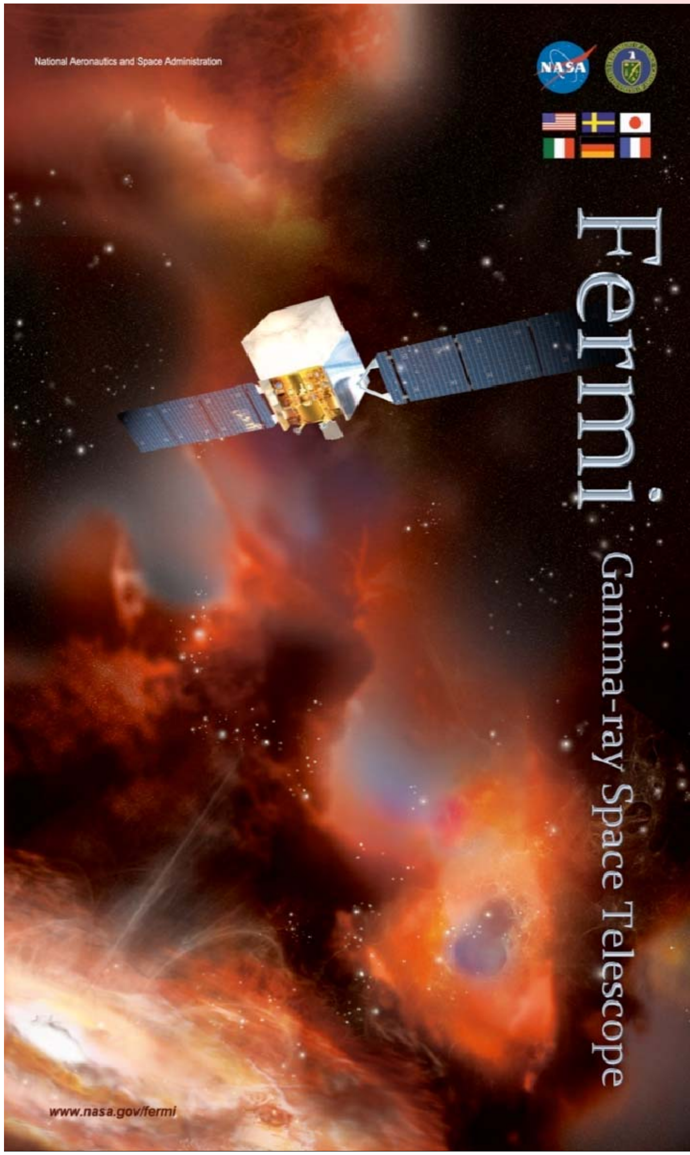

High Energy Supernova Remnants and Pulsar Wind Nebulae

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Dipartimento Interateneo di Fisica and INFN Sez. Bari

For the Fermi-LAT Collaboration

Scineghe 2010

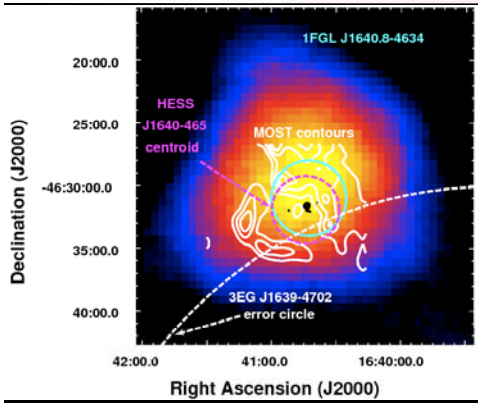
The Afterlife of a star

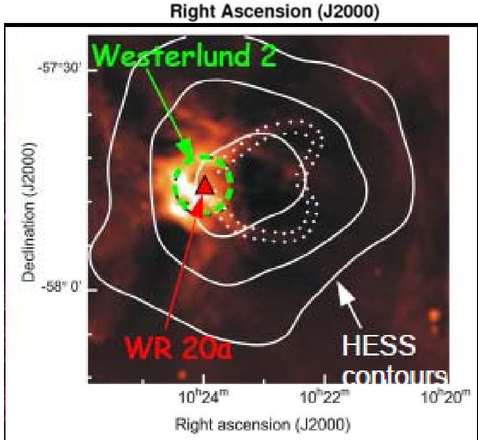
Depending on the its mass a star mass may evolve into a white dwarf or a neutron star.
The neutron star may radiate energy in pulses (PSR).
The PSR may also interact with the surrounding medium originating a PWN

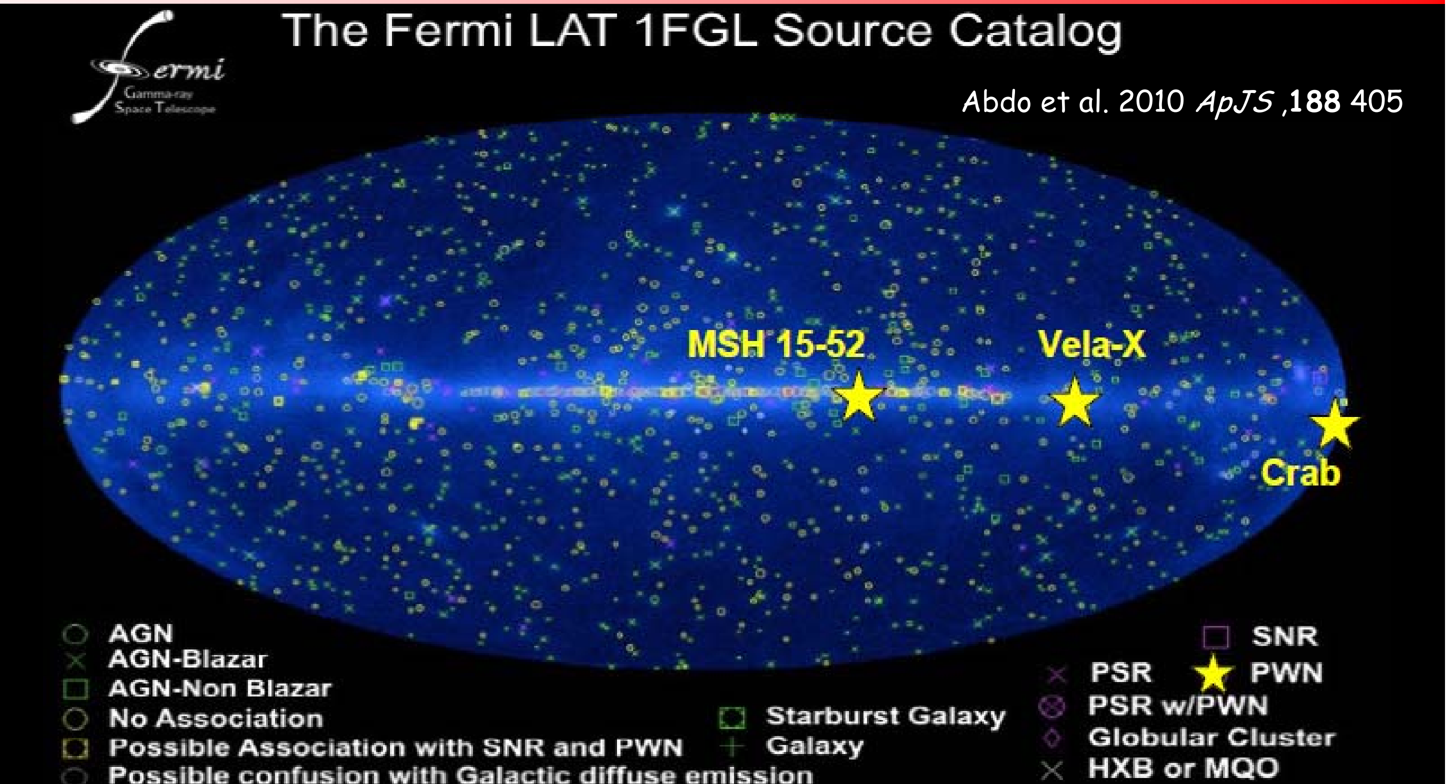
and/or

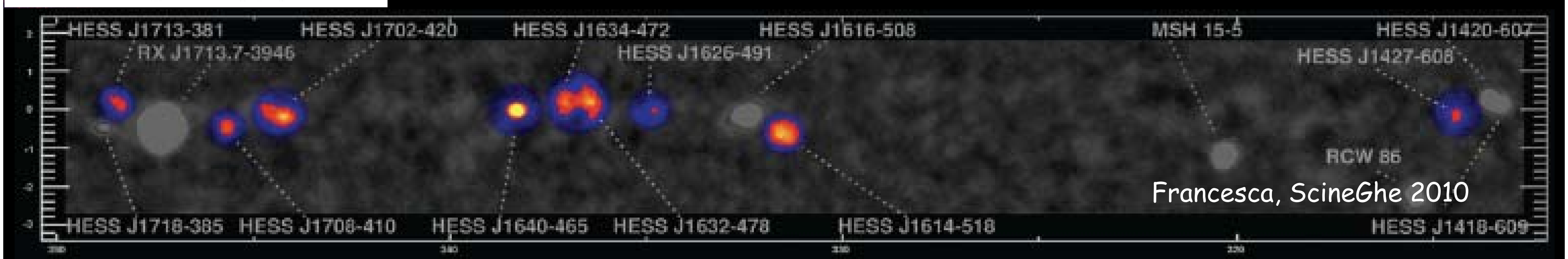
The shock waves of the explosion interacting with the surrounding medium may produce radiation at different wavelenghts

