OBSERVATION OF GAMMA-RAY BURSTS AND SHORT DURATION TRANSIENTS WITH FERMI/LAT

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OUTLINE

- Introduction
- Present:
  - results on Gamma-Ray Bursts above 100 MeV
- Future:
  - New algorithm and the first 100 LAT GRBs
  - blind search
- Bonus:
  - the Multi-Mission Maximum Likelihood framework (3ML)

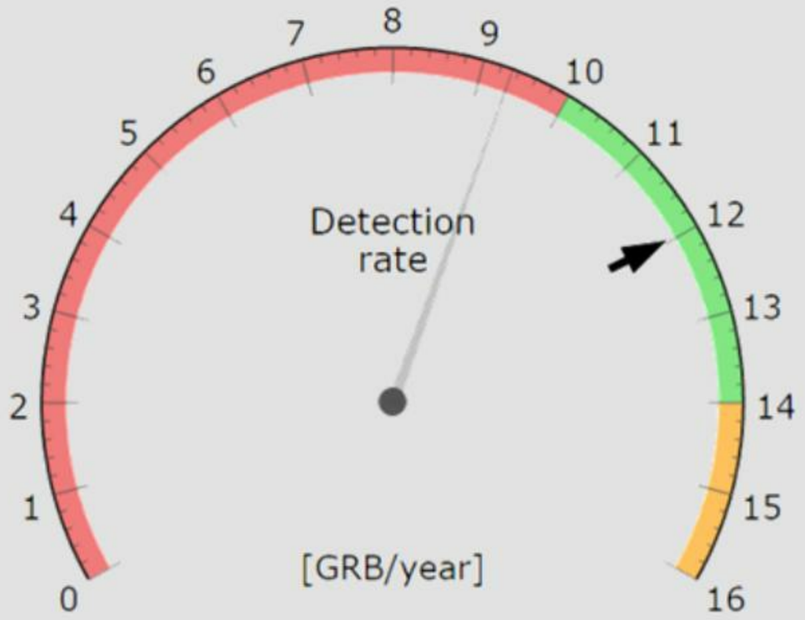
prezi:

https://prezi.com/xamnsnpptkcs/fermilat-observations-of-grbs/

MISSING GAMMA-RAY BURSTS?

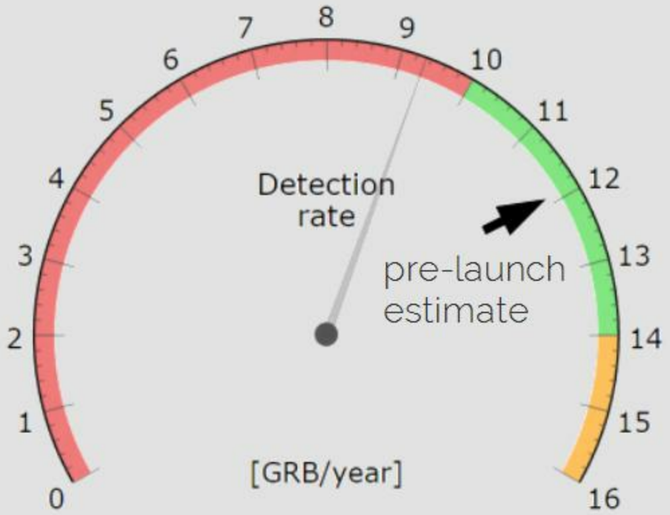
During the first 3 years we seemed to observe less GRBs than expected (~5% probability for 3 years).

Lower Lorentz factors (Guetta et al. 2010)? Spectral cutoffs? ...

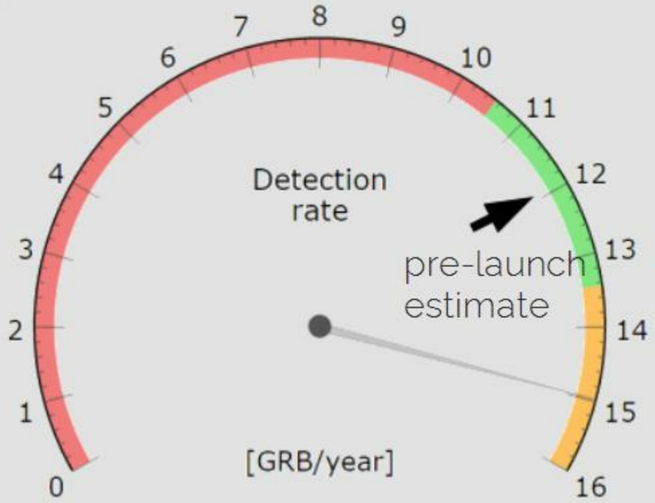


3 years:
predicted 36 [Band et al. 2009]
observed 28 [Ackerman et al., 2013]

New search algorithm



(Pass 6, old algorithm)

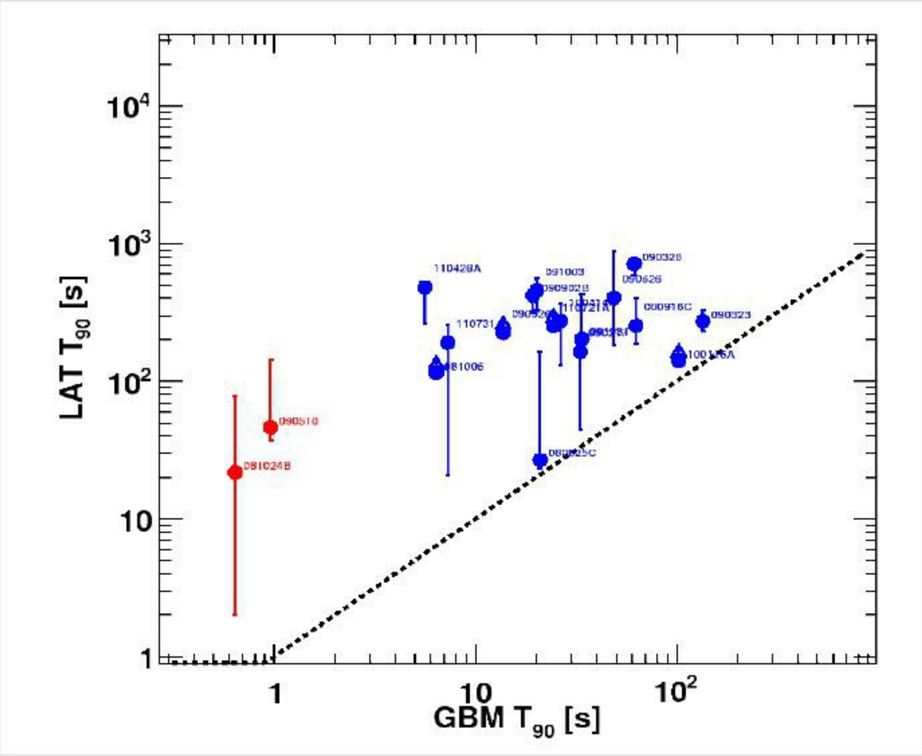


(Pass 8 + new algorithm)

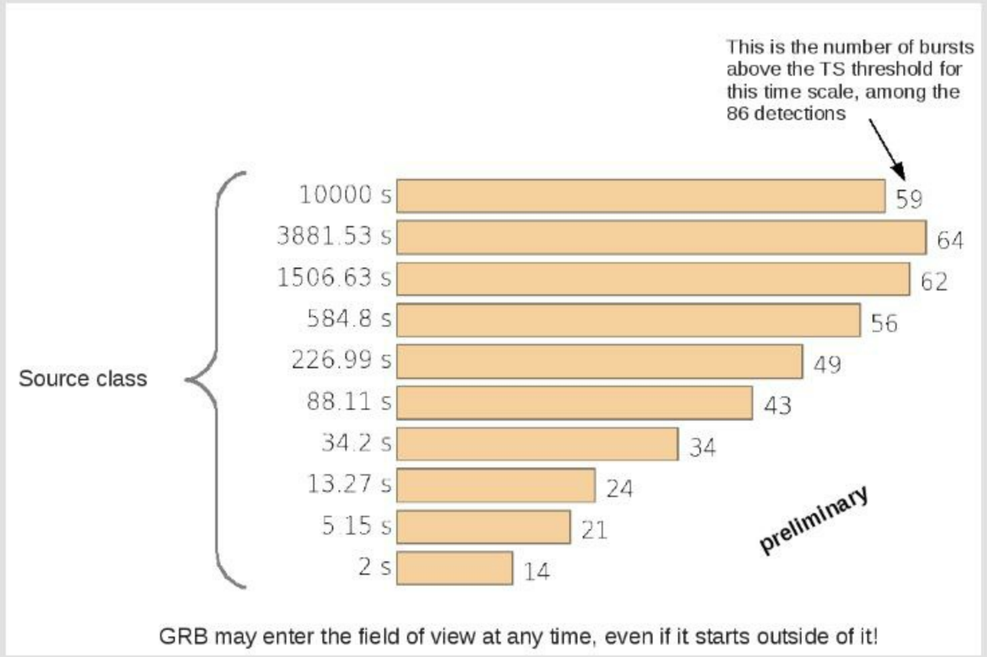
HOW ?

