Monthly Notices of the Royal Astronomical Society LETTERS

Mon. Not. R. Astron. Soc. **415,** L81–L84 (2011) doi:10.1111/j.1745-3933.2011.01084.x

Low-resolution sodium D absorption is a bad proxy for extinction

Dovi Poznanski,[1,2]★† Mohan Ganeshalingam,[2] Jeffrey M. Silverman[2] and Alexei V. Filippenko[2]

[1] *Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Berkeley, CA 94720, USA*
[2] *Department of Astronomy, University of California, Berkeley, CA 94720-3411, USA*

Accepted 2011 May 24. Received 2011 May 23; in original form 2011 April 11

ABSTRACT

Dust extinction is generally the least tractable systematic uncertainty in astronomy, and particularly in supernova science. Often in the past, studies have used the equivalent width of Na I D absorption measured from low-resolution spectra as proxies for extinction, based on tentative correlations that were drawn from limited data sets. We show here, based on 443 low-resolution spectra of 172 Type Ia supernovae for which we have measured the dust extinction as well as the equivalent width of Na I D, that the two barely correlate. We briefly examine the causes for this large scatter that effectively prevents one from inferring extinction using this method.

Key words: supernovae: general – dust, extinction – galaxies: ISM.

1 INTRODUCTION

The ubiquity of dust in galactic environments, most notably in star-forming regions where many supernovae (SNe) explode, makes extinction correction one of the most pervasive and probably the least tractable systematic uncertainty in the study of SNe. When an object's intrinsic colours are unknown, as occurs frequently with rare and new classes, one is bound to look for indirect measurements of the amount of extinction and reddening that need to be taken into account.

The absorption doublet of sodium Na I D, at 5890 and 5896 Å, is a well-known tracer of gas, and its strength is generally expected to indicate the amount of dust along the line of sight. Ferlet, Vidal-Madjar & Gry (1985), for example, show that the column densities of Na I D correlate with those of hydrogen in the diffuse interstellar medium. However, line saturation often makes density estimations arduous (e.g. Mugglestone & O'Mara 1965). Variations in dust-to-gas ratios in different galaxy types (see, for example, Issa, MacLaren & Wolfendale 1990; Lisenfeld & Ferrara 1998) make the jump from sodium to dust somewhat more uncertain. Depletion of metals on dust grains (e.g. Savage & Mathis 1979) further complicates the picture. It would therefore be quite surprising to find a tight correlation between the strength of sodium absorption and dust extinction.

Richmond et al. (1994) have shown, using 57 high-resolution stellar spectra compiled from the literature, that the equivalent width (hereafter EW) of the individual components of Na I D does indeed correlate with the colour excesses measured for these stars, with a noticeable scatter. Munari & Zwitter (1997) add a body of 32 stars observed with a somewhat lower resolution ($R \approx 16\,500$ versus $R \approx 60\,000$–$600\,000$); they constrain the non-linearity of the relation, extensively discuss its pitfalls (such as when there are multiple absorption components, or when the extinction is higher than $E(B-V) \approx 0.4$ mag), and find that the precision is limited to about $\delta E(B-V) \approx 0.05$–$0.15$ mag. They also show how at EW > 0.5 Å the Na I D_1 line saturates and the relation flattens.

Type Ia SNe – understood to be the result of the thermonuclear disruption of a white dwarf (see, for example, Hillebrandt & Niemeyer 2000 for a review) – are very effective distance indicators through 'standardization' of their light curves; they were used to discover the accelerating expansion of the Universe (Riess et al. 1998; Perlmutter et al. 1999) and to accurately measure the Hubble constant (Riess et al. 2011, and references therein). Since their luminosity is found to correlate well with their light-curve shape (Phillips 1993), various methods fit those light curves to templates in order to extract a distance (e.g. Riess et al. 1999; Guy et al. 2005; Conley et al. 2008). In the process, dust extinction – effectively a nuisance parameter – is treated in various ways, either fit separately or as part of a more generic colour dispersion term.

