5TH FERMI SYMPOSIUM

MAGIC
Major Atmospheric Gamma Imaging Cerenkov Telescopes

Discovery of TeV gamma-ray emission from the Pulsar Wind Nebula 3C 58 by MAGIC

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Abstract

The Pulsar Wind Nebula (PWN) 3C 58 is energized by one of the highest spin-down power pulsars known (5% of Crab pulsar) and it has been compared to the Crab Nebula due to their morphological similarities. This object was detected by Fermi-LAT with a spectrum extending beyond 100 GeV. We analyzed 81 hours of 3C 58 data taken with the MAGIC telescopes and we detected VHE gamma-ray emission for the first time at TeV energies with a significance of 5.7 sigma and an integral flux of 0.65% C.U. above 1 TeV. The differential energy spectrum between 400 GeV and 10 TeV is well described by a power-law function $d\Phi/dE=f_o(E/1TeV)^{-\Gamma}$ with $f_o=(2.0\pm0.4_{stat}\pm0.6_{sys})\ 10^{-13}cm^{-2}s^{-1}TeV^{-1}$ and $\Gamma=2.4\pm0.2_{stat}\pm0.2_{sys}$. This leads 3C 58 to be the least luminous PWN ever detected at VHE and the one with the lowest flux at VHE to date. According to time-dependent models in which electrons up-scatter photon fields, the best representation favors a distance to the PWN of 2 kpc and FIR comparable to CMB photon fields. If we consider an unexpectedly high FIR density, the data can also be reproduced by models assuming a 3.2 kpc distance. A low magnetic field, far from equipartition, is required to explain the VHE data. Hadronic contribution from the hosting supernova remnant (SNR) requires unrealistic energy budget given the density of the medium, disfavoring cosmic ray acceleration in the SNR as origin of the VHE gamma-ray emission.

Context

- The SNR 3C 58 (SNR G130.7+3.1) has a flat radio spectrum and it is brightest near the center, and hence it is classified as a PWN [1]
  - Centered on PSR J0205+6449 discovered in 2002 with the Chandra X-ray observatory [2]
  - Widely assumed that to be located at a distance of 3.2 kpc [3], but a new H-I measurement suggests a distance of 2 kpc [4].
  - The estimated age of the system ranges from 0.8 kyr up to 7 kyr.
- The pulsar wind nebula (PWN) 3C 58 is one of the historical very-high-energy (VHE; E >100 GeV) γ-ray source candidates.
- Previously observed by imaging atmospheric Cherenkov telescopes (Whipple, VERITAS and MAGIC), although not detected, with an upper limit of 2.4 % Crab Unit (C.U.) at VHE [5,6,7].
- Between the two γ-ray pulsed peaks, the Fermi Collaboration reported the detection of emission from 3C 58 [8]. The differential energy spectrum between 100 MeV and 316 GeV is well described by a power-law with photon index Γ = 1.61 ± 0.21.

The MAGIC Telescopes

- MAGIC is a stereoscopic Imaging Atmospheric Cherenkov telescope situated on the island of La Palma (2225 m.a.s.l.). It can achieve a sensitivity of (0.76 ± 0.03)% of the Crab Nebula flux in 50 hours. The energy threshold achieved by the telescope for observations at low zenith angle is 50 GeV.

MAGIC Telescopes placed in the island of la Palma.

Discovery

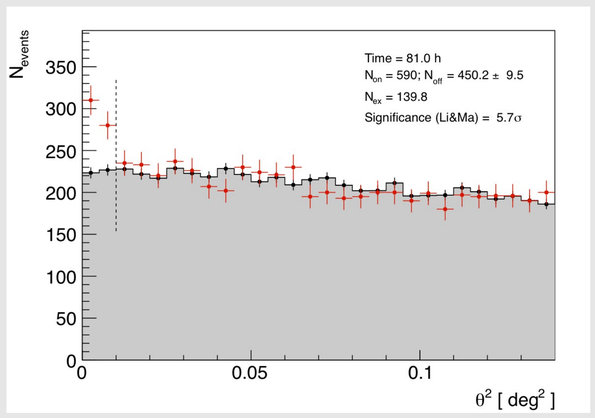
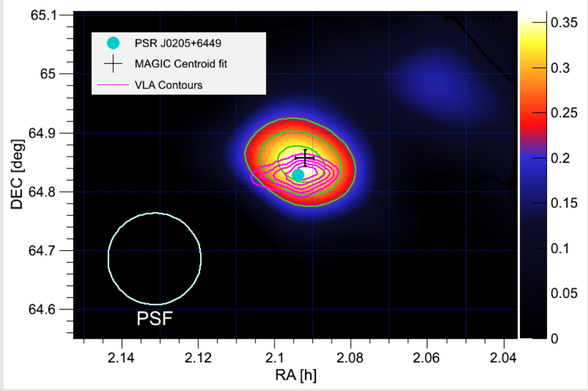


Fig. 1: Distribution of squared angular distance, θ^2, between the reconstructed arrival directions of gamma-ray candidate events and the position of PSR 0205+6449 (red points). The distribution of θ^2 for the OFF positions is also shown (grey filled histogram).

