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Dynamical traction and black hole orbital migration⋆

I. Angular momentum transfer and a fragmentation-driven instability

C.M. Boily,⋆⋆[1], T.L. François[1,2], J. Freundlich[1], F. Combes[3,4], A.-L. Melchior[3], Y. Hénin[1,5]

[1] Observatoire astronomique de Strasbourg, Université de Strasbourg, CNRS UMR 7550, 10 rue de l'Université, Strasbourg F-67000
e-mail: christian.boily@astro.unistra.fr
[2] School of Mathematics and Physics, University of Surrey, Guildford, Surrey GU2 7XH, U.K.
[3] LERMA, Sorbonne Université, Observatoire de Paris, Université PSL, CNRS, F-75014, Paris, France
[4] Collège de France, 11 Place Marcelin Berthelot, 75005 Paris, France
[5] Télécom Physique Strasbourg, Pôle API, 300 Bd Sébastien Brant, F 67412 Illkirch Graffenstaden Cedex, France

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ABSTRACT

Context. Observations with the *James Webb Space Telescope* of massive galaxies at redshift z up to $\sim$ 14, many with quasar activity, require a careful accounting of the orbital migration of seed black holes to the heart of the host galaxy on timescales of 300 Myr or less.

Aims. We investigate the circumstances which allow a black hole to remain put at the system barycentre when the equilibrium galactic stellar core is anisotropic.

Methods. A Fokker-Planck treatment is developed to analyse the migration of a massive black hole which focuses on exchanges of orbital angular momentum with the stars. We further use a set of N-body calculations to study the response of stellar orbits drawn from a Miyamoto-Nagai disc embedded in a larger, isotropic isochrone (Hénon) background potential.

Results. When the black hole has little angular momentum initially, but orbits in a sea of stars drawn from an odd $f[E, L_z]$ velocity distribution function, a wake in the stellar density sets in which pulls on the black hole and transfers angular momentum to it. We call this *dynamical traction* in contrast with the more familiar Chandrasekhar dynamical friction. We argue that this phenomenon takes place whenever the kinetic energy drawn from $f[E, L_z]$ has an excess of streaming motion over its (isotropic) velocity dispersion. We illustrate this process for a black hole orbiting in a dynamically warm disc with no sub-structures. We then show for a dynamically cold disc that the outcome depends on both the orbit of the black hole and that of the stellar sub-structures stemming from a Jeans instability. When the stellar clumps have much binding energy, a black hole may scatter off of them after they formed. In the process the black hole may be dislodged from the centre and migrate outward due to dynamical traction. When the stellar clumps are less bound, they may still migrate to the centre where they either dissolve or merge with the black hole. The final configuration is similar to a nuclear star cluster which may yet be moving at $\sim$ 10 km s^{-1} with respect to the barycentre of the system.

Conclusions. The angular momentum transferred to a black hole by dynamical traction delays the migration to the galactic centre by several hundred million years. The efficiency of angular momentum transfer is a strong function of the fragmented (cold) state of the stellar space density. In a dynamically cold environment, a black hole is removed from the central region through a two-stage orbital migration instability. A criterion against this instability is proposed in the form of a threshold in isotropic velocity dispersion compared to streaming motion (i.e., angular momentum). For a black hole to settle at the heart of a galaxy on timescales of $\sim$ 300 Myr or less requires that a large fraction of the system angular momentum be dissipated, or, alternatively, that the black hole grows *in situ* in an isotropic environment devoid of massive sub-structures.

Key words. black hole physics – gravitation – instabilities – Galaxies: kinematics and dynamics

⋆ Dedicated to the memory of our colleague T. Padmanabhan.
⋆⋆ Corresponding author