Detection of distant and proximate metagalactic sources 1739+522, 3c454.3 and Mkn 421, Mkn 501, NGC 1275

V. G. Sinitsyna, T. P. Arsov, F. I. Musin, S. I. Nikolsky, V. Y. Sinitsyna, G. F. Platonov

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

***Abstract*— The observation results of two type of metagalactic sources: BLLacs Mkn 421 (z = 0.031), Mkn 501 (z = 0.034) and Seyfert galaxy NGC 1275 (z=0.0179) are presented. The integral average gamma-ray fluxes of Mkn 421 and Mkn 501 were estimated as $(0.63 \pm 0.14) \times 10^{-12}\ cm^{-2}s^{-1}$ and $(0.86 \pm 0.13) \times 10^{-12}\ cm^{-2}s^{-1}$ respectively. NGC 1275 is being intensively studied by SHALON and gamma-ray flux are found to be $(0.78 \pm 0.13) \times 10^{-12}\ cm^{-2}s^{-1}$. The new distant metagalactic sources 1739+522 (z=1.375) and 3c454.3 (z=0.857) are detected at energy of > 0.8 TeV with fluxes $(0.53 \pm 0.10) \times 10^{-12}\ cm^{-2}s^{-1}$ and $(0.43 \pm 0.13) \times 10^{-12}\ cm^{-2}s^{-1}$ respectively. The gamma -quantum spectra and images of the sources are presented. The spectra and fluxes of known blazars Mkn 421, Mkn 501 and far FSRQs 1739+522 and 3c454.3 are discussed. These observations are carrying out with SHALON mirror telescope at the Tien-Shan high mountainous station of P.N. Lebedev Physical Institute.**

INTRODUCTION

The cosmological processes, connecting the physics of matter in active galactic nuclei will be observed in the energy spectrum of electromagnetic radiation. The understanding of mechanisms in active galactic nuclei requires the detection of a large sample of very high energy gamma-ray objects at varying redshifts. The redshifts of very high energy gamma-ray sources observed by SHALON hrange from z=0.0179 to z=1.375.

The gamma - astronomical researches are carrying out with SHALON mirror telescope at the Tien-Shan high mountainous station since 1992. During the period 1992 - 2006 SHALON has been used for observations of metagalactic sources: Mkn 501, Mkn 421, NGC 1275, 3c454.3, 1739+522 and galactic sources: Crab Nebula, Cyg X-3, Tycho's SNR, Geminga, 2129+47XR [1 - 9]. Our method of the data processing is described in [1], [2], [4] and [5]. Some representative results are shown figs 1 and 3. Our data for Crab, Mkn 421 and Mkn 501 are compared with those from other experiments in space, within a wide energy range $10^8 - 10^{14}$ eV. As is seen from fig. 1, 3 the SHALON results for these known gamma-sources are consistent with the data by telescope EGRET of the Compton Observatory (CGRO), obtained in the energy region $10^2 - 10^3$ MeV.

MARKARIAN 421

The Bl Lac Mkn 421 was detected as the first and the nearest (z = 0.031) metagalactic source of blazar type of TeV energy gamma-quanta in 1992 year using Whipple telescope.

TABLE I

THE METAGALACTIC GAMMA-QUANTUM SOURCES CATALOGUE, OBSERVED BY SHALON; AT THE COLUMN RELATIVE INTENSITY OF SOURCE THE CRAB NEBULA INTENSITY IS TAKEN AS A UNIT

Sources	Observable flux ($cm^{-2}s^{-1}$)	Distance (Mpc)	Relative intensity of source (in Crab units)
Mkn 421	$(0.63 \pm 0.14) \times 10^{-12}$	124	3.8×10^9
Mkn 501	$(0.86 \pm 0.13) \times 10^{-12}$	135	4.46×10^9
NGC 1275	$(0.78 \pm 0.13) \times 10^{-12}$	71	1.2×10^9
3c4543	$(0.43 \pm 0.13) \times 10^{-12}$	4685	5.3×10^{12}
1739+522	$(0.53 \pm 0.10) \times 10^{-12}$	7500	1.4×10^{13}

