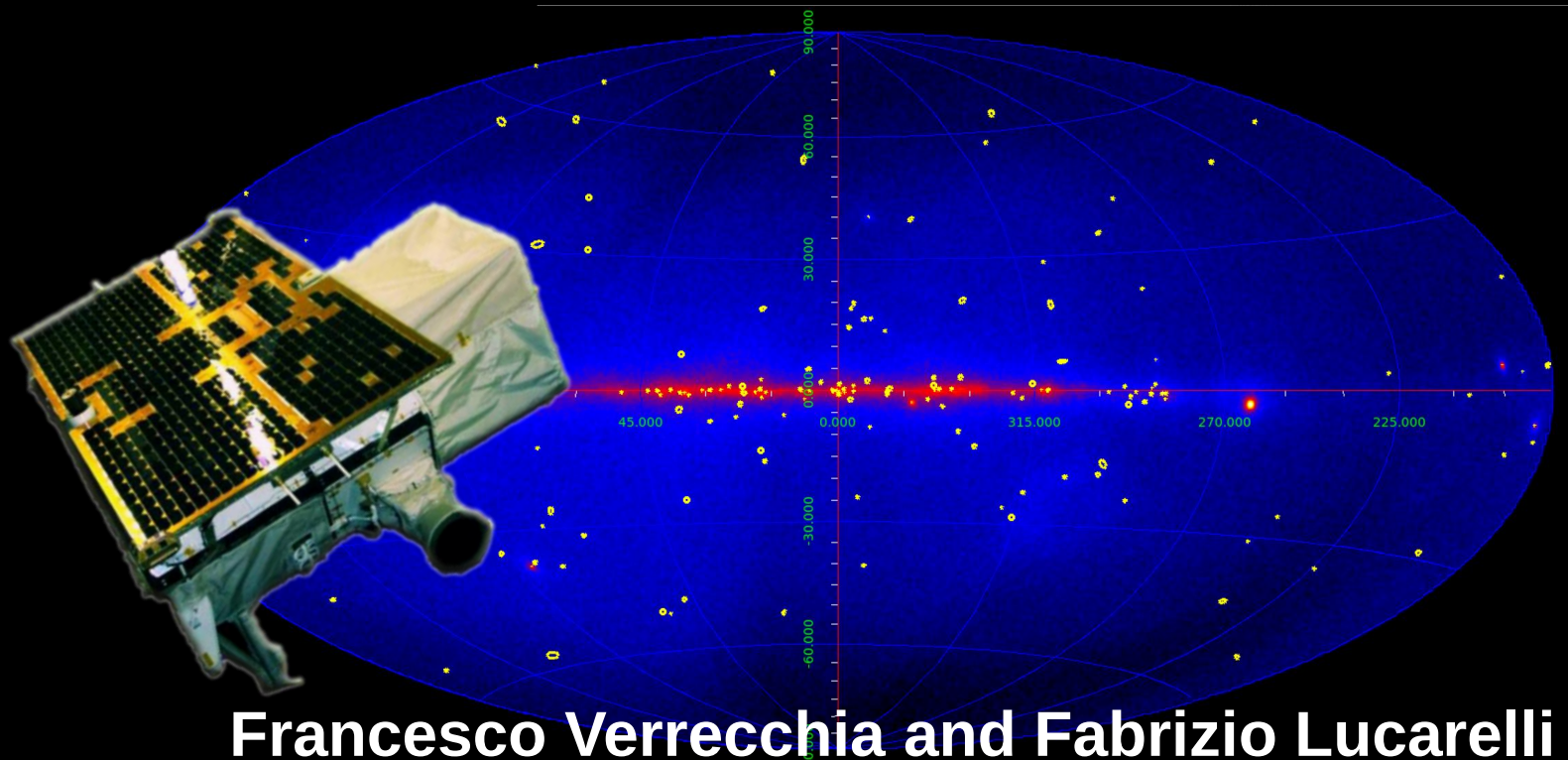
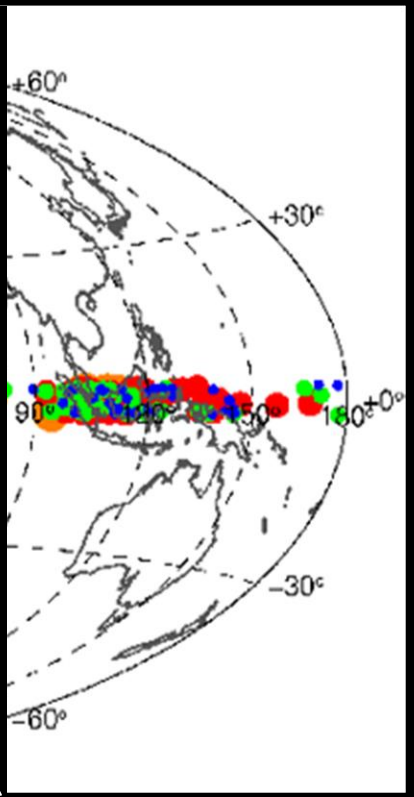
Overview of AGILE Catalogues, GRID & MCAL





Francesco Verrecchia and Fabrizio Lucarelli
on behalf of the AGILE Data Center, ASI SSDC & INAF-OAR

Treasures Hidden in HE Catalogues, Toulouse, May 18, 2018

The AGILE instrument

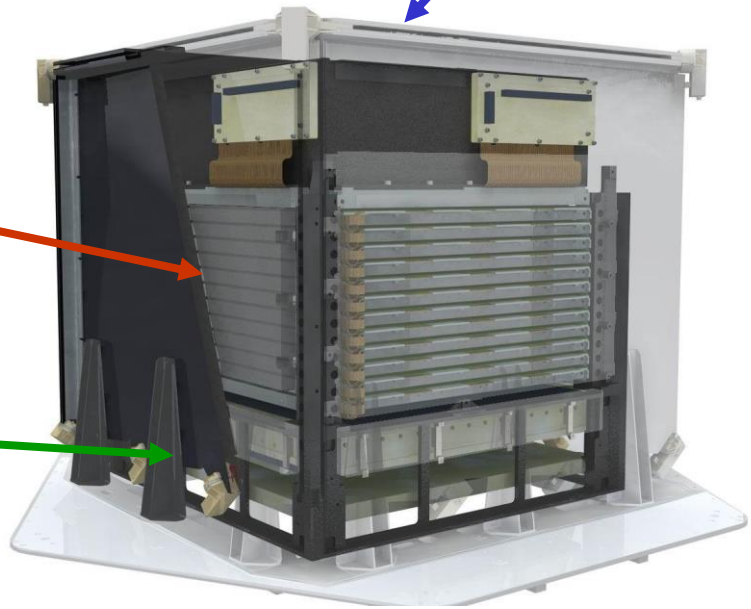
- **AGILE is unique combination of X-ray and gamma-ray detectors ->GW counterpart search**
- **two co-aligned imaging detectors in hard X-rays (Super-AGILE) and gamma (GRID)**

+ omnidirectional MCAL

Super-AGILE
Coded aperture
18 – 60 keV
~1 sr FoV

Gamma Ray Imaging
Detector Silicon tracking
detector 30 MeV – 50 GeV
~2.5 sr FoV

Mini-calorimeter
non imaging scintillator
0.3 – 200 MeV
almost all-Sky FoV



The AGILE instrument

Gamma-ray imaging detector (GRID)

Energy range 30 MeV–50 GeV

Field of view ~2.5 sr

Flux sensitivity (E > 100 MeV, 5σ in 10^6 s) 3 × 10^−7 (ph cm^{-2} s^{-1})

Angular resolution at 100 MeV (68% cont. radius) 4.3 degrees

Angular resolution at 1 GeV (68% cont. radius) 0.7 degrees

Source location accuracy (high Gal. lat., 90% C.L.) ~15 arcmin

Energy resolution (at 400 MeV) $\Delta E/E \sim 1$ =>+energy dispersion

In flight Crab radial profile from AGILE Pointing mode data compared to the Fermi/LAT «front» event one (P7REP).

Sabatini et al. 2015

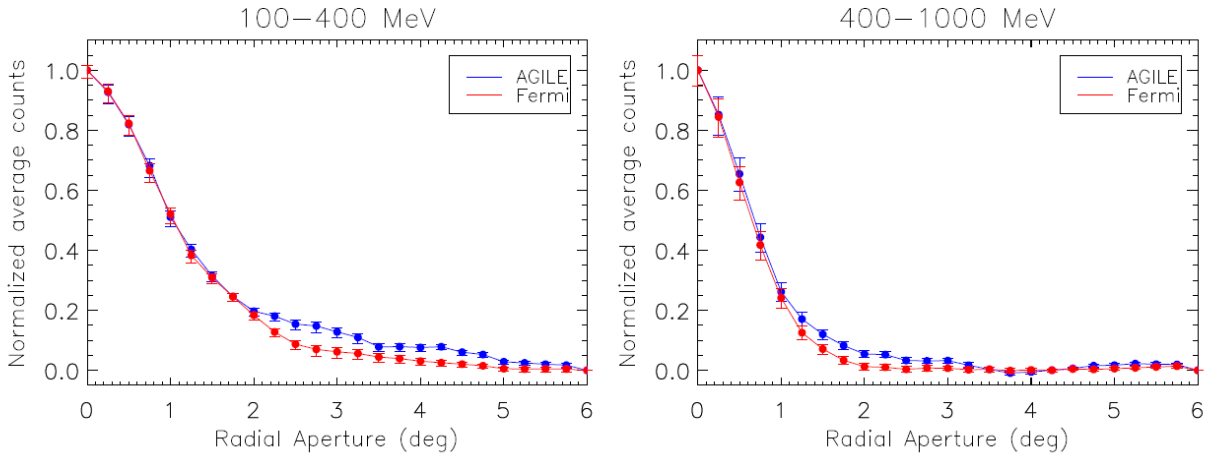


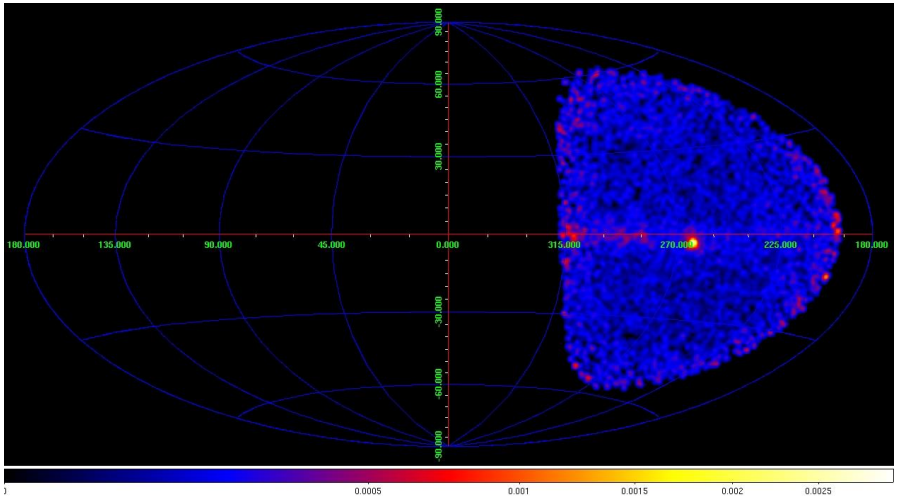
Figure 8. Average count radial profiles for circular apertures of increasing radii at steps of 0.25 of the Crab (pulsar + Nebula); in-flight data for the *AGILE*/GRID (blue data points) and *Fermi*/LAT (red data points). Left panel: 100–400 MeV energy range. Right panel: 400–1000 MeV energy range.

