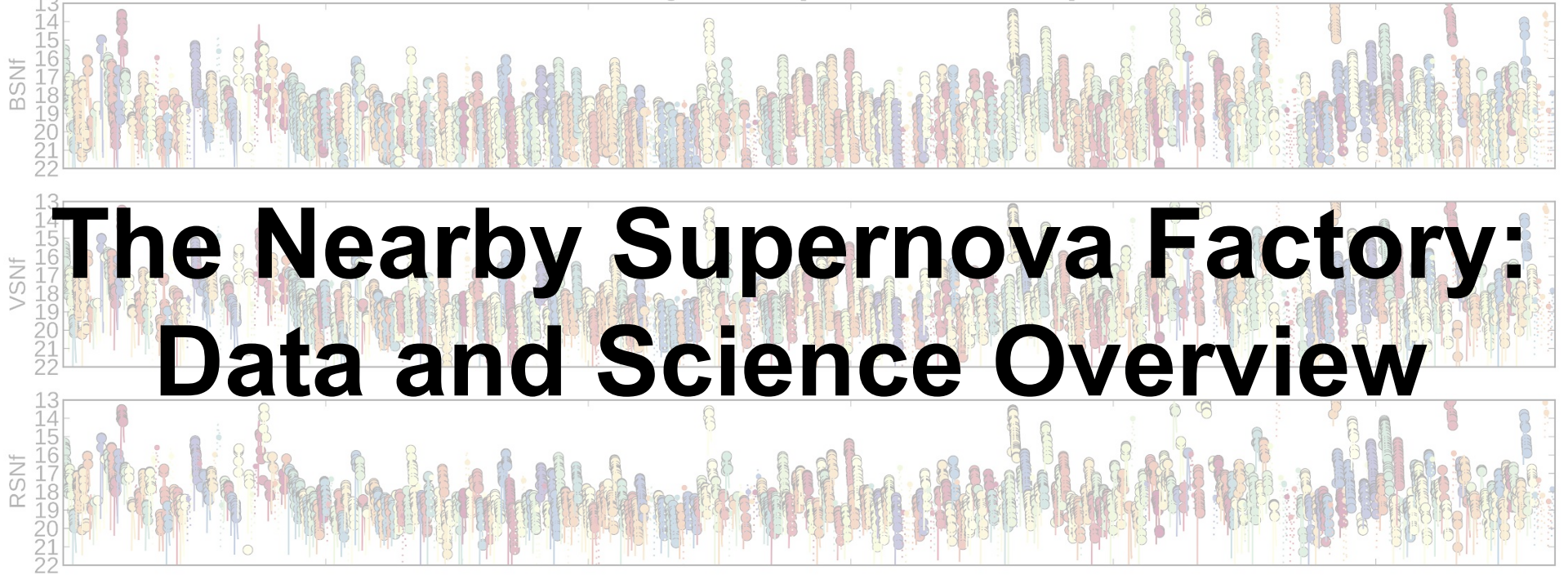

The Nearby Supernova Factory: Data and Science Overview

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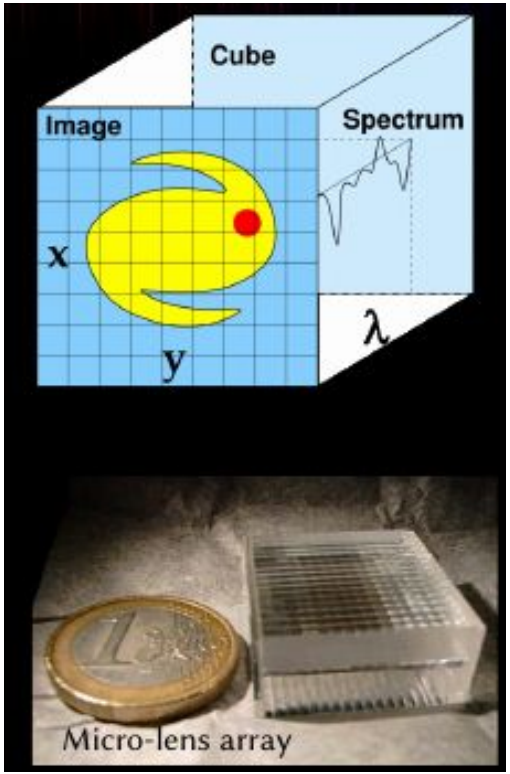
BERKELEY LAB

