Supernova Remnants interacting with molecular clouds as seen with H.E.S.S.

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Rencontres de Moriond
Very High Energy Phenomena in the Universe
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Features of SNRs interacting w/ MCs:

SNRs interacting w/ MCs:
*W28N, W49B, W51C, IC443, W44*
- Luminous GeV & weak TeV sources
- Spectral break at a few GeV, steep at VHE

<table>
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<tr>
<th>SNR</th>
<th>ΔIndex</th>
<th>$E_{\text{break}}$ (GeV)</th>
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<tbody>
<tr>
<td>W28N</td>
<td>0.65±0.30</td>
<td>1.0±0.2</td>
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<tr>
<td>W49B</td>
<td>0.72±0.20</td>
<td>4.8±1.6</td>
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<tr>
<td>IC443</td>
<td>0.63±0.11</td>
<td>3.3±0.6</td>
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<tr>
<td>W44</td>
<td>0.96±0.10</td>
<td>1.9±0.2</td>
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<tr>
<td>W51C</td>
<td>1.3±0.1</td>
<td>1.7±0.5</td>
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0.6-1.3 GeV
1-5 GeV

*Ackermann et al., 2013
Abdo et al., 2009
Abdo et al., 2010
Aleskic et al., 2012*
3 H.E.S.S. sources associated to a SNR-MC interaction
3 H.E.S.S. sources coincident w/ SNR-MC interaction but PWN emission possibly dominant
4 new H.E.S.S. sources *possibly* associated to a SNR-MC interaction
J1834-087: Discovered with the HESS survey (Aharonian et al., 2005)
MAGIC dedicated paper (Albert et al., 2006)

Images at the same scale

Black contours: $^{12}$CO 90 cm VLA radio contours
★ MAGIC tracking positions
○ MAGIC analysis source region
- 2 H.E.S.S. components from the center of the remnant: Pt-like (coincident w/ CCO) + Extended (Ø=21’) components

- coincident w/ SNR G23.3-0.3 (W41): 4.2 kpc, 6x10^4 yrs, Ø=27’

- coincident w/ 12CO (Dame et al., 1986) & 13CO (Jackson et al., 2006)  
  13CO peak density not compatible w/ VHE emission  
  Possible OH maser (Green et al., 1996) but not confirmed

- X-ray CCO at the center of the remnant, no pulsations  
  Nonthermal X-ray diffuse emission => PWN candidate  
  (Misanovic et al., 2011; Mukherjee et al., 2009)

- coincident w/ a Fermi-LAT extended source (compatible w/ CCO)  
  PL spectrum (no exp. cutoff)
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- coincident w/ a Fermi-LAT extended source (compatible w/ CCO) PL spectrum (no exp. cutoff)
Possible PWN emission

- 2 H.E.S.S. components from the center of the remnant:
  - Pt-like (coincident w/ CCO) + Extended (Ø=21’) components
  - coincident w/ SNR G23.3-0.3 (W41): 4.2 kpc, 6x10^4 yrs, Ø=27’
  - coincident w/ \(^{12}\text{CO}\) (Dame et al., 1986) & \(^{13}\text{CO}\) (Jackson et al., 2006)

\(^{13}\text{CO}\) peak density not compatible w/ VHE emission
Possible OH maser (Green et al., 1996) but not confirmed

- X-ray CCO at the center of the remnant, no pulsations
  Nonthermal X-ray diffuse emission => PWN candidate
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coincident w/ a Fermi-LAT extended source (compatible w/ CCO)
PL spectrum (no exp. cutoff)

Possible SNR-MC shock
**SNR-MC interaction scenario:**
- Fermi + HESS extended region spectra
- Hadronic emission: $W_{CR} \sim 10^{50}$ erg
- Broad GeV platform: 1-100GeV $\Rightarrow E_{\text{break}} \sim 100$ GeV

**PWN scenario:**
- HESS central region spectrum
- Spin down power: $10^{36}$ - $10^{37}$ erg/s

**SNR-MC and PWN scenario:**
- Fermi + 2 HESS components spectra

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**HESS J1834-087:**

$\delta$ CCO
SNR (NRAO, 20 cm)
$^{13}\text{CO}$ (GRS, 74-82 km/s)

$\phi_{\text{extended}}(1\text{-}30 \text{TeV}) \approx 5\% \text{ Crab}$
$\phi_{\text{central}}(1\text{-}30 \text{TeV}) \approx 2\% \text{ Crab}$

D. FERNANDEZ - March 9-16, 2013
**HESS J1832-092:**

- H.E.S.S. source: point-like or extension ≤ 0.09° (99% CL)
- close to the G22.7-0.2 radio rim
- coincident with 2 clouds: $^{13}$CO (J=0-$\rightarrow$1) (*Jackson et al., 2006*)
- X-ray point-like source 1’ away from the H.E.S.S. source best-fit position (No pulsations - No extended emission)
- No counterpart with Fermi-LAT (*Nolan et al., 2012*)
Against **SNR-MC** scenario
- H.E.S.S. source: *point-like* or extension ≤ 0.09° (99% CL)
- close to the G22.7-0.2 radio rim
- coincident with 2 clouds: $^{13}$CO (J=0-$\rightarrow$1) (Jackson et al., 2006)

Against **PSR-PWN** scenario
- X-ray point-like source 1’ away from the H.E.S.S. source best-fit position (*No pulsations - No extended emission*)
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Possible SNR-MC shock
Possible PSR-PWN scenario
**HESS J1832-092:**

