

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

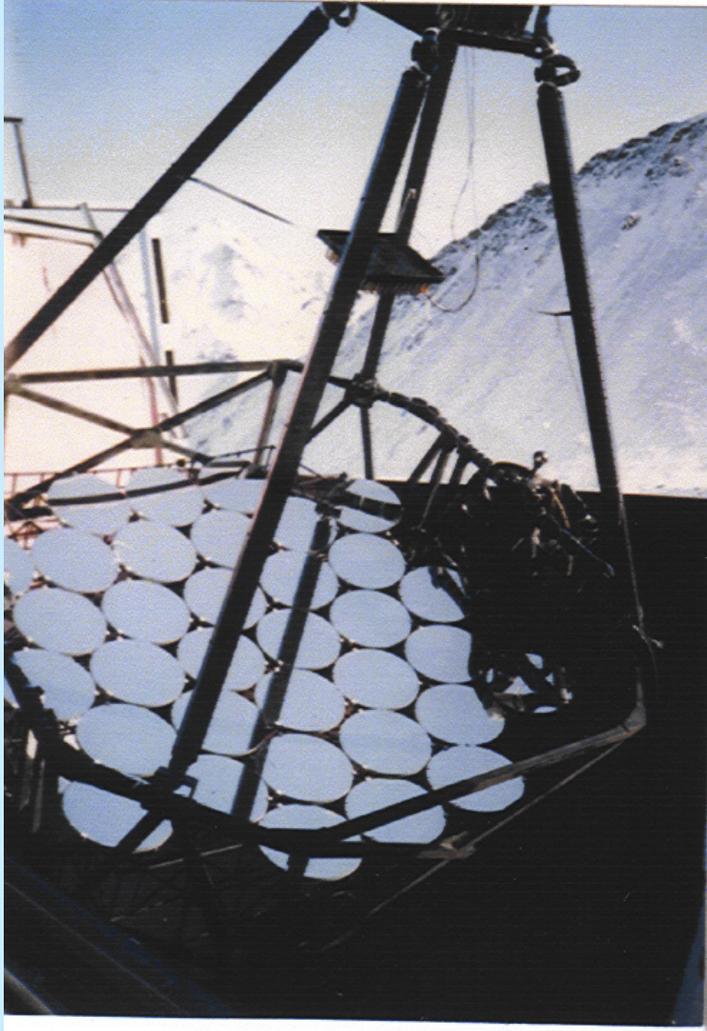
V. G. SINITSYNA, A.A. MALYSHKO, F. I. MUSIN,  
S. I. NIKOLSKY, V. Y. SINITSYNA

*P. N. Lebedev Physical Institute,  
Leninsky prospect 53, Moscow, 119991 Russia*



