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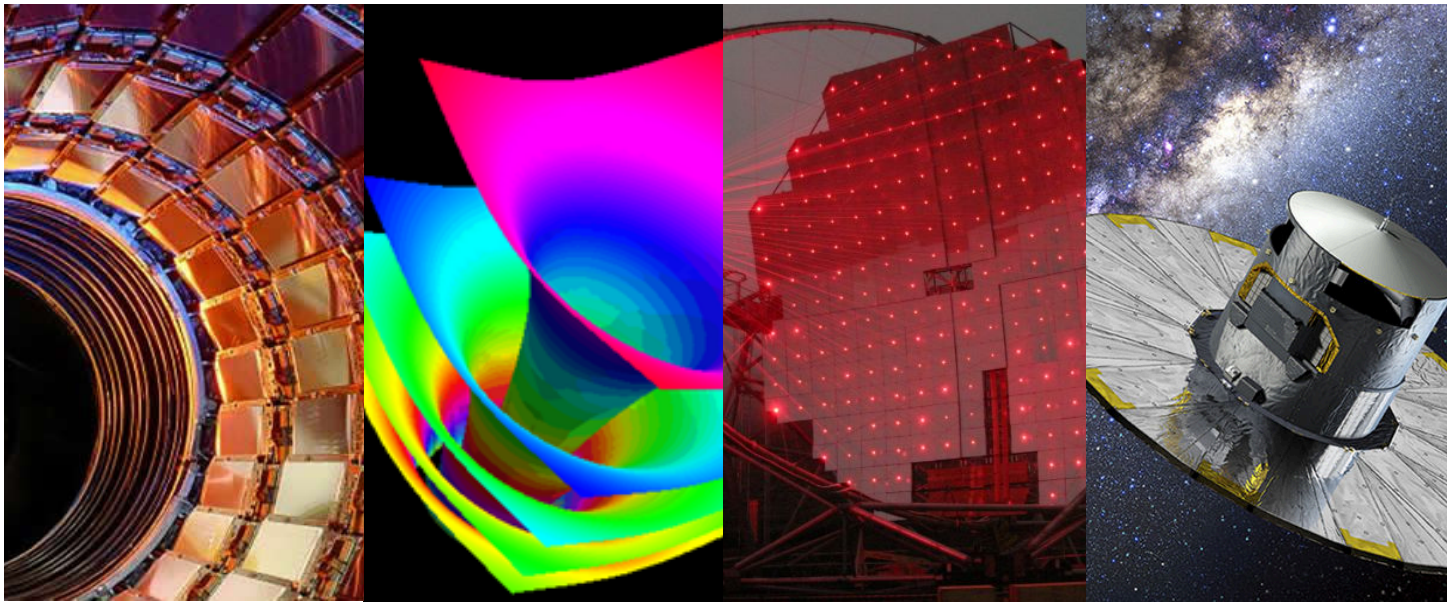


Unidentified Gamma-ray Sources and e-ASTROGAM

Josep M. Paredes

Institute of Cosmos Sciences

Universitat de Barcelona

e-ASTROGAM workshop: the extreme Universe

28 February to 2 March 2017

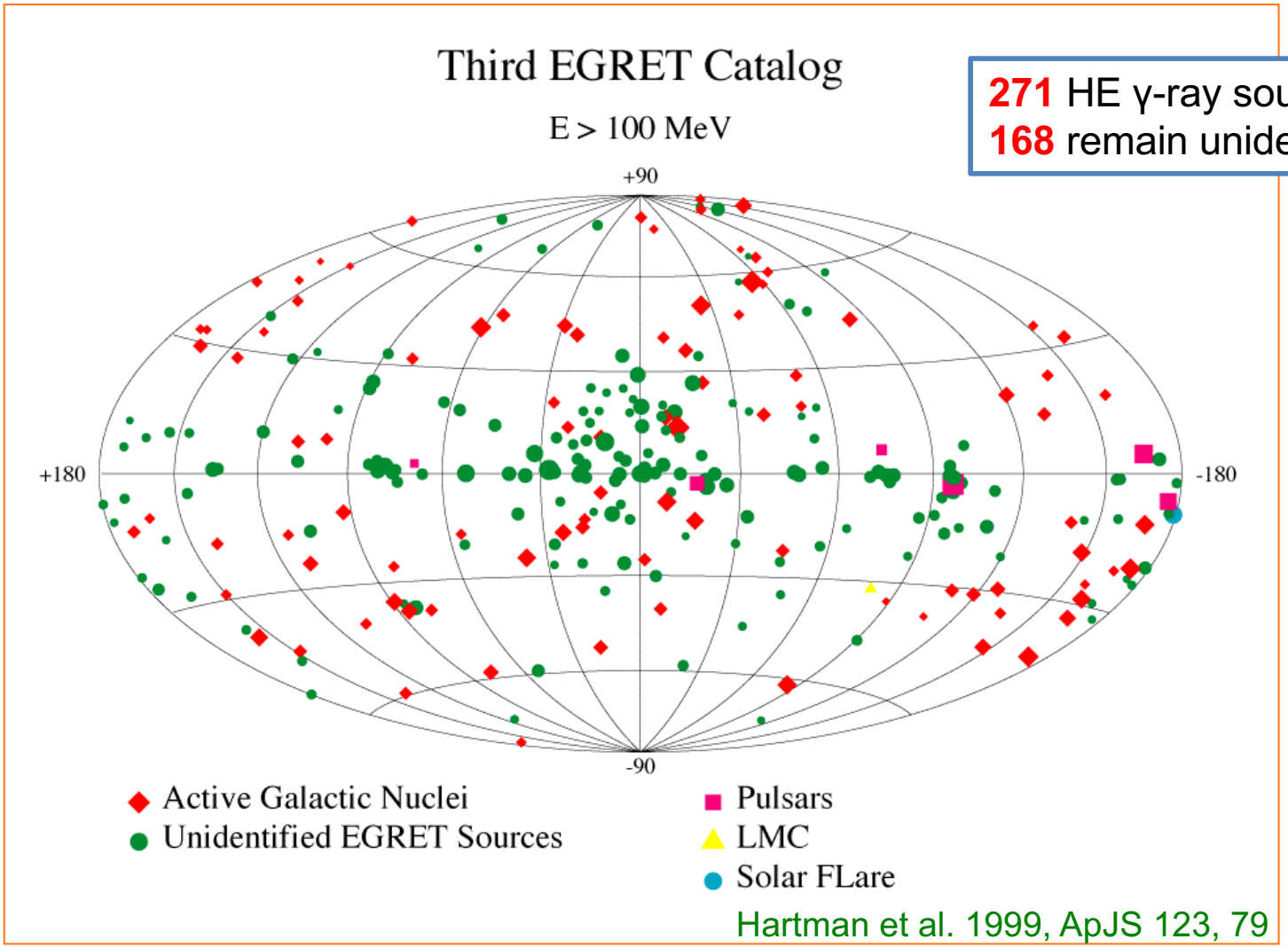
Padova

Italy

Universitat de Barcelona

The EGRET gamma-ray sky

E > 100 MeV



271 HE γ-ray sources
168 remain unidentified

Hartman et al. 1999, ApJS 123, 79

The COMPTEL gamma-ray sky

E: 0.75-30 MeV

Type of Source	Number of Sources	Comments
Spin-Down Pulsars:	3	Crab, Vela, PSR B1509−58.
Stellar Black Hole Candidates:	2	Cyg X−1, Nova Persei 1992 (GRO J0422+32).
Supernova Remnants: (Continuum Emission)	1	Crab nebula.
Active Galactic Nuclei:	10	CTA 102, 3C 454.3, PKS 0528+134, GRO J 0516−609, PKS 0208−512, 3C 273, PKS 1222+216, 3C 279, Cen A, PKS 1622−297.
Unidentified Sources:		
• $\|b\| < 10°$	4	GRO J1823−12, GRO J2228+61 (2CG 106+1.5), GRO J0241+6119 (2CG 135+01), Carina/Vela region (extended).
• $\|b\| > 10°$	5	GRO J1753+57 (extended), GRO J1040+48, GRO J1214+06, HVC complexes M and A area (extended), HVC complex C (extended).
Gamma-Ray Line Sources:		
• 1.809 MeV (^{26}Al)	3	Cygnus region (extended), Vela region (extended, may include RX J0852−4621), Carina region.
• 1.157 MeV (^{44}Ti)	2	Cas A, RX J0852−4621 (GRO J0852−4642).
• 0847 and 1.238 MeV (^{56}Co)	1	SN 1991T.
• 2.223 MeV (n-capture)	1	GRO J0317−853.
Gamma-Ray Burst Sources: (within COMPTEL field-of- up to Phase IV/Cycle-5)	31	Location error radii vary from 0.34° to 2.79° (mean error radius: view 1.13°).

