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Host galaxy extinction of Type Ia supernovae: co-evolution of interstellar medium structure and the extinction law with star formation

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ABSTRACT

This paper presents a mechanism that may modify the extinction law for Type Ia supernovae (SNeIa) observed at higher redshift. Starting from the observations that (i) SNeIa occur predominantly in spiral galaxies, (ii) star formation ejects interstellar medium (ISM) out of the plane of spirals, (iii) star formation alters the extinction properties of the dust in the ISM, and (iv) there is substantially more star formation at higher redshift, I propose that spiral galaxies have a dustier halo in the past than they do now. The ejected material's lower value of R_V will lead to a lower average value (\bar{R}_V) for SNeIa observed at higher redshift.

Two relations in SNIa observations indicate evolution of the average R_V : the relation of observed R_V with inclination of the host galaxy at low redshift and the matching of the distribution of extinction values (A_V) for SNeIa in different redshift intervals. The inclination effect does point to a halo with lower R_V values. In contrast, the distributions of A_V values match best for an $\bar{R}_V(z)$ evolution that mimics the relation of SNIa dimming with redshift attributed to the cosmological constant. However, even in the worse-case scenario, the evolution \bar{R}_V cannot fully explain the dimming of SNeIa: host galaxy extinction law evolution is not a viable alternative to account for the dimming of SNeIa.

Future observations of SNeIa – multicolour light curves and spectra – will solve separately for values of A_V and R_V for each SNIa. Solving for evolution of \bar{R}_V (and A_V) with redshift will be important for the coming generation of cosmological SNIa measurements and has the bonus science of insight into the distribution of dust-rich ISM in the host galaxies in the distant past.

Key words: supernovae: general – dust, extinction – galaxies: ISM – galaxies: high-redshift – distance scale – cosmology: observations.

1 INTRODUCTION

Type Ia supernova (SNIa) distance modulus measurements have grown into a powerful measurement of the equation of state of our Universe. Accurate cosmological distances combined with redshift measurements allow for a precise characterization of the Hubble flow as well as the additional acceleration attributed to the cosmological constant (Riess et al. 1998; Perlmutter et al. 1999). The increasing statistics of SNIa measurements together with more information for each separate SN event have progressively lowered the observational uncertainties: dust extinction, photometric error and light curve characterization (see e.g. Knop et al. 2003; Tonry et al. 2003; Barris et al. 2004; Astier et al. 2006; Conley et al. 2006).

Extinction by dust remains a problematic systematic uncertainty in SNIa observations because the applicable extinction law remains poorly understood. This will need to be addressed in order to use SNeIa in the next step in accuracy for a cosmological probe. Dust

attenuation affects both the observed SNIa rate and the distance modulus. Extinction by dust occurs in three instances before observation of the SNIa light: (i) in our own Milky way, (ii) in intergalactic space, and (iii) in the host galaxy of the SNIa.

Galactic extinction (i) is a well-studied problem, because it is a ubiquitous one. Burstein & Heiles (1984) produced a map of Galactic extinction based on H I maps and distant galaxy counts. It was superseded by the map of Schlegel, Finkbeiner & Davis (1998), based on *COBE* and *IRAS* far-infrared (far-IR) and submillimetre maps. The latter map is now generally used, together with the Galactic extinction law to correct extragalactic sources (Cardelli, Clayton & Mathis 1989; Fitzpatrick 1999); the inferred extinction along a line-of-sight is proportional to the reddening: $A_V = R_V E(B - V)$. The canonical value of R_V is 3.1 with occasionally lower values towards the Galactic Centre (Udalski 2003) and higher elsewhere (Cardelli et al. 1989; Fitzpatrick 1999).

