FERMI Observations of the Tycho Supernova Remnant

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Abstract

After two years of data taking in sky survey mode, the Fermi LAT telescope has detected a gamma ray emission from the Tycho Supernova Remnant (SNR). The Tycho SNR is among the youngest remnants in the Galaxy, originated by a Type Ia Supernova in AD 1572.
The gamma ray integral flux from 1 GeV to 100 GeV has been measured to be (6.7 ± 0.5) 10^{-10} ph/cm²/s with a photon index of 2.3 ± 0.1. The spectrum can plausibly be explained by a shock-accelerated proton population producing gamma-rays via interaction with the ambient medium and subsequent π^0-decay.

Introduction

The explosion was first observed by Tycho Brahe in AD 1572. The SNR is one of the most extensively studied.

- classified as Type Ia based on observations of its light curve and light echo spectrum [1]
- The radio flux is 40.4 Jy at 1.4 GHz with an index of 0.65
- The X-ray spectrum is dominated by very strong line features of Si, S and Fe arising in the shocked ejecta.
- The majority of the X-ray continuum emission in the 4 - 6 keV band is due to non-thermal synchrotron emission (60%) rather than thermal bremsstrahlung.
- TeV-observations were carried out by HEGRA (3σ upper limit) and VERITAS [4] resulting in the detection of a flux at the level of 1% of the Crab.

The distance is not very well constrained.

- D = 3.8 (2.7 – 5.3) kpc based on observations of optical echo [1]
- D = 4 (3 – 5) kpc by combining velocity of shocked ejecta with proper motion measurements [2]

The average expansion parameter v of 0.47 (radio) and 0.52 (X-rays) is slightly greater than the value for a pure Sedov phase (v=0.4), thereby indicating that the remnant is in a transition period from the ejecta-dominated phase to the Sedov phase.

FERMI LAT Observations

The analysis for a point-like source has been done using the FERMI Science Tools version v9r23-00, publically available from the Fermi Science Support Center (FSSC) with the following parameters:

- Data-set: 24 months
- Zenith-angle cut: <100 deg
- Energy range: 1 – 100 GeV
- Galactic diffuse model: gll_iem_v02
- Isotropic diffuse model: isotropic_iem
- Binned analysis mode

The gamma-ray spectrum for Tycho gives an integral flux above 1 GeV of:
(6.7 ± 0.5) X 10^{-10} cm^{-2} s^{-1}

The photon index is 2.3 ± 0.1 and the significance is 5 standard deviations.

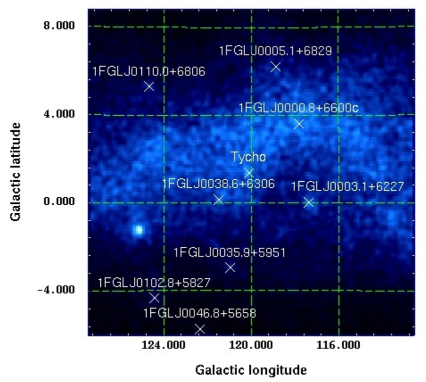

Figure 1: *Count map for photons above 1 GeV. The crosses indicate the positions of the 1FGL catalogue sources.*

Source localisation

A TS-map in the energy range 1 – 100 GeV has been created around the Tycho supernova remnant. The green contours correspond to the XMM-Newton map in the 4.5 – 5.8 keV energy range. The pointlike emission can be localised at 95% confidence level within the black line, thus implying that the best fit is compatible with Tycho's supernova position.

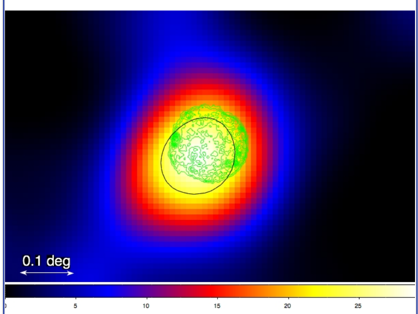

Figure 2: *Fermi TS map in celestial coordinates of Tycho in the 1 GeV – 100 GeV energy range. The green contours are from XMM-Newton and the black line denotes the 95% confidence area for the FERMI position.*

Origin of the gamma-ray signal ?

GENERAL CONSTRAINTS

[3] have analysed the emission from the region between the forward shock and the contact discontinuity with the ejecta, which is the prime zone of GeV gamma-ray production. We will follow their model which assumes self-similar evolution driven by ejecta distributed as r^{-7} outside the central plateau.
As the main uncertainty is the distance to the source, We extract the dependence of the observational constraints on the distance:

$$n_0 = 388\ D_{kpc}^{-7}\ E_{51}^{2}\ \mathrm{cm}^{-3}$$

GAMMA-RAY EMISSION

Two different cases are considered in the following:
1) Nearby scenario: total energy output of SNR is fixed to standard value of 10^{51} erg. This results in a distance of 2.78 kpc assuming the max. allowed density of the ambient medium 0.3 cm^{-3}.
2) Far scenario: D = 3.5 kpc, supernova energy and ambient density is 2x10^{51} erg and 0.24 cm^{-3} respectively.

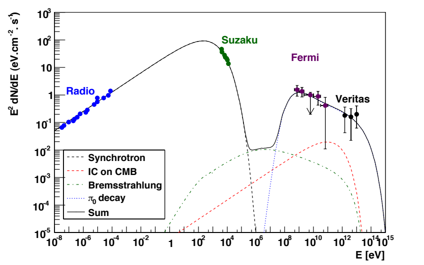

Figure 3: *Broadband SED model of Tycho SNR for the far scenario.*

Case	D_{kpc}	n_H [cm^{-3}]	E_{SN} [10^{51}erg]	$E_{p,tot}$ [10^{51}erg]	K_{ep}
Far	3.50	0.24	2.0	0.150	4.5x10^{-4}
Nearby	2.78	0.30	1.0	0.061	7.0x10^{-4}

In both cases the synchrotron flux is constrained by the radio and synchrotron data. The data indicates that a population of shock-accelerated electrons described by a power-law with spectral index 2.2 – 2.3 and an exponential cut-off energy of 6 - 7 TeV is at the origin of the synchrotron emission provided B_d ~ 215 µG as inferred by X-ray measurements [3]. However, this population of electrons would be unable to produce the observed gamma-ray flux by Inverse Compton emission due to interaction with the CMB. Moreover, given the synchrotron radio flux and the density constraint of < 0.3 cm^{-3}, bremsstrahlung is also unlikely to account for the Fermi-LAT measurement. γ-rays from π^0-decay originating from a population of shock-accelerated protons and interacting with the ambient medium are able to produce the FERMI and VERITAS spectra (see Table for details).

Conclusions

The detection of a GeV emission from Tycho SNR is reported measuring an integral flux above 1 GeV of (6.7 ± 0.5) x 10^{-10} cm^{-2} s^{-1}. The localisation of this emission is consistent with the position of Tycho SNR at 95% confidence level. The Fermi-LAT Spectrum finds plausible explanation in a shock-accelerated proton population which produces gamma-rays via π^0-production and decay.

References

[1] Krause et al. arXiv:0810.5106v1
[2] Hayato et al., arXiv:1009.6031v1
[3] Cassam-Chenai et al., ApJ 665, 2007
[4] Acciari et al. arXiv:1102.3871