorates rapidly (months)
- Purely propulsive momentum management



# Trajectory Options for LRO

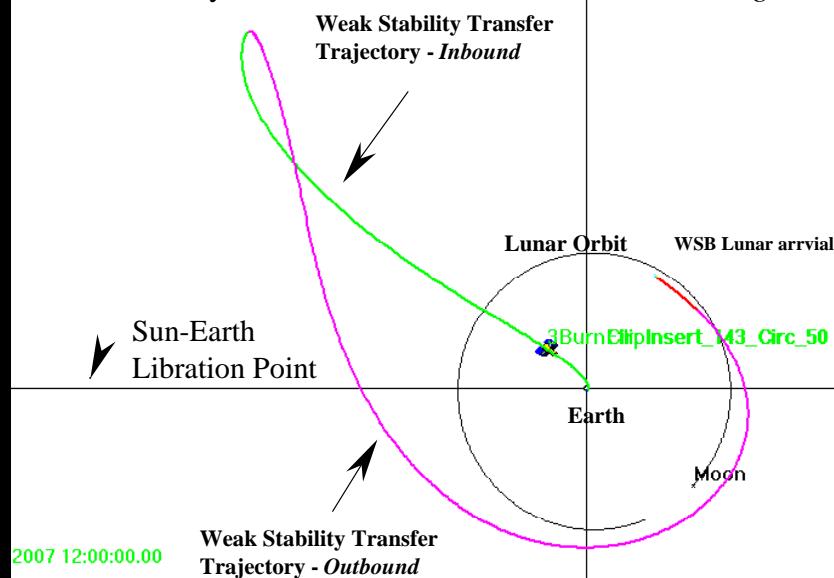
Electric Propulsion Spiral

e.g. SMART-1



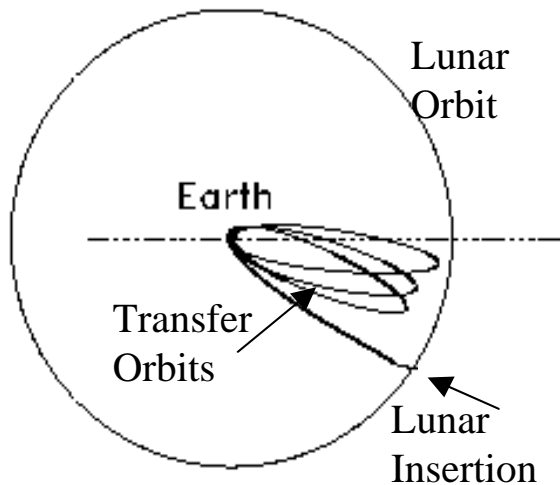
Weak Stability Transfer

e.g. TBD



Transfer via Phasing Loops

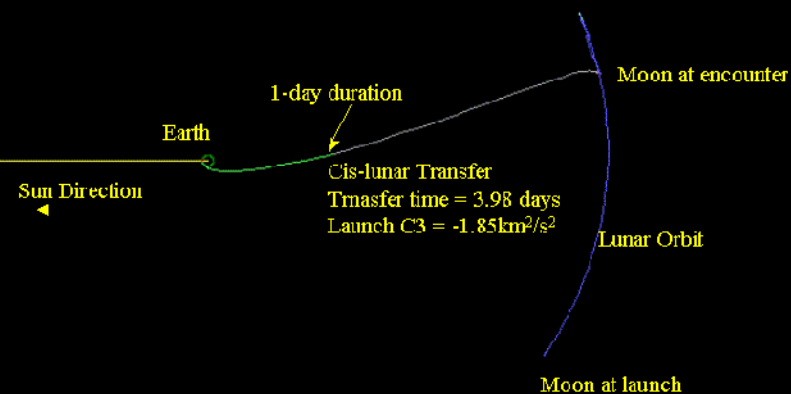
e.g. Clementine



Direct Lunar Transfer

e.g. Apollo, Lunar Prospector

Solar Rotating Coordinates



Nominal Cis-Lunar Trajectory

## Electric Propulsion Spiral

- launch 5760 kg into low Earth orbit
- requires 1675 kg of fuel (Isp = 2500 s)
- delivers 4085 kg to low lunar orbit
- takes 2 to 3 years to complete transfer
- requires > 10 kW of power
- spends several weeks in radiation belts

