FROM **FERMI GRBS** TO **LIGO** DISCOVERIES:

# THE NEEDLE IN THE 100 DEG$^2$ HAYSTACK

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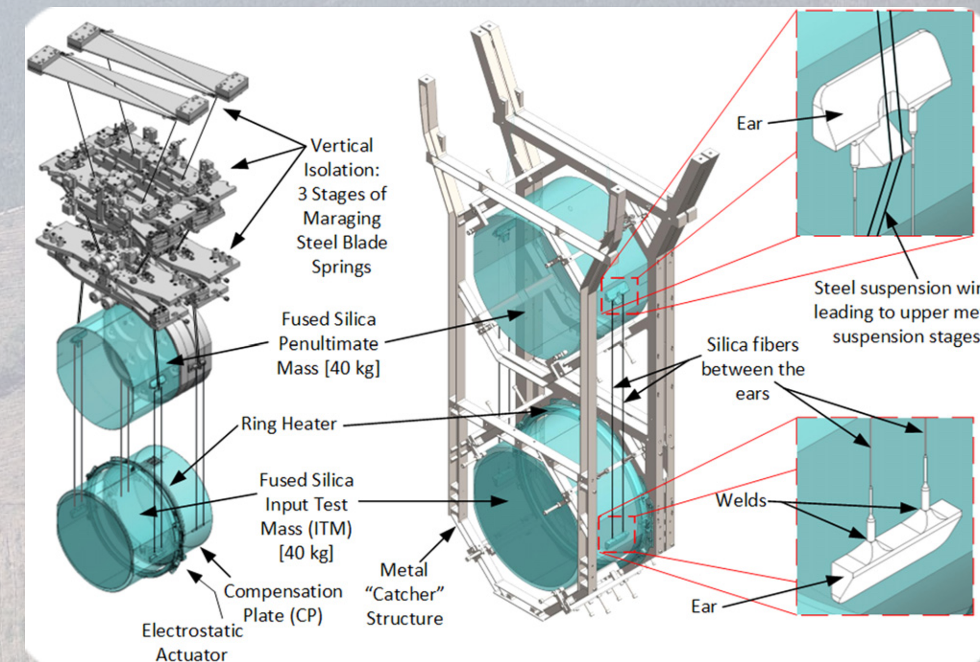
# ADVANCED LIGO + VIRGO




Aasi+ 2015

- Laser Interferometer Gravitational-wave Observatory
- An 8-km L-shaped Michelson interferometer;
  arms are two 4-km long Fabry-Perot optical cavities
- Sensitive to fractional changes in arm length of a few parts in $10^{-22}$,
  or changes in length of ~$10^{-16}$ cm, for 2 decades in frequency around 100 Hz
  (~0.001 fm displacements at audio frequencies)
- End mirrors are 40 kg test masses made of fused silica,
  suspended from active multi-stage pendula; quasi-free-falling trajectories are
  perturbed by passage of gravitational waves
- Designed to detect gravitational waves from (among other sources) binary
  neutron star mergers

http://www.ligo.org/multimedia/gallery/llo-images/Aerial%201%20small.jpg

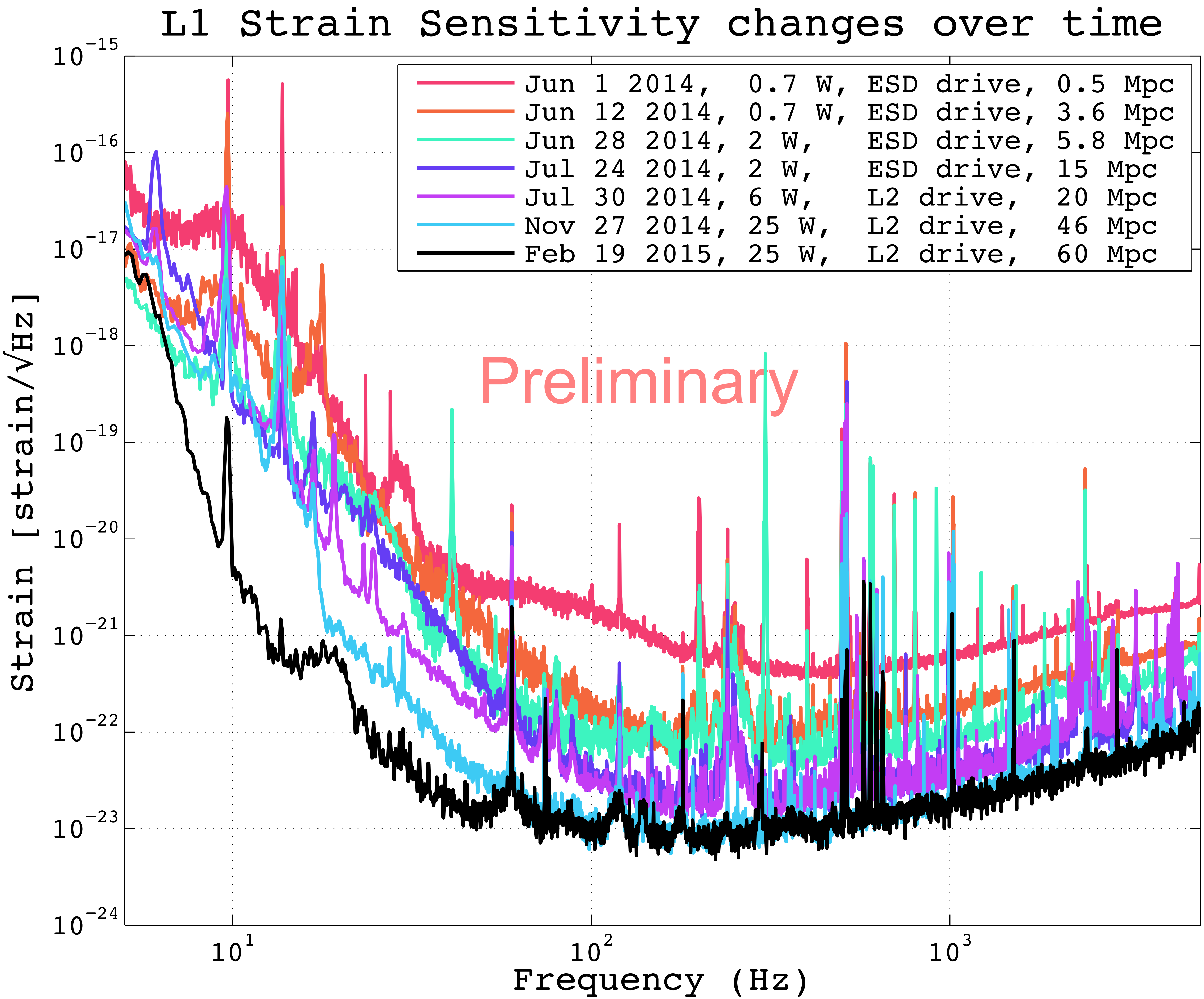
http://www18.i2u2.org/elab/ligo/home/project.jsp

http://www.phys.ufl.edu/~bernard/IREU2008/images/largeimages/Virgo0.jpg

# The story so far

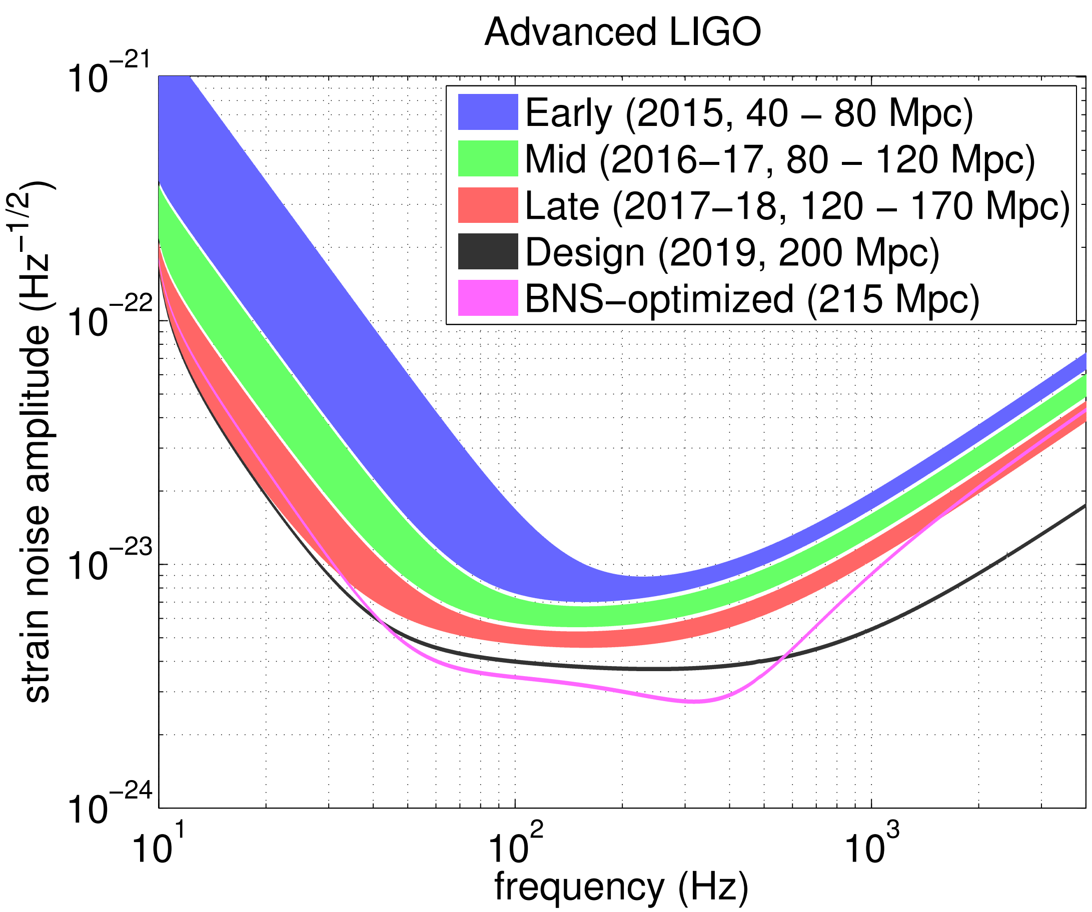
- Global network of 3 multi-km interferometric observatories:
  LIGO–Hanford, LIGO–Livingston, Virgo
- During joint LIGO–Virgo science run in Summer—Fall 2010,
  sent alerts to astronomers to point telescopes see Abadie et al. 2012, A&A 541, A155
- Entirely redesigned Advanced detectors are currently being commissioned, first science data expected in late 2015 to early 2016. ***Both LHO and LLO have been locked now!***
- Final design sensitivity (toward end of decade) is 10x initial LIGO's.
- More detectors under construction or planned: KAGRA, LIGO–India

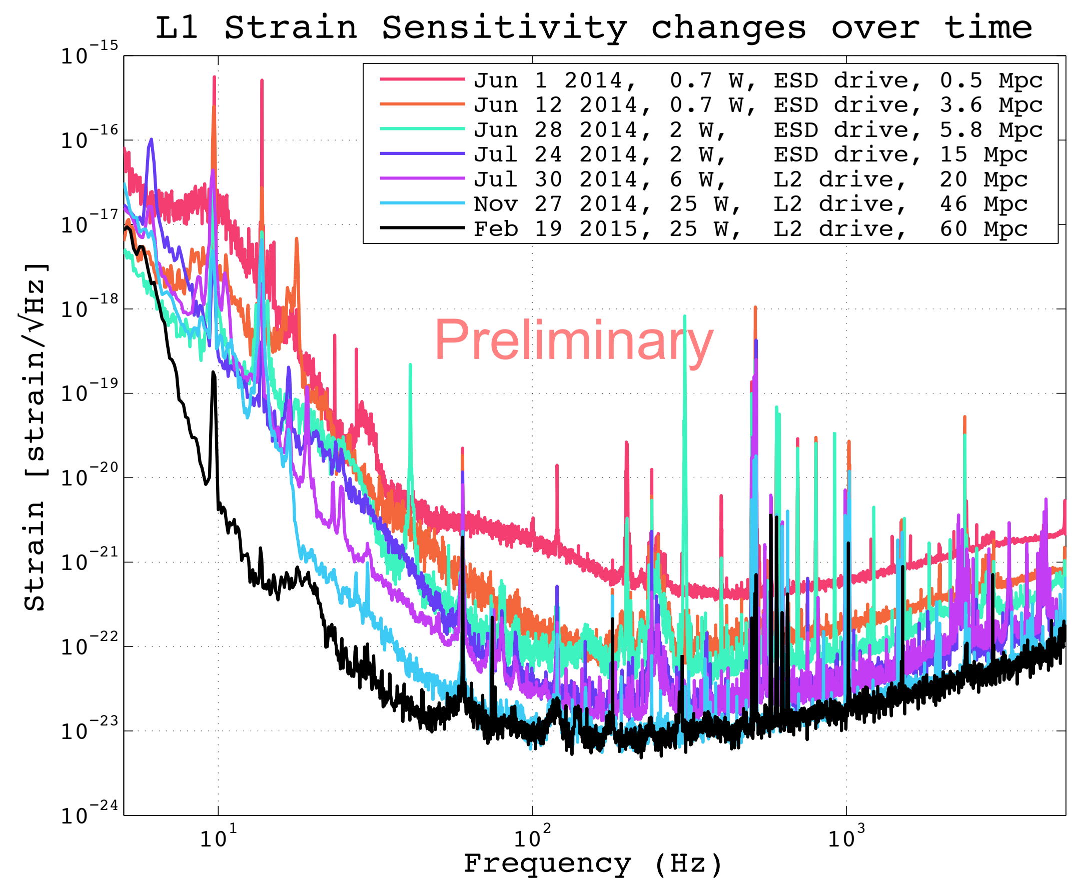
Some breaking news:



L1 Strain Sensitivity changes over time
Jun 1 2014, 0.7 W, ESD drive, 0.5 Mpc
Jun 12 2014, 0.7 W, ESD drive, 3.6 Mpc
Jun 28 2014, 2 W, ESD drive, 5.8 Mpc
Jul 24 2014, 2 W, ESD drive, 15 Mpc
Jul 30 2014, 6 W, L2 drive, 20 Mpc
Nov 27 2014, 25 W, L2 drive, 46 Mpc
Feb 19 2015, 25 W, L2 drive, 60 Mpc
Preliminary
Strain [strain/√Hz]
Frequency (Hz)

# L1 sensitivity is right on target!




| Epoch | Estimated Run Duration | $E_{\rm GW} = 10^{-2} M_\odot c^2$ Burst Range (Mpc) | | BNS Range (Mpc) | | Number of BNS Detections | % BNS Localized within | |
|---|---|---|---|---|---|---|---|---|
| | | LIGO | Virgo | LIGO | Virgo | | 5 deg$^2$ | 20 deg$^2$ |
| 2015 | 3 months | 40 – 60 | – | 40 – 80 | – | 0.0004 – 3 | – | – |
| 2016–17 | 6 months | 60 – 75 | 20 – 40 | 80 – 120 | 20 – 60 | 0.006 – 20 | 2 | 5 – 12 |
| 2017–18 | 9 months | 75 – 90 | 40 – 50 | 120 – 170 | 60 – 85 | 0.04 – 100 | 1 – 2 | 10 – 12 |
| 2019+ | (per year) | 105 | 40 – 80 | 200 | 65 – 130 | 0.2 – 200 | 3 – 8 | 8 – 28 |
| 2022+ (India) | (per year) | 105 | 80 | 200 | 130 | 0.4 – 400 | 17 | 48 |

