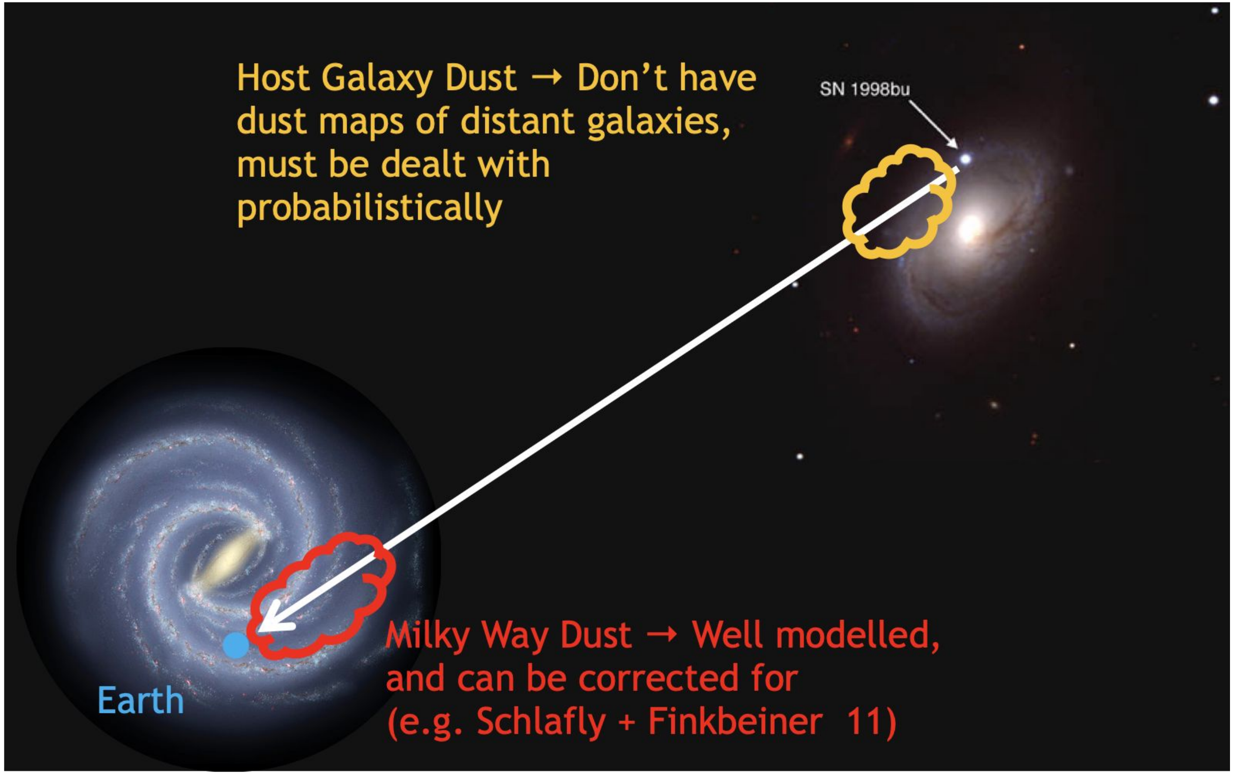
BayeSN: Scaling Bayesian Inference for Next Generation Surveys

Matt Grayling

Part 1: The BayeSN Model

Motivation



NASA/JPL-Caltech/ESO/R. Hurt
Nicholas B. Suntzeff

Why worry about dust?

