Session 14: 3158

Summary of Ground Station Performance in Five Years of Laser Ranging Operation to Lunar Reconnaissance Orbiter

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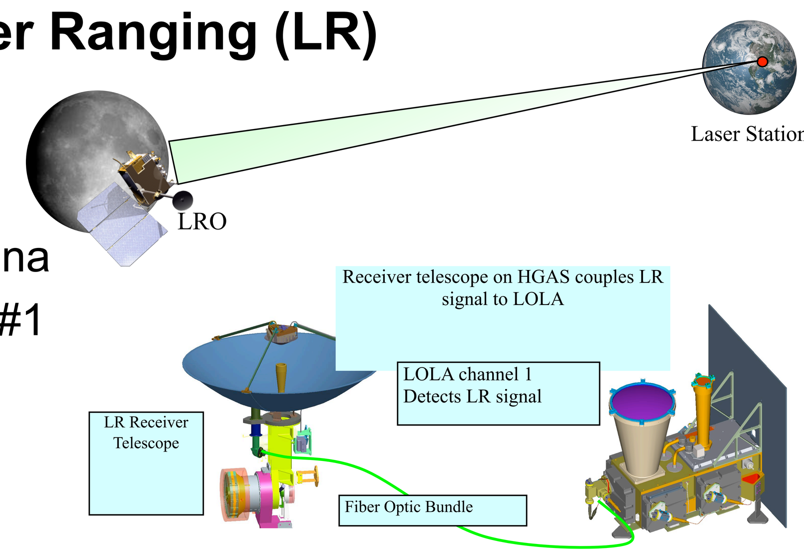
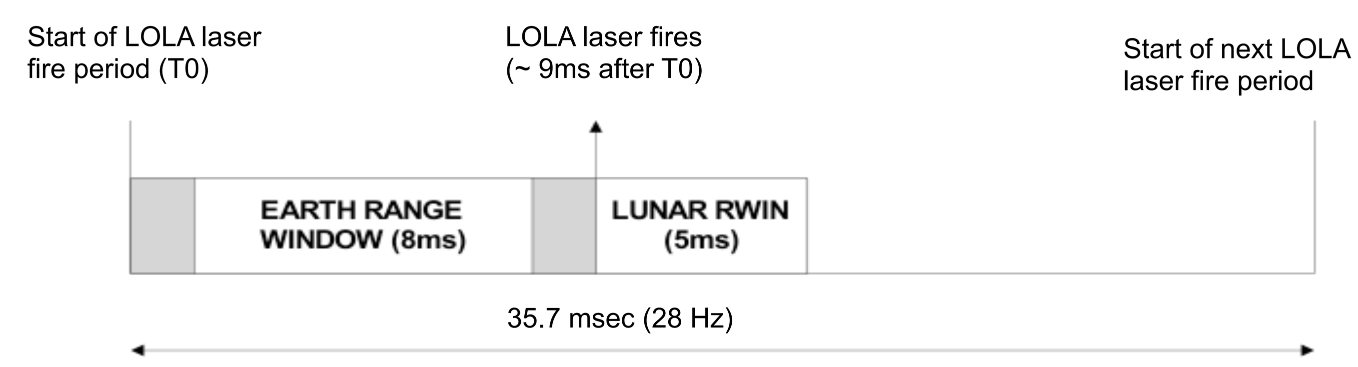
Lunar Reconnaissance Orbiter (LRO) – Laser Ranging (LR) Overview

- Flight Segment:
  - 3.81 cm diameter aperture mounted on High Gain Antenna
  - Fiber optic bundle carries the light to the LOLA detector #1
- Ground Segment:
  - Transmit 532 nm laser pulses at <= 28 Hz
  - Departure time stamped at ground station



