Pan-STARRS1 Observations of Ultraluminous SNe

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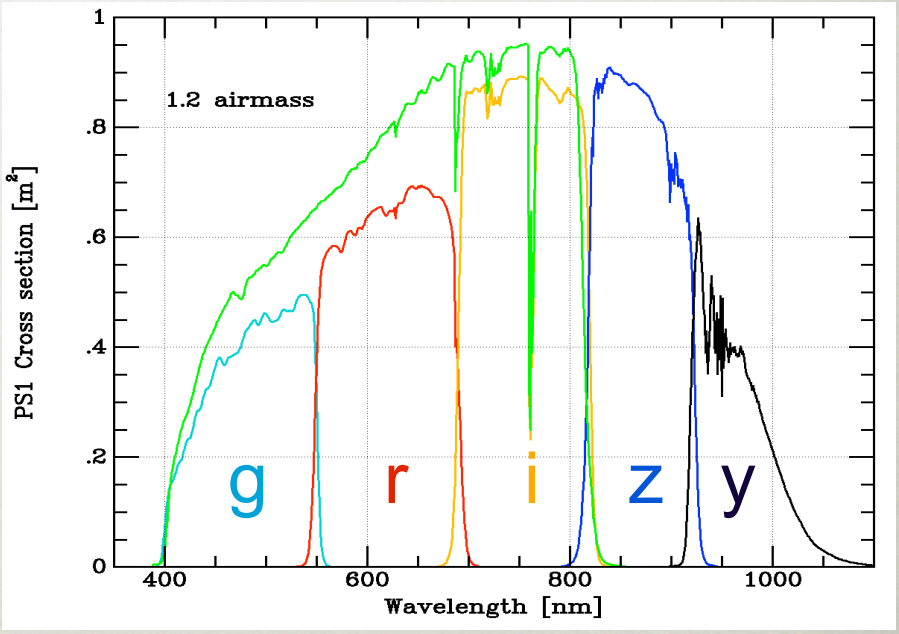
Pan-STARRS1

- 1.8 m telescope on Haleakala, Maui
- 1.4 Gigapixel camera
- 7.2 sq. deg. (0.258” / pix)
- Median image FWHM=1.13”
- Full survey operations began in May 2010



Tonry, Stubbs, et al.

Surveys

3Pi	59%
Medium Deep	24%
SweetSpot	5%
Transit Survey	4%
M31	2%
PI/Stds/STARE	6%

Key Projects

- Inner Solar System
- Outer Solar System
- Low-mass/young stars
- Stellar transits
- Milky Way Structure
- M31
- SN progenitors (Smartt, QUB)
- CIVET (Stubbs, Tonry, Riess)
- Galaxy properties
- AGN and high-z QSOs
- Lensing
- Large Scale Structure

CfA

Edo Berger
Pete Challis
Laura Chomiuk
Ryan Chornock
Ian Czekala
Ryan Foley
Bob Kirshner
Camille Leibler
Ragnhild Lunnan
Raffaella Margutti
Howie Marion
Danny Milisavljevic
Gautham Narayan
Nathan Sanders
Alicia Soderberg
Chris Stubbs

STScI

Armin Rest

IfA / Hawaii

Mark Huber
John Tonry

Johns Hopkins

Suvi Gezari
Adam Riess
Steve Rodney
Dan Scolnic

Medium Deep Survey (MDS)

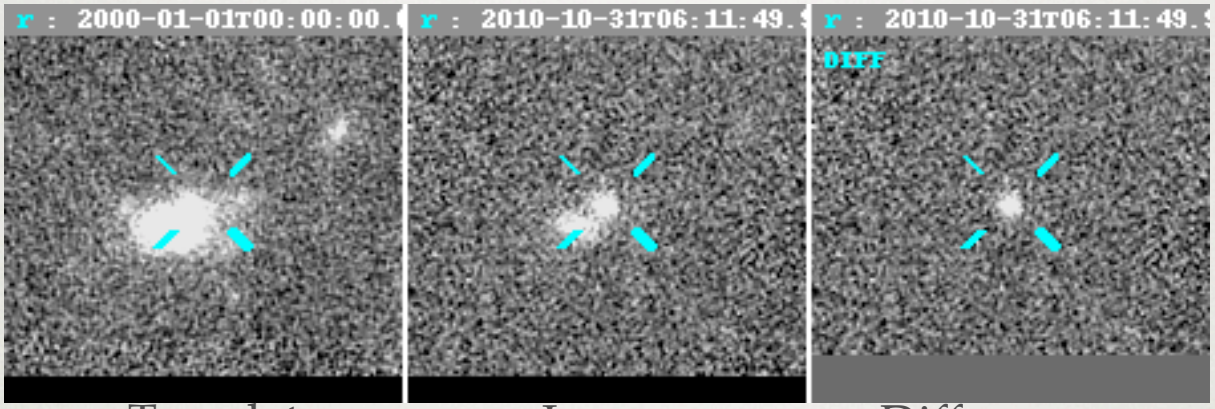
- 10 fields across sky (each 7.2 sq. deg.)
- 4-5 observed nightly
- ~3 day cadence for each filter
- Limiting mag ~24 in griz

Table 3
Pan-STARRS1 Medium-Deep Survey, Typical Cadence

Night	Filter	Exposure Time
1	g_{P1} and r_{P1}	8×113 s each
2	i_{P1}	8×240 s
3	z_{P1}	8×240 s
Repeats...	...	...
FM $\pm$ 3	y_{P1}	8×240 s

Notes. Observations taken three nights on either side of full moon are done only in the y_{P1} band.

Harvard/JHU Transient Pipeline



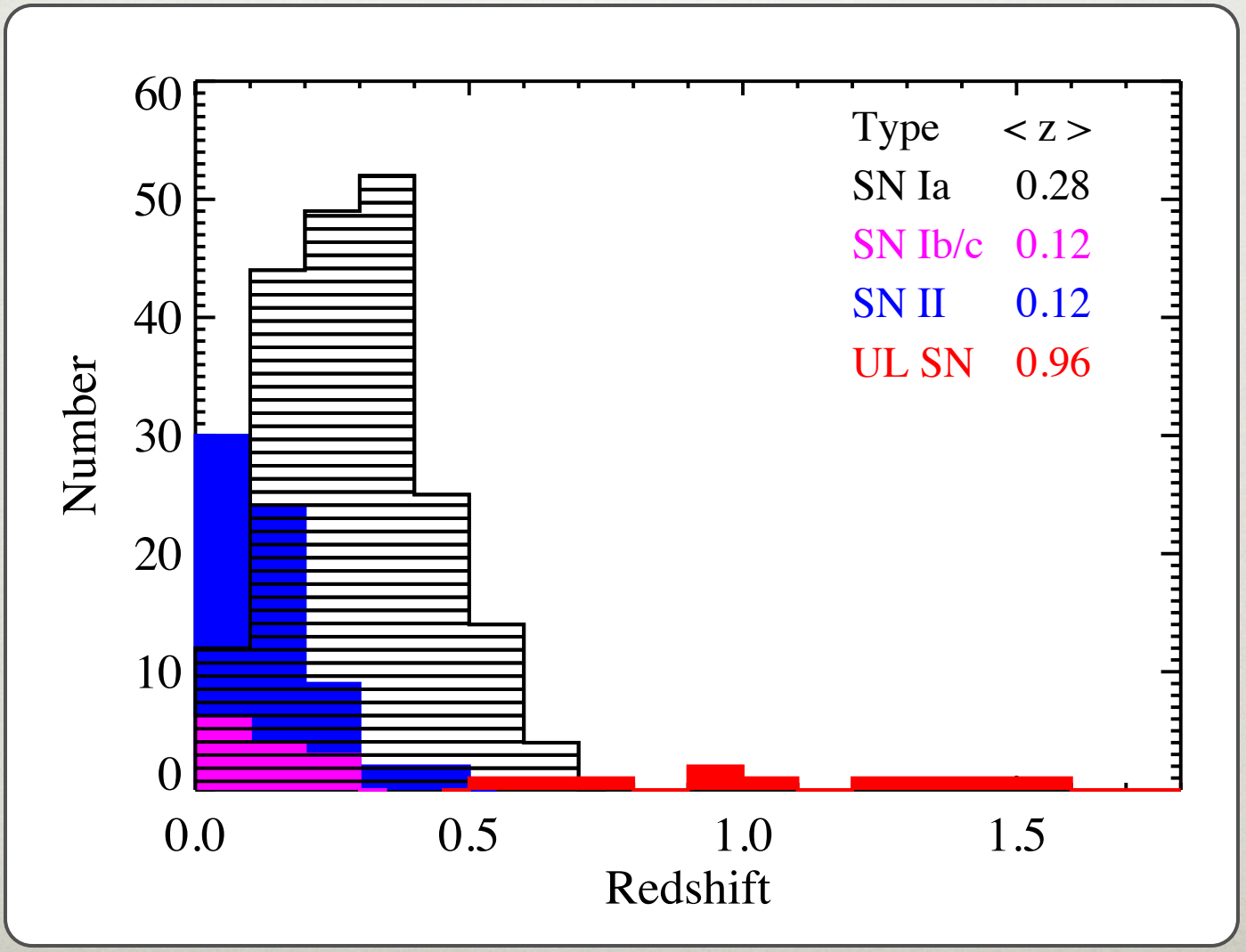
Template Image Difference

- Nightly MDS stacks downloaded from IfA
- Subtractions vs. template images performed using *photpipe*
- Typical limiting mag of ~23.5 AB (in difference images)
- In 2011: 1,450 likely SNe, 160 spectroscopically confirmed

