PROCEEDINGS OF SCIENCE

Cosmology with Type Ia supernovæ: environmental effects

Matthieu Roman[*]
Laboratoire de Physique Nucléaire et des Hautes Energies (LPNHE)
UPMC Univ. Paris 6, UPD Univ. Paris 7, CNRS IN2P3
4 place Jussieu, 75005 Paris, France
E-mail: matthieu.roman@lpnhe.in2p3.fr

Delphine Hardin[†]**, Marc Betoule**[†]
[†] *Laboratoire de Physique Nucléaire et des Hautes Energies (LPNHE)*
UPMC Univ. Paris 6, UPD Univ. Paris 7, CNRS IN2P3
4 place Jussieu, 75005 Paris, France

PoS(EPS-HEP2017)052

We measure host galaxy photometry and local fluxes within 3 kpc for 882 Type Ia supernovæ (SNIa) spanning the redshift range $0.01 < z < 1$ and use SED fitting techniques to derive host properties such as stellar masses and local $U-V$ rest-frame colors. The latter is an indicator of the luminosity weighted age of the stellar population in a galaxy. We find that local $U-V$ color brightness dependence is at least as significant as it is for properties of the host galaxy as a whole (host stellar mass or global $U-V$ rest-frame color). Once selection requirements are chosen, we perform cosmological fits using local color as a third standardization variable and find its step significance at the level of 7σ, indicating that the remaining luminosity variations in SNIa samples can be reduced using a third standardization variable taking the local environment into account. Even after a mass step correction, a correlation of 4.6σ is found between local $U-V$ color and Hubble diagram residuals. We find that using the local color in place of the stellar mass results in a change in the measured value of the dark energy equation of state parameter of 0.6%. The precise analysis of local environment of SNIa will be of great importance for the forthcoming surveys, and in particular LSST for which uncertainties on the dark energy equation of state will be comparable to the reported effects [1].

The European Physical Society Conference on High Energy Physics
5-12 July, 2017
Venice

---

[*] Speaker.

1. Introduction

The Supernova Legacy Survey (SNLS) has been regularly publishing constraints on the dark energy fluid characterization using Type Ia supernovæ (SNIa). The latest such release was a joint analysis between the SNLS and Sloan Digital Sky Survey (SDSS) teams designated the *Joint Light-curve Analysis* [2], which provided a 6% measurement of the dark energy equation of state parameter. Type Ia supernovæ's success as a cosmological probe is based on them being *standardizable* candles, i.e. correcting the supernova rest-frame B peak magnitude using empirical light-curve width (stretch) and color dependence laws (brighter-bluer). This correction reduces the SNIa peak magnitude dispersion down to ~ 0.15 mag. However, the remaining dispersion reflects the fact that the standardization procedure does not entirely capture the physical processes at play during the explosion, leaving room for at least one more variable correlating with supernova brightness.

Therefore, the search for correlations between SNIa characteristics and the properties of their parent galaxies is strongly motivated. A direct hint of local environmental effects was provided by results from [3], hereafter R13, obtained using observations from the Nearby Supernova Factory: they showed evidence that SNIa standardized magnitudes depend on the star formation of the supernova environment within a radius of 1 kpc, traced by Hα surface brightness. In [4], hereafter R15, they upheld their conclusion that SNIa from locally star forming environments are fainter after standardization than those from locally passive environments. However, with a significant increase of the SNIa sample, [5] on the contrary found little evidence for a star-formation bias.

We measure the local environment of a large sample of SNIa over the whole Hubble diagram and compare with properties of host galaxies as a whole. We demonstrate, as claimed by R13, that the local information is crucial, and constitutes an important systematic effect to be taken into account in on-going and future surveys.

2. Supernovæ sample and host photometry

The compilation used here is assembled as part of an effort to derive cosmological constraints from the full SNLS spectroscopic sample. In all cases, the SALT2 model [6] is adjusted to the available multiband photometry and consistent selection requirements are applied to the whole sample in order to obtain a sample of 994 SNIa. A few modifications are applied compared to the most recent SNIa compilation from JLA [2] in terms of supernova selection. The low redshift part of the compilation is dominated by SNIa from the third and fourth releases of data acquired at the F. L. Whipple Observatory of the Harvard-Smithsonian Center for Astrophysics (CfaIII [7] and CfAIV [8]). It also includes data from the Carnegie Supernova Project [9, 10]. The intermediate redshift part of our sample is provided by the SDSS-II supernova survey [11]. Then, our sample includes spectroscopically-confirmed high redshift SNIa from the full five year SNLS survey, built from the deep component of the CFHT Legacy Survey.

