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Orbital eccentricity influences the obliquity stability of retrograde-rotating planets

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Abstract

A terrestrial planet's obliquity, or axial tilt, largely governs changes in the planet's climate. Therefore, it is essential to understand how a planet's obliquity varies over time when judging its habitability. Previous studies suggest that planets that rotate retrograde (backward with respect to their orbital motion) may generally experience less severe obliquity variations than those that rotate prograde (the same direction as the orbital motion) [3, 1]. Opposing this claim, we find that the orbital eccentricity of a retrograde-rotating planet can influence its obliquity stability. This influence is due to a spin-orbit resonance that occurs when an orbital frequency overlaps with the planet's rotation axis precession frequency. This overlap can lead to obliquity variations that are significant in the consideration of habitability. We demonstrate this phenomenon by simulating test cases of a simple Earth-Jupiter system with the use of a modified integrator within the `mercury` package [2]. The orbital and rotation axis precession frequencies of this system are shown in the figure below. We discuss the physical mechanism that drives this resonance, and find a simple relationship that characterizes the responsible orbital frequency.

References

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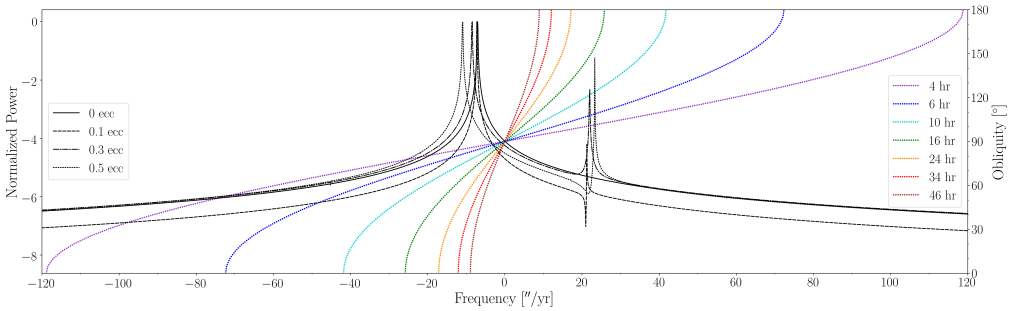

Figure 1: For each eccentricity considered, the black lines are paired with the left and bottom axes, and correspond to the Earth's orbital frequencies. The colored lines are paired with the right and bottom axes, and correspond to the Earth's rotation axis precession frequencies for a range of rotational periods and obliquities. Note the positive orbital frequency peak that is present for the eccentric cases. Regions of obliquity instability exist for retrograde-rotating Earths (having positive rotation axis precession frequencies) with rotation periods > 16 hours due to a spin-orbit resonance with this orbital frequency.