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Can We Detect Changes in the Solar Flattening with an Artificial Planet?

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Abstract

The gravitational quadrupole moment of the sun provides information on internal structure and dynamics. Estimates of this parameter from helioseismology are uncertain and model dependent. A proposed approach to improve estimation by tracking Mercury and an artificial planet, out of the plane of the ecliptic, is discussed.

1. Introduction

The sun is a gaseous body with a dynamic interior that likely has a gravity field that changes with time due to processes that cause 11- and 22-year cycles in solar electromagnetic output, particle radiation, and changes in the solar magnetic field. The magnitudes of these changes, if they exist, are speculative, but dynamic models and helioseismological results suggest a gravitational flattening of degree 2 [e.g., 1-6] exists, although there is no evidence for temporal variations.

To estimate the gravity field of a planet, tracking data of one or more spacecraft are generally analyzed for their gravitational perturbations. The present dynamic solutions for the degree-2 solar gravity field are derived from the orbital motion of Mercury, which has an orbit of near-zero inclination (~4^{o}) with respect to the solar equator, thus limiting its accuracy and the ability to detect any variation. We suggest that improvements and possible changes in the present degree-2 zonal coefficient in the solar gravity field, could be obtained if an additional "planet" in a similar orbit to Mercury existed, but at a higher orbital inclination.

2. An Artificial Planet

We suggest that an artificial planet, referred to here as AP1, could be placed in an orbit inclined to the ecliptic and tracked by optical or microwave systems to provide the orbital behavior of AP1 at the highest possible accuracy for a period of several years [cf. 7]. In combination with orbital data already available for Mercury from the MESSENGER mission, and data expected from the upcoming BepiColombo mission, estimates of the degree- and order-2 solar gravity field, and its possible variation, could be obtained, or at least bounded. Figure 1 shows a sketch of the general concept.

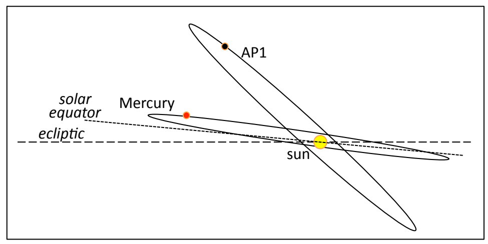

Figure 1: Concept of Mercury and an artificial planet (AP1) for estimating the low-degree solar gravity field.

3. Orbit

The orbit of AP1 will need to be a balance between the desire for a substantially higher inclination than Mercury and the ability to achieve the out-of-the-ecliptic trajectory necessary at launch. As the inclination increases, the sensitivity to the zonal coefficients of degree 2 becomes less. For the orbit of Mercury and the proposed orbit of AP1, the ability to detect any degree-3 or higher gravity terms are almost impossible due to the radii of the orbits being approximately 100 times the solar radius. We suggest an orbital radius similar to that of Mercury would be adequate because we know that at that distance the degree-2 zonal term is measureable. But a closer orbit would be much preferable, if physically possible, and would improve the chances of detecting any variations, both zonal and longitudinal.

Attaining a high solar inclination is challenging but has been achieved in the past, as for example the Ulysses mission, which used a gravitational assist from Jupiter to obtain a solar inclination of ~79^{o} [8].

The detection of the solar gravity field will most likely be from the secular or long-period perturbations of the node and argument of perihelion, and so it is advisable to avoid an inclination of ~63.4^{o} where the degree-2 motion of the perihelion is zero. In addition, if there is any possibility of detecting the degree-3 zonal term, then an inclination of ~31.1^{o} should be avoided. We therefore suggest an inclination to the solar equator of 45^{o} to 50^{o} would ensure an observable signal from the degree-2 gravity field from the motion of both the node and perihelion.

4. Radiation & Tracking

Equally challenging will be the compensation of solar radiation pressure, nearly 7 times larger at Mercury than at Earth, and thus likely requiring some form of “drag-free” system. However, systems on Earth-orbiting spacecraft have managed to compensate for air drag, a much larger force than that from solar radiation at Mercury. The tracking of the AP1 could be performed at microwave or optical frequencies, but the former will require a large antenna that might make the s/c more massive and complicated than we think necessary. We therefore believe laser tracking is preferable.

5. Summary and Conclusions

An artificial planet in an appropriate orbit will be sensitive to the degree-2 gravity field of the sun. Observation of Mercury’s orbit from observations of the MESSENGER spacecraft have already estimated the degree-2 zonal term, but there is a probability that the coefficient could be changing slowly as result of decadal periodic changes occurring within the sun. Observations of the orbital motion of another planetary body in a similar orbit to Mercury, together with present and future Mercury observations, would improve the accuracy and may enable any long period changes to be detected. Such a detection would provide evidence of present-day structural and dynamic processes deep within the sun, possibly related to the 11- and 22-year solar cycle.

We recognize that the design and operation of this mission will not be trivial, but if we can measure the changes in solar gravity field, and infer changes occurring deep in the solar interior, we will have advanced our understanding of our solar system and of the dynamics of sun-like stars.

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