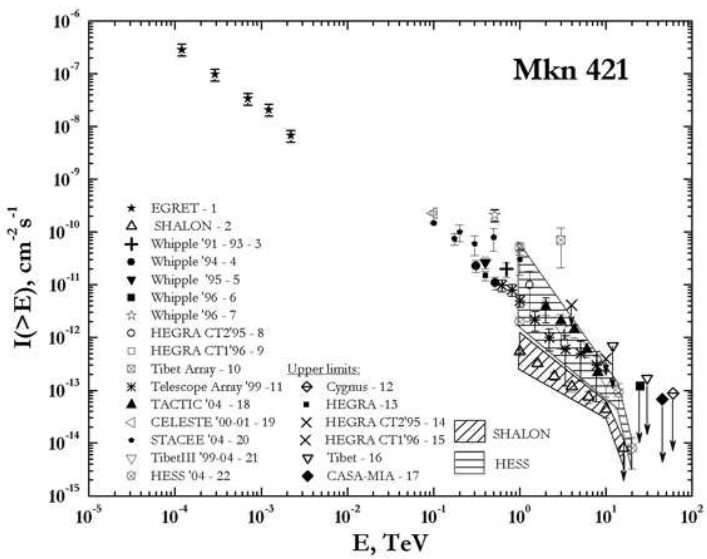

Fig. 1. The Mkn 421 gamma - quantum ($E > 0.8$ TeV) integral spectrum by SHALON in comparison with other experiments [2 - 16].

Presently this source is systematic studied by different experiments: VERITAS, SHALON, TACTIC, HESS, MAGIC (fig. 1). Mkn 421 is being intensively studied since 1994 by SHALON. As is seen from fig. 1 the SHALON results for this known gamma-source are consistent with the data by best world telescopes. An image of gamma-ray emission from Mkn 421 is shown in Fig. 2. The integral averaged

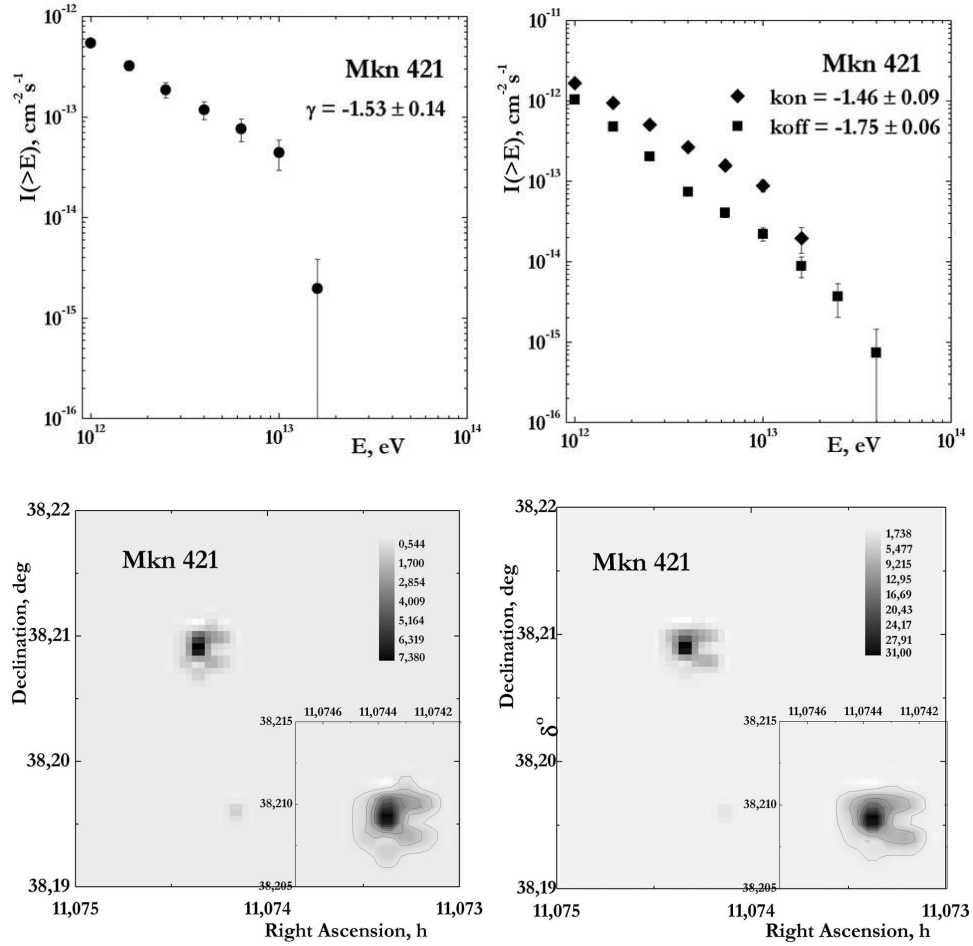

Fig. 2. **top:** left – The Mkn 421 gamma-quantum integral spectrum with power index of $k_\gamma = -1.53 \pm 0.14$; right – The event spectrum from Mkn 421 with background with index of $k_{ON} = -1.46 \pm 0.09$ and spectrum of background events observed simultaneously with Mkn 421 with index $k_{OFF} = -1.75 \pm 0.06$; **bottom:**left – The Mkn 421 image at energy range of more then 0.8 TeV; right – The energy image (in TeV units) of Mkn 421 by SHALON.

