Possible Systematic Effects in SN Ia Standardization with SALT II

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Introduction

Use of SN Ia as distance measures depends on standardization
Currently uses two parameters:

- Stretch/Δm_{15}/etc.
- Color

Residual scatter $\sim 10\%$.

- Random?
- Correlated with host galaxy properties?
- Correlated with parameters that evolve with redshift?

Would like to clear this up for precision cosmology. New SN surveys (SDSS-SN, CfA3) inspire us to try.

Type Ia Light Curve Fitting

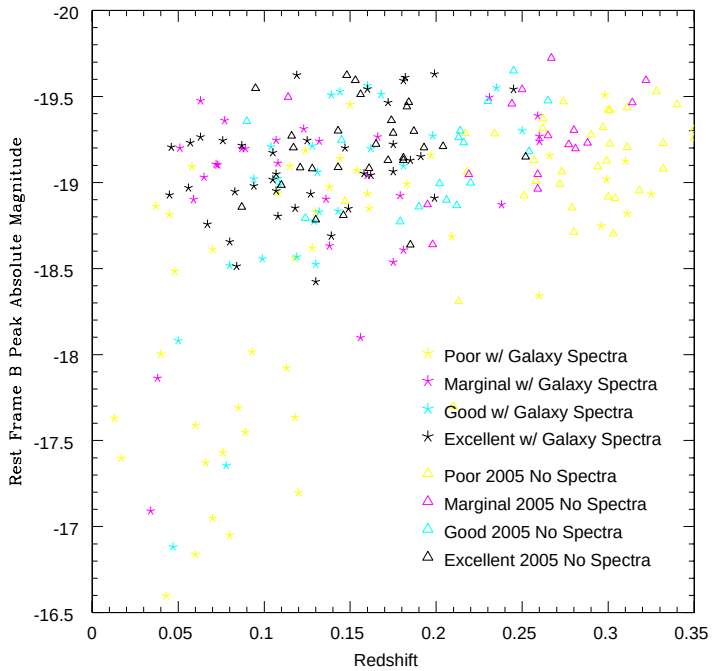
- Use light curve templates to fit and standardize SNe
- SALT: light curve fitter of Guy et al. (2005, 2007)
  - Uses templates derived from nearby, distant SN (we focus on low redshift SN here)
  - Revised version (SALT II, 2007) includes spectral templates
- Procedure:
  - Correct for Milky Way dust
  - Convert light curve to SN rest frame using user-supplied filters
  - Fit all bands simultaneously in rest frame
  - Output fit parameters, light curves in lab frame
- Output parameters:
  - X1 (similar to stretch)
  - Color
  - Rest-frame peak B "magnitude"

The Datasets

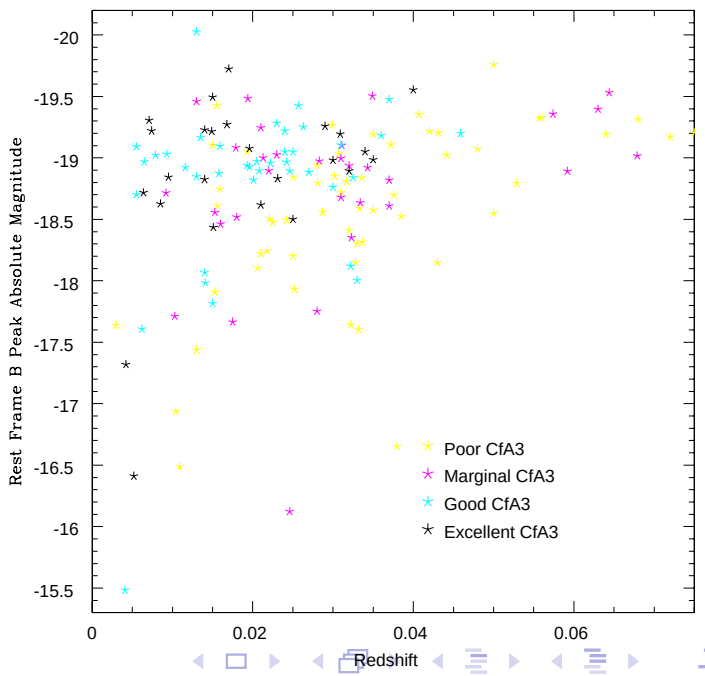
New datasets offer large, uniformly selected samples of Type Ia's.

