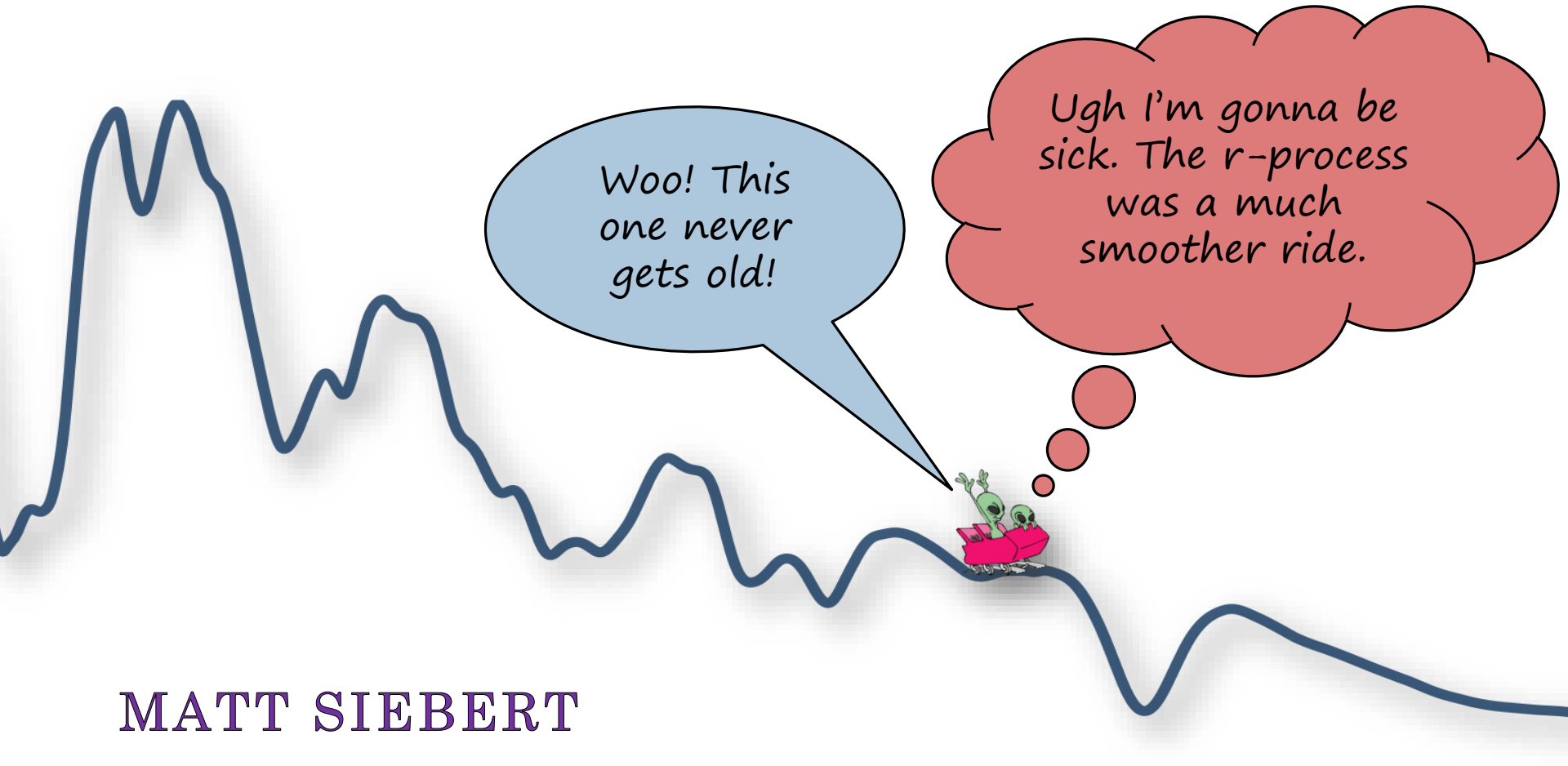
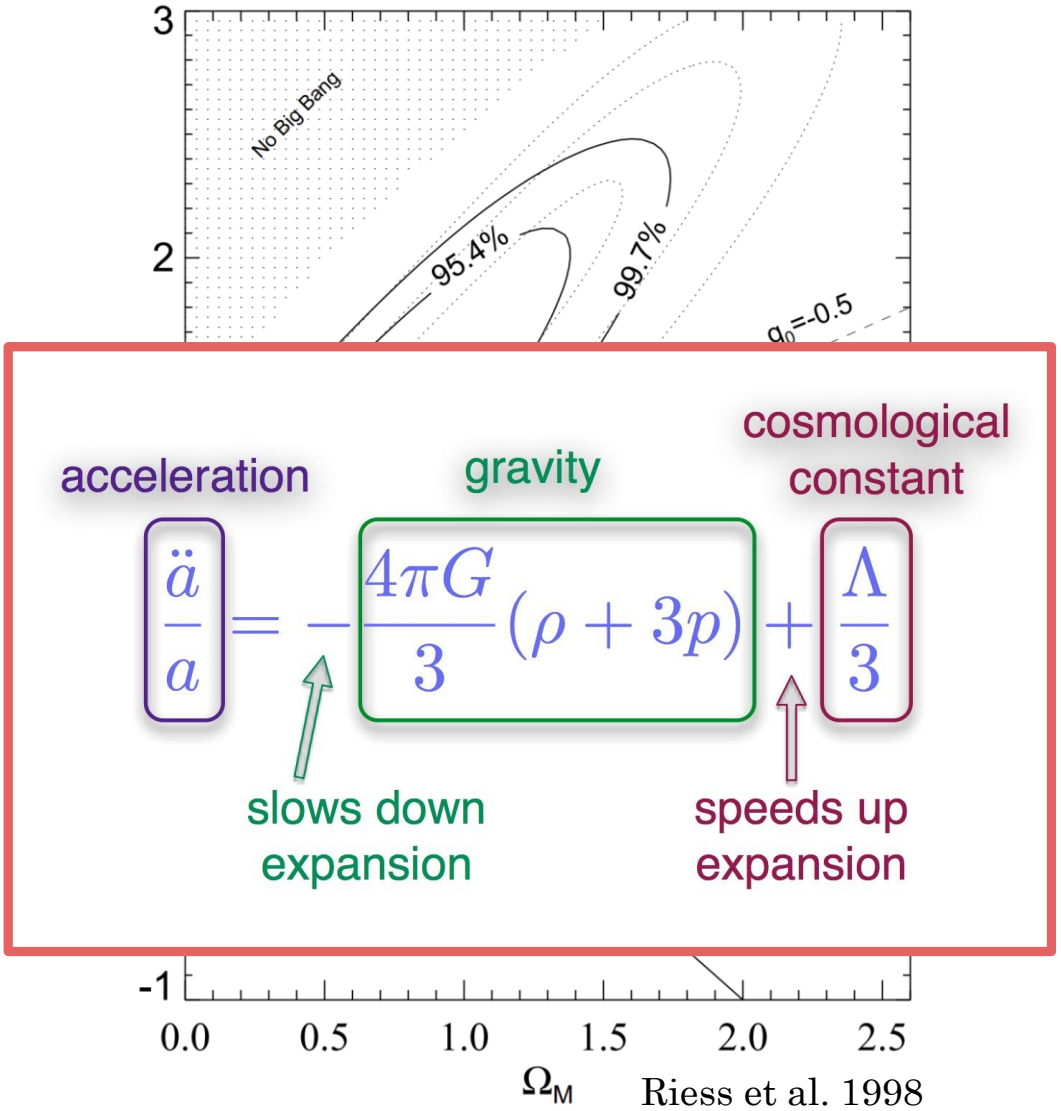
Familiar and Exotic Events in the Current Transient Landscape



MATT SIEBERT

Accelerating Universe



Riess et al. 1998

Λ

$$w = \frac{p}{\rho c^2} = -1$$

Perlmutter et al. 1999

What is Dark Energy?

The Cosmological Constant Problem

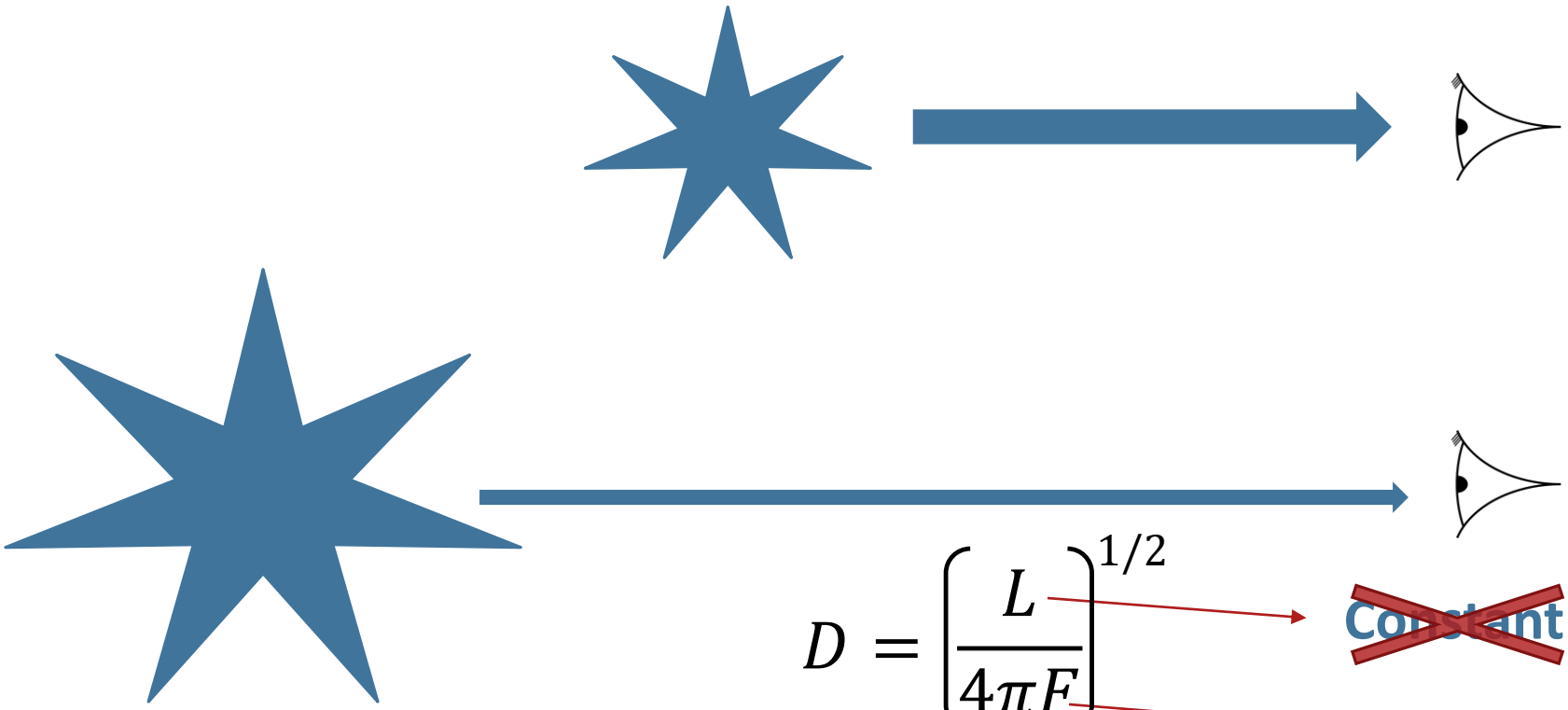
$$\rho_{vac}^{(theory)} \sim 10^{120}\ \rho_{vac}^{(obs)}$$

The Coincidence Problem

$$\Omega_m \sim \Omega_\Lambda$$

Why now?

SNe Ia are NOT Standard Candles



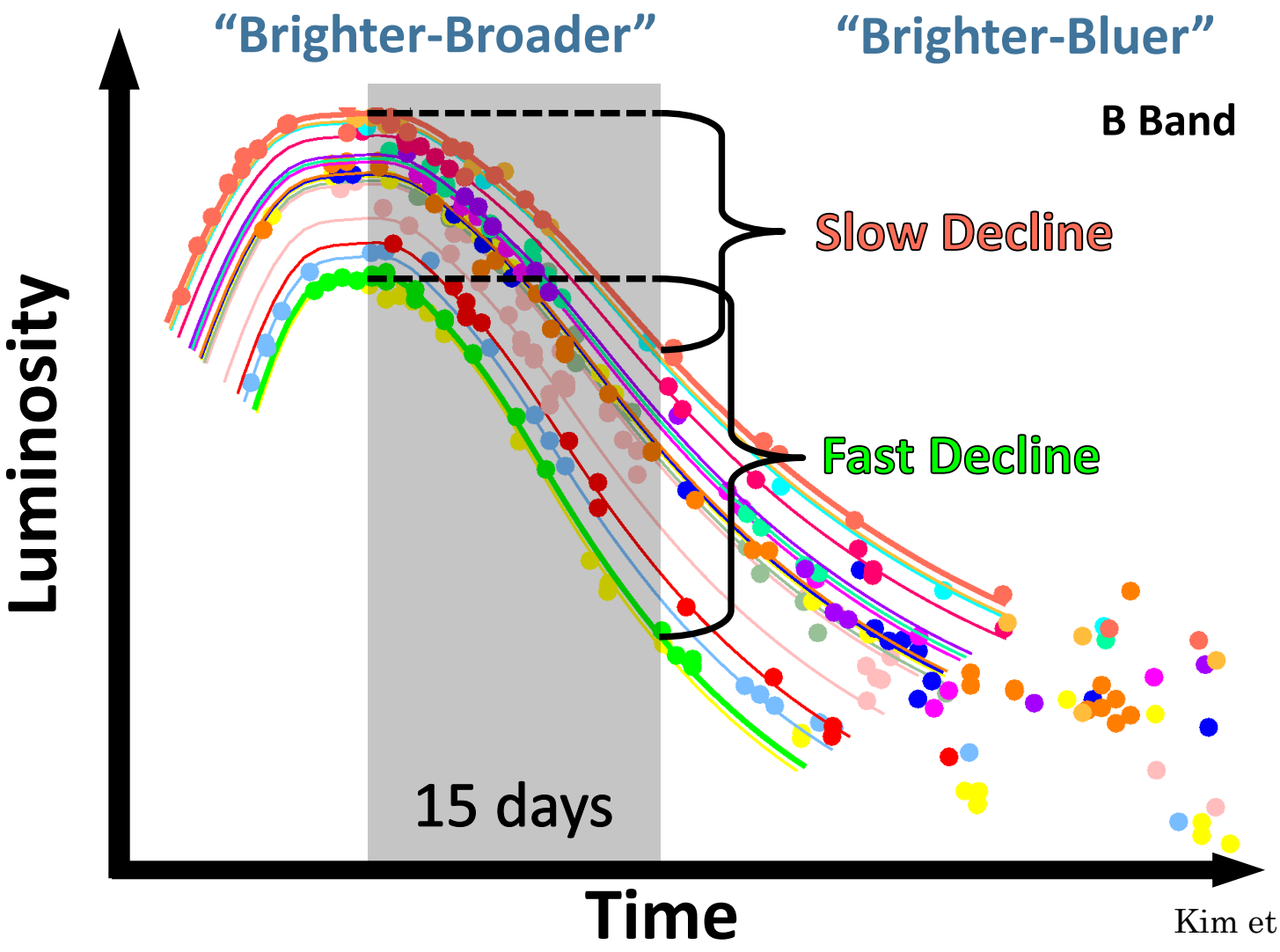
$$D = \left(\frac{L}{4\pi F}\right)^{1/2}$$

