Laser Ranging to the Lunar Reconnaissance Orbiter

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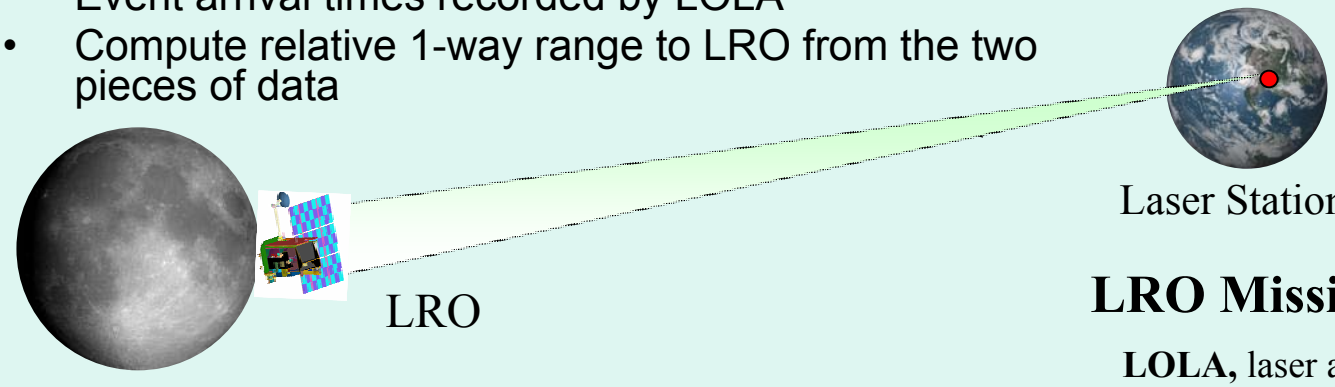
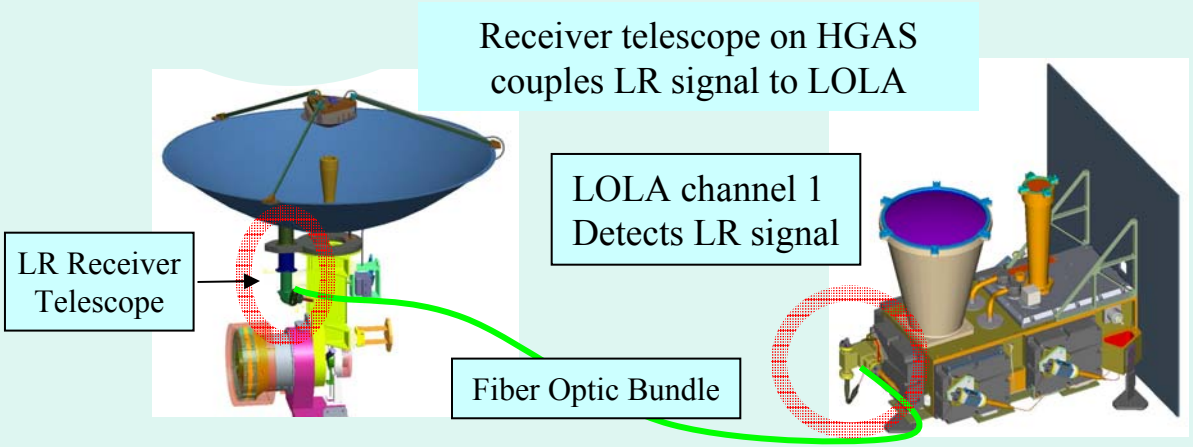
http://lrolr.gsfc.nasa.gov

Lunar Reconnaissance Orbiter (LRO) – Laser Ranging (LR) Overview

Sub-network of ILRS will support LRO for one-way laser ranging

- Transmit 532 nm laser pulses at =< 28Hz to LRO
- Time stamp departure times at ground station
- Event arrival times recorded by LOLA
- Compute relative 1-way range to LRO from the two pieces of data





LRO Mission Includes:

