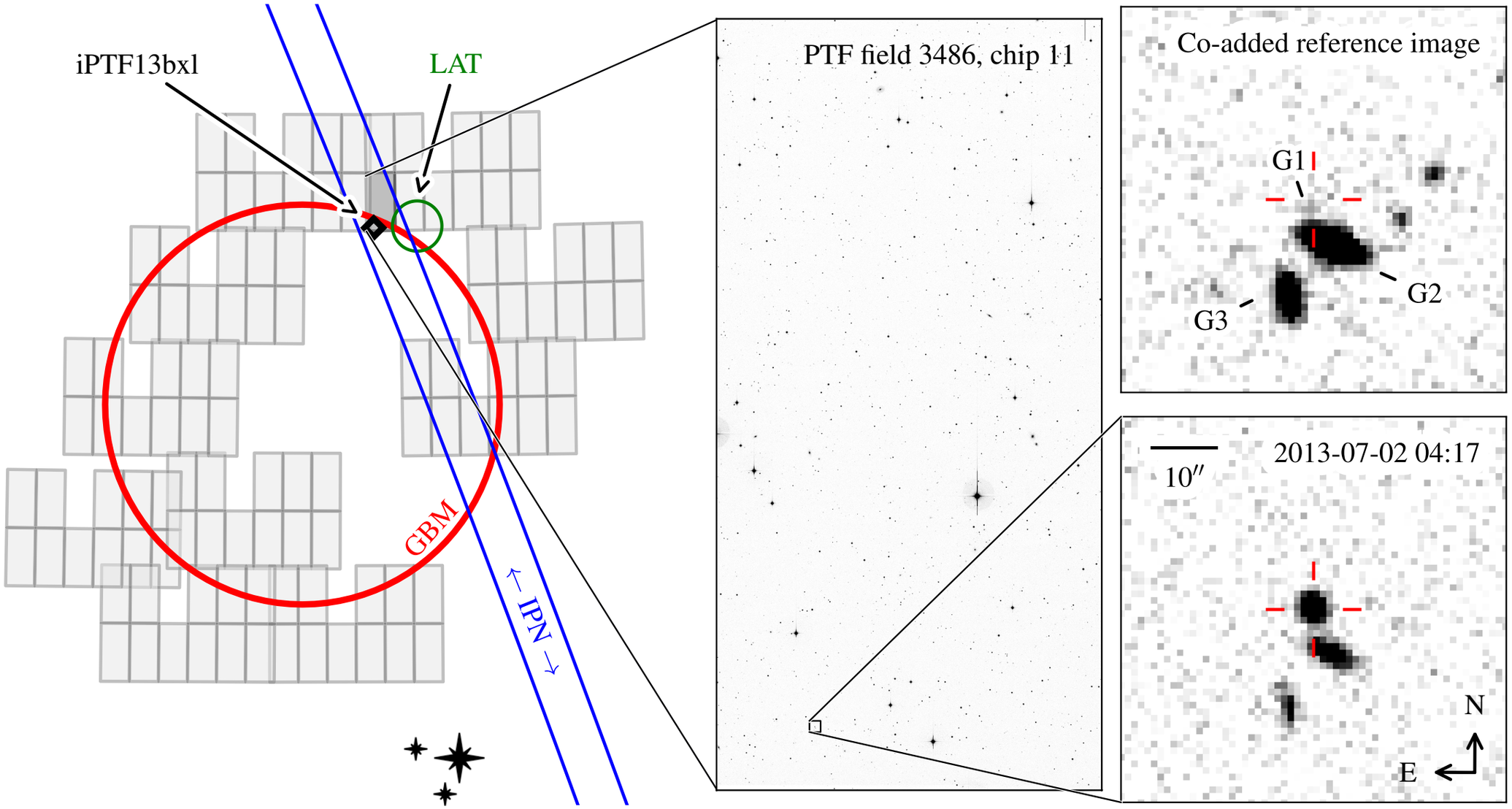


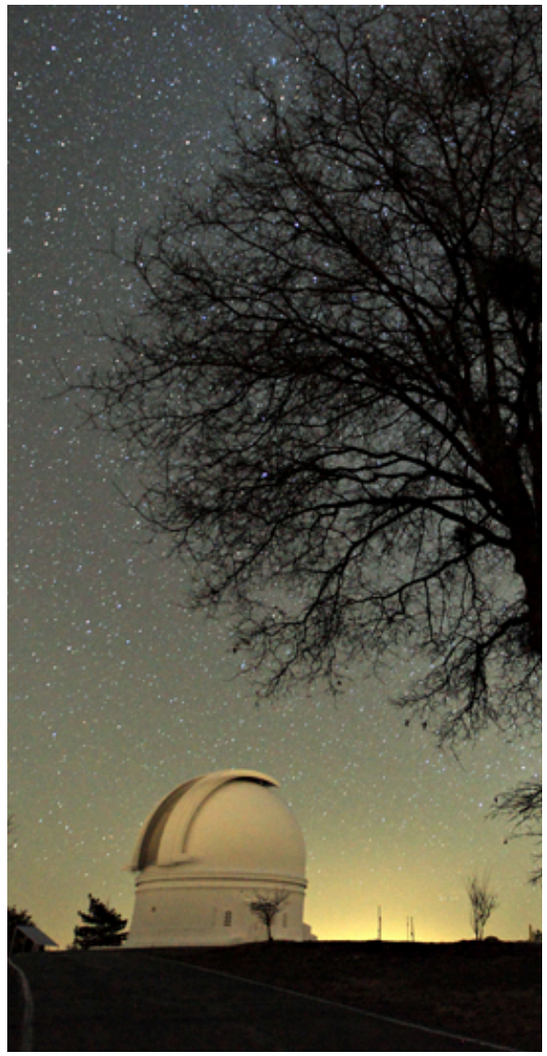
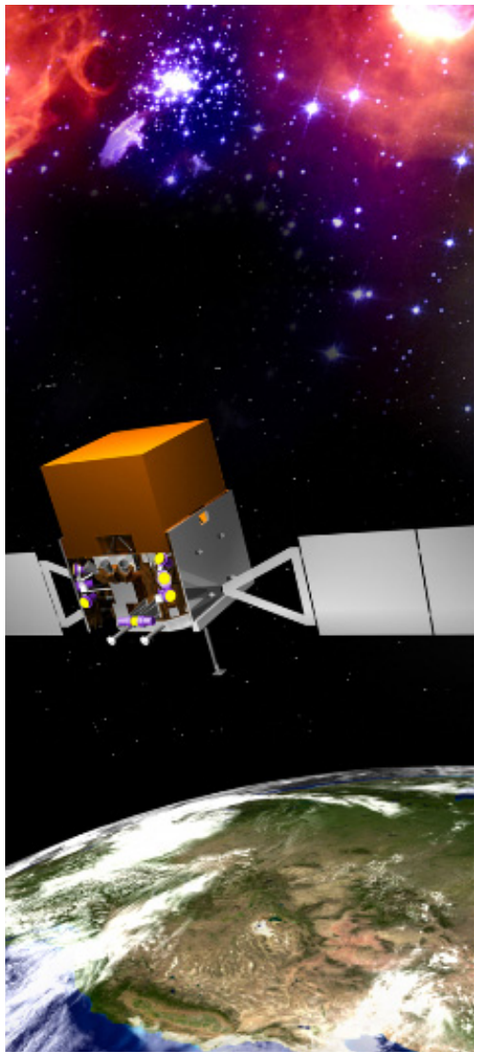
PALOMAR TRANSIENT FACTORY

DISCOVERY & REDSHIFT OF AN OPTICAL AFTERGLOW IN 71 SQUARE DEGREES

accepted ApJL, http://arxiv.org/abs/1307.5851

LEO SINGER / SANTORINI, GREECE / 20 SEPT 2013

lsinger@caltech.edu


images: Iair Arcavi, NASA/GSFC, LIGO Laboratory

1. Palomar Transient Factory, *Fermi* GBM, and LIGO:
what do they have in common? what can we learn from afterglows of *Fermi* bursts?

2. Afterglows of *Fermi* GRBs:
how do we hunt for them?

3. 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!

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

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

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

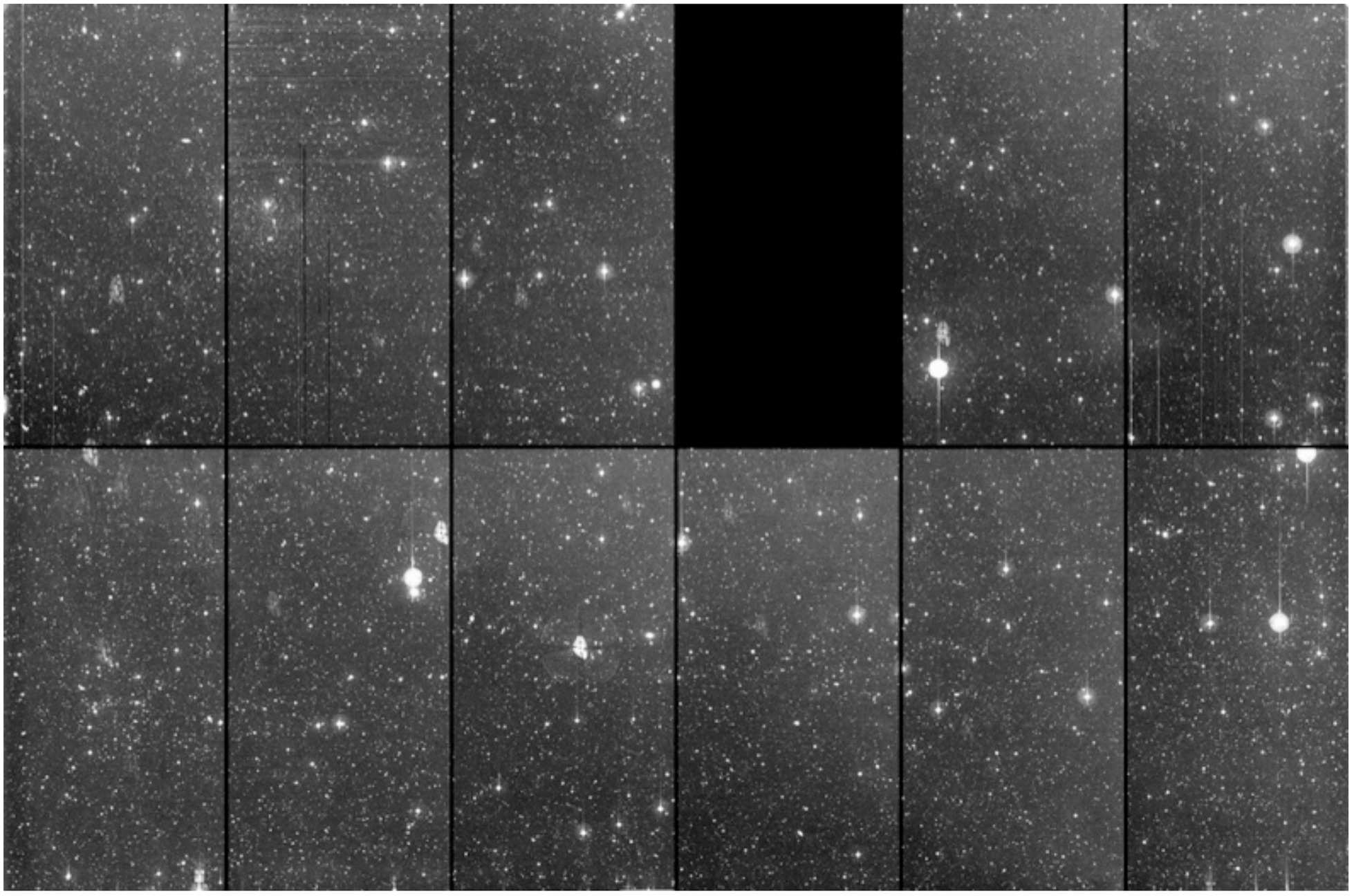
Palomar Transient Factory:

the assembly line

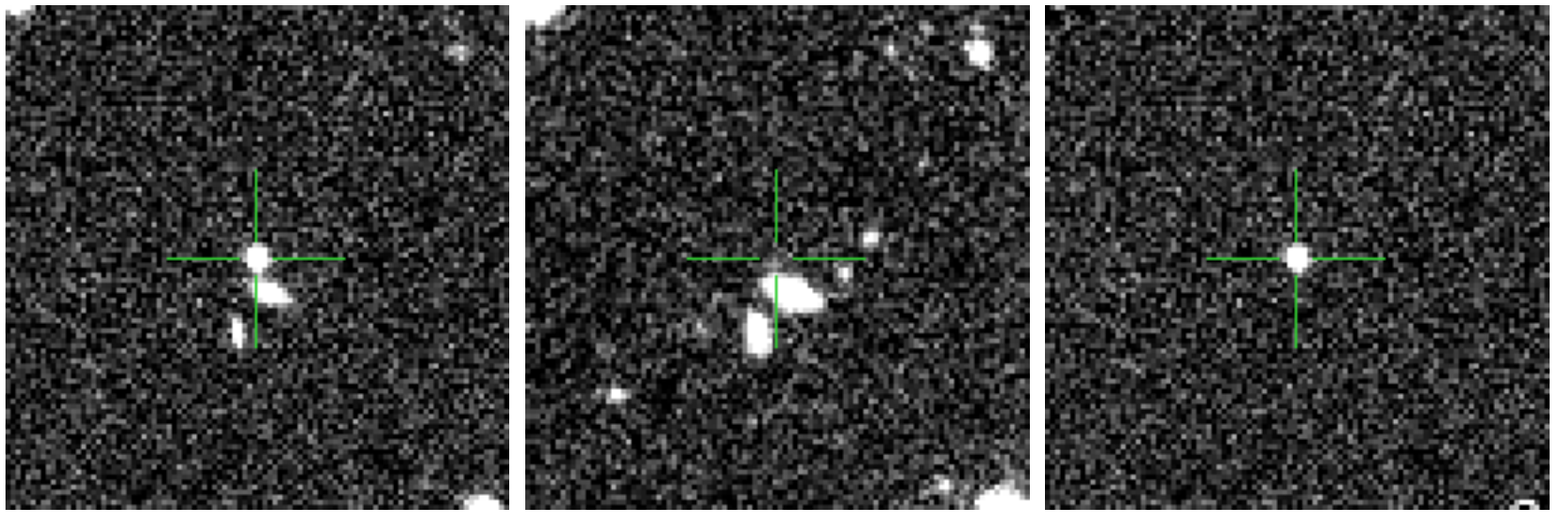
P48 Survey telescope (≈7 deg^2 FOV, R≈20.6 mag in 60 s)

