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Testing robustness of supernovae cosmological parameter inference with Gaussian process

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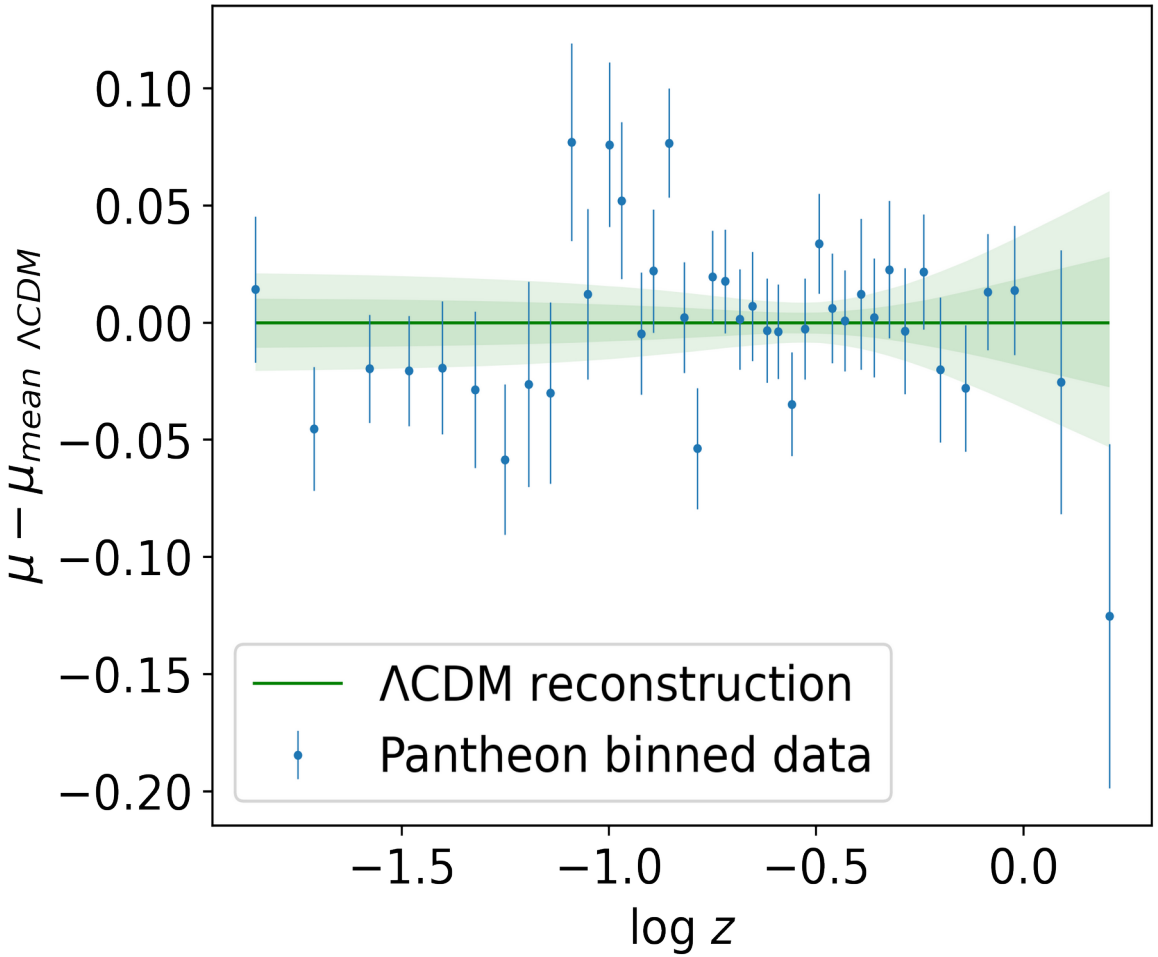
Outline

- Pantheon (Scolnic et al. 2018)
  - Motivation for testing
  - Methodology
  - Constraints on additional covariance and impact on parameter inference
- Pantheon+ (Scolnic et al. 2021)
  - Motivation for testing
  - Constraints on additional covariance and impact on parameter inference
- Conclusions and Outlook