Spectroscopic Followup

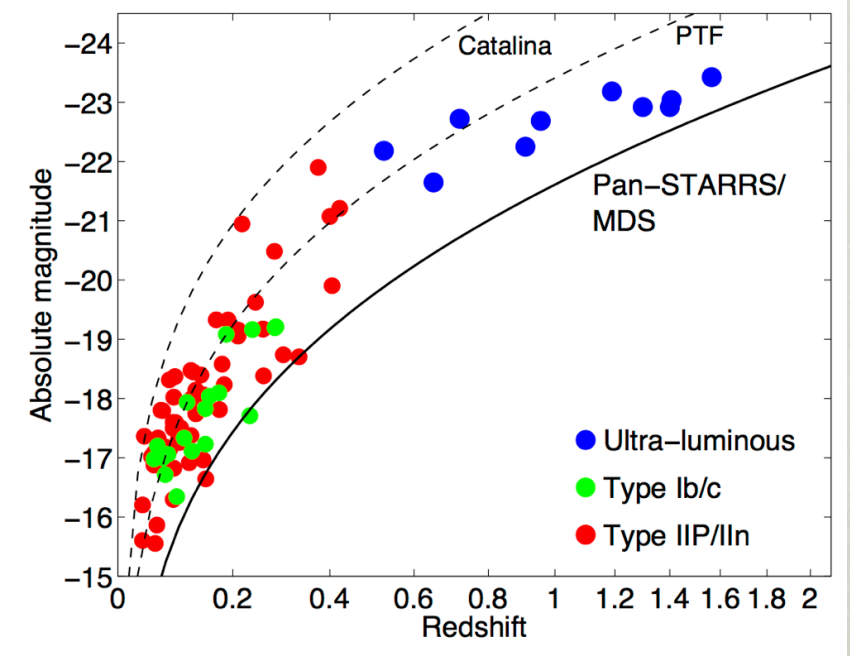
- We're finding ~150 new transients per month
- ~10% spectroscopic completeness (in between PTF and LSST)
- Most spectroscopic followup from MMT / Blue Channel and Hectospec (PI: Berger), also Magellan and Gemini

300 spectroscopically confirmed supernovae so far, mostly SNe Ia



The Advantages of PS1

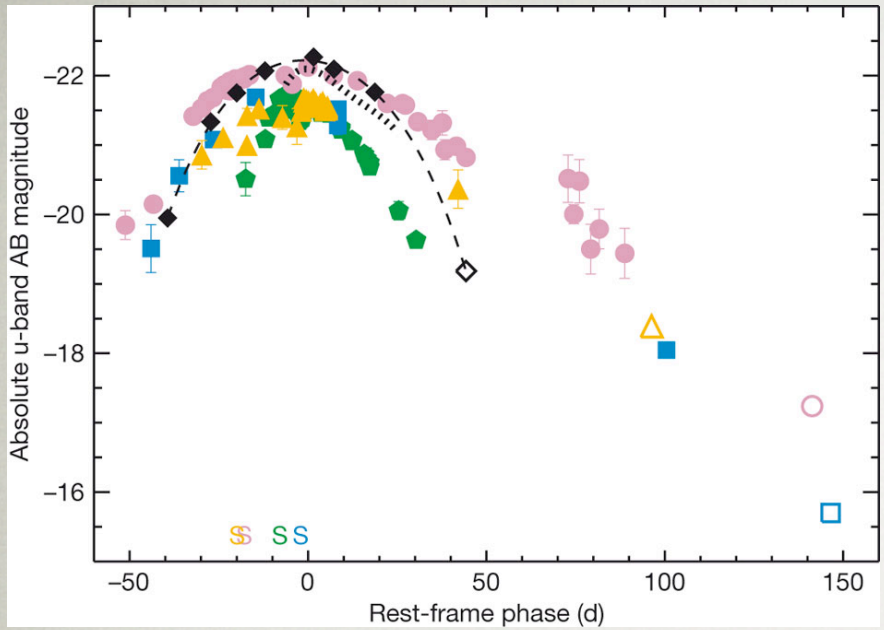
- Deep limits let us push to high redshift
- Observe rest-frame UV
- Multicolor light curves for free
- Find red objects



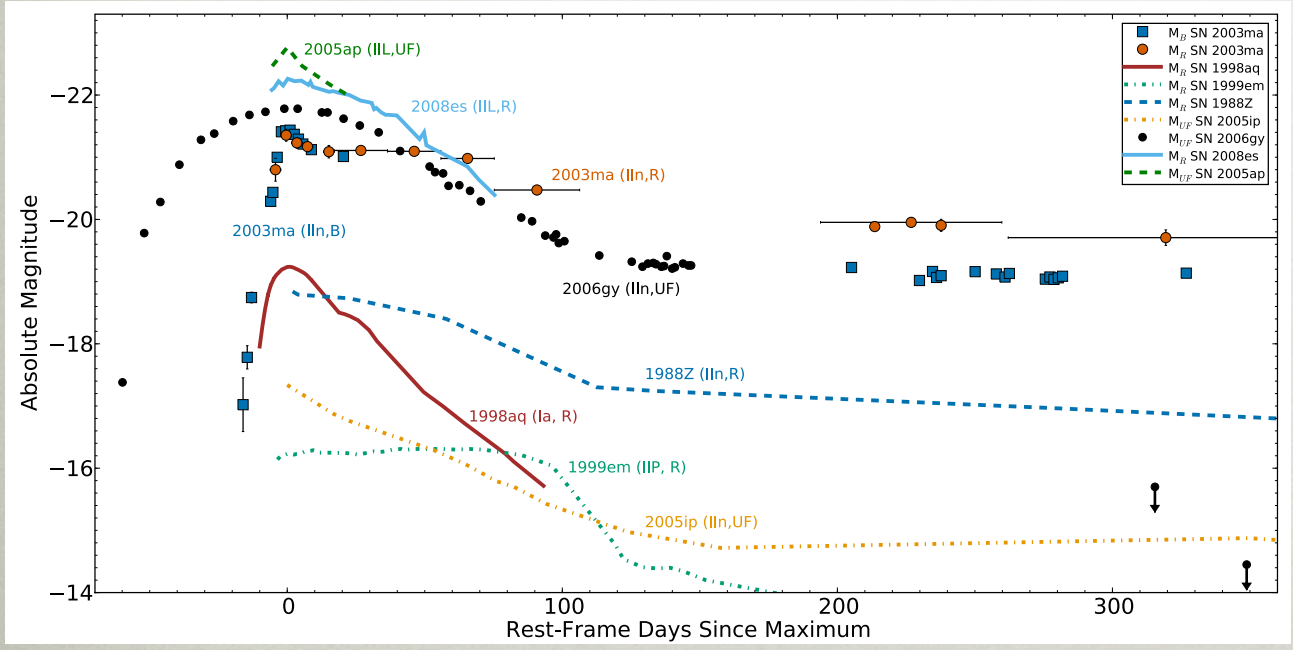
Berger et al., in prep.