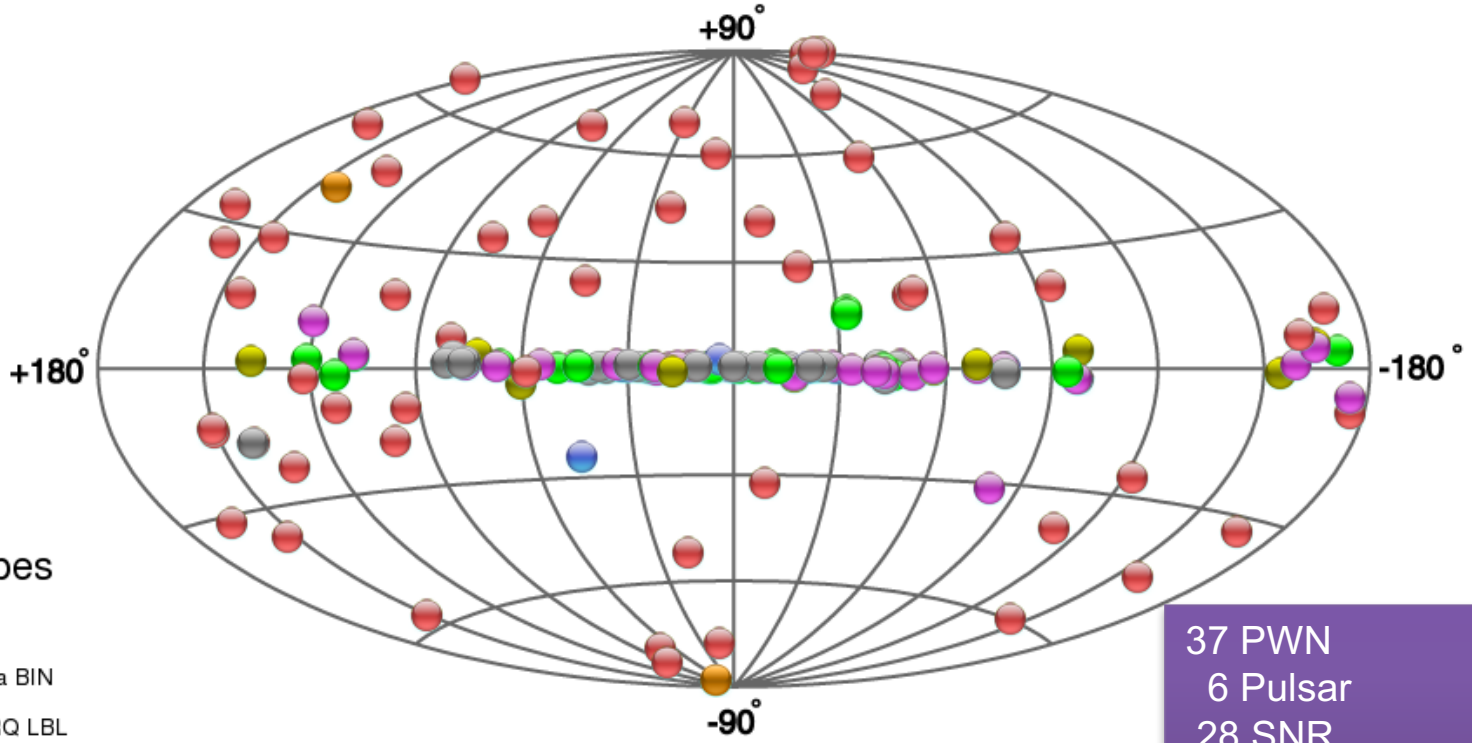
Schönfelder et al. 2000, A&ASS 143, 145

Unidentified sources published after the 1st COMPTEL Source Catalog:

- GRO J1411-64: l/b: 311.5/-2.5
  Zhang et al., AA 396, 923 (2002)
- GRO J1035-55: l/b: 285.4/1.1
  Zhang/Collmar, Ap&SSS 307, 23Z (2007)
- 3EG J0520+2556: detection by COMPTEL at low energies in search for EGRET unidentfied sources in the COMPTEL data
  Zhang et al., AA 421, 983 (2004)

The VHE gamma-ray sky

E > 100 GeV



Source Types

- PWN
- XRB PSR Gamma BIN
- HBL IBL FRI FSRQ LBL AGN (unknown type)
- Shell SNR/Molec. Cloud
- Starburst
- DARK UNID Other
- uQuasar Star Forming Region Globular Cluster Cat. Var. Massive Star Cluster BIN BL Lac (class unclear) WR

73 extragalactic
87 galactic
44 unidentified

37 PWN
6 Pulsar
28 SNR
9 BS
4 MSC
4 GC
SFR, 2 Bubble
} 87

http://tevcat.uchicago.edu/

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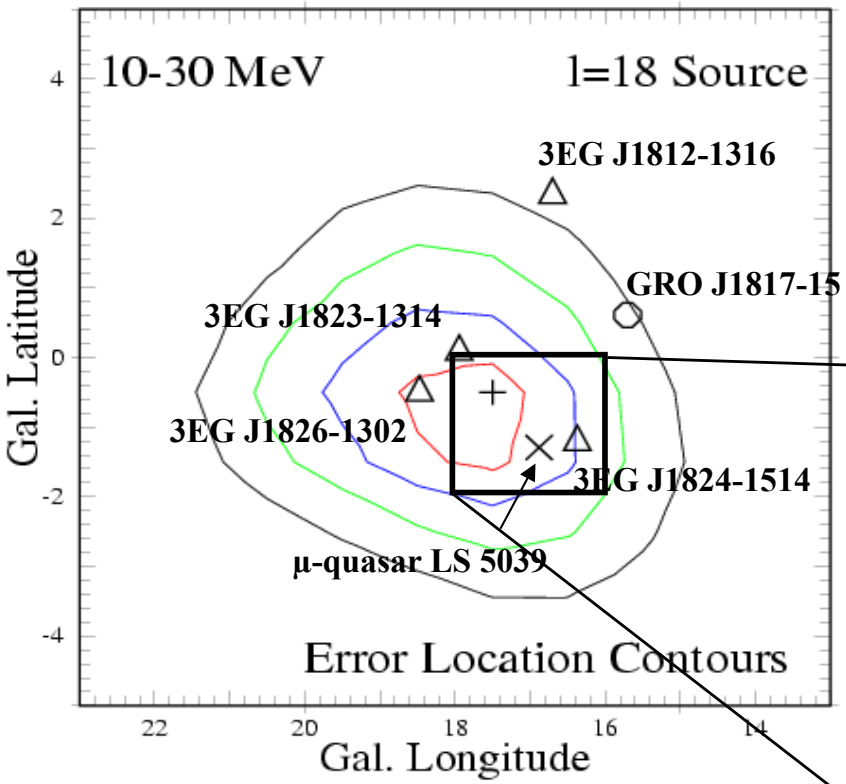
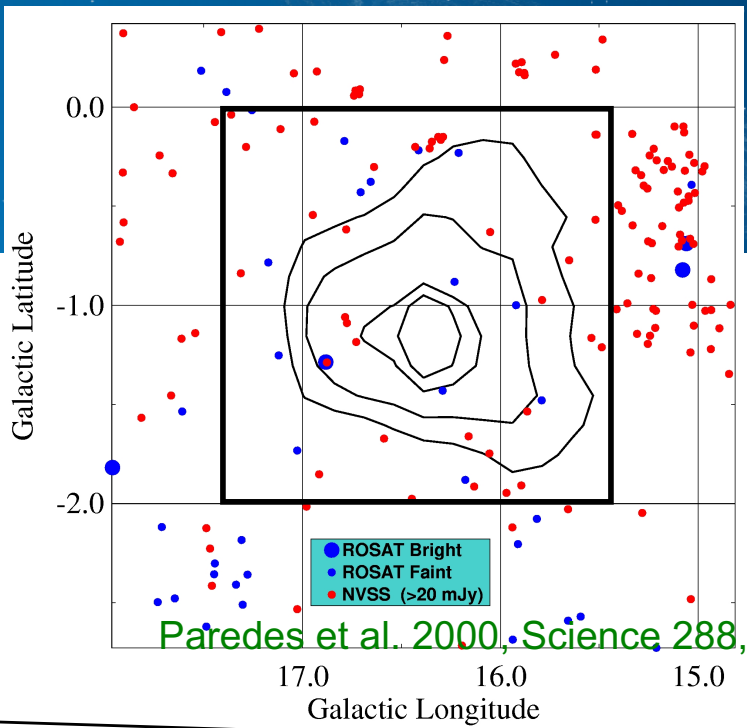
3EG J1824-1514
GRO J1823-12

COMPTEL



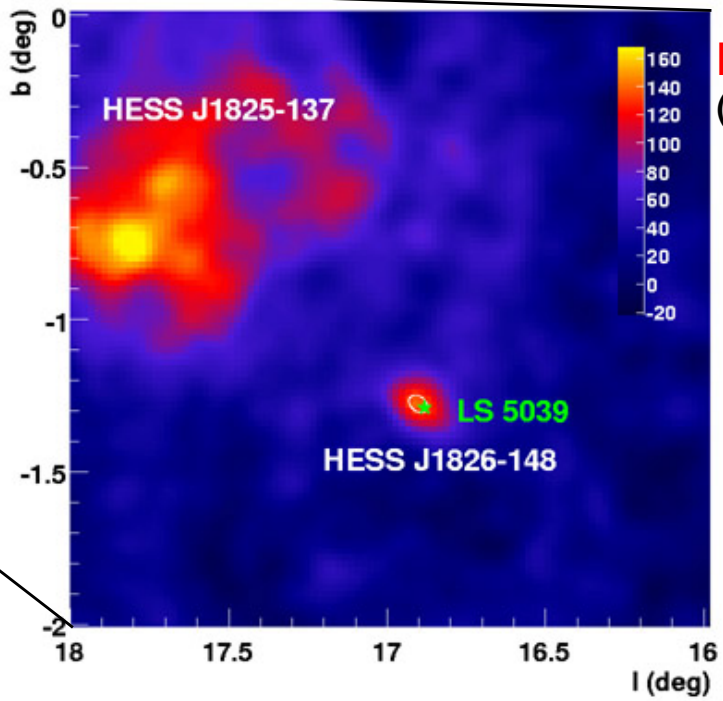
Collmar 2003, Proc. 4th Agile Science Workshop

