A detailed study of the nearby type Ia supernova SN2008Q

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Abstract

Aims. In this work the study of the optical, near-infrared (NIR) and spectroscopic properties of the type Ia supernova (SN Ia) SN2008Q is presented.

Methods. A set of optical, NIR and low-resolution long slit spectra was obtained using a number of facilities. The observations started nine days before the maximum and ended 24 days after the maximum light. The optical photometry was corrected with the S-correction technique.

Results. The $UBVRIJHK$ light curves and the colour indexes for SN2008Q show a good concordance with those from normal SNeIa. SN2008Q peaked with $B_{max} = 13.477$mag at JD= 2454505.88. The light curve fits show that SN2008Q has stretch $s = 0.859$ and $\Delta m_{15} = 1.30$ suggesting that SN2008Q is photometrically normal. The SN2008Q photometry derived in this work was compared with the photometry from other authors and its consistency was confirmed. The observed blue $B - V$ colour of SN2008Q at maximum $B - V \simeq 0.01$ and the absence of interstellar NaI absorption lines at the redshift of the host galaxy indicates that SN2008Q likely did not suffer from dust reddening in its host galaxy. At $t_{B_{max}}$, $\Re$(Si), SiIIλ6355Å velocity and the pseudo equivalent width of the SiIIλ5972Å and SiIIλ6355Å lines were 0.32, -11462km s^{-1}, 93.8Å and 21.9Å, respectively. This values are concordant with the ones from typical SNeIa.

Keywords: stars: supernovae: general; stars: supernovae: individual: SN 2008Q; methods: observational; techniques: photometric; techniques: spectroscopic

1 Introduction

A Supernova (SN) is an astronomical class of events where a star explodes emitting an enormous amount of energy, making this events as bright as their host galaxy. The SNe which present hydrogen in their spectra are classified as type II and the others are classified as type I (see for instance Turatto et al. (2007)). Encompassed in type I, we have the type Ia supernovæ (SNeIa), which are differentiated from the other type I due to the presence of SiII in their spectra. SNeIa are of particular importance to cosmology since their high intrinsic luminosity ($M_V \approx -19.2mag$) and their relatively homogeneous proprieties makes them a very powerful tool in the determination of cosmological distances (Branch and Tammann (1992)).

Evidences suggest that SNeIa originate from degenerate stars called white dwarves. This star, through a process of mass accretion from a main-sequence companion star or through the merger with another white dwarf, reaches a mass, close to Chandrasekhar's mass $\approx 1.4 M_\odot$, which is high enough to start a thermonuclear reaction that will make the star explode (Hillebrandt and Niemeyer (2000)).

Due to the very high opacity of the white dwarf, the observed light curves are not powered by the energy of the explosion itself, but by the radioactive decay of one of its by-products ^{56}Ni and its daughter nuclides (Arnett (1982)). This makes the main responsible for the light curves absolute magnitudes and their scatter the total ^{56}Ni mass produced during the explosion. SNeIa's lightcurves have shown to have an empirical correlation between their peak luminosity and the decline rate after maximum: the brightest supernovæ have the slowest decline rates and vice-versa (Phillips (1993)). Despite this strong correlation, peculiar subluminous events similar to SN1991bg, SN2002cx or SN2005E and superluminous similar to SN1991T have been found.

In terms of spectra SNeIa present very distinctive indicators that include the absence of hydrogen and helium absorption lines, and the strong absorption line near 6100Å due to the doublet of singly ionized silicon with wavelengths of $\lambda\lambda$6347Å and 6371Å. Other characteristic lines near maximum light have been identified (e.g. Leibundgut (2000)). Variations also appear within SNeIa's spectra which leaded to the creation of several sub-classifications like the ones from Branch et al. (2006) which divides SNeIa into four sub-groups according to the pseudo-equivalent-widths (pEW, Folatelli (2004)) SiIIλ5972Å SiIIλ6355Å at B_{max} and Wang et al. (2009) that uses the SiIIλ6355Å line velocity to distinguish between Normal or High-velocity SNeIa.

