The objects in observations of Perseus Cluster region

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Abstract

The results of 20-year observations of the Perseus cluster centering on the NGC 1275 including IC 310 radio galaxy and extragalactic supernova SN 2006gy at energies 800 GeV - 45 TeV by the SHALON telescope are presented. Also, the emission from the galactic source of nonthermal radio and X-ray emission GK Per (Nova 1901) of classical nova type was found as it accompanied to the observations. For NGC 1275, it was found, that the TeV γ-ray emission at energies > 800 GeV has an extended structure with a distinct core centered at the NGC 1275 nucleus and well correlates with the photon emission regions viewed in X-rays by Chandra and anti-correlates with radio-structures. Also, the variations of TeV γ-ray flux both at year- and day- scales were found. The obtained data indicate that the part of TeV γ-ray emission is generated by relativistic jets in the nucleus of NGC 1275. Whereas, the presence of an extended structure around NGC 1275 and the slow rise of the γ-ray flux is the evidence of the interaction of cosmic rays and magnetic fields generated in the jets at the galactic center with the gas of the Perseus cluster.

Introduction

The Perseus galaxy cluster with the central galaxy NGC 1275 has long been considered as an ideal candidate both for studying the physics of relativistic jets from Active Galactic Nuclei and for the revealing of the central galaxy feedback role. NGC 1275 is a powerful source of radio and X-ray emission. In the radio band, the object is also known as Perseus A and 3C 84, has a structure with an extremely bright compact core and extended jets which. Having a supermassive black hole (with a mass of $3.4 \times 10^8 M_\odot$) at its center, NGC 1275 also exhibits jet precession, which can be interpreted as a demonstration of the fact that NGC 1275 is the result of a merger between two galaxies. The radio emission extends to great distances and shows a clear interaction with the gas inside the Perseus cluster of galaxies. ROSAT and, subsequently, Chandra observations revealed cavities in the gas located inside the cluster coinciding with the radio structures (Fig.1), which suggests that the jets from 3C 84 sweep up numerous "bubbles" in the atmosphere of the Perseus cluster. Here, we present the results of twenty-year investigations of the NGC 1275 and its surroundings obtained at 0.8 - 50 TeV with SHALON telescope since 1996 [2, 3], as well as the experimental approach to searching for the γ-ray emission mechanisms in clusters of galaxies and AGNs located in the cluster atmosphere.

NGC 1275 viewed in TeV gamma-rays

The long-term studies of NGC 1275 by SHALON yield the detection of γ-ray emission of $E > 800$ GeV from NGC 1275 [1, 2, 3, 4] at the level of 33.7σ [5] with the average integral flux $(7.8 \pm 0.5) \times 10^{-13}$ cm^{-2} s^{-1} . The γ-ray energy spectrum in the energy range 800 GeV - 45 TeV is well described by: $dF/dE = (6.9 \pm 0.09) \times 10^{-13} \times E^{-2.61 \pm 0.16} \times exp(-E/28 \pm 9$ TeV) cm^{-2} sec^{-1} TeV^{-1} with $\chi^2/DoF = 0.94$ (with $DoF = 9$). (see Fig. 1, $\triangle$). Also, to analyze the emission originated at very NGC 1275 core, we extracted the component corresponding to the region of NGC 1275 of $32''$ in size. Gamma-ray emission associated with the central region of NGC 1275 was detected at energies above 0.8 TeV at a 13.5σ with an average integral flux $(3.26 \pm 0.30) \times 10^{-13}$ cm^{-2} s^{-1}. Fig. 1 shows the spectral energy distributions of NGC 1275 ($\triangle$) and its central region ($\blacktriangle$) by SHALON (1996 - 2012, 2015, 2016) [3] with the Fermi LAT (2009 - 2011) [6]; 8 year catalogue and other experimental data (see refs in [3]).

In order to find the mechanisms of generation of very high energy emission in the source the correlation of the emission regions in the wide energy range including radio, X-rays and TeV γ-rays should be established.

In Fig. 1 an TeV emission map of NGC 1275 by SHALON is overlaid with ones in X-rays and radio. In X-rays and TeV γ-rays, both, the images of Perseus cluster center demonstrate a circular symmetric structure with the distinct emission from the position of NGC 1275 core. The X-ray surface brightness maxima around the core are coincides with maxima of TeV flux to the east and west of the nucleus of NGC 1275. The clearly seen minima in the X-rays and in the TeV γ-rays to the north and south from NGC 1275 coincides with outer radio lobes (black lines) which are further surrounded with bright X-ray arc regions. The interpretation is that the intense emission from these rims comes from the shells surrounding the radio lobes [7].

