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CREEP TIDES. A NEW MODEL TO STUDY THE TIDAL EVOLUTION OF CLOSE-IN SATELLITES AND EXOPLANETS

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New theory of the bodily tide problem based on only one physical law: the Newtonian creep. It shows that rocky and gaseous bodies do not respond to tidal stresses in the same way. Almost all results of the theory result from the creeping first-order differential equation.

This communication summarizes a new rheophysical approach to tides in celestial bodies (Ferraz-Mello, 2013). In this approach, the body tends always to creep towards the hydrostatic equilibrium by the only action of the gravitational forces acting on it (self-gravitation and tidal potential) and does it with a rate inversely proportional to its viscosity. The adopted creep law is Newtonian (linear), and at every instant the stress is assumed to be proportional to the distance from the equilibrium. The coefficient of proportionality is the relaxation factor γ.

One result of this theory is that the rotation of one body is damped by tides to the neighborhood of a stationary state, as in classical Darwin's theory (see Ferraz-Mello et al. 2008). However, the final state now depends on the viscosity of the body. In the near inviscid limit (i.e. $\gamma \to \infty$), the body tends to a final rotational state which, if the eccentricity (e) is not zero, has a speed higher than the orbital mean motion (n). The excess of rotation speed is given by $\sim 6ne^2$. However, when the viscosity is large and $\gamma \ll n$ (e.g. in rocky bodies), no matter if the eccentricity is large or small, the final stationary rotation is a small oscillation about a synchronous rotation. In the case of rocky bodies, the tide component due to the eccentricity does not create the strong torque responsible for the super-synchronous rotation of gaseous bodies.

Another particular result concerns dissipation. The energy dissipation is proportional to $(\frac{\nu}{\gamma} + \frac{\gamma}{\nu})^{-1}$ (ν is the frequency of the main tide component). The maximum dissipation is reached when that frequency equals γ and decreases symmetrically when ν is different of γ no matter if larger or smaller. When $\nu \ll \gamma$ the energy dissipation is proportional to ν. This is what happens in gaseous planets and stars. When $\nu \gg \gamma$, the energy dissipation is inversely proportional to ν. This is the behavior of dissipation in rocky bodies as extensively discussed by Efroimsky and Lainey (2007) and Efroimsky (2012).

The relaxation factor γ plays a role of critical frequency and one body may behave in different ways under the action of two tidal components of different frequencies if one is larger and the other smaller than the critical frequency γ. The creep tide theory does not use the quality factor Q. In classical theories, the quality factor Q is related either to the semi-diurnal tide – in the case of a freely rotating body – or to the monthly/annual tide – in the case of a near-synchronous companion. In classical applications, these two cases are very distinct and we can adopt one of them. However, in the case of high-eccentricity exoplanets, this separation no longer occurs. The dissipation is shared in comparable parts by the semi-diurnal and the monthly/annual tide and we get different values of Q following we consider one tide component or another.

A pure creeping theory however fails to give the actual shape of the tide, observed in the Earth and in planetary satellites in synchronous rotation. For that sake, it is necessary to include in the approach a superposed elastic tide, which affects the shape of the observed tide but which is torque free.

The results show some important differences with respect to the existing theories, but also some coincidences. The way in which creep and elastic tides combine to give rise to geodetic lags of rocky bodies increasing when the frequency decreases, is appealing and may serve as a justification to the modern theories of Efroimsky and collaborators. In what concerns the differences, it is important to know if they refer to observable phenomena or not. Generally, scarce observational data make impossible to know which of the theories is correct.

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