Barbon et al. (1990) and Turatto, Benetti & Cappellaro (2003) used this property of SNe Ia to compare the EW of Na I D measured in low- to medium-resolution spectra to the extinction they derived from light-curve fitting. This would extend the method to the significantly more common occurrence, when one does not have high-resolution spectra and the doublet is blended. Using few spectra in each case (6 and ∼30, respectively), they derived tentative scaling relations which have been widely used in the literature over the last two decades. However, as we show below through a similar analysis of a much larger sample [and as shown by Blondin et al. (2009) using 31 SNe], these relations are of little predictive power. While a correlation indeed exists between extinction and the EW of Na I D, the very large scatter makes it essentially useless when only low-resolution measurements are available.[1]

★E-mail: dovi@berkeley.edu
†Einstein Fellow.

[1] See also a similar discussion by N. Elias de la Rosa at http://online.kitp.ucsb.edu/online/snovae07/eliasdelarosa/ and Elias-Rosa (2007).

© 2011 The Authors
Monthly Notices of the Royal Astronomical Society © 2011 RAS

Downloaded from https://academic.oup.com/mnrasl/article-abstract/415/1/L81/965276 by University of Southampton user on 22 May 2019

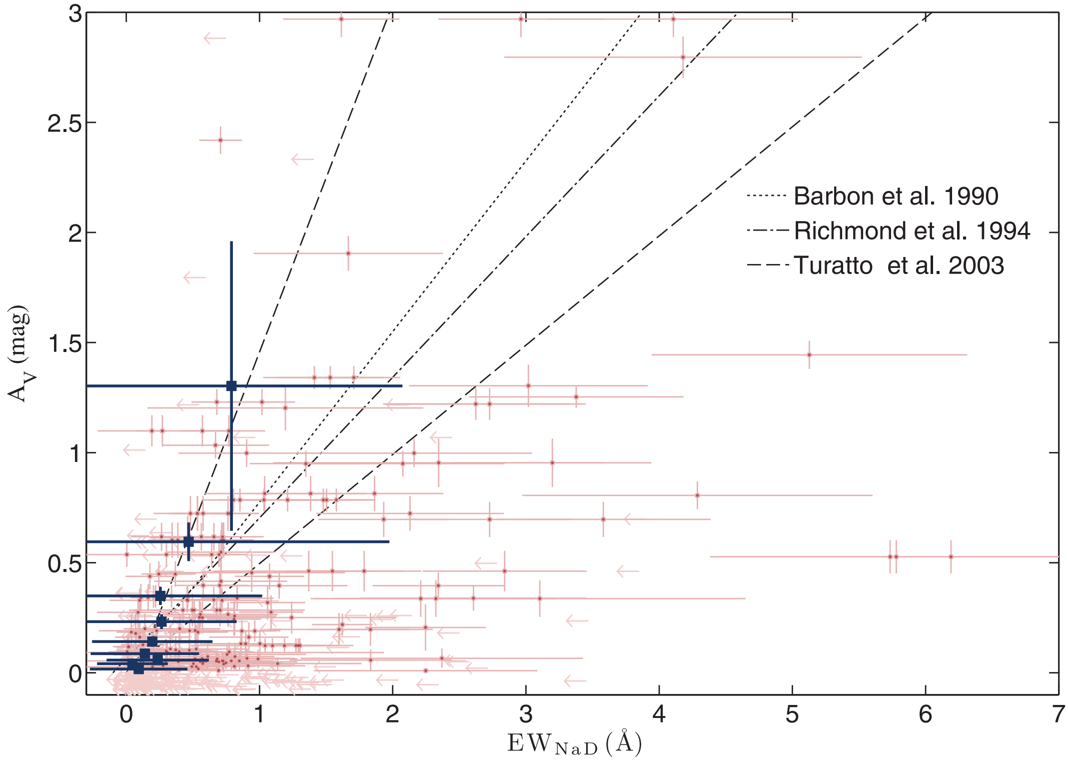

Figure 1. In red, extinction along the line of sight, A_V, from template fitting to the light curves versus the equivalent width of Na I D as measured from low-resolution spectra of SNe Ia. The large blue squares are weighted averages in bins of equal sample size. Non-detections are marked by arrows located at the 1σ limit. In addition we show the various correlations proposed by Barbon et al. (1990), Richmond et al. (1994) and Turatto et al. (2003, two different lines). While there is indeed a correlation as seen in the mostly monotonic rise of the binned data, the scatter is far too great to make this spectral feature an effective predictor of dust extinction.

2 DATA AND MEASUREMENT

For over a decade the Lick Observatory SN search (LOSS; Li et al. 2000; Filippenko et al. 2001) with the Katzman Automatic Imaging Telescope (KAIT) has been one of the most successful systematic discovery engines of nearby SNe. KAIT has also conducted follow-up photometry of hundreds of SNe, along with the Nickel 1-m telescope at the Lick Observatory. Moreover, the LOSS team has obtained spectra of these SNe with multiple telescopes, but mostly with the Kast double spectrograph (Miller & Stone 1993) mounted on the Lick Observatory 3-m Shane reflector, the Low Resolution Imaging Spectrometer (LRIS; Oke et al. 1995) mounted on the 10-m Keck telescopes, and the Deep Imaging Multi-Object Spectrograph (DEIMOS; Faber et al. 2003) on the 10-m Keck II telescope. The photometric data are presented by Ganeshalingam et al. (2010), and the spectroscopy by Silverman et al. (in preparation). In addition, we have compiled photometry from the Calán/Tololo SN search (Hamuy et al. 1996) and the Harvard CfA samples (Riess et al. 1999; Jha et al. 2006; Hicken et al. 2009a).

