Lunar Reconnaissance Orbiter (LRO) Navigation Overview

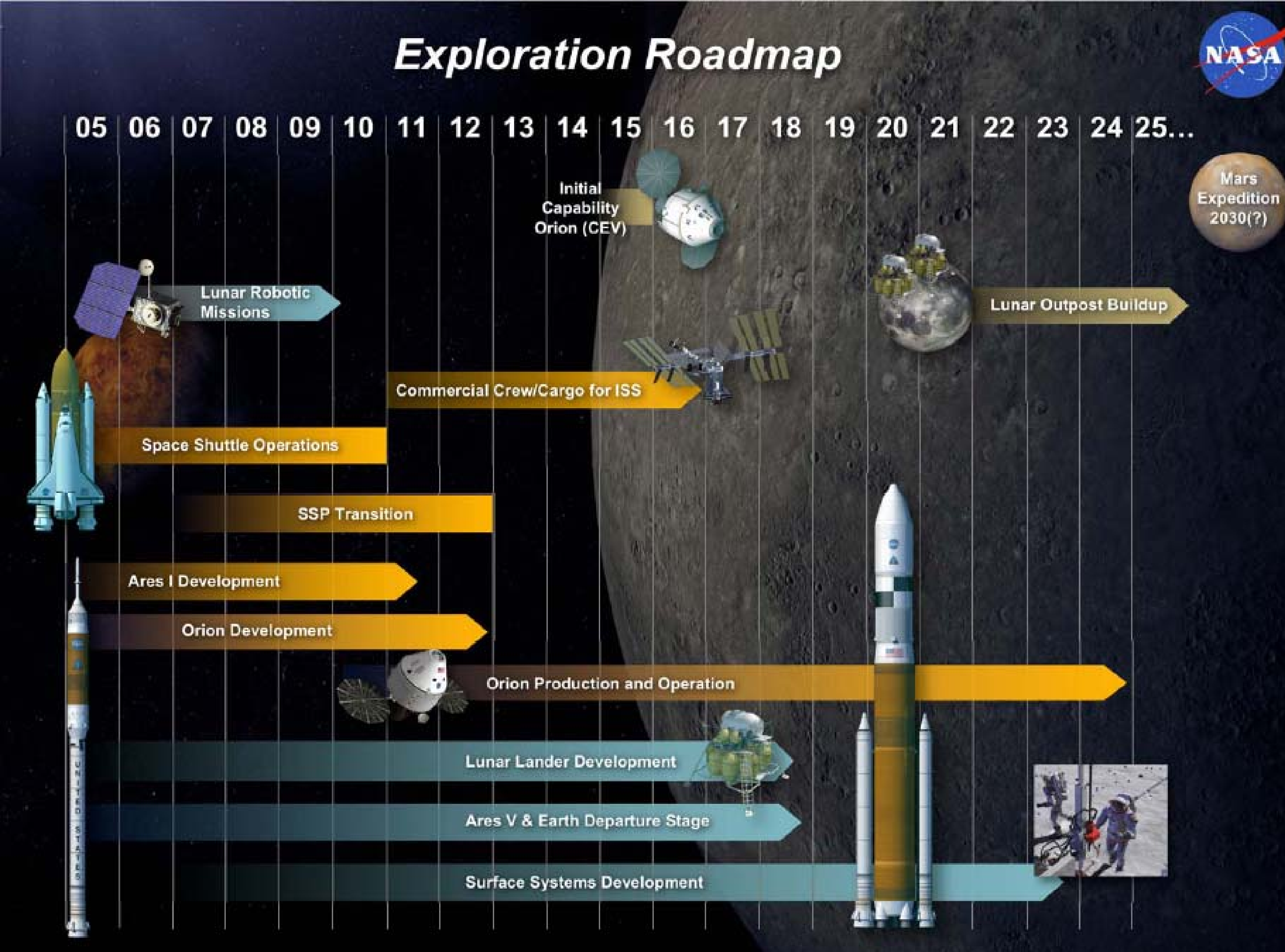
May 21, 2008

Rivers Lamb

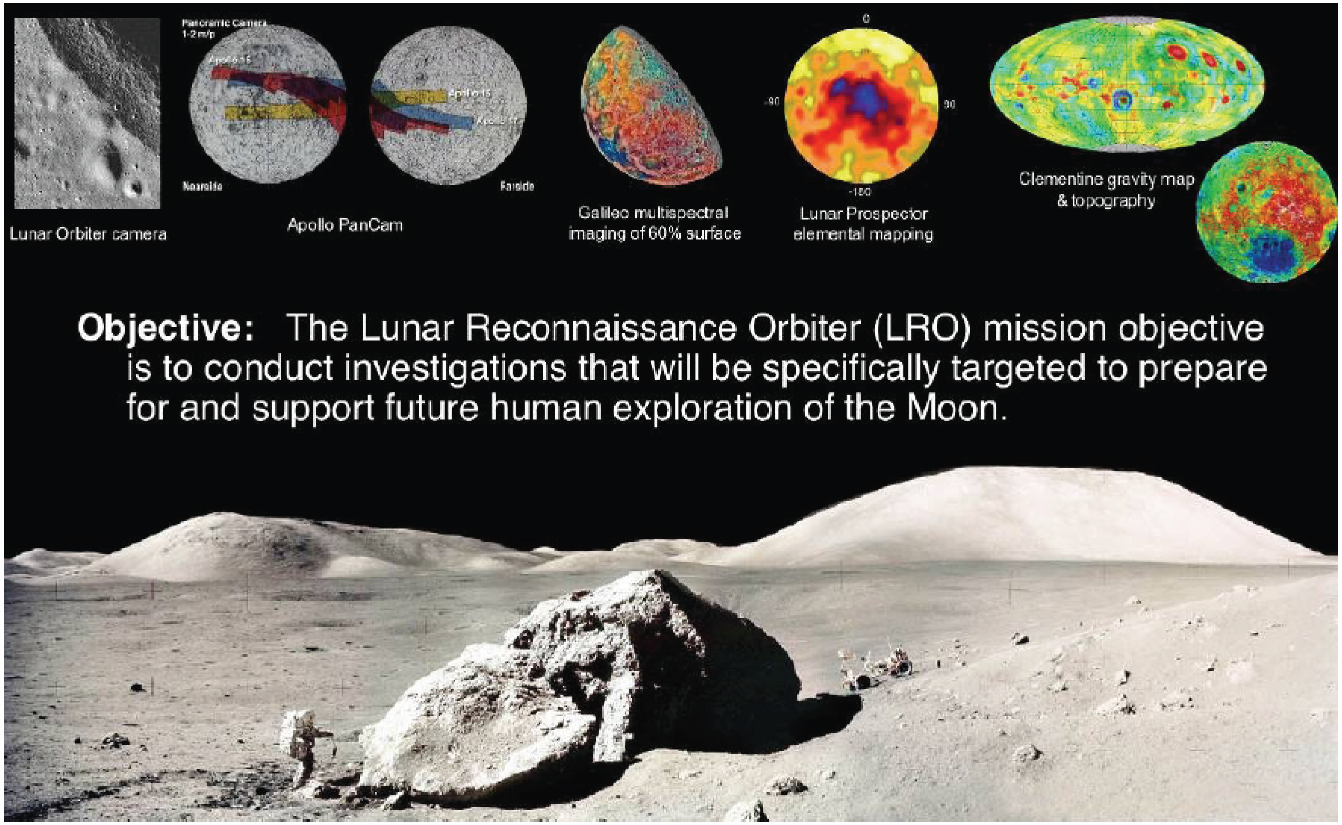
Who am I?

