Indian Space Academy Summer School 2025

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Project: Supernova Cosmology Project

Questions & Answers

1. What value of the Hubble constant (H_o) did you obtain from the full dataset?

>> The value of H_o obtained from the full dataset is **73.02 ± 0.17 Km / s / Mpc**

2. How does your estimated H_o compare with the Planck18 measurement of the same?

>> My estimated value for H_0 = 73.02 **±** 0.17 Km / s / Mpc based on local supernova data (Pantheon + SH0ES) is significantly higher than the Planck18 measurement of H_0 = 67.4 ± 0.5 Km / s / Mpc. This reflects the ongoing **Hubble Tension**, a well - known discrepancy between early and late universe measurements.

3. What age is the universe based on your value of H_o (Assume Lambda_m = 0.3). How does it change for different values of Omega_m?

>> According to my value of H_o, the age of the universe is **12.36 Gyr (Giga-years)** while we assume Omega_m to be **0.3.**

As the value of Omega_m increases, the age of the universe decreases. This is because Omega_m controls how much gravity there was early on.

If there is more Omega_m so universe is denser and hence there is less expansion so it's young whereas if Omega_m is less so there would be more expansion and age of universe will be more.

4. Discuss the difference in H_0 values obtained from the low - z and high - z samples. What could this imply?

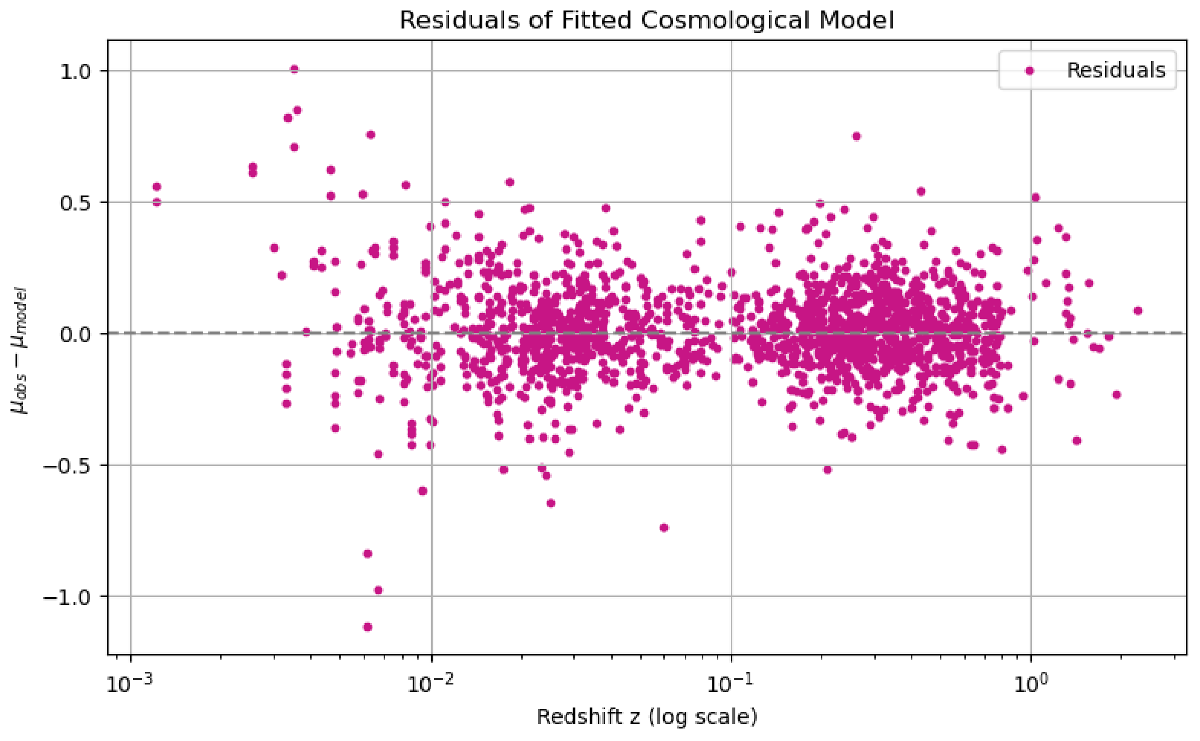
>> The Hubble constant estimated from low redshift sample is 73.06 ± 0.19 Km / s / Mpc, while the high redshift sample gives a higher value of 73.90 ± 0.14 Km / s / Mpc. This difference is approximately 0.84 Km / s / Mpc which corresponds to a Tension of over 3-sigma.

