The puzzling case of HESS J1640-465 and HESS J1641-463 as seen by the Fermi-LAT

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The discovery of a GeV counterpart to HESS J1641-463 with the Fermi-LAT shed new light on the origin of the gamma-ray emission from HESS J1641-463 and the neighboring bright source HESS J1640-465. A detailed analysis of this region and different scenarios for each source are presented.

Abstract

Thanks to a longer dataset and improved sensitivity afforded by the P7 reprocessed data of the Fermi Large Area Telescope (LAT), the TeV source HESS J1641-463 is now detected by the Fermi-LAT. This new detection implies a change in the GeV spectrum of the neighboring bright source associated to HESS J1640-465 which was previously contaminated by the Fermi source associated with HESS J1641-463. The newly obtained GeV spectrum associated with HESS J1640-465 is harder and links up naturally with the spectral points obtained by H.E.S.S., suggesting a hadronic origin. This is not the case for the overall spectral energy distribution of HESS J1641-463 whose origin remains enigmatic. A detailed analysis of this region with the Fermi-LAT is presented as well as different scenarios to explain the gamma-ray emission observed from both sources.

The field of view

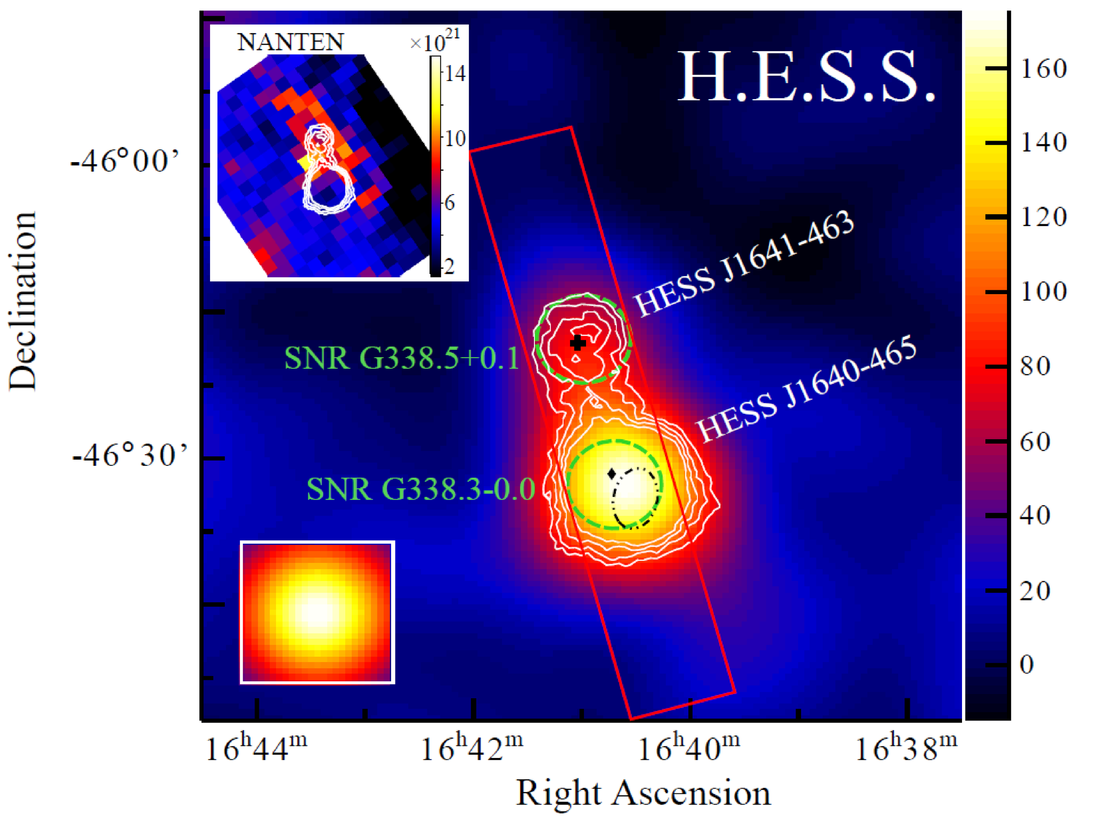

Fig 1. HESS view of the two sources HESS J1640-465 and HESS J1641-643 above 4 TeV [2]. White contours denote the 5,6,7 and 8 sigma levels. Green circles show the position and extension of the two supernovae remnants. Dash-dotted circle is the 95% confidence error position level of 1FHL J1640.54634. The left inset shows the distribution of HII column density estimated from NANTEN CO data [11,12] together with the H.E.S.S. significance contours.

