# SUPERLUMINOUS SUPERNOVAE

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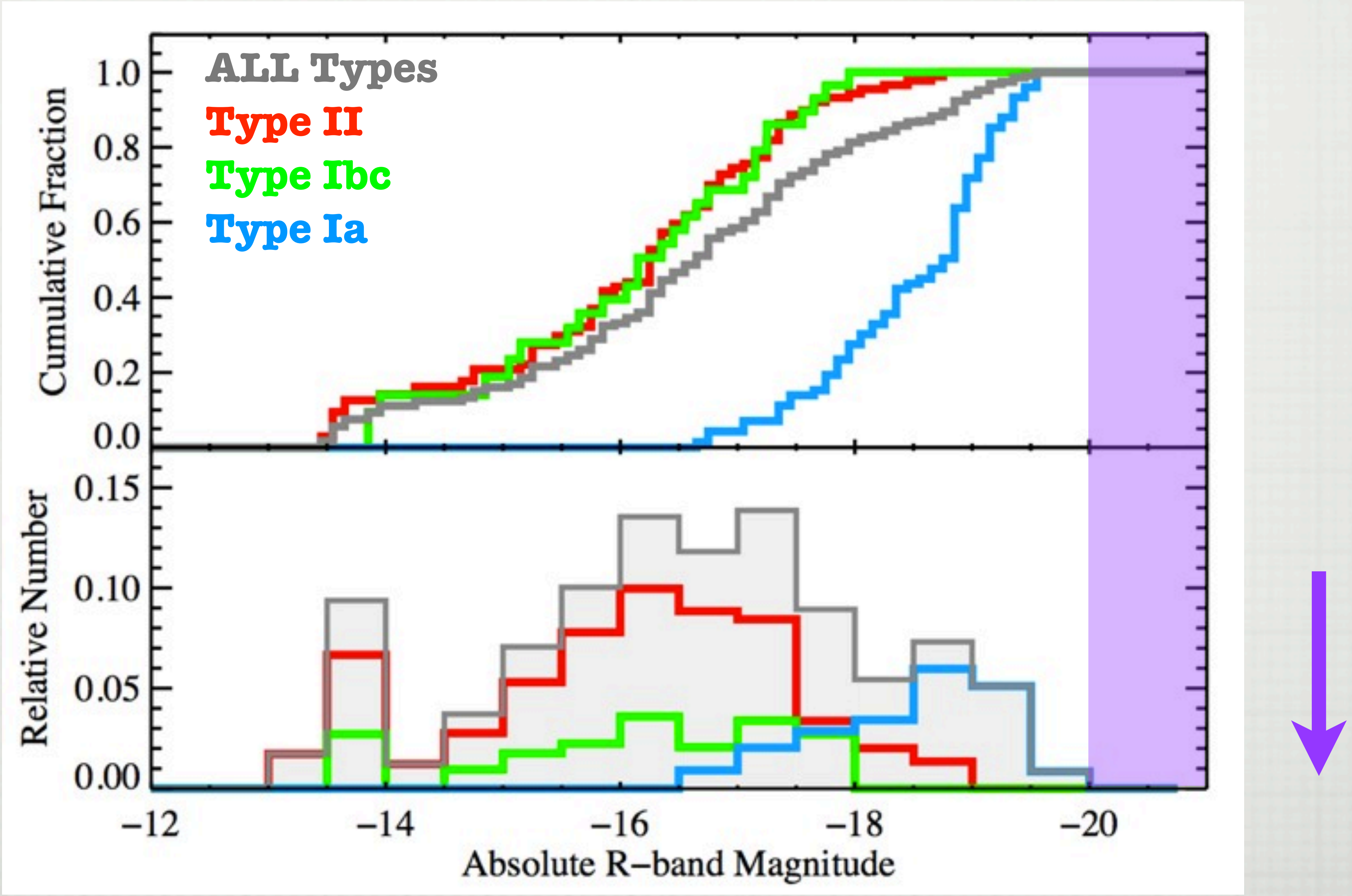
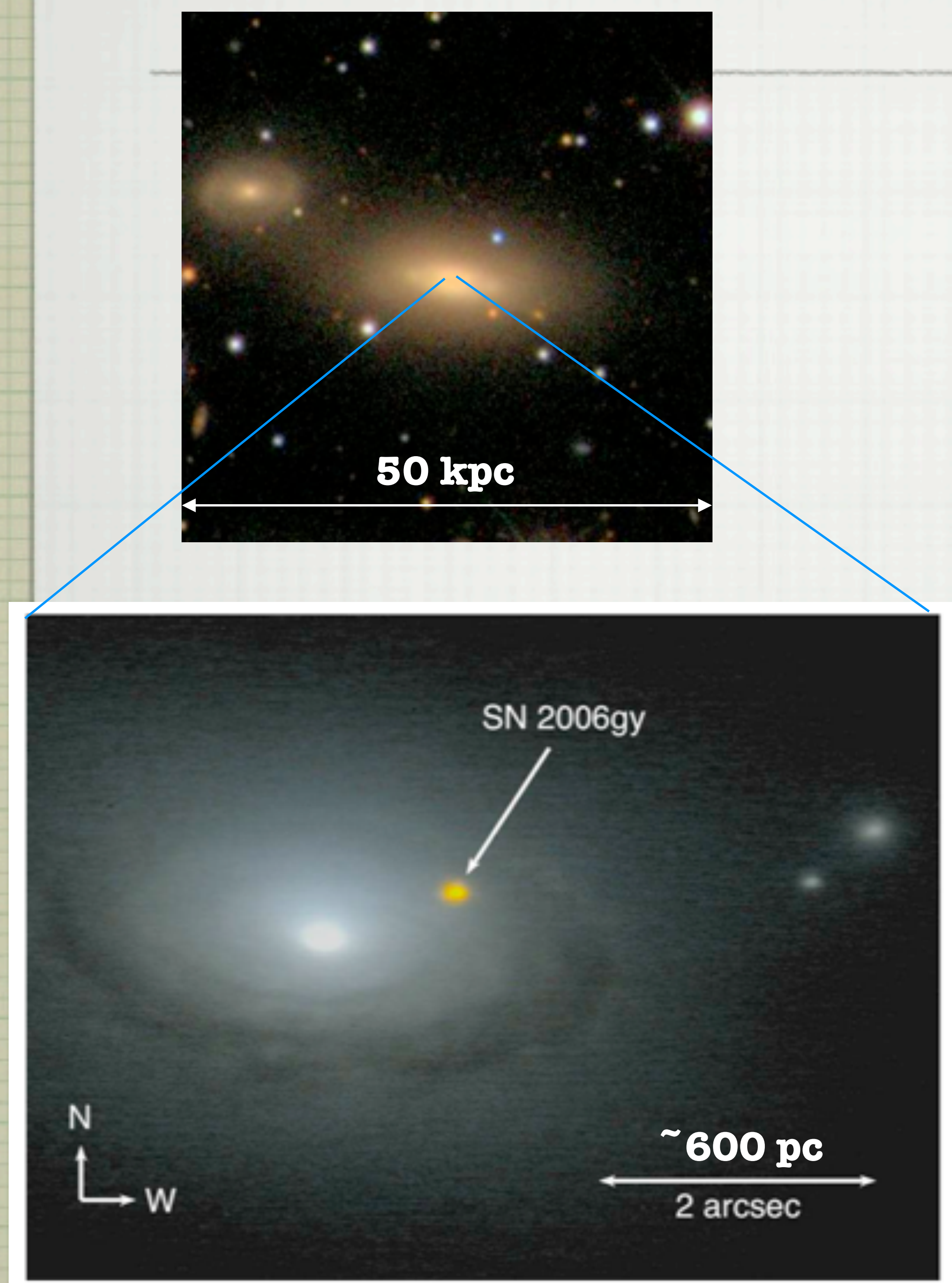
March 12, 2012