In this work the analysis of the observations of the nearby SN2008Q discovered in the vicinity of S0-a galaxy NGC524 by Giancarlo Cortini in January 26th (Villi et al. (2008)) and later confirmed by Vallery Stanishev as a type Ia supernova (Stanishev and Pursimo (2008)) is presented.

This supernova was observed in the optical in the NOT (La Palma), Asiago (Mount Ekar) telescopes and by two amateur astronomers J. M. Llapasset and Joel Nicolas. Spectroscopy was obtained in the two aforementioned telescopes plus the TNG (La Palma). NIR JHK observations were also performed with the REM telescope (La Silla, Chile).

2 Observations and data reduction

2.1 Optical photometry

Due to the time of the year and the position of the galaxy it was only possible to obtain data from 31/01/2008 until 03/03/2008 since after this the object got behind the Sun rendering any further observation close to the time of maximum impossible.

Images in the UBVRI were obtained in NOT (ALFOSC and MOSCA) and Asiago (AFOSC) and in BVRI in the two small amateur telescopes . Along with the observations of the supernova, standard field stars from Landolt (1992) were also observed in order to derive the telescopes' colour terms using the transformation equations:

$$U_{std} = u_{inst} + u_0 + u_1(U-B)_{std} + u_2X + u_3X(U-B)_{std} \quad (1)$$
$$B_{std} = b_{inst} + b_0 + b_1(B-V)_{std} + b_2X + b_3X(B-V)_{std} \quad (2)$$
$$V_{std} = v_{inst} + v_0 + v_1(B-V)_{std} + v_2X \quad (3)$$
$$R_{std} = r_{inst} + r_0 + r_1(V-R)_{std} + r_2X \quad (4)$$
$$I_{std} = i_{inst} + i_0 + i_1(V-I)_{std} + i_2X \quad (5)$$

where Y_{std} is the standard magnitude in the Y filter, y_{inst} is the instrumental magnitude in the Y filter y_0 is the zero point, y_1 is the colour term of the instrument used, y_2 is the first order extinction, y_3 is the second order extinction, X is the airmass and y=U,B,V,R,I.

The CCD images were bias and flat-field corrected and cosmic-rays were identified and removed using the algorithm from van Dokkum (2001).

The supernova is distant enough from the galaxy for its background contamination to be considered negligible. Because of this there was no need to subtract the galaxy, and aperture photometry with aperture size of 2FWHM of the stellar profile was used to perform all the measurements needed. The SN magnitudes were measured differentially with respect to the field stars identified in figure 1 already measured by Candia et al. (2003).

For each image, the zero-point was computed for each of the field stars using transformation equa-

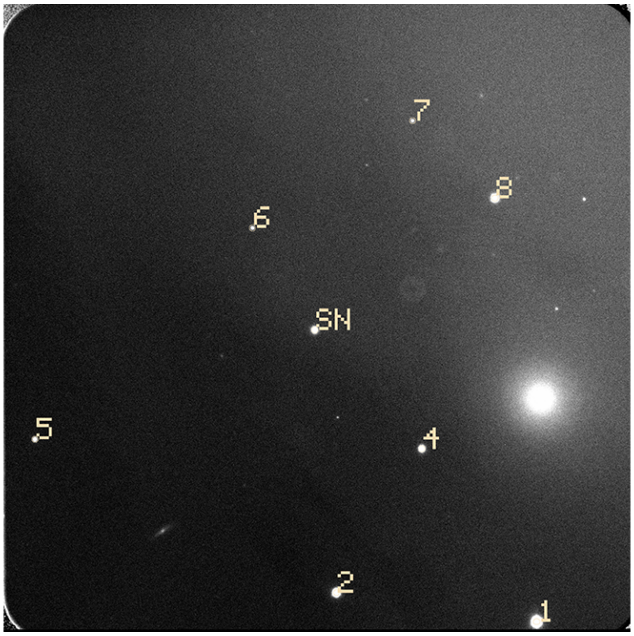

Figure 1: SN 2008Q Finding chart

tions. These individual zero-points were averaged with points that deviate more than 3σ or have error bigger than 0.030 mag removed. The error of the averaged zero-points is the standard-deviation of the post-clipped values. Using these averaged zero-points the magnitudes of the supernova in the natural systems of the telescopes X were computed:

$$m_X^{nat} = m_X^{insrx} + zp_X. \quad (6)$$

The natural magnitudes were converted to the standard $UBVRI$ system by the S-correction Stanishev et al. (2007) since the transformation above referred does not work well when applied to SNIa since their spectra is very different from the stellar spectra from the field stars. The system responses of each of the telescopes were computed and provided by V. Stanishev. For computing the S-correction the spectra of SN 2008Q also provided by V.Stanishev were used.

2.2 Spectroscopy and JHK

In addition to the optical photometry, optical spectroscopy (using the same telescopes plus TNG in La Palma) and NIR JHK photometry with the REM telescope in La Silla (Chile) were also obtained. These data were reduced and provided by V.Stanishev to be included in the analysis.

The spectral observations were reduced following the algorithm described in Horne (1986). Efforts were done to minimize the differential losses due the presence of atmosphere and the consequent differential atmospheric losses (Filippenko (1982)). Despite these efforts some minor corrections were done to match the observed photometry, as the relative flux calibration was not always sufficiently accurate. This process is described in detail in Stanishev et al. (2014). The NIR images were pre-processed in the standard way for NIR imaging. The SN magnitudes were calibrated with stars measured by 2MASS survey.

The pseudo equivalent widths for the SiII λ5972Å and λ6355Å lines and the ratio between the fractional depth of the bluer line with the redder one ($\Re$(Si)) were determined using a combination of the methods described in Nugent et al. (1995) and Folatelli (2004): we fit a pseudo-continuum through the two maxima that encompass a particular feature, in our case one of the SII valleys, and determine the corresponding equivalent width and fractional depth of that feature. The blueshifts of the absorption-line minima of Siλ6355Å were measured by fitting a Gaussian to the line absorption troughs. These blueshifts are refereed as the velocities of the Siλ6355Å line and are by convention negative.

3 Results and discussion

3.1 Light curves

In figure 2 the light curves of SN 2008Q are presented. These light curves are typical for a normal SN Ia presenting the characteristic shoulder in R band and the second maximum in the redder bands. SN 2008Q had its maximum in the B filter at JD= 2454505.88 with $B_{max} = 13.477$mag. In order to determine the main light curve parameters of SN 2008Q, the light curves were fitted using the stretch approach with a program written by Stani-

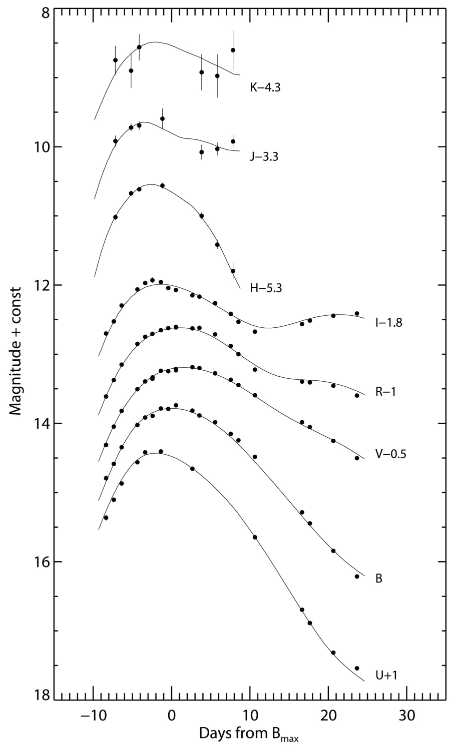

Figure 2: UBVRIJHK light curve of SN 2008Q along with the best fits.

