Gamma-ray sources detection using PGWave

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based on Francesca Marcucci PhD thesis

(see http://www.fisica.unipg.it/~marcucci/tesi.pdf)

OUTLINE

- Overview of source detection methods
- The PGWave Package
- Results of PGWave test on GLAST DC1, LightSim and EGRET data
- Conclusions and Future work

The Source Detection Problem

The detection of localized signals (1D) or structures (2D) is one of the most challenging aspects of image processing.

These methods can be divided in:

“a priori“ methods (e.g. Wavelet)

“a posteriori” methods (e.g. Likelihood)

The Source Detection Problem

The main difference between "a priori" and "a posteriori" methods is that the former ones do not need any "a priori" knowledge of a source model.

However, both methods assume that:

- PSF shape
- Background (noise) statistical properties

are known

In general, only a combination of the two approaches can help to reach the result we are looking for ....and this is particularly true in Gamma-Ray Astrophysics.

PGWave

PGWave* is the "a priori" source detection method developed by INFN-Perugia and used to analyse DC1, EGRET and LightSim simulated data.

It is a medley of several methods:

- Wavelet Transform
- Thesholding
- Sliding Cell
- Iterative Denoising

*** Download the *wavelet* package from the GLAST CVS to test it**

PGWave characteristics

PGWave was designed to be:

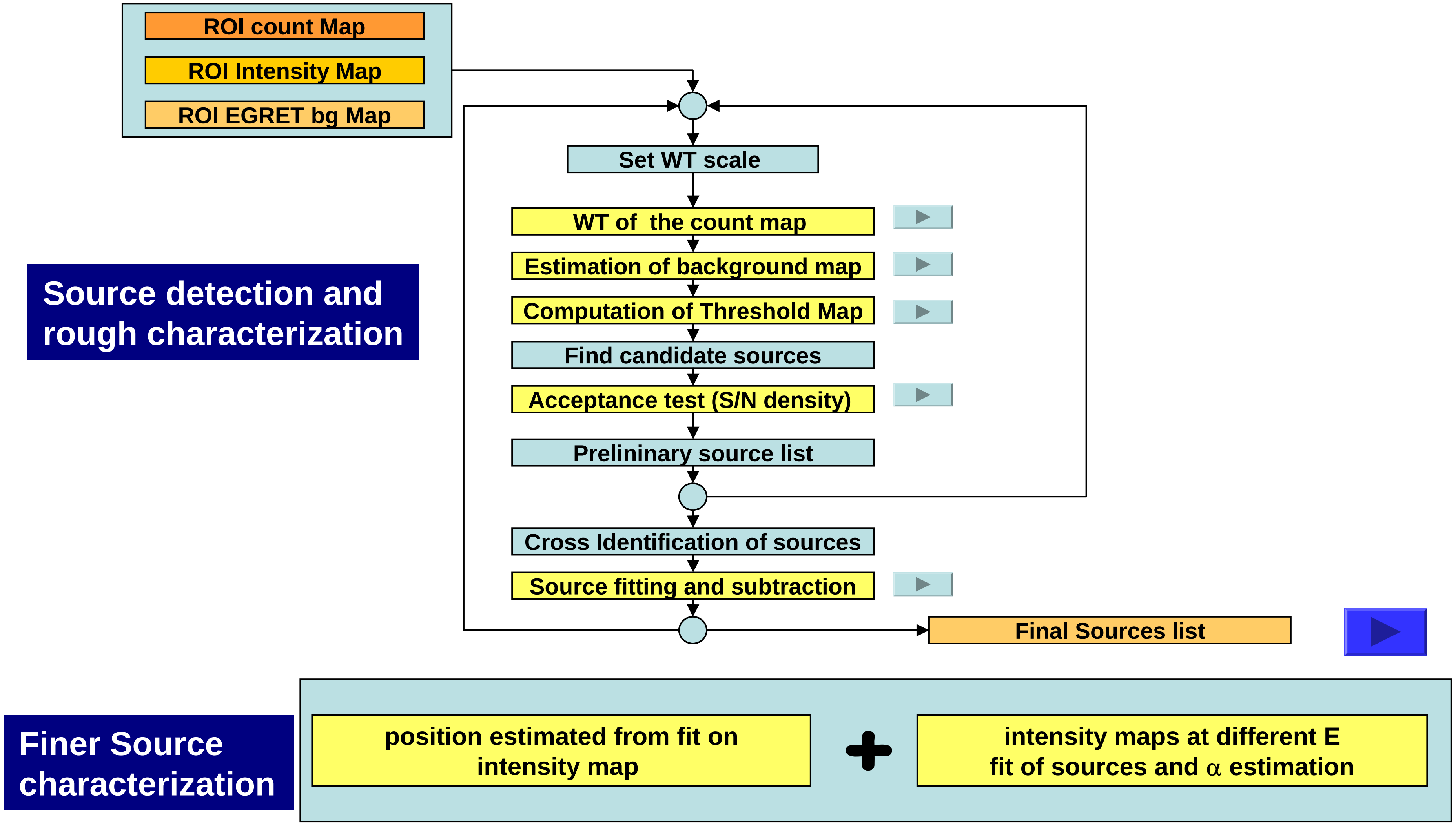
- Fast & Efficient (source detections using Wavelets)
- Reliable (it yields only a small number of spurious detections)

and include options for:

- Characterization of sources (position, spectral properties and total flux)

PGWave may be a candidate for the Quick Look analysis of LAT data.

Block Diagram of the PGWave algorithm



The Wavelet Transform (WT) of input maps

- PGWave uses WT as a 2-D spatial filter

- WT is a multiscale transform providing a representation of data to easily extract both position and shape of features (for images or light curves).

- WT decomposes the signal in translated and scaled versions of an original function (the mother wavelet).

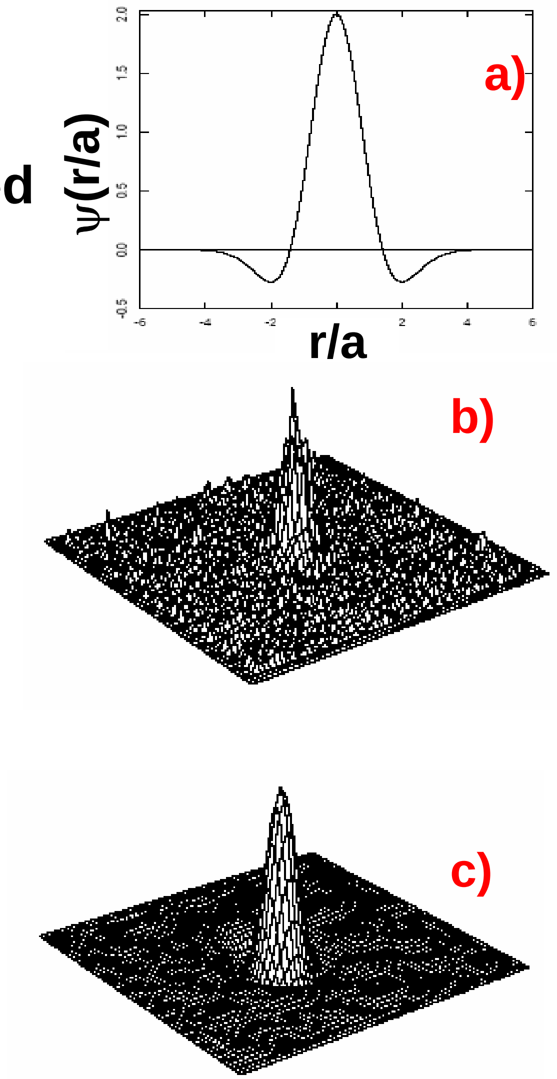
- WT enhances the signal contribution and attenuates the background.

WT have been widely used in X-ray astronomy and both CHANDRA and XMM Analysis Software includes WT based packages for source detection.

