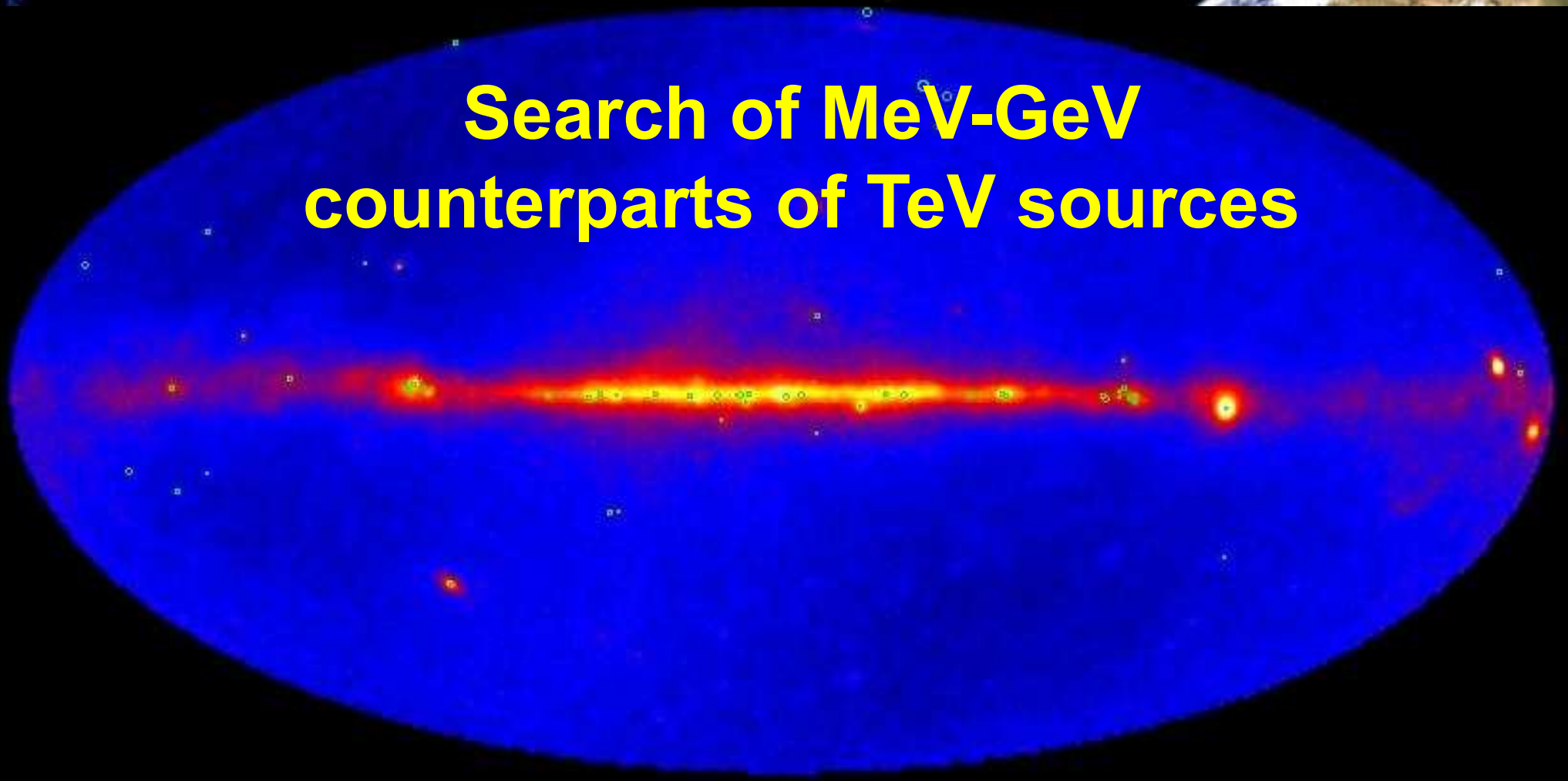
Search of MeV-GeV counterparts of TeV sources



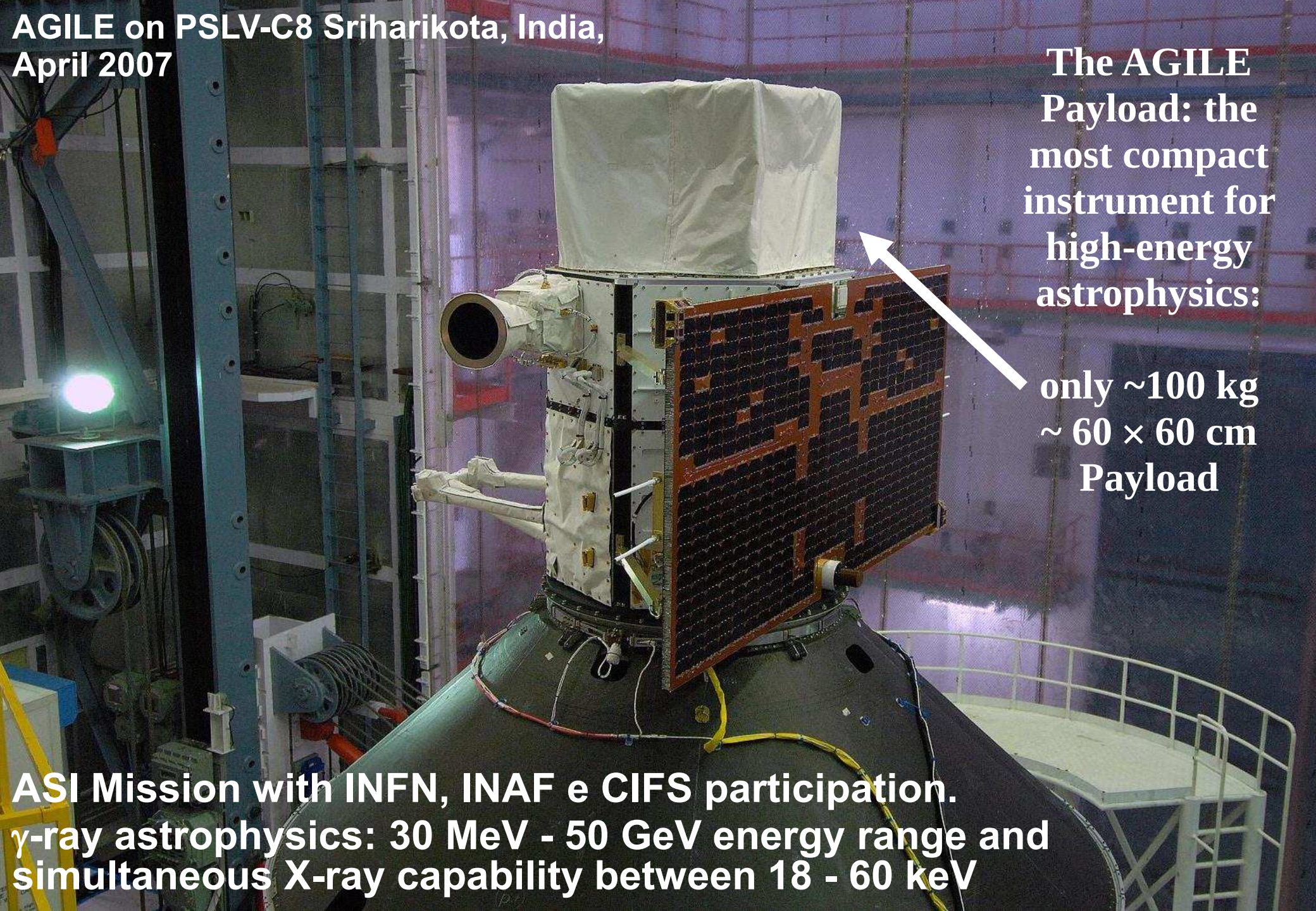
Carlotta Pittori (ASDC and INAF-OAR)
Coauthors:
A. Rappoldi, F. Lucarelli, P. W. Cattaneo, F. Longo, F. Verrecchia

Vulcano Workshop 2016

Outline

- The AGILE space mission
- Systematic search for TeV counterparts in the AGILE data
- Analysis of selected UNID TeV sources
- Summary and outlook

The AGILE Mission

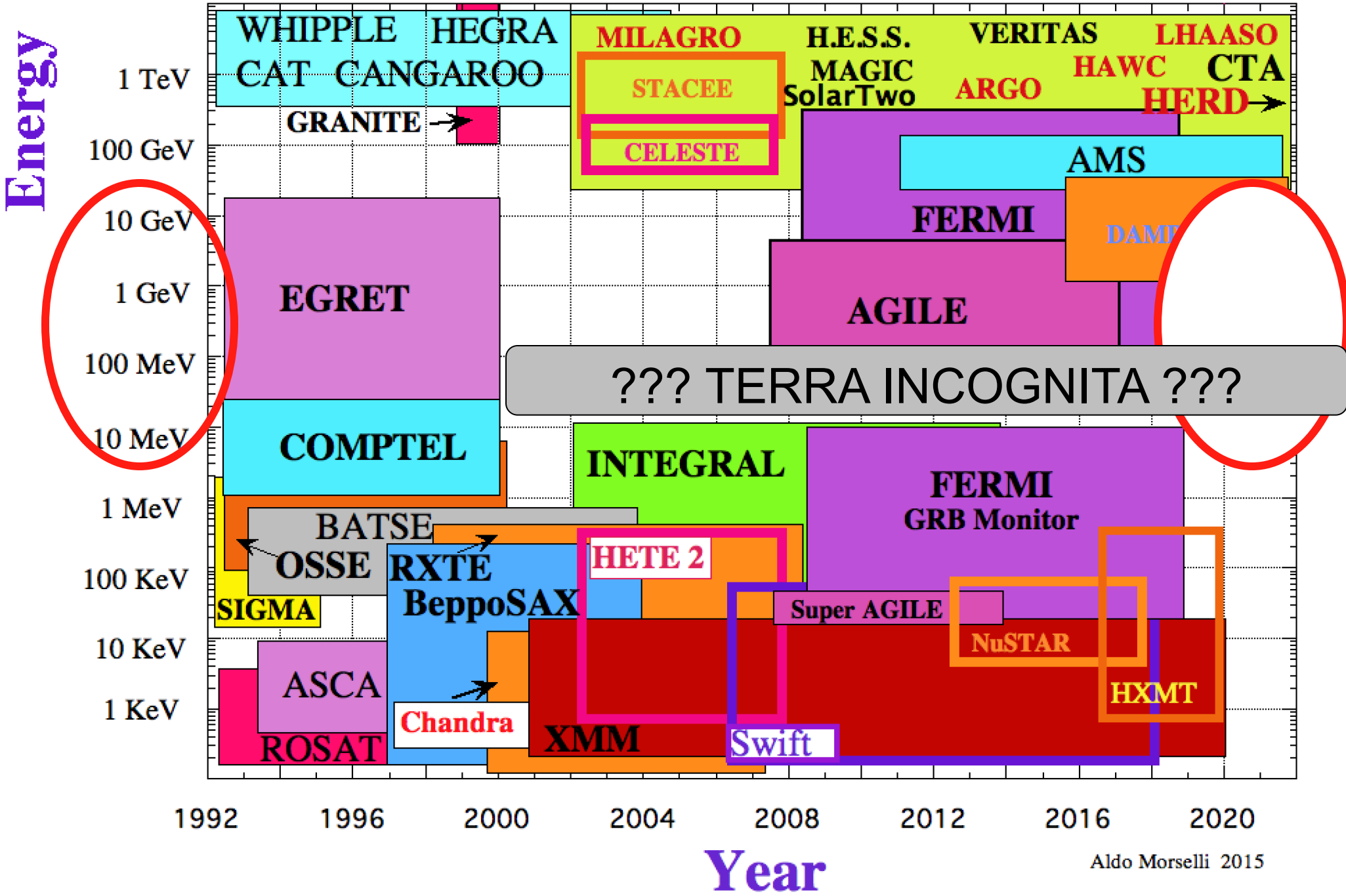

AGILE on PSLV-C8 Sriharikota, India,
April 2007
The AGILE Payload: the most compact instrument for high-energy astrophysics:
only ~100 kg
~ 60 × 60 cm Payload
ASI Mission with INFN, INAF e CIFS participation.
γ-ray astrophysics: 30 MeV - 50 GeV energy range and simultaneous X-ray capability between 18 - 60 keV

