II. 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 II. 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, based on reviewer feedback, I incorporated the SPARC (Spitzer Photometry & Accurate Rotation Curves) database to work with the previously created numerical method of applying thermodynamic gravity to galactic rotation curves. To enhance the quality of the method, I enhanced the developed a numerical fitting method in order to calculate the best fits and a reduced chi-squared value. In order to account for the observational uncertainties and improve the fit, I let the mass-to-light ratio of the galactic disc vary as a free parameter, while constraining the outer boundary to the observed value. Using this new method, I improved and resubmitted the manuscript mentioned below. An example of this new method applied to the galaxy discussed in our work is presented in Figure 1.

Furthermore, the planetary precession was investigated by using GravityLab (`https://pypi.org/project/GravityLab/`). The numerical simulation showed that under similar starting conditions, thermodynamic gravity results in precession, as seen in Fig. 2. This research avenue, if further investigated, could potentially yield Solar system-regime tests of thermodynamic gravity, or predictions about the gravitational stability of planetary systems.

Further research is underway to produce fits for the rest of the SPARC sample, considering the uncertainties in the observed inclinations and distances of the galaxies. If a large enough sample is investigated, Bayesian analysis should provide a potential way to compare the model's success with other, more developed mainstream models, such as various dark matter frameworks or the external field effect realisation of MOND (Modified Newtonian Dynamics). Additionally, developing a proper numerical method for cylindrical symmetric systems, to improve the fits of the [2] sample, while investigating enhancements to the applied staggered grid method.

Publications

- Manuscript under review (after 2nd round):

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

- Published science communication article:

  G. Balázs, K. Bánhalmi, B. Creusot, K. Császár, E. Gasteiger, Á. Horti-Dávid, P. Horváth, M. Kovács, N. Koródi, S. Marek, C. Porpaczy, M. Pszota: A korai univerzum vörös lámpása: hiányzó láncszem lehet a távoli kvazár, csillagaszat.hu, 19th May 2024
  (`https://www.csillagaszat.hu/hirek/a-korai-univerzum-voros-lampasa-hianyzo-lancsz`