Gamma-rays: HESS J1641-463 is located about 0.25° away from HESS J1640-465 and only shows up at very high energy (above 4TeV) on the excess maps due to its hard spectrum [2]. HESS J1640-465 has a softer spectrum [3] and therefore overwhelms the neighboring weaker source at lower energies (<1TeV).
X-rays: pulsar and pulsar wind nebula (PWN) counterparts to HESS J1640-465 [4,5], no clear counterpart to HESS J1641-463 [2].
Radio: Each TeV source is in spatial coincidence with a supernova remnant (SNR) [10,13]. Presence of dense molecular clouds traced by the CO(1-0) line [11,12].

HESS J1640-465 : Timeline

- **2006:** Discovery by H.E.S.S., spatially coincident with SNR G338.3-0.0 [6] ⟶ **Hadronic?**
- **2007:** X-ray PWN candidate discovered by XMM-Newton [4] ⟶ **Leptonic?**
- **2009:** Confirmation by Chandra and detection of a point-source pulsar candidate [5] ⟶ **Leptonic?**
- **2010:** Detection of GeV counterpart by Fermi: PWN modeling by [7] ⟶ **Leptonic?**
- **2011:** New radio measurements do not show the presence of the PWN [8,3] ⟶ **Hadronic?**
- **2014:** Discovery of pulsations in X-rays from the point-source pulsar candidate PSR J1640-4631 [9] ⟶ **Leptonic?**
- **2014:** Discovery of the neighboring source HESS J1641-463 by Fermi [1] ⟶ **Hadronic?**

Since its discovery in 2006, the origin of the gamma-ray emission from HESS J1640-465 has been constantly revised. First, its spatial coincidence with SNR G338.3-0.0 suggested that hadronic cosmic-rays accelerated in the remnant were interacting in the molecular cloud complex. Then the discovery of an X-ray counterpart brought a PWN scenario with accelerated leptons to mind . But finally new GeV data seem to favor the hadronic origin despite the recent discovery of pulsation in X-rays from the pulsar counterpart candidate. However, it is also possible that the overall gamma-ray emission stems from both leptons from the PWN and hadrons from the SNR.

Fermi analysis

Analysis details:

- 5 years of data in survey mode: from 2008 August 04 to 2013 December 04
- Region of 20° around the position of HESS J1640-465
- P7REP_SOURCE_V15 IRFs and Source class gamma-ray events selected
- Events coming from a zenith angle > 100° excluded
- Galactic diffuse model: gll_iem_v05.fits
- Isotropic diffuse model: iso_source_v05.txt
- Source model from internal 4-year 3FGL catalog list
- Spectral parameters from sources within a 5° ROI are left free

Spectral results:

- **HESS J1640-465**:
$\Gamma=1.99\pm0.04_{stat}\pm0.07_{syst}$
$\Phi_{>100\,MeV} = (4.5\pm0.2_{stat}\pm0.2_{syst})\times10^{-5}$ MeV cm^{-2} s^{-1}
- **HESS J1641-463:**
$\Gamma=2.47\pm0.05_{stat}\pm0.06_{syst}$
$\Phi_{>100\,MeV} = (2.6\pm0.2_{stat}\pm0.5_{syst})\times10^{-5}$ MeV cm^{-2} s^{-1}

Morphological analysis with pointlike:

	Spatial Model	R.A. (°)	Dec. (°)	σ (°)	TS (3 – 300 GeV)	N.d.o.f.**
A	1 Point Source	250.14	−46.56		148	4
B	1 Gaussian Source	250.17	−46.52	0.12	186	5
C	1 Gaussian Source with 2 power-law type components	250.17	−46.52	0.12	191	7
D	2 Point Sources	250.13 / 250.27	−46.57 / −46.35		216	8
E	1 Gaussian + 1 Point Source	250.15 / 250.27	−46.59 / −46.34	0.06 / –	222	9
F	HESS J1640−465 Gaussian*	250.17	−46.54	0.07	166	2
G	HESS J1640−465 Gaussian* + HESS J1641−463 Point Source*	250.17 / 250.26	−46.54 / −46.30	0.07 / –	208	4

