An explanation of the rotational state of Mercury

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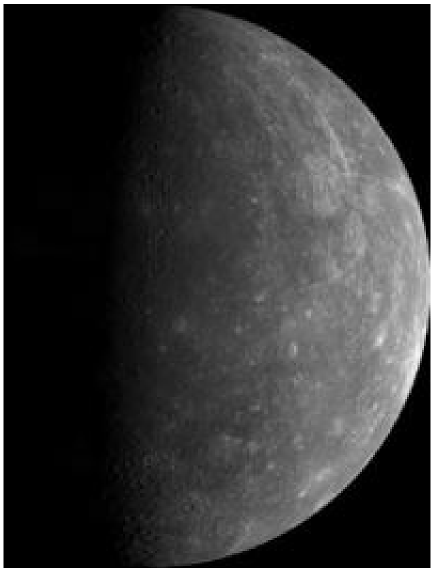

Mercury. Credit: NASA

Planetary scientists announced a new explanation of the current rotational state of the planet Mercury. The report was presented by Dr. Benoit Noyelles of the University of Namur, Belgium, to the meeting of the Division for Planetary Sciences of the American Astronomical Society, held in Denver, CO. This work has been carried out in collaboration with Drs. Julien Frouard of the University of São Paulo, Rio Claro, Brazil, and Valeri Makarov and Michael Efroimsky of the US Naval Observatory, Washington, DC. The study explains why the rotation period of Mercury is exactly two thirds of its orbital one, and how the planet avoided being trapped into higher spin-orbit resonances or into synchronous rotation. The released study sheds light on the likely state of Mercury during the early stages of its dynamical history.

Mercury is the innermost planet of the solar system, orbiting at one third of the Sun-Earth distance. Its dynamics is unique in that it has a significantly elongated orbit around the Sun, and its rotation period with respect to distant stars is exactly two thirds (58 days) of the period of its orbital revolution (88 days). This state is a particular case of dynamical resonance, whose origin has been discussed since the 1960s. Mercury is believed to have had a much faster rate of rotation at its creation, which declined to its current value relatively quickly on the scale of its lifetime, probably within a few tens of million years. The challenge is to explain why Mercury stopped to slow down at the 3:2 resonance, instead of synchronizing its rotation in the commonly observed 1:1 resonance, examples whereof are rendered by the Moon and other natural satellites.

A critical difficulty of this problem resides in adequate modeling of the tidal torques inducing rotational deceleration. In the case of Mercury, this is a torque due to the solar tides. The gravitational pull exerted by the Sun raises bodily tides on Mercury—a complex picture of time-dependent tidal stress and of the resulting tidal strain in the planet. A tidal bulge of a complex shape and spectrum emerges on Mercury's surface and runs across the circumference of the planet, causing relatively small in amplitude but nevertheless massive upheavals of the solid material. Internal friction dissipates the kinetic energy of Mercury's rotation. Slightly leading the direction of the external gravitational force, the tidal bulge elongates the figure of Mercury, which gives rise to an additional torque responsible for the deceleration. The tidal torque gets superimposed with a larger torque caused by the permanent figure of the planet. To model the deceleration adequately, it is necessary to take both factors into account.

The mills of God grind slowly but relentlessly. Tidal dissipation in the planet and the ensuing deceleration of its spin inevitably carry the planet through a sequence of the spin-orbit resonances. The question then becomes in which of these resonances the planet should eventually get trapped. The intensity of tidal dissipation strongly depends on the properties of the material constituting Mercury, affecting the way the tidal response depends on the frequency of excitation. Classical models proposed a few decades ago by planetary scientists failed to account for subtle variations of this response in the vicinity of resonances, which resulted in persistent difficulties in explaining the current 3:2 spin-orbit resonance of Mercury.

Recently, Michael Efroimsky and Valeri Makarov of the US Naval Observatory developed a new model of bodily tides, a model based on the laws of solid-state physics and on up-to-date geodetic, seismological, and laboratory measurements. Utilizing this model of tidal response, the international team revisited the problem of tidal evolution of Mercury's spin and found that the 3:2 resonance is indeed the most probable end-state. The frequency-dependent tidal torque acts as an efficient trap for the planet trying to traverse a resonance. The efficiency of the trap strongly depends on the value of orbital eccentricity, as well as on the temperature and viscosity of Mercury's mantle. Among the implications of the released study are, to name a few, a fast tidal spin-down, a relatively cold (i.e., not fully molten) state of the planet at the early stages of its life, and a possibility that the internal segregation and formation of the massive liquid core happened after Mercury's capture into the resonance.

This study has also shown that entrapment into the 3:2 spin-orbit resonance is likely to occur in exoplanetary systems, which are often tighter and more eccentric than in the solar system. Mercury-like states should be common among the hundreds of discovered and confirmed exoplanets, including potentially habitable super-Earths orbiting M dwarf stars. The results of this investigation provide additional insight into the possibilities of known exoplanets to support extraterrestrial life.

Mercury is currently the target of the American NASA space mission MESSENGER and will be visited by the European/Japanese ESA/JAXA mission Bepi-Colombo during the next decade. The data collected by these two spacecraft should help to further refine the tidal models of Mercury and similar planets of terrestrial composition.

Provided by University of Namur

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