~~Constant~~

Measure

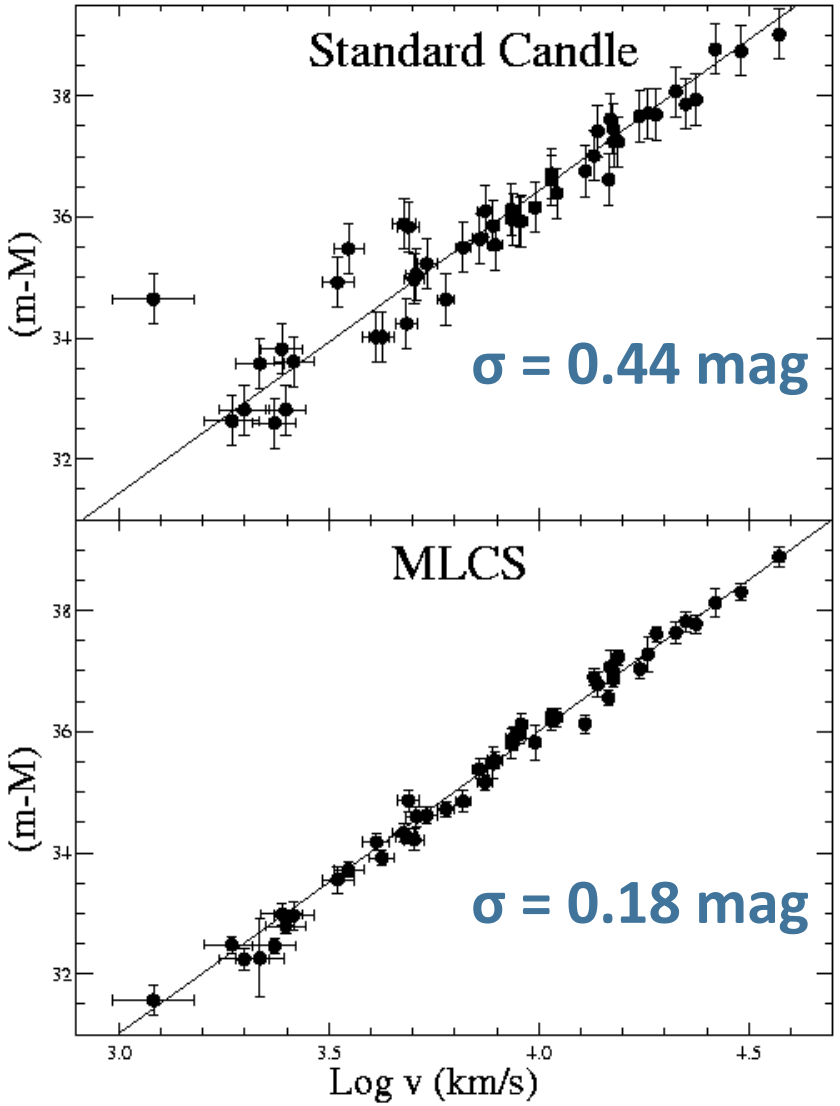
$$D = f(z, \Omega, w(z), \dots)$$

SNe Ia are Standardizable Candles



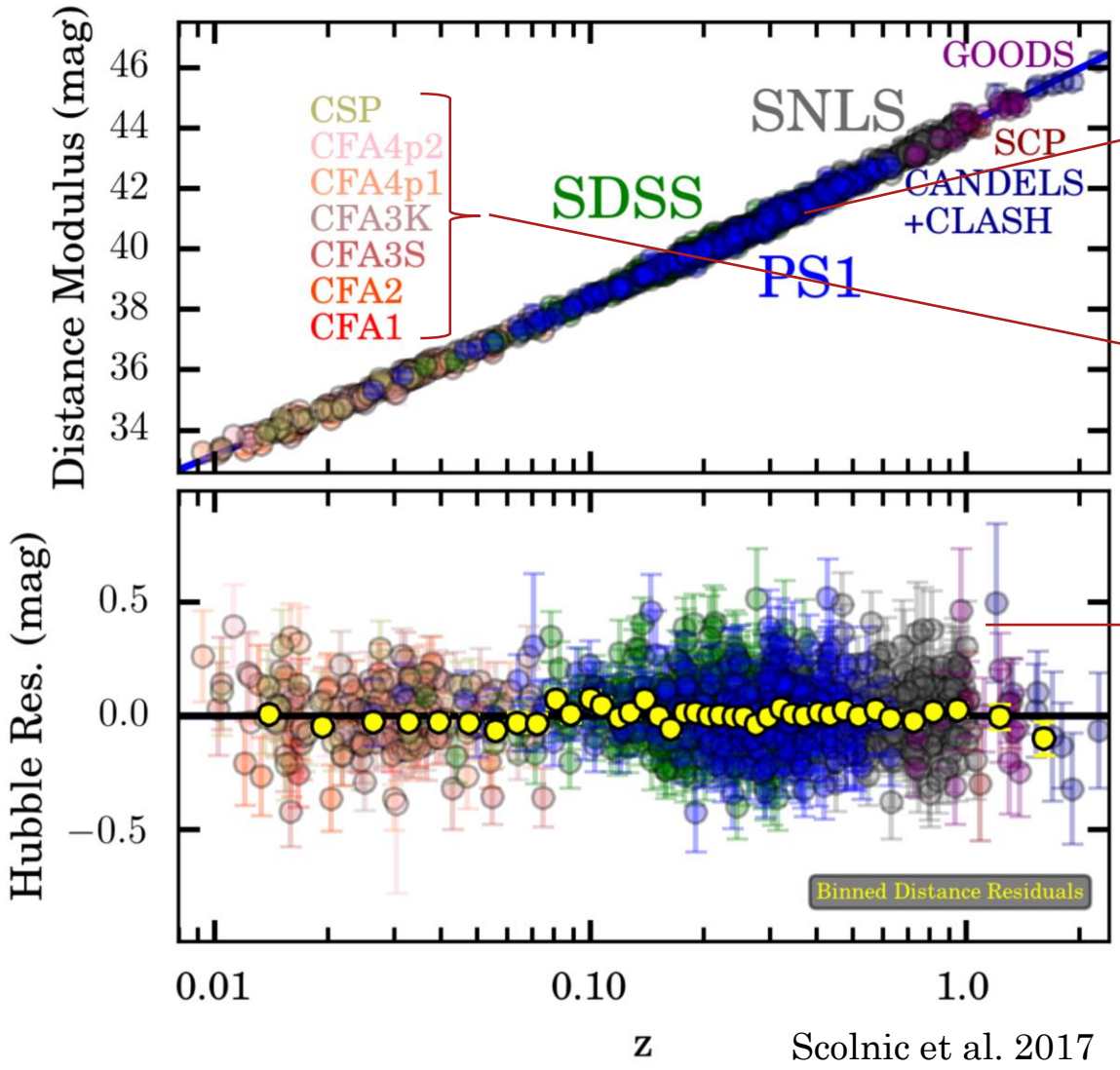
Kim et al. 2007

SNe Ia are Standardizable Candles



Jha et al. 2007

Recent Hubble Diagram



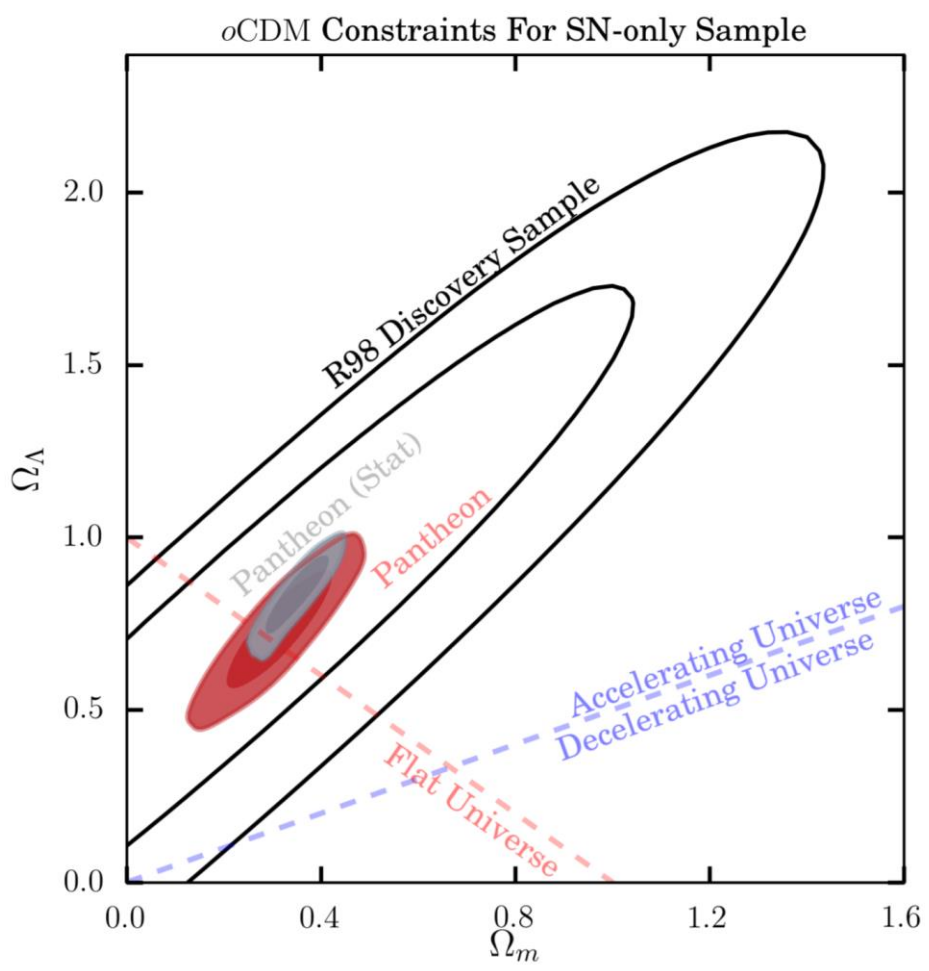
Scolnic et al. 2017

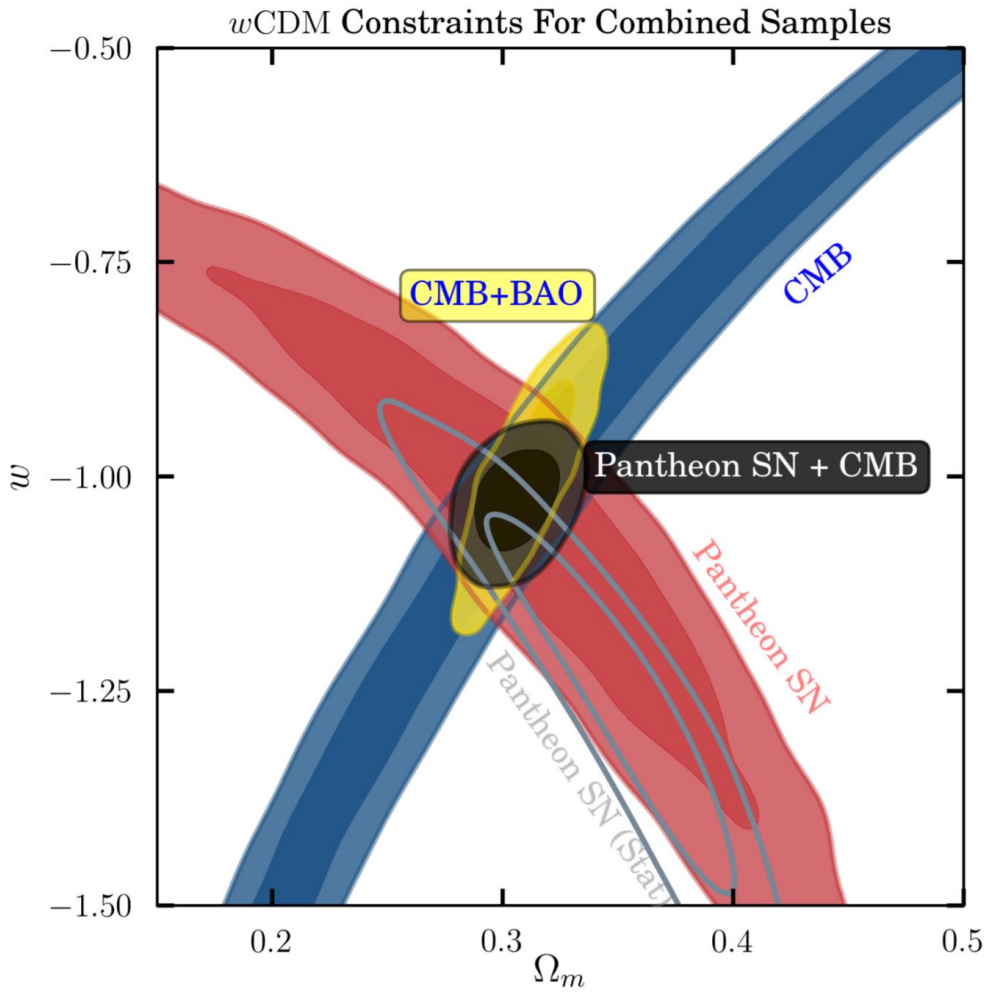
SNe dimming with redshift

Inhomogeneous low-z dataset

Photometric error alone cannot account for scatter

Systematics Need to be Addressed



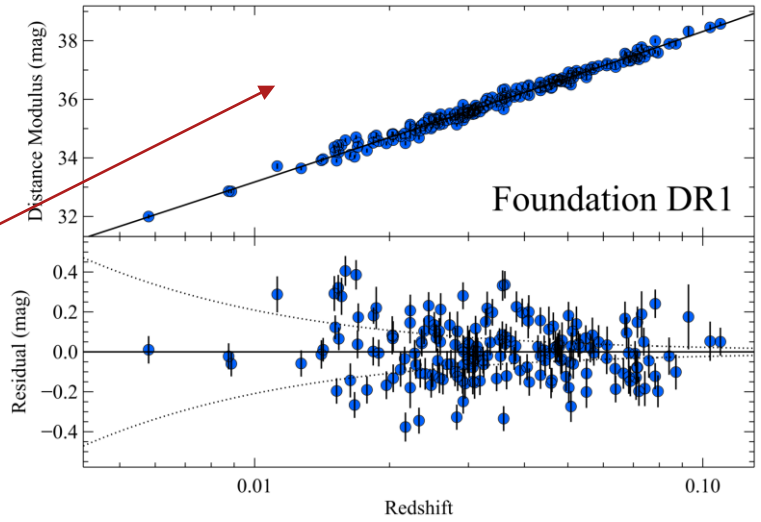


Scolnic et al. 2017

Systematic Uncertainties

	w shift	$\sigma_w^{\rm syst}$	Fraction of $\sigma_w^{\rm (stat)}$
Stat. Uncertainty	+0.000	0.031	1.000
Total Sys Uncertainty	+0.031	0.025	0.814
Calibration			
SALT2 Cal	-0.002	0.014	0.457
Survey Cal	+0.006	0.009	0.285
HST Cal	-0.006	0.006	0.177
Supercal	+0.002	0.003	0.098
SN Modeling			
Selection	+0.010	0.007	0.233
Intrinsic Scatter	+0.019	0.005	0.170
β Evol.	-0.001	0.007	0.238
γ Evol.	-0.002	0.000	0.000
$m_{\rm step}$Shift	-0.002	0.002	0.064
External			
MW Extinction	+0.010	0.008	0.262
Pec. Vel.	+0.000	0.003	0.103

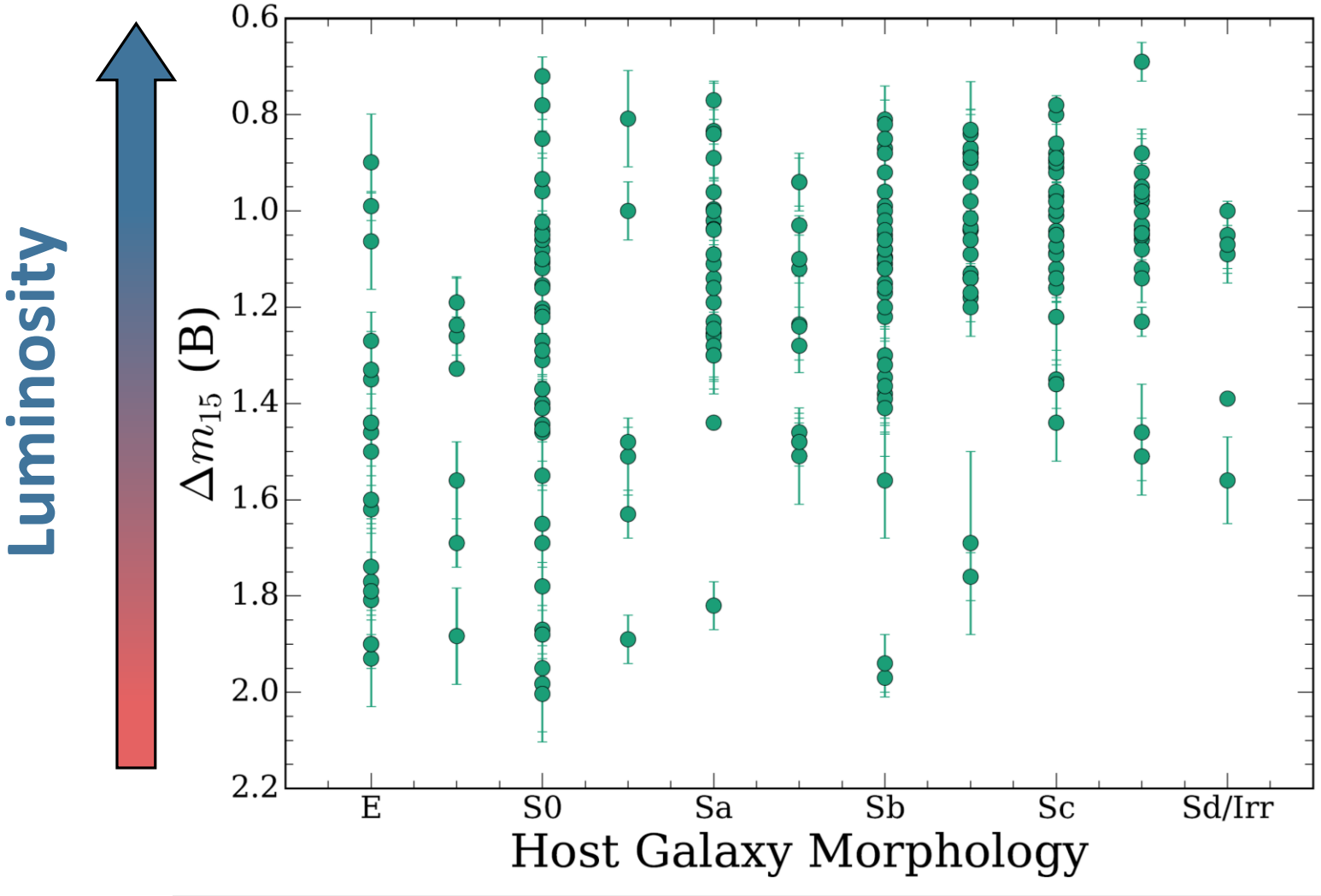
Scolnic et al. 2017



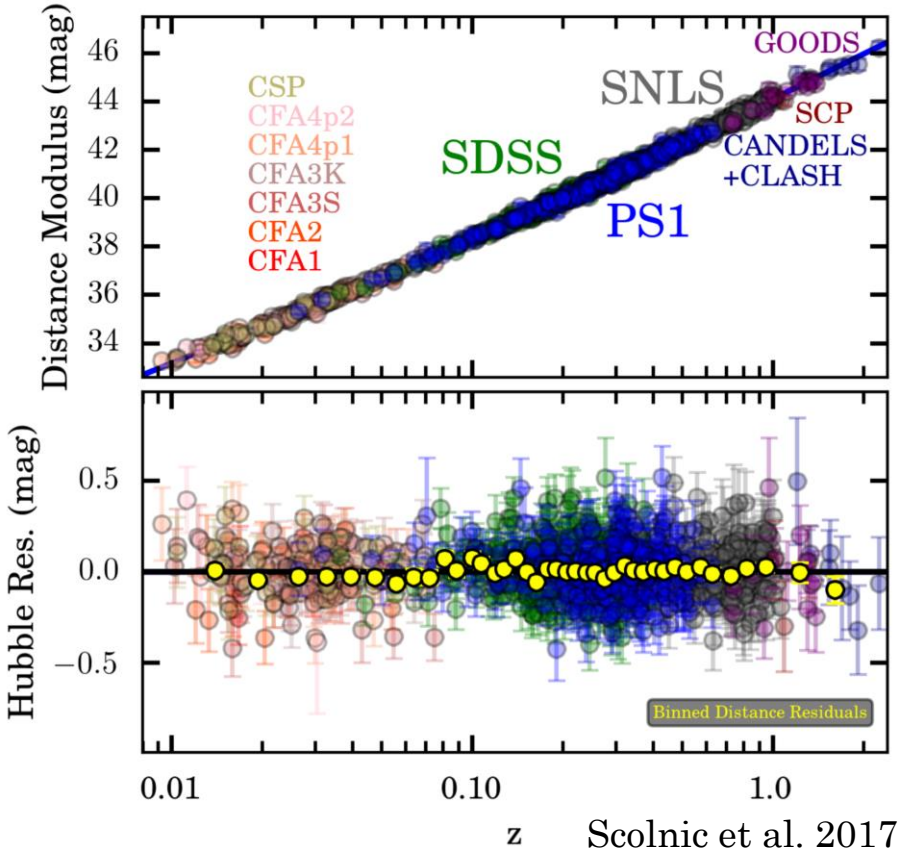
Foley et al. 2018

Explosion Physics

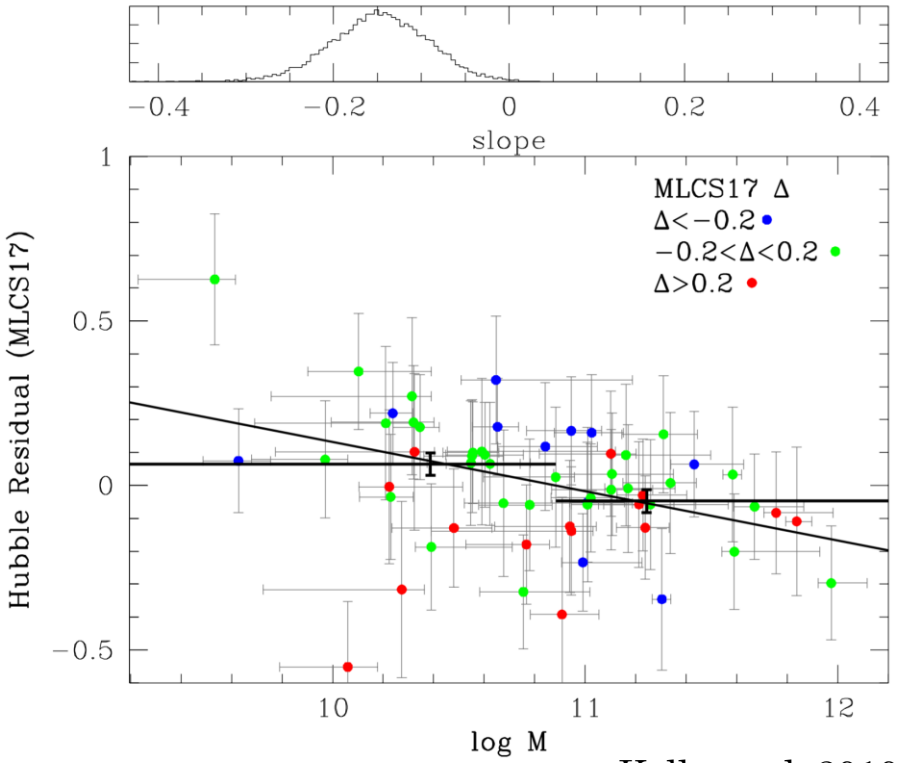
Environmental Dependence



Environmental Dependence

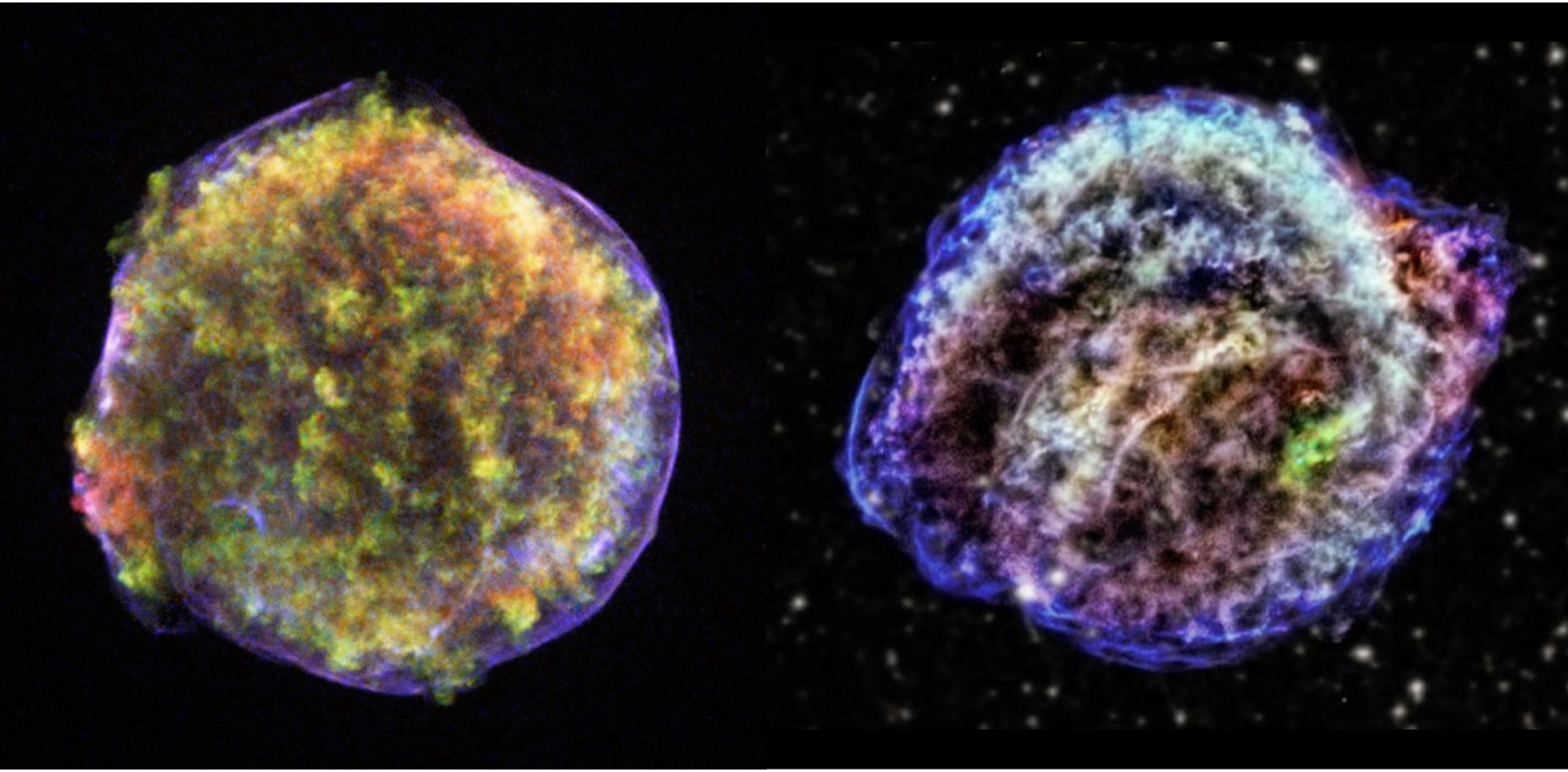


Scolnic et al. 2017

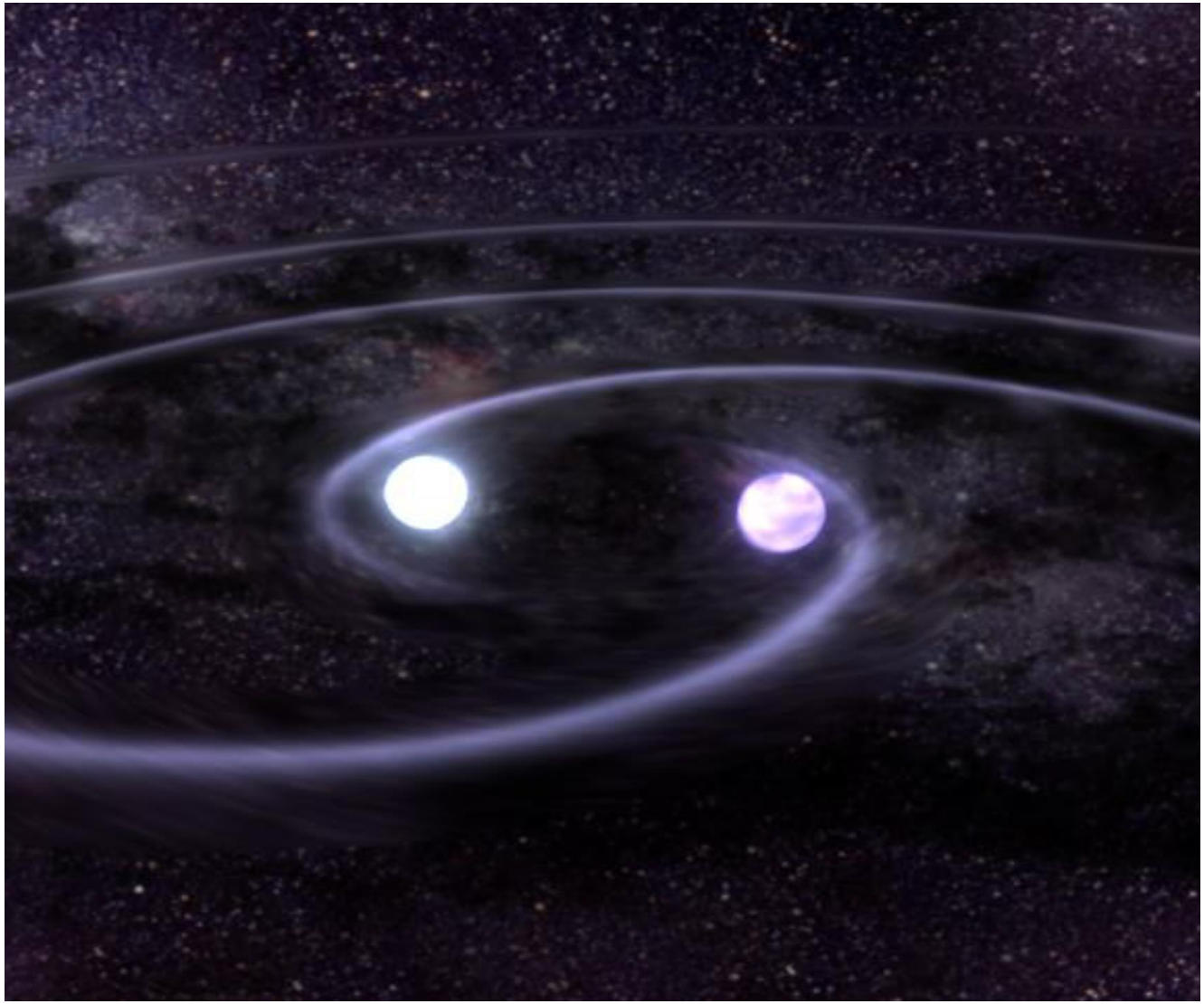


Kelly et al. 2010

Different Progenitors?