Extinction by dust in intergalactic space (ii) has been proposed as an alternative explanation for SNIa dimming, which is generally attributed to the cosmological acceleration (Aguirre 1999a,b; Aguirre & Haiman 2000). The resulting extinction law of this dust

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would effectively be grey¹ because the attenuating dust would be spread over all redshifts along every line-of-sight. The coincidence of both uniform distribution in both sky and redshift space does give this explanation a somewhat contrived appearance. The injection of dust into the intergalactic medium would have to be constant and substantial. Models of a dusty universe (Goobar, Bergström & Mörtzell 2002; Robaina & Cepa 2007) find this grey dust explanation increasingly inconsistent with observational data (see also e.g. Riess et al. 2007).

Extinction within the SNIa's host galaxy (iii), dust in the immediate surroundings and any disc, ring or spiral arm the line-of-sight passes through in projection, is an observationally evident, yet not fully constrained uncertainty. The Dark Energy Task Group Report (Albrecht et al. 2006) notes this as a primary source of uncertainty for SNIa measurements.

Three characteristics of the host galaxy's dust could – and are expected to – change over the history of the universe: (1) total dust content or mass, (2) dust distribution within the host galaxy and (3) dust composition. The overall effect on the effective extinction law is of interest for the distance determination from SNIa light curves.

Dust mass (1) is a variable in several spectral energy distribution (SED) studies of distant galaxies. Calzetti & Heckman (1999) modelled the overall dust content of galaxies over time and found that a maximum occurred either at $z = 1$ or at 3. Rowan-Robinson (2003) modelled the SEDs from distant galaxies and similarly found a maximum dust content at $z = 1$. Iglesias-Páramo et al. (2007) find a steady increase in dust mass with time from the ultraviolet–IR (UV–IR) SED of galaxies. The typical dust mass found in distant galaxies is very much a function of the selected sample. Far-IR selected samples point to dust-rich galaxies, similar to Arp 220 (Rowan-Robinson et al. 2005), optical/UV selected samples point to discs very similar to the local ones (Sajina et al. 2006) and Lyman α galaxies point to low-extinction discs (Nilsson et al. 2007).

However, more dust mass should not affect the SNIa distance determinations if the extinction law remains the same for nearby and distant galaxies. More dust in the distant galaxies will predominantly affect the observed SNIa *rate* (Hatano, Branch & Deaton 1998; Cappellaro, Evans & Turatto 1999; Goobar et al. 2002; Riello & Patat 2005; Mannucci, Della Valle & Panagia 2007), as heavily obscured SNeIa drop from observed samples.

The dust distribution in host galaxies (2) is commonly modelled as a double exponential, one radial and one vertical, sometimes with rings to mimic spiral arms. The radial scale of the dust distribution is assumed to be similar to the stellar one and the vertical dust scale is supposed to be much smaller than the stellar one. Previous observations of the scaleheight in nearby (edge-on) galaxies appeared to corroborate the small scaleheight (e.g. Xilouris et al. 1999; Holwerda et al. 2005; Bianchi 2007) but recent observations indicate a much higher scaleheight for the dust (Seth, Delcanton & de Jong 2005; Kamphuis et al. 2007), similar to the stellar scale.

If the average scaleheight of the dust distribution was higher in the past, then SNeIa in the plane of the disc will encounter more extinction, especially when viewed in an inclined system. The different distribution has a similar effect to variation in the dust content of galaxies and only the observed SNIa rate will be affected, unless dust composition and distribution are related.

The dust composition (3), notably the ratio of small to large grains, directly affects the observed extinction law (see the review by Draine 2003). Evolution in the average extinction law is the most-

troubling possibility, as this would affect the extinction correction of SNeIa and indirectly the measured Hubble flow and acceleration. For local SNeIa, variations in the extinction law have been observed (e.g. Riess, Press & Kirshner 1996; Jha, Riess & Kirshner 2007). Wang (2005) explained the different observed extinction law for some SNeIa as the effect of circumstellar material around the SNIa progenitor. This is a plausible scenario as the massive-star SNe are very efficient dust producers (Sugerman et al. 2006). Patat et al. (2007) and Wang & Mukherjee (2007) report observations of such material.

