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15-year observation of TeV gamma-ray emission from NGC 1275 by SHALON

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Abstract: Galaxy clusters have been consider as sources of TeV gamma-rays emitted by high-energy protons and electrons accelerated by large scale structure formation shocks, galactic winds, or active galactic nuclei. The Perseus cluster of galaxies is one of the best studied clusters due to its proximity and its brightness. Galaxy NGC 1275 is the central dominant galaxy of the Perseus Cluster of Galaxies and is of Seyfert galaxy class. NGC 1275 is known as powerful X-ray and radio source. In 1996 year a new metagalactic source was detected by SHALON at TeV energies. This object was identified with Seyfert galaxy NGC1275; its image is presented. The maxima of the TeV gamma-ray, X-ray and radio emission coincide with the active nucleus of NGC 1275. But, the X-ray and TeV emission disappears almost completely in the vicinity of the radio lobes. The correlation TeV with X-ray emitting regions was found. The integral gamma-ray flux of NGC1275 is found to be $(0.78 \pm 0.05) \times 10^{-12} cm^{-2} s^{-1}$ at energies of > 0.8 TeV. Its energy spectrum from 0.8 to 40 TeV can be approximated by the power law with index $k = -2.25 \pm 0.10$. The NGC 1275 has been also observed with the Tibet Array (5TeV) and then with Veritas telescope at energies about 300 GeV at 2009. The recent detection by the Fermi LAT of gamma-rays from the NGC1275 makes the observation of the energy $E > 100$ GeV part of its broadband spectrum particularly interesting.

Keywords: Active Galactic Nuclei; Seyfert galaxy; NGC 1275; SN2006 gy; Extragalactic Supernova explosion.

Introduction

The γ-astronomical researches are carrying out with SHALON [1, 2, 4, 3, 5] mirror Cherenkov telescope at the Tien-Shan high-mountain observatory. The SHALON mirror telescopic system consists of composed mirror with area of $11.2\ m^2$. It is equipped with 144 photomultipliers receiver with the pixel of 0.6° and the angular resolution of the experimental method of $< 0.1^\circ$. It is essential that our telescope has a large matrix with full angle $> 8^\circ$ that allows us to perform observations of the supposed astronomical source (ON data) and background from extensive air showers (EAS) induced by cosmic ray (OFF data) simultaneously. Thus, the OFF data are collecting for exactly the same atmospheric thickness, transparency and other experimental conditions as the ON data.

An additional selection of electron-photon showers among the net cosmic rays EAS becomes possible through an analysis of a light image which, in general, emerging as an elliptic spot in light receiver matrix. The selection of gamma-initiated showers from the background of proton showers is performed by applying the following criteria:

- $\alpha < 20^\circ$;
- $length/width > 1.6$;
- the ratio $INT0$ of Cherenkov light intensity in pixel with maximum pulse amplitude to the light intensity in the eight surrounding pixels exceeds > 0.6;
- the ratio $INT1$ of Cherenkov light intensity in pixel with maximum pulse amplitude to the light intensity in the in all the pixels except for the nine in the center of the matrix is exceeds > 0.8;
- $distance$ is less than 3.5 pixels.

Our analysis of the distributions of listed shower image parameters suggests that the background is rejected with 99.92% efficiency (see Refs. [1, 2, 4, 3, 5]), whereas the amount of background showers to the selected gamma-showers does not exceed of 10%.

During the period 1992 - 2011, SHALON has been used for observations of galactic and metagalactic sources; among them are the known blazars Mkn421 (z=0.031), Mkn501 (z=0.034) and Seyfert galaxy NGC1275 (z=0.0179). The observation results of two type of metagalactic sources: Seyfert galaxy NGC1275[1, 2, 4, 3, 5] and SN 2006gy are presented. The explosion of SN2006gy extragalactic supernova (z = 0.019) was detected at TeV energies with SHALON telescope during the observations of NGC1275.

