One-way LASER Ranging to LRO

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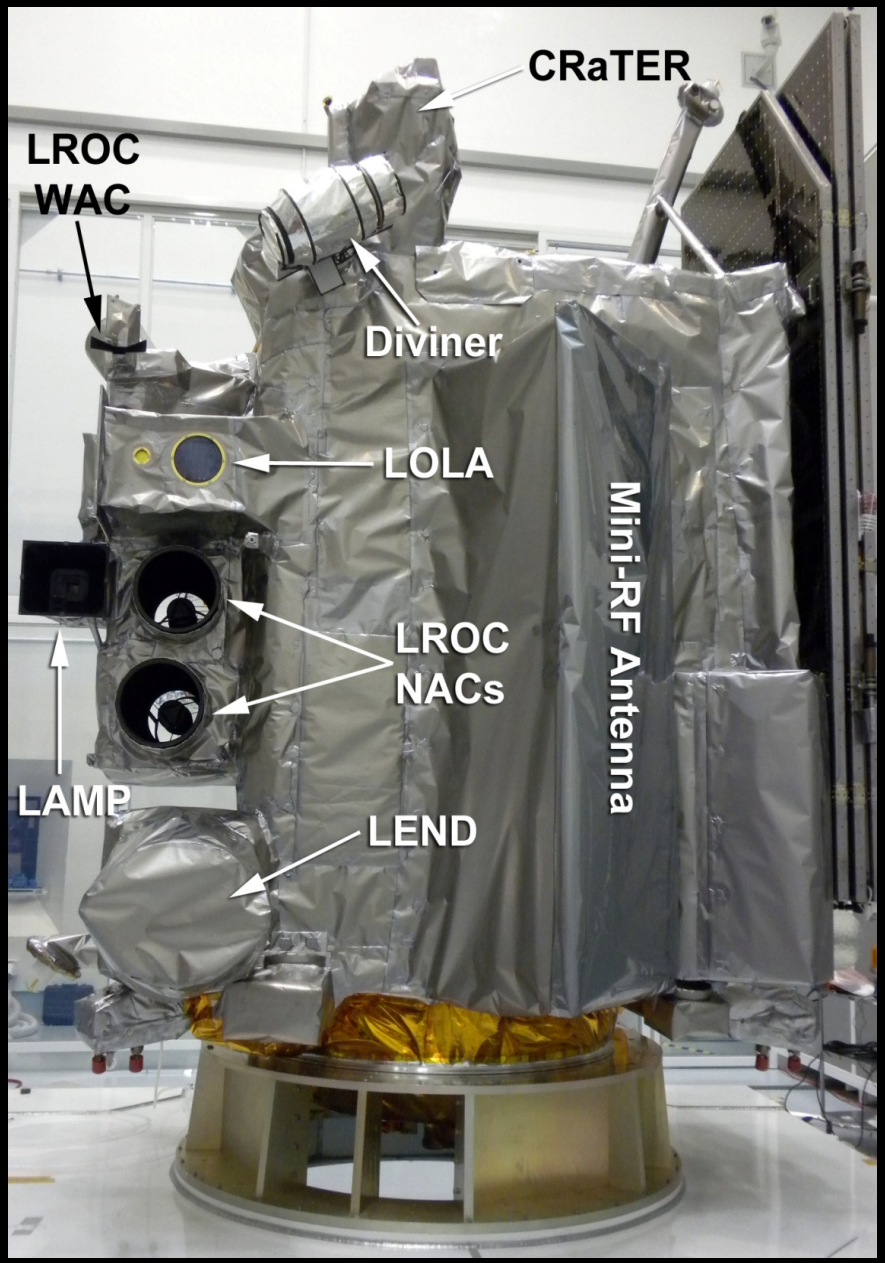
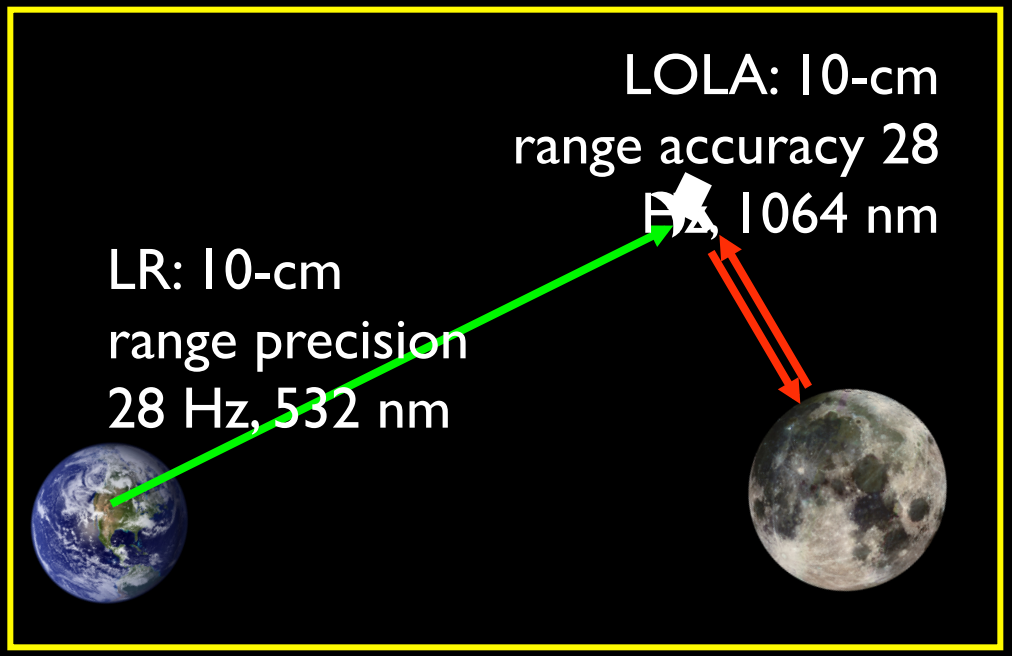
Outline

