Unveiling the nature of the sources of High-Energy
- Recent discoveries from TeV and X-ray observations

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Searching for the origins of Galactic CRs

- Why using HE observations to search for CR accelerators
- Opportunities in the unidentified sources
- Evidence of e- acceleration using X-ray observations
  -> The case of the PWN J0855-4644
- TeV emission from shell SNRs
  -> The case of the SNR HESS J1731
- The GeV-TeV connection with the Fermi satellite
- CTA, the next generation of Cherenkov telescope
Cosmic rays accelerators

- Where are accelerated hadrons (99% of CRs)? CRs are deflected by Galactic B field
- What is the contribution of PWNe?
- Candidates need to reproduce observed flux and $E_{\text{max}}$
<table>
<thead>
<tr>
<th>Survey</th>
<th>Nb of sources</th>
<th>Unid. src</th>
<th>Possible Gal. counterpart</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTEGRAL IBIS/ISGRI</td>
<td>723</td>
<td>210</td>
<td>binaries, PSR/PWN</td>
</tr>
<tr>
<td>Bird+ 10</td>
<td></td>
<td></td>
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<tr>
<td>Fermi-LAT</td>
<td>1451</td>
<td>630</td>
<td>PSR, middle aged SNR, SNR/MC</td>
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<tr>
<td>Abdo+ 10</td>
<td></td>
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<tr>
<td>H.E.S.S.</td>
<td>60</td>
<td>30</td>
<td>PWN, young SNR, SNR/MC</td>
</tr>
<tr>
<td>Chaves+08</td>
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</tbody>
</table>
Cherenkov astronomy

30 out ~60 Galactic sources are unidentified

Chaves et al. HESS (2008)
SNRs at TeV energies

- **Shell-morphology**
  - young SNRs: $t \sim 1 \text{kyr}$
  - Vela Jr, RX J1713-3946, RCW 86 (?), SN 1006

- **Interacting with molecular clouds**
  - older SNRs: $t \sim 10 \text{kyrs}$
  - IC 443, W28, W51

- Possibility to directly investigate proton acceleration through hadronic process
Nature of the TeV emission: hadronic/leptonic

SN 1006

Fabio Acero
PWNe at TeV energies

**Young PWNe**

Crab, G0.9+0.1, MSH 15-52, G21.5-0.9, Kes 75...

**Offset PWNe**

Vela-X

- Leptonic TeV emission: Probing the Magnetic field
- SED modelization difficult. One population model not valid (e.g. Vela-X)
Discoveries in X-rays:
A new PWN in the VelaJr region
Motivations to observe PSR J0855-4644

**ROSAT > 1.3 keV**

**HESS excess map (Aharonian+07)**

**Pulsar parameters**

\[ P = 64 \text{ ms} \]
\[ \dot{E} = 1.1 \times 10^{36} \text{ ergs/s} \]
\[ d = 4 \text{ kpc (from DM)} \]

Kramer+03, Redman+05
Discovery of a new PWN in the VelaJr region

VelaJr SE rim

PWN

1.2-6.0 keV

XMM-Newton
PWN radial profile

Point source nearby

- Fitted PSF
- PSF from Calibration

Surface Brightness vs. Radius in arcsecs

PSR J0855-4644 BANDLMH

- Total
- Fitted PSF
- Fitted PWN

Surface Brightness vs. Radius in arcsecs

point source subtracted
PWN morphology

1.2-2.0 keV

σ = 61.2'' ± 2.2''
**PWN morphology**

- Energy range: 2.0-4.0 keV
- Spatial resolution: $\sigma = 53.2'' \pm 1.8''$
- Visualisation with a circular outline of 60'' radius.
Pulsar parameters

- $P = 64 \text{ ms}$
- $\dot{E} = 1.1 \times 10^{36}$ ergs/s
- $\tau_c = 150 \text{ kyr}$

- $n_H = 0.40 \pm 0.08 \times 10^{22}$ cm$^{-2}$
- $\Gamma_{psr} = 1.25 \pm 0.06$
- $F_{2-10\text{keV}} = (2.2 \pm 0.4) \times 10^{-13}$ (ergs/cm$^2$/s)

$kT$ and $n_H$ from Vela thermal emission fixed from the nebula
• PSR is likely to lie at a distance <2kpc, i.e. in the foreground of the Vela Molecular Ridge (VMR, d=1 kpc)

• \( n_H(\text{VelaJr SE rim}) \approx 0.5 \times 10^{22} \text{ cm}^{-2} \) and dist \( \approx 0.7 \text{ kpc} \)
Changing distance changes everything

- A nearby energetic pulsar
- Why wasn’t it discovered before?
  -> Embedded in a complex region

Only psr with $E_{\text{dot}} > 10^{35}$ ergs/s selected
Morphology

- Vela PSR
- 3C58 PSR
Jet structures?

