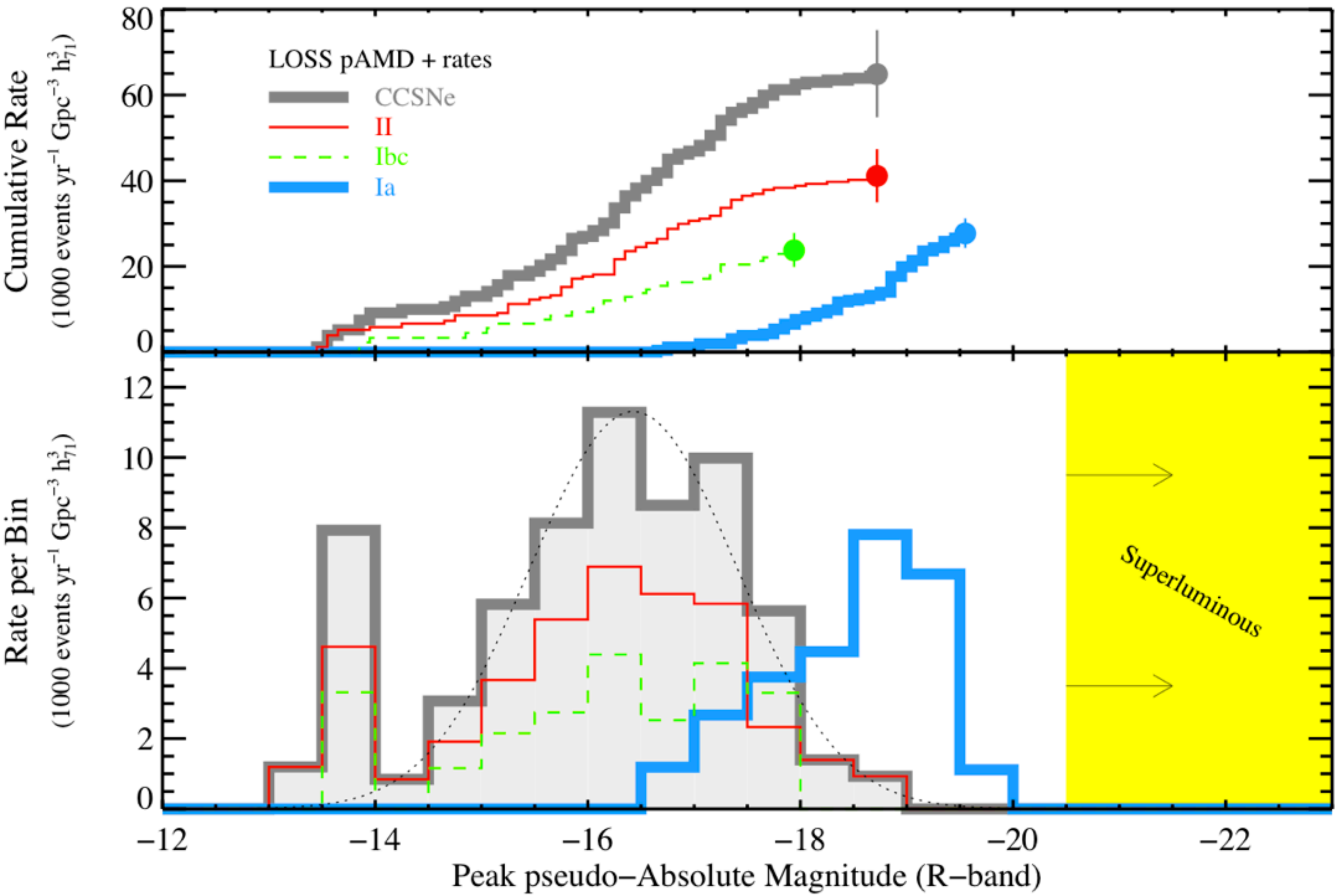
Unusually Bright Supernovae

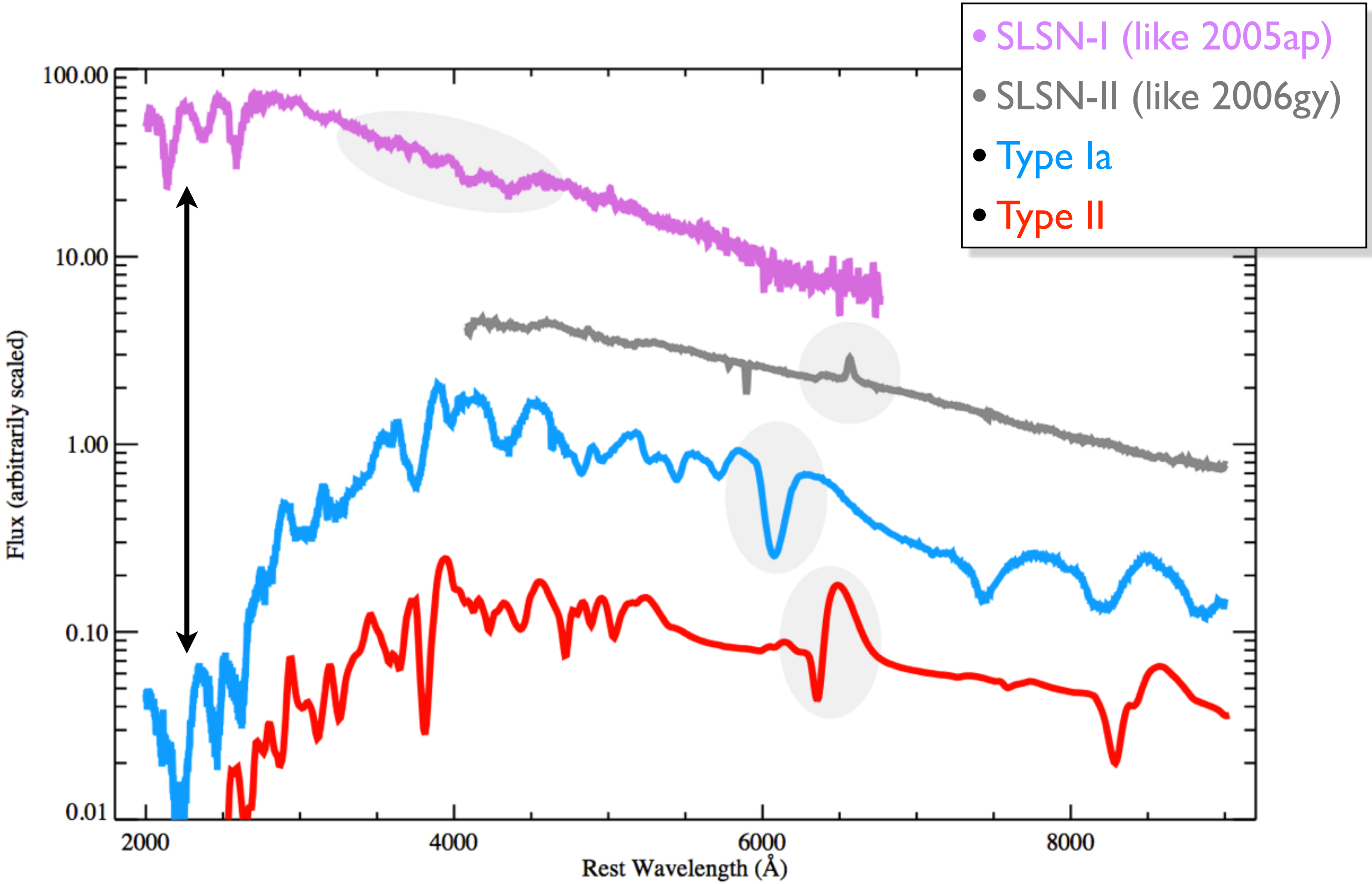
Robert Quimby

Absolute Magnitude Distributions of Supernovae

Data from LOSS (Li et al. 2011)



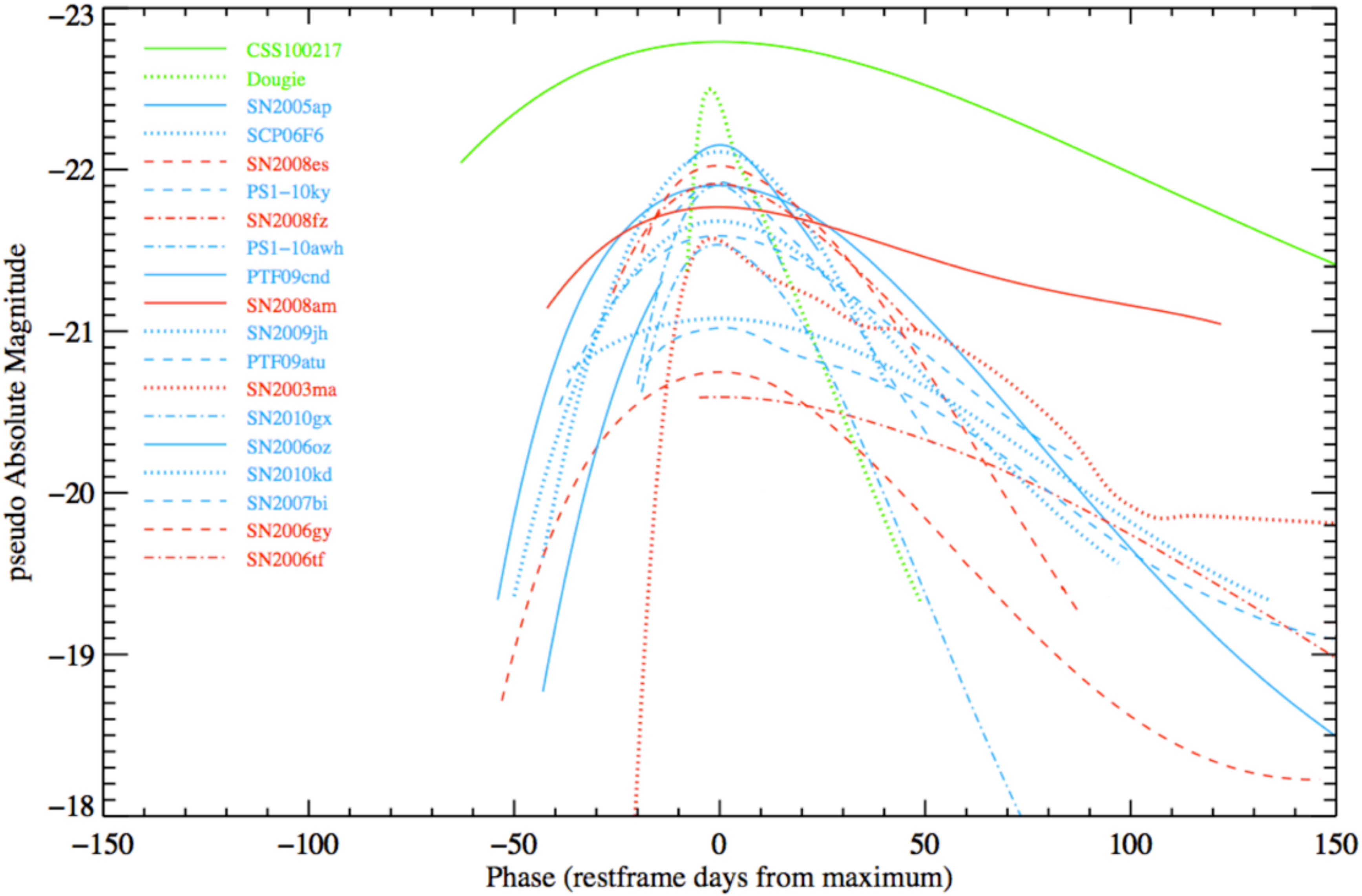
SLSN Spectra

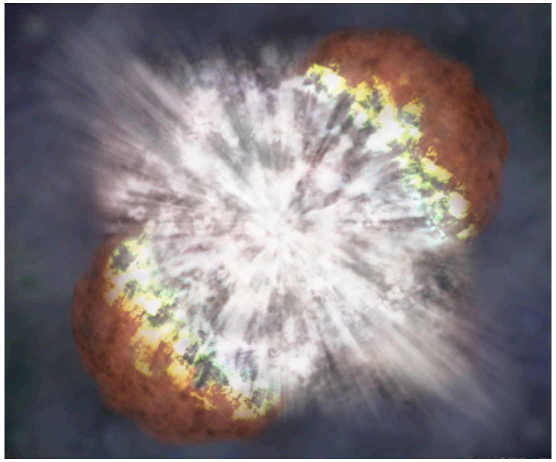


Hundreds of times brighter than SNIa in the UV!