- **2 sources with position and morphology compatible with the TeV sources HESS J1640-465 and HESS J1641-463 found in this new analysis [1]**

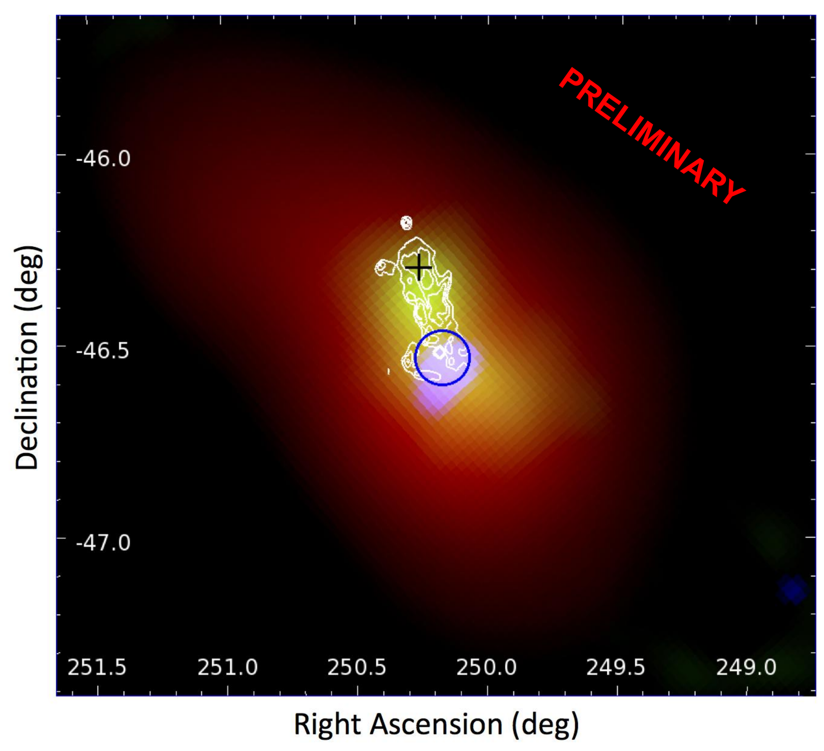

Fig 2. Fermi-LAT composite TS map of the region containing the two TeV sources in the 0.3-3.0 GeV (red), 3.0-30.0 GeV (green) and 30.0-300.0 GeV(blue) energy ranges, in equatorial coordinates (J2000) [1]. The best position of the H.E.S.S. Point source HESS J1641-463 is marked with a black plus while the best position and extension of the H.E.S.S. Gaussian HESS J1640-465 is represented by the blue circle. The red diamond indicates the position of the pulsar PSR J1640-4631, while the yellow cross shows the position of the only close-by source from the internal Fermi-LAT source list located in the region. Radio continuum at 843 MHz is shown as white contours [13]. The maximal TS values are 255, 100 and 43 for the red, green and blue map respectively.

