

A BayeSN view of the ZTF SN Ia DR2

M. Ginolin^{1,★}, M. Grayling¹, K.S. Mandel^{1,2} et al.

¹ Institute of Astronomy and Kavli Institute for Cosmology, Madingley Road, Cambridge CB3 0HA, UK

² Statistical Laboratory, DPMMS, University of Cambridge, Wilberforce Road, Cambridge, CB3 0WB, UK

★ Contact e-mail: madeleine.ginolin@ast.cam.ac.uk



I. Introduction

Type Ia Supernovae (SNe Ia) are a key probe to constrain the expansion history of our Universe. However, the link with their astrophysical environment, which influences their magnitude, and thus inferred cosmological parameters, is still not fully understood, and is now the biggest source of systematics in dark energy measurements.

Data

We use light curves from the ZTF SN Ia DR2 [1], which includes all spectroscopically confirmed SNe Ia detected by ZTF between March 2018 and December 2020. We make use of the four environmental tracers available: stellar mass and (g-z) colour, both global (whole host galaxy) and local (2kpc aperture around the SN), as shown in Fig. 1. To bypass correcting for selection effects, we limit ourselves to the volume-limited ($z < 0.06$) version of the sample, which comprises 932 SNe.

BayeSN model

BayeSN [2, 3] models the rest-frame Spectral Energy Distribution (SED) of a SN $S^s(t, \lambda)$ as:

$$-2.5 \log_{10} \left[\frac{S^s(t, \lambda)}{S_0(t, \lambda)} \right] = M_0 + \delta M^s + W_0(t, \lambda) + \theta_1^s W_1(t, \lambda) + A_V^s \xi(\lambda; R_V^s) + \epsilon^s(t, \lambda)$$

S_0 is a given SED template [4], wrapped by a W_0 surface. W_1 combined with a per-SN θ_1^s described the slower-brighter relation, A_V^s is a per-SN dust extinction, drawn from an exponential prior $\tau_A^{-1} \exp(-A_V^s/\tau_A)$ if $A_V^s > 0$, 0 otherwise, combined with a given dust law ξ . δM^s captures the grey scatter and ϵ^s the leftover variability, including intrinsic colour.