WT of input count maps

PGWave uses the Mexican Hat WT

- ✓gamma-ray detectors have PSF well described by one or more gaussian functions;
- ✓MH has a shape similar to the detector PSF;
- ✓It is insensitive to bg gradients;
- ✓Widely used in optical/X-ray



Def.: $$w(x,y,a) = \int\int \psi\left(\frac{x-x'}{a}, \frac{y-y'}{a}\right) f(x',y')\,dx'\,dy'$$

With:

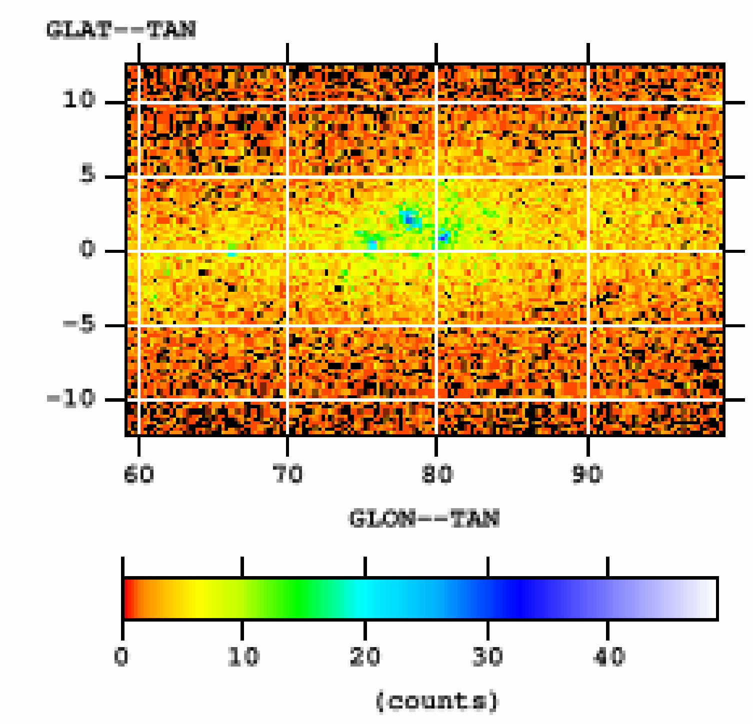
$$\psi\left(\frac{x}{a}, \frac{y}{a}\right) = \psi\left(\frac{r}{a}\right) = \left(2 - \frac{r^2}{a^2}\right) e^{-\frac{r^2}{2a^2}}$$

$(r^2 = x^2 + y^2)$

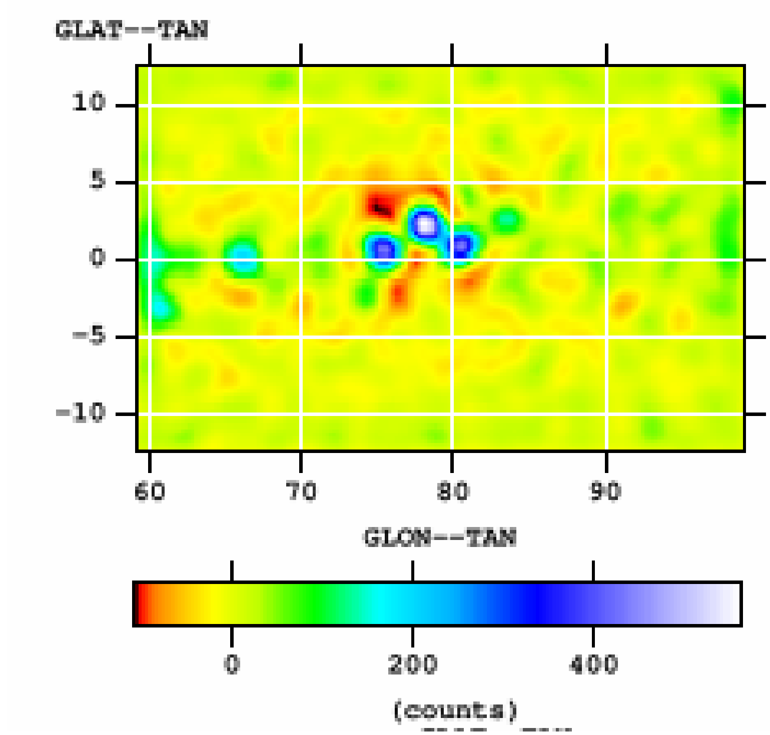
WT of input count maps

ES: CYGNUS REGION

INPUT count map



Wavelet transform (scale 4)



Background estimation

- the background map is produced by filtering the image:

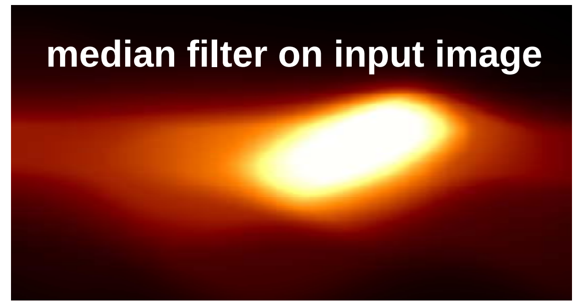
1)Gaussian filter on count map to reduce non uniformities.

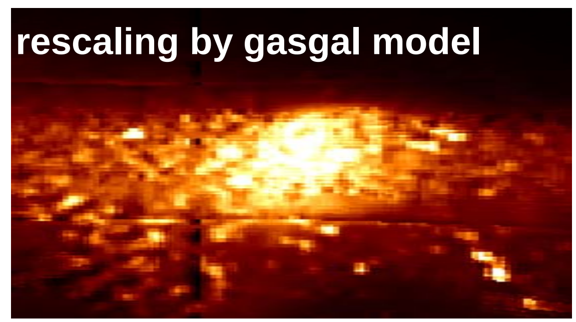
2)Sigma clipping (Stobie algorithm) or median filter.

3)Flat-Fielding

-EGRET diffuse galactic emission map is used to introduce in the smoothed background map (steps 1 and 2) small scale structures.

-The procedure is derived from the flat-field technique used in optical/IR but in this case we introduce structures



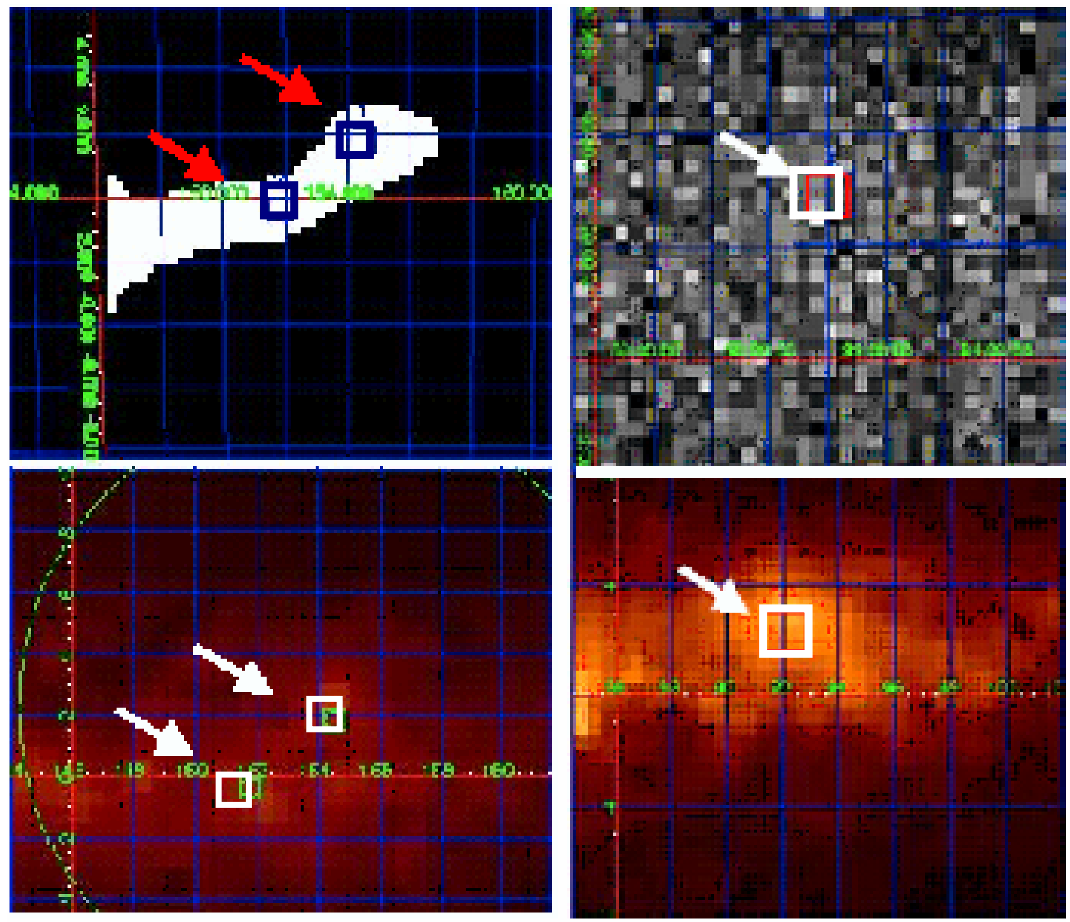


Background estimation

CORRECT BG ESTIMATION → **Reduce spurious detection arising from complex structures of background emission**