=>**photon-by-photon data**

The "two" AGILE lives

- **Pointing mode till Nov 2009, 60° radius FoV**

coverage:1/5 of the sky



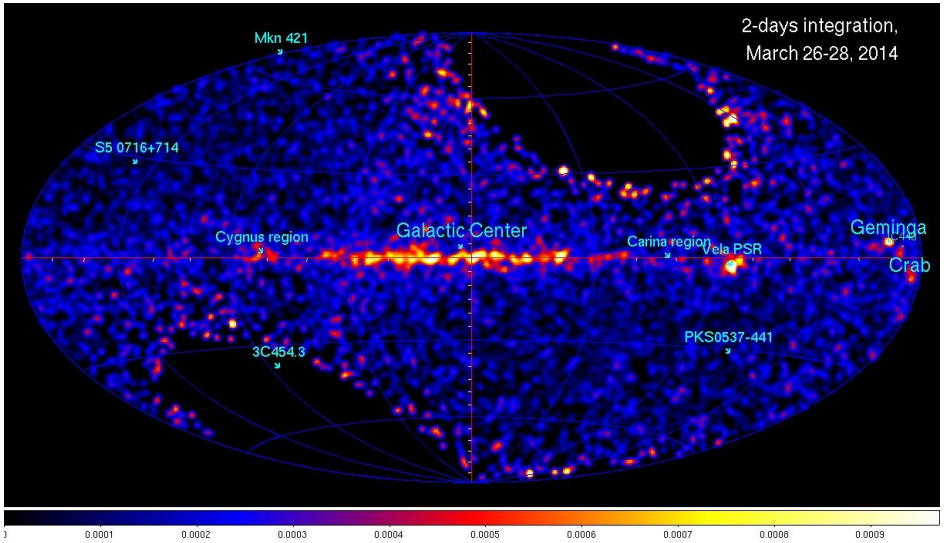
2d exposure

- **Spinning mode after,**

sky scanning (with solar panels constraints)

coverage: about 80% of the sky in

~ 7 min



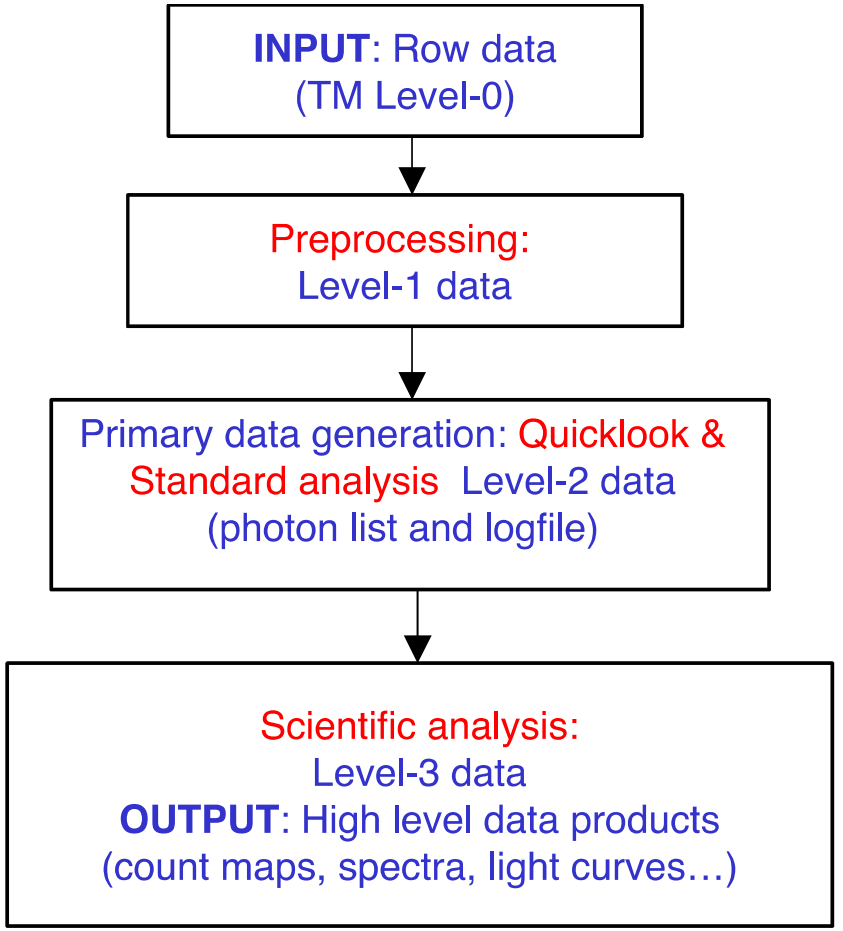
2d exposure

- The ADC, based at SSDC c/o ASI-HQ (Rome), is in charge of all the scientific oriented activities related to the analysis and archiving of AGILE data:

the processing and archiviation of all the data levels, from scientific telemetry (TM) Level-0,

- Preprocessing ->Level-1
- Creation of main archive -> Level-2 (photon lists and spacecraft files), within Quick-Look & Standard analysis
- Scientific analysis -> Level-3 scientific maps (counts, exposure and diffuse gamma-ray background maps), for various procedures

->source detections (positions, flux and significances), spectra, light curves



AGILE Science Alert System

- The system is distributed among the ADC @ SSDC and the AGILE Team Institutes (Trifoglio, Bulgarelli, Gianotti et al.)
- Automatic Alerts to the AGILE Team are generated within **T_0 + 100 min (GRID)**
- GRID Alerts are sent via email (and sms) both on a contact-by-contact basis and on a daily timescale
- Refined manual analysis on most interesting alerts performed every day (daily monitoring) by dedicated advocates

Standard procedure for AGILE-GRID gamma-ray "all data" catalogues:

catalog of sources on incremental exposure time

0) LV2 archive update: event list creation =>AGILE "event filter" based on a Kalman filter
→select event of different class types having decreasing probability to be a photon

a) **Level-3 scientific products: creation of scientific maps** (counts, exposure and diffuse gamma-ray background maps) on the "whole dataset", integrated, centered at **HEALPix** pixels, in standard full band **E > 100 MeV**, and in a set of sub-bands to later evaluate source spectra

b) Preliminary blind search algorithmS: "source candidate positions" (feeds) extraction, AGILE "spotfinder", Ximage/detect, SExtractor -> candidate source list

c) scientific analysis: AGILE "multi-source" Maximum Likelihood Estimator (MLE) analysis, evaluating Test Statistics (TS) build as the ratio of the ML functions for the null (background only) and the alternate (source presence) hypotheses. Evaluate source parameters (position, significance, flux, spectral index and errors) and diffuse emission parameters **=>iterative algorithm, but due to high number of sources & to reduce the parameter space, we execute an iterative procedure:**

- **First step:** evaluate first guess for source fluxes and then SINGLE source position refinement and galactic diffuse parameters, keeping fixed a mean spectral index (-2)
- **2nd step:** repeat flux and significance evaluation at fixed position&diffuse par. ->reiterate (?)
- **Final:** estimation of spectra for most significant sources

Concluding source selection based on significance and MLE 95% c.l position contours

Other types of catalogues

II: AGILE-GRID gamma-ray "all data" catalogues of preselected class of sources

In this case source positions are known in advance -> mainly execution of MLE **at fixed position** with a **lower significance threshold** (≥3σ) and/or allowing positions refinement for specific class of sources

=>For Pointed observations:

III: AGILE-GRID gamma-ray "single observations":

Similar procedure as first type of catalog but on usually a single or few maps; known dependence of source detection with the off-axis angle with respect of the map center

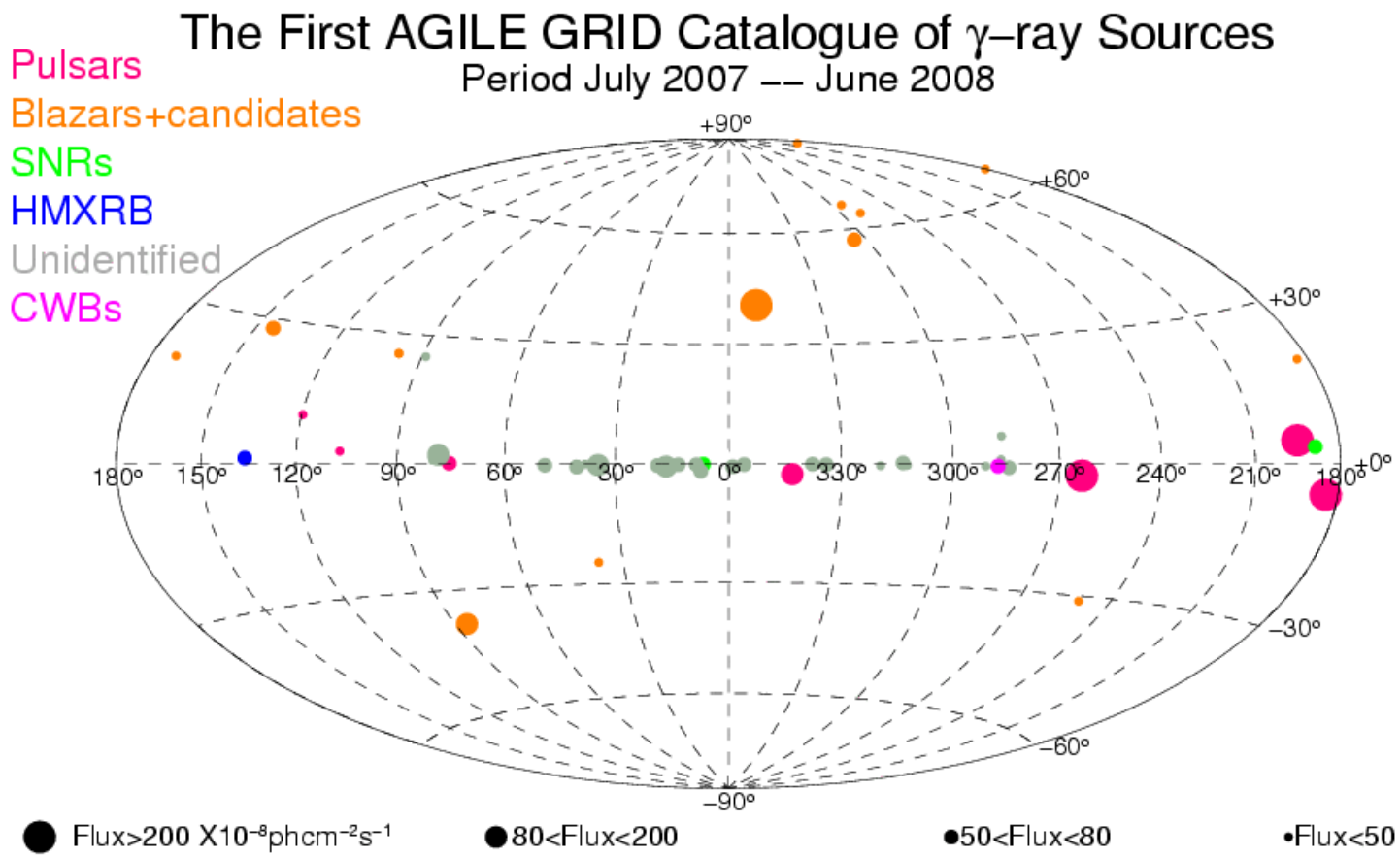
Review of AGILE-GRID catalogues on long integration time scales…..
….not exhaustive:

→all on Pointing mode

→not considering transients (days)

Treasures in a complete GRID archive still not completely investigated

All catalogs on-line version from ADC web page http://agile.ssdc.asi.it/



C. Pittori et al., A&A 506, 2009

47 high confidence 1AGL sources E> 100 MeV:

- 21 confirmed and candidate **Pulsars**,
- 13 **Blazars** (7FSRQ, 4BL Lacs, 2 unknown type),
- 2 possible **HMXRB**s,
- 2 possible **SNR**s,
- 1 **Colliding-wind Binary System** (Eta-Car)
- 8 «**Unidentified**» sources.

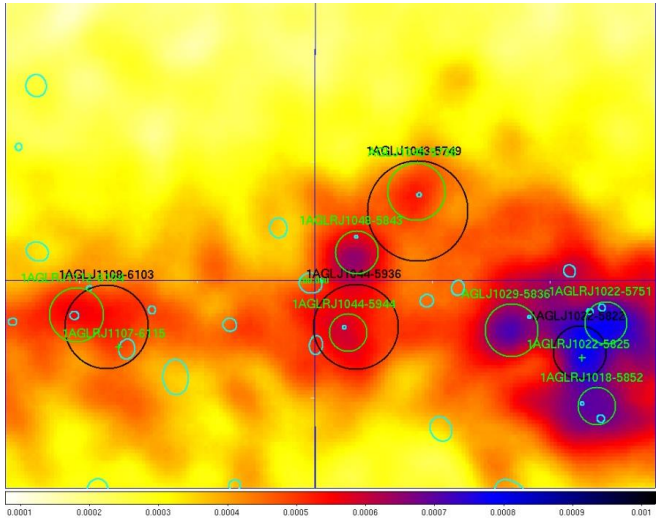
An updated list of AGILE bright γ-ray sources and their variability in pointing mode

(F. Verrecchia et al., 2013, A&A, 558, A137)

Variability study of an **improved source list** compared to 1AGL, preliminarly revised on the 2.3 yrs “all data” maps of the whole AGILE pointed observations (OB)