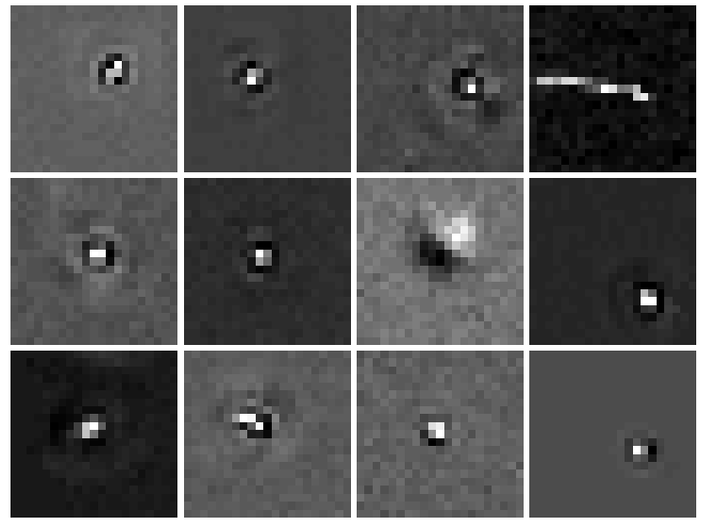
P60 Robotic, photometric follow-up

P200 Spectroscopy, classification→SED machine



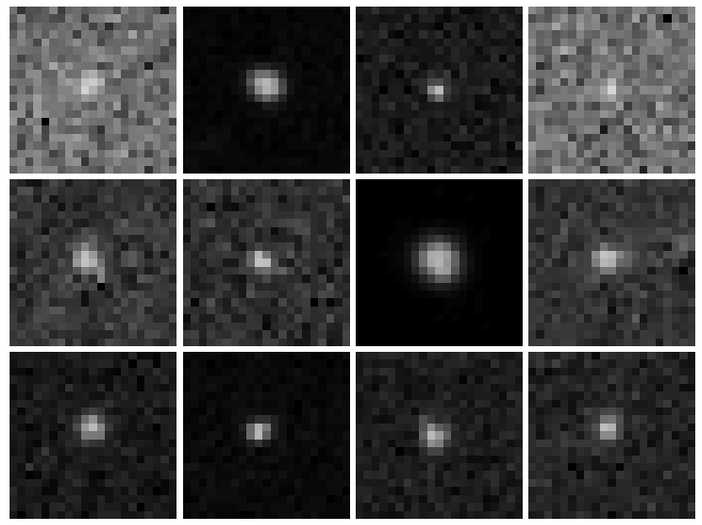
NEW REF SUB





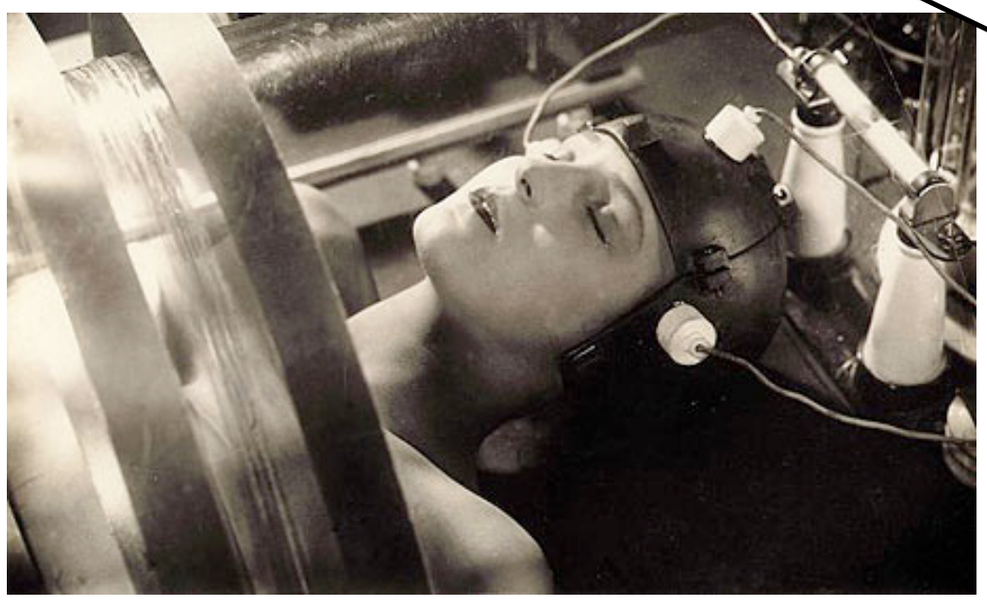
Visit same tiles again and again,

subtract deep co-adds from new images



Machine learning: real or bogus?

