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

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on behalf of the
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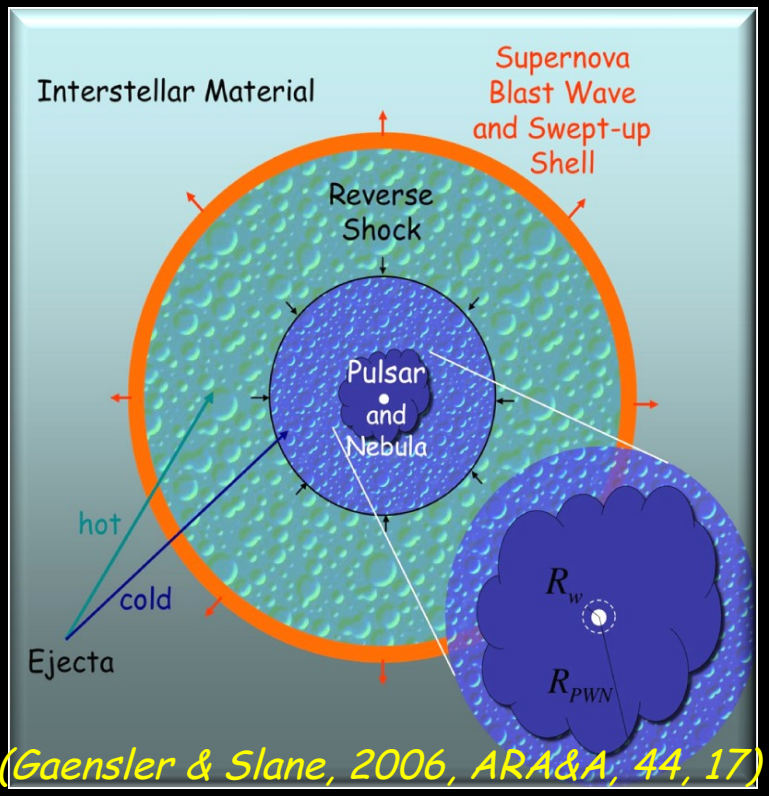
Pulsar Wind Nebulae

- *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*



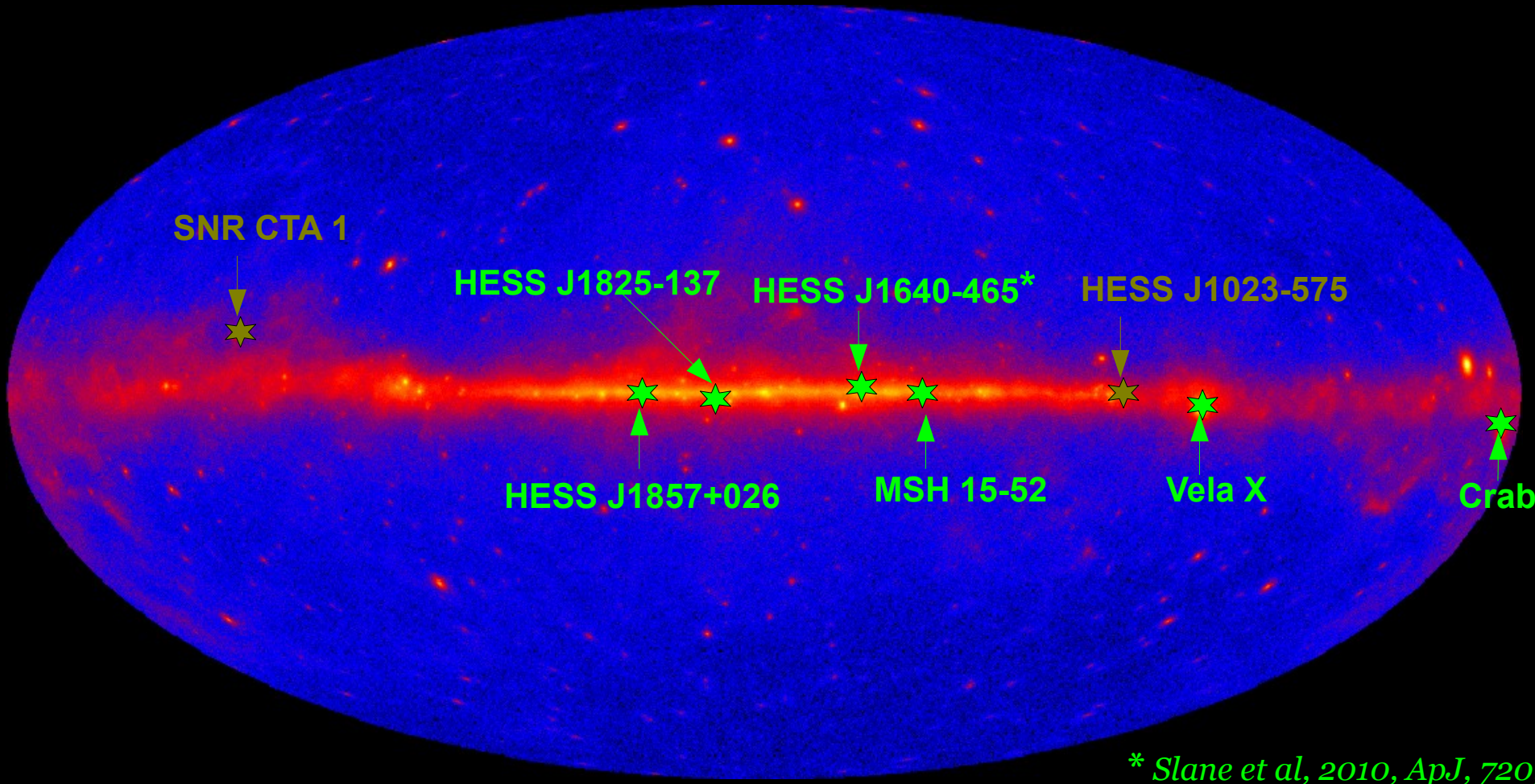
(Gaensler & Slane, 2006, ARA&A, 44, 17)