Gamma-ray emitting PWNe

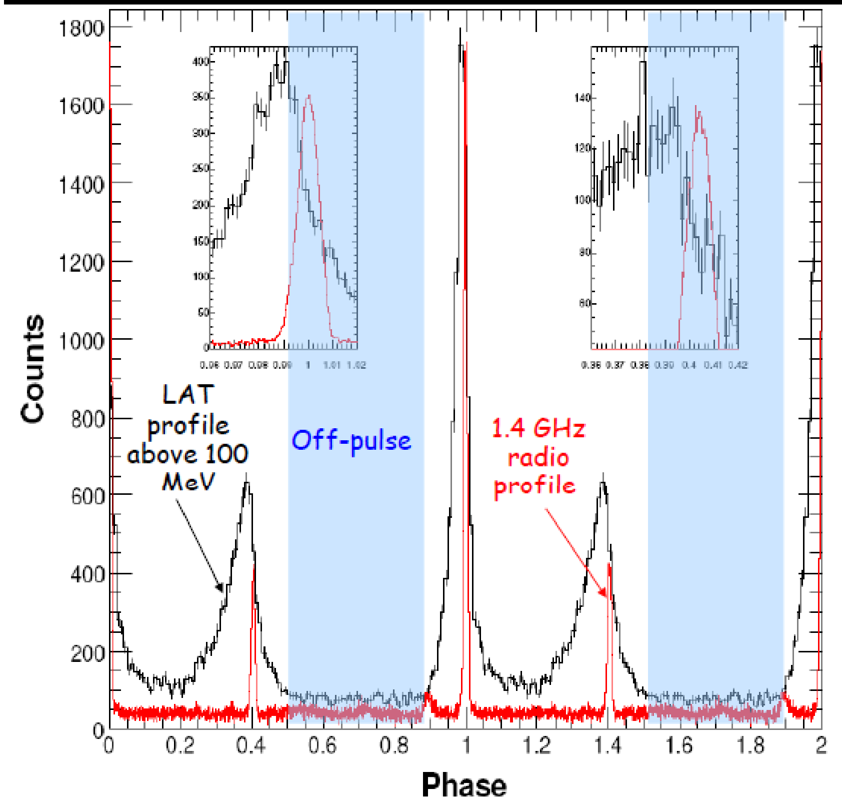




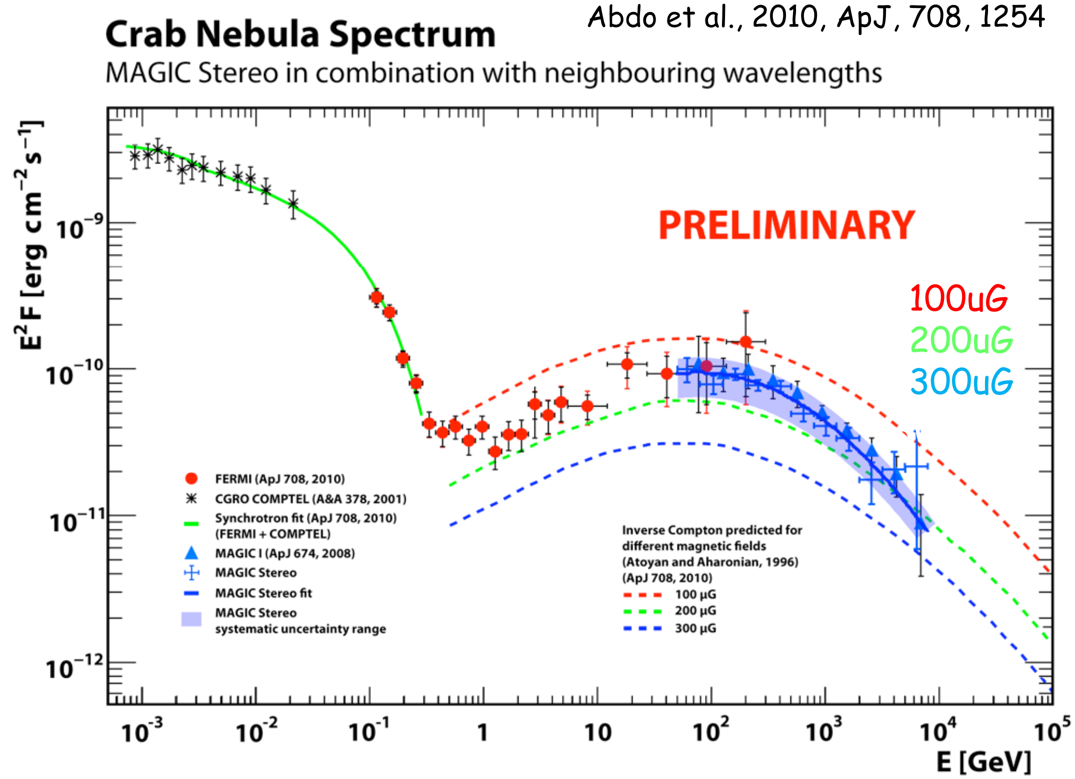




Two "easy" cases: The CRAB PWN and…

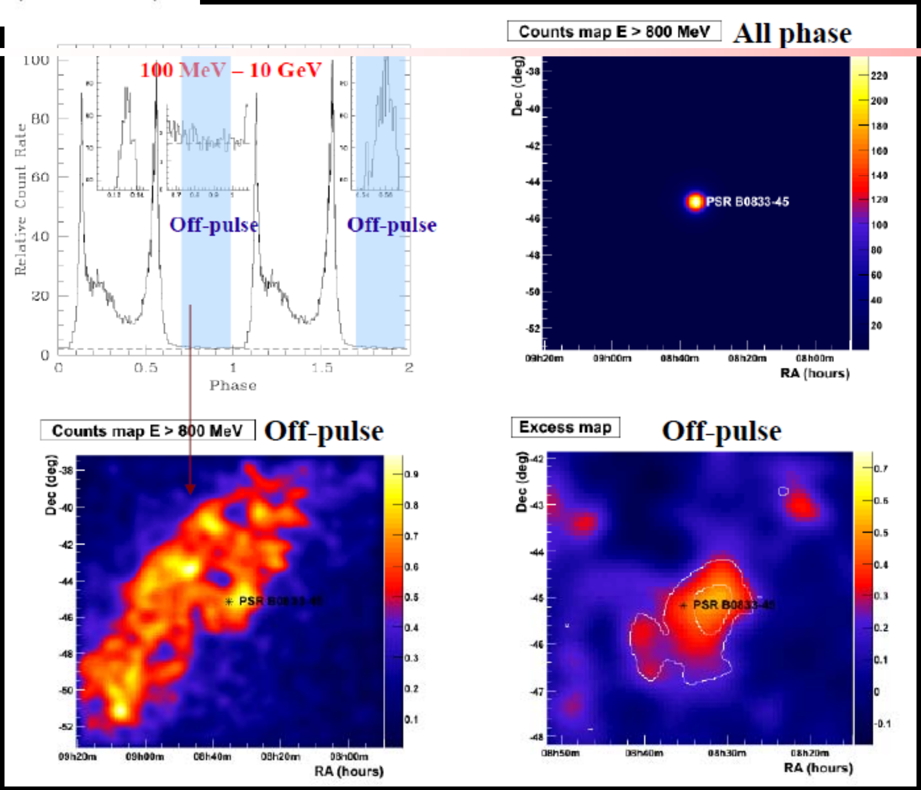


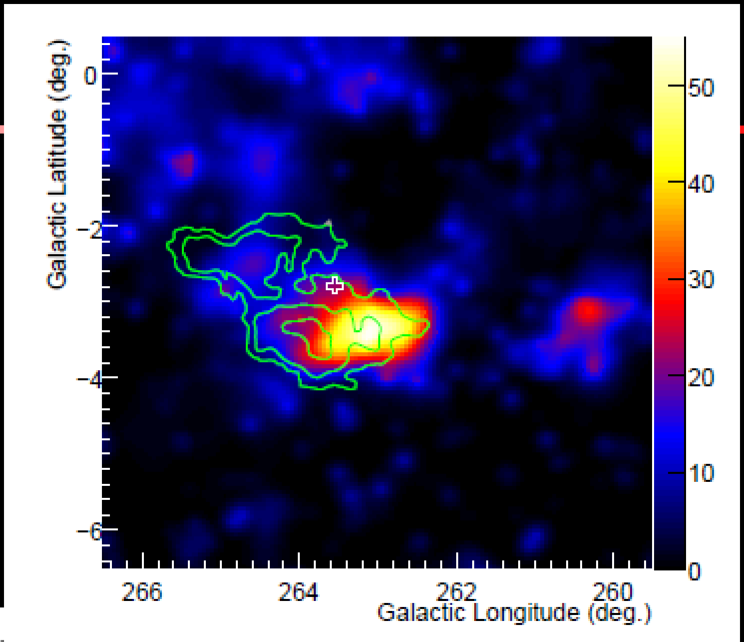
Abdo et al., 2010, ApJ, 708, 1254

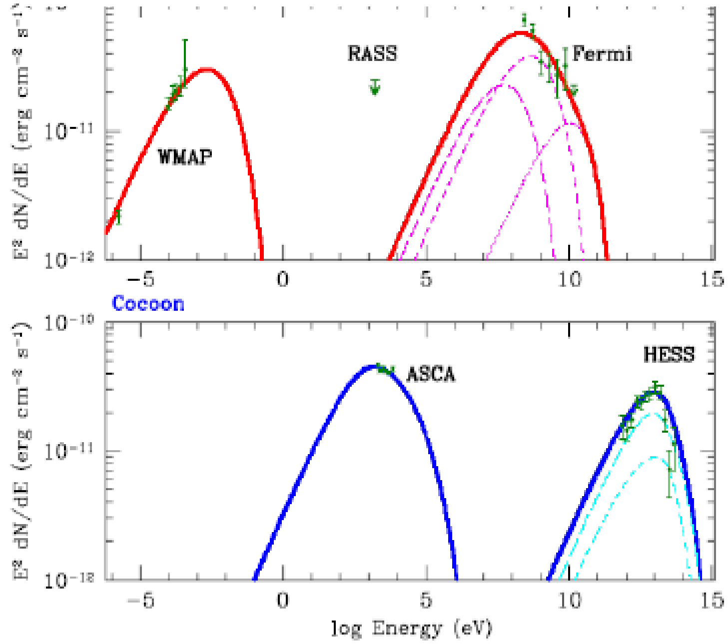


…the Vela PWN

A. A. Abdo *et al* 2010 *ApJ* **713** 146





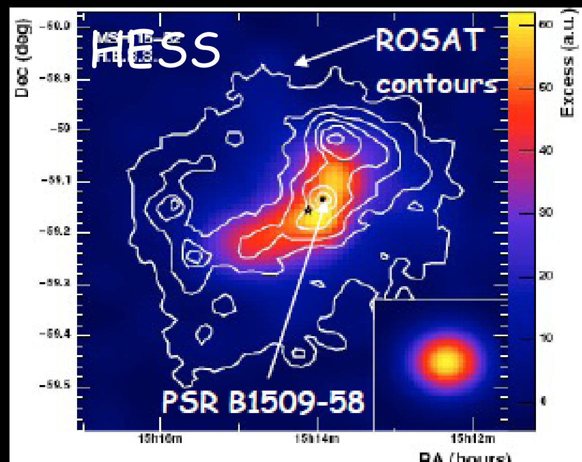


- Spectral index = 2.41 (soft spectrum)
- Flux E>100 MeV = 4.73 $\times 10^{-7}$ cm^{-2} s^{-1}

- the SED strongly favors a <u>two</u> component leptonic model