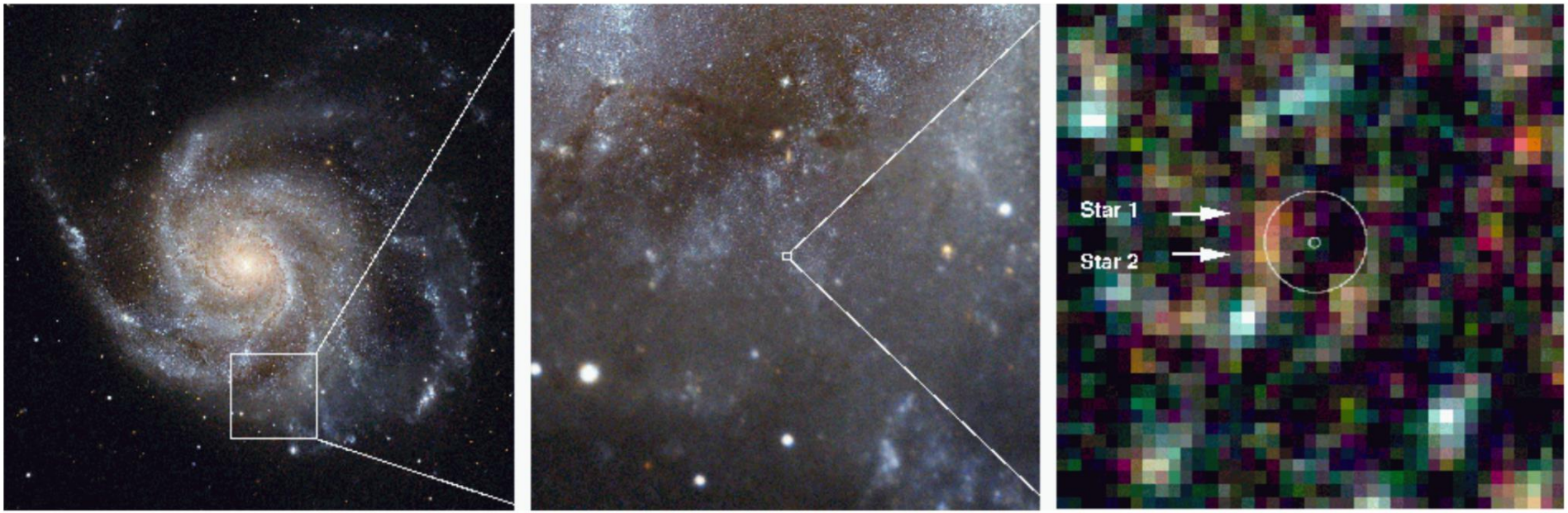


Double Degenerate Scenario



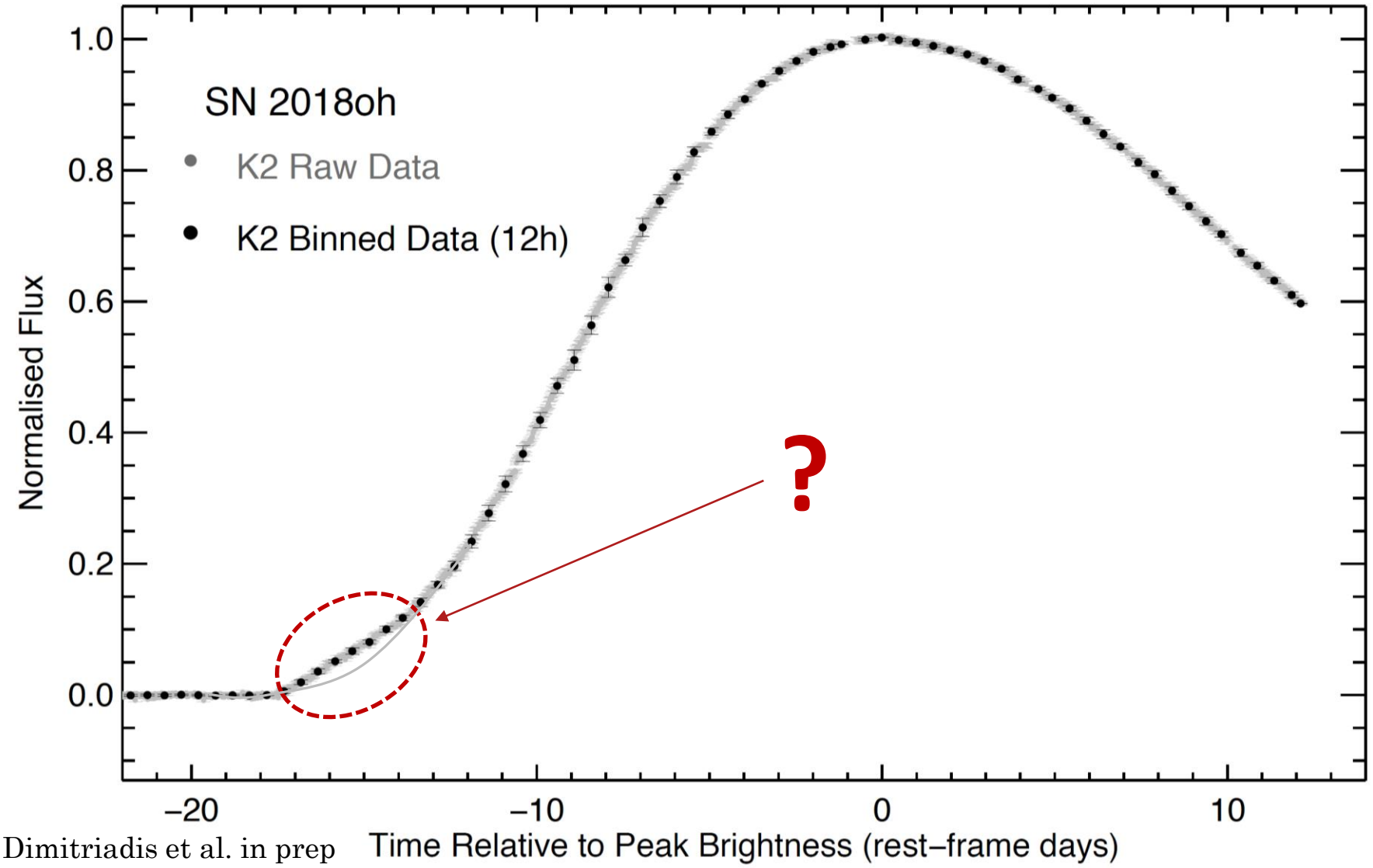
Single Degenerate Scenario

DD Evidence – SN2011fe



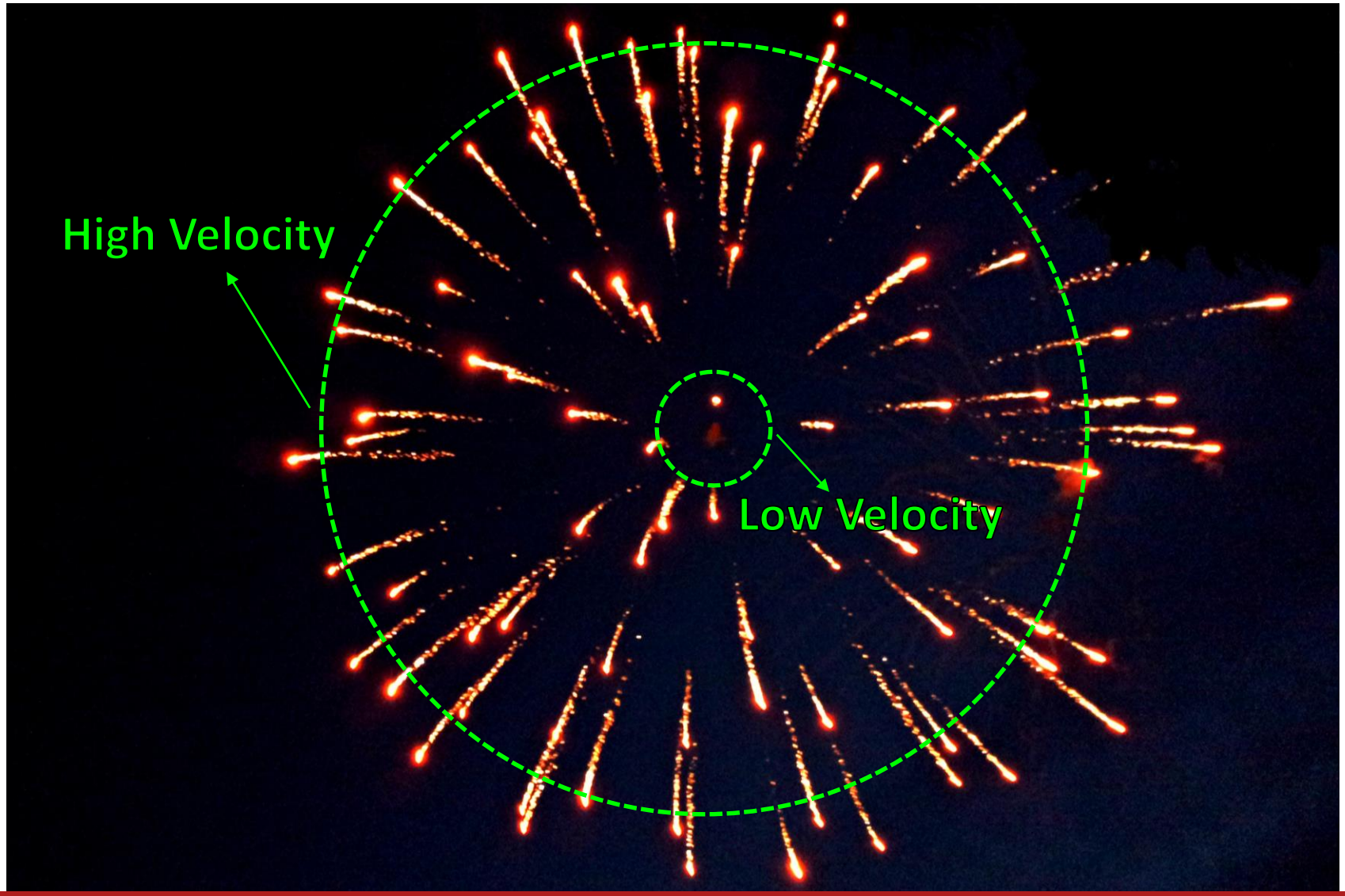
Li et al. 2011

SD Evidence – Early Excess Flux

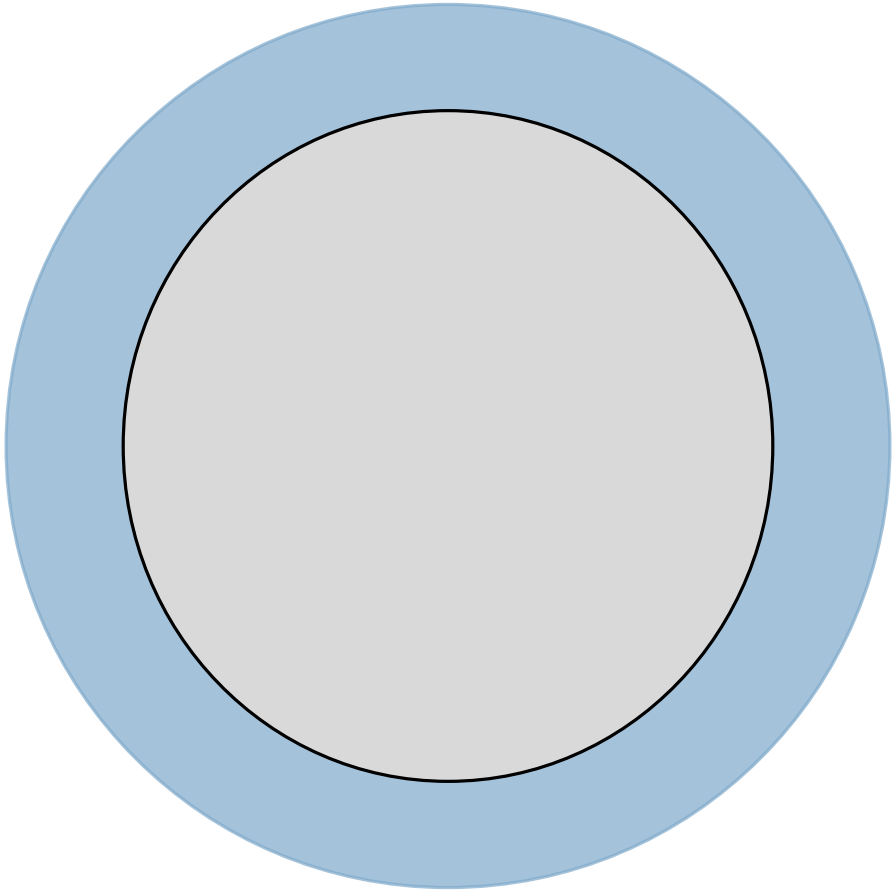


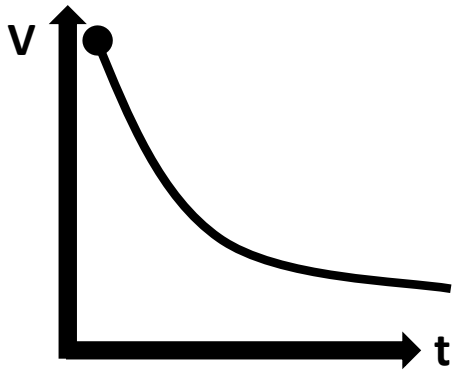
Dimitriadis et al. in prep

Supernova Explosion



Supernova Explosion

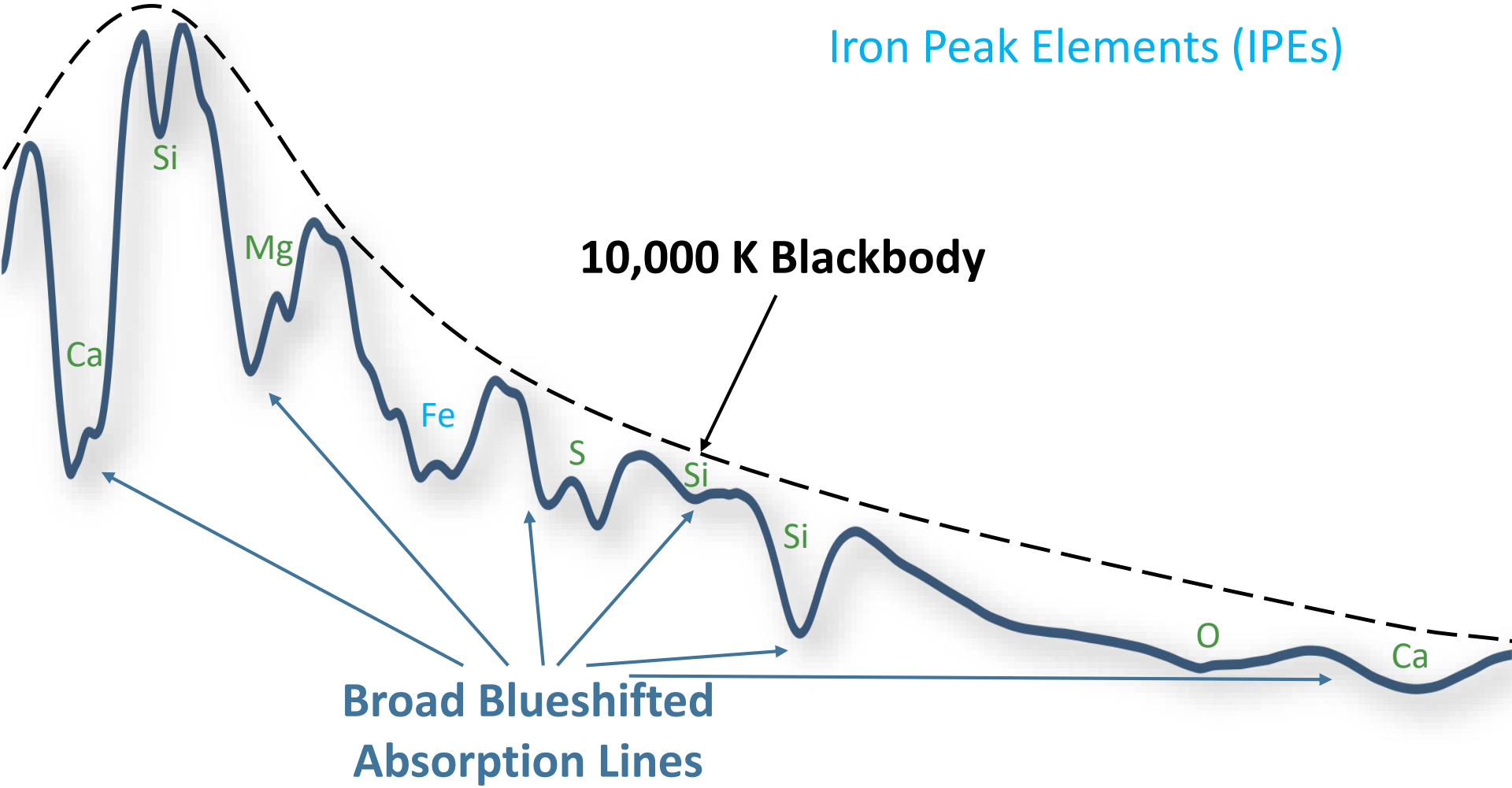




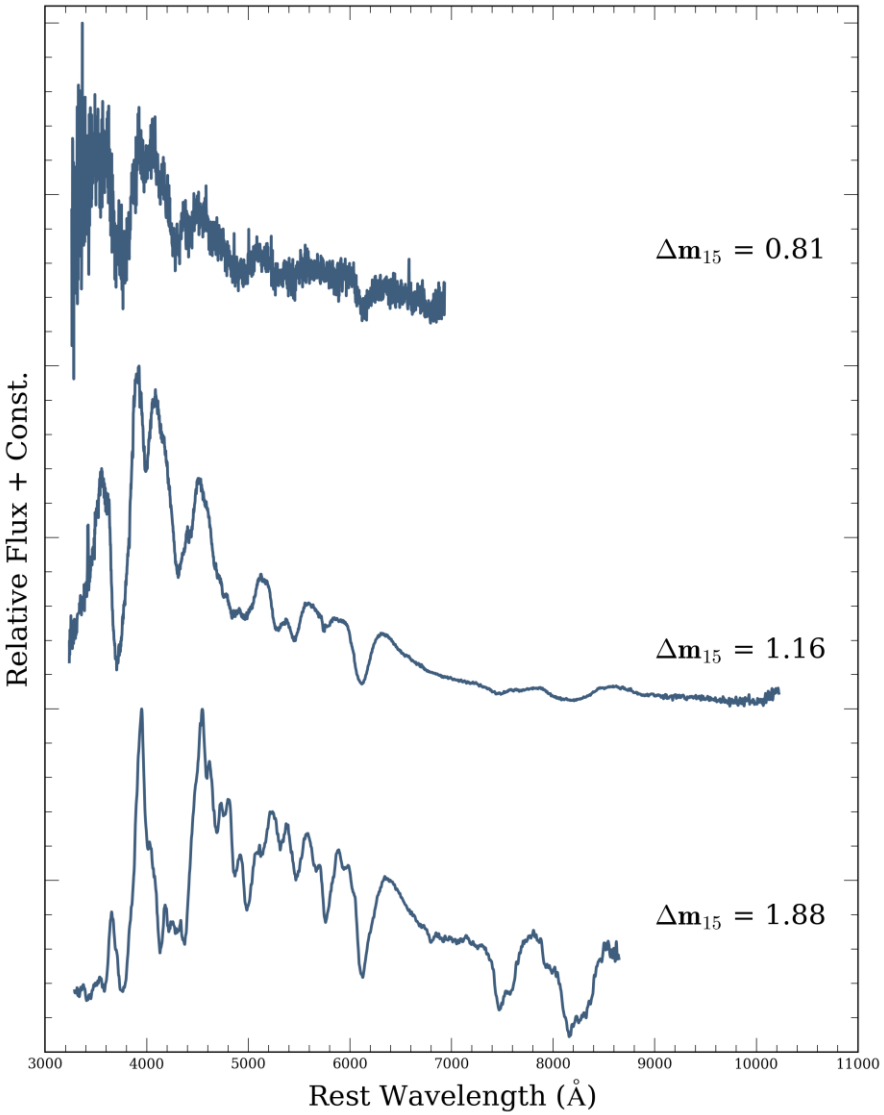
Maximum Light SED

Intermediate Mass Elements (IMEs)

Iron Peak Elements (IPEs)