LOLA, laser altimeter

LROC, camera

LAMP, Lyman alpha telescope

LEND, neutron detector

DIVINER, thermal radiometer

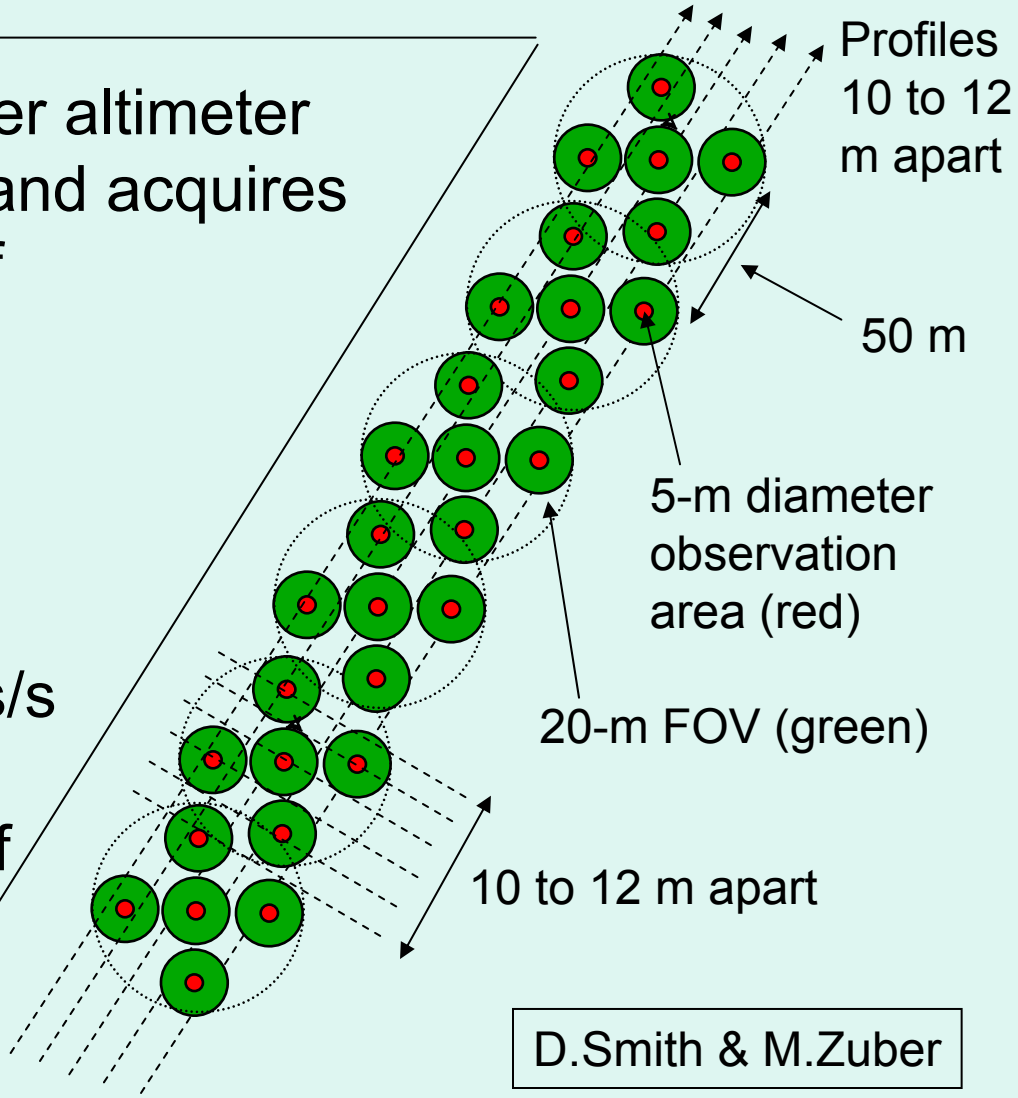
CRATER, cosmic ray detector

mini-RF, radar tech demo

Lunar Obiter Laser Altimeter (LOLA)

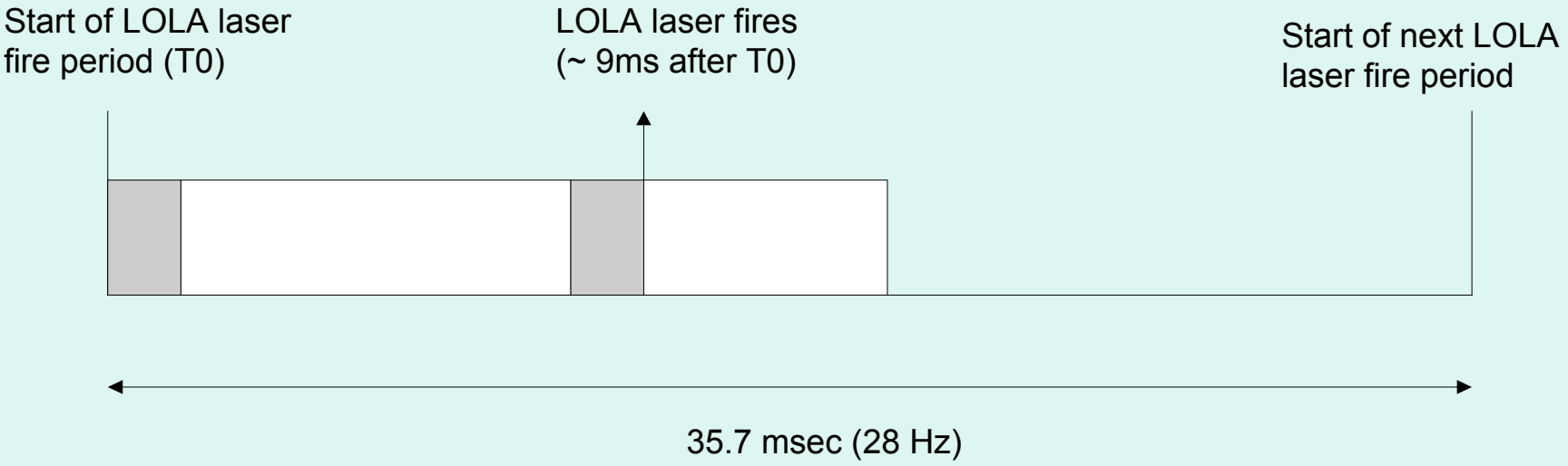
- LOLA is a 5-beam laser altimeter that operates at 28 Hz and acquires 140 measurements/s of
  - altimetry
  - surface roughness
  - surface reflectance

and 180 measurements/s of derivable surface slopes with baselines of 25 to 50 m.



