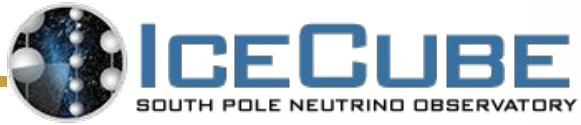
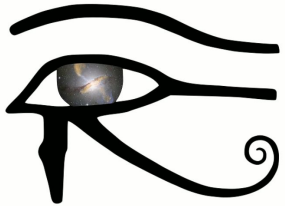
Realtime Gamma Ray - Neutrino Coincident Analyses with AMON

Jimmy DeLaunay
AMON Team
IceCube Collaboration





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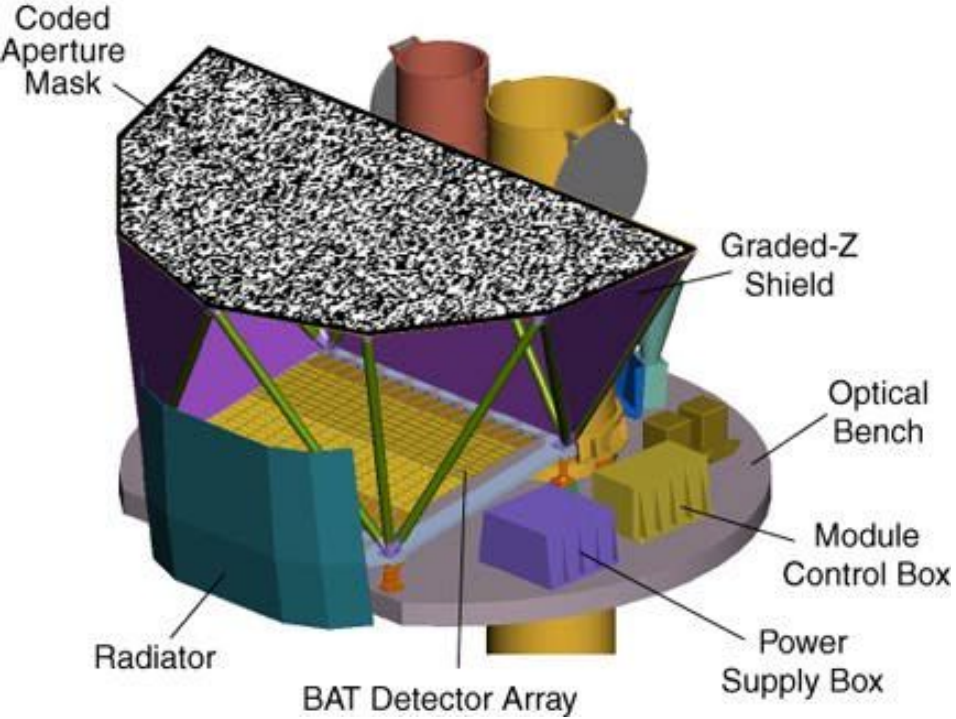
- AMON has been in realtime operations for over a year
  - Provided pass-through alerts of high-energy IceCube events to followup community
- Working on starting streams of γ - ν coincident alerts
  - Goal is to find statistically interesting candidates for followup
- This talk; proposed search with subthreshold Swift BAT and IceCube events
  - Alerts will have
    - ~4 arcminute localizations
    - Reliable and Tunable FARs (False Alarm Rates)
    - Latency of a few hours