Spectroscopic Diversity



Individual Spectra

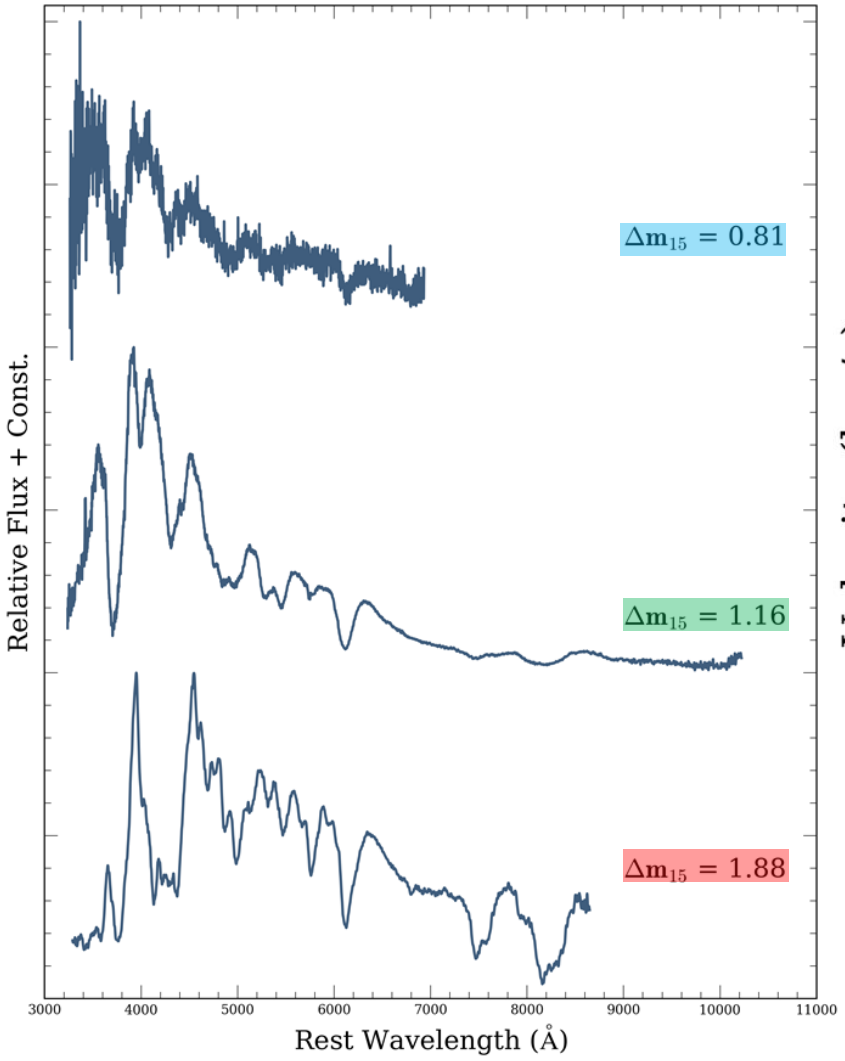
Heterogeneous

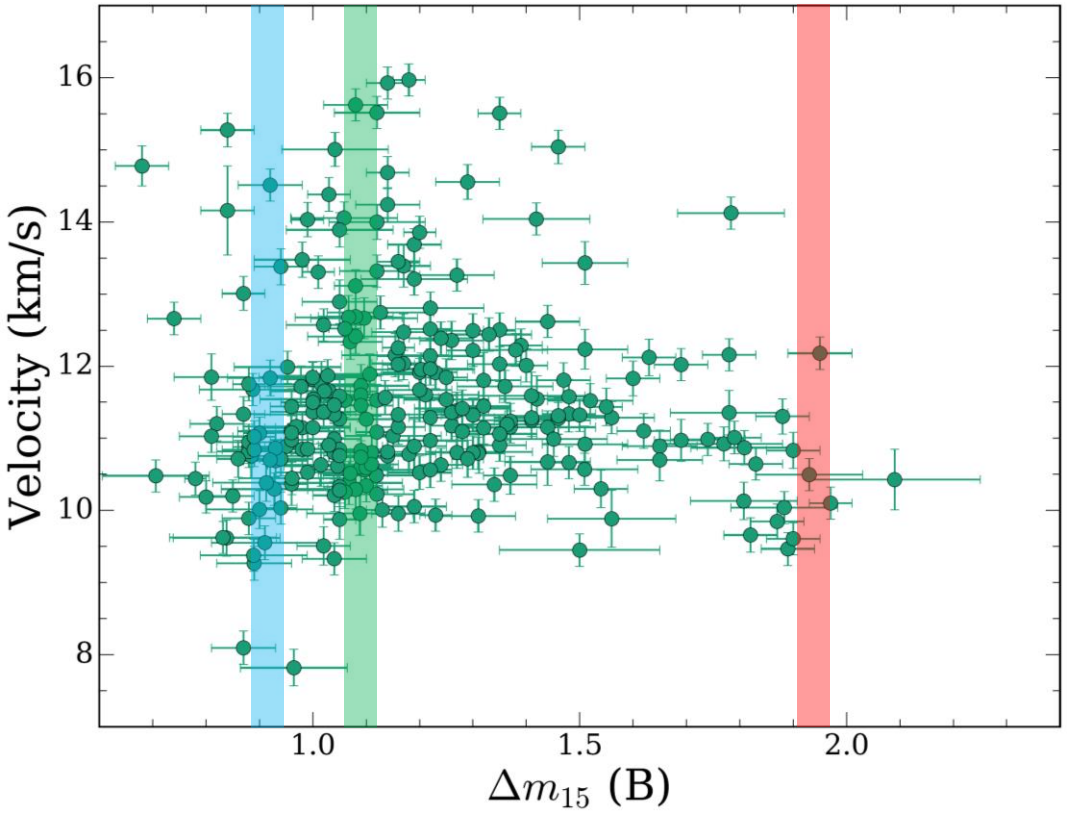
Signal

Wavelength Coverage

Spectral Features

No Correlation with Velocity



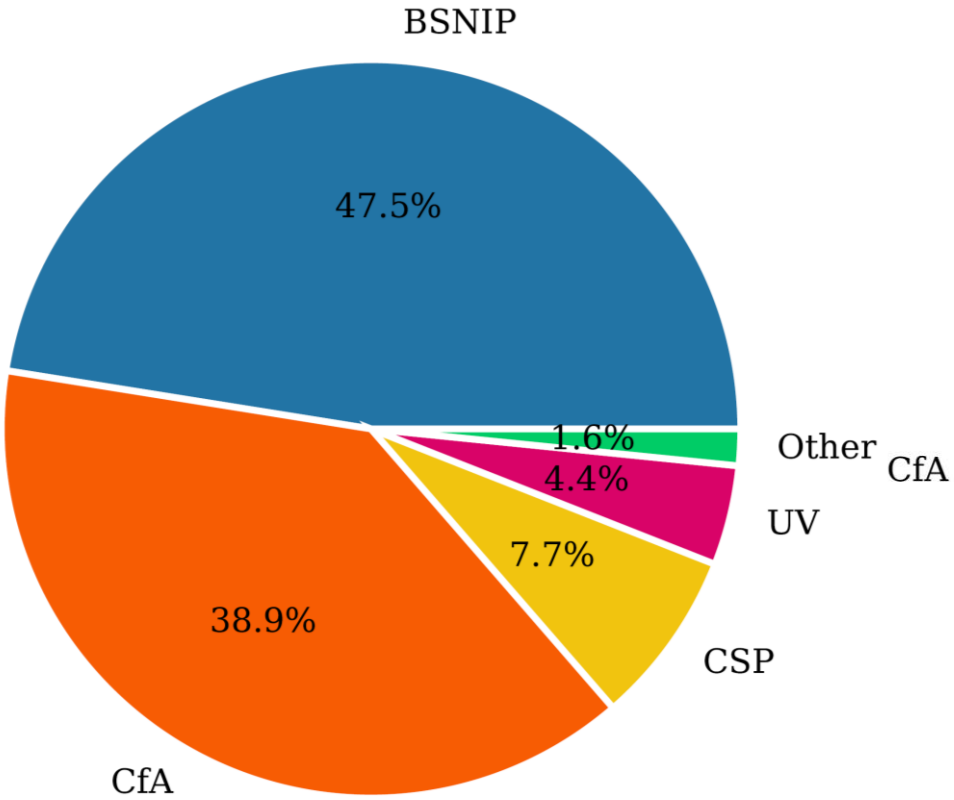


SN Ia Relational Database

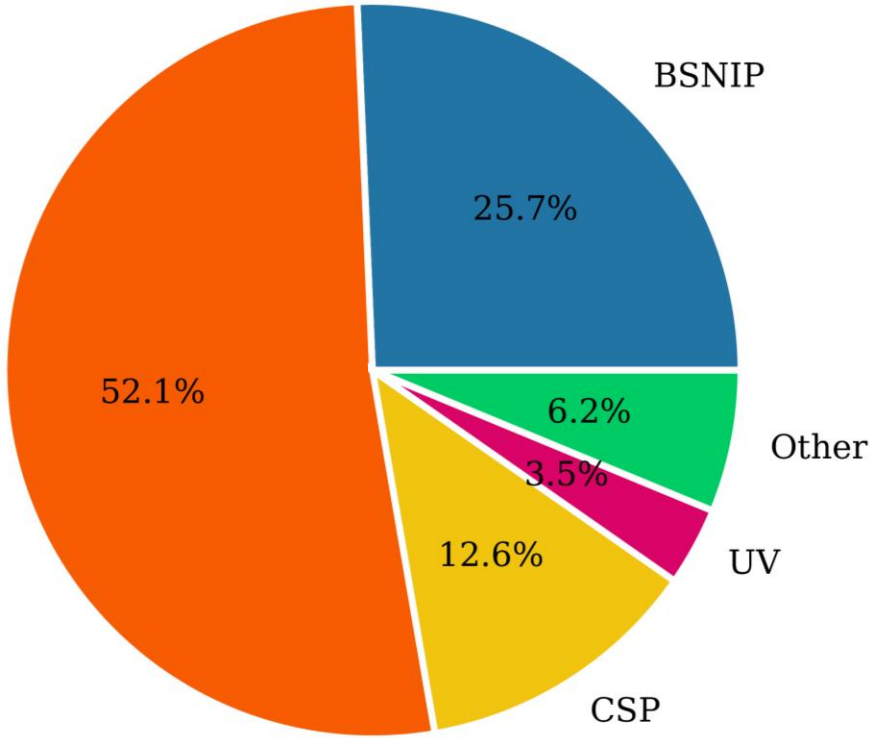
*Contrived acronym pending

Siebert et al. in prep

N = 784 SNe

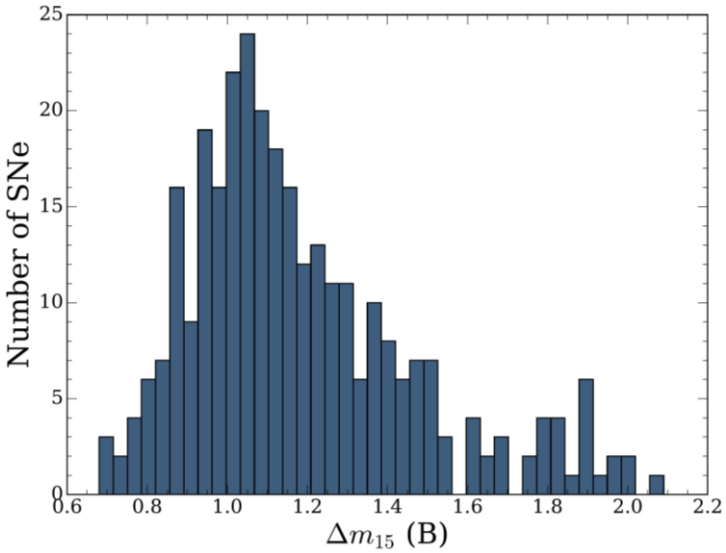


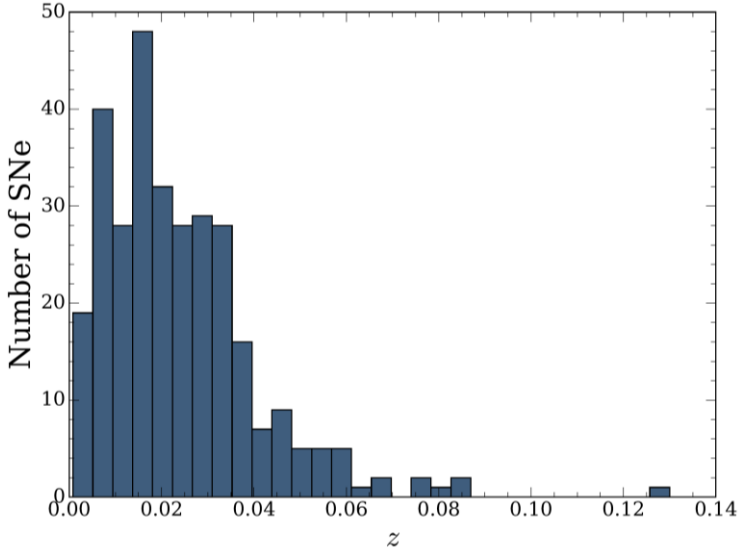
4972 Spectra

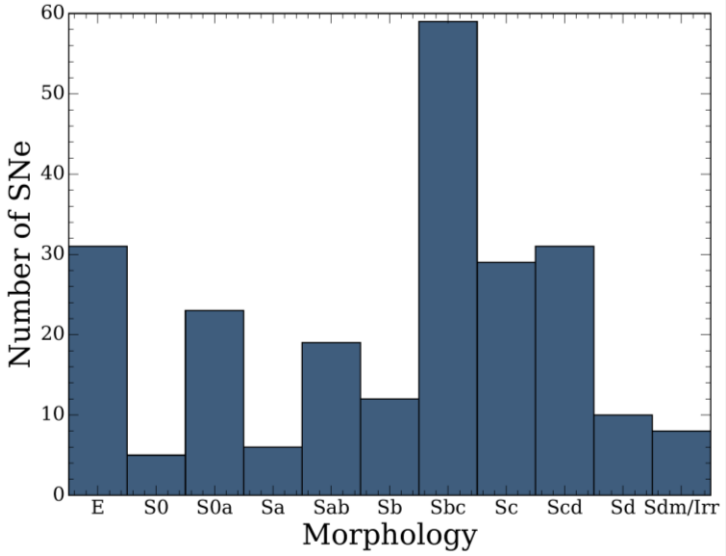


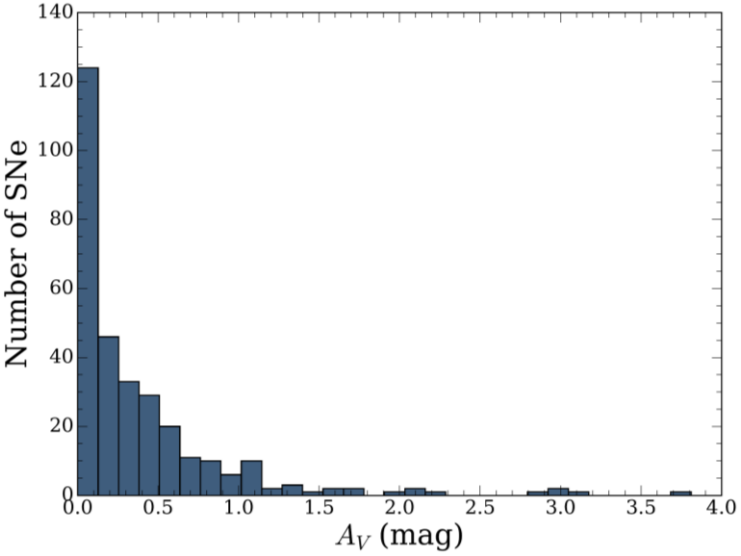
Metadata

Siebert et al. in prep







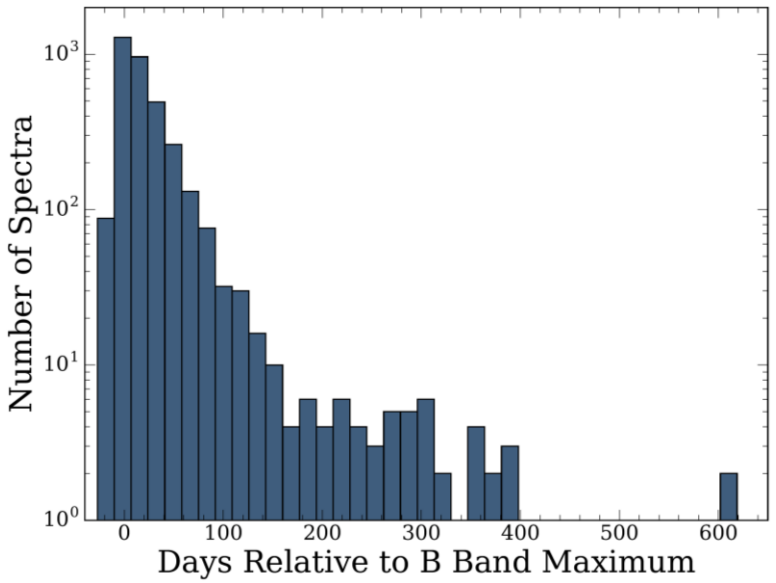


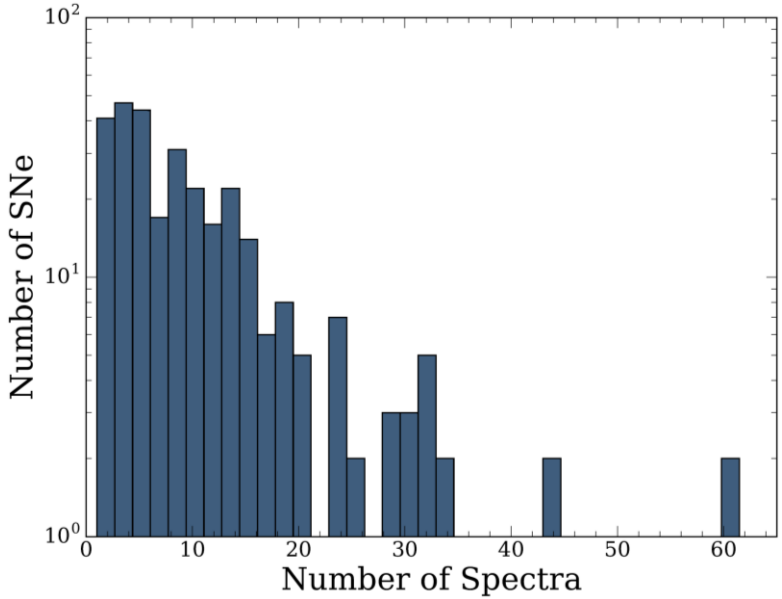
Demographics

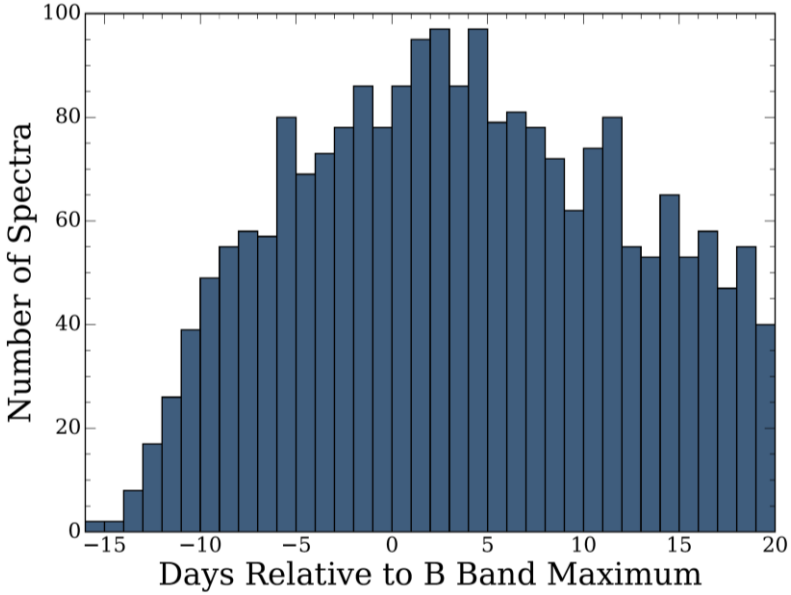
- Subsample requirements
  - Phase estimate
  - Host extinction estimate from light curve fit

