Evidence for a spectral turnover in the broadband gamma-ray emission from SNR Puppis A revealed by H.E.S.S. observations

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Introduction

Puppis A (G260.4-3.4) is a supernova remnant (SNR) located at a distance of 2.2 ± 0.3 kpc. It represents the interesting case of study of an intermediate type between the young, shell-type SNRs, and middle-aged SNRs interacting with molecular clouds (MCs). Puppis A is detected in the high energy (HE) γ-ray domain with the *Fermi*-LAT. Its luminosity of $2.7 \times 10^{34}(d/2.2\ \text{kpc})^2$ erg s^{-1} in the 1 - 100 GeV band is slightly higher than those of the low-luminosity, HE-emitting SNRs such as Cygnus Loop, S147 and HB21, and about a factor ten lower than those measured from the archetypal SNRs known to be interacting with MCs. With a HE gamma-ray spectrum well described by a power law with no indication of a break or cutoff [1], it constitutes an intriguing target to be studied in the VHE domain with the H.E.S.S. array of Cherenkov telescopes. The results shown here are published in [2].

Conclusions

The H.E.S.S. observations reveal an unexpected lack of emission from this exceptional SNR. An indication of a spectral turnover at energies around a few hundred GeV is found. In the context an on-going DSA process, it is difficult to reconcile the constraints on the magnetic field and ISM density derived from the broadband emission modelling [1]. However, multi-wavelength data suggest that Puppis A has already interacted with MCs in some localised regions coincident with the bulk of GeV emission. If this is true, the acceleration of particles could have ceased some time ago, and either a radiative cutoff or a break of non-radiative origin could be expected.

H.E.S.S. analysis

Dataset

- 25 h between 2005 and 2013.

Technique

- Model analysis [3] using *standard* cuts.
- Analysis ON-region defined as a circular region matching the measured location and extension from *Fermi*-LAT.
- Similar analyses performed for two half-disc regions as defined in [1].

Results

- No significant signal, eight excess events found corresponding to a significance of 0.1σ.
- Differential flux upper limits (UL) derived following [4].

