“Barrel Instability” for Elongated Secondaries in Binary Asteroids

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Background

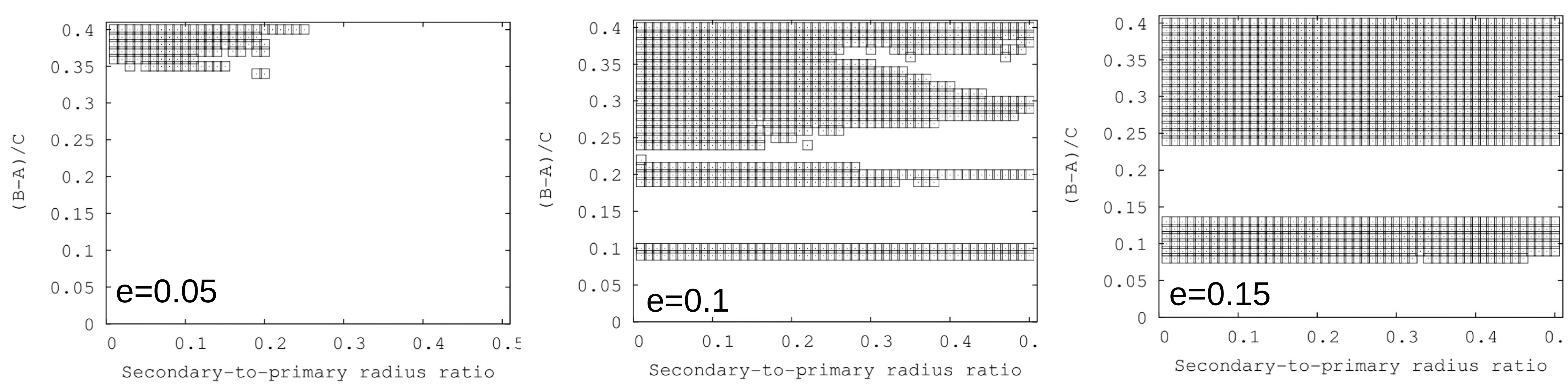
Most close-in planetary satellites are in synchronous rotation, which is usually the stable end-point of tidal despinning. Saturn's moon Hyperion is a notable exception by having a chaotic rotation. Hyperion's dynamical state is a consequence of its high eccentricity and its highly prolate shape (Wisdom et al. 1984). Chaotic rotation is expected for elongated moons in eccentric binaries (Ćuk & Nesvorný 2010; **Figure 1**) due to resonances between librations and orbital motion, and a minority of asteroidal secondaries may be in that state (Pravec et al. 2016). Secondary rotation is relevant for the action of the BYORP effect, which can quickly evolve orbits of synchronous (but not non-synchronous) secondaries (Ćuk & Burns 2005). BYORP requires secondary having long-term leading and trailing hemispheres, which is not the case in chaotic rotation.

Our Simulations

Using the integrator RSISTEM (Cuk et al. 2016, *Nature*) we find that in binary systems with a large secondary and significant spin-orbit coupling, a different kind of non-synchronous rotation may arise (**Figures 2-4**). In this "barrel instability" the secondary slowly rolls along its long axis, while the longest dimension is staying largely aligned with the primary-secondary line. This behavior of the secondary may be more difficult to detect through lightcurves than a regular asynchronous or a fully chaotic rotation in which the long axis can have any orientation. However, barrel instability would still completely arrest BYORP migration. Unlike fully chaotic rotation, barrel instability can happen even at low eccentricities, due to smaller energy requirements for this long-axis rotation of a prolate body in a tidal field.

Two-Dimensional Dynamics (Ćuk and Nesvorný, 2010)

Figure 1. Results of a planar simulation of spin-orbit dynamics in a system with an oblate primary and prolate secondary, from Cuk and Nesvorny (2010). Panels plots integration results for grids in secondary sizes (x-axis) and secondary elongations (y-axis). Binary separation was 4 primary radii; rectangles plot parameters resulting in chaotic rotation. The three panels plot results for initial eccentricities of 0.05, 0.1 and 0.15.