EGRET



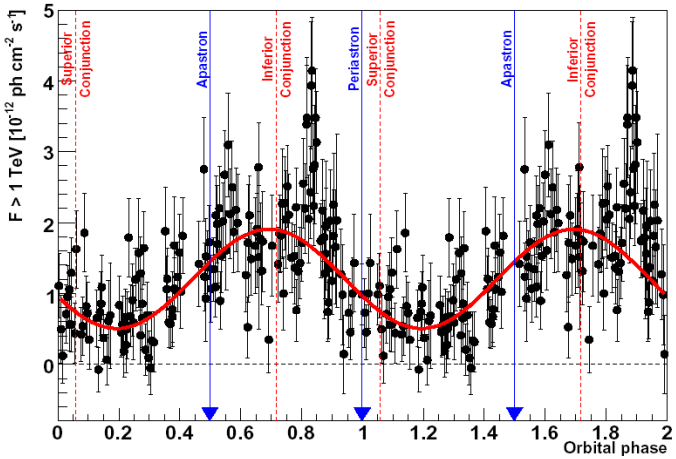
Paredes et al. 2000, Science 288, 2340

HESS
(> 100 GeV)

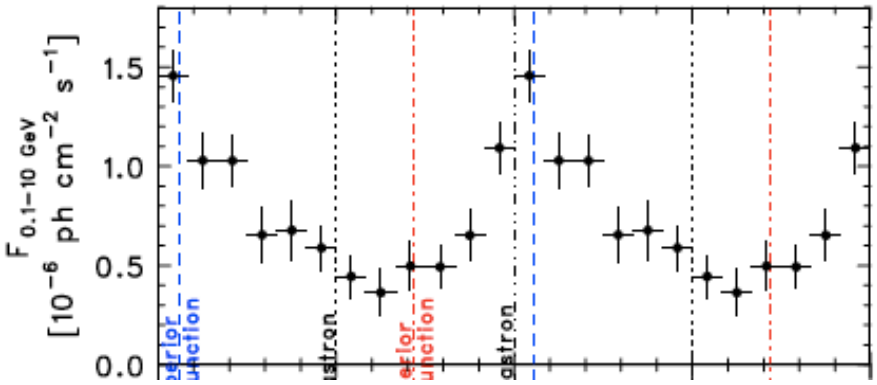


Aharonian et al. 2005, Sci 309, 746

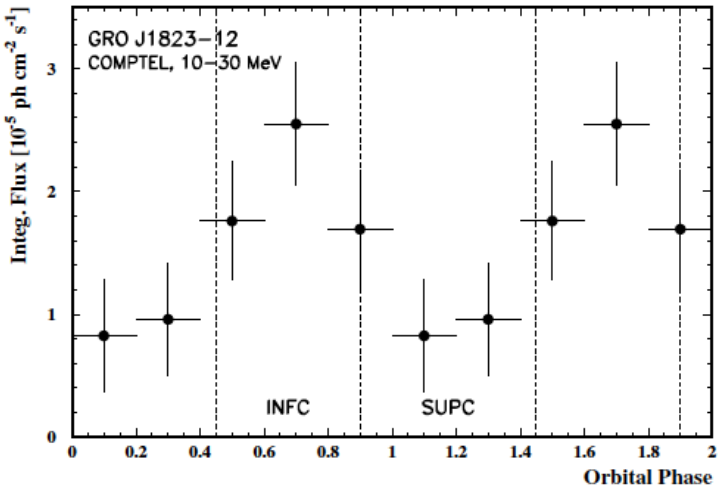
Orbital modulation



H.E.S.S. Aharonian et al. 2006, A&A 460, 743



Fermi (> 100 MeV) Abdo et al. 2009, ApJ 706, L56

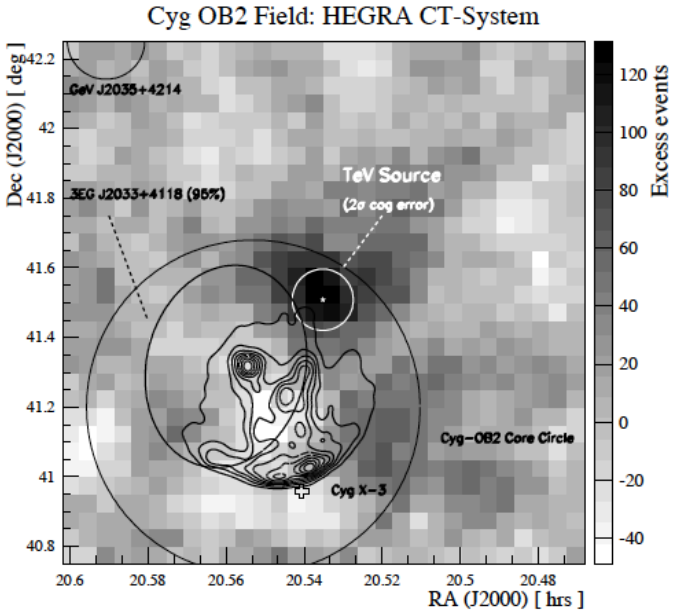


COMPTEL Collmar & Zhang 2014, A&A 565, A38

First unidentified TeV source: TeV J2032+415

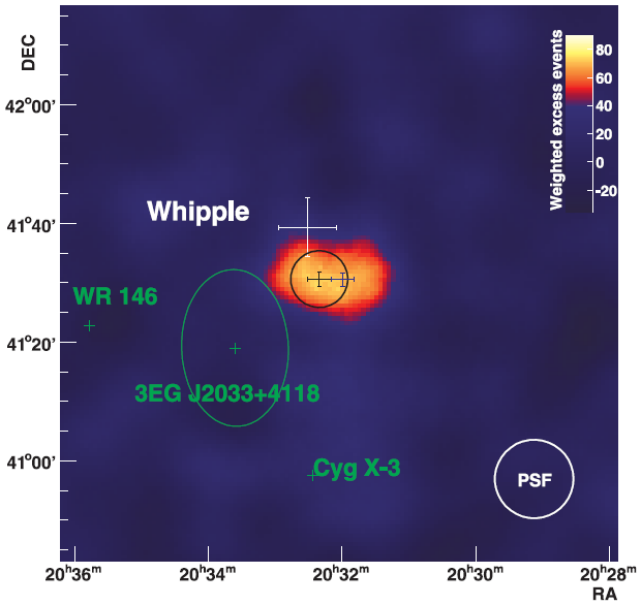
E > 100 GeV

HEGRA



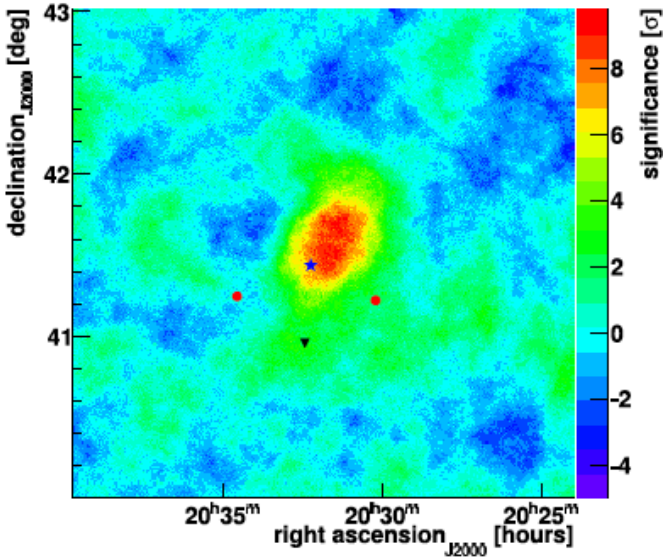
Aharonian et al. 2002, A&A 393, L37

MAGIC

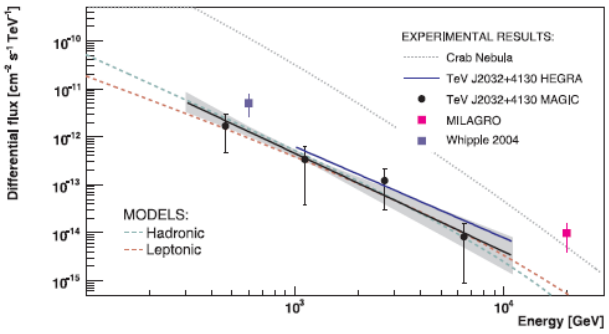


Albert et al. 2008, ApJ 675, L25

VERITAS



Aliu et al. 2014, ApJ 783,16



No flux variability over 3 yr, compatible with HEGRA

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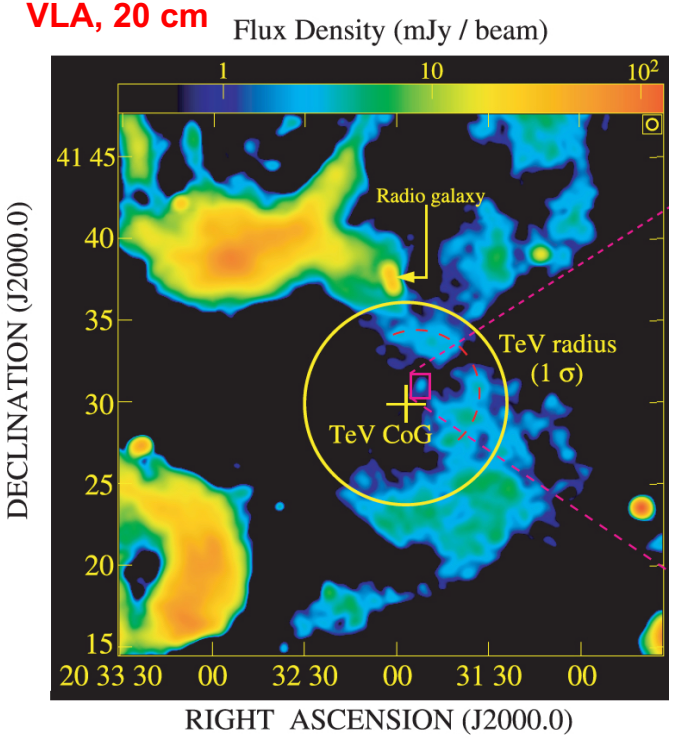
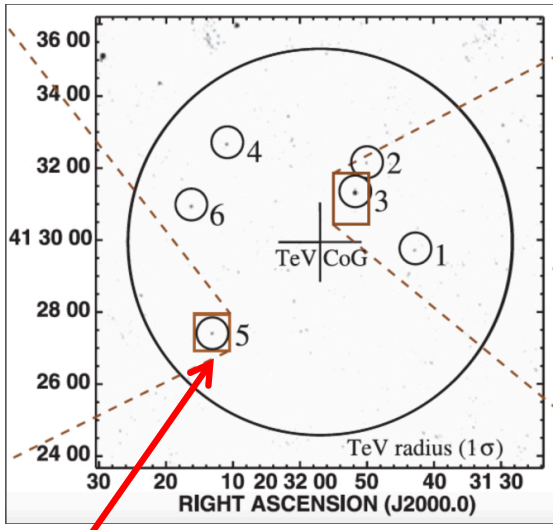
TeV J2032+415: Multiwavelength approach

