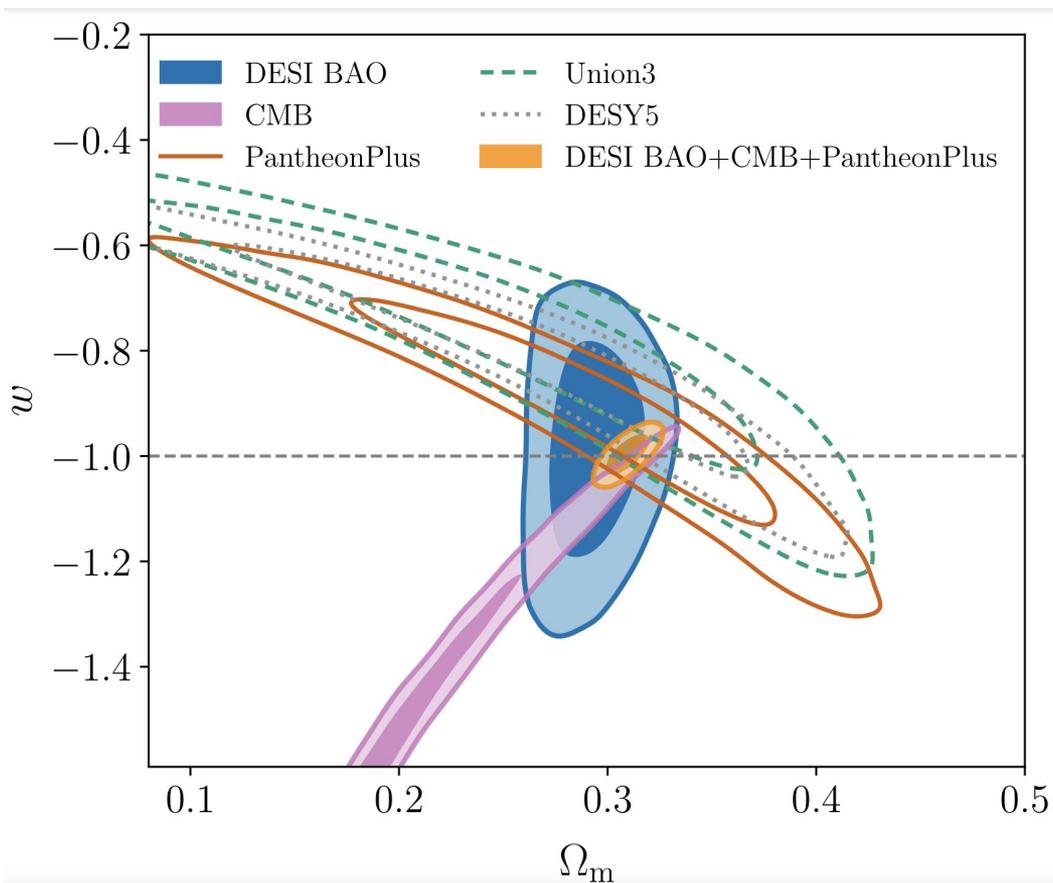


GPU-accelerated Hierarchical Bayesian Modelling of Type Ia Supernovae

Matt Grayling, Kaisey Mandel, Stephen Thorp
Institute of Astronomy



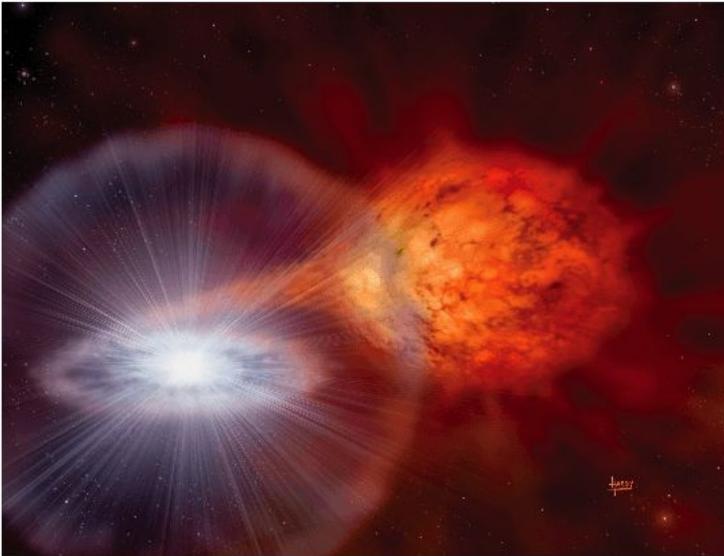
Supernova Cosmology



