The Palomar Transient Factory and Implications for IceCube

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WEIZMANN INSTITUTE OF SCIENCE
מכון ויצמן למדע

Talk Layout

- PTF goals/overview
- Capabilities and products
- Highlights
- Implications for IceCube
- The future:
  - ZTF
  - ULTRASAT

PTF collaboration

Law et al. 2009, Rau et al. 2009

PI: S. R. Kulkarni

Caltech, LCOGT, Berkeley, LBL, IPAC, Columbia, Oxford, Weizmann

PTF system overview

- 48" Oschin Schmidt camera (Palomar obs.)
- 7.26 deg^2 FOV (92 Mpix)

PTF system overview

- 48" Oschin Schmidt camera (Palomar obs.)
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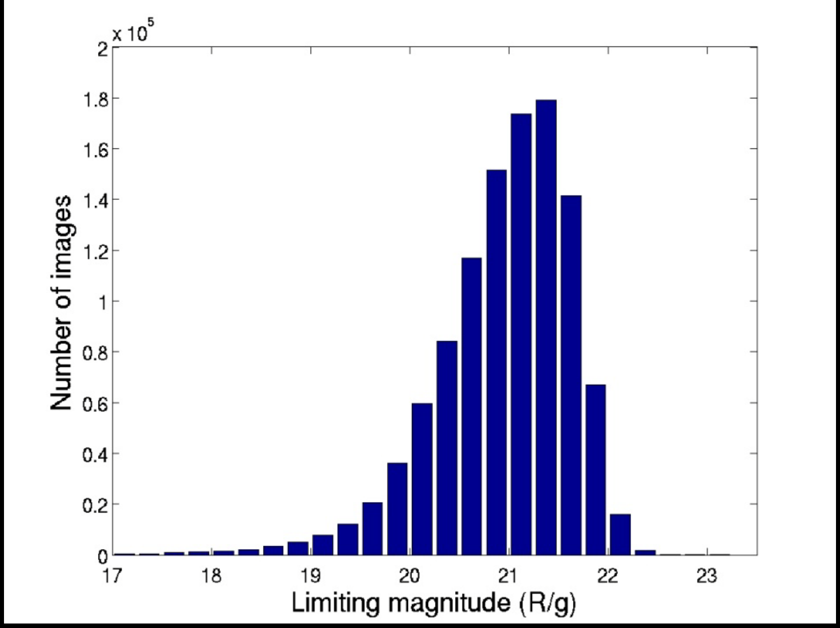
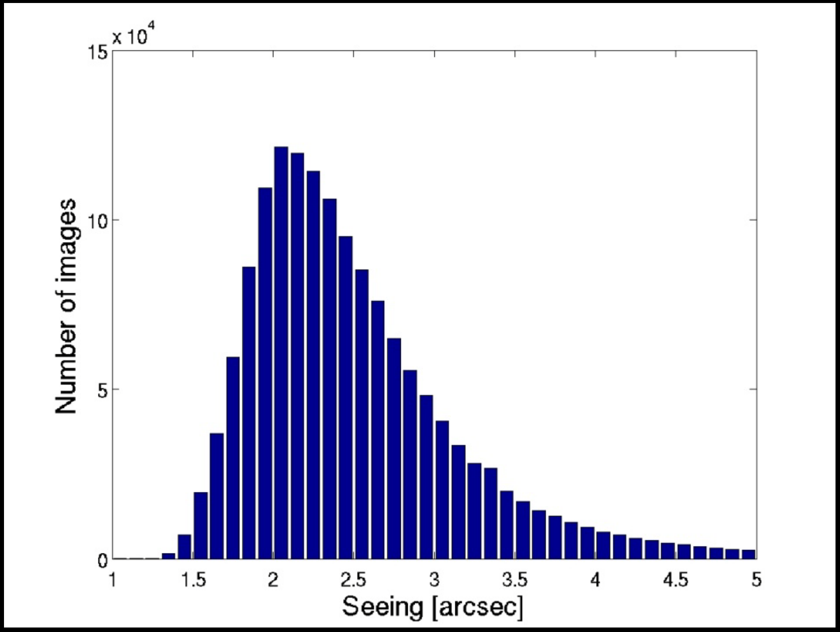
- Scale: 1"/pix, lim. mag ~21





PTF system overview

- 48" Oschin Schmidt camera (Palomar obs.)
- 7.26 deg^2 FOV (92 Mpix)
- Scale: 1"/pix, lim. mag ~21
- Robotic telescope & scheduler
  - Full automatic operation
  - Auto. Selection of science targets

PTF system overview

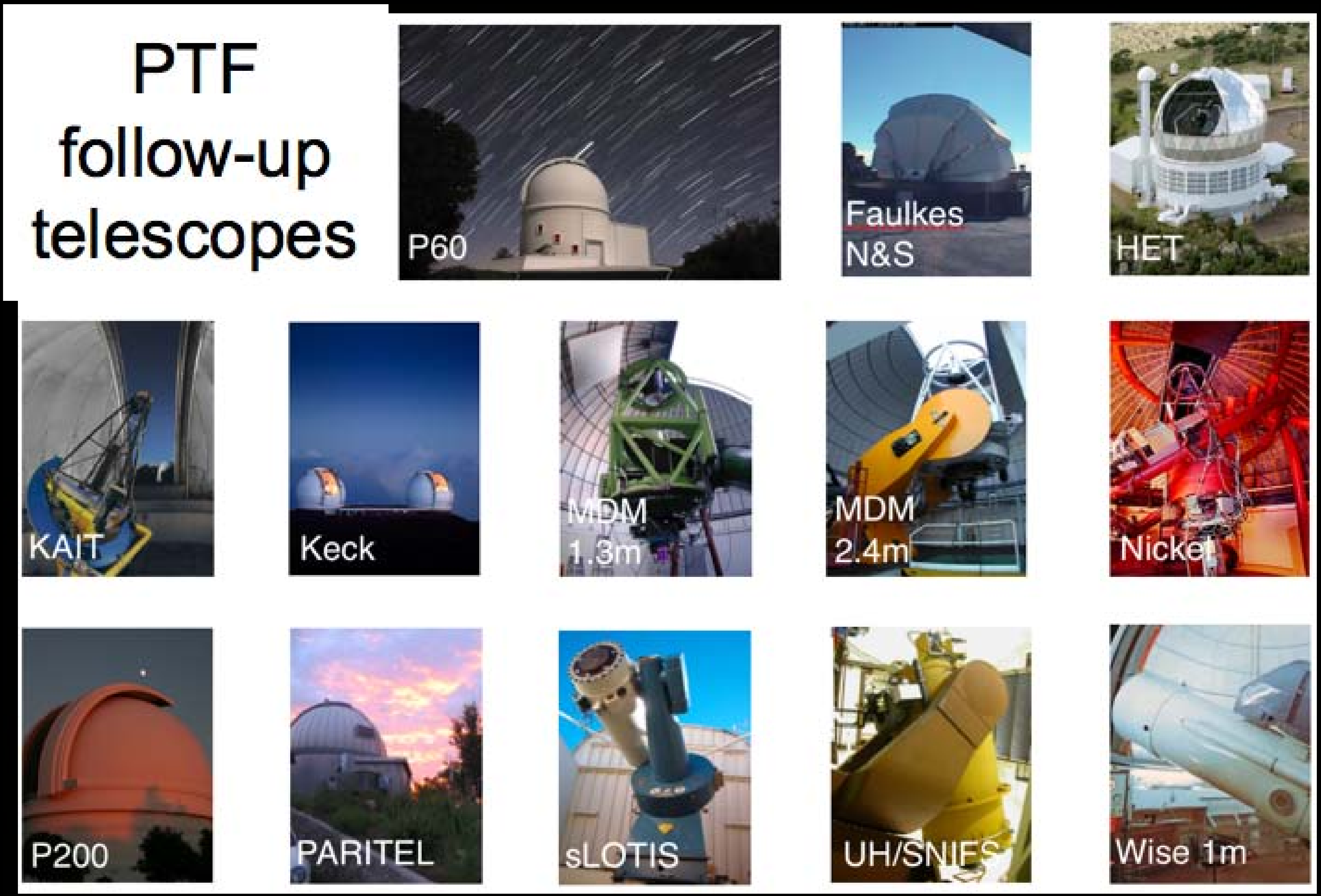
- 60s exposure + 35s readout
  ~500,000 deg^2 yr^{-1}
- Filters: g, R, Hα+
- Real time image Subtraction and Transient classification

PTF observing strategy

Observing strategy
CHANGES ALL THE TIME

- 70% : 1-3 day cadence (flexible)
- 10% : All sky Hα survey
- 20% : Galactic science

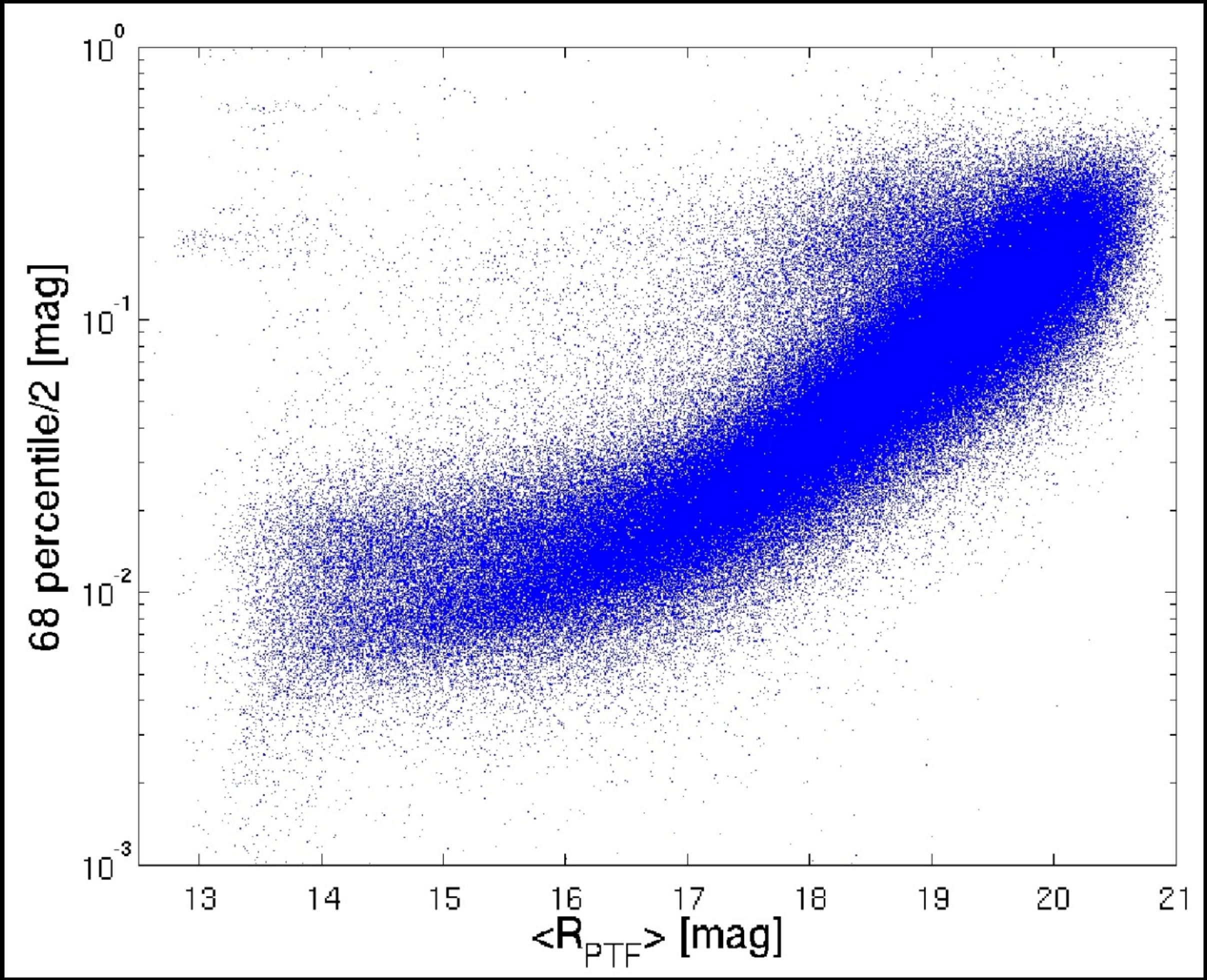
PTF followup



Calibrated photometry

Ofek et al. 2012a,b

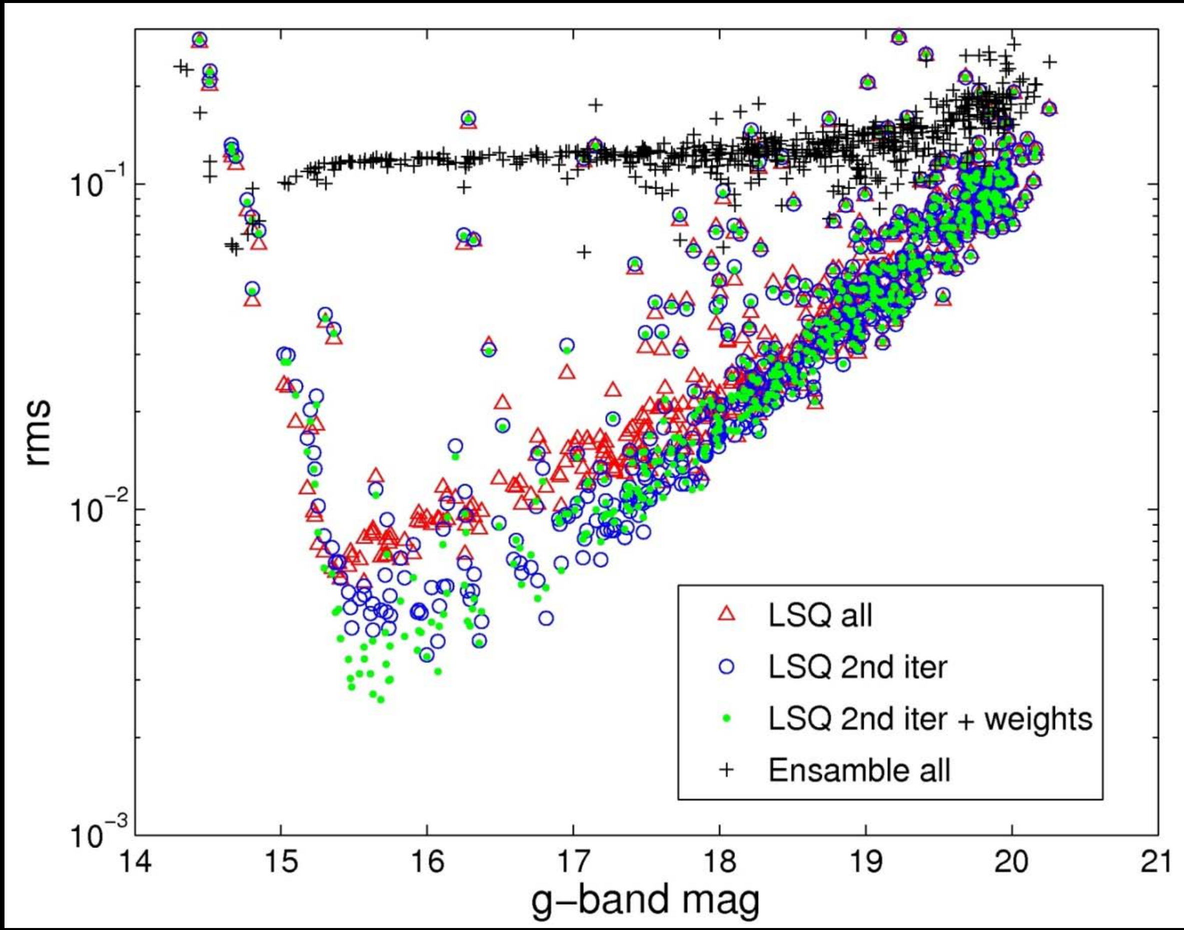
- Photometry calibration good to 2-3%



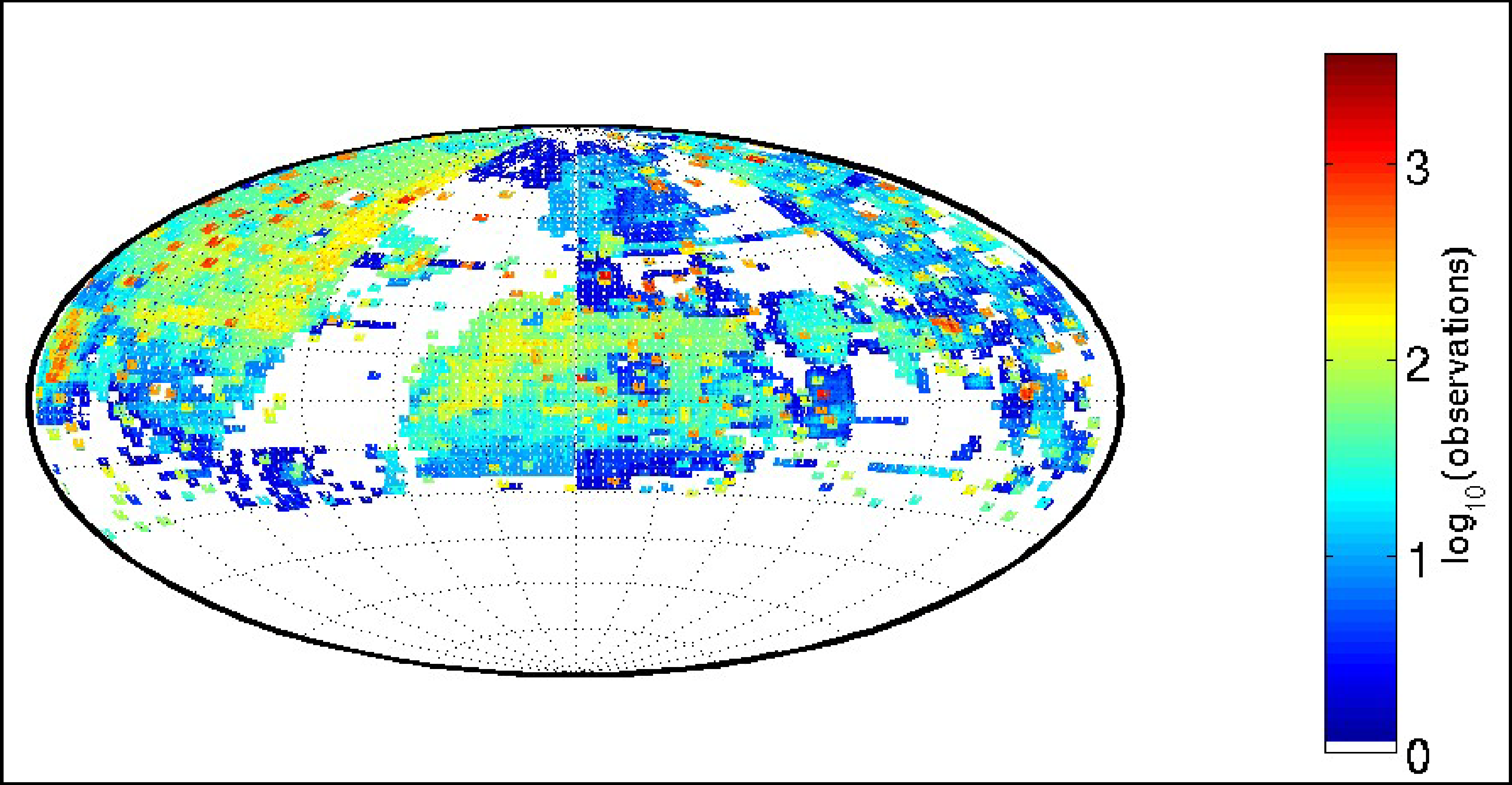
Relative photometry

Method presented in: Ofek et al. 2011 ApJ 740, 65

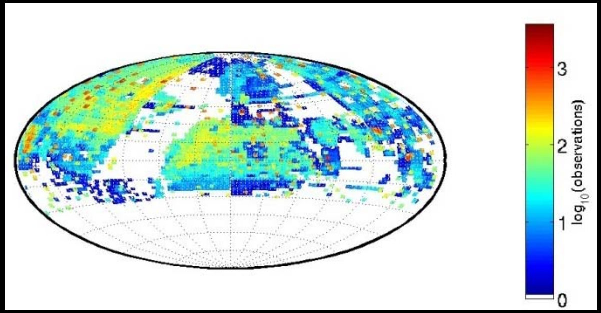
- Relative photometry ~3-5mmag



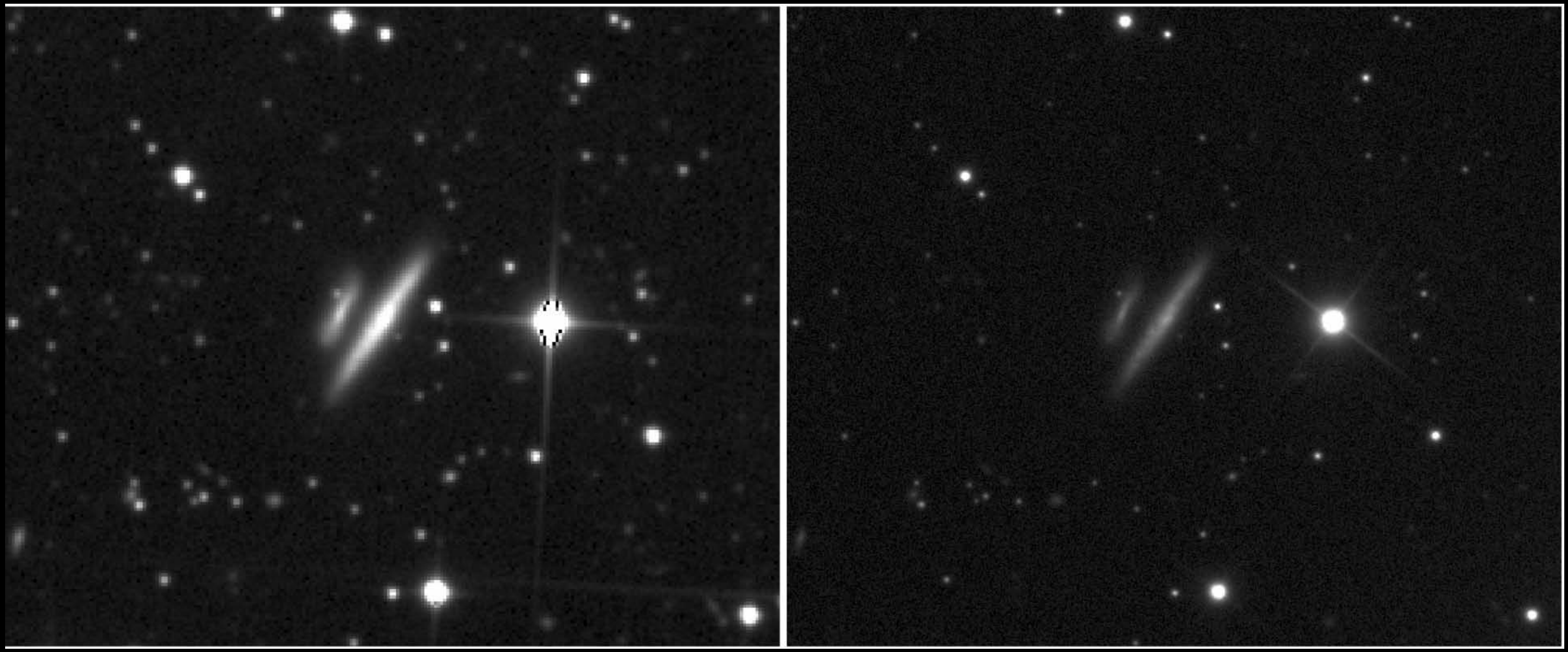
What did we observe so far?