One LOLA Detector does both Earth and Lunar

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



LR Objectives and Instrumentation

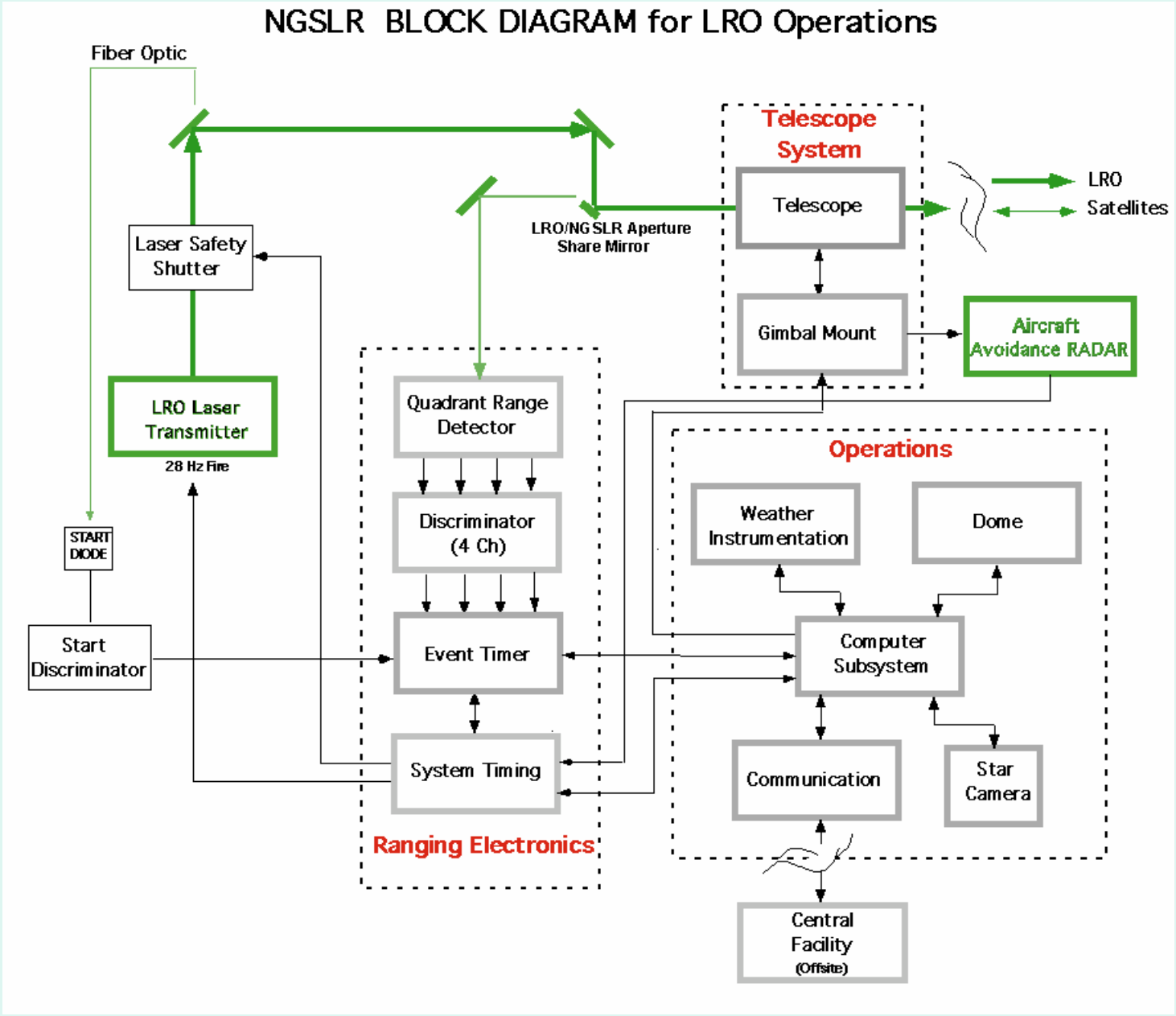
➢ Objective of LR is to enable the spacecraft to achieve its precision orbit determination (OD) requirement. The OD supports the generation of an accurate topographic model from LOLA's measurements.

➢ Designed to measure centimeter-level orbit perturbations over a few seconds of flying time and meter-level perturbations from pole to pole.

➢ Flight Instrument:
- 3.81 cm diameter aperture mounted on High Gain Antenna
- Fiber optic bundle carries the light to the LOLA detector #1
- LR FOV is ~ 1.7 deg (earth diameter is ~2 deg as viewed from moon)
- 532 nm bandpass filter with 0.3 nm FWHM
- Ultrastable OCXO oscillator: Symmetricom 9500 (2x10-12 over 1 hour)
- Onboard software controls threshold setting using detector noise counts.