for the period 1994 to 2006 gamma-ray flux above 0.8 TeV was estimated as $(0.63 \pm 0.14) \times 10^{-12}\ cm^{-2}s^{-1}$. Within the range 1 - 10 TeV, the integral energy spectrum is well described by the power law $F(> E_O) \propto E^{k_\gamma}$, with $k_\gamma = -1.53 \pm 0.14$ (fig. 2). Extreme variability in different wavelengths including VHE gamma rays on the time-scales from minutes to years is the most distinctive feature of BL Lac objects. The increase of the flux over the average value was detected in 1997 and 2004 observations of Mkn 421 by SHALON and estimated to be $(1.01 \pm 0.25) \times 10^{-12}\ cm^{-2}s^{-1}$ and $(0.96 \pm 0.2) \times 10^{-12}\ cm^{-2}s^{-1}$, respectively. The similar variations of the flux over the average value was also observed with the telescopes of Whipple, HEGRA, TACTIC, HESS ($60^o - 67^o$), MAGIC (45°).

MARKARIAN 501

The detection of Mkn 421 as metagalactic VHE gamma-ray source initiated a search for VHE emission from several other active galactic nuclear of blazar type. This led to detection of BL Lac object Mkn 501 (z = 0.034) by Whipple in 1995. In contrast to Mkn 421, EGRET had not detected this source,

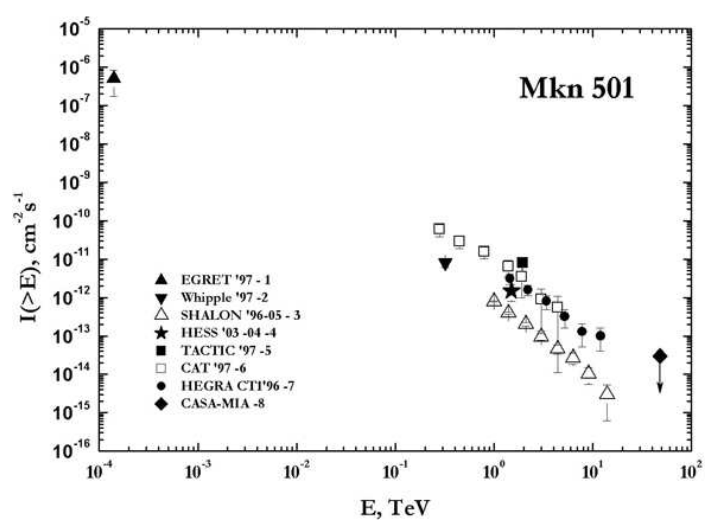

Fig. 3. The Mkn 501 gamma - quantum ($E > 0.8$ TeV) integral spectrum by SHALON in comparison with other experiments [2 - 16];