Deep coadd



- Deep sky:
  ~10 images lim. mag. ~22.3
  ~100 images lim. mag. ~23.5



PTF Science highlights
Galactic

- ~200 dwarf novae; 7 AM CVn — Groot et al., in prep.; Levitan et al. 2011; Levitan et al. 2013
- Asteroids rotation — Polishook et al. 2012
- Protostellar objects — Covey et al. 2011; Miller et al. 2011

PTF Science highlights
Extragalactic

- Since March 2009:
  - >10,000 transient candidates
  - 1861 spectroscopically confirmed SNe
    - 1256 Ia
    - 89 Ibc
    - 445 II
- ~3% of these "SNe" are weird and hard to classify into existing scheme:
  e.g., faint and fast, Ca rich, luminous, etc.

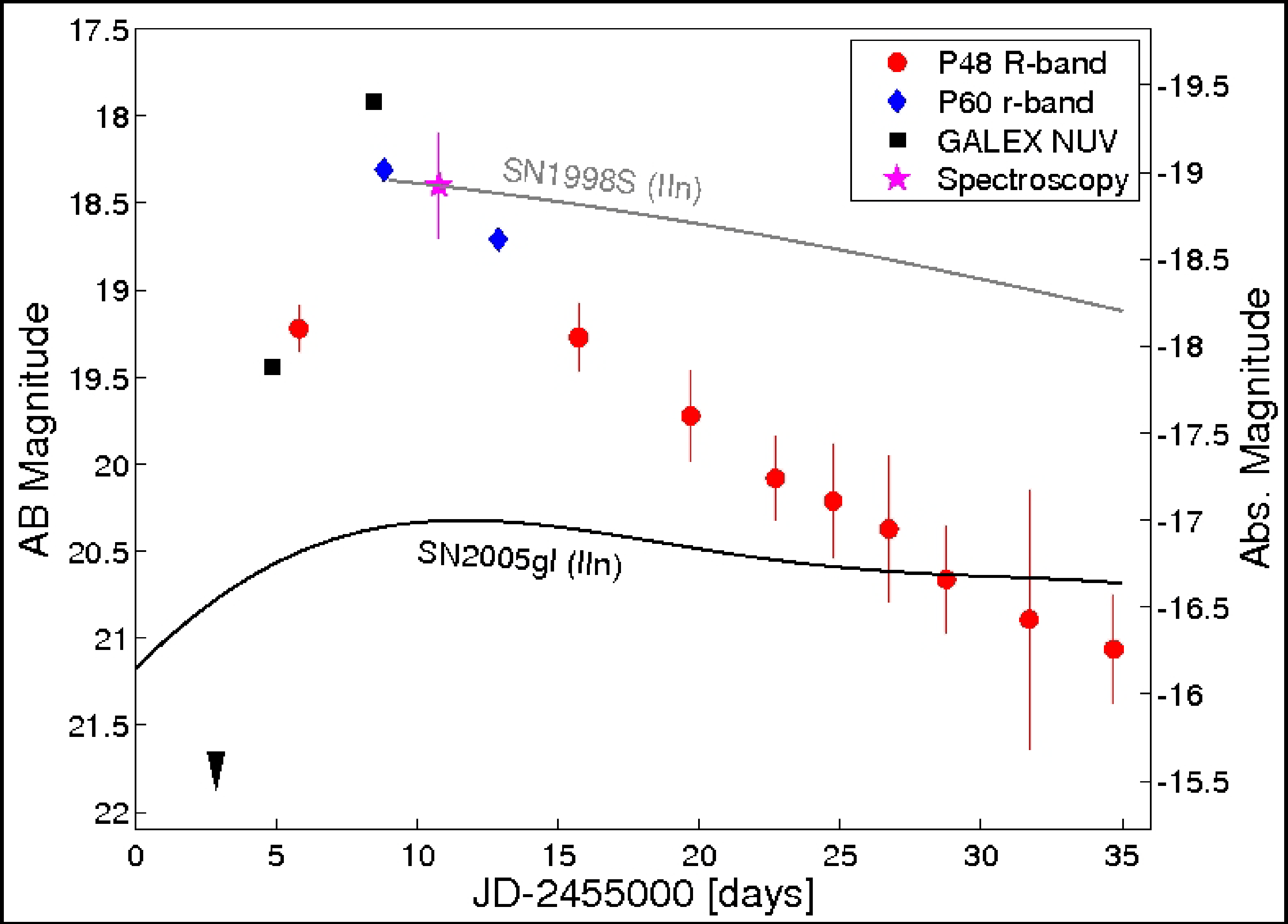
  Kasliwal et al. 2010; Kasliwal et al. 2011; Gal-Yam et al. 2011; Smith et al. 2011; Maguire et al. 2011; Cenko et al. 2010;…
- First possible detection of a GRB/orphan In optical wavebands Cenko et al., submitted

Implications for IceCube

- Followp
  of double neutrino events (~10/yr)
- Constrains on jet-component in CC SNe
  Large sample of nearby CC SNe with explosion time known to better than a day.
- Collisonless shocks from type-IIn SNe

Shock breakout in CSM

PTF 09uj



Ofek et al. 2010, Apj

Shock breakout / PTF

PTF 09uj

$$\tau = \frac{c}{v}$$

$$aT^4 \approx \frac{7}{2}\rho v^2 \approx \frac{7c}{2t\kappa}$$

$$L_\lambda \approx \frac{v}{c} L_\lambda^{BB} \approx 4\pi^2 r^2 v \frac{2k_B T}{\lambda^4}$$

$$r = vt$$

$$v \sim 13{,}000 km/s$$

$$n \sim 5\times10^{10} cm^{-3}$$

$$T \sim 90{,}000 K$$

$$M \sim 0.3 M_{sun}$$

$$\dot{M} \sim 0.1 M_{sun} / year$$

$$E \sim 5\times10^{50} erg$$

Ofek et al. 2010
See also:
Chevalier & Irwin 2011;
Balberg & Loeb 2011;…

Collisionless shocks

- Katz et al./Murse et al. 2011: If dense CSM then the radiation mediated and dominated shock transforms to a collisionless shock (TeV netrinos…)

Chevalier & Irwin 2012
Svirski et al. 2012

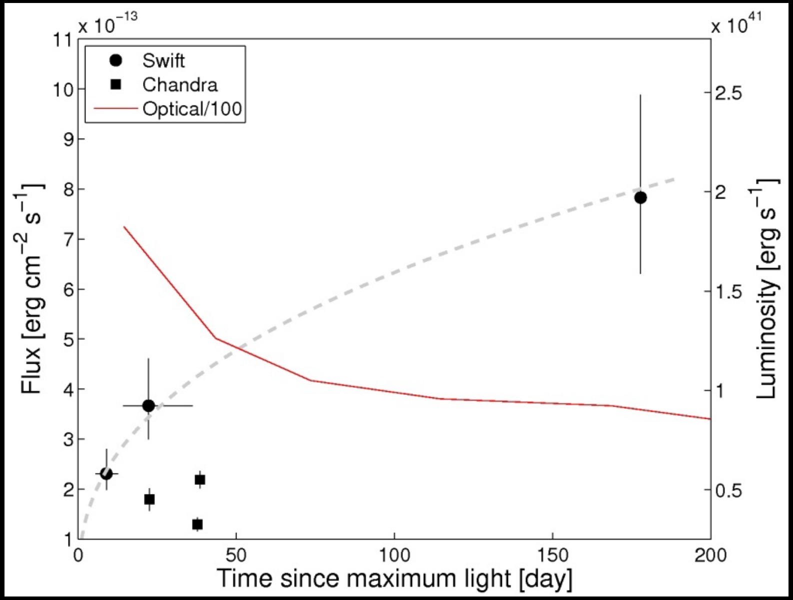
- X-rays produced at late times

- Sample of 28 SNe IIn; Ibn and SLSN For which Swift-XRT observations are available… Ofek et al. 2013a

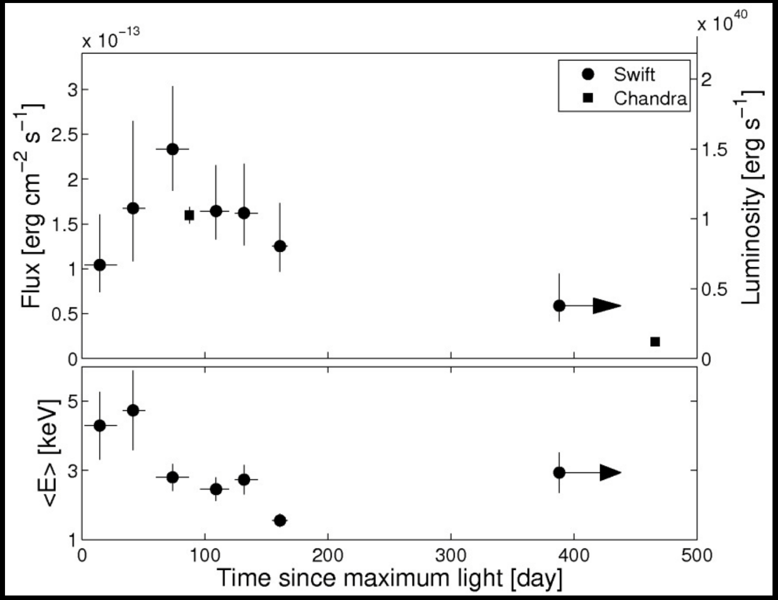
Collisionless shocks

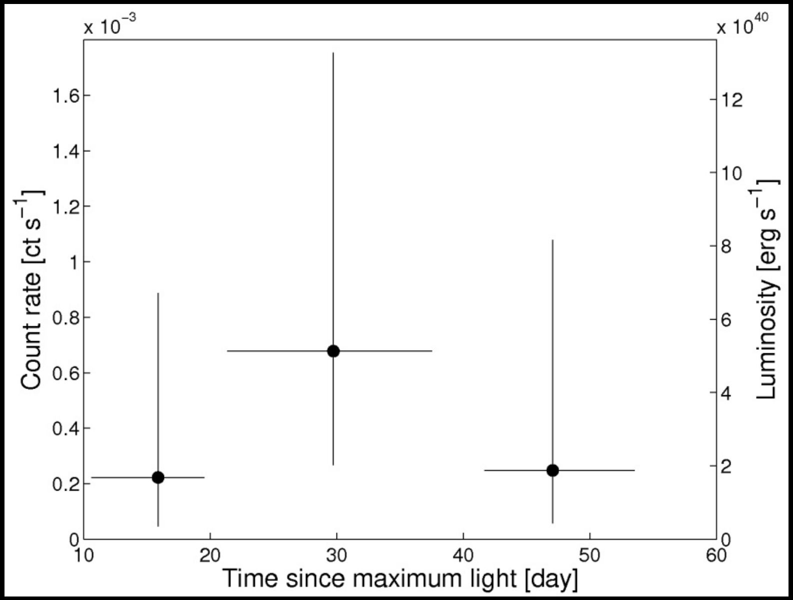
Ofek et al. 2013a

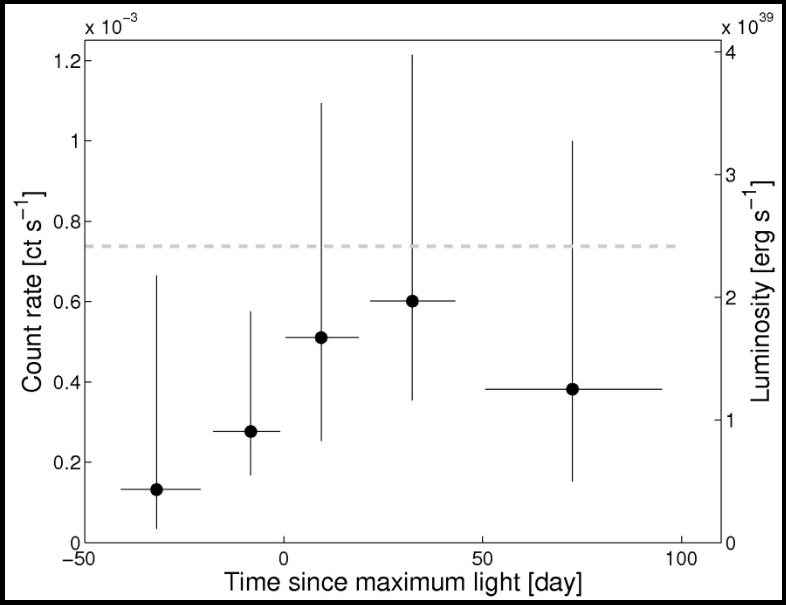
See also: Chandra+ 2012



See also: Immler+ 2007

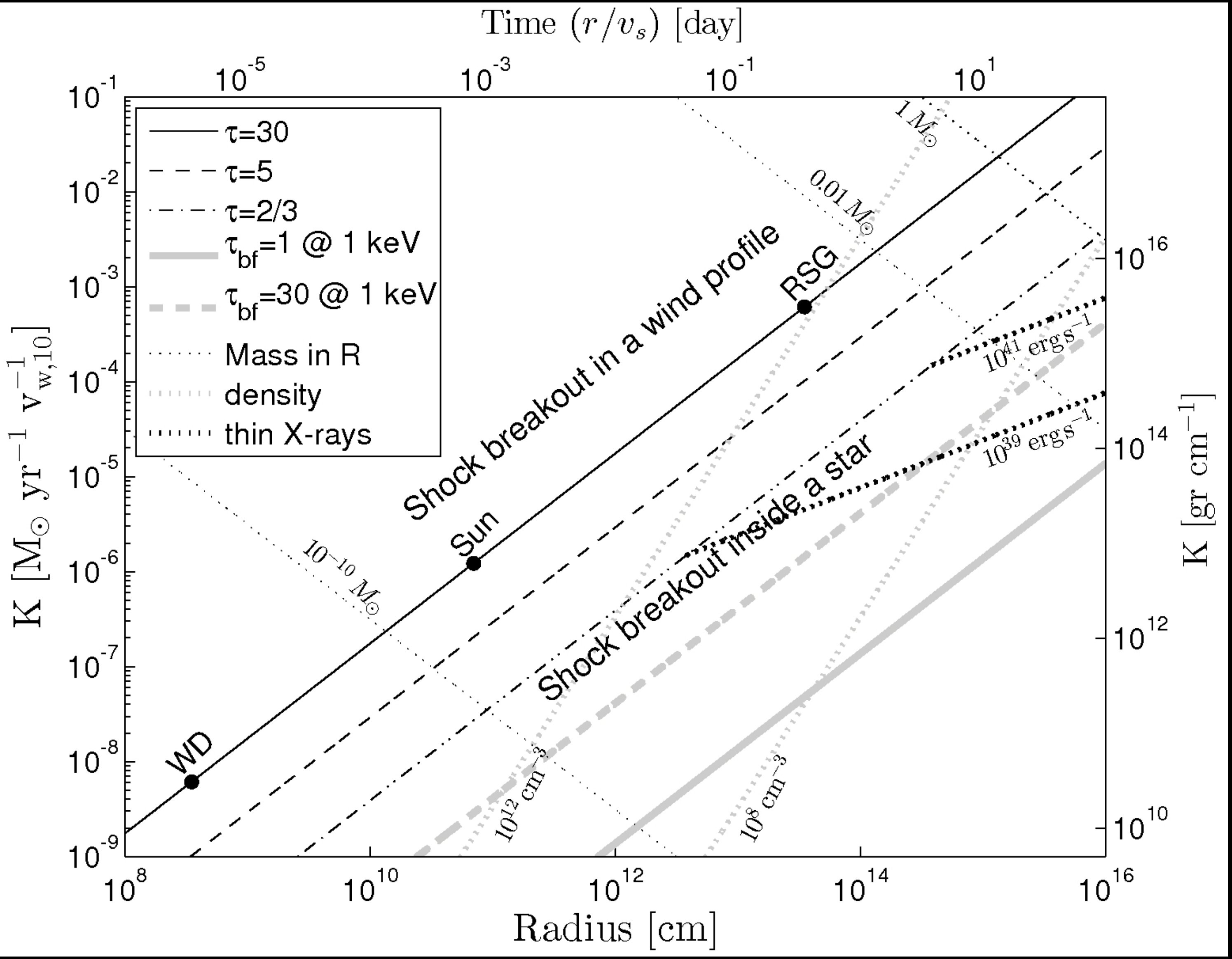






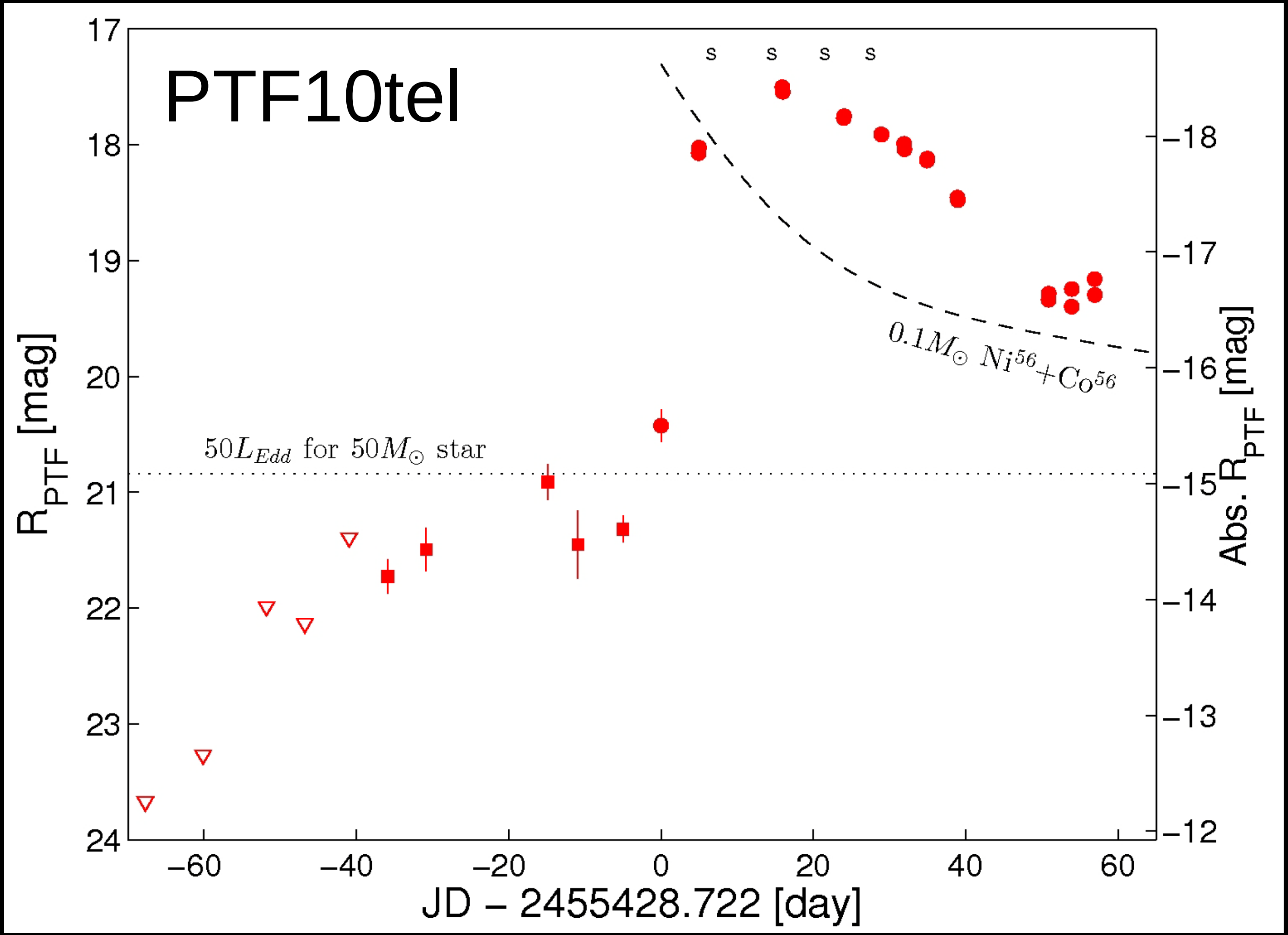
Collisionless shocks

Ofek et al. 2013a



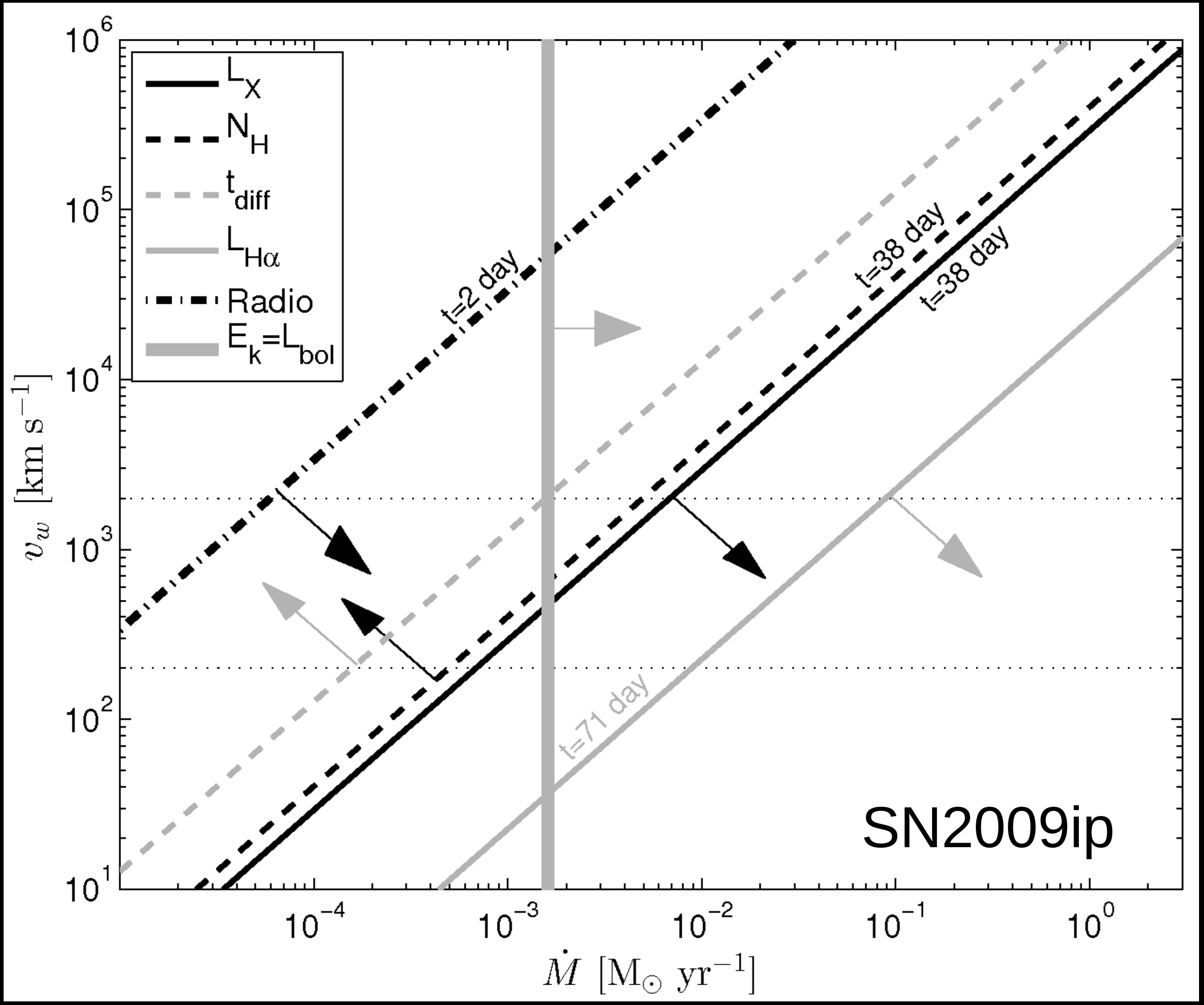
Mass loss measurements

Ofek et al. 2013b, Nature in press



Mass loss measurements

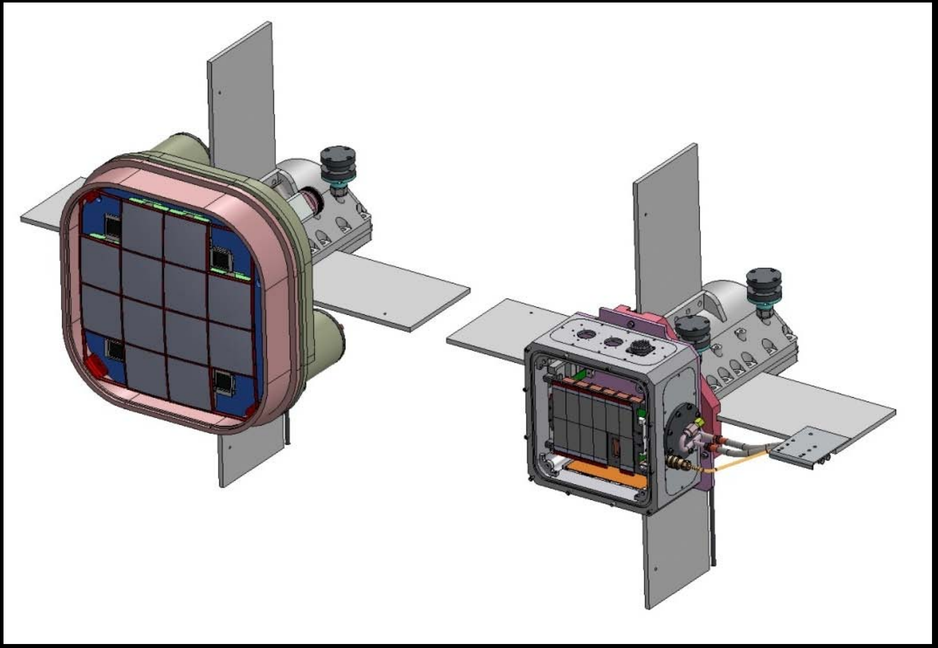
Ofek et al. 2013c, submitted



ZTF

Thinking about the next project…

- ZTF will have a ~36 deg^2 camera
  Mounted on the 48" schmidt telescope
- ~16,000 deg^2 day^{-1}
- Scheduled for 2015