- Guy with the weird name
- Born and raised in North Carolina
- Grew up with Star Wars and Star Trek
- Really wanted to be a professional goalkeeper, but…
- Graduated from Virginia Tech in Aerospace Engineering in 2003
- Started as a co-op in Flight Dynamics Analysis Branch in 2001
- Primary experience in mission design and maneuver planning
  - Mission design for Solar Dynamics Observatory (SDO)
  - Re-entry planning for Tropical Rainfall Measurement Mission (TRMM)
  - Launch and early operations support for Aura
  - Mission design and maneuver planning for Space Technology 5 (ST5)
- Currently Flight Dynamics Ground System Lead for LRO
  - Responsible for the maneuver planning and navigation support
- Please ask questions!

Vision for Space Exploration


Exploration Roadmap
NASA
05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25…
Initial Capability Orion (CEV)
Mars Expedition 2030(?)
Lunar Robotic Missions
Lunar Outpost Buildup
Commercial Crew/Cargo for ISS
Space Shuttle Operations
SSP Transition
Ares I Development
Orion Development
Orion Production and Operation
Lunar Lander Development
Ares V & Earth Departure Stage
Surface Systems Development
UNITED STATES

LRO Objectives

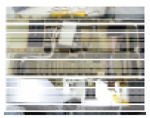
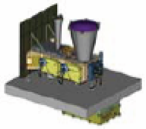
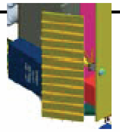


Safe Landing Sites
High resolution imagery
Global geodetic grid
Topography
Rock abundances

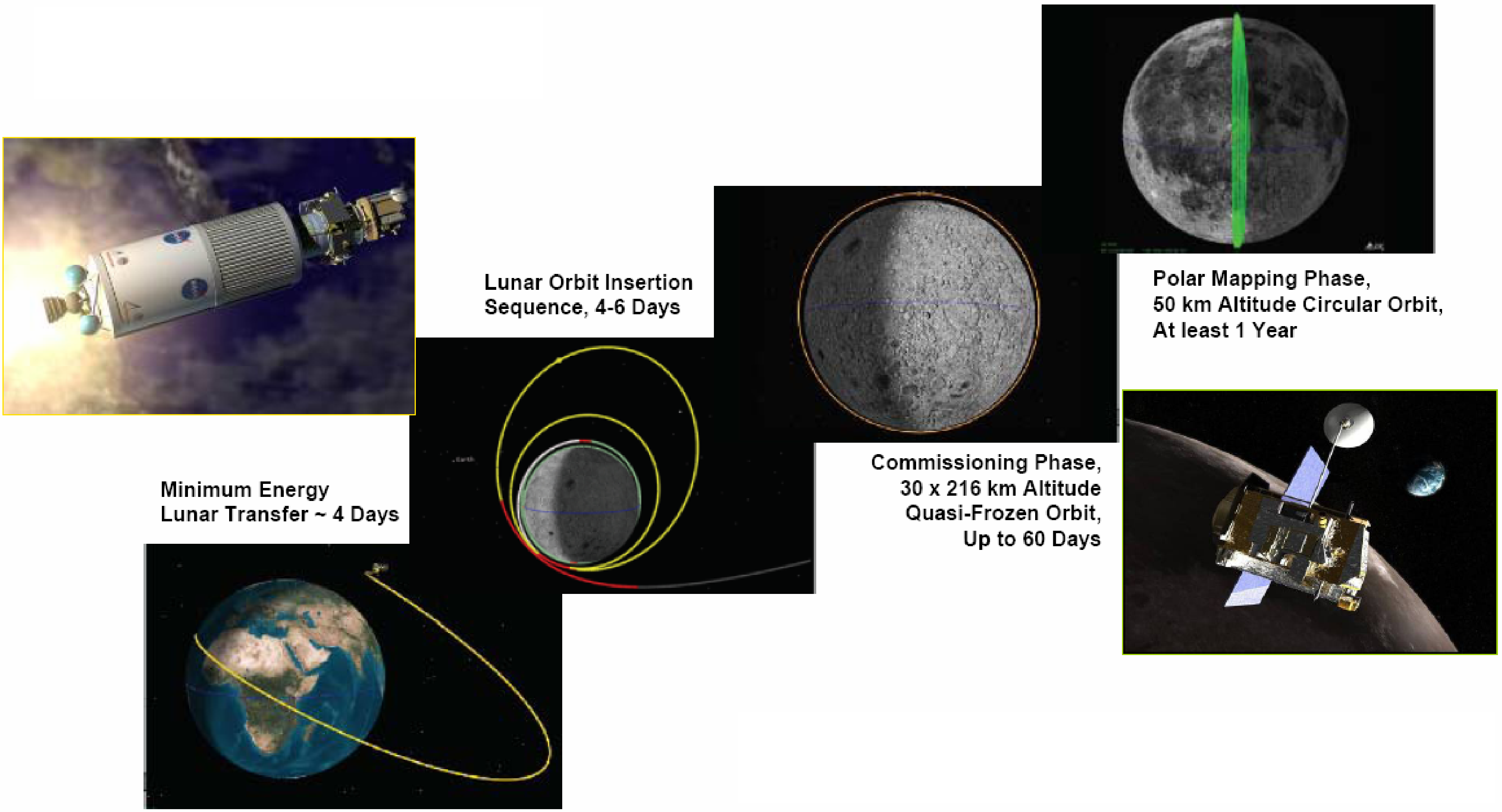
Locate Potential Resources
Hydrogen/water at the lunar poles
Continuous solar energy
Mineralogy