DESI Collaboration
2024

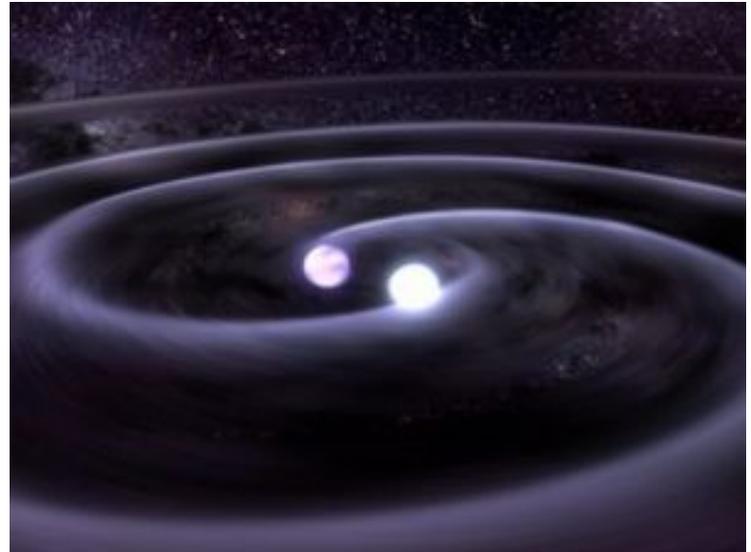
Type Ia Supernovae

Single degenerate



Credit: David A. Hardy, © David A. Hardy/astroart.org

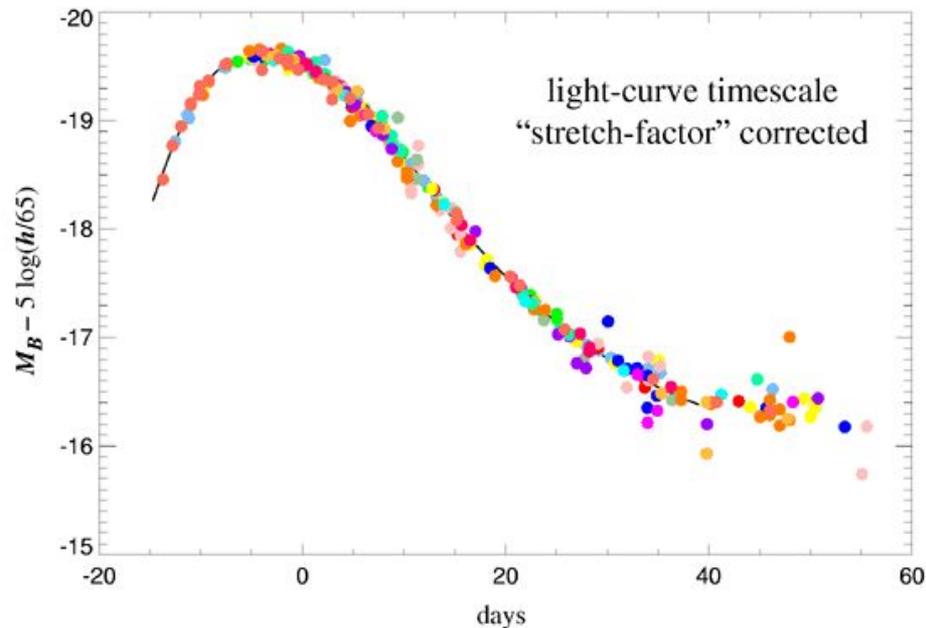
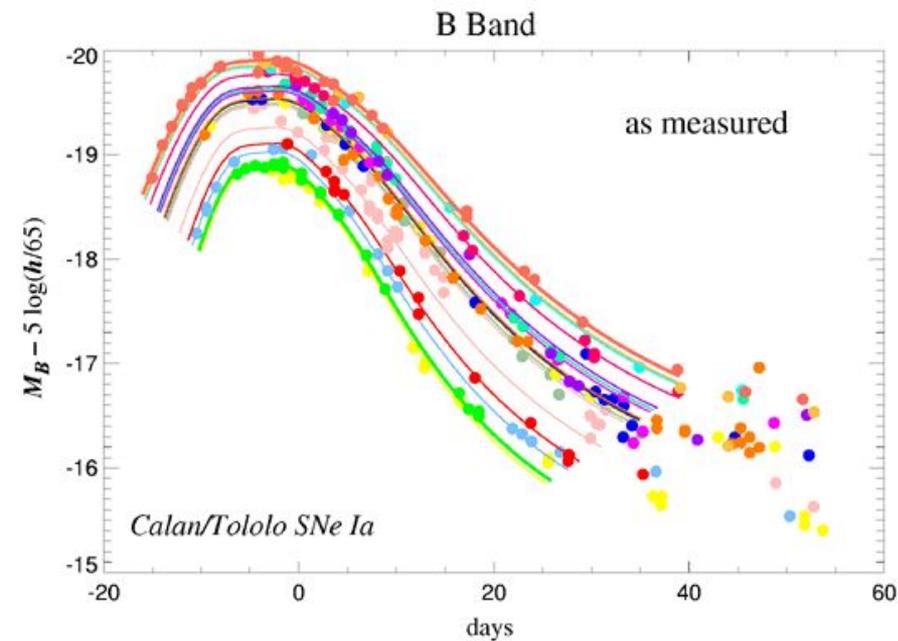
Double degenerate



