The Impact of Type Ia Supernova Siblings in the Rubin-LSST era

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Next generation surveys in the Rubin-LSST era
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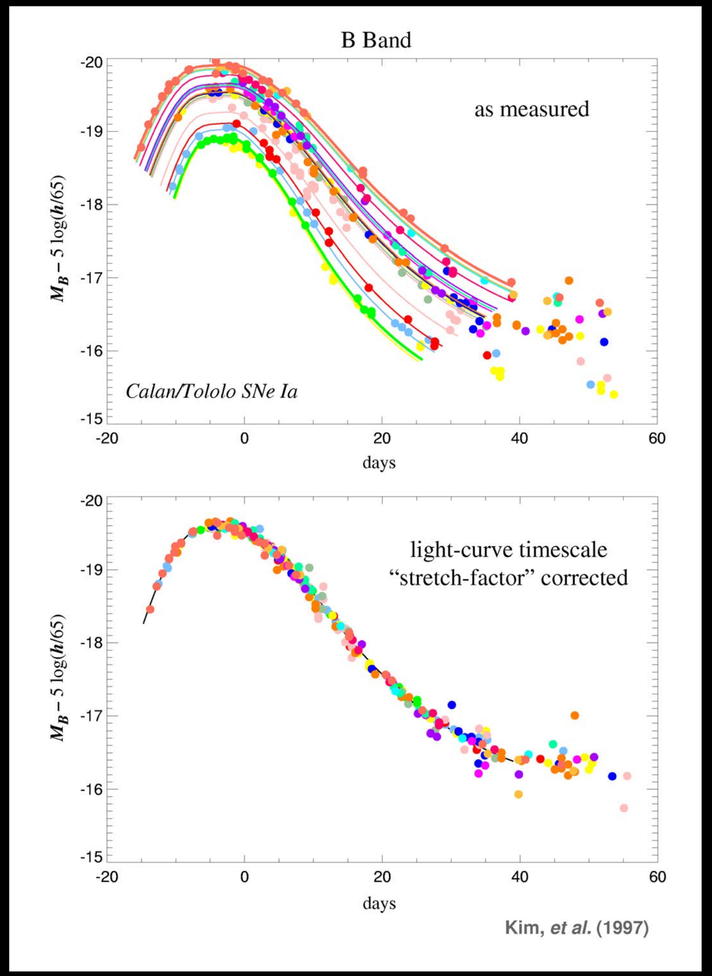
GOTO
GRAVITATIONAL-WAVE OPTICAL TRANSIENT OBSERVER

UNIVERSITY OF PORTSMOUTH

Cosmology with Type Ia Supernovae

- SNIa as standardisable candles
  - ~0.35mag luminosity dispersion
- Phillips relations - “brighter-slower” and “brighter-bluer”
  - ~0.15mag luminosity dispersion after colour (c) and stretch (x1) corrections
- Is this the limit to which SNe Ia are standardisable?

