Chaotic Dynamics of Stellar Spin in Binaries and the Production of Misaligned Hot Jupiters

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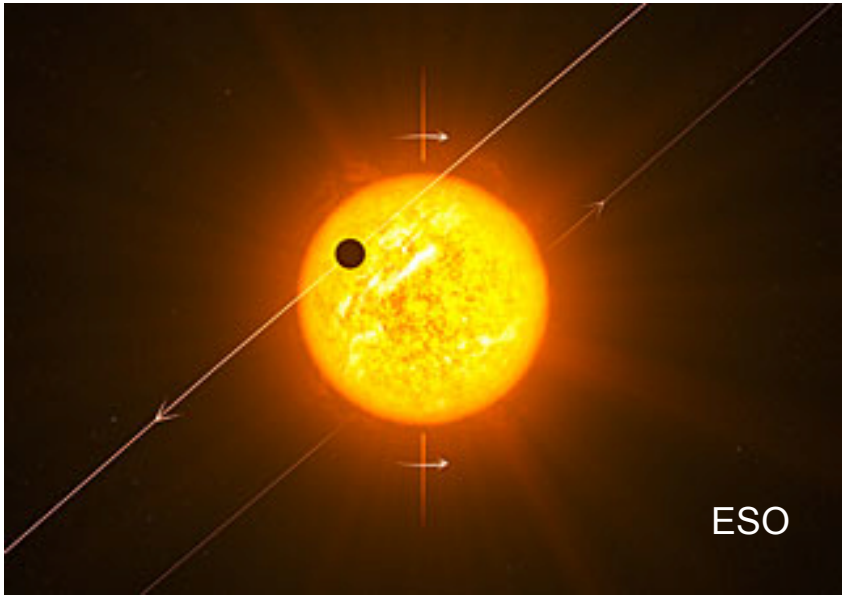
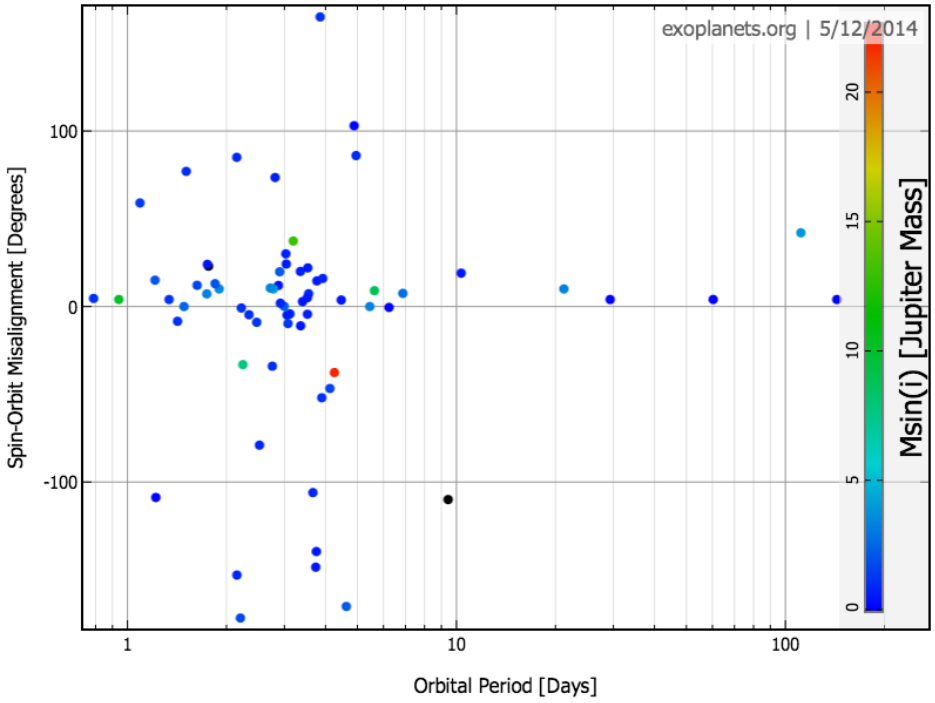
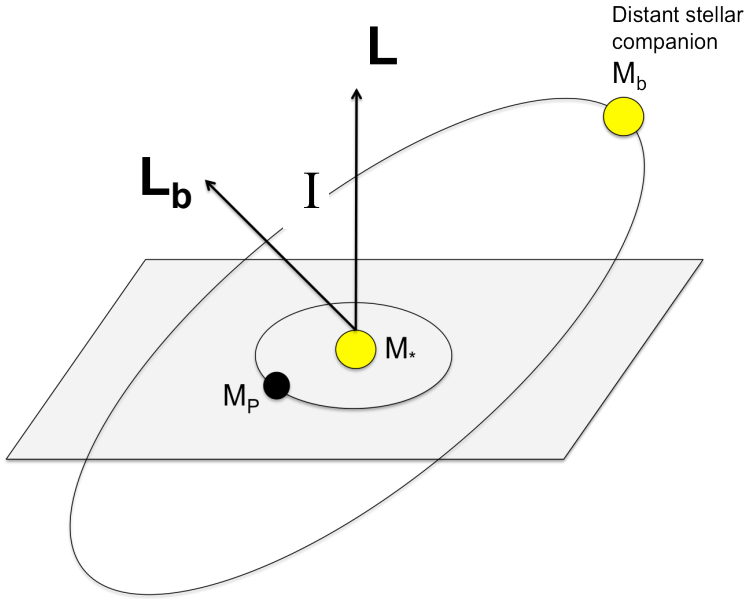
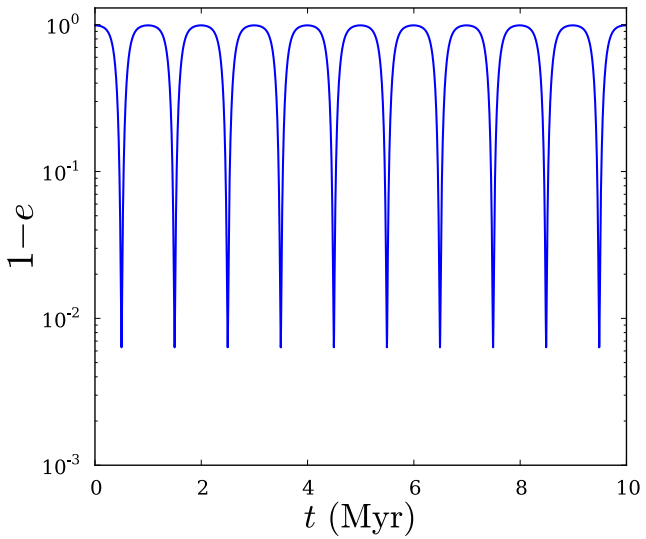
Many hot Jupiter systems have been found to exhibit misalignment between the orbital axis (**L**, the axis perpendicular to the orbital plane) and the rotation axis (**S**) of its host star

