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VHE γ-ray observations of starburst galaxies with H.E.S.S.

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Abstract: Starburst galaxies are characterized by extremely high star-formation rates and, as a consequence, very high supernova rates. These rates, as well as the gas density, are orders of magnitude higher than in the Milky Way. Starburst galaxies contain both a high cosmic-ray flux and high density of target material for proton-proton and inverse-Compton interactions. These objects are therefore viable candidates for observable levels of VHE γ-ray emission. Nearby starburst galaxies, such as NGC 253 and M83, allow a study of general processes during galaxy formation and evolution of high redshift galaxies. These two galaxies were observed with H.E.S.S. stereoscopic array of atmospheric-Cherenkov telescopes. Upper limits from these observations are presented here.

Introduction

Starburst galaxies are galaxies with very intense star formation rate in the central region. The starburst activity could be triggered by mechanisms such as a galaxy merger, causing compression of the interstellar gas. Consequent high star formation is responsible for a high supernovae explosion rate in this region. Supernovae then provide shocks necessary for accelerating cosmic-ray particles.

Detectable levels of VHE γ-ray emission are predicted for starburst galaxies such as M82 [1] and NGC 253 [2], [3]. Gas densities in the starburst regions reach values 100 times larger than in the Milky Way. Such high densities provide enough target material for inelastic proton-proton collisions of cosmic-ray protons. Resulting π^0 mesons decay into high energetic γ-ray photons, that can be detected by earthbound Cherenkov imaging telescopes.

Despite encouraging predictions no significant detection of VHE γ-rays has been confirmed from starburst galaxies so far.

Results of M83 observations and re-observations of NGC 253 with the full array of four H.E.S.S. telescopes are presented here.

H.E.S.S. experiment

The H.E.S.S. Collaboration operates an array of four imaging atmospheric-Cherenkov telescopes (IACTs), located in Namibia. Each telescope has 107 m^2 mirror area and a camera consisting of 960 pixels providing a wide field-of-view of 5^o. Images of γ-ray showers are analysed in order to reconstruct the direction and energy of the primary γ photon. Background suppression is based on a system of cuts on the image parameters (e.g. width). All results presented here are obtained using the standard Hillas-based H.E.S.S. analysis. For further details see [4]. All upper limits are calculated assuming a power-law spectrum with the photon index $\Gamma = 2.1$ of the γ rays, at the 99.9% confidence level (CL) [5]. Not included in the upper limits is a 20% systematic error on flux.

Observed targets

NGC 253

NGC 253 is the closest (D $\sim$ 2.5 Mpc [6]) starburst galaxy viewed edge-on. It is considered to be, along with M 82, an archetypal starburst galaxy [7].

The object is very well studied in all wavelengths from radio to X-rays. Chandra X-ray observations [8] show, that the central region of size $\sim$100 pc exhibits very intense starburst activity. The central region is surrounded by a torus of dense gas collimating a galactic wind driven by the starburst [9].

NGC 253 is suggested as a possible source of detectable VHE γ-ray flux (see for example [3]).

Several instruments have already published upper limits on γ-ray emission from NGC 253. CANGAROO III published results of 12.5 hours on-source observations [10]. The outcome was a 2σ upper limit of 3.4×10^{-12} ph. cm^{-2} s^{-1} above 450 GeV, corresponding to 4.5% of Crab flux. H.E.S.S. observed NGC 253 for 24.6 hours with 2 telescopes and for 3.4 hours using 3 telescopes. The result was an upper limit of 1.9×10^{-12} ph. cm^{-2} s^{-1} above 300 GeV (1.4% of Crab flux using Crab spectrum of [4]) at 99% CL. [2]. Upper limits were also determined by the HEGRA experiment [11] at 11% Crab units at 99% CL. EGRET set an upper limit at lower energies of $F(> 100\text{MeV}) < 3.4 \times 10^{-8}$ ph. cm^{-2} s^{-1} [12].

H.E.S.S. observed NGC 253 in several campaigns during 2003 and 2005. The total live time used for analysis (after applying current data selection criteria) is 21.3 hours taken with only two telescopes and 14.2 hours performed using the full array of four telescopes.

No VHE significant signal is found. The angular distribution of on-source and off-source events shows no hint of a γ-ray excess (see Figure 1) from the NGC 253 region. The 99.9% upper limit on the integral flux is $I_{\text{ul}}(> 270GeV) = 1.2 \times 10^{-12}$ ph. cm^{-2} s^{-1}, corresponding to 0.7% of the Crab Nebula flux. The upper limits are considerably lower than all the previously published limits [2], [10].