2.1 Extinction estimation

Ganeshalingam et al. (in preparation; see also Ganeshalingam et al. 2010) fit every SN Ia to templates using the multicolour light-curve shape fitter, MLCS2k2.v006 (hereafter MLCS; Riess, Press & Kirshner 1996; Jha, Riess & Kirshner et al. 2007), providing an estimate of the amount of extinction suffered by the SN in its host galaxy. Milky Way reddening is removed by using the dust maps of Schlegel, Finkbeiner & Davis (1998). Two independent fits are performed, using a galactic line of sight prior extinction law with the Milky Way average of $R_V = 3.1$ or a steeper $R_V = 1.7$ (e.g. Wang et al. 2009; Hicken et al. 2009b, and references therein). While the two sets give systematically different values for the amount of extinction A_V, the results are highly correlated and do not affect our conclusions below. For simplicity, we discuss only the values derived with $R_V = 3.1$, which is consistent with the value of $R_V = 2.8 \pm 0.3$ found by Chotard et al. (2011).

While there may be some debate as to the accuracy of the derived extinction values with MLCS due to the dependence on the prior dust law and to the degeneracy between intrinsic colour variance and external reddening, the precision has been widely tested and vetted, far beyond our needs for this work.

2.2 Na I D equivalent width

From our data base of 1613 spectra of 743 SNe Ia (Silverman et al., in preparation), we choose every spectrum of SNe having an MLCS estimate, resulting in 724 spectra of 239 individual SNe. In order to simplify the analysis we further cull the sample with the following criteria. (1) Objects that are found to be normal (i.e. non-peculiar) SNe Ia based on matching with the SN identification code (SNID; Blondin & Tonry 2007). (2) Only spectra obtained with the three main spectrographs named above. (3) Redshift $z > 0.005$, in order to avoid contamination of the EW measurement with observer-frame absorption from our own Galaxy. (4) MLCS goodness of fit of $\chi^2 < 2$, and estimated uncertainty in A_V of $\delta A_V < 0.2$ mag. These cuts result in a sample of 443 spectra of 172 SNe. This sample is still more than an order of magnitude greater than in previous studies. Our results below are independent of the precise cuts applied (such as the redshift limit or minimal goodness of fit).

