Integral spectra, spectral energy distributions and images of the distant VHE metagalactic sources 1739+522 (z=1.375) and 3c454.3 (z=0.859)

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Abstract*— The cosmological processes, connecting the physics of matter in active galactic nuclei will be observed in the energy spectrum of electro- magnetic 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 range from z=0.0179 to z=1.375. During the period 1992 - 2008, SHALON has been used for observations of the metagalactic sources NGC1275 (z=0.0183), SN2006gy (z=0.019), Mkn421 (z=0.031), Mkn501 (z=0.034), Mkn180 (z=0.046), OJ 287 (z=0.306), 3c454.3 (z=0.895), 1739+522 (z=1.375). The most distant object 1739+522 (with redshift z=1.375), seen in TeV energy, is also the most powerful: its integral gamma-ray flux is found to be $(0.53 \pm 0.10) \times 10^{-12}\ cm^{-2}s^{-1}$ at energies of > 0.8 TeV. The integral gamma-ray flux of 3c454 (z=0.859) was estimated as $(0.43 \pm 0.13) \times 10^{-12}\ cm^{-2}s^{-1}$. 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. The gamma-ray spectra and fluxes of known blazars Mkn421, Mkn501 as the spectrum of NGC1275 and distant flat-spectrum radio quasars 1739+522 and 3c454.3 are presented: for NGC 1275 $k_\gamma = -2.26 \pm 0.10$; for Mkn 421 $k_\pm = -1.87 \pm 0.11$; for Mkn 501 $k_\gamma = -1.89 \pm 0.11$; for 3c454.3 $k_\gamma = -0.95 \pm 0.10$; for 1739+522 $k_\gamma = -1.09 \pm 0.06$. So, the energy spectrum of metagalactic sources Mkn421, Mkn501, NGC 1275 at range $10^{12} - 10^{13}$ eV differs from spectra of distant quasars 1739+522 and 3c454.3 that don't contradict to united energy spectrum $F(> E_\gamma)\ E_\gamma^{-1.2\pm0.1}$. The most distant currently known source 1739+522 is about 10^{11} times more powerful than the full emission from all known sources of the Galaxy. Thus, the modern gamma-astronomical observations put forward the question: what mechanisms might be responsible for the currently observed gamma-ray fluxes from the remote metagalactic sources? Observations of distant metagalactic sources have shown that the Universe is more transparent to very high energy gamma-rays than previously believed.

I. 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 range from z=0.0179 to z=1.375.

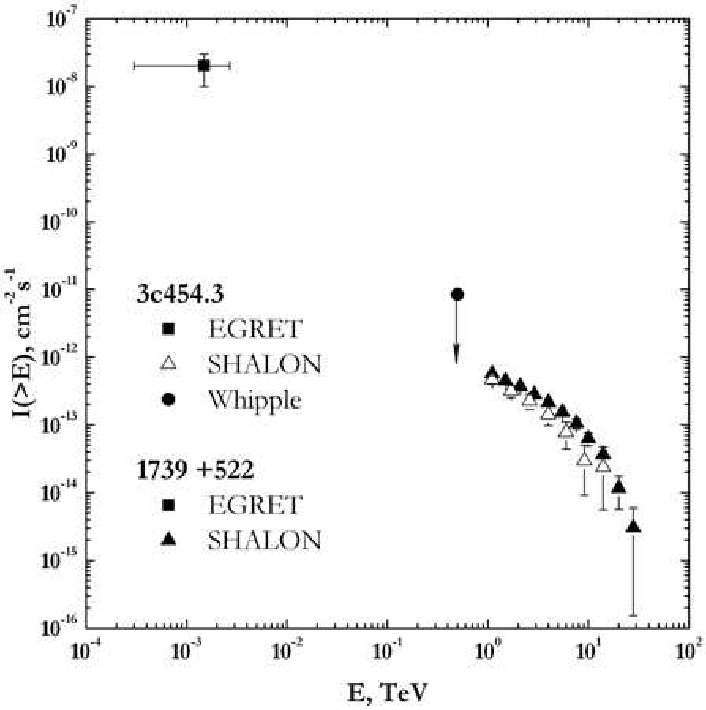


Fig. 1. The 3c454.3 and 1739+522 gamma - quantum ($E > 0.8$ TeV) integral spectra by SHALON in comparison with EGRET and Whipple data.