Space Environment
Energetic particles
Neutrons

Science Instruments

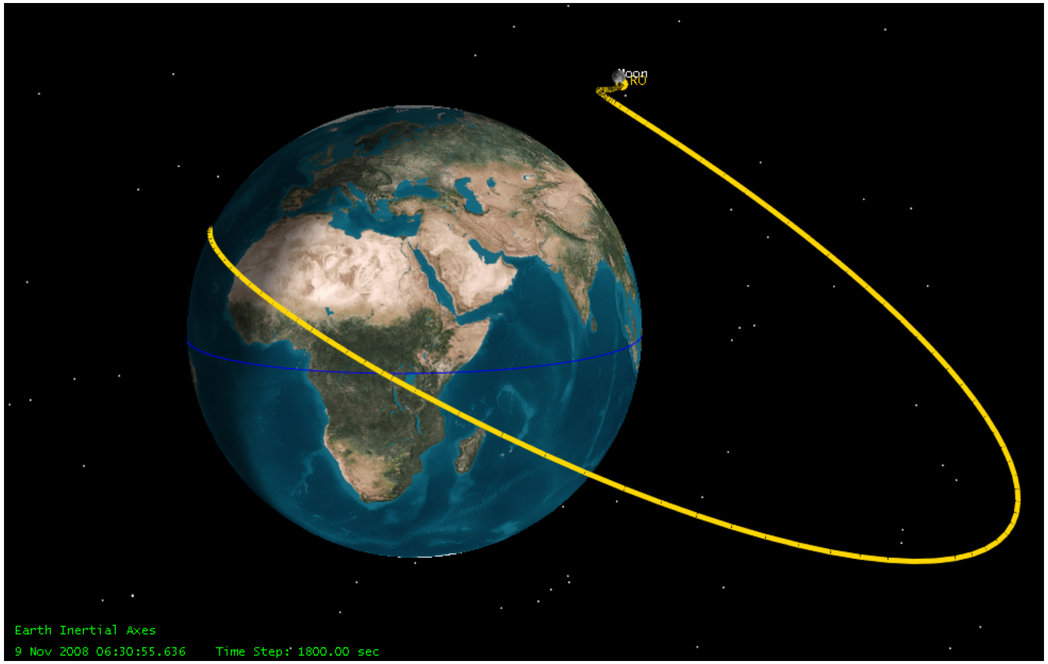
INSTRUMENT	SPONSORSHIP	MEASUREMENT	LVL 1 RQMTS TRACEABILITY
CRaTER Cosmic Ray Telescope for the Effects of Radiation 	PI:Harlan Spence, BU IM: Rick Foster, MIT ISE: Bob Goeke, MIT	*Tissue equivalent response to radiation* *LET energetic particle spectra 200 keV – 1 GeV /nuc*	*M10 - Radiation Environment* *M20 - Radiation on Human-equivalent tissue*
DLRE Diviner Lunar Radiometer Experiment 	PI: David Paige, UCLA IM: Wayne Hartford, JPL ISE: Marc Foote, JPL	*Better than 500m scale maps of temperature, rock abundances, mineralogy*	*M50 - Surface Temperatures* *M80 - Surface Features and Hazards* *M90 - Polar Illumination* *M100 - Regolith Resources*
LAMP Lyman-Alpha Mapping Project 	PI: Alan Stern, SwRI IM: Ron Black, SwRI ISE: Dave Slater, SwRI	*UV Albedo maps of the permanently shadowed areas* *Maps of frosts in permanently shadowed areas, 3km resolution*	*M60 – Images of PSRs* *M70 – Subsurface Ice*
LEND Lunar Exploration Neutron Detector 	PI: Igor Mitrofanov, IKI Deputy PI: Roald Sagdeev, UMD IM: Anton Sanin, IKI ISE: Maxim Litvak, IKI	*Maps of hydrogen in upper 2m of Moon at 10km scales* *Global distribution of neutrons around the Moon*	*M10 – Radiation Environment* *M70 – Subsurface Ice* *M110 – Hydrogen Mapping*
LOLA Lunar Orbiter Laser Altimeter 	PI: David Smith, GSFC Co-PI: Maria Zuber, MIT IM: Glenn Jackson,GSFC ISE: John Cavanaugh, GSFC	*~50m scale polar topography at <10cm vertical, and roughness and slope data*	*M30 - Topography Grid* *M40 - Topography Resolution* *M60 – Images of PSRs* *M80 - Surface Features and Hazards* *M90 – Polar Illumination*
LROC Lunar Reconnaissance Orbiter Camera 	PI: Mark Robinson, ASU IM: Scott Brylow, MSSS ISE: Mike Caplinger, MSSS	*$1000s^2$ of 50cm/pixel images (125km), and entire Moon at 100m visible, 400m UV*	*M40 – Topography Resolution* *M80 – Surface Features and Hazards* *M90 – Polar Illumination* *M100 – Regolith Sources*
Mini-RF *Technology Demonstration* 	POC: Keith Raney, JHU/APL PM: Bill Marinelli, NAWC DPM: Dean Huebert, NAWC	*X&S-band Radar imaging and radiometry*	*P160 - Demonstrate new lightweight SAR Technologies*

