Return to the Moon

NASA's LCROSS and LRO Missions

National Aeronautics and Space Administration

Lunar Crater Observation & Sensing Satellite (LCROSS)

We're returning to the Moon!

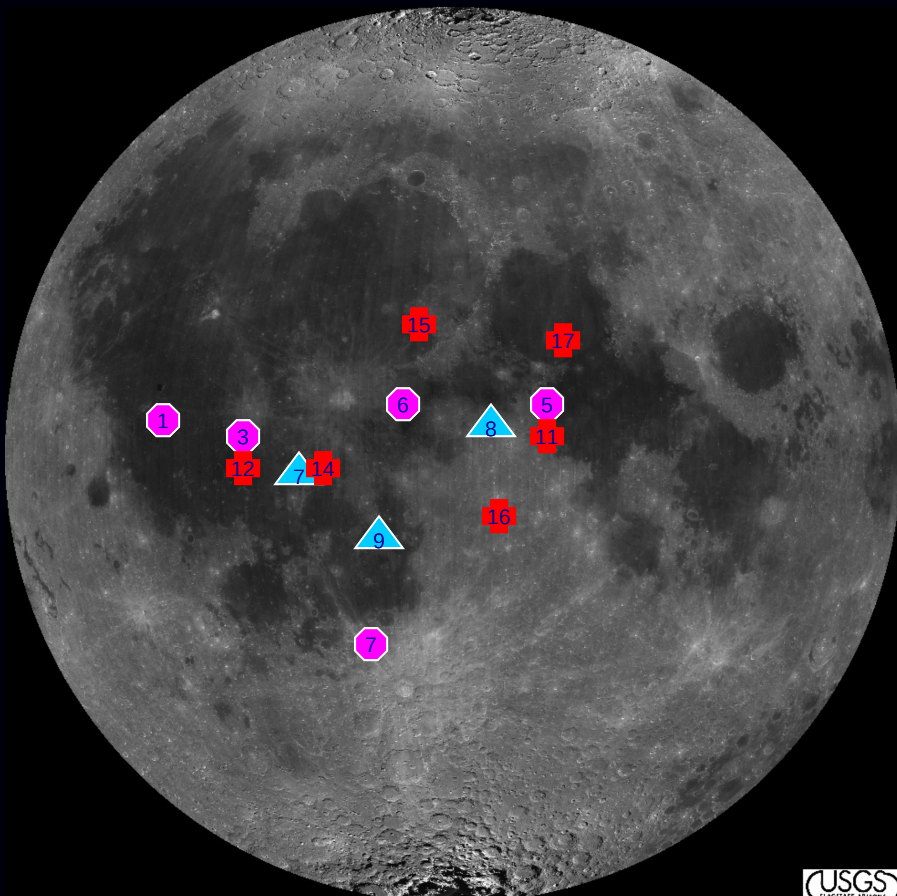
- **NASA's goals include objectives for robotic and human spaceflight:**
  - – Implement a sustained and affordable human and robotic program to explore the solar system and beyond;
  - – Extend human presence across the solar system, starting with a human return to the Moon by the year 2020, in preparation for human exploration of Mars and other destinations;
- **A lunar outpost is envisioned… but where will it be???**

Previous U.S. Landing Sites

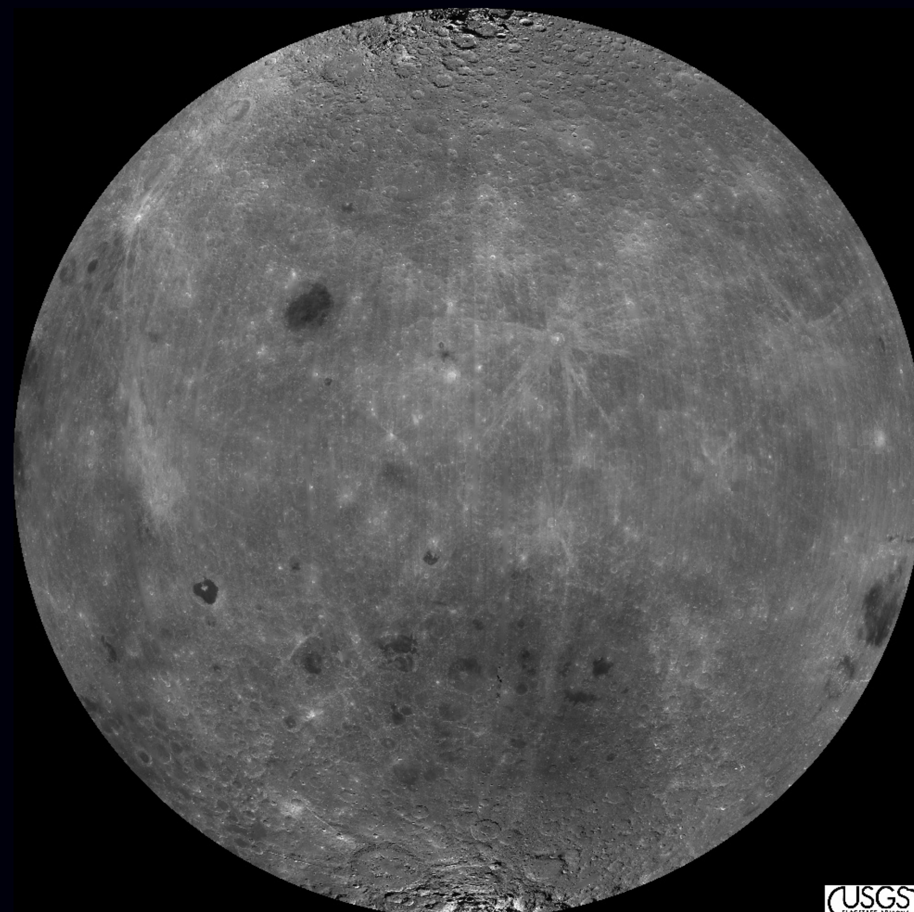
Apollo

Ranger

Surveyor



Near-side



Far-side

Lunar Outpost Site Selection

Site Considerations:

1) **General accessibility of landing site (orbital mechanics)**

2) **Landing site safety**

3) **Mobility**

4) **Mars analog**

5) **Power**

6) **Communications**

7) **Geologic diversity**

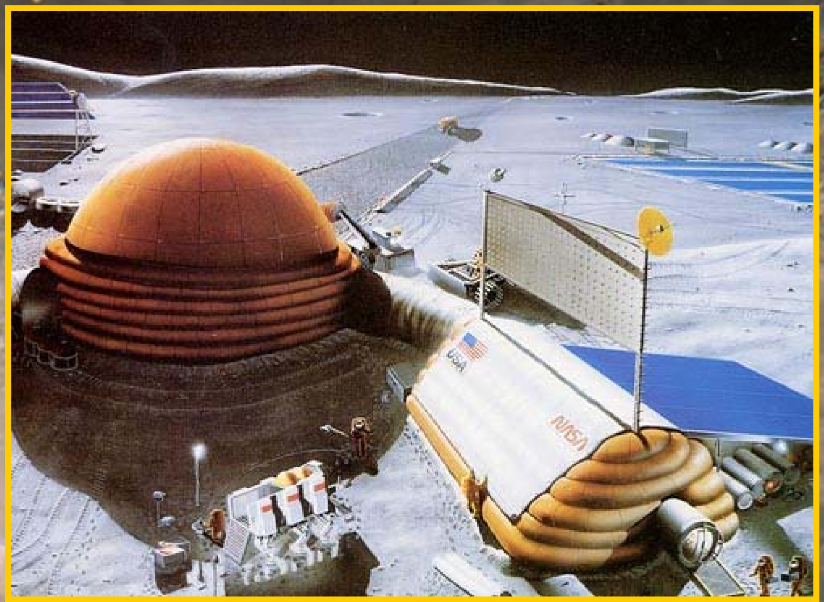
8) **ISRU considerations**

Why look for water?

- **Humans at a lunar outpost will need water:**
  – Option 1: Carry it there.
  – Option 2: Use water that may be there already!

- **Carrying water to the moon will be expensive!**

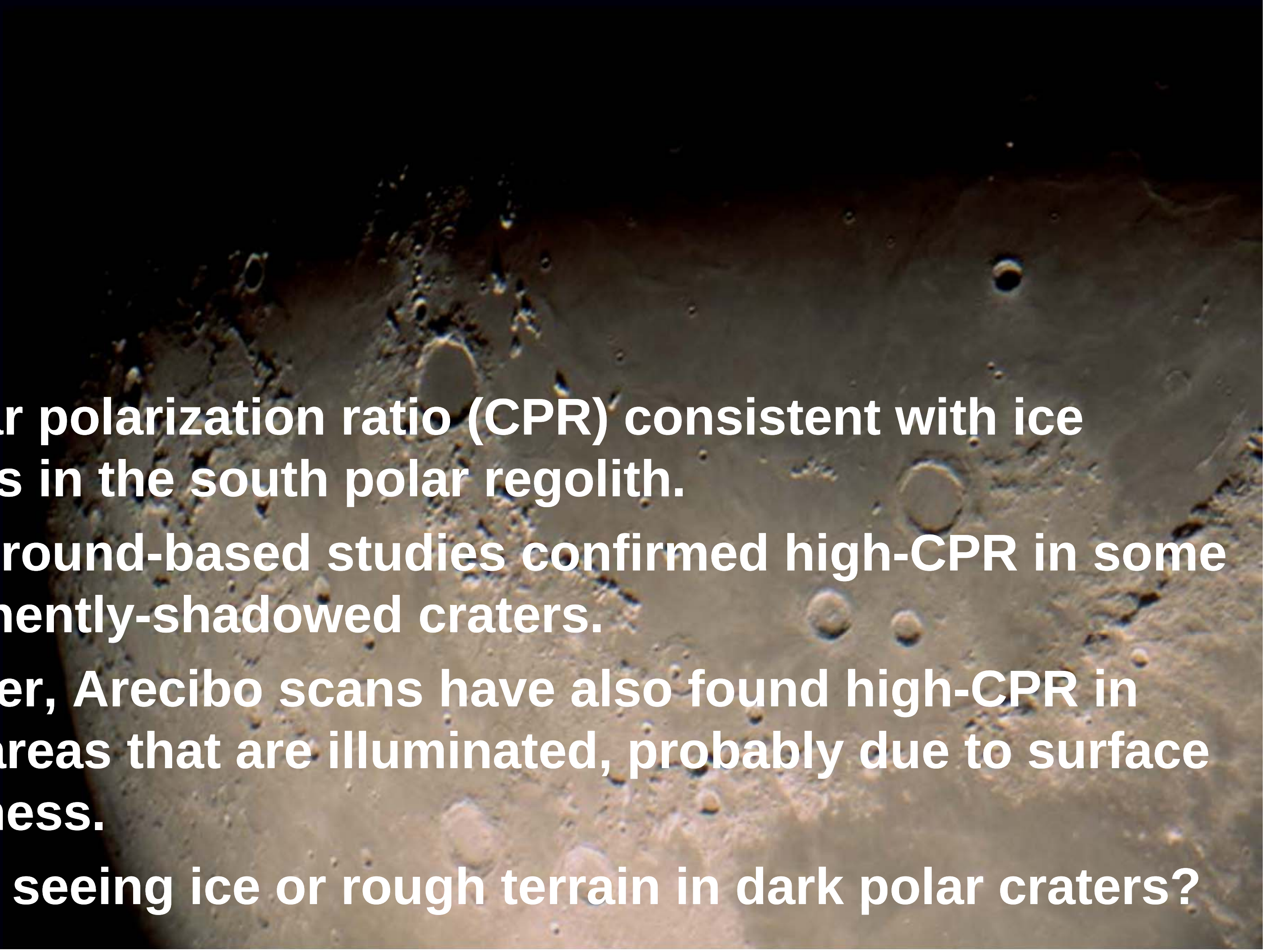
- **Learning to “Live off the land” would make a lunar outpost sustainability easier.**



Living off the land

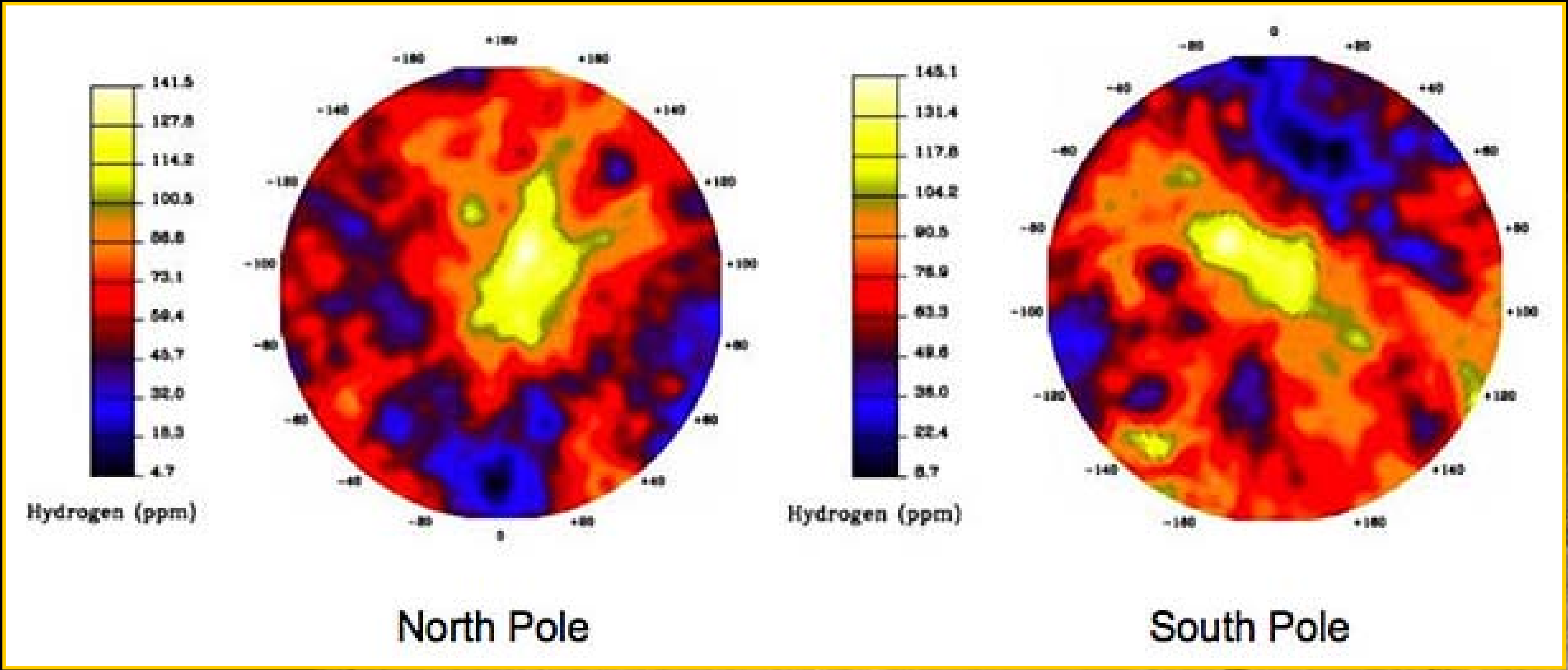
- Even compared to many meteorites, the Moon is highly depleted in volatile elements and compounds, especially water.
- However, oxygen does exist within various mineral structures. Hydrogen from the solar wind can also be obtained from the lunar soil.
- Very energy intensive to obtain these key raw materials (have to heat regolith to at least 700° C).
- Life would be much easier and cheaper if we could just find H_2O on the Moon.

Clementine bistatic radar - 1994



- **Circular polarization ratio (CPR) consistent with ice crystals in the south polar regolith.**
- **Later ground-based studies confirmed high-CPR in some permanently-shadowed craters.**
- **However, Arecibo scans have also found high-CPR in some areas that are illuminated, probably due to surface roughness.**
- **Are we seeing ice or rough terrain in dark polar craters?**

Hydrogen has been detected at the poles by Lunar Prospector in 1999. Is it water ice???



Lunar Prospector neutron spectrometer maps of the lunar poles. These low resolution data indicate elevated concentrations of hydrogen at both poles; it does not tell us the form of the hydrogen. Map courtesy of D. Lawrence, Los Alamos National Laboratory.

How could there be water at the lunar poles?

