10 years of Flaring activity of Cygnus X-3 and new galactic Binary 2129+47XR.

V.G. Sinitsyna, A.Y. Alaverdyan, F.I. Musin, S.I. Nikolsky, V.Y. Sinitsyna

P.N. Lebedev Physical Institute,
Moscow, Russia
Email: sinits@sci.lebedev.ru

***Abstract*— 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 is 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 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 $k_{OFF} = -1.73 \pm 0.11$. 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 $k = -1.28 \pm 0.06$, $k_{ON} = -1.65 \pm 0.11$ and $k_{OFF} = -1.74 \pm 0.11$. Earlier, in 1997, a comparable increase of the flux over the average value was also observed and estimated to be $(1.2 \pm 0.5) \times 10^{-12}\ cm^{-2}s^{-1}$. 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. The new galactic gamma-source neutron star 2129+47XR is detected at energy $>$ 0.8 TeV with flux $(0.19 \pm 0.9) \times 10^{-12}\ cm^{-2}s^{-1}$ and indices of the integral spectra are $k_\gamma = -1.05 \pm 0.10$, $k_{ON} = -1.54 \pm 0.10$ and $k_{OFF} = -1.74 \pm 0.10$.**

I. INTRODUCTION

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 – 65 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

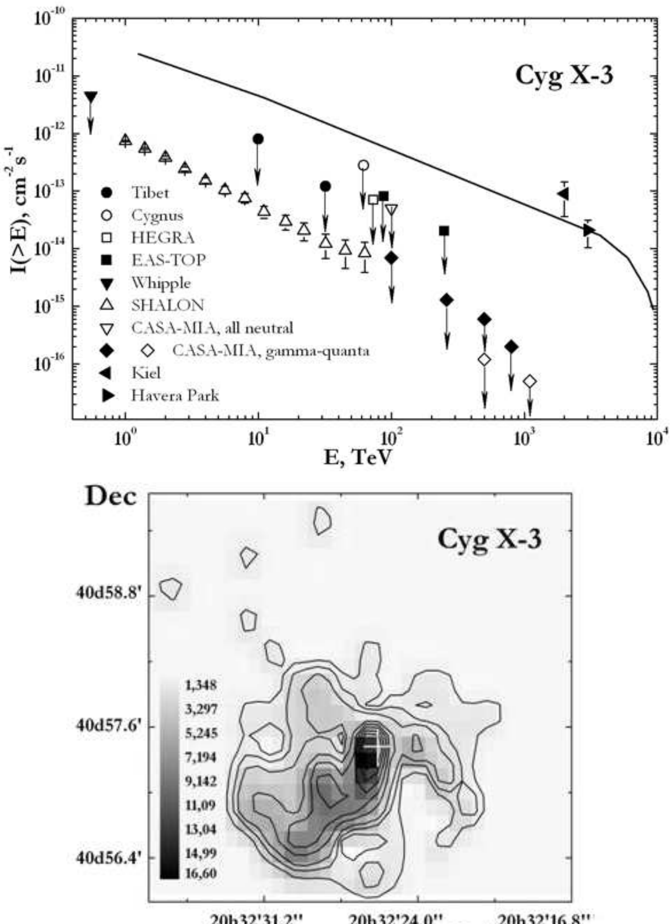

Fig. 1. **Top:** The Cygnus X-3 gamma-quantum ($E > 0.8$ TeV) integral spectrum by SHALON in comparison with other experiments: TIBET, [8] 2 - CYGNUS [9], [10], 3 - HEGRA [11], 4 - EAS-TOP [12], [13], 5 - Whipple [14], [15], 6 - SHALON [20], [30], diamonds - CASA-MIA [16], Kiel [18], Havera Park [19], the solid line is the theoretical calculation (Hillas) [5], [6]. The Cygnus X-3 gamma-quantum spectrum with power index of $k_\gamma = -1.21 \pm 0.05$; **Bottom:** The image of gamma-ray emission from Cygnus X-3