Alternatively, there is substantial evidence for a link between star formation and extinction law in star-forming galaxies (see the review in Calzetti 2001, and the references therein). Star formation produces more small grains and the intense UV fields alter grain composition.

Since it is not unreasonable to suppose that star formation affects both the distribution and the extinction characteristic of dust in spiral discs, I propose a simple model for the evolution of the extinction law applicable to SNIa measurements.

The aim of this paper is to explore this link between the extinction law for SNeIa and star formation of host galaxies and to investigate how much extinction law evolution could reasonably influence SNIa distance measurements. This paper is organized in a brief review of present observations of evolution in host galaxy dust and R_V (Section 2), a description of the model (Section 3), two tests based on current SNIa observations (Section 4), and discussion and conclusions (Section 5).

2 OBSERVATIONAL STATUS

Observational evidence for a different extinction law at higher redshifts comes from lensed quasars, quasi-stellar object (QSO) reddening by damped Lyman α systems and gamma-ray burst (GRB) afterglows, as well as SNIa measurements.

Gravitational lenses of QSOs find a range of values for R_V up to a redshift of 1 (Nadeau et al. 1991; Falco et al. 1999; Toft, Hjorth & Burud 2000; Motta et al. 2002; Goicoechea, Gil-Merino & Ullán 2005; Elíasdóttir et al. 2006). However, the lenses are often elliptical galaxies, which are not typical SNIa hosts. Pei, Fall & Bechtold (1991) find evidence of QSO reddening by Lyman α systems but this is disputed by Murphy & Liske (2004), both based on the SDSS sample. York et al. (2006) find an Small Magellanic Cloud (SMC) type extinction based on all SDSS QSOs with a Lyman α system. Kann, Klose & Zeh (2006) compare extinction for different GRB afterglows and find evidence for dust in the GRB hosts. None of these observations effectively constrain the extinction law applicable to SNeIa.

In the SNIa literature, the problem of SNIa host galaxy dust extinction is well recognized (Albrecht et al. 2006; Astier et al. 2006; Conley et al. 2006; Wood-Vasey et al. 2007). Observations of high-redshift SNeIa tell us that their spectra are similar to local ones (Garavini et al. 2005; Hook et al. 2005; Garavini et al. 2007), with no anomalous reddening (Knop et al. 2003) and dust masses of host galaxies similar to those of local galaxies (Clements et al. 2004, 2005, based on submillimetre data).

Several studies look at the relations between SNIa light curve properties (peak brightness, duration, and colour) and host galaxy properties (type, stellar mass, extinction, and star formation). A relation between SN peak brightness and host galaxy type is well established (Hamuy et al. 1996, 2000; Saha et al. 1997, 1999; Parodi et al. 2000; Sandage, Tammann & Saha 2001; Sullivan et al. 2003; Reindl et al. 2005). Sullivan et al. (2006) refine the relation

¹ The term grey extinction is used to denote that there is no relation between the reddening of an object and its extinction.

to one between the SNIa light curve and star formation in the galaxy: passive galaxies, with no star formation, preferentially host faster-declining/dimmer SNeIa, while brighter events are found in systems with ongoing star formation. The SNeIa related to ongoing star formation could well dominate the population at higher redshift (Sullivan et al. 2006; Howell et al. 2007; Mannucci et al. 2007), as there is much more star formation. Host galaxy extinction is of equal importance as any change in the SNIa population. Sullivan et al. (2003) report dimmer SNeIa for spiral galaxy hosts, especially when projected in or through the inner part of the disc. Arbutina (2007) also finds a radial dependence of the extinction of local SNeIa. Values for R_V different from the canonical $R_V = 3.1$ have been found for individual SNeIa (Riess et al. 1996; Krisciunas et al. 2006, 2007). Based on their entire sample, Reindl et al. (2005) find a value of 2.65. Jha et al. (2007) find a mean value of 2.7 for heavily obscured SNe and 2.9 for the less-extinguished ones. The explanations for deviant R_V values are circumstellar material (Wang & Mukherjee 2007) or a different dust composition (Riess et al. 1996; Krisciunas et al. 2006). Evolution in R_V may be critical for precision cosmology, and the SNeIa themselves are also the best probe to characterize this evolution.