# Absolute Magnitude Distribution of Supernovae

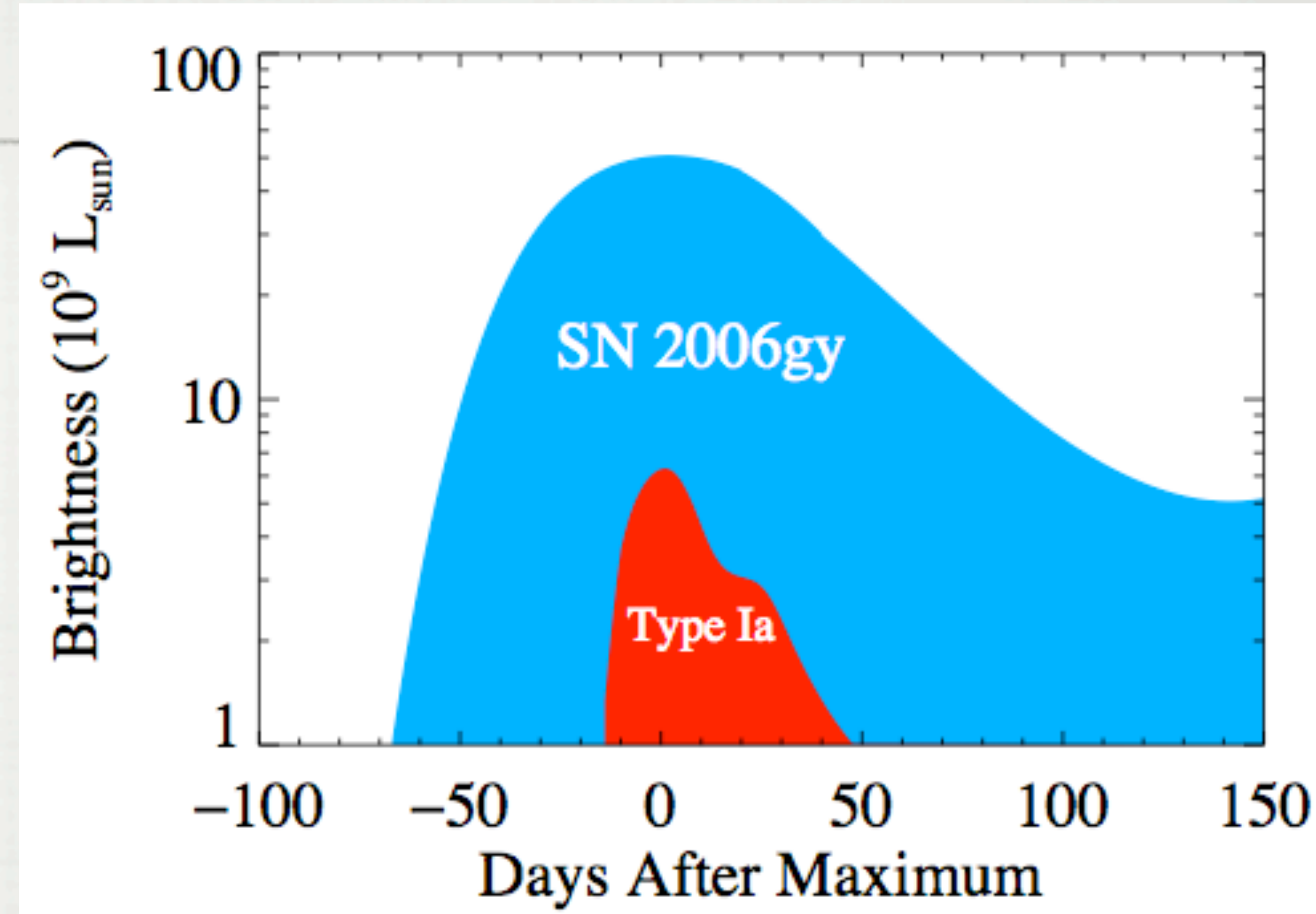



**Data from LOSS (Li et al. 2011)**

# SN 2006gy

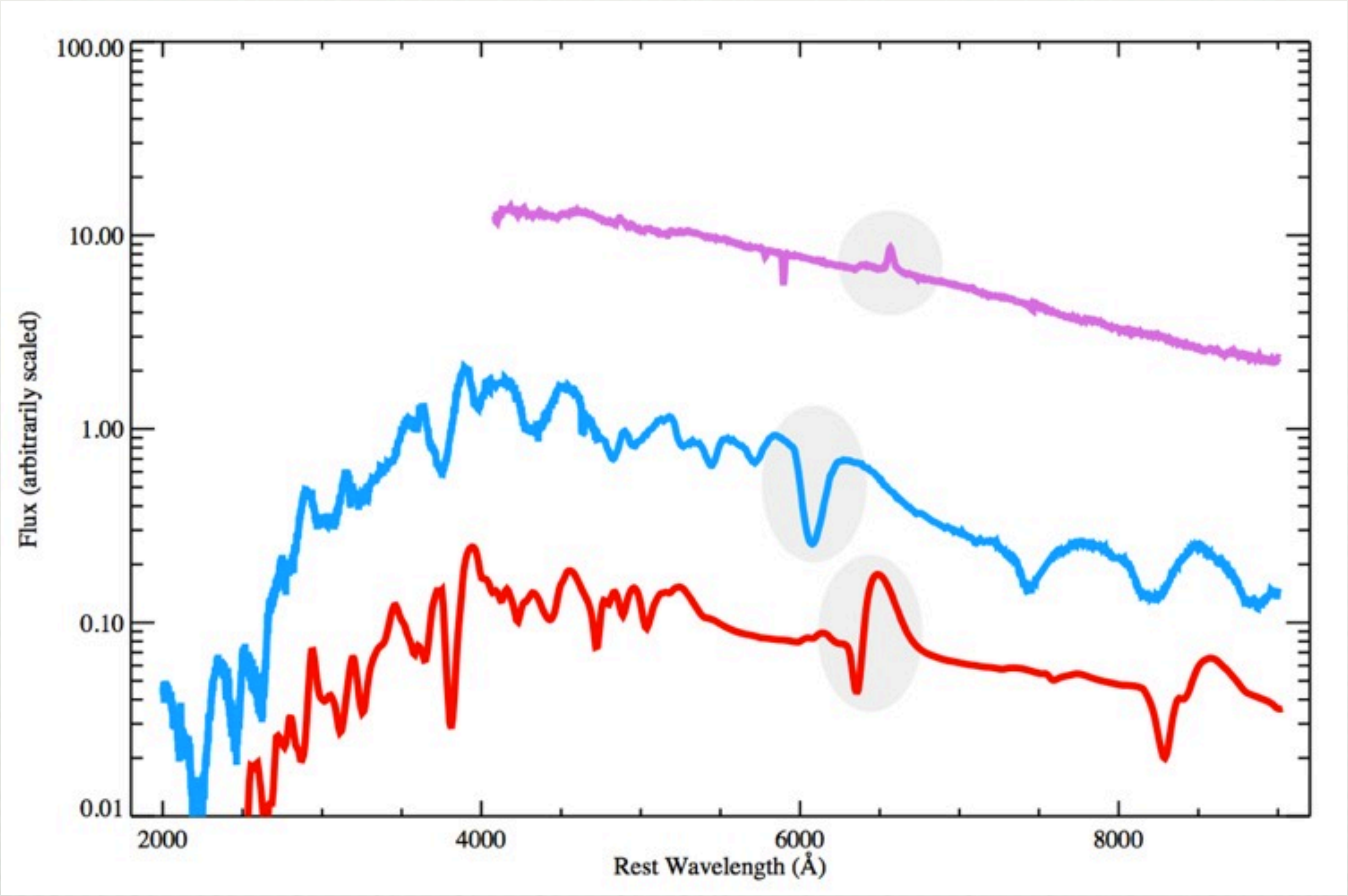



Smith et al. 2008

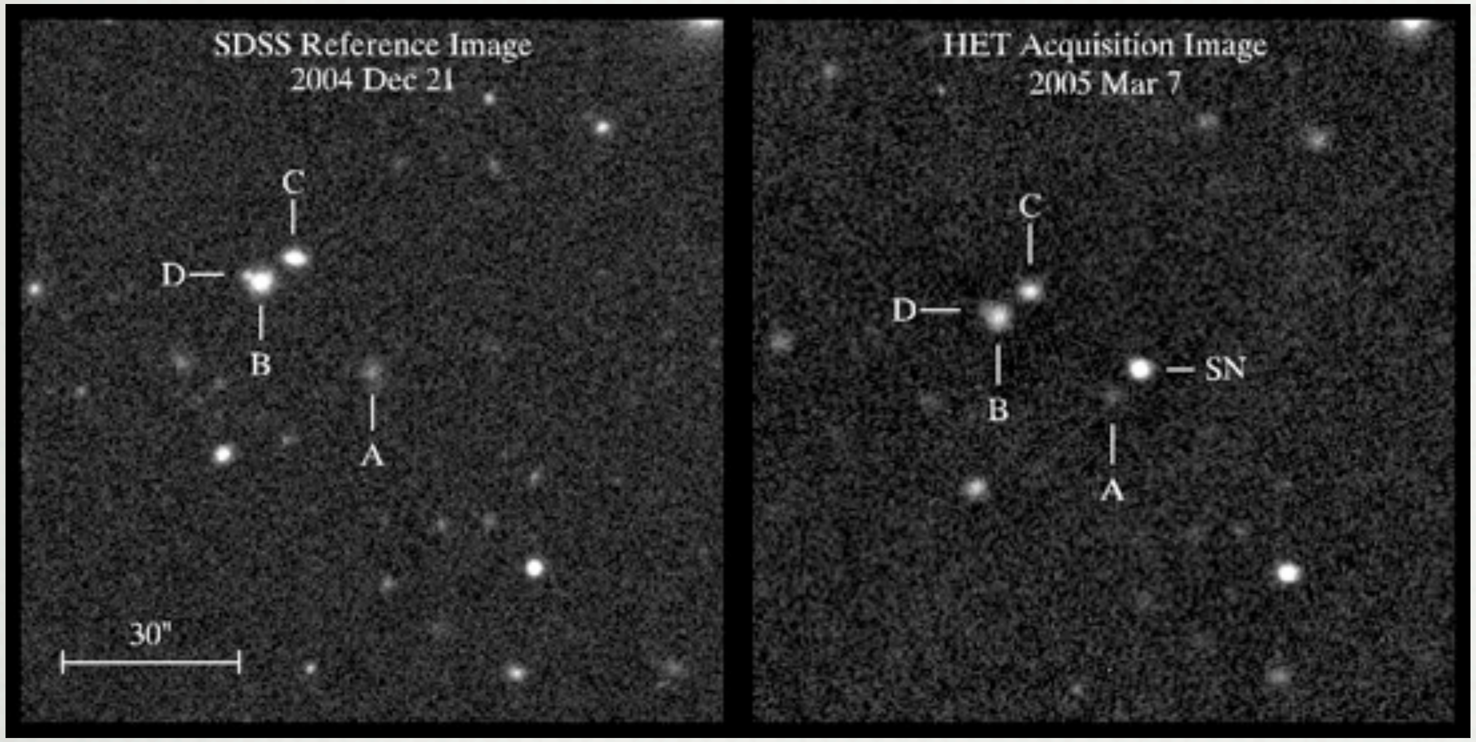


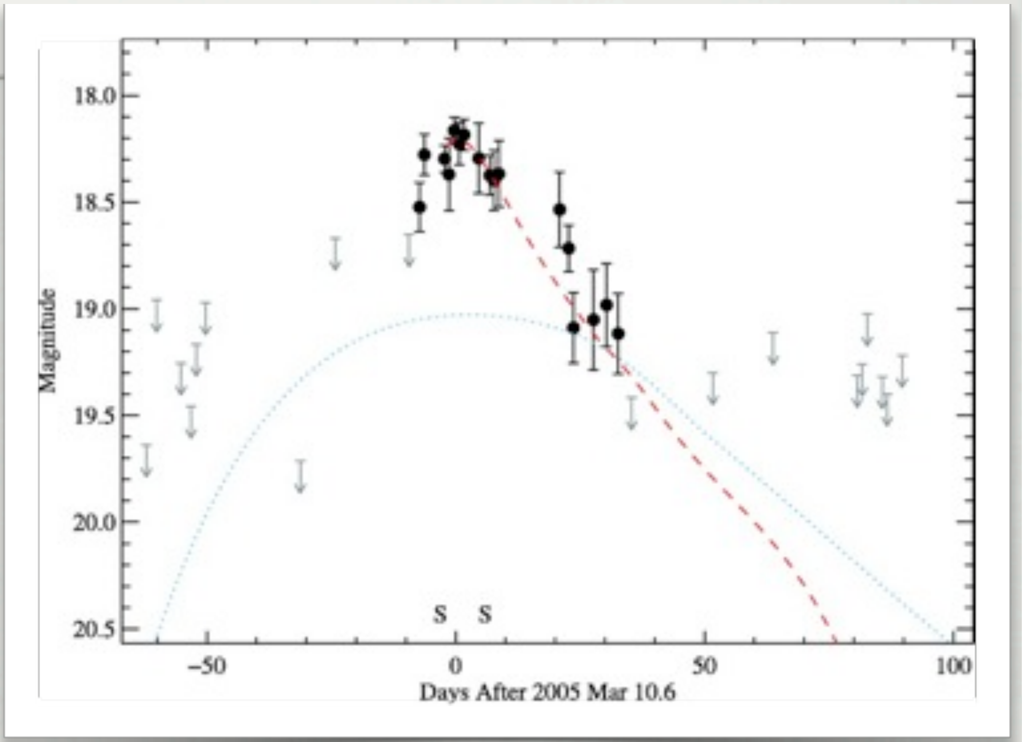

- **Peak absolute magnitude nearly -22**
- **Brighter than -21 mag for ~100 days**
- **Integrated light >$10^{51}$ erg**
- **See: Ofek+ 2007, Smith+ 2007, Smith & McCray 2007, Agnoletto+ 2009, Kawabata+ 2009...**