ULTRASAT

Thinking about the next project…

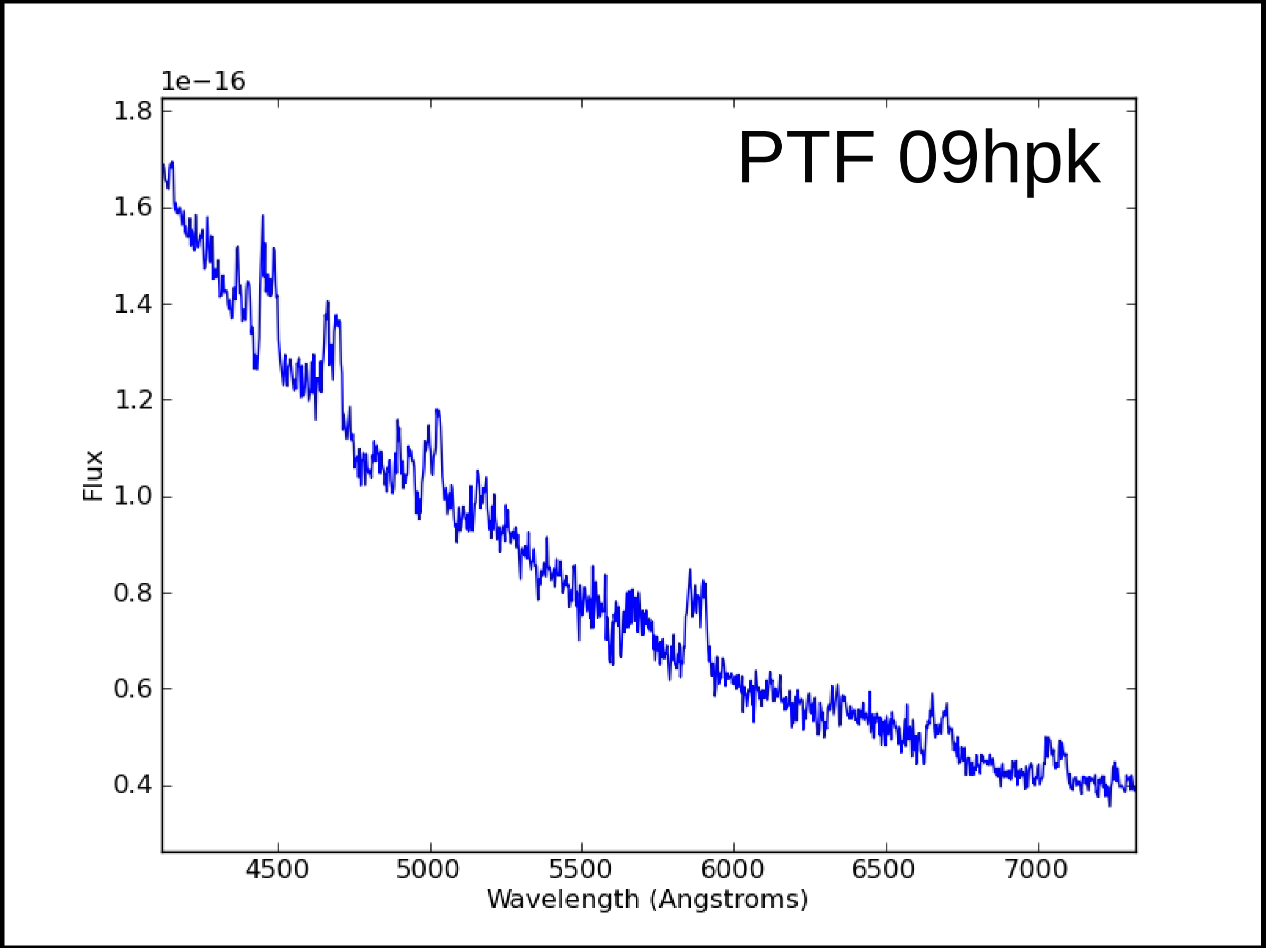
- Wide field UV telescope (484 deg^2)
- Detection of >100 young SNe/yr
- Scheduled for 2018

End

Thank you!

AM CVn

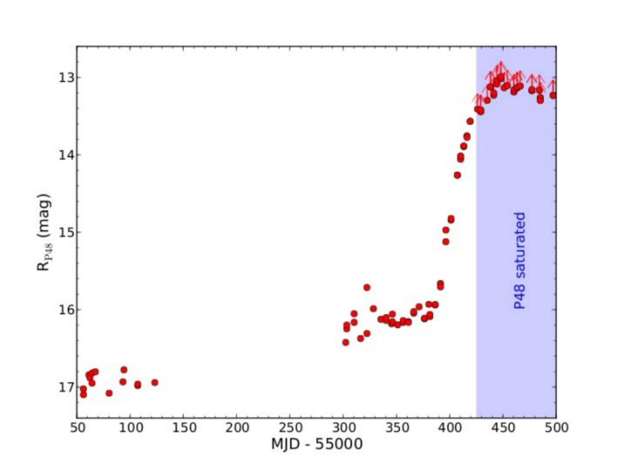
- Primary background noise for LISA

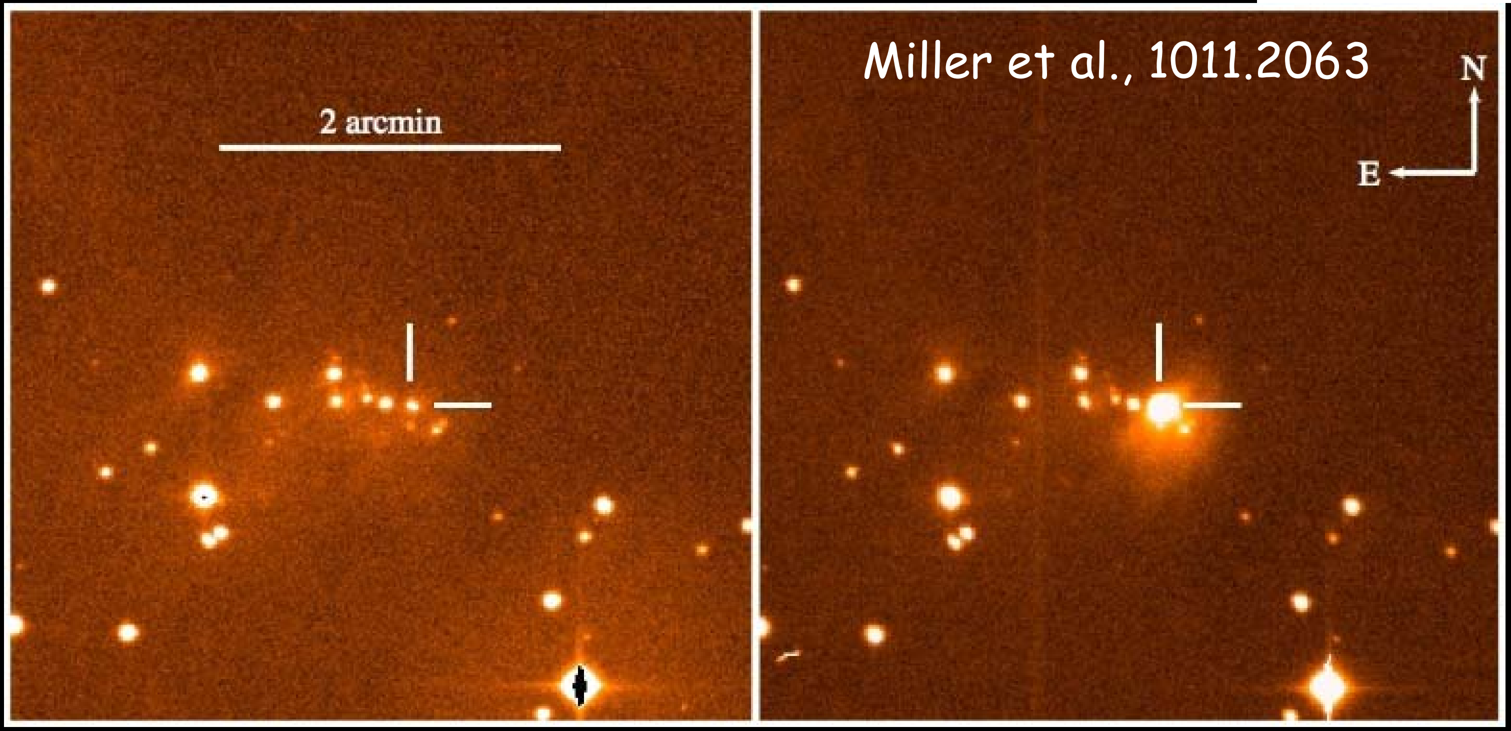


Levitan et al. 2011

FU Ori and other

- PTF10qpf: new FU Ori star

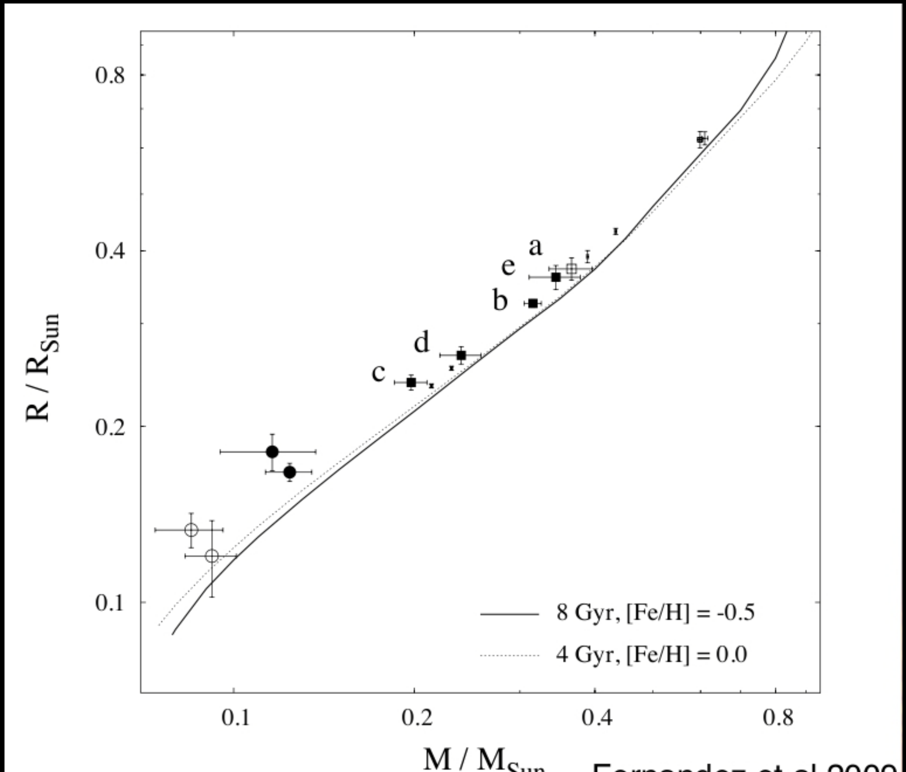




Planets around M-dwarfs

Law et al., in prep.

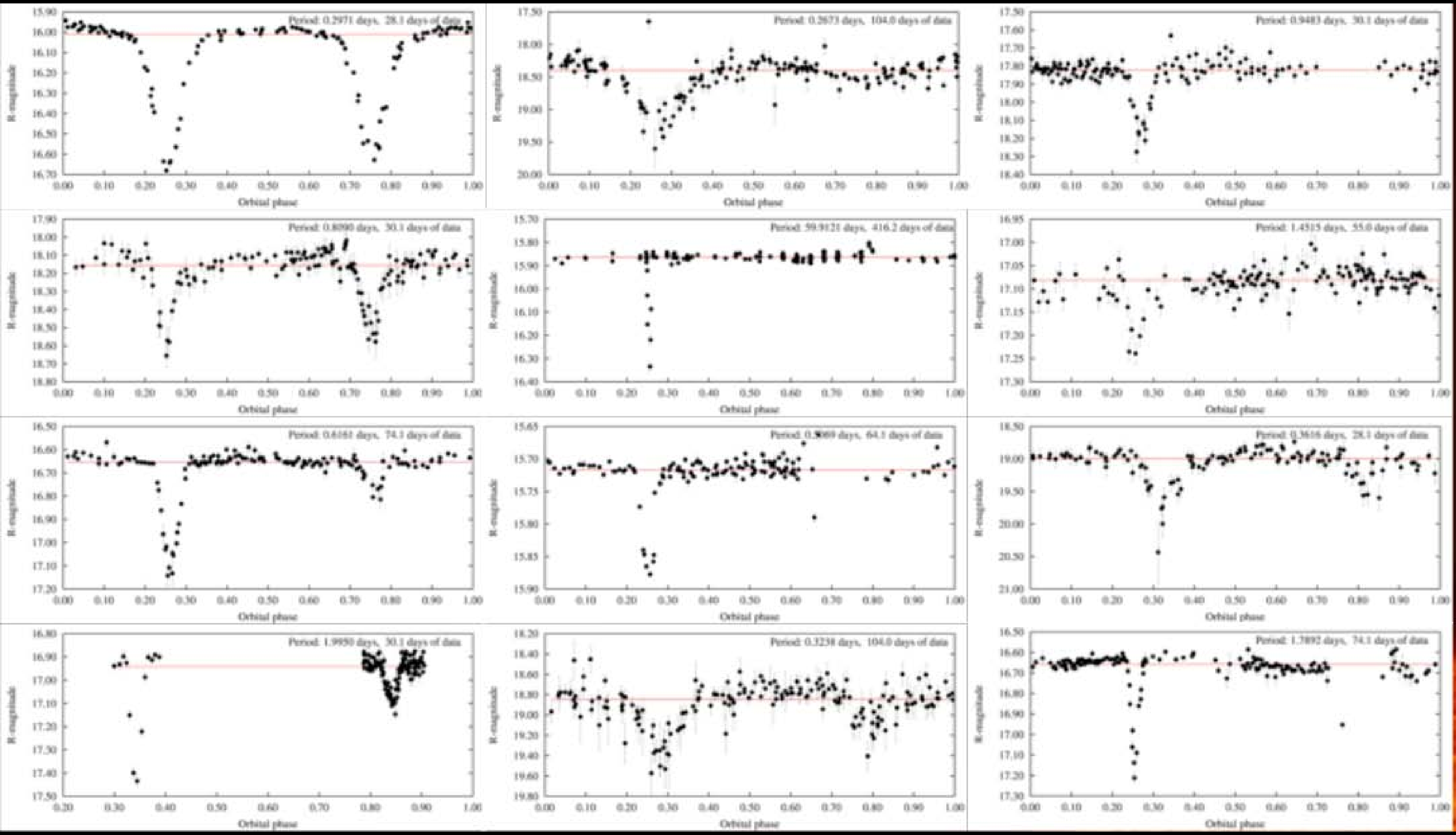
- ★ Possible to find planets in the habitable zone...
- ★ Calibrating the mass-radius relation of M-dwarfs