© 2011 The Authors, MNRAS **415,** L81–L84
Monthly Notices of the Royal Astronomical Society © 2011 RAS

Downloaded from https://academic.oup.com/mnrasl/article-abstract/415/1/L81/965276 by University of Southampton user on 22 May 2019

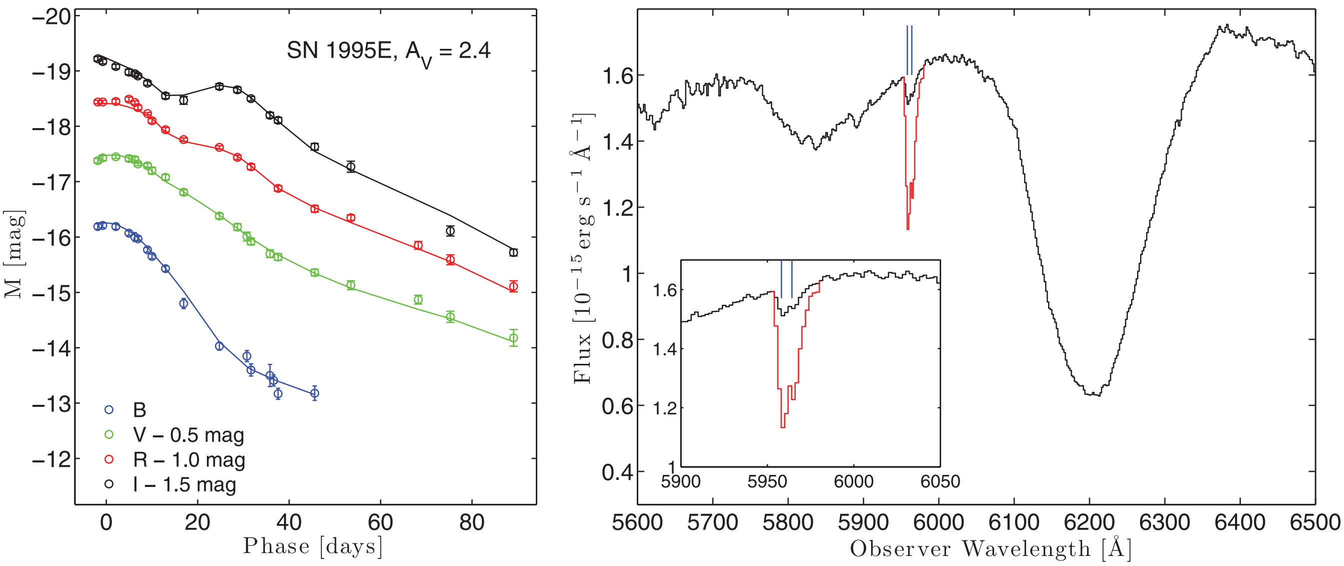

Figure 2. Left: multicolour light curves of SN 1995E together with the best-fitting MLCS templates, from which a large extinction of $A_V = 2.4$ mag is derived. Right: low-resolution spectrum of SN 1995E (inset shows the Na I D feature in detail; blue lines mark the wavelengths of the doublet), indicating that the EW of Na I D is rather small, about 0.7 Å. In red we show what the line should look like in order to have the EW predicted by the relation of Richmond et al. (1994).