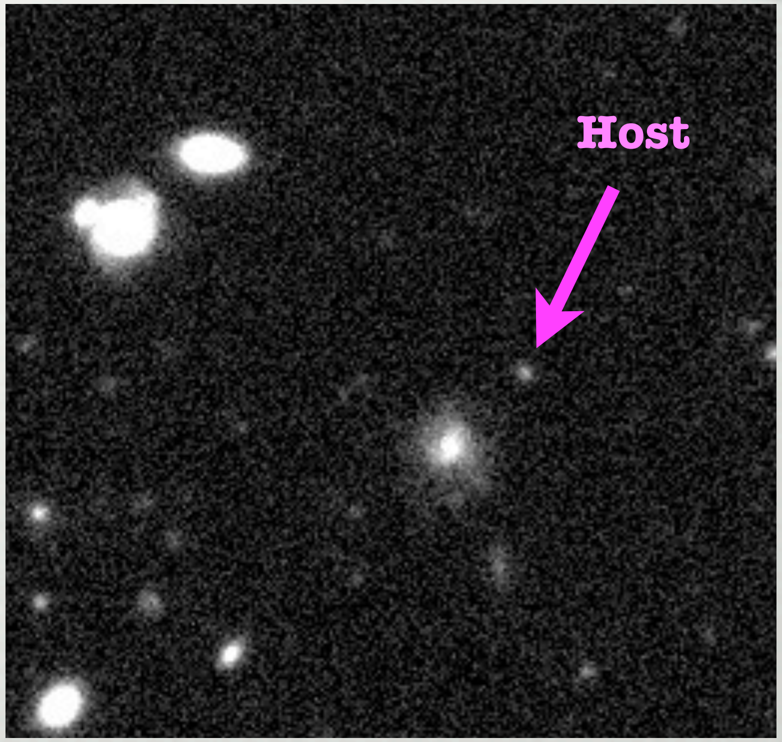
# SLSN-IIn Spectra



# SN 2005ap

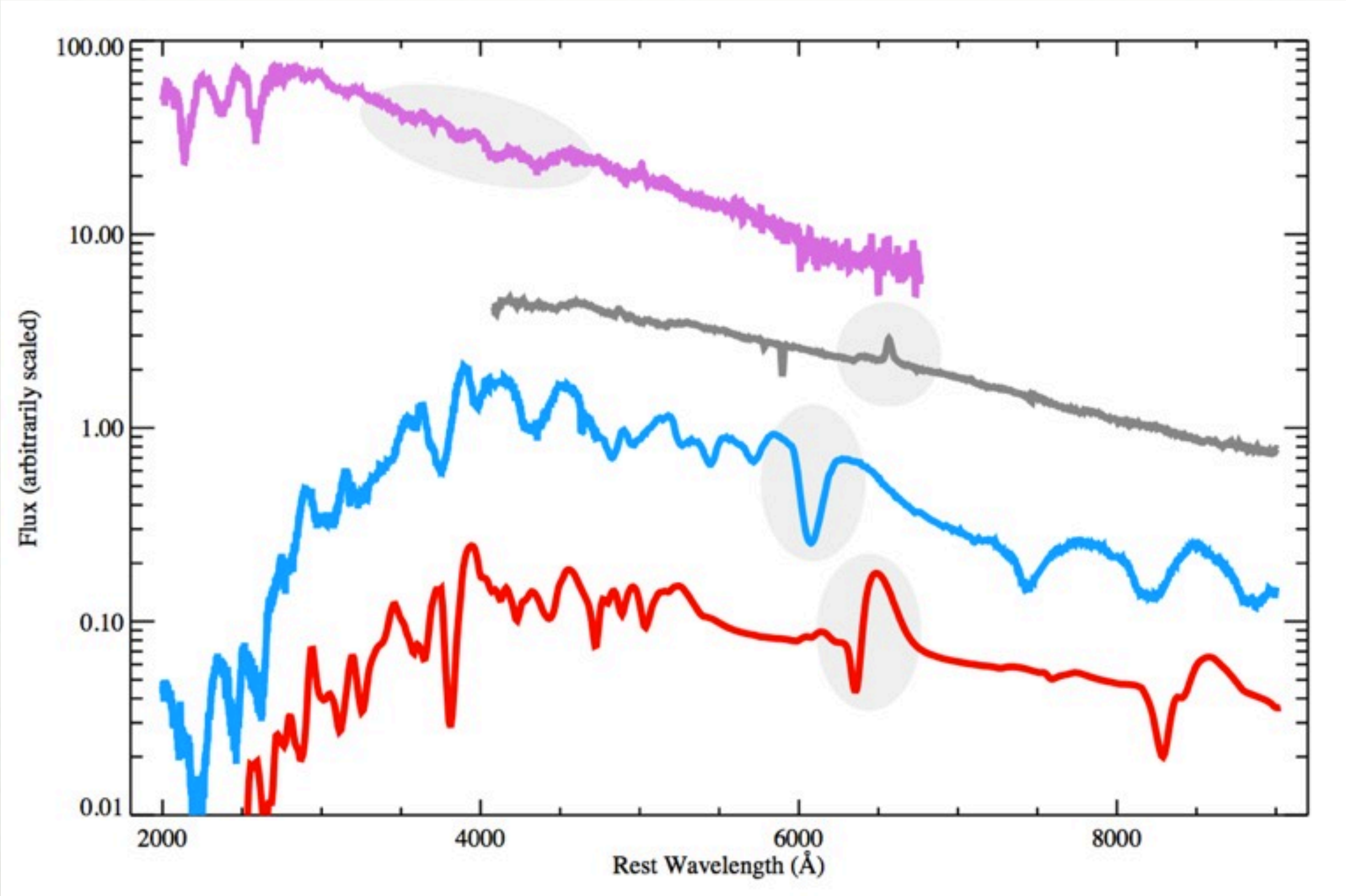


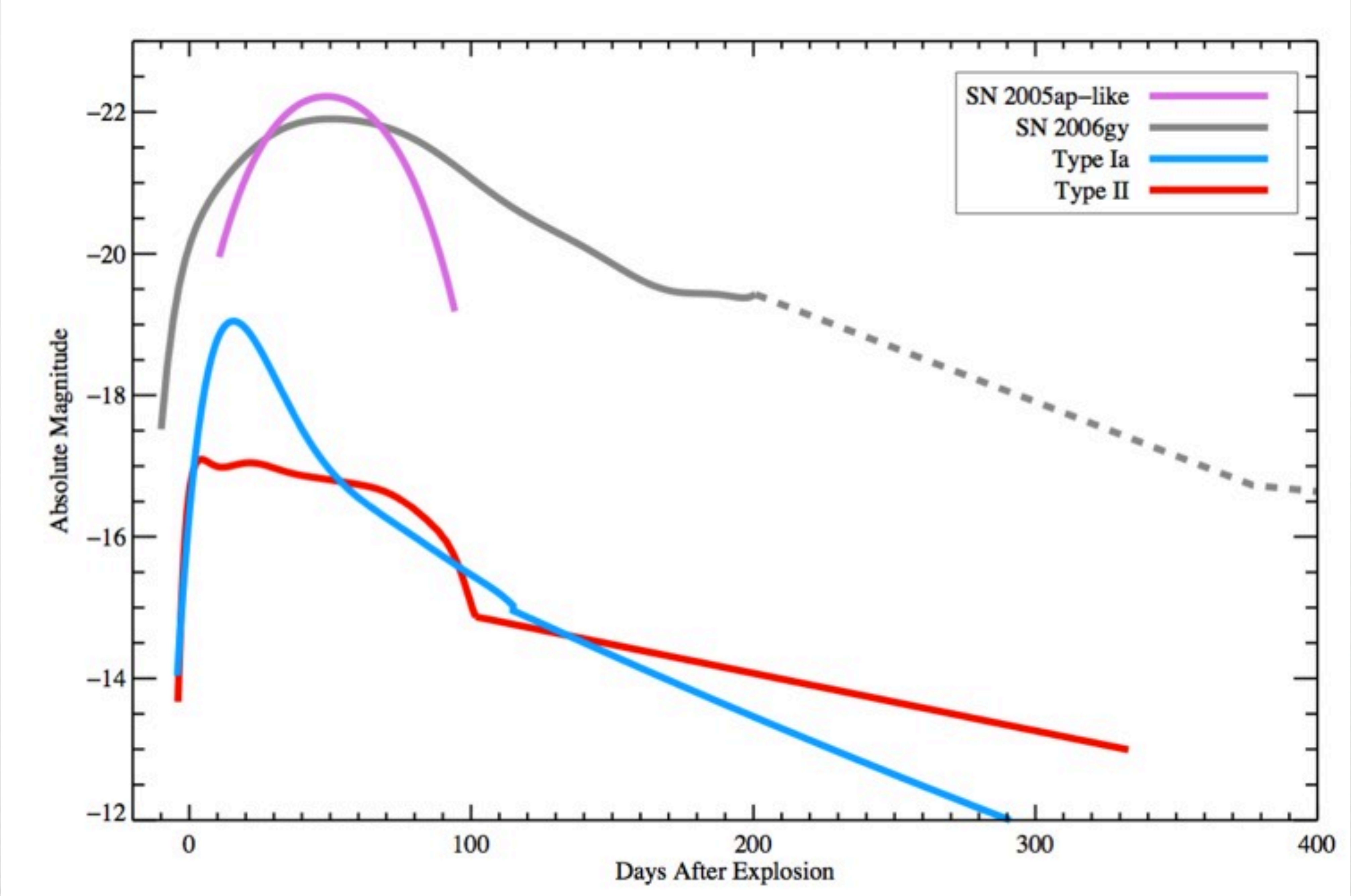




- Spectroscopic redshift z=0.283
- Peak absolute magnitude about -22.7 (unfiltered)
- Observed light curve rise = 7 days
- Estimated rise time >20 days?