- *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



* *Slane et al, 2010, ApJ, 720, 266*

See talk by P. Slane

Fermi LAT counts map

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

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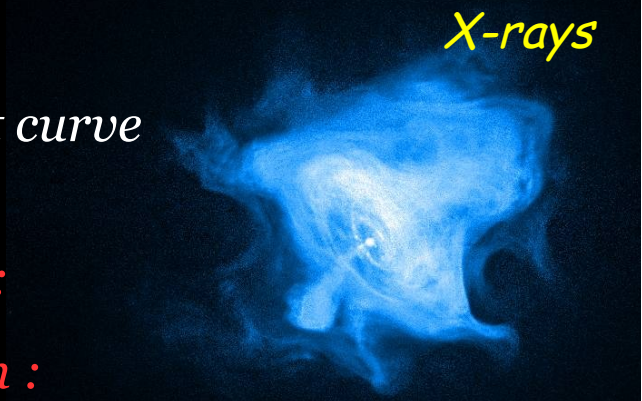
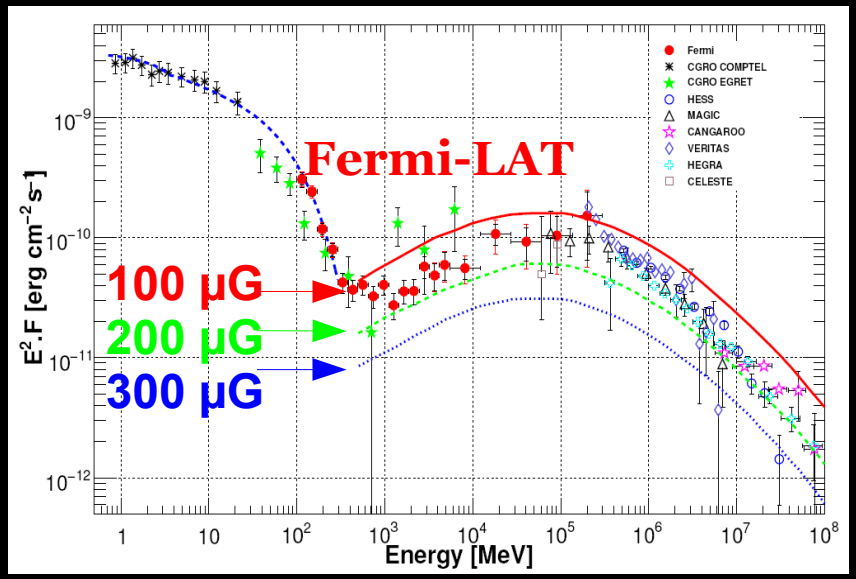
The Crab Nebula

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



- 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 $(9.8 \pm 0.7 \pm 1.0) \times 10^{-7}$ cm^{-2} s^{-1}
- Spectrum can be modeled with the sum of two power-laws :
  - Synchrotron:
    - $\Gamma_{sync} = (3.99 \pm 0.12 \pm 0.08)$
  - Inverse Compton :
    - $\Gamma_{IC} = (1.64 \pm 0.05 \pm 0.07)$
    - Using predictions of Atoyan & Aharonian (1996, MNRAS, 278, 525)

      → constraints on the magnetic field : $100 < B < 200$ μG, 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)