The gamma - astronomical researches are carrying out with SHALON [1] mirror telescope at the Tien-Shan high mountainous station since 1992. During the period 1992 - 2007 SHALON has been used for observations of metagalactic sources: Mkn 421, Mkn 501, Mkn 180, NGC 1275, SN2006 gy, 3c454.3, 1739+522 and galactic sources: Crab Nebula, Cyg X-3, Tycho's SNR, Geminga, 2129+47XR [2 –

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 – **R**

Sources	Type of source	Observable flux ($\times 10^{-12} cm^{-2}s^{-1}$)	Distance (Mpc)	**R**
Mkn 421	Blazar	(0.63 ± 0.14)	124	3.8×10^{9}
Mkn 501	Blazar	(0.86 ± 0.13)	135	4.46×10^{9}
Mkn 180	Blazar	(0.65 ± 0.23)	182	6.2×10^{9}
NGC 1275	Seyfert Galaxy	(0.78 ± 0.13)	71	1.2×10^{9}
SN2006 gy	Extragalactic Supernova	(3.71 ± 0.65)	83	4.2×10^{9}
3c4543	FSRQ	(0.43 ± 0.13)	4685	5.3×10^{12}
1739+522	FSRQ	(0.53 ± 0.10)	7500	1.4×10^{13}

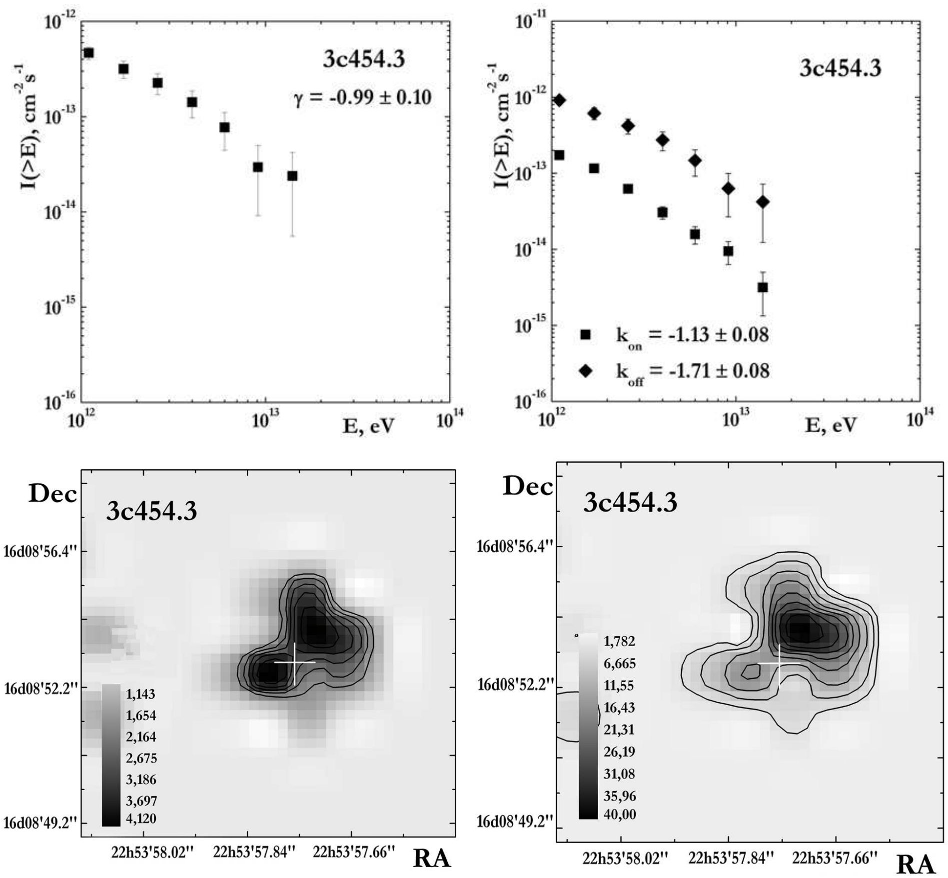


Fig. 2. **Top. left:** The 3c454.3 gamma-quantum integral spectrum with power index $k_\gamma = -0.99 \pm 0.10$; **right:** The event spectrum from 3c454.3 with background with index of $k_{ON} = -1.13 \pm 0.08$ and spectrum of background events observed simultaneously with 3c454.3 with index $k_{OFF} = -1.71 \pm 0.08$; **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.

