I. Semester report

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Ph.D. Thesis title: Consequences of thermodynamic constraints in the classical theory of gravitation
(Termodinamikai kényszerek következményei a klasszikus gravitációelméletben)

2023/2024 I. semester

[1]HUN-REN Wigner RCP

Introduction

My planned research applies extensions of modern continuum theories to produce astrophysically relevant predictions. In the investigated theory [1], the second law of thermodynamics is used as a constraint in a nonequilibrium framework. The derived evolution equation with an introduced scalar field yields Poisson's equation of Newtonian gravity, or in an extended version, its modified form. The extension results in nonlinear field equation, which is tested against astrophysical phenomena, specifically against galactic rotation curves. This method allows the explanation of some dark matter-related phenomena without introducing exotic, new matter or particles. Modified gravity has been researched for decades to explain cosmological phenomena and issues with the dark matter model, but in my research, a novel and unique approach is tested. Furthermore, its potential applications for the explanation of non-galactic phenomena is considered an open issue, which warrants further research.

Description of research work carried out in current semester

In this semester, I further developed the previously created algorithm to introduce numerical fitting to the observed galactic rotation curves. The method takes the difference between the resulting numerical rotation curve and the observational data and fits the parameter K (with optionally the outer boundary condition as well), using the least squares method of the curve_fit function of the Scipy.optimize python module. The result yields a better-aligned rotation curve and an error estimation from the fit for its value. One such result is shown in Fig. 1.

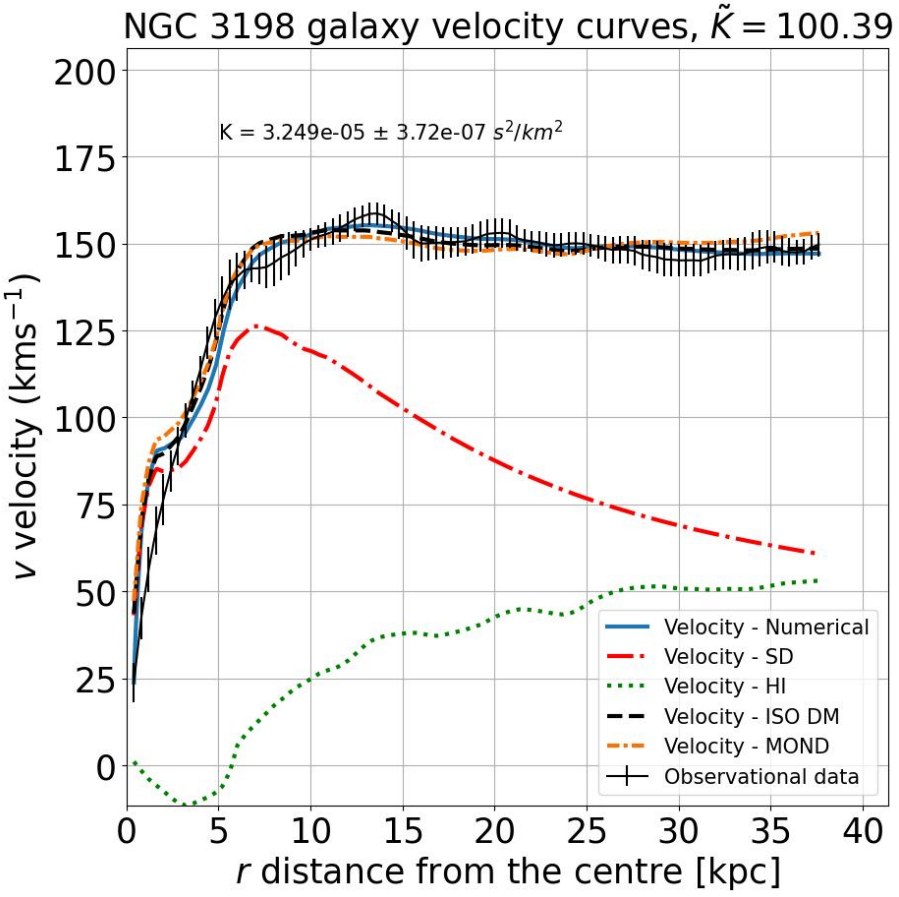

Figure 1: Numerical fitting for the galaxy NGC 3198, with K and the outer boundary condition being a free parameter.

Furthermore, the modelling technique for the galaxies was further developed. A more befitting coordinate system is the cylindrical one, compared to the previously used spherical, thus in cases where a compatible density distribution could be tested, the more appropriate former was used. This allowed me to test the larger number of galaxies in [2], in the form of coadded rotation curves. The density distribution here was an infinitely thin disk, characterised by its mass and exponential length scale. One such example is shown in Fig. 2.

