Pippin: An end to end cosmology pipeline

Patrick Armstrong - Australian National University

Chris Lidman (ANU)
Brad Tucker (ANU)
Rick Kessler (UChicago)
Dillon Brout (Harvard)

Who am I?

4th year PhD student at ANU

Forward Modelling and Approximate Bayesian Computation methods in Supernova Cosmology

Member of DES-SN

Current Pippin Maintainer and Developer

DEBass - Spectroscopic followup

Infrastructure Lead

Goal: How do we do statistics in Supernova Cosmology? Can we do better?

Pippin - From lightcurves to cosmological parameter estimates

Simulated Data
Prepare / simulate lightcurves for analysis

Lightcurve Fitting
Fit SALT2 parameters to data and simulations using SNANA

Classification
Photometrically classify lightcurves with SuperNNova or Scone

Contamination and Bias Correction
Correct for contamination and bias using BEAMS with Bias Correction (BBC)

Systematic Covariance Matrix
Compute a systematic covariance matrix, account for many systematic uncertainties

Cosmological Fitting
Perform cosmological parameter inference with Bayesian methods like COSMOSIS or WFIT

Designed by Sam Hinton
Developed and maintained by me

Who uses Pippin?

For cosmological studies:

- **DES 5yr SNIa analysis**
  (Vincenzi et al, in prep)
- **LSST-DESC: SNIa using Photo-z**
  (Mitra et al, int. review)
- **LSST-DESC: DC2-SNIa**
  (Sanchez et al 2022)
- **Pantheon+ Analysis**
  (Brout et al, 2022)

For systematic studies:

- **DES: RedMaGiC Galaxies**
  (Chen et al, 2022)
- **A revised SALT2 surface**
  (Taylor et al, 2021)
- **Binning is Sinning**
  (Brout et al, 2021)
- **It's Dust - Solving the mystery of intrinsic scatter**
  (Brout & Scolnic, 2021)
- **DES: SN Core Collapse Systematics**
  (Vincenzi et al, 2021)

Guy et al. (2007)
Kessler et. al. (2009)

Simulating realistic datasets with SNANA and SALT2

$f_\lambda = x_0 \times [M_0(p, \lambda) + x_1 M_1(p,\lambda)] \times \exp[cCL(\lambda)]$

