# (i)PTF searches for fast transients: Discoveries to Date and Future Predictions

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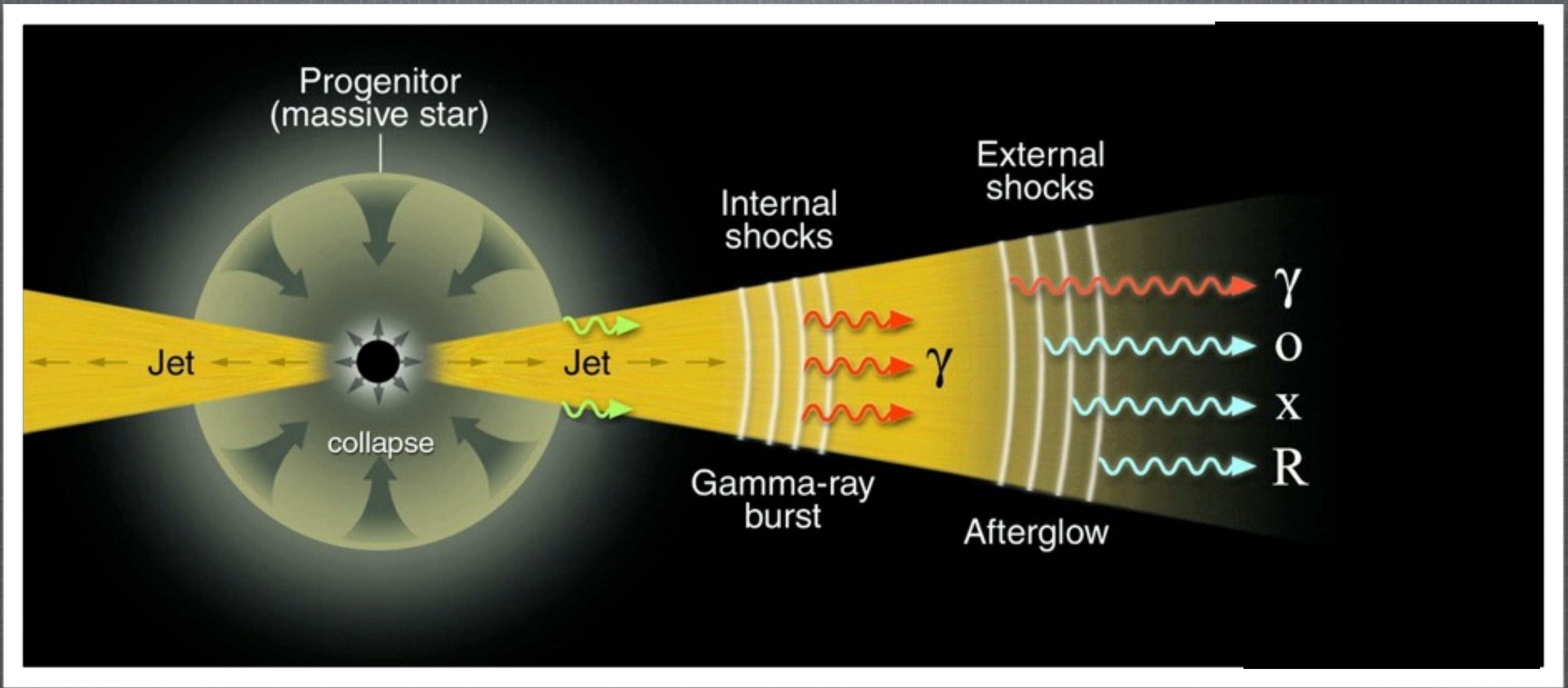
iPTF Team Meeting - 4 June 2014

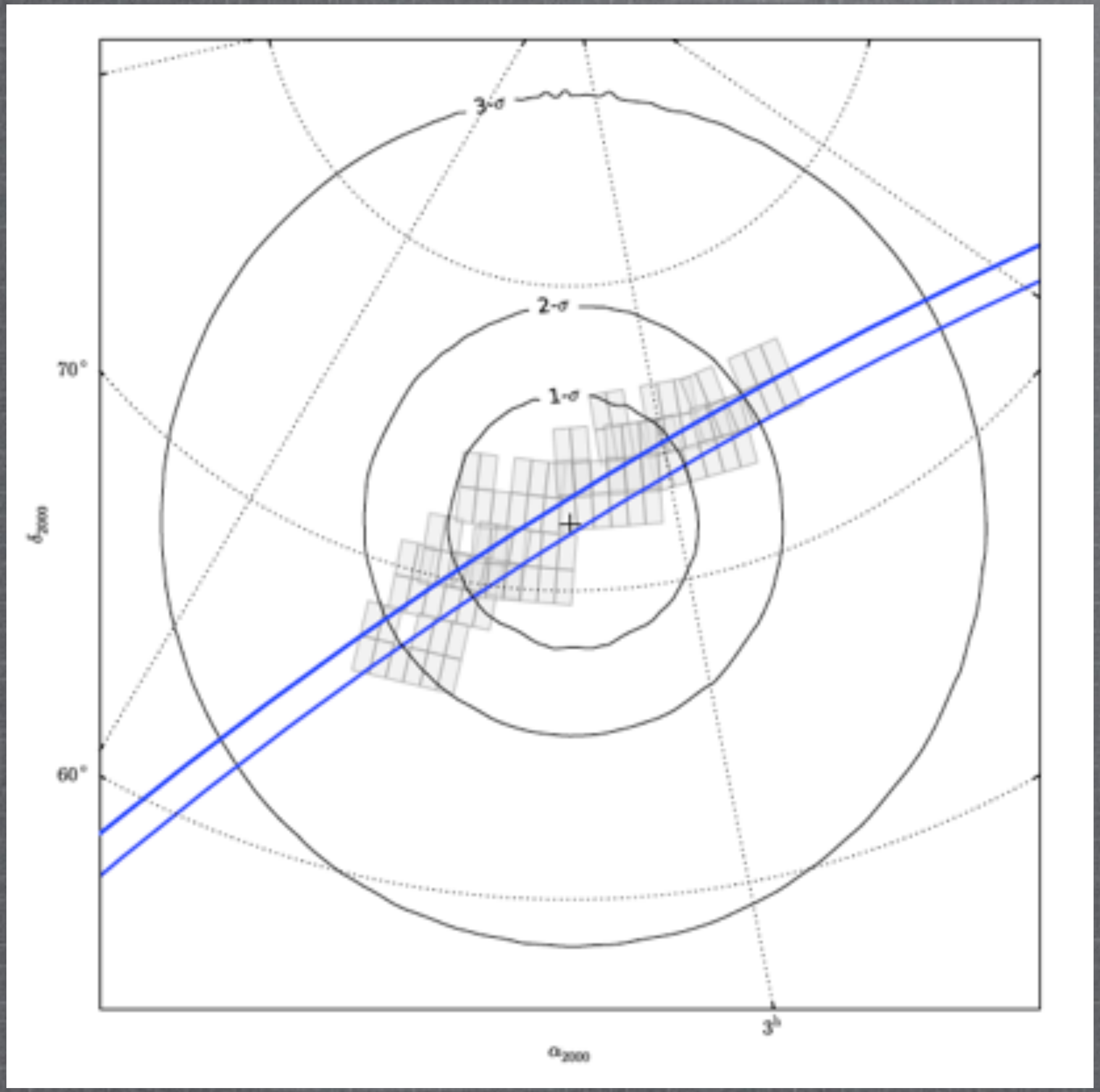
- Part I: *Triggered Follow-up* of *Fermi*-GBM Gamma-ray Bursts: On the path towards Advanced LIGO / Virgo
- Part II: *Untriggered* searches for distant, relativistic outbursts: Beaming and Jet Composition in Gamma-ray Bursts

# GRB OVERVIEW




A narrowly collimated, ultra-relativistic outflow generated from the core-collapse of a massive star

# GBM+PTF LOGISTICS




- Respond to automated localizations when field promptly available, otherwise use (more accurate) human-in-the-loop localizations
- Worked with GBM team to test out probability contours
- Limited to 10 fields (71 deg$^2$), ~ 1-2 triggers per month
- Focus on bright events (fluence, peak count rate) and short-hard GRBs
- Run through full iPTF machinery