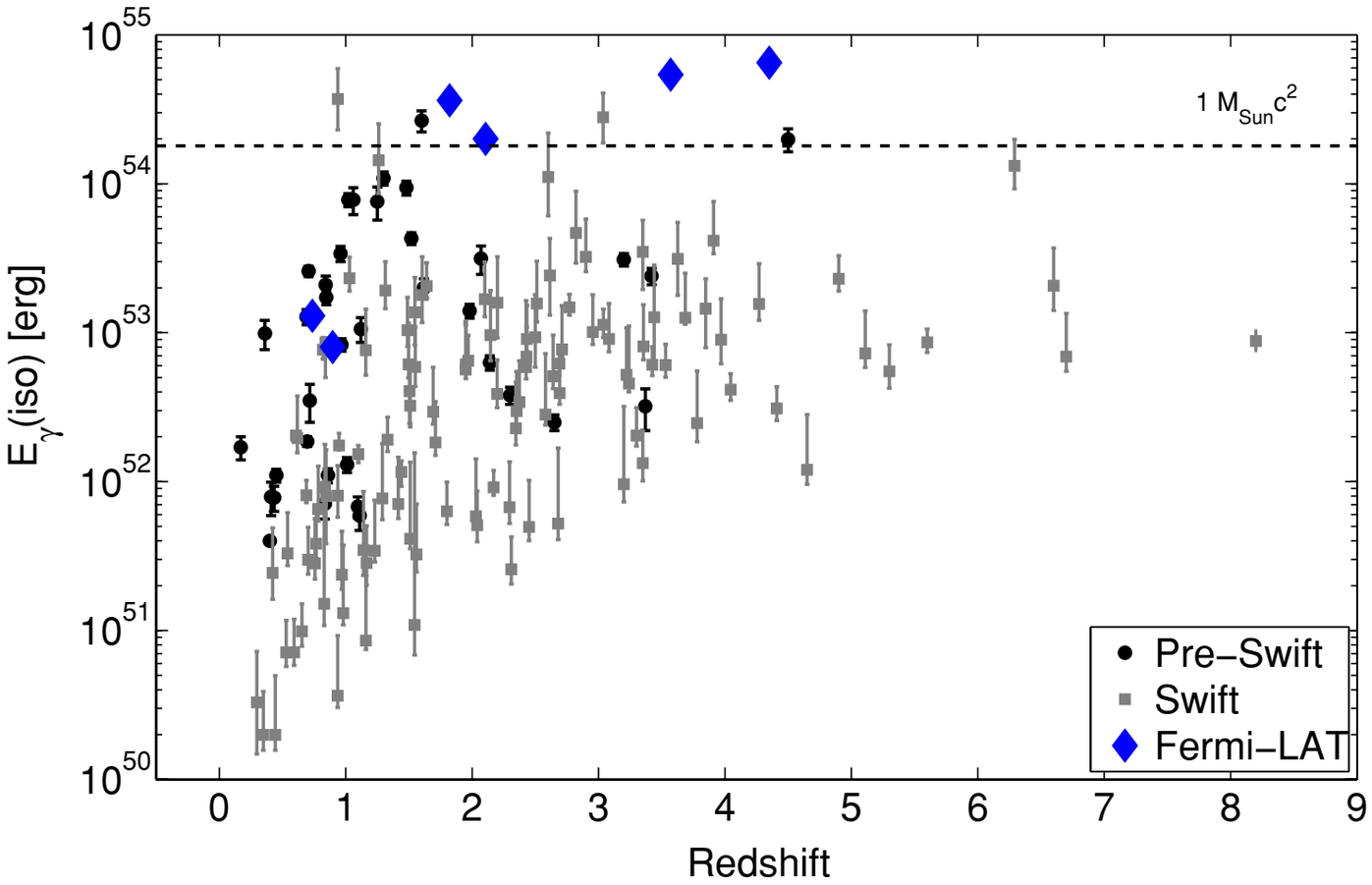
Brink et al. 2012, arXiv:1209.3775



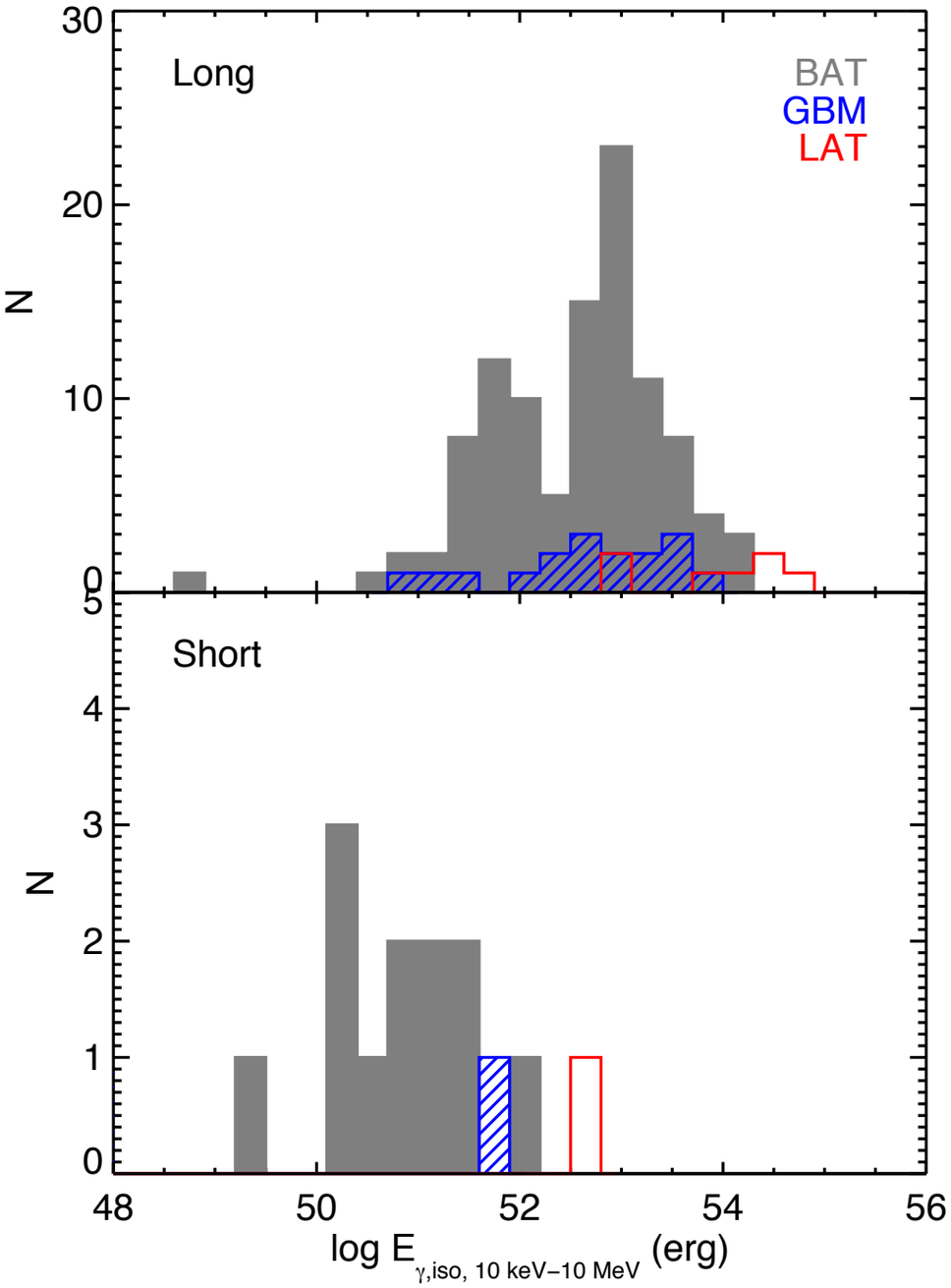
Human + machine

follow-up target selection

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

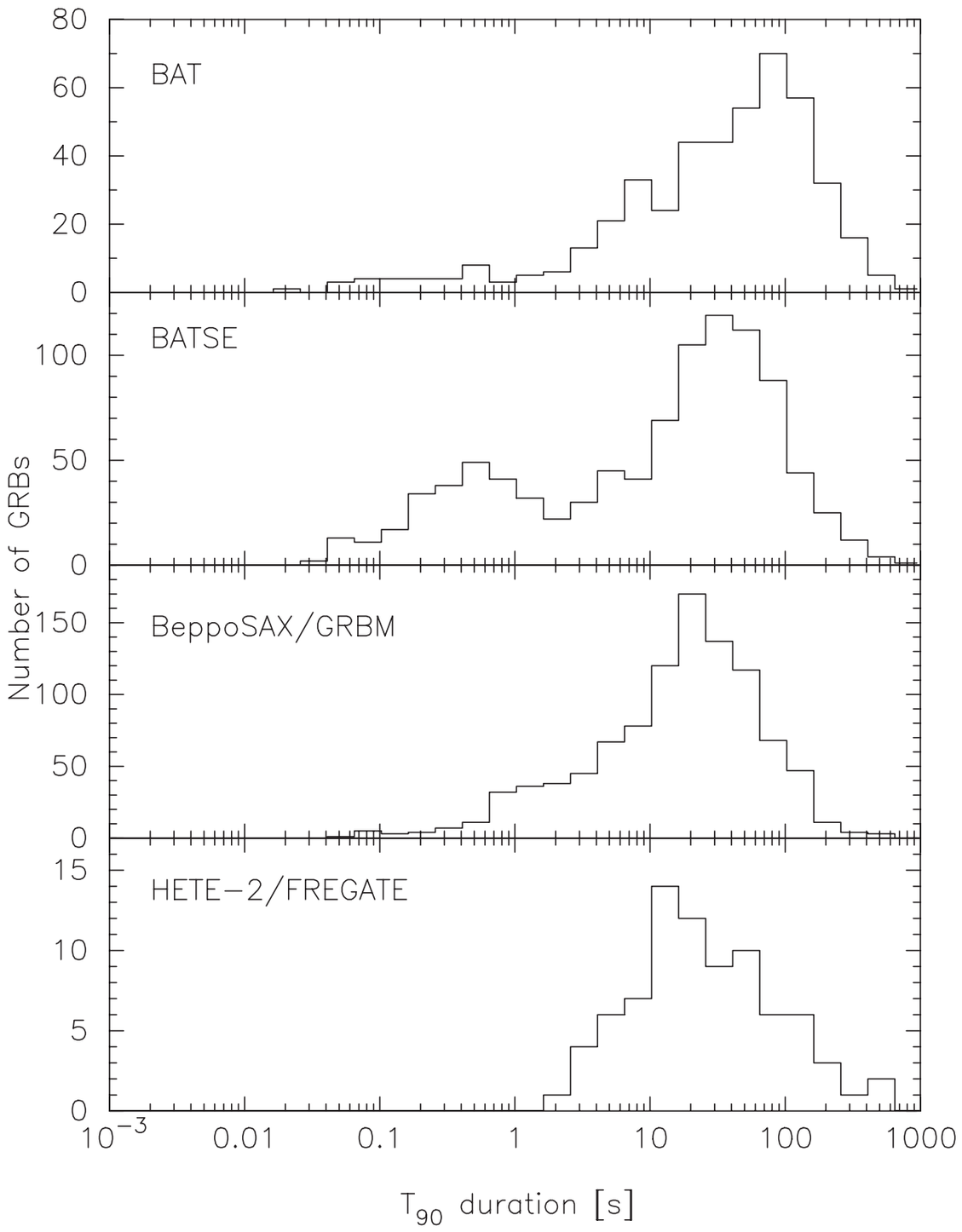


Cenko et al. (2011, ApJ 732:29)



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

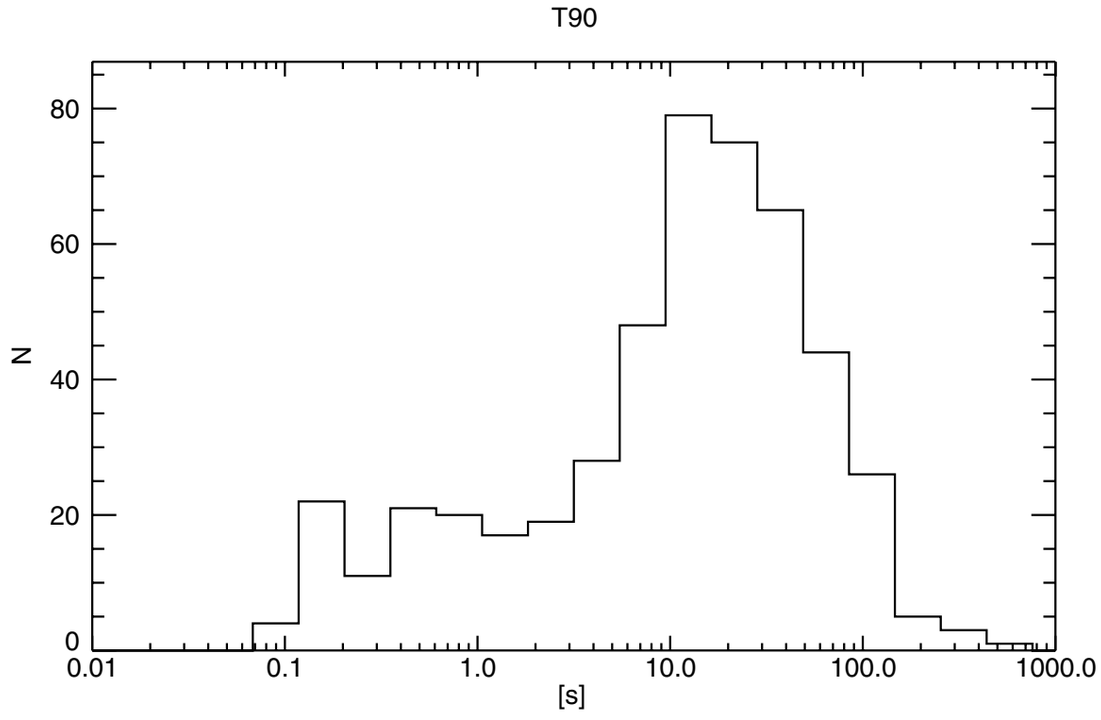
Swift BAT, 2004–2009, 476 GRBs



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’

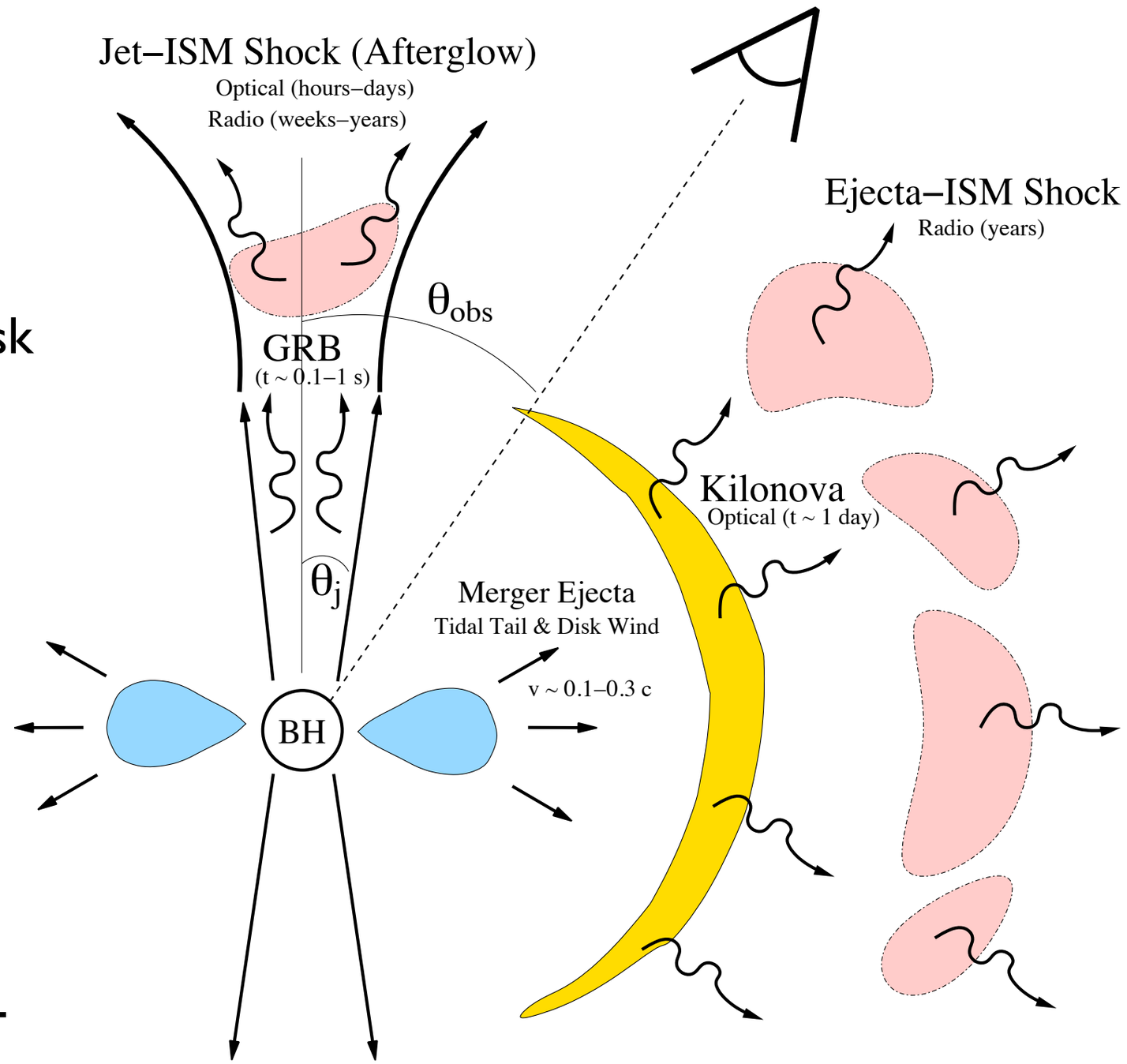
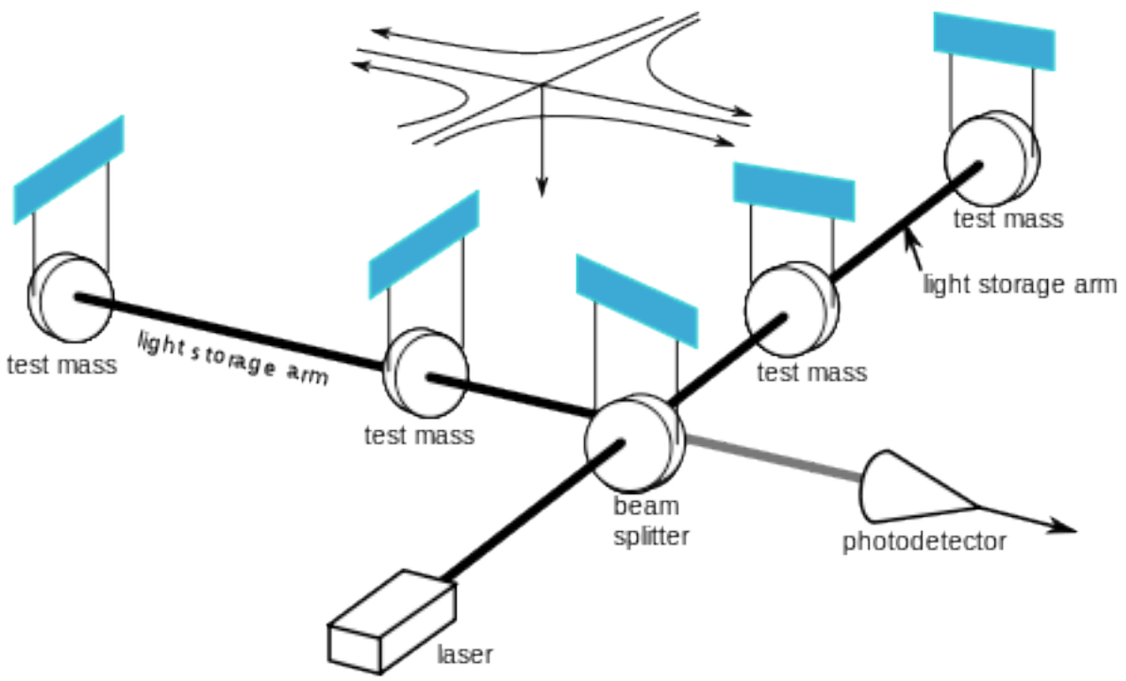


