Galactic Science with Fermi-LAT

Di Venere L.

Caragiulo M.

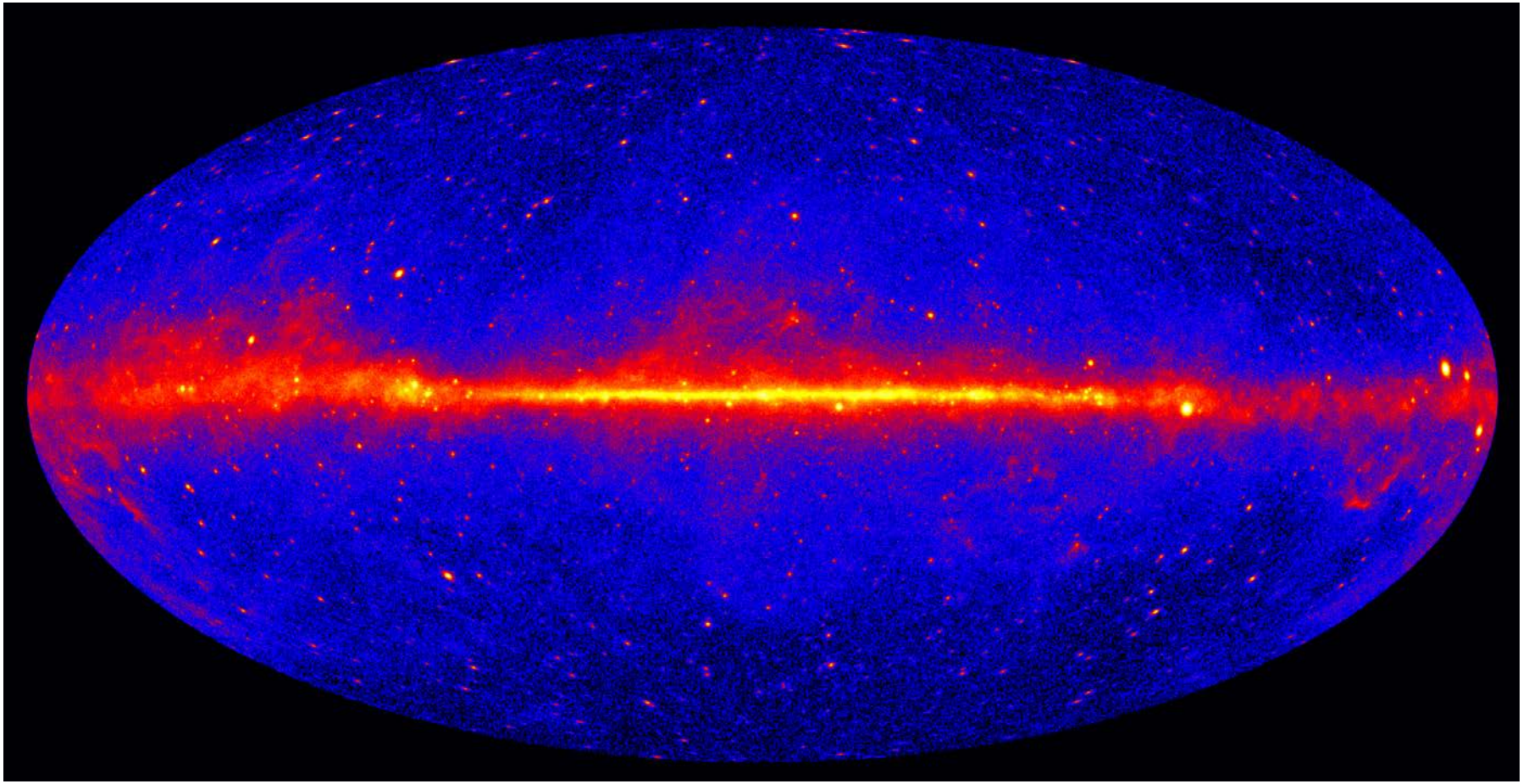
for the Fermi-LAT collaboration

University and INFN of Bari

IFAE

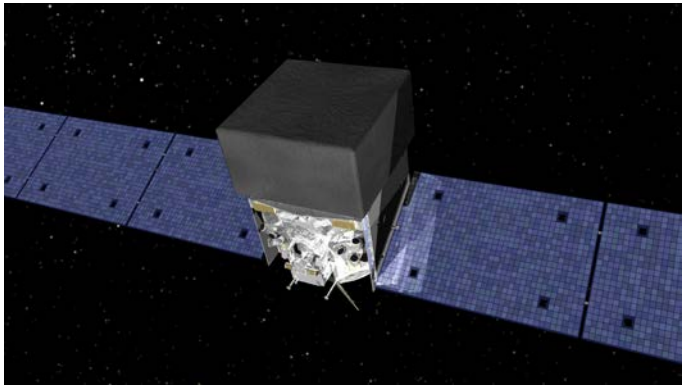
Genova, 31st March 2016

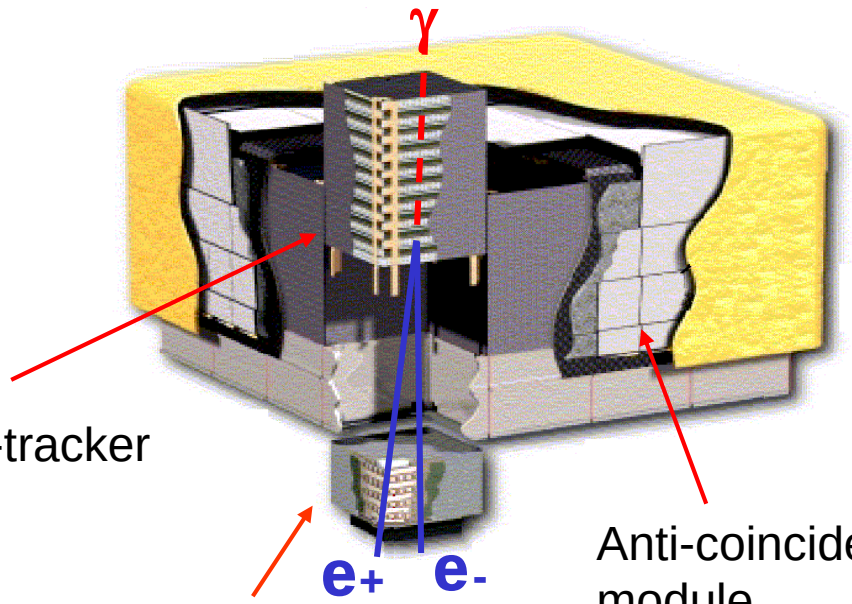
Gamma-ray sky

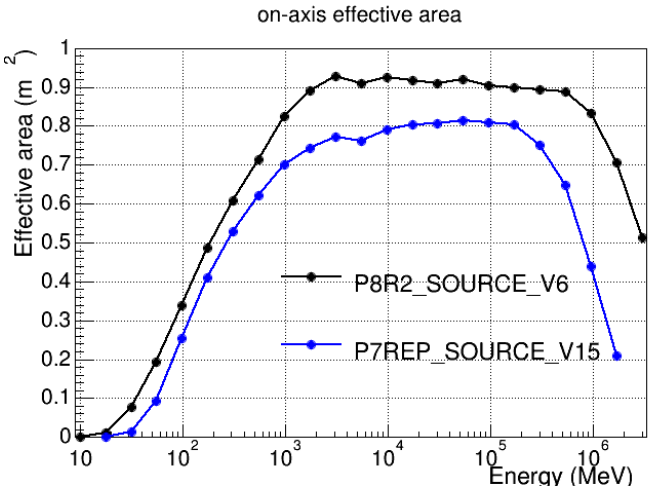


Gamma-ray sky obtained with 5 years of Fermi-LAT data with E>1GeV

The Fermi-LAT experiment







Pass 8 data release:

- Increased effective area
- Better Point Spread Function (PSF)
- Introduction of PSF and EDISP subclasses

What does Fermi see?