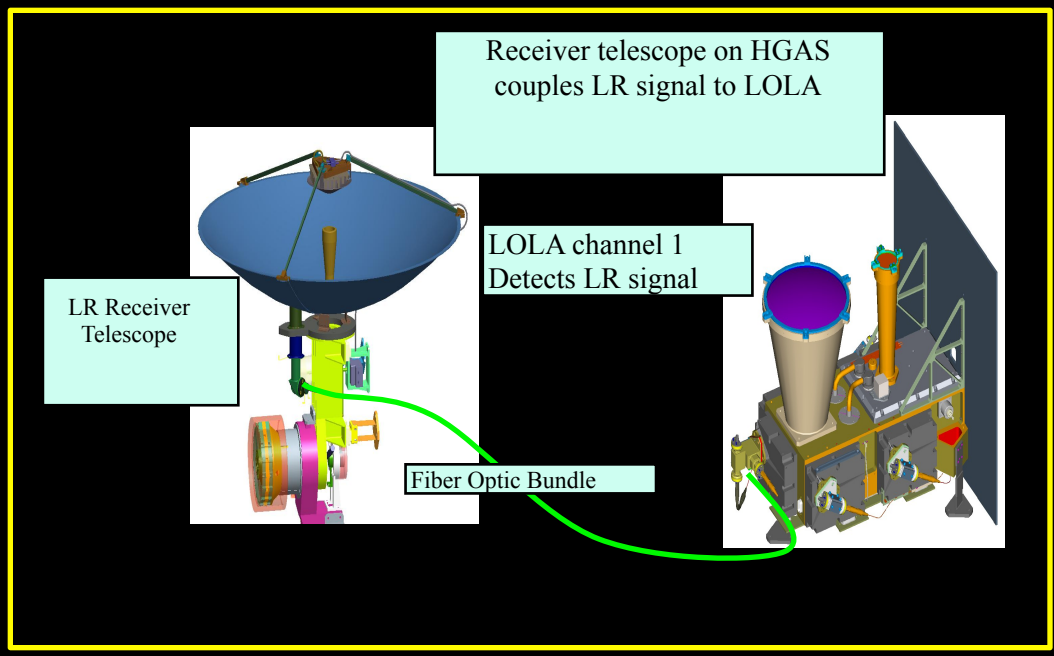
- Current status
- Data summary
- Orbit determination using LR data and GRAIL420c1a gravity model:
- Laser Communication
- Time transfer experiment:
- Summary

