Thermal & Fluids Analysis Workshop

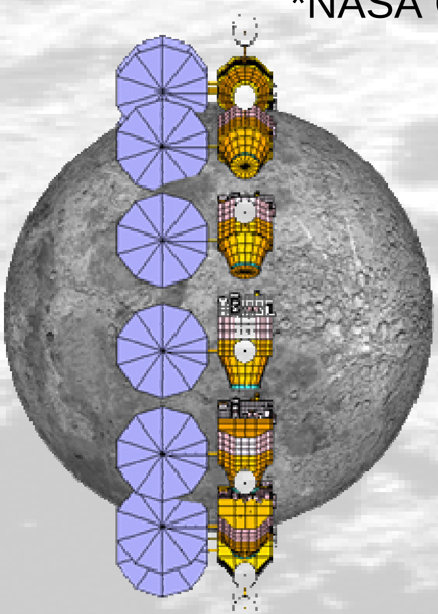
TFAWS 2005

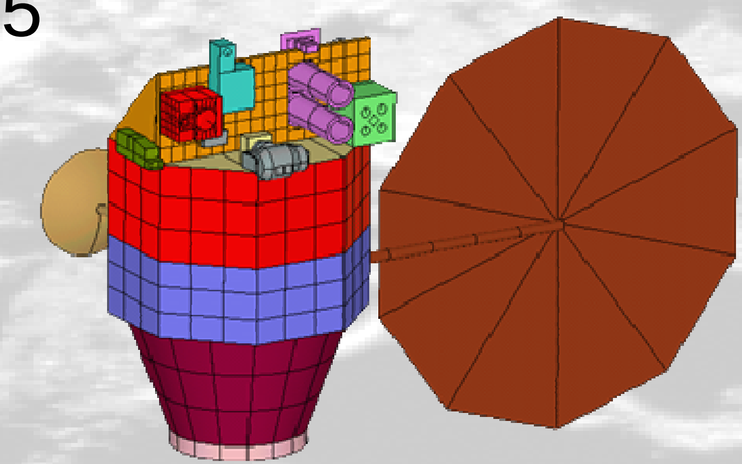
Lunar Reconnaissance Orbiter (LRO) Thermal Design Drivers and Current Thermal Design Concept

A. J. Mastropietro*, Cynthia Simmons[@], William Chang[@], Christine Cottingham[#], Charles Baker*

*NASA Goddard, [@]Edge Space Systems, Inc., [#]Lockheed Martin, Inc.

August 8, 2005



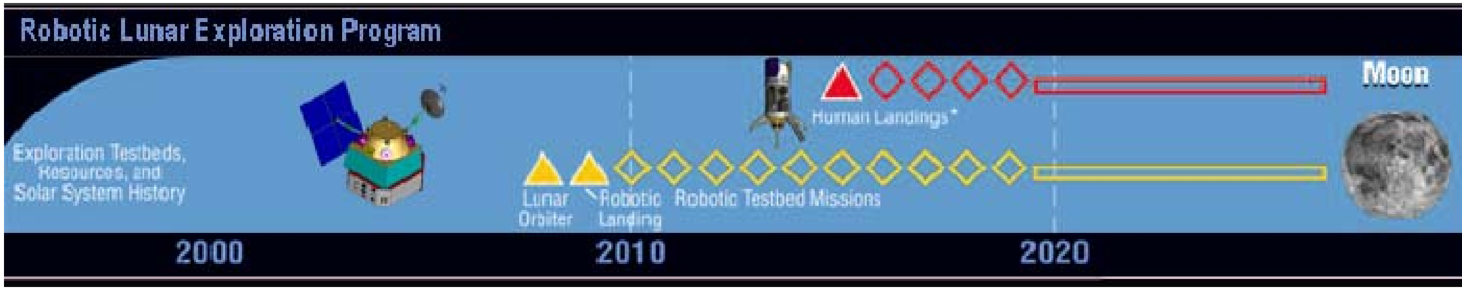


Outline

- LRO Mission Objectives
- Historical Perspective
- Mission Overview
- Mission Timeline
- Rapidly Evolving Spacecraft Concept
- Lunar Thermal Environment
- LRO Thermal Design Challenges
- Lessons Learned from Early Modeling
- Beyond LRO?
- Conclusions

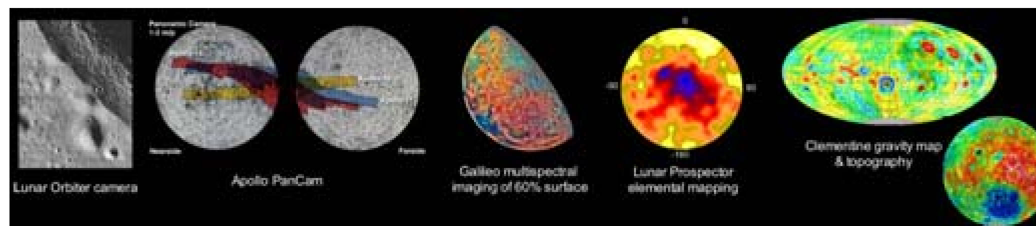
2008 Lunar Reconnaissance Orbiter (LRO) Mission Objectives

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**

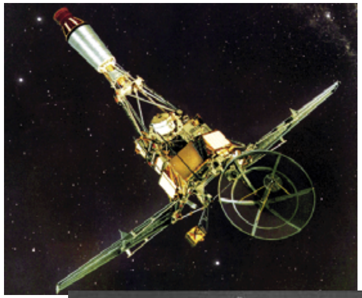


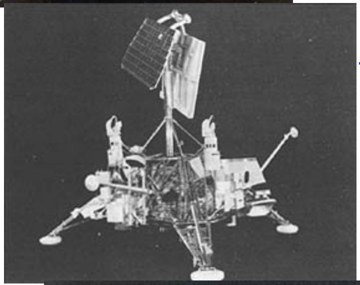
Objective: The Lunar Reconnaissance Orbiter (LRO) mission objective is to conduct investigations that will be specifically targeted to prepare for and support future human exploration of the Moon.