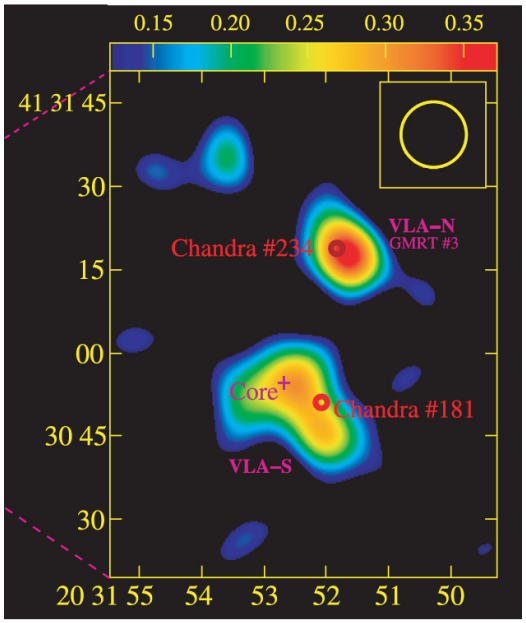
VLA, 20 cm



GMRT, 45 cm



VLA, 6 cm



Paredes et al. 2007, ApJ 654, L135

- ✧ *Fermi*: GeV pulsar LAT PSR J2032+4127
  Abdo et al. 2009, Sci 325, 840
- ✧ GBT: radio pulsar Camilo et al. 2009, ApJ 705,1
  same position and period GeV pulsar
  same position than GMRT#5 Be star
- ✧ Binary nature, P~20-30yr Lyne et al. 2015, MNRAS 451, 581

- ○ Gamma-ray pulsar: hard to explain the full extended γ-ray emission
- ○ Emission originated by more than one source?

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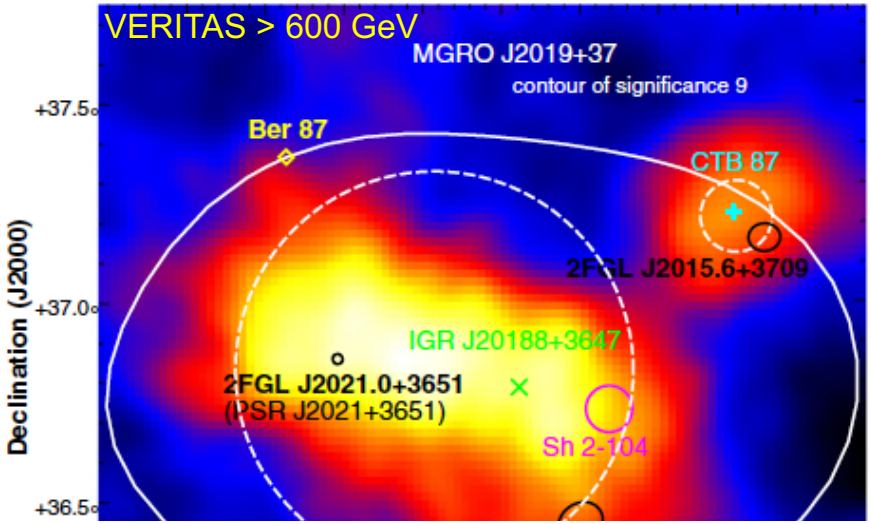
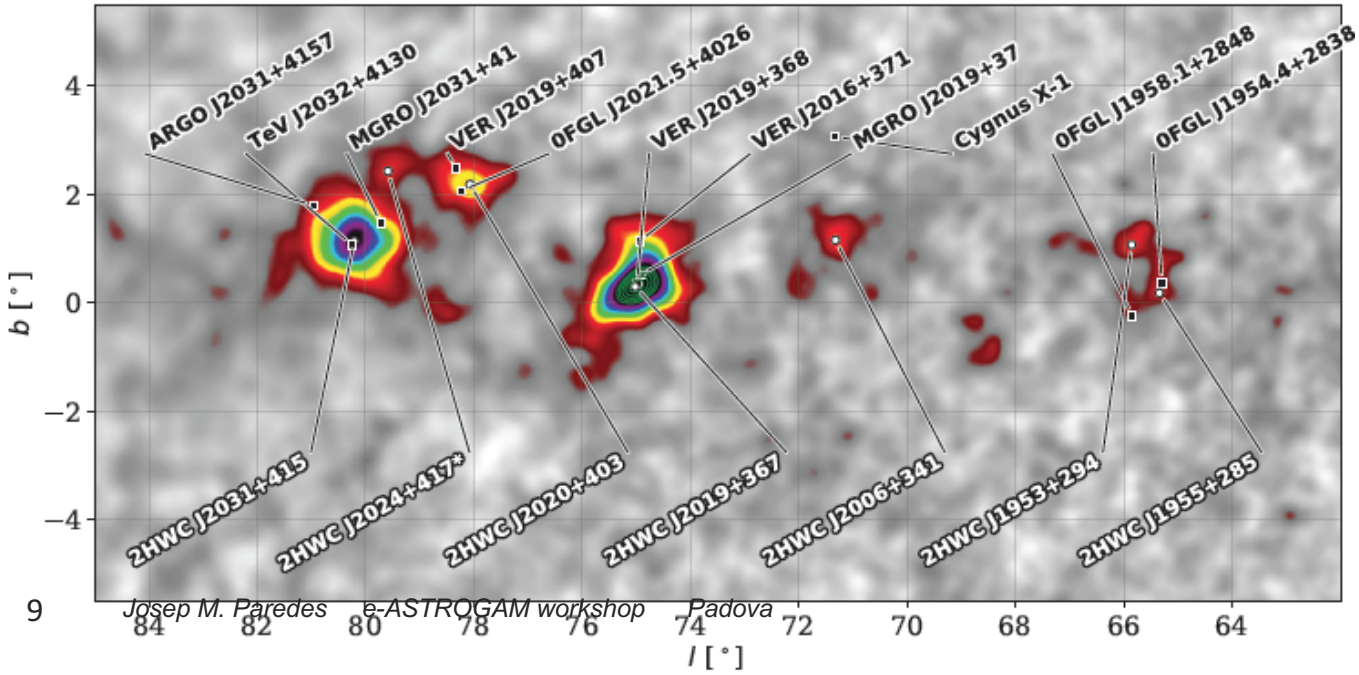
MGRO J2019+37: extended VHE source



VER J2016+371 overlaps CTB 87, a filled-center remnant (SNR).

VER J2019+368 is a bright extended (~1°) source that likely accounts for the bulk of the Milagro emission and is notably coincident with PSR J2021+3651 and the star formation region Sh 2−104.

Aliu et al. 2014 ApJ 788, 78



Abeysekara et al. 2017
arXiv:1702.02992
THE 2HWC HAWC OBSERVATORY GAMMA RAY CATALOG

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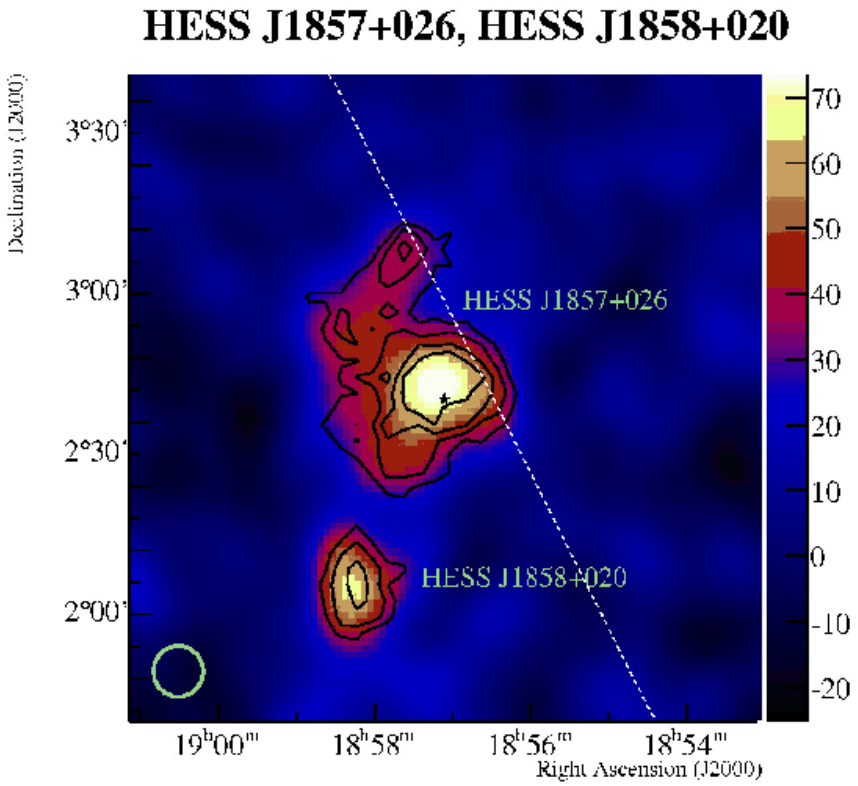
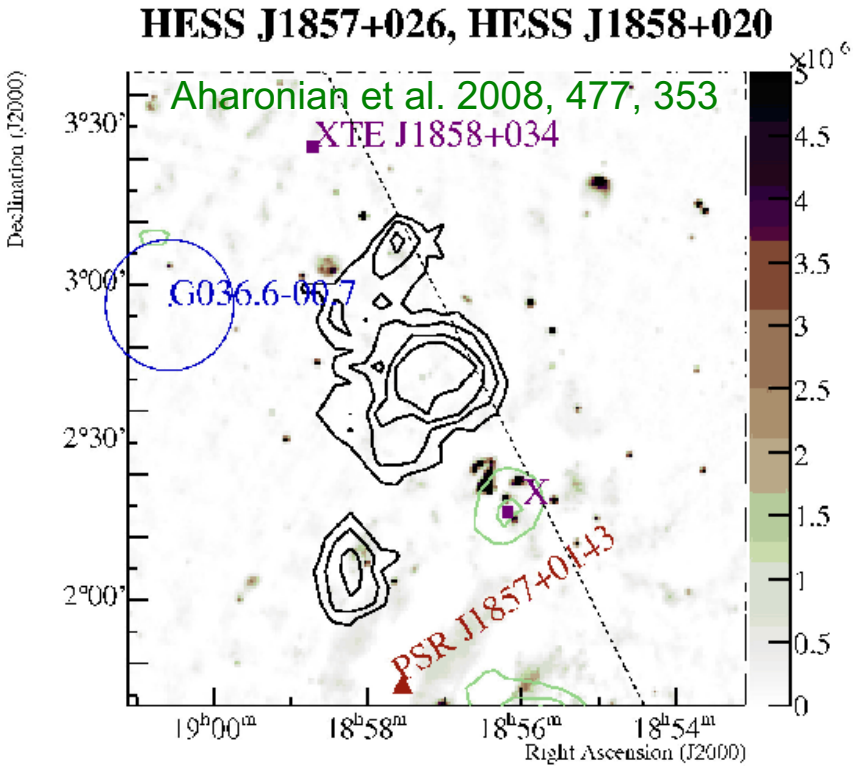
HESS Galactic Plane Survey: unidentified sources