# GBM+PTF LOGISTICS

**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

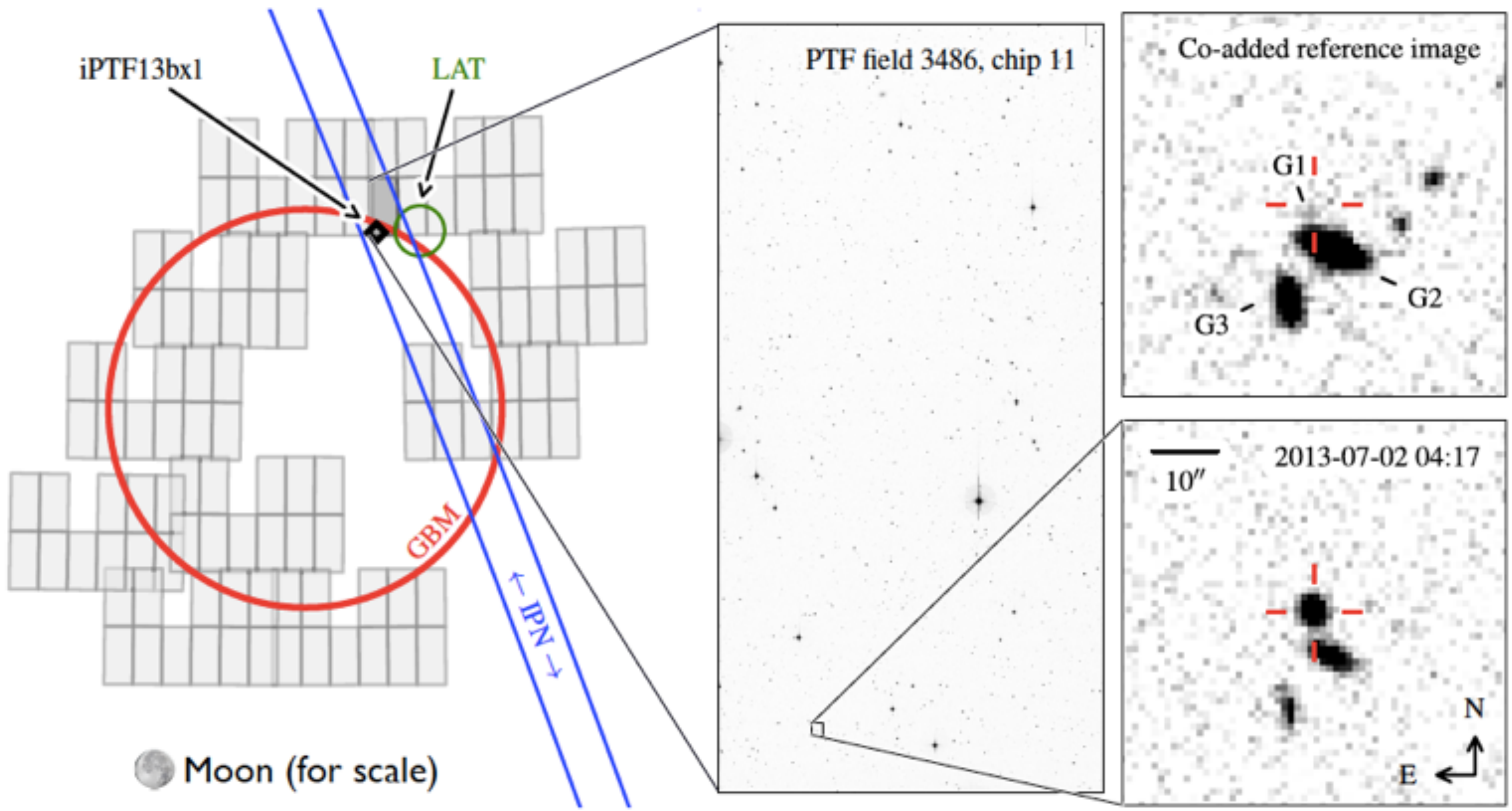
**7** sources saved by humans

**3** afterglow-like candidates scheduled for follow-up

# GBM+PTF SUCCESSES

(Almost exactly) one year after IPN GRB:

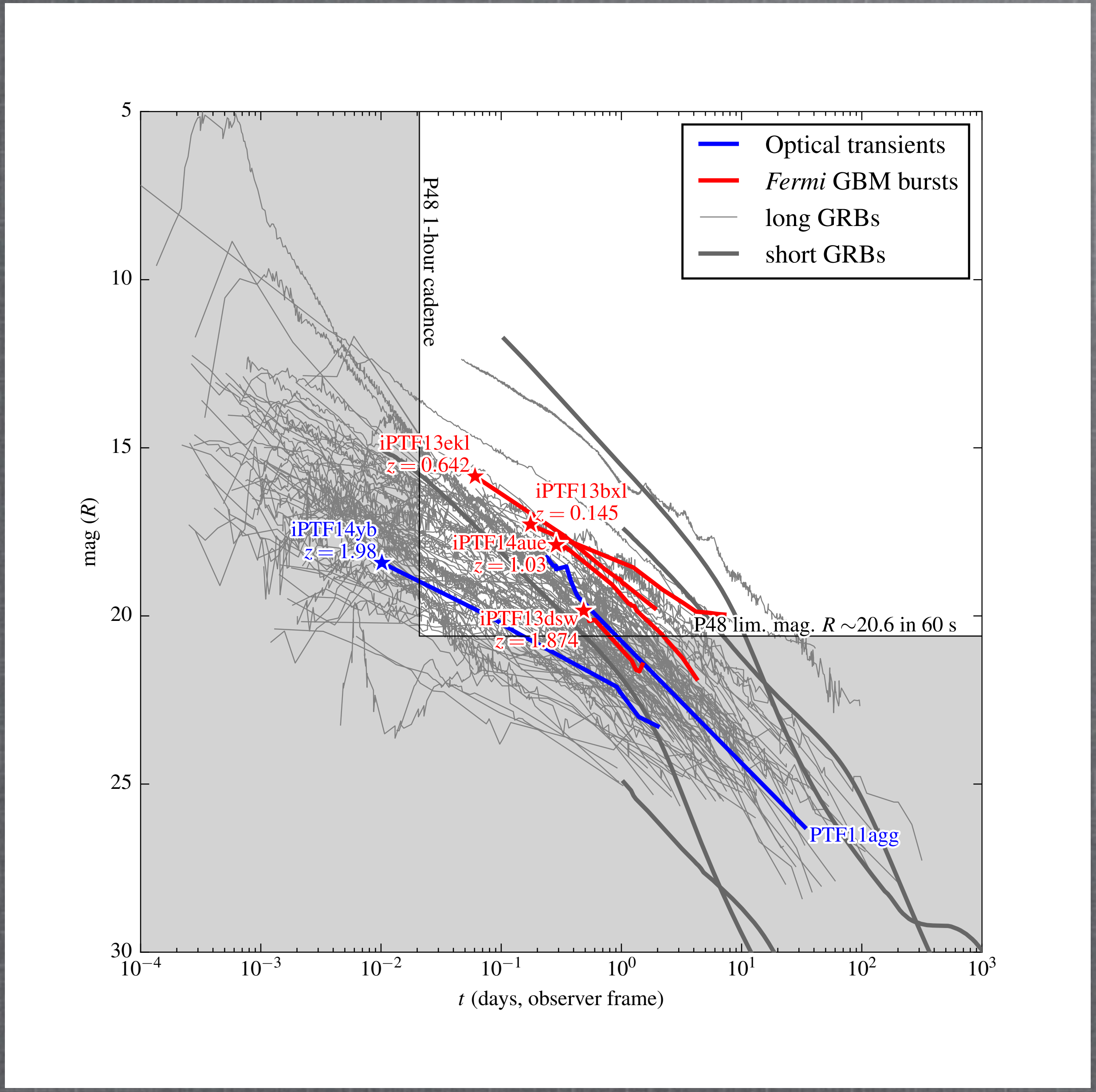
## Discovery & redshift of a GBM GRB in 71 deg$^2$