The AGILE payload

GRID performances:

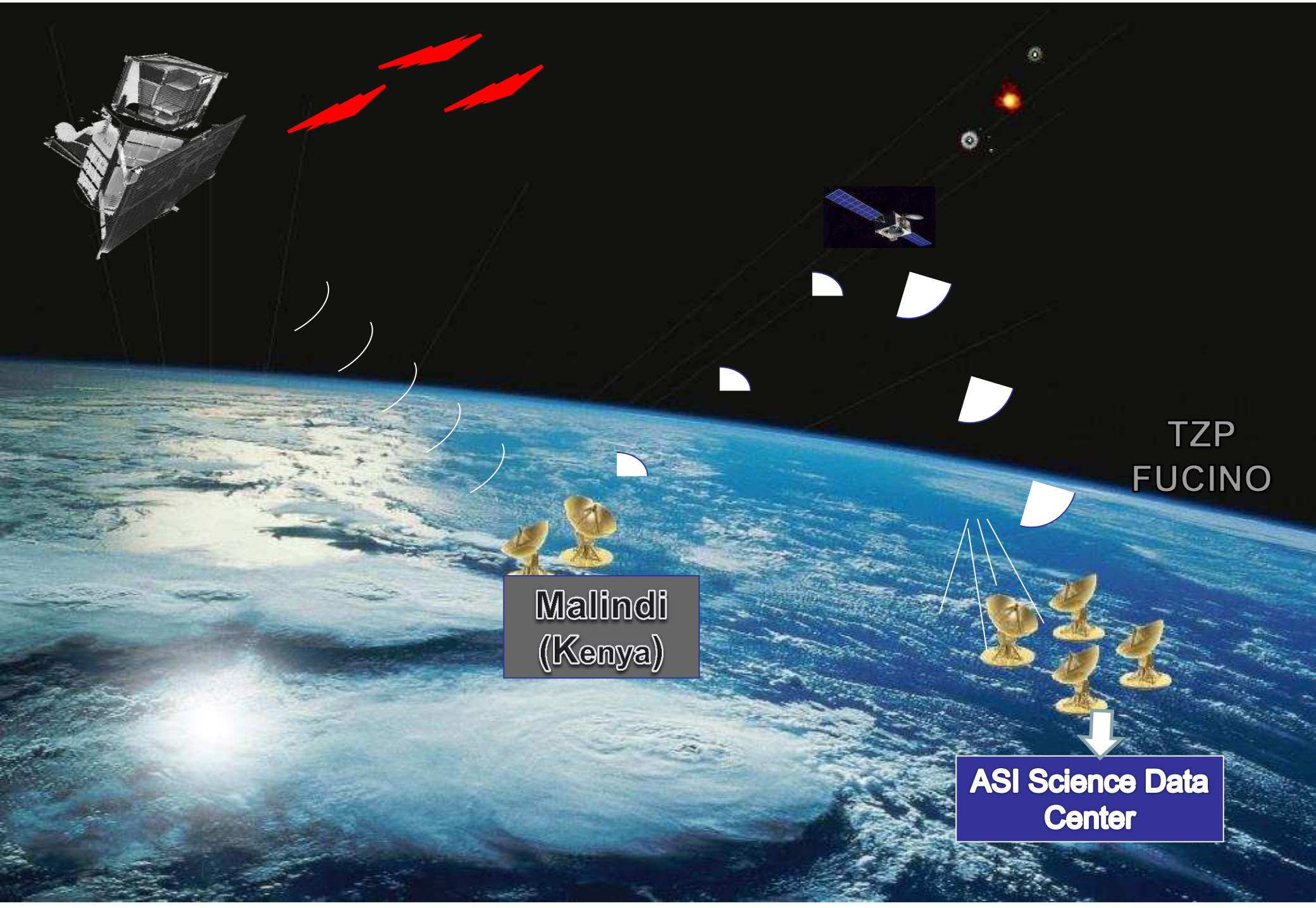
A_eff = 300-350 cm^2 @ 100 MeV (~500 cm^2 above 400 MeV)

Angular Res. (68% cont.radius) = 3.5° @100 MeV (1.2° @ 400 MeV)


Energy
1 TeV
100 GeV
10 GeV
1 GeV
100 MeV
10 MeV
1 MeV
100 KeV
10 KeV
1 KeV
WHIPPLE
HEGRA
CAT
CANGAROO
GRANITE
MILAGRO
STACEE
CELESTE
H.E.S.S.
MAGIC
SolarTwo
VERITAS
ARGO
HAWC
LHAASO
CTA
HERD
AMS
FERMI
DAMI
EGRET
AGILE
??? TERRA INCOGNITA ???
COMPTEL
INTEGRAL
FERMI
GRB Monitor
BATSE
OSSE
RXTE
BeppoSAX
SIGMA
HETE 2
Super AGILE
NuSTAR
HXMT
ASCA
ROSAT
Chandra
XMM
Swift
1992
1996
2000
2004
2008
2012
2016
2020
Year
Aldo Morselli 2015

April 23, 2007: Launch!

Baseline Equatorial orbit: 550 Km, < 3º inclination


TZP
FUCINO
Malindi
(Kenya)
ASI Science Data
Center

Two "lifes" of AGILE

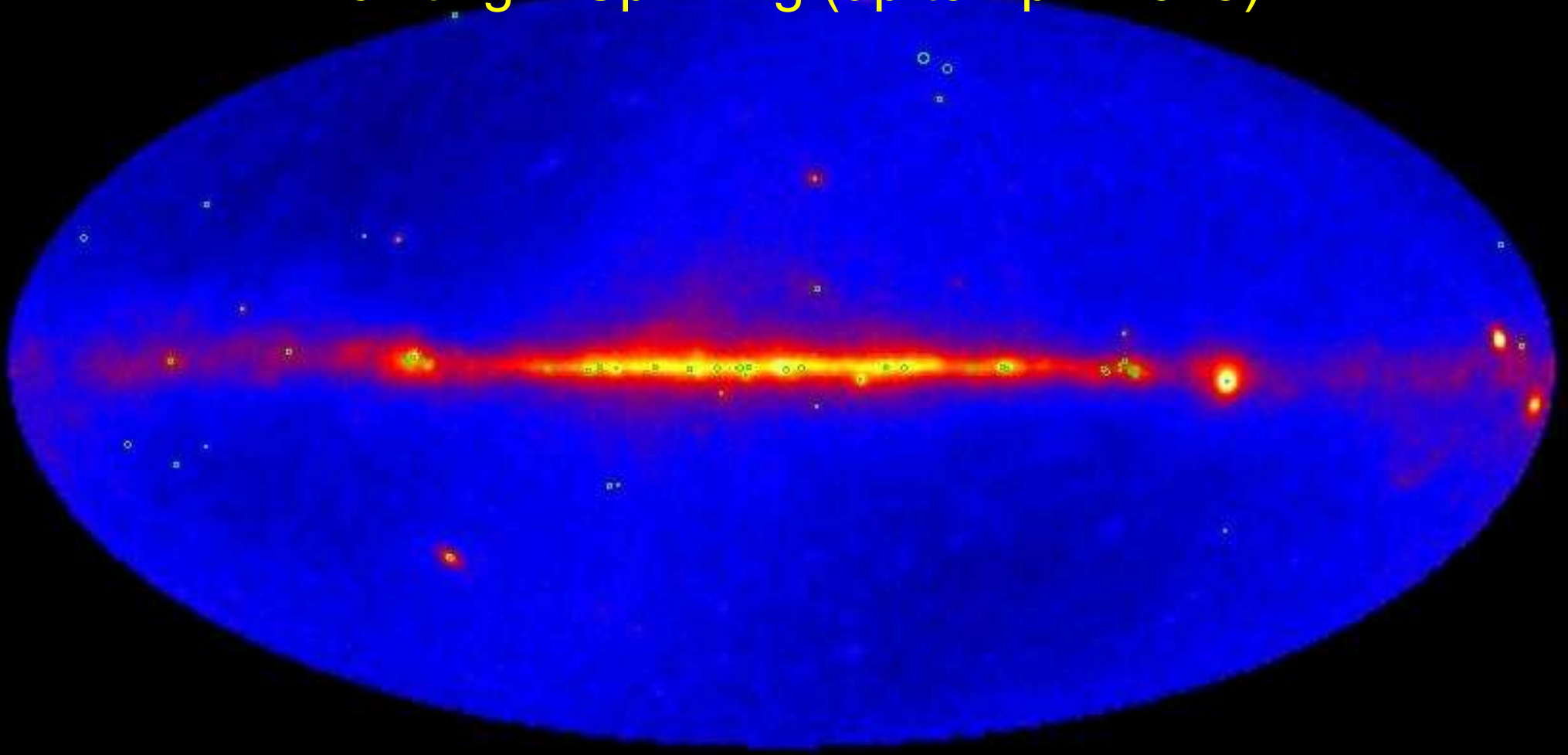
AGILE	POINTING	SPINNING
time period	Jul.07 – Oct.09	Nov. 2009 - today
attitude	fixed	variable (rotation ~ 0.8º/sec)
sky coverage	1/5	~ 70-80 %
1-day exposure (≤ 30 deg off-axis, @ 100 MeV)	~ 2 x 10^7 (cm^2 sec)	(0.5 - 1) x 10^7 (cm^2 sec)

1-yr Flux sensitivity in spinning (E>100 MeV):

(1÷8) x 10^{-7} ph cm^{-2} s^{-1}

AGILE Total Intensity Map (E > 100 MeV)

Pointing + Spinning (up to April 2015)



