Type-Ia Supernova Properties as a Function of the Distance to the Host Galaxy in the SDSS-II/SNe Survey

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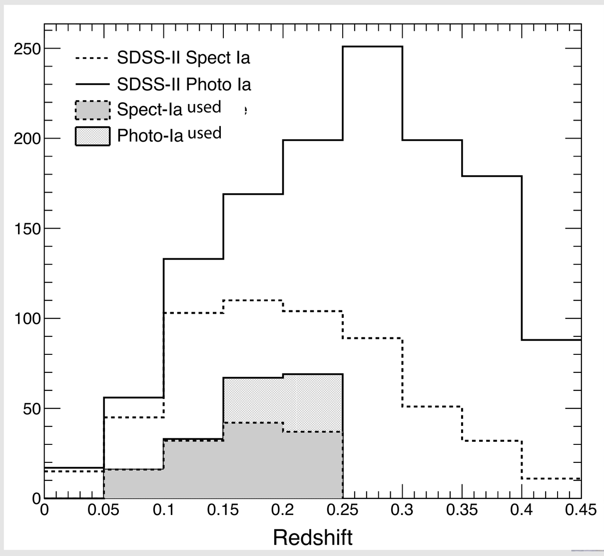
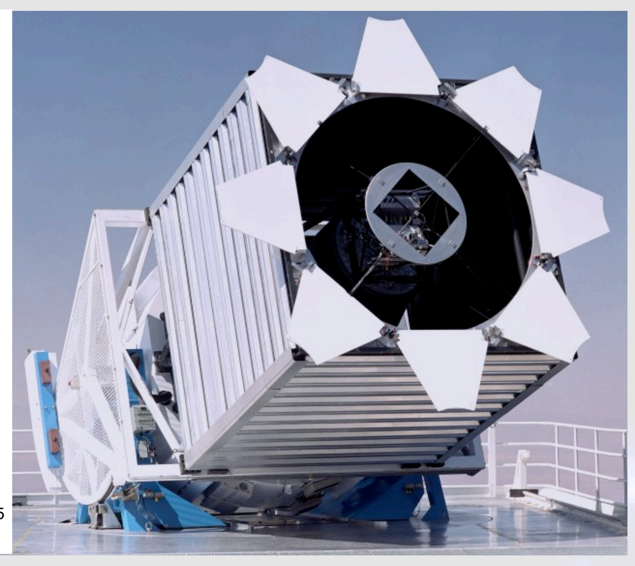
We use the three-year sample of type-Ia supernovae (SNe Ia) discovered by the SDSS-II/SNe Survey to look for dependencies of SN Ia properties with the projected distance to the host galaxy center (GCD), using the distance as a proxy for local galaxy properties (local star-formation rate, local metallicity, etc.). For this analysis we select a sample of almost 200 SNe at redshifts below 0.25, where the efficiency of the survey is high. These supernovae have either been spectroscopically confirmed as SNe Ia or have been identified as SNe Ia by their light-curves and have a spectroscopically measured host-galaxy redshift. Multi-wavelength photometric parameters are obtained for the host galaxies from SDSS Data Release 7. The sample is split in two groups depending on the morphology of the host (spirals or ellipticals). We fit SN Ia light-curves using both SALT2 and MLCS2K2, and determine the following parameters for each SNIa: extinction (A_V), color (c), light-curve width (Δ and x_1), and Hubble-diagram residuals. Then, we correlate these parameters with several definitions of the distance to the center of the host galaxy, either normalized or not, and look for trends in the mean values of these parameters with increasing distance. We do not find any significant correlations at 3σ between light-curve parameters or Hubble residuals, and the GCD. However, we find some hints with lower significance.

SNe Sample

The Sloan Digital Sky Survey-II Supernova Survey has identified and measured light-curves for intermediate redshift ($0.01 < z < 0.45$) type Ia supernovae during the three Fall seasons from 2005 to 2007, using the dedicated SDSS 2.5m telescope at APO. The whole SDSS-II/SNe sample consists of **1293 type Ia SNe, 562 confirmed spectroscopically, and 731 photometrically classified by their light-curves**, and with spectroscopic redshift of the host galaxy measured by SDSS-II or SDSS-III/BOSS.