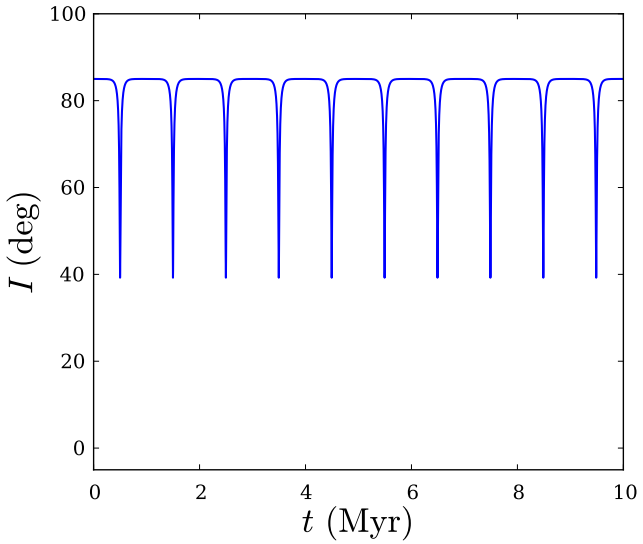




A distant (~100 AU) binary companion (M_b) of the planet-hosting star (M_*) can change the eccentricity (e) and inclination (I, the angle between **L** and the binary axis $\mathbf{L_b}$) of the planet (M_p) in a periodic way -- This is called Kozai-Lidov oscillation



