



Fermi
Gamma-ray Space Telescope

Recent detections of TeV Pulsar Wind Nebulae with the Fermi-Large Area Telescope

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&

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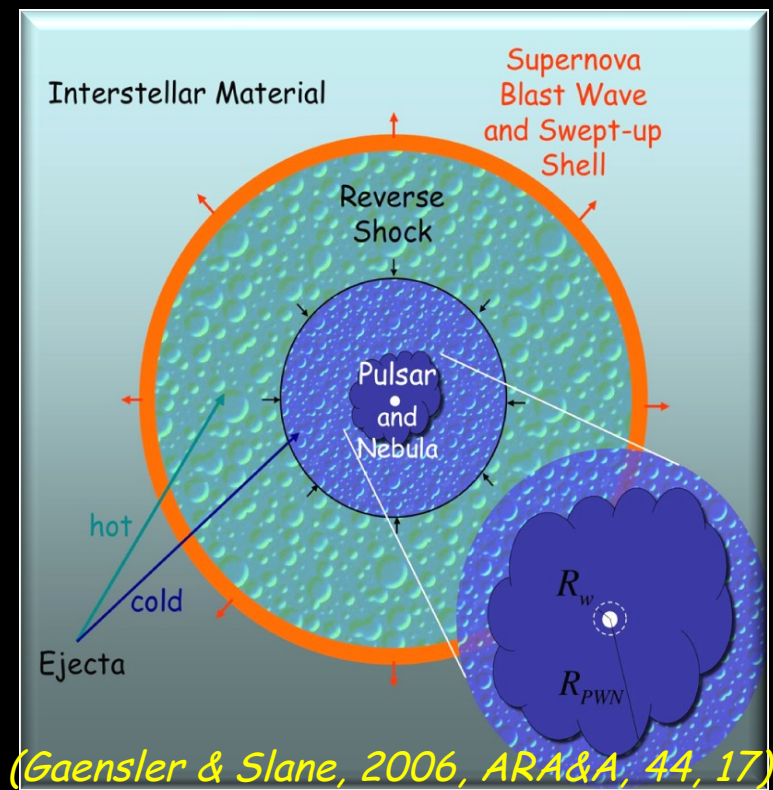
CENBG, Bordeaux (France)

*on behalf of the
Fermi-LAT Collaboration &
the Pulsar Timing Consortium*

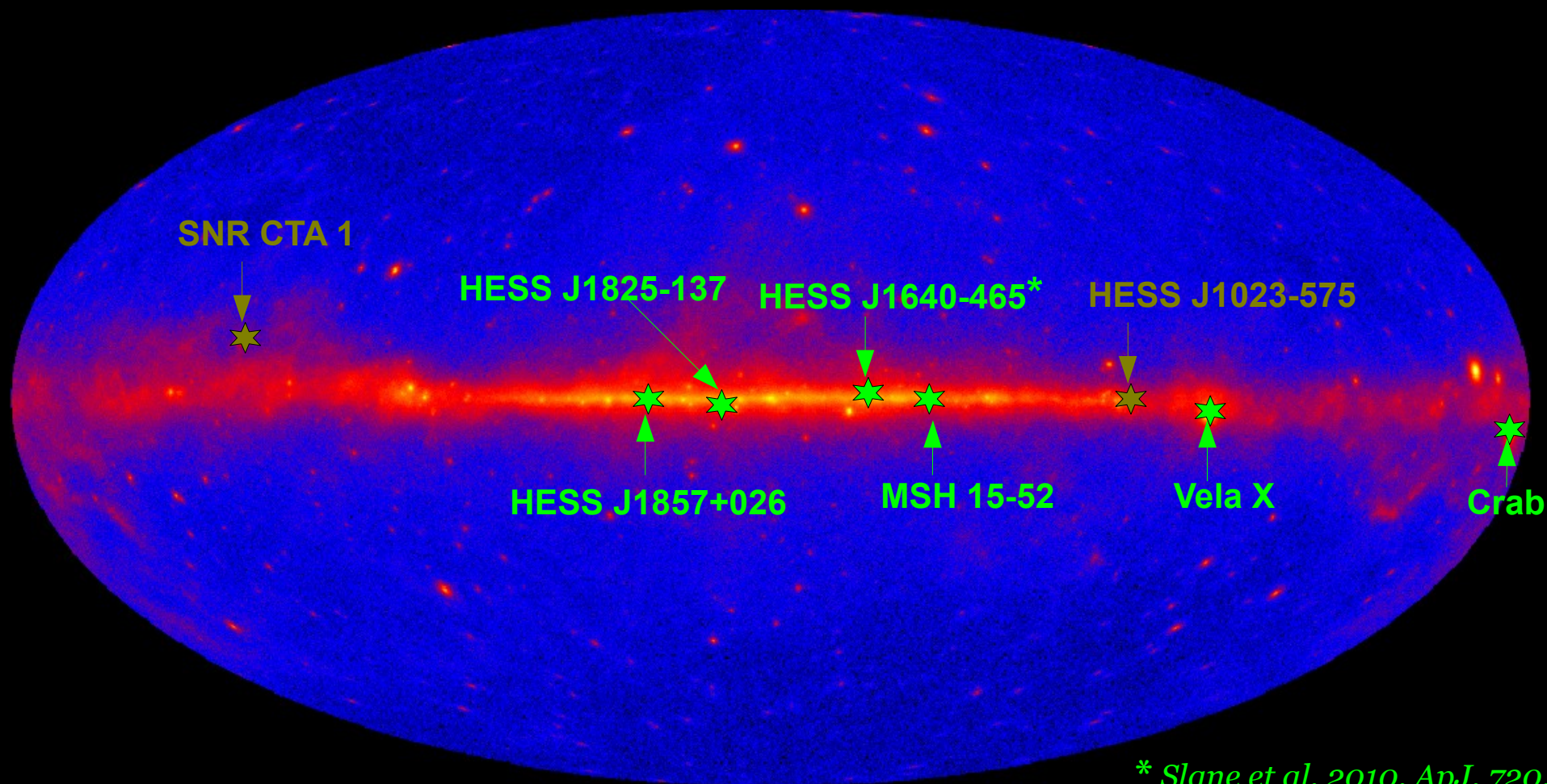
***Fermi Symposium 2011
(Roma, Italy, 12 May 2011)***