$< 0.1°$. 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

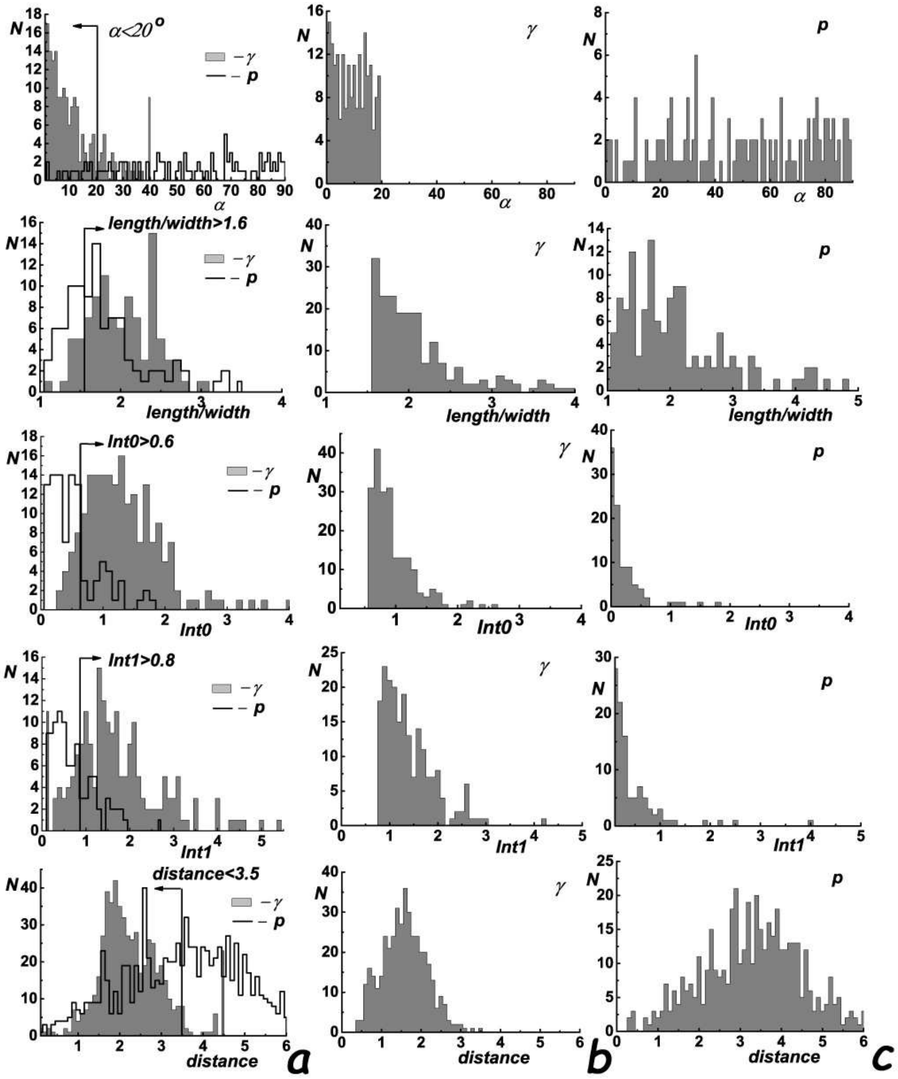

Fig. 2. The distributions of 5 image parameters (α, *length/width*, *Int0*, *Int1*, *distance*) for gamma- and proton-initiated air showers

(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.

Figure 2a shows the Monte Carlo distributions of the image parameters for gamma- and proton-induced showers. Tn Fig. 2b the distributions of the image parameters of the gamma-showers extracted from the SHALON observations of the point sources are presented, while Fig. 2c showes the distributions of parameters of cosmic-ray protons extracted from the zenithal SHALON observations. Our analysis of these distributions suggests that the background was rejected with 99.8% efficiency (see Refs. [2], [4], [20], [30]).