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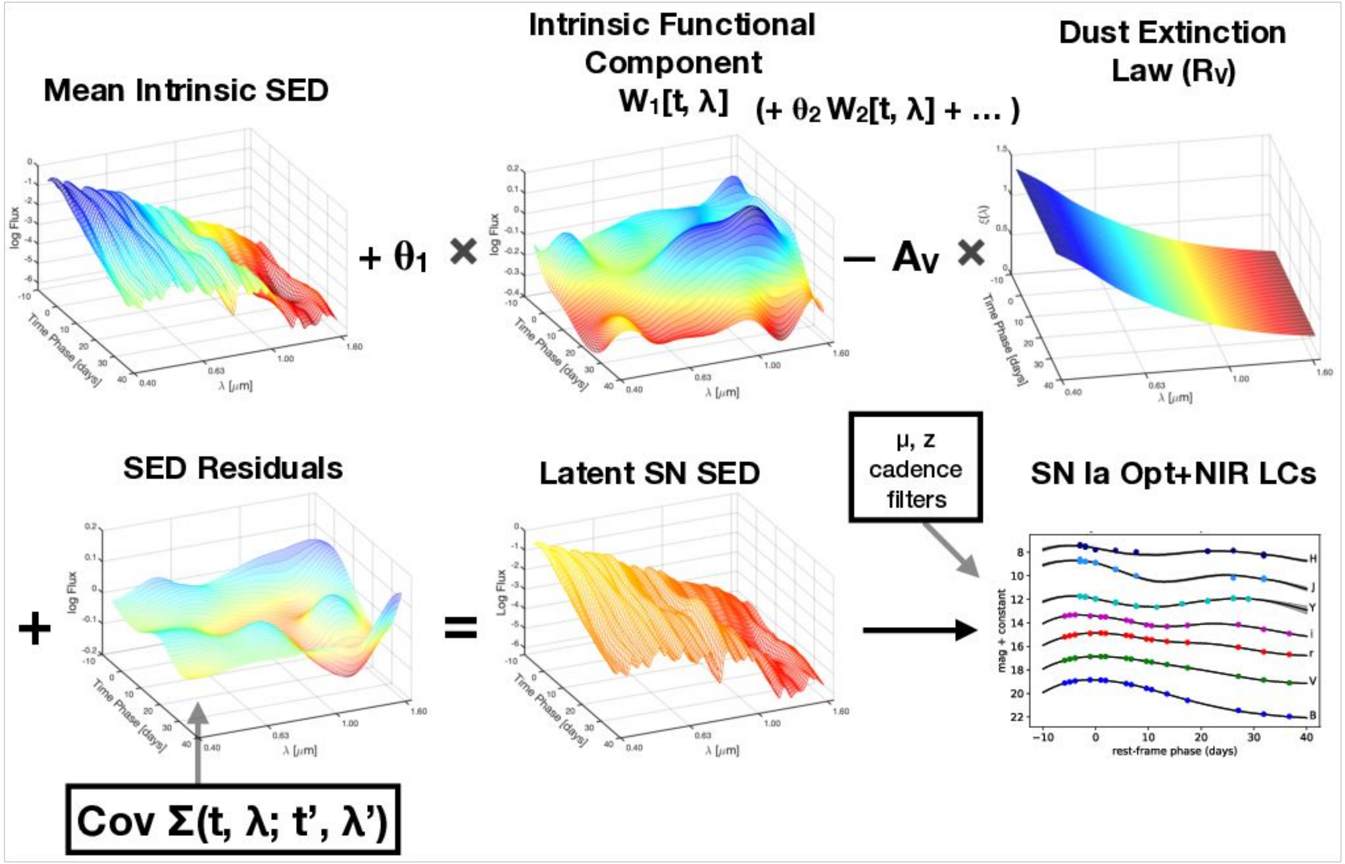
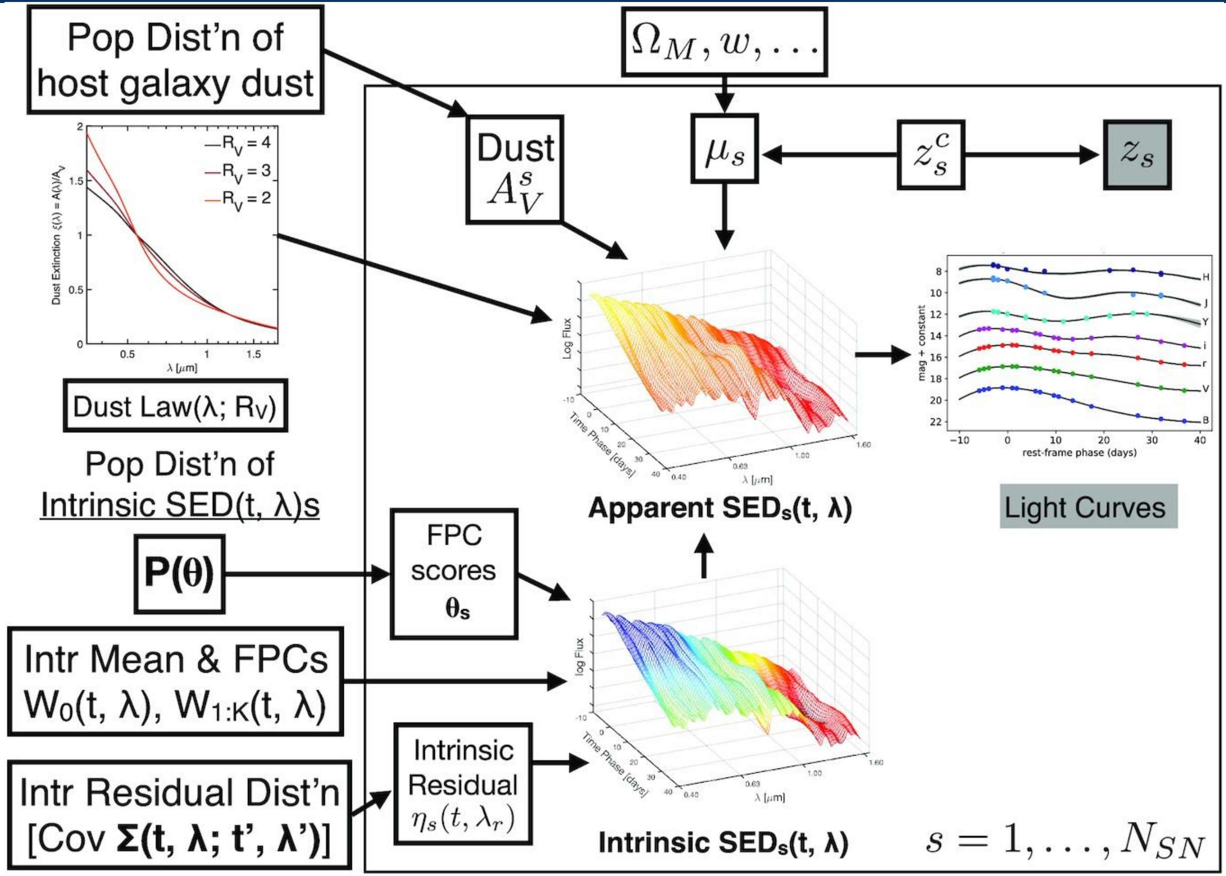
- Correctly handling dust (and SN Ia colour–luminosity correlations more generally) is key to correctly estimating SN Ia distances
- Observed correlation ("mass step") between SN Ia magnitudes and host mass $\rightarrow$ dust would be one explanation
- If dust correlates with host mass, could create z-dependent biases if not accounted for
- If intrinsic effect misattributed to dust, could lead to bias