SLSN Light Curves

unfiltered ROTSE-IIIb (optical) magnitudes



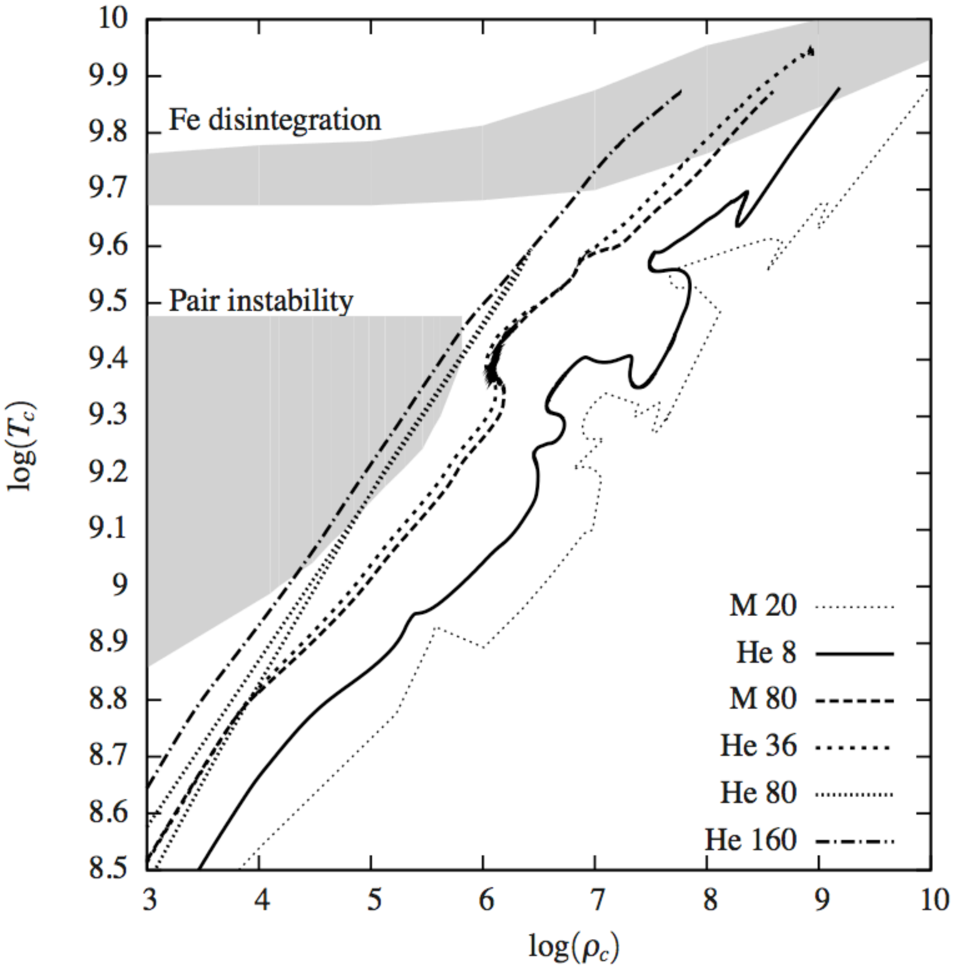


What are SLSNe Physically?

Three possibilities under consideration:

1) Pair Instability supernovae?
2) Supernovae powered by ejecta/wind interaction?
3) Supernovae powered by a compact remnant?

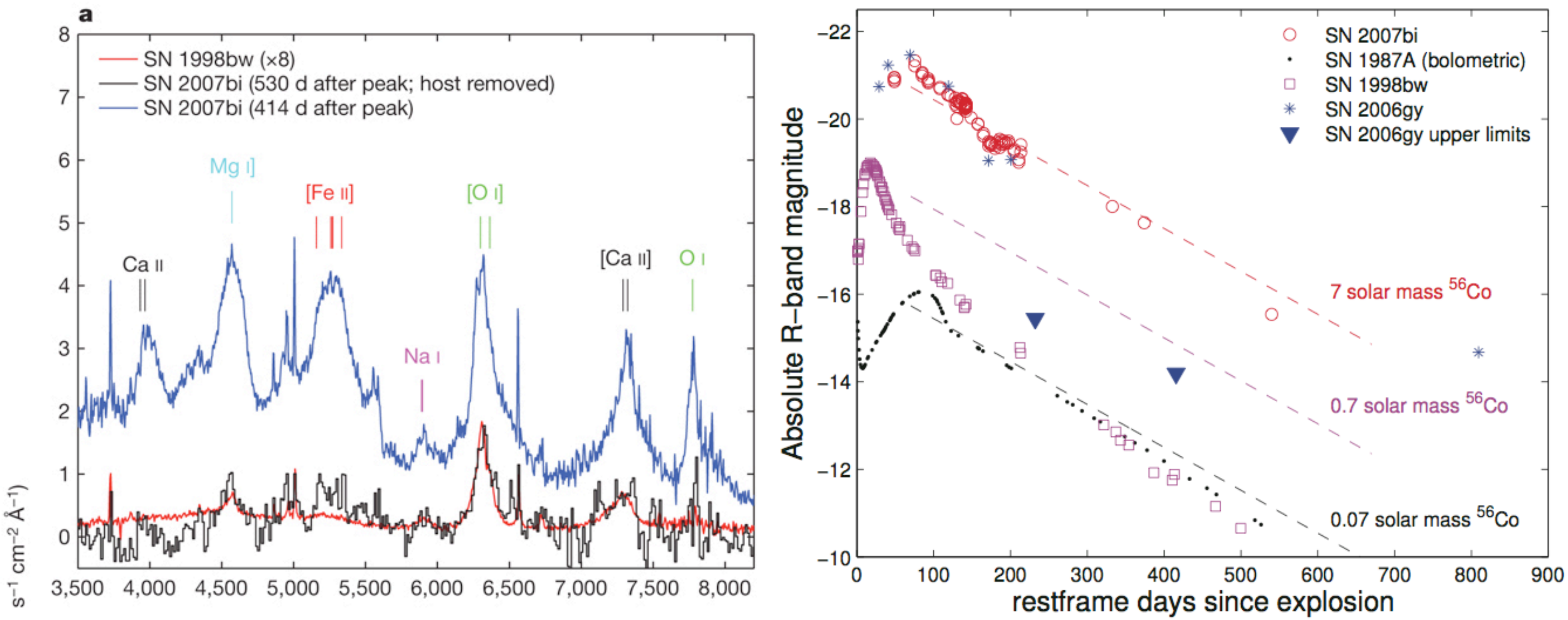
Are SLSNe: 1) Pair-Instability SNe?



Waldman 2008

- First Proposed it the 1960's (Rakavy et al. 1967; Barkat et al. 1967)
- Massive stars are supported by radiation pressure
- At high temperatures, photons are created with E > e+e-
- Losses to pair production soften the EOS, and lead to instability
- Expected fate of the first (low metal, high mass) stars

SN 2007bi: A Slowly Fading SLSN-I

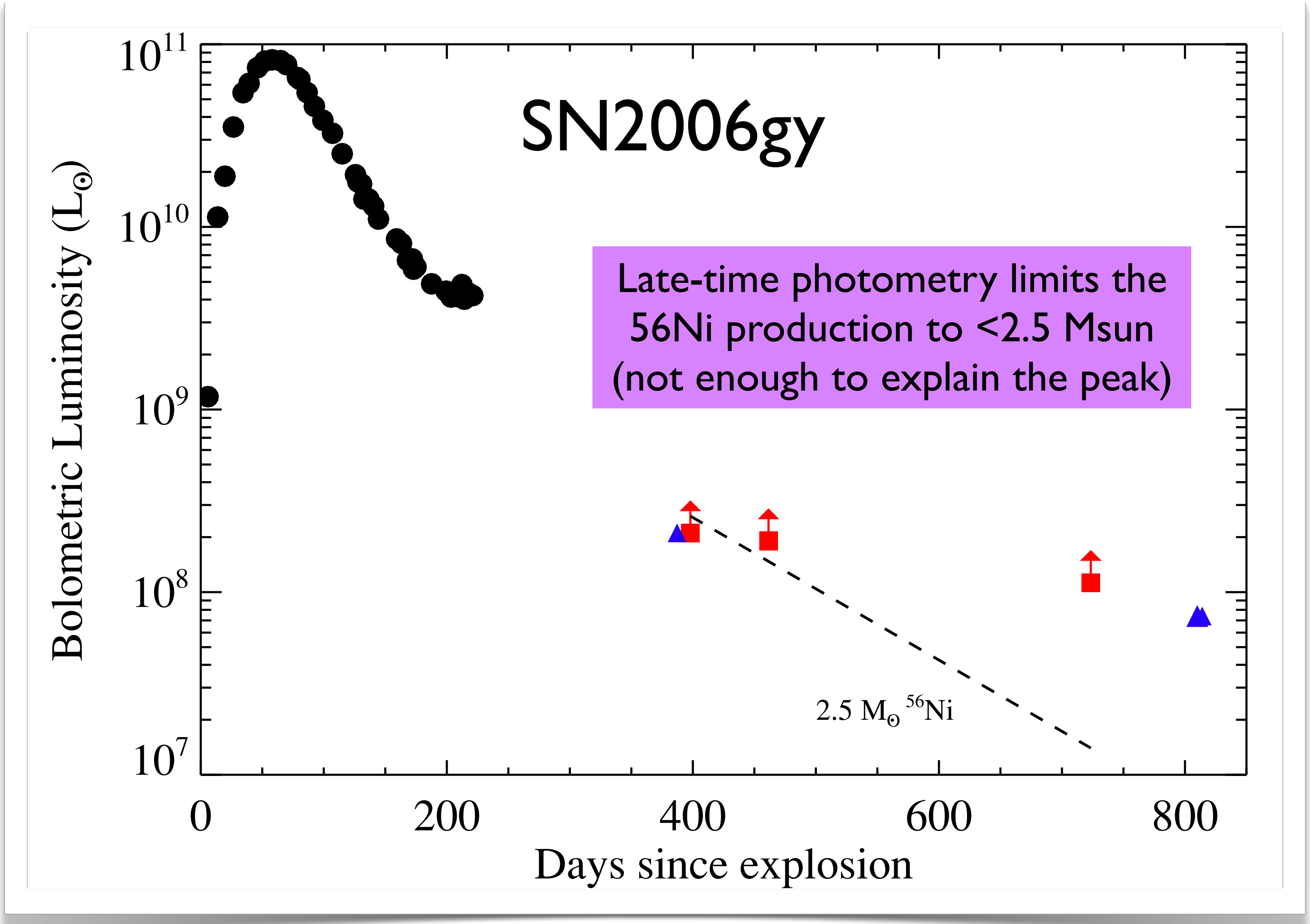


Gal-Yam et al. 2009

- Optical light curve decay rate consistent with ~7 $M_\odot$ of ^{56}Ni
- Iron abundance in nebular spectra also consistent with ~4–7 $M_\odot$ of ^{56}Ni