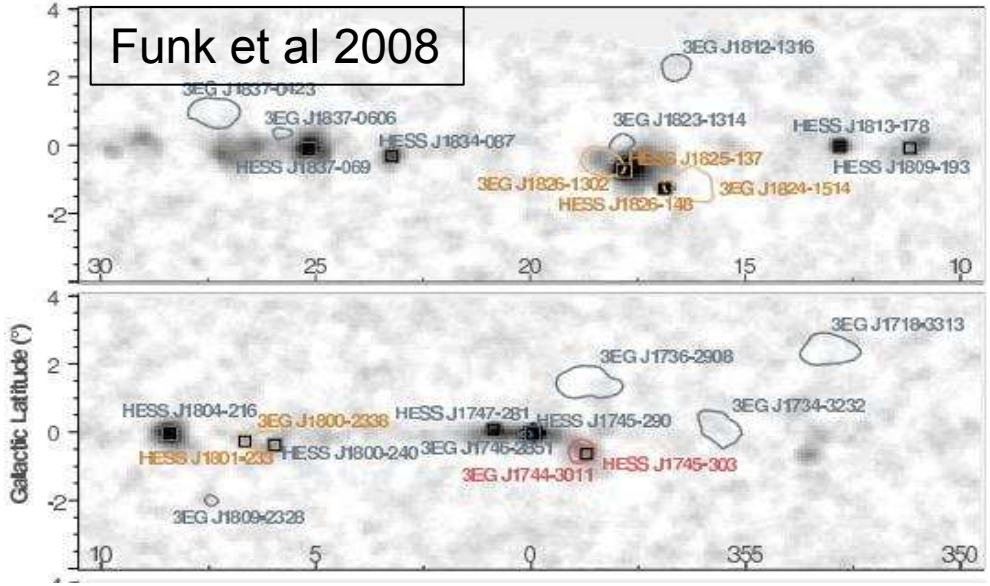
(green circles: AGILE sources, first year of operations)

"The First AGILE-GRID Catalog of High Confidence Gamma-Ray Sources", C. Pittori et al., A&A 506, 2009 and

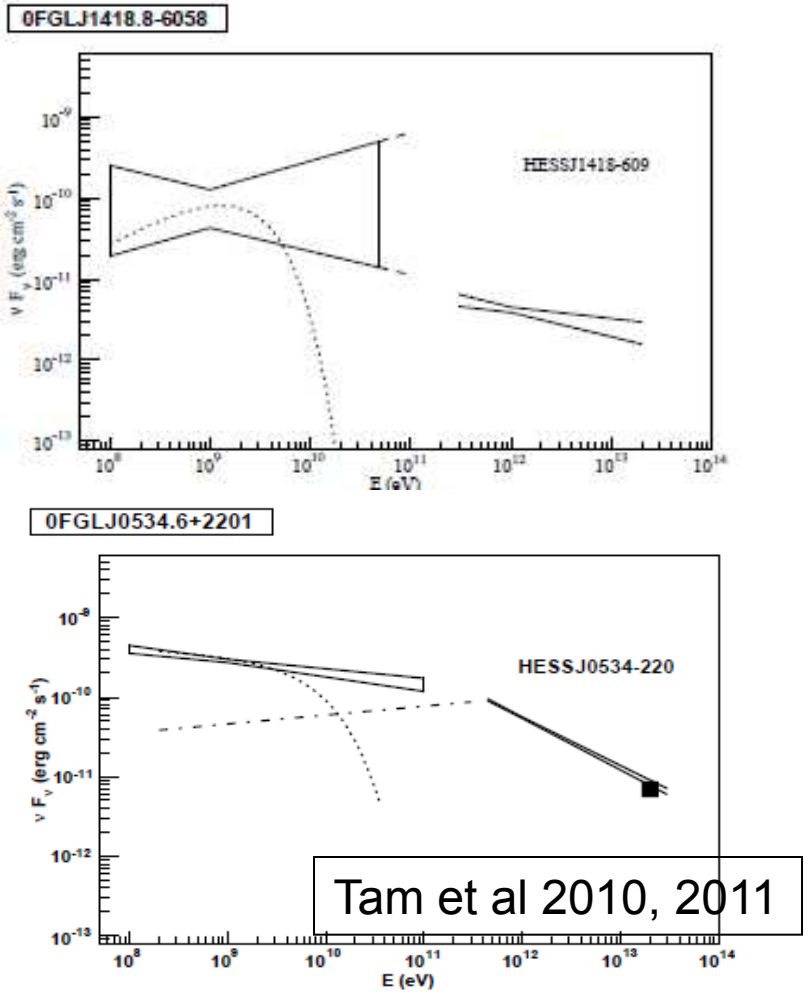
"An updated list of AGILE bright γ-ray sources and their variability in pointing mode", F. Verrecchia et al., A&A 558, 2013

MeV-GeV and TeV correlation

HESS-EGRET correlation



TeV-0FGL/1FGL correlation



- Spatial correlation.
- SED studies => emission mechanisms.
- Identification of UNID TeV sources.

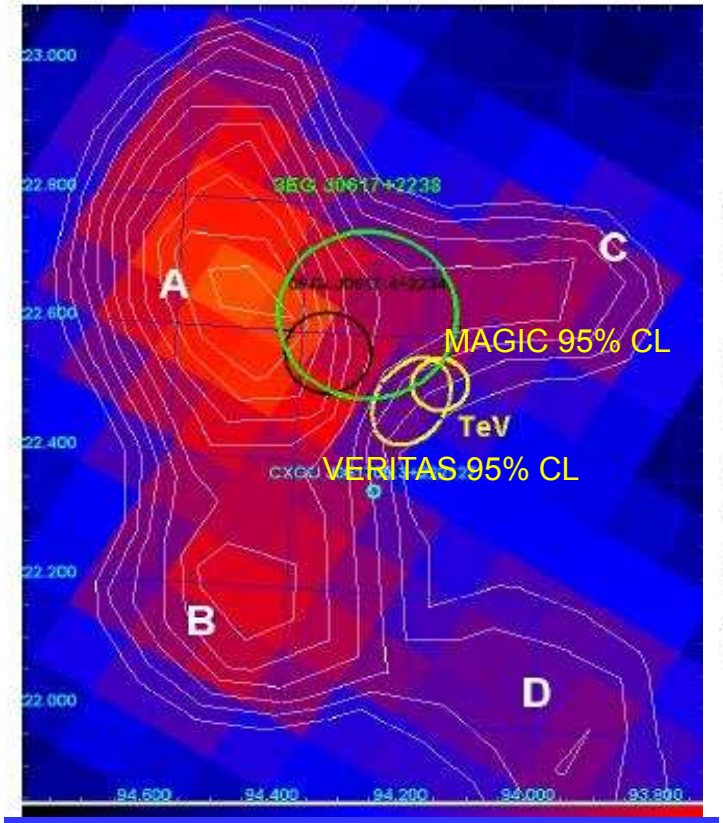
AGILE main results on TeV sources

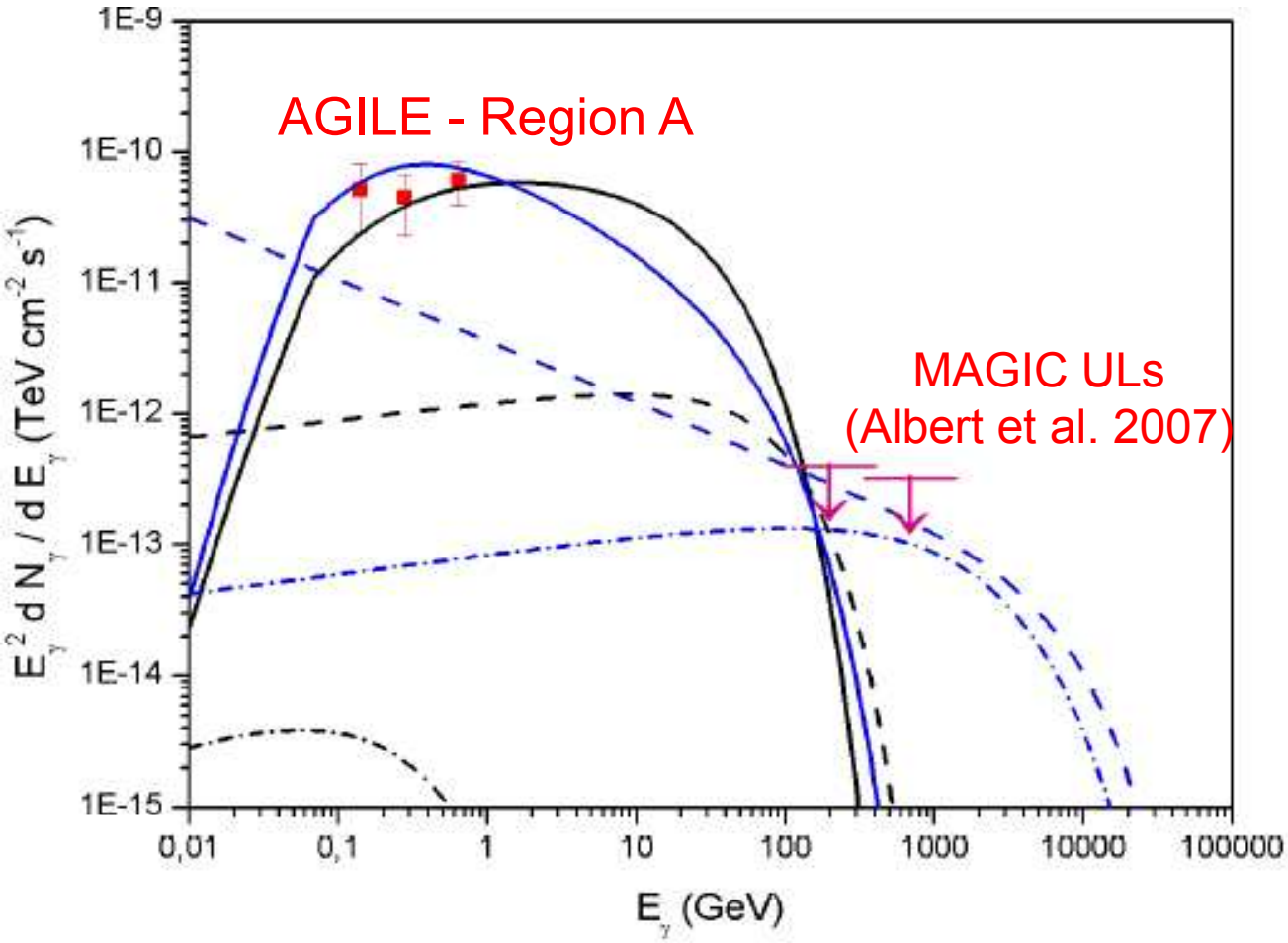
- **Extra-galactic:**
  - Mkn 421 (Donnarumma et al. 2009, ApJ 691)
  - S5 0716+714 (Giommi et al. 2008 A&A 487, Chen et al. 2008 A&A 489)
  - W Comae (Acciari et al. 2009, ApJ 707)
  - PG 1553+113 (Aleksic et al. 2010, A&A 515)
  - PKS 1510-089 (Pucella et al. 2008, A&A 491, D'Ammando et al. 2009, A&A 508)
- **Galactic:**
  - IC 443 (Tavani et al. 2010, ApJL 710)
  - SNR W28 (Giuliani et al. 2010, ApJL)
  - Cygnus X-1 (Sabatini et al. 2010, Del Monte et al 2010)
  - Vela X (Pellizzoni et al 2010, Science 327)
  - Crab Nebula (Tavani et al. 2011, Science 311)