Ultraluminous Supernovae

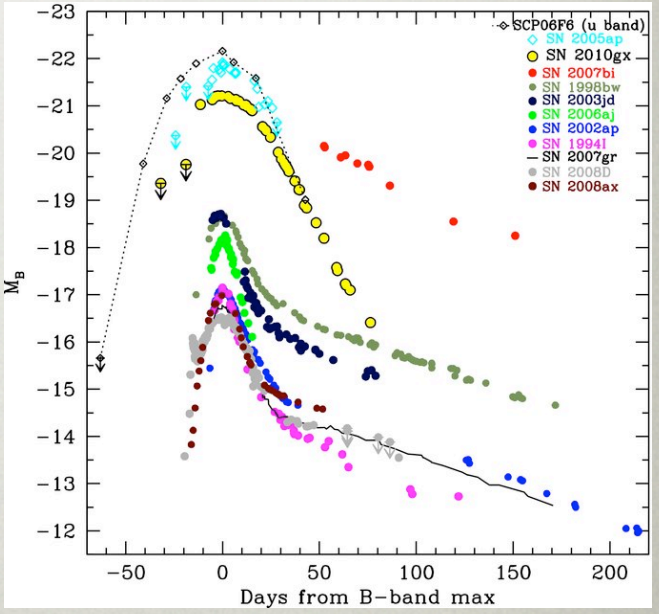
M < -21 mag



Quimby et al. 2011

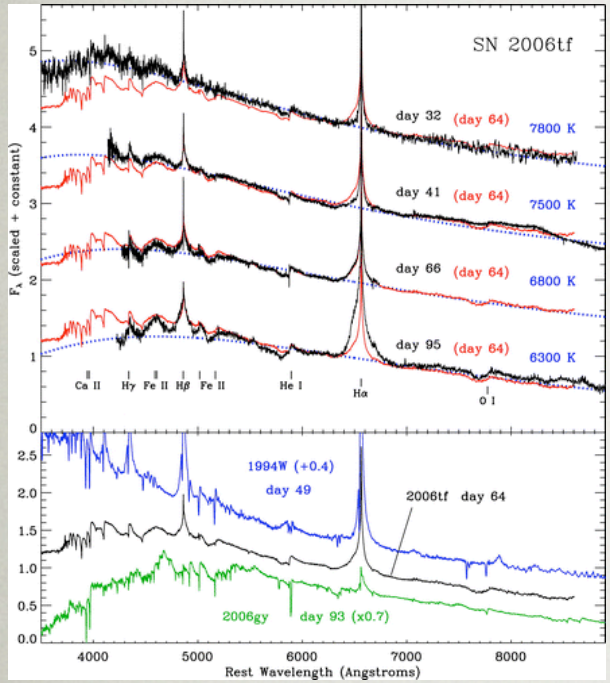


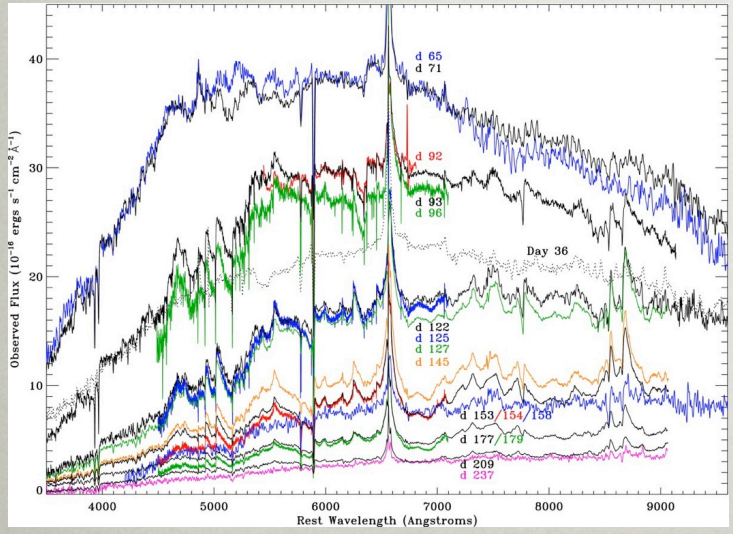
Rest et al. 2009



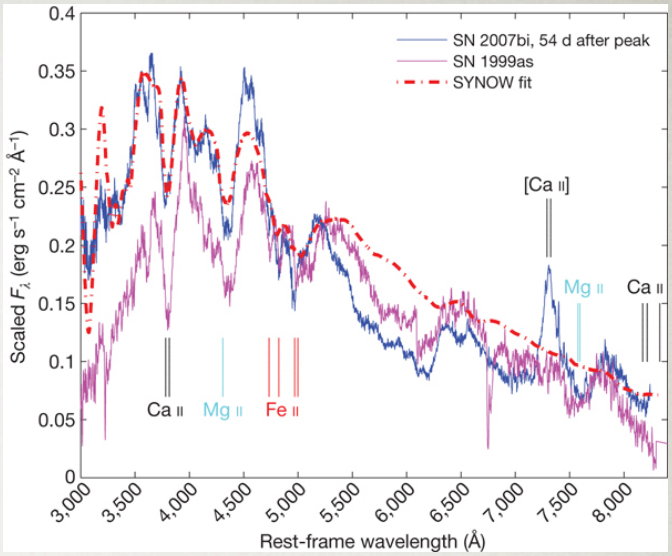
Pastorello et al. 2010

A Diverse Population

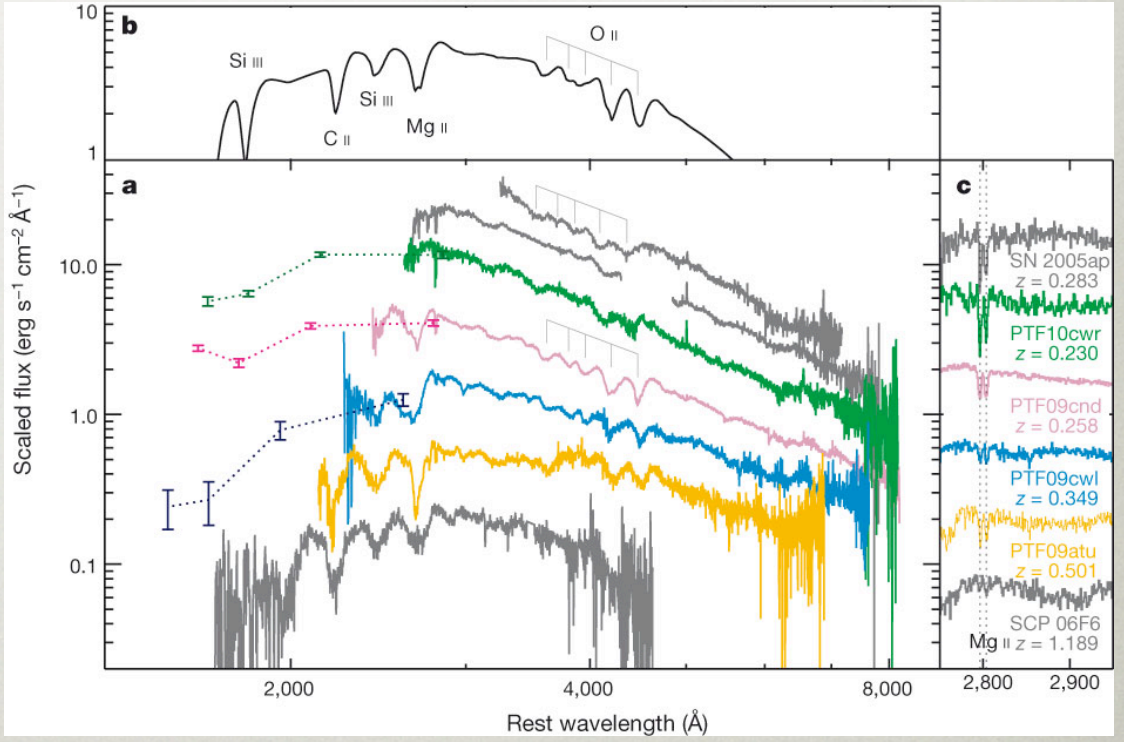




SN 2006tf, 2006gy: Smith et al. 2007,2009,2010



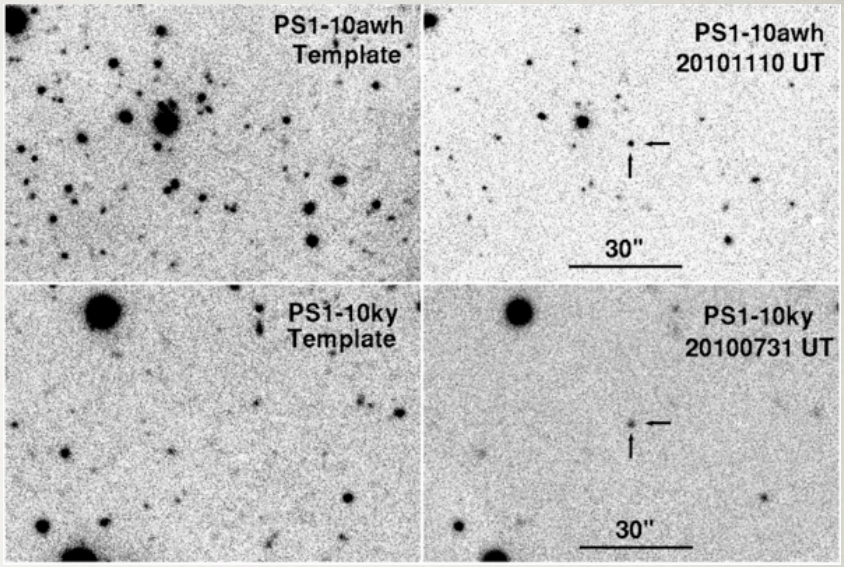
SN 2007bi: Gal-Yam et al. 2009; Young et al. 2009