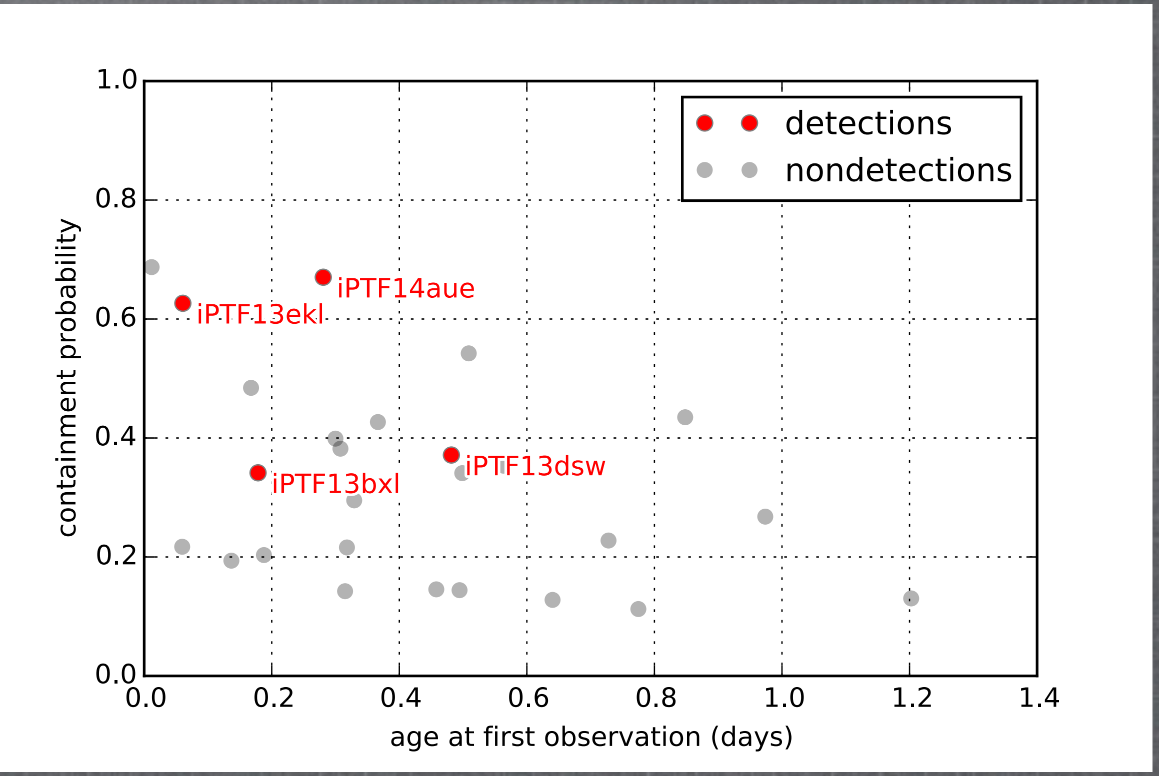



Singer et al.(2013, 2013, ApJL 776:34)

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

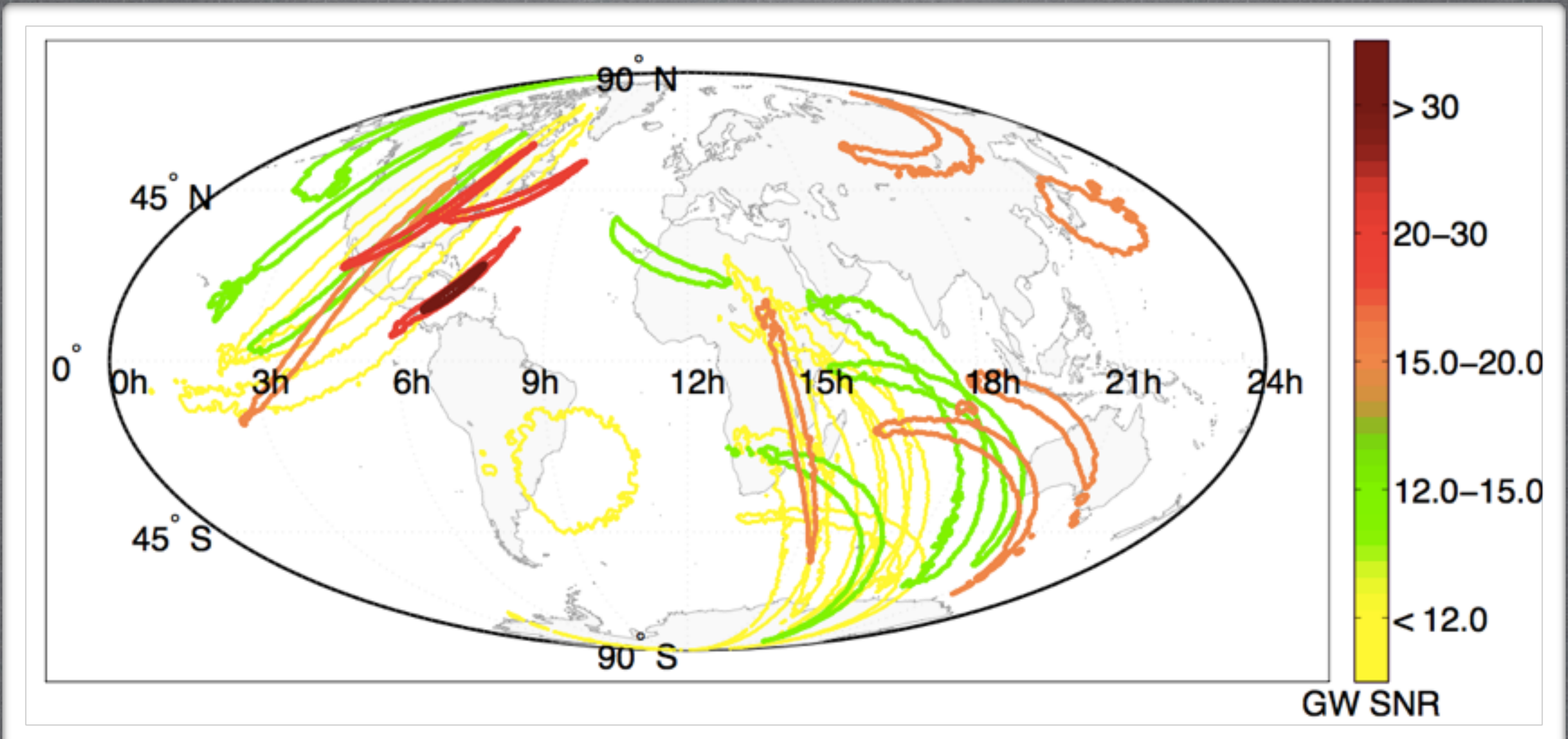
# GBM+PTF SCORECARD




Singer *et al.*, in prep.

