The Ages of Type Ia Supernova Progenitors

IAP Colloquium

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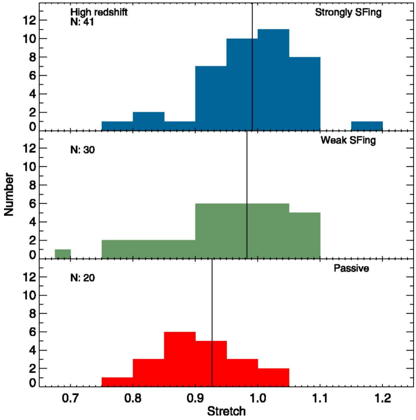
Background: Prompt Type Ia Supernovae?

- 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 →



Sullivan et al. (2006)

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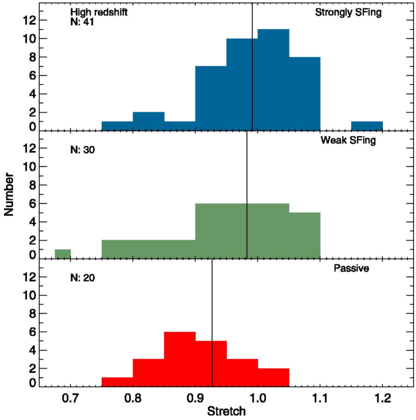
Questions:

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

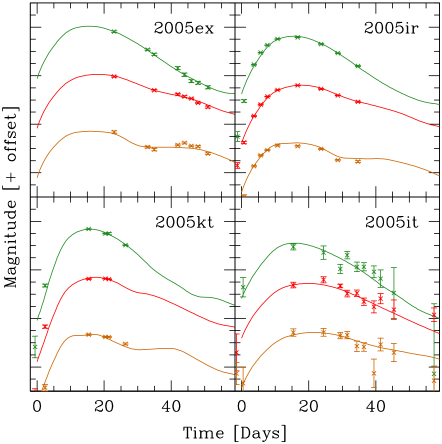
- Confirm and quantify association of luminous, high stretch SNe with young stars

The Data: SDSS-SN

SDSS-SN, part of SDSS II

- Scanned 270 deg^2 repeatedly for a total of nine months
  - $-50° < \mathrm{RA} < 59°$, $-1.25° < \mathrm{Dec} < 1.25°$
- 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



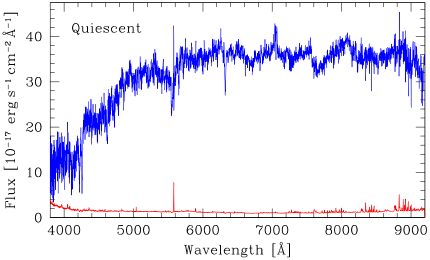
Brandt et al. (2010)

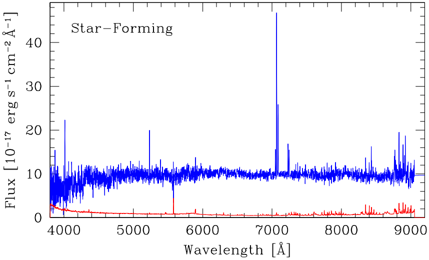
SDSS Stripe 82

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

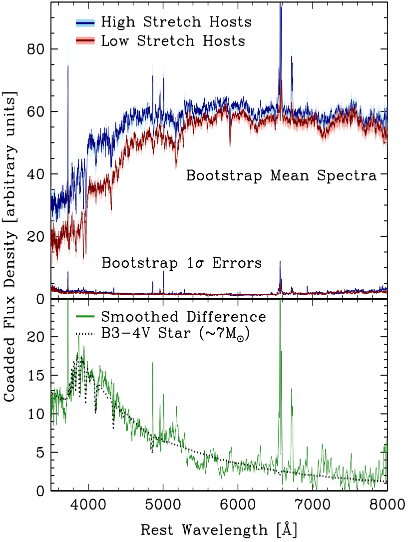
Association of high stretch SNe, young populations clear in earlier work

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: $\mathrm{SN}\,\mathrm{yr}^{-1}\,\mathrm{M}_{\odot}^{-1}$
- 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, M_i = total stellar mass in age bin i

