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# Kozai-Lidov dynamics in galactic nuclei

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**Abstract.** Discovery of young stars in the Galactic centre promoted the idea of star formation via gravitational fragmentation of a gaseous disc orbiting a supermassive black hole (SMBH). Hydrodynamical models suggest that the newly formed stars are orbiting the SMBH on initially aligned eccentric orbits. By means of *N*-body integrations we investigate how such a disc evolves in time with particular focus on onset of Kozai-Lidov (K-L) oscillations of individual orbits.

**Key words.** celestial mechanics – Galaxies: nuclei – stars: kinematics and dynamics

## 1. Introduction

Our model consists of 500 stars orbiting the SMBH on initially aligned orbits either with common value of eccentricity, $e_0 = 0.4$, or radial gradient growing from zero at the inner edge to 0.9 at the outer edge of the disc which spans from 0.04 pc to 0.4 pc. The disc of total mass $M_\mathrm{d} \approx 2 \times 10^4\,M_\odot$ is embedded in a spherical star cluster modelled by an analytic potential and parametrised by its mass, $M_\mathrm{c}$, within the disc outer radius. Dynamical evolution is followed by Aarseth's NBODY6 code.

## 2. Kozai-Lidov mechanism

Orbit of a star around the SMBH undergoes periodic changes of orbital elements provided it is perturbed by an axisymmetric source of gravity. Beside the semi-major axis, $a$, and the component of the angular momentum parallel to the symmetry axis of the perturbation, $c \equiv \sqrt{1-e^2}\cos i$, mean value of the perturbing potential along the orbit, $\bar{H}_\mathrm{p}$, is an integral of motion. The integrals of motion imply coupled evolution of orbital eccentricity, $e$, inclination, $i$, and argument of the pericentre, $\omega$. A convenient way of inspecting orbital evolution for given $a$ and $c$ are plots of isocontours of $\bar{H}_\mathrm{p}$ in the $e$–$\omega$ space, which determine possible evolutionary tracks. Fig. 1 presents a typical example of resonant topology. Magnitude of the oscillations is known to be modified if an additional, *extended and spherically symmetric*, source of gravity is present.

Left panel of Fig. 2 shows isocontours of $\bar{H}_\mathrm{p}$ in such a case – orbits from the inner rotation zone undergo only marginal oscillations of eccentricity. The more massive the spherical cluster is, the larger is the inner rotation zone. High amplitude oscillations reaching extreme values of eccentricity are thus possible only for a subset of orbits starting from relatively high initial eccentricity. Fig. 2 shows example of such an orbit from our *N*-body setup.

## 3. Abundance of high-eccentric orbits

K-L oscillations are capable to push stars around the SMBH to orbits plunging the tidal

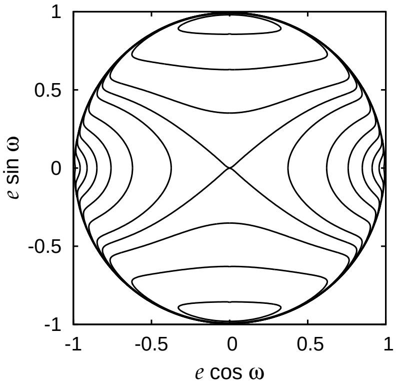


**Fig. 1.** Isocontours of $\bar{H}_p$ for ring-like perturbation and $c = 0.1$.

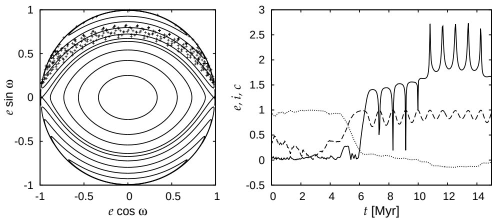


**Fig. 2.** Left: Evolution of eccentricity (dashed), inclination (solid) and $c$ (dotted) for a sample orbit from the $N$-body setup. Right: Positions of the orbit in the $e$–$\omega$ space for $t > 6$ Myr over isocontours of $\bar{H}_p$ of composition of a ring and a spherical cluster.

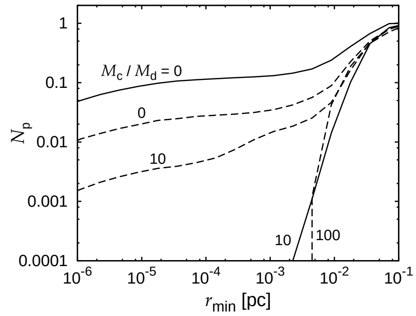


**Fig. 3.** Cumulative distributions of closest approaches to the SMBH. Solid and dashed lines correspond to models with initially gradient and constant eccentricity, respectively.

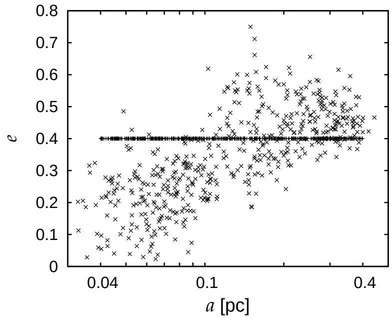


**Fig. 4.** Semi-major axes and eccentricities at $t = 0$ (plus signs at $e = 0.4$) and after $\approx 2$ Myr of dynamical evolution (crosses) for model with $M_c/M_d = 10$.

radius. Rates of tidal disruptions of stars (or tidal break-ups of stellar binaries) strongly depend on parameters of the components of the galactic nucleus. One of the most important is the ratio of masses of the disc and spherical cluster. In Fig. 3 we evaluate fractions of stars reaching the SMBH within a distance smaller than $r_{min}$ for several setups. While the highest rates of tidal disruptions are naturally expected for the case of $M_c = 0$, a large number of tidal disruption events may be obtained even for $M_c/M_d \approx 10$ with a suitable configuration of the disc. K-L cycles appear to be nearly completely damped for $M_c/M_d \gtrsim 100$, regardless of the detailed properties of the stellar disc.

The relatively high fraction of oscillating orbits for $M_c$ as large as $10\,M_d$ is possible only due to complex dynamical evolution of the disc, which leads to transfer of the angular momentum between different groups of orbits (see Fig. 4).

As a result, a considerable amount of orbits is pushed to high eccentricities, i.e. to the resonant zone. K-L oscillations further drive them to $e \gtrsim 0.99$. Interestingly, this angular momentum transfer is supported by gravity of the spherical cluster, i.e. while it damps the K-L oscillations on one hand, it pushes stars to the reduced resonant zones on the other.

## References

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