AGILE and TeV Galactic Sources I

IC 443

Tavani et al. 2010, ApJL 710



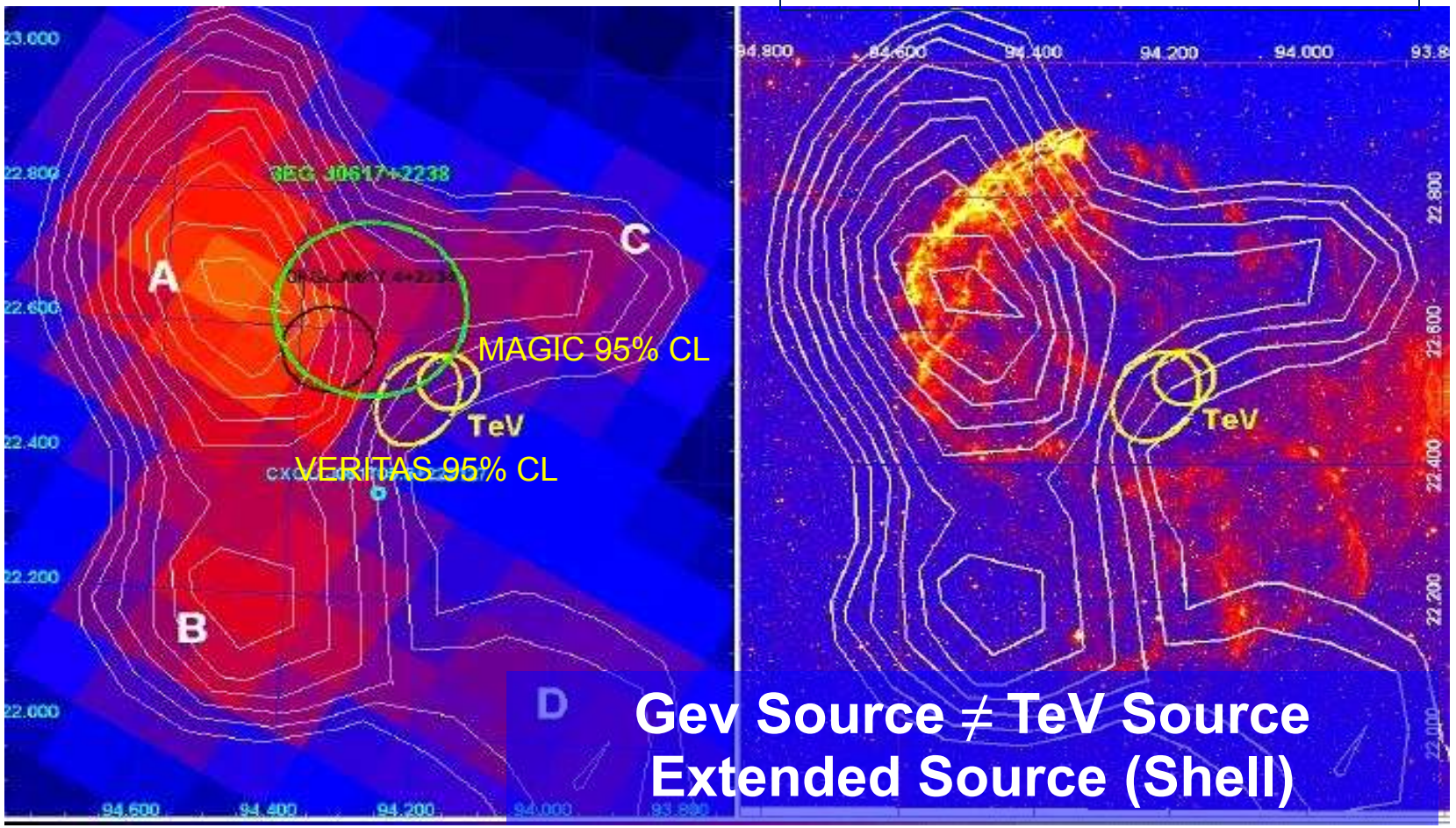


Gev Source ≠ TeV Source
Extended Source (Shell)