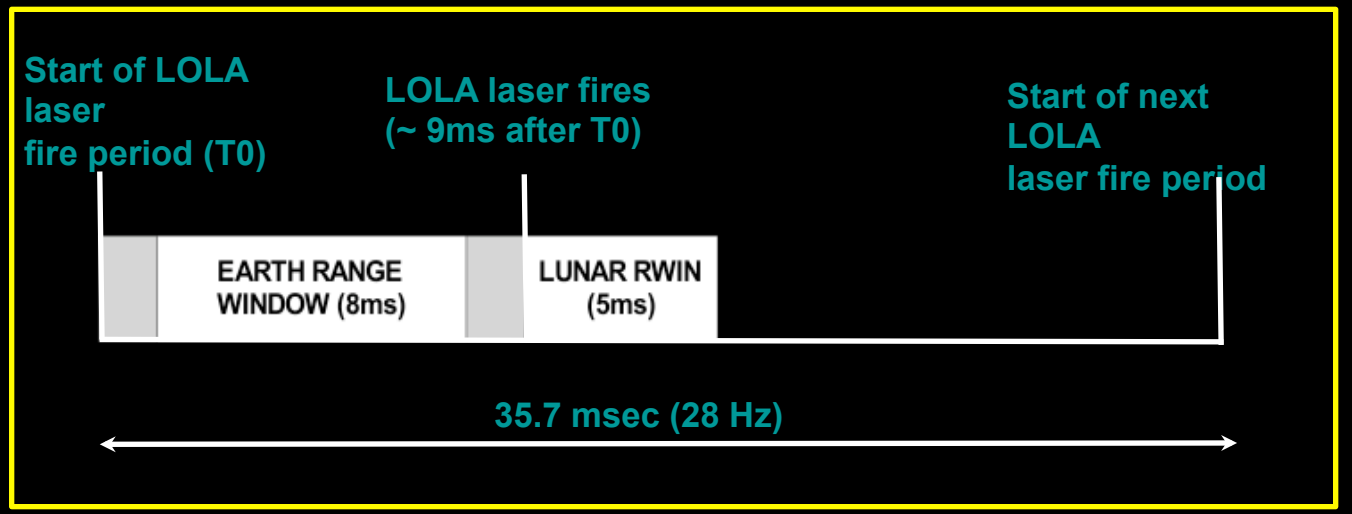
Lunar Reconnaissance Orbiter in Clean Room