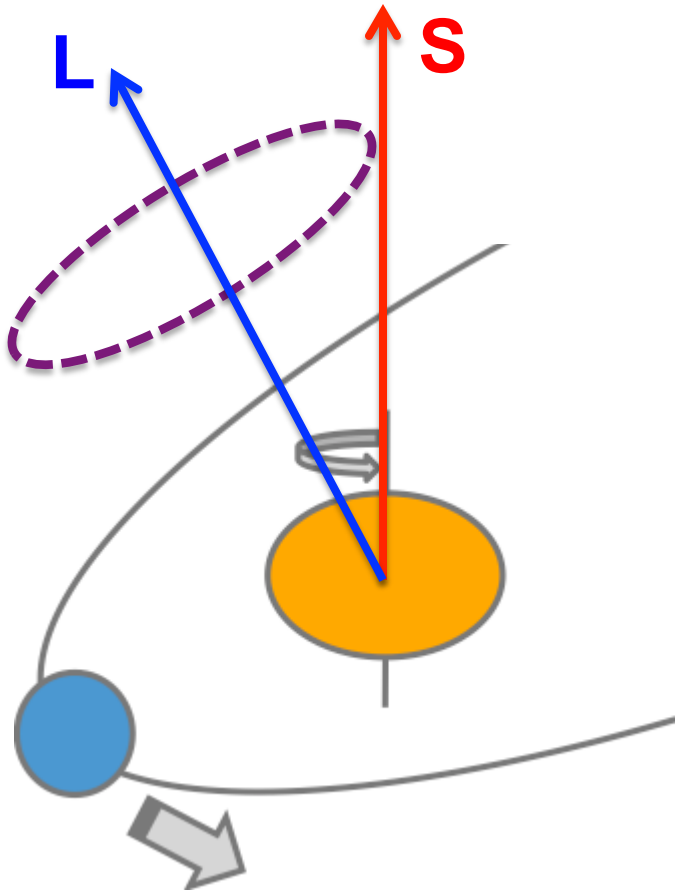




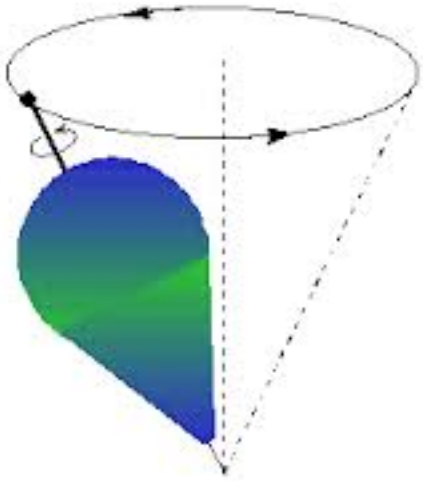
Stellar Spin Dance

The host star is spinning, and therefore has an oblate shape.

Gravity from the planet acting on the oblate star makes **S** (the rotation axis of the star) precess around **L** (the orbital axis of the planet).