**Against SNR-MC scenario**
- H.E.S.S. source: point-like or extension ≤ 0.09° (99% CL)
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**Assuming a SNR-MC interaction:**

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<th>$\Gamma = 2.5$</th>
<th>$\Gamma = 2.1 + 10 \text{ TeV cutoff}$</th>
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<tbody>
<tr>
<td>Cloud (a)</td>
<td>$2.5 \times 10^{50}$ erg</td>
<td>$7.0 \times 10^{48}$ erg</td>
</tr>
<tr>
<td>Cloud (b)</td>
<td>$2.6 \times 10^{50}$ erg</td>
<td>$7.2 \times 10^{48}$ erg</td>
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4 new H.E.S.S. sources possibly associated to a SNR-MC interaction
HESS J1640-465: Extended H.E.S.S. source
- Coincident w/ the northern part of the G338.3-0.0 SNR shell:
  D≈8kpc or D≈13kpc (Lemière et al., 2009; Davies et al., 2012), Ø=8’
- HII region between SNR G338.3-0.0 & SNR G338.5+0.1
  Nearby stellar cluster Mc81
- Coincident w/ an extended X-ray source (Funk et al., 2007)
  + Pt-like X-ray source (Lemière et al., 2009)
- Coincident w/ a Fermi-LAT source (Slane et al., 2010)
HESS J1640-465:

- Extended H.E.S.S. source
- Coincident w/ the northern part of the G338.3-0.0 SNR shell:
  \( D \approx 8 \text{kpc or } D \approx 13 \text{kpc} \) \( (\text{Lemière et al., 2009; Davies et al., 2012}) \), \( \emptyset = 8' \)
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- Coincident w/ an extended X-ray source \( (\text{Funk et al., 2007}) \)
  + Pt-like X-ray source \( (\text{Lemière et al., 2009}) \)
- Coincident w/ a Fermi-LAT source \( (\text{Slane et al., 2010}) \)

⇒ First interpreted as PSR-PWN scenario \( (\text{Lemière et al., 2009; Slane et al., 2010}) \)
The new H.E.S.S. results and MWL data suggest that at least part of the TeV emission is likely of hadronic origin.

Total energy in interacting protons of up to \( W_p n_H \approx 4 \times 10^{52} \frac{d}{10 \text{ kpc}} \) erg cm\(^{-3}\)
HESS J1641-463:

- H.E.S.S. source: pt-like or small extension (Ø=3.6’)
- Coincident w/ SNR G338.5-0.1:
  D≈11kpc (Kothes & Dougherty, 2007)
  Ø=9’ (Green, 2009) or Ø=5’ (Whiteoak et al., 1996)
- HII region between SNR G338.3-0.0 & SNR G338.5+0.1
  Nearby stellar cluster Mc81
- No evident X-ray counterpart
- No GeV counterpart
HESS J1641-463:

- H.E.S.S. source: pt-like or small extension ($\varnothing=3.6'$)
- Coincident w/ SNR G338.5-0.1:
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  $\varnothing=9'$ (Green, 2009) or $\varnothing=5'$ (Whiteoak et al., 1996)
- HII region between SNR G338.3-0.0 & SNR G338.5+0.1
  Nearby stellar cluster Mc81
- *No evident X-ray counterpart*
- No GeV counterpart

SNR shell much larger than VHE source: PWN scenario ?

Against

PSR-PWN scenario
- H.E.S.S. source: pt-like or small extension (Ø=3.6′)
- Coincident w/ SNR G338.5-0.1:
  D≈11kpc (Kothes & Dougherty, 2007)
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- HII region between SNR G338.3-0.0 & SNR G338.5+0.1
  Nearby stellar cluster Mc81
- No evident X-ray counterpart
- No GeV counterpart

HII bridge + similarities between the 2 SNRs:
Emission from same hadronic origin?
H.E.S.S. sources associated and possibly associated to a SNR-MC interaction.
Comparison of integrated GeV and TeV fluxes for different kind of TeV sources coincident w/ a SNR

TeV emission from:
- SNR-MC shock
- Possible SNR-MC shock
- Isolated SNR
Ratio of integrated GeV and TeV fluxes vs SNR age for different kind of TeV sources coincident w/ a SNR

TeV emission from:
- SNR-MC shock
- Possible SNR-MC shock
- Isolated SNR
Conclusion and outlook (1/2) :

Some trends between the two populations of SNRs (SNR-MC & isolated SNRs) are apparent in the data :

- **SNRs interacting w/ MCs**: *W28, W51C, W49B, IC443*
  \( I_{\text{GeV}} \gg I_{\text{TeV}} \): Steepening of the spectra around \( E_\gamma = 1-10 \) GeV

- **Isolated SNRs**: *Vela Jr, HESS J1731-347, RCW 86, RX J1713.7-3946, SN1006...*
  Young SNRs
  \( I_{\text{GeV}}/I_{\text{TeV}} \) much lower than for SNR-MC systems: Hard GeV & strong TeV sources

- **H.E.S.S. new sources possibly interacting w/ MCs**: *HESS J1834-087, HESS J1832-092, HESS J1640-465, HESS J1641-463*
  \( I_{\text{GeV}} \) vs \( I_{\text{TeV}} \): sources between the two populations of SNRs
  \( I_{\text{GeV}}/I_{\text{TeV}} \) vs Age: sources between the two populations of SNRs
Conclusion and outlook (2/2):

**H.E.S.S. II**: lower energy threshold
Improved sensitivity and resolution

**W44**: a SNR-MC undetected at VHE

Will be further explored with H.E.S.S. II

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Ackermann et al., 2013
Thank you for your attention.