N = 308 SNe 3453 Spectra

Siebert et al. in prep

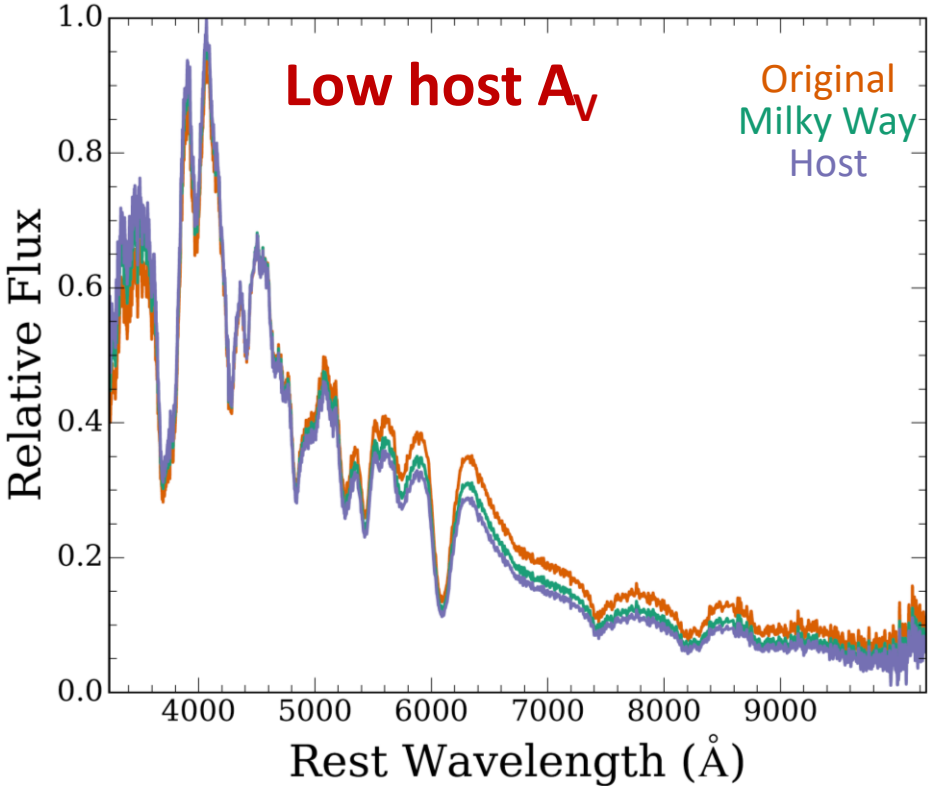


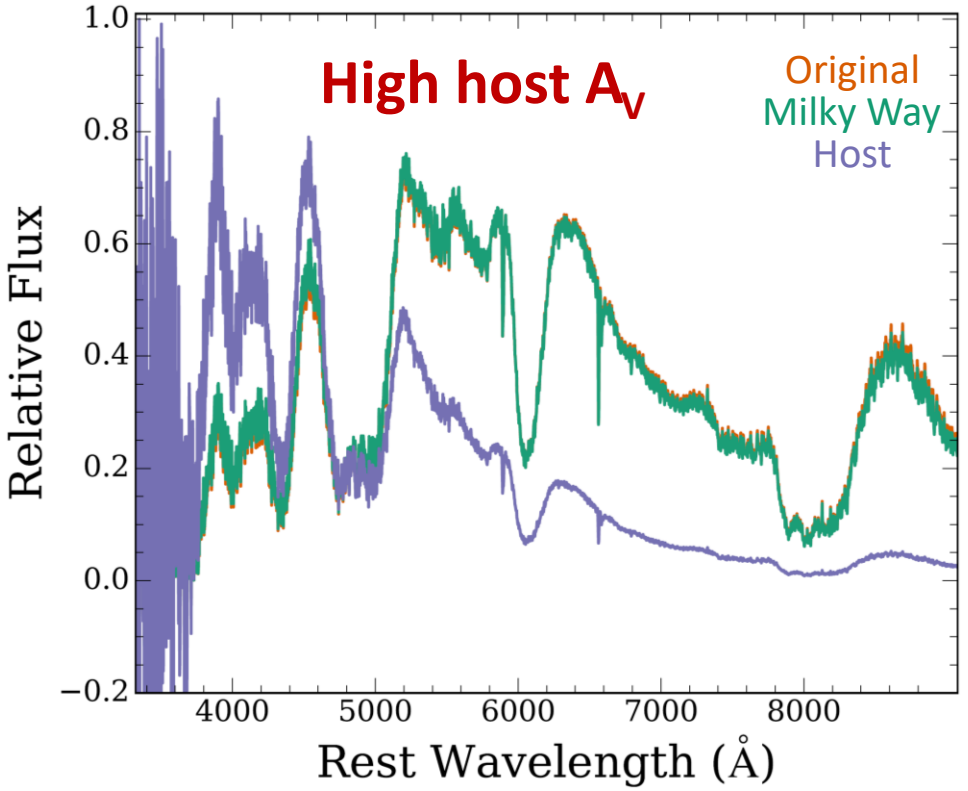




Reddening Corrections

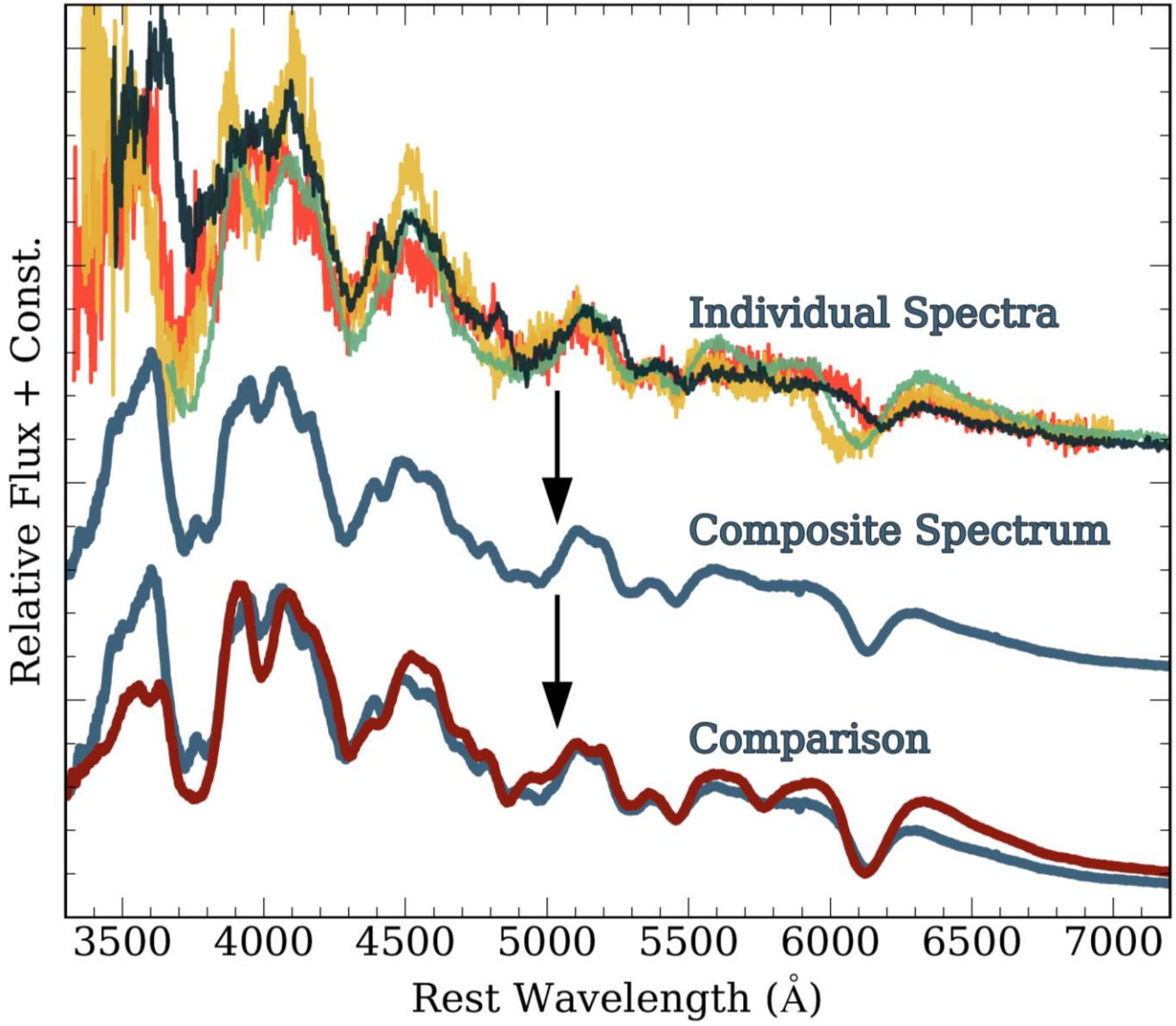
Siebert et al. in prep





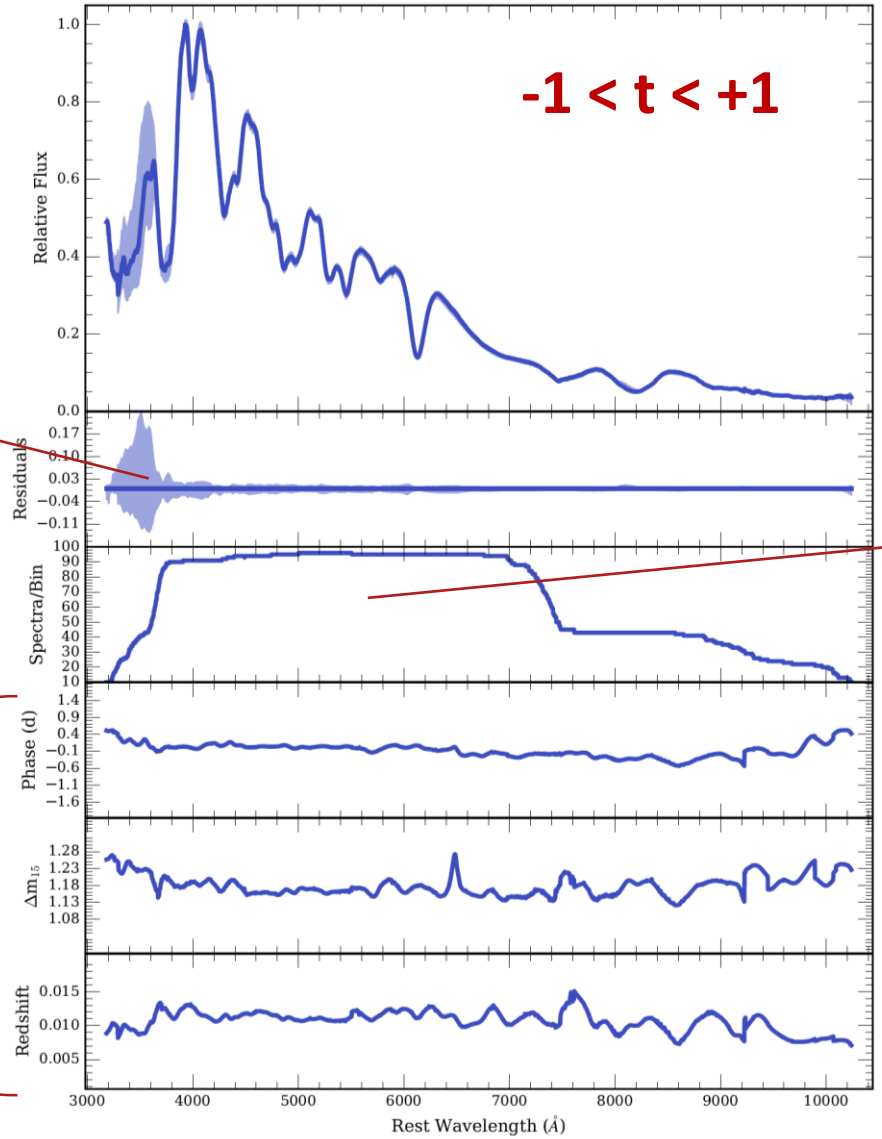
Composite Spectra

Siebert et al. in prep



Composite Spectra

Siebert et al. in prep

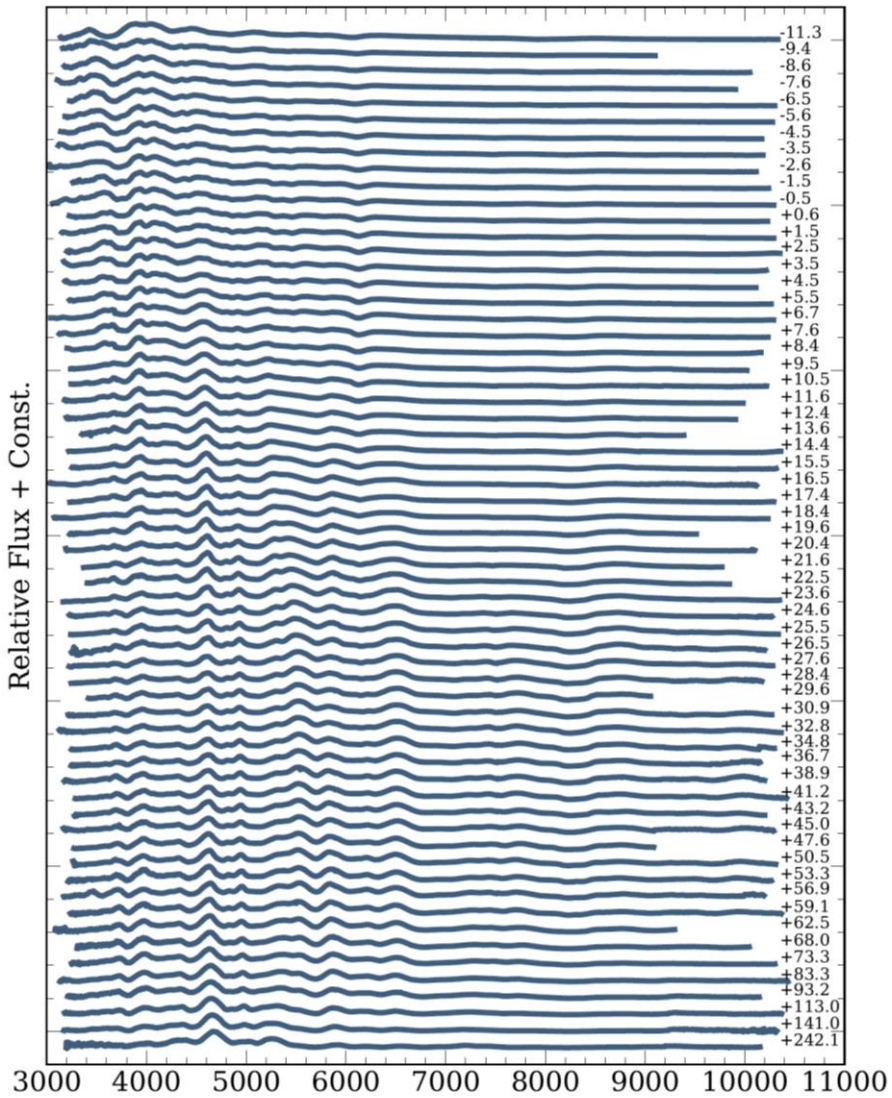


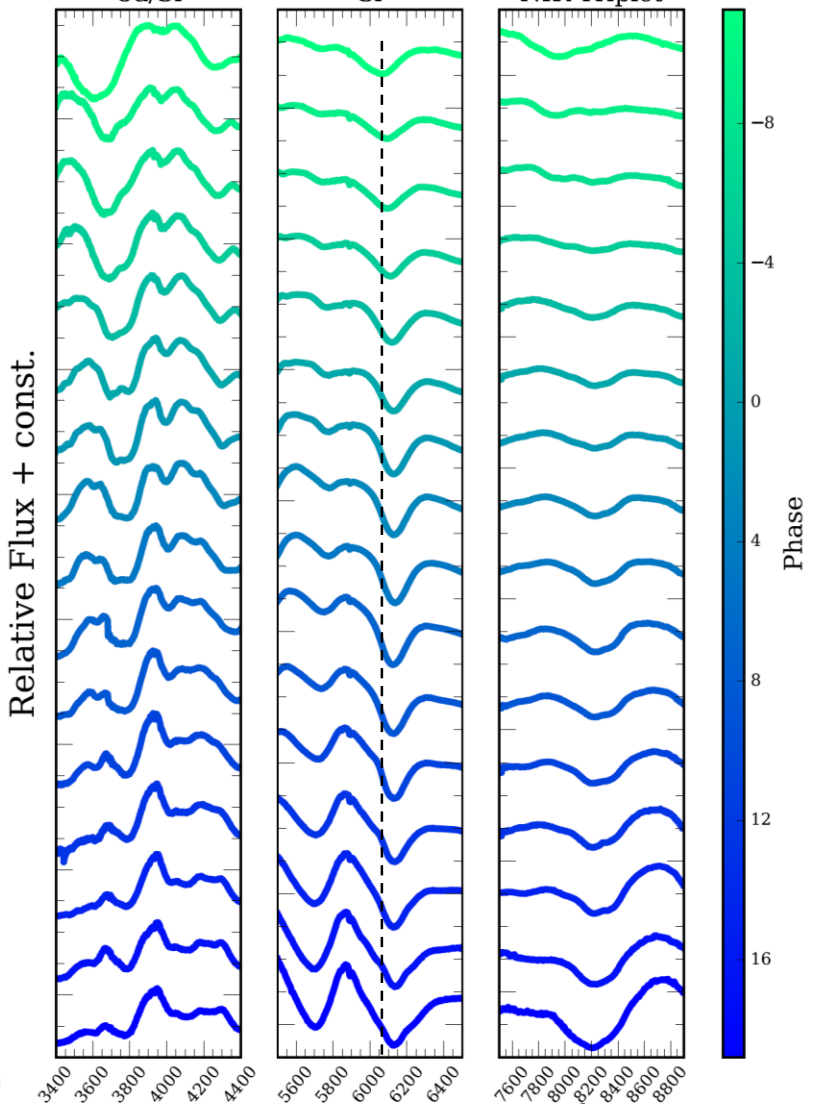
1σ error

97 Spectra

Average properties

Composite Spectra Evolve Smoothly

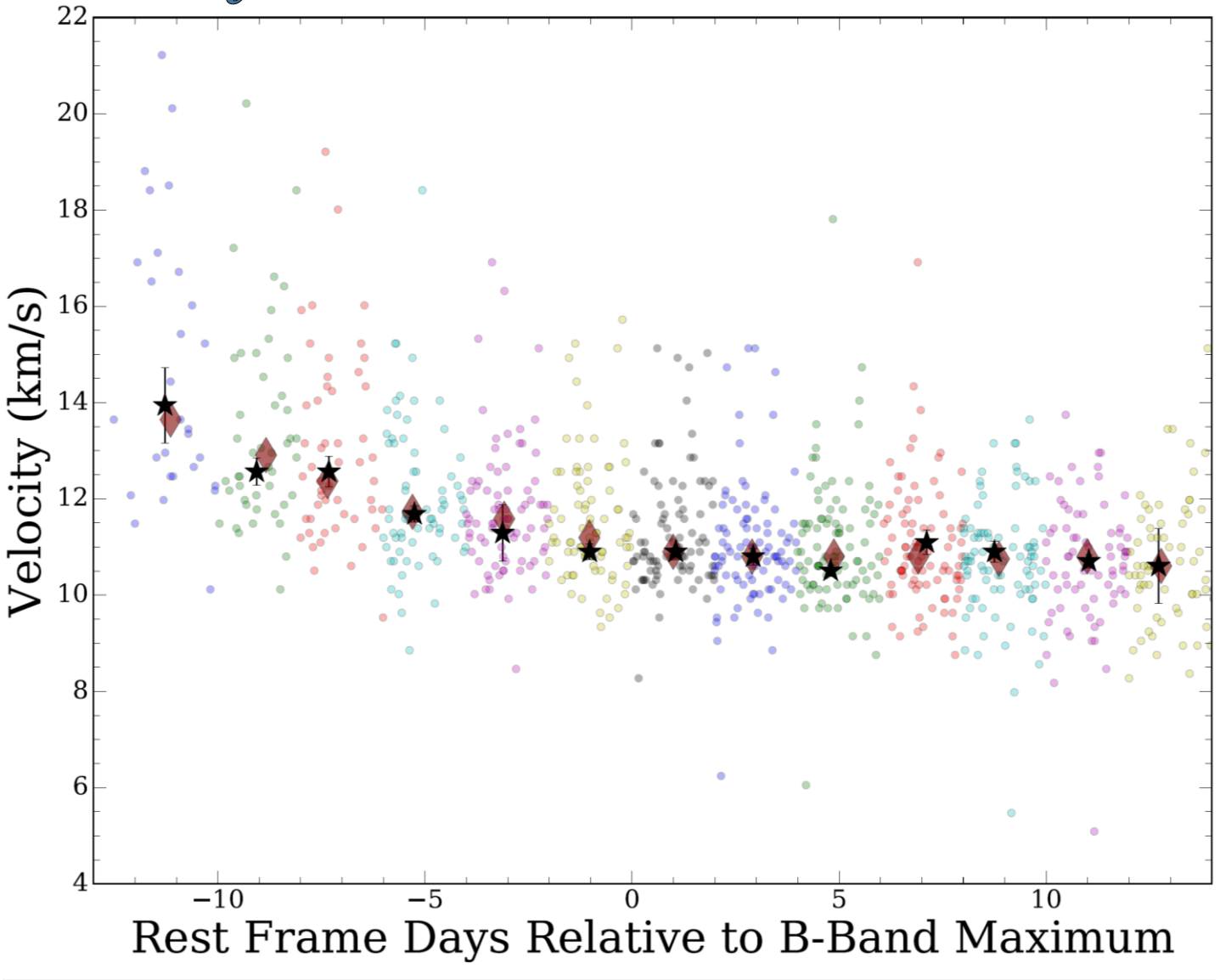




Siebert et al. in prep

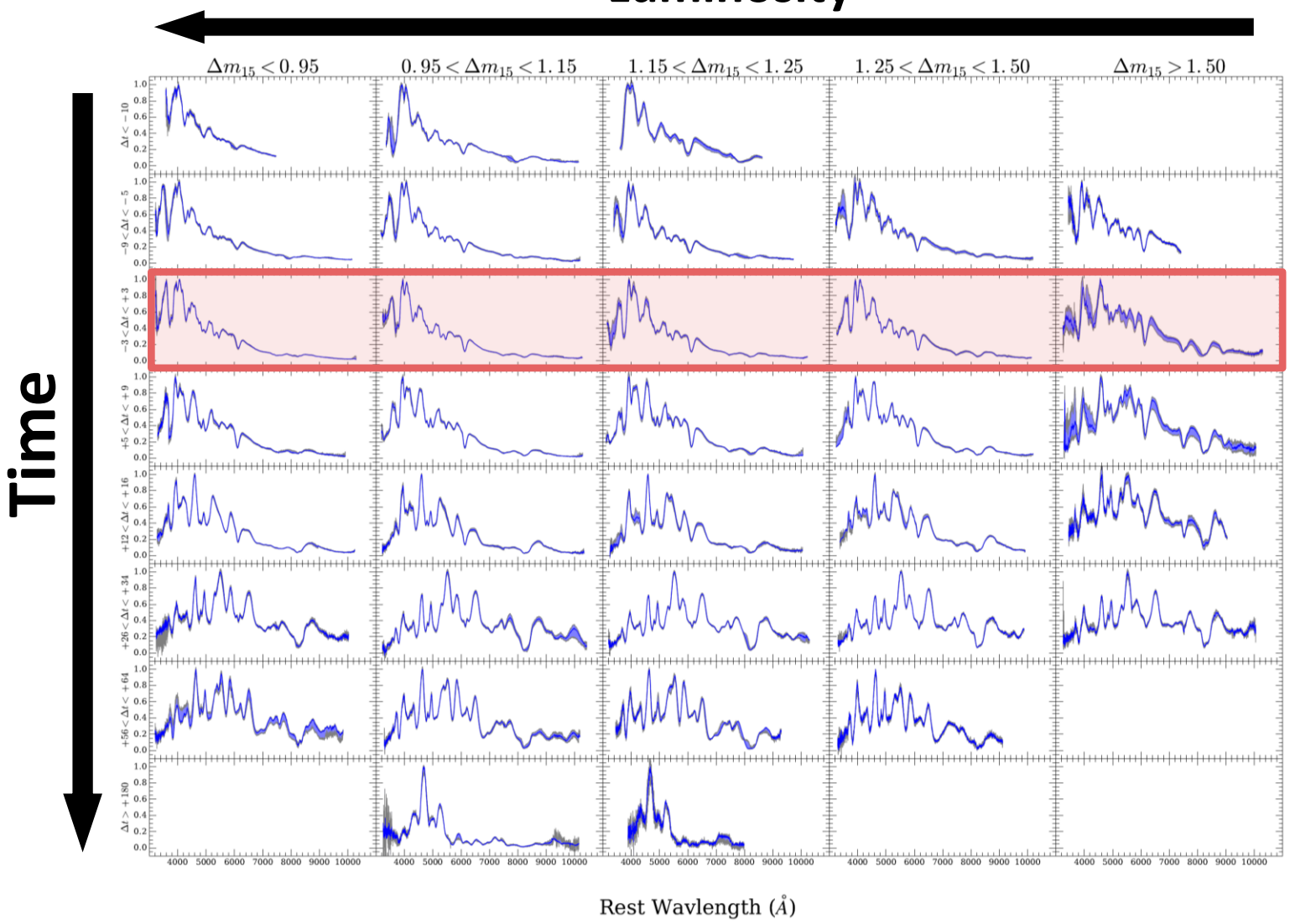
Velocity Evolution

Siebert et al. in prep



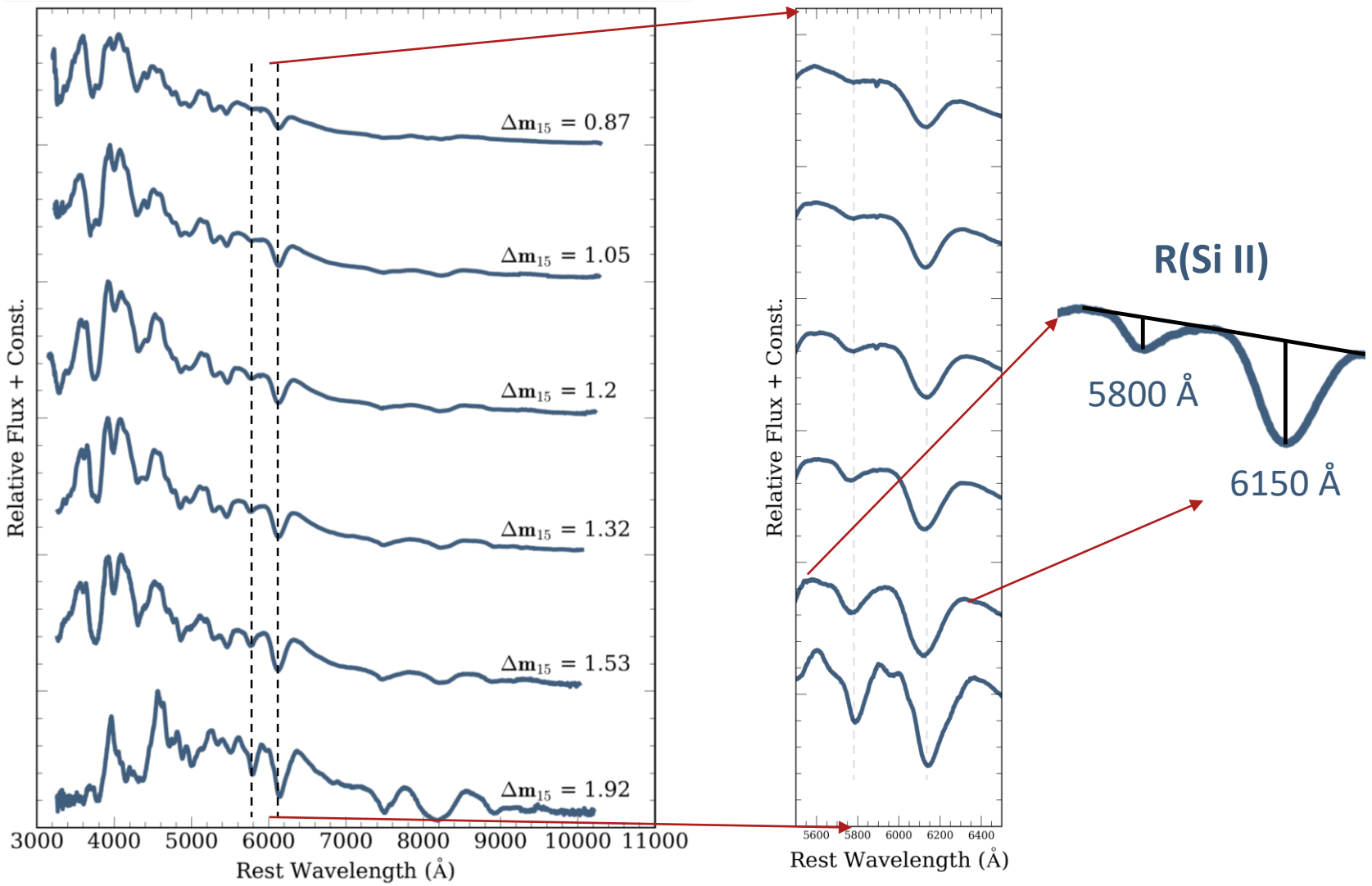
Parameter Hyperspace

Siebert et al. in prep



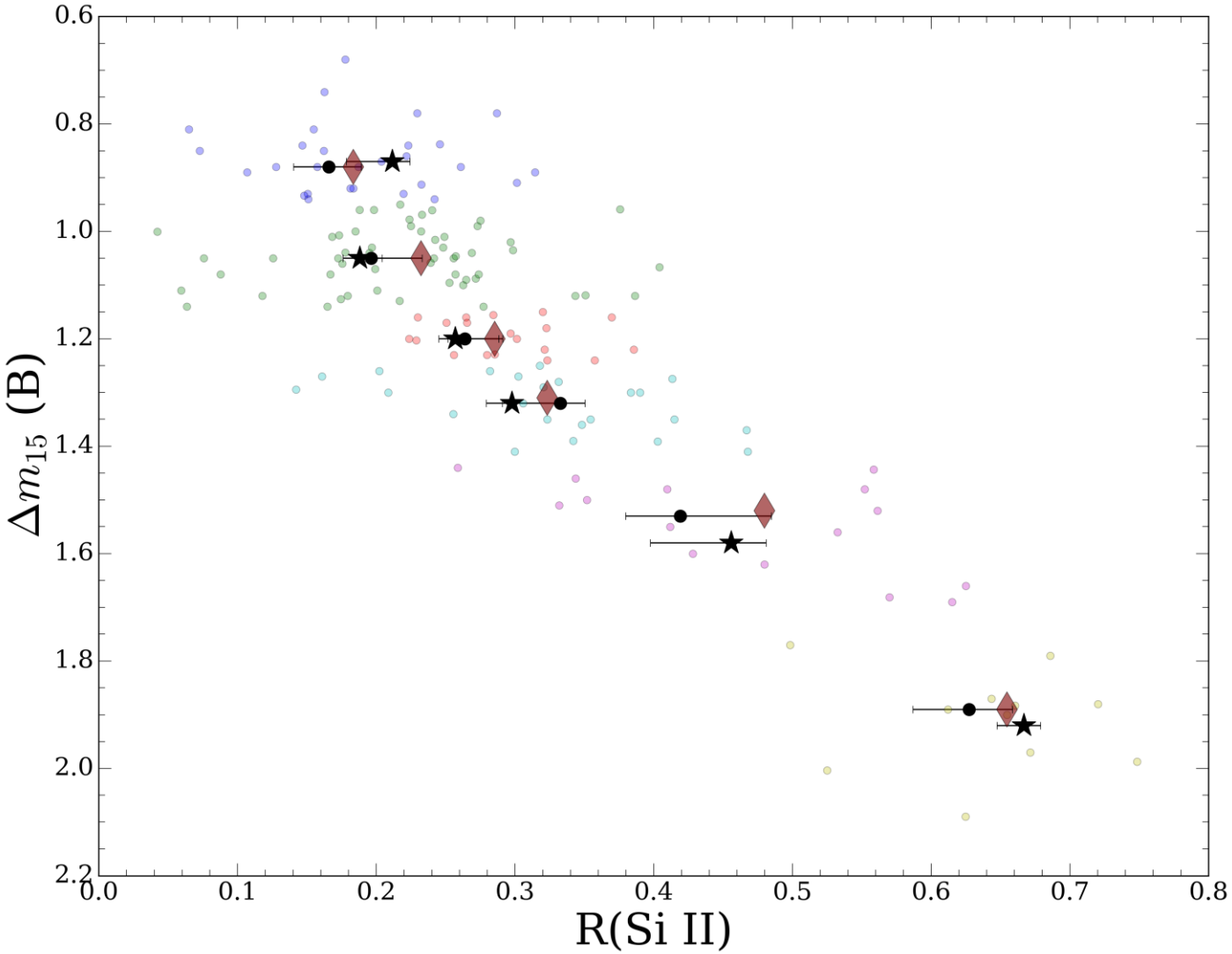
Light Curve Shape – Δm_{15}

Siebert et al. in prep



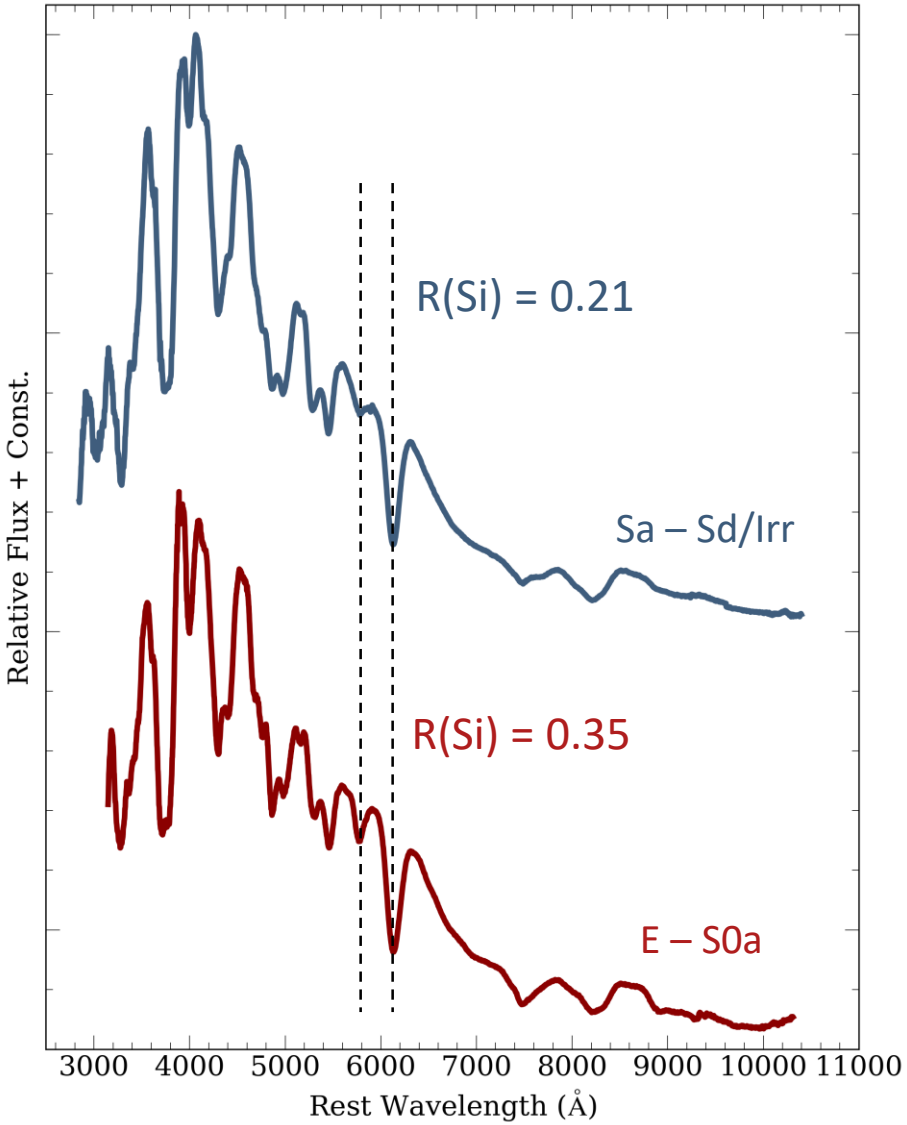
Silicon Ratio – R(Si II)

