Gamma-rays at energy range 1 - 100 TeV from 2129+47XR and 10 years of Cygnus X-3 observations

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***Abstract*— The new galactic gamma-source (neutron star) 2129+47XR is detected at energy > 0.8 TeV with flux $(0.19 \pm 0.09) \times 10^{-12}\ cm^{-2}s^{-1}$ and indices of the integral spectra are $k_\gamma = -1.12{\pm}0.06$, $k_{ON} = -1.28{\pm}0.07$ and $k_{Off} = -1.73{\pm}0.07$. The results of almost ten-year observation of galactic source Cygnus X-3 by SHALON mirror Cherenkov telescope are presented. The Cygnus X-3 binary, known for more than 20 years as a source with variable intensity $< 10^{-11} - 5 \times 10^{-12} cm^{-2}s^{-1}$ have been regularly observed since a 1995 with average gamma-quantum flux $F(E_O > 0.8TeV) = (6.8 \pm 0.7) \times 10^{-13}\ cm^{-2}s^{-1}$. The flux in 2003 year is $(1.79 \pm 0.33) \times 10^{-12}\ cm^{-2}s^{-1}$. Earlier, in 1997, the increase of flux was also observed and estimated to be $(1.2 \pm 0.5) \times 10^{-12}\ cm^{-2}s^{-1}$. The Cygnus X-3 flux obtained by SHALON is one order of magnitude lower than upper limits published before.**

I.

The Cherenkov gamma-telescope SHALON [1, 2] 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 – 65 TeV [1 - 16]. 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 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. In Figure 1a shows the

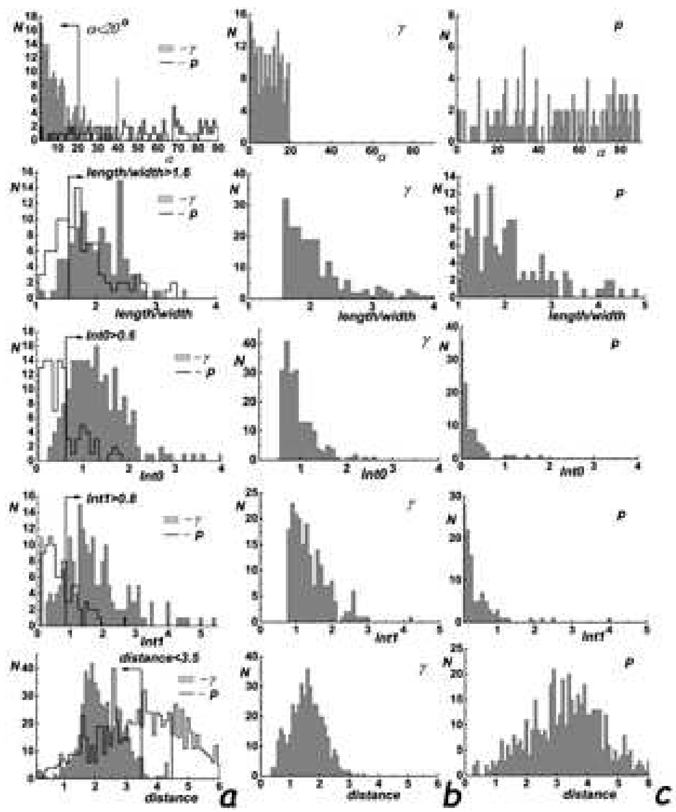

Fig. 1. Monte Carlo distributions of five image parameters (α, $length/width$, $INT0$, $INT1$ and $distance$) for gamma- and proton-initiated showers

