Kozai-Lidov dynamics in galactic nuclei

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Introduction

Discovery of young stars in the Galactic centre led to the idea of star formation via gravitational fragmentation of a gaseous disc orbitting a supermassive black hole (SMBH). Hydrodynamical models suggest that the newly formed stars are orbitting 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.

Our model consists of 2000 stars orbiting the SMBH (fixed Keplerian potential) 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 stellar cluster modelled by an analytical potential and parametrised by its mass, M_c, within the disc outer radius. Dynamical evolution of the disc is followed by Sverre Aarseth's NBODY6 code.

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, ω. A convenient way of inspecting orbital evolution for given a and c are plots of isocontours of $\bar{H}_\mathrm{p}$ in the e–ω space, which determine possible evolutionary tracks. Fig. 1 presents a typical example of resonant topology.

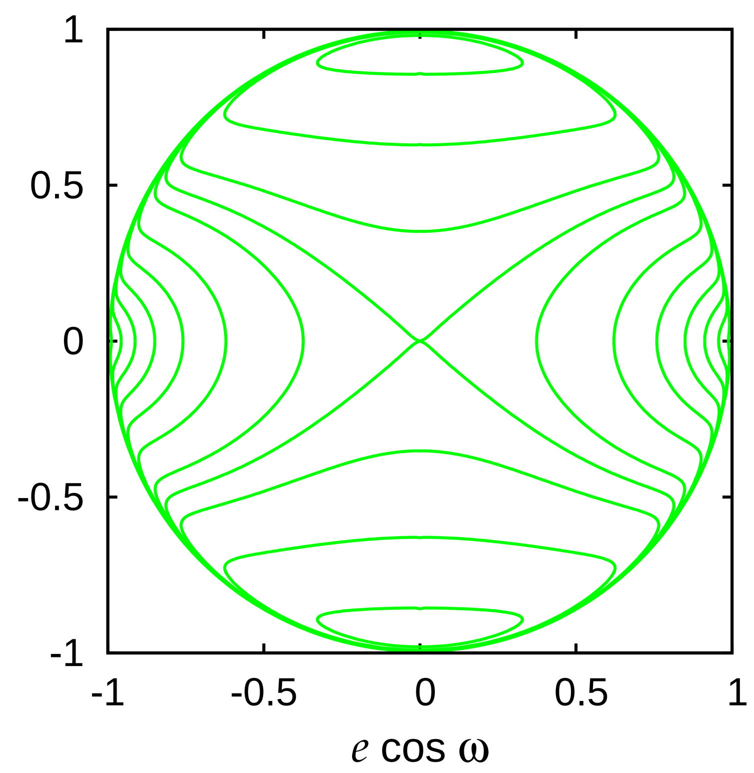

Figure 1: Isocontours of $\bar{H}_\mathrm{p}$ for ring-like perturbation and $c = 0.1$.

Magnitude of the oscillations is known to be modified (damped, in general) if an aditional, *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 is the spherical cluster, the larger is the inner rotation zone. Still, high amplitude oscillations reaching extreme values of eccentricity are possible for a subset of orbits starting from relatively high initial eccentricity. Fig. 2 shows example of such an orbit from our N-body setup.

