H.E.S.S. TeV Gamma-ray Sources
Associated with Pulsar Wind Nebulae

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Galactic plane at TeV energies
Identified PWNe

Matching morphology with radio or X-ray PWN

- MSH 15-52
- Vela X
- Rabbit
- K3 in Kookaburra
- HESS J1356-645
Identified PWNe

Spectral steepening away from the pulsar

**HESS J1825-137**

Dalton et al. (HESS Collaboration)
ICRC 2009 (Preliminary)

**HESS J1303-631**
(Identified) PWNe

Unresolved HESS source coincident with a resolved radio or X-ray PWN

Crab
G0.9+0.1
G21.5-0.9
Kes 75
N157B in LMC

Komin et al. (HESS Collaboration), ICRC 2009
PWN candidates: TeV source with nearby energetic pulsar

**HESS J1708-443**

Other PSRs:
- J1617-5055
- J1718-3825
- B1800-21
- J1809-1917
- J1119-6127

Djannati-Atai et al. (HESS Collaboration), 2009 Boston SNR/PWN Workshop
Which Pulsars create TeV PWNe?

Grey: Radio pulsars
Red: TeV PWNe

ATNF pulsar catalog
Mattana et al. 2009
Pulsar — TeV Source Coincidences

Some energetic pulsars have TeV-bright nebulae.

Chance Probability = 0.1%

Wenig et al. 2008
What determines the TeV luminosity?

Mattana et al. 2009
Pulsar — PWN Evolution Timescales

Pulsar spin-down timescale \( t_{SD} \sim 10^2 - 10^3 \) years

TeV electron synchrotron cooling timescale \( t_{cool} \sim 10^4 - 10^6 \) years

\[ t_{cool} \approx 130 \text{ kyr} \left( \frac{B}{10 \mu G} \right)^{-2} \left( \frac{E_e}{1 \text{ TeV}} \right)^{-1} \]

Mattana et al. 2009
Unidentified TeV sources $\rightarrow$ Old PWNe?

Aharonian et al. (HESS Collaboration) 2008
Why are PWNe offset from their pulsar?
PWN Evolution Phases

Free expansion

Crushed by SNR reverse shock

SNR forward shock

SNR reverse shock

Pulsar

PWN: a low-density bubble of relativistic electrons / positrons

radius

time (yrs)
Inhomogeneous ISM → Asymmetric Crushing

Offset Relic PWN

Simulations by Blondin et al. 2001
Vela SNR and PWN “Vela X”

Vela PSR B0833-45
Distance 0.3 kpc
Characteristic age 11 kyr
Vela SNR diameter 8 deg

Note: offset not caused by pulsar motion!

HESS 2006
HESS 2009 Measurement of Vela X

TeV nebula as extended as radio nebula

Ring spectrum is indistinguishable from cocoon spectrum

Circles centered on TeV emission center at RA = 08h35m00, Dec = -45°36' (J2000)

Dubois et al. ICRC 2009,
Glück et al., 2009 Boston SNR/PWN Workshop
Fermi gives a more complete overview of the energetic pulsars in our Galaxy!

Characteristics:
- **Spin-down flux (erg s\(^{-1}\) kpc\(^{-2}\))**
- **Grey:** Radio pulsars
- **Red:** TeV PWNe
- **Green:** GeV pulsars

ATNF pulsar catalog
Mattana et al. 2009
Abdo et al. 2009
Thank you for your attention!
Summary

• PWNe are possibly the largest population of Galactic TeV sources
  • All identified PWNe associate with a young and energetic pulsar, but no correlation of TeV luminosity with pulsar characteristic age or spin-down flux
  • Many of the unidentified TeV sources might be old PWNe

• Two evolutionary stages are observed:
  • Younger: Freely expanding into unshocked SNR ejecta
  • Older: crushed by SNR reverse shock and often offset

• Fermi gives a more complete overview of energetic pulsars in our Galaxy, improving TeV source identification and population studies in the future
References

• Abdo et al. (Fermi Collaboration) 2009, arXiv0910.1608A
  “The First Fermi Large Area Telescope Catalog of Gamma-ray Pulsars”

• Aharonian et al. (HESS Collaboration) 2008, A&A, 477, 353A
  “HESS very-high-energy gamma-ray sources without identified counterparts”

  “Pulsar Wind Nebulae in Evolved Supernova Remnants”

• Chaves (HESS Collaboration) 2009 arXiv0907.0768C
  “Extending the H.E.S.S. Galactic Plane Survey”

  ATNF Pulsar Catalog v1.37 @ http://www.atnf.csiro.au/research/pulsar/psrcat/

  “The evolution of the gamma- and X-ray luminosities of pulsar wind nebulae”

• Wenig et al. (HESS Collaboration) 2008, AIPC, 1085, 698W
  “Statistical Search for Counterparts of Galactic VHE Gamma-Ray Sources”