RELATIVISTIC EXPLOSIONS WITH THE PALOMAR TRANSIENT FACTORY

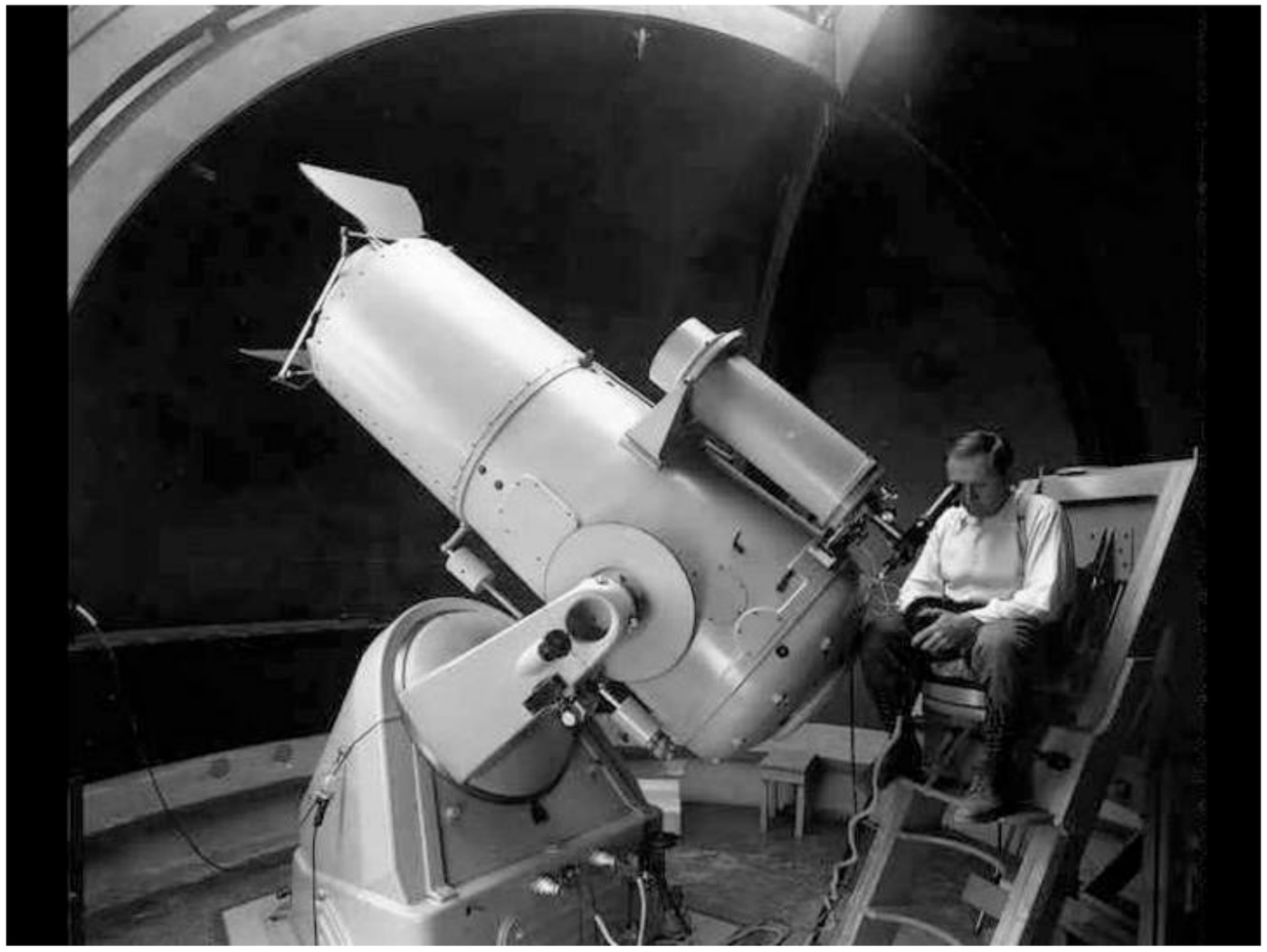
photograph: Iair Arcavi

LEO SINGER lsinger@caltech.edu

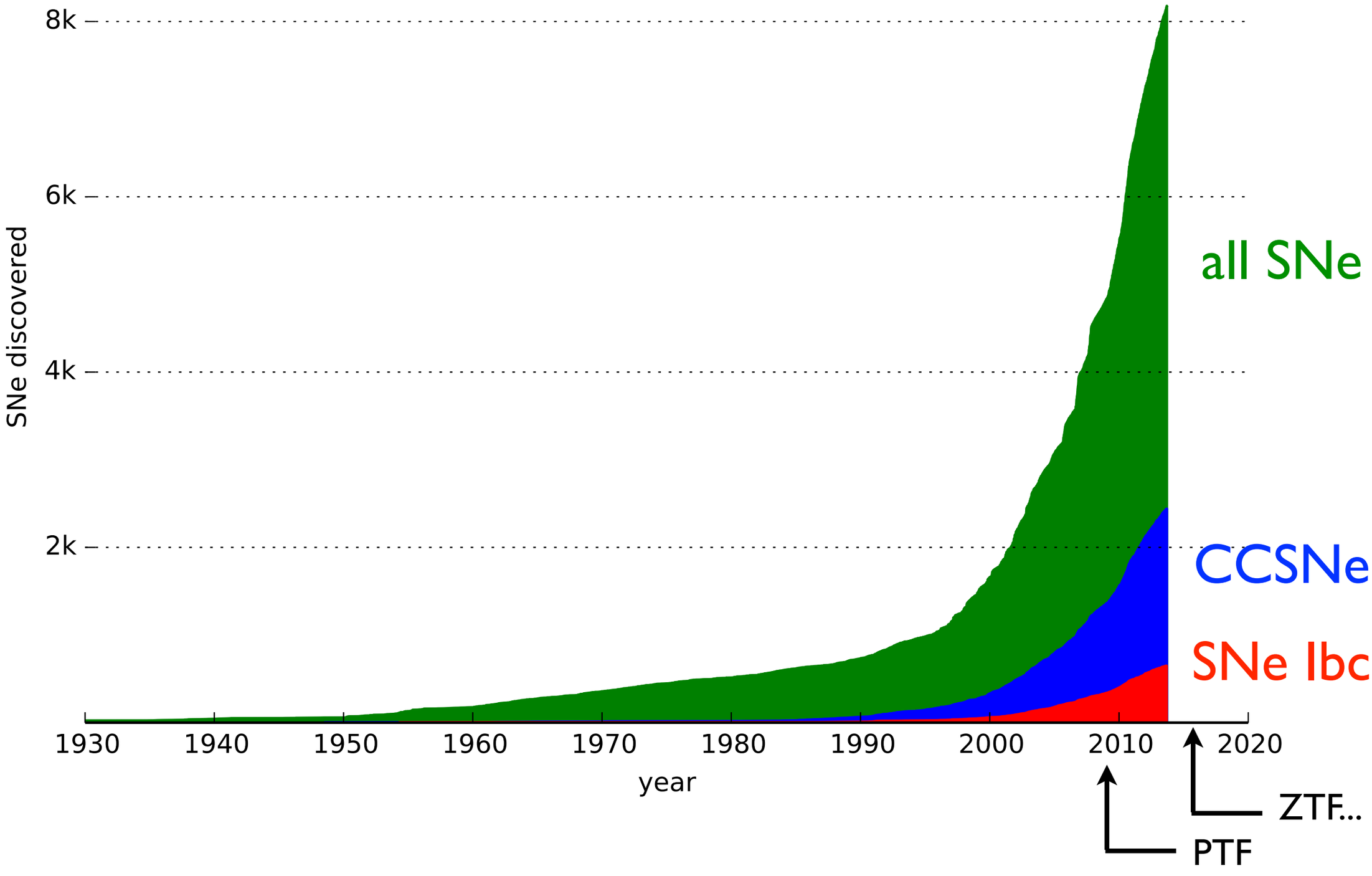
on behalf of the PTF collaboration

Moscow, Russia / 7 Oct 2013

Palomar Transient Factory



The Pace of Discovery



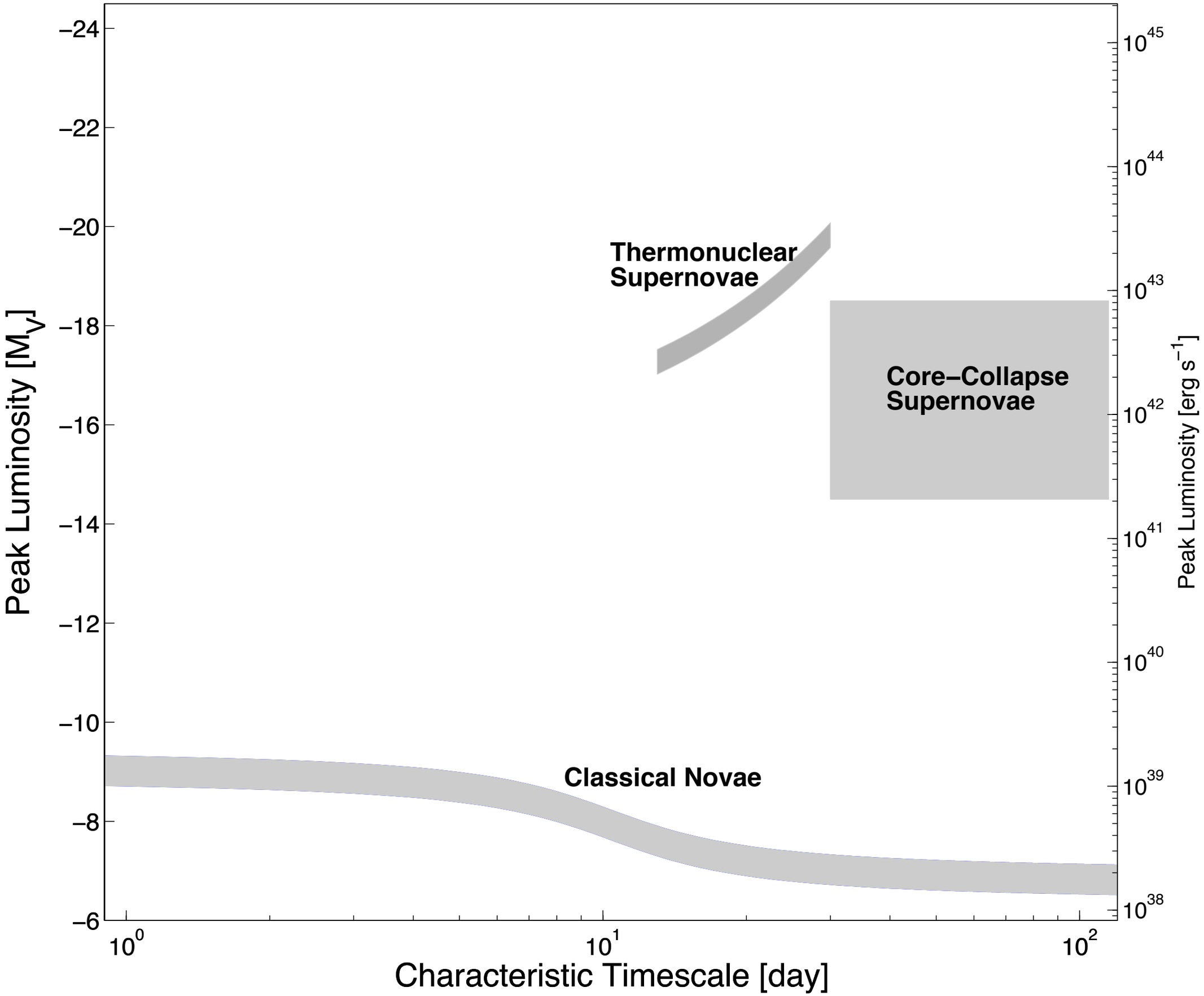


Image: M. Kasliwal

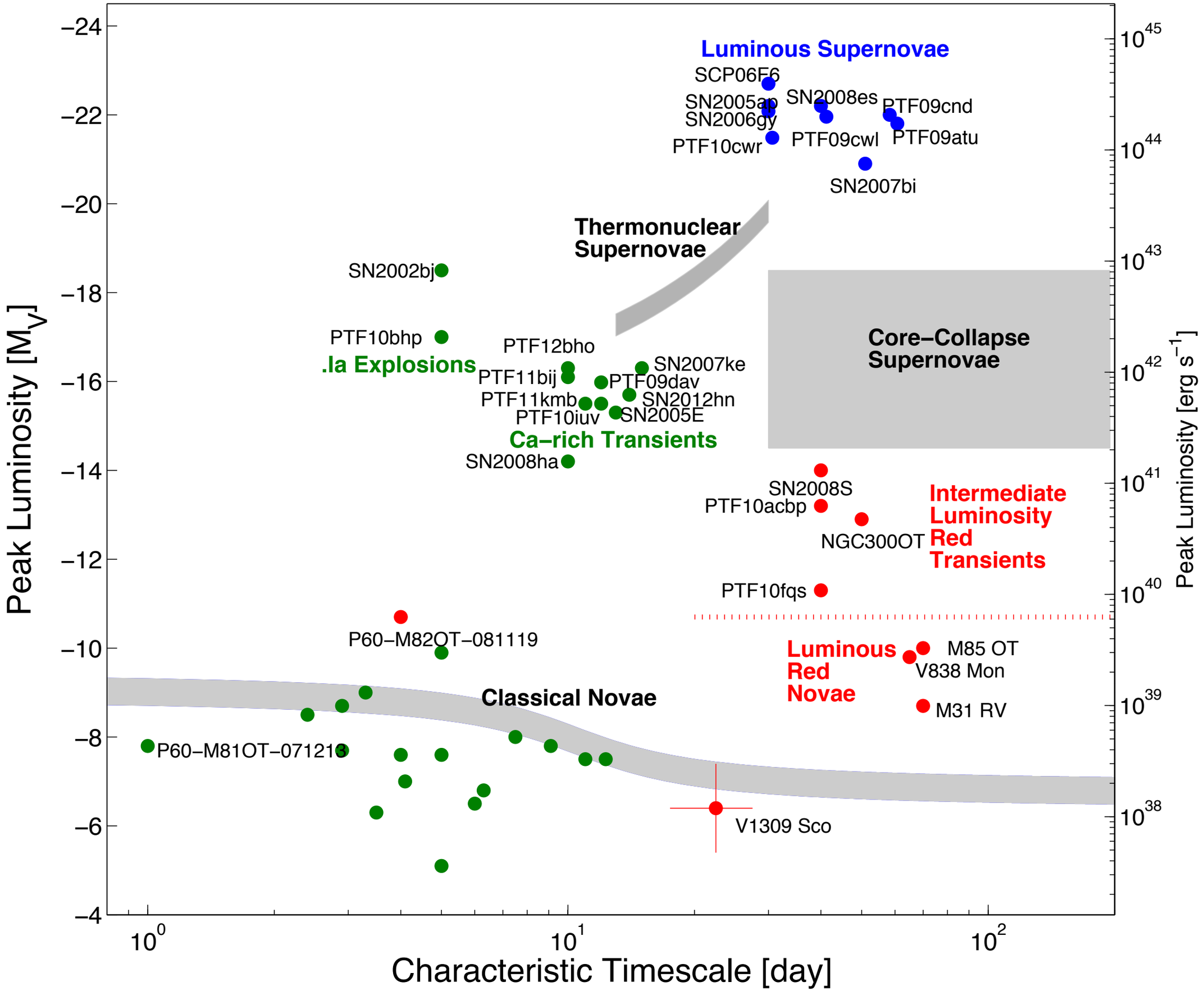


Image: M. Kasliwal

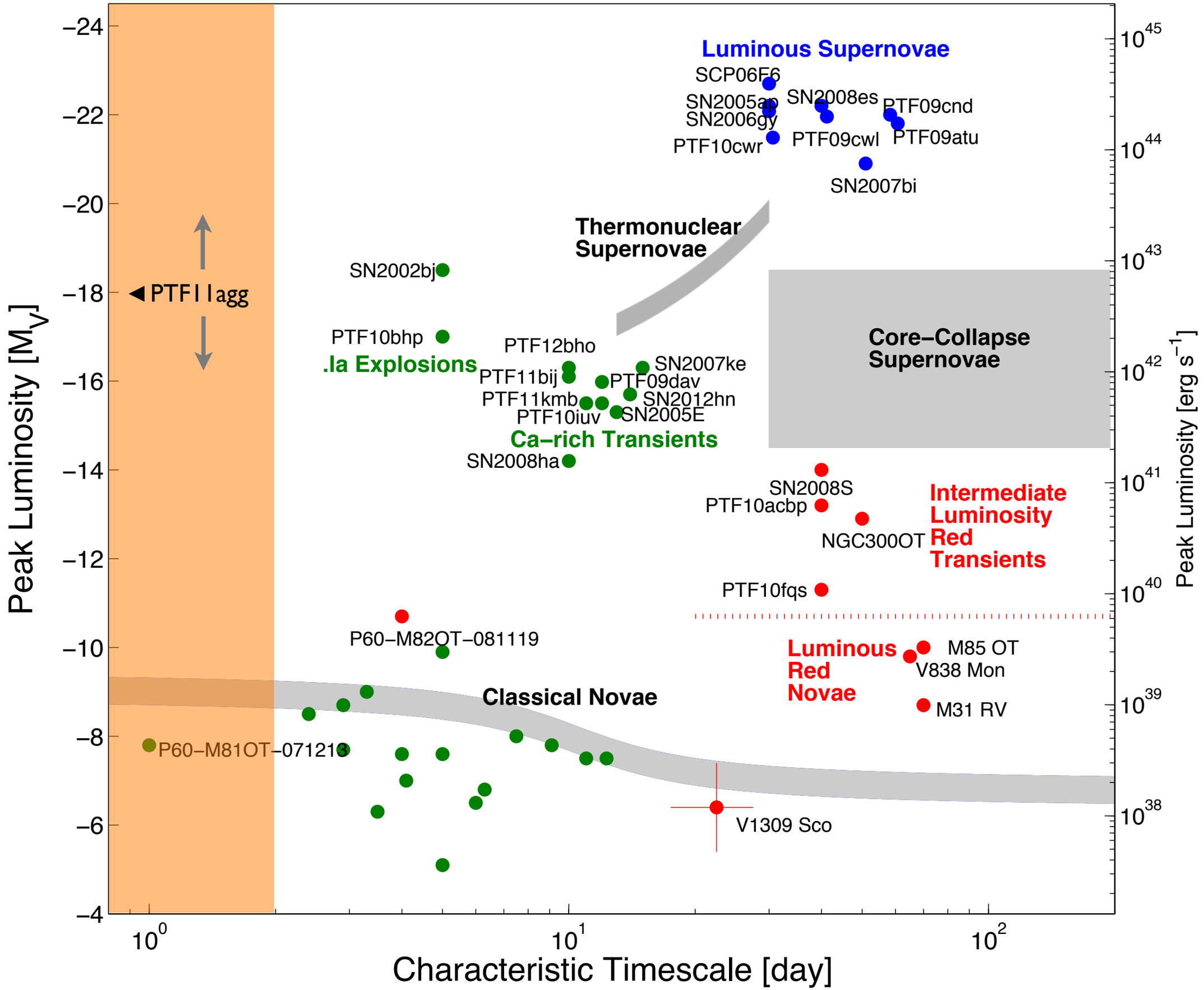


Image: E. Bellm, M. Kasliwal

image credit: Palomar Observatory, Caltech; legend: E. Bellm

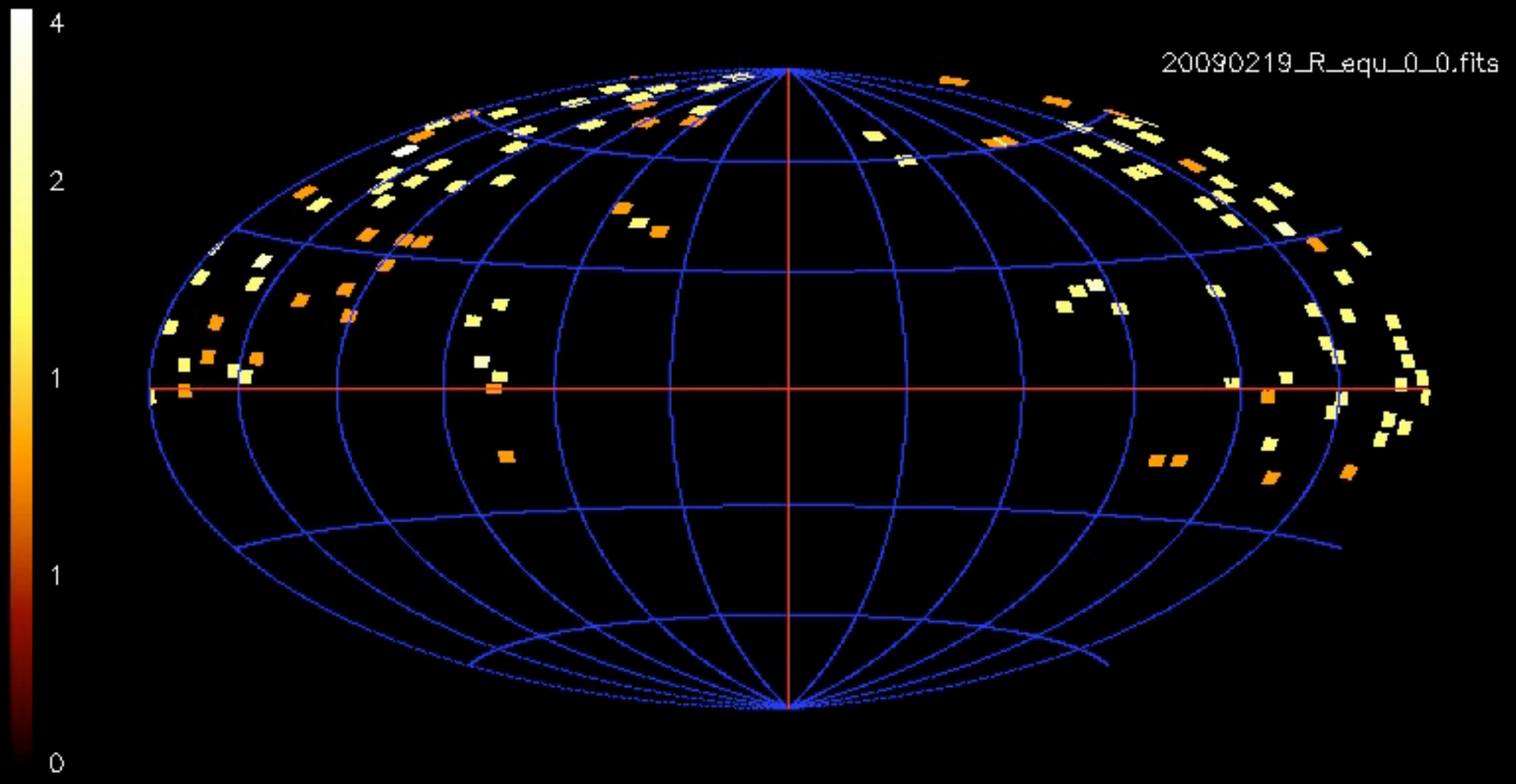
Palomar Transient Factory:

the assembly line