IC 443 Zoom

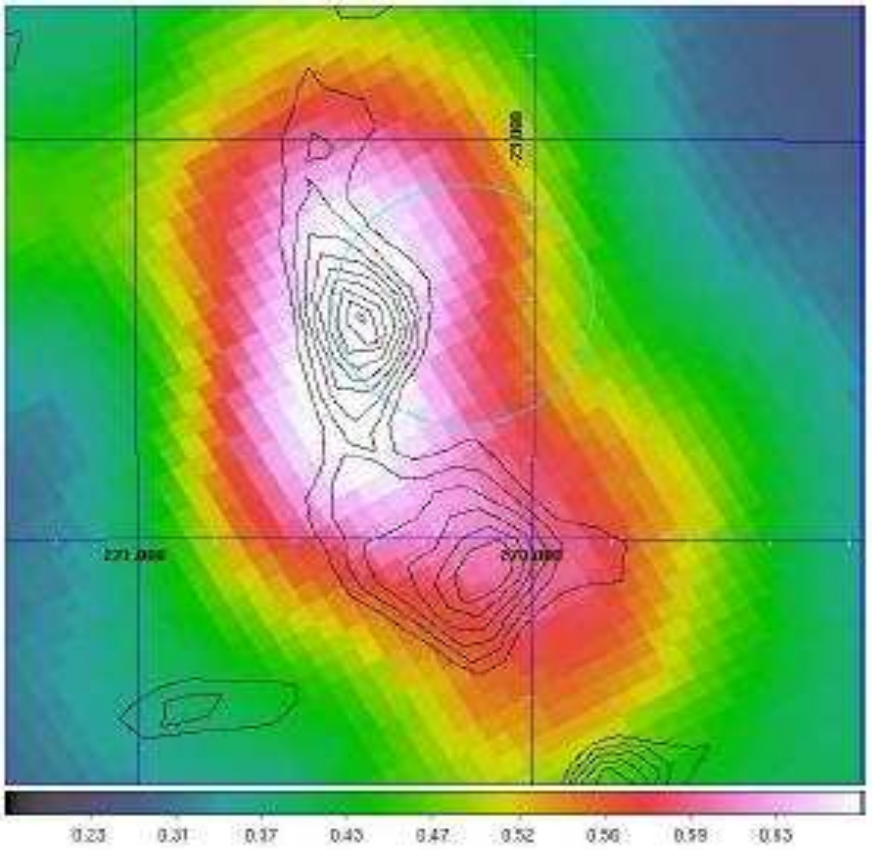
IC 443

Tavani et al. 2010, ApJL 710

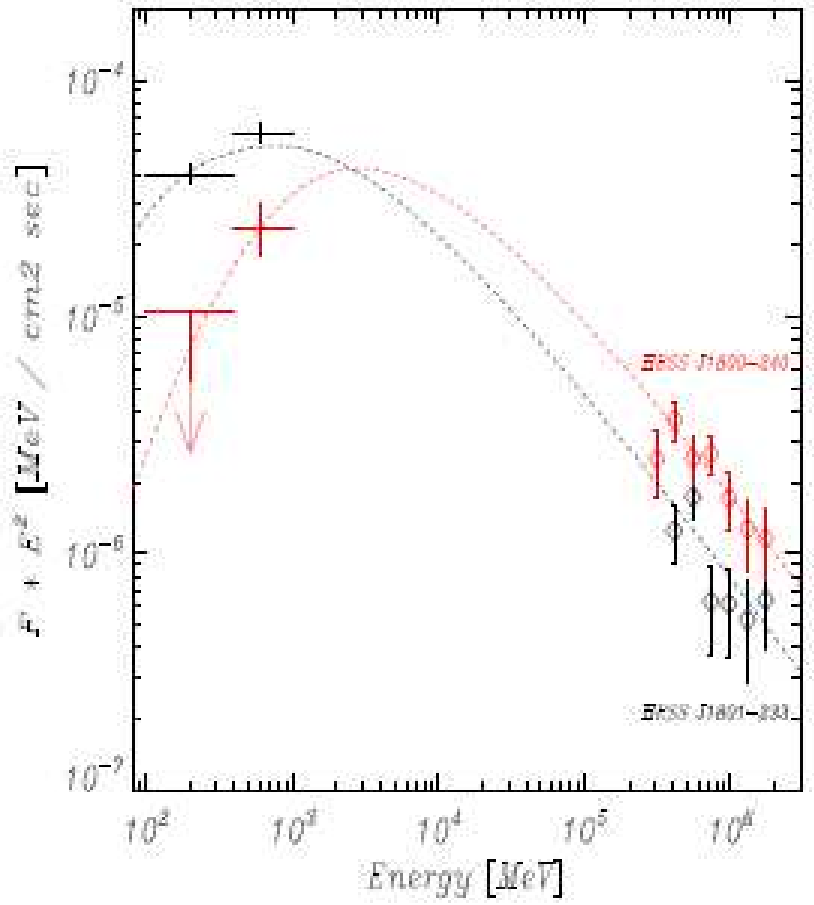


AGILE and TeV Galactic Sources II

W28 SNR

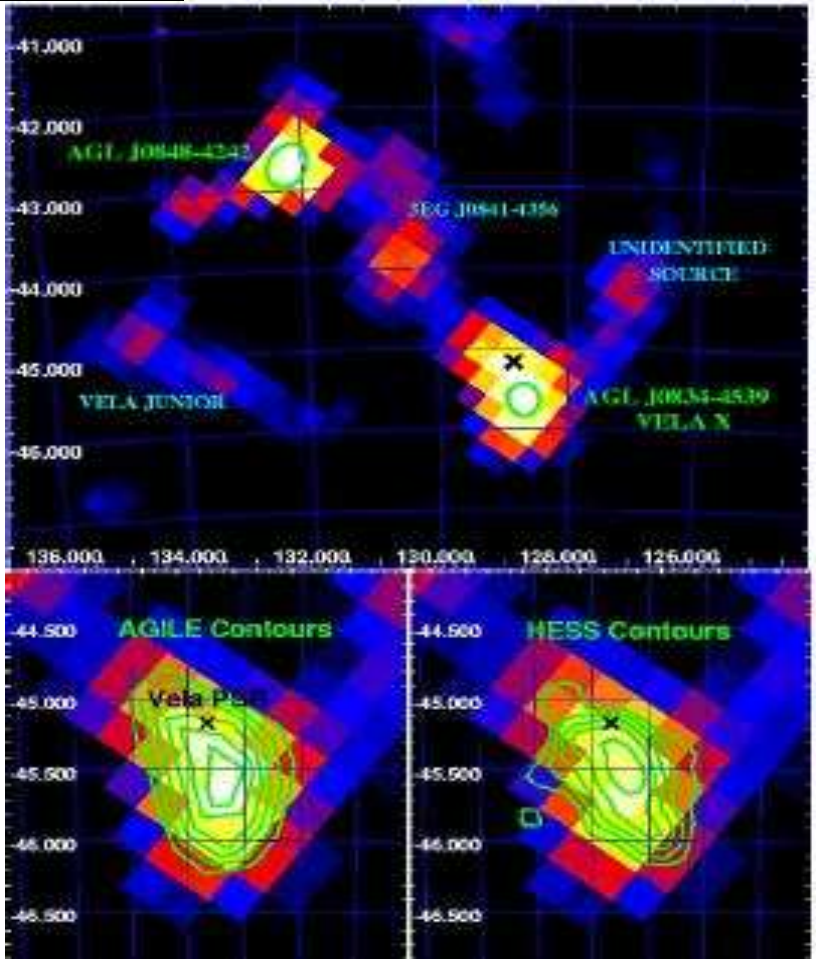


Giuliani et al. 2010, ApJL

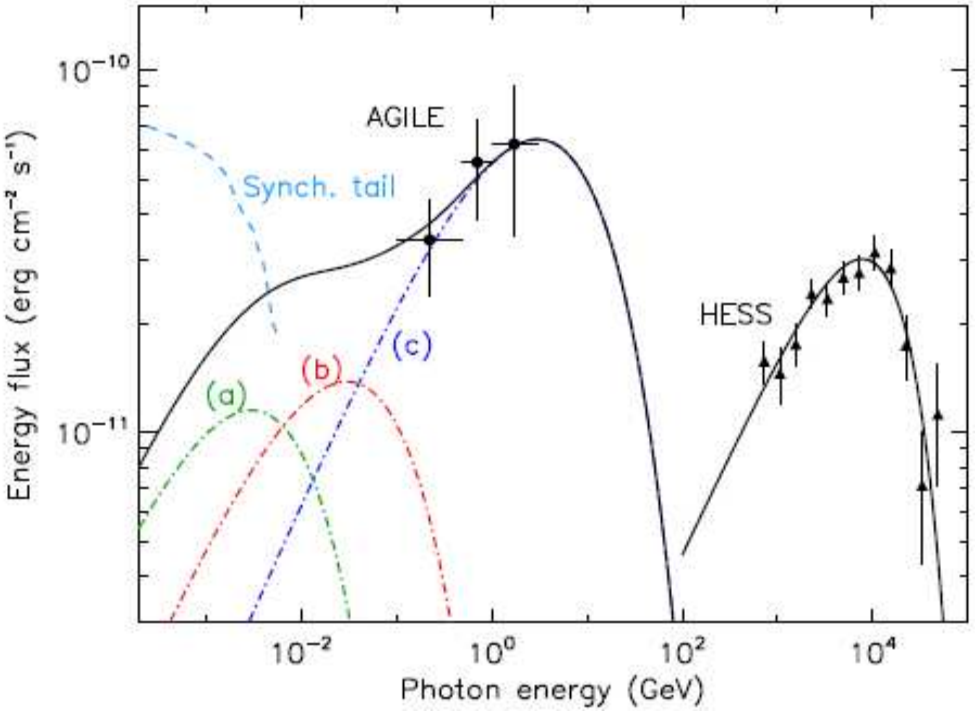


AGILE and TeV Galactic Sources III

Vela X

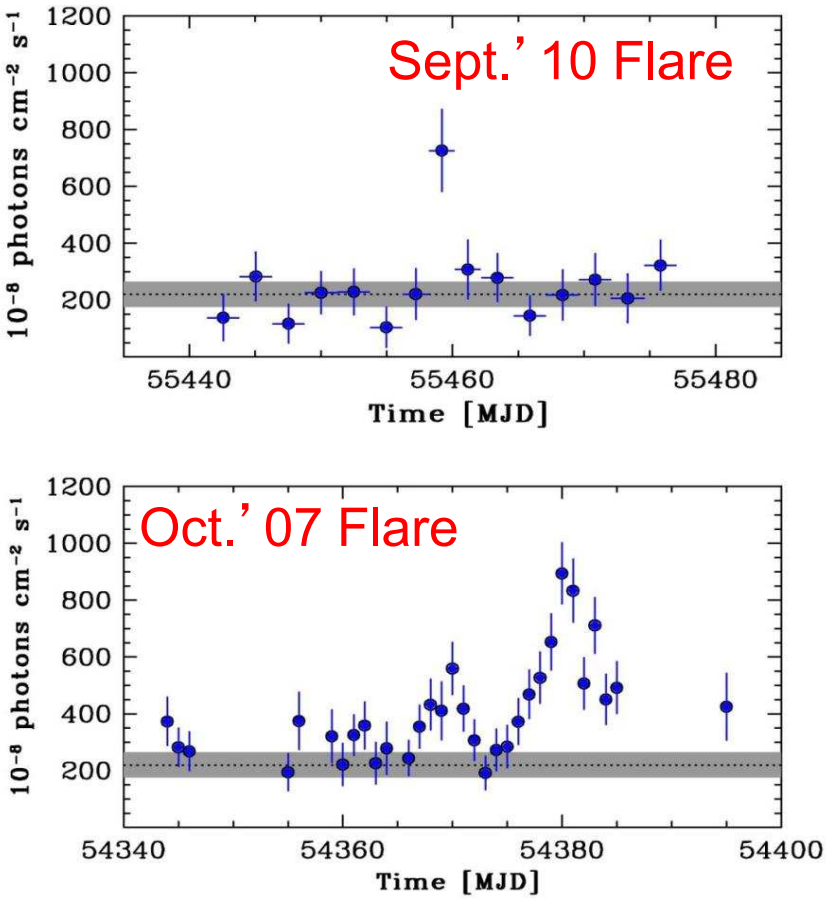


Pellizzoni et al 2010, Science 327

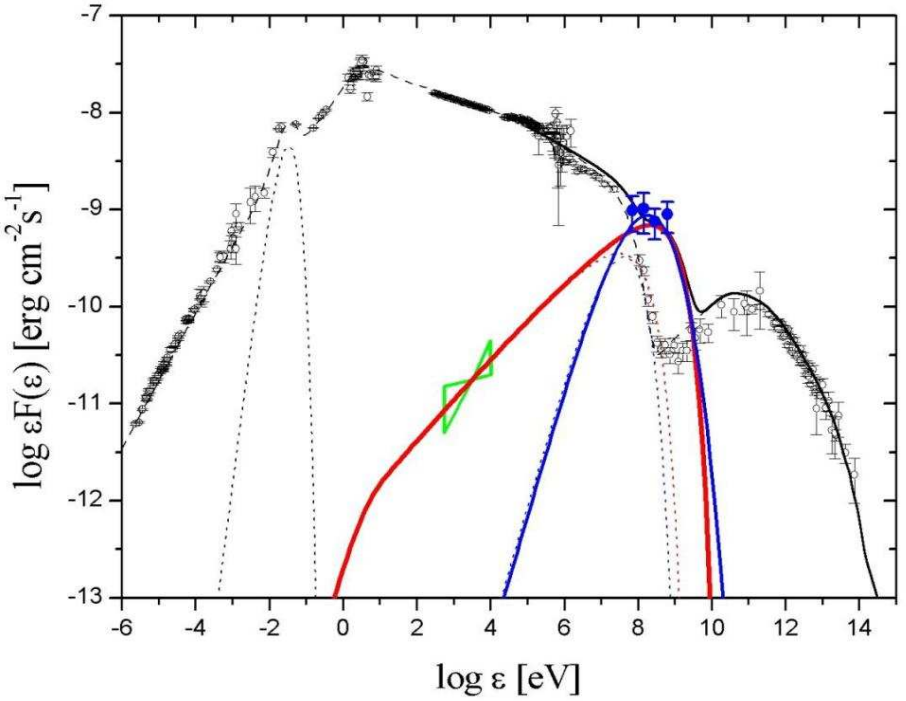


AGILE and TeV Galactic Sources IV

Crab Nebula



Tavani et al. 2011, Science 311

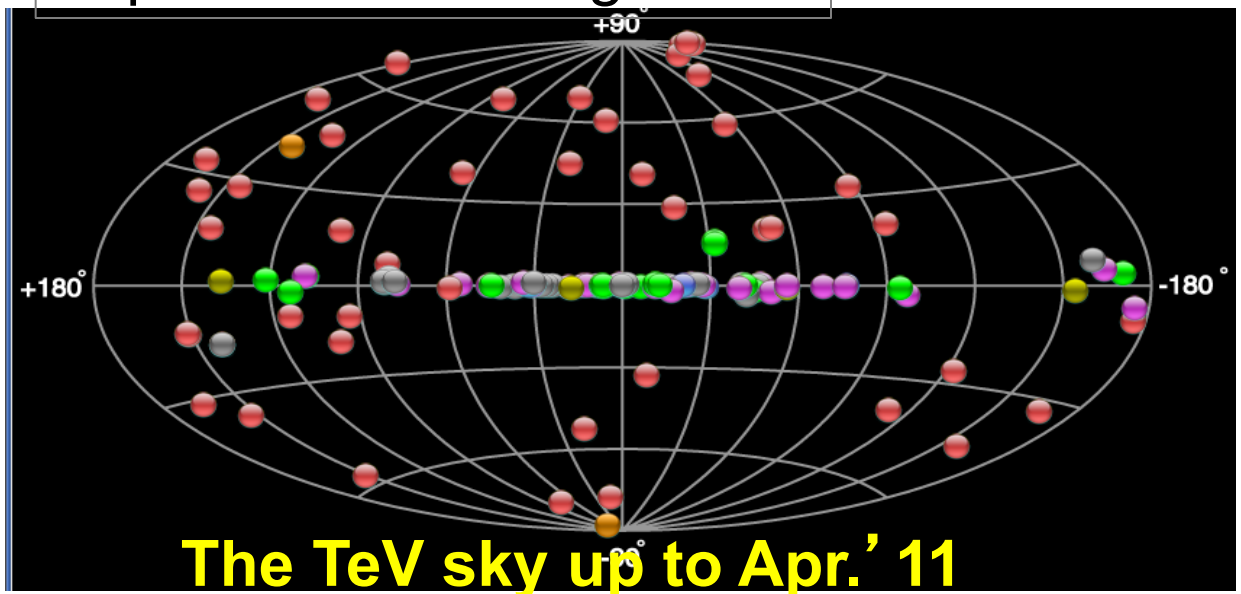


Systematic Search for MeV-GeV counterparts of TeV sources

- **Automated search for E>100 MeV excess spatially correlated with known TeV sources:** A. Rappoldi et al., A&A 587, A93 (2016)
- **Using AGILE-GRID pointing period data of 2.3 yrs**
- **AGILE-GRID public data archive at ASDC**
- **Data analysis criteria: multi-source Maximum Likelihood (ML) analysis around the TeV position (Mattox et al. 1996, Chen et al. 2010)**

