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LOCAL HOST GALAXY PROPERTIES OF TYPE IA SUPERNOVAE FROM THE NEARBY SUPERNOVAE FACTORY

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Abstract. Type Ia supernovae are key tools to study accelerating expansion of the Universe. However despite active research, physics of such objects remain uncertain. To better understand potential systematics we investigate on local host galaxy properties. In this preliminary analysis, we find gas derived quantities such as metallicity and star formation rate compatible to those present in literature. Finally we show a relationship between SALT2 color and x_1 with star formation activity.

Keywords: Observational cosmology, Type Ia supernovae, Host galaxy, Gas properties

1 Introduction

Type Ia supernovae (SNe Ia) were key luminosity distance indicators in the discovery of the accelerating expansion of the Universe (Riess et al. 1998; Perlmutter et al. 1999). As their intrinsic peak luminosity variations are small – less than 0.15 magnitude after standardization – SNe Ia are used as cosmological standard candles. Despite ongoing research, the physical nature of progenitor system and the explosion mechanism remain however uncertain.

In recent years, numerous samples of SNe Ia have been observed and approximately 600 spectroscopically-confirmed SNe Ia are available for cosmological analyses (Amanullah et al. 2010). With such a large sample, investigating systematic uncertainties has grown into a major preoccupation. In particular, global host properties might have an important impact on the properties and standardization of SNe Ia (Howell et al. 2006; Lampeitl et al. 2010; Sullivan et al. 2010; Konishi et al. 2011).

The *Nearby Supernovae Factory* collaboration (SNfactory, Aldering et al. 2002) has collected a sample of more than 200 SN Ia spectrophotometric time series. Each series typically consists of 15 spectra plus two or

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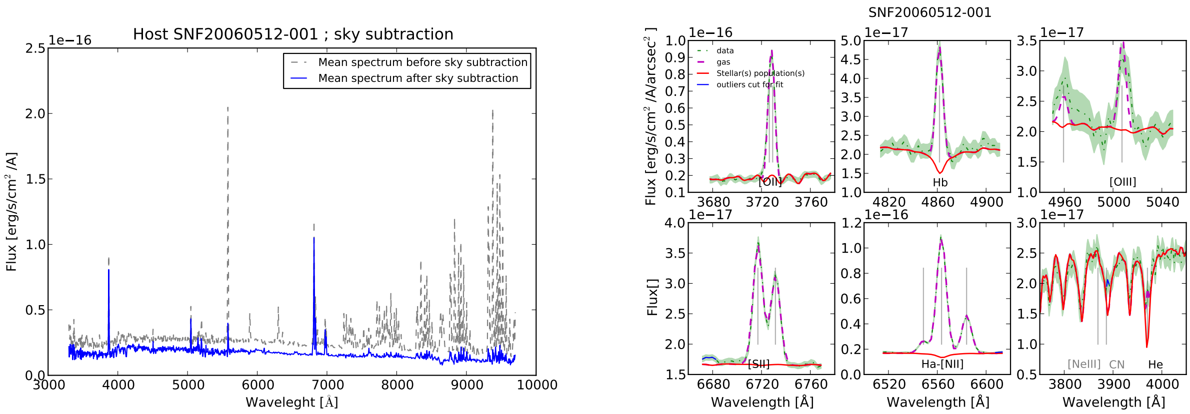

Fig. 1. Left: Mean spectra extracted from merged cube of both B and R channels for the darkest observation night of SNF20060512-001 host galaxy. The gray dashed-line represent the host galaxy + sky spectrum while the blue solid-line is the galaxy spectrum obtained after sky subtraction. **Right:** Zooms on relevant part of the galaxy spectrum. The data is the dashed-point green line with best ULySS fit split in two component: the SSP is the solid-red line while the gas in plotted in dashed-magenta line.

more local host observations taken at least one year after the explosion (final references). SNfactory observations are made using an Integral Field Spectrograph (IFS) with a field-of-view (FoV) of few arcsec, allowing to collect simultaneously SN Ia point source as well as its local environment. This peculiarity offers unique conditions that might help to constrain progenitor populations better than a global host study.