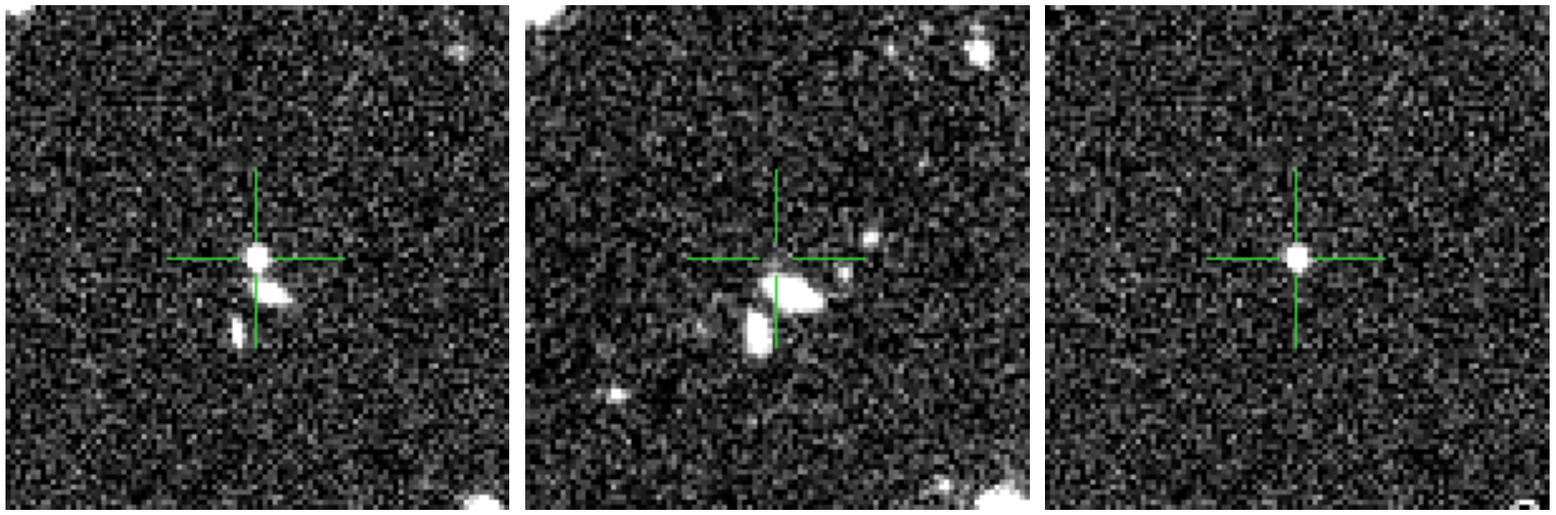
P48 Survey telescope (≈7 deg^2 FOV, R≈20.6 mag in 60 s)

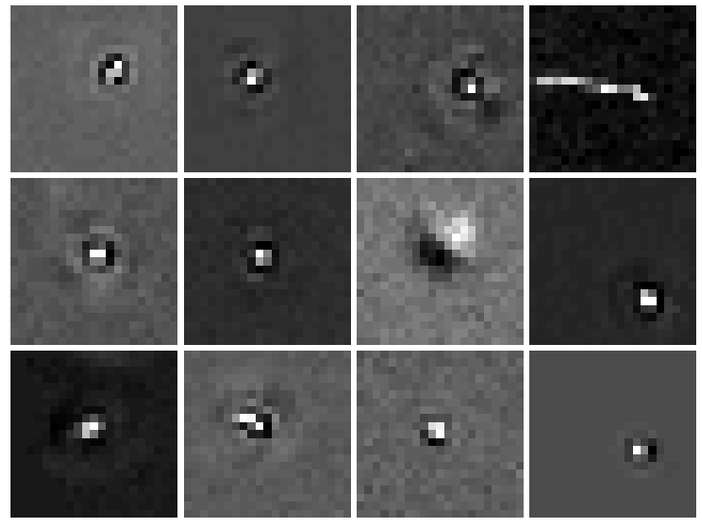
P60 Robotic, photometric follow-up

P200 Spectroscopy, classification→SED machine


20090219_R_equ_0_0.fits
4
2
1
1
0

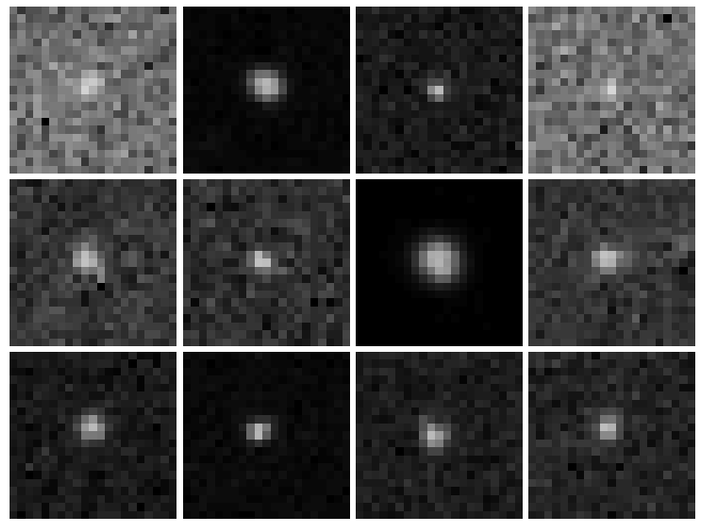
NEW REF SUB





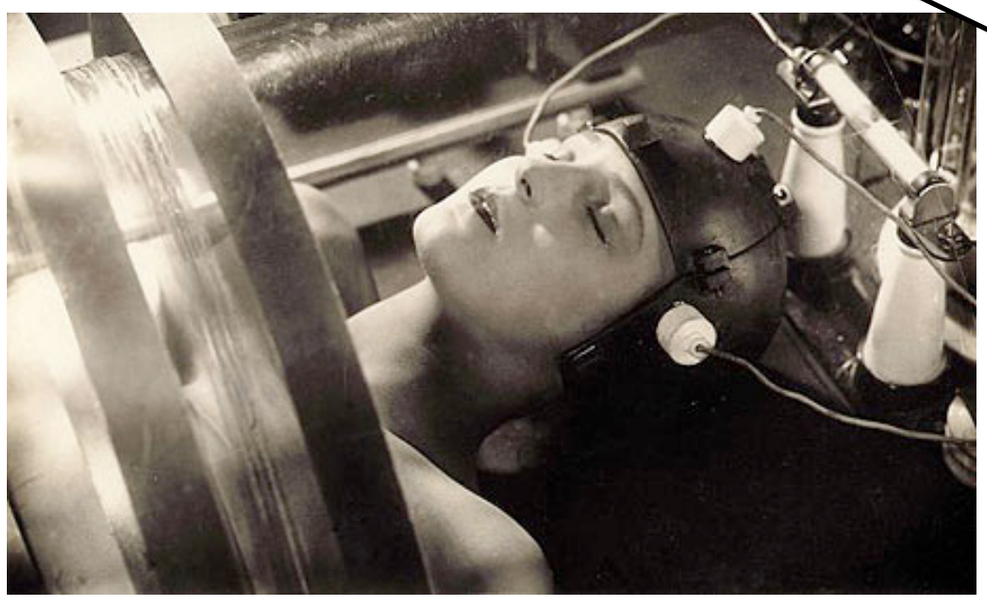
Visit same tiles again and again,

subtract deep co-adds from new images



Machine learning: real or bogus?

Brink et al. 2012, arXiv:1209.3775



Human + machine

follow-up target selection

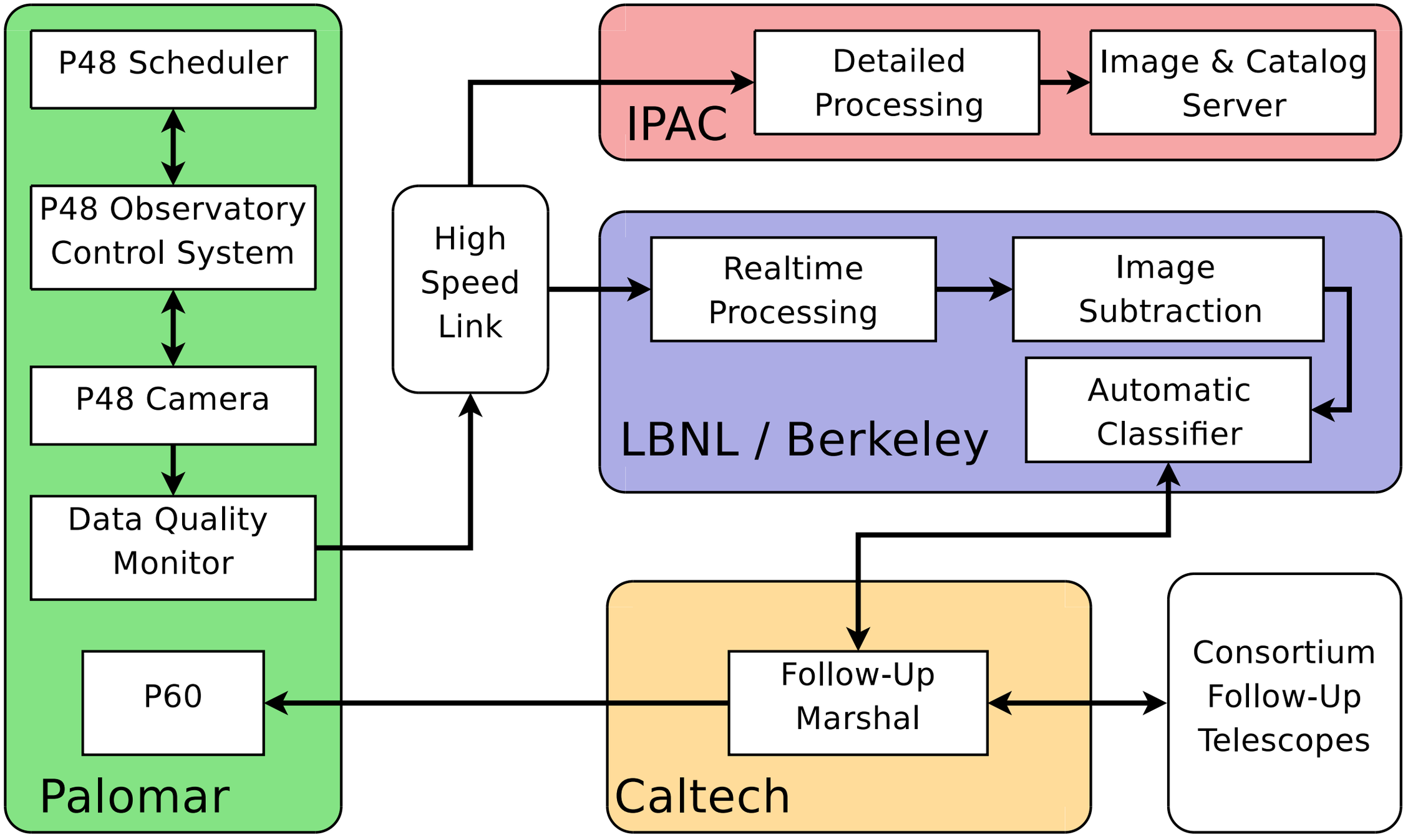
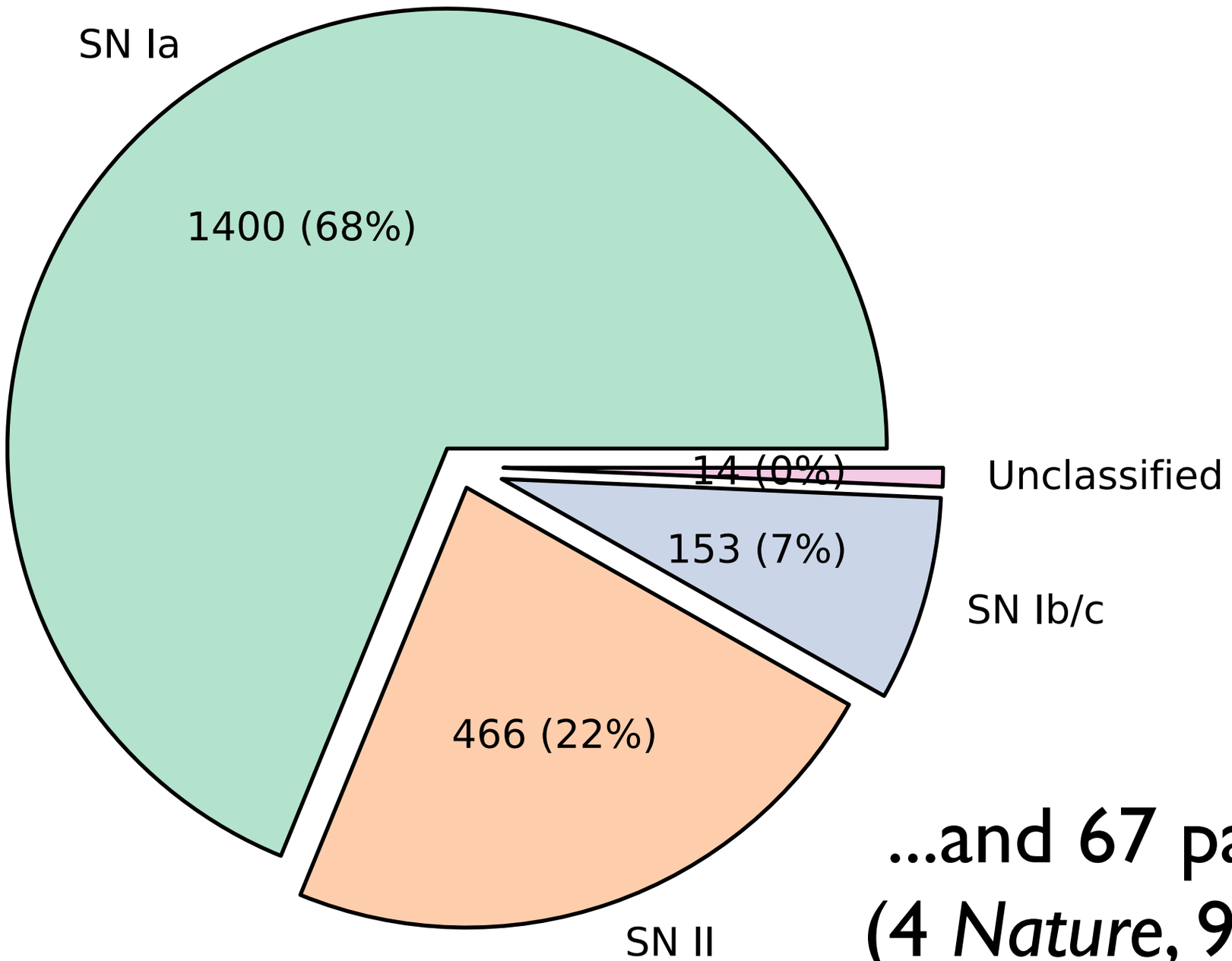
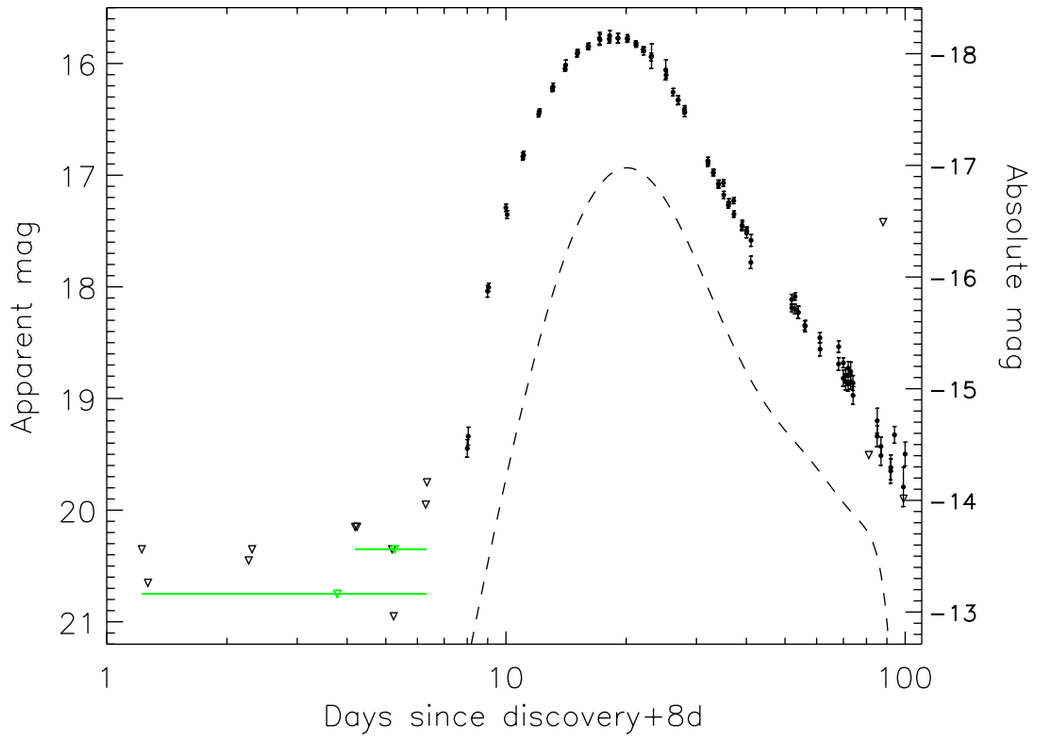