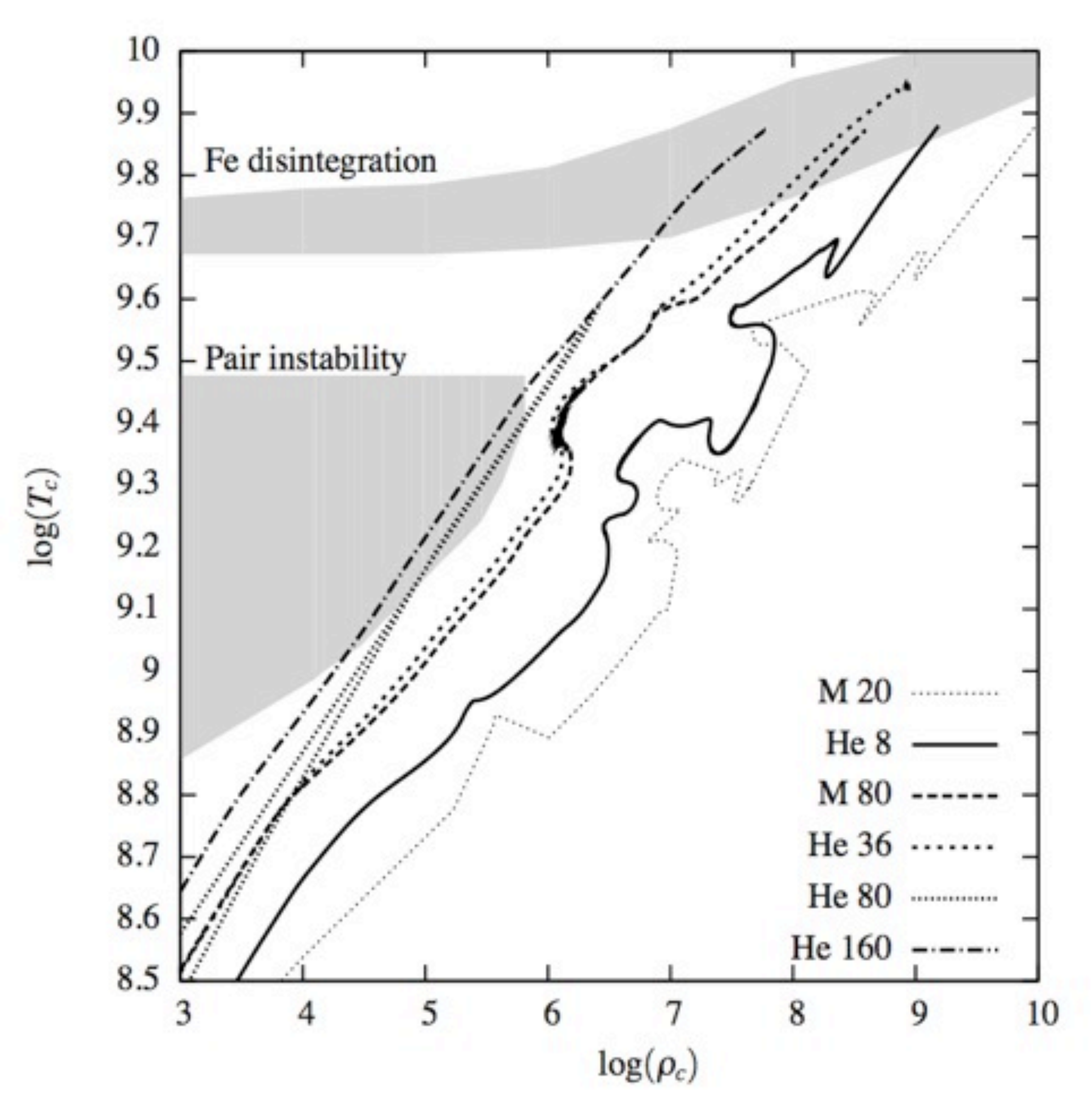
# SLSN-Ic Spectra



# SLSN Light Curves



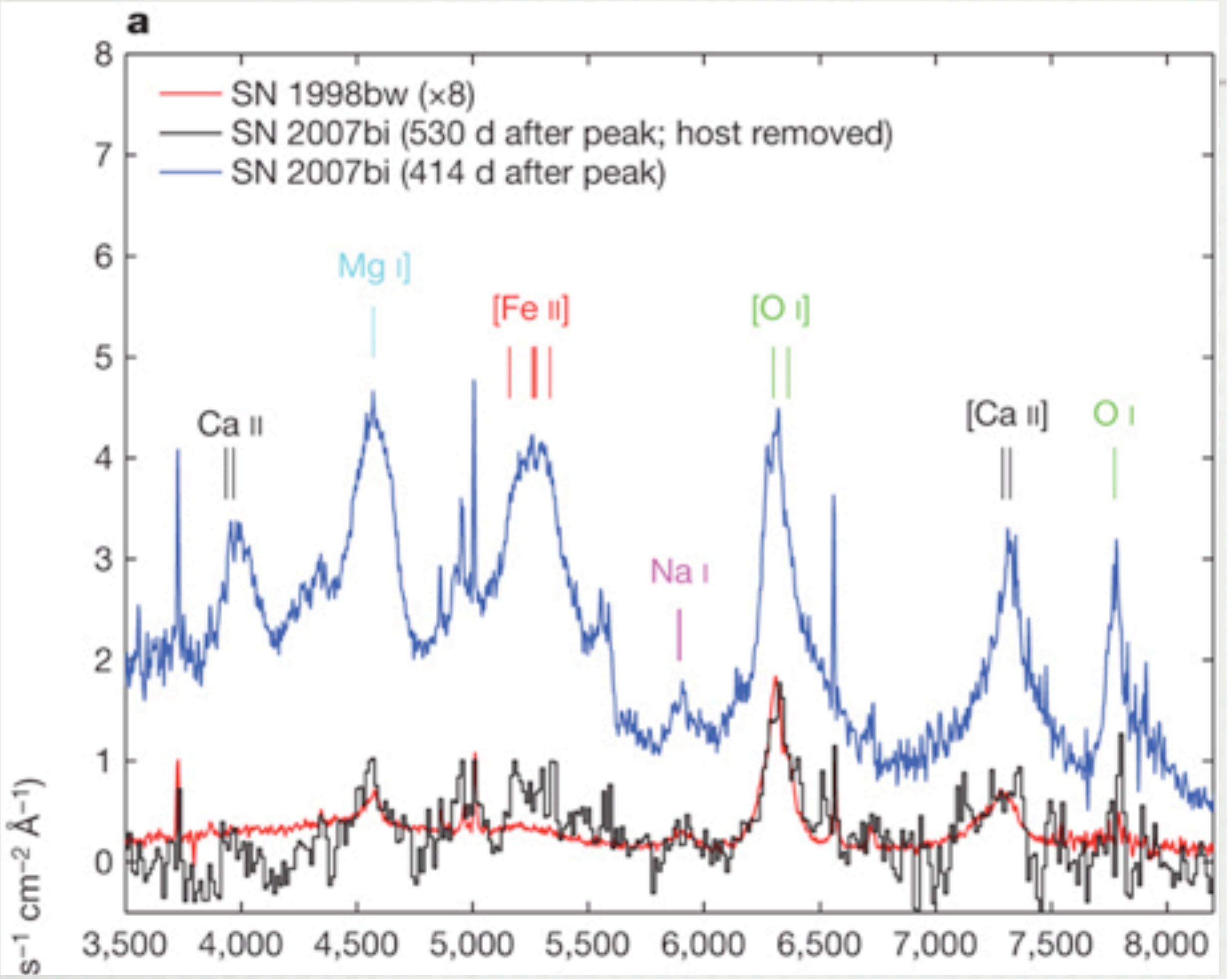
# Pair-Instability SNe

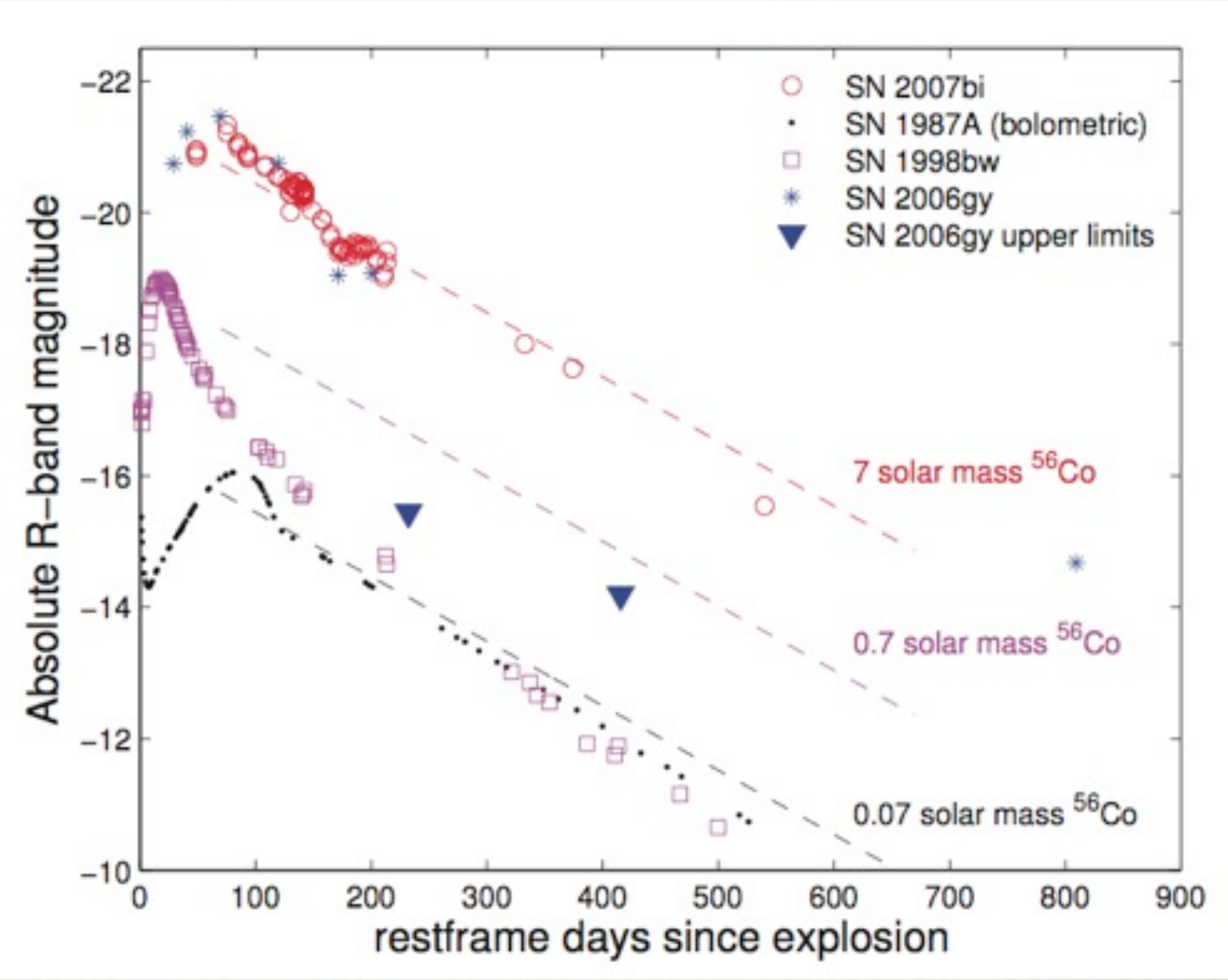



Waldman 2008

- 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

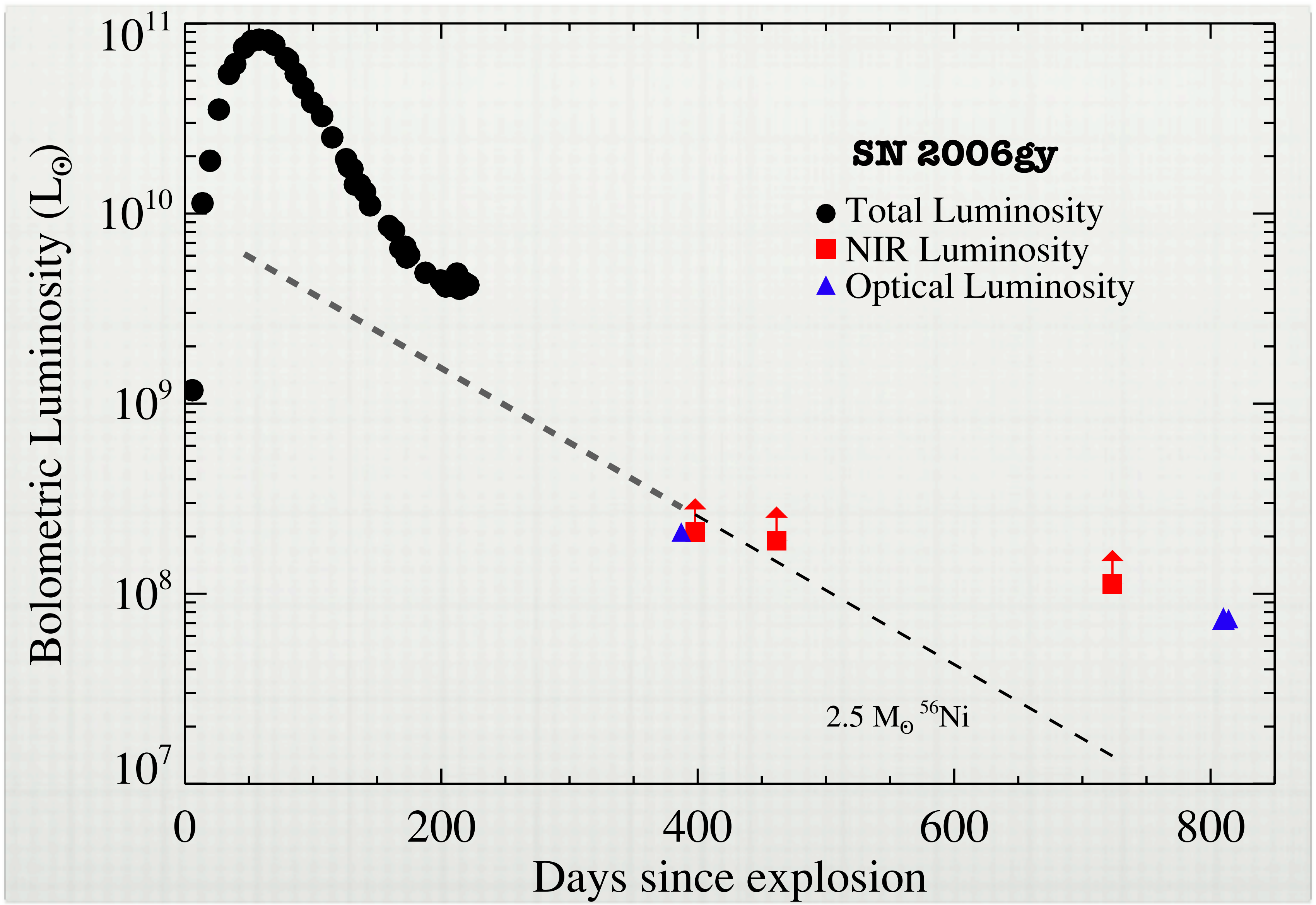



Gal-Yam et al. 2009

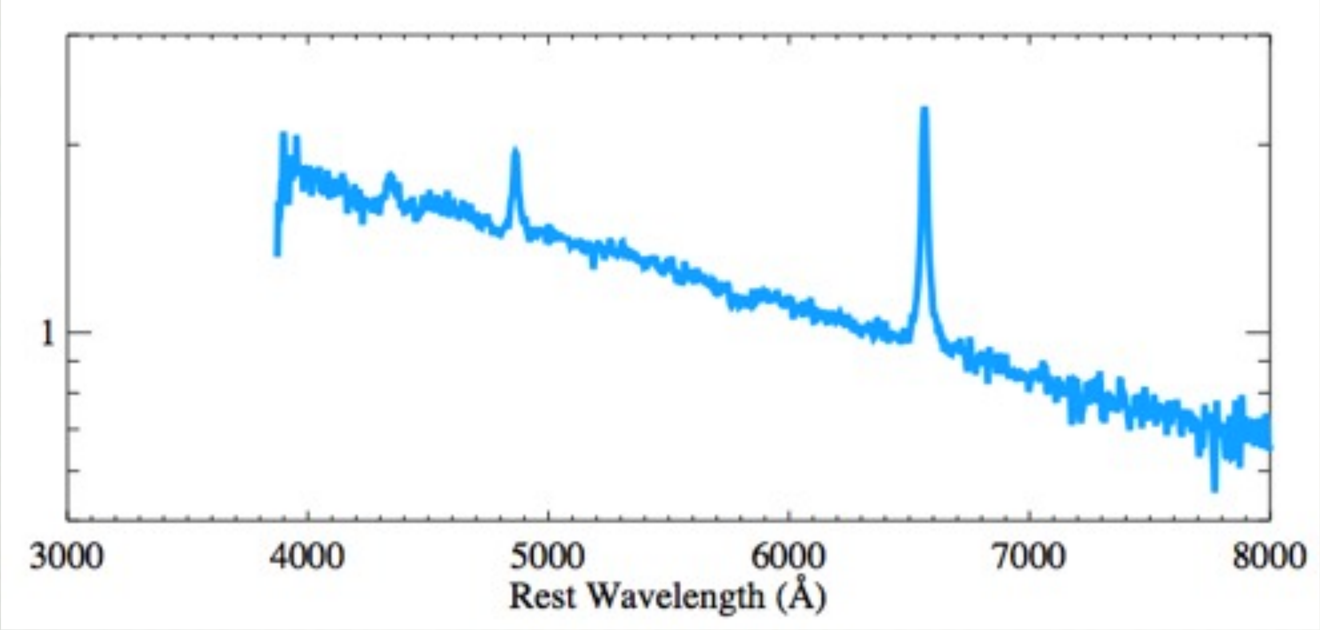
- Optical light curve decay rate consistent with ~7 $M_\odot$ of $^{56}$Ni
- Iron abundance in nebular spectra also consistent with ~4-7 $M_\odot$ of $^{56}$Ni