Primary Ground System: NASA's Next Generation Satellite Laser Ranging System (NGSLR)

- 50 mJ Northrop Grumman laser (532.2 nm wavelength, 6 ns pulsewidth).
- Software controlled laser triggers - producing 28 Hz laser fires that arrive at LRO when the LOLA Earth Window is open.
- 55 microradian laser beam divergence (~20 km spot at moon).
- Aircraft avoidance radar (FAA regulations for non-eyesafe lasers).
- Honeywell Event Timer (ET) with 30 picosecond accuracy.
- Symmetricom Cesium oscillator (CS-4310) provides 10 Mhz time base for ET.
- TrueTime XL-DC GPS steered Rubidium provides station timekeeping.
- Arcsecond precision tracking mount, pointing accurate to a few arcseconds.



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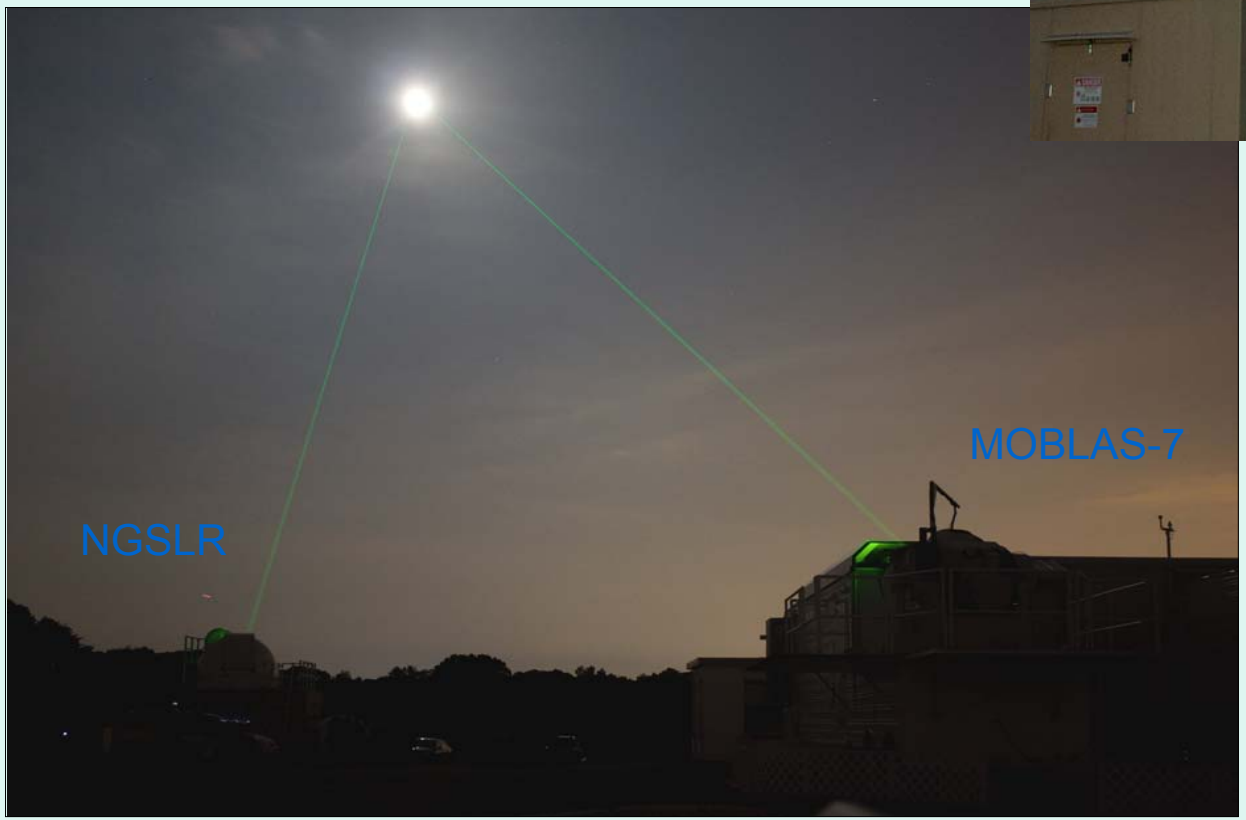
NGSLR & MOBLAS-7



NGSLR

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Participating Stations from the International Laser Ranging Service (ILRS)

- NASA's Next Generation Laser Ranging System (NGSLR): Maryland.

- Also ranging to LRO:
  - McDonald Laser Ranging System (MLRS): Texas
  - Herstmonceux: Great Britain
  - Zimmerwald: Switzerland
  - MOBLAS-7: Maryland

- Working toward ranging to LRO:
  - Wettzell: Germany
  - Hartebeesthoek: South Africa
  - Yarragadee: Australia
  - Monument Peak: California

Ground Station Characteristics

➢Station fire rate and probable events per second in LOLA Earth Window with system configurations:

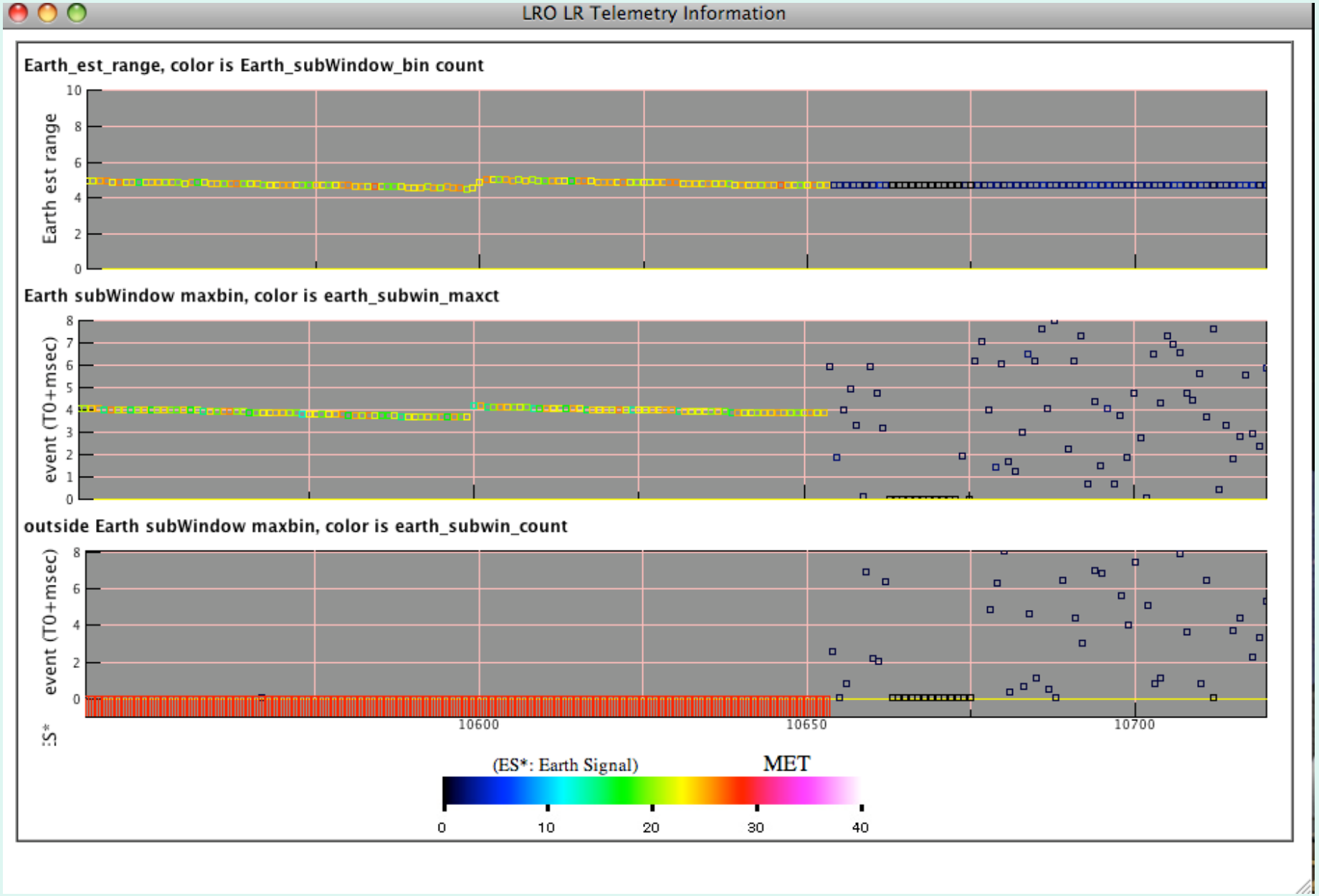
	Synch?	FireRate	Events/second in Earth Window	Energy per pulse at LRO fJ/cm^2
NGSLR	YES	28Hz	28	2 to 5
MLRS	NO	10Hz	2 to 4	4 to 10
Zimmerwald	YES	14Hz	14	2 to 10
Herstmonceux	YES	14Hz	14	1 to 3
Hartebeesthoek	NO	10 Hz	2 to 4	1 to 2
Yarragadee	NO	10 Hz	2 to 4	1 to 2
Monument Peak	NO	10 Hz	2 to 4	1 to 2
MOBLAS-7	NO	10 Hz	2 to 4	1 to 2

➢Requirement: between 1 – 10 femtoJoules per square centimeter at LRO and between 1 and 28 events per second in LOLA Earth Window.

Data Products for LRO-LR

- Predictions (CPFs) generated by GSFC Flight Dynamics Facility (FDF):
  - Accuracy < 4 km (3D, 3 sigma)
- SCLK file relates spacecraft time (MET) to UTC for synchronous firing.
- Go/NoGo file. Set to NoGo to stop all stations from firing within 5 mins.
- Fire times recorded at each station:
  - Accuracy to UTC < 100 ns
  - Relative fire time error RMS < 200 ps (over 10 sec)
- Real-time feedback from spacecraft:
  - LOLA flight software performs signal processing on LR events
  - Results come down in LOLA housekeeping and are displayed on website
  - Latency is between 10 to 30 seconds
  - Stations use website to determine if they are hitting LRO

Real-time Telemetry Website



Preliminary Results from First 3 Months

- RMS of individual ranges is ~0.8 ns, (~24 cm), after removal of outliers. Calibration will improve these numbers. (Analysis by Greg Neumann).

- Precision of 2-way altimetry is 12 cm.

