The Ages of Type Ia Supernova Progenitors

RESCEU/DENET Summer School, Kochi

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Type Ia Supernovae

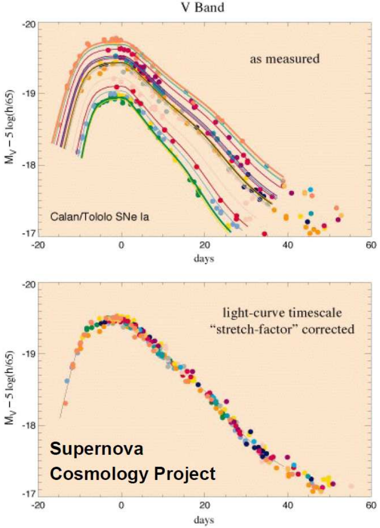
Thermonuclear explosions of accreting C+O white dwarfs

- Energy budget
- Lack of hydrogen in spectra
- Light curve decay

Key Questions:

- Progenitor systems
- Explosion mechanism

Cosmology: Light curve width (*stretch*) - luminosity relation allows calibration of SNe Ia as standard candles



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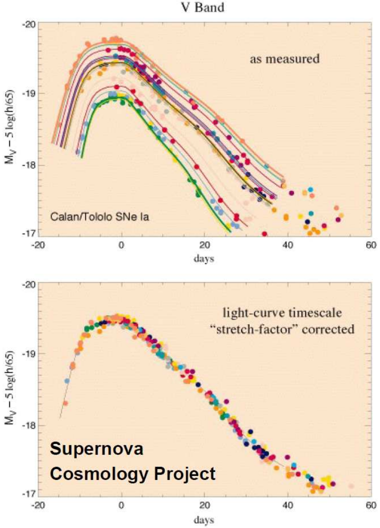


Background

We have never seen a Type Ia supernova progenitor!

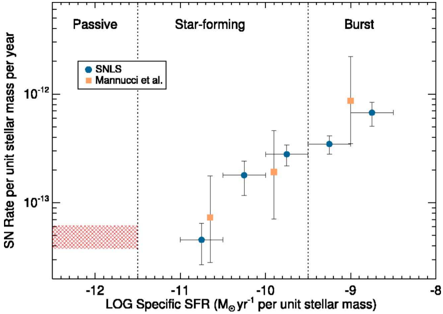
$\Rightarrow$ Statistical analyses of hosts/environments

- Use variation in galaxy properties to constrain progenitor ages

Existing calculations either:

1. Calculate SN Ia rates for different host galaxy types, or
2. Parametrize the supernova rate.
   - Most successful:
     SNR $\sim AM_* + B\dot{M}_*$
     (Scannapieco & Bildsten 2005)

More SNe in star-forming hosts

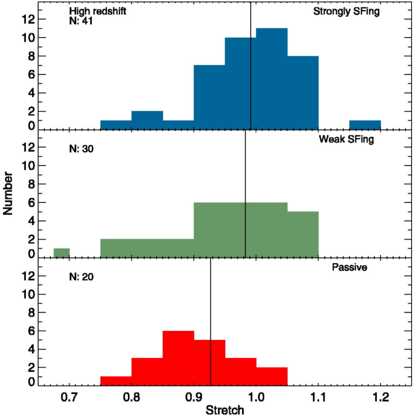


Sullivan et al. (2006)

Background: Prompt Type Ia Supernovae?

- SN rates differ in quiescent vs. star-forming hosts.
- SN *properties* also differ.
  - SNe with wider, *stretched* light curves live in star-forming hosts

High Stretch/Luminous →



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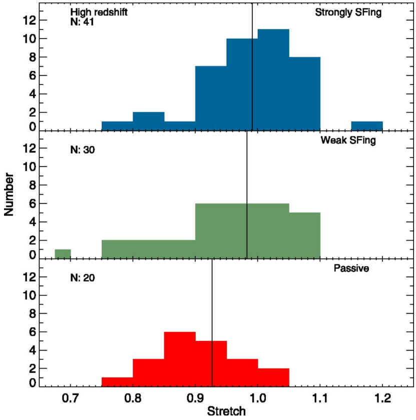
Questions:

1. Are there two populations of Type Ia SNe?
2. What are the ages of Type Ia progenitors?

High Stretch/Luminous →



Sullivan et al. (2006)

Our Work

Sample: SDSS-SN

- Untargeted, difference-imaging survey
- Survey area already well-covered by SDSS spectroscopy