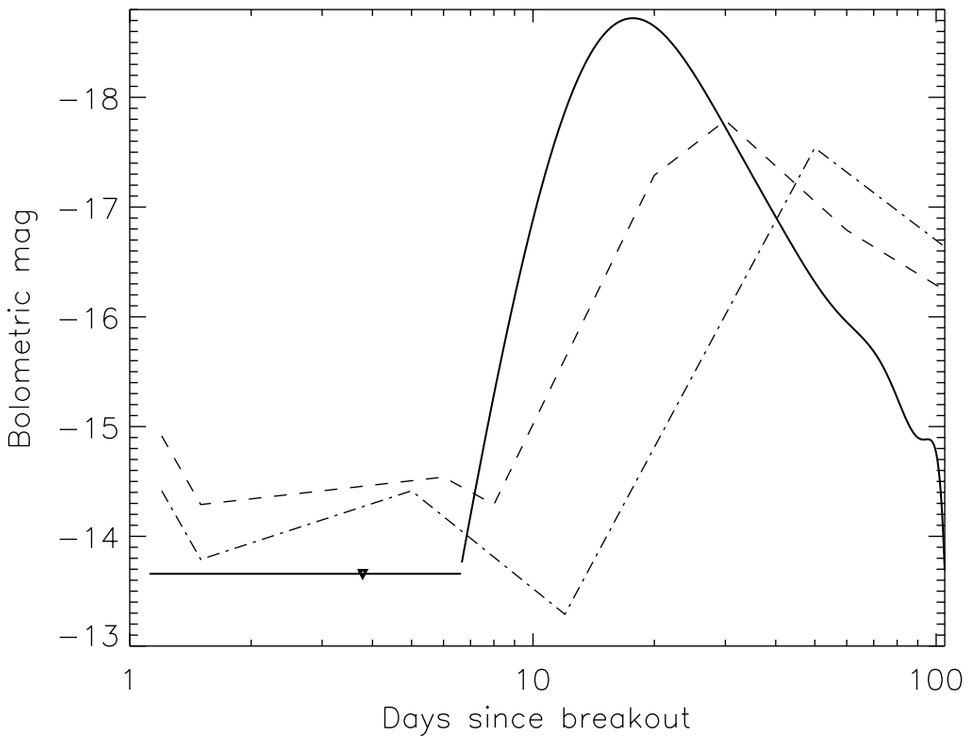
image credit: Law et al. (2009, PASP 121, 1395)

2,034 PTF Discoveries to Date



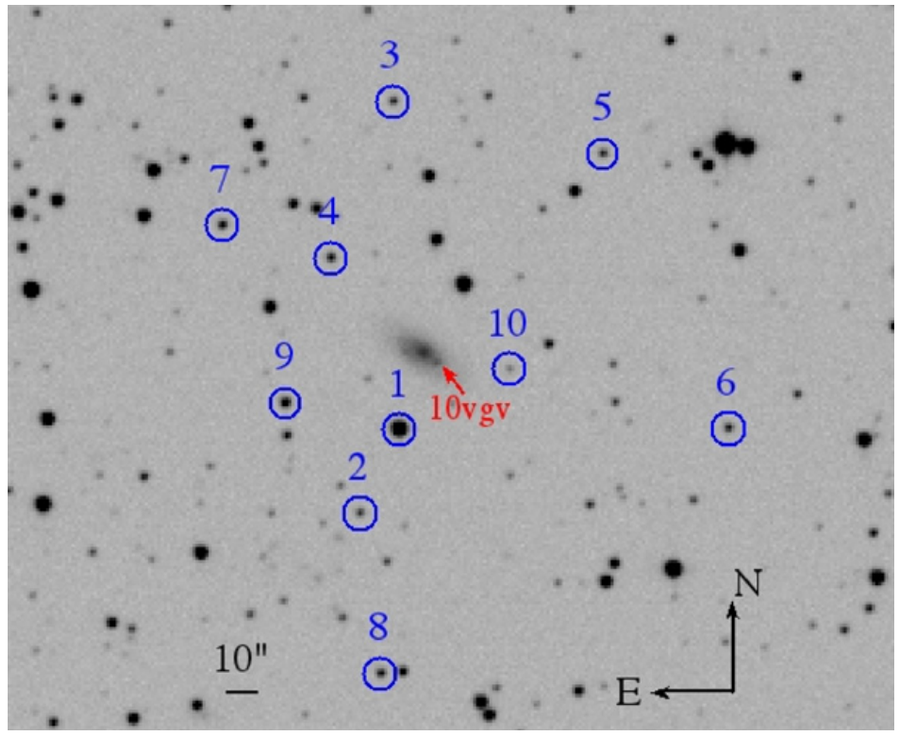
...and 67 papers
(4 *Nature*, 9 *ApJL*)





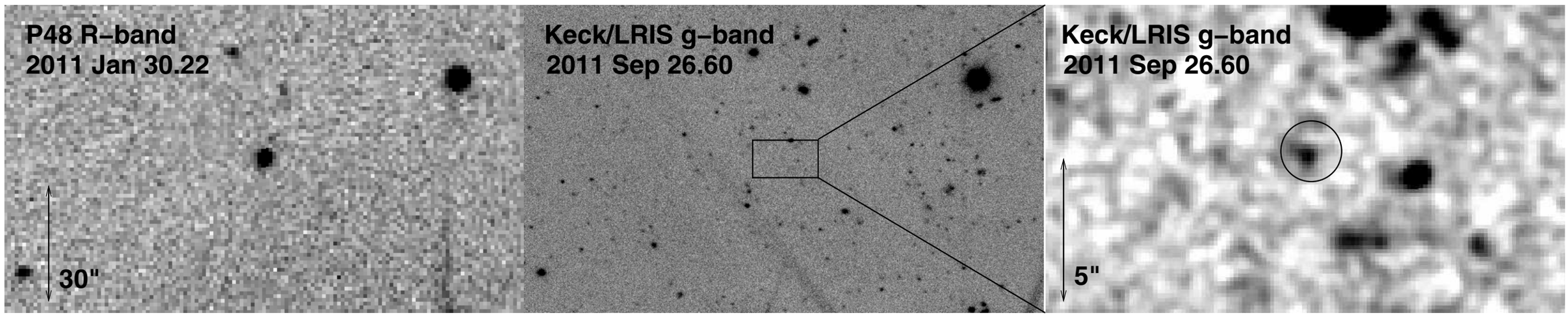
PTF 10vgv

SN Ic with evidence for a compact Wolf-Rayet progenitor



Corsi et al. (2013, ApJL 747, 5)

PTF11agg, an orphan afterglow?



Cenko et al. (2013, ApJ 769, 130)

PTF11agg light curve

- Detected in 11 intra-night visits of Praesepe cluster
- Bright
  R_{max}=18.3 mag
- Fades rapidly
  ΔR=4 mag in 2 days
- No GRB detected!
- No GRB detected!
- Quiescent optical source
- Long-lived radio source

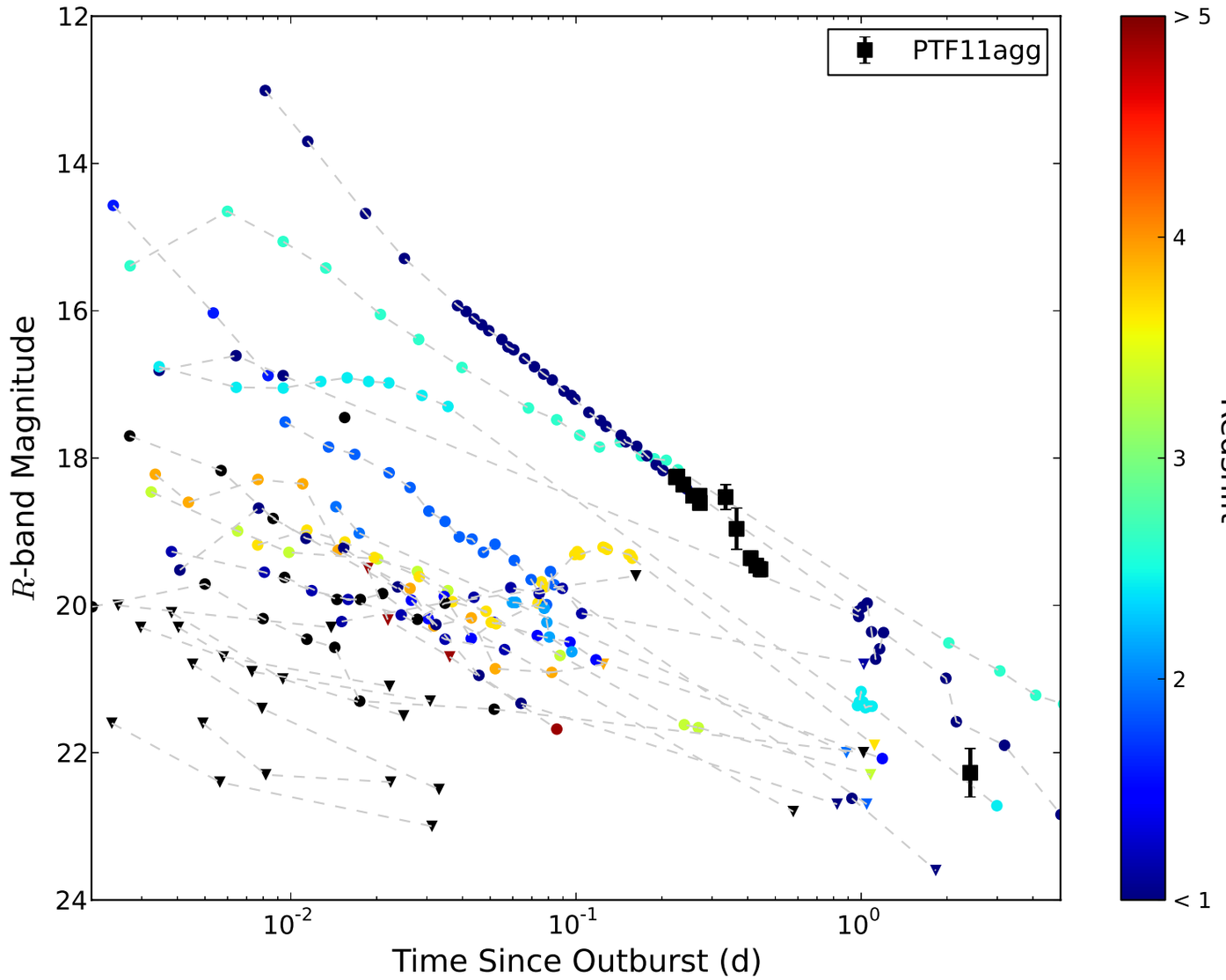


image credit: Cenko et al. (2013)

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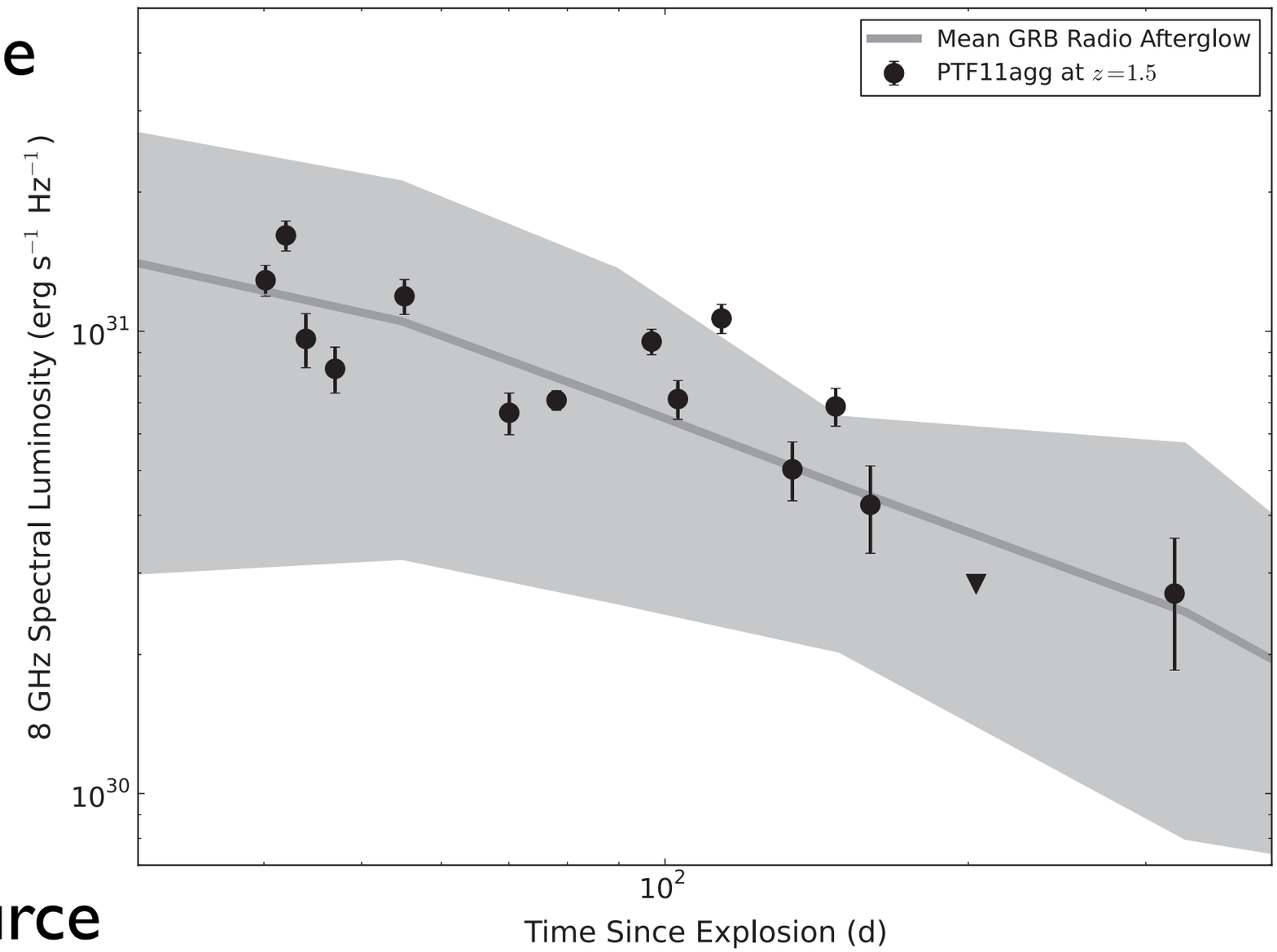


image credit: Cenko et al. (2013)

Galactic stellar flare? Probably not.

Quiescent source too faint to be a galactic main sequence star.

Black: Luminosity of observed radio source, assuming minimum distance for non-detection in NIR of a quiescent source of that spectral type