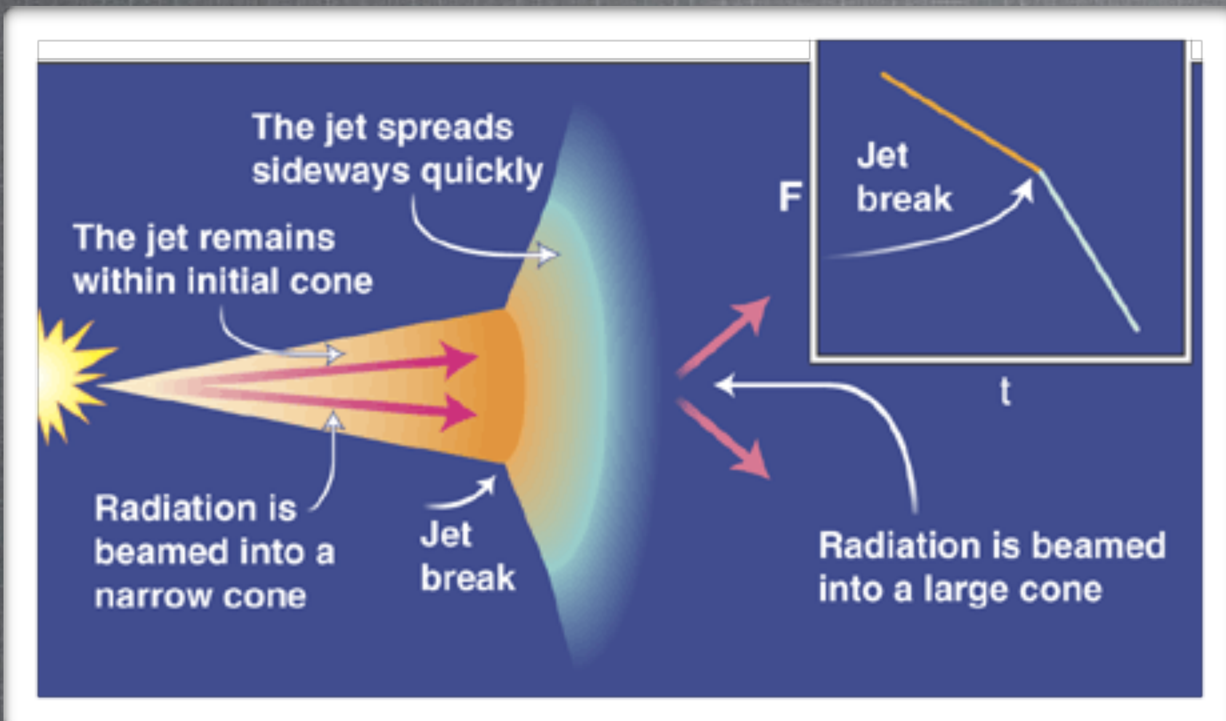
# FUTURE I: aLIGO/VIRGO



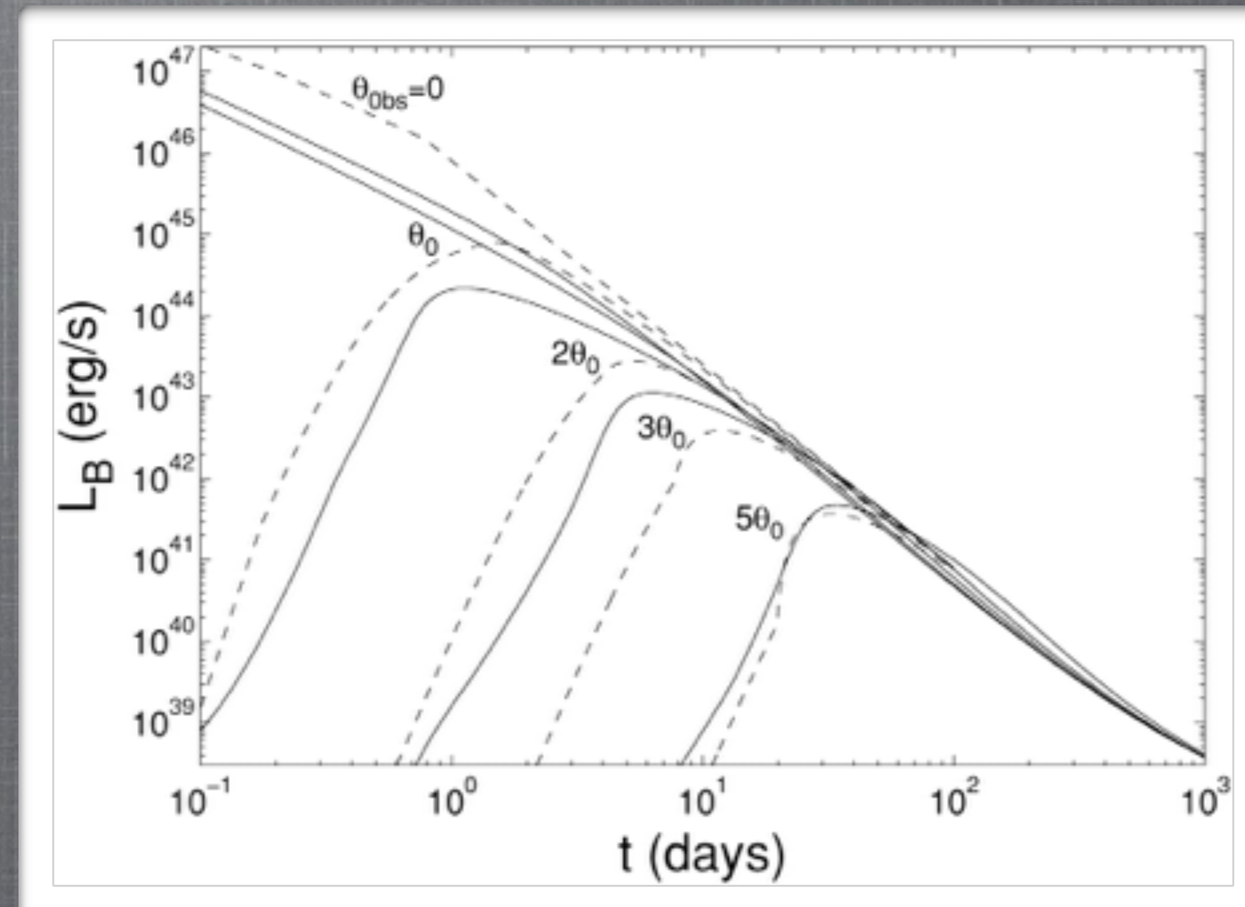

Kasliwal & Nissanke, 2013

Predicted electromagnetic signatures are faint, rapidly fading, and these sources will be very poorly localized

# BEAMING IN GRBS




Piran 2004



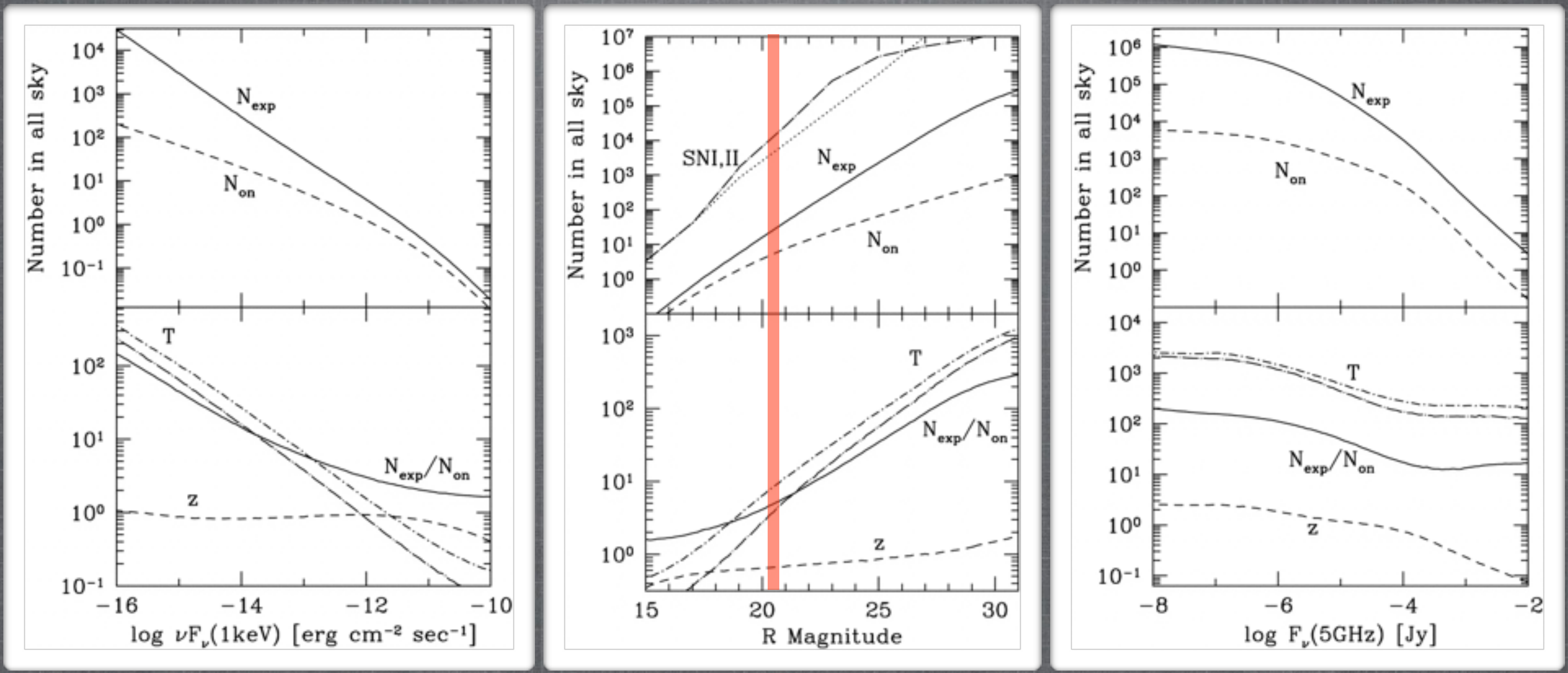

Granot et al., 2002

While initially highly collimated, lateral spreading of jet and decrease in relativistic beaming lead to illumination of increasing fraction of sky

For every on-axis event, ~ 100 "orphan" GRB afterglows. Off-axis observers should see fast rise and rapid decline.

# BEAMING IN GRBS

X-rays Optical Radio

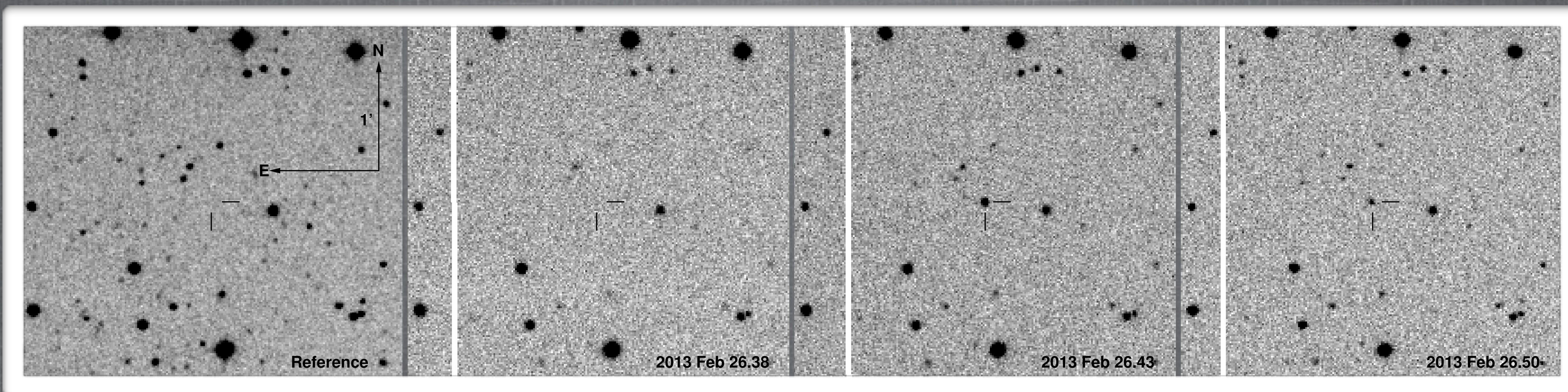



Totani & Panaitescu, 2002

At PTF limits, expect ~ 3 off-axis orphans for every on-axis event

# iPTF14yb: "UNTRIGGERED" GRB

Reference 2013 Feb 26.38 2013 Feb 26.43 2013 Feb 26.50




SBC+, in prep.