Capitalizing on the results of the first catalog, and
on our improved understanding of the detector

Lesson 1: LAT signal longer than prompt emission

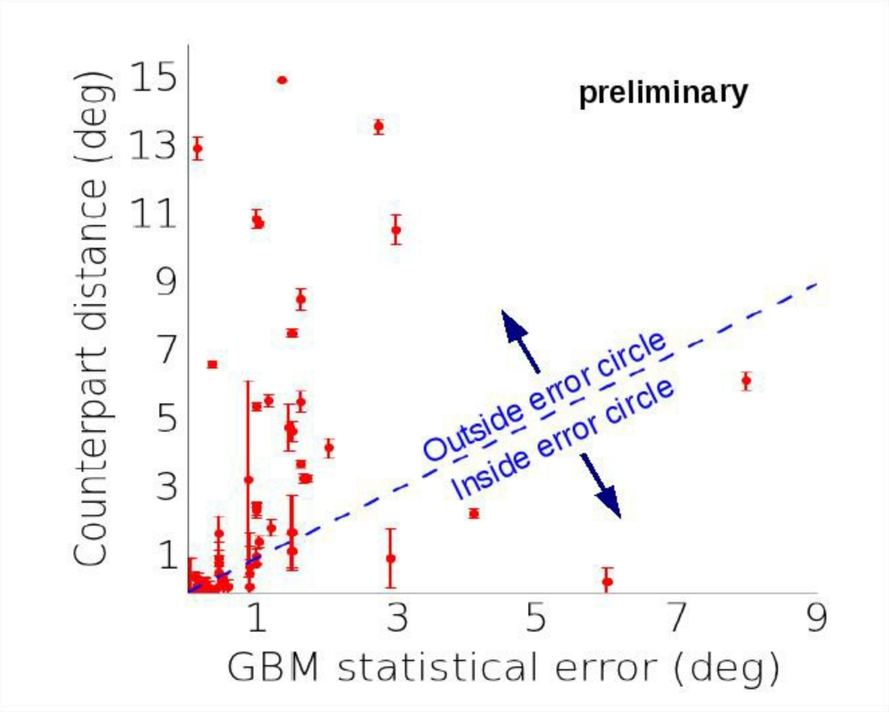


(first LAT GRB Catalog, Ackermann et al. 2013)

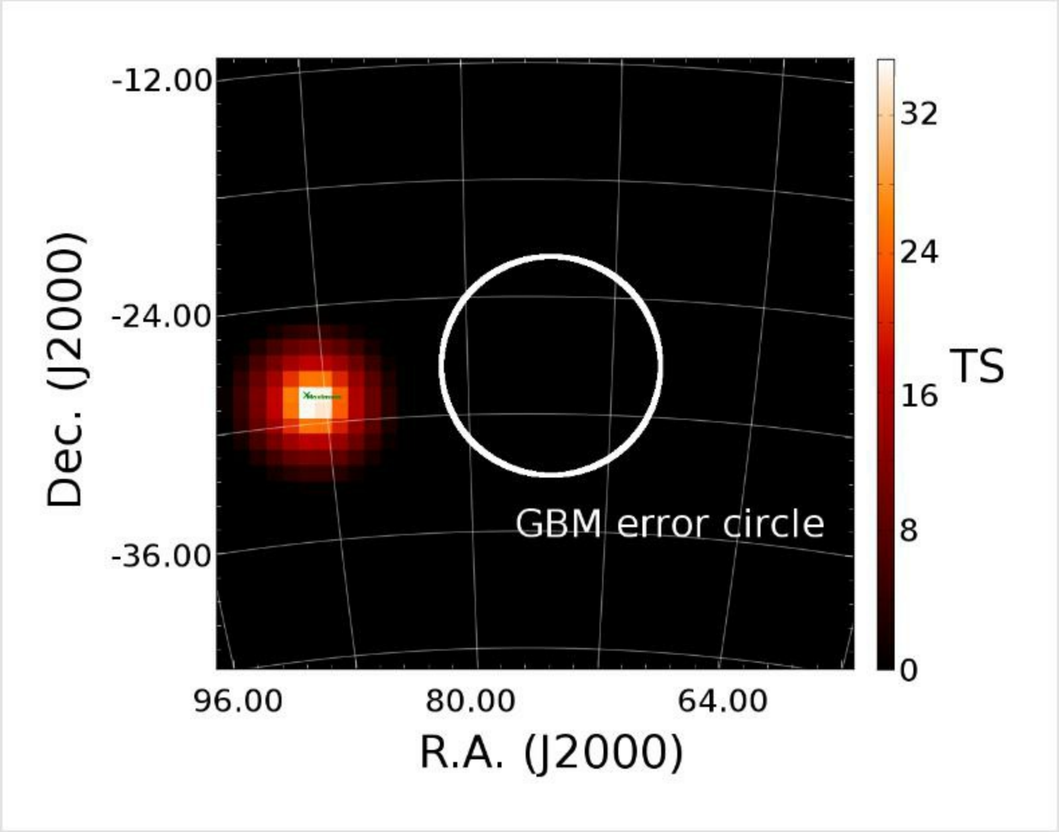


✔ Multiple time scales

Lesson 2: localization systematic error



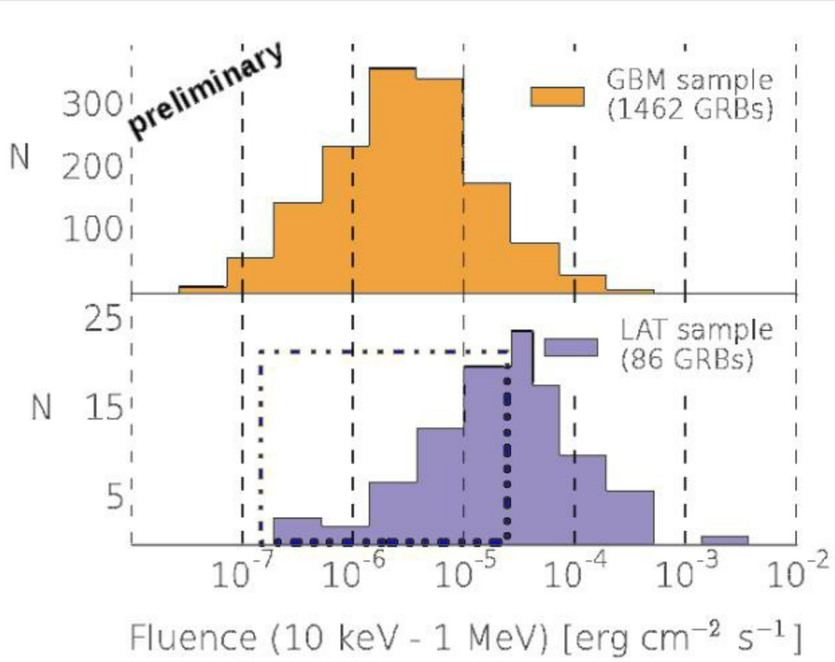
(Connaugthon et al. 2015)



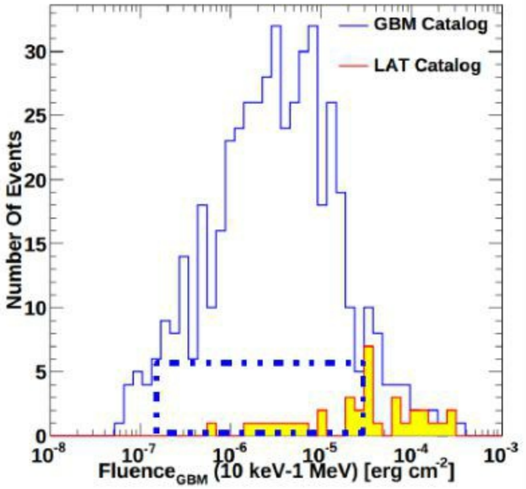
✔ TS map on large search region

Better sensitivity

More mid- and low-fluence GRBs



(this work)