This is analogous to the precession of a spinning top due to Earth's gravity



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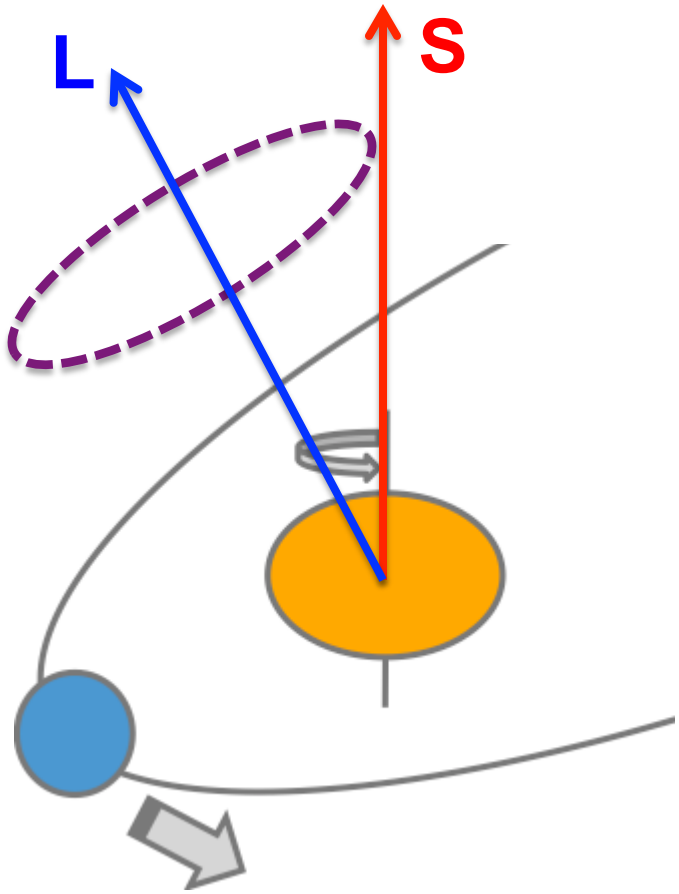
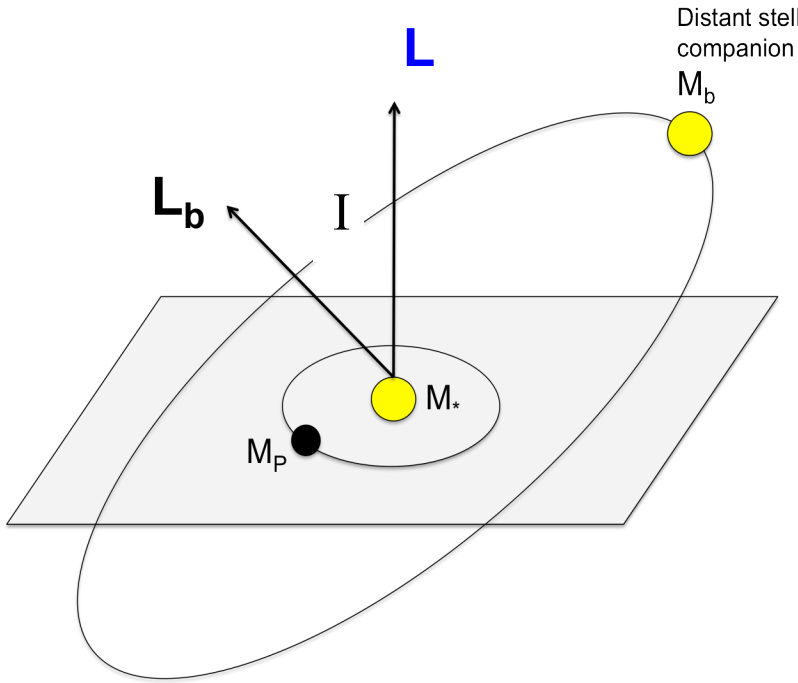


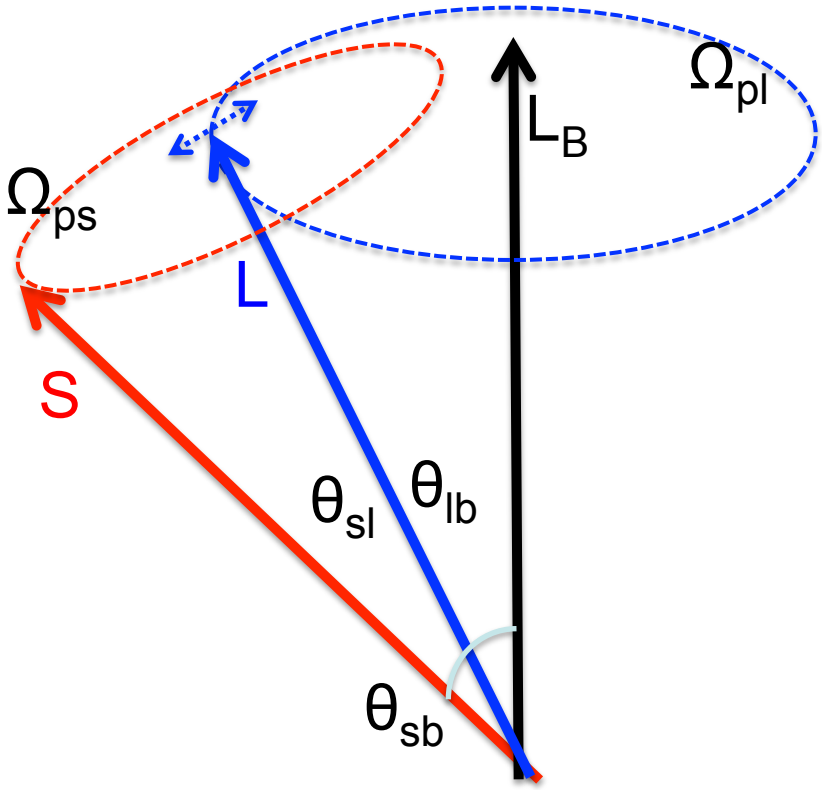
However, recall that **L** itself is changing due to the gravity from the distant binary companion