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

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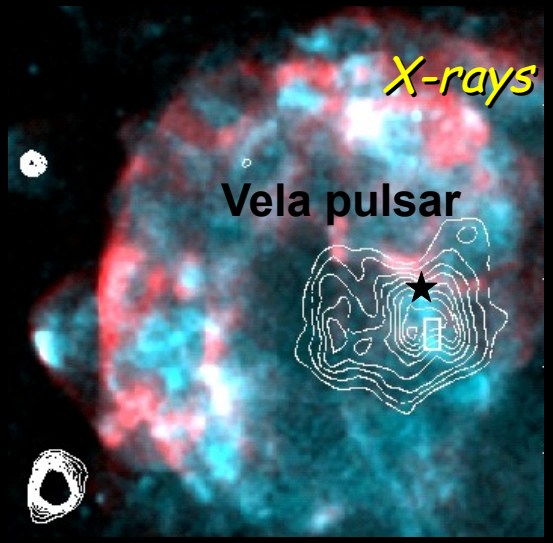
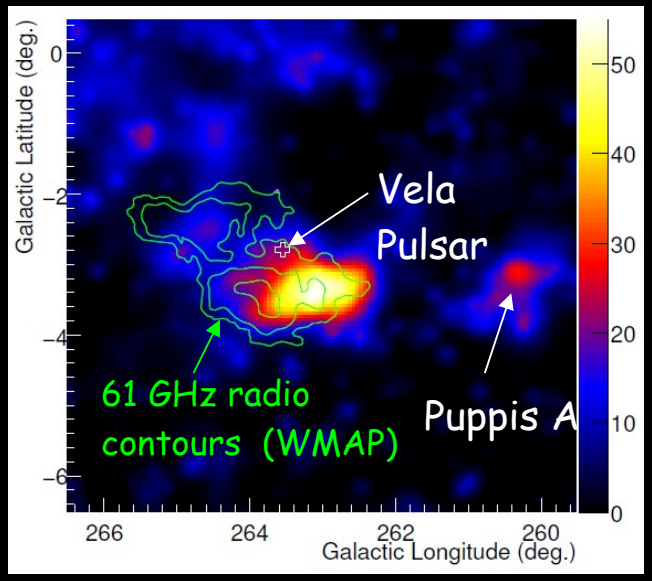
Vela X

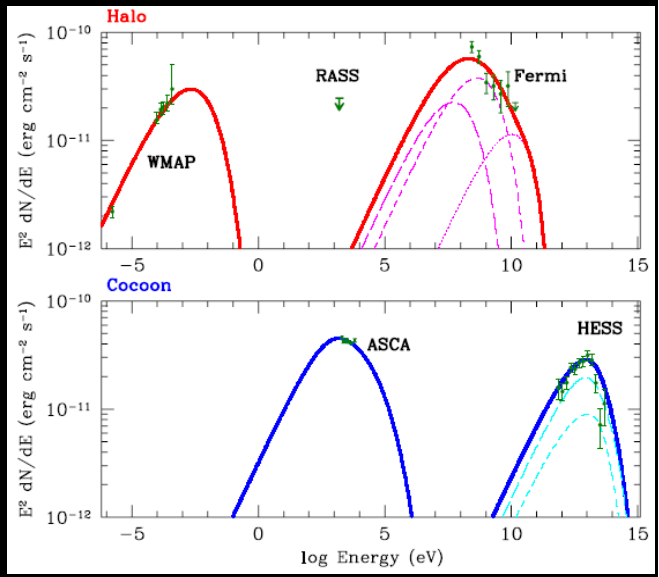
(Abdo et al., 2010, ApJ, 713, 146)



- 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 : $R_{disk} = 0.88° \pm 0.12°$
  - 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 : $(4.73 \pm 0.63 \pm 1.32) \times 10^{-7}$ cm^{-2} 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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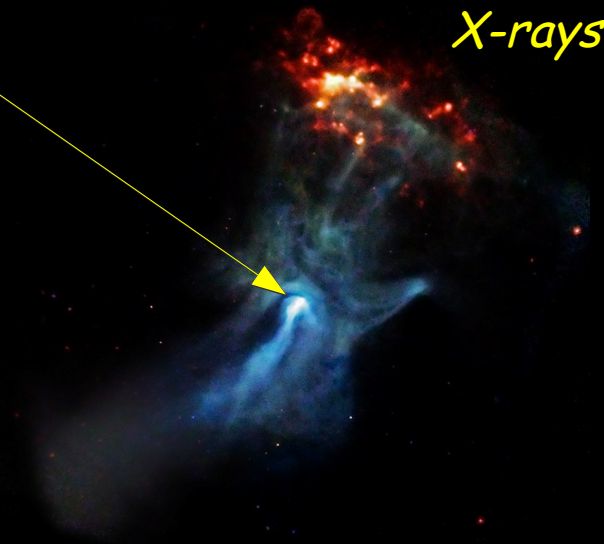
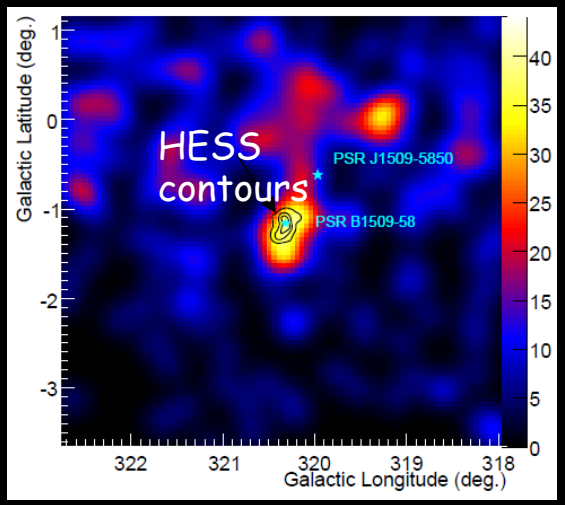
MSH 15-52

