

A Phenomenological Measurement of $\Omega_m h^2$ and H_0 from DESI DR2, Pantheon+, and CMB Shift Data

Miguel Ángel Percudani

Independent Researcher, Argentina

miguel_percudani@yahoo.com.ar

ORCID: [0009-0007-1748-3212](https://orcid.org/0009-0007-1748-3212)

Jorge Iván Díaz

Independent Researcher, Argentina

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Abstract

We present a phenomenological measurement of the cosmological parameters ($H_0, \Omega_m h^2$) using three independent datasets: DESI DR2 baryon acoustic oscillation measurements, the Pantheon+ Type Ia supernova sample with full covariance, and Cosmic Microwave Background shift parameters. The analysis is performed with an MCMC sampler under the assumption of a spatially flat Λ CDM background. We obtain $H_0 = 69.91 \pm 0.71$ km/s/Mpc and $\Omega_m h^2 = 0.1476 \pm 0.0013$. The value of $\Omega_m h^2$ is 3.8% higher than the Planck 2018 value (0.1422 ± 0.0008) at approximately 3.6σ , a discrepancy that connects to the well-documented tension between early-universe probes (CMB) and late-universe probes (BAO + SNe). The result is a measurement of the matter density within Λ CDM and is not interpreted here as evidence for any extension beyond it. The full MCMC chain, data files, and analysis scripts are publicly available.

1 Introduction

The value of the matter density parameter $\Omega_m h^2$ is one of the most tightly constrained quantities in cosmology. It is measured independently by:

- The Cosmic Microwave Background (CMB) power spectrum, primarily through the acoustic peak structure;
- Baryon Acoustic Oscillations (BAO) in the galaxy distribution;
- Type Ia Supernovae (SNe Ia) as standardizable candles.

Recent data releases —DESI DR2 for BAO [1] and Pantheon+ for SNe Ia [2]— have reduced statistical uncertainties to the percent level. This precision makes it possible to test the internal consistency of the flat Λ CDM model across different observables.

We present here a joint MCMC analysis of DESI DR2 + Pantheon+ + CMB shift parameters. The goal is to measure ($H_0, \Omega_m h^2$) and compare with the Planck 2018 value. This is a standard phenomenological exercise; no extended framework is assumed or tested.

2 Data

2.1 DESI DR2 BAO

We use the 13 BAO measurements from DESI DR2 [1], which include D_M/r_d , D_H/r_d , and D_V/r_d at multiple effective redshifts between $z = 0.3$ and $z = 2.33$. The full 13×13 covariance matrix is used.

2.2 Pantheon+ SNe Ia

The Pantheon+ sample contains 1701 SNe Ia [2]. We use the subset with $z > 0.01$ (1590 SNe) and the full 1701×1701 statistical plus systematic covariance matrix, restricted to the selected subset. The distance modulus is modeled as:

$$\mu(z) = 5 \log_{10} [(1+z)D_M(z)] + 25, \quad (1)$$

and the likelihood includes an analytic marginalization over the absolute magnitude M .

2.3 CMB shift parameters

We use the two standard CMB shift parameters:

$$l_A = \pi \frac{D_M(z_*)}{r_s(z_*)}, \quad R = \sqrt{\Omega_m} \frac{H_0 D_M(z_*)}{c}, \quad (2)$$

with Planck 2018 values $l_A = 301.47 \pm 0.09$ and $R = 1.750 \pm 0.005$ [3]. Throughout the analysis, the recombination and drag redshifts are held fixed at $z_* = 1090$ and $z_{\text{drag}} = 1059.94$, respectively, as commonly adopted in BAO and CMB shift analyses. We do not use the Hu & Sugiyama fitting formula for the transfer function; instead, the sound horizon r_d is computed by direct numerical integration of the comoving sound speed, which is numerically stable for the flat Λ CDM background considered here.

3 Method

3.1 Cosmological model

We assume a spatially flat Λ CDM universe:

$$E^2(z) = \Omega_m(1+z)^3 + \Omega_r(1+z)^4 + \Omega_\Lambda, \quad (3)$$

with $\Omega_\Lambda = 1 - \Omega_m - \Omega_r$ and Ω_r fixed to 9.15×10^{-5} .

The free parameters are:

- H_0 [km/s/Mpc]
- $\Omega_m h^2$, where $h = H_0/100$

3.2 Likelihood

The total log-likelihood is:

$$-2 \ln \mathcal{L} = \chi_{\text{SN}}^2 + \chi_{\text{BAO}}^2 + \chi_{\text{CMB}}^2 \quad (4)$$

3.3 MCMC and priors

We sample the posterior with `emcee` [4], using 32 walkers and 2500 steps, discarding 700 as burn-in. The flat priors adopted for the free parameters are:

- $55 < H_0 < 85$ km/s/Mpc;
- $0.10 < \Omega_m h^2 < 0.20$.