spurious detections

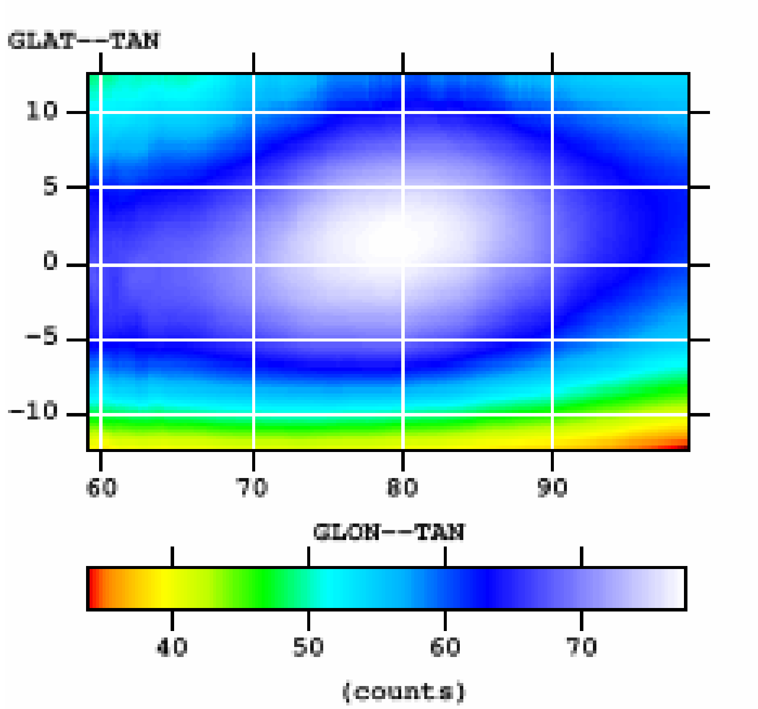
correspondence in EGRET bg map



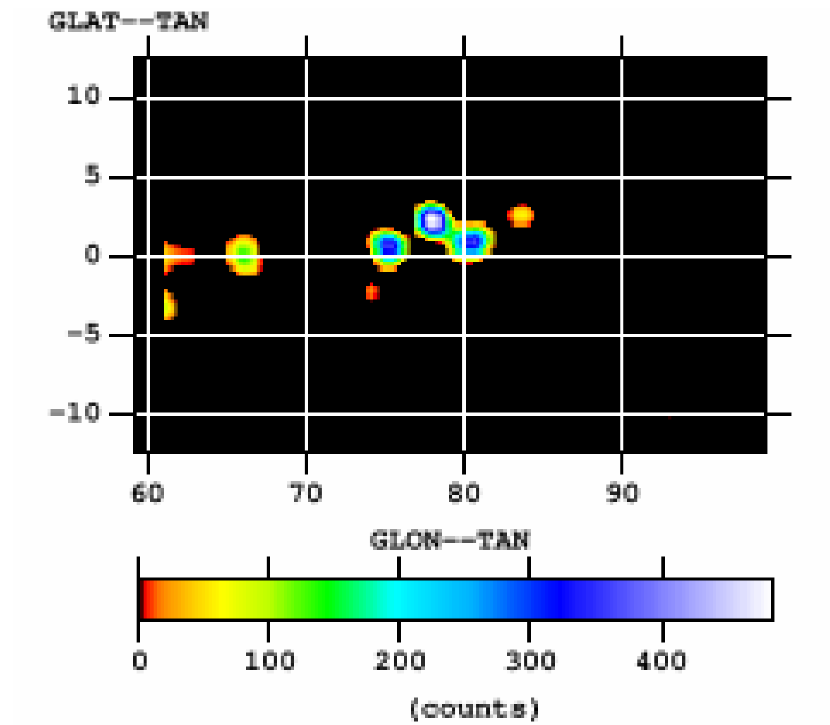
Threshold estimation

ES: CYGNUS REGION

THRESHOLD map



OVER THRESHOLD map



Damiani et al. (1997) method for threshold estimation has been used.

Acceptance test (S/N density)

PGWave follows a procedure similar to sliding cell to perform the final acceptance/rejection test

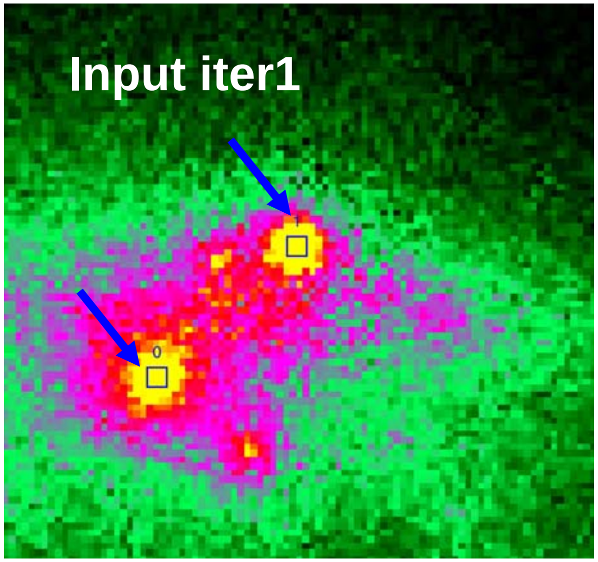
✓ **estimate (at each iteration) the typical ratio between the count map and background densities in a box of scale size**

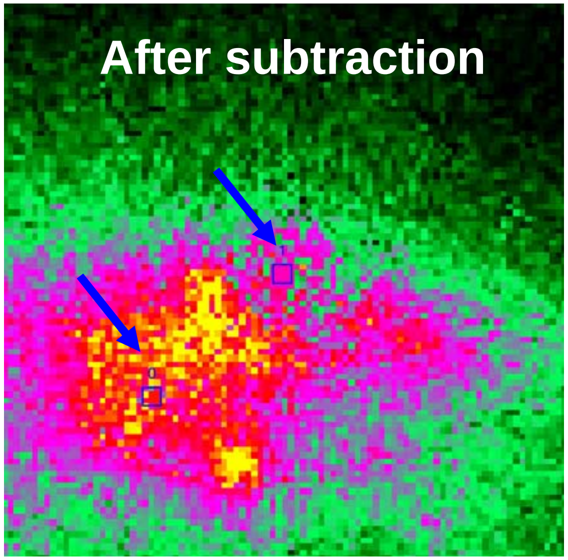
✓ **discrimination between false detections and true sources based on this ratio**

(The value of the ratio to accept sources decreases with iteration step)

Source Fitting

- ✓ **At each iteration the accepted sources are fitted with a double or single gaussian function (that well represents the PSF) and if the fit converges their contribution is subtracted and the result count map is used as input for next iteration**



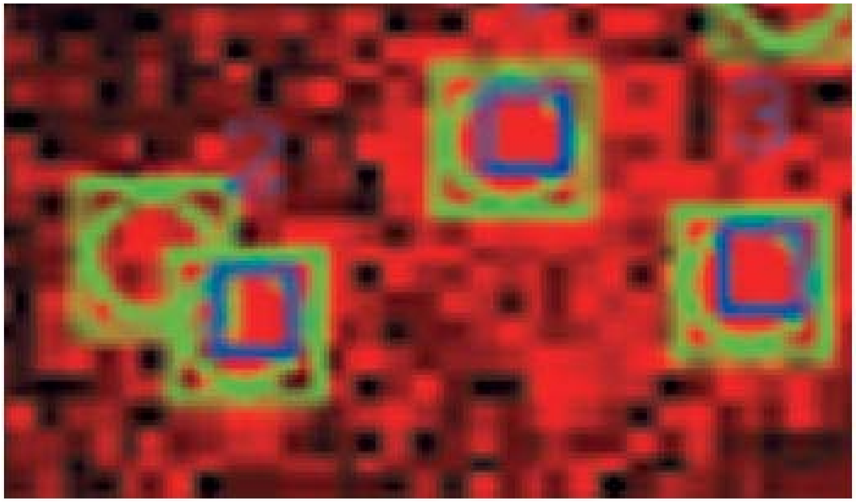


The advantages are...

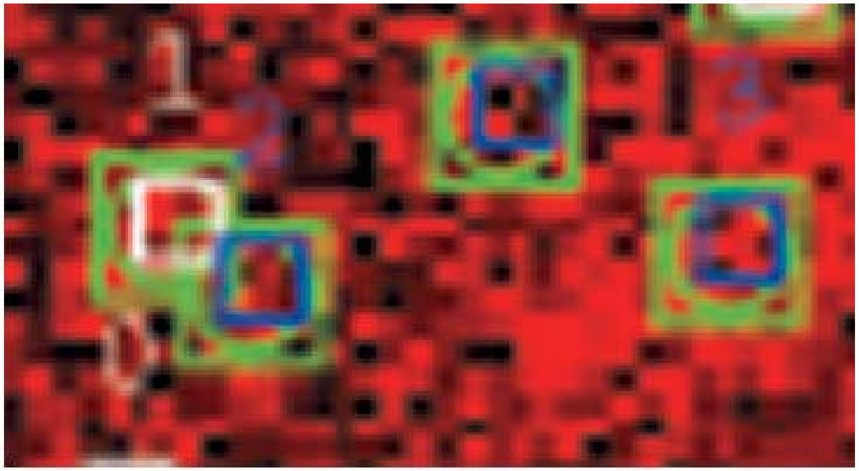
Substraction of brighter sources

→ Detection of faint and/or overlapped sources….