Pantheon SNe sample

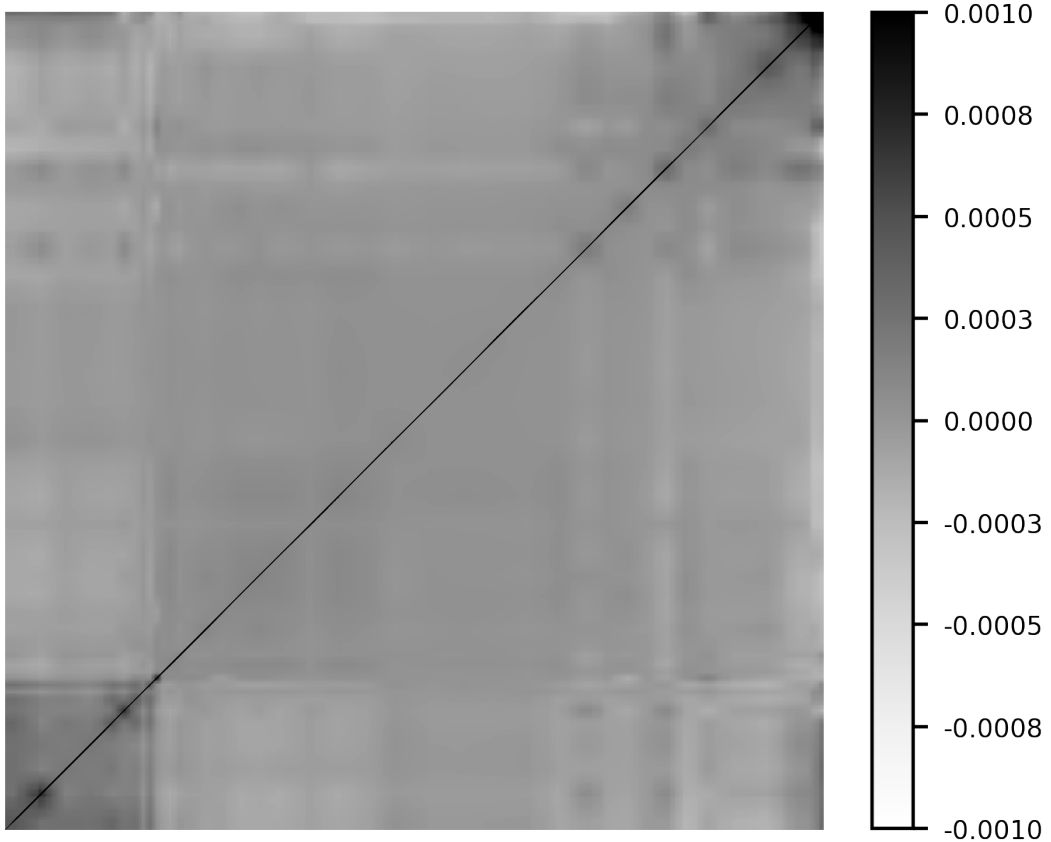
Distance modulus residuals

- Does data have excess of correlation?
- How does it affect parameter estimate?



Covariance

- Evaluated with binned data
- Are some systematic errors missing?



Data ref.: Scolnic et al. 2018, Riess et al. 2016;

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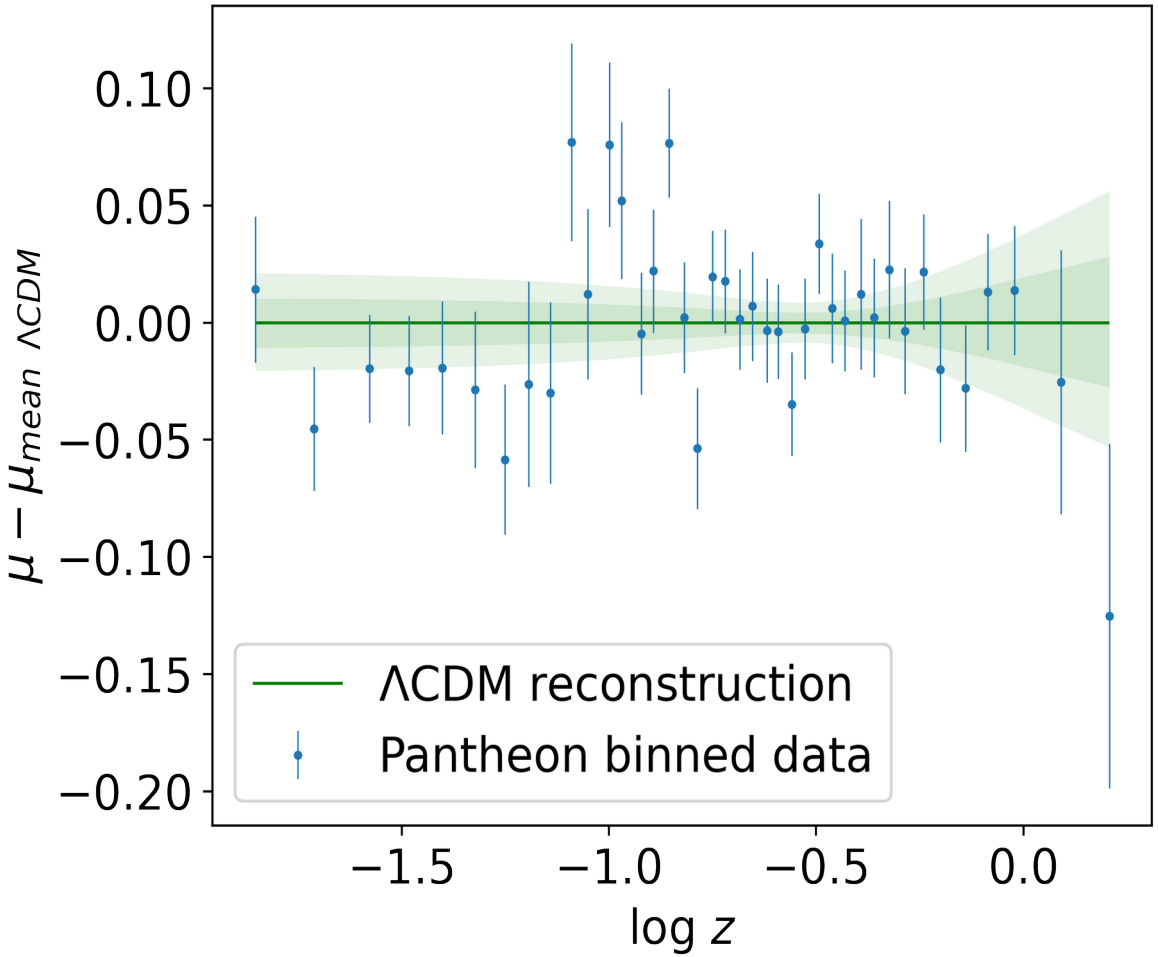
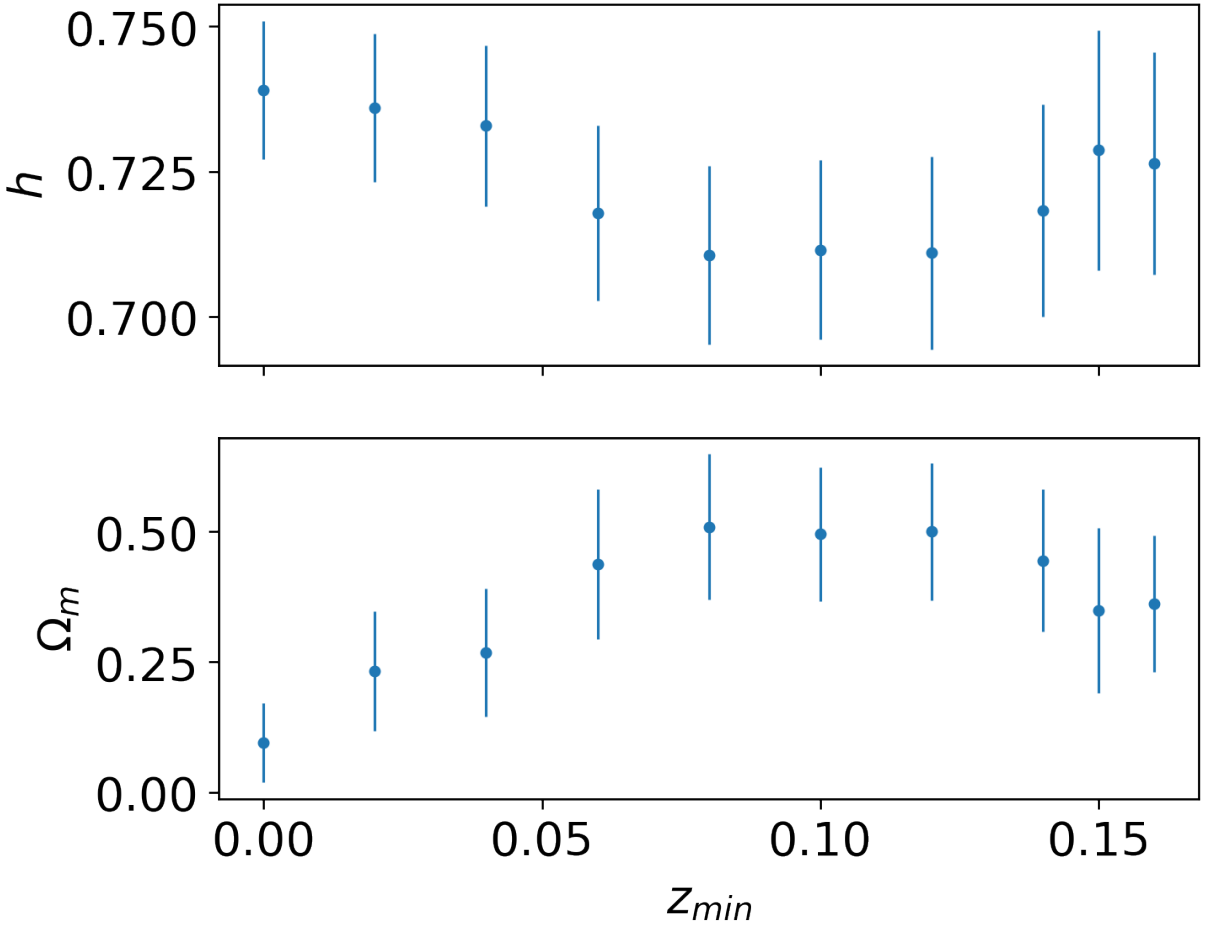