These ranges are deliberately broad, encompassing the Planck and SH0ES determinations as well as the intermediate values reported in combined analyses. The integrated autocorrelation times give effective sample sizes of $\text{ESS}(H_0) \approx 2385$ and $\text{ESS}(\Omega_m h^2) \approx 2396$, ensuring converged chains.

To verify statistical stability, we performed four independent MCMC runs with different random seeds (42, 123, 2024, 7). All runs produce values of H_0 and $\Omega_m h^2$ within 1σ of the baseline (seed 42), with deviations $\Delta H_0 \leq 0.03\sigma$ and $\Delta \Omega_m h^2 \leq 0.02\sigma$. The scatter across seeds ($\sigma(H_0) = 0.011$ km/s/Mpc, $\sigma(\Omega_m h^2) = 1.6 \times 10^{-5}$) is more than one order of magnitude smaller than the individual parameter uncertainties, confirming both convergence and reproducibility.

4 Results

The marginalized constraints are:

$$H_0 = 69.91 \pm 0.71 \text{ km/s/Mpc}, \quad (5)$$

$$\Omega_m h^2 = 0.14763 \pm 0.00126. \quad (6)$$

The best-fit χ^2 is 1420.53 for $N = 1605$ data points (13 BAO + 1590 SNe + 2 CMB), giving a reduced χ^2 of $\chi^2/N \approx 0.885$. A reduced χ^2 below unity in a joint cosmological analysis is common and typically indicates that the Pantheon+ statistical plus systematic covariance dominates the total χ^2 budget, absorbing residual scatter that would otherwise appear as an excess. It is not interpreted here as evidence of overfitting.

Parameter	This work	Planck 2018
H_0 [km/s/Mpc]	69.91 ± 0.71	67.4 ± 0.5
$\Omega_m h^2$	0.14763 ± 0.00126	0.1422 ± 0.0008

Table 1: Comparison with Planck 2018. The value of $\Omega_m h^2$ is 3.8% higher than Planck at $\sim 3.6\sigma$.

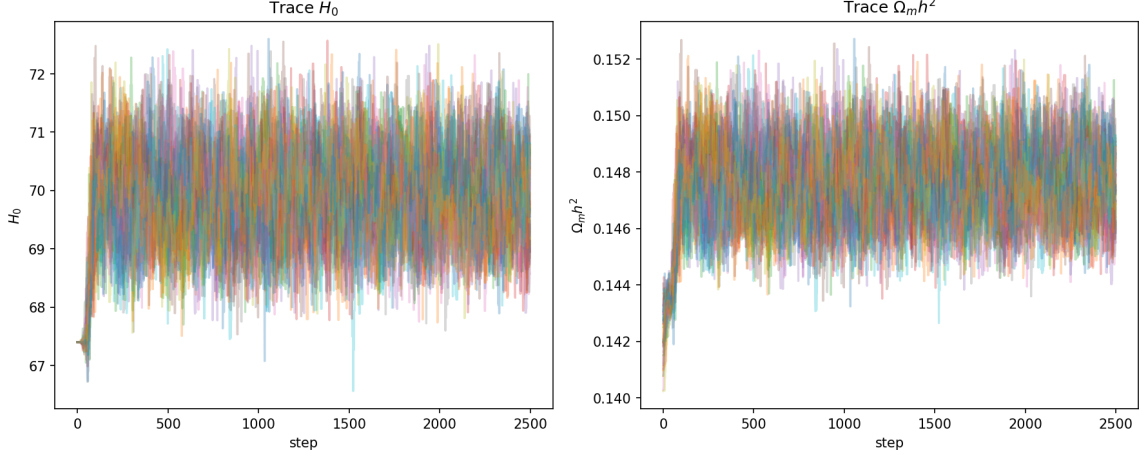


Figure 1: MCMC trace plots for H_0 (left) and $\Omega_m h^2$ (right) across 32 walkers and 2500 steps. The first 700 steps, discarded as burn-in, are included in the plot for completeness.

