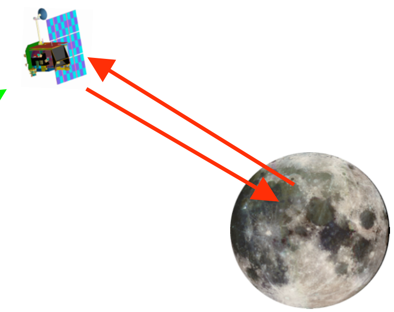
Laser Ranging to the Lunar Reconnaissance Orbiter (LRO)



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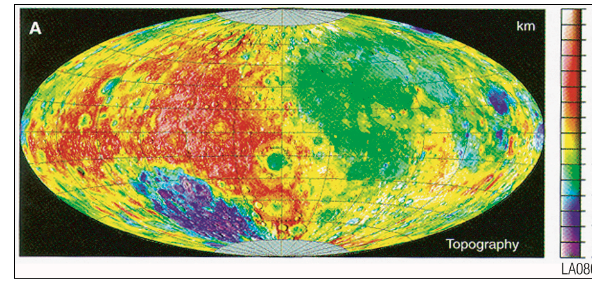
3 - SGT Inc/GSFC
4 - SAO

Geodetic Measurement Objectives of the Robotic Lunar Exploration Program

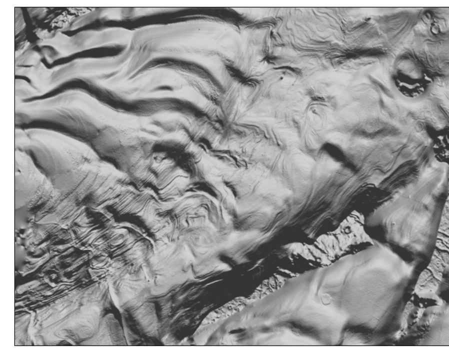
1. Determine the topography of the Moon to geodetic quality from global to landing-site relevant scales.



Topography of the Moon from Clementine
(2 deg resolution, 100 m radial acc.)

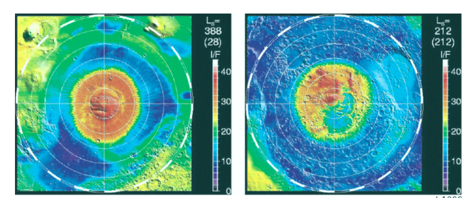
2. Image the lunar surface in permanently shadowed regions on landform scales.

3. Characterize the illumination of the polar region environment at relevant temporal scales.



South polar icecap of Mars: MOLA

4. Identify the locations of appreciable surface water ice in the permanently shadowed regions of the Moon's polar cold traps.



Polar icecaps, Mars: CO_2, H_20

5. Assess meter and smaller-scale features to facilitate safety analysis of potential future lunar landing sites.

The LRO Mission

- 7 instruments

  LOLA, laser altimeter
  LROC, camera
  LAMP, Lyman alpha telescope
  LEND, neutron detector
  DIVINER, thermal radiometer
  CRATER, cosmic ray detector
  mini-RF, radar tech demo

- Launch Oct 2008
- Polar orbit
- Average altitude, 50 km with orbital maintenance every 30 days (30-70 km altitude range)
- 1 year nominal mapping mission

LOLA Instrument Measurement Objectives

1. Topography of the Moon to an accuracy ± 1 meter and 0.1 meter precision.
2. Surface slopes in 2 directions to better than 0.5 degrees on a 50 meter scale.
3. Surface roughness to 0.3 meters.
4. Surface reflectance of the Moon at 1064 nm to ~ 5%.
5. Establish a global lunar geodetic coordinate system.
6. Improve knowledge of the lunar gravity field

Along-track sampling in latitude 25 meters

Across-track sampling in longitude 0.04 degrees (~25 meters above latitude 85 and ~1.2 km at the equator), after 1 year of operation.