Pulsar Wind Nebulae

- ◆ *Relativistic particles (e^\pm) injected by the central pulsar*
 - ◆ *Ejecta of the supernova swept up*
 - ◆ *Flow decelerated by the shock*
 - ◆ *Particle are accelerated at the shock (Diffusive Shock Acceleration, Resonant cyclotron absorption, etc.) and radiate*
-
- ◆ *Observations of PWNe in γ -rays*
 - *constraints on the nature (leptonic/hadronic) of the radiation processes responsible for the high energy component of the photon spectrum*
 - ◆ *Multi-wavelength observations of PWNe & spectral modeling*
 - *constraints on the physical properties of the sources (magnetic field, injection spectrum of the particles, etc.)*



Fermi detections of TeV PWNe



See talk by P. Slane

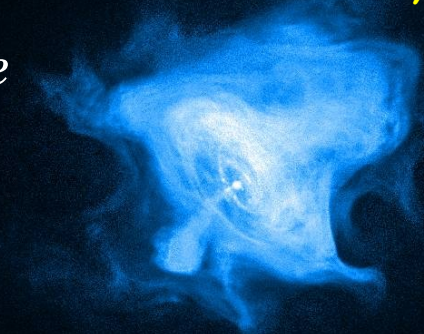
Fermi LAT counts map

(front events above 200 MeV, back events above 400 MeV,
24 months of survey data)

The Crab Nebula

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

X-rays



- ◆ Powered by the *energetic Crab Pulsar* (PSR B0531+21)
- ◆ *Significant emission* in the off-pulse of the Crab Pulsar light curve
- ◆ *Flux* above 100 MeV of $(9.8 \pm 0.7 \pm 1.0) \times 10^{-7} \text{ cm}^{-2} \text{ s}^{-1}$
- ◆ *Spectrum* can be modeled with the sum of *two power-laws* :

◆ Synchrotron:

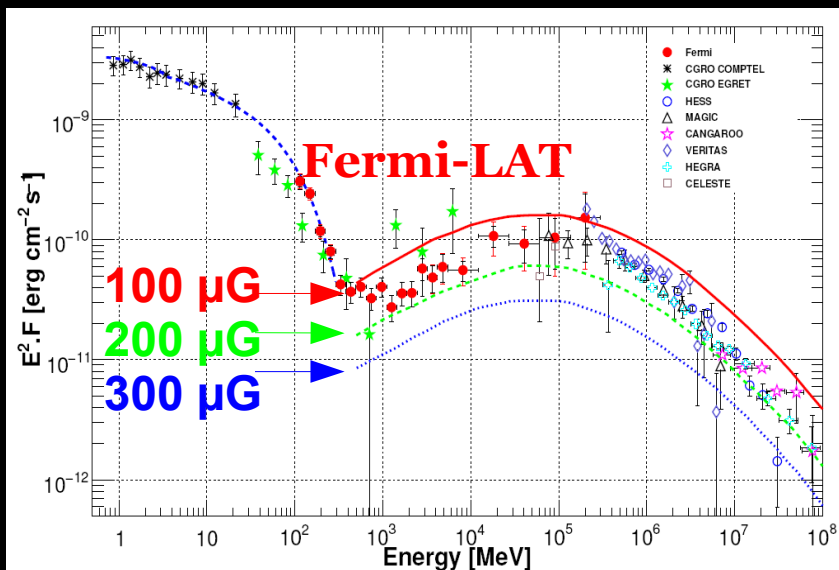
$$\Gamma_{\text{sync}} = (3.99 \pm 0.12 \pm 0.08)$$

◆ Inverse Compton :

$$\Gamma_{\text{IC}} = (1.64 \pm 0.05 \pm 0.07)$$

- ◆ Using predictions of *Atoyan & Aharonian* (1996, MNRAS, 278, 525)