★ 8 VHE gamma-ray sources ★ Angular sizes 3-18' ★ Spectrum: power-law (2.1-2.5)
No clear counterpart in lower-energy wavebands. If confirmed → a new VHE class?





Thirty-one TeV sources (11 unid., 10 PWN, 2 binaries, 7 SNR, 1 Blazar) have no counterparts in 3FGL Acero et al. 2015, ApJSS 218, 23

NVSS (grey scale)

ROSAT

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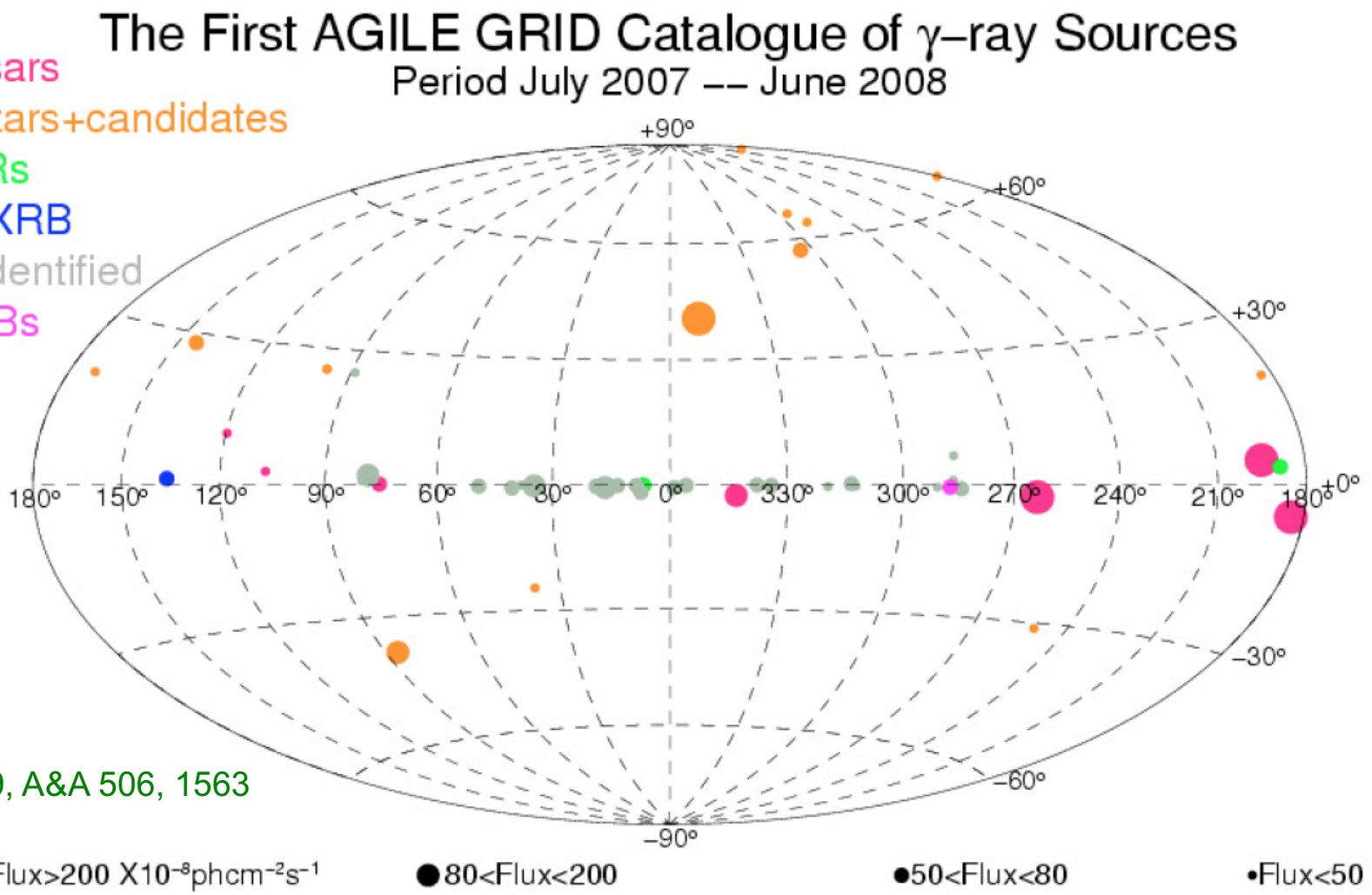
First AGILE GRID Catalogue

E > 100 MeV

21 Pulsars
13 Blazars+candidates
2 SNRs
2 HMXRB
8 Unidentified
1 CWBs



Pittori et al. 2009, A&A 506, 1563

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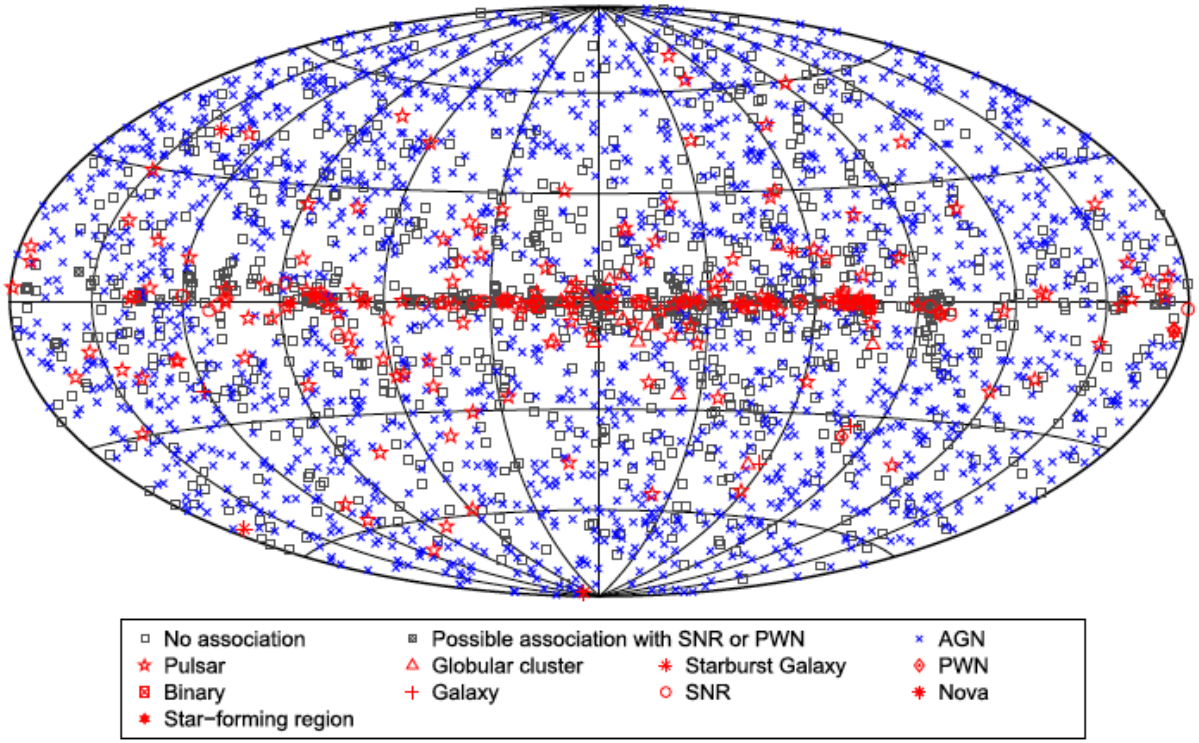
FERMI LAT THIRD SOURCE CATALOG (3FGL)