The BayeSN Model



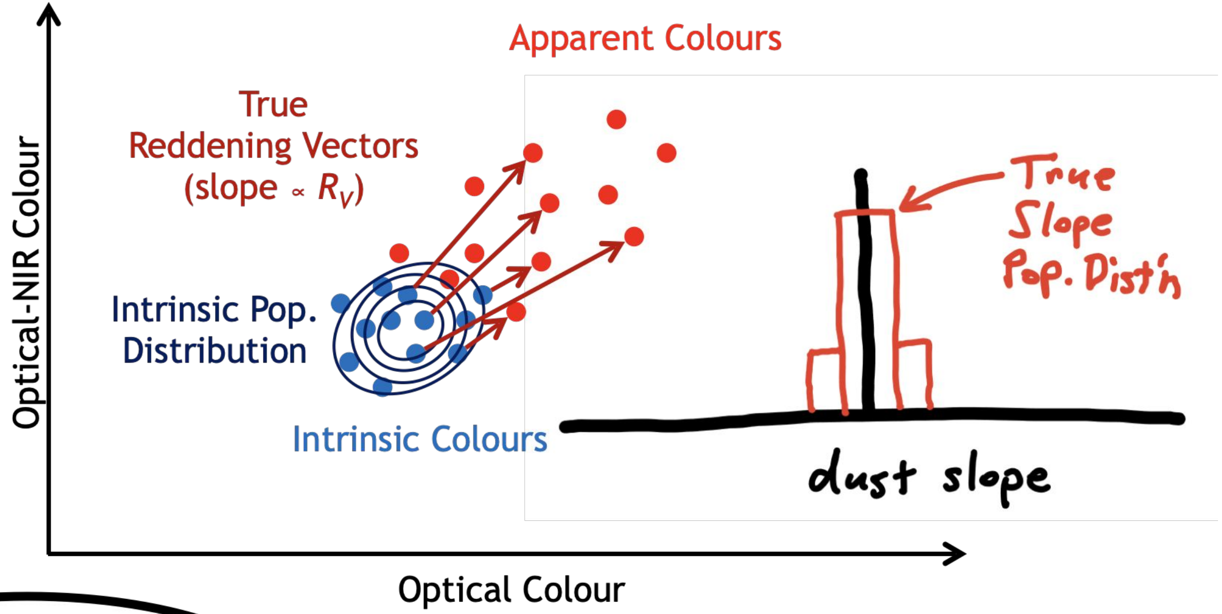
Mandel (2020)

The BayeSN Model



Mandel (2020)

Why include intrinsic colour variation?