→ *constraints on the magnetic field* : $100 < B < 200 \mu\text{G}$, *beyond the equipartition field in the Crab nebula, 300 μG*



Gamma-ray spectrum of the Crab Nebula

- ◆ *Recent flares of the synchrotron component* (Oct. 2007, Feb. 2009, Sept. 2010, Apr. 2011) :
- ◆ *Emission comes from a region very close to the pulsar*
(Abdo et al., 2011, Science, 331, 739)

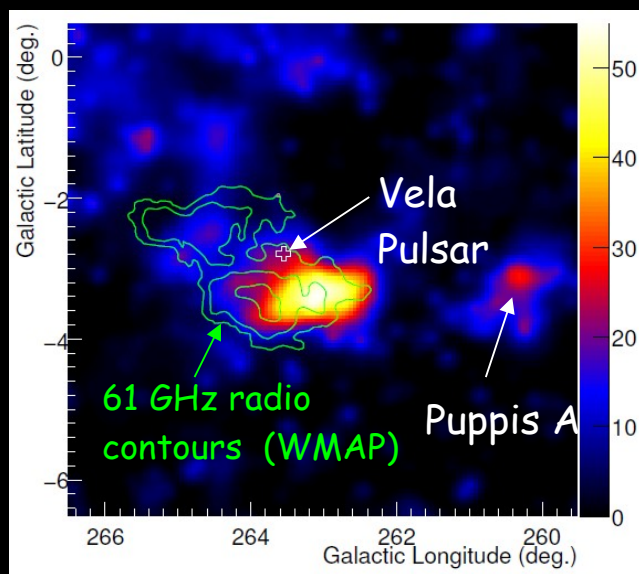
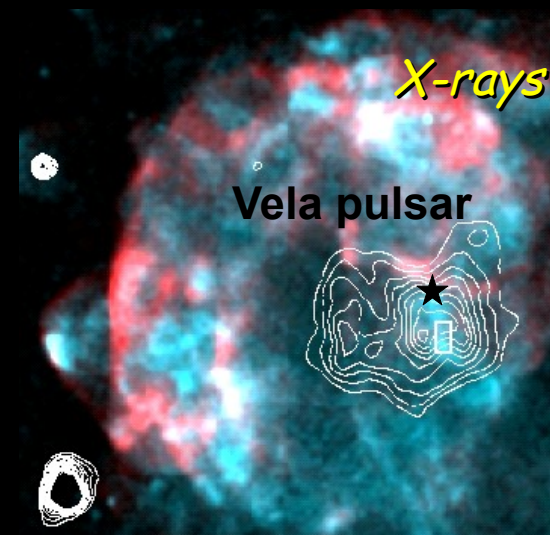
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Roma (Italy)

See talks by R. Buehler,
W. Bednarek &
C. Wilson-Hodge
+ poster by E. Hays

Vela X

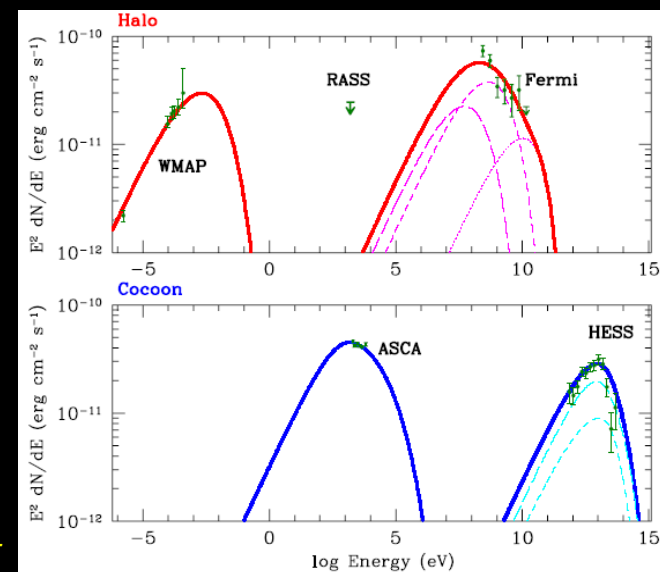
(Abdo et al., 2010, ApJ, 713, 146)

- ◆ Associated with the Vela Pulsar ($d = 290$ pc)
- ◆ Significant γ -ray emission in the off-pulse of the Vela Pulsar
 - ◆ Spatially correlated with the Vela-X halo (seen in radio)
 - ◆ Significantly extended : $R_{\text{disk}} = 0.88^\circ \pm 0.12^\circ$
 - ◆ Soft spectrum in the $0.2 - 20$ GeV energy range:
 - ◆ Spectral index : $\Gamma = 2.41 \pm 0.09 \pm 0.15$
 - ◆ Flux above 100 MeV : $(4.73 \pm 0.63 \pm 1.32) \times 10^{-7} \text{ cm}^{-2} \text{ s}^{-1}$
- ◆ Multiwavelength spectrum :
 - ◆ strongly favors a *two-component leptonic model* (as suggested by de Jager et al., 2008, ApJ, 689, L125) : one young population for the X-ray/VHE-peak cocoon & a relic one for the radio/MeV-peak halo.