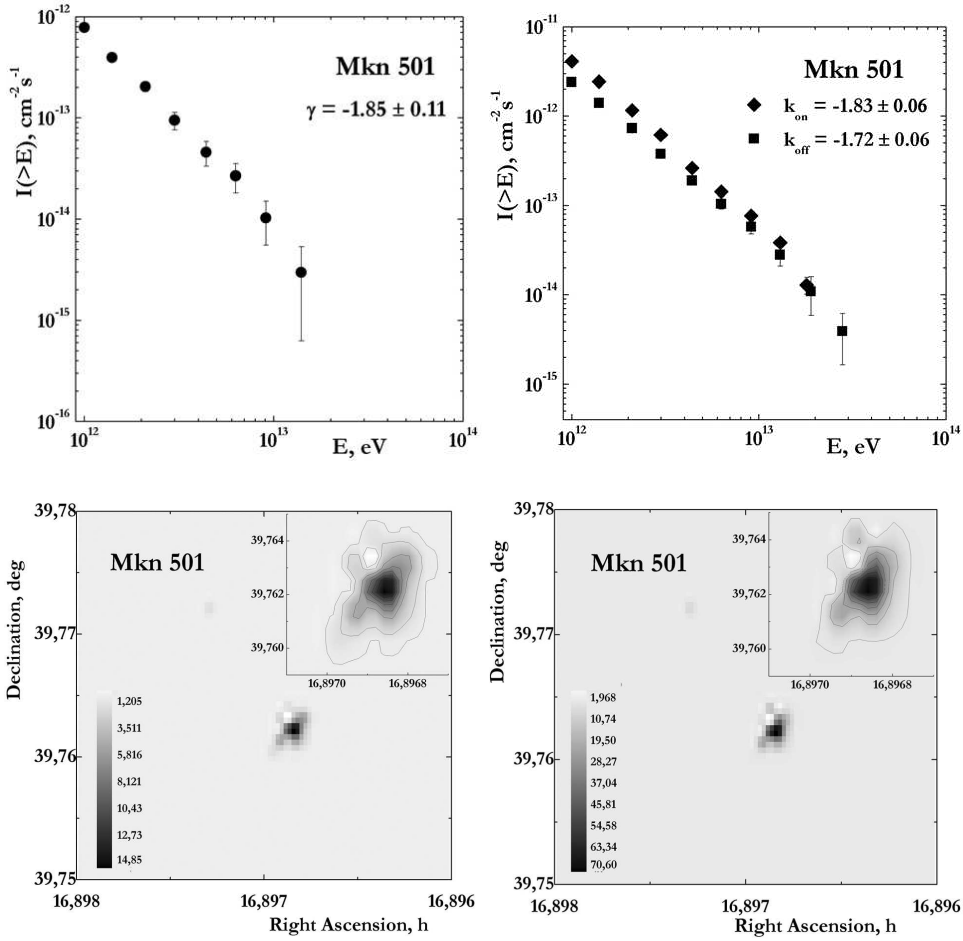

Fig. 4. **top:** left – The Mkn 501 gamma-quantum integral spectrum with power index of $k_\gamma = -1.85 \pm 0.11$; right – the event spectrum from Mkn 501 with background with index of $k_{ON} = -1.83 \pm 0.06$ and spectrum of background events observed simultaneously with Mkn 501 with index $k_{OFF} = -1.72 \pm 0.06$; **bottom** left – The Mkn 501 image at energy range of more then 0.8 TeV; right – The energy image (in TeV units) of Mkn 501 by SHALON.

as significant source of gamma rays. So Mkn 501 was the first object to be discovered by as gamma-ray source from the ground. As is seen from fig. 3 the SHALON results for this gamma-source are consistent with the data telescopes of Whipple, TACTIC, HESS, MAGIC. An image of gamma-ray emission from Mkn 501 by SHALON telescope is shown in Fig. 4. The integral average gamma-ray flux above 0.8 TeV was estimated as $(0.86 \pm 0.13) \times 10^{-12}\ cm^{-2}s^{-1}$ and the power index of the integral spectrum is $k_\gamma = -1.85 \pm 0.11$. The significant increase of Mkn 501 flux was detected in 1997 with the VHE ground telescopes all over the world. The integral gamma-ray flux by SHALON telescope was estimated as $(1.21 \pm 0.13) \times 10^{-12}\ cm^{-2}s^{-1}$ that is comparable with flux of powerful galactic source Crab Nebula.

NGC 1275

In 1996 year a new metagalactic source are detected by SHALON at TeV energies (fig. 5). This object was identified with Seyfert galaxy NGC 1275 (with redshift z=0.0179); its image is shown in fig. 6. The integral gamma-ray flux for this source is found to be $(0.78 \pm 0.13) \times 10^{-12}$ at energies of > 0.8 TeV. The energy spectrum of NGC 1275 at 0.8 to 20

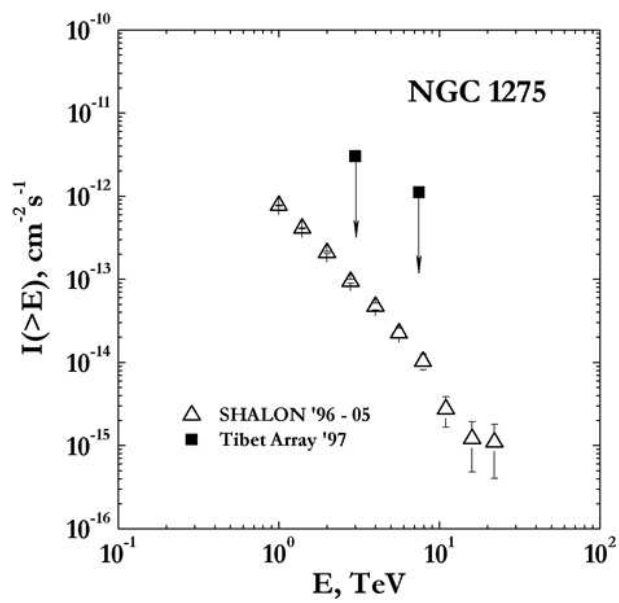

Fig. 5. The NGC 1275 gamma - quantum ($E > 0.8$ TeV) integral spectrum by SHALON in comparison with Tibet Array data;