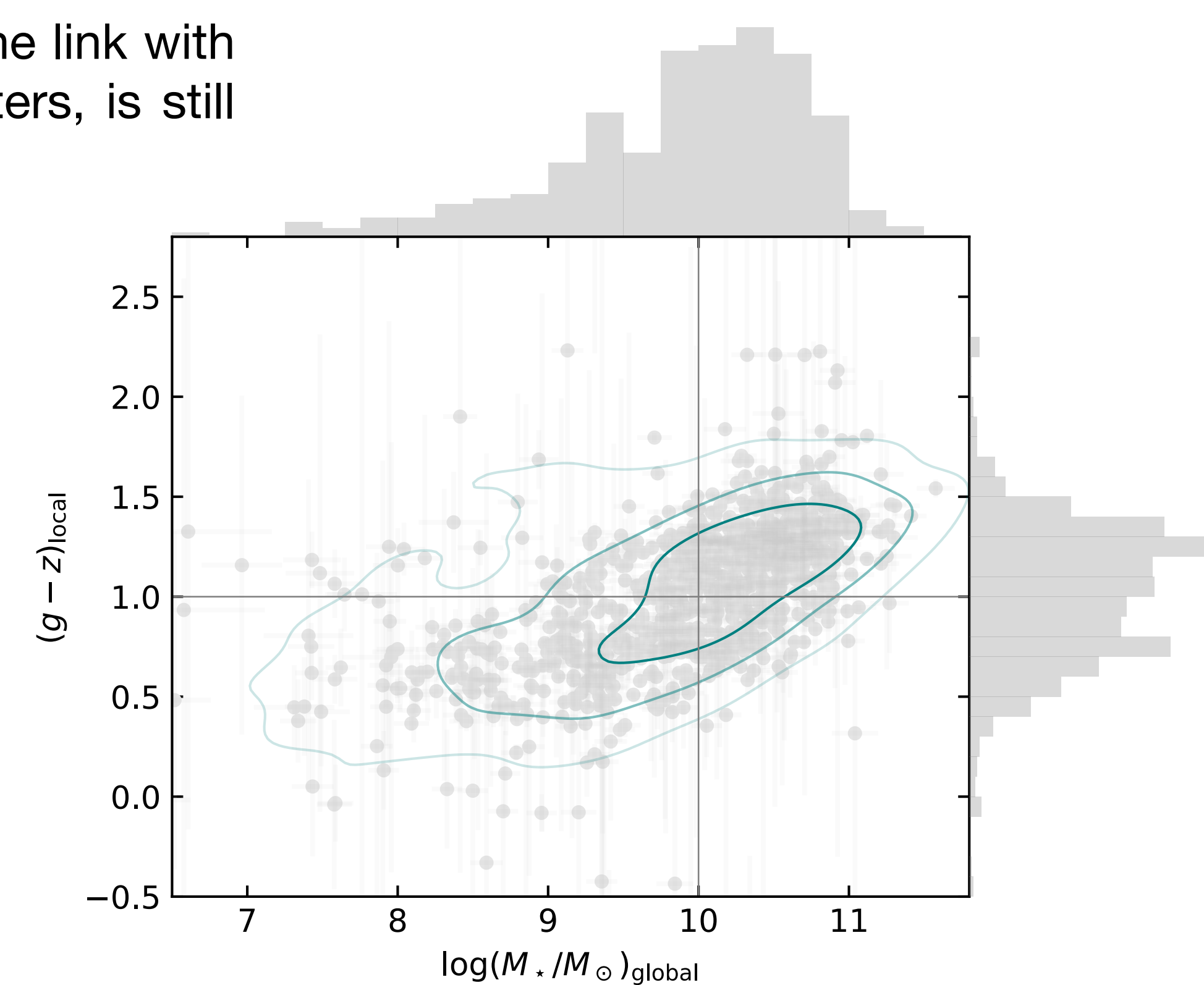


Figure 1: Global mass against local colour

II. Light curve properties

We fit the light curves with the newest BayeSN model [5]. Below is an example of a light curve fit of a random SN.