II. Cygnus X-3

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.

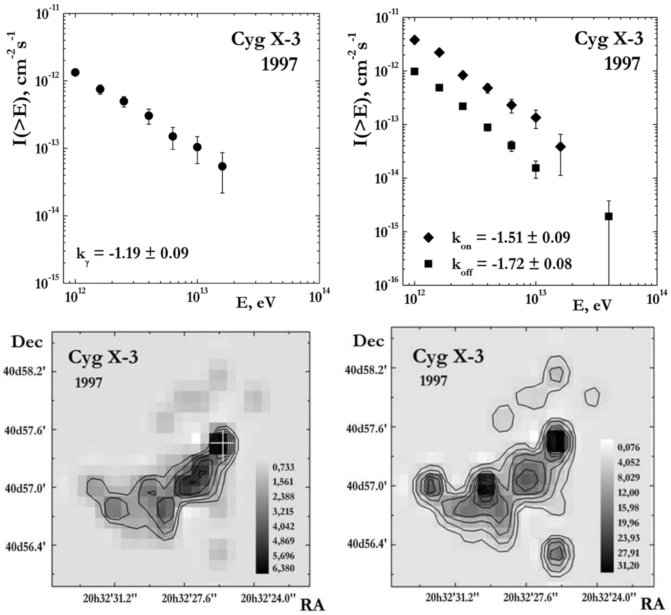

Fig. 3. **Top. left:** The Cygnus X-3 gamma-quantum spectrum in 1997 with power index of $k_\gamma = -1.19 \pm 0.09$; **right:** The event spectrum from Cygnus X-3 with background $k_{ON} = -1.51 \pm 0.09$ and spectrum of background events observed simultaneously with Cygnus X-3 - $k_{OFF} = -1.72 \pm 0.09$; **Bottom. left:** The image of gamma-ray emission from Cygnus X-3 in 1997; **right:** The energy image of Cygnus X-3 in 2003 (in TeV units) by SHALON.

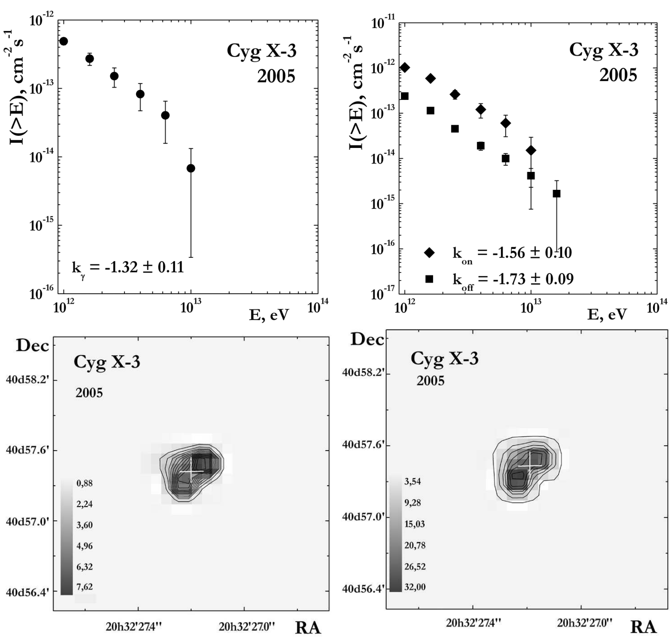

Fig. 4. **Top. left:** The Cygnus X-3 gamma-quantum spectrum in 2005 with power index of $k_\gamma = -1.32 \pm 0.11$; **right:** The event spectrum from Cygnus X-3 with background $k_{ON} = -1.56 \pm 0.10$ and spectrum of background events observed simultaneously with Cygnus X-3 - $k_{OFF} = -1.73 \pm 0.09$; **Bottom. left:** The image of gamma-ray emission from Cygnus X-3 in 2005; **right:** The energy image of Cygnus X-3 in 2005 (in TeV units) by SHALON.