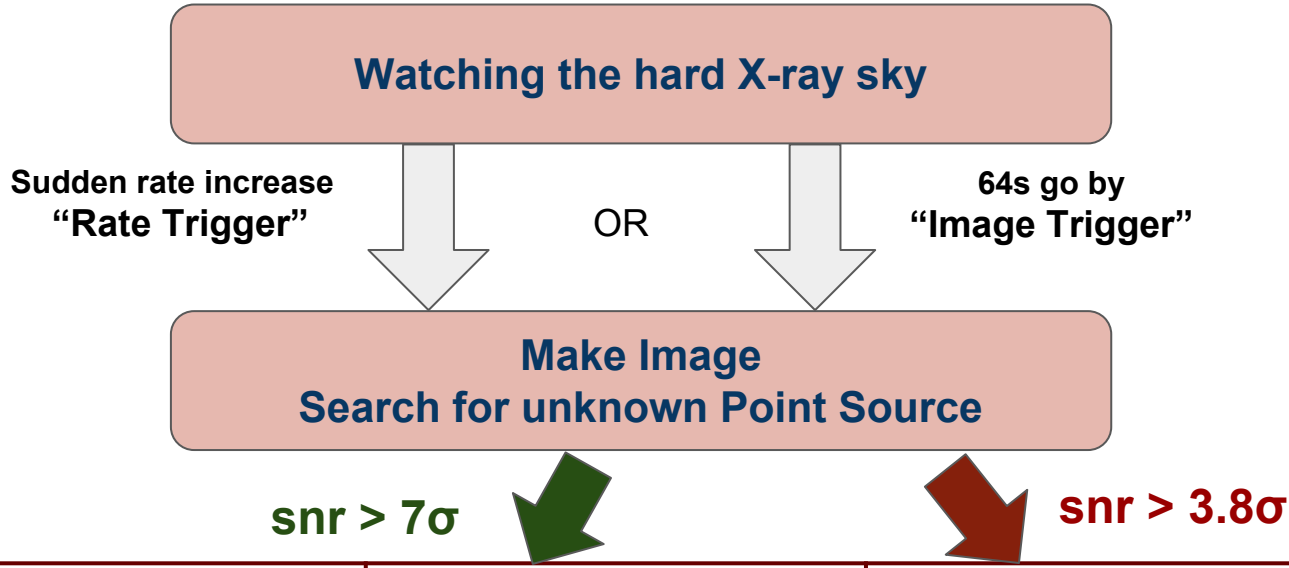
Swift's Burst Alert Telescope (BAT)



http://swift.gsfc.nasa.gov/about_swift/bat_desc.html

- Found > 1000 GRBs!
- Archival data back to 2004
- FOV ~ 15% of sky
- Uptime ~ 80%
- 15-150 keV coded imaging
  - Up to ~500 keV count rates
- Localizes GRBs to < 3 arcmin
  - Done onboard in seconds

Swift Mission Operations Center located at Penn State

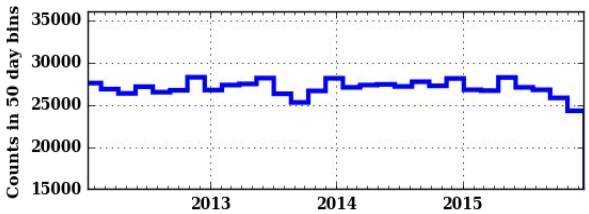
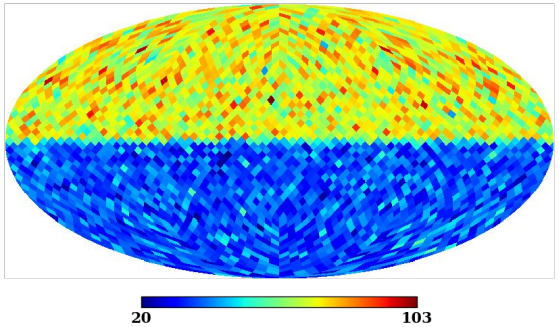


Trigger Type	Above-Threshold	Sub-Threshold
Rate	~100 per year	~500/day (~10^5/year)
GCN Latency	seconds	1 - 8 hours
False Detections*	~10% are noise/errors	~99.7% are noise
90% containment	1 - 3 arcmin	4 arcmin

