Search for new cosmic-ray acceleration sites within the Galactic plane 4FGL sources

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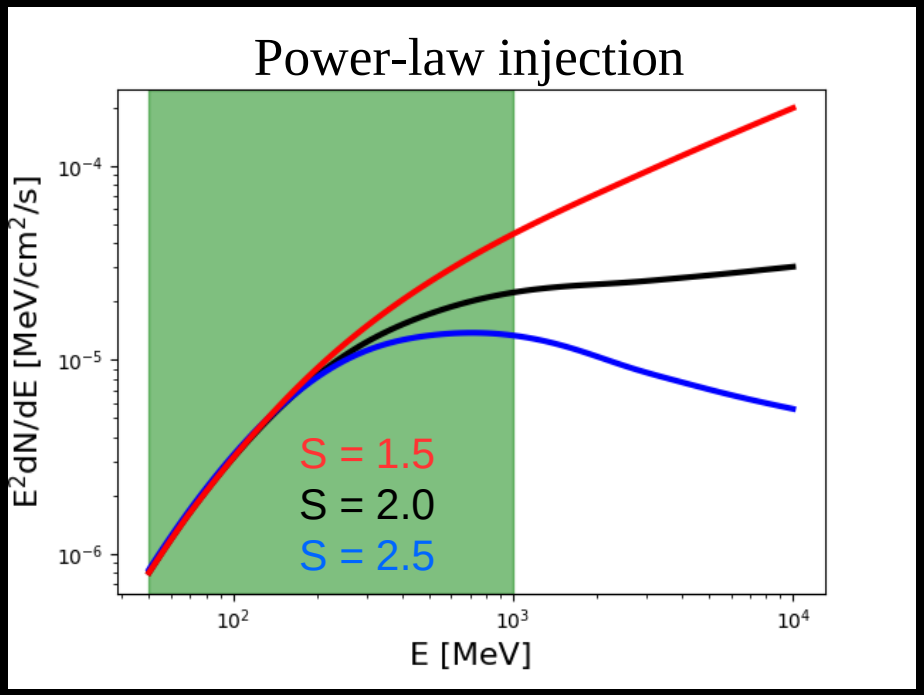
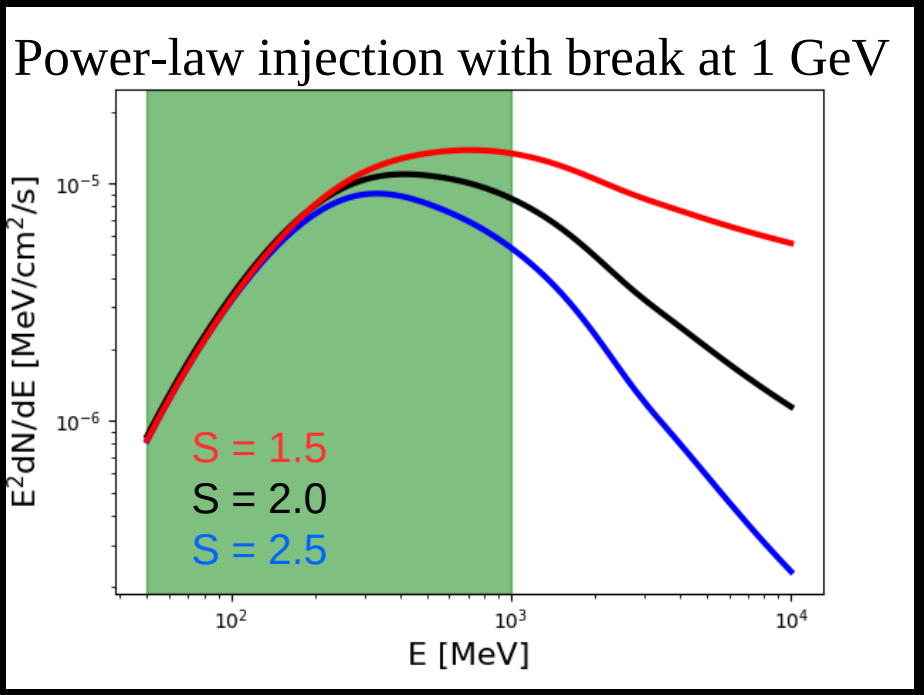
π^0-decay gamma-rays: probe of accelerated protons

γ-ray spectral shape is determined solely by dN/dp (proton spectrum)

