Long term TeV observations of Cygnus X-3

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Abstract:
Cygnus X-3 is a peculiar X-ray binary system discovered about 40 years ago. Cyg X-3 has been regularly observed since 1995 by SHALON Atmospheric Cherenkov telescope. The energy spectrum of Cygnus X-3 at 0.8 - 100 TeV is obtained and the average integral flux is $F(E_O > 0.8 \text{TeV}) = (6.8 \pm 0.5) \times 10^{-13} \text{cm}^{-2} \text{s}^{-1}$. The binary Cygnus 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 $(1.47 \pm 0.24) \times 10^{-12} \text{cm}^{-2} \text{s}^{-1}$. This intensity increase was also observed by Crimea Observatory and the integral flux was estimated as $F(E_O > 1 \text{TeV}) \sim (3-5) \times 10^{-12} \text{cm}^{-2} \text{s}^{-1}$. Earlier, in 1997 and 2003 a comparable increase of the flux over the average value was also observed and estimated to be $(1.79 \pm 0.33) \times 10^{-12} \text{cm}^{-2} \text{s}^{-1}$ and $(1.2 \pm 0.5) \times 10^{-12} \text{cm}^{-2} \text{s}^{-1}$ respectively. In observations of SHALON telescope the formation of jets (like jet of active galactic nuclei) during the activity periods have been found. The last significant increase of very high energy gamma-quantum flux have detected in May 2009, which is correlated with flaring activity at lower energy range of X-ray and at observations of Fermi LAT. Confirmation of the variability 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. The variability of very high-energy gamma-radiation and correlation of radiation activity in the wide energy range can, also, provide essential information on the particle mechanism production the up to the very high energies.

Keywords: Cygnus X-3, High-Mass X-ray Binary System, Cherenkov Telescope.

Introduction

Cocconi proposed in 1959 ICRC, Moscow an air shower array at extreme mountain altitude to detect $10^{12}$ eV $\gamma$-rays from astrophysical sources [1]. 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 $\gamma$-rays with energy in excess of $10^{15}$ eV from the X-ray binary Cyg X-3.

The Cherenkov gamma-telescope SHALON (fig. 1)[2, 3, 4] 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, 3, 4, 6, 7, 8, 9, 10, 12, 11, 13, 14, 15, 16, 17, 18]. Selection of the electron-photon showers among the net cosmic rays EAS becomes possible through the analysis of a light image which, in general is 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 criteria (see [2, 3, 4]). Our analysis of the distributions of shower image parameters suggests that the background is rejected with 99.92% efficiency (see Refs. [2, 3, 4, 11, 15]).
Figure 2: The spectral energy distribution of Cyg X-3. Black points are the archival data from Cordova [5]. 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 [6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18] in comparison with other experiments: Fermi [19, 20], TIBET, [21] HEGRA [24], EAS-TOP [25, 26], Whipple [27, 28], Magic [29], CASA-MIA [30, 31], Kiel [32], Havera Park [33].

Cyg X-3

Cyg X-3 has been observed throughout wide range of the electromagnetic spectrum (fig. 2). It is one of 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, Cyg X-3 is seen in the IR 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 is closely linked with the X-ray emission and the different X-ray states. Based on the detections of ultra high energy γ-rays, Cyg 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 ‘70s and continued through the mid ‘80s. Two observations were particulary important: the Kiel results [32] and contemporaneous observation at Haverah Park [33]. These results indicated a very large UHE flux from Cyg X-3. So, these results stimulated the construction of many of new detectors (see Refs. [34, 35, 36]). The upper limits of the Cyg X-3 flux are over an order of magnitude lower than the detected in the ‘80s levels. Figures 2 and 3 show upper limits on the steady flux from Cyg X-3 reported between ‘90 and ‘95 compared with earlier observations. The Cyg X-3 flux obtained by SHALON is one order of magnitude lower than upper limits published before.

The observational data obtained with SHALON telescope for the Cyg 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 $5 \times 10^{-12}$ to $10^{-11} \text{cm}^{-2} \text{s}^{-1}$); the average γ-ray flux from Cyg X-3 for $E > 0.8 \text{TeV}$ is estimated as $F(E_O > 0.8\text{TeV}) = (6.8 \pm 0.5) \times 10^{-13} \text{cm}^{-2} \text{s}^{-1}$. The average energy spectrum of Cyg X-3 at $0.8 \sim 65 \text{TeV}$ can be approximated by the power law $F(E) \propto E^{k_\gamma}$, 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 binary Cyg X-3 came to the period of flaring activity at radio- and X-ray energies in 2006 (fig. 5). In May and July 2006 the significant increase of the Cyg X-3 flux have detected with SHALON at TeV energy with flux values $(4.12 \pm 1.01) \times 10^{-12} \text{cm}^{-2} \text{s}^{-1}$ and $(1.62 \pm 0.75) \times 10^{-12} \text{cm}^{-2} \text{s}^{-1}$ respectively. The γ-ray flux in the
The γ-ray flux detected by SHALON in 2003 was estimated as $(1.79 \pm 0.33) \times 10^{-12}\, \text{cm}^{-2}\text{s}^{-1}$ (fig. 4). Earlier, in 1997, a comparable increase of the flux over the average value was also observed and estimated to be $(1.2 \pm 0.5) \times 10^{-12}\, \text{cm}^{-2}\text{s}^{-1}$ (Fig. 4).

The last significant increase of very high energy γ-quantum flux has detected in May 2009: $(3.1 \pm 0.98) \times 10^{-12}\, \text{cm}^{-2}\text{s}^{-1}$. The increase is correlated with the flaring activity at lower energy range of X-ray and at observations of Fermi LAT [19, 20] with average flaring flux of $F = (190 \pm 40) \times 10^{-9}\, \text{phcm}^{-2}\text{s}^{-1}$ above 100 MeV (fig. 2). In the autumn of 2009 Cyg X-3 comes again in the quiet period in TeV energies. The average γ-quantum flux from Cyg X-3 for energies more than 0.8 TeV is estimated as $(0.46 \pm 0.07) \times 10^{-12}\, \text{cm}^{-2}\text{s}^{-1}$ with $k_{\gamma} = -1.10 \pm 0.12$.

During the period of observations of Cyg X-3 with SHALON six significant flux increases were detected at energies above 0.8 TeV. To reveal possible correlation of periods of activity in the TeV energy range with the flaring activity at lower energy range of X-ray and at observations of Fermi LAT [19, 20] with average flaring flux of $F = (190 \pm 40) \times 10^{-9}\, \text{phcm}^{-2}\text{s}^{-1}$ above 100 MeV (fig. 2).

The significant anticorrelation of the fluxes at TeV and hard X-rays and the correlation of very high energy flux and soft X-ray were found. It is noted, that TeV flaring activities occur close (within the 4 - 5 days) to strong radio flares. Probably, it is linked with the powerful ejection from the regions are close to the centers blackhole. This ejection is accompanied with a relativistic shock where the relativistic electrons and magnetic field are generated effectively. Similar relation of TeV and soft X-ray fluxes were found in the 1997 observation period. But the flux increase of 2003 didn’t obey this scheme, it was in the quite period in the soft X-rays. In general, the correlation soft X-ray and very high energy γ-ray fluxes is traced since 1996.

Confirmation of the variability of very high-energy gamma-radiation from Cyg X-3 by the future observations would be important for understanding the nature of this astrophysical object.

**References**

Figure 5: The light curves of Cyg X-3 in the wide energy range [29].


