OPTICAL RANGING IN THE SOLAR SYSTEM: SCIENCE REQUIREMENTS AND OPPORTUNITIES.

D. E. Smith[1], M. T. Zuber[1], and X. Sun, [1]Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139 USA (smithde@mit.edu); [2]Solar System Exploration Division, NASA Goddard Space Flight Center, Greenbelt, MD 20771 USA.

Introduction: The making of very precise range measurements over planetary distances has been a hope and objective for many years but progress has been slow and the accomplishments modest. Experiments have been conducted over the last two decades that have demonstrated limited capabilities and established engineering and instrumental requirements for accurate planetary ranging.

The experiments conducted thus far have highlighted some of the challenging physical and scientific modeling requirements for analyzing these data.

To date, routine ranging over an astronomical unit has yet to be demonstrated.

Observational Quality: Optical ranging has usually been tied to optical communication, the latter of which is a much more difficult capability, although it does not require it. Range and range rate measurements are the basic observation types needed for planetary geodesy and geophysics and are usually “two-way”, although “one-way” measurements that require additional knowledge at both the transmit and receive station can be very valuable for certain science investigations that require less absolute accuracy. Accuracy is the main issue for optical ranging, sometimes referred to as laser ranging, since the current performance at microwave wavelengths is extremely capable and meets many science requirements, as has been demonstrated on many planetary missions over many years.

Quality is key to the value of any observation and planetary-scale optical tracking needs to at least equal, and preferably exceed, the present routine microwave capability of the order of 0.1 mm/s for a 1-second integration time (X-band), and in particular circumstances such as the GRAIL spacecraft to spacecraft tracking in lunar orbit [1], exceed the 1 micron/s for a 1-second integration time. One of the benefits of optical wavelengths is independence from the effects of the interplanetary medium in the measurement, which can be severe for many microwave frequencies when the ray passes close to the sun, for example.

Experimental Observations: Many experiments have been possible because of the presence of laser altimeters on several planetary missions in which the altimeter laser acts as a transmitter and the altimeter detector functions as the receiver. One of the earlier experiments [2] demonstrated an uplink capability to the 50-cm receiver telescope of the MOLA instrument [3] on Mars Global Surveyor while in Mars orbit for a range in excess of 84 million km. No downlink capability was possible due to the previous failure of the MOLA oscillator that triggered laser transmitter.

A second experiment utilized the Mercury Laser Altimeter (MLA) [4], on the MESSENGER spacecraft en-route to Mercury demonstrated the two-way capability over 28 million km [5]. The two-way measurement enabled the range and velocity of the spacecraft to be determined and the calibration of the MESSENGER clock to Earth time at the Earth laser tracking station. If this capability were possible on a routine basis it would permit full knowledge of the spacecraft trajectory at a level comparable to the Deep Space Network.

Although limited, these experimental results enabled the one-way experiment [6] on the Lunar Reconnaissance Orbiter (LRO) spacecraft using the LOLA [7] instrument and a dedicated receiver attached to the spacecraft high gain antenna. This experiment, which was conducted continuously for nearly 5 years, showed that routine one-way laser tracking of a spacecraft in lunar orbit was possible and able to provide orbital information comparable to microwave tracking and that weather at the ground station (Greenbelt, Maryland) was not limiting factor.

The latest, and most comprehensive experiment was the Lunar Laser Communications Demonstration (LLCD) [8] experiment on the LADEE mission [9] to the Moon. This experiment was for demonstration of very high data communication between lunar orbit and Earth, in both directions, and also provided high precision range observations between the spacecraft. Although the experiment was limited to a few hours of data over several weeks it demonstrated that reliable two-way communication and ranging were routinely possible over lunar distances with every expectation of similar performance on a planetary scale.

Opportunities: Future missions, such as outer solar system missions JUICE and Europa Clipper, will probably enable further experiments and even full laser communication opportunities. But it is likely that these will also be experimental or demonstrations since obtaining measurements over greater ranges than the Moon will introduce additional complications of an engineering and analysis nature.

The application of high quality optical range measurements will likely be used initially for navigation during cruise and orbit determination at a planet or asteroid where routine performance is more important than the quality of the measurement. Eventually, optical ranging at the millimeter level will lead to improvements in spacecraft tracking that will improve planetary and asteroid gravity field modeling.

Although scientific knowledge may be a driver of the technology, the implementation will most likely be driven by the future human exploration of the solar system in which the improvements in gravity and topography of planetary bodies are likely to be demanded for reasons of safety, and by the need for the high data rates of the future.

References:

[1] Zuber M. T. et al. (2013) *Space Sci. Rev. 178,* 3-24, doi:10.1007/s11214-012-9952-7. [2] Abshire J. B. et al. (2006) *Conf. on Laser Electro-Optics (CLEO),* doi: 0.1109/CLEO.2006.4628090, Long Beach, CA. [3] Zuber M. T. et al. (1992) *J. Geophys. Res.* 97, 7781–7797. [4] Cavanaugh J. F. et. al. (2007) *Space Sci. Rev. 131,* 451-479, doi: 10.1007/s11214-007-9273-4. [5] Smith D. E. et al. (2006) *Science 311,* 53, doi: 10.1126/science.1120091. [6] Zuber M. T. et al. (2010) *Space Sci. Rev. 150,* 63–80, doi:10.1007/s11214-009-9511-z. [7] Smith D. E. et al. (2010) *Space Sci. Rev. 150,* 209-241, doi:10.1007/s11214-009-9512-y. [8] Boroson D. M. et al. (2009) *Third IEEE Conf. on Space Mission Challenges for Information Technology*, pp. 23-28, doi: 10.1109/SMC-IT.2009.57, Pasadena, CA. [9] Elphic R. C. et al. (2014) *LPSC 45*, abstract #2677.