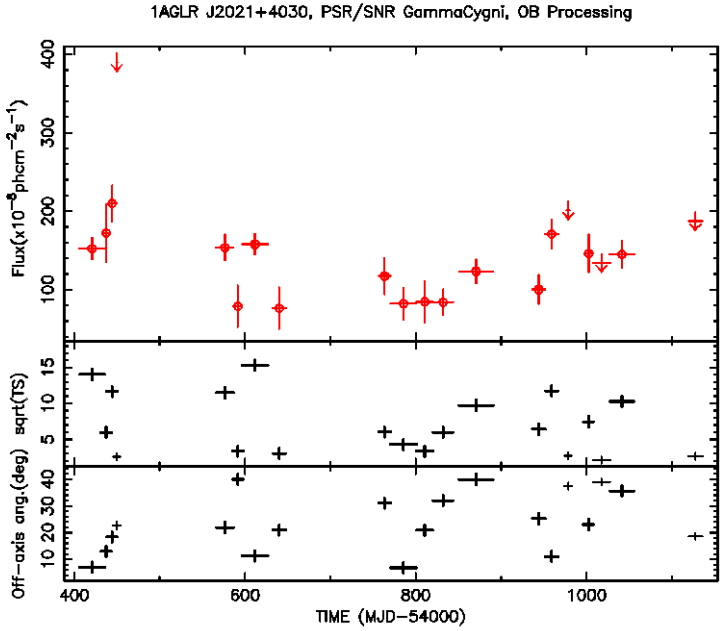
No complete source blind search executed, similar to type II catalogues

Refined positioning of some 1AGL sources: the Carina/W2 region



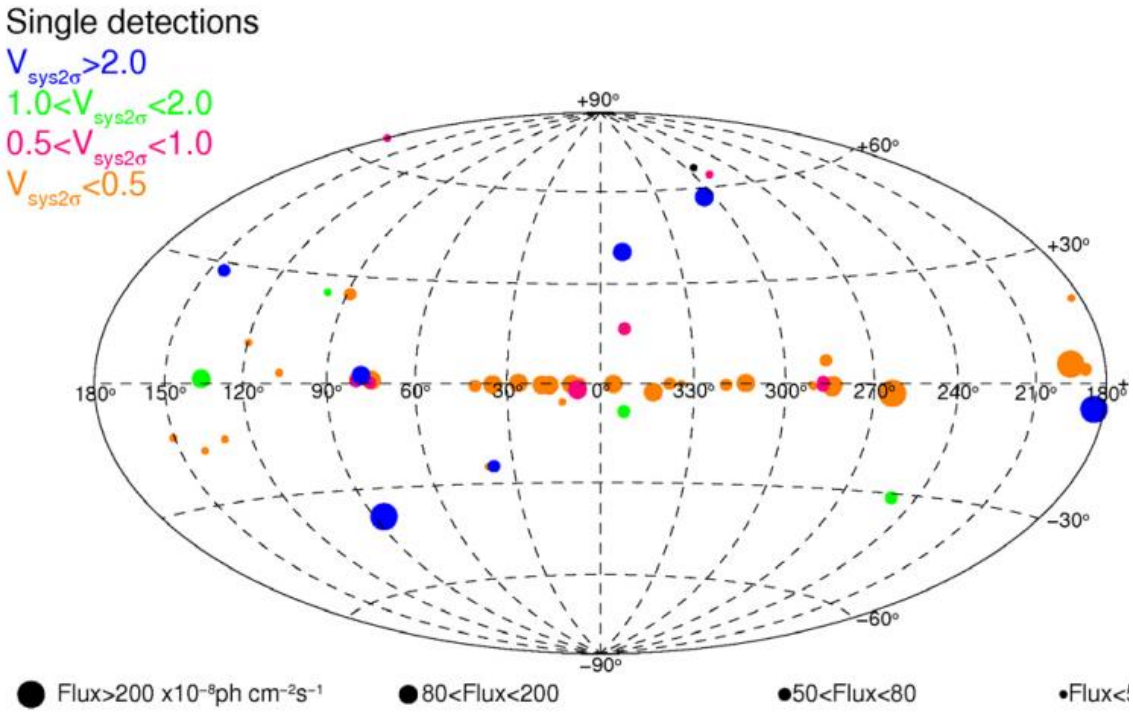
Processing of EACH SINGLE Obs (duration 1-45d) in E > 100 MeV band allowed to detect 54 sources, among which 15 new one =>variability results

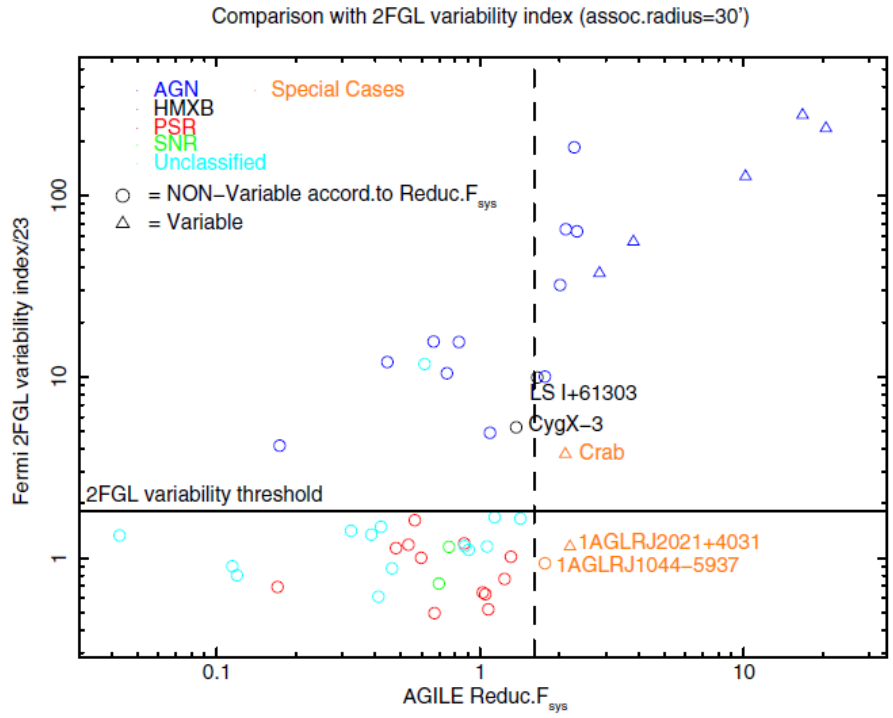
OB time scale light curves →



An updated list of AGILE bright γ-ray sources and their variability in pointing mode

Variability indices compared with 1FGL, 2FGL: 12 well known variable sources, named **1AGLR**





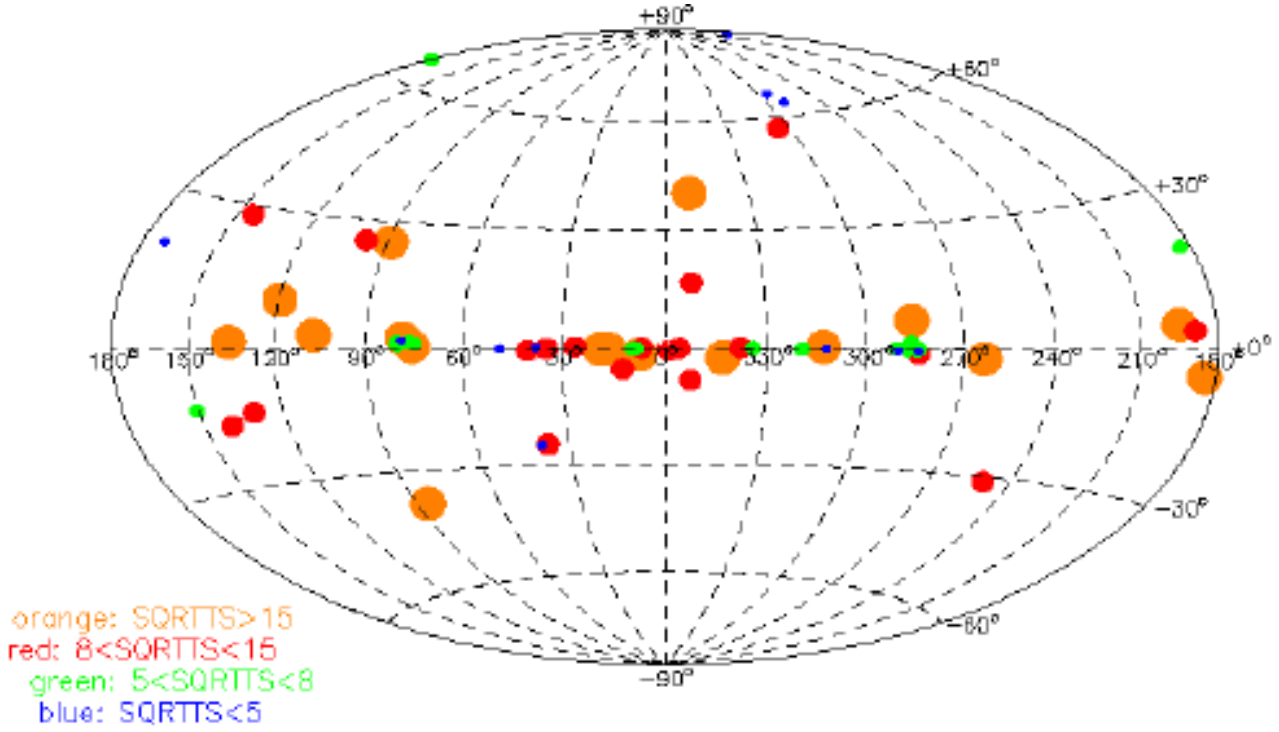
No mean fluxes on “ALL data” maps published.

The AGL-ALL catalogue project: incremental catalogue

The 1AGLR lack of updated **mean fluxes** on all pointing data => new calibration delivered so need to have homogeneous “mean” source parameters.

Executed a data processing in E > 100 MeV band on an input list of 65 1AGL + 1AGLR sources on new Pointing dataset maps generated with new calibration

=>defined a new procedure at fixed source position (cat of type II)



Results:

61/65 significant 1AGL/1AGLR,

4 sources not detected,

=>flaring sources or too weak

Source list presented at 2015 13th AGILE Workshop

Then updated with new sources from specific publications

Search of MeV-GeV counterparts of TeV sources with AGILE in pointing mode

A. Rappoldi, F. Lucarelli, C. Pittori, F. Longo, P.W. Cattaneo, F. Verrecchia, et al., A&A, 2016

Exploring TeV-GeV connection

TeV sources input list: 147 Tev source positions taken from the **TeGeVCat** (Carosi et al. 2016 ->previous Lucarelli's talk)

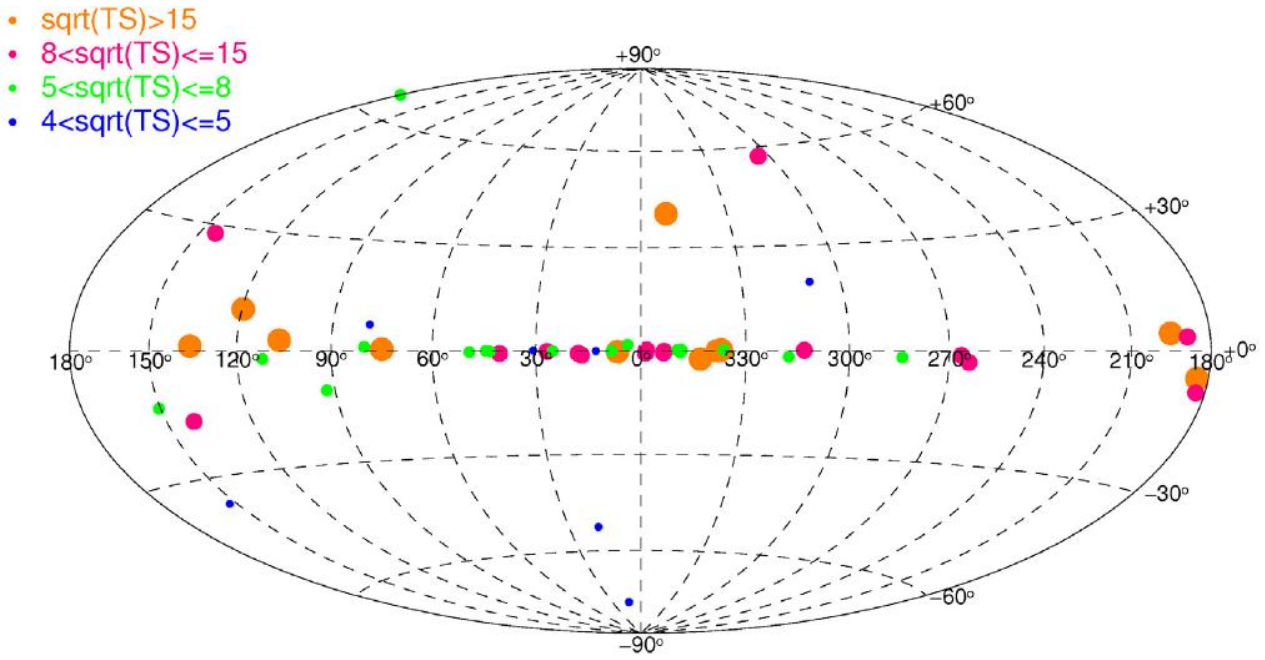
Procedure: type III catalogue

- dataset: the **pointing mode** observations (Jul 2007—Oct 2009)
- Input list of TeV source + AGL-ALL reference list
- Iterative analysis procedure based on MLE with source detection and
- localization in two steps
  - fixed position (at the TeVCat coordinates)
  - free position (near to the original one)
- Spectral analysis for the most significant ones