Dark matter search
- Dwarf Spheroidal Galaxies
- Galactic center

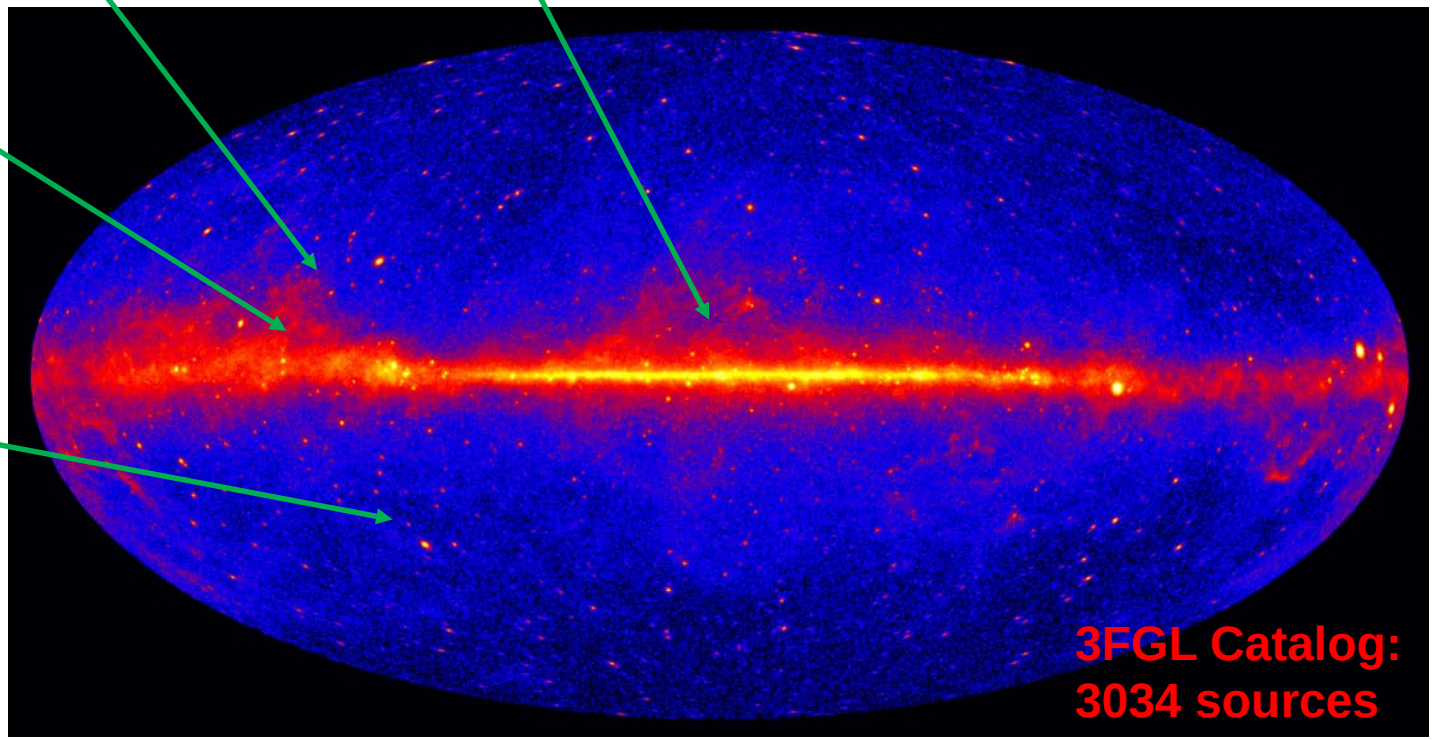
Diffuse emission
- CR interaction with gas and IRF

Solar system
- Sun
- Moon

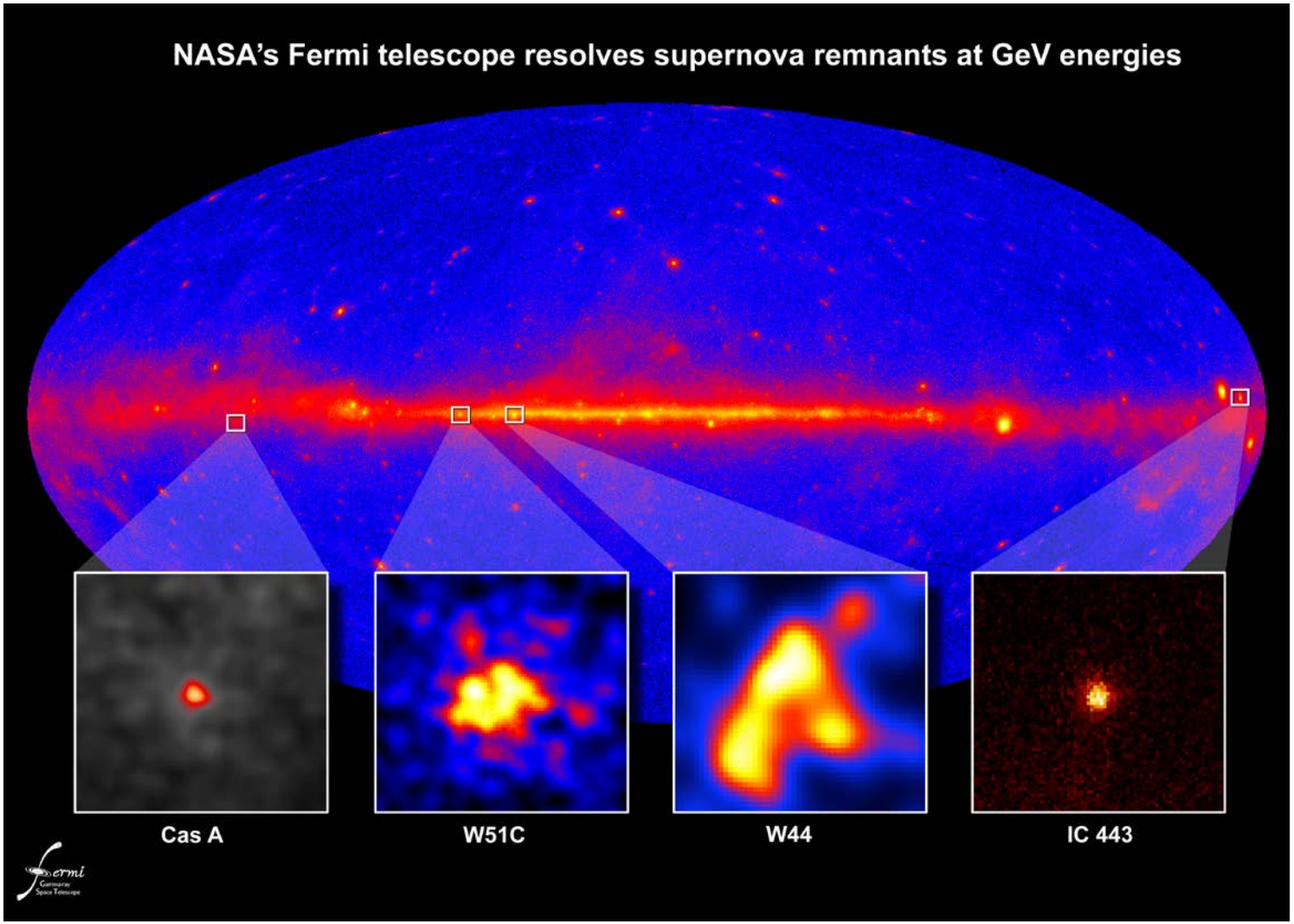
Transients
- GRBs
- Solar flares
- GW?

Galactic sources
- SNRs
- Pulsars
- PWNe

Extragalactic sources
- Mostly AGN
- Many unidentified



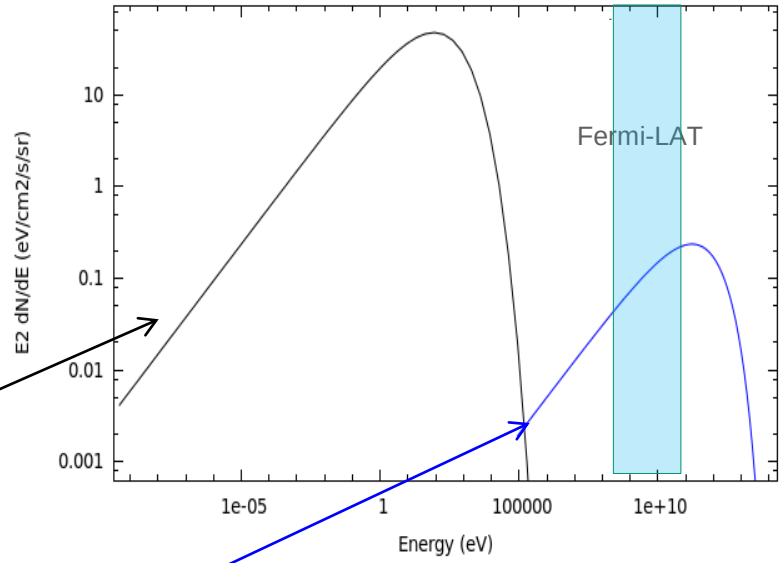
Supernova Remnants



Spectral energy distribution (SED) of SNRs

Thought to be cosmic ray sources:

γ-ray flux originates from the interaction of accelerated particles with the SNR environment:
SNR paradigm for Cosmic Rays



Radio to X-ray range
- Synchrotron peak

Three competitor processes for GeV-TeV energy range
- Inverse Compton
- Bremsstrahlung
- Pion decay

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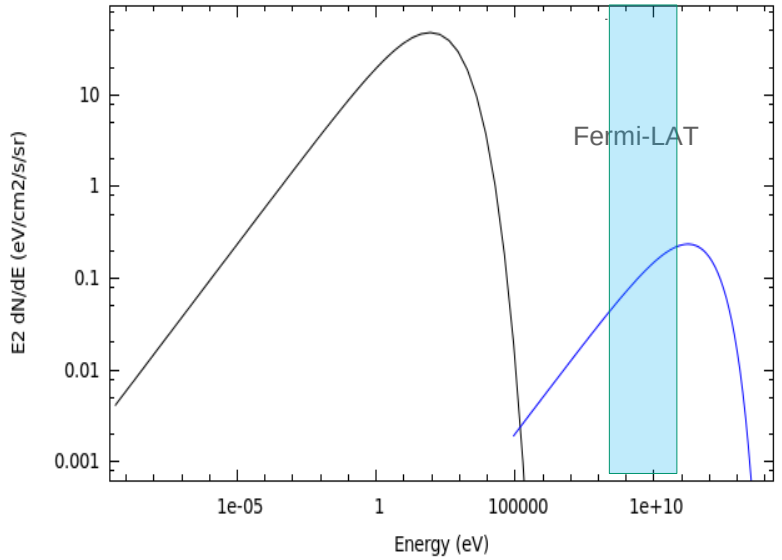