Without subtraction



After subtraction



LEGEND:

Green=simulated

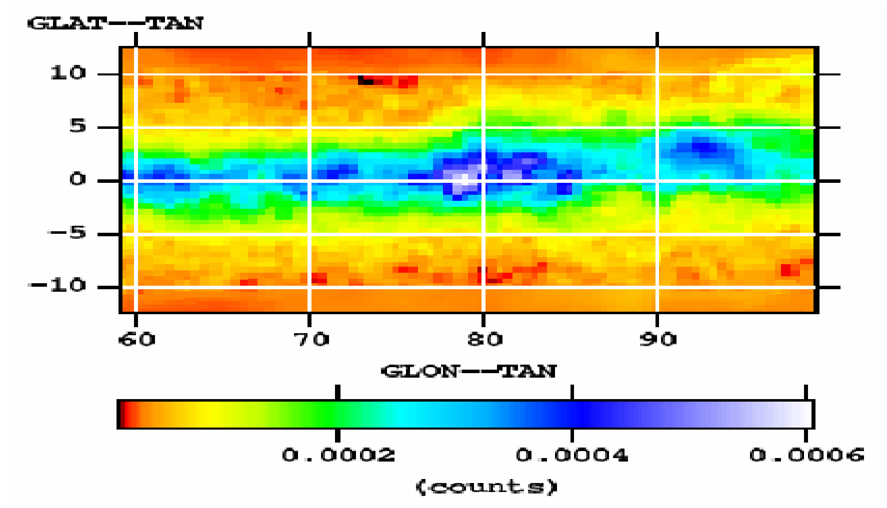
Blue= 1 iter

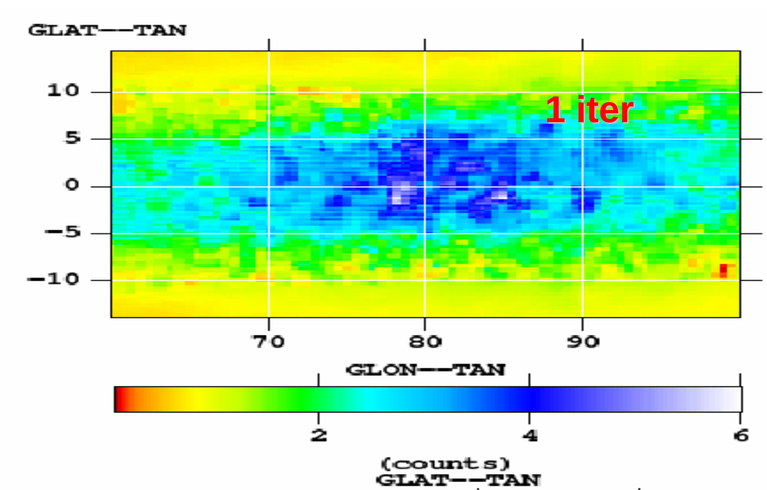
White= 2 iter

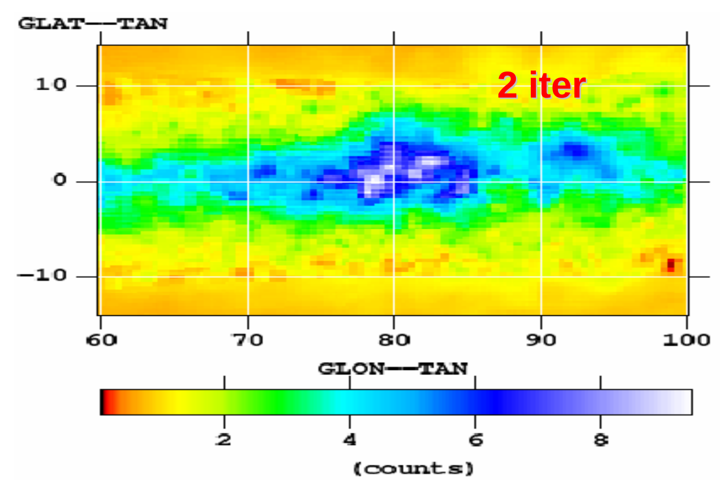
Substraction of brighter sources

→ better bg estimation

EGRET model



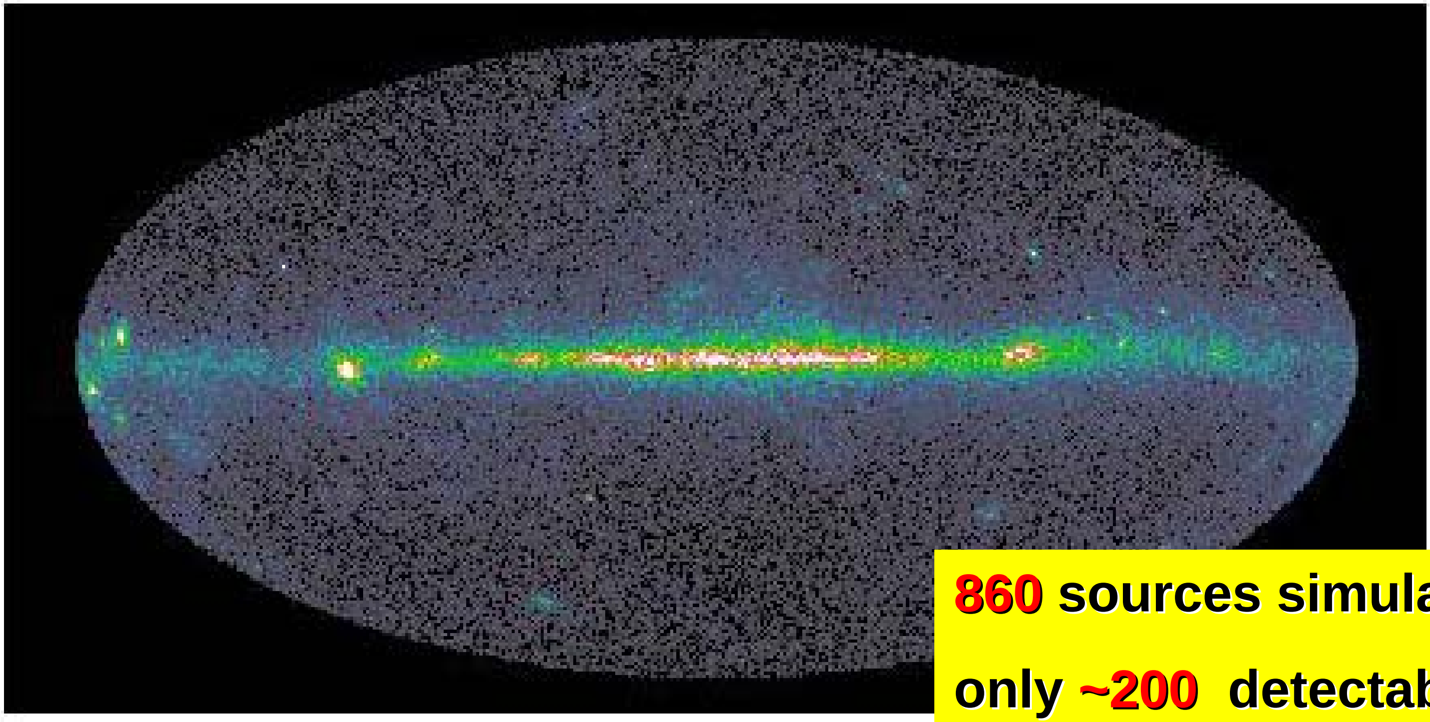




PGWave Analysis of simulated GLAST DC1 data

Application to simulated GLAST DC1 data

Method was tested on 6 days DC1 all sky (scanning mode) GLAST simulated data.
The produced photon list was used to generate binned count maps with, the expected PSF is well described by a narrow gaussian with exponential tails.