*Info from https://gcn.gsfc.nasa.gov/gcn/swift.html

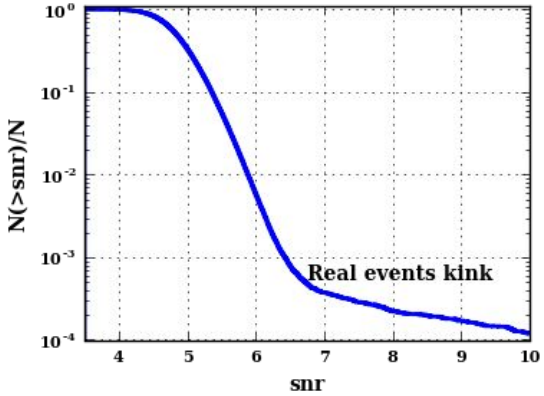
	BAT	IceCube

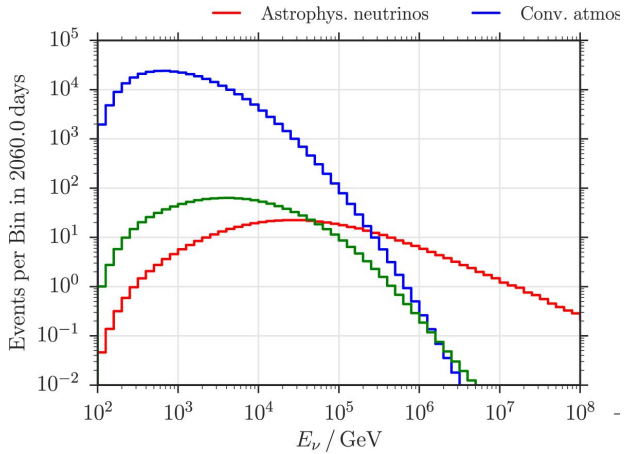
Realtime Data	Subthreshold triggers received through GCN	- Events that pass IceCube's Gamma Ray Followup (GFU) filter
		  - Used in IceCube's realtime clustering analyses*
		- Selects muon tracks that are,
		  - Likely to be of an astro. ν origin
		  - Well reconstructed
		- New and improved GFU filter launching nowish

Data used in this talk	4 years of archival subthreshold triggers 	Fake arrival time and directions Made to match old GFU filters up and down going rates 

*Info about IceCube's realtime system and filters can be found at https://arxiv.org/abs/1612.06028 (IceCube Collaboration, 2016)

	BAT	IceCube
Signal	New γ-ray or x-ray transients	High energy ν's of astro. origin
Background	Detector Noise Fluctuations - Rate changes across detector	Up-going: Atm. ν's, Mis-reconstructed atm. muons Down-going: Atm. muons, Atm. ν's
How signal-like	Signal to noise ratio	Work in progress Energy is best discriminator between atm. and astro. ν's





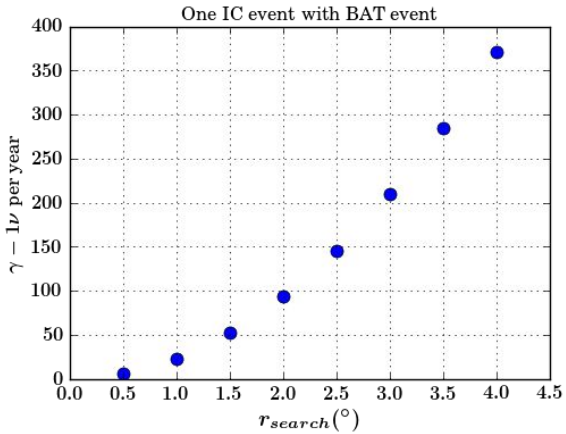
Expected number of **astro. ν's**, vs. **atm. ν's** In 6 years of muon tracks (IC Colab 2016)

DOI: 10.3847/0004-637X/833/1/3

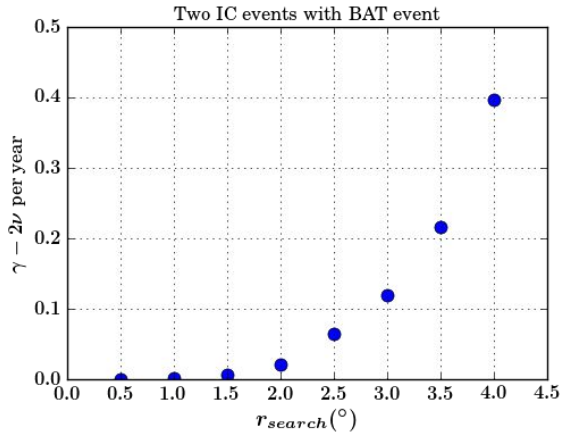
The Search Technique

For each BAT event, look for IceCube events within ΔT and r_{search}
- ΔT = BAT exposure + 200s
  - window goes 100s before and after exp.
  - Gives wiggles room for transient's actual duration
- 90% containment of GFU ν's ~ 3° (IC realtime paper)
  - Good estimate for r_{search}