- SDSS-SN: 246 objects (134 from Holtzman et al. 2008, additional 112 with preliminary data)
  - Data in u, g, r, i, z SDSS filters, but u and z data are poor
- CfA3: 185 objects in U, B, V, R/r', I/i' (Hicken et al. 2009)

SDSS Redshift Distribution



CfA3 Redshift Distribution

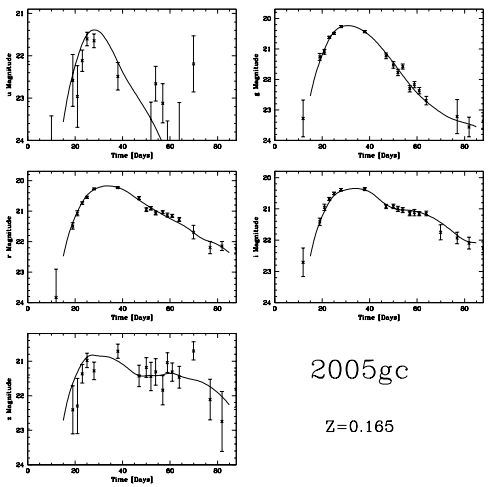


Quality of Observations and Fits

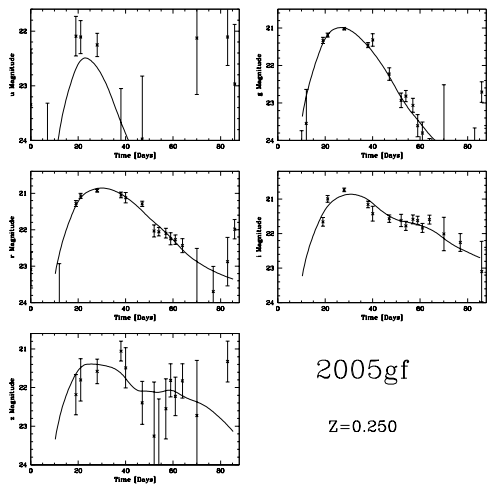
How to measure the data quality?

- SALT II provides standard error both $X1$ and color (C)
- Subjective quality estimates provide an independent measure
- Ratings on a scale from 0 to 3 in each band, based on both data and fit quality:

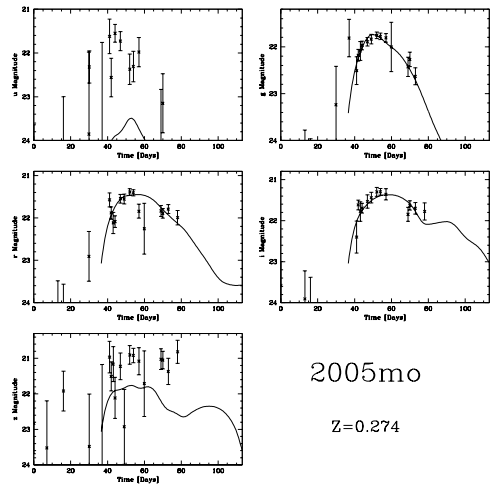
$Q_g = 3 \quad Q_r = 3 \quad Q_i = 3$



$Q_g = 2 \quad Q_r = 2 \quad Q_i = 1$



$Q_g = 1 \quad Q_r = 1 \quad Q_i = 1$



Host Galaxy Properties

Previous work: investigate relations between SN and host galaxy properties derived from broadband colors (Gallagher et al. 2005, Sullivan et al. 2006, etc.)