See however Dessart et al. 2012

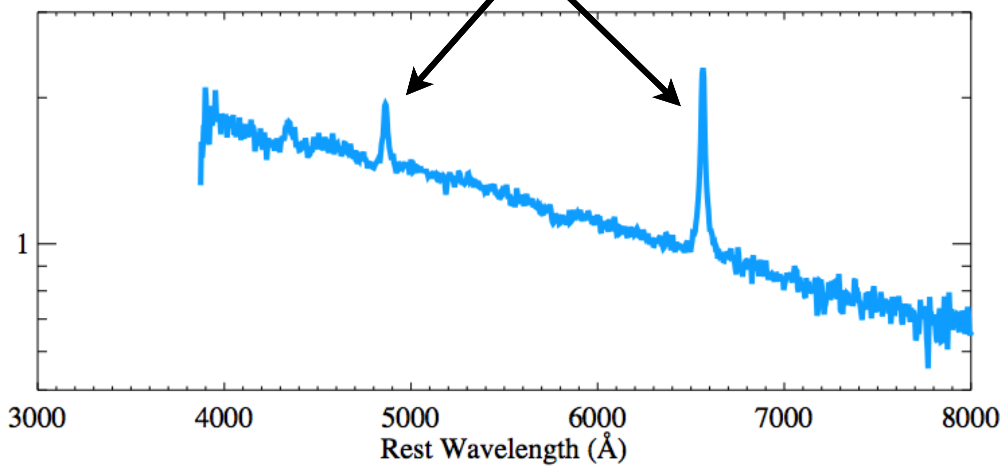
Some SLSN Fade Fast



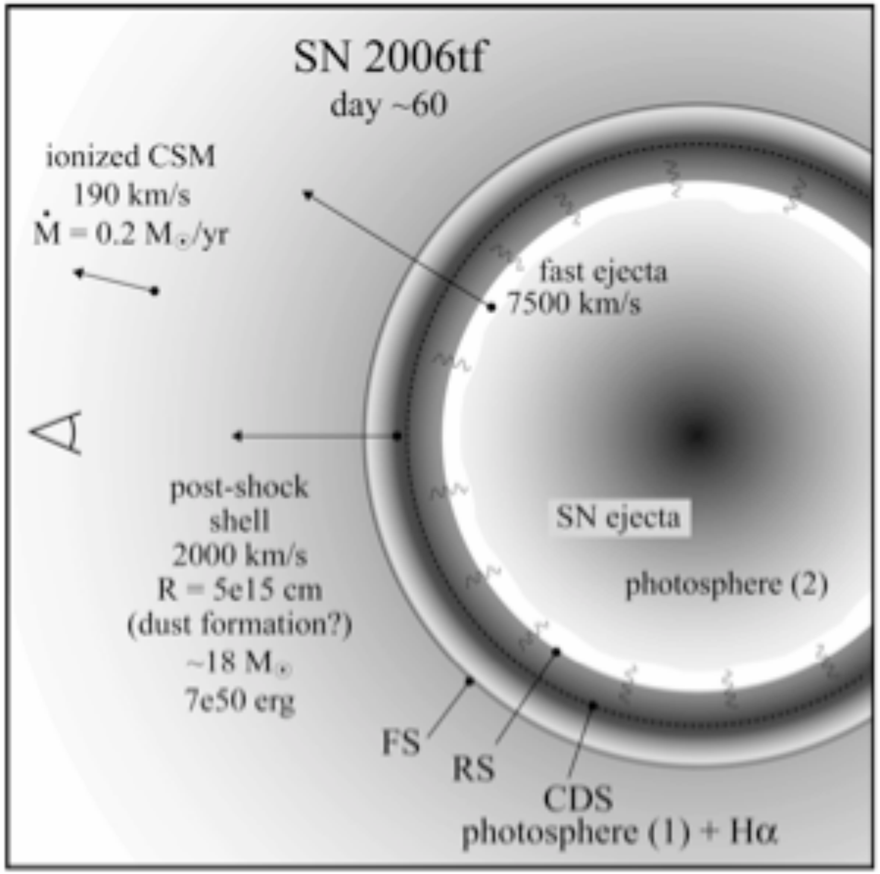
Miller et al. 2010

Are SLSNe: 2) Powered by Interactions?

Narrow emission lines indicate ejecta/wind interaction



Ejecta run into surrounding material (progenitor wind, shells, etc.) and convert kinetic energy into luminosity

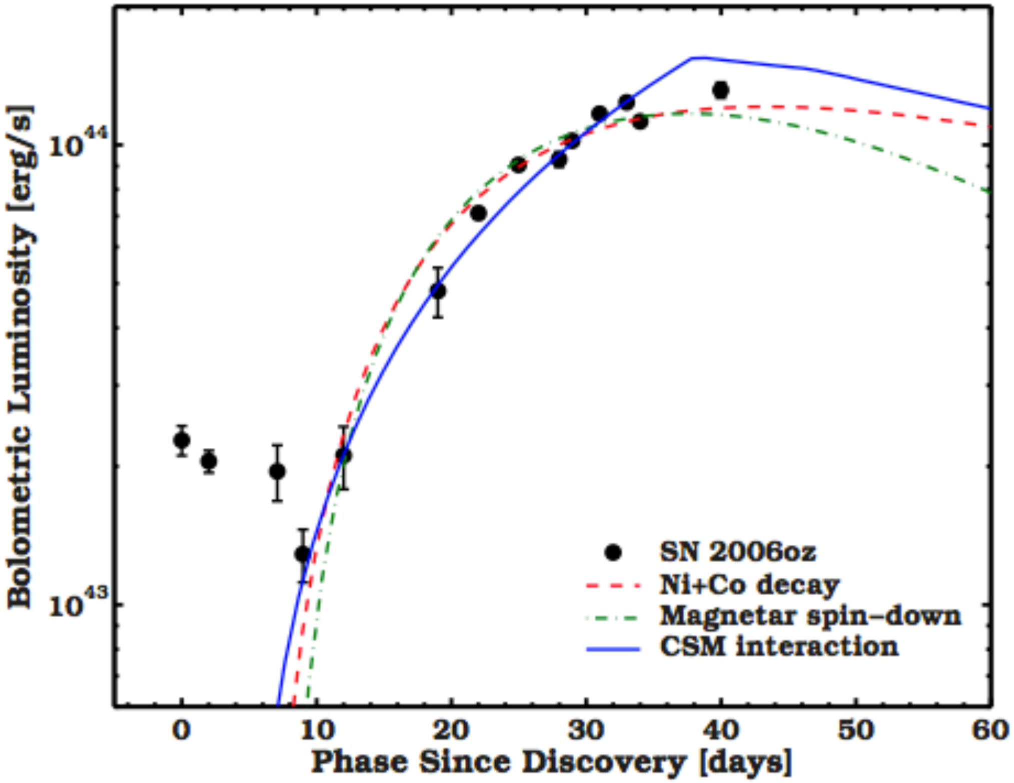


Smith et al. 2008

see also Smith & McCray 2007, Chevalier & Irwin 2011

Initial Plateau in SLSN-I?

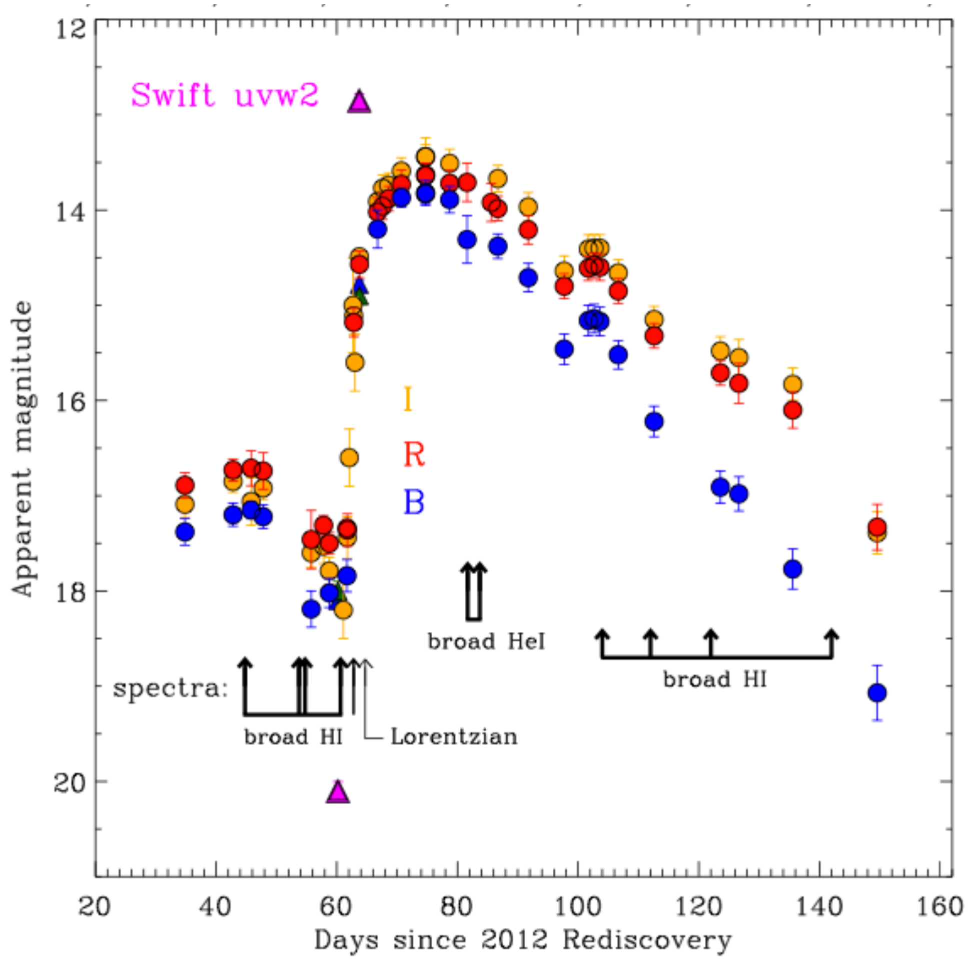
SN 2006oz (SLSN-I)



Leloudas et al. (2012)

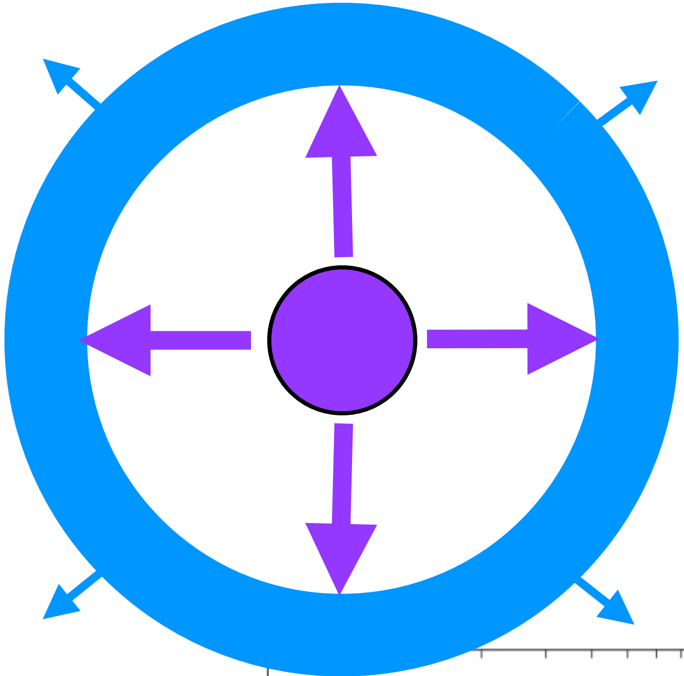
see also Moriya et al. 2012

"SN 2009ip" (LBV turned SN)



Mauerhan et al. (2012)

Are SLSNe: 3) Powered by Magnetars?