To find False Alarm Rate, find how often IceCube events randomly fall near BAT events
- Take random year section of BAT data
- Generate year of fake IC events
- Find number of BAT events that have an IC event within ΔT and r_{search}
- Repeat 1000 times



γ - ν pairs happen often



2ν's coincident with a BAT event is very rare

Likelihood Analysis
Needed to cut down rate

Log Likelihood for γ-ν Pairs

3 major terms

$$\lambda = \lambda_{\nu,PSF} + \lambda_{\gamma} + \lambda_{\nu}$$

$$\lambda_{\nu,PSF}\left(\sigma_{\nu},\ d_{\gamma-\nu}\right) = \log\left(\frac{1}{2\pi\sigma^2}\exp\left(-\frac{d^2}{2\sigma^2}\right)\right)$$

- Log of ν's position probability density at the BAT position
  - For now just assume a Gaussian PSF, σ=1°
  - Actual PSF, work in progress

$$\lambda_{\gamma}\left(x_{\mathrm{det}},\ \Delta T,\ snr\right) = -\log\left(FPRD\left(x_{\mathrm{det}},\ snr\right)\cdot\Delta T\right)$$

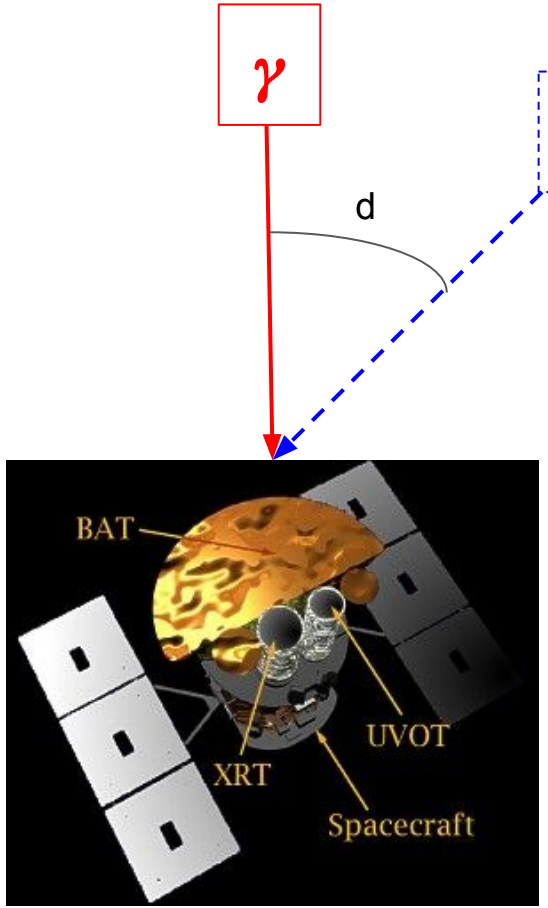
- Log of the expected number of BAT false positives per solid angle
  - With a greater than or equal snr
  - FPRD: False Positive Rate Density