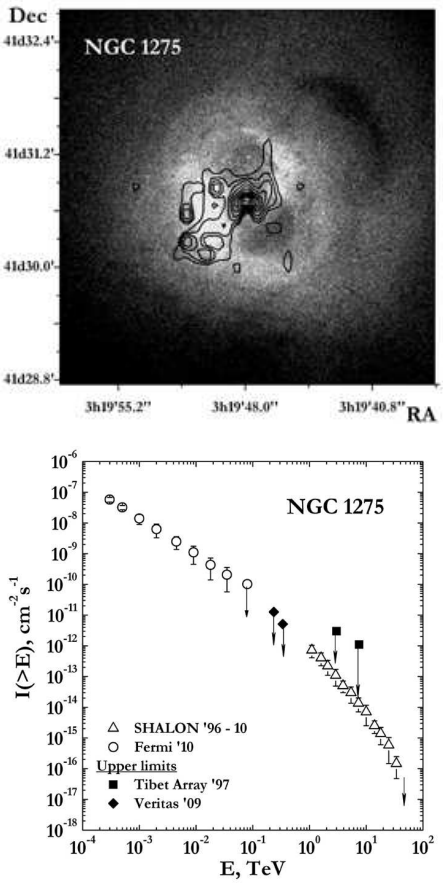

Figure 1: Chandra X-ray image of NGC 1275 together with SHALON data. The contour lines show the TeV - structure by SHALON observations. The TeV energy spectrum of NGC 1275 from SHALON, 15 year observations in comparison with other experiments: Fermi LAT [7], Veritas [8], Tibet Array [9].

NGC 1275

Galaxy clusters have been consider as sources of TeV γ-rays emitted by high-energy protons and electrons accelerated by large scale structure formation shocks, galactic winds, or active galactic nuclei. The Perseus cluster of galaxies is one of the best studied clusters due to its proximity and its brightness. Galaxy NGC 1275 is the central dominant galaxy of the Perseus Cluster of Galaxies and is of Seyfert galaxy class. NGC 1275 is known as powerful X-ray and radio source. Many studies explored correlations of X-ray, radio,(fig. 1) optical and ultraviolet emission (see e.g. [11]).

In 1996 year a new metagalactic source are detected by SHALON at TeV energies (figs. 1, 2, 3). This object was identified with Seyfert galaxy NGC 1275[1, 2, 4, 3, 5] (with redshift z=0.0179); its image is shown in fig. 1, 3. The maxima of the TeV gamma-ray, X-ray [12] and radio emission coincide with the active nucleus of NGC 1275. In contrast,

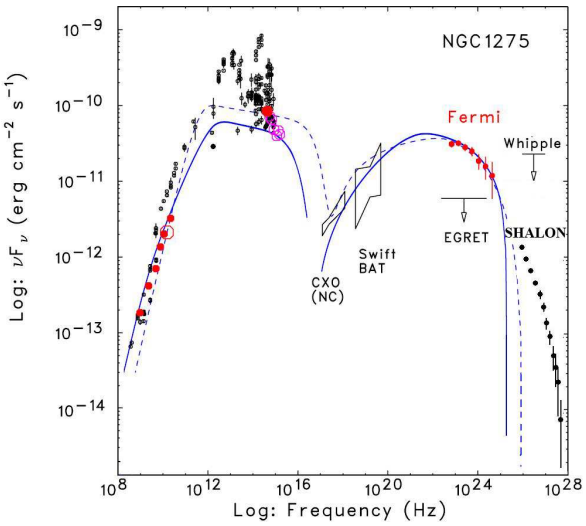

Figure 2: Overall spectral energy distribution (SED) of NGC 1275. The low energy data from [7]. The SED is fitted with a one-zone synchrotron/SSC model (blue dashed curve) and a decelerating flow model (blue solid curves) [10].

the X-ray and TeV emission disappears almost completely in the vicinity of the radio lobes. The correlation TeV with X-ray emitting regions was found. The gamma-ray emission from the position of NGC 1275 was detected above 800 GeV with a statistical significance of 29.1 σ (for 263.4 hours) [6]. The integral γ-ray flux for this source is found to be $(0.78 \pm 0.05) \times 10^{-12} cm^{-2} s^{-1}$ at energies of > 0.8 TeV. The energy spectrum of NGC 1275 at 0.8 to 30 TeV can be approximated by the power law $F(> E_O) \propto E^{k_\gamma}$, with $k_\gamma = -2.25 \pm 0.10$. The detailed spectra, image and energy image are shown on Figure 3. The variations of the gamma-ray flux on the year scale are no more than 20% of average value.