TeV source input list

http://tevcat.uchicago.edu/

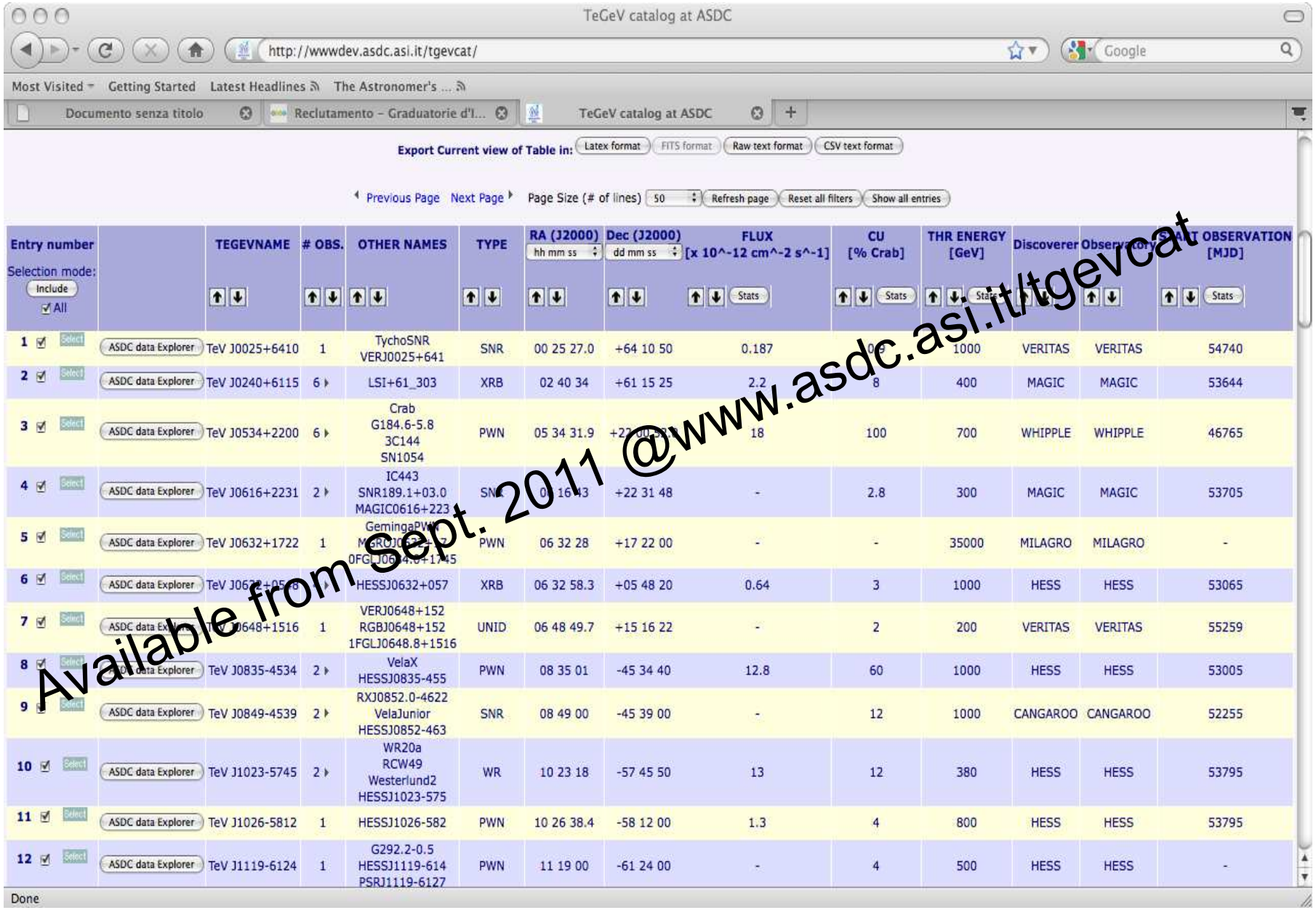


PWN 24
Starburst 2
AGN 45 (HBL 29)
Other Galact 3
SNR /MC 14
UNID 25
PSR, XRB 3
Total: 116 sources

Revision of all TeV positions made at @ ASDC
(Carosi, Lucarelli, Antonelli and Capalbi)

New TeV source catalog available from the ASDC interactive web pages (access to all ASDC MW tools and archives). Updated to 2015

The TeV catalog @ ASDC

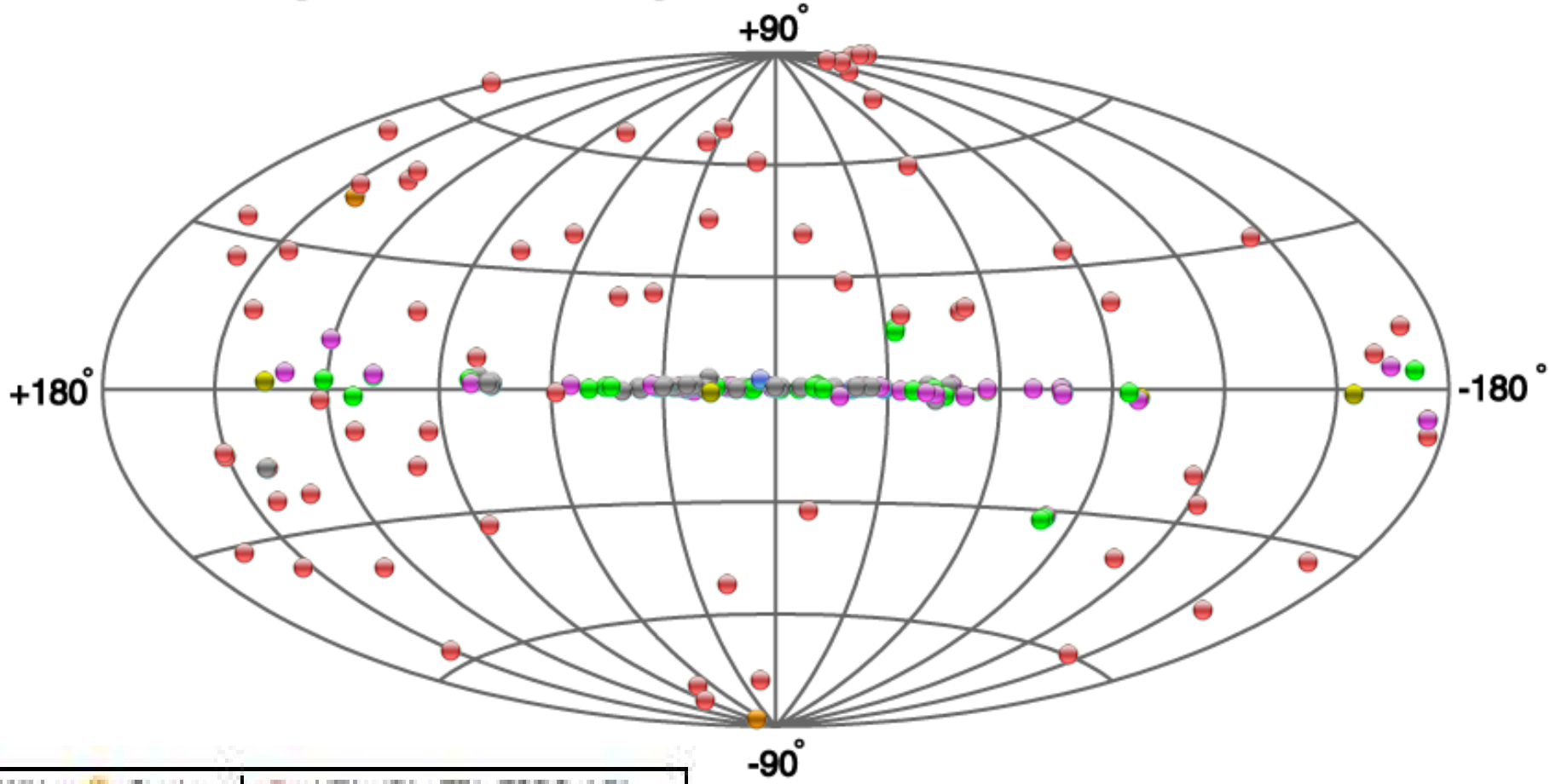


Entry number		TEGEVNAME	# OBS.	OTHER NAMES	TYPE	RA (J2000) hh mm ss	Dec (J2000) dd mm ss	FLUX [x 10^-12 cm^-2 s^-1]	CU [% Crab]	THR ENERGY [GeV]	Discoverer	Observatory	FIRST OBSERVATION [MJD]
1	ASDC data Explorer	TeV J0025+6410	1	TychoSNR VERJ0025+641	SNR	00 25 27.0	+64 10 50	0.187	8	1000	VERITAS	VERITAS	54740
2	ASDC data Explorer	TeV J0240+6115	6	LSI+61_303	XRB	02 40 34	+61 15 25	2.2	8	400	MAGIC	MAGIC	53644
3	ASDC data Explorer	TeV J0534+2200	6	Crab G184.6-5.8 3C144 SN1054	PWN	05 34 31.9	+22 00 52	18	100	700	WHIPPLE	WHIPPLE	46765
4	ASDC data Explorer	TeV J0616+2231	2	IC443 SNR189.1+03.0 MAGIC0616+223	SNR	06 16 43	+22 31 48	-	2.8	300	MAGIC	MAGIC	53705
5	ASDC data Explorer	TeV J0632+1722	1	GemingaPWN 0FGLJ0634.0+1745	PWN	06 32 28	+17 22 00	-	-	35000	MILAGRO	MILAGRO	-
6	ASDC data Explorer	TeV J0632+05		HESSJ0632+057	XRB	06 32 58.3	+05 48 20	0.64	3	1000	HESS	HESS	53065
7	ASDC data Explorer	TeV J0648+1516	1	VERJ0648+152 RGBJ0648+152 1FGLJ0648.8+1516	UNID	06 48 49.7	+15 16 22	-	2	200	VERITAS	VERITAS	55259
8	ASDC data Explorer	TeV J0835-4534	2	VelaX HESSJ0835-455	PWN	08 35 01	-45 34 40	12.8	60	1000	HESS	HESS	53005
9	ASDC data Explorer	TeV J0849-4539	2	RXJ0852.0-4622 VelaJunior HESSJ0852-463	SNR	08 49 00	-45 39 00	-	12	1000	CANGAROO	CANGAROO	52255
10	ASDC data Explorer	TeV J1023-5745	2	WR20a RCW49 Westerlund2 HESSJ1023-575	WR	10 23 18	-57 45 50	13	12	380	HESS	HESS	53795
11	ASDC data Explorer	TeV J1026-5812	1	HESSJ1026-582	PWN	10 26 38.4	-58 12 00	1.3	4	800	HESS	HESS	53795
12	ASDC data Explorer	TeV J1119-6124	1	G292.2-0.5 HESSJ1119-614 PSRJ1119-6127	PWN	11 19 00	-61 24 00	-	4	500	HESS	HESS	-