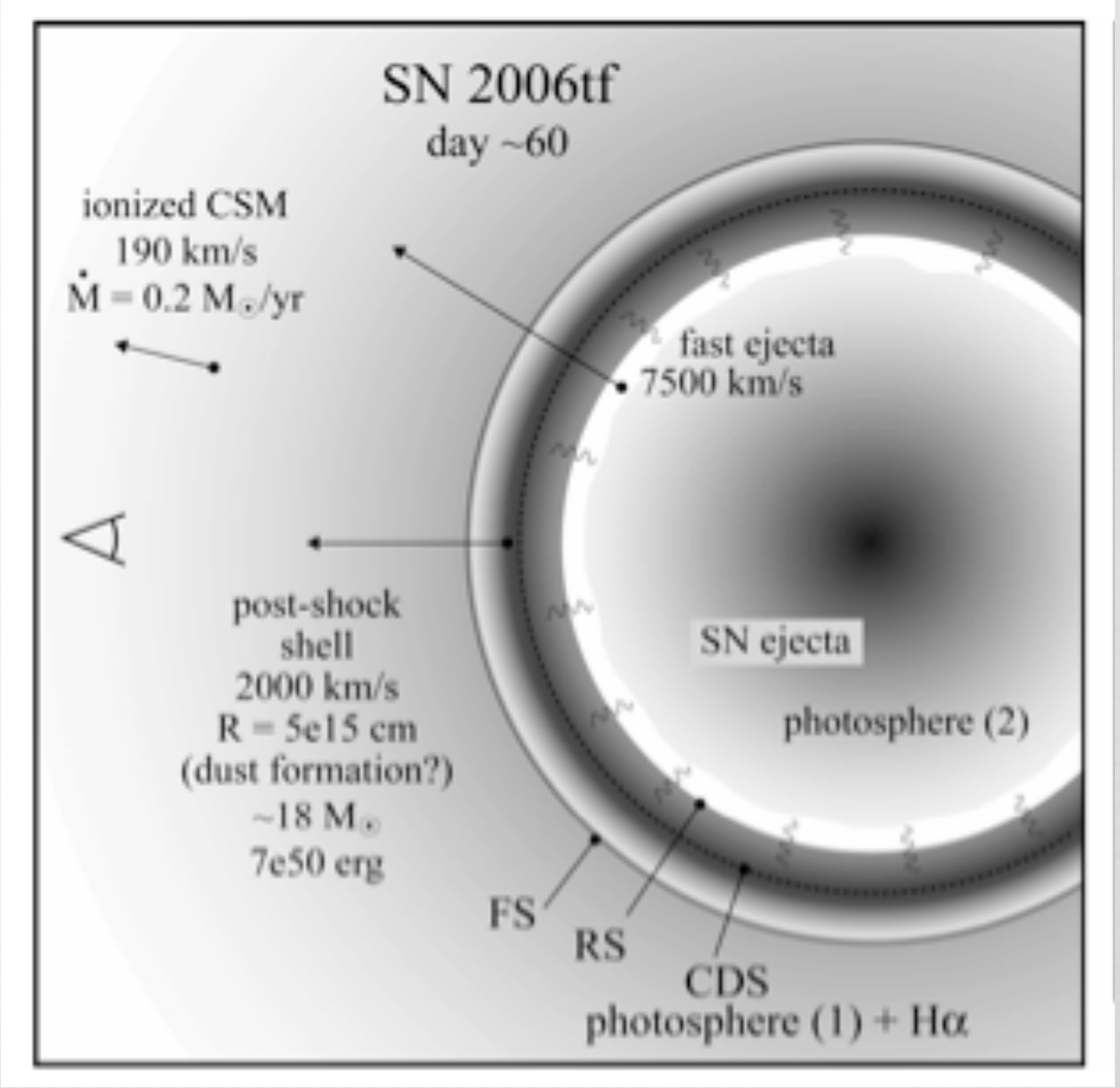
# Late-Time Light Curve




Miller et al. 2010

# Interaction Power

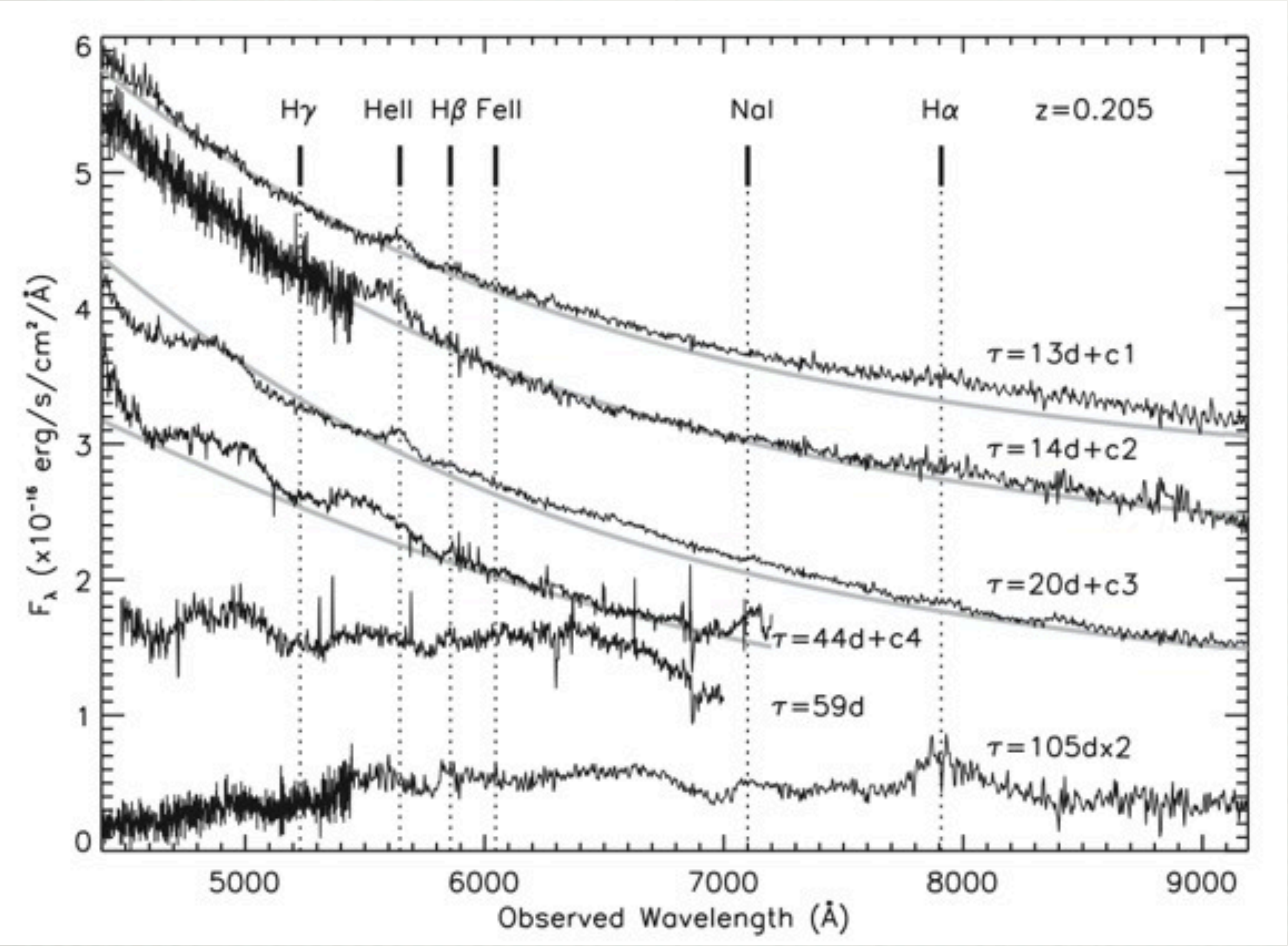


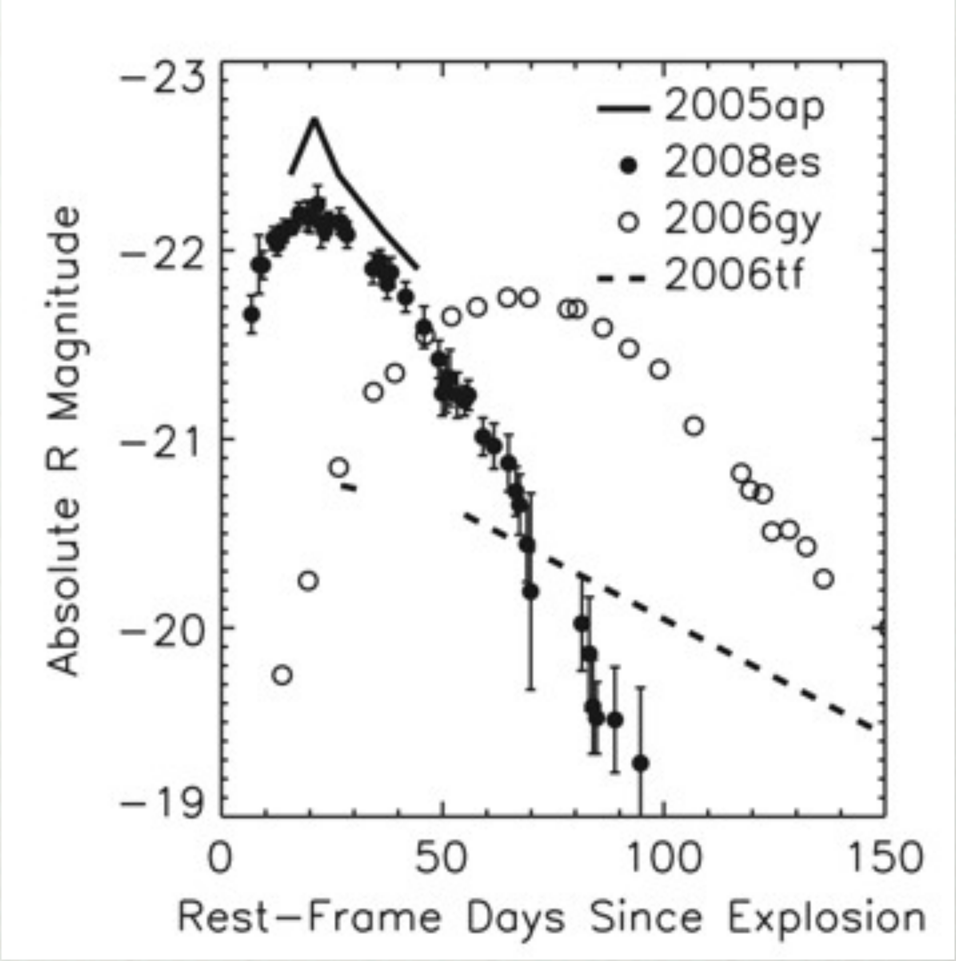




Smith et al. 2008

**Ejecta run into surrounding material (progenitor wind, shells, etc.)**

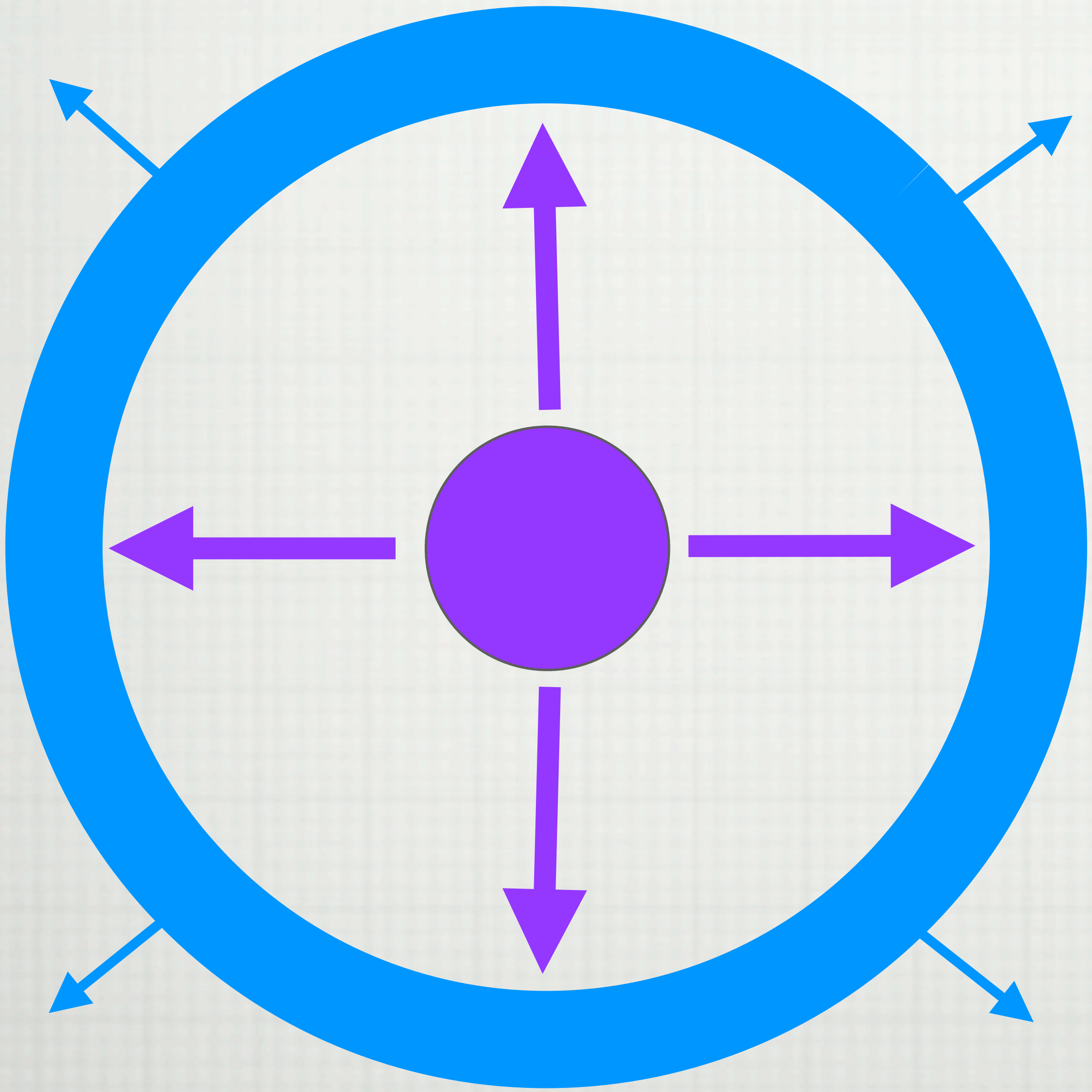
# SN 2008es (SLSN-II)



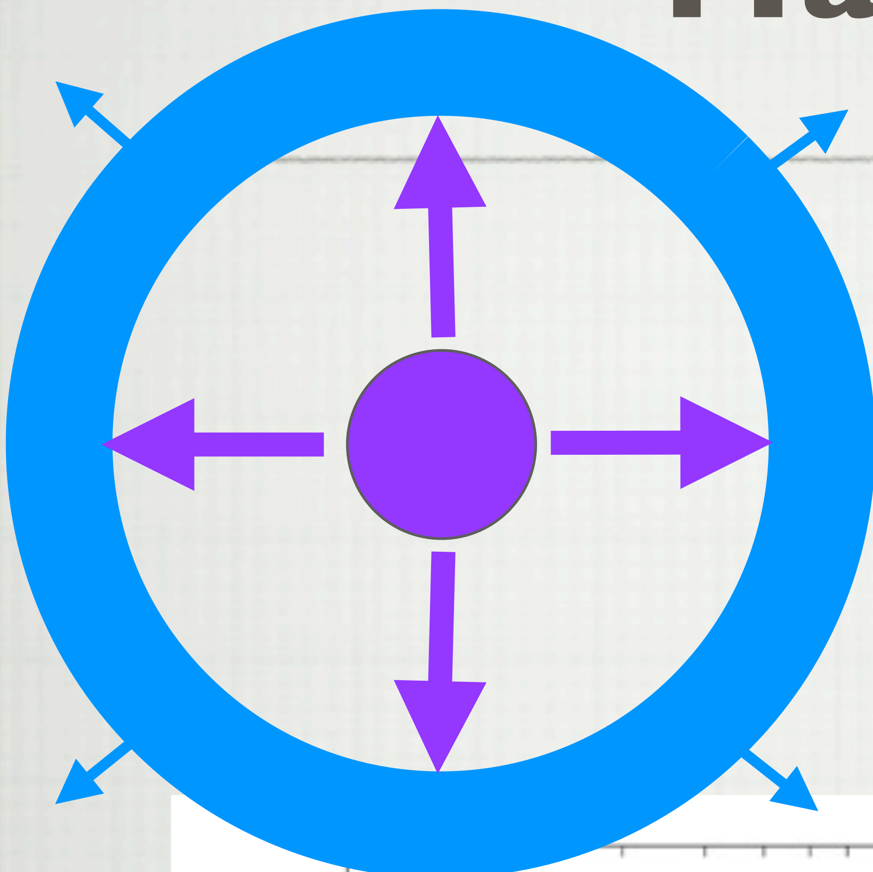