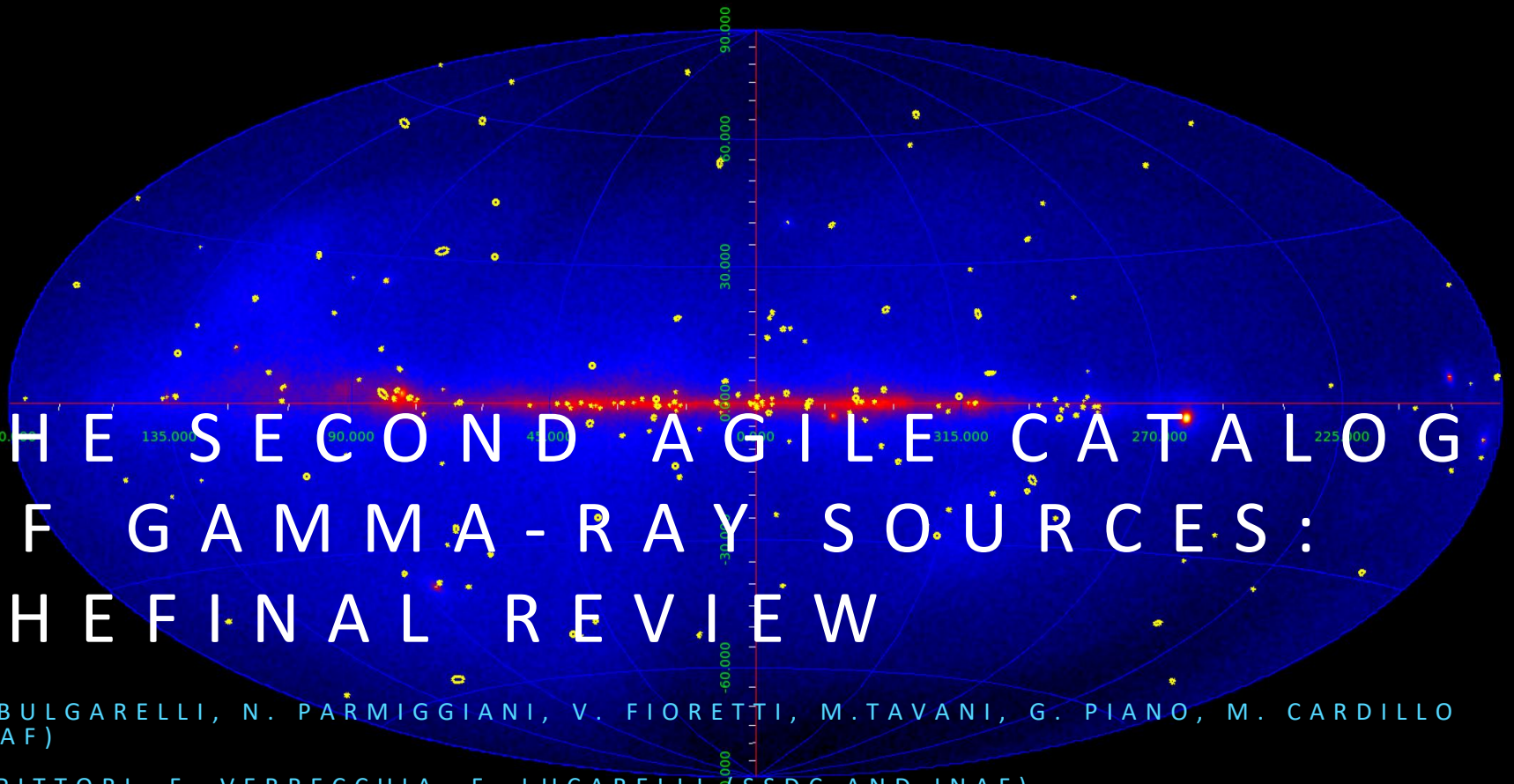
for TeV source counterparts search possible displacement was investigated, comparing it with TeV source "extension" and poor angular resolution

Results: known and new sources

- **52** TeV sources show a significant *count excess* in the AGILE data in pointed observations period, 35% of the original sample
- **26** have a spatial association with already known AGILE sources from 1AGL/1AGLR catalogs: 15 galactic, 6 extra-galactic, 5 unassociated
- **26** detections represent new AGILE sources (with respect to the reference catalogs): 15 galactic, 7 extra-galactic, 4 unidentified



Source Type	*Detected / Total*	*Source Class*	*Detected / Total*
Extra-galactic	13 / 61 (21%)	Blazar	0 / 1 (0%)
		HBL	5 / 44 (11%)
		IBL	2 / 5 (40%)
		LBL	2 / 3 (67%)
		FSRQ	2 / 3 (67%)
		Sbs	0 / 2 (0%)
		FRI	2 / 3 (67%)
Galactic	30 / 58 (52%)	PWN	11 / 28 (39%)
		SNR	7 / 11 (64%)
		PWN/SNR	2 / 2 (100%)
		SNR/MC	5 / 8 (63%)
		BIN/XRB	3 / 5 (60%)
		GC	1 / 1 (100%)
		WR	1 / 3 (33%)
Unidentified	9 / 28 (32%)	---	---



THE SECOND AGILE CATALOG OF GAMMA-RAY SOURCES: THEFINAL REVIEW

A. BULGARELLI, N. PARMIGGIANI, V. FIORETTI, M.TAVANI, G. PIANO, M. CARDILLO (INAF)

C. PITTORI, F. VERRECCHIA, F. LUCARELLI (SSDC AND INAF)

A. RAPPOLDI, P. CATTANEO (INFN-PV)

A. ABOUDAN (CISAS)

- The 2th AGILE Catalog of gamma-ray sources: the final review

Evolved a lot through the last years following various calibration versions and sw improvements.

After development of new BUILD sw (SCI) and new calibration files (IRFS)

- AGILE/GRID observations covering the time period July 4, 2007, to October 15, 2009 (**the AGILE POINTING MODE**).
- The analysis is based on data in the
  - 100 MeV to 50 GeV energy range
  - A check in the "*low*" energy range 30 MeV - 100 MeV has been performed for the most significant sources
- Source detection is based on the integrated data set, i.e., sources are detected according to their average fluxes over about 27 months.

UPDATES

- A long path:
  - The catalog adopts now different spectral shapes
    - Simple Power Law
    - Power Law with exponential cutoff
    - Power Law with super exponential cutoff
    - Log Parabola

$$\frac{dN}{dE} = N_0 \left(\frac{E}{E_0}\right)^{\gamma}$$

$$\frac{dN}{dE} = N_0 \left(\frac{E}{E_0}\right)^{\gamma_1} \exp\left(-\left(\frac{E}{E_c}\right)\right)$$

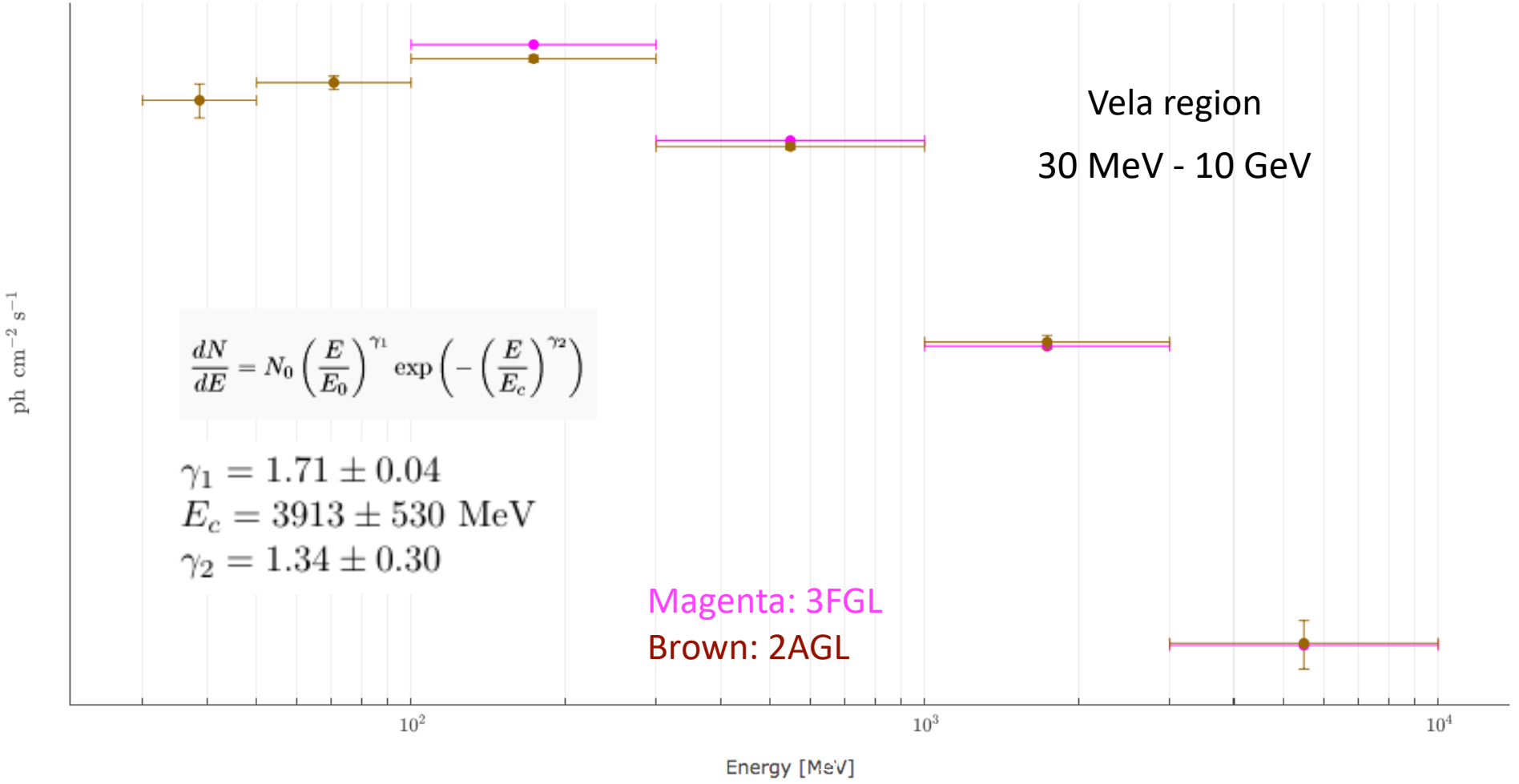
$$\frac{dN}{dE} = N_0 \left(\frac{E}{E_0}\right)^{\gamma_1} \exp\left(-\left(\frac{E}{E_c}\right)^{\gamma_2}\right)$$

$$\frac{dN}{dE} = N_0 \left(\frac{E}{E_b}\right)^{-(\alpha+\beta\log(E/E_b))}$$

  - The NEW BUILD25 (AGILE/GRID Science Tools) has been used, that include also the energy dispersion correction factor (EDP)
  - New Instrument Response Functions: H0025 -> energy range

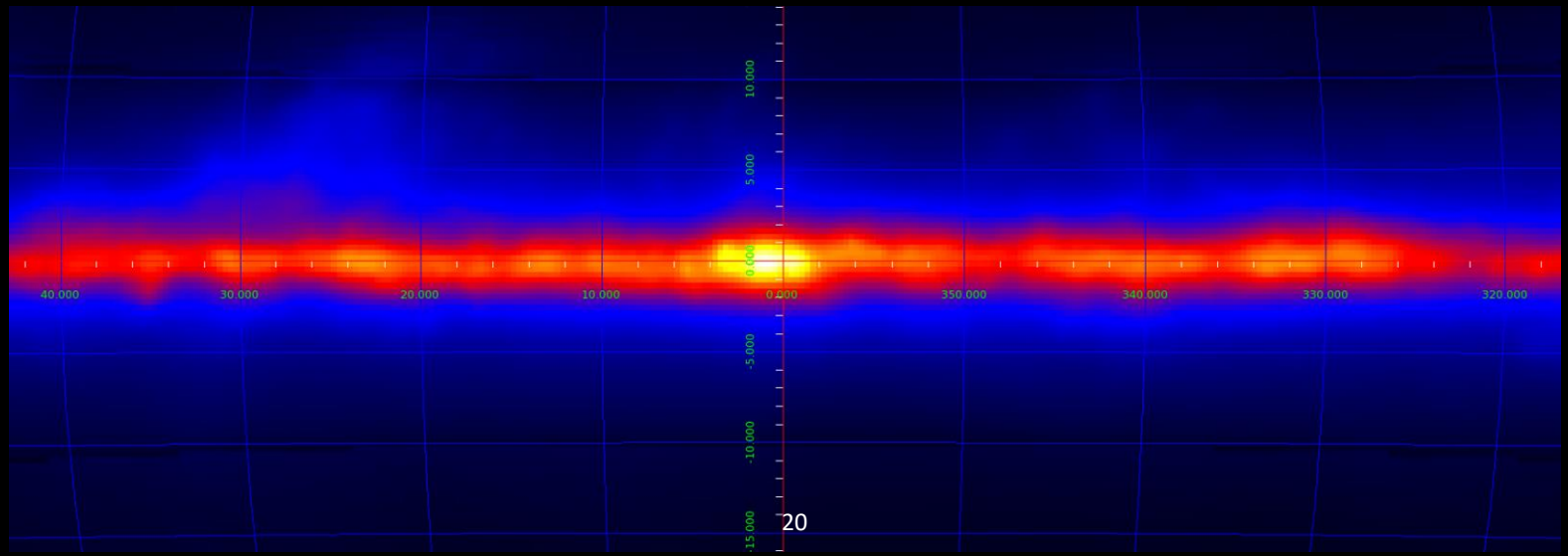
➔spectral comparison with Fermi/LAT: same spectral bins till 10GeV