Our analysis:

1. Compare host galaxies of SNe Ia with different properties
2. Perform a Monte-Carlo analysis to constrain SN Ia progenitor ages

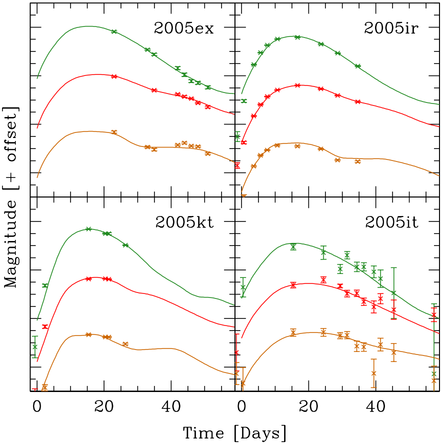
- Confirm and quantify association of luminous, high stretch SNe with young stars

The Data: SDSS-SN

SDSS-SN, part of SDSS II

- Scanned 270 deg^2 repeatedly for a total of nine months
  - $-50^\circ < \mathrm{RA} < 59^\circ$, $-1.25^\circ < \mathrm{Dec} < 1.25^\circ$
- Untargeted: discovered over 400 local ($z \lesssim 0.3$) SNe Ia in a nearly unbiased manner
- Lots of well-sampled light curves

Sample Light Curves



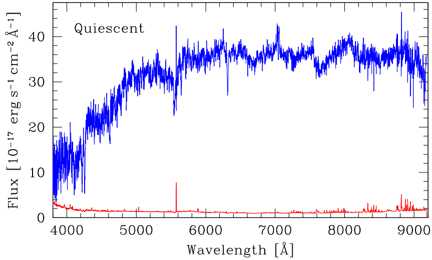
Brandt et al. (2010)

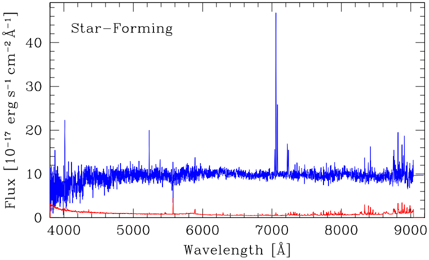
SDSS Stripe 82

SDSS DR7 has spectra of 77,000 galaxies in the area surveyed!

- 133 of the 77,000 were SDSS-SN SN Ia hosts
- Hodge-podge of selection criteria for the 77,000 galaxies, but:
- SN Ia hosts are a real, controlled subsample of the 77,000
- Our sample: select 101 of 133 SNe with well-sampled light curves

$\Rightarrow$ 77,000 *spectroscopic* control galaxies, 101 hosts of well-observed SNe Ia





Star Formation Histories

Stellar population synthesis with VESPA (Tojeiro et al. 2007): star formation histories for 77,000 galaxies

- Spectral: fits entire SDSS spectrum (excluding emission lines)
- Adaptive: recovers higher resolution star formation histories only when warranted

We degrade all star formation histories to three bins to minimize systematics

- Uncertainties in dust modeling
- Uncertainties in modeled stellar spectra

Bin	Age Range (Gyr)	MS Spectral Types
1	0.002 – 0.42	O and B
2	0.42 – 2.4	A
3	2.4 – 14	F and later

Two Populations

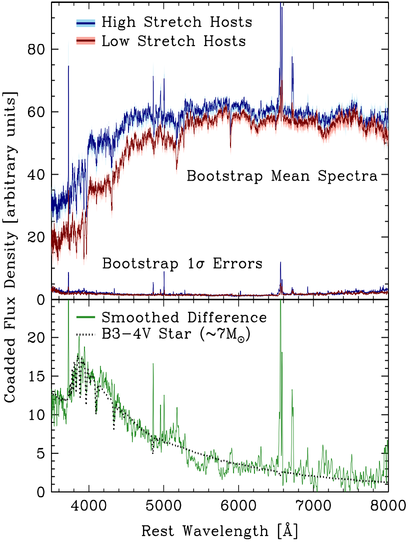
Association of high stretch SNe, young populations clear in earlier work

Can we see it in our host spectra?

- Divide the sample at $s = 0.92$
- Coadd spectra of high and low stretch hosts separately
- Use bootstrap resampling to derive means and variances

The difference between high and low stretch hosts is a B star plus nebular emission lines!

$\Rightarrow$ Two populations, no black box!