We use VErsatile SPectral Analysis (Tojeiro et al. 2007), a stellar population synthesis code, to analyze host *spectra* from an SDSS subsample of 138 SNe

- Adaptive: VESPA returns only detail warranted by the data
- Outputs: star formation history, metallicity, dust reddening
- Modest data quality $\Longrightarrow$ star formation condensed into four temporal bins for all objects:
  - 0–74 Myr, 74–425 Myr, 425 Myr–2.44 Gyr, 2.44–14 Gyr

Standardization with SALT II

Simple linear model for standardization:

$$M_B = m_B^* + \alpha \cdot X1 - \beta \cdot C$$

M_B = standardized magnitude, m_B^* = rest-frame peak B "magnitude,"

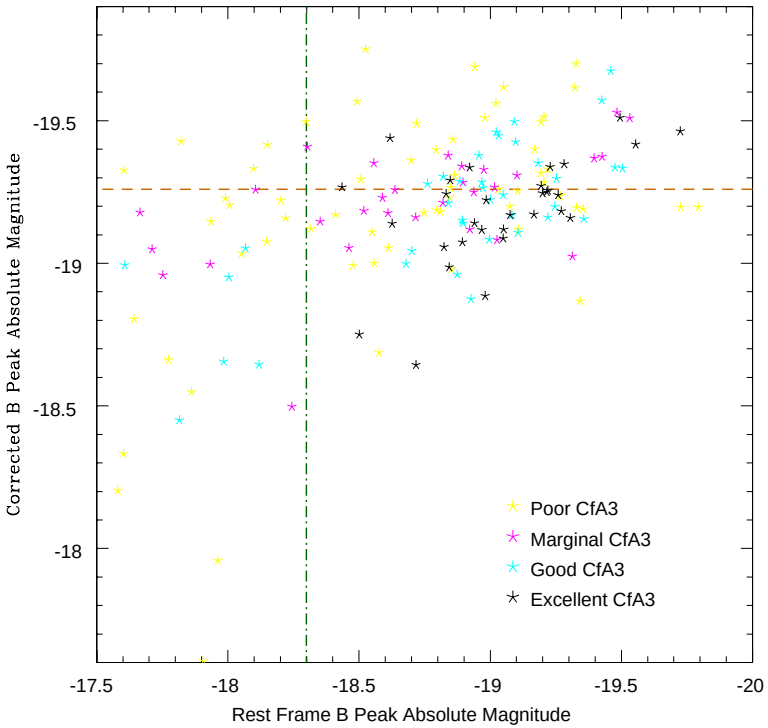
$X1$ = stretch-like parameter, C = color parameter

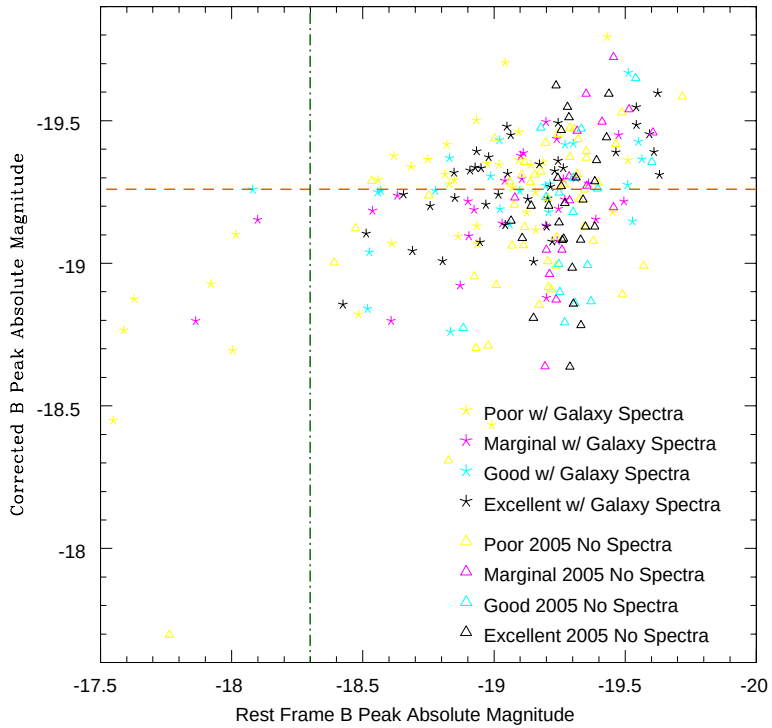
- Often used with distance modulus in place of M_B to fit cosmology simultaneously
- Λ_{CDM} cosmology of Kowalski et al. (2008) assumed here for simplicity ($\Omega_\Lambda = 0.71$)
- α and β derived from a χ^2 fit
  - Intrinsic dispersion σ_{int} added in quadrature to make reduced $\chi^2 = 1$
  - My results: $\sigma_{int} \approx 0.16$ mag