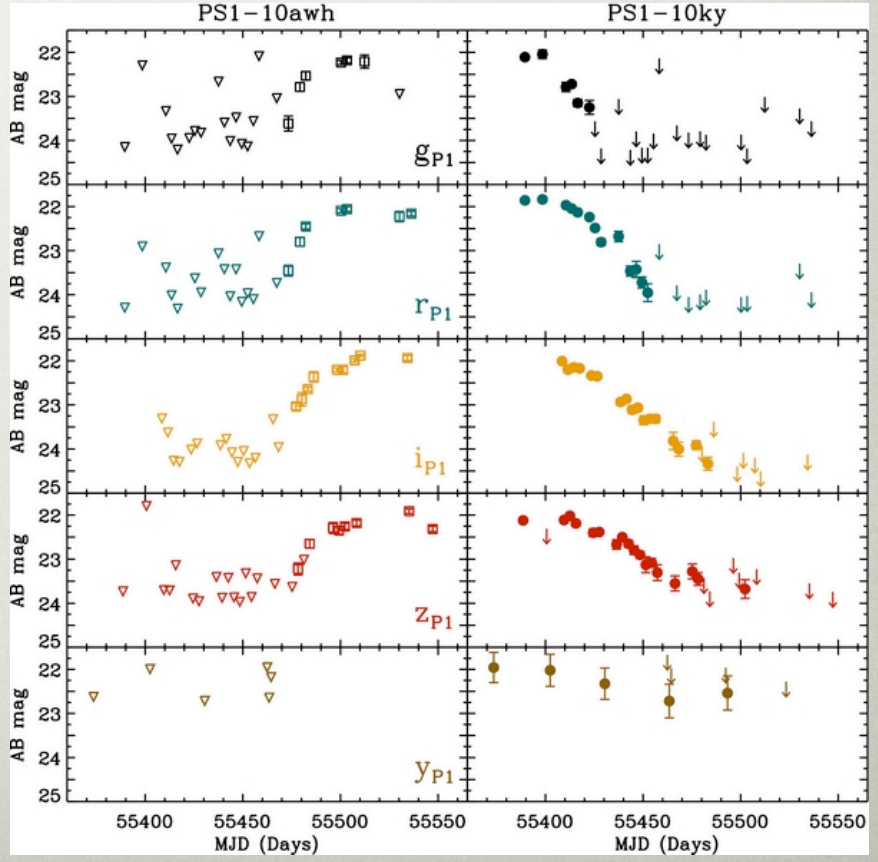


SN 2005ap-like: Quimby et al. 2007, 2011

Our first two UL SNe

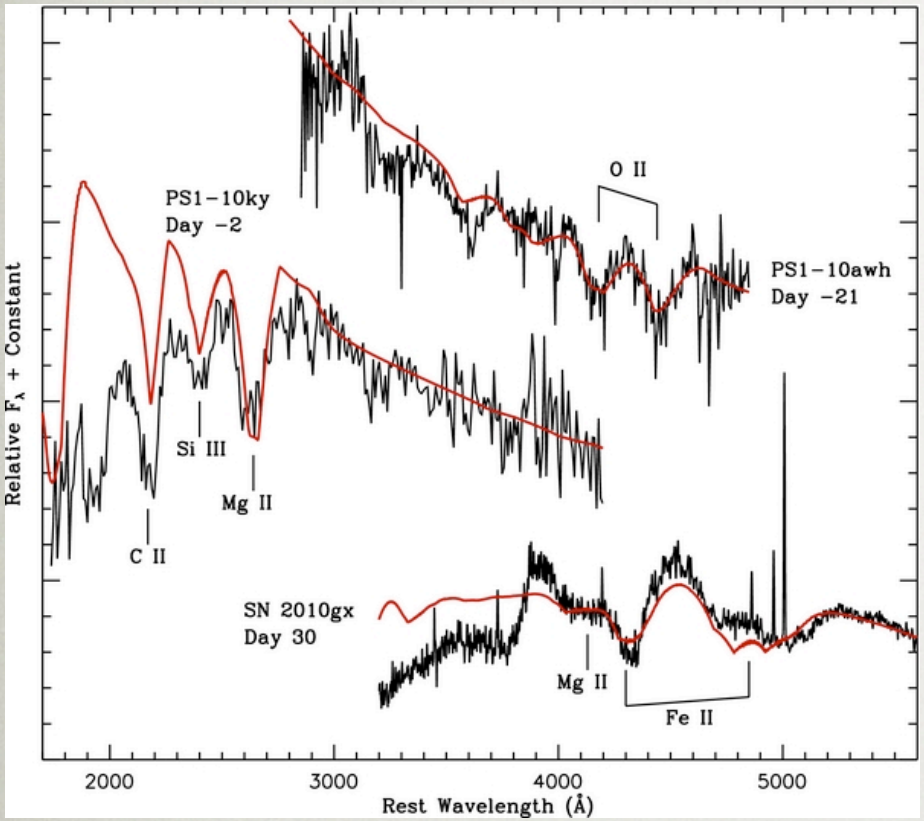
- PS1-10awh (z=0.908)
- PS1-10ky (z=0.956)

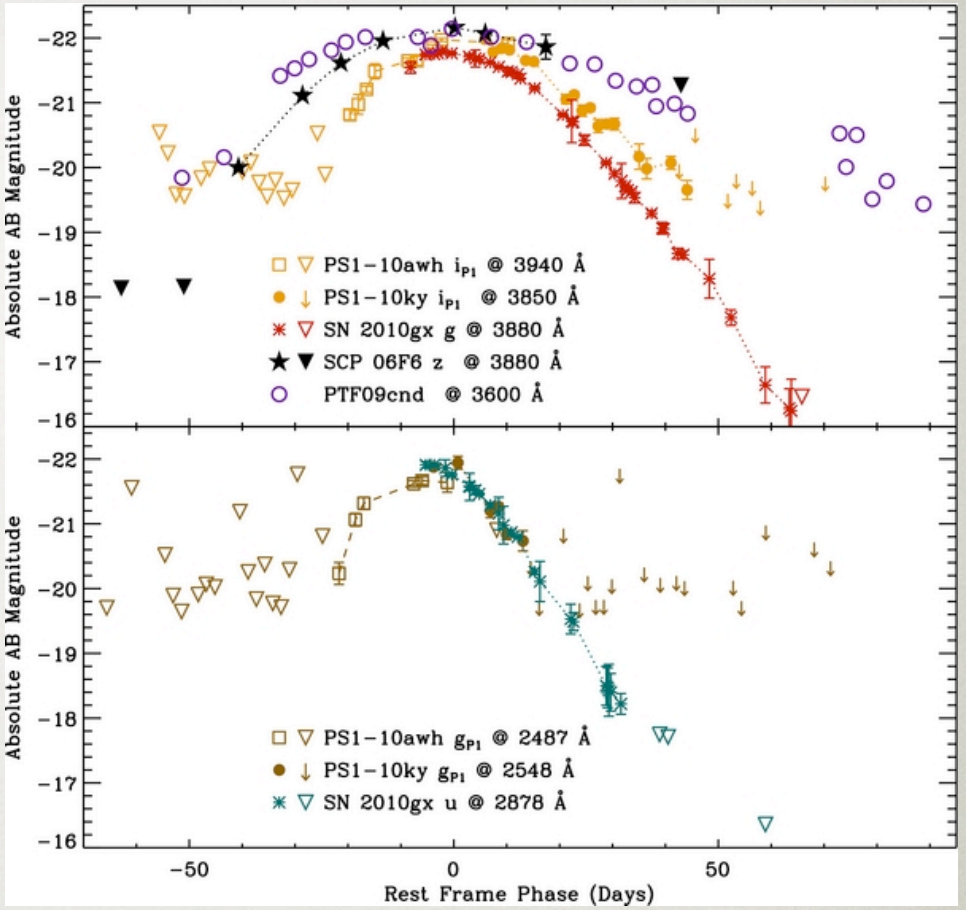




Chomiuk, Chornock, et al., 2011

Chomiuk et al., 2011





- High luminosities (M_{bol} ~ -22.5 mag)
- No H, He in spectra (SN 2005ap-like; Quimby et al. 2011)
- E_{rad} ~ (0.9-1.4) x 10^{51} ergs

What Powers These Objects?

