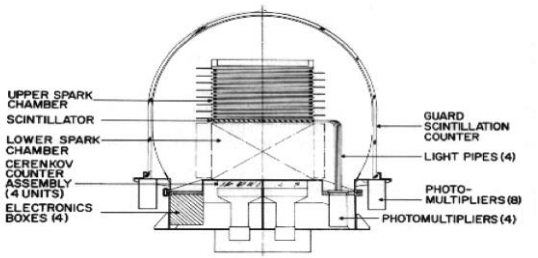
Our Gamma-Ray Universe

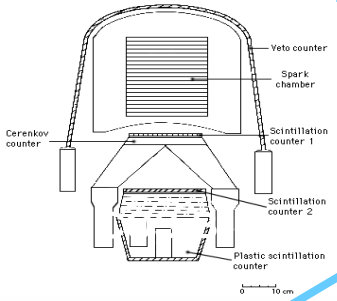
Patrizia Caraveo
INAF

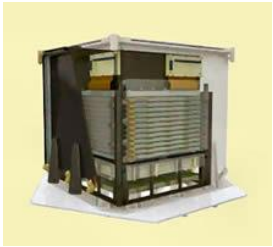
Going higher in Energy : a brief History of γ-ray Trackers

SAS-2 **1972-73**



COS-B **1975-82**



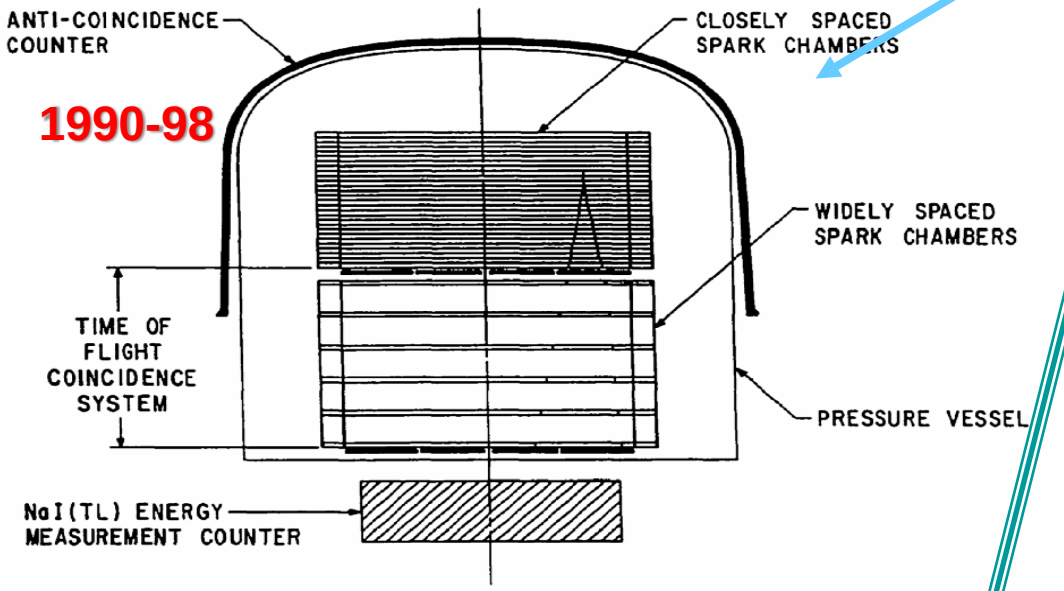


2007…

AGILE

EGRET

1990-98



2008…

First γ-ray skymap- 1972

OSO-3
Launched 1967

621 events
E > 50 MeV

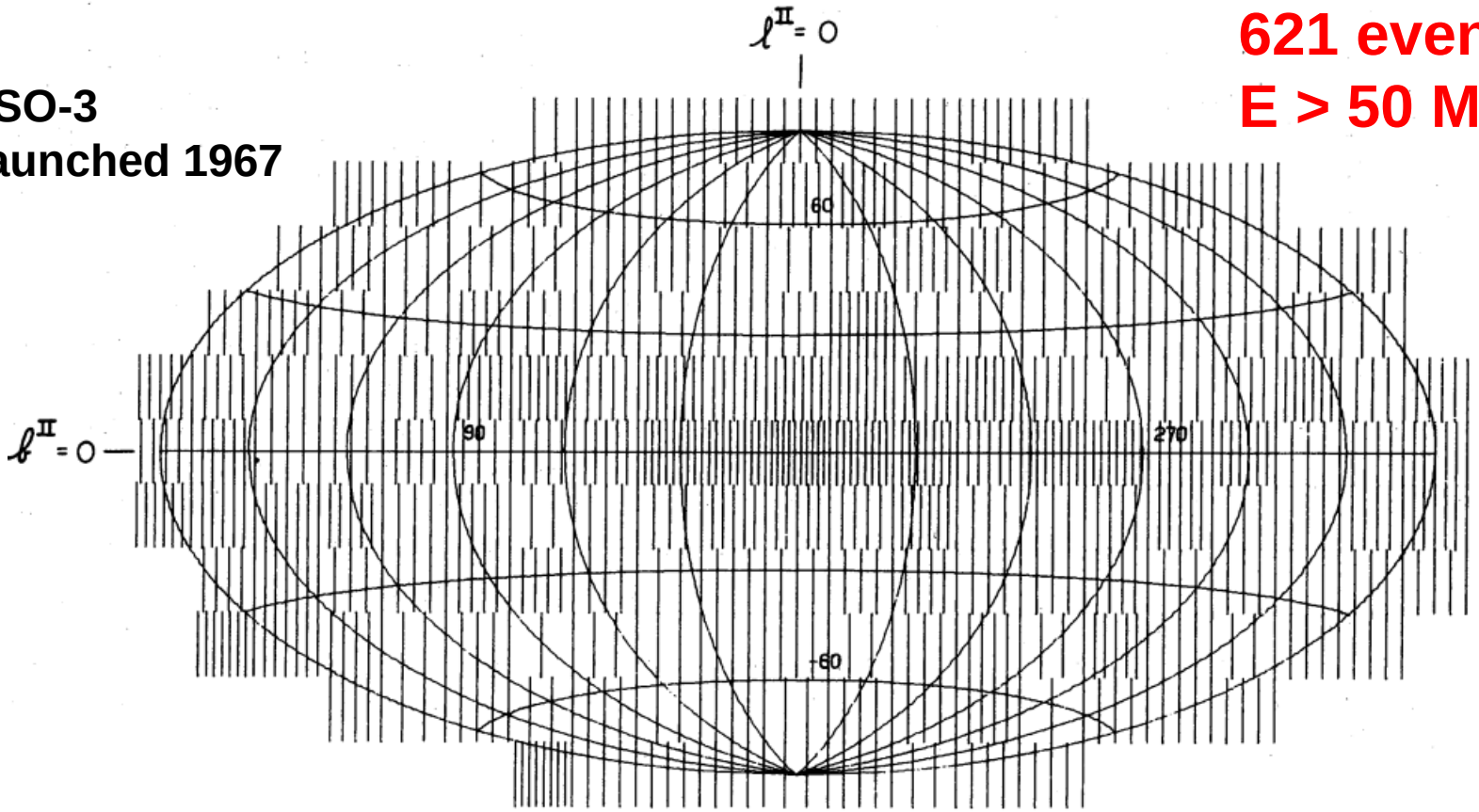
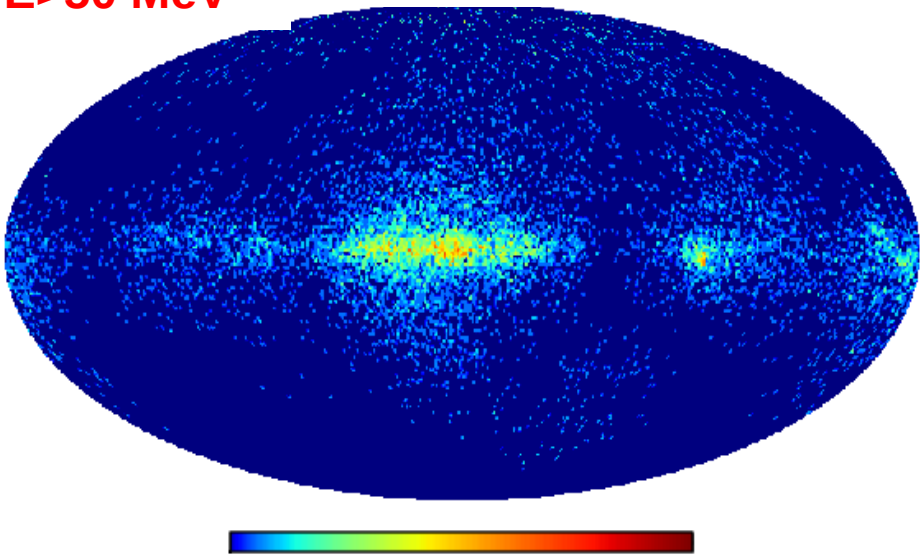


FIG. 8.—Sky map of the γ-ray intensity in galactic coordinates. The element of area on the map to which the formula given in the text applies is approximately 245 square degrees.

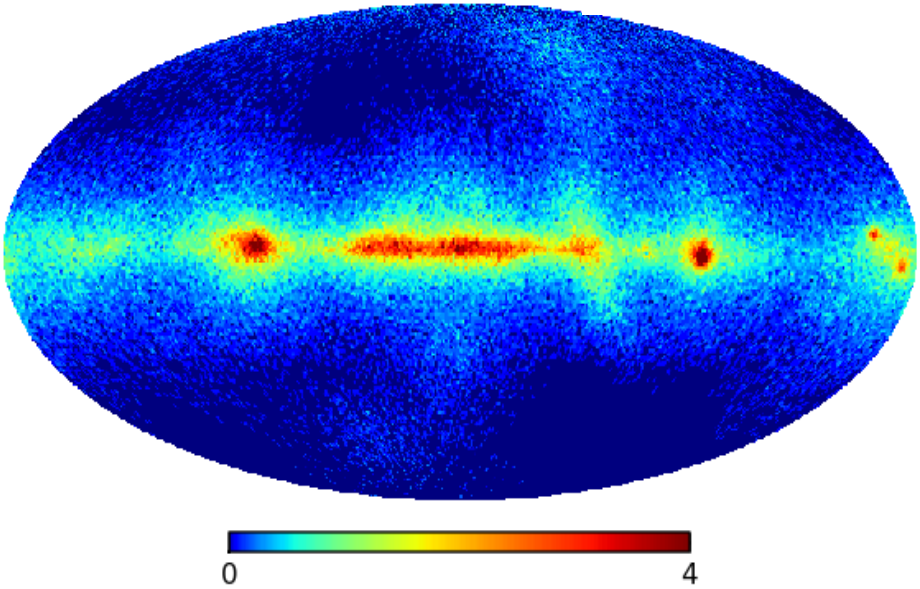
11,762 γ-rays
E>50 MeV

SAS-2 (‘72-’73)

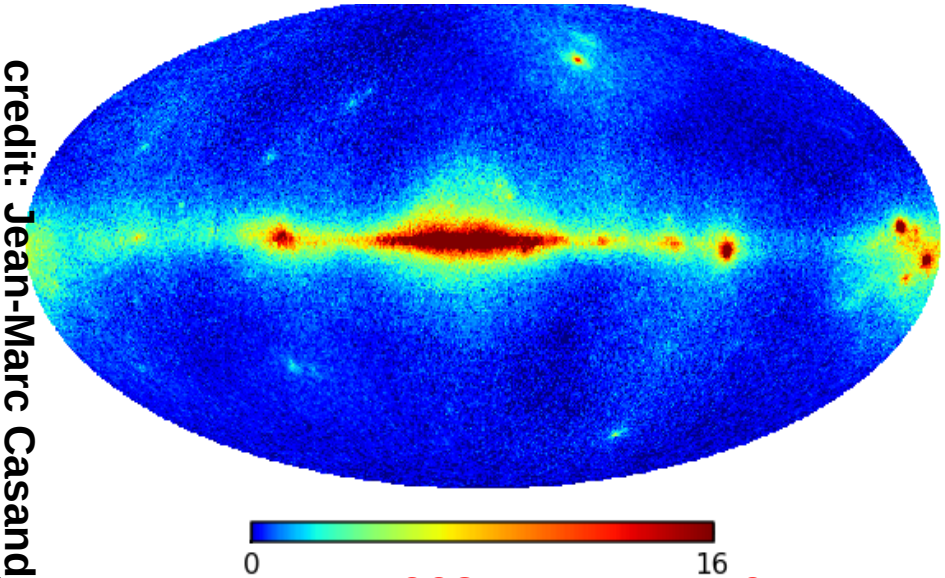


COS-B (‘75-’82)