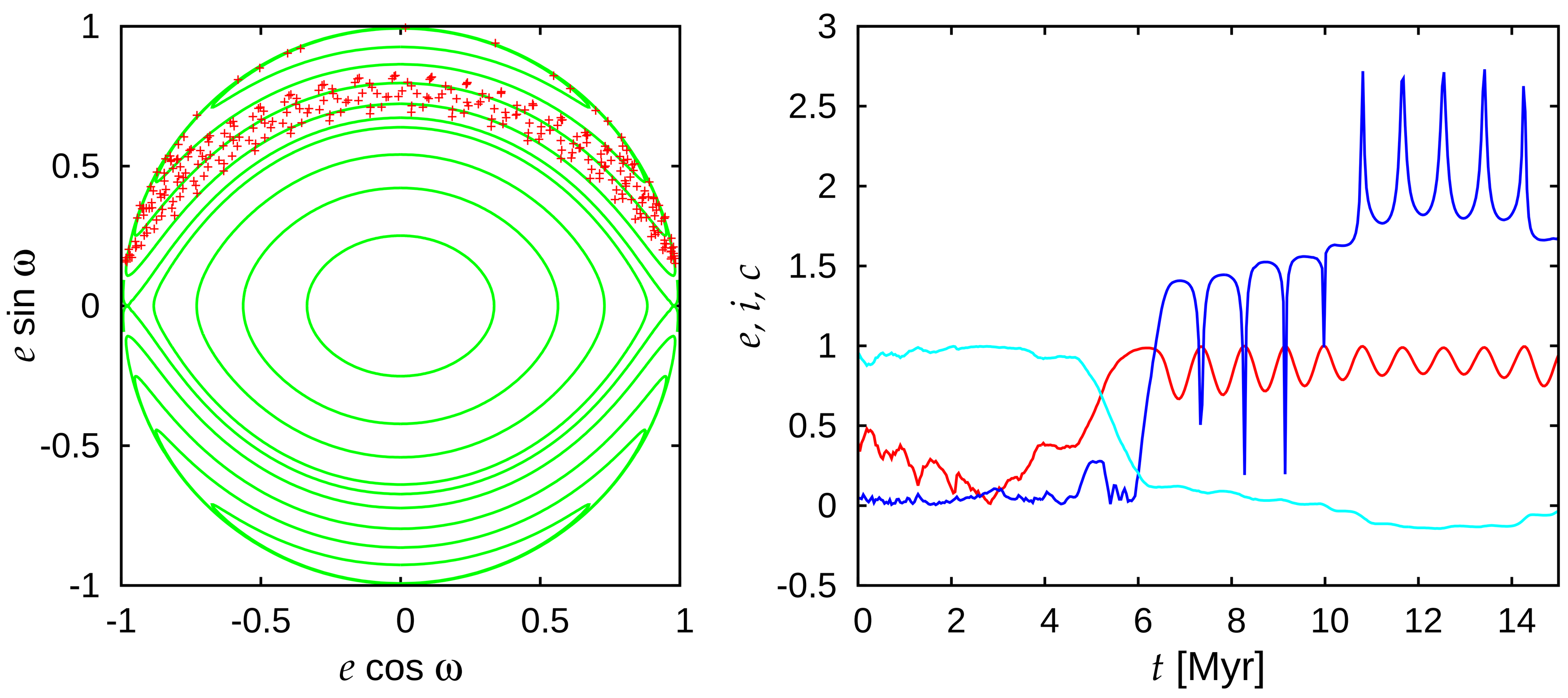

Figure 2: Right: Evolution of eccentricity (red), inclination (blue) and c (cyan) for a sample orbit from the N-body setup. Left: Positions of the orbit in the e–ω space for $t > 6$ Myr plotted over isocontours of $\bar{H}_\mathrm{p}$ for the perturbation formed by a ring and a spherical cluster.

Abundance of high-eccentric orbits

K-L oscillations are capable to push stars around the SMBH to orbits plunging the tidal 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 $M_\mathrm{c} = 0$, even for $M_\mathrm{c}/M_\mathrm{d} \approx 10$, a large number of tidal diruption events may be obtained for a suitable configuration of the disc. K-L cycles appear to be nearly completely damped for $M_\mathrm{c}/M_\mathrm{d} \gtrsim 100$, regardless of the detailed properties of the stellar disc.

