Integral spectra, spectral energy distribution and images of Cygnus X-3

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***Abstract*. Cygnus X-3 is an X-ray binary system located about 10 kpc from earth. However, the nature of Cygnus X-3 is still unresolved. It is one of the brightest Galactic X-ray sources, displaying high and low states and rapid variability in X-rays. The radio activity with the huge radio outbursts is closely linked with the X-ray emission and the different X-ray states. Attempts of detection of TeV emission from Cygnus X-3 were first made in the mid of 1970s and continued through the mid 1980s. Two observations were particularly important: the Kiel results and contemporaneous observation at Haverah Park. These results indicated a very large UHE flux from Cygnus X-3. The more then 10 year's observation results of point source Cygnus X-3 by SHALON mirror Cherenkov telescope are presented. The binary Cyg X-3 came to the period of flaring activity at radio- and X-ray energies in 2006. In May and July 2006 the significant increase of Cyg X-3 flux have detected with SHALON at TeV energy. The gamma-ray flux detected by SHALON in 2006 was estimated as $(1.47 \pm 0.24) \times 10^{-12} cm^{-2} s^{-1}$. The gamma-ray flux detected by SHALON in 2003 was estimated as $(1.79 \pm 0.33) \times 10^{-12} cm^{-2} s^{-1}$. Earlier, in 1997, a comparable increase of the flux over the average value was also observed and estimated to be $(1.2 \pm 0.5) \times 10^{-12} cm^{-2} s^{-1}$. The spectral energy distribution and integral spectra of Cyg X-3 are presented together with the images of Cyg X-3 during the flaring periods in TeV range. These results provide an evidence for a variability of the flux.**

***Keywords*: galactic binary system, Cygnus X-3, TeV gamma-rays, flaring activity**

I. Introduction

The attempts of detection of TeV emission from Cygnus X-3 were first made in the mid of 1970s and continued through the mid 1980s. In 1983 the Kiel group announced that they had observed a large flux of γ - rays with energy in excess of 10^{15} eV from the X-ray binary Cyg X-3. But earlier, Cocconi proposed in 1959 ICRC, Moscow an air shower array at extreme mountain altitude to detect 10^{12} eV γ - rays from astrophysical sources [1]. The Cherenkov gamma-telescope SHALON [2], [4], [3] located at 3338 m a.s.l., at the Tien Shan high-mountain observatory of Lebedev Physical Institute, has been destined for gamma - astronomical observation in the energy range 1 – 100 TeV [2 – 34]. 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 $< 0.1°$. It is essential that our telescope has a large matrix with full angle $> 8°$ 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

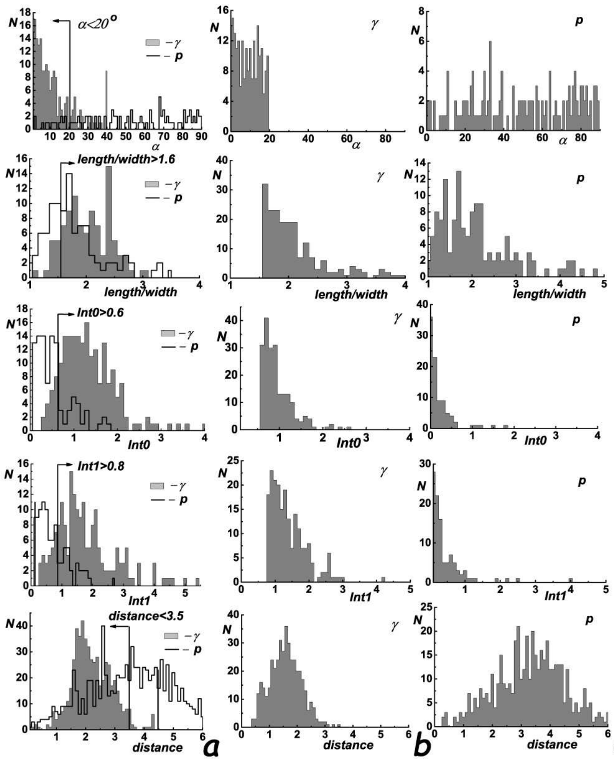

Fig. 1: The distributions of 5 image parameters (α, *length/width*, *Int0*, *Int1*, *distance*) for gamma- and proton-initiated air showers