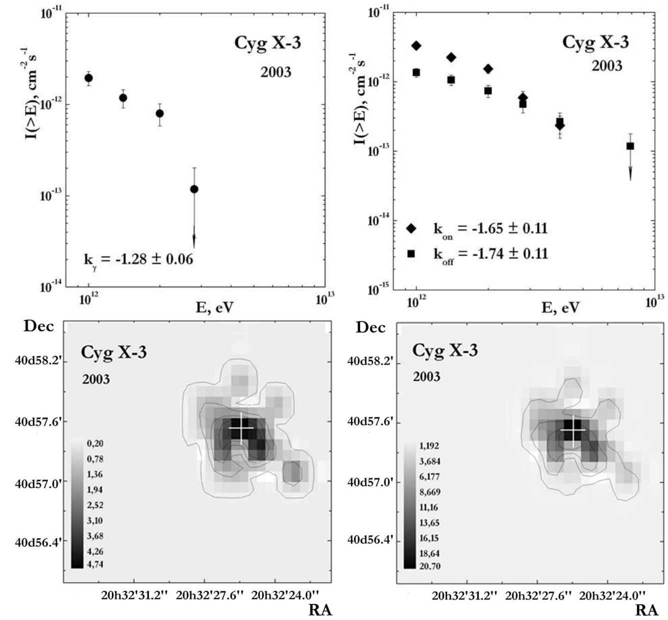

Fig. 5. **Top. left:** The Cygnus X-3 gamma-quantum spectrum in 2003 with power index of $k_\gamma = -1.28 \pm 0.06$; **right:** The event spectrum from Cygnus X-3 with background $k_{ON} = -1.65 \pm 0.11$ and spectrum of background events observed simultaneously with Cygnus X-3 - $k_{OFF} = -1.74 \pm 0.11$; **Bottom. left:** The image of gamma-ray emission from Cygnus X-3 in 2003; **right:** The energy image of Cygnus X-3 in 2003 (in TeV units) by SHALON.

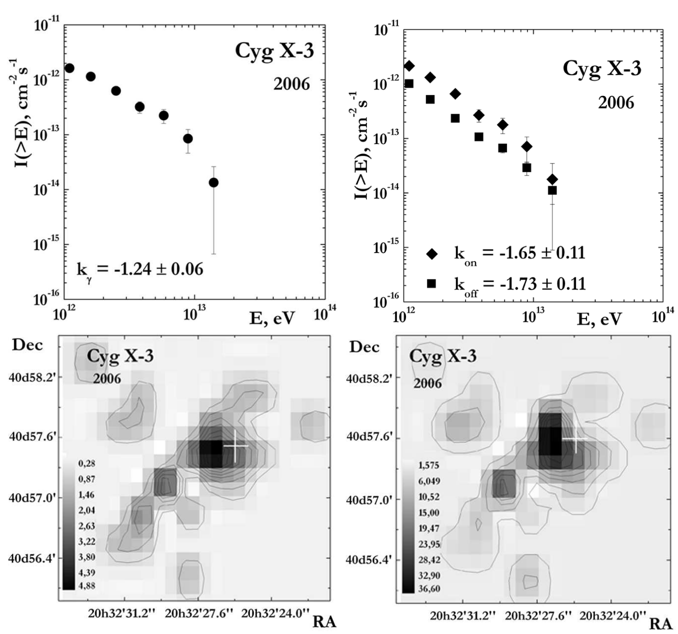

Fig. 6. **Top. left:** The Cygnus X-3 gamma-quantum spectrum in 2006 with power index of $k_\gamma = -1.24 \pm 0.06$; **right:** The event spectrum from Cygnus X-3 with background $k_{ON} = -1.65 \pm 0.11$ and spectrum of background events observed simultaneously with Cygnus X-3 - $k_{OFF} = -1.73 \pm 0.11$; **Bottom. left:** The image of gamma-ray emission from Cygnus X-3 in 2006; **right:** The energy image of Cygnus X-3 (in TeV units) in 2006 by SHALON.