Available from Sept. 2011 @www.asdc.asi.it/tgevcat

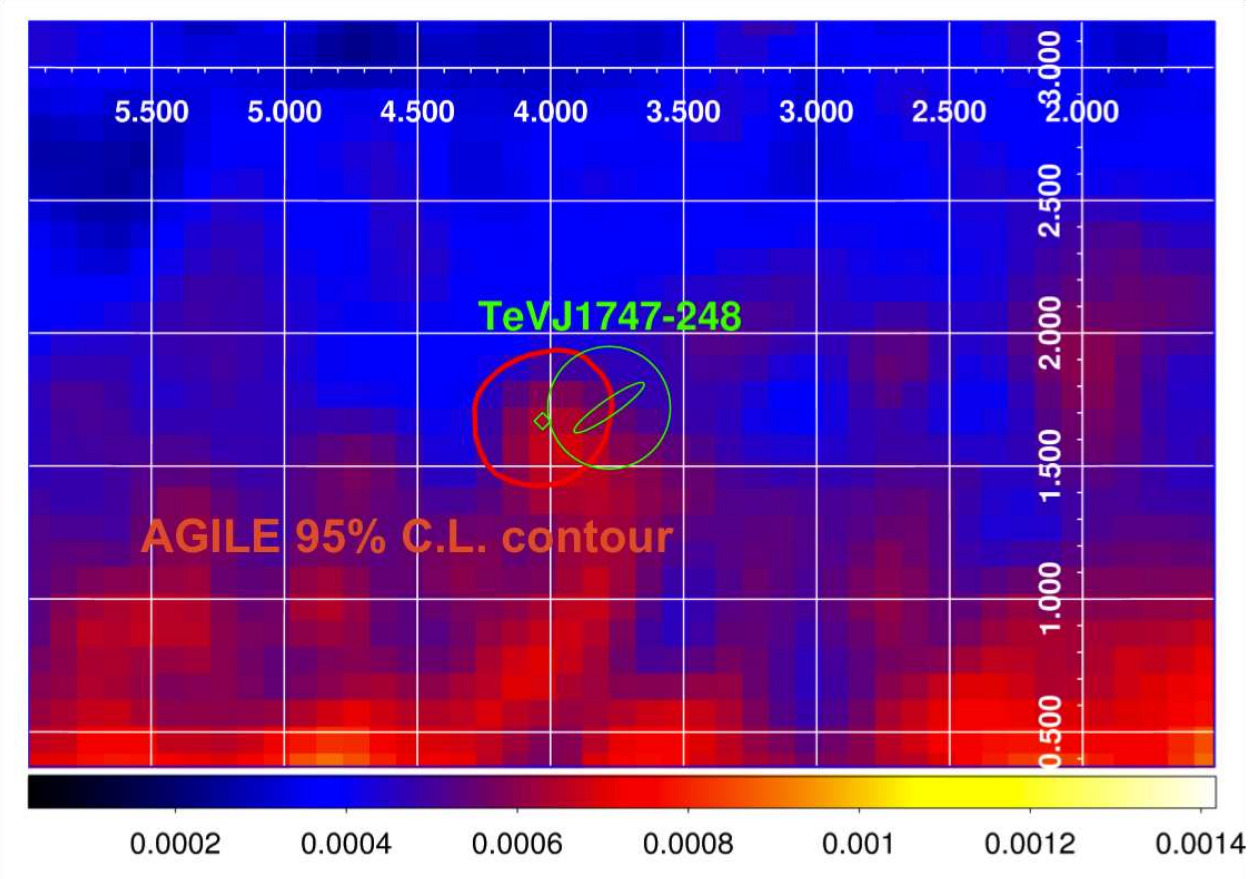
Updated TeV source input list (2015)

Input subsample = 152 TeV sources



Cross-matching criteria: AGILE – TeV sources

1. **Extended TeV sources of approx circular shape:**
   a) Sum up the TeV extension radius (ER_{TeV}) to the AGILE source position error circle (95% C.L.).
   b) AGILE detection associated *if* angular distance between TeV emission centroid and AGILE gamma-ray peak position ***dist*** **<** $\boldsymbol{ER_{TeV}}$ **+** $\boldsymbol{R_{AGILE}}$
2. **Extended TeV sources of approx elliptical shape:**
   a) Assume for the TeV extension a circle with radius equals to the ellipse semi-major axis.
   b) Repeat point 1.b: if ***dist*** **<** $\boldsymbol{ER_{TeV}}$ **+** $\boldsymbol{R_{AGILE}}$ *==> AGILE-TeV sources cross-matched*
3. **Point-like TeV sources:**
   - *If* ***dist*** **<** $\boldsymbol{R_{TeV}}$ **+** $\boldsymbol{R_{AGILE}}$ *==> AGILE-TeV sources are cross-matched,* where R_{TeV} is the radius of the error circle on the TeV emission centroid (if available).



AGILE intensity map showing the detection (red contour) at the position of the extended (green circle) source TeV J1747-248 (Terzan 5). The AGILE detection and the TeV source fulfill the cross-matching criteria shown before.

Results

- 52 TeV sources out of 152, corresponding to **34% of the analysed sample, show a significant excess in the AGILE data** covering the pointing observation period

- **26 new AGILE sources** with respect to the AGILE reference catalogs were found, 15 of which are Galactic, 7 extragalactic and 4 are unidentified.

Results

- sqrt(TS)>15
- 8<sqrt(TS)<=15
- 5<sqrt(TS)<=8
- 4<sqrt(TS)<=5

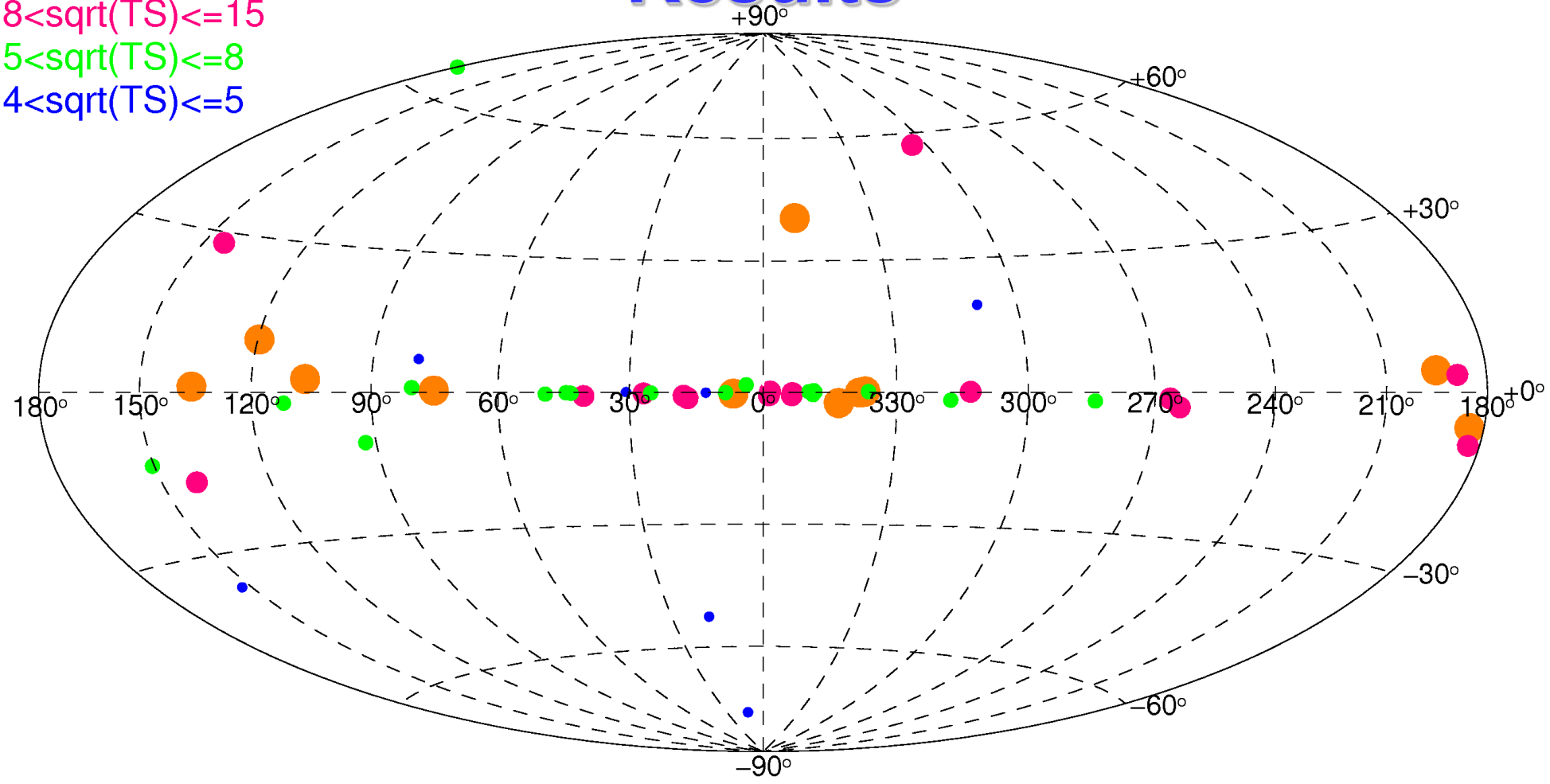


Figure 3. Aitoff map in Galactic coordinates of all the detections according to the criteria specified in the text, corresponding to TeV sources showing a significant excess in the AGILE data.

Results

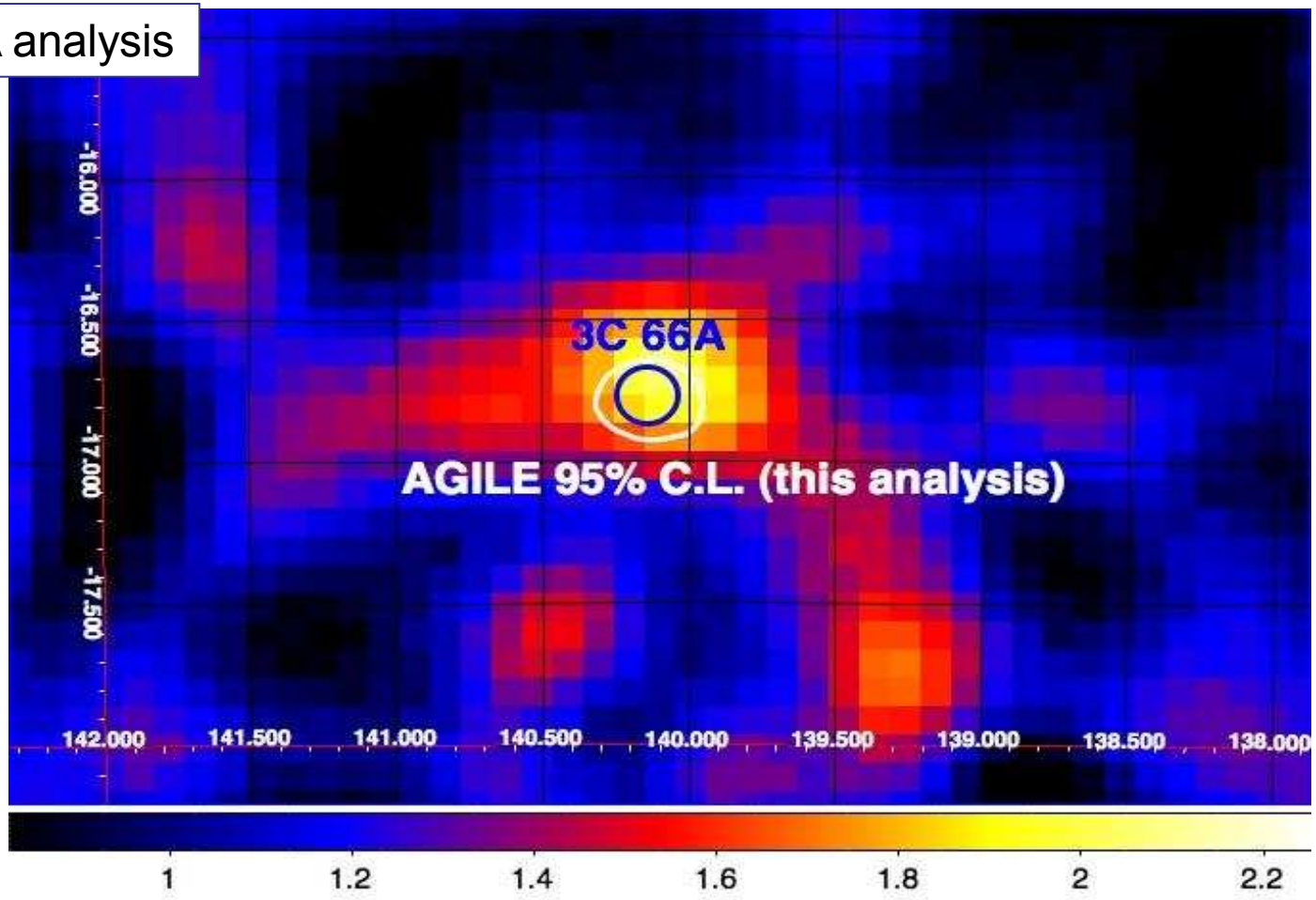
Source type	*Detected / Total*	*Source class*	*Detected / Total*
EXTRAGALACTIC	13 / 66 (20%)	Blazar	0 / 1 (0%)
		HBL	5 / 44 (11%)
		IBL	2 / 7 (29%)
		LBL	2 / 3 (67%)
		FSRQ	2 / 5 (40%)
		Sbs	0 / 2 (0%)
		Superbubble	0 / 1 (0%)
		FRI	2 / 3 (67%)
GALACTIC	30 / 58 (52%)	PWN	11 / 28 (39%)
		SNR	7 / 11 (64%)
		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%)	-	-