*Assessment: requires long transfer, use of immature propulsion technology, and oversized power system*

## Transfer via Phasing Loops

- launch 1498 kg into highly elliptical orbit
- requires 752 kg of fuel (Isp = 305 s)
- delivers 746 kg to low lunar orbit
- takes 2 to 3 weeks to complete transfer
- has no special power requirements
- multiple passes through radiation belts

*Assessment: simple, proven approach providing enhanced performance at the cost of additional fuel and operational complexity*

## Weak Stability Transfer

- launch 865 kg into weak stability transfer
- requires 280 kg of fuel (Isp = 305 s)
- delivers 585 kg to low lunar orbit
- takes 90 - 100 days to complete transfer
- has no special power requirements
- only one pass through the radiation belts

*Assessment: complex mission design requiring ultra-precise targeting and control of flight path*

## Direct Lunar Transfer

- launch 910 kg into direct lunar transfer
- requires 343 kg of fuel (Isp = 305 s)
- delivers 567 kg to low lunar orbit
- takes 4 to 4.5 days to complete transfer
- has no special power requirements
- only one pass through the radiation belts

*Assessment: simple, proven approach providing adequate performance at lowest overall cost and risk*

# LRO Launch Vehicle Options

Launch Vehicle	Description	P/L Capability (kg) (C3 = -2 km <sup>2</sup> /s <sup>2</sup> )	Comment
Taurus 3113	5 stage	400	Inadequate capability.
Delta 2920-9.5	2 Stage w/9 SRMs	725	Two stage vehicle offer increased volume and no requirement for spinning.
Delta 2925-9.5	3 Stage w/9 SRMs	1285	
Delta 2920H-9.5	2 Stage w/9 Heavy SRMs	910	
Delta 2925H-9.5	3 Stage w/9 Heavy SRMs	1485	Three stage vehicle offers increased performance.
Atlas V (551)	2 stage EELV with SRMs	6560	Excessive capability.
Delta 4 (4050H-19)	2 stage EELV with SRMs	9615	

# Lunar Reconnaissance Mission Considerations

	Performance Requirement	Systems Implications/Challenges	LRO Design Response
0	<b>Lunar Mission</b>	Large propulsion system (~1500 m/s) with significant thrust (~45 N) required. Spacecraft mass is approximately 50% fuel. Mass efficiency is critical as every kg cost a kg in fuel.	Chemical propulsion system baselined
I	<b>High resolution (meter scale) global observation requires stable, precise pointing in low circular lunar orbit for approximately 1 year</b>	3-axis stabilized platform required	Reaction Wheel/Star Tracker/IMU System
		Lunar far side passage results in 1 hour communication and power generation outage	Large data storage required
			Large, lightweight battery required
		Irregular lunar gravity field greatly perturbs low orbit. Lack of far side knowledge drives requirement for frequent ground tracking and orbit maintenance burns	Near continuous tracking via S-band
Propulsion system sized to maintain orbit 50 km for 13 months.			
II	<b>Instruments will require high data volume</b>	Communications and data systems must potentially handle up to 900 Gb/day	High bandwidth capabilities required
III	<b>Thermal accommodation of instruments must be consistent with heritage instrument designs.</b>	The Moon's lack of an atmosphere, high solar absorbance, and long day results in severe hot cases at low beta angles while lack of sun at high beta angles results in severe cold cases. Worse than earth or Martian orbital environment.	Spacecraft bus to provide active heat rejection for instruments if required. Overall configuration optimized for thermal efficiency.
IV	<b>Spacecraft must survive long earth-moon eclipse periods</b>	Spacecraft must be able to safely operate autonomously at low power levels during extend communication and power generation outages.	LRO designed to operate in eclipse hibernation mode when required.