Gezari et al. 2009; see also Miller et al. 2009

# Shell Scenario



- outer shell expanding at a few 1000 km/s
- energy injected from with in

# Magnetar Power

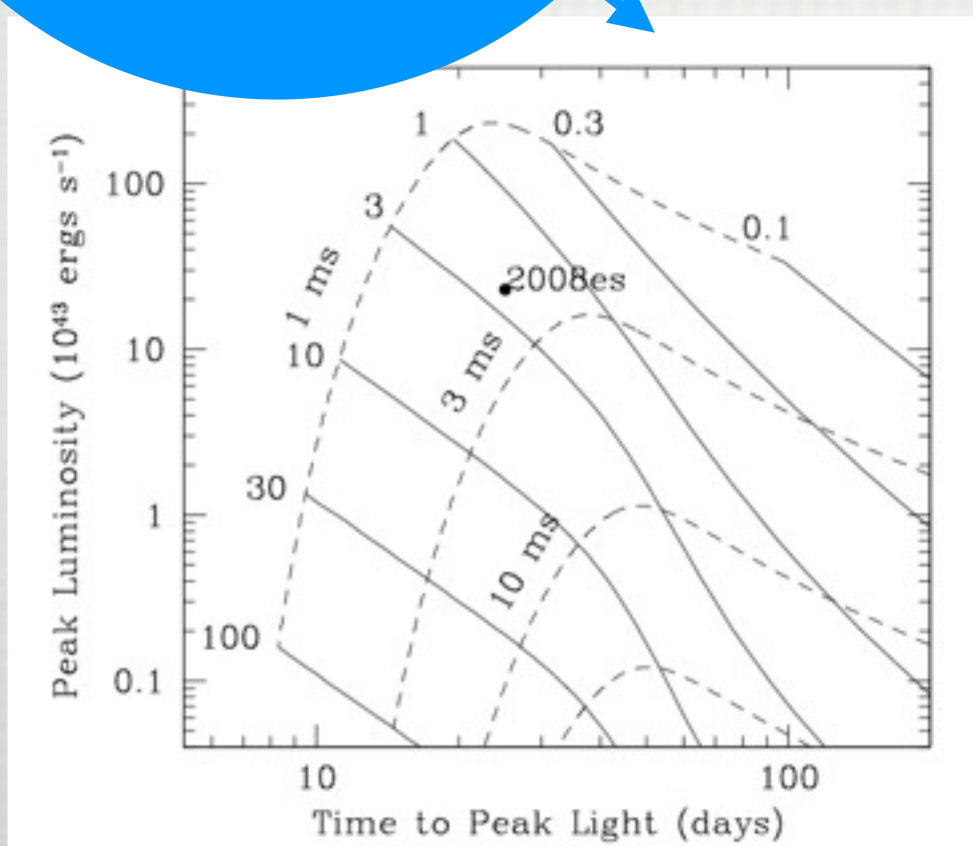


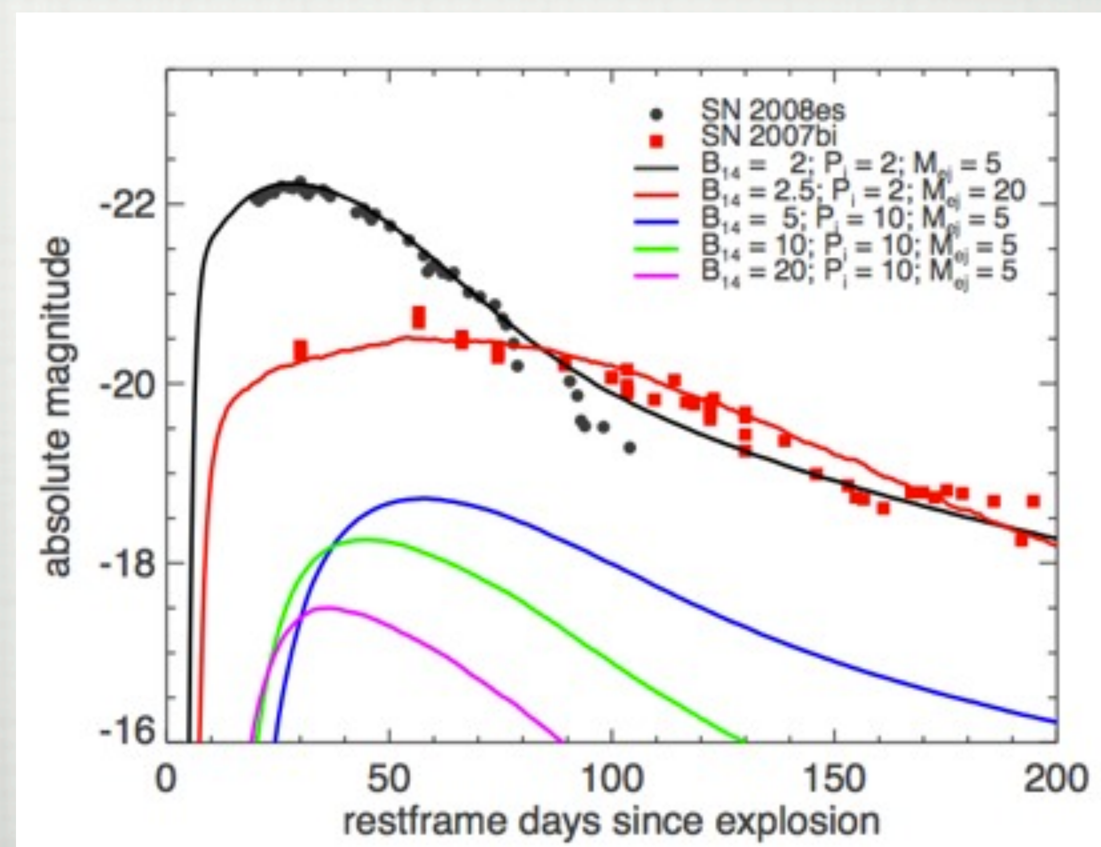
$$E_{\rm p} = \frac{I_{\rm ns}\Omega_{\rm i}^2}{2} = 2\times10^{50} P_{10}^{-2} \text{ ergs},$$