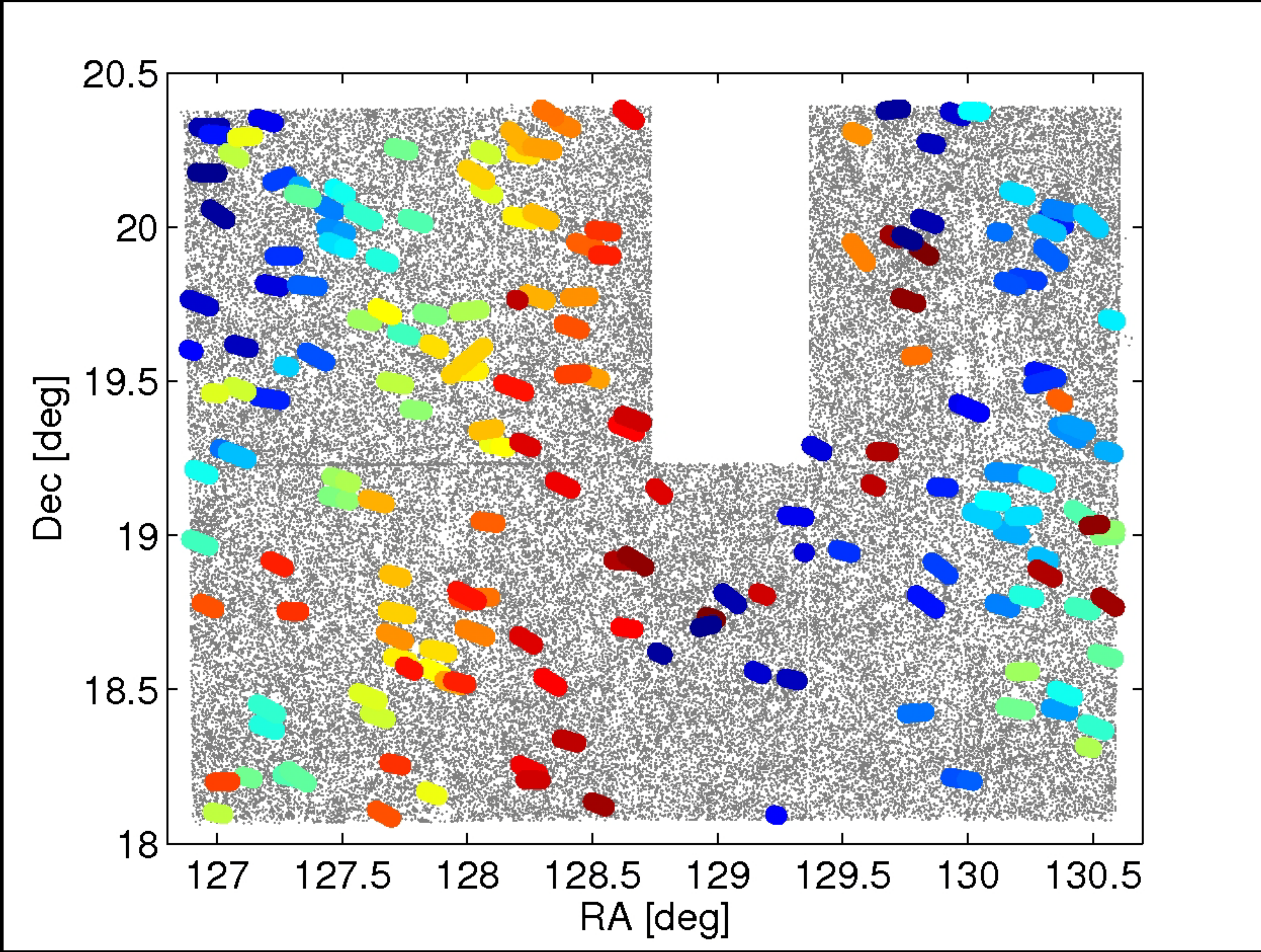
Fernandez et al 2009

Planets around M-dwarfs

Some eclipsing M-dwarfs we found…

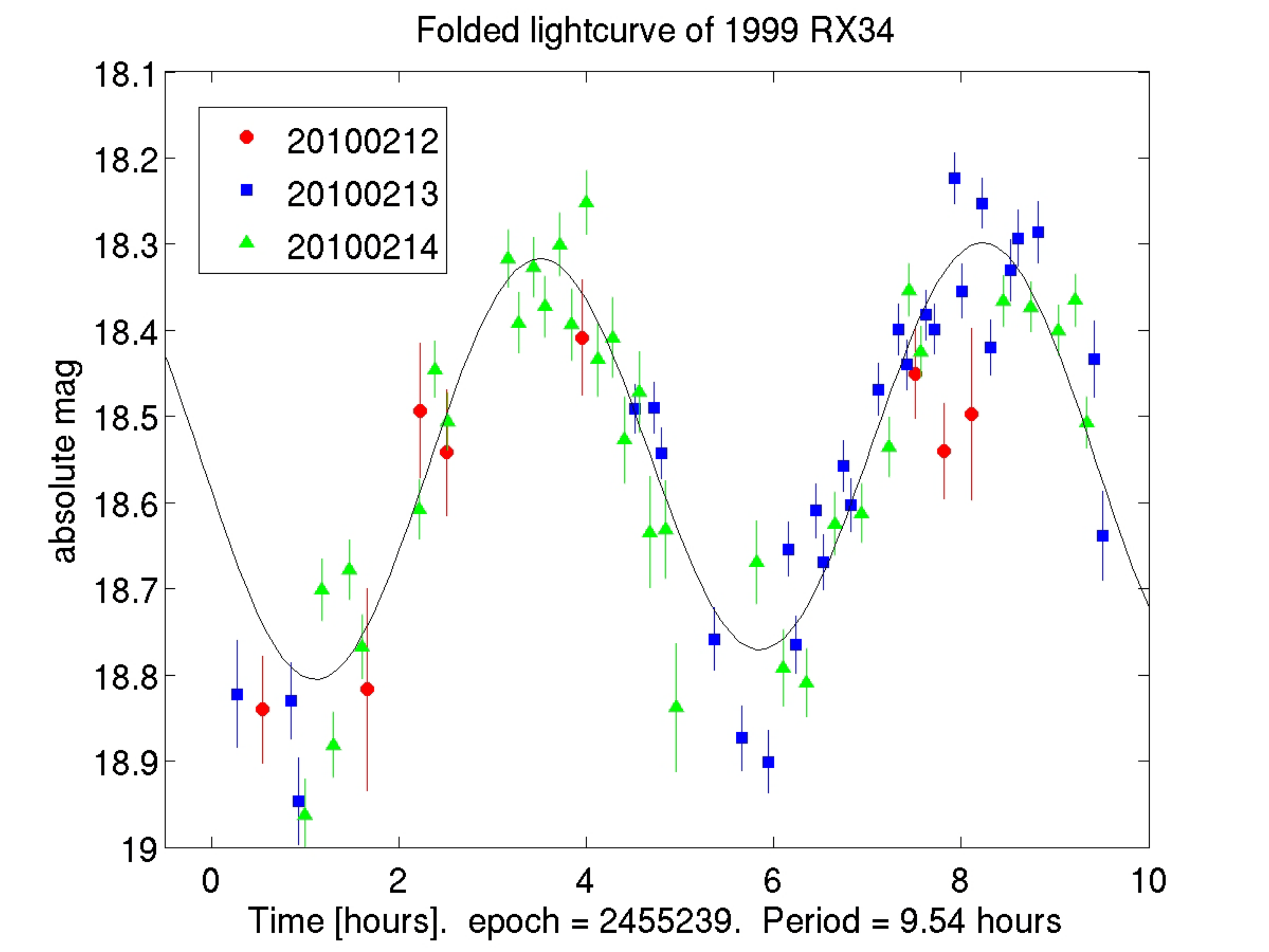


Asteroids rotation



Poolishok et al., submitted

Asteroids rotation

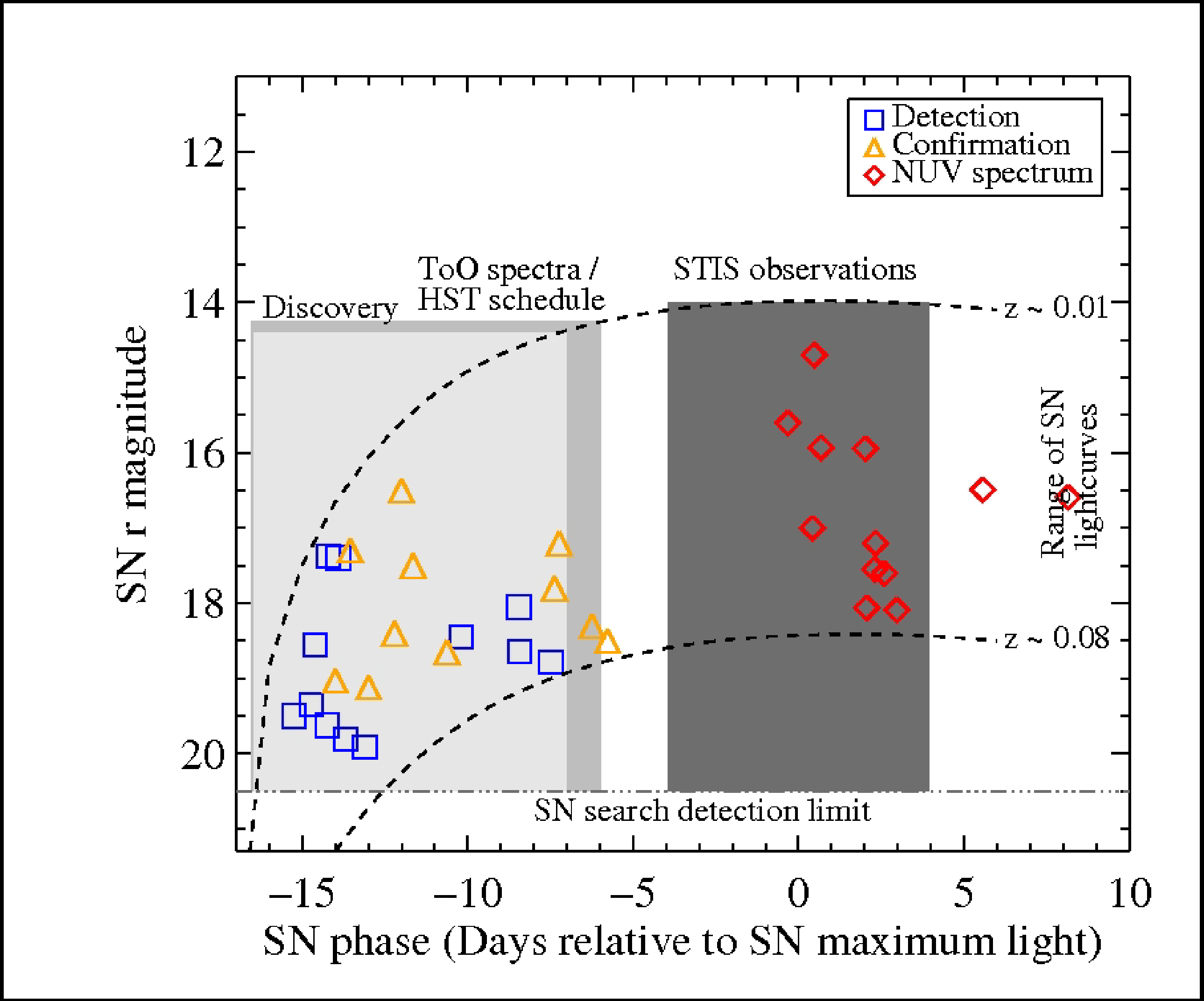


Poolishok et al., submitted

HST UV spectra of Ia SNe

- PTF Can find SN Ia early

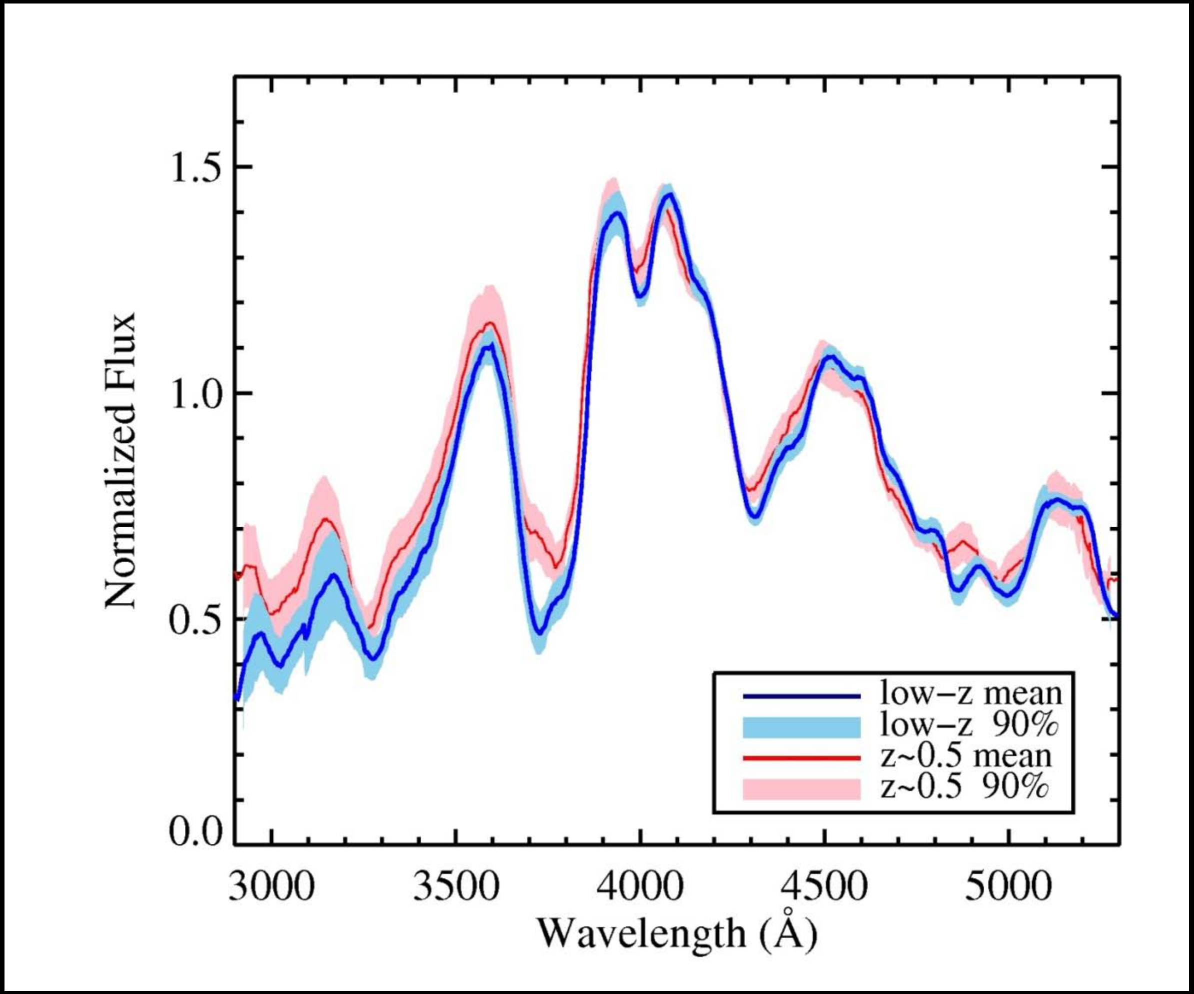
PI: R. Ellis



HST UV spectra of Ia SNe

Cooke et al. 2011

- The mean UV spectrum of the z~0 and z~0.5 agree, but some differences in metallic absorptions



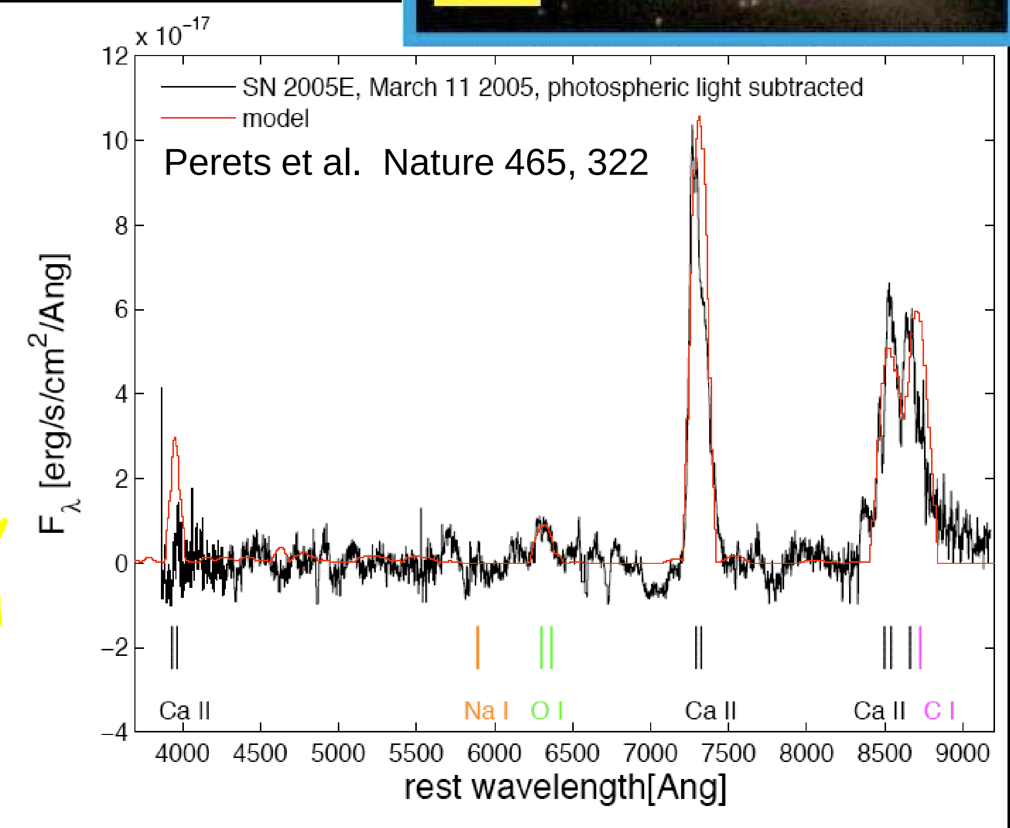
The SN2005E family

- >23 kpc from NGC 1032
  No host: M_R>-7
  Spec: He burning products
  Ca reach

- Possibilities:
  Acc. Induced Collapse
  .Ia

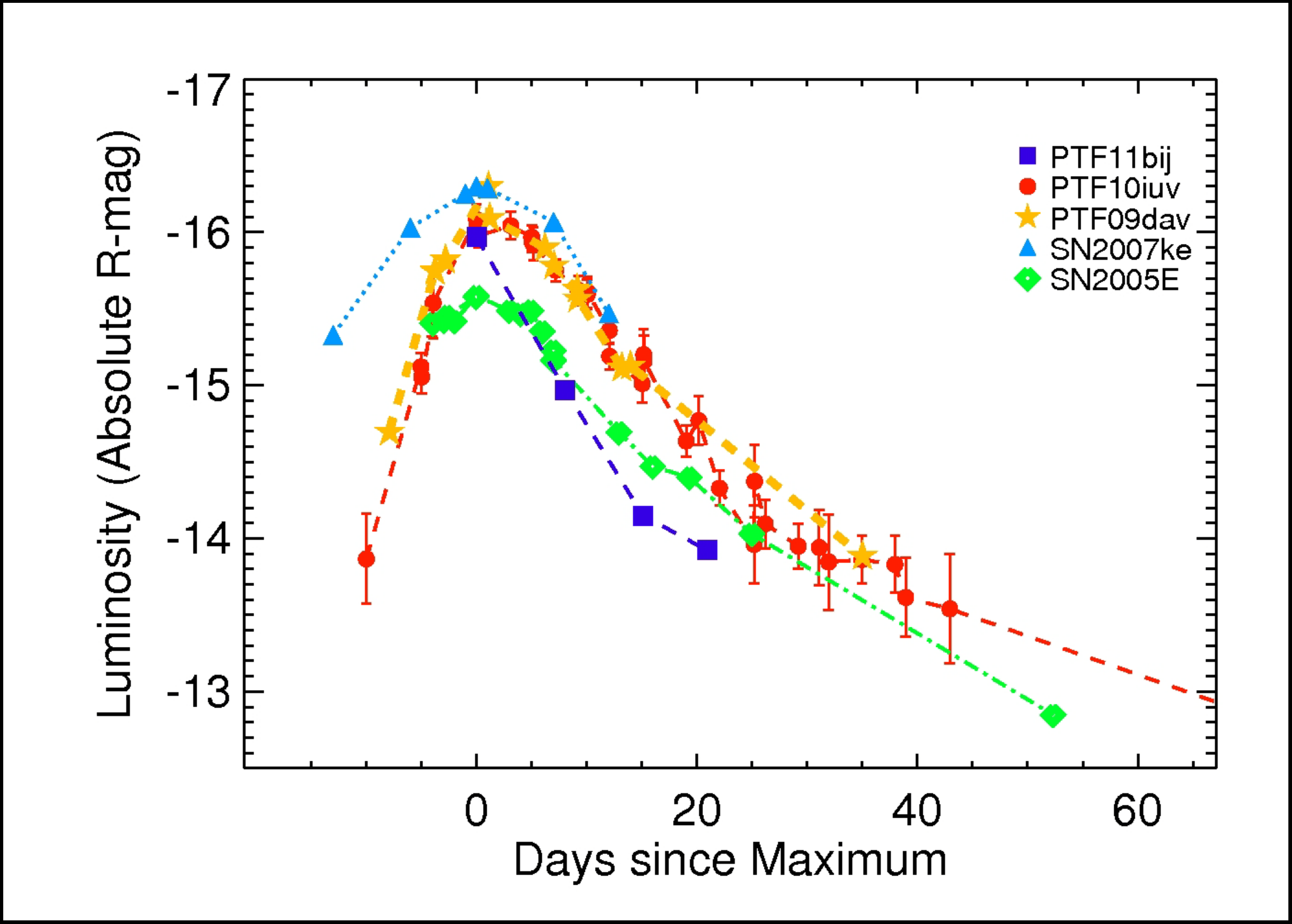
- May solve puzzles:

  ^{44}Ca in Solar System
  ^{44}Ti->^{44}Ca via b decay
  Positrons annihilation
  in Galactic bulge

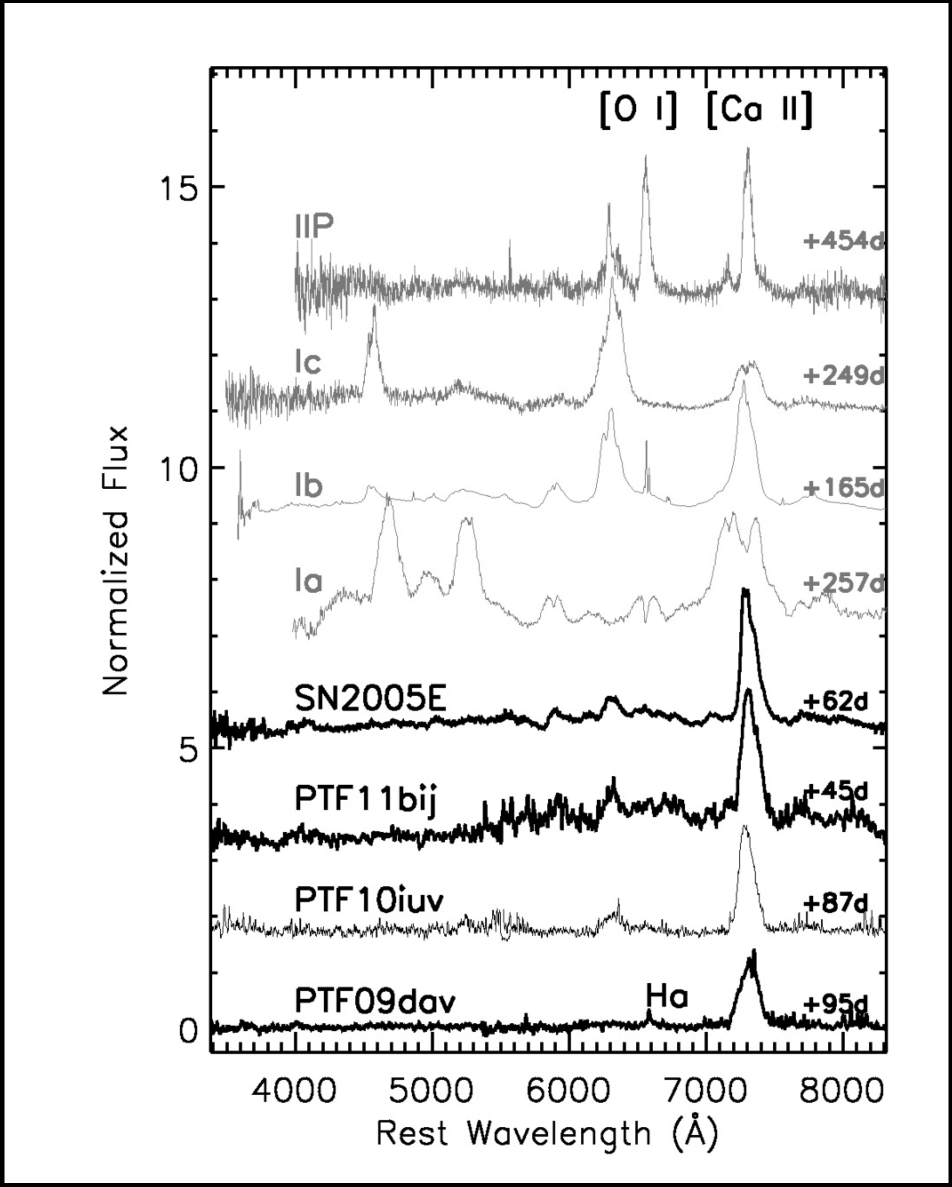


The SN2005E family

Kasliwal et al. 2011; Sullivan et al. 2011

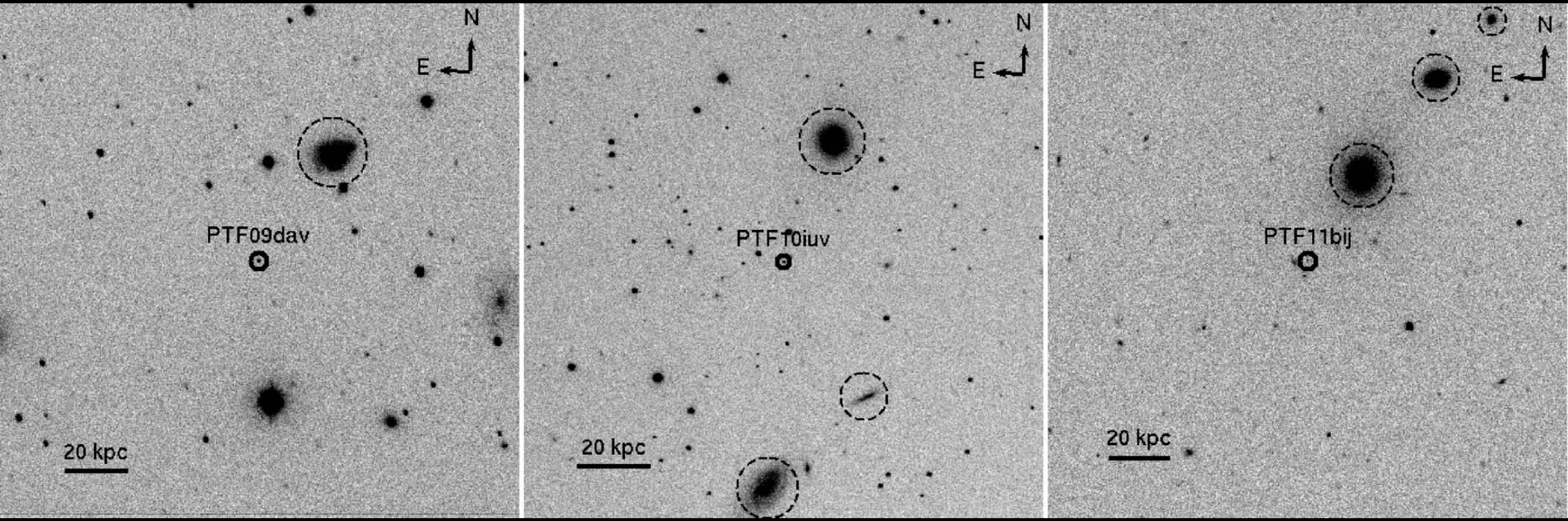


The SN2005E family



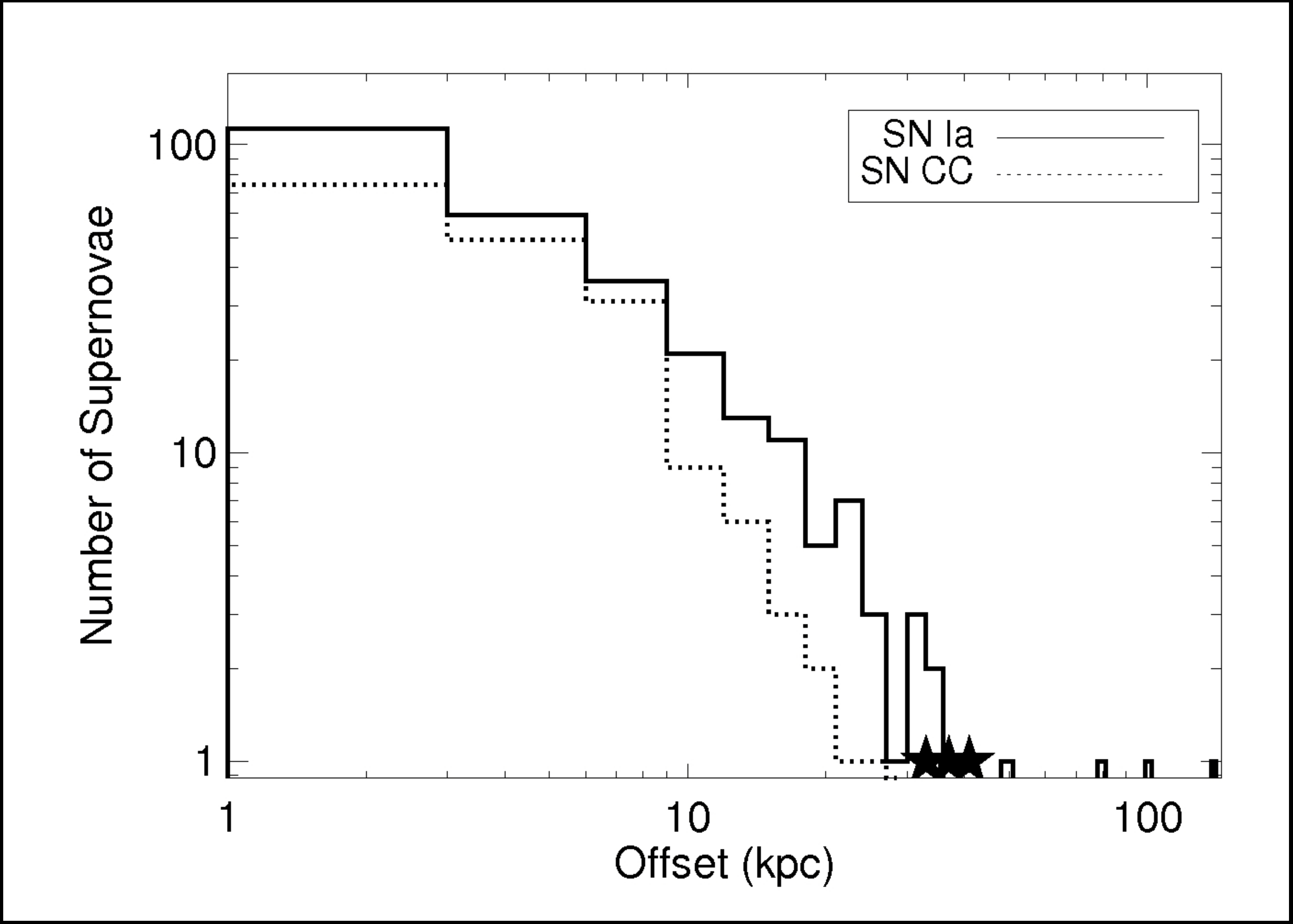
Kasliwal et al. 2011; Sullivan et al. 2011