In this analysis we restricted the sample to redshifts $z < 0.25$ where the detection efficiency of the SDSS-II/SNe survey remains high. In total, this provides a sample of 576 SNe, of which 379 are spectroscopically confirmed and 197 photometrically identified as a type Ia SN.





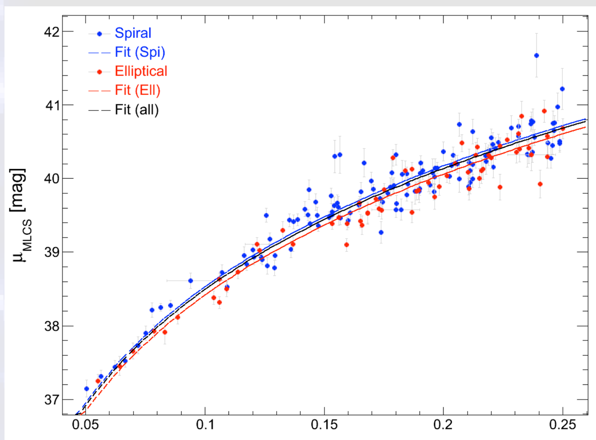
Host matching

We have attempted to match every SN in our sample to **the closest galaxy within an angular separation of 20 arcsec** from the SN using the SDSS Data Release 7 (DR7), which contains imaging of more than 8,000 square degrees of the sky in the five optical bandpasses ugriz.

There are some SNe which could not be associated to any host, so we are left with 560 SNe in our sample, 366 Spect-Ia and 194 Photo-Ia. For the matched galaxies we obtained multi-wavelength photometric parameters needed for the morphology typing and for the measurement of the separation of the SN from the center of the galaxy.

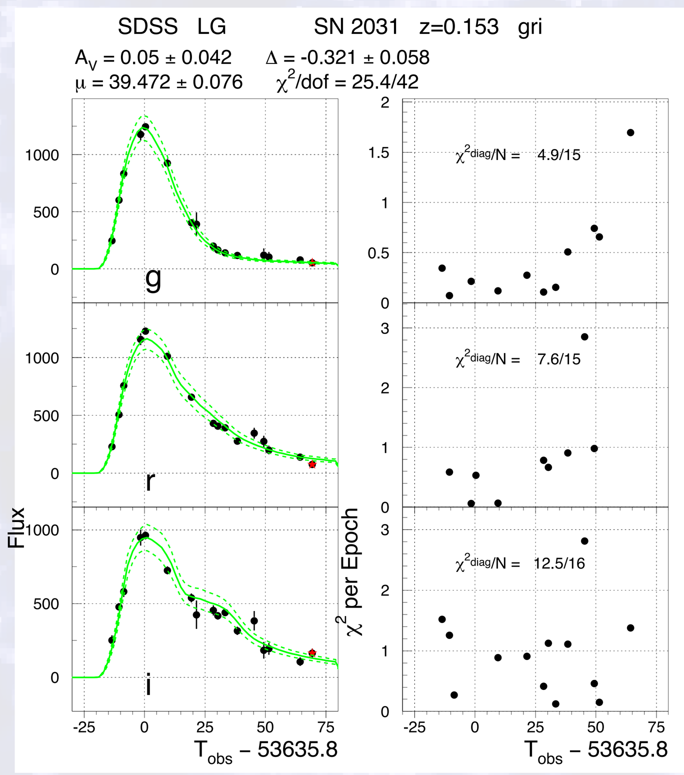
LC fitting

We fit supernova light-curves using the publicly available package SNANA which includes implementations of the **SALT2 and MLCS2k2** light-curve fitters. We used the host galaxy extinction (**A_V**), the width of the light-curve (**Δ**), and distance modulus (μ_{MLCS}) from MLCS2K2 fitter, and the color of the supernova (**c**), the stretch of the light-curve (**x_1**), and the apparent magnitude at maximum brightness in B band (m_B) from SALT2. The **Hubble Resiudals** can be obtained directly from MLCS2K2, and with



$$\mu_{SALT2} = m_B - M + \alpha x_1 - \beta c$$

for SALT2, where we take M as −19.41±0.04, and the values of α and β used are based on the three-year SDSS-II/SNe sample independent of cosmology (α=0.131±0.052 and β=3.26±0.49). We assumed a flat cosmology with Ω_M=0.274=1−Ω_Λ, and we used the value for H_0 which minimizes the scatter of this sample: 64.85 for MLCS2K2, and 60.47 for SALT2.