Figure 1 of Meztger & Berger 2012, ApJ, 746, 48

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



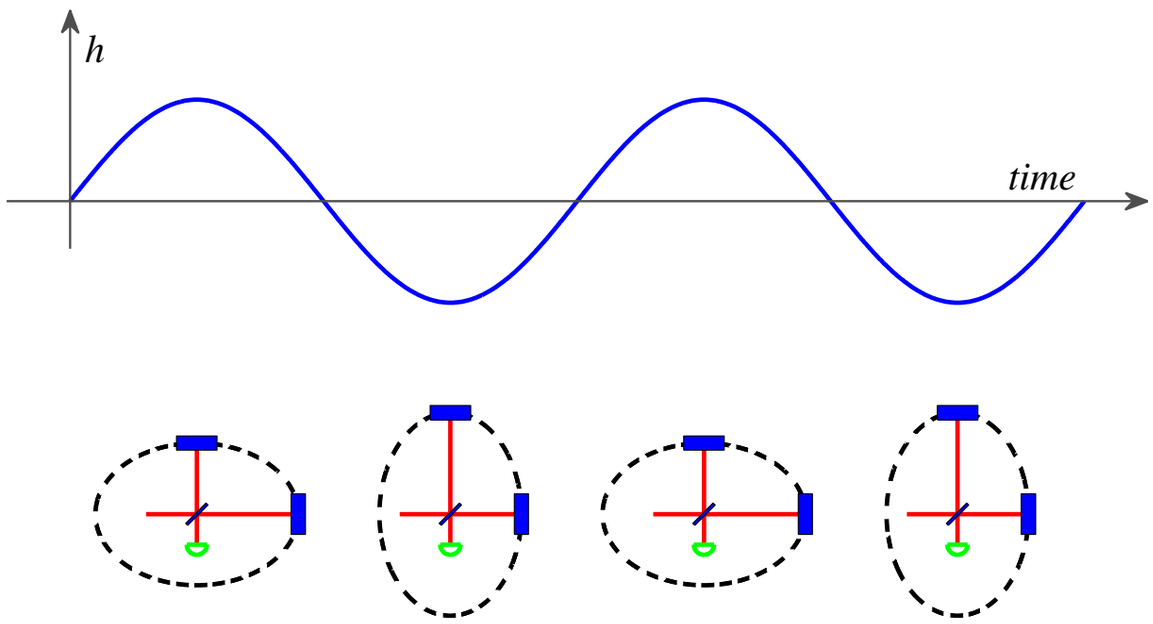


Image credits: http://en.wikipedia.org/wiki/File:Ligo.svg,
Rep. Prog. Phys. 72 (2009) 076901

Typical GW localizations:

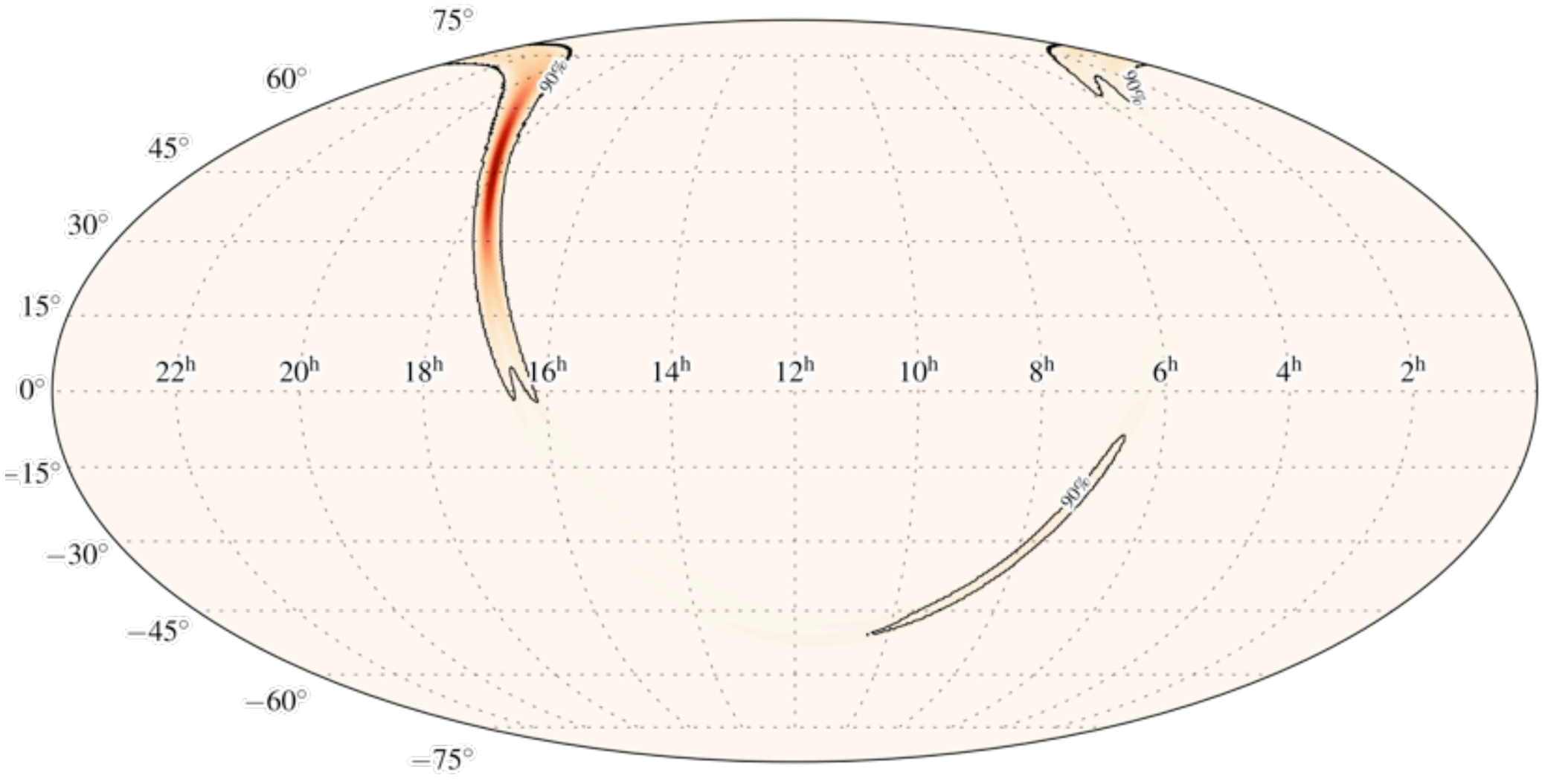
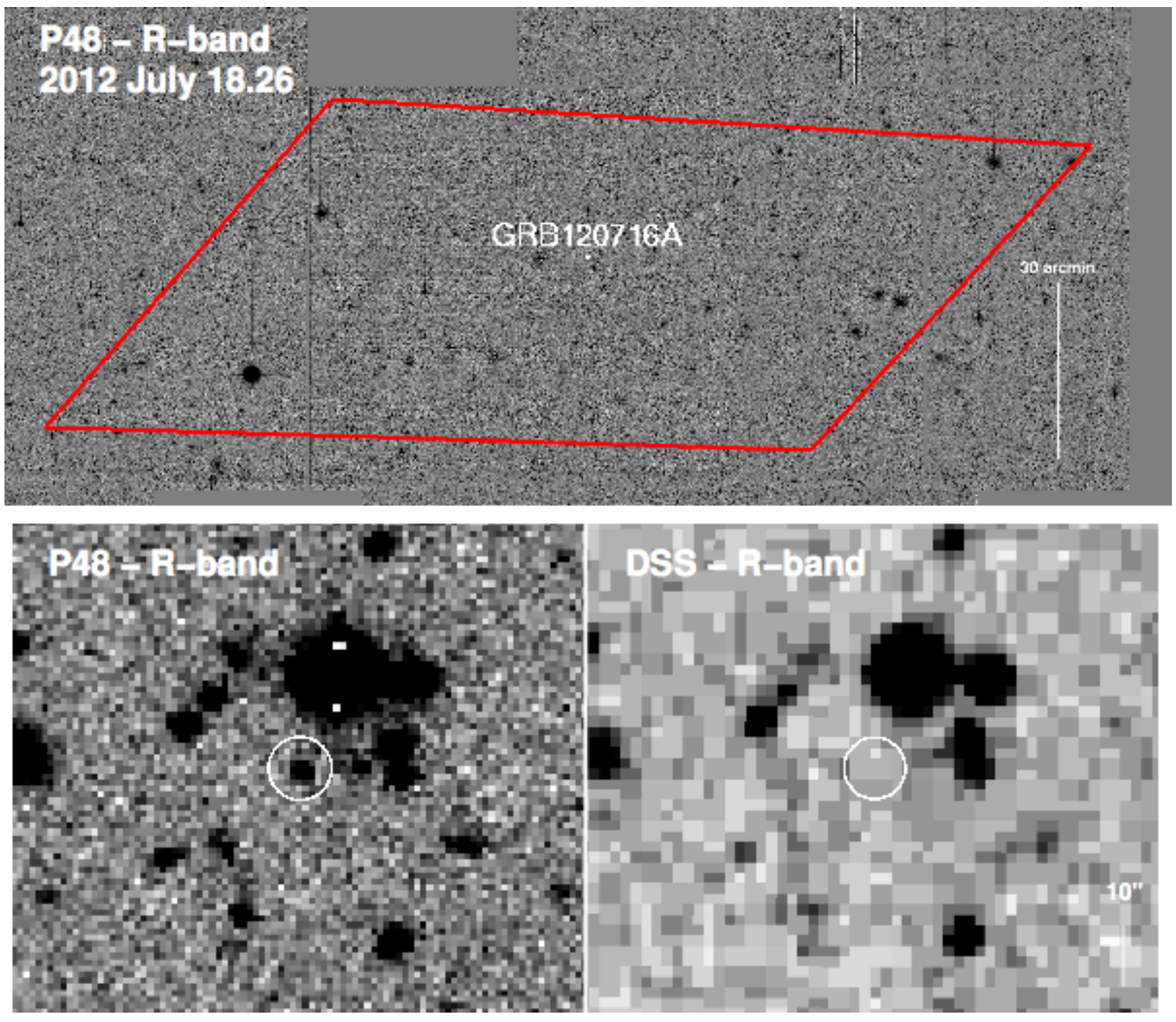


image from Singer et al. (2013, in prep.)

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)