LRO Mission Timeline



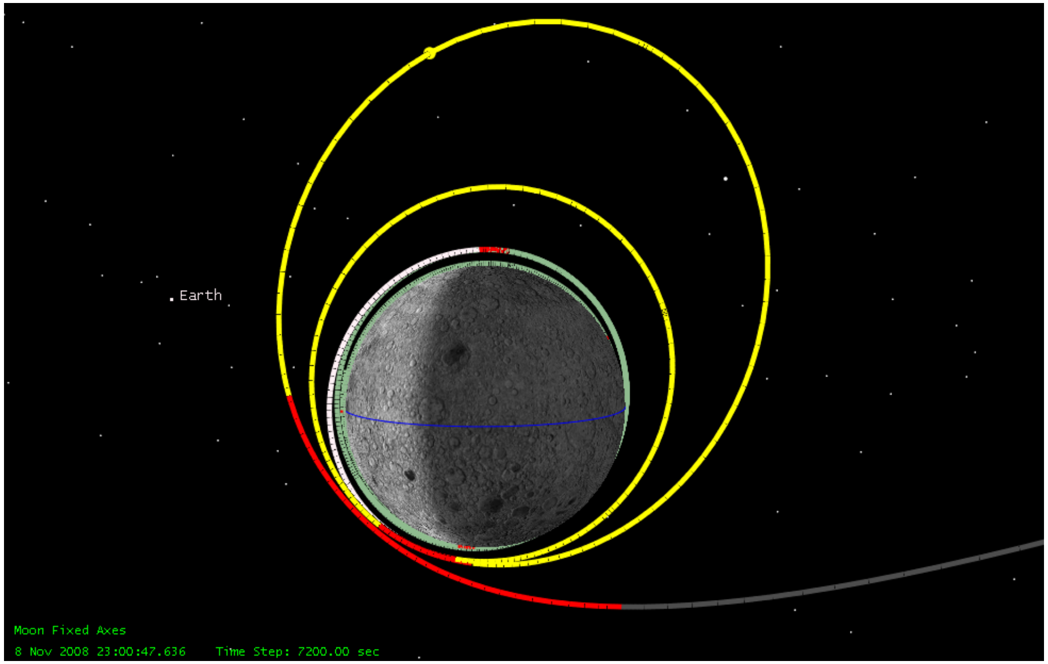
Trajectory Overview – Launch and Cruise

- LRO is scheduled to launch in late 2008 on Atlas V with LCROSS
- Direct transfer to moon is 4-5 days
- Two planned maneuvers correct for launch dispersions
  - MCC-E at Separation + 22 hours
  - MCC-1 at Separation + 24 hours



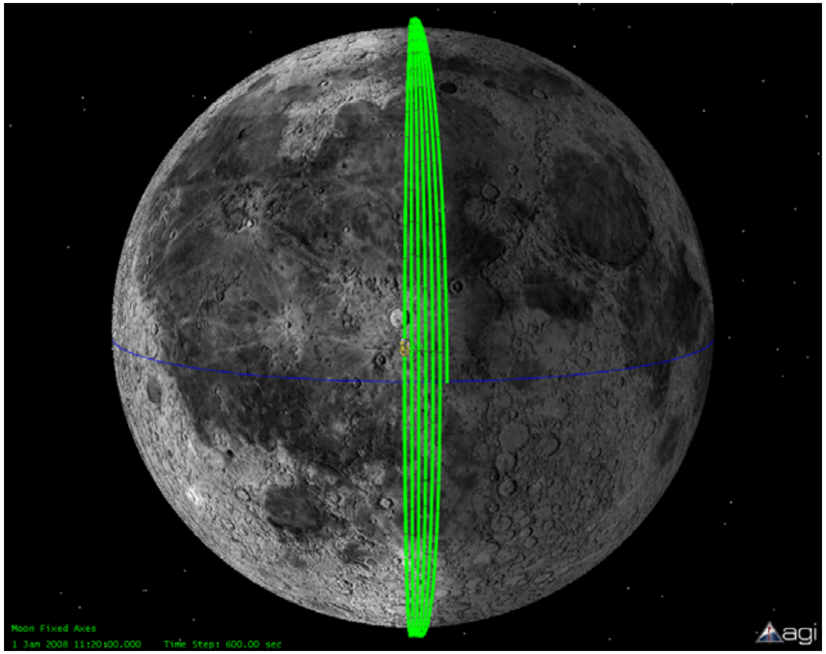
Trajectory Overview – Lunar Orbit Insertion

- Lunar Orbit Insertion (LOI) maneuver sequence (over 4-5 days)
  - LOI-1 captures into polar lunar orbit with 5 hour period
  - Total of 5 LOI maneuvers achieves Commissioning Orbit (26 x 216 km)
- Commissioning Orbit (up to sixty days)
  - No orbit maintenance maneuvers needed