$dN/dp \propto p^{-s} \exp(-p/p_m)$ s=1.5, 2.0, 2.5

Very hard spectrum below 300 MeV for any reasonable index

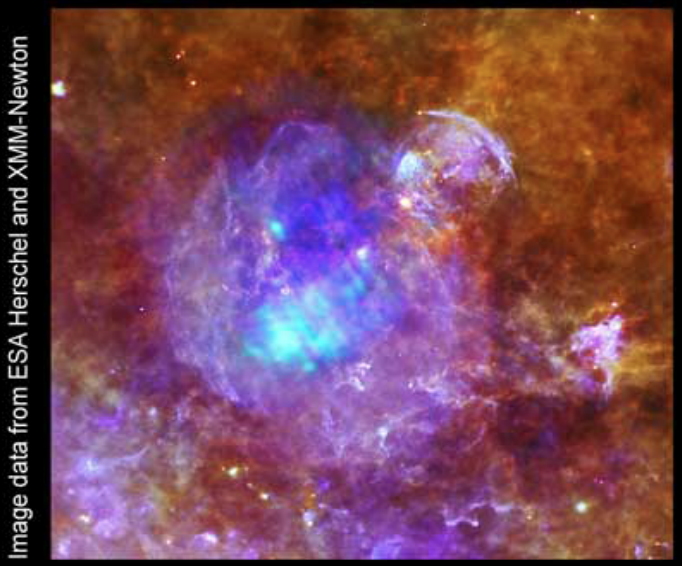


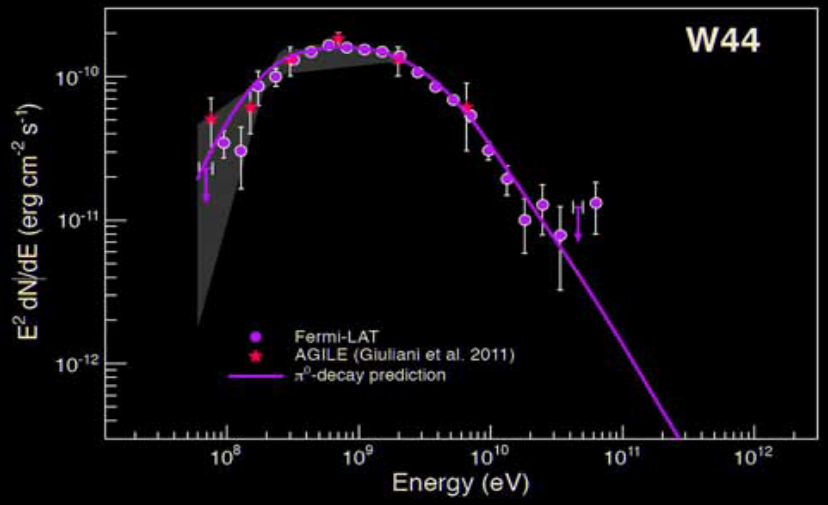


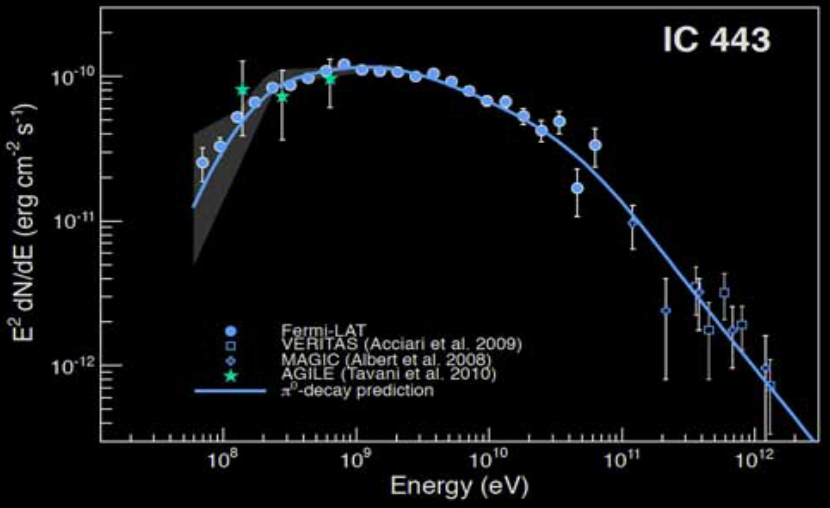
NASA press release (Feb 2013) : CR protons in SNRs

« NASA's Fermi Proves Supernova Remnants Produce Cosmic Rays »

Supernova W44 & IC 443 Neutral Pion Decay Spectral Fit







Looking for low-energy spectral breaks

Aim:

- Search for low energy spectral break among Galactic 4FGL sources

- 4FGL sources tested: Significance (300 MeV – 1 GeV) > 3σ between [-5°, 5°] in latitude => 311 candidates

- Use the 4FGL catalog and the associated diffuse backgrounds released

Why ?

1- 4FGL spectra are performed between 50 MeV and 1 TeV => they are dominated by photons close to the pivot energy (~1 GeV) and could miss spectral breaks

2- 4FGL catalog only provides the fit with a LogParabola (or a super exponential cut-off)

3- Low energy spectral breaks expected for proton-proton interaction

How ?

- Files produced for the 4FGL catalog

- Pass 8 PSF3 & PSF2 source events in a 20x20° binned analysis

- E = [50 MeV, 1 GeV] ; Zmax = 80° ; IRF= P8R3_SOURCE_V3 ; edisp_bins = - 3

- Fit with LogPL, SBPL and SBPL with Γ=2 (SBPL2)

More details in arxiv:2205.03111

The famous pion-bump of IC 443

Middle-aged SNR with characteristic pion bump signature (Ackermann et al. 2013)

Very significant break detected with our pipeline :

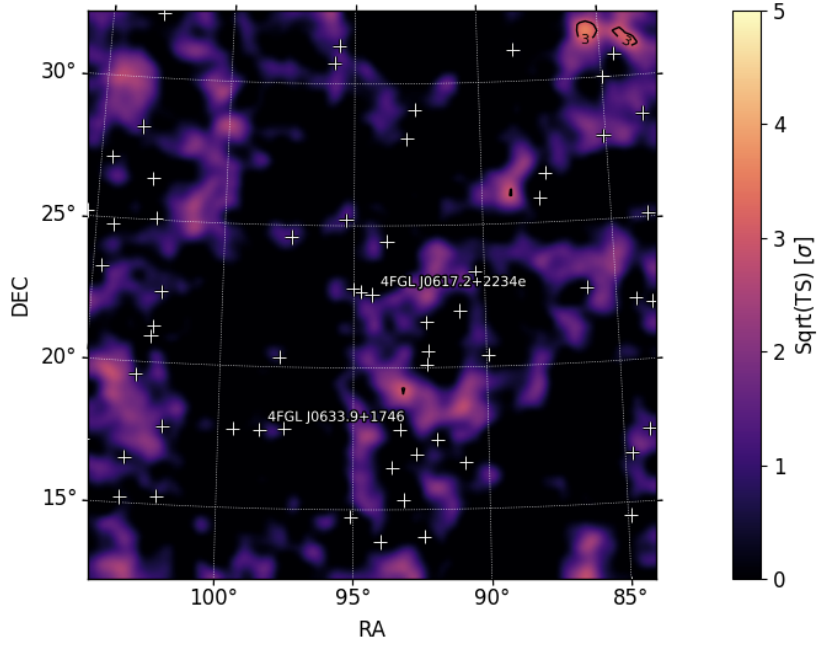
$\Delta TS_{LogP-PL}$ = 93 ; $\Delta TS_{SBPL-PL}$ = 99 ; $\Delta TS_{SBPL2-PL}$ = 80