Three competitor processes for GeV-TeV energy range
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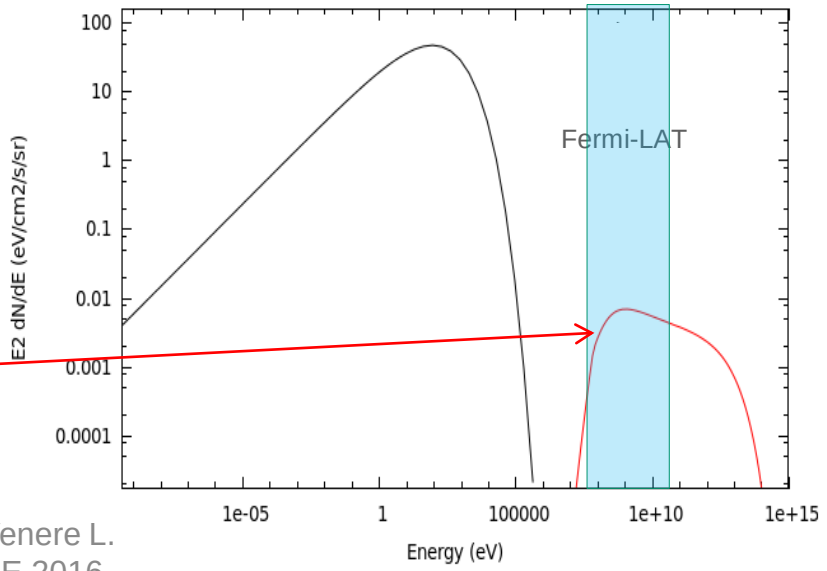
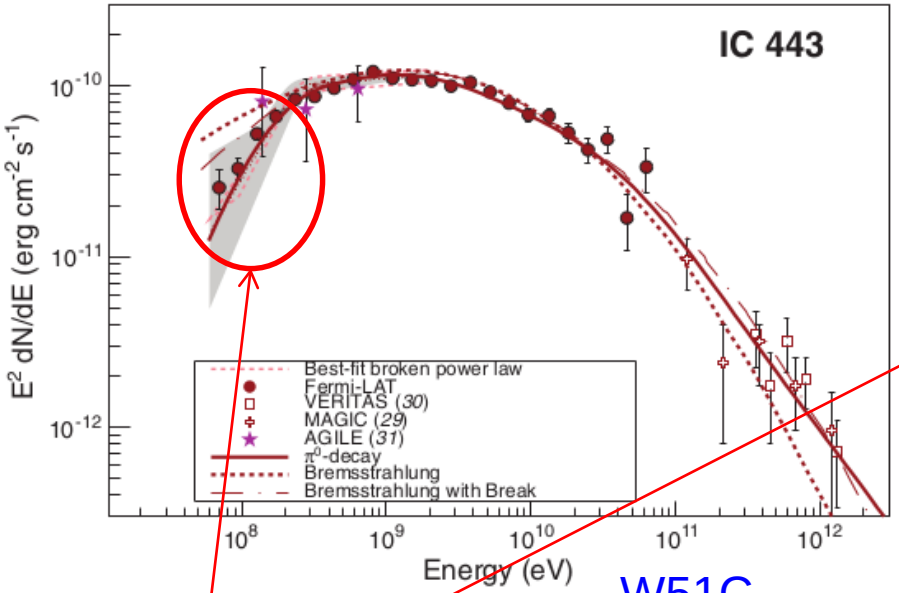
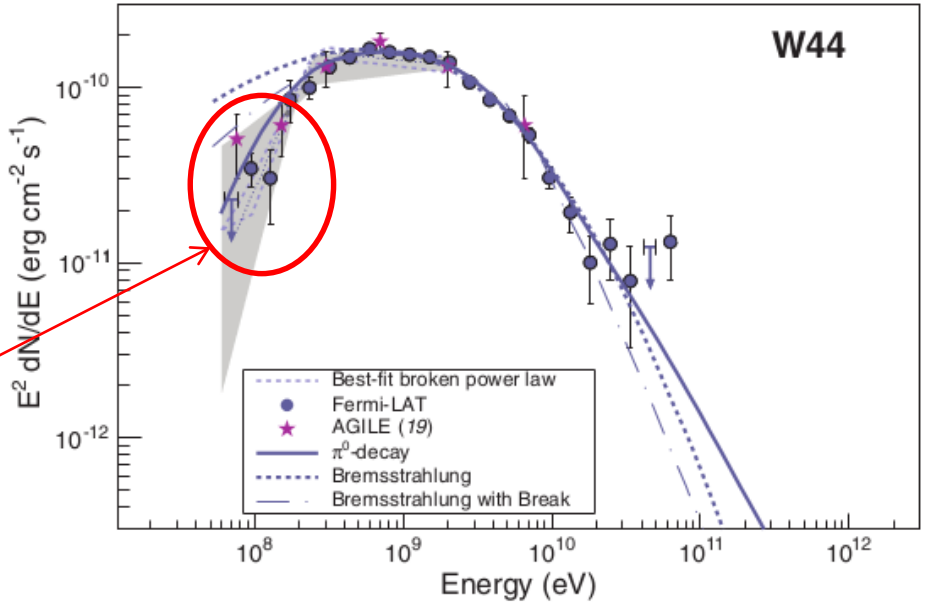


‘Pion bump’ in SNRs

IC443 and W44

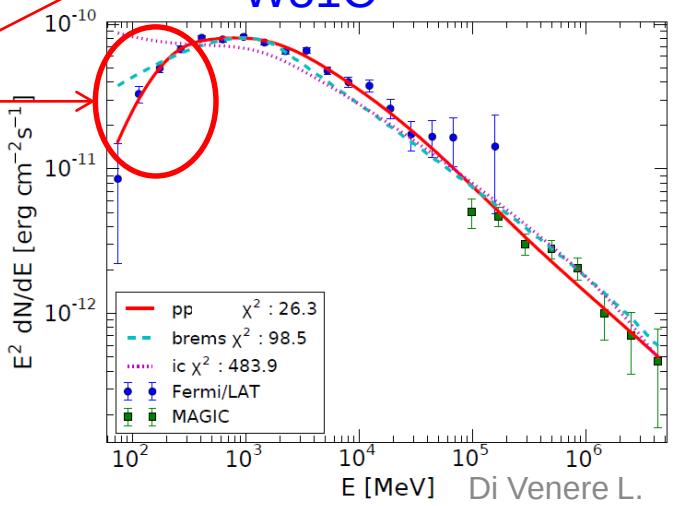




M. Ackermann et al., Science 339 (2013), 807.

‘pion bump’

W51C



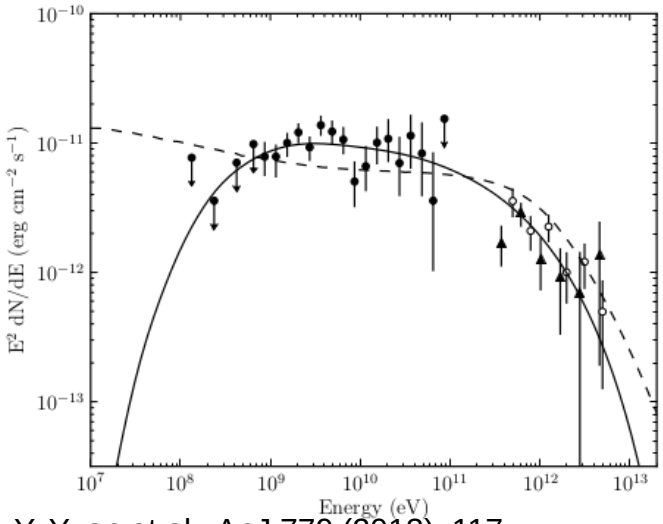
T. Jogler and S. Funk, ApJ 816 (2016), 100