NEW BUILD25: CURVED SPECTRAL ANALYSIS



- Cross check with previous BUILD22@SSDC: only confirmed detections are included in the catalog

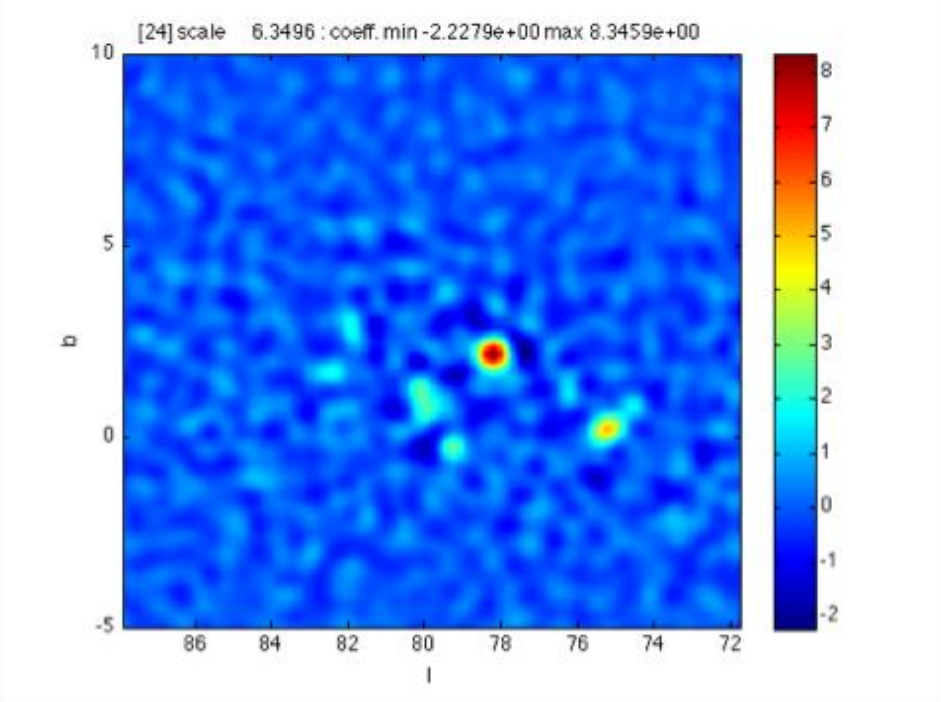
- The gamma-ray diffuse model used in the analysis has been improved. The diffuse model is particularly important for sources from low to mid Galactic latitudes.

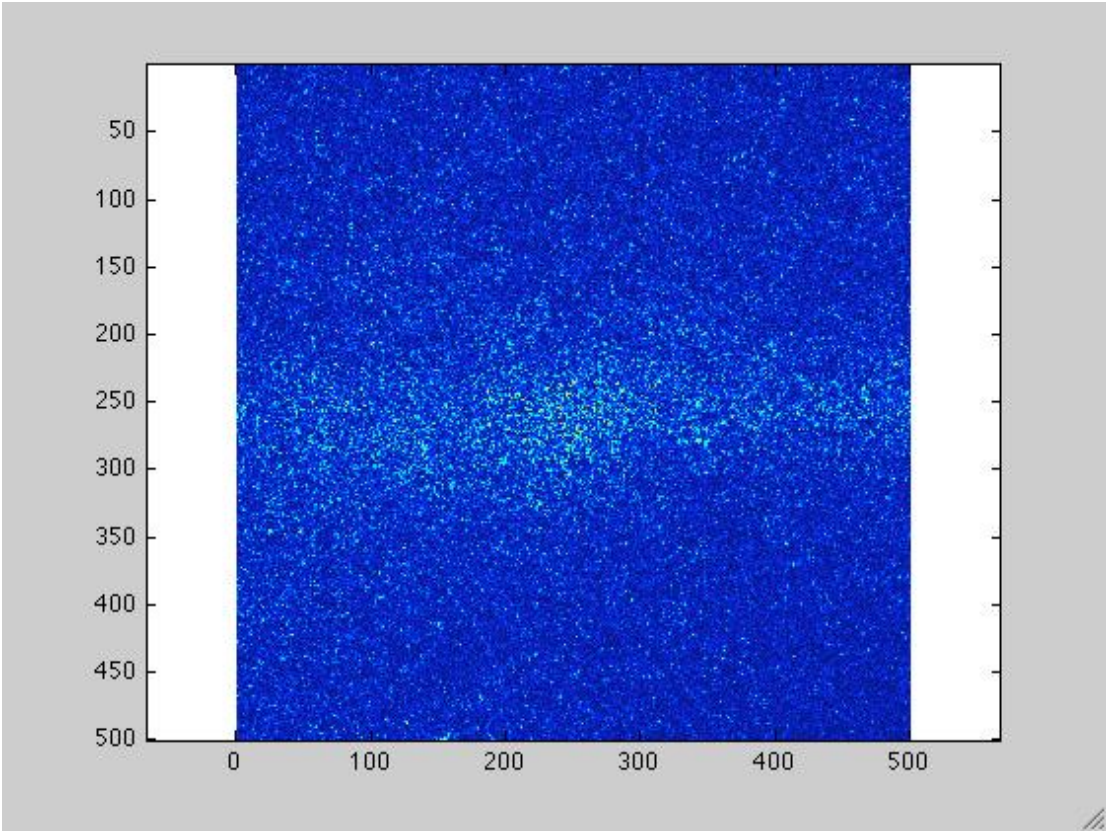


First step: the seeds

source blind search

WAVELET ALGORITHM (THE SEED METHOD N° 1)





Second step

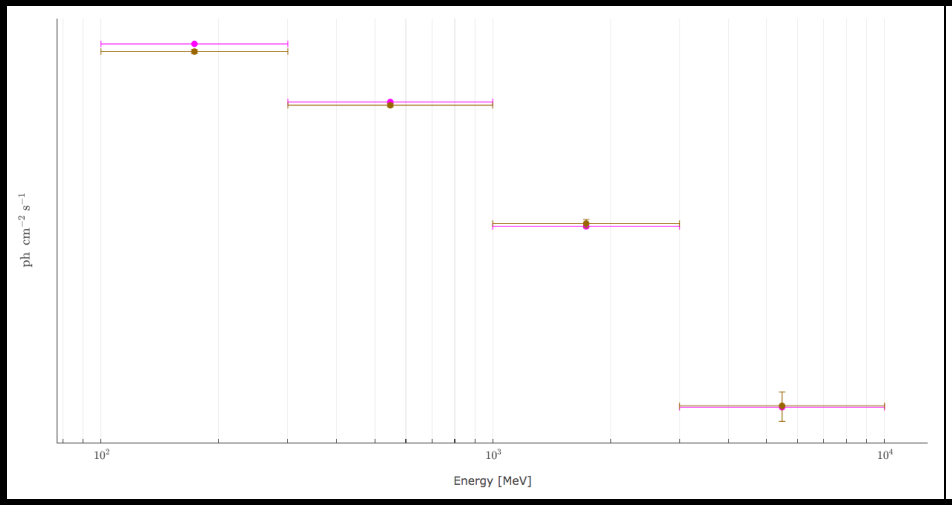
MANUAL ANALYSIS

- From the list of seeds using all methods…
  - Manual analysis
  - Final determination of position and flux

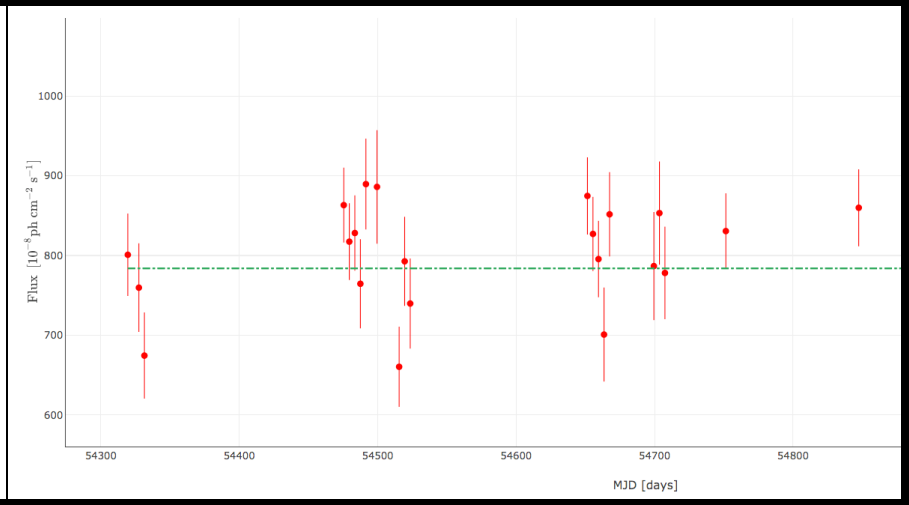
Third step

CHECK THE RESIDUAL TS MAP

PRODUCTS



Spectra (100-10000 MeV)



Light curves (4 days)

Curvature Index

Lets TS_0 the value of TS evaluating all the time bins at the same time but considering a constant flux, TS_1^i the value of TS optimizing the flux in each period of time i.

The variability index is

$TS_{var} = \sum_{i=1}^{N} TS_1^i - TS_0$

If the null hypothesis is correct TS_{var} is distributed as χ^2 with N degrees of freedom, and a value of $TS_{var} > h(N)$ is used to identify variable sources at a 99% confidence level.

It is possible to introduce a corrective factor (similar to (Nolan 2012)):

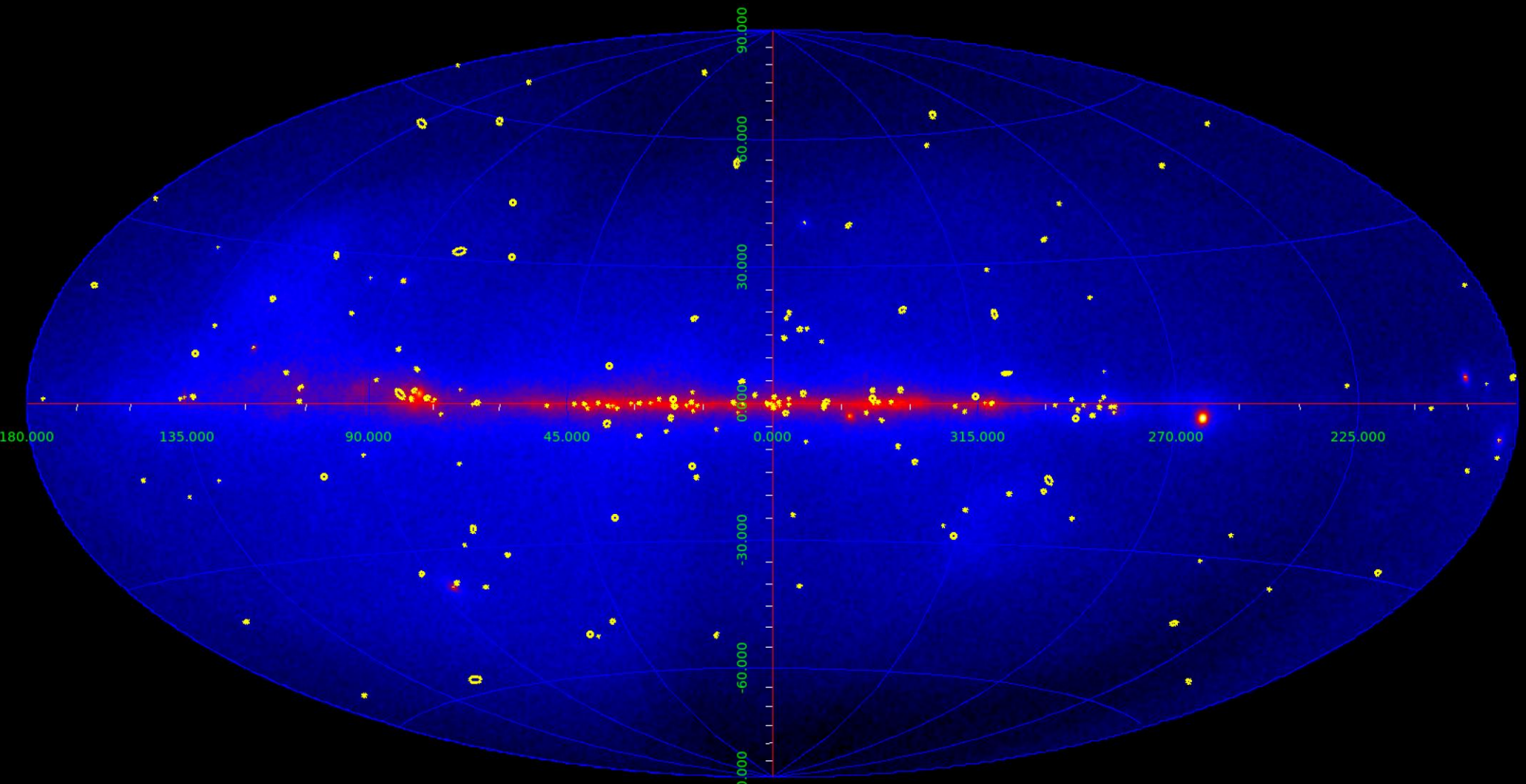
$TS_i^{corr} = F_{sigma_i}^2/(F_{sigma_i}^2 + f^2 * F_0^2)$

