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

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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

 Observations of PWNe in $\gamma$-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.)

– M.-H. Grondin, Fermi Symposium 2011 – Roma (Italy)
Fermi detections of TeV PWNe

Fermi LAT counts map
(front events above 200 MeV, back events above 400 MeV,
24 months of survey data)

– M.-H. Grondin, Fermi Symposium 2011 –
Roma (Italy)

See talk by P. Slane
The Crab Nebula

- 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:
    \[ \Gamma_{IC} = (1.64 \pm 0.05 \pm 0.07) \]
  \[ 100 < B < 200 \mu G, \text{ beyond the equipartition field in the Crab nebula, 300 } \mu G \]

- Emission comes from a region very close to the pulsar (Abdo et al., 2011, Science, 331, 739)

- M.-H. Grondin, Fermi Symposium 2011 – Roma (Italy)

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

- 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: $R_{\text{disk}} = 0.88° \pm 0.12°$
- 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: $(4.73 \pm 0.63 \pm 1.32) \times 10^{-7} \text{ cm}^{-2} \text{ s}^{-1}$
- Multiwavelength spectrum:

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

young composite supernova remnant

bright X-ray and TeV PWN powered by PSR B1509-58 (detected above 30 MeV)

$\gamma$-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: $(2.91 \pm 0.79 \pm 1.35) \times 10^{-9} \text{ cm}^{-2} \text{ s}^{-1}$
  - 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

See talk by M. Pilia

– M.-H. Grondin, Fermi Symposium 2011 – Roma (Italy)
A PWN candidate in the region of Wd 2?


- **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**


- Discovered during the H.E.S.S. Galactic Plane Survey
- Energy-dependent morphology at VHE due to cooling mechanisms
- 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)

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**Fermi LAT TS map above 10 GeV**

**Spectral energy distribution of HESS J1825-137**

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– M.-H. Grondin, Fermi Symposium 2011 –
Roma (Italy)
**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 $\sigma$) :
  - Spatially correlated with the TeV source
  - No significant extension ($T_{\text{ext}} < 4 \sigma$)

See poster by R. Rousseau

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LAT TS Map above 10 GeV

PRELIMINARY

– M.-H. Grondin, Fermi Symposium Roma (Italy)
Observations of HESS J1356-645


- Discovered during the HESS Galactic plane Survey
- Detection of a significant (8.5 $\sigma$) 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

- 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 J1825-137
HESS J1857+026
HESS J1023-575
Crab Nebula
SNR CTA 1
HESS J1640-465
MSH 15-52
Vela X
Population studies


- 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


- 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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