9] Our method of the data processing is described in [1], [2], [4], [5]. Some representative results are shown in [2 – 9] and figures in these proceedings. 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 [2 – 9] and fig. 2 (these proc.) the SHALON results for these known gamma-sources are consistent with the data by telescope EGRET telescope of the Compton Observatory (CGRO), obtained in the energy region $10^2 - 10^3$ MeV.

3C454.3

In 1998 year a new metagalactic source 3c454.3 (z=0.859) 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. 1). It is consistent with the upper limit 0.84×10^{-11} $cm^{-2}s^{-1}$ obtained by Whipple telescope at energy more than 0.5 TeV [10], [11]. Taking into account that the spectrum from 3c454.3 measured by EGRET in the energy range $\sim$ 30 MeV to 50 GeV can be

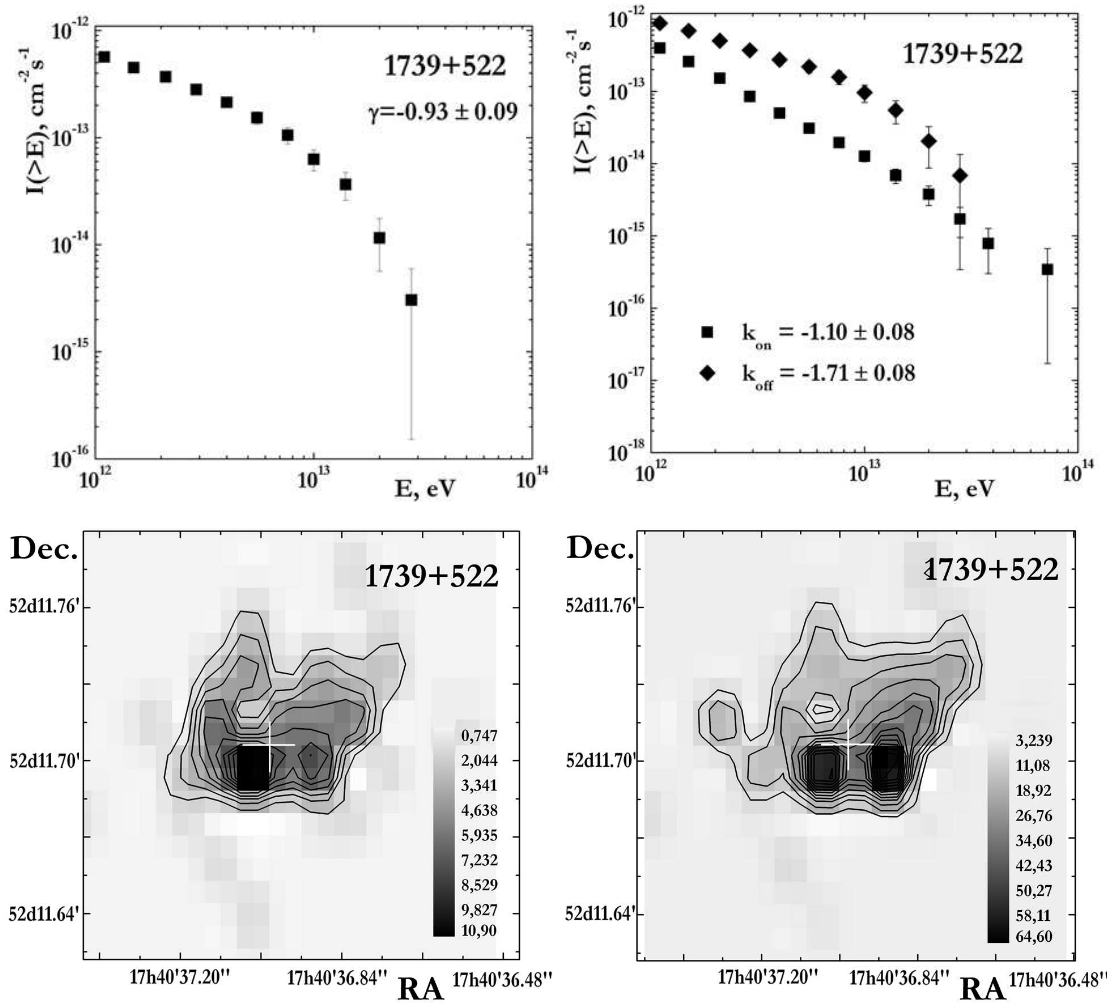
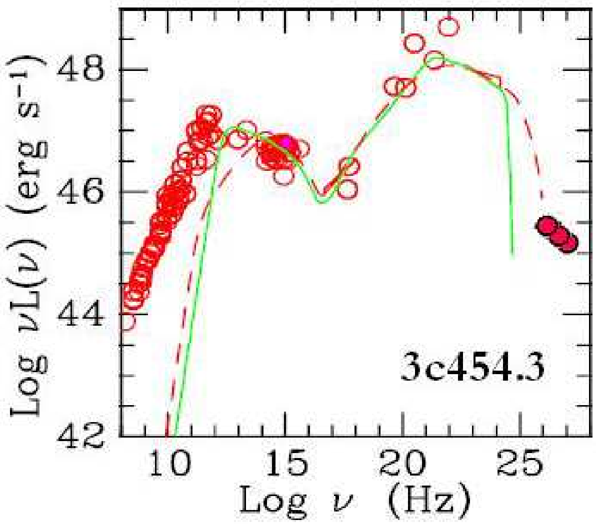