3 EVOLUTION MODEL OF HOST GALAXY EXTINCTION

Let us consider four observational facts: (i) SNeIa occur predominantly in spirals (Sullivan et al. 2003; Reindl et al. 2005), (ii) star formation ejects interstellar medium (ISM) from the planes of spiral discs and the ejected material takes some time to rain back (Howk & Savage 1997, 1999; Howk 1999; Dalcanton, Yoachim & Bernstein 2004; Thompson, Howk & Savage 2004; Howk 2005; Kamphuis et al. 2007), (iii) star formation modifies the extinction characteristics (lower R_V , Gordon et al. 2003; Krisciunas et al. 2006) and (iv) there is an order of magnitude more star formation at and beyond $z = 1$ (Madau, Pozzetti & Dickinson 1998; Steidel et al. 1999; Giavalisco et al. 2004; Thompson, Eisenstein & Fan 2006; Hopkins 2007). Therefore, at $z \sim 1$, spiral discs are likely to have a halo of ISM, recently processed and ejected by star formation. For the distance measurement with SNeIa, this is especially important as their light will encounter more $R_V < 3.1$ type dust as a result (see Fig. 1). Hence, the *average* value of R_V (\bar{R}_V) might be lower for SNeIa at higher redshift. The simplest parametrization of the \bar{R}_V evolution is a second-order polynomial:

$$\bar{R}_V = az^2 + bz + 3.1, \quad (1)$$

with the parameters depending on the choice of the \bar{R}_V value for the different epochs.

Out of the four assertions above, the relation between star formation and extinction law (iii) is the most tenuous. Evidence for

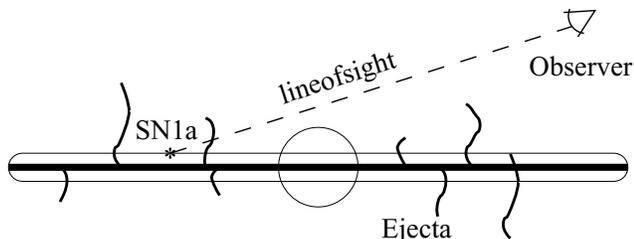


Figure 1. A cartoon of our model: star formation ejects plumes of ISM with lower R_V values out of the disc of the host galaxy. A line-of-sight to an SNIa can intersect such plumes. The higher star formation at $z \sim 1$ results in more plumes and hence a higher probability for a SNIa line-of-sight intersecting one.

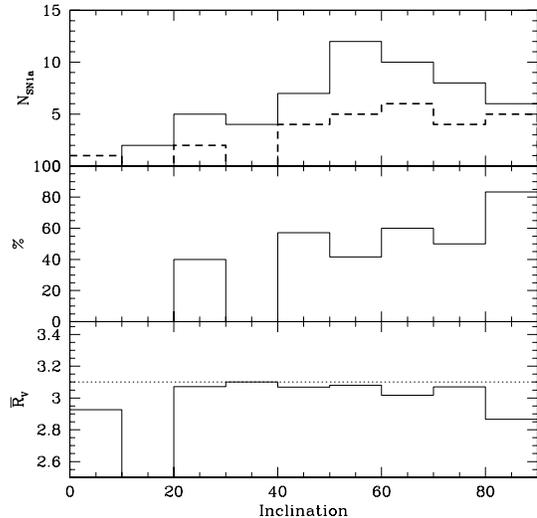


Figure 2. The relation between inclination and R_V values from Jha et al. (2007), for the late-type galaxies. Top panel: the number of SNeIa with $R_V = 3.1$ and the number with deviant values (dashed line). Middle panel: the percentage of SNeIa with deviant R_V values. Bottom panel: the average value of R_V . There are very few SNe observed in perfectly face-on galaxies. In higher inclined discs, the average value of R_V is lower, indicating a possible effect of ejecta in the galaxy’s halo.