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

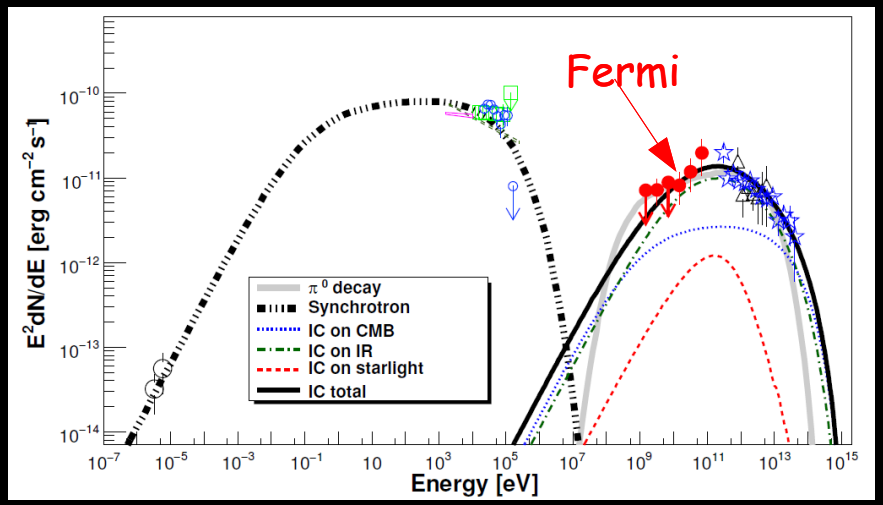
- young composite supernova remnant
- bright X-ray and TeV PWN powered by PSR B1509-58 (detected above 30 MeV) See talk by M. Pilia
- γ-ray emission spatially correlated with the PWN :
  - Significantly extended : $R_{disk} = (0.25 \pm 0.05)°$
  - Hard spectrum observed above 1 GeV :
    - Flux above 1 GeV : $(2.91 \pm 0.79 \pm 1.35)\ 10^{-9}\ cm^{-2}\ s^{-1}$
    - 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



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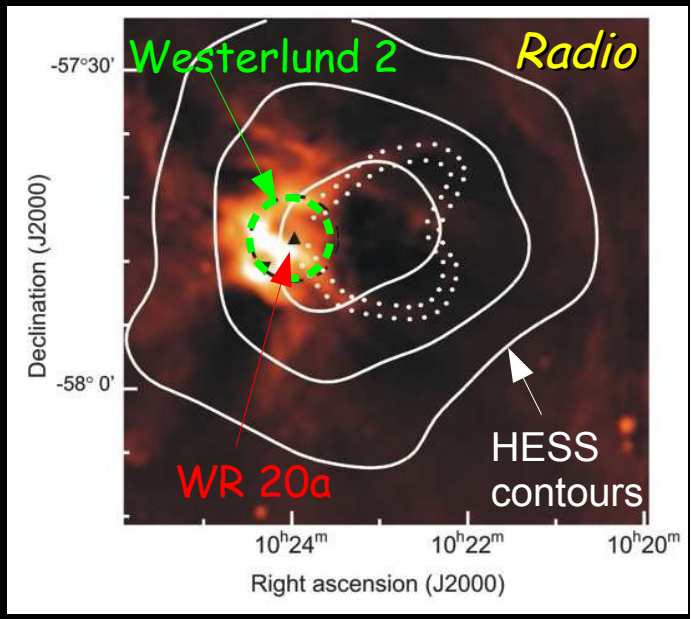
A PWN candidate in the region of Wd 2?

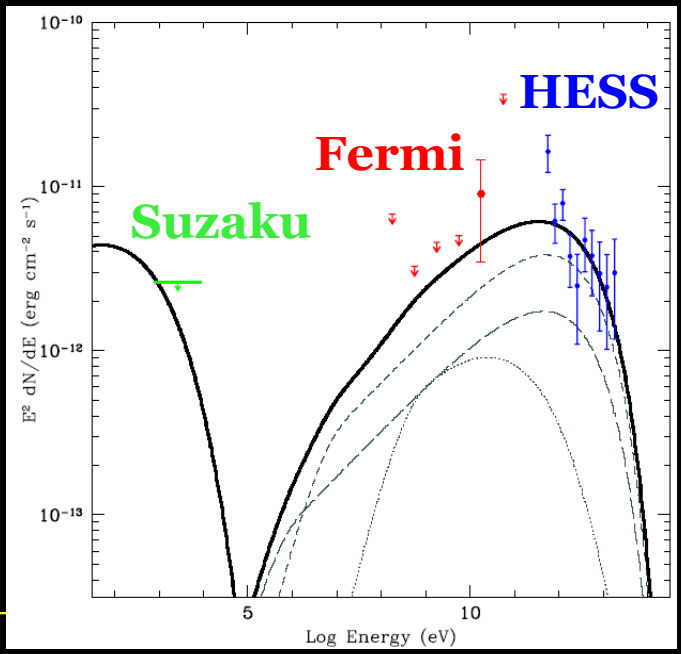
(Ackermann et al, 2011, ApJ, 726, 35)