09:04 UT:
P48 Non-detection

10:17 UT:
P48 r = 18.16

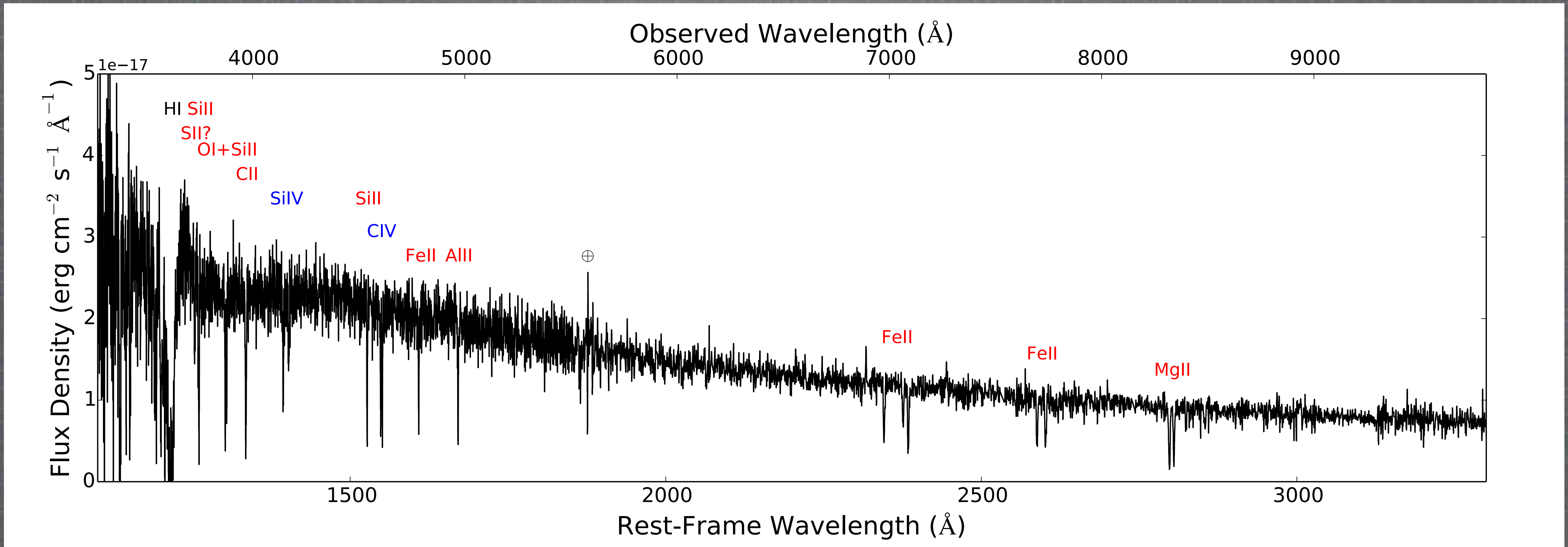
12:01 UT:
P48 r= 19.77

12:46 UT:
Flagged by software

15:26 UT:
Keck/LRIS Spectrum

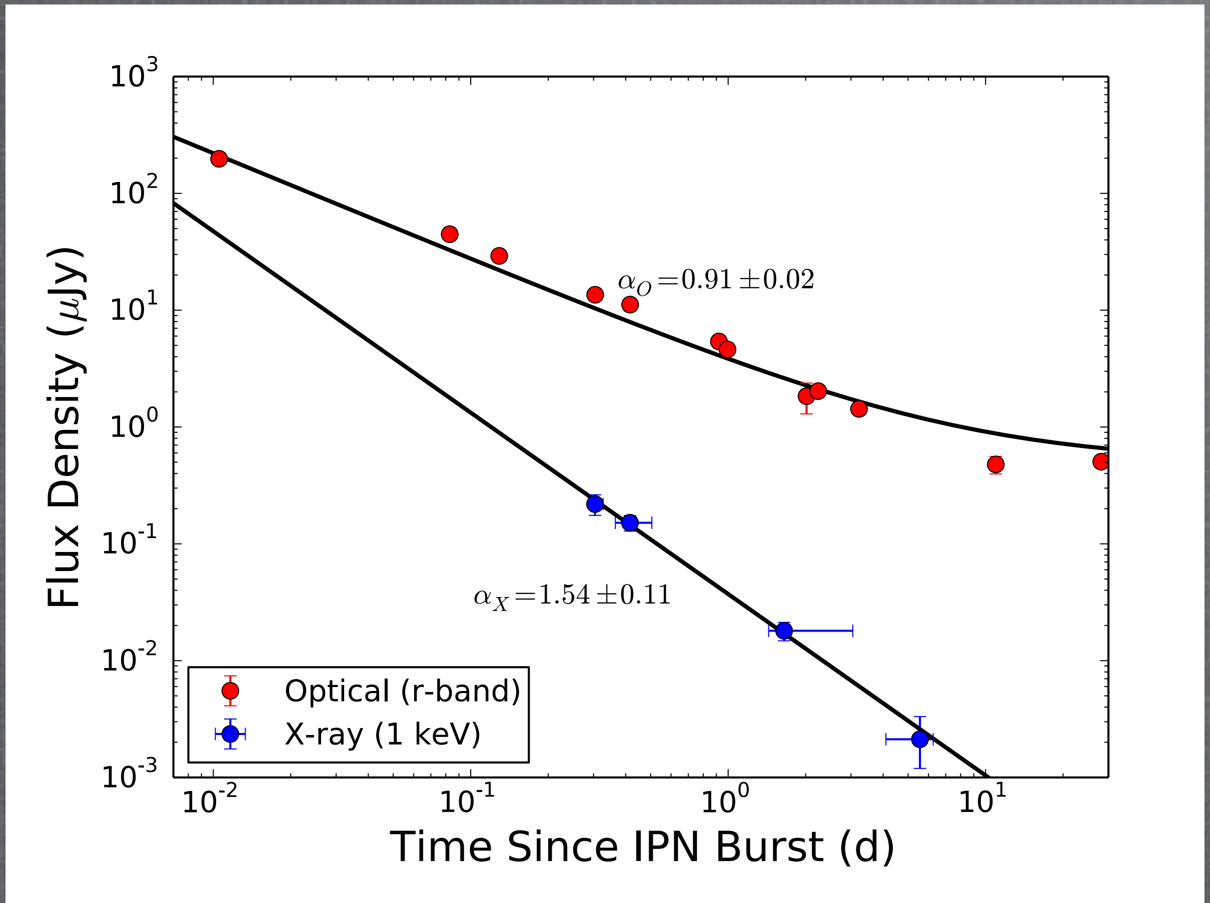
17:11 UT:
*Swift* X-ray+UV

# iPTF14yb: SPECTRUM

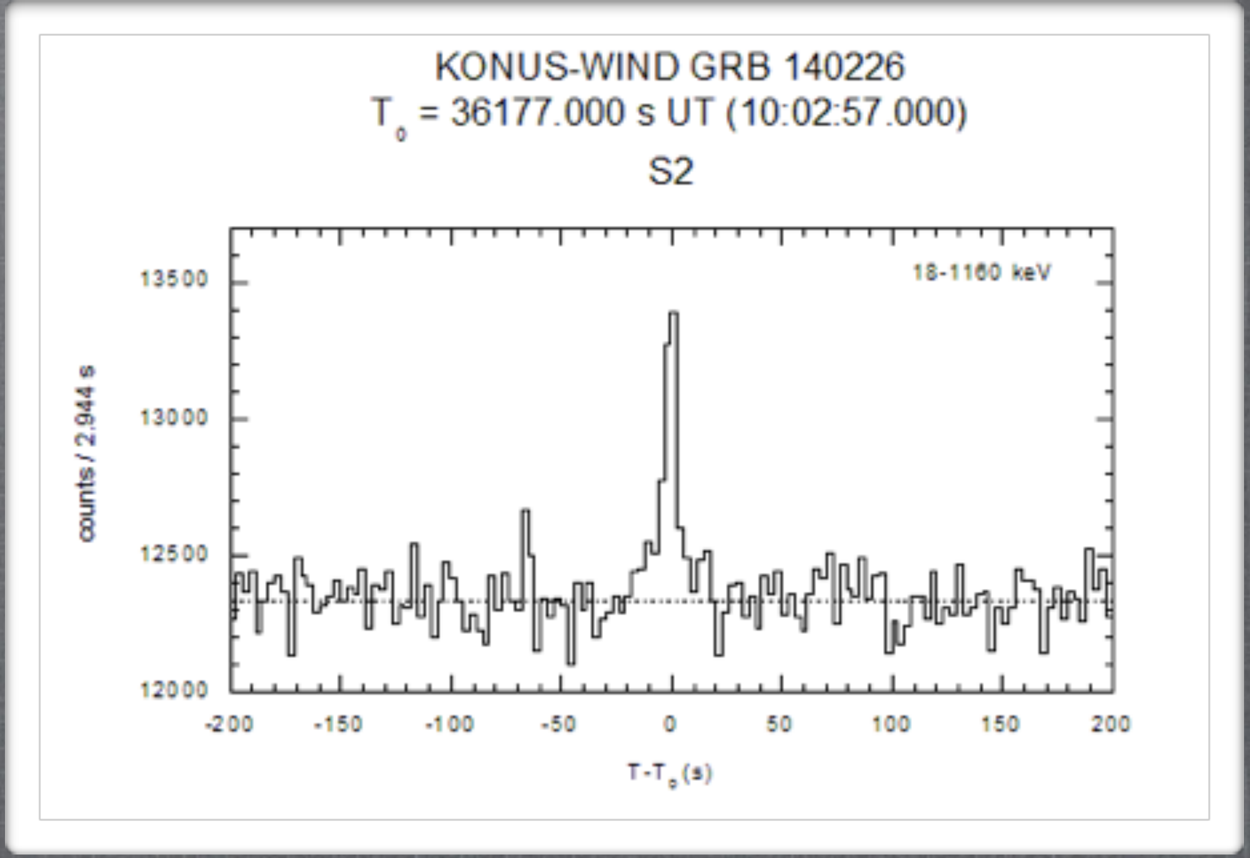



Power-law continuum with narrow absorption features from z = 1.97 host (high- and low-ionization metals, Lyα, and forest) super-imposed

# iPTF14yb: “PARENT” GRB



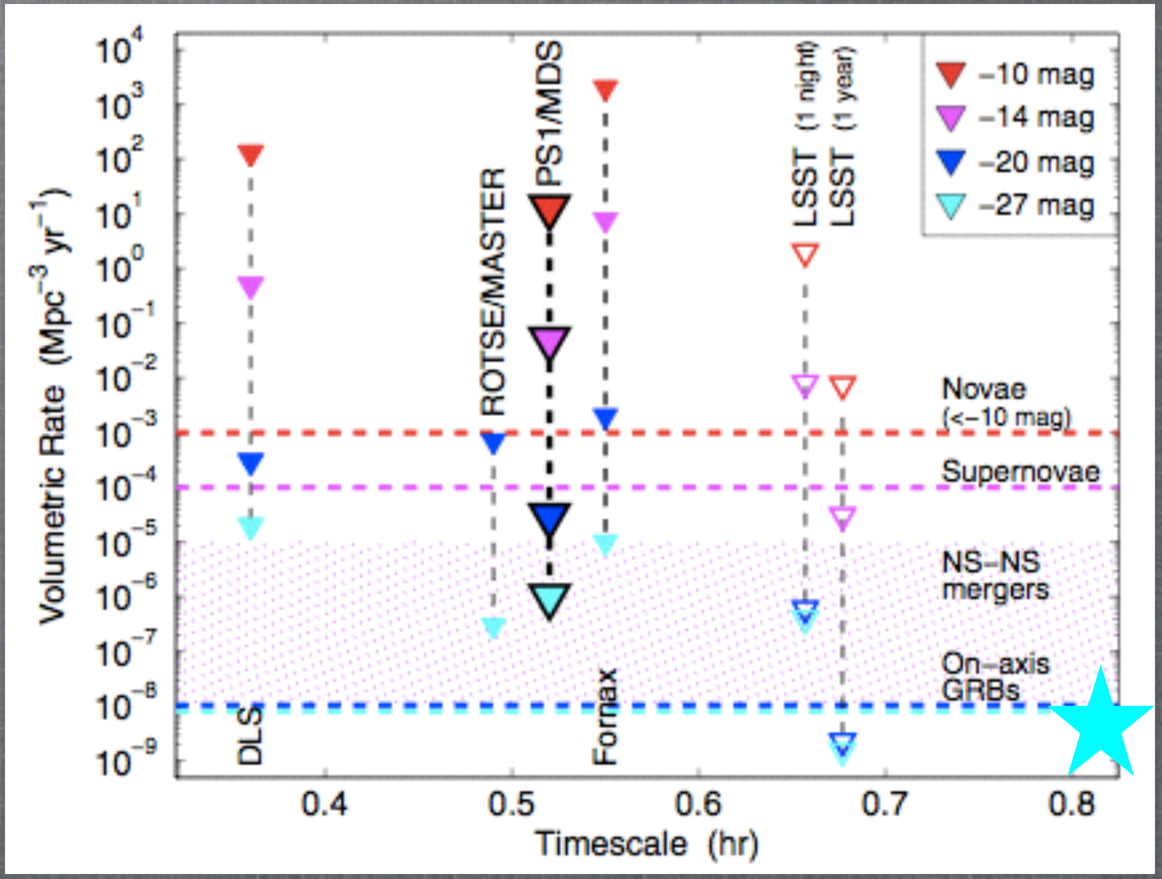

Optical and X-ray light curves behave like normal, on-axis GRB