Supernova Rates

We really want the supernova rate as a function of progenitor age: the Delay Time Distribution (DTD):

- Explosion rate ε for stars of a given age
- Units: $\mathrm{SN\,yr^{-1}\,M_\odot^{-1}}$
- Three age bins i, two kinds of SN (high stretch h and low stretch l) $\Rightarrow$ six rates $\varepsilon_{h,i}$ and $\varepsilon_{l,i}$

Total Type Ia supernova rate is:

$$\mathrm{SNR} = \sum_{i=1}^{3} \varepsilon_{h,i} M_i + \sum_{i=1}^{3} \varepsilon_{l,i} M_i,$$

- $i \in \{1, 2, 3\}$ = age bin, $\quad M_i$ = total stellar mass in age bin i

Our Method

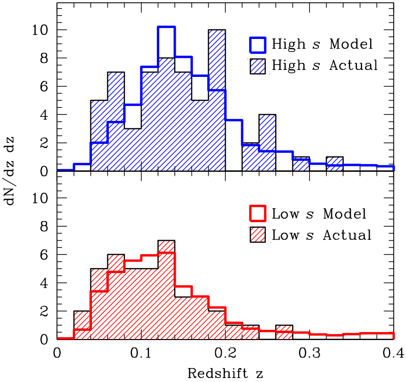
Towards a DTD

- Use Monte Carlo to explore ε_i parameter space
- Generate a sample of mock hosts using

$$\text{SNR} = \sum_{i=1}^{3} \varepsilon_{h,i} M_i + \sum_{i=1}^{3} \varepsilon_{l,i} M_i .$$

$\Rightarrow$ Construct detection efficiency to reproduce SN redshifts.

- Compute a likelihood for each DTD realization.



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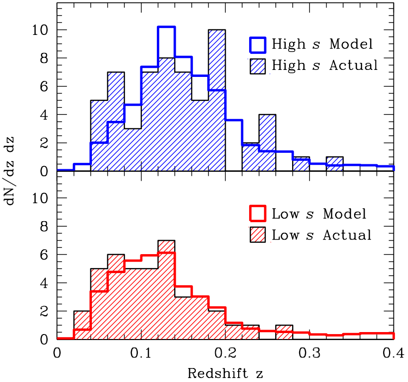


A Likelihood Function: Comparing Average Spectra

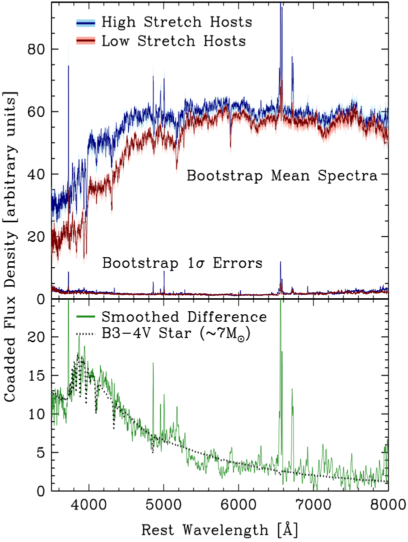
Compute average spectra of mock hosts, do a χ^2 comparison to observed spectra

Advantages:

- No stellar population synthesis on actual hosts
- Random errors in recovered stellar masses average out
- Very weak dependence on detection function

Disadvantages:

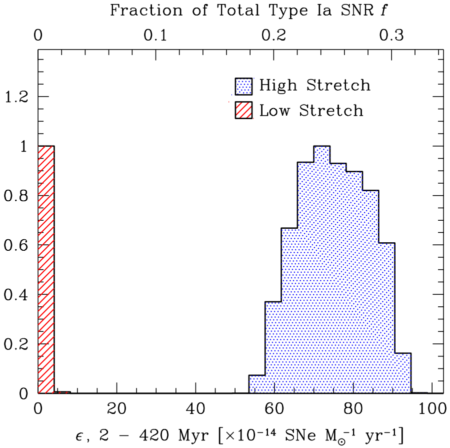
- Bootstrap errors too conservative?