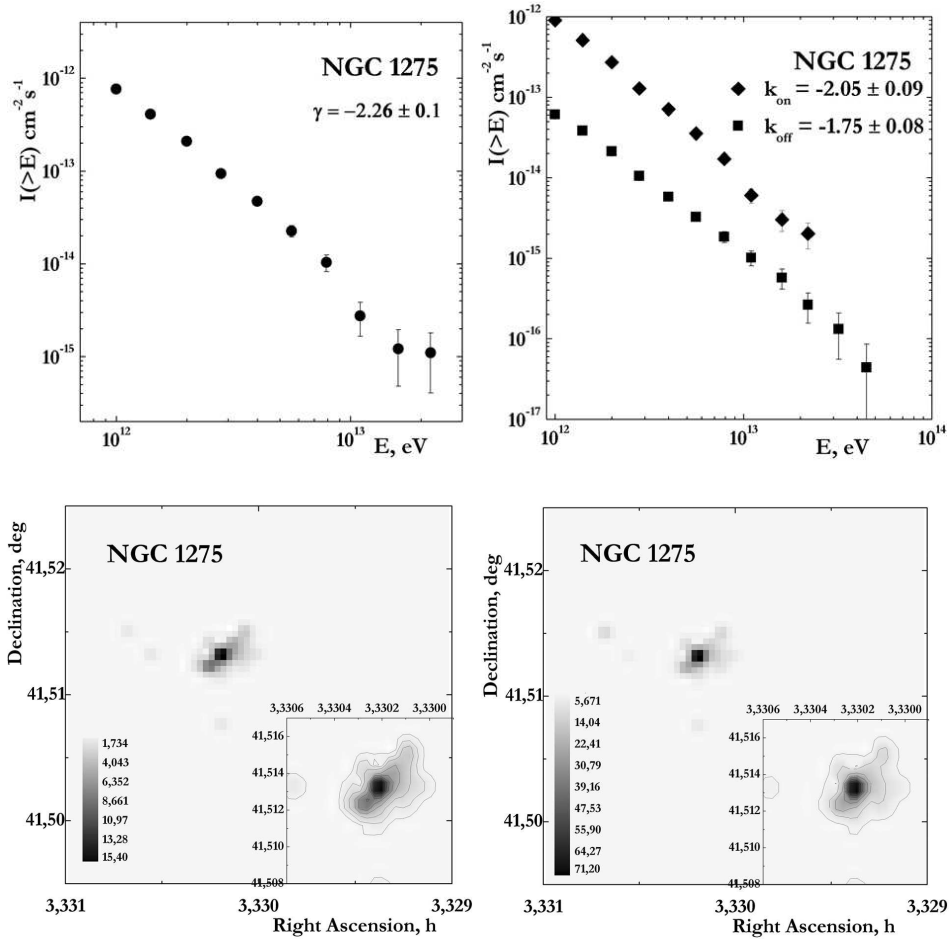

Fig. 6. **top:** left – The NGC 1275 gamma-quantum integral spectrum with power index of $k_\gamma = -2.26 \pm 0.10$; right – The event spectrum from NGC 1275 with background with index of $k_{ON} = -2.05 \pm 0.09$ and spectrum of background events observed simultaneously with NGC 1275 with index $k_{OFF} = -1.75 \pm 0.08$; **bottom:** left – The NGC 1275 image at energy range of more then 0.8 TeV; right – The energy image (in TeV units) of NGC 1275 by SHALON.

TeV can be approximated by the power law $F(> E_O) \propto E^{k_\gamma}$, with $k_\gamma = 2.26 \pm 0.10$. The spectra of events satisfying the selection criteria (spectral index $k_{ON} = -2.05 \pm 0.09$) and of the background events observed simultaneously with the source (spectral index $k_{OFF} = -1.75 \pm 0.08$) are both shown in Fig. 6 for comparison. The Seyfert galaxy NGC 1275 has been also observed with the Tibet Array (fig. 5).