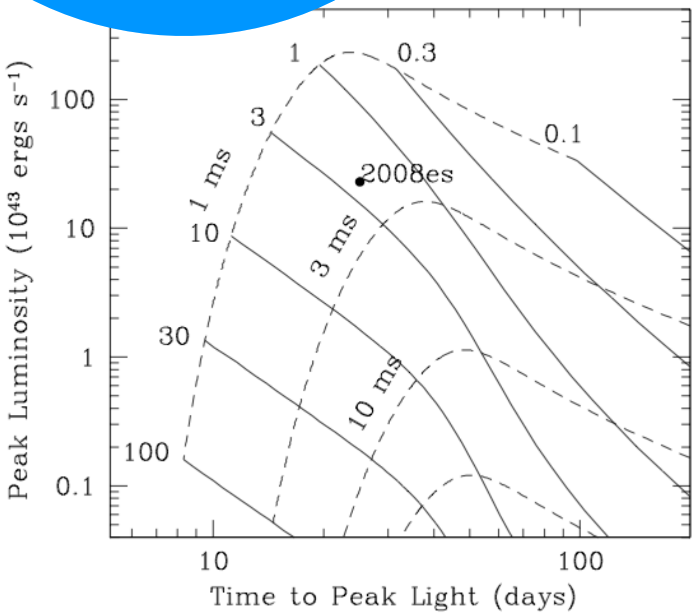


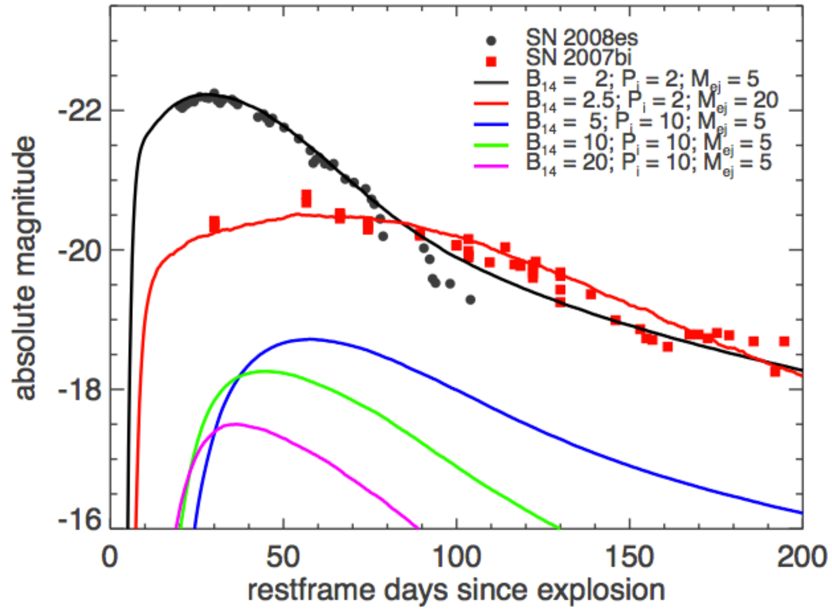
$$E_{\rm p} = \frac{I_{\rm ns}\Omega_{\rm i}^2}{2} = 2\times10^{50}P_{10}^{-2}\ \text{ergs},$$

$$t_{\rm p} = \frac{6I_{\rm ns}c^3}{B^2R_{\rm ns}^6\Omega_{\rm i}^2} = 1.3B_{14}^{-2}P_{10}^2\ \text{yr},$$

$$L_{\rm peak} \sim \frac{E_{\rm p}t_{\rm p}}{t_{\rm d}^2} \sim 5\times10^{43}B_{14}^{-2}\kappa_{\rm es}^{-1}M_5^{-3/2}E_{51}^{1/2}\text{erg s}^{-1}$$

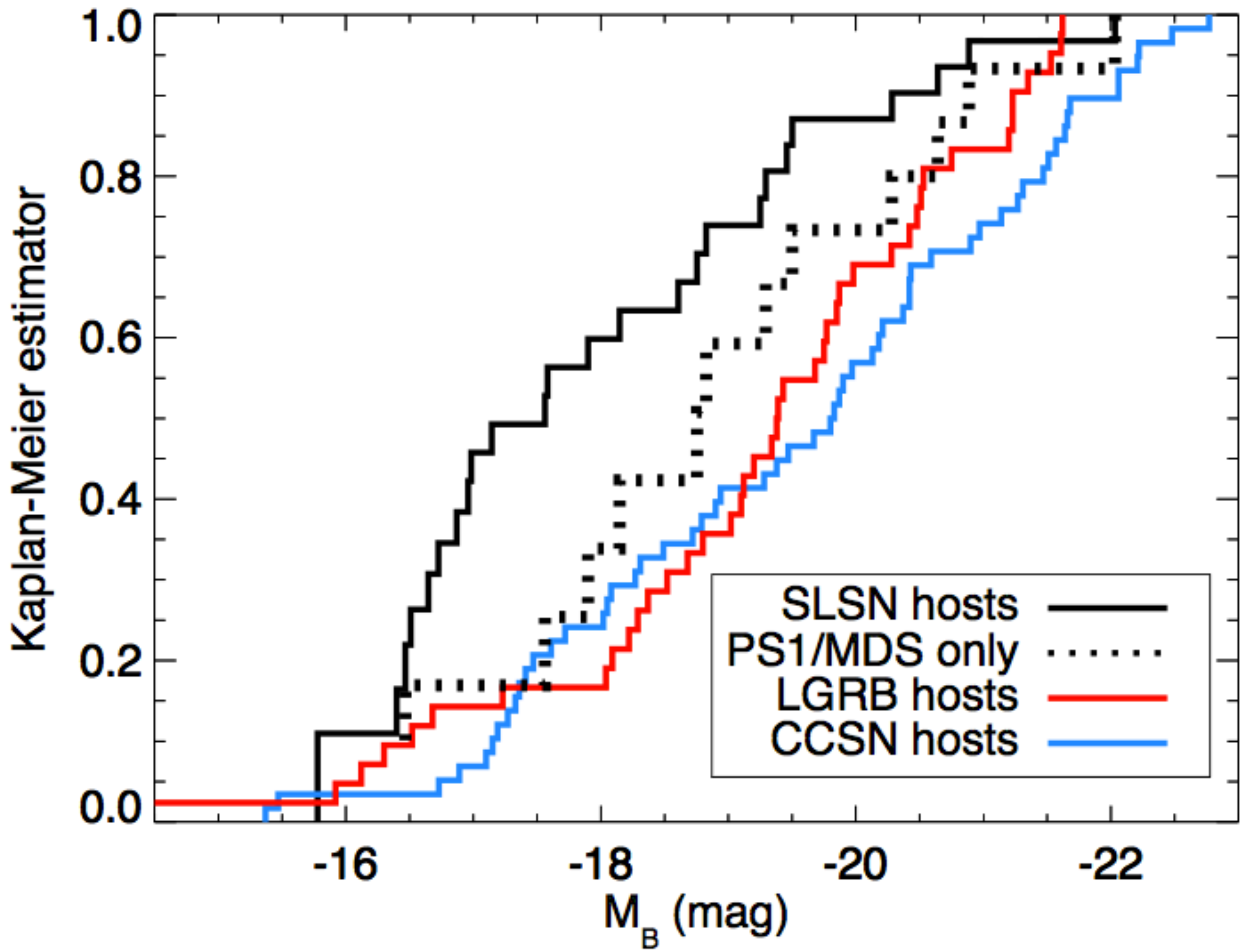
Kasen & Bildsten 2010; see also Woosley 2010





SLSN-I Host Galaxies

- Prefer less luminous hosts that CCSN
- May be similar to LGRB hosts



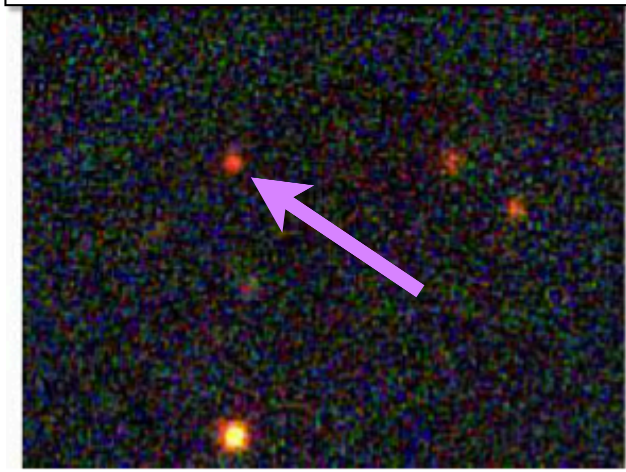
Lunnan et al. 2014

Discovery of PS1-10afx

(Pan-STARRS1 Team)

First Detected:
August 31, 2010

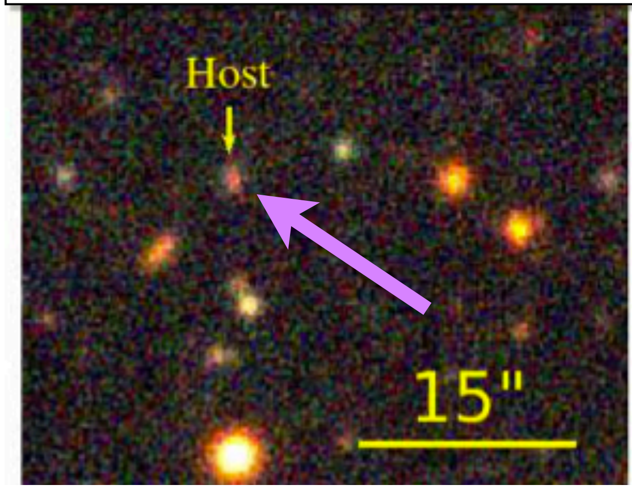
Explosion
(short exposure)



Chornock et al. (2013)

Sky Position
RA = 22:11:24.162
Dec. = +00:09:43.49
(Aquarius)