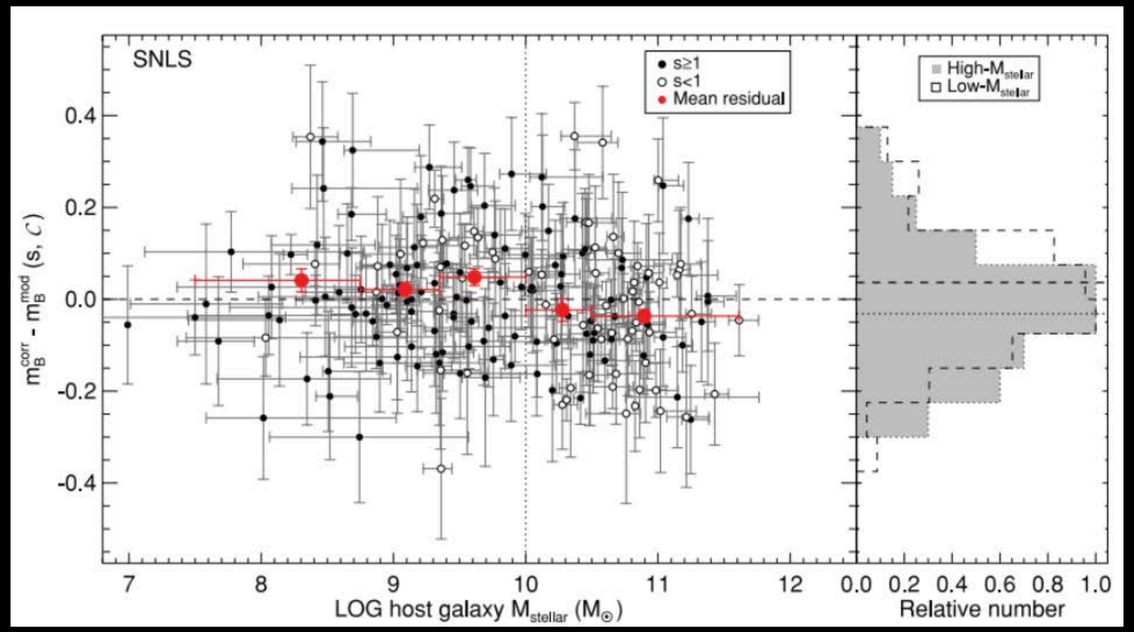


$$\mu_{\text{obs}} = m_B - M_0 + \alpha x_1 - \beta c$$

Cosmology with Type Ia Supernovae

- Colour and stretch corrected brightness correlates with stellar mass of host galaxy
- Ia in high-mass, passive galaxies are brighter than those in lower-mass, star-forming galaxies (after standardisation)

Dimmer



Brighter

Brightness offset of ~0.06mag.

Sullivan et al. 2010

$$\mu_{\rm obs} = m_B - M_0 + \alpha x_1 - \beta c$$

Supernova Siblings

Multiple SNe Ia associated with the same host galaxy

“Supernova Siblings” first termed by Brown 2014

HST 17194 - PI Kelsey

Supernova Siblings

Why are they important?

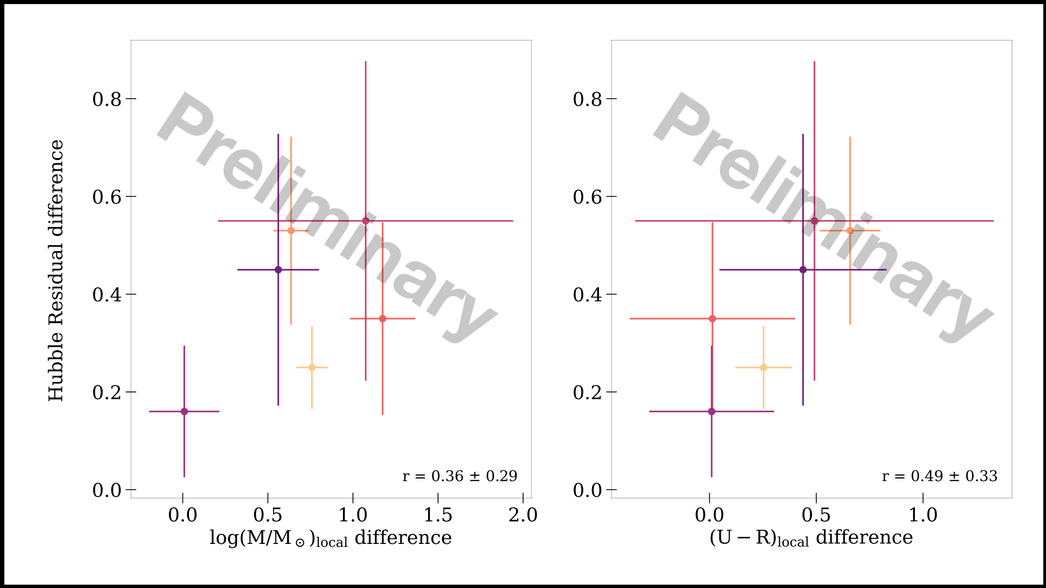
Solving SNe Ia Environment Correlations

- Share host galaxy properties, and systematic uncertainties from redshift, peculiar velocities and gravitational lensing.
- Any differences in brightness, stretch, colour, Hubble residual between siblings cannot be due to host galaxy properties.
- Must be due to sub-galactic differences in environments, dust distributions, progenitor scenarios, explosion mechanisms, or unknown physics.