- *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 ~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.*





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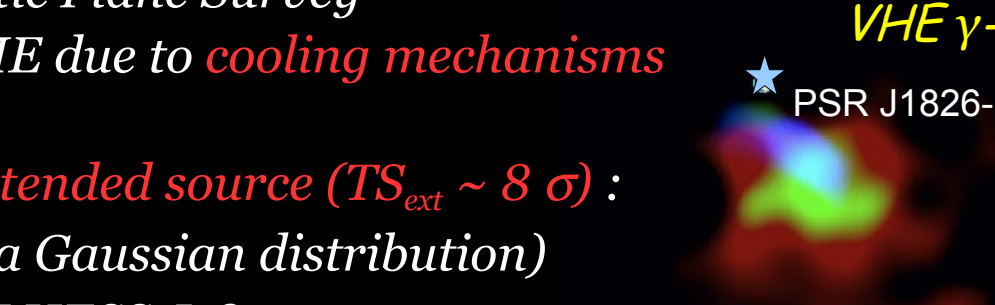
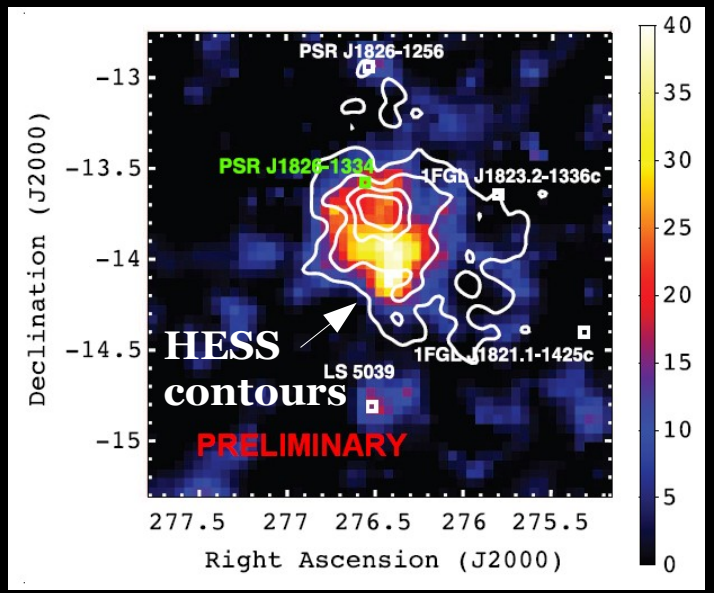
HESS J1825-137

(Grondin et al, 2011, ApJ, submitted)