100 MeV to 300 GeV



LAT 3FGL Source Classes

Description	Identified		Associated	
	Designator	Number	Designator	Number
Pulsar, identified by pulsations	PSR	143	...	...
Pulsar, no pulsations seen in LAT yet	...	...	psr	24
Pulsar wind nebula	PWN	9	pwn	2
Supernova remnant	SNR	12	snr	11
Supernova remnant/pulsar wind nebula	...	...	spp	49
Globular cluster	GLC	0	glc	15
High-mass binary	HMB	3	hmb	0
Binary	BIN	1	bin	0
Nova	NOV	1	nov	0
Star-forming region	SFR	1	sfr	0
Compact steep spectrum quasar	CSS	0	css	1
BL Lac type of blazar	BLL	18	bll	642
FSRQ type of blazar	FSRQ	38	fsrq	446
Non-blazar active galaxy	AGN	0	agn	3
Radio galaxy	RDG	3	rdg	12
Seyfert galaxy	SEY	0	sey	1
Blazar candidate of uncertain type	BCU	5	bcu	568
Normal galaxy (or part)	GAL	2	gal	1
Starburst galaxy	SBG	0	sbg	4
Narrow-line Seyfert 1	NLSY1	2	nlsy1	3
Soft-spectrum radio quasar	SSRQ	0	ssrq	3
Total	...	238	...	1785
Unassociated	...	...	...	1010

PSR (167)

AGN (1771)

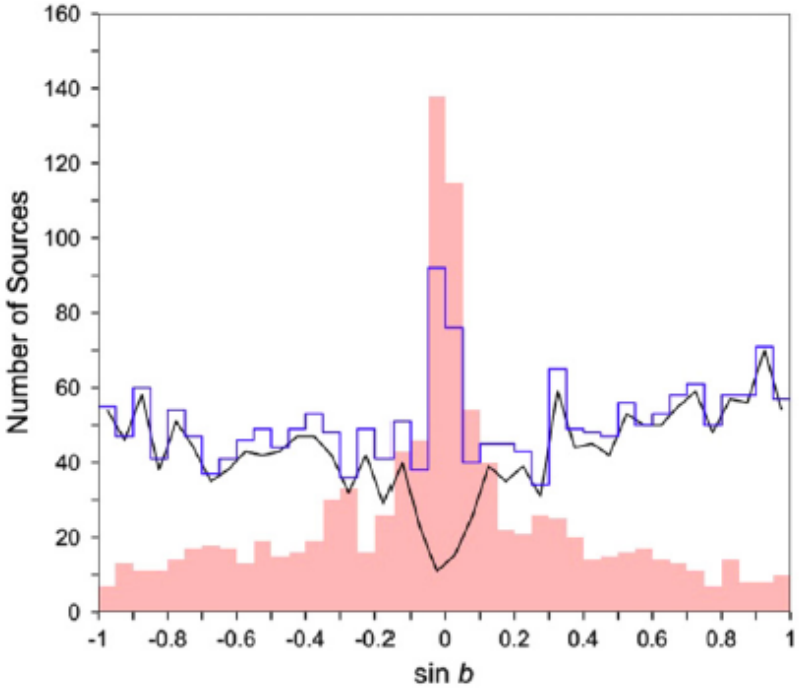
Note.
The designation "spp" indicates potential association with SNR or PWN (see Table 7). Designations shown in capital letters are firm identifications; lowercase letters indicate associations. In the case of AGNs, many of the associations have high confidence. Among the pulsars, those with names beginning with LAT were discovered with the LAT.

Acero et al. 2015, ApJSS 218, 23

FERMI LAT THIRD SOURCE CATALOG (3FGL)

100 MeV to 300 GeV

Association: close positional correspondence
Identification: correlated variability at other wavelengths or characterization of the 3FGL source by its angular extent



Galactic latitude *b* of unassociated sources
All associated sources
All active galaxy source classes

4 yr, 3033 sources

238 identified sources
1785 associated sources
1010 unassociated

|b| > 5° , 675 sources
|b| < 5° , 335 sources

Acero et al. 2015, ApJSS 218, 23

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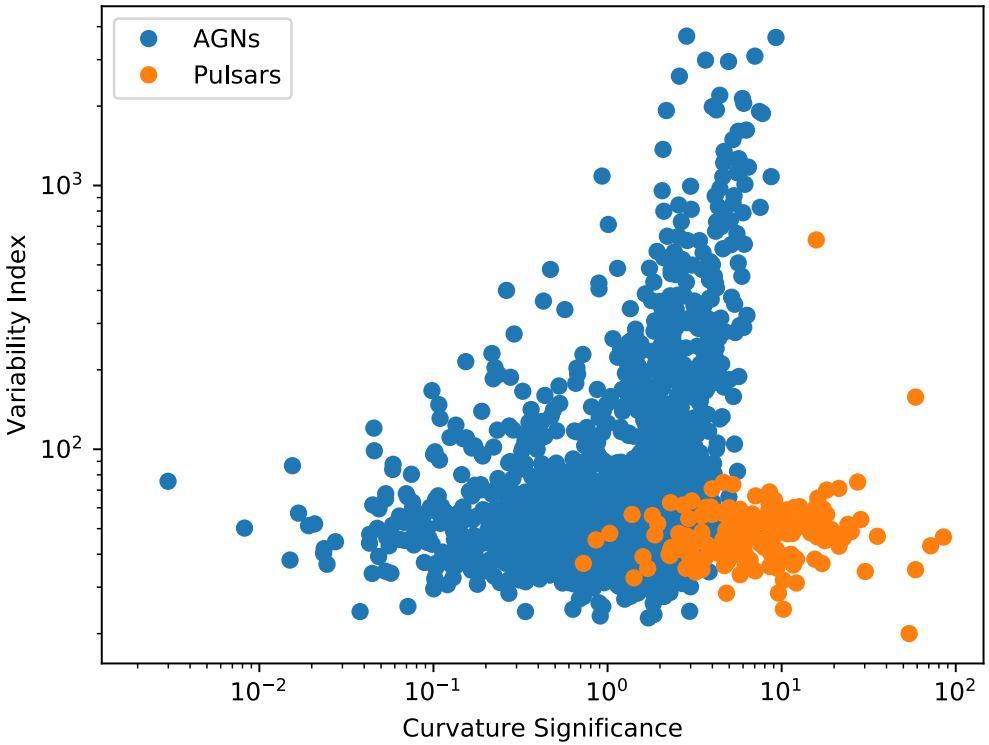
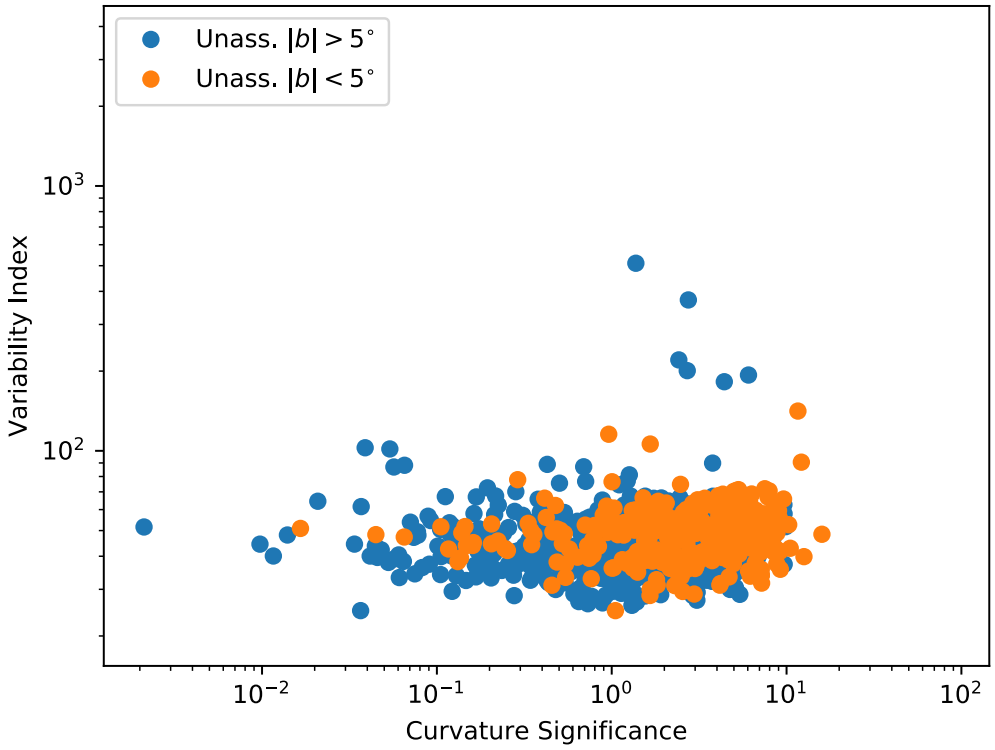
The likely nature of 3FGL unassociated sources



