SOLAR SYSTEM TESTS OF GRAVITATIONAL THEORY AND MEASUREMENT OF J2 FOR THE SUN

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In 2015 ESA is planning to launch its first mission to Mercury, called BepiColombo. This mission will place two satellites in orbit around the planet. One is the Mercury Planetary Orbiter (MPO), and it will be inserted into a 400 km by 1500 km altitude orbit. This orbit will make possible quite complete mapping of the gravity field of Mercury, and detailed studies of its northern hemisphere as well as its southern hemisphere.

The MPO will carry a dual-frequency microwave transponder based on that flown on the Cassini mission, but with substantial improvements. These include the use of a pseudo-random ranging code, as well as a quite high code rate. The limitations on the accuracy of ranging from Earth to MPO due to the transponder and the intervening medium is expected to be 10 cm. Doppler measurements will permit the gravity field of Mercury and the orbit of MPO to be determined very accurately, so that the main contribution to the uncertainty in the center-of-mass distance from Earth to Mercury will be from limitations in the ranging stations on the Earth, unless substantial improvements are made. The largest error source is likely to be from imperfect knowledge of geometry changes with time in the ranging system antennas.

An extensive analysis has been carried out of how well our knowledge of the dynamics of the inner part of the solar system and other quantities such as various parameters from the Parametrized Post-Newtonian (PPN) formulation of gravitational theory can be determined from the BepiColombo mission ranging data. The results have been published by Ashby, Bender and Wahr [Phys. Rev. D 75, 022001 (2007)]. The analysis method used makes allowance for the fact that systematic errors in the measured ranges are likely to be more of a limitation than purely random errors.

The parameters to be determined include 9 orbital parameters for the pair of planets, the Cavendish constant G times the mass of the Sun, an improved limit on the possible rate of change of G suggested by some theories, J2 for the Sun, and up to 6 PPN parameters. Besides the orbital parameters for the Earth and Mercury, the most striking improvement in accuracy would be for J2 of the Sun. On the assumption that general relativity is correct, the uncertainty in J2 could be reduced by a factor 40 to about one part in a billion. This would give valuable new information on the rotation of the deep interior of the Sun that apparently cannot be determined in other ways.

To achieve the full accuracy for determining J2 for the Sun and all of the other parameters of interest, it is important that the X-band and Ka-band ranging to MPO be carried out from the 34 meter antennas of the NASA Deep Space Network (DSN). In addition, although very careful calibration measurements have been carried out for these antennas, it is important that efforts to improve the calibrations be pursued in the remaining roughly 10 years before MPO is inserted into its orbit around Mercury. Only then can the full potential accuracy of 10 to 15 cm for the ranging data be achieved.

In view of the above, we believe that improvements in the ranging accuracy for the DSN 34 meter antennas, and use of the DSN to improve knowledge of solar system dynamics and test gravitational theory, should be an important part of the NASA science strategy, particularly in the next 10 years.