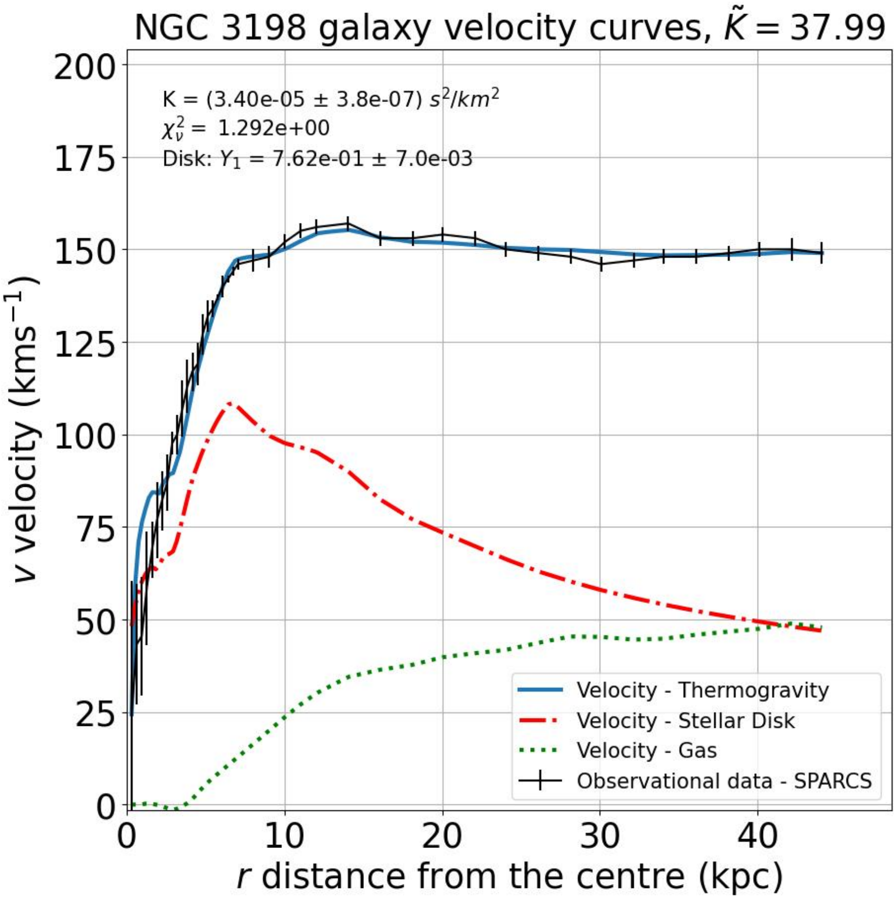

Figure 1: Numerical fitting for the galaxy NGC 3198, with K and the mass-luminosity ratio (Y_1) being a free parameter.

Studies in current semester

- Structure of compact stars (Kompakt csillagok szerkezete) (FIZ/5/025)

  During this course, we learned about the evolution, physical properties, nuclear physics- and general relativistic description of compact stars. The topics covered the evolution of stars, the Hertzsprung-Russel Diagram, the Tolman–Oppenheimer–Volkoff equation, relativistic field theory and rotation of neutron stars. At the end of the semester, we present a chosen topic and a recent article covering a related topic.

- Physics of the interstellar medium II. (Az intersztelláris anyag fizikája II.) (FIZ/5/032)

  During this course, we learned and prepared about various topics regarding interstellar medium (ISM), and submitted a researched written summary for the thesis topics. This seminar was the continuation of a similar course from the previous semester, and in this one we covered additional topics.

- The art of scientific publishing (A tudományos közlés művészete) (cg2n1tkz)

  During this seminar, we learned about tricks and methods in the general and more specifically, the astronomical scientific publishing, and at the end of the semester, we jointly prepared a science communication article as a group, which was published on csillagaszat.hu.

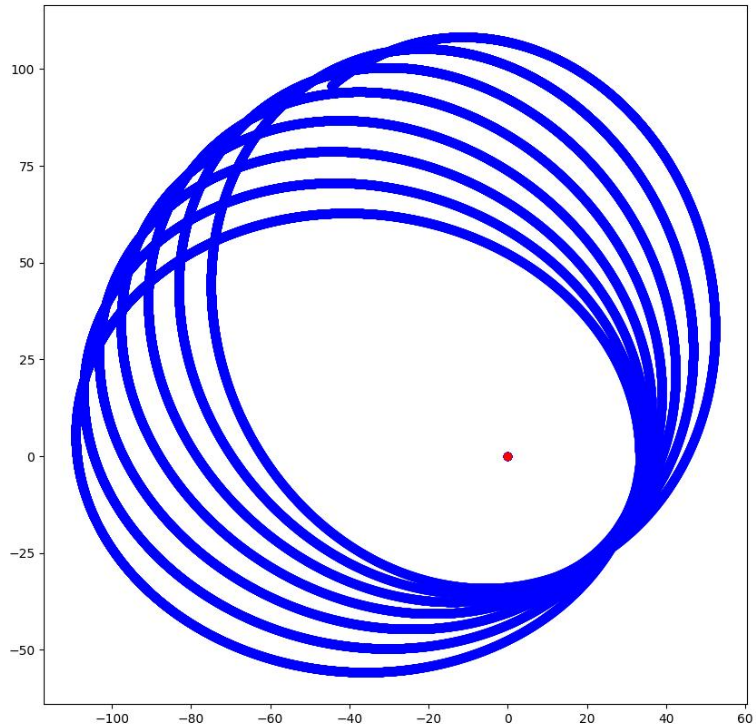

Figure 2: A simulation with bodies reflecting the Sun-Earth mass ratio, with $K = 10^{-5}$ (relative to other the simulation parameters) TG parameter.

Conferences in current semester

- Participation at the XII Bolyai–Gauss–Lobachevsky Conference (BGL-2024): Non-Euclidean Geometry in Modern Physics and Mathematics, Budapest, Hungary, 1-3 May 2024
- Participation at the Exploring the Dark Side of the Universe Tools 2024 - 5th World Summit, Île de Noirmoutier, France, 2-7 June 2024

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).

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.