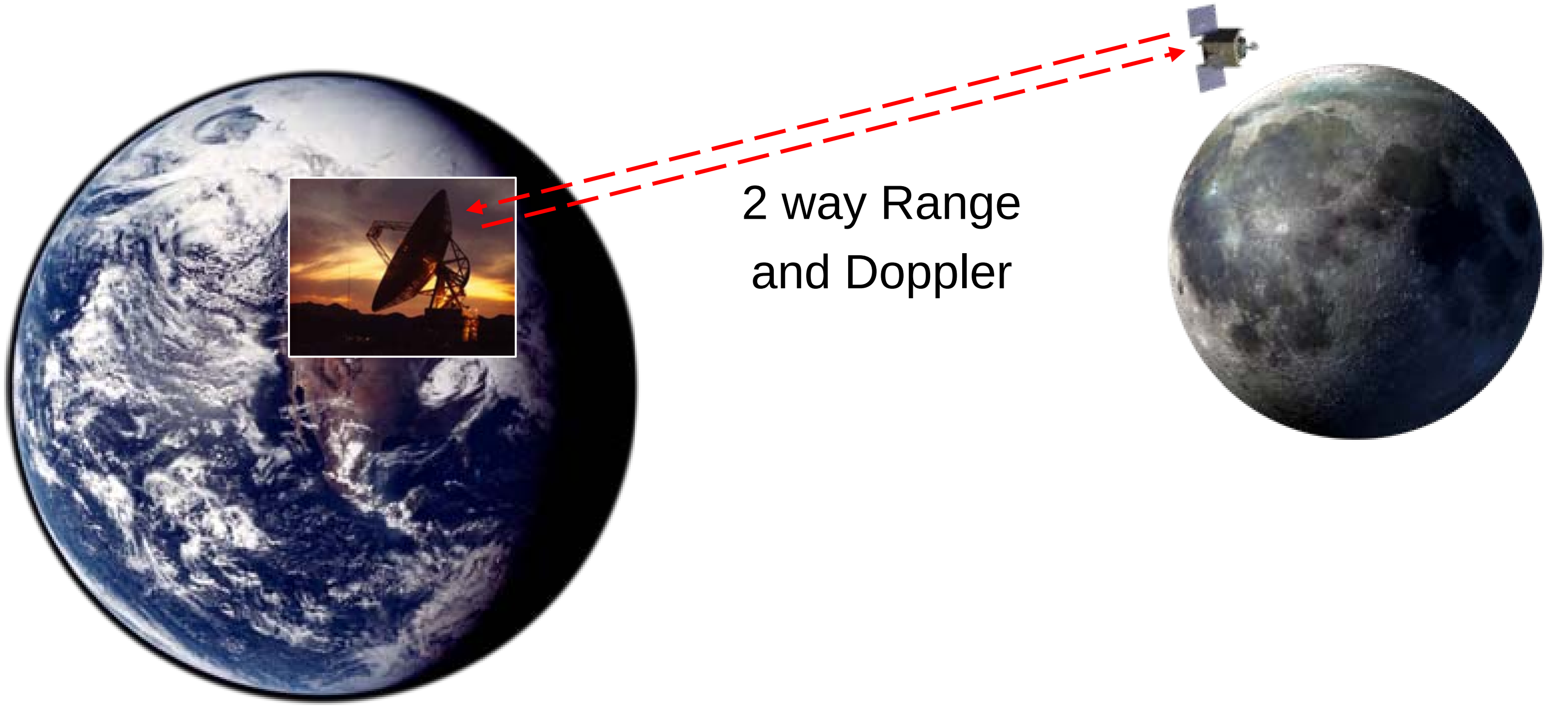
Trajectory Overview – Mission Orbit Insertion

- Mission Orbit Insertion (MOI) maneuver sequence
  - Total of 3 maneuvers achieves Mission Orbit (50 km ±20 km altitude)
- Mission Orbit (one year)
  - One pair of stationkeeping (SK) maneuvers every 27 days km
  - Momentum management maneuvers executed once every two weeks