Parameter inference

- Moving redshift bin parameter estimate show some degree of redshift dependence

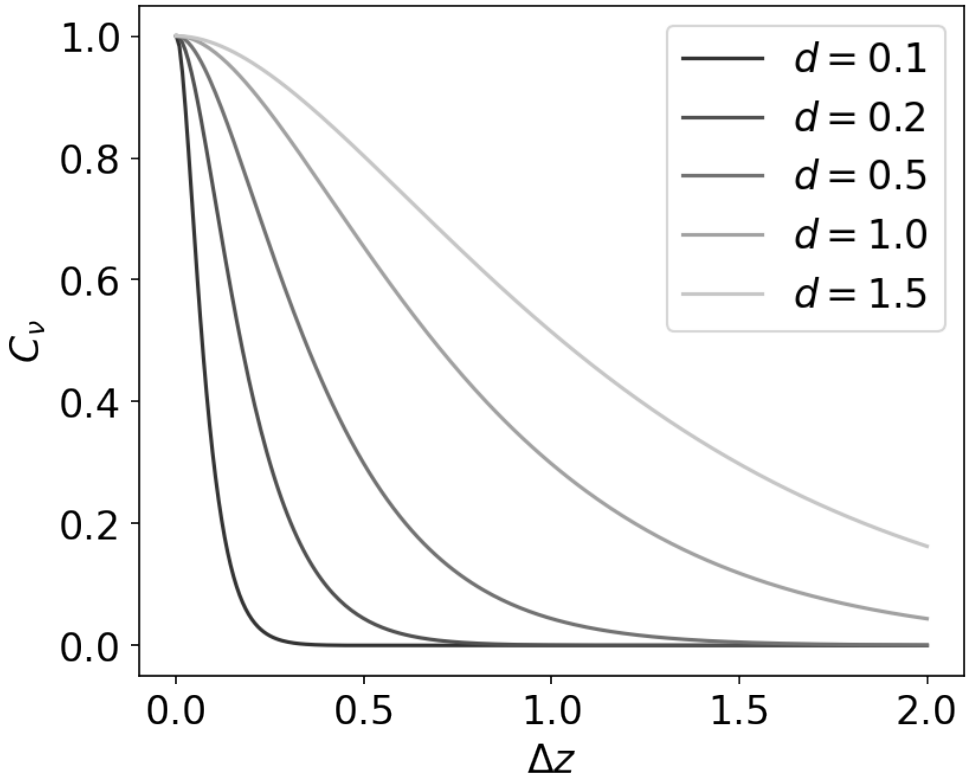


Dataset ref.: Scolnic et al. 2018, Riess et al. 2016; See also: Colgáin 2019

Introducing additional covariance

- Stationary Gaussian process described by Matérn kernel
- Defined by separation in redshift space
- Three additional parameters:
  - Amplitude
  - Characteristic scale
  - Smoothness

$$C_\nu(\Delta z) = \sigma^2 \frac{2^{1-\nu}}{\Gamma(\nu)} \left(\sqrt{2\nu}\frac{\Delta z}{d}\right)^\nu K_\nu \left(\sqrt{2\nu}\frac{\Delta z}{d}\right)$$