BERKELEY CENTER *for* COSMOLOGICAL PHYSICS

Overview of SNfactory

G. Aldering, P. Antilogus, S. Bailey, C. Baltay, S. Bongard, K. Boone, C. Buton, N. Chotard, Y. Copin, S. Dixon, D. Fouchez, E. Gangler, R. R. Gupta, B. Hayden, W. Hillebrandt, X. Huang, A. G. Kim, M. Kowalski, P.-F. Leget, F. Mondon, J. Nordin, R. Pain, E. Pecontal, R. Pereira, S. Perlmutter, K. A. Ponder, D. Rabinowitz, M. Rigault, D. Rubin, K. Runge, G. Smadja, C. Saunders, S. Taubenberger, C. Tao, R. C. Thomas

- Worldwide collaboration (US, France, Germany, China)
- UH 2.2 m Telescope with SNIFS
- Integral Field Spectroscopy (IFU)
- Dominated by targets from dedicated, unbiased SN searches
- Spectrophotometric time series of over 300 SNeIa
- Wavelength coverage: 3200 - 10,000 Å
- Median number of epochs: 14
- $0.02 < z \lesssim 0.08$



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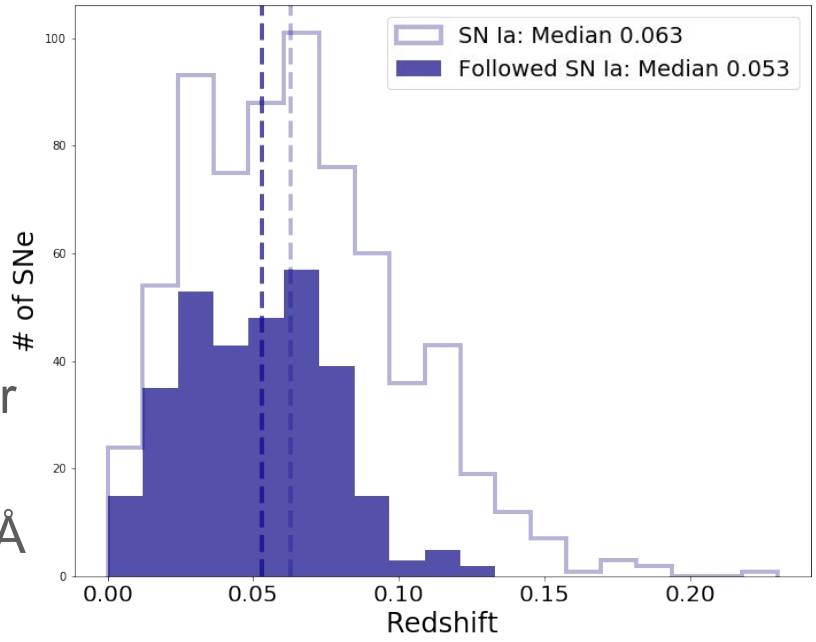
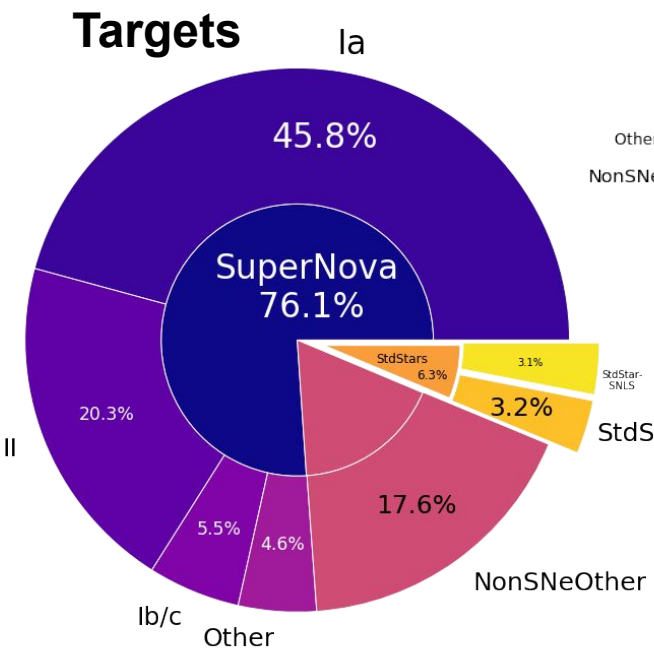
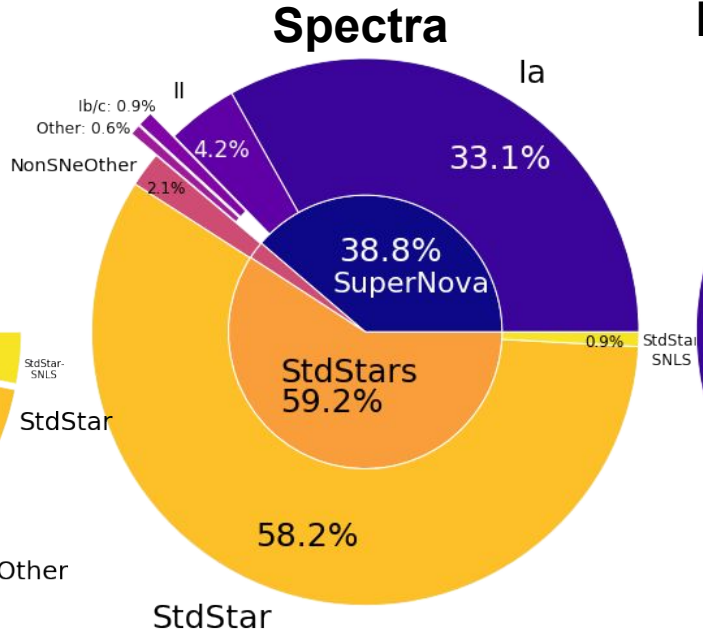
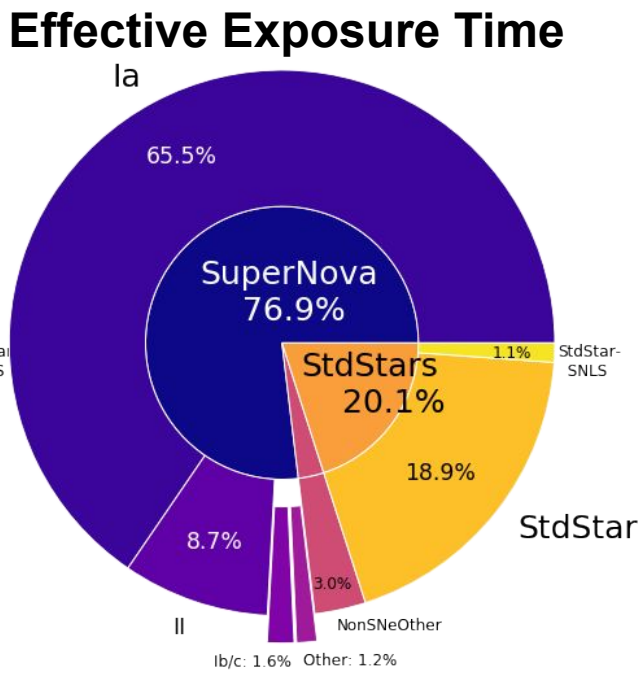








- First Comprehensive Data release expected early 2020 with
  - 927 Supernova
  - 577 SNe Ia
  - 45 Standard Stars

Note: Pie charts show full database not necessarily release statistics.