Posterior Probability Distributions

Compare average spectra to generate posterior probability distributions for:

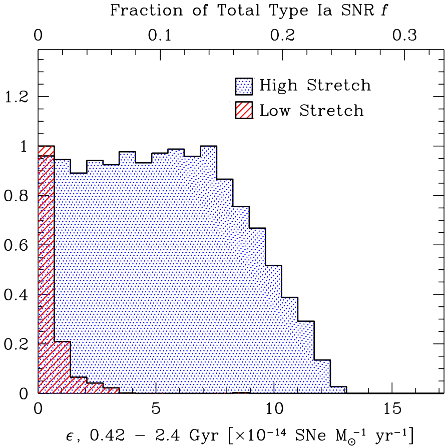
Young (O and B) stars



Posterior Probability Distributions

Compare average spectra to generate posterior probability distributions for:

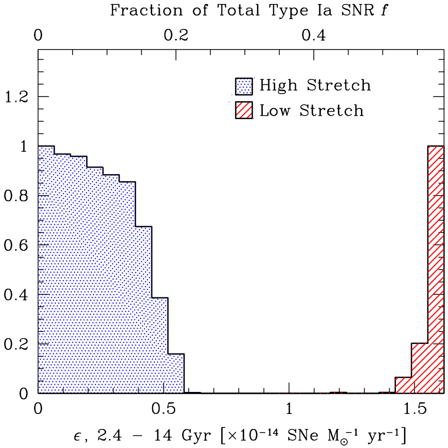
Middle-aged (A) stars



Posterior Probability Distributions

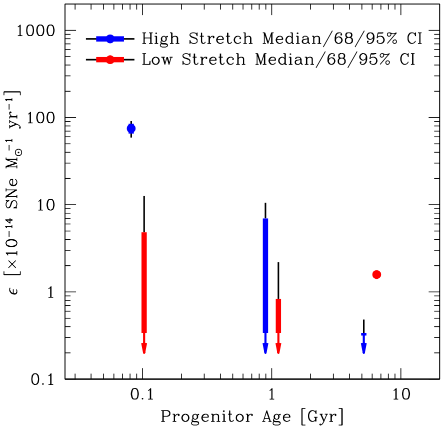
Compare average spectra to generate posterior probability distributions for:

Old (F and later) stars



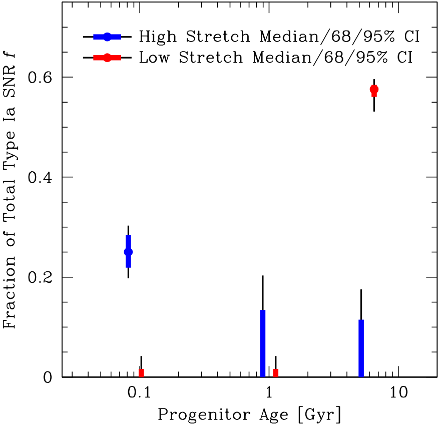
Posterior Probability Distributions

The DTD in Physical Units:



Posterior Probability Distributions

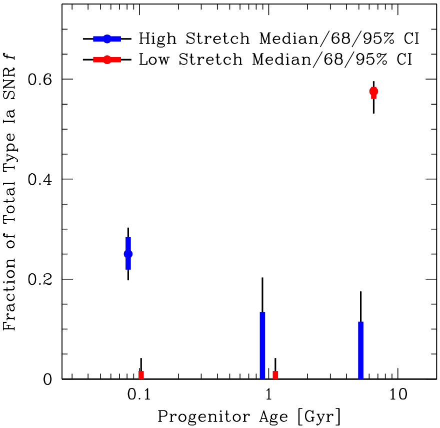
The DTD as Fractions of the Local Type Ia Rate:



Posterior Probability Distributions

The DTD as Fractions of the Local Type Ia Rate:

- Most high stretch SNe have progenitors younger than ~ 400 Myr
  - Average spectra hint at an age ~ 50 Myr
- Most low stretch SNe have progenitors older than 2-3 Gyr



Future Prospects

Two main avenues for improvement:

1. Shrink the error bars
   - Need more SNe
2. Improve the temporal resolution of the DTD
   - Need better stellar models and/or UV data

Spectroscopy of all SDSS-SN hosts is ongoing, could be ~ 300 objects with stretches

- Also need a deep, volume-limited spectroscopic control sample (Galaxy And Mass Assembly, GAMA?)

GALEX photometry can be added to our sample now

- How much new information can we recover?

Summary

We know there are two populations.

- Luminous SNe Ia are from stars $\lesssim$ 400 Myr
- Subluminous SNe Ia are from stars $\gtrsim$ 2 - 3 Gyr
- Precise age ranges are unclear, improvements will require better stellar spectral modeling

We don't know whether this matters for cosmology.

We still don't know what the physical progenitors are.