Semester report
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Ph.D. Thesis title: Cosmic Dipole, Hubble-tension, cosmic coincidence – tests and attempts to solve the problems of the ΛCDM cosmological model

Introduction

Although the current concordance cosmological model, the Lambda Cold Dark Matter (ΛCDM) model is in very good agreement with observations, it requires the introduction of not yet fully explored constituents and mechanisms, such as dark matter, dark energy and cosmic inflation, to explain these observations. The model faces several known unsolved problems, such as the discrepancies between observations of the early and late universe, e.g. Hubble-tension (Riess 2020) and S_8-tension (Di Valentino 2021), or the cosmic dipole anomaly (Secrest 2021), as well as other problems and anomalies (Casado 2020, Perivolaropoulos & Skara 2022), that may indicate the need for further improvements in the theory.

Examining alternative models, such as coasting cosmological models, can be a suitable tool for a deeper understanding of the theoretical problems that arise in the framework of standard cosmology. In coasting cosmologies, the temporal evolution of the universe is linear or quasi-linear. Strictly linear cosmologies are free of several problems that are unsolved in the standard model, without the need of dark matter, dark energy and an inflationary phase, and show remarkably good agreement with the databases used to test cosmological models (Melia 2018). Therefore, by analysing coasting cosmologies we may come closer to understand why we live in a universe where coasting models are consistent with cosmological data.

Description of research work carried out in current semester

In the current semester, we continued the fitting of different coasting cosmological models (with different curvatures and prior assumptions) and the Flat ΛCDM model to the database of supernovae and quasars. For this purpose, we used the python code I developed in the previous semester. By running this code, one can fit an arbitrary cosmological model to the database of supernovae and quasars using an MCMC algorithm. The code, in addition to determining the optimal parameter values, can handle outlier rejection and assumptions about the prior distributions of the fitted parameters.

We also had many discussions about the details of the fitting process that determines the optimal parameter values, about the correct way of comparing the results of different cosmologies and how to present our results in a paper. We studied many articles on similar topics to make sure we are using the right methods.

As a result, I made improvements on the python code, concerning the correct way of sigma clipping and parameter estimation methods. I also made technical improvements that make it more user-friendly (since the code will be publicly available on GitHub as an attachment to our article) and suitable for longer runs as well. In addition to these, it produces the necessary data for model comparison, and it already prepares the tables and figures in a form that will be included in our publication.

Meanwhile, I studied the cosmology of an inhomogeneous Einstein-de Sitter universe in view of the separate universe conjecture. The conception of this model is based on an inhomogeneous universe consisting of a large number of separate spherical universes averaged over large scales. The description and analysis of the evolution of such a universe can be realized by numerical simulations. This model was also pre-tested with my python code.

My other main research task is the development of a method for measuring the cosmic dipole with gravitational-wave signals of compact binaries and testing it with simulations and then, in the future with detected gravitational-wave signals. This work will lead to a paper of which I will be the first author. In the previous semester, I already started to study the essence of our method and the data to be used. In the current semester, I collected the recent publications in this topic and mapped the differences between the methods of various authors. I am currently working on my strategy, what tasks I need to complete and how to structure the article.

Publications

Publications planned for this calendar year:

- Test of coasting cosmological models - I will be a co-author.
- Cosmology of an inhomogeneous Einstein-de Sitter universe in view of the separate universe conjecture - I will be a co-author.
- Measuring the cosmic dipole with gravitational-wave signals of compact binaries - I will be the first author.

Studies in current semester

- FIZ/5/021 Gravitational-wave Astrophysics
- FIZ/5/025 Structure of Compact Stars
- FIZ/5/032 Physics of Interstellar Medium II.

Teaching activity in current semester

- Physics Laboratory 2: I was the instructor of four measurements (once a week for four hours), corrected and graded the submitted reports.
- I provided teaching assistance to my supervisor in teaching Astrophysics to Physics BSc students. The teaching assistance consisted of correcting and supervising written exam.

References

Brout, D., et al.; ApJ 938, 2, 110 (2022)
Casado, J.; Ap&SS 365, 1, 16 (2020)
Di Valentino, E.; Astroparticle Physics 131, 102604 (2021)
Melia, F.; MNRAS 481, 4, 4855 (2018)
Perivolaropoulos L. & Skara, F.; New Astron. Rev. 95, 101659 (2022)
Riess, A. G.; Nature Reviews Physics 2, 10 (2020)
Riess, A. G., et al.; ApJL 934, 1, L7 (2022)
Secrest et al.; ApJL 908, 2, L51, (2021)