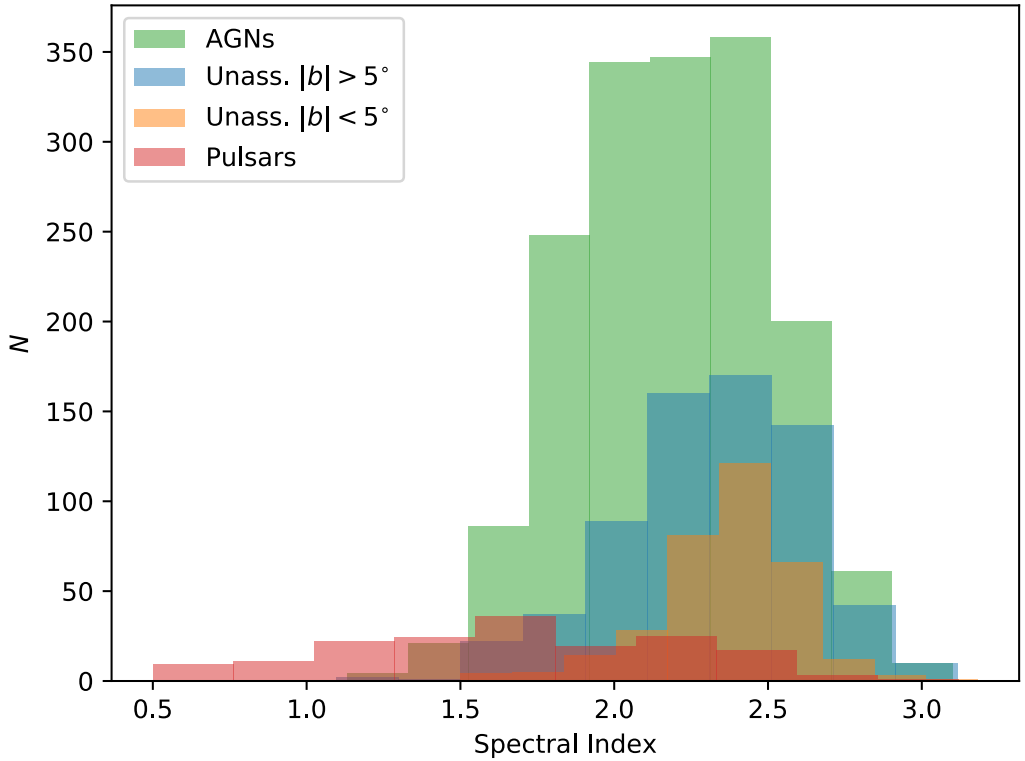


AGNs and PSR: The two main classes of gamma-ray sources
Roughly distinguished by their **timing** and spectral properties

AGNs: Variability on month-long timescales Pulsars: Tend to be non-variable (on long timescales)

- The majority of unassociated γ-ray sources do not show significant γ-ray variability and could be considered steady γ-ray emitters
- Diffuse Galactic emission: Some fraction of the unassociated sources at low latitudes may be local emission maxima of diffuse Galactic emission that are not adequately modeled Nolan et al 2012, ApJSS 199, 31

The likely nature of 3FGL unassociated sources



AGNs and PSR: The two main classes of gamma-ray sources
Roughly distinguished by their timing and **spectral** properties

AGNs: Energy spectra breaks more softly than pulsars in the LAT energy band

Pulsars: Spectra with more curvature, PL + exponential cutoff at a few GeV

The likely nature of 3FGL unassociated sources

❑ **Source density extrapolation** Acero et al. 2015, ApJSS 218, 23

1010 unassociated

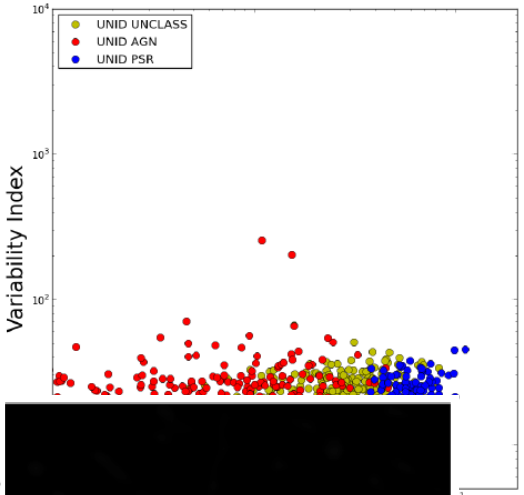
|b| > 5° , 675 sources
|b| < 5° , 335 sources

→ ~ 100 AGN 110 PSR
103 SNR 21 other

❑ **Artificial Neural Networks algorithms** Saz Parkinson et al. 2016, ApJ 820, 8

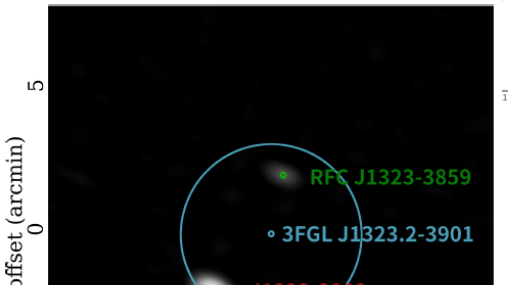
1008 unassociated sources:

334 (33%) being classified as likely PSR
559 (55%) as likely AGN



❑ **Radio follow-up** on all unassociated gamma-ray sources from the 3FGL catalog

ATCA + VLA, 4-0 – 10.0 GHz
Schizel et al. 2017, arXiv:1702.07036



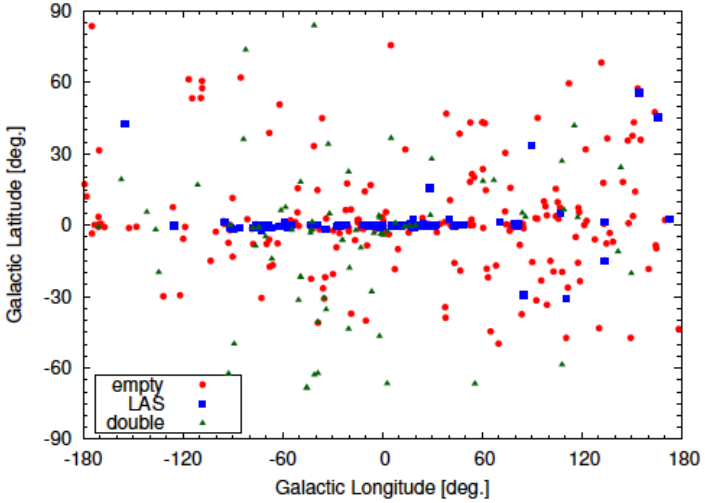
2097 radio candidates

✧142 new AGN associations (VLBI follow-up)

✧245 empty fields:

unassociated γ-ray sources with not a single compact radio source above 2mJy within 3σ of their γ-ray localization

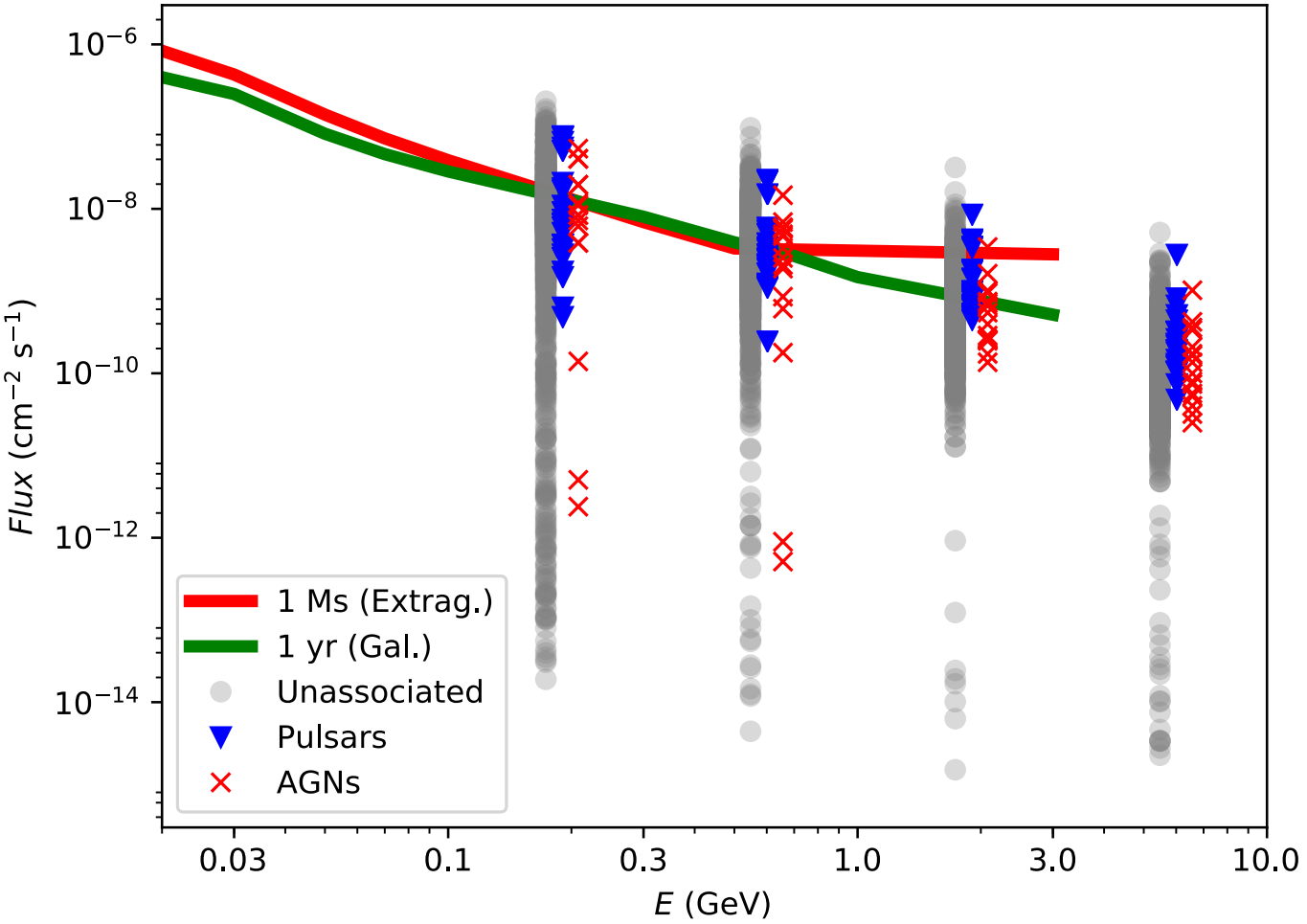
39% of them are located away from the GP



✧ 36 extended radio sources that are candidates for association with a corresponding γ-ray object:

19 of which are most likely SNR or HII regions
17 could be radio galaxies.