Historical Perspective

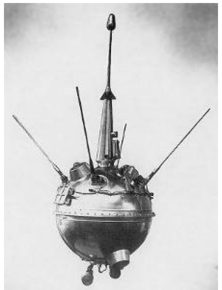
Lunar Exploration Past and Present

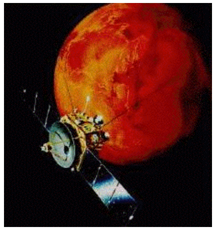
robotics preparing the way

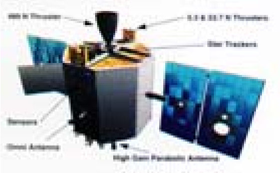

Ranger
1961-1965


Surveyor
1966-1968

Luna
1959-1976



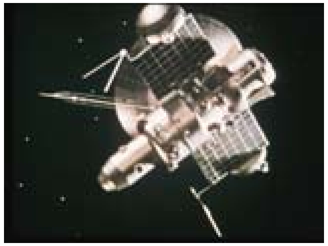

MUSES-A
1990

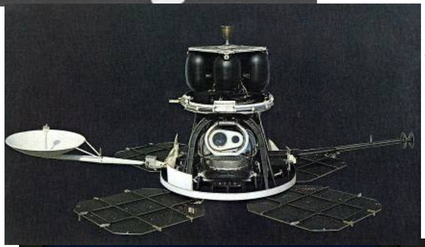

Clementine
1994

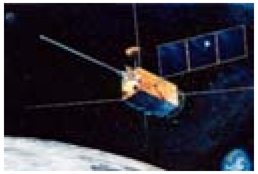

Lunar Prospector 1998

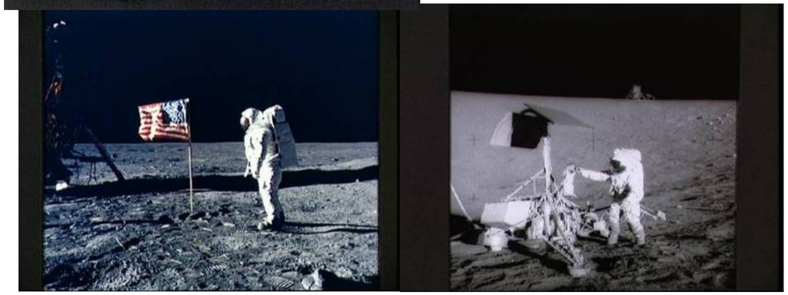

ESA SMART-1
(2005-...)

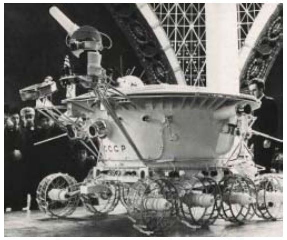
Zond
1965-1970

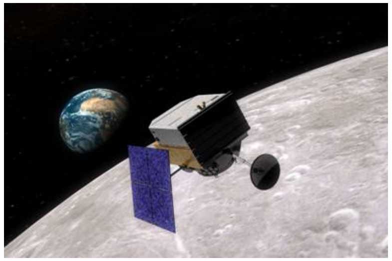



Lunar Orbiter
1966-1967


Selene (2007)


Apollo 1969-1972

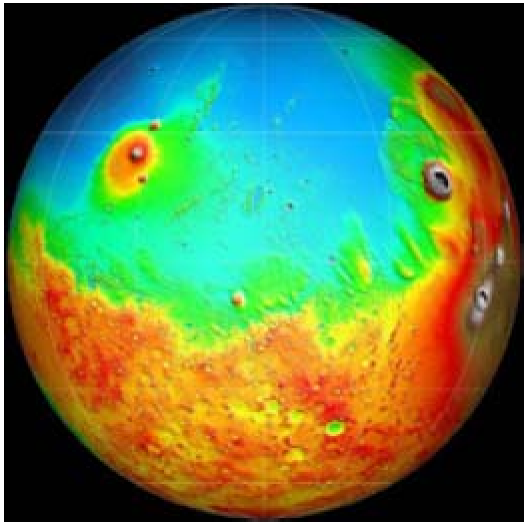

Lunokhod
1970


LRO
2008

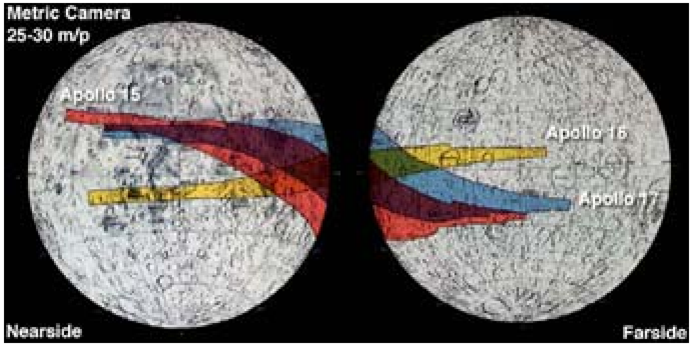
Historical Perspective (con't)

- **Existing Data Sets**
  - Earth Based Telescopes
  - Ranger
  - Surveyor
  - Lunar Orbiter
  - Apollo Photography & Laser Altimetry
  - Earth Based Radar
  - Clementine Imaging, Gravity, & Topography
  - Lunar Prospector Elemental Maps
  - Soviet Data

- **What is missing?**
  - Uniform global geodetic model (topography, gravity, position)
  - Uniform global high resolution, high fidelity (color) mineralogical/compositional data
  - Uniform global high resolution morphology
  - Very high resolution (sub-meter) imaging outside of Apollo targets
  - Uniform global regolith characterization
  - Knowledge of interior of polar shadowed craters