207,213 γ-rays
E>50 MeV

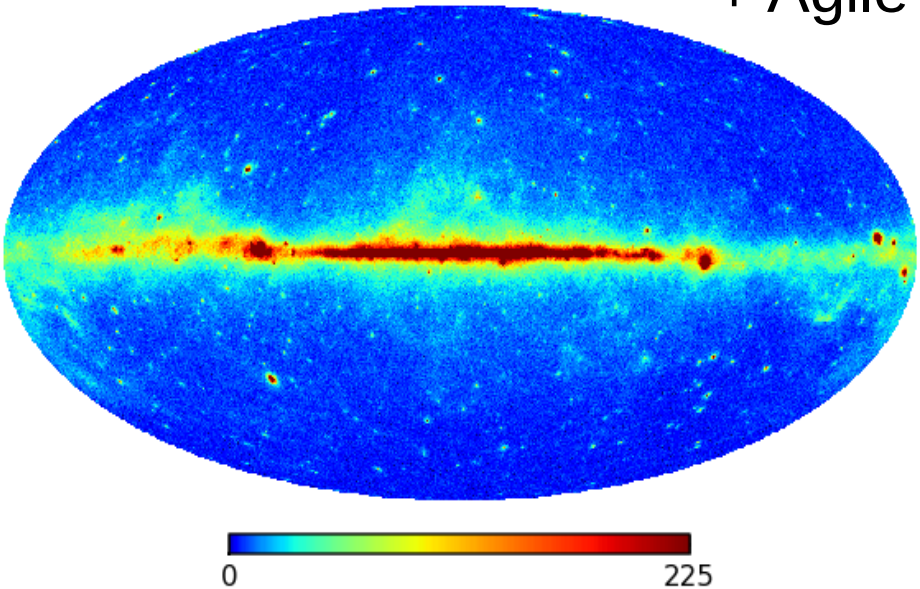


EGRET –GRO- 1990-’98



1,151,662 γ-rays E>50 MeV

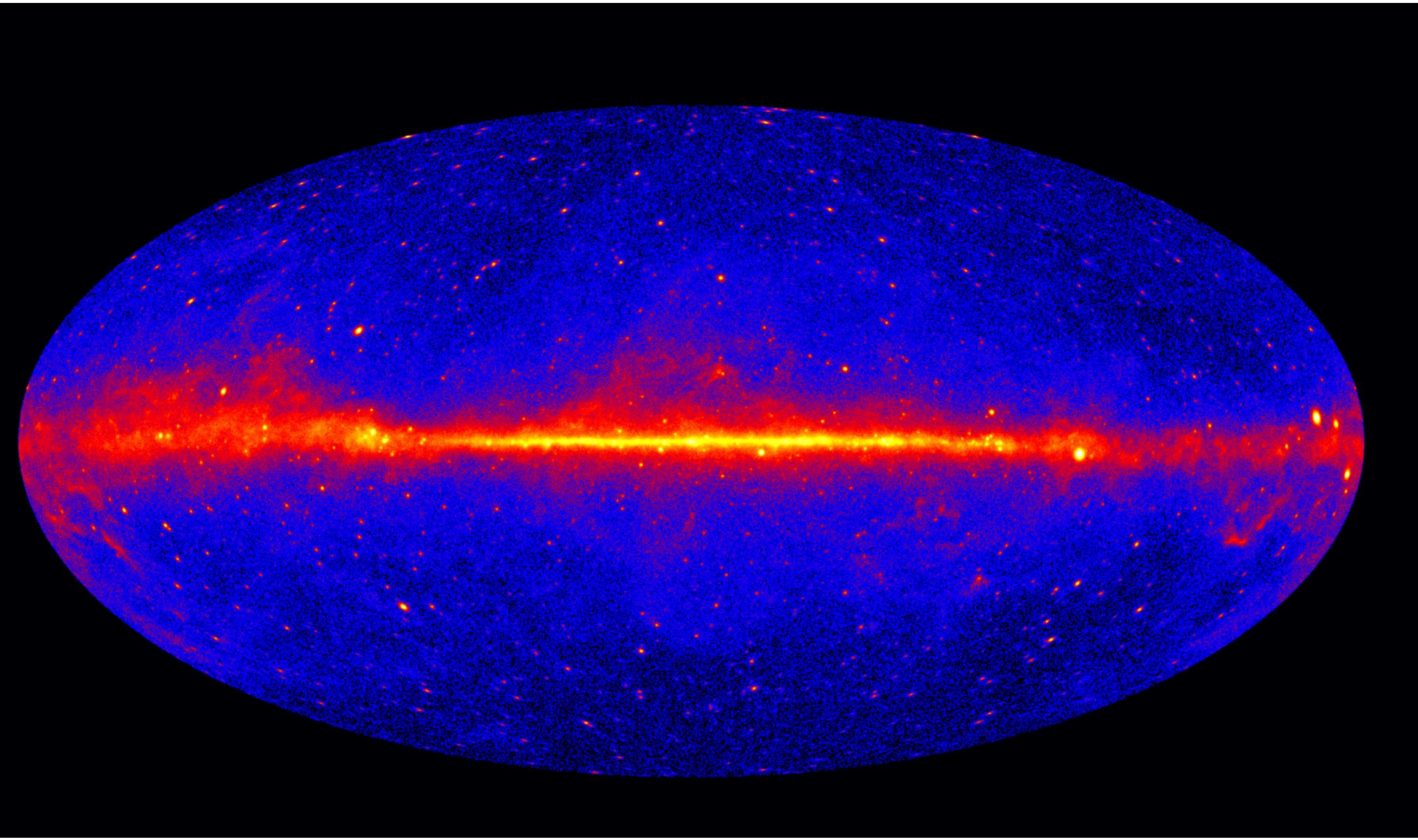
Fermi - Large Area Telescope + Agile



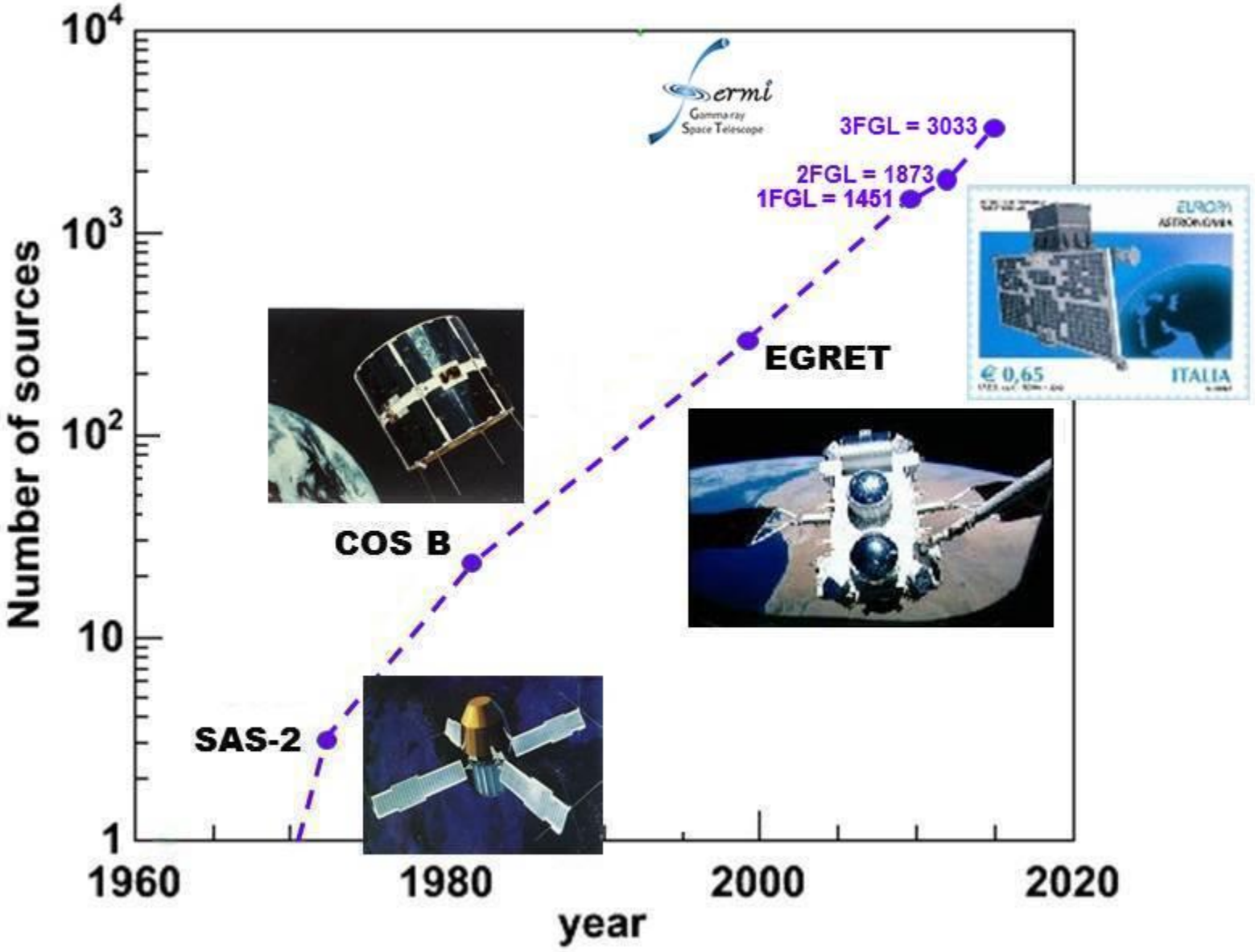
43,109,003 γ-rays E>50 MeV

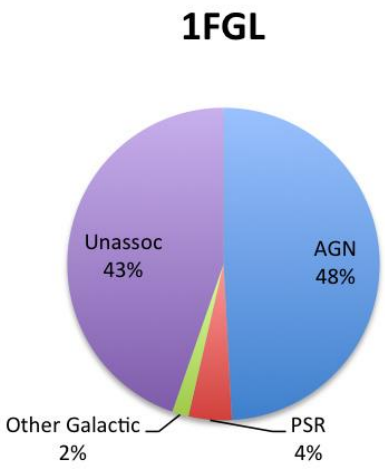
credit: Jean-Marc Casandjian

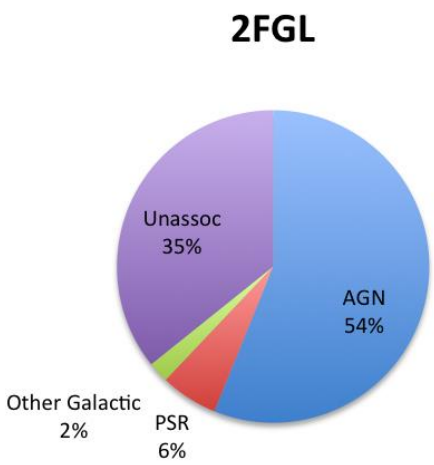
Fermi gamma-ray image

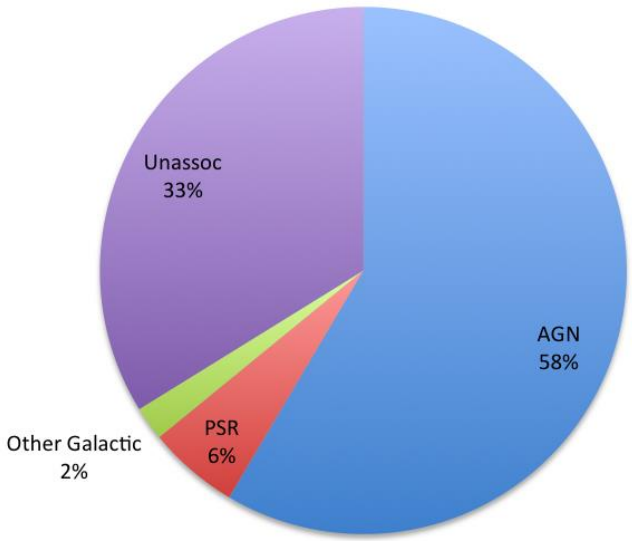


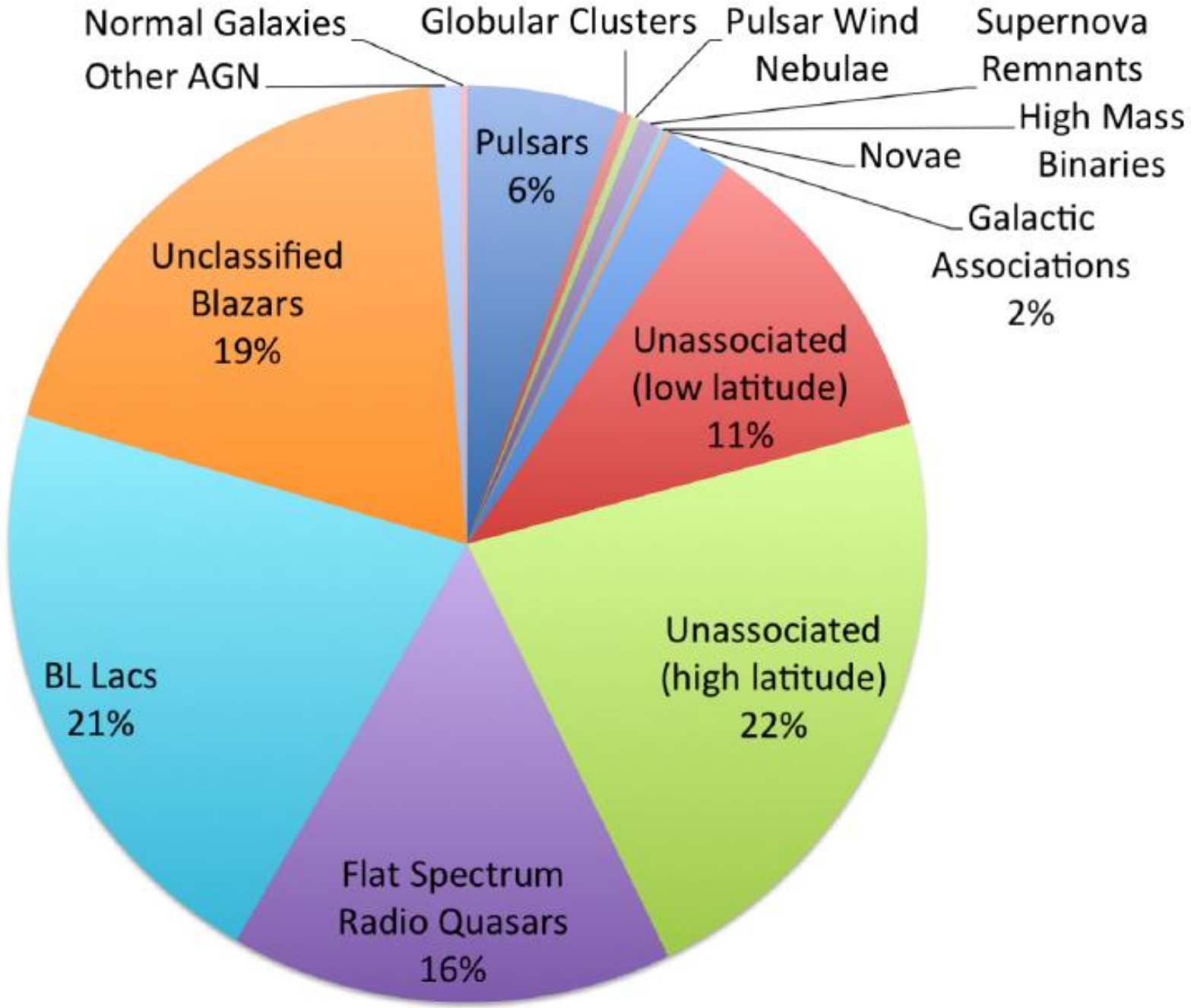
4 decades of γ-ray astronomy from space



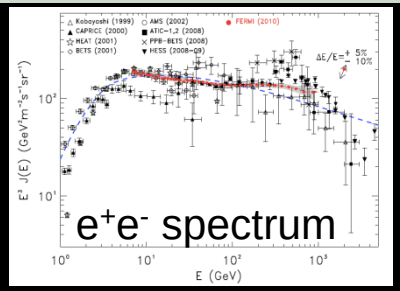

1FGL
Unassoc
43%
AGN
48%
Other Galactic
2%
PSR
4%

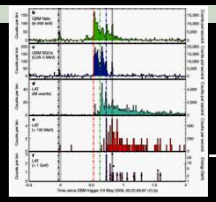

2FGL
Unassoc
35%
AGN
54%
Other Galactic
2%
PSR
6%


3FGL
Unassoc
33%
AGN
58%
Other Galactic
2%
PSR
6%

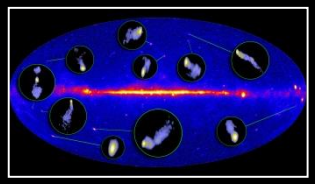

Normal Galaxies
Other AGN
Globular Clusters
Pulsar Wind Nebulae
Supernova Remnants
High Mass Binaries
Novae
Galactic Associations 2%
Pulsars 6%
Unassociated (low latitude) 11%
Unassociated (high latitude) 22%
Flat Spectrum Radio Quasars 16%
BL Lacs 21%
Unclassified Blazars 19%