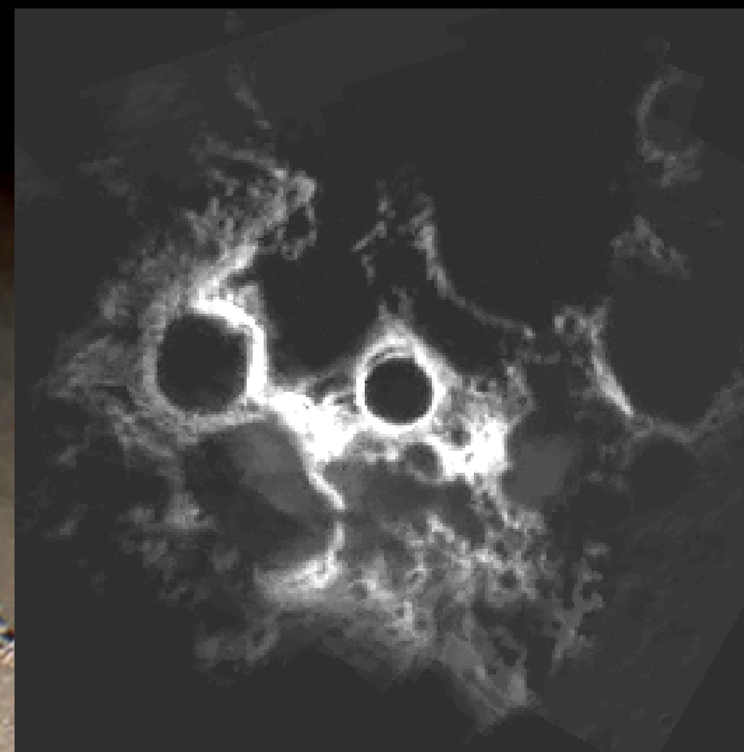
The sun never gets more then several degrees about the polar horizon, thus topography can provide “permanent” shade.

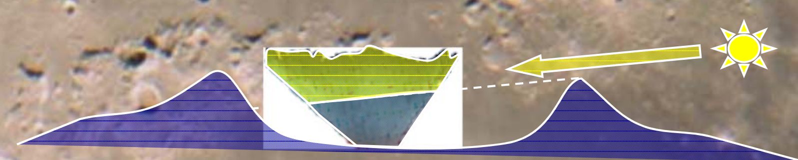
Permanently shadowed regions (PSRs) may have temperatures < -200° C (-328° F).

Over the history of the Moon, when comets or asteroids impact the Moon's surface they briefly produce a very tenuous atmosphere that quickly disperses into space.

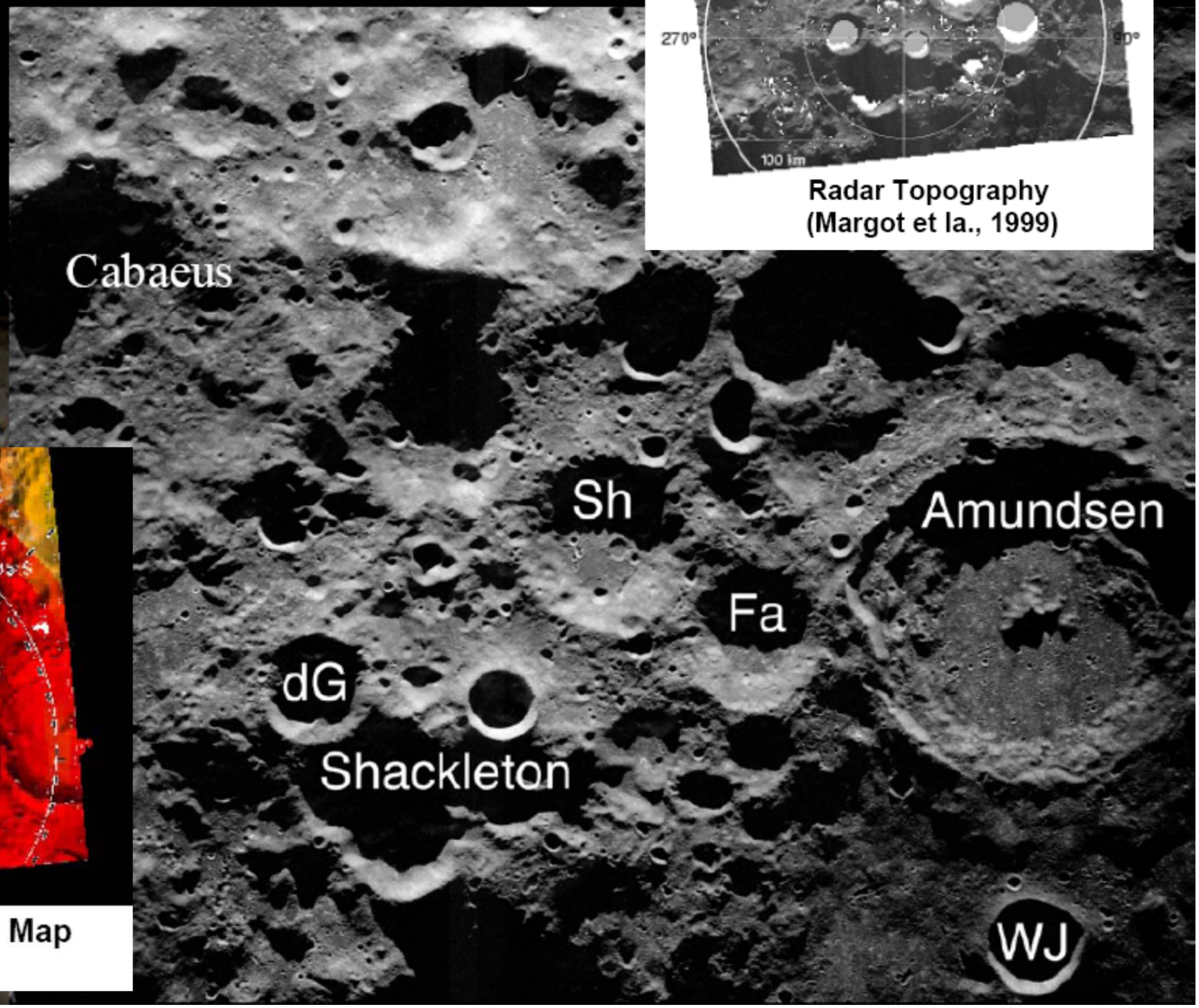
However, PSRs could act as cold-traps. Volatile gasses that enter could condense and accumulate for billions of years.

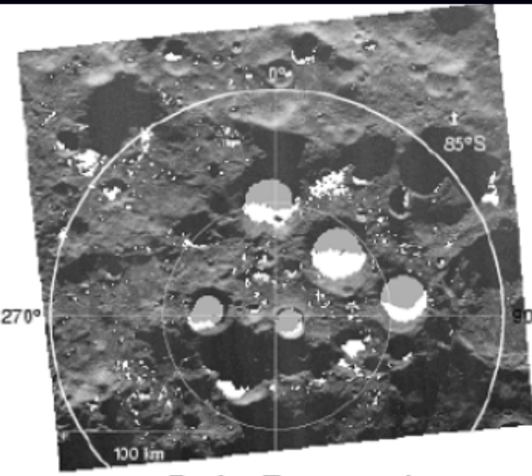
Clementine Mosaic - South Pole



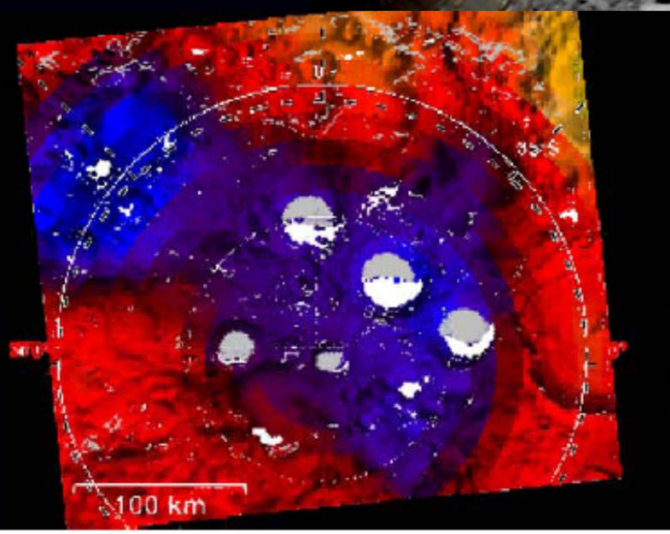


Where will we look?





Radar Topography
(Margot et la., 1999)



Lunar Prospector Hydrogen Map
(Maurice et la., 2003)

How can we look for water?

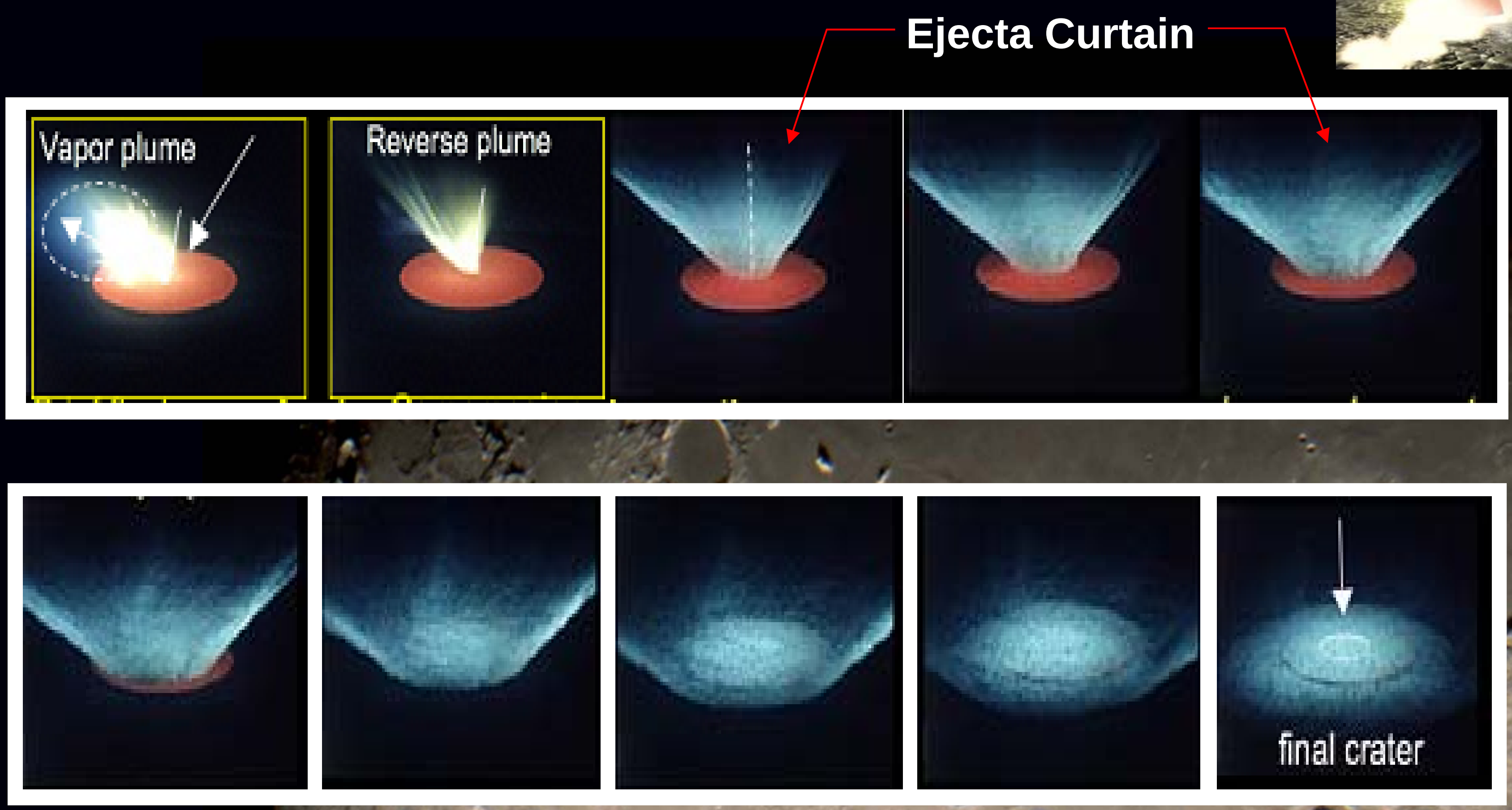
Lunar Reconnaissance Orbiter
LRO

Lunar Crater Observation and Sensing Satellite
LCROSS

Lunar Reconnaissance Orbiter

- **LROC – image and map the lunar surface in unprecedented detail**
- **LOLA – provide precise global lunar topographic data through laser altimetry**
- **LAMP – remotely probe the Moon’s permanently shadowed regions**
- **CRaTER - characterize the global lunar radiation environment**
- **DIVINER – measure lunar surface temperatures**
- **LEND – measure neutron flux to study hydrogen concentrations in lunar soil**

LCROSS Mission Concept

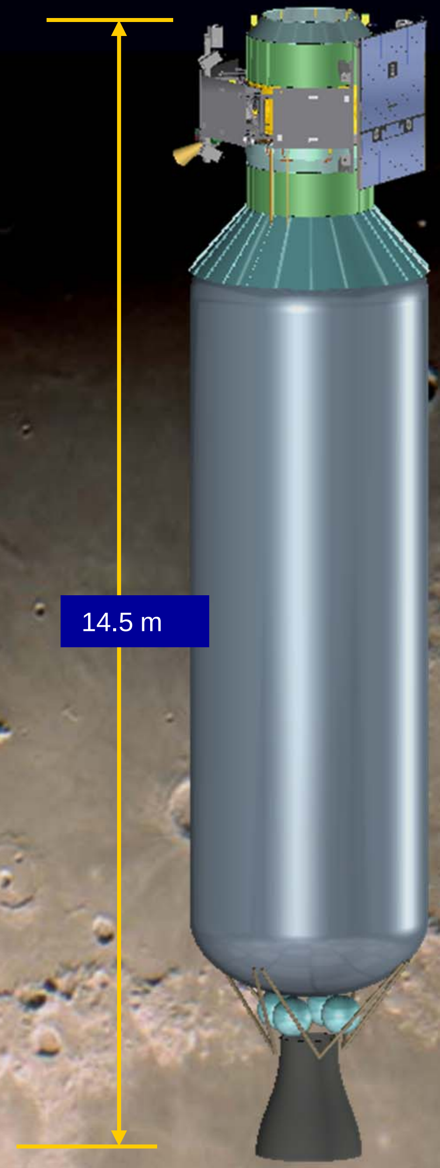


Peter Schultz

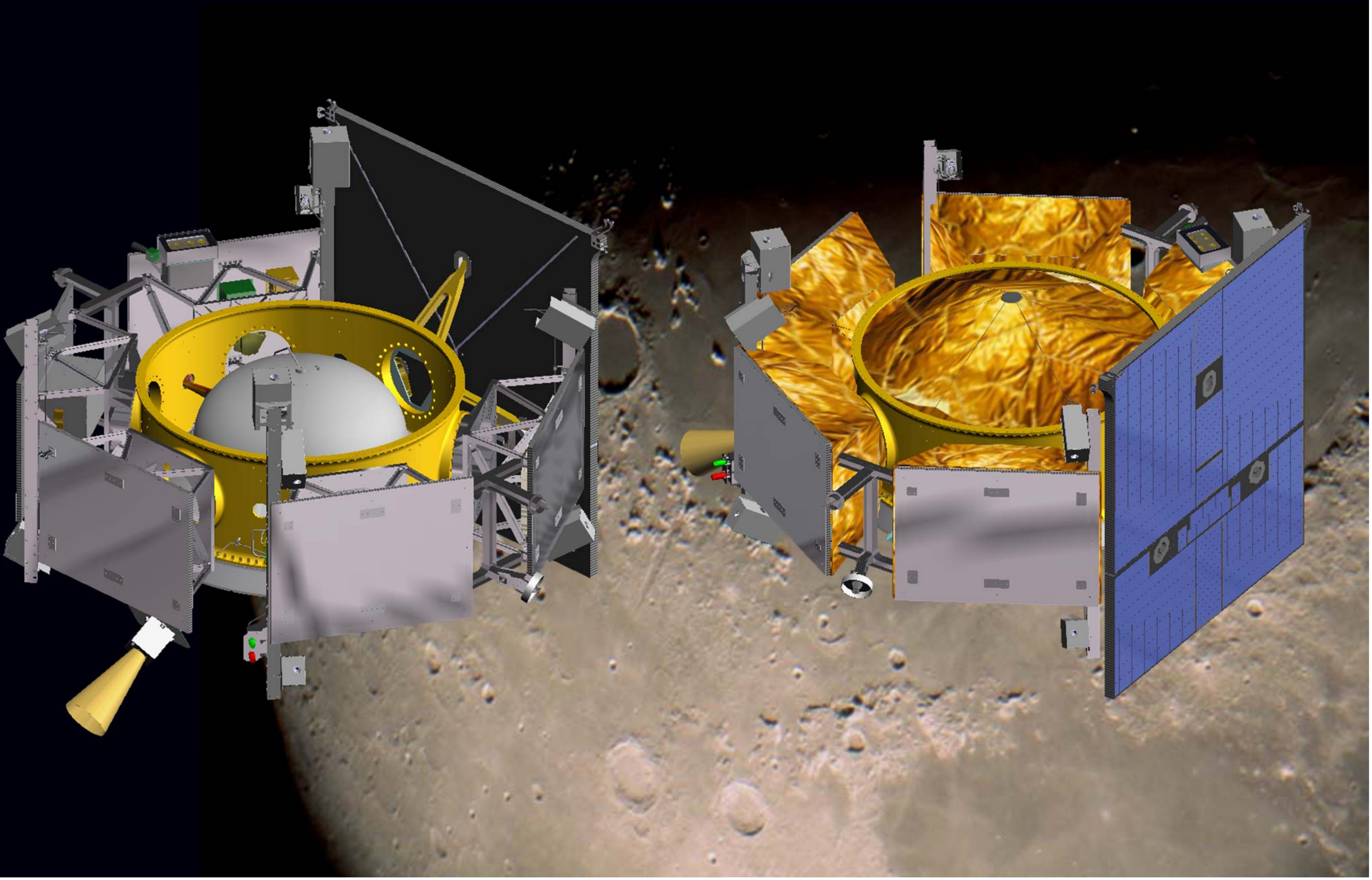
- Impact the Moon at 2.5 km/sec with a Centaur upper stage and create an ejecta cloud that may reach over 10 km about the surface
- Observe the impact and ejecta with instruments that can detect water

