Declaration of research interests

Joan Alcaide-Núñez[1]

[1]Fakultät für Physik, Ludwig-Maximilians-Universität München,
Geschwister-Scholl-Platz 1, München, Germany

October 25, 2025

Joan Alcaide Núñez is a Physics B.Sc. student at the Ludwig-Maximilians-Universität München and a young student researcher. He's research interests lie in the crossroad of multi-messenger astronomy and cosmology, particularly the issue of the Hubble Tension (also referred to as the Crisis in Cosmology) and the fundamental nature of dark energy. Here, his past projects are briefly outlined and then current interests, projects, and future work explained.

1 THE CRISIS IN COSMOLOGY

Since the discovery of the expansion of the Universe by Edwin Hubble and Georges Lemaître in the late 1920s, we have defined the expansion rate of the Universe as the Hubble-Lemaître constant H_0. This is a special time point for the Hubble parameter $H(t)$, which describes the expansion rate with the evolution of time t. With modern instrumentation and technology, H_0 can be measured with $\sim 1\%$ uncertainty. Currently, there are two main methods to measure this parameter, either based in the local (late) Universe or the early Universe. These two types of methods provide different results for H_0, in fact, as their uncertainties have reduced (due to better telescopes) the measurements have diverged. Today, there is a 1/1,000,000 chance that the Hubble Tension is a statistical error.

The distance ladder method consists of a 'ladder' of standard candles objects (Parallax, then Cepheids/ TRGB/JAGB, then Type Ia Supernovae) which allow us to measure distances to nearby galaxies (up to $z \sim 1$). The other method builds from observations of the very first light (Cosmic Microwave Background, CMB) or galaxy clustering (Baryonic Acoustic Oscillations, BAO), these observations can be used to simulate the entire Universe to our time. The Hubble Tension therefore is caused by one of these two potential issues (or a combination):

1. Our methods to measure cosmological distances using the distance ladder methods are not accurate/correct enough. Meaning that we are lacking understanding on how to measure distances to other objects/galaxies.

2. Our model(s) of the Universe are not correct and therefore, we are failing to compute H_0 from early Universe observations.

Of course, other distance-ladder-independent methods have been tested to measure the distance to galaxies (for instance, other types of stars, galactic properties or gravitational lensing). Our telescopes have also been improved from Hubble Space Telescope (HST) to James Webb (JWST) for distance ladder observations, and from the Cosmic Background Explorer (COBE) to Wilkinson Microwave Anisotropy Probe (WMAP) to Planck Satellite for (CMB) measurements, for example. However, the more precise our measurements, the stronger their diverge. It may be a good idea to find alternative ways to measure the cosmological expansion of the Universe, i.e., the Hubble-Lemaître constant H_0.

2 FIRST PROJECTS

Joan Alcaide Núñez's interest in cosmology began with the first project in 11th grade (2023) in which he reproduced Hubble's measurement of H_0, with the same methods but with much modern data. Using galactic spectra from the NED Database and Cepheid luminosities (magnitudes) from the Konkoly

Observatory, all archived data, he recomputed the Hubble-Lemaître constant with a value of $H_0 = 72.26 \pm 7.1$ Kms^{-1}Mpc^{-1}. Later on, in summer 2024 and following the distance ladder, he expanded his distance measurements with SNIa data. Using infrared data from ESO archives he computed a new value for H_0, now taking into account the acceleration of the expansion, i.e., the density parameters Ω_m and Ω_Λ, yielding $H_0 = 69.96 \pm 1.58$ kms^{-1}Mpc^{-1}.

Once that Joan had first learned about coding and astrophysics specific programming systems, the basics of astronomy, of researching and paper reading, and of results sharing (also at research institutes). He decided to venture to an alternative method, with potential for independent H_0 measurements.

3 MULTI-MESSENGER COSMOLOGY (GRB+GW)

Gamma-ray bursts (GRBs) are the most energetic events, outshining the rest of the night sky when one occurs. They are transient events radiating the equivalent energy of the Sun in its entire life, but they last only a few seconds. Hence, they can be observed at very high redshift (up to $z \sim 8$, i.e., very far) and have been proposed as independent 'standard candles' for the high-z Universe. Additionally, since the first detection of gravitational waves (GW) in 2015 by LIGO, we have been trying to measure H_0 with this data, which is at most independent from other methods, since it based on gravitational and not electromagnetic waves (EM). Combining these two methods: GRBs and GWs for cosmology is part of the multi-messenger astronomy endeavor of the field, which focuses on learning about the nature of the Universe through all its channels.

