Supernova Cosmology Inference with Probabilistic Photometric Redshifts

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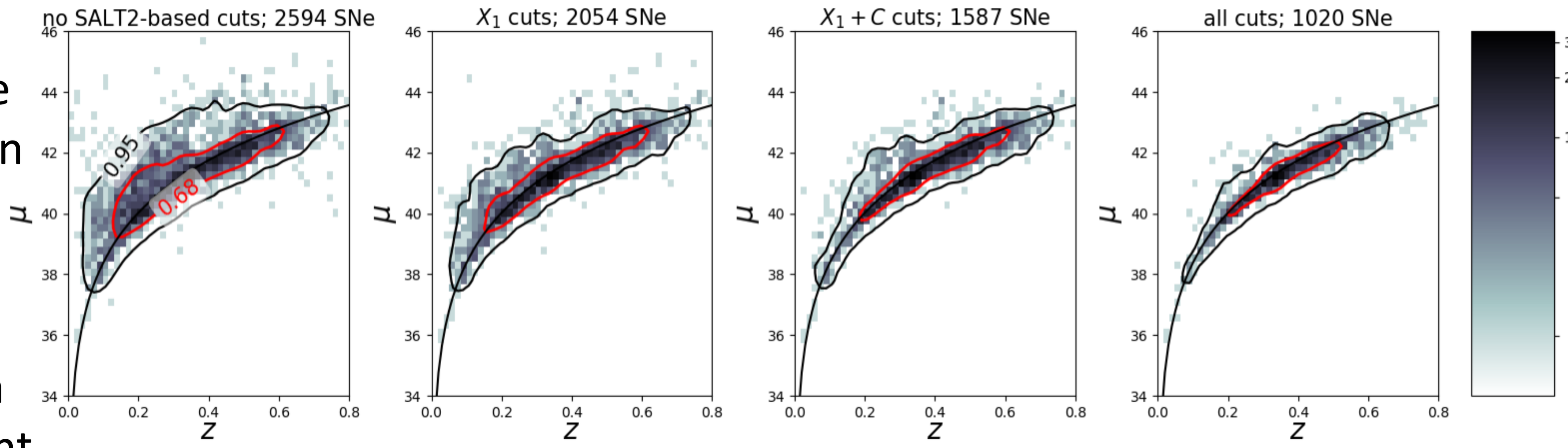
Motivation: ***How does one perform cosmological analysis on a heterogeneous population of supernovae without spectroscopic confirmation of redshift and type?***

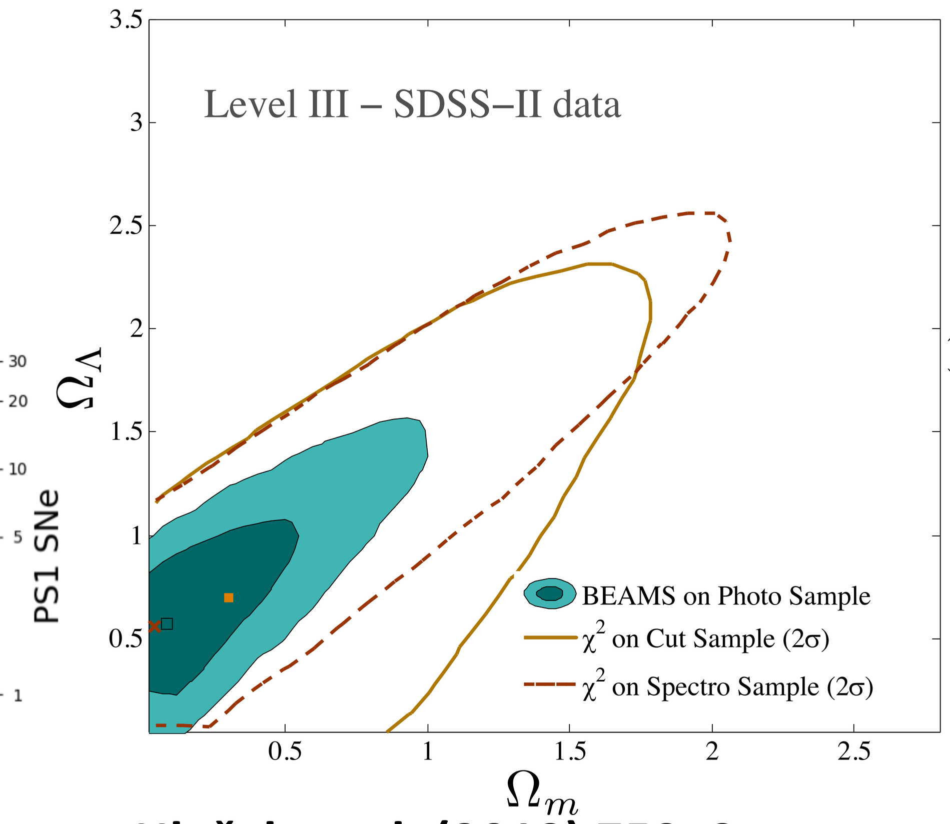
The future of supernova cosmology is photometric. Ambitious survey telescopes like the Large Synoptic Survey Telescope (LSST; LSST Science Collaboration, 2009, arXiv:0912.0201) will yield more than two orders of magnitude more candidate supernova detections than all past surveys, a combination of the more cosmologically informative Type Ia supernovae and interlopers such as core-collapse events and interesting objects without spectroscopic follow-up. The supernova cosmology community needs new methods to perform cosmological inference with photometric redshifts and uncertain transient type classifications.