Laser Ranging to LRO via LOLA







Sites Ranging to LRO via LOLA

10 stations: US, Europe, and Australia

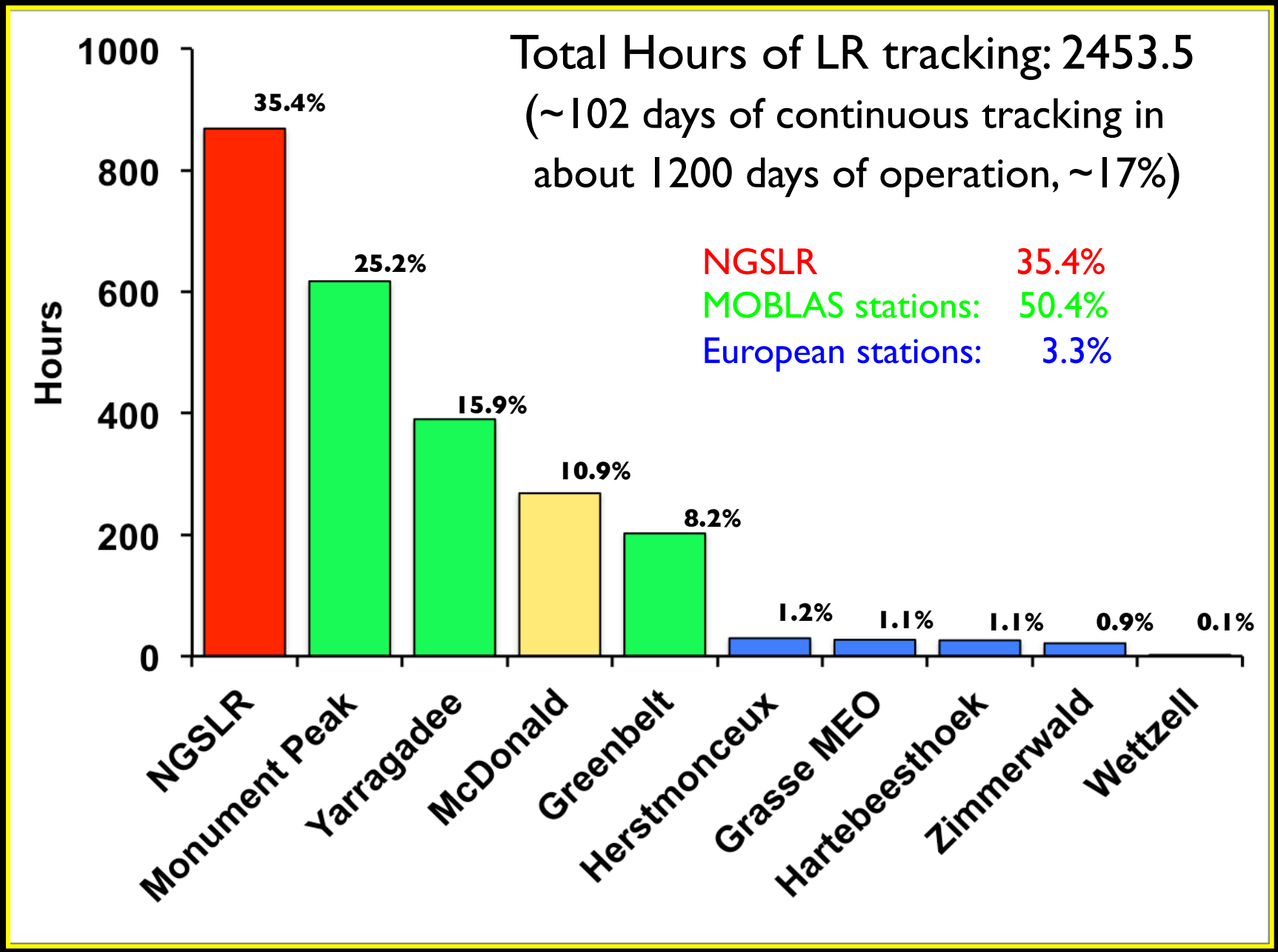
Main station: NGSLR, MD
28 Hz, synchronous

synchronous stations:
ZIML, HERL
14 Hz, 14 events/s

Non-synchronous stations:
10Hz, 2~4 events/s

LR Data Summary

Sep. 20, 2009 through Oct. 5, 2012



LRO Orbit Determination with GRAIL420c1a

Orbital Solutions for 14 days

	LR only		S-band only			S-band plus LR						
	rms (m)	num	rms (cm/sec)	num	rms (m)	num	rms (cm/sec)	num	rms (m)	num	rms (m)	num	
20090831	0.29	5203	0.05	64679	1.16	57407	0.05	64742	1.22	57407	0.41	5203	20090831
20091023	0.30	15954	0.08	76259	1.09	70984	0.10	76261	2.21	70984	0.39	15954	20091023
20091120	0.22	16613	0.05	74957	0.77	68530	0.06	75124	0.80	68530	0.23	16613	20091120
20100309	0.17	10338	0.05	72156	1.32	67421	0.06	72424	1.54	67421	0.20	10338	20100309
20100405	0.27	9859	0.05	69298	1.39	63528	0.06	69632	1.72	63528	0.29	9859	20100405
20100419	0.28	21185	0.06	70072	1.44	64602	0.08	70627	1.71	64602	0.30	21185	20100419
20100530	0.29	19306	0.05	78974	0.79	74166	0.07	79600	1.41	74166	0.30	19306	20100530
20100614	0.22	20554	0.06	64239	0.96	60551	0.07	64304	1.16	60551	0.23	20554	20100614
20110507	0.38	17397	0.70	66540	1.93	59389	0.72	66540	1.51	59389	0.39	17397	20110507
20110520	0.16	11978	1.02	66650	2.22	60286	1.03	66650	1.66	60286	0.22	11978	20110520
20110630	0.32	11524	0.71	65279	2.66	57984	0.72	65279	2.64	57984	0.36	11524	20110630
20110810	0.69	20800	0.08	79229	1.18	71040	0.11	79229	1.50	71040	0.70	20800	20110810
average	0.30	15059	0.25	70694	1.41	64657	0.26	70868	1.59	64657	0.34	15059	average