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 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 1 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.

Figures 1, 3, 4, 5 and 6 collect observational data obtained with SHALON mirror Cherenkov telescope for the Cygnus 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 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 [30] 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 $k_\gamma = -1.21 \pm 0.06$ (fig. 6), $k_{ON} = -1.65 \pm 0.11$ and $k_{OFF} = -1.73 \pm 0.11$ (fig. 6).

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 $k_\gamma = -1.32 \pm 0.11$ (fig. 4), $k_{ON} = -1.56 \pm 0.10$ 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 $k_\gamma = -1.28 \pm 0.06$ (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 $(1.2 \pm 0.5) \pm 10^{-12}$ $cm^{-2}s^{-1}$ (Fig. 3). 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.

III. 4U 2129+47

Another source type for the studding at very high energies is low-mass X-ray binary. These binary systems usually consist of the neutron stars which are usually paired with a low mass (in contrast to Cyg X-3) companion and radiation is a result of accretion. The accretion mechanism is different in the cases of low mass companions. 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 ADC source 4U 2129+47 is strongly believed to be a neutron star since it has exhibited a Type I X-ray burst [35]. Since 1983, 4U 2129+47 has been in a quiescent state. The 4U 2129+47 binary is currently the only accretion disk corona source in a low state [36].

The 4U 2129+47 as a new galactic gamma-source is detected at energy > 0.8 TeV with flux $(0.19 \pm 0.05) \times 10^{-12}$ $cm^{-2}s^{-1}$ and indices of the integral spectra are $k_\gamma = -1.10 \pm 0.08$, $k_{ON} = -1.23 \pm 0.10$ and $k_{OFF} = -1.73 \pm 0.09$ (fig. 7). This source has a hard spectrum and it is characterized with the weak flux in TeV energy range.

IV. 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.

The new galactic gamma-source neutron star 4U 2129+47XR of LMSB type is detected with extremely low gamma-quantum flux at very high energies $(0.19 \pm 0.05) \times 10^{-12}$ $cm^{-2}s^{-1}$ and hard spectrum.