860 sources simulated BUT only ~200 detectable in 6 days

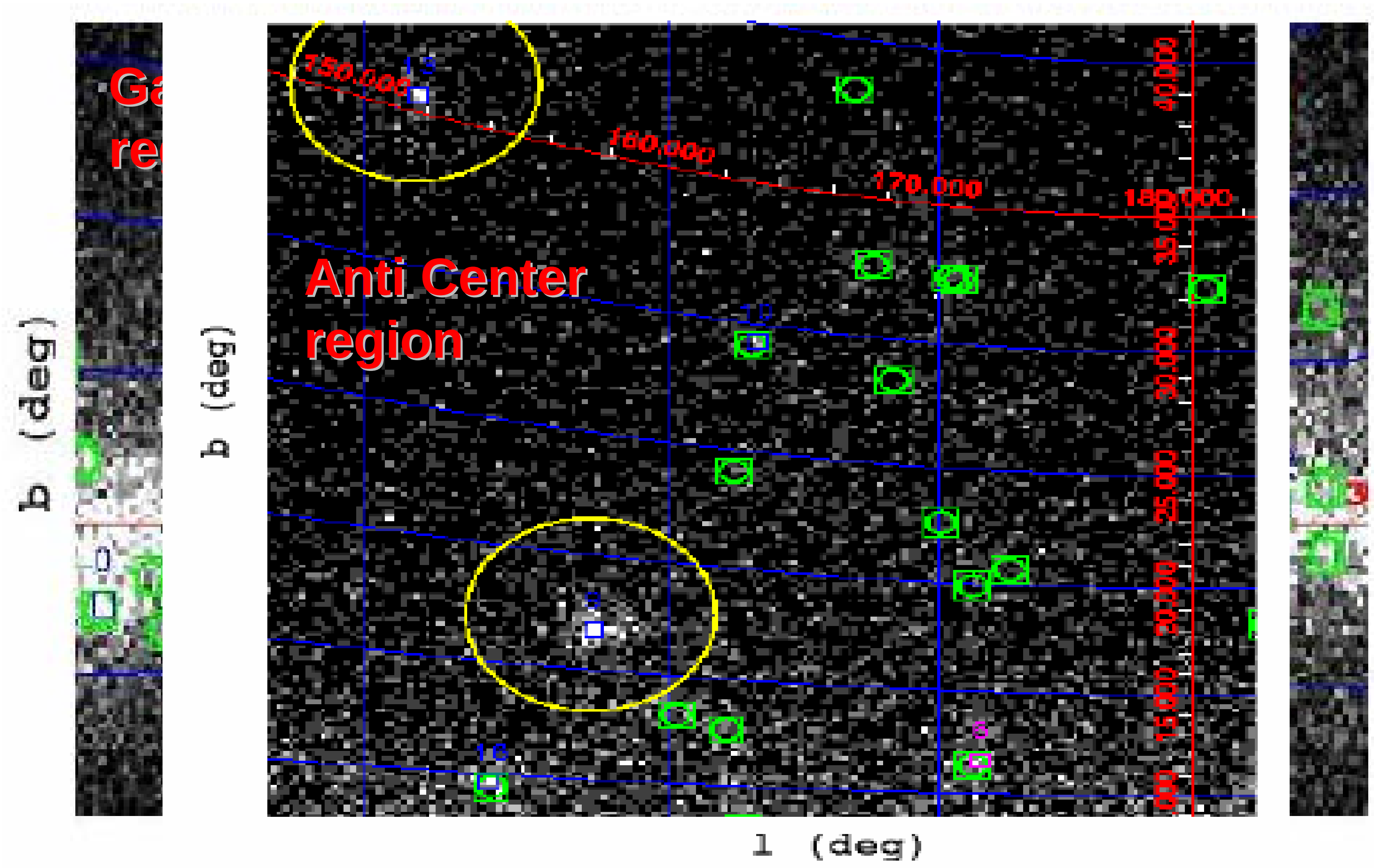
Bin size: 0.25 deg

Projection = -TAN , -SIN (at poles)

2 iterations

4 sigma threshold analysis

Application to simulated GLAST DC1 data



blue = WT detection
green =simulated sources

Application to simulated GLAST DC1 data

PGWave detections on 6 day all sky simulated data:

172 detection

139	d<0.5 deg
19	d<1.0 deg
2	d<1.5 deg

24 associated to faint blazars
7 associated to *unid-halo*
6 associated to GRB's
the rest with 3EGC

12 spurious detection

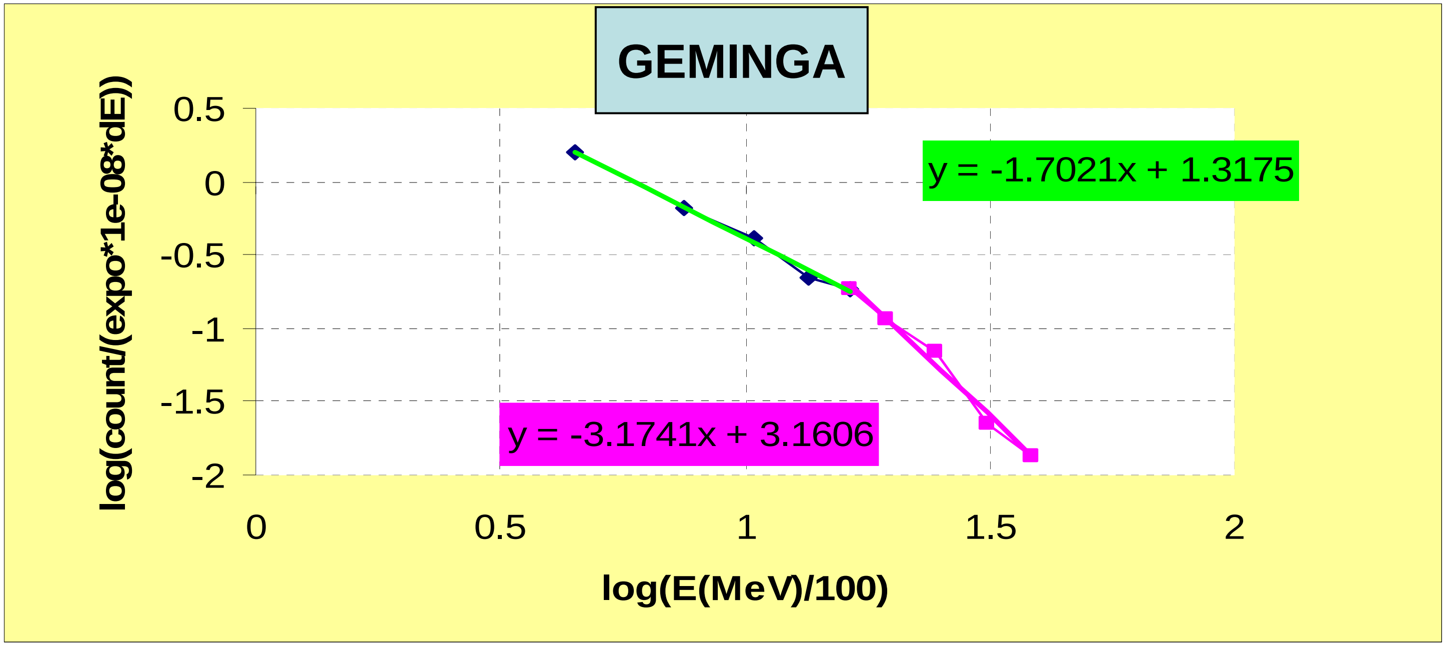
4 because of bad fitting/subtraction

Computing Time : 600s - 4 iterations on a 25°x25° region

(PGWave uses direct convolution. Better performances can be obtained using FFT for the largest Wavelet scales. Work is in progress to use the *fftw* package)

Application to simulated GLAST DC1 data

For the brightest sources we proceeded to their characterization...



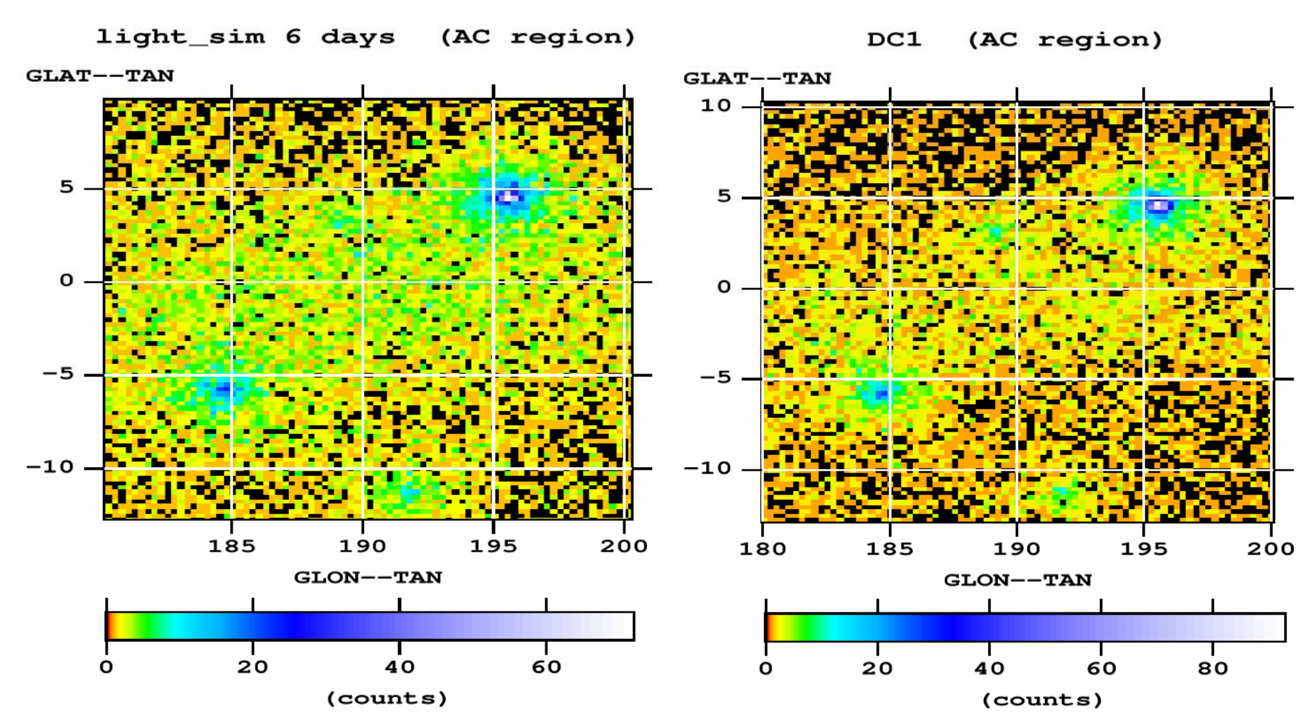
Spectral index	*position:*
found vs simulated values	l = 195.17 ± 0.16 (195.06)
$\alpha 1$ = - 1.70 ± 0.08 (- 1.66)	b = 4.45 ± 0.16 (4.32)
$\alpha 2$ = - 3.2 ± 0.2 (- 3.1)	