Average RMS: 30 cm (1 nsec) | 2.5 mm/s | 3.0 mm/s | 34 cm

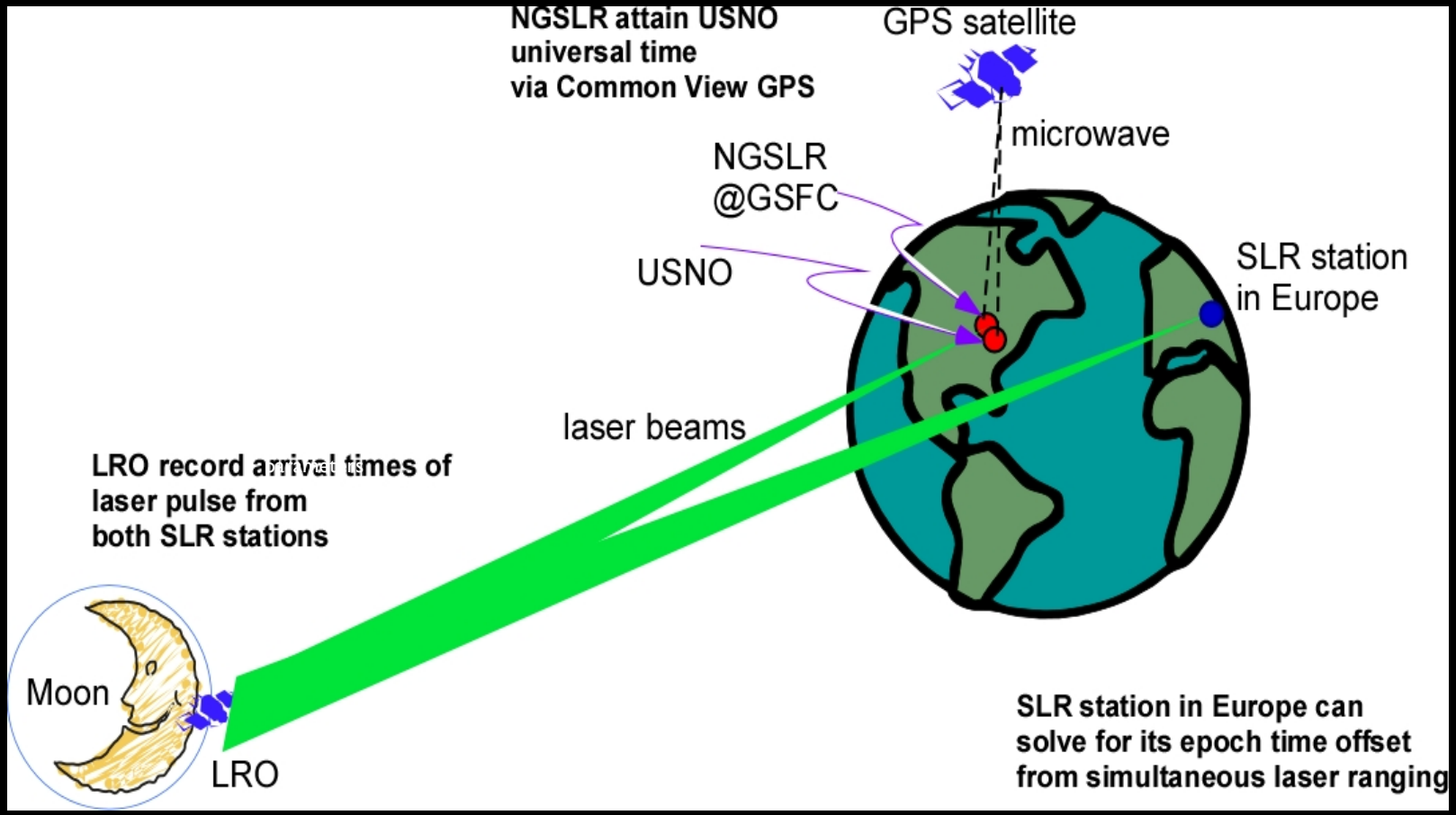
Orbital solutions significantly improved with a GRAIL gravity model and improved further with LR.