PSR J0855-4644

Chandra FWHM: 1"
XMM FWHM: 6"

Chandra proposal has been submitted
Discoveries at TeV energies:
HESS J1731 a new TeV shell type SNR
PostDoc: HESS J1731-347

F. Acero for the HESS collaboration, 2011
PostDoc: HESS J1731-347

- Only the 4\textsuperscript{th} example of gamma TeV shell SNR!
- First shell SNR discovered based on Gamma observations!!
- Non-thermal shell seen in radio, X-rays, Gamma-rays

F. Acero for the HESS collaboration, 2011
HESS J1731-347 & J1729-245

Radial profile

Gamma-ray excess

Radial profiles

F. Acero for the HESS collaboration, 2011

- Spatially coincident with radio shell
- 4th TeV SNR with significant shell morphology
**HESS J1731-347**

**Distance estimate**

- $N_H$ from X-rays
- $N_H$ from $^{12}$CO+HI integrated up to 3.2 kpc

![Map showing Estimated Distance](image)

$d = 3.2$ kpc

**SNR**
Clouds in the line of sight

Molecular Cloud
$M=10^5 \, M_{\text{sun}}$
$d=6 \, \text{kpc}$
HESS J1731 - Spectral energy distribution

Leptonic model

\[ W_e = 3 \times 10^{47} \left( \frac{d}{3.2 \text{ kpc}} \right)^2 \text{ ergs} \]
\[ B = 25 \mu \text{G} \]

+ Reasonable energetic budget
- Spectral slope not reproduced

Hadronic model

\[ W_p = 6 \times 10^{50} \left( \frac{n}{1 \text{ cm}^{-3}} \right)^{-1} \left( \frac{d}{3.2 \text{ kpc}} \right)^2 \text{ ergs} \]
\[ E_{SN} \sim 10^{51} \text{ ergs} \]
\[ B = 50 \mu \text{G} \]

+ Spectral slope
- Energetic budget
HESS J1731 - What about Fermi?

Fermi Test Significance map
Only photons of $E > 1$ GeV
Sky model: Gal. and extragal.

Velocity integrated $^{12}$CO map
(Dame+01)
White: HESS contours
Black Fermi 1 yr catalog sources
**RX J1713-3946: hadronic or leptonic?**

**Red --- (Berezhko 2010):**
- $B=142 \ \mu G$
- $nH=0.25 \ \text{cm}^{-3}$ (bubble cavity)
- $W_p=0.45 \times 10^{50} \ \text{ergs}$

**Blue --- (Ellison, 2010):**
- $B=10 \ \mu G$
- $nH=0.25 \ \text{cm}^{-3}$ (uniform ISM)

**γ-ray emission is dominated by leptonic processes**
Have we found the Galactic CRs accelerators?

**Shell SNRs**

- TeV emission seems dominated by leptonic scenario
  \[ n_{\text{target}} \] too weak for a significant hadronic signal

- Importance of multi-\(\lambda\) observations for the modelization (distance, \(n_{\text{target}}\))

- Search for other young SNRs
  expected number in the Galaxy \(\sim 40\)

- Other sources for CRs?
  Superbubbles?

- Sources possibly already detected
  \(\sim 50\%\) of Fermi\&HESS src are unId.

- Joint H.E.S.S.II-Fermi
  + multi-\(\lambda\) counterpart search
The Cherenkov Telescope Array

- Large array of telescopes (3 different sizes) operating in $100 \text{ GeV} < E < 100 \text{ TeV}$

- A factor of 5-10 in sensitivity and $\sim 3$ in angular resolution

- Extend our horizon of detectability for SNRs and PWNe
Towards a complete census of young SNRs in our Galaxy

- Shell morphology spatially resolved for only ~20% of the SNRs
- Source confusion will be higher for CTA in Galactic central regions
- Multi-λ observations will be critical for CTA for source identification
**CTA simulation : Morphology**

**RX J1713**

**Observation**

*HESS* $r_{68\%} (\text{PSF}) = 0.08^\circ$

Aharonian et al, 2007

**CTA simulation**

$CTA \ r_{68\%} (\text{PSF}) = 0.04^\circ$

M. Renaud & F. Acero

CTA simulation based on the X-ray map

$T_{\text{obs}} = 50 \text{ h}$
CTA simulation : Morphology

RX J1713

**Observation**

**HESS** $r_{68\%}^{\text{(PSF)}} = 0.08^\circ$

Aharonian et al, 2007

**CTA simulation based on the X-ray map**

$T_{\text{obs}} = 50 \text{ h}$

**CTA** $r_{68\%}^{\text{(PSF)}} = 0.02^\circ$

M. Renaud & F. Acero
Thank you!

SN 1006 supernova remnant