The data about TeV γ-rays from NGC 1275 have been collected in SHALON experiment since 1996, and the intensity of NGC 1275 was found to be variable in the very high energies (see Fig.2). The SHALON telescope has detected four short-time (within five days) increases of the TeV γ-ray flux [3] in the entire time of observations of NGC 1275, and a light curve shows a slow TeV γ-ray flux increase after the 2001 year. The archive light curves at radio [8], X-ray data [9, 10] and Fermi LAT year fluxes at $E > 100$ MeV [11] are presented in Fig. 1 together with NGC 1275 γ-ray fluxes by SHALON. The red triangles indicate the integral fluxes from the SHALON data averaged over each year of observations. In case of the flare localization, two points are presented: open triangles are the fluxes averaged over the observation year, and red ones are the flux without the flaring period.

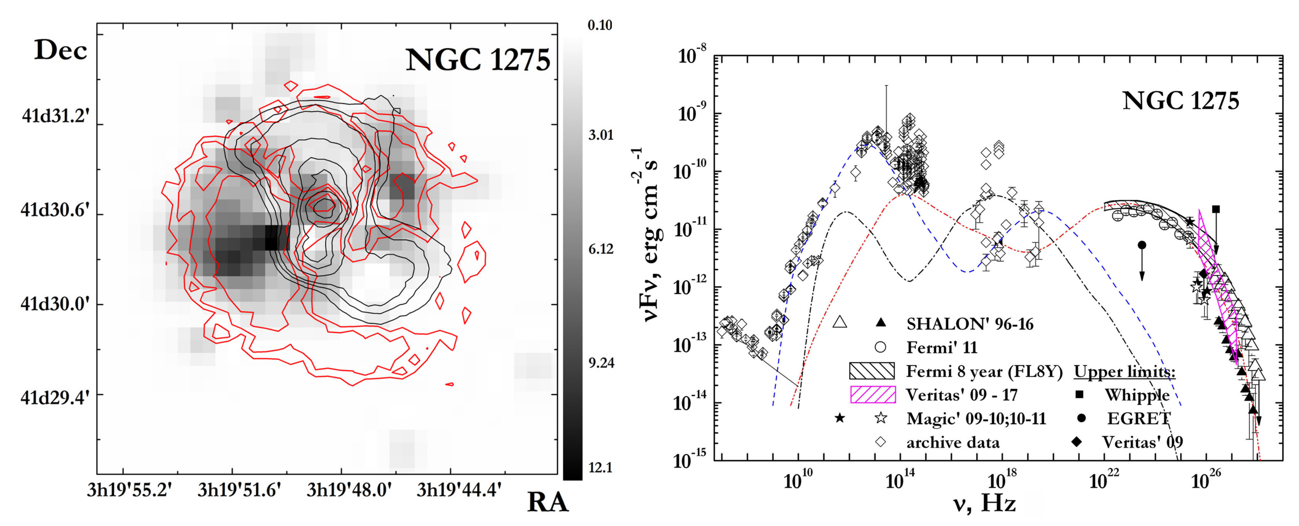

Figure 1: The image of NGC 1275 by SHALON in 0.8 - 45 TeV γ-rays (grey scale); the red contours indicate the image of NGC 1275 in X-ray (1.5-3.5 keV) by Chandra [9] the black contours are the radio structures by VLA (332 MHz); Spectral energy distribution of the γ-ray emission from NGC 1275 by SHALON ($\triangle$ and $\blacktriangle$) in comparison with experimental data and models;