a different extinction law in star-forming galaxies has been found by Calzetti, Kinney & Storchi-Bergmann (1994). However, for extended sources such as H II regions, one would need to disentangle the effects of processed dust grains and a clumpy medium (See Natta & Panagia 1984).

Gordon et al. (2003) presents extinction-law measurements for single stars, and hence lines-of-sight, in different regions in the SMC and Large Magellanic Cloud (LMC). They find evidence of dust processing by star formation and lower values of \bar{R}_V in the star-forming parts. Their average R_V values are: SMC bar, $\bar{R}_V = 2.74$; LMC supershell, $\bar{R}_V = 2.76$; LMC average sample, $\bar{R}_V = 3.41$. I note that the values for the regions with higher star formation are lower than the average for the LMC.

In this paper, I explore three models: Model A assumes no evolution in \bar{R}_V . Model B takes the LMC and SMC values as a template for the galaxies at $z = 1$ and earlier: star-forming galaxies at $z \sim 1$ have $\bar{R}_V = 2.7$ and gas-rich galaxies at $z \sim 2$ and beyond have $\bar{R}_V \approx 3.4$. Model C leaves the parameters in equation (1) free to fit the distributions of SNIa extinction values (A_V) in a low-, intermediate- and high-redshift sample of SNIa observations.

4 OBSERVATIONAL TESTS WITH SNEIA

There are two suggestive observations of SNeIa that support a general model of evolution in host galaxy extinction: (i) the relation between \bar{R}_V for SNeIa and host galaxy disc inclination and (ii) the distribution of inferred extinction (A_V) for a sample of high-, intermediate- and low-redshift SNeIa.

Jha et al. (2007) use the multifilter light curves available for a sample of 133 SNeIa to independently fit the value of R_V as well as the light curve peak and SNIa colour. The inclination and host galaxy type are from Hyperleda² and R_V values from table 4 in Jha et al. (2007). Fig. 2 shows the distribution of these SNeIa as a function of disc inclination of the late-type host galaxies for those

² <http://leda.univ-lyon1.fr/>

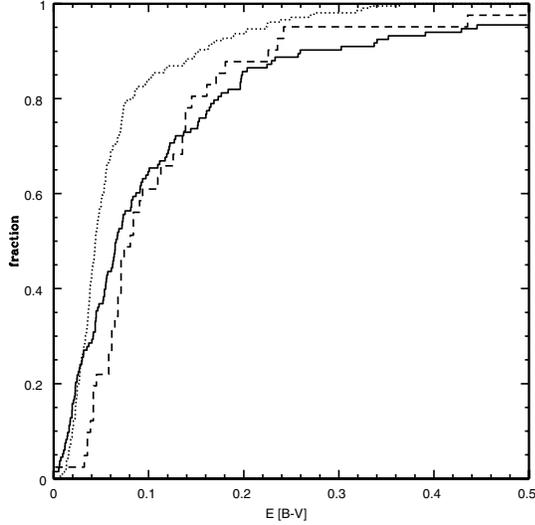


Figure 3. The cumulative histogram of SNIa reddening for three samples: the nearby SNIa sample (Jha et al. 2007, solid line), the intermediate-distance sample from the ESSENCE survey (Wood-Vasey et al. 2007, dotted line) and the high-redshift sample (Riess et al. 2007, dashed line). The differences in distribution point to evolution of the extinction in host galaxies, either in A_V or in R_V or in both.