Siebert et al. in prep



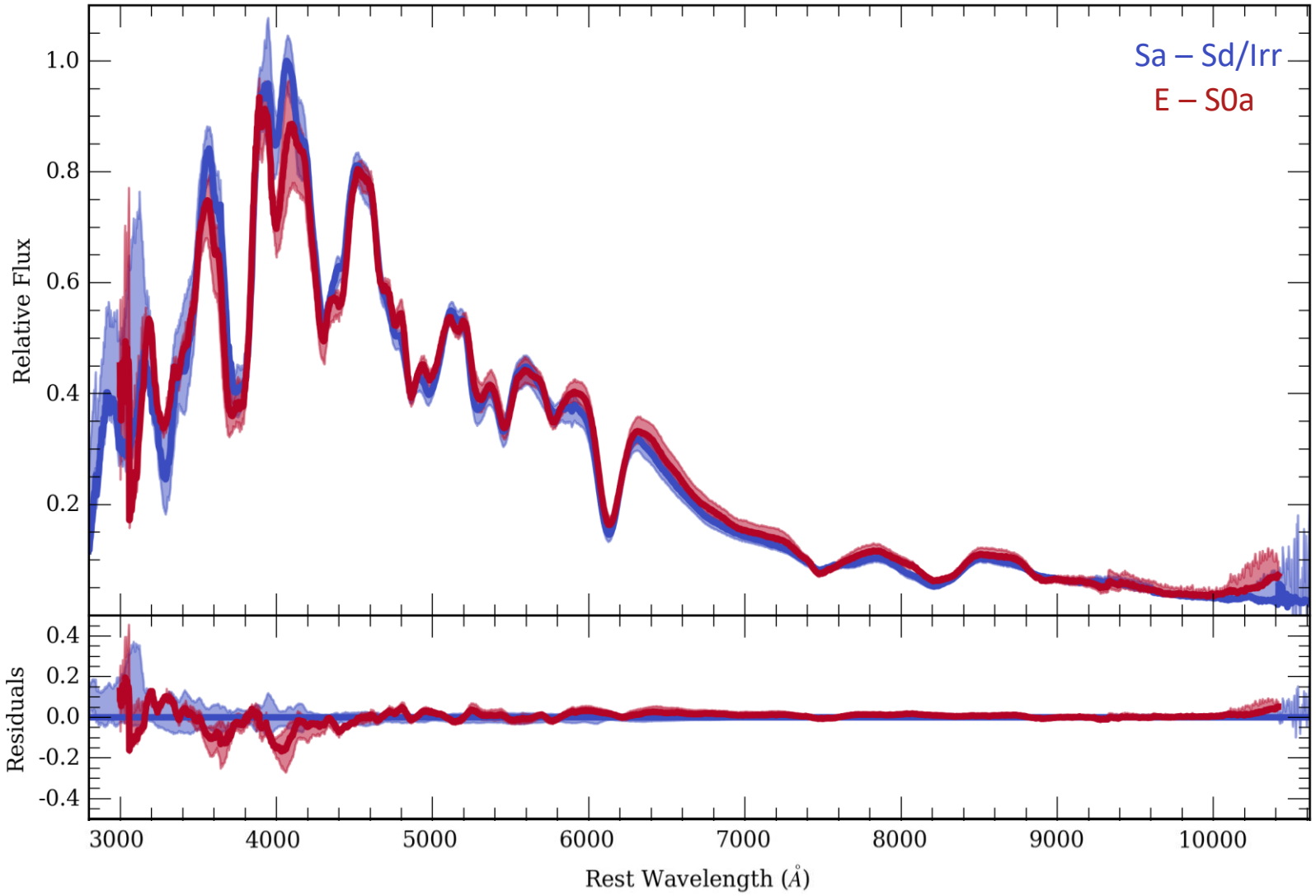
Host Galaxy Morphology

Siebert et al. in prep

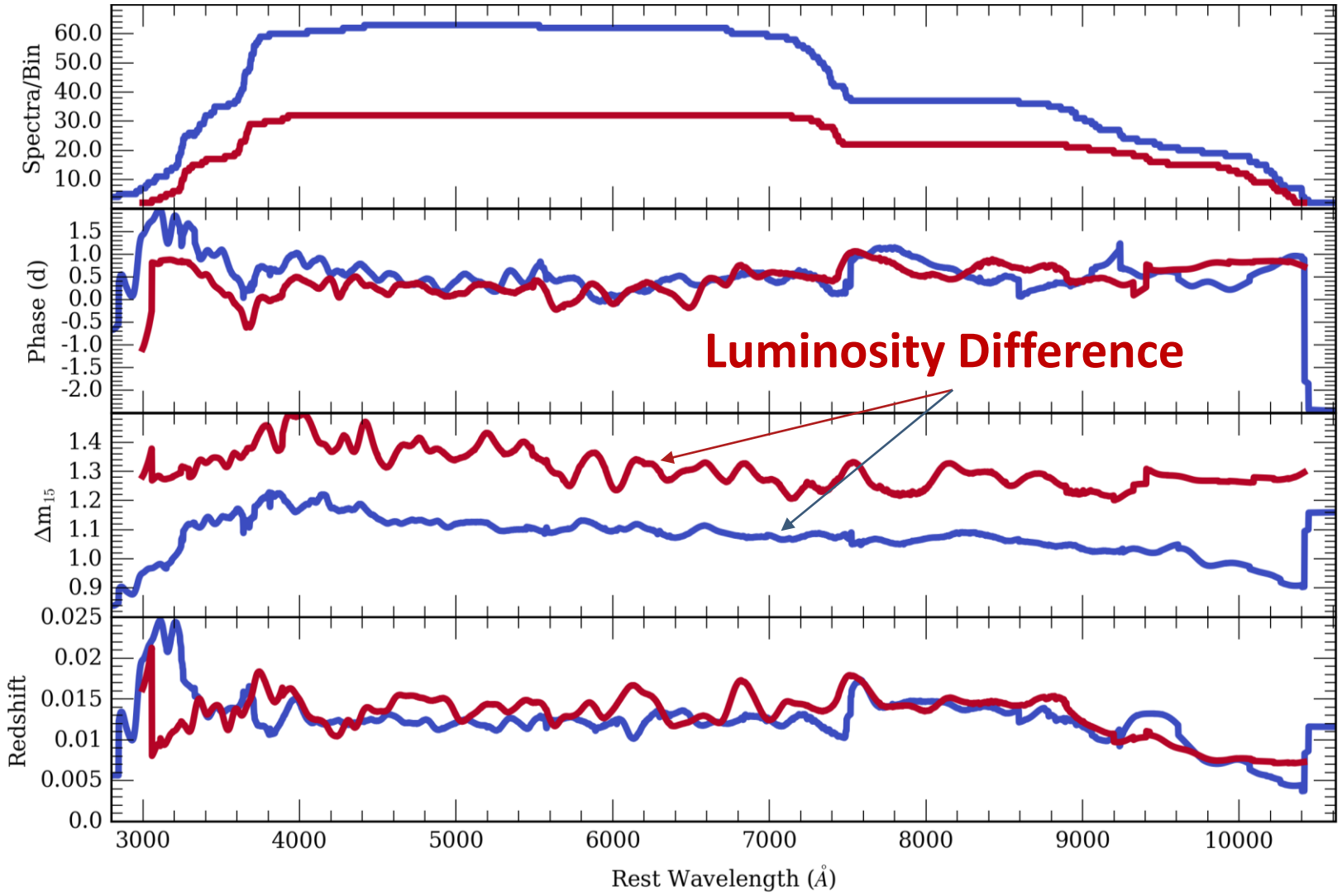


Host Galaxy Morphology

Siebert et al. in prep

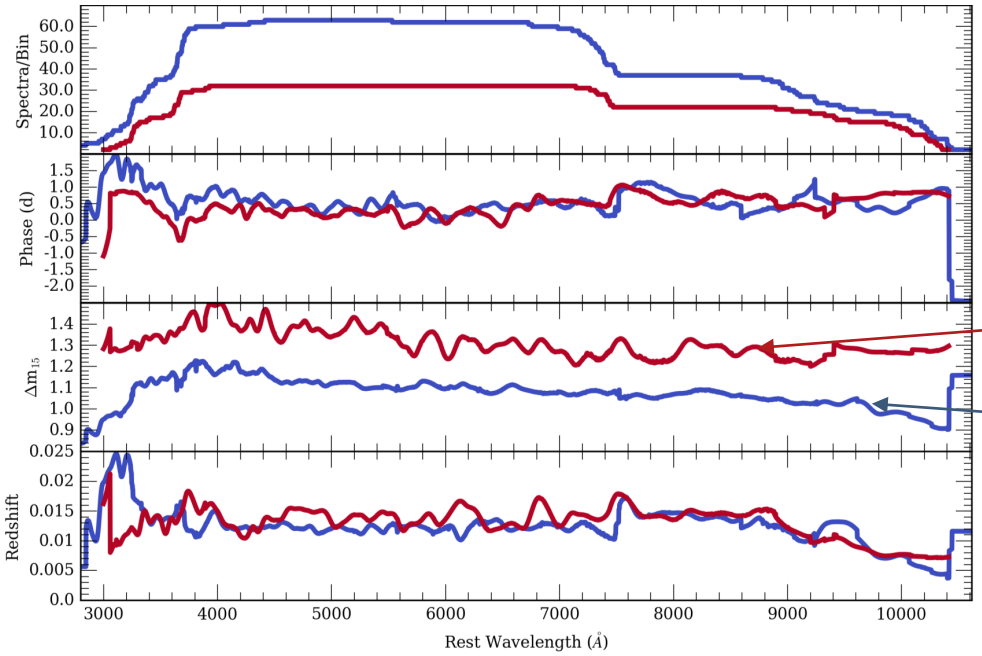


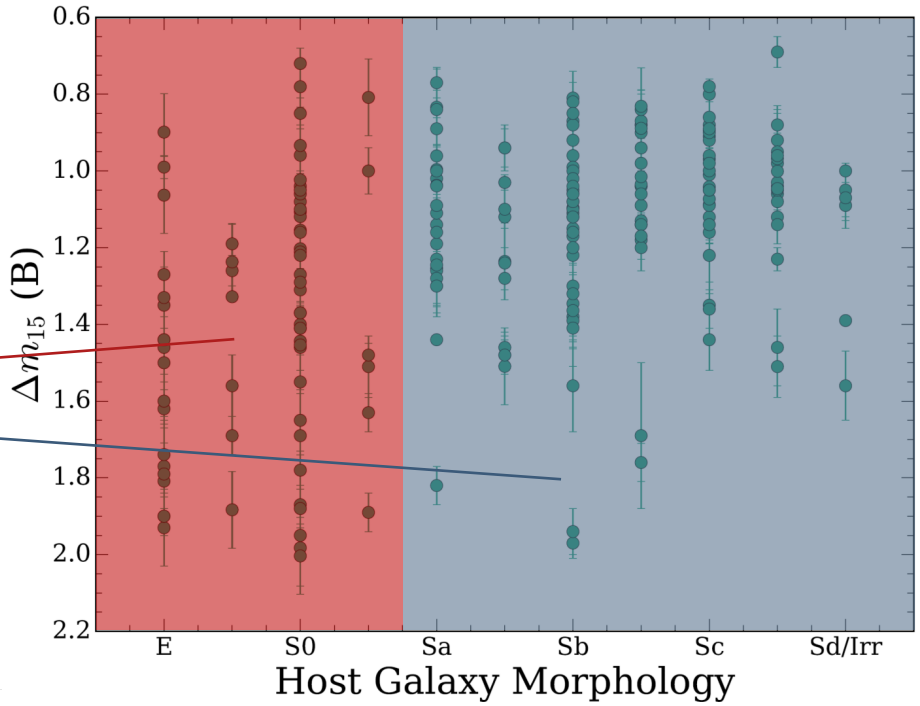
Host Galaxy Morphology



Host Galaxy Morphology

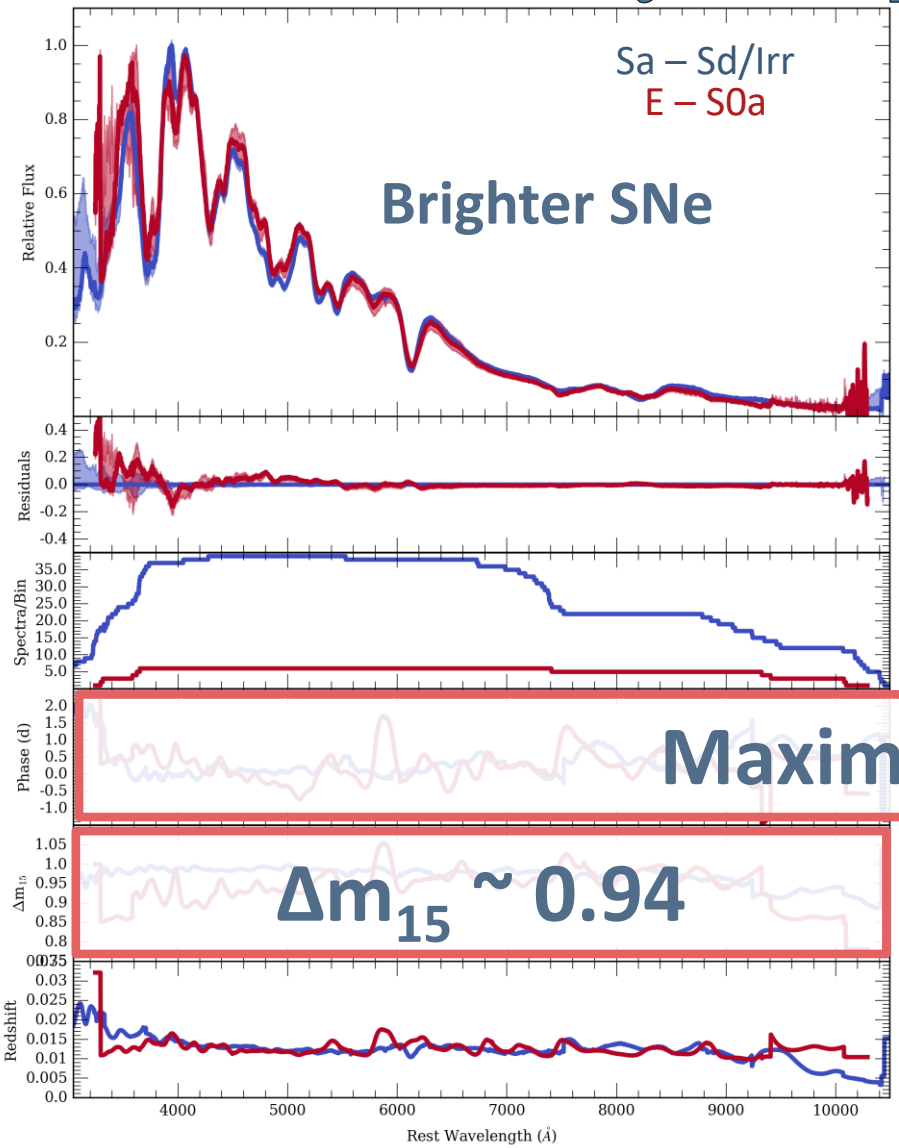
Siebert et al. in prep

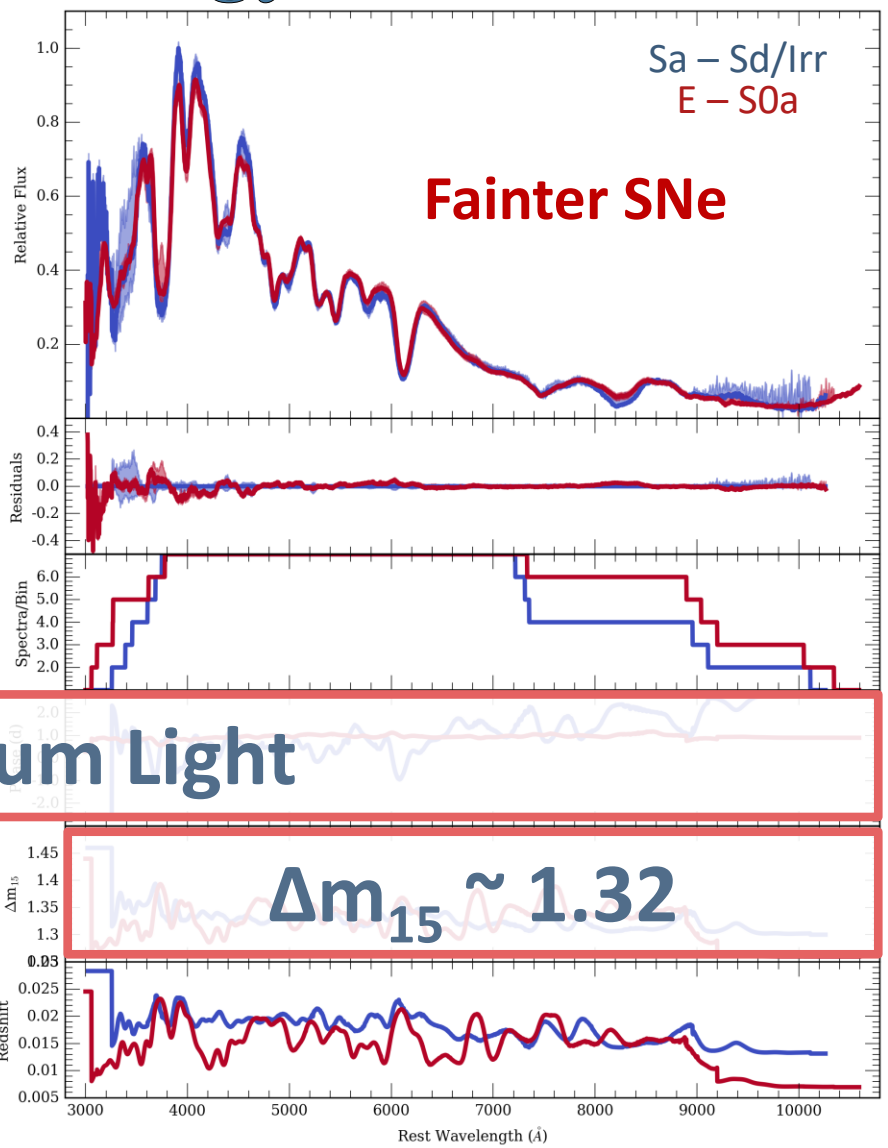




Host Galaxy Morphology

Siebert et al. in prep





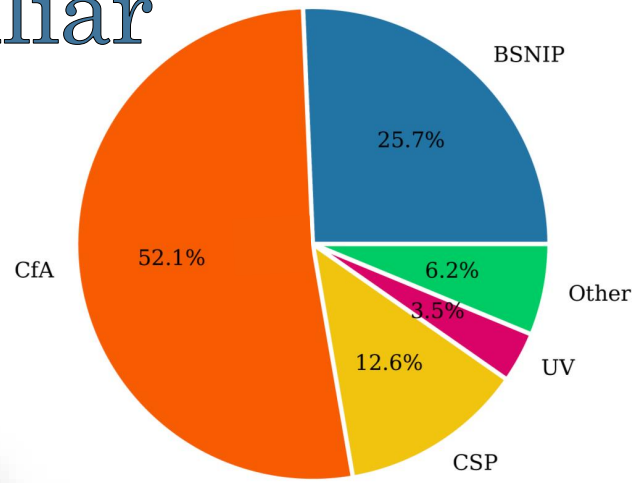
Maximum Light

$\Delta m_{15} \sim 0.94$

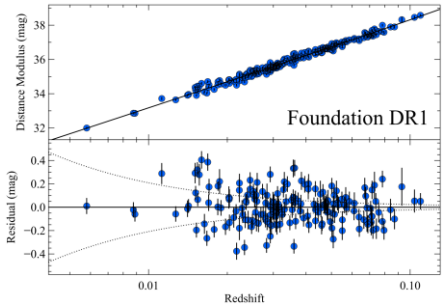
$\Delta m_{15} \sim 1.32$

Conclusions – The Familiar

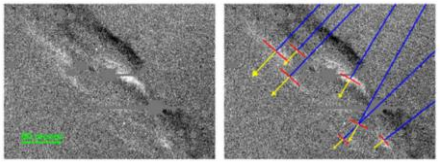
- Open source relational database for SNe Ia
  - Large amount of useful metadata
- Composite spectra are useful tools
  - Reproduce known correlations
- Investigate more parameters
  - Hubble residuals, velocity, color, carbon presence, etc.
- Add more data
  - Foundation sample
  - Other transient classes
- Sub-classification
- Light echoes



