Using distance to correlate SNe properties to their environment

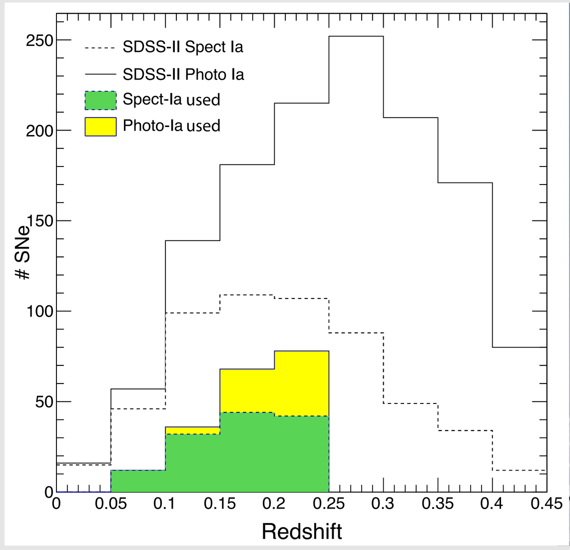
Lluís Galbany, CENTRA-IST Lisbon

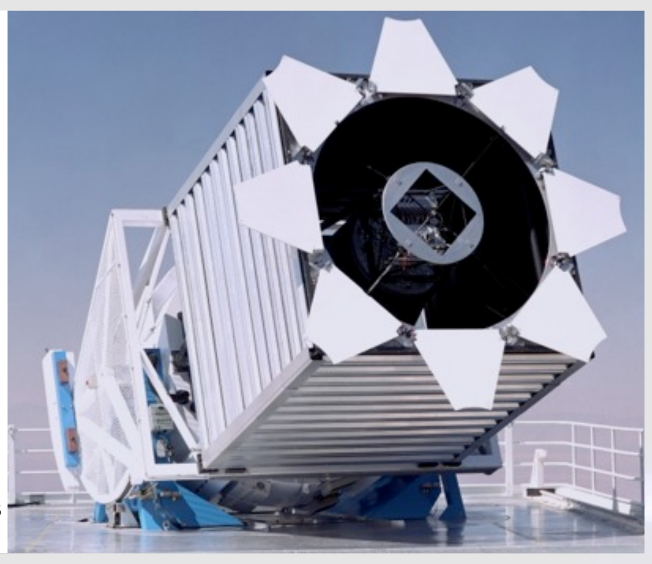
We use Type Ia supernovae (SNe Ia) discovered by the Sloan Digital Sky Survey-II SN Survey to search for dependencies between SN Ia properties and the projected distance to the host-galaxy center, using the distance as a proxy for local galaxy properties (local star formation rate, local metallicity, etc.). The sample consists of almost 200 spectroscopically or photometrically confirmed SNe Ia at redshifts below 0.25. The sample is split into two groups depending on the morphology of the host galaxy. We fit light curves using both MLCS2k2 and SALT2, and determine color (A_V, c) and light-curve shape (Δ, x_1) parameters for each SN Ia, as well as its residual in the Hubble diagram. We then correlate these parameters with both the physical and the normalized distances to the center of the host galaxy and look for trends in the mean values and scatters of these parameters with increasing distance. The most significant (at the 4σ level) finding is that the average fitted A_V from MLCS2k2 and c from SALT2 decrease with the projected distance for SNe Ia in spiral galaxies. We also find indications that supernovae (SNe) in elliptical galaxies tend to have narrower light curves if they explode at larger distances, although this may be due to selection effects in our sample. We do not find strong correlations between the residuals of the distance moduli with respect to the Hubble flow and the galactocentric distances, which indicates a limited correlation between SN magnitudes after standardization and local host metallicity.

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 **1318 type Ia SNe, 559 confirmed spectroscopically, and 759 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 (~95%). In total, this provides a sample of 608 SNe, of which 376 are spectroscopically confirmed and 232 photometrically identified as a type Ia SN.