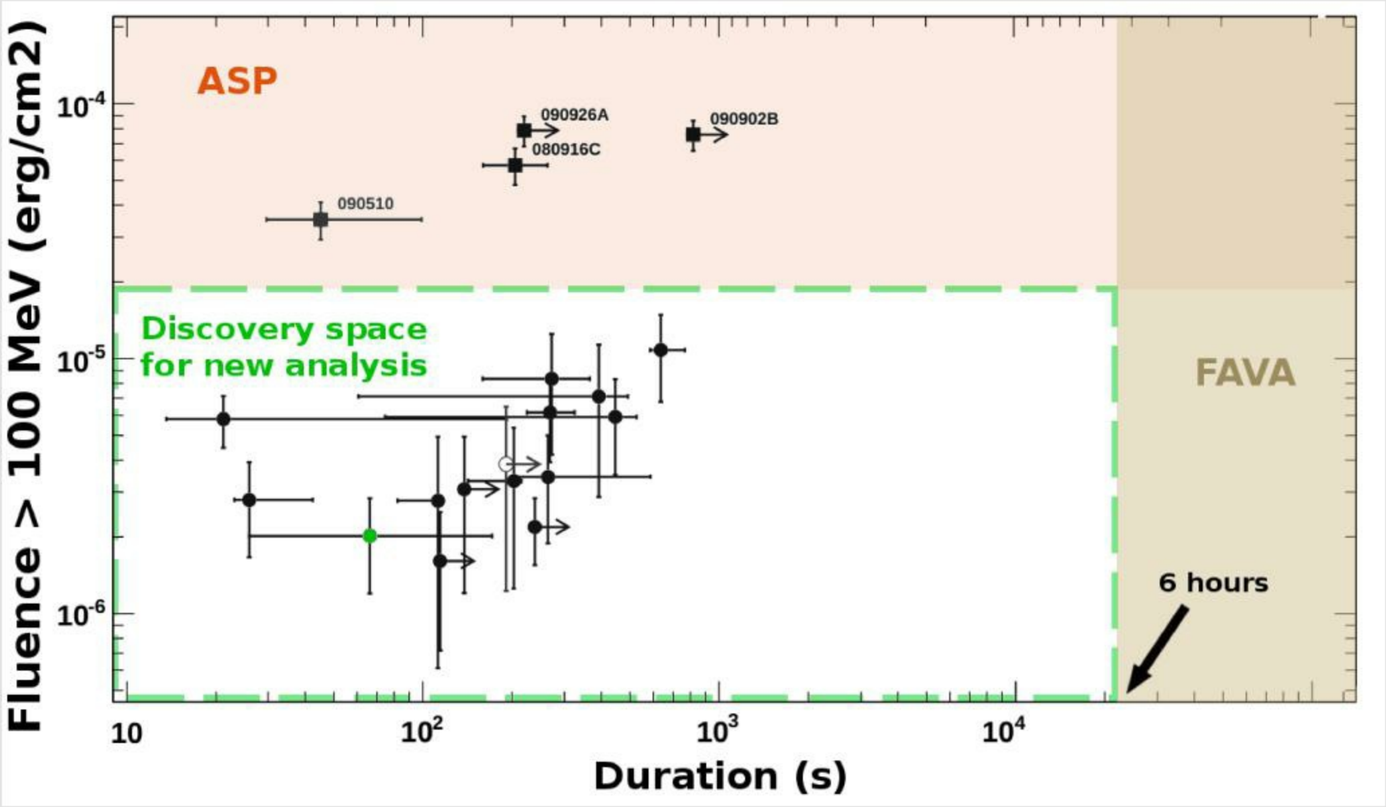
(Ackerman et al. 2013)

- The first catalog hinted for a class of super-energetic GRBs: is it real ?
- Is there a class of GRBs which do NOT emit at high energy?
    - The strange case of GRB 100724B
- Very high energy photons (> 10 GeV) seems to come late: is this effect real ? Is this evidence for IC emission ?
- ...

What can you do with > 100 GRBs

BLIND SEARCH

Look for transients in 6 years of data
(~1 billion photons/events!)

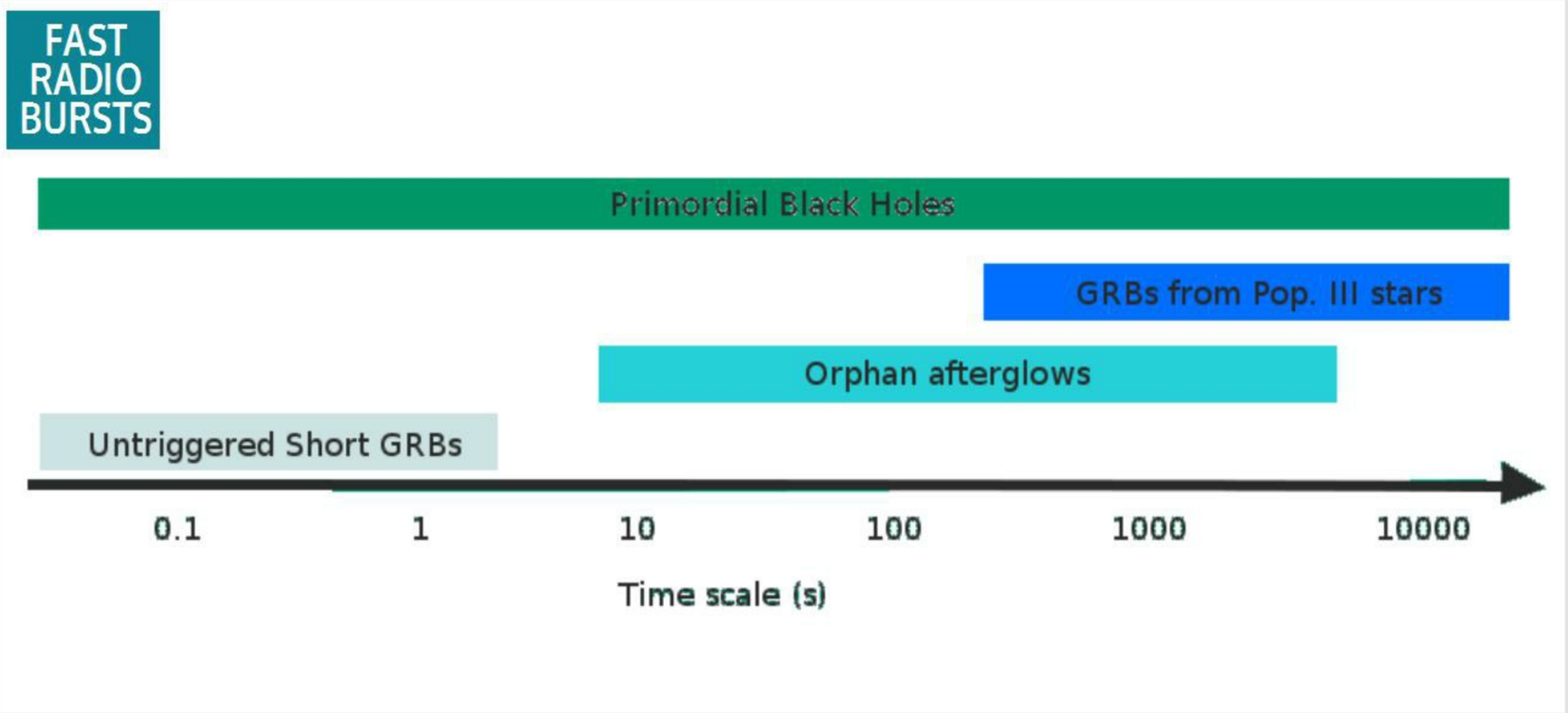


GRBs from the first GRB catalog

Room for discoveries

Can we do better for short duration and not-very-bright transients?

IS THERE ANYBODY IN THERE?