Fermi Highlights and Discoveries

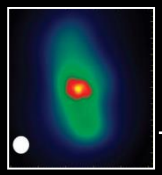




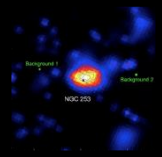
GRBS



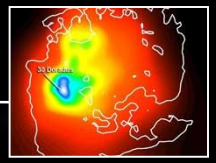
BLAZARS



RADIO GALAXIES

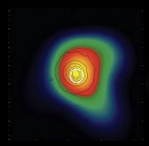


STAR BURST GALAXIES



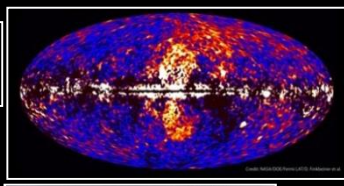
LMC & SMC

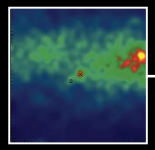
Extragalactic



GLOBULAR CLUSTERS

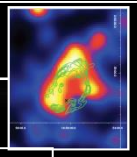
FERMI BUBBLE





NOVAE

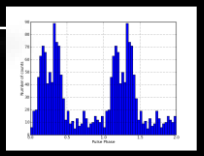
SNRS & PWN



Galactic

GAMMA-RAY BINARIES

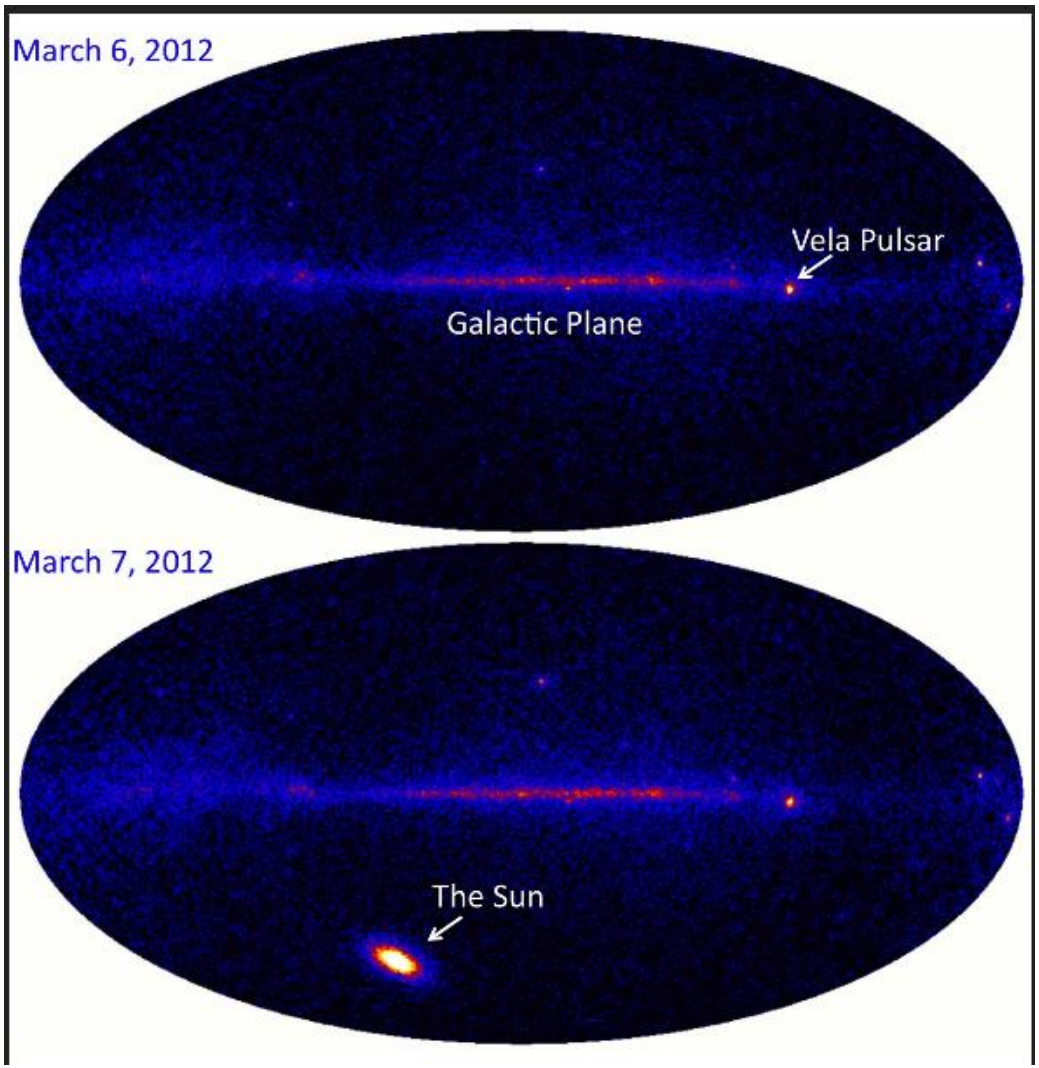
PULSARS: isolated, binaries, & MSPs



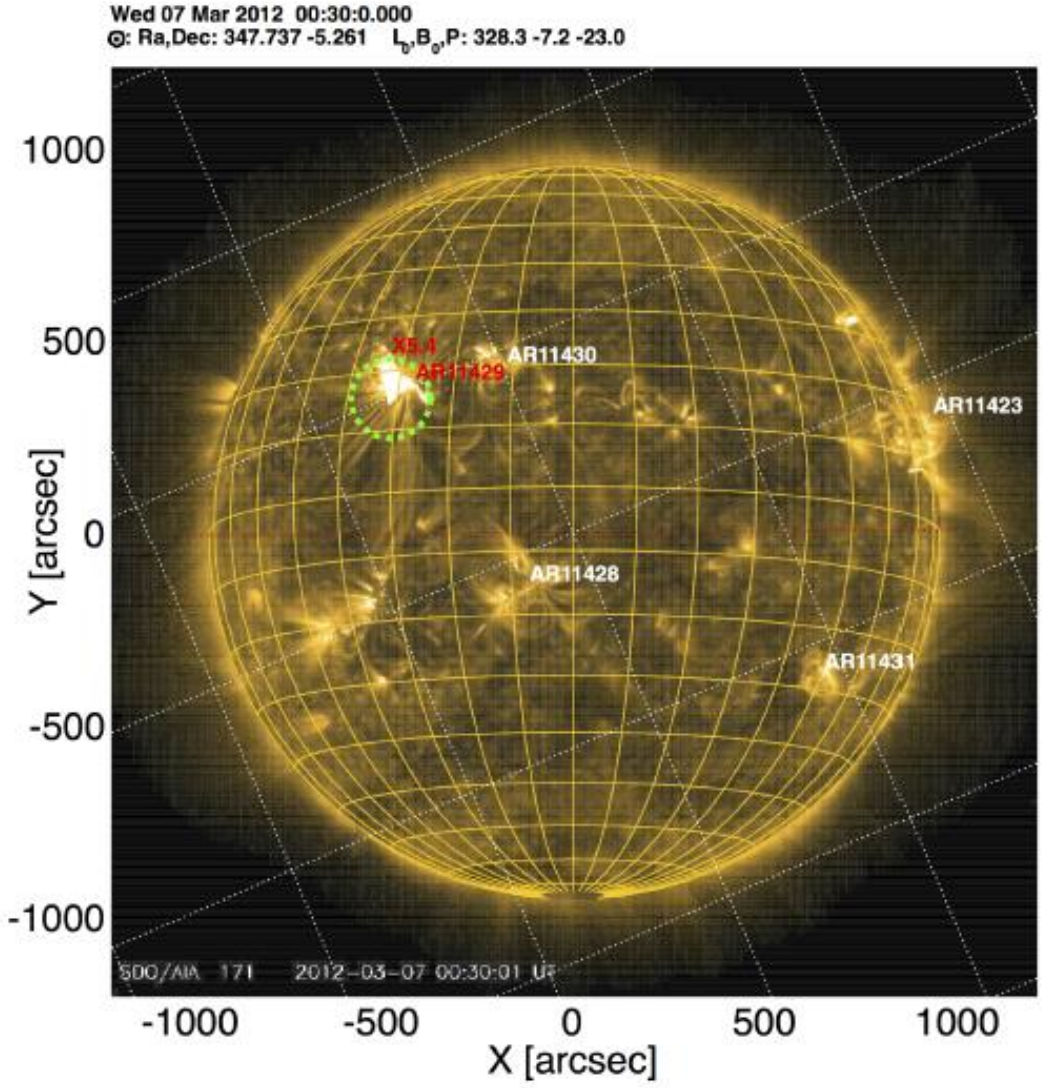
SUN: *flares* & CR interactions

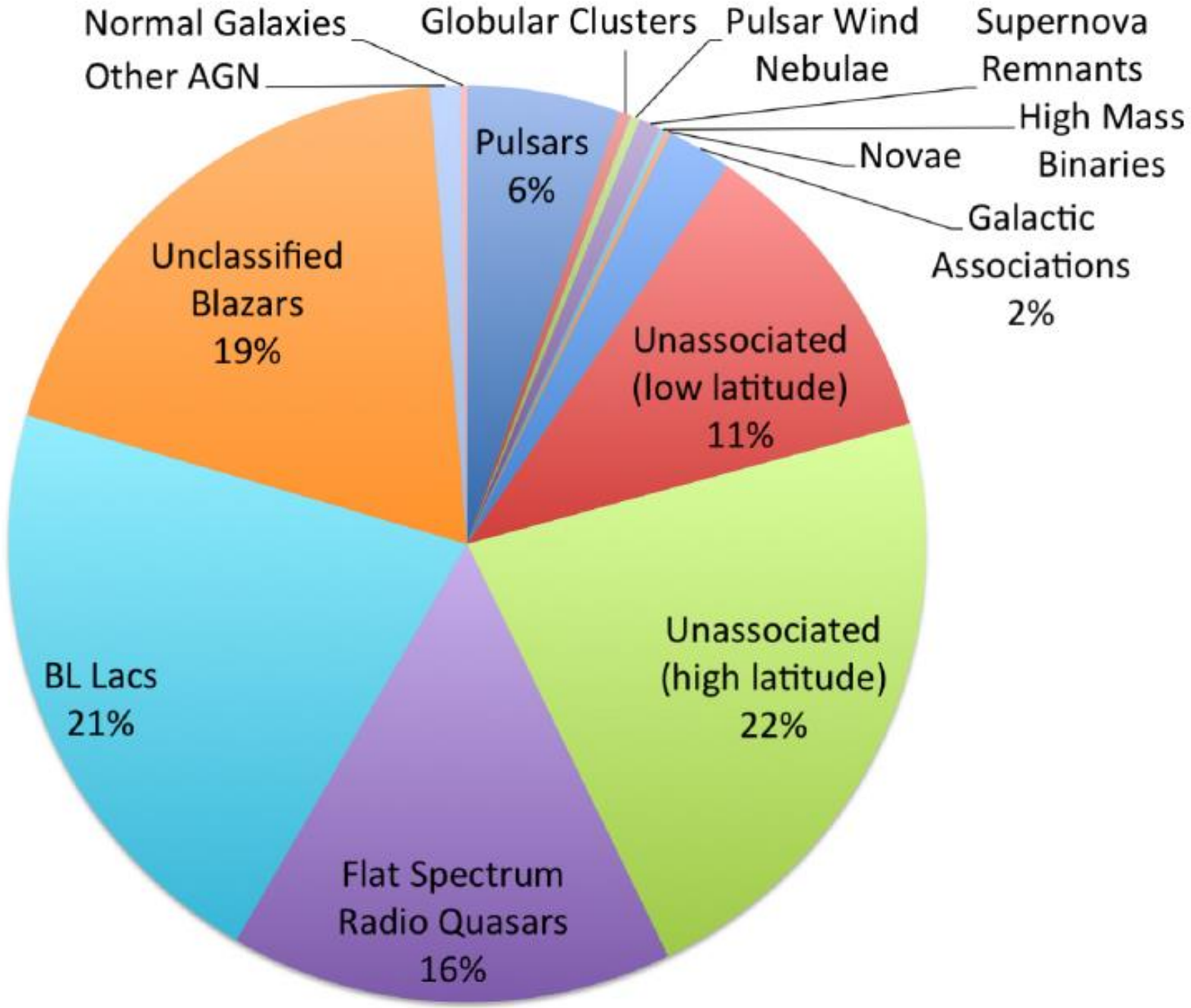
TGFS

The Flaring Sun – our nearest gamma-ray source



The Flaring Sun – March 7, 2012: pinpointing a flare

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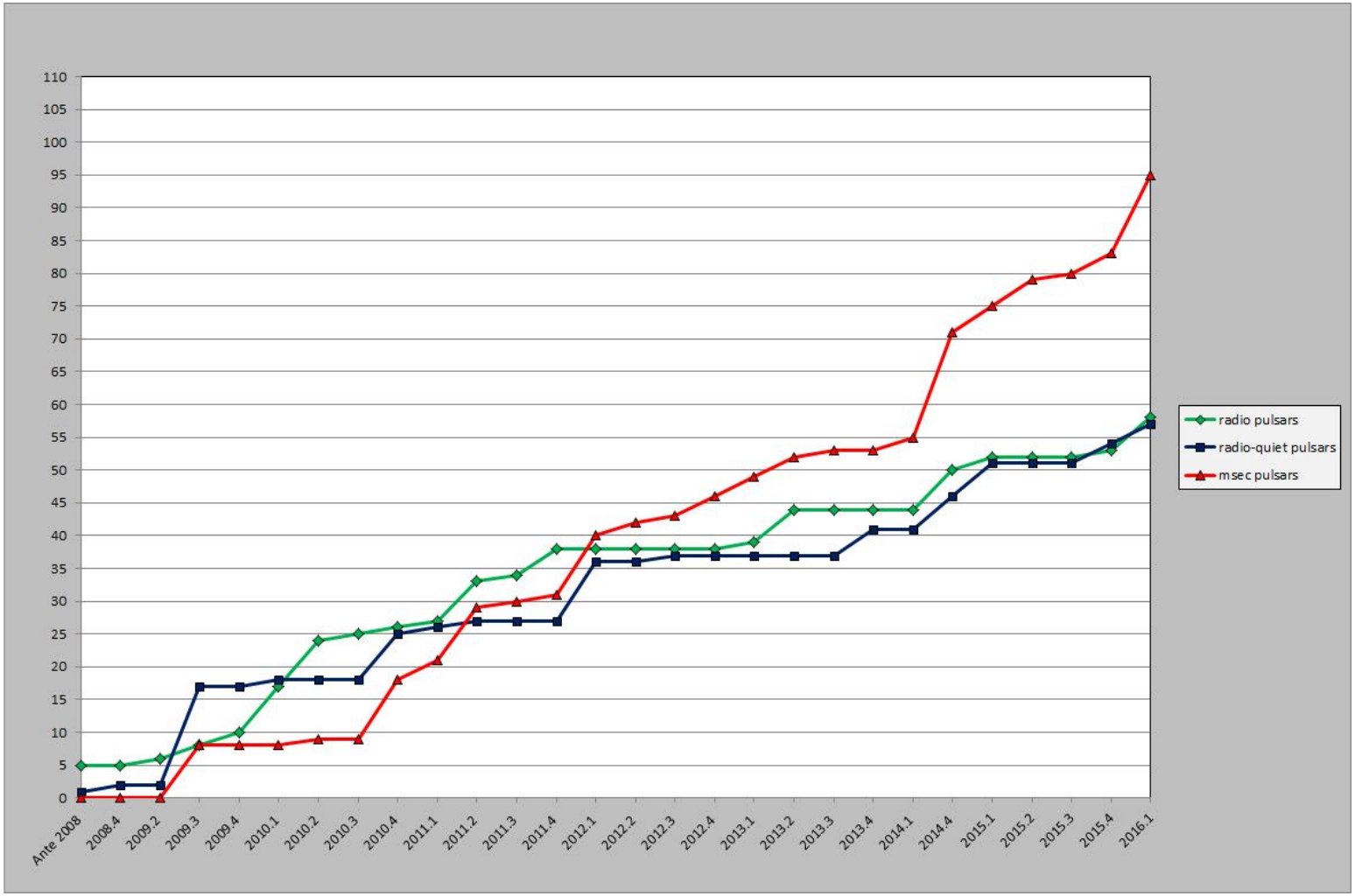
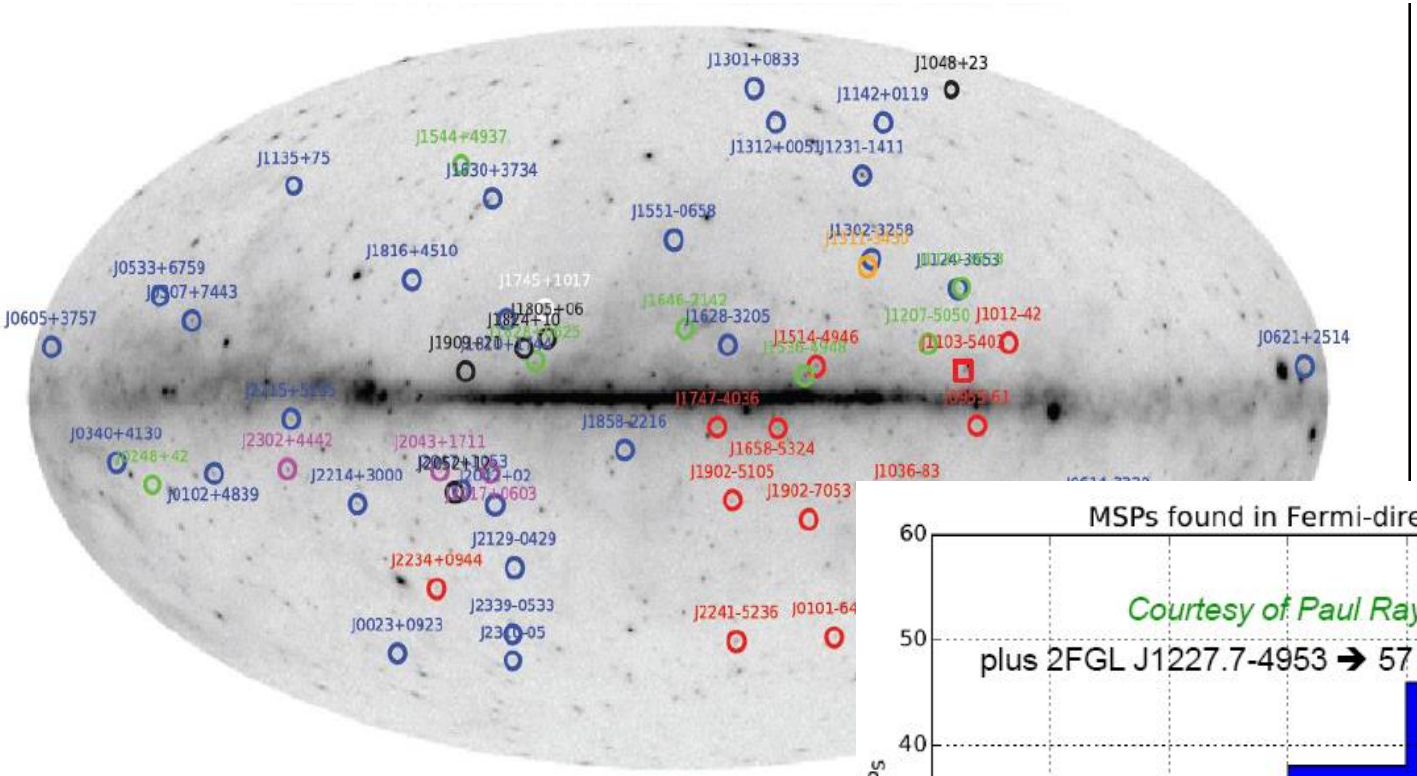
Gamma-Ray Pulsar Revolution