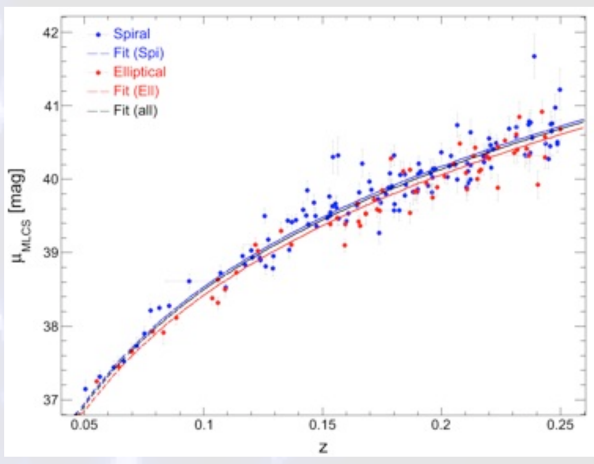


Host matching

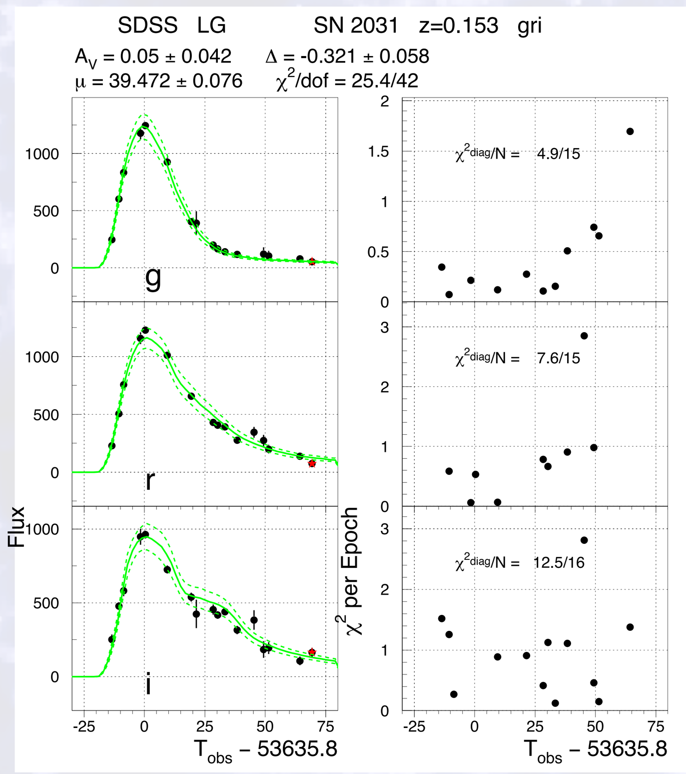
We have matched every SN in our sample to **the closest galaxy within an angular separation of 20 arcsec** from the SN using the SDSS Data Release 7 (DR7), which contains imaging of more than 8,000 square degrees of the sky in the five optical bandpasses *ugriz*. There are some SNe (17) which could not be associated to any host, so we are left with 591 SNe in our sample, 363 Spect-Ia and 228 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 Resiuals** 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 mag, 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 $\Omega_M=0.274=1-\Omega_\Lambda$, and we used the value for H_0 which minimizes the scatter of this sample: 64.9 km s^{-1} Mpc^{-1} for MLCS2K2, and 60.5 km s^{-1} Mpc^{-1} for SALT2.

We apply the following selection cuts in the LC fit:

- 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}

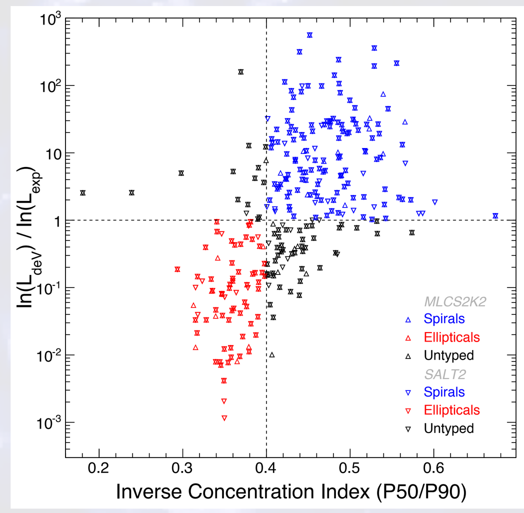
We also removed SNe with extreme values of the light-curve parameters in order to have a pure sample not affected by those peculiar values. For MLCS2K2 we restrict the sample to Δ>−0.4, while for SALT2 the allowed ranges are set to −0.3<c<0.6 and −4.5<x_1<2.0. Finally, after all the cuts, it remains 313 SNe with values from the MLCS2K2 fitter and 320 SNe with values from SALT2, which we use to correlate the light-curve parameters with the separation to the center of the SN hosts.

Summary of the remaining SNe after each cut

	Spec-Ia MLCS	Spec-Ia SALT2	Photo-Ia MLCS	Photo-Ia SALT2	Total MLCS	Total SALT2
SN Ia sample ($z < 0.45$)	559		759		1318	
Redshift < 0.25	376		232		608	
Identified host galaxy	363		228		591	
LC quality cuts	228	217	115	125	343	342
LC parameter cuts	203	209	110	111	313	320
Determined host type	160	164	79	82	239	246
Distance cuts	127	131	63	64	190	195

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:



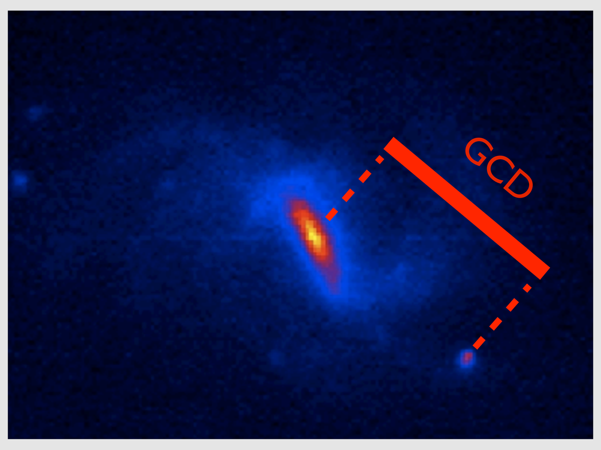
$$I(r) = I_0 \exp\left[-a_n (r/r_e)^{1/n}\right] = I_e \exp\left\{-a_n\left[(r/r_e)^{1/n} - 1\right]\right\}$$