The procedure for deriving the EW of Na I D for every spectrum is as follows. The spectrum is inspected visually, and if a line is noticeable its edges are manually marked. We perform numerical integration of the line over this marked range, dividing the result by the integration over the pseudo-continuum which is assumed to be linear. We divide the spectrum by a low-order polynomial fit to the rest-frame range of 5800–6000 Å and measure the noise of the spectrum, N, defined as the 5σ clipped standard deviation around the flattened spectrum. The uncertainty in the EW is assumed to be dominated by N. We calculate the uncertainty, δEW, as $\delta\text{EW} = N \times W/2$, where W is the width (in Å) of the line (the factor of 2 accounts for the approximately triangular shape of the feature). In cases where no line was detectable, we set EW = 0, and for the uncertainty we use the average width for the line in our spectra (20 Å).[2]

2.3 Variability

For 85 of the SNe in our sample we have more than one spectrum, the majority with three or more spectra. For every such SN, we examine the stability of the EW of Na I D by comparing the result for a given spectrum to the weighted mean for all spectra of that object. In only four cases (out of 254 spectra) do we find an EW that is inconsistent by more than 2σ with other spectra of the same SN. In two of those cases we find that this is due to a slight underestimation of the uncertainty. For the remaining two SNe, SN 2006bq and SN 2006cm, the variation in EW seems to arise from a varying amount of host-galaxy light spilling into the spectroscopic slit. This finding raises some concerns regarding the reliability of the EW of Na I D as a good proxy for dust extinction, as measurements for the same SN can, on occasion, vary significantly.

3 CORRELATION

In Fig. 1 we show in red the value of A_V derived from MLCS compared to the EW of Na I D. Non-detections are marked with arrows at the 1σ limit. We bin the EW measurements, with a variable bin size in order to have the same number of spectra per bin (about 50). We plot with large blue squares the weighted mean (in EW and A_V) for each bin. Here a shadow of the correlation arises, but the dispersion around it is too great to make it a useful tool. Our measurements are effectively consistent with all the tentative correlations suggested by Barbon et al. (1990), Richmond et al. (1994), and Turatto et al. (2003), as shown in the figure. Our best fit correlation is $E(B-V) = 0.43$ EW [Å] $- 0.08$, with a systematic scatter of 0.3 mag (1σ). A similar scatter is observed when plotting EW versus MLCS A_V values for $R_V = 1.7$ or the SALT2 c term (Guy et al. 2007).

In Figs 2 and 3 we illustrate the two most extreme outliers in our sample, SNe 1995E and 2006et. Both are well fit by MLCS, with A_V of 2.4 and 0.5 mag (respectively), but their Na I D EW values are about 0.7 and 6 Å. While these are far from typical, Fig. 1 shows that they are clearly not unique, and they demonstrate the risk associated with deriving extinctions from Na I D EW measurements in low-resolution spectra.

4 CONCLUSIONS

Our finding is that the EW of Na I D, as measured from low-resolution spectra, only very weakly tracks the amount of extinction suffered by a SN, at least as long as the extinction is in the range we probed, $A_V < 3$ mag. Many effects conspire to minimize the amount of inference one could make. SN spectra are typically contaminated with host-galaxy light, and the continuum emission will dilute the line strength. This contamination is highly dependent on the slit width and position, as well as on observing conditions.

In addition, low-resolution spectra cannot resolve the Na I D doublet and therefore the different curves of growth of the two components are blended. Variations in gas-to-dust ratios in particular regions or galaxy types, multiple gas clouds at different velocities along the line of sight, and line saturation at large optical depths, all contribute to the theoretical and practical explanation for our results.

[2] A table including all of our measurements is available at http://astro.berkeley.edu/∼dovi/Poznanski2011_SN_nad.dat.