The Fits

Plot standardization result M_B for each survey against the "rest frame B peak absolute magnitude" $M^*_{B_0} = m^*_B - \log\left(D_L/10\mathrm{pc}\right)^2$

- Want a horizontal line with magnitude scatter $\sigma_{int} \approx 0.16$
- Use $\alpha = 0.108$, $\beta = 2.36$, consistent with fits to both surveys





Standardization Results

- Guy's original results (2007, neaby SN, SNLS):
  - $\alpha = 0.13 \pm 0.013$, $\beta = 1.77 \pm 0.16$
- My results, using only quality data ($Q_g + Q_r + Q_i \geq 4$ for SDSS, $Q_U + Q_B + Q_V + Q_{R/r'} + Q_{I/i'} \geq 6$ for CfA3), discarding intrinsically faint SNe ($M_B > -18.3$) and very local SNe (z$<$ 0.01):
  - $\alpha = 0.104 \pm 0.012$, $\beta = 2.33 \pm 0.16$ (SDSS-SN, 145 SN)
  - $\alpha = 0.112 \pm 0.017$, $\beta = 2.40 \pm 0.19$ (CfA3, 76 SN)

Results from two large, uniformly selected, independent surveys agree extremely well with one another.

Reasonable agreement on Phillips parameter α, little agreement with Guy et al. on color.

Systematics of parameters, residuals

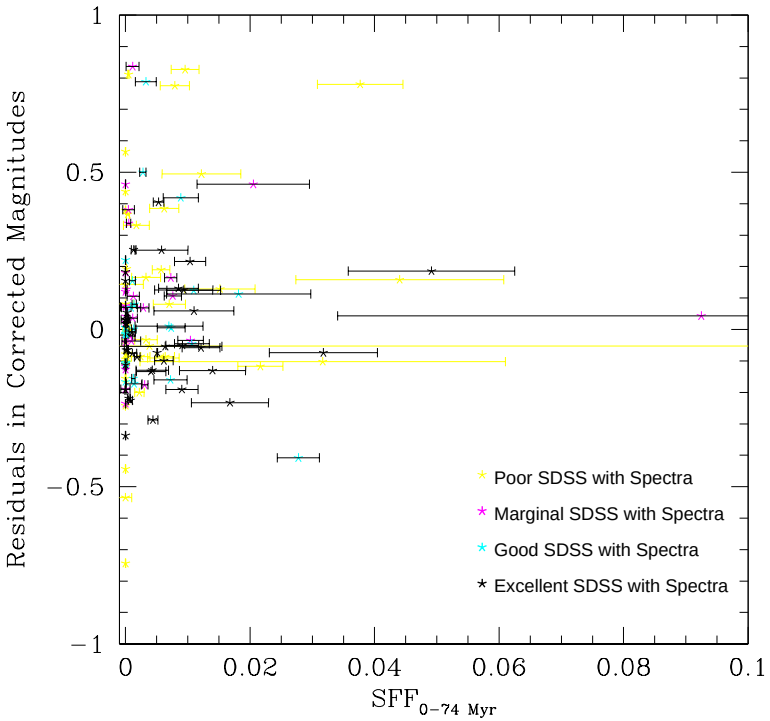
Obvious residual correlation: intrinsically faint objects not sufficiently brightened. Ideas? Other comments/effects:

- β somewhat higher, α smaller for lower (subjective) quality objects
  - Problems handling extinction?
  - Problems with intrinsic color?
- Objects of all subjective quality levels show similar patterns in residuals
- Parameters based on star formation history (e.g. star formation fraction $SFF_{0-74\mathrm{Myr}}$ from VESPA) do not significantly ($> 1.5\sigma$) reduce the residuals
  - SDSS spectra too poor for high signal to noise SFFs