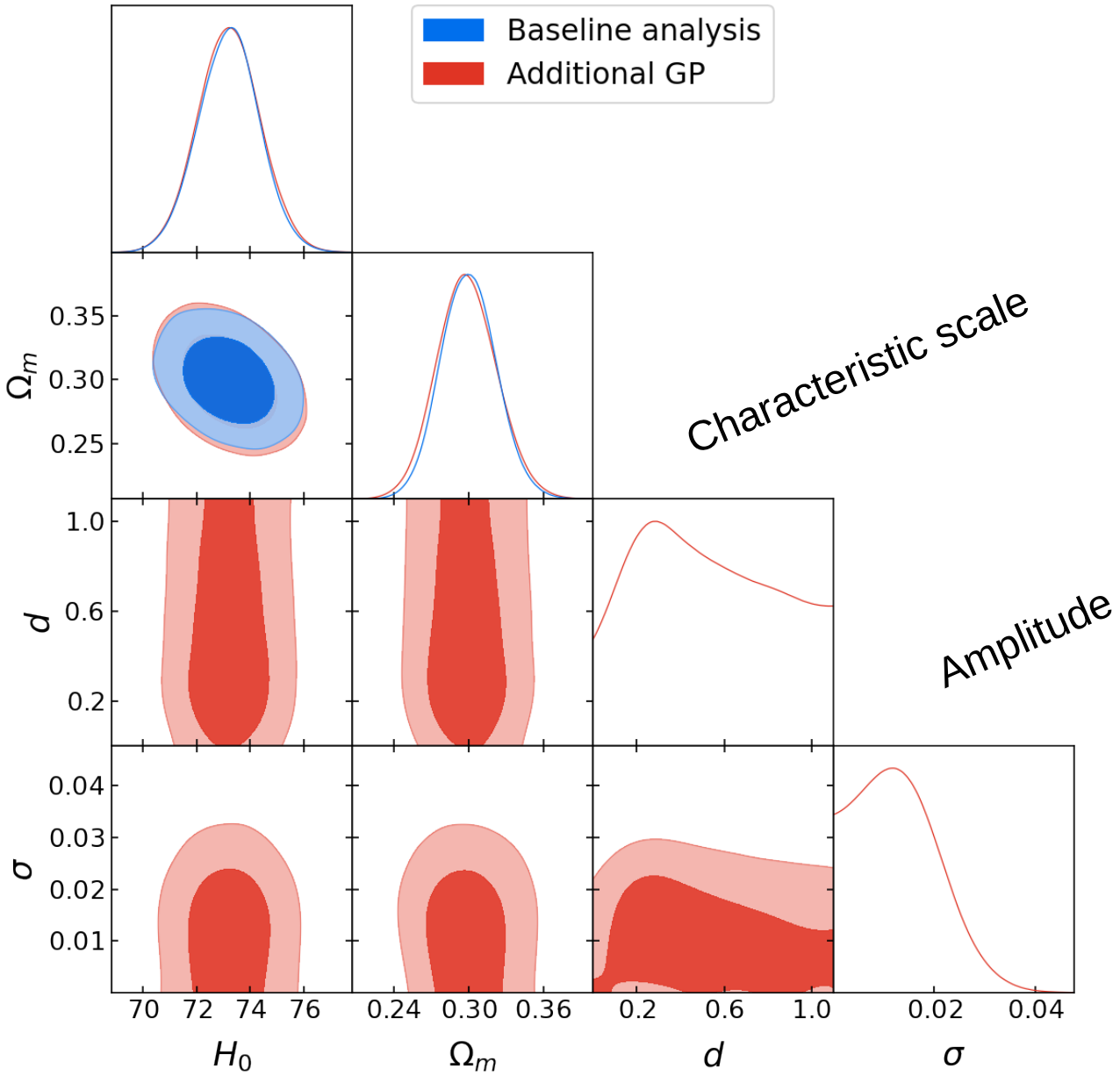


- Normalization is part of the likelihood

$$\ln(\mathcal{L}) = \frac{1}{2}\boldsymbol{\delta}^T(\boldsymbol{C_{Pantheon}} + \boldsymbol{C_\nu(\Delta z)})^{-1}\boldsymbol{\delta} -$$

$$- \frac{1}{2}\ln(\det(\boldsymbol{C_{Pantheon}} + \boldsymbol{C_\nu(\Delta z)}))$$

Constraints on GP parameters



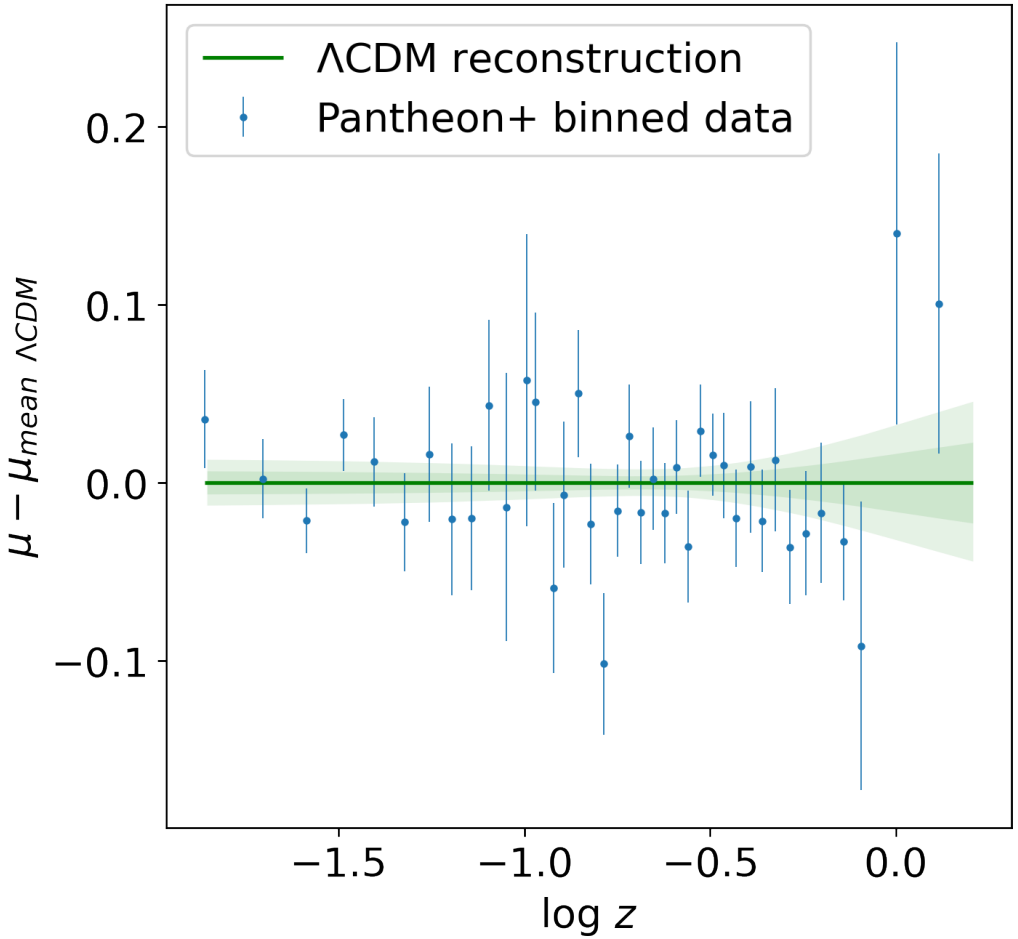
- No change in the cosmological parameter estimate
- Presence of slight peak in d distribution
- No strong evidence for presence of additional covariance
- Slight impact of prior range on covariance amplitude estimate