LCROSS Mission System

- **Shepherding Spacecraft**
- **Centaur Upper Stage**



LCROSS Shepherding Spacecraft



LCROSS Work Breakdown

ARC provides the overall Project Management, Science, Payload, Systems Engineering, Risk Management, Mission Operations, and Safety & Mission Assurance for the LCROSS mission

ARC, JPL, and GSFC provide the Navigation and Mission Design role

Northrop-Grumman provides the Spacecraft and Spacecraft integration with the Payload for this mission as well as launch systems integration support

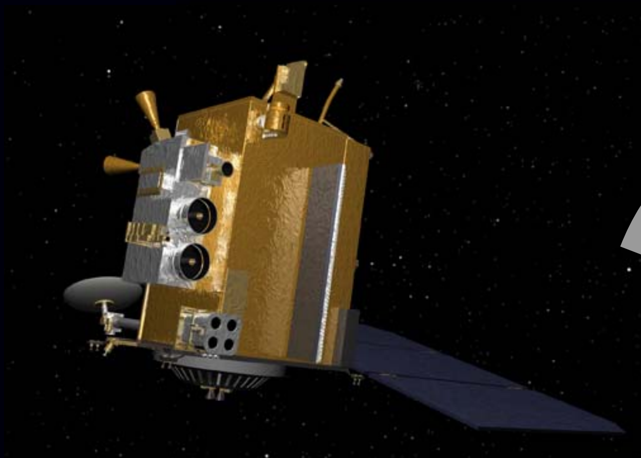
JPL is providing Deep Space Network services

KSC/Lockheed-Martin is providing Launch Vehicle services (Atlas V – 401)

Payload/Spacecraft Details

- The Payload is the business end of the LCROSS Spacecraft, housing all scientific instruments used for the Mission
- The Spacecraft provided by NGST consists of Command & Data Handling, Communications, Power, Propulsion, and Guidance, Navigation & Control systems
- The Spacecraft consists of 6 radiator panels mounted on a central ring, housing the various systems
- The Payload is mounted on one of these 6 panels
- ARC personnel designed and fabricated the Payload using Commercial Off-The-Shelf (COTS) instruments except for the Total Luminance Photometer which was designed and built by ARC.

'Low-Cost and Quick' Achieved with a Little Help From a Friend



Use Existing Designs

Buy Parts Together

Northrop Grumman Technical Services is building LRO avionics

Share Software

Share Documentation

Make use of a Structure Already Designed to Carry Heavy Payloads During Launch

Put LRO on top

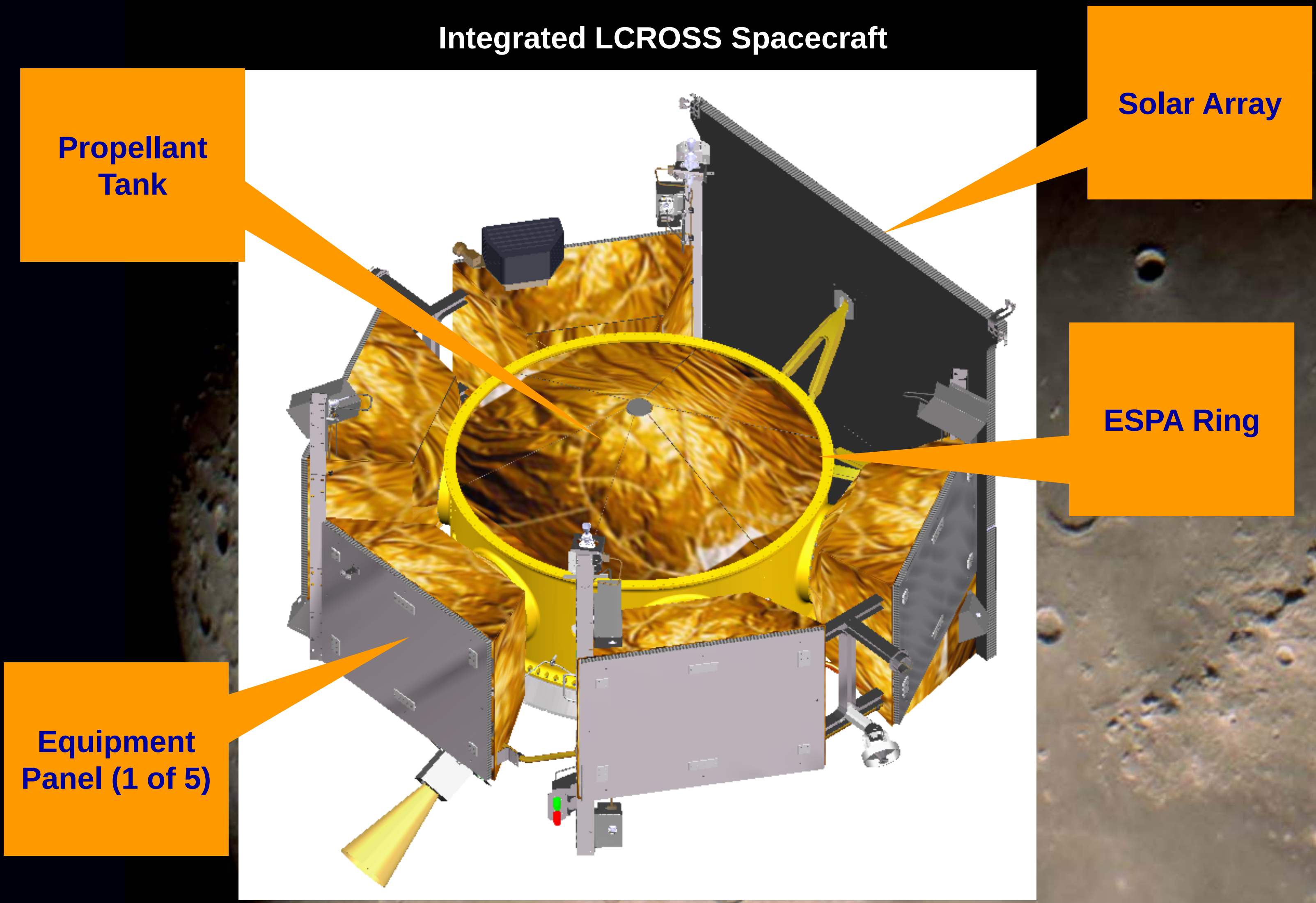
EELV Secondary Payload Adapter or ESPA Ring

Use ESPA ring to make LCROSS spacecraft

Attach bottom of ESPA Ring to top of rocket

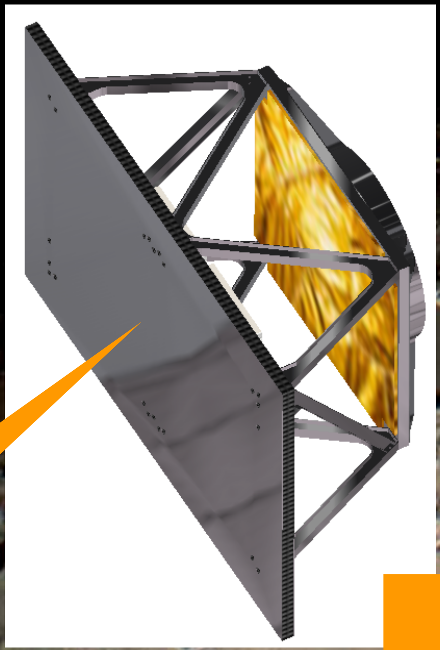
But how do you make a spacecraft out of something that looks like a sewer pipe?

Answer: Put Equipment Around the Rim and Tank in the Middle

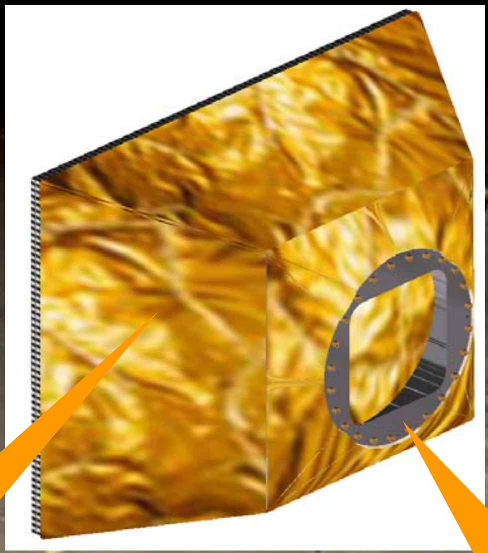


Each Panel Carries Equipment to Operate LCROSS

Panel Structure without Insulation Blanket



Panel Structure with Insulation Blanket



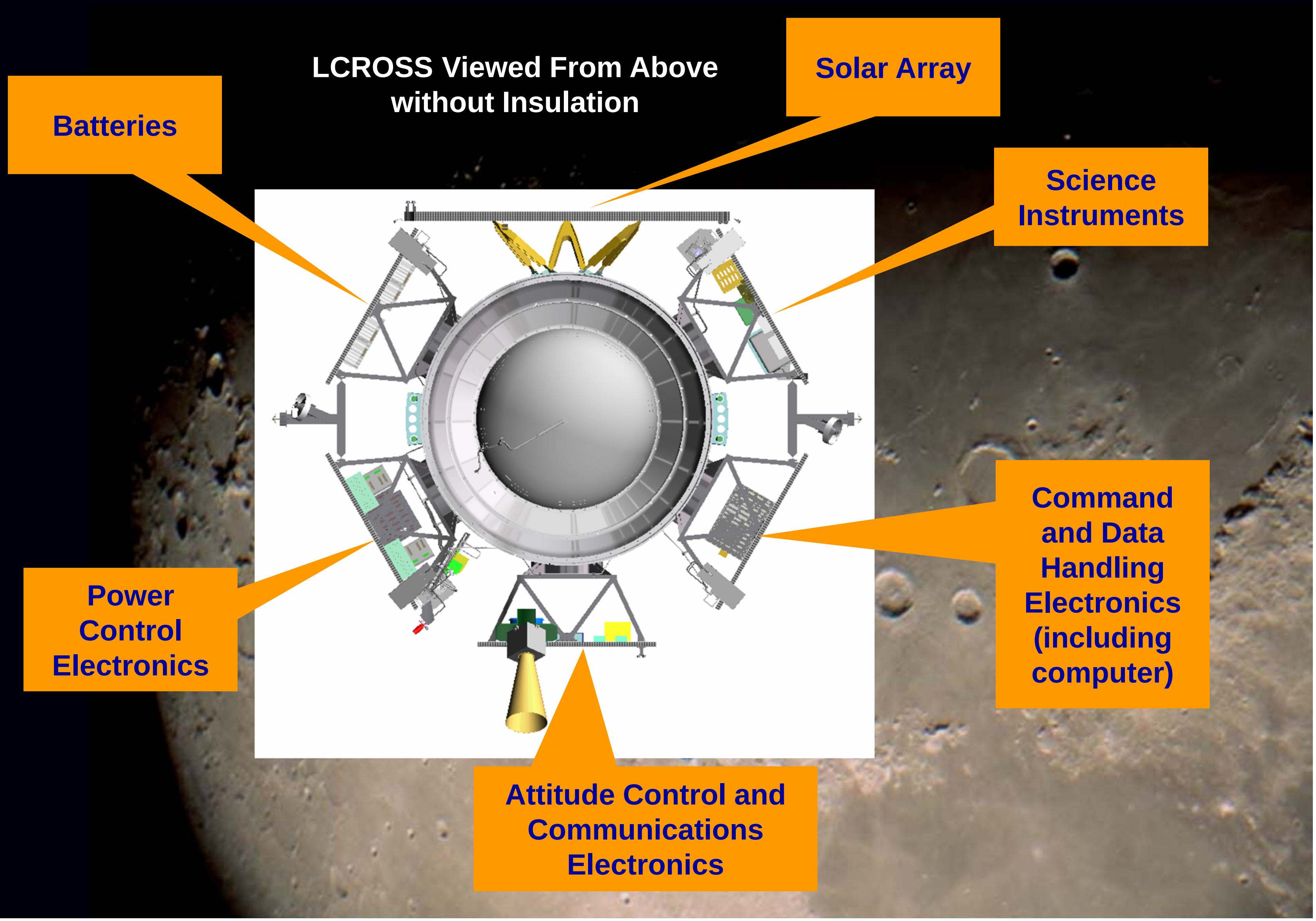
Electronics Bolted to Radiator Panel

Multi-Layer Insulation

Attaches to ESPA Ring

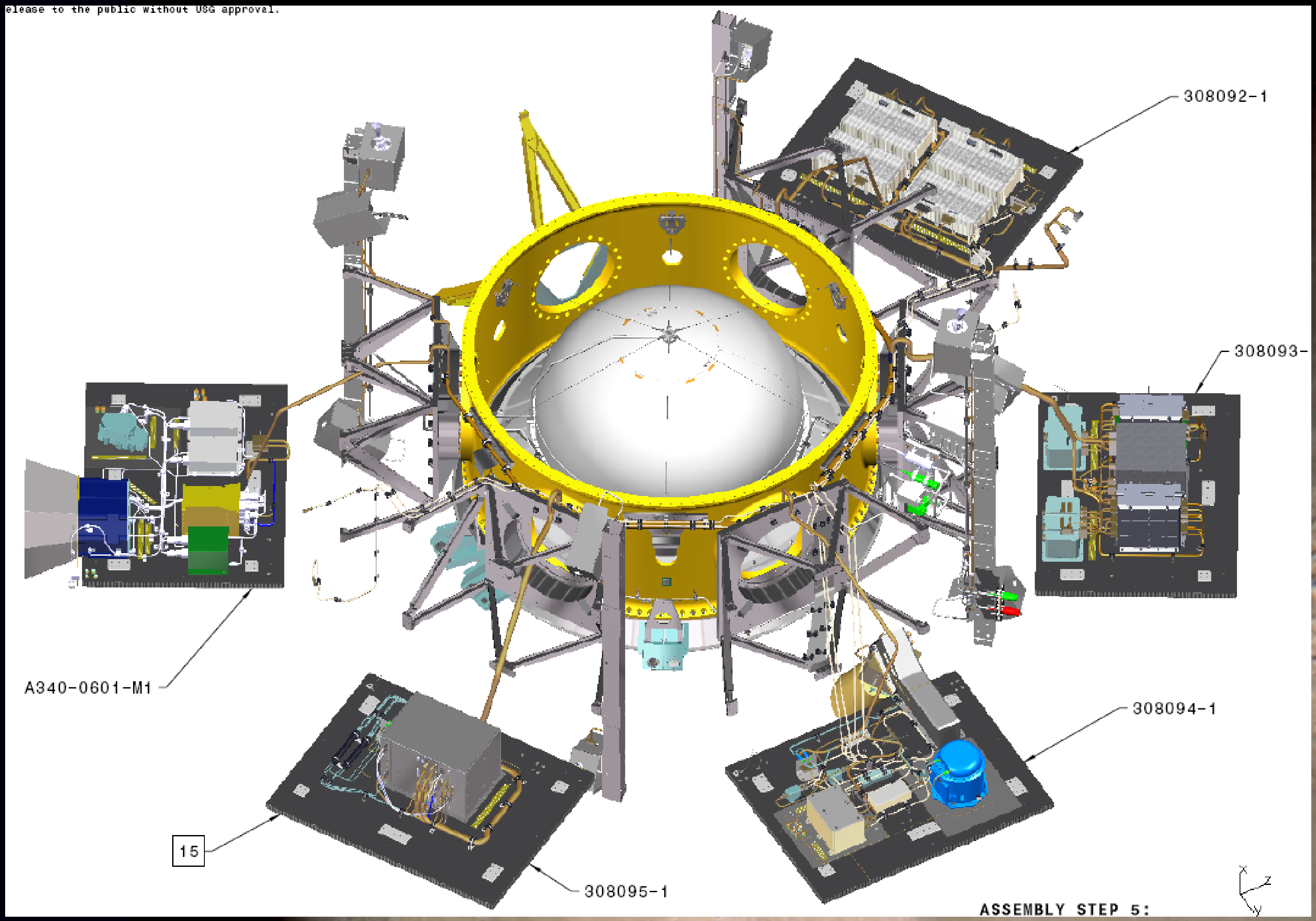
Panel design also assists keeping electronics at correct operating temperature