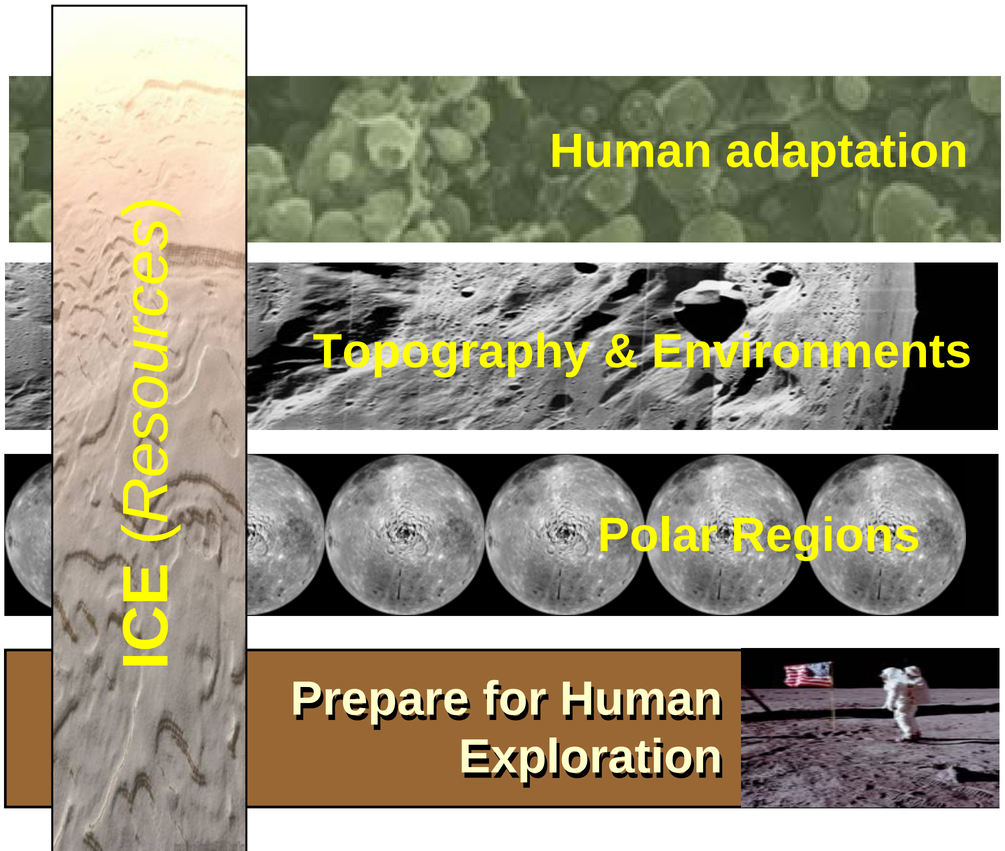
Mars MOLA Geodetic Model



Apollo Metric Camera Coverage

LRO Mission Overview

Science and Exploration Objectives



When • Where • Form • Amount

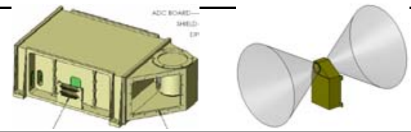
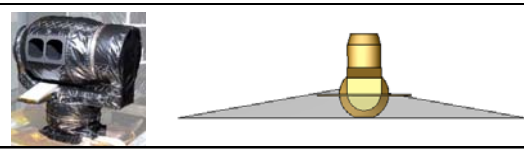
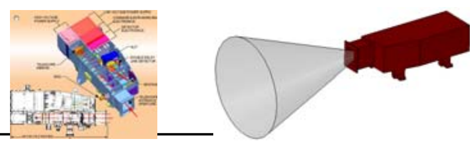
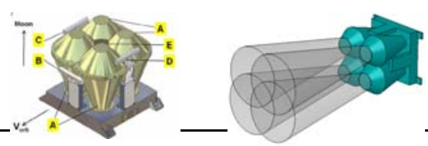
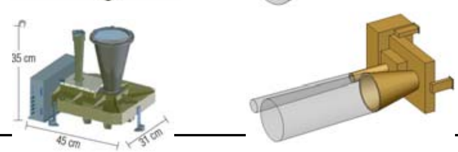
Biological adaptation to lunar environment ***(radiation, gravitation, dust...)***

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)***

LRO Mission Overview (con't)

Suite of Six Science Instruments

Instrument		Benefit	Deliverables
CRaTER (BU+MIT)		**Shielding constraints**	***Tissue equivalent response to radiation***
Diviner (UCLA)		**Surface temperatures**	***300m scale maps of Temperature, surface ice, rocks***
LAMP (SWRI)		**Frosts? "atmosphere"?**	***Maps of frosts in permanently shadowed areas, etc.***
LEND (Russia)		**Ice in regolith down to 1 m ?**	***Maps of water ice in upper 1 m of Moon at 5km scales***
LOLA (GSFC)		**Precision, safe navigation (3D)**	***~50 m scale polar topography at < 1 m vertical, roughness***
LROC (NWU+MSSS)		**Landing hazards and some resources**	***1000's of 50cm/pixel images (125km^2), and entire Moon at 100m in UV, Visible***

LRO Addresses National Academy Science Priorities for the Moon *(NRC Decadal, 2002)*

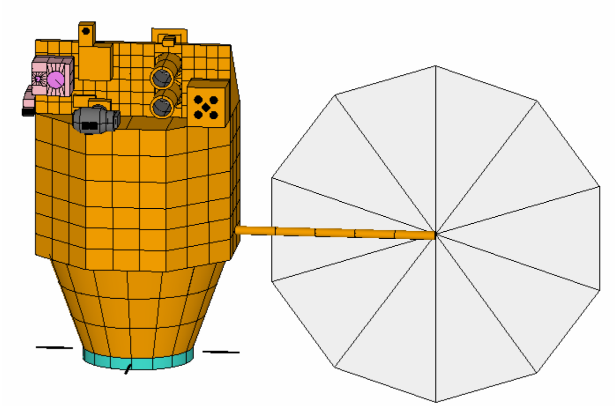
LRO Mission Overview (con't)

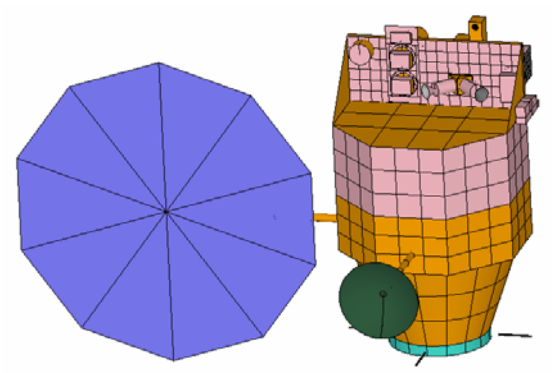
Flight Plan – Direct using 3-Stage ELV

- Launch on a Delta II class rocket into a direct insertion trajectory to the moon.
- On-board propulsion system used to capture at the moon, insert into and maintain 50 km altitude circular polar reconnaissance orbit.
- 1 year mission
- Orbiter is a 3-axis stabilized, nadir pointed spacecraft designed to operate continuously during the primary mission.
- LRO is designed to be capable of performing an extended mission of up to 4 additional years in a low maintenance orbit.