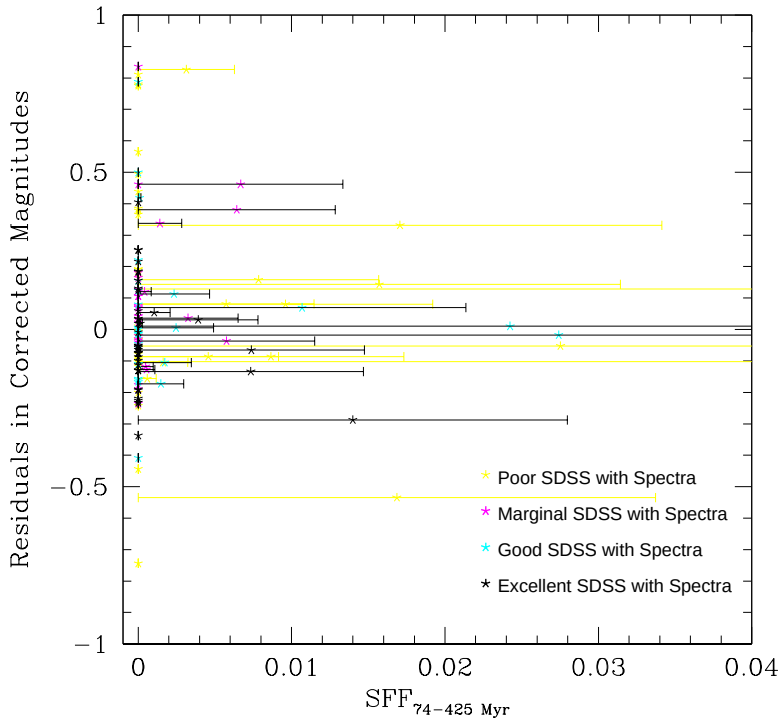
Plots with Star Formation History (I)

No correlation seen between residuals and stellar ages.