Our Method

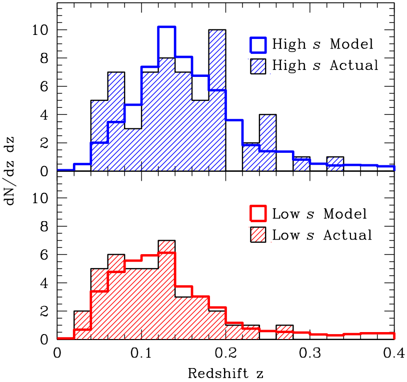
Towards a DTD

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

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

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

- Compute a likelihood for each DTD realization.



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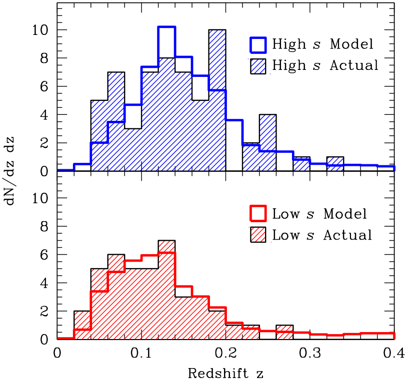


A Likelihood Function: Comparing Average Spectra

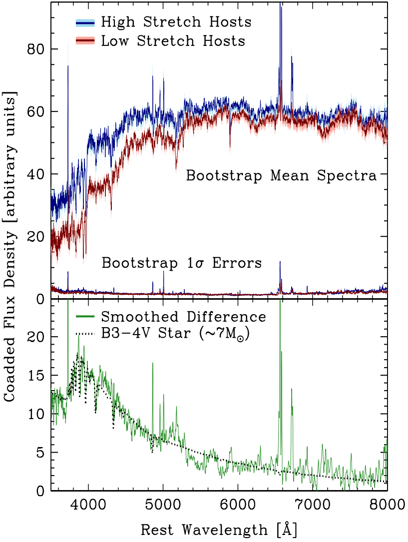
Compute average spectra of mock hosts, do a χ^2 comparison to observed spectra

Advantages:

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

Disadvantages:

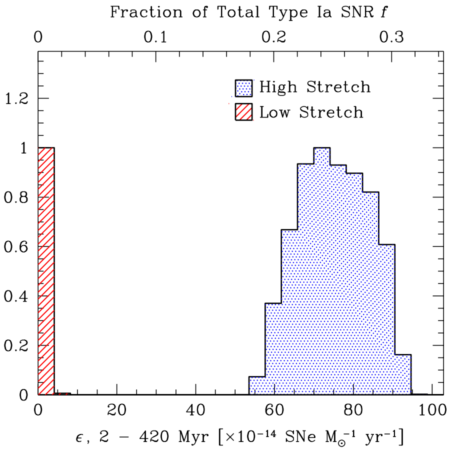
- Bootstrap errors too conservative?



Posterior Probability Distributions

Compare average spectra to generate posterior probability distributions for:

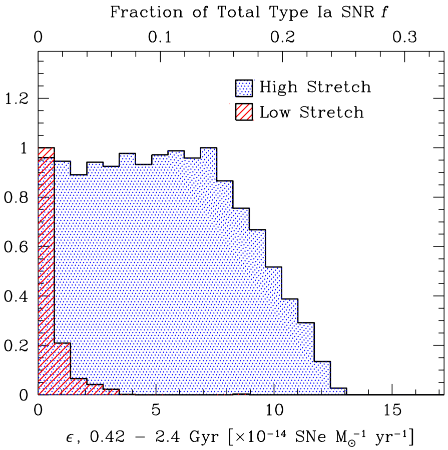
Young (O and B) stars



Posterior Probability Distributions

Compare average spectra to generate posterior probability distributions for:

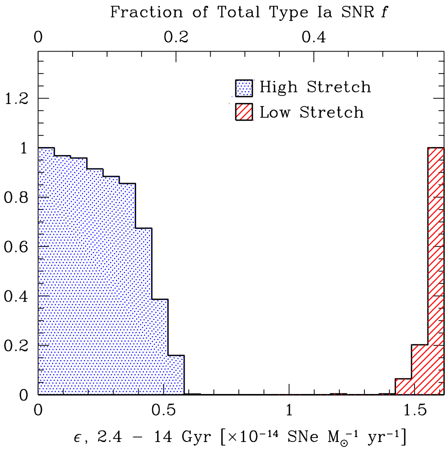
Middle-aged (A) stars



Posterior Probability Distributions

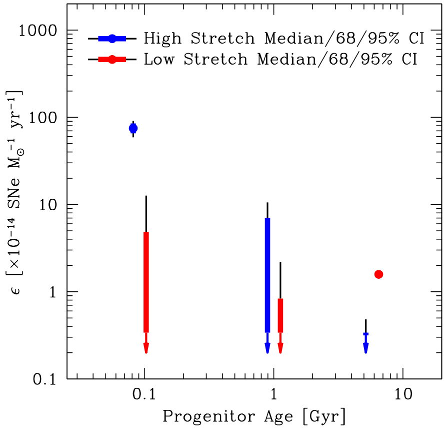
Compare average spectra to generate posterior probability distributions for:

Old (F and later) stars



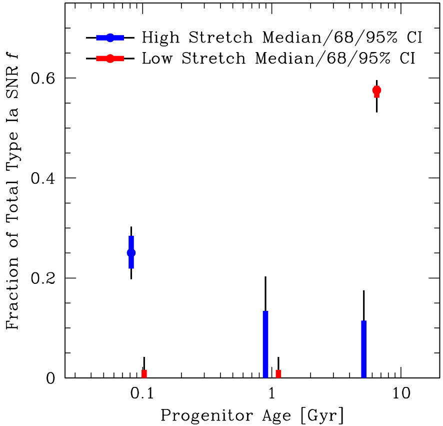
Posterior Probability Distributions

The DTD in Physical Units:



Posterior Probability Distributions

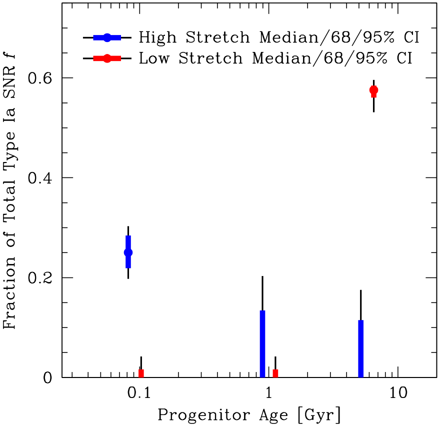
The DTD as Fractions of the Local Type Ia Rate:



Posterior Probability Distributions

The DTD as Fractions of the Local Type Ia Rate:

- Most high stretch SNe have progenitors younger than $\sim$ 400 Myr
  - Average spectra hint at an age $\sim$ 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

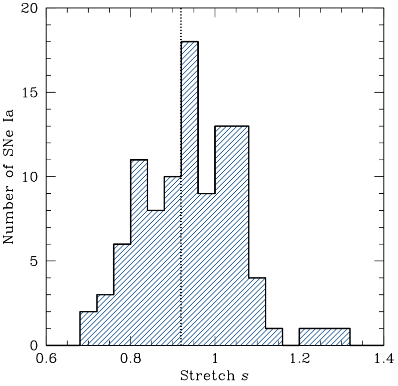
We don't know whether this matters for cosmology.

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

Two Populations?

Make a stretch histogram for 104 SNe Ia

More Luminous $\longrightarrow$



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Make a stretch histogram for 104 SNe Ia

Weight each SN by its host galaxy's average star formation rate in a given age bin.