$$\lambda_{\nu} = ?$$

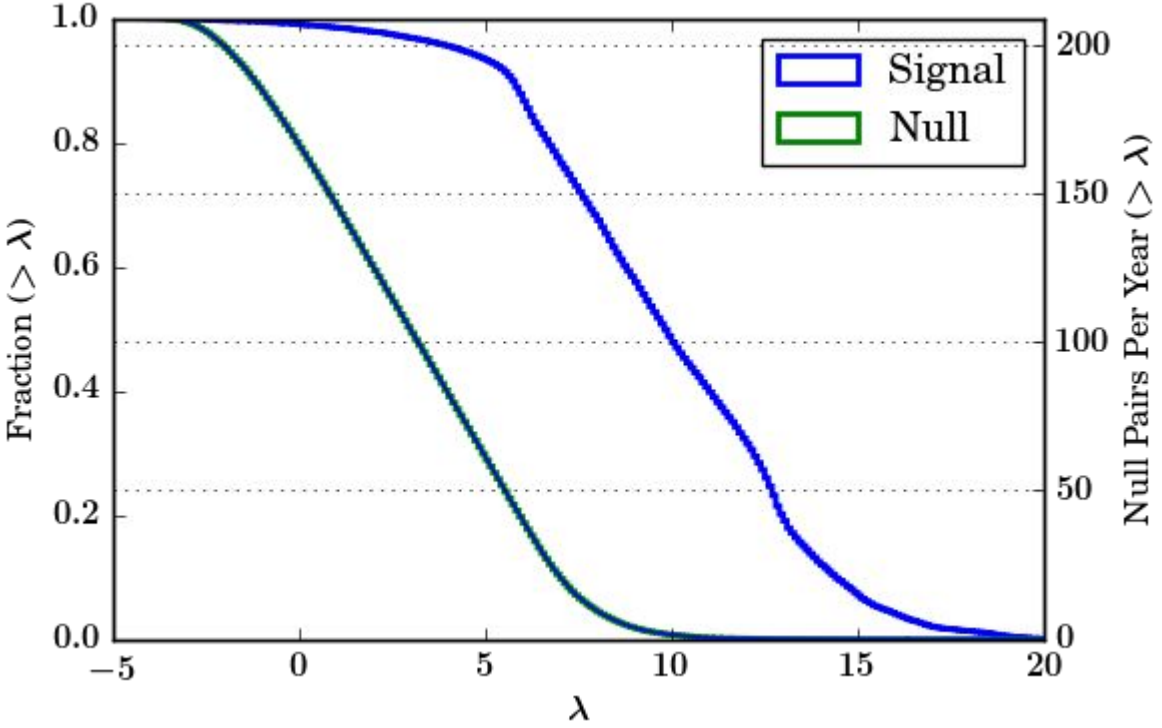
- Background term like λ_{γ}
- zenith dependent background rate
- Probability of being astro. ν, and not atm. ν or muon

Faking Some Signal Pairs

- Make a set of fake γ - ν pairs originating from random point source locations
  - Use these to make a “Signal” λ distribution
- Random incoming angle to BAT detector
- ν location placed d degrees away
  - Based off of overall GFU-sample PSF from MC
- BAT snr based off of toy model
  - Only keep subthreshold snr’s, 3.8 - 7
    - Distribution pretty much flat
  - 1s and 64s exposures



https://www.swift.psu.edu/



- Null = BAT data - Fake IC Pairs
- Signal = Fake Pairs
- Null gives the False Alarm Rates
- Signal distribution gives the Signal Efficiency
- **Signal Efficiency is still high at reasonable False Alarm Rates**