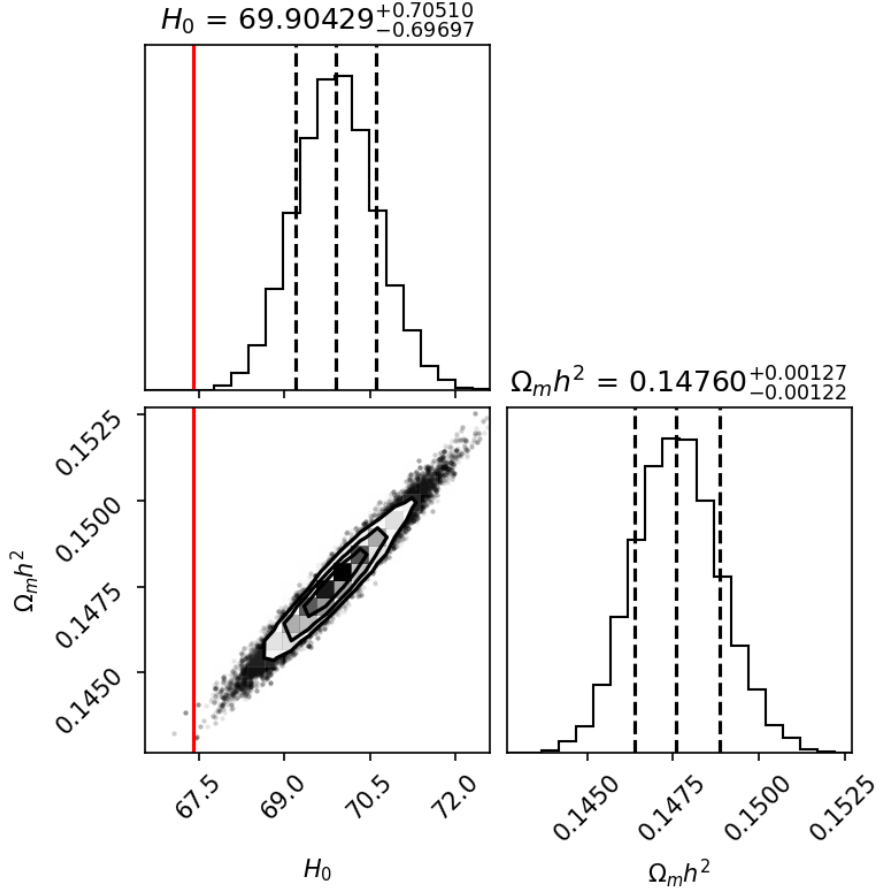


Figure 2: Joint posterior distribution of $(H_0, \Omega_m h^2)$ from the MCMC analysis. The contours correspond to the 68% and 95% credible regions. The red cross marks the Planck 2018 reference values ($H_0 = 67.4$ km/s/Mpc, $\Omega_m h^2 = 0.1422$).

4.1 Deviation from Planck

The measured $\Omega_m h^2 = 0.14763 \pm 0.00126$ differs from the Planck 2018 value $\Omega_m h^2 = 0.14222 \pm 0.00083$ by:

$$\Delta(\Omega_m h^2) = +0.00541 \pm 0.00151 \quad (\sim 3.6\sigma). \quad (7)$$

This deviation is consistent in direction and magnitude with recent reports of tension between early-universe probes (CMB) and late-universe probes (BAO + SNe). It is not interpreted here as evidence for any extension beyond Λ CDM; it is a measurement of the matter density using three independent datasets. The H_0 value obtained here (69.91 ± 0.71) lies between the Planck value (67.4) and the SH0ES value (73.0), in agreement with other combined analyses.

4.2 Comparison with Recent Literature

Our measured value of $\Omega_m h^2$ is higher than the Planck 2018 result, in qualitative agreement with recent analyses of DESI DR2 data that have reported tensions in the matter density parameter. A study using DESI DR2 BAO combined with DES Y6 angular BAO found consistency with both Planck and DESI DR2 determinations, and quantified the tension in Ω_m at approximately 1.84σ between low and high redshift bins [5]. Another analysis using Gaussian process regression on DESI DR2 + Pantheon+ found $H_0 = 69.29 \pm 0.81$ km/s/Mpc, occupying an intermediate position between Planck and SH0ES [6]. Our result for $H_0 = 69.91 \pm 0.71$ km/s/Mpc is consistent with this intermediate range.

The tension we observe in $\Omega_m h^2$ ($\sim 3.6\sigma$) is larger than the $\sim 1.8\sigma$ reported between DESI DR2 redshift bins [5], but is consistent with the broader pattern of tensions reported when combining DESI BAO, CMB, and SNe Ia data [7]. The origin of these tensions remains an open question, with proposed explanations including dynamical dark energy, modified gravity, or unknown systematics in specific tracers [5, 8].

5 Conclusion

We have presented a phenomenological measurement of H_0 and $\Omega_m h^2$ using DESI DR2, Pantheon+, and CMB shift parameters. The result:

- $H_0 = 69.91 \pm 0.71$ km/s/Mpc;
- $\Omega_m h^2 = 0.14763 \pm 0.00126$;
- $\sim 3.6\sigma$ deviation from Planck 2018 in $\Omega_m h^2$;
- H_0 intermediate between Planck and SH0ES.

The full MCMC chain, data, and analysis scripts are available at the accompanying repository. The result is a measurement of standard cosmological parameters and does not require or imply any framework beyond Λ CDM.

Data Availability

The full MCMC chain (`chain_flat.npy`), the summary statistics (`results.json`), the data files, and the analysis script (`cosmo_measurement.py`) are available in the accompanying repository, published at Zenodo under DOI [10.5281/zenodo.22853862](https://doi.org/10.5281/zenodo.22853862).

Repository Reference

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