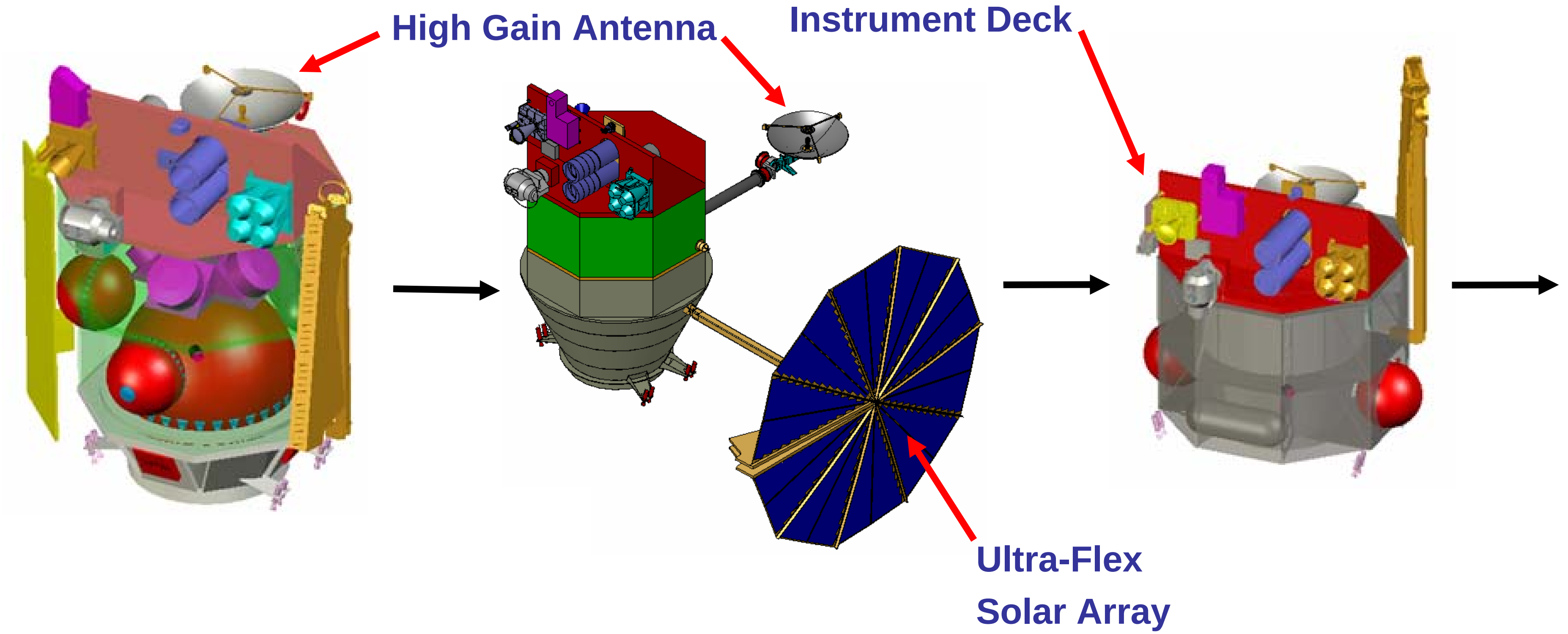
LRO Mission Timeline

- Feb. 2004 – Jun. 2004 PIP
- Jun. 2004 – Oct. 2004 Program Review of AO Proposals
- Oct. 2004 – Dec. 2004 AO Selection
- Jan. 2005 – May 2005 Instrument Kickoff and Accommodations Review
- May 2005 – Oct. 2005 PDR
- Oct. 2005 – Jul. 2006 CDR
- Jul. 2006 – Jul. 2007 Start of I&T
- Jul. 2007 – Nov. 2007 PER
- Nov. 2007 – Jul. 2008 Environmental Testing and PSR
- Jul. 2008 – Sep. 2008 Launch site Preps and Launch
- Sep. 2008 – Nov. 2008 LRO Commissioning and Start of Science
- Nov. 2008 – Jan. 2010 50 ± 20 km Science Mission





