On the origin of the complex energy-dependent structure of HESS J1702-420

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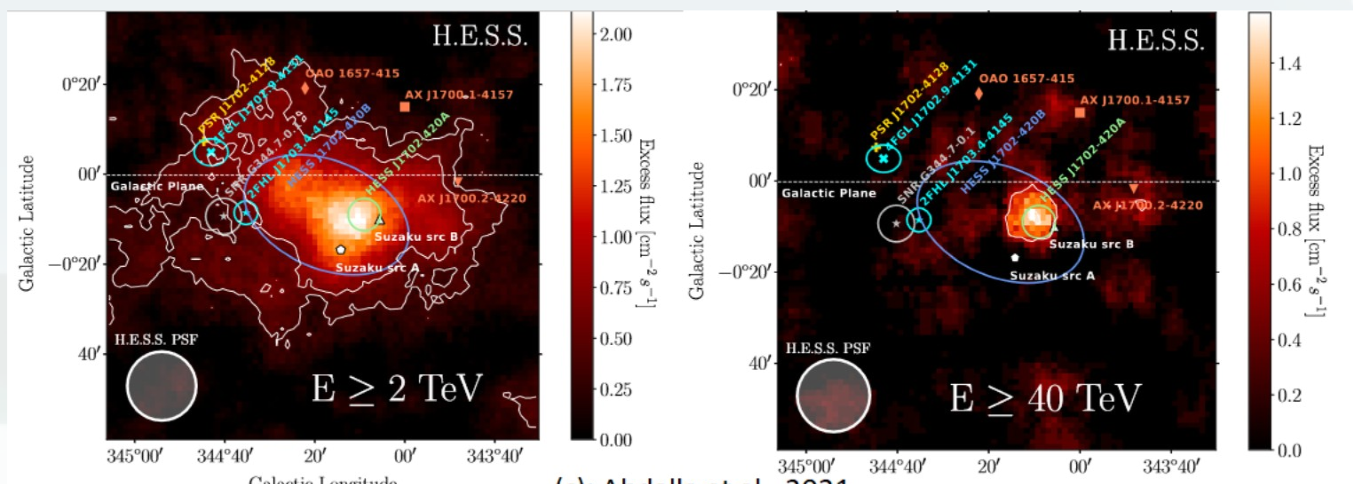
Abstract

HESS J1702-420 is an unidentified multi-TeV gamma-ray source with a peculiar energy-dependent morphology which most naturally can be explained as a composition of two independent emission components with significantly different spatial and energy distributions. Here we propose an alternative interpretation assuming that we deal with a single hadronic accelerator injecting protons with energies extending to at least 0.5 PeV.

In the suggested scenario, both the soft extended and the hard compact point-like component have the same origin associated with the interactions of injected protons with the surrounding dense gas environment but are produced at different stages of proton propagation.

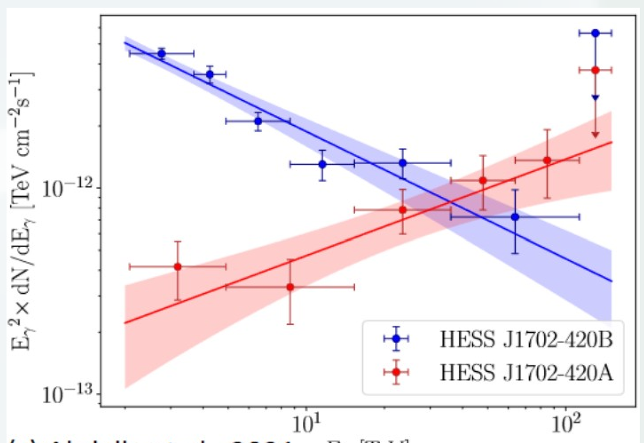
The joint analysis of these two components allows us to derive the power-law index of the acceleration spectrum, the proton injection rate, and the energy-dependent diffusion coefficient. Assuming the distance to the source d=0.3 kpc, the characteristic medium density of ~100 cm^{-3} and diffusion coefficient $D(E)=3 \times 10^{26}\ cm^2/s$ we argue that the system can be well described by the protons' injection rate ~8 x 10^{37} erg/s.

INTRODUCTION



(c): Abdalla et al., 2021

- Discovered in 2006 during the first HESS galactic plane survey
- ~15° away from the GC; origin unknown
- 2021, Abdala et al.: Diffuse source with energy dependent morphology
- Size changes from ~ 0.3° below 5 TeV to point-like above 30-40 TeV
- Morphology: point-like HESS J1702-420A + diffuse HESS J1702-420B