Three-Dimensional Dynamics (work in progress)

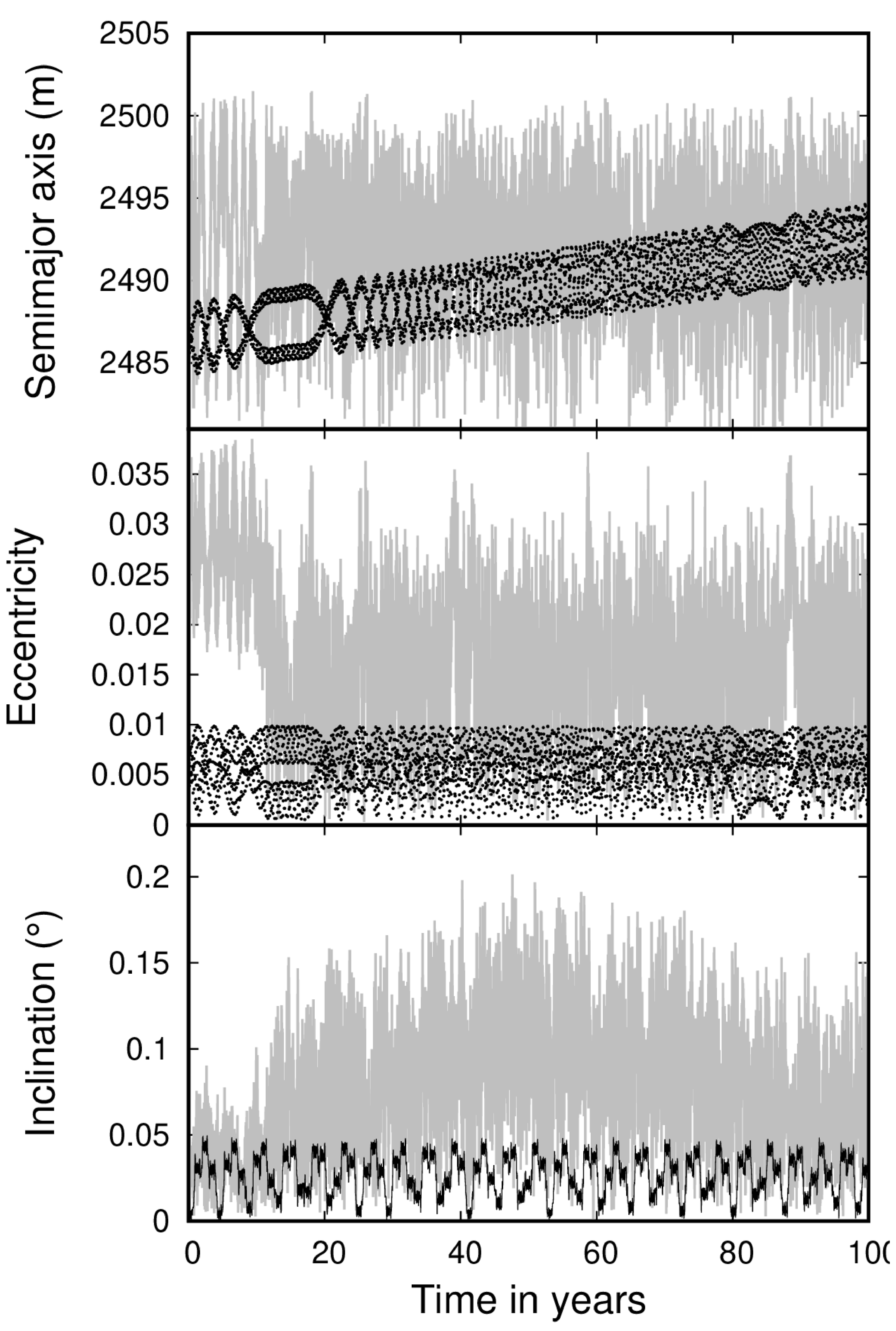


Figure 2: Mutual orbital parameters in two numerical integrations of a binary consistent (within uncertainties) with 1996 FG3. The black line shows a run with synchronous rotation, while the gray line shows “barrel” instability (the only difference was initial eccentricity).