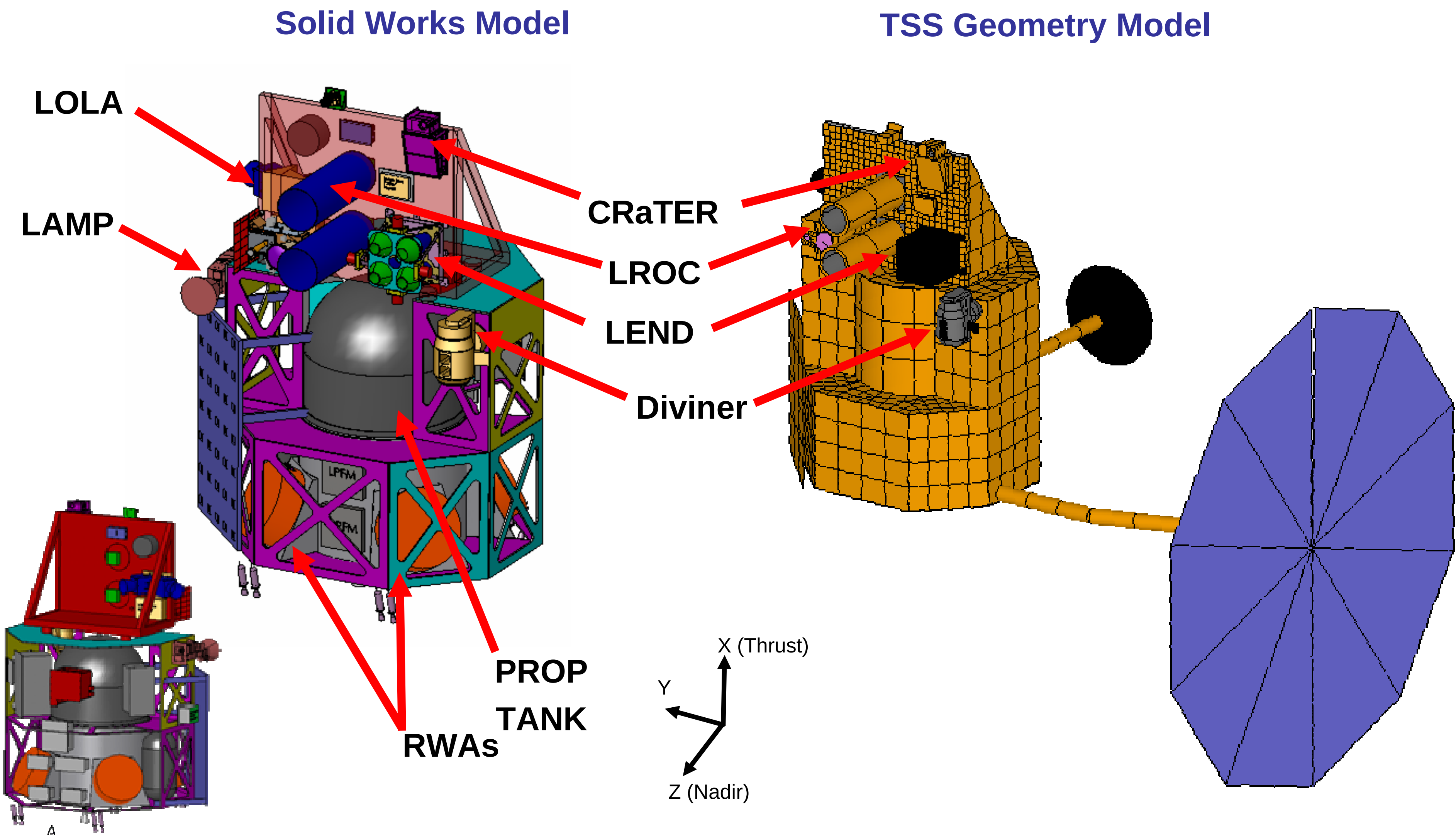
Rapidly Evolving Spacecraft Concept



Major Design Issues:

- **Bi-prop versus mono-prop, & mono-prop with 1, 2, or 3 tanks, tanks inside or protruding?**
- **Spacecraft packaging inside or “inside out” configuration?**
- **All instruments on the optics deck or some located elsewhere?**
- **Separate avionics and propulsion modules or integrated?**

Current Spacecraft Concept

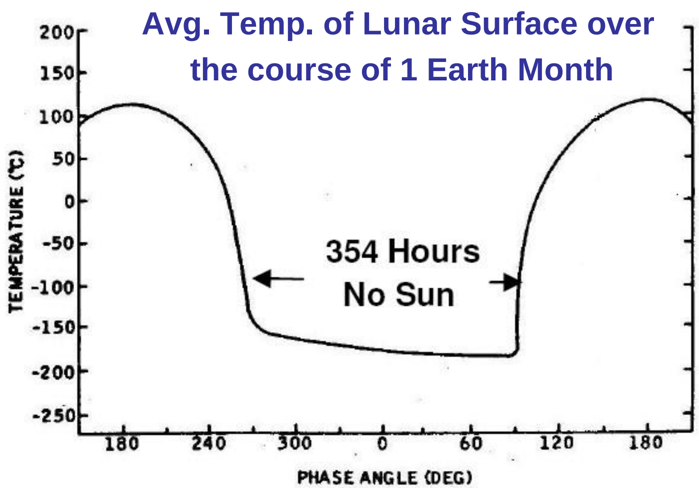


Lunar Thermal Environment

The lunar thermal environment is more severe than LEO, GEO, and Mars.

It resembles the harsh Mercury environment.

LUNAR NIGHT	LUNAR DAY
354 Hours without Sun	**354 Hours with Sun**
Min. Surface Temp. is -280F (-173C, 100K)	**Max. Surface Temp. is 250F (121C, 395K)**

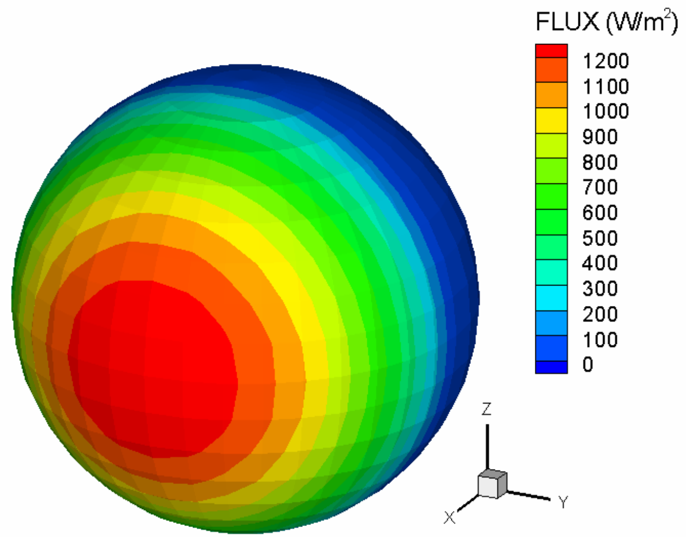


Temperature of the Moon. The average temperature of the Moon as a function of phase, or time, is shown here. The exact shape of the curve varies somewhat with geographical position on the Moon and is determined by the thermal properties at each position.