Spin-Orbit Evolution

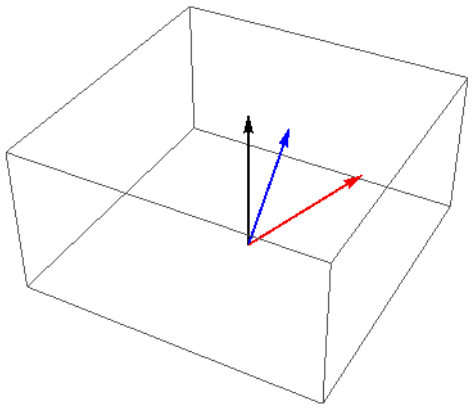
So we have:

- **L** moves around $\mathbf{L_B}$ (the orbital axis of the binary, which is not changing) at frequency Ω_{pl}
- **S** moves around **L** at frequency Ω_{ps}



This coupled motion of **S** and **L** gives rise to complex (even chaotic) evolution of the star's spin axis and the spin-orbit angle

For Ω_{pl} much larger than Ω_{ps}:



L_B

L

S

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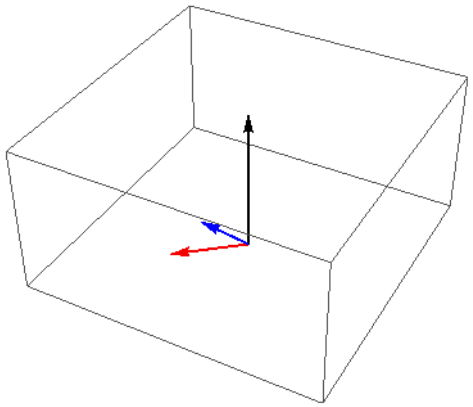
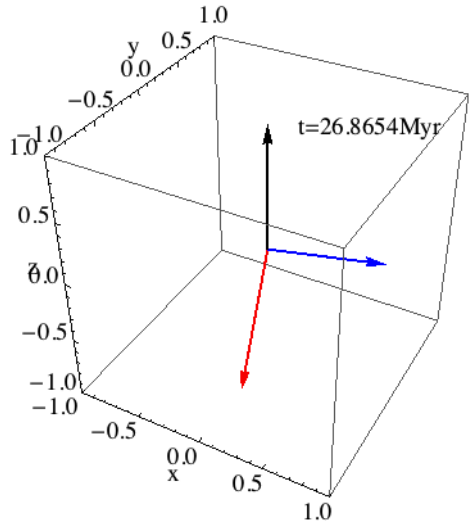


L_B

L

S

For Ω_{pl} comparable to Ω_{ps}:



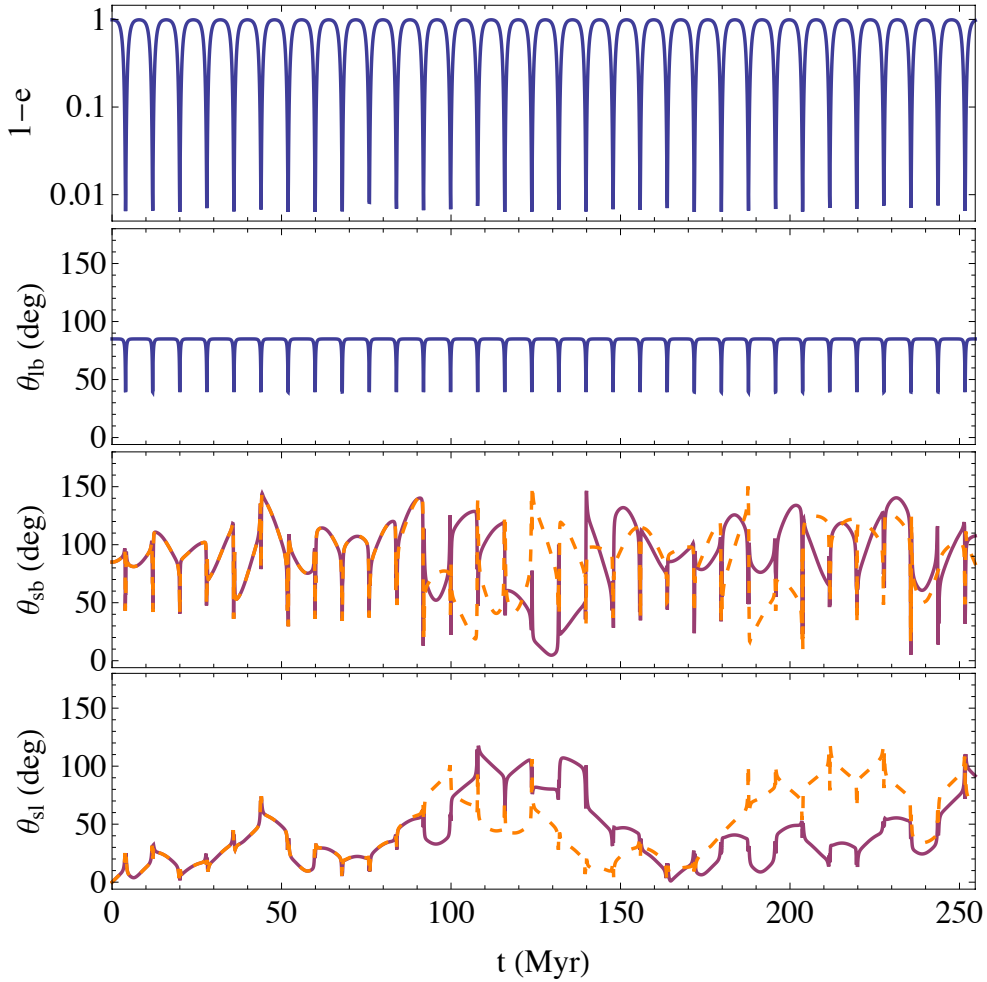
L_B

L

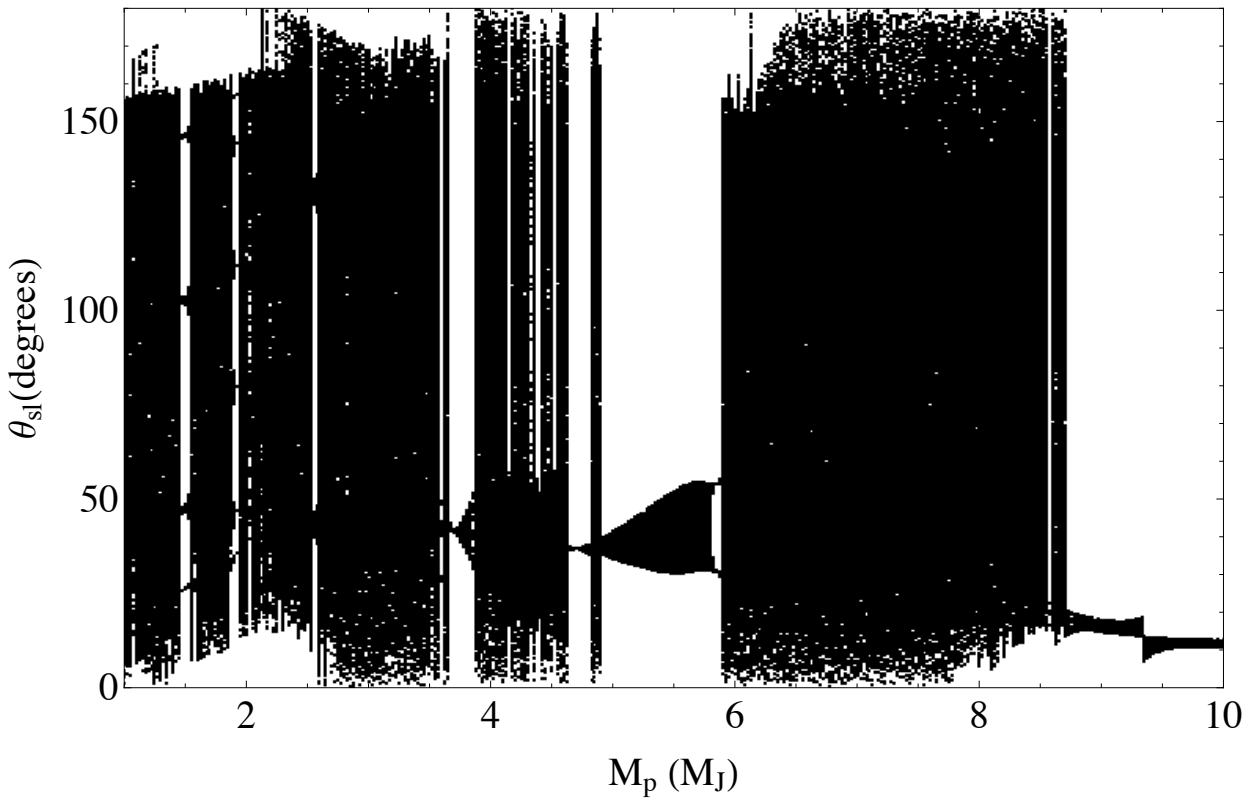
S

Evolution of Stellar Spin and Planetary Orbit

We see that the spin-orbit angle (bottom panel) evolves erratically even when the planet's orbital eccentricity evolves regularly. In fact, the spin