Copyright: GSFC/D. Berry.

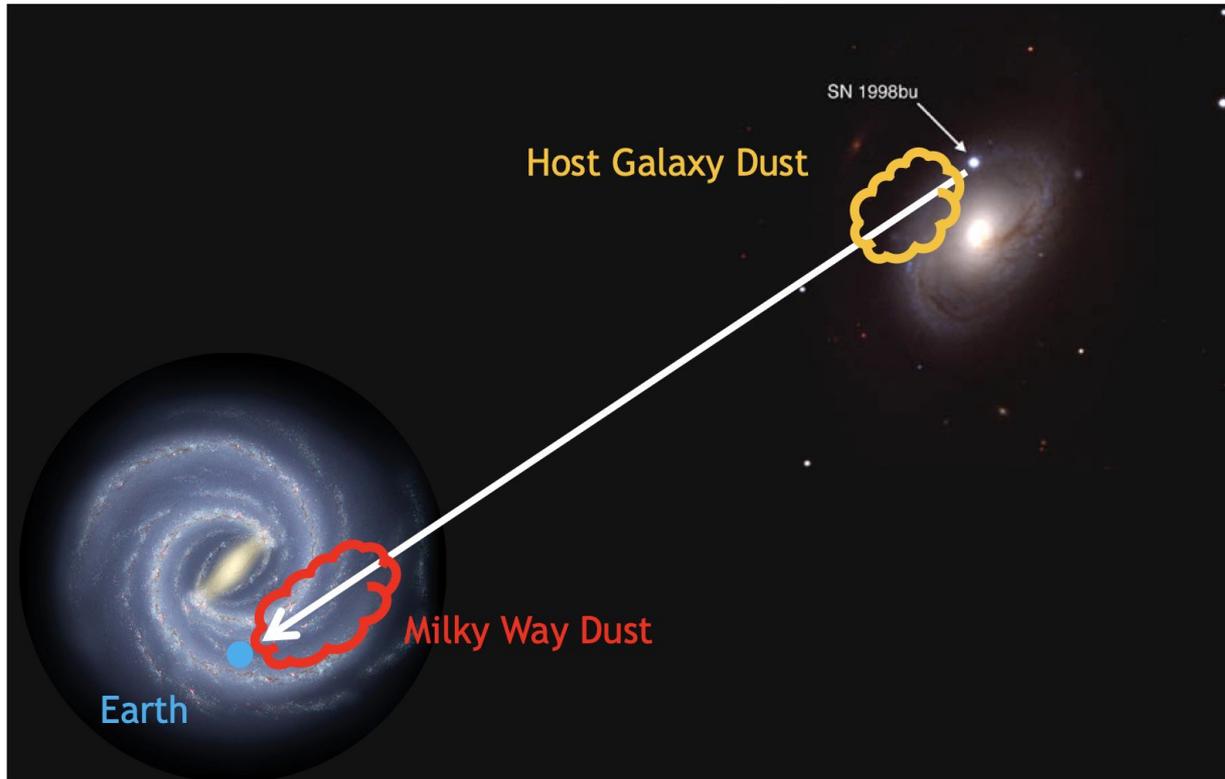
Standard(isable) Candles

From Supernova Cosmology Project



$$\mu^s = m_B^s - M + \alpha x_1^s + \beta c^s$$