Hubble Diagram Scatter

The spread in the Hubble diagram below is caused by including SNe with a range of type probability. Cuts in the photometric supernovae data can reduce the spread, but removes some of the statistical power of the sample, as shown in the figure at right. Given a rigorous classification algorithm and the resultant purity of the sample, these cuts can be justified, but including all the data weighted by the type probability provides a more robust treatment.



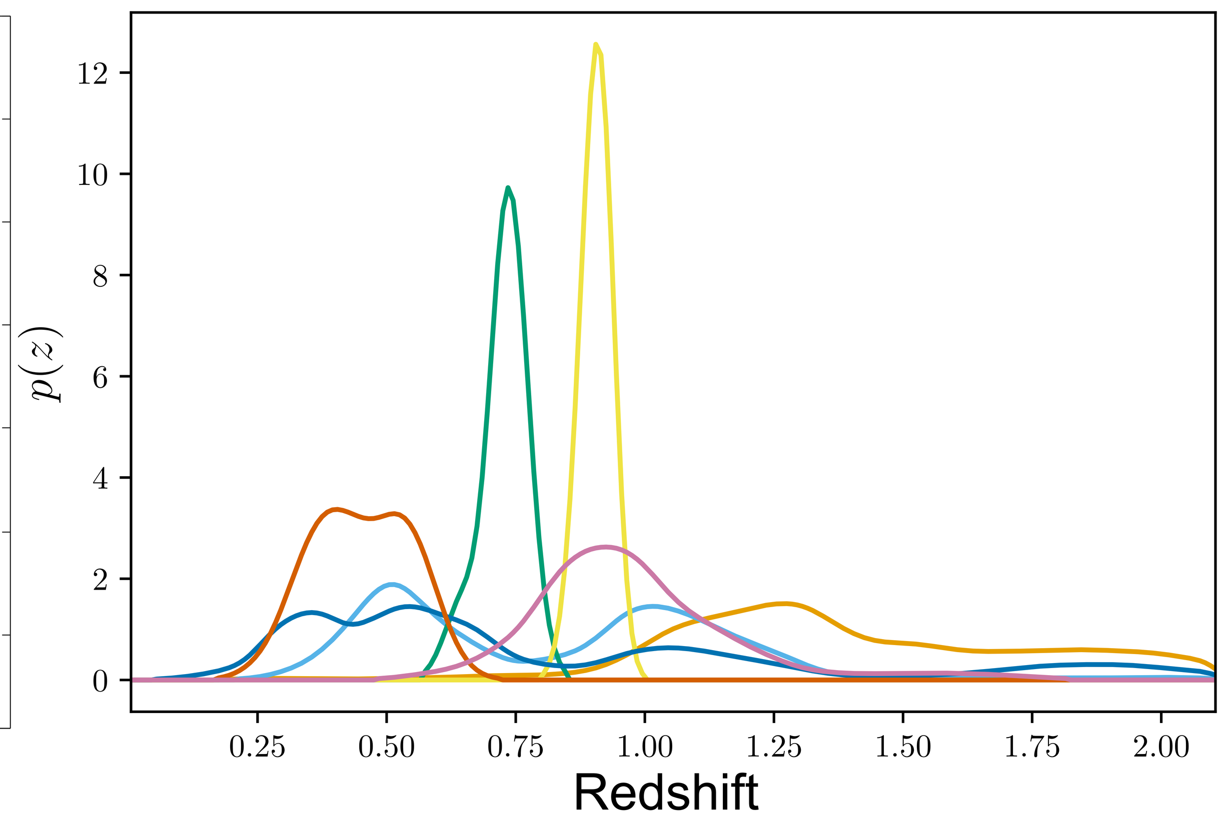
Jones *et al.* (2017) ApJ 843, 6



Hložek et al. (2012) 752, 2

Host Galaxy Photometric Redshift

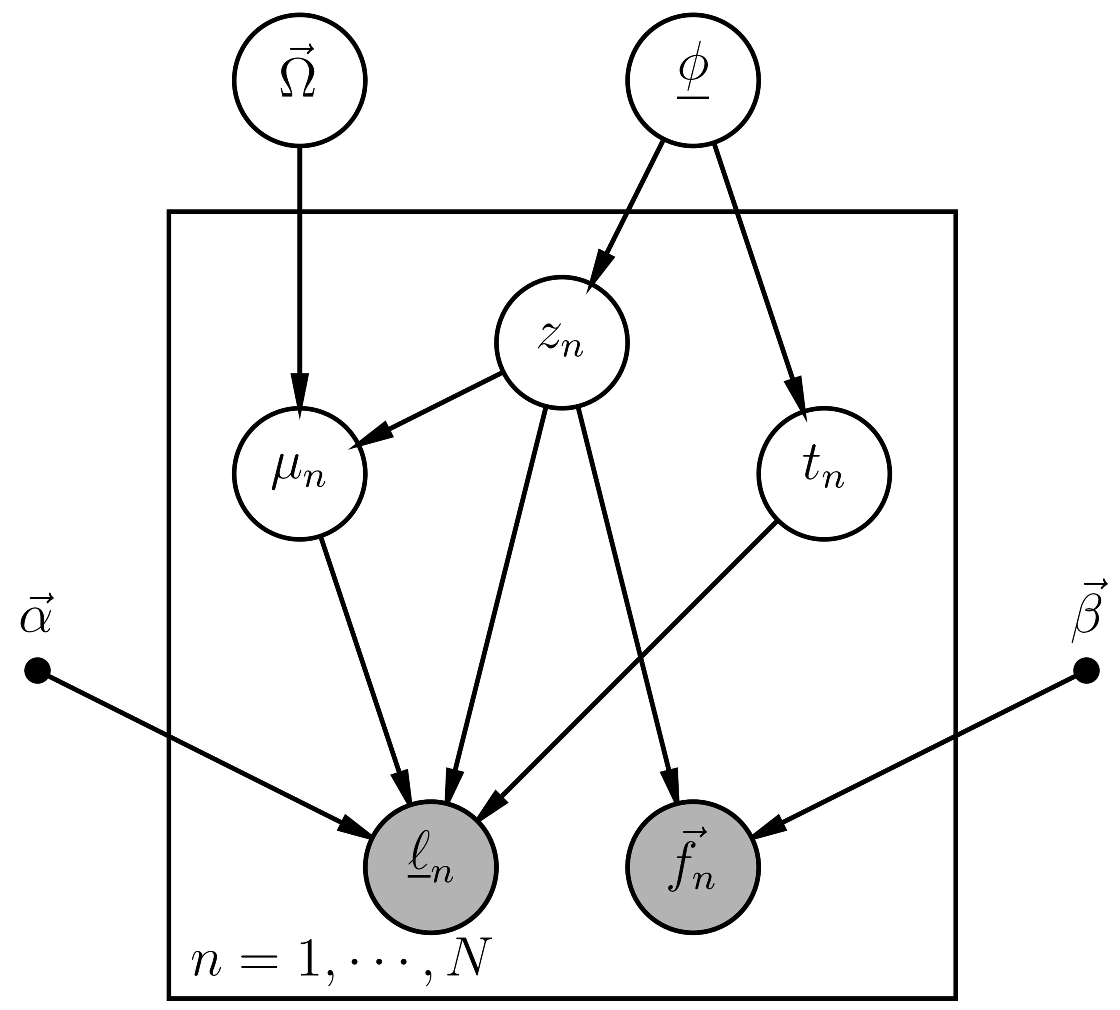
Observed host galaxy photometry informs about the host galaxy redshift. At right are example photo-z probability density functions (PDFs) from a mock LSST dataset:



Malz *et al.* in prep. **`github.com/aimalz/qp`**

Model

This directed acyclic graph illustrates our Supernova Cosmology Inference with Probabilistic Photometric Redshifts (scippr) model. We use this model to perform hierarchical inference of the cosmological parameters and redshift-dependent type proportion parameters without estimation of intermediate parameters.



All random variables are shown in circles, with observed variables shown in shaded circles. The box indicates that there are N independent copies of the relationships between boxed parameters, each statistically independent of all others. The arrows encode the relationships between variables, going from parameters defining probability distributions to variables drawn from those probability distributions.