Independent Measurement of H_0

- *If siblings also share their galaxy with a Cepheid variable star (5 such cases so far).*
- Multiple independent distance measurements to the same host galaxy.
- Calibrate zero-point of Hubble diagrams from large surveys using sibling SN independently, different values of H_0 are obtained, providing uncertainties on the measurement.

Supernova Siblings



Thesis - Kelsey 2021
Kelsey et al. (in prep)

Siblings with the largest difference in local mass or local U-R have the largest difference in Hubble residual.

Independent of global galaxy properties - highlights need for local corrections in cosmology. Simply correcting for global host parameters may not encompass the relationships seen here, as each sibling in a pair would be corrected in the same way.

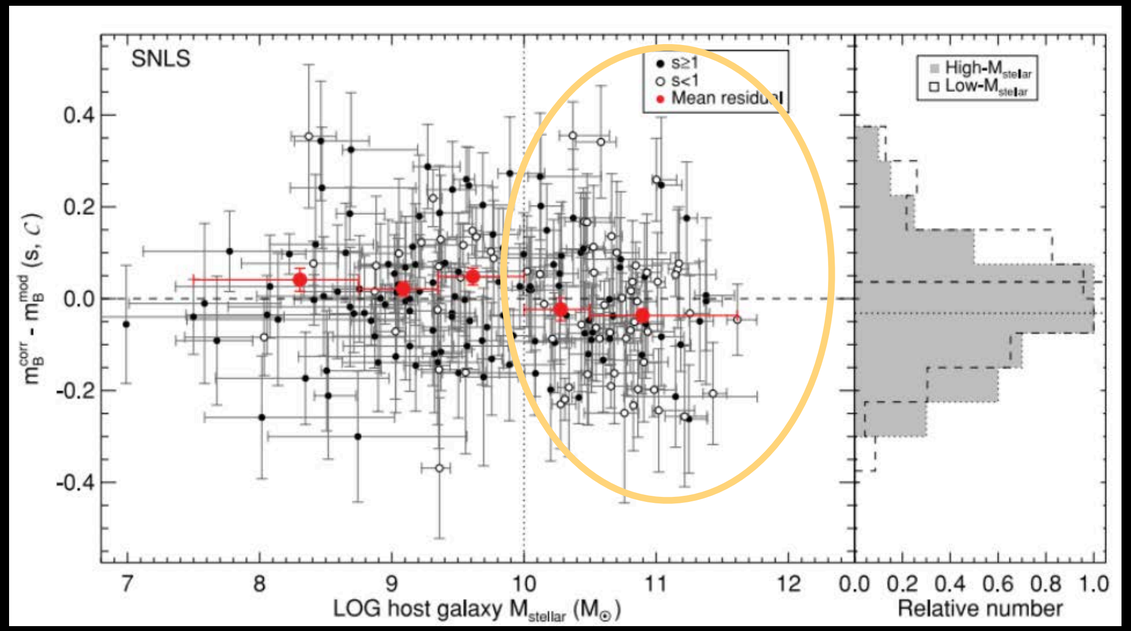
$$\mu_{\text{obs}} = m_B - M_0 + \alpha x_1 - \beta c$$

However…

Supernova Siblings

An issue…

- Rate of detection of siblings in a single survey is limited by survey length
- SNe Ia rate is higher in more massive galaxies
- More likely siblings found from single surveys are associated with high-mass galaxies - as shown in DES (Scolnic + 2020)
- More massive, passive hosts typically host faster (lower x1) SNe Ia
- Correlation between x1 and age -> more likely to occur from older progenitors



Sullivan et al. 2010

= bias

Supernova Siblings

The current picture…

- 8 pairs of sibling SN Ia in DES - Scolnic + 2020
- 4 pairs of sibling SN Ia in ZTF - Graham + 2021
- 12 pairs of sibling SN Ia in Pantheon + (compilation of surveys) - Scolnic + 2022
- Compilation of 12 literature siblings - Burns + 2020
- A few individual galaxies hosting siblings studied - Hamuy + 1991, Elias-Rosa + 2008, Stritzinger + 2010, Biswas + 2022, Gallego-Cano + 2022, Hoogendam + 2022, Ward + 2022

The idea!

Are there any missing siblings if we combine archival public data?