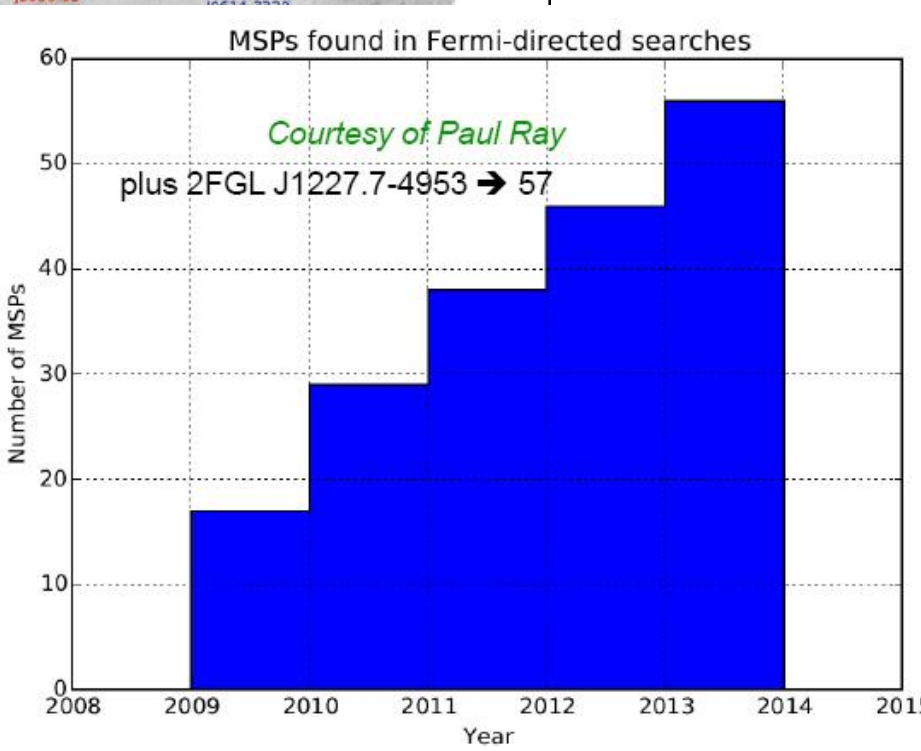
Patrizia A. Caraveo

Annu. Rev. Astron. Astrophys. 2014. 52:211–50

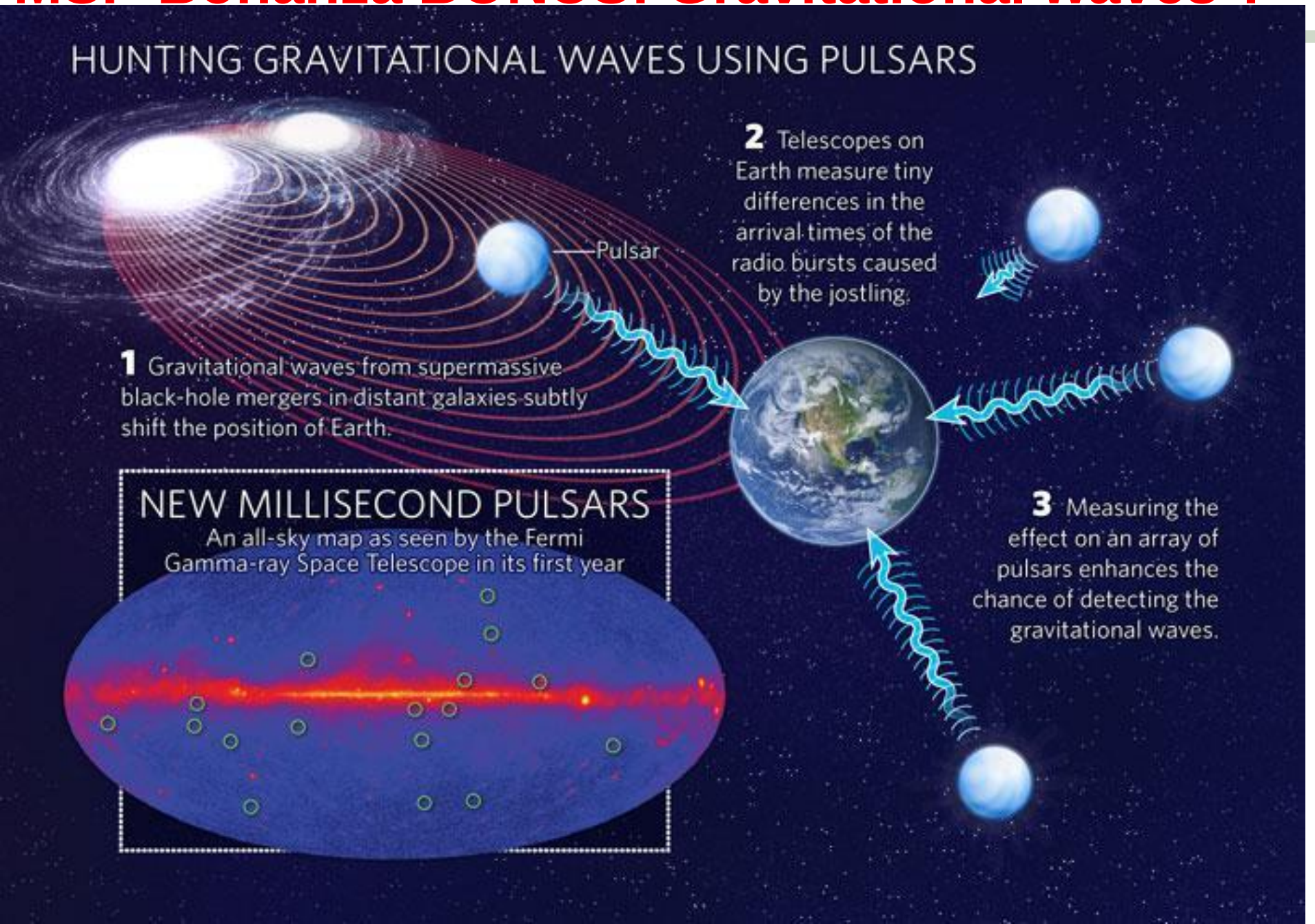


57 new radio MSPs within Fermi error boxes: a good fraction of all field MSPs

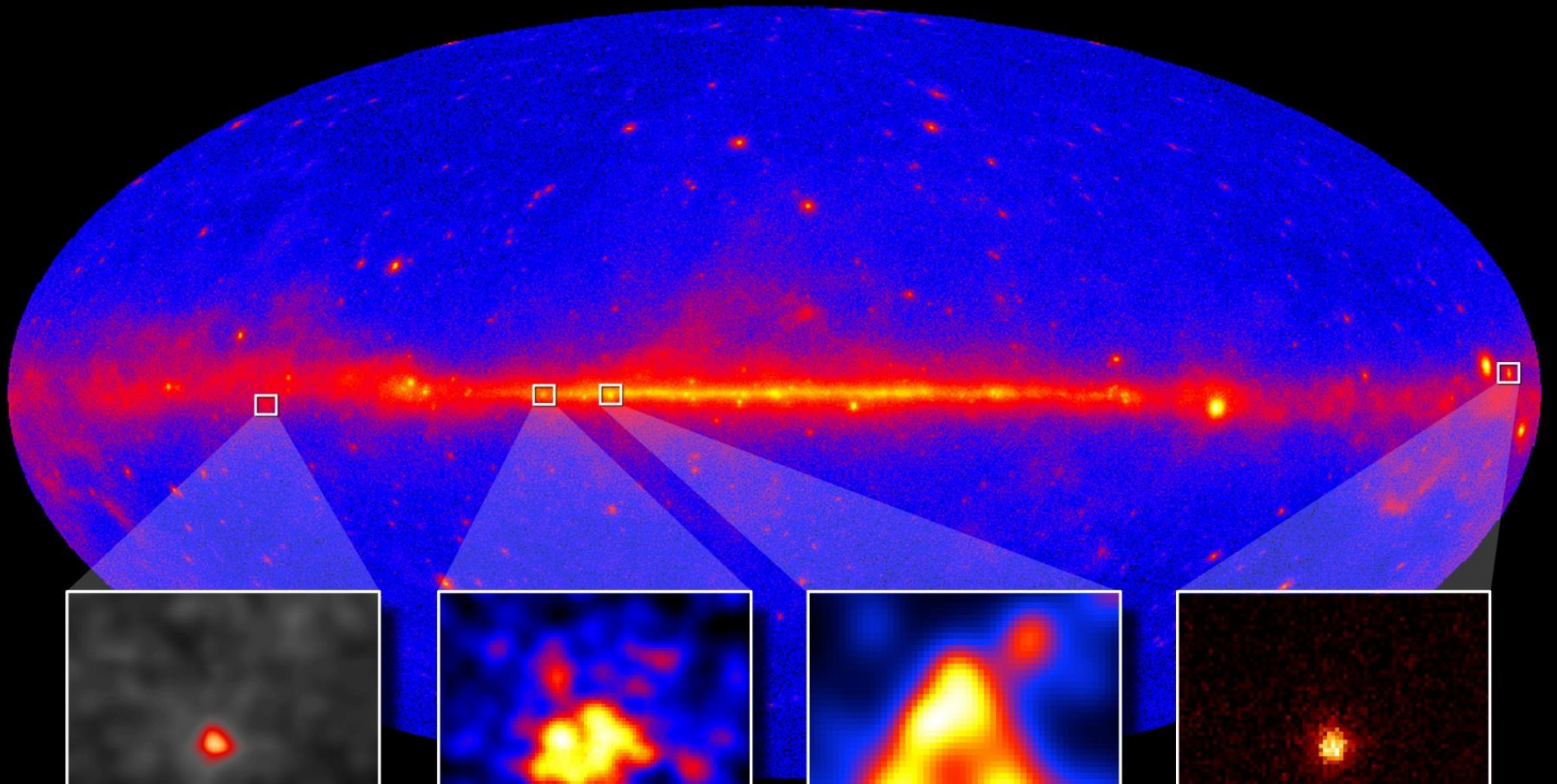




MSP Bonanza BONUS: Gravitational waves ?