The Problem? Dust!



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

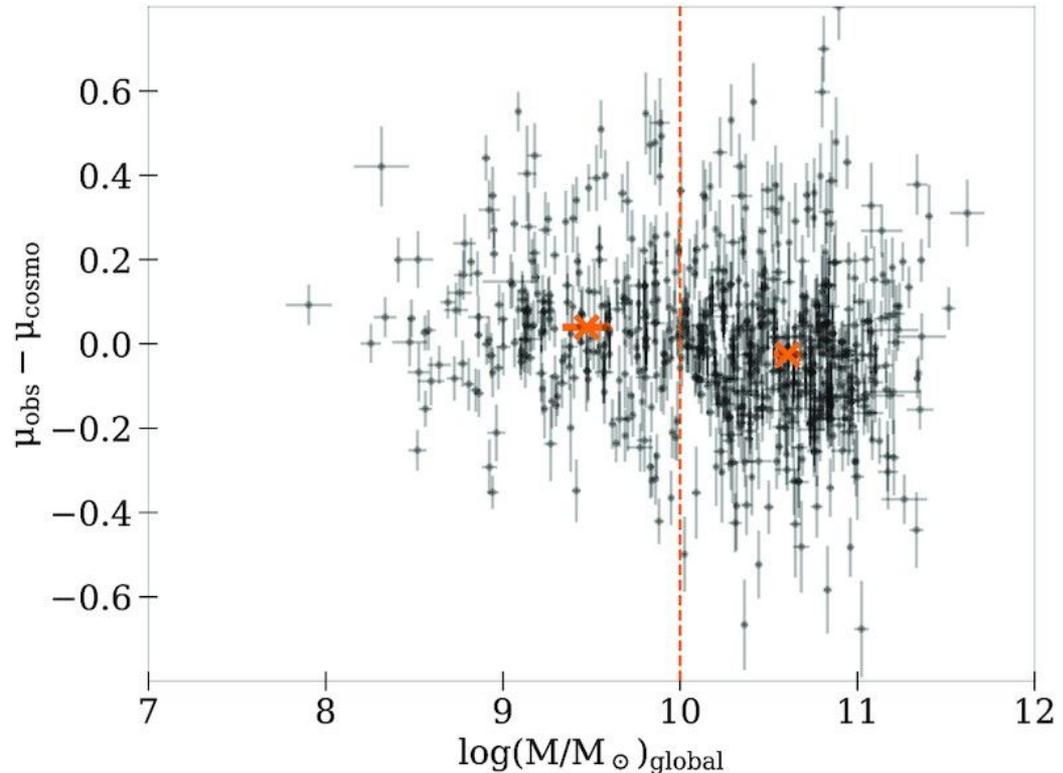
$$\mu^s = m_B^s - M + \alpha x_1^s + \beta c^s$$