3C454.3

In 1998 year a new metagalactic source 3c454.3 (z=0.857) has been detected by SHALON at TeV energies. The integral gamma-ray flux above 0.8 TeV was estimated as $(0.43 \pm 0.13) \times 10^{-12}\ cm^{-2}s^{-1}$ (Table I, Fig. 7). It is consistent with the upper limit $0.84 \times 10^{-11}\ cm^{-2}s^{-1}$ obtained by Whipple telescope at energy more than 0.5 TeV [10]. Taking into account that the spectrum from 3c454.3 measured by EGRET in the energy range ~ 30 MeV to 50 GeV can be approximated as $E^{-1.2}$ [12], the net data are well described by the uniform power law $F(> E) \propto E^\gamma$ at whole energy range $10^8 - 10^{13}$ eV, (Fig. 8) [2 - 16].

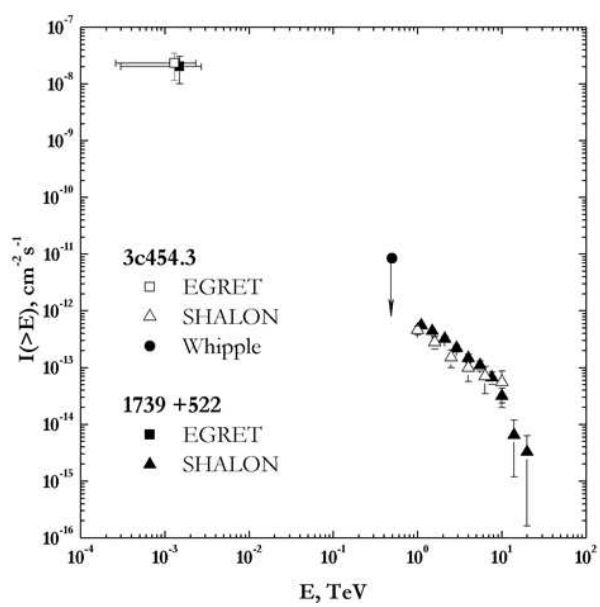

Fig. 7. The 3c454.3 and 1739+522 gamma - quantum ($E > 0.8$ TeV) integral spectra by SHALON in comparison with EGRET and Whipple data.