PGWave Analysis of LightSim* GLAST data

*see Marcucci PhD thesis, download the *light_sim* package from the GLAST CVS to test it

Test of PGWave with LightSim GLAST data

GLAST Simulated data produced with LightSim



DC1 comparison (6 days)

Fastness:

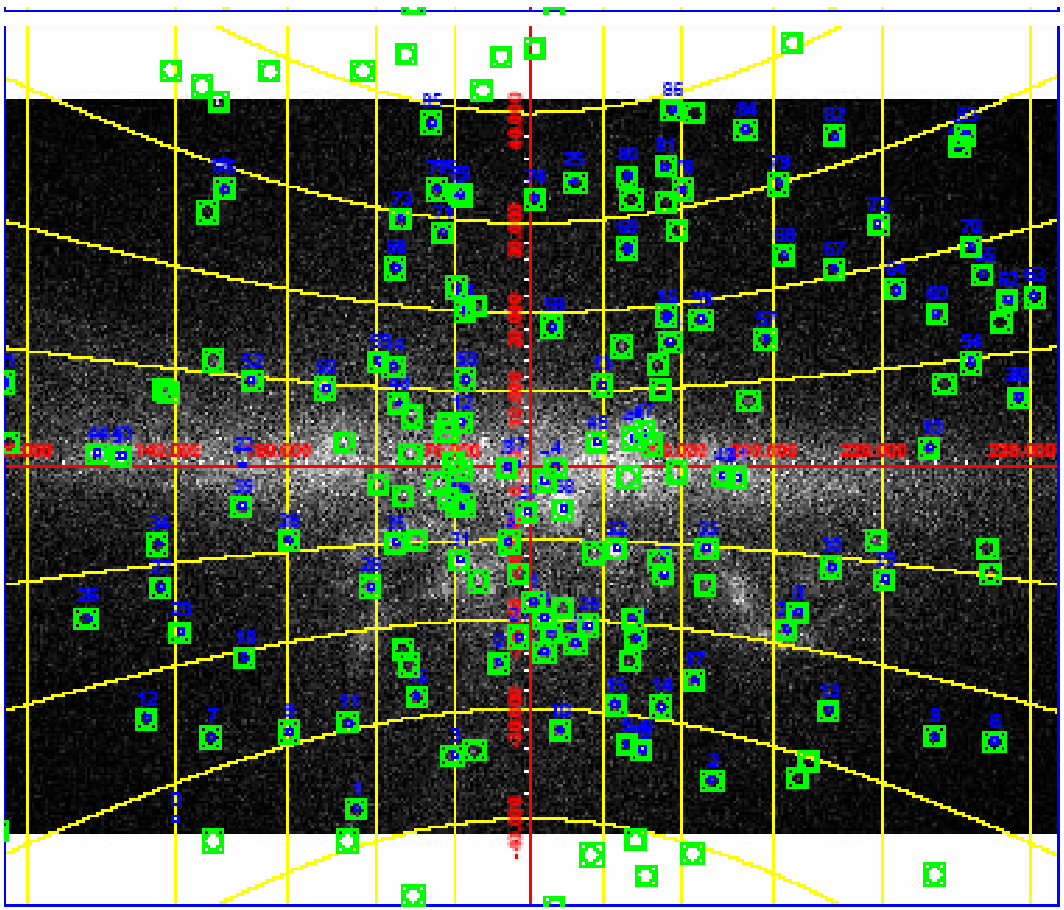
G4 simulation: 2 days (60 CPUs)

LightSim: 5 hours (1 CPU)

Test of PGWave with LightSim GLAST data

ES: AC REGION

6 days



DC1 IRF

18 good

1 spurious (fit)

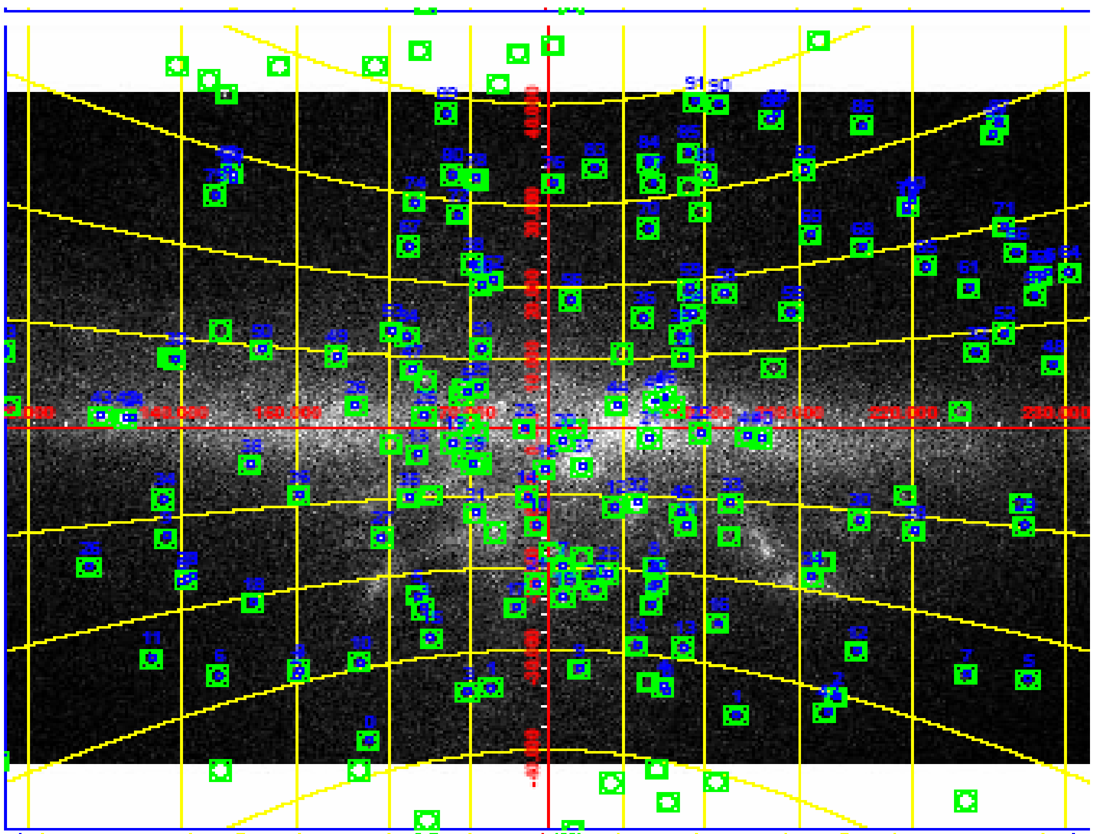
Glast25 IRF

53 good

0 spurious

Test of PGWave with LightSim GLAST data

AC REGION



55 days

DC1 IRF

48 good

7 spurious (5 from fit)

Glast25 IRF

137 good

10 spurious (9 from fit)

Test of PGWave with LightSim GLAST data

DC1

region	6 days			1 month			55 days		
	G	S	S_fit	G	S	S_fit	G	S	S_fit
AC	18	0	1	34	6	5	48	2	5
GC	19	2	0	45	2	2	86	6	1
l270b0	3	0	0	8	0	0	17	0	0

Glast25

	6 days	1 month	55 days
total	297	647	763
G	289 (288 within 0.5°)	616 **(613)** within 0.5°)	703 (702 within 0.5°)
S	6	10	34
S_fit	2	21	26