E_{break} = 276 ± 19 ± 3 MeV

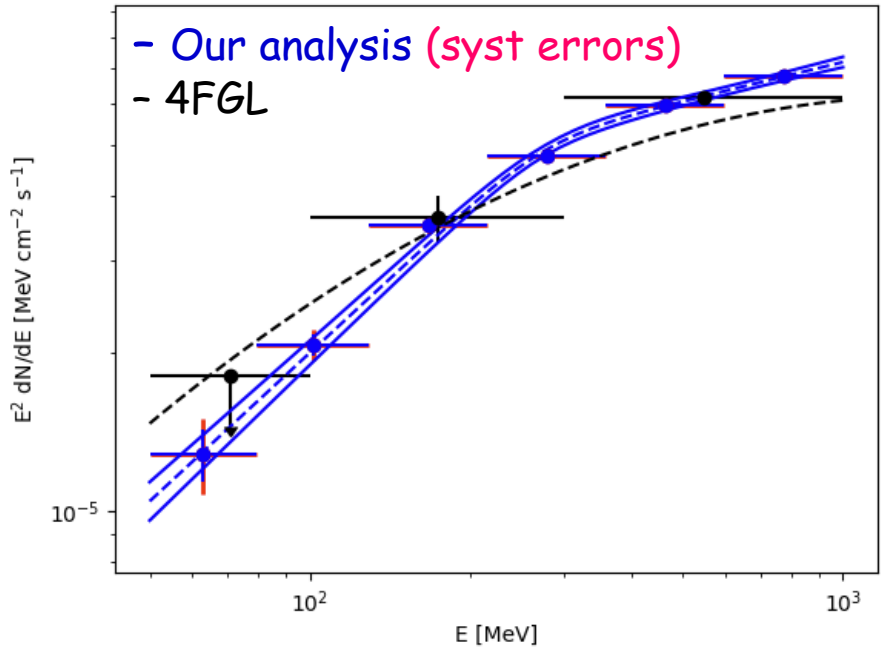
Γ_1 = 1.06 ± 0.05 ± 0.03 ; Γ_2 = 1.75 ± 0.03 ± 0.03

(Credit: Chandra X-ray: NASA/CXC/B.Gaensler et al; ROSAT X-ray: NASA/ROSAT/Asaoka & Aschenbach; Radio Wide: NRC/DRAO/D.Leahy; Optical: DSS)

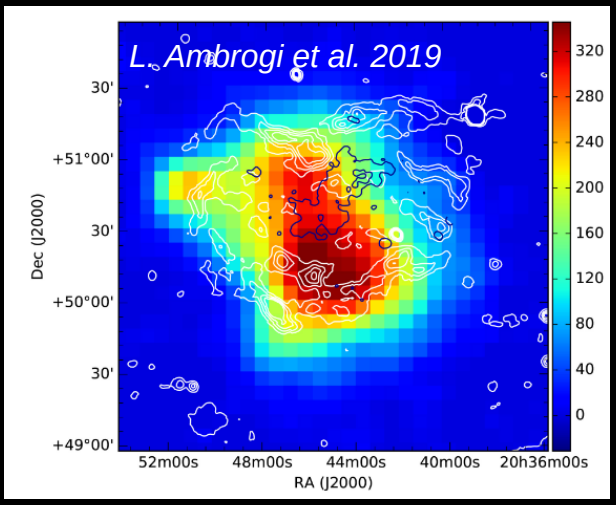
Residual TS map



Spectral Energy Distribution



Another SNR candidate : HB21



Similar to IC 443 and W44, HB 21 is also a mixed morphology SNR

Age : few tens of thousands years

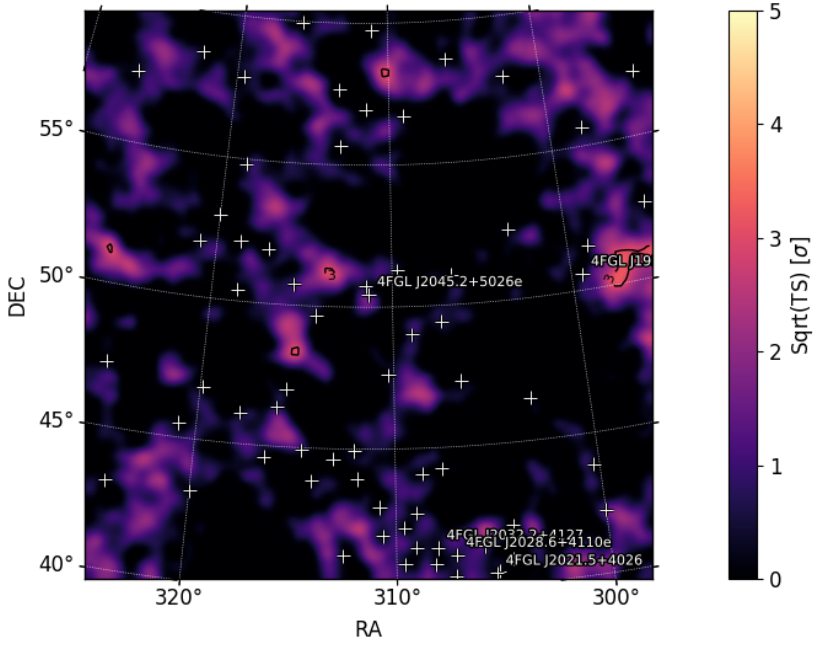
(Koo& Heiles 1991; Leahy & Aschenbach 1996)

Distance : 0.8 kpc (Tatematsu et al. 1990; Koo et al. 2001)