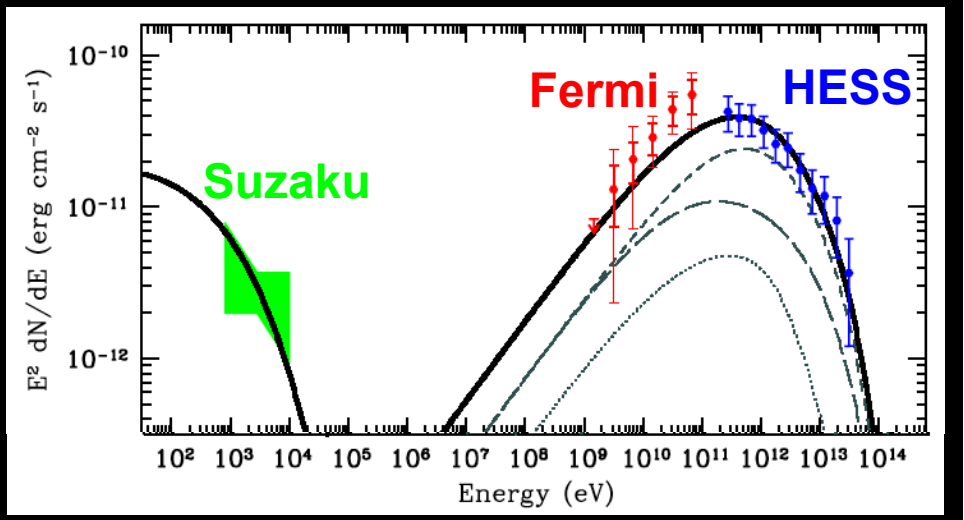
- *Discovered during the H.E.S.S. Galactic Plane Survey*
- *Energy-dependent morphology at VHE due to cooling mechanisms (Aharonian et al, 2006, A&A 460, 365)*
- *Fermi-LAT detection (~10 σ) of an extended source (TS_{ext} ~ 8 σ) :*
  - *Extension : σ = 0.56° ± 0.07° (for a Gaussian distribution)*
  - *Spatially coincident with the PWN HESS J1825-137*
  - *Hard spectrum modeled with a power-law (1 – 100 GeV) :*
    - *Flux (>1 GeV) : (6.50 ± 0.21 ± 3.90) x 10^{-9} cm^{-2} s^{-1}*
    - *Spectral Index : Γ = 1.38 ± 0.12 ± 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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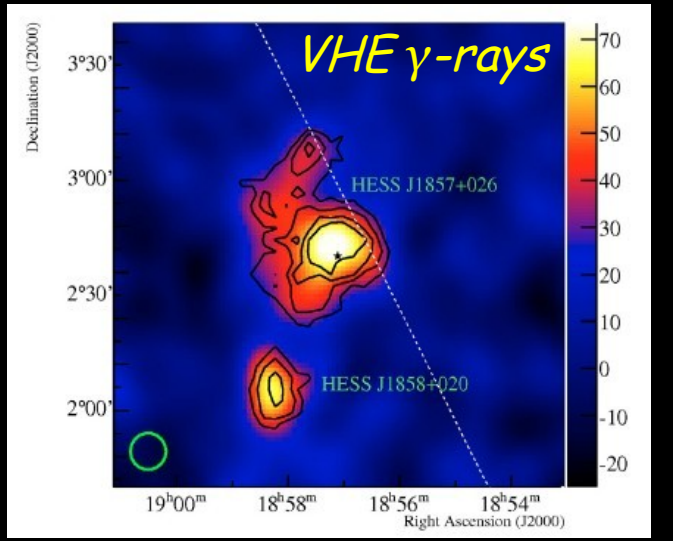
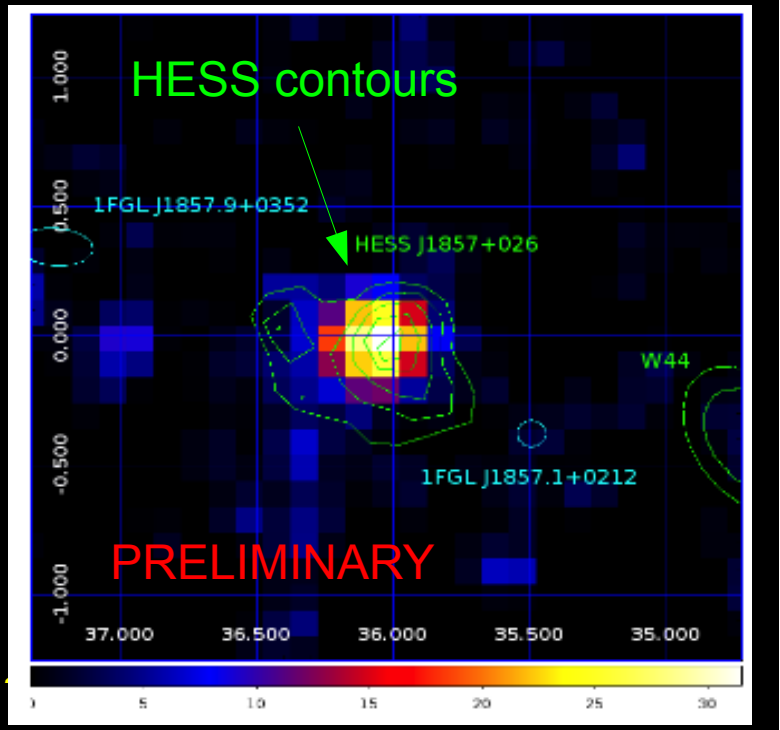
HESS J1857+026

(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 (~6 σ) :*
  - *Spatially correlated with the TeV source*
  - *No significant extension* (TS_{ext} < 4 σ)