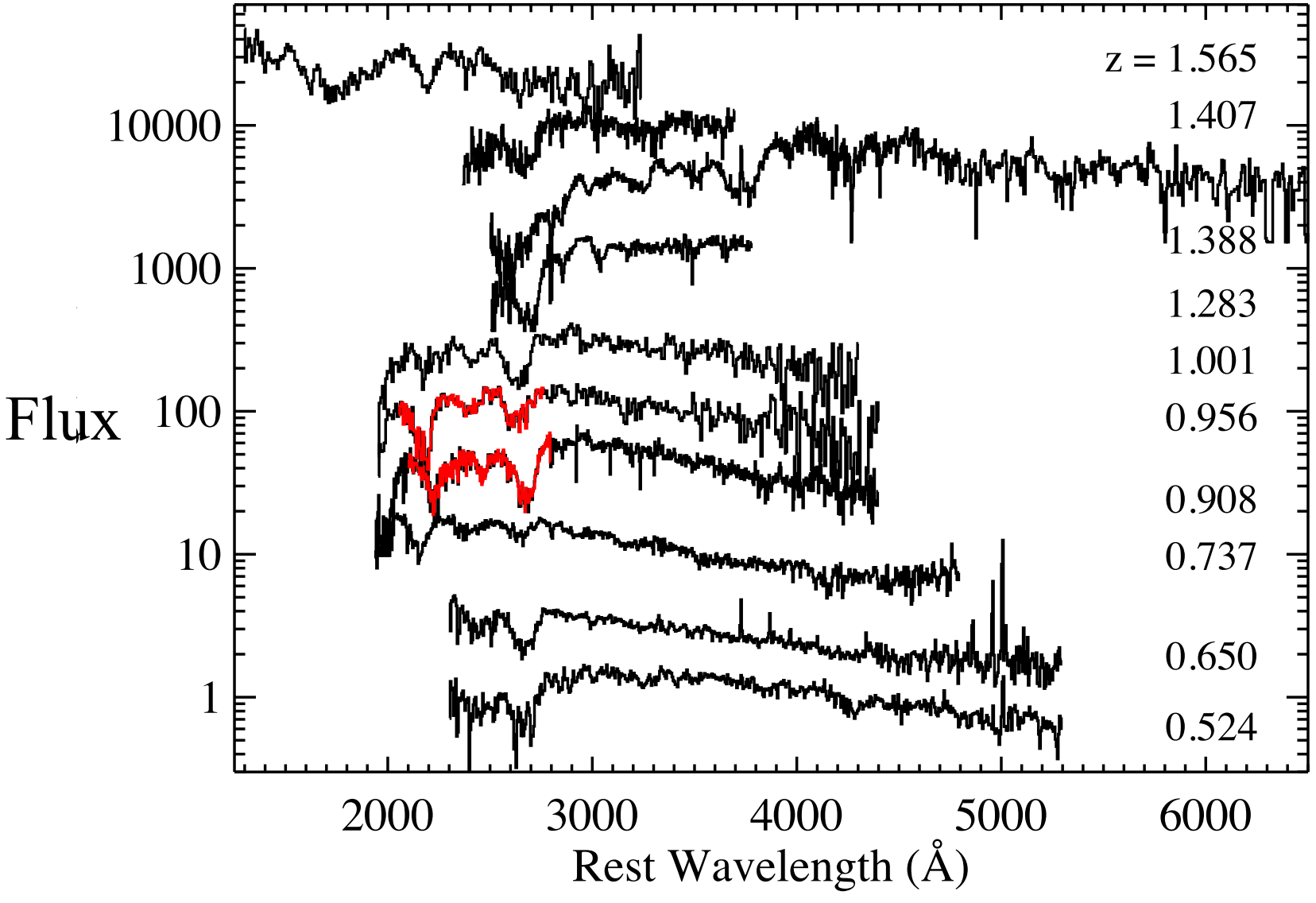
- Radioactive decay? No! Peak luminosity inconsistent with shape of light curve ($M_{ej} < M_{Ni}$)

- Shock breakout through dense CSM? (e.g., Chevalier & Irwin 2011) Requires a circumstellar medium with ~6 $M_\odot$ within 3 x 10^{15} cm.

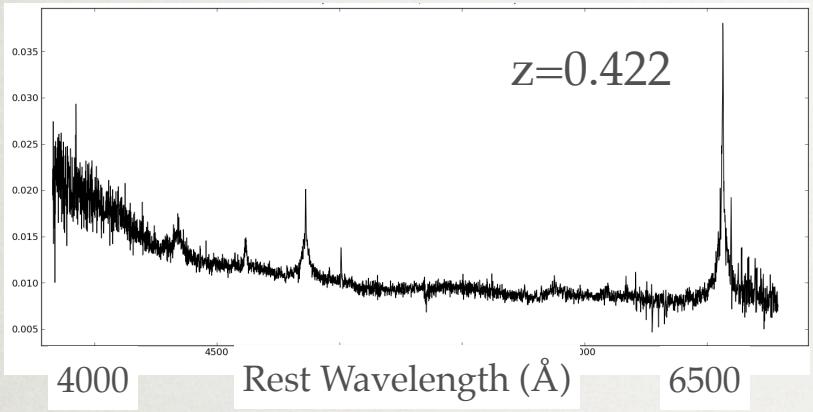
- Magnetar spindown? (Kasen & Bildsten 2010; Woosley 2010) Fit with: B = 3 x 10^{14} G, P = 1.2 ms (near maximal spin), M_{ej} = 5 $M_\odot$