One LOLA Detector does both Earth and Lunar Measurements



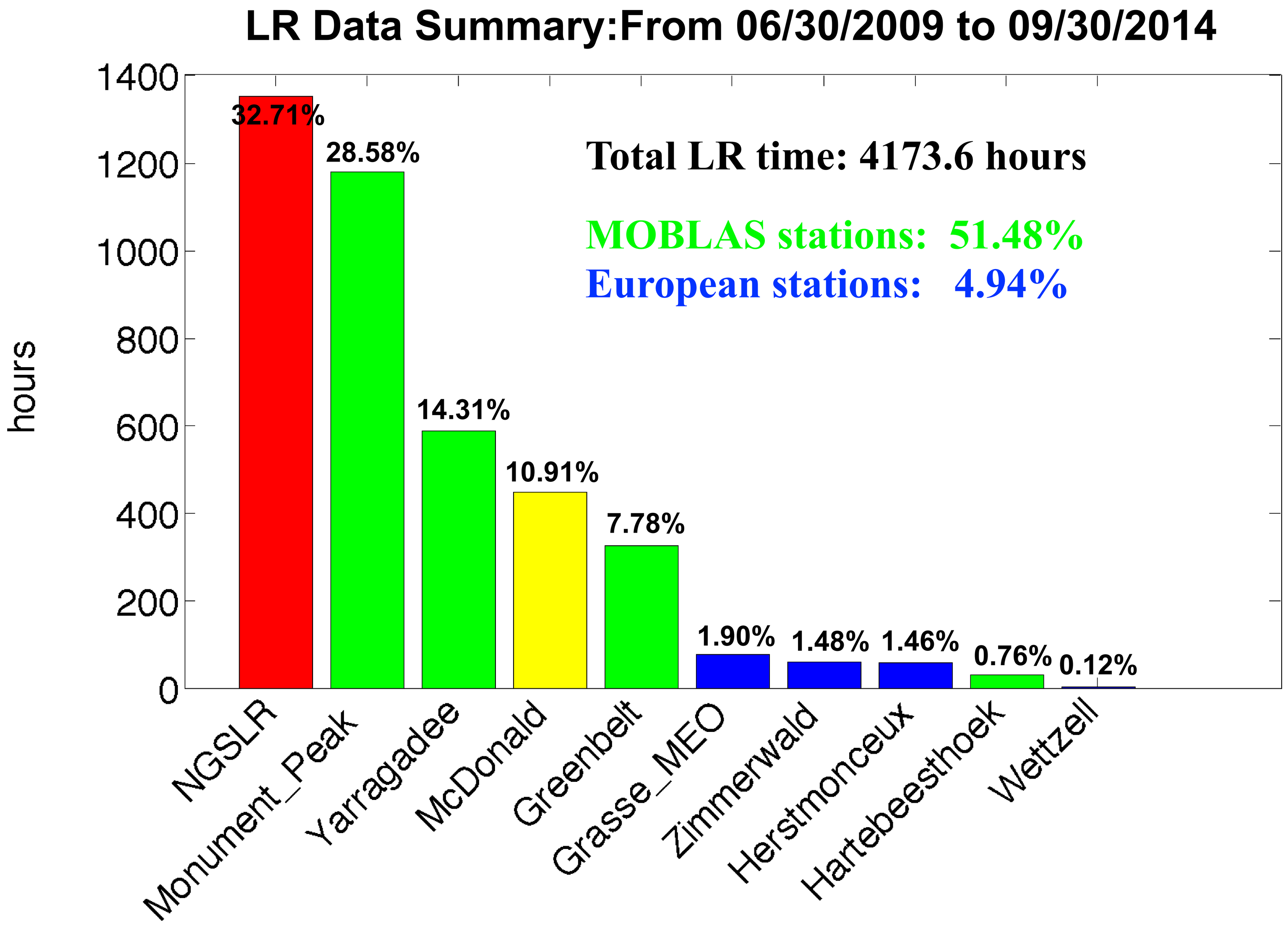
- Two range windows in one detector: 8 msec earth and up to 5 msec lunar
- Range to LRO changes ~ 5-10 ms over an hour's visibility

Ten Participating Stations from the International Laser Ranging Service (ILRS)

- Fire times recorded at each station:
  - Accuracy to UTC < 100 ns
  - Relative fire time error RMS < 200 ps (over 10 sec).