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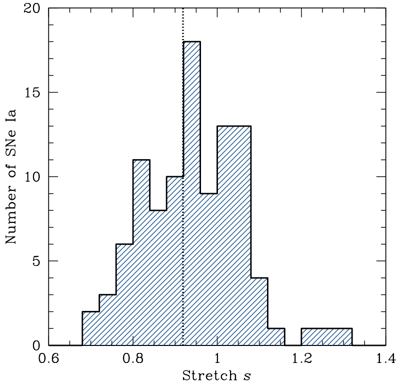

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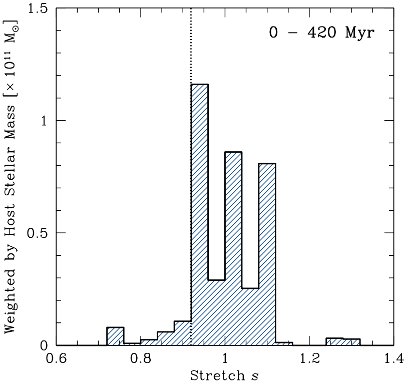

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Make a stretch histogram for 104 SNe Ia

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- High stretch SNe Ia associated with recent star formation

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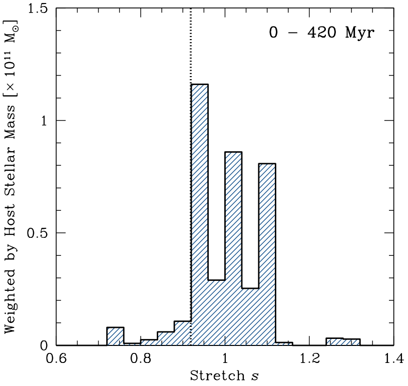

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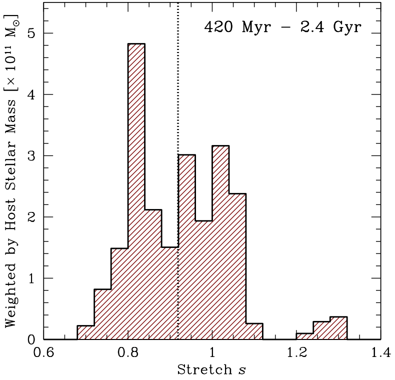

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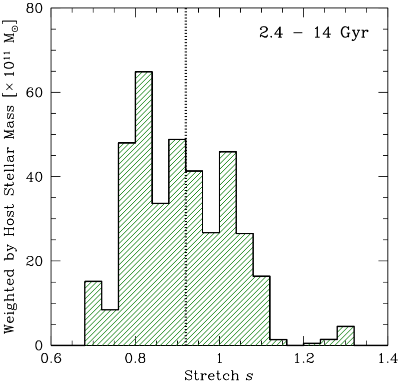

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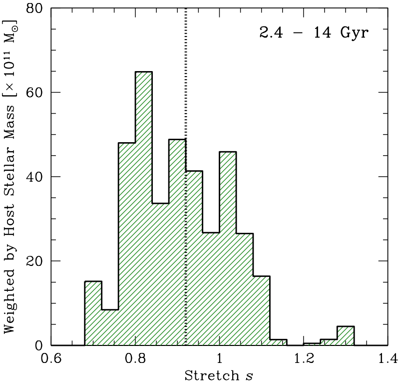
- High stretch SNe Ia associated with recent star formation
- Low stretch SNe associated with old star formation

More Luminous $\longrightarrow$



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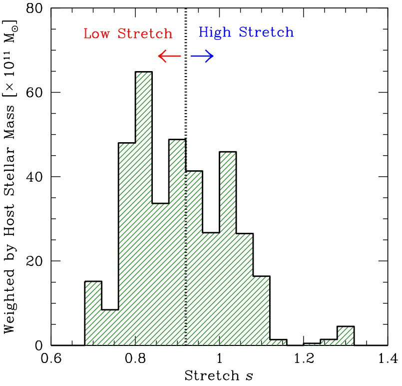

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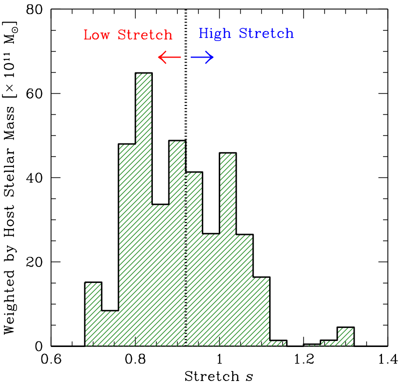

Two populations? Yes.