LAT TS Map above 10 GeV

See poster by R. Rousseau

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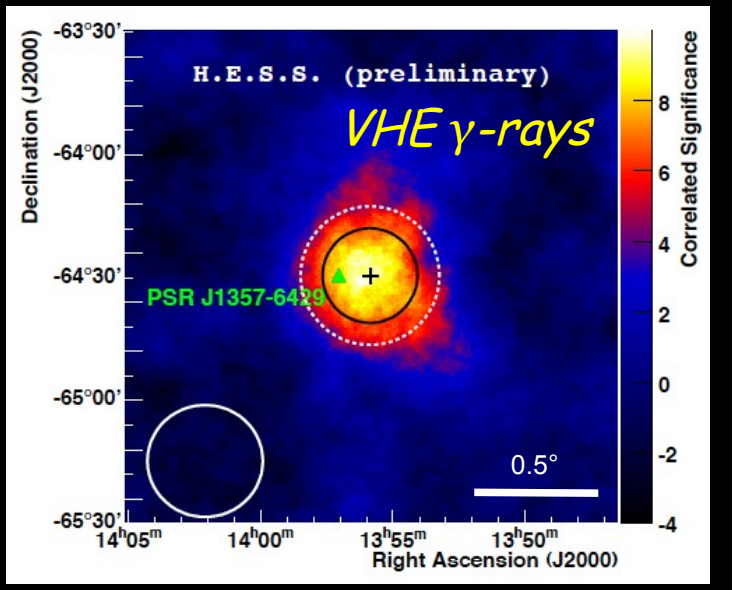
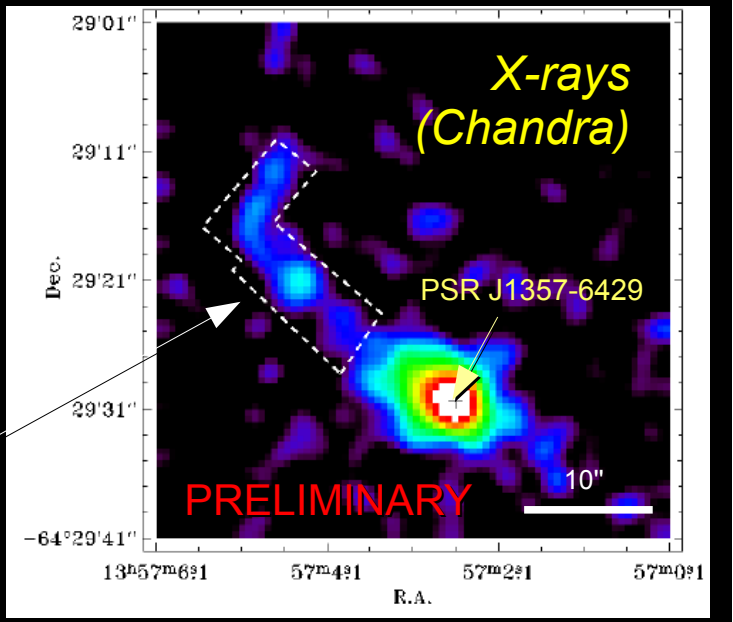
Observations of HESS J1356-645

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

- Discovered during the HESS Galactic plane Survey
  - Detection of a significant (8.5 σ) and extended (σ=0.2°) 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)



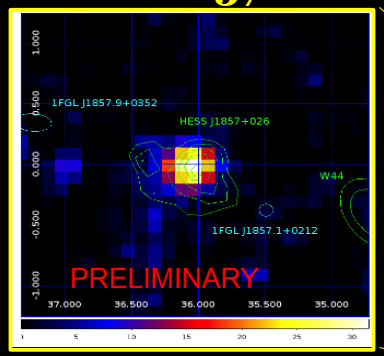


See talk by D. Smith & poster by X. Hou

Summary

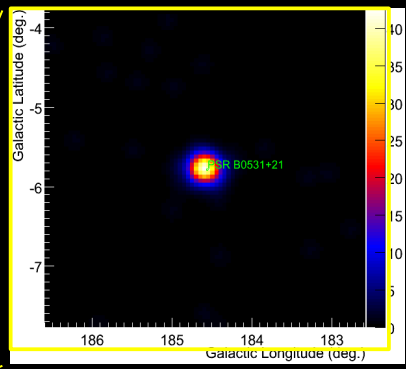
- *6 PWNe firmly identified by Fermi*
- *2 PWN candidates coincident with the pulsar PSR J1023-5746 and the SNR CTA 1 + other candidates coincident with composite SNRs : MSH 11-62, MSH 15-56, etc.*