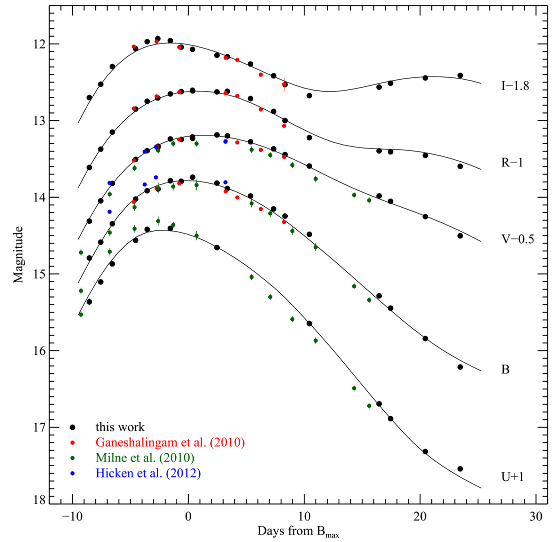

Figure 3: Comparison of the results for 2008Q (in black) against the values obtained by Ganeshalingam et al. (2010) (in green), Milne et al. (2010) (in red) and Hicken et al. (2012)(in blue)

shev et al. (2014) that employs Hsiao et al. (2007) $UBVRI$ template light curves. In the NIR templates derived by V. Stanishev a large number of NIR observations of SNeIa are used. The derived peak magnitudes were then corrected for the Milky Way dust extinction based on the extinctions determined by Schlegel et al. (1998) and recalculated by Schlafly and Finkbeiner (2011) taken from NED (http://ned.ipac.caltech.edu).

The best fit are obtained for stretch $s = 0.84$, which as one can see describes the light curves quite well even though, the stretch approach usually does not perform well for the R and I bands. The derived stretch of 0.84 corresponds to $\Delta m_{15} = 1.3$, which is slightly lower than a typical SNIa, but still well in the range observed in normal SNeIa.

Observations of SN 2008Q were performed by other groups and are compared in Figure 3. Before maximum the light curve obtained by Ganeshalingam et al. (2011) closely resembles the one derived here in the BVR and for the I band there is a good agreement over the whole light curve. After maximum the BVR bands seem to be almost systematically dimmer than the results derived in this work. This difference appears not to originate from the field stars, since for the five stars common to the ones used here the average difference is only of up to 0.02 mag. This and the fact that the difference is not constant throughout the observations suggests that the deviations come from differences in the calibration processes. The observations of Milne et al. (2010) were performed with the telescope UVOT onboard the SWIFT satellite using a non-standard set of ubv filters. Even though these filters are not very far from the standard and deliver light curves with a similar shape to the ones derived here, the systematic differences between the two data sets are evident. Compared with the photometry performed by Hicken et al. (2012), a striking systematic difference in the B band is evident, and no explanation could be found. The V band on the other end is well behaved, very similar to the measurements presented in this work.

In the NIR range, the template JHK light curves derived from observations of other normal SNeIa describe the observations of SN 2008Q (Figure 2) very well.

3.1.1 Colour indexes evolution

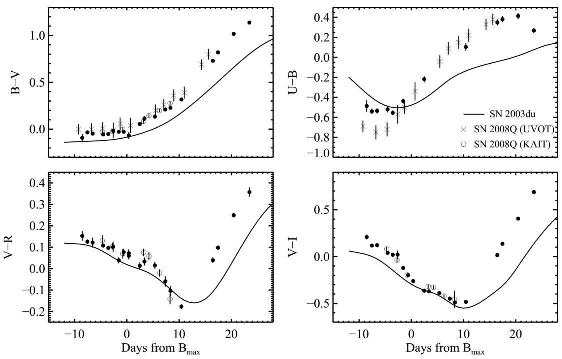

Figure 4: Comparison of the Milky Way extinction corrected optical colour indices of SN 2008Q and the photometry performed by Ganeshalingam et al. (2010) and Milne et al. (2010) with a loci from the normal SNI2003du Stanishev et al. (2007).