Observed also by AGILE
Giuliani, Cardillo, Tavani et al., ApJL 742 (2011)2, L30

Young SNRs

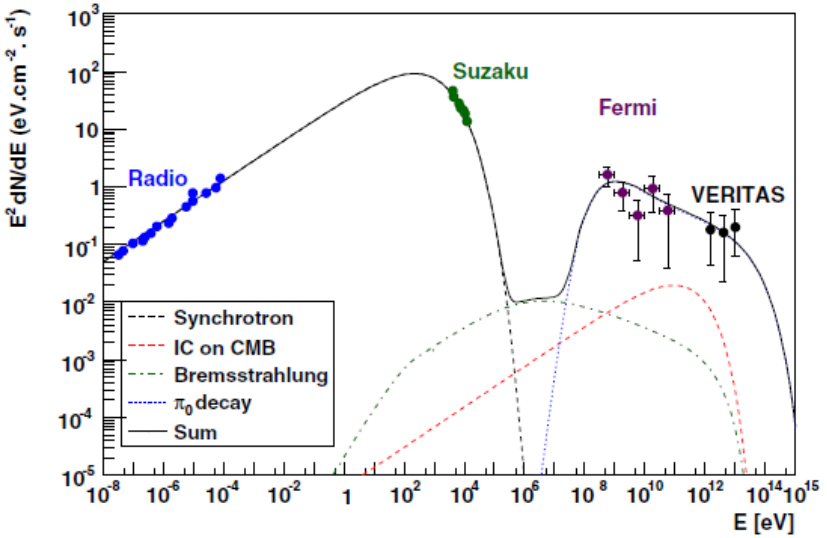
Hadronic

Cassiopeia A



Y. Yuan et al., ApJ 779 (2013), 117.

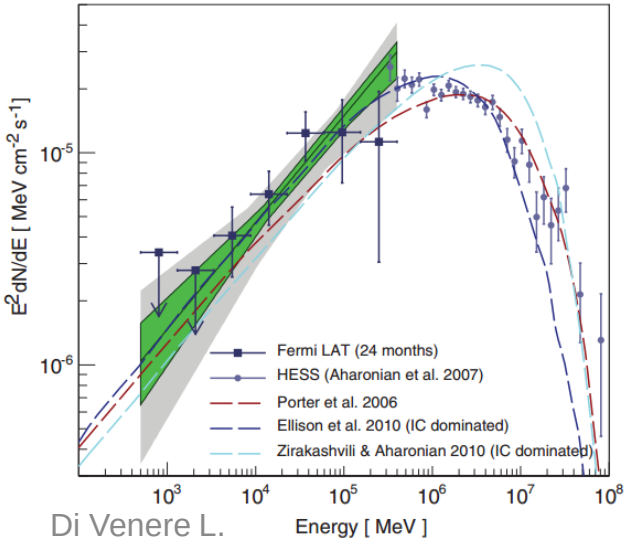
Tycho



F. Giordano et al., ApJL 744 (2012) L2

Leptonic

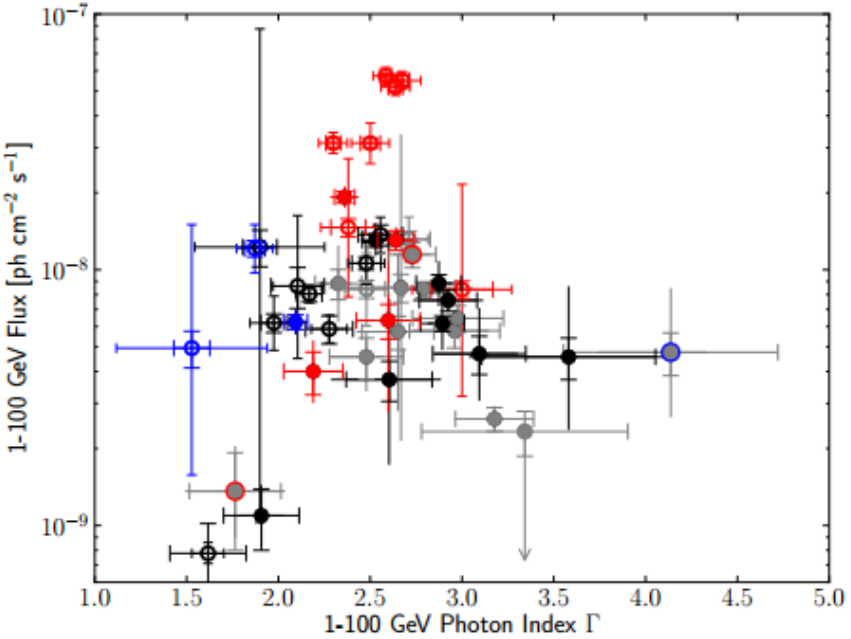
RX J1713.7-3946



A. A. Abdo et al., ApJ 734 (2010), 28

1st Supernova Remnant Catalog

- **Search of known SNRs in 3 years of Fermi-LAT data**
- **36 SNR candidates with spatial association with radio counterparts**
  - **17 extended sources: 4 new**
  - **13 point-like sources: 10 new**

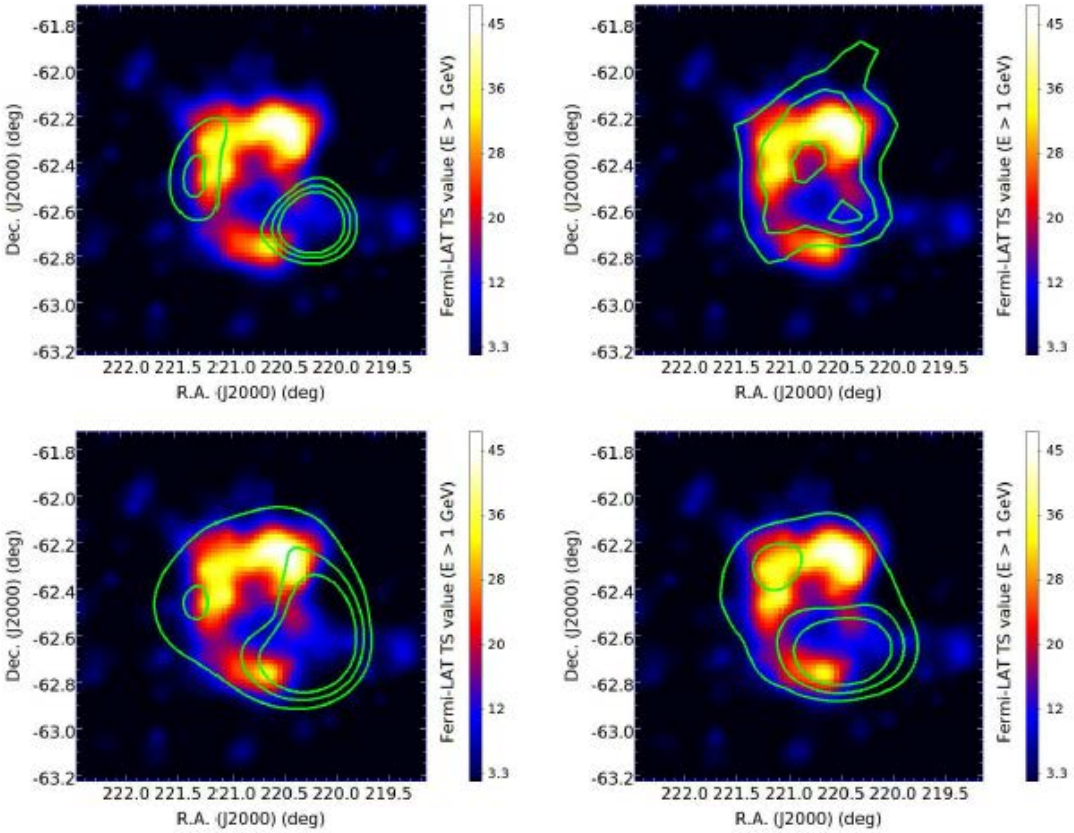


F. Acero et al., arXiv:1511.06778

- Interacting SNRs
- Young SNRs
- Classified candidates
- Marginal candidates
- Point-like sources
- Extended sources