Different Panels Perform Different Functions



Panel Approach Makes LCROSS Easier to Put Together

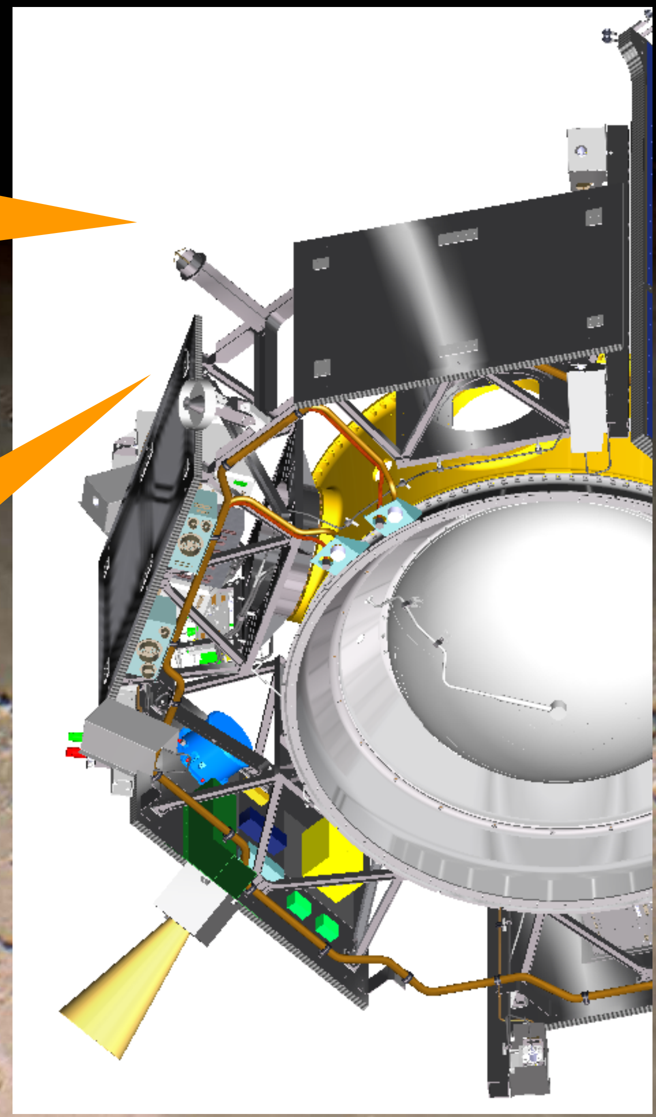
LCROSS with Panels Laid Flat for Integration of Electronics



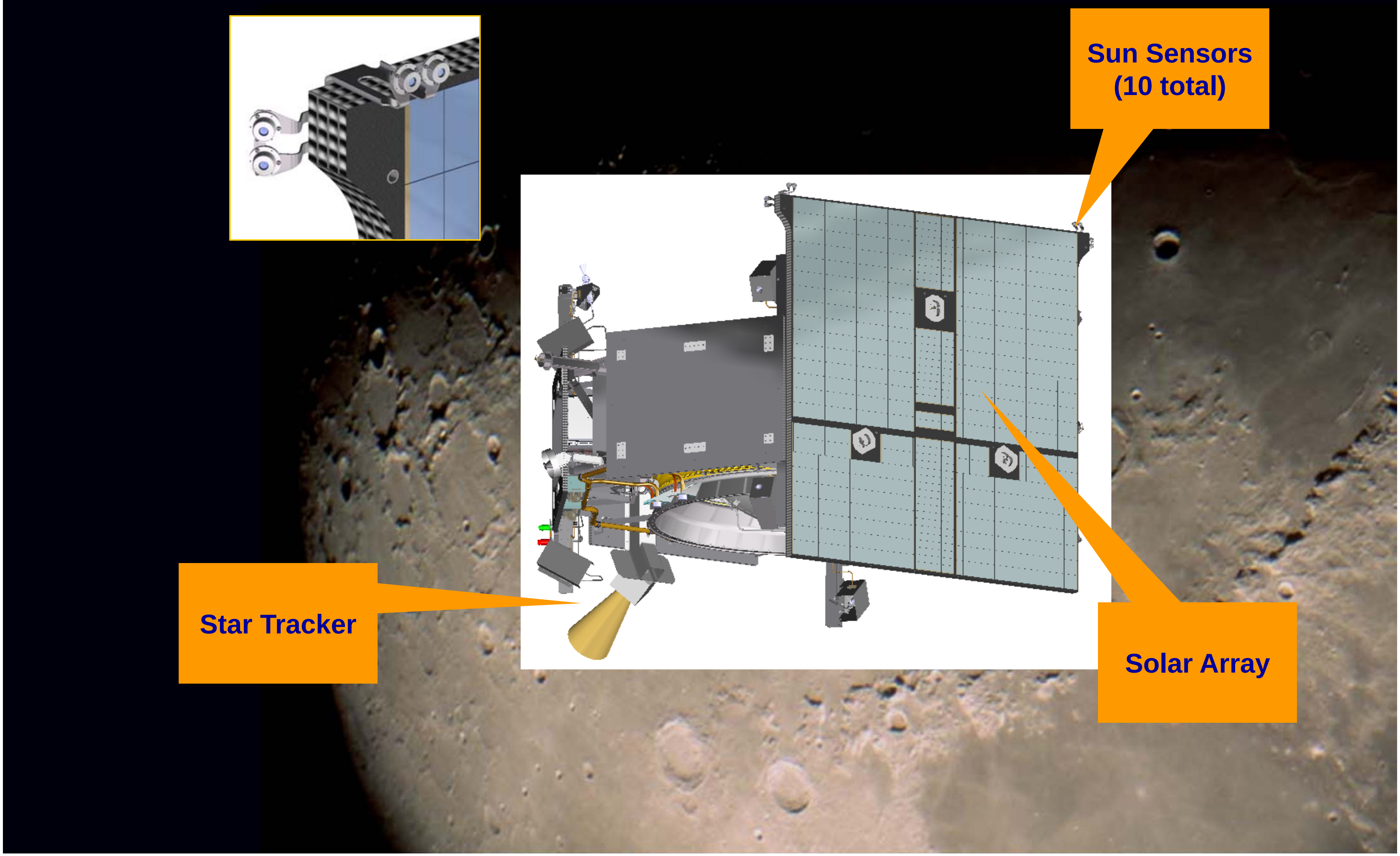
Other Equipment Includes Two Types of Antennas to Talk Back to Earth

Omni (Low Gain) Antenna (1 on each side)

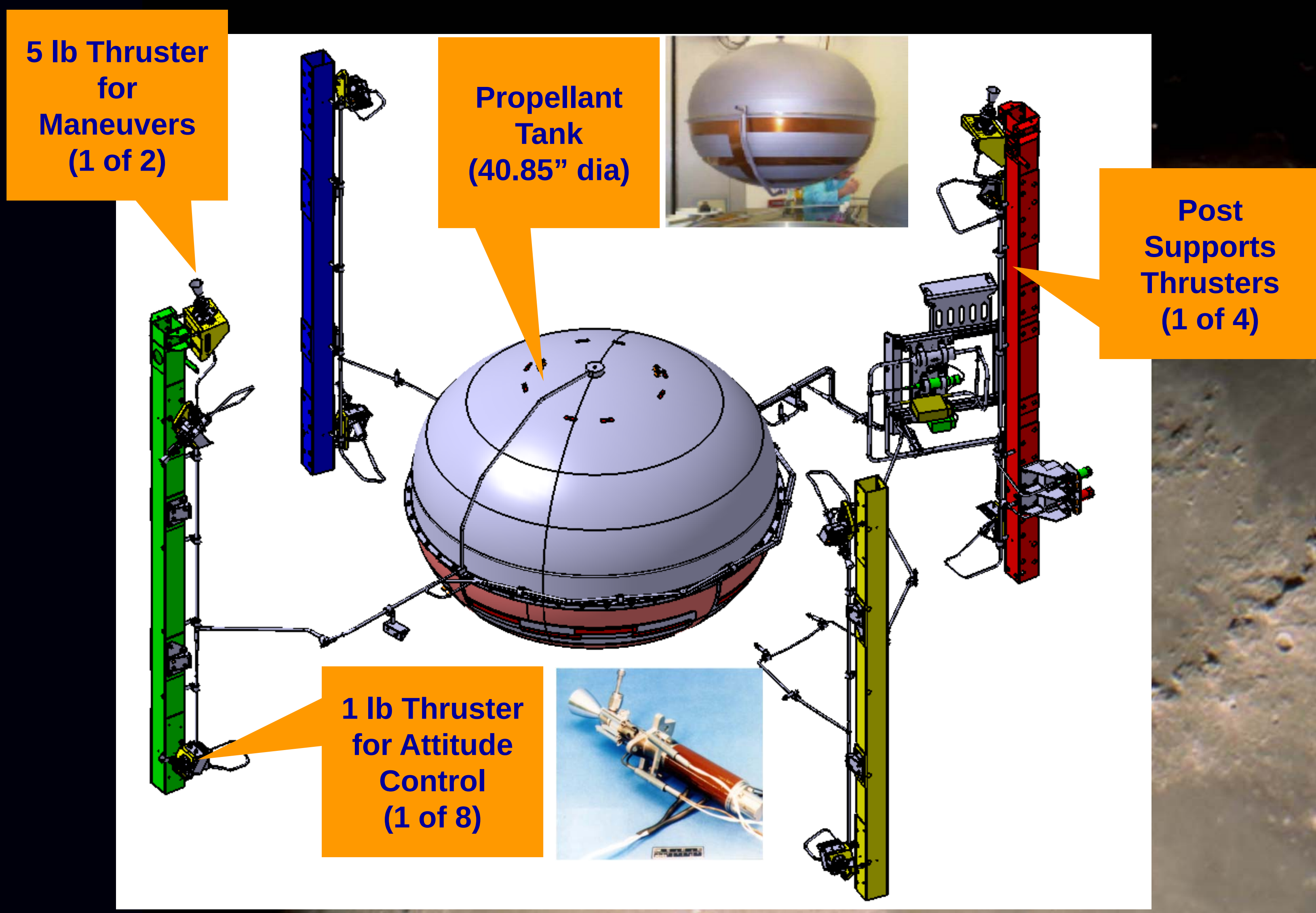
Medium Gain Antenna (1 on each side)



And Sensors to Determine Spacecraft Attitude (Pointing)



Propulsion System Must Maneuver and Point the Spacecraft

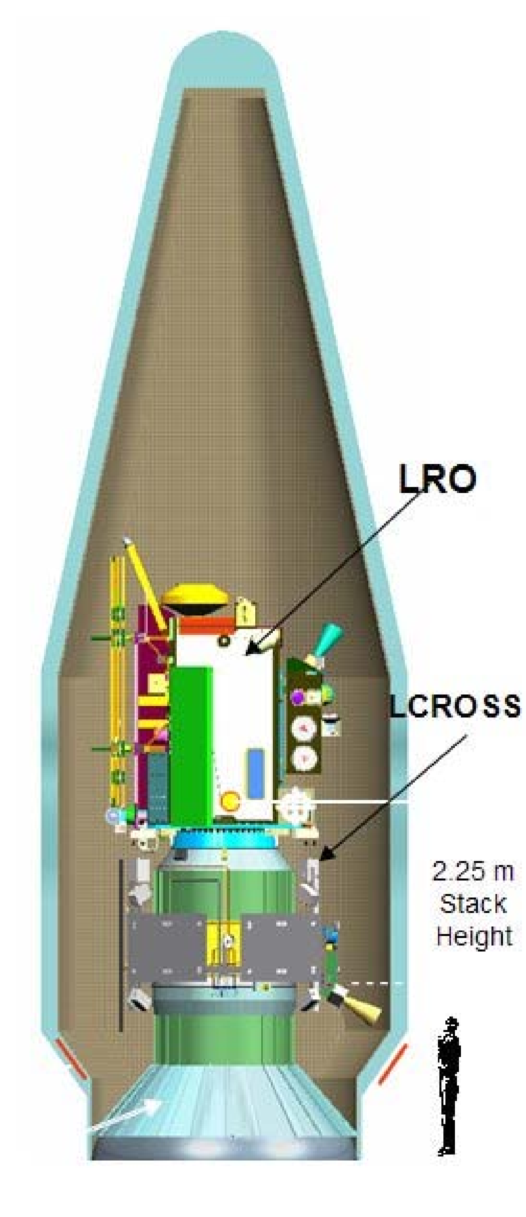


LCROSS Instruments

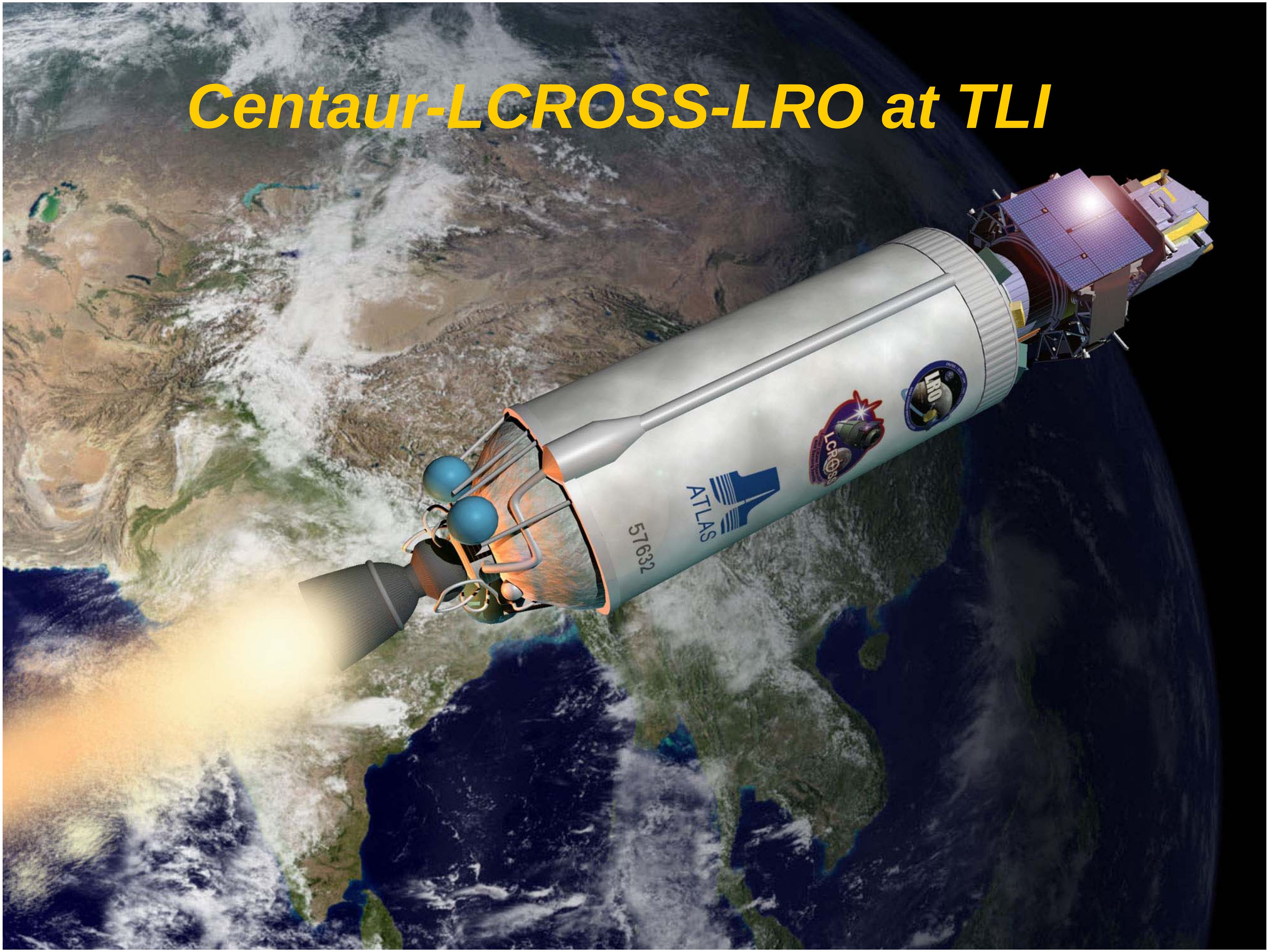
LCROSS Payload Science Instrument		Sponsorship	Measurement
	Visible Camera	Ecliptic Enterprises RocketCam	Visible context imagery; Monitor exacta cloud morphology; Determine visible grain properties
	Near Infrared Cameras	Goodrich Sensors Unlimited SU320-KTX	NIR (1.1-1.7 um) context imagery; Monitor exacta cloud morphology; Determine NIR grain properties; Water concentration maps
	Mid-Infrared Cameras	Thermoteknix MIRIC TB2-30	MIR (6.5-15 um) thermal image; Monitor the exacta cloud morphology; Determine MIR grain properties; Measure thermal evolution ejecta cloud; Remnant crater imagery
	Visible Spectrometer	Ocean Optics	Visible (260-660 nm) emission and reflectance spectroscopy of vapor plume, ejecta cloud; Measure grain properties; Measure emission H2O vapor disso iation, OH- (308nm) and H2O+ (609nm) fluorescence
	Near Infrared Spectrometers	Polychromix	NIR (1.4-2.4 um) emission and reflectance spectroscopy of vapor plume, ejecta cloud; Measure grain properties; Measure broad H2O ice features; Occultation viewer to measure water vapor absorption by cloud particles
	Total Luminance Photometer (TLP)	Ames	Measure total impact flash luminance (400-1000 nm), magnitude and decay of luminance curve
	Data Handling Unit (DHU)	Ecliptic Enterprises	Instrument control and data acquisition