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

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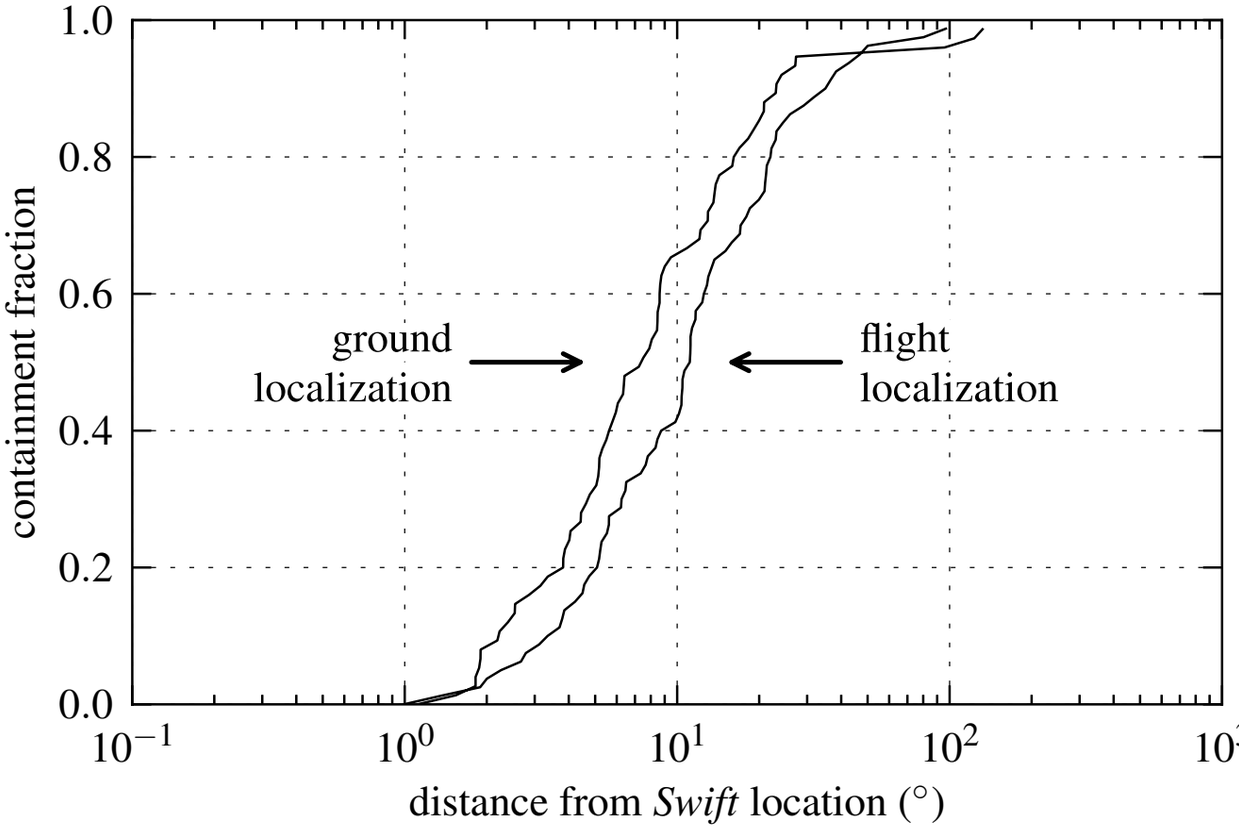
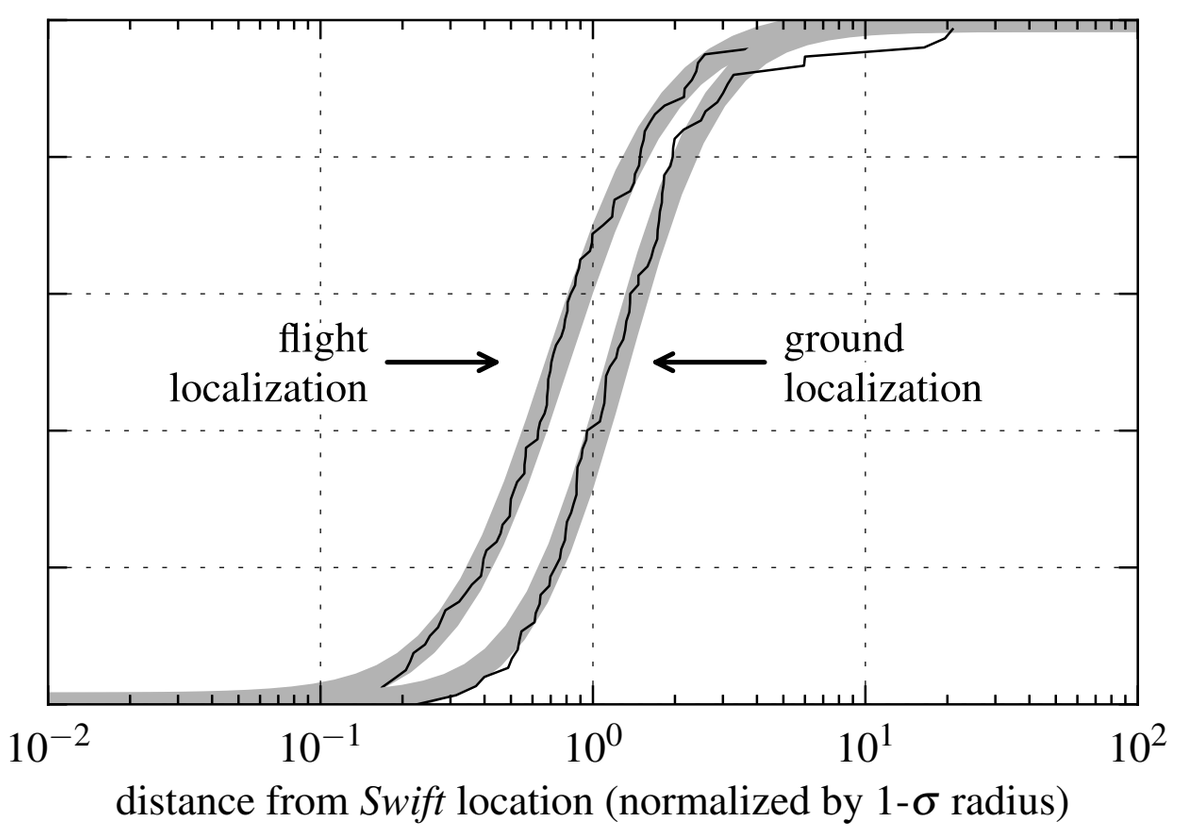
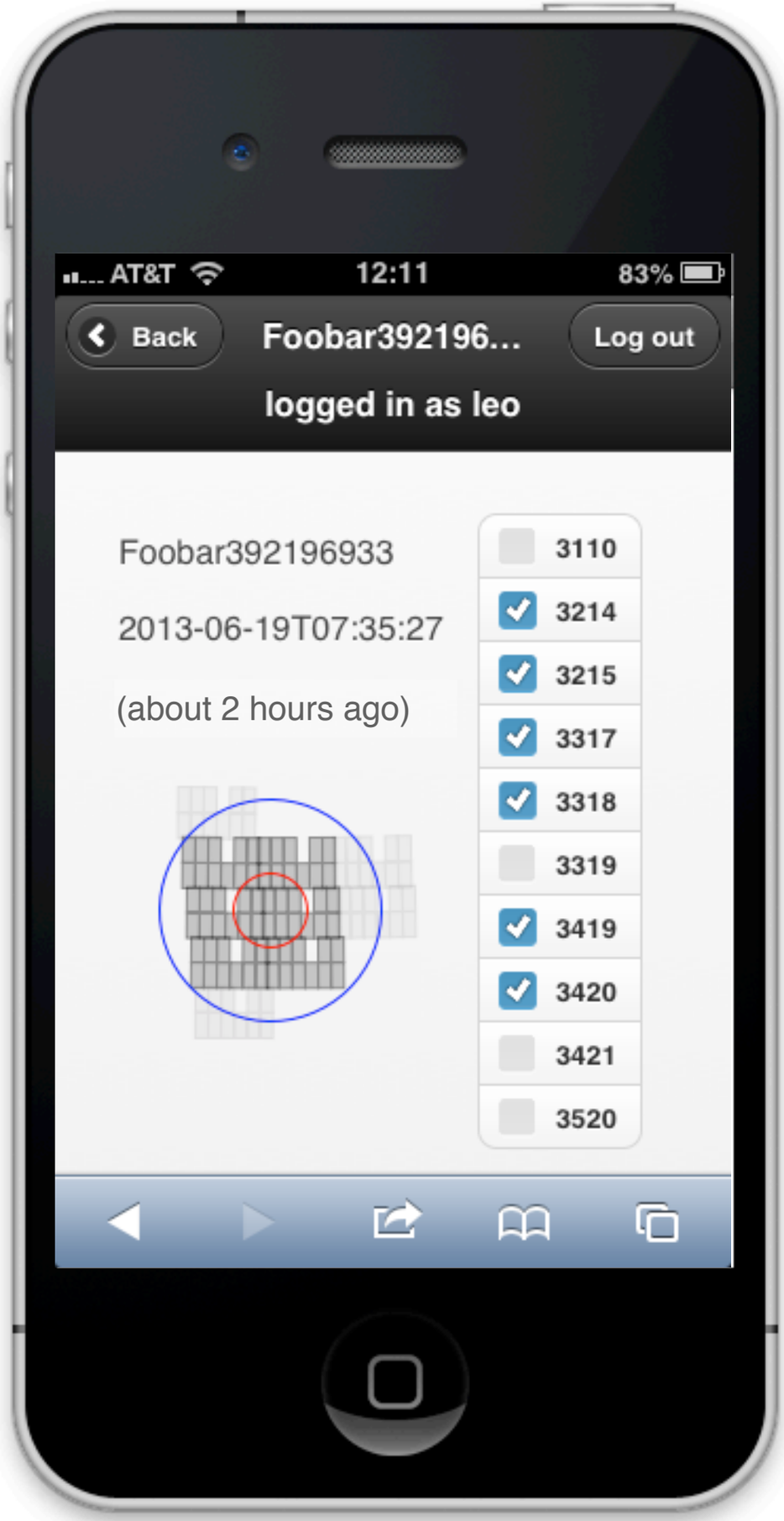
2. Afterglows of *Fermi* GRBs:

how do we hunt for them?

Parse GCN notice,
translate GBM error circle to probability map.






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

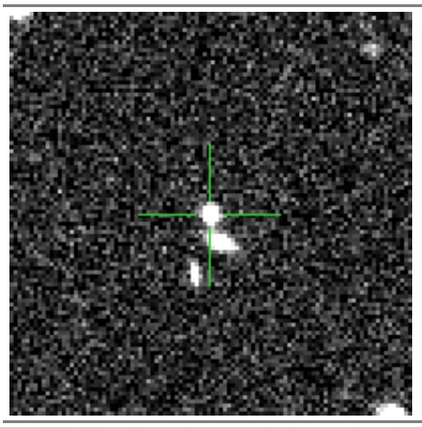
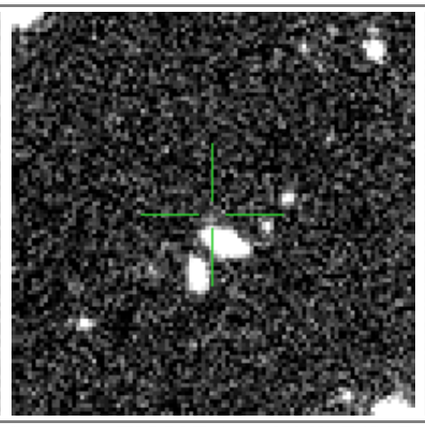
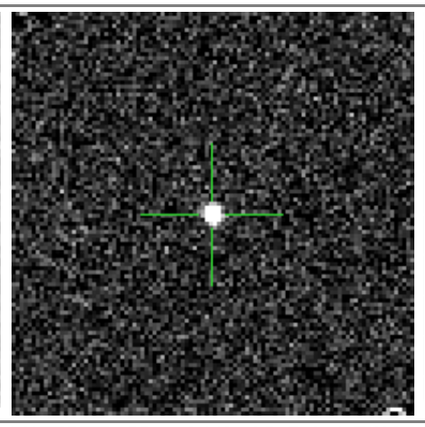
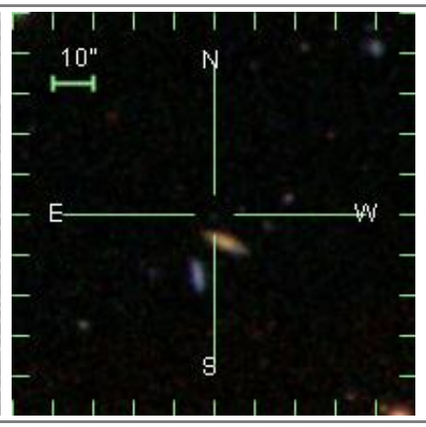
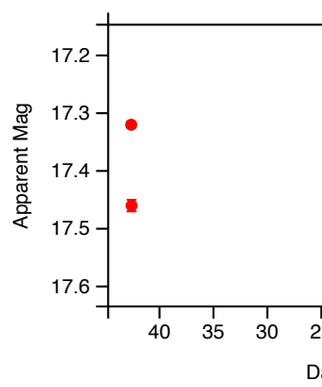
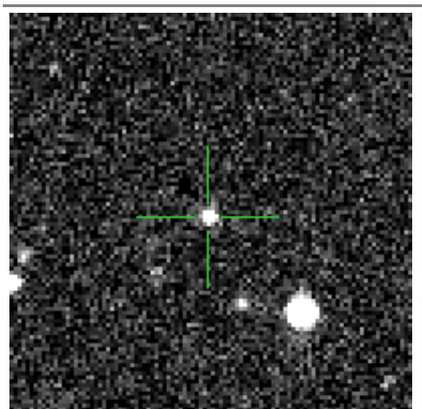
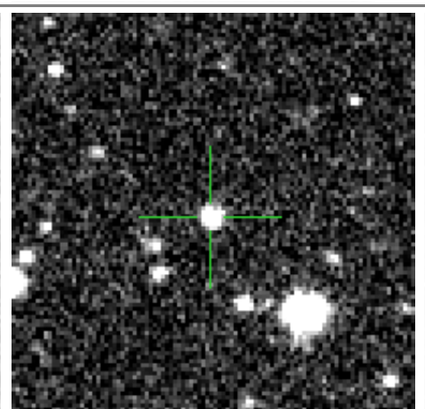
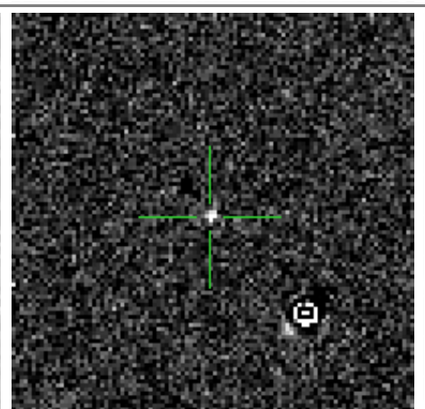
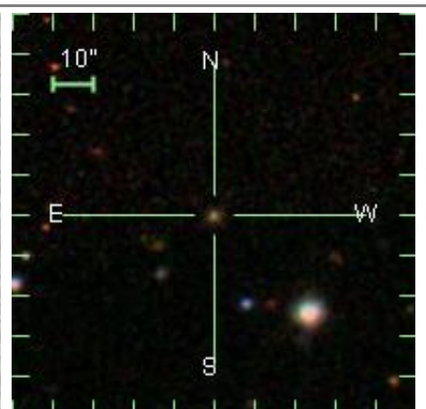
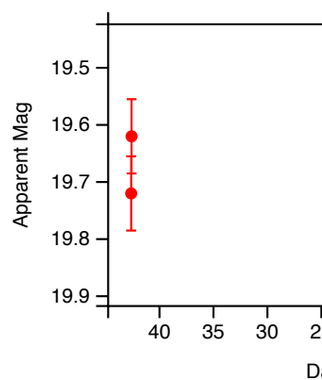
Change query parameters:

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

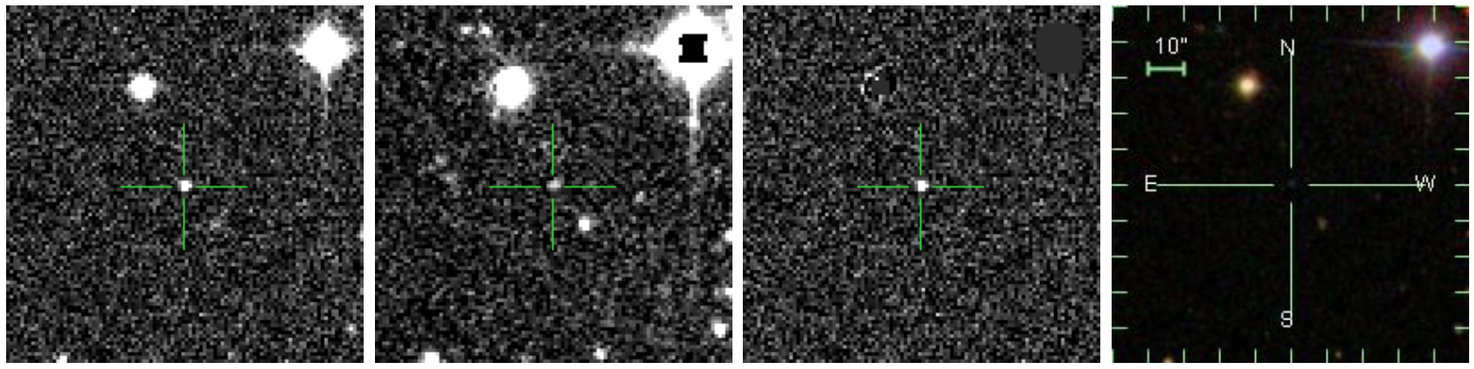
3 afterglow-like candidates scheduled for follow-up

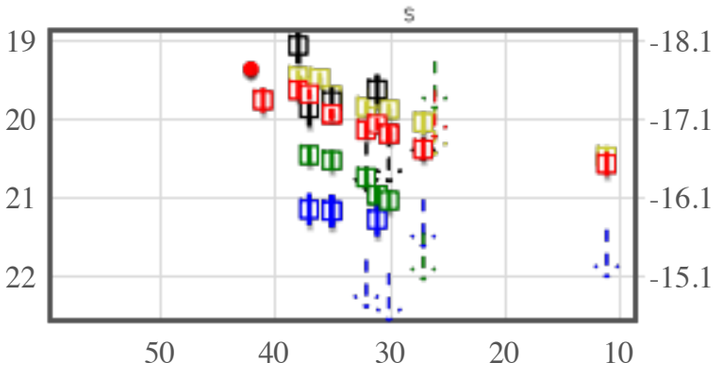
13bxj SN II

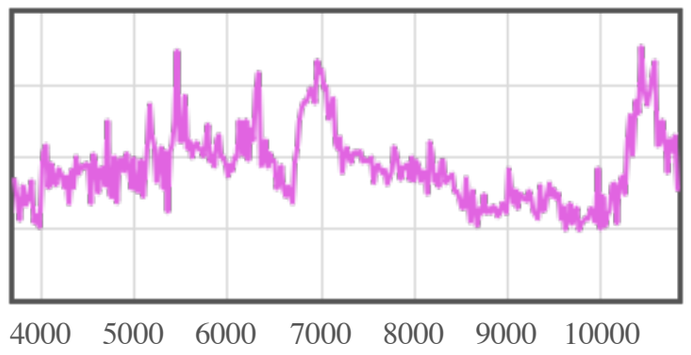
14:20:59.41 +15:09:42.1
215.247521 +15.161706

View another

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







r = 19.4 (42.2 d) | Upload New Photometry

z = 0.06 | Upload New Spectroscopy
DM (approximate) = 37.11

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 Jul 16 sagi [redshift]: 0.06
2013 Jul 16 sagi [classification]: SN II
2013 Jul 16 sagi [phase]: +7 days
2013 Jul 16 sagi [comment]: SSF best match is to SN 1987K at +7 days [view attachment]
2013 Jul 15 iair [info]: Observed at P200+DBSP
2013 Jul 02 duncan [info]: Observation triggered by Fermi/GBM trigger Fermi394416326
2013 Jul 02 ofer [info]: Faint host. No limits.
2013 Jul 02 ofer [type]: Transient

Add a Comment:

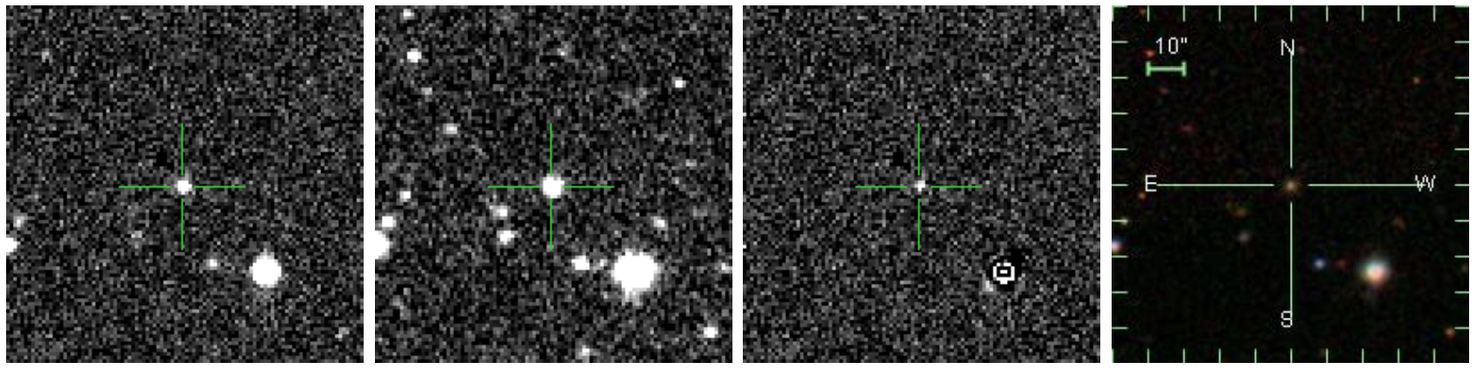
Attach File: Choose File no file selected
info Save Comment

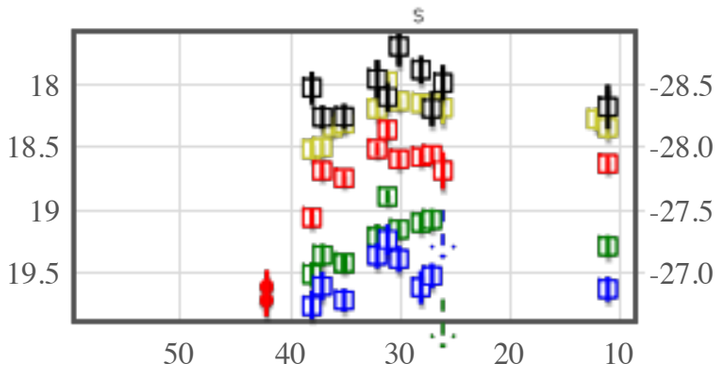
13bxk AGN

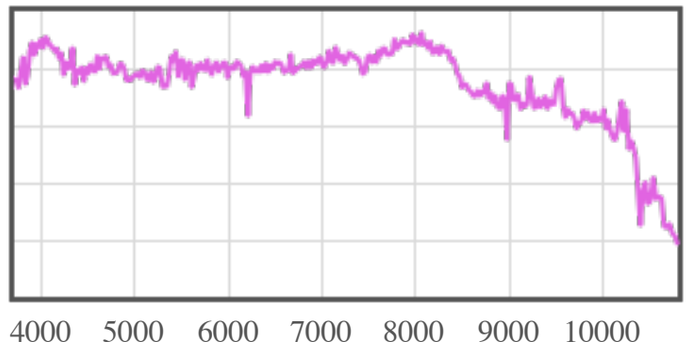
14:27:42.19 +16:02:55.5
216.925803 +16.048758

View another

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







r = 19.6 (42.2 d) | Upload New Photometry

z = 2.405 | Upload New Spectroscopy
DM (approximate) = 46.47

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 Jul 16 avishay [comment]: Resolved Mg II 2800A + weak CIV 1549
2013 Jul 16 sagi [classification]: AGN
2013 Jul 16 sagi [info]: Quasar
2013 Jul 16 sagi [redshift]: 2.405
2013 Jul 15 iair [info]: Observed at P200+DBSP
2013 Jul 02 duncan [info]: Observation triggered by Fermi/GBM trigger Fermi394416326
2013 Jul 02 ofer [info]: Dwarf/far-away host. No previous photometry.
2013 Jul 02 ofer [type]: Transient

Add a Comment:

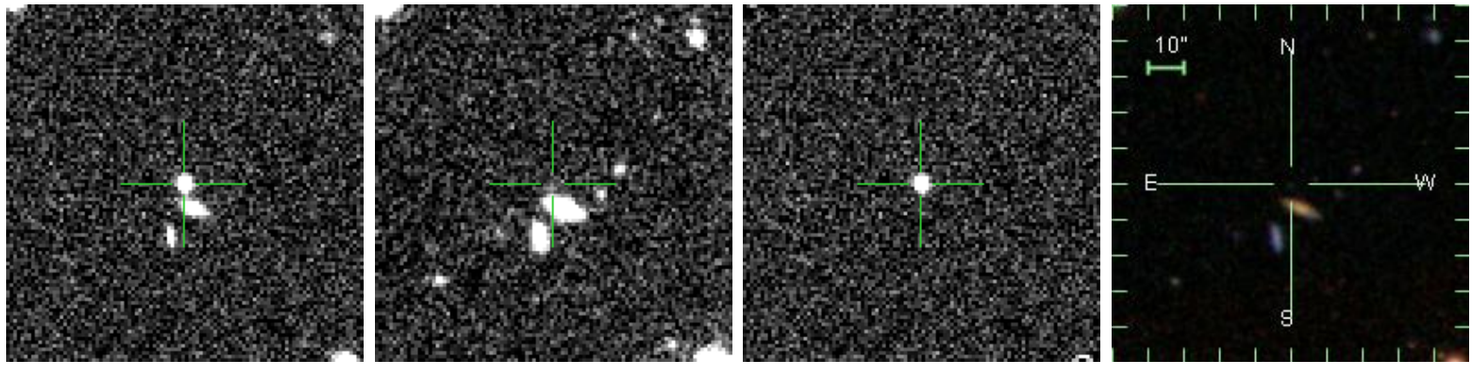
Attach File: Choose File no file selected
info Save Comment

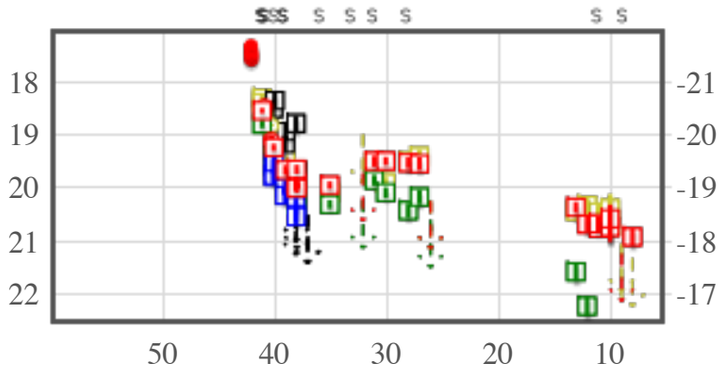
13bxl

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

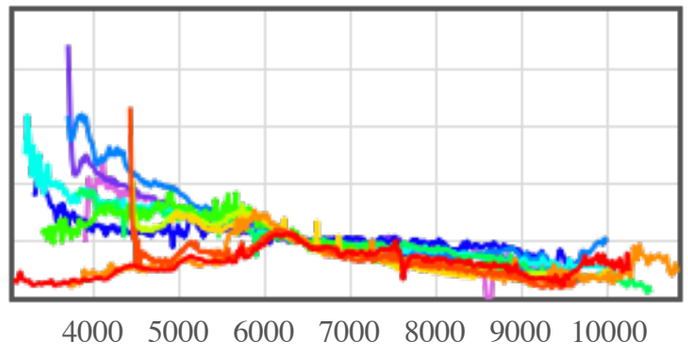
View another

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]