Left : TS map of the off-pulse window above 800 MeV.

Right : Multi-wavelength spectrum of Vela X

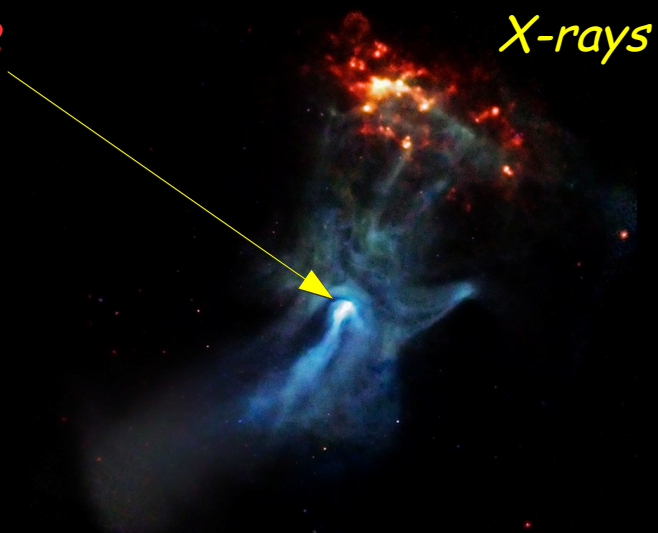


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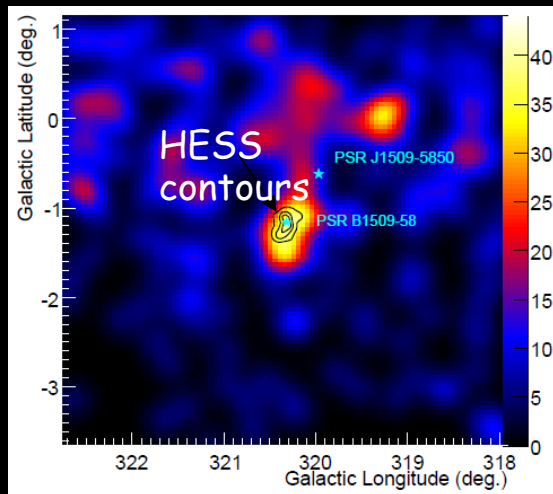
MSH 15-52

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

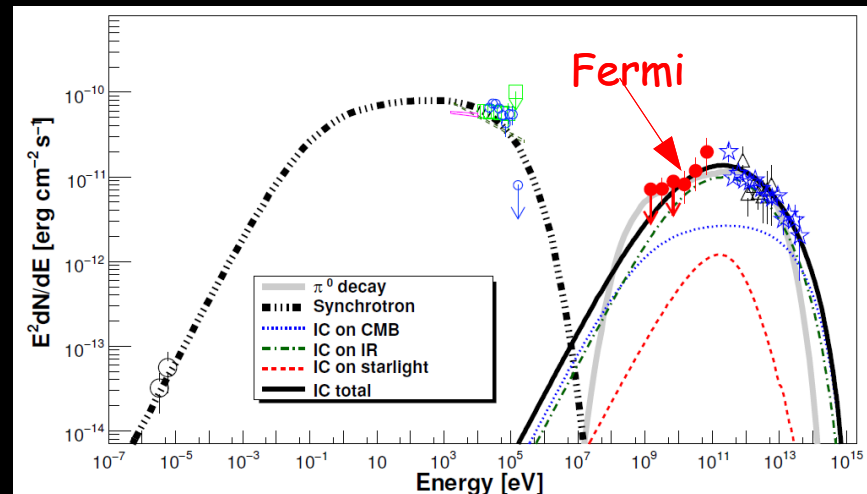
- ◆ young composite supernova remnant
- ◆ bright X-ray and TeV PWN powered by PSR B1509-58
(detected above 30 MeV) See talk by M. Pilia
- ◆ γ -ray emission spatially correlated with the PWN :
 - ◆ Significantly extended : $R_{\text{disk}} = (0.25 \pm 0.05)^\circ$
 - ◆ Hard spectrum observed above 1 GeV :
 - ◆ Flux above 1 GeV : $(2.91 \pm 0.79 \pm 1.35) 10^{-9} \text{ cm}^{-2} \text{ s}^{-1}$
 - ◆ Spectral index : $\Gamma = (1.57 \pm 0.17 \pm 0.13)$
- ◆ Multiwavelength spectrum :
 - ◆ hadronic scenario is disfavored (energetic point of view)
 - ◆ high energy emission explained by Inverse Compton scattering (FIR photon field)