Scheduled Launch: Late 2008

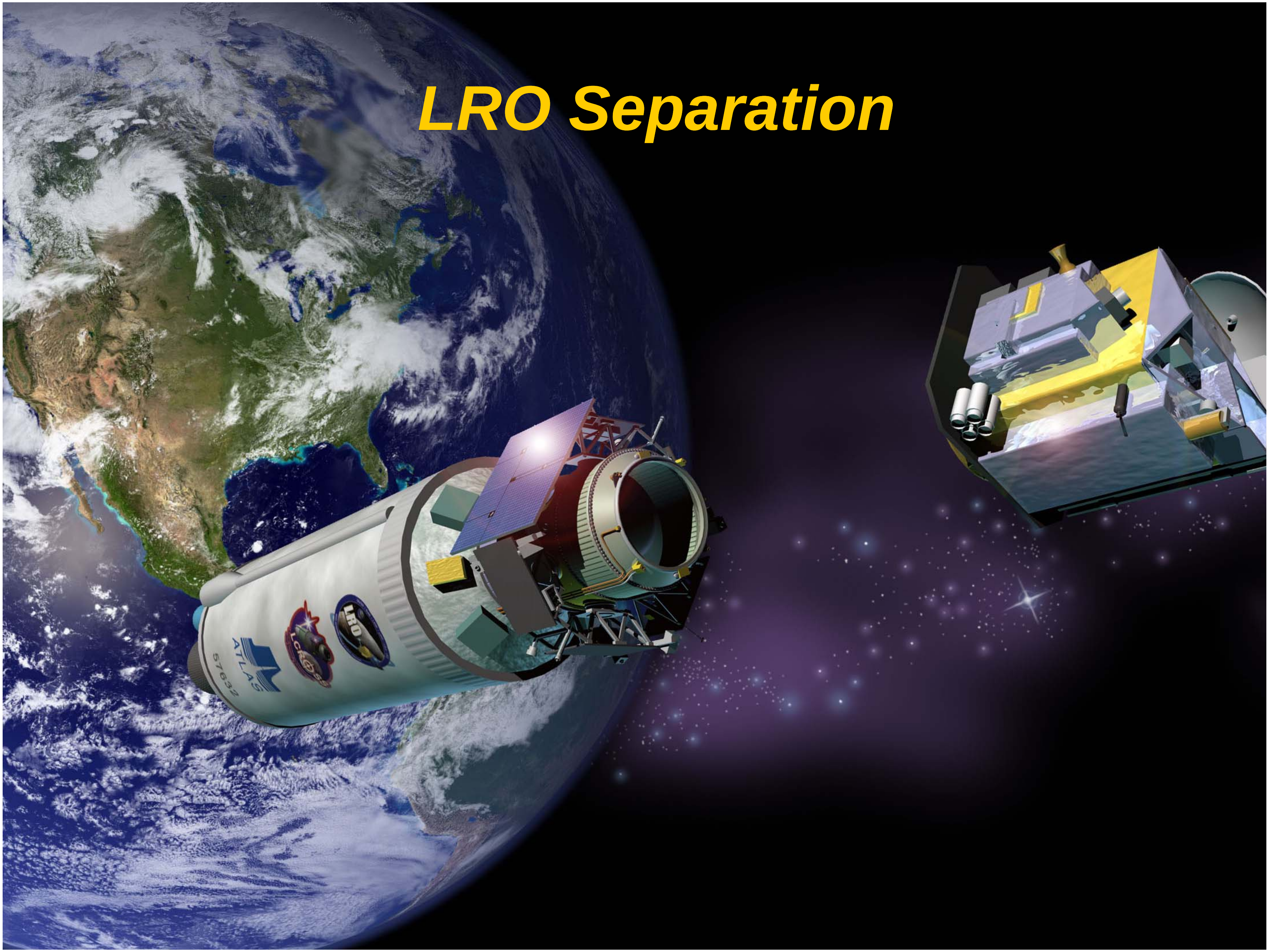
- Both LCROSS and LRO will share space aboard an Atlas V launch vehicle
- Launch will occur at Cape Canaveral



Centaur-LCROSS-LRO at TLI



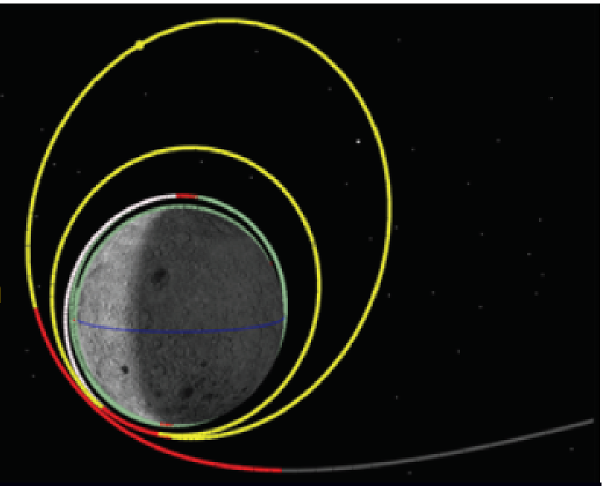
LRO Separation



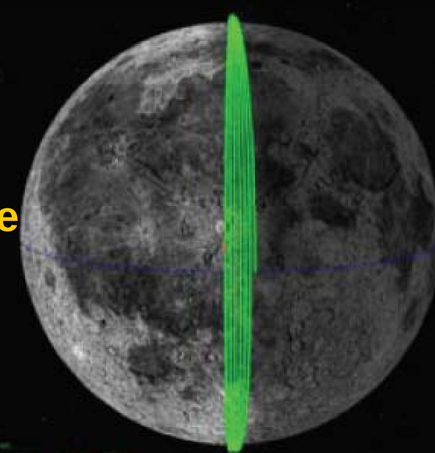
LRO Mission Overview

- On-board propulsion system used to capture at the Moon, insert into and maintain 50 km mean altitude circular polar reconnaissance orbit.

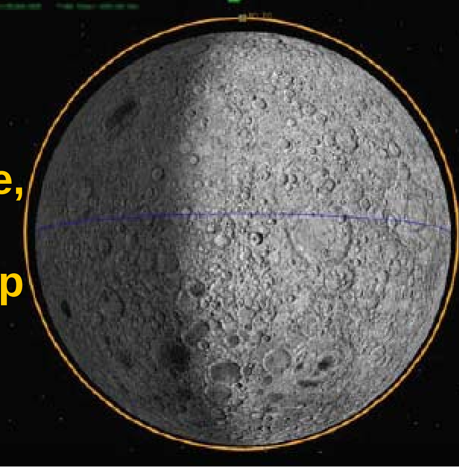
- 1 year exploration mission followed by handover to NASA science mission directorate.