Residuals against $SFF_{0-74\mathrm{Myr}}$

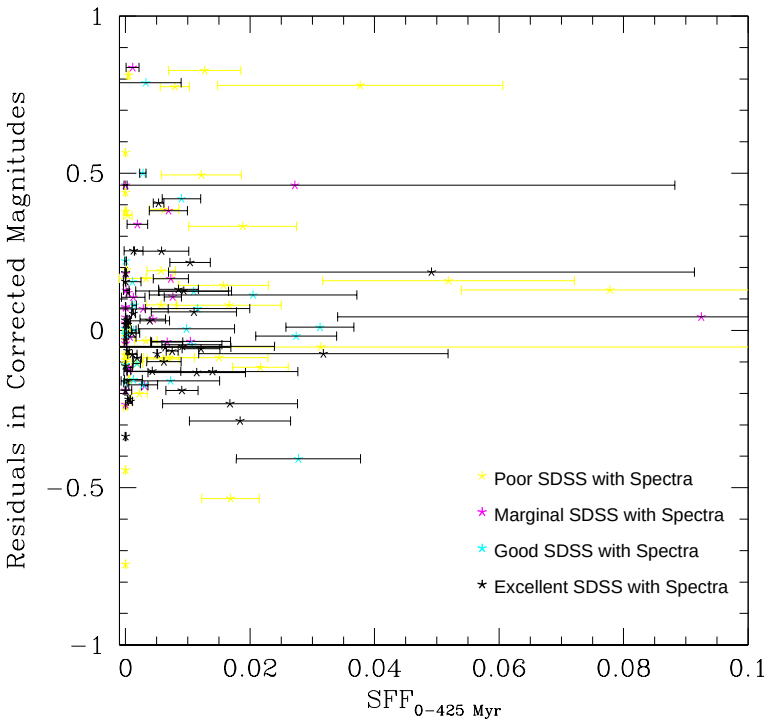


Residuals against $SFF_{74-425\mathrm{Myr}}$

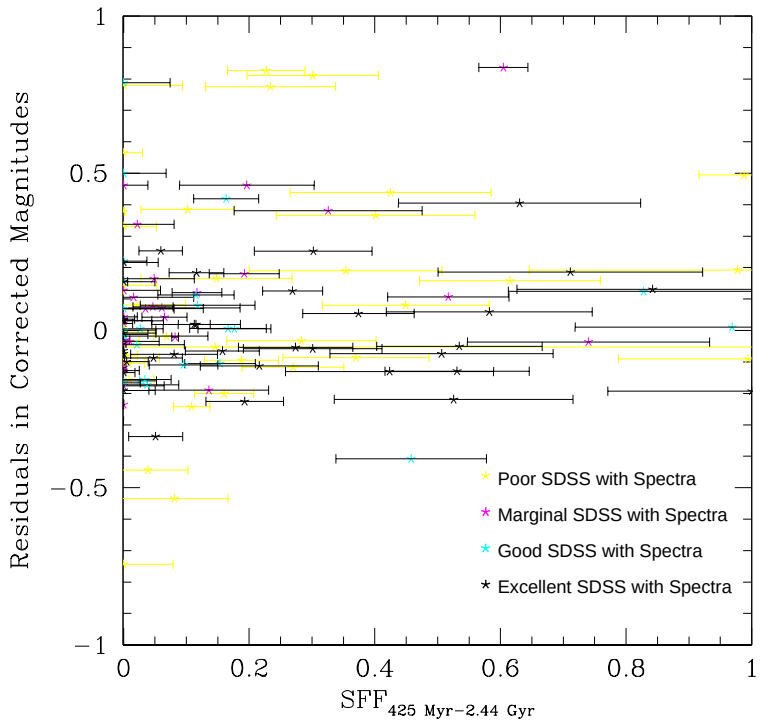


Plots with Star Formation History (II)

Residuals against $SFF_{0-425\mathrm{Myr}}$



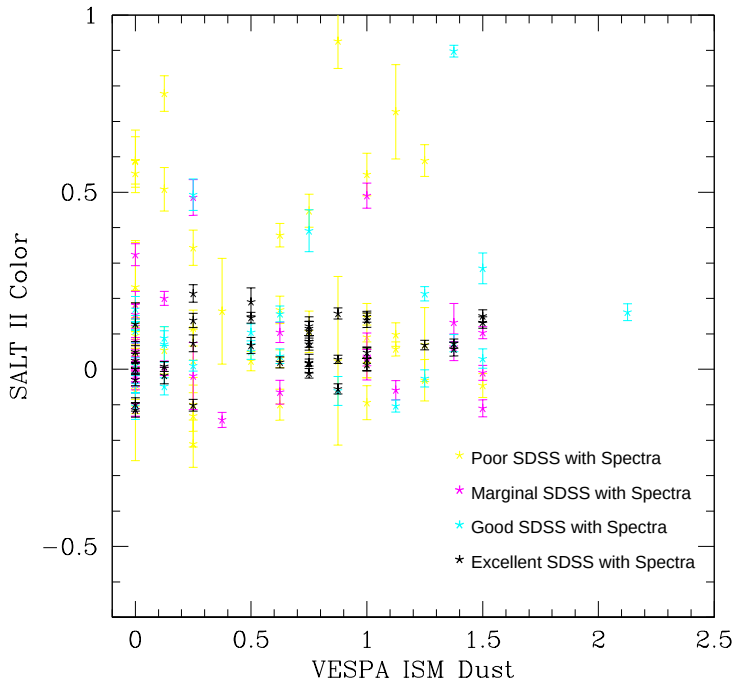
Residuals against $SFF_{425\mathrm{Myr}-2.44\mathrm{Gyr}}$