Spurious

< 8%

best fit →

< 4%

G= *good* **S=** *spurious* **S_fit =** *spurious because bad fitted*

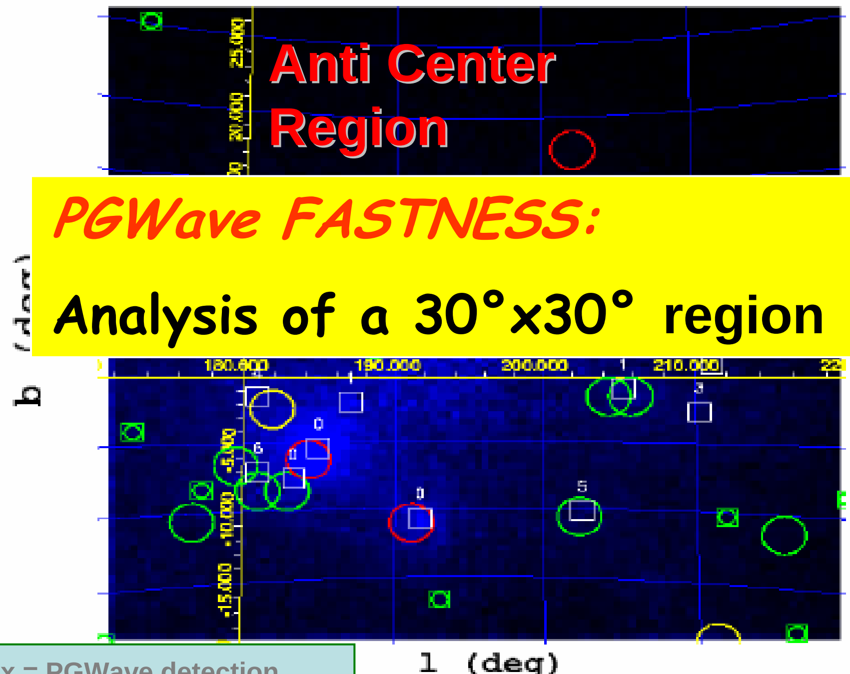
PGWave Analysis of EGRET Data

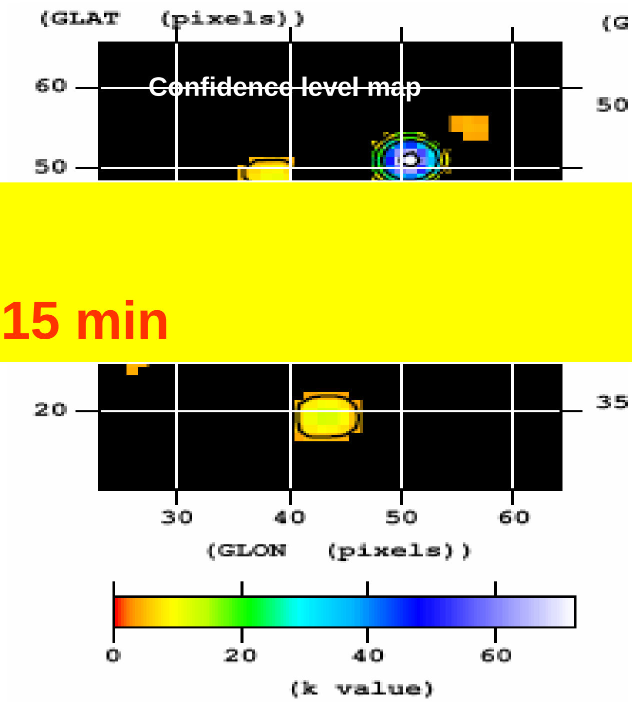
Analysis of EGRET Data

PGWave was used to analyze 4 typical regions: Anti Center, Cygnus, 3c279 and Vela

Bin size: 0.5 deg
Projection = -TAN , -SIN (at poles)

3 iterations
4 sigma threshold analysis





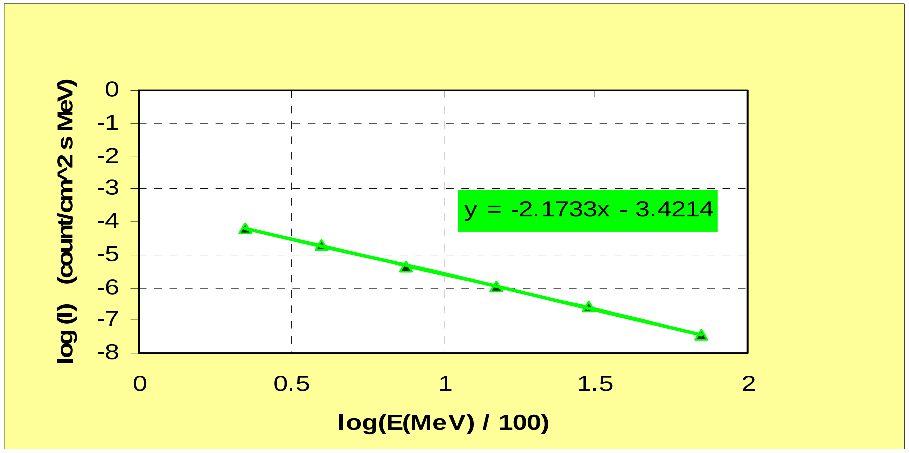
PGWave FASTNESS:

Analysis of a 30°x30° region ~ 15 min

White Box = PGWave detection
Red Circle = 3EG identified sources
Green Circle = 3EG unidentified
Green Box = Unofficial EGRET List

Analysis of EGRET Data

CRAB

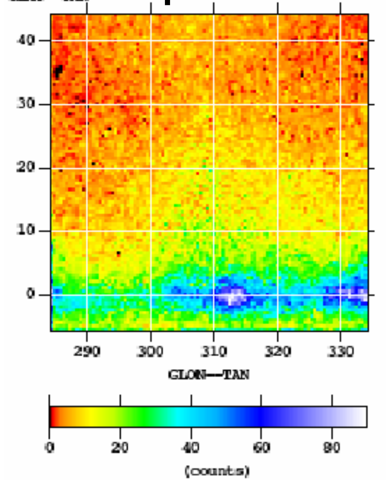


NAME	l	b	counts (C)	α_1
3C 279	305.7 ± 0.5 (304.982)	57.5 ± 0.5 (57.03)	(14.5 ± 4)× 10^2 (1487)	-1.90 ± 0.06 (-1.96 ± 0.04)
Vela	263.9 ± 0.3 (263.527)	-2.5 ± 0.3 (-2.86)	(10.4 ± 1)×10^2 (10320)	-1.71 ± 0.03 (-1.69 ± 0.01)
Crab	184.9 ± 0.4 (184.53)	-5.5 ± 0.4 (-5.84)	(55.1 ± 7)× 10^2 (5314)	-2.17 ± 0.02 (-2.19 ± 0.02)
Geminga	195.5 ± 0.3 (195.06)	4.7 ± 0.3 (4.32)	(65.3 ± 8)× 10^2 (6329)	- 1.70 ± 0.10 (-1.66 ± 0.01)

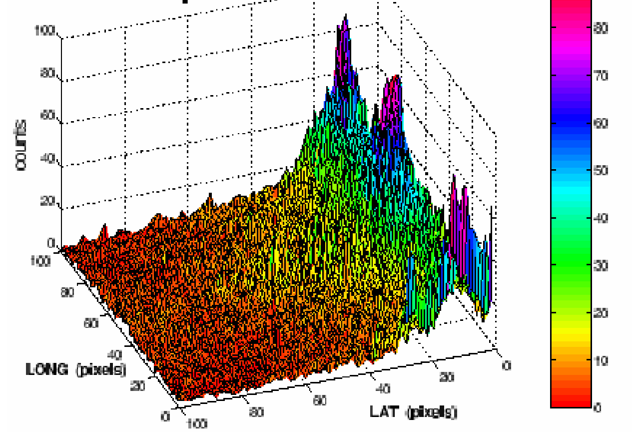
Table 5.8: Results of finer analysis of EGRET data for 4 typical γ-ray sources, compared with *3EG* values (in brackets).

