A precision Measurement of the Hubble Constant from Observations from the Local Universe in the Advanced Levels of the Physics Degree

Borja Serrano-González, Antonio J. Cuesta, Antonio Ortiz-Mora

Departamento de Física, Universidad de Córdoba,
Campus de Rabanales, Edificio Albert Einstein,
E-14071 Córdoba, España.

We offer a direct determination of the Hubble constant H_0 from the Local Universe observations. We have used the cosmic distance ladder technique following a modification of the method proposed by **Riess et al. 2009**, as a way to develop treatment and reduction data competences within Physics Degree studies.

The standard candles used for calibration are type Ia supernovae and Cepheid variable stars. The data catalogs for both types of standard candles are available in open and public-access databases.

A value for the Hubble constant of $\mathbf{H_0 = (71 \pm 4)\ km\ s^{-1}\ Mpc^{-1}}$ has been obtained. This result is compatible with the most recent determinations published to date from Local Universe observations. The uncertainty in the value that we obtain for H_0 is reduced to 6%, a comparable precision to the published one using a much more elaborate methodology.

Our result fulfills a double objective: on the one hand, it illustrates the power of the method despite having been simplified; on the other, it highlights the value and importance of working with observational data from public access databases at the advanced levels of the Physics Degree.

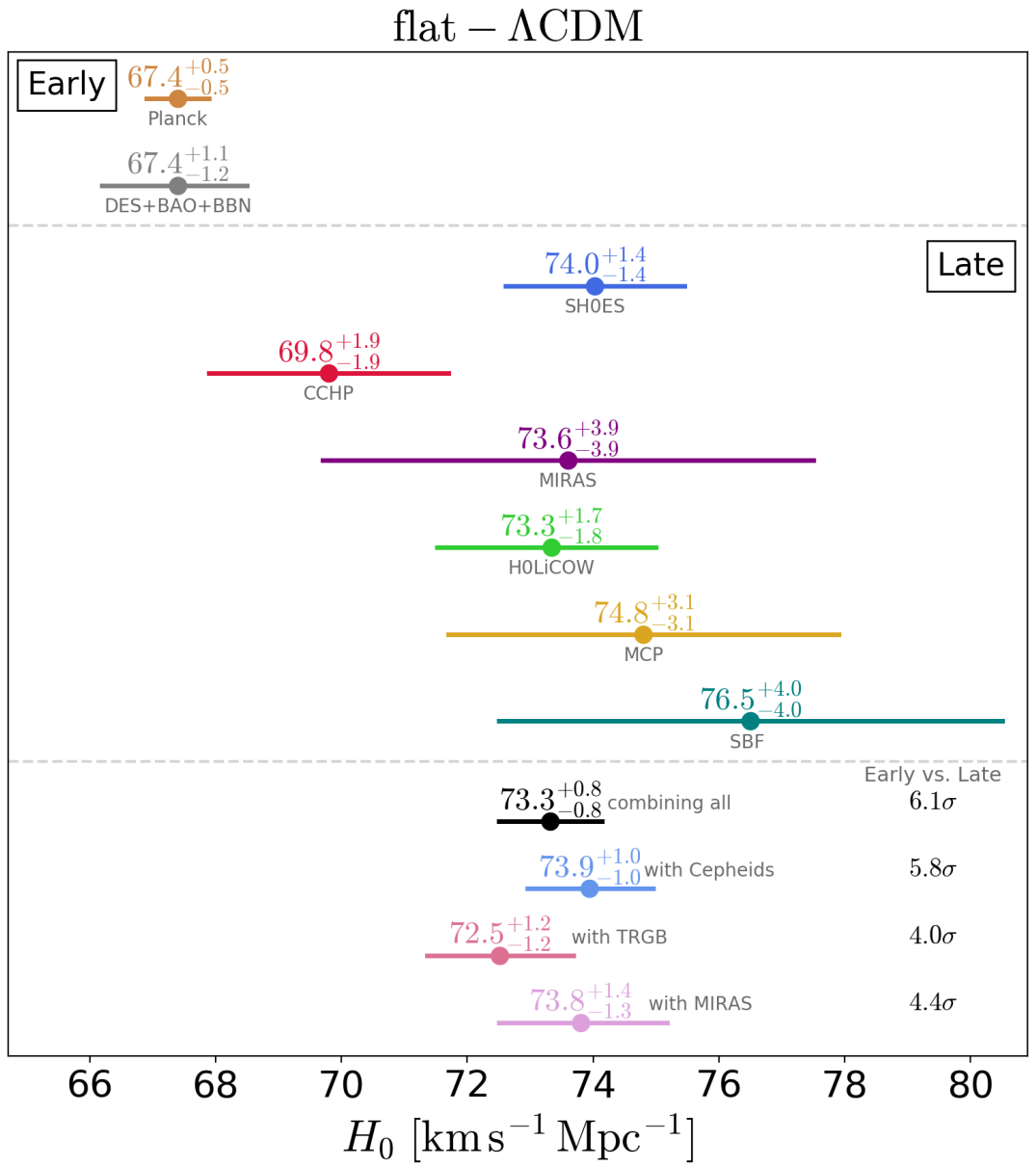
Context

*Need to reinforce students skills in data processing with advanced numerical and programming techniques.

*Approach to a cutting-edge research topic: Modern cosmology has unveiled a discrepancy between Hubble constant values from Local Universe observations and the predictions of a cold dark matter cosmological model with cosmological constant (ΛCDM).

*Estimation of the Hubble constant from the cosmic distance ladder method in which a simplification has been made regarding the method followed in Riess et al. (2009).

*Use of freely accessible catalogs with relevant data from standard candles: Cepheid variable stars and Type Ia supernovae.



Comparison of the results of the different methods for calculate the Hubble constant.
Source: Verde, Treu, & Riess (2019), *Tensions between the early and late Universe* Nature Astronomy, Volume 3, p. 891-895

Description of Methodology

A cosmic ladder with 3 ”rungs” Hubble constant

1.- Geometric distance measurement to NGC 4258
(already known: μ_{4258} = 29.3870 ± 0.0568, Herrstein et al. 1999)

2.- Period-luminosity relation of Cepheid variables in anchor galaxy NGC 4258 and type Ia SN hosts

3.- Redshift-magnitude relation from type Ia supernovae

Hubble constant calculation

Riess et al. (2009). *A redetermination of the Hubble constant with the Hubble Space Telescope from a differential distance ladder.* The Astrophysical Journal, 699(1), 539.