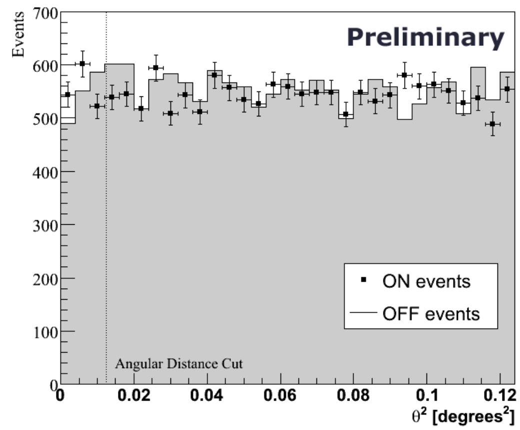

Figure 1: Angular distribution of on-source and off-source events of the H.E.S.S. observations of NGC 253

M 83

M83 is a nearly face-on spiral galaxy with high metallicity around twice the solar value [13]. The central $\sim$300 pc is shown to host a starburst nucleus [14]. M83 is slightly further away (D $\sim$ 4.5 Mpc [15]) and the FIR flux is also lower than in the case of NGC 253. This makes M83 a slightly worse VHE candidate with respect to NGC 253. On the other hand, M83 does not show any sign of a galactic wind, contrary to NGC 253. The convective losses of high-energy cosmic rays may thus be considerably lower than in the case of NGC 253, implying a detectable γ-ray flux as well.

M83 was observed by H.E.S.S. in July 2006. The total live time used for analysis is 8.2 hours of good-quality data. No significant VHE γ-ray emission is found. The angular distribution of on-source and off-source events (see Figure 2) does not show any hint of an excess. The resulting upper limit on the integral flux is $I(> 330GeV) = 2.2 \times 10^{-12}$ cm^{-2} s^{-1} at the 99.9% confidence level. These are the first VHE γ-ray upper limits to be presented for M83. The integral flux upper limits are also shown in the Figure 2.

In addition, no other significant signal is found in the field-of-view of M83.

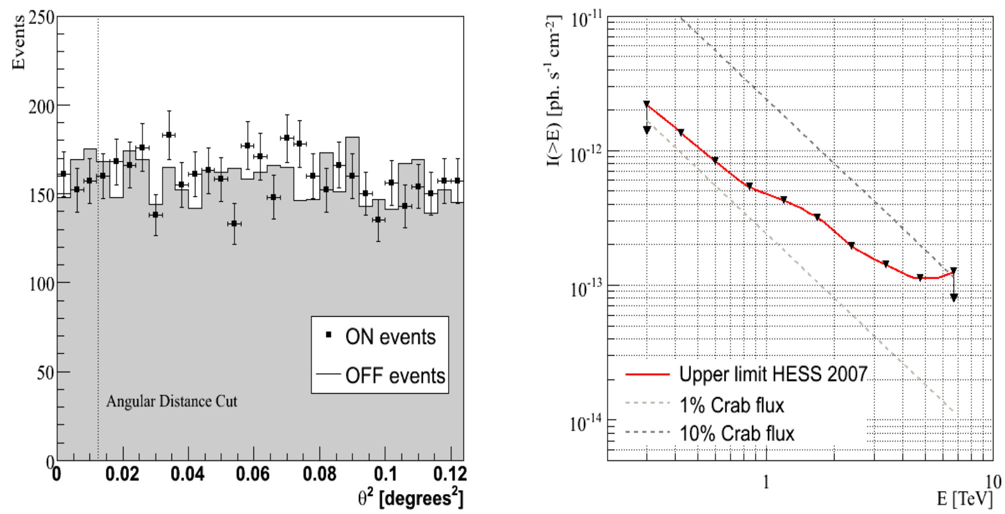

Figure 2: Left panel: Angular distribution of on-source and off-source events for M83. Right panel: Upper limit on the M83 integral flux above the energy, E. The H.E.S.S. results are compared to 1% and 10% of Crab integral flux according to [4].

Summary and conclusions

No significant VHE γ-ray signal was found in the H.E.S.S. follow-up observations of NGC 253 or in the observations of M83. Upper limits from these observations are presented. These limits are already very close to the theoretical predictions. Since there is only limited space for uncertainties in the flux-prediction models, the detection of starburst galaxies by the current or future generation of γ-ray experiments seems to be inevitable. Starburst galaxies thus remain very good candidates for future observations.

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