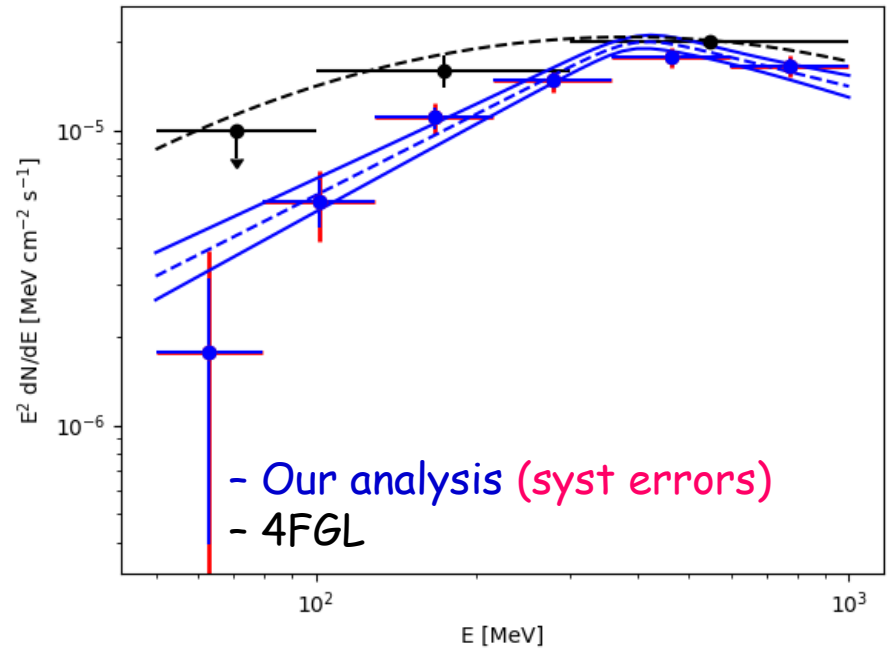
Fermi-LAT low energy turn over was already detected by L. Ambrogi et al. 2019

Very significant break in our analysis : $\Delta TS_{LogP-PL} = 42$; $\Delta TS_{SBPL-PL} = 42$; $\Delta TS_{SBPL2-PL} = 34$

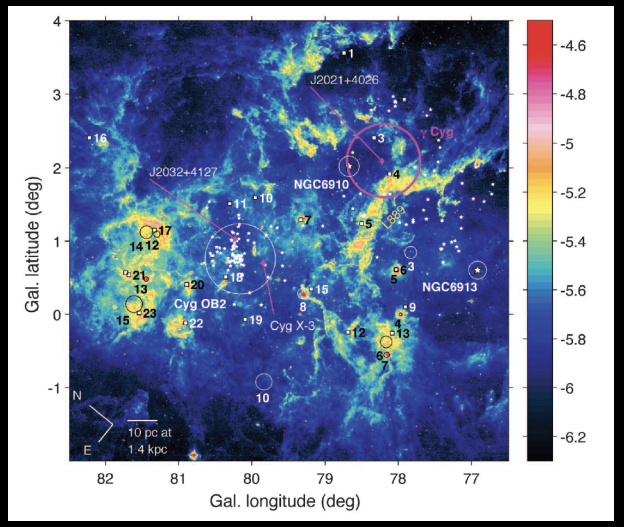
Residual TS map



Spectral Energy Distribution



A star forming region : Cygnus



Region located in the Local Arm of the Galaxy at ~1.4 kpc

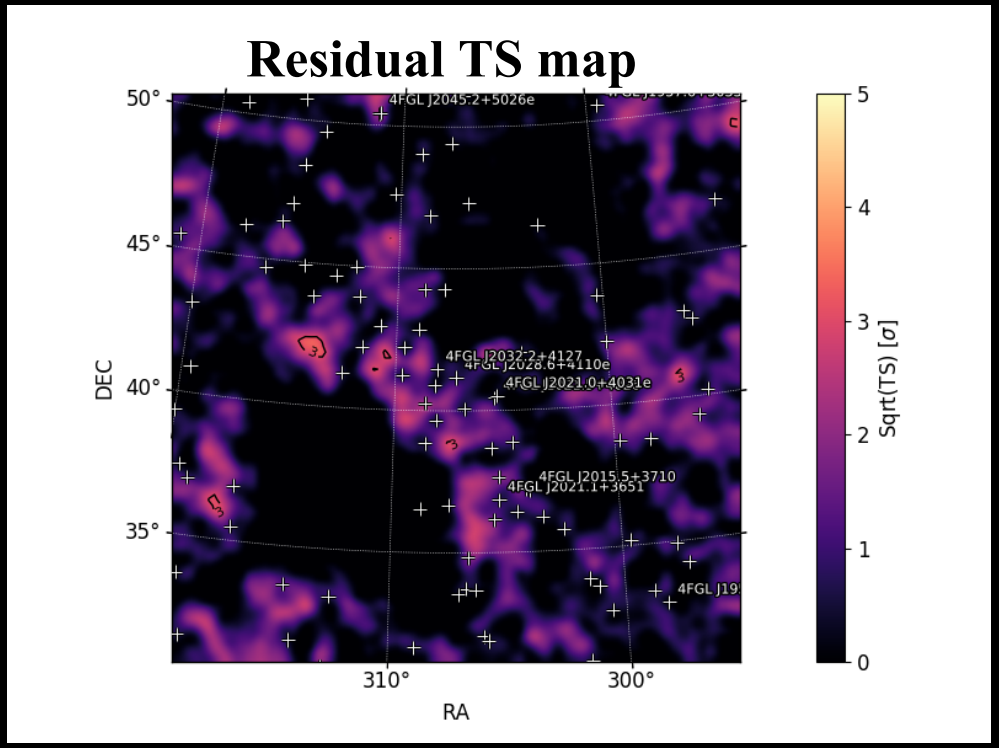
LAT discovery of a 50-pc wide cocoon of freshly-accelerated CRs
Ackermann et al. 2011