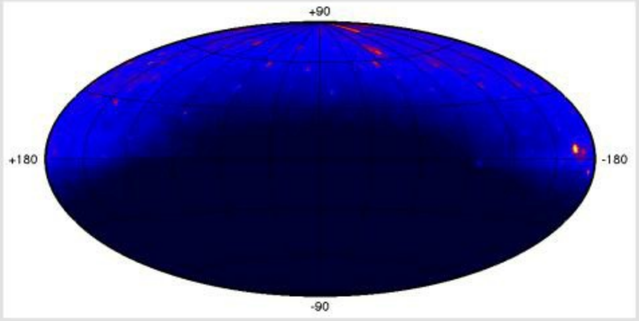
LTF BLIND SEARCH

+ Scale-agnostic search

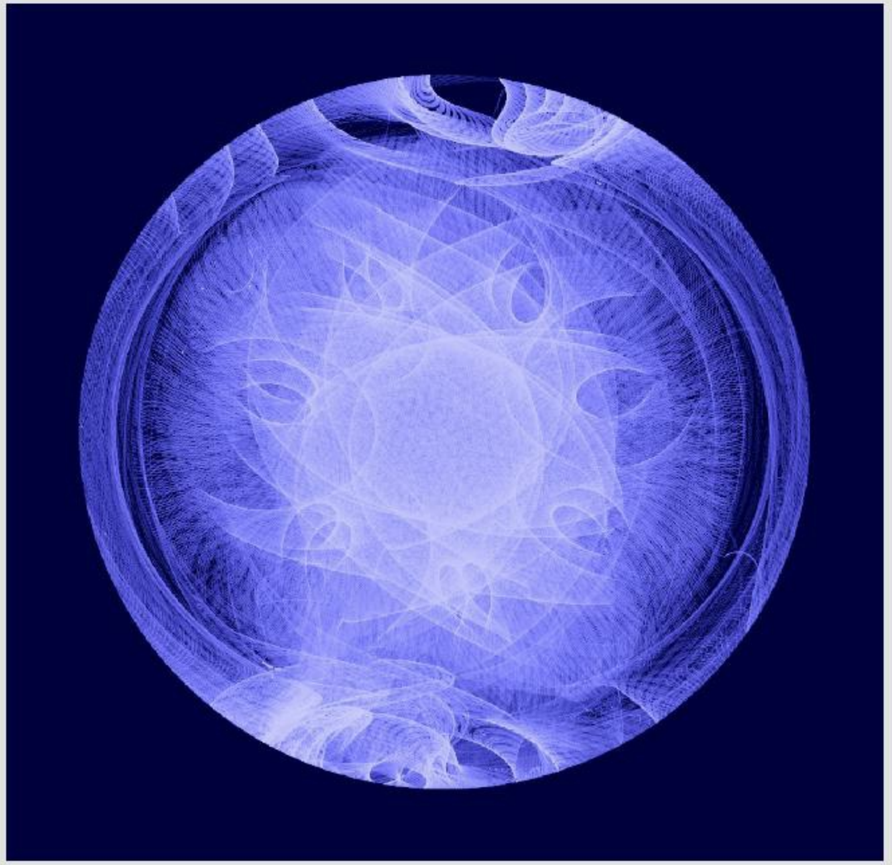
+ Exploit our knowledge about the gamma-ray sky

Survey mode

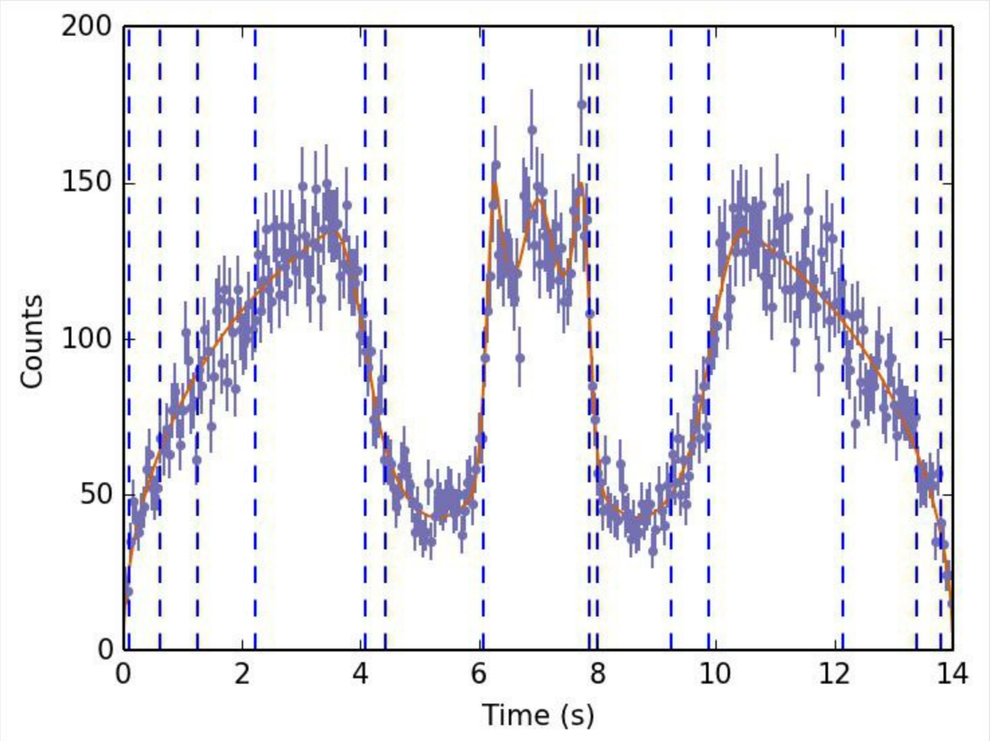
- Field of view is ~1/3 of the sky
- Full sky coverage every ~3.2 h
- Orbit precesses with a ~53.4 d period
- Effective area varies with the off-axis angle



Exposure over ~3.5 hours, map in Galactic coordinates



Path of the Vela pulsar in instrumental coordinates over 2 y of observations

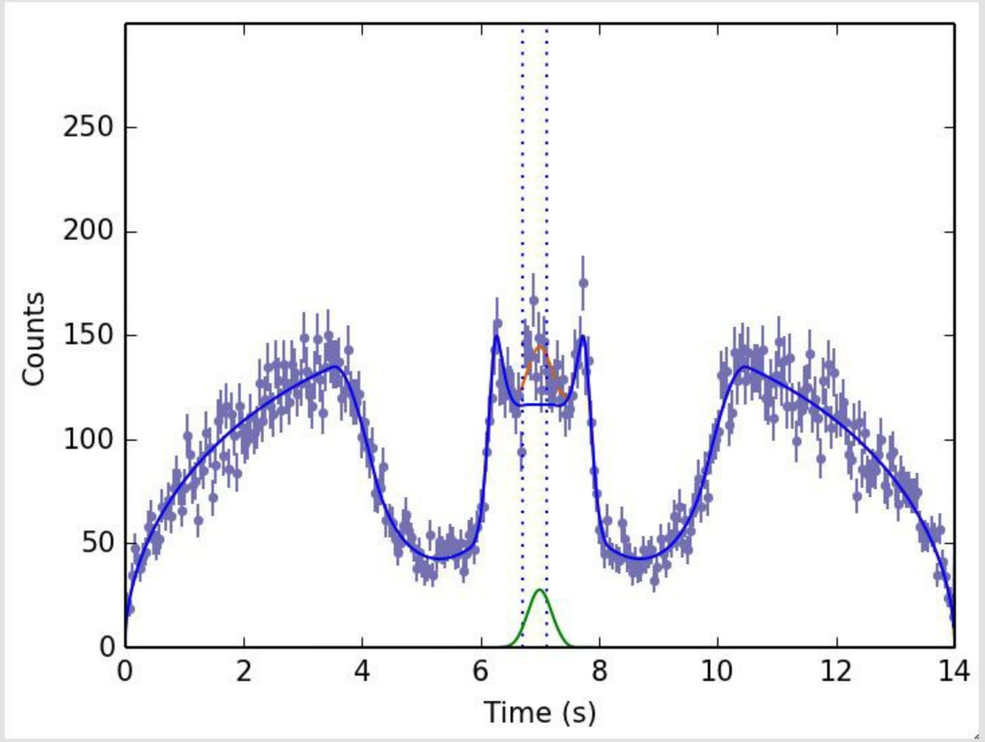


STANDARD BB DOES NOT WORK FOR US

- BB works in the counts space (Poisson statistic)
- Even if the source flux is constant, the count rate changes following the effective area variation as the source moves in the F.O.V.