Lunar Thermal Environment (con't)

Lunar Orbit Environment Parameters

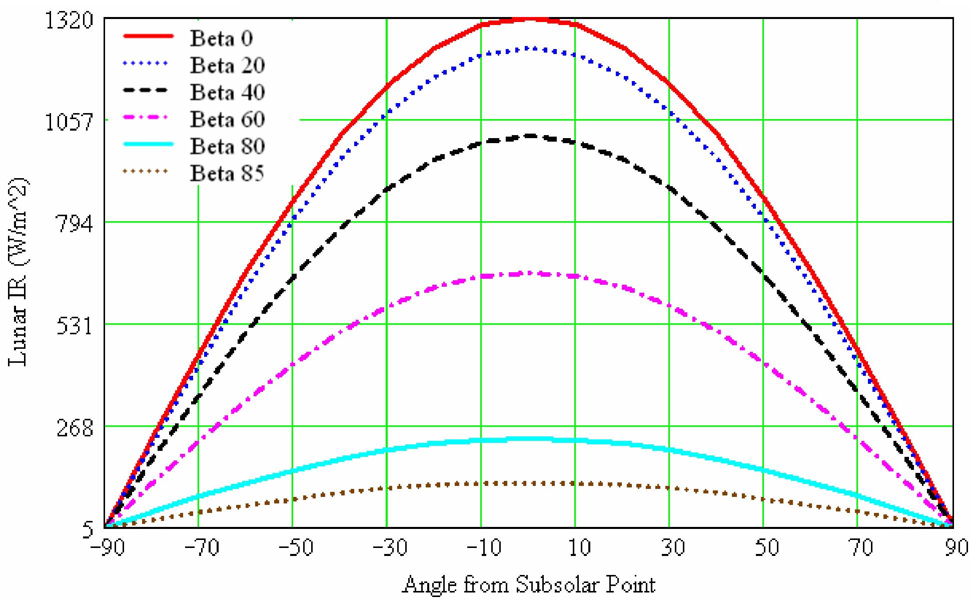
	Hot	Cold	Nom
Direct Solar [W/m²]	**1420**	**1280**	**1368**
Albedo	**0.13**	**0.06**	**0.073**
IR Max. [W/m²] **(subsolar peak)**	**1320**	**1226**	**1268**
IR Min. [W/m²] **(dark side)**	**5.2**	**5.2**	**5.2**



Lunar IR Emission as a Function of Beta Angle

$$q''_{IR} = [(C_1 - C_2)*\cos(\beta)*\cos(\theta)] + C_2$$

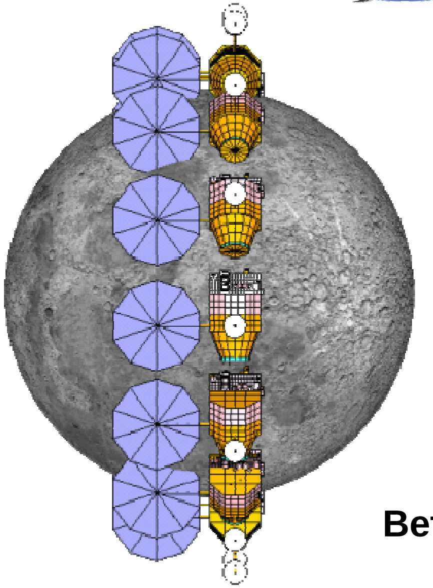
where:
q''_{IR} = IR flux from Lunar surface
C_1 = peak flux at subsolar point
C_2 = minimum flux emitted from shaded Lunar surface
β = Beta angle
θ = Angle from subsolar point



LRO Thermal Design Challenges

LRO Orbit Parameters:

Type	Lunar Circular
Altitude	50±20km
Inclination	90° (polar orbit)
Orbit Period	113 minutes
Full Sun Orbits	Beta 90.0° to 76.4° (55 days/yr)
Eclipsed Orbits	Beta 76.4° to 0.0° (310 days/yr)
Max. Eclipse	48 minutes (beta 0°)



Beta 0°

LRO Bounding Thermal Cases:

<u>Beta 0° is the Hot Op Case</u>

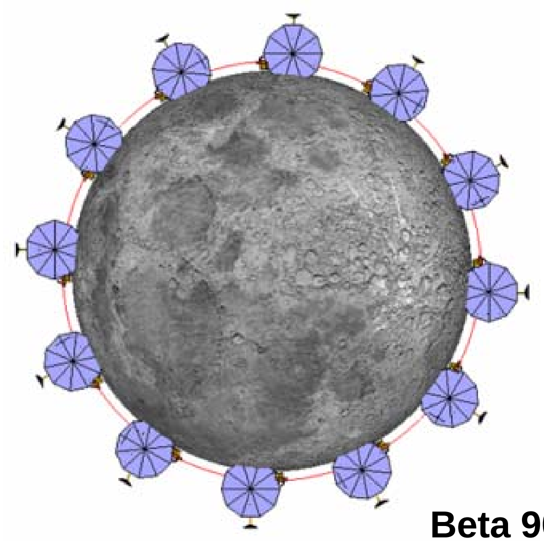
- Most severe IR loading
- Zenith facing radiators flip through sun
- Instrument apertures "see" sun near dawn and dusk 74°off bore site at 70 km

<u>Beta 90° is the Cold Op Case</u>

- Zenith facing radiators look at deep space
- Minimal IR loading

<u>-Y Sun Pointing Safehold Attitude</u>

- Zenith facing radiators can be edge on to the moon



Beta 90°

LRO Thermal Design Challenges (con't)

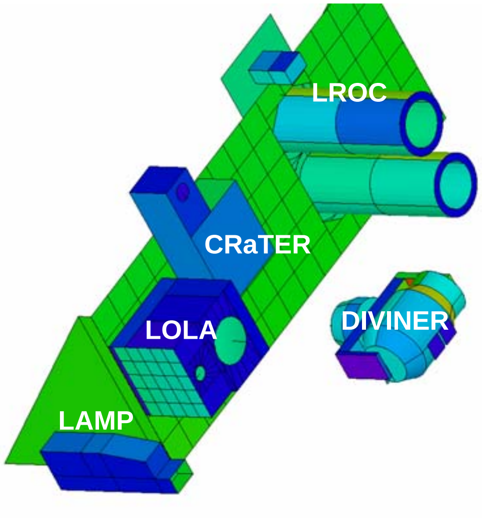
- Class C mission → "single string" design for components
  - Cost, size, power, and mass constraints drive the thermal design to be a passive thermal design → challenge is that the lunar thermal environment is NOT benign
- Radiator placement severely limited
  - Nadir pointing surfaces have too high of an IR loading to function as a radiator, especially at low Beta angles
  - Ram and wake surfaces also experience high IR loading at low Beta angles, combined with UV loading
  - Zenith surfaces are logical radiator locations, however, they also have a view of an atypically hot solar array
- Solar array thermal design
  - Must take into consideration that the front side will have solar heating while at the same time the backside will receive lunar IR nearly equivalent to the solar flux in the worst hot operational case

