One-way ranging to spacecraft at planetary distances

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Abstract: Laser ranging is technically challenging at planetary distances and the opportunities for experiments or demonstrations are limited. However, the scientific value of such measurements is very high and the concept deserves serious attention. Conventional 2-war ranging requires active transmitters at both ends and considerable resources in space and on the ground. One-way ranging in which the transmitter is on the ground is less demanding but requires an accurate clock on the spacecraft and some way of monitoring its performance. The system developed for LRO in lunar orbit, which only had a requirement of 10 cm, was designed as a supplementary tracking system to the routine microwave system to improve on the orbital and positional knowledge of the LRO spacecraft. Individual tests to the Mars Global Surveyor, and the MESSENGER spacecraft in cruise to Mercury helped identify ground-based and space-based difficulties with the approach. The LRO operation worked as planned and exceeded expectations and even enabled a demonstration of uplink laser communication. The same concept is equally viable at much greater distances within the solar system and with greater range accuracy and with much higher uplink communication fidelity than LRO for relatively minimal cost and complexity. The application of this technology for orbit determination has been demonstrated by LRO and the international SLR network has routinely and successfully tracked LRO for over 3 years. It is hoped that there will be further incremental steps in the near future for laser ranging on a planetary scale.

Past Experiments: The first effective laser ranging experiment at planetary or lunar distance was with MESSENGER spacecraft in which both an uplink and downlink observations were made to the laser altimeter (MLA)[1,2] and provided range, velocity, and time transfer between the spacecraft and the laser ground station. We also obtained waveforms of the MLA transmit beam. The observations were made at distance of 24×10^6 km. The second experiment was a one-way uplink to the Mars Global Surveyor (MGS) spacecraft at a distance of 80×10^6 km. In both the Mercury and Mars experiments the spacecraft were required to scan a region that include the Earth laser station to obtain a link into the altimeter receiver which, although time consuming, provided information on the pointing of the laser receiver with respect to the spacecraft attitude. The third experiment was the Lunar Reconnaissance Orbiter (LRO) Laser Ranging (LR) [3] experiment to obtain routine one-way, Earth to LRO, laser range measurements for demonstrating lunar spacecraft orbit determination. The experiment has been in successful operation since July 2009 and operates in conjunction with the 5-beam laser altimeter (LOLA) [4,5] on LRO. The data have been used to regularly determine the orbit of LRO for periods of 14 days to accuracies of better than 20 meters.

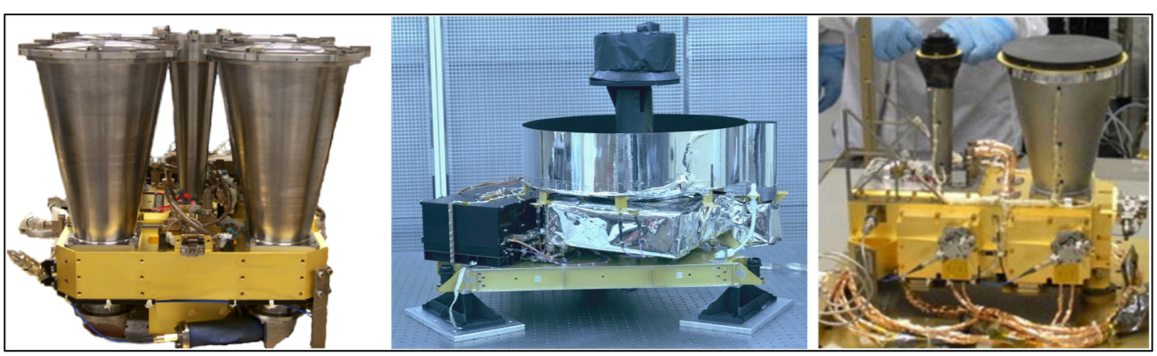

Figure 1: The altimeters MLA, MOLA, LOLA used in the planetary laser ranging experiments.