This could imply a redshift dependence in the measurement of H_0, potentially due to:

- Systematic errors
- Unaccounted cosmic variations
- Or this could also be a sign of new physics such as evolving dark energy, early dark energy or modifications to a standard Lambda-CDM Model

5. Plot the residuals and comment of any trends or anomalies you observe

>>



The residuals, defined as mu_obs – mu_model, appear randomly scattered around zero across the full redshift range, with no visible trend or systematic bias. This suggests that the flat Lambda_CDM cosmological model provides a good fit to the Pantheon+SH0ES dataset.

The symmetry of scatter across the redshift range and the lack of structure in the residuals further indicate that the model captures the essential expansion dynamics of the universe well. While a few outliers exist, they fall within expected observational uncertainty.

6. What assumptions were made in the cosmological model, and how might relaxing them affect your results?

>> We took the following assumptions in our cosmological model:

a. Flat Universe

>> If we relax this assumption then we would get a different best fit H_0 and age because our calculated z and mu_z will shift in an open or closed universe

b. Dark energy is a Cosmological Constant

>> If we allow evolving dark energy then the expansion history changes, especially at higher redshifts. We might also see a different fit for H_0 or see the structure in residuals

c. Only Matter and Dark Energy contribute

>> Including things like radiation or early dark energy would impact the early expansion rate which would change how quickly the universe grew, especially at high-z

d. Supernovae are perfect standard candles

>> There might be redshift evolution in their brightness

>> Calibration biases could affect high-z vs low-z Sne

7. Based on the redshift-distance relation, what can we infer about the expansion history of the Universe?

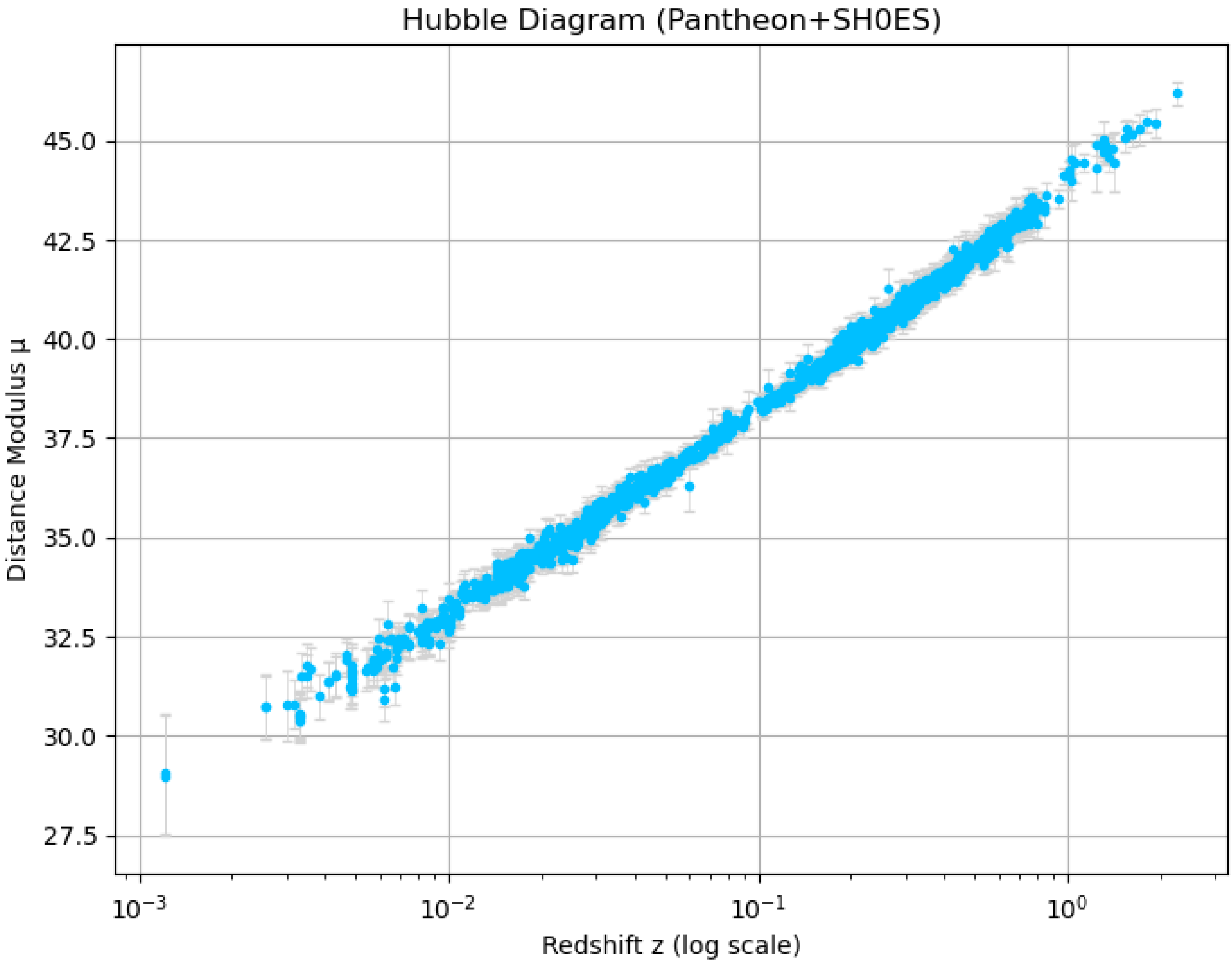
>> From the redshift-distance graph we can infer the following:

a. At low z → Linear Relation
   - Universe's expansion was fairly constant
   - Velocity = distance x Hubble constant