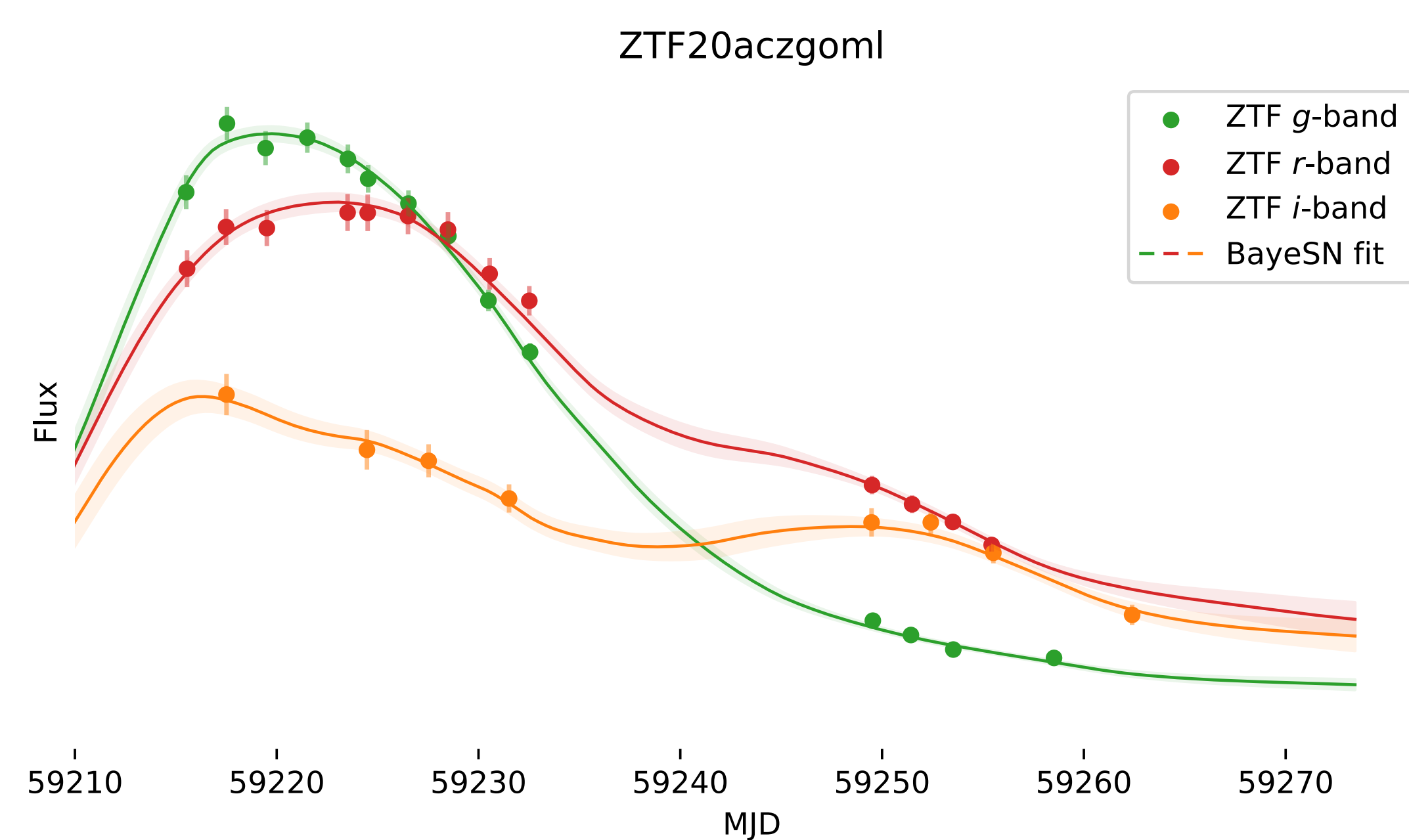


Figure 2: Example of a BayeSN fit

SALT comparison

In Fig. 2, we plot the per-SN BayeSN parameters against their SALT counterparts.

BayeSN θ_1 and x_1 are inversely correlated, with a non-linear correlation at the large θ_1 end (low x_1). This might be because the θ_1 is a linear effect in log flux, whereas x_1 is a linear effect in flux. It also might be a signature of the non-linear stretch-residuals relation found in [6], which is present at a 13.4σ level when fitting a broken- W_1 model with BayeSN.

SALT colour and A_V are strongly correlated, but at null A_V a scatter in c is visible, which points towards an intrinsic colour variability in SNe.

The scatter in Hubble residuals ($\sigma_{\text{STD}}=0.177$, $\sigma_{\text{nMAD}}=0.225$) is slightly smaller than the SALT scatter for standardised Hubble residuals ($\sigma_{\text{STD}}=0.181$, $\sigma_{\text{nMAD}}=0.230$).