“Parent” GRB later identified by (all-sky) InterPlanetary Network

# iPTF14yb RATES

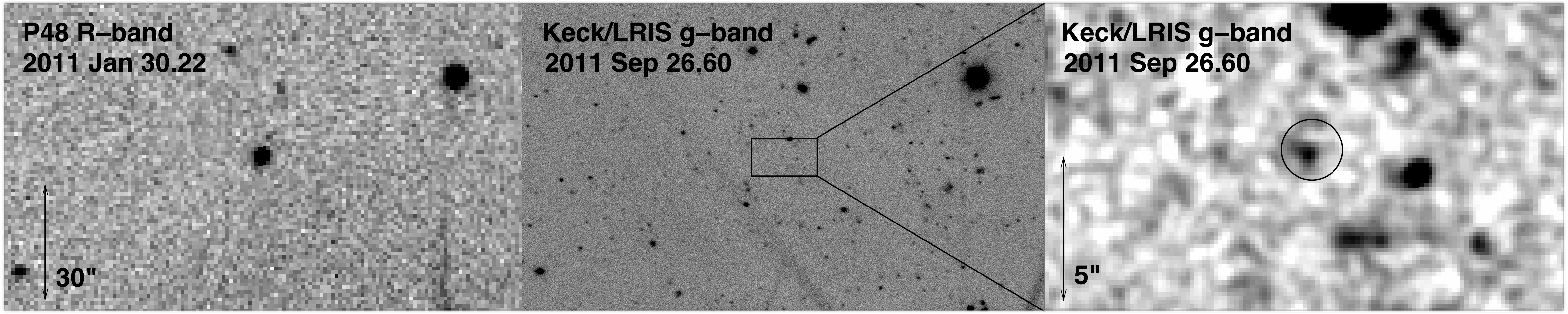
| Survey | Areal Exposure ($\deg^2$ day) | Limiting Magnitude | $R_{FOT}$ ($\deg^{-2}$ day$^{-1}$) |
|---|---|---|---|
| PS1/MDS | 40.4 | 22.5 | $\lesssim 0.12$ |
| DLS | 1.1 | 23.8 | $\lesssim 6.5$ |
| Fornax | 1.9 | 21.3 | $\lesssim 3.3$ |
| ROTSE-III | 635 | 17.5 | $\lesssim 0.005$ |
| MASTER | ... | 17.5 | $\lesssim 0.003$ |
| LSST | 62 | 23.5 | $\lesssim 0.07$ |
| | $1.6 \times 10^4$ | 23.5 | $\lesssim 3 \times 10^{-4}$ |
| **iPTF** | **$1.8 \times 10^5$** | **20.0** | **$4 \times 10^{-5}$** |