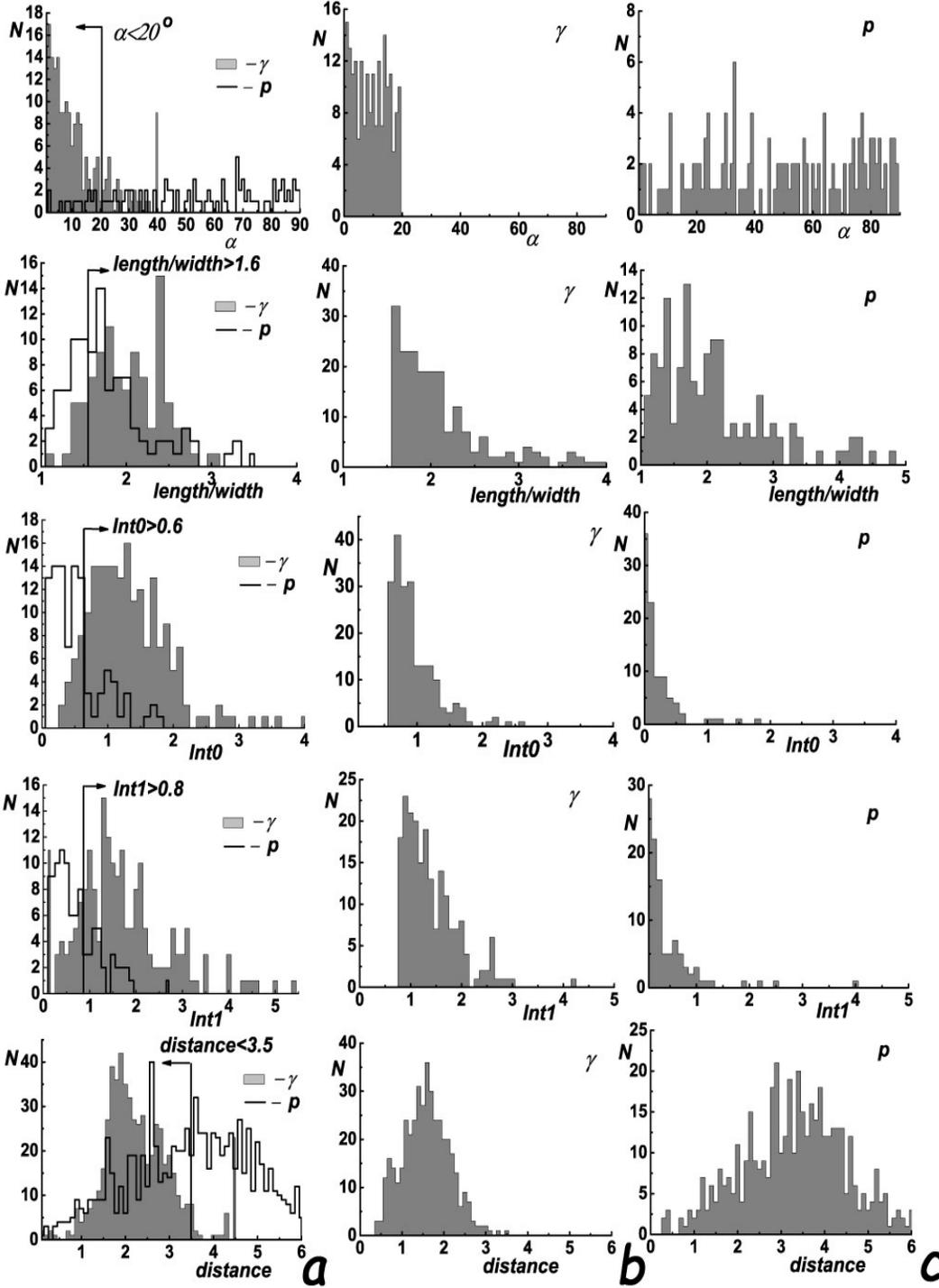
# HIGH MOUNTAINOUS OBSERVATORY SHALON ALATOO

SHALON mirror Cherenkov telescope created at Lebedev Physical Institute and stated in 1991 - 1992



- Total area of spherical mirror — 11.2 m<sup>2</sup>
- Radius of mirror curvature — 8.5 m
- The angle range of telescope turn:
  - azimuth — 0°-360°
  - zenith — 0°-110°
- The accuracy of telescopic axis pointing — ≤0.1°
- The photomultiplier tube camera (12x12) — 144 elements
- Field of view > 8°
- Weight 6 ton
- altazimuth mounting

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.