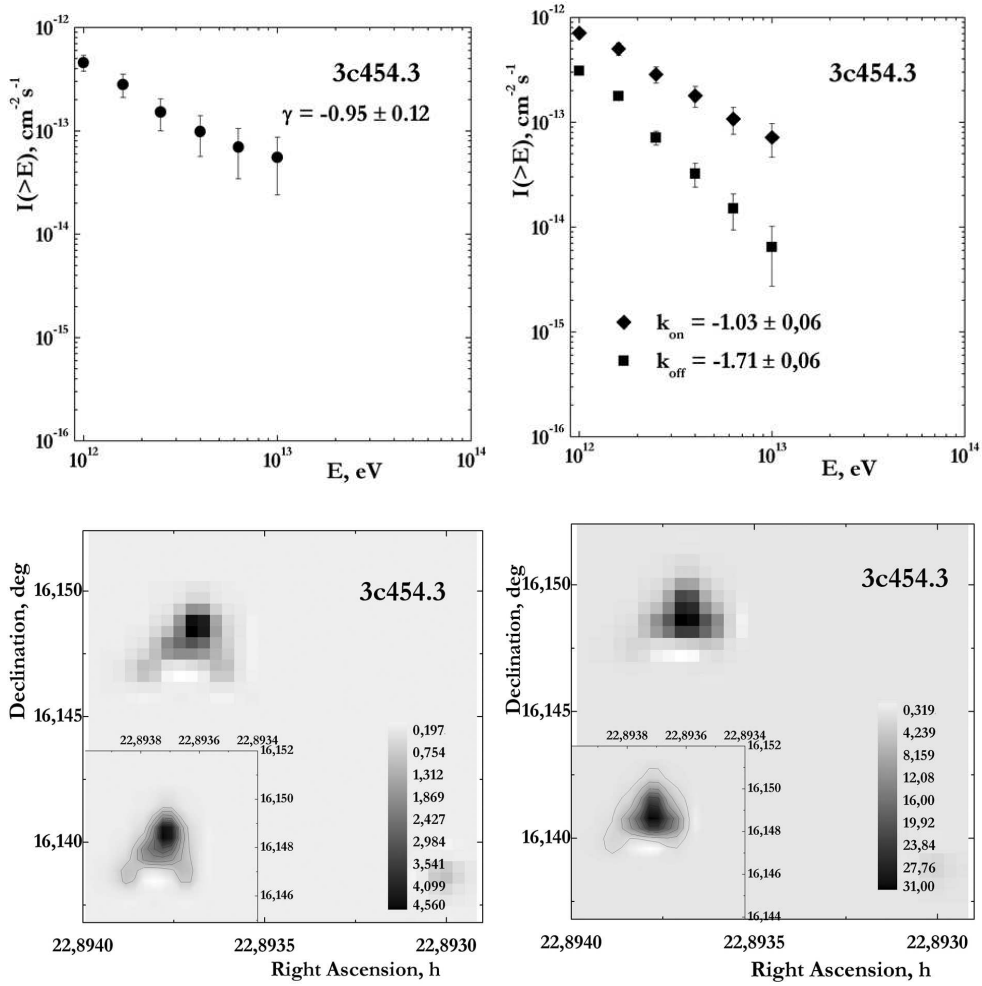

Fig. 8. **top:** left – The 3c454.3 gamma-quantum integral spectrum with power index $k_\gamma = -0.95 \pm 0.12$; right – The event spectrum from 3c454.3 with background with index of $k_{ON} = -1.03 \pm 0.06$ and spectrum of background events observed simultaneously with 3c454.3 with index $k_{OFF} = -1.71 \pm 0.06$; **bottom:** left – the 3c454.3 image at energy range of more then 0.8 TeV; right – The energy image (in TeV units) of 3c454.3 by SHALON.

1739+522

One more remote metagalactic gamma - source was detected by SHALON in 1999 and is being intensively studied since then. This object was identified with the active galactic nucleus 1739+522; its image is shown in fig. 9. This the most distant object (with redshift z=1.375) is also the most powerful: its integral gamma-ray flux is found to be $(0.53 \pm 0.10) \times 10^{-12}$ at energies of > 0.8 TeV. Within the range 0.8 - 7 TeV, the integral energy spectrum is well described by the single power law $I(> E_\gamma) \propto E_\gamma^{-1.09 \pm 0.04}$ (fig. 9). The integral spectrum of the events from source has the power index $k_{ON} = -1.12 \pm 0.06$ while the spectral index of the background events observed simultaneously with the source is $k_{OFF} = -1.75 \pm 0.06$. The average gamma-flux measured by EGRET in the range ~ 30 MeV to 50 GeV is about $2 \times 10^{-8}\ cm^{-2} s^{-1}$ with integral spectrum index about -1.2 [12].

According to our analysis, the energy spectra of distant quasars 3c454.3 and 1739+522 differ from those of the known blazars Mkn 421 (z=0.031) and Mkn 501 (z=0.034): $F_{Mkn\ 421}(> E_\gamma) \propto E_\gamma^{-1.53 \pm 0.14}$ and $F_{Mkn\ 501}(> E_\gamma) \propto E_\gamma^{-1.85 \pm 0.11}$. The indices of integral spectra of events from Mkn 421 and Mkn 501 are respectively, $k_{ON} = -1.46 \pm 0.09$ and $k_{ON} = -1.83 \pm 0.06$ and the spectral indices of background events are $k_{OFF} = -1.75 \pm 0.06$ and $k_{OFF} = -1.72 \pm 0.06$. Hence, the average energy spectrum of these two metagalactic sources differs from spectra of remote objects 1739+522 and 3c454.3 within the energy range $10^{12} - 10^{13}$

TABLE II
THE INTEGRAL SPECTRUM INDICES OF SHALON SPECTRA IN ACTIVE GALACTIC NUCLEI

Sources	z	k_γ	k_{ON}	k_{OFF}
NGC 1275	0.0179	-2.26 ± 0.10	-2.05 ± 0.09	-1.75 ± 0.08
Mkn 421	0.031	-1.53 ± 0.14	-1.46 ± 0.09	-1.75 ± 0.06
Mkn 501	0.034	-1.85 ± 0.11	-1.83 ± 0.06	-1.72 ± 0.06
3c4543	0.859	-0.95 ± 0.12	-1.03 ± 0.06	-1.71 ± 0.06
1739+522	1.375	-1.09 ± 0.04	-1.12 ± 0.06	-1.75 ± 0.06

