The HE and VHE emission from pulsars and their surroundings according to Fermi LAT and HESS


on behalf of H.E.S.S. Collaboration

Rencontres de Moriond, La Thuile, March 9-16 2013
Outline

- Gamma-ray pulsars
- Magnetospheric winds as carriers of spin-down power
- GeV/TeV Sources powered by PSRs and their Winds:
  a) Pulsar Wind Nebulae
  b) GeV/TeV binaries
  c) Globular clusters
Fermi LAT, $E > 100\text{MeV}$

121 $\gamma$-ray pulsars!

Cf. https://confluence.slac.stanford.edu/display/GLAMCOG/Public+List+of+LAT-Detected+Gamma-Ray+Pulsars

As of February 2013 (L. Guillemeot)

41 young radio- and X-ray-selected (green circles, cyan crosses)
36 young $\gamma$-ray-selected (white squares)
43 radio-selected MSPs (red diamonds) + 1 $\gamma$-ray-selected MSP (yellow diamond)
Gamma-ray pulsars (red and blue) as of 2010.
Why do pulsars radiate in high energy domain?

1) Rotating, strongly magnetized neutron stars -&gt; unipolar inductors

2) Maximum potential drop (for vacuum rotator)

\[ V_{\text{max}} \approx 6 \times 10^{12} B_{12} P^{-2} \text{ Volts,} \]

i.e. for young pulsars \( V_{\text{max}} \) can exceed \( 10^{16} \) Volts.

Realistic potential drops are much smaller, but high enough to accelerate particles to ultrarelativistic energies.
Young, energetic “outer-gap” pulsars are likely to be VHE gamma-ray pulsars.

The case of the Crab pulsar
Before the VHE discoveries by VERITAS and MAGIC

The Crab Pulsar and 3D Outer Gap Model

Hirotani, 2009

Synchro-curvature + ICS (pairs with IR)
Intrinsic: black lines
Escaping: red line

\[ \alpha = 60 \text{ deg} \]
\[ \zeta = 113 \text{ deg} \]

MAGIC @ 25 GeV

CTA
The Crab Pulsar and 3D Outer Gap Model – 3 yrs later

MAGIC Coll.+ Hirotani (Aleksic et al. 2011)
Slot Gaps and Outer Gaps

( example for the Crab parameters)

Multiplicities:

\[ M_{e^\pm} \sim 10^4 - 10^5 \]

The rate of \( e^\pm \)-pairs
in cold, ultrarelativistic wind:

\[ M_{e^\pm} \frac{dN_{GJ}}{dt} \approx 3 \times 10^{38} \text{ s}^{-1} \]
Radiation from a **Pulsar-wind-nebula** complex

- **Pulsed inside LC**
  - Pulsar
  - \( R, O, X \)
  - \( \gamma: \text{MeV/GeV; TeV (?)} \)

- **Pulsed outside LC**
  - Unshocked wind
  - Only \( \gamma: \text{GeV or TeV} \)

- **Unpulsed**
  - Synchrotron nebula
  - \( R, O, X \)
  - \( \gamma: \text{MeV/GeV/TeV} \)

- Interstellar medium

Aharonian, Bogovalov 2002
Spectral energy distribution in HE-VHE of the Crab Nebula (PWN) and its surprises at HE

Super flare on 2011 April 15-16 AGILE
Generating pulsed VHE emission within the wind zone

Aharonian et al. 2012, Nature

Pulsed $\gamma$-ray emission of Crab

Key model parameters

- $\Gamma_w = 10^6$, $R_w : 20R_L - 50R_L$
- $\Gamma_w = 5.5 \times 10^5$, $R_w : 1R_L - 30R_L$
- $\Gamma_w = 4 \times 10^5$, $R_w = 32R_L$
- $\Gamma_w = 6 \times 10^5$, $R_w = 32R_L$
- $10\Gamma_w = 6 \times 10^5$, $R_w = 30R_L$

Flux (J m$^{-2}$ s$^{-1}$)

Energy (GeV)
The online catalog *TeVCat* as of Nov 2011

(based on H.E.S.S., MAGIC, VERITAS)
Red dots: PWNe in VHE and their LAT pulsars
Blue dots: other LAT pulsars
## Five confirmed Gamma-ray Binaries

<table>
<thead>
<tr>
<th>System</th>
<th>Orbital Period</th>
<th>Eccentricity</th>
<th>Companion Star</th>
<th>Pulsar Period</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LS 5039</strong></td>
<td>3.9 d</td>
<td>0.35</td>
<td>O6V</td>
<td>?</td>
</tr>
<tr>
<td><strong>PSR B1259-63</strong></td>
<td>3.4 yr</td>
<td>0.87</td>
<td>B2Ve</td>
<td>47.7 ms</td>
</tr>
<tr>
<td><strong>LSI 61 303</strong></td>
<td>26.5 d</td>
<td>0.75</td>
<td>B0Ve</td>
<td>?</td>
</tr>
<tr>
<td><strong>HESS J0632+057</strong></td>
<td>321±5d</td>
<td>0.83</td>
<td>B0pe</td>
<td>?</td>
</tr>
<tr>
<td><strong>1FGL J1018.6-5856</strong></td>
<td>16.6 d</td>
<td>?</td>
<td>O6V</td>
<td>?</td>
</tr>
</tbody>
</table>
Conclusion: Very likely, the HE emission (LAT) and the VHE emission (HESS) are not connected to each other, i.e. they are due to different processes.
Potential diagnostic tools to study Pulsar Wind Zones at small scales (~100 – 1000 R\textsubscript{LC})
LS 5039: HE-VHE energy distribution around INFC and SUPC
folded with $P = 315$ d
folded with $P = 321\, \text{d}$
HESS J0632+057 - TeV/X-ray binary

No detection at ~ GeV even during the periastron passage

(Caliandro & Hill on behalf of Fermi-LAT Collab.)