SNIa with $R_V = 3.1$ (the default) and those with deviant values ($R_V \neq 3.1$). Notably, the deviant values start to dominate at the higher inclinations. Fig. 2 also shows the \bar{R}_V value for each inclination bin; it diminishes with increasing inclination. This supports our model of recent ejecta lowering the value of \bar{R}_V .

The second test is to compare the distributions of A_V of SNIa at different redshifts. Fig. 3 shows the distribution of extinction values (A_V), based on reddening and an R_V value of 3.1, for three samples of SNIa, a local, an intermediate- and a high-redshift one. Local SNIa are those from the sample of Jha et al. (2007). The intermediate-redshift sample is the ESSENCE data from Wood-Vasey et al. (2007) and the highest redshift data are from Riess et al. (2007). Sample sizes are very different: 133, 189 and 33 for the low-, intermediate- and high-redshift samples, respectively. The assumption is that the reddening measurements are comparable between these samples. Each of these studies uses a ‘prior’ distribution for the extinction values to optimize the fit to the light curves and I assume here that the effect of this prior is negligible on the reported distribution (see for a good discussion of extinction priors Wood-Vasey et al. 2007). The distributions of extinction values in Fig. 3 show that there is some type of evolution in A_V from one redshift sample to the next. SNIa searches use a ‘gold’ and ‘silver’ standard for SNIa light curves. To mimic these, I limit the samples to $A_V < 0.25$ and $A_V < 0.5$, respectively, in the following analysis.

In Fig. 4, I compare the three different models for R_V evolution (top panels) using the recomputed A_V distribution for each model (bottom panels). I limit the comparison to the SNIa ‘silver’ standard to maximize statistics. Fig. 4 shows Model A (no evolution, $\bar{R}_V = 3.1$) and two evolution models (B and C). Model B uses the Magellanic Cloud values from Gordon et al. (2003) to parametrize the dependence of $\bar{R}_V(z)$. Model C uses the best fit of equation (1) to minimize the differences between the A_V distributions, assuming for each sample the same parent distribution, that is, random lines of sight through a disc of a spiral galaxy.

The Kolmogorov–Smirnov (KS) probability that all three A_V populations are from the same parent populations without a change

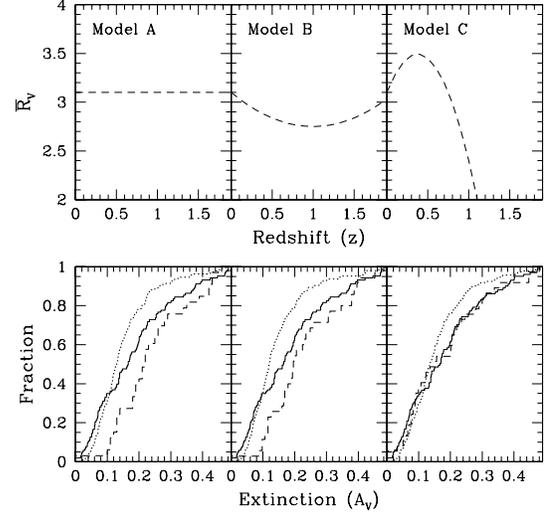


Figure 4. Top panels: the three models considered for evolution of $\bar{R}_V(z)$: (A) no \bar{R}_V evolution, (B) $\bar{R}_V = az^2 + bz + 3.1$ with $\bar{R}_V(z = 1) = 2.75$ and $\bar{R}_V(z \sim 2) = 3.4$, and (C) with $\bar{R}_V = az^2 + bz + 3.1$ fit to minimize the difference between the distribution of Jha et al. (2007) and the other two distributions [$R_V(z_{\max} = 0.25-0.3) = 3.2-4.1$]. Bottom panels: the cumulative histogram of A_V of SNIa from a nearby (solid line, Jha et al. 2007), intermediate (dotted line, Wood-Vasey et al. 2007) and distant sample (dashed line, Riess et al. 2007) for the different models in the top panels.