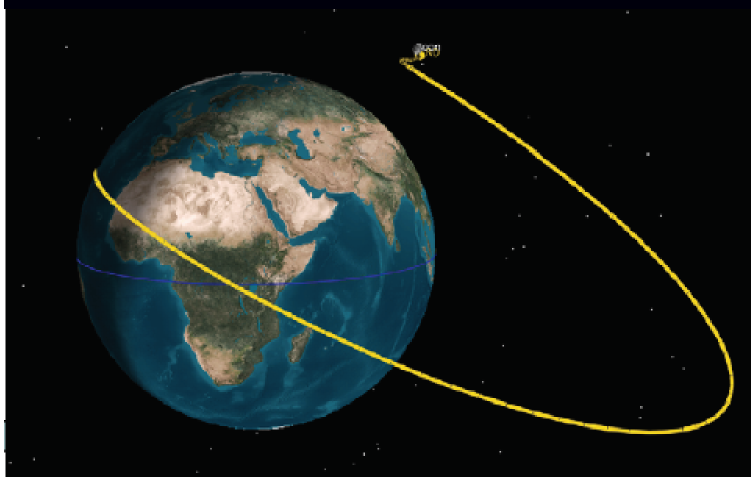
Lunar Orbit Insertion Sequence



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

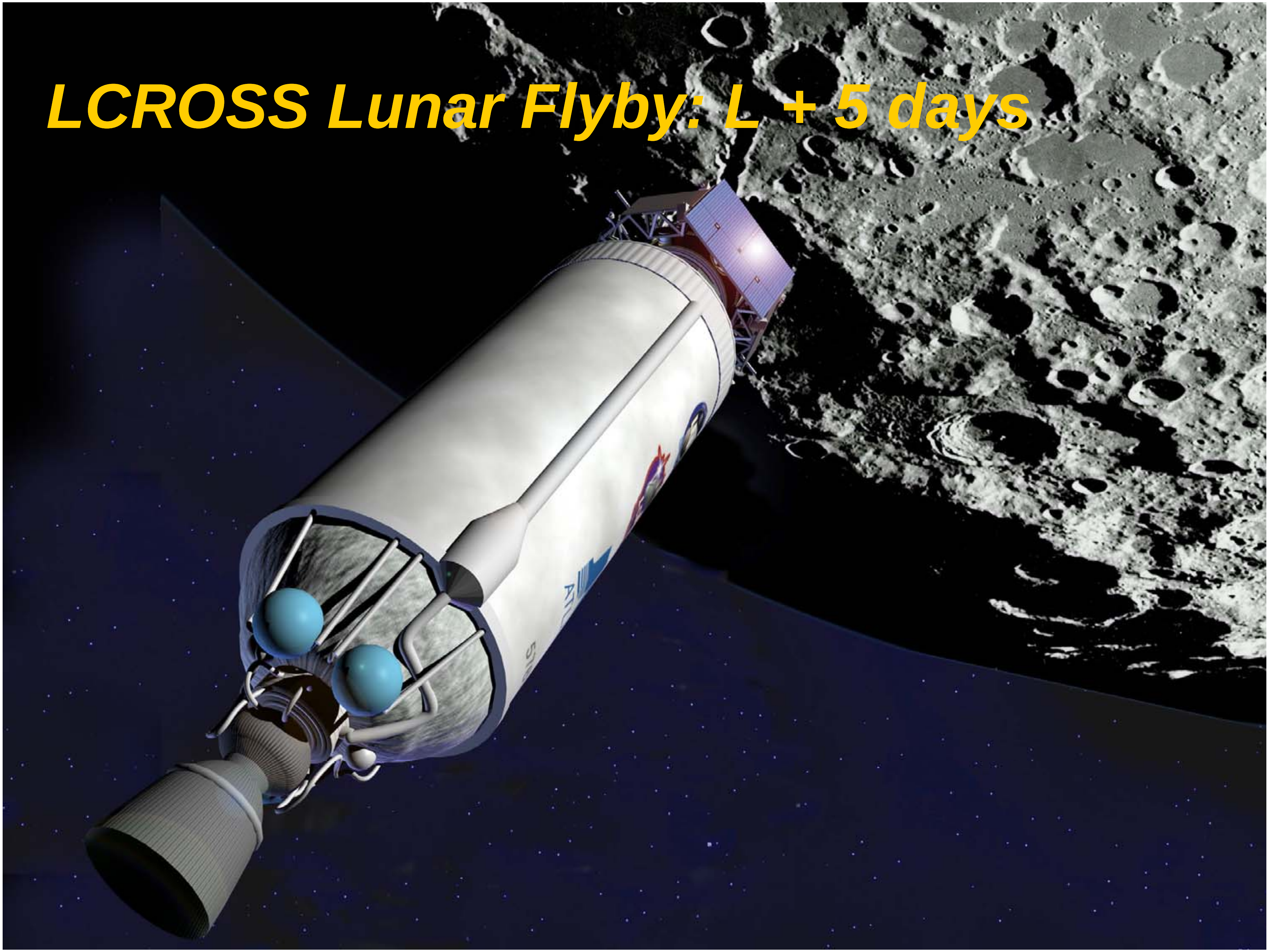


Commissioning Phase, 30 x 216 km Altitude Quasi-Frozen Orbit, Up to 60 Days



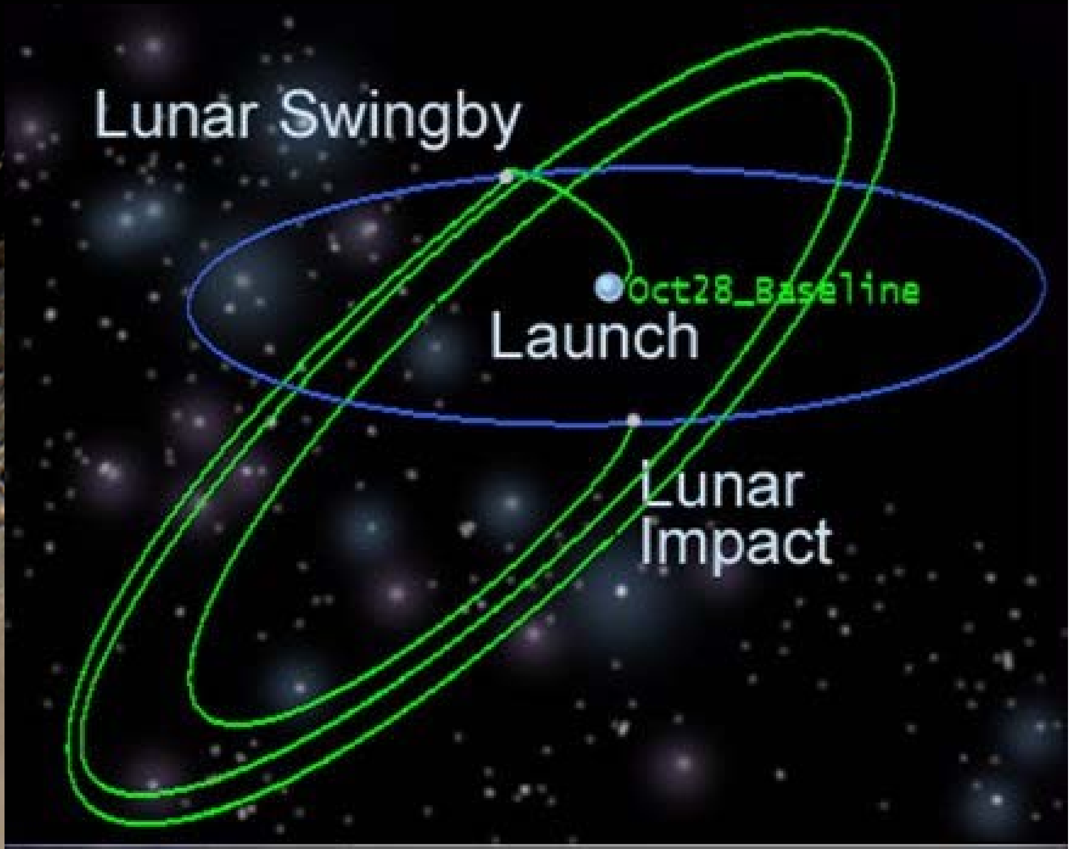
Minimum Energy Lunar Transfer

LCROSS Lunar Flyby: L + 5 days

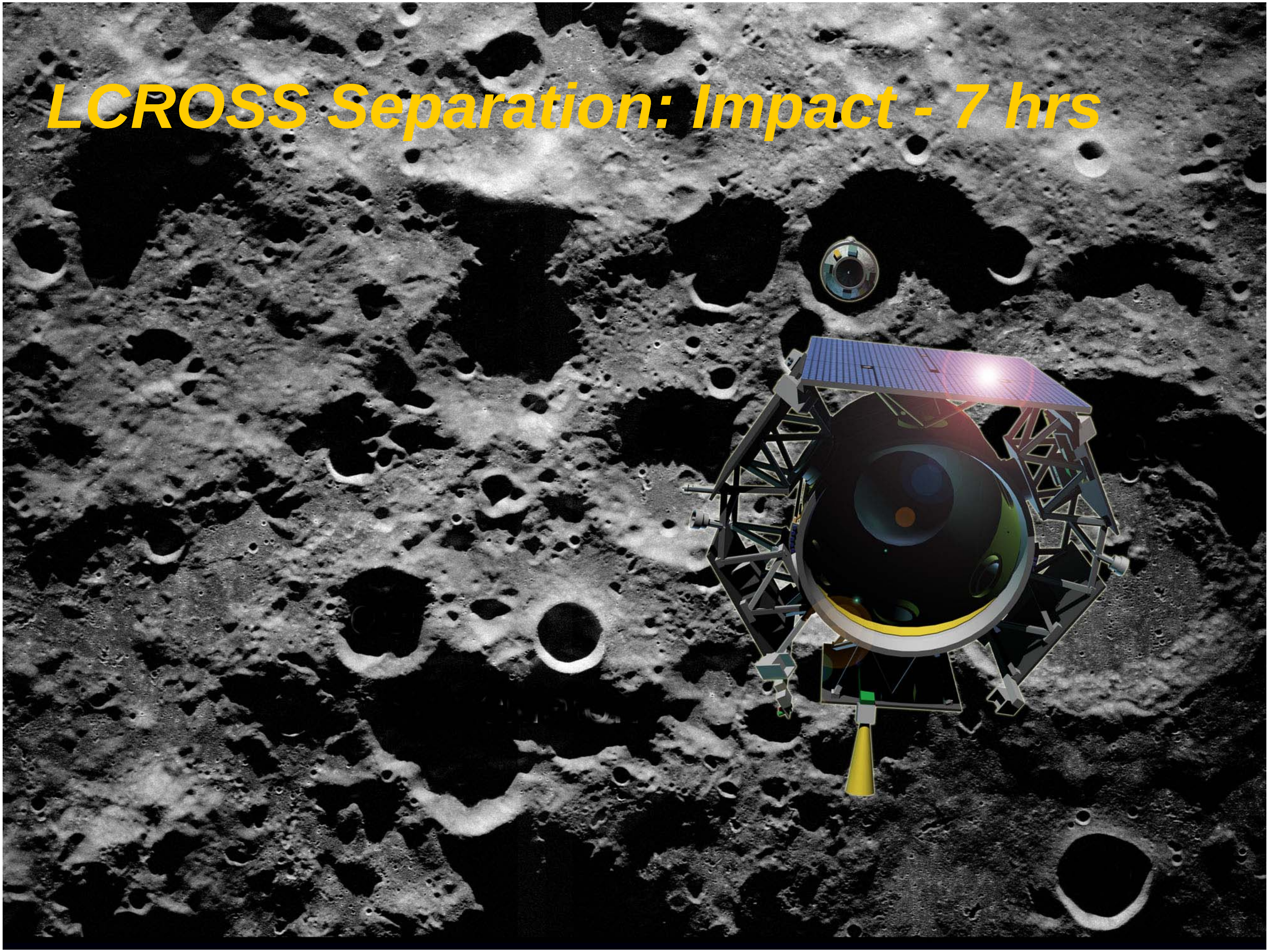


LCROSS Trajectory: The Long and Winding Road

- 3, 3.5, or 4 month cruise depending on launch date
- Flyby transitions to Lunar Gravity Assist Lunar Return Orbits (LGALRO)
- 3, 3.5, or 4 Lunar orbits about Earth (27 day period)
- 2, 2.5, or 3 LGALRO orbits about Earth (~38 day period)
- Long transit also provides time to vent any remaining fuel from Centaur

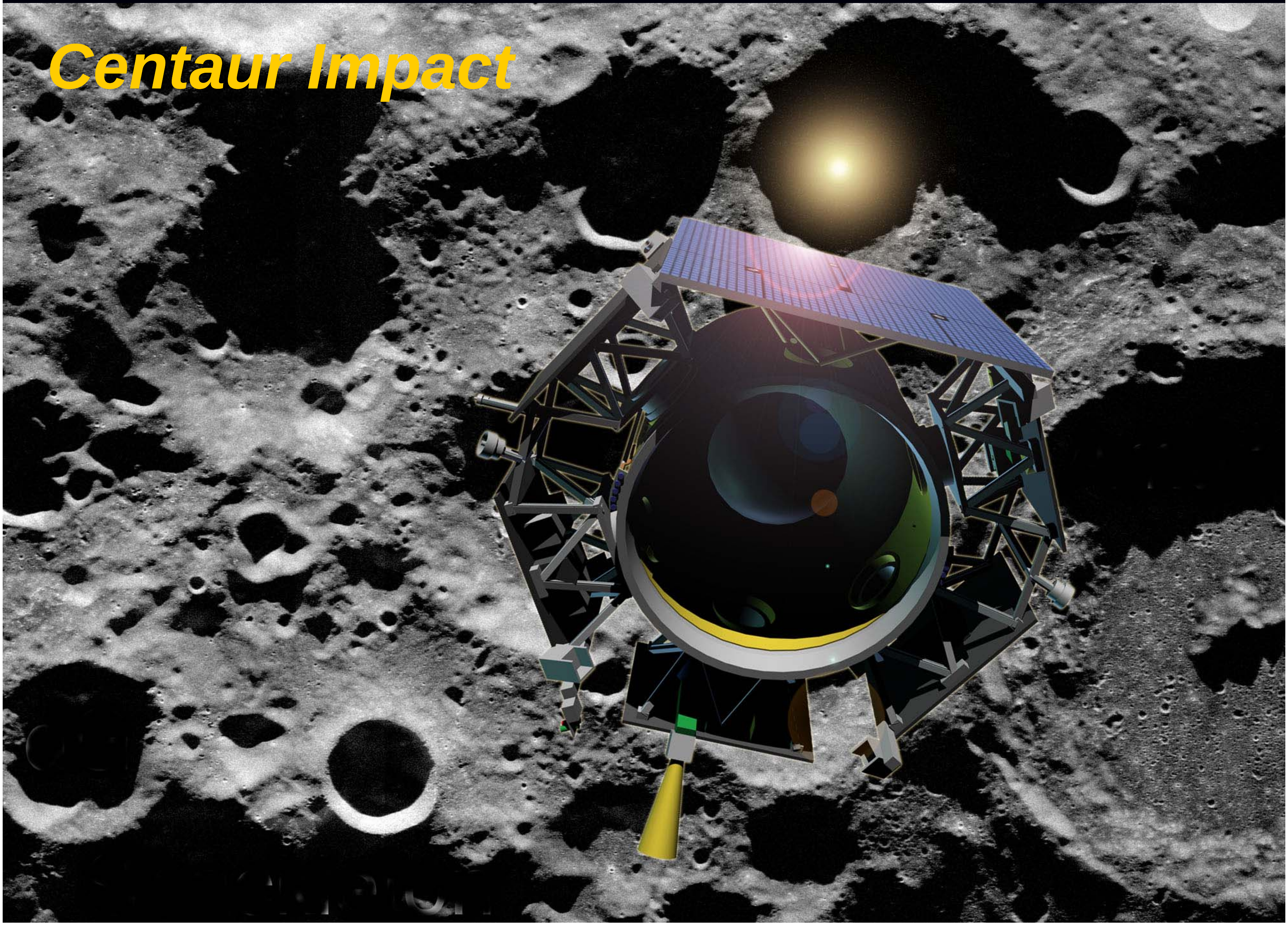


LCROSS Separation: Impact - 7 hrs



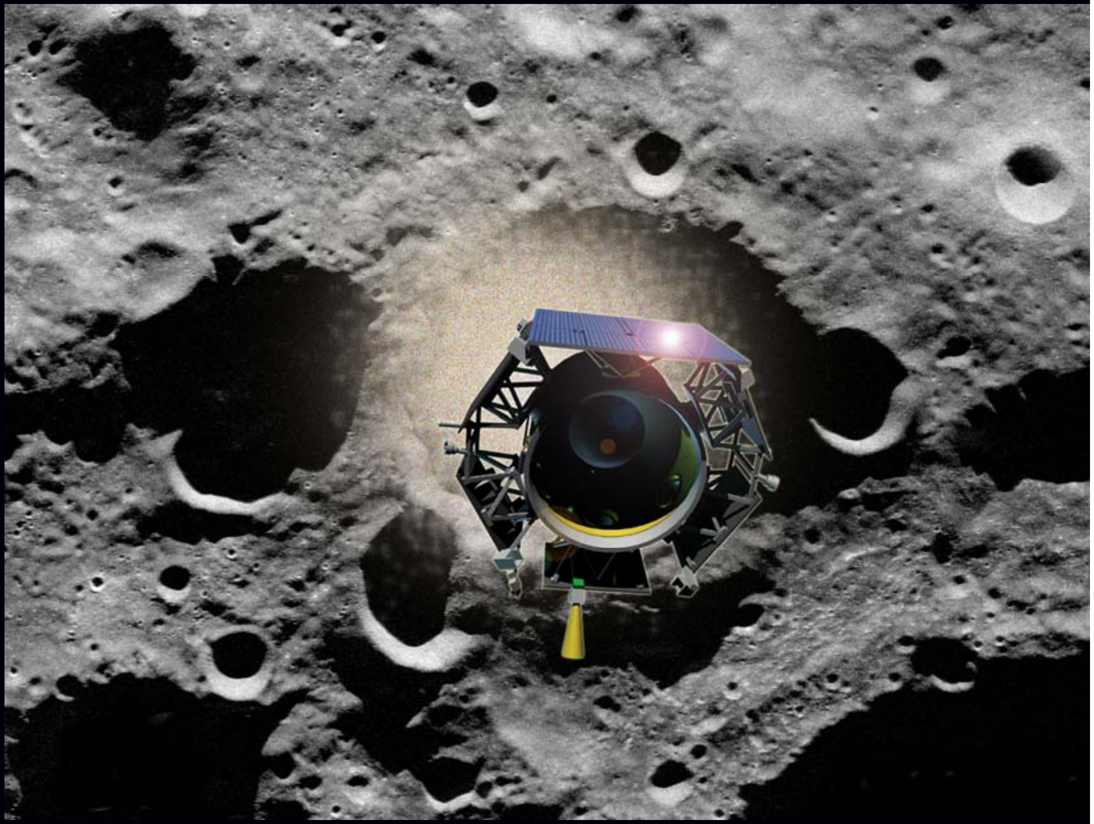

Centaur Impact

Centaur Impact

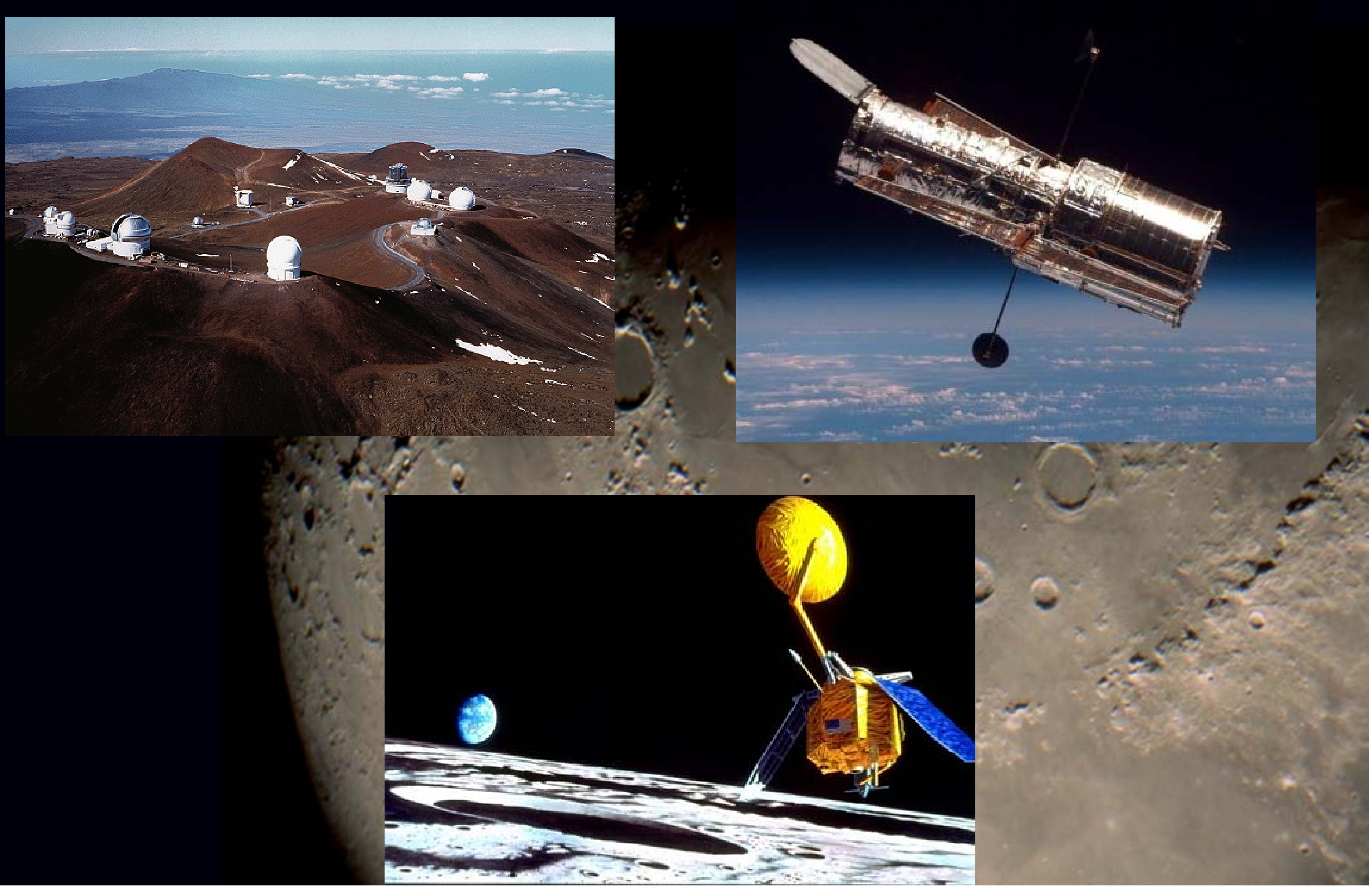


Into the Plume

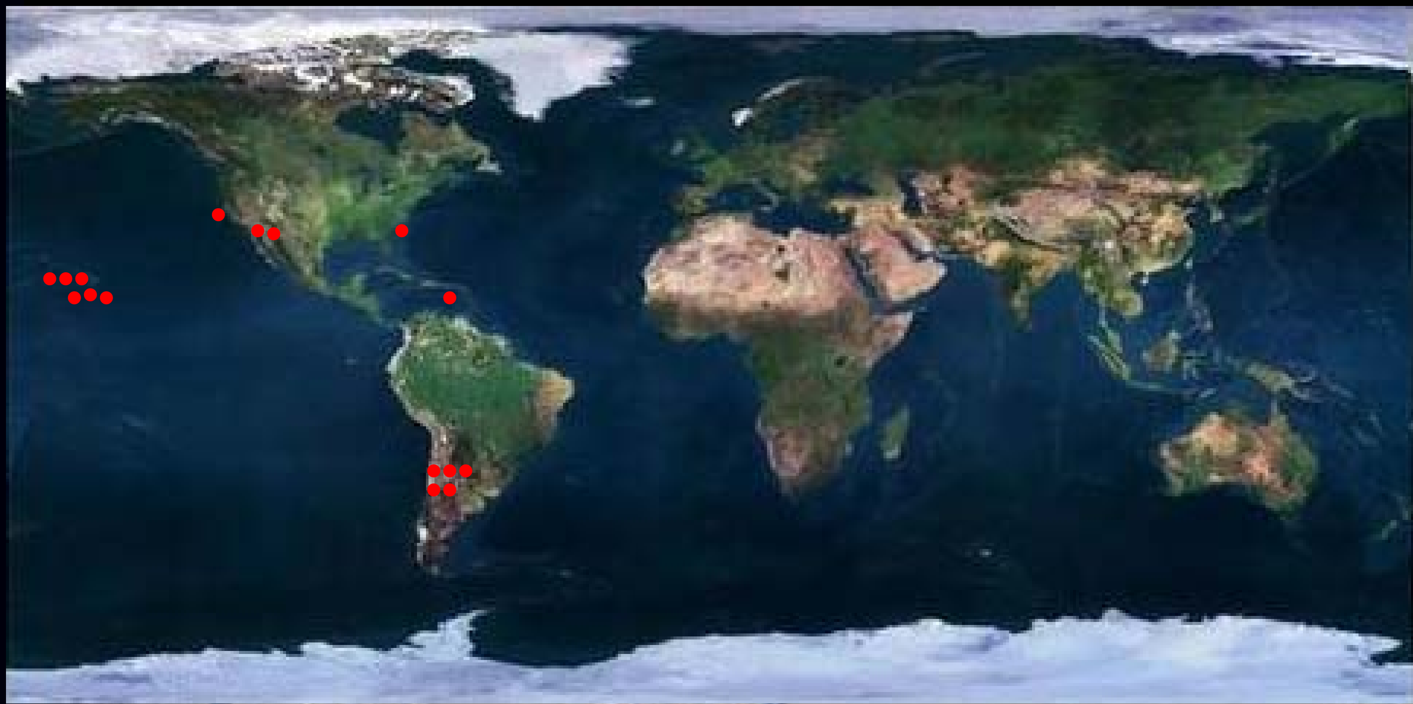
- During the next 4 minutes, the Shepherding Spacecraft descends into the debris plume, measuring its morphology and composition, and transmitting this information back to Earth.
- The Shepherding Spacecraft then ends its mission with a second impact on the Moon