We apply the following selection cuts:

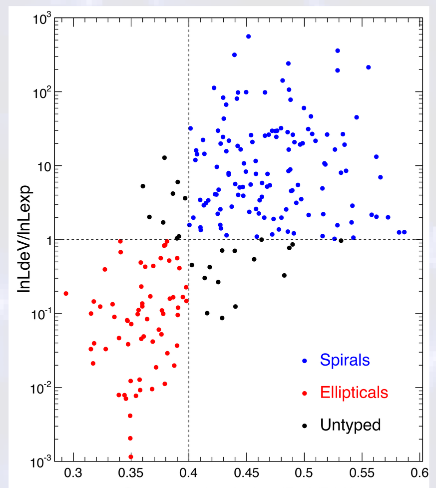
- 5 obs. in -20d < T_{rest} < +70d (+60d for SALT2) rel. to $T_{B,max}$
- At least 1 obs. T_{rest} < -2d (0d) days before $T_{B,max}$
- At least 1 obs. after T_{rest} < +10d (9.5d) days after $T_{B,max}$
- At least 1 obs. with S/N>5 for each of g, r and i bands.
- P_{fit} > 0.001, light-curve fit probability of being a SN-Ia based on the χ^2/N_{dof}

We also removed SNe with extreme values of the light-curve parameters in order to have a pure sample not affected by those peculiar values. The ranges allowed for MLCS2K2 parameters are 0< A_V<1 and Δ>−0.4, while for SALT2 parameters are −0.3<c<0.6 and −4.5<x_1<2.0. Finally, after all the cuts, it remains 310 SNe with values from the MLCS2K2 fitter and 308 SNe with values from SALT2, which we use to correlate the light-curve parameters with the separation to the center of the SN hosts.

	Spec-Ia		Photo-Ia		Total	
	MLCS	SALT2	MLCS	SALT2	MLCS	SALT2
SDSS-II/SNe sample ($z < 0.45$)	562		731		1293	
Redshift $z < 0.25$	379		197		576	
Host in DR7	366		194		560	
Fit from SNANA	254	210	116	113	370	323
LC pars cut	214	205	96	103	310	308
Host typed	160	164	73	82	233	246
Distance cuts	128	132	58	64	186	196

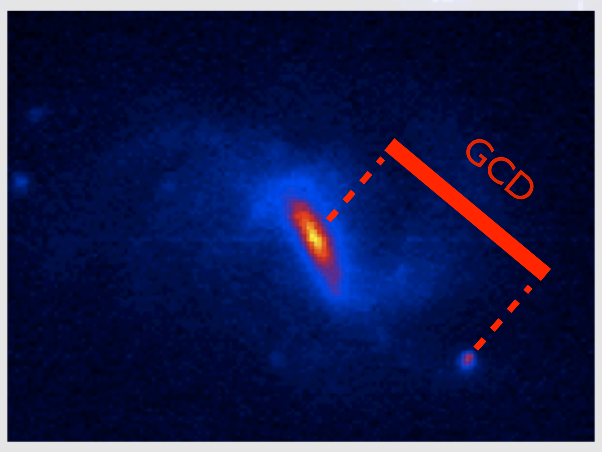
Host typing

We split the SN sample into two groups depending on the morphology of the host (spirals or ellipticals). To do this we consider two photometric parameters: the **inverse concentration index** (CI, ratio between the radii of two circles containing 50% and 90% of the Petrosian flux), and the best likelihood for a fit to a **Sérsic brightness profile** (LH). All galaxies in SDSS Data Release 7 have their brightness profile fitted to the Sérsic pattern:



$$I(r) = I_0 \exp\left[-a_n \left(r/r_e\right)^{1/n}\right] = I_e \exp\left\{-a_n \left[\left(r/r_e\right)^{1/n} - 1\right]\right\}$$

where r_e is the radius which contains half of the luminosity and $I_e = I(r_e)$, the effective intensity at r_e. Two specific patterns are used: a pure exponential profile (n=1, a_1=1.68) and a de Vaucouleurs profile (n=4, a_4=7.67). The exponential profile describes better the decrease in brightness for spiral galaxies, and the de Vaucouleurs profile for ellipticals. We consider that a galaxy has elliptical morphology when it has both an CI<0.4, and the LH_{DEV}>LH_{EXP}. A galaxy is assigned a spiral morphology if the CI<0.4, and LH_{EXP}>LH_{DEV}. When both indicators point to different type, the SN is removed from the analysis. After the typing process the sample is reduced to 233 SNe for MLCS2K2 and 246 for SALT2.