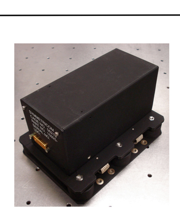
Tracking station	Station ID	Synchronous	FireRate	Events/ second in Earth Window	Energy per pulse at LRO (fJ/cm^2)
NGSLR (Greenbelt,MD,USA)	GO1L	YES	28 Hz	28	2 to 5
McDonald (TX,USA)	MDOL	NO	10 Hz	2 to 4	4 to 10
Monument Peak (CA,USA)	MONL	NO	10 Hz	2 to 4	1 to 2
Yarragadee (Australia)	YARL	NO	10 Hz	2 to 4	1 to 2
Hartebeesthoek (South Africa)	HARL	NO	10 Hz	2 to 4	1 to 2
Greenbelt (MD, USA)	GODL	NO	10 Hz	2 to 4	1 to 2
Herstmonceux (Great Britain)	HERL	YES	14 Hz	14	1 to 3
Zimmerwald (Switzerland)	ZIML	YES	14 Hz	14	2 to 10
Wettzell (Germany)	WETL	EFFECTIVELY	7 Hz	7	1 to 2
Grasse (France)	GRSM	NO	10 Hz	2 to 4	1 to 2

LR Data Summary:From 06/30/2009 to 09/30/2014



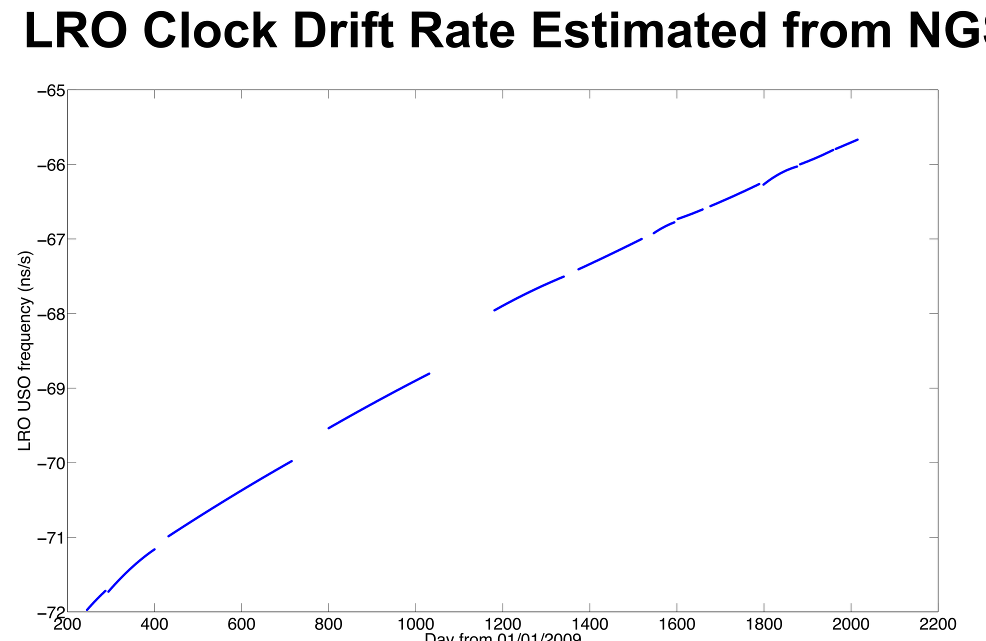
Stations	# 2-way passes	Stations	#2-way passes
GO1L, GODL	61	HARL, HERL	1
GO1L, MDOL	139	HARL, ZIML	4
GO1L, MONL	318	GRSM, ZIML	49
GODL, MDOL	58	GRSM, HERL	16
GODL, MONL	93	ZIML, HERL	5
MDOL, MONL	151	HERL, WETL	3
ZIML,GO1L	1	ZIML,WETL	1
Stations	**# 3-way passes**	**Stations**	**# 3-way passes**
GO1L, GODL, MDOL	48	GODL, MDOL, MONL	58
GO1L, GODL, MONL	116	GRSM, HERL, ZIML	2
GO1L, MDOL, MONL	257		
Stations	**#4-way passes**		
GO1L, GODL, MDOL, MONL	6		