evolution can be chaotic: starting from almost the same initial condition, the spin-orbit angles quickly diverge.



Periodic Islands in a Chaotic Ocean



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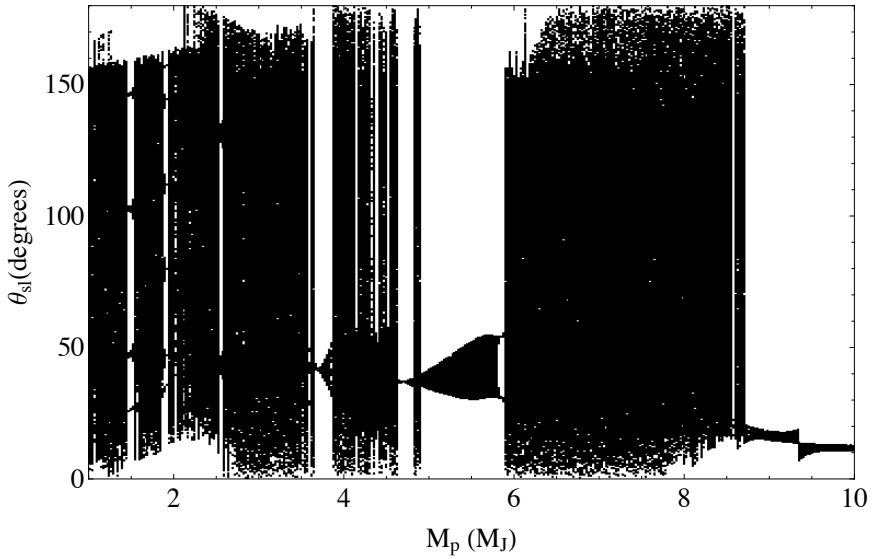
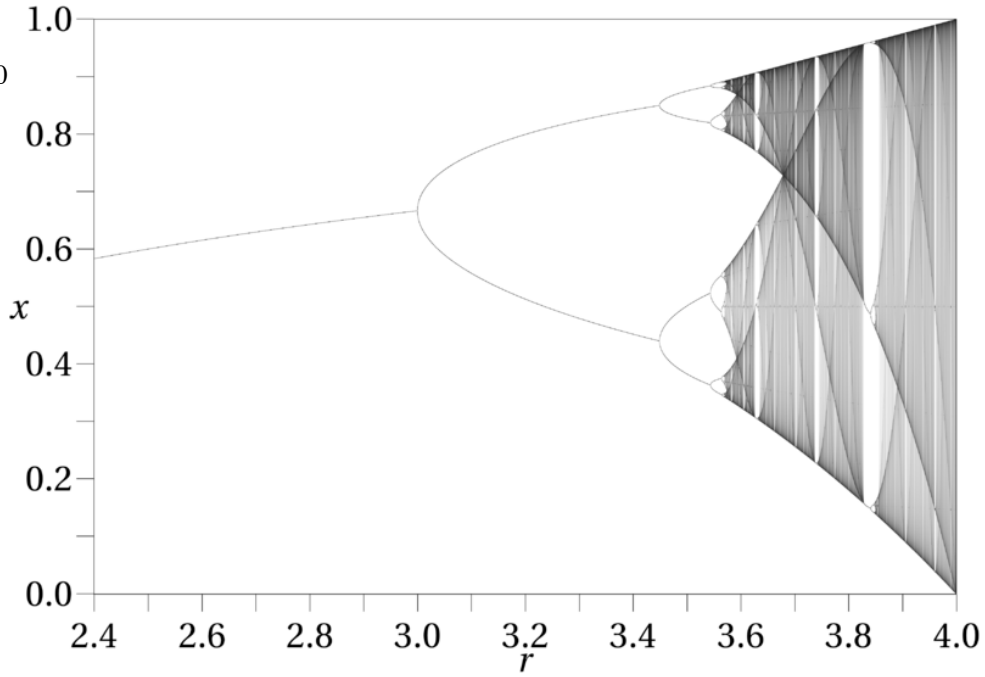