Galactocentric Distance (GCD)

Galaxies have different morphologies and sizes. This is the motivation for using a normalization radius that allow us to compare among them. We can easily measure the angular separation between SN and its host, and calculate the physical distance in kpc using the redshift measured. We then use different normalizations: the **Petrosian 50 radius** (P50); a Sérsic profile: **de Vaucouleurs** (DEV) profile (n=4) for ellipticals, and a **pure exponential** (EXP) profile (n=1) for spirals; and the **isophotal radius** (ISO). All these normalizations are available in SDSS DR7.

It should be clear that all these measurements of the distance are lower limits of the real separation from the center of the host galaxy due to the inclination of the galactic plane with respect to the observer. We therefore refer to these distances as projected GCD.

In some cases the matched host lacks these parameters, or the SN is too far from the center of the matched host. The final sample is composed of 186 SNe for MLCS2K2 and 196 for SALT2.

Method

We correlate four light-curve parameters (A_V, Δ, x_1, c) and the Hubble residuals with different measurements of the distance to the center of the host galaxy (Projected GCD in kpc, and Normalized Projected GCD in P50, DEV, EXP, and ISO). For every combination of LC parameter and measurement of distance, we **bin the SNe in distance** and calculate in each bin: the mean value, the weighted mean, and the median (errors computed with bootstrap). Then we perform a linear fit, and calculate the reduced χ^2, and the significance of the slope. We also look for the same correlations but splitting the sample in only **two bins**, "**Near**" and "**Far**", imposing the same number of SNe in each bin.