Need to account for intrinsic colour scatter when inferring R_V!

Why include intrinsic variation?

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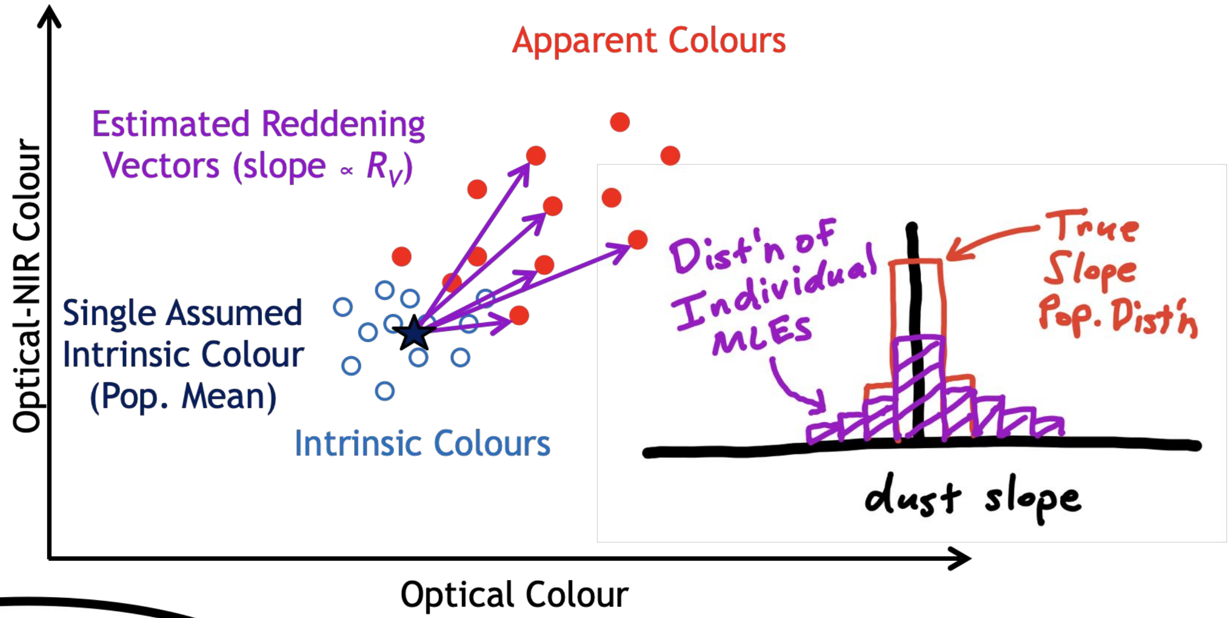

Otherwise width of R_V distribution will be overestimated!

Why use Optical + NIR?

