Gamma Rays from SNR W28

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SNR W28

**Distance:** 1.8 - 3.3 kpc

**Age:** > 35 yrs

**Size:** 20-35 pc (50')

*Mixed morphological characteristics*
SNR W28 in Radio

- Shell structure clearly visible
- Spectral index $328 / 1415 \text{ MHz}$
  $$a = -0.35 \pm 0.18$$
- Large local variations, correlated with the flux density (Dubner et al. 2000)
- $\rightarrow$ Non-thermal emission from relativistic electrons

Map of VLA 90 cm radio emission
$^{12}$CO ($J = 1 \rightarrow 0$) molecular line observations (NANTEN telescope) integrated over the velocity range 3 to 27 km s$^{-1}$ (dynamical distances compatible with W28 System of molecular clouds associated with the SNR (Mizuno & Fukui, 2004).

Two main complexes close to the northwestern (cloud N) and southern (cloud S) part of the SNR.
Evidence of interaction between the remnant and the system of molecular clouds

- 1720 Mhz OH maser emission (Frail et al., 1994) and

- high value of the ratio CO \((J = 3 - 2)/(J = 2 - 1)\) (Arikawa et al., 1999).
Cloud N: 20000 $M_{\text{sol}}$ near the SNR

Cloud S: 40000 $M_{\text{sol}}$ ~ 10 pc far from the SNR

W28 is an ideal Laboratory for studying CR acceleration and diffusion
Good correlation between TeV and $^{12}$CO(J=1-0) emission

The two mol. clouds correspond to

HESS J1801-233 (Cloud N)

and

HESS J1800-240 A, B and C (Cloud S)

(Aharonian et al., 2006).
AGILE counts map 
$E > 400$ MeV

The blue circle indicates the radio location of the supernova remnant W28.

The black contours indicate the CO intensity emission

Emission concentrated on Cloud N
Problems for the leptonic models

Inverse Compton: \( \text{electrons + ISRF photons} \rightarrow \gamma \text{ rays} \)
Problems for the leptonic models

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Disfavoured because of the strong correlation (in both GeV and TeV band) between the gamma-ray intensity and dense gas
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Electron Bremsstrahlung: \textit{electrons + ISM nuclei} $\rightarrow$ $\gamma$ rays
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Electron Bremsstrahlung: \( \text{electrons} + \text{ISM nuclei} \rightarrow \gamma \text{ rays} \)

TeV gamma-rays are produced by \( \sim 10 \text{ TeV} \) electrons.

These energetic electrons are expected to be produced only at the early epochs of the SNR (Gabici et al., 2009) can only marginally survive for the age of this source because of strong synchrotron and IC cooling.

\[
t_{IC}(E) = 3 \times 10^8 \left( \frac{1 \text{ eV cm}^{-3}}{w_r} \right) \left( \frac{1 \text{ GeV}}{E} \right) \text{ yr}
\]
E > 400

400 MeV > E > 100 MeV

100 MeV > E > 50 MeV

W28 disappears below 100 MeV!
W28 Spectrum - cloud N

Pion Bump!

AGILE

HESS
AGILE/GRID Observations
E$>400$ MeV (+HESS contours)

HESS signif. map
(+ AGILE contours)

Giuliani et al. 2010  A&A
Region B is brighter than region A in TeV band (with similar spectra)

In the E>100 MeV band, A is brighter than B
Model for W 28: spectral studies

Gamma ray by $\pi^0$ decay

Proton spectrum @ SNR: $F \sim E^{-2.2}$

Diffusion:
$D = 10^{26} \ (E/10 \ GeV)^{0.5}$

Distances of targets:
- cloud A: 2000 s.m.
- cloud B: 4500 s.m.

Age of the SNR: 45 kyrs
cloud N at 4 pc
cloud B at 9 pc

AGILE N
AGILE S

HESS N
HESS S

Giuliani et al. 2010 A&A
\[ E_{\text{cut}} = \left( \frac{R^2}{4tD_0} \right)^{\frac{1}{\delta}} \]

cloud N at 4 pc
cloud B at 9 pc

AGILE N
AGILE S

HESS N
HESS S

Giuliani et al. 2010  A&A
cloud N at $4 \pm 1 \ (D_0/10^{26})^{0.5}$

cloud S at $9 \pm 1 \ (D_0/10^{26})^{0.5}$

\[ E_{cut} = \left( \frac{R^2}{4tD_0} \right)^{\frac{1}{5}} \]

AGILE N

AGILE S

HESS N

HESS S
Fermi Observations (preliminar)

Region A ->
Region B ->

E = 500 MeV    E=1.5 GeV    E=5 GeV    E=15 GeV
A cloud at 4, 5, 6 pc
B cloud at 9, 10, 11 pc

Cloud A

Cloud B

HESS A

HESS B
Model for W 28: morphological studies

Gamma ray by $\pi^0$ decay

Proton spectrum @ SNR: $F \sim E^{-2.2}$

Diffusion: $D = 10^{26} \ (E/10 \text{ GeV})^{0.5}$

Distances of targets:
- cloud A $\sim 4 \text{ pc (2000 s.m.)}$
- cloud B $\sim 9 \text{ pc (4500 s.m.)}$

Age of the SNR: 45 kyrs
Model for W 28
Model for W 28: protons distribution

1 TeV

1 GeV
Model for W 28: gamma emission

>400 MeV

>3 GeV

>400 GeV
Model for W 28: gamma emission (+PSF)
Model vs Observations:
AGILE, Fermi and HESS

AGILE
Fermi
HESS

>400 MeV
>3 GeV
>400 GeV
Conclusion for SNR W 28

SNR W28 is an ideal laboratory for studying CR emission from SNRs

Gamma-rays emission from SNR W28 arise from two Giant Molecular Cloud

The GeV and TeV spectrum of the two clouds can be easily explained in terms of protons diffusing from the SNR shell

Gamma Rays observations (GeV + TeV) can give constrains on the CR diffusion coefficient
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Strong indication of a hadronic scenario.
Thanks !
W28 X rays