LRO Spacecraft Positioning

- LOLA (and other LRO instruments) require accurate orbits of LRO

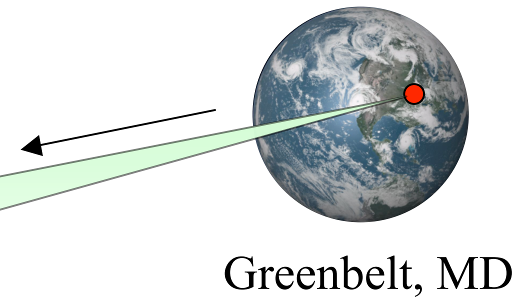
  - high quality tracking
  - improvement in the lunar gravity field

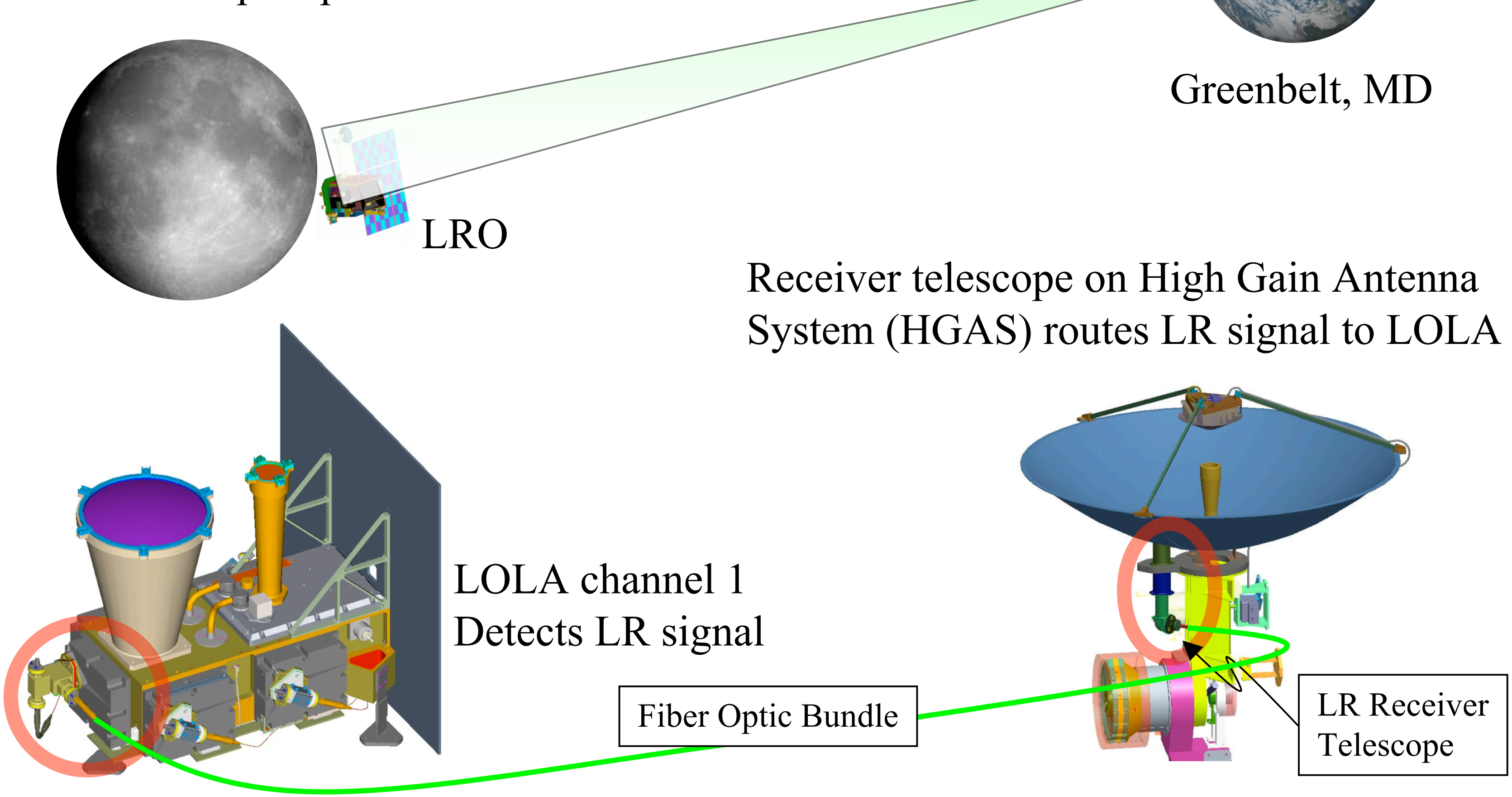
- Baseline tracking of LRO is S-band Doppler at 1 mm/s at 5 second rate from White Sands (NM), and 8 mm/s from other S-band systems enabling 24 hours/day, 7 days/week coverage (when LRO is visible).