Transient above the Batman curve

(http://mathworld.wolfram.com/BatmanCurve.html)



MODIFIED BB

+ Need to know the background distribution as function of time

+ Search for changes with respect to the background

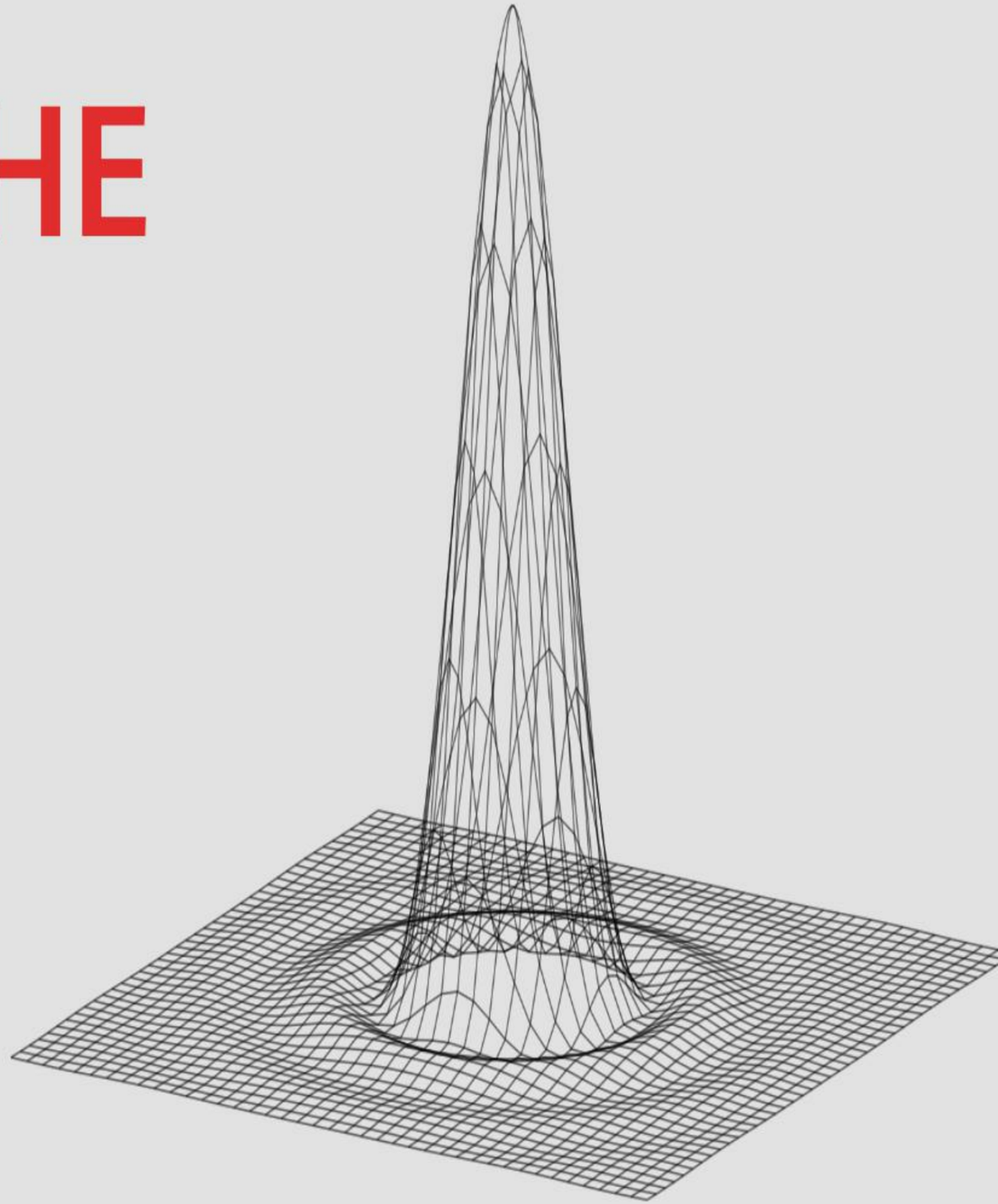
+ Automatically account also for data gaps (BTI) and variations in livetime

Transient above the Batman curve

(http://mathworld.wolfram.com/BatmanCurve.html)

WHAT ABOUT THE SPATIAL DIMENSION?

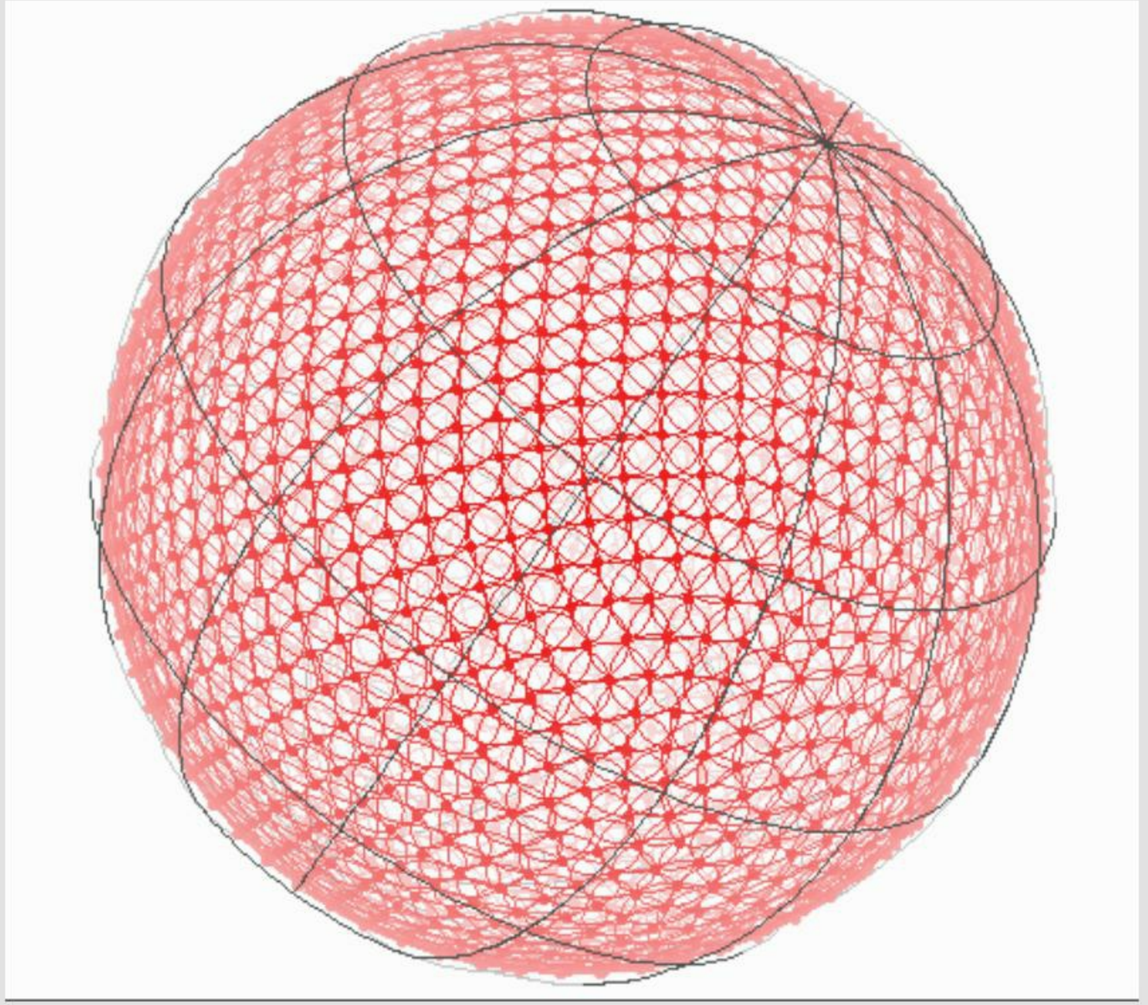
BB is a time-domain algorithm, while we require a transient to be a point source, not just any excess



DIVIDE ET IMPERA

+ Dividing in many small regions, excesses within regions are clustered by construction.