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

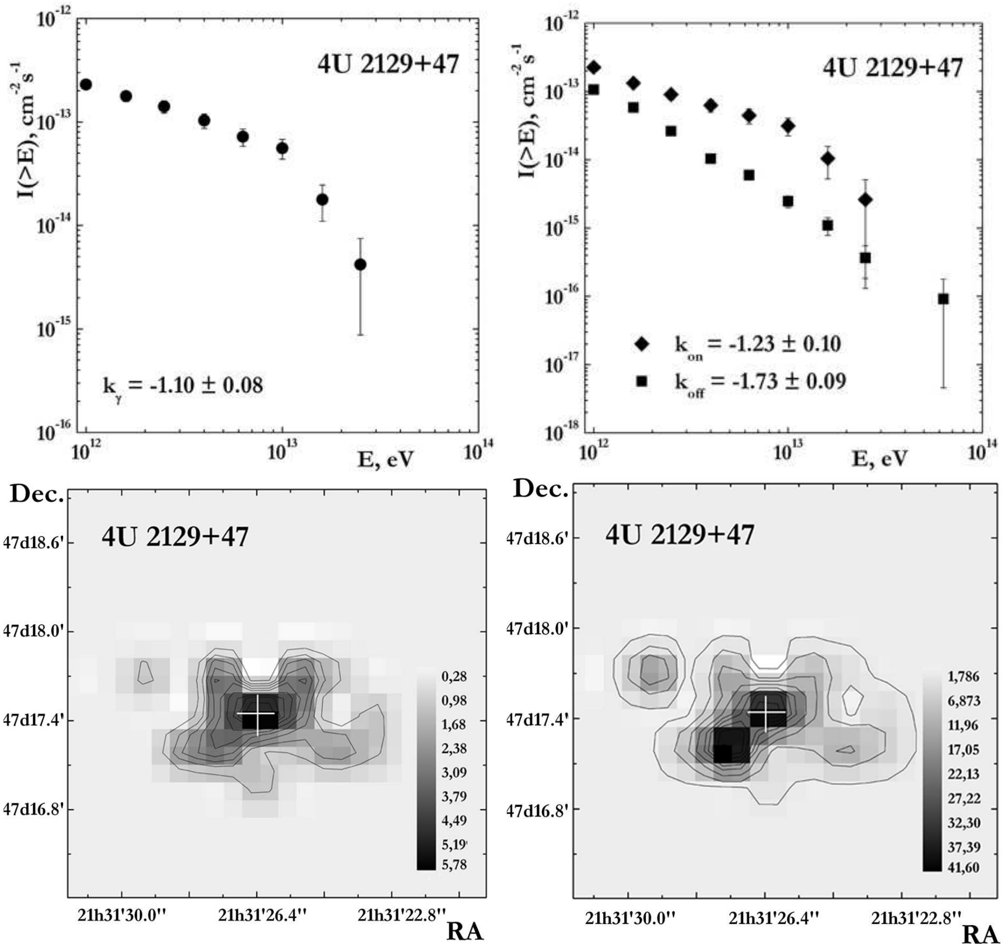

Fig. 7. **Top. left:** The 2129+47XR gamma-quantum spectrum with power index of $k_\gamma = -1.10 \pm 0.08$; **right:** The event spectrum from 2129+47XR with background $k_{ON} = -1.23 \pm 0.10$ and spectrum of background events observed simultaneously with 2129+47XR - $k_{OFF} = -1.73 \pm 0.09$; **Bottom. left:** The image of gamma-ray emission from 2129+47XR; **right:** The energy image of 2129+47XR by SHALON.

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.

REFERENCES

[1] J.Cocconi, in Proc VIth Int. Cosmic Ray Conf., Moscow, 2, (1960) p. 309

[2] S.I. Nikolsky and V. G. Sinitsyna, VANT, Ser. TFE 1331, (1987) p. 30.

[3] S. I. Nikolsky and V. G. Sinitsyna, *in Proc. Int. Workshop on VHE γ-ray Astronomy*, Crimea, ed. A. A. Stepanian *et al.*, (1989) p. 11.

[4] V.G. Sinitsyna, Nuovo Cim., 19C, (1996) p. 965.

[5] A.M. Hillas, Nuovo Cim. 19C, (1996) p. 701; Nature 312, (1984) p. 50.

[6] J.W. Cronin, Nuovo Cim. 19C, (1996) p. 847.

[7] C.M. Hofman, C. Sinnis, P. Fleury, et al., Rev. Mod. Phys. 71, (1999) p. 897.

[8] M. Amenomori et al., in Proc. 23rd Int. Cosmic Ray Conf., Calgary 1, (1993) p. 342.

[9] D.E. Alexandreas et al.,Astrophys. J. 418, (1993) p. 832.

[10] D.E. Alexandreas et al.,in Proc. 23rd Int. Cosmic Ray Conf., Calgary 1, (1993) p. 373.

[11] A.D.Karle et al.,Astropart. Phys. 4, (1995) p. 1.

[12] P.L. Ghia et al., Proc. 24th Int. Cosmic Ray Conf., Rome 2, (1995) p.421.

[13] M.Aglietta et al.,Astropart.Phys. 3, (1995) p.1.

[14] T.C. Weekes Proc. 25th Int. Cosmic Ray Conf., Durban 5, (1997) p. 251.

[15] M. Catanese and T. C. Weekes, Preprint Series No. 4811, (1999); No 4450, (1996).