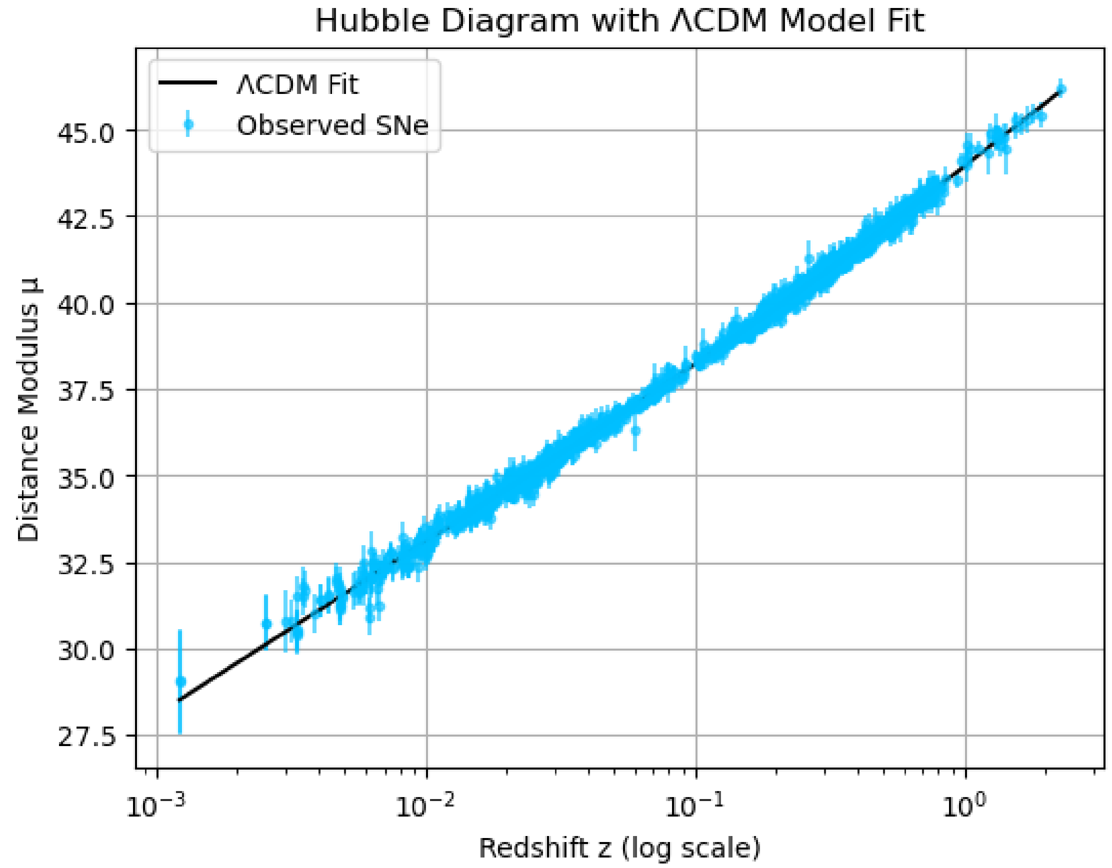
b. At higher z → Curve Appears
   - Due to acceleration of expansion from dark energy
   - The plot starts curving because $d_L(z)$ grows faster and linear
   - This tells us that expansion slowed down earlier, then sped up