Followup observatories can choose what to observe based off of False Alarm Rates

Conclusions/Future

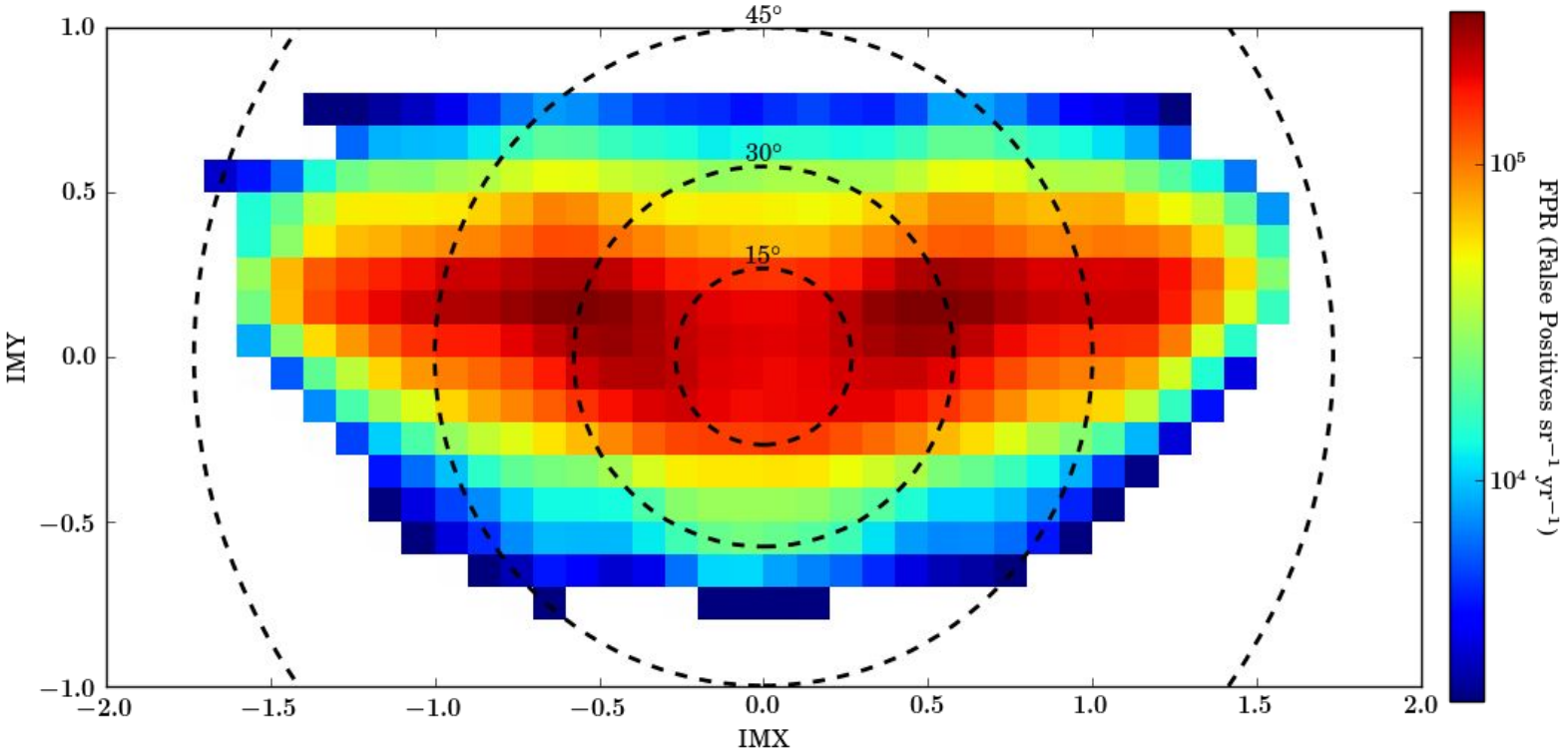
- This analyses can provide statistically interesting candidates for followup
  - Tunable False Alarm Rates
  - Latency of a few hours
  - A few arcminute localizations

- Likelihood analysis in its development stages can already discriminate well between null and signal populations
  - Need to add in IceCube's actual PSF and Signalness
  - Also need to run on real scrambled data

- AMON infrastructure all ready to go

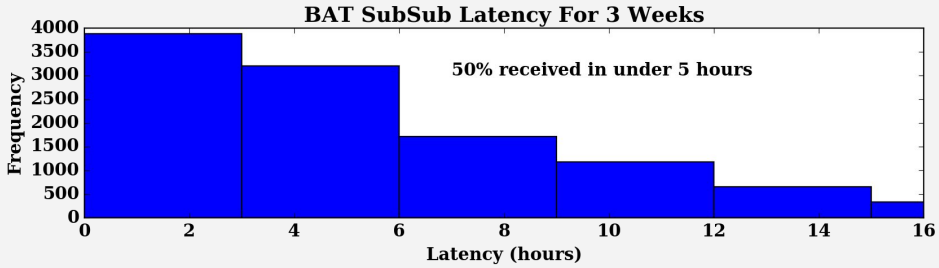
Backup Slides

PENNSTATE

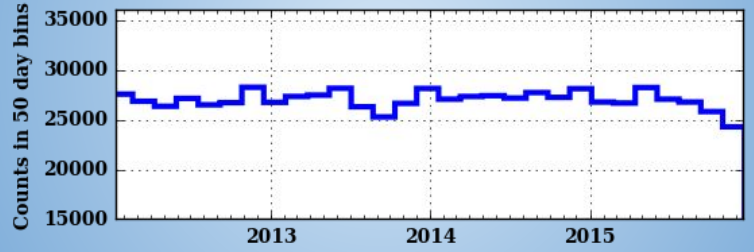

45°
30°
15°
1.0
0.5
0.0
−0.5
−1.0
IMY
−2.0
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5
2.0
IMX
10^5
10^4
FPR (False Positives sr^{-1} yr^{-1})