SN2006 gy

The flux increase was detected from the region NGC 1275 in autumn 2006. The detailed analysis of gamma-shower direction turned out the detection of metagalactic object. This object was identified with the supernova SN2006 gy (see fig. 4) [13] that is about 10 minutes away from NGC 1275.

Observations had been done in cloudless nights of moonless periods of 2006 September, October, November, December and then during the winter of 2007. No flux increase was found in September observations. In the flare, observed on October 22, the flux increased 6 times from the NGC 1275 average flux and stayed on this level all October moonless period. After the standard analysis, a excess corresponding to a 6.2σ [6] was determined. The

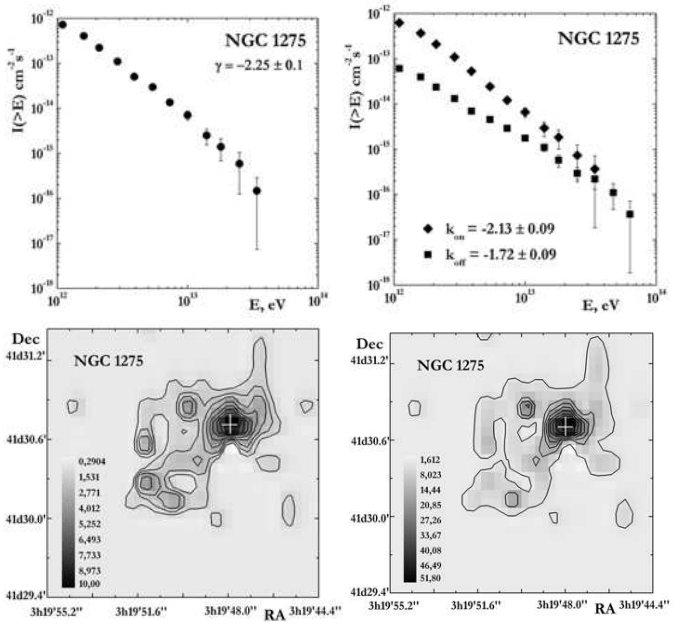

Figure 3: The NGC 1275 observational data by SHALON: **Top left:** the γ-quantum integral spectrum; **right:** The event spectrum from the source with background with index of k_{ON} and spectrum of background events observed simultaneously with the object with index k_{OFF}; **Bottom left:** The NGC 1275 image at energy range of > 0.8 TeV; **right:** The energy image (in TeV units) of NGC 1275.

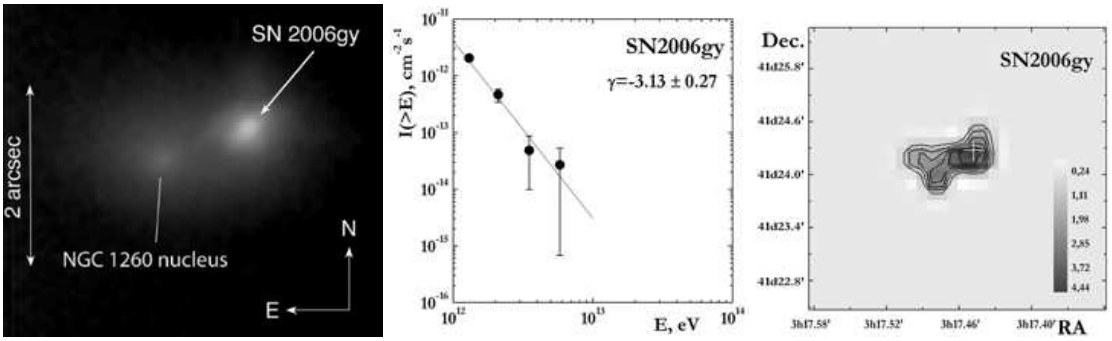

Figure 4: The image of SN2006 gy (Chandra) and the nucleus of NGC 1260 at three wavebands: J band(1.25 m), H band (1.65 m), and Ks band (2.2 m). The SN2006gy by SHALON: **left:** the γ-quantum integral spectrum; **right:** The SN2006gy image at TeV energy range.

integral gamma-ray flux for SN 2006gy is found to be $(3.71 \pm 0.65) \times 10^{-12} cm^{-2} s^{-1}$ at energies of > 0.8 TeV. The energy spectrum of SN2006 gy at 0.8 to 7 TeV can be approximated by the power law $F(> E_O) \propto E^{k_\gamma}$, with $k_\gamma = -3.13 \pm 0.27$ (fig. 4). An image of gamma-ray emission from SN2006 gy by SHALON telescope is shown in Fig. 4.