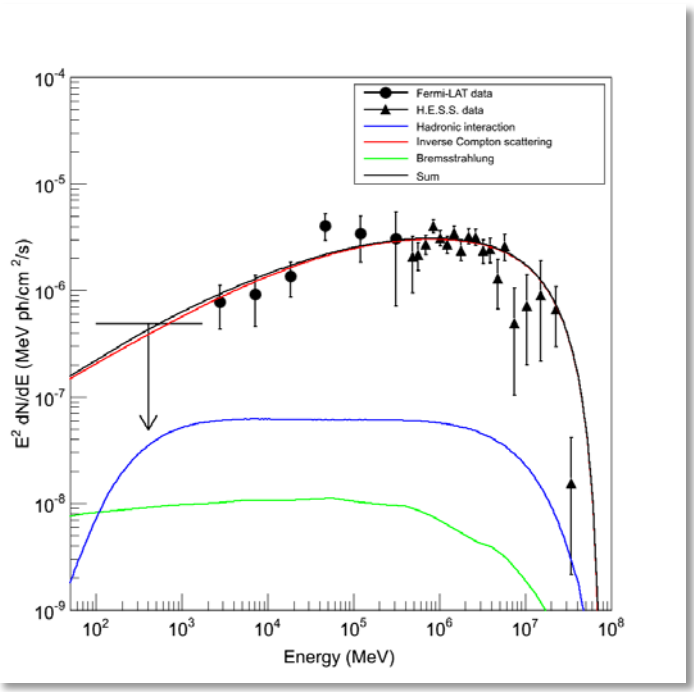
Morphology studies with Pass 8

RCW 86



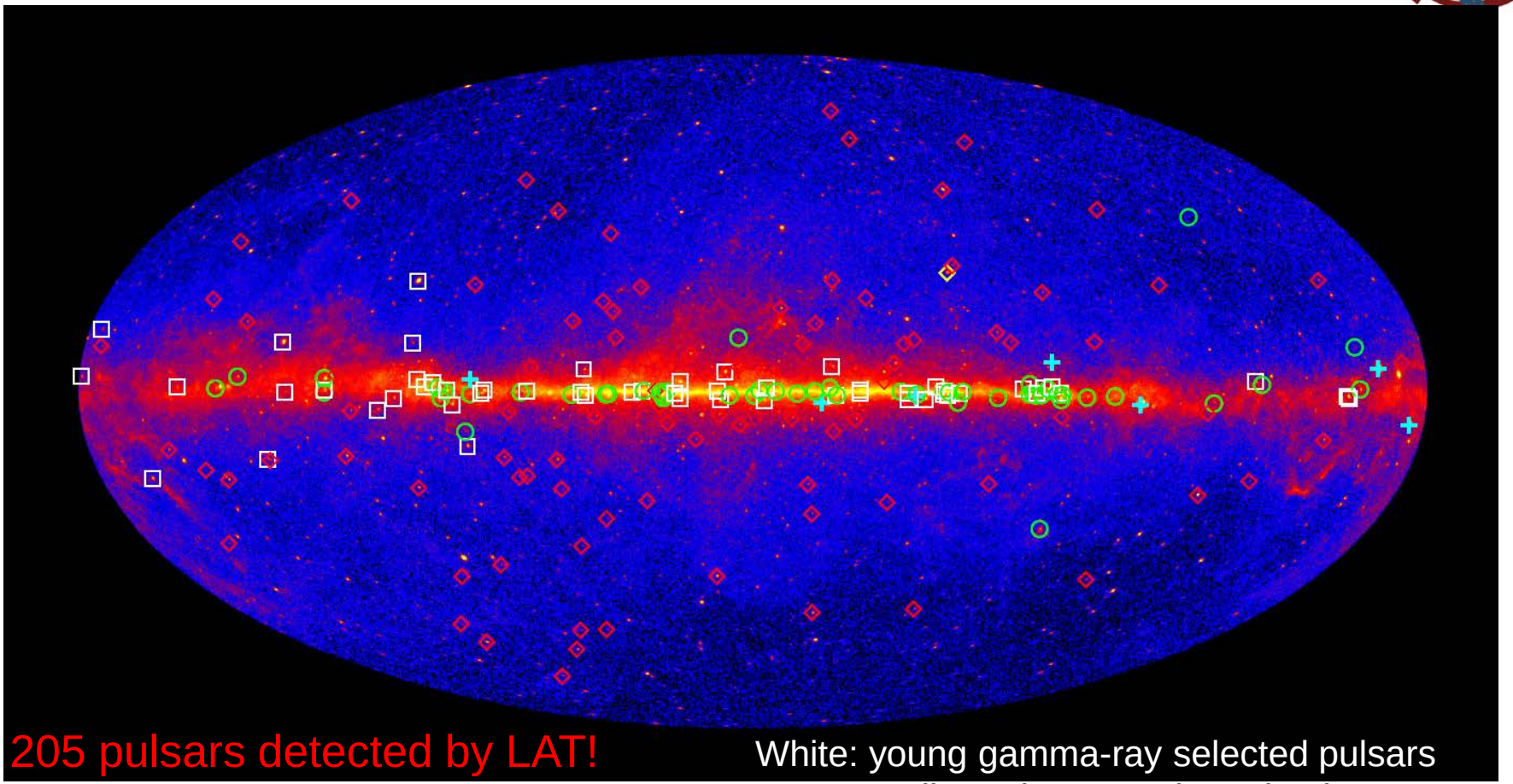
M. Ajello et al., ApJ 819 (2016) 98

Leptonic interpretation



See M.Caragiulo poster

Fermi-LAT pulsars



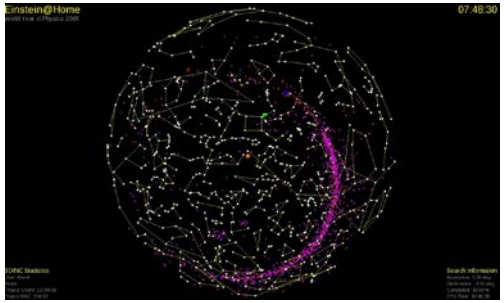
205 pulsars detected by LAT!

White: young gamma-ray selected pulsars
Green: radio and X-ray selected pulsars
Cyan: CGRO pulsars
Red: radio selected millisecond pulsars
Yellow: gamma-ray selected millisecond pulsars

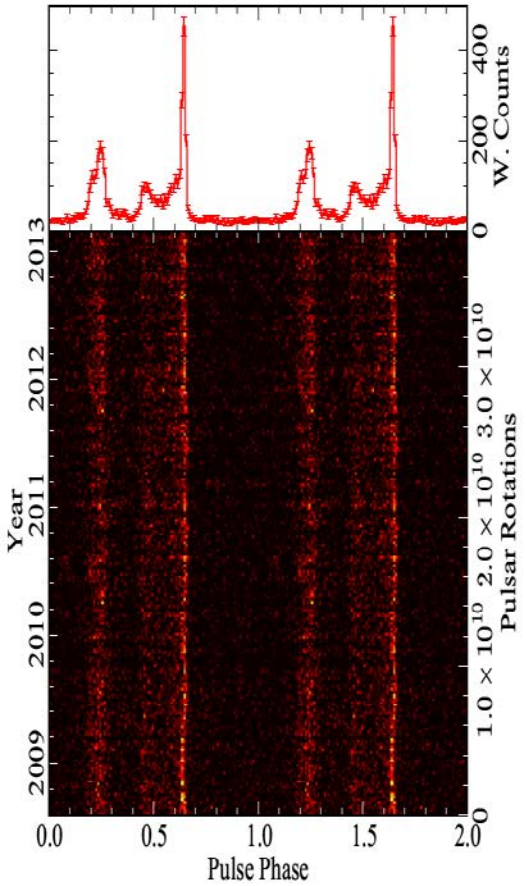
Public list of Fermi detected pulsars
https://confluence.slac.stanford.edu/x/5Jl6Bg

Fermi-LAT pulsar search

- **Search for known radio or X-ray pulsars in LAT data using given timing models**
- **Multi-wavelength observations of LAT unassociated sources: search for pulsations in radio and X-ray**
- **Blind pulsation search: Einstein@Home project**



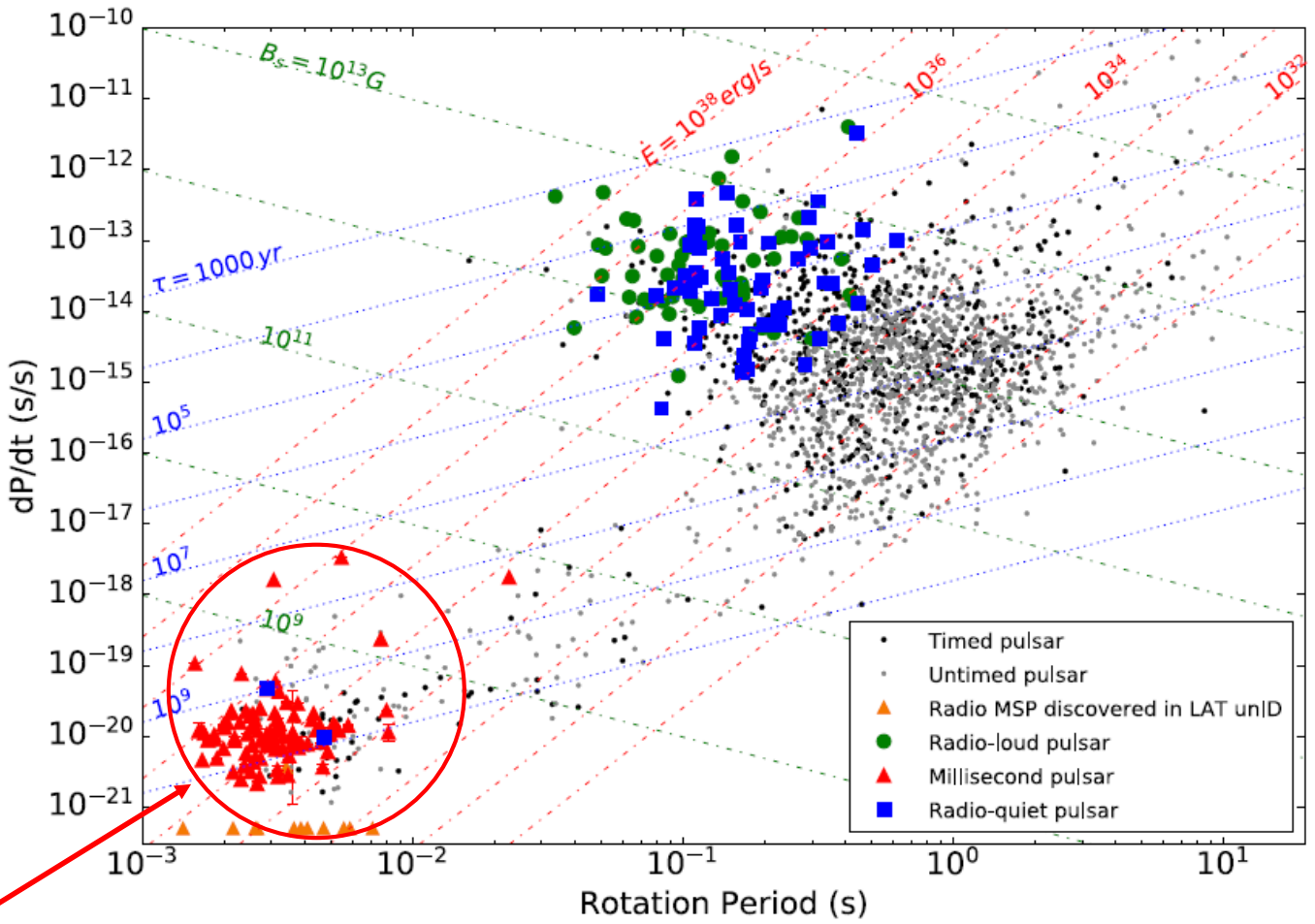
More than 10000 yrs of CPU time!
14 new gamma-ray pulsar detected!