- Non-stationarity assumption does not improve constraints

Pantheon+ SNe sample

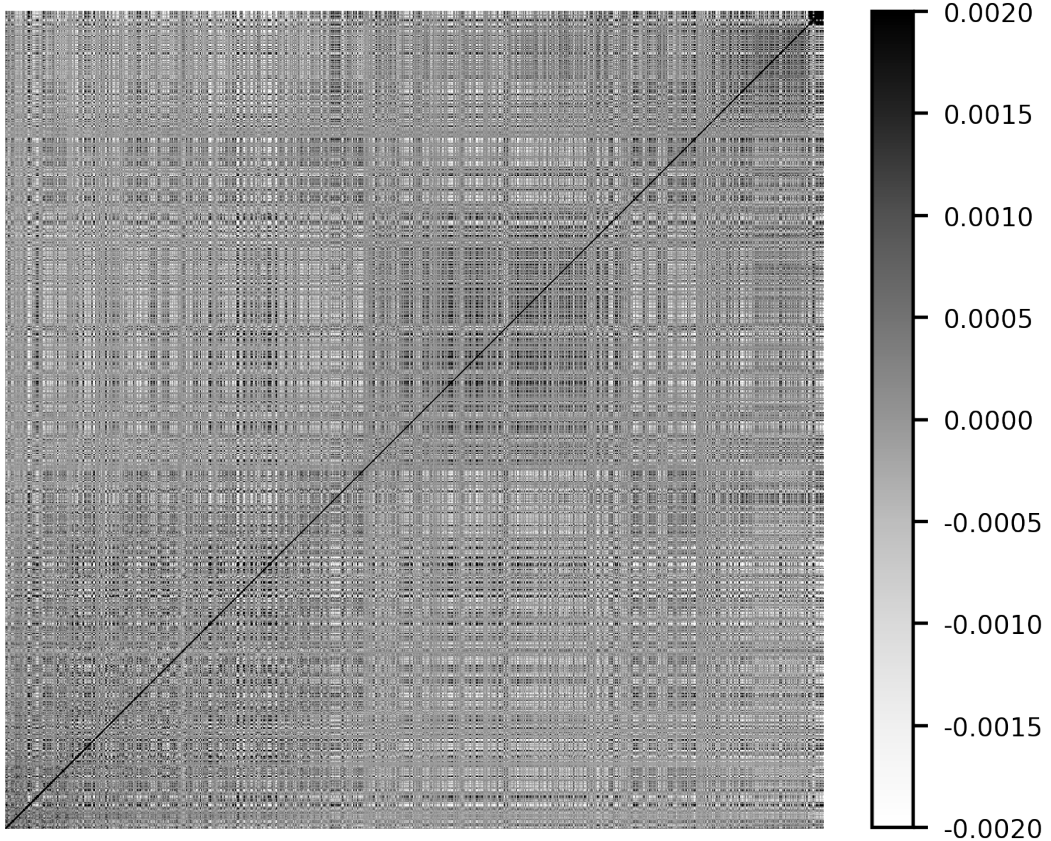
Distance modulus residuals

- Less correlation in the data
- Is effect on parameters still there?



Covariance

- Evaluated for individual SNe
- Calibrators are included



Data ref.: Scolnic et al. 2021, Riess et al. 2021;