Fit from a lightcurve

x_0 = Amplitude, with $m_B = -2.5\log_{10}(x_0)$

x_1 = Stretch Parameter

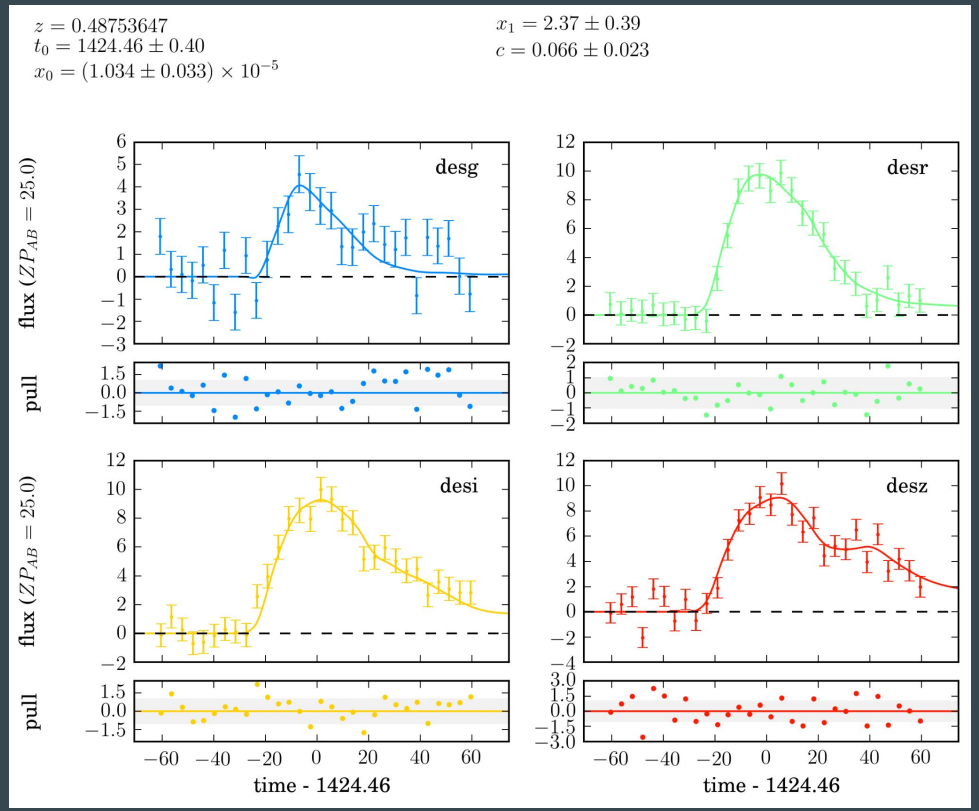
c = Colour Parameter

Empirically derived from a SALT2 model

M_0 = Mean SED

M_1 = First order deviation around SED

CL = Colour Law



Calculated | Observable | Unknown

Credit: https://dessn.github.io/sn-doc/doc/out/html/inv_gauss.html

Recap - Simulation

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SNANA and SALT2 framework is used to model lightcurves of type Ia supernovae

Producing a new SALT2 surface is very slow

SALT2Jacobian produces an approximate SALT2 surface very quickly (360 times faster), and very accurately (<0.1% difference on average)

Lightcurve Fitting - SALT2

Contamination and Bias correction
Later stage of Pippin

$$\mu_{SN} = m_B + \alpha x_1 - \beta c - M + \Delta\mu_{bias}$$

SALT2
Lightcurve Fit

Nuisance Parameter

Calculated | Observable | Unknown

Möller & de Boissière (2020)
Qu et. al. (2021)

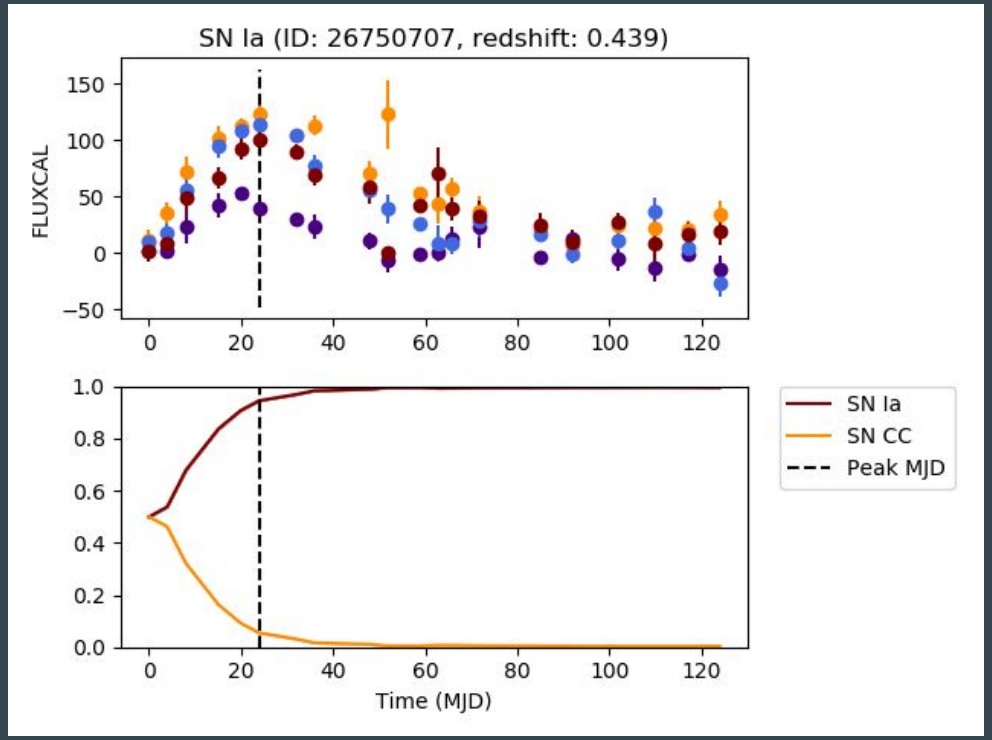
Photometric Classification - SuperNNova & Scone