Pulsar J1231-1411
(P ~ 3.684 ms)

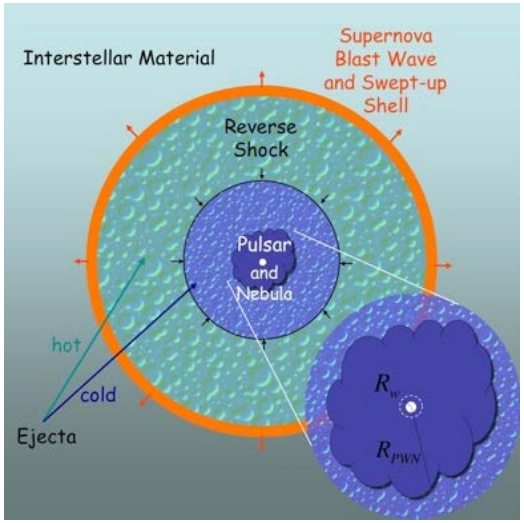
‘P – Pdot’ diagram

Pulsar spin-down



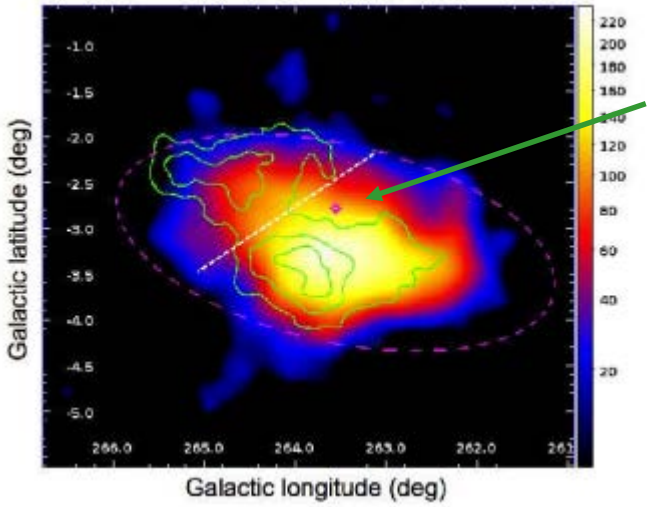
Millisecond pulsars

Pulsar Wind Nebulae



- Energy is carried away in a magnetized wind of charged particles.
- PWNe contain both the relic accelerated particles from the pulsar and particles accelerated within the termination shock.

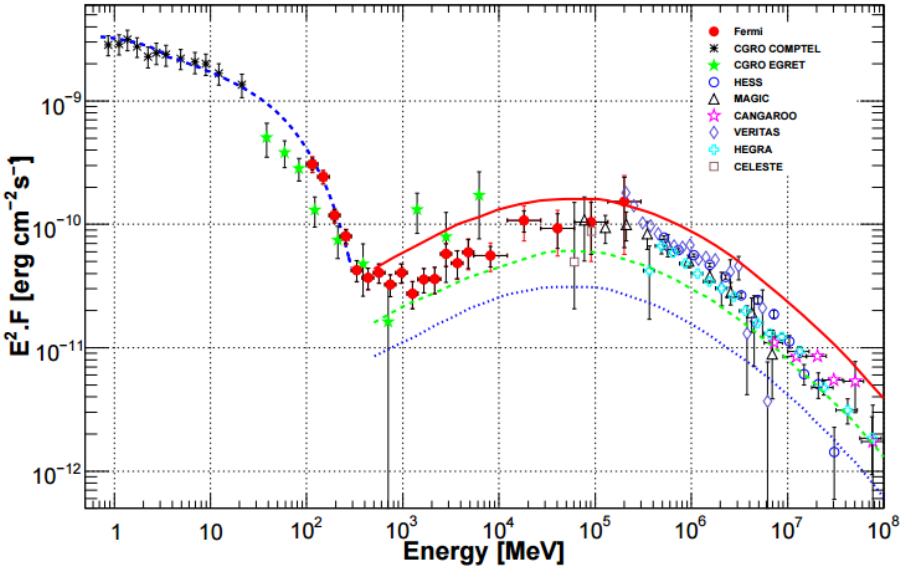
Vela X



Vela pulsar

M. H. Grondin et al., ApJ 774 (2013), 110

Crab



A. A. Abdo et al., ApJ 708 (2010), 1254

Conclusions

There is much more to say…

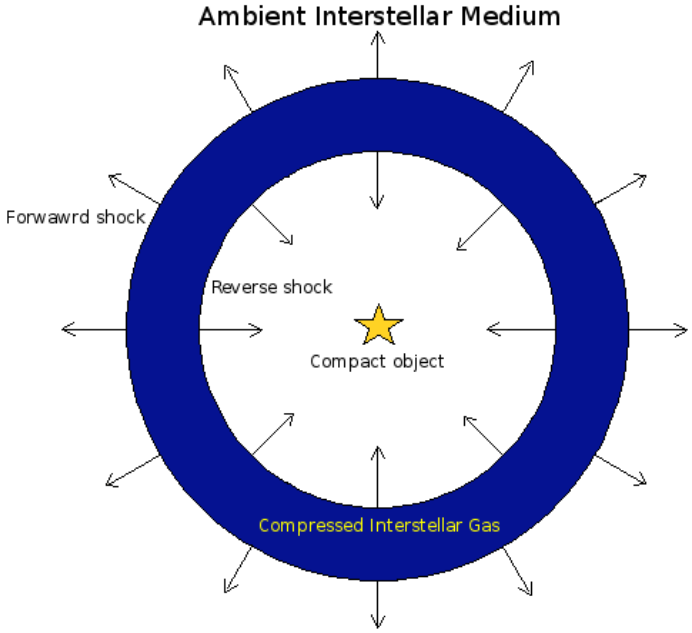
- **Gamma-ray binaries**
- **Novae**
- **Crab flare**
- **…**

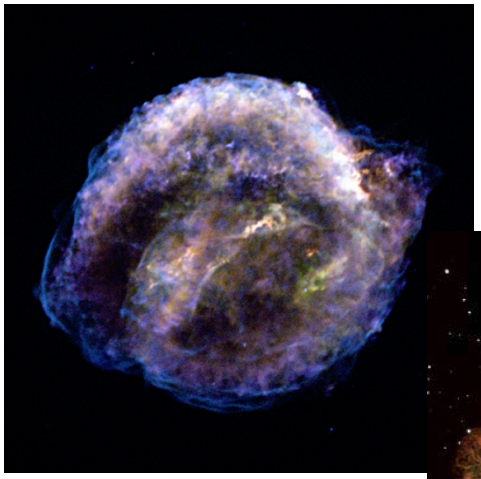
… and much more to be discovered!

Stay tuned for more Fermi-LAT results!