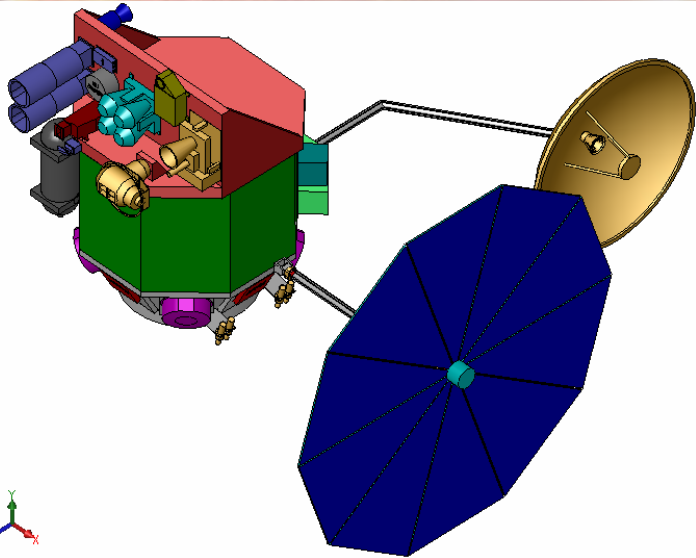


# Lunar Reconnaissance Mission Considerations

	<b>LRO Design Response</b>	<b>Technical Implementation</b>	<b>Key Characteristics</b>
<b>0</b>	Chemical propulsion system baselined	Mono propellant system is viable but bi-propellant system offers increased performance at greater cost. Trade ongoing.	System wet mass 570 to 660 kg.
<b>I</b>	Reaction Wheel/Star Tracker/IMU System	Wide range of legacy and state-of-the-art hardware available.	30-50 kg
	Large data storage required	Lightweight, modular SSR being designed for LRO	200-400 Gb storage capacity
	Large, lightweight battery and gimbaled solar array required.	All available Li-Ion space flight battery cell designs being evaluated and tested by GSFC. Shared gimbal design for both SA and HGA.	Battery capacity:40-80 AH, Solar Array: 1 KW EOL. Shared gimbal design for both SA and HGA.
	Near continuous tracking via S-band	LRO plans to utilize a combination of existing GN and SN resources. Upgrade of commercial assets also being considered.	50- 100 Kbps TT&C & DTE/DFE Tracking
	Propulsion system sized to maintain orbit for 13 months.	Propulsion system to budget for extended mission.	559 m/s
<b>II</b>	High bandwidth capabilities required	Ka-band required for observation data downlink. Existing ground network assets to be upgrade for high rate near-earth Ka-band operation.	125 Mb/s downlink data rate
<b>III</b>	Spacecraft bus to provide active heat rejection for instruments if required. Overall configuration optimized for thermal efficiency.	Spacecraft designed to provide zenith viewing radiators for instruments and subsystems. Active cooling loops to be used if passive design inadequate. Detailed analysis on-going.	Zenith radiators must dissipate almost all of spacecraft heat. Thermal system:15-40 kg
<b>IV</b>	LRO designed to operate in eclipse hibernation mode when required.	Hibernation mode to be designed into spacecraft operational modes and accounted for in thermal and power system designs.	Power generation and communication blackout for ~ 4 hours.