Counts maps above 10 GeV



Spectral energy distribution of the MSH 15-52

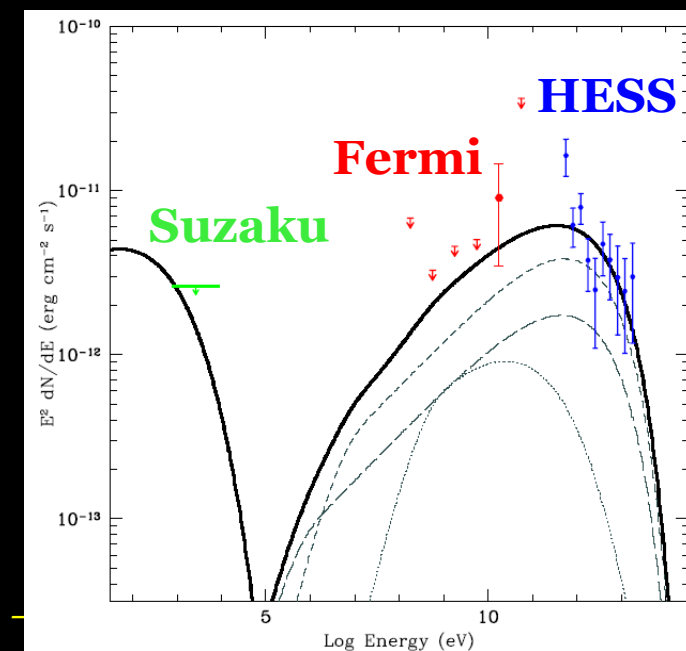
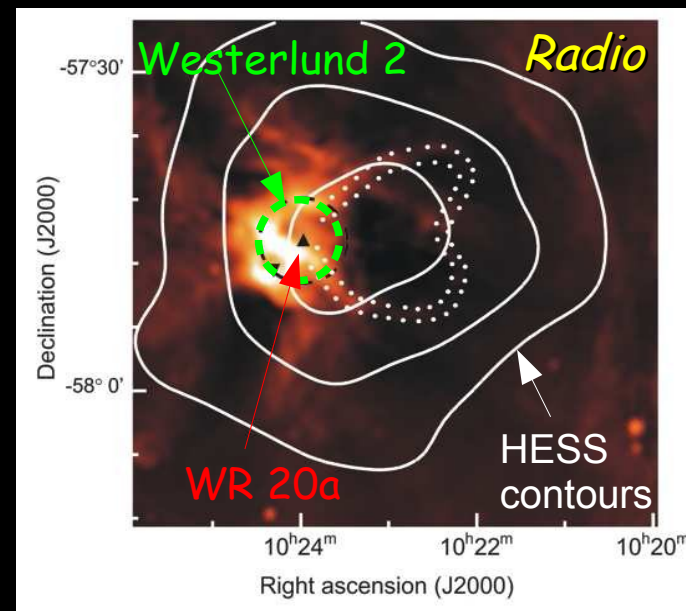


A PWN candidate in the region of Wd 2?

(Ackermann et al, 2011, ApJ, 726, 35)

- ◆ HESS J1023-575 : extended TeV source first associated with either the massive **WR binary system WR 20a** or the **young stellar cluster Wd 2**
- ◆ Fermi-LAT analysis of the **off-pulse of the γ -ray blind search pulsar PSR J1023-5746**
 - detection of a **significant emission above 10 GeV**:
 - ◆ spatially coincident with the energetic pulsar
 - ◆ spatially coincident with the TeV source
 - ◆ characterized by a hard spectrum
- ◆ PSR J1023-5746 is young and energetic (spin-down power of $\sim 10^{37}$ erg/s)
- ◆ The TeV source is extended

→ These elements strongly point towards an **identification of the GeV off-pulse emission and the TeV source as the PWN powered by the young pulsar PSR J1023-5746.**



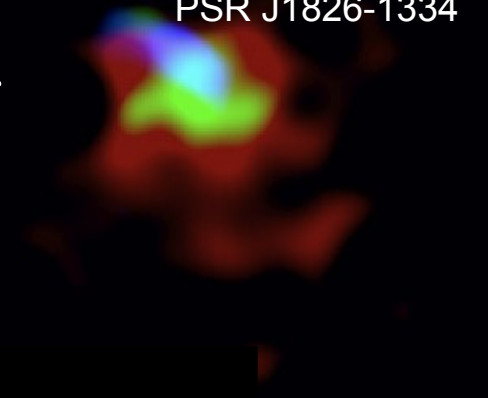
HESS J1825-137

(Grondin et al, 2011, ApJ, submitted)