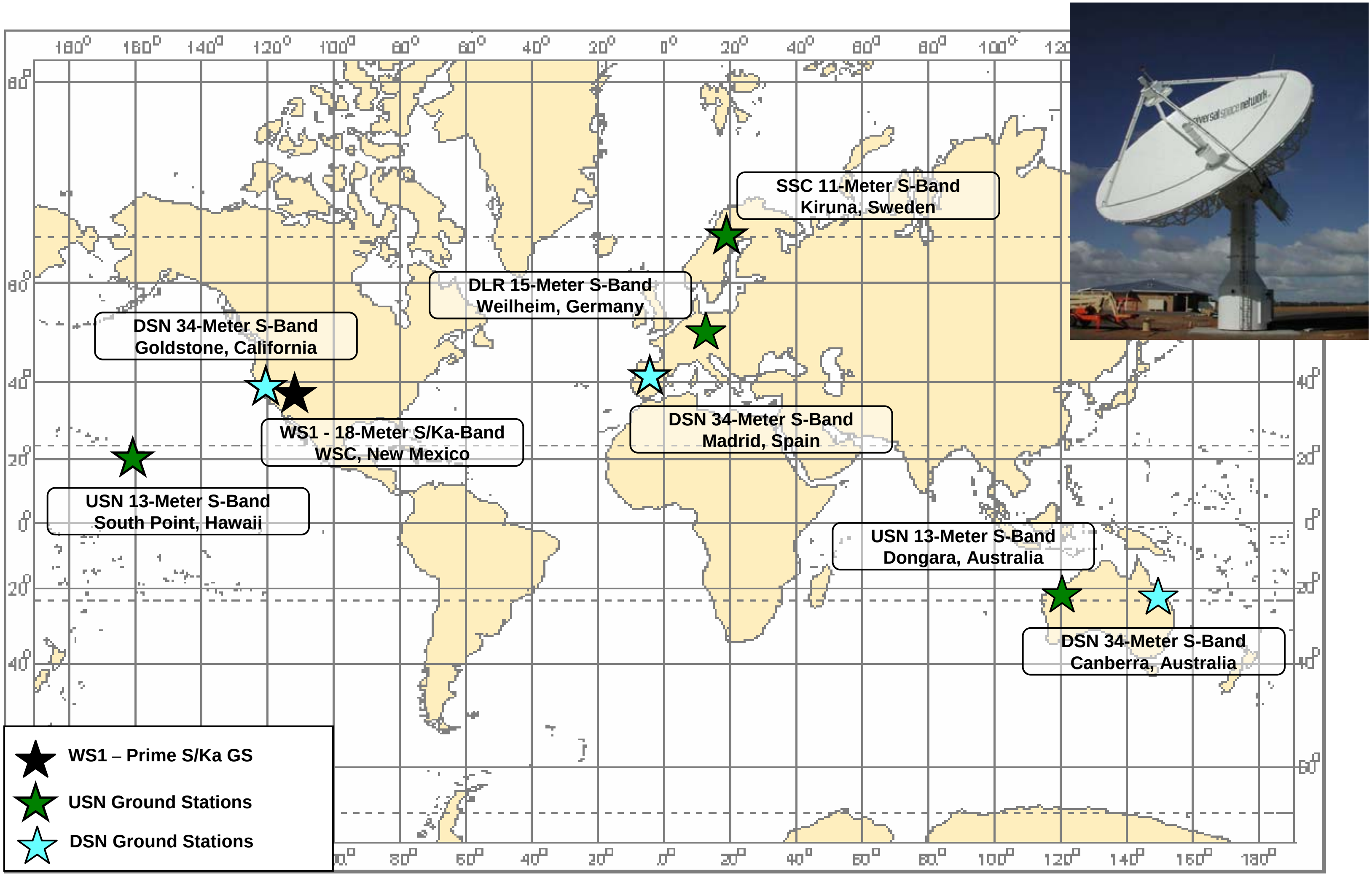


Communications Overview

- Tracking, Telemetry, and Command functions are provided through ground-based S-band communication
- Range requirement of 10 m; Doppler requirement of 1 or 3 mm/s



Ground Stations



Flight Dynamics Facility

- Range and Doppler measurements are sent to the Flight Dynamics Facility (FDF)

- FDF is an institutional GSFC facility
- Secured operational control center
- Supports ELVs, ISS, STS, other spacecraft
- Primary navigation and mission design for past two US lunar missions: Clementine and Lunar Prospector

- Primary support for LRO:
  - Tracking Data Evaluation
  - Orbit Determination
  - Mission Product Generation
  - Mission Design
  - Maneuver Planning

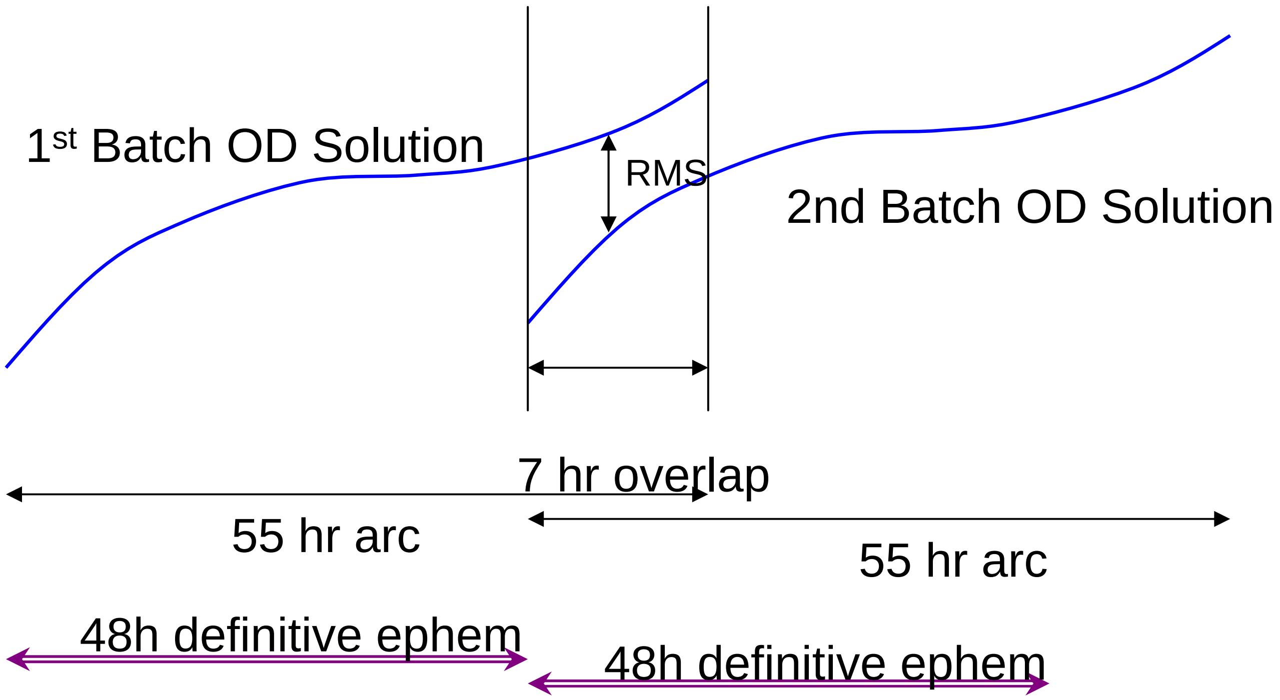
- The Goddard Trajectory Determination System (GTDS) is used for LRO orbit determination

Daily Navigation Support for LRO

- Requirements on S-band Tracking Data Provided to FDF
  - SCN required to provide 30 minutes of tracking data every lunar orbit
  - Coherent Doppler and range measurements
    - Range accuracy 10 meters (1 sigma)
    - WS1 and DSN Doppler accuracy 1 mm/s (1 sigma)
    - Other S-band stations Doppler accuracy 3 mm/s (1 sigma)
- Orbit Determination Requirements
  - Daily OD using S-band tracking data
    - Predictive ephemeris requirement in lunar orbit is 800 m after 84 hours
    - Definitive ephemeris is 500 m RSS and 18 m radial
  - Post-maneuver OD using S-band tracking data
    - No predictive or definitive accuracy requirements
    - Primary goal is to update station acquisition data and MOC products