Red: radio luminosities of ultracool stars

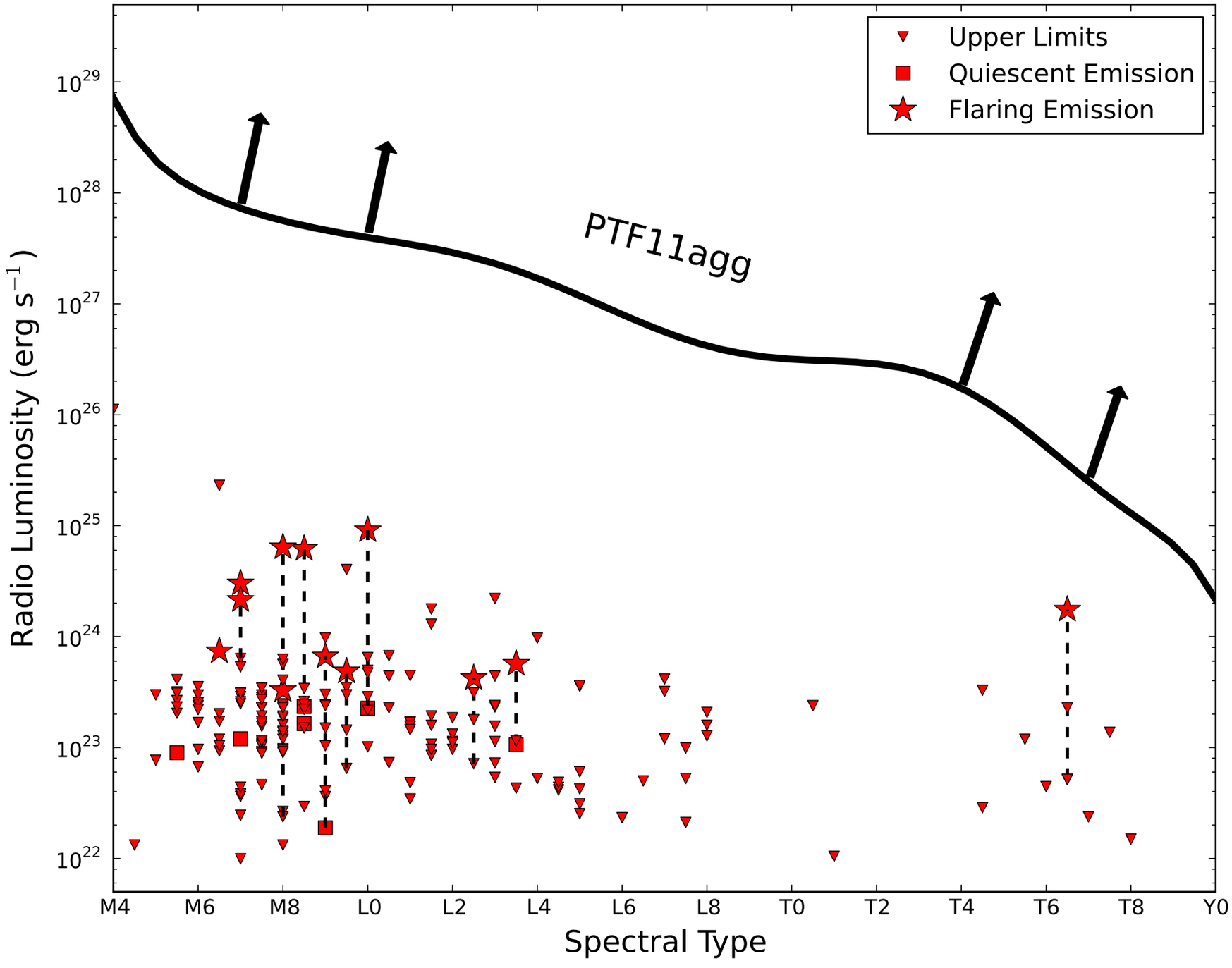
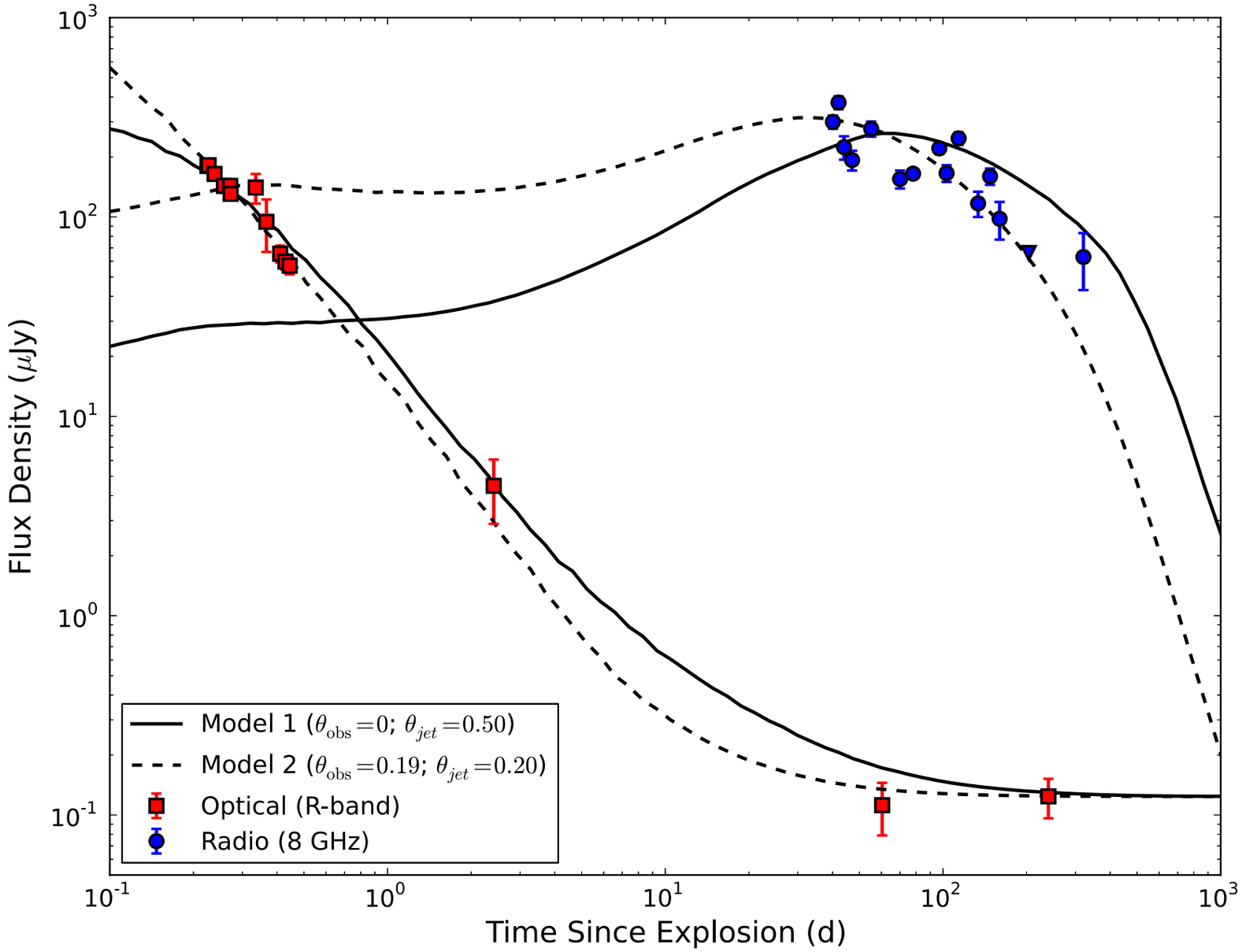


image credit: Cenko et al. (2013)

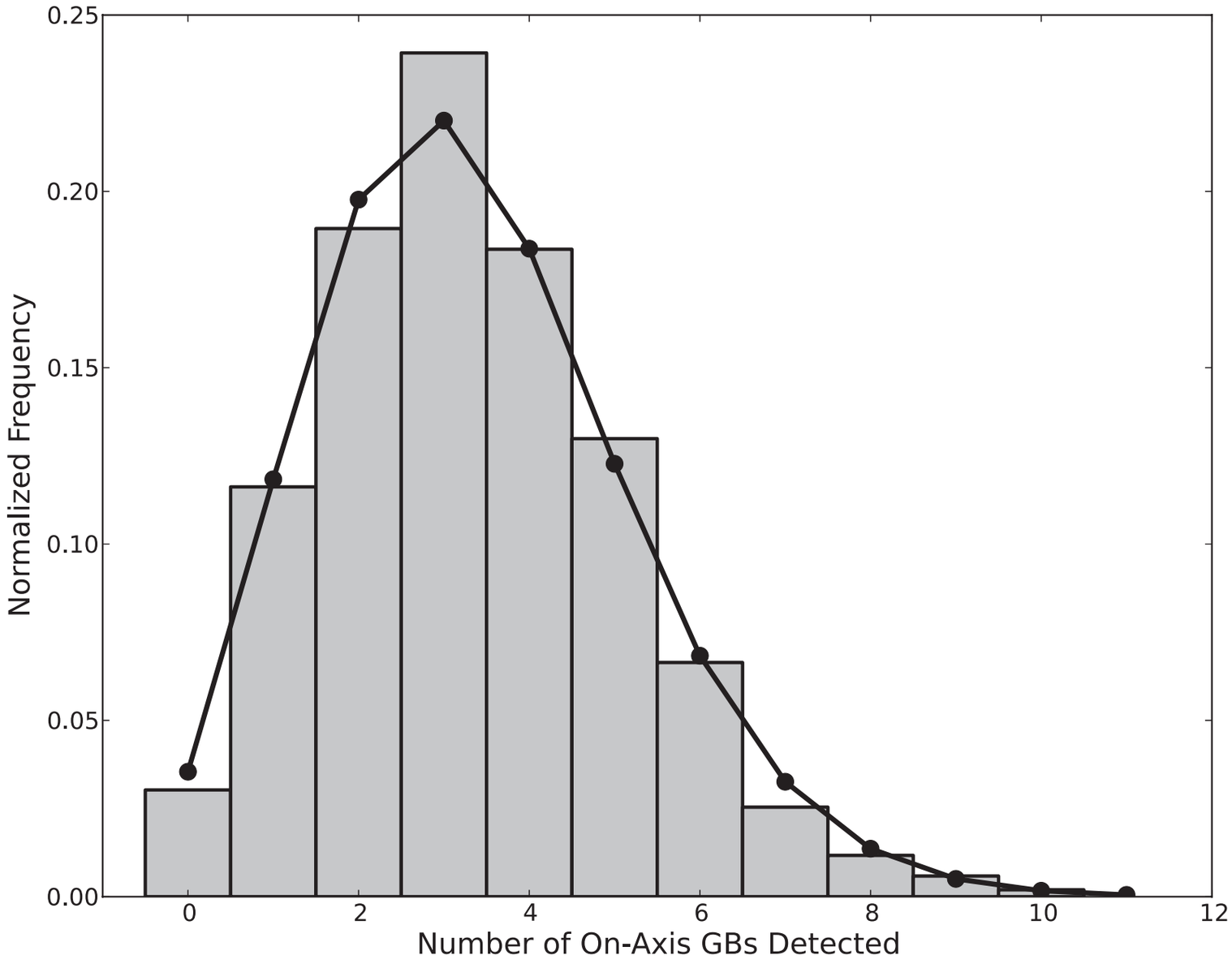
GRB afterglow? Looks tempting...

image credit: Cenko et al. (2013)



- Redshift $0.5 \lesssim z \lesssim 3$
- At least modestly relativistic: $\Gamma > 1.2$
- Well fit (but not constrained) by van Eerten numerical afterglow model
- Hard to reconcile radio emission with off-axis afterglow

Serendipitous on-axis afterglow?



Should occur a *few times per year* in normal PTF fields, but *rarely* in high-cadence fields like this one.

N	$N_{\rm Det}$	$N_{\rm Obs}$
1	1311	11376
2	1583	40101
3	228	5889
4	118	825
5	30	693
6	31	305
7	6	189
8	4	113
9	3	54
>10	26	426

Inconsistent with long GRB rate with 97.4% confidence

$\Longrightarrow$ new, more common kind of relativistic transient?

PTF, *Fermi*, LIGO

images: Iair Arcavi, NASA/GSFC, LIGO Laboratory

A. Palomar Transient Factory, *Fermi* GBM, and LIGO:

what do they have in common? what can we learn from afterglows of *Fermi* bursts?

B. Afterglows of *Fermi* GRBs:

how do we hunt for them?

C. GRB 130702A and iPTF13bxl:

a nearby wimpy monster? z=0.145,
spectroscopic SN Ic-BL, 33 GCN circs, 2 ApJL papers,
proof of principle for Advanced LIGO!

A. Palomar Transient Factory, *Fermi* GBM, and LIGO:

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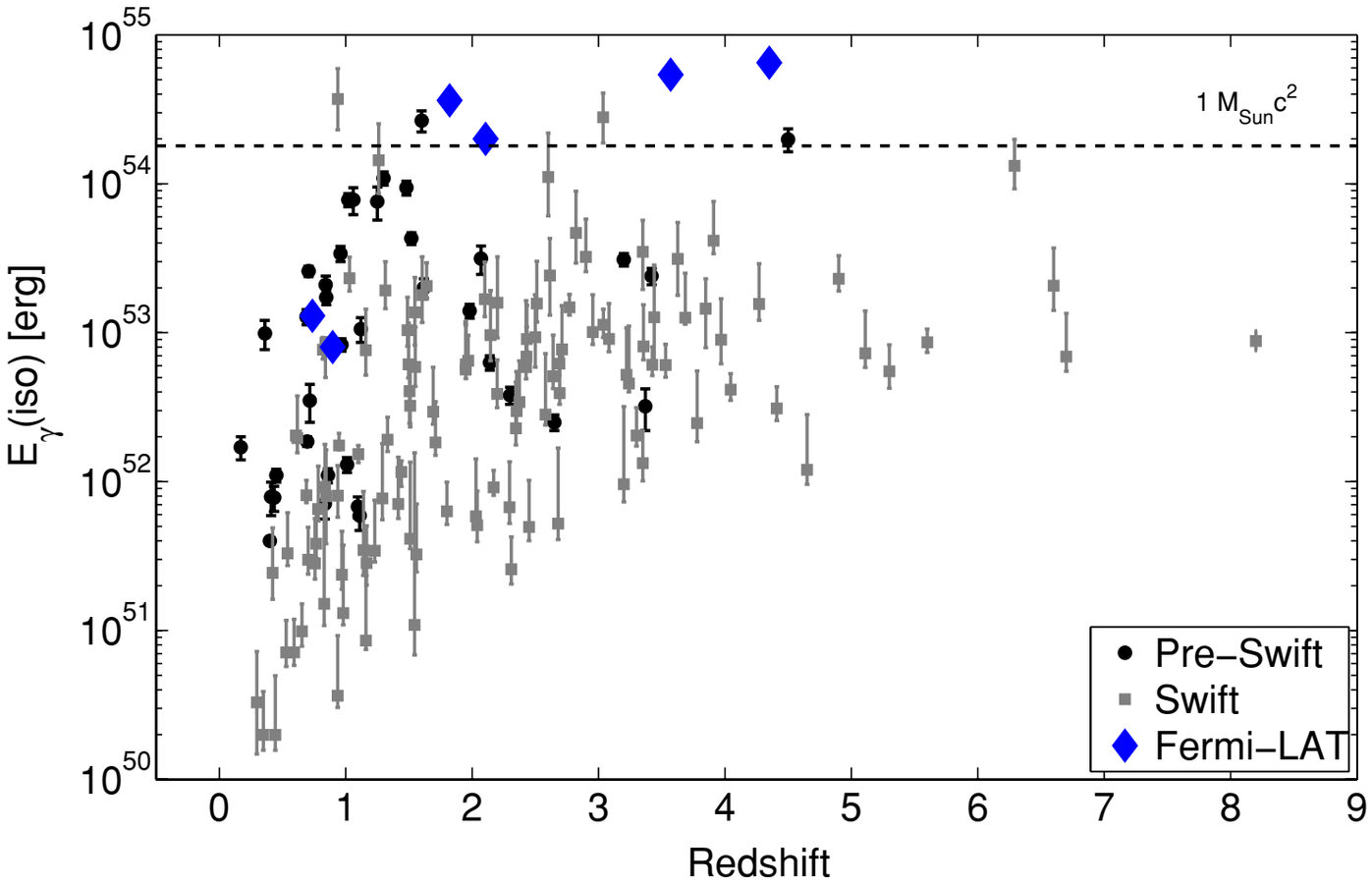
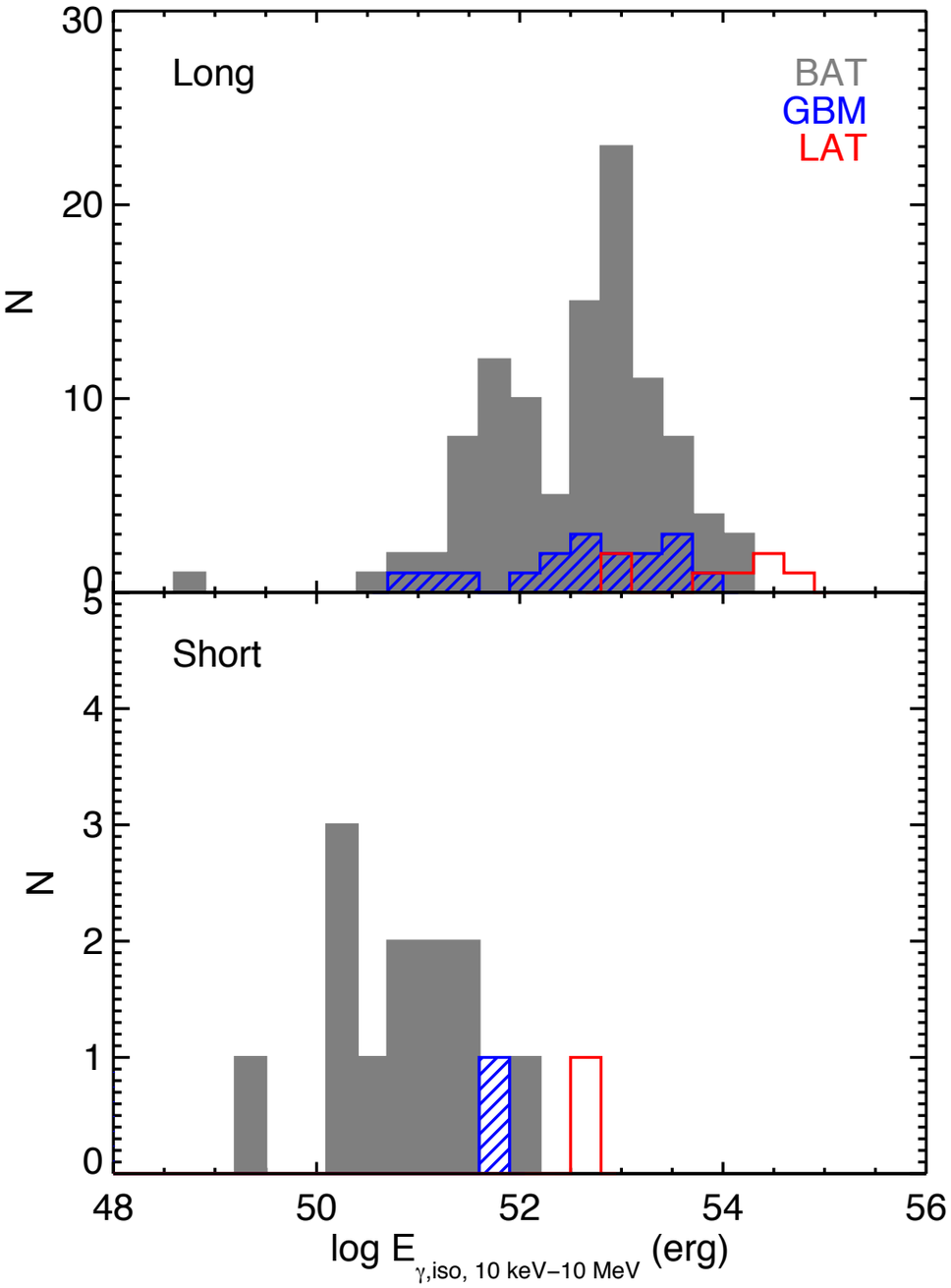
Fermi GRBs are more energetic than *Swift* GRBs. Tip of the *Swift* distribution, or qualitatively different?