The SN2005E family



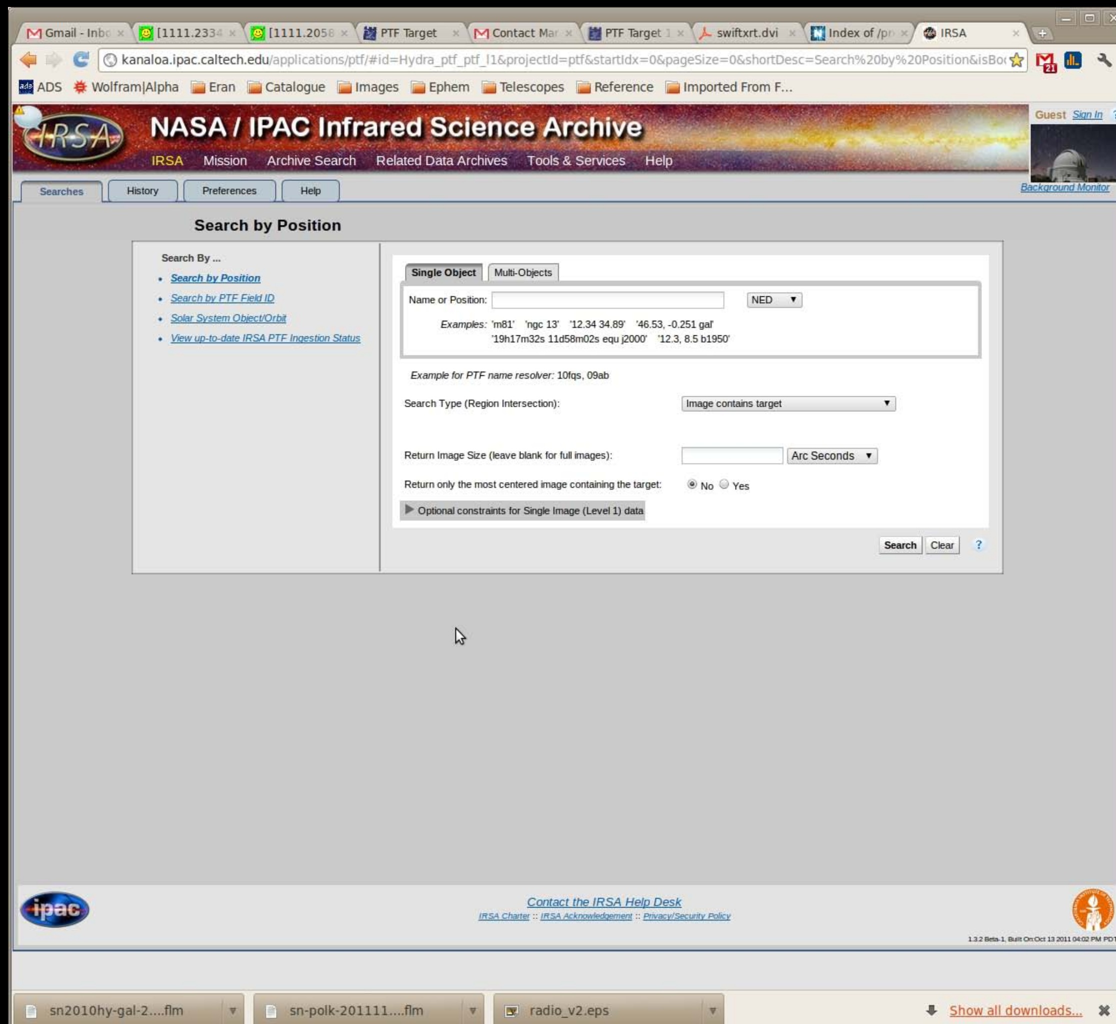
Kasliwal et al. 2011; Sullivan et al. 2011

The SN2005E family



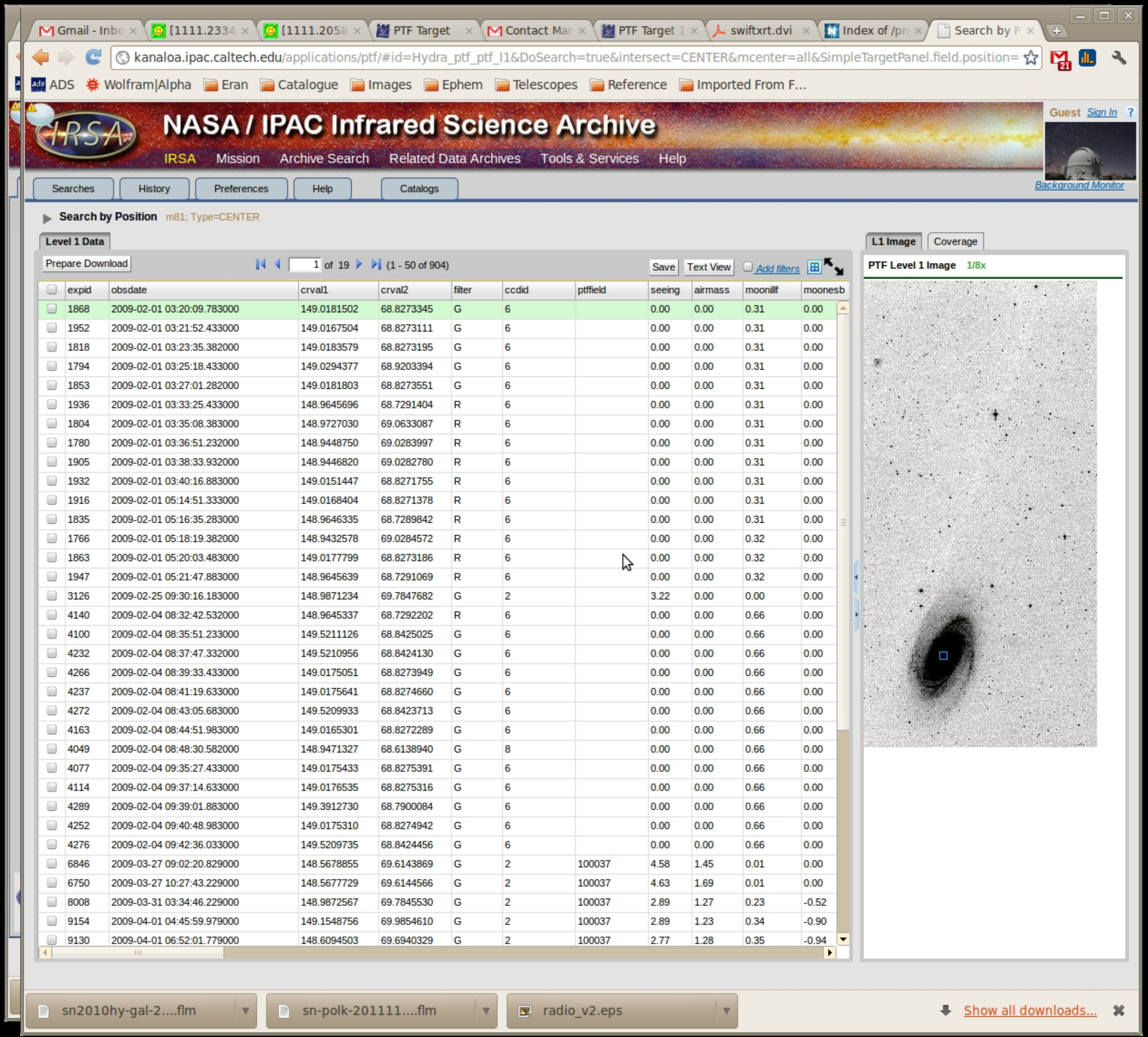
Kasliwal et al. 2011

Data Release



Data Release

- First public data release: 2012



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1868	2009-02-01 03:20:09.783000	149.0181502	68.8273345	G	6		0.00	0.00	0.31	0.00
1952	2009-02-01 03:21:52.433000	149.0167504	68.8273111	G	6		0.00	0.00	0.31	0.00
1818	2009-02-01 03:23:35.382000	149.0183579	68.8273195	G	6		0.00	0.00	0.31	0.00
1794	2009-02-01 03:25:18.433000	149.0294377	68.9203394	G	6		0.00	0.00	0.31	0.00
1853	2009-02-01 03:27:01.282000	149.0181803	68.8273551	G	6		0.00	0.00	0.31	0.00
1936	2009-02-01 03:33:25.433000	148.9645696	68.7291404	R	6		0.00	0.00	0.31	0.00
1804	2009-02-01 03:35:08.383000	148.9727030	69.0633087	R	6		0.00	0.00	0.31	0.00
1780	2009-02-01 03:36:51.232000	148.9448750	69.0283997	R	6		0.00	0.00	0.31	0.00
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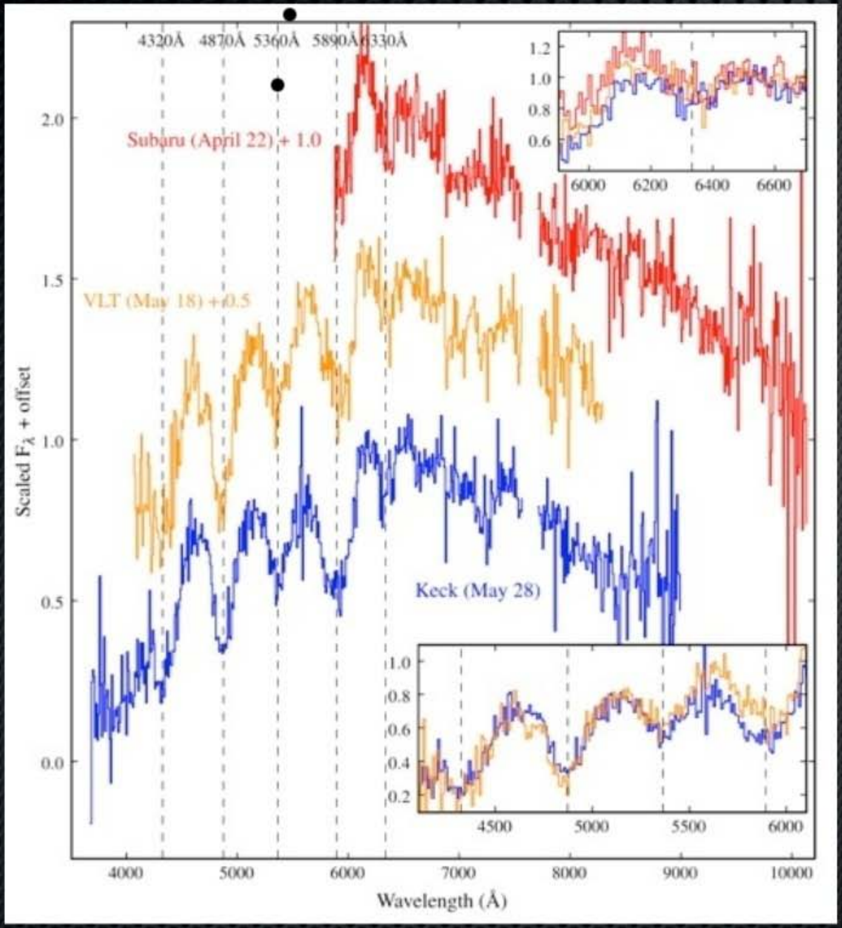
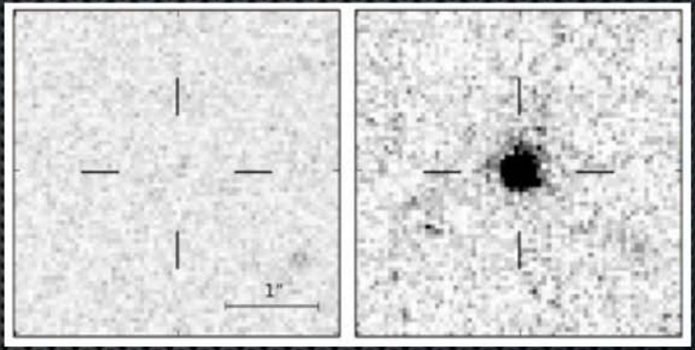
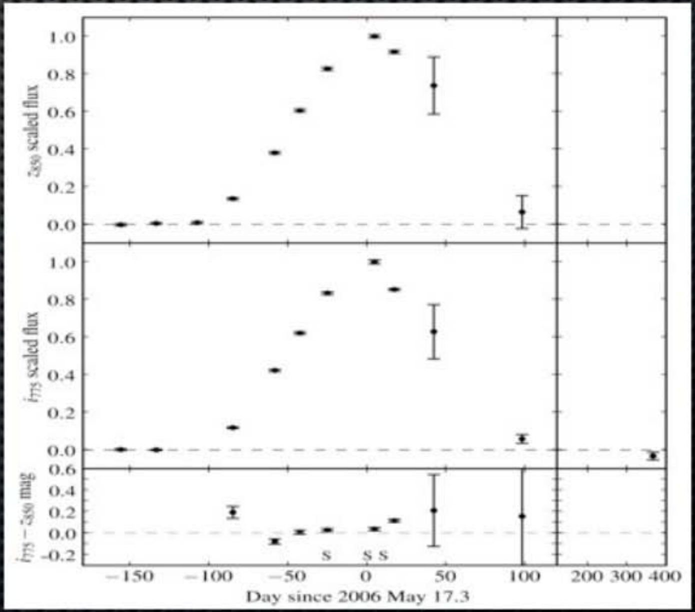
1932	2009-02-01 03:40:16.883000	149.0151447	68.8271755	R	6		0.00	0.00	0.31	0.00
1916	2009-02-01 05:14:51.333000	149.0168404	68.8271378	R	6		0.00	0.00	0.31	0.00
1835	2009-02-01 05:16:35.283000	148.9646335	68.7289842	R	6		0.00	0.00	0.31	0.00
1766	2009-02-01 05:18:19.382000	148.9432578	69.0284572	R	6		0.00	0.00	0.32	0.00
1863	2009-02-01 05:20:03.483000	149.0177799	68.8273186	R	6		0.00	0.00	0.32	0.00
1947	2009-02-01 05:21:47.883000	148.9645639	68.7291069	R	6		0.00	0.00	0.32	0.00
3126	2009-02-25 09:30:16.183000	148.9871234	69.7847682	G	2		3.22	0.00	0.00	0.00
4140	2009-02-04 08:32:42.532000	148.9645337	68.7292202	R	6		0.00	0.00	0.66	0.00
4100	2009-02-04 08:35:51.233000	149.5211126	68.8425025	G	6		0.00	0.00	0.66	0.00
4232	2009-02-04 08:37:47.332000	149.5210956	68.8424130	G	6		0.00	0.00	0.66	0.00
4266	2009-02-04 08:39:33.433000	149.0175051	68.8273949	G	6		0.00	0.00	0.66	0.00
4237	2009-02-04 08:41:19.633000	149.0175641	68.8274660	G	6		0.00	0.00	0.66	0.00
4272	2009-02-04 08:43:05.683000	149.5209933	68.8423713	G	6		0.00	0.00	0.66	0.00
4163	2009-02-04 08:44:51.983000	149.0165301	68.8272289	G	6		0.00	0.00	0.66	0.00
4049	2009-02-04 08:48:30.582000	148.9471327	68.6138940	G	8		0.00	0.00	0.66	0.00
4077	2009-02-04 09:35:27.433000	149.0175433	68.8275391	G	6		0.00	0.00	0.66	0.00
4114	2009-02-04 09:37:14.633000	149.0176535	68.8275316	G	6		0.00	0.00	0.66	0.00
4289	2009-02-04 09:39:01.883000	149.3912730	68.7900084	G	6		0.00	0.00	0.66	0.00
4252	2009-02-04 09:40:48.983000	149.0175310	68.8274942	G	6		0.00	0.00	0.66	0.00
4276	2009-02-04 09:42:36.033000	149.5209735	68.8424456	G	6		0.00	0.00	0.66	0.00
6846	2009-03-27 09:02:20.829000	148.5678855	69.6143869	G	2	100037	4.58	1.45	0.01	0.00
6750	2009-03-27 10:27:43.229000	148.5677729	69.6144566	G	2	100037	4.63	1.69	0.01	0.00
8008	2009-03-31 03:34:46.229000	148.9872567	69.7845530	G	2	100037	2.89	1.27	0.23	-0.52
9154	2009-04-01 04:45:59.979000	149.1548756	69.9854610	G	2	100037	2.89	1.23	0.34	-0.90
9130	2009-04-01 06:52:01.779000	148.6094503	69.6940329	G	2	100037	2.77	1.28	0.35	-0.94