- Hadronic model is disfavoured

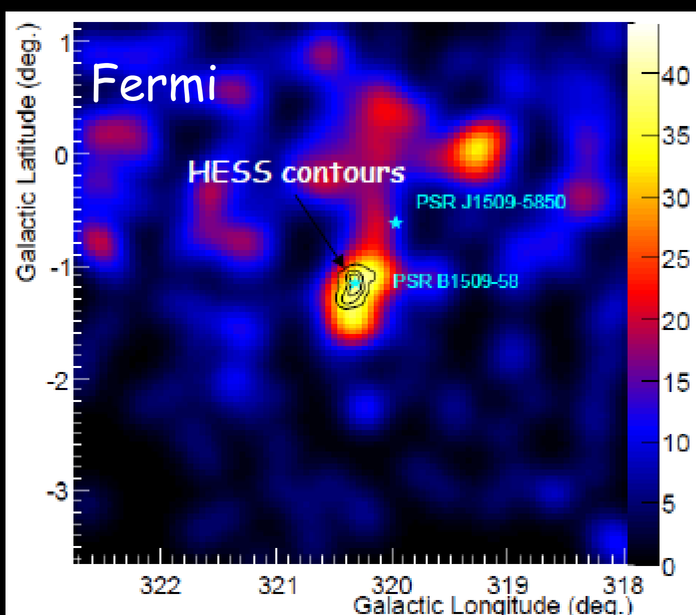
Another lady: the MSH15-52

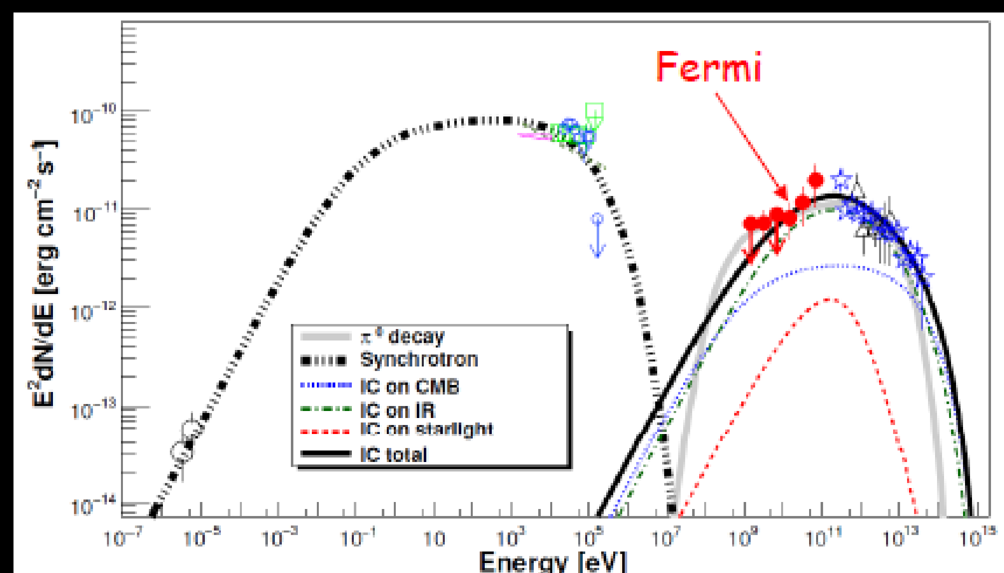
(Abdo et al., 2010 *ApJ* **714** 927)



- •Source extended : Rdisk = (0.25 ±0.05)°
- •Flux (E>1 GeV) : ~ 3×10^{-9} cm^{-2} s^{-1}
- •Spectral index : 1.6 ± 0.2

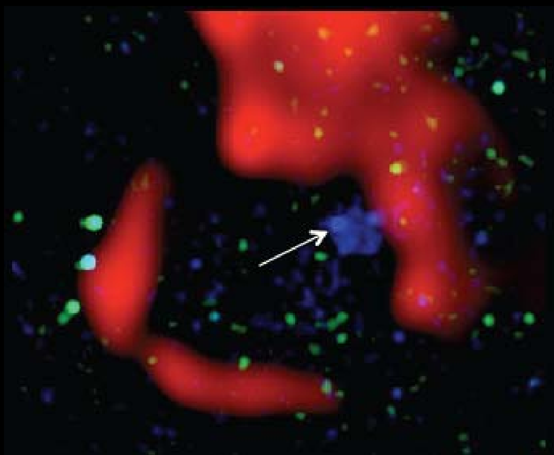
high energy emission can be explained by Inverse Compton scattering (mostly on FIR photon field)



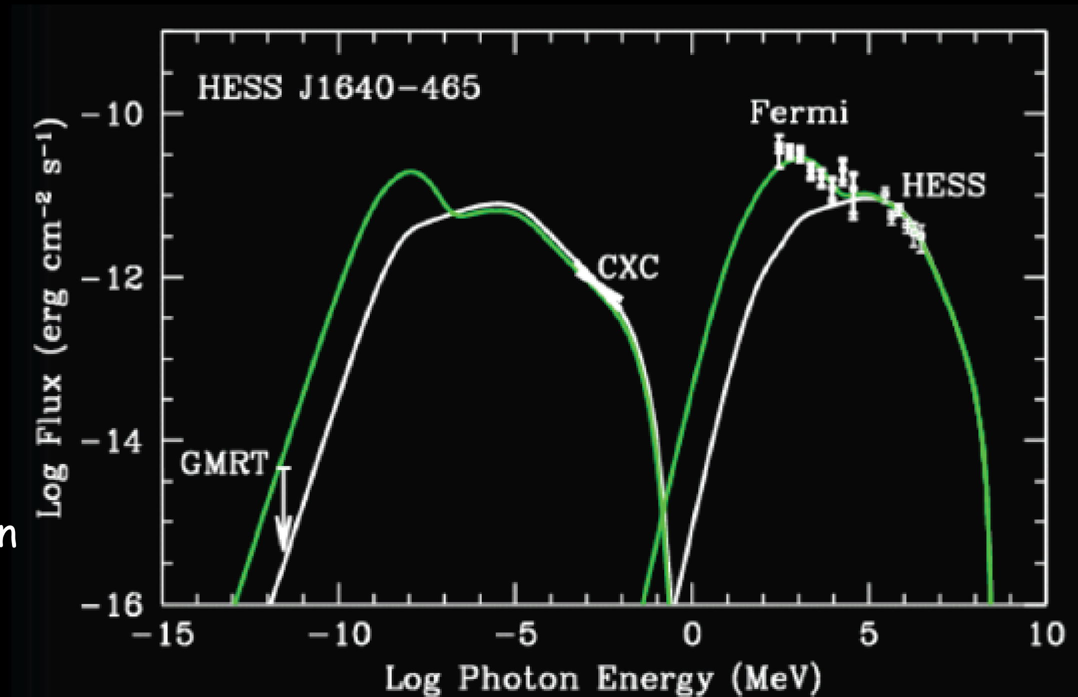


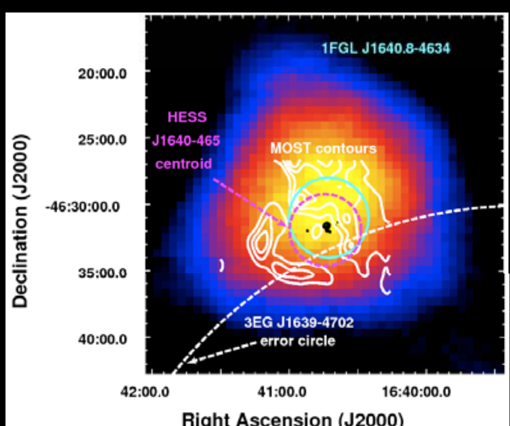
The latest HESS J1640-465

(Slane et al., 2010, ApJ, 726)