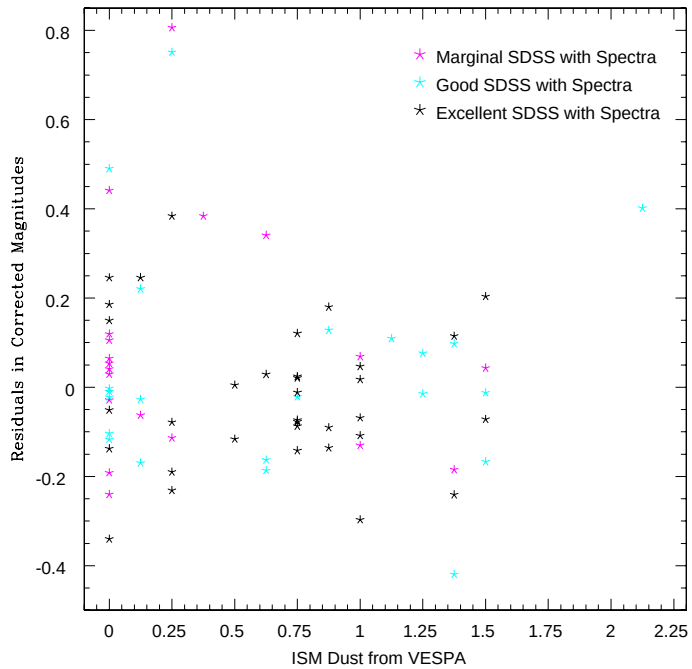


Host Galaxy ISM Dust

Residuals appear uncorrelated with $\tau_V^{\rm ISM}$ as fit by VESPA.
Color parameter C is also uncorrelated. Either:

- VESPA is not recovering ISM dust in the SN neighborhood, or
- Observed SNIa environments are relatively free of dust

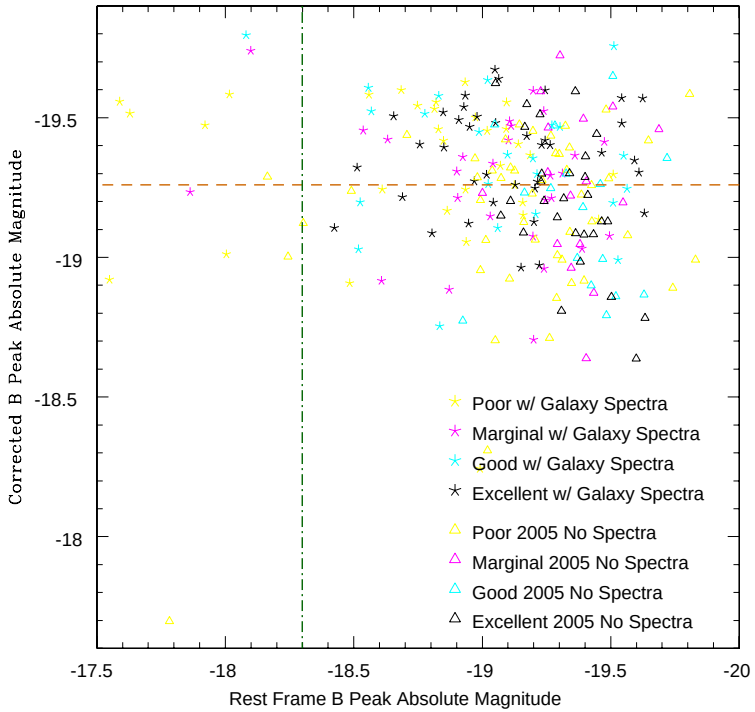




The Intrinsic Dispersion Fudge

Eliminating σ_{int} vastly increases reduced χ^2 (to ~ 7), but eliminates the correlation between "observed peak" and standardized luminosities

- $\alpha \approx 0.13$, $\beta \approx 3.6$ (SDSS-SN) [reduced $\chi^2 \neq 1$, so no errors given]
- Color parameter very different from both Guy's original quoted $\beta = 1.77 \pm 0.17$, earlier fit of $\beta = 2.42 \pm 0.16$
- α (Phillips relation) varies little across samples and fitting methods



Moving Forward

SN are vital distance measures, but the standardization game remains treacherous. Our results:

- Fail to detect any correlation between Type Ia and host galaxy properties; more and better spectra needed (SN Factory, CfA3, etc.!)
- Uncover disturbing evidence of incomplete standardization (faint SNe tend to remain slightly faint even after standardization)
- Highlight our poor understanding of SN color
  - Value of color coefficient β heavily dependent on σ_{int}
  - Color affected by Milky Way dust, host galaxy dust, circumstellar dust, radioactivity (the energy source), and radiative transfer in the expanding ejecta

The residual correlation is particularly disturbing

- Any thoughts?

Thank you!