Gamma-rays, CRs and supernovae: smoking gun evidence



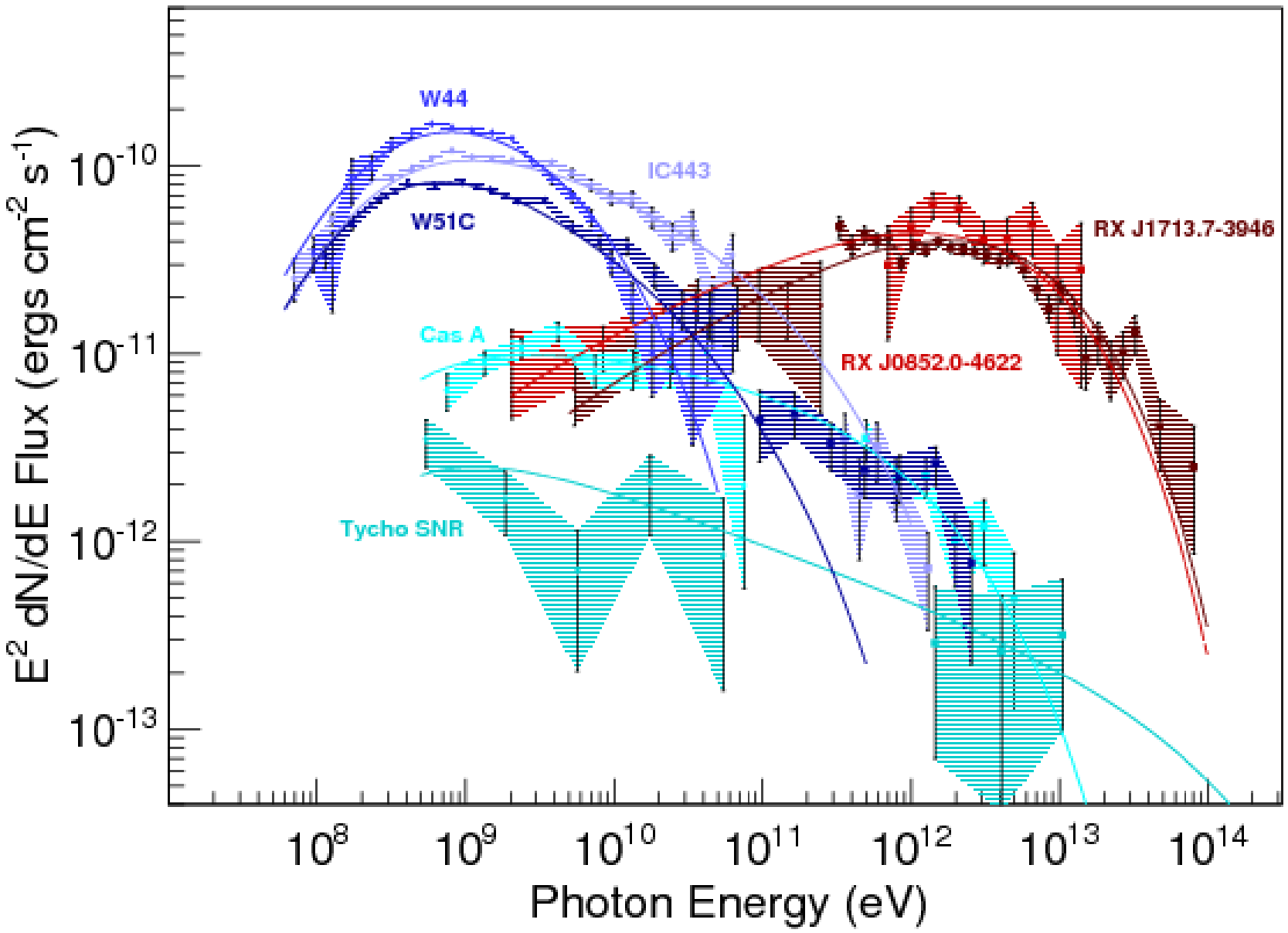
Cas A

W51C

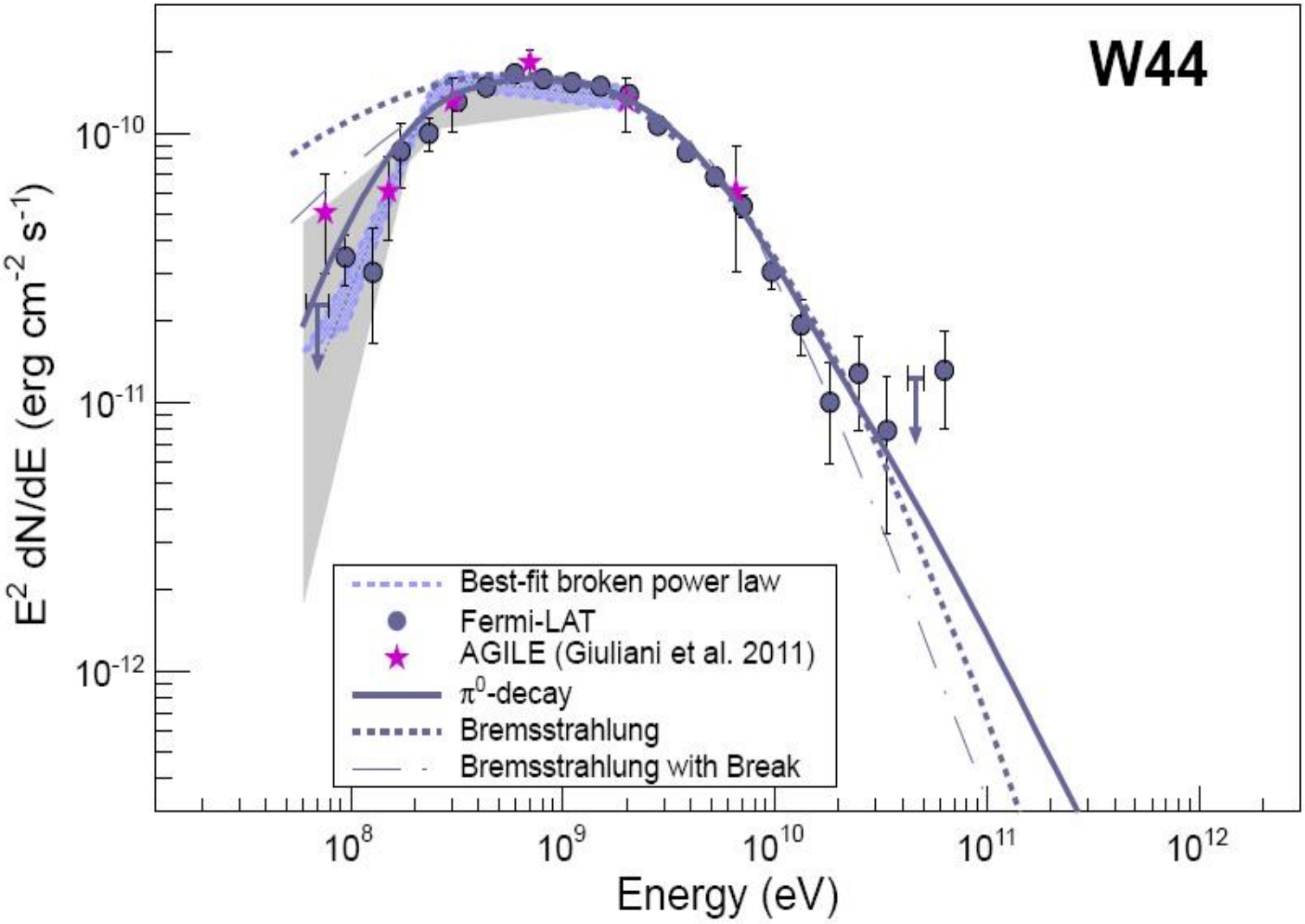
W44

IC 443

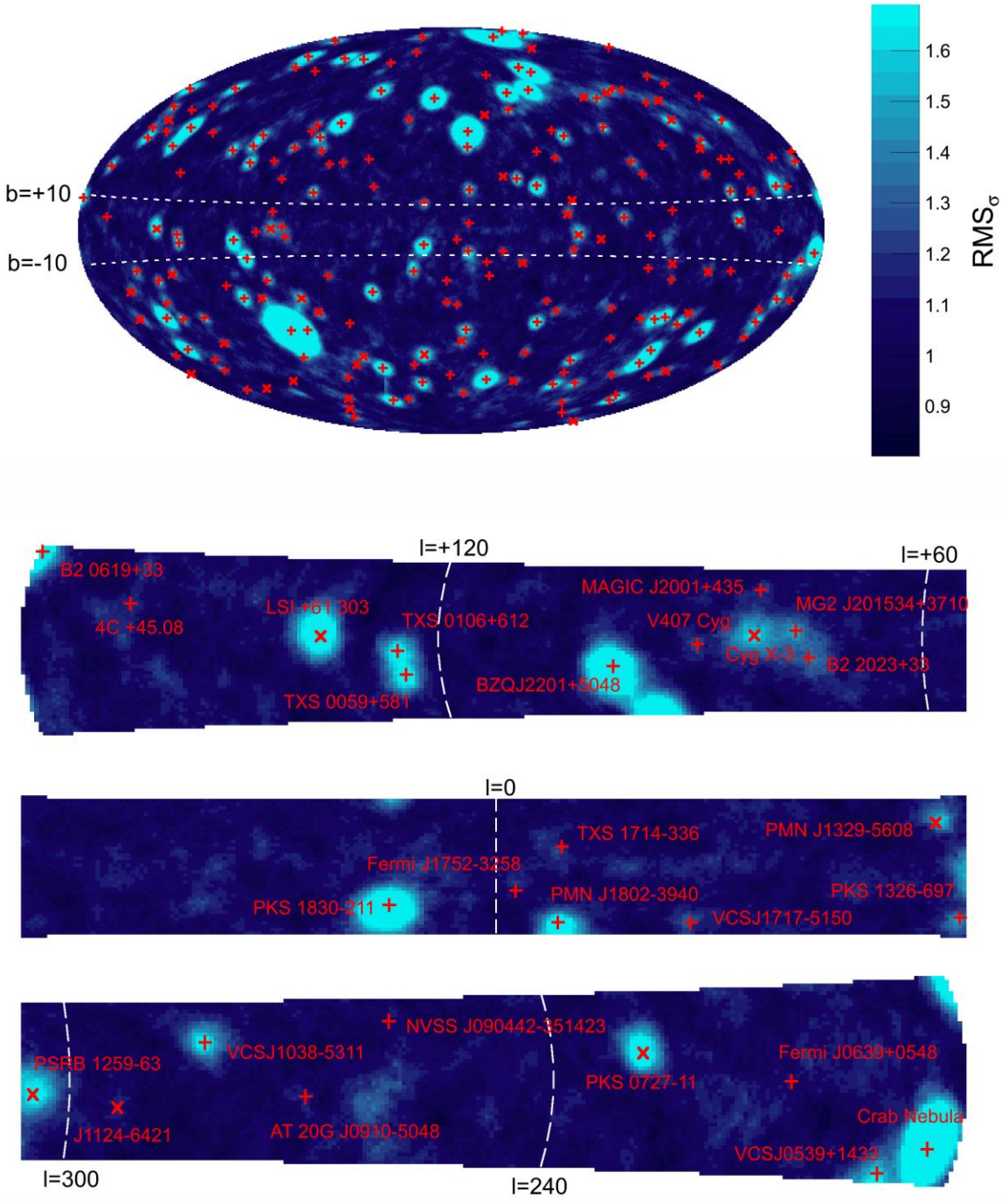
Fermi Gamma-ray Space Telescope


W44
IC443
W51C
RX J1713.7-3946
Cas A
RX J0852.0-4622
Tycho SNR
E^2 dN/dE Flux (ergs cm^{-2} s^{-1})
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^8
10^9
10^{10}
10^{11}
10^{12}
10^{13}
10^{14}
Photon Energy (eV)

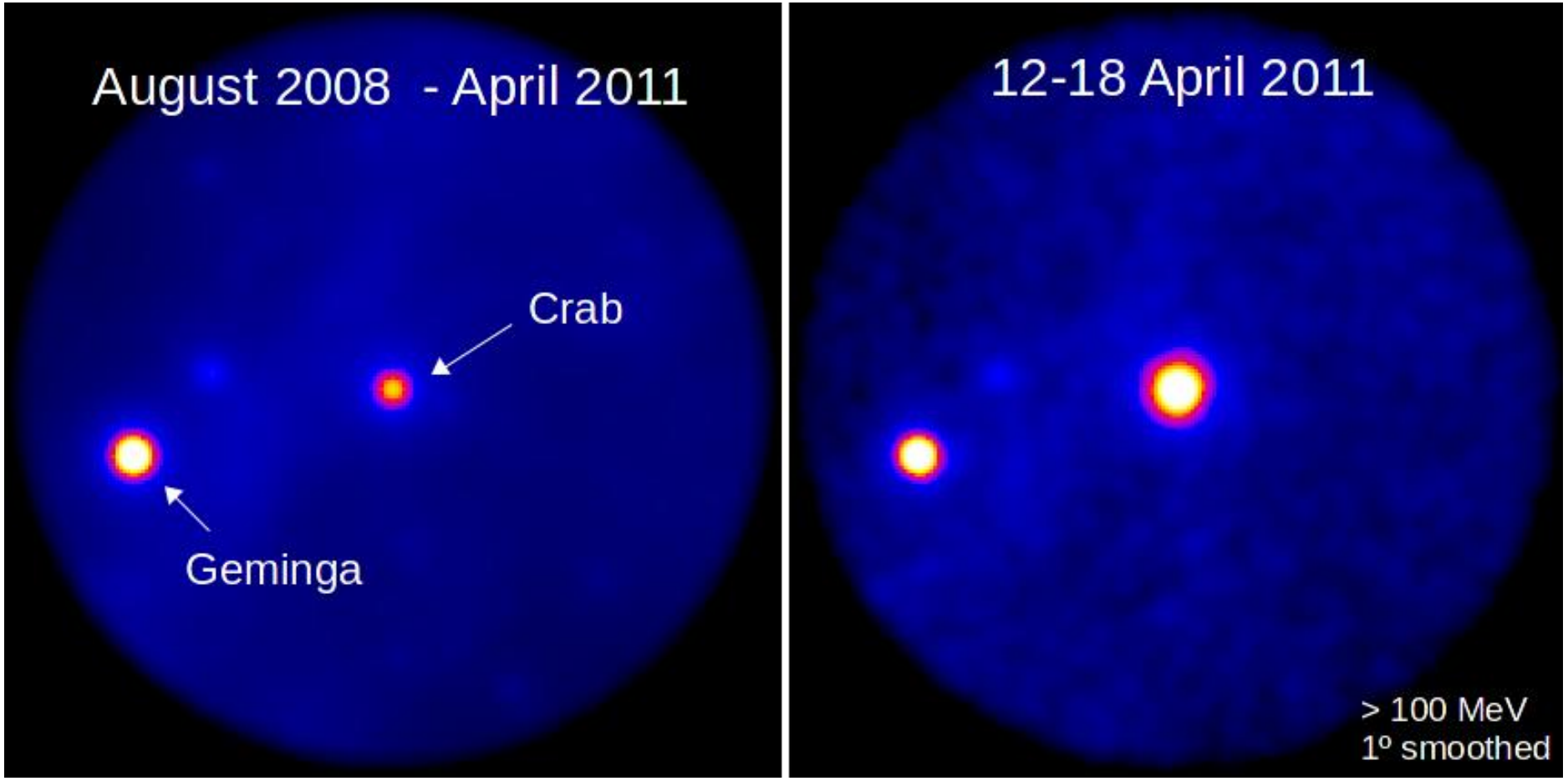
At long last!! a π^0 bump in the W44 spectrum



How to find variable sources anywhere in the sky?



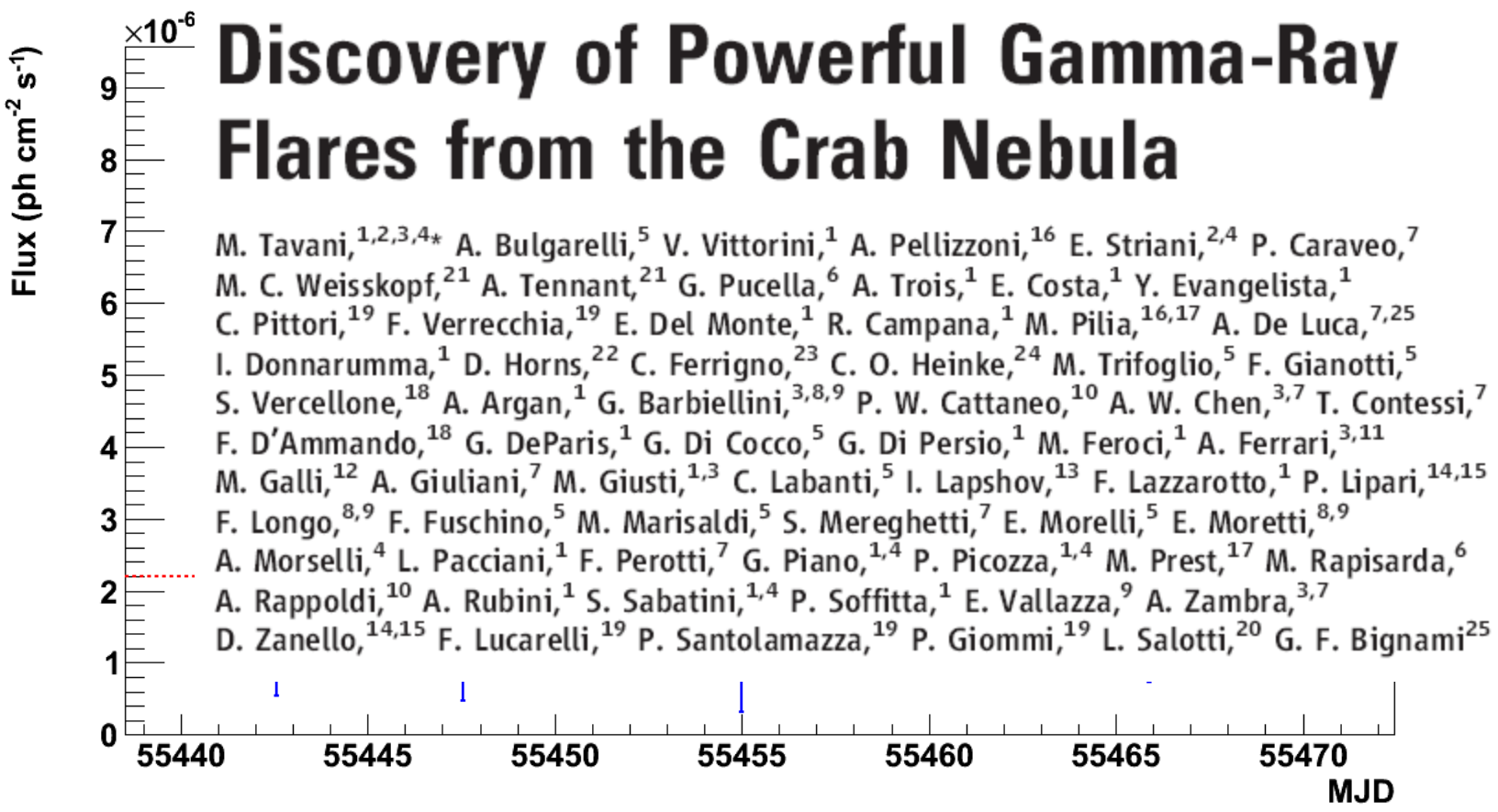
Surprise: the Crab that roared



Variable Nebular emission!

AGILE discovers a flare from the Crab Nebula 19-22 sept 2010

REPORTS



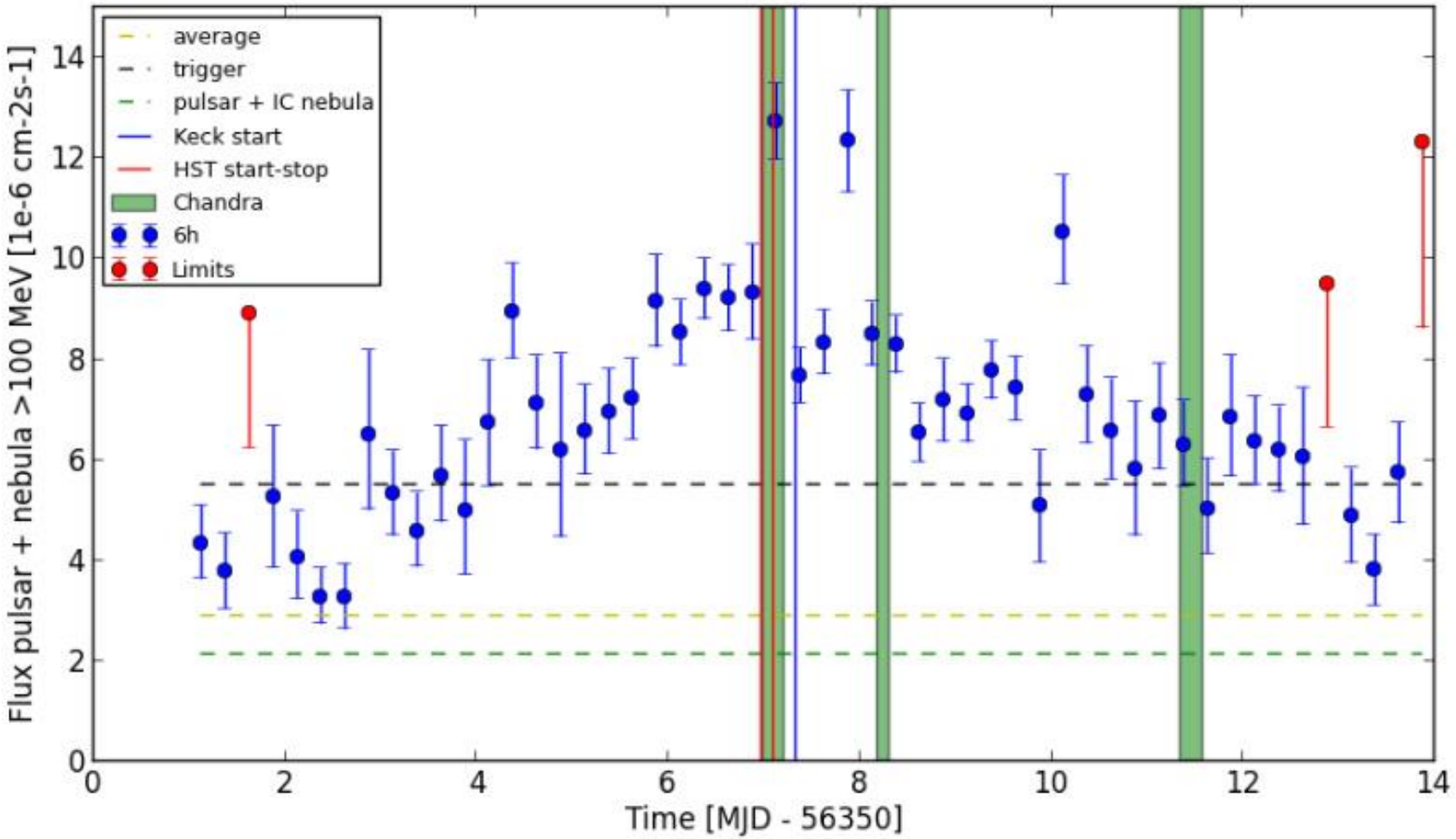
Discovery of Powerful Gamma-Ray Flares from the Crab Nebula

M. Tavani,[1,2,3,4]* A. Bulgarelli,[5] V. Vittorini,[1] A. Pellizzoni,[16] E. Striani,[2,4] P. Caraveo,[7] M. C. Weisskopf,[21] A. Tennant,[21] G. Pucella,[6] A. Trois,[1] E. Costa,[1] Y. Evangelista,[1] C. Pittori,[19] F. Verrecchia,[19] E. Del Monte,[1] R. Campana,[1] M. Pilia,[16,17] A. De Luca,[7,25] I. Donnarumma,[1] D. Horns,[22] C. Ferrigno,[23] C. O. Heinke,[24] M. Trifoglio,[5] F. Gianotti,[5] S. Vercellone,[18] A. Argan,[1] G. Barbiellini,[3,8,9] P. W. Cattaneo,[10] A. W. Chen,[3,7] T. Contessi,[7] F. D'Ammando,[18] G. DeParis,[1] G. Di Cocco,[5] G. Di Persio,[1] M. Feroci,[1] A. Ferrari,[3,11] M. Galli,[12] A. Giuliani,[7] M. Giusti,[1,3] C. Labanti,[5] I. Lapshov,[13] F. Lazzarotto,[1] P. Lipari,[14,15] F. Longo,[8,9] F. Fuschino,[5] M. Marisaldi,[5] S. Mereghetti,[7] E. Morelli,[5] E. Moretti,[8,9] A. Morselli,[4] L. Pacciani,[1] F. Perotti,[7] G. Piano,[1,4] P. Picozza,[1,4] M. Prest,[17] M. Rapisarda,[6] A. Rappoldi,[10] A. Rubini,[1] S. Sabatini,[1,4] P. Soffitta,[1] E. Vallazza,[9] A. Zambra,[3,7] D. Zanello,[14,15] F. Lucarelli,[19] P. Santolamazza,[19] P. Giommi,[19] L. Salotti,[20] G. F. Bignami[25]