© 2011 The Authors, MNRAS **415,** L81–L84
Monthly Notices of the Royal Astronomical Society © 2011 RAS

Downloaded from https://academic.oup.com/mnrasl/article-abstract/415/1/L81/965276 by University of Southampton user on 22 May 2019

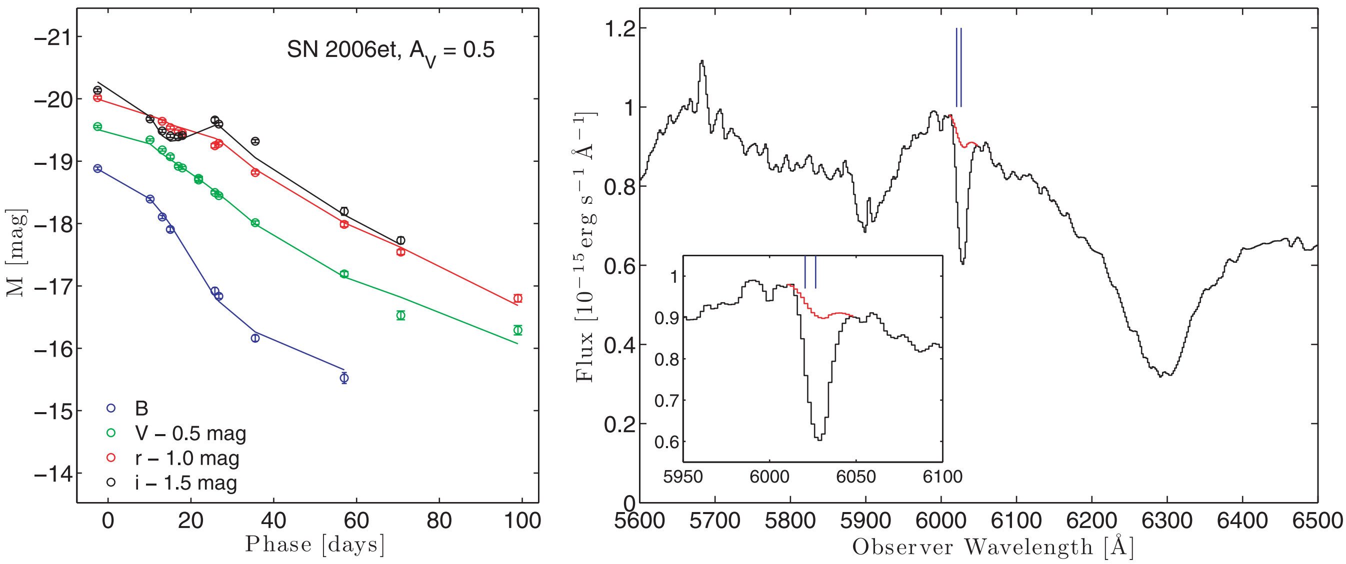

Figure 3. Left: multicolour light curve of SN 2006et together with the best-fitting MLCS templates, from which a moderate extinction of $A_V = 0.5$ mag is derived. Right: low-resolution spectrum of SN 2006et (inset shows the Na I D feature in detail; blue lines mark the wavelengths of the doublet), indicating that the EW of Na I D is extremely large, about 6 Å. In red we show what the line should look like in order to have the EW predicted by the relation of Richmond et al. (1994).

ACKNOWLEDGMENTS

We thank A. A. Miller, J. S. Bloom and P. E. Nugent for useful comments on this manuscript. DP is supported by an Einstein Fellowship from NASA. The research of AVF's supernova group at UC Berkeley has been generously supported by the US National Science Foundation (NSF; most recently through grants AST–0607485 and AST–0908886), the TABASGO Foundation, US Department of Energy SciDAC grant DE-FC02-06ER41453, and US Department of Energy grant DE-FG02-08ER41563. KAIT and its ongoing operation were made possible by donations from Sun Microsystems, Inc., the Hewlett-Packard Company, AutoScope Corporation, Lick Observatory, the NSF, the University of California, the Sylvia & Jim Katzman Foundation, the Richard and Rhoda Goldman Fund, and the TABASGO Foundation. Some of the data presented herein were obtained at the W. M. Keck Observatory, which is operated as a scientific partnership among the California Institute of Technology, the University of California and NASA; the observatory was made possible by the generous financial support of the W. M. Keck Foundation. We thank the staffs of the Lick and Keck Observatories for their assistance with the observations.