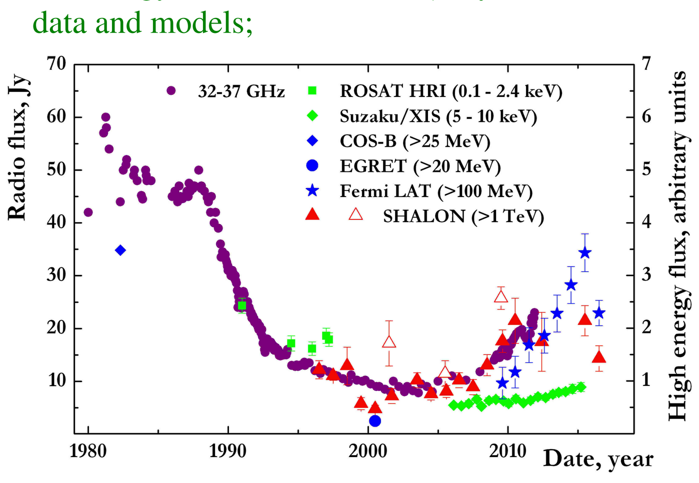

Figure 2: Light curve for NGC1275. The fluxes are presented in arbitrary units: for X-ray data is in the units of 7×10^{-12} erg cm^{-2}s^{-1}; High energy year fluxes from Fermi LAT, data from COS-B and EGRET upper limits are in 1.67×10^{-7} cm^{-2}s^{-1}; Very high energy year integral fluxes from SHALON observations (red triangles) are in the units of 7×10^{-13} cm^{-2}s^{-1}.

SN 2006gy

The flux increase was detected from the region NGC 1275 in autumn 2006. The detailed analysis yielded the detection of the new object identified with the extragalactic supernova SN 2006gy that is about $0.46°$ away from NGC 1275 (see details in [12]). Observations were done in Sep.- Dec. of 2006 and then during the winter of 2007. No flux increase was found in Sep. observations. In the flare, detected at Oct. 22, the flux increased 6 times from the NGC 1275 average flux and stayed on this level all Oct. moonless period. The γ-ray flux for SN 2006gy is $I(> 0.8\text{TeV}) = (3.71 \pm 0.65) \times 10^{-12}$ cm^{-2}s^{-1}. Follow-up observations in Nov., Dec. period shown that the flux of SN 2006gy had dropped to a level of $(0.69 \pm 0.17) \times 10^{-12}$ cm^{-2}s^{-1}. The results of 2007 observations revealed no TeV γ-ray emission from the region of SN 2006gy.

GK Per (Nova 1901)

During the observations of NGC 1275 the SHALON field of view contains the source of non-thermal radio and X-ray emission GK Per (Nova 1901) of classical nova type. The γ-ray source associated with the GK Per was detected above 2 TeV with average γ-flux $(2,9 \pm 1,3) \times 10^{-13} cm^{-2}s^{-1}$ at level of of 9.2σ. The image of GK Per at TeV-energies by SHALON are shown with Fig. 3, right. Our analysis revealed the main TeV-emission region coinciding with the position of central source of GK Per and the weak emission of shell, that is also observed in X-ray by Chandra.

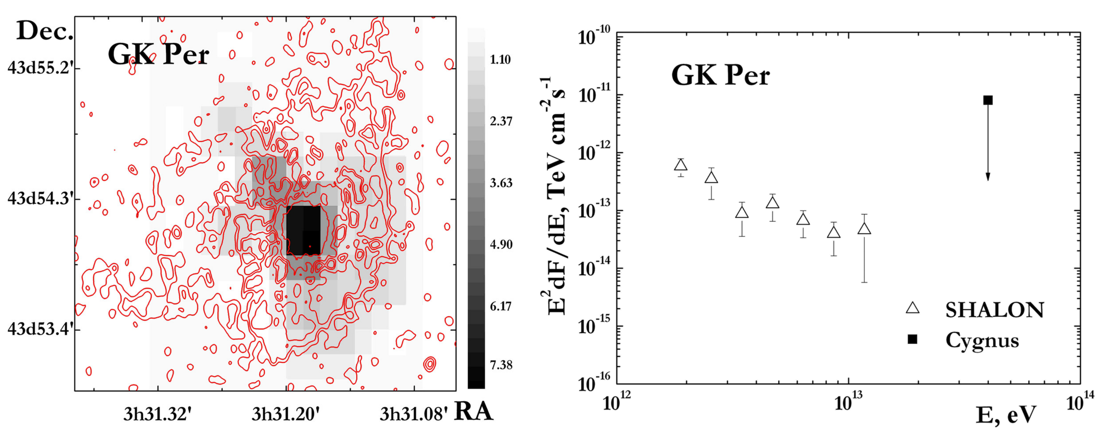

Figure 3: GK Per images. Grey scale - SHALON data in 0.8 - 40 TeV; red contours - X-ray data by Chandra X-ray $(1.5 - 3.5$ keV); Spectral energy distribution of GK Per. $\triangle$ - the data from the SHALON.