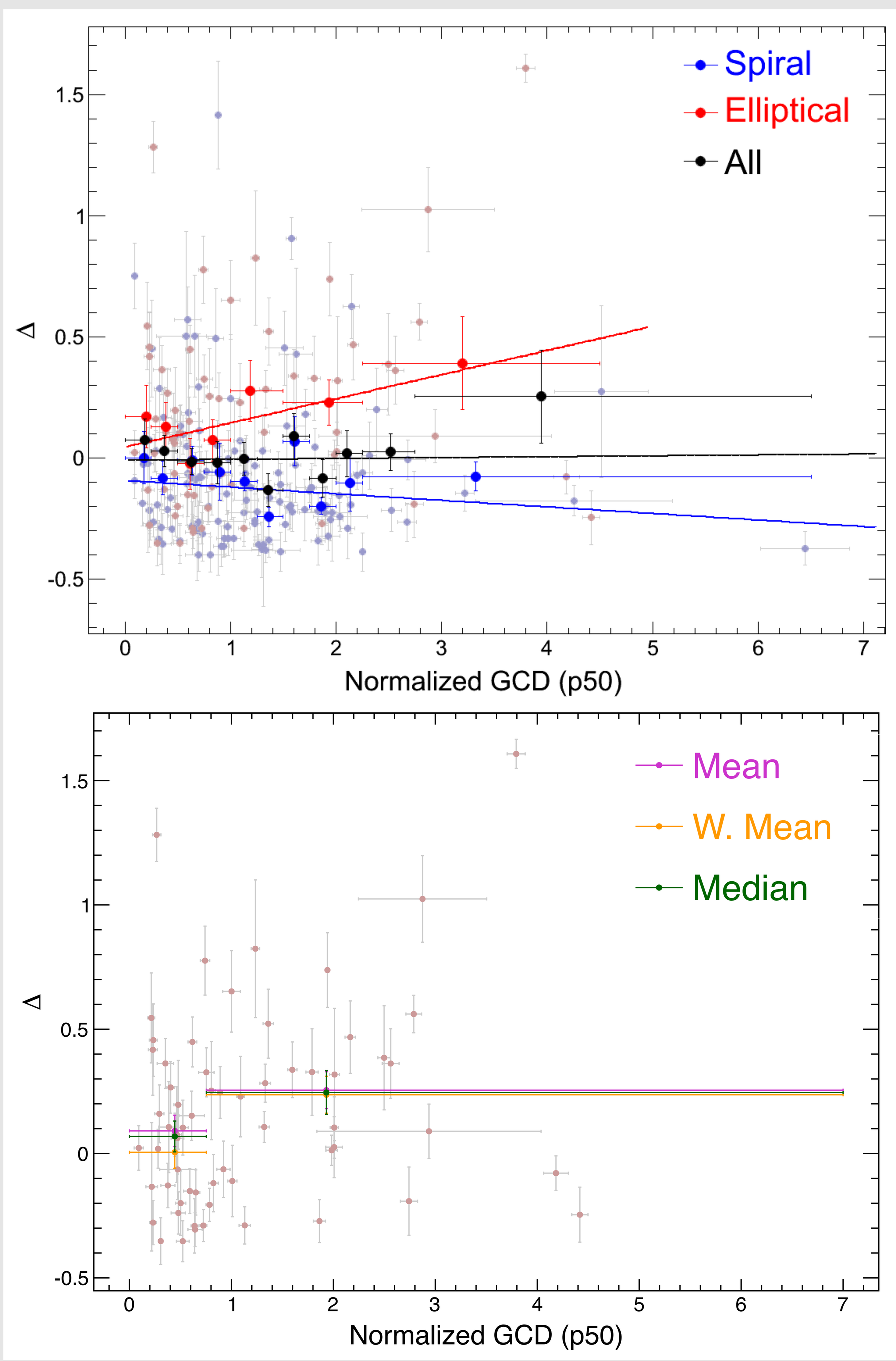
Results

We did not find any significant correlations (>3σ) between light-curve parameters or Hubble residuals, and the GCD. However, we found some hints with low significance (> 2σ).

Correlations with Projected GCD (in kpc):
- Δ parameter in elliptical galaxies increases with the separation from the center of the host galaxy, seen in both methods, linear fit of the mean value in each bin, and splitting the sample in two bins.

Correlations with Normalized Projected GCD:
- Δ increases with distance in elliptical hosts in all normalizations (P50, ISO and DEV). We also see this behavior in 2-bin analysis. In some cases we see an inverse relation in spirals.
- A_V decreases with distance when using the P50 normalization for spirals. We recover the hint in A_V vs P50 for spirals when split the sample in 2 bins.
- We see a negative correlation of x_1 with distance using P50 normalization in ellipticals. This relationship confirms the behavior seen in Δ using the same normalizations.
- When considering the whole sample we also see a positive correlation using ISO normalization. We recover the hint in x_1 vs ISO considering the whole sample when split the sample in 2 bins.
- For SALT2-$\delta\mu$, we found that it increases with the EXP normalized distance in spirals.

The most remarkable result is the significant trend in Δ parameter in elliptical hosts for all normalizations: **Δ increases** for larger distances. We recover the same trend in x_1 for P50 and ISO normalizations. The width of the light-curve is related to the SN brightness (Phillips 1993), so we can extract from this result that the SNe exploding farther from the center, have **narrower** light-curves and tend to be **fainter**.



Parameter	Method	Distance	Type	Result	σ
Δ	Fitted slope	kpc	ELL	0.029±0.011	+2.65
	Far - Near	kpc	ELL	0.175±0.097	+1.80
	Fitted slope	P50	ELL	0.100±0.055	+1.81
	Far - Near	P50	ELL	0.164±0.097	+1.68
	Fitted slope	DEV	ELL	0.126±0.048	+2.64
	Far - Near	DEV	ELL	0.157±0.098	+1.61
	Fitted slope	ISO	ELL	0.881±0.511	+1.72
	Far - Near	ISO	ELL	0.156±0.098	+1.60
A_V	Fitted slope	P50	SPI	-0.032±0.022	-1.47
	Far - Near	P50	SPI	-0.083±0.040	-2.06
x_1	Fitted slope	P50	ELL	-0.277±0.105	-2.15
	Fitted slope	ISO	ELL+SPI	0.826±0.445	+1.86
	Far - Near	ISO	ELL+SPI	0.305±0.151	+2.02
$\delta\mu_{SALT2}$	Fitted slope	EXP	SPI	0.030±0.014	+2.19