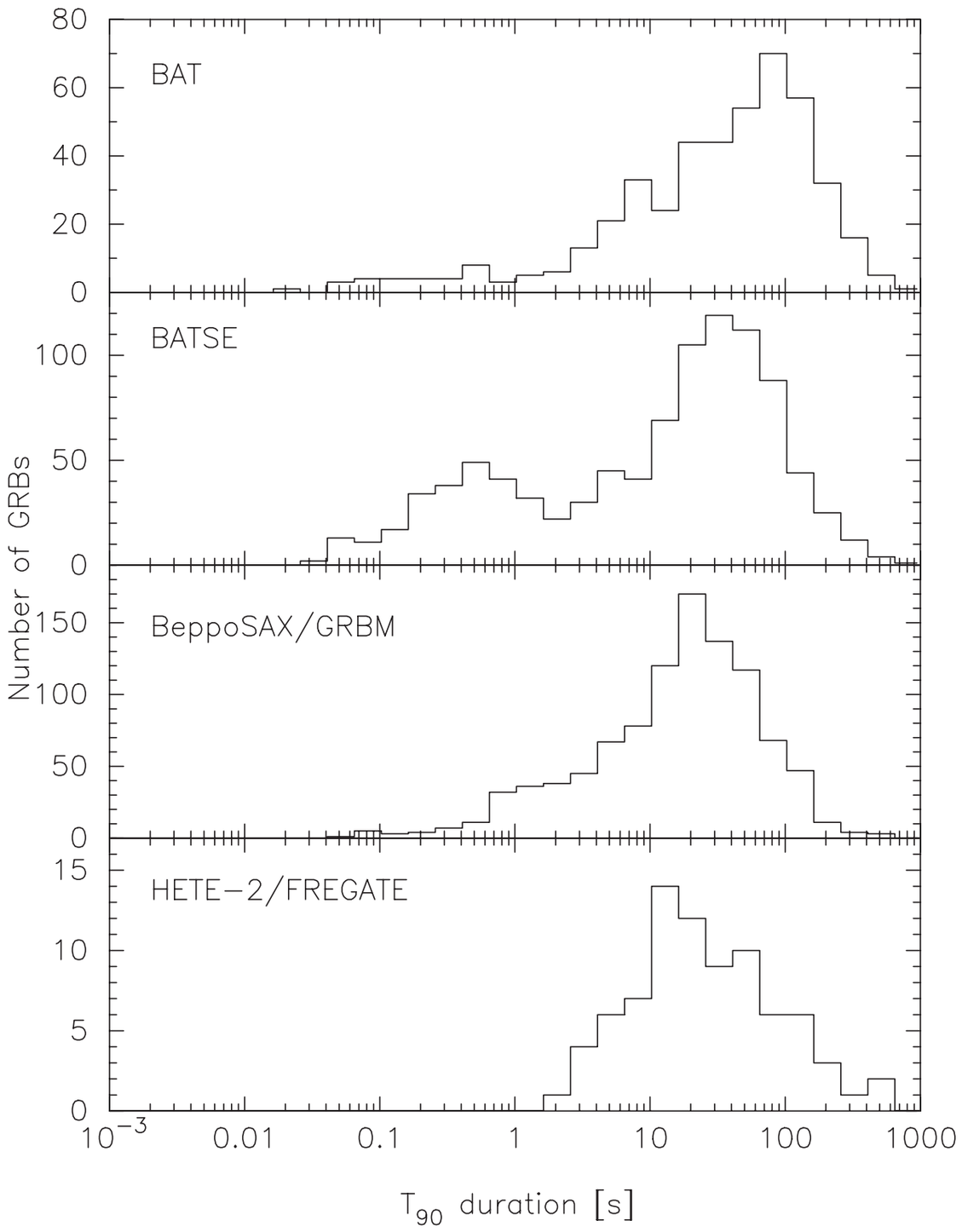


Cenko et al. (2011, ApJ 732:29)



Racusin et al. (2011, ApJ 738:138)

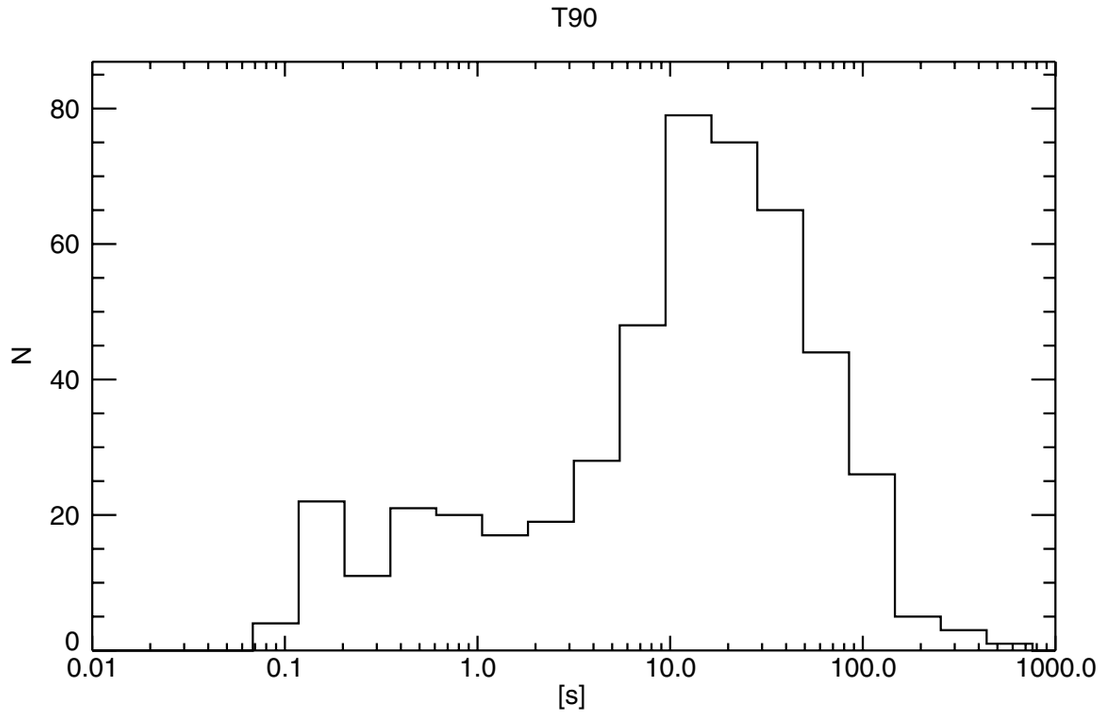
Swift BAT, 2004–2009, 476 GRBs



Sakamoto et al. (2011, ApJS 195:2)

Fermi detects **more**, **shorter**, and **harder** GRBs than *Swift*.

Fermi GBM, 2008–2010, 491 GRBs



Paciesas et al. (2012, ApJS 199:18)

Fermi GBM

- Prolific detection rate (twice that of *Swift*)
- With LAT, access to MeV—GeV regime
- All-sky (~70% of sky)
- Strengths for detecting short-hard bursts
- But very coarse localization, >1°

Possible electromagnetic counterparts

- 2 neutron stars merge, form compact object and accretion disk
- Accretion feeds pair of jets
- Shocks in jet produce prompt ɣ-ray burst
- Shock between jet and ISM produces optical afterglow
- Radioactive decay of heavy elements synthesized in neutron-rich ejecta power faint ‘kilonova’

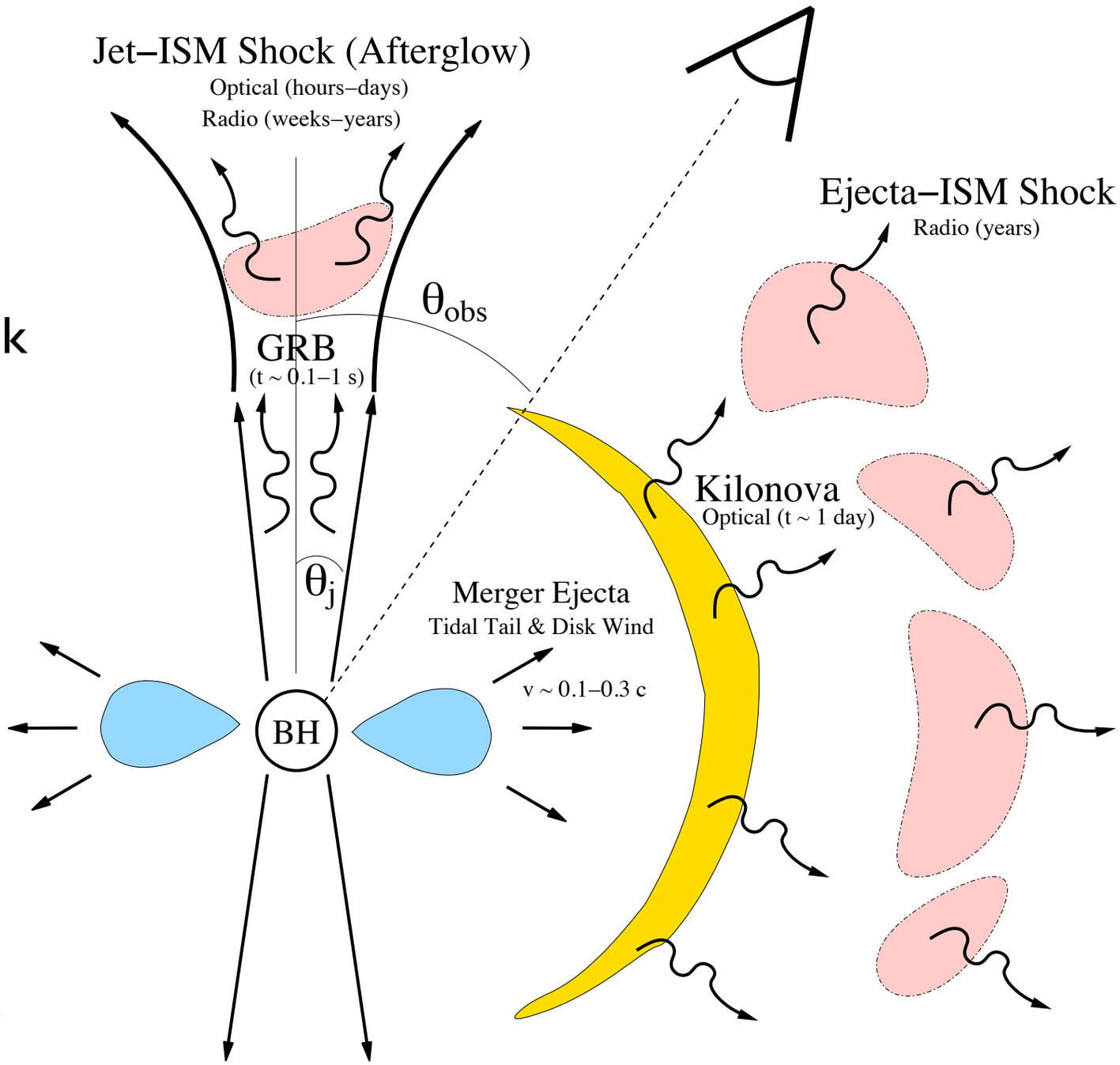
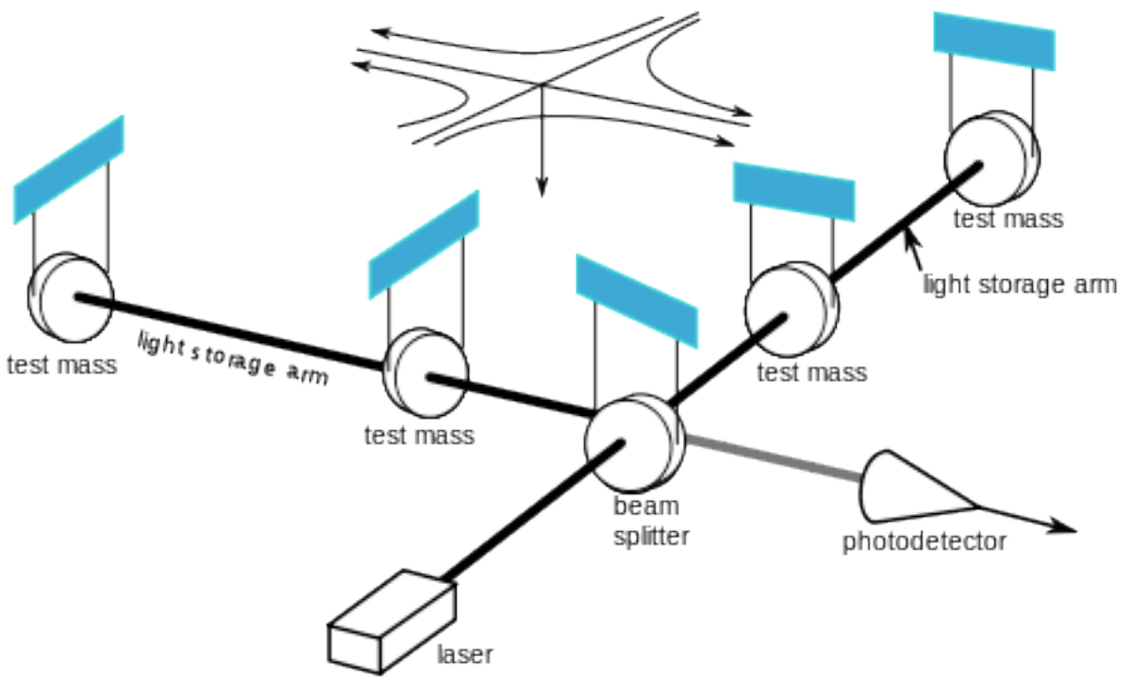


Figure 1 of Meztger & Berger 2012, ApJ, 746, 48

Fermi GRBs as a dress rehearsal for Advanced LIGO transient searches.



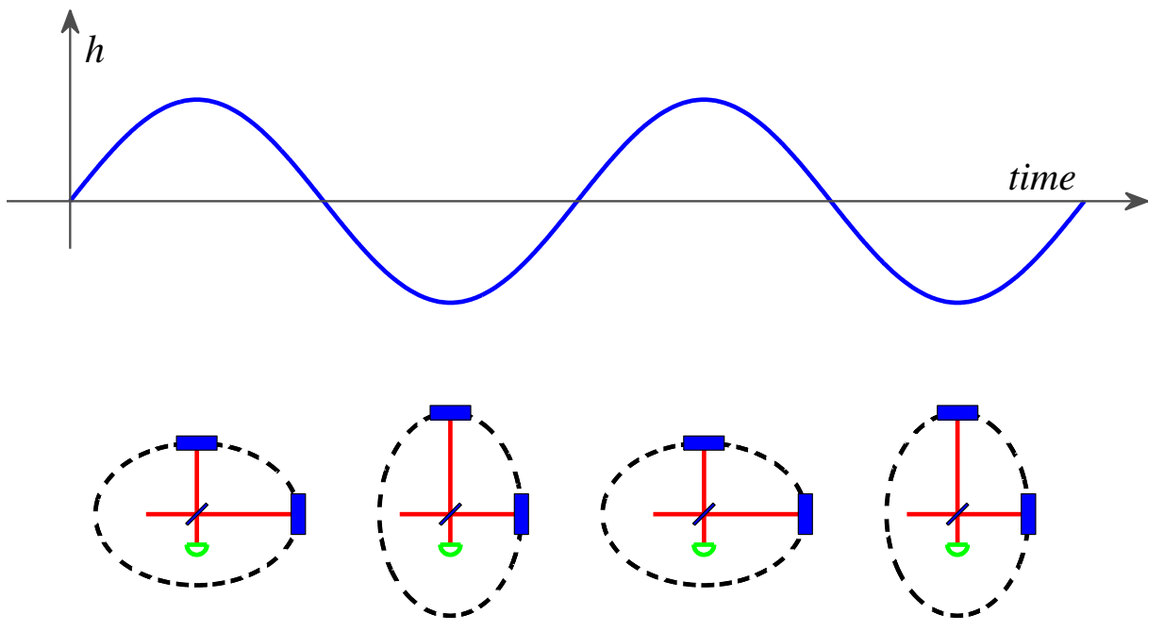


Image credits: http://en.wikipedia.org/wiki/File:Ligo.svg,
Rep. Prog. Phys. 72 (2009) 076901

Typical GW localizations:

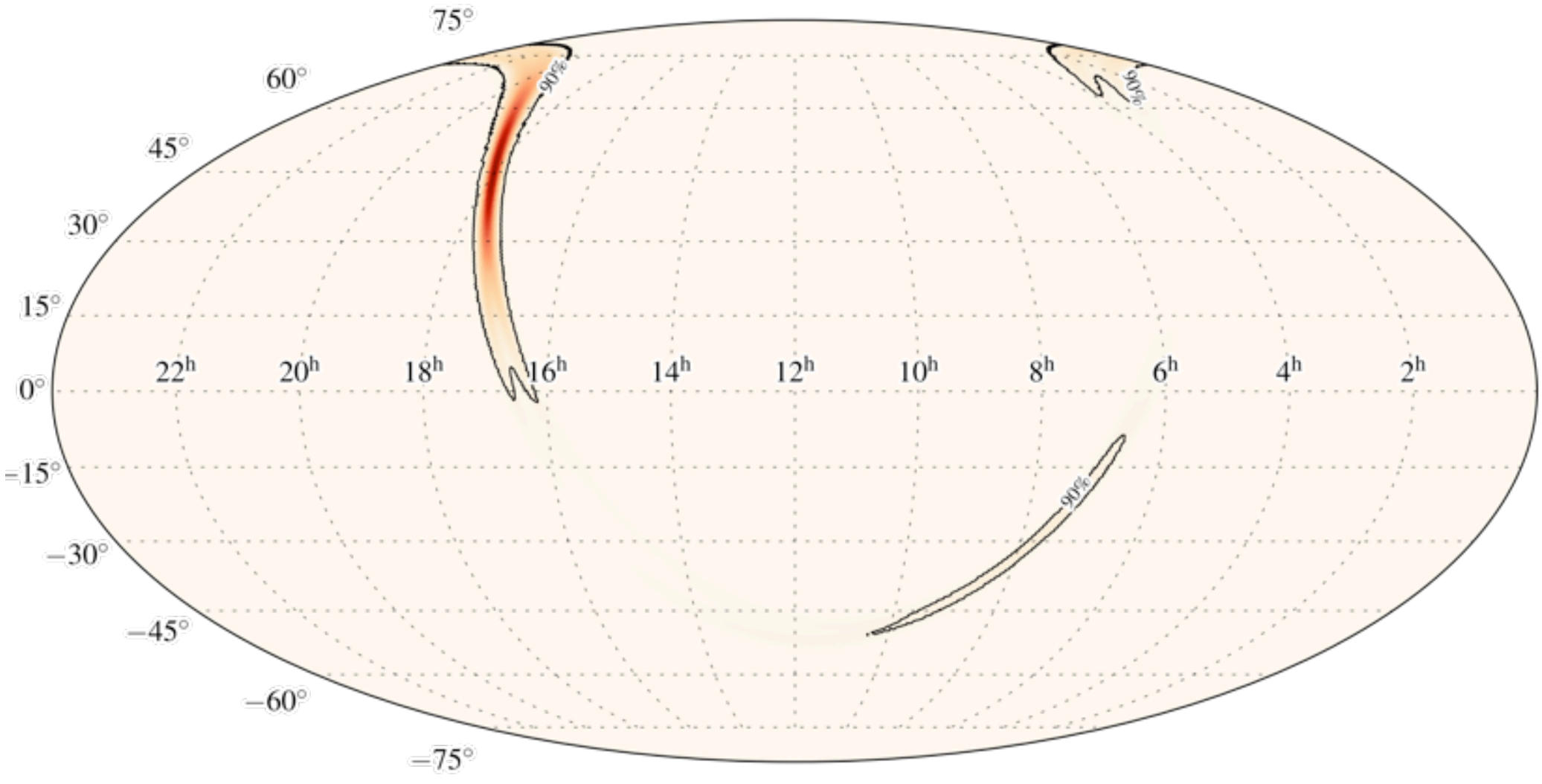
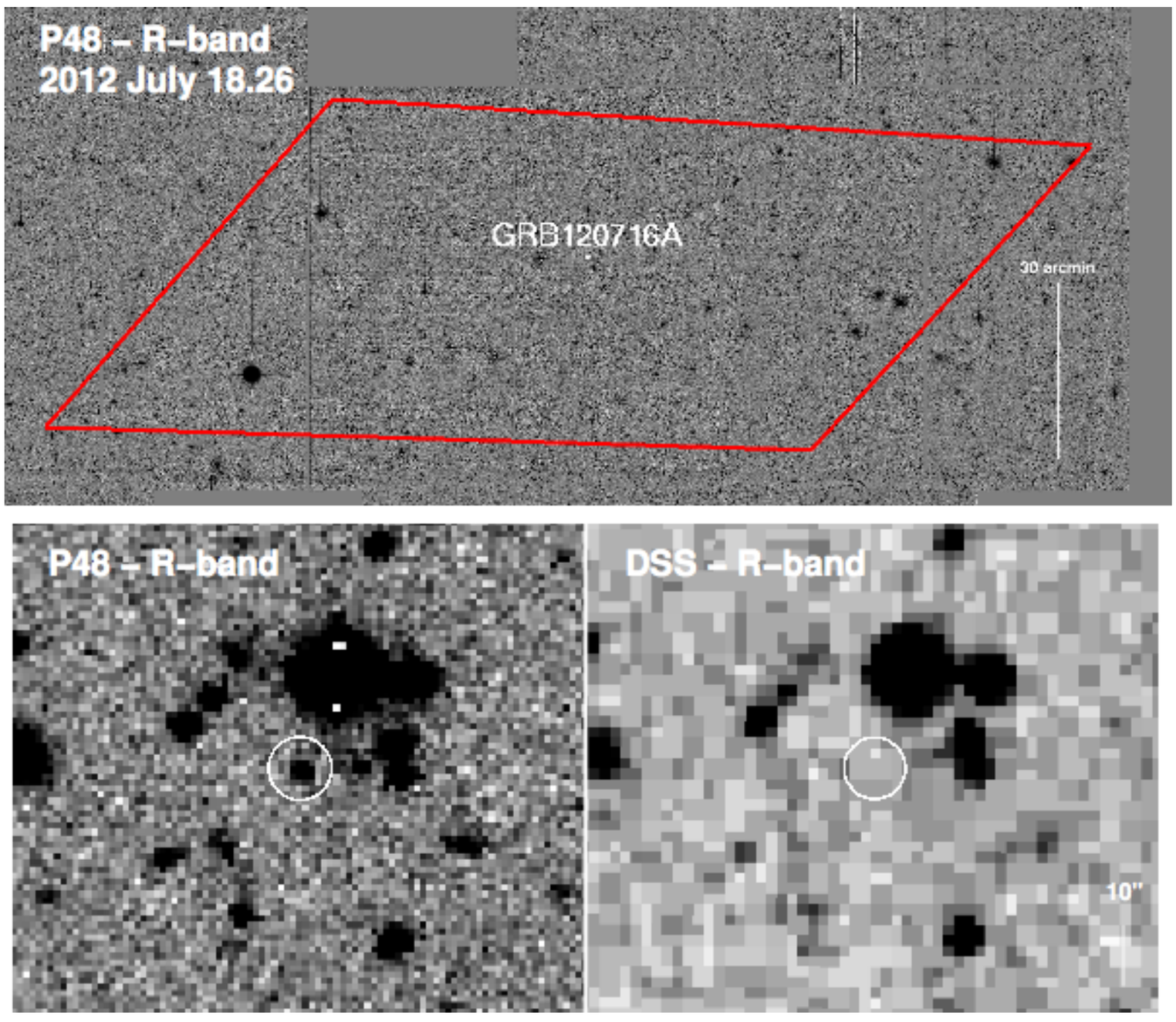


image from Singer et al. (2013, in prep.)