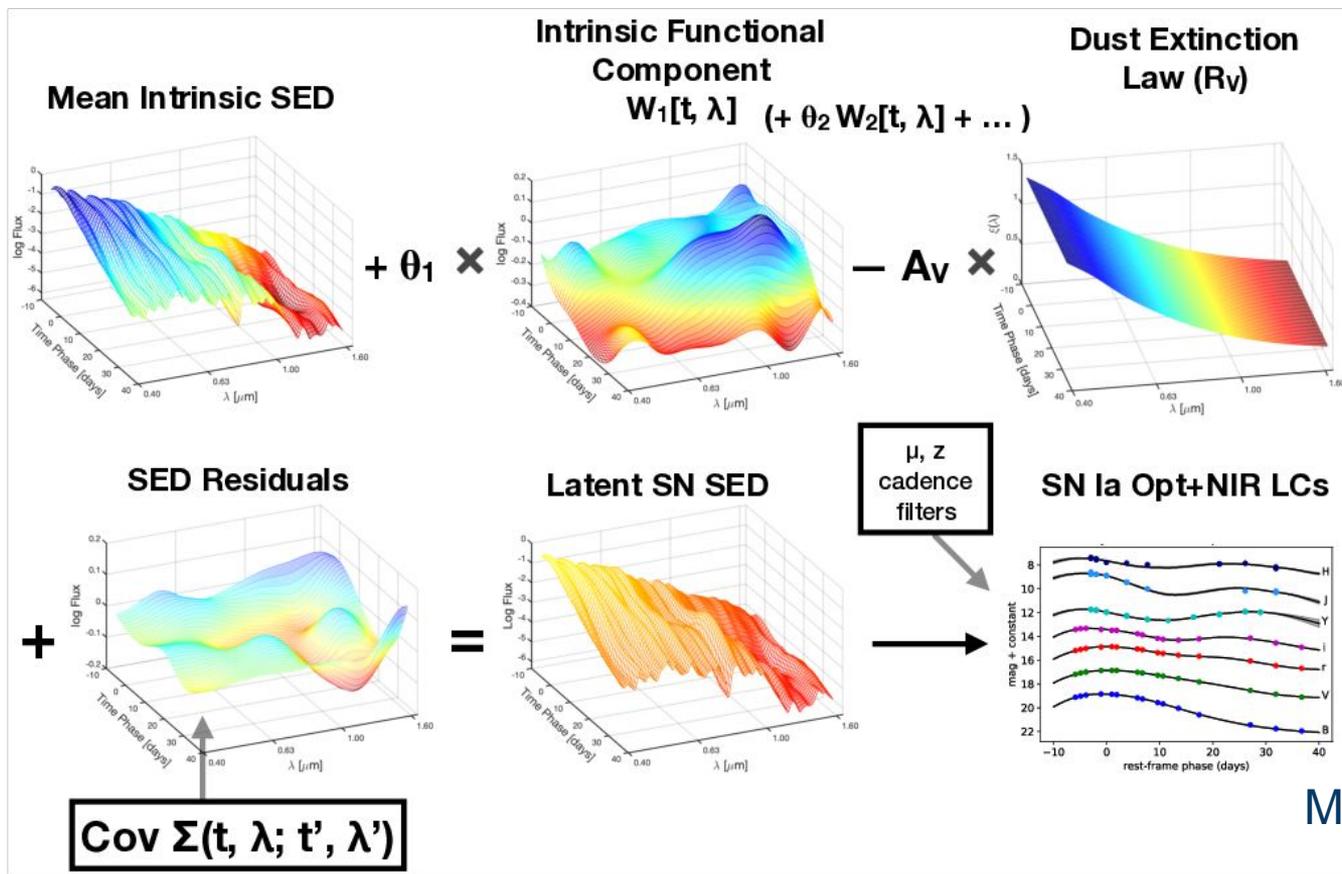
One parameter, two effects

The 'Mass Step'

- Disentangling intrinsic variation from dust vital to understanding host galaxy 'mass step'
- Just different dust properties?
 - SN populations identical, just appear different?
- Or intrinsic differences?
 - Interesting physical implications, different progenitor channels?

