What do supernova remnants interacting with molecular clouds reveal


for the H.E.S.S. Collaboration

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Supernova remnants and cosmic rays

• Blast waves passing through the interstellar medium
  ⇒ the plausible particle accelerators at work in the Galaxy

• First-order Fermi acceleration mechanism
  – gain energy by multiple passage through the supersonic shock
  – expect ~ 10% of the explosion energy accelerates hadrons
  – enough power to compensate cosmic-ray escape from the Galaxy

• We miss an undisputable experimental evidence
  ⇒ very high energy $\gamma$ rays are good tracers for such mechanism
The High Energy Stereoscopic System

• Four Imaging Atmospheric Cherenkov Telescopes
• Khomas Highlands of Namibia at 1800 m a. s. l.
  Southern hemisphere => inner Galactic plane => most emitters

• Completed in December 2003
  => more than 4 years in full configuration mode
The H.E.S.S. telescope

- 5° field of view, fine grain, fast readout cameras
- Detects Cherenkov light from atmospheric showers in stereoscopic mode

- Resolution: $\Delta \theta \sim 0.15^\circ$
- Energy range: 0.2 - 50 TeV; $\Delta E/E \sim 15\%$
Particle acceleration in shell-type SNRs

\[ \gamma \] rays may come from:
- electrons in \(~a few \mu G\)
- hadrons in \(~100 \mu G\)

\[ \Rightarrow \] hadron acceleration is not proved

First shell resolved in VHE \[ \gamma \] rays
- Spectral index close to 2 up to 30 TeV
- \[ \Rightarrow \] particles accelerated beyond 100 TeV
- Correlation with non-thermal X rays

Spectra differ below 100 GeV:
- GLAST FGST will help disentangling these processes
Molecular clouds probe cosmic rays

- Molecular clouds host supernova remnants
  - **Natural association**: birth place of massive stars ending as SNe

- Matter provides a target for accelerated hadrons $\rightarrow \pi^0 \rightarrow \gamma \gamma$
  - We expect a correlation between matter density and $\gamma$-ray emission
  => CRs accelerators associated with dense clouds should help to discriminate them from electrons accelerators

- Molecular cloud detection
  - Rotational lines in radio (CO, CS)
    => line intensity proportional to $\text{H}_2$ column density (main component)
1720 MHz OH maser (10^{-17} TeV !)

- OH population inversion only via collisionnal pumping with H$_2$
  
  
  Specific conditions : $10^3 - 10^5$ cm$^{-3}$, $T \sim 25$ K - 200 K
  
  => A blast wave passing through a molecular cloud
  
  maser effect if line of sight tangent to blast wave
  
  Strong suppression outside these temperature and density ranges
  
  => No detection does not mean no shocked cloud
  
- BUT ! Detection means true interaction of SNR with MC
  
  No fake associations due to imprecise distance determination
  
  Several surveys towards SNRs in the 1720 MHz line
  
  
- 18 SNRs showed 1720 MHz OH maser emission line
  
  Not exhaustive ... More surveys needed
The W28 (SNR G6.4-0.1) field

- Complex region in MWL
  - Several SNRs
  - Star formation regions
  - H" ii regions
- Northern excess coincident with EGRET source
- Interaction of the remnant with a dense molecular cloud seen in NANTEN CO observations
  - Northern gamma-ray emission coincident
  => Energy compatible with CRs accelerated by the SNR and interacting with the cloud
  => hadronic scenario likely
  - 2% Crab flux
**HESS J1714-385 & CTB 37A**

- Recently discovered by H.E.S.S.
  - Close to RX J1713.7-3946
  - Coincident with SNR G348.5+0.3 (CTB 37A)
  - Spectral index: $\Gamma = 2.30 \pm 0.13$
  - Extended source: $\sigma \sim 4'$
  - 3% Crab flux

**3EG J1714-3857 counterpart?**

Spectral compatibility

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Fabrice Feinstein, SCINEGHE 2008, Padova, October 8 - 10, 2008
Cosmic rays hitting molecular clouds?

- SNR interacting with several molecular clouds
  - OH masers (1720 Mhz)
  - Dense molecular clouds detected in CO observations
- Hadronic scenario possible
  - Gamma-ray energetics compatible with CRs accelerated by CTB 37A
  
  => [4% - 30%] of the SN explosion energy into CRs

Aharonian et al. A&A in press
arXiv: 0803.0702
Recent X-ray observations
- Chandra & XMM-Newton

Thermal emission from the interior of the remnant
- Possibly associated with CTB 37A

PWN candidate discovered coincident with the remnant
- X-ray luminosity implies a spin-down luminosity around $10^{37}$ erg/s, rather powerful
  => ~0.1% conversion in $\gamma$ rays
  => Leptonic scenario possible
HESS J1745-303

- Discovered in 2004: Galactic scan
  - 2005–2007: statistics increase
    ⇒ complex morphology, possibly multiple
    ⇒ unidentified
- Power law of index $\Gamma = 2.71 \pm 0.1$
- Candidate for part A?
  - Unidentified EGRET source (95% CL)
    - EGRET flux compatible
    - no XMM counterpart
    - 1.5% Crab flux

Fabrice Feinstein, SCINEGHE 2008, Padova, October 8 - 10, 2008
CRs accelerated by G359.1-0.5?

- SNR G359.1-0.5
  - H1 abs. => near GC : 7.6 ± 0.4 kpc
  - Blast wave interacts with a ring of matter
    - OH masers at 1720 MHz towards the rim of the SNR
    - CO observations [-100 km/s, -60 km/s], comp. with GC, reveal a coincidence with $\gamma$-ray source
  - Hadrons interact with the cloud ?
    $\Rightarrow$ 15% to 60% of the SN explosion energy into cosmic rays

A new candidate: HESS J1923+141

- 2007 scan + 2008 pointed observations
- 16.5 hours live-time
- Peak significance of 6.7σ (oversampling 0.22°)
  ⇒ 4.4σ after trials

$^{13}$CO (DENSE !) cloud at 60-80 km/s
maser at 70 km/s

- Source extends more than PSF

3 % Crab flux

⇒ Discovery of a new VHE γ-ray source by H.E.S.S.
**HESS J1923+141: possible counterparts**

- Morphological study is in progress
- Several possible counterparts
  - PWN detected by Chandra CXO J192318.5+1403035
    - Spin-down luminosity implied by the X-rays $\sim 3 \times 10^{36}$ erg/s at 6 kpc
    - $\Rightarrow$ conversion of less than 1/1000 of this luminosity into gamma-rays
  - Shocked molecular clouds in the vicinity of SNR G49.2-0.7
    - Presence of 1720 MHz OH masers coincident with the rim of the remnant
    - Elongated molecular cloud coincident with the rim of the remnant and the masers
    - $\Rightarrow$ hadronic scenario plausible

$\Rightarrow$ new H.E.S.S. source coincident with an OH maser emitting SNR
Several SNR/MC associations have been observed by HESS

- Physical associations revealed by OH masers at 1720 MHz
- EGRET counterpart possible to lower energy for all of them
- A hadronic scenario is plausible for each case

=> Gamma-ray flux compatible with CRs accelerated by the SNR

A leptonic scenario can be considered for some of them

=> But the charges against the usual suspect accumulate!

- All these sources are in the 1% - 3% Crab flux range
- FGST and HESS 2 sensitivities very handy
- We must build CTA and we’ll see dozens of these sources

=> We may be able to map the CR density and confront models directly