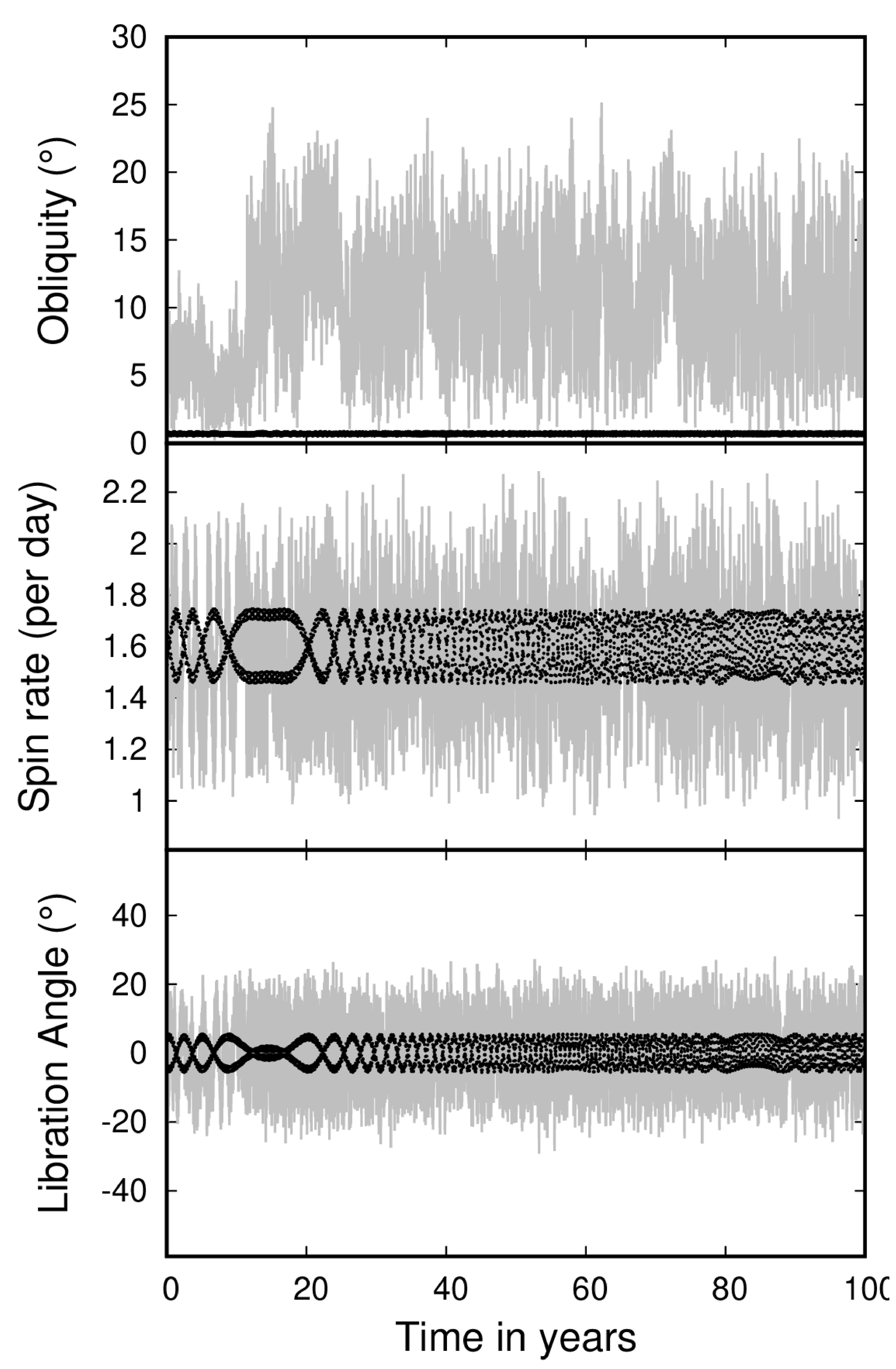


Figure 3: Top and middle plot the obliquity and spin rate of the secondary in the same simulations as shown in Fig. 2. The bottom panel plots the angle between the primary-secondary line and the secondary’s long axis (including out-of-plane misalignment due to obliquity.)

