



shift) to a supernova model, with the most widely used being that of the empirical SALT2 model (Guy et al. 2007, 2010). This model is trained separately before fitting the supernovae light curves for the cosmology selected supernova sample (Guy et al. 2010; Mosher et al. 2014). The resulting output from the model is, for each supernova, a characterised amplitude  $x_0$  (which can be converted into apparent magnitude  $m_B = -2.5 \log(x_0)$ ), a stretch term  $x_1$  and colour term  $c$ , along with a covariance matrix describing the uncertainty on these summary statistics. As such, the product at the end is a (redshift dependent) population of  $m_B$ ,  $x_1$  and  $c$ .

The underlying actual supernova population is not as clear cut, and indeed accurately characterising this population, its evolution over redshift and effects from environment is one of the challenges of supernova cosmology. However, given some modelled underlying population that lives in the redshift dependent space  $M_B$ ,  $x_1$  and  $c$ , the introduction of cosmology into the model is simple – it is encoded in the functional map between those two populations, from apparent magnitude space to absolute magnitude. Specifically, for any given supernova our functional map may take the traditional form:

$$M_B = m_B + \alpha x_1 - \beta c - \mu(z) + \text{corrections}, \quad (1)$$

where  $\alpha$  is the stretch correction (Phillips 1993), and  $\beta$  is the colour correction (Tripp 1998) that respectively encapsulate the empirical relation that broader and bluer supernovae are brighter. The corrections term at the end often includes corrections for host galaxy environment, as this has statistically significant effects on supernova properties (Kelly et al. 2010; Sullivan et al. 2010; Rigault et al. 2013; Uddin et al. 2017). The cosmological term,  $\mu(z)$  represents the distance modulus, and is precisely known given cosmological parameters and an input redshift.

Do I need to put more here?

---

Review old methods **done**

Review current methods **not done**

Potential places for improvement **not done**

### 3 OUR METHOD

General comments about the method (BHM), Stan

#### 3.1 General Description

Mapping population of observables on a population of underlying SN, where the map function encodes cosmology. Difficulty is creating an underlying SN population that is flexible enough to not introduce bias whilst still being physically motivated.

Observables -> Transformation function (latent, mass, cosmology, systematics) -> Underlying pop (and outlier)

#### 3.2 Applied to Spectroscopic Sample

Minimal outliers

## 4 APPLICATION TO DES

### 4.1 Simulating DES SN data

### 4.2 Model validation

approximate\_simple\_test.py  
multisim  
bulk

### 4.3 Results on simulated data (ie projections)

#### 4.3.1 Spectroscopic Sample

#### 4.3.2 Photometric sample

### 4.4 Comparison with bells and whistles fixed

## 5 SYSTEMATICS STRENGTH TEST

systematics test

## 6 INTERESTING IMPLEMENTATION DETAILS

Anything interesting.

Also talk about non-analytic correction factors (and their failure - mc integration, GP, NNGP)

## 7 CONCLUSIONS

## ACKNOWLEDGEMENTS

## REFERENCES

- Abbott T., et al., 2016, *Monthly Notices of the Royal Astronomical Society*, 460, 1270
- Alam S., et al., 2017, *Monthly Notices of the Royal Astronomical Society*, 470, 2617
- Amanullah R., et al., 2010, *The Astrophysical Journal*, 716, 712
- Astier P., et al., 2006, *Astronomy and Astrophysics*, 447, 31
- Bailey S., et al., 2008, eprint arXiv:0810.3499
- Balland C., et al., 2009, *Astronomy and Astrophysics*, 507, 85
- Bernstein J. P., et al., 2012, *The Astrophysical Journal*, 753, 152
- Betoule M., et al., 2014, *Astronomy & Astrophysics*, 568, 32
- Conley A., et al., 2011, *The Astrophysical Journal Supplement Series*, 192, 1
- Contreras C., et al., 2010, *The Astronomical Journal*, 139, 519
- Freedman W. L., et al., 2009, *The Astrophysical Journal*, 704, 1036
- Guy J., et al., 2007, *Astronomy and Astrophysics*, 466, 11
- Guy J., et al., 2010, *Astronomy and Astrophysics*, 523, 34
- Hicken M., et al., 2009, *The Astrophysical Journal*, 700, 331
- Hinshaw G., et al., 2013, *The Astrophysical Journal Supplement Series*, 208, 19
- Ivezic Z., et al., 2008, eprint arXiv:0805.2366
- Jennings E., Wolf R., Sako M., 2016, eprint arXiv:1611.03087, pp 1–22
- Kelly P. L., Hicken M., Burke D. L., Mandel K. S., Kirshner R. P., 2010, *The Astrophysical Journal*, 715, 743
- Kessler R., Scolnic D., 2017, *The Astrophysical Journal*, 836, 56
- Kowalski M., et al., 2008, *The Astrophysical Journal*, 686, 749
- LSST Science Collaboration et al., 2009, eprint arXiv:0912.0201
- Mandel K. S., Wood-Vasey W. M., Friedman A. S., Kirshner R. P., 2009, *The Astrophysical Journal*, 704, 629

- March M. C., Trotta R., Berkes P., Starkman G. D., Vaudrevange P. M., 2011, *Monthly Notices of the Royal Astronomical Society*, 418, 2308
- March M. C., Karpenka N. V., Feroz F., Hobson M. P., 2014, *Monthly Notices of the Royal Astronomical Society*, 437, 3298
- Mosher J., et al., 2014, *The Astrophysical Journal*, 793, 16
- Perlmutter S., et al., 1999, *The Astrophysical Journal*, 517, 565
- Phillips M. M., 1993, *The Astrophysical Journal*, 413, L105
- Planck Collaboration et al., 2013, *Astronomy & Astrophysics*, 571, 66
- Rest A., et al., 2014, *The Astrophysical Journal*, 795, 44
- Riess A. G., et al., 1998, *The Astronomical Journal*, 116, 1009
- Rigault M., et al., 2013, *Astronomy & Astrophysics*, 560, A66
- Roberts E., Lochner M., Fonseca J., Bassett B. A., Lablanche P.-Y., Agarwal S., 2017, eprint arXiv:1704.07830
- Rubin D., et al., 2015, *The Astrophysical Journal*, 813, 15
- Scolnic D., Kessler R., 2016, *The Astrophysical Journal Letters*, 822
- Shariff H., Jiao X., Trotta R., van Dyk D. A., 2016, *The Astrophysical Journal*, 827, 1
- Sullivan M., et al., 2010, *Monthly Notices of the Royal Astronomical Society*, 406, 782
- Suzuki N., et al., 2012, *The Astrophysical Journal*, 746, 85
- Tripp R., 1998, A two-parameter luminosity correction for Type IA supernovae. Vol. 331, EDP Sciences [etc.], <http://adsabs.harvard.edu/abs/1998A%7B26A...331..815T>
- Uddin S. A., Mould J., Lidman C., Ruhlmann-Kleider V., Zhang B. R., 2017, eprint arXiv:1709.05830
- Weyant A., Schafer C., Wood-Vasey W. M., 2013, *The Astrophysical Journal*, 764, 116
- Wood-Vasey W. M., et al., 2007, *The Astrophysical Journal*, 666, 694

## APPENDIX A: PAPERS

This paper has been typeset from a  $\text{\TeX}/\text{\LaTeX}$  file prepared by the author.