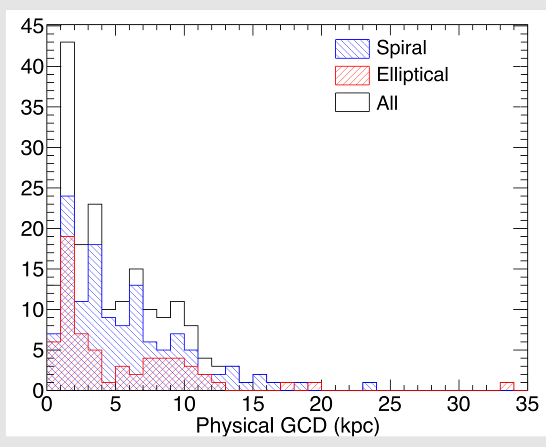
where r_e is the radius which contains half of the luminosity and $I_e = I(r_e)$, the effective intensity at r_e. Two specific patterns are used: a pure exponential profile (n=1, a_1=1.68) and a de Vaucouleurs profile (n=4, a_4=7.67). The exponential profile describes better the decrease in brightness 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 239 SNe for MLCS2K2 and 246 for SALT2.

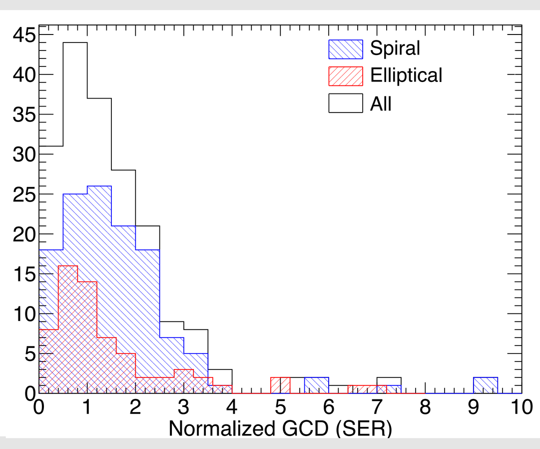
Galactocentric Distance (GCD)

Galaxies vary in morphology and size, thus it makes sense to normalize the SN–galaxy separation in order to be able to compare the LC parameters for SNe in the entire sample. We measured the angular separation between SN and its host, and calculated the physical distance in kpc using the redshift measured. We then used the normalization derived from the shape of the galaxy described by a Sérsic profile ellipse, distinguishing between elliptical galaxies fitted with a **de Vaucouleurs** profile (DEV, n=4), and spiral galaxies fitted with a **pure exponential** profile (EXP, n=1). 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 190 SNe for MLCS2K2 and 195 for SALT2.







Method

We examined correlations for the complete sample, as well as when dividing the sample according to host-galaxy morphology (spiral and elliptical). We correlated four light-curve parameters (A_V, Δ, x_1, c) and the Hubble residuals with two different measurements of the distance to the center of the host galaxy (physical projected GCD in kpc, and Normalized projected GCD in units of Sérsic radius (DEV/EXP). For every combination of LC parameter and distance measurement, we **binned the SNe in distance** (0.5 kpc for the physical GCD, and 0.25 for the normalized GCD) and calculated the mean value in the bin, both for the LC parameter and the distance. When a bin contained less than five SNe, this bin was joined with the next one until there were at least five SNe in the bin. Then, the uncertainty in the mean LC parameter was calculated as the RMS in the bin divided by the square root of the number of SNe in the bin, while the uncertainty in the distance was taken as the width of the bin. Finally, we performed a linear fit, and calculated the reduced χ^2, and the significance of the slope. We also looked for the same correlations but splitting the sample in only **two bins**, "**Near**" and "**Far**", imposing the same number of SNe in each bin, in order to cross-check the results found with the previous method.

Results

- We find some indications (~2σ) that **SNe in elliptical galaxies tend to have narrower LC** (larger Δ, fainter SNe) if they explode farther from the galaxy core.

  This could be explained by the difficulty to detect faint SNe close to the galaxy center, where the galaxy light is stronger (*selection effect*).

- We find strong indications (~4σ) of a **decrease in color with distance**.

  If most of the variability in color is due to dust, and dust is expected to decrease with distance from the center, this would be expected.

  Due to the difficulty to observe faint SNe close to the galaxy center, we would expect fewer dust extincted SNe (with high A_V) at small distances. However, this is opposite of what we find, so maybe the *selection effect* is not too large.

- We do not find **any correlation between the Hubble residuals and the GCD**.

  Since GCD can be used as a proxy for the local metallicity, this can be seen as an indication of a limited correlation between Hubble residuals and local metallicity.

  This does not confirm a recent result (*D'Andrea et al., 2012, ApJ, 743, 172*), which finds a correlation between Hubble residuals and global metallicity.