Science with SNfactory data

Recent and Upcoming Papers

- Comprehensive Data Release :
  - Pipeline
  - w-Cosmology
  - Calibration
  - SNIFS
  - SN Search
- SNEMO - Saunders et al. (2018)
  - arXiv:1810.09476
- SUGAR - Leget et al. (accepted)
  - arXiv: 1909.11239

- **SN 2011by + 11fe - Xiaosheng Huang**
- **Third Color Parameter - Alex Kim**
- **Manifold Twins - Kyle Boone**

Talks at SCAM

- SNEMO - Ben Rose
  - **Wed 2:00 PM - 2:20 PM**
- SNEMO - Sam Dixon
  - **Wed 2:20 PM - 2:40 PM**
- SUGAR - Florian Mondon
  - **Wed 2:40 PM - 3:00 PM**
- SNfactory Calibration - Greg Aldering
  - **Thurs 9:00 AM - 9:20 AM**
- Host Galaxy Studies - Mickael Rigault
  - **Thurs 4:20 PM - 4:40 PM**

Comparing SN 2011by & SN 2011fe

Xiaosheng Huang

References:

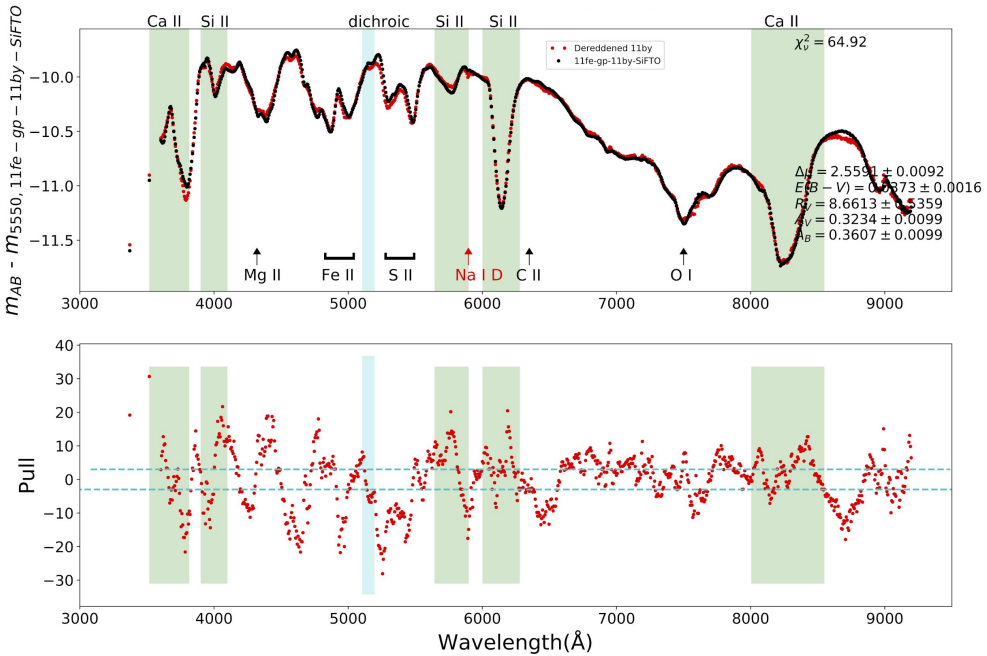
- Huang + SNfactory (2017)
- Pereira + SNfactory (2013)
- Fakhouri, Boone + SNfactory (2015)
- Foley & Kirshner (2013)
- Graham et al (2015)
- Foley et al (2018)

Comparison between “twins” SN 2011fe and SN 2011by

- We have shown spectrophotometric “twins” have per-object RMS ~ 0.08 mag
- SN 2011by and SN 2011fe are spectrally similar
- Cepheid-based distances have suggested they are not photometric twins at 4σ , i.e. they have different brightnesses (Foley+2018)
- SNfactory observed
  - 11by at 7 phases
  - 11fe at 32 phases

Using the extinction curve from Fitzpatrick (1999), we simultaneously fit for E(B-V), R_V, and the difference in distance modulus (Δμ). As in Huang++(2017).