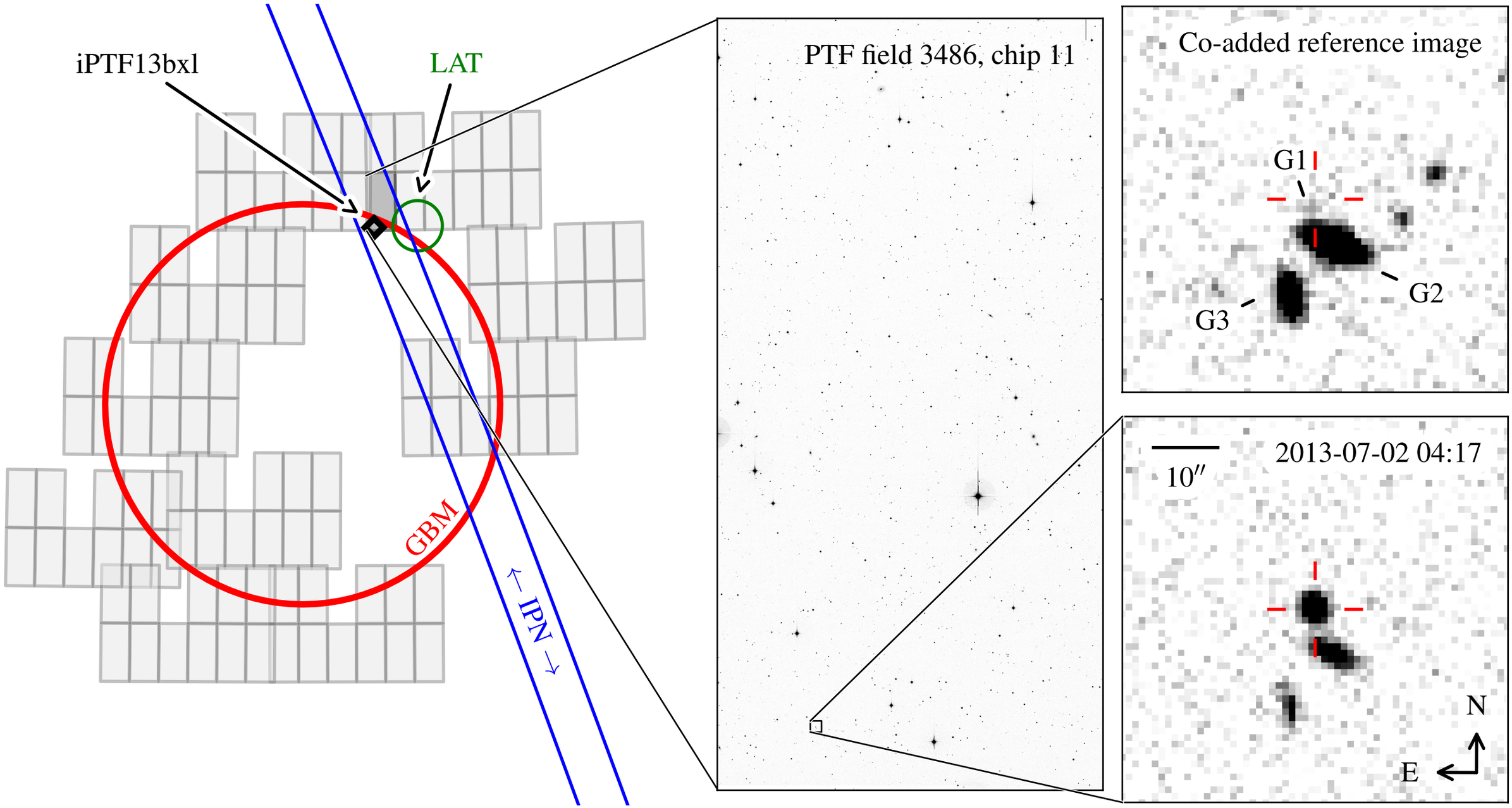
1. Palomar Transient Factory, *Fermi* GBM, and LIGO:
what do they have in common? what can we learn from afterglows of *Fermi* bursts?

2. Afterglows of *Fermi* GRBs:
how do we hunt for them?

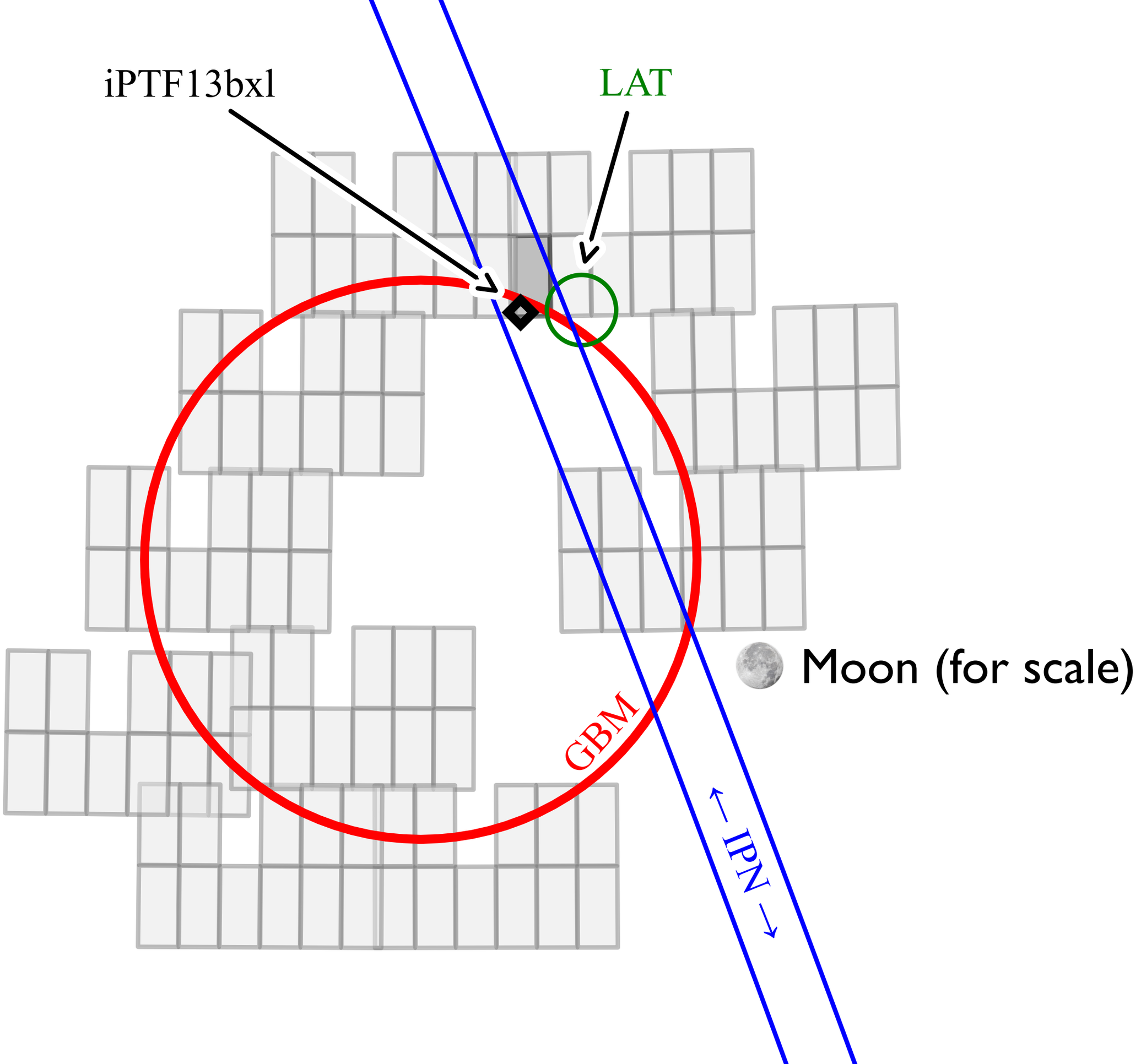
3. GRB 130702A and iPTF13bxl:
a nearby wimpy monster? z=0.145,
spectroscopic SN Ic-BL, 33 GCN circs, 2 ApJL papers,
proof of principle for Advanced LIGO!

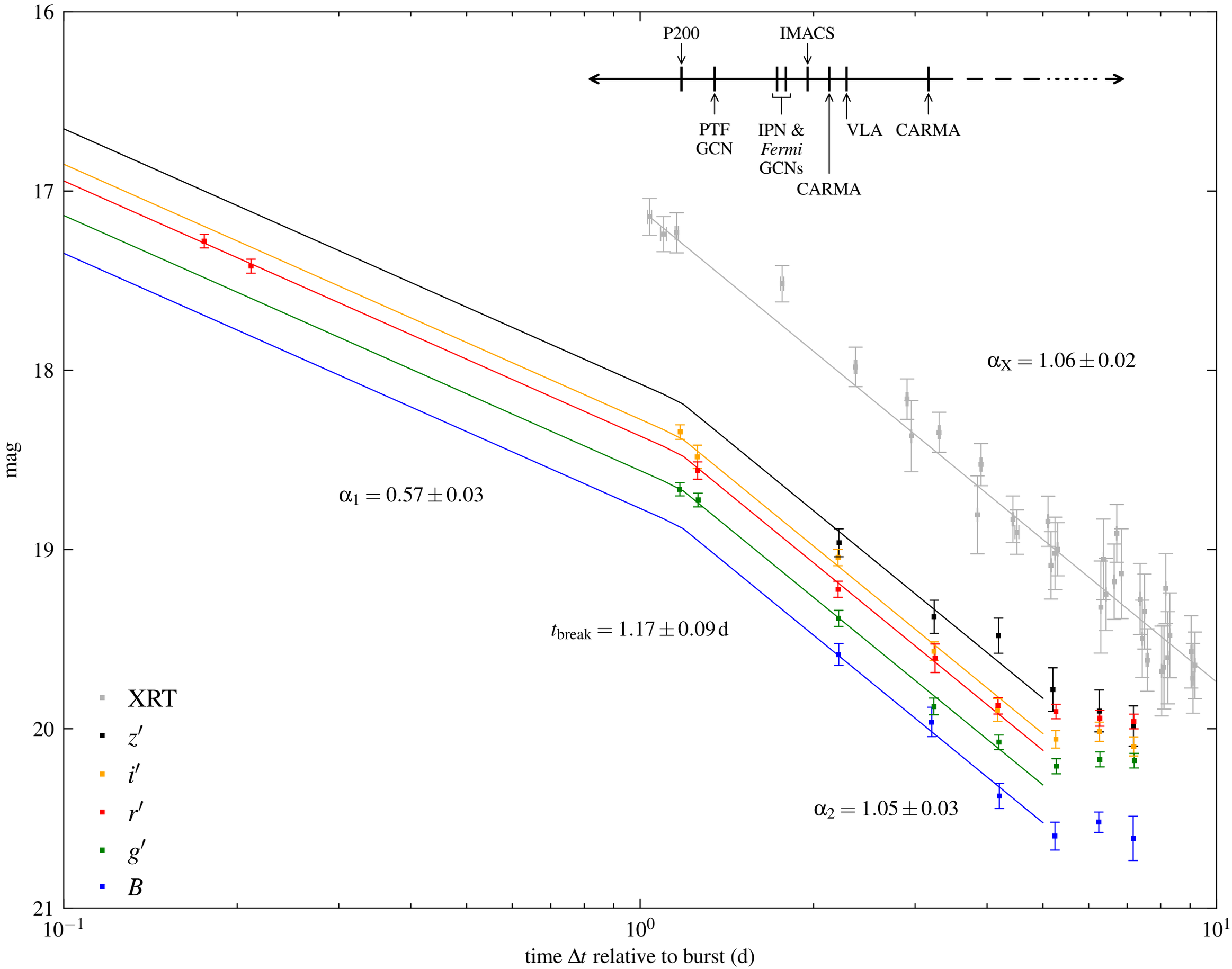
(Almost exactly) one year after IPN GRB:

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



accepted ApJL, http://arxiv.org/abs/1307.5851


iPTF13bxl
LAT
GBM
← IPN →
Moon (for scale)


P200
IMACS
PTF
GCN
IPN &
Fermi
GCNs
CARMA
VLA
CARMA
$\alpha_X = 1.06 \pm 0.02$
$\alpha_1 = 0.57 \pm 0.03$
$t_{break} = 1.17 \pm 0.09$ d
$\alpha_2 = 1.05 \pm 0.03$
XRT
z'
i'
r'
g'
B
mag
16
17
18
19
20
21
10^{-1}
10^{0}
10^{1}
time Δt relative to burst (d)

A: constant-density circumburst medium
B: wind model
C: wind model, but with very hard
electron distribution (p=1.55)

P48 + P60

VLA

CARMA

model "B"

model "C"

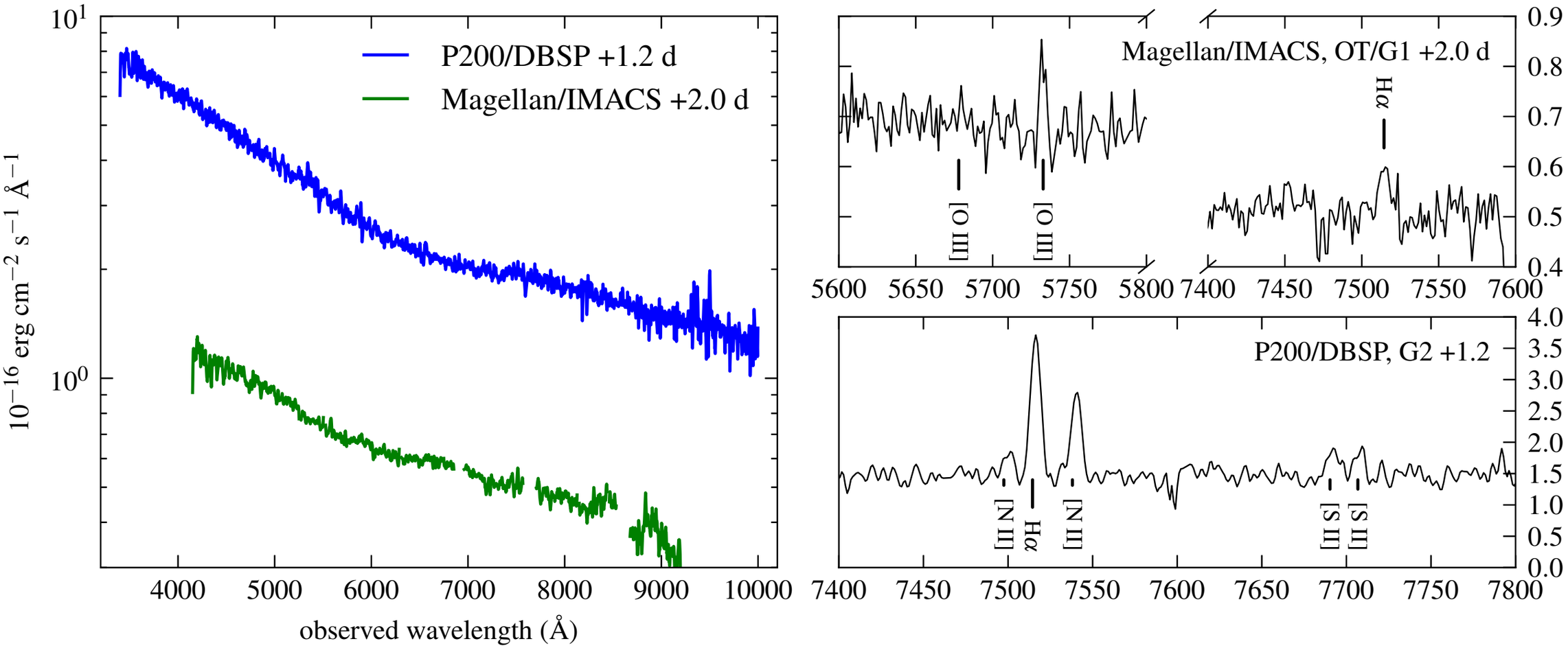
model "A"