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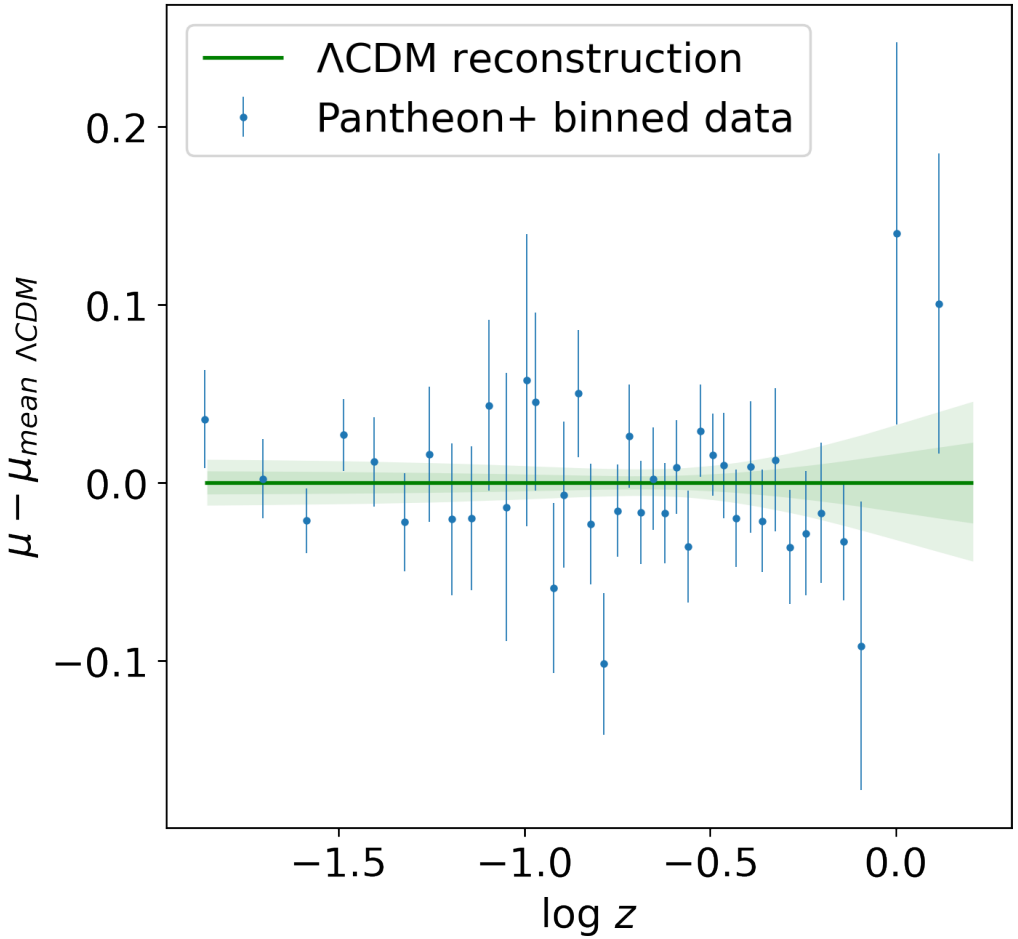
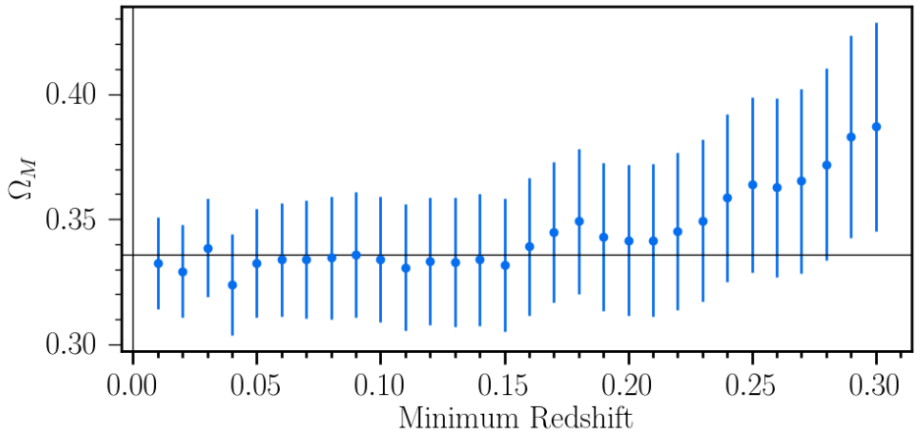
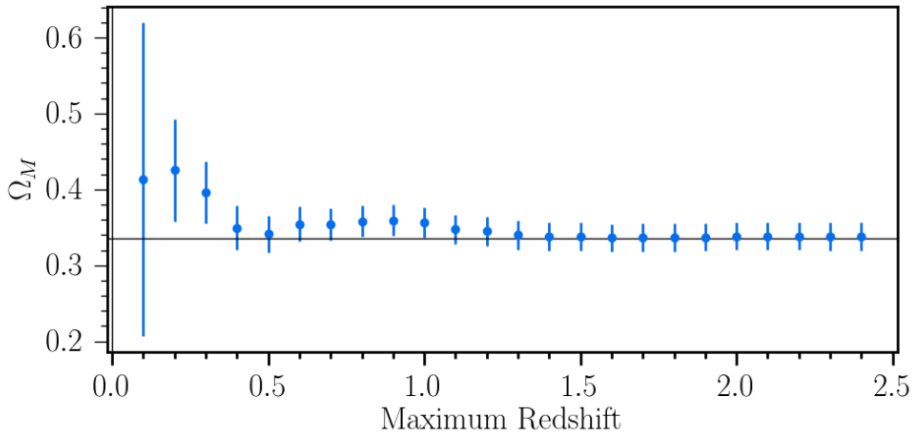