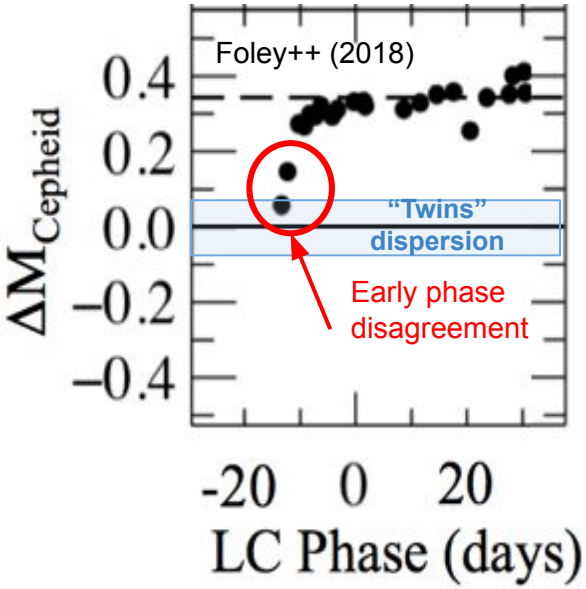
Phase: +5.9 days



SN 2011by (dereddened + Δμ-corrected)
SN 2011fe (interpolated)

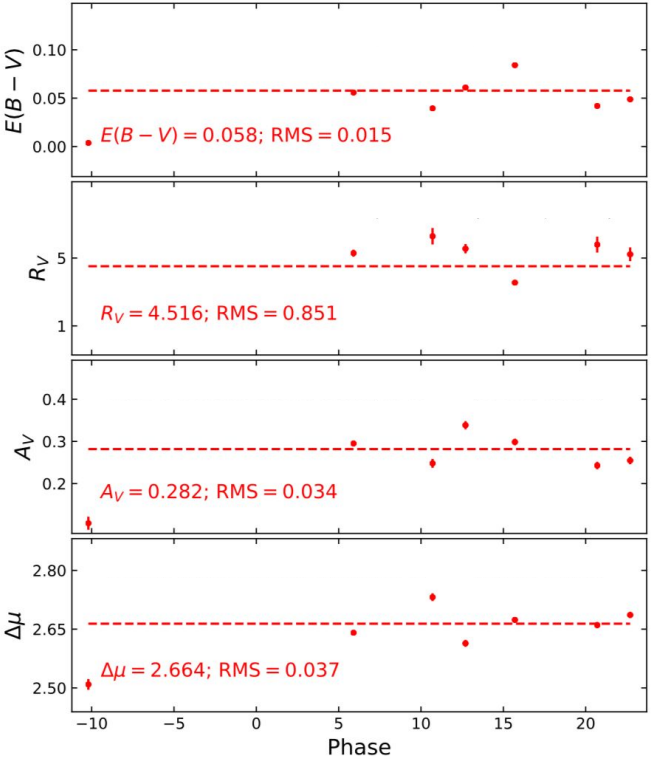
Slides from Xiaosheng Huang

Comparison between “twins” SN 2011fe and SN 2011by



- Accounting for twins dispersion lowers tension to 2.6σ
- **Not really twins** at early phases causing error in relative phase determination
- Removing -10 day LC point shifts relative phase by 1 day
- RMS is 2x better and results in more dust
- Lowers the Cepheid and twins tension to 1.8σ

Results
(Δμ=distance modulus difference)



