

# Preface

Over the past decades, both theoretical and observational efforts have led to a common view that most galactic nuclei host a massive central body, presumably a supermassive black hole (hereafter SMBH). It has been further accepted that galactic nuclei contain extremely dense star clusters that belong to the very old and only slowly evolving stellar population from the more distant parts of galaxies. In the first approximation, these star clusters may be considered roughly spherically symmetric. Their dynamical evolution in the potential of the central SMBH has been studied by various authors in the past, starting with the series of papers by Peebles (1972a, b) and Bahcall and Wolf (1976, 1977).

One specific target of such investigations has always been, due to its proximity, the centre of our own Galaxy. Surprisingly, the observations of this region that have been carried out during the last 20 years have established that, in addition to the old spherical cluster, the closest vicinity of the central SMBH is also occupied by very young stars (Allen et al. 1990; Genzel et al. 2003; Ghez et al. 2003, 2005; Paumard et al. 2006; Bartko et al. 2009, 2010). Moreover, it has also turned out that the spatial configuration of a substantial subset of these young stars is rather unexpected, in particular, many of them appear to belong to a coherently rotating disc-like structure identified for the first time by Levin and Beloborodov (2003). The dynamical evolution of such a stellar disc has been analysed by Alexander et al. (2007) and Cuadra et al. (2008) by means of numerical modelling. These works, however, are based on several simplifications. Among others, the most limiting one seems to be the approximation of an isolated stellar system, i.e. a system that is not influenced by any other sources of gravity except for its own and the central SMBH. Other works include the perturbative influence of a possible second stellar disc (Nayakshin et al. 2006; Löckmann et al. 2008; Löckmann and Baumgardt 2009; Löckmann et al. 2009) or the old spherical star cluster (Kocsis and Tremaine 2011).

A stellar disc similar to the one detected in the Galactic Centre has also been reported in the central parts of our neighbouring galaxy M31 (Bender et al. 2005; Lauer et al. 2012). Hence, it appears that such structures might represent generic component of galactic nuclei. In this thesis, we thus attempt to broaden the previous analyses and further investigate the evolution of the initially thin stellar discs around the SMBH. By means of numerical  $N$ -body modelling, we include the perturbative influence of an extended spherically symmetric star cluster ([Chap. 2](#)).

We discuss the case when the cluster is emulated by a predefined analytic potential in contrast to the case when it is treated in the full  $N$ -body way, as a large number of gravitating stars. In the later one, our results reveal a significant impact of the cluster gravity upon the evolution of the embedded disc. Furthermore, we consider the perturbative gravitational influence of a distant axisymmetric source which approximates massive gaseous torus, another widely expected component of the active galactic nuclei. We develop a simple semi-analytic model for this setting (Chap. 3) and apply this model to the young stellar system in the Galactic Centre, confronting the results with direct numerical  $N$ -body calculations (Chap. 4).

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In this book version of my thesis, I have corrected several typos and misleading expressions and sentences.

## References

- Alexander R. D., Begelman M. C., Armitage P. J., 2007, *ApJ*, 654, 907  
 Allen D. A., Hyland A. R., Hillier D. J., 1990, *MNRAS*, 244, 706  
 Bahcall J. N., Wolf R. A., 1976, *ApJ*, 209, 214  
 Bahcall J. N., Wolf R. A., 1977, *ApJ*, 216, 883  
 Bartko H. et al., 2009, *ApJ*, 697, 1741  
 Bartko H. et al., 2010, *ApJ*, 708, 834  
 Bender R. et al., 2005, *ApJ*, 631, 280  
 Cuadra J., Armitage P. J., Alexander R. D., 2008, *MNRAS*, 388, L64  
 Genzel R. et al., 2003, *ApJ*, 594, 812  
 Ghez A. M. et al., 2003, *ApJ*, 586, L127  
 Ghez A. M., Salim S., Hornstein S. D., Tanner A., Lu J. R., Morris M., Becklin E. E., Duchêne G., 2005, *ApJ*, 620, 744  
 Kocsis B., Tremaine S., 2011, *MNRAS*, 412, 187  
 Lauer T. R., Bender R., Kormendy J., Rosenfield P., Green R. F., 2012, *ApJ*, 745, 121

- Levin Y., Beloborodov A. M., 2003, ApJ, 590, L33  
Löckmann U., Baumgardt H., Kroupa P., 2008, ApJ, 683, L151  
Löckmann U., Baumgardt H., 2009, MNRAS, 394, 1841  
Löckmann U., Baumgardt H., Kroupa P., 2009, MNRAS, 398, 429  
Nayakshin S., Dehnen W., Cuadra J., Genzel R., 2006, MNRAS, 366, 1410  
Paumard T. et al., 2006, ApJ, 643, 1011  
Peebles P. J. E., 1972a, Gen. Rel. Grav., 3, 63  
Peebles P. J. E., 1972b, ApJ, 178, 371



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