LSC & Virgo 2013, arXiv:1304.0670

# BINARY NEUTRON STAR MERGERS

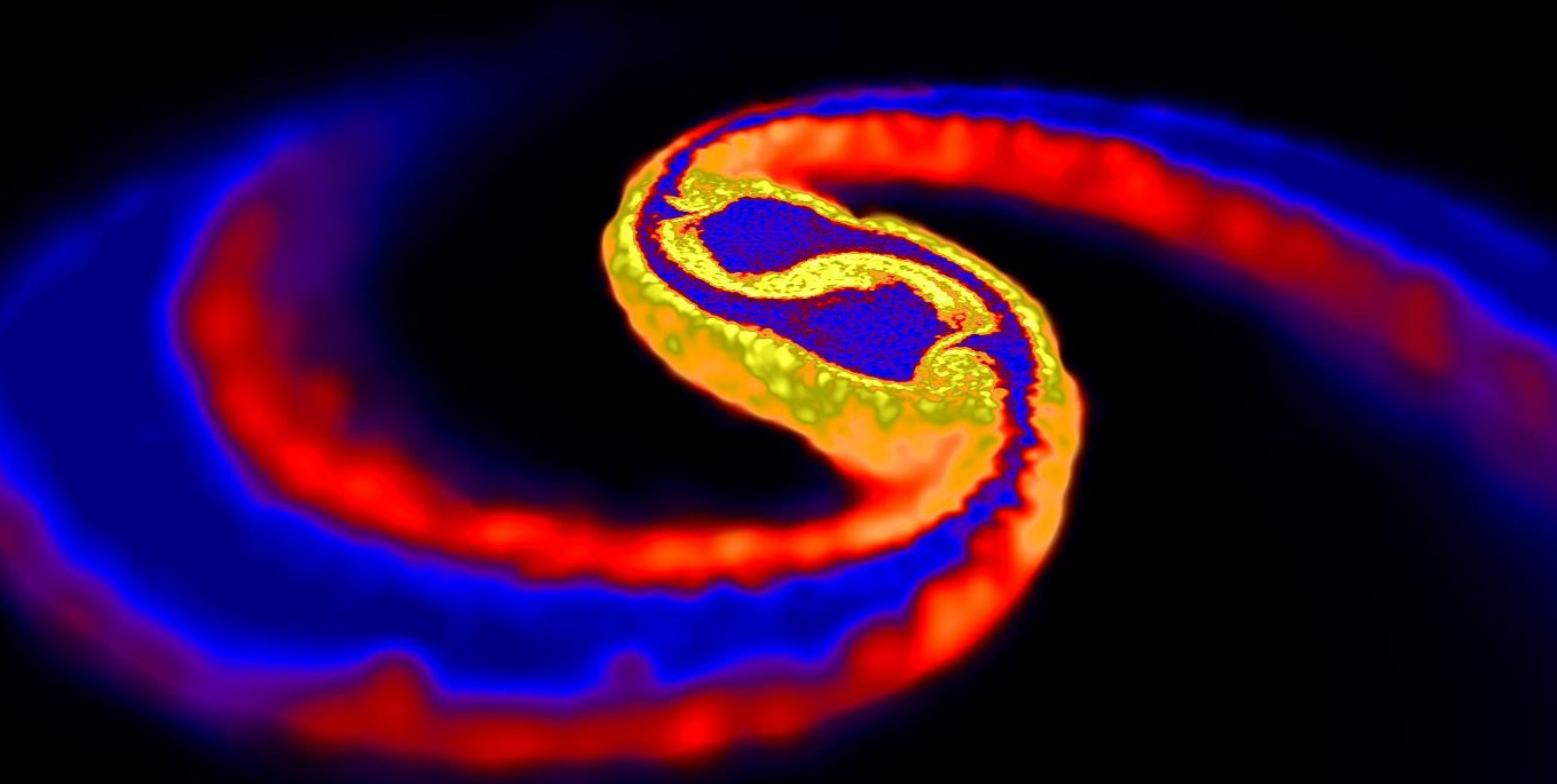
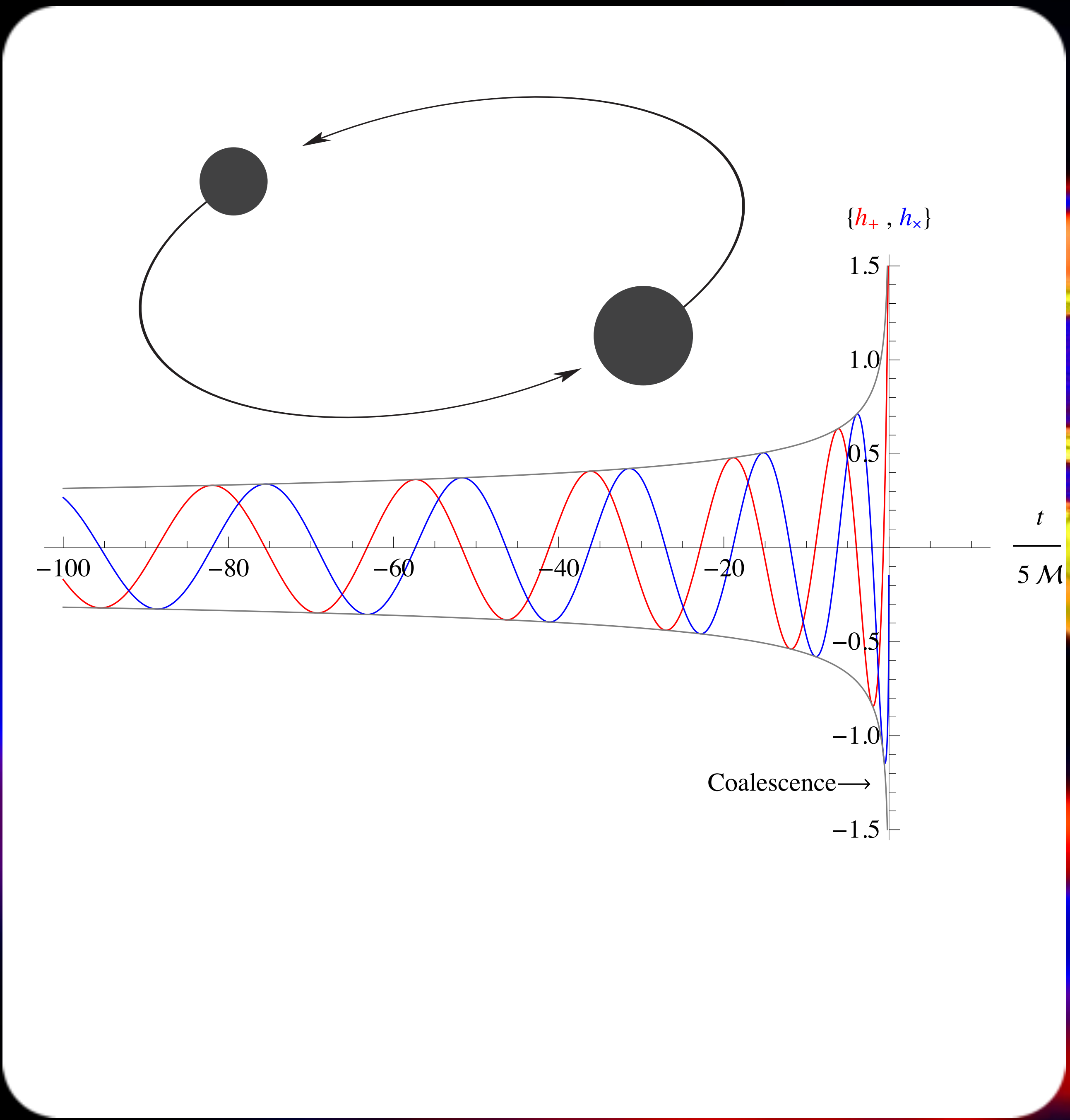
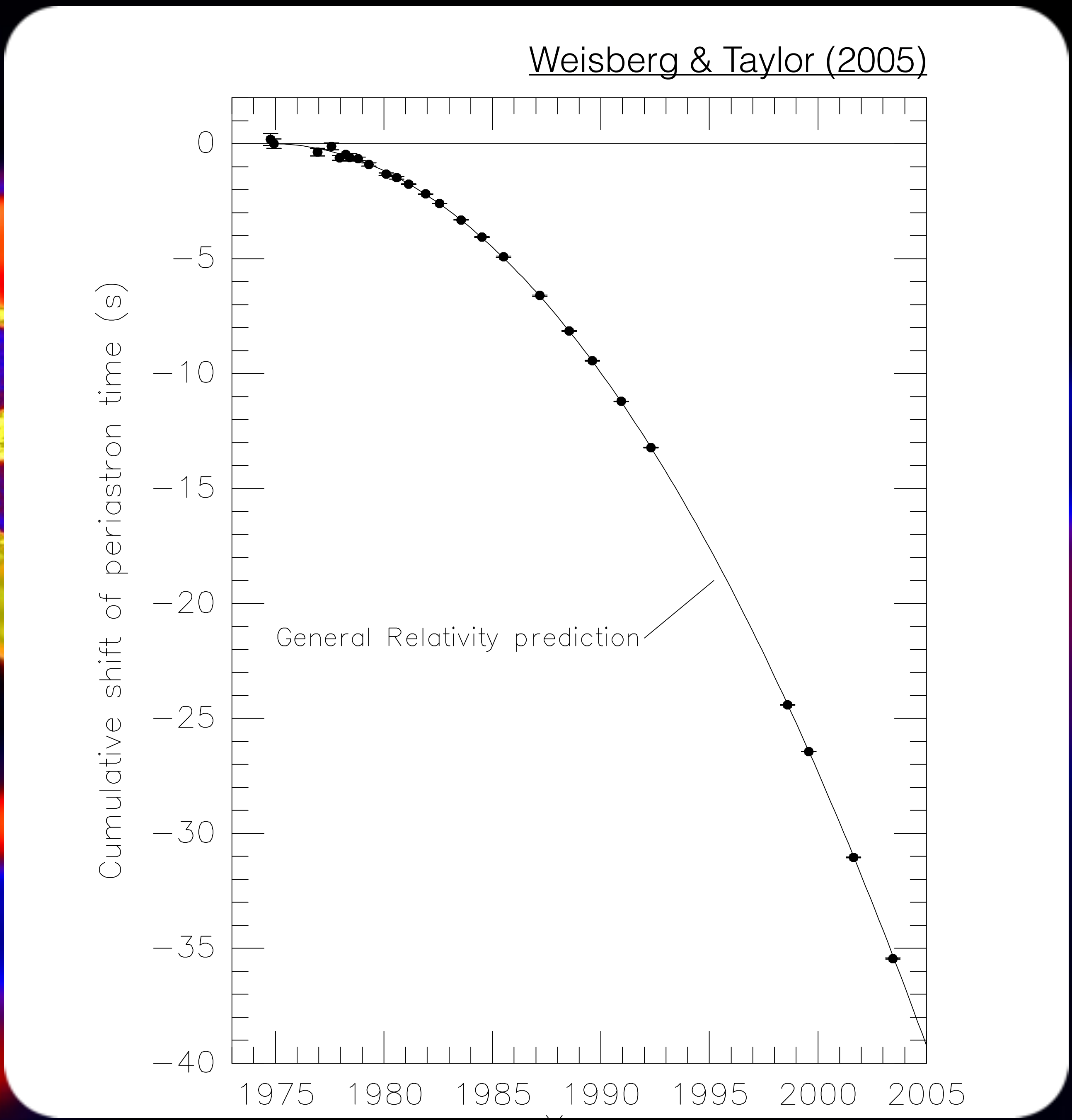


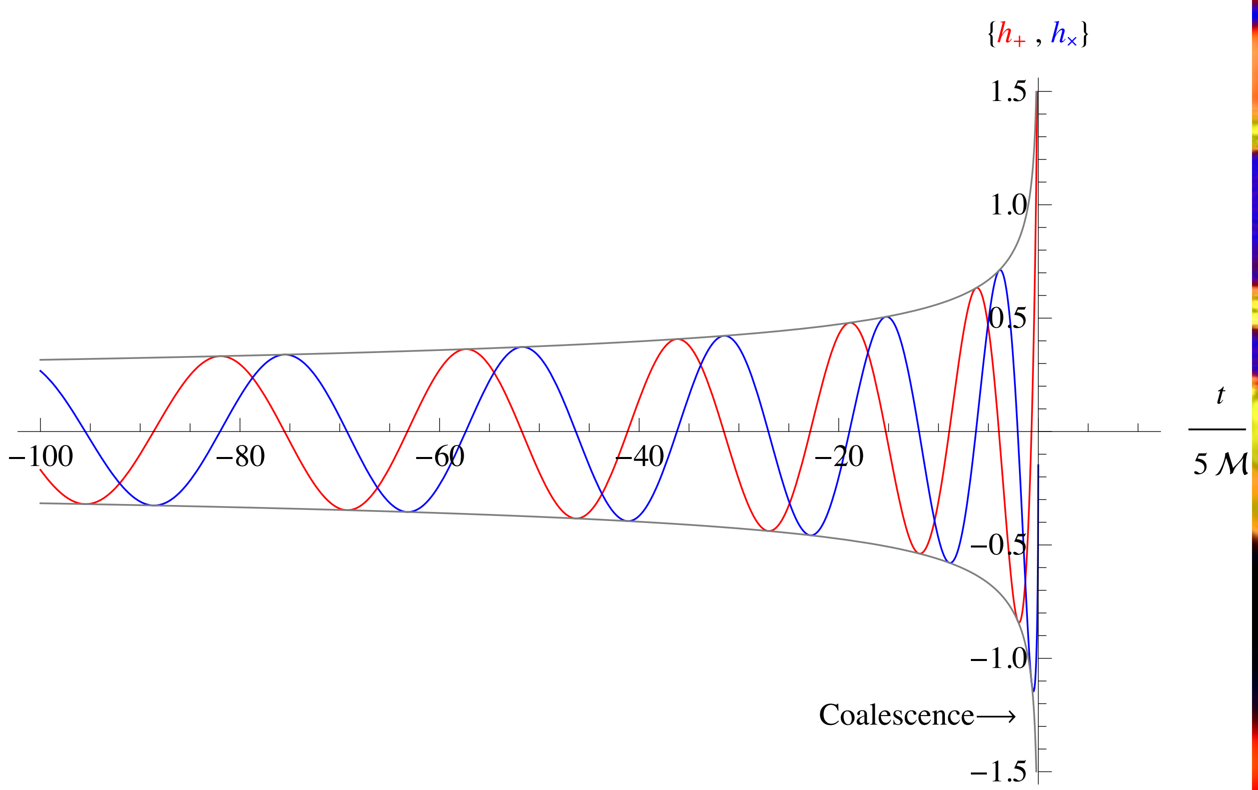
image credit: Daniel Price (U/Exeter) and Stephan Rosswog (Int. U/Bremen)
Price & Rosswog 2006

# BINARY NEUTRON STAR MERGERS



# BINARY NEUTRON STAR MERGERS



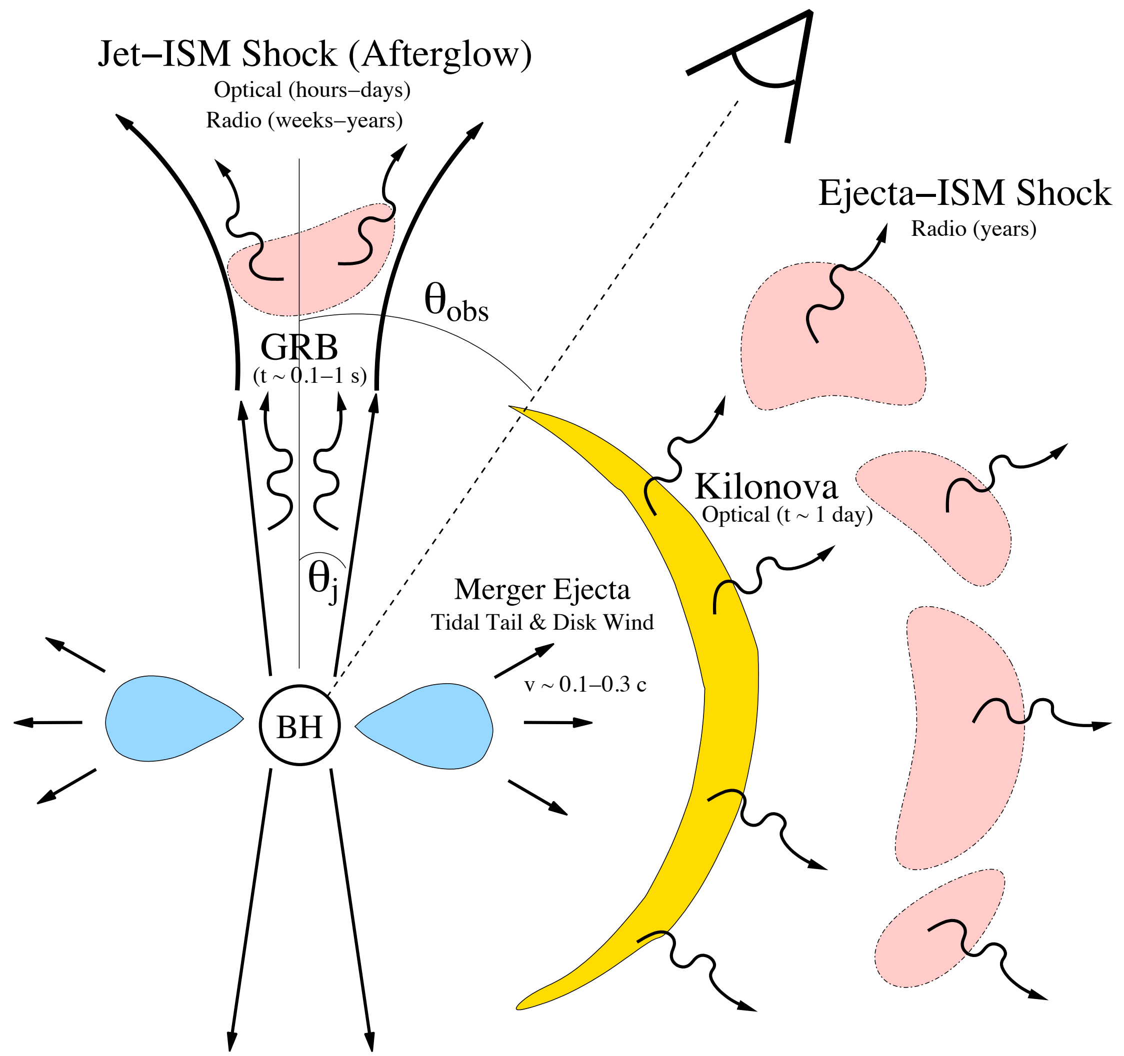




Figure 1 of Meztger & Berger 2012

# What will we learn from a compact binary merger detection?

**From GWs alone:**

- Strong-field, dynamical test of general relativity
- Measure masses, spins, and luminosity distance
- Test alternative theories of gravity (Will 2006; Del Pozzo+ 2013)
- Constrain equation of state of neutron stars (Read+ 2009)

**In combination with electromagnetic observations:**

- Redshift → "calibration-free" standard sirens (Schutz 1986; Holz & Hughes 2005; Dalal+ 2006; Nissanke+ 2010)
- Reveal the nature of short gamma-ray bursts (Paczynski 1986; Eichler+ 1989; Narayan+ 1992; Rezzolla+ 2011)
- Conditions in ejecta / kilonova (Li & Paczyński 1998; Barnes & Kasen 2013; etc.)
- Host environment

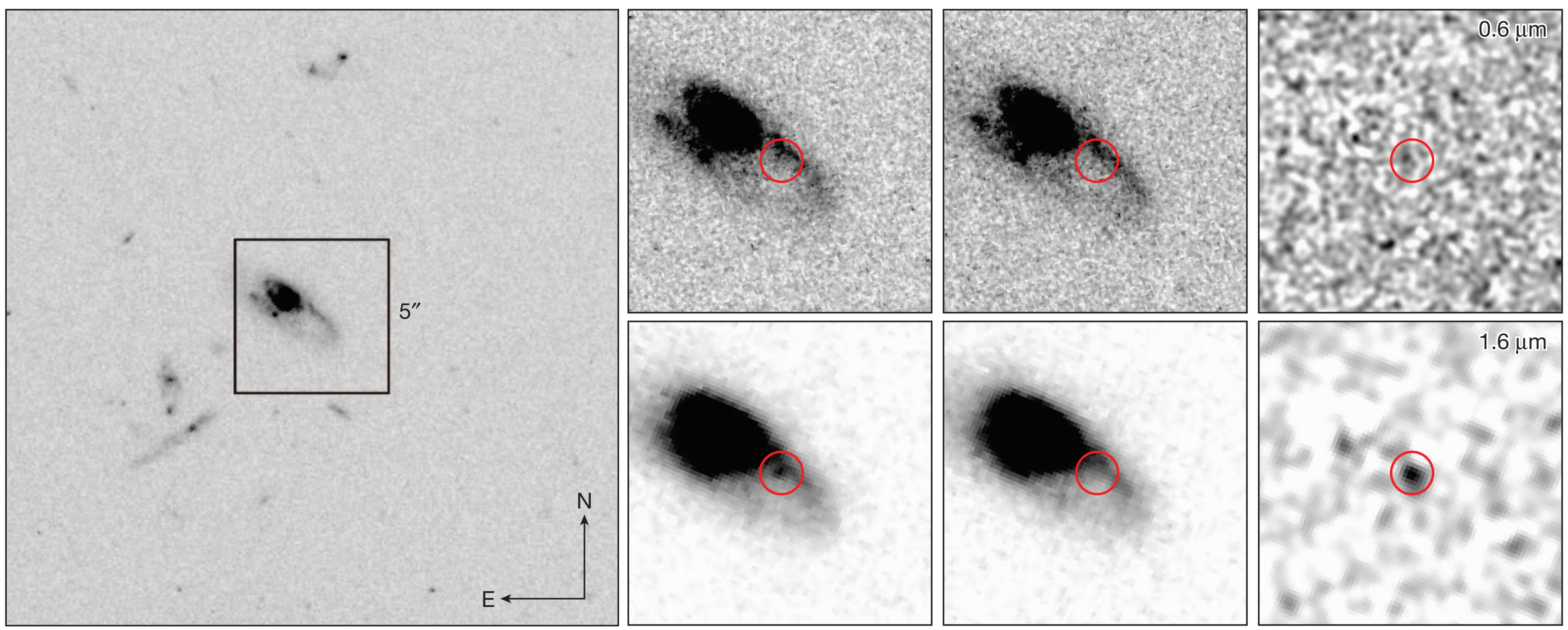
# The first ever observation of a kilonova?

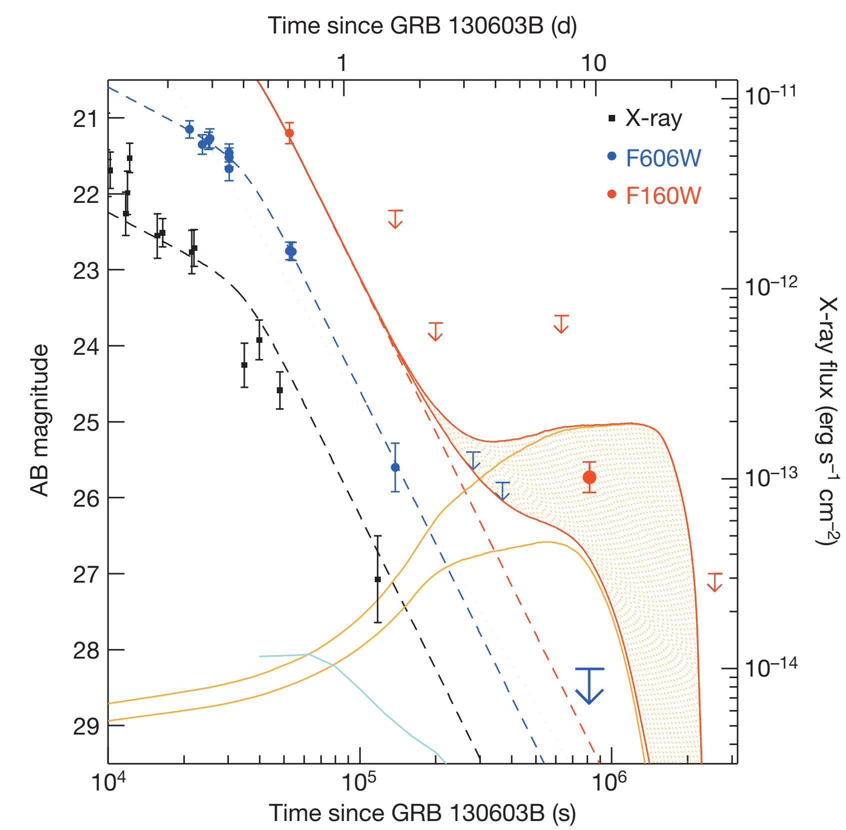
LETTER

doi:10.1038/nature12505

## A 'kilonova' associated with the short-duration γ-ray burst GRB 130603B

N. R. Tanvir[1], A. J. Levan[2], A. S. Fruchter[3], J. Hjorth[4], R. A. Hounsell[3], K. Wiersema[1] & R. L. Tunnicliffe[2]




"Bling nova:" kilonovae in neutron star mergers may be important sites for the production of heavy *r*-process elements with *A*>140 (Goriely+ 2011, Wanajo+ 2014, etc.)

# Let's bring this down to Earth.

Literally.