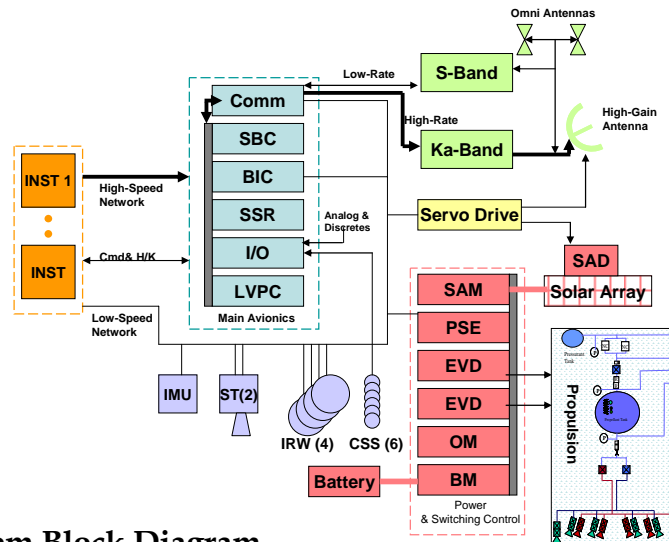
# LRO Technical Overview - Spacecraft

## Space Segment Conceptual Design



Example LRO Design Case

LRO Flight Segment Mass & Power Estimates		
<i>Range of on-going design trades</i>		
Subsystem	Mass (kg)	Orbit Average Power (W)
Instrument Payload	100	100
Spacecraft Bus (Dry)	454 - 484	300 - 355
Propellant	396 - 583	
<b>Total:</b>	<b>980 - 1137</b>	<b>400 - 455</b>
Launch Vehicle Capability (C3 = -2.0)	1285 - 1485	



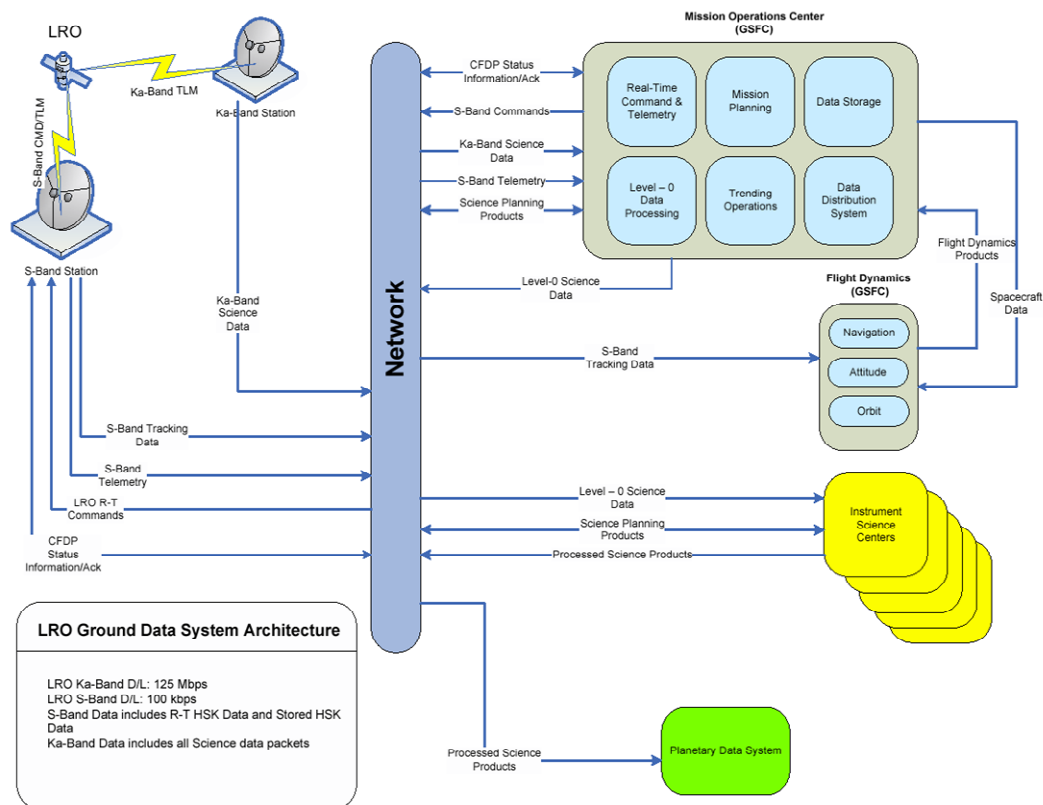
Preliminary System Block Diagram

# LRO Technical Overview - Ground System

- LRO Ground System and Mission Operations concepts are established

## LRO Operations Synopsis

- 2-4 hours of Ka-band downlink/day
- Near continuous Tracking 30min/hr (near-side)
- Plan 1 command upload/day
- Orbit adjust required ~ monthly
- MOC routes Level 0 data to PI SOCs
  - SOCs deliver to PDS
  - MOC maintains short term archive



## Conclusion



- LRO project and engineering team ready to engage selected instrument developers and begin preliminary design.
- Technical challenges well understood.