iPTF + FERMI: “BUY FOR A DOLLAR, SELL FOR TWO”

Gamma-Ray Bursts
Supernovae
Blazars
Pulsars
X-ray Binaries
NEW WIDE-FIELD CAPABILITIES

The Palomar Transient Factory (PTF), et al.

- Palomar 48 inch Schmidt telescope + CFHT12k ⇒ 7.2 deg² field-of-view

- Supernova search (2-3 day cadence) + more regular monitoring of nearby galaxies

- Automated discovery + multi-color photometry (P60)

- Large spectroscopic follow-up programs (Keck, Gemini, P200, Lick, etc.)

Over 2100 spectroscopically confirmed supernovae to date
PALOMAR TRANSIENT FACTORY

Wide-Field Discovery + Automated Multi-Color Follow-Up

Summit of Palomar Mountain

P48 = Discovery

P200+Keck+Lick+Gemini = Spectroscopy

P60+PAIRITEL = Filtered Photometry

Factory = Fully automated, end-to-end discovery + follow-up
JOINT iPTF+FERMI INVESTIGATIONS

- GBM Afterglow Discovery
- Unidentified LAT Source identification (short-period pulsars)
- “New Relativistic Explosions”
GBM+PTF MOTIVATIONS

Swift BAT, 2004–2009, 476 GRBs

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

Fermi GBM, 2008–2010, 491 GRBs


Predicted electromagnetic signatures are faint, rapidly fading, and these sources will be very poorly localized.
GBM+PTF LOGISTICS

• Receive Human-in-the-loop (HITL) localizations (time delay ~ 1 hour)

• Scaled confidence intervals (now use refined localization contours)

• Limited to 10 fields (71 deg), ~ 1-2 triggers per month

• Focus on bright events (fluence, peak count rate) and short-hard GRBs

• Run through full iPTF machinery
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

(April exactly) one year after IPN GRB:
Discovery & redshift of a GBM GRB in 71 deg²

http://dx.doi.org/10.1088/2041-8205/776/2/L34
GBM+PTF SUCCESSES

GRB 130702A’s supernova: comparison with SN 2006aj (Ic)
GBM+PTF SUCCESSES

Amati et al. (2013, GCN Circ. 15025)
GBM+PTF SUCCESSES

GRB 131011A (Fermi trigger 403206457)

$z = 1.874$; limited broadband follow-up
GBM FOLLOW-UP STATUS

• ~ 12 GBM bursts followed-up to date (but only covered fraction of error circle for each, some later than others)

• 2 SHBs followed up (same night!) - no afterglows to ~ 20 mag at t ~ 7 hr. This is not really constraining, need to think about strategy

• Helping to consume and develop prompt localization contours (including systematic uncertainty)
UNIDENTIFIED LAT SOURCES

The Fermi LAT 1FGL Source Catalog

Credit: Fermi Large Area Telescope Collaboration
UNIDENTIFIED LAT SOURCES

Searching for short (<= few hours) period optical counterparts to find more candidate BW/redback pulsars
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.
PTF11AGG: ORPHAN AFTERGLOW?

- Long-lived, scintillating radio counterpart $\Rightarrow$ angular size $\sim 20$ mas at $\Delta t \sim 40$ d

- At cosmological distances, requires (modestly) relativistic ejecta ($\Gamma > 1.5$)

- No obvious high-energy counterpart, but not particularly constraining

- Likelihood of chance (on-axis) GRB detection by PTF is modest ($\sim$ few percent)

- Either very lucky or more common class of relativistic outbursts

SBC+, 2013
"UNTRIGGERED" GRB?

\[ \text{Swift/BAT: } 2 \text{ sr FOV, } f > 6 \times 10^{-9} \text{ erg cm}^2 \]

\[ \text{Fermi/GBM: } 8 \text{ sr FOV, } f > 4 \times 10^{-8} \text{ erg cm}^2 \]

\[ \text{Inter-Planetary Network: all-sky, } f > 6 \times 10^{-7} \text{ erg cm}^2 \]

\[ \sim 40\% \text{ of non-detection by both } \text{Swift} \text{ and } \text{Fermi} \text{ for events with fluence below IPN sensitivity} \]
FUTURE I: 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
FUTURE II: BROADER VIEW

**FIG. 3.** Cumulative distribution of number of pointings necessary to tile localization arcs at all sky positions by LIGO-H and LIGO-L. Color represents telescope diameter: 0.5m-class (green), 1m-class (red), 4m-class (purple) and 8m-class (blue). Line style represents camera angle: few tens of deg$^2$ (solid), several deg$^2$ (dashed) and few deg$^2$ (dotted).

**TABLE 1**

<table>
<thead>
<tr>
<th>Facility</th>
<th>Aperture (m)</th>
<th>Field-of-View (deg$^2$)</th>
<th>Exposure (sec)</th>
<th>Overhead (sec)</th>
<th>Sensitivity (5σ, i-mag)</th>
<th>Detectable Fraction (-16; -14; -12 mag)</th>
<th>Lag (hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Palomar: Zwicky Transient Facility (ZTF)$^a$</td>
<td>1.2</td>
<td>47</td>
<td>600</td>
<td>15</td>
<td>22.2</td>
<td>0.94; 0.35; 0.06</td>
<td>1 ± 2</td>
</tr>
<tr>
<td>BlackGEM-4 (BG4)$^b$</td>
<td>4×0.6</td>
<td>4×2</td>
<td>600</td>
<td>15</td>
<td>22.2</td>
<td>0.65; 0.12; 0.06</td>
<td>12 ± 2</td>
</tr>
<tr>
<td>Pan-STARRS1 (PS1)$^c$</td>
<td>1.8</td>
<td>7.0</td>
<td>180</td>
<td>10</td>
<td>21.9</td>
<td>0.76; 0.18; 0.06</td>
<td>3 ± 2</td>
</tr>
<tr>
<td>ATLAS$^d$</td>
<td>0.5</td>
<td>30</td>
<td>600</td>
<td>5</td>
<td>21.0</td>
<td>0.53; 0.06; 0.06</td>
<td>3 ± 2</td>
</tr>
<tr>
<td>CTIO: Dark Energy Camera (DECAM)$^e$</td>
<td>4.0</td>
<td>30</td>
<td>10</td>
<td>30</td>
<td>22.8</td>
<td>0.53; 0.47; 0.12</td>
<td>12 ± 2</td>
</tr>
<tr>
<td>Subaru: HyperSuprimeCam (HSC)$^f$</td>
<td>8.2</td>
<td>1.77</td>
<td>1</td>
<td>20</td>
<td>22.4</td>
<td>0.47; 0.47; 0.18</td>
<td>3 ± 2</td>
</tr>
<tr>
<td>Large Synoptic Survey Telescope (LSST)$^g$</td>
<td>8.4</td>
<td>9.6</td>
<td>1</td>
<td>2</td>
<td>22.4</td>
<td>1.00; 1.00; 0.65</td>
<td>12 ± 2</td>
</tr>
</tbody>
</table>