ARTICLE

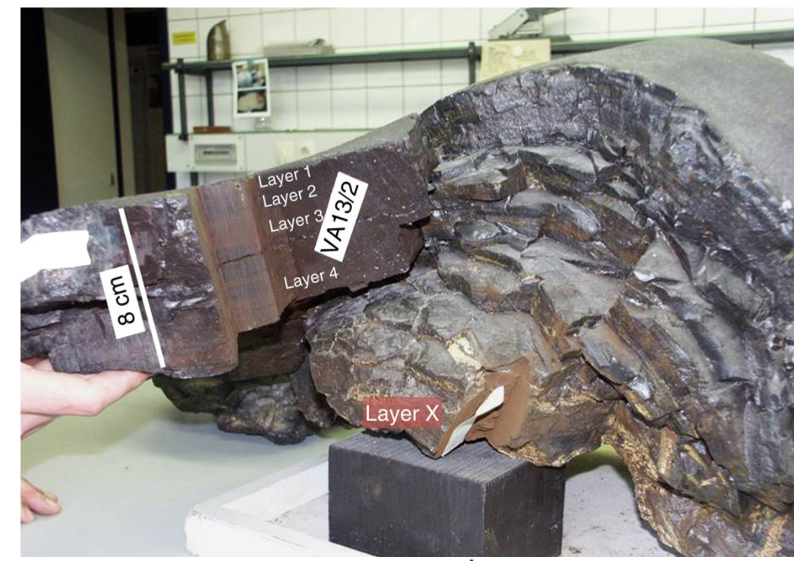
Received 30 Mar 2014 | Accepted 26 Nov 2014 | Published 20 Jan 2015 DOI: 10.1038/ncomms6956 OPEN

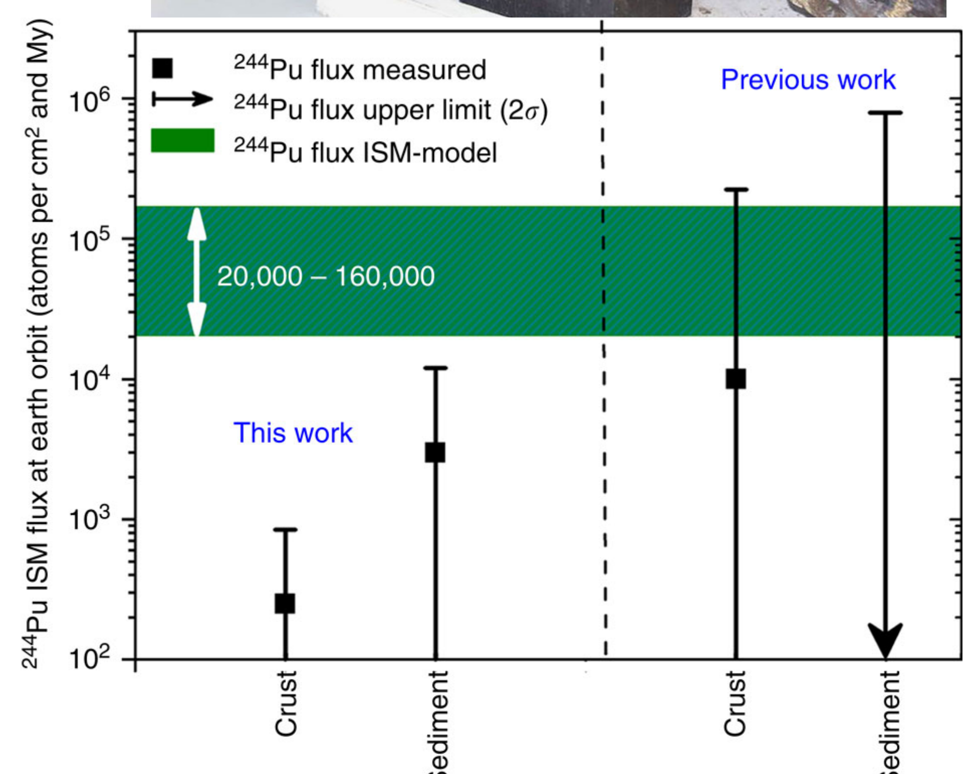
# Abundance of live $^{244}$Pu in deep-sea reservoirs on Earth points to rarity of actinide nucleosynthesis

A. Wallner[1,2], T. Faestermann[3], J. Feige[2], C. Feldstein[4], K. Knie[3,5], G. Korschinek[3], W. Kutschera[2], A. Ofan[4], M. Paul[4], F. Quinto[2,†], G. Rugel[3,†] & P. Steier[2]

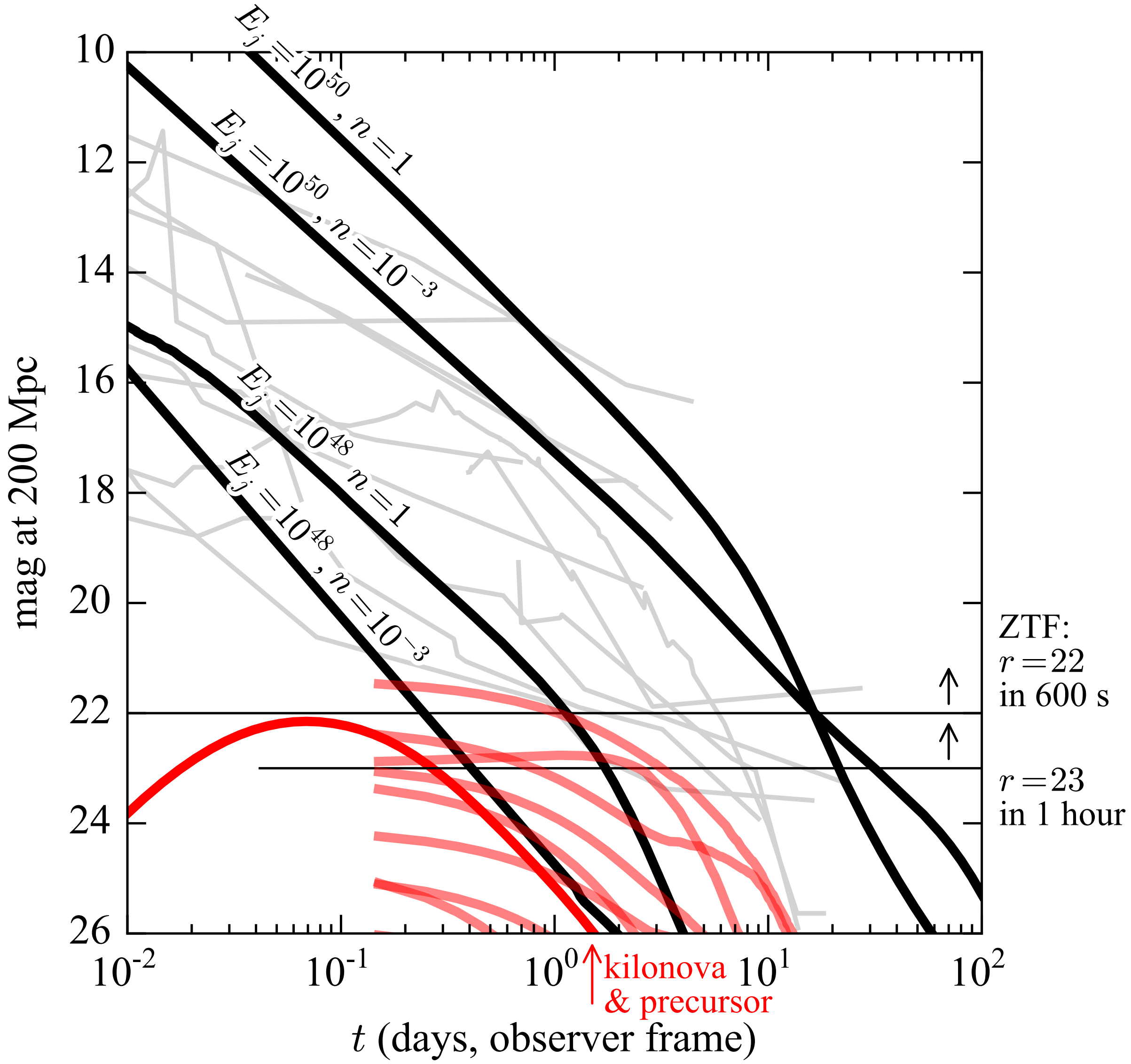
Half of the heavy elements including all actinides are produced in *r*-process nucleosynthesis, whose sites and history remain a mystery. If continuously produced, the Interstellar Medium is expected to build-up a quasi-steady state of abundances of short-lived nuclides (with half-lives $\leq$100 My), including actinides produced in *r*-process nucleosynthesis. Their existence in today's interstellar medium would serve as a radioactive clock and would establish that their production was recent. In particular $^{244}$Pu, a radioactive actinide nuclide (half-life = 81 My), can place strong constraints on recent *r*-process frequency and production yield. Here we report the detection of live interstellar $^{244}$Pu, archived in Earth's deep-sea floor during the last 25 My, at abundances lower than expected from continuous production in the Galaxy by about 2 orders of magnitude. This large discrepancy may signal a rarity of actinide *r*-process nucleosynthesis sites, compatible with neutron-star mergers or with a small subset of actinide-producing supernovae.

"…Our experimental results indicate that SNe, at their standard rate of ~1 to 2 per 100 years in the Galaxy, did not contribute significantly to actinide nucleosynthesis for the past few hundred million years and actinide nucleosynthesis, as mapped through live $^{244}$Pu, seems to be very rare. ***Our data may be consistent with a predominant contribution of compact-object mergers, which are $10^2$ to $10^3$ less frequent than core-collapse SNe*[1].**"



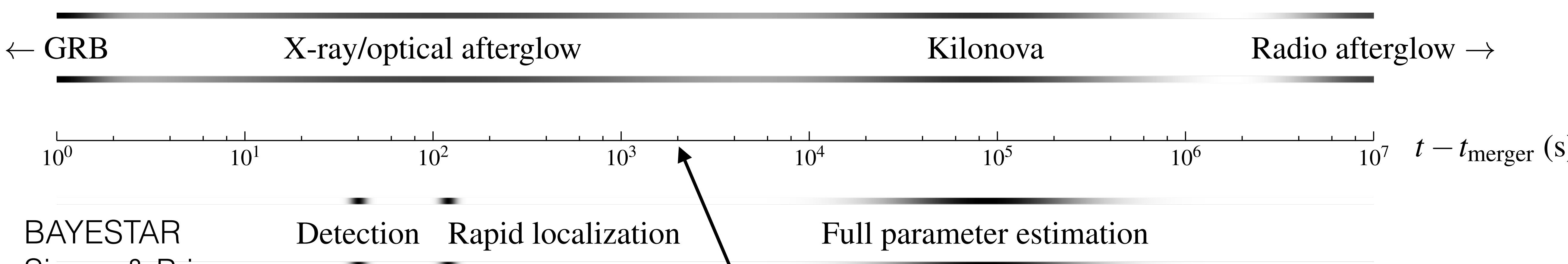
Singer et al. (2015)
with afterglows from Kann et al. (2011),
afterglow models from van Eerten & MacFadyen (2011),
kilonova models from Barnes & Kasen (2013),
and precursor models from Metzger et al. (2015)




# Challenge 1:

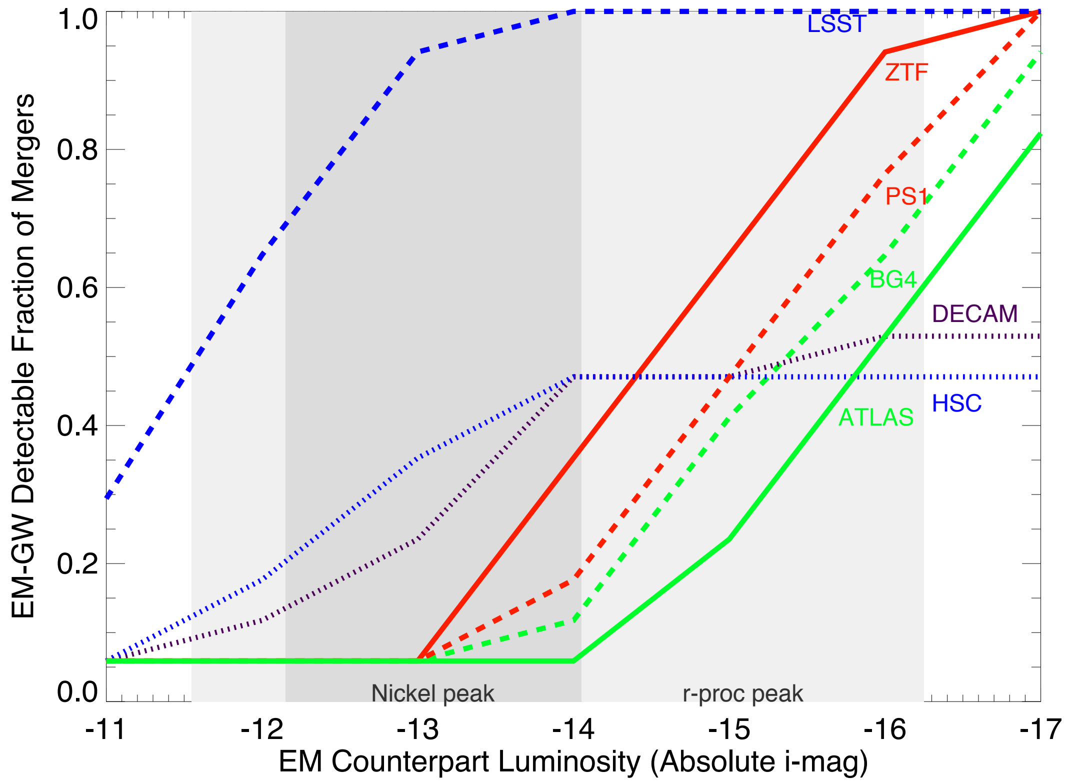
Optical counterparts of GW events are expected to be *faint* (R >(>) 22 mag) and *fast* (peaking at an hour–day time scale).

Singer et al. (2014)




BAYESTAR
Singer & Price
(in prep.)

Achieved in last science run, Abadie et al. 2012, A&A

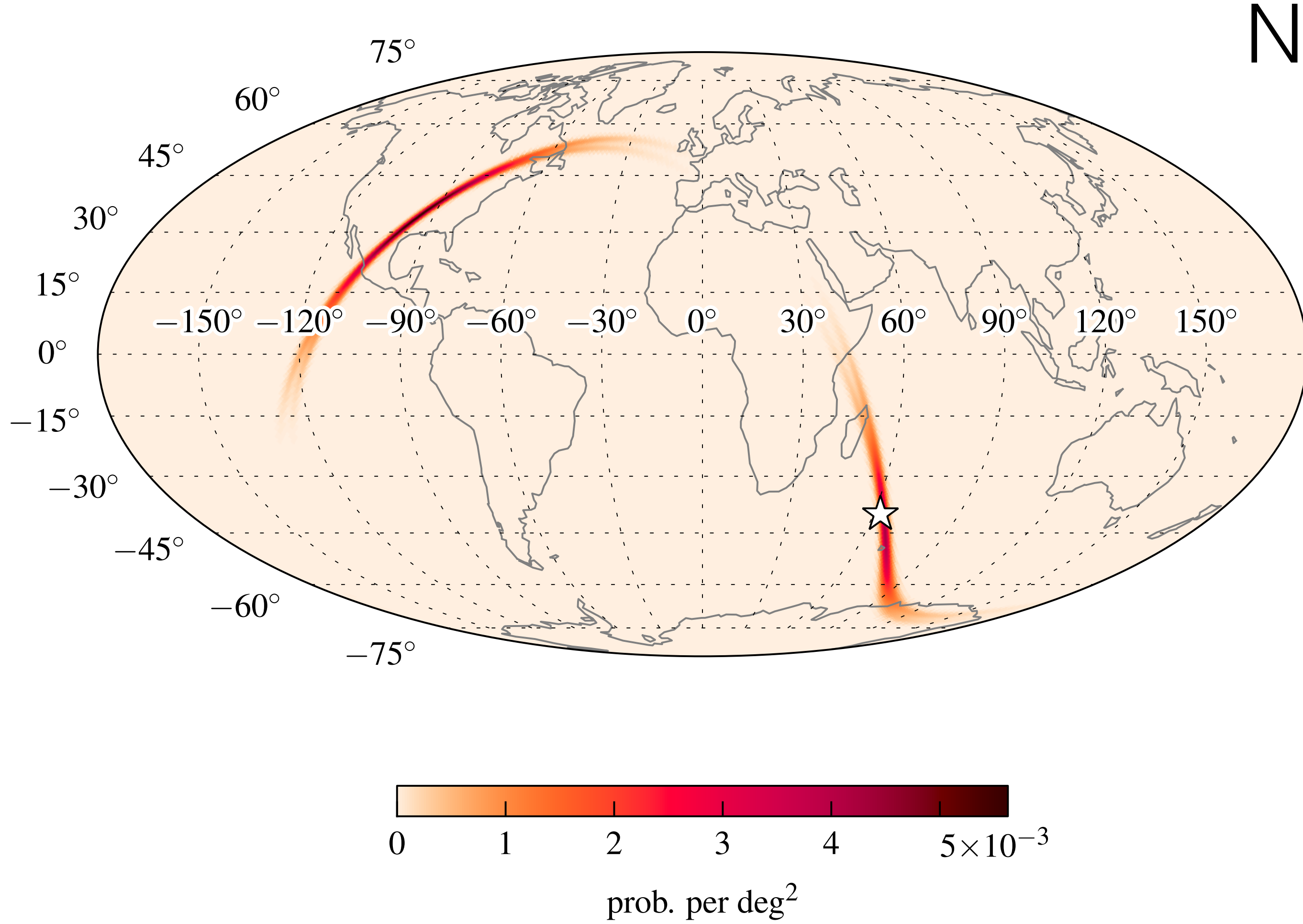



Kasliwal & Nissanke 2014

# Challenge 2:

GW events are expected to be poorly localized, starting at ≈600 $deg^2$ in 2015 and reaching ~10 $deg^2$ late in the decade.

Need to search sky deeply and quickly!