Slides from Xiaosheng Huang

Evidence for Third Color Parameter

Alex Kim

Modeling SN Ia Colors

- Broad-band (UBVRI) synthesized magnitudes at peak

Intercept

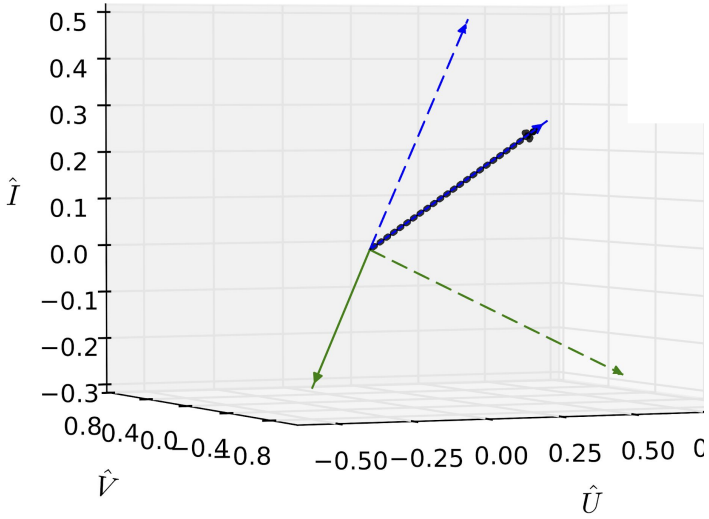
Color Terms

grey offset

$$\begin{pmatrix}\hat{U}\\ \hat{B}\\ \hat{V}\\ \hat{R}\\ \hat{I}\end{pmatrix} = \Delta\vec{1} + \begin{pmatrix}c_{\hat{U}}\\ c_{\hat{B}}\\ c_{\hat{V}}\\ c_{\hat{R}}\\ c_{\hat{I}}\end{pmatrix} + a\begin{pmatrix}\alpha_{\hat{U}}\\ \alpha_{\hat{B}}\\ \alpha_{\hat{V}}\\ \alpha_{\hat{R}}\\ \alpha_{\hat{I}}\end{pmatrix} + b\begin{pmatrix}\beta_{\hat{U}}\\ \beta_{\hat{B}}\\ \beta_{\hat{V}}\\ \beta_{\hat{R}}\\ \beta_{\hat{I}}\end{pmatrix}$$

- Fitting this linear model…

- … yields α and β consistent with the Fitzpatrick (1999) dust model



α and β (solid) and Fitzpatrick model (dashed) span the same plane in color space

Slides from Alex Kim

Add One More Latent Color Parameter to the Model

- α and β still consistent with the Fitzpatrick dust model
- New color vector φ detected at high signal-to-noise (>99% confidence)
- New SN color parameter "p" is correlated with host mass at 2σ

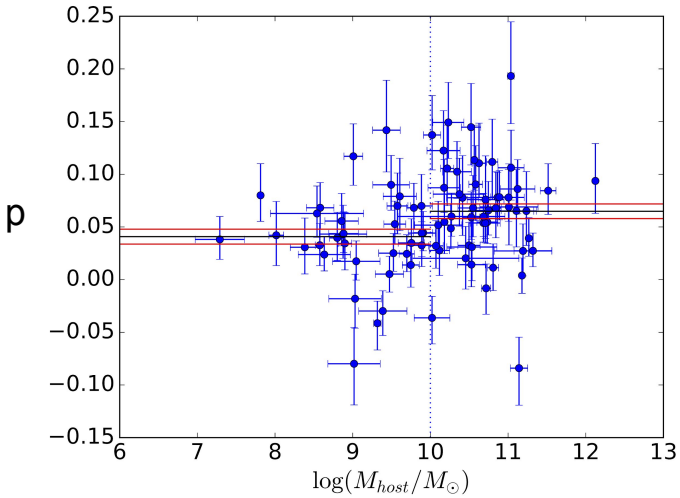
grey offset

Intercept

Proxy for dust Color terms

New Color term

$$\begin{pmatrix}\hat{U}\\ \hat{B}\\ \hat{V}\\ \hat{R}\\ \hat{I}\end{pmatrix} = \Delta\vec{1} + \begin{pmatrix}c_{\hat{U}}\\ c_{\hat{B}}\\ c_{\hat{V}}\\ c_{\hat{R}}\\ c_{\hat{I}}\end{pmatrix} + a\begin{pmatrix}\alpha_{\hat{U}}\\ \alpha_{\hat{B}}\\ \alpha_{\hat{V}}\\ \alpha_{\hat{R}}\\ \alpha_{\hat{I}}\end{pmatrix} + b\begin{pmatrix}\beta_{\hat{U}}\\ \beta_{\hat{B}}\\ \beta_{\hat{V}}\\ \beta_{\hat{R}}\\ \beta_{\hat{I}}\end{pmatrix} + p\begin{pmatrix}\phi_{\hat{U}}\\ \phi_{\hat{B}}\\ \phi_{\hat{V}}\\ \phi_{\hat{R}}\\ \phi_{\hat{I}}\end{pmatrix}$$