An Archival Search for SN Ia Siblings

Kelsey 2023

- Combined Open Supernova Catalog, Qin 2022 Extragalactic Transient Host Galaxy Database, and published siblings from the literature

158 galaxies
containing 327 SN Ia siblings

Over 10 times larger than prior sibling samples

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Over 10 times larger than prior sibling samples

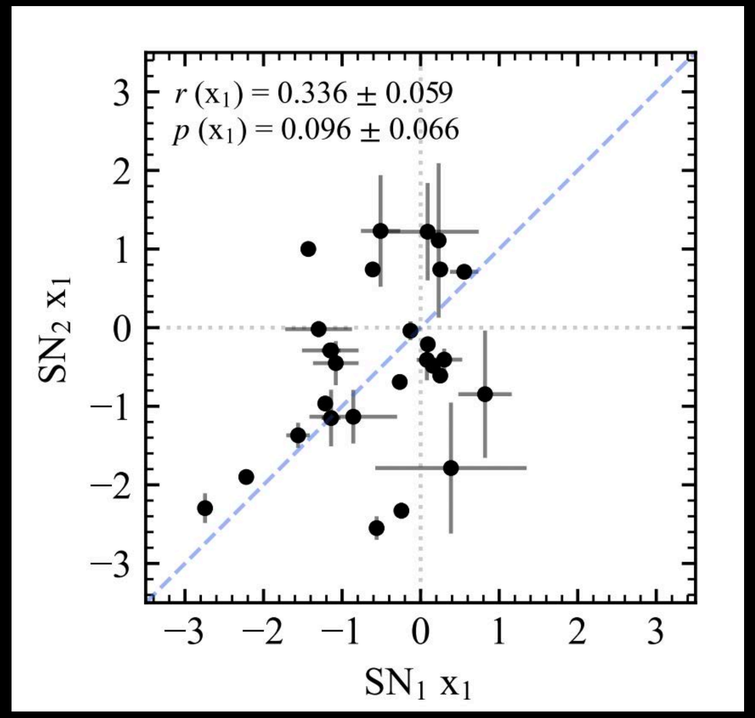
An example use case for the sample:

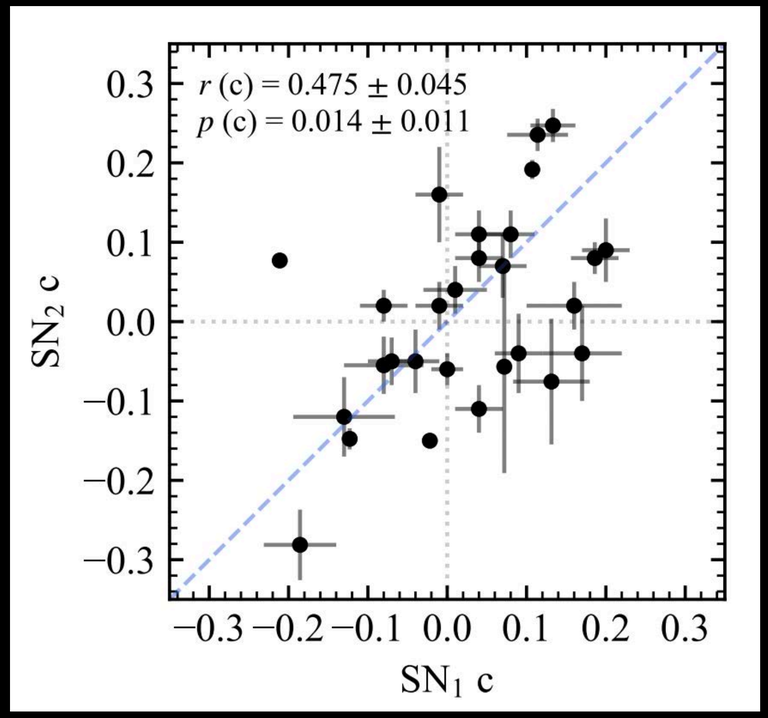
- Give SALT2 public photometry data for each object
- Apply standard JLA-like quality cuts
- 101 SNe Ia pass quality cuts
- **24 host galaxies, containing 50 SNe Ia = 28 pairwise combinations**