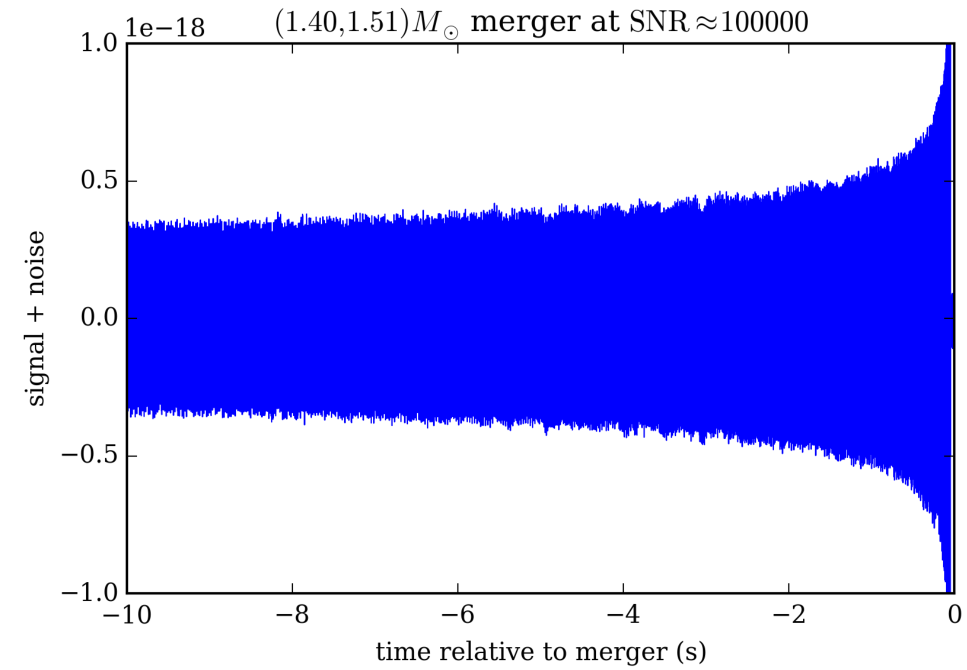



Singer et al. (2014)
http://www.ligo.org/scientists/first2years

# Key problems on LIGO side have been solved.

**Challenges:**

- Operating near detection threshold requires matched filters and Bayesian approach to parameter estimation
- Curse of dimensionality: large model space (15D)
- Signals in LIGO band for up to ~1000 s
- Traditional algorithms (FFT convolution, MCMC) are inherently high-latency




**Solutions:**

- Real-time detection pipeline: latency drops from 1 week to 1 minute after merger
  Compressed representation of template bank w/ SVD and multi-rate filtering, FFT filtering of "time slices"
  Cannon+ 2012 (note: corresponding author)
- Rapid Bayesian position reconstruction: although full PE takes days, but can get all sky localization information in under a minute (**BAYESTAR**, Singer & Price 2015, in prep., chapter 4 in my thesis)
- Reduced order modeling: lossy compression of model space (Canizares+ 2015)

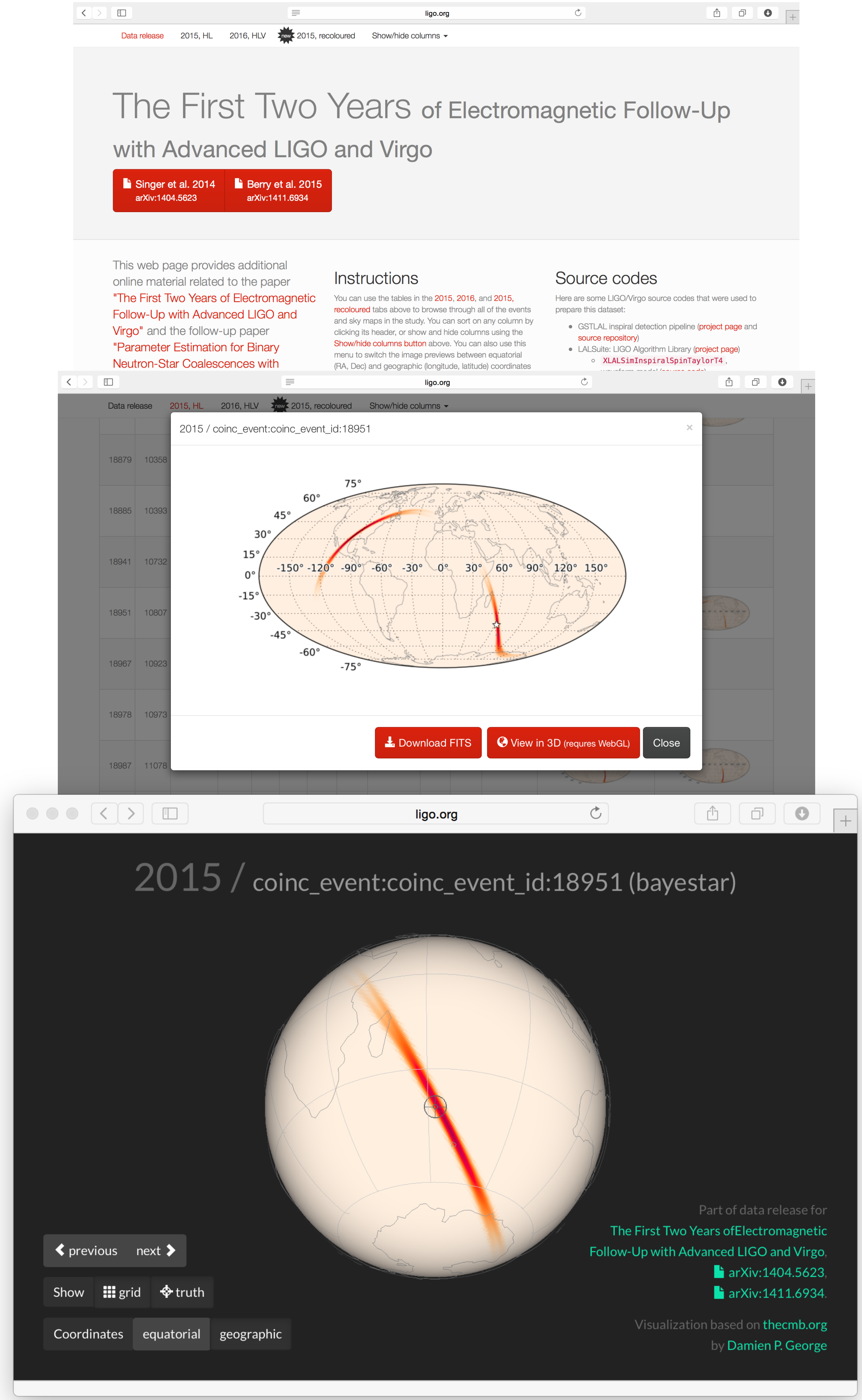
Singer+ 2014, ApJ, 795, 105
end-to-end demonstration of aLIGO realtime analysis
sky localization + morphology
"first detection" scenarios
transition from 2 to 3 detectors

Berry+ 2015, arXiv:1411.6934
+glitchy ("recolored") noise
mass and distance estimates

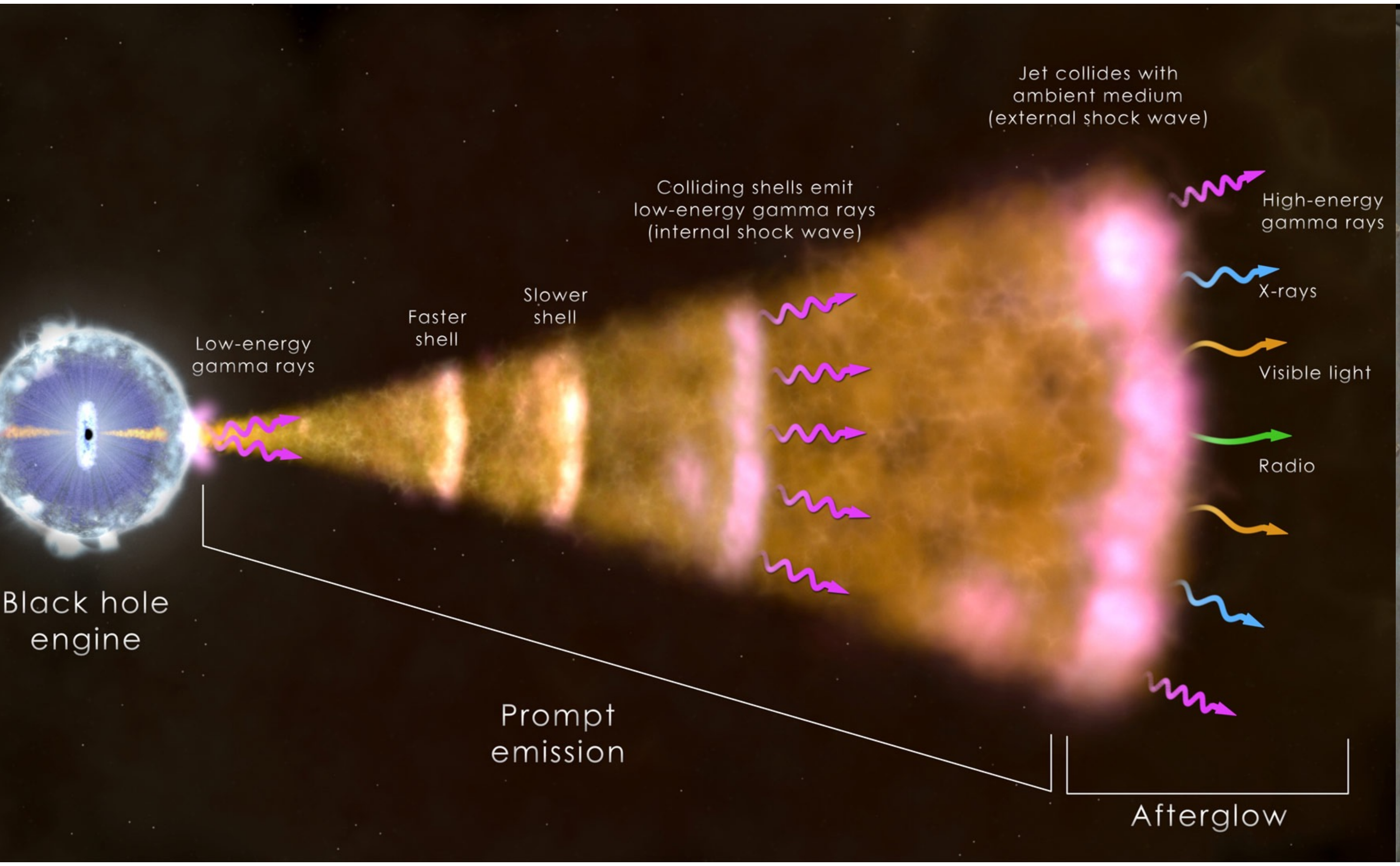
www.ligo.org/scientists/first2years
interactive sky map atlas
machine readable catalog
sample FITS files
3D sky map viewer

# THE FIRST TWO YEARS

## of Electromagnetic Follow-Up with Advanced LIGO and Virgo



# Bootstrap with model problem: *Fermi* gamma-ray bursts



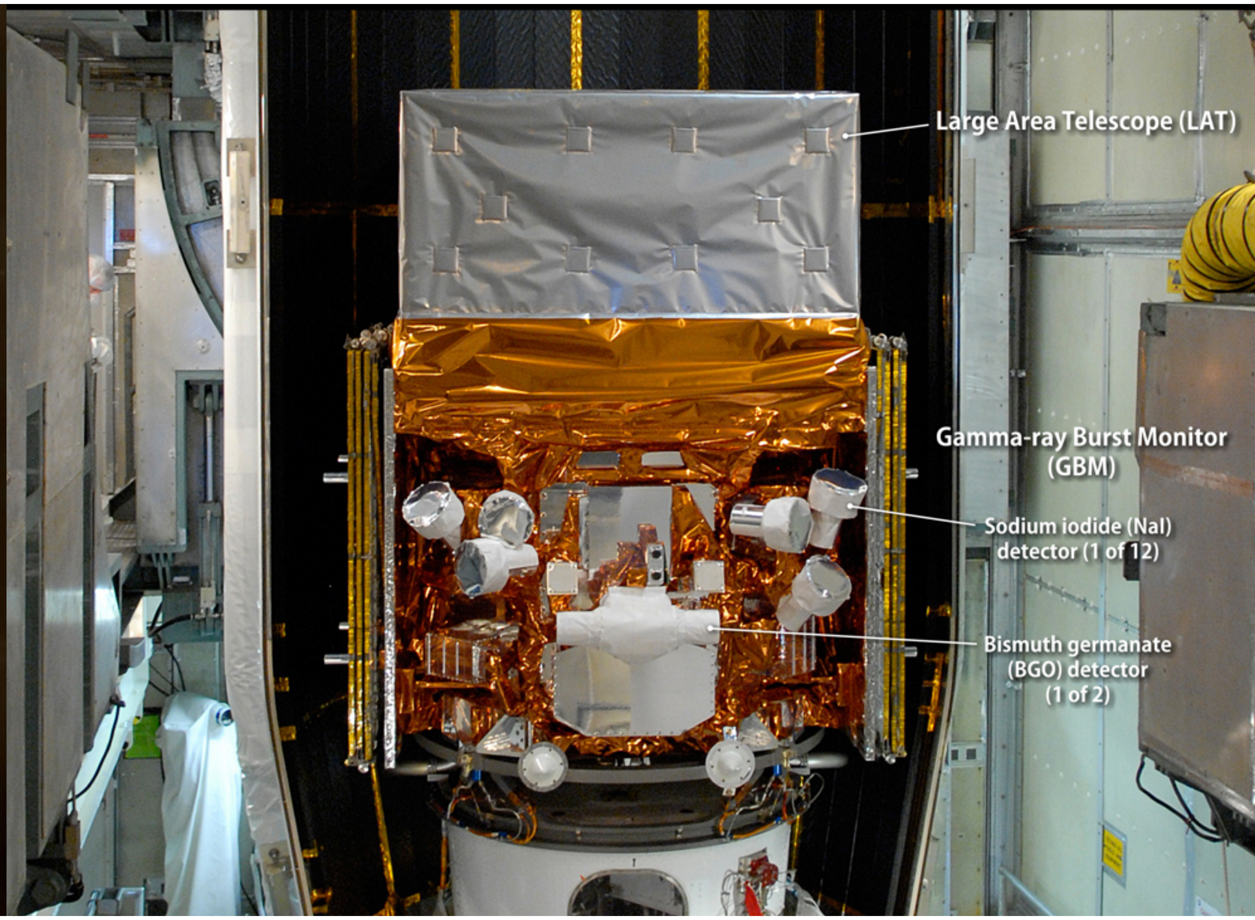
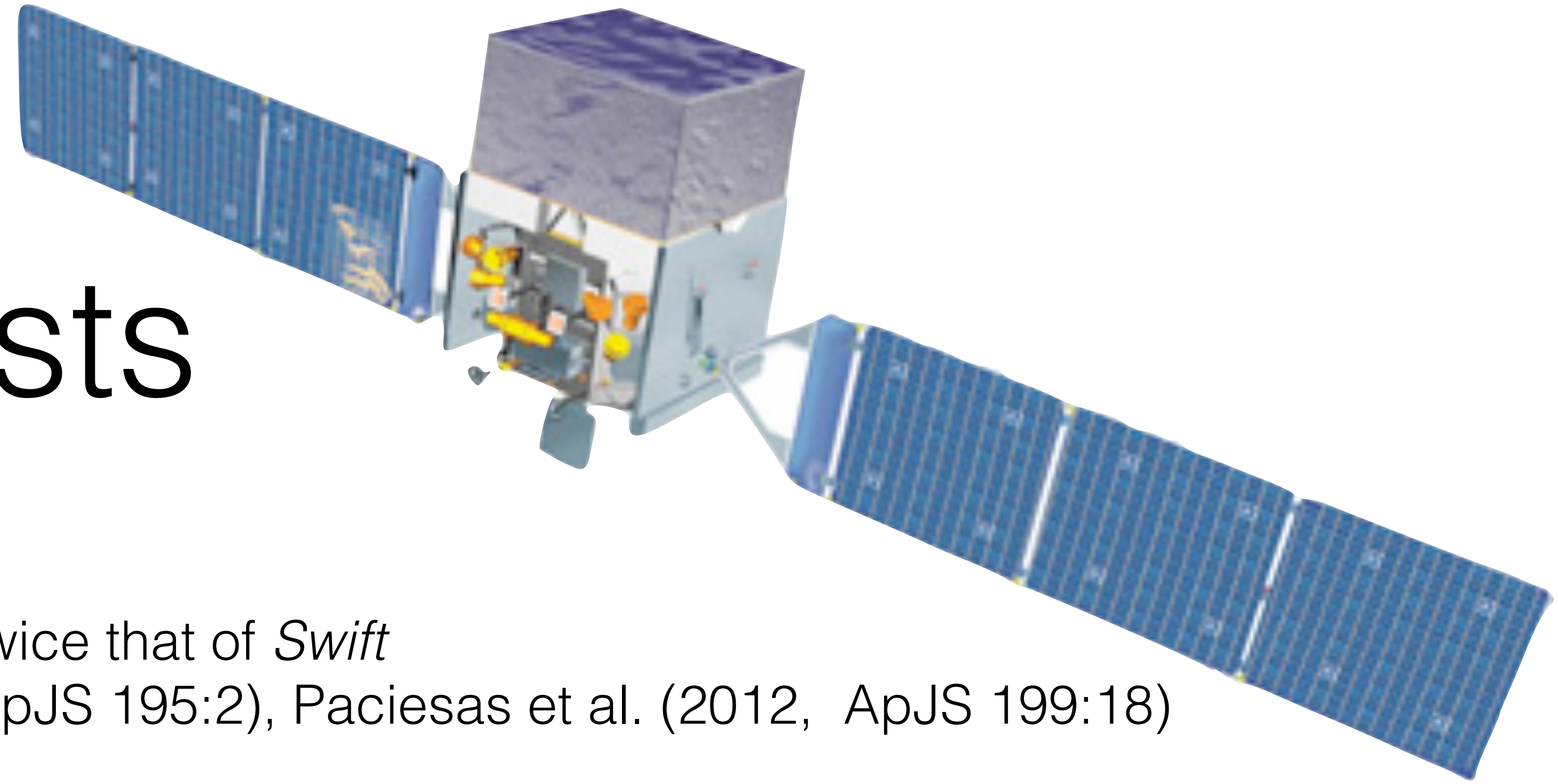




Image credit: NASA/Jim Grossmann
http://www.nasa.gov/mission_pages/GLAST/news/vision-improve.html

image: NASA/GSFC

# *Fermi*
# GBM bursts



- + Prolific detection rate: ≈twice that of *Swift*
  Sakamoto et al. (2011, ApJS 195:2), Paciesas et al. (2012, ApJS 199:18)
- + With LAT, access to MeV—GeV regime
  →delayed onset of GeV emission Abdo et al. (2009, Science 323:1688)
- + GBM: all-sky monitor (~70% of sky)
- + Strengths for detecting short-hard bursts
  - - Coarse localization, ~10–100 deg$^2$, unless also detected by LAT or *Swift*
- + Vast majority **not observed outside gamma-rays!**

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

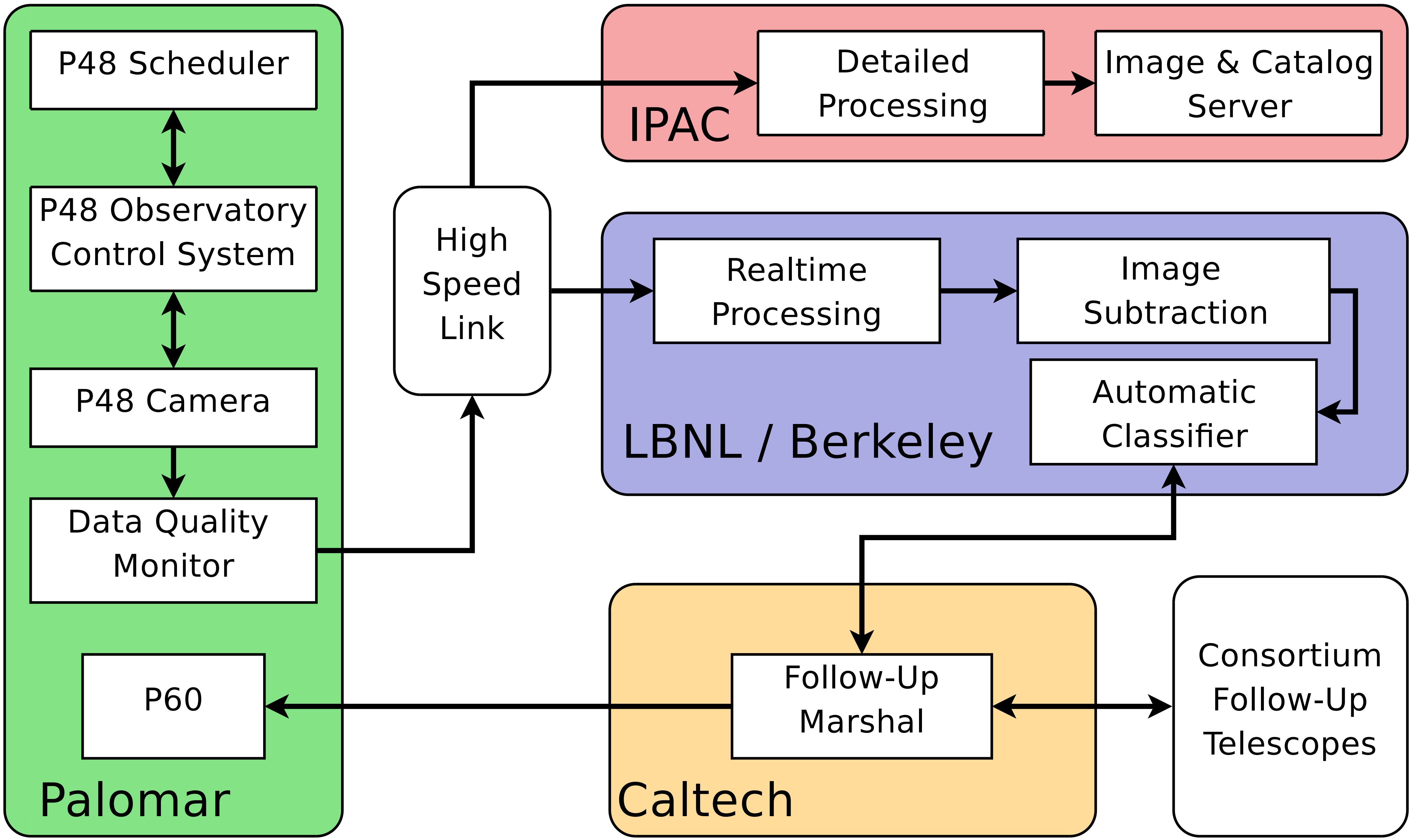



image credit: Law et al. (2009, PASP 121, 1395)

# iPTF/GBM afterglow discovery process

**Automated** Tile GBM error circle 2–3 times with at least 0.5 hour cadence

**Automated** iPTF real/bogus classification

**Automated** Reject candidates that are detected in only one visit (eliminates solar system objects)

**Automated** Reject candidates that coincide with stars (SDSS)

**Machine-aided** Visual scanning and light curve vetting (~100 candidates), deeper archival analysis (~10-20 candidates)