Huge areas: ~$10^{2\text{-}3}$ deg^2 (HL, 2015), ~$10^{1\text{-}2}$ deg^2 (HLV, 2016)
Multiple islands of probability
No such thing as an "error circle": banana-shaped arcs common

GRB 120716A: PTF discovery of a likely optical afterglow of an IPN GRB in 2 square degrees



Cenko (2012, GCN Circ. 13489)

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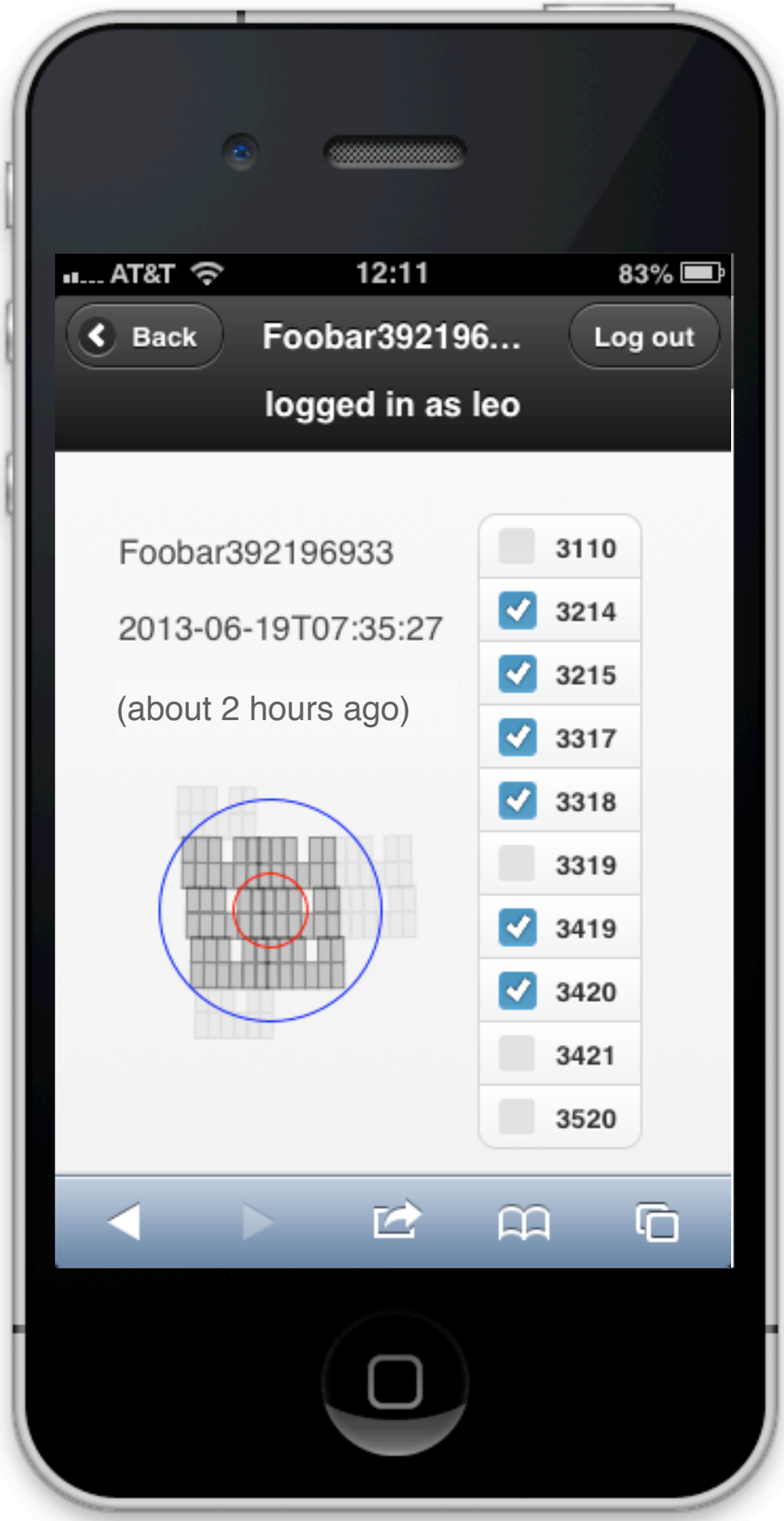

AT&T
12:11
83%
Back
Foobar392196...
Log out
logged in as leo
Foobar392196933
2013-06-19T07:35:27
(about 2 hours ago)
3110
3214
3215
3317
3318
3319
3419
3420
3421
3520

Send P48 ToO.


Carrier
8:26 AM
Back
Fermi394416326
Log out
logged in as leo
Fermi394416326
2013-07-02T00:05:20
Observed fields
3075
3076
3180
3282

Limit query (boolean):

Young Only 0 & Local Universe Only 0 & Co-add Only 0 & New Only 0 & Hide Rocks 1 & Field 3486

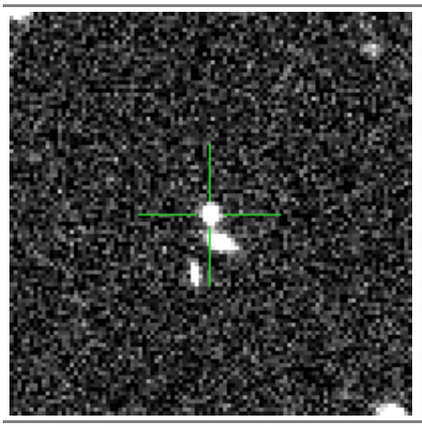
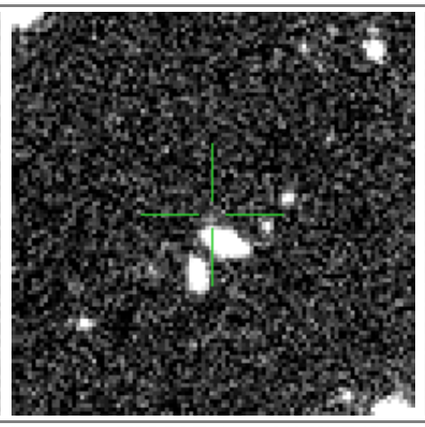
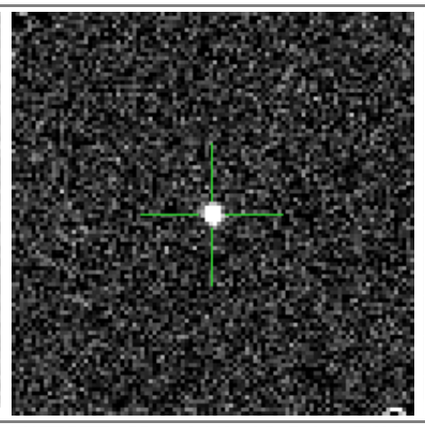
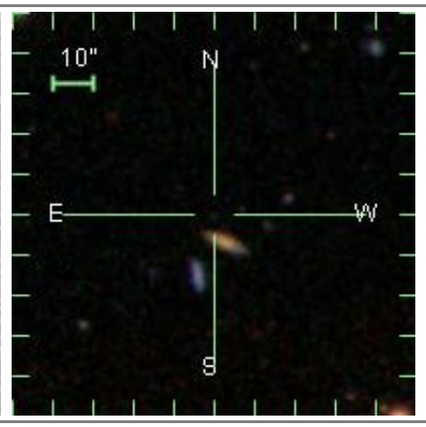
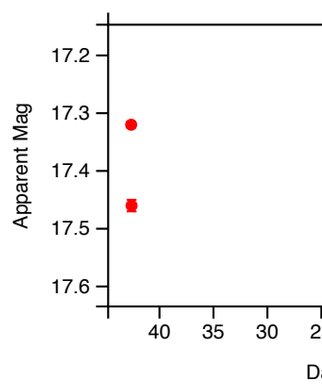
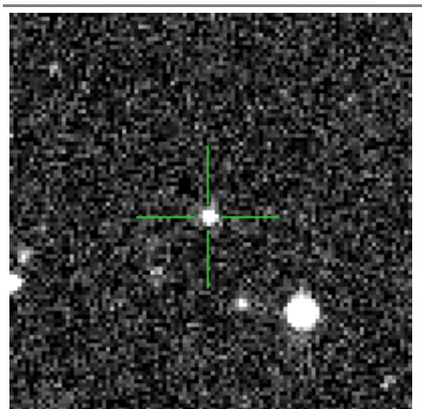
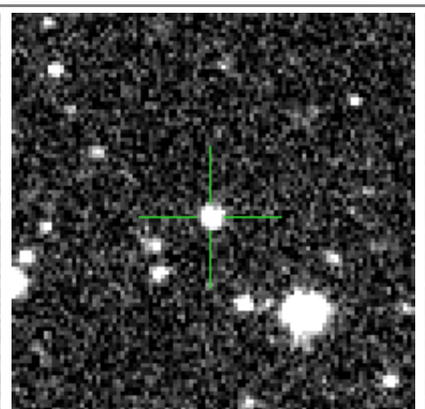
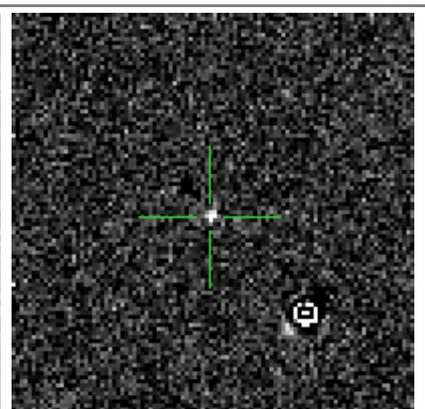
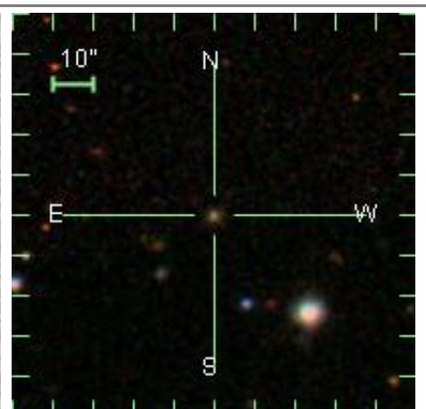
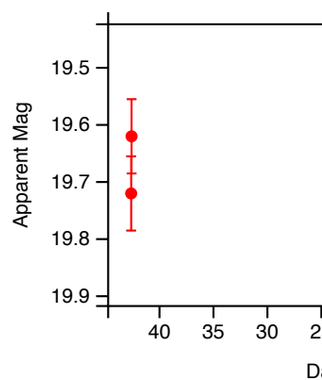
Change query parameters:

Observation date > 20130701 & Realbogus > 0.2 & Match radius (deg) < 0.000277 & Match time (days) > 0.020833 & Number of Candidates < 200 & Fraction of best candidates < 0.03 &

Reload Page

SELECT acnd.id, acnd.rb2, acnd.mag, acnd.ra, acnd.dec, acnd.x_sub, acnd.y_sub, acnd.lu_match_id, bcnd.id as bid, acnd.sub_id as subid FROM candidate as acnd, candidate as bcnd, subtraction a
q3c_join(acnd.ra, acnd.dec, bcnd.ra, bcnd.dec,0.000278) AND acnd.sub_id=asub.id and bcnd.sub_id=bsub.id AND acnd.rb2 > 0.2 and bcnd.rb2 > 0.2 AND asub.id >= 232052 and bsub.id >= 2320
acnd.is_star='f' and bcnd.is_star='f' AND asub.ptffield != 120001 AND bsub.ptffield != 120001 AND asub.ptffield != 4138 AND bsub.ptffield != 4138 AND asub.image_id != -1 and bsub.image_id !=
bsub.ptffield = 3486 GROUP BY acnd.id,bid ORDER BY acnd.rb2 desc, acnd.ra desc LIMIT 200;

20130701 - Found 2 candidates with RB2 >= 0.2:
Only showing unique candidates

New	Ref	Sub	SDSS		
				**ID:** 68144320 Examine , 232606 Zoom-Sub **RB2:** 0.83 **Mag:** 17.46 **iPTF** 13bxl 0 Matches in iPTF DB before tonight 0 Matches in PTF/best DB Not a bad sub. 0.007, 0.138, 0.495 Transient Save	
				**ID:** 68144281 Examine , 232606 Zoom-Sub **RB2:** 0.49 **Mag:** 19.62 **iPTF** 13bxk 0 Matches in iPTF DB before tonight 0 Matches in PTF/best DB Not a bad sub. 0.007, 0.138, 0.495 Transient Save	

27,004 transient/variable candidates found by real-time iPTF analysis

26,960 not known minor planets

2740 sources without SDSS detections brighter than *r'*=21

43 sources detected in both P48 visits, presented to human scanners

7 sources saved by humans

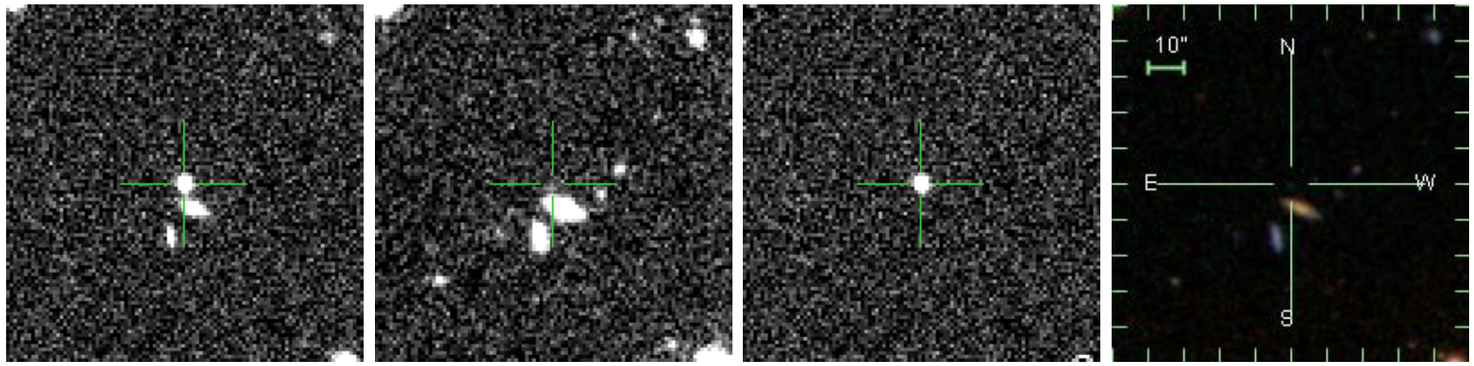
3 afterglow-like candidates scheduled for follow-up

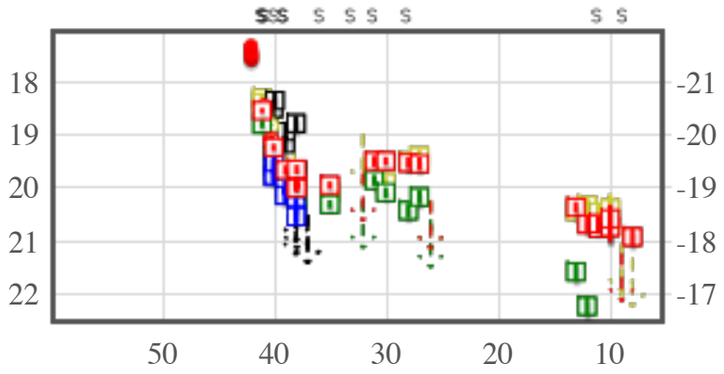
13bxl

14:29:14.78 +15:46:26.4
217.311582 +15.774013

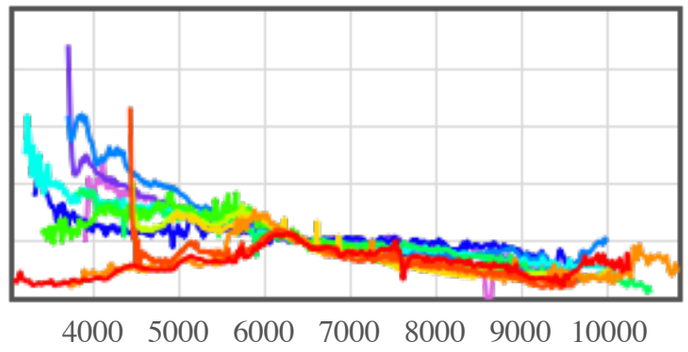
View another

NEW **REF** **SUB** **SDSS**





r = 17.6 (42.2 d) | Upload New Photometry



z = 0.145 | Upload New Spectroscopy
DM (approximate) = 39.19

ADDITIONAL INFO

NED | SIMBAD | VizieR | HEASARC | SkyView | PyMP | Extinction
IPAC | DSS | WISE | Subaru | VLT | Variable Marshal (Search) | ADS

Add to Cart

FOLLOW UP

PROGRAMS

COMMENTS

2013 Aug 04 sumin [info]: observed with LRIS
2013 Jul 15 iair [info]: Observed at P200+DBSP (PA 166.1)
2013 Jul 14 jesper [info]: Latest Keck spectrum (July 11) looks like 2006aj close to Max. The fit with 98bw is less good.
2013 Jul 11 sumin [info]: observed with lick 3-m kast, g-band and R-band images
2013 Jul 11 sumin [info]: observed with Lick Kast g-band image, 130711
2013 Jul 09 brad [info]: Broad features identified in NOT spectrum (GCN 14994) are clearly visible. But it doesn't look like an exact match to 98bw to me (see attached). [view attachment]
2013 Jul 08 robert [info]: Light curve is still fading as a powerlaw (see attached plot). Could have been a break in the LC before 10^5 seconds. [view attachment]
2013 Jul 06 jesper [info]: interesting features, and about right timing. Although some structure also in earlier spectra. SNID attached. /jesper [view attachment]
2013 Jul 06 avishay [info]: SN signatures seem to be already emerging, as light curve decline slows down. Comparison with SN 1998bw and SN 2006aj attached. [view attachment]
2013 Jul 05 ofer [comment]: Quick reduction (to be compared with final one)
2013 Jul 04 mansi [redshift]: 0.145
2013 Jul 04 iair [info]: Observed with P200+DBSP
2013 Jul 03 iair [redshift]: 0.145
2013 Jul 03 iair [comment]: possible redshift based on narrow H, O I, O III
2013 Jul 03 eric [info]: Observed with P200-DBSP 130703
2013 Jul 03 duncan [info]: There is a Fermi/LAT detection (GRB130702A). The best LAT on-ground location is found to be: RA, DEC = 216.4, 15.8 (J2000), with an error radius of 0.5 deg (90% containment, statistical error only) This position is 4 deg from the best GBM position (RA, Dec = 218.81, +12.25 with a 4 deg radius), and 0.8 deg from the position of the optical afterglow.
2013 Jul 02 eric [info]: Observed with P200-DBSP 130702
2013 Jul 02 duncan [info]: Final Fermi GBM position: +14h 35m 14s, +12d 15' 00" (218.810d, +12.250d) (J2000) Error 3.99 [deg radius, statistical only]

A. Palomar Transient Factory, *Fermi* GBM, and LIGO:

what do they have in common? what can we learn from afterglows of *Fermi* bursts?