We present our data sample and the local host galaxy spectrum extraction in § 2; § 3 exposes the method used to measure the gas emission and we discuss our results in § 4.

2 Data analysis

The spectra was obtained by the SNfactory collaboration between 2004 and 2010 with the *SuperNovae Integral Field Spectrograph* (SNIFS, Lantz et al. 2004), a fully integrated instrument optimized for automated observations of point sources on a structured background over an extended optical window at moderate spectral resolution. The IFS possesses a fully-filled $6''.4 \times 6''.4$ spectroscopic FoV subdivided into a grid of 15×15 spatial elements (spaxels). The dual-channel spectrograph covers simultaneously 3200–5200 Å (B-channel) and 5100–10000 Å (R-channel). More details about SNIFS are presented in Thomas et al. (2011), and the software pipeline is summarized in Aldering et al. (2006). The inter-channel dichroic implies a 200 Å wide range around 5100 Å with a bigger variance and some yet unresolved data-reduction issues. This impacts the measurement of H_β and [OIII] for redshifts $0.028 < z < 0.07$ and $z < 0.038$, respectively. Thus, excepted for highest signal over noise ratio spectra, this domain can not be directly used for analysis yet.

SNIFS does not have a sky channel, and given its small FoV, it is usually impossible to isolate a pure sky signal as can be done in long slit spectrography. We therefore developed a technique to model the sky contribution on the observed spectra. This model is obtained from studies of night skies observed during standard star exposures. We use more than 1000 spectra and feed them to a Principal Component Analysis (PCA) to extract relevant contributions. The PCA will be performed independantly on the red sky emission lines (PCA_R) – after subtraction of a 4^{th}-order Legendre polynomial continuum – and the blue continuum plus lines (PCA_B). The resulting sky model is therefore a linear combination of 18 parameters: 8 PCA_R coefficients plus a 4^{th}-order Legendre polynomial for the R-channel, and 5 PCA_B coefficients for the B-channel.

The sky subtraction algorithm for a given x, y, λ cube is then the following. First extract the mean spectrum of the say 10 spaxels with the lowest galaxy signal, to get an high contrast "raw sky". In this sky, galaxy signal, in particular gas emission lines, could still remain. To avoid subtracting this galaxy signal, we then fit our sky model to this raw sky to get the "modeled sky": since host gas emission lines are not part of the model, the modeled sky will not have any galaxy feature. We can then proceed by subtracting the spatially uniform sky model from each spaxels of the observed cube. Fig. 1 shows the result of such a sky subtraction. The strong emission lines that disappear above 7200 Å are atmospheric lines modeled in the PCA_R, whereas the remaining lines are gas galactic emission.

To increase the signal over noise ratio of the host galaxy spectrum, we add to final references the "galaxy + SN" cubes from which the SN point source was subtracted. A "super cube" is created by merging all sky- (and potentially SN-) subtracted cubes after proper Atmospheric Differential Refraction (ADR) correction and registration. We discard cubes with strong flux residuals at the SN location (from PSF subtraction leftovers), and cubes with strong dichroic effects.

Finally, we extract the mean local galaxy spectrum at the SN location from brightest spaxels in the IFS FoV. This spectrum represent the brightest contribution of the galaxy to the direct environment of the SN.

3 Fitting emission lines

A galaxy is a combination of various physical elements that have a different incidence on the observed spectrum: stars create a black body continuum with an absorption structure depending on their age and metallicity; the gas contributes for emission lines, as a function of its metallicity and ionization; the dust absorbs light over the whole wavelength range. The dust absorption law is supposed to be a Cardelli law (Cardelli et al. 1989, $R_V = 3.1$).

