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SEARCH FOR GAMMA-RAY EMISSION FROM THE SUPERNOVA REMNANT IC 443 WITH THE MAGIC TELESCOPE

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RESUMEN

Observaciones de muy alta energía (TeV) de remanentes de supernova y, en particular, de aquéllos que parecen estar relacionados físicamente con fuentes detectadas por el satélite EGRET constituyen un objetivo primario para el telescopio MAGIC. Su resolución espacial y sensibilidad pueden usarse para verificar el principal mecanismo responsable de la producción de fotones de alta energía en los alrededores de un remanente de supernova. Siguiendo los resultados de un análisis sistemático reciente del entorno molecular localizado en la vecindad de todas los remanentes detectados por EGRET, se seleccionó el remanente IC 443 para su observación con MAGIC. Aquí se describe brevemente la estrategia observacional que dio lugar a la detección de una nueva fuente de rayos gamma de muy alta energía: MAGIC J0616+225.

ABSTRACT

TeV observations of Supernova remnants (SNRs) and, in particular, of SNRs which appear to be physically related to EGRET sources are a prime target for the MAGIC telescope. MAGIC's spatial resolution and sensitivity can probe the main mechanism responsible for producing high energy photons in the SNR neighbourhood. Based on a recent systematical analysis of the molecular environment of the vicinity of all SNR-EGRET source pairs, the IC 443 remnant was chosen for observations with MAGIC. We briefly describe the observational strategy which provided the detection of a new very-high energy gamma-ray source: MAGIC J0616+225.

Key Words: gamma rays: observations — ISM: individual (IC 443, MAGIC J0616+225) — supernova remnants

1. INTRODUCTION: THE COSMIC RAYS PROBLEM

Cosmic rays constitute a continuous flow of relativistic particles, mainly protons and alpha particles (99%). Their energy spctrum is a power-law $\propto$ $E^{-2.2}$, which spans many orders of magnitude indicating a non-thermal origin. Their energy density equals that of "normal" stellar light reaching the Earth. For $E > 10^8$ eV their chemical composition resembles that of solar system, but it is very different isotopically.

Up to 10^{15} eV their origin is mainly Galactic, but what are the acceleration mechanisms operating in the Galaxy? Currently, there is only one known to be efficient enough: the first-order Fermi mechanism. In this scenario, particles crossing a shock front can be scattered randomly inside and outside the front gaining momentum and, finally, escape with a higher velocity. This mechanisms produces a flux spectrum proportional to $E^{-\alpha}$ with $\alpha \gtrsim 2$.

Where this mechanism could be working? A clue: total cosmic rays power amounts to $\sim$ 10% of average supernova power. However, direct observation of cosmic rays in the line of sight of a supernova remnant (SNR) does not provide information of their source because, being charged particles, they are affected by Galactic magnetic fields. On the other hand, gamma-ray production is expected in the same environment and carries the location information.

There are two main production mechanisms for gamma-rays: electron acceleration by magnetic fields, with X-ray synchrotron production and gamma-ray production by inverse Compton with a spectrum $\propto E^{-2.6}$; and accelerated protons interacting with a nucleus producing pions which decay in gamma-rays with a spectrum $\propto E^{-2.2}$. These last ones can be used to probe mechanisms for particle acceleration.

Why IC 443 was selected? Following the systematical analysis of Torres et al. (2003), in which all positional coincidences between SNRs and unidentified γ-ray sources listed in the *Third EGRET Catalog* at low Galactic latitudes are discussed on a case by case basis, it was found that one of the most powerful unidentified sources is positionally coincident with this SNR. It is a symmetric shell-type SNR