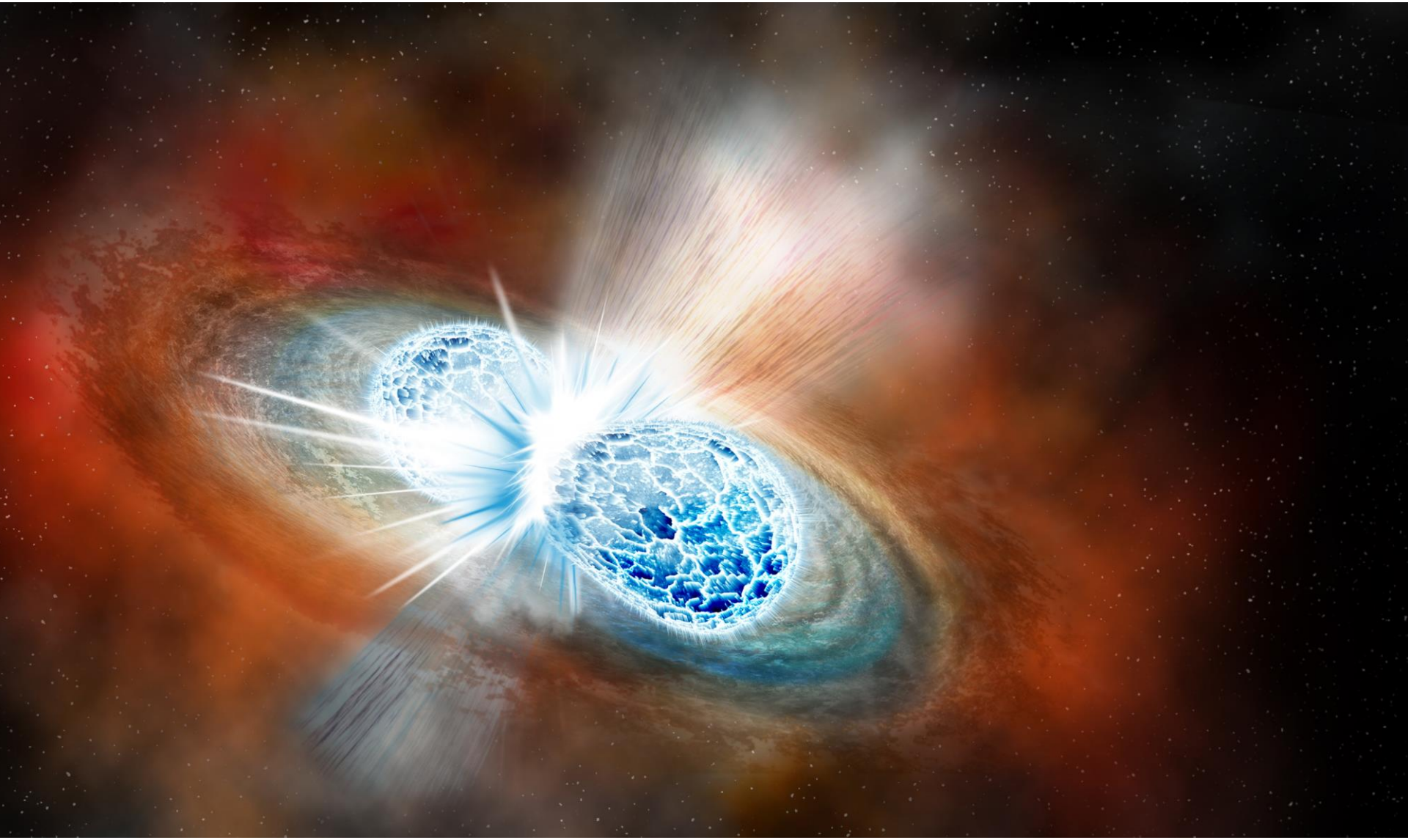
Foley et al. 2018



Rest et al. 2014



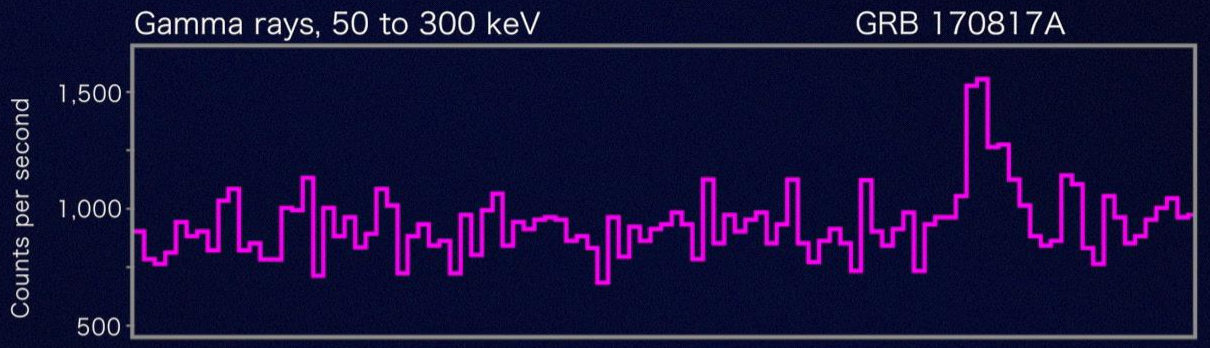
The Exotic



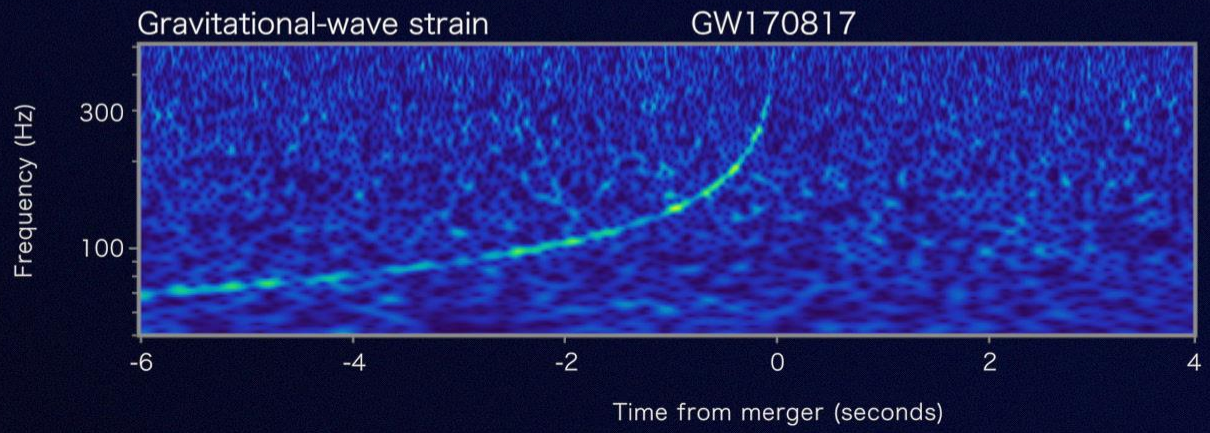
Coincident GW/GRB Trigger

Abbott et al. 2017

Fermi

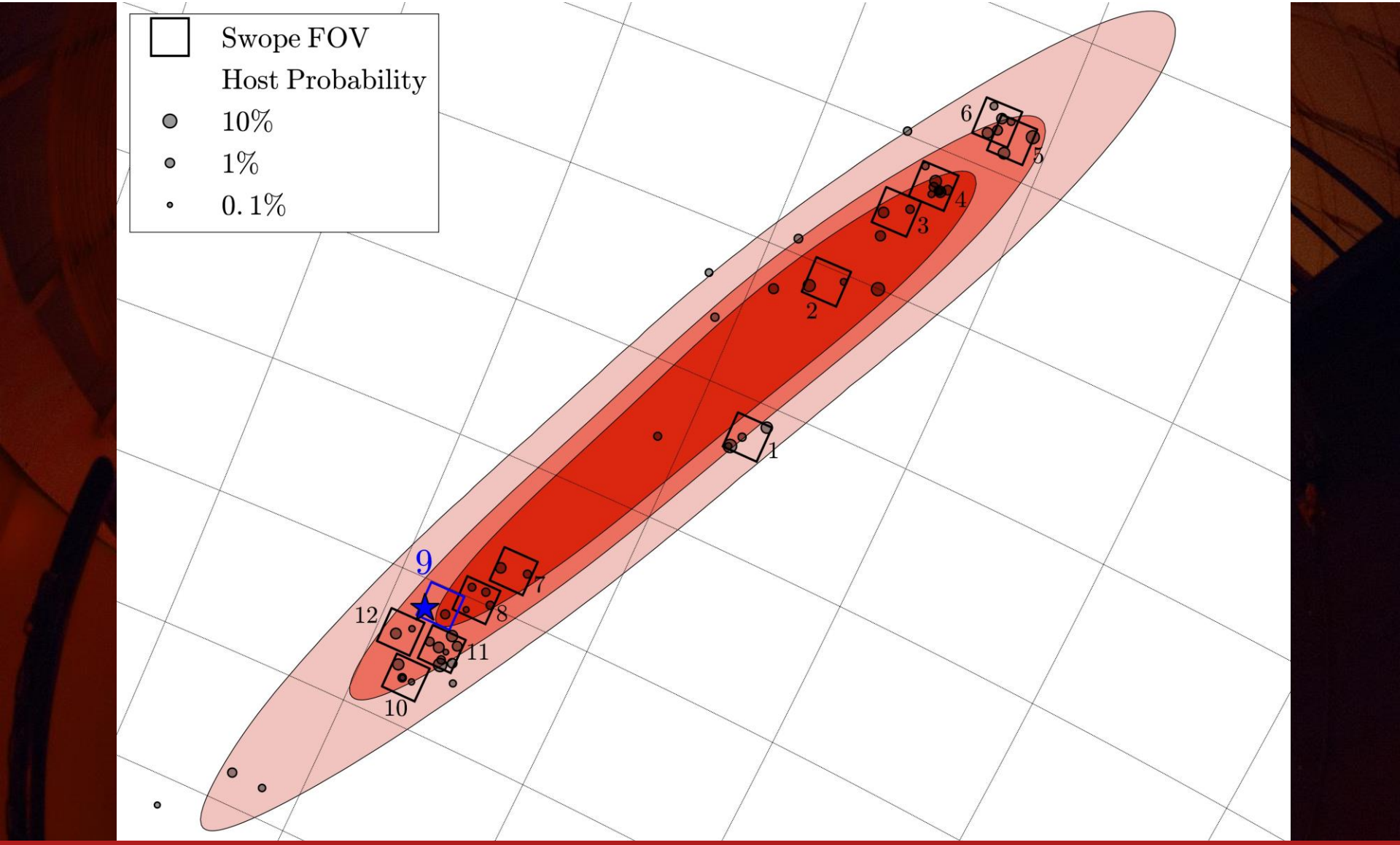


LIGO

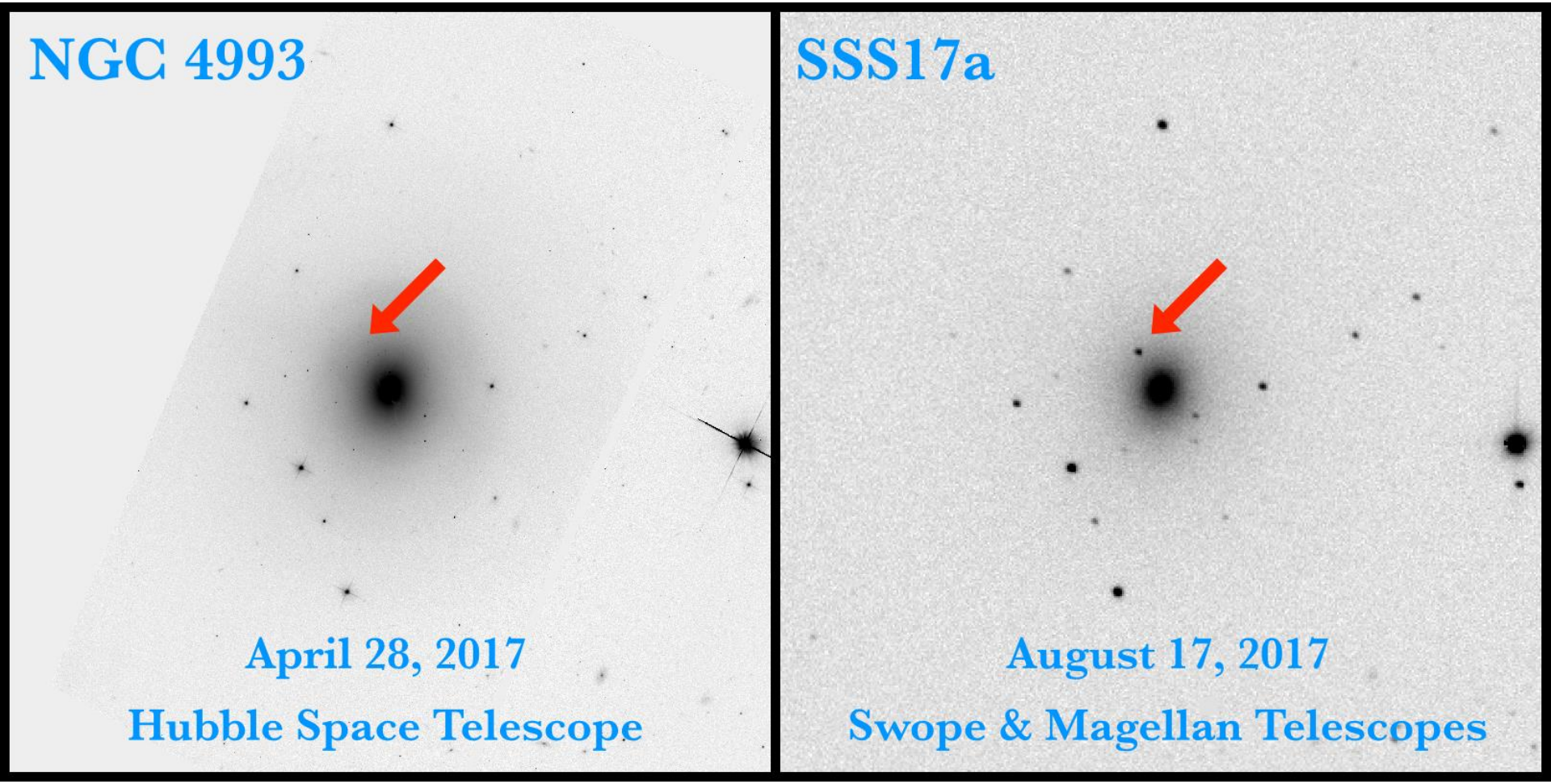


Counterpart Discovery

Coulter et al. 2017



Counterpart Discovery

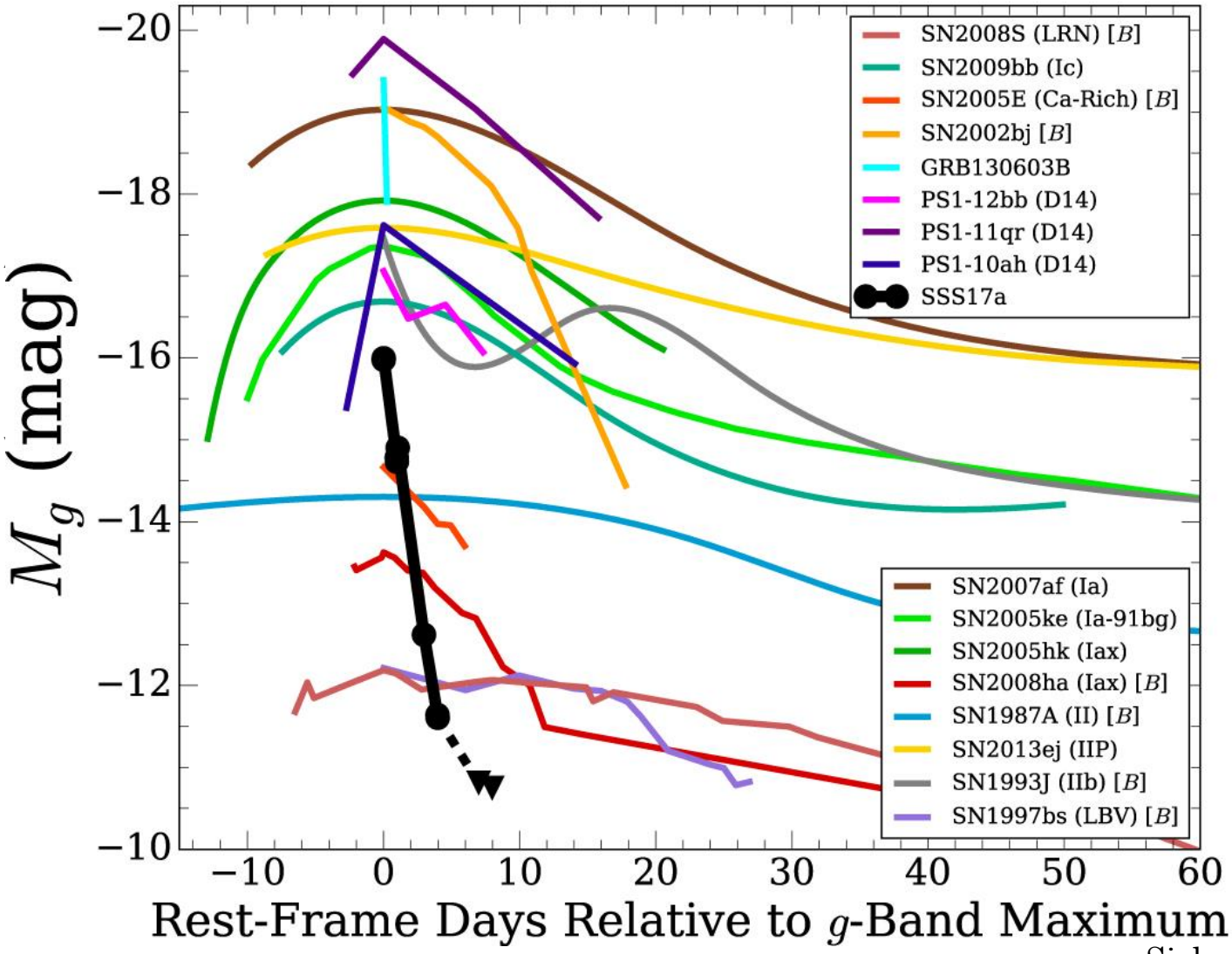


Coulter et al. 2017

Multi-Messenger Astrophysics Begins

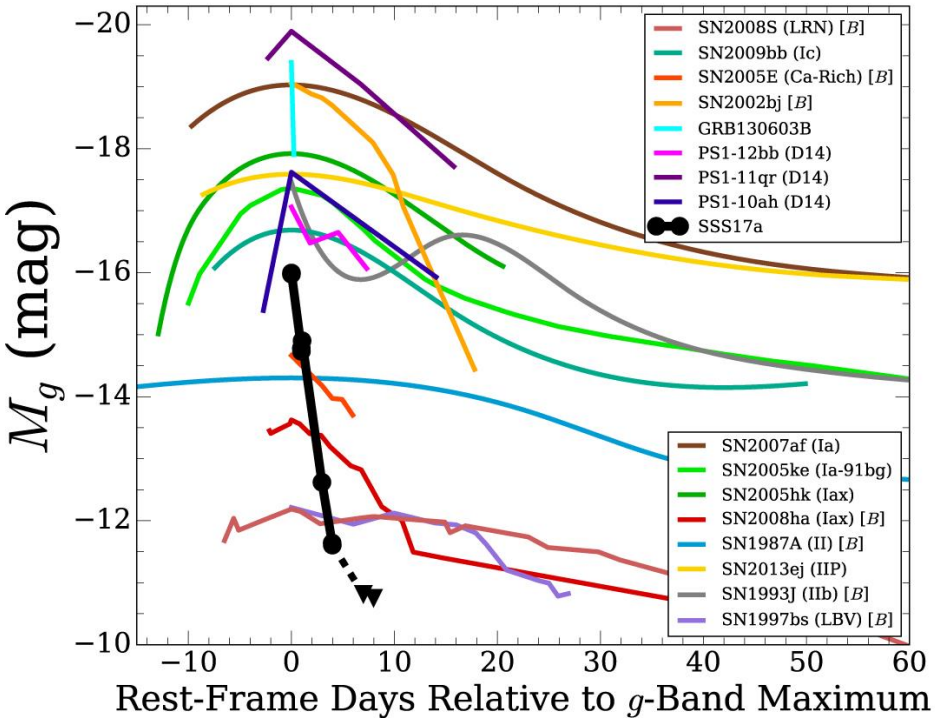

SAO/NASA Astrophysics Data System (ADS)
Query Results from the ADS Database
gw170817
Search again
Retrieved 200 abstracts, starting with number 1. Total number selected: 228.
BILLIONS AND BILLIONS MORE!