We consider $f = 0.01$ in our analysis. The variability index is

$TS_{var}^* = \sum_{i=1}^{N}(TS_i^{corr} * TS_1^i) - TS_0$

Variability Index

RESULTS



190 2AGL sources

PRELIMINARY ASSOCIATIONS

- Positional coincidence only
- These associations are not in general to be taken as firm identifications: a physical relationship is not established between gamma-ray sources and sources in other wavelenghts.
- 20 AGILE-only (no 3FGL) sources

AGN

Description	number
BCU (Blazar candidate of uncertain type)	10
BLL (BL Lac type of blazar)	17
FSRQ (FSRQ type of blazar)	31
RDG (Radio galaxy)	2 (CenA, NGC1275)
BIN (Binary)	1 (Eta Carinae)
GLC (Globular cluster)	1 (Terzan 5)
HMB (High-mass binary)	3
PSR (positional only)	50
PWN	3
SNR	9
SPP	7
	134

HMB (High-mass binary)	LSI+61 303, 1FGLJ1018.6-5856, Cygnus X-3
SNR	IC443, CTB37A, W28, W30, W44, W49B, W51, GammaCygni, HB21
PWN	Crab Nebula, HESSJ1632-478, PWNG0.13-0.11)

FUTURE:

- New catalogue «integrated» maps: including Spinning mode data

→lower acquisition efficiency, currently used in specific work

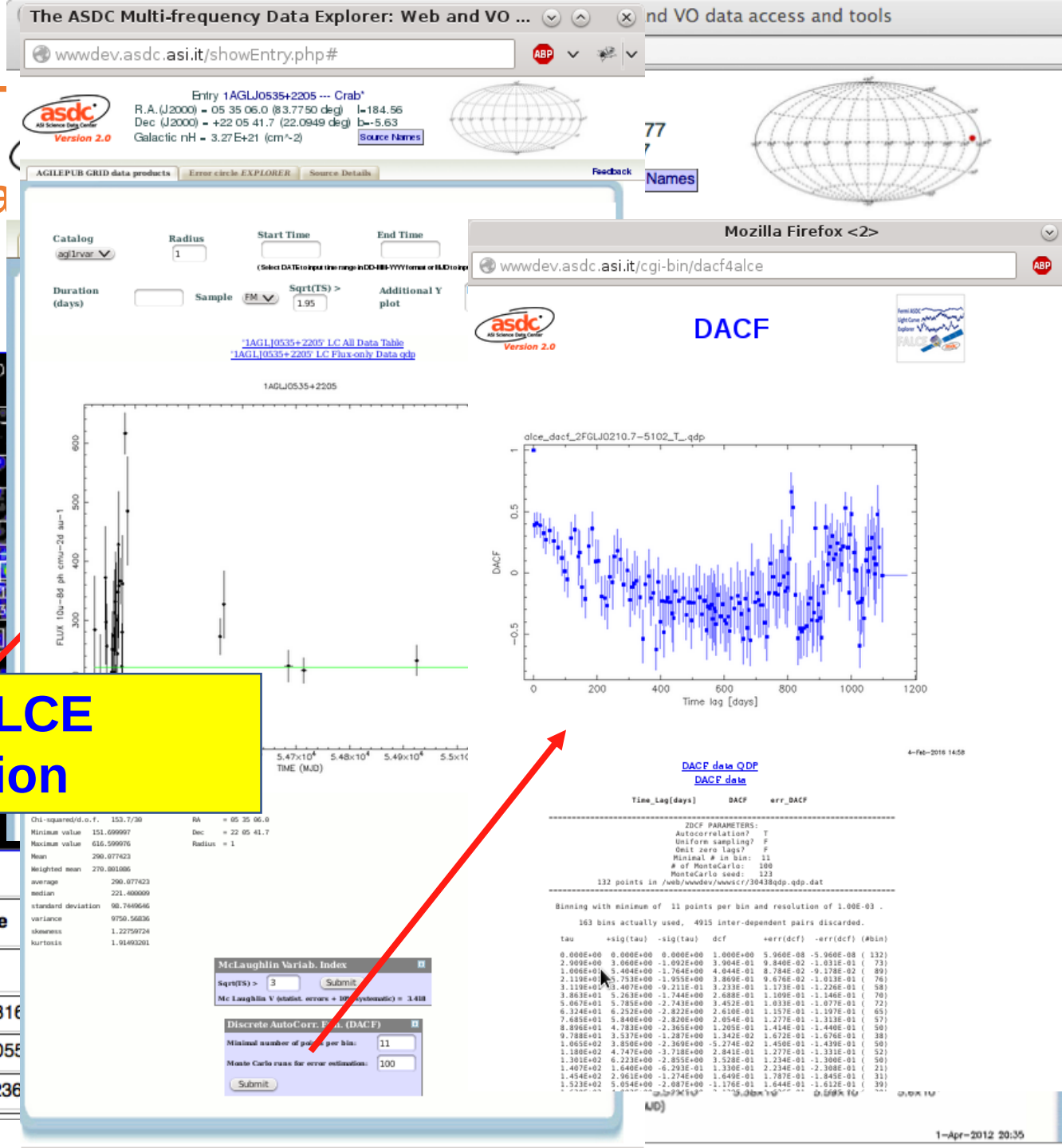
- New homogeneous «transient» source catalogue: on both archives ; Variability catalog(s) based on experience from 2AGL

and using ADC light curve tool (ALCE) and LV3 tool (Lucarelli's talk)

SSDC Data Explorer

Quick Look AGILE da

Example of the ALCE Tool, simple version

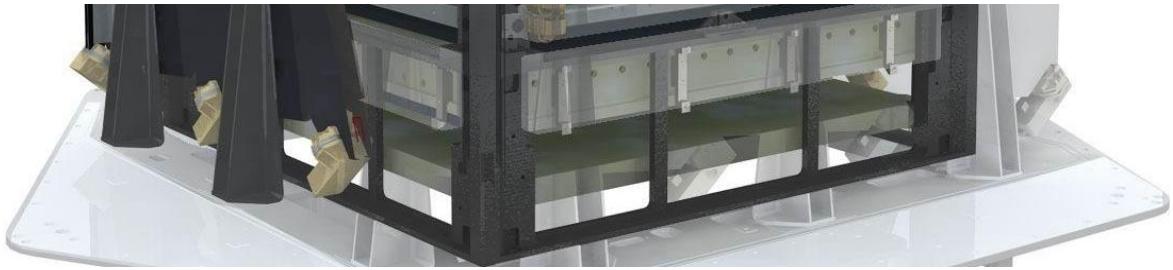


Available parameters

- Name
- Ra
- Dec
- Gal
- Iso
- Cnts
- Cnts Err.
- Sqrt(TS)
- XimageId
- Flux
- Flux Err
- Distance from FOVCent.
- Ximage
- SNR
- Sp_Index
- Err_sp_index
- Other_name1

Entry number		AGILE name
Selection mode: inclusive		Stat
1 Select	ASDC Data Explorer	AGL J0634+1816
2 Select	ASDC Data Explorer	AGL J1049+8055
3 Select	ASDC Data Explorer	AGL J0832-1236

MCAL catalogues

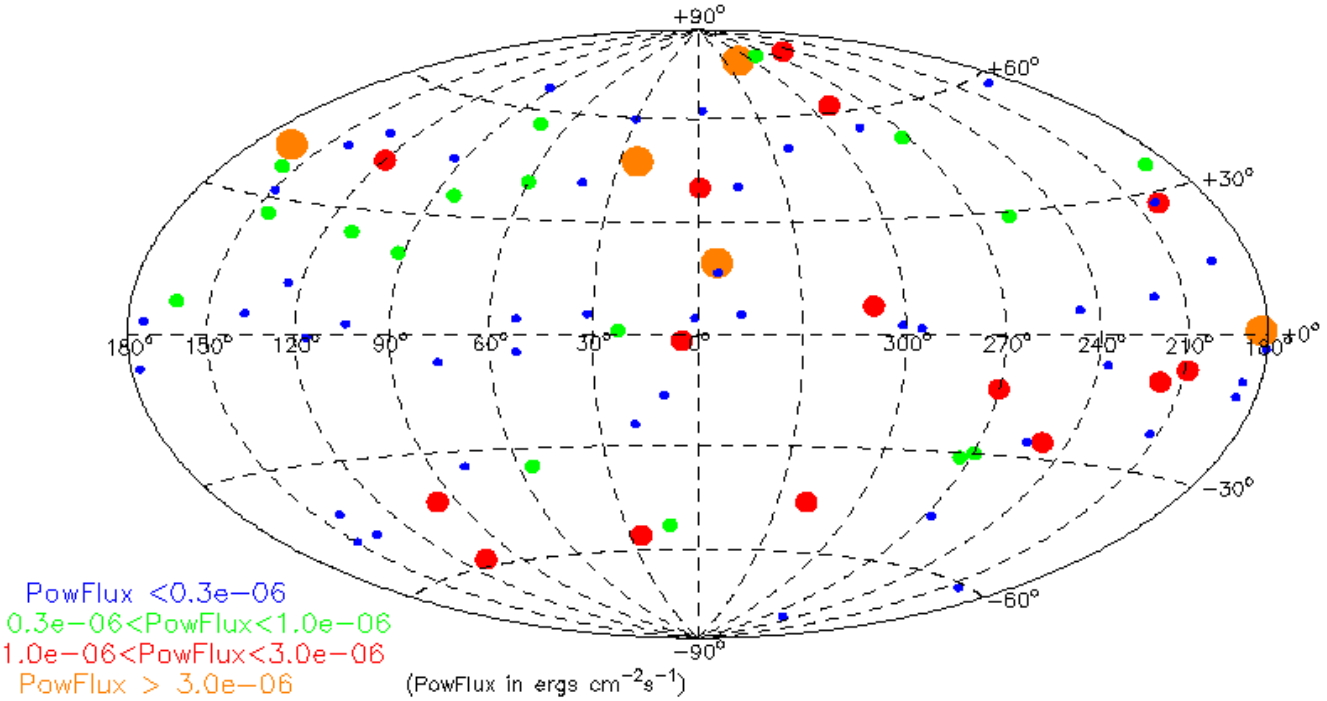


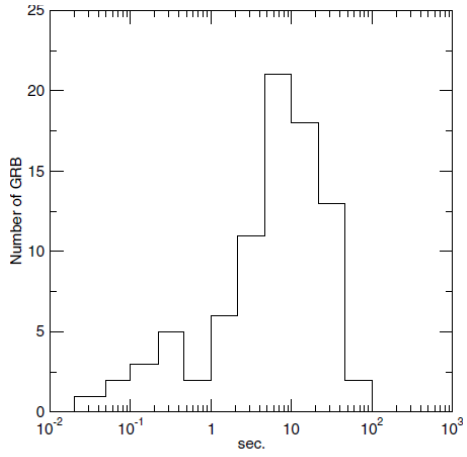
MCAL GRB Catalog

(M. Galli et al., 2013)

Photon-by-photon data from launch till Oct 2009: high-energy emission from GRB. →detected 85 GRB, 24 with spectral data