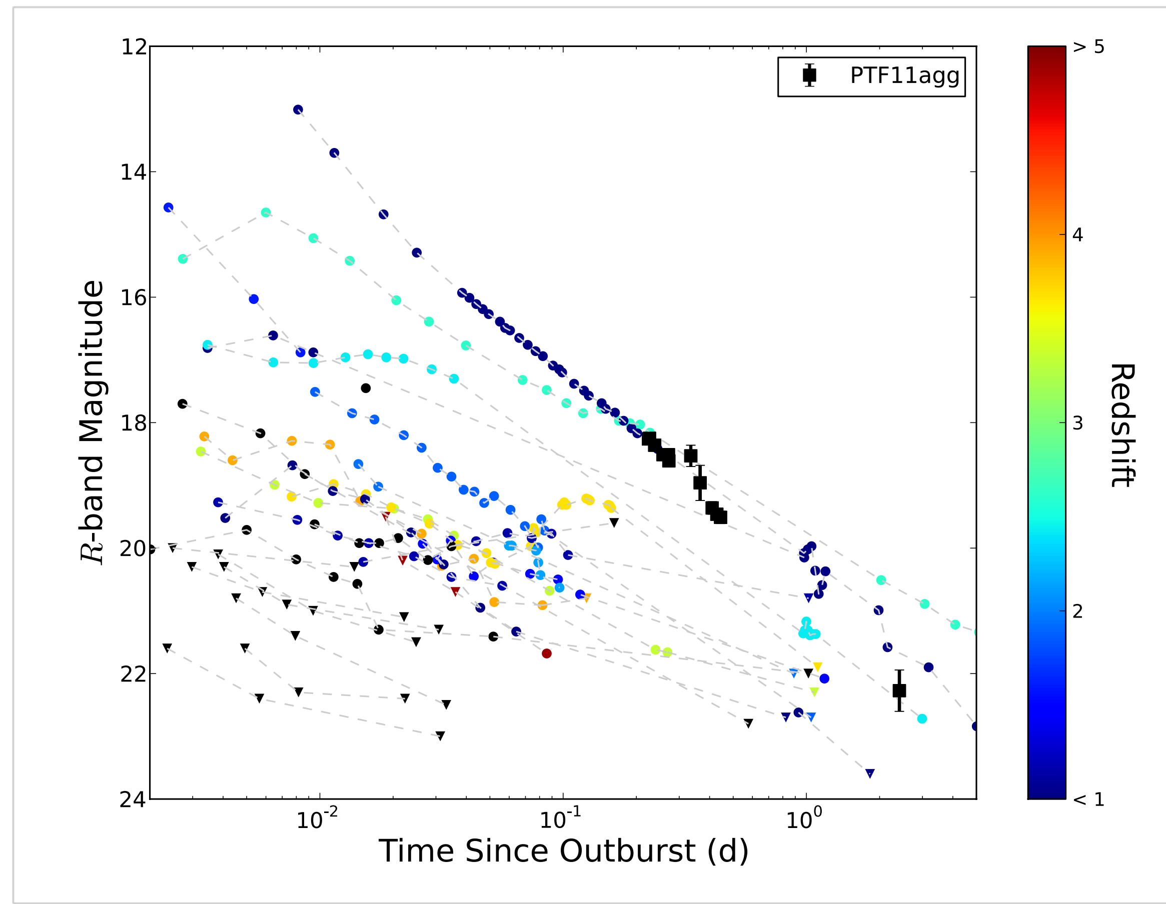

Berger *et al.*, 2013

For the first time, we can detect on-axis events without high-energy trigger. But where are the orphans?

# PTF11AGG: ORPHAN AFTERGLOW?

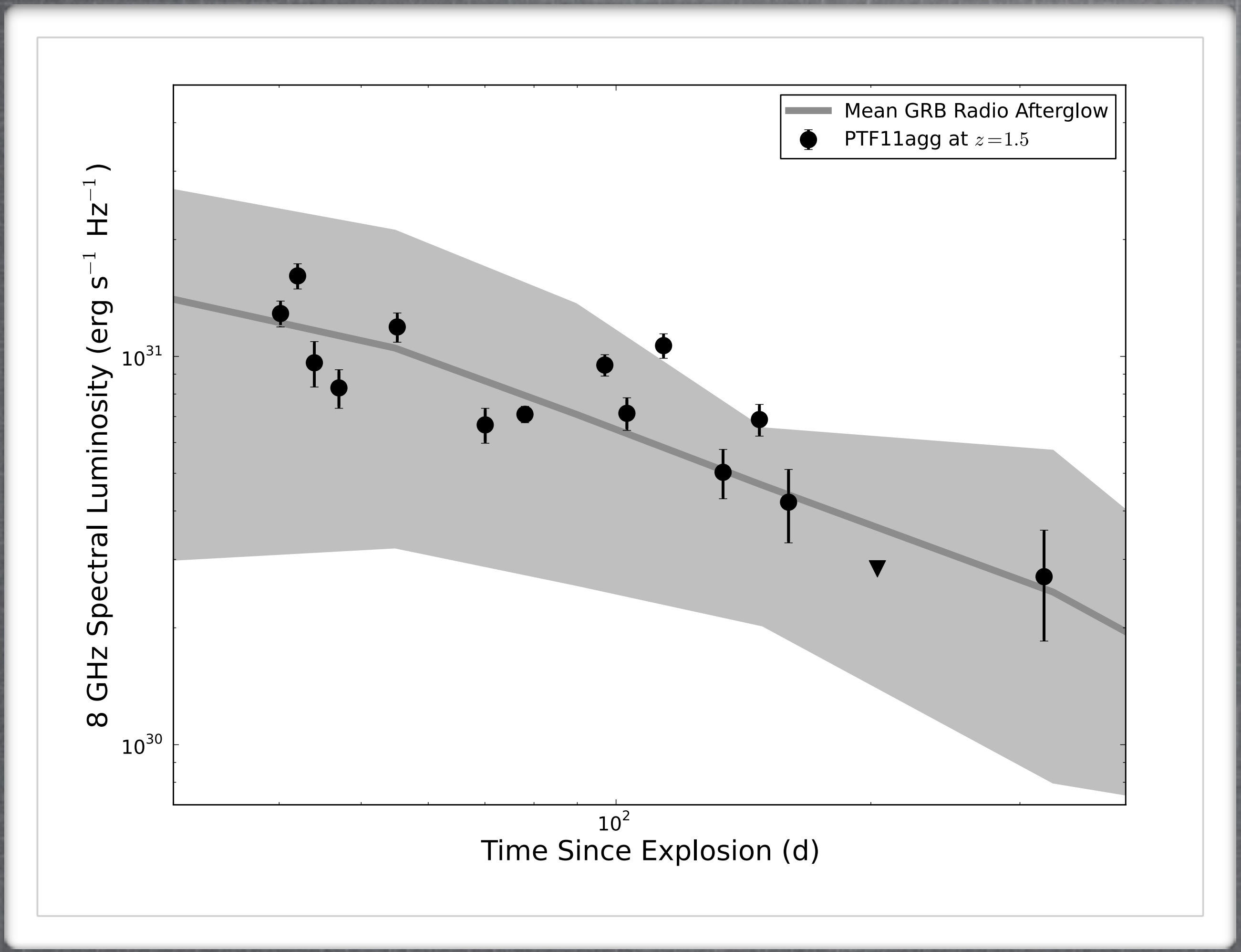



**PTF11agg**: discovered at R = 18.0 mag on Jan 30, faded by 1.5 mag in 5 hours, 4 mag in 2 days, 8 mag in 2 weeks. Quiescent counterpart with R = 26.0 mag, blue color.




SBC+, 2013

# PTF11AGG: ORPHAN AFTERGLOW?




SBC+, 2013

- Long-lived, scintillating radio counterpart ⇒ angular size ~ 20 mas at Δt ~ 40 d
- At cosmological distances, requires (modestly) relativistic ejecta ($\Gamma > 1.5$)
- No obvious high-energy counterpart
- Does not appear consistent with off-axis models
- Perhaps a more common class of relativistic outbursts lacking high-energy emission?