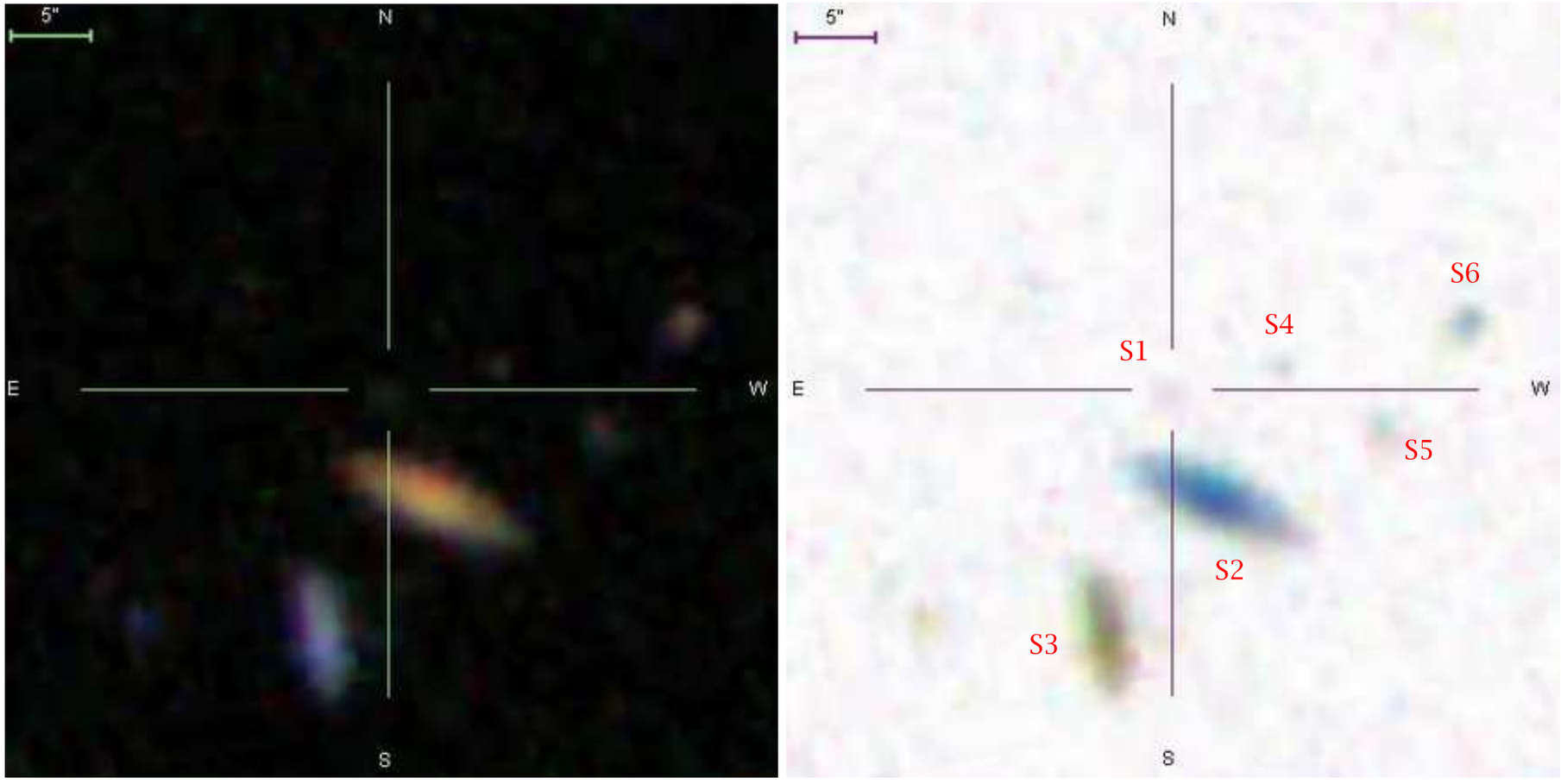
XRT

f_ν (mJy) at $\Delta t = 2.73$ day

ν (observed, GHz)

Redshift of host: z=0.145

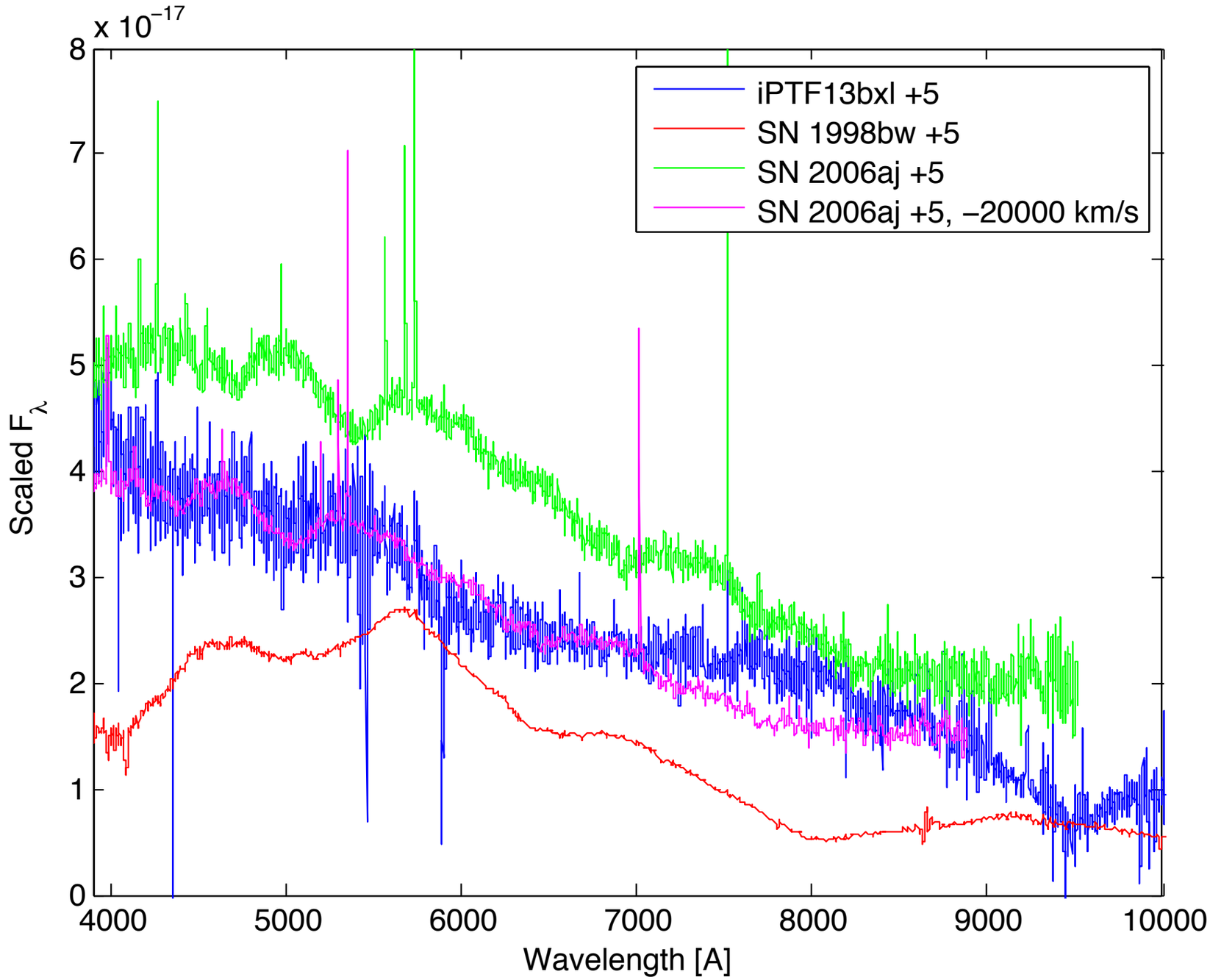




Metallicity of host environment:

see Kelly et al. (2013, http://arxiv.org/abs/1307.5103v1, submitted to ApJL)

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

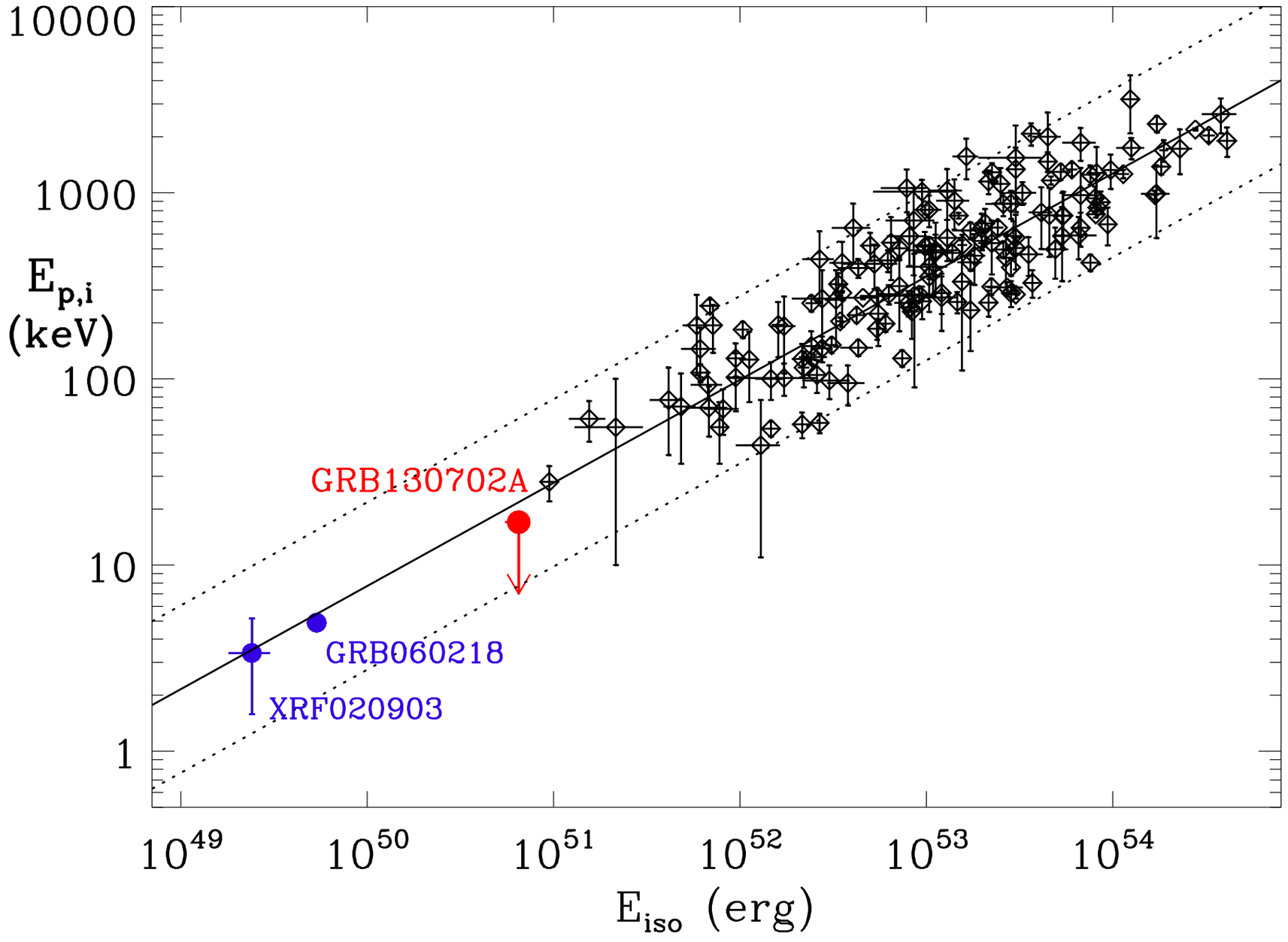


comparison in Transient Marshal by A. Gal-Yam

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)

Conclusions

- *Fermi* GBM bursts: well worth the hunt
- Luck is very important, but so is good software and plentiful follow-up resources
- Try same for IPN?
- GRB 130702A / iPTF13bxl: connection between cosmological GRBs and sub-luminous GRBs with well-studied SNe Ibc
- Next time: try for same-night photometric & spectroscopic follow-up → enter SED Machine
- Advanced LIGO: transfer infrastructure and lessons learned to future surveys (ZTF, BlackGEM, Pan-STARRS, LSST)

THANK YOU

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Astropy

HEALPix

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