Table 1. The values for two different toy models, the peak redshift and peak value of \bar{R}_V and the KS test.

	ESSENCE			Riess et al. (2007)		
	z_{\max}	R_{\max}	P_{KS}	z_{\max}	R_{\max}	P_{KS}
Gold						
$(A_V < 0.25)$						
Model B	1	2.75	0.3	1	2.75	0.5
Model C	0.3	4.1	72	0.25	3.2	97
Silver						
$(A_V < 0.5)$						
Model B	1	2.75	0.2	1	2.75	2
Model C	0.4	4.3	33	0.4	3.4	99

in \bar{R}_V (Model A, Fig. 4, top left-hand panel) is extremely low ($P_{\text{KS}} \sim 0$, Fig. 4, bottom left-hand panel). Hence, some type of evolution is present in the distribution of SNIa extinction values (A_V) or extinction law (\bar{R}_V).

Model B is what one naively would expect on the basis of the narration in Section 3: the star-forming galaxies have a lower \bar{R}_V , which rises with gas fraction at higher z and using the Gordon et al. (2003) values as a template. The top middle panel in Fig. 4 shows the \bar{R}_V values. I recomputed the values for A_V with the model $\bar{R}_V(z)$ (Fig. 4, bottom middle panel). This model does not significantly improve the match between the three distributions of SNIa extinctions at different redshifts (see Table 1). If this model is true, there is substantial independent evolution in the distribution of A_V .

Model C is a fit of the parameters in equation (1) to recompute the A_V distribution and maximizing the probability that they are from the same parent distribution. The best-fitting values are in Table 1 and Fig. 4 shows the inferred \bar{R}_V (top right-hand panel) and computed A_V distribution (bottom right-hand panel). The best model to match the intermediate- and high-redshift samples to the

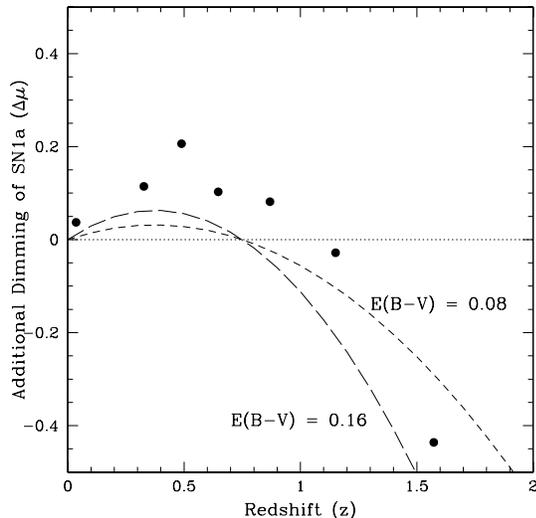


Figure 5. The maximum possible difference in extinction correction for the ‘silver’ ($A_V = 0.5$ for all SNeIa) and ‘gold’ ($A_V = 0.25$ for all SNeIa) samples between $R_V = 3.1$ and Model C. The points are the binned SNIa residuals, after subtracting the empty universe model from Riess et al. (2007) (Fig. 6). Even if all the SNeIa are affected by the maximum A_V and Model C holds true, evolution in \bar{R}_V alone cannot explain the residuals in average distance moduli of SNeIa.

low-redshift reference peaks at $z_{\max} = 0.25\text{--}0.3$ with a high value of $\bar{R}_V(z_{\max})$. In this case, little or no evolution in A_V is needed. However, the values of \bar{R}_V for each epoch are counter to expectations of Section 3.

Fig. 5 shows the observed average dimming of SNeIa as a function of redshift with the maximum possible impact of \bar{R}_V evolution plotted: Model C with the maximum $E(B - V)$ value for each SNIa allowed by the silver and gold sample selection. In this worst-case scenario, I assume that all SNeIa are affected by the maximum reddening allowed for selection into the gold or silver samples, even though they are clearly not (Fig. 3). The worst-case scenario (pure \bar{R}_V evolution) has the same shape as the dimming observed in SNeIa, but the effect of \bar{R}_V evolution is not strong enough to fully account for the observed dimming of SNeIa.