- Simulations of the LRO mission show only S-band tracking will not provide enough information to precisely determine the lunar gravity field.

LR Operations Overview

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





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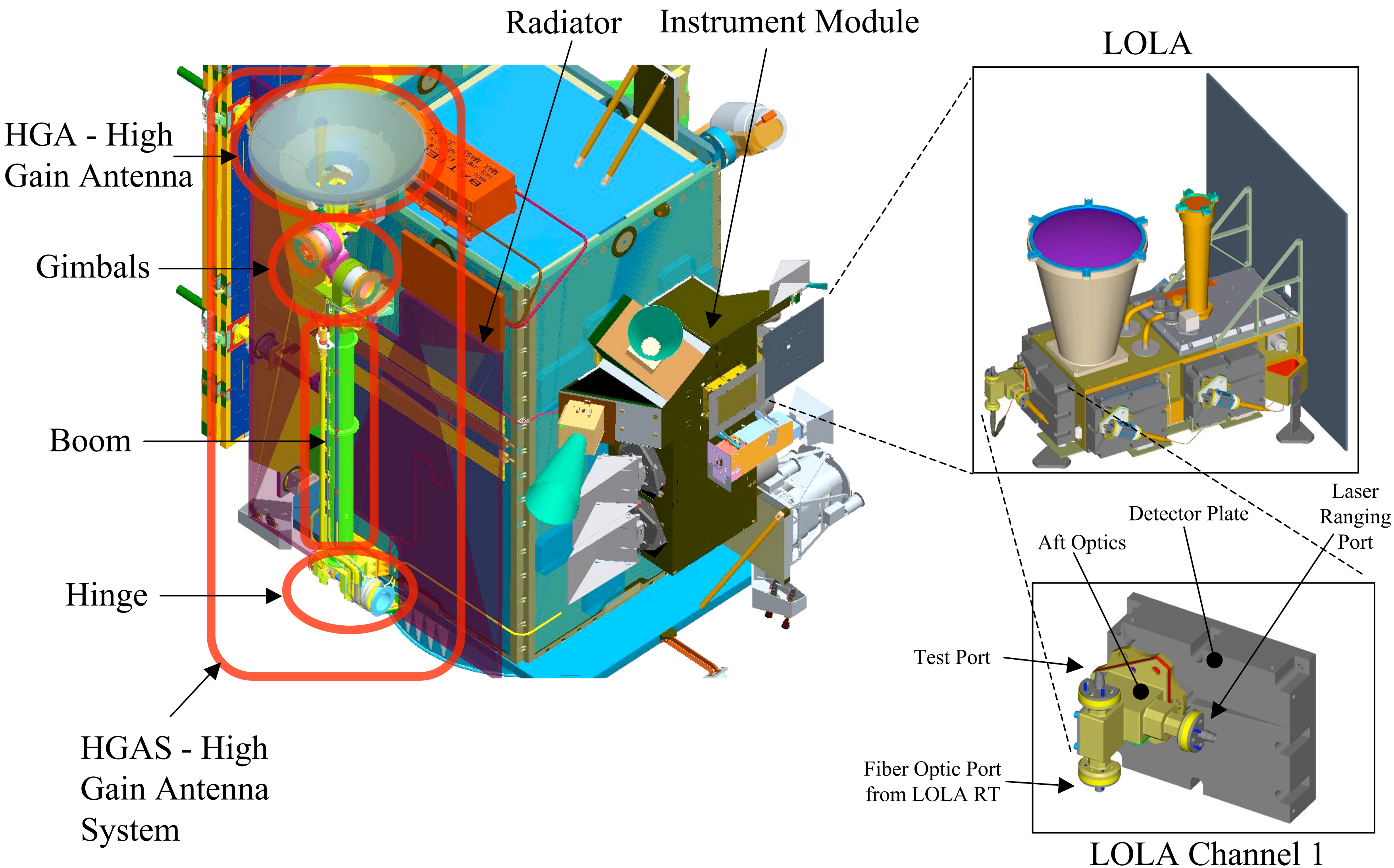
LR Flight System Components