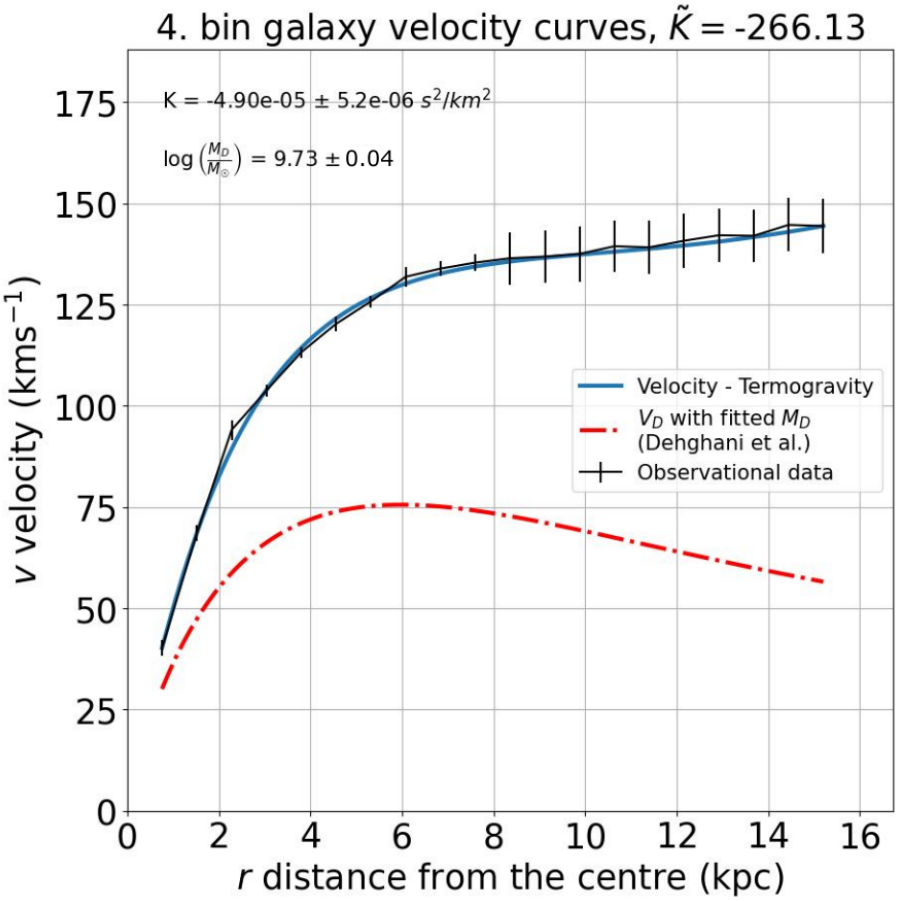

Figure 2: Numerical fitting for the coadded rotation curves of bin 4 from [2], with the mass of the exponential disk (M_D) and the parameter K being a free parameter.

Further research is underway in investigating a potentially more appropriate numerical method, by using a more suited cylindrical or spherical derivative of $r\nabla\varphi$ and $r^2\nabla\varphi$ instead of $\nabla\varphi$ in the staggered grid method.

Publications

- Manuscript under submission:

  Field equation of thermodynamic gravity and galactic rotational curves
  (`https://arxiv.org/abs/2306.01825`)

- Published science communication article:

  P. Ván, M. Pszota: Equivalence principles and gravitation theories, Fizikai Szemle, December 2023
  (`https://fizikaiszemle.elft.hu/szemle/123`)

Studies in current semester

- Chapters from modern celestial mechanics (Fejezetek a modern égi mechanikából) (FIZ/5/053)

  During this course, I participated in a project using numerical simulation software (Gadget-2, Gyrfalcon), which was used to simulate the temporal evolution of galaxies with a given initial condition. The generated images of these galaxies were used in photometric software to infer the morhopoligcal indices and parameters. The goal of this project was to determine the possible connection between the manually set initial conditions and the final galactic morphologies.

- Physics of the interstellar medium I. (Az intersztelláris anyag fizikája I.) (FIZ/5/031)

  During this course, we learned and prepared about various topics regarding interstellar medium (ISM), and submitted a researched written summary for the thesis topics.

Conferences in current semester

- Participation at the Wigner 121 Scientific Symposium, Budapest, Hungary, 18-20 September 2023

- Oral presentation at the Zimányi School 2023 (23rd Zimányi School Winter Workshop on Heavy Ion Physics) with the title *Galactic hydrodynamics with thermodynamic gravity*, Budapest, Hungary (`http://zimanyischool.kfki.hu/23/`), December 4-8, 2023

Further activities

Teaching activity in current semester

I participated in teaching the Classical Physics Laboratory (laboratory practice), for 8x4 hours (once per week 4 hours, for a total of 32 hours).

Science communication

I participated in the organisation of the Náboj physics contest for secondary school students on 3rd November 2023 and in the Night of Researchers demonstrations at the ELTE on 29th September 2023.

References

[1] Peter Ván and Sumiyoshi Abe. Emergence of extended Newtonian gravity from thermodynamics. *Physica A: Statistical Mechanics and its Applications*, 588:126505, 2022.

[2] Dehghani, R., Salucci, P., and Ghaffarnejad, H. Navarro-Frenk-White dark matter profile and the dark halos around disk systems. A&A, 643:A161, 2020.