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

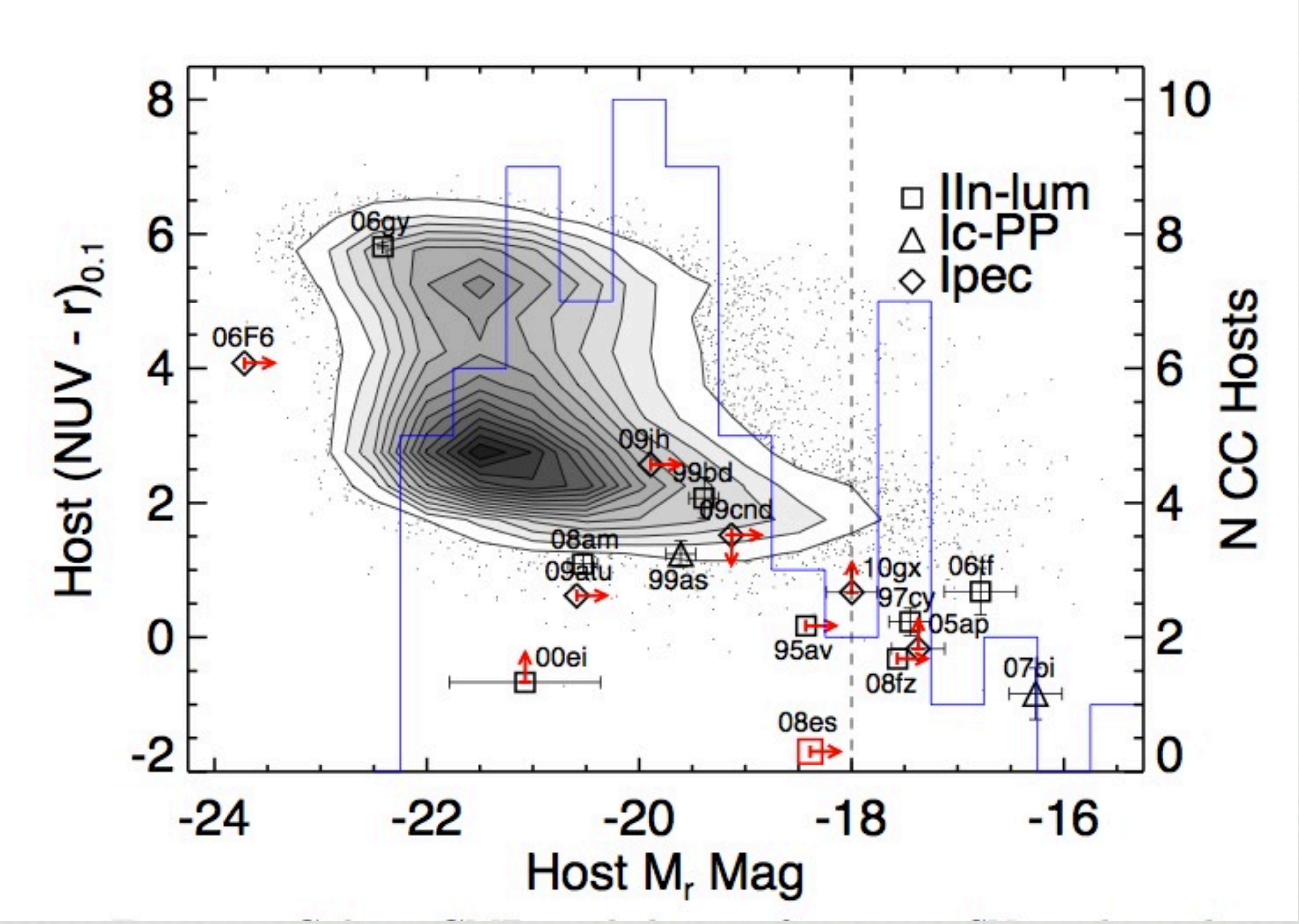
$$L_{\rm peak} \sim \frac{E_{\rm p} t_{\rm p}}{t_{\rm d}^2} \sim 5\times10^{43} B_{14}^{-2} \kappa_{\rm es}^{-1} M_5^{-3/2} E_{51}^{1/2} \text{erg s}^{-1}$$

**Kasen & Bildsten 2010; see also Woosley 2010**



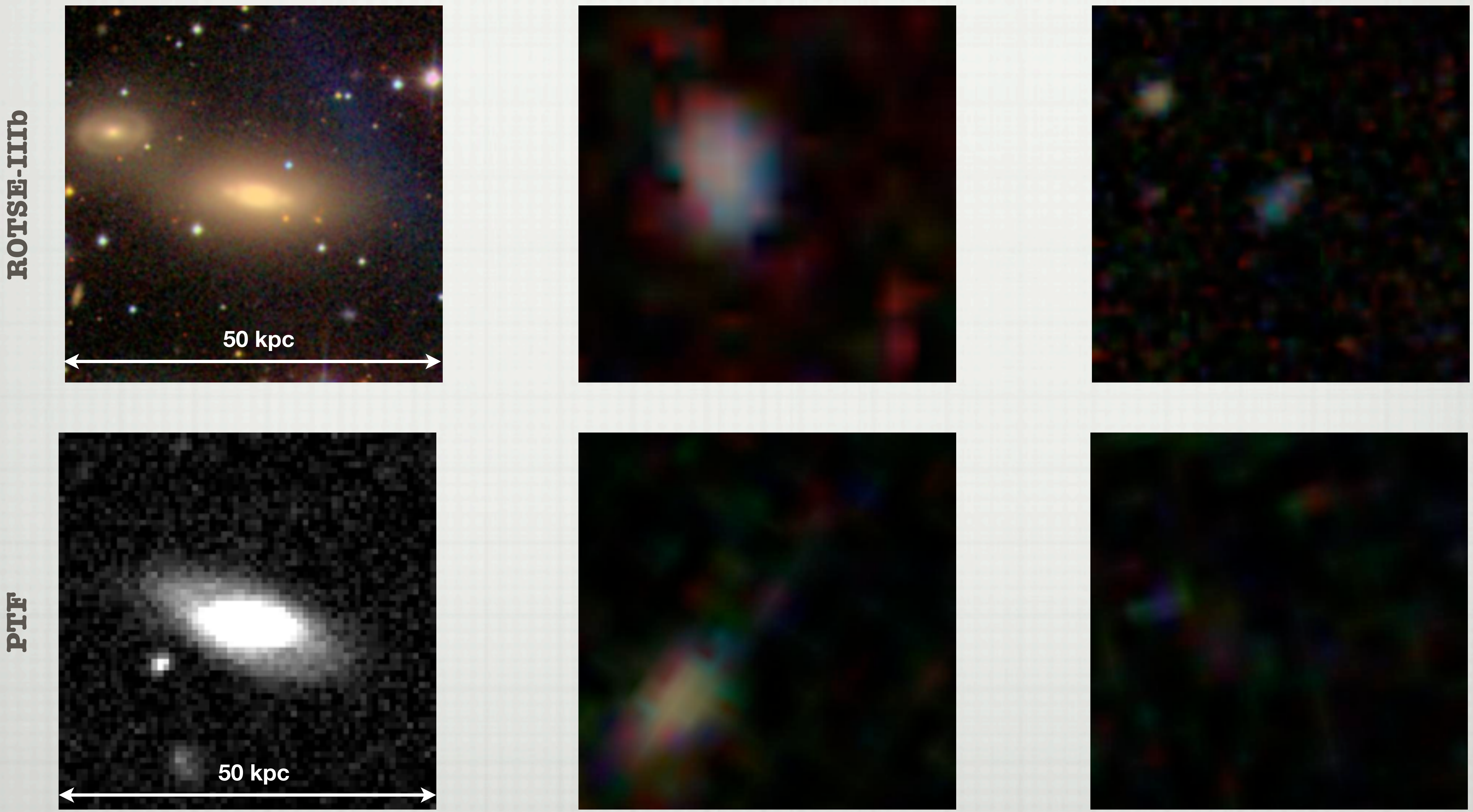



# Host Galaxies

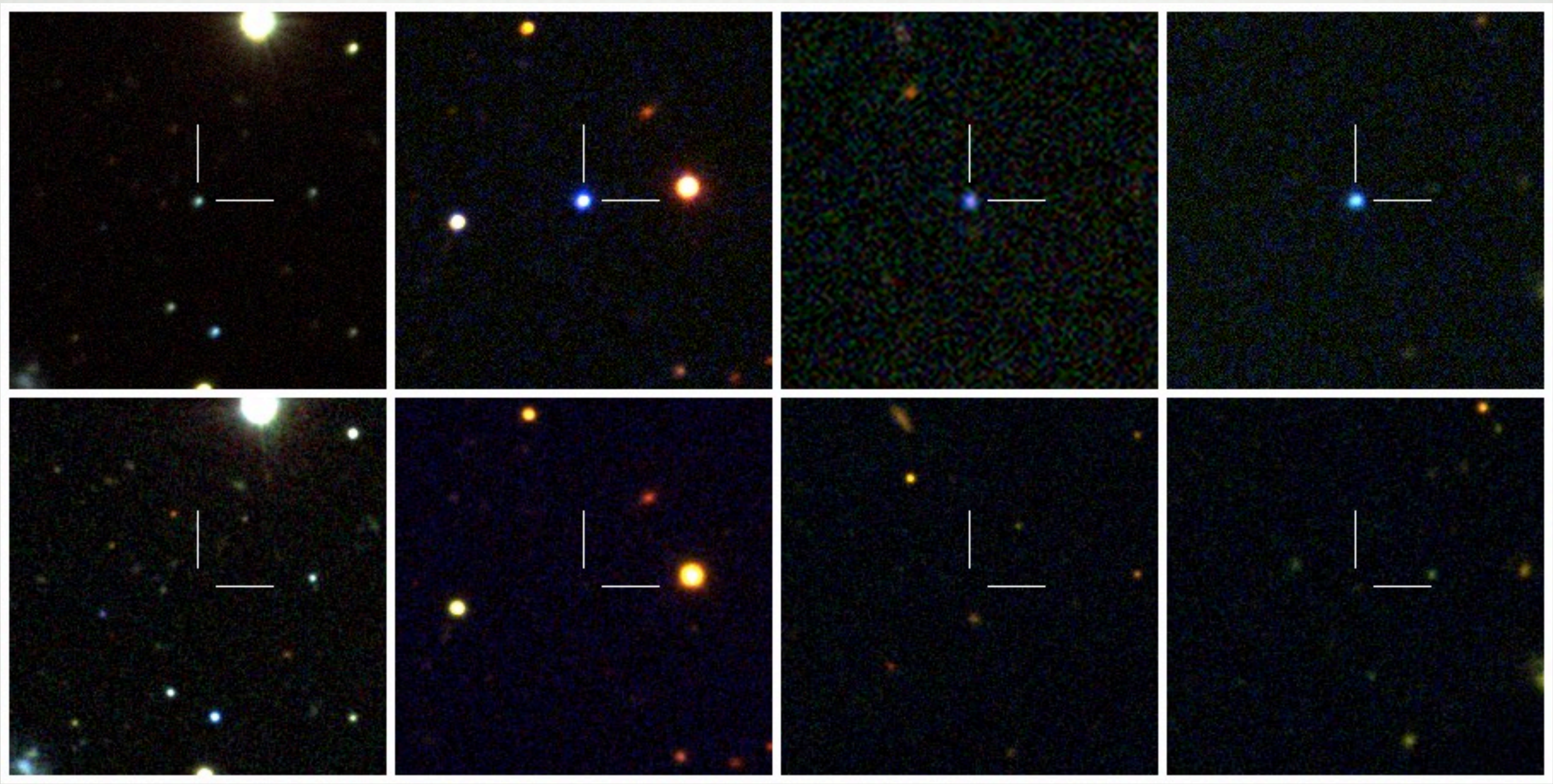



Neill et al. 2011

# SLSN-IIn Hosts

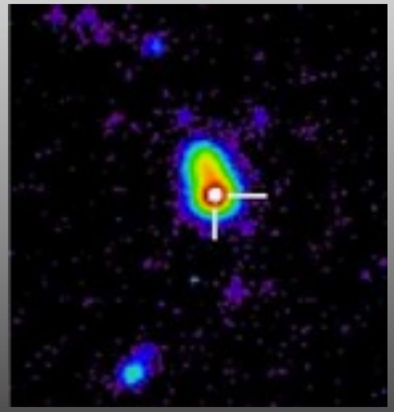


# SLSN-Ic Hosts



# Local SLSN Rates (based on ROTSE-IIIb sample)

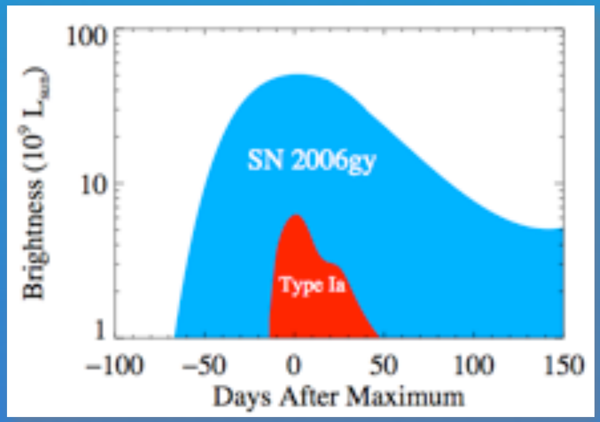
*still preliminary*



All SLSN-like events

(z~0.2; M = -22.0±0.5 mag):