[16] A. Borione et al., Phys Rev. 55, (1997) p. 1714.

[17] A. Borione , et al., Proc. 24 ICRC 2 (1995) p. 430.

[18] M. Samorscki and W. Stamm, Astrophys. J. 268 (1983) L17.

[19] J. Lloyd-Evans, R.N. Coy, A. Lampert, J. Lapikens, M. Patet, R.J. Reid and A. Watson, Nature 305 (1983) p. 784.

[20] V.G. Sinitsyna et al., Nucl. Phys. B (Proc.Suppl.) 151, (2006) p. 489.

[21] V. G. Sinitsyna, S. I. Nikolsky , et.al., Nucl., Phys. B. 122 (2003) 247, p. 409; 97 (2001) 215, 219; 75A (1999) p. 352.

[22] V. G. Sinitsyna, Rayos Cosmicos 98, ed. Medina J. (Departamento de Fisica Universidad de Alcala) (1998) pp. 383, 367.

[23] V. G. Sinitsyna, AIP 515 (1999) pp. 205, 293.

[24] V. G. Sinitsyna, Toward a Major Atmospheric Cherenkov Detector-I, ed. P. Fleury, G. Vacanti (Frontieres) (1992) p. 299; Detector -II, ed. R. C. Lamb (Iowa State University) (1993) p. 91; Detector-IV, ed. M. Cresty (PapergrafPD) (1995) p. 133; Detector-V, ed. O.C. de Jager (WESPRINT, Pocherfstroom) (1997) pp. 136, 190; Detector-VII ed. B. Degrange, G. Fontain (2005) pp. 57, 105, 111.

[25] V. G. Sinitsyna, S. I. Nikolsky, et.al., The Universe viewed in Gamma Rays, ed. R. Enomoto, M.Mori, S. Yanagita, (Universal Academy Press, INC, 2003) pp. 503, 211, 235, 383.

[26] V. G. Sinitsyna, S. I. Nikolsky, et.al.,Proc. 29th ICRC. 4 (2005) p. 235, Proc. 28th ICRC. 4 (2003) pp. 2007, 2369, 2473; 3 (2003) p. 1517; Proc. 27th ICRC. 6 (2001) p. 2509, 7 (2001) pp. 2665, 2798; Proc. 26th ICRC. 3 (1999) pp. 334, 406.

[27] V. G. Sinitsyna, S. I. Nikolsky et.al., Chakaltaya Meeting on Cosmic Ray Physics, ed. O. Saavedra, M. Bertaina, C. Vigorito (Societa de Italiana di Fisica Bologna), (2000) p. 785.

[28] S. I. Nikolsky, V. G. Sinitsyna, et.al., Izv. RAN., ser. fiz. 66(11) (2002) 1667, 1660; 66(3) (1999) 608; 61(3) (1997) p. 603.
[29] S. I. Nikolsky and V. G. Sinitsyna, Physics of Atomic Nuclei 67(10) (2004) p. 1900.
[30] V.G. Sinitsyna, S. I. Nikolsky, et al., Izv. Ross. Akad. Nauk Ser. Fiz. 69(3), (2005) p. 422.
[31] V. G. Sinitsyna *et al., Int. J. Mod. Phys. A* no. 29, (2005) p. 7023, 7026, 7029.
[32] V. G. Sinitsyna *Rad. Phys. and Chem.*, 75, (2006) pp. 880.
[33] V. G. Sinitsyna, in Proc. Int. Cosmic Ray Workshop "Aragats-2007", Nor-Amberd, Armenia, ed. B. Pattison and R. Martirosov, (2007) p. 12.
[34] V. Y. Sinitsyna, *ibid*, (2007) p. 23.
[35] M. R. Garcia, J. E. Grindlay, ApJ, 313, (1987), p. L59
[36] M.R. Garcia, P. J. Callanan, Astron. J., 118, (1999) p. 1390.