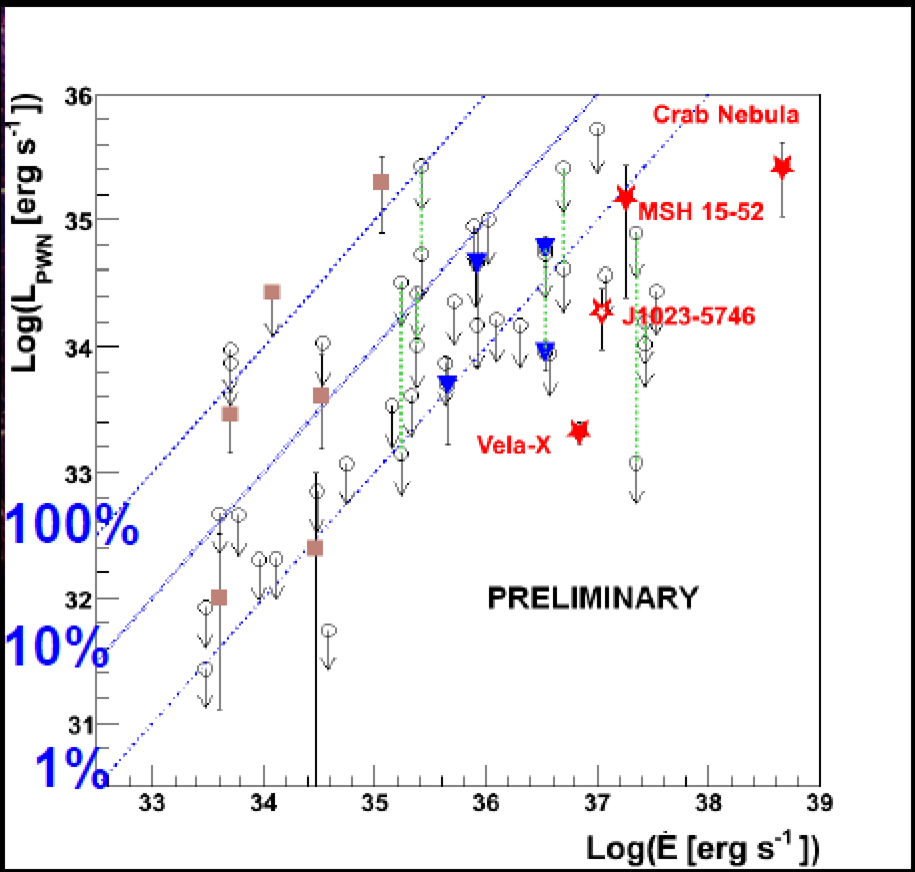
PWN model with evolved power law electron spectrum fits X-ray and TeV emission
- Fermi emission falls well above model





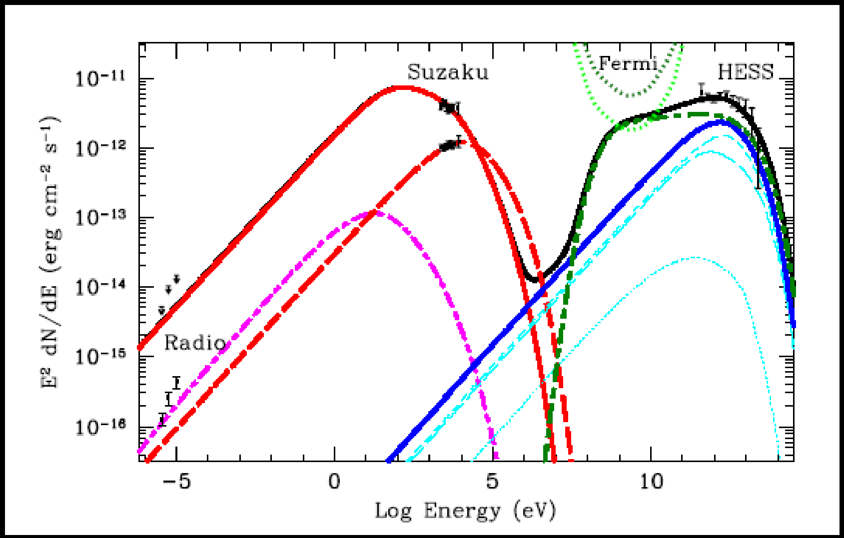
Modifying low-energy electron spectrum by adding Maxwellian produces GeV emission through inverse Compton scattering:
- primary contribution is from IR from dust (similar to Vela X)
- mean energy ($\gamma=10^5$) and fraction in power law (~4%) consistent w/ particle acceleration model

Is it time for a HE PWNe Catalog?



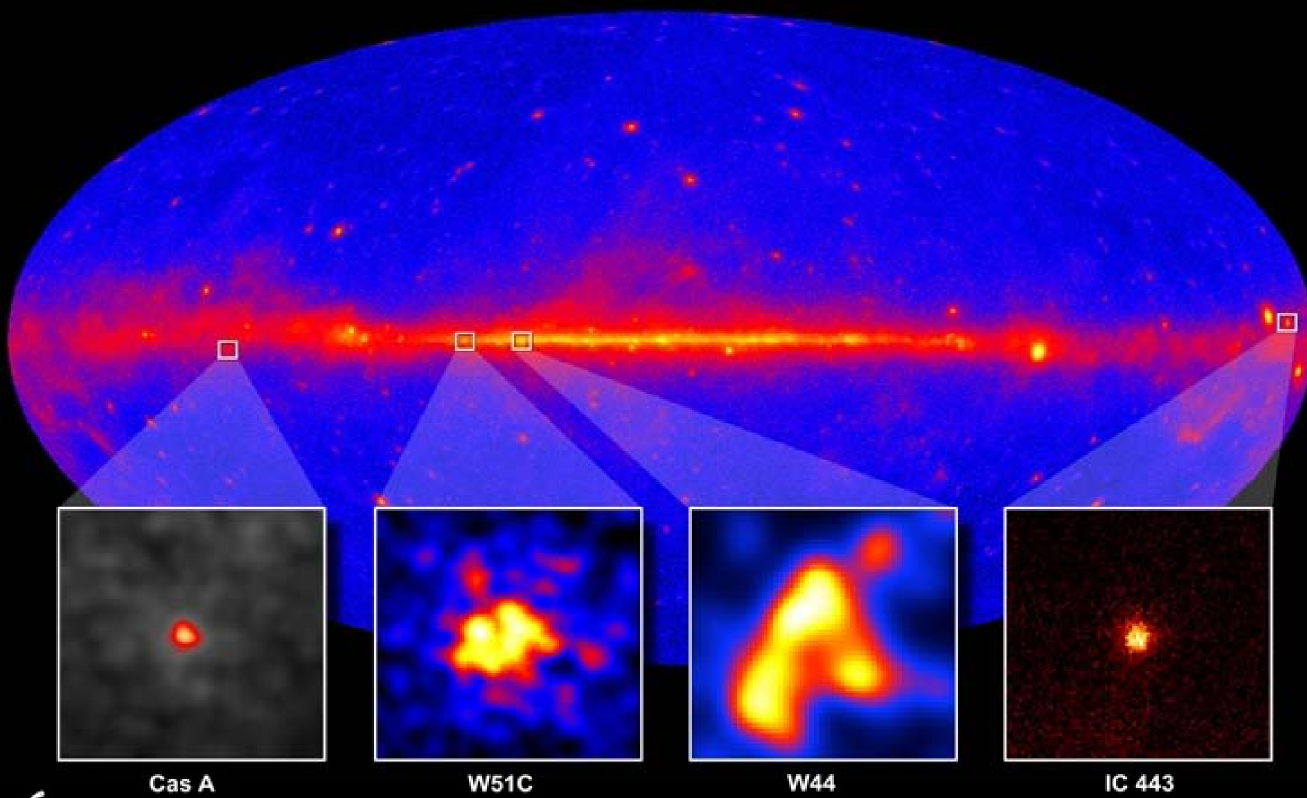
Lemoine-Goumard, COSPAR 2010

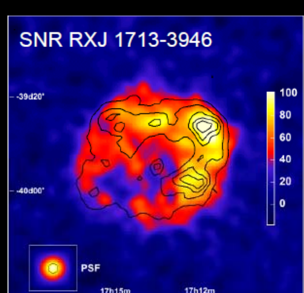
- low gamma-ray efficiency in the Fermi-LAT energy range
- Lack of detection of several Vela-like Pulsars (e.g. J1418-6058) suggest that these spectra have a low energy turn-over as expected from IC scattering off an electron spectrum of index ~2.3

