LETTERS TO THE EDITOR

ASTROPHYSICS

A Radar Determination of the Rotation of the Planet Mercury

During the recent inferior conjunction of the planet Mercury in April, 1965, radar observations were obtained by the Arecibo Ionospheric Observatory in Puerto Rico (operated by Cornell University with the support of the Advanced Research Projects Agency under a Research Contract with the Air Force Office of Scientific Research). The system operated at a frequency of 430 Mc/s, with an antenna gain of 56 dB and a transmitted power of 2 MW. The resulting sensitivity was sufficient to obtain significant echoes not only from the nearest part of the planetary disk but also from more distant regions, removed by up to 0·06 of the planet's radius. By using short transmitted pulses of 500 μsec duration, it was possible to isolate the echo power from these more distant regions, and to carry out a Fourier analysis of their spectral composition.

Since the source of the delayed echoes can quite reliably be associated with a known area of the planetary surface, the magnitude of the apparent planetary rotation can be inferred from the measured spectral dispersion through a simple geometrical relationship. The apparent rotation is the vector sum of an intrinsic rotation and a contribution arising from the relative motion of the observer and the target planet. Since the latter is quite accurately calculable from the known orbital motions of the Earth and Mercury and the known rotation of the Earth, a constraint is set on the allowable vector magnitude and position assigned to the intrinsic planetary rotation.

By carrying out observations spread over a period of time it is possible to solve for both the magnitude and direction of the planetary rotation. In the present series of observations, data have been obtained for April 6, 10, 12 and 25, 1965. On most of these days it was possible to check the results by comparing the inferred angular rotation obtained from data at various delays measured with respect to the earliest (and strongest) echo component. From this comparison a degree of confidence could be established, and an estimate obtained of the measurement error.

The data were used to compute a most likely value of intrinsic planetary rotation with a procedure developed by Dr. Irwin Shapiro of the Lincoln Laboratory, Massachusetts Institute of Technology. Fig. 1 shows the measurements together with the best fit curve. The curve for a retrograde rotation which would be permitted on the basis of the data of April 6, 10 and 12 alone is also included, as is the behaviour that would be expected on the assumption of rotation which is synchronous with the orbital period. As shown in Fig. 1, the rotation is direct with a sidereal period of 59 ± 5 days. The direction of the pole is not well-determined from these limited data, but is approximately normal to the planetary orbit.

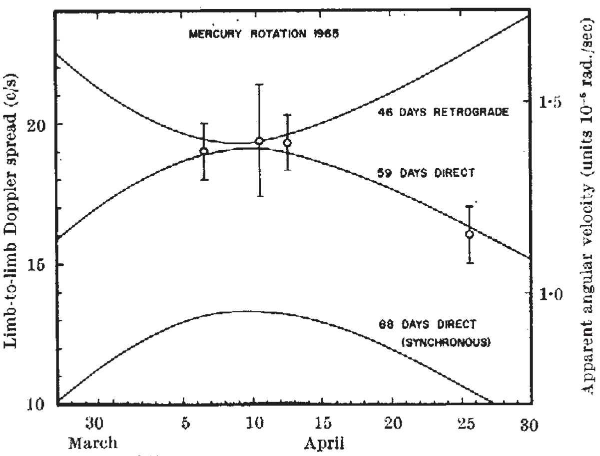

Fig. 1. Plot of the apparent rotational angular velocity of the planet Mercury versus date for several values of rotation during the inferior conjunction of April 1965. The values inferred from the measurements are shown with their estimated errors

The finding of a value for the rotational period of Mercury which differs from the orbital period is unexpected and has interesting theoretical implications. It indicates either that the planet has not been in its present orbit for the full period of geological time or that the tidal forces acting to slow the initial rotation have not been correctly treated previously, as suggested in the following communication.

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Rotation of the Planet Mercury

Solar tidal friction must be an intense effect for Mercury, and it must be expected that the planet's spin would have relaxed from any original value to one that is under the control of this effect in a time short compared with the age of the solar system. The retarding torque exerted by the Sun on a planet is proportional to $1/r^6$ (where r is the distance Sun-planet), a factor which is some 300 times greater for Mercury than for the Earth. For a planet on a circular orbit the final condition would then be one of synchronous rotation like the motion of the Moon with respect to the Earth. Mercury's motion around the Sun takes 88 days and for synchronous rotation the sidereal period would thus be 88 days also. The observed value of 59 ± 5 days differs markedly from this (see preceding communication).

For a planet with substantial orbital eccentricity the condition is different, however, and synchronous rotation with the orbital period need not then be expected. With the $1/r^6$ dependence the tidal torque at perihelion will exceed that at other times, and the angular velocity of the planet will thus settle at a value greater than the mean orbital angular velocity, but not quite as great as the orbital angular velocity at perihelion. For Mercury, where the eccentricity is 0·2, 2π times the reciprocal of the orbital angular velocity at perihelion is 56·6 days. A spin with a sidereal period lying between 56 and 88 days thus must be expected.

A more precise calculation may be made based on the consideration that the final angular velocity of the planet will be such that the time average of the tidal torque around the orbit is zero. No further change in the planet's spin will then occur except on the much longer time scale on which other orbital elements can be influenced by tidal friction, effects which probably are unimportant in the age of the solar system. The precise calculation of the angular velocity to fit this condition can be made without a quantitative description of the dissipation properties of the planet, but involving certain assumptions. The tidal phase lag has to be assumed to be a small angle only, and one may make the calculation with Q being dependent on amplitude and frequency in a variety of ways ($1/Q$ is the specific dissipation function[1]). If Q is assumed to be inde-

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