BAT Subthreshold Data

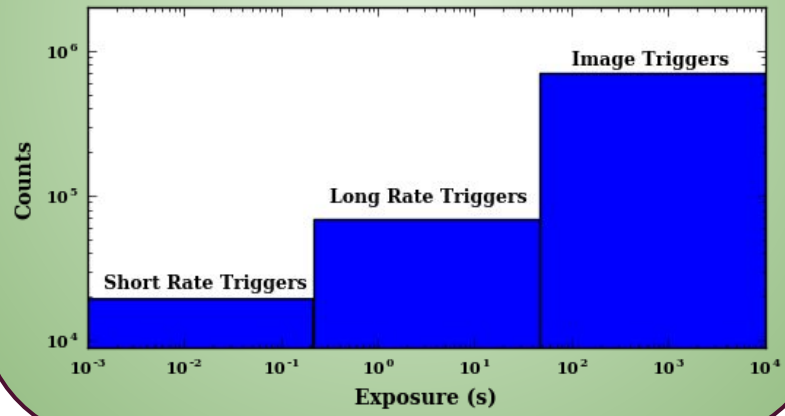
Sent over GCN with a median latency of 5 hours



All Subthreshold data is archived
Here I'll use 4 years of data from 2012 - 2015
788068 total events, very stable rate



- **Includes every source candidate found in an image with an snr > 3.8σ (from image or rate triggers)**
- **Exposures range from milliseconds to minutes**
  - **70% are 64s**
  - **12% are rate triggers**

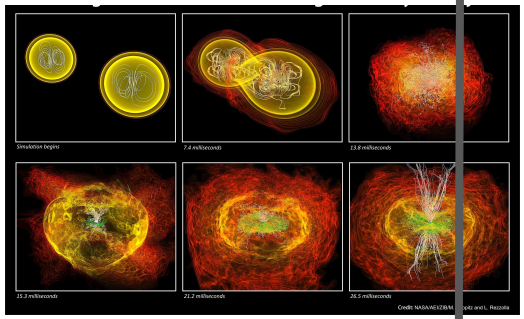


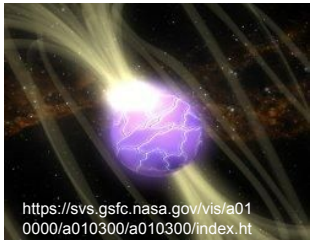
What Triggers BAT?

- Mostly GRBs, but some other stuff too
  - ~90% normal GRBs

Short Triggers

Short GRBs, $T_{90} < 2s$





SGRs, magnetar flares

- galactic

Long Triggers

Long GRBs

T_{90} ~ 2s - 10^3s

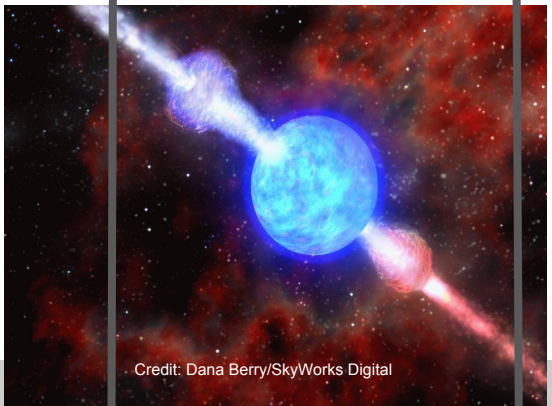
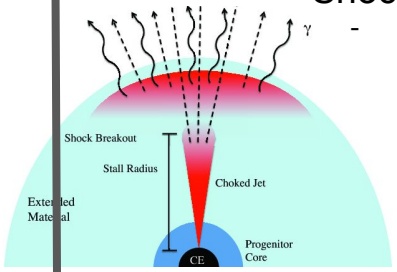