LOLA/LR Clock Oscillator Long-Term Stability

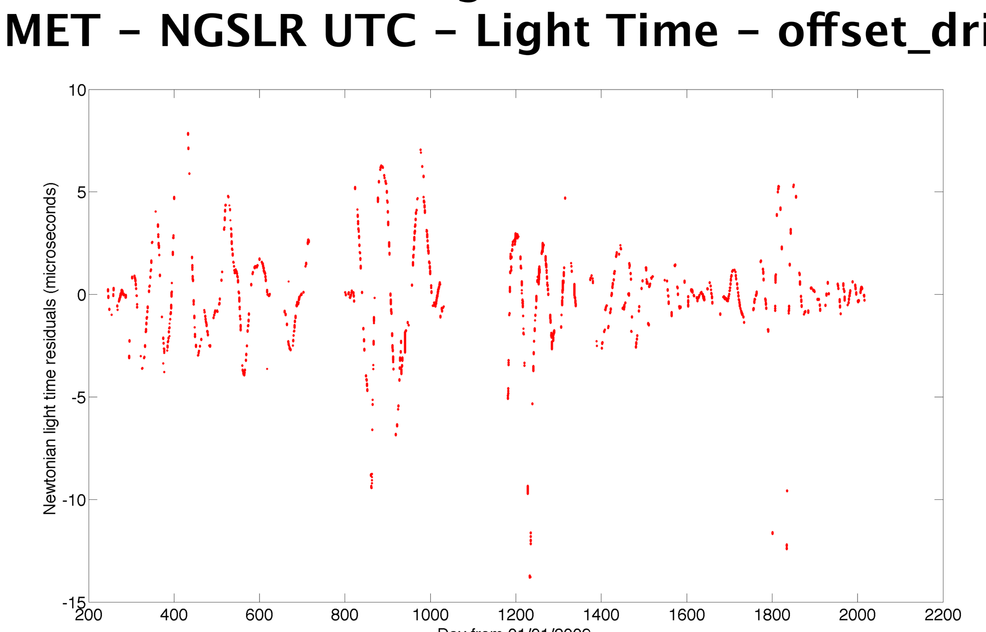


Symmetricom 9500 series Oven Controlled Crystal Oscillator

LRO Clock Drift Rate Estimated from NGSLR

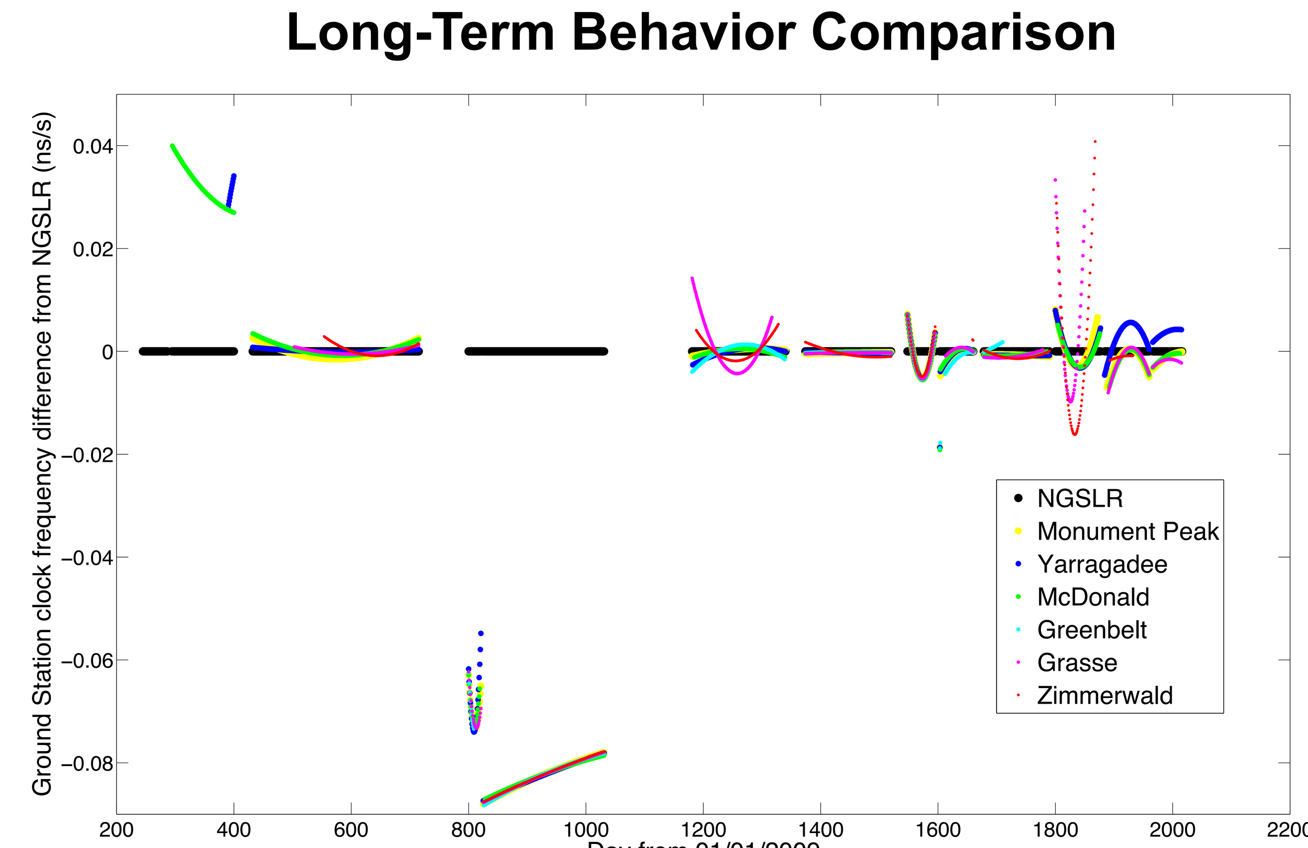


Newtonian Light Time Residual = LRO MET – NGSLR UTC – Light Time – offset_drift_aging



- Oscillator long term frequency stability is about +/-1.5e-12s per day before removing the temperature effect
- The drift rate of the LRO project-supplied spacecraft clock is approximately 1.00000006754 seconds per 1 s clock tick at present, and the clock has been slowing down gradually and steadily
- After removing a constant time offset, a linear time drift, a quadratic frequency aging, a cubic frequency aging rate, and a calculated light time, the residuals are less than 15 us for the entire mission, which is ~200 times better than the 3 ms mission requirement
- LRO sun-safe incidents showed impacts on LRO clock's drift and aging rates due to the change of clock temperature

Ground Station Clocks Long-Term Behavior Comparison



- Ground stations are using different time sources, such as Rb clocks, Cs clocks, H-masers, etc.
- Time at NGSLR has been monitored to sub-nanosecond with an absolute accuracy of ~1ns and a stability mainly governed by the station clock, 4e-15 for the hydrogen maser (since January, 2013) and 1e-13 for the cesium clock source (before January, 2013) .
- Using LRO oscillator as a common clock, long term behaviors of most ground station clocks are compared with respect to NGSLR (shown in the figure above).
- Comparison results for each station are shown in separate figures, which are attached to the poster.