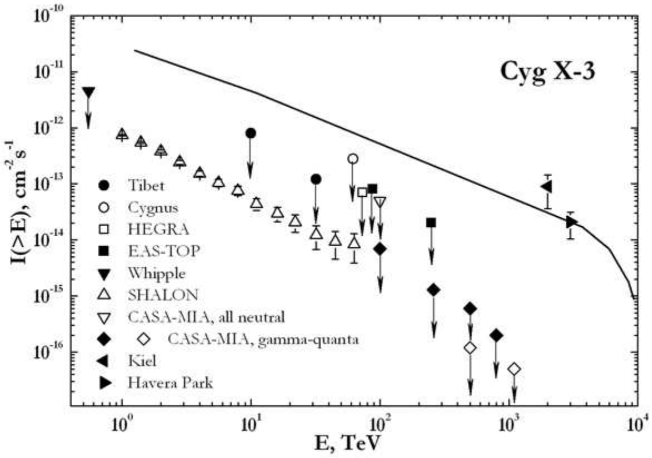

Fig. 2. The Cyg X-3 gamma-quantum ($E > 0.8$ TeV) integral spectrum by SHALON in comparison with other experiments: 1 - TIBET,[6] 2 - CYGNUS,[7, 8] 3 - HEGRA,[9] 4 - EAS-TOP,[10, 11] 5 - Whipple,[12, 13] 6 - SHALON, [15, 16] diamonds - CASA-MIA,[14] the solid line is the theoretical calculation (Hillas) [3, 4].

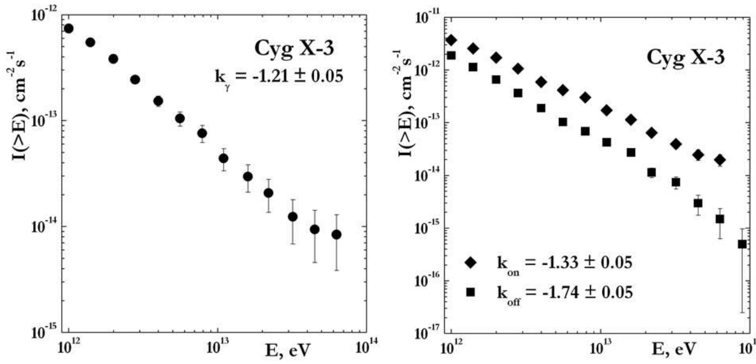

Fig. 3. left – The Cygnus X-3 gamma-quantum spectrum with power index of $k_{\gamma} = -1.21 \pm 0.05$; right - The event spectrum from Cygnus X-3 with background $k_{ON} = -1.33 \pm 0.05$ and spectrum of background events observed simultaneously with Cygnus X-3 - $k_{OFF} = -1.74 \pm 0.05$.

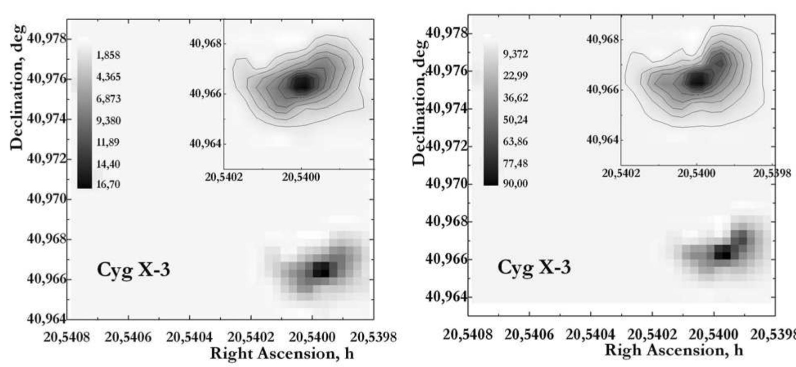

Fig. 4. left – The image of gamma-ray emission from Cygnus X-3; right – The energy image of Cygnus X-3 by SHALON.

Monte Carlo distributions of image parameters of gamma- and proton- induced showers. In Fig. 1a the distributions of image parameters of the gamma showers extracted from the SHALON observations of point sources are presented, while Fig. 1b, c shows the distributions of parameters of cosmic ray protons extracted from zenithal SHALON observations. Our analysis of these distributions suggests that the background was rejected with 99.8% efficiency (more detailed description of the analysis procedures see Refs [1, 2, 15, 16]).