The exact origin of \bar{R}_V evolution can be either changes in the immediate surroundings of SNeIa or evolution in the ISM of host galaxies.

Because high-redshift observations of SNIa light curves are often limited to two filters to minimize observatory time spent on a given object, the applied extinction correction is mostly the fiducial $R_V = 3.1$. Occasional evidence from higher redshift spectra already point to very low values of R_V (A. Riess, private communication). Fig. 5 shows that multifilter and/or spectroscopic determination of R_V for observed SNeIa is crucial to accurately determine the equation of state of our Universe from SNIa distances.

5 DISCUSSION AND CONCLUSIONS

It seems likely that the distribution of A_V values for SNIa light curves will vary as a function of redshift. In this paper, I treated this as evolution of the average extinction law (\bar{R}_V). There, however, are the following three possible explanations for the behaviour of the A_V distribution, apart from a fit-prior artefact.

(i) \bar{R}_V does not change much, but due to dust ejection and/or additional dust production (from the elevated star formation in each galaxy), each SNIa at higher redshift is seen through more host galaxy dust.

(ii) The host galaxies are similar to nearby spirals but SNeIa occur preferentially in different environments at each redshift. At higher redshifts, they occur in more dust-rich parts of spirals (e.g. the spiral arms or in interacting galaxies).

(iii) \bar{R}_V – and hence A_V – does evolve as a combination of its dependence on dust composition and dust distribution in the host galaxy.

Options (i) and (ii) mean that the observed difference in A_V distribution (Fig. 4) at different redshifts is real and the inferred distances from SNIa light curves suffer no ill effects. In option (iii), however, the evolution in the host galaxy extinction law could skew the observations of the acceleration of the expansion of the Universe and the inferred cosmology.

I would like to stress that option (iii) is not as far-fetched as cosmic grey dust and even the worst-case scenario would not fully explain the SNIa dimming (Fig. 5). However, a realistic model would require (i) the relative positions in the disc of SNeIa at higher redshifts to characterize the importance of scenario (ii), and (ii) fits of their light curves which include R_V as a fit parameter, similar to those of Jha et al. (2007), to constrain scenario (iii). Given enough statistics, the SNIa measurements can then be used as probes of the distribution and severity of host galaxy extinction in discs at high redshift. In this paper, I assumed that the distributions of reddening values are uniformly derived and the choice of prior in the light curve analysis did not matter. In future work, one would prefer the same prior in all redshift samples and prefer even more sufficient information to conclusively determine A_V and R_V for each SNIa light curve.

In conclusion, we infer the following.

(i) There is a second plausible mechanism that modifies the extinction law for SNeIa in higher redshift host galaxies (Section 3); host galaxy dust evolution in addition to material around the SNIa progenitor.

(ii) The toy model of this mechanism does not match the A_V distribution of SNIa samples at different redshifts (Section 4, Fig. 4, Model B).

(iii) Matching up A_V distributions leads to a \bar{R}_V evolution model that resembles the shape and peak of the observed average dimming of SNeIa (Section 4, Fig. 4, Model C).

(iv) Taken as a worst-case scenario, this model still cannot account for the observed average dimming of SNeIa with redshift.

(v) It is likely that there is evolution in the distribution of A_V values with redshift, making it impossible to deduce \bar{R}_V evolution from these distributions alone. As both affect the precision cosmology to be done with the next generation of SNIa measurements, it is paramount that new SNIa observations solve for both A_V and R_V separately.

(vi) The bonus science of measuring both A_V and R_V for each SNIa is a probe in the distribution, content and composition of dust in their host galaxies.

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