SuperNNova:

- Deep Learning Recurrent Neural Network
- 99.55 ± 0.06% accuracy with redshift
- 96.92 ± 0.09% accuracy **without** redshift

Scone:

- Conventional Neural Network
  - Typically used for image processing
- Train on photometric data only
  - No redshift information needed
- 99.73 ± 0.26% accuracy **without** redshift
- Much slower than SuperNNova



Credit: https://supernnova.readthedocs.io/en/latest/visualization/index.html

Kuntz et. al (2012)
Kessler & Scolnic (2017)

Contamination and Bias Correction - BBC

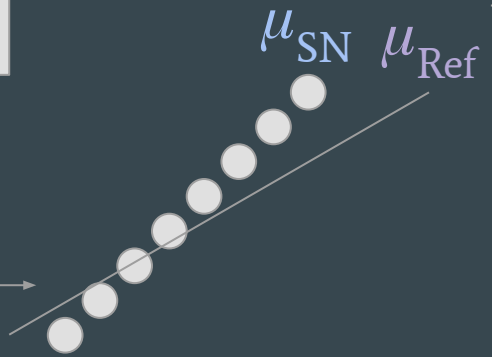
Biascor Sim (Simulation)

x_0, x_1, c (Lightcurve Fitting)

P_{Ia} (Classification)

μ_{Ref} (Theory)

BEAMS with Bias Correction



Cosmology independent fit to α, β, and M

Contamination and bias corrected, redshift binned Hubble Diagram

Calculated | Observable | Unknown

Recap - Lightcurve Fitting, Classification, and BBC

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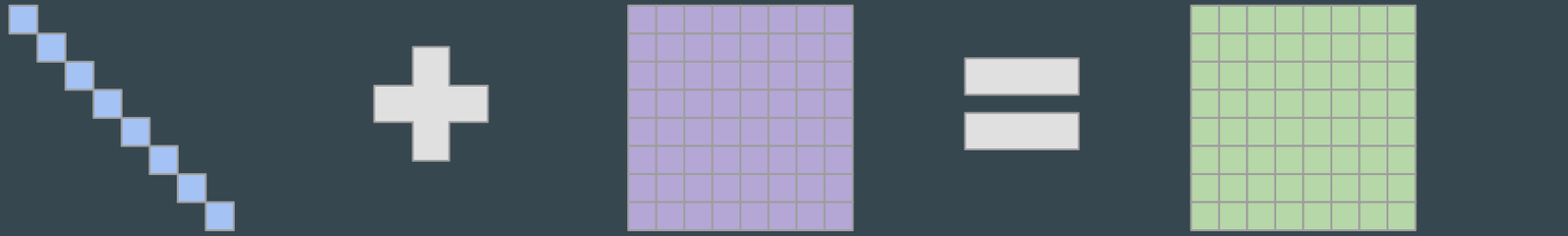
SNANA uses SALT2 framework to fit x_0, x_1, and c from lightcurves.

