# Lectures on stellar dynamics (Publications of the Scuola Normale Superiore)

Mon. Not. R. Astron. Soc. **000**, 1–13 (0000) Printed March 4, 2013 (MN LaTeX style file v2.2)

arXiv:1301.5165v3 [astro-ph.GA] 1 Mar 2013

## Relaxation of N-body systems with additive $r^{-\alpha}$ interparticle forces

PierFrancesco Di Cintio[1]*, Luca Ciotti [2], and Carlo Nipoti[2]
[1] *Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Straße 38, D-01187 Dresden Germany*
[2] *Department of Physics and Astronomy, Bologna University, viale Berti-Pichat 6/2, I-40127 Bologna Italy*

Submitted 2013, January 22; Resubmitted 2013, March 1

**ABSTRACT**
In Newtonian gravity the final states of cold dissipationless collapses are characterized by several structural and dynamical properties remarkably similar to those of observed elliptical galaxies. Are these properties a peculiarity of the Newtonian force or a more general feature of long-range forces? We study this problem by means of $N-$body simulations of dissipationless collapse of systems of particles interacting via additive $r^{-\alpha}$ forces. We find that most of the results holding in Newtonian gravity are also valid for $\alpha \neq 2$. In particular the end products are triaxial and never flatter than an E7 system, their surface density profiles are well described by the Sérsic law, the global density slope-anisotropy inequality is obeyed, the differential energy distribution is an exponential over a large range of energies (for $\alpha \geqslant 1$), and the pseudo phase-space density is a power law of radius. In addition, we show that the process of virialization takes longer (in units of the system's dynamical time) for decreasing values of $\alpha$, and becomes infinite for $\alpha = -1$ (the harmonic oscillator). This is in agreement with the results of deep-MOND collapses (qualitatively corresponding to $\alpha = 1$) and it is due to the fact the force becomes more and more similar to the $\alpha = -1$ case, where as well known no relaxation can happen and the system oscillates forever.

**Key words:** gravitation – stellar dynamics – galaxies: kinematics and dynamics – methods: numerical

### 1 INTRODUCTION

One of the most striking properties of elliptical galaxies is the remarkable quasi-homology of their surface brightness profiles, described by the so called Sérsic model, a generalization of the de Vaucouleurs $R^{1/4}$ model (see e.g. Caon et al. 1993, Andredakis et al. 1995, Courteau et al. 1996, Graham & Colless 1997, Prugniel & Simien 1997, Graham 1998, Trujillo et al. 2001, Bertin et al. 2002; see also Ciotti 2009 and references therein). Albeit minor (but important) departures from the Sérsic model are common, overall the profiles on large scale are very well represented by the Sérsic law. What is the origin of such regularity? $N$-body numerical simulations revealed that cold dissipationless and collisionless collapses lead to virialized end-states described almost perfectly by $R^{1/4}$ profiles (e.g. van Albada 1982, Londrillo et al. 1991). More recently it has been shown that collapses in pre-existing dark matter halos are also well described by the Sérsic profile, with a wide range of values of the Sérsic index (Nipoti et al. 2006ab, hereafter N06ab). In addition, it is also known that the Sérsic family is characterized by an exponential differential energy distribution, over a large range of accessible energies (e.g. Binney 1982; Ciotti 1991). These results can be understood in terms of the physics of violent relaxation in collisionless collapses (e.g. Lynden-Bell 1967, Bertin & Stiavelli 1984, Bertin & Trenti 2003, Trenti & Bertin 2005, Trenti et al. 2005). Finally, it has been proved analytically that in Newtonian gravity a large class of spherically symmetric equilibrium systems are characterized by the so-called Global Density Slope-Anisotropy Inequality (hereafter GDSAI, see Ciotti & Morganti 2010ab; van Hese et al. 2011, An et al. 2012; see also An & Evans 2006), a constraint between their anisotropy and density profiles. Numerical simulations suggest that the GDSAI may be a much more general result, holding true also for the final states of dissipationless collapses (see e.g. Hansen & Moore 2006).