Luminous supernovae

The Mysterious SCP 06F6



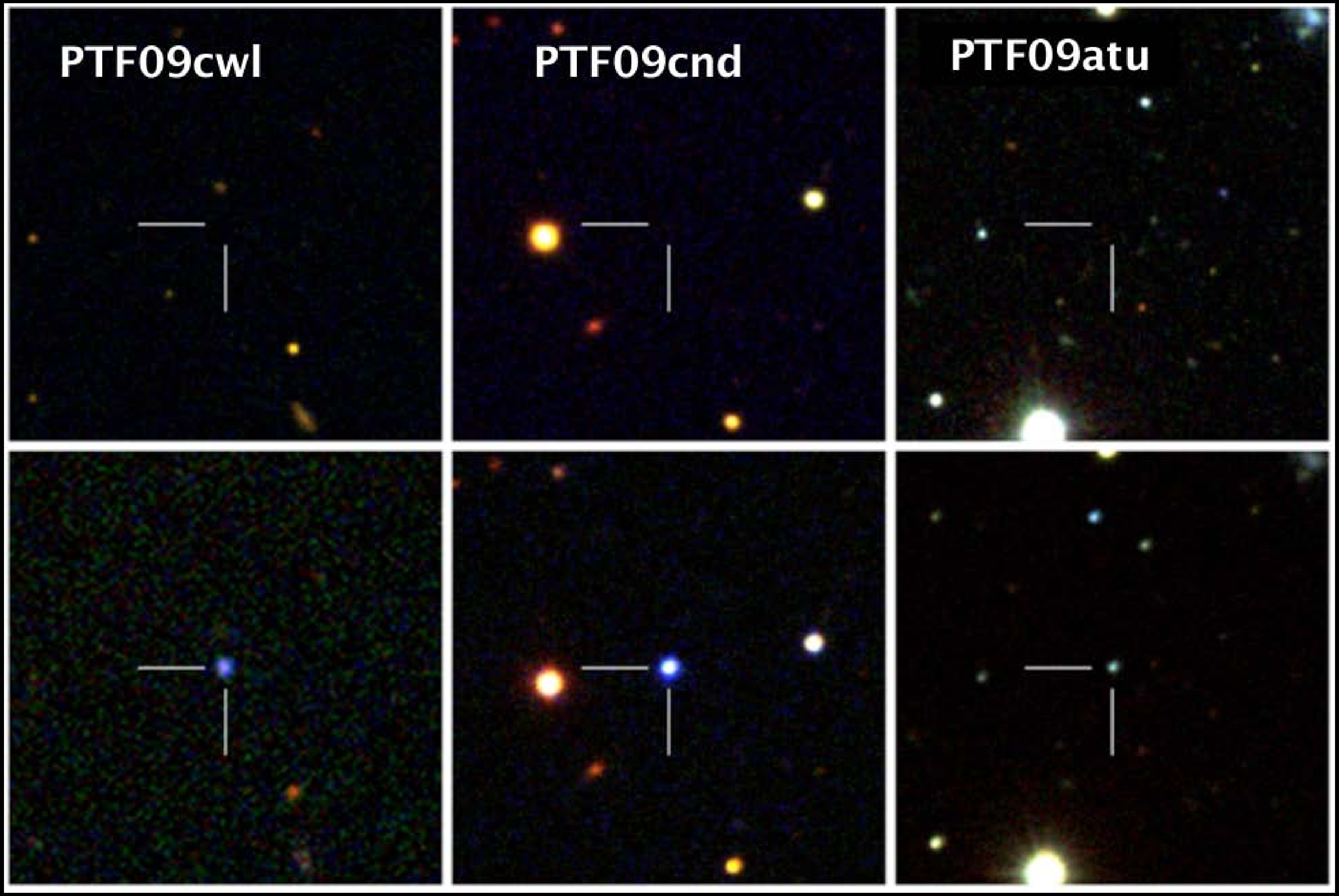




Barbary et al. 2009

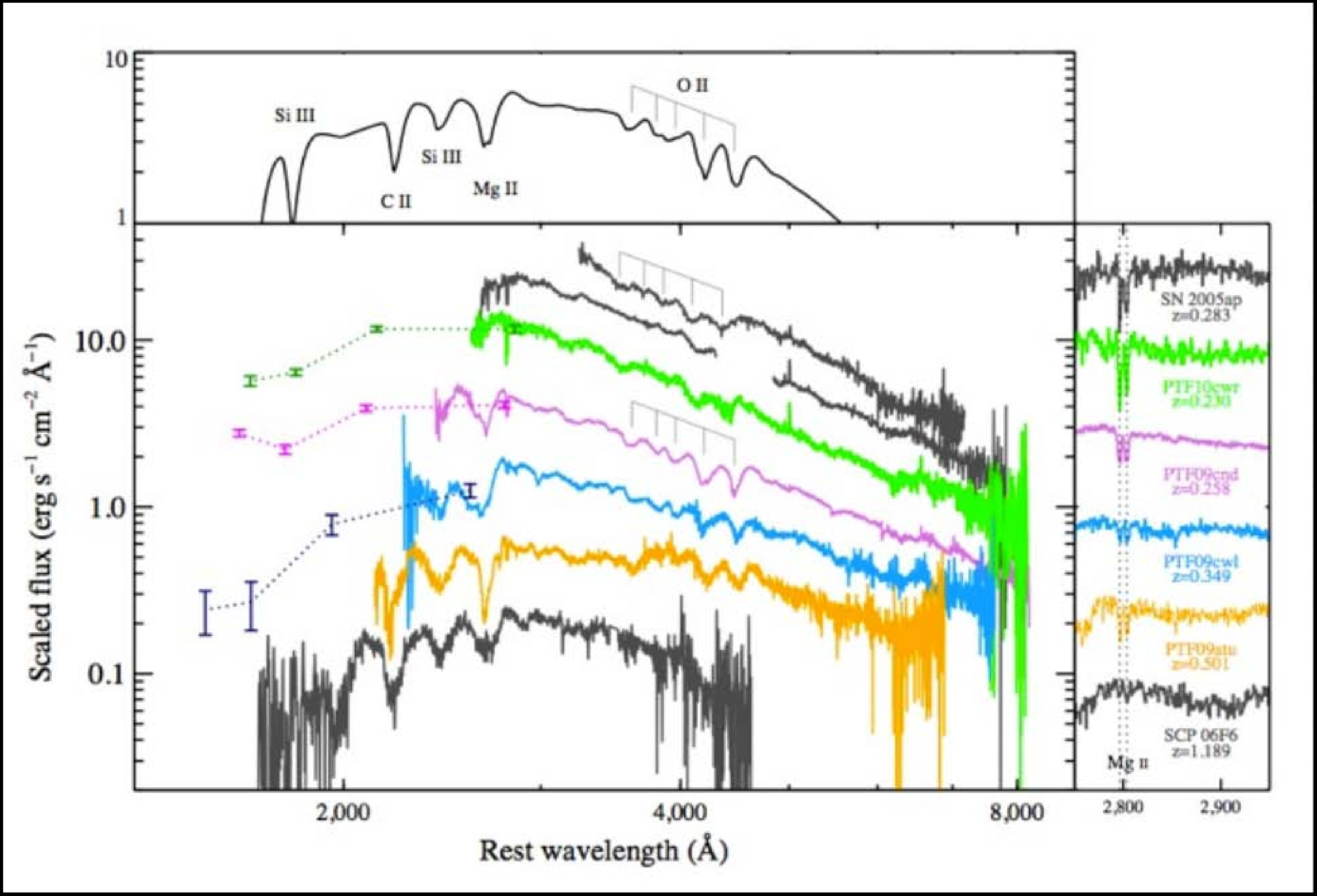
Luminous supernovae

Quimby et al., 2011, Nature



Luminous supernovae

Quimby et al., 2011 Nature



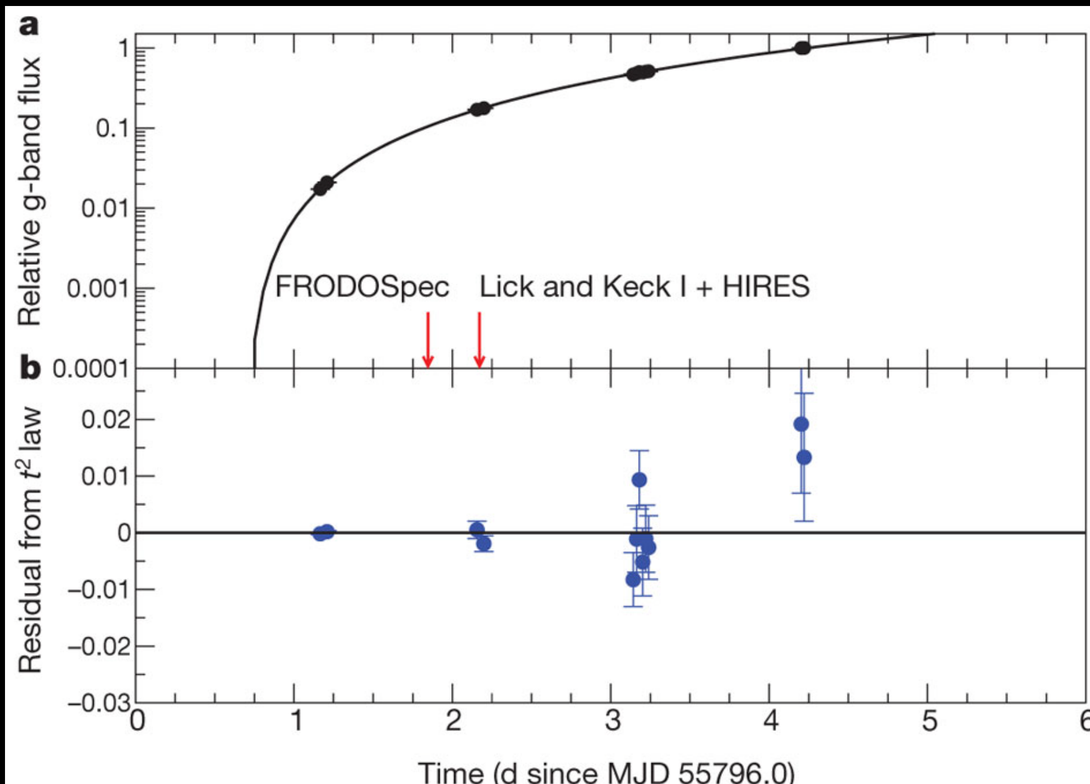
Shock breakouts & PTF

- First photons emerge from the Sne when the photon diffusion time scale become shorter than the hydrodynamical time scale (i.e., photons are moving faster than the ejecta).
- Time scale and luminosity sensitive probes of progenitor radius

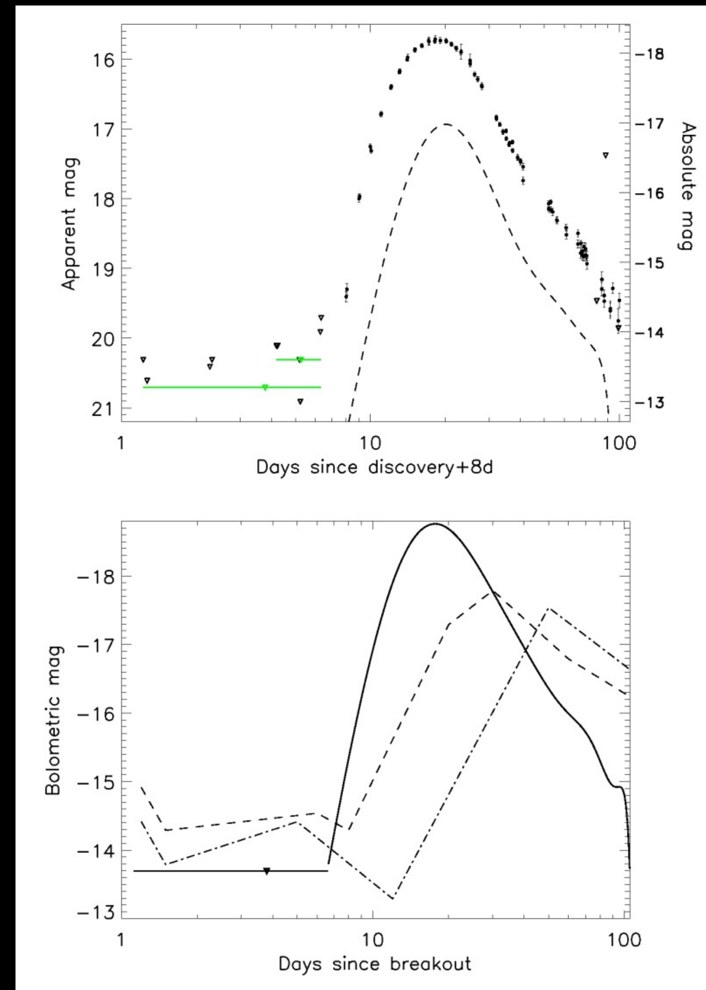
e.g., Colgate 1974; Matzner & McKee 1999
Nakar & Sari 2010; Rabinak & Waxman 2011

Obs: Soderberg+2008,...

Limits on progenitor radii

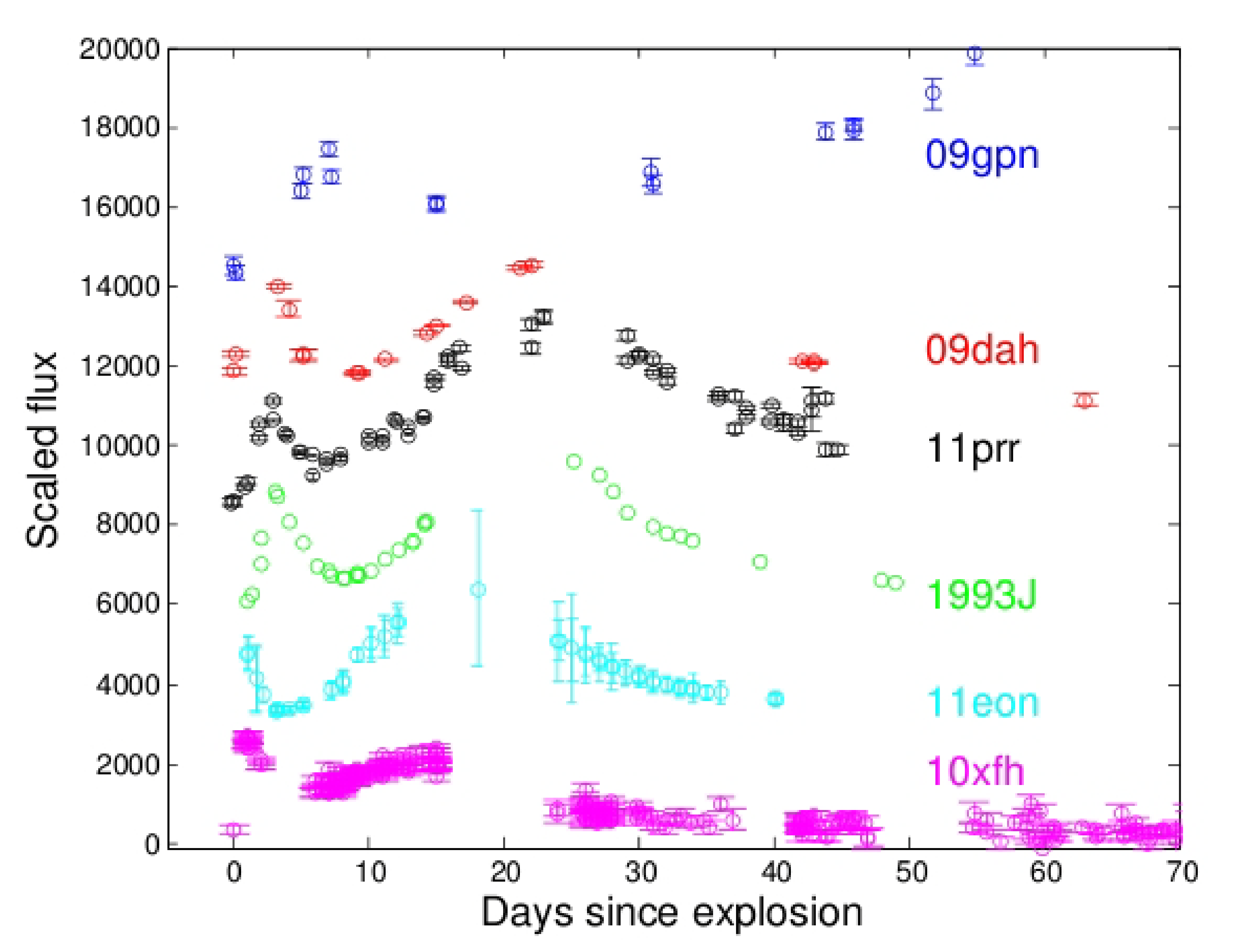


PTF 11kly/2011fe (Ia)
Nugent et al., 2011 Nature
(see also: Bloom et al. 2012; Brown et al. 2012)



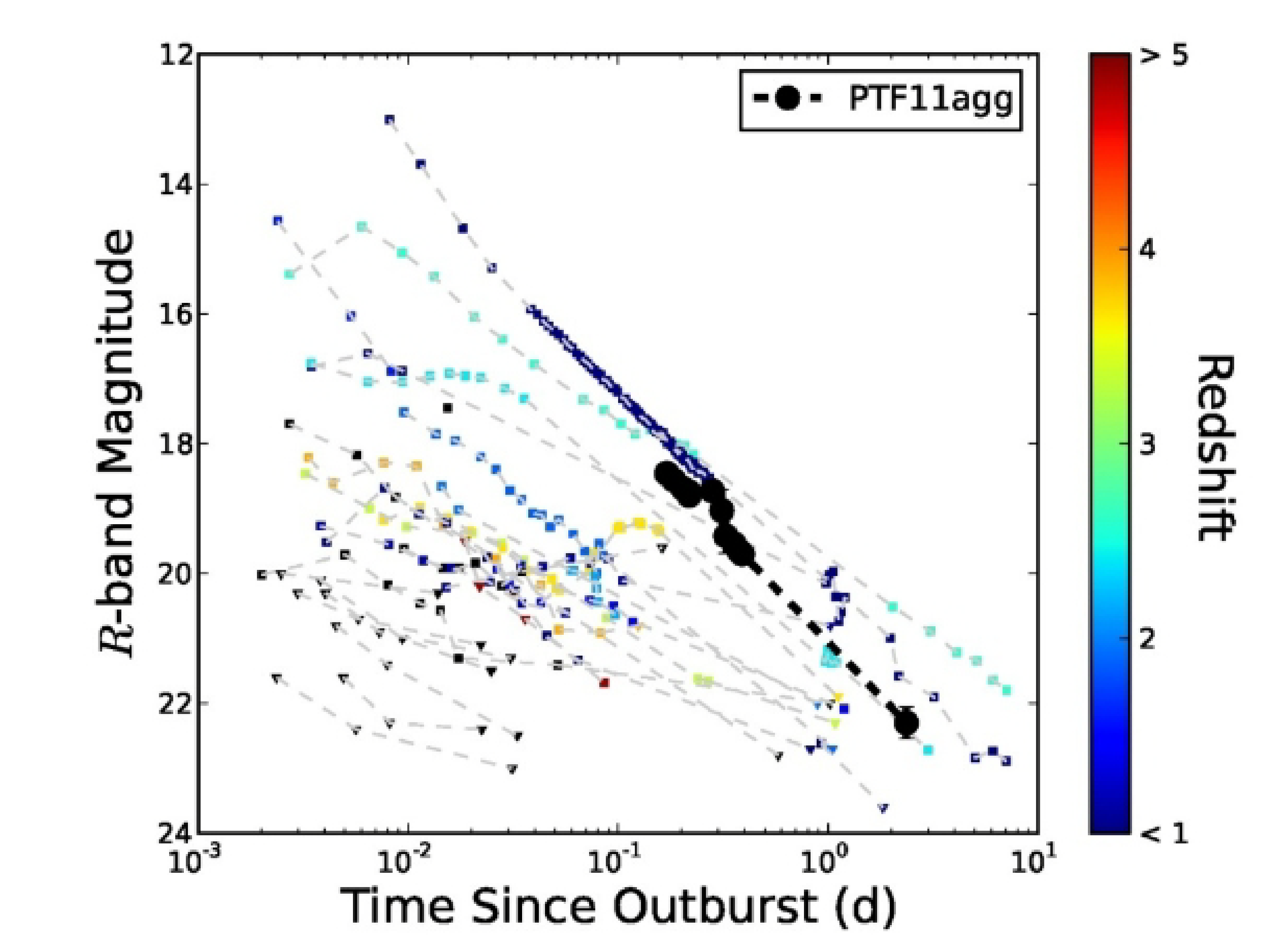
PTF 10vgv (Ic)
Corsi et al., 2011 ApJ

Shock breakout examples



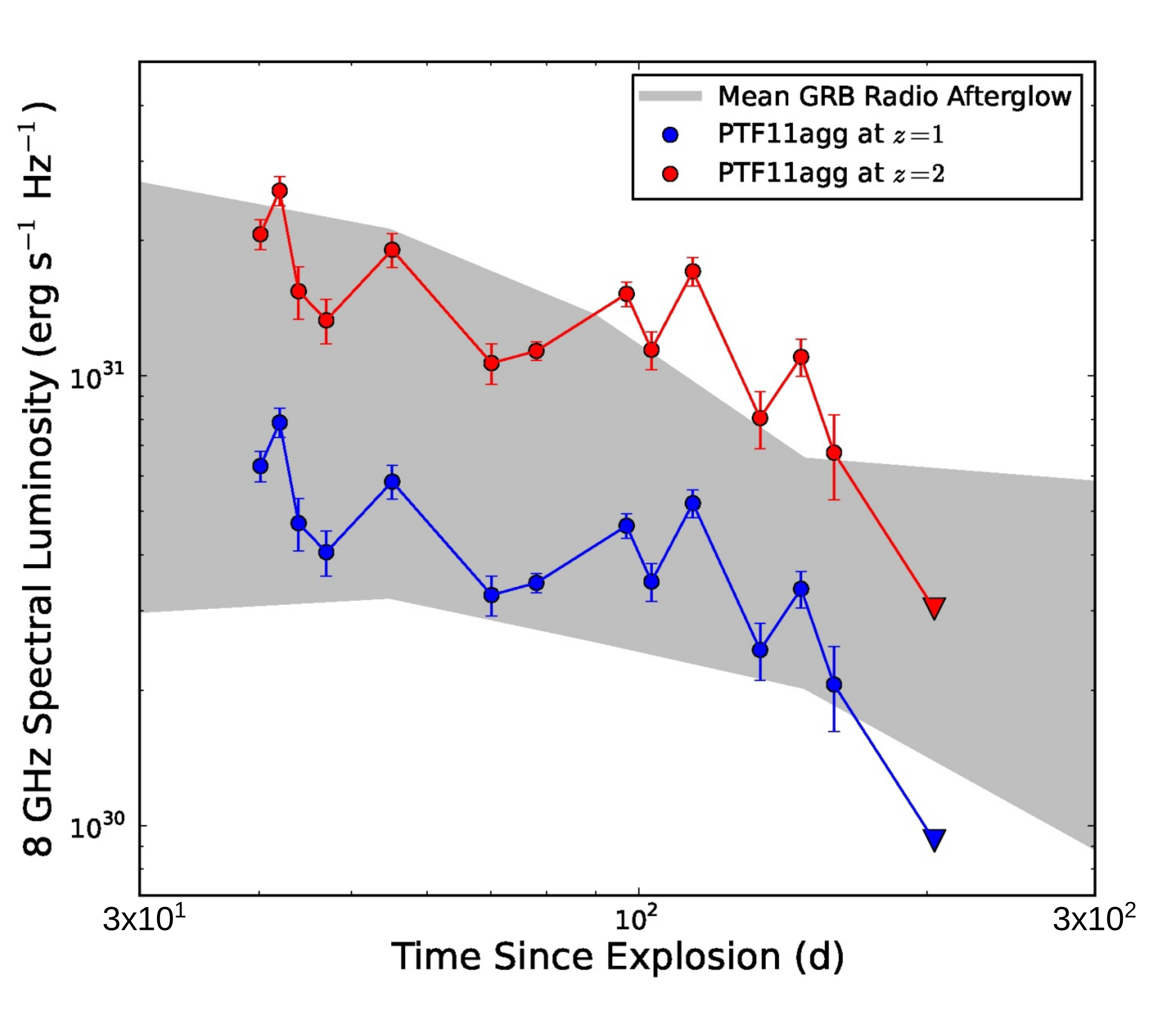
Arcavi+ in prep; Ofek+ in prep

PTF 11agg



Cenko et al., in prep.

PTF 11agg



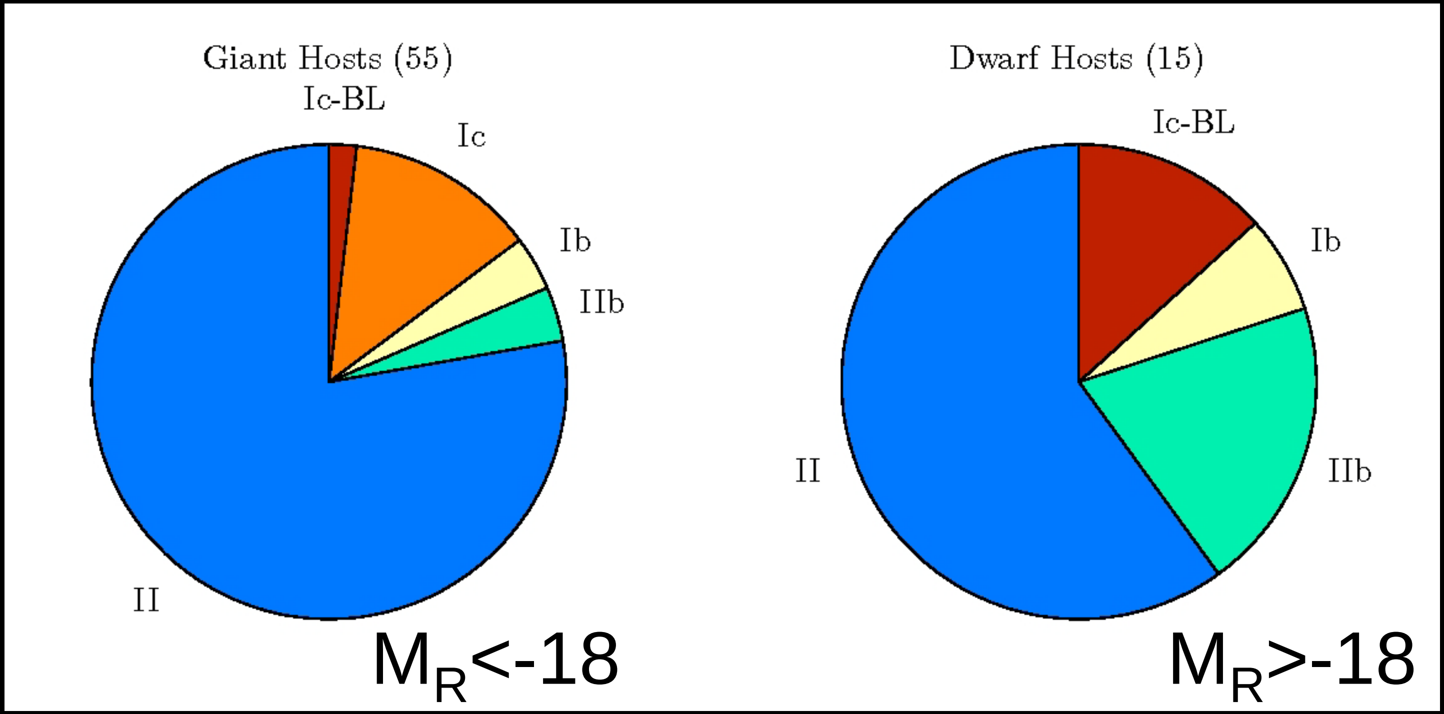
Cenko et al., in prep.