34% of TeV sources show counterparts in AGILE first 2.3 yrs data

Results

Example: 3C 66A analysis

Source included and detected in a variability analysis of an updated AGILE source list in Pointing Mode(Verrecchia et al., 2013)



Results

Eight of the AGILE detected TeV sources have no Fermi-LAT 3FGL official association and will be further investigated in a dedicated paper:

– ID 88*: TeV J1634-472 (HESS J1634-472)
– ID 96: TeV J1713-382 (CTB 37B)
– ID 103: TeV J1729-345 (HESS J1729-345)
– ID 104: TeV J1732-347 (HESS J1731-347)
– ID 105: TeV J1741-302 (HESS J1741-302)
– ID 116*: TeV J1813-178 (HESS J1813-178)
– ID 133: TeV J1911+090 (W49B)
– ID 134: TeV J1912+101 (HESS J1912+101)

- The spatial association of a TeV source with an AGILE source may be due to chance.

- Probability of serendipitous association estimated: the number of serendipitous associations is found to be 0.82 for a |b|<3 deg band around the Galactic plane, and 0.08 elsewere.

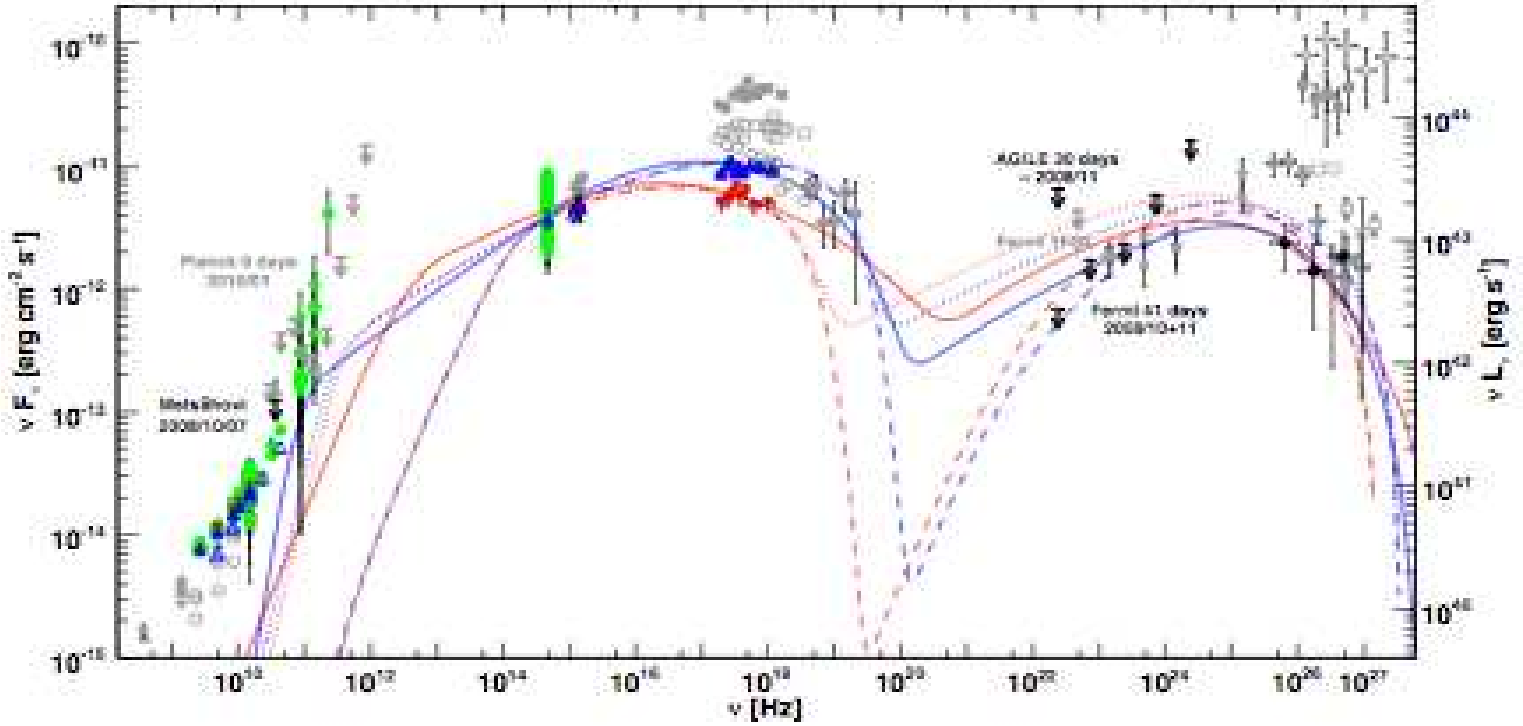
- Spectral index analysis results for the most significant sources

- Fluxes and corresponding detection significances are average values integrated over a 2.3 year timeperiod.

- No flaring source analysis.

MWL campaigns on TeV sources

- **1ES2344+514 (Rugamer et al., arXiv:1211.2608v1)**



PKS1510 (Feb. 12 flare), Mrk180, 1ES1011+496, ...

AGILE-GRID lightcurves (E>100 MeV)

- GRID Level 3 Archive: 1-day integration EXP, COUNTS and (diffuse) GAS maps produced from the official LV2 STD AGILE archive, covering the whole AGILE data set.

- Using a new AGILE-LV3 Tool it is possible to easily investigate the behaviour of the TeV sources at GeV energies over ~ 9 years (July 2007 -- Aug. 08 not covered by Fermi-LAT), producing lightcurves with different time binning (2, 7, 28-days).

- Comparison with the Pointing OB analysis lightcurves

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(password restricted access)
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active Archive
Mission Selected
AGILE-LV3
AGILE-LV3 Tutorial
Enter source name or coordinates:
PKS 1510-089
RA, DEC
L, B
Lon, Lat
(e.g. CYGX-1 or 19 58 21.7, +35 12 05.8 or 299.590333, 35.201611 or 71.334960, 3.066917)
NEW TOOL: web interface for official interactive on-line ML analysis on AGILE data archive under validation!
Durat
1, 2,
Submit

On-line science ready ML results (no need to install any software)

1) **Source detection**: significance, average gamma-ray flux (or flux upper limit) (Max

2) **Source light curve** in few minutes (depends on # of chosen timebins):

AGILE Legacy Archive and on-line tools to optimize science and discovery potential in the years to come

AG_Multi4 1.4 - Wed

Input

Psf	/data/agile/agil
Raeff	/data/agile/agil
Edp	/data/agile/agil

Gal Mode	Iso Mode
1	1

Map	Name
1	/data/agile/agile

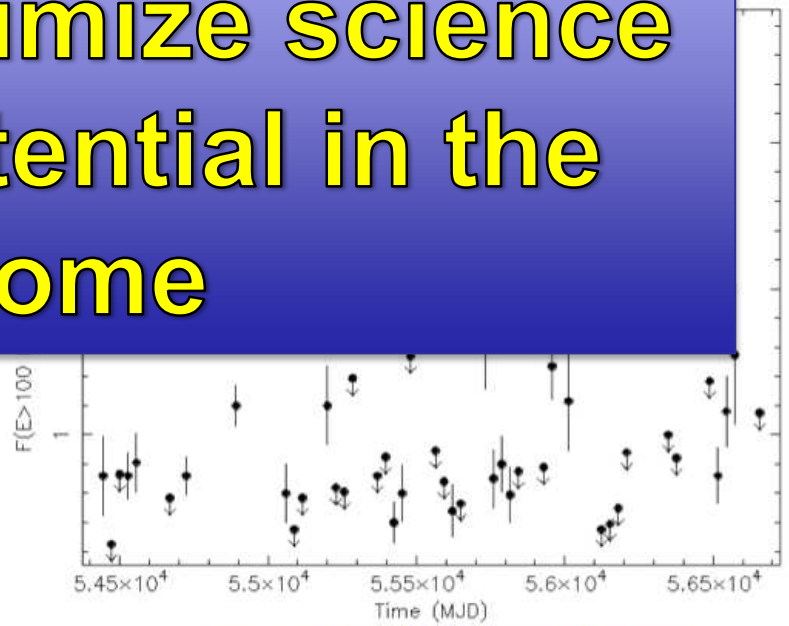
Map	Counts	Date sta									
1	5933	2011-06-06 12:00:00	2011-07-04 12:00:00	100..50000	0..60	337.5, 41.8103	90	0.25	4	90	

Source	Flux	Index	L	B	sqrt(minTS)	FixFlag
1AGLRJ1513-0906-ORIG	1e-06	2.1	351.373	40.091	2	1

Output

DiffName	Coeff	Err	+Err	-Err
Galactic	0.7	0	0	0
Isotropic	13.8561	0.888729	0.902918	-0.874694

SrcName	sqrt(TS)	L	B	Radius	Exp	Counts	Err	Flux	Err	Flux UL	Index	Err
1AGLRJ1513-0906-ORIG	4.89402	351.373	40.091	0	2.26688e+07	41.3843	11.6043	1.82561e-06	5.11906e-07	2.95956e-06	2.1	0



DOWNLOAD: 1AGLRJ1513-0906-ORIG_28dd-timebin_input_for_SED.dat

Total number of GOOD bins in the lightcurve: 45/69

Download GRID ML results

ASDC SED Builder access:
(click below to include SED data points)

Add data to SED

Summary

- **A systematic search of MeV-GeV counterparts of TeV sources in the AGILE first 2.3 yrs of data has been performed.**
- **Our results show E>100 MeV counterparts for ~34% of the 152 TeV sources analysed.**
- **Refined analysis on particular sources on different timescales is ongoing.**
- **New AGILE source Catalog *in progress.***
- **AGILE-GRID LV3 archive and on-line analysis tool will help to investigate source flaring activity over more than 9 years of AGILE data easily and in a very short computing time.**

Thank you!

asdc ASI Science Data Center

agenzia spaziale italiana

INFN Istituto Nazionale di Fisica Nucleare

INAF ISTITUTO NAZIONALE DI ASTROFISICA NATIONAL INSTITUTE FOR ASTROPHYSICS

Consiglio Nazionale delle Ricerche

AGILE 14th Science Workshop
"AGILE on the wave"
June 20 and 21, 2016
ASI Headquarters, Via del Politecnico, Rome

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