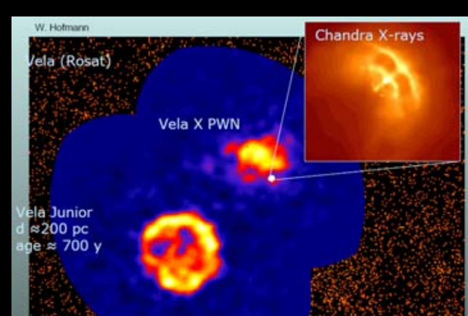


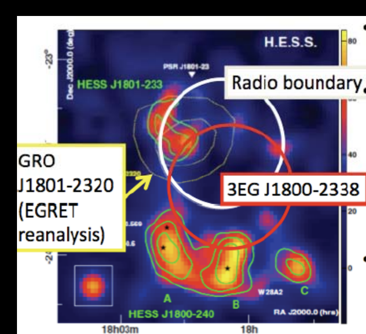
Van Etten, Romani arxiv.org/abs/1001.4807v1

High Energy SNRs







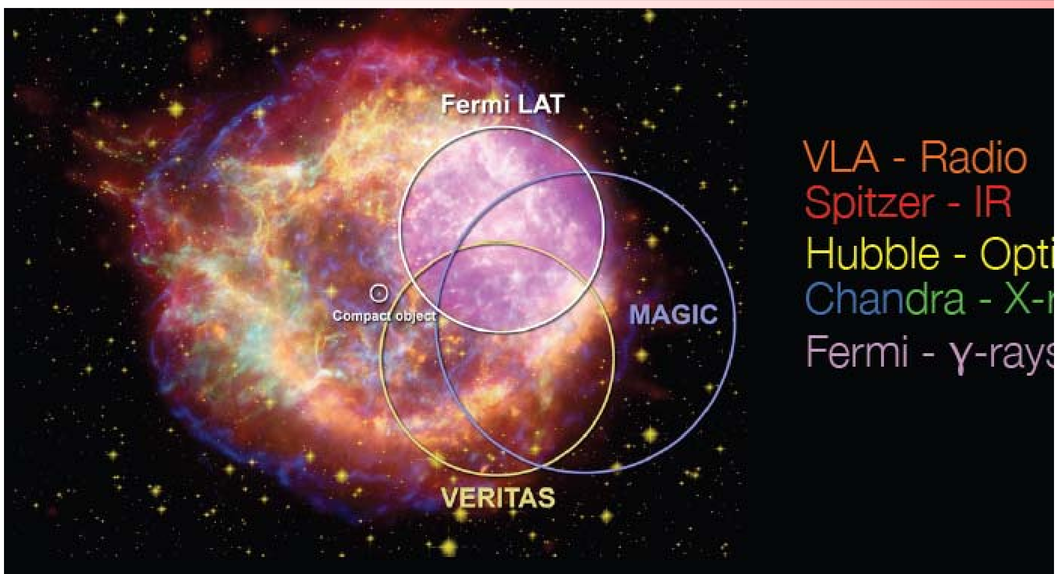


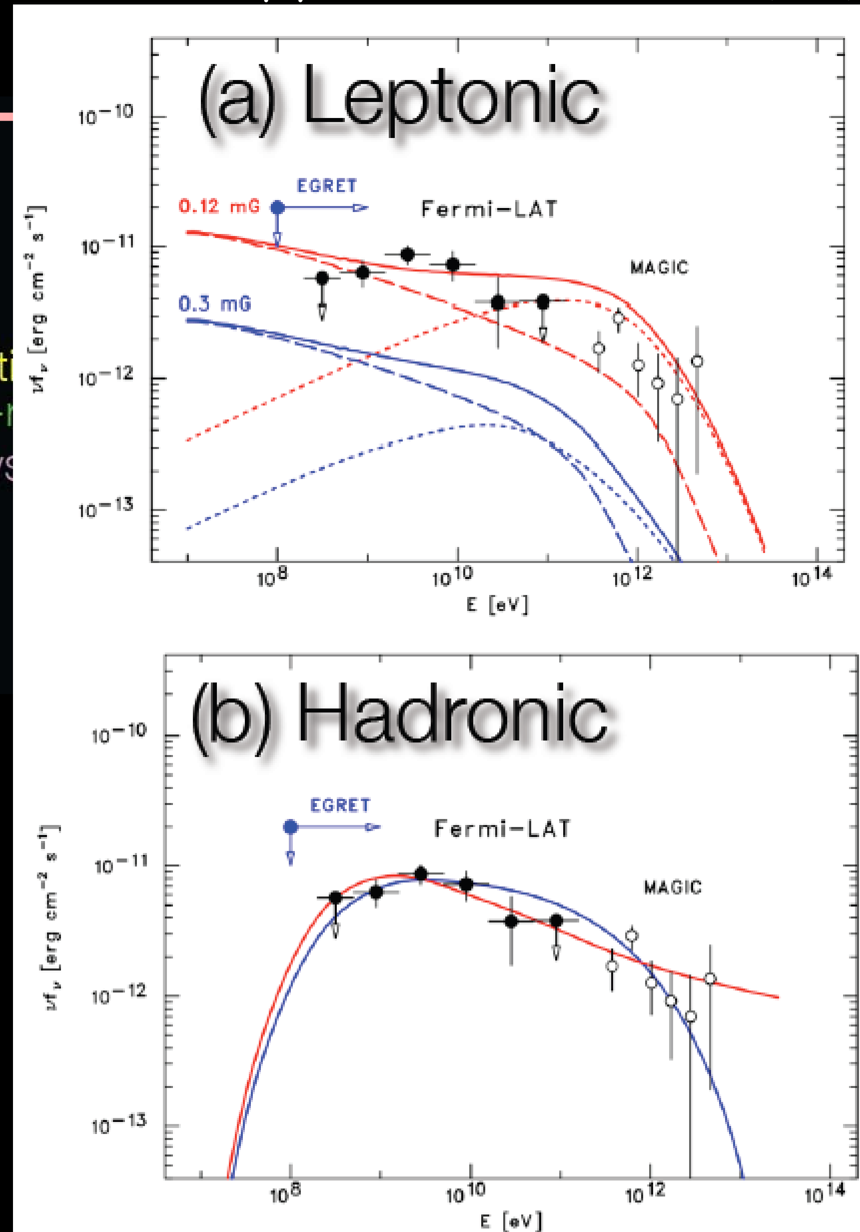
Fermi-detected SNRs (1yr)

Object	Diameter	Age	Cloud Interaction	L_γ 1-100 GeV
Cas A	5 pc	330 yr	No	4×10^{34} erg/s
W49B	10 pc	~3000 yr	Yes	9×10^{35} erg/s
3C 391	15 pc	~6000 yr	Yes	6×10^{34} erg/s
G349.7+0.2	17 pc	~6000 yr	Yes	9×10^{34} erg/s
IC 443	20 pc	~10000 yr	Yes	8×10^{34} erg/s
W44	25 pc	~10000 yr	Yes	3×10^{35} erg/s
W28	28 pc	~10000 yr	Yes	9×10^{34} erg/s
CTB 37A	50 pc	~20000 yr	Yes	9×10^{34} erg/s
G8.7-0.1	63 pc	~30000 yr	Yes	8×10^{34} erg/s
W51C	76 pc	~30000 yr	Yes	8×10^{35} erg/s

CasA

The Astrophysical Journal Letters 710, L92 (2010)

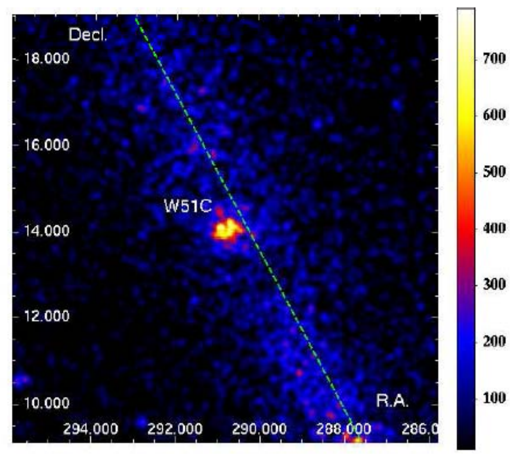


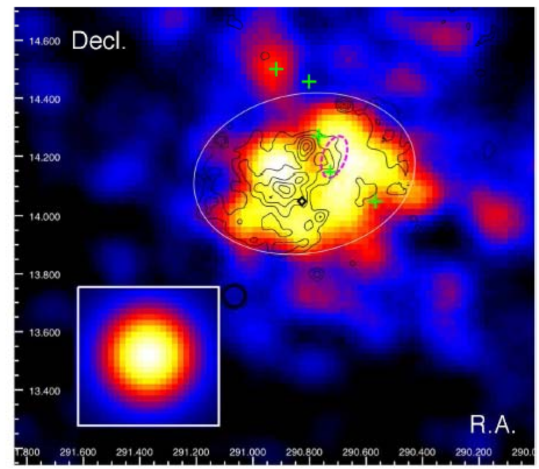


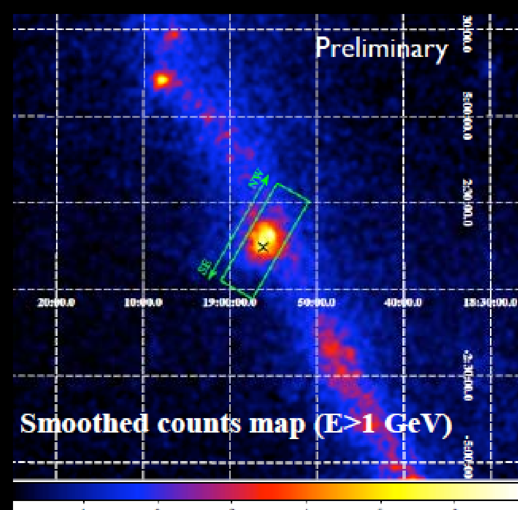
Leptonic scenario (Brems + IC):
B = 0.12 mG
– CR eletrons: We=1×10^{49} erg
• Hadronic scenario (π^0 decay):
B > 0.12 mG
Good fit with proton spectral index ~2.3 (red) or ~2.1 (blue) with cut-off at 10 GeV
– Total proton content: Wp=3×10^{49} erg