Backup

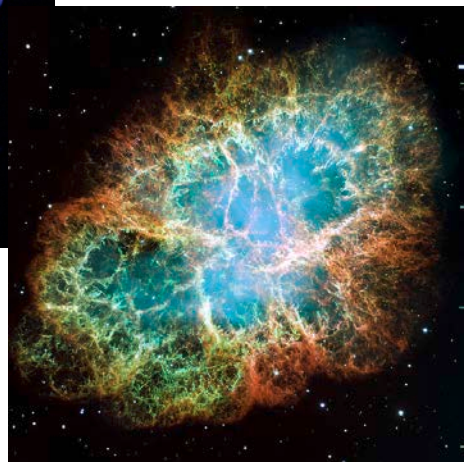
Supernova Remnants





Kepler SNR

Crab Nebula



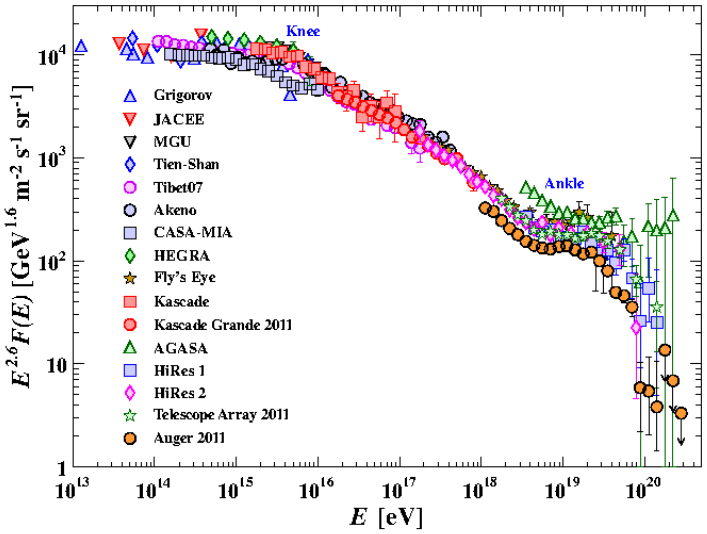
Energetics of SNRs

- SN explosion energy E_{SN}~10^{51} erg
- Rate of explosion in the Galaxy R_{SN}~3 SN/century
- Confinement time of cosmic rays τ_e~10 Myr
- Cosmic-ray energy density ρ_{CR}~1 eV cm^{-3}

$$\rho_{CR} = R_{SN}\, E_{SN}\, \tau_e\, \epsilon$$

Acceleration efficiency required ε ≤ 10%

SNRs as sources of CRs



Galactic Cosmic ray spectrum

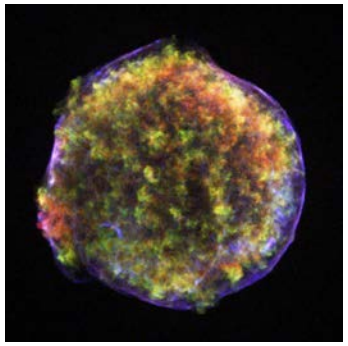
$$N(E) \propto E^{-2.7}$$

$$N(E) = Q_{inj}(E)\tau_{esc}(E)$$

$$\tau_{esc}(E) \propto E^{-0.6 \div -0.3}$$

from B/C ratio measurements

$$Q_{inj}(E) \propto E^{-2.1 \div -2.4}$$



Tycho SNR in X-ray light
Chandra X-ray Observatory

- SN explosion energy E_{SN}~10^{51} erg
- Rate of explosion in the Galaxy R_{SN}~3 SN/century
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- Cosmic-ray energy density ρ_{CR}~1 eV cm^{-3}

$$\rho_{CR} = R_{SN}\, E_{SN}\, \tau_e\, \epsilon$$

Acceleration efficiency required ε ~ 10%

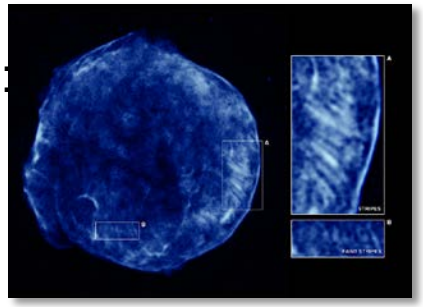
Non-linear diffusive shock acceleration theory

Diffusive Shock Acceleration

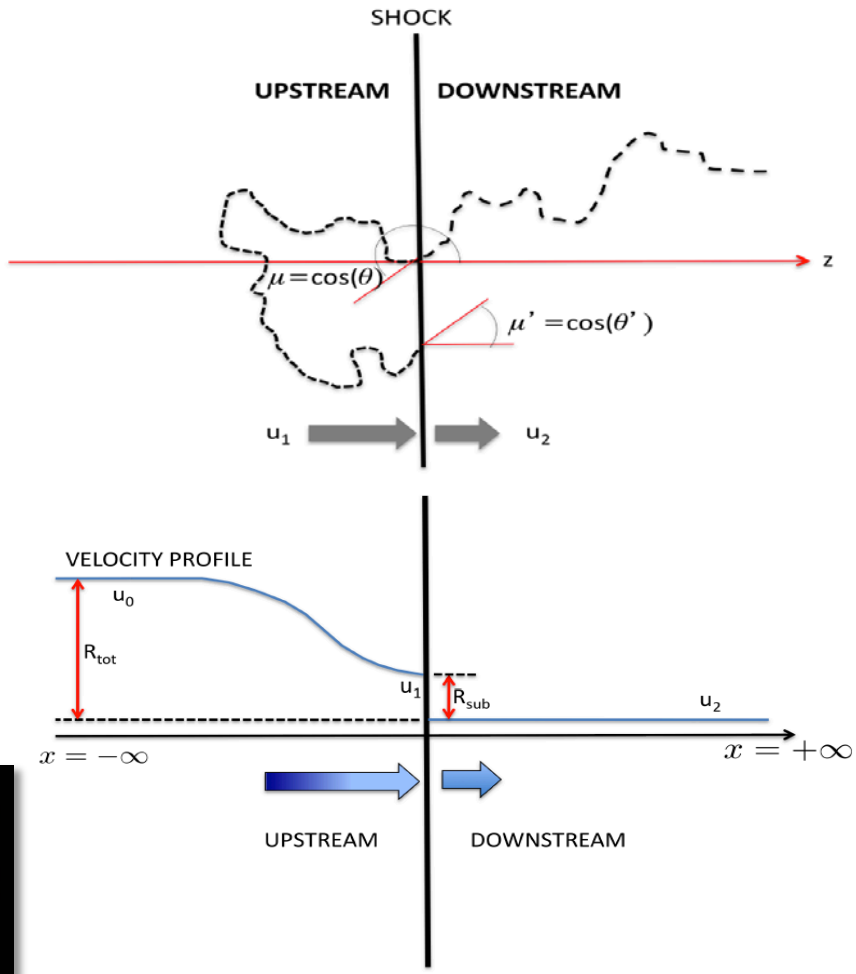
- Conservation of mass, momentum and energy
- Predicts an accelerated particle distribution $\propto E^{-q}$, with $q = 2$ in case of strong SNR shocks
- The required acceleration efficiency is not so small ⟶ dynamical reaction of accelerated particles on the shock.

Non linear Diffusive Shock Acceleration

- Generalization of conservation equations with the introduction of CR contribution
- Predicts softer accelerated particle distribution: $q = 2.1 - 2.4$
- Magnetic field amplification: most important evidence of NLDSA



Credit: NASA/CXC/ Rutgers/K.Eriksen et al.

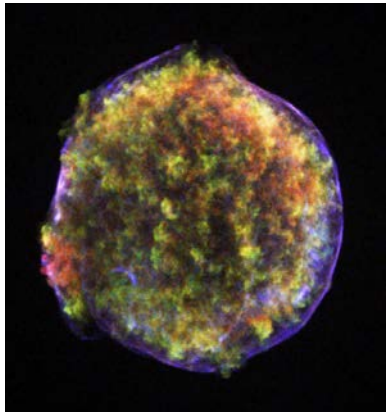


Blasi, P.: 2013, Astron. Astrophys. Rev. 21, 70

Tycho and RCW86

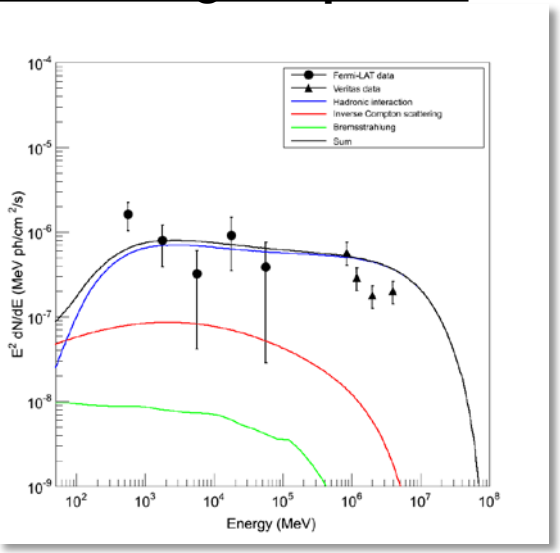
Tycho

- Young type Ia SNR
- Evidence of magnetic field amplification
- Point-like source in the GeV-TeV energy range
- Hadronic interpretation of the SED



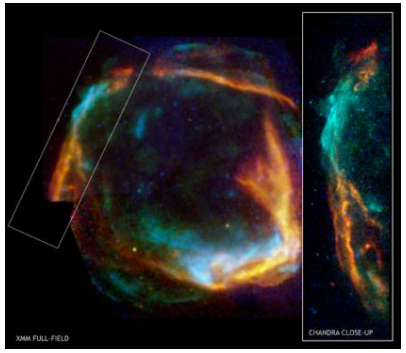
Tycho SNR in X-ray light
Chandra X-ray Observatory