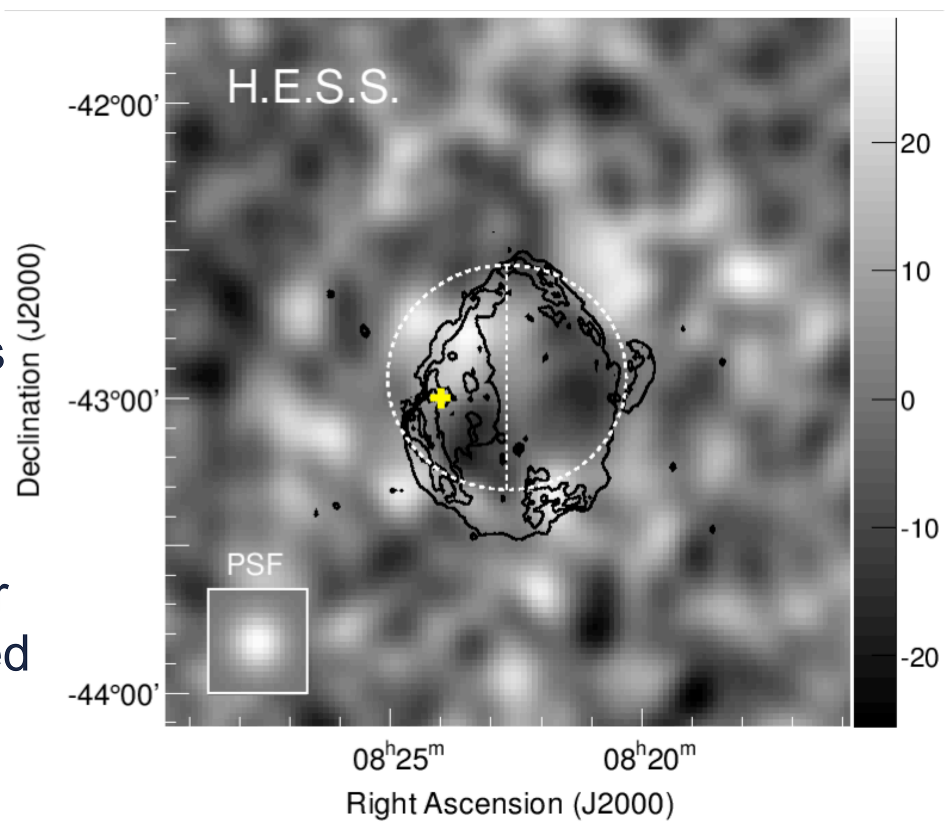


Image of the H.E.S.S. gamma-ray excess centred on the Puppis A SNR. The excess was smoothed with a Gaussian of width 0.06° corresponding to the H.E.S.S. angular resolution. The circular analysis region of radius 0.38°, matching the *Fermi*-LAT best-fit morphological model, is shown as a dashed circle, with the two hemispheres indicated. The black contours represent the 1.4 GHz radio emission [5] at the 5, 10, 20 and 50 mJy/beam levels. The yellow cross indicates the position of the bright eastern knot [6]. Figure from [2].

Spectral turnover location

Methodology

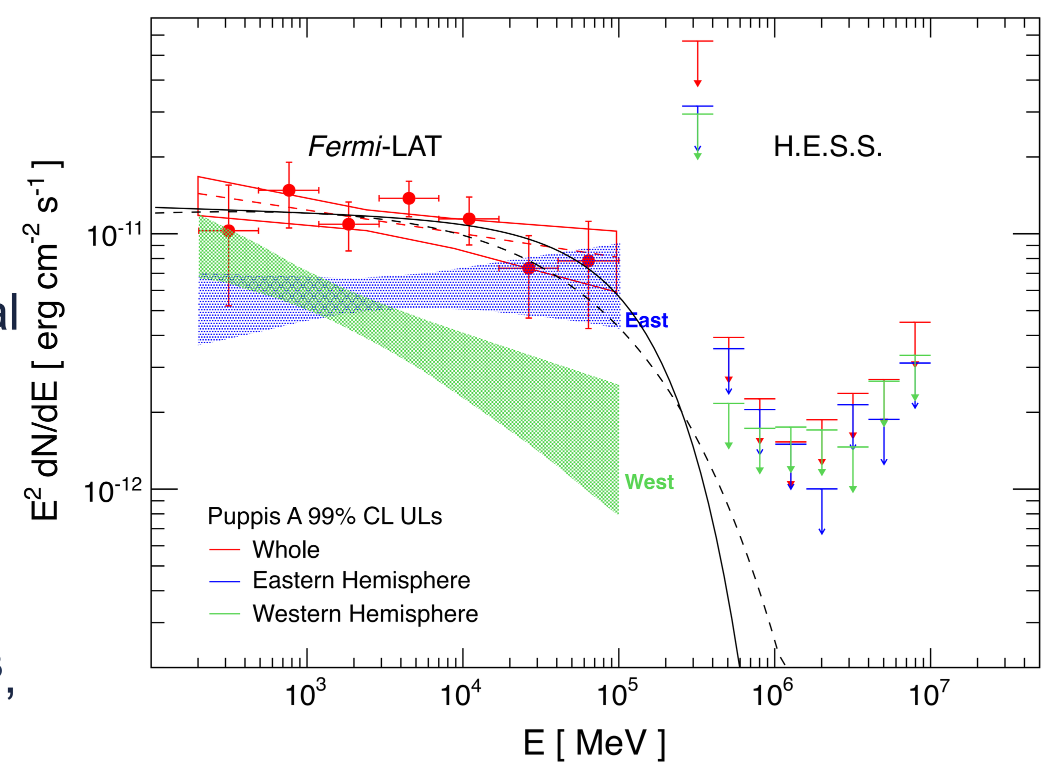
- Based on a likelihood ratio test, combining both *Fermi*-LAT and H.E.S.S. results.
- Derive the UL of the spectral feature at the 99% CL.