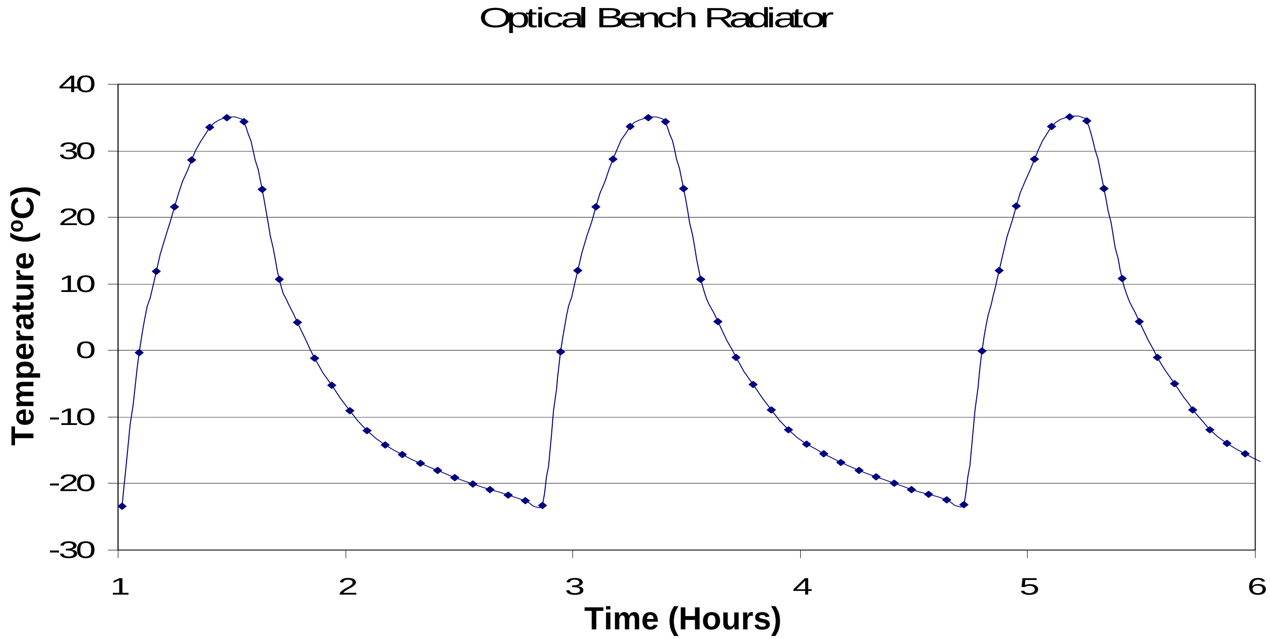
LRO Thermal Design Challenges (con't)

- Instrument optical bench is its own radiator
  - Instrument thermal control, in general, is achieved thru isolation from the lunar environment and by using passive means to conduct heat to a zenith radiator; note, however, some instruments require conductive isolation from optical bench, whereas some require conductive coupling to bench
  - Heaters on nadir facesheet at instrument interfaces are linearly coupled to a zenith facesheet which has a view to space → makes it difficult to minimize heater power in the worst case cold thermal conditions
  - Since optical bench size also has to be minimized due to mass constraints, it's difficult to minimize thermal gradients and meet stability requirements
- Thermal coatings requirements on instruments
  - Thermal design challenge for those instruments that require high emittance coatings (i.e., DIVINER) which also have direct and continuous views to the lunar surface
  - Several instruments with views to the sun have specularity requirements that limit the use of solar reflective coatings

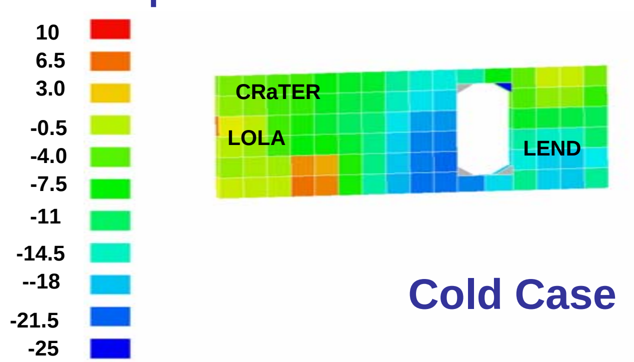
LRO Thermal Design Challenges (con't)

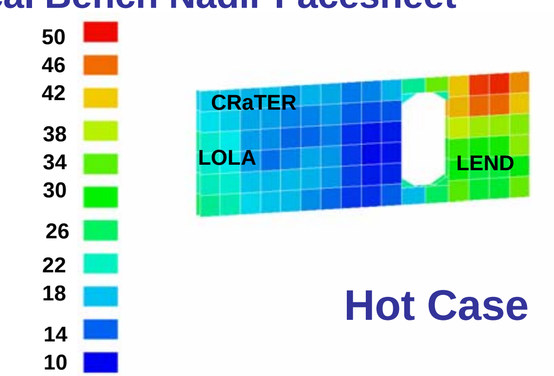
Extreme temperature swing during operational cases as spacecraft travels from sun side to dark side of the moon