Parameter inference

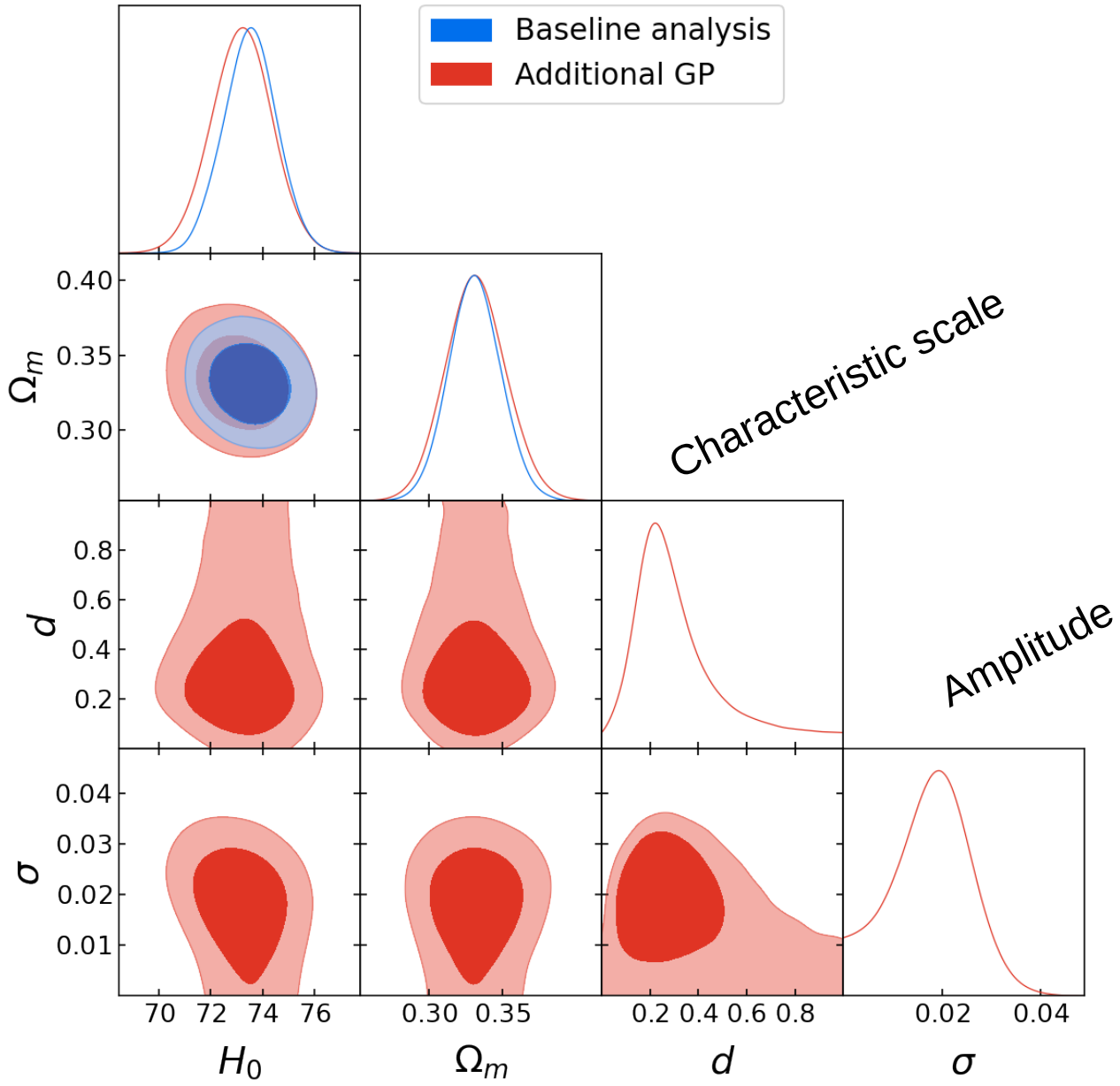
- Constraints with moving upper and lower boundaries show weaker redshift dependence