VHE γ -rays

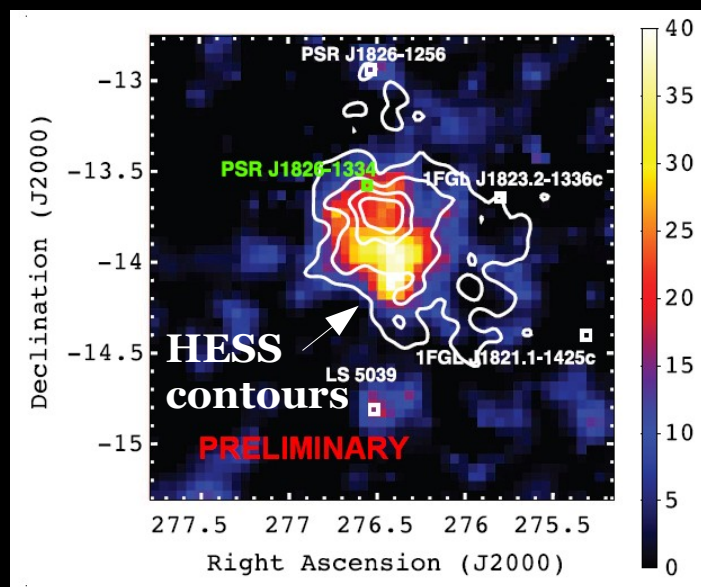


PSR J1826-1334

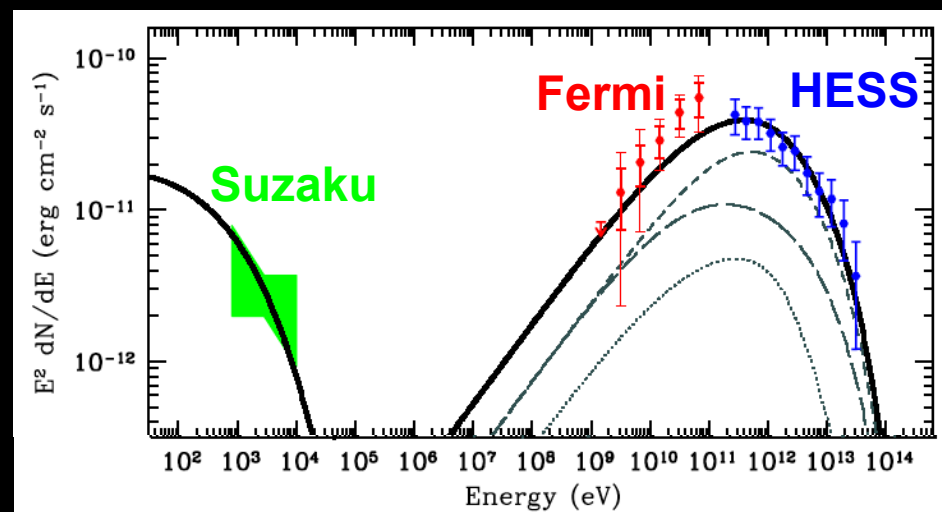


- ◆ Discovered during the H.E.S.S. Galactic Plane Survey
- ◆ **Energy-dependent morphology** at VHE due to **cooling mechanisms** (Aharonian et al, 2006, A&A 460, 365)
- ◆ **Fermi-LAT detection** ($\sim 10 \sigma$) of an **extended source** ($TS_{\text{ext}} \sim 8 \sigma$) :
 - ◆ Extension : $\sigma = 0.56^\circ \pm 0.07^\circ$ (for a Gaussian distribution)
 - ◆ Spatially coincident with the PWN HESS J1825-137
 - ◆ **Hard spectrum** modeled with a power-law (1 – 100 GeV) :
 - ◆ Flux (>1 GeV) : $(6.50 \pm 0.21 \pm 3.90) \times 10^{-9} \text{ cm}^{-2} \text{ s}^{-1}$
 - ◆ Spectral Index : $\Gamma = 1.38 \pm 0.12 \pm 0.16$
- ◆ Multiwavelength spectrum : favors a **leptonic injection** & implies a low magnetic field (3-4 μG)

Fermi LAT TS map above 10 GeV



Spectral energy distribution of HESS J1825-137



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HESS J1857+026

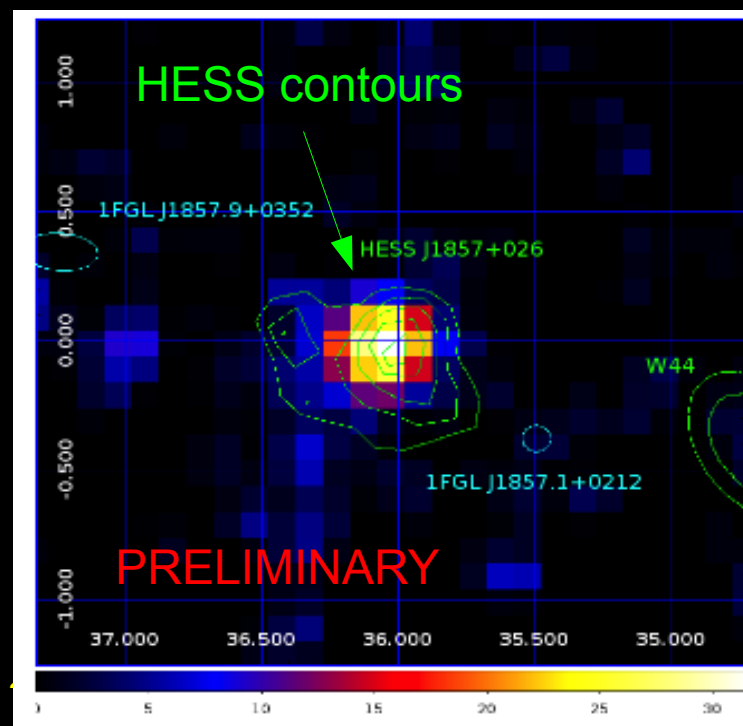
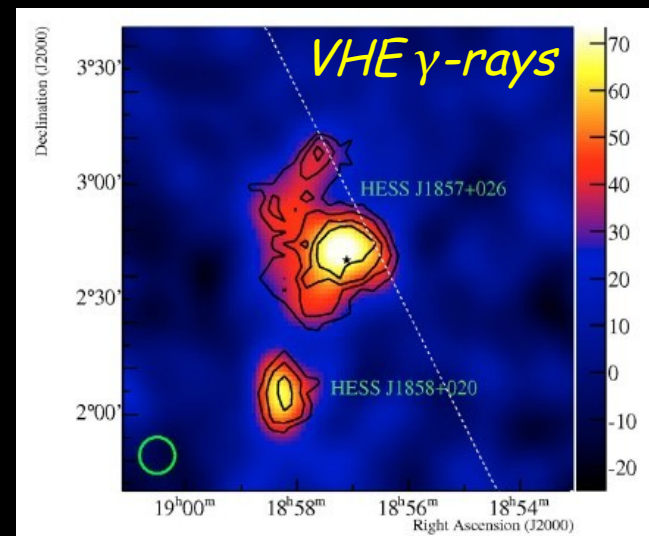
(Fermi collaboration, 2011, in preparation)