In figure 4 a comparison of the observations of SN2008Q with a loci derived from the observations of the normal SN 2003du (Stanishev et al. (2007)) is presented. Apart from the $U-B$, SN 2008Q is slightly redder than SN 2003du before B_{max} and after that it evolves much faster to red. This is expected since SN 2008Q has a lower stretch than SN 2003du. Milne et al. (2010) found that SN 2008Q belongs to a small group of objects with UVOT $u-b$ colour indexes (CI) bluer by 0.5 mag than most other SNe. The observations presented here do show a $U-B$ colour index that is bluer than than the normal SN 2003du, but redder than the ones from Milne. The difference between Milne's CI and the one derived in this work is probably due to the different filters and the fact that the UV brightness of the SN might cause S-corrections not to be accurate in the U band leading to an underestimation of its magnitude. Despite the differences in photometry discussed in the previous section, the colour indexes from Ganeshalingam et al. (2010) are in good agreement with the ones derived here.

A comparison of the data for SN 2008Q presented in this work with a database of light curves of normal supernovæ in the Johnson-Cousins $BVRI$ standard system was performed and it the closest match in all the CI was found to be SN 2002ha and SN 2002he. The other supernovæ presented significant differences in at least one of the colour indexes (see Figure 5).

The $B-V$ colour of SNeIa at B_{max} can be used to estimate the dust reddening in the SN host galaxy. Dust along the line of sight both dims and reddens the SN light. Thus, dust is one of the factors that can seriously affect the cosmological use of SNeIa to study the expansion history of the Universe. A pristine, un-reddened SNIa with $\Delta m_{15} = 1.3$ should have maximum $B-V$ colour around zero. The observations of SN 2008Q show that at maximum its $B-V \simeq 0.01$, indicating that it is likely that SN 2008Q did not suffer from dust reddening in its host galaxy. This conclusion is also supported by analysis of the single high-resolution Echelle spectrum which was obtained with FIES spectrograph at NOT. The inspection of the Echelle spectrum revealed that no interstellar NaI lines were present at the redshfit of the host galaxy. The presence of these lines is almost always associated with interstellar dust and there is a correlation between the reddening and the equivalent width of the NaI lines (Munari and Zwitter (1997)). An upper limit for the equivalent width of the NaI line was set at EW$\simeq$ 0.04Å, corresponding to an upper limit of ~ 0.04 mag dust extinction in the B band.

3.1.2 Spectra

Figure 6 shows the spectral sequence of SN 2008Q. The spectra closely resemble those of the core normal SNIa class. This can be better seen in Figure 7, where the spectra of SN 2008Q are compared to other normal SNeIa at three selected epochs. The spectra are dominated by intermediate mass elements, which is typical for the normal SNe. FeIII and NiIII lines, which are observed in the superluminous SNeIa at these epochs, are weak and no TiII