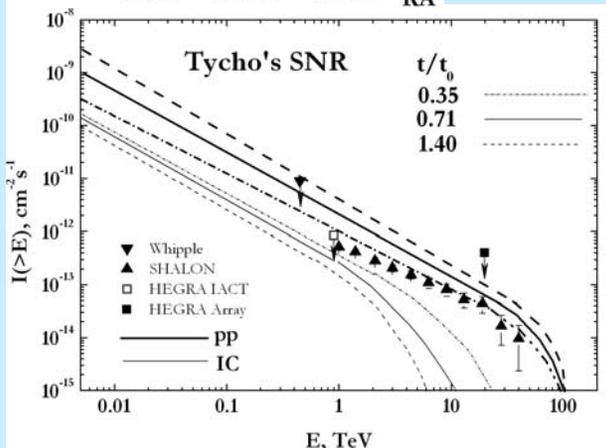
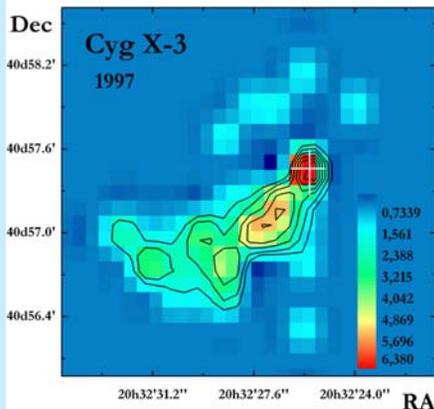
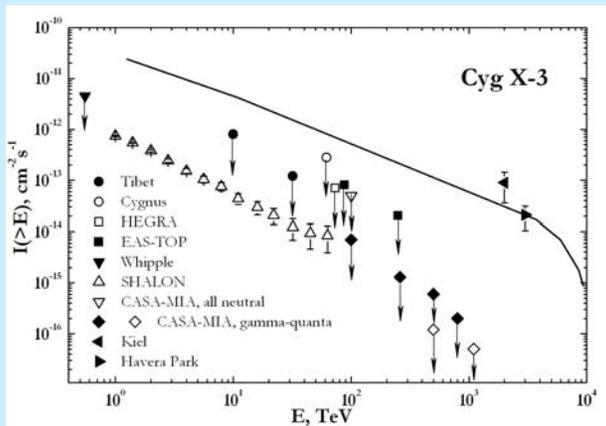


The selection of gamma-initiated showers from the background of proton showers is performed by applying the following criteria:

- 1)  $\alpha < 20^\circ$ ;
- 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.

It is essential that our telescope has a large matrix with full angle  $> 8^\circ$  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.

# TeV gamma-rays from Galactic sources



During the period 1992 - 2008 12 metagalactic and galactic sources have been observed. Among them are galactic sources Crab Nebula (supernova remnant), Cygnus X-3 (binary), Tycho's SNR (supernova remnant), Geminga (radioweak pulsar) and 2129+47 (binary)

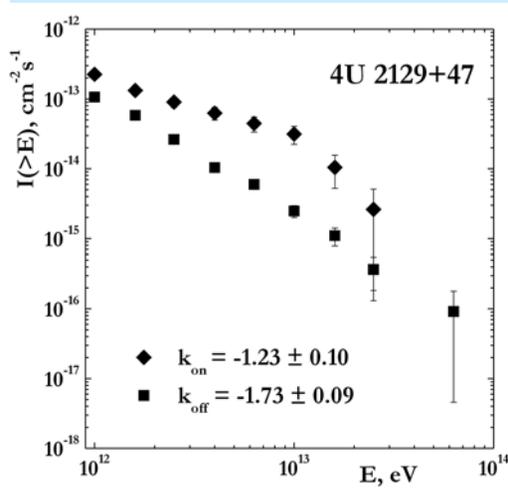
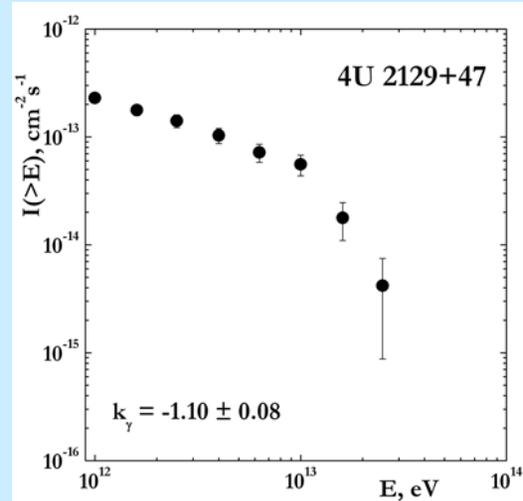
The energy spectrum of Cyg X-3 at 0.8-65 TeV can be approximated by the power law  $F(>E) \propto E^{k_\gamma}$ , with  $k_\gamma = -1.21 \pm 0.05$ . This flux, measured for the first time, is several times less than the upper limits established in the earlier observations.

Tycho's SNR has long been considered as a candidate to cosmic ray hadrons source in Northern Hemisphere, although it seemed that the sensitivity of the present generation of Imaging Atmospheric Cherenkov System's too small for Tycho's detection. The expected  $\pi^0$ -decay gamma-quantum flux  $F_\gamma \propto E_\gamma^{-1}$  extends up to  $\sim 30$  TeV, whereas the Inverse Compton gamma-ray flux has a cutoff above the few TeV. So, the detection of gamma-rays at energies of  $\sim 10$ -40 TeV by SHALON telescope is the evidence of hadron origin.