- ◆ Discovered during the HESS Galactic plane Survey
- ◆ Powered by the energetic radio-loud pulsar PSR J1856+0245
- ◆ Located close to SNR W44 (very bright source in the Fermi-LAT energy range)
- ◆ Fermi-LAT detection ($\sim 6\sigma$) :
 - ◆ Spatially correlated with the TeV source
 - ◆ No significant extension ($TS_{\text{ext}} < 4\sigma$)

See poster by
R. Rousseau

LAT TS Map above 10 GeV

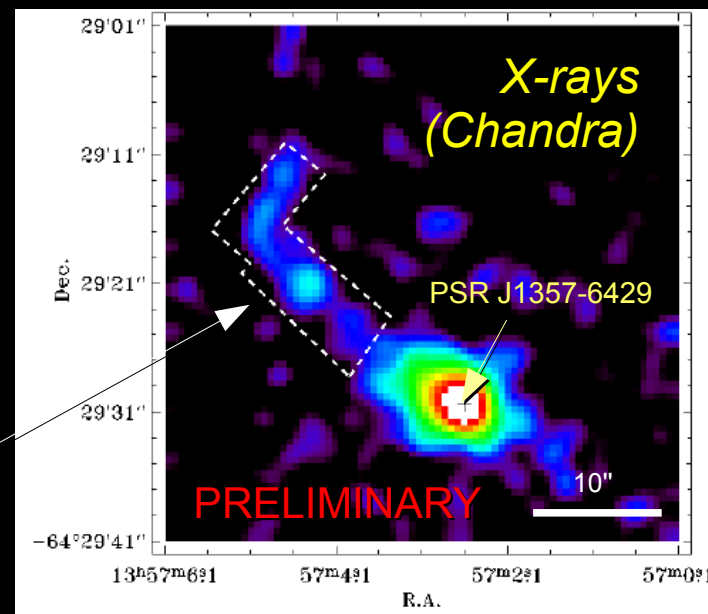
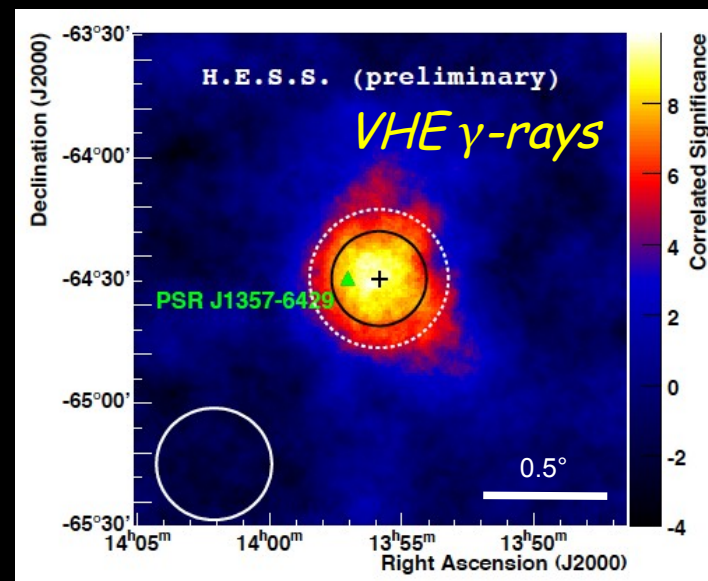
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Roma (Italy)



Observations of HESS J1356-645

(Lemoine-Goumard, Zavlin et al., 2011, A&A, in prep)