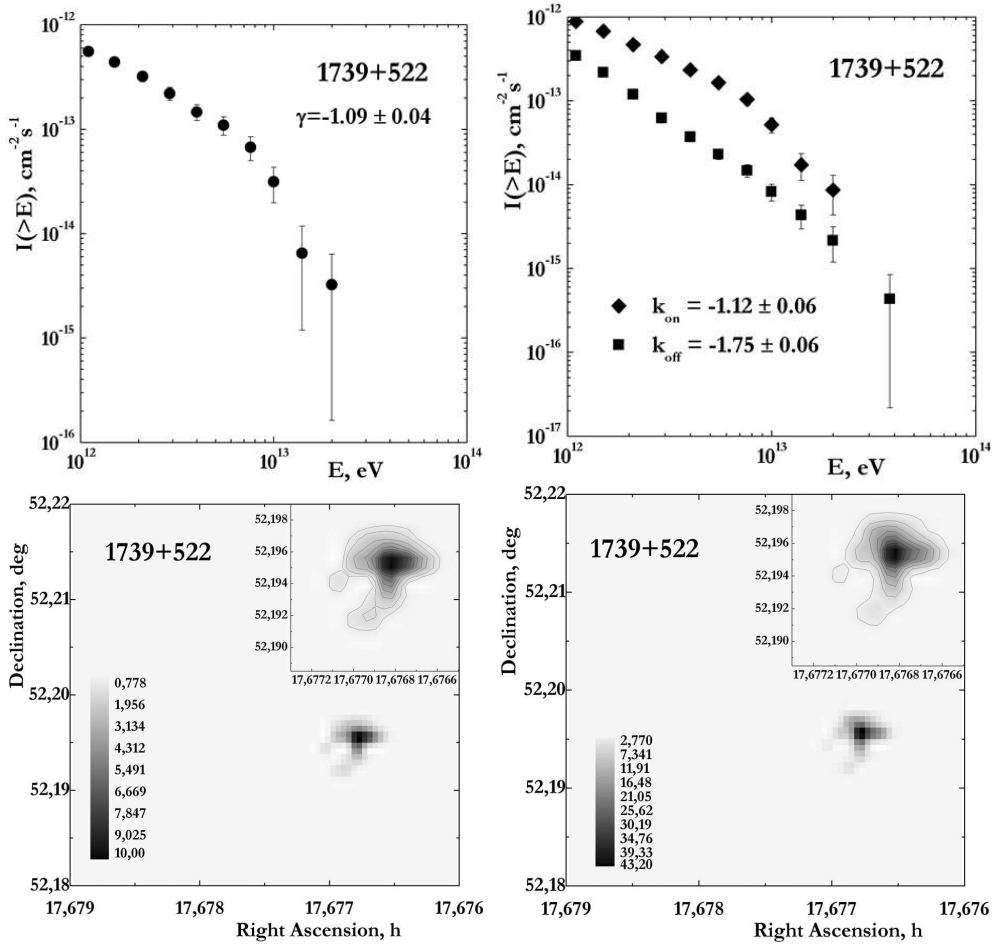

Fig. 9. **top:** left – The 1739+522 gamma-quantum integral spectrum with power index of $k_\gamma = -1.09 \pm 0.04$; right – the event spectrum from 1739+522 with background with index of $k_{ON} = -1.12 \pm 0.06$ and spectrum of background events observed simultaneously with 1739+522 with index $k_{OFF} = -1.75 \pm 0.06$; **bottom:** left – The image of gamma-ray emission from 1739+522; right – The energy image of 1739+522 by SHALON.

eV. This observation does not contradict to unified energy spectrum $F(> E_\gamma) \propto E_\gamma^{-1.2\pm0.1}$.

CONCLUSION

Another problem arises when one collates the gamma-ray energy releases of the galactic and metagalactic sources. The power of metagalactic sources exceeds that of the gamma-sources from our Galaxy by 10^8 (Table I). The most distant currently known source 1739+522 is about 10^{11} times more powerful than the full gamma-emission from all known sources of our Galaxy! Thus, the modern gamma-astronomical observations put forward the two key questions: (1) what mechanisms might be responsible for the currently observed gamma-ray fluxes from the remote metagalactic sources? (2) which processes compose the uniform cosmic - ray spectrum close to the power law $dF/dE \propto E^{-2.72\pm0.01}$ over the wide energy range from $\sim 10^{11}$ to 10^{19} eV and distinctly different from the harder energy spectrum of the powerful metagalactic gamma-emitters?

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