Two-body relaxation of thin stellar disc around SMBH

Jaroslav Haas and Ladislav Šubr

Astronomical Institute, Charles University, Prague, Czech Republic

haas@sirrah.troja.mff.cuni.cz, subr@sirrah.troja.mff.cuni.cz

By means of direct numerical N-body modelling, we investigate two-body relaxation of an initially thin and circular, central mass dominated stellar disc. We find that it leads to rapid changes of the radial density profile of the disc. Given the parameters of the young stellar system observed in the Galactic Centre, the corresponding time-scale is of the order of magnitude 10^6 Myr, making two-body relaxation a non-negligible process for this system. We further show that the presence of primordial binaries in the disc does not alter this conclusion.

Motivation

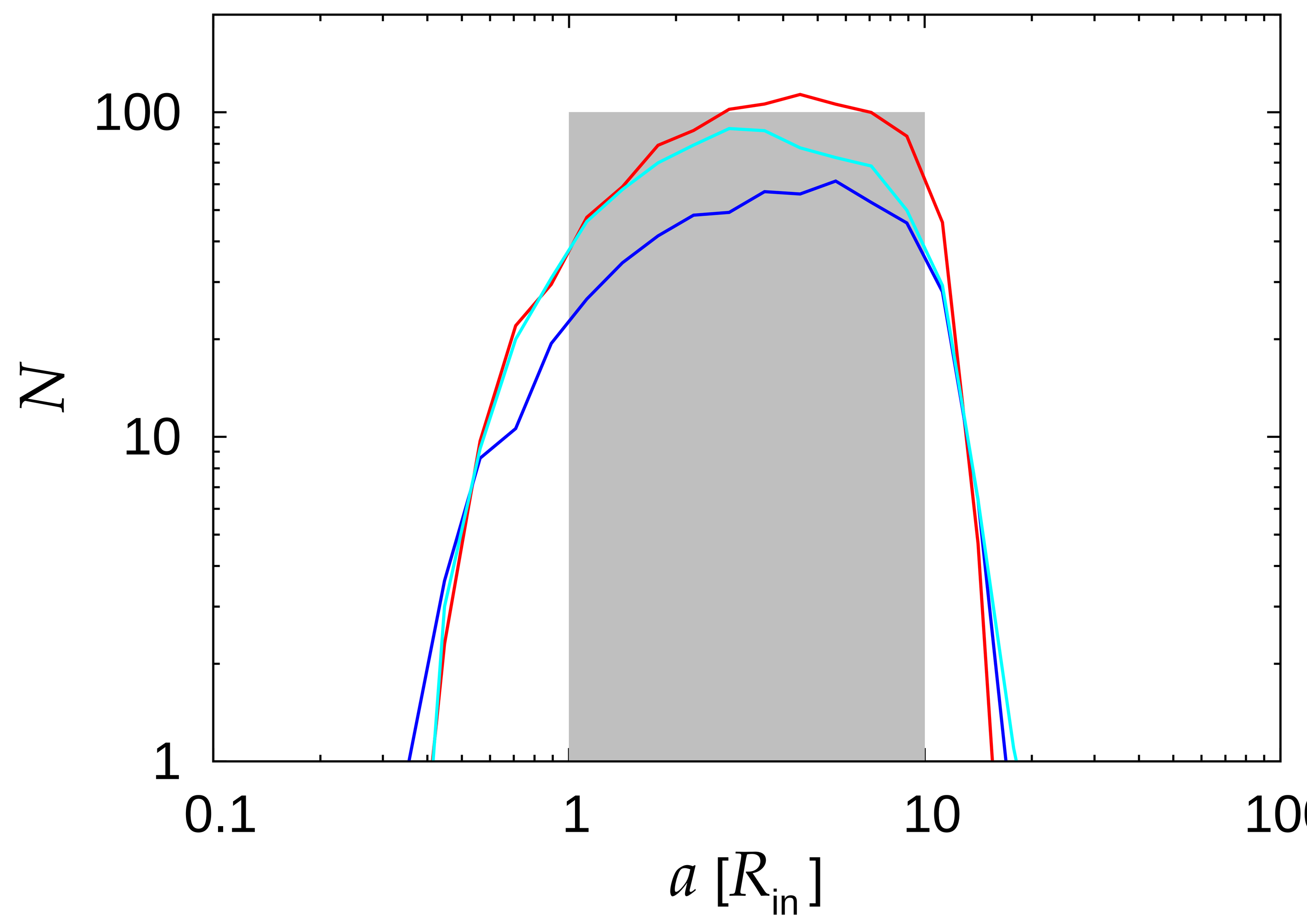
The characteristic time-scale, $T_{\rm relax}$, of two-body relaxation follows relation $T_{\rm relax} \propto \sigma^3$, where σ denotes the velocity dispersion within the investigated stellar system (see, e.g., Binney & Tremaine 1987). For many astrophysical systems, such as galaxies or globular star clusters, σ can be estimated by the typical orbital–crossing velocity of the stars. As we have shown in our recent paper Šubr & Haas (2014), however, the situation changes dramatically in the case of an initially thin and circular disc of stars around a dominating central mass, a supermassive black hole (SMBH). In such a system, σ is very small due to coherent motions of the stars, leading to an orders of magnitude decrease of $T_{\rm relax}$. Here, we investigate, how this conclusion is affected by the presence of primordial binaries in the disc.