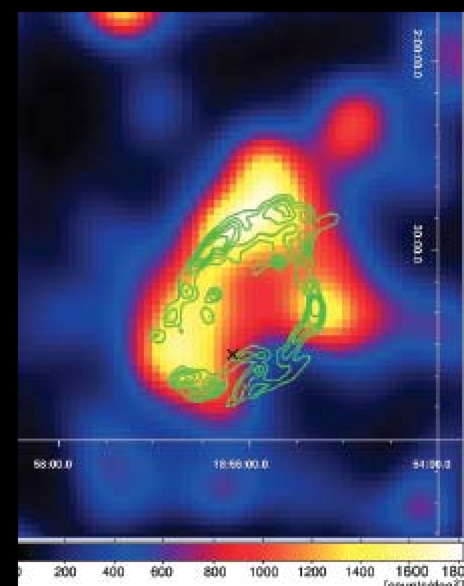
W51C* & W44**: Morpholgy and…

- Ages: 3 000 ÷ 50 000 years
- Interaction with molecular clouds can act as target material for π^0 production
- Typically rather steep (compared to young remnants)
- Rollover or break in proton spectrum at ~10GeV/c
- Extremely luminous (W51C: 10^{36} erg/s at 6 kpc)
- Detection of remnants interaction with clouds favours p+





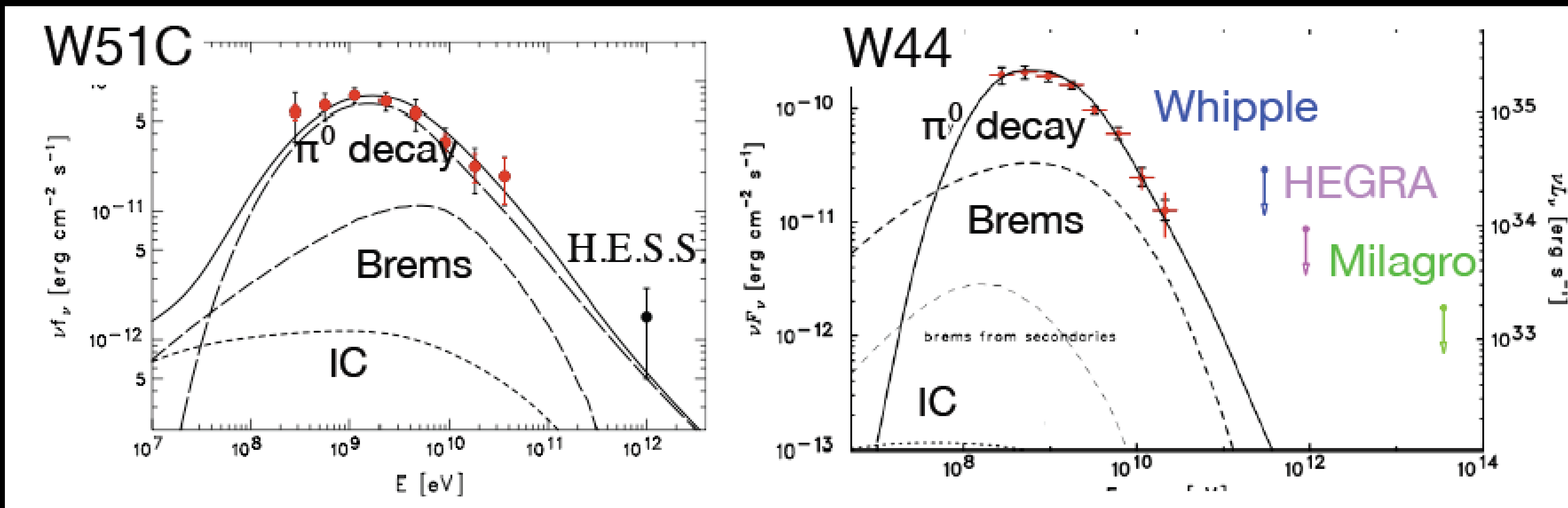




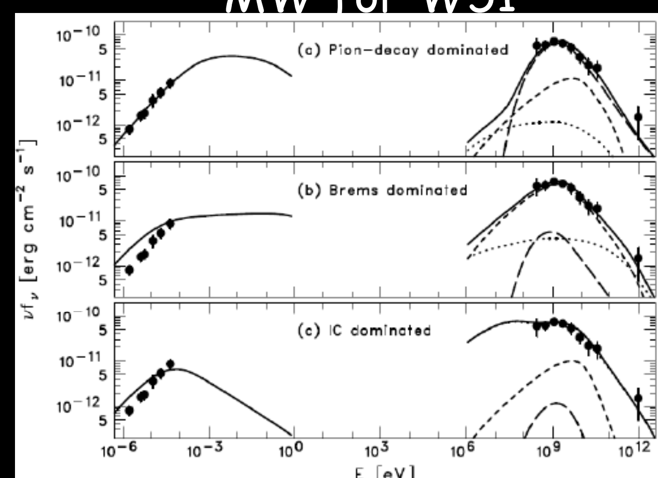
*Abdo et al., 2009, ApJ, 706, L1

** Abdo et al. *Science* 26 Febrary 2010 pp. 1103 - 1106

…spectra



MW for W51



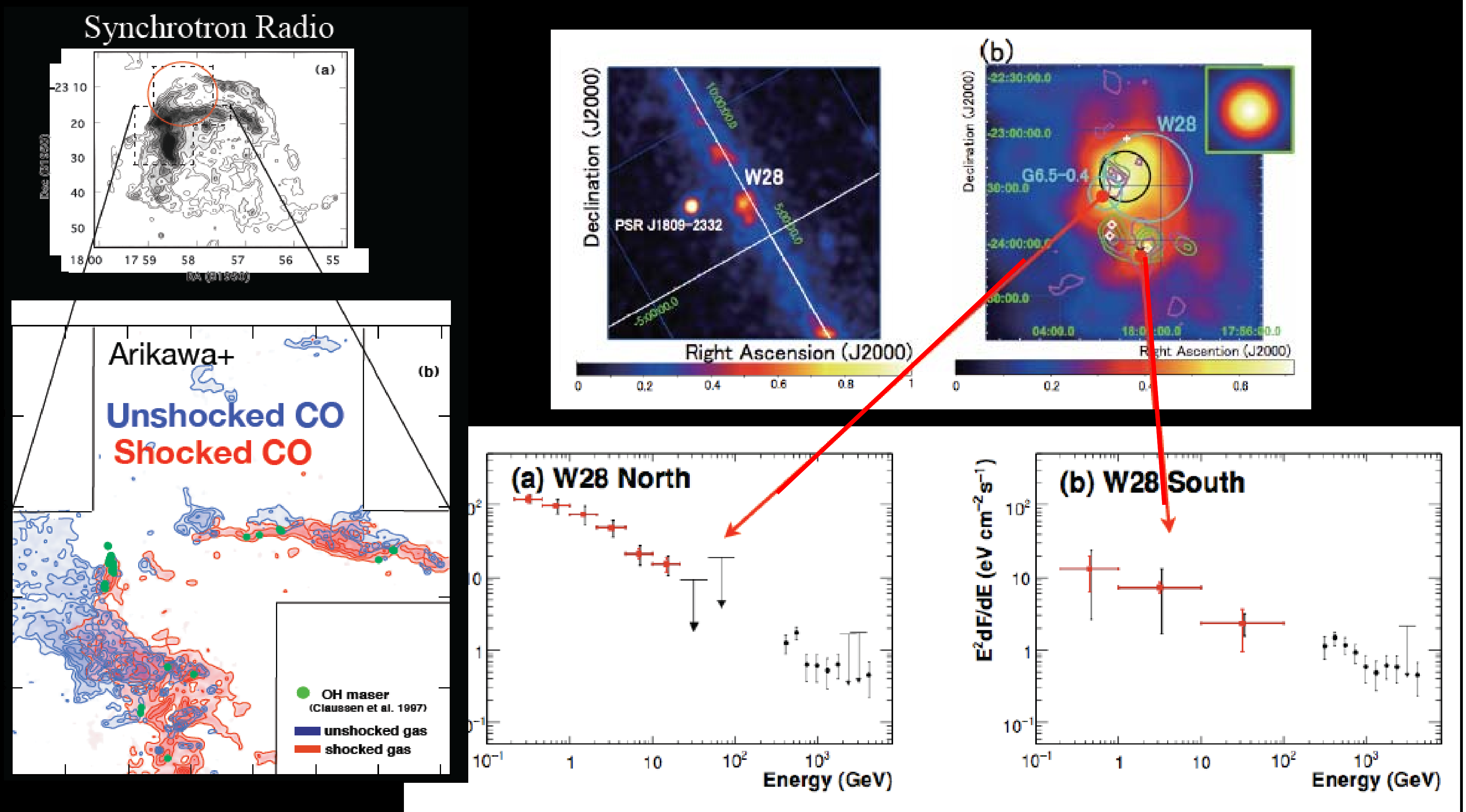
Leptonic models need large electron/proton ratios; piondecay is favoured