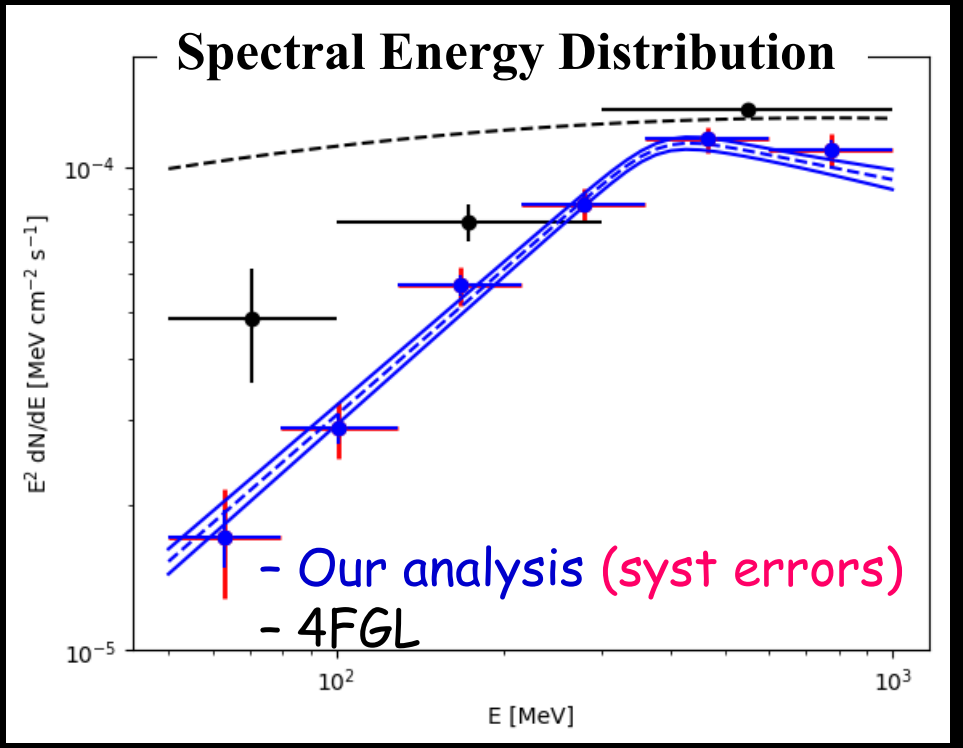
VHE detection of a counterpart HAWC J2030+409
Abeysekara et al. 2021

LAT+HAWC emissions likely due to hadronic interactions

Coincident with LHAASO J2032+4102 with E_{max} = 1.42 ± 0.13 PeV
Zhen Cao et al. 2021

Significant spectral break detected with our pipeline :
$\Delta TS_{LogP-PL}$ = 120; $\Delta TS_{SBPL-PL}$ = 106; $\Delta TS_{SBPL2-PL}$ = 99





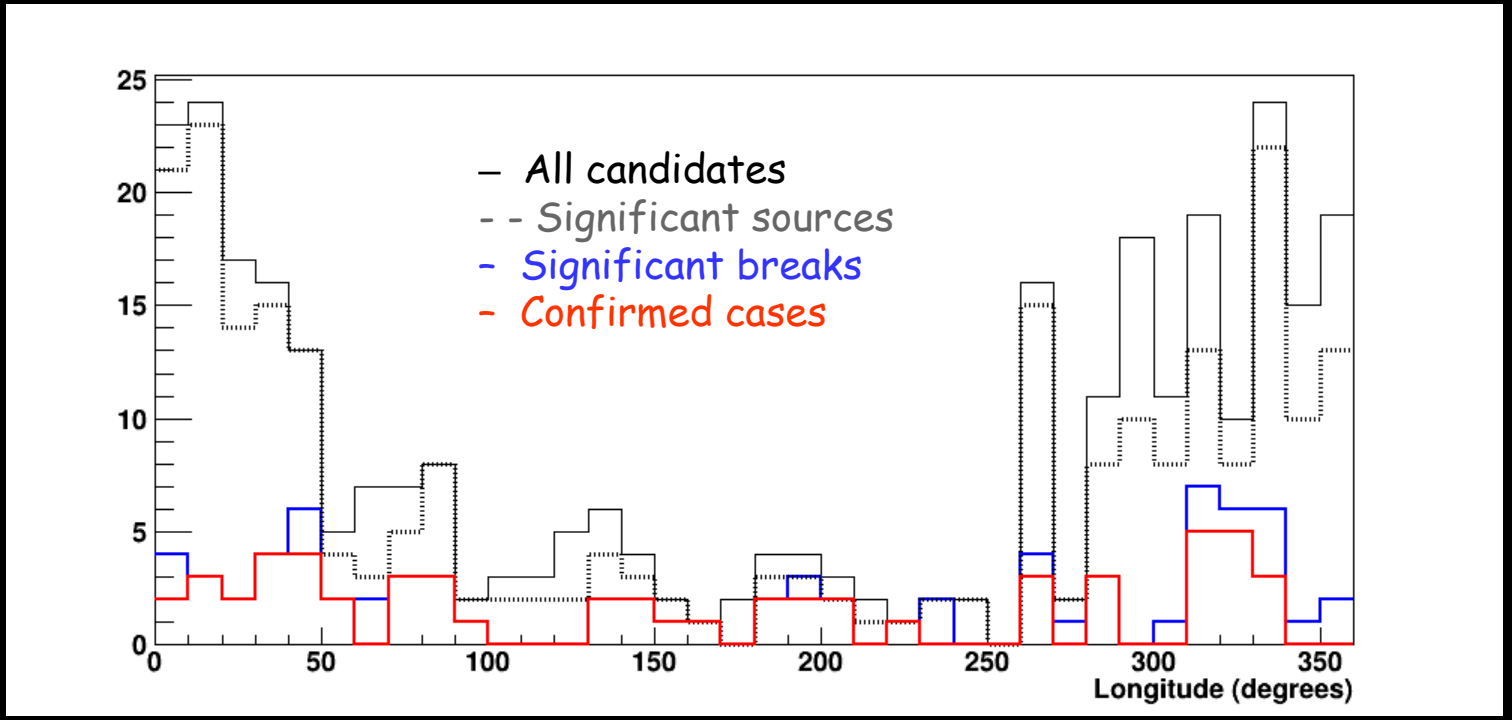
Results

Analysis carried on 311 candidates

77 sources have $\Delta TS_{SBPL-PL} > 12$ or $\Delta TS_{SBPL2-PL} > 9$

56 sources are confirmed by our systematics study

Sources showing breaks are distributed uniformly in Galactic longitude



Population study

Among these 56 candidates :