- ◆ Discovered during the HESS Galactic plane Survey
 - ◆ Detection of a significant (8.5σ) and **extended** ($\sigma=0.2^\circ$) source (Renaud et al, 2008, arXiv:0811:1559)
- ◆ **Associated to the young and energetic radio-loud pulsar PSR J1357-6429**
- ◆ High energy gamma-rays (Fermi-LAT) :
 - ◆ Significant **detection of PSR J1357-6429** (H-test value of 89.6)
 - ◆ **Upper limits on the PWN emission**
→ Constraints on the physical properties of the PWN (Abramowski et al, 2011, A&A, in prep)
- ◆ X-rays :
 - ◆ Detection of **pulsations** (XMM-Newton)
 - ◆ Detection of a **diffuse emission surrounding the pulsar** (Chandra)

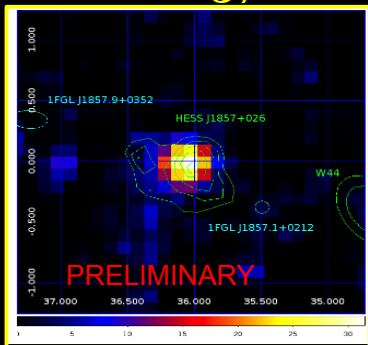


See talk by D. Smith &
poster by X. Hou

Summary

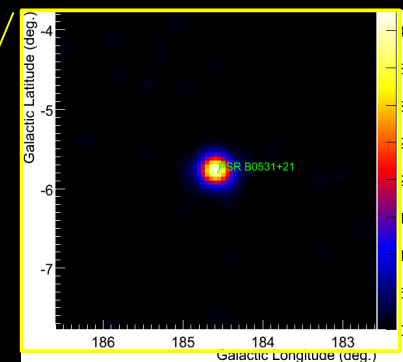
- ◆ 6 PWNe firmly identified by Fermi
- ◆ 2 PWN candidates coincident with the pulsar PSR J1023-5746 and the SNR CTA 1 + other candidates coincident with composite SNRs : MSH 11-62, MSH 15-56, etc.

HESS J1857+026



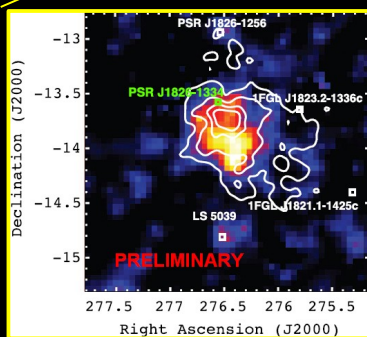
HESS J1023-575

Crab Nebula

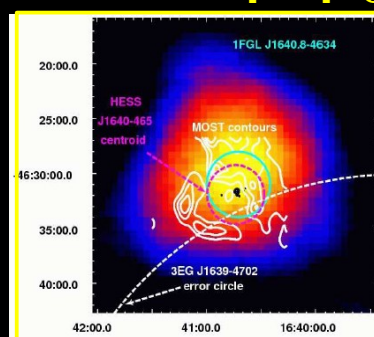


SNR CTA 1

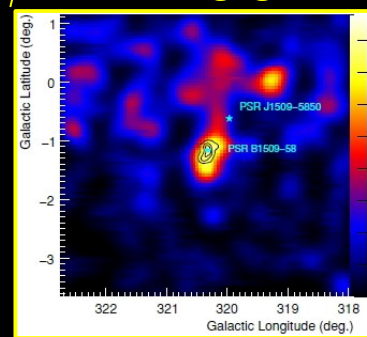
HESS J1825-137



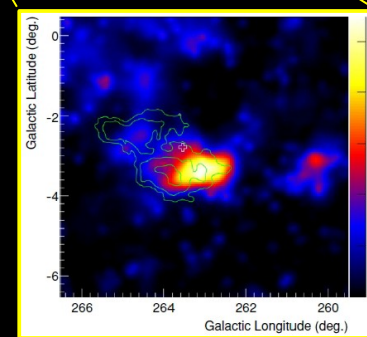
HESS J1640-465



MSH 15-52



Vela X



Population studies

(Ackermann et al, 2011, ApJ, 726, 35)

- ◆ In association with multi-frequency studies, Fermi provides *new constraints on the emission models and physical properties of the nebula* (magnetic field, injection spectrum, etc.)
- ◆ *Each PWN (or PWN candidate) detected by Fermi is associated to a TeV source*
- ◆ Population studies performed in the Fermi-LAT collaboration in the off-pulse windows of LAT pulsars
 - ◆ *Upper limits on the γ -ray emission of famous TeV PWNe such as Kookaburra & Rabbit, MGRO J1908+06, G21.5-0.9 (Ackermann et al, 2011, ApJ, 726, 35) and HESS J1356-645 (Lemoine-Goumard, Zavlin et al, 2011, A&A, in prep)*
 - ◆ Recent detection by Fermi & VERITAS of a *significant emission in the vicinity of the SNR CTA1*
→ PWN origin favored

See talk by B. McArthur & poster by K. Wood

→ Fermi detects PWNe powered by *bright and young Pulsars*

Gamma-ray
Efficiency