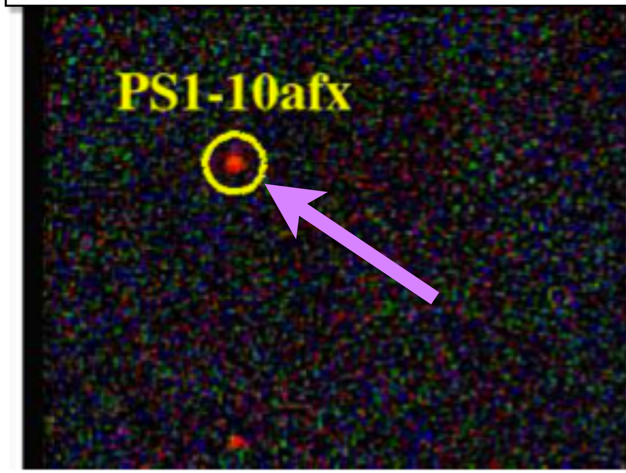
Before Explosion
(long exposure)



Chornock et al. (2013)

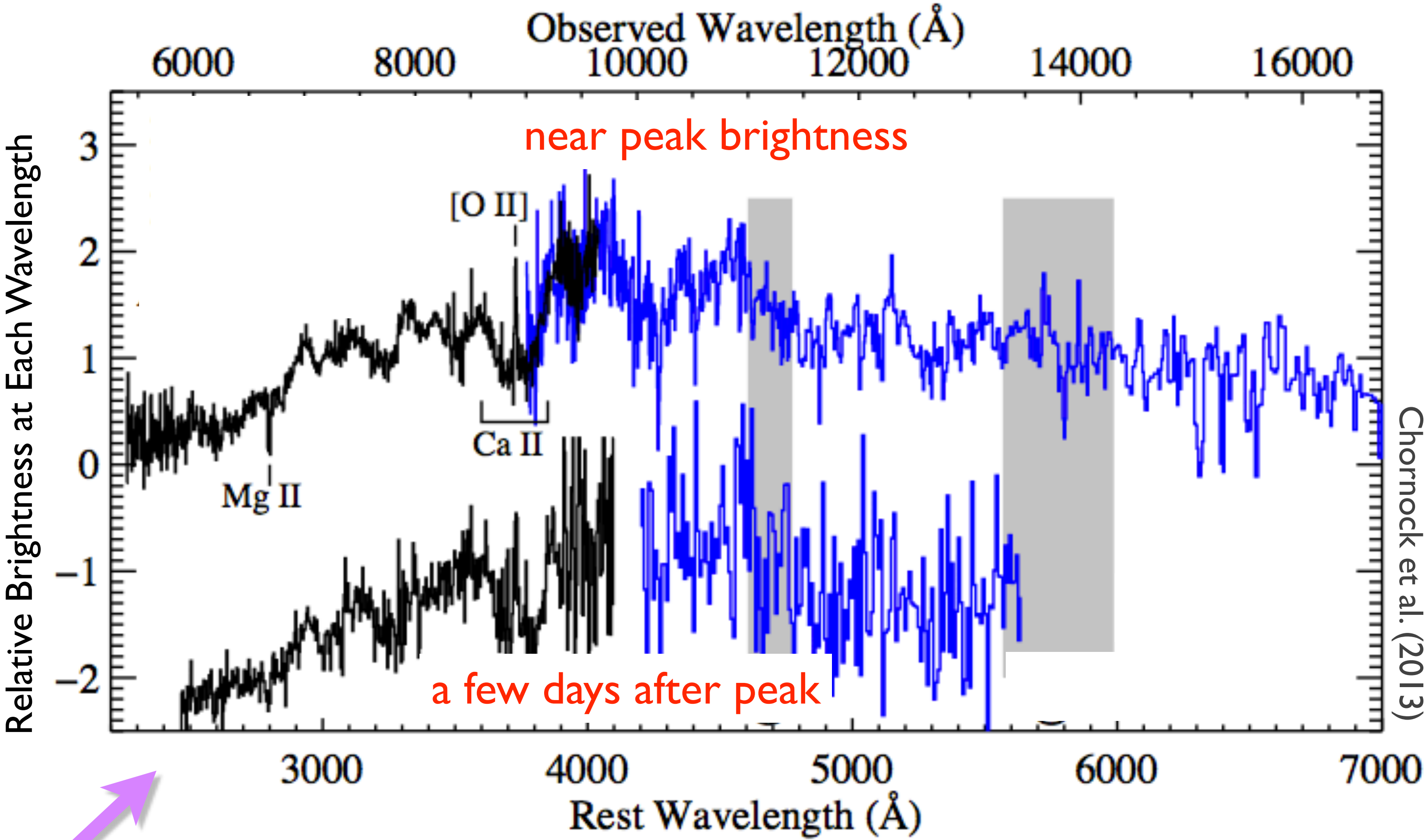
Peak Brightness:
~22 mag (i-band)
~24 mag (r-band)

Difference



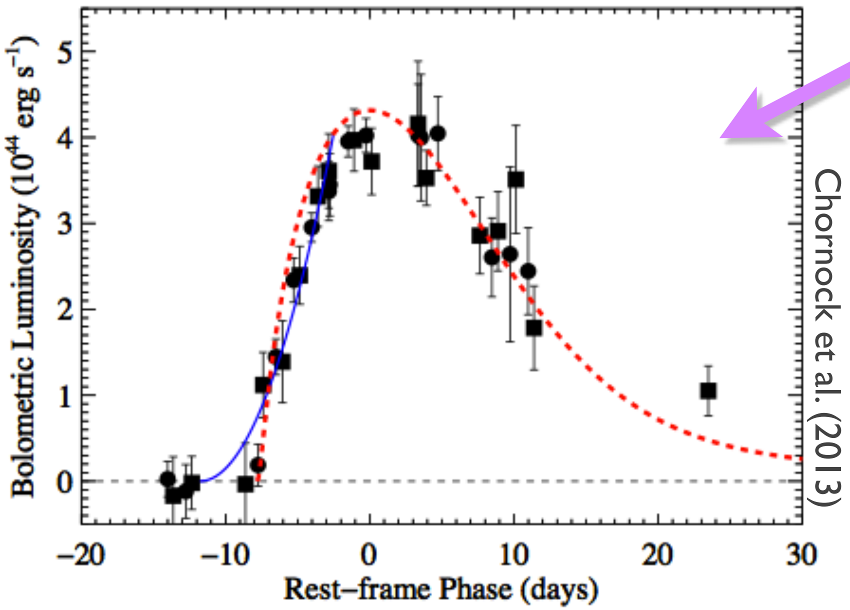
Chornock et al. (2013)

Unusually red color!



Spectra

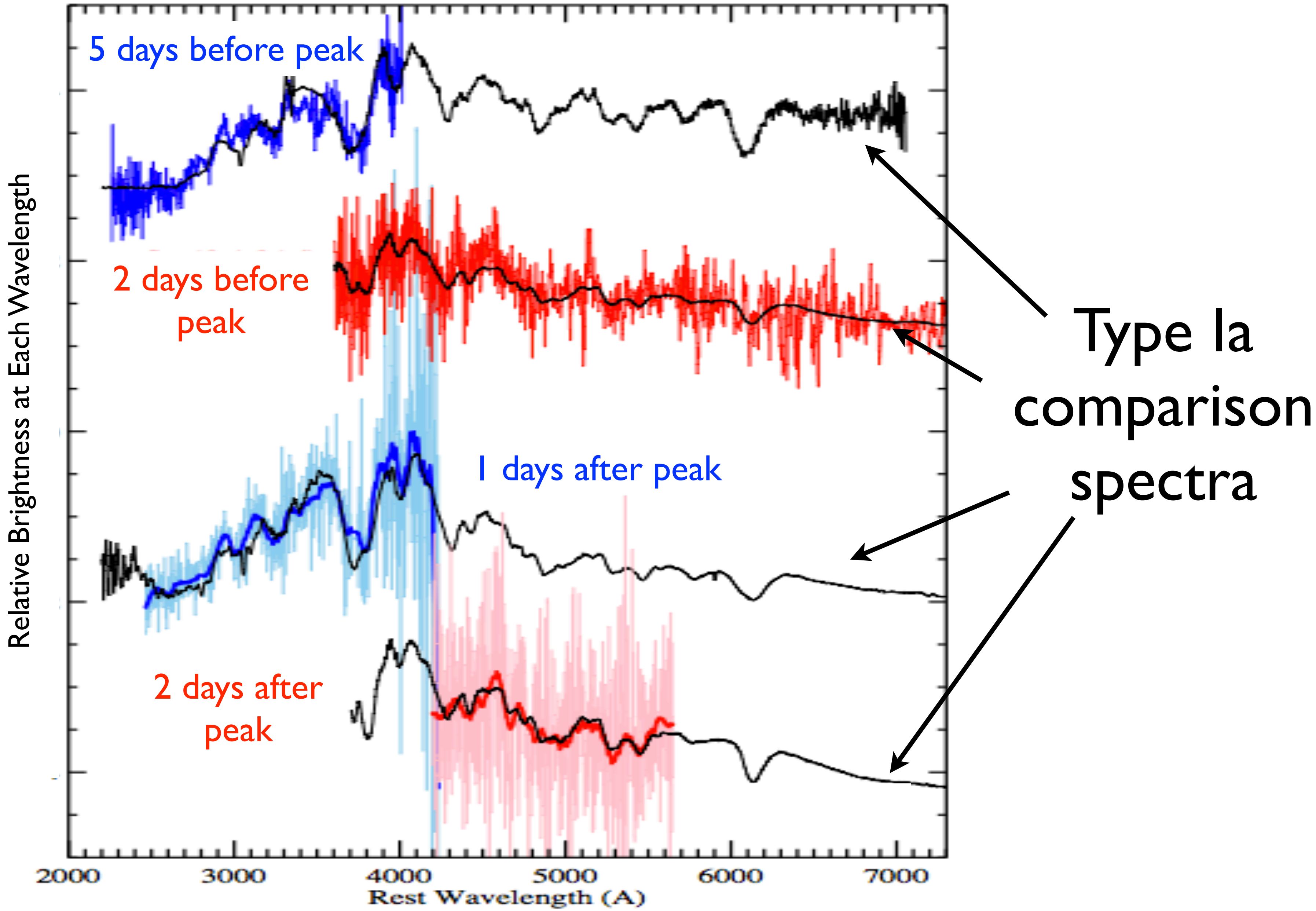
Redshift z=1.388 from narrow host lines and supernova features. Color is relatively red for superlumious supernovae