+ Each region is independent -> Massive parallelization

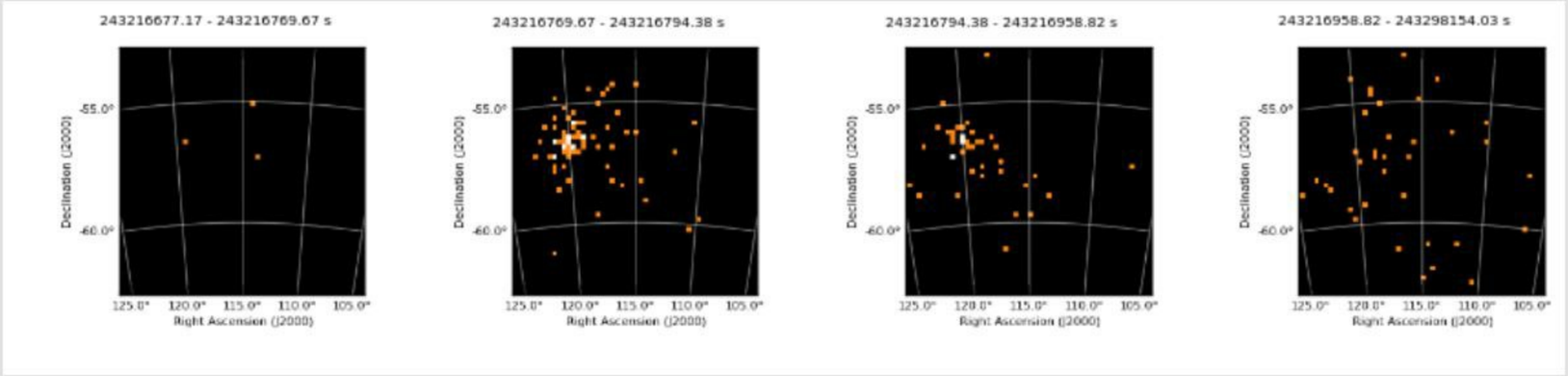


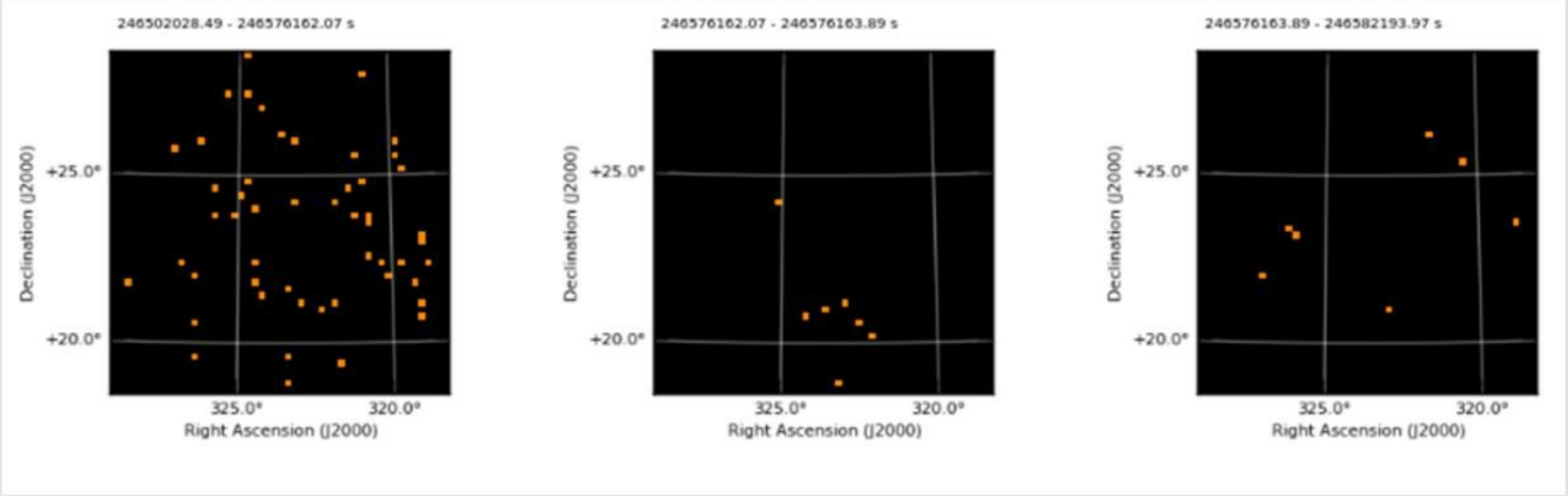
1712 overlapping circular region with a ~5 deg radius

(hitting unsolved mathematical problem...)

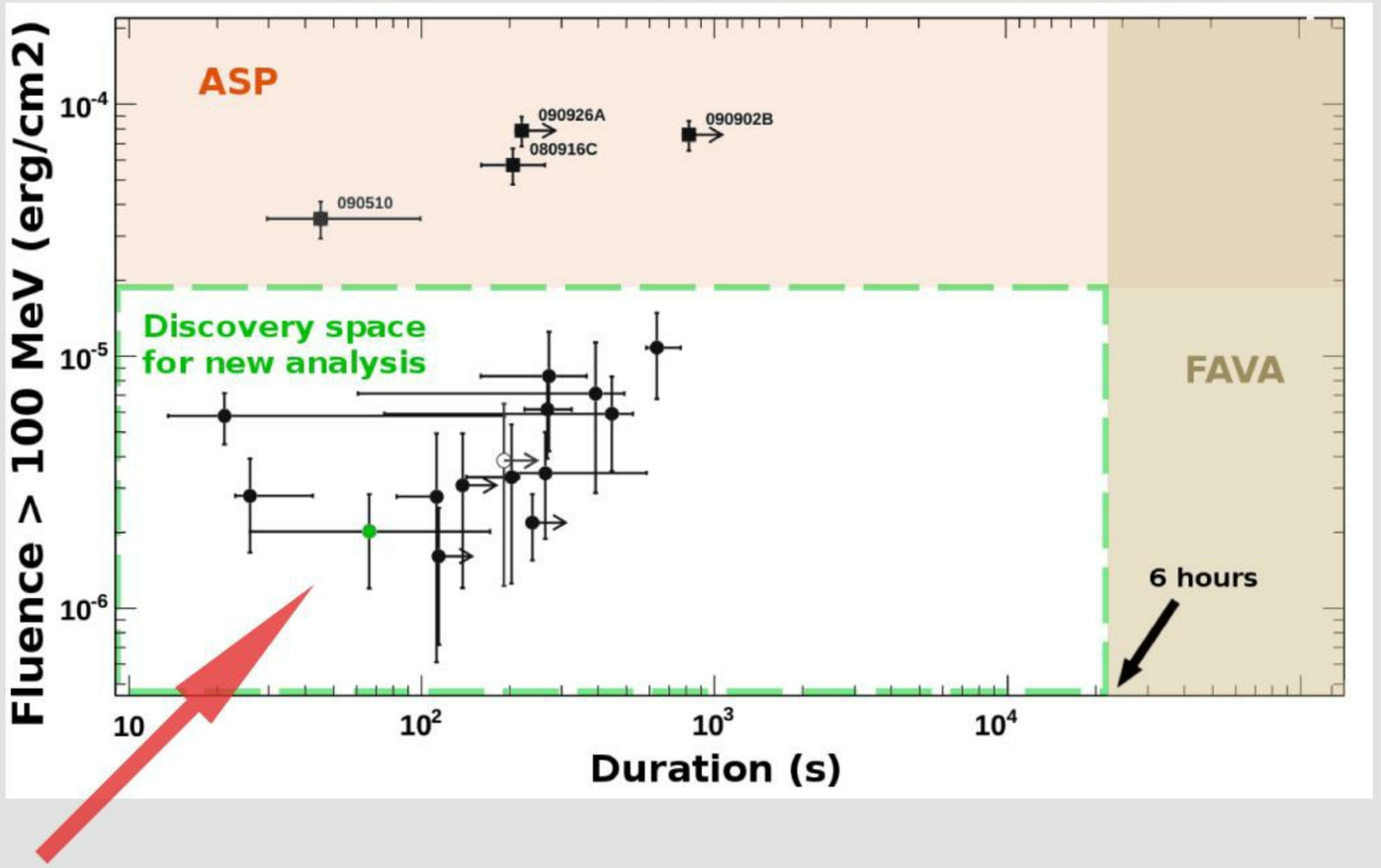
FIRST LIGHT

Two days with two known GRBs (a bright long one, and a faint short one not found by other algorithms)





