**CURRENT AND FUTURE LUNAR SCIENCE FROM LASER RANGING.** J. G. Williams[1], D. H. Boggs[1], J. T. Ratcliff[1], J. O. Dickey[1], and T. W. Murphy[2], [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, 91109 (e-mail James.G.Williams@jpl.nasa.gov), [2]University of Washington, Seattle, WA, 98195.

**Introduction:** The interior properties of the Moon influence lunar tides and rotation. Three-axis rotation and tides are sensed by tracking lunar landers. The Lunar Laser Ranging (LLR) experiment has acquired three decades of accurate ranges from observatories on the Earth to four corner-cube retroreflector arrays on the Moon. Lunar Laser Ranging is reviewed in [1].

**Lunar Science Questions:** What is the deep interior structure and properties? What are the core properties? Is there an inner core? What causes strong tidal dissipation? What roles did tidal and core dissipation play in the dynamical and thermal evolution? What stimulates free librations?

**Moment of Inertia:** Analyzing tracking data on orbiting spacecraft gives the second-degree gravity harmonics $J_2$ and $C_{22}$. From LLR one obtains the moment of inertia combinations (C-A)/B and (B-A)/C. Combining the two sets gives $C/MR^2$, the polar moment normalized with the mass M and radius R [2].

**Elastic Tides:** Elastic tidal displacements are characterized by the lunar (second-degree) Love numbers $h_2$ and $l_2$. Tidal distortion of the second-degree gravity potential and moment of inertia depends on the Love number $k_2$. Love numbers depend on the elastic properties of the interior including the deeper zones where the seismic information is weakest. LLR detects tidal displacements [3], but more accurate is the determination of $k_2 = 0.0266\pm0.0027$ through rotation [4]. The orbiting spacecraft determination through variation of gravity field is $k_2 = 0.026\pm0.003$ [5]. Simple model values of $k_2$ are lower than both determinations and a partial melt above the core and below the deep moonquakes, previously suspected from the seismic data [6], would improve agreement [4].

**Tidal Dissipation:** The tidal dissipation Q is a bulk property which depends on the radial distribution of the material Qs. LLR detects four dissipation terms and infers a weak dependence of tidal Q on frequency [3]. The tidal Qs are surprisingly low, but LLR does not distinguish the location of the low-Q material. At seismic frequencies low-Q material, suspected of being a partial melt, was found for the zone above the core.

**Dissipation at a Liquid-Core/Solid-Mantle Interface:** A fluid core does not share the rotation axis of the solid mantle. While the lunar equator precesses, a fluid core can only weakly mimic this motion. The resulting velocity difference at the core-mantle boundary causes a torque and dissipates energy. Several dissipation terms are considered in the LLR analysis in order to separate core and tidal dissipation. Applying Yoder's turbulent boundary layer theory [7] yields 1-sigma upper limits for the core radius of 352 km for molten iron and 374 km for the Fe-FeS eutectic [3].

**Inner Core:** A solid inner core might exist inside the fluid core. Gravitational interactions between an inner core and the mantle could reveal its presence.

**Evolution and Heating:** Both tidal and core-mantle dissipation would have significantly heated the Moon when it was closer to the Earth [3,8]. Early dynamical heating could have approached radiogenic heating helping to promote convection and a dynamo.

**Core Ellipticity:** A fluid core also exerts torques if the core-mantle boundary (CMB) is elliptical. LLR detection of elliptical effects is marginal. Core ellipticity influences solutions for the Love number and the above $k_2$ value has a preliminary ellipticity correction.

**Free Librations:** Lunar free libration modes are subject to damping so the observed amplitudes imply active or geologically recent stimulation [9]. If the mode analogous to Chandler wobble is stimulated by eddies at the CMB [10] then such activity might be revealed as irregularities in the path of polar wobble.

**Site Positions:** The moon-centered locations of four retroreflectors are known with submeter accuracy [11]. These positions are available as control points for current [12,13] and future networks.

**Future:** Important time scales for lunar science observations span 1/2 month to decades and continued accurate tracking of multiple lunar retroreflectors will give further results. A ranging system with improved accuracy and sensitivity is being assembled [14] which will improve results. It will allow ranging to single corner-cube reflectors which even small landers could carry. A wider spread of reflector locations would improve the determination of rotation and tides so reflectors on future landers would benefit lunar science.

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