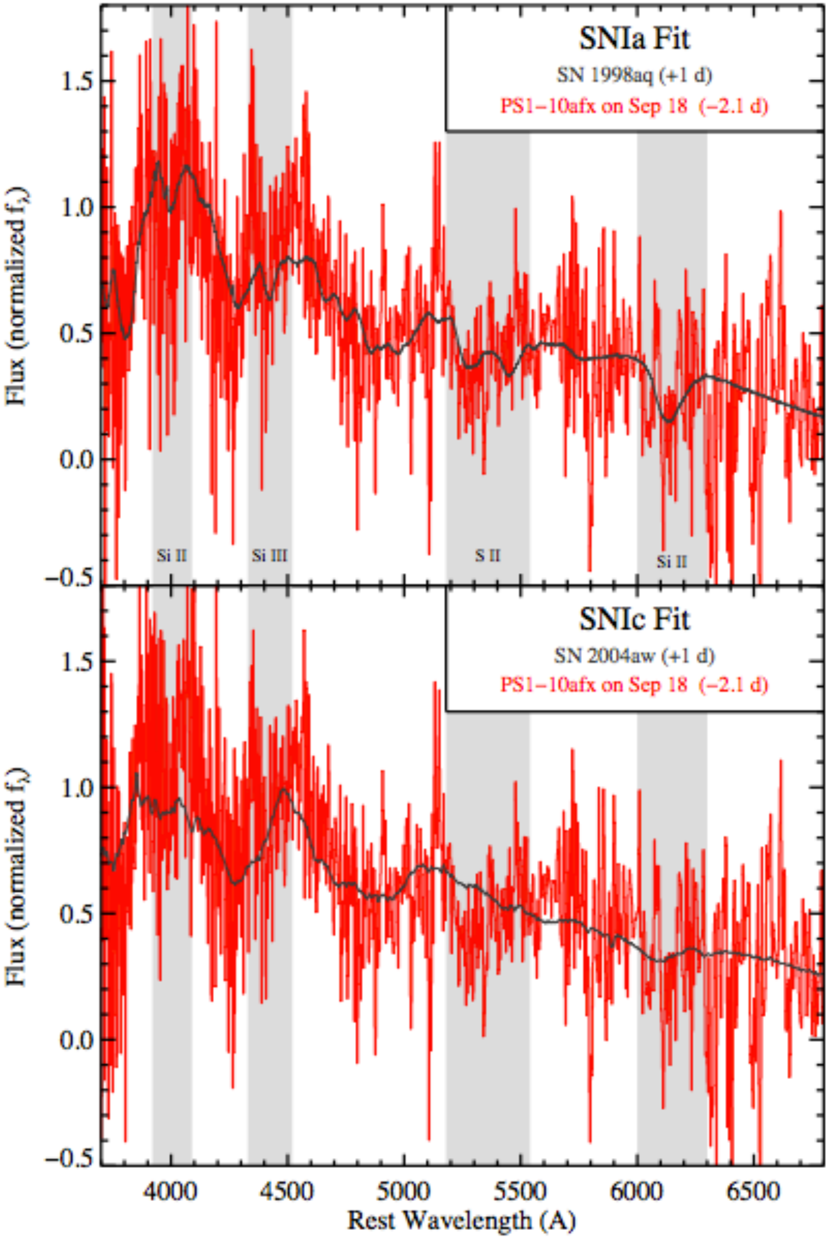
Photometry

Observed brightness combined with luminosity distance (from redshift) implies high luminosity, but evolution is much faster than typical superluminous supernovae

PS1-10afx Has Spectra Similar to Type Ia Supernovae

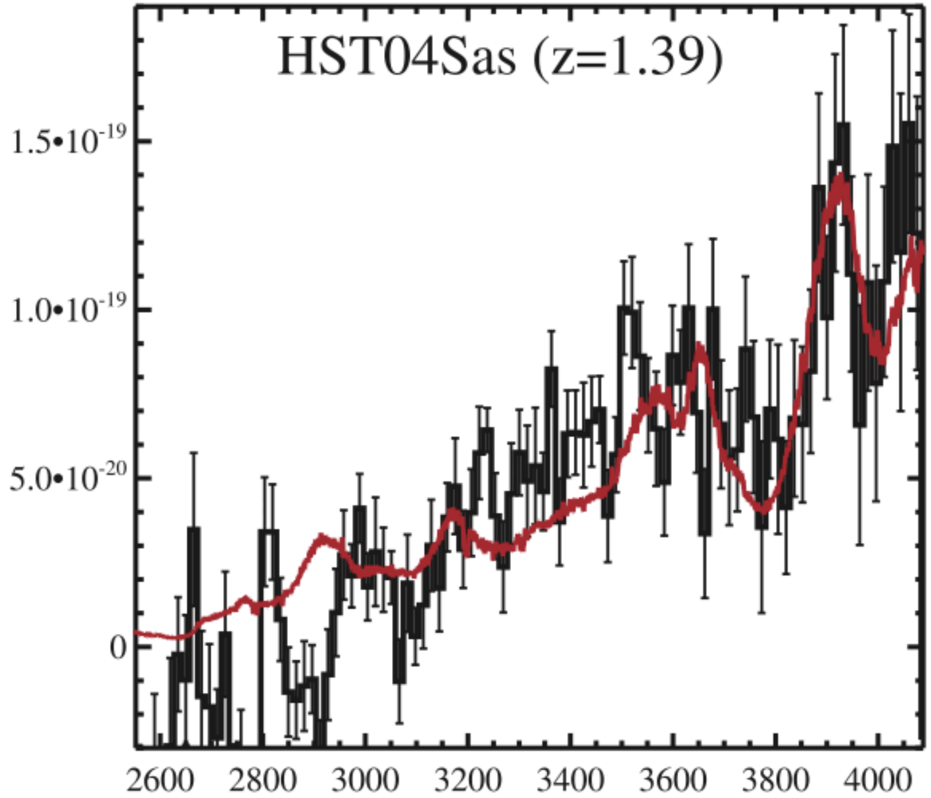


PS1-10afx Spectra: good match to SNIa, but not SNIc



HST04Sas................	53,156.2 (+1)	*HST* ACS	1.39[a,b]

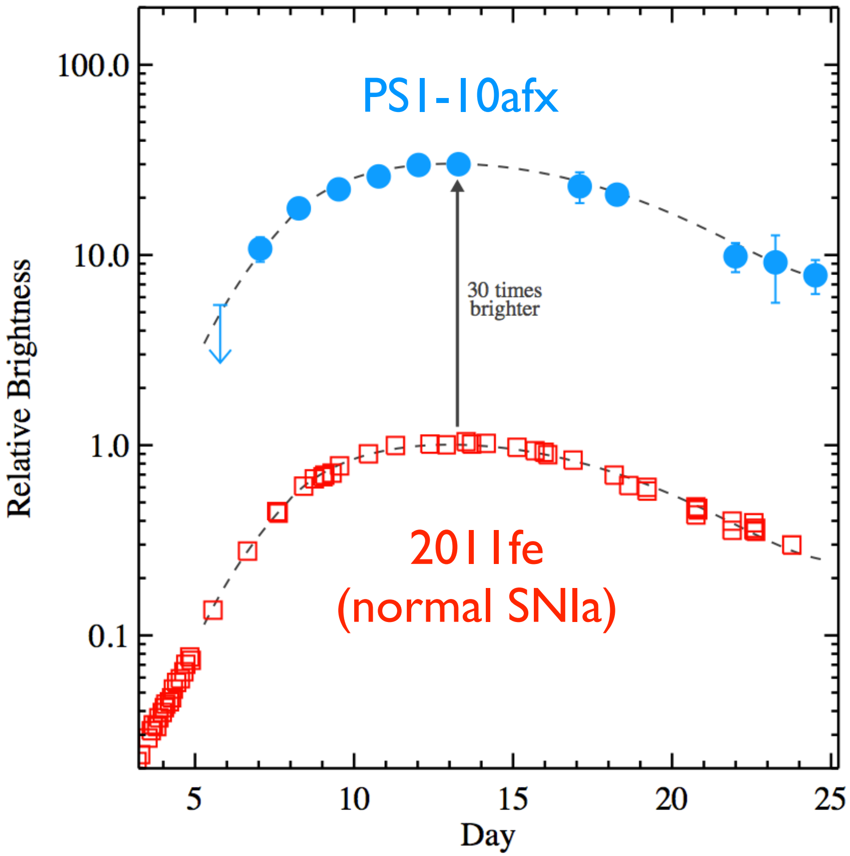
[a] From cross-correlation with broad SN features.
[b] Classified as SN Ia with high confidence from spectrum.



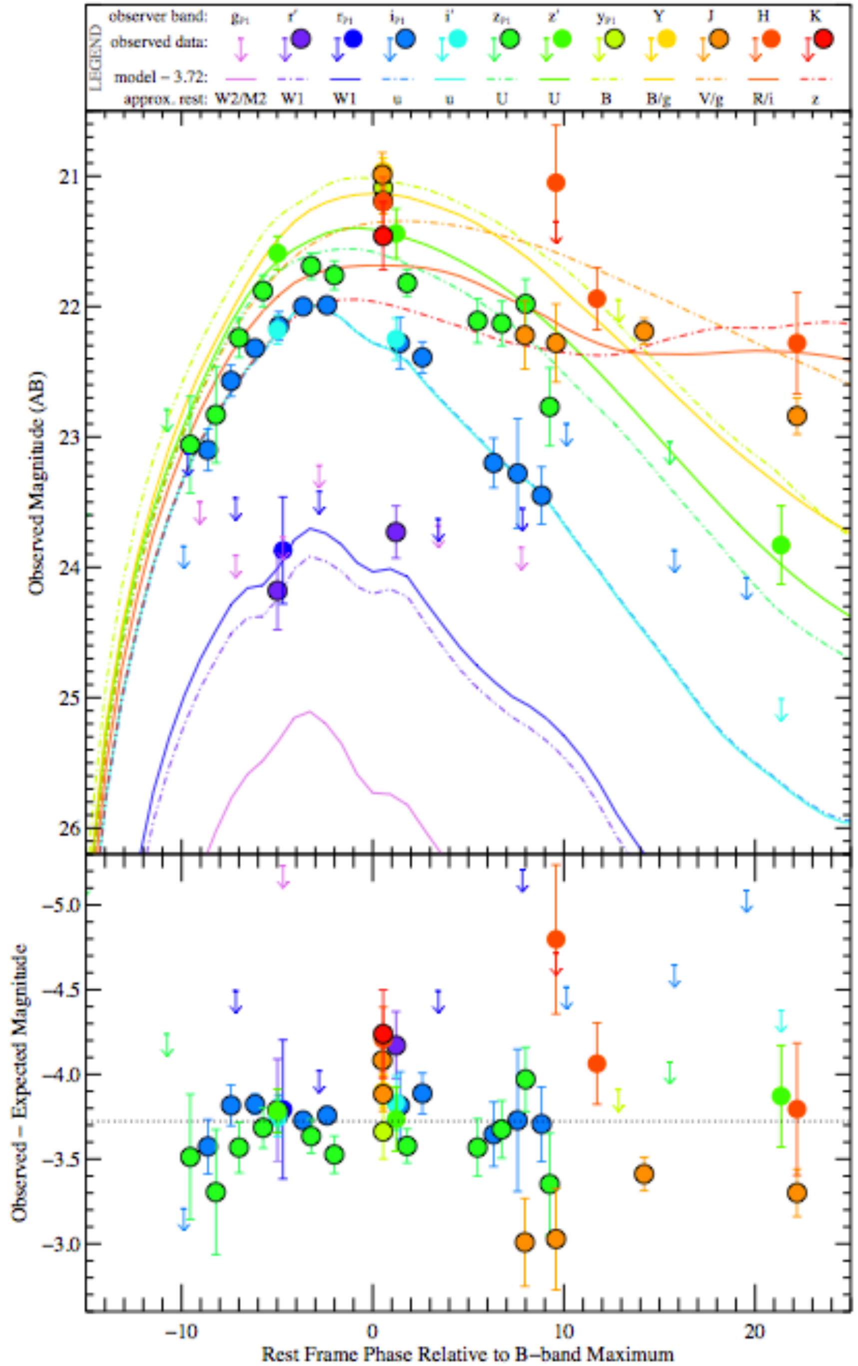
Riess et al. (2007)