**Semi-automated** Photometric follow-up

Spectroscopic follow-up

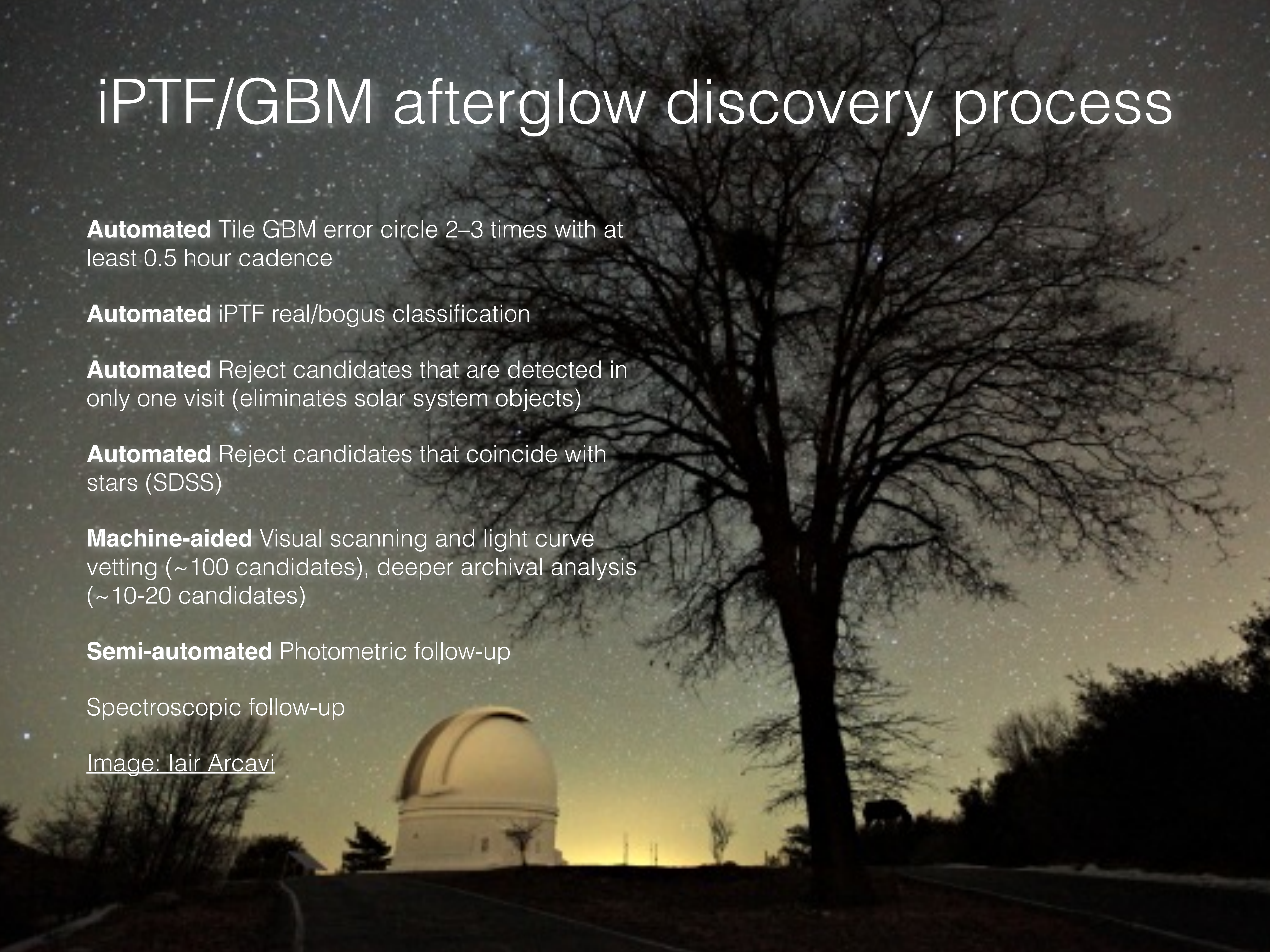
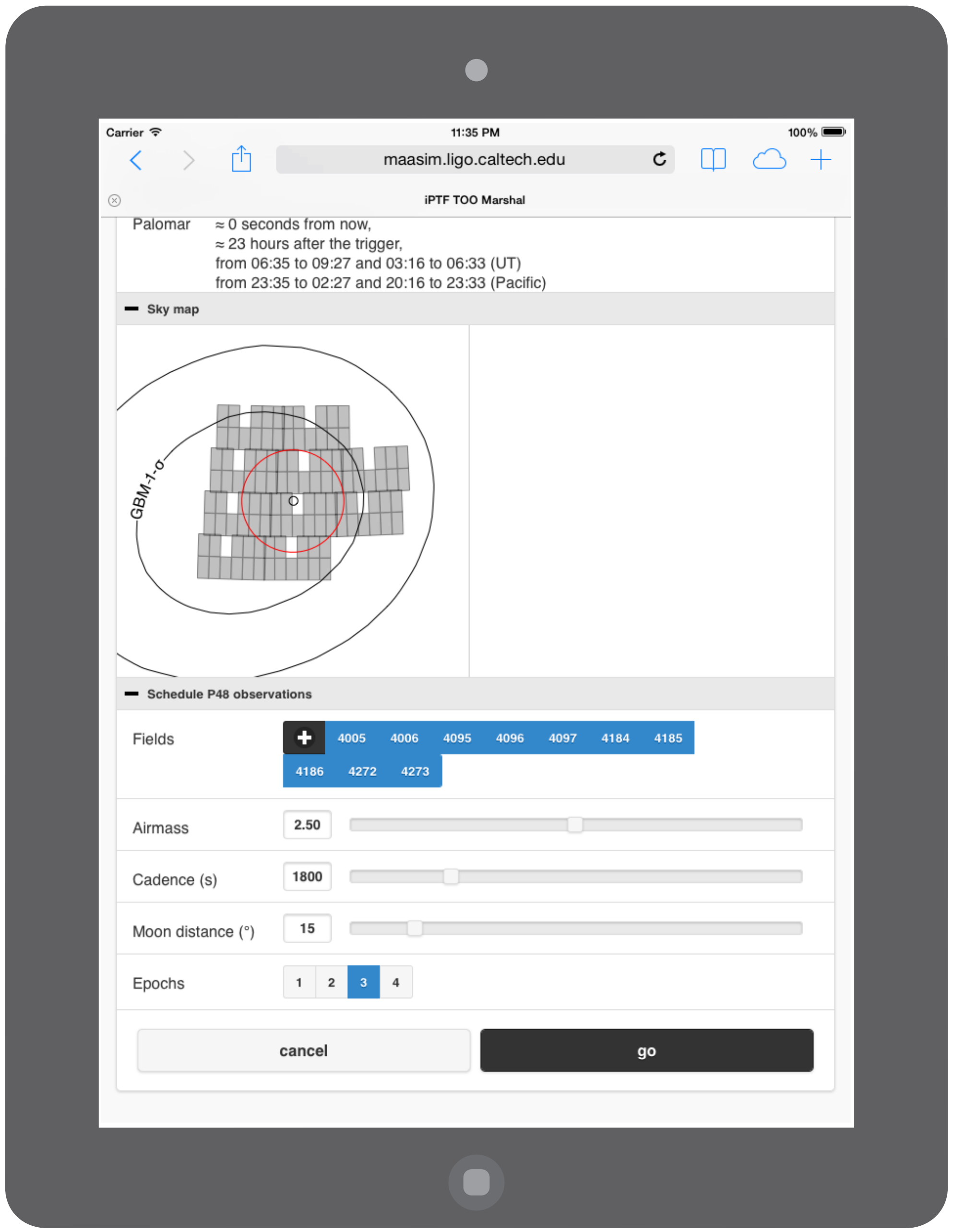
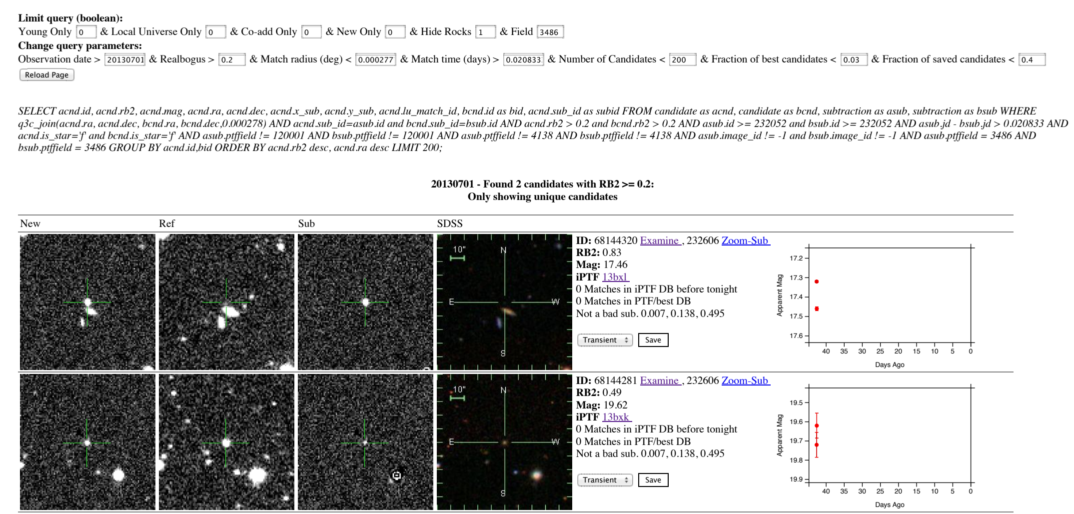


Image: Iair Arcavi

# iPTF Marshals




# Finding the afterglow among tens or hundreds of thousands of candidates

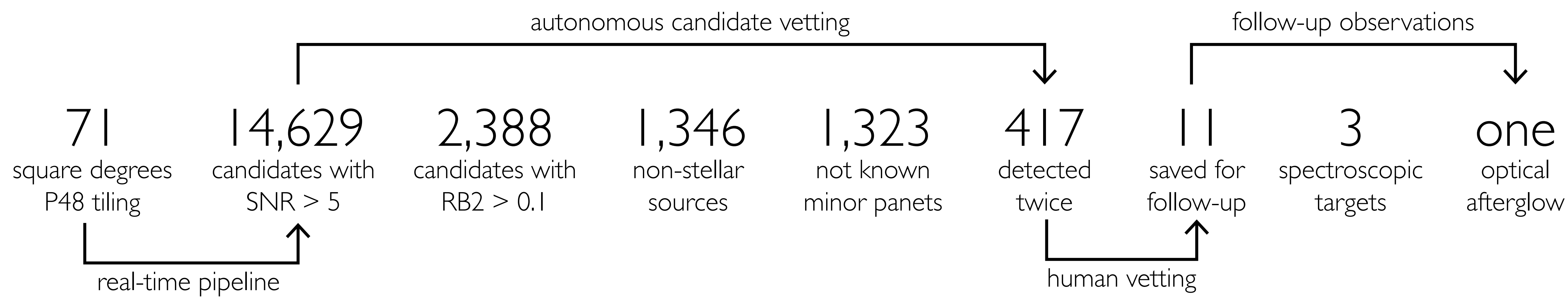
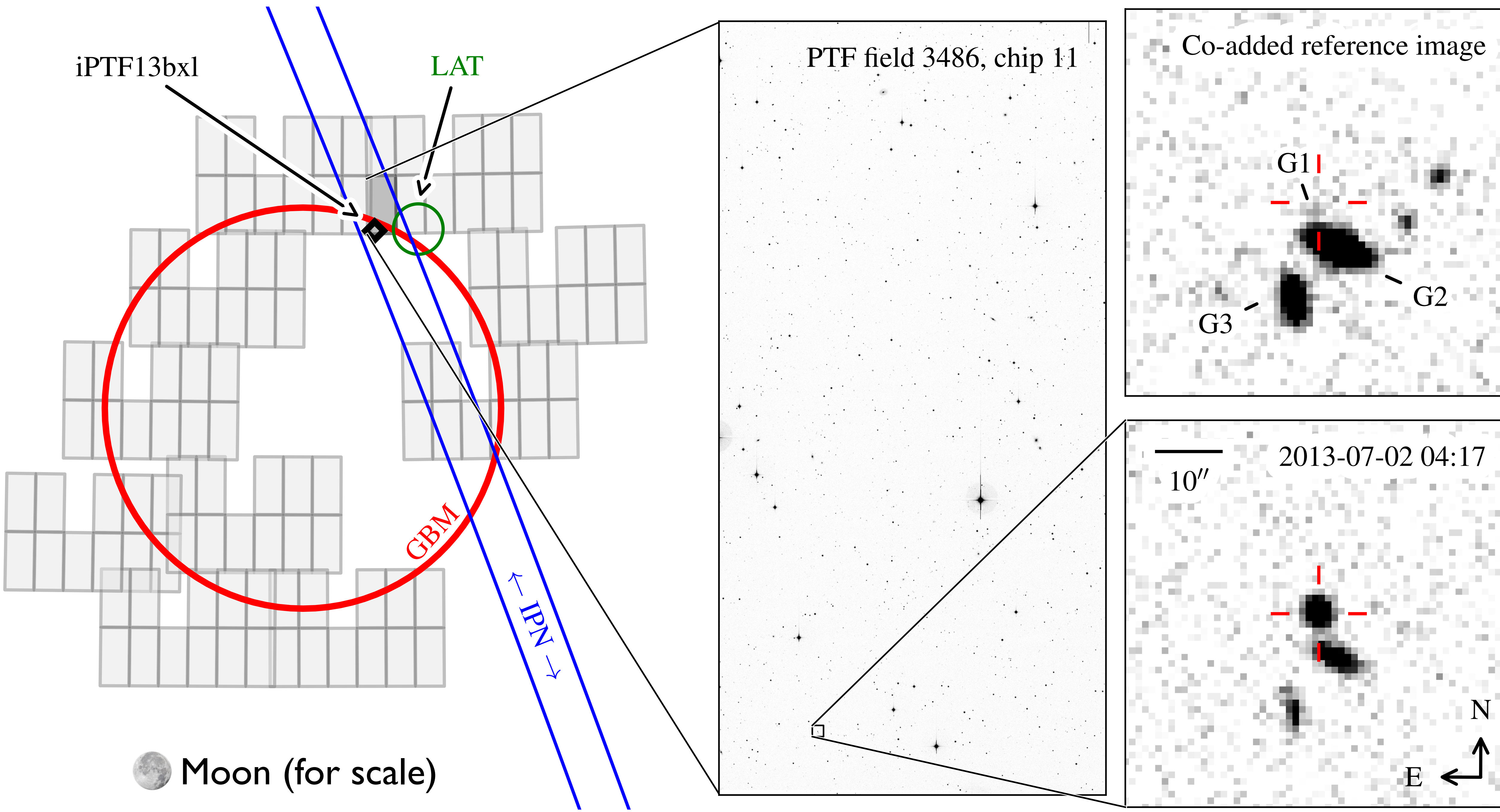



**Table 1**
Number of optical transient candidates surviving each vetting stage

| GRB | SNR $> 5$ | RB2 $> 0.1$ | not stellar | not in MPC[a] | detected twice | saved for follow-up |
|---|---|---|---|---|---|---|
| 130702A | 14 629 | 2 388 | 1 346 | 1 323 | 417 | 11 |
| 131011A | 21 308 | 8 652 | 4 344 | 4 197 | 434 | 23 |
| 131231A | 9 843 | 2 503 | 1 776 | 1 543 | 1 265 | 10 |
| 140508A | 48 747 | 22 673 | 9 970 | 9 969 | 619 | 42 |
| 140606B | 68 628 | 26 070 | 11 063 | 11 063 | 1 449 | 28 |
| 140620A | 152 224 | 50 930 | 17 872 | 17 872 | 1 904 | 34 |
| 140623A | 71 219 | 29 434 | 26 279 | 26 279 | 442 | 23 |
| 140808A | 19 853 | 4 804 | 2 349 | 2 349 | 79 | 12 |
| median reduction | | 36% | 17% | 16% | 1.7% | 0.068% |

[a] Not in Minor Planet Center database

# Discovery & redshift of a GBM GRB in 71 deg²




=SN2013dx

Singer et al.(2013, 2013, ApJL 776:34)

http://dx.doi.org/10.1088/2041-8205/776/2/L34

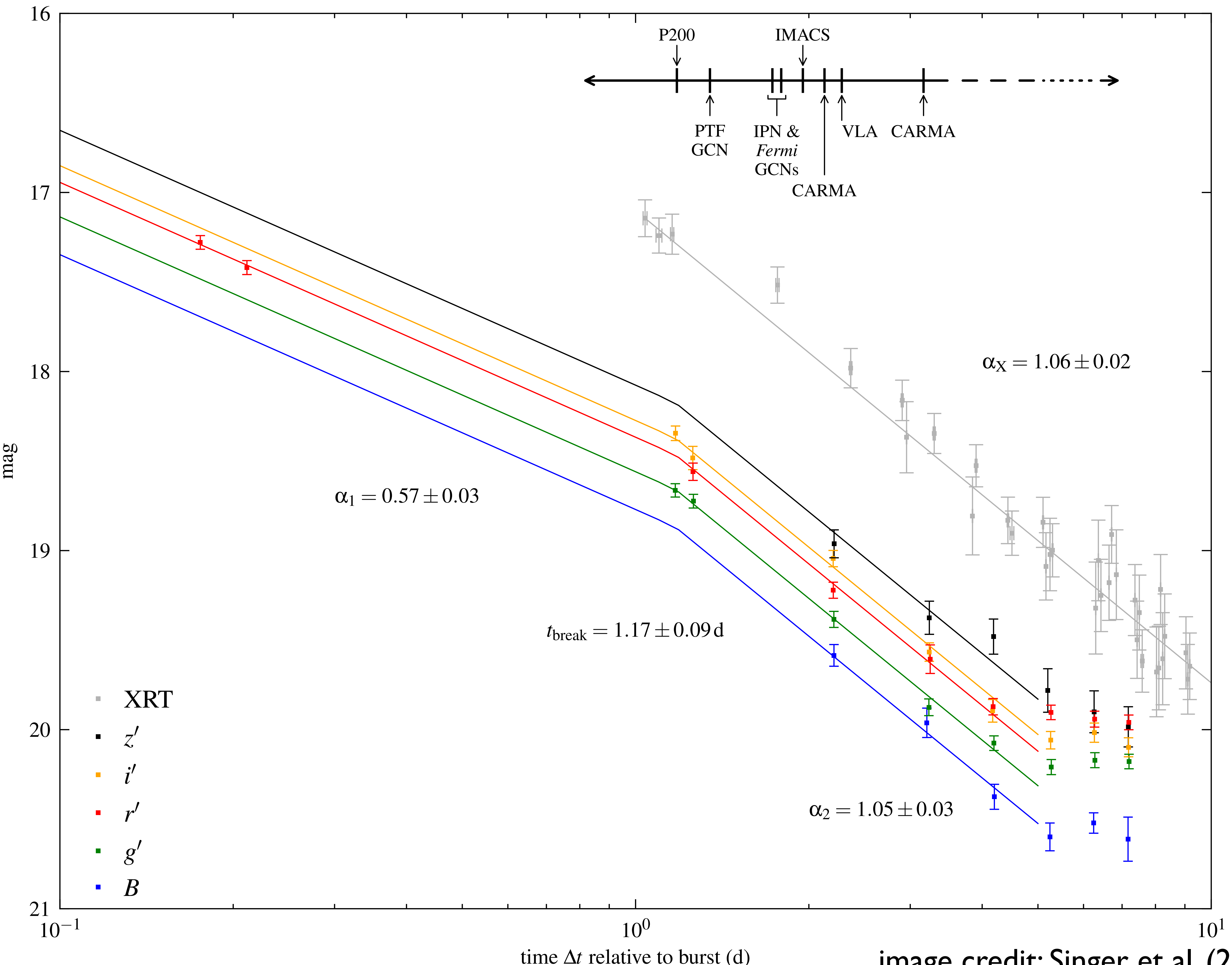



image credit: Singer et al. (2013)