REFERENCES

Barbon R. et al., 1990, A&A, 237, 79
Blondin S., Tonry J. L., 2007, ApJ, 666, 1024
Blondin S., Prieto J. L., Patat F., Challis P., Hicken M., Kirshner R. P., Matheson T., Modjaz M., 2009, ApJ, 693, 207
Chotard N. et al., 2011, A&A, 529, L4
Conley A. et al., 2008, ApJ, 681, 482
Elias-Rosa N., 2007, in di Salvo T. et al., eds, AIP Conf. Ser. Vol. 924, The Multicolored Landscape of Compact Objects and Their Explosive Origins. Am. Inst. Phys., New York, p. 395
Faber S. M. et al., 2003, in Iye M., Moorwood A. F. M., eds, Proc. SPIE Vol. 4841, p. 1657
Ferlet R., Vidal-Madjar A., Gry C., 1985, ApJ, 298, 838
Filippenko A. V., Li W. D., Treffers R. R., Modjaz M., 2001, in Paczynski B., Chen W.-P., Lemme C., eds, ASP Conf. Ser. Vol. 246, Proc. IAU Colloq. 183, Small Telescope Astronomy on Global Scales. Astron. Soc. Pac., San Francisco, p. 121
Ganeshalingam M. et al., 2010, ApJS, 190, 418
Guy J. et al., 2007, A&A, 466, 11
Guy J. et al., 2005, A&A, 443, 781
Hamuy M. et al., 1996, AJ, 112, 2408
Hicken M. et al., 2009a, ApJ, 700, 331
Hicken M. et al., 2009b, ApJ, 700, 1097
Hillebrandt W., Niemeyer J. C., 2000, ARA&A, 38, 191
Issa M. R., MacLaren I., Wolfendale A. W., 1990, A&A, 236, 237
Jha S. et al., 2006, AJ, 131, 527
Jha S., Riess A. G., Kirshner R. P., 2007, ApJ, 659, 122
Li W. D. et al., 2000, in Holt S. S., Zhang W. W. eds, AIP Conf. Ser. Vol. 522, Cosmic Explosions. Am. Inst. Phys., New York, p. 103
Lisenfeld U., Ferrara A., 1998, ApJ, 496, 145
Miller J. S., Stone R. P. S., 1993, Technical Report, Lick Obs. Tech. Rep. 66. Lick Observatory, Santa Cruz
Mugglestone D., O'Mara B. F., 1965, MNRAS, 129, 41
Munari U., Zwitter T., 1997, A&A, 318, 269
Oke J. B. et al., 1995, PASP, 107, 375
Perlmutter S. et al., 1999, ApJ, 517, 565
Phillips M. M., 1993, ApJ, 413, L105
Richmond M. W. et al., 1994, AJ, 107, 1022
Riess A. G. et al., 1998, AJ, 116, 1009
Riess A. G. et al., 1999, AJ, 117, 707
Riess A. G. et al., 2011, ApJ, 730, 119
Riess A. G., Press W. H., Kirshner R. P., 1996, ApJ, 473, 88
Savage B. D., Mathis J. S., 1979, ARA&A, 17, 73
Schlegel D. J., Finkbeiner D. P., Davis M., 1998, ApJ, 500, 525
Turatto M., Benetti S., Cappellaro E., 2003, in Hillebrandt W., Leibundgut B., eds, From Twilight to Highlight: The Physics of Supernovae. Springer-Verlag, Berlin, p. 200
Wang X. et al., 2009, ApJ, 699, L139

This paper has been typeset from a TEX/LATEX file prepared by the author.

Downloaded from https://academic.oup.com/mnrasl/article-abstract/415/1/L81/965276 by University of Southampton user on 22 May 2019