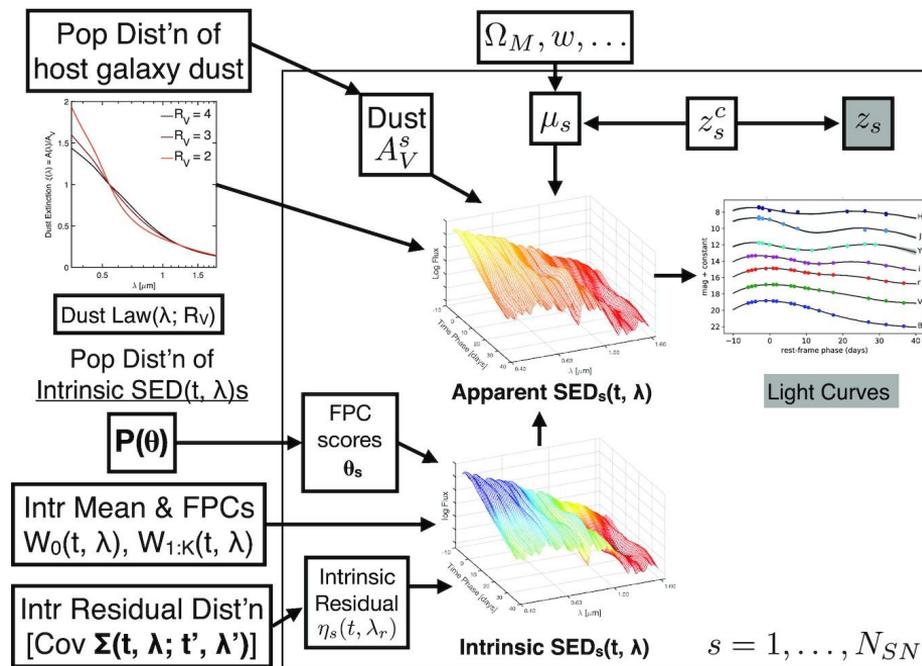


The BayeSN Model

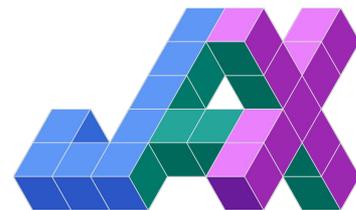


Advantages of BayeSN

- Explicit treatment of dust
- Hierarchical Bayesian Model
 - Allows for separate treatment of dust and intrinsic variation across population
- Infer distance from full light curve, marginalised over intrinsic and extrinsic variation