In order to get accurate fluxes of gas emission lines, it is necessary to fit all galaxy components together. To do so, we use a modified version of the *University of Lyon Spectroscopic analysis Software*[*] (ULySS, Koleva et al. 2008, 2009). This allows us to fit a single stellar population (SSP) or a combination of multiple SPs (MSP) simultaneously with a set of emissions lines together with a multiplicative continuum that corrects both for dust extinction and large scale flux mismatch. Fig. 1 shows zooms of relevant elements of the host spectrum adjusted by ULySS in rest frame after Milky-Way dereddening. We see that some lines are unaffected by the underlying stellar continuum – such as [NII] or [OII] – while others – such as H_β – are sensitive to the SSP (or MSP) estimate.

Emission lines give information about physical properties such as the extinction through the color excess $E(B-V)$, the star formation rate (SFR) or the gas metallicity (log(O/H) + 12). $E(B-V)$ is computed using Balmer's emission lines, namely H_α, H_β or H_γ which have predictable ratios. Comparing the theoretical relationship to the observed ones yields to $E(B-V)$ (Osterbrock 1989; Gordon et al. 2003) assuming $R_V = 3.1$. After extinction correction, we measure the SFR from H_α luminosity (Kennicutt 1998). To get an intensive value, we divide this quantity with the physical observed surface to define the $\mathrm{SFR}_{SD}[M_\odot \mathrm{a}^{-1}\mathrm{kpc}^{-2}]$ (SD for Surface Density, Konishi et al. 2011). Finally, the gas metallicity is obtained using the Kewley & Dopita (2002) [OII]/[NII] method. Due to the distance between these two lines, this method is very sensitive to the $E(B-V)$ estimate. We therefore limit our sample to the 53 host in which a precise measurement of $E(B-V)$ is possible. However, we add 12 hosts for the SFR study since it is barely dependent on the measured extinction. Added spectra are those removed because of strong dichroic effect – preventing accurate measurement of H_β – but with a good H_α detection.

4 Results

Fig. 2 shows the repartition of gas properties of the SN Ia direct environment for hosts where $E(B-V)$ can be measured. We plot for comparison the same quantities as presented by Konishi et al. (2011) for SDSS global host gas properties.

Our local gas analysis gives us a maximal probability of $E(B-V)$ at 0.45 with a few negative measurement and an upper distribution tail extending to 1. This distribution is in a good agreement with the compared literature. The galaxy spectra are then corrected for this extinction. Since $E(B-V)$ should be positive, the small number of negative measurements are set to zero.

As in Konishi et al. (2011) the SFR_{SD} presence probability reaches a maximum at 0.12 $M_\odot$ $\mathrm{a}^{-1}\mathrm{kpc}^{-2}$ and raises up to 3. Lowest values are found in well detected hosts but with very thin gas presence, e.g. in elliptical galaxies, or in low detection hosts which limit our capacity to get accurate measurement of very low SFR_{SD}.

The local gas metallicity distribution peaks at 9.0 dex in agreement with the existing literature. Moreover we seem to have a second peak at 8.6 which could arise from our metallicity estimate method that begin to be degenerate with lower metallicities around this value. The few points bellow 8.5 should not be taken into consideration regarding the [NII]/[OII] Kewley & Dopita (2002) metallicity estimation.