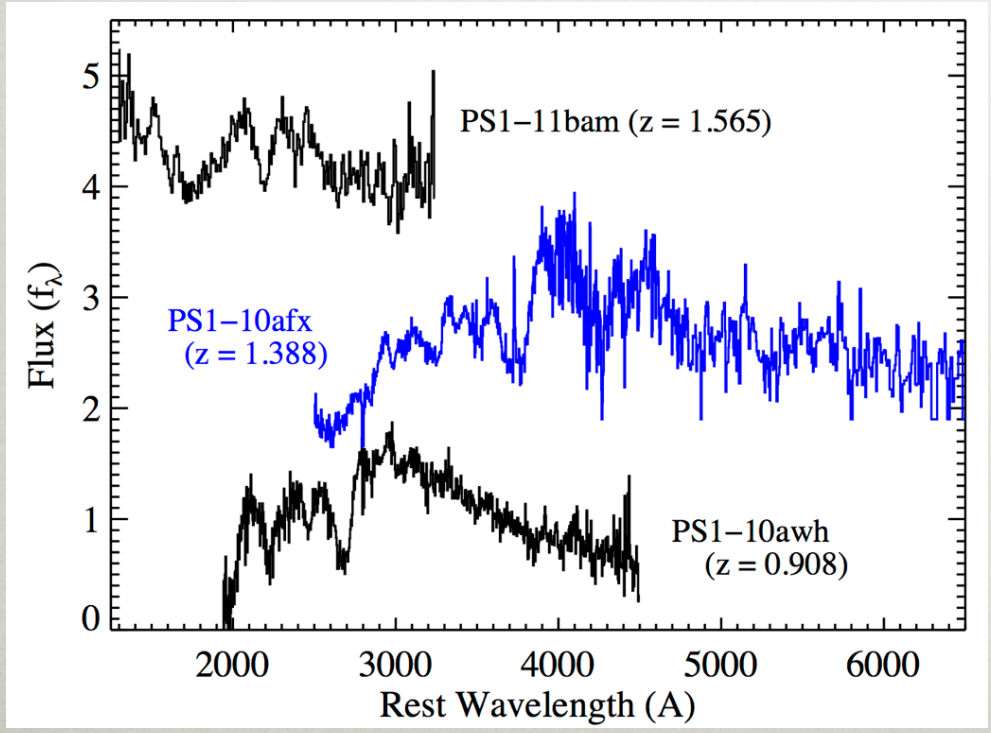
Chomiuk et al., 2011

Building a sample of UL SNe



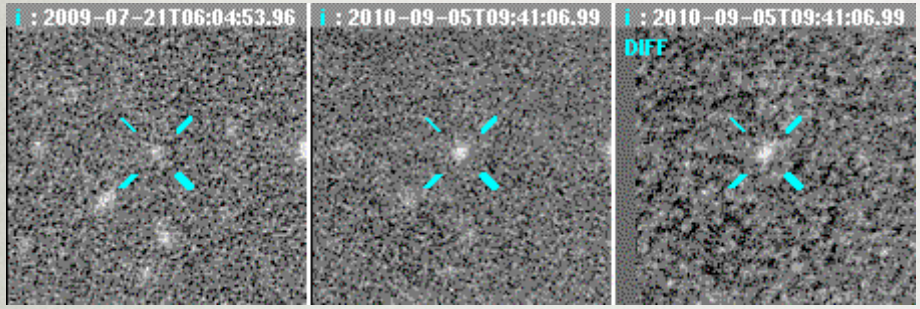
A Diversity of Spectra

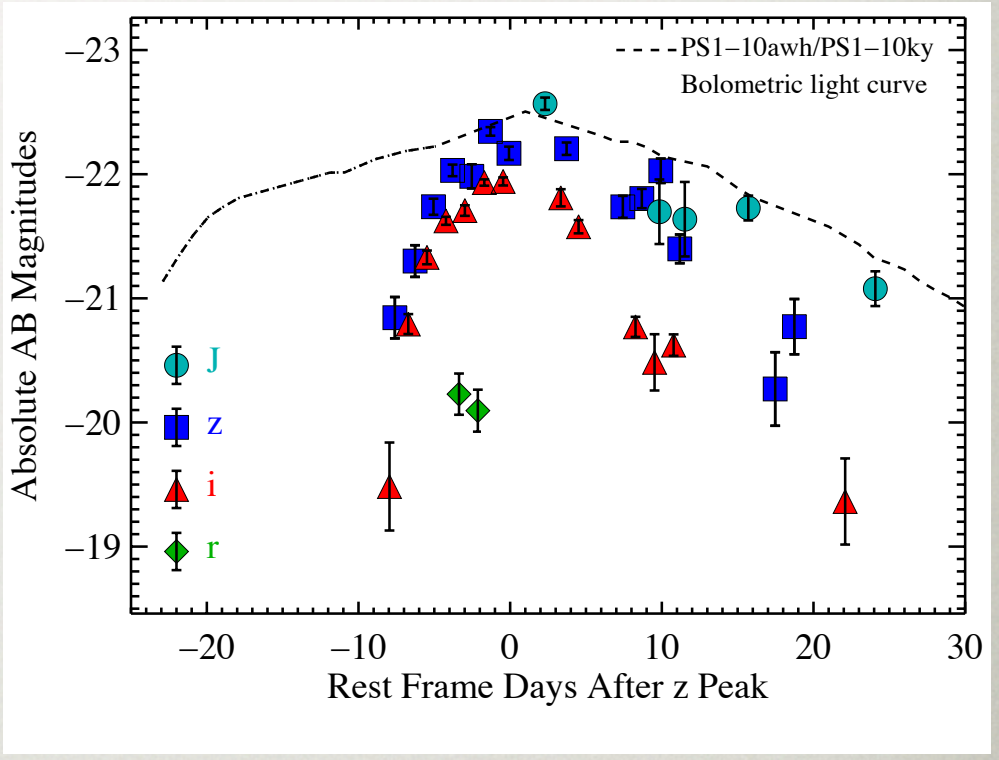




- A few very luminous SNe IIn
- Most at highest luminosities (M<-21.5 mag) are UL SNe Ic

A New, Unique PS1 Discovery



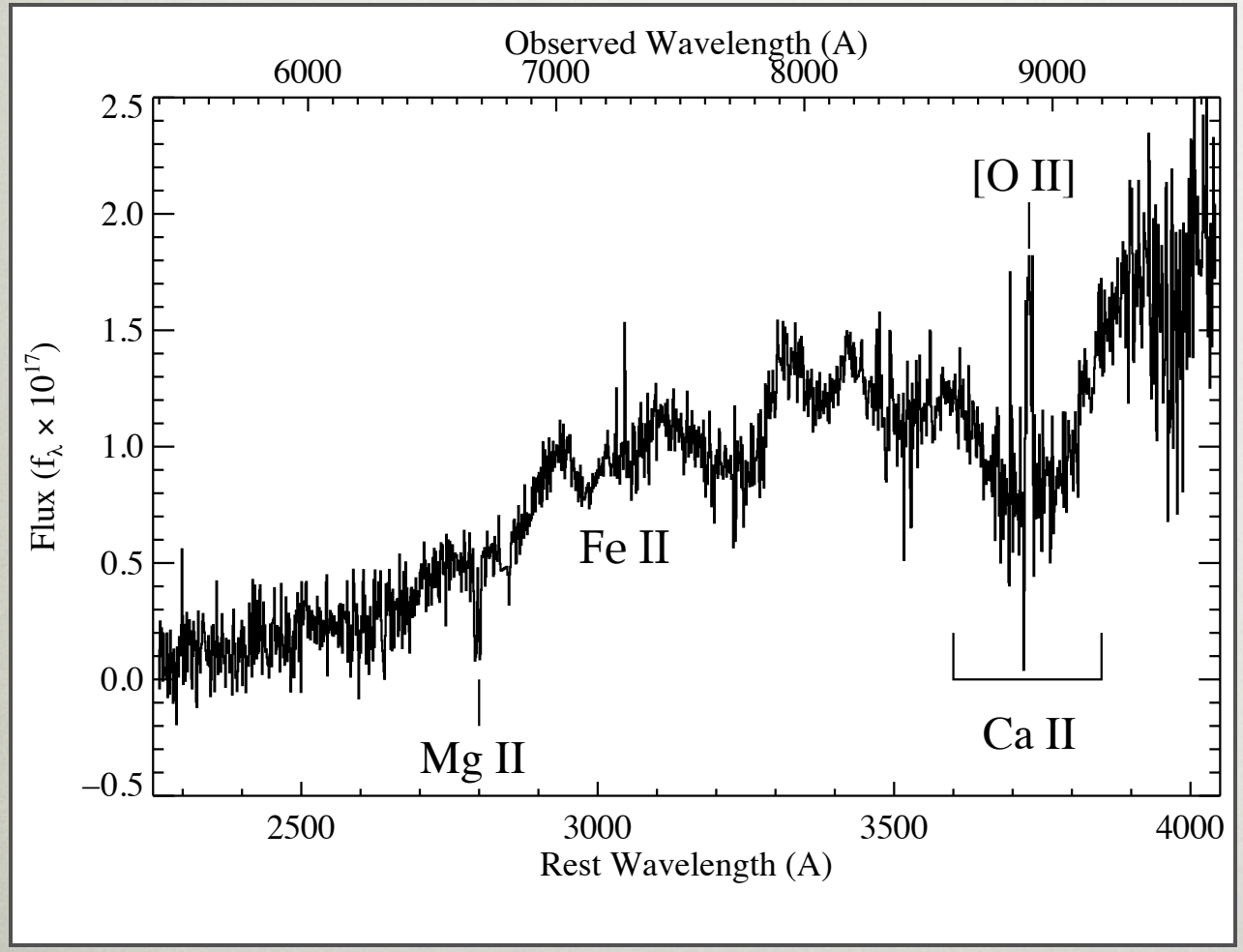


PS1-10afx

Chornock et al., in prep.

- Note red r-i color, fast timescale

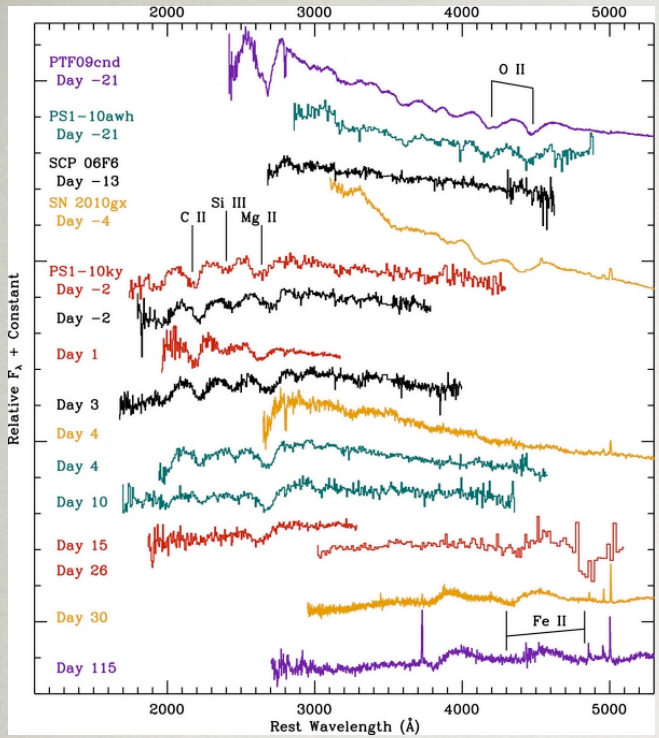
A High-Redshift SN



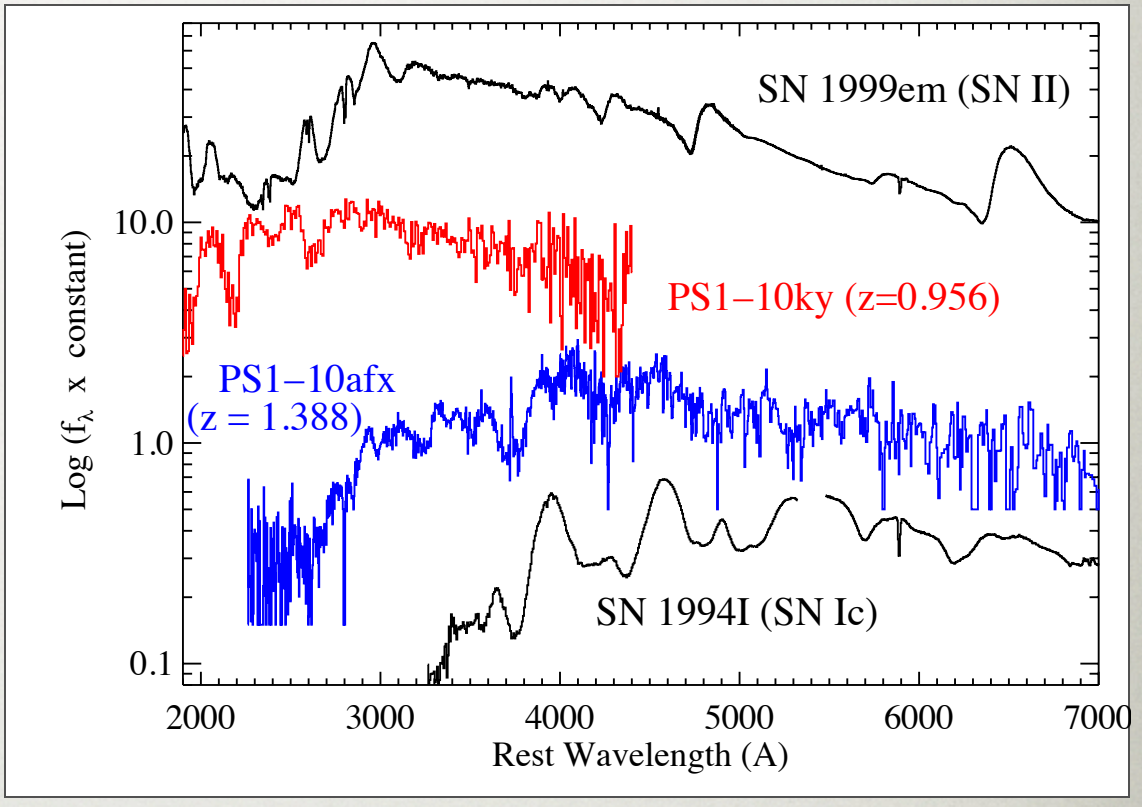
- z=1.388
- z_{peak}=21.6 (AB)
- m-M=45.0