PS1-10afx Photometry

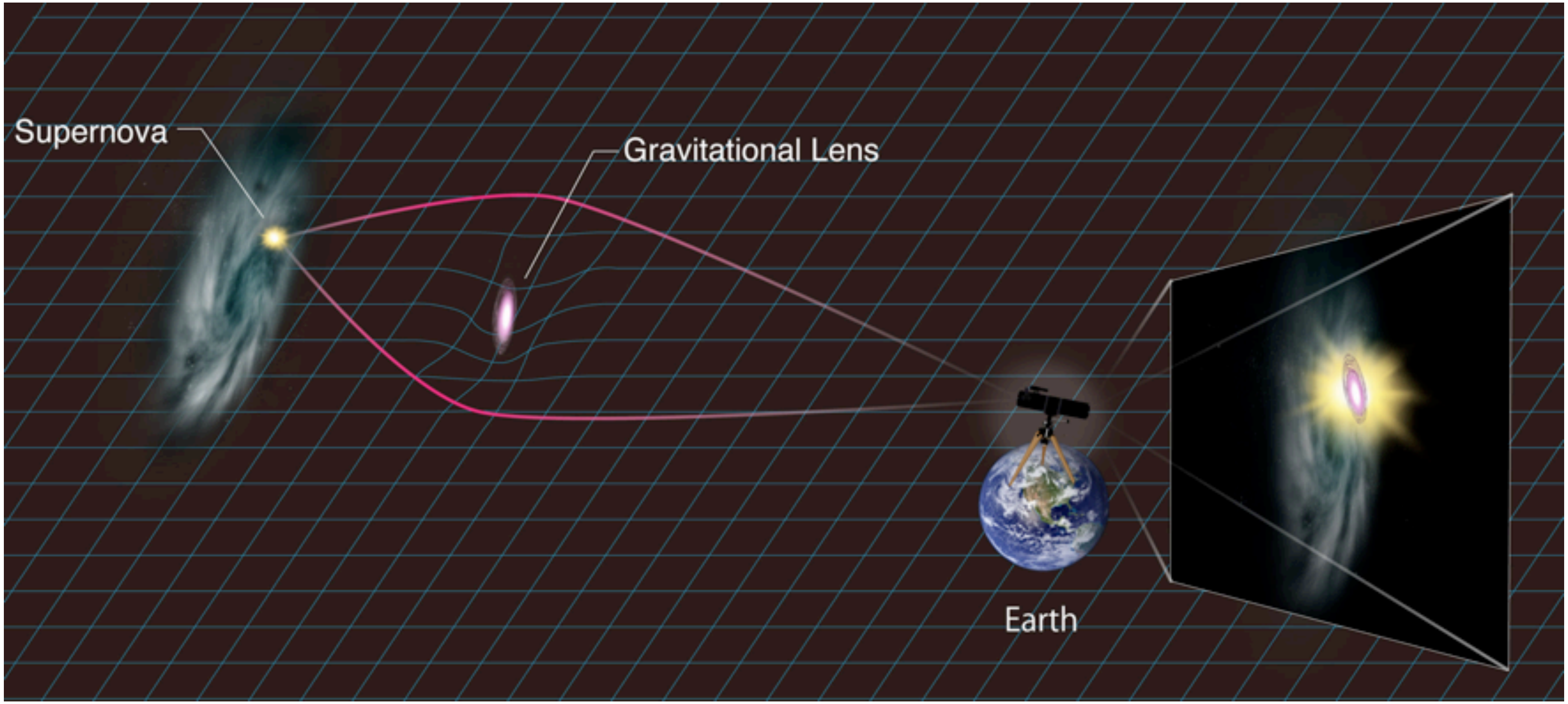
Compared to a Normal SNIa



Compared to SNIa Templates



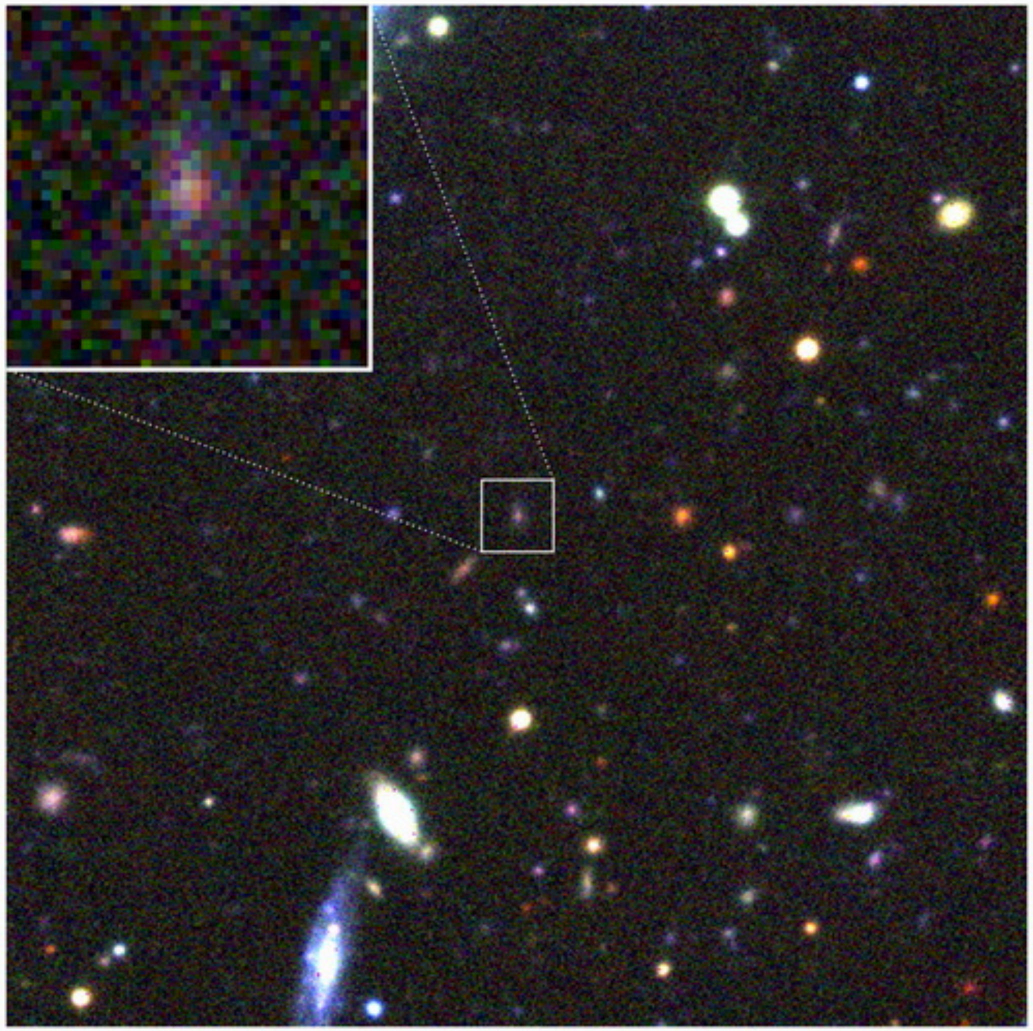
PS1-10afx is a Type Ia Supernova Magnified by a Gravitational Lens



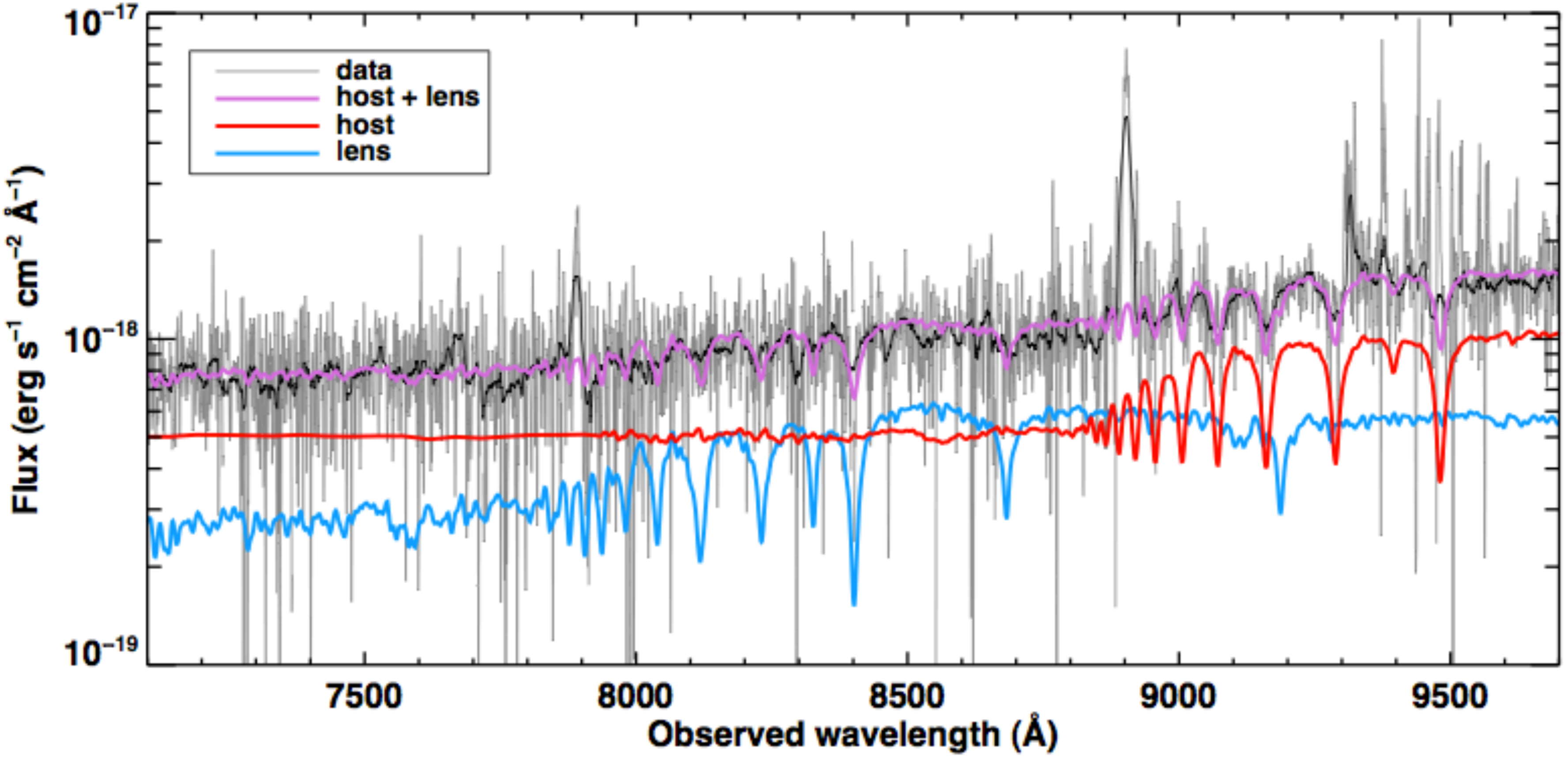
A. Tsuboi/Kavli IPMU

First strongly lensed Type Ia supernova!

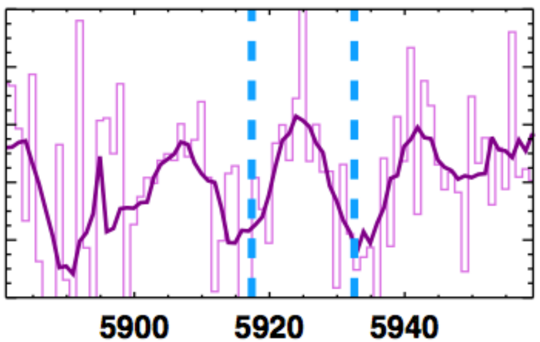
So Where is the Lens?