See M.Caragiulo poster

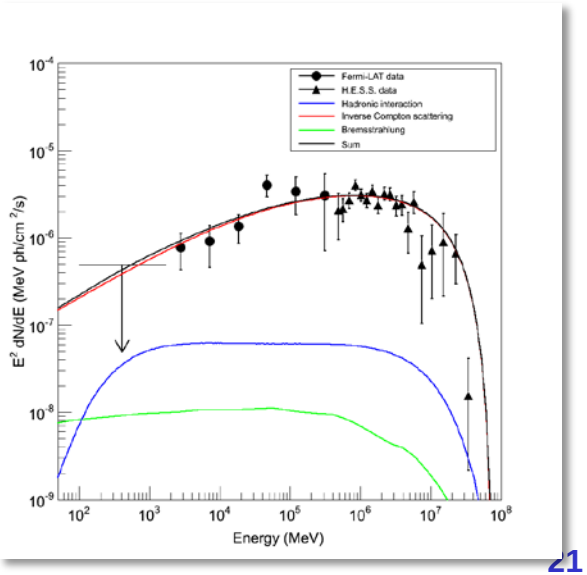


RCW 86

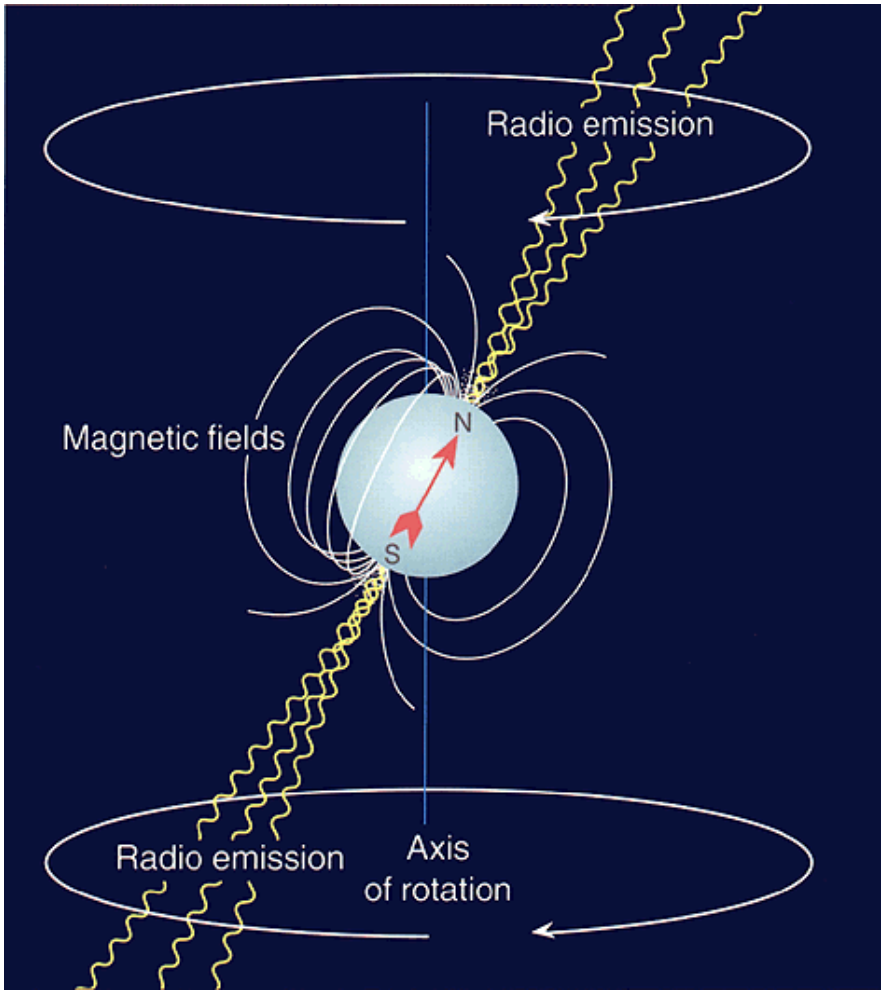
- Young type Ia SNR
- Detected as extended source also in the GeV-TeV energy range
- Leptonic interpretation of the SED



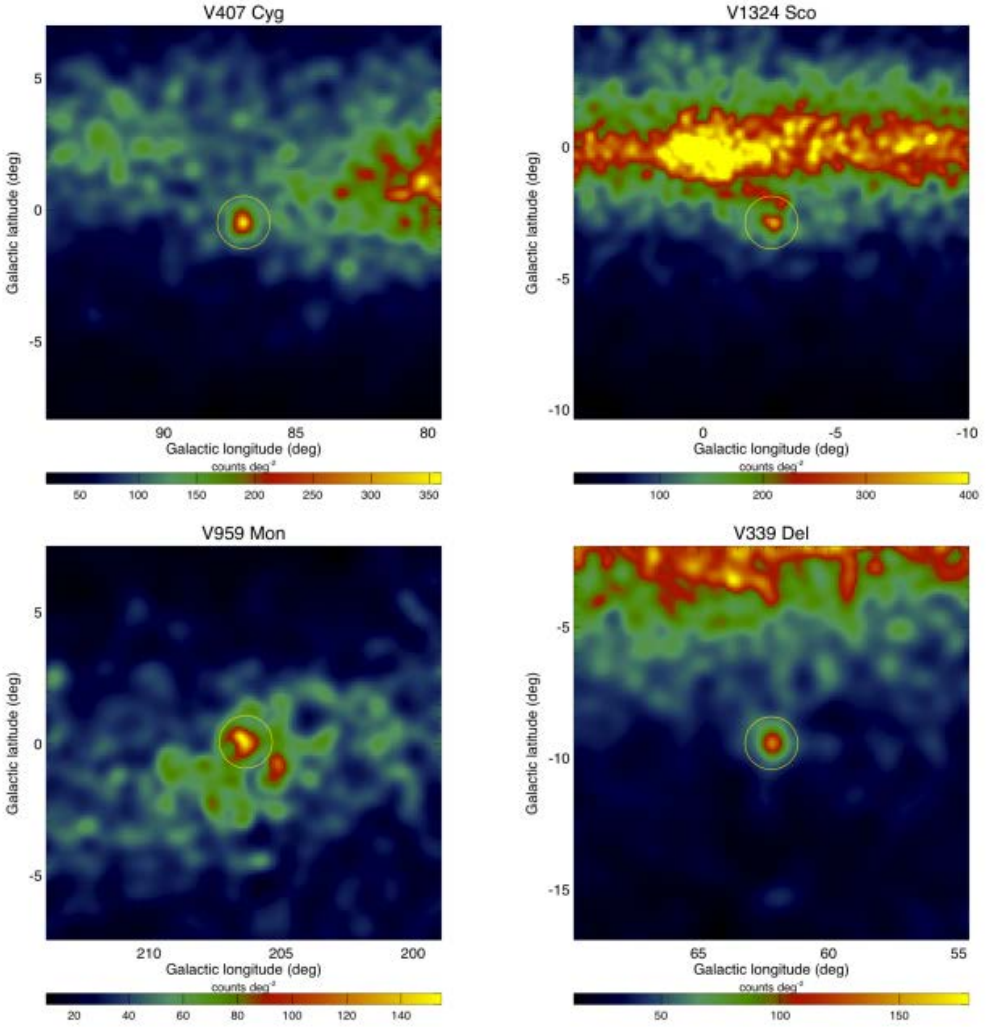
RCW 86 SNR in X-ray light obtained with Chandra X-ray observatory e XMM-Newton.



Pulsar


Radio emission
Magnetic fields
N
S
Radio emission
Axis
of rotation

Novae

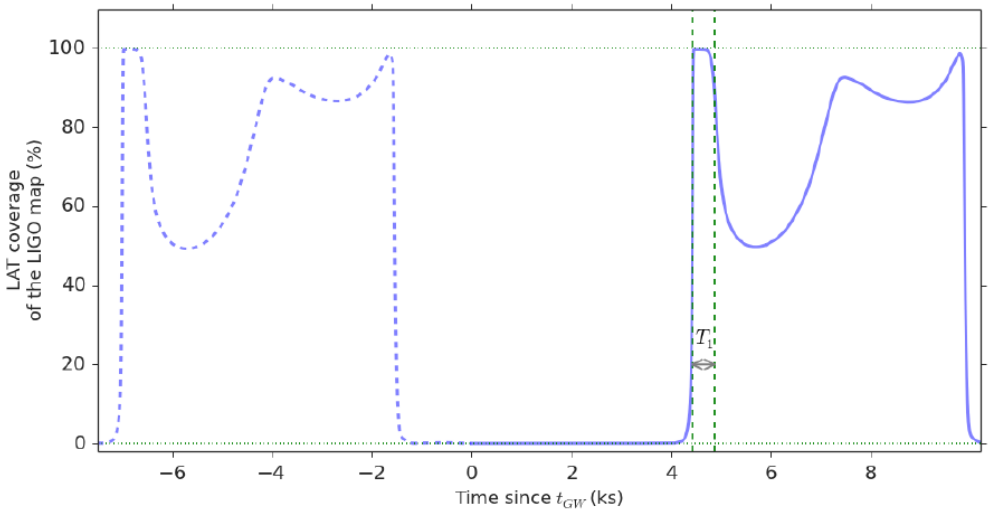


M. Ackermann et al., Science 345.6196 (2014), 554

GW150914 – Fermi-LAT observation

LAT short baseline search

The GW region was not in LAT FoV at the time of the GW event: search at t_{GW}+[4442-4867]s



Flux ULs