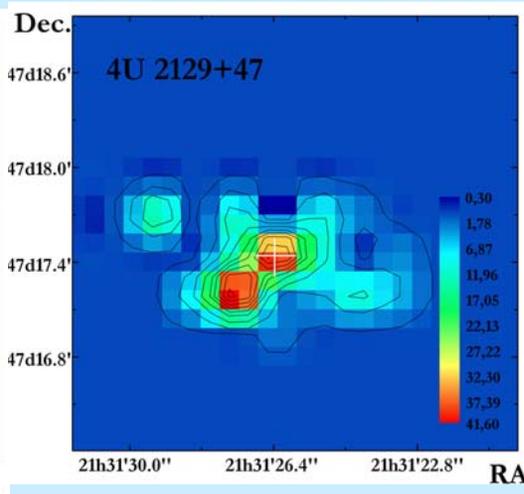
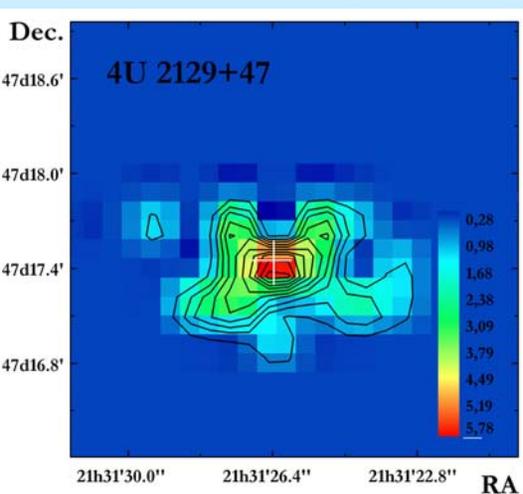
## SHALON catalogue of galactic gamma -quantum sources

Source	Observable flux, $\text{cm}^{-2}\text{s}^{-1}$	Distance, kpc
Crab Nebula	$(1.70 \pm 0.15) \times 10^{-12}$	2.0
Cygnus X-3	$(0.68 \pm 0.07) \times 10^{-12}$	10
Geminga	$(0.48 \pm 0.17) \times 10^{-12}$	0.25
Tycho's SNR	$(0.52 \pm 0.09) \times 10^{-12}$	2.3
2129+47XR	$(0.19 \pm 0.09) \times 10^{-12}$	6.0

# 4U 2129+47



4U 2129+47 is a low-mass X-ray binary that undergoes high-low transitions in its X-ray flux. It shows evidence of an extended X-ray emission region often called an accretion disk corona. The 4U 2129+47 is currently the only accretion disk corona source in a low state.



The 4U2129+47 as a new galactic gamma-source is detected at energy  $>0.8$  TeV with flux

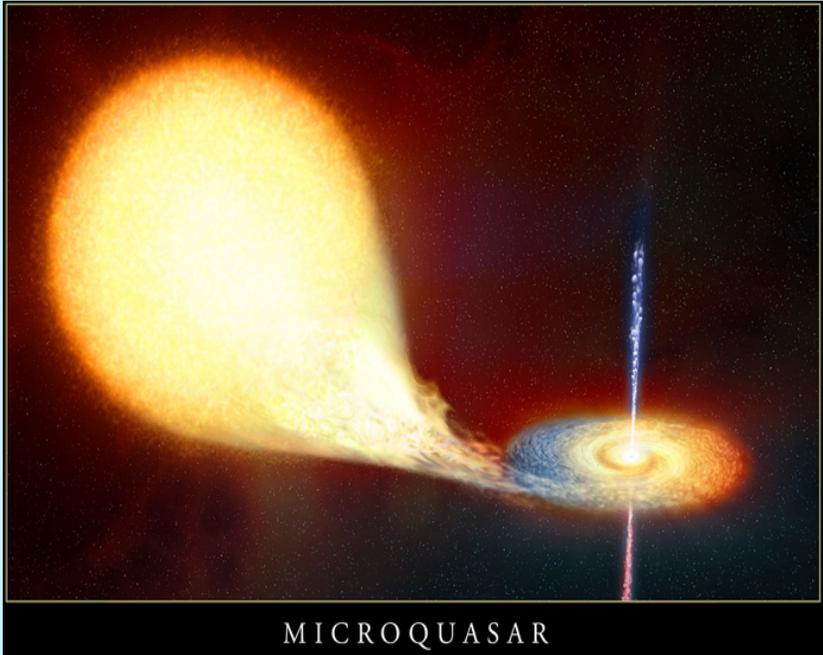
$(0.19 \pm 0.05) \times 10^{-12} \text{ cm}^{-2} \text{ s}^{-1}$  and indices of the integral spectra are