Brems: hard to reproduce the radio synchrotron spectrum => less likely but not fully excluded

IC: very large energy content in electrons and very low density => very unlikely

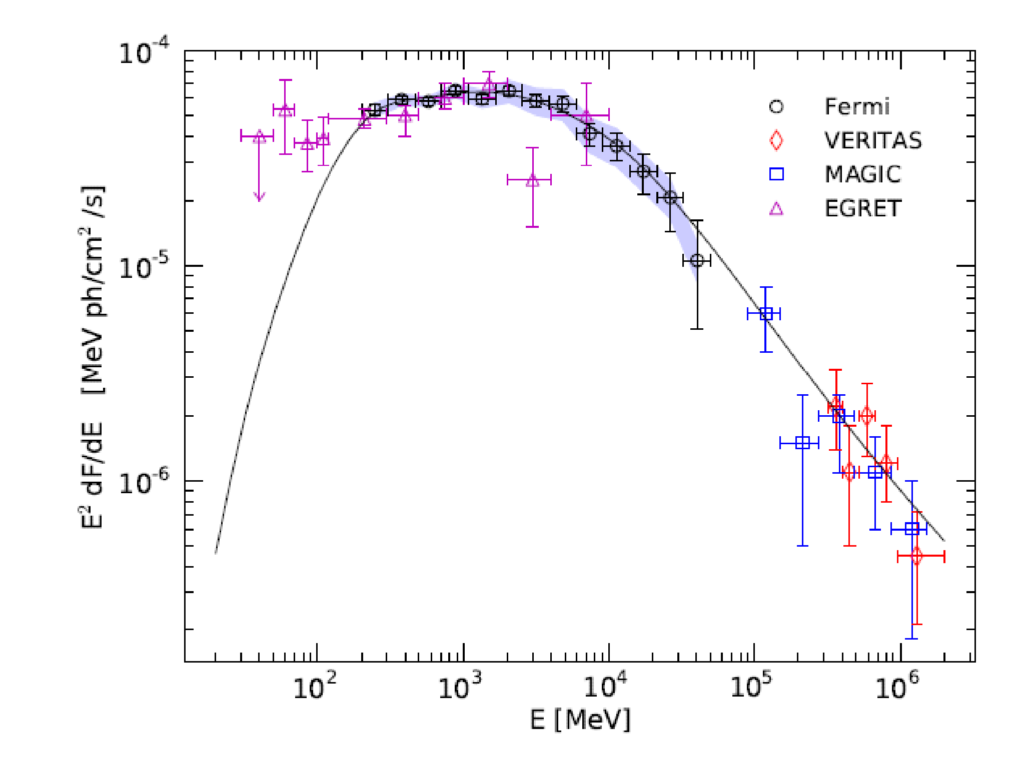
The W28 Case

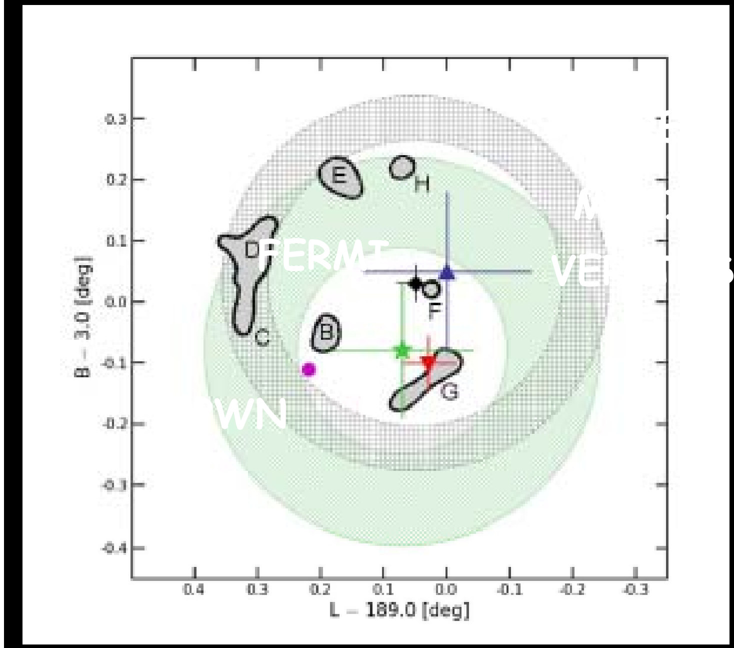
A. A. Abdo *et al* 2010 *ApJ* ,**718**, 348



The IC443 complex

Abdo et al., 2010, ApJ, 712, 459





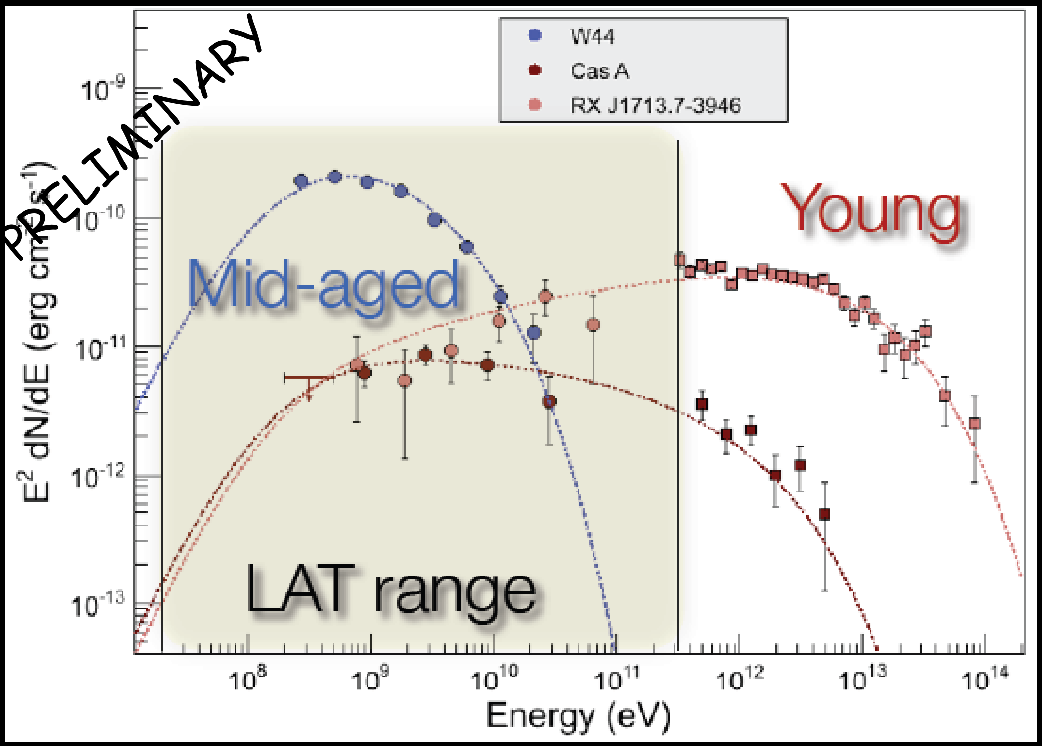
•Electron bremsstrahlung can hardly explain the observed IC 443 gamma-ray emissivity

•In a hadronic scenario, pion-producing proton population with a broken power-law spectrum well fit the data

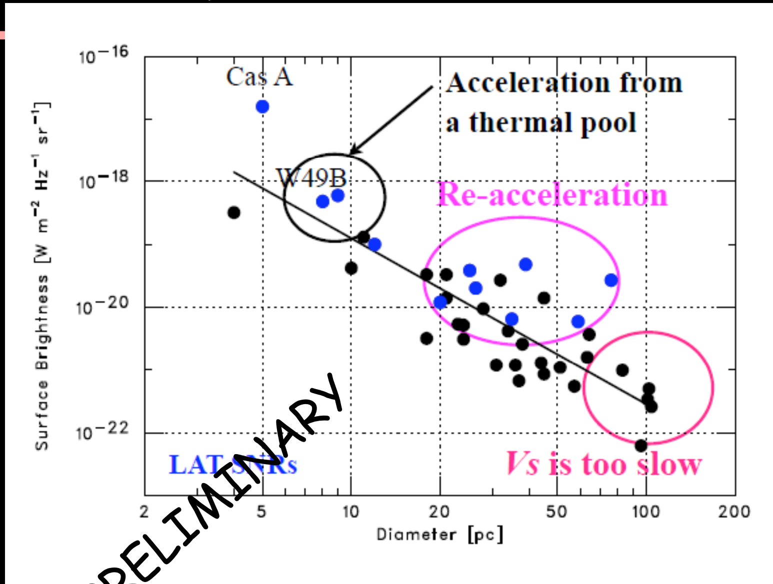
•The bremsstrahlung likely makes a non-negligible contribution below E = 200 MeV where the EGRET data points exceed the best-fit pionic spectrum

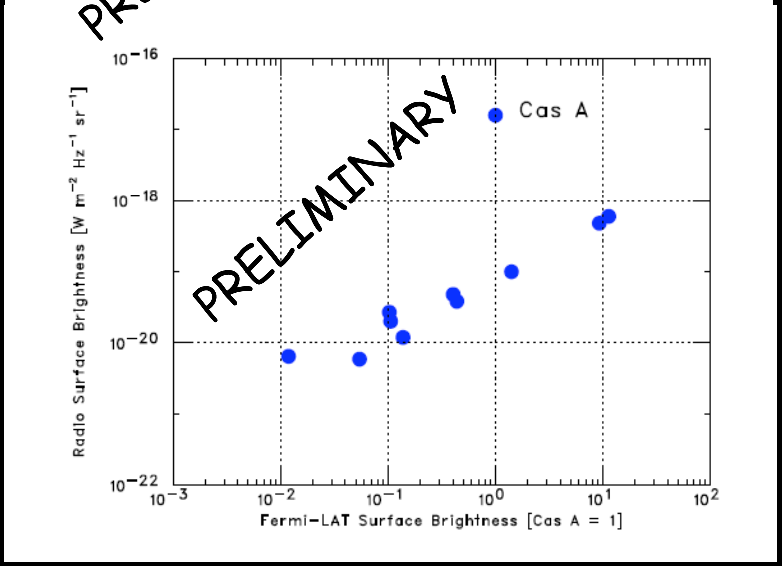
A unique scenario for γ-emitting SNRs?

