CAN COMBINATION OF 'KOZAI EFFECT' AND TIDAL FRICTION PRODUCE CLOSE STELLAR AND PLANETARY ORBITS?

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In binary stars, tidal friction dissipates a fraction of the orbital energy at constant angular momentum and will circularise binary orbits on a rather short timescale compared with the nuclear timescale, provided that at least one star of the binary has a radius comparable to the separation between binary components. This dissipation effectively ceases once the orbit is circularised. In a hierarchical triple system such dissipation cannot cease entirely, as neither inner nor outer orbit can become exactly circular because of the perturbation of the third distant body. Thus in such systems tidal friction can lead to a steady secular decrease of the inner semimajor axis, accompanied by transfer of angular momentum from the inner to the outer pair, persisting over the whole nuclear lifetime of the system. The situation can be even more dramatic if two orbits have high relative inclination $i > 40^o$ It can be shown analytically and numerically (see e.g., Kozai 1962, Marchal 1990, Kiseleva 1996 and references therein) that for triple systems with high relative inclination there is a quasi-periodic change of the inner eccentricity (on a timescale $\sim P_{\rm out}^2/P_{\rm in}$) during which it reaches a maximum value $e_{\rm in}^{\rm max}$. This value only depends on the inclination i between the two orbital planes; other parameters affect only the timescale. For example, if we approximate a triple stellar system like β Per (Algol) ($m_1 = 0.8M_\odot, m_2 = 3.7M_\odot, P_{\rm in} = 2.87$ days; $m_3 = 1.7M_\odot, P_{\rm out} = 1.86$ yr, $e_{\rm out} = 0.23$; $i = 100^o$) as three point masses, then the inner eccentricity $e_{\rm in}$ cycles rather smoothly between 0 and 0.985, while i fluctuates between 100^o and 140^o. We call these fluctuations 'Kozai cycles'. Such 'Kozai cycles' do not actually occur in this semi-detached system: they can be damped to a small value by tidal friction, but in fact they are also strongly reduced by the non-dissipative effect of the quadrupole moments of the two stars in the inner pair. This effect produces apsidal motion which is much more rapid than the apsidal motion due to the third star, and so prevents the Kozai cycles from operating.

However, the situation may have been different at an early stage in Algol's evolution if we assume that (i) the stars in the inner semi-detached system were smaller at zero age, and (ii) the inner period was longer. In this case, the Kozai cycles are not damped by the quadrupole distortion, as in actual Algol. Instead, after one or less commonly a few Kozai cycle, which brings the inner pair of stars close together at periastron at the peak of the cycle, the semimajor axis is rapidly decreased. In all cases the orbit only shrinks to the size which allows tidal friction to kill the next Kozai cycle and to circularise the orbit. After that the orbit remain nearly of the same size with $e_{\rm in}$ close to zero.

Fig. 1 shows the evolution of the orbit of a Jupiter-mass ($M \sim 10^{-3}M_\odot$) planet around a solar type companion in a rather wide binary stellar system. The

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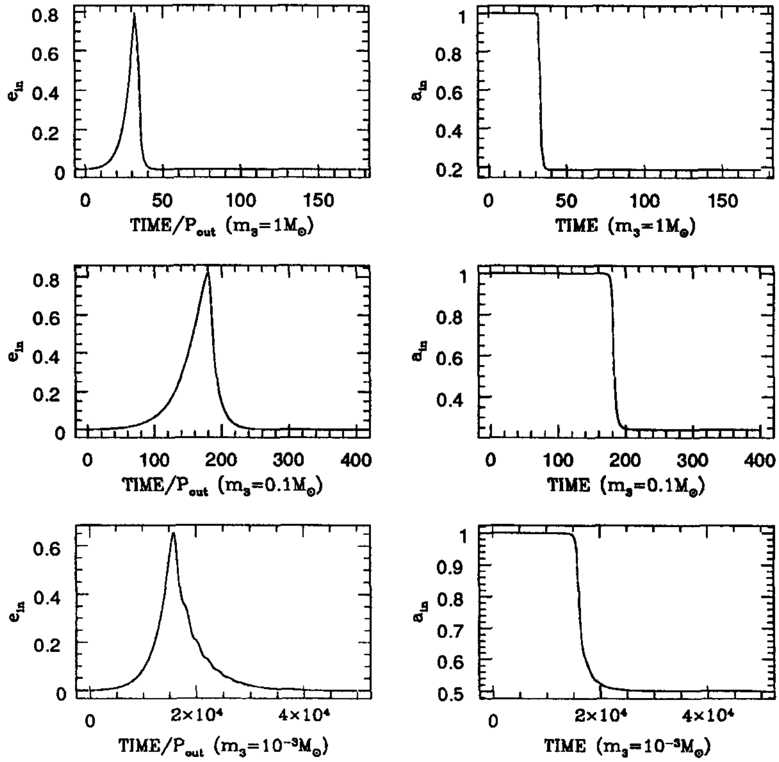

Fig. 1. A Kozai cycle, and its destruction by TF, in a 'Sun-Jupiter' system with a third body of $1M_\odot$ (top panels), $0.1M_\odot$ (middle panels) and $10^{-3}M_\odot$. The orbits are inclined at 100^o. The cycle developed to the much the same peak of eccentricity in all three cases (left panels), but more slowly with the lower-mass third body. Tidal friction shrank the orbit drastically at the peak of the cycle (right panels).

inclination of the planetary orbital plane with respect to the binary orbit is taken to be the same as in β Per - 100^o. Such a high inclination does not seem very improbable (e.g. Holman et al. 1997). For each mass of third body considered, we see that a single cycle takes place which brings the 'Sun-Jupiter' pair close together and allows tidal friction to recircularise the orbit at a considerably shorter period. Thus, although the combination of third body (which might perhaps be of very low, even planetary, mass) and tidal friction may only be important within a limited range of parameters, it may produce some fraction of *close* binary-star or star-planet systems, such as 51 Peg or τ Boo.

References

Holman, M., Touma, J. and Tremaine, S.: 1997, *Nature*, **386**, 254

Kiseleva, L. G.: 1996, in *Dynamical Evolution of Star Clusters*, eds. P. Hut & J. Makino, p233

Kozai, Y.; 1962, *Astron. J.*, **67**, 591.

Marchal, C:. 1990, *The Three-Body Problem*, Elsevier, Amsterdam