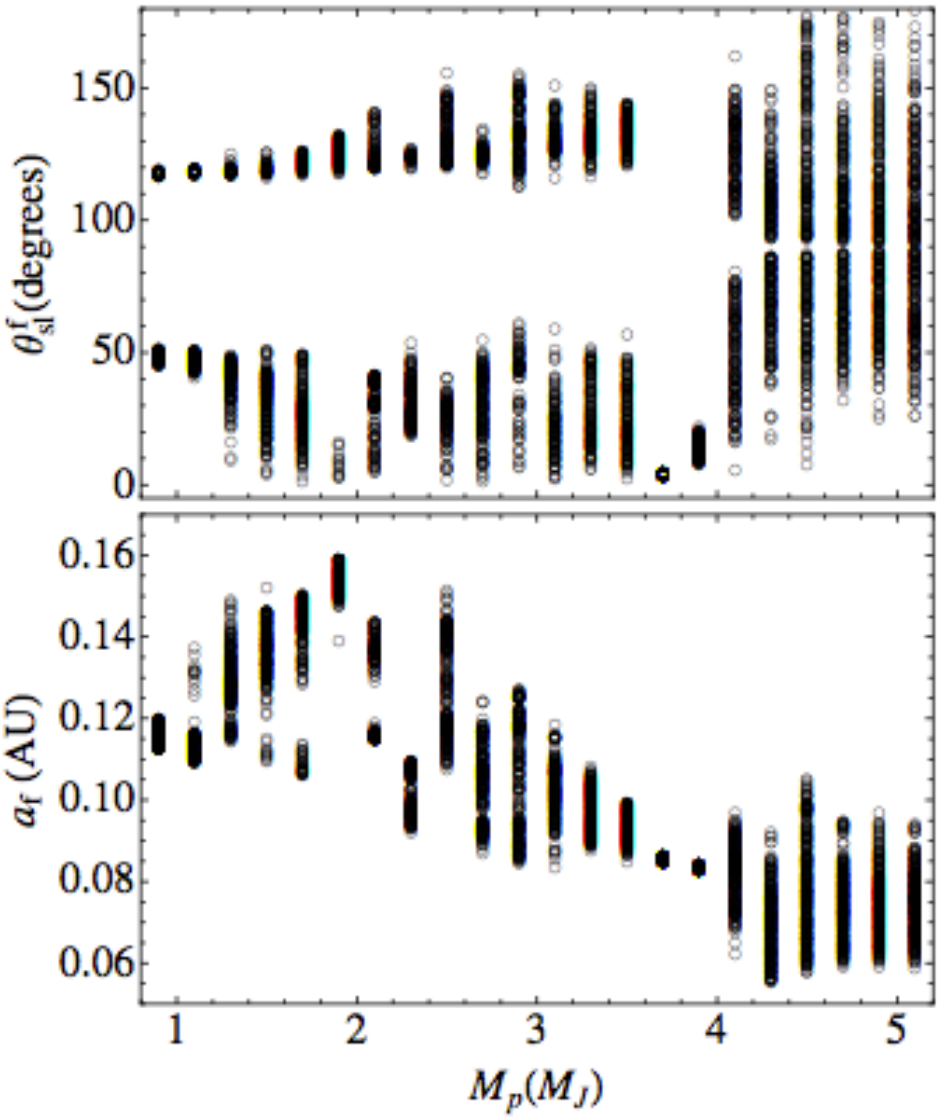
This is analogous to the logistic map:



From wikipedia

Memory of Chaos

A tiny spread in initial conditions can lead to a large spread in the final spin-orbit misalignment



The complex spin evolution can affect the observed distribution of the spin-orbit misalignment angle of hot Jupiter systems.