Model and method

The studied system consists of the central SMBH, modelled by the Keplerian potential, and the stellar disc which is treated as a group of N gravitating equal-mass particles. We consider the disc to be initially formed either by $N_{\rm s} = N$ single stars or $N_{\rm bin} = N/2$ binaries, i.e., the binary fraction, $f = N_{\rm bin}/(N_{\rm s} + N_{\rm bin})$, equals either 0 or 1. The orbits of the 'objects' (single stars or centres of mass of binaries) around the SMBH as well as the relative orbits of the individual binary components are constructed to be initially circular (and coplanar with the plane of the disc). The dynamical evolution of the system is followed numerically, by means of the N-body integration code NBODY6 (Aarseth 2003).

Results

Our calculations reveal that the presence of primordial binaries in the disc does not affect its two-body relaxation significantly. This is demonstrated in the upper panel of Fig. 1 which shows the comparison of the initial distribution function (grey rectangle) of the semi-major axes of the orbits of the objects around the SMBH and its evolved state (coloured lines). The red line describes the model with no primordial binaries included while the blue and cyan lines denote the results for the models with initial population of tight and loose binaries, respectively. As we can see, the evolved distribution is similar in all three cases and differs significantly from its initial state. Note that the difference in the absolute number counts of the three distributions is due to different numbers of objects present in the disc at a given time, which results from the different rates of binary disruption in the three models (see the lower panel of Fig. 1).



