Fermi-LAT detection of the massive star forming region W49A in high-energy gamma rays

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The W49 region

VLA (21 cm) observations (Brogan & Troland).

- **SNR W49B**
  - Mixed-morphology SNR (radio shell of $\sim 3' \times 4'$, centrally filled with thermal X rays)
  - Age $\sim 1 - 4$ kyr (Moffett & Reynolds 1994)
  - $D \sim 10$ kpc (Zhu et al. 2014)
  - Interacting with dense MC

- **Star forming region W49A**
  - $D = 11.1 \pm 0.7$ kpc (Zhang et al. 2013)
  - Located in the densest 15 pc of a $10^6 M_\odot$ GMC of $\sim 100$ pc
  - Powered by the equivalent of $\sim 100$ O7 Stars (Vacca 1994) and contains numerous UC HII regions (De Pree et al. 1997)
  - One of the most massive star forming regions outside the Galactic centre

The W49 region & FL8Y

- FL8Y J1910.2+0904 coincident with the massive star forming region W49A
  - RA = 287.5535°, Dec = 9.0756°
  - Signif_Avg = 10.321

- FL8Y J1911.0+0905 coincident with the SNR W49B (see Fermi+H.E.S.S. paper)
W49A analysis

- Fermi re-analysis (with the Enrico package):
  - XML Model
    - From FL8Y list of sources:
      - ROI of 15°
      - Fix params if more than 5° away from the source or Signif_Avg < 5
- Data
  - Dates: 05/08/2008 → 05/01/2018
  - Energy range: 300 MeV - 300 GeV
- Analysis
  - P8R2_SOURCE_V6, Evclass = 128, Evtype = 56 (PSF1,2,3)
W49A analysis : Results

- **Nice residuals map**

- **Source parameters**:
  - TS = 213.8
  - Index = 2.32 $\pm$ 0.05$_{\text{stat}}$ $\pm$ 0.09$_{\text{syst}}$
  - $E_p = 4204.31$ MeV
  - Prefactor = $(14.16 \pm 0.99_{\text{stat}} \pm 2.43_{\text{syst}}) \times 10^{-14}$ cm$^{-2}$s$^{-1}$MeV$^{-1}$
  - **Systematics estimation**:
    - Re-fit and fix the scale of the obtained galactic diffuse to 0.94 and 1.06
W49A analysis : SED

- Nice agreement with FL8Y spectrum

Nice agreement with the spectrum obtained in FL8Y!
W49A analysis: comparison with TeV data

- SED: Comparison with TeV data
  - No detection at TeV with H.E.S.S.

VHE $\gamma$-ray emission is observed towards W49A with the primary analysis but it could not be confirmed (above 5$\sigma$) with the cross-check analysis. Therefore, only the VHE emission coincident with W49B is discussed in the following.

W49B stats:
$(ON, OFF, \alpha) = (1141, 16017, 0.047) \rightarrow N_\gamma = 388.2$

With the same background estimation, to get 5$\sigma$ $N_{ON} = 897$. This corresponds to $N_\gamma = 145.2$

Scaling the W49B spectrum by the ratio (assuming same index)...
W49A analysis: comparison with TeV data

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Break around 300 GeV in the gamma-ray spectrum?
Hadronic model fits using naima

- MCMC fitting routines of naima (Zabalza, 2015)
- 2.5σ improvement with an exponential cut-off
- Low cut-off energy in proton spectrum = 500 (+600 / -200) GeV
- Exp PL index = 2.1 ± 0.1
- PL index = 2.4 ± 0.1
- \( W_p (E > 1 \text{ GeV}) = 2.5 (± 0.6) \times 10^{51} \text{ erg/cm}^3 \) for Exp PL; \( 3.5 (± 0.4) \times 10^{51} \text{ erg/cm}^3 \) for simple PL
A major factory of Galactic cosmic-rays?

- Similar differential luminosities
- Gamma-ray spectral index ~ 2.3 in all cases
- Points towards same acceleration mechanism: interacting winds of massive stars
- Using a catalog of O stars (Wu et al. 2016), one can estimate $E_{\text{kin}} > 7 \times 10^{37}$ erg/s in W49A vs $E_{\text{kin}} = 2 \times 10^{38}$ erg/s for Cygnus Cocoon
- This difference cannot explain the apparent high energy break in W49A

Would be due to lack of SNRs in W49A?

Wind interactions are less efficient than SNR shocks?
Summary & Outlook

- SFR are cosmic-ray factories and shine at gamma-rays
- Cygnus cocoon was the only confirmed case, a few candidates
  - Are SFR PeVatrons?

- W49A is in the FL8Y source list, re-analysed in this work
- Comparison with TeV data: energy break at rather low energies ($\sim 300 \text{ GeV} \rightarrow E_{\text{max, } p} < 10 \text{ TeV}$)
- Potentially showing that collective effects of stellar winds are less efficient than a SNR shockwave

- Prime sources for CTA!
Additionnal slides
The Cygnus cocoon

- Extended gamma-ray emission from the Cygnus region detected by the Fermi-LAT
- Freshly accelerated CRs fill a cavity probably created by Cyg OB2 & NGC 6910
- First evidence of CR acceleration from collective effect of the winds of massive stars
  - SFRs can be CR factories
  - ARGO results: $E_{\text{max}, p} = 150$ TeV
G25.0+0.0

- Fermi-LAT detection of extended gamma-ray emission in the G25 region (Katsuta et al. 2017)

G25A 1,2,3 + G25B 2,3 : Hard spectrum ($\Gamma = 2.1$)

- Likely association with a massive SFR
  - As in Cygnus X : a « cocoon » scenario is favored (but PWNe are present)
Other candidates?

- **NGC 3603** (Yang & Aharonian, 2017)
  - Extended (~ 1° radius) HE gamma-ray emission coincident with the most massive HII region in the Galaxy
    ... but crowded region with possible counterparts (SNRs/PWNe)
- **Westerlund 1** (HESS Collaboration, 2012)
  - Same as above
- **Westerlund 2** (HESS 2007 & 2011, Lemoine-Goumard et al. 2011)
  - TeV and GeV emission detected by HESS and the Fermi-LAT
    ... but the LAT also detected a very young and energetic pulsar (PSR J1023-5746). The emission is most probably a PWN.
Other candidates?

- **W43** (Lemoine-Goumard et al. 2011, HESS 2018)
  - GeV and TeV detection of a source coincident with W43 but the GeV spectrum has a Pulsar-like spectrum, contamination?

- **FHES J2129.9+5833** (Ackermann et al. 2018)
  - Extended off-plane source partially overlapping IC 1396 but the association remains to be confirmed

- **HESS J1808-204 and HOTS J1907+091** (HESS 2018)
  - Coincident with stellar clusters
    - ... but also with magnetars (and the part of a SNR shell for HOTS J1907+091)
  - New FL8Y source coincident with HOTS J1907+091