In addition, LR was used to monitor the performance of the LRO oscillator to better than 0.25 milliseconds, demonstrate the transfer of time between Earth laser stations, and as an uplink communications system to LRO by sending images using a coded pulsed laser position modulation approach [6].

Parameter	GGAO	MLA
Transmitter:		
Wavelength nm	1064	1064
Pulse energy, mJ	14	18
Pulse repetition rate, Hz	240	8
Pulse width, ns	10	6
Beam divergence (FWHM), μrad	55	50
Receiver:		
Telescope diameter, m	1.2	0.23
Detector field of view, μrad	260	400
Alignment		
Transmitter-receiver boresight,μrad	25	50
MLA alignment wrt s/c instrument deck, mrad		3.5

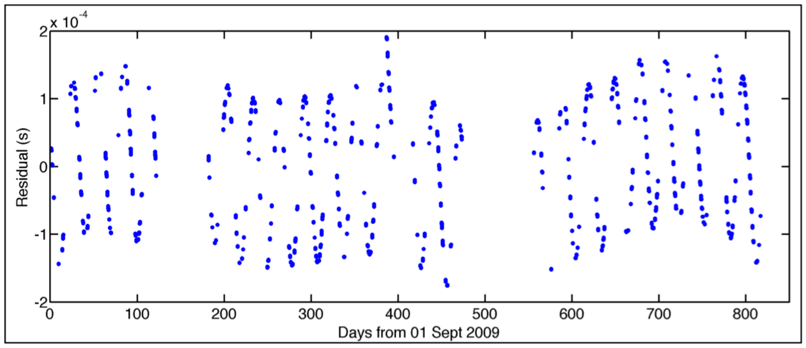

Figure 2: Left, Table of lasers used in Mercury experiment; right, LR monitoring of LRO clock showing effect of relativity on the observation.

Future Experiments:

One-way laser ranging is much simpler than two-way ranging, particularly if the spacecraft carries a laser altimeter. But the opportunities for these observations are dependent on the availability of planetary missions and instruments. In principle, there is no limit due to range in one-way uplink ranging but the requirement for spacecraft clock stability increases as the one-way light-time correction increases. At Jupiter, for example, the light-time correction is of order 3000 seconds placing a constraint on the performance of the spacecraft clock. To date, all planetary laser ranging experiments have utilized instrumentation on spacecraft that, at least in part, was designed for laser altimetry and was not optimized for ranging. Consequently, the experiments have so far been limited by the performance of the onboard altimeter performance and spacecraft capabilities.

It was demonstrated on LRO that a one-way laser ranging could be used as communications link. In the LRO experiment the effective datarate was only a few hundred bits/second but that was a limitation of the receiver electronics that was only designed with approximately 0.5 nanosecond resolution to provide ranges at the 10 cm level. If LR had been designed into the LOLA altimeter at the outset the resolution could have been significantly better enabling a much higher datarate that could, in principle, have provided a backup to the microwave communications system for up-linking commands to a spacecraft.

References:

1. Zuber, M.T. et al, Seconds of Data…..YEARS OF TRYING, Photonics Spectra, May, 2006
2. Cavanaugh, J.F. et al, The Mercury Laser Altimeter instrument for the MESSENGER mission, Space Sci. Rev., 131, 451-480, doi: 10.1007/s11214-007-9273-4, 2007.
3. Zuber, M.T. et al, The Lunar Reconnaissance Orbiter laser ranging investigation, Space Sci. Rev., 150 doi: 10.1007/s11214-009-9511-z, 63-80, 2010.
4. Smith, D.E. et al, The Lunar Orbiter Laser Altimeter investigation on the Lunar Reconnaissance Orbiter mission, Space Sci. Rev., 150 doi:10.1007/s11214-009-9512-y, 209-241, 2010.
5. Smith, D.E. et al, Two-way laser link over interplanetary distance," Science 311(5757), 53 (2006).
6. Sun, X. et al, Simultaneous laser ranging and communication from an Earth-based satellite laser ranging station to the Lunar Reconnaissance Orbiter in lunar orbit, Optics Express, Jan 2013.