A VIEW OF THE LUNAR INTERIOR THROUGH LUNAR LASER RANGE ANALYSIS.

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Introduction: Laser ranges between observatories on the earth and retroreflectors on the moon started in 1969 and continue to the present. Recent range accuracies are 2 cm while earliest ranges are an order of magnitude less certain. Four retroreflectors are ranged: three located at the Apollo 11, 14, and 15 sites and one on the Lunakhod 2 rover. Accurate analysis of the range data determines a number of lunar science parameters. The lunar interior variables include a fluid core parameter.

Data Analysis: The Lunar Laser Ranging effort is reviewed in [1]. Many parameters are detected through their influence on rotation. Also detected are solid-body tides and accurate selenocentric reflector locations. Determined through the rotation are moment-of-inertia differences, gravitational harmonics, potential Love number, and dissipation effects due to tides and molten core. The rotation of the moon is not at its minimum energy state; some recently active process has caused free librations [2]. The moment differences contributed to the recent improvement of the moon's moment of inertia from the Lunar Prospector gravity field [3]. The Love numbers provide bulk elastic properties. Future possibilities for measurement include oblateness of the core-mantle boundary, and core moment.

Dissipation: A study of dissipation signatures in the rotation determines tidal Q vs frequency and concludes that the moon has a molten core [4]. At 1 month the tidal Q is 37 and at 1 yr it is 60. The core radius is $\leq$352 km for iron and $\leq$374 km for the Fe-FeS eutectic. The core detection exceeds three times its uncertainty. The spin of the core is not aligned with the spin of the mantle and torque arises from the velocity difference at the boundary. Yoder's turbulent boundary layer theory [5, 6] is used to compute the radii.

Tidal Heating: The present heat generation from tides and core interaction is minor compared to radiogenic heating. The heating for ancient times is more interesting. Peale and Cassen [7] investigated lunar tidal heating while the lunar orbit expanded due to tides on earth. Their calculations predate the measurement of Q and should be multiplied by 3.45 to match the lunar-laser-determined Love number and monthly Q. Tidal heating computations depend on how fast the lunar orbit evolved and whether the tidal dissipation is localized. Neither is known, but plausible assumptions lead to early central region temperature increases of several hundred degrees. Most of the energy is deposited early in the moon's history.

Core Heating: The turbulent boundary layer theory allows a prediction of energy dissipated at the core-mantle boundary during orbit evolution. Under the assumption that the properties of the early core are the same as at present, the energy dissipated by core-mantle interaction is about the same as for tidal dissipation, but it is deposited in a smaller volume. This source of energy is capable of promoting convection in an early fluid core and driving a dynamo. This is a transient phase with a duration depending on the rate of orbit evolution. Plausible assumptions lead to a duration of a few hundred million years. Thus, the remnant magnetization of many lunar rocks is compatible with a brief global magnetic field powered by dynamical energy dissipation.

Future Data: Analysis of the lunar laser ranges is providing information on lunar geophysics. Future data will improve accuracies of present solution parameters, and several more interior effects should be detectable.

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