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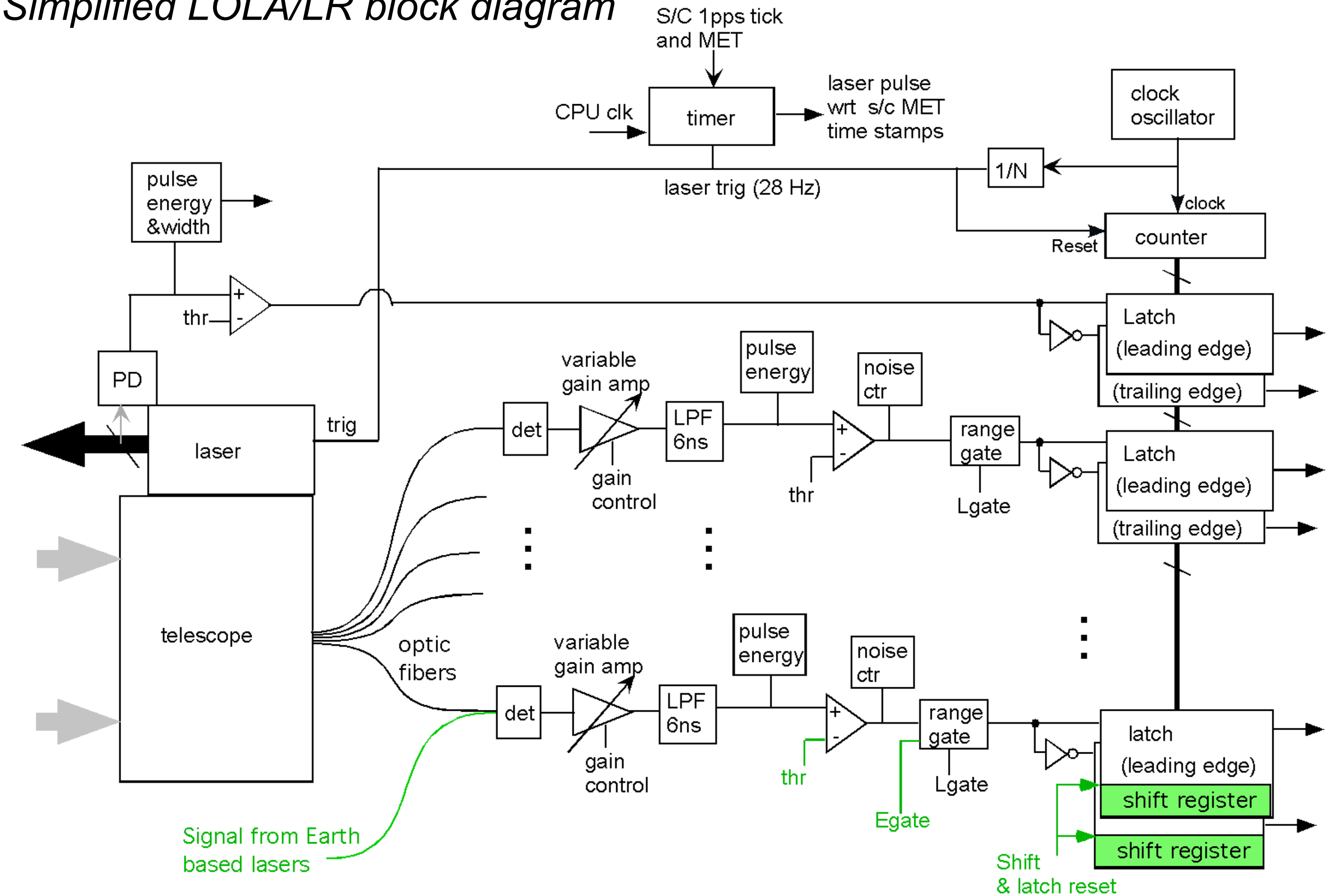
Resulting Products Overview