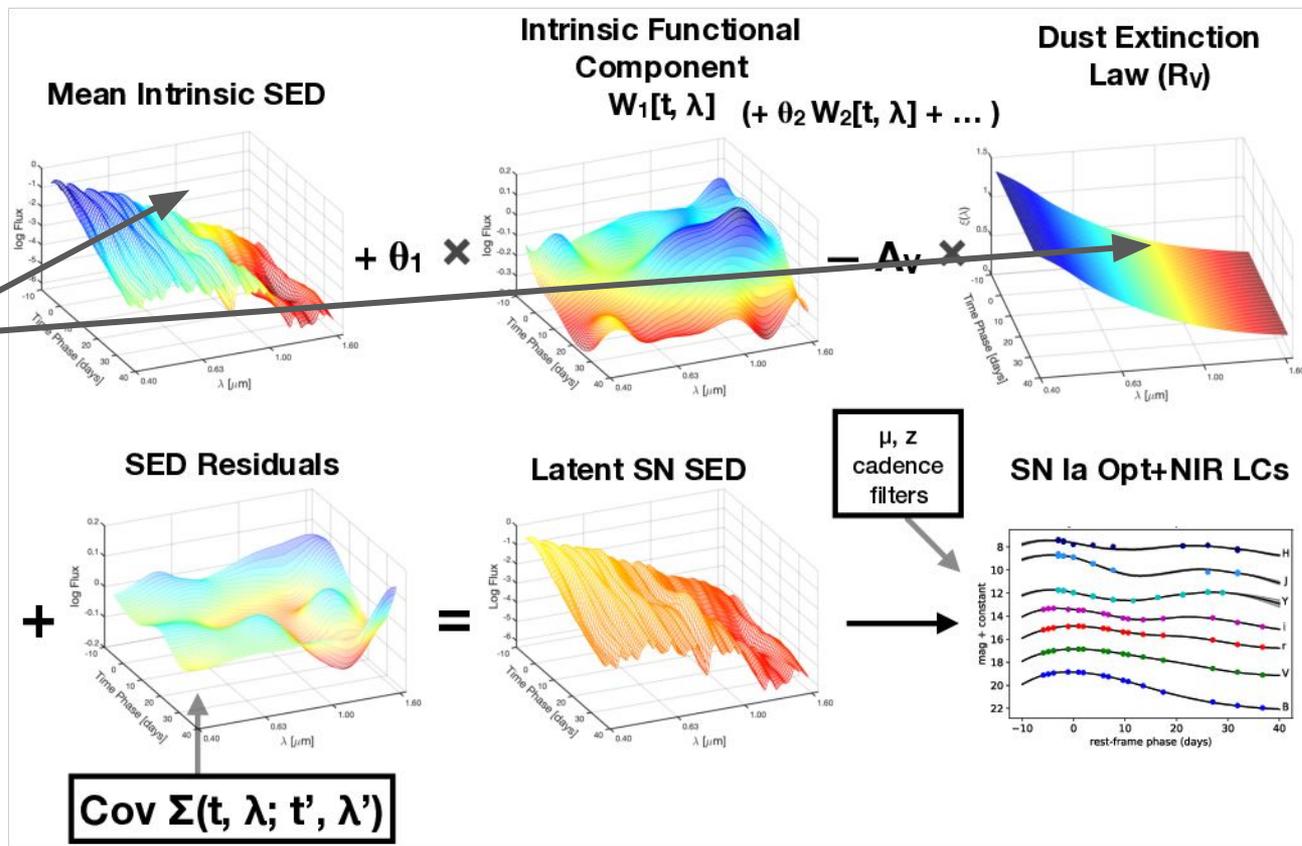


- BayeSN is computationally expensive...
- ...but we have been able to achieve 100x speed ups using numpyro/jax and running on GPU
 - No emulation, just doing HMC very fast
- Inferences that used to take days now take minutes
- BayeSN is scalable for LSST