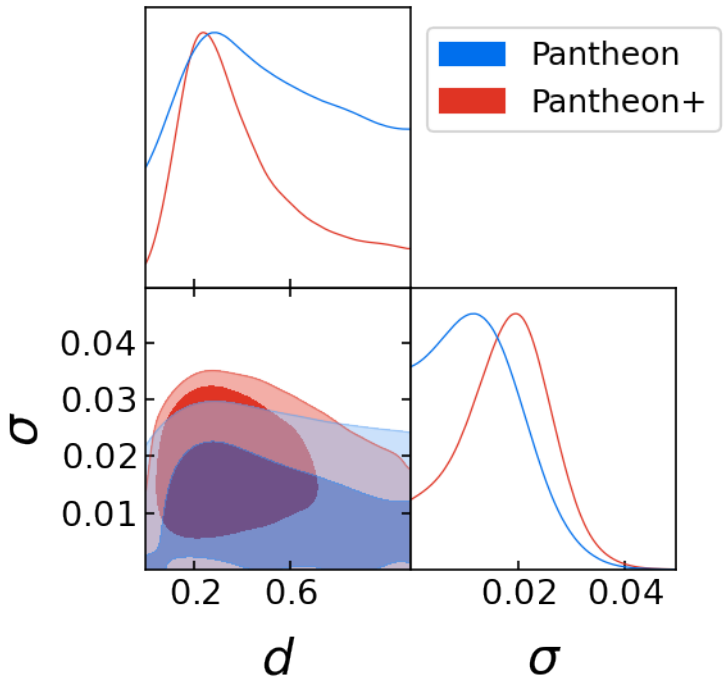


Data ref.: Scolnic et al. 2021, Riess et al. 2021; Fig.:Brout et al. 2022

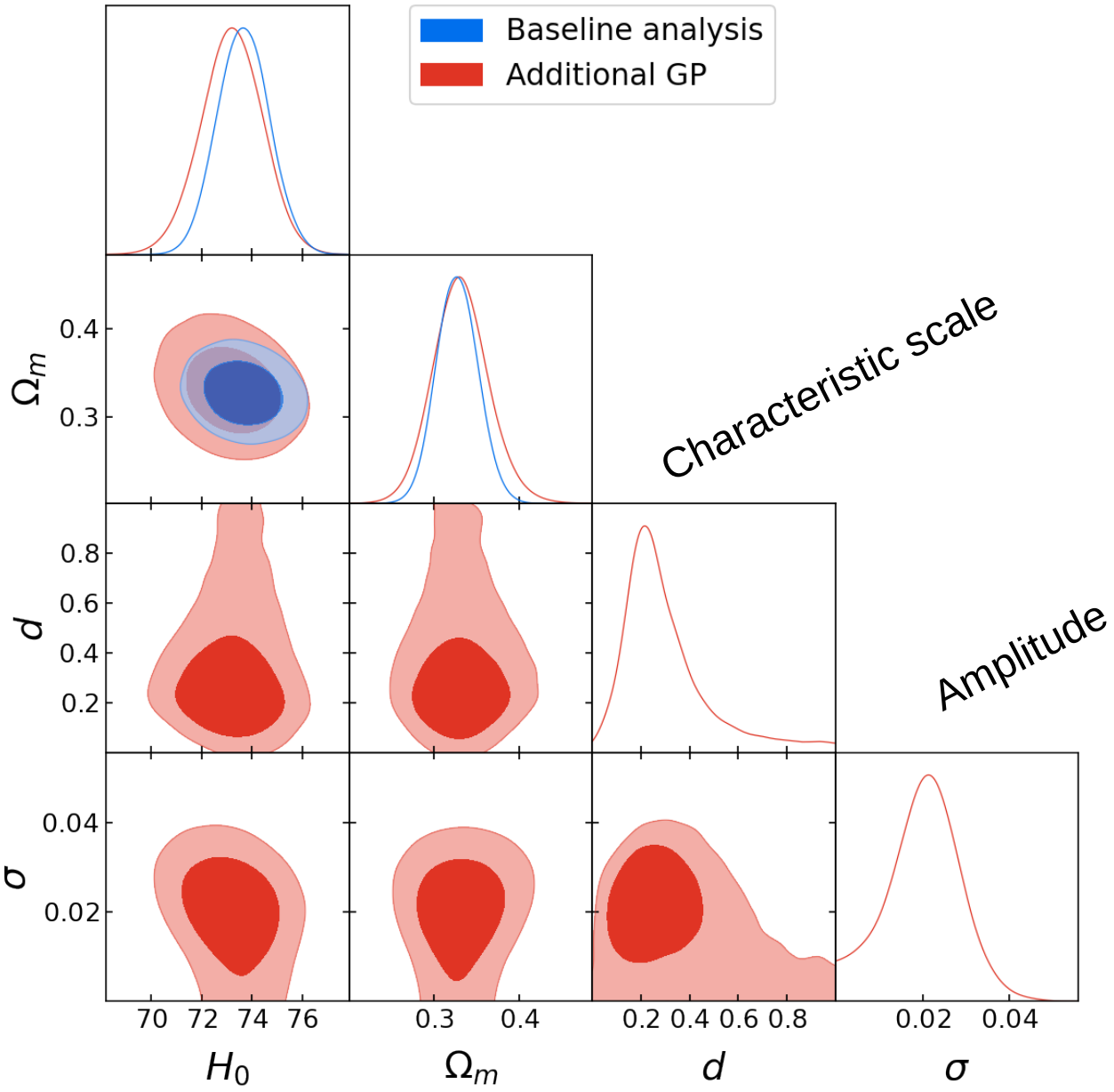
Constraints on GP parameters



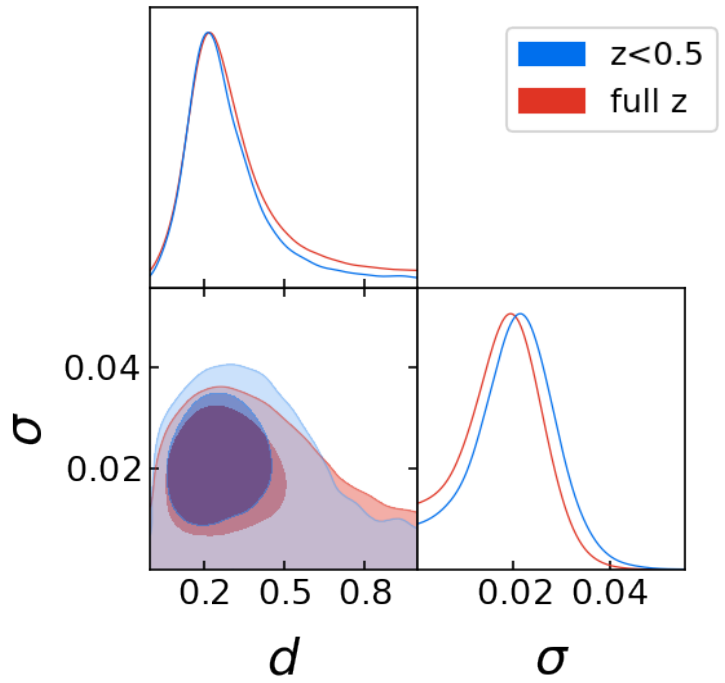
- Slight change in the cosmological parameter estimate (can lower tension by 1sigma)
- Presence of peak in d distribution
- Weak evidence for presence of additional covariance



Constraints on GP parameters with z<0.5



- Slightly better constraints on GP parameters can be a hint for non-stationarity
- Adding GP have more impact on cosmological parameters



Conclusions and outlook

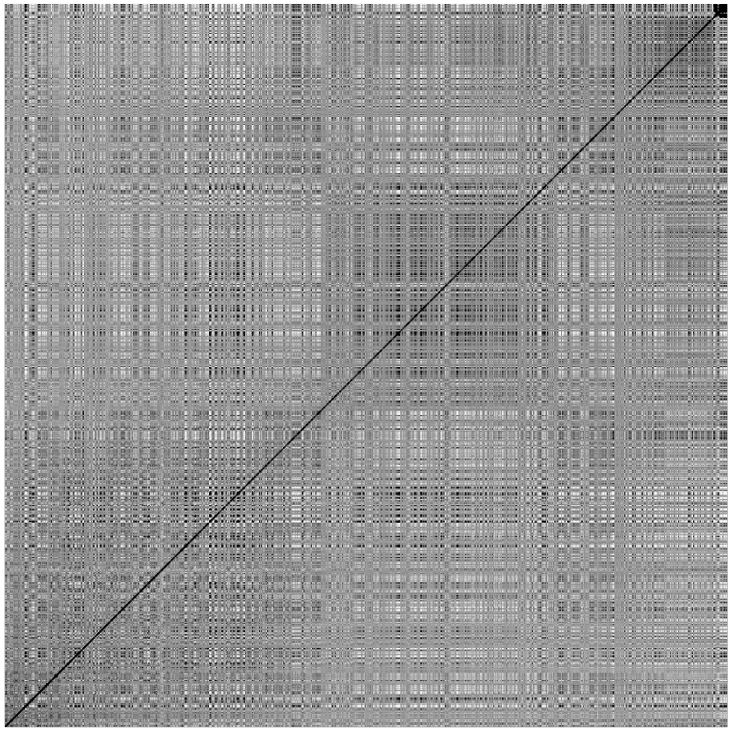
- Additional covariance have small impact on cosmological parameter estimate
- There is a characteristic covariance redshift scale present in the data

We are planing to explore

- Definition of “distance” in covariance:
  - Sky position separation
  - Cosmological distances
  - Difference in color and other properties of SNe
- Non-stationary Gaussian process
- Replacement of present estimate of systematics instead of addition (e.g. intrinsic scatter)

Change in covariance

Pantheon+



Matérn kernel

Sum