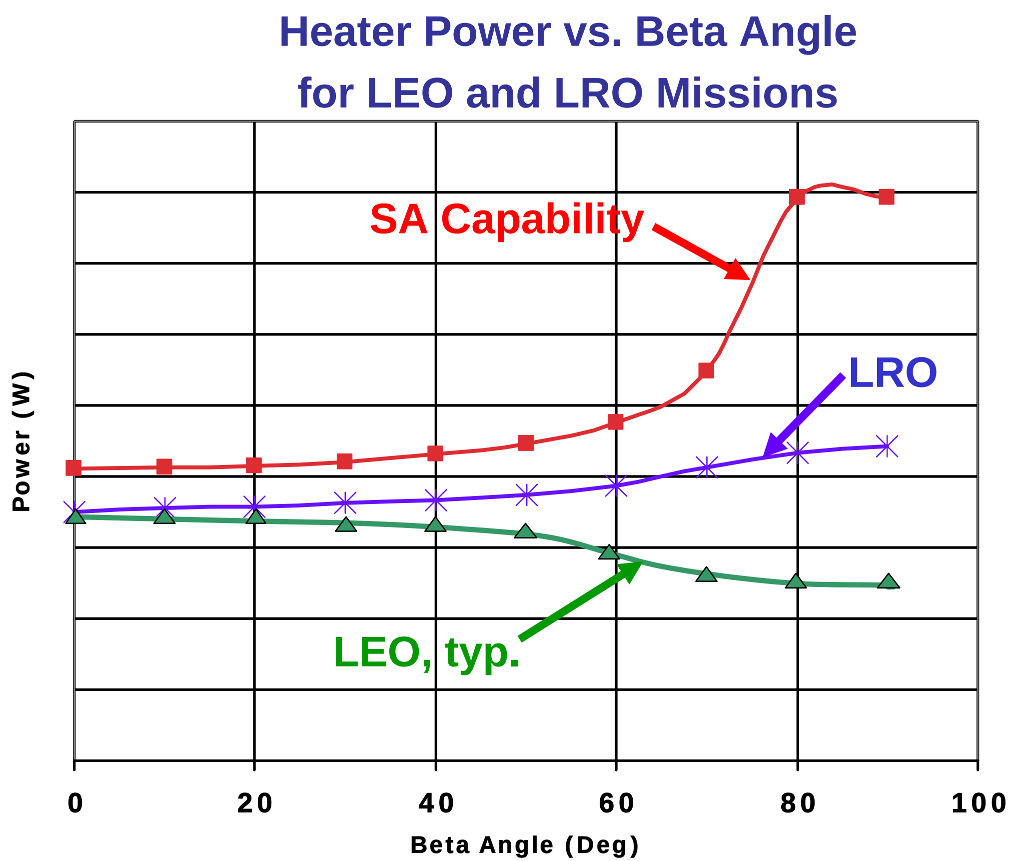
Temperature Gradients on the Optical Bench Nadir Facesheet





LRO Thermal Design Challenges (con't)

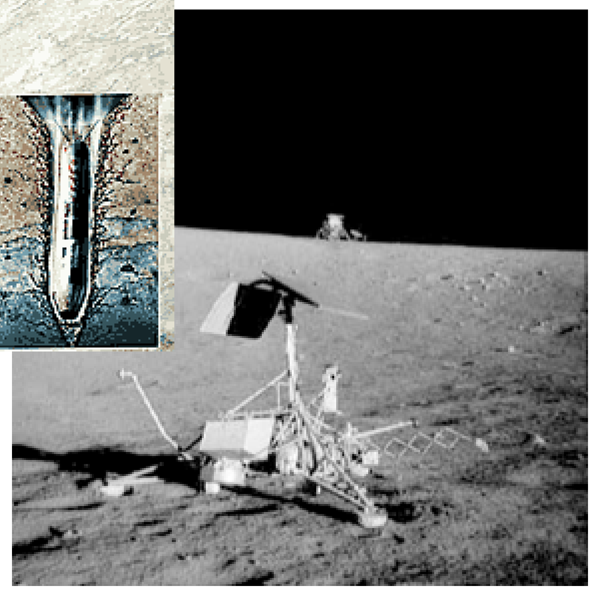
- Critical understanding of heater power profile as a function of beta angle for power margin verification is required early on



Lessons Learned from Early Modeling

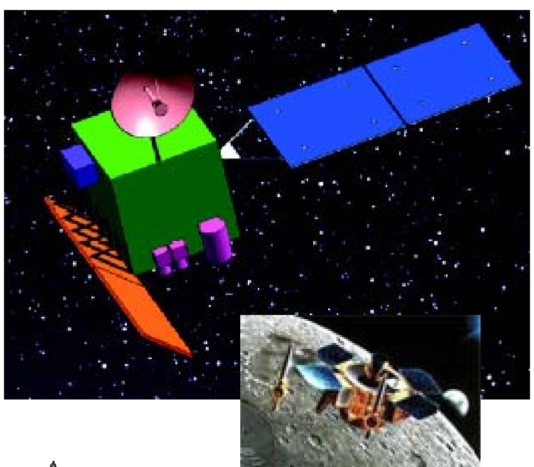
- Identified sensitivities
  - Thermal performance of instruments is very sensitive to the linear coupling from the instrument optical bench to the spacecraft
  - Thermal masses of instruments must also be modeled correctly
- Discovered potential “cross talk” between optical bench heaters that are in proximity to one another
- Instrument designs are highly dependent upon understanding the heat flow across the interface between the optical bench and each instrument
- Thermal control on the instrument optical bench is most effective when the instruments are conductively isolated from the bench, but since LRO forced to take a different approach, modeling required to optimize location of instruments on bench
- In order to minimize heater power for battery (has strictest temperature limits of all avionics), it should be placed on the zenith radiator which has a direct view to solar array in Beta 90 case

Beyond LRO?



Beyond LRO?
Exploration of a potential resource:
Validation of water ice and in situ biological sentinel experiments?

Some options…



Beyond LRO?:
Follow-on to LRO, filling key gaps, including regolith characterization in 3D, far-side gravity, landing site hazards, Telecomm. infrastructure?

Beyond LRO? ***Potential lunar experiment returns and demos?***

Conclusions

- LRO seeks to answer many pressing questions about the moon in preparation for future manned missions
- LRO has an aggressive schedule in order to meet the 2008 launch date
- The Lunar thermal environment is as severe as Mercury and it poses many design challenges that typical LEO and interplanetary missions don't need to address
- Numerous instruments with different requirements for coupling to an optical bench that functions as its own radiator poses a difficult thermal problem that requires careful analysis
- Early thermal analysis has been extensive and strives to keep pace with a rapidly evolving mechanical design
- Stay tuned for PDR analysis and design effort!