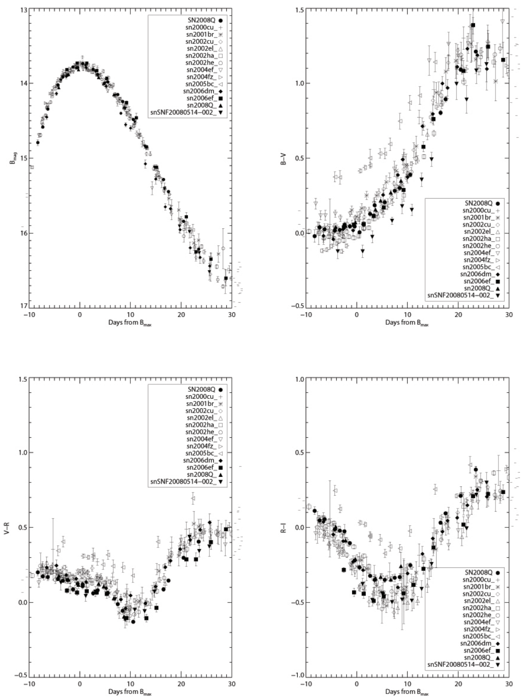

Figure 5: Comparison of SN 2008Q with lightcurves with a similar Δm_{15}

lines typical for the subluminous 1991bg-like SNe are detected. Furthermore, the line widths are not too broad or narrow, so SN 2008Q is clearly not 2002cx-like or broad-line normal SNIa. In the following sections quantitative measurements on the spectra are performed to further demonstrate this point by comparing them with a large number of SNeIa from different sub-classes.

3.1.3 Si λ5972Å and λ6355Å lines

The pseudo-equivalend widths (pEW) of the SiIIλ5972Å and SiIIλ6355Å and the $\Re$(SiII) parameter were determined using the methods discribed in Nugent et al. (1995) and Folatelli (2004). Both the $\Re$(Si) and the ratio between the SiIIλ5972Å and SiIIλ6355Å pEWs showed to remain approximately constant before the maximum in the B filter.

In figure 8 the pEW of SiIIλ5972Å *vs.* SiIIλ6355Å at B_{max} is plotted with the data from Blondin et al. (2012). In this diagram the four Branch sub-classes (Branch et al. (2006)) occupy different regions. As one can see, SN 2008Q lies in the middle of the core-normal sub-class thus confirming its classification.

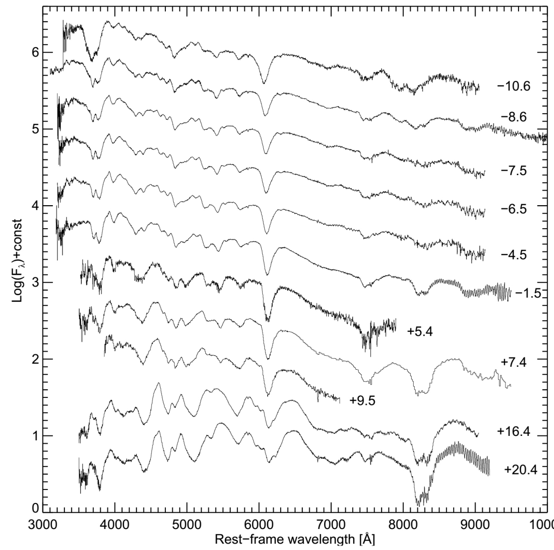

Figure 6: Spectral evolution of the SN 2008Q, from: Stanishev et al. (2014)

3.1.4 SII velocity

The velocities of the SiIIλ6355Å line were measured by fitting a Gaussian to the line absorption troughs. In figure 10 the velocity evolution of SN 2008Q is plotted along other normal SNIa. As it can be observed, the SN 2008Q has a similar SiIIλ6355Å velocity evolution to the normal SNeIa, starting at $\approx -13500\mathrm{km\,s^{-1}}$ at phase≈ -10 days and declining until it reaches $t_{B_{max}}$ at $\approx -113002\mathrm{km\,s^{-1}}$. After B_{max}, the velocity decreases slowly, which is typical for the normal SNeIa (e.g. Benetti and Cappellaro (2005)).

In figure 9 the line velocity for SiIIλ6355Å at $t_{B_{max}}$ is ploted versus the pEW of the same line of SN 2008Q and the sample from Blondin et al. (2012). Again, SN 2008Q falls well into the middle of the spectroscopically normal SNIa as defined by Wang et al. (2009).

In conclusion, all spectroscopic indicators point to the fact that SN 2008Q was a core-normal SNeIa.

