Constraining Dark Energy Models Using Pantheon+ Supernovae

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Introduction

Type Ia supernovae are luminous and reliable standard candles used in cosmology to measure distances across the universe. These stellar explosions occur in binary systems where a white dwarf, the dense remnant of a sun-like star, accretes matter from a companion star. The uniformity in the brightness of Type Ia supernovae, due to the consistent mass at which these explosions occur, allows astronomers to use them to refine measurements of various cosmological parameters. By analyzing light curves from these supernovae across different redshifts, scientists can trace how the expansion rate of the universe has changed over time, providing critical insights into dark energy properties and the overall geometry of the universe.

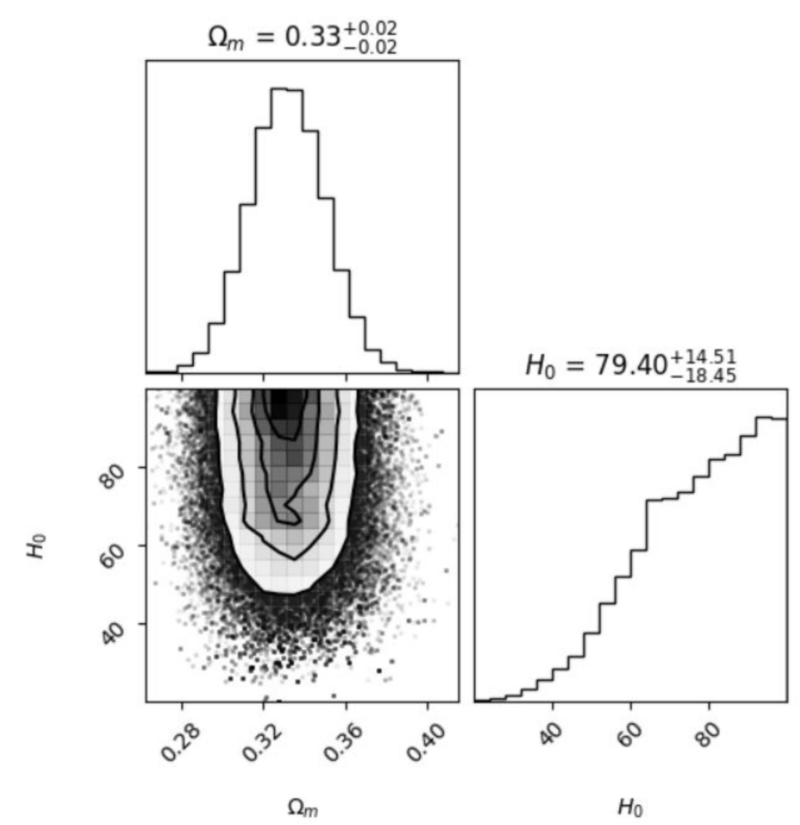
Methodology

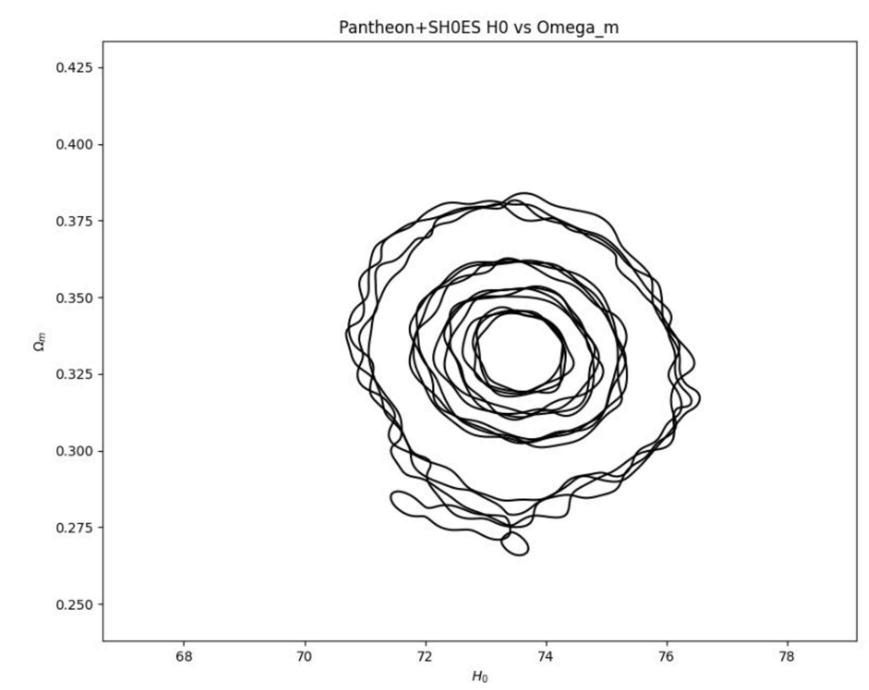
The Pantheon+ dataset, which includes over 1,000 Type Ia supernovae, provides precise measurements of distance moduli across a wide range of redshifts. In this research, we analyzed cosmological parameters from the dataset using advanced computational tools:

- CAMB for calculating theoretical predictions of the Cosmic Microwave Background
- MCMC simulations in Cobaya for identifying the most likely values of H0, Ωm, and other parameters

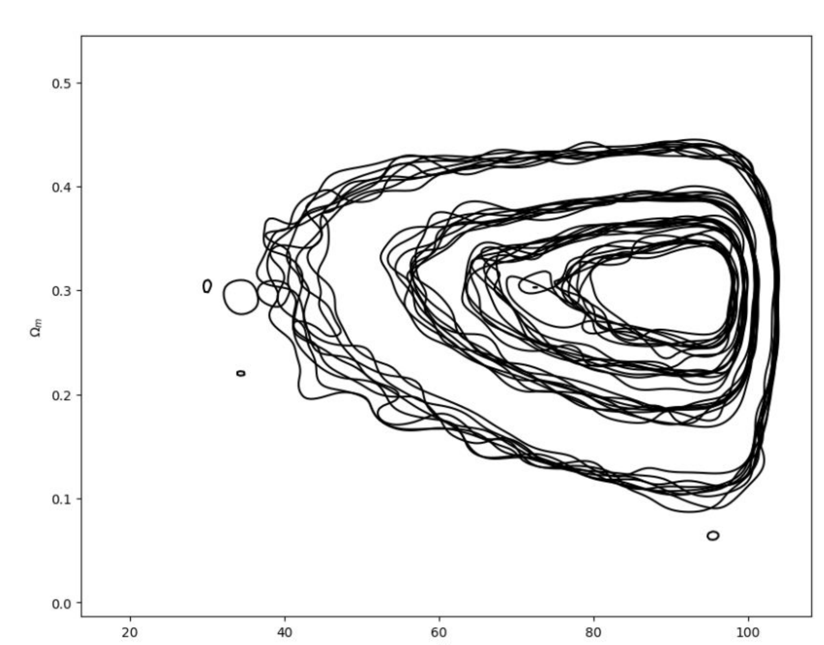
Our analysis focused on both the Lambda Cold Dark Matter (ΛCDM) model and its extensions, the wCDM and w0waCDM models. Varying the dark energy equation of state parameters, w0 and wa, allowed us to explore the implications of different dark energy models.

Results





Our analysis supports the ΛCDM model as a robust framework for describing the universe, aligning with the previous findings. Specifically, observed in the contour map above, we obtained a value for the Hubble constant of H0 = 79.40 km s⁻¹ Mpc⁻¹ and a value for the matter density parameter of Ωm = 0.33 ± 0.02, corroborating current cosmological models.



Compared to the ΛCDM model (which assumes w = −1), we see a difference in the contour shapes in the wCDM model above due to the additional freedom it allows for w to vary. The contours appear elongated and roughly elliptical, indicating a degeneracy between H0 and Ωm. This tells us that a higher H0 can be compensated by a lower Ωm, and vice versa.

Conclusion

Our results, consistent with previous research, emphasize the reliability of Type Ia Supernovae for cosmological studies.

Although Pantheon+ typically reports a Hubble constant of H0 = 73.04 ± 1.04 km s⁻¹ Mpc⁻¹, the slightly higher value of H0 in our analysis reflects ongoing discussions in the field, often referred to as the Hubble tension.

Future efforts will focus on integrating Pantheon+ data with the dark energy extension models (wCDM and w0waCDM), to further refine cosmological parameter estimates and gain additional insights into properties of dark energy.

Acknowledgments

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References

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