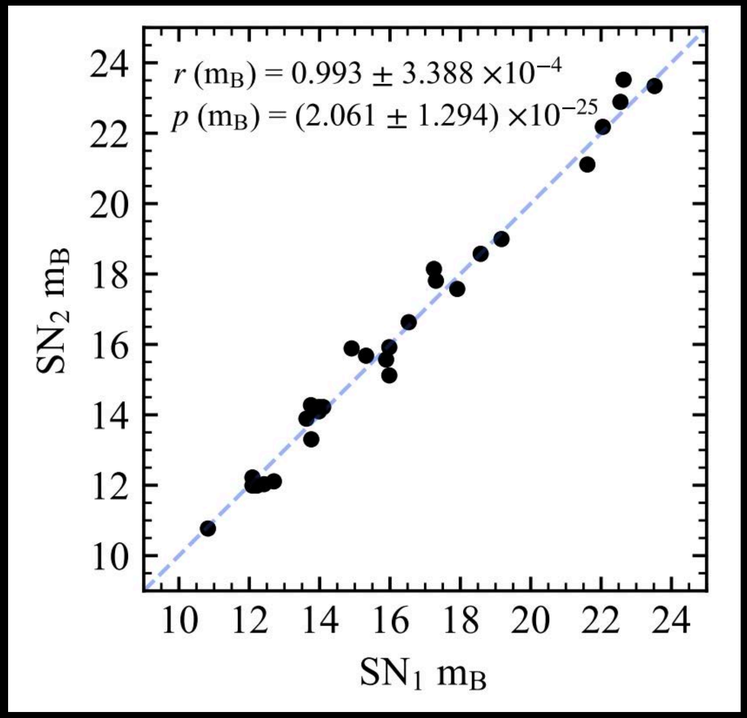
$$\mu_{\text{obs}} = m_B - M_0 + \alpha x_1 - \beta c$$

Cosmology with SN Ia Siblings

Comparing light-curve properties between siblings







Kelsey 2023

Compared to a simulation of 28 random pairs of SNe from Pantheon +, repeated 10,000 times…

Cosmology with SN Ia Siblings

Comparing light-curve properties between siblings

Standard deviations of differences may provide more answers…

Property	Data σ	Simulation σ	Significance of difference
Δx_1	0.687 ± 0.093	0.811 ± 0.110	0.862
Δc	0.069 ± 0.009	0.072 ± 0.010	0.211
Δm_B	0.273 ± 0.037	2.506 ± 0.341	6.509

Kelsey 2023

Differences in scatter are insignificant for all but the apparent magnitude.

Suggests x1 and c are no more similar between SNe Ia associated with the same host galaxy than for any random pair of SNe Ia.

Raises questions about the validity of global host galaxy corrections in the standardisation of SNe Ia for use in cosmology.

The Future of SN Ia Siblings

- LSST predicted to find ~800 SN Ia Siblings (Scolnic et al. 2020)
- If using siblings to improve standardisation based on environmental properties, need to ensure we aren’t biasing our sample set
  - Number of siblings constantly increasing as new SNe discovered
  - Monitor new SNe Ia discoveries to find “missing siblings”
    - Match with previously discovered SNe Ia
    - Highlights the need for open data and collaboration

The Future of SN Ia Siblings

Happening now!

- HST 17194 “Local Environments of Low-redshift Type Ia Supernova Siblings”: PI Kelsey
  - With collaborators: Lluís Galbany, Or Graur, Bhavin Joshi, Ben Rose, Mat Smith, Louis-Gregory Strolger, Phil Wiseman
  - Allocated 32 orbits
  - High resolution photometry of SN Ia sibling environments
  - Compare between the sets of siblings to understand how sub-galactic environments vary for sibling SN Ia hosts.
  - Compare relationships between local environment colours and cosmological parameters to define the optimal route to standardising SNe Ia

Conclusions

- SNIa Siblings provide a unique perspective on environmental corrections and the Hubble Tension
- Kelsey 2023 - Largest sample of SN Ia siblings to date
  - Siblings no more similar than any random pair of SNe
- Number of siblings constantly increasing - large sample to aid in our understanding of SN Ia astrophysics, cosmological standardisation and Hubble Tension
- Exciting things to come!