- Have collected over 44 hours of laser ranging data at LRO.

- One-way LR link is strong from NGSLR. Can range through thin clouds.

Sky on a night of successful ranging to LRO.

Thin clouds, high humidity as seen from camera on NGSLR mount.

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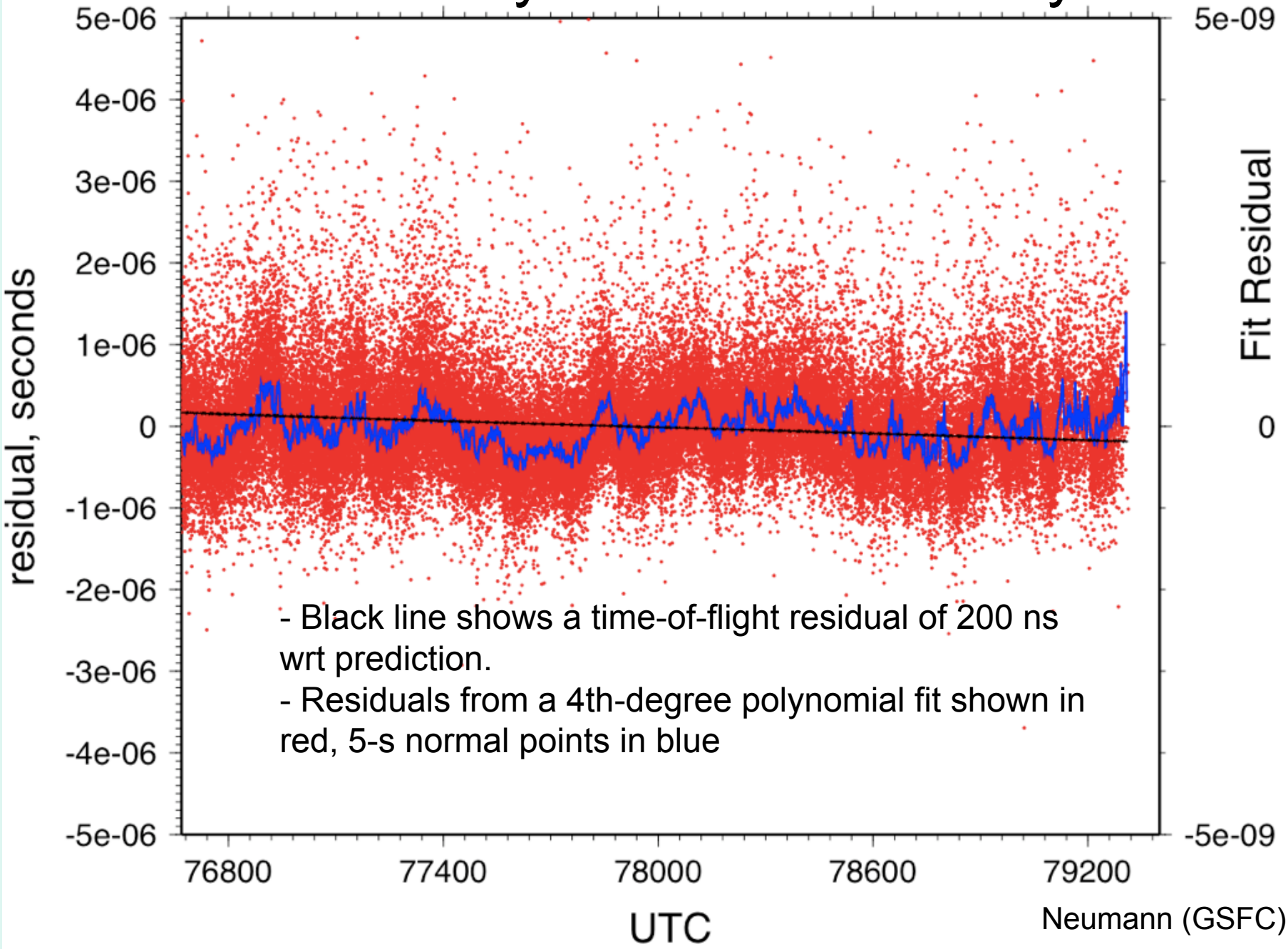
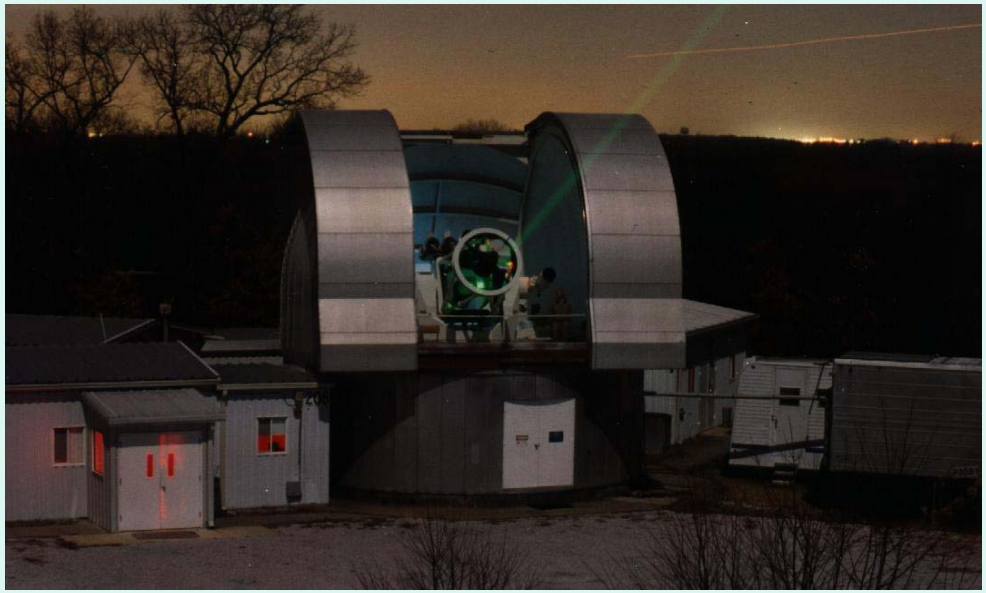
Preliminary Performance Analysis