First application to EGRET extended sources: CenA

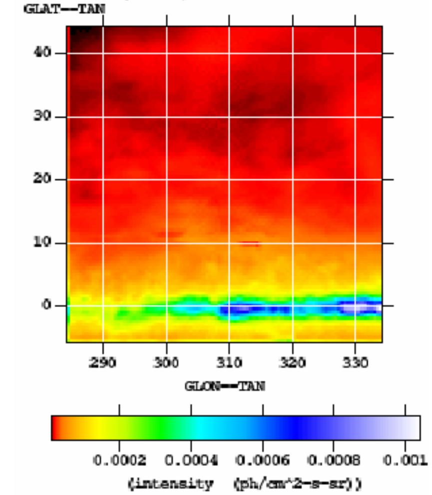
input



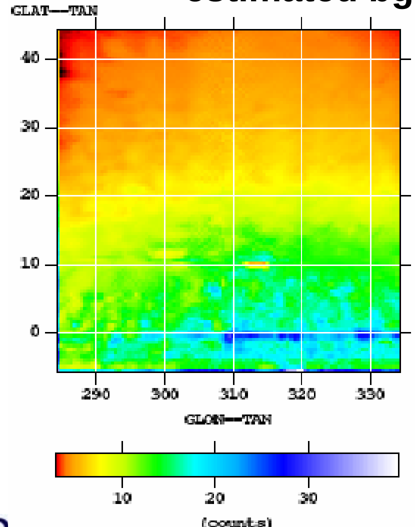
3D-input



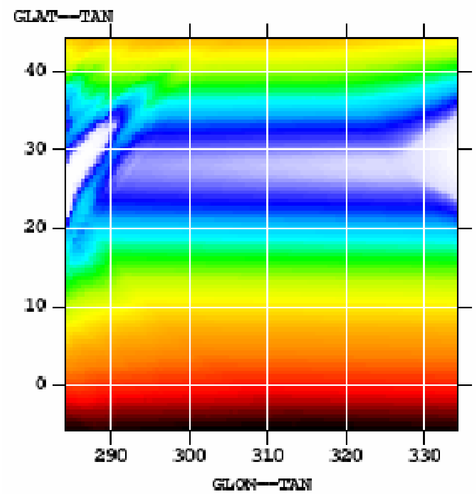
EGRET bg



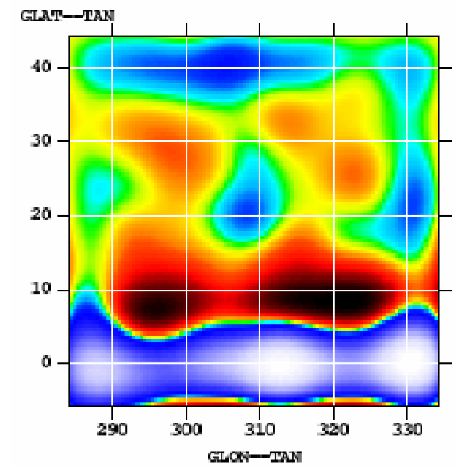
estimated bg



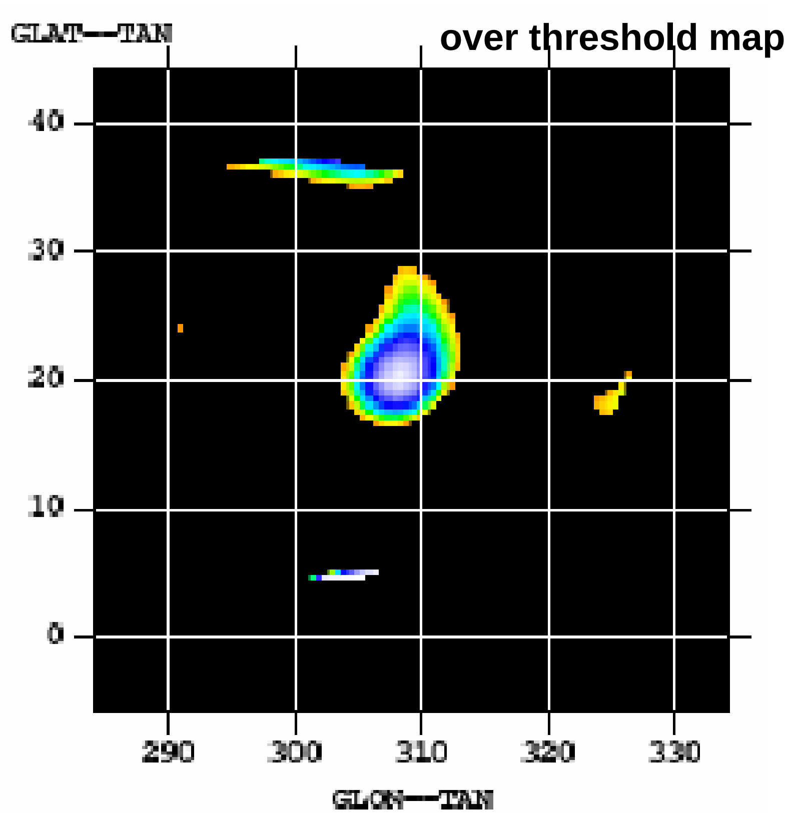
threshold

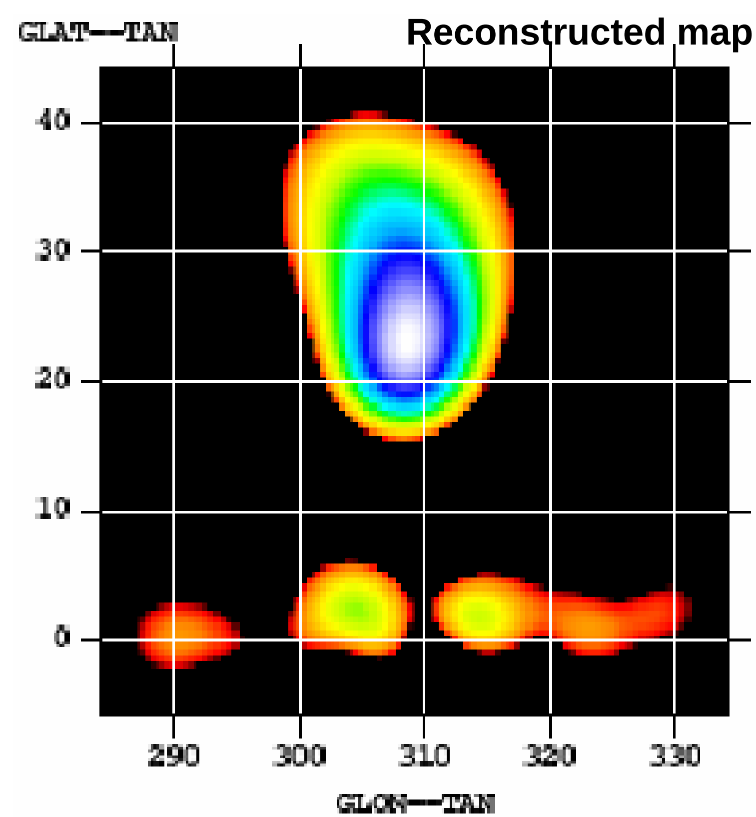


Wavelet transform



First application to EGRET extended sources: CenA





Analysis of EGRET Data

Summary of the results on the 4 EGRET Fields:

- All Identified 3EG sources were detected by PGWave, except a faint source close to 3C279

- All PGWave undetected sources are 3EG unidentified and for some of these sources no excess were found on the counts map.

- PGWave "new" sources are always associated with real counts excess and most of these were detected at a distance less than 30' from well known radio and/or X-ray sources.

Conclusion: PGWave and LAT Catalog compilation

Sources list from gamma-catalogs (EGRET)

possible gamma-source candidates

Source-list from PGWave Quick Look analysis (rough estimation of source parameters)

LIKELIHOOD analysis

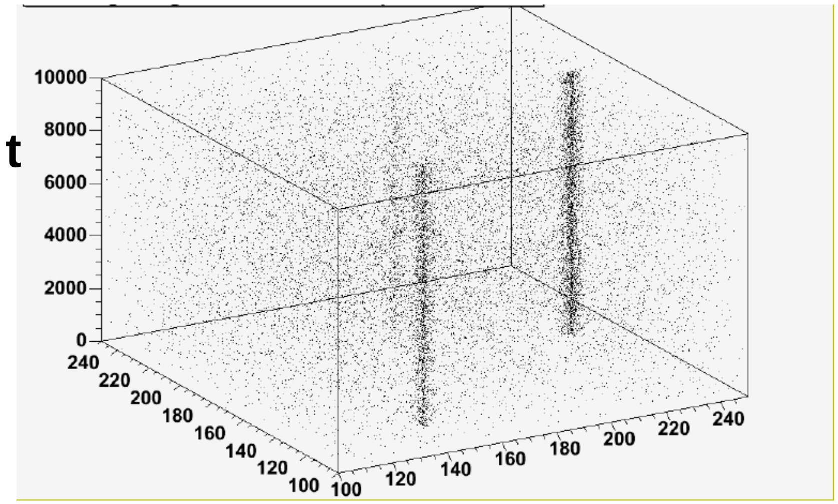
diffuse background model

source list with confidence interval and estimated parameters

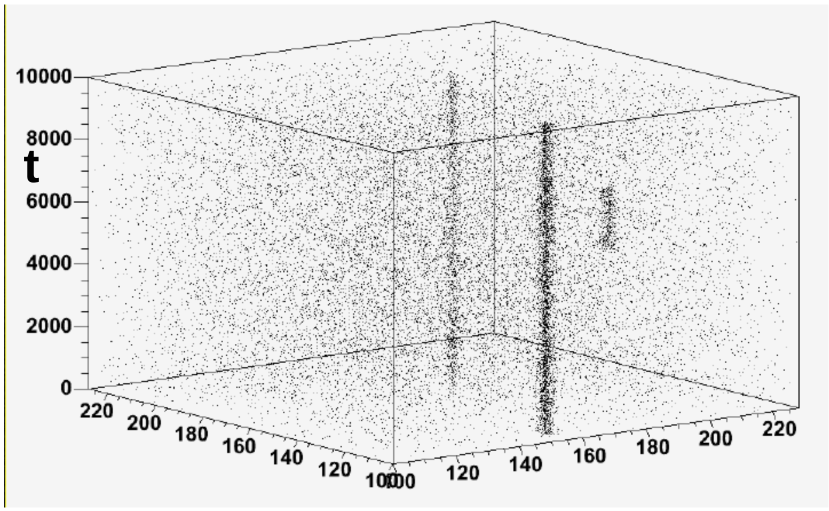
official LAT Catalog

Future developments

Next step: PGWave-3D → (x,y,t)/(x,y,E)



Constant sources are cilinder in 3D space



variable sources can be detected in 3D space becouse they exist only for short intervals

............work is in progress