1. Relative range measurements to LRO spacecraft at <10cm precision at 1 Hz

2. Gravity model with sufficient accuracy to calculate knowledge of spacecraft position to within 50 m along track, 50 m cross track, and 1 m radial
   - Requires LR Ranges, S-band tracking data and LOLA Science data

LR Signal Detection with LOLA

Simplified LOLA/LR block diagram



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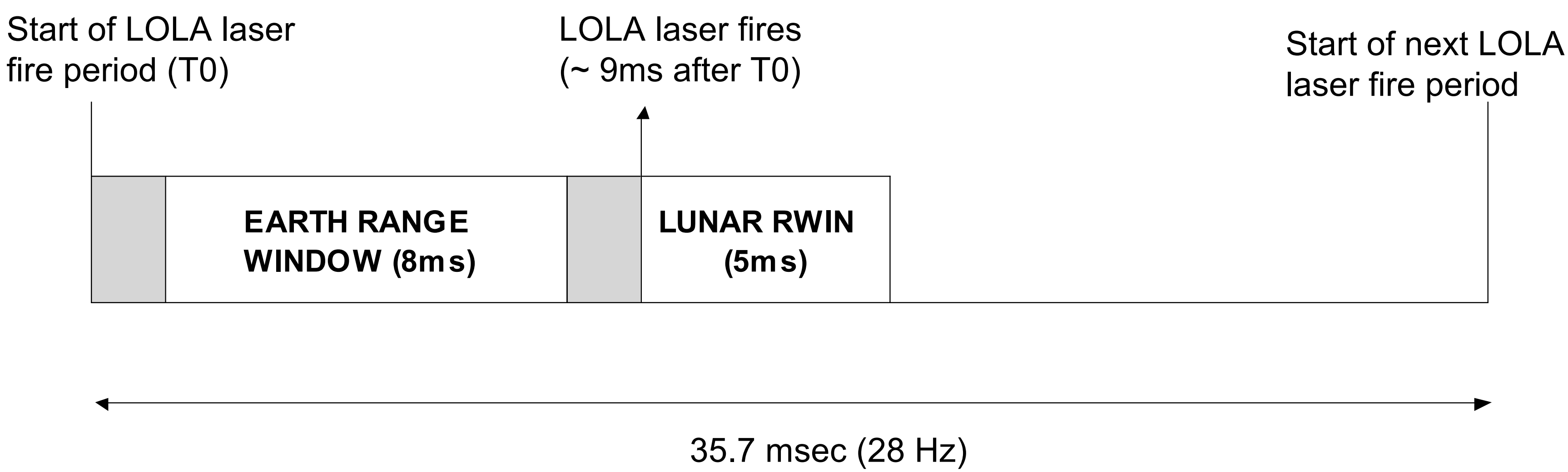
One LOLA Detector does both earth and lunar

- Two range windows in one detector: fixed 8 msec earth and up to 5 msec lunar.
- Range to LRO changes ~ 5-10 ms over an hour's visibility.
- Need to synchronize the ground laser fires to LOLA to ensure SLR2000 pulses land in every Earth Window, or fire asynchronously to LOLA (eg 10Hz).