To accurately compare properties of host galaxies as a whole with properties from the local environment, we limit ourselves to a sample for which host photometry is measurable on SNLS and SDSS images only. It corresponds to 7 SNIa from the CSP survey, 55 from CfAIII, 34 from CfAIV, 389 from SDSS and 397 from the SNLS survey. In total, the baseline sample is composed of 882 SNIa.

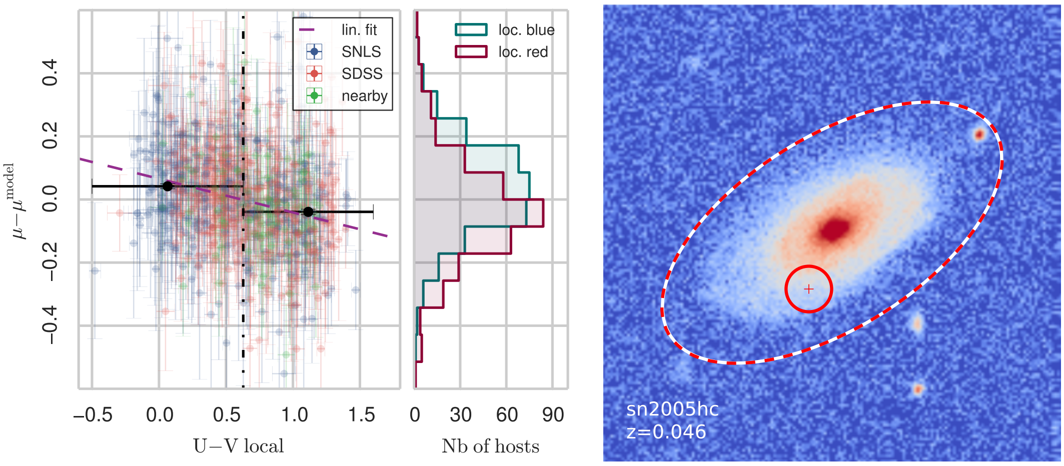

Figure 1: Left: Standardized Hubble diagram residuals as a function of local $U-V$ color. With a bin separation at the median, the step significance is of 7σ. Histograms represent the distributions of locally red and blue regions. **Right:** Example of a 3 kpc radius (solid red circle) around the explosion location of *sn2005hc* from the SDSS survey. Properties of the host galaxy are measured within the dashed red ellipse.

3. A third standardization parameter

The distance estimator assumes that supernovæ with identical color, shape and galactic environment have on average the same intrinsic luminosity at all redshifts. We assume the standardized distance modulus writes:

$$\mu = m_B^* - (M_B - \alpha \times x_1 + \beta \times c) \tag{3.1}$$

where m_B^* is the observed peak magnitude in rest-frame B band, and α, β and M_B are nuisance parameters. Hubble diagram residuals thus represent the difference between this quantity and the cosmological model prediction. The third variable is taken into account in the cosmological fit through a step function for the absolute magnitude M_B, assuming a bimodal distribution with a separation at the median. We follow the procedure which defines a magnitude step written as follows:

$$M_B = \begin{cases} M_B & \text{if} \;\; X < X_{\rm lim} \\ M_B + \Delta M_B & \text{if} \;\; X > X_{\rm lim} \end{cases} \tag{3.2}$$

with X being any kind of variable related to host galaxy properties and $X_{\rm lim}$ the bimodal distribution limit. An illustration of how local and global host properties are measured is drawn in the right panel of Fig. 1. When performing a cosmological fit using the host stellar mass as a third variable, we find the median at $10^{10.5}\mathscr{M}_\odot$ and $|\Delta M_B| = 0.070 \pm 0.013$, corresponding to a significance of 5.5σ. This value is consistent with latest results obtained in [2]. Considering local $U-V$ color as the third standardization parameter, we find the median at $U-V \sim 0.63$ and $|\Delta M_B| = 0.091 \pm 0.013$, so the change in M_B magnitude with a local color step is at a significance of about 7σ. Its amplitude is compatible with similar local age-bias measurements from R13 and R15.