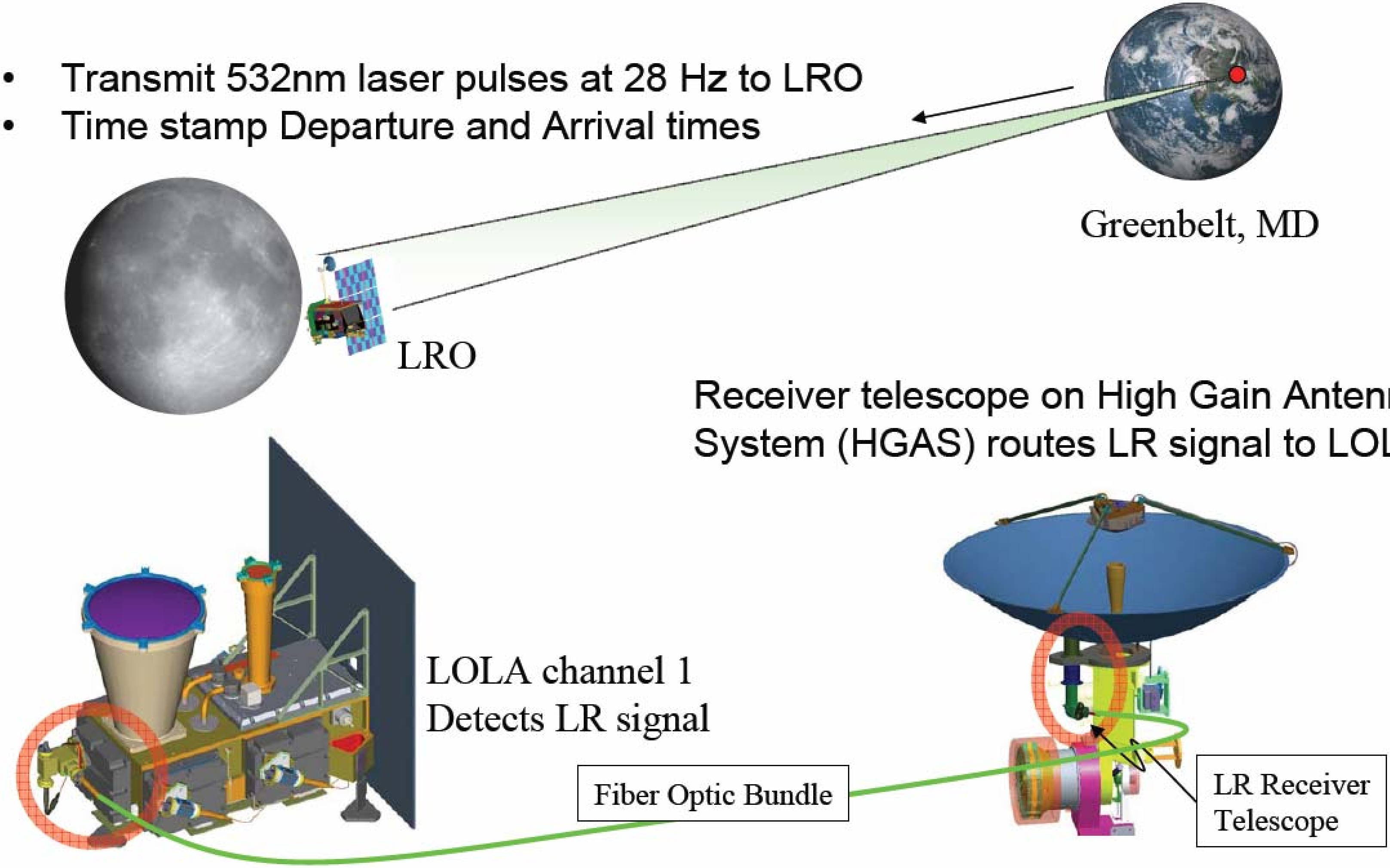
Lunar Prospector Results

- Reprocessed LP data shows overlap compares to 60 m RSS (1-sigma) and 6 m radial (1-sigma) – meets requirement!



One-Way Laser Ranging

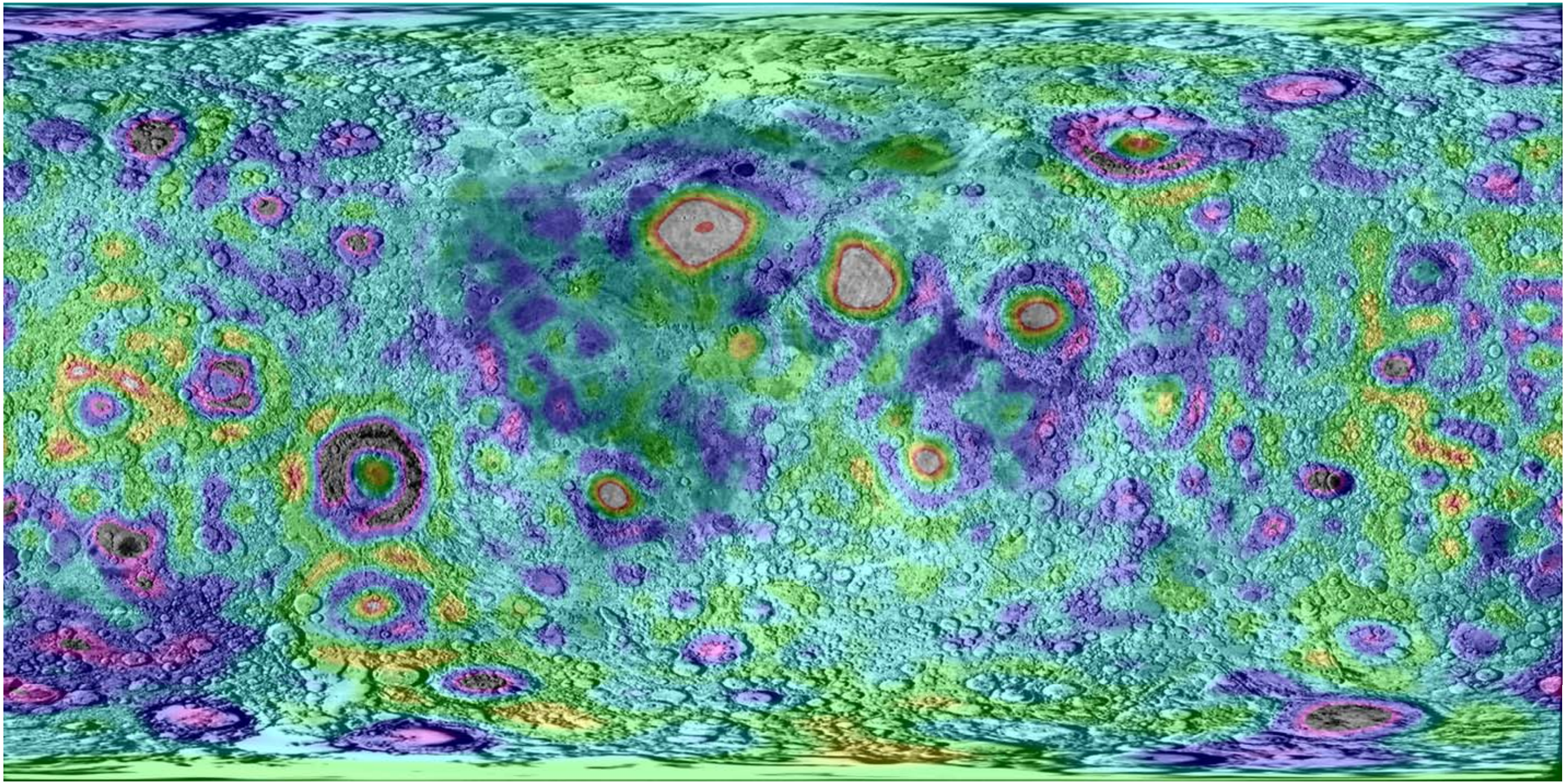
- Transmit 532nm laser pulses at 28 Hz to LRO
- Time stamp Departure and Arrival times