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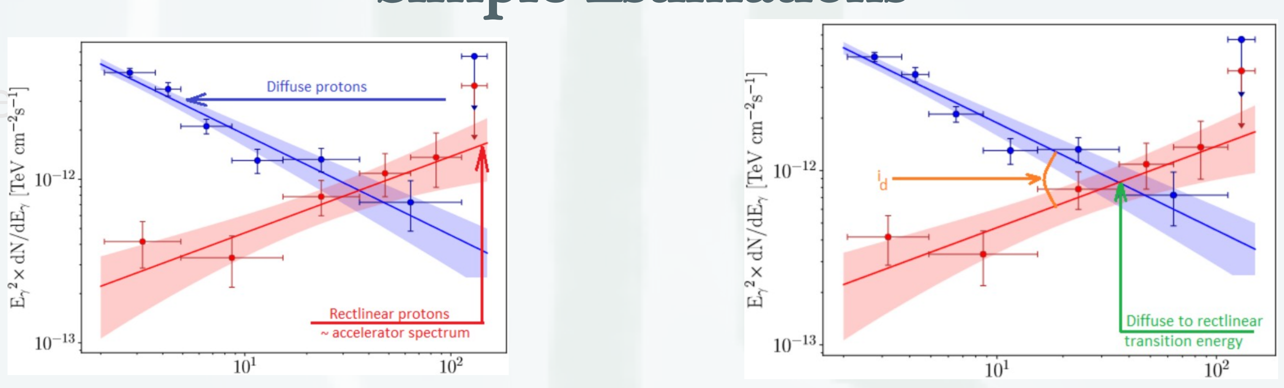
Spectra: no cut-off indication up to 100 TeV
- J1702-420A: Γ = 1.53 ± 0.19stat ± 0.20syst
- J1702-420B: Γ = 2.62 ± 0.10stat ± 0.20syst
- Motivation: Describe simultaneously and self-consistently spectral/spatial behaviour of both (A+B) sources.

Simple Estimations



An accelerator energetics and spectrum: point-like source spectrum $dN/dE \propto Q100(Ep/1T\ eV)^{i_p}$; $i_p \sim 1.5$

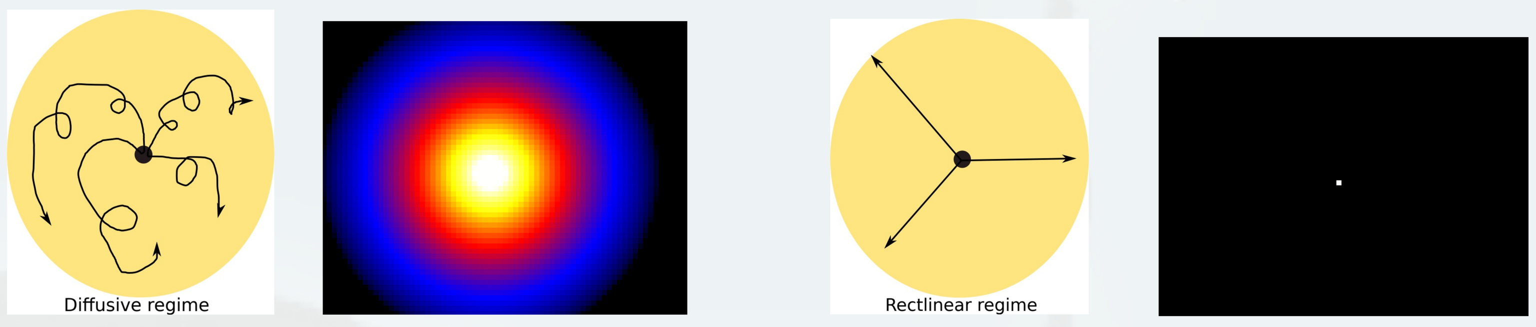
$$F_{ph} = \frac{\kappa L_p}{4\pi D^2}\frac{t_{esc}}{t_{pp}} \simeq 10^{-12}\frac{Q_{100} n_0}{10^{39}\mathrm{erg/s\ cm^{-3}}}\frac{\kappa}{1/6}\frac{R}{2\mathrm{pc}}\left(\frac{D}{0.3\mathrm{kpc}}\right)^{-2}\ \mathrm{erg/s/cm^2}$$

Diffusion coefficient index: difference of diffuse and point-like sources spectral indexes: $i_d \sim 1$

Diffusion coefficient normalisation: transition energy:

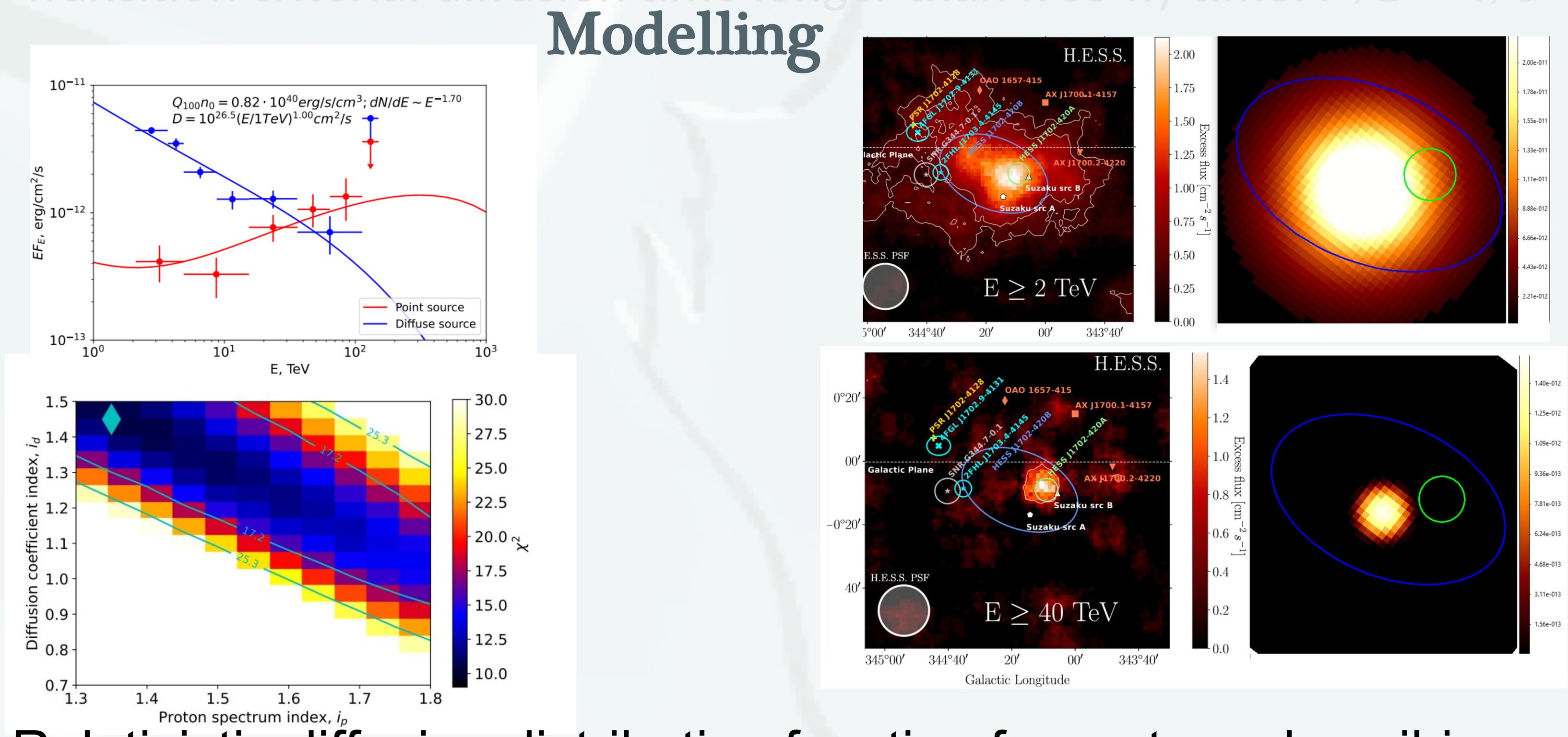
$$D_0 \lesssim \frac{Rc\beta}{(E_c/1TeV)^{i_d}} \sim 6\cdot 10^{25}\frac{R}{2pc}\left(\frac{E_c}{30TeV}\right)^{-i_d}\frac{\beta}{0.01}\ cm^2/s$$

Energy dependent diffusion



An accelerator of VHE protons at the center of HI cloud.
Observed emission is due to π^0 decay.
- Propagation of protons is described with energy dependent diffusion $D(E) = D0(E/1\ TeV)^{id}$
- "Low" energies: diffusive propagation; protons are entangled and randomized in momenta space ⇒ "Extended" source
- High" energies: rectlinear propagation of protons ⇒ "point-like" source
- Transition criteria: diffusion time longer than free-fly time: $r^2/D \gg r/c$

Modelling



- Relativistic diffusion distribution function for protons describing evolution in space and momenta space: analytical expression from [2]; photon emission processes – calculations with naima [3].
- Bohm-like diffusion is not excluded (fit prefers $i_d \sim 1.45$).
- $D_0 \approx 10^{26.5}\ cm^2/s$ at 1 TeV, by a factor of 10 faster then Bohm for $B_0 = 10\ \mu G$. For Bohm-like diffusion $Q_{100} n_0 \sim 8.2 \cdot 10^{39}\ erg/cm^3$. Comparable to Crab energetics for $n_0 \sim 10\ cm^{-3}$
- The model well describes the energy-dependent changes of HESS J1702-420 morphology. Offset of the point-like source from the center of diffuse source. Misaligned proton accelerator? Space-dependent diffusion coefficient?

Conclusions

- Energy-dependent diffusion allows to explain energy-dependent morphology of VHE sources.
- HESS J1702-420 can be modelled as a proton accelerator embedded into HI cloud + energy-dependent diffusion + π^0-decay emission
- The data is well described with Bohm-like diffusion (~ 10 times faster for B = 10 μG). The required energetics of the accelerator is about 10% of Crab for the medium density $n_0 \sim 100\ cm^{-3}$
- Strongly misaligned accelerator (PeVatron) could illuminate nearby cloud which will show soft spectrum. The hard-spectrum accelerator remains invisible or visible just at highest energies.

References

[1] Abdala et al, 2021, A&A, 653, A152
[2] Prosekin et al. 2015, Phys. Rev. D 92, 083003
[3] Zabalza et al, 2015, PoS ICRC2015 922

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