[*]`http://ulyss.univ-lyon1.fr`

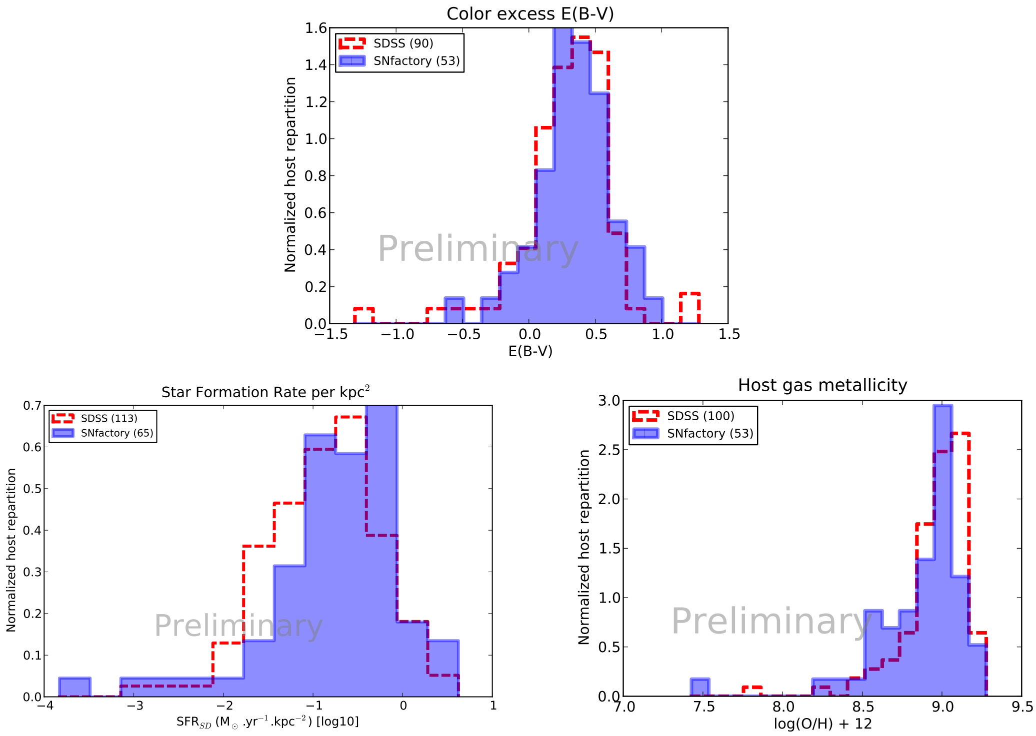

Fig. 2. For the three plots, our local host gas properties are represented in filled blue histograms for the 53 SN Ia host spectra. Empty dashed-red histogram represent same quantities from SDSS SN Ia host global analysis added for comparison (Konishi et al. 2011) ($0.05 < z < 0.4$). **Upper panel:** The color excess $E(B-V)$. **Left bottom panel:** The Star Formation Rate per Surface Density SFR$_{SD}$. **Right bottom panel:** The gas metallicity $\log(\mathrm{O/H}) + 12$.

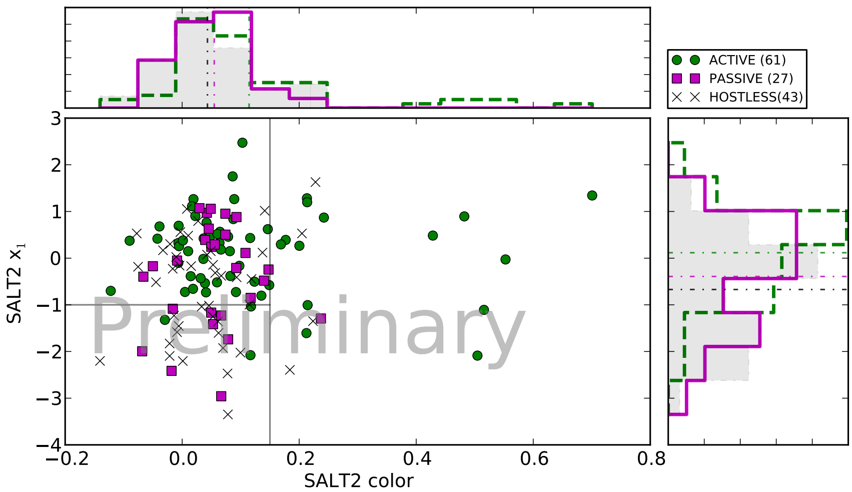

Fig. 3. The SALT2 x_1 and color repartition split as function of the SNe Ia host activity sub-classification: in circle-green "active" galaxies, in square-magenta "passive" ones and black cross for "hostless" SNe. Upper and right histograms are repartition of the SALT2 x_1 and color, respectively, for the three subclasses: dashed-green lines for "active", solid-magenta lines for "passive" and filled histograms for "hostless".