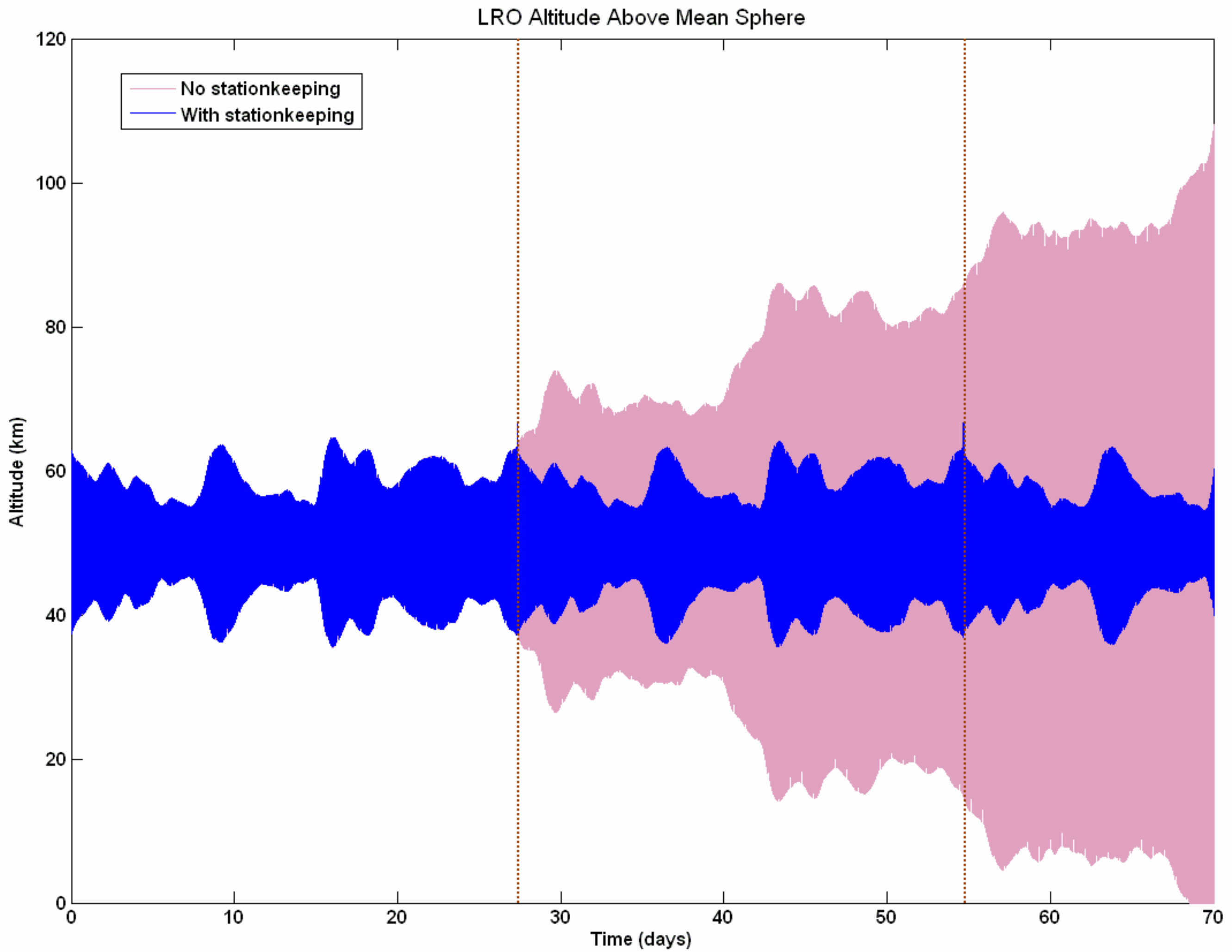
OD Reprocessing Using Laser Data

- Goal: Orbit accuracy of 50 m RSS and 1 m radial
- Reprocessing of definitive OD using S-band and laser tracking data
  - Performed twice during mission: at L+3 months, end of nominal mission
  - Uses updated lunar gravity model provided by LR team
- Key force model upgrades to improve accuracy
  - Gravity modeling (biggest error source)
  - Solar and lunar radiation modeling
  - Lunar solid tide accelerations due to the Earth and Sun on the Moon

Accelerations due to Lunar Gravity



Lunar Gravity Impact on Mission Orbit



Conclusion

- LRO will provide the most accurate map of the Moon yet!