PhD in Astrophysics – XXXV cycle – 2nd year report

PhD candidate: Antonio Mancino

Tutors: Prof. Luca Ciotti, Prof. Silvia Pellegrini

Research Project: *Dynamical modelling of early-type galaxies: analytical multi-component systems, and application to hydrodynamical simulations*

My PhD thesis is mainly aimed at studying the structural and dynamical properties of spheroidal galaxy models in presence of a central black hole (BH). During this second year I have focused on two main projects: one in the field of Fluid Dynamics, and another in the field of Stellar Dynamics.

In the first work (Mancino, Ciotti & Pellegrini, to be submitted) we study the polytropic accretion of gas onto the BH at the center of spherical galaxies, by adopting as model galaxies the J3 galaxy models, the spherical limit of one of the two families of ellipsoidal models we constructed and fully analised during my first year (JJe and J3e models; see Ciotti et al. 2021). The J3 models are two-component (stellar plus dark matter) galaxy models in which the stellar density is described by a Jaffe (1983) profile, and the total density follows a r^{-3} law at large radii, so that the resulting dark matter profile can be made similar to the Navarro-Frenk-White profile. To study the motion of gas flows we generalise the classical Bondi (1952) problem by taking into account the effects of the additional gravitational field of the host galaxy, and the radiation pressure due to electron scattering. The hydrodynamical and stellar dynamical properties are linked by imposing that the gas temperature is proportional to the virial temperature of the stellar component. In the isothermal and monoatomic adiabatic cases, we show that the radial profile of the Mach number and the value of the critical accretion parameter can be analytically calculated; thus, in these two peculiar regimes, we showed that a fully analytical solution of the accretion problem at the centre of the J3 galaxies is possible. Unsurprisingly, for generic values of the polytropic index the problem cannot be solved analytically, and so a numerical investigation of the general polytropic case is performed. Finally, we elucidate some important thermodynamical properties of accretion, and determine the underlying cooling/heating function leading to the phenomenological value of the polytropic index.

In the second work (Mancino, Giannetti & Ciotti, in preparation) we focus on the homoeoidal expansion technique (Ciotti & Bertin 2005), a flexible mathematical tool we used to study JJe and J3e models. In this technique, the initial ellipsoidally stratified density, and the associated potential, are expanded at the linear order in terms of the density flattening η. The resulting model can be interpreted in two different ways: as a genuinely non-spherical system of finite flattening, or as the first-order expansion of the ellipsoidal parent galaxy in the limit of vanishing flattening. In the first interpretation ("η-quadratic" models), the Jeans equations (JEs) will contain up to quadratic terms in the flattening. In the second interpretation ("η-linear" models), only linear terms in the flattening must be retained. For simplicity, in Ciotti et al. (2021) we limited ourselves to the discussion of this second interpretation, and so we considered only the linear terms in the flattening. In this framework, η-quadratic models offer the unique opportunity to investigate in a direct way higher order effects of the flattening on the solution of the JEs. In practice, we are exploiting this opportunity by solving the JEs for the Perfect Ellipsoid (de Zeeuw 1985) and the ellipsoidal Plummer (1911) model. The consideration of quadratic terms in the flattening does not present special difficulties, and intrinsic dynamics can be easily studied analytically; projected dynamics requires instead the use of numerical tools. As an application, the results obtained will be compared with observations of weakly flattened Globular Clusters.

Finally, the implementation of the JJe models in hydrodynamical numerical simulations of gas flows inside axisymmetric Early-Type Galaxies hosting a central supermassive BH is currently in progress (Ciotti et al. 2022, to be submitted).

References:

Bondi H., 1952, MNRAS, 112, 195
Ciotti L., Bertin G., 2005, A&A, 437, 419
Ciotti L., Mancino A., Pellegrini S., Ziaee Lorzad A., 2020, MNRAS, 500, 1054
Ciotti L. et al., ApJ, 2022 (to be submitted)
de Zeeuw P. T., 1985, MNRAS, 216, 273
Jaffe W., 1983, MNRAS, 202, 995
Mancino A., Giannetti F., Ciotti L., MNRAS, 2022 (in preparation)
Mancino A., Ciotti L., Pellegrini S., MNRAS, 2021 (to be submitted)
Plummer H. C., 1911, MNRAS, 71, 460

Workshops, Conferences & Meetings

- 14 - 18 September 2021: ONSCI – *Officina di Narrazione della Scienza*, Bologna, Italy (Unibo Online Workshop)
- 12 - 16 April 2021: Extragalactic spectroscopic surveys – *Past, Present and Future of Galaxy Evolution*, Chile (ESO Online Workshop)
- 3 - 4 December 2020: Linking the Galactic and Extragalactic – *stellar dynamics and stellar populations of the Milky Way and its siblings*, Sydney, Australia (Virtual Meeting)

Internal Courses

- 5 - 14 May 2021: Writing, talking and presenting Science, University of Bologna, Bologna, Italy
- 19 - 23 April 2021: Gamma Ray Bursts – from observations to physical properties, University of Bologna, Bologna, Italy
- 30 November - 2 December 20210: The Interstellar Medium, University of Bologna, Bologna, Italy

ISA Lectures

- 28 September 2021 – *How the Brain Controls Pain*, M. Heinricher, Oregon Health and Science University, USA
- 6 July 2021 – *How positive pedagogy can address mental health and wellbeing of students?*, Priyank Shukla, Ulster University, UK
- 15 December 2020 – *Translating texts which do not exist. Pseudo-originality, multistable figures, and Fortini's literary reception of Heine and Brecht*, Irene Fantappiè, Institut für Romanische Philologie, Freie Universität Berlin, Germany

Research Period Abroad

Planned for 4 months (1 April 2022 - 1 August 2022) at the Leiden Observatory (Leiden University, Netherlands). During this period, under the supervision of Prof. Dr. P. T. de Zeeuw, I shall explore the possibility of deriving information about the phase-space Distribution Function for homoeoidally expanded galaxy models.

Publications

- *Dynamical modelling of weakly flattened ellipsoidal systems. Application to Galactic Globular Clusters*, A. Mancino, F. Giannetti, L. Ciotti, MNRAS, 2022 (in preparation)
- *A parameter space exploration of numerically evolved early type galaxies including AGN feedback and accurate dynamical treatment of stellar orbits*, L. Ciotti, J. P. Ostriker, Z. Gan, B. X. Jiang, S. Pellegrini, C. Caravita, A. Mancino, ApJ, 2022 (to be submitted)
- *On the polytropic Bondi accretion in two-component galaxy models with a central massive BH*, A. Mancino, L. Ciotti, S. Pellegrini, MNRAS, 2021 (to be submitted)