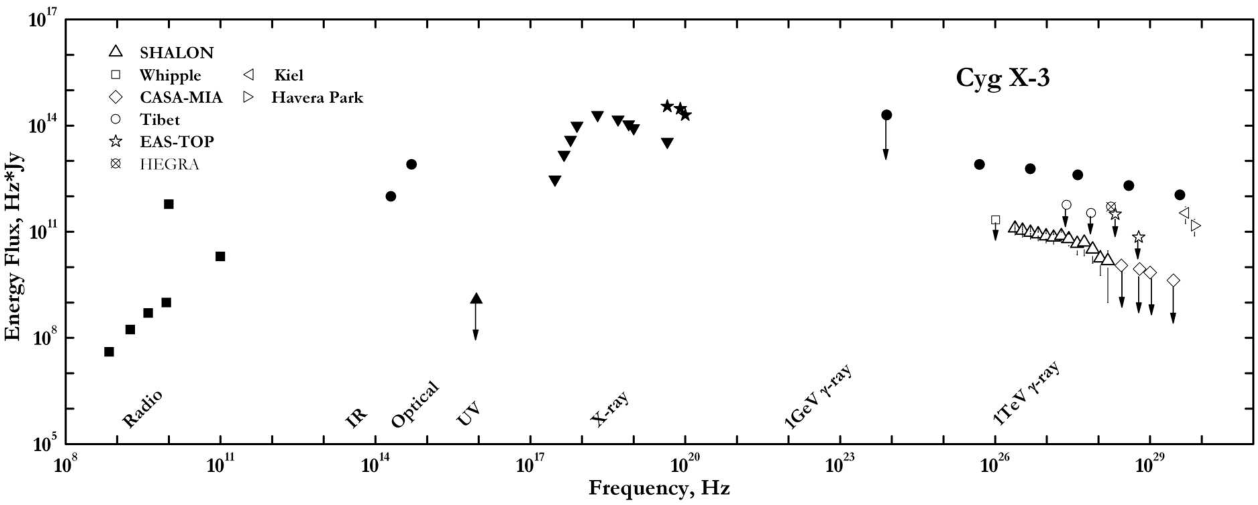

Fig. 2: The spectral energy distribution of Cygnus X-3. Black points are the archival data from Cordova, (1986). The high level points in radio and X-ray bands correspond to radio-frequency activity and increased x-ray activity of the source. TeV range is represented with integral spectrum by SHALON [20], [28] in comparison with other experiments: TIBET, [8] HEGRA [11], EAS-TOP [12], [13], Whipple [14], [15], CASA-MIA [16],Kiel [18], Havera Park [19]

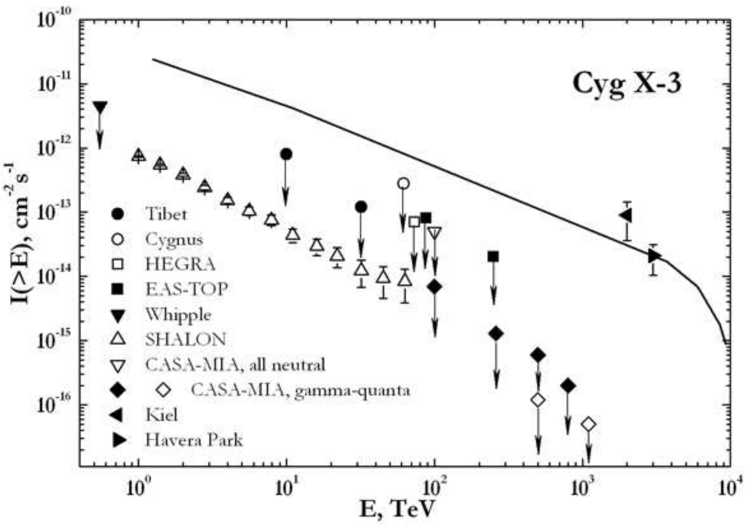

Fig. 3: The Cygnus X-3 gamma-quantum ($E > 0.8$ TeV) integral spectrum by SHALON in comparison with other experiments: TIBET, [8] 2 - CYGNUS [9], [10], 3 - HEGRA [11], 4 - EAS-TOP [12], [13], 5 - Whipple [14], [15], 6 - SHALON [20], [28], diamonds - CASA-MIA [16], Kiel [18], Havera Park [19], the solid line is the theoretical calculation (Hillas) [5], [6].

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:

1) $\alpha < 20°$;

2) $length/width > 1.6$;

3) 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;

4) 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;

5) $distance$ is less than 3.5 pixels.

Our analysis of distributions of shower image parameters suggests that the background was rejected with 99.8% efficiency (see fig. 1 and Refs. [2], [4], [20], [28]).