10 sources are firm SNR identifications

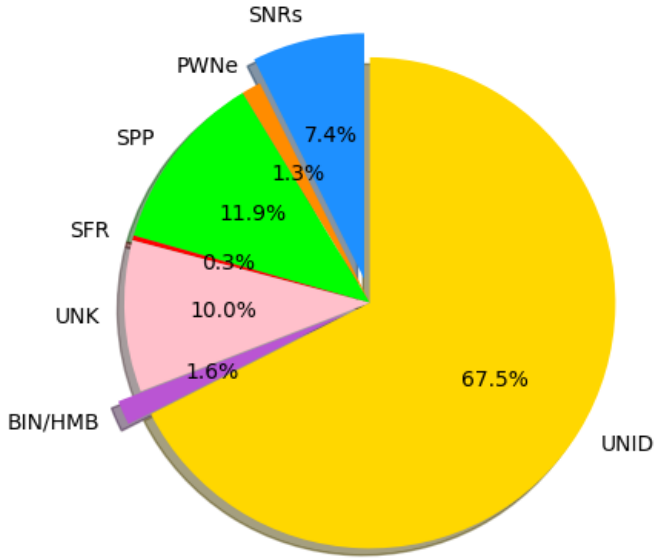
3 are associated with SNRs

6 are SPP (SNRs or PWNe candidates)

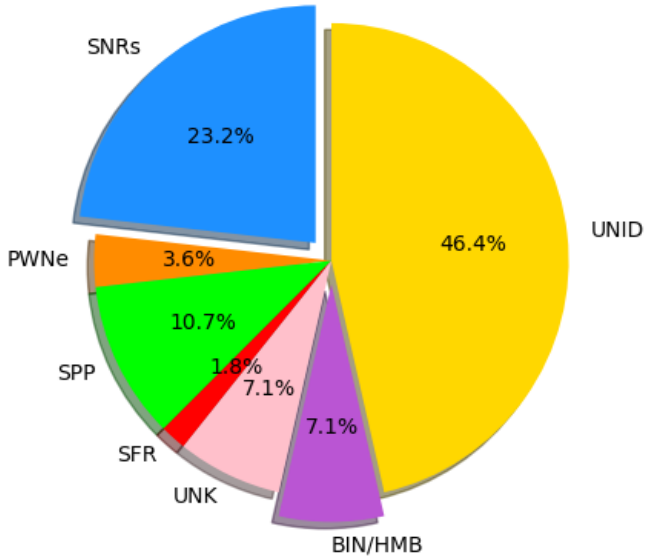
This makes SNRs the dominant class of sources showing spectral breaks in this analysis

Despite their small fractions, binaries also seem to contribute significantly

Population class of the 311 sources analyzed



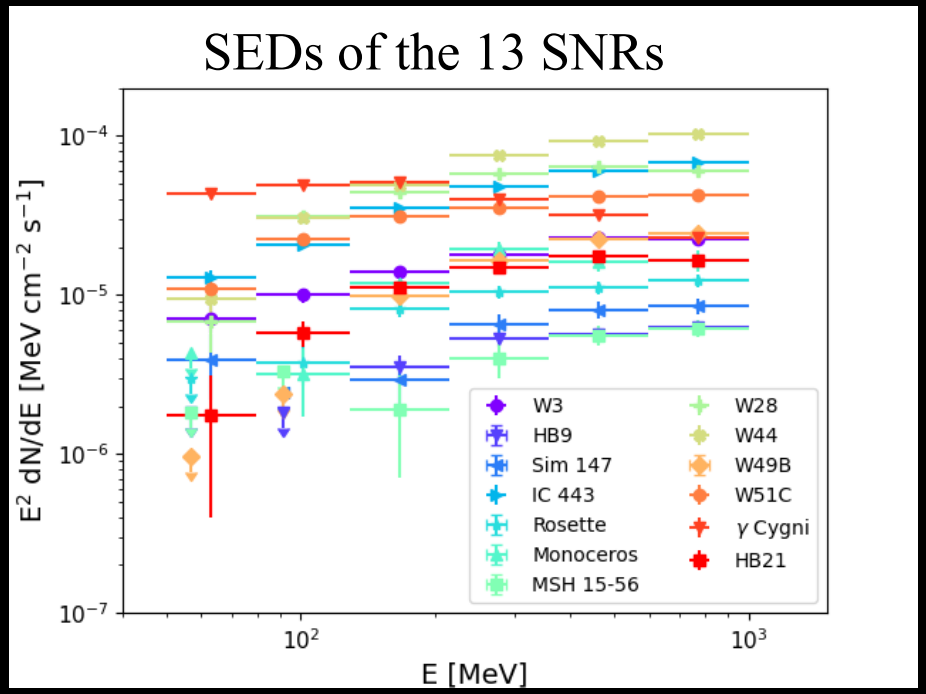
Population class of the 56 candidates detected