Uchiyama et al. 2010 arXiv:1008.1840v1



S.Funk HEAD 2010





- may probe **how** particles are accelerated
- and later released in the Galaxy

Conclusions

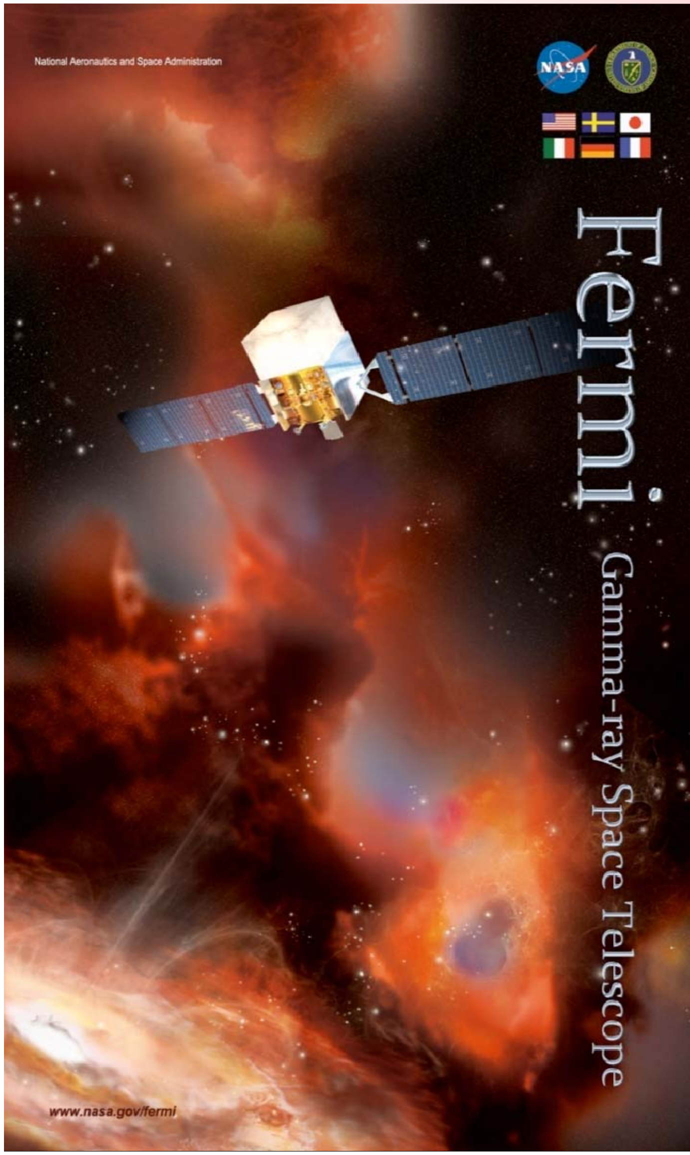
PWNe and SNRs are HE gamma-ray sources

More informations is being added in the comprehension of acceleration mechanisms and sites

Some PWNe and SNRs have been and many others are being detected in different evolutionary stages and in different environments

Stay tuned!!!

Fermi
Gamma-ray
Space Telescope



Thanks for your attention!

Cosmic ray content in SNRs

	Cas A	RX J1713.7 -3946	IC443	W44	W51C
Age (kyears)	0.3	2	10	20	30
$n_{average}$ (cm-3)	10	0.1	10	100	10
$CR_{fraction}$	2%	50%	25%	5%	10%

- Can now start to determine the CR content in SNRs
- Significant fraction of the explosion energy (uncertainty by factor of a few)

Fermi Gamma-ray Space Telescope

Before results… a bit of Analysis

• Gamma-ray Pulsars are everywhere !!!
One can use only the unpulsed signal to analyse most of these sources => we keep only ~1/3 of the signal for analyses such as Crab, Vela-X…

• SNR & PWN are steady sources: we don't have the variability as an identification tool (as for AGNs) and no timing information (as for Pulsars)

• SNR & PWN are predominantly located in the Galactic Plane => contamination from the Galactic diffuse background

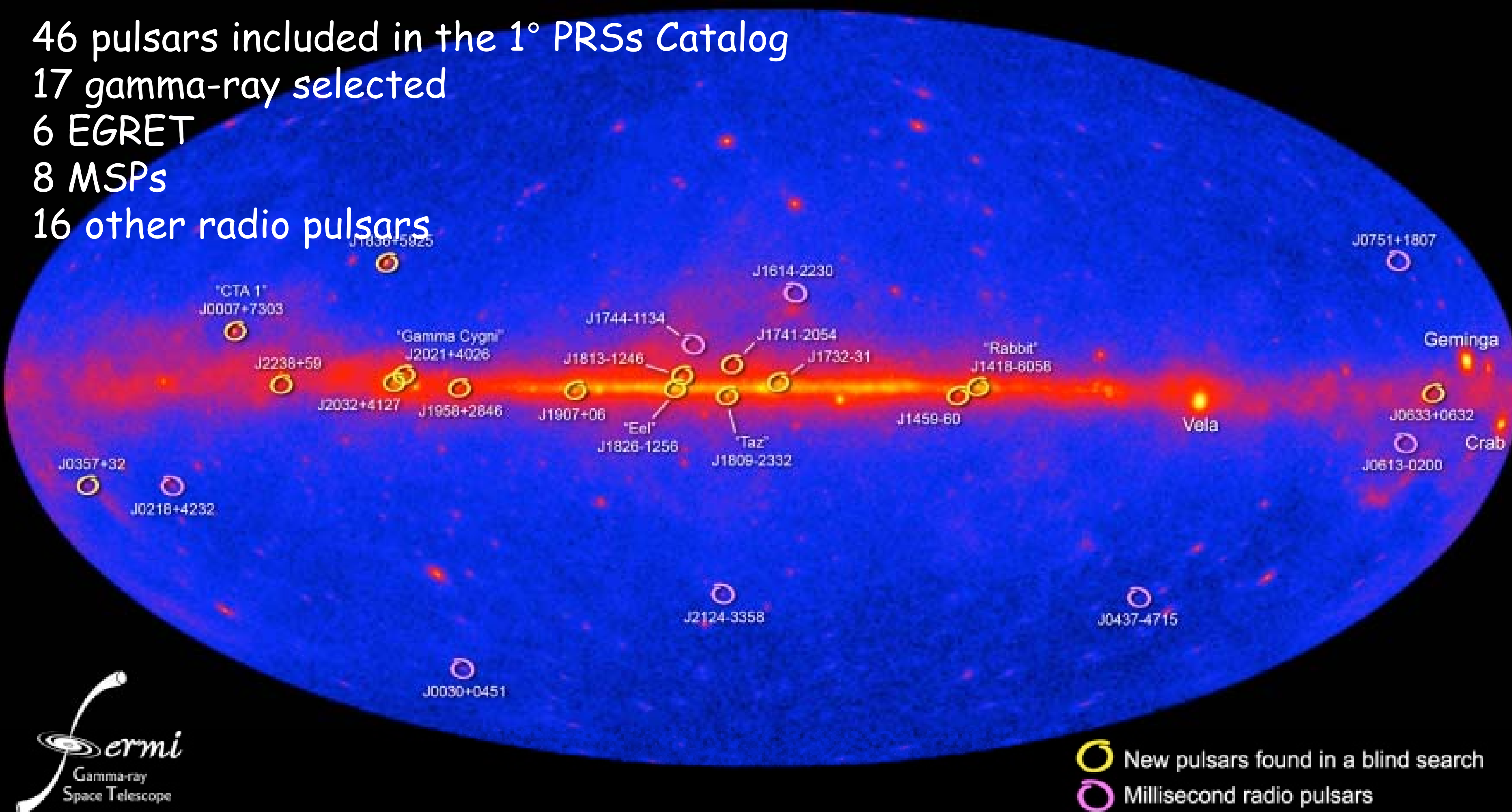
• SNR & PWN can be extended sources (W44, Vela-X…): gamma-ray photons are spread over larger regions which render the analysis and identification with a potential counterpart very hard (and even more in the Galactic plane !)

It is not an easy job… but there's a lot of fun!!!

We can not - not start from pulsars…

Abdo et al. 2010, ApJS, **187**, **460**

46 pulsars included in the 1° PRSs Catalog
17 gamma-ray selected
6 EGRET
8 MSPs
16 other radio pulsars



Vela PWN: energy spectrum and models