CYGNUS X-3

Cygnus X-3 has been observed throughout wide range of the electromagnetic spectrum (fig. 2). It is one of

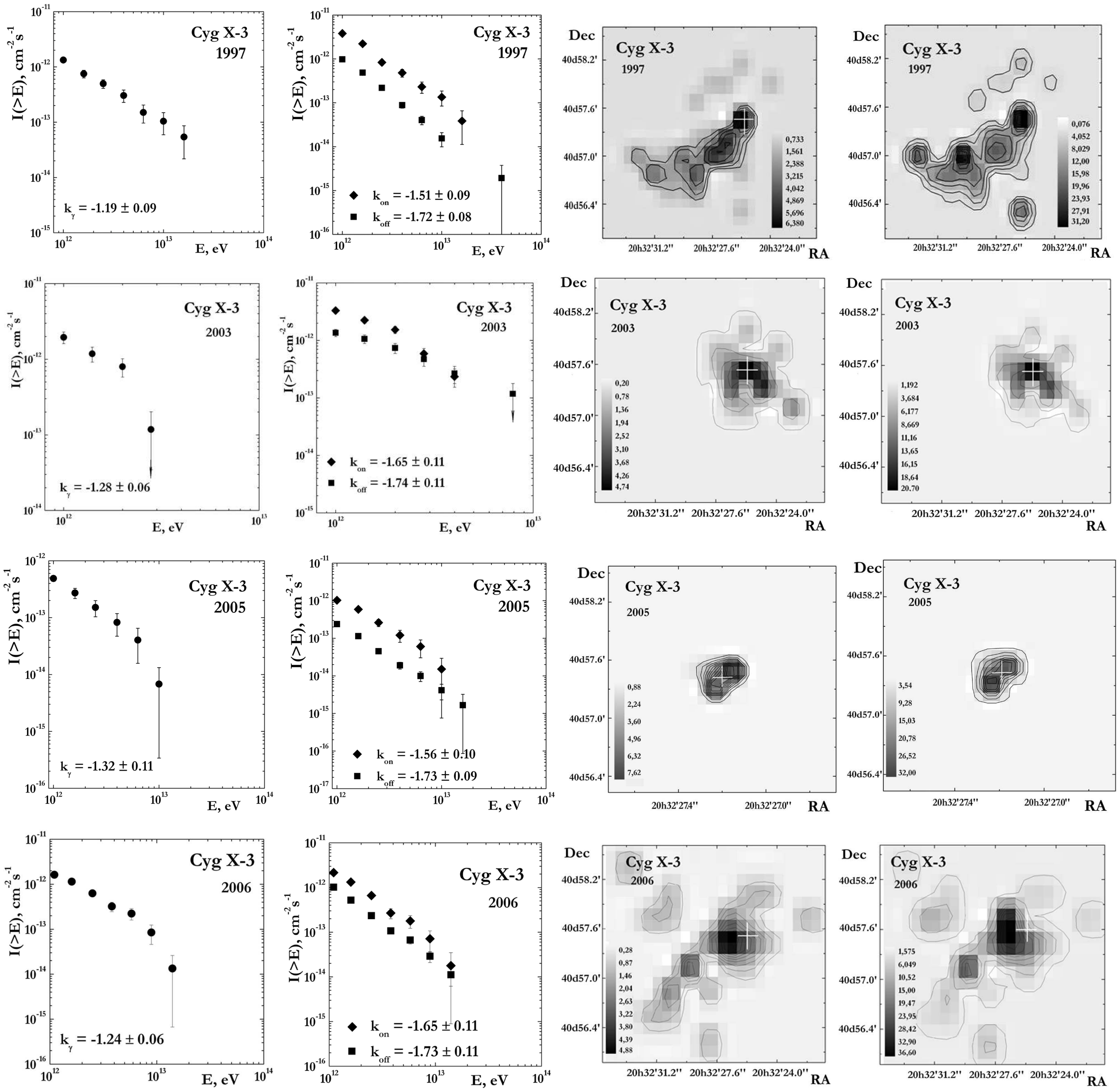

Fig. 4: The Cygnus X-3 in 1997, 2003, 2005 and 2006: (from left to right) The gamma-quantum spectrum k_γ; The event spectrum from Cygnus X-3 with background k_{ON} and spectrum of background events observed simultaneously with Cygnus X-3 - k_{OFF}; The image of gamma-ray emission from Cygnus X-3 and The energy image of Cygnus X-3 (in TeV units) by SHALON.