Ground System Requirements

• Deliver between 1 and 10 femtoJoules per sq.cm of signal to the receiver aperture. For SLR2000 (55 microrad laser divergence) ➔ 30mJ per pulse.

• Wavelength must be 532.x . Wavelength will be determined in spring 2007. Filter assembly will be sent to all interested stations (2007) to determine if station laser meets wavelength requirements. Filter width is 0.3 nm (FWHM).

• Laser pulsewidth =< 8ns (onboard system bandwidth is ~6ns).

• Maintain the transmitted pulse time stamp accuracy to within 100 ns of UTC.

• Measure the relative laser time of fire to better than 200 ps (1 sigma) shot-to-shot over a 10 sec period. Laser fire time must be recorded to <100 psec resolution.

• Deliver laser pulses into the LOLA earth window at least once per second.
Laser fire rate cannot exceed 28 Hz!

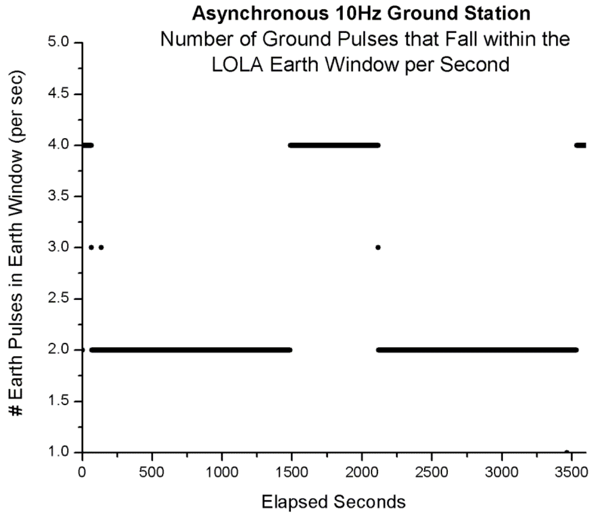
• Shot to shot measurement of the output laser energy is desired.

• Data should be delivered to CDDIS in new (but simple) format daily (or faster).

Getting Pulses into the LOLA Earth Window

- **Method #1 (SLR2000): synchronize to LOLA**
  - -Must compensate for range changes (5-10 msec per hour).
  - -Knowledge of UTC to spacecraft MET will be good to < 3 msec.
  - -Start of LOLA fire interval (35.7 ms) is sychronized to MET.
  - -LOLA earth window opens 0.5 msec after start of fire interval.
  - -LOLA earth window is open for 8 msec.

- **Method #2: run asynchronous to LOLA but at a fire rate that ensures at least one pulse per second into the earth window.**
  - -Ground system fire rate of 10Hz ensures 2-4 pulses per second get into the earth window.
  - -No control of laser is needed.



Operational Considerations

• LRO orbit is nominally 50 km, polar, with 2 hour period. Orbital velocity is 1.6 km/sec. LRO is on near side of moon ~ 1 hour out of every two.

• Scheduling will be coordinated by HTSI (Horvath). Participating stations will get schedule of possible passes for next month and will indicate to HTSI which passes they will support for that month. HTSI will send confirmation to LRO of which stations are ranging and when.