Calibration with the period-luminosity relationship in Cepheids

Geometric measurement of distance to NGC 4258

Redshift-magnitude relationship in Ia supernovae

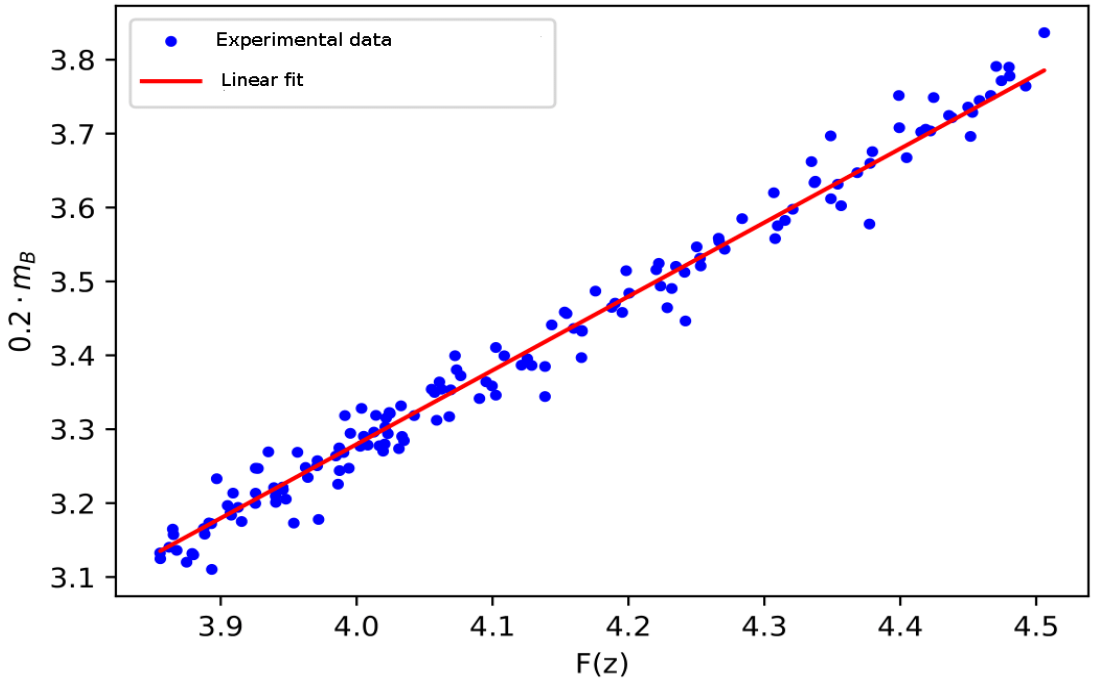
$$\log\left[\frac{H_0}{\mathrm{Km\ s^{-1}\ Mpc^{-1}}}\right] = \frac{(m_{B,4258} - \mu_{4258}) + 5a_B + 25}{5}$$

Observational data available from https://archive.stcis.edu/prends/ps1cosmo/scolnic_datatable.html and Table 2 in arXiv:1103.2976 https://iopscience.iop.org/0004-637X/730/2/119/suppdata/apj383673t2_mrt.txt

For more details, see Serrano-González, Cuesta, Ortiz-Mora (2020). *Determinación de la constante de Hubble mediante observaciones del Universo Local*. Revista Española de Física, 2020, vol. 34, nº1, p. 35-41

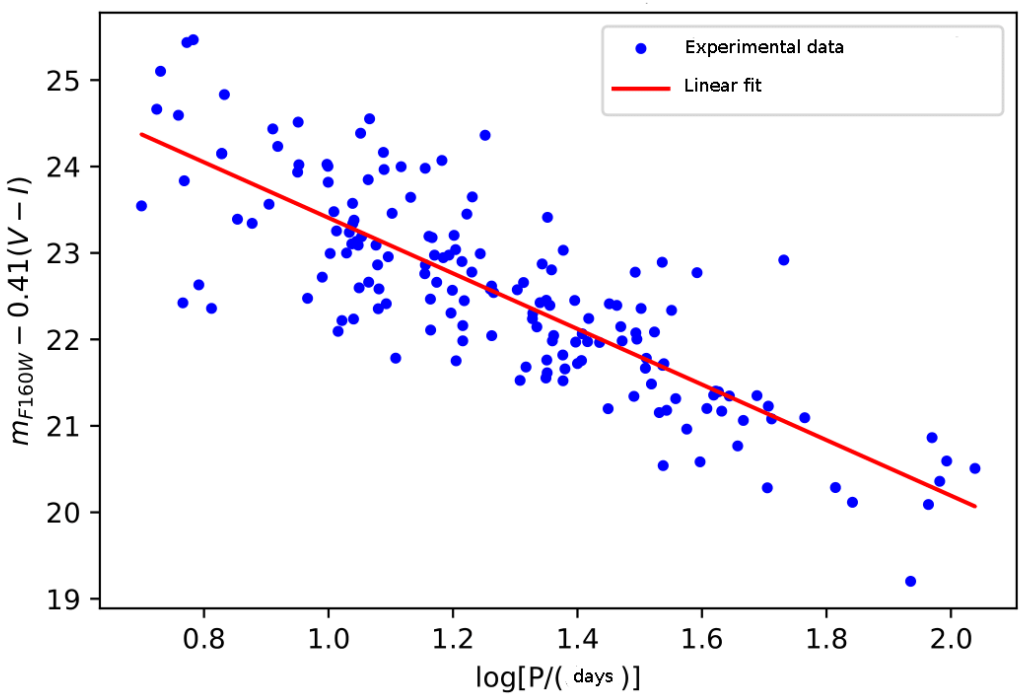
Redshift-magnitude relation in type Ia SNe