In summer 2025, Joan Alcaide Núñez started collaborating with Dr. Giancarlo Ghirlanda and Dr. Om Sharan Salafia on the implications of multi-messenger astronomy for cosmology. An initial project consisted of using E_{peak} and E_{iso} GRB data by the Swift telescope to constraint the $(\Omega_m, \Omega_\Lambda)$ parameters. Later on, we also included simulated data of gravitational wave events, in order to explore how future GW signals detected by new observatories (Einstein Telescope (ET), Laser Interferometer Space Antenna (LISA), Cosmic Explorer) can change our perspective on the Hubble Tension.

The reason for why these methods are independent from distance ladder measurements is because they do not need any parallax or other standard candle observations in order to be calibrated. For GRBs, there exists a relation between the peak energy and isotropic equivalent energy E_{peak}-E_{iso}, which is cosmology dependent through $d_L(z; H_0, \Omega_m, \Omega_\Lambda)$ and can be used to estimate those parameters. Moreover, the strain signal of GWs provides us with direct distance measurements (with no extinction due to GW nature, instead of EM waves). The degeneracy between distance and the plane angle of the binary neutron star (BNS) system is resolved by observing the transient EM event (GRBs and/or kilonova) that happens at the merger. Thus, one can easily build a classical Hubble diagram and fir $d_L(z; H_0, \Omega_m, \Omega_\Lambda$ to z. In a few words, that means that we can measure distances without requiring a cosmological assumption or calibration through other methods, establishing a powerful tool for cosmological parameter measurement.

4 CURRENT AND FUTURE PROJECTS

Joan Alcaide Núñez is current involved in 3 main projects:

1. Completing the Bachelor's degree in physics (aiming to further studies)
2. Extend work conducted at the research stay at OAB-INAF
3. The CAPIBARA Collaboration's γ- & X-ray mission

In the following, the latter two projects are briefly presented. Future work extending beyond the initial OAB-INAF project involved computing the best fit of the $(\Omega_m, \Omega_\Lambda)$ parameters with the E_{peak}-E_{iso} relation on short GRBs (SGRBs), which are directly related to the GW events. Thus, with the multi-messenger observation of a single event, obtaining both GW and EM (i.e. γ-ray/X-ray) signals, we could perform two independent analysis of the data and parameter measurements. Moreover, the study of how the amount of GW signals affect the final constraints, under the question how many events do we need to detect to obtain $\sim 1\%$ constraints on H_0, which would make them comparable to other methods in terms of measurement uncertainty. Personally, Joan Alcaide Núñez is also looking forward to learning more about the physics of GRBs and the physics behind obtaining distance measurements from GW signals.

The second project being discussed here is the Collaboration for the Analysis of Photonic and Ionic Bursts and Radiation's (CAPIBARA Collaboration) γ- & X-ray mission (referred to as CAPIGX, still to be found a proper name). The CAPIBARA Collaboration is a group of high school and undergraduate students across disciplines from physics through biology and engineering, with the aim to exploring the high energy cosmos, and demonstrated the capabilities of young student researchers. One of the collaboration's two mission is CAPIGX, which constitutes it's biggest ambition and long-term goal. CAPIGX is being planned to be a constellation of 3 CubeSats equipped with both detectors for photons within the 1 keV – 2 MeV, with a bridge at 150 keV, due to the different detector materials for the separation between hard X-ray and soft γ-ray radiation. The goal of this mission is to support flagship high energy observatories in the monitoring of transient events as well as to provide high precision source localization through triangulation and, potentially, intensity interferometry. The CAPIBARA Collaboration aims for a launch not before 2035 in order to coincide with the new wave GW observatories (Einstein Telescope, LISA, Cosmic Explorer) and flagship high energy missions by ESA (THESEUS, NewAthena).

5 SUMMARY

Early before the start of university education, Joan started to learn about the field of cosmology first recomputing the Hubble-Lemaître constant H_0 with Cepheids and later SNIa. Through research stays, both at home and abroad, he continued developed his interest further learning about both the cosmological measurements and the status of the field as well as the mathematical and programming skills required to conduct those projects.

Currently, Joan is more interested in alternative methods and solution to the Crisis in Cosmology involving distance ladder independent methods. Since we still need a model to fit our data to, he is also interested in studying the different proposed dark energy theories/models and perhaps using multi-messenger observations to gain knowledge about the nature of dark energy.