Hyperparameters we infer:
- $\vec{\Omega}$: cosmological parameters
- $\underline{\Phi}$: redshift-dependent type proportions

Latent parameters drawn from probability distributions defined by the hyperparameters:
- μ_n : distance moduli
- z_n : redshifts
- $\underline{t}_n$: supernova types

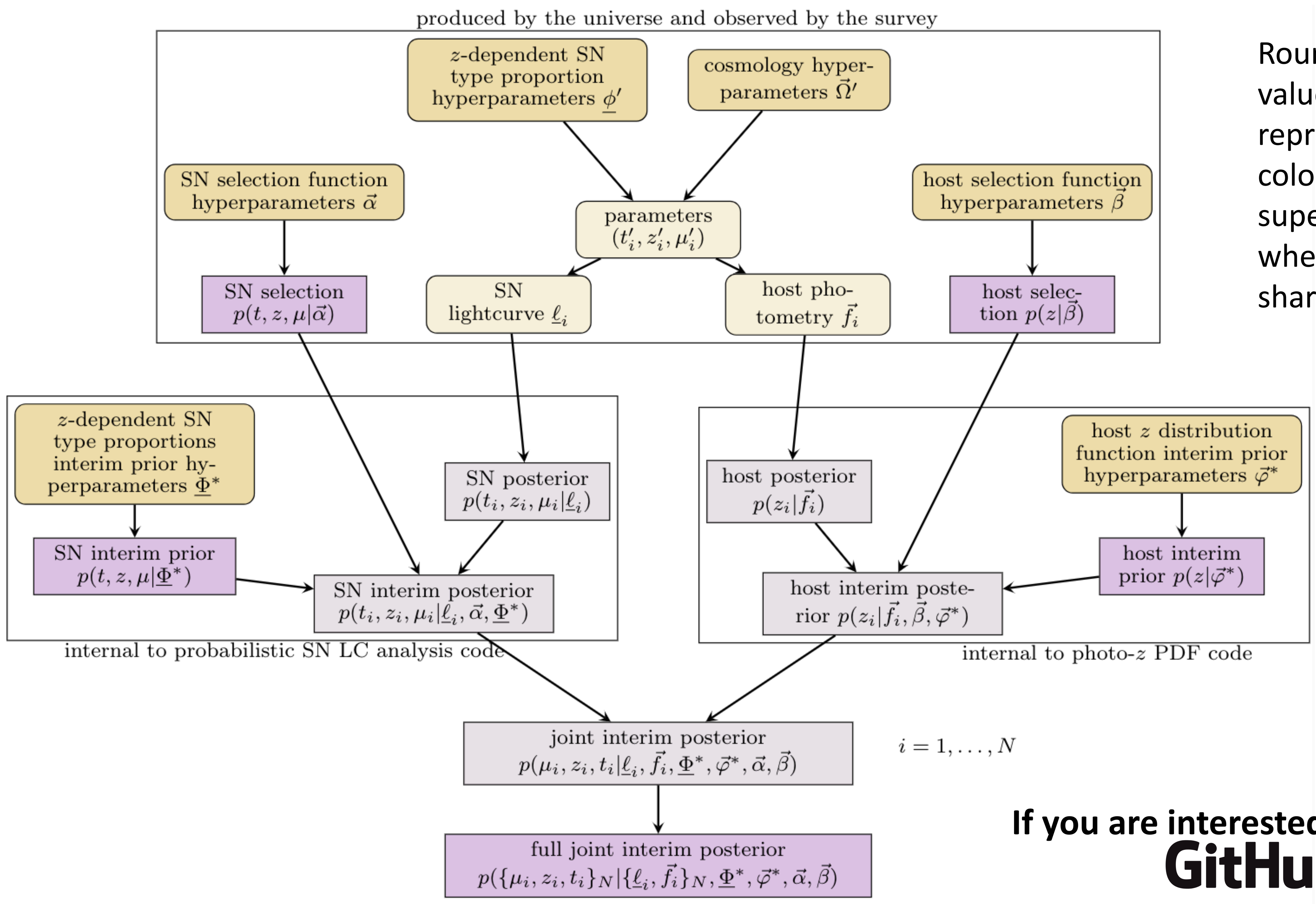
Observables:
- $\vec{f}_n$: host galaxy colors
- $\underline{\ell}_n$: multi-band supernova lightcurves

Known constants that factor into the model:
- α : observed lightcurve selection function
- β : host galaxy selection function

Method

`scippr` is intended to be run over a catalog of pairs of joint interim posterior probability density functions (PDFs), one over SN type, distance, modulus, and redshift, produced by a probabilistic lightcurve fitter, and another over redshift produced by a probabilistic photometric redshift code.

Probabilistic lightcurve fitters and photometric redshift codes are currently under development, so we simulate these data products using a forward model.



Rounded, yellow boxes represent parameter values, whereas squared, purple boxes represent probability distributions. Lighter colors represent quantities defined for each supernova-host galaxy pair in a survey, whereas darker colors represent quantities shared across all observed objects.

Once we have generated mock data (purple box at the bottom of the diagram) we can apply the `scippr` code to infer the cosmological parameters.

Our upcoming tests will compare the performance of `scippr` against traditional approaches of handling photometric supernova data, e.g. a small spectroscopically confirmed sample and making cuts on the probability of type SN Ia.

If you are interested in this project, please check us out at GitHub*`.com/aimalz/scippr`*