LRO Orbit Differences with GRAIL420c1a

Orbital Solutions for 14 days

	LR minus 2.5 day S-band				S-band minus 2.5 day S-band				LR and S-band minus 2.5 day S-band			
	2 week LR only minus 2.5 day S-band				2 week S-band only minus 2.5 day S-band				2 week LR and S-band minus 2.5 day S-band			
date	along	cross	radial	total	along	cross	radial	total	along	cross	radial	total
20091023	25.61	8.81	1.94	28.62	14.96	9.51	1.36	18.97	14.55	7.57	0.57	17.46
20091120	4.15	1.42	1.6	4.78	5.08	2.48	1.2	6.24	6.25	3.82	0.57	8.06
20100309	13.11	8.76	1.28	17.54	6.9	7.74	0.79	11.21	5.77	4.08	0.58	7.81
20100323	16.32	24.02	5.68	30.31	11.14	15.35	2.11	20.3	3.52	4.25	0.45	6.15
20100405	11.33	5.99	2.09	13.75	12.93	7.04	0.61	15.7	10.31	4.4	0.56	11.6
20100419	12.53	7.37	3.84	15.63	6.07	2.71	0.61	7.09	6.1	2.54	0.59	6.85
20100530	8.94	4.22	1.72	10.39	7.7	4.33	1.28	9.72	6.23	3.33	0.5	7.77
20100614	10.13	1.51	2.12	10.55	6.07	2.98	0.98	7.19	6.39	2.25	0.83	7.01
20100724	43.41	19.59	12.23	50.83	15.58	8.79	3.39	18.68	2.99	1.94	0.36	3.77
20100806	15.61	10.21	1.53	20.29	13.22	9.84	0.86	17.8	7.53	4.44	0.63	9.56
20100916	9.94	8.55	1.87	13.84	9.74	7.55	1.18	13.07	7.38	6.78	0.36	10.82
20110227	11.62	8.03	2.02	14.94	5.66	2.76	0.91	6.69	6.25	3.51	0.63	7.62
20110408	15.53	4.43	3.82	17.37	12.72	4.1	1.62	14.54	13.85	4.16	1.48	15.77
20110422	5.99	5.69	1.11	9.21	6.58	5.28	1.29	9.27	6.42	5.74	1.21	9.59
20110810	9.91	6.31	2.36	13.97	6.97	7.44	1.02	11.47	8.78	9.85	1.09	14.69
average	14.28	8.33	3.01	18.13	9.42	6.53	1.28	12.53	7.49	4.58	0.69	9.64
Total (m)				18.3				12.5				9.6

Time Transfer



- Station clocks behave differently
- Regular simultaneous ranging from multiple stations, forms strong constrains for orbit determination

Time Transfer

- Many pairs of time transfer passes taken
- Current NGSLR & MOBLAS7 time transfer accuracy ~ 10 ns
- Current GPS time accuracy <100 ns
- GOAL: accuracy 0.5 ns

- Simultaneous LASER ranging from multiple stations
- Epoch timing from USNO via GPS All-View receivers to NGSLR event timer
- Out-going laser pulses from both stations time-tagged by the NGSLR timer, epoch time accuracy < 1 ns
- All ground time delay from electronics and cables to be remeasured

Summary

- Data from the international LASER ranging network continues to be taken – ten stations tracked in October 2012.
- The quality of orbit determined with only LR data is comparable to using all available tracking data
- LR data improves knowledge of the LRO orbit from that determined with S-band alone: about 10 m rms
- Laser Communication has been demonstrated
- Time transfer experiment has been demonstrated
- LR further demonstrates the ability to range to planetary distances