Image Triggers

Low-Luminosity GRB/
Shock Breakout GRB

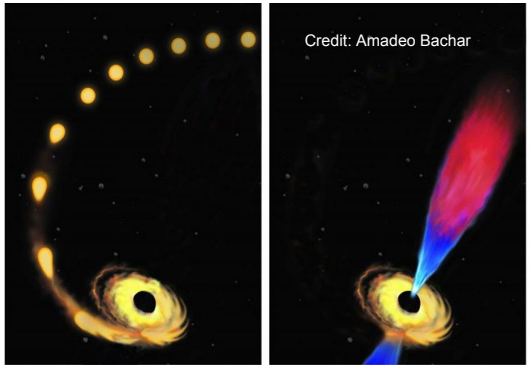
- GRB 060218, S. Campana et. al. 2006
  - $T_{90} > 10^3$ s
  - z = .033

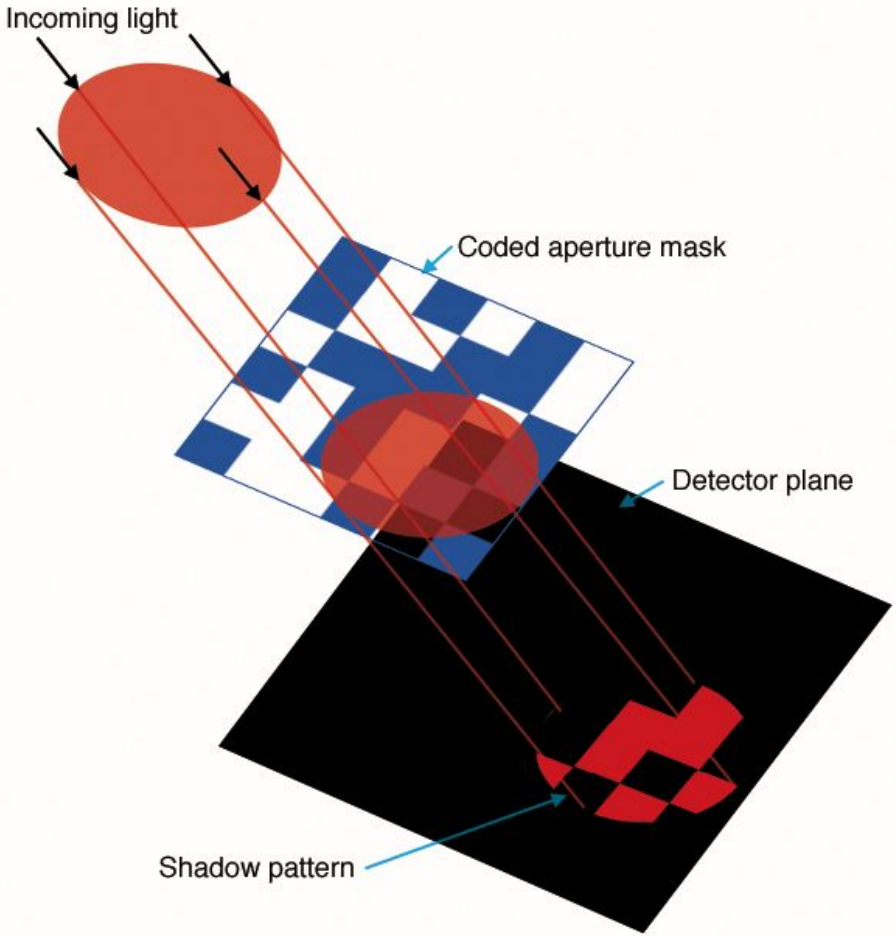


Senno et. al. 2016

Jetted Tidal Disruption Event

- Sw J1644+57, massive star ripped to shreds by SMBH
- D. N. Burrows et. al. 2011
  - T_{90} ~ days





https://imagine.gsfc.nasa.gov/Images/features/exhibit/coded_aperture.jpg