3FGL Unassociated sources and e-ASTROGAM



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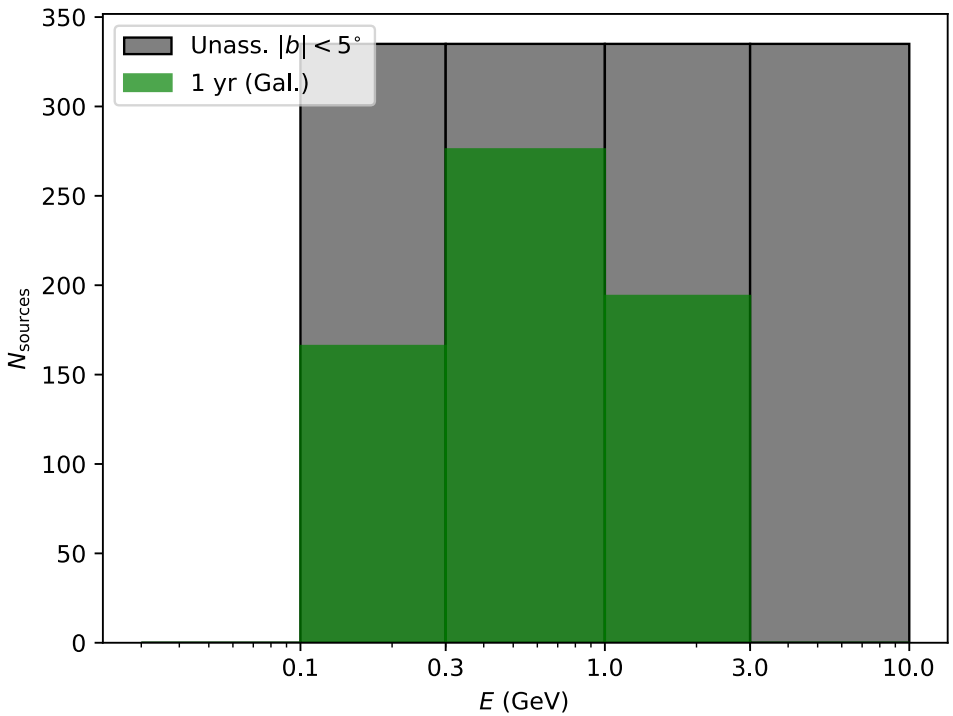
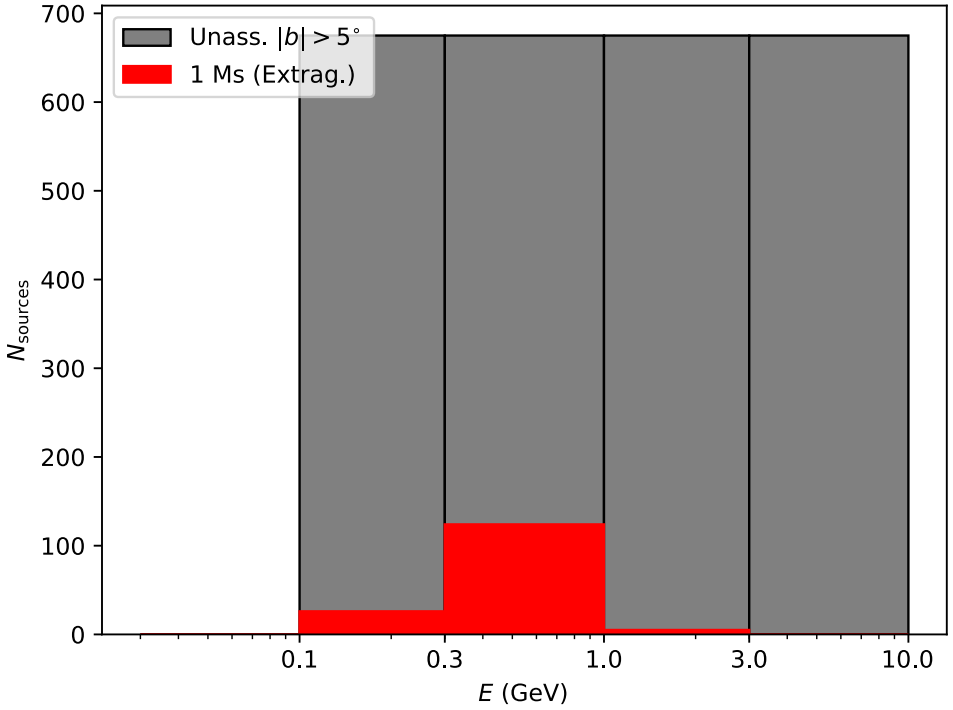
3FGL Unassociated sources and e-ASTROGAM



335 unassociated sources at |b| < 5°

0.1 – 0.3 GeV 166 (50%)
0.3 – 1.0 GeV 276 (82%)
1.0 – 3.0 GeV 194 (58%)



675 unassociated sources at |b| > 5°

0.1 – 0.3 GeV 26 (4%)
0.3 – 1.0 GeV 124 (18%)
1.0 – 3.0 GeV 5 (0.7%)

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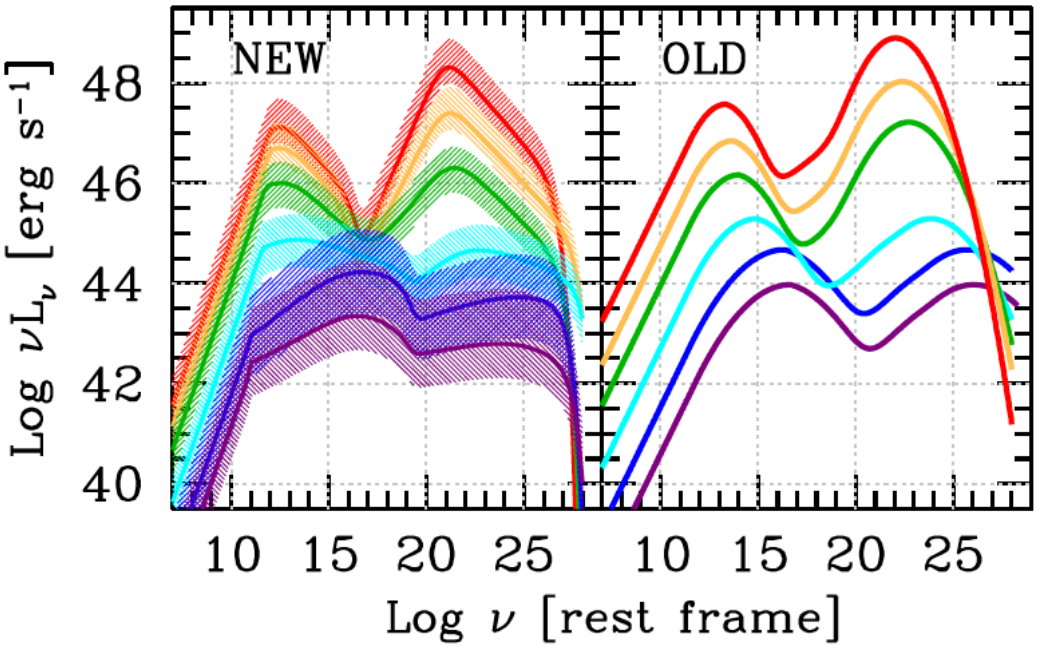
3FGL Unassociated sources and e-ASTROGAM

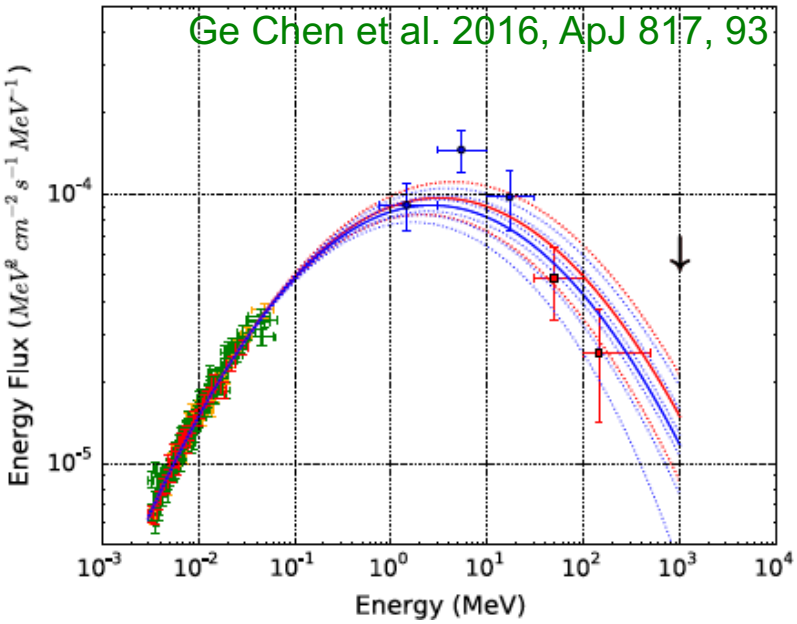
The majority of the sources (2415 out of 3033) from the 3FGL Catalog of GeV-band sources have power-law spectra (at energies larger than 100 MeV) steeper than E^{-2}, implying that their peak energy output is below 100 MeV



Ghisellini et al. 2017, arXiv:1702.02571

Most powerful AGNs peak in the MeV region

PSR B1509−58



γ-ray pulsars typically have spectral peaks in the GeV energy band (Thompson 2004).

Some exceptions: PSR B1509− 58 energy spectrum peaks at 2.6± 0.8 MeV (Ge Chen et al 2016)

Summary

	Detected	Unidentified	
EGRET	271	168	62%
COMPTEL 1st cat	32	9	28%
AGILE 1st cat	47	8	17%
FERMI 3FGL	3033	1010	33%
CHERENKOV	204	44	22%

- e-ASTROGAM will detect:
  82% of the 3FGL unassociated at |b| < 5º → 276 sources
  18% of the 3FGL unassociated at |b| > 5º → 124 sources

- e-ASTROGAM will study their low energies simultaneously and will contribute to associate them to AGN, pulsars, other

- e-ASTROGAM will detect all (11) COMPTEL unidentified sources

- e-ASTROGAM will detect new unidentified sources

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