Gamma-Ray Flares from the Crab Nebula

A. A. Abdo,[1] M. Ackermann,[2] M. Ajello,[2] A. Allafort,[2] L. Baldini,[3] J. Ballet,[4] G. Barbiellini,[5,6] D. Bastieri,[7,8] K. Bechtol,[2] R. Bellazzini,[3] B. Berenji,[2] R. D. Blandford,[2*] E. D. Bloom,[2] E. Bonamente,[9,10] A. W. Borgland,[2] A. Bouvier,[2] T. J. Brandt,[11,12] J. Bregeon,[3] A. Brez,[3] M. Brigida,[13,14] P. Bruel,[15] R. Buehler,[2*] S. Buson,[7,8] G. A. Caliandro,[16] R. A. Cameron,[2] A. Cannon,[17,18] P. A. Caraveo,[19] J. M. Casandjian,[4] Ö. Çelik,[17,20,21] E. Charles,[2] A. Chekhtman,[22] C. C. Cheung,[1] J. Chiang,[2] S. Ciprini,[10] R. Claus,[2] J. Cohen-Tanugi,[23] L. Costamante,[2] S. Cutini,[24] F. D'Ammando,[25,26] C. D. Dermer,[27] A. de Angelis,[28] A. de Luca,[29] F. de Palma,[13,14] S. W. Digel,[2] E. do Couto e Silva,[2] P. S. Drell,[2] A. Drlica-Wagner,[2] R. Dubois,[2] D. Dumora,[30] C. Favuzzi,[13,14] S. J. Fegan,[15] E. C. Ferrara,[17] W. B. Focke,[2] P. Fortin,[15] M. Frailis,[28,31] Y. Fukazawa,[32] S. Funk,[2*] P. Fusco,[13,14] F. Gargano,[14] D. Gasparrini,[24] N. Gehrels,[17] S. Germani,[9,10] N. Giglietto,[13,14] F. Giordano,[13,14] M. Giroletti,[33] T. Glanzman,[2] G. Godfrey,[2] I. A. Grenier,[4] M.-H. Grondin,[30] J. E. Grove,[27] S. Guiriec,[34] D. Hadasch,[16] Y. Hanabata,[32] A. K. Harding,[17] K. Hayashi,[32] M. Hayashida,[2] E. Hays,[17] D. Horan,[15] R. Itoh,[32] G. Jóhannesson,[35] A. S. Johnson,[2] T. J. Johnson,[17,36] D. Khangulyan,[42] T. Kamae,[2] H. Katagiri,[32] J. Kataoka,[37] M. Kerr,[38] J. Knödlseder,[11] M. Kuss,[3] J. Lande,[2] L. Latronico,[3] S.-H. Lee,[2] M. Lemoine-Goumard,[30] F. Longo,[5,6] F. Loparco,[13,14] P. Lubrano,[9,10] G. M. Madejski,[2] A. Makeev,[22] M. Marelli,[19] M. N. Mazziotta,[14] J. E. McEnery,[17,36] P. F. Michelson,[2] W. Mitthumsiri,[2] T. Mizuno,[32] A. A. Moiseev,[20,36] C. Monte,[13,14] M. E. Monzani,[2] A. Morselli,[39] I. V. Moskalenko,[2] S. Murgia,[2] T. Nakamori,[37] M. Naumann-Godo,[4] P. L. Nolan,[2] J. P. Norris,[40] E. Nuss,[23] T. Ohsugi,[41] A. Okumura,[42] N. Omodei,[2] J. F. Ormes,[40] M. Ozaki,[42] D. Paneque,[2] D. Parent,[22] V. Pelassa,[23] M. Pepe,[9,10] M. Pesce-Rollins,[3] M. Pierbattista,[4] F. Piron,[23] T. A. Porter,[2] S. Rainò,[13,14] R. Rando,[7,8] P. S. Ray,[27] M. Razzano,[3] A. Reimer,[2,43] O. Reimer,[2,43] T. Reposeur,[30] S. Ritz,[44] R. W. Romani,[2] H. F.-W. Sadrozinski,[44] D. Sanchez,[15] P. M. Saz Parkinson,[44] J. D. Scargle,[45] T. L. Schalk,[44] C. Sgrò,[3] E. J. Siskind,[46] P. D. Smith,[12] G. Spandre,[3] P. Spinelli,[13,14] M. S. Strickman,[27] D. J. Suson,[47] H. Takahashi,[41] T. Takahashi,[42] T. Tanaka,[2] J. B. Thayer,[2] D. J. Thompson,[17] L. Tibaldo,[4,7,8] D. F. Torres,[16,48] G. Tosti,[9,10] A. Tramacere,[2,49,50] E. Troja,[17] Y. Uchiyama,[2] J. Vandenbroucke,[2] V. Vasileiou,[20,21] G. Vianello,[2,49] V. Vitale,[39,51] P. Wang,[2] K. S. Wood,[27] Z. Yang,[52,53] M. Ziegler[44]

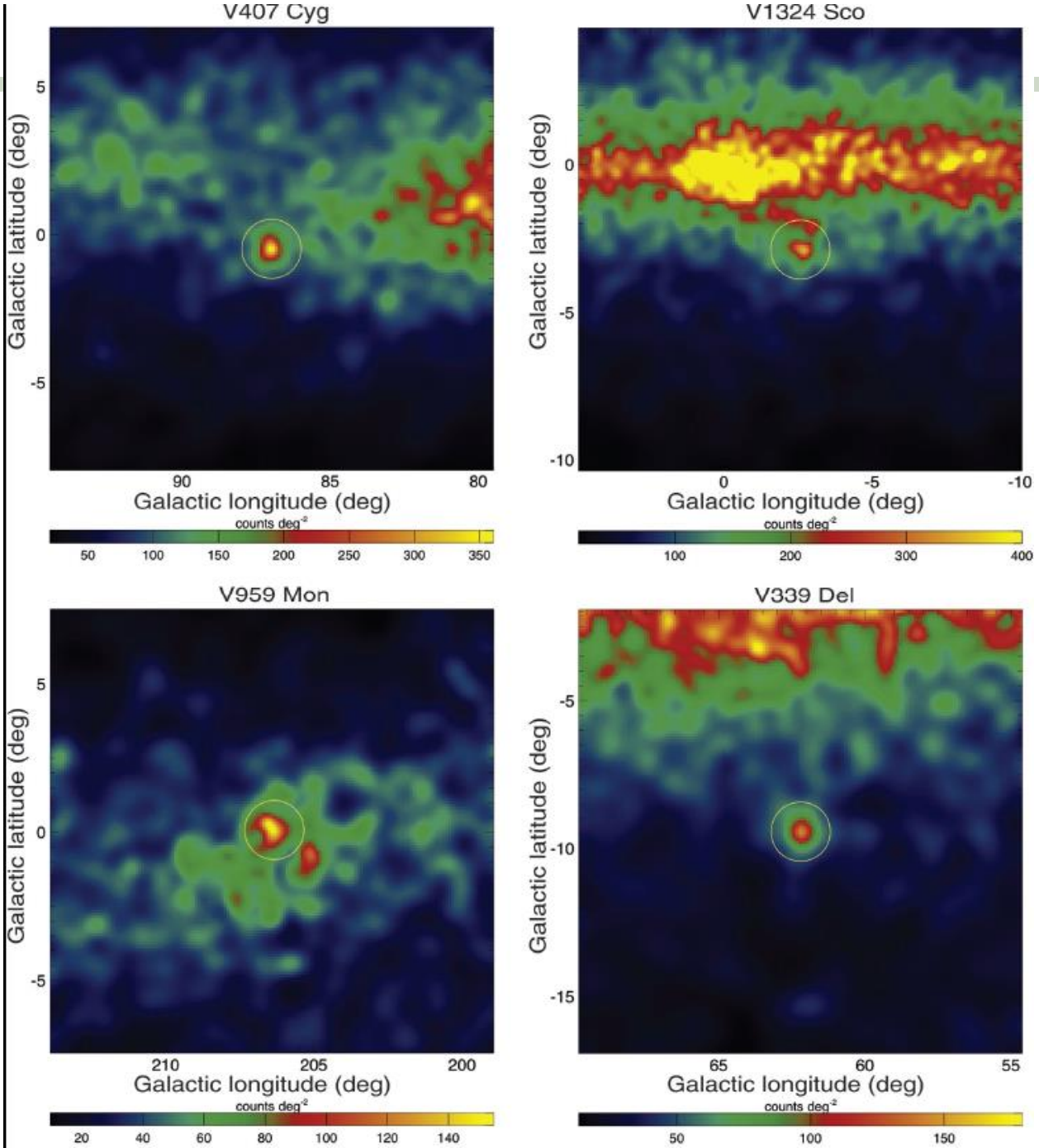
Not a unique event. Once per year?



March 2013 flare

More on variable galactic sources

γ-rays from Novae



NOVAE

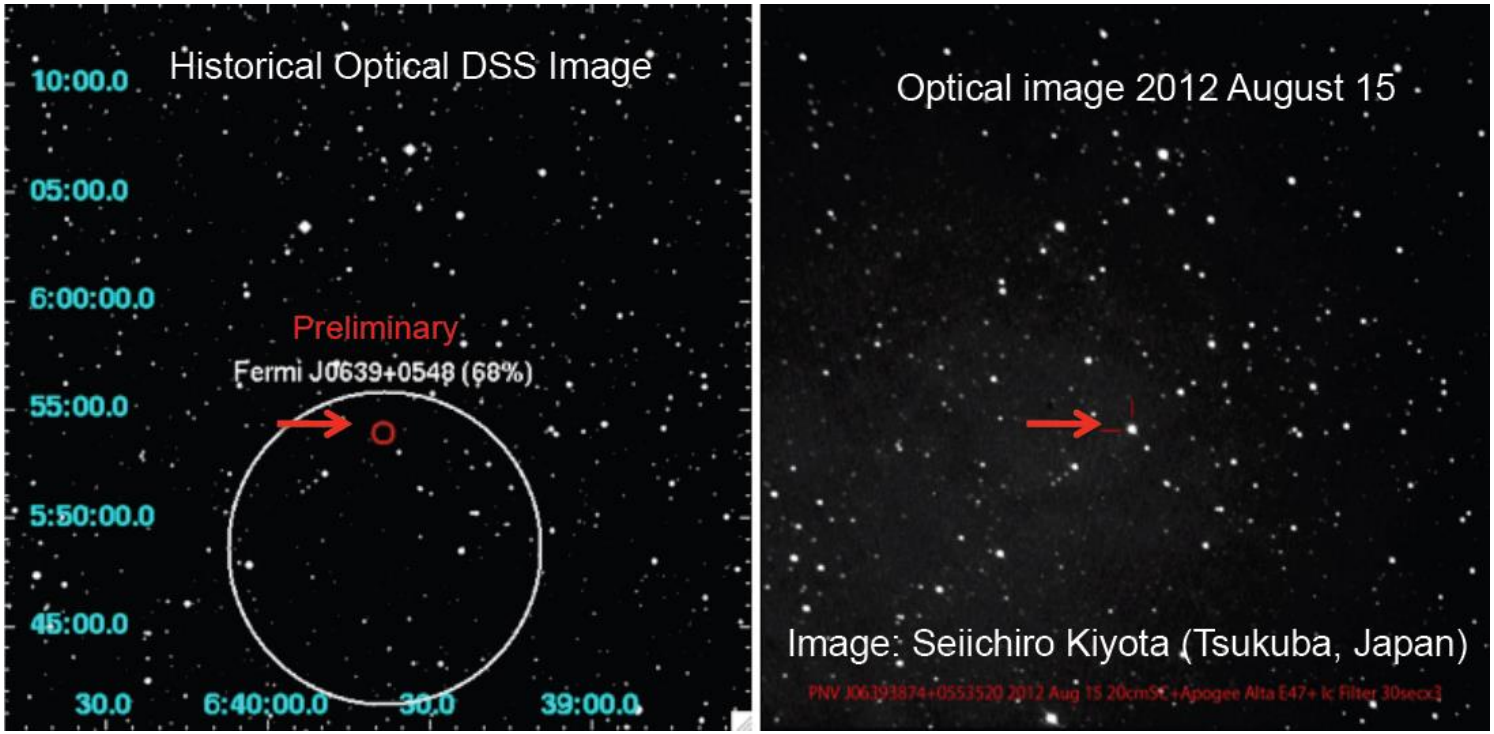
Fermi establishes classical novae as a distinct class of gamma-ray sources

The Fermi-LAT Collaboration*†

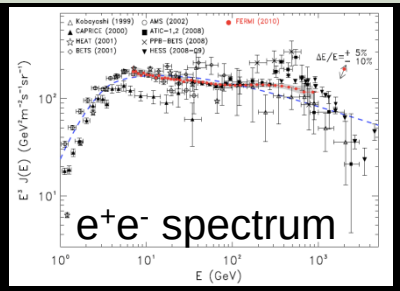
A classical nova results from runaway thermonuclear explosions on the surface of a white dwarf that accretes matter from a low-mass main-sequence stellar companion. In 2012 and 2013, three novae were detected in γ rays and stood in contrast to the first γ-ray–detected nova V407 Cygni 2010, which belongs to a rare class of symbiotic binary systems. Despite likely differences in the compositions and masses of their white dwarf progenitors, the three classical novae are similarly characterized as soft-spectrum transient γ-ray sources detected over 2- to 3-week durations. The γ-ray detections point to unexpected high-energy particle acceleration processes linked to the mass ejection from thermonuclear explosions in an unanticipated class of Galactic γ-ray sources.