the luminous X-ray sources in our Galaxy, displaying high and low states and rapid variability in X-rays. In addition to being a powerful x-ray source, Cygnus X-3 is seen in the infrared and is a strong and variable radio source. It is also the strongest radio source among X-ray binaries and shows both huge radio outbursts and relativistic jets. The radio activity are closely linked with the X-ray emission and the different X-ray states. Based on the detections of ultra high energy gamma-rays, Cygnus X-3 has been proposed to be one of the most powerful sources of charged cosmic ray particles in the Galaxy. The searches for TeV emission had been carried out since the mid of 1970s and continued through the mid 1980s. Two observations were particulary important: the Kiel results and contemporaneous observation at Haverah Park. These results indicated a very large UHE flux from Cygnus X-3. So, these results stimulated the construction of many of new detectors. The upper limits of the Cygnus X-3 flux are over an order of magnitude lower than the detected in the 1980s levels. Figures 2, 3 shows upper limits on the steady flux from Cygnus X-3 reported between 1990 and 1995 compared with earlier observations. The Cygnus X-3 flux obtained by SHALON is one order of magnitude lower than upper limits published before.

The observational data obtained with SHALON mirror

Cherenkov telescope for the Cygnus X-3 point source are presented in Figures 2, 3 and 4. This galactic binary system regularly observed since a 1995 is known as a source with variable intensity (from 5×10^{-12} to $10^{-11} cm^{-2}s^{-1}$); the average gamma-quantum flux from Cygnus X-3 for $E > 0.8$ TeV is estimated as $F(E_O > 0.8TeV) = (6.8 \pm 0.7) \times 10^{-13} cm^{-2}s^{-1}$. The standard output of the SHALON data processing consists of the integral spectrum of events coming from a source under investigation; spectrum of the background events coming simultaneously, during the observation of the source; temporal analysis of the source and background events; and the source image. The energy spectrum of Cygnus X-3 at $0.8 - 65$ TeV can be approximated by the power law $F(> E_O) \propto E^{k_\gamma}$, with $k_\gamma = -1.21 \pm 0.05$. This flux, measured for the first time, is several times less than the upper limits established in the earlier observations. The spectra of events satisfying the selection criteria (spectral index $k_{ON} = -1.33 \pm 0.05$) and of the background events observed simultaneously with the source (spectral index $k_{OFF} = -1.74 \pm 0.05$) are both shown in Figures of [28] for comparison.

The binary Cyg X-3 came to new period of flaring activity at radio- and X-ray energies in 2006. In May and July 2006 the significant increase of Cyg X-3 flux have detected with SHALON at TeV energy. The gamma-ray flux detected by SHALON in 2006 was estimated as $(1.47 \pm 0.24) \times 10^{-12}$ $cm^{-2}s^{-1}$ with the indices of integral spectra are $k_\gamma = -1.21 \pm 0.06$, $k_{ON} = -1.65 \pm 0.11$ and $k_{OFF} = -1.73 \pm 0.11$ (fig. 4).

In the 2005 Cyg X-3 was in the quiet period in TeV energies. The average gamma-quantum flux from Cygnus X-3 for $E > 0.8$ TeV is estimated as $F(E_O > 0.8TeV) = (5.4 \pm 0.73) \times 10^{-13}$ $cm^{-2}s^{-1}$ with the indices of integral spectra are $k_\gamma = -1.32 \pm 0.11$, $k_{ON} = -1.56 \pm 0.10$ and $k_{OFF} = -1.74 \pm 0.09$ (fig. 4). The images and spectra of Cyg X-3 in silent period at 2005 are shown at Fig. 4. The are no features found at flaring periods.

The gamma-ray flux detected by SHALON in 2003 was estimated as $(1.79 \pm 0.33) \times 10^{-12}$ $cm^{-2}s^{-1}$ with the indices of integral spectra are $k_\gamma = -1.28 \pm 0.06$, $k_{ON} = -1.65 \pm 0.11$ and $k_{OFF} = -1.74 \pm 0.11$ (fig. 4). Earlier, in 1997, a comparable increase of the flux over the average value was also observed and estimated to be $(1.2 \pm 0.5) \pm 10^{-12}$ $cm^{-2}s^{-1}$ (Fig. 4). These results provide an evidence for a variability of the flux. Confirmation of the variability (and, perhaps, periodicity) of very high-energy gamma-radiation from Cygnus X-3 by the future observations would be important for understanding the nature of this astrophysical object.

CONCLUSION

Cygnus X-3 galactic binary system has been regularly observed since a 1995 by SHALON Atmospheric Cherenkov telescope. The energy spectrum of Cygnus X-3 at 0.8 - 65 TeV $F(> E_O) \sim E^{-1.21 \pm 0.05}$ is obtained for the first time with flux on the order the less than upper limits published before. The results of observation analysis provide an evidence for a variability of the flux. Confirmation of the variability (and, perhaps, periodicity) of very high-energy gamma-radiation from Cygnus X-3 by the future observations would be important for understanding the nature of this astrophysical object.

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