Truly sampling a new discovery space



BOTTOM LINE

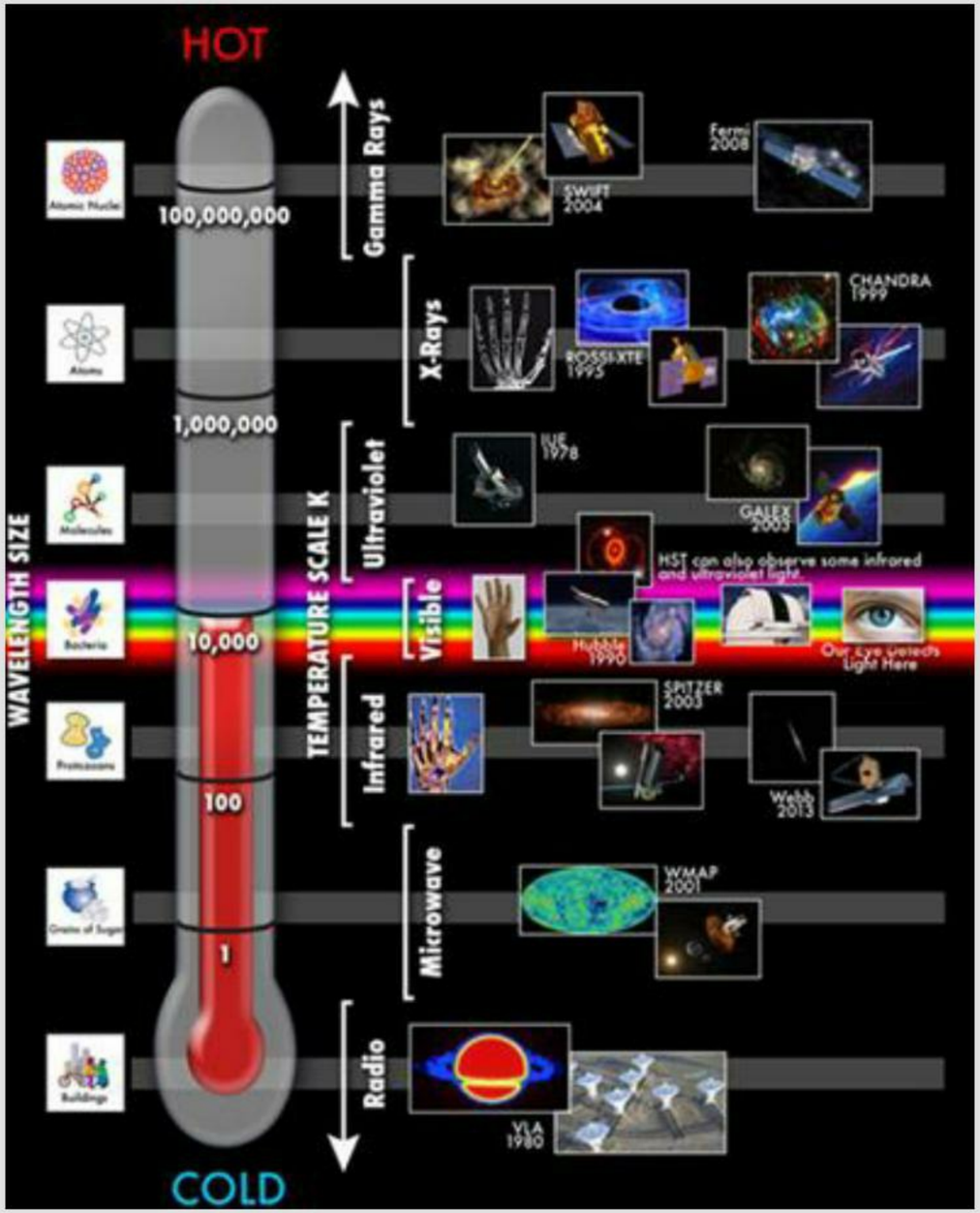
- LTF-blind is coming online: a scale-agnostic blind-search algorithm for short-duration transients
- Covers the parameter space which is not cover by currently running algorithms
- Stay tuned!

THE MULTI-MISSION MAXIMUM LIKELIHOOD FRAMEWORK (3ML)

Easy multi-wavelength, multi-instrument spectral and spatial modeling

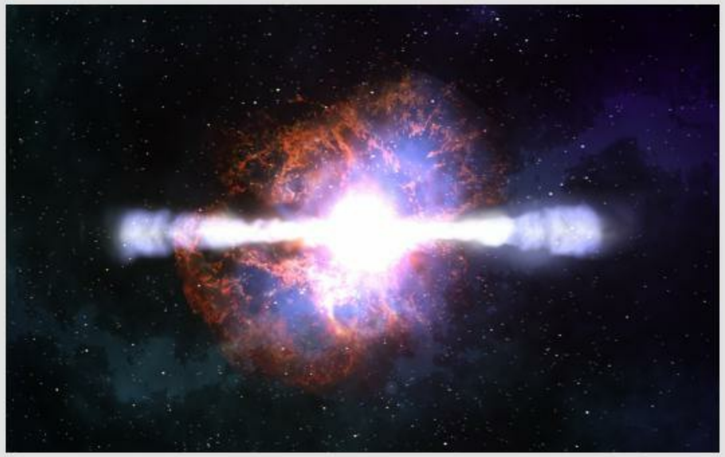
AN OLD PROBLEM

- key information from multi-wavelength modeling
- Multi-wavelength -> multi-instrument
- Different analysis, issues, data formats, software...
- How to combine them ?

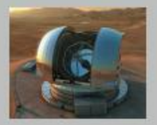


The observation process

Reality

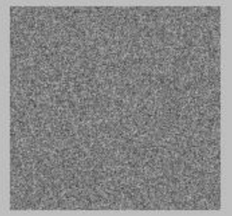


Observation



+

Noise



Data

theoretical models

convolution

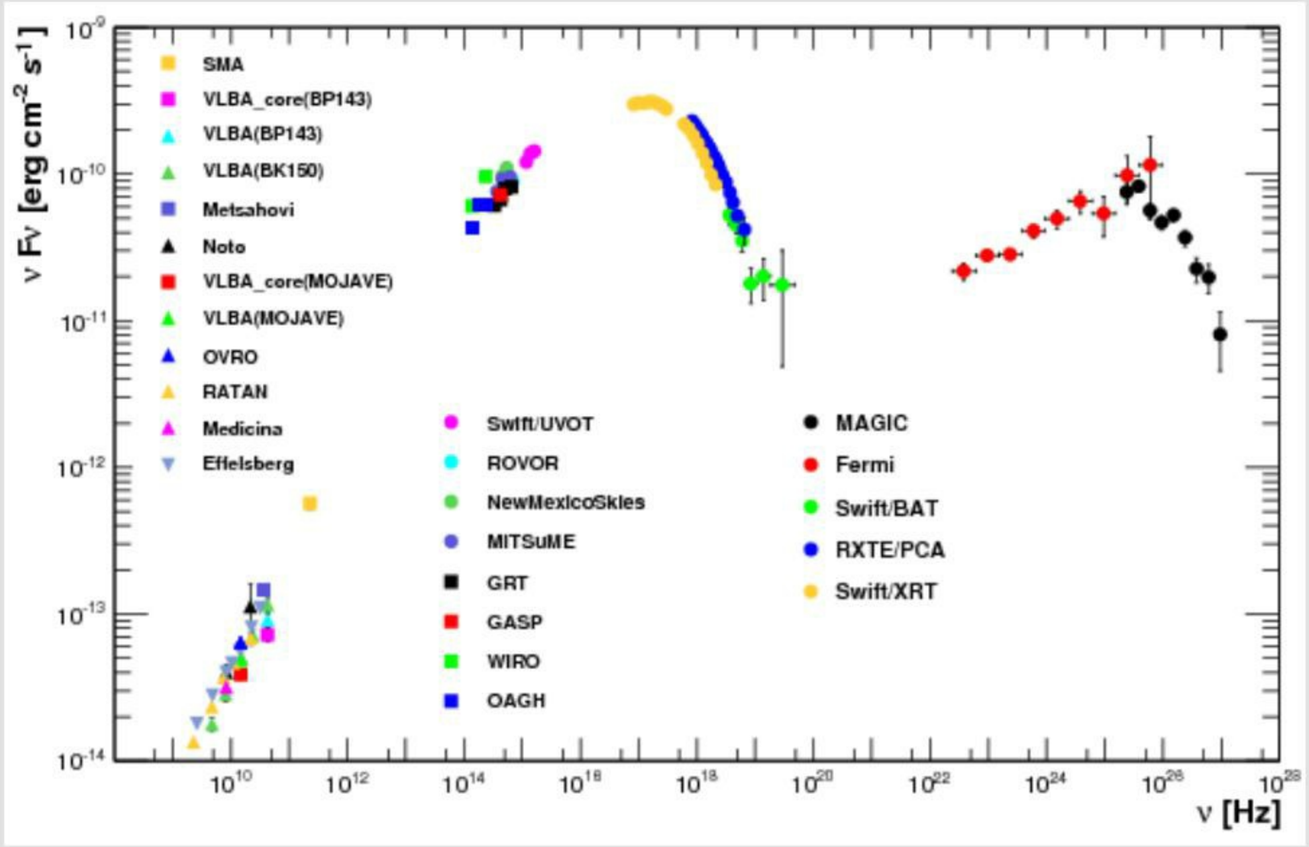
Instrument response
+
noise model

de - convolution

Images, spectra, ...