The hosts of CC SNe

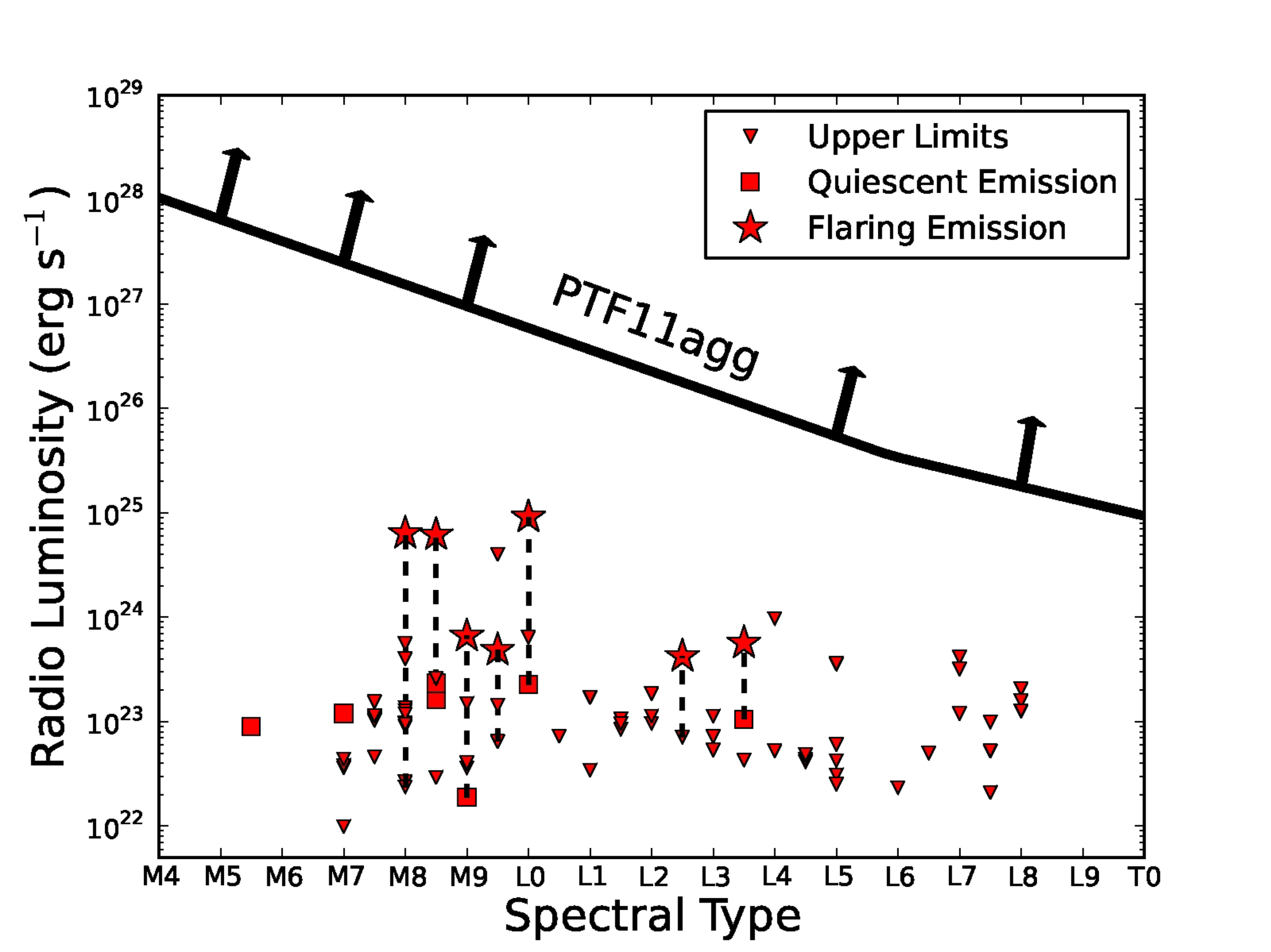
Arcavi et al. 2010

★ Ic-BL and IIb are more common in dwarf hosts, Stripped CC (Ic) are not seen in dwarf hosts.

Probably because in lower metallicity hosts, Metallicity-driven mass loss is reduced.



PTF 11agg

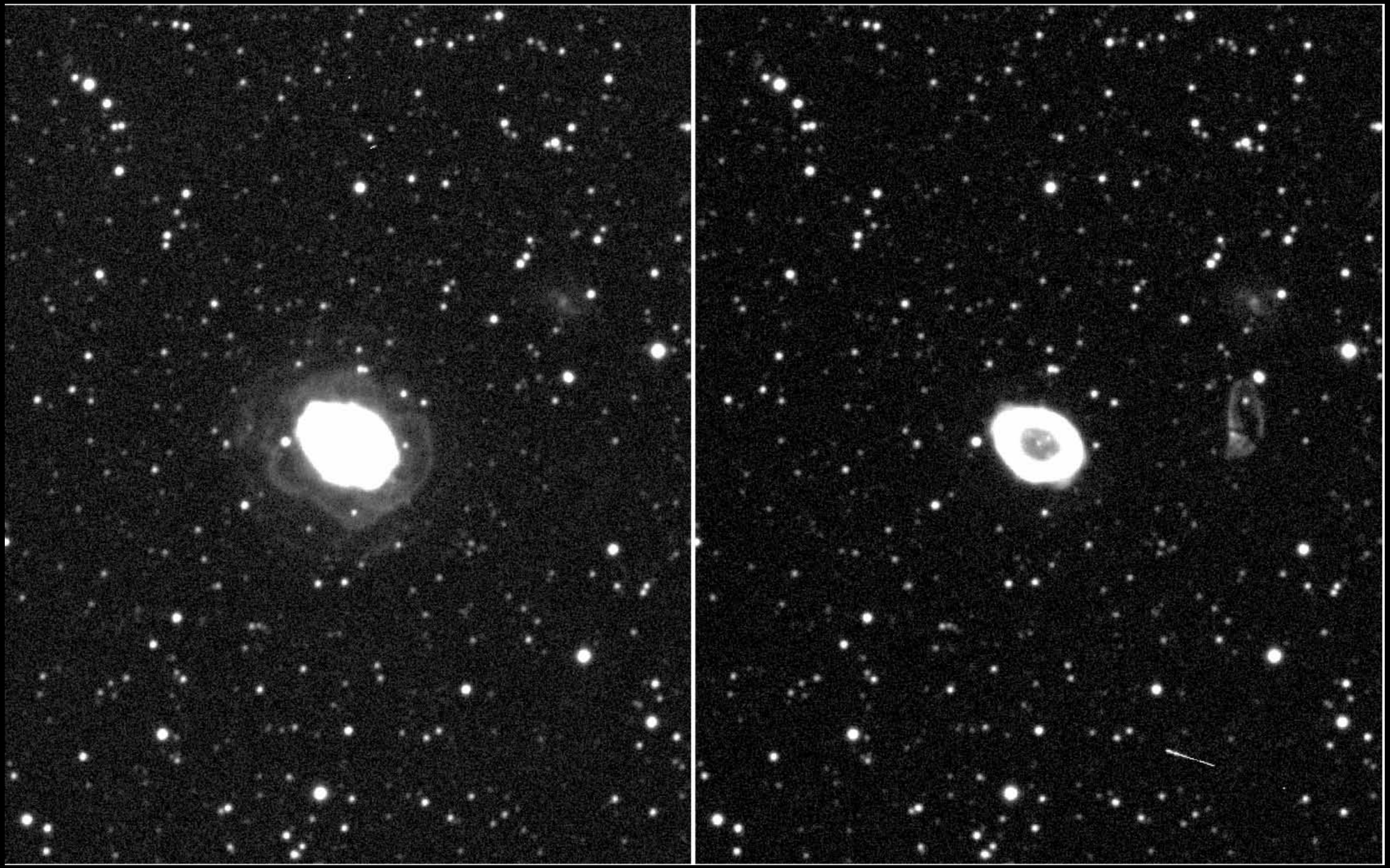


Cenko et al., in prep.

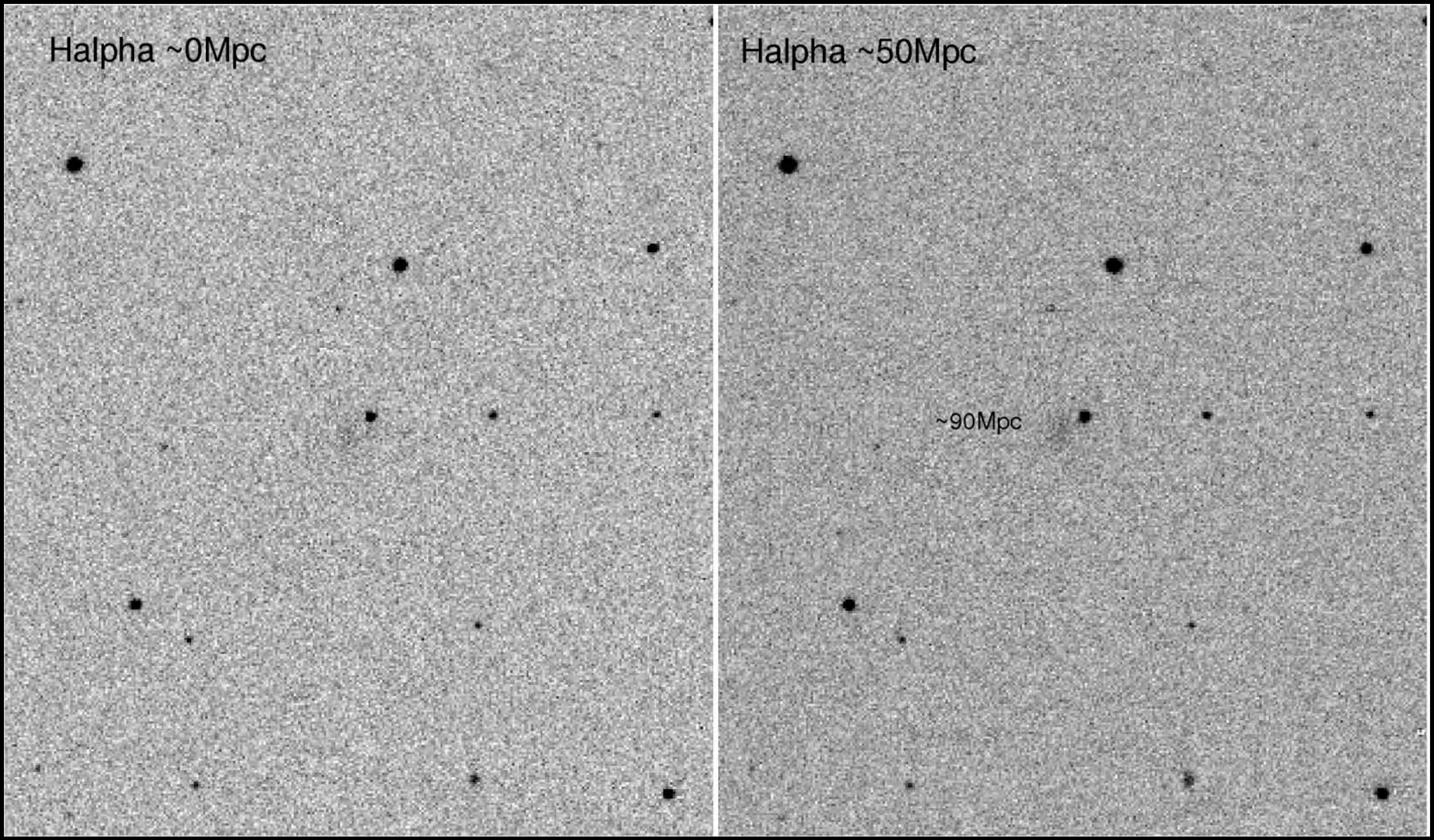
Shock breakout / Intro

- Photons first emerge from SN (breakout) when they diffuse ahead of the shock faster than the shock propogates
- Happens at optical depth: $\tau = c/v$
- duration: ~r/c
- Decay time: ~r/v

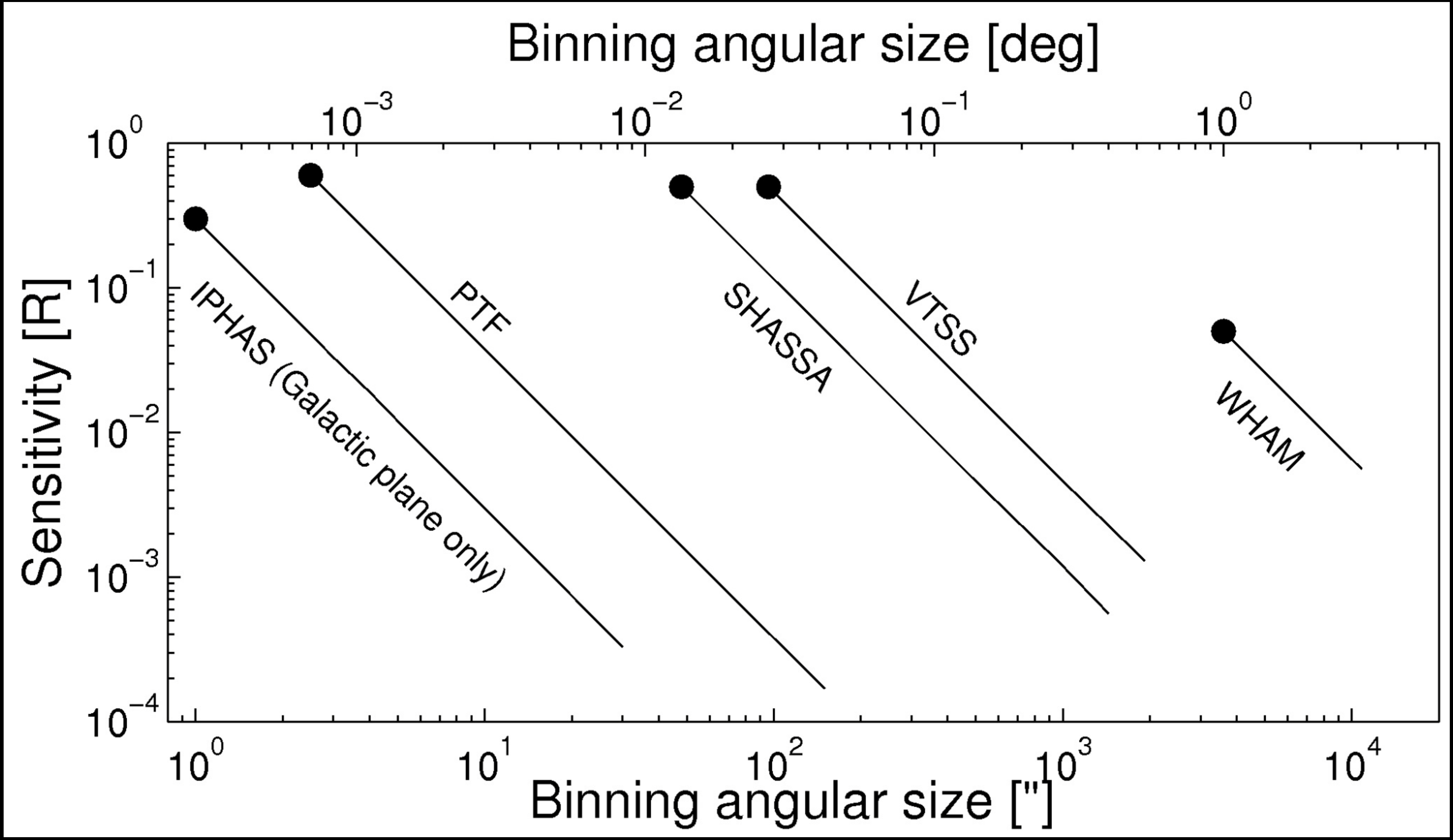
H alpha survey



H alpha survey



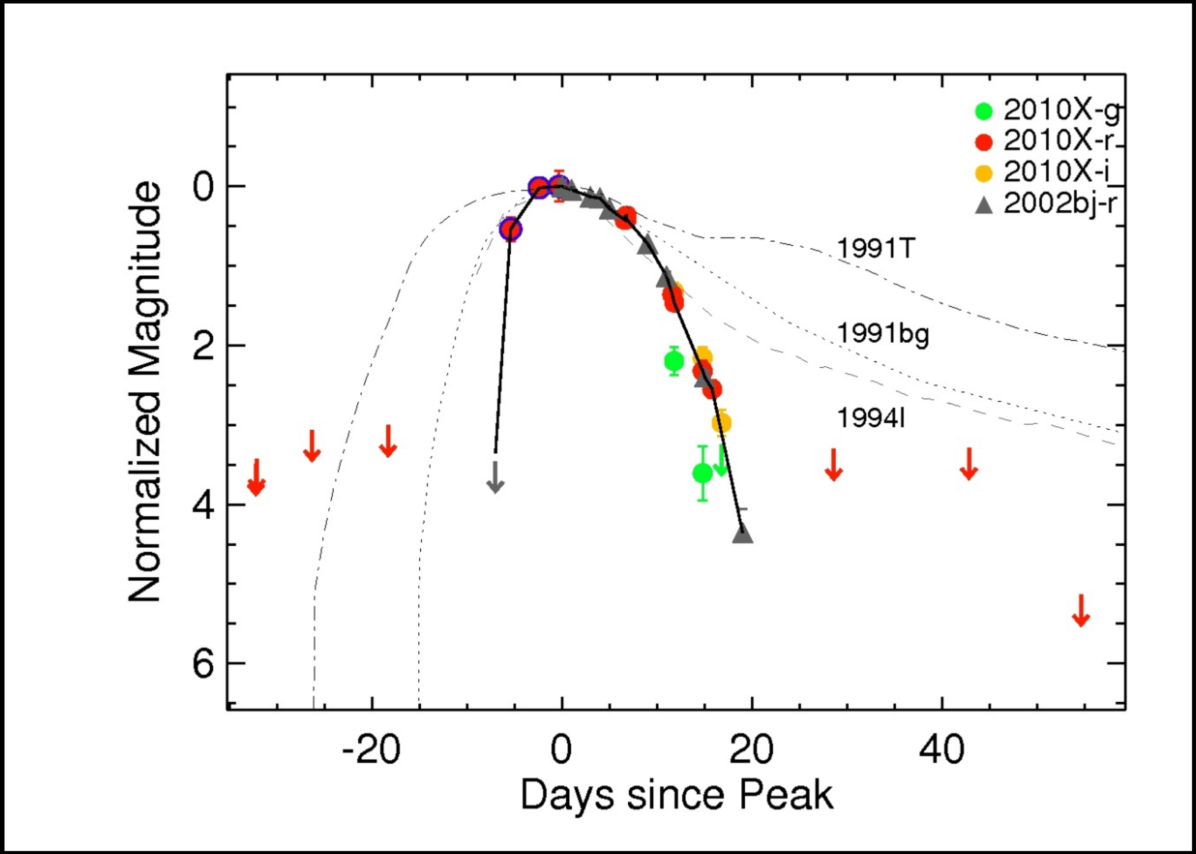
H alpha survey



Fast supernovae: 10bhp

Kasliwal et al., ApJ 723, 98

- Very fast: decay ~5 days, M_R~-17 (e.g., similar to SN200bj, [Poznanski+10])

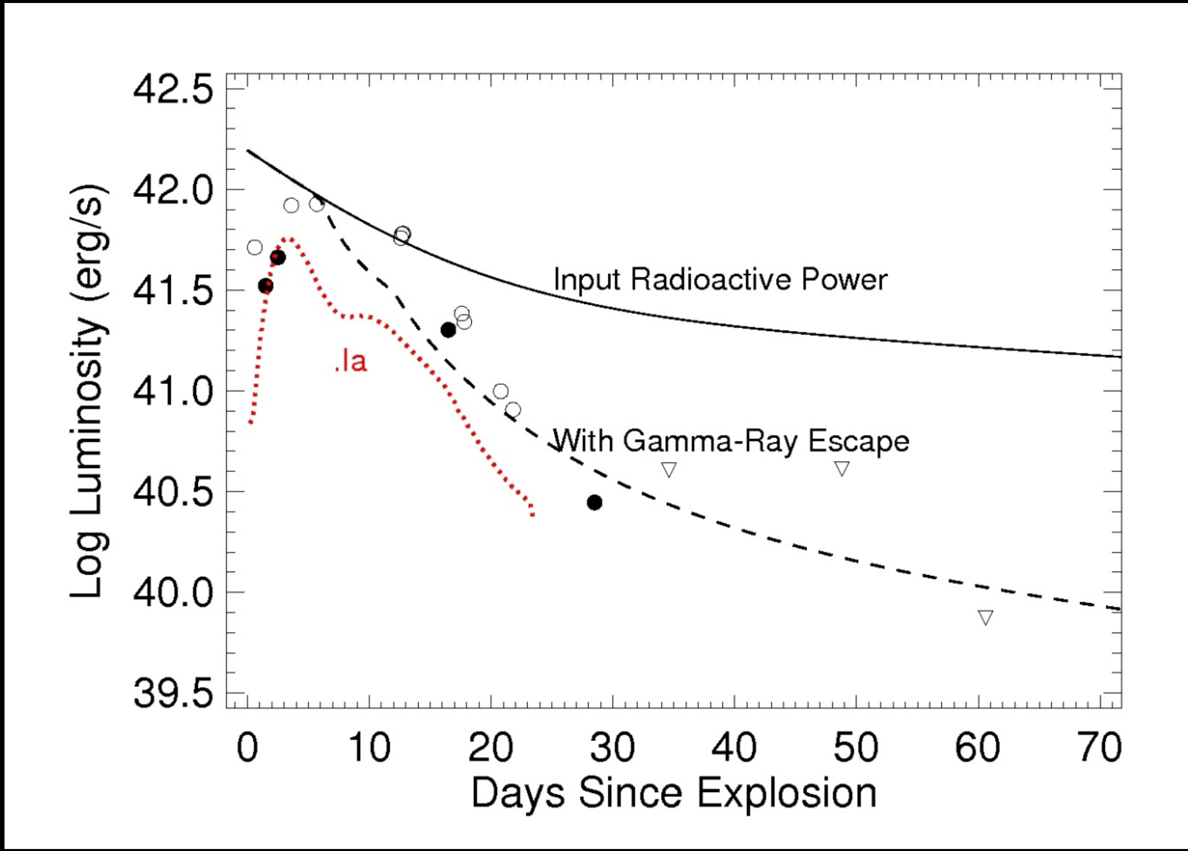


Fast supernovae: 10bhp

Kasliwal et al., ApJ 723, 98

- If powered by ^{56}Ni then Ni mass ~0.02 M_{sun} and SN quickly becomes optically thin to γ-rays.