Cygnus X-3 is peculiar X-ray binary system discovered about 40 years ago. The system has been observed throughout wide range of the electromagnetic spectrum. It is one of the brightest Galactic X-ray sources, displaying high and low states and rapid variability in X-rays. 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,

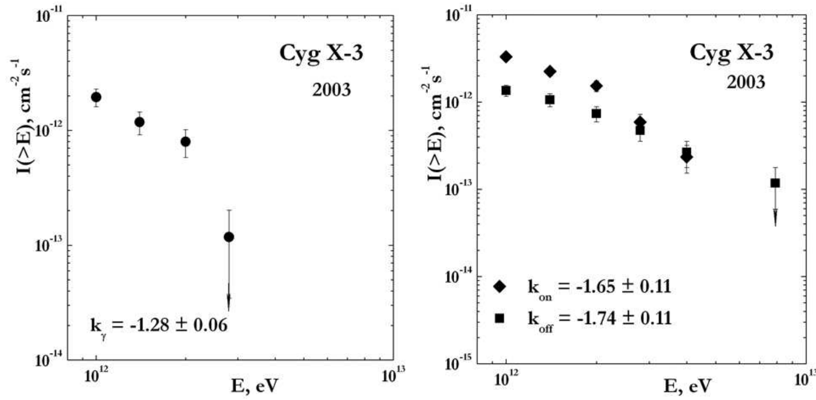

Fig. 5. left – The Cygnus X-3 gamma-quantum spectrum with power index of $k_\gamma = -1.28 \pm 0.06$; right - The event spectrum from Cygnus X-3 with background $k_{ON} = -1.65 \pm 0.11$ and spectrum of background events observed simultaneously with Cygnus X-3 - $k_{OFF} = -1.74 \pm 0.11$;

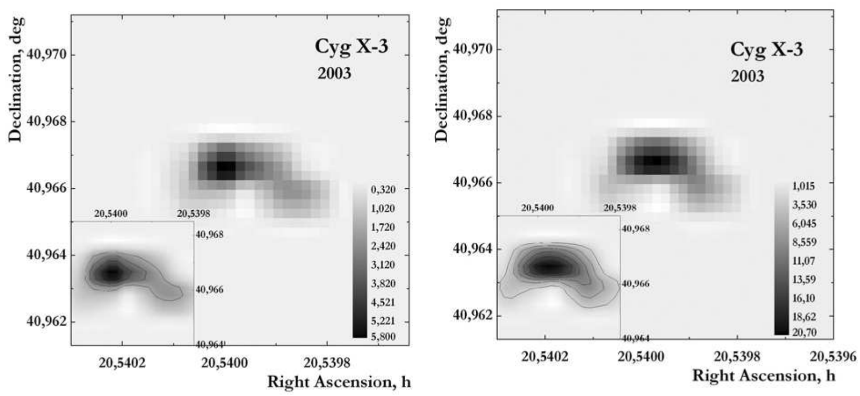

Fig. 6. left – The image of gamma-ray emission from Cygnus X-3 in 2003; right – The energy image of Cygnus X-3 in 2003 by SHALON.

Cygnus X-3 has been proposed to be one of the most powerful sources of charged cosmic ray particles in the Galaxy.

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. 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. Figure 2 shows upper limits on the steady flux from Cygnus X-3 reported between 1990 and 1995 compared with earlier observations. The limits on gamma-rays from Cygnus X-3, the source that results stimulated the construction of many of new detectors are presented. These upper limits and SHALON fluxes are now more than a factor 100 less than the fluxes originally reported by Kiel and Haverah Park.

Figures 2, 3, 4, 5, and 6 collect observational data obtained with SHALON mirror Cherenkov telescope for the Cyg X-3 point source. 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 Cyg 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 Cyg 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 Fig. 3 for comparison.