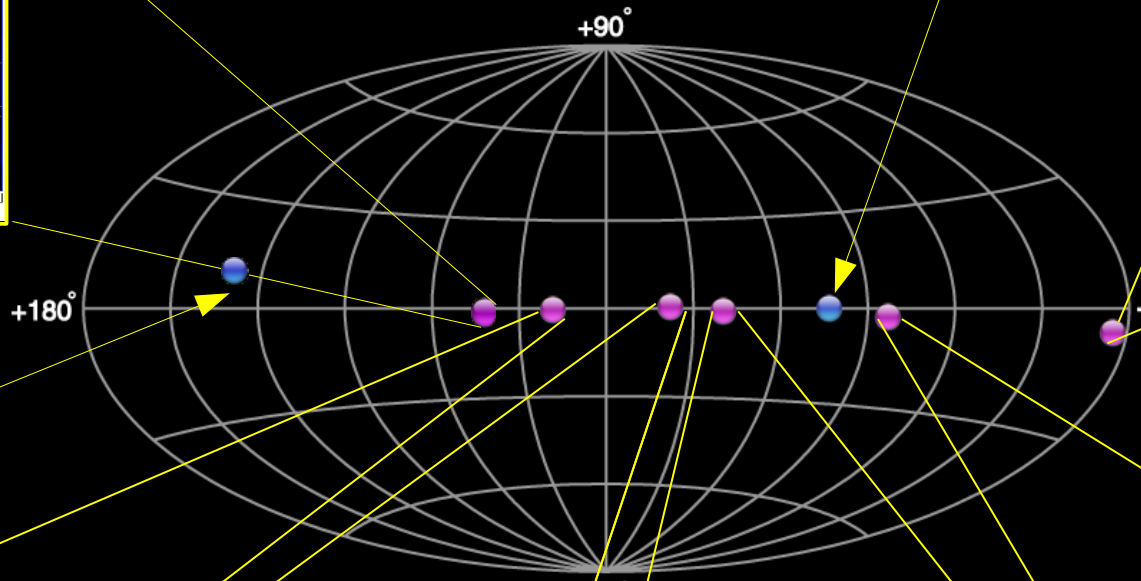
HESS J1857+026



HESS J1023-575

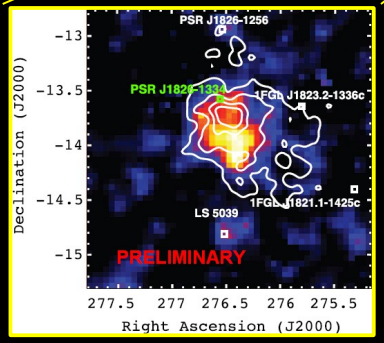
Crab Nebula



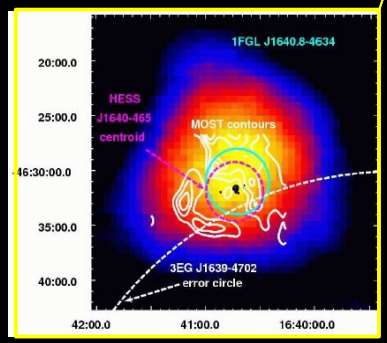


SNR CTA 1

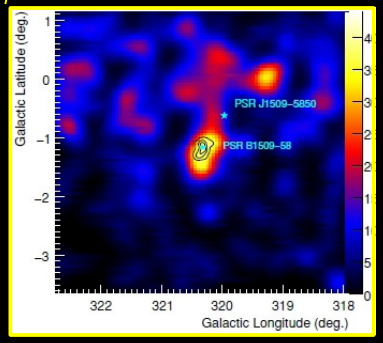
HESS J1825-137



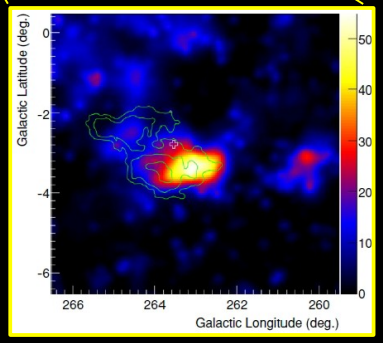
HESS J1640-465



MSH 15-52



Vela X



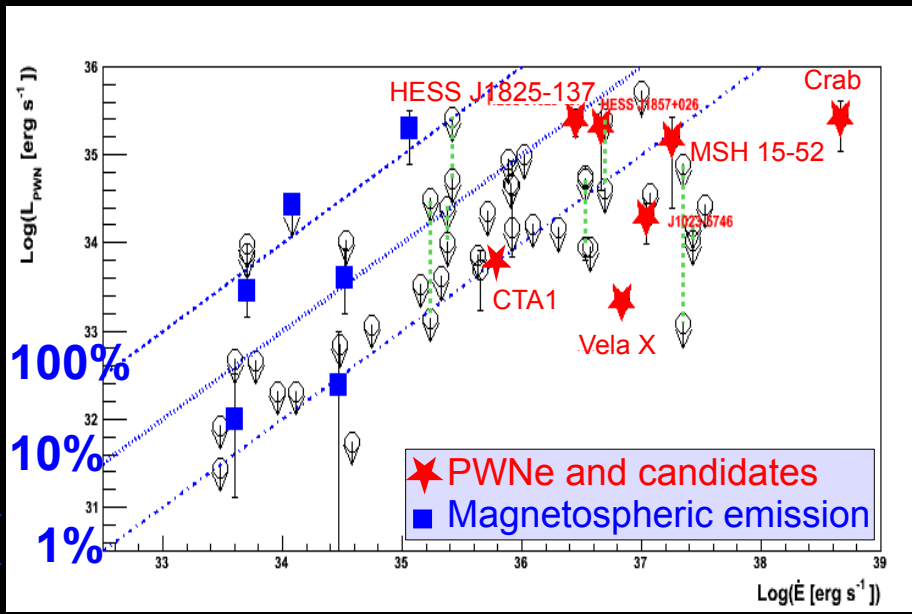
Population studies

(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*



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