$F(z) = 0.2\, m_B + a_B$ $\quad a_B = 0.7203 \pm 0.023$

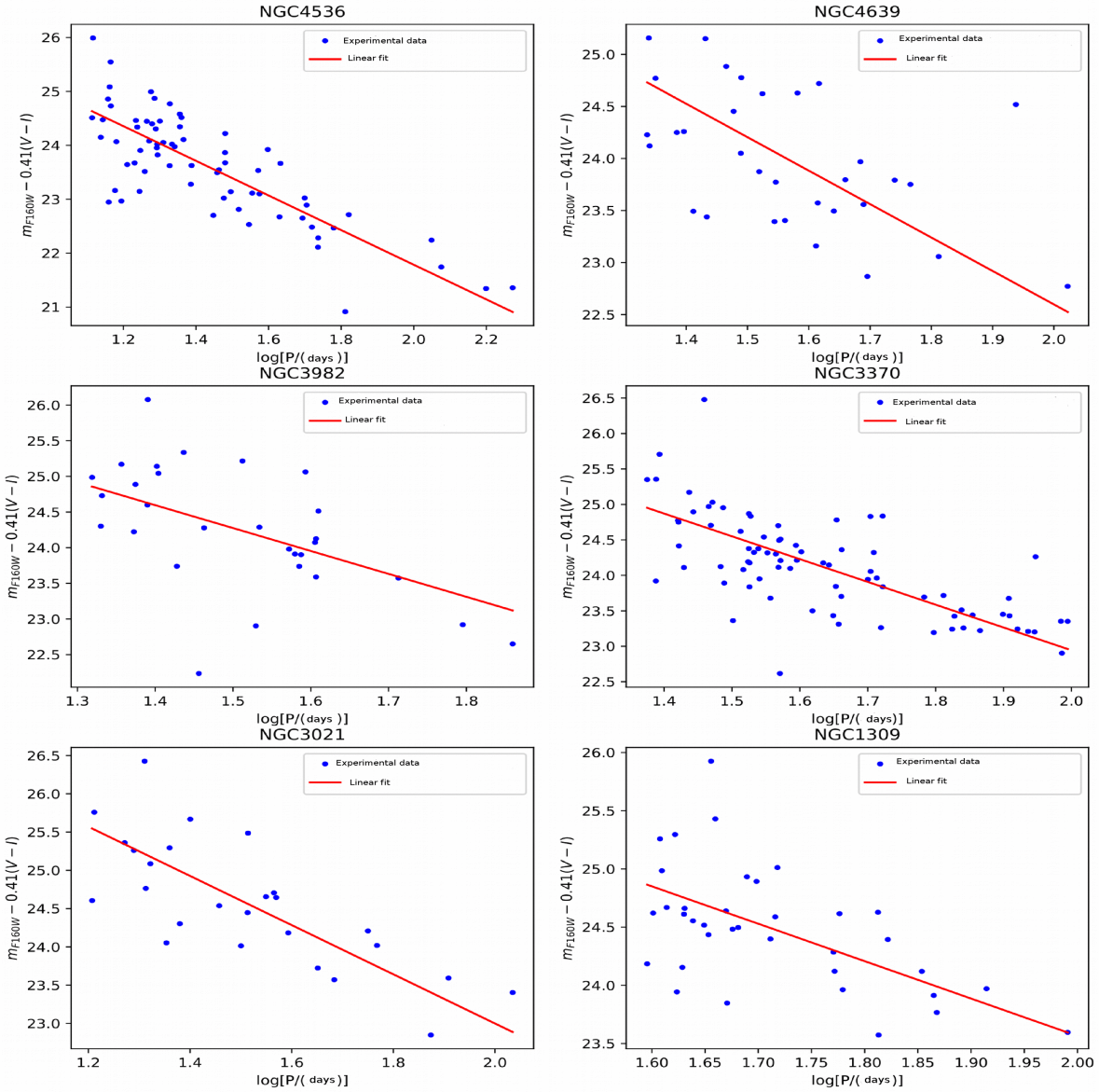


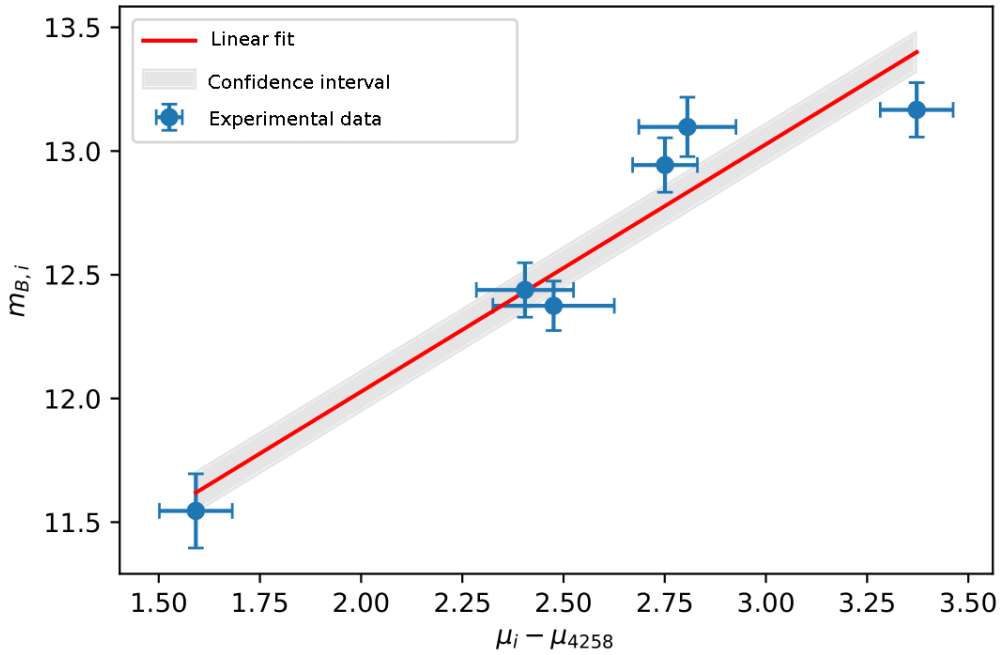
Calibration of the Redshift-magnitude relation of type Ia supernovae in the Local Universe $z \in [0.023, 0.1]$

Period-luminosity relation in Cepheids



Calibration of the period-luminosity relation of Cepheid variable stars in the anchor galaxy NGC 4258





The relative distances between these six type Ia supernova host galaxies can be used to calibrate the magnitude of a hypothetical type Ia supernovae in NGC4258: $m_{B,4258} = 10.03 \pm 0.08$

Period-luminosity relation of the six type Ia supernova-host galaxies in which Cepheids have been measured by the WFC3 in the Hubble Space Telescope.

Final estimation of the Hubble constant:
$H_0 = (71 \pm 4)$ Km s^{-1} Mpc^{-1}

Impacts and prospect to the future

.- The precision of this result shows both the power of this method and the importance to combine observations from various sources whose cosmological information is complementary.

.- Employed data catalogs with the astrophysical objects are free to use and available online, which allows their use in teaching, as well as the reproduction and possible improvements of these results.

.- The discrepancy between the measurement based on the distance ladder and the ΛCDM cosmological model prediction will need future studies to help relax this tension between different results. In the meantime, undergraduates can be trained to experience this cutting-edge problem in modern Cosmology.

.- The importance of working with data from high-precision observations with public access at the advanced levels of the Physics degree is key to improve our undergraduate students' data analysis skills.