Spin-Orbit Resonant Rotation of Mercury

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Abstract. One of the main characteristics of Mercury is its 3 : 2 spin-orbit resonance. The analytical 2-degrees of freedom model proposed here takes into account this phenomenon thanks to the introduction of two suitable resonant variables. Our model must be considered as a base for future computations; it does not include perturbations due to the influence of the other planets, the non-alignment of spin axis with the normal to the equatorial plane and the non-rigidity of the body. These perturbations will be added later on. However the results obtained by our simplified model for the angular variables frequencies are coherent with those given by existing complete numerical models.

1 Introduction

Mercury has received few attention from the astronomical and spatial community; the last and unique space mission concerning Mercury was Mariner 10 launched in 1973. The spacecraft flew by Mercury three times in a retrograde heliocentric orbit and returned images and data of the planet. The scientific objectives of the mission were to measure Mercury’s environment, atmosphere, surface, and body characteristics. Mariner 10 encountered the orbit of Mercury on March 29, 1974, at a distance of about 704 km from the surface, on September 21, 1974, at an altitude of 48,069 km, and on March 16, 1975, at an altitude of 327 km. The mission concluded that Mercury had no atmosphere, a cratered Moon-like surface, a small magnetic field and a relatively large iron-rich core. Concerning the gravitational field coefficients, estimations about $J_2$ and $C_{22}$ were given with large errors; the most precise values available now are taken from [1] and are: $J_2 = (6.0 \pm 2.0) \times 10^{-5}$ and $C_{22} = (1.0 \pm 0.5) \times 10^{-5}$.

For the other coefficients, the values are still purely speculative.
Two recent space missions have been programmed to explore the planet Mercury: BepiColombo\textsuperscript{1}, scheduled for a launch in 2012, and MESSENGER\textsuperscript{2}, launched on the 3rd August 2004, to unlock the secrets of Mercury, the last unknown terrestrial planet. This double departure to the forgotten planet represents a new challenge for building complete or complementary models, numerical as well as analytical, for the rigid body and its inner structure.

The particularity of Mercury, discovered in the sixties, is to be captured in a 3 : 2 spin-orbit resonance; this is the only case in the Solar System, some satellites like the Moon or Europa, are blocked in a 1 : 1 synchronous resonance, but the ratio 3 : 2 for such a resonance is unique. The papers written in the years following this discovery, were mainly devoted to the analysis of mechanisms explaining the capture in such an unusual situation, or to the description of this resonant motion. Let us mention the pioneer papers of [11] and [2, 5, 8, 12] or [4] as examples. The explanation usually accepted is that Mercury was pushed in this resonance by the tidal effects; reasonable values for the probabilities of capture were deduced, to explain the present observed situation, but they did not really privilege this resonance with respect to the other ones, like the 2 : 1 for example. However, recently, with the new numerical techniques and the power of the nowadays computers, [9] published very convincing results, showing that the probability of capture of Mercury in such a 3 : 2 resonance was higher than 0.5, as a result of its chaotic orbital dynamics.

To compute and reproduce the behavior of this insolite motion, simplified models were proposed by the authors mentioned above, as toys models, to describe the effect of the dissipations on the capture process. Unfortunately, probably due to the lack of data and the complexity of the resonant rotation, complete analytical models of rotation, using classical perturbation techniques (developed for other planets or satellites), were not applied for Mercury.

The interest of getting such a model for the space missions is obvious, even if, besides, very sophisticated numerical integrations are performed. The analytical model of rotation can be used to analyze the effect of each contribution on the motion of the satellite, through the corresponding variation equations. Let us mention, as examples, the coefficients of the gravitational field, the obliquity or the combined motion of the axes of figure and of the spin axis. The analytical methods allow to keep the unknown constants (like the higher zonal and tesseral coefficients) as parameters and to stress their influence on several variables.

Furthermore analytical orbital theories are available for Mercury, and some of them can give a precise motion over periods of time of 100 years; the idea is to build a model of rotation quite complete, in which a theory of motion is

\textsuperscript{1}Mission of the European Space Agency and ISAS, Japan's Institute of Space Astronautical Sciences

\textsuperscript{2}MErcury Surface Space ENvironment, Geochemistry and Ranging, spatial mission of NASA