Slides from Alex Kim

Manifold Twins

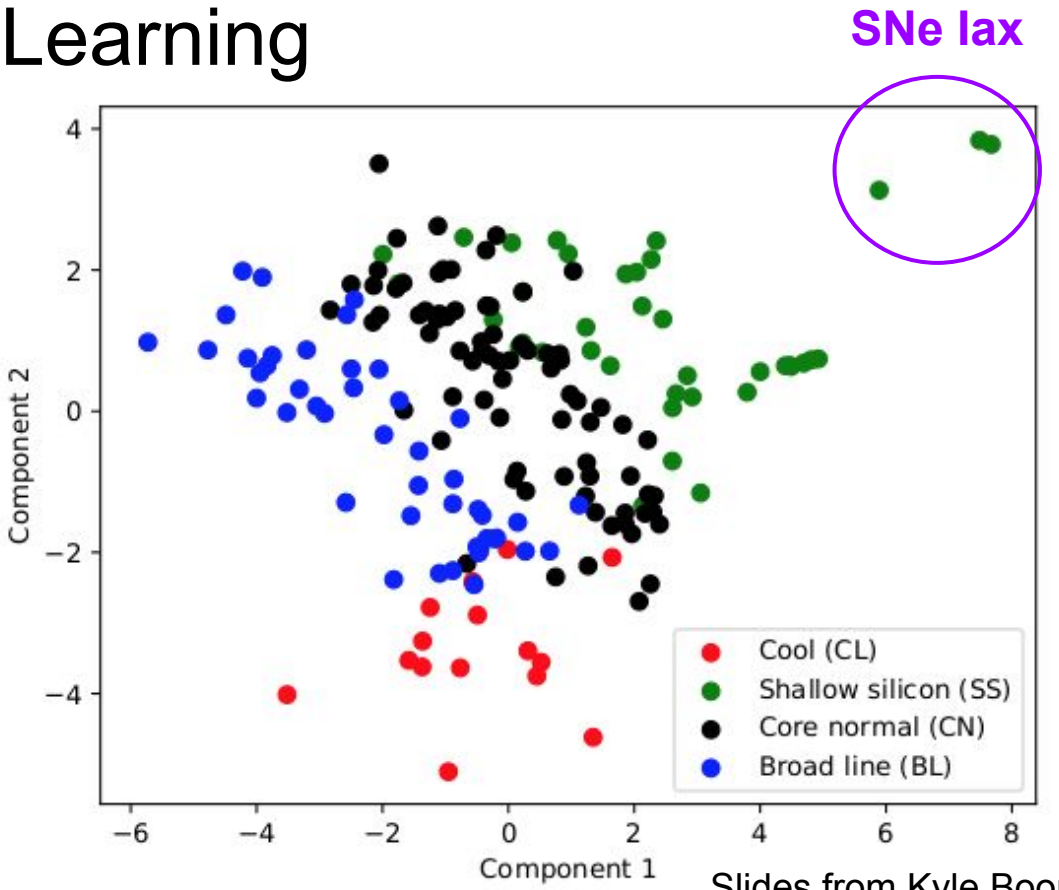
Kyle Boone

References:

- Fakhouri, Boone + SNfactory (2015)

Mapping SN Ia Diversity with Manifold Learning

- Using manifold learning we can parametrize the diversity of the spectra of SNe Ia at maximum light.
- We find that 3 nonlinear components are required (versus SALT2 which only uses 1 linear component: x1)
- Dispersion at 0.082 mag*