Impact Observation Campaign



Ground-based Telescopes

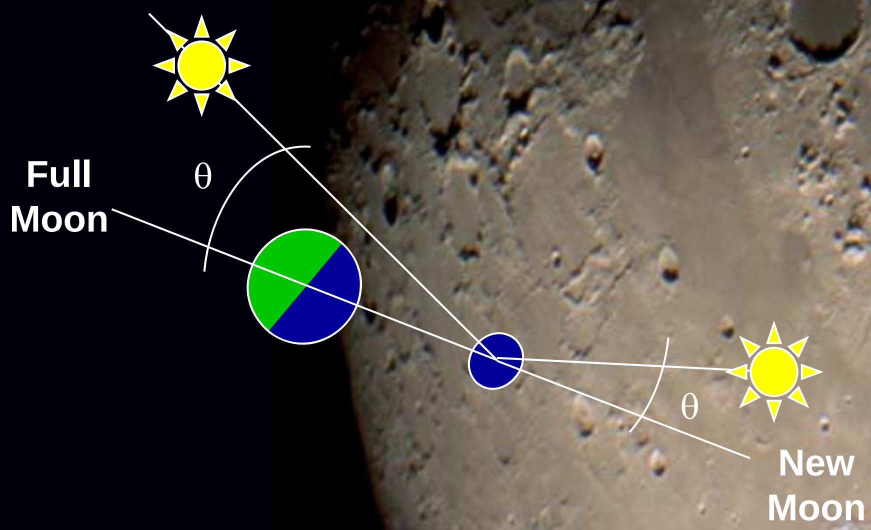


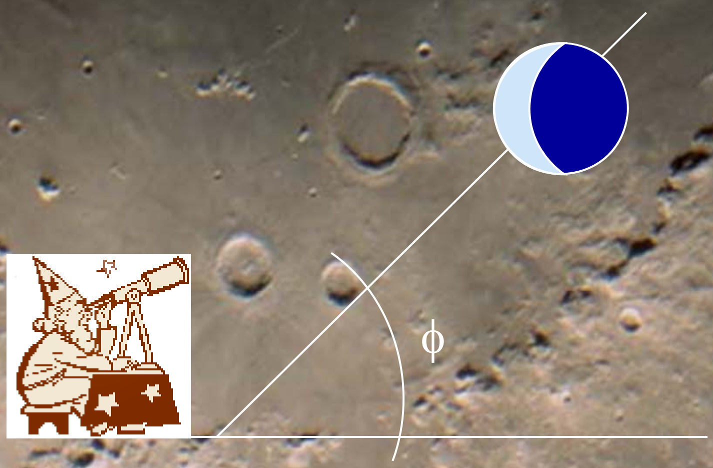
Timing of impacts to allow simultaneous observations from Hawaii, Continental U.S., and South America.

Impact Observations Support

The opportunity for ground based assets to observe the impact depends on the date and time of impact:

- Phase of the moon: $\theta > 30^\circ$ from new or full moon
- Moon position in the night sky: <3 air masses ($\phi > 30^\circ$ from horizon) with >2 hours of observing time





Participatory Exploration

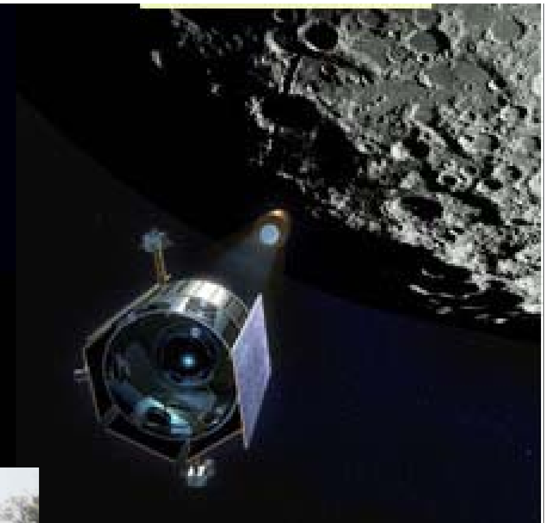
- **We cannot expect our audiences to be satisfied with being passive second-hand recipients of mission information**
- **The act of participation is vital for students and the public in realizing the relevance of a mission, increasing their interest and buy-in for the mission**
- **Stardust, Mars HiRISE, and Deep Impact are great examples**

LCROSS Education and Public Outreach

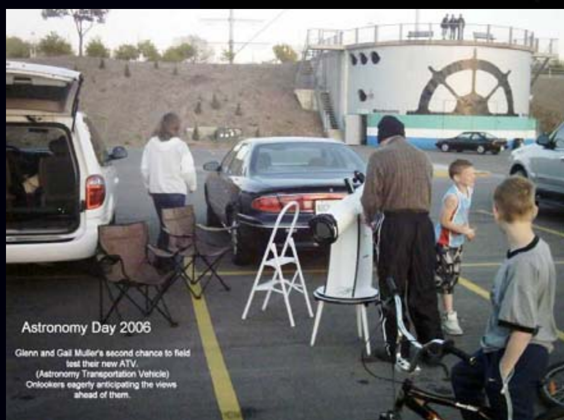
Numerous Components Including

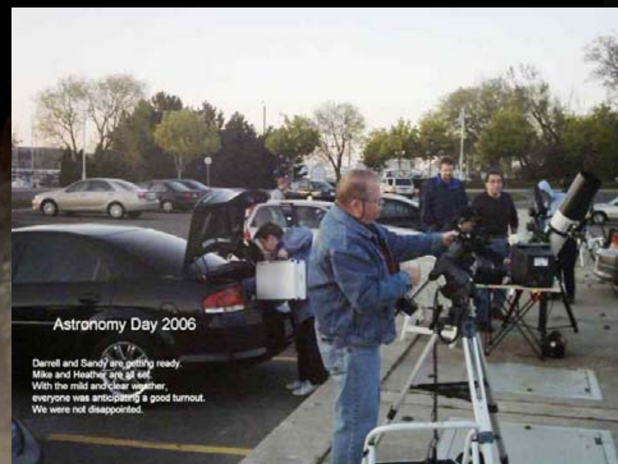
- **Student and Public Observation Campaign**
- **Student Telemetry Program**
- **Planetarium Program**
- **NASA Quest Challenges**
- **Museum Programs**
- **Cohort Programs**
- **Family Nights**
- **Impact Extravaganza**
- **Workshops**
- **Spacecraft Naming Contest**

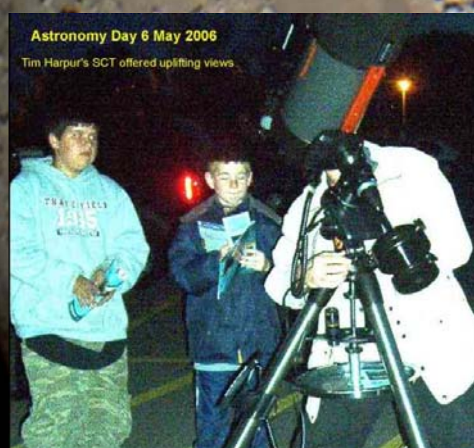
This is an exciting mission!

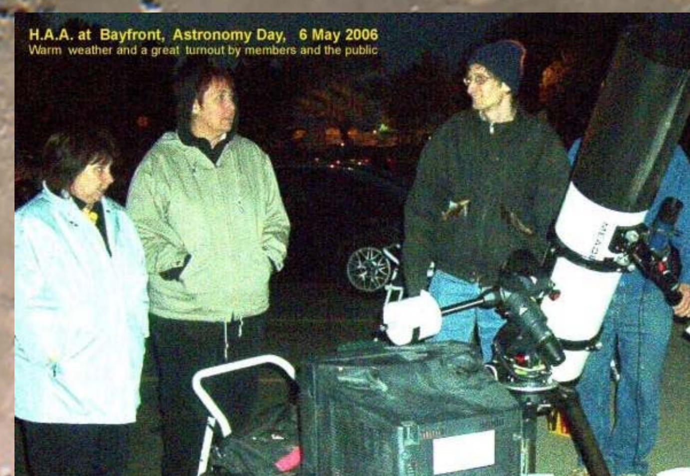


We believe reasonable grade amateur telescopes may be able to witness the impact plume.









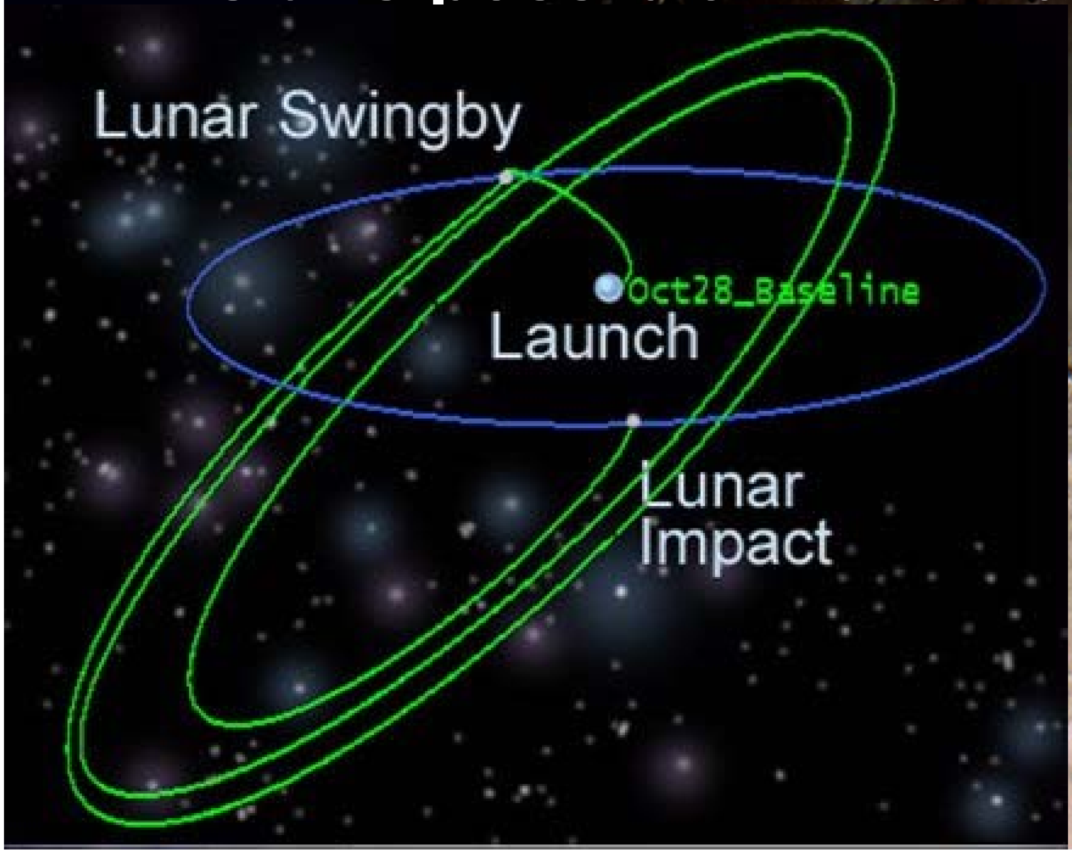
www.amateurastronomy.org

Public and Student Observation Campaign

- **Current estimates indicate that impact plume should be visible in 10 to 12-inch telescopes**
- **Modern amateur telescopes and CCD cameras are capable of recording details detectable only in professional equipment a few years ago**
- **Large numbers of such systems among amateurs and colleges**
- **Could contribute scientifically valuable data**
- **Critical not to oversell – we don’t know what we’ll see**

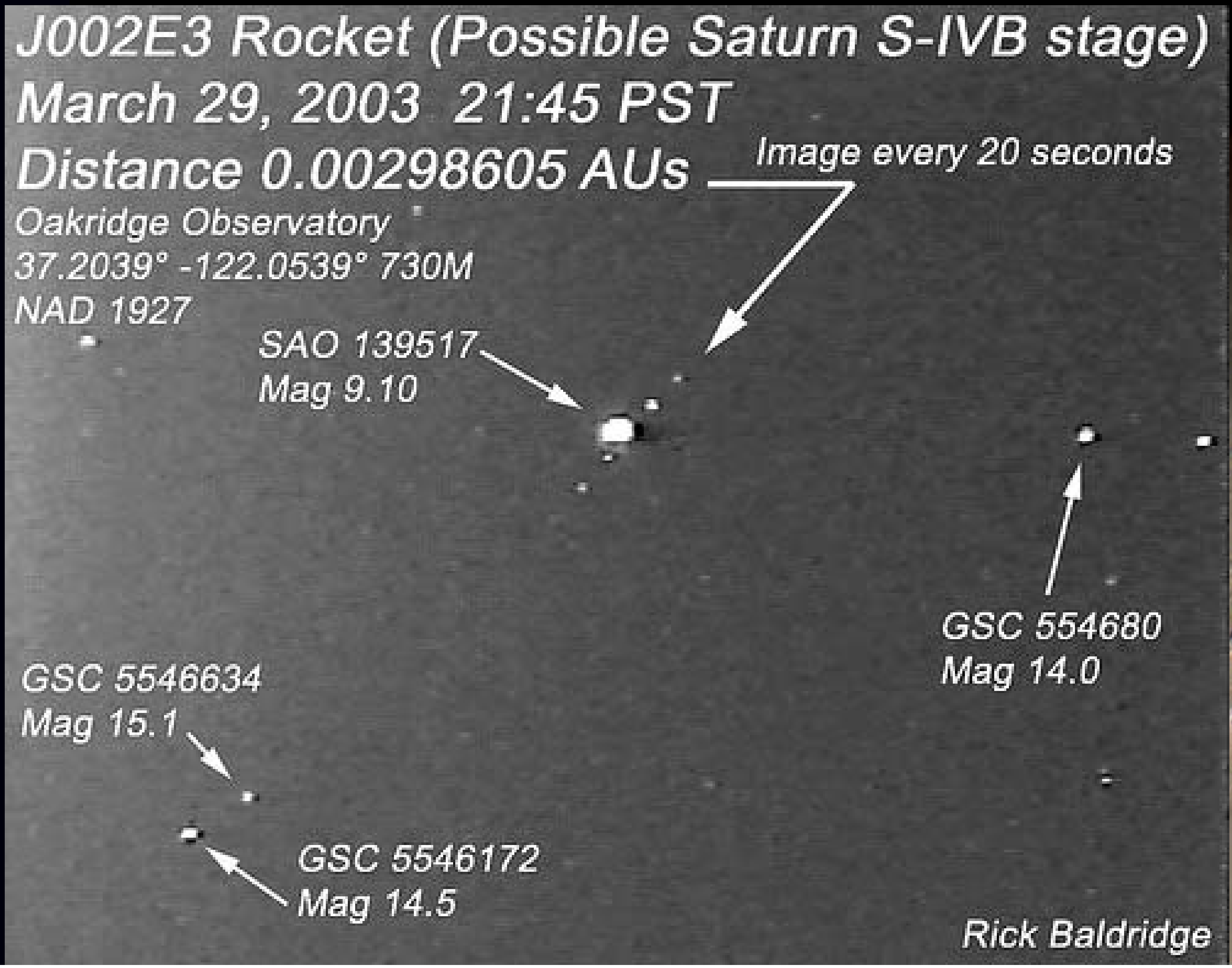
Public and Student Observation Campaign

- Also have public and students optically track spacecraft during LGALRO transit
- Is this possible with amateur equipment?