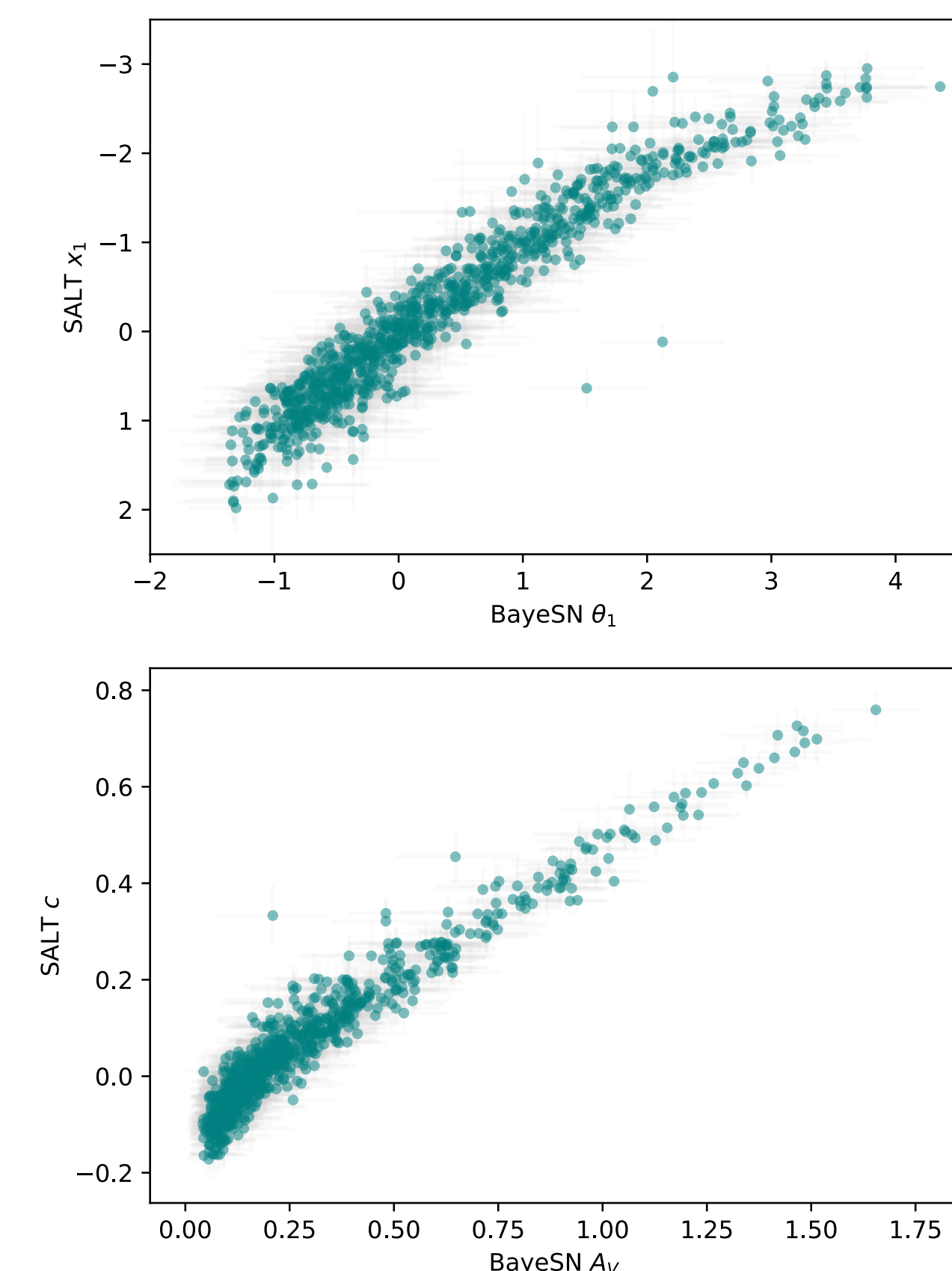


Figure 3: BayeSN θ_1 against SALT x_1 (top), BayeSN A_V against SALT c (bottom)

III. Environmental steps

A posteriori steps

We compute steps for the four environmental tracers available in the DR2, using the output distance modulus from our BayeSN fits. We compare them to the a posteriori steps from [6]. This method tends to underestimate the step as it is not fitted jointly with the rest of the SN Ia standardisation, but it allows for a direct comparison between BayeSN and SALT steps.

Tracer	BayeSN	SALT
Local colour	0.086 ± 0.010 (8.3 σ)	0.089 ± 0.010 (8.5 σ)
Global colour	0.080 ± 0.010 (7.8 σ)	0.083 ± 0.010 (7.9 σ)
Local mass	0.070 ± 0.010 (6.8 σ)	0.087 ± 0.011 (8.2 σ)
Global mass	0.103 ± 0.010 (10.1 σ)	0.099 ± 0.010 (9.5 σ)

Table 1: Environmental step (in mag) and their significance across a range of tracers, computed with the distance modulus from BayeSN light curve fits, compared with the a posteriori steps from [6].

Intrinsic steps

We then compute steps following the method from [7], where an achromatic step is fitted along with different R_V populations and τ_A for low- and high-mass hosts. This allows for the simultaneous fit of an intrinsic and a dust-related step. Contrary to the binary split implemented in [7], we use a continuous probability of being in a low/high-mass host between 0 and 1, which takes into account errors on the chosen environmental tracer.

Tracer	Intrinsic step	$\Delta E(R_V)$	$\Delta \tau_A$
Local colour	0.085 ± 0.019 (4.5 σ)	0.165 ± 0.132 (1.2 σ)	-0.047 ± 0.028 (1.7 σ)
Global colour	0.072 ± 0.019 (3.7 σ)	0.155 ± 0.126 (1.2 σ)	-0.045 ± 0.030 (1.5 σ)
Local mass	0.081 ± 0.019 (4.3 σ)	0.086 ± 0.148 (0.6 σ)	-0.203 ± 0.030 (6.8 σ)
Global mass	0.103 ± 0.018 (5.6 σ)	0.146 ± 0.139 (1.0 σ)	-0.035 ± 0.030 (1.2 σ)

Table 2: Intrinsic step (in mag), along with difference in mean R_V and τ_A across environments.

IV. Conclusion and prospects

The a posteriori steps are comparable between BayeSN and SALT, confirming that the large steps seen in [6] were not due to the SALT light curve fits or the standardisation process. The intrinsic steps, while smaller, are still significant. This means that the step is at least partially intrinsic, in accordance with [5,7]. Further understanding the origin and size of the environmental step is crucial for upcoming SNe Ia cosmological analyses, e.g. LSST. Upcoming low- z surveys will also be crucial to confirm these results.

References

- [1] Rigault M., et al., 2025, A&A, 694, A1
- [2] Mandel K. S., et al., 2022, MNRAS, 510, 3939
- [3] Thorp S., et al., 2021, MNRAS, 508, 4310
- [4] Hsiao E.Y., et al., 2007, ApJ, 663, 1187
- [5] Grayling et al. in prep
- [5] Ginolin M., et al., 2025a, A&A, 694, A4
- [6] Ginolin M., et al., 2025b, A&A, 695, A140
- [7] Grayling M., et al., 2024, MNRAS, 531, 953