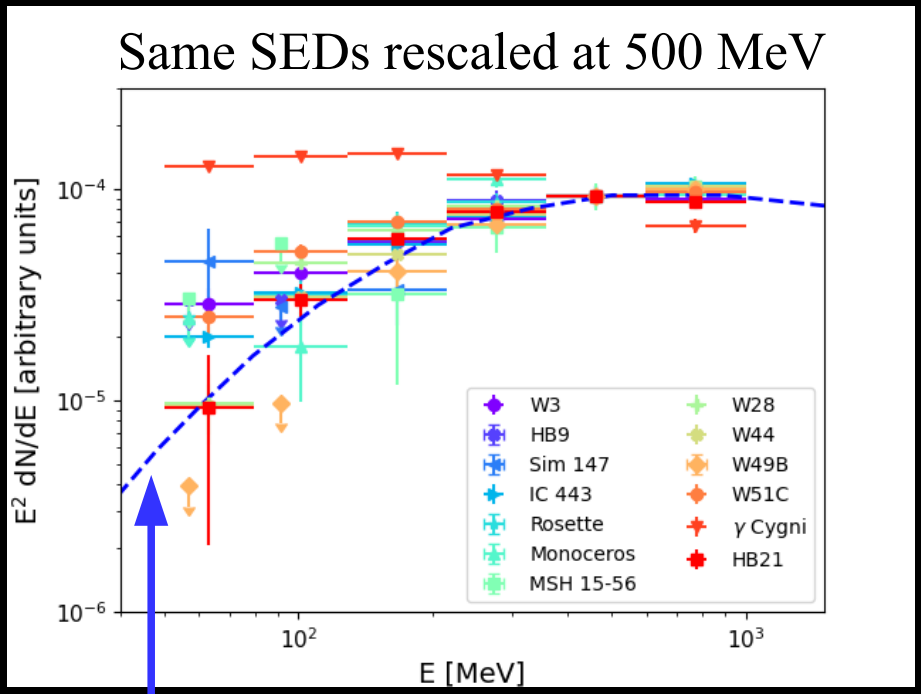


SNRs with significant breaks

12 SNRs follow the gamma-ray emission expected for a proton spectrum with index=2.4
=> hadronic emission favoured

Only exception is gamma Cygni
=> probable contamination by the bright pulsar PSR J2021+4026





Gamma-ray emission expected for a proton spectrum with index=2.4

Interesting candidates with significant breaks

4FGL J1633.0-4746e :

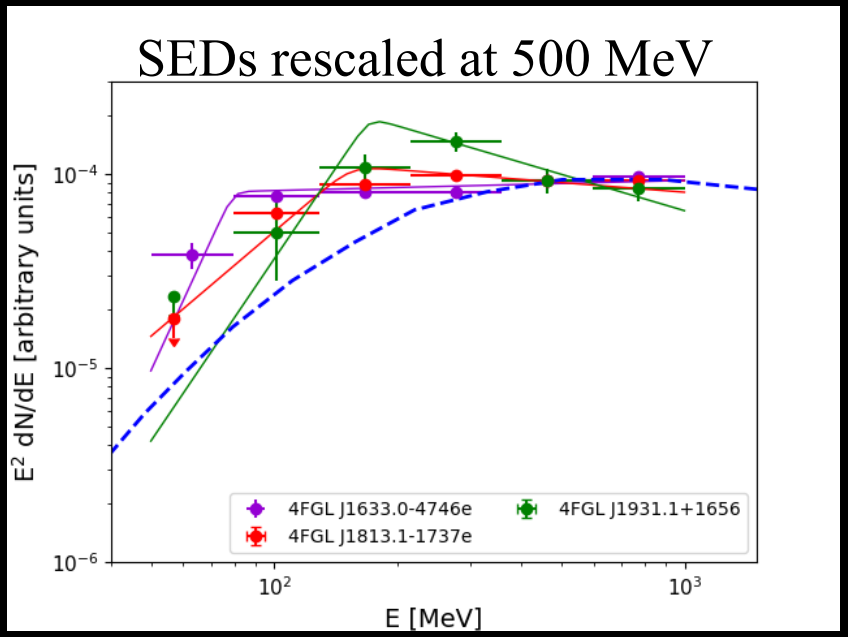
overlaps with the TeV PWN candidate HESS J1632-478 and the unidentified source HESS J1634-472
presence of dense clumps in this region traced by $NH_3(1,1)$ emission (de Wilt et al. 2017)

4FGL J1813.1-1737e :

coincident with the compact TeV PWN candidate HESS J1813-178 & the SNR G12.82-0.02
Araya (2018) proposed an association with the giant star-forming region (SFR) W33

4FGL J1931.1+1656 :

coincident with the SNR candidate G52.37-0.70 detected in a THOR+VGPS analysis (Anderson et al. 2017)
VLA observations (Driessen et al. 2018) seem to indicate that this candidate is unlikely to be an SNR



Conclusions

311 sources analyzed between 50 MeV and 1 GeV

77 sources show a significant break using the Galactic diffuse and the IRFs released by the LAT collaboration

56 sources are confirmed by our systematic studies (IRFs + Diffuse)

SNR is the dominant class of identified sources in this analysis

Binaries could also play a significant role

Interesting new candidates

Need to confirm them all by looking at the density of the surrounding environment

More details in arxiv:2205.03111

A binary system : Eta Carinae

System composed by a Luminous Blue Variable (LBV)

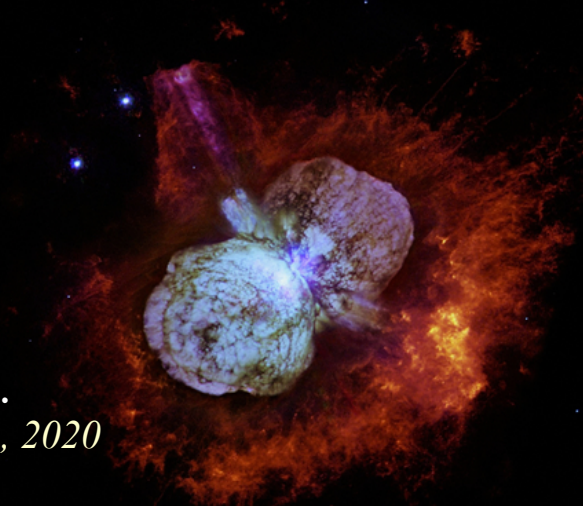
O- or B-type companion star

Orbital period of ~5.5 years

Collision region of the stellar winds => efficient particle acceleration

Detected in X-rays, HE gamma-rays with Fermi and TeV with H.E.S.S.