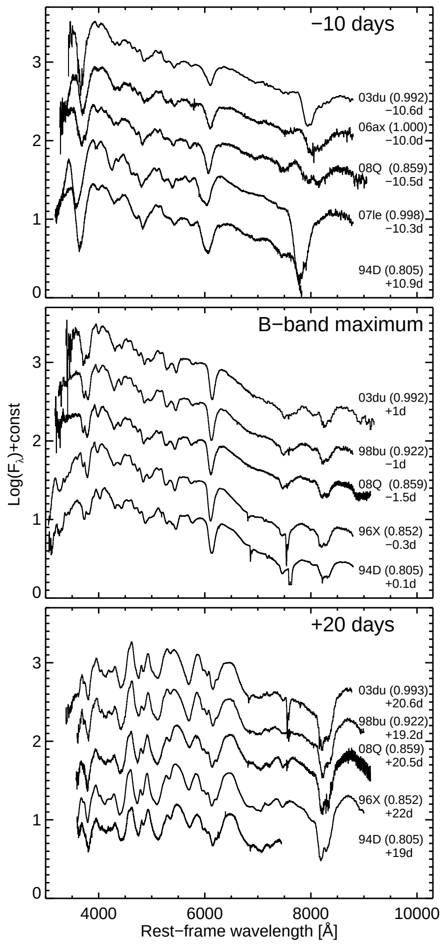

Figure 7: Comparison of spectra of SN 2008Q with other normal SNeIa at three selected epochs. From: Stanishev et al. (2014)

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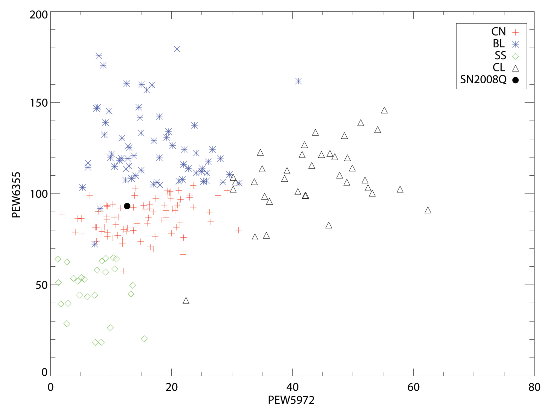

Figure 8: Comparison of the pseudo-equivalent width of the SiIIλ6355Å and SiIIλ5972Å with the core-normal (CN), broad-line (BL), shallow silicon(SS) and cool (CL) SNeIa from Blondin et al. (2012)

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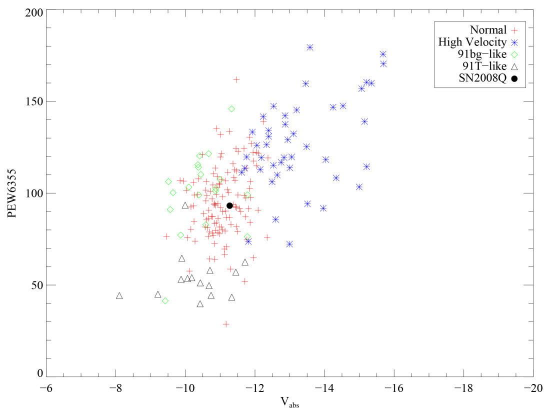

Figure 9: Comparison of the line velocity with the pseudo-equivalent width of the SiIIλ6355Å line with the data sample from Blondin et al. (2012)

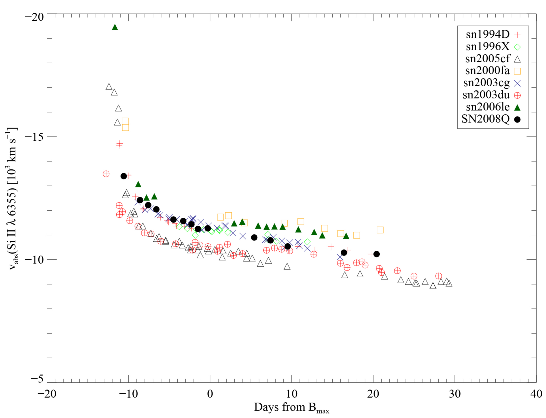

Figure 10: Time evolution of the line velocity of the SiIIλ6355Å . Over plotted are several line velocities of normal SNIa.

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