- Similar bimodal T90 distribution to lower energies, with 21% short GRB

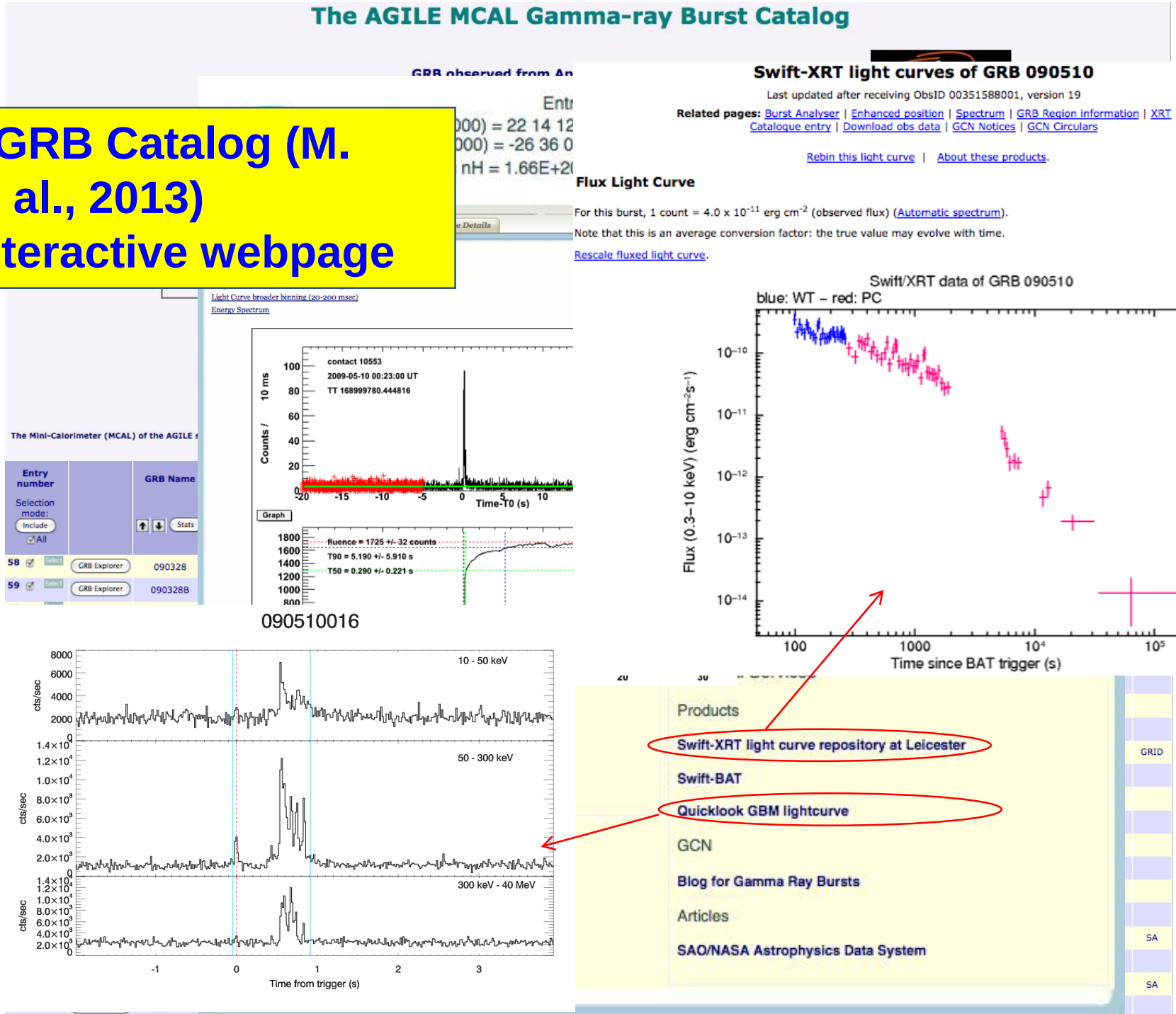




. 3. T_{90} distribution.

→a new catalog is in progress after development of new pipeline for GW counterpart searches

MCAL GRB Catalog (M. Galli et al., 2013) ADC interactive webpage



MCAL Terrestrial Gamma-ray Flash Catalogs

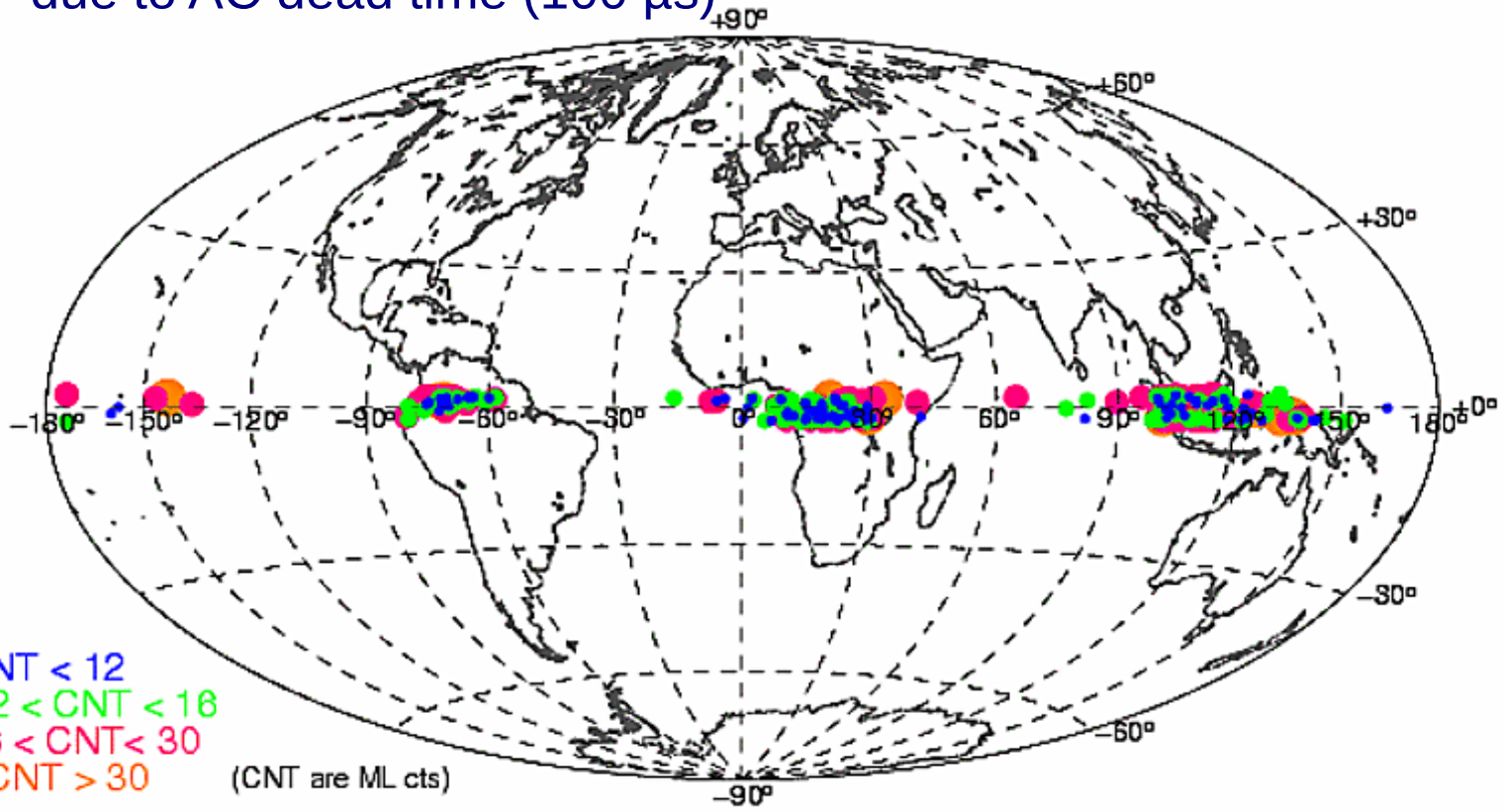
First catalog of MCAL TGF published in Marisaldi et al. 2014

"**Properties of Terrestrial Gamma-Ray Flashes detected by AGILE MCAL below 30 MeV**"

on data from March 2009 to July 2012

->detected 308 TGF below 30 MeV

- Longitudinal distribution similar to previous ones; comparison with RHESSI and Fermi/GBM sample; correlation with WWLLN radio on ground →larger durations due to AC dead time (100 μs)



Catalog web page to access light curves

and new dedicated tool

MCAL Terrestrial Gamma-ray Flash Catalogs

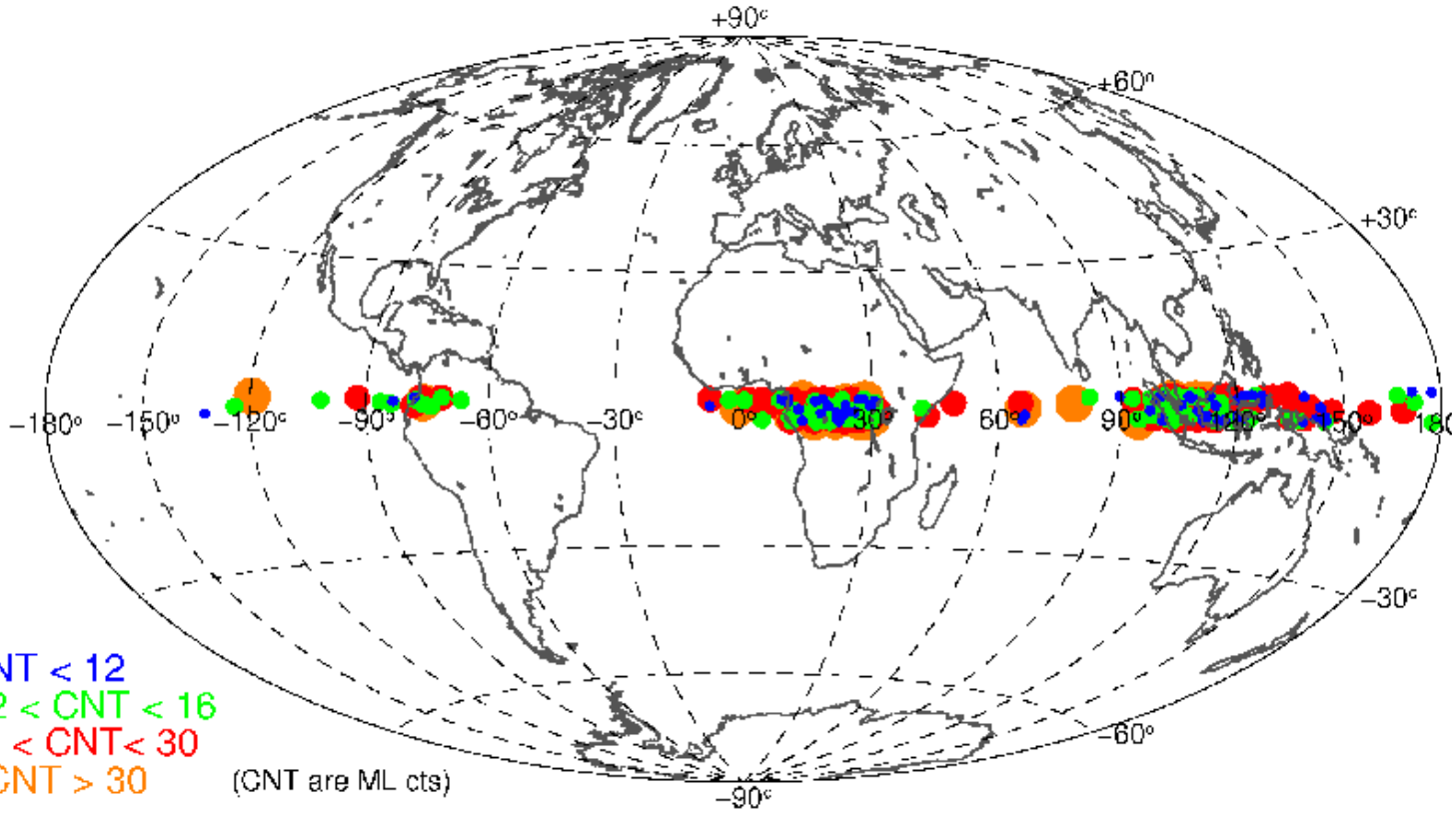
2nd catalog of MCAL TGF published in Marisaldi et al. 2015

"**Enhanced detection of Terrestrial Gamma-Ray Flashes by AGILE**"

on data from 23 March to 24 June 2015 ONLY with the AC Veto disabled!