# The Rate of Fast Optical Transients

## BAYESIAN RATE ESTIMATION SCHEME

$$p(R|n, \mathrm{s}) = \frac{P(n|R, \mathrm{s})}{P(n|\mathrm{s})}\, p(R|\mathrm{s})$$

$$\text{POSTERIOR} = \frac{\text{LIKELIHOOD} \times \text{PRIOR}}{\text{EVIDENCE}}$$

### Likelihood function

Approximate as a Poisson counting experiment

$$\begin{aligned}\mathcal{L}(R) &= P(n|R, \mathrm{s}) \\ &= \frac{(T_{\mathrm{eff}} R)}{n!} \exp\left(-T_{\mathrm{eff}} R\right)\end{aligned}$$

Starting with a flat prior,

$$\frac{p(R|\mathrm{s})}{P(n|\mathrm{s})} = T_{\mathrm{eff}}$$

| | |
|---|---|
| $n$ | Total number of fast transients detected |
| $\mathrm{s}$ | Specs of several wide-field surveys |
| $R$ | Yearly rate of detectable transients |

### Effective timescale

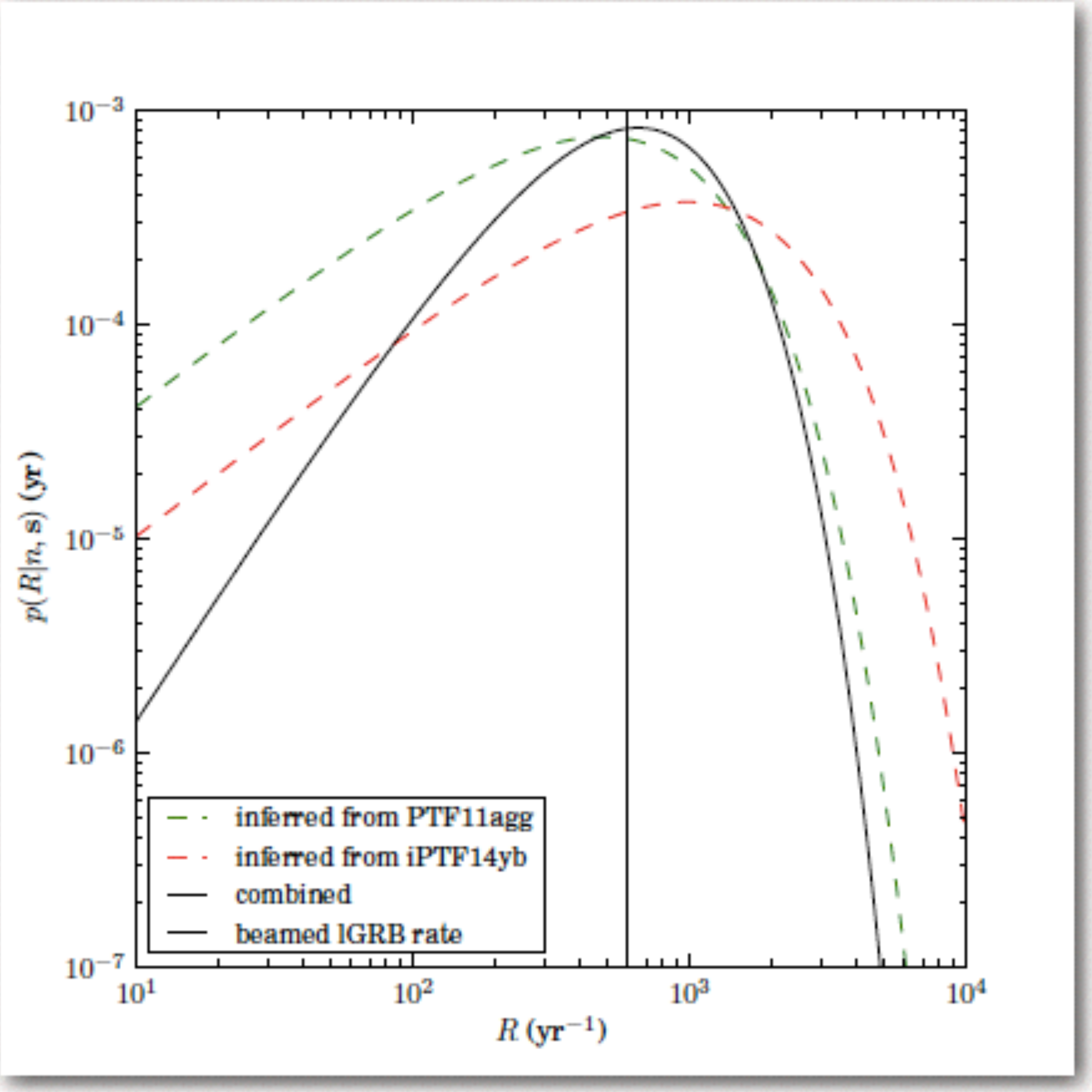
$$T_{\mathrm{eff}} = \sum_{i=1}^{N} T_i$$

Sum over total searched time from *N* surveys

$$T_i = \frac{\Omega_i}{4\pi} \times$$ Total amount of time covered by 2+ images of the same field in 1 night

$\Omega_i$ Survey field of view

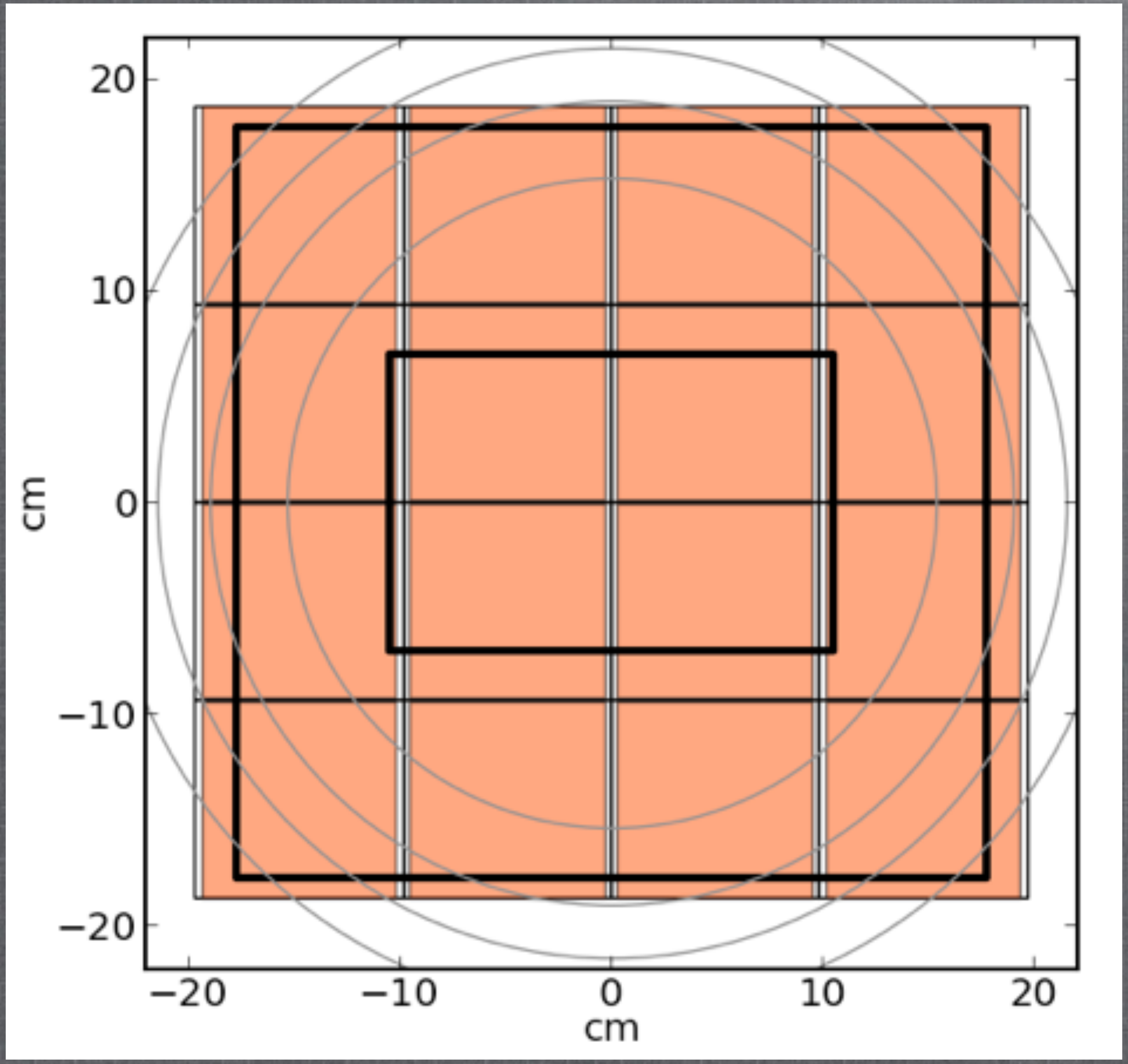
# The Rate of Fast Optical Transients




INFERRED RATES COMPARABLE TO CLASSICAL LONG GRBS!

# FUTURE II: ZTF

## Zwicky Transient Facility (ZTF)




- New camera populating entire focal plane of P48, ~ 45 $deg^2$ (i.e., a factor of 6 larger area than current camera)
- With faster readout and shorter (30 s) exposures, survey volume increases by ~ 14x
- Expected Discoveries:
  - 1 young (< 24 hr) SN per night
  - 5 orphan afterglows per year
  - 20 11agg-like events per year
  - > 250 pointings of all Northern sky