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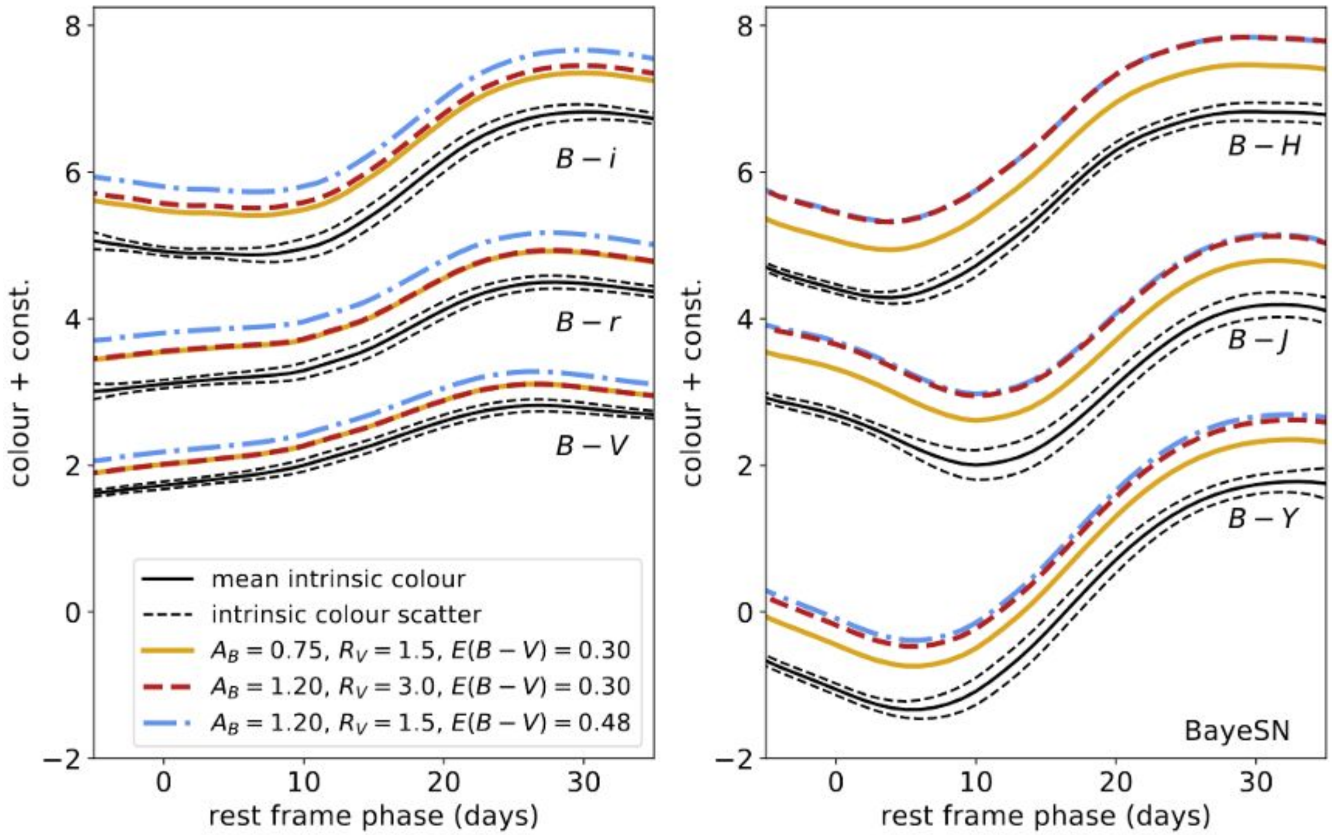

Thorp & Mandel (2022)

Advantages of BayeSN

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- Hierarchical Bayesian Model
  - Allows for joint inference of global and individual SN properties
  - Better estimation of global Rv distribution using hierarchical approach than just taking mean/standard deviation of individual estimates
  - Can constrain/marginalise over intrinsic SN colour variation
- Model extends into NIR wavelengths, allowing for better constraint of host galaxy dust
- Improved Hubble diagram scatter (~20-30% better than SALT2 and SNooPy)

Disadvantages of BayeSN

- Lots of parameters!

Part 2: Scaling to Next Generation Surveys

Scaling BayeSN

Problem:

Scaling BayeSN for next generation data sets without compromising functionality

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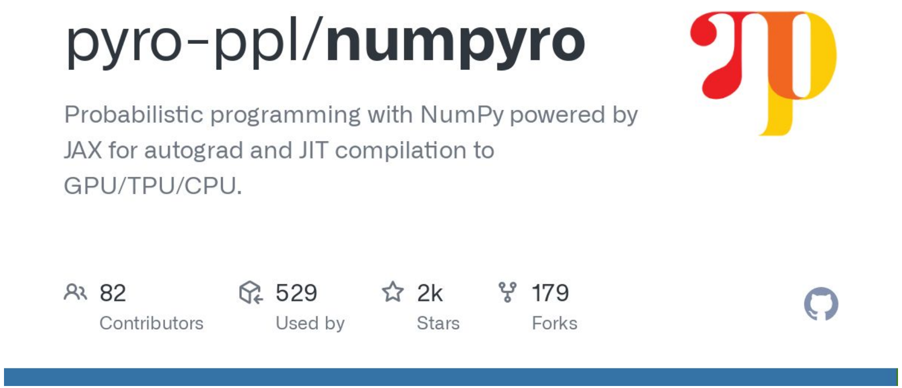
Scaling BayeSN for next generation data sets without compromising functionality

Solution:



Jax and Numpyro

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Jax

- Python package very similar to numpy, but includes JIT compilation at runtime for any device including GPUs

Numpyro

- Probabilistic programming package for Python built on Jax

Vectorized posterior evaluation + GPUs = Fast Bayesian inference

Examples

Mandel+20:

- Trained on 79 *BVriYJH* light curves compiled in Avelino+19
- Approximately 4600 parameters
- Previous training ~5 days → now ~20 minutes