Photometric classification using SuperNNova or Scone neural networks

Combine biascor simulation, lightcurve fit, and classification to produce contamination and bias corrected Hubble Diagram

Conley et. al. (2011)
Brout et. al. (2019a)

Systematic Covariance Matrix



$$C_{stat} = \sigma^2_{\mu SN}$$

$$C^{ij}_{syst} = \sum^{N}_{k=1} (\partial \mu^{i}_{SN} / \partial S_k)(\partial \mu^{j}_{SN} / \partial S_k) \sigma^2_{Sk}$$

$$C = C^{ij}_{stat} + C^{ij}_{syst}$$

Assumes independent, gaussian systematics

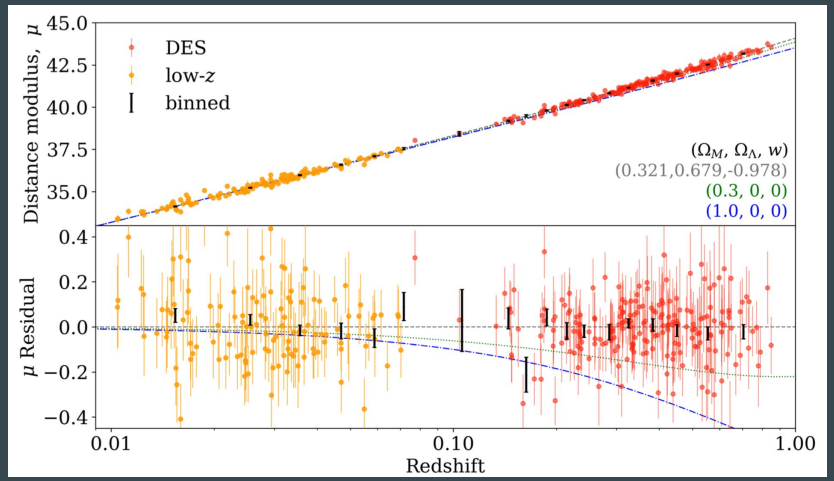
Calculated | Observable | Unknown

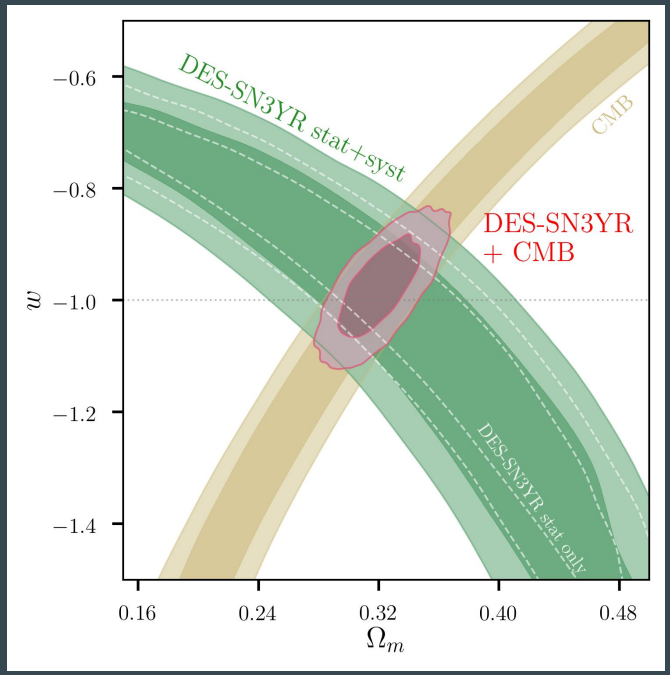
Brout et. al. (2019a)
Abbott et. al. (2019)

Cosmological Fitting - WFit, COSMOSIS, CosmoMC, etc...

$$\chi^2 = D^T C^{-1} D$$

$$D_i = \mu_{SN}(z_i) - \mu_{Cosmo}(z_i)$$





Calculated | Observable | Unknown

Credit: https://www.darkenergysurvey.org/

Recap - Systematic Covariance Matrix and Cosmological Fitting

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Systematic covariance matrix measures offset in BBC distances caused by systematics

Assumes independent, gaussian systematics

Minimise $\chi^2 = D^T C^{-1} D$, maximise posterior

↓

COSMOLOGY!!!