We then split our host galaxy sample in three categories: "active" (defined as galaxies with a SFR$_{SD} \geq 10^{-1.3}$, 61 hosts), "passive" (SFR$_{SD} < 10^{-1.3}$, 27 hosts) and "hostless" (host without any detected signal in our FoV, 27 hosts). Note that if no galaxy signal has been detected, this corresponds to the absence of H$_\alpha$, thus supposing SFR$_{SD} \ll 10^{-1.3}$: this hostless subclass could be assimilated to the passive one.

We now investigate the SN Ia properties as function of the host activity sub-classification. Fig. 3 shows the repartition of SALT2 (Guy et al. 2007) x_1 and color for our SN sample, split with respect to the host activity. This can be compared to Fig. 2 of Lampeitl et al. (2010) for the the SDSS global host study.

We can do two comments on Fig. 3. 1. SNe Ia with a color larger than 0.15 are mostly from active hosts. 2. as found by Lampeitl et al. (2010), low-stretch ($x_1 < -1$) SNe Ia tend to be found in "passive" hosts – i.e. old stellar population – or "hostless" hosts – i.e. supposedly passive local environment.

5 Conclusion

SNfactory offers the unprecedented possibility to study SN Ia local host properties. After extraction of the mean local host spectrum we investigated the gas characteristics by measuring $E(B-V)$, SFR_{SD} and $\log(\mathrm{O/H})+12$. We have found a repartition of those quantities in our sample in good agreement with existing literature looking at global host properties. Having split our 119 hosts into three subsamples according to their star formation activity, we notice, as observed by Lampeitl et al. (2010), that passive hosts galaxies tend to form lower SALT2 x_1 SNe Ia, and that all but one SNe Ia with $c > 0.15$ are coming from active galaxies.

Further studies on local host properties are in progress. As our IFS allows us to investigate gradient properties such as the H_α spatial distribution around the SN locations, studying structures could give us a better understanding of the direct environment of the SN progenitors.

References

Aldering, G., Adam, G., Antilogus, P., et al. 2002, SPIE, 4836, 61

Aldering, G., Antilogus, P., Bailey, S., et al. 2006, ApJ, 650, 510

Amanullah, R., Lidman, C., Rubin, D., et al. 2010, ApJ, 716, 712

Cardelli, J. A., Clayton, G. C., & Mathis, J. S. 1989, ApJ, 345, 245

Gordon, K. D., Clayton, G. C., Misselt, K. A., Landolt, A. U., & Wolff, M. J. 2003, ApJ, 594, 279

Guy, J., Astier, P., Baumont, S., et al. 2007, A&A, 466, 11

Howell, D. A., Sullivan, M., Nugent, P. E., et al. 2006, Nature, 443, 308

Kennicutt, R. C. 1998, ApJ, 498, 541

Kewley, L. J. & Dopita, M. A. 2002, ApJS, 142, 35

Koleva, M., Prugniel, P., Bouchard, A., & Wu, Y. 2009, A & A, 501, 1269

Koleva, M., Prugniel, P., Ocvirk, P., Le Borgne, D., & Soubiran, C. 2008, MNRAS, 385, 1998

Konishi, K., Cinabro, D., Garnavich, P. M., et al. 2011, 1101.4269

Lampeitl, H., Smith, M., Nichol, R. C., et al. 2010, ApJ, 722, 566

Lantz, B., Aldering, G., Antilogus, P., et al. 2004, Proc. SPIE, 5249, 146

Osterbrock, D. 1989, Astrophysics of gaseous nebulae and active galactic nuclei (Mill Valley CA: University Science Books)

Perlmutter, S., Aldering, G., Goldhaber, G., et al. 1999, ApJ, 517, 565

Riess, A. G., Filippenko, A. V., Challis, P., et al. 1998, ApJ, 116, 1009

Sullivan, M., Conley, A., Howell, D. A., et al. 2010, MNRAS, 406, 782

Thomas, R. C., Aldering, G., Aragon, C., et al. 2011, arXiv:1109.1312