$$k_\gamma = -1.10 \pm 0.08,$$

$$k_{\text{ON}} = -1.23 \pm 0.10$$

$$k_{\text{OFF}} = -1.73 \pm 0.09.$$

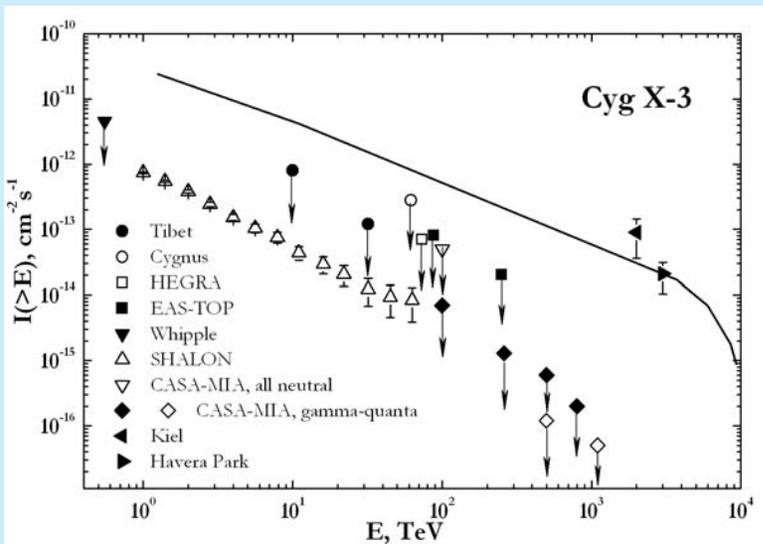
# Cygnus X-3



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 radioactivity 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 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. 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 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.

# Cygnus X-3



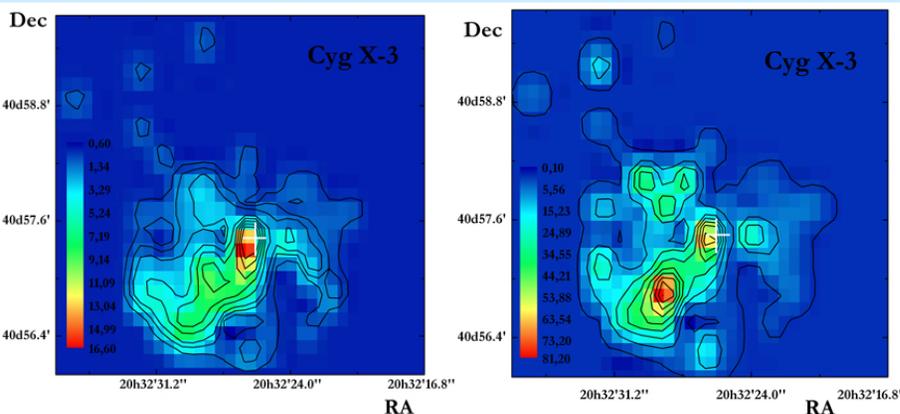
Figures collect observational data obtained with SHALON mirror Cherenkov telescope for the Cygnus X-3 point source. This galactic binary system regularly observed since a 1995 is known as a source with variable intensity (from  $5 \times 10^{-12}$  to  $10^{-11} \text{ cm}^{-2} \text{ s}^{-1}$ ); the average gamma-quantum flux from Cygnus X-3 for  $E > 0.8 \text{ TeV}$  is estimated as

$$F(E_0 > 0,8 \text{ TeV}) = (6.8 \pm 0.7) \cdot 10^{-13} \text{ cm}^{-2} \text{ s}^{-1}.$$