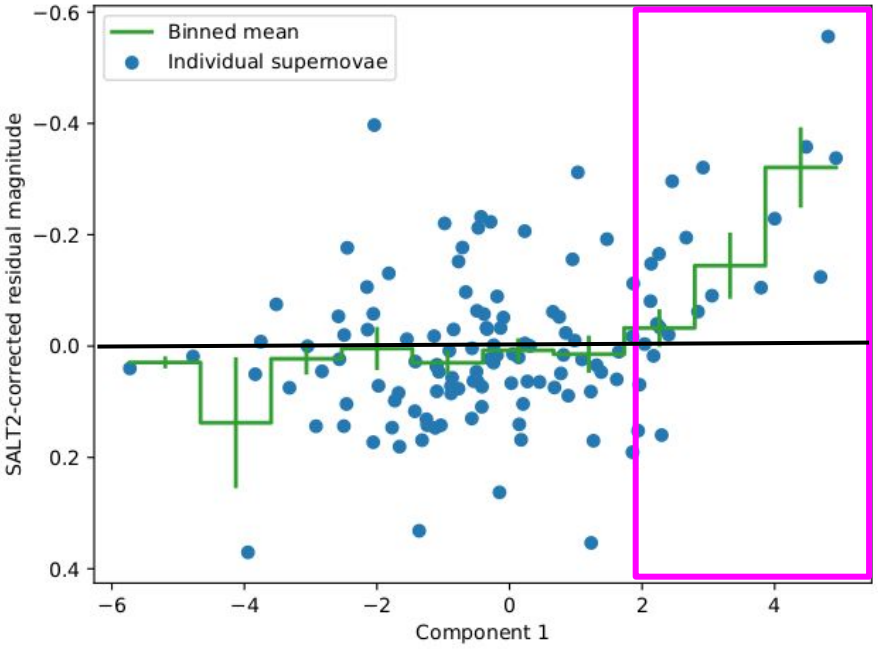
* for training dataset

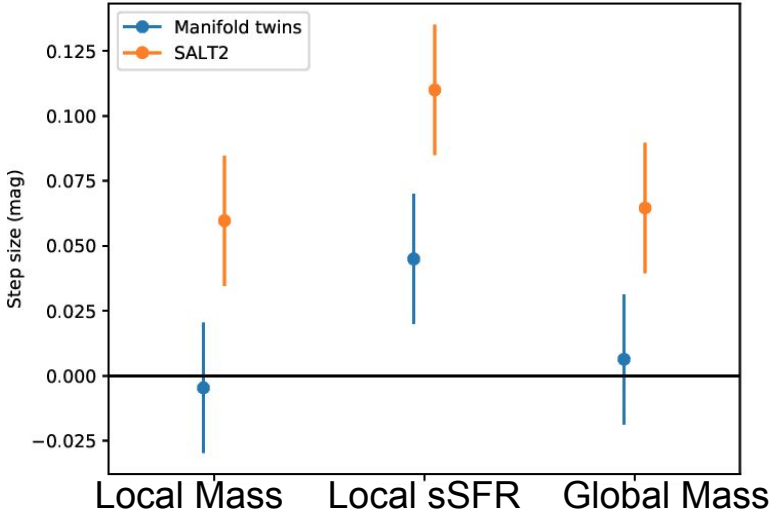
Slides from Kyle Boone

Key Findings:

SALT2 Hubble residuals have a bias of **up to 0.3 mag** when comparing to areas of Component 1 parameter space.

SALT2 is missing some SNe Ia diversity!





Using Manifold Twins significantly reduces correlations with host properties.

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Thank you

Summary:

- SNfactory expecting a comprehensive data release early 2020.
- Many science talks this week using its data!

- Good “twins” still have some variation: Xiaosheng Huang xhuang@lbl.gov
- Several projects indicate that SALT2 is not covering the full diversity of SNeIa. Some proposed solutions to this include:
  - Additional color terms: Alex Kim agkim@lbl.gov
  - Non-linear correlations: **Kyle Boone kyboone@uw.edu (Look for Thesis Talk at AAS Winter 2020)**

SNfactory Collaborating Institutions

- Physics Division, Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Berkeley, CA, 94720
- Universite de Lyon, F-69622, Lyon, France; Universite de Lyon 1, Villeurbanne; CNRS/IN2P3, Institut de Physique Nucleaire de Lyon
- Centre de Recherche Astronomique de Lyon, Universite Lyon 1, 9 Avenue Charles Andre, 69561 Saint Genis Laval, France
- Sorbonne Universite, Universite Paris Diderot, CNRS/IN2P3, Laboratoire de Physique Nucleaire et de Hautes Energies, 4 Place Jussieu, Paris, France
- Department of Physics, Yale University, New Haven, CT, 06250-8121
- Max-Planck-Institut fur Astrophysik, Karl-Schwarzschild-Str. 1, D-85748 Garching, Germany
- Tsinghua Center for Astrophysics, Tsinghua University, Beijing 100084, China
- Institut fur Physik, Humboldt-Universitat zu Berlin, Newtonstraße 15, 12489 Berlin, Germany