Public and Student Observation Campaign

Yes! The strange case of J002E3:

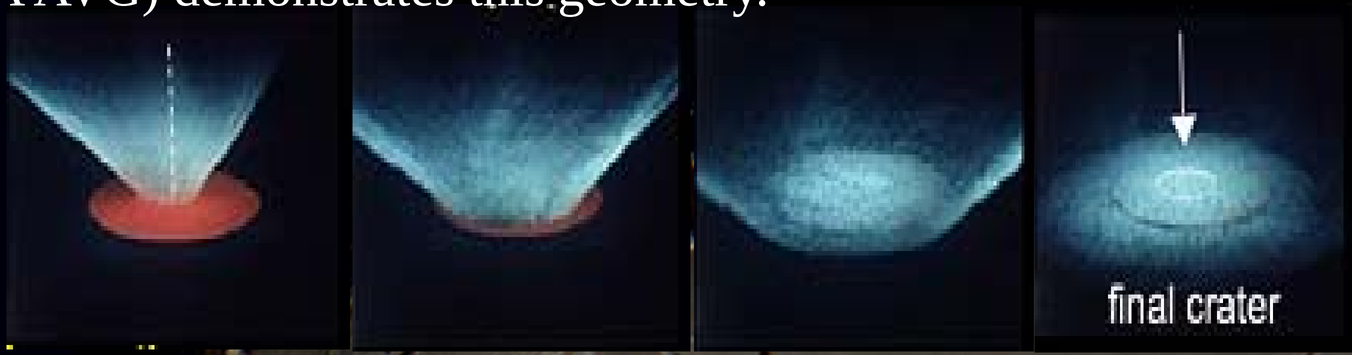


Public and Student Observation Campaign

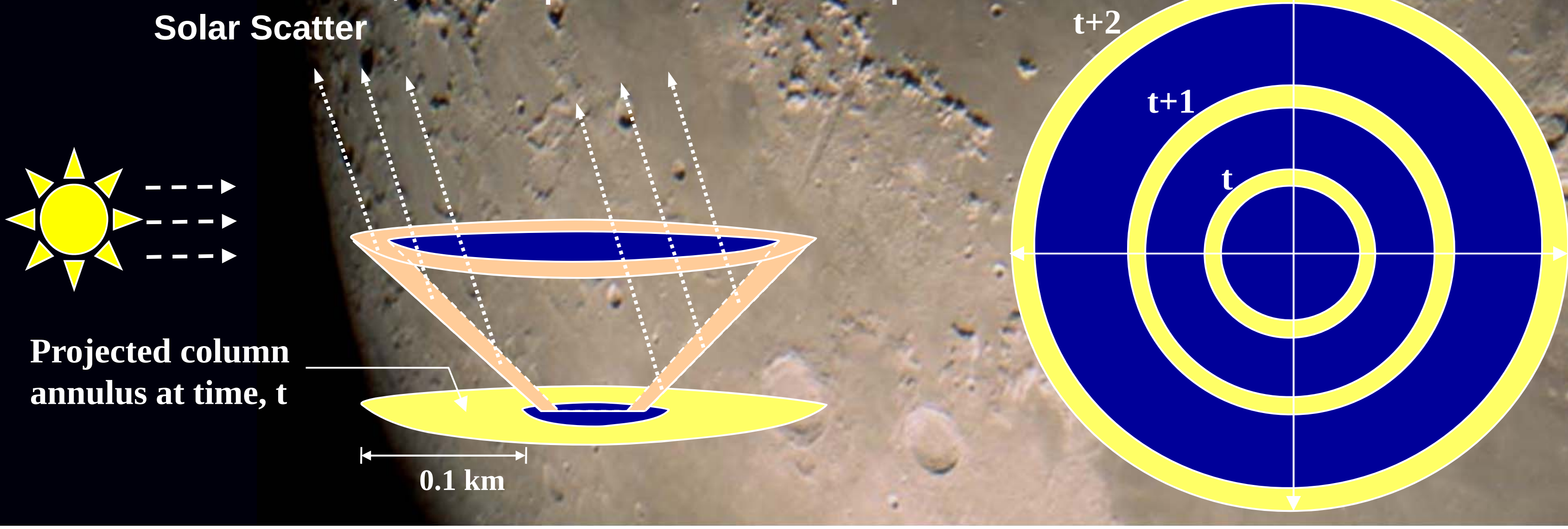
- **Effective participation will be aided through online community for collaborating public observers**
- **Facilitate exchange of ideas, techniques, equipment recommendations**
- **Established through partnership with NASA CoLab**

Ejecta Mass

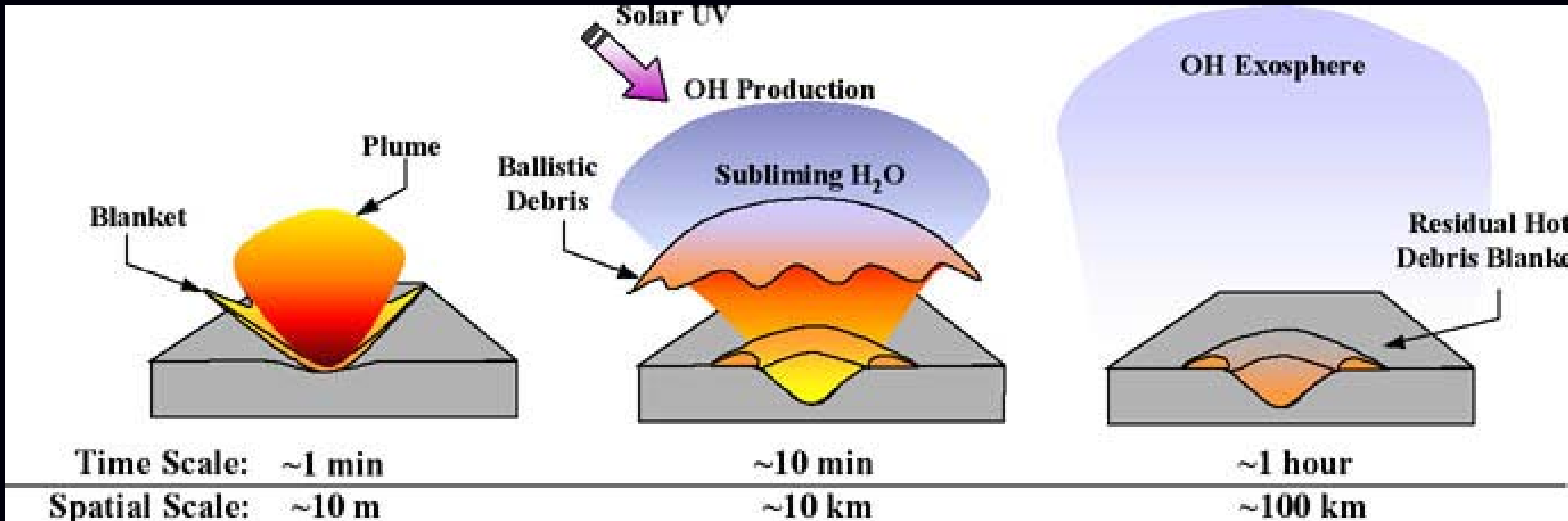
The ejecta cloud will more-or-less look like an expanding conical section (an upside-down lampshade). The figure below (images from a hypervelocity shot at the NASA AVG) demonstrates this geometry.



Ejecta cloud optical depth modeled with a truncated conical section, the “upside-down lampshade” model.



Impact Observation Strategy



- Bright Impact Flash
- Thermal OH Production
- Rapid Thermal Evolution

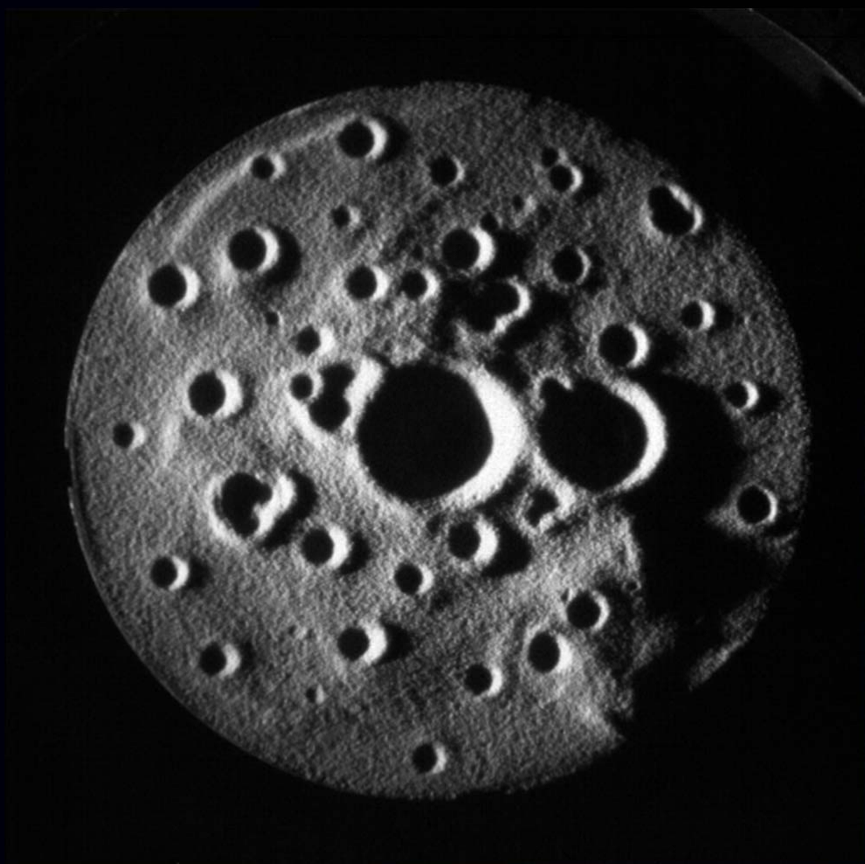
- Expansion of Plume
- Thermal Evolution
- H_2O ice sublimation
- Photo-production of OH

- Residual Thermal Blanket
- Expanding OH Exosphere

The combination of ground-based, orbital and in-situ platforms span the necessary temporal and spatial scales: from sec/meters to hours/km

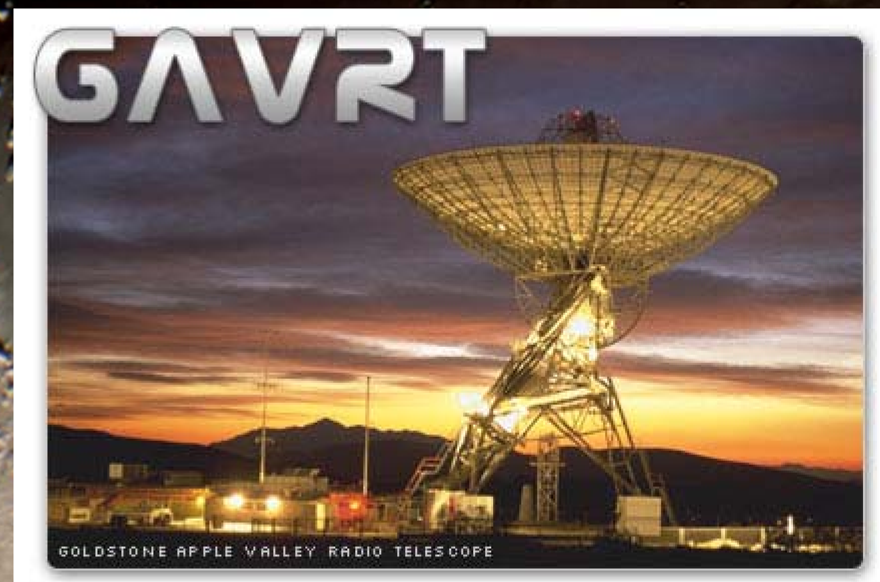
The LCROSS mission has multiple layers of observing

ARC Vertical Gun Experiments



Student Telemetry Program

- GAVRT – Goldstone Apple Valley Radio Telescope run by Lewis Center for Educational Research
- 34m DSS-12 dish
- Used by thousands of K-12 students around the world



Student Telemetry Program

- **Monitor spacecraft omni during LGALRO transit**
- **Conduct Doppler studies en route**
- **Monitor medium gain transmissions during terminal approach and determine time of LOS**
- **Outstanding partnership opportunity for other mission post LCROSS, including LRO!**

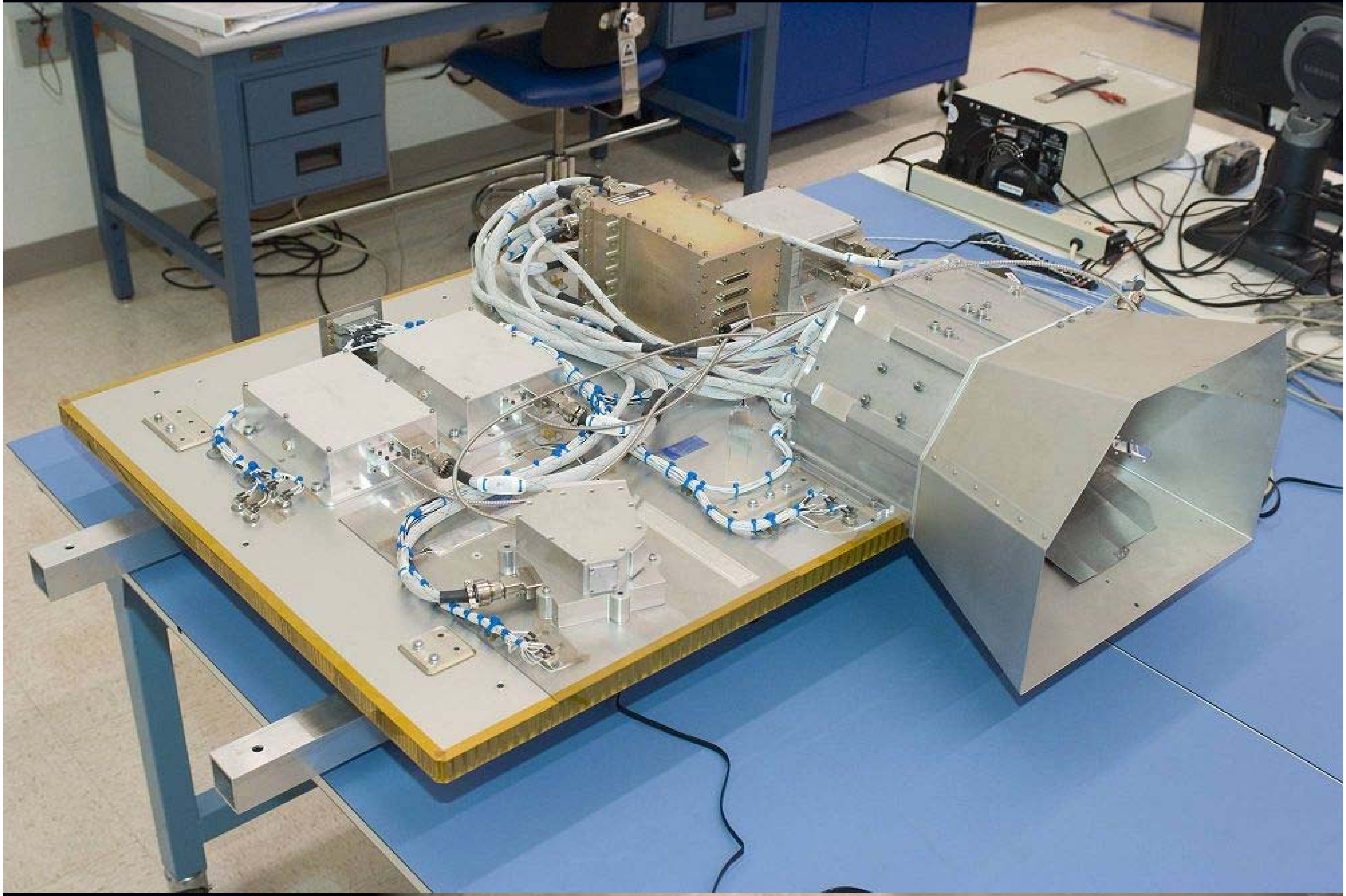
Mounting ESPA Ring to Propulsion Tank Support

Spacecraft Structure

Moving Structure on to Pallet

Wrapped Up For Move to Highbay for Integration

Payload Mounted on Spacecraft Radiator Panel



Payload Instrument Suite


Questions