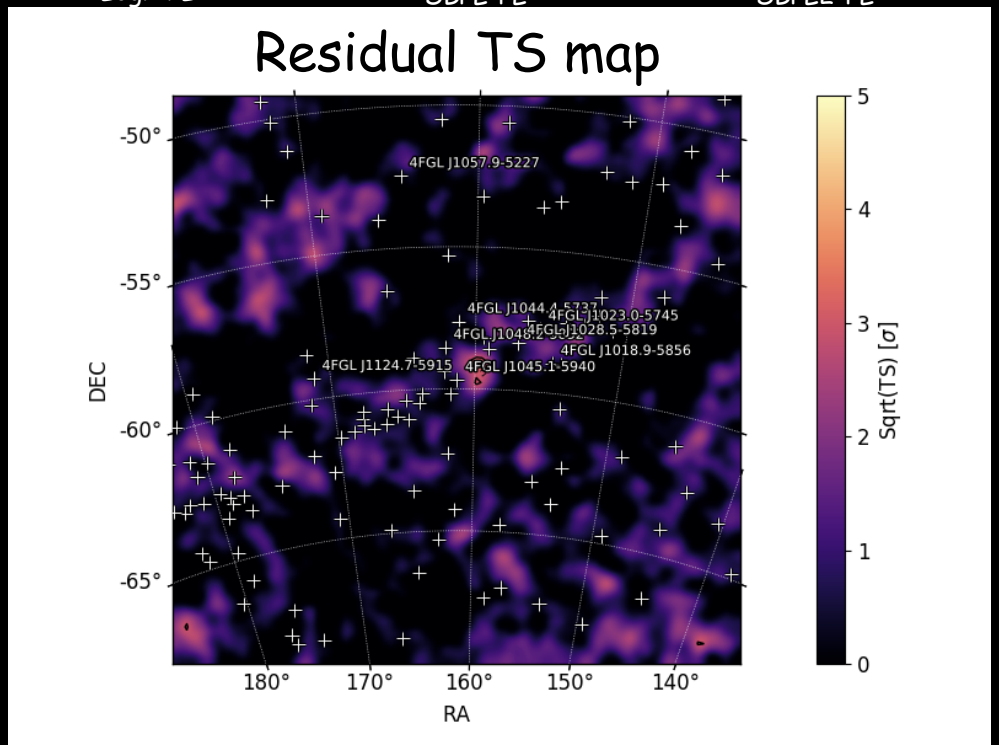
Humphreys & Martin 2012 ; Reitberger et al. 2015 / Balbo & Walter 2017 ; Abdalla et al., 2020

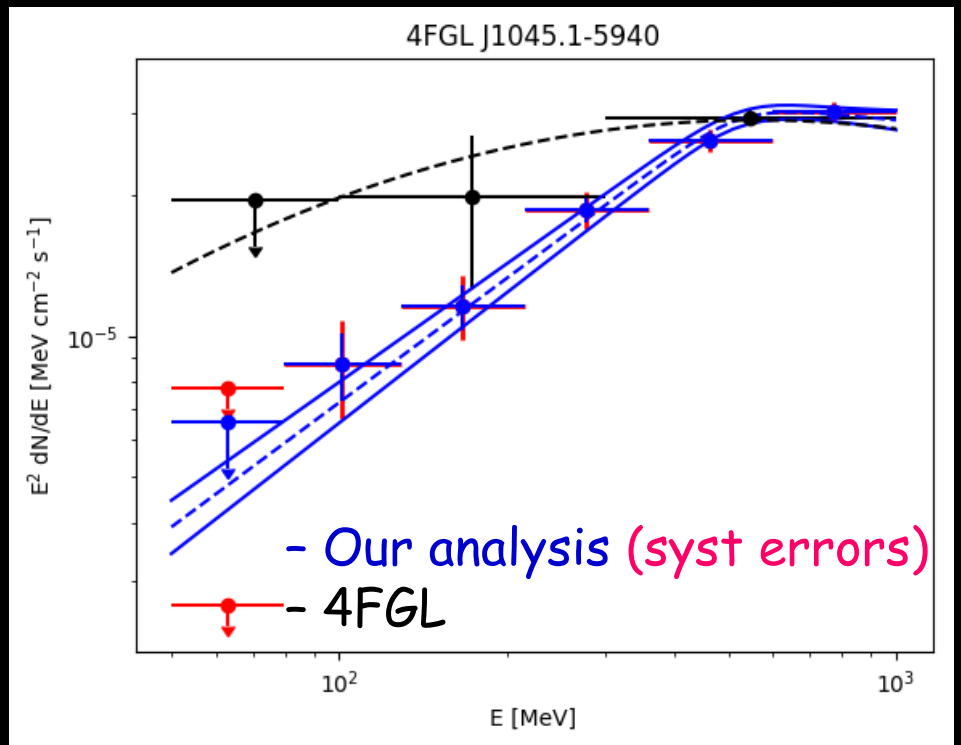


Credit: Nathan Smith (University of California, Berkeley), and NASA

Significant spectral break detected with our pipeline :

$\Delta TS_{LogP-PL} = 16$; $\Delta TS_{SBPL-PL} = 19$; $\Delta TS_{SBPL2-PL} = 17$





Many different checks

Systematics :

- Test all sources with $\Delta TS_{SBPL-PL} > 12$ or $\Delta TS_{SBPL2-PL} > 9$ with the « old » diffuse model rescaled for Pass 8 source analysis gll_iem_v06.fits => redo the whole pipeline

- Test all sources with $\Delta TS_{SBPL-PL} > 12$ or $\Delta TS_{SBPL2-PL} > 9$ with the bracket IRFs associated with the effective area (symmetrically bracket the standard effective area and flip from one extreme to the other at the measured value of the break energy) => start from the optimized ROI

=> We only keep the candidates that also show $\Delta TS_{SBPL-PL} > 12$ or $\Delta TS_{SBPL2-PL} > 9$ with both checks

Tests with simulations :

The goal was to test the effect of the number of bins as well as the edisp_bins on the results using 200 simulations of IC443

These simulations help to decide on the final configuration used : edisp_bins=-3 and 12 energy bins