Due to the relevance of these results for the understanding of the process of collisionless relaxation, a natural question arises about their apparent universality. In particular, are the Sérsic law, the associated differential exponential energy distribution and the GDSAI peculiar features of Newtonian gravity or are they more general properties of the

* E-mail: pdicint@pks.mpg.de

Buy Lectures on stellar dynamics (Publications of the Scuola Normale Superiore) on whataboutitaly.com ? FREE SHIPPING on qualified orders.The lectures address selected topics in stellar dynamics, presented in a deductive approach. Completeness is Publications of the Scuola Normale Superiore.Title: Lecture notes on stellar dynamics. Authors: Ciotti, L. Affiliation: AA(Bologna Astronomical Observatory, Italy). Publication: Pisa, Scuola Normale Superiore.Visiting Lecturer of Stellar Dynamics at Scuola Normale Superiore, Pisa ( and Tutor of Astronomy and Astrophysics, Collegio Superiore of the Bologna Journal of Plasma Physics, European Physical Journal, Publications of the.out a publication lectures on stellar dynamics will certainly opened up an individual to think far better, to Scuola Normale Superiore) on whataboutitaly.com FREE.All Monthly Notices of the Royal Astronomical Society, All RAS Journals, All Journals . The extension of this result to stellar dynamics is given in Binney & Tremaine (). .. which relies on the maximum principle for the solution to some classes of the elliptic partial differential equations. Scuola Normale Superiore.Dissipationless collapses in modified Newtonian dynamics (MOND) are studied Notes on Stellar Dynamics (Pisa: Scuola Normale Superiore).notice that the study of the dynamics under the effect of power-law forces is by no means new: orbits that can be imposed onto a physically acceptable equilibrium stellar system is .. CIOTTI, L. Lecture Notes on Stellar Dynamics. Scuola Normale Superiore, Series: Publications of the Scuola Normale Superiore.[C] Ciotti, L., Lecture Notes on Stellar Dynamics, Scuola Normale Superiore di Pisa editore, Dover Publications, Inc., New York, MR Dynamical properties of two-component galaxy models whose stellar density distribution is Lecture Notes on Stellar Dynamics. Scuola Normale Superiore.Director Collegio Superiore Alma Mater Studiorum - University of Bologna. Deputy Director of DIFA. Hobby Harpsichord  Teaching -- Lecture Notes on Stellar Dynamics -- AMS Campus Scuola Normale Superiore, Pisa.Ciotti, L Lecture Notes on Stellar Dynamics. Scuola Normale Superiore Pisa, Italy, editions Scuola Normale Superiore, Series.Lecturer (Maitre de Conferences) at the University of Strasbourg since september Member of the . Member of local organizing committee of the conference "Galactic & Stellar Dynamics", March and after the Reionization (Now ERC Post-Doc at the Scuola Normale Superiore, Pisa, Italy) PUBLICATIONS.Currently, I am a Senior Lecturer in the School of Physics at the University of Melbourne. Italy's most selective and prestigious institution: Scuola Normale Superiore, shaped Publications of the Astronomical Society of Australia. ; THE CLOSE STELLAR COMPANIONS TO INTERMEDIATE-MASS BLACK HOLES.Academic writing: criteria, methods and tips for framing successful publication strategies February 16, - 3 pm - GSSI Main Lecture Hall Speaker: Andrea Ferrara (Scuola Normale Superiore - Pisa) as viable alternative to dark matter: application to stellar dynamics and to fundamental plane of elliptical galaxies.Ph.D. in Physics at the Scuola Normale Superiore: 70/70 cum laude. Invited Lecturer at the Beijing Lensing Workshop and Summer School Beijing, China, o Journals:

Astrophysical Journal, Astronomy & Astrophysics, Monthly Notices of A Stellar dynamics and time delays of gravitational lens galaxies; the.

[PDF] Paper Buying Primer
[PDF] Lineare Algebra fur Wirtschaftswissenschaftler: Mit Aufgaben und Losungen (German Edition)
[PDF] The Bear Inside Her: A Werebear Shifter Erotic Fairy Tale
[PDF] Pensive... Part I: Relationships
[PDF] The Philosophy of Peter Abelard
[PDF] Neros Fiddle (The Artifact Hunters Book 3)
[PDF] Fifty (50) Famous Australians