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 $k_\gamma = -1.28 \pm 0.06$ (fig. 5), $k_{ON} = -1.65 \pm 0.11$ and $k_{OFF} = -1.74 \pm 0.11$ (fig. 5). Earlier, in 1997, a comparable increase of the flux over the average value was also observed and estimated to be $(1.2 \pm 0.5) \pm 10^{-12}$ $cm^{-2}s^{-1}$. 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

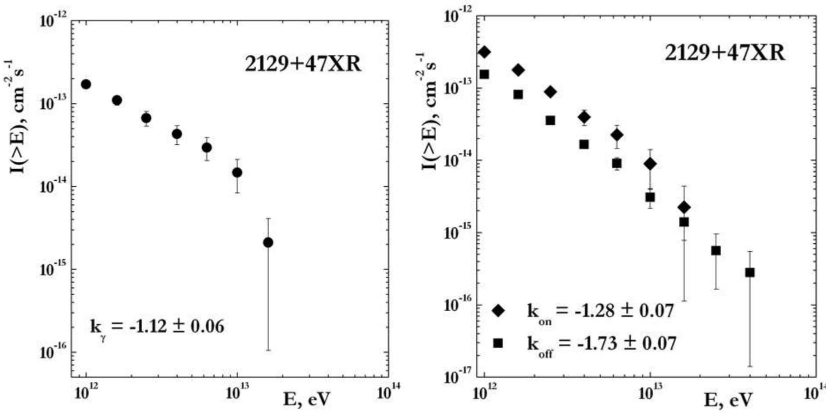

Fig. 7. left – The 2129+47XR gamma-quantum spectrum with power index of $k_\gamma = -1.12 \pm 0.06$; right – The event spectrum from 2129+47XR with background $k_{ON} = -1.23 \pm 0.07$ and spectrum of background events observed simultaneously with 2129+47XR - $k_{OFF} = -1.73 \pm 0.07$;

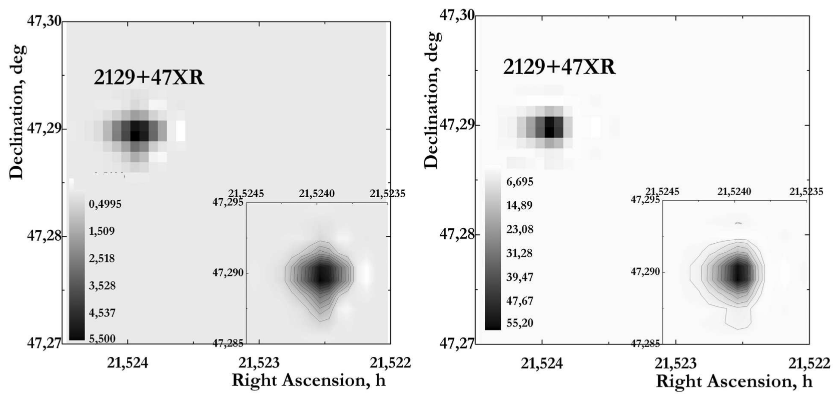

Fig. 8. left – The The image of gamma-ray emission from 2129+47XR; right – The energy image of 2129+47XR by SHALON.

understanding the nature of this astrophysical object.

4U 2129+47 is a low-mass X-ray binary that undergo high-low transitions in its X-ray flux. It shows evidence of an extended X-ray emission region often called an accretion disk corona (ADC). The 4U 2129+47 is currently the only ADC source in a low state [17]. The 4U2129+47 as a new galactic gamma-source is detected at energy > 0.8 TeV with flux $(0.19 \pm 0.09) \times 10^{-12}\ cm^{-2}s^{-1}$ and indices of the integral spectra are $k_\gamma = -1.12 \pm 0.06$, $k_{ON} = -1.28 \pm 0.07$ and $k_{OFF} = -1.73 \pm 0.07$ (fig. 7, 8).

II. Conclusion

Unlike a spectrum of cosmic protons and nuclei, the energy spectrum of gamma-quanta is hard, $F_\gamma(E_\gamma)dE_\gamma \propto E_\gamma^{-2.2}dE_\gamma$. This lead to a rather small contribution of gamma-quanta to the total flux of cosmic ray with energies $\geq 6 \times 10^5$ GeV. But in the energy range of GZK cutoff, the contribution of gamma-quanta grows up to 20% of the total cosmic-ray flux. It is possible that the gamma-spectrum is not changed up to super-high energies and thus it carries a unique information on super-high-energy processes in the Metagalaxy. All the above-mentioned put a further development in experimental gamma-astronomical researches and in observational methods for gamma-quanta of energies $10^3 - 10^9$ GeV to the list of the most important physical problems.

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