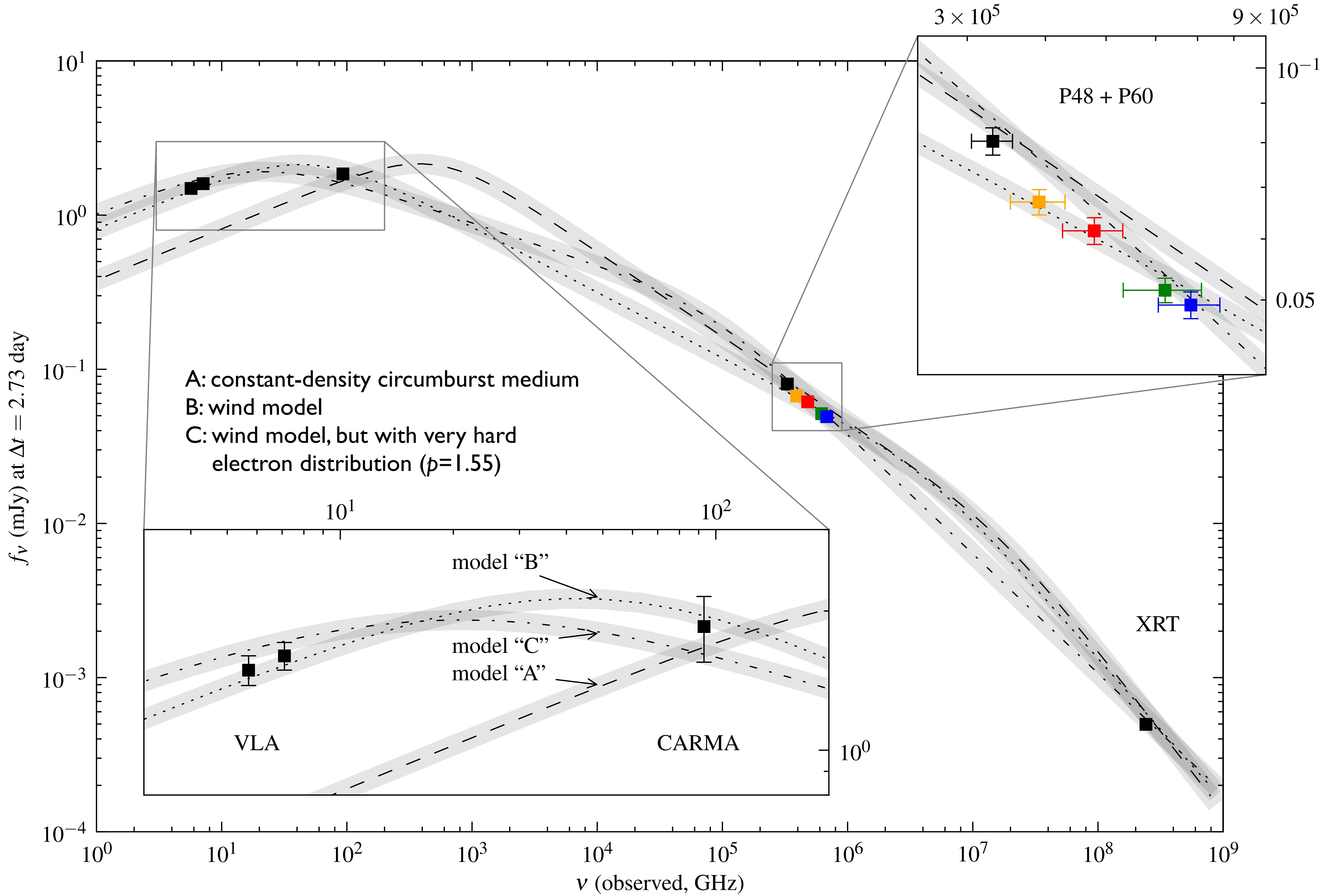
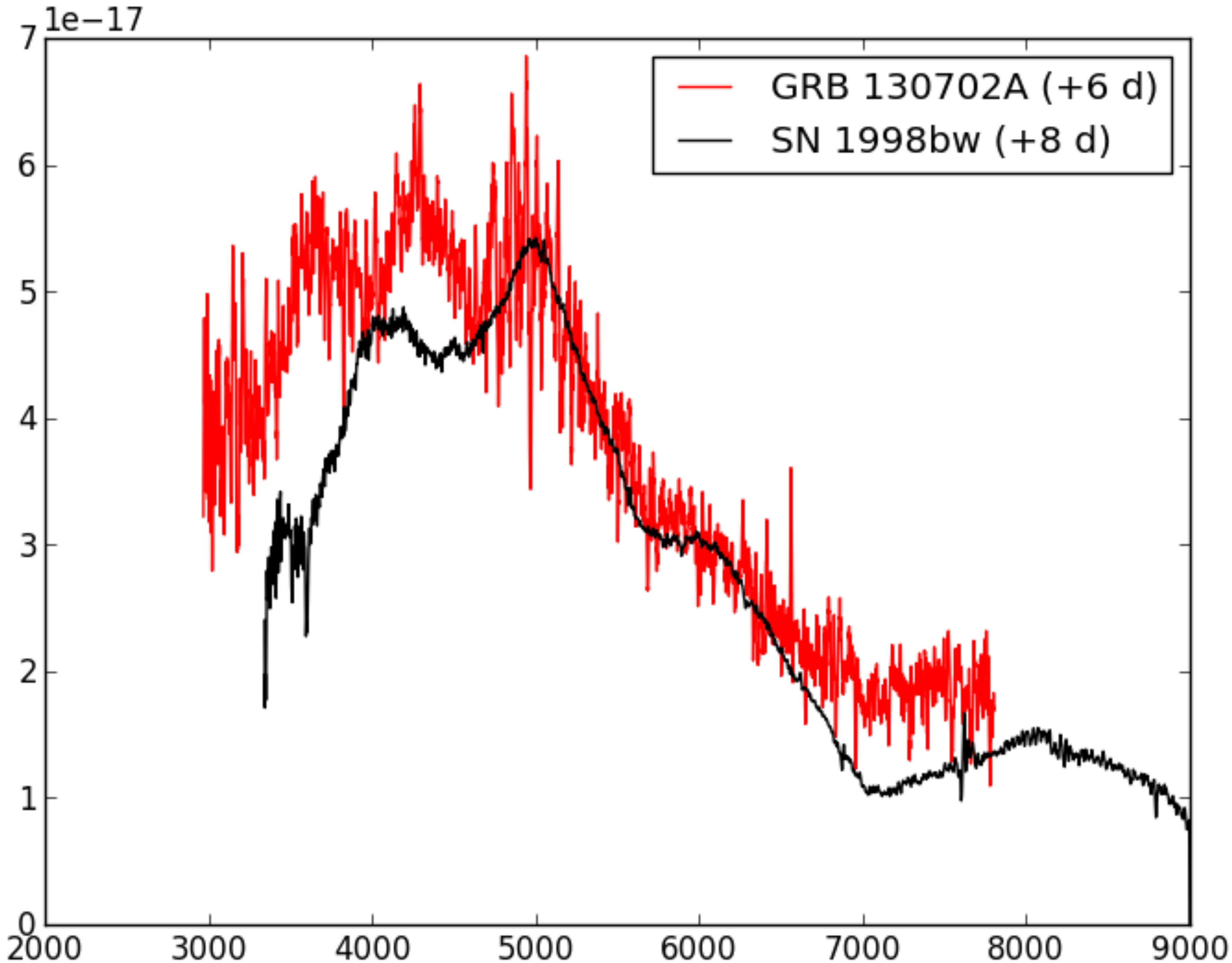



image credit: Singer et al. (2013)

# iPTF13bxl = SN2013dx




NOT spectrum (Schulze et al. 2013, GCN 14994)
plot by S. B. Cenko

# More on GRB 130702A / SN 2013dx

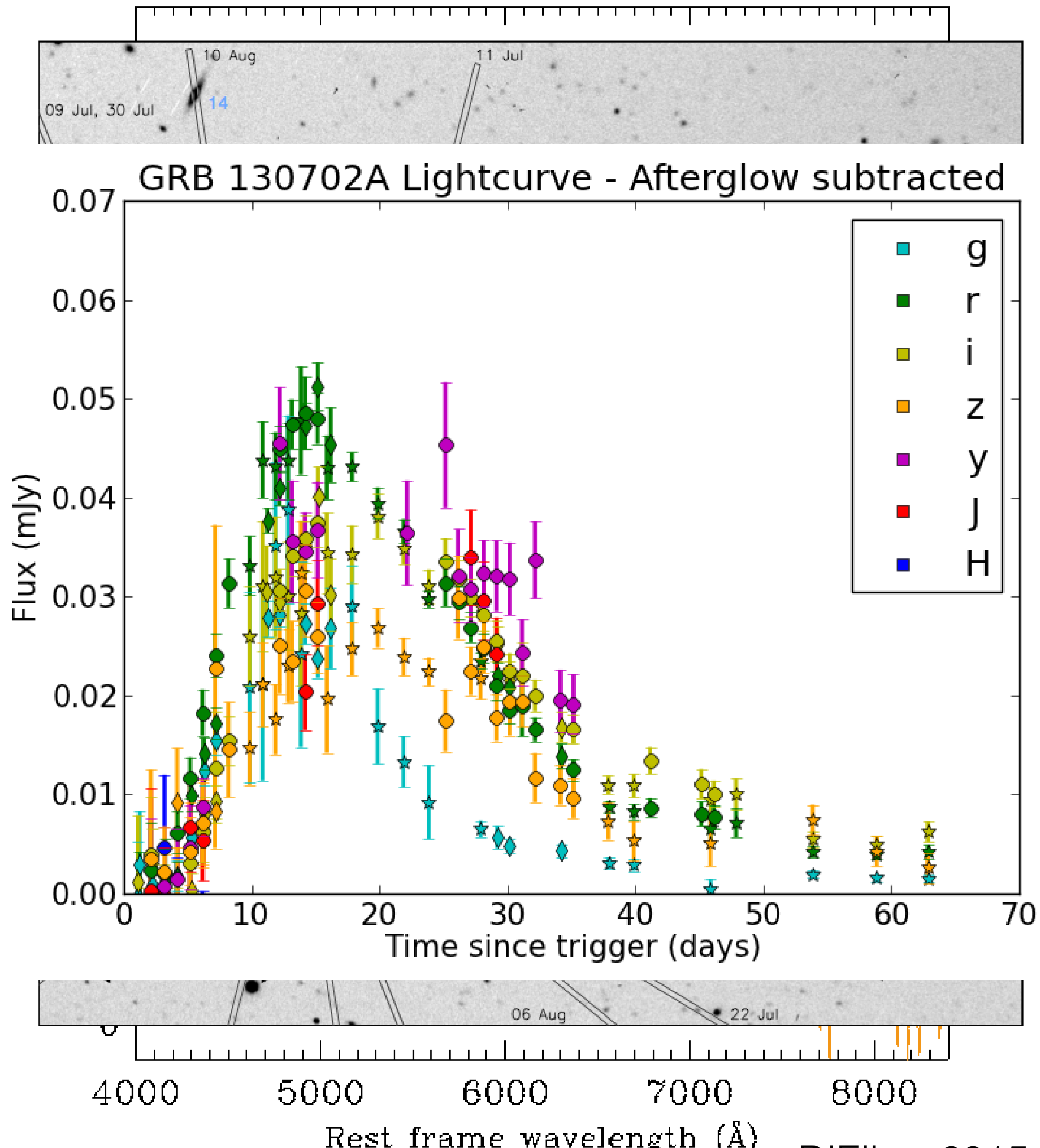
- Dwarf satellite host galaxy, metallicity of host
  Kelly+ 2013

- Detailed monitoring of SN, characterization of galaxy group/cluster
  D'Elia+ 2015

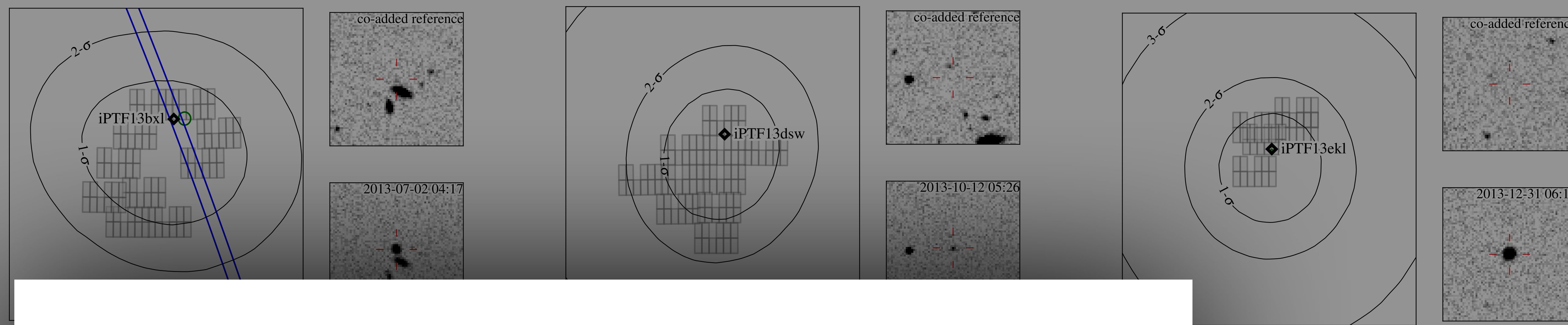
- Analysis w/ more RATIR/Liverpool/P60 photometry, additional spectra
  Vicki Toy + S.B. Cenko, in prep.

- Detailed afterglow modeling
  A. J. van der Horst+, in prep.

- Search for other SNe associated with *Fermi* GBM bursts
  Kovacevic+ 2014



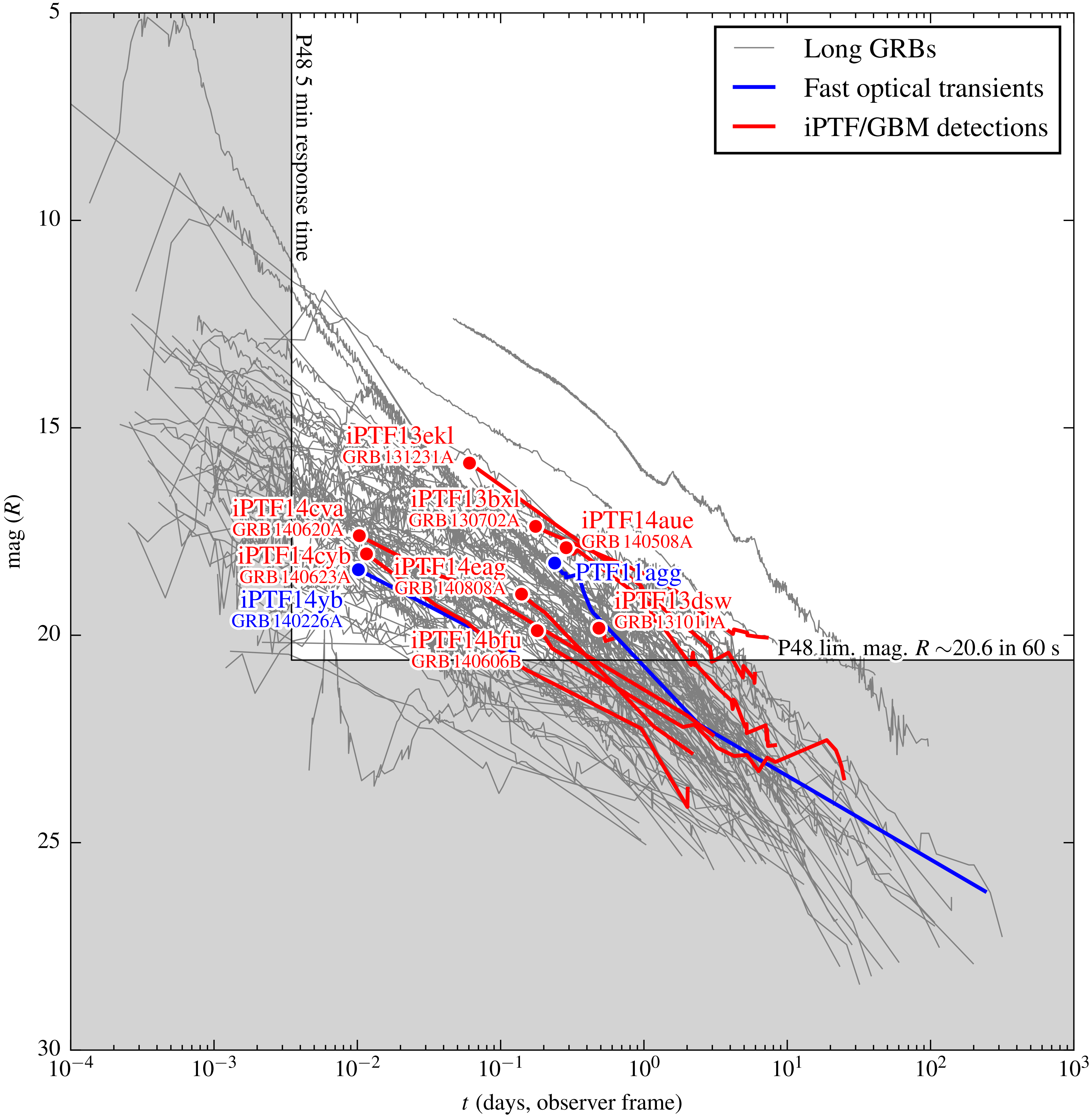

D'Elia+ 2015




Singer+ 2015, arXiv:1501.00495, accepted by ApJ
The Needle in the 100 deg2 Haystack: Uncovering Afterglows of Fermi GRBs with the Palomar Transient Factory

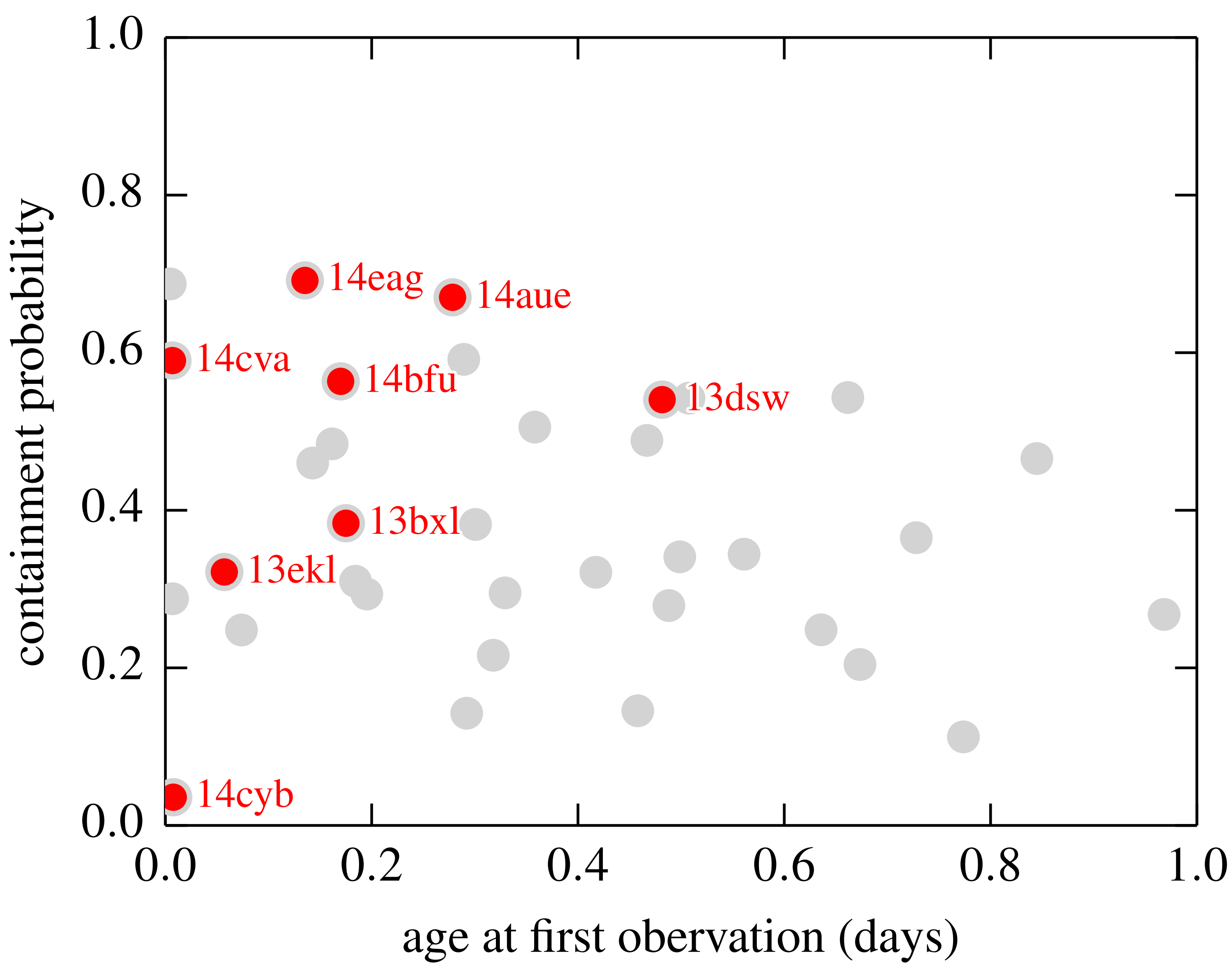
**Table 1**
iPTF/GBM detections.