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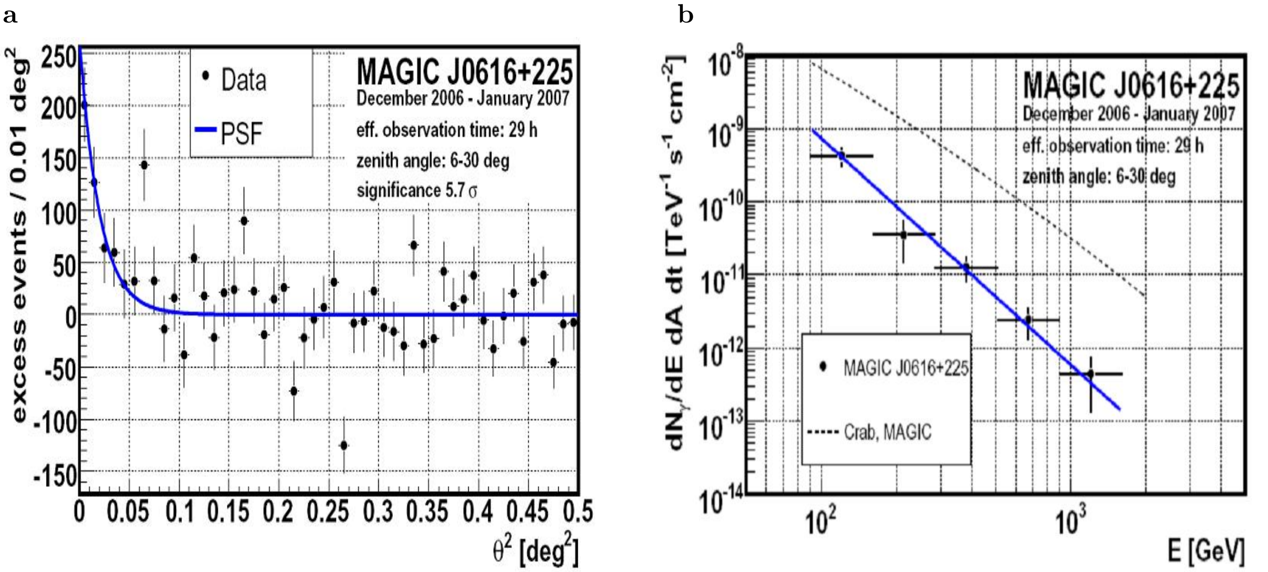

Fig. 1. (a) Distribution of excess γ-ray candidate events as a function of the squared angular distance from the excess center of the source MAGIC J0616+225 (*points*), compared to the expected distribution for a point like source (*solid line*) corresponding to the MAGIC point spread function (PSF). (b) VHE γ-ray spectrum of this source compared to the spectrum of the Crab Nebula as measured by MAGIC. Both figures are taken from Albert et al. (2007).

with 45′ diameter, at $\sim$ 1.5 kpc, detected also in radio and X rays (presence of accelerated electrons). Furthermore, there is a large amount of molecular mass ($\sim 10^4\ M_\odot$) consistent with the distance to the SNR (possibility of pion production). Also, a 1720 MHz maser emission is detected: shocked gas, thus acceleration expected. And, finally, a pulsar wind nebula (PWN) is located near the SNR shell. On the other hand, only upper limits to the very-high energy (VHE) γ-ray emission had been established previously for this source.

2. OBSERVATIONS AND RESULTS

The MAGIC (Major Atmospheric Gamma Imaging Cerenkov) telescope is a 17m diameter atmospheric imaging Cherenkov detector, with a mirror surface of 236 m^2 and photomultiplier tubes of optimal efficiency. With the accent on best light collection, it can detect cosmic gamma-rays at a low energy threshold (70 GeV). It is located at the Roque de los Muchachos Observatory in the island of La Palma (Canary Islands). A second twin telescope is under construction and will start its operations at the end of 2008.

A first observing run of IC 443 was carried out in December 2005–January 2006 (10 hours), and its analysis showed evidence of signal (3σ excess on a 0.05 deg^2 region out of a 2.25 deg^2 map). This excess was supposed to be associated with a γ-ray source and additional 40 hours of observation were approved for December 2006–January 2007 (only 29 useful). Its analysis confirmed the previous hypothesis.

As a result, a new VHE gamma-ray source was discovered: MAGIC J0616+225 (Figure 1a). It appears to be a point like source, spatially coincident with a high density molecular cloud and maser emission, but marginally coincident with the EGRET unidentified source (probably unrelated to it). It seems to be also unrelated to the PWN located closely.

Figure 1b shows that its spectrum is $\propto E^{-3.1\pm0.3}$, which is far from that expected for pure proton acceleration. Currently, a good model for this source is lacking. A detailed analysis of the multi-wavelength data available, as well as a deeper discussion of this result can be found in the paper by Albert et al. (2007).

IN MEMORIAM. Maurizio Panniello, PhD student at the Instituto de Astrofísica de Canarias and a very active member of the MAGIC Collaboration, carried out part of the 2007 observations that allowed this discovery. Very sadly, he suffered an accident inside a cave at the North of the island of Tenerife in February of that year and passed away. This work is dedicated to his memory.

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