->detected 279 TGF below 30 MeV

- TGF rate increased by 1 order of mag! Most with duration < 100 μs as expected
- First unbiased by dead time sample →correlation with Fermi/GBM sample
- Better correlation with WWLLN



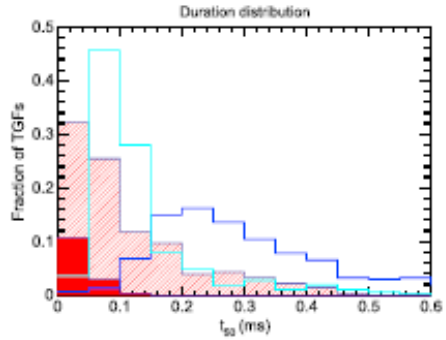


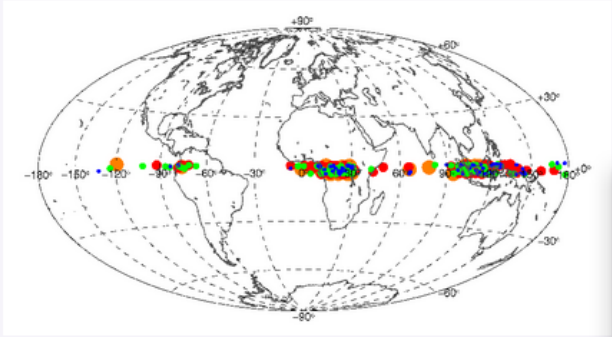
Figure 2. Normalized duration (t_{50}) distribution for the enhanced (red hatches) and standard (blue line) TGF samples. Red filled histogram: t_{50} distribution of the enhanced TGFs with a simultaneous WWLLN match normalized to the total number of the enhanced sample. Cyan histogram: Fermi GBM t_{50} distribution calculated for counts above 300 keV, from *Connaughton et al.* [2013], Figure 3.

MCAL Terrestrial Gamma-ray Flash Catalogs

Enhanced detection of Terrestrial Gamma-Ray Flashes by AGILE

TGF (E < 30 MeV) observed from March 2015 to June 2015

Help | Show/hide columns | Advanced filtering | Print current view of table | Print complete table | Reset all filters



Search table columns [Search]

M. Marisaldi et al. 2015, Geophys. Res. Lett., 42, 94819487 (2015). Doi: 10.1002/2015GL066100 - D

online version of the second AGILE Terrestrial Gamma-ray Flashes (TGF) catalog below 30 MeV detected by the Minicalorimeter (MCAL) instrument o
configuration change aimed at the inhibition of the anti-coincidence veto signal on the MCAL instrument, in order to improve the TGF detection pe
respect to the previous configuration.
The interactive web table includes 279 TGF detected by AGILE MCAL selected to have the maximum photon energy up to 30 MeV, and

Columns description

The first AGILE/MCAL TGF catalog on-line web table, Marisaldi et al. 201

Export Current view of Table in: Latex format | FITS format | Raw text format | CSV text format

Previous Page Next Page Page Size (# of lines) 200 Reset all filters Show all entries

This view includes 279 entries

Entry number (Selection mode: Include, All)		TGF ID	GeoLon	GeoLat	Date (UTC)	Trigger Time T0 (MET in s)	T0_micro (μs)	T50 (ms)
1	TGF LC	150323.44645	-1.87	0.52	2015-03-23T10:42:54	354192174	410073	86
2	TGF LC	150323.70148	-132.93	-1.04	2015-03-23T16:50:08	354214208	140446	204
3	TGF LC	150323.85364	-71.92	2.46	2015-03-23T20:29:15	354227355	550377	61
4	TGF LC	150323.96107	119.48	-1.48	2015-03-23T23:03:57	354236637	71008	27
5	TGF LC	150324.21907	3.68	-2.12	2015-03-24T05:15:28	354258928	267858	40
6	TGF LC	150324.42976	5.27	0.92	2015-03-24T10:18:52	354277132	262591	103
7	TGF LC	150324.45177	118.06	1.5	2015-03-24T10:50:33	354279033	734131	67
8	TGF LC	150324.57062	8.24	2.4	2015-03-24T13:41:42	354289302	175046	86

The SSDC TGF Data Explorer - Mozilla Firefox

www.ssdc.asi.it/explorer_TGF.php 50%

SSDC

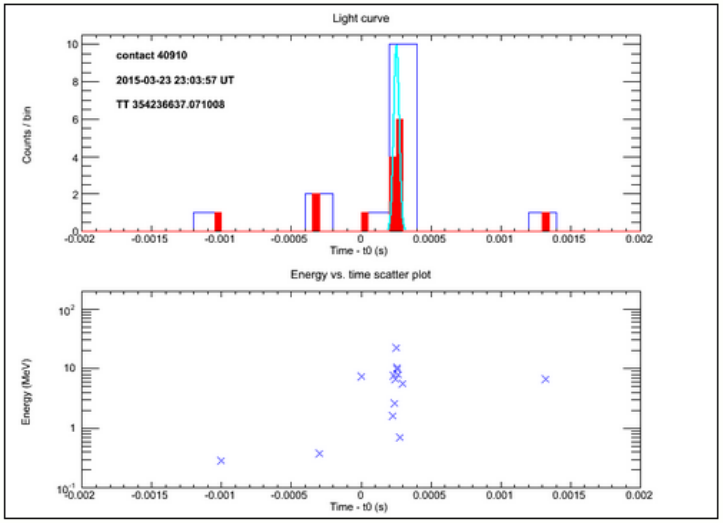
Entry 150323
GeoLong. = 119.48
GeoLat. = -1.48

AGILE MCAL Data Products | Source Details

Standard Products

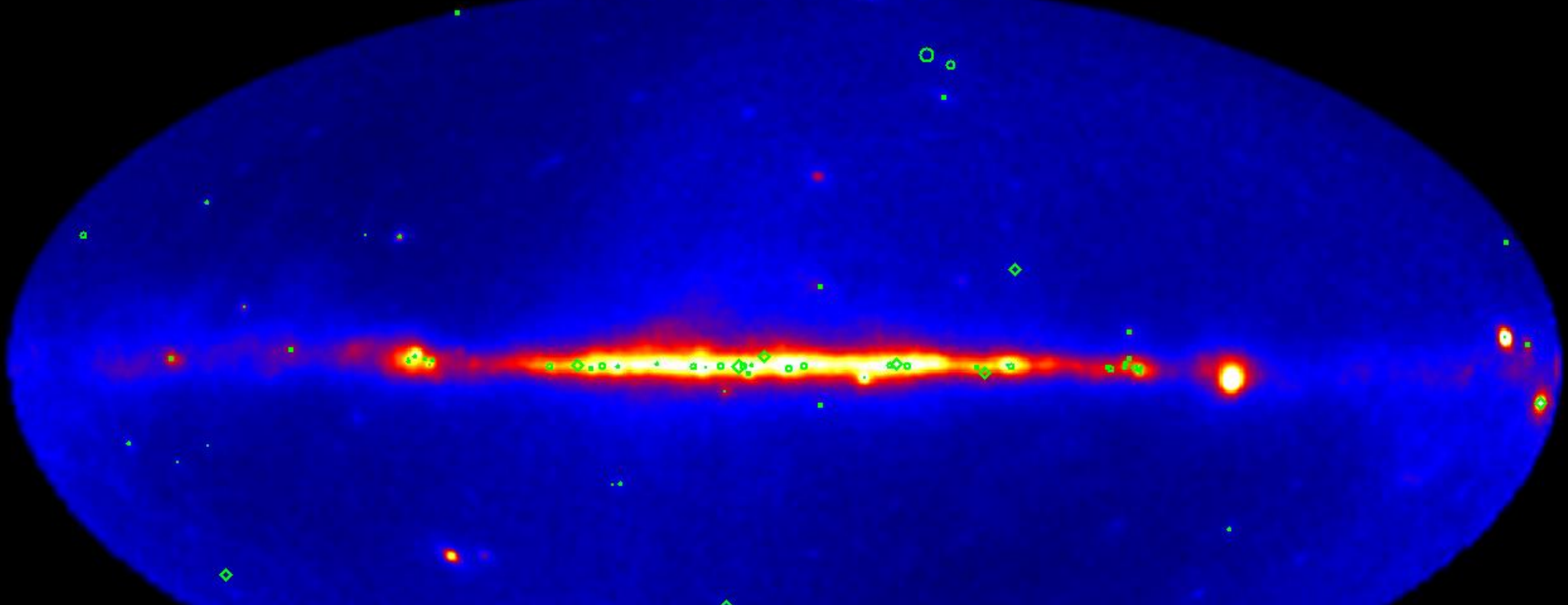
Light Curve Legend:

Blue histogram: 200 microsec time bin
Red filled histogram: finer binning 50 microsec
Cyan curve: maximum likelihood Gaussian fit



AGILE Total Intensity Map (E> 100 MeV):

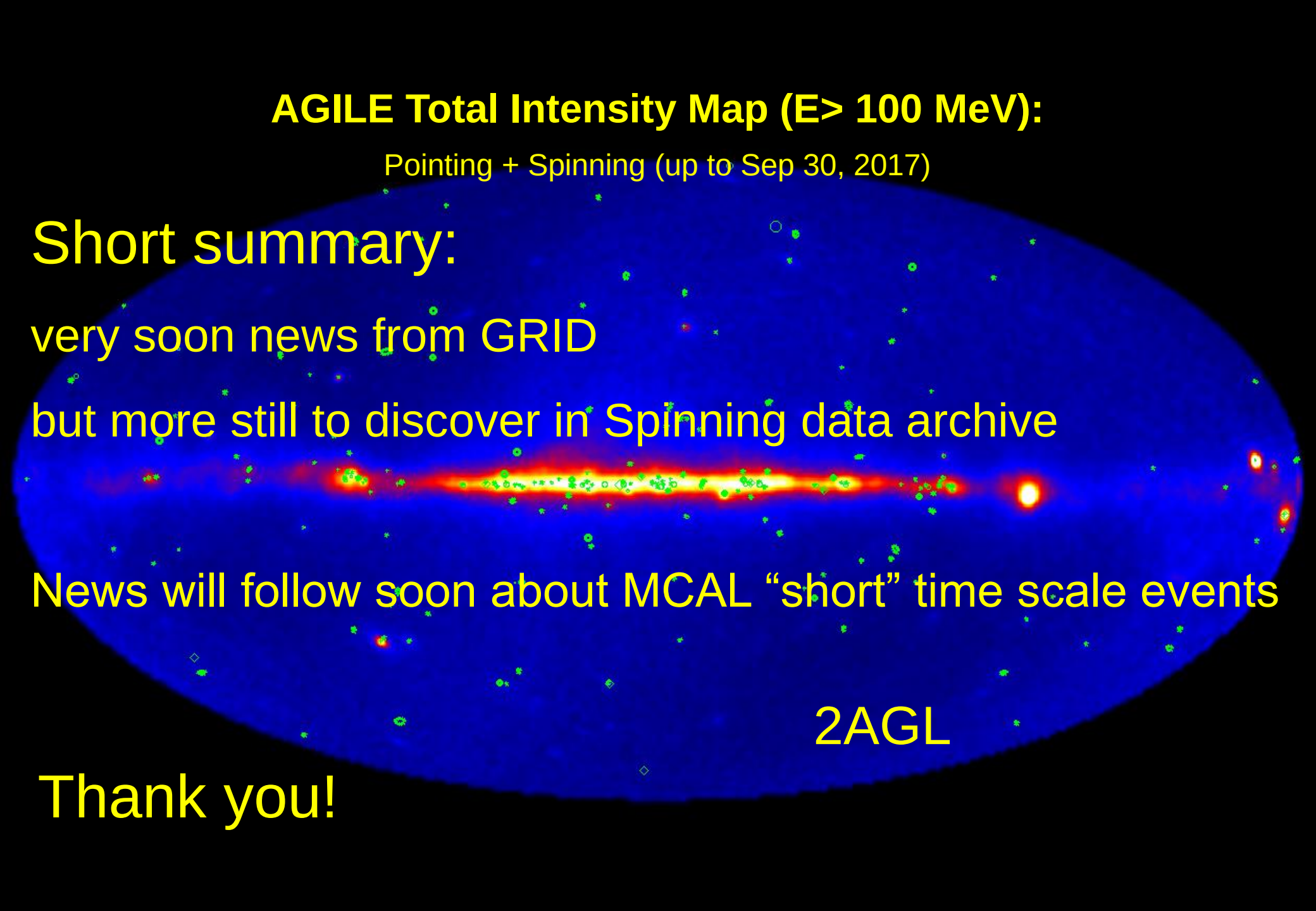
Pointing + Spinning (up to Sep 30, 2017)



AGL-ALL: 1AGL/1AGLR + some new one from TeV processing

AGILE Total Intensity Map (E> 100 MeV):

Pointing + Spinning (up to Sep 30, 2017)



Short summary:

very soon news from GRID

but more still to discover in Spinning data archive

News will follow soon about MCAL “short” time scale events

2AGL

Thank you!