HESS J1640-465

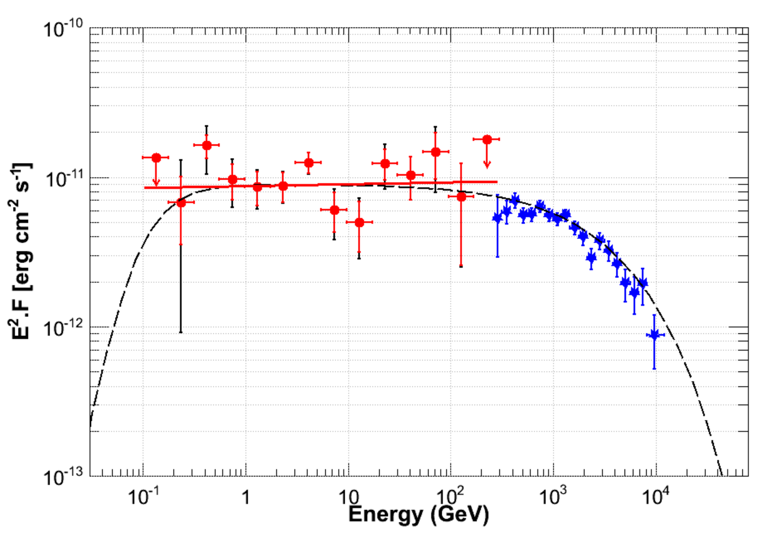

Fig 3. Gamma-ray spectra of HESS J1640-465, using the best Gaussian spatial model from [2]. The red line shows the fit with a power-law to the Fermi spectrum derived above 100 MeV. The red data points indicate the fluxes measured in each energy bin. Red error bars are statistical only while black error bars take into account statistical and systematical errors [1]. The blue data points are taken from [2]. The hadronic model derived for this source is represented by the dashed black line [1].

- Hard Fermi spectrum connects perfectly with TeV spectrum
- $L_{>100MeV}$~7.3x10^{35} (D/10kpc)^2 erg s^{-1}
- Typical of SNR interacting with molecular clouds detected with Fermi (IC443, W51C) [14,15]
- Protons accelerated in the shell of SNR G338.3-0.0 and interacting in the G338.4+0.1 HII complex [3]?
- Hadronic scenario: gamma-ray spectrum produced by π^0 decay [16]:
  - Gas density of 150 cm^{-3}
  - Particle index of 2.0
  - Energy cutoff at 50 TeV
- 0.9x10^{50} erg in cosmic-rays needed to reproduce the data
- 9% of supernova kinetic energy
- But part of the Fermi flux could also be produced by either the PWN in SNR G338.3-0.0 or by PSR J1640-4631

HESS J1641-463

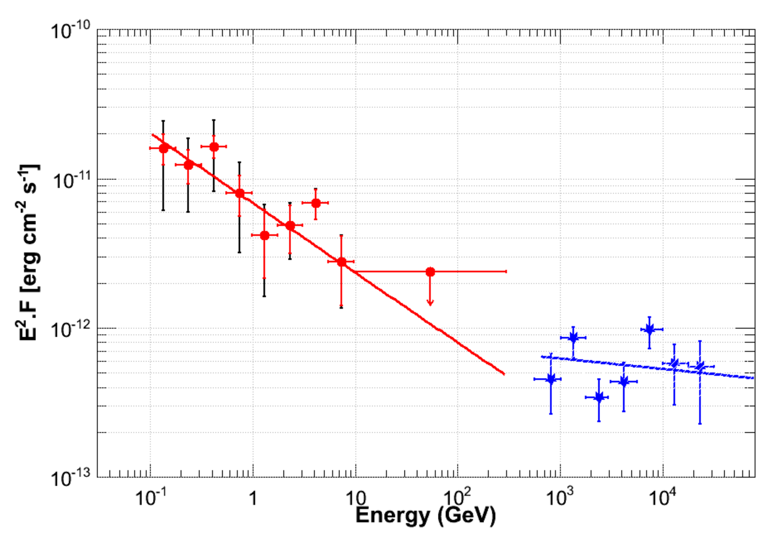

Fig 4. Gamma-ray spectra of HESS J1641-463, using the best point source position from [2]. The Fermi data points and spectrum are shown with the same convention as Fig. 2 [1]. The blue data points and the best spectral fit (blue line) are taken from [2].

- Connection between Fermi and H.E.S.S. spectrum unclear
- Two different mechanisms or sources for the GeV and TeV emissions?

1) Emission from a pulsar in GeV and from the associated PWN in TeV
   - Such as HESS J1356-645, PWN associated to PSR J1357-6429 seen by Fermi [17]
   - X-ray potential counterpart 15 times less energetic than TeV source [2]
   - Dark TeV source and weak X-ray synchrotron PWN?
2) Binary system
   - Such as LS 5039 and LSI +61° 303 [18]
   - Pulsar-like spectrum at GeV energies which does not connect to the TeV spectrum
   - But no variability or spectral curvature due to lack of statistics
3) Hadronic origin linked to the SNRs
   - Fermi sees the shell of SNR G338.5+0.1
   - H.E.S.S. detects the runaway cosmic-rays from one of the two remnants interacting with the HII complex

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