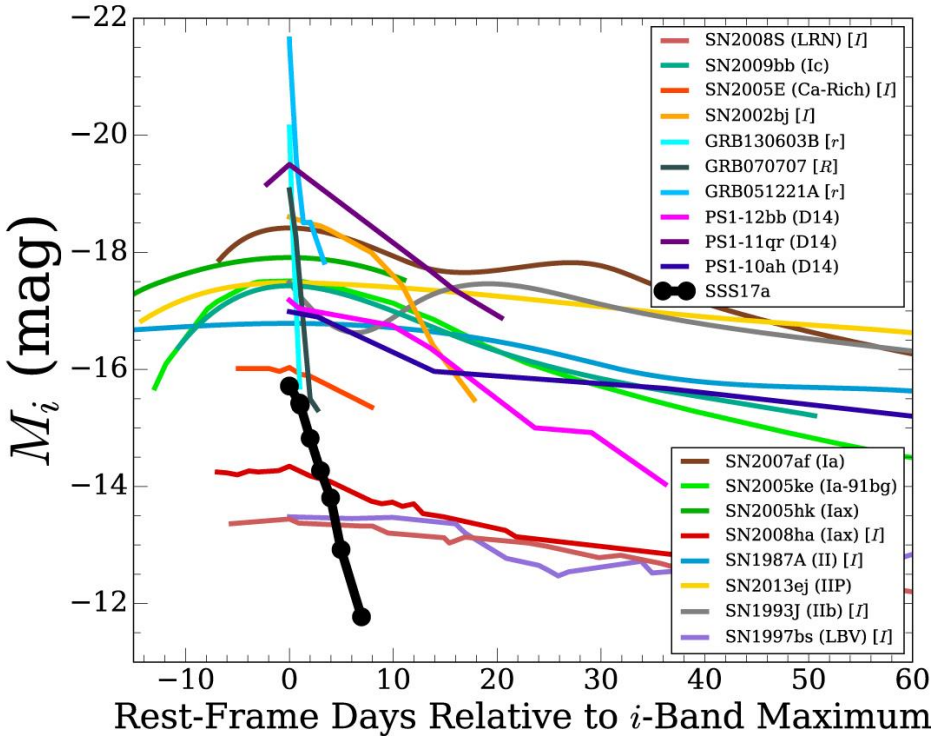
Light Curve



Siebert et al. 2017

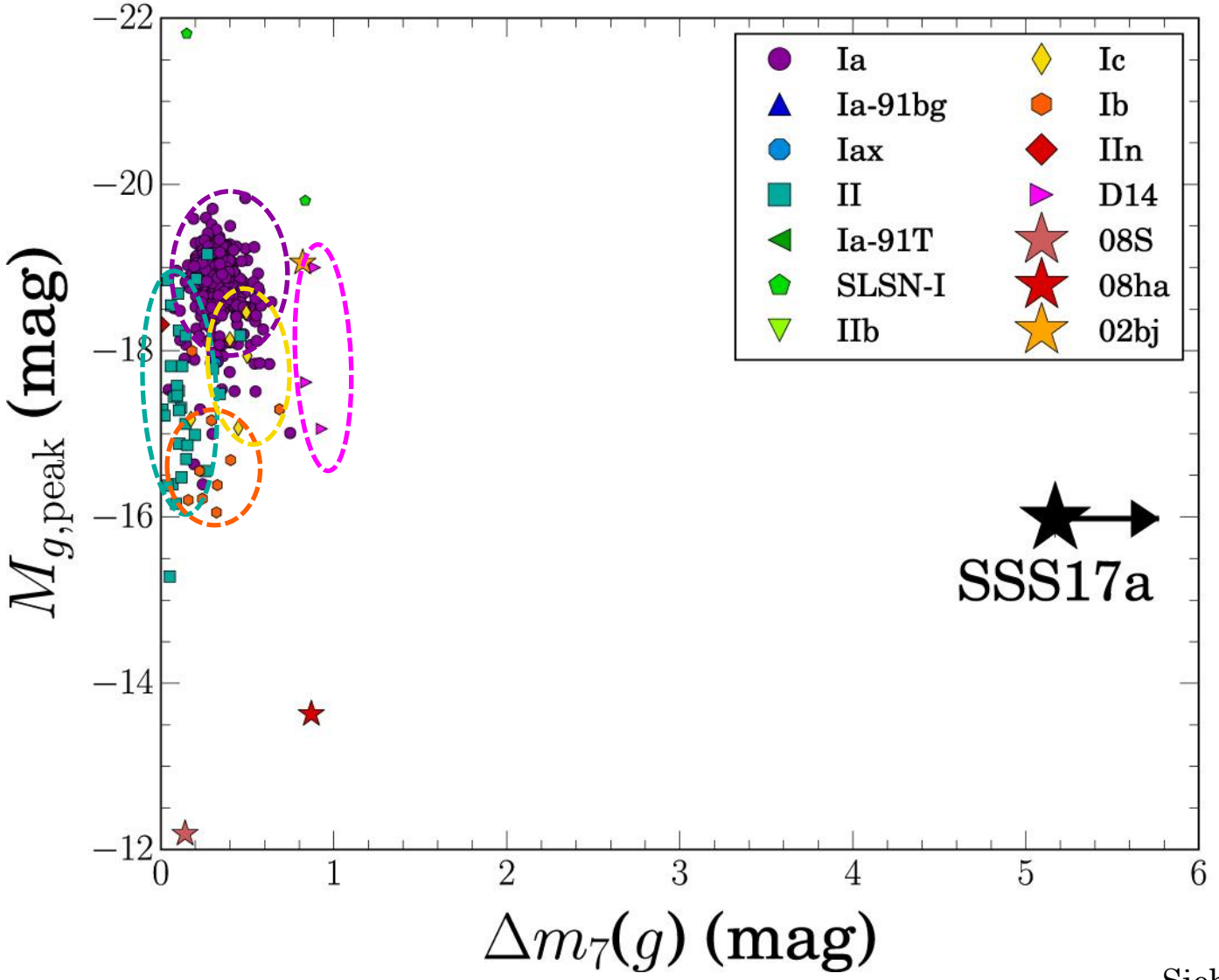
Light Curve





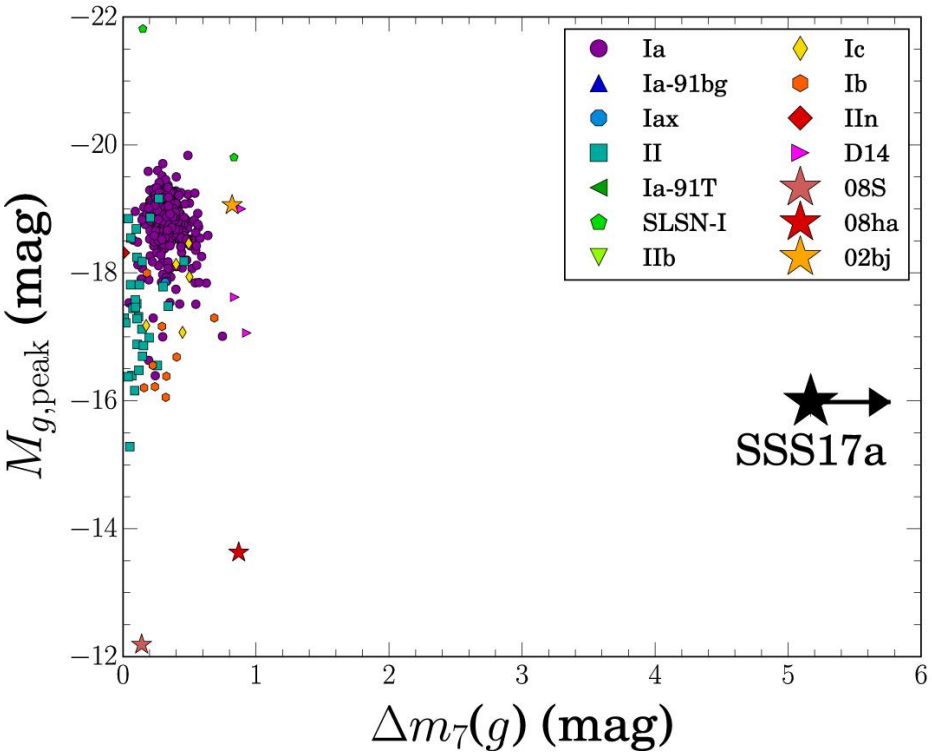
Siebert et al. 2017

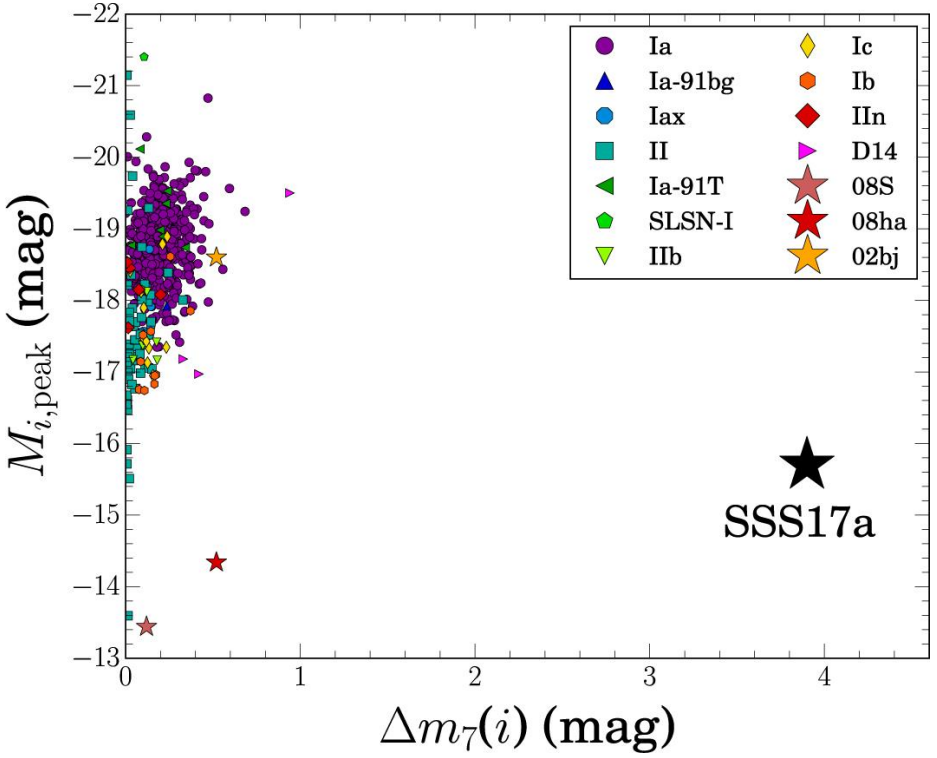
Decline Rate



Siebert et al. 2017

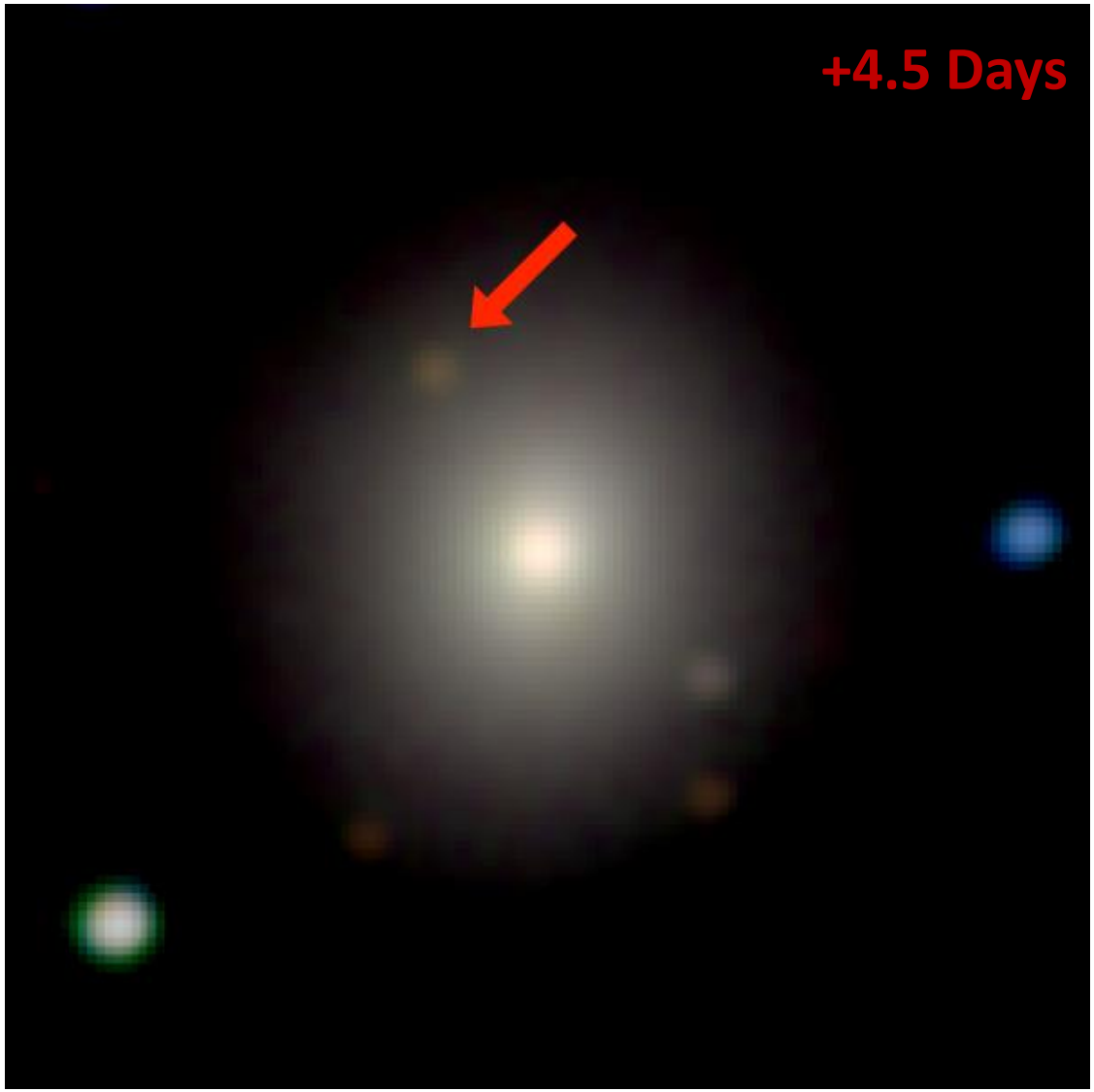
Decline Rate



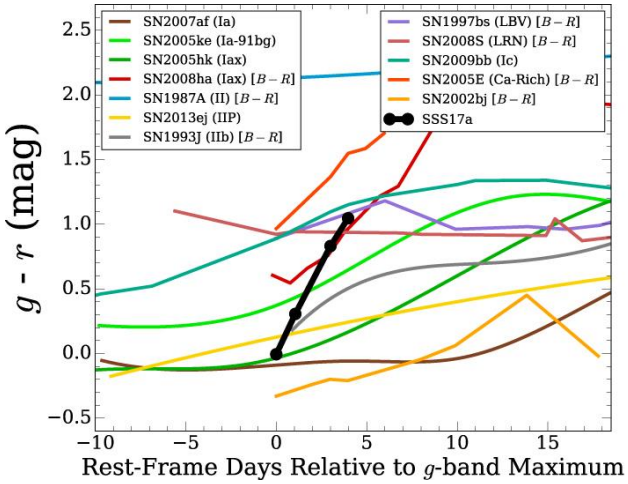


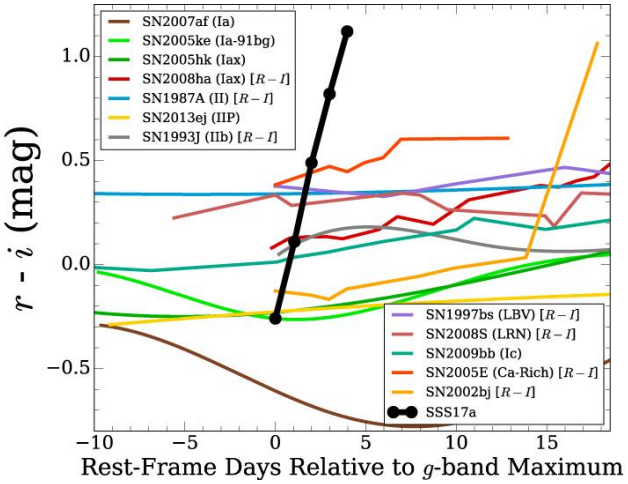
Siebert et al. 2017

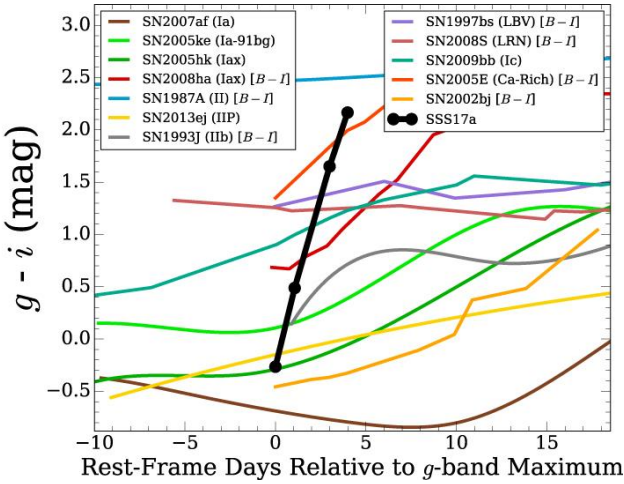
Color Evolution



Color Evolution



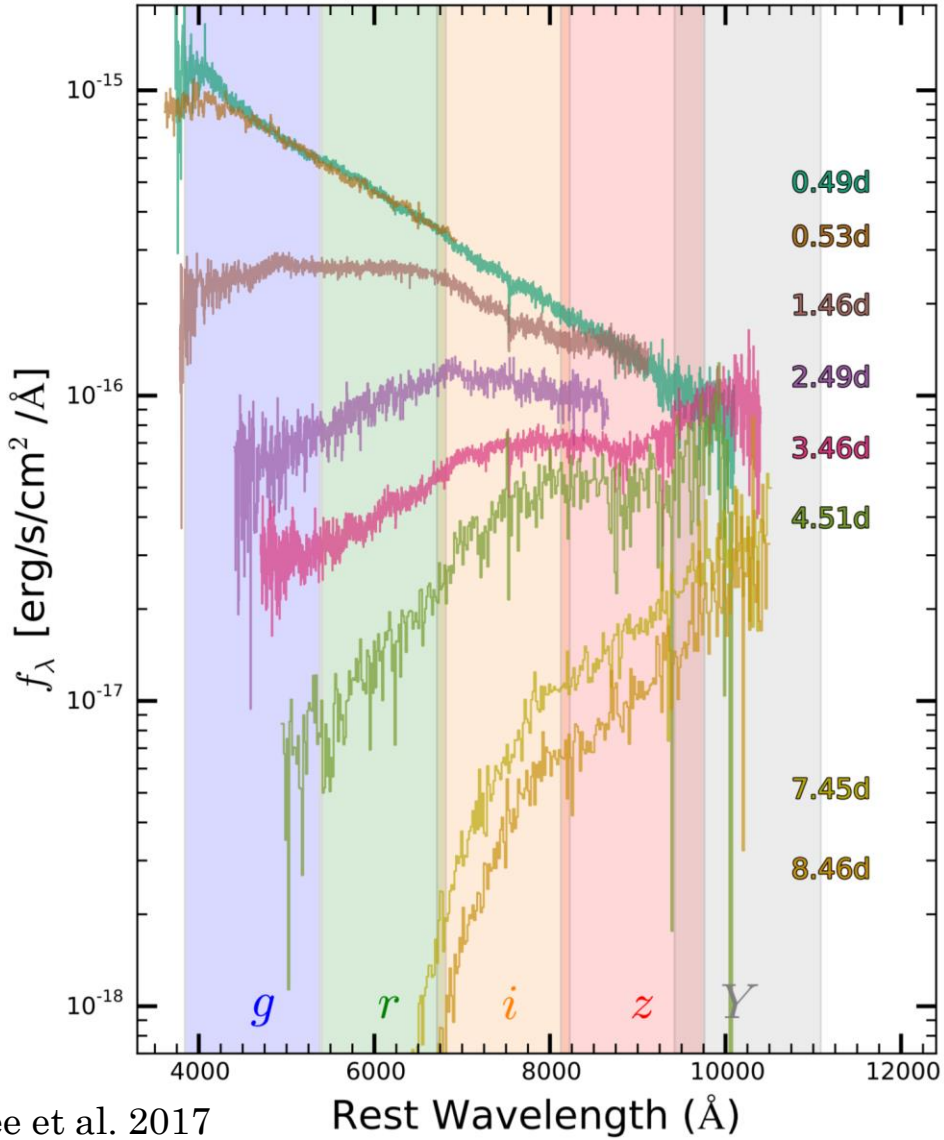


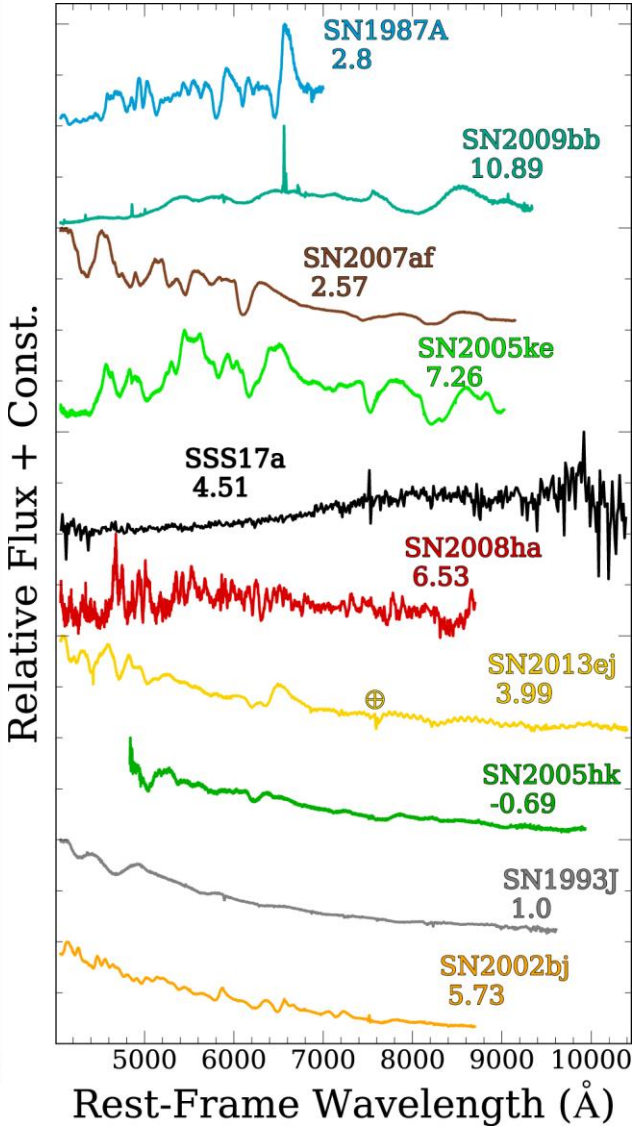


Siebert et al. 2017

Spectroscopic Evolution

Siebert et al. 2017





Shappee et al. 2017

Fraction of SSS17a-like Transients

How constraining are past SN surveys?

Need 2 detections

↓

~15 Mpc

↓

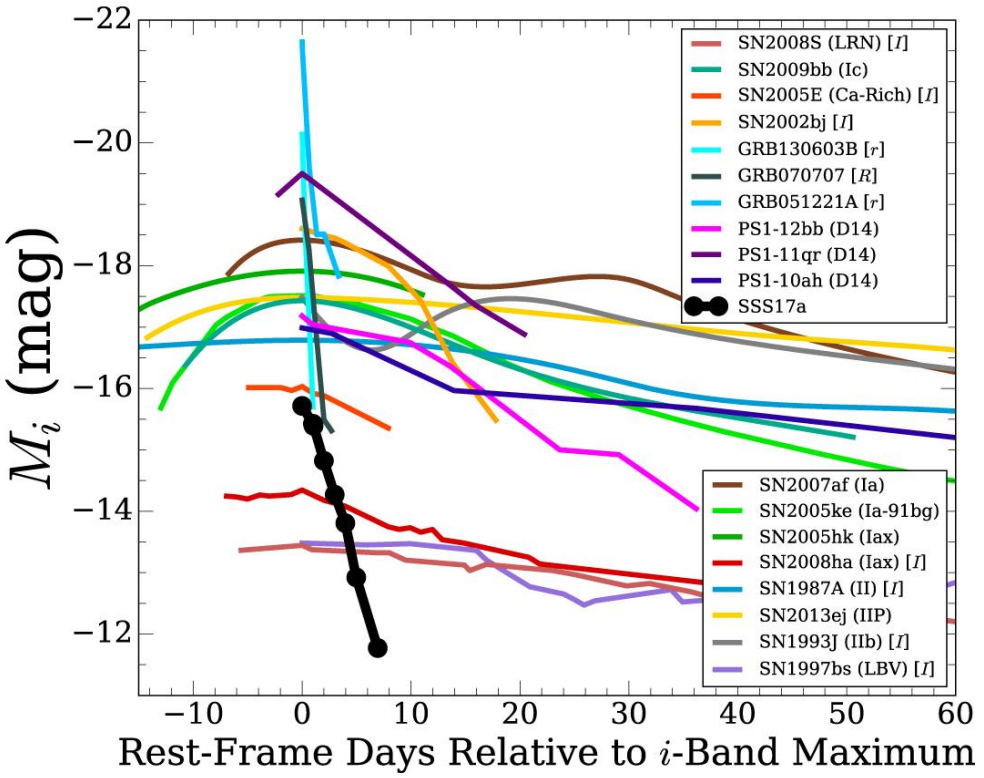
58 SNe since 2008

↓

Difficulty of observing

↓

$f_{SSS17a} \leq 0.16$ * total SN rate
(90% confidence)



Siebert et al. 2017

Chance of Coincidence

Coulter et al. 2017

40 ± 7 Mpc in 31 deg^2

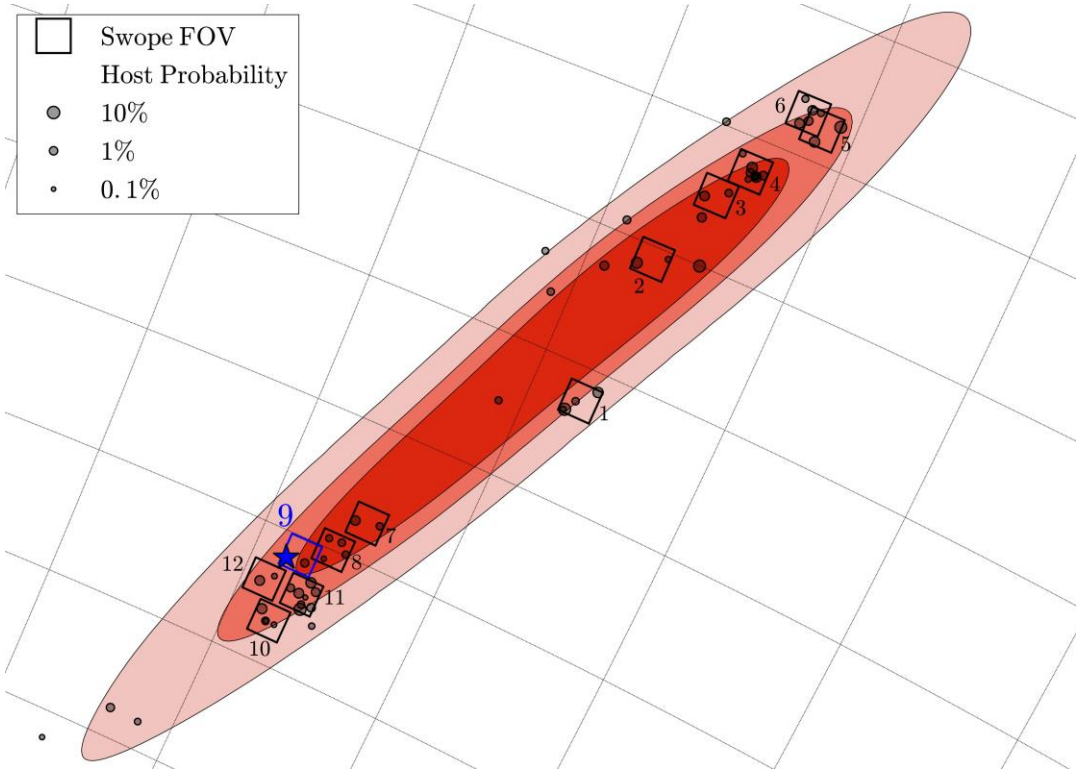
↓

RLVC ~ 0.01 SNe yr-1

↓

t_{nd} ~ 2 days

↓



$P_{chance} \leq f_{SSS17a} \times R_{LVC} \times t_{nd} \leq 9 \times 10^{-6}$ at 90% confidence

Rate of SSS17a-like transients

LVC

$1.5^{+3.2}_{-1.2} \times 10^3$ Gpc^{-3} yr^{-1}

$0.018^{+0.038}_{-0.014}$ per century in the MW

Rate of "SSS17a-like" events

$\leq 1.6 \times 10^4$ Gpc^{-3} yr^{-1}

≤ 0.19 per century in the MW

r-process in the Milky Way

$m_{r\text{-}p} \approx 0.06\ M_\odot$ per "SSS17a-like event" Kilpatrick et al. 2017

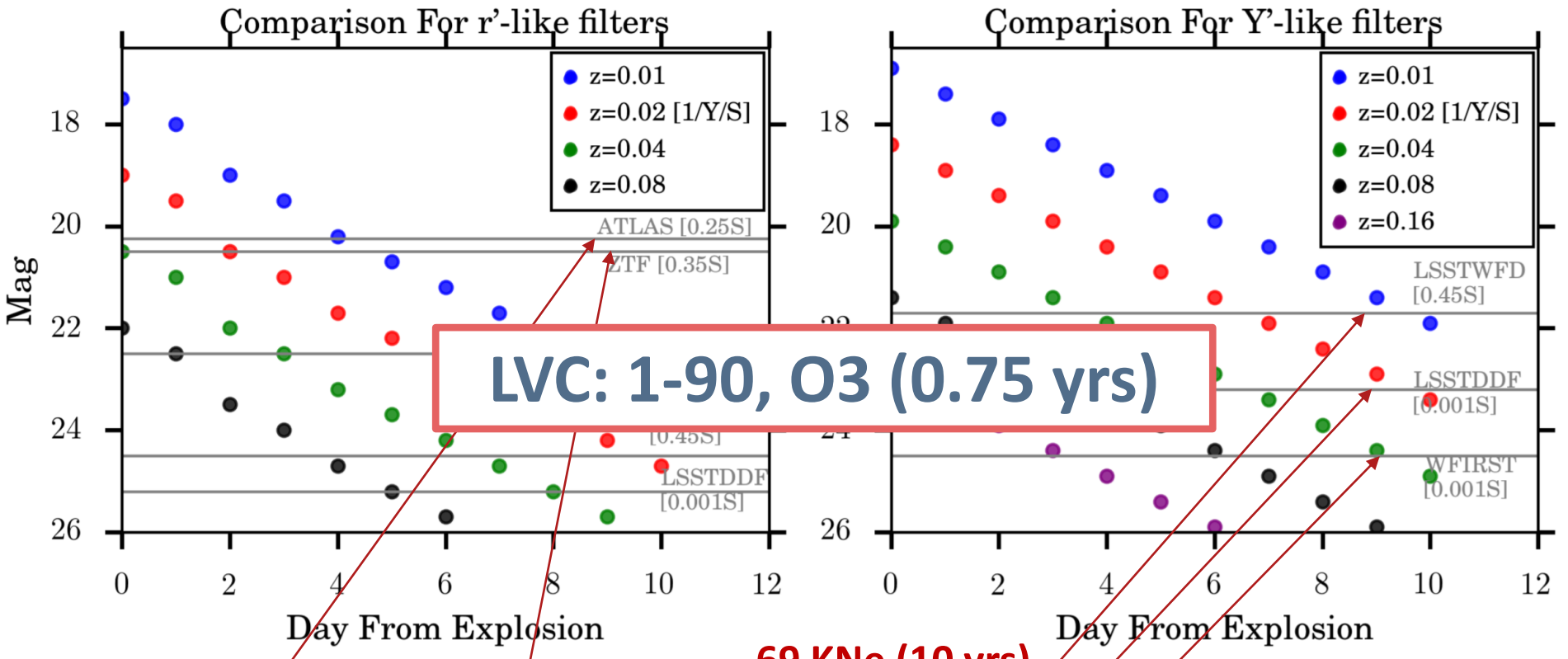
$M_{r\text{-}p} = 1.1^{+2.3}_{-0.9} \times 10^5\ M_\odot$

$M_{r\text{-}p} \leq 1.1 \times 10^6\ M_\odot$

$M_{r\text{-}p} \approx 10^4\ M_\odot$ Kafle et al. 2014

Grevesse et al. 2007

Future Independent Survey Design



LVC: 1-90, O3 (0.75 yrs)

8.3 KNe (5 yrs)

10.6 KNe (5 yrs)

69 KNe (10 yrs)

5.5 KNe (10 yrs)

16.0 Kne (2 yrs)

Scolnic et al. 2017

High Cadence / Shallow

Low Cadence / Deep

Conclusions – The Exotic

- SSS17a has extremely unique optical properties
  - Rapidly fades and reddens
- Rate of events like these must be < 16% total SN rate
- Probability of chance coincidence is extremely low
- Independent surveys must have high cadence in redder bands