Fig. 2: Relative flux (excess/background) map for MAGIC observations,

- MAGIC observed 3C 58 during the period between 4 August 2013 to 5 January 2014.
- The cuts applied and the zenith angle yield an energy threshold of 420 GeV.
- Position is compatible with PSRJ0205+6649 if systematic errors are taken into account.
- The extension is compatible with the PSF.



Spectrum

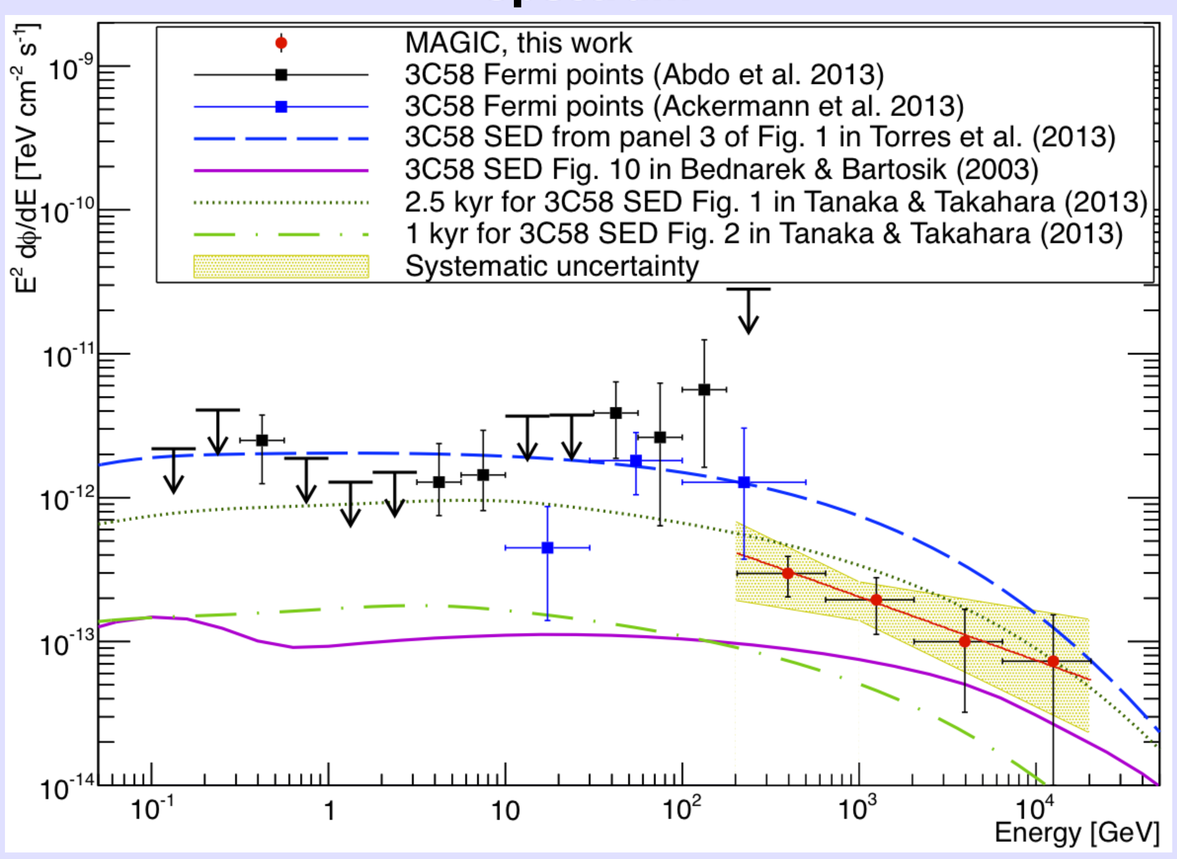


Fig. 3: 3C58 spectral energy distribution in the range between 0.1 GeV and 20 TeV.

- A one zone model of the spectral evolution of PWNe for a distance of 3.2 kpc [9] predicts a γ-ray flux above 400 GeV about an order of magnitude lower.
- IC scattering only from the CMB is consistent with the observed spectrum [10]. However, it leads to B ∼14μG and it underestimates the radio emission of the nebula.
- A time-dependent model of the spectral evolution of PWNe including synchrotron emission, synchrotron self-Compton and IC [11] fits the VHE for an age of 1 kyr.
- A different time-dependent leptonic diffusion-loss equation model without approximations, [12,13] foresees the VHE emission for high FIR background.
- Production by hadronic emission in the SNR G130.7+3.1[14] leads to acceleration efficiency larger than 100%.

Conclusion: The measured luminosity and flux make 3C 58 the least luminous VHE γ-ray PWN known and the object with the lowest flux at VHE to date. Only a closer distance of 2 kpc or a high local FIR photon density can reproduce the multiwavelength data of this object qualitatively among published models. Since the high FIR density is unexpected, the closer distance with FIR photon density comparable with the averaged value in the Galaxy is favored. The models fitting the γ- ray data derived magnetic fields which are very far from equipartition. Following the assumptions in [16] the measured flux is highly unlikely to come from hadronic emission of the SNR.

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This result: MAGIC Collaboration. 2014, Astron.Astrophys., 567, L8