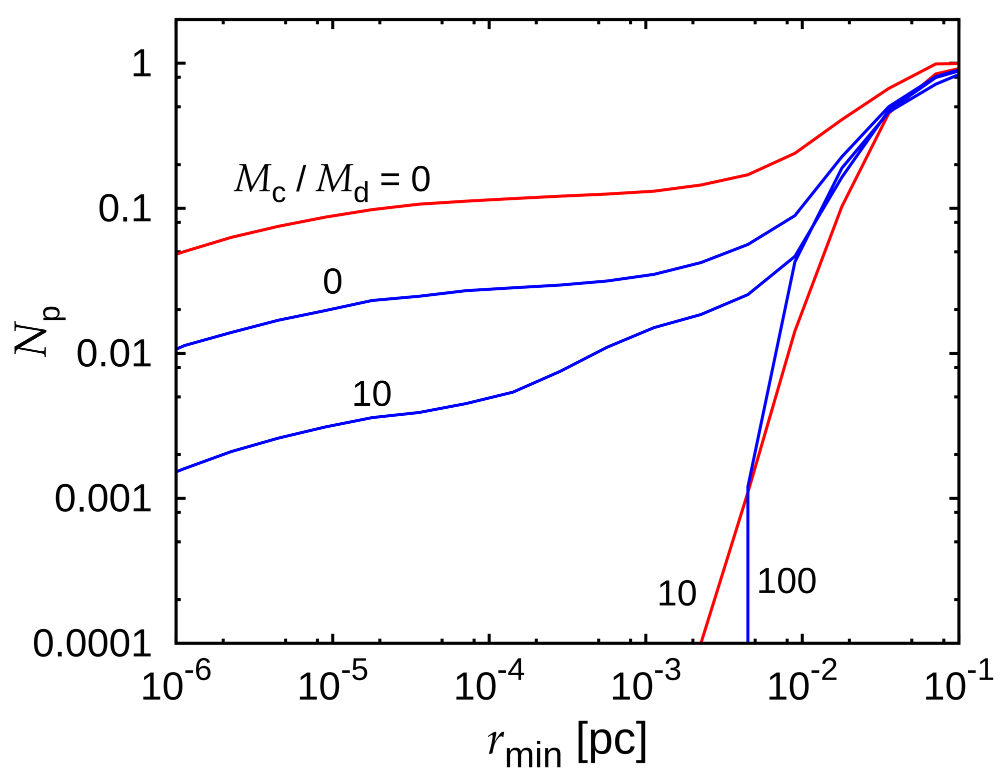

Figure 3: Cumulative distributions of closest approaches to the SMBH. Red and blue lines correspond to models with initially gradient and constant eccentricity, respectively.

The relatively high fraction of oscillating orbits for M_c as large as $10\, M_\mathrm{d}$ 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.

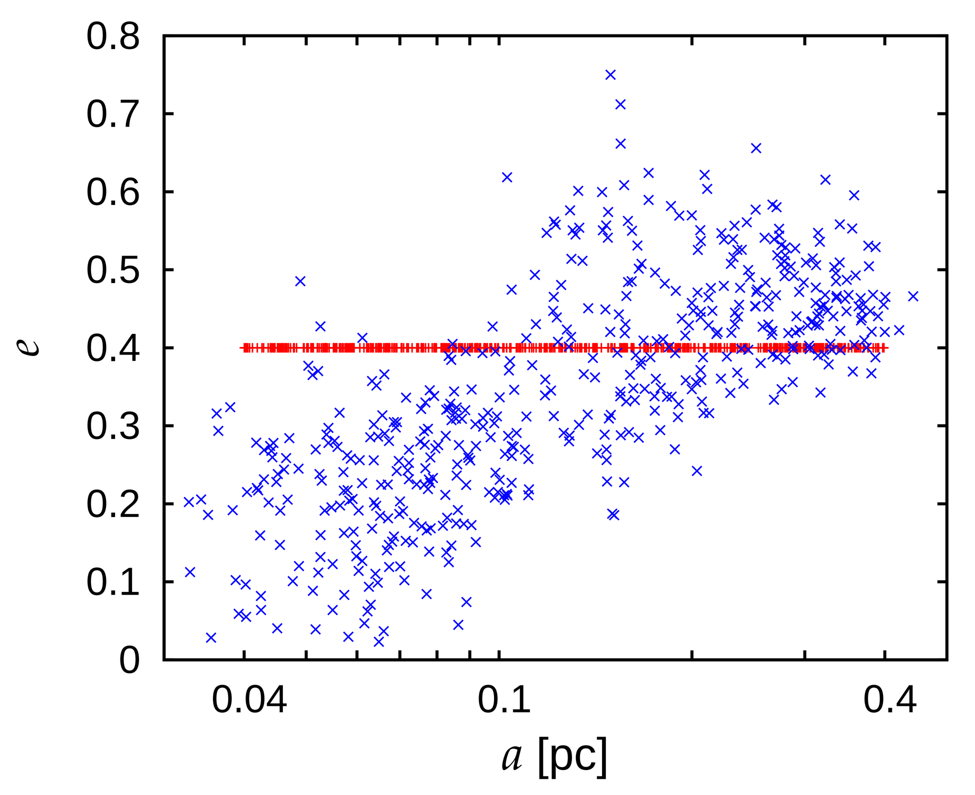

Figure 4: Semi-major axes and eccentricities at $t = 0$ (red) and after ≈ 2 Myr of dynamical evolution for the model with $M_\mathrm{c}/M_\mathrm{d} = 10$.

See also

Haas & Šubr, 2016, ApJ, in press, arXiv:astro-ph/1602.05582