Follow-up observations on end of November showed that the flux of SN2006 gy had dropped to a flux level of about $(0.69 \pm 0.17) \times 10^{-12} cm^{-2} s^{-1}$ and was constant during the November, December period. The results of observation analysis of 2007 have no revealed TeV gamma-ray emission from region of SN 2006gy. So, the explosion of extragalactic supernova was observed at TeV energies for the first time with SHALON Cherenkov telescope.

No other significant variations of the gamma-quantum flux during the observations of NGC1275 were found during all the period of observations.

VHE observations of NGC 1275

Experimental limits on the very high energy gamma-ray emission from the Perseus cluster and its central galaxy NGC1275 have been obtained by the other experiments [7, 8, 9, 14, 15]. The Seyfert galaxy NGC 1275 has been also observed with the Tibet Array [9] (about 5 TeV) and

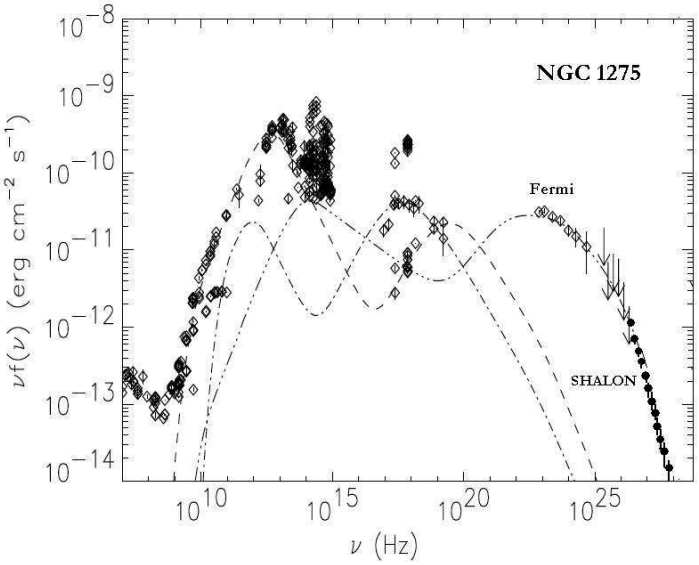

Figure 5: Overall spectral energy distribution (SED) of NGC 1275. The TeV energy spectrum of NGC 1275 from SHALON, 15 year observations in comparison with other experiments: Fermi LAT [7], and upper limits: Veritas [8], MAGIC [14].

then with Veritas [8] telescope at energies about 300 GeV at 2009. The radio-galaxy NGC 1275 has been recently detected by Fermi [7] as a source of high-energy gamma rays with an average flux and power-law photon index of $F(> 100MeV) = (2.31 \pm 0.13) \times 10^{-7} cm^{-2} s^{-1}$ and $\gamma = 2.13 \pm 0.02$, respectively. The recent detection by the Fermi LAT of high-energy gamma-rays from the radio galaxy NGC 1275 makes the observation of the very high energy ($E > 100$ GeV) part of its broadband spectrum particularly interesting. The overall spectral energy distribution of NGC 1275 from the low energies to the TeV energies is presented (fig. 2, 5). The spectrum of NGC 1275 from SHALON 15 year observations is also shown.

Conclusion

The Perseus cluster as a many other galaxy clusters is expected to be a source of gamma-ray emission due to various emission mechanisms [16] In the model discussing [16] the photon emission at the wide energy range is produced by three components with a specific jet-blob structure that is able to reproduce the observed multi-frequency spectral energy distribution (fig. 5). The available high and very high energy data for NGC 1275 are well fitted in this model with three components, in which the second, most energetic and smaller blob produces a SSC emission observed at gamma-ray energies [16] (fig. 5).

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