B. Afterglows of *Fermi* GRBs:

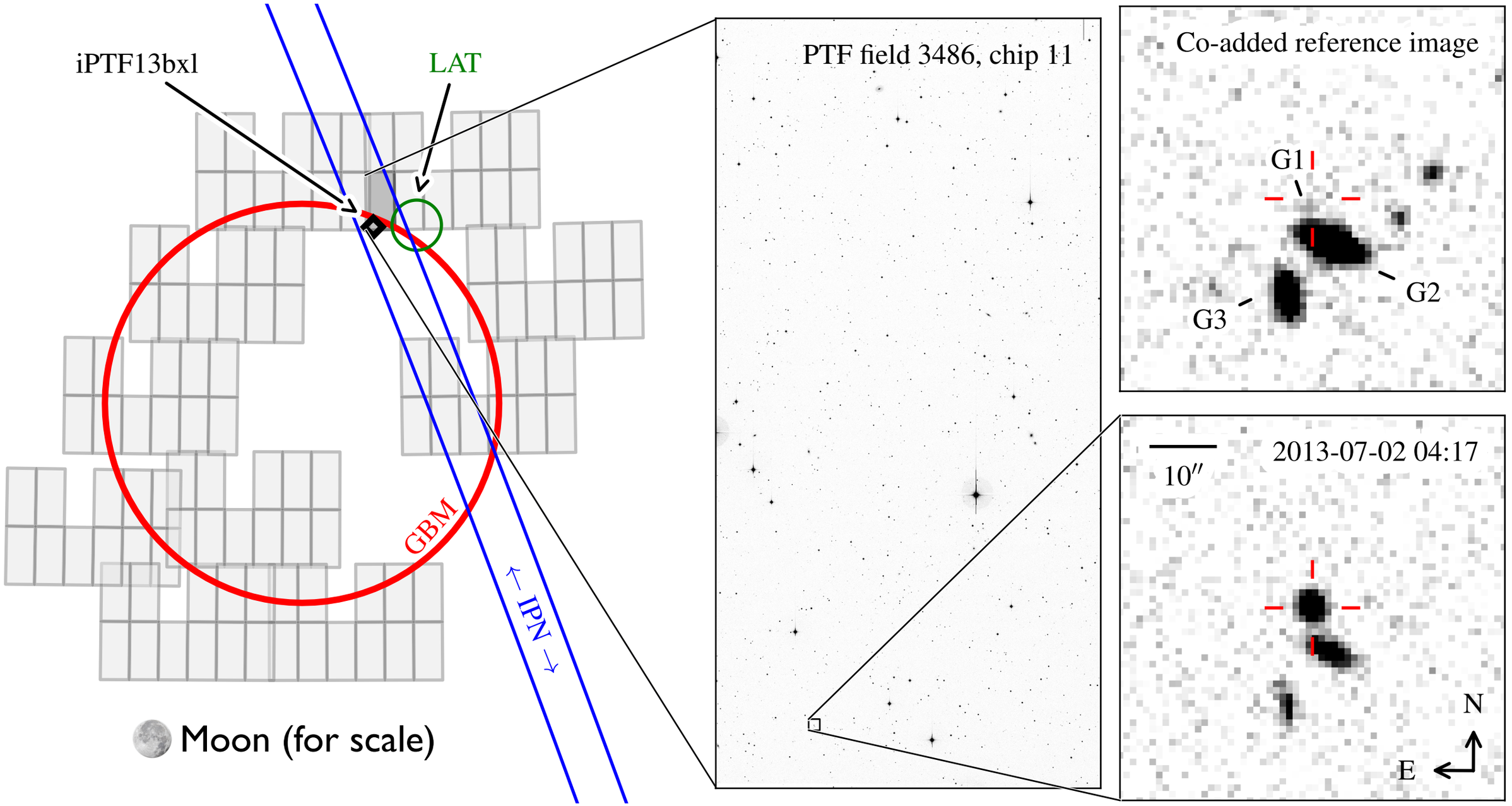
how do we hunt for them?

C. GRB 130702A and iPTF13bxl:

a nearby wimpy monster? z=0.145,
spectroscopic SN Ic-BL, 33 GCN circs, 2 ApJL papers,
proof of principle for Advanced LIGO!

(Almost exactly) one year after IPN GRB:

Discovery & redshift of a GBM GRB in 71 deg^2



to appear in ApJL this week, http://arxiv.org/abs/1307.5851

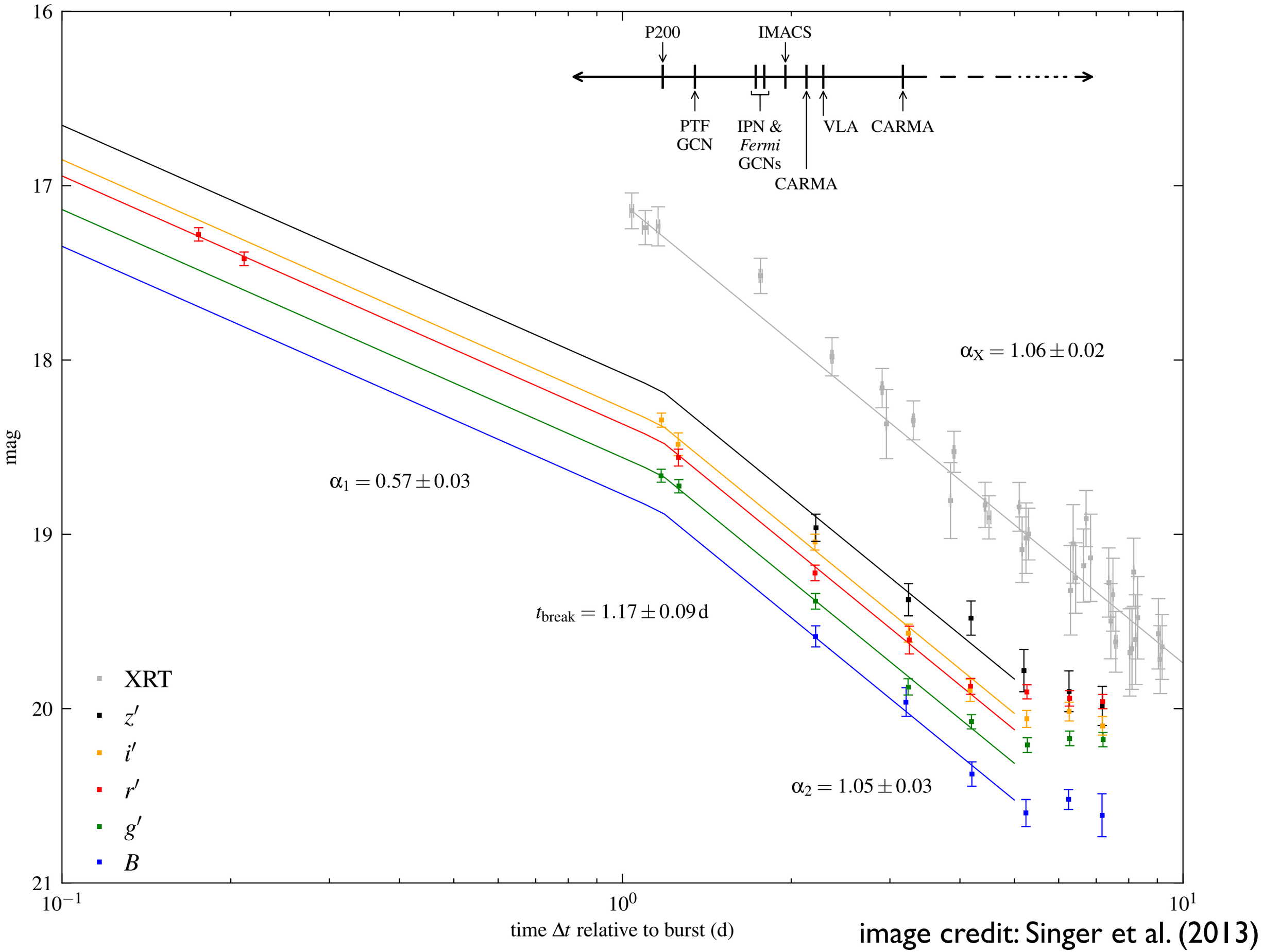


image credit: Singer et al. (2013)

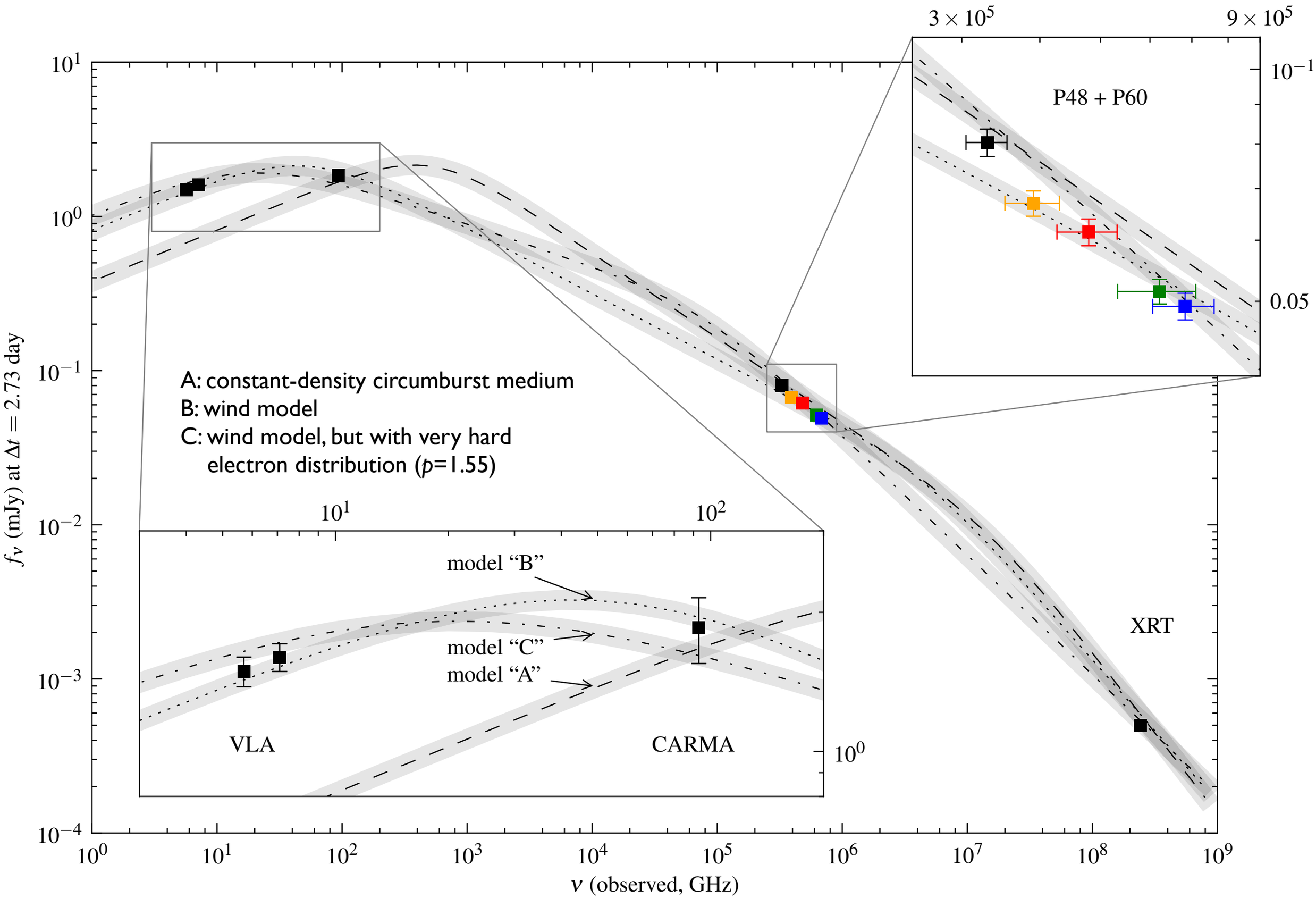


image credit: Singer et al. (2013)

Redshift of host: z=0.145

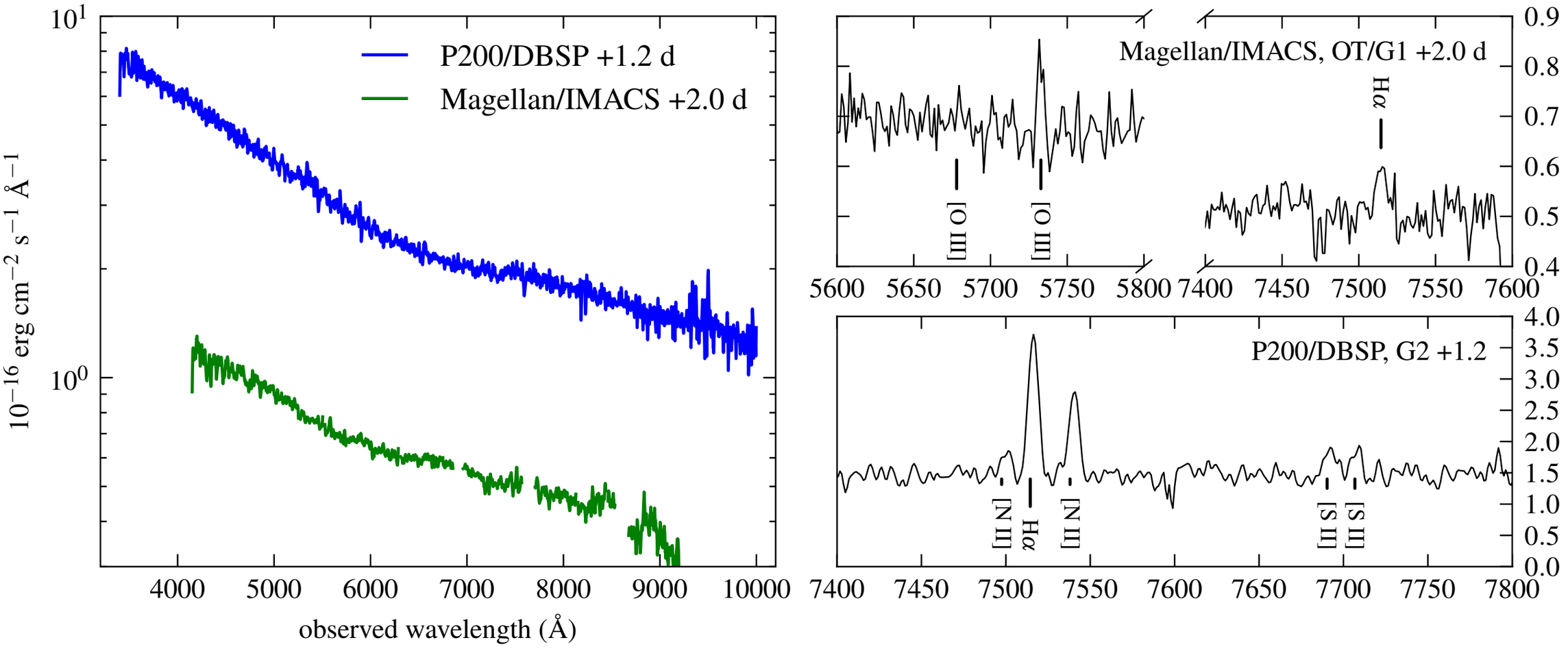
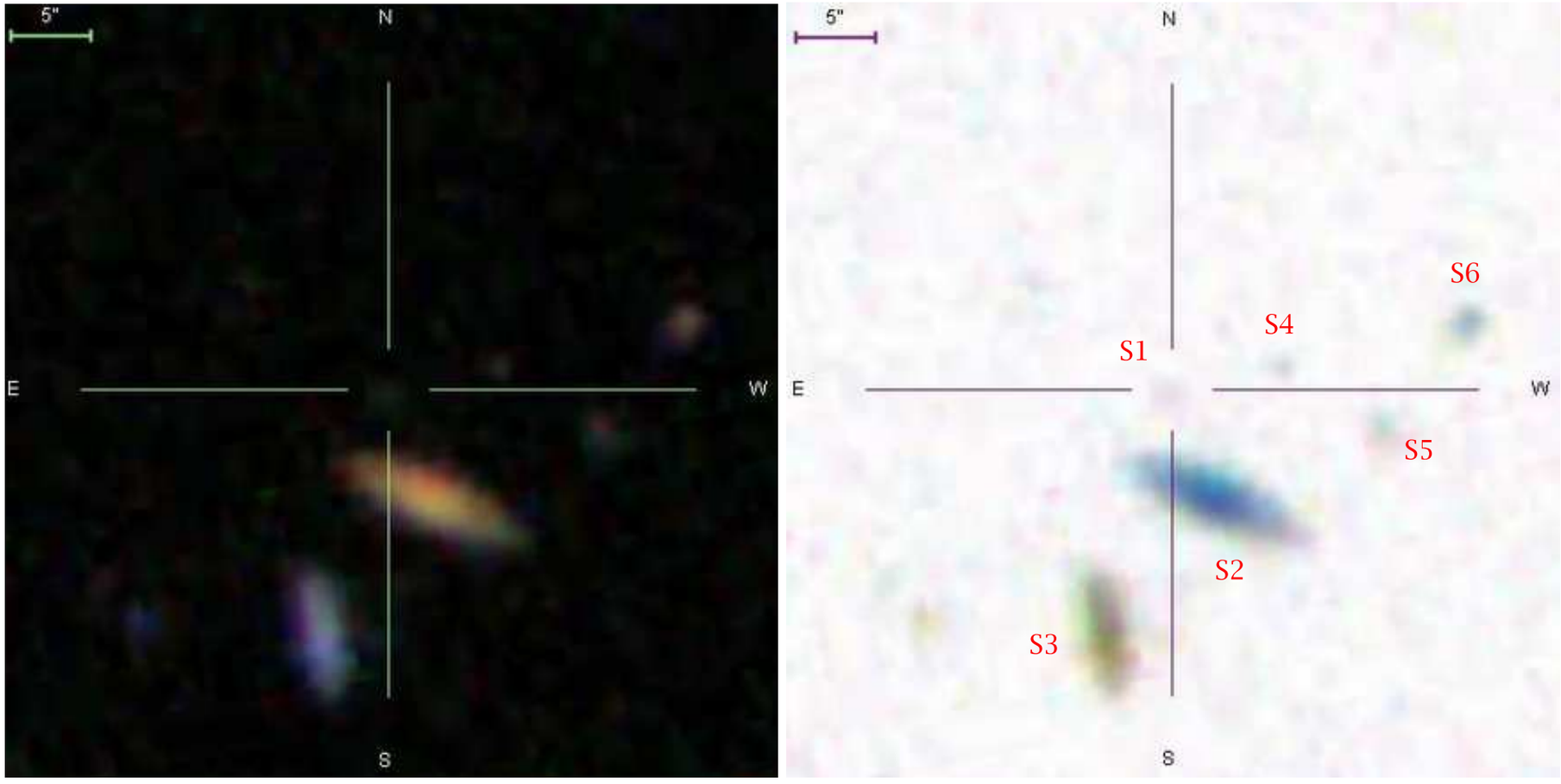