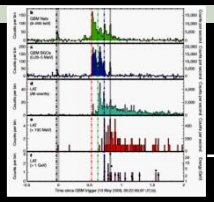
If need be, Fermi can discover Novae

V959 Mon was discovered by Fermi when the source was not observable

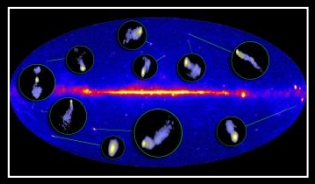


Fermi Highlights and Discoveries

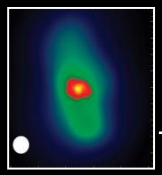




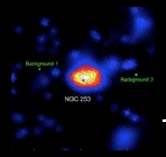
GRBS



BLAZARS

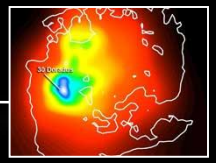


RADIO GALAXIES



STAR BURST GALAXIES

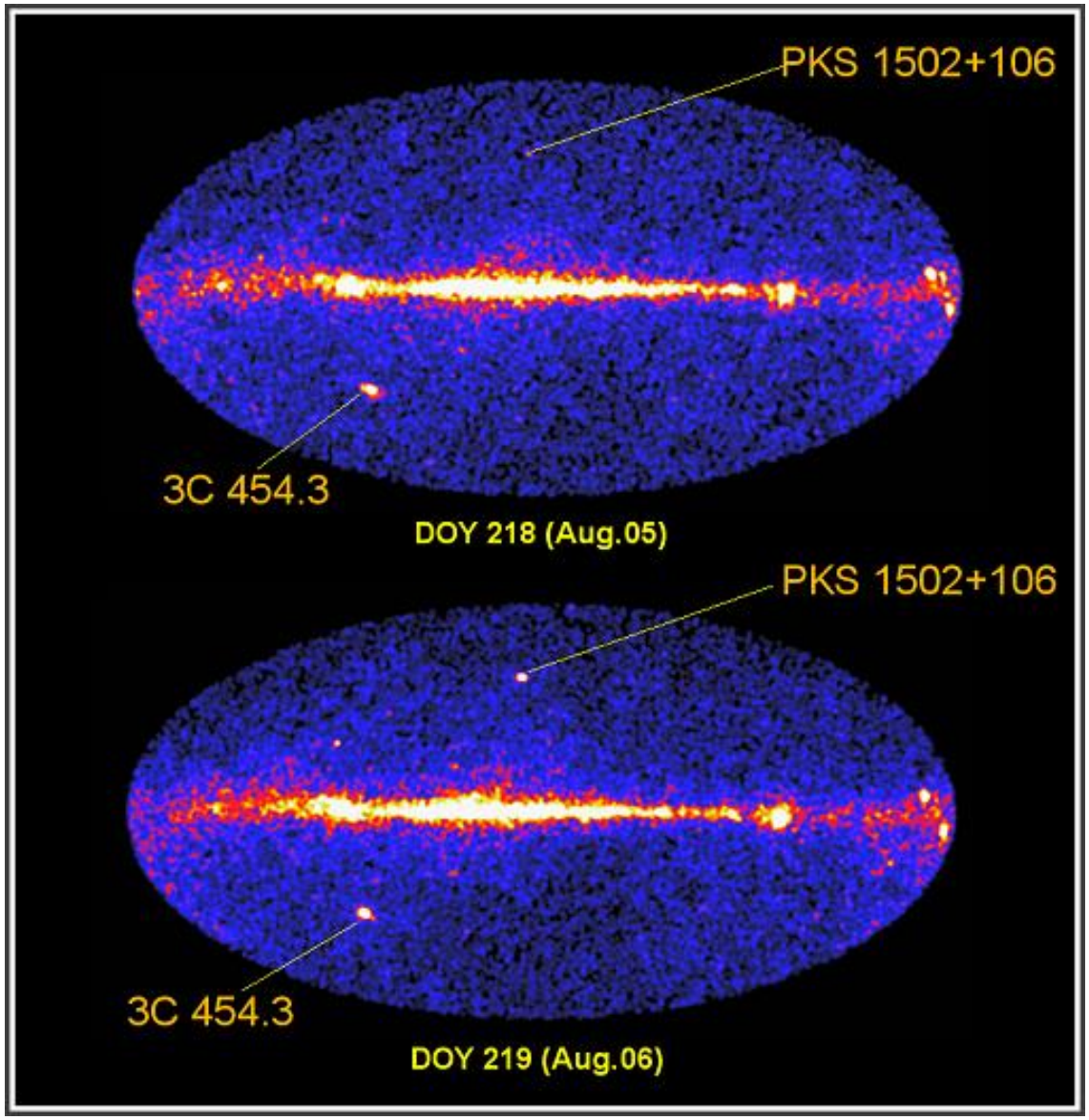
LMC & SMC



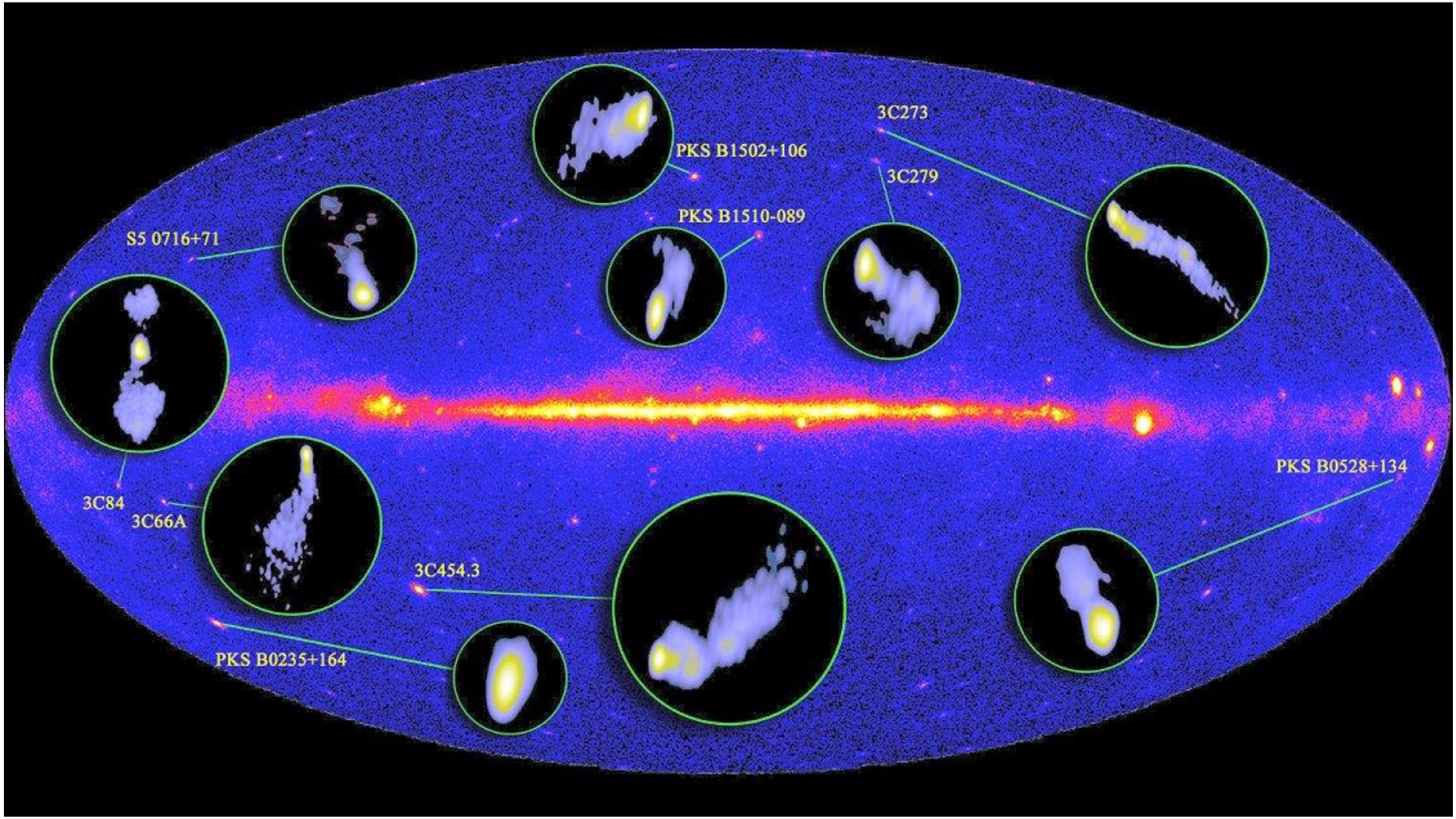
Extragalactic

Galactic

Flaring AGNs



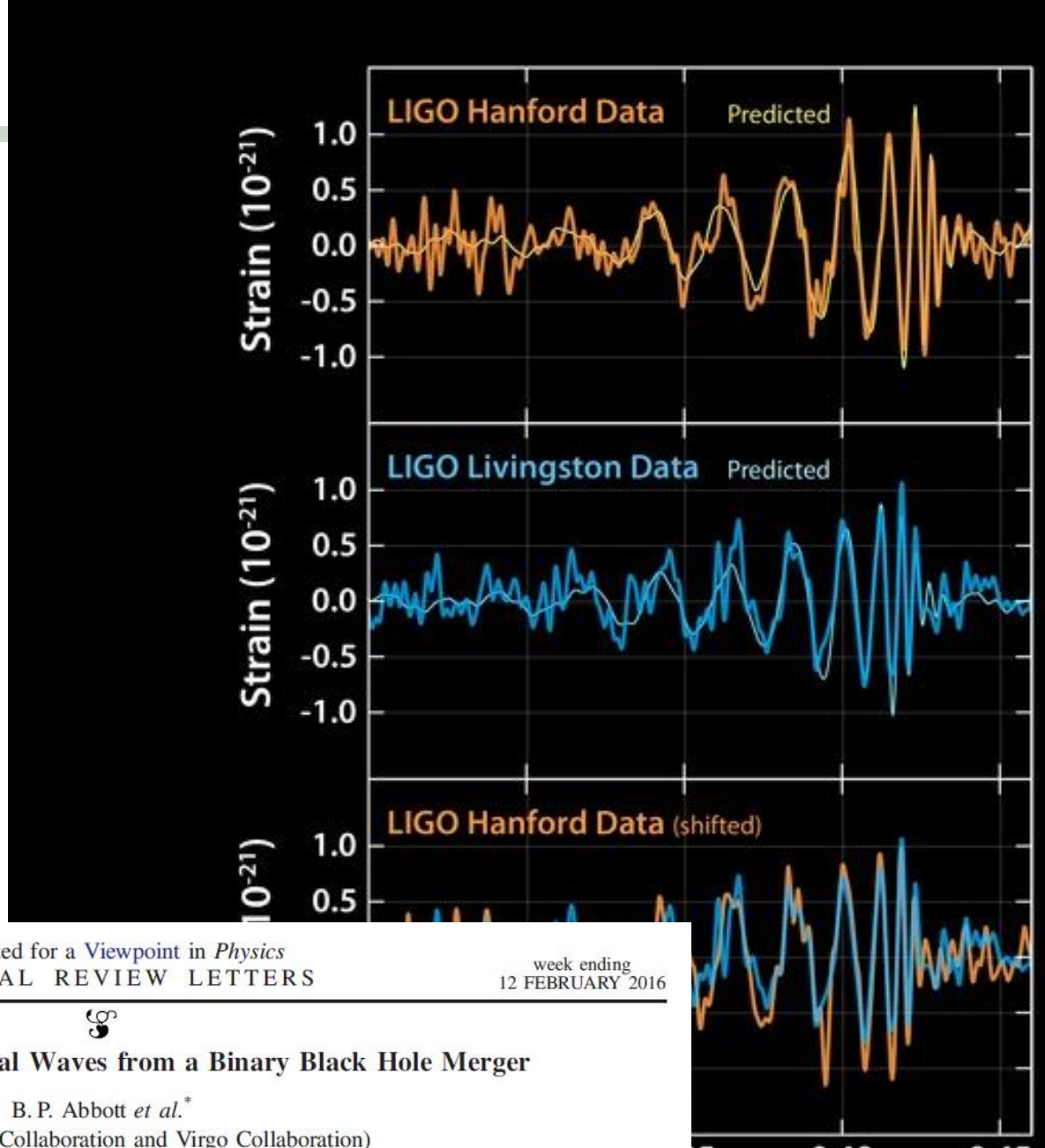
The Fermi catalog is dominated by AGNs….



Gamma-ray telescopes in the Gravitational Era

The big Field of View of gamma-ray telescopes (together with the scanning mode) is an important asset to chase GWs

Sept 14, 2015



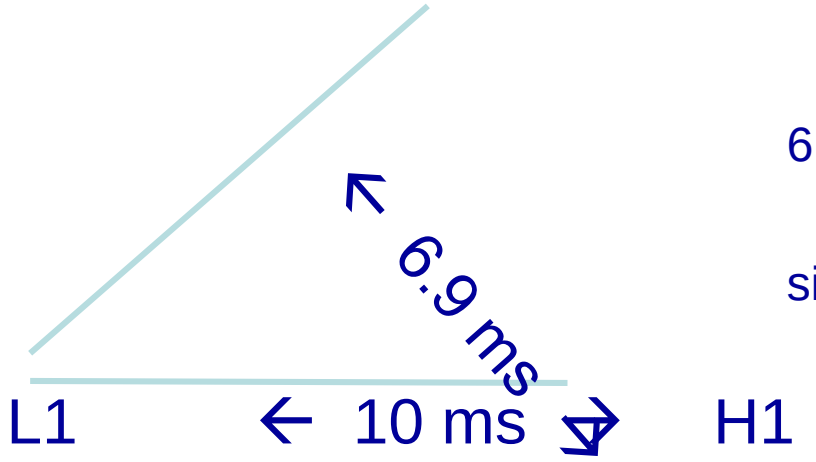
Selected for a Viewpoint in *Physics*
PRL **116,** 061102 (2016) PHYSICAL REVIEW LETTERS week ending 12 FEBRUARY 2016

Observation of Gravitational Waves from a Binary Black Hole Merger

B. P. Abbott *et al.*[*]
(LIGO Scientific Collaboration and Virgo Collaboration)
(Received 21 January 2016; published 11 February 2016)

On September 14, 2015 at 09:50:45 UTC the two detectors of the Laser Interferometer Gravitational-Wave Observatory simultaneously observed a transient gravitational-wave signal. The signal sweeps upwards in

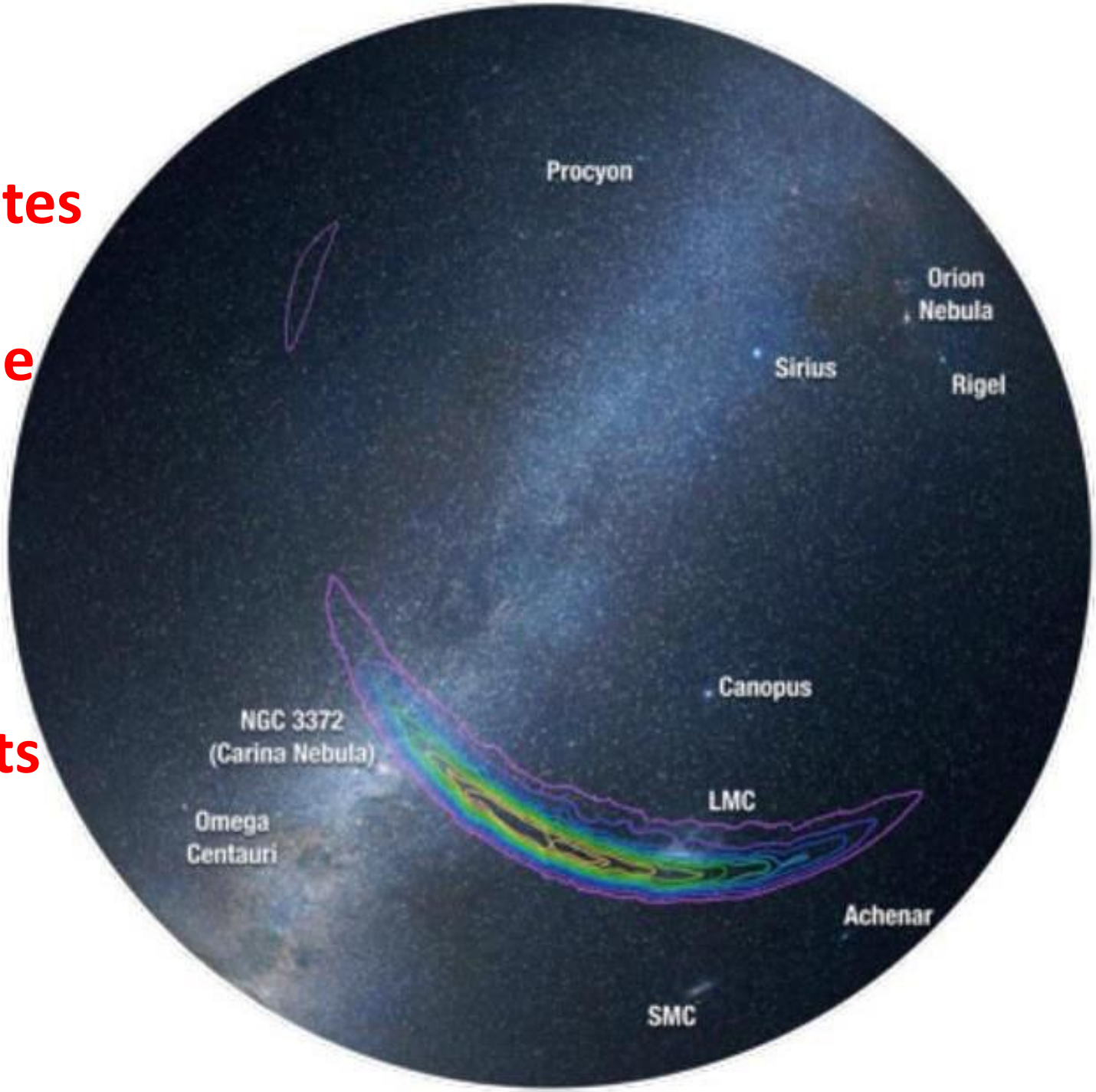
Where from ??