Classical solution: Spectral Energy Distribution

- De-convolution (data -> model):
  - instruments measure integrated flux over a band
  - if the band is small, differential flux can be computed
  - if not or energy dispersion important (x-ray, gamma-ray), we need to assume a spectral model
    - the fainter the source, the more the results will be model-dependent, i.e., statistically equivalent models can give different SEDs
- Modeling the SED with a model different from the one used to extract is error-prone
- Only possible for point sources, no extended



SED of Mkn 521, from Abdo et al. 2011

The idea of 3ML

+ Convolution (model -> data):

  - compare model with data through likelihood

  - model selection, parameter estimation etc. justified on solid statistical ground

  - possible for any source (faint, bright, point-like, extended)

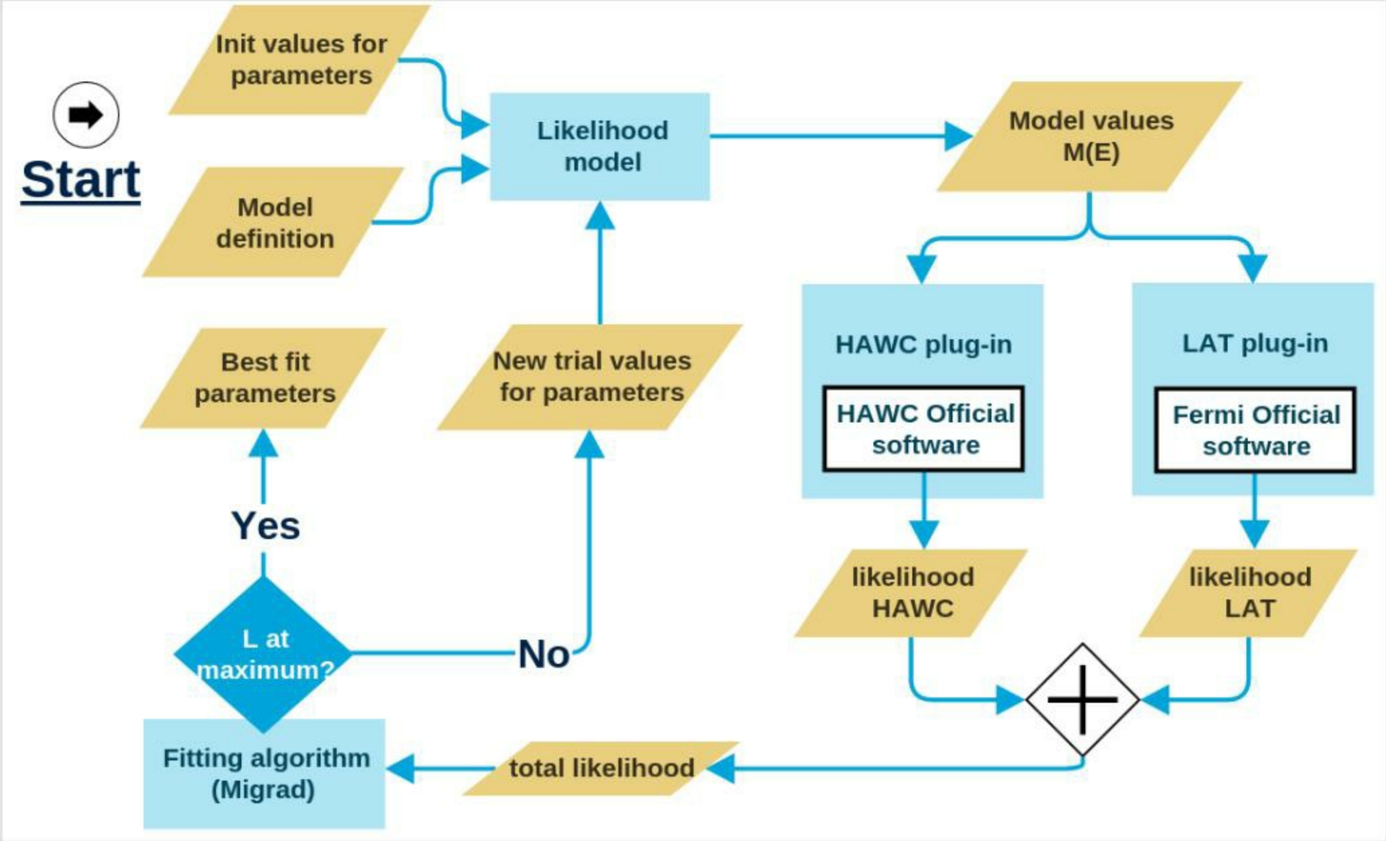
+ convolution (forward-folding) routinely used in many software (Xspec, Fermi Science Tools, Chandra sherpa...)

  - 3ML is different because is based on plugins which compute the likelihood for each instrument using the official instrument software

why plug-ins

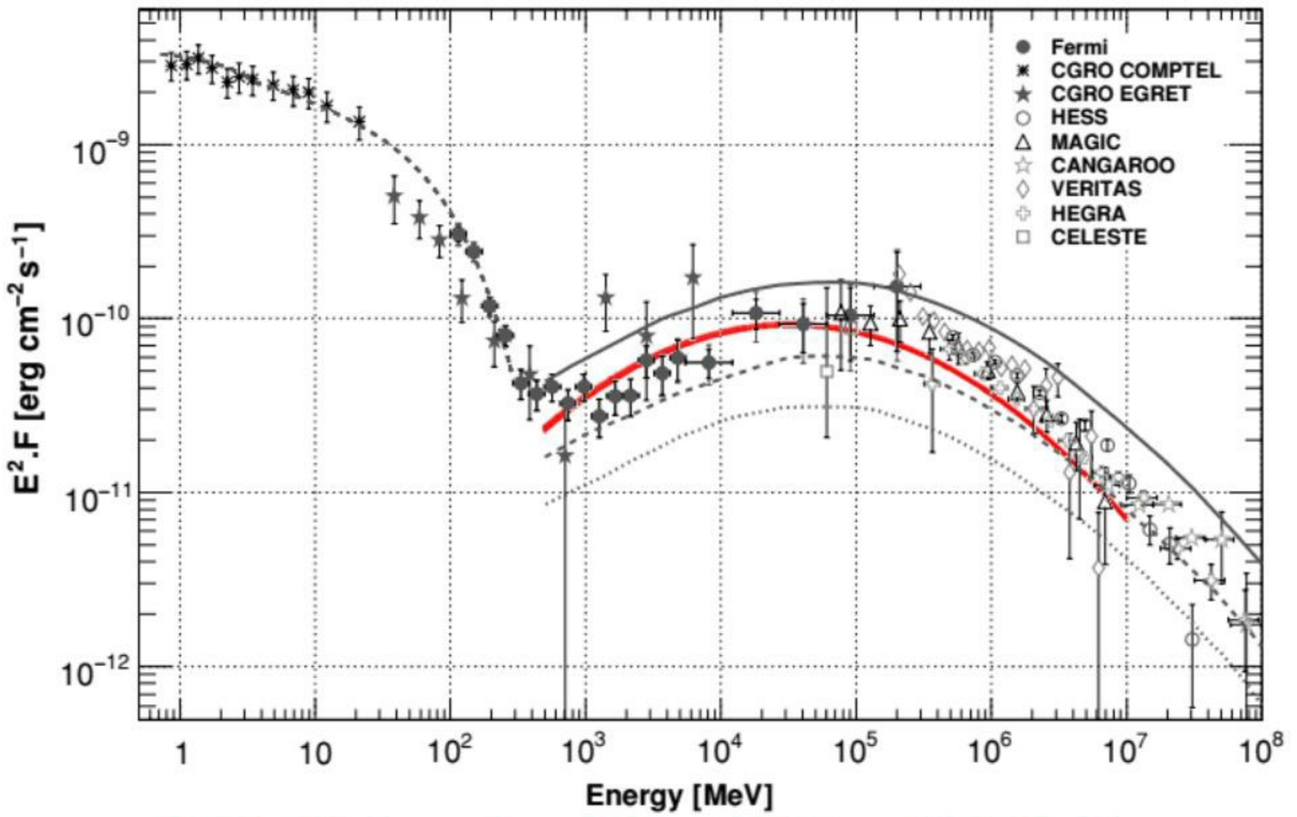
- Complete decoupling between 3ML and the instrument details
  - no constraints on data formats
  - data can keep their dimensions
    - example: Fermi/GBM has time and energy, Fermi/LAT also space, HAWC has nhits instead of energy...
  - can accommodate any instrument / technology
  - each instrument can use its own likelihood based on the appropriate noise model (Poisson, Gaussian, mixed...)
  - plug-ins are easy to implement (~100-200 lines of code) and must be changed rarely
  - any development in the instrument software transfers to 3ML automatically through the plug-in
  - all results are obtained with 100% official software and methods
- even multi-messenger analysis possible (if the theoretical model can predict for example neutrinos)

Analysis chain



EARLY RESULT

Joint Fermi-HAWC 3ML fit of the Crab spectrum



3ML fit of 29 days of Fermi-LAT and 30 days of HAWC data

Status

- People involved from Fermi, HAWC, Swift, VERITAS and HESS working on the plugins
- More instruments welcome
- Point source analysis is ready
- Extended source analysis in development
- In-the-cloud system in development
- Proof of concept ready, applied for funding (grants)
- Website (slightly outdated): threeml . stanford . edu
- Code repository (open source): https://github.com/giacomov/3ML
- Join in if you are interested!

the end