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No Pseudosynchronous Rotation for Terrestrial Planets and Moons

V. Makarov,[1] **M. Efroimsky**[2]
(1) US Naval Observatory, Washington DC 20392 USA (valeri.makarov @ usno.navy.mil)
(2) US Naval Observatory, Washington DC 20392 USA (michael.efroimsky @ usno.navy.mil)

Abstract

We reexamine the popular belief that a telluric planet or satellite on an eccentric orbit can, outside a spin-orbit resonance, be captured in a quasi-static tidal equilibrium called pseudosynchronous rotation. The existence of such configurations was deduced from oversimplified tidal models assuming either a constant tidal torque or a torque linear in the tidal frequency. A more accurate treatment requires that the torque be decomposed into the Darwin-Kaula series over the tidal modes, and that this decomposition be combined with a realistic choice of rheological properties of the mantle. This development demonstrates that there exist no stable equilibrium states for solid planets and moons, other than spin-orbit resonances.

Motivation

The recent revival of interest in tidal interactions is partly due to the importance of planet's rotation for the prospects of finding habitable worlds near other stars.

Unfortunately, some of the published far-reaching conclusions about specific exoplanets were based on *ad hoc* models, which should not be used for solid planets at all. For example, the comprehensive analysis of the possible spin states of the planet GJ 581d and of the role of its obliquity evolution was carried out in [5] through consideration of two oversimplified models of the tidal torque – the constant angular lag model and the constant time lag model.

Both these toy models, introduced in [4] mainly for the ease of analytical treatment, predict quasi-static pseudosynchronous rotation states, with the planet being trapped in a slowly changing equilibrium state at a faster than synchronous rotation rate and a vanishing orbit-averaged tidal torque. This conclusion has been often cited in the literature and has made it to textbooks [8].

Except in specific (very narrow) frequency bands, these models are incompatible with the rheological properties of realistic mantles and crusts [1, 2, 3]. Analysis based on realistic rheologies demonstrates the impossibility of pseudosynchronous rotation for oceanless terrestrial objects [6]. Whether this prohibition extends to planets and moons with internal or surface oceans remains an open issue.

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