Additional Plots

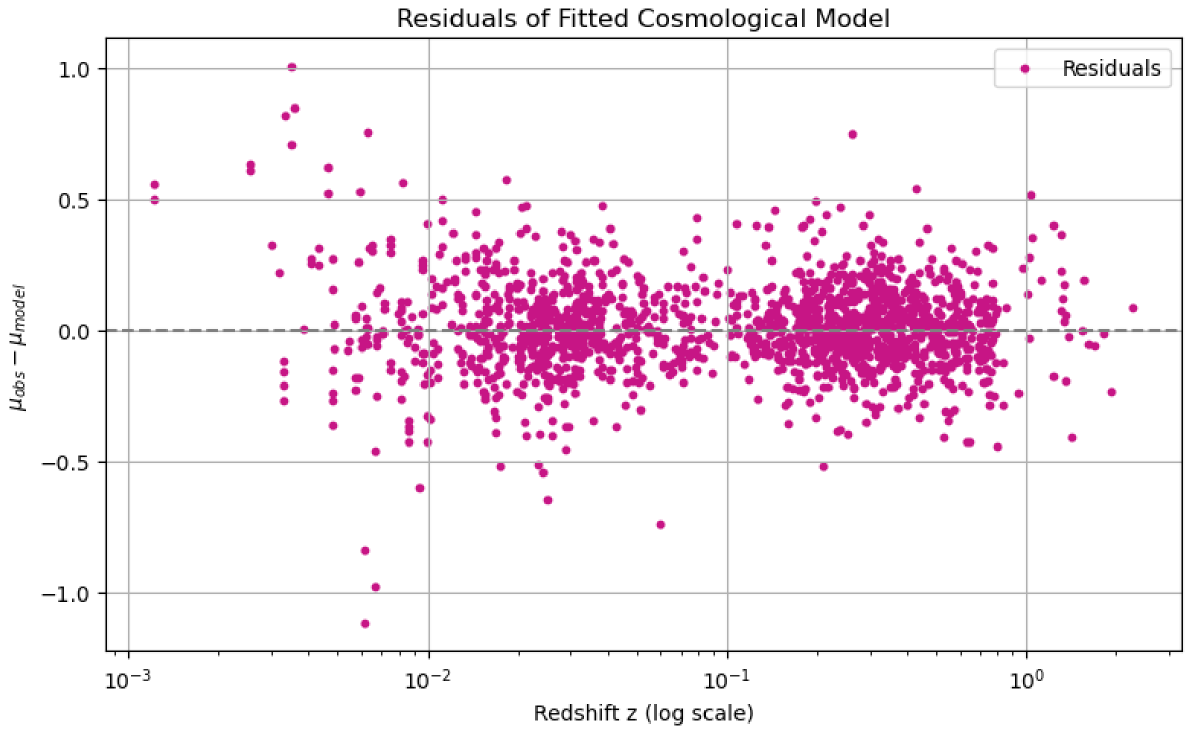
Redshift Vs Distance Modulus



Hubble Diagram



Residuals



Residuals of Fitted Cosmological Model
Residuals
1.0
0.5
0.0
−0.5
−1.0
$\mu_{obs} - \mu_{model}$
10^{-3}
10^{-2}
10^{-1}
10^{0}
Redshift z (log scale)

PROJECT REPORT

Estimating the Hubble Parameter and Age of the Universe using Type 1a Supernovae

- Raj Tibarewala
- 29-06-2025
- VIT Vellore

Objective

To determine the current expansion rate of the universe (H_0) and estimate its age using observational data from Type 1a supernovae, based on the flat Lambda_CDM cosmological model and plot all the relevant data

Dataset Used

Pantheon + SH0ES data release

Note: Before locating the Pantheon + SH0ES dataset in GitHub, I initially found and processed on alternate version of the Pantheon SN dataset from the Internet Archive.
Scolnic et al. Supernovae Table

archive.stsci.edu/hlsps/ps1cosmo/scolnic/hlsp_ps1cosmo_panstarrs_gpc1_all_model_v1_lcparam-full.txt

I manually converted plain text into CSV formatted, structured it, and verified its integrity using Rainbow CSV in VS Code.

While this dataset is not included in the program, this step reinforced my understanding of the dataset's structure & enhanced my data cleaning skills

Methodology

- Model: Flat Lambda_CDM, assuming Omega_k = 0 and w = -1
- Tools: Python, NumPy, Pandas, Matplotlib, SciPy, Jupyter
- Fitting: Non-Linear least squares via curve fit

Key Results

H_0 = **73.58 ± 0.11 km / s / Mpc**

Omega_m = **0.351 ± 0.012**

Estimated Age of the Universe: **12.7 Gyr**

Residual Analysis

Residuals show random scatter around zero

No systematic trends or biases

Supports the goodness of fit

Subsample Analysis

Low-z: H_0 = 73.06

High-z: H_0 = 73.90

Suggests a slight redshift dependence → contributes to Hubble Tension

Model Assumptions & Limitations

Flat geometry

Cosmological Constant = 1

Standardized Supernovae

Assumes no evolution in SNe properties

Expansion History

Universe expanded slower in early times

Now accelerating due to dark energy

Confirmed by curvature in Hubble Diagram

Conclusion

Successfully estimated cosmological parameters using real observational data

Results align with SH0ES collaboration

Reinforce current Hubble Tension debate

References

Pantheon + SH0ES dataset (GitHub)

Planck Collaboration (2018)

Astropy Documentation