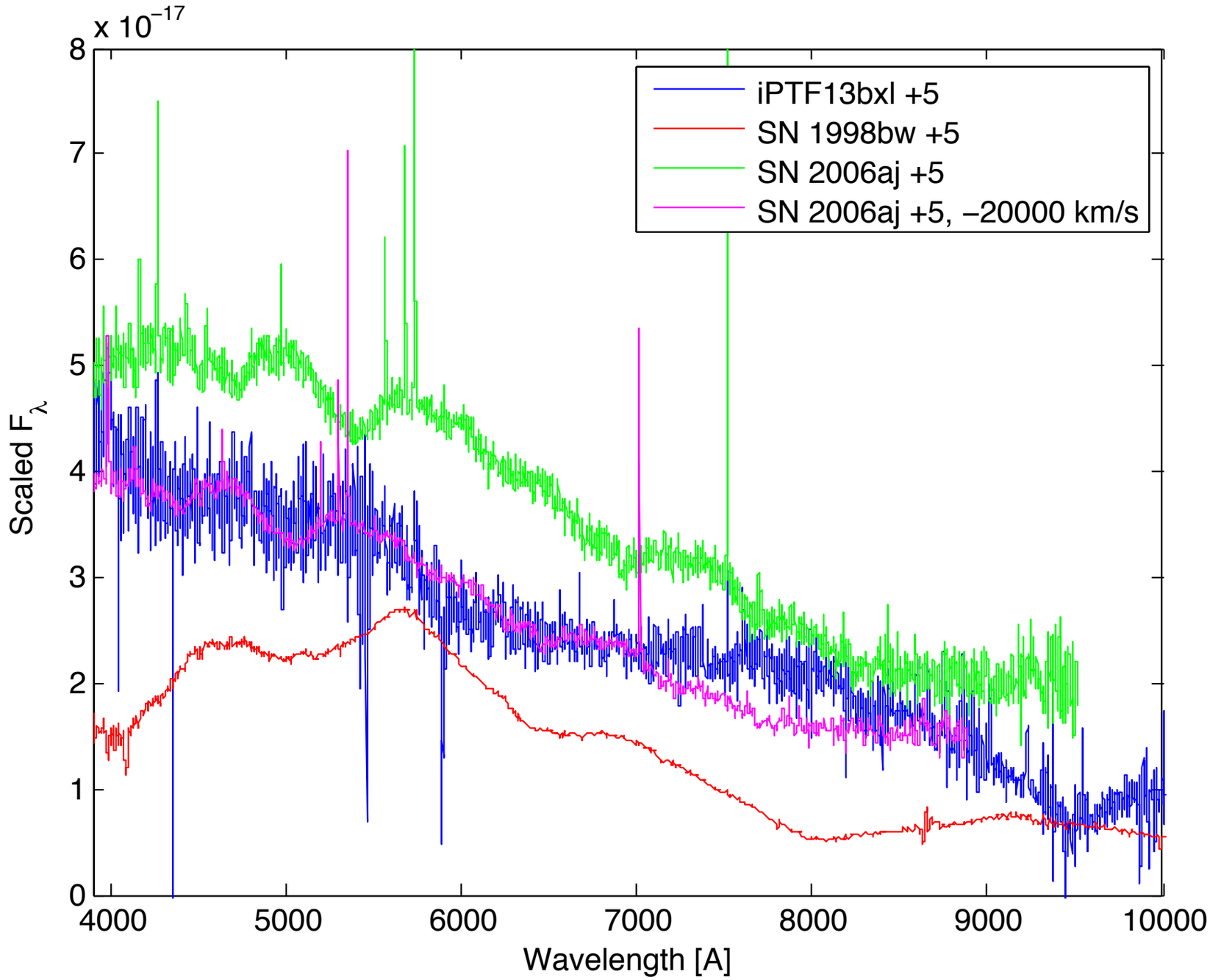
image credit: Singer et al. (2013)



Metallicity of host environment:

see Kelly et al. (2013, ApJL 775, 5)

GRB 130702A's supernova: comparison with SN 2006aj (Ic)

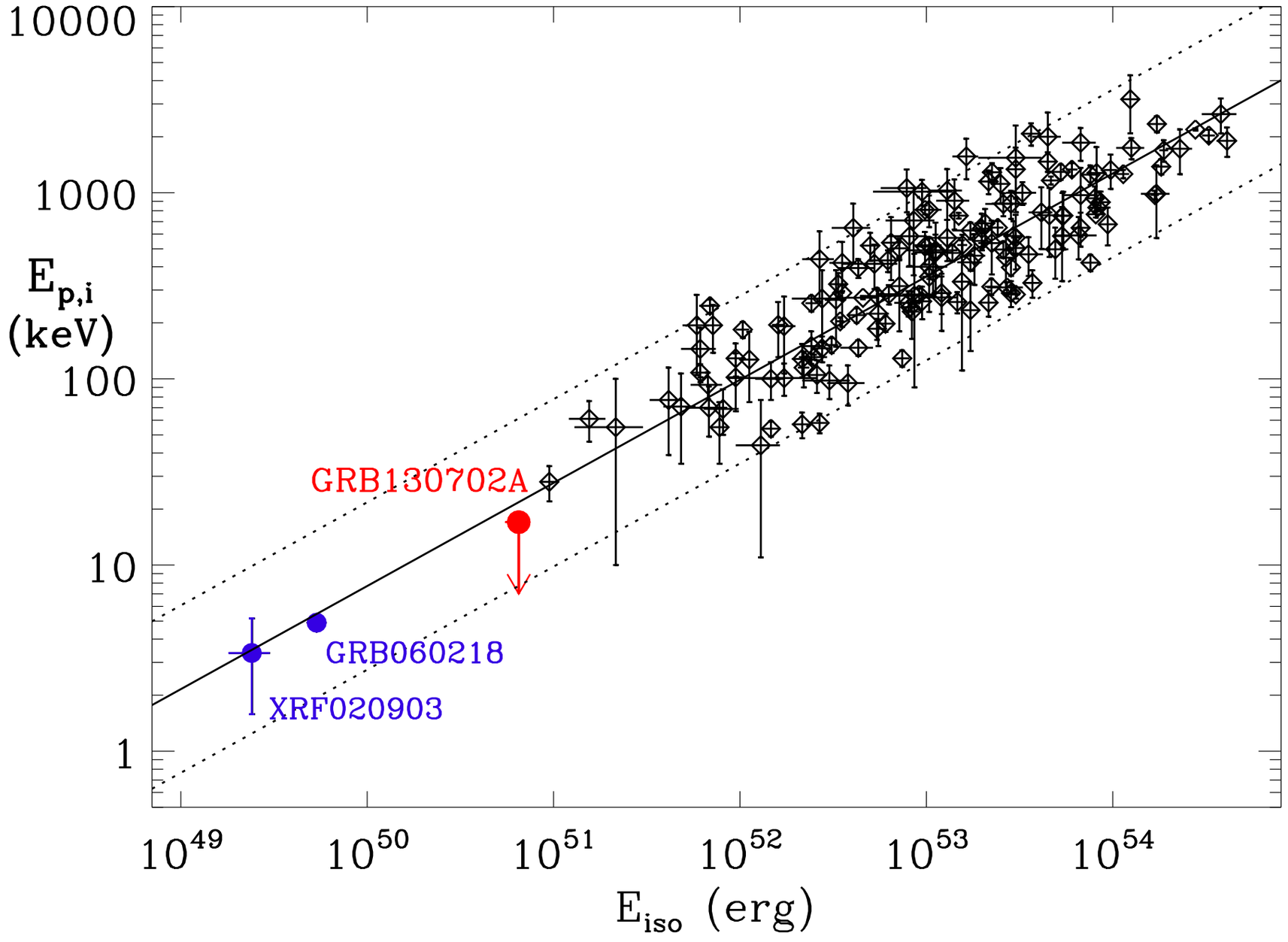


comparison in Transient Marshal by A. Gal-Yam

130702A bridging the gap:

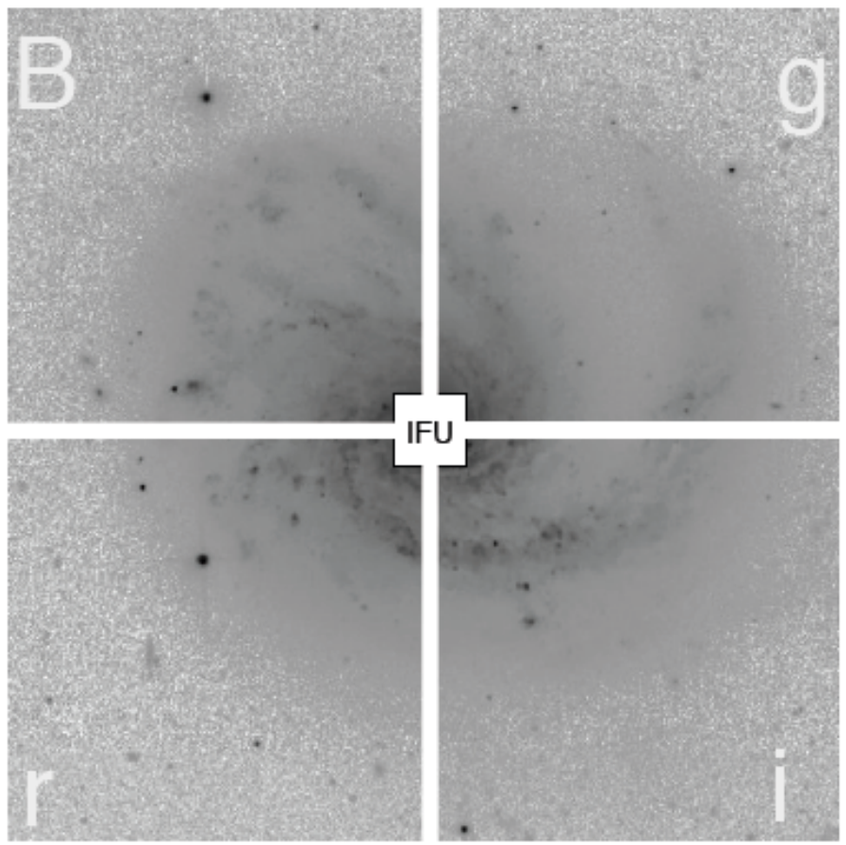
much wimpier than cosmological GRBs,

not nearly as wimpy as GRBs with spectroscopic SNe

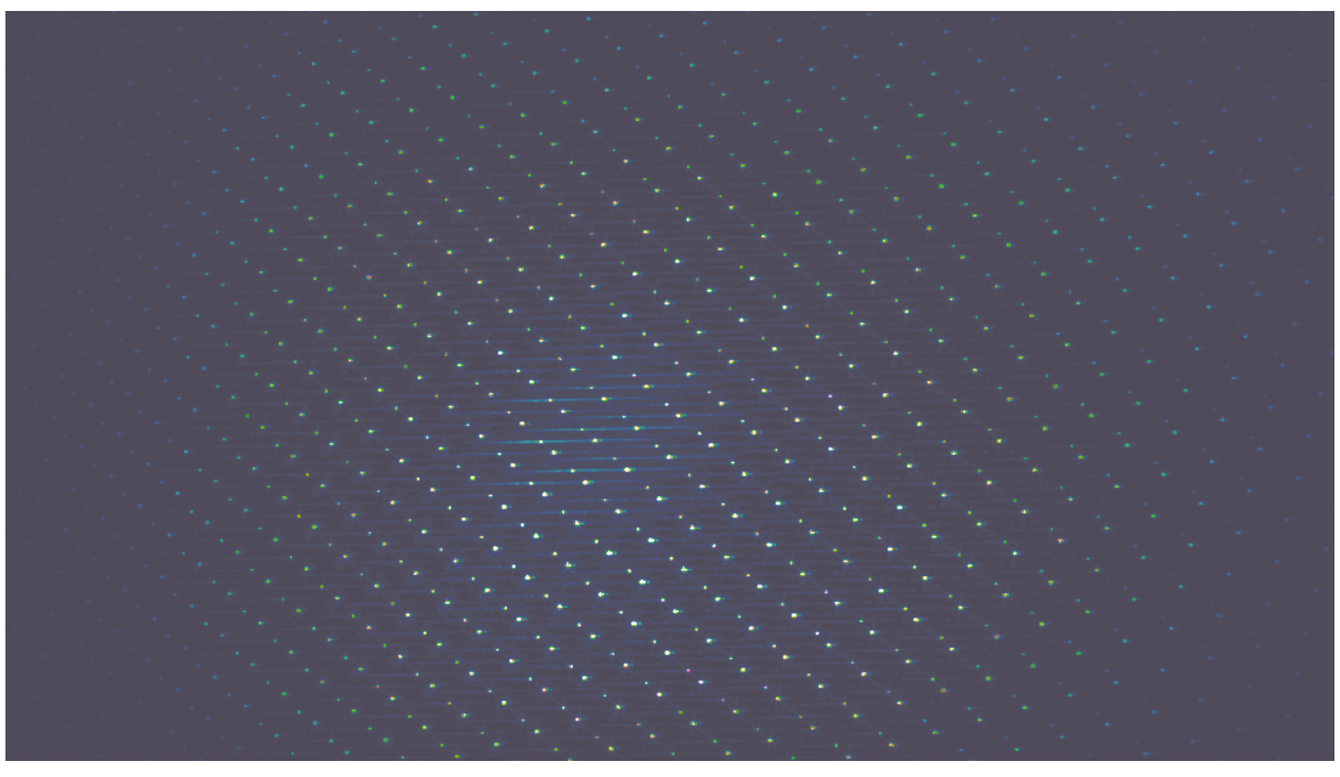


Amati et al. (2013, GCN Circ. 15025)

What's next for PTF?



images:
Kondaris (2013)



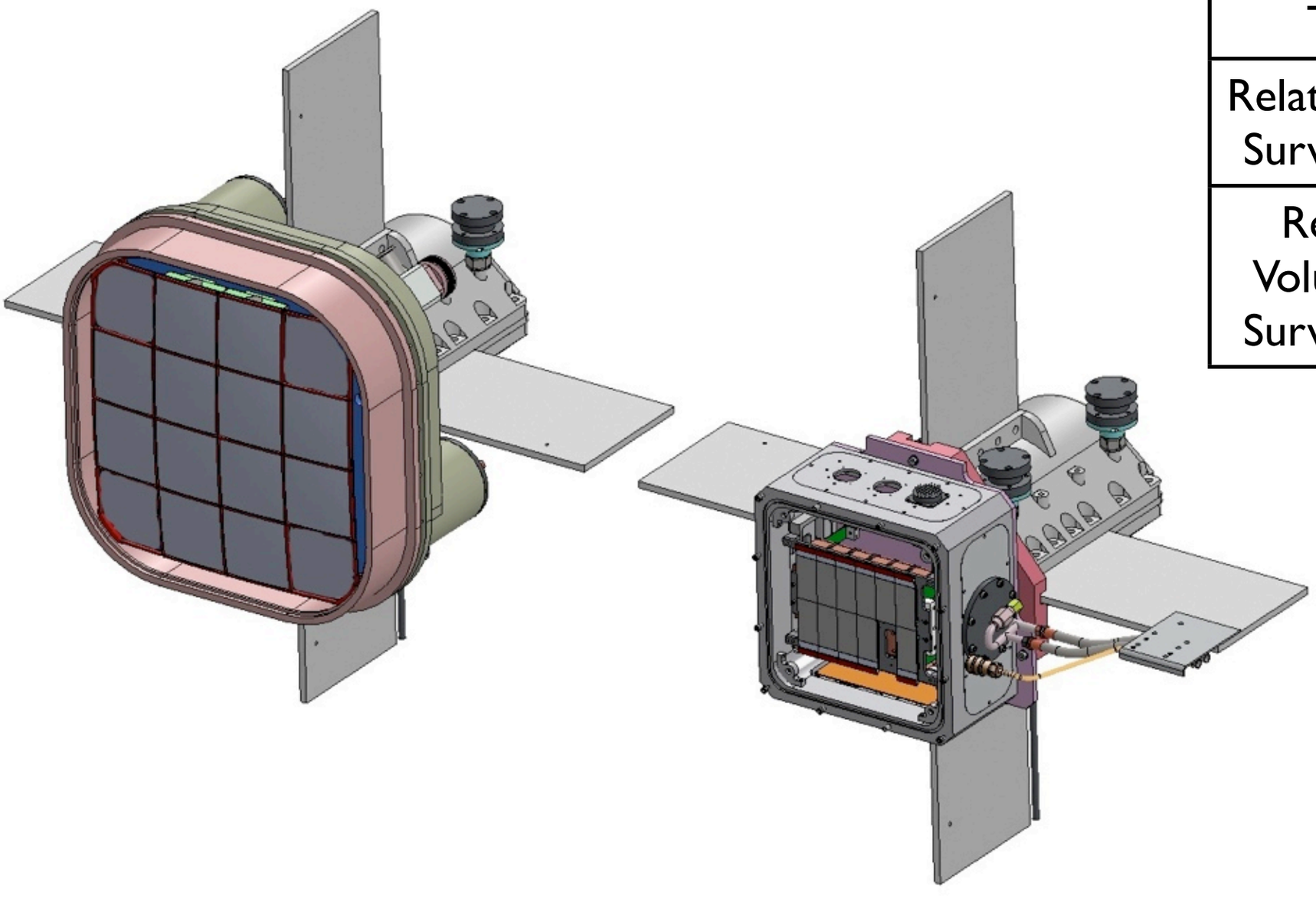
What's next?

SED Machine

ugri imager and fully robotic IFU spectrograph, now installed on Palomar 60" telescope, first light in June 2013

What's next?
The Zwicky Transient Facility

3800 deg^2/hour ⇒ 3π survey in 8 hours



	PTF	ZTF
Active Area	7.26 deg^2	45 deg^2
Readout Time	36 sec	10 sec
Exposure Time	60 sec	30 sec
Relative Areal Survey Rate	1x	14.7x
Relative Volumetric Survey Rate	1x	12.3x

THANK YOU

Alan Weinstein & Shri Kulkarni

Brad Cenko & Mansi Kasliwal

Dan Perley, Eran Ofek, Duncan Brown, Peter Nugent, Alessandra Corsi, Dale Frail, Eric Bellm, John Mulchaey, Iair Arcavi, Tom Barlow, Josh Bloom, Yi Cao, Neil Gehrels, Assaf Horesh, Frank Masci, Julie McEnery, Arne Rau, Jason Surace, Ofer Yaron

Astropy

HEALPix

NSF Graduate Research Fellowship