Similar values of the step significances are obtained by computing *a posteriori* correlations between Hubble diagram residuals estimated through a regular standardization and host stellar masses or local $U-V$ colors. The left panel of Fig. 1 shows these correlations.

4. Conclusions

We envisage the possibility that, in addition to stretch and color, a third variable related to the close environment of supernovæ must be used in light-curve cosmological fitters. We find that local $U-V$ color is well-suited to be chosen as a third standardization parameter and that its impact is more significant than other global variables we measure such as the host stellar mass. Although this analysis is blind regarding the actual values of cosmological parameters, we have access to the expected order of magnitude of the change in w and Ω_m when correcting for local color. The change is $\Delta w \sim 0.01$ and $\Delta\Omega_m \sim 0.003$ when compared to a two parameter standardization. Comparing the local color correction and the host mass correction gives $\Delta w \sim 0.006$ and $\Delta\Omega_m \sim 0.002$. This is important enough to take into account in current and future surveys since their expected precision is close to the parameter shift we find. For more details on the analysis and more information on the various robustness tests we performed, we refer the reader to [1].

References

[1] M. Roman, D. Hardin, M. Betoule et al., *The Dependence of Type Ia Supernova Luminosities on Their Local Environment*, *ArXiv e-prints* (June, 2017) , [1706.07697].

[2] M. Betoule, R. Kessler, J. Guy, J. Mosher, D. Hardin, R. Biswas et al., *Improved cosmological constraints from a joint analysis of the SDSS-II and SNLS supernova samples*, *AAP* **568** (Aug., 2014) A22, [1401.4064].

[3] M. Rigault, Y. Copin, G. Aldering, P. Antilogus, C. Aragon, S. Bailey et al., *Evidence of environmental dependencies of Type Ia supernovae from the Nearby Supernova Factory indicated by local Hα*, *AAP* **560** (Dec., 2013) A66, [1309.1182].

[4] M. Rigault, G. Aldering, M. Kowalski, Y. Copin, P. Antilogus, C. Aragon et al., *Confirmation of a Star Formation Bias in Type Ia Supernova Distances and its Effect on the Measurement of the Hubble Constant*, *APJ* **802** (Mar., 2015) 20, [1412.6501].

[5] D. O. Jones, A. G. Riess and D. M. Scolnic, *Reconsidering the Effects of Local Star Formation on Type Ia Supernova Cosmology*, *APJ* **812** (Oct., 2015) 31, [1506.02637].

[6] J. Guy, P. Astier, S. Baumont, D. Hardin, R. Pain, N. Regnault et al., *SALT2: using distant supernovae to improve the use of type Ia supernovae as distance indicators*, *AAP* **466** (Apr., 2007) 11–21, [astro-ph/0701828].

[7] M. Hicken et al., *CfA3: 185 Type Ia Supernova Light Curves from the CfA*, *APJ* **700** (July, 2009) 331–357, [0901.4787].

[8] M. Hicken et al., *CfA4: Light Curves for 94 Type Ia Supernovae*, *APJ* **200** (June, 2012) 12, [1205.4493].

[9] C. Contreras et al., *The Carnegie Supernova Project: First Photometry Data Release of Low-Redshift Type Ia Supernovae*, *AJ* **139** (Feb., 2010) 519–539, [0910.3330].

[10] M. D. Stritzinger, M. M. Phillips, L. N. Boldt, C. Burns, A. Campillay, C. Contreras et al., *The Carnegie Supernova Project: Second Photometry Data Release of Low-redshift Type Ia Supernovae*, *AJ* **142** (Nov., 2011) 156, [1108.3108].

[11] M. Sako, B. Bassett, A. C. Becker, P. J. Brown, H. Campbell, R. Cane et al., *The Data Release of the Sloan Digital Sky Survey-II Supernova Survey*, *ArXiv e-prints* (Jan., 2014) , [1401.3317].

PoS(EPS-HEP2017)052