Assumed turnover models

1. Energy cutoff from power law with exponential cutoff: $dN/dE = N_0 E^{-\Gamma} \exp(-E/E_{cut})^{\beta}$, with β = 1 and 0.5.
2. Break energy from a broken power law.

Results

- E_{cut}, (β = 1) → 450 GeV
- E_{cut}, (β = 0.5) → 280 GeV
- E_{break} → 450 GeV



H.E.S.S. 99% CL upper limits on the differential flux (arrows), together with the *Fermi*- LAT spectra from Puppis A, as reported in [1]. Red, blue and green symbols correspond to *Fermi*-LAT and H.E.S.S. measurements for the whole SNR, the eastern and western hemisphere, respectively. The data points show the LAT fluxes and 1σ statistical and systematic errors, whilst the bow-tie areas define the 68% CL bands. The solid and dashed lines indicate the preferred gamma-ray spectra for the exponential and sub-exponential cutoff models, respectively. Figure from [2].

Discussion

Interpretation of spectral turnover

- In SNR evolution, particles are accelerated at the forward shock up to a maximum energy E_{max}, typically determined by the SNR's finite age, finite size, or radiative losses. These effects become relevant when the characteristic timescales are close to the acceleration timescale, leading to cutoffs in the spectra of accelerated particles residing in the SNR.
- Alternatively, a radiative spectral break can be present at the particle energy E_{break} for which the radiative loss timescales equal the SNR age.

Constraints on B and n_0 based on standard DSA predictions (assuming Bohm diffusion) and the ULs on the maximum particle energy derived from the *Fermi*-LAT and H.E.S.S. measurements.

Scenario	Constraints
Radiative losses τ_{rad}:	$(\tau_{acc} > \tau_{rad})$
τ_{p-p}	$B_{\mu G} < 1.1 \times 10^{-4}\, n_0\, E_{max}$
τ_{br}	$B_{\mu G} < 1.8 \times 10^{-4}\, n_0\, E_{max}$
τ_{syn}	$B_{\mu G} > 3400\, E_{max}^{-2}$
Age-limited: $\tau_{acc}(E_{max}) > \text{age}$	$B_{\mu G} < 1.4\, E_{max}$
Size-limited: $\frac{D(E_{max})}{v_{sh}} > \chi R_{sh}$	$B_{\mu G} < 0.1\, \chi_{0.1}^{-1}\, E_{max}$

$B_{\mu G}$, n_0, and the maximum particle energy E_{max} are in units of μG, cm^{-3} and TeV, respectively. The shock velocity v_{sh}=700 km s^{-1} is used as it leads to conservative constraints on $B_{\mu G}$. The ratio between the diffusion length of particles at E_{max} and the shock radius defines the upstream diffusion region size, where $\chi_{0.1} = \chi/0.1$ (e.g [7]). τ_{p-p}, τ_{br}, and τ_{syn} are the radiative loss timescales for p-p collision, Br, and synchrotron processes, τ_{acc} and τ_{rad} are the acceleration and radiative timescales, respectively, and $D(E_{max})$ the diffusion coefficient at the maximum energy. Table from [2].

Maximum particle energy

- For bremsstrahlung (Br), inverse Compton (IC) or proton-nucleus interactions (e.g. p-p) radiation mechanisms, the results of this analysis corresponds to a particle energy cutoff at 2 TeV, 3 TeV, or 5 TeV, respectively.
- These limits to the particle energy are compared with the expectations from DSA theory taken in its simplest form for the characteristics of Puppis A allowing to derive constraints on both the on the magnetic field (B) and interstellar medium density (n_0).

Comparison outcome

- None of the known limitations in the simple context of a single population of particles continuously accelerated at the SNR shock can explain the lack of VHE emission from Puppis A.
- If the SNR shock has encountered a MC some time ago, the acceleration of particles could have ceased because of ion-neutral damping.
- Puppis A is known to be interacting at several locations throughout the shell and thus a cloud interaction could be responsible for a break in the HE/VHE γ-ray spectrum.

References

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