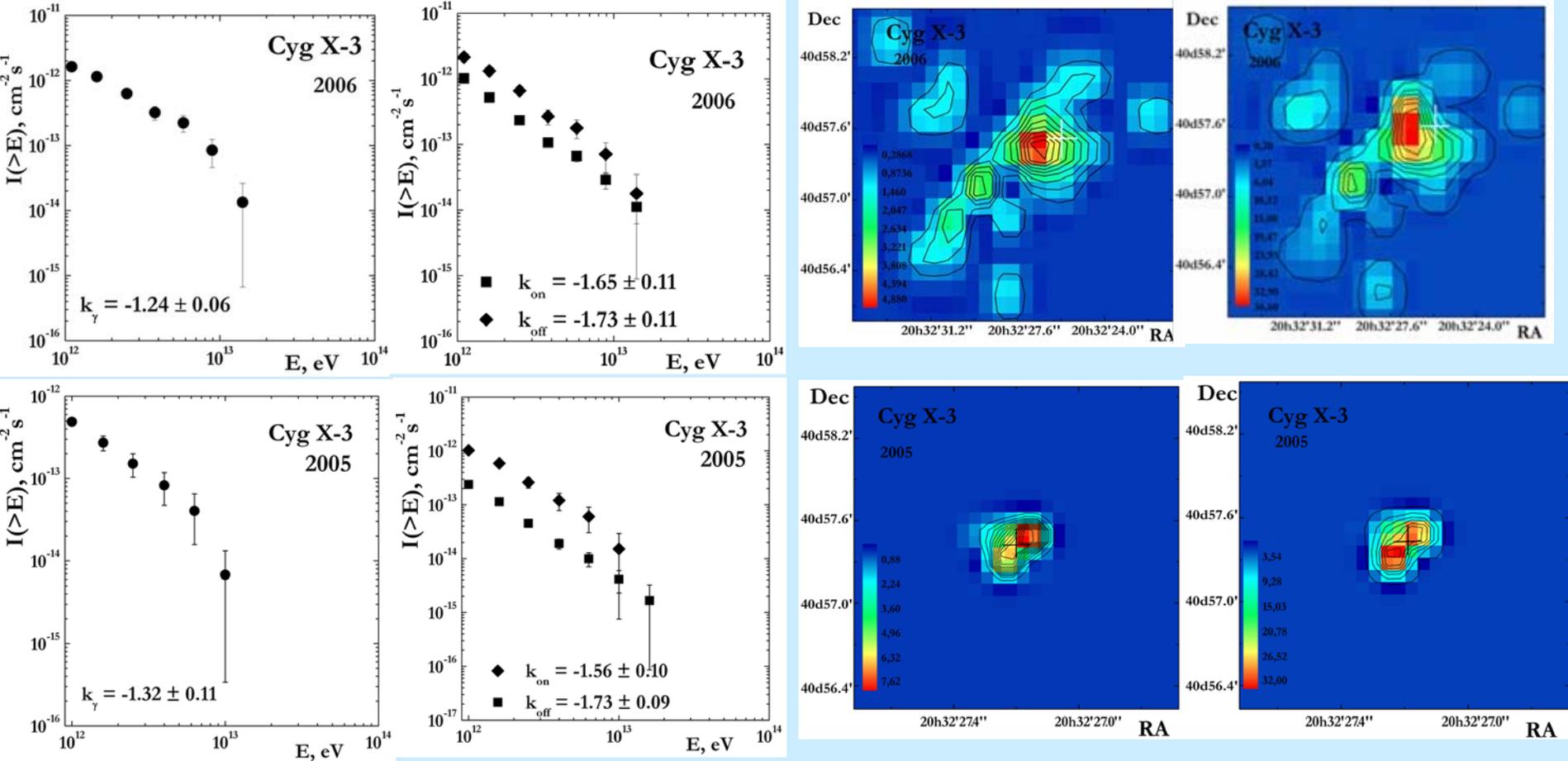
The standard output of the SHALON data processing consists of the integral spectrum of events coming from a source under investigation; spectrum of the background events coming simultaneously, during the observation of the source; temporal analysis of the source and background events; and the source image. The energy spectrum of Cygnus X-3 at 0.8 - 65 TeV can be approximated by the power law  $F(>E_0) \propto E^{k_\gamma}$ , 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 Cygnus X-3 gamma-quantum ( $E > 0.8 \text{ TeV}$ ) integral spectrum by SHALON in comparison with other experiments: TIBET, [7]; 2 - CYGNUS, [8, 9]; 3 - HEGRA, [10]; 4 - EAS-TOP, [11, 12]; 5 - Whipple, [13, 14]; 6 - SHALON, [16, 17]; diamonds - CASA-MIA, [15]; the solid line is the theoretical calculation (Hillas) [4, 5]. The Cygnus X-3 gamma-quantum spectrum with power index of  $k_\gamma = -1.21 \pm 0.05$ .