1FGL J1018.6-5856 - GeV/X-ray binary

(Fermi-LAT Collab, Science, 2012)

Positionally coincident with HESS J1018-589

(de Ona-Wilhelmi, 2010)
Globular Clusters contain many MSPs (e.g. 33 MSPs in Ter 5)

=> are expected to be the sources of pulsed and unpulsed VHE radiation

Basic characteristics to be inferred from observations:

- spatial extent of the VHE emission,
- the shape of the VHE spectrum,
- its relation to the HE emission,
FIG. 2: Spectral energy distribution \((E^2 dN/\gamma dE)\) of the Fermi source seen toward 47 Tuc. The solid line shows the fit of an exponentially cut-off power law obtained for the energy range 100–10,000 MeV. The dashed line indicates the energy cut-off.

FIG. 1: Fermi LAT gamma-ray image (280 MeV to 10 GeV) of a 1.5° x 1.5° region centered on the position of 47 Tuc. The map was adaptively smoothed by imposing...
Discovery of VHE emission from the direction of Terzan 5

\[ \Gamma = 2.5 \pm 0.3 \]

half-mass radius – black
tidal radius - cyan
Search for VHE gamma-ray emission from Galactic globular clusters with H.E.S.S.

Abramowski et al. 2013

**Table 1.** The GC sample studied in this work.

<table>
<thead>
<tr>
<th>GC name</th>
<th>long. (°)</th>
<th>lat. (°)</th>
<th>zenith (°)</th>
<th>offset (°)</th>
<th>livetime (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NGC 104 (47 Tuc) (*)</td>
<td>305.89</td>
<td>-44.89</td>
<td>49.8</td>
<td>0.9</td>
<td>23.1</td>
</tr>
<tr>
<td>NGC 6388 (*)</td>
<td>345.56</td>
<td>-6.74</td>
<td>23.6</td>
<td>0.7</td>
<td>17.9</td>
</tr>
<tr>
<td>NGC 7078 (M 15)</td>
<td>65.01</td>
<td>-27.31</td>
<td>37.5</td>
<td>0.7</td>
<td>12.3</td>
</tr>
<tr>
<td>Terzan 6 (HP 5)</td>
<td>358.57</td>
<td>-2.16</td>
<td>24.6</td>
<td>1.8</td>
<td>15.2</td>
</tr>
<tr>
<td>Terzan 10</td>
<td>4.49</td>
<td>-1.99</td>
<td>18.1</td>
<td>1.6</td>
<td>4.2</td>
</tr>
<tr>
<td>NGC 6715 (M 54)</td>
<td>5.61</td>
<td>-14.09</td>
<td>18.3</td>
<td>0.7</td>
<td>11.8</td>
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<tr>
<td>NGC 362</td>
<td>301.53</td>
<td>-46.25</td>
<td>49.5</td>
<td>1.3</td>
<td>5.0</td>
</tr>
<tr>
<td>Pal 6</td>
<td>2.10</td>
<td>1.78</td>
<td>19.4</td>
<td>1.4</td>
<td>24.7</td>
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<tr>
<td>NGC 6256</td>
<td>347.79</td>
<td>3.31</td>
<td>20.5</td>
<td>1.3</td>
<td>5.3</td>
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<tr>
<td>Djorg 2</td>
<td>2.77</td>
<td>-2.50</td>
<td>15.9</td>
<td>1.7</td>
<td>4.6</td>
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<td>36.20</td>
<td>-2.21</td>
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<td>1.5</td>
<td>8.2</td>
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<td>NGC 6144</td>
<td>351.93</td>
<td>15.70</td>
<td>26.8</td>
<td>1.4</td>
<td>4.7</td>
</tr>
<tr>
<td>NGC 288</td>
<td>152.30</td>
<td>-89.38</td>
<td>11.8</td>
<td>1.4</td>
<td>46.7</td>
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<tr>
<td>HP 1 (BH 229)</td>
<td>357.44</td>
<td>2.12</td>
<td>14.3</td>
<td>1.5</td>
<td>5.6</td>
</tr>
<tr>
<td>Terzan 9</td>
<td>3.61</td>
<td>-1.99</td>
<td>18.4</td>
<td>1.5</td>
<td>5.2</td>
</tr>
</tbody>
</table>
One of several models for Ter 5 covering the range HE-VHE

*** Terzan 5 ***

\[ N_{\text{PSR}} = 31 \]
\[ d = 5.5 \text{ kpc} \]

\[ \mathcal{B}_{\text{GC}}: \ 0.3 \mu \text{G (black), 3 \mu G (light green), 30 \mu G (brown)} \]
The first gamma-ray pulsar found in a globular cluster PSR J1823-3021A in NGC 6624 $(P = 5 \text{ ms})$
SUMMARY

- Gamma-ray pulsars are a dominant class of galactic GeV sources
- Pulsar Wind Nebulae are a dominant class of galactic TeV sources
- GeV/TeV binaries with putative\(^*\) pulsars as compact objects offer an opportunity to study colliding winds and wind-disk collisions
- Globular clusters found to be GeV sources (14); expected TeV emission not found so far (the status of Ter 5 detection by H.E.S.S. still unclear)

\(^*\) except for PSR B1259-63