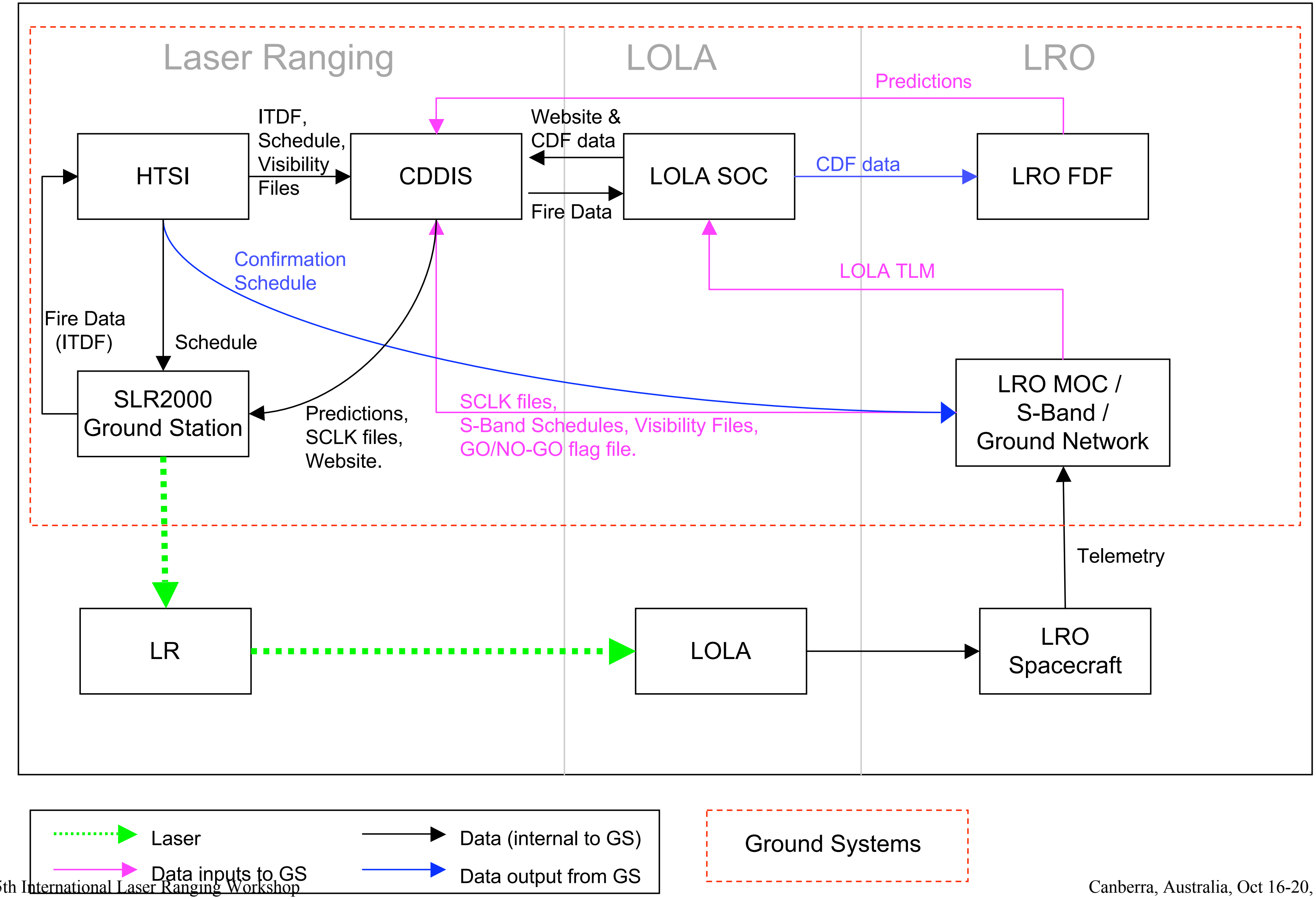
• Predictions will be in new CPF (Ricklefs / Rowlands are working on code for stations), and will be obtained from CDDIS.

• Fire times and other ancillary data will be sent in new (ITDF) format to CDDIS. (We will get this format out on CDDIS shortly).

• CDDIS will host website which will contain real-time LOLA Telemetry and other pertinent information for stations: http://lrolr.gsfc.nasa.gov