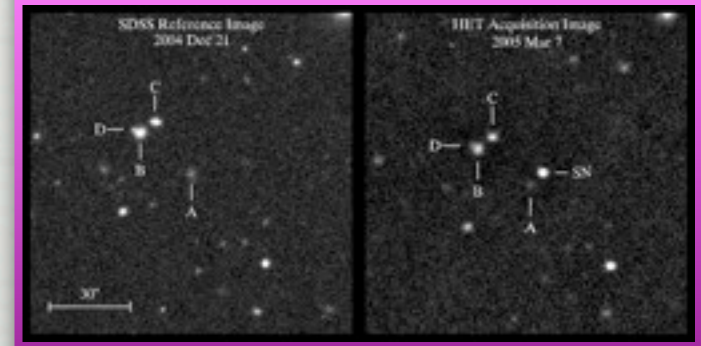
~$10^{-7}$ events/year/$Mpc^3$




SLSN-IIn (2006gy-like events)

(z~0.1; M = -21.5±0.5 mag):

~$10^{-7}$ events/year/$Mpc^3$



SLSN-Ic (2005ap-like events)

(z~0.2; M = -22.5±0.5 mag):

~$10^{-8}$ events/year/$Mpc^3$

**Compare to CCSN: ~1x$10^{-4}$ events/year/$Mpc^3$ and SNIa: ~3x$10^{-5}$ SN/year/$Mpc^3$**

# Growing SLSN Sample

| Supernova | Redshift | Absolute peak [mag] | Radiated energy [erg] | Reference |
|---|---|---|---|---|
| SLSN-PI | | | | |
| SN 2007bi | 0.1289 | -21.3 | $1-2\times10^{51}$ | Gal-Yam et al. 2009 |
| SN 1999as | 0.12 | -21.4 | | Hatano et al. 2001 |
| SLSN-II | | | | |
| CSS100217 | 0.147 | -22.7 | $1.3\times10^{52}$ | Drake et al. 2011 |
| SN 2008fz | 0.133 | -22.3 | $1.4\times10^{51}$ | Drake et al. 2010 |
| SN 2008am | 0.2338 | -22.3 | $2\times10^{51}$ | Chatzopoulos et al. 2011 |
| SN 2008es | 0.205 | -22.2 | $1.1\times10^{51}$ | Gezari et al. 2009; Miller et al. 2009 |
| SN 2006gy | 0.019 | -22.0 | $2.3-2.5\times10^{51}$ | Ofek et al. 2007; Smith et al. 2010 |
| SN 2003ma | 0.289 | -21.5 | $4\times10^{51}$ | Rest et al. 2011 |
| SN 2006tf | 0.074 | -20.7 | $7\times10^{50}$ | Smith et al. 2008 |
| SLSN-I | | | | |
| SN 2005ap | 0.2832 | -22.7 | $1.2\times10^{51}$ | Quimby et al. 2007; 2011 |
| SCP 06F6 | 1.189 | -22.5 | $1.7\times10^{51}$ | Quimby et al. 2011 |
| PS1-10ky | 0.956 | -22.5 | $0.9-1.4\times10^{51}$ | Chomiuk et al. 2011 |
| PS1-10awh | 0.908 | -22.5 | $0.9-1.4\times10^{51}$ | Chomiuk et al. 2011 |
| PTF10atu | 0.501 | -22.0 | | Quimby et al. 2011 |
| PTF10cnd | 0.258 | -22.0 | $1.2\times10^{51}$ | Quimby et al. 2011 |
| SN 2009jh | 0.349 | -22.0 | | Quimby et al. 2011 |
| SN 2010gx | 0.230 | -21.2 | $6\times10^{50}$ | Quimby et al. 2011; Pastorello et al. 2010 |

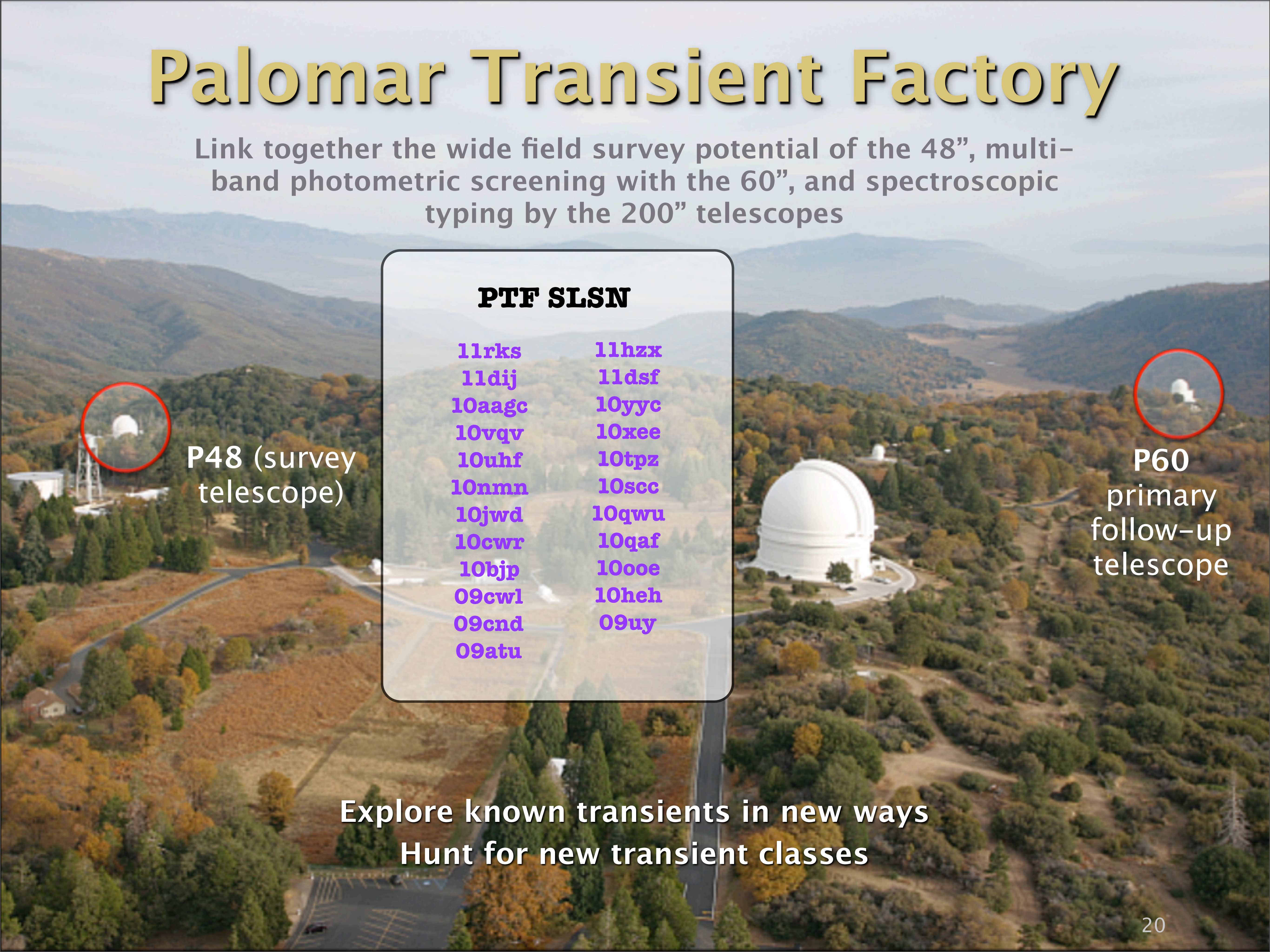
**Gal-Yam (submitted)**

# Palomar Transient Factory

Link together the wide field survey potential of the 48”, multi-band photometric screening with the 60”, and spectroscopic typing by the 200” telescopes

**PTF SLSN**

| | |
|---|---|
| 11rks | 11hzx |
| 11dij | 11dsf |
| 10aagc | 10yyc |
| 10vqv | 10xee |
| 10uhf | 10tpz |
| 10nmn | 10scc |
| 10jwd | 10qwu |
| 10cwr | 10qaf |
| 10bjp | 10ooe |
| 09cwl | 10heh |
| 09cnd | 09uy |
| 09atu | |

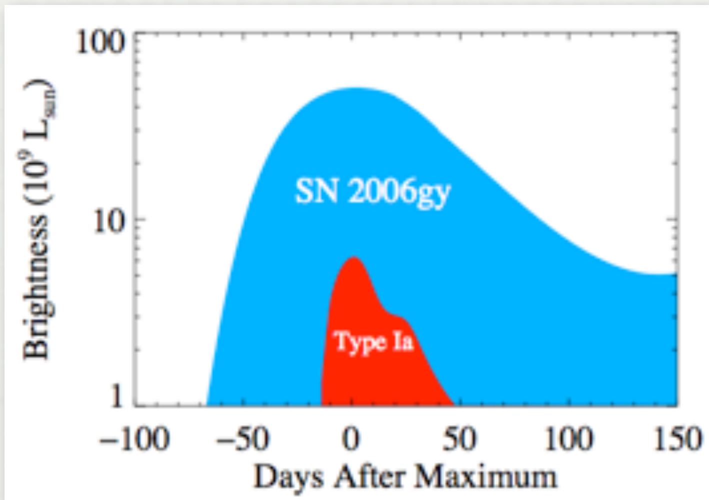



**Explore known transients in new ways**
**Hunt for new transient classes**

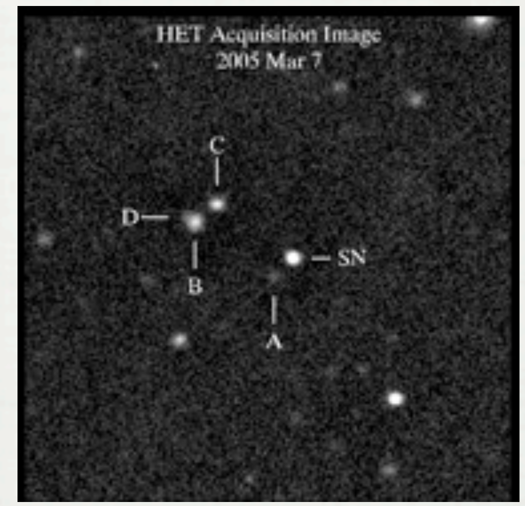
# SLSN Flavors

## Have Hydrogen | No Hydrogen

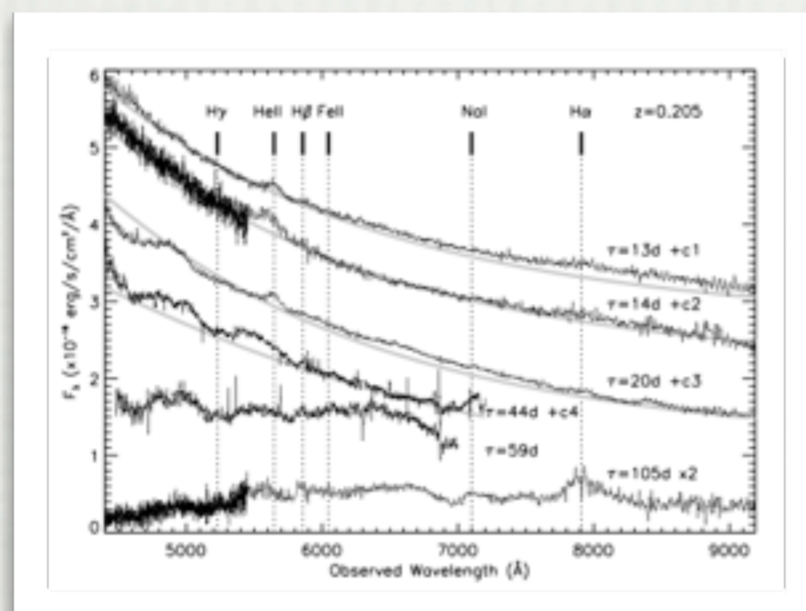
**narrow lines** / SN 2006gy




**fast decline** / SN 2005ap




**no narrow lines** / SN 2008es




**slow decline** / SN 2007bi