| GRB | OT | $z$ | $E_{\rm peak}$ (keV) | $E_{\gamma,\rm iso}$ ($10^{52}$ erg) | $T_{90}$ (s) | $t_{\rm discovery} - t_{\rm burst}$ (h) | $m_R$ (discovery) | P48 area (deg$^2$) | Containment probability |
|---|---|---|---|---|---|---|---|---|---|
| GRB 130702A | iPTF13bxl | 0.145 | 18±3 | <0.065±0.001 | 58.9±6.2 | 4.21 | 17.38 | 74 | 38% |
| GRB 131011A | iPTF13dsw | 1.874 | 632±86 | 85.083±4.451 | 77.1±3 | 11.64 | 19.83 | 73 | 54% |
| GRB 131231A | iPTF13ekl | 0.644 | 270±10 | 17 ±1 | 31.2±0.6 | 1.45 | 15.85 | 30 | 32% |
| GRB 140508A | iPTF14aue | 1.03 | 430±100 | 21 ±1 | 44.3±0.2 | 6.88 | 17.89 | 73 | 67% |
| GRB 140606B | iPTF14bfu | 0.384 | 352±40 | 0.15 ±0.04 | 22.8±2.1 | 4.33 | 19.89 | 74 | 56% |
| GRB 140620A | iPTF14cva | 2.04 | 234±15 | 6.392±0.347 | 45.8±12.1 | 0.25 | 17.60 | 147 | 59% |
| GRB 140623A | iPTF14cyb | 1.92 | 1022±467 | 7.832±0.848 | 114.7±9.2 | 0.28 | 18.04 | 74 | 4% |
| GRB 140808A | iPTF14eag | 3.29 | 494±33 | 8.063±0.536 | 4.5±0.4 | 3.36 | 19.01 | 95 | 69% |

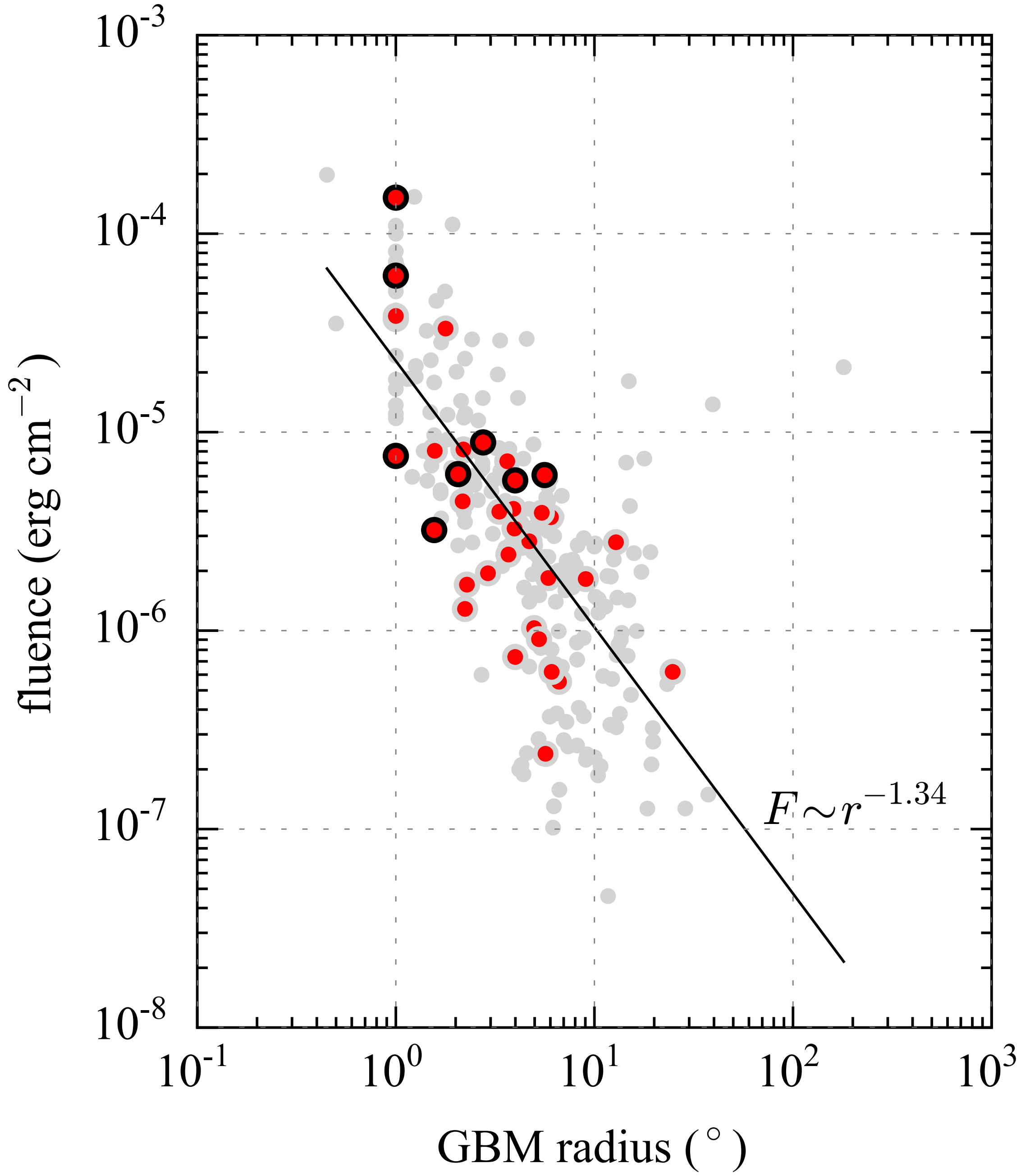


Long GRBs
Fast optical transients
iPTF/GBM detections
P48 5 min response time
P48 lim. mag. R ~20.6 in 60 s
iPTF13ekl
GRB 131231A
iPTF13bxl
GRB 130702A
iPTF14aue
GRB 140508A
iPTF14cva
GRB 140620A
iPTF14cyb
GRB 140623A
iPTF14eag
GRB 140808A
PTF11agg
iPTF13dsw
GRB 131011A
iPTF14yb
GRB 140226A
iPTF14bfu
GRB 140606B
mag (R)
t (days, observer frame)
5
10
15
20
25
30
$10^{-4}$
$10^{-3}$
$10^{-2}$
$10^{-1}$
$10^{0}$
$10^{1}$
$10^{2}$
$10^{3}$

# Detection efficiency




- Dominated by coverage of GRB localization and LF of optical afterglows at age of P48 observations.
- Can predict expected number of detections to date using historical optical afterglow sample.
- Expected: 6–8. Observed: 8 ✓

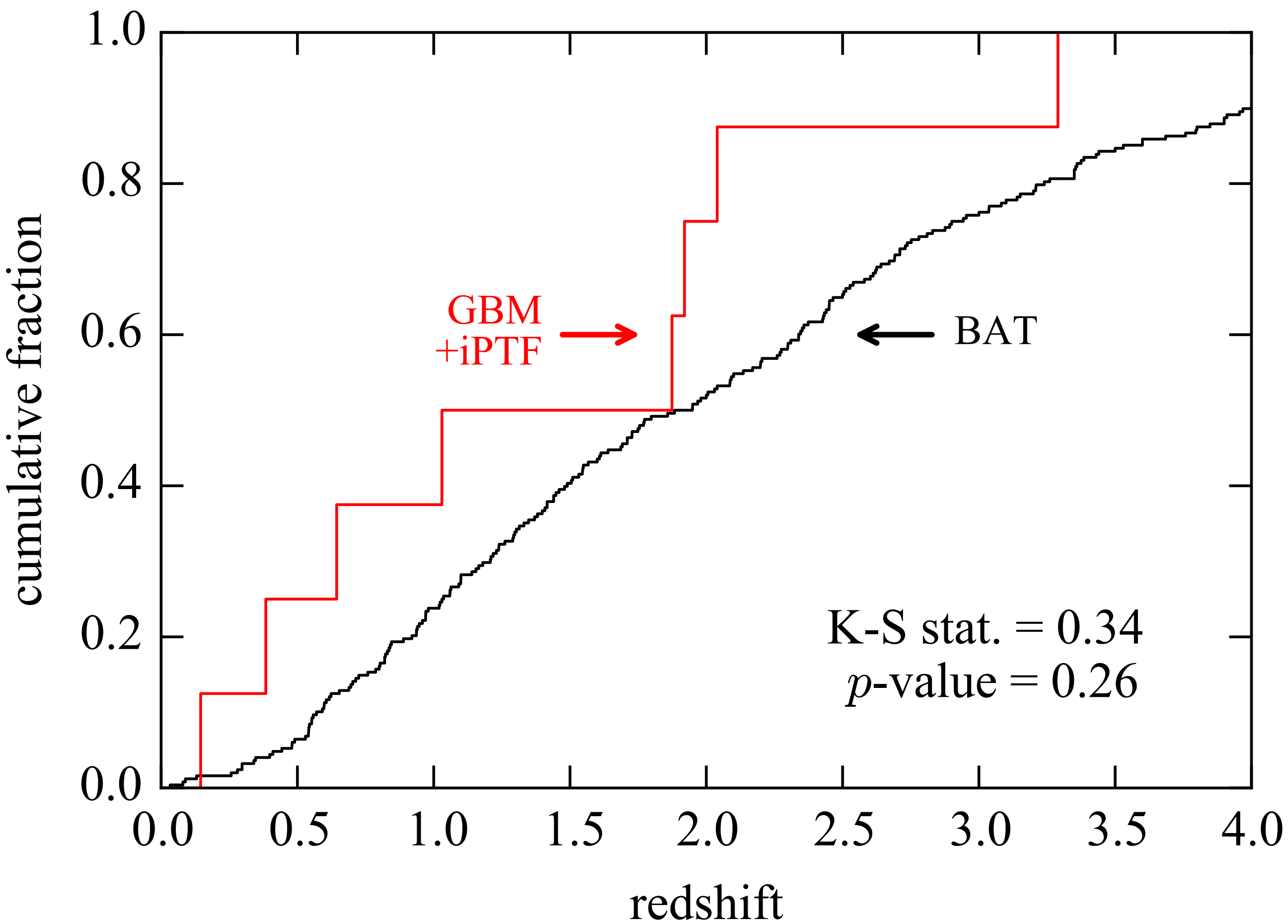



Preference for well localized GRBs

→ slight bias toward high-fluence events

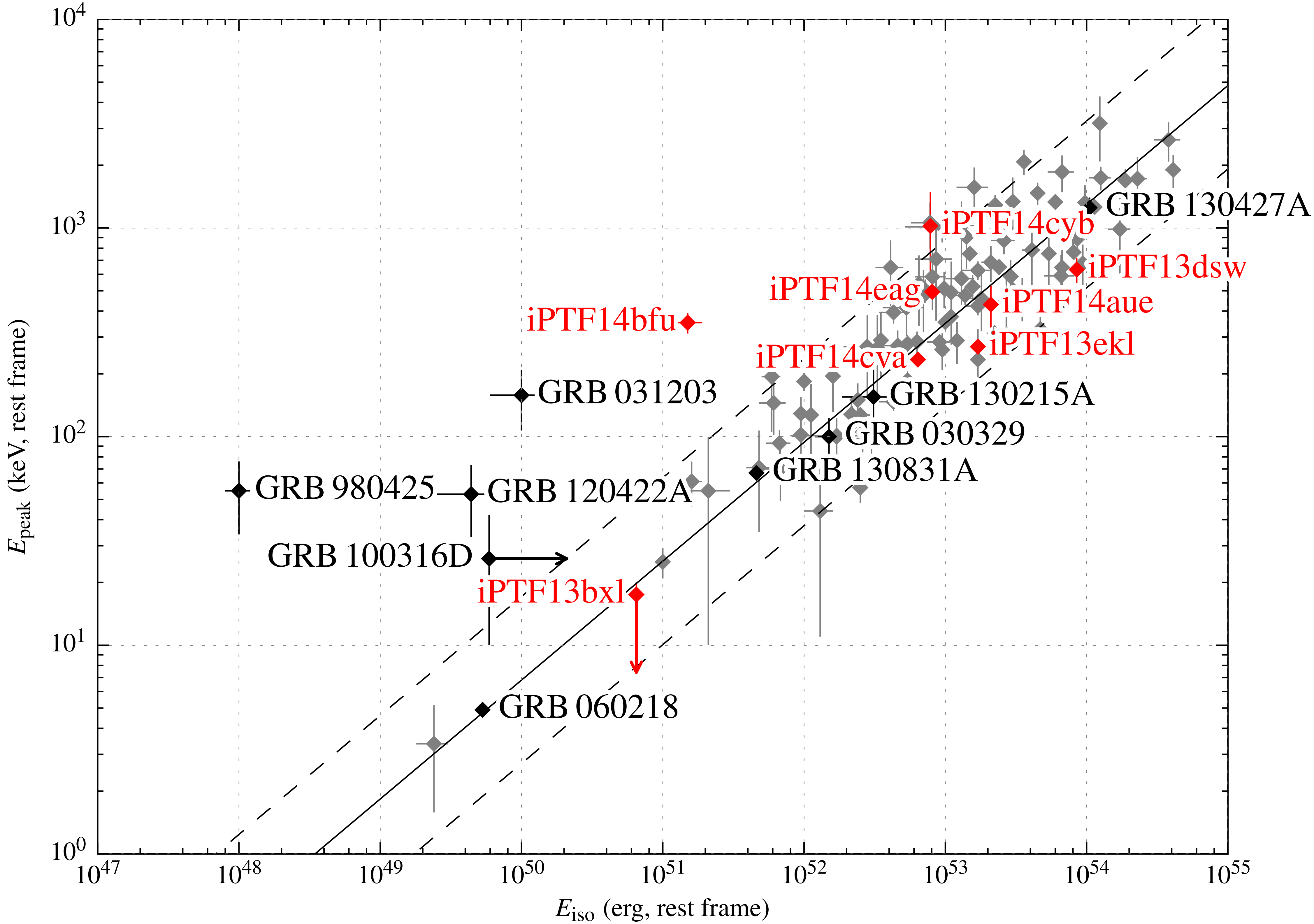
→ very weak preference for bright optical afterglows

(due to very weak correlation between gamma and optical brightness, Nyswander et al. 2009)



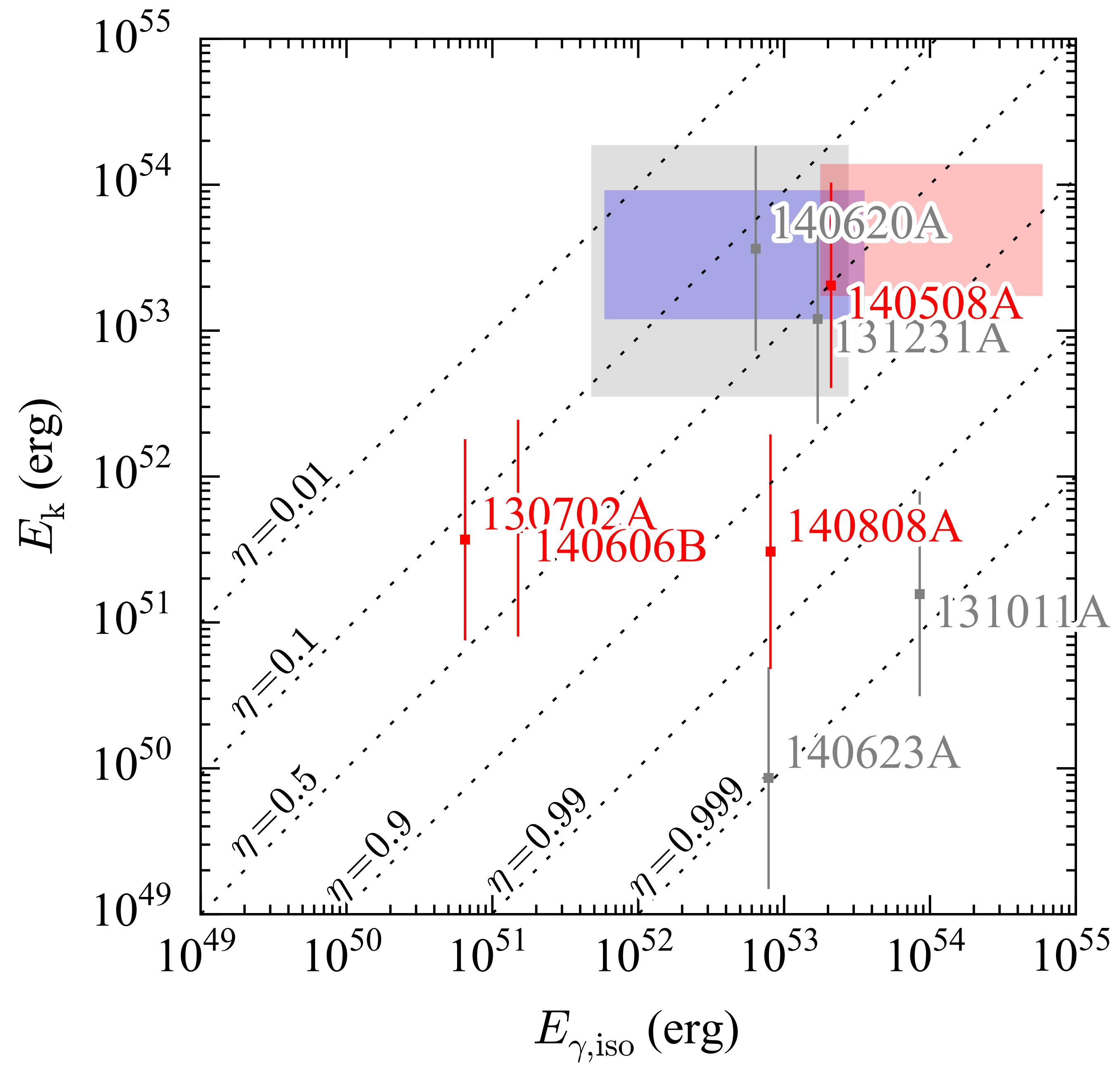

Slight preference for lower redshifts compared to *Swift* BAT (median of $z$=1.5 versus $z$=1.9), but not statistically significant with small sample size

# Energetics in context



# Radiative efficiency

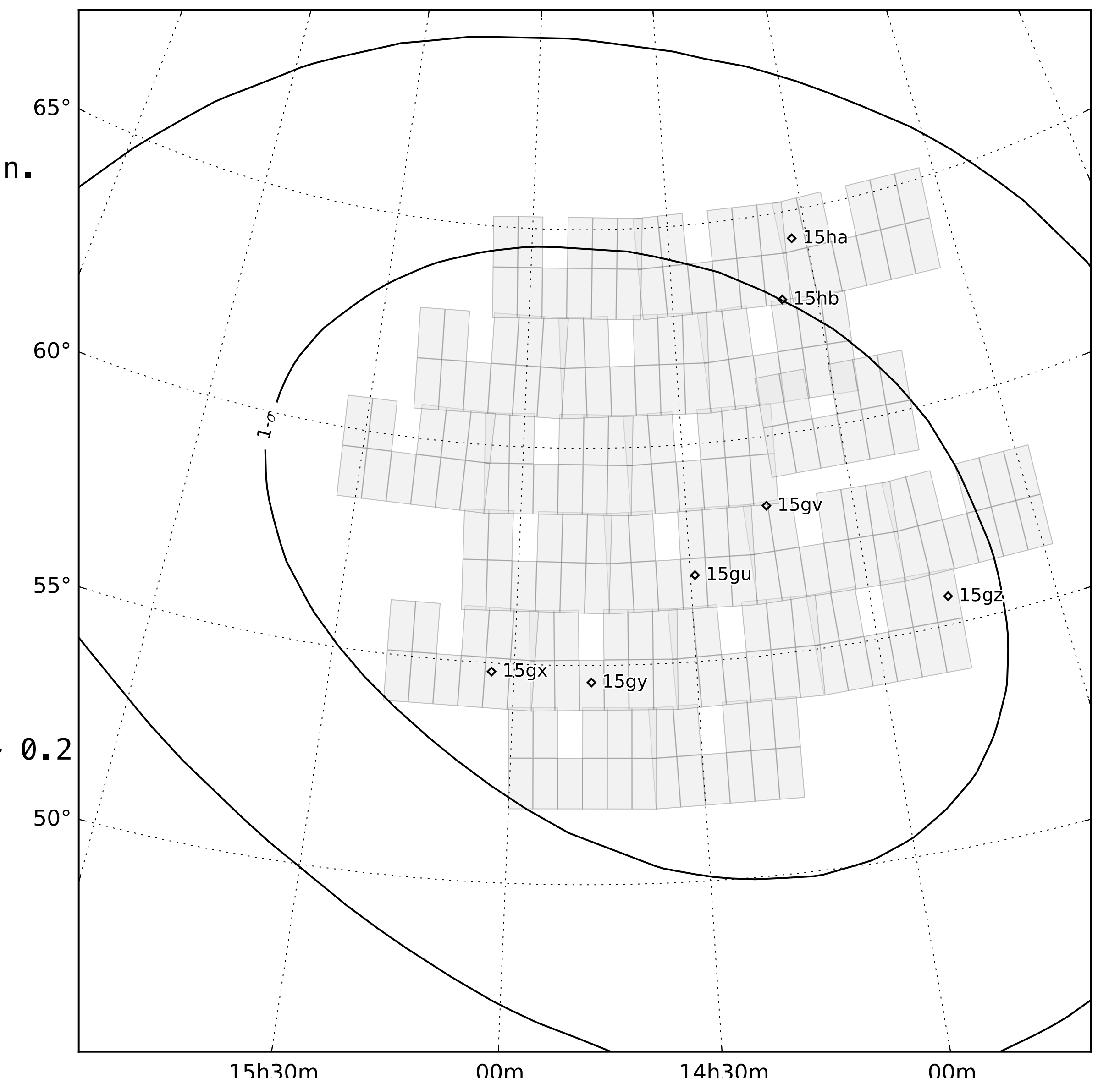
- X-ray afterglow is (usually) a clean diagnostic of the explosion's kinetic energy (Freedman & Waxman 2001)
- GRBs 130702A and 140606B are both subluminous *and* subenergetic
- Similar in radiative efficiencies to "normal" GRBs (Racusin et al. 2011)