IC 310

The radio galaxy IC 310 is located at $0.6°$ from NGC 1275. IC 310 radio morphology consists of a bright "head", located at the core of the galaxy, and "tail" of a radio lobe pointing away from the center of the cluster (Fig. 4, left). In X-rays IC 310 looks as a point source at the position of the radio "head" with luminosity suggesting an existing of active nucleus. IC 310 was detected by SHALON at > 0.8 TeV at level of 19.8σ [5] with integral flux $(0.89 \pm 0.09) \times 10^{-13}$ cm^{-2}s^{-1} (see [12] for details). The differential spectrum of γ-rays from IC 310 in the 0.8 - 40 TeV energy range is well fitted with: $dF/dE = (0.83 \pm 0.09) \times 10^{-12} \times E^{-1.56 \pm 0.16} \times exp(-E_\gamma/11.5 \pm 3$ TeV) TeV^{-1} cm^{-2}s^{-1}. The variations of TeV γ-ray flux on the day-scale were detected in the periods of Nov. 2003, Nov. - Dec. 2004, Oct. 2005, Oct. 2007 and Nov. 2008. IC 310 image in TeV γ-rays by SHALON is overlaid in Fig. 4 with radio emission map from WENSS [13] and X-ray image from ROSAT. The main TeV γ-ray emission region of IC 310 corresponds to the core visible in X-rays and coincides with the "head" of the radio structure. The detection of TeV γ-rays from the core of IC 310 galaxy and the day scale flux variability point out the origin of this emission in the relativistic outflow from the active nucleus.

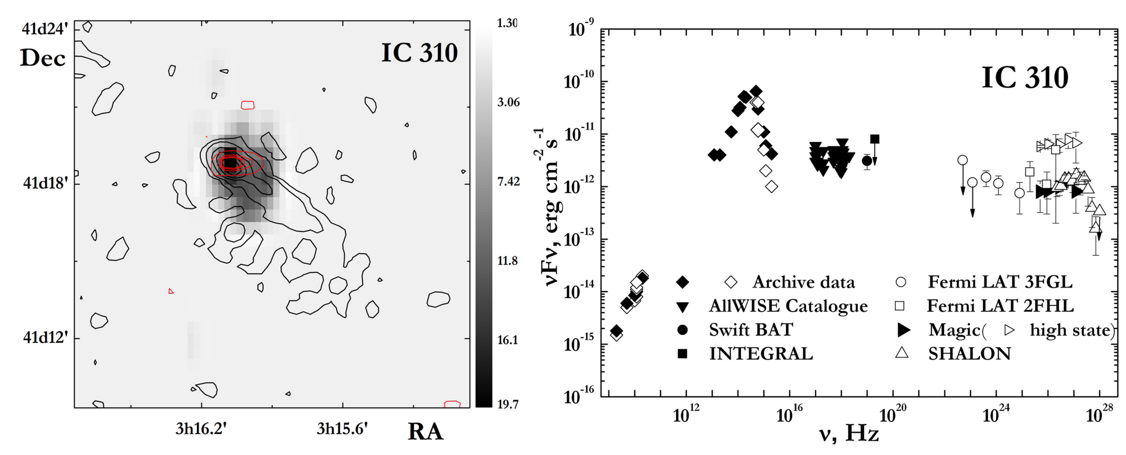

Figure 4: IC 310 images. Grey scale - SHALON data in 0.8 - 50 TeV; red contours - X-ray data by ROSAT; black contours are the radio structures from WENSS sky survey. **right:** Spectral energy distribution of IC 310. $\triangle$ - the data from the SHALON.

Conclusions

The results of twenty-year-long observations of the Perseus cluster centering on NGC 1275 at energies 800 GeV - 45 TeV by the SHALON are presented. The characteristics of IC 310 radio galaxy, extragalactic supernova SN 2006gy and GK Per classical nova accompanying the investigation of NGC 1275 are obtained. The emission regions of TeV γ-rays observed by SHALON from NGC 1275 well correlate with ones viewed in X-rays by Chandra and anti-correlate with radio-structures. This TeV γ-ray emission recorded by SHALON has an extended structure with a distinct core centered at the source's position. The emission component corresponding to the core of NGC 1275 was fully identified. Also, the variations of TeV γ-ray flux both at year- and day- scales were found. The data obtained at very high energies, namely the images of the galaxy and its surroundings, and the flux variability indicate that the TeV γ-ray emission is generated by a number of processes: in particular, part of this emission is generated by relativistic jets in the nucleus of NGC 1275 itself. Whereas, the presence of an extended structure around NGC 1275 and the slow rise of the γ-ray flux is evidence of the interaction of cosmic rays and magnetic fields generated in the jets at the galactic center with the gas of the Perseus cluster.

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