Applying BayeSN to the Mass Step

Infer separately
for high- and
low-mass galaxies

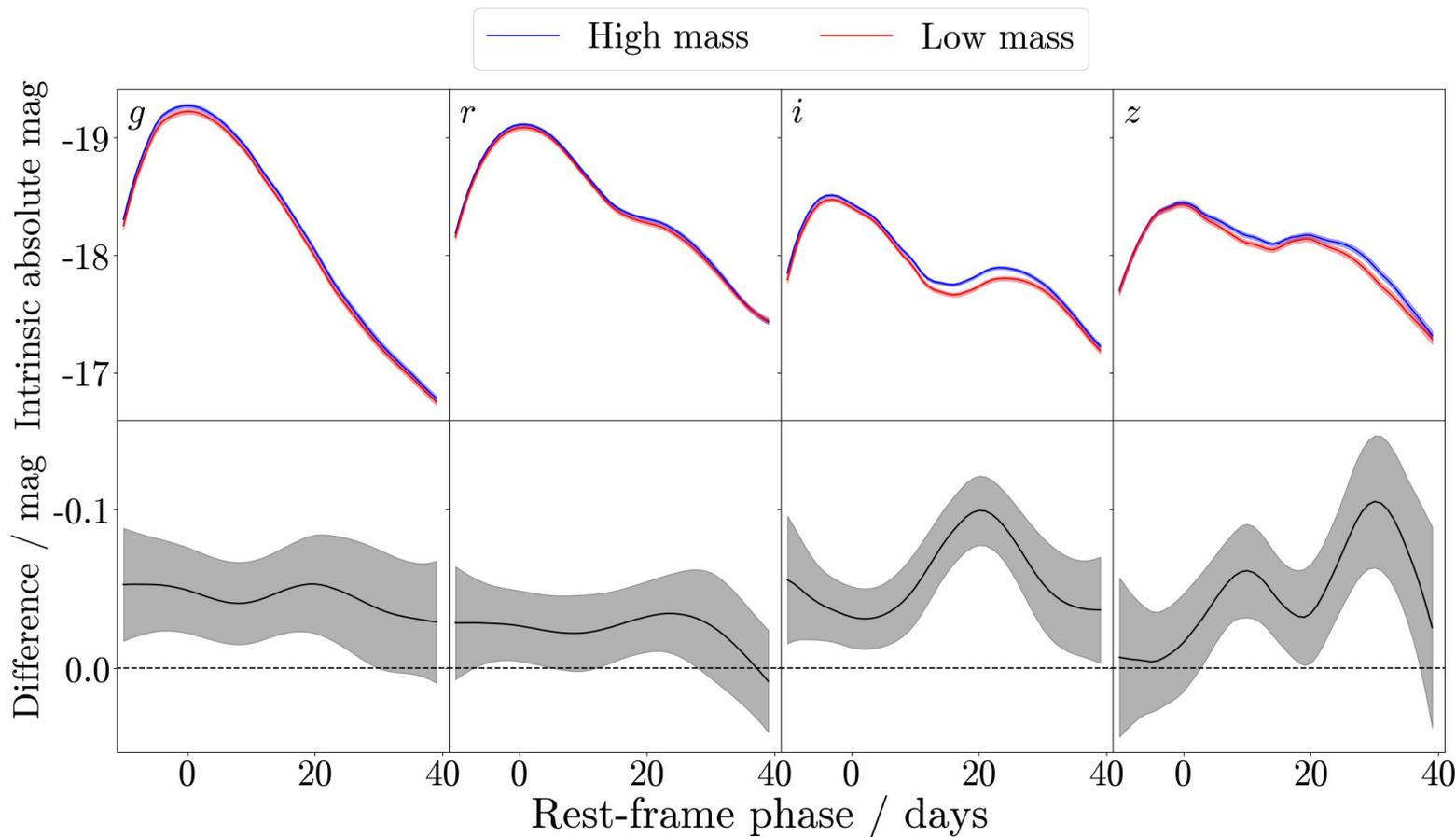


Results: The Mass Step

| Method | $\Delta M_0 / \text{mag}$ | $\Delta(g - r)_{\text{peak}}^{\text{int}}$ | μ_R | | τ_A / mag | |
|---------------------|---------------------------|--|-----------------|-----------------|-----------------------|-----------------|
| | | | HM | LM | HM | LM |
| Intrinsic mag diff. | -0.049 ± 0.016 | – | 2.51 ± 0.16 | 2.74 ± 0.35 | 0.18 ± 0.01 | 0.11 ± 0.01 |
| Intrinsic SED diff. | -0.049 ± 0.027 | -0.022 ± 0.010 | 2.26 ± 0.14 | 3.36 ± 0.51 | 0.19 ± 0.02 | 0.15 ± 0.02 |

- 475 SNe Ia from Foundation, PanStarrs Medium Deep and DES3YR
- Our results support the existence of intrinsic differences between SNe Ia in each mass bin
- Depending on our assumptions, our results may also indicate differences in host galaxy dust properties

Intrinsic Mean Light Curves



- Currently incorporating BayeSN for distance estimation within ‘industry standard’ SN cosmology pipelines
- The dream: hierarchical cosmological inference within BayeSN, marginalised over the SED model
- Arbitrary selection effects are a big challenge for likelihood-based approaches
- Simulation-based inference provides a way to do this!
 - Karchev, Grayling et al. 2024 validated TMNRE for SNe, comparing it with HMC on the same data with promising results

Conclusions

- BayeSN has many statistical advantages over other methods, and GPU acceleration has made it scalable for LSST
- We have investigated the SN Ia ‘mass step’, finding evidence to support the existence of intrinsic differences between SN Ia in different environments
- SBI can unlock new, powerful ways of doing supernova cosmology



GPU-HMC paper



TMNRE paper