# What can go wrong?

- Observability window, weather, filter choice, instrument maintenance, pipeline issues
- Light curve is more useful discriminator if follow-up is early
- Galactic latitude: fields with $|b| \lesssim 10°$ fill up DB rapidly; excluded from normal processing

```
TITLE:   GCN CIRCULAR
NUMBER:  17415
SUBJECT: GRB 150206B: iPTF Optical Observations
DATE:    15/02/06 21:06:32 GMT
FROM:    Leo Singer at GSFC/iPTF  <leo.p.singer@nasa.gov>

L. P. Singer (NASA/GSFC), M. M. Kasliwal (Carnegie Observatories/Princeton),
and S. B. Cenko (NASA/GSFC) report on behalf of the intermediate Palomar
Transient Factory (iPTF) collaboration:

Fermi detected GRB 150206B (Fermi trigger 444908790 / bn150206407) at
2015-02-06 09:46:27.48. At 2015-02-06 10:23:45, 37 minutes after the
burst, we began searching for optical counterparts using the Palomar
48-inch Oschin telescope (P48).

We imaged 20 fields covering an area of 144 deg^2 mostly inside the
1-sigma statistical+systematic region of the final Fermi GBM localization.
We estimate a 51% prior probability that these fields contain the true
location of the source. Sifting through candidate variable sources using
image subtraction and standard iPTF vetting procedures, we detected the
following optical transient candidates:

iPTF15gz, at the coordinates:
 RA(J2000)  =  13h 47m 18.31s (206.826292 deg)
 Dec(J2000) = +55d 38' 33.7"  (+55.642694 deg)
No source is visible at this position in archival SDSS and iPTF images.
The following P48 photometry is suggestive of fading:
 +116.7 min:   R = 20.25 +/- 0.13
 +160.7 min:   R = 20.54 +/- 0.19

iPTF15hb, at the coordinates:
 RA(J2000)  =  14h 07m 09.34s (211.788915 deg)
 Dec(J2000) = +63d 02' 20.6"  (+63.039047 deg)
This position is near the galaxy SDSS J140709.19+630218.3, with photoZ ~ 0.2
suggesting an absolute magnitude of M_R ~ -21, consistent with typical
optical afterglows. We report the following photometry:
 +98.20 min:   R = 18.94 +/- 0.05
 +142.2 min:   R = 18.87 +/- 0.04
 +186.3 min:   R = 19.00 +/- 0.04

iPTF15gv, at the coordinates:
 RA(J2000)  =  14h 15m 28.31s (213.867960 deg)
 Dec(J2000) = +58d 24' 47.8"  (+58.413284 deg)
This coincides with the galaxy SDSS J141527.96+582447.9, with photoZ ~ 0.085,
suggesting M_R ~ -18. Although this is fainter than a typical optical
afterglow, the source is rapidly fading:
 +125.3 min:   19.89 +/- 0.07
 +169.3 min:   20.33 +/- 0.11
which fits a power law relative to the time of the burst, F_nu ~ t^-alpha,
with alpha = 1.3 +/- 0.4.

Times are relative to the GBM trigger. Magnitudes are in the Mould R
filter and in the AB system, calibrated with respect to point sources in
SDSS as described in Ofek et al. (2012, http://dx.doi.org/10.1086/664065).
```



TITLE: GCN CIRCULAR
NUMBER: 17421
SUBJECT: GRB 140206B: Continued iPTF Observations
DATE: 15/02/07 09:02:26 GMT
FROM: Leo Singer at GSFC/iPTF <leo.p.singer@nasa.gov>

L. P. Singer (NASA/GSFC), M. M. Kasliwal (Carnegie Observatories/Princeton), and S. B. Cenko (NASA/GSFC) report on behalf of the intermediate Palomar Transient Factory (iPTF) collaboration:

Using the Palomar 48-inch Oschin telescope (P48) and the robotic 60-inch telescope (P60), we have continued observing the optical transients that we reported (Singer et al., GCN 17415) in connection with GRB 140206B (Burns & Yu, GCN 17417). At about 20 hours after the burst, all three of the candidates (iPTF15gz, iPTF15hb, and iPTF15gv) are still clearly detected in host-subtracted images, despite relatively coarse 3" seeing. They show no statistically significant fading. We therefore dismiss them as counterparts of the GRB.

TITLE:   GCN CIRCULAR
NUMBER:  15686
SUBJECT: Fermi410578384: iPTF optical afterglow candidates for a possible short GRB
DATE:    14/01/05 16:37:28 GMT
FROM:    Leo Singer at CIT/PTF  <lsinger@caltech.edu>

L. P. Singer (Caltech), M. M. Kasliwal (Carnegie Observatories/Princeton) and S. B. Cenko (NASA/GSFC) report on behalf of the intermediate Palomar Transient Factory (iPTF) collaboration:

At 2014-01-05 01:33:01, Fermi GBM and INTEGRAL SPI-ACS triggered on a possible short event (Fermi trigger 410578384). From 7.4 to 10.5 hours after the burst, we imaged 74 deg^2 with the Palomar 48-inch Oschin telescope (P48), covering some of the intersection between the Fermi 1-sigma statistical+systematic error region and the IPN 3-sigma annulus. Sifting through 60,191 candidate variable sources using standard iPTF vetting procedures, we find the following optical afterglow candidates:

iPTF14x, at R=19.7 mag, possibly fading, and near the galaxy SDSS J140427.10+485556.9, at the coordinates:
 RA(J2000)  =  14h 04m 27.27s (211.113610 deg)
 Dec(J2000) = +48d 55' 55.3"  (+48.932017 deg)

iPTF14ac, at R=20.1 mag, near the galaxy SDSS J142230.44+482916.8 and in an apparent galaxy cluster at z=0.07, at the coordinates:
 RA(J2000)  =  14h 22m 30.60s (215.627501 deg)
 Dec(J2000) = +48d 29' 21.5"  (+48.489310 deg)

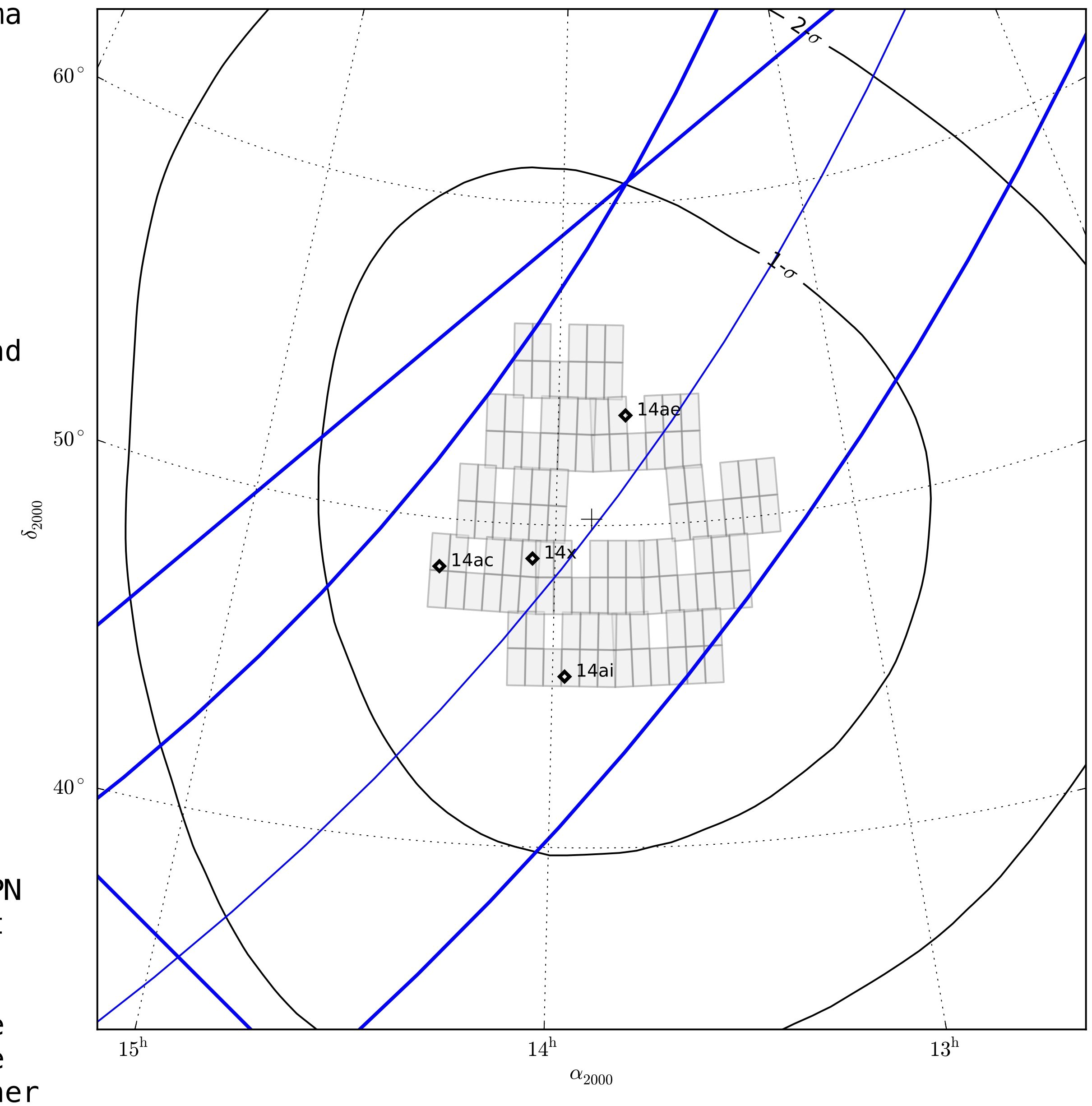
iPTF14ae, at R=20.1 mag, possibly fading, near the source SDSS J134527.33+532615.3 (which SDSS classifies as a galaxy), at the coordinates:
 RA(J2000)  =  13h 45m 27.34s (206.363914 deg)
 Dec(J2000) = +53d 26' 16.9"  (+53.438029 deg)

iPTF14ai, at R=20.6 mag, coincident with no obvious source in our reference images or in SDSS, at the coordinates:
 RA(J2000)  =  13h 57m 46.05s (209.441870 deg)
 Dec(J2000) = +45d 16' 09.3"  (+45.269258 deg)

A diagram of the locations of these candidates, the Fermi-GBM and IPN localizations, and the ten P48 fields that we imaged can be found at <http://www.its.caltech.edu/~lsinger/iptf/Fermi410578384.pdf>.

We caution that many contaminating transient or variable sources are found in any such wide-area targeted search, and that it is possible that none of our candidates are associated with the short GRB. Further observations are encouraged to determine the nature of these sources, and whether one of them is related to the Fermi and INTEGRAL trigger.

We thank the Fermi and IPN teams for supplying us with the localizations.



TITLE:   GCN CIRCULAR
NUMBER:  15696
SUBJECT: GRB 140105A: continued iPTF observations and rejection of optical candidates
DATE:    14/01/07 06:03:23 GMT
FROM:    Leo Singer at CIT/PTF  <lsinger@caltech.edu>

L. P. Singer (Caltech), M. M. Kasliwal (Carnegie Observatories/Princeton),
S. B. Cenko (NASA/GSFC), E. Bellm (Caltech), and Y. Cao (Caltech) report
on behalf of the intermediate Palomar Transient Factory (iPTF)
collaboration:

We have continued to observe four optical transients (Singer et al., GCN 15686) in the Fermi GBM error circle for GRB 140105A (Xiong & Connaughton, GCN 15688) with the Palomar 48-inch Oschin telescope (P48), the robotic Palomar 60-inch (P60), and the Palomar 200-inch (P200) equipped with the Double Beam Spectrograph (DBSP).

At 33 hours after the burst, with the P48 we obtain the following host-subtracted magnitudes in the Mould R filter:
 iPTF14x,  R = 20.0
 iPTF14ac, R = 20.3
 iPTF14ae, R = 20.5

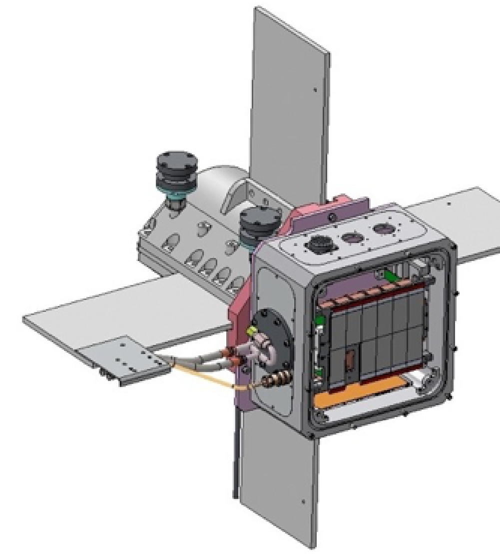
With the P60, at 34 hours after the burst, we obtain the following magnitude in the SDSS system:
 iPTF14ai, r = 20.4

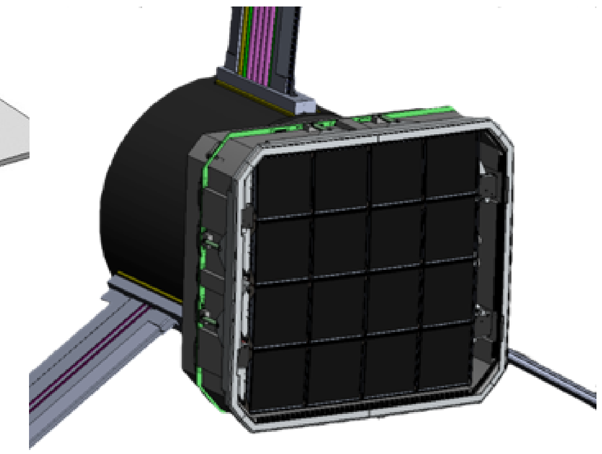
We obtained spectra of all four with the P200. iPTF14x resembles a Type II supernova. Our spectra for iPTF14ac, iPTF14ae, and iPTF14ai show a mostly featureless continuum.

The lack of significant optical fading in any of the four candidates strongly argues against association with the GRB.

# What’s next?

# LIGO + ZTF

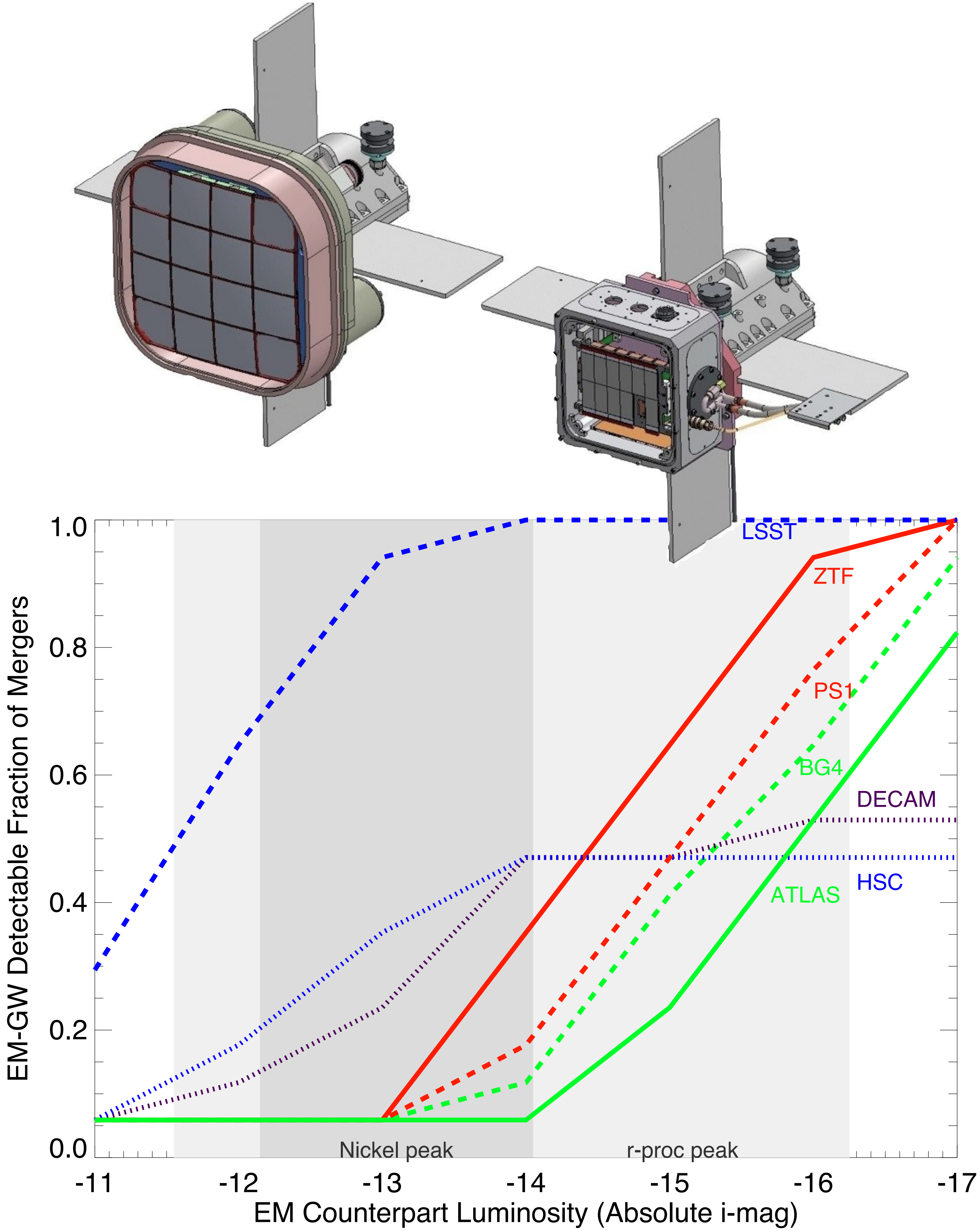




- Zwicky Transient Facility
- New camera, 7x increase in FOV; order of magnitude faster survey rate
- Faster readout for deep co-adds, guiding for long exposures
- Improved real/bogus classification →higher purity discovery stream
- Combine GW posterior with local universe galaxy catalog (Nissanke+ 2013)

| | PTF | ZTF |
|---|---|---|
| Active Area | 7.26 $\text{deg}^2$ | 47 $\text{deg}^2$ |
| 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** |

E. Bellm
Bellm+ 2014
Smith+ 2014




# Kilonovae+ZTF

Kasliwal & Nissanke (2014)
http://dx.doi.org/10.1088/2041-8205/789/1/L5

+ See also Metzger, Bauswein, Goriely, & Kasen (2014, http://arxiv.org/abs/1409.0544)

  bluer, faster-rising kilonova precursor

# Next steps

- Retarget iPTF TOO program to short bursts to force us to look deeper and fainter
- Need to constantly improve response time, machine learning purity, and efficient presentation of relevant information to humans
- Gap in early-mid follow-up for GRB search, clear value in meter-class follow-up going from Palomar to Hawaii
- Large synoptic surveys: expanding survey rate, ZTF, LSST, reach into KN phase space

# Next steps

- Rapid detection and sky localization pipeline ready for Advanced LIGO now
- Broadband follow-up outside of the well-studied *Swift* GRB sample
- Sample of challenges to come with searching for optical counterparts of Advanced LIGO events
- Next steps are challenging: how do we make the best use of the diversity of depths, wavelengths, FOVs within the GW follow-up community?