New Spectra Show...Two Galaxies!

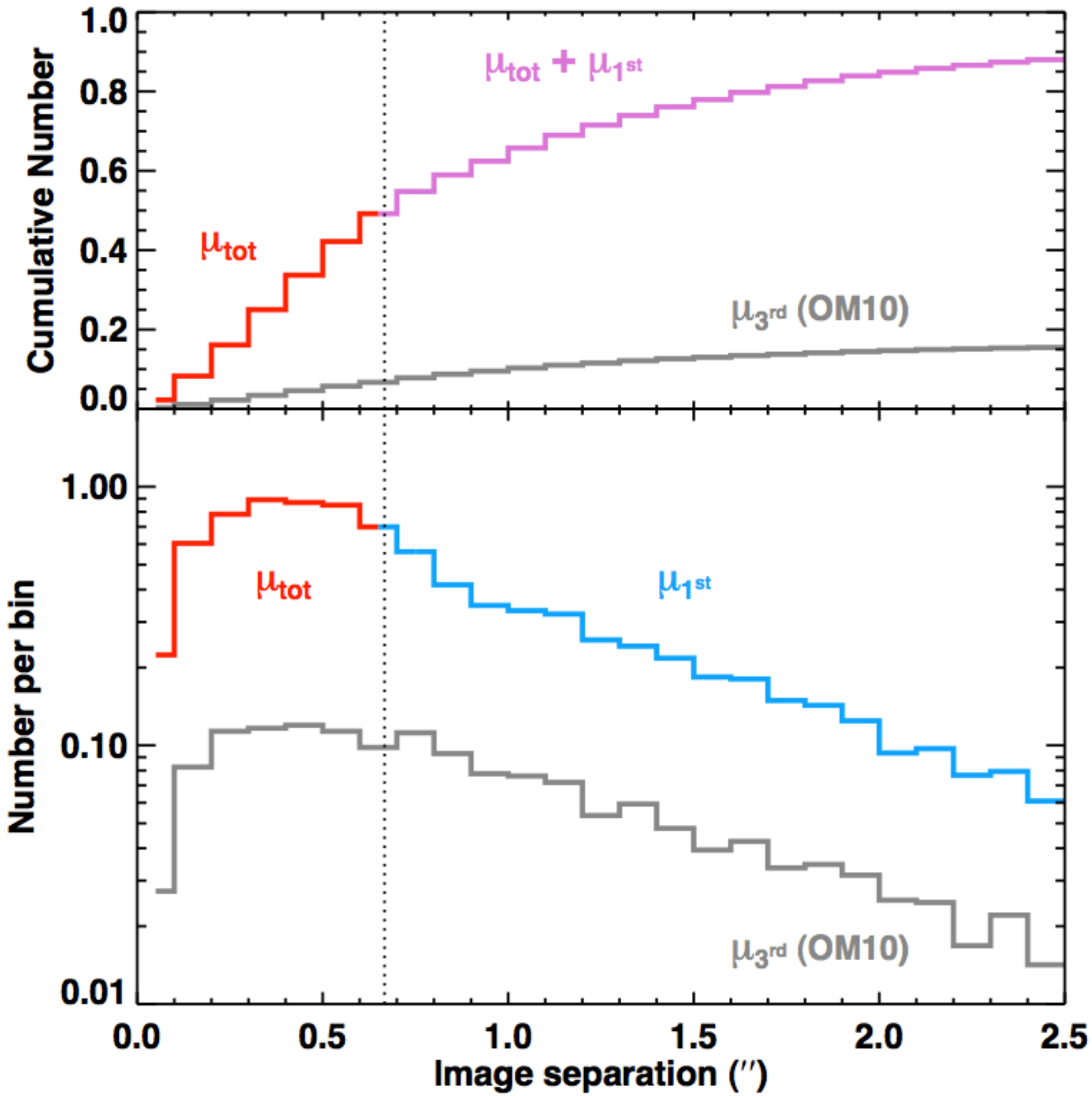


Lens MgII

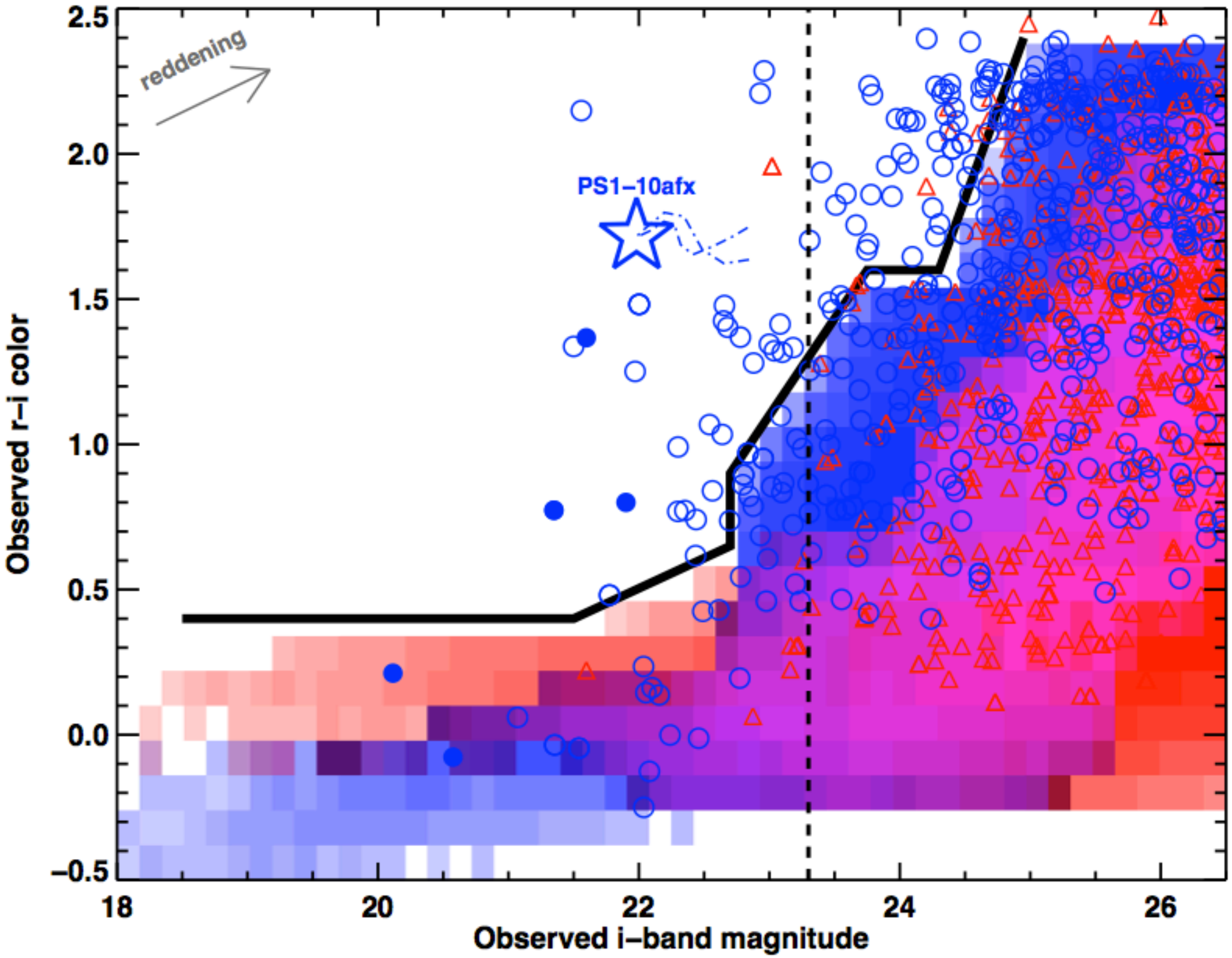


- Host OII (and MgII) at z=1.39
- Lens OII (and MgII) at z=1.12

Smaller Image Separations are Easier to Find

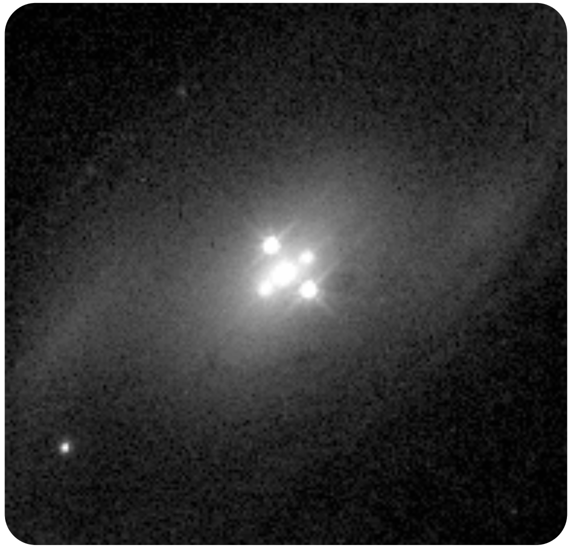


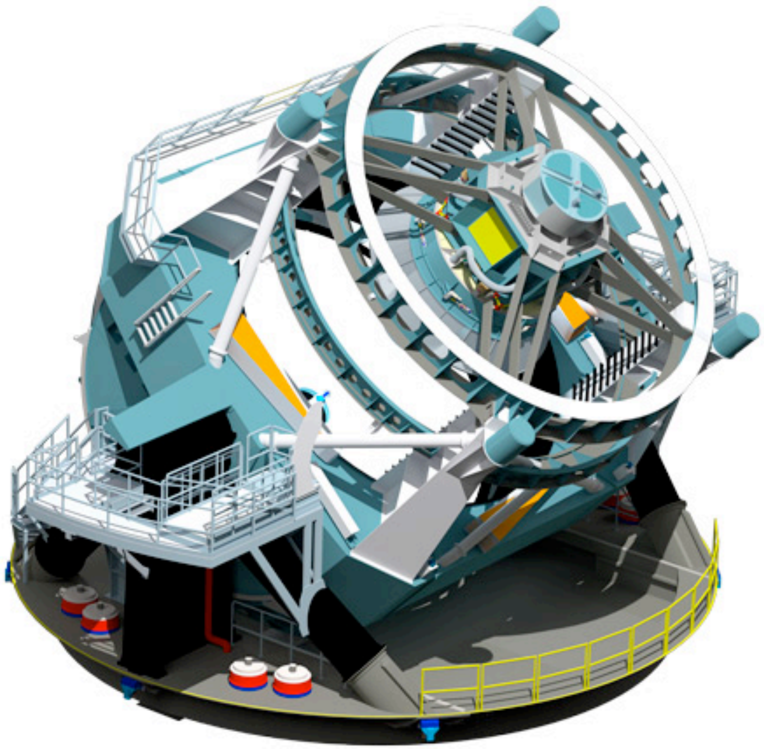
How to Identify Lensed SN



Direct H_0 Measurement with Lensed SNeIa

- Each lensed image traverses a different path
- Path length differences lead to time delays
- Delays are inversely proportional to H_0





Oguri & Marshall 2010

Survey	SN (Ia) $N_{\rm non\text{-}lens}$	SN (Ia) $N_{\rm lens}$	SN (cc) $N_{\rm non\text{-}lens}$	SN (cc) $N_{\rm lens}$
LSST	1.39×10^6	45.7 (32 per cent)	2.88×10^6	83.9 (30 per cent)

×10?

- Use color selection to find more lensed SNIa
- Use HST or AO to confirm and follow-up