Neumann (GSFC)

On-orbit Calibration of LOLA from NASA's 1.2 m Telescope



Multi-user facility built in 1973-74. Arcsecond precision tracking telescope.

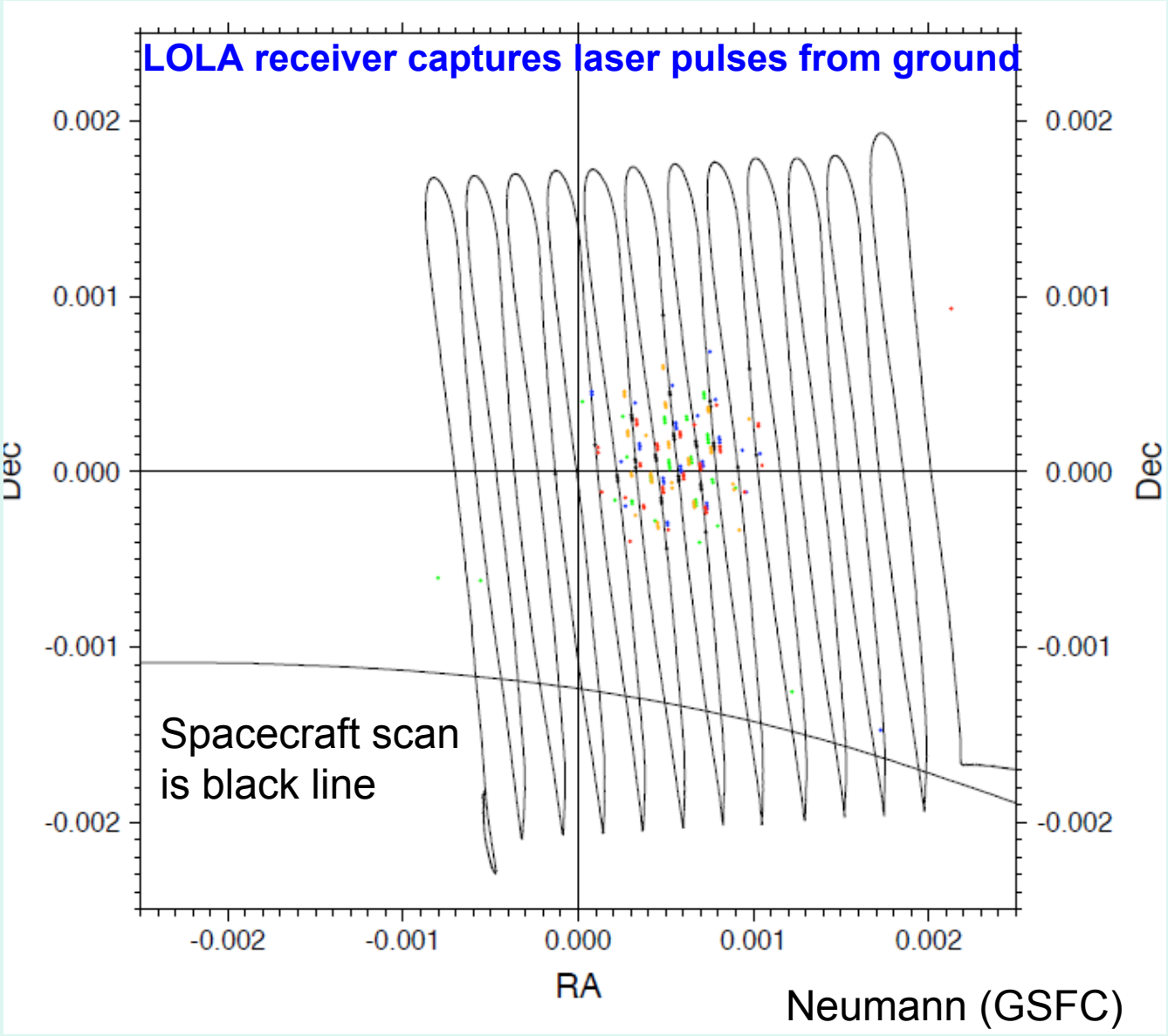
Has supported many experiments including in 2005:

- **2-way ranging to Mercury Laser Altimeter (MLA) on MESSENGER (24 Mkm), and**
- **1-way ranging to Mars Orbiter Laser Altimeter (MOLA) on MGS (orbiting Mars at 80 Mkm).**

Successful on-orbit calibration of LOLA (2-way ranging) in 2009: 8/25, 9/13, 9/14.