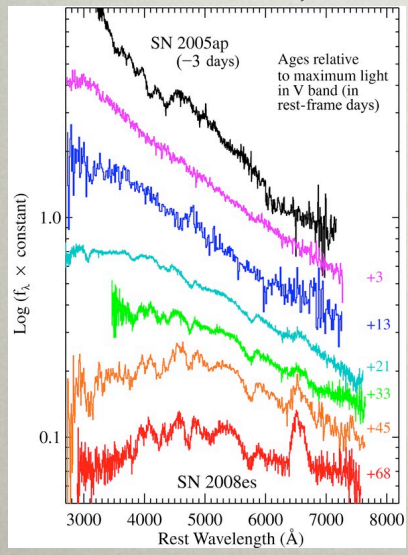
For comparison:
HST04Sas at z=1.39
peaked at M_{850LP} ~ 24.75 (Vega)
(Riess et al. 2007)

Unique spectrum



SN 2005ap-like objects: Quimby et al. 2007,2011; Barbary et al. 2008; Pastorello et al. 2010; Chomiuk et al., 2011



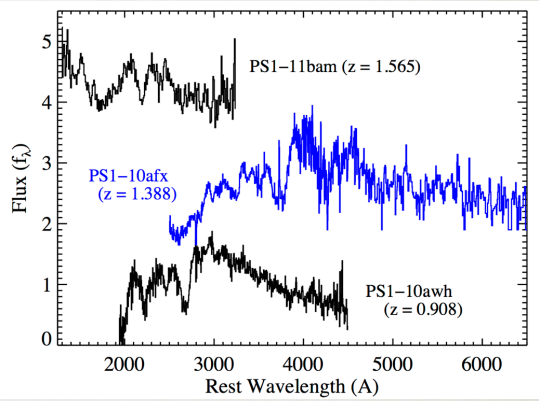


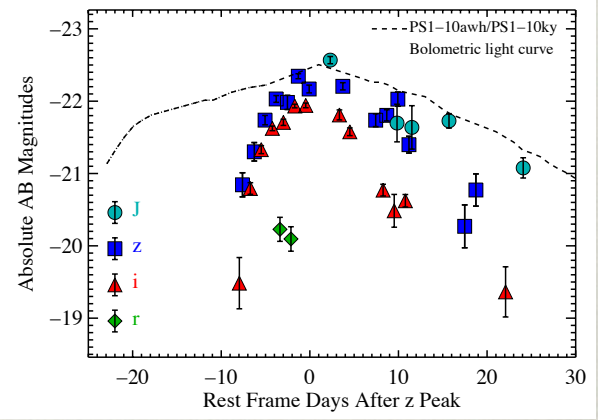
SN 2008es: Miller et al. 2009; Gezari et al. 2009

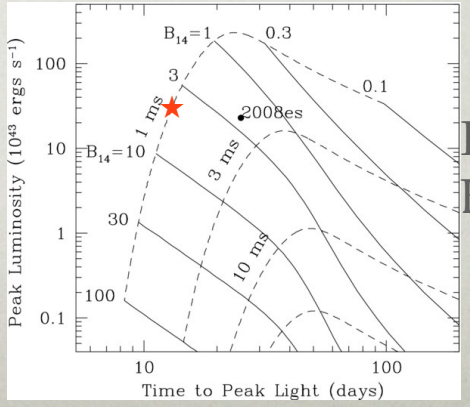
Other ULSNe are bluer, lack Ca II H&K P-Cygni at early times (or have H)

What Powers These Objects?

- Radioactive decay? No! Peak luminosity inconsistent with shape of light curve ($M_{ej} < M_{Ni}$)
- Shock breakout through dense CSM? (e.g., Chevalier & Irwin 2011) Can interaction produce spectra with P-Cygni absorption profiles like those observed?
- Magnetar spindown? PS1-10afx rises too fast for its peak luminosity (M ~ -22.5 mag)





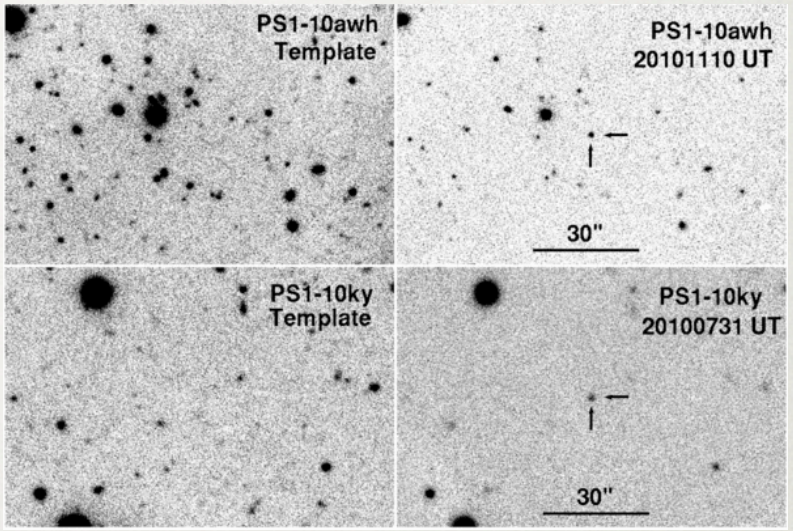


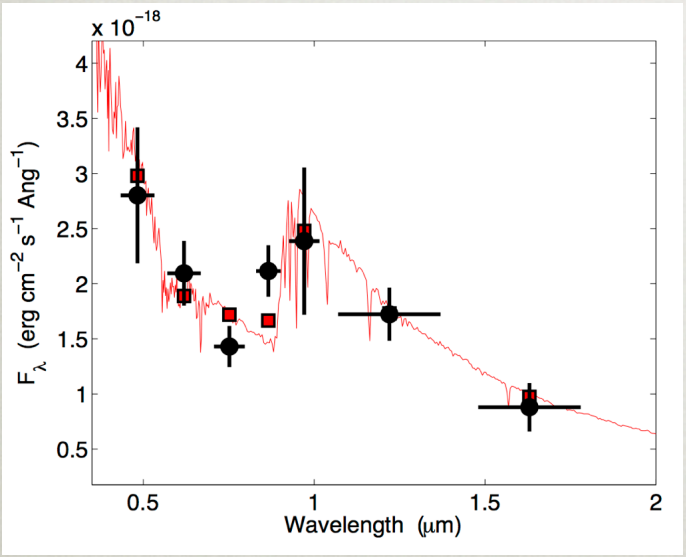
Kasen & Bildsten 2010

A Variety of Hosts

Hosts of PS1-10ky and PS1-10awh:

- $M_B \gtrsim -18.4$ mag and
  $M_B \gtrsim -19.4$ mag
- SFR $\lesssim 1\ M_\odot/yr$





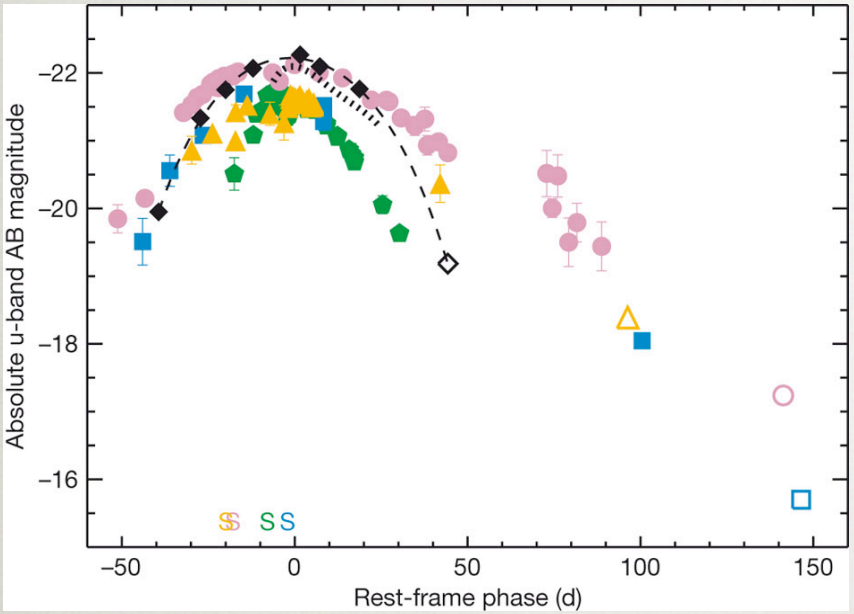
Host of PS1-10afx at z=1.388:

- K = 19.5 mag (Vega)
- Using Maraston models:

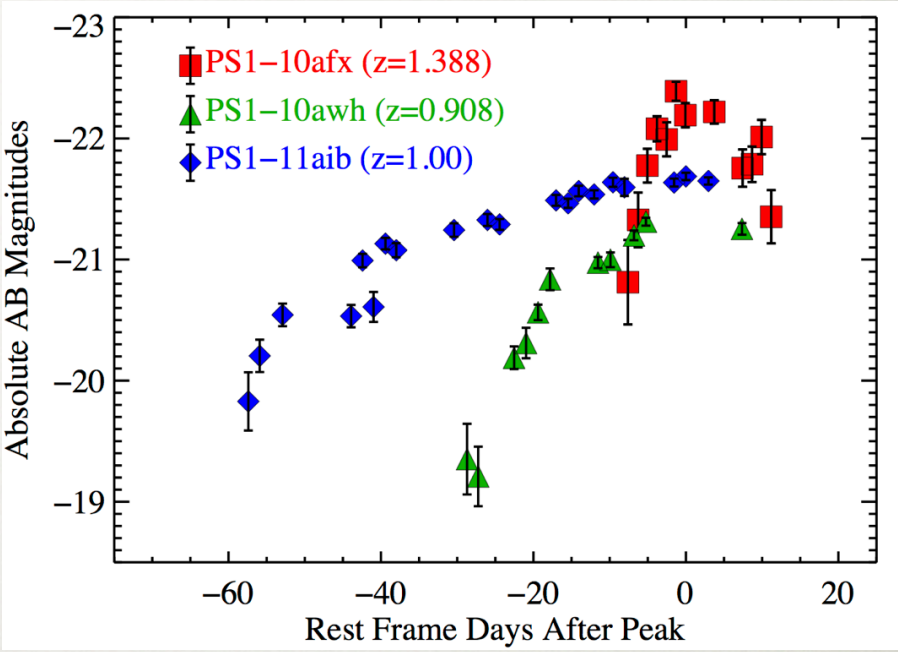
  Age=0.1 Gyr

  $M_\star = 2.1 \times 10^{10}\ M_\odot$

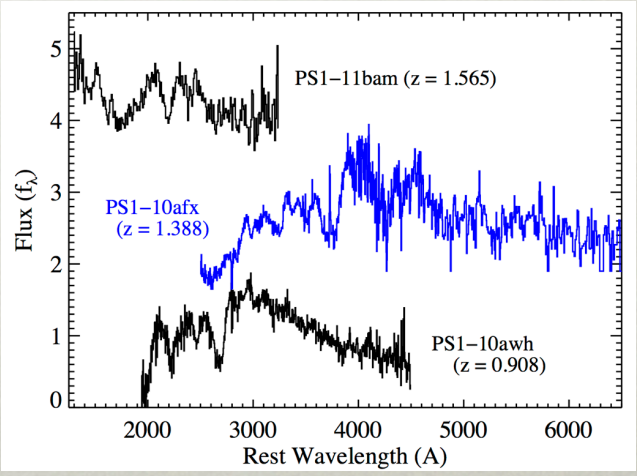
A Variety of Light Curves



Quimby et al. 2011



Light curves near 3600-3900 Å

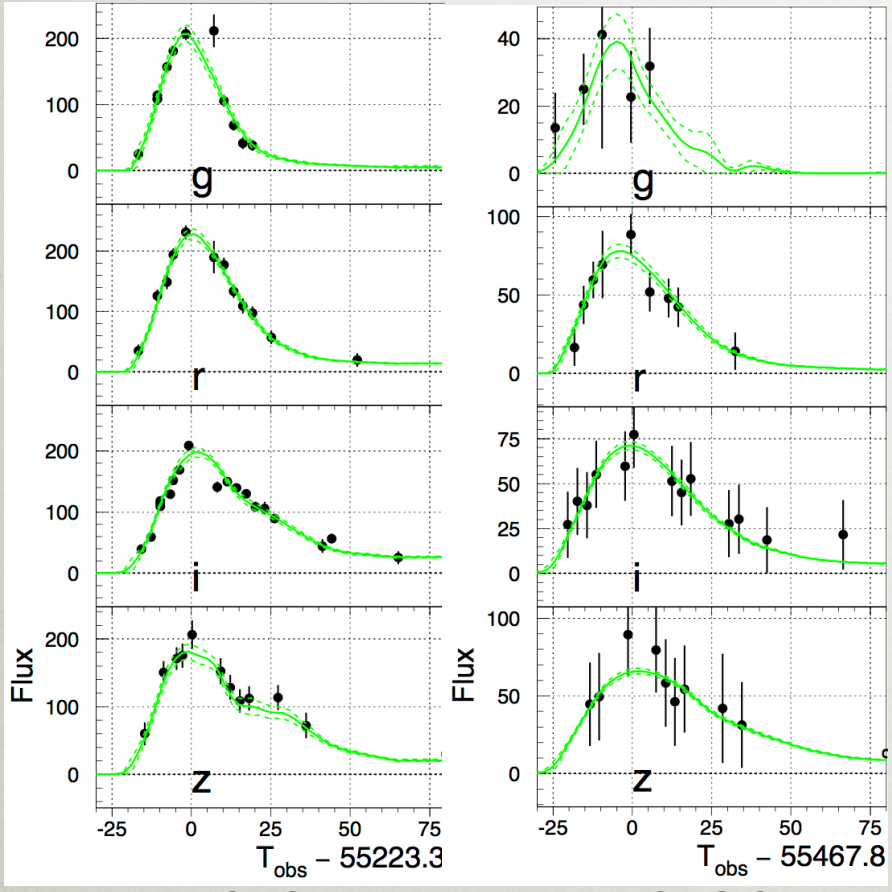


Summary

- Pan-STARRS1 has been in full operation for almost 2 years
- ~150 transients/month in MDS
- We are finding an UL SN about once a month
- These objects exhibit a diversity of properties, but some sort of CSM interaction may be best explanation

PS1 SNe Ia

Calibration uncertainties dominate cosmology!
PS1 can do z=0-0.7 with one well-understood photometric system

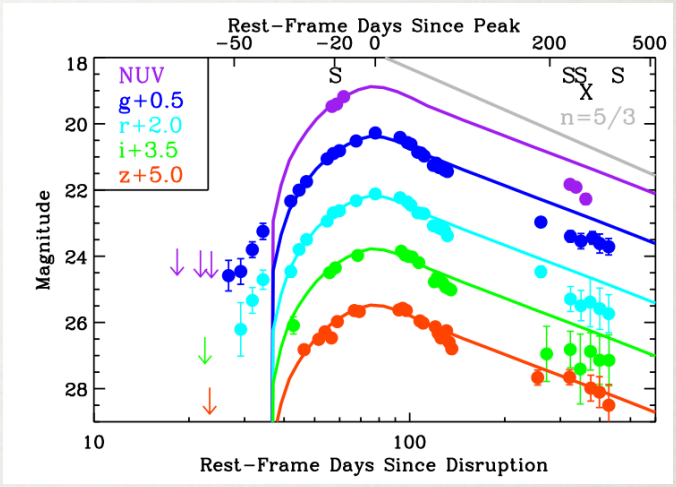


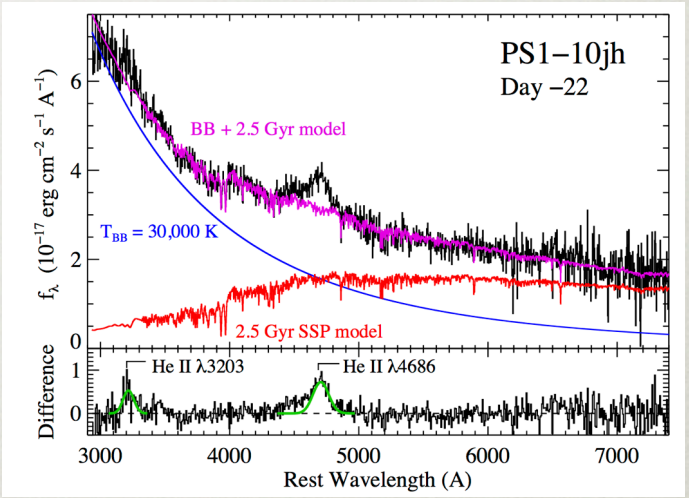
z=0.31 **z=0.635**

Rest, Scolnic, et al., in prep.

TDEs

PS1 + GALEX discovery of a tidal disruption event in an early-type galaxy





Gezari, Chornock, Rest, et al. *Nature*, in press