Fermi-LAT observations of Supernova Remnants

F. de Palma
(INFN Torino)

on behalf of the
Fermi-LAT Collaboration

Very High Energy Phenomena in the Universe
14th Rencontres du Vietnam
Outline

• Single source analysis:
  – Morphologies
  – Spectra
• Catalog studies
• Future experiments: CTA
MORPHOLOGIES
RCW 86 Morphology & Spectrum

- Detected as extended with Pass8: radius \( \sim 0.37° \pm 0.02° \)
- Best morphological photon distribution: H.E.S.S. template
- Not statistically relevant improvements splitting the templates

- Pure power-law function
- The broadband emission from radio to TeV cannot be described by a pure hadronic scenario
RX J1713 morphological analysis

- *Fermi*-LAT analysis with 7.5 years of Pass 8 data
- A nice shell matching the TeV morphology
- Break in the spectrum of the whole remnant at 17 GeV
- Difference between low energy index in the two regions at 3.5 σ

Condon B.+ @ Gamma 2016
• Composite SNR + PWN region
• Disentangled with a sub-selection of new Pass8 data
• MW modelling in the hadronic scenario

Devin, J. + arXiv:1805.11168
SNRs with hadronic emission

Ackermann, M. + 2013 Science (detected also by AGILE: Giuliani+ 2011)
Young SNRs

- Approx. few thousands years old
- Simple environments
- Small energy losses

Ideal targets to test the acceleration theory and look for ‘Pevatrons’

**Leptonic scenario**

RX J1713.7-3946

RCW 86

\[ \gamma \text{-ray emission dominated by Inverse Compton} \]

B. Condon+ @ Gamma 2016

Young SNRs

Hadronic scenario

Cassiopeia A

\[ \gamma\text{-ray emission dominated by pion decay} \]

Presence of accelerated protons

Tycho

\[ \gamma\text{-ray emission dominated by pion decay} \]

Presence of accelerated protons


Giordano, F. + ApJL 2012
An SNR in another galaxy: N132D in the LMC

- Brightest x-ray SNR in the LMC
- High energy reacceleration?
- Both leptonic and hadronic models require $E_{cr} > 10^{51}$ erg

Castro, D.+ @Fermi Symposium 2017
CATALOGS
Fermi Galactic Extended Source (FGES) Catalog

- Study of extended sources in the Galactic plane
- Detected 46 extended sources:
  - 16 are new
  - 13 agree with previous publications
  - 17 have a different morphology.
  - Only 4 known LAT extended sources were not detected since they don’t have emission above 10 GeV

Data:
- Pass 8,
- 6 Years,
- 10 GeV - 2 TeV
Sources modeled as flat disk

New extended sources in FGES: CTB109

- First detection of gamma-ray extension (point source in Castro+ 2012)
- Good agreement with x-ray/radio size
- Rules out giant molecular cloud west of remnant
- Good candidate for TeV observation
Characterized 279 regions containing known radio SNRs:

- 102 candidates have significant GeV emission:
  - 36 candidates classified through spatial association with radio data:
    - 17 extended: 4 new!
    - 2 show spectral curvature
    - 13 point-like hypothesis preferred: 10 new!
  - 2 are flagged for IEMs systematics
  - 4 identified as other sources (Crab, binary, and PWN/PSR)
- 14 marginally classified candidates
- For the 245 candidates that don’t have a significant GeV emission or that fail classification, we report their ULs.
- All the detected sources were tested for effects related to the choice of IEMs.

F. de Palma @ VHEPU 2018

Acero+ 2016 APJS
If radio and GeV emission arise from the same particle population(s), under simple assumptions, the GeV and radio indices should be correlated:

- **Young SNRs**: seem consistent
- **Others**, including interacting SNRs: softer than expected

Data now challenge model assumptions!
- Underlying particle populations may have different indices.
- Emitting particle populations may not follow a power law: breaks?
- Multiple emission zones?

\[ \pi^0 \text{ decay or } e^+/^- \text{ brem.} \]

\[ \text{Inverse Compton w cooling} \]

\[ \text{inverse Compton w/o cooling} \]
Assuming that the whole gamma ray emission arises from the interaction of CR with the ISM.

- **SNRs above** the $\epsilon_{CR} = 1$ ($E_{CR} = E_{SN} = 10^{51}$ erg) → higher density than derived from X-ray or assumed → **interacting** SNRs are in dense environment.

- **Young SNRs** $\epsilon_{CR} \sim 0.1$ → IC processes may contribute to their measured luminosity.

![Graph](image)

F. de Palma @ VHEPU 2018
2HWC catalog follow ups

- Analysis in Fermi-LAT and Veritas data of 13 sources that are more than 3° away from known TeV sources.
- VERITAS found weak gamma-ray emission in the region of PWN DA 495 coinciding with 2HWC J1953+294
- LAT detected a GeV counterpart of SNR G54.1+0.3, a known TeV source detected by both VERITAS and HAWC associated to a PWN.

Park, N. + ICRC 2017 Arxiv:1708.05744v1

For more on Fermi-LAT catalogs, see J. Ballet talk Thursday
CHERENKOV TELESCOPE ARRAY
The CTA Consortium, Science with the Cherenkov Telescope Array, arxiv:1709.07997

CTA: Key Science Projects (KSP)

GPS PeVatrons

<table>
<thead>
<tr>
<th>CRs acc.</th>
<th>Extreme environments</th>
</tr>
</thead>
<tbody>
<tr>
<td>What are the sites of high-energy particle acceleration in the universe?</td>
<td>✓ ✓ ✓</td>
</tr>
<tr>
<td>What are the mechanisms for cosmic particle acceleration?</td>
<td>✓ ✓ ✓</td>
</tr>
<tr>
<td>What role do accelerated particles play in feedback on star formation and galaxy evolution?</td>
<td>✓ ✓ ✓</td>
</tr>
<tr>
<td>What physical processes are at work close to neutron stars and black holes?</td>
<td>✓ ✓ ✓</td>
</tr>
<tr>
<td>What are the characteristics of relativistic jets, winds and explosions?</td>
<td>✓ ✓ ✓</td>
</tr>
<tr>
<td>How intense are radiation fields and magnetic fields in cosmic voids, and how do these evolve over cosmic time?</td>
<td></td>
</tr>
</tbody>
</table>

See S. Funk talk Thursday
Morphology studies for RX J 1713

Simulated morphologies for different emission mechanisms with 50h of observation.

Conclusions

- *Fermi* has proved to be *extremely* successful in studying Supernova Remnants.
- Pass 8 is allowing detailed studies of the morphology of extended sources, *better identifying emitting regions at different energies*.
- Detailed spectral studies, with MW information, are increasingly improving our knowledge of *emission mechanisms*.
- Relevant new results from catalogs.
- CTA observations of the Galactic plane will strongly improve our understanding of the Galactic high energy emission.
- Spatial resolved spectroscopy will be possible given CTA high spatial and spectra resolution.