The spectra of events satisfying the selection criteria (spectral index  $k_{\text{ON}} = -1.33 \pm 0.05$ ) and of the background events observed simultaneously with the source (spectral index  $k_{\text{OFF}} = -1.74 \pm 0.05$ ) are both shown in Figure for comparison.



The image of gamma-ray emission from Cygnus X-3;  
The energy image of Cygnus X-3 by SHALON.



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

$(1.47 \pm 0.24) \times 10^{-12} \text{cm}^{-2}\text{s}^{-1}$  with the indices of integral spectra are

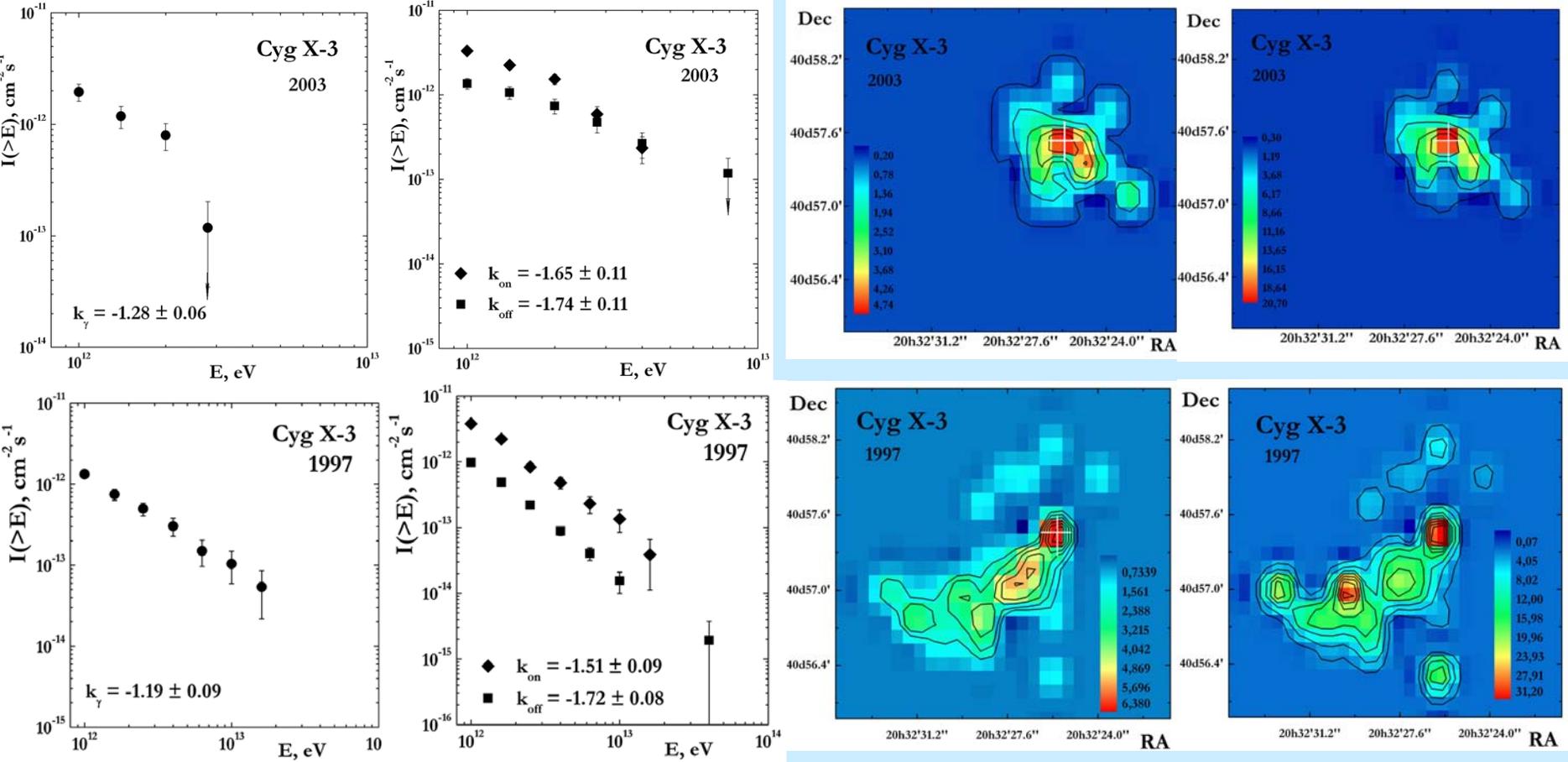
$k_\gamma = -1.21 \pm 0.06$ ,  $k_{\text{ON}} = -1.65 \pm 0.11$  and  $k_{\text{OFF}} = -1.73 \pm 0.11$ .