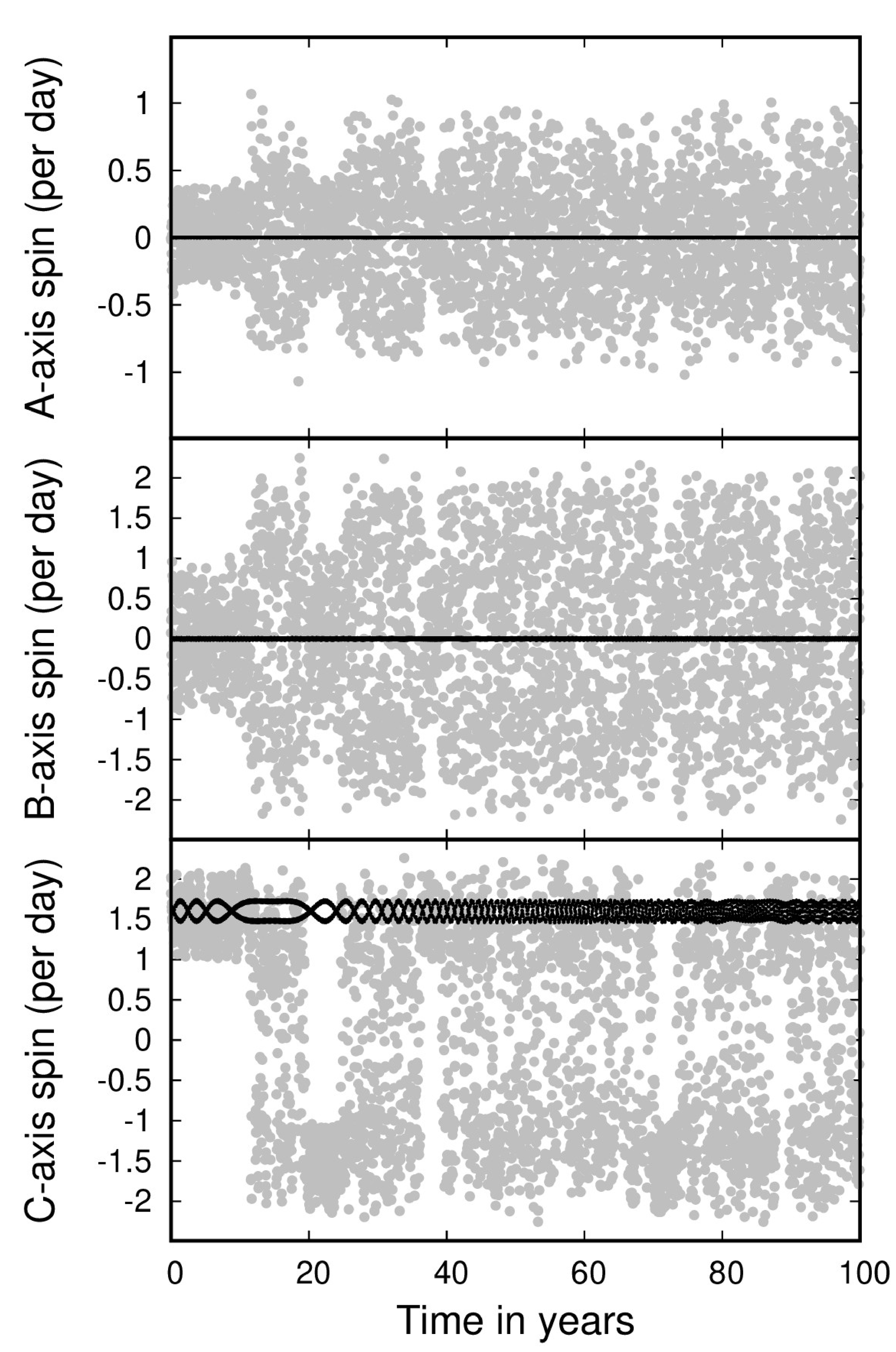


Figure 4: Rotation rates around the three principal axes (longest axis in top, shortest in the bottom panel) in the same simulations as shown in Fig. 2. The barrel instability simulation (gray line) starts out as fully synchronous, and later has short episodes of fixed pole rotation.