Thorp+21:

- Trained on 157 *griz* light curves from Foundation DR1
- Approximately 4600 parameters
- Previous training ~1 day → now ~10 minutes

Examples

1000 simulated Foundation-like SNe:

- Training (conditioning global parameters on data)
  - 27,500 parameters
  - 45 mins
- Fitting (inference of supernova properties)
  - 27,000 parameters
  - 15 mins

Applications to Next Generation Surveys

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- Previously, training and fitting on data-sets > 10,000 SNe would have been computationally unfeasible
- The use of numpyro + GPUs makes this achievable in relatively short timescales
- We are able to scale Bayesian inference approaches to LSST-size data sets

LSST

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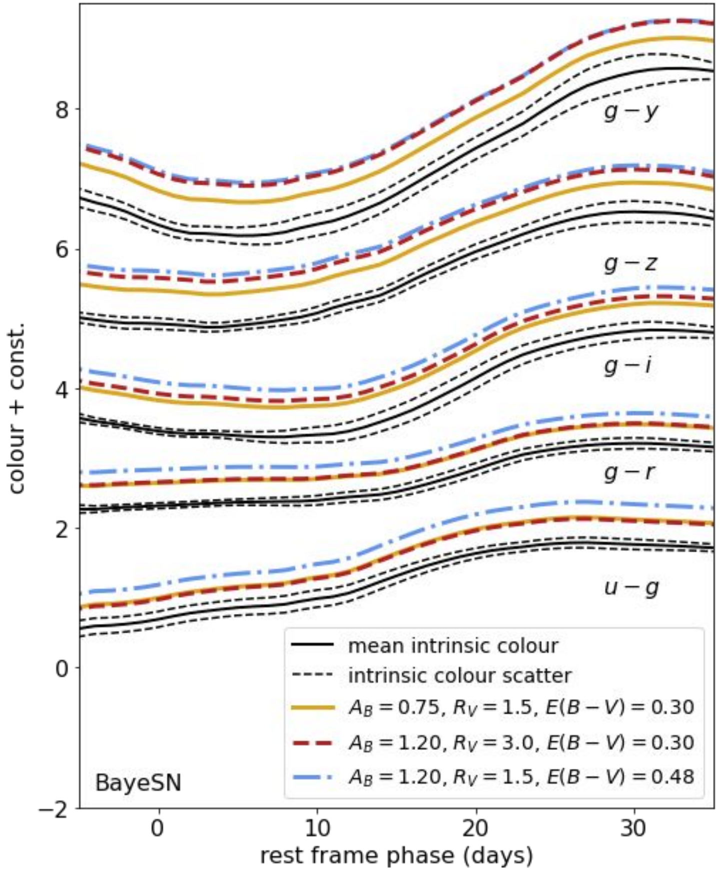
SN Ia Colour Curves Simulated Using BayeSN (in LSST passbands)



Wealth of colour information in LSST data!

Will get rest frame z-band out to $z \approx 0.15$, rest frame i-band out to $z \approx 0.35$

Ongoing Work

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Improving the model:

- Replacing HMC with variational inference (Ana-Sofia Uzsoy)
  - Rather than trying to sample from posterior, assume its shape and match to the true posterior - turns Bayesian inference into an optimisation problem
- Using Gaussian Markov random fields and Integrated Nested Laplace Approximation (Collin Politsch)
  - Reduces intrinsic colour variation to far fewer parameters while maintaining complexity, alternative approach for fitting
- Improving and incorporating spectroscopy (Ben Boyd)
  - Training on spectra and using new spectroscopic templates
- Implementing BayeSN within SNANA (Stephen Thorp)
  - Will allow for full BayeSN cosmological analysis

Ongoing Work

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Applying the model:

- A BayeSN distance ladder (Suhail Dhawan)
- Hierarchical analysis of SN siblings (Sam Ward)
- Analysis of dust and intrinsic colour distributions (Erin Hayes)
- Training BayeSN using YSE DR1 (Matt Grayling)
- Analysis of environmental dependence on intrinsic colour (Matt Grayling + Suhail Dhawan)

Conclusions

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- BayeSN is a powerful Bayesian hierarchical model for standardising type Ia supernovae
- LSST will provide a fantastic sample of *ugrizy* light curves and allow for good constraint of host galaxy dust
- Our work on scaling BayeSN means that it can be applied to next generation surveys
- Lots of ongoing work to improve and apply BayeSN