In the 2005 Cyg X-3 was in the quiet period in TeV energies. The average gamma-quantum flux from Cygnus X-3 for energies more than 0.8 TeV is estimated as

$(0.54 \pm 0.07) \times 10^{-12} \text{cm}^{-2}\text{s}^{-1}$  with the indices of integral spectra are

$k_\gamma = -1.32 \pm 0.11$ ,  $k_{\text{ON}} = -1.56 \pm 0.10$  and  $k_{\text{OFF}} = -1.74 \pm 0.09$

The images of Cyg X-3 in silent period at 2005 have no revealed the features found at flaring periods.



The gamma-ray flux detected by SHALON in 2003 was estimated as  $(1.79 \pm 0.33) \times 10^{-12} \text{cm}^{-2} \text{s}^{-1}$  with the indices of integral spectra are  $k_\gamma = -1.28 \pm 0.06$ ,  $k_{\text{ON}} = -1.65 \pm 0.11$  and  $k_{\text{OFF}} = -1.74 \pm 0.11$ .

Earlier, in 1997, a comparable increase of the flux over the average value was also observed and estimated to be  $(1.2 \pm 0.5) \times 10^{-12} \text{cm}^{-2} \text{s}^{-1}$  with the indices of integral spectra are  $k_\gamma = -1.19 \pm 0.09$ ,  $k_{\text{ON}} = -1.51 \pm 0.09$  and  $k_{\text{OFF}} = -1.72 \pm 0.08$ .

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.

# Cygnus x-3 flaring activity during 10 years of observation and new galactic binary 2129+47XR.

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  $(1.47 \pm 0.24) \times 10^{-12} \text{ cm}^{-2}\text{s}^{-1}$  with the indices of integral spectra are  $k_{\gamma} = -1.21 \pm 0.06$ ,  $k_{\text{ON}} = -1.65 \pm 0.11$  and  $k_{\text{OFF}} = -1.73 \pm 0.11$ . The gamma-ray flux detected by SHALON in 2003 was estimated as  $(1.79 \pm 0.33) \times 10^{-12} \text{ cm}^{-2}\text{s}^{-1}$  with the indices of integral spectra are  $k_{\gamma} = -1.28 \pm 0.06$ ,  $k_{\text{ON}} = -1.65 \pm 0.11$  and  $k_{\text{OFF}} = -1.74 \pm 0.11$ . Earlier, in 1997, a comparable increase of the flux over the average value was also observed and estimated to be  $(1.2 \pm 0.5) \times 10^{-12} \text{ cm}^{-2}\text{s}^{-1}$ . 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  $>0.8\text{TeV}$  with flux  $(0.19 \pm 0.9) \times 10^{-12} \text{ cm}^{-2}\text{s}^{-1}$  and indices of the integral spectra are  $k_{\gamma} = -1.05 \pm 0.10$ ,  $k_{\text{on}} = -1.23 \pm 0.10$  and  $k_{\text{off}} = -1.73 \pm 0.09$ .