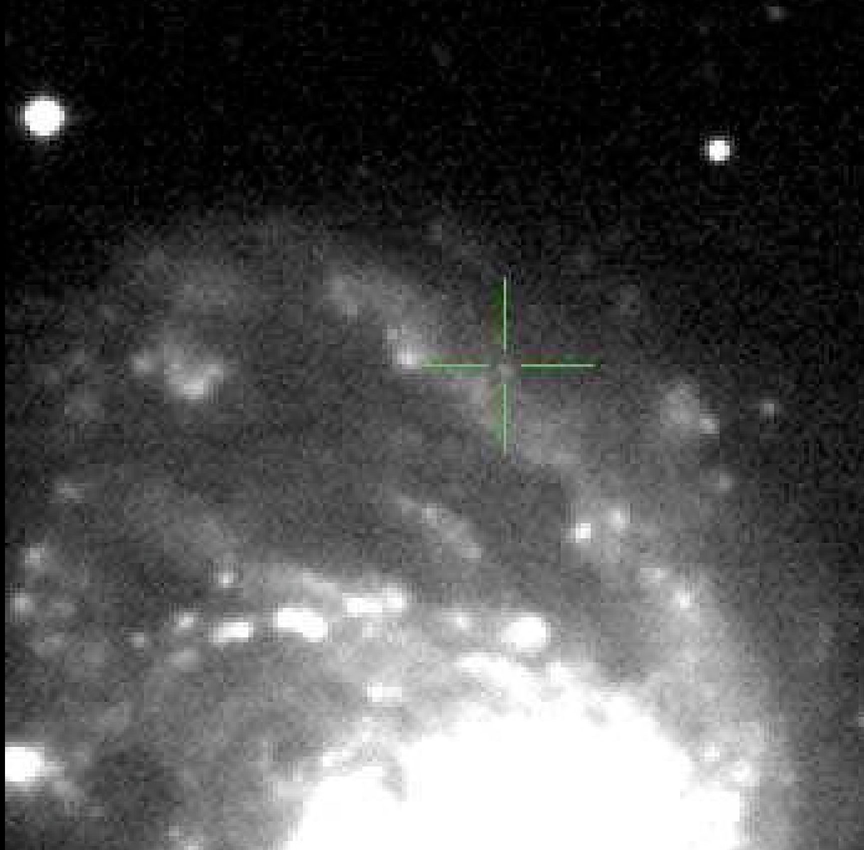
- AIC (?)
  .Ia (?)

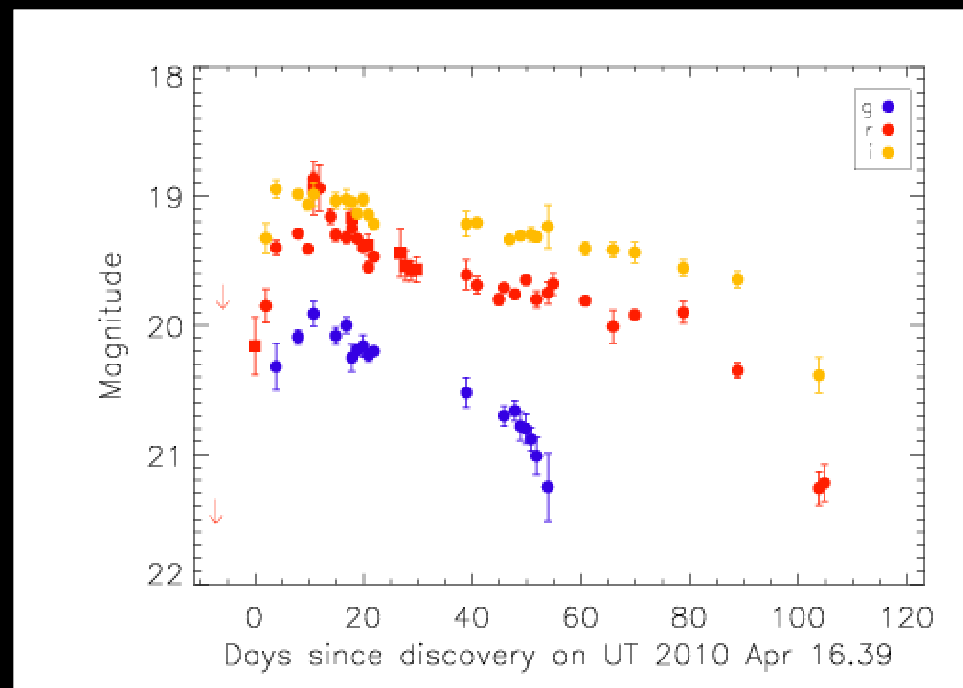


Luminous red nova
PTF 10fqs in M99

Kasliwal et al., 1005.1455

- ★ Faint/slow event in M99: M_R~-11

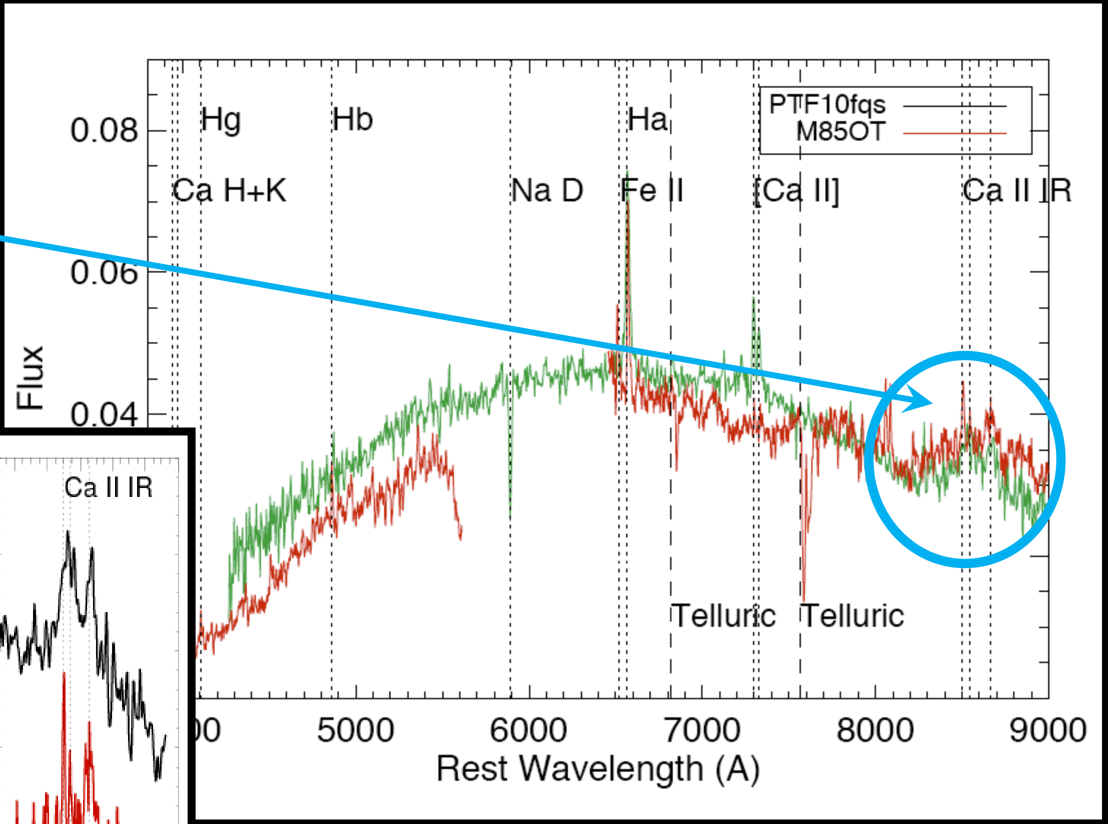


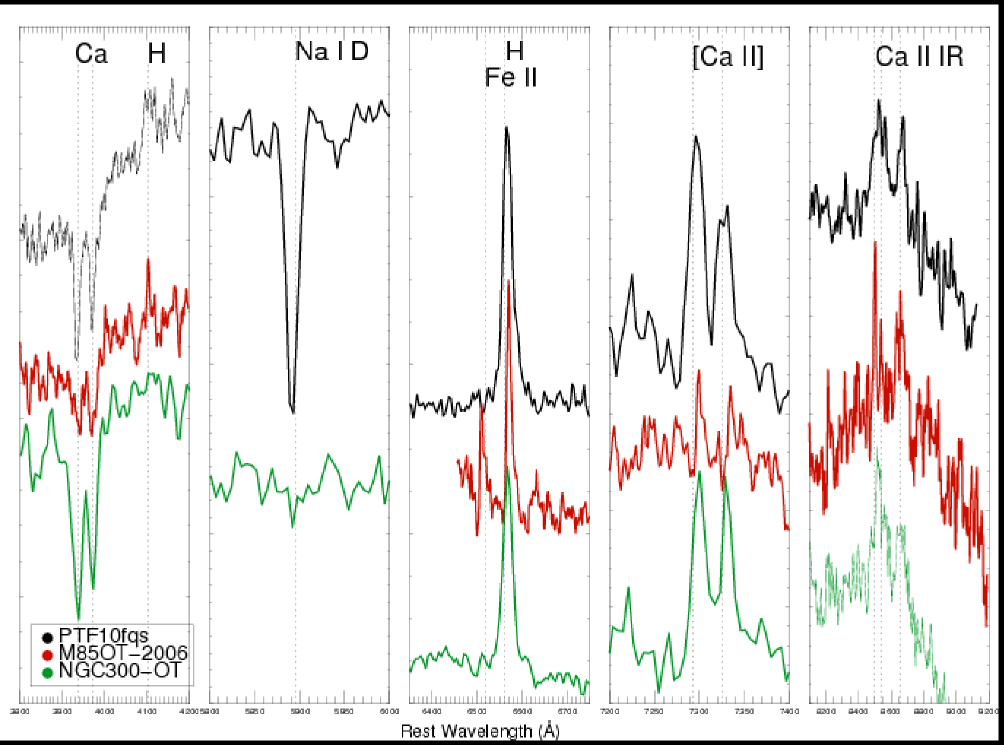


PTF 10fqs

Kasliwal et al., 1005.1455

~10,000 km/s (?)





Search for SB in Chandra archive

with Mike Muno

- Downloaded the entire Chandra archive
- Search for transients and highly variable Objects (on short time scale)

First pass completed:
complete for events brighter than 40 counts

No SN 2008D-like events (Soderberg et al. 2008)

Next: calc. efficiency and extend to faint sources

Relative photometry

Solution using linear least squares

Solving per field (overlap between fields not guaranteed)

i-star (1..p), j-image (1..q)

m_{ij} – instrumental mag

σ_{ij} – instrumental mag err

$$m_{ij} = \overline{m}_j + z_i$$

Relative photometry

Using linear least squares

$$m_{ij} = \overline{m}_j + z_i$$

$$\begin{vmatrix} 1 & 0 & 0 & \cdots & 1 & 0 & 0 & \cdots \\ 1 & 0 & 0 & \cdots & 0 & 1 & 0 & \cdots \\ 1 & 0 & 0 & \cdots & 0 & 0 & 1 & \vdots \\ \vdots & \vdots & \vdots & \ddots & \vdots & \cdots & & \ddots \end{vmatrix} \vec{P} \cong \begin{vmatrix} m_{11} \\ m_{12} \\ m_{13} \\ \vdots \end{vmatrix}$$

$$\begin{vmatrix} 0 & 1 & 0 & \cdots & 1 & 0 & 0 & \cdots \\ 0 & 1 & 0 & \cdots & 0 & 1 & 0 & \cdots \\ 0 & 1 & 0 & \cdots & 0 & 0 & 1 & \vdots \\ \vdots & \vdots & \vdots & \ddots & \vdots & \cdots & & \ddots \end{vmatrix} \quad \begin{vmatrix} m_{21} \\ m_{22} \\ m_{23} \\ \vdots \end{vmatrix}$$

$$\vdots$$

H ("design matrix")

Observations

$$\vec{P} = \begin{vmatrix} \vdots \\ z_j \\ \vdots \\ \vdots \\ \overline{m}_i \\ \vdots \\ ? \\ ? \\ ? \end{vmatrix}$$

Free parameters

Relative photometry

Solution using linear least squares

$$m_{ij} = \overline{m}_j + z_i$$

We need to solve (in the presence of errors):

$$\chi^2 = (\vec{m}_{ij} - HP)^T \left|\sigma_{ij}^2\right|^{-1} (\vec{m}_{ij} - HP)$$

Relative photometry

Simultaneous absolute calibration

$$\begin{vmatrix} 1 & 0 & 0 & \cdots & 1 & 0 & 0 & \cdots \\ 1 & 0 & 0 & \cdots & 0 & 1 & 0 & \cdots \\ 1 & 0 & 0 & \cdots & 0 & 0 & 1 & \vdots \\ \vdots & \vdots & \vdots & \ddots & & \vdots & \cdots & \ddots \end{vmatrix} \vec{P} \cong \begin{vmatrix} m_{11} \\ m_{12} \\ m_{13} \\ \vdots \end{vmatrix}$$

$$\begin{vmatrix} 0 & 1 & 0 & \cdots & 1 & 0 & 0 & \cdots \\ 0 & 1 & 0 & \cdots & 0 & 1 & 0 & \cdots \\ 0 & 1 & 0 & \cdots & 0 & 0 & 1 & \vdots \\ \vdots & \vdots & \vdots & \ddots & & \vdots & \cdots & \ddots \end{vmatrix} \qquad \begin{vmatrix} m_{21} \\ m_{22} \\ m_{23} \\ \vdots \end{vmatrix}$$

$$\vdots$$

H is (pq)x(p+q) matrix
However, rank is p+q-1

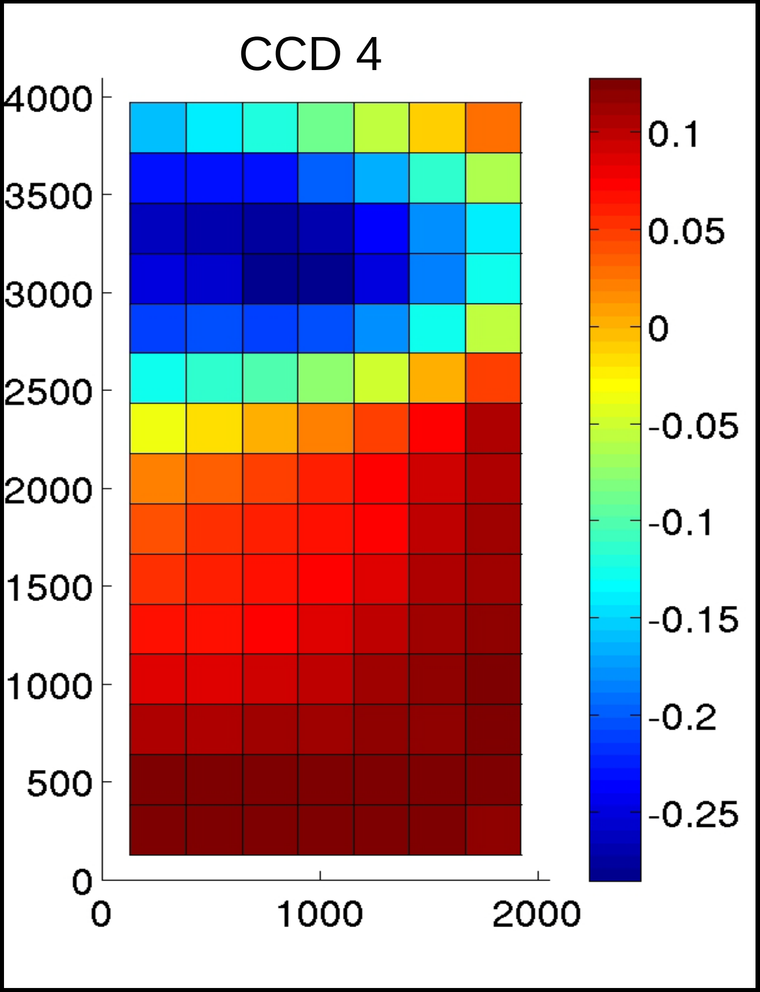
$$\begin{vmatrix} 0 & 0 & 0 & \cdots & 1 & 0 & 0 & \cdots \\ 0 & 0 & 0 & \cdots & 0 & 1 & 0 & \cdots \\ 0 & 0 & 0 & \cdots & 0 & 0 & 1 & \vdots \\ \vdots & \vdots & \vdots & \ddots & & \vdots & \cdots & \ddots \end{vmatrix} \qquad \begin{vmatrix} M_1 \\ \vdots \\ M_j \\ \vdots \end{vmatrix}$$

Adding calibration block

Calibrated photometry

Ofek et al. 2011 submitted

- Photometry calibration good to 2-3%
- Using SDSS stars as standard stars to calibrate fields outside SDSS footprint (photometric nights)



Relative photometry

Additional de-trending

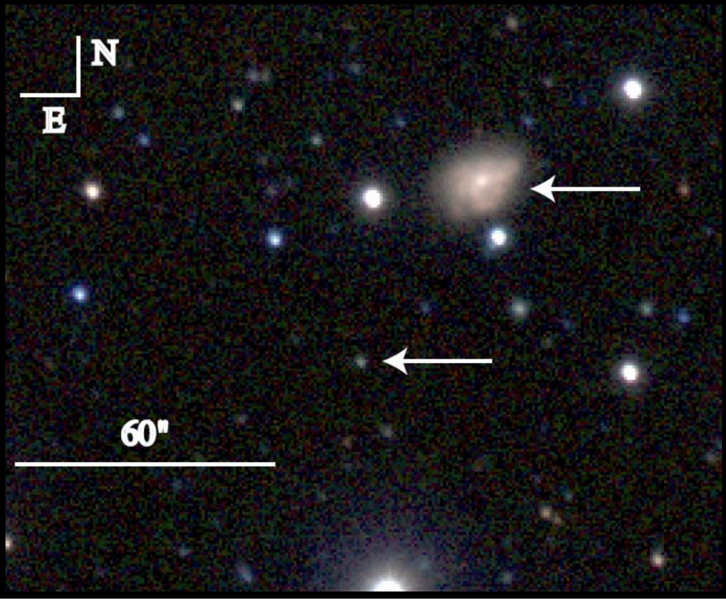
We can add more columns to H and P.
For example:

Airmass x color term ← Δm_b^{obs}

Positional terms

Multiple CCDs (i.e, overlap)

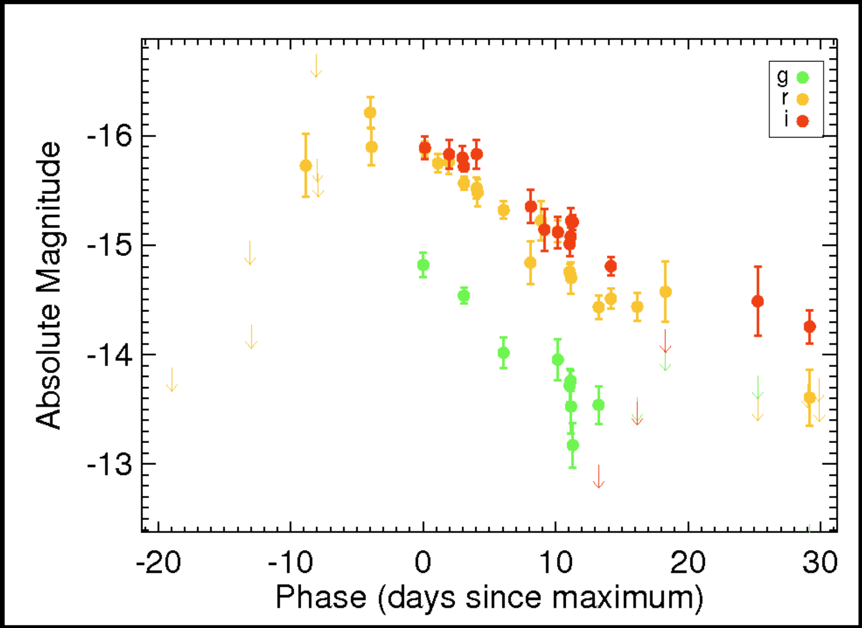
The SN2005E family: 09dav

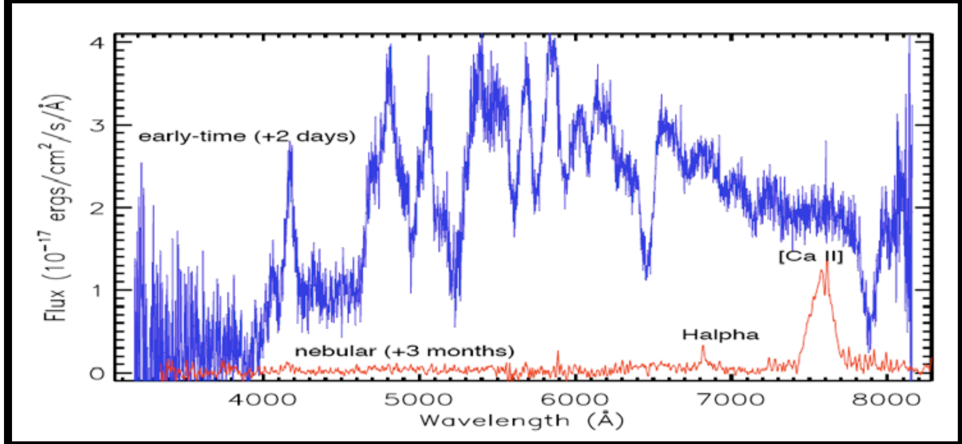


40kpc from putative spiral host
Abs R mag ~-15
Fast: 1 mag in 10 day
Very red, g-r = 1.2

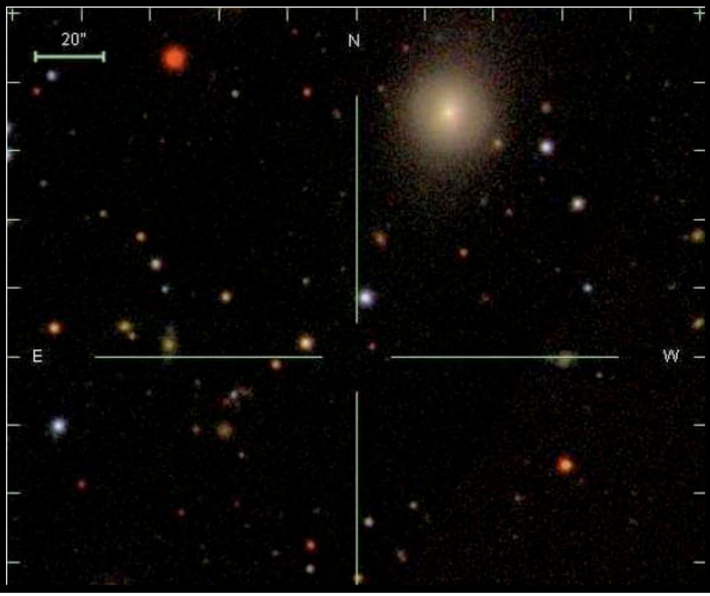
Similar to SN1991bg but with He
Hydrogen in nebular phase

Kasliwal et al., in prep.
Sullivan et al., in prep.





The SN2005E family: 10iuv



37 kpc from putative host
Abs R. mag ~ -15.
Fast: 1 mag in 10 days
Intriguing Nebular Spectra

Kasliwal et al., in prep.