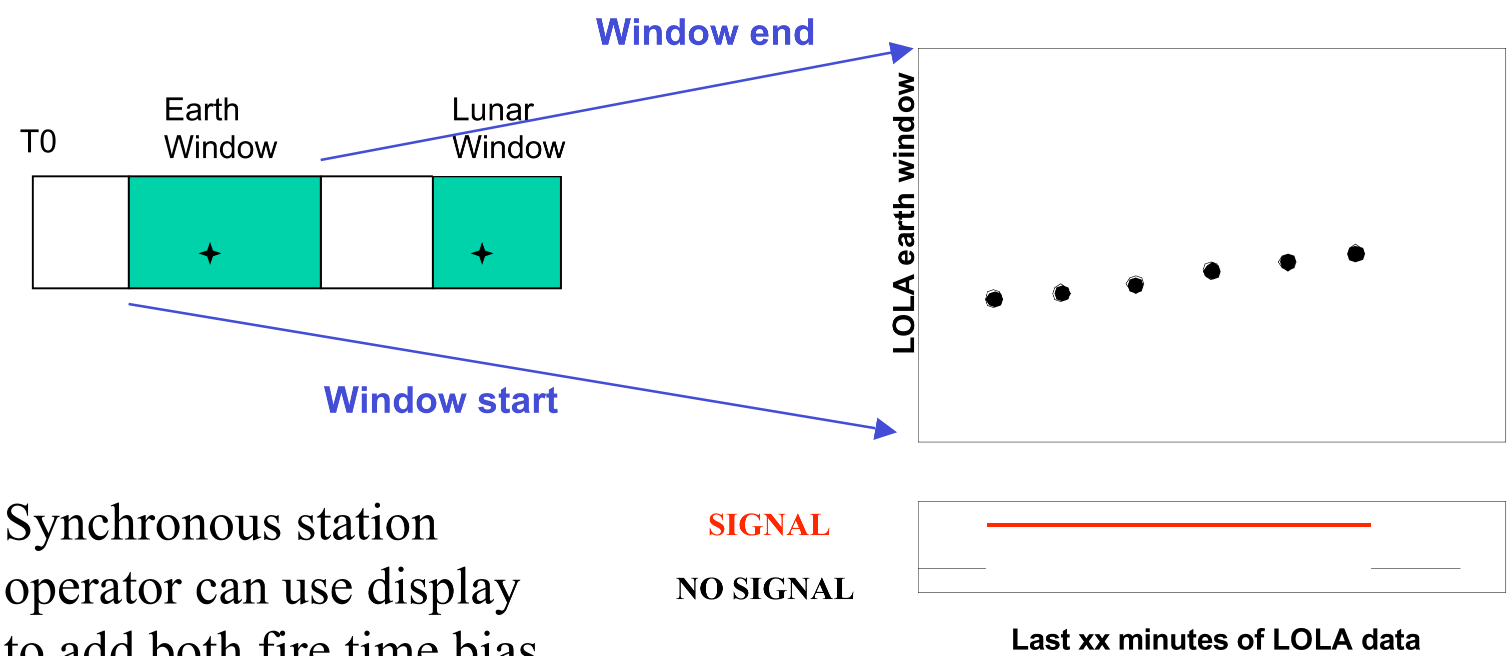
• We are negotiating with LRO/FDF to use Go/No-Go flag which would be available from CDDIS website.

Laser Ranging Network Block Diagram



Website Feedback from LOLA

- **LOLA onboard algorithm determines if it sees earth pulses and if so it estimates the earth pulse event time.**
- **Each dot represents estimate over one second of time.**
- **If synchronous fire control is correct the dots will form a straight line with almost no slope.**
- **Onboard algorithm will not be able to pick out asynchronous ground laser fires from noise but LOLA SOC ground processing software can.**



Synchronous station operator can use display to add both fire time bias to control laser fire.

SUMMARY

➢ Additional stations ranging to LRO can shorten time to an improved lunar gravity model. The wider the global coverage the better.

➢ LOLA SOC is expected to be able to handle multiple stations ranging to LRO at same time – but global coordination (scheduling) will still need to be performed.

➢ This work has implications for the future of SLR and we hope that many of you will consider joining us in this exciting experiment!

➢ Contacts:
- ILRS contact for LRO-LR: Mike Pearlman
- Ground station technical questions: Jan McGarry
- LRO Project PIs: Dave Smith (NASA/GSFC), Maria Zuber (MIT)