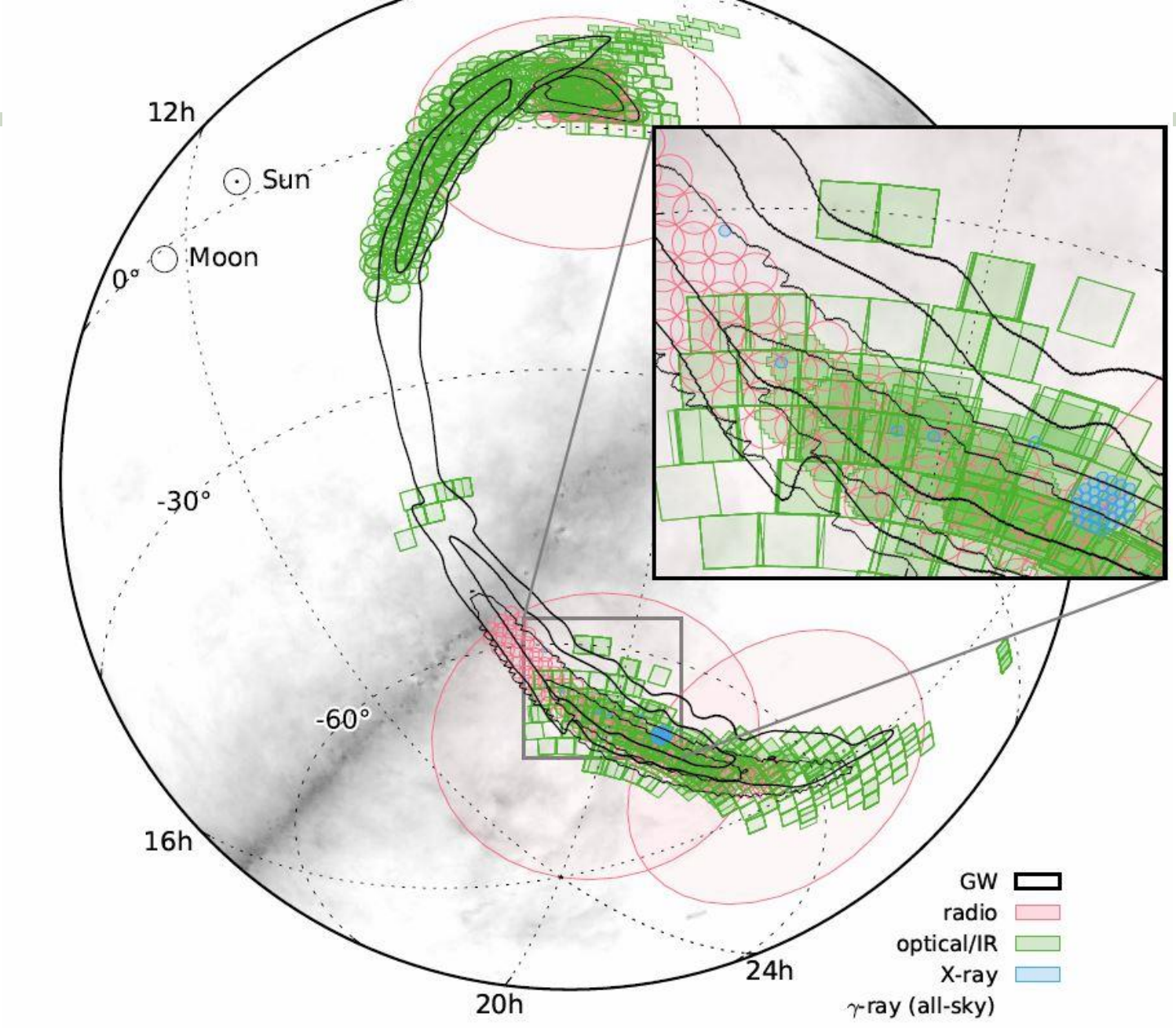


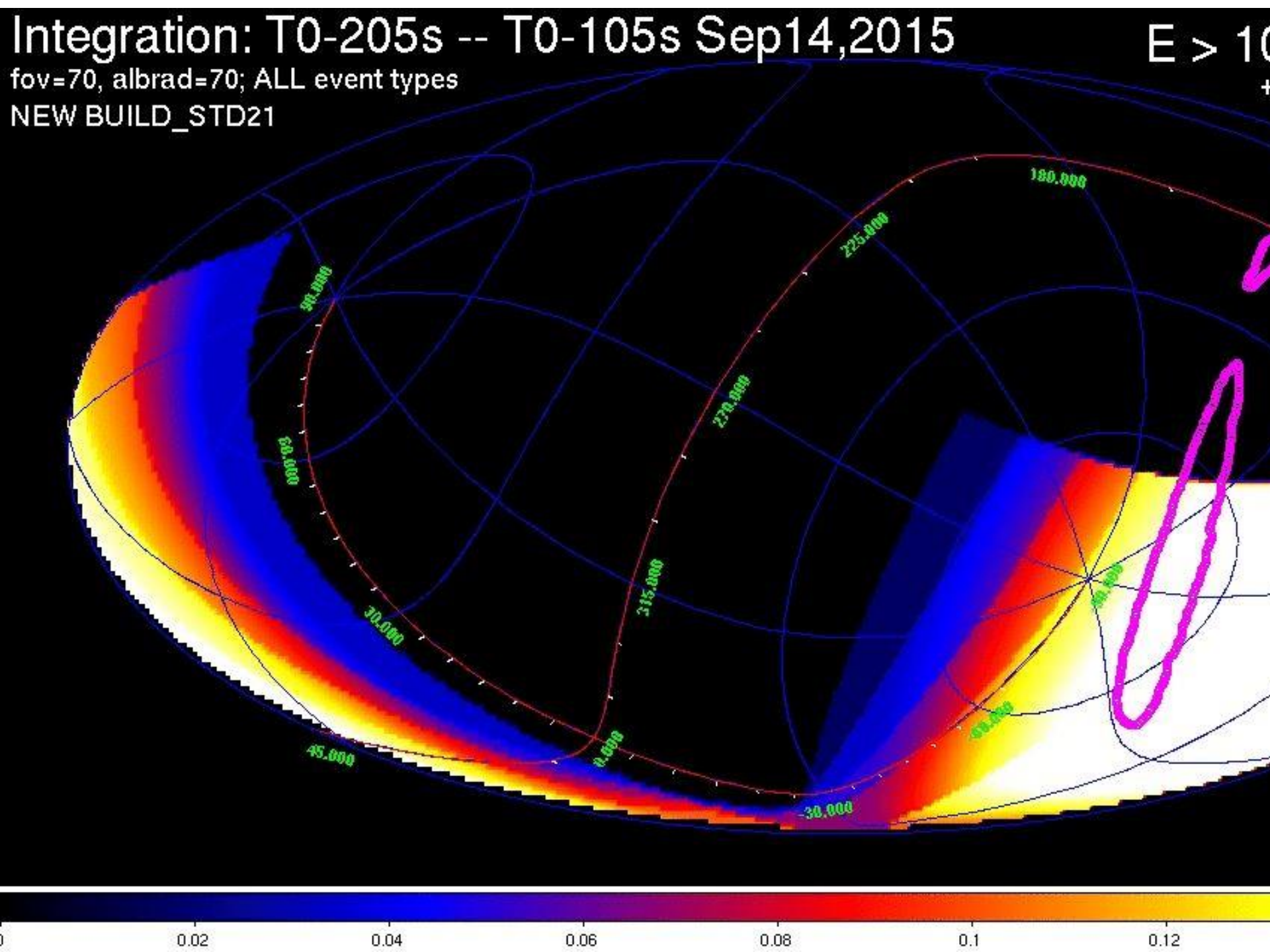
6.9 ms between the two LIGO detectors

$\sin^{-1}(6.9/10) = 44^\circ$ from zenit.

This translates into a big region in the sky which must be covered to search for counterparts




12h
Sun
Moon
0°
-30°
-60°
16h
20h
24h
GW
radio
optical/IR
X-ray
γ-ray (all-sky)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NEW BUILD_STD21
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225.000
270.000
315.000
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60.000
90.000
45.000
-30.000
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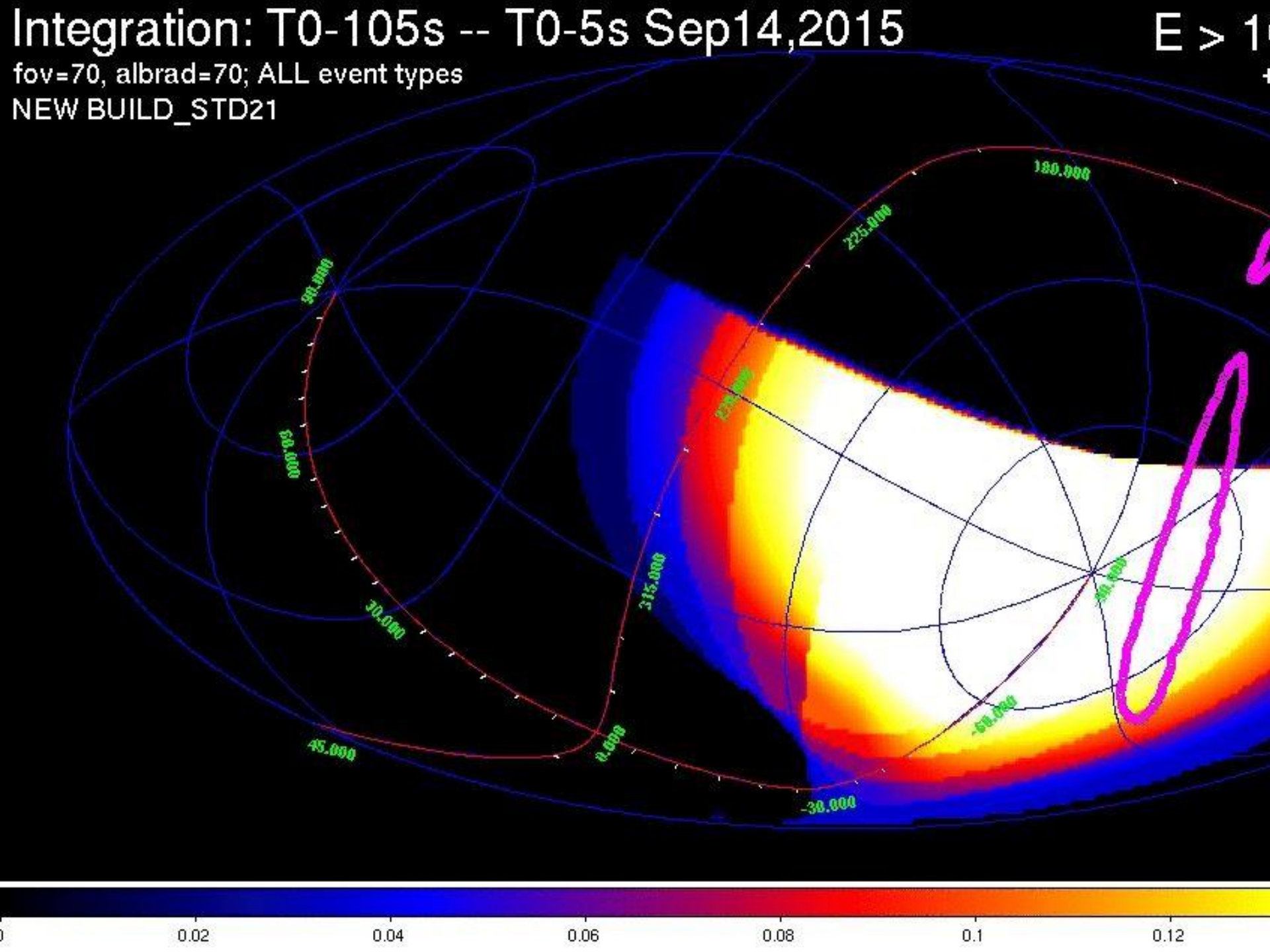
0.04
0.06
0.08
0.1
0.12


Integration: T0-105s -- T0-5s Sep14,2015
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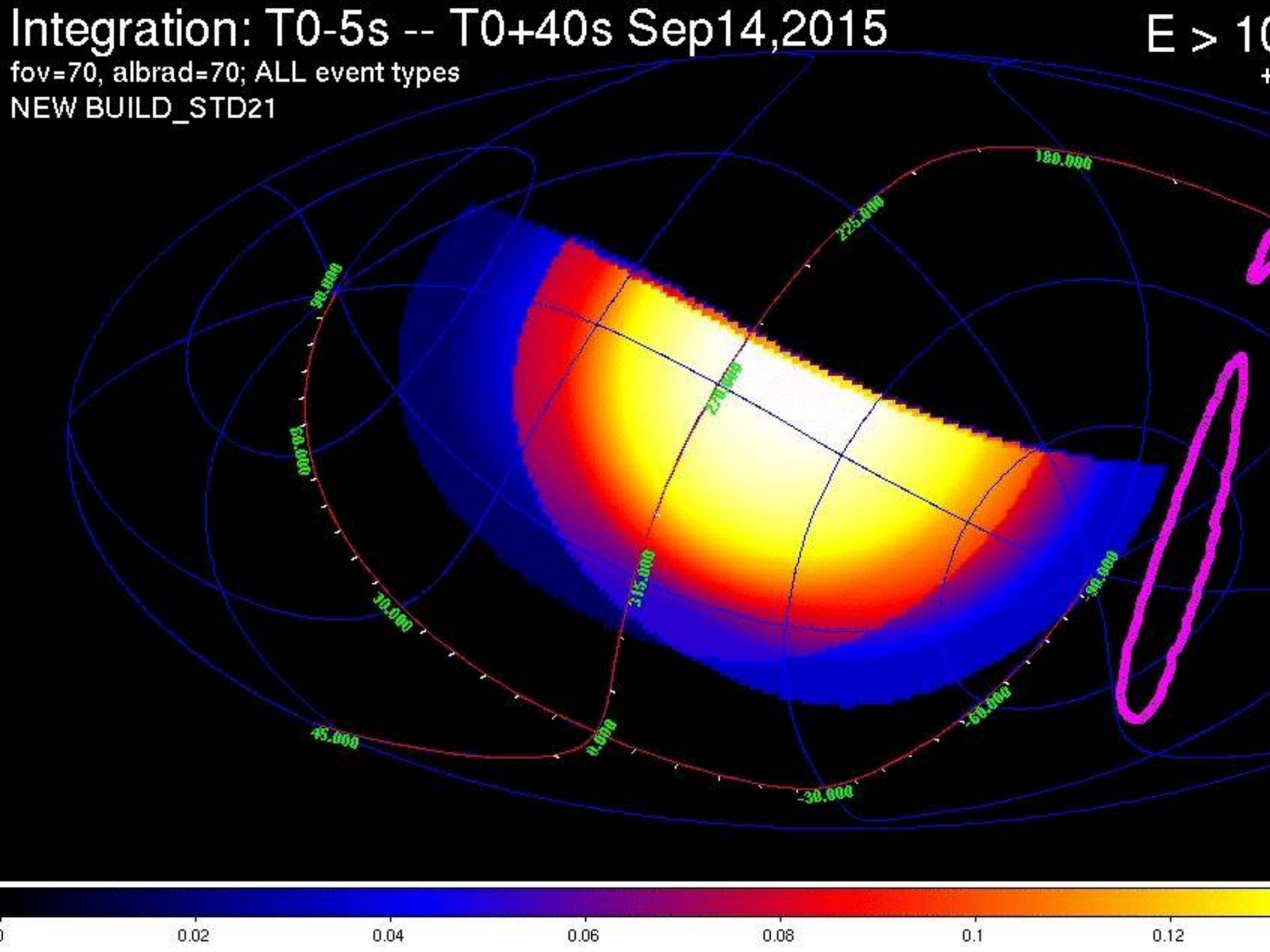
0.1
0.12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0.08
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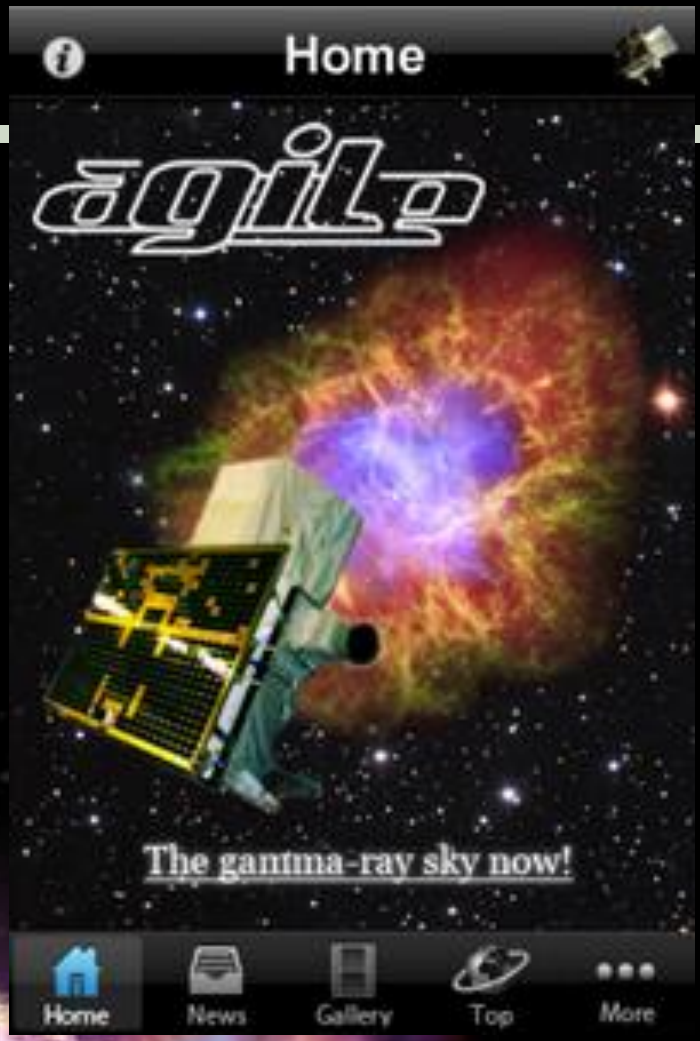
0.12

News in real time



SWIFT