Properties of Type Ia Supernova Host Galaxies

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Abstract. We study the effect of environment on the properties of type Ia supernovae by analyzing the integrated spectra of 57 host galaxies. Integrated spectra of galaxies best represent the global properties of the host and can be used to directly compare with spectra of high-redshift galaxies. From the spectra we deduce the metallicity, current star-formation rate and star-formation history of the hosts and compare these to the supernova decline rate which is an indicator of the luminosity. Our results show no significant correlation between spiral host galaxy metallicity and SNIa light curve decline rate. The Hα equivalent width (EW) of the host galaxy is an indicator the current star-formation rate compared to average rate in the past. The range of SNIa luminosities increases with decreasing EW which suggests that the variation in SNIa $^{56}\text{Ni}$ production is primarily due to progenitor mass and population age.

1. Introduction

The peak luminosities and colors of type Ia supernovae (SNIa) appear to correlate well with their light curve decay rate [Phillips 1993; Hamuy et al. 1996; Reiss, Press, & Kirshner 1996] making SNeIa exquisite distance indicators and powerful probes for cosmology (Garnavich et al. 1998; Riess et al. 1998). But the origin of the diversity seen in SNIa is a mystery that limits their reliability. It is well accepted that a SNIa occurs when a carbon-oxygen white dwarf has accreted matter from a companion star and approaches the Chandrasekhar limit. At some point the pressure at the center is sufficient to ignite the CO and a detonation/deflagration unbinds the star and generates a large mass of $^{56}\text{Ni}$ which powers the visible light curve. This single-degenerate, Chandrasekhar-mass scenario predicts very consistent explosion energies, indeed, the peak brightness of most SNIa fall in a narrow range spanning about 0.5 magnitudes in $B$. There is also a fraction of SNIa that are significantly fainter than the typical event and these SNIa may represent a tail of the main distribution or come from a completely different set of progenitors.

One clue to the origin of diversity in SNIa is that light curve shape (i.e., peak luminosity) shows a dependence on host galaxy morphology as first pointed out by [Hamuy et al. 1996]. Ellipticals/S0 galaxies tend to host fast-declining (low luminosity) events compared with spiral hosts. As shown in Figure 1, the trend has become clearly established as more SNIa have been analyzed. Galaxy morphology, however, is too blunt a tool to determine what causes luminosity variations. For example, NGC 2841 is classified as a Sa galaxy, but has an extremely small Hα emission rate while NGC 632 is listed as an S0 galaxy but has a star burst at its core. To better define the environments of the supernovae,
we have obtained integrated spectra of 57 SNIa host galaxies. From these spectra we determine the current star-formation rate, the current rate compared to the average rate in the past (the Scalo ‘b’ parameter), and the metallicity for hosts with strong emission lines.

![Diagram](image)

Figure 1. The host galaxy morphology versus light curve decline rate parameter $\Delta m_{15}(B)$.

2. Metallicity

The diversity in SNIa brightness comes from the range of $^{56}\text{Ni}$ produced in the explosions. The carbon to oxygen ratio in the white dwarf could effect the amount of radioactive Ni synthesized and this ratio can be influenced by the initial metallicity of the progenitor (Timmes, Brown, & Truran 2003) or the initial mass of the progenitor (Umeda et al. 1999). In Figure 2 we plot the host galaxy metallicity derived from emission line ratios (Kewley & Dopita 2002) against the supernova light curve decay rate. The light curve shape is parameterized by $\Delta m_{15}(B)$ which describes the number magnitudes the supernova fades 15 days after maximum light in the $B$-band. There is no significant correlation between $\Delta m_{15}(B)$ and host metallicity over an order of magnitude in metal content. Relying on emission lines restricts this analysis to active star-forming galaxies, so we have supplemented our data with elliptical galaxies published by Hamuy et al. (2000). These additional data enlarge the range of $\Delta m_{15}(B)$ covered, but still do not reveal any correlation with metallicity.

3. Star Formation

The rate of current star formation in a galaxy is related to its H$\alpha$ luminosity. The ratio between current star formation and the average rate in the past can be derived from the H$\alpha$ equivalent width. This ratio is also known as the Scalo ‘b’ parameter and we plot the Scalo b versus $\Delta m_{15}(B)$ in Figure 3. For hosts
Figure 2. SNIa decline rate parameter versus host galaxy metallicity derived from emission line ratios. The dashed line shows the Timmes, Brown, & Truran (2003) prediction of how progenitor metallicity effects $^{56}$Ni yield. Open symbols indicate elliptical hosts studied by Hamuy et al. (2000).

Figure 3. SNIa decline rate parameter versus host galaxy Hα equivalent width.

with measurable emission lines, there is no clear correlation between the decay rate and Scalo b, but the range of SNIa luminosity increases as the Scalo b parameter declines. We conclude that the age of the stellar population has more of an influence over SNIa diversity than does host metallicity.
The binary nature of the standard SNIa model means that the mass of the secondary controls the time-scale for mass transfer (Umeda et al. 1999). A simplified picture of the single degenerate model is illustrated in Figure 4 where stars in the binary are selected at random from a steep initial mass function (IMF). The primary is assumed to form a white dwarf after its main sequence life time and explode when the secondary evolves off the main sequence if its ejected envelope is sufficient to raise the primary white dwarf to the Chandrasekhar limit. The steep IMF means that most SNIa come from binaries made of two low-mass stars that take 3 to 4 Gyr to explode (as found by Strolger et al. (2004)). Populations older than 5 Gyr will have SNIa binaries made of a massive primary and a low-mass secondary that takes a very long time to evolve off the main sequence. If the $^{56}\text{Ni}$ yield is inversely correlated with the primary mass, then many of the observed properties of SNIa and their host galaxies are explained.

Figure 4. An illustration of how progenitor age (primary mass) can explain the observed correlation between SNIa luminosity and host population. Panel a shows the range of primary masses and secondary main sequence life times that permit the primary white dwarf to reach the Chandrasekhar limit. Panel b displays the delay time for explosion after a burst of star-formation and its similarity to the delay found in high-redshift events. Panels c and d show how this model translates to SNIa light curve shape.

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