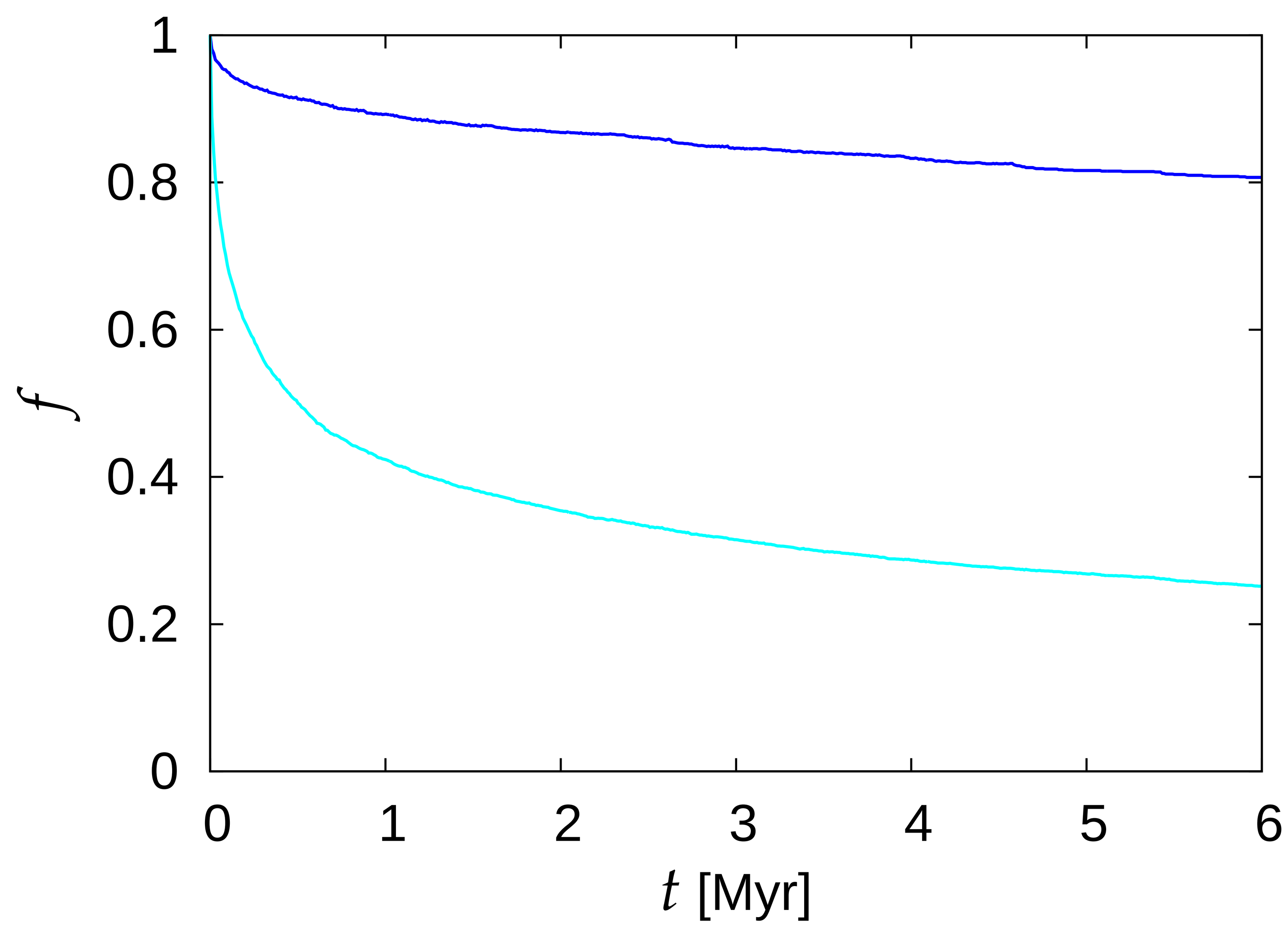


Figure 1: Top: Distribution of semi-major axes of the orbits of the objects around the SMBH: $t = 0$ (grey rectangle), $t = 6\,\mathrm{Myr}$ (coloured lines). Bottom: Evolution of the binary fraction in the disc. Scaled to the parameters of the young stellar system in the Sgr A* region.

The results in Fig. 1 are scaled to the parameters of the young stellar disc observed in the Sgr A* region (Galactic Centre). Hence, we see that two-body relaxation strongly affects its radial density profile on time-scales comparable to the estimated age of the young stars ($\approx$ 6 Myr; Paumard et al. 2006, Lu et al. 2013).

References and acknowledgments

Aarseth S. J., 2003, Gravitational N-Body Simulations, Cambridge Univ. Press

Binney J., Tremaine S., 1987, Galactic Dynamics, Princeton Univ. Press

Lu J. R. et al., 2013, ApJ, 764, 155

Paumard T. et al., 2006, ApJ, 643, 1011

Šubr L., Haas J., 2014, ApJ, 786, 121

This work has been supported by project LD12065 of the research programme COST CZ of the Czech Ministry of Education, Youth and Sports.