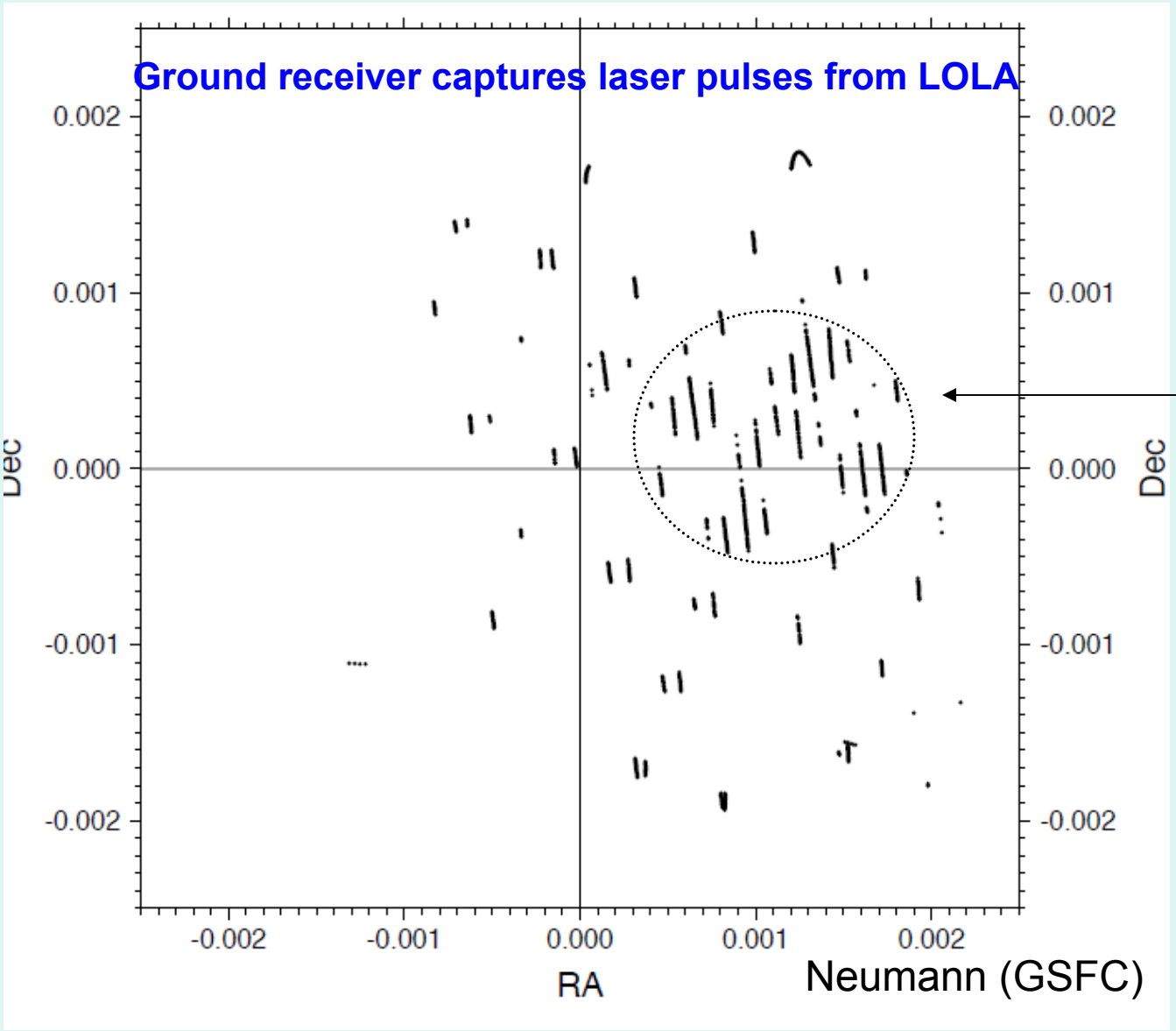
Very Preliminary Analysis of Sep 13 Scan

Plot of LOLA received events on scan location

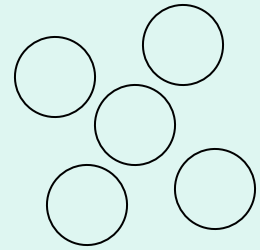


Very Preliminary Analysis Sep 13 Scan

Plot of ground received events on LRO scan location



5 laser spots can be seen:



Goddard Geophysical and Astronomical Observatory (GGAO)
Birthplace of Satellite Laser Ranging in early 1960s

Photo ~1980

- **Located ~ 3 miles from GSFC on Springfield Road (in middle of BARC).**

- **Home to NASA SLR, VLBI, GNSS and DORIS:**
  1.2 meter telescope,
  NGSLR,
  MOBLAS-7,
  VLBI MV3,
  and numerous other facilities and experiments.

Part of this afternoon's tour

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