Fig. 3. **Top. left:** The 1739+522 gamma-quantum integral spectrum with power index of $k_\gamma = -0.93 \pm 0.09$; **right:** The event spectrum from 1739+522 with background with index of $k_{ON} = -1.10 \pm 0.08$ and spectrum of background events observed simultaneously with 1739+522 with index $k_{OFF} = -1.71 \pm 0.08$; and **Bottom. left:** The image of gamma-ray emission from 1739+522; **right:** The energy image of 1739+522 by SHALON.

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. 1) [2 - 14] Figure 4 presents Spectral energy distributions of 3c454.3. Black circles is SHALON data. The data marked with open circles; solid and dashed lines refer to the synchrotron self-Compton (SSC) and external Compton (EC) model described in [15]

II. 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. 3. 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 $I(> E_\gamma) \propto E_\gamma^{-0.93\pm0.09}$ (fig. 3). The integral spectrum of the events from source has the power index $k_{ON} = -1.10 \pm 0.08$ while the spectral index of the background events observed simultaneously with the source is $k_{OFF} = -1.71 \pm 0.08$. The average gamma-flux measured by EGRET telescope of Compton Observatory (CGRO)in the range $\sim$ 30 MeV to 50 GeV is about 2×10^{-8} $cm^{-2}s^{-1}$ with integral spectrum index about -1.2 [12]. Spectral energy distributions of 1739+522 is presented on Figure 4. Black circles is SHALON data. The data marked with open circles; solid and dashed lines refer to the synchrotron (SSC) and (EC) model described in [15] 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): $F_{Mkn\ 421}(> E_\gamma) \propto E_\gamma^{-1.87\pm0.11}$ and $F_{Mkn\ 501}(> E_\gamma) \propto E_\gamma^{-1.85\pm0.11}$. The indices of integral spectra of events from Mkn 421 and Mkn 501 are respectively, $k_{ON} = -1.85\pm0.10$ and $k_{ON} = -1.83\pm0.06$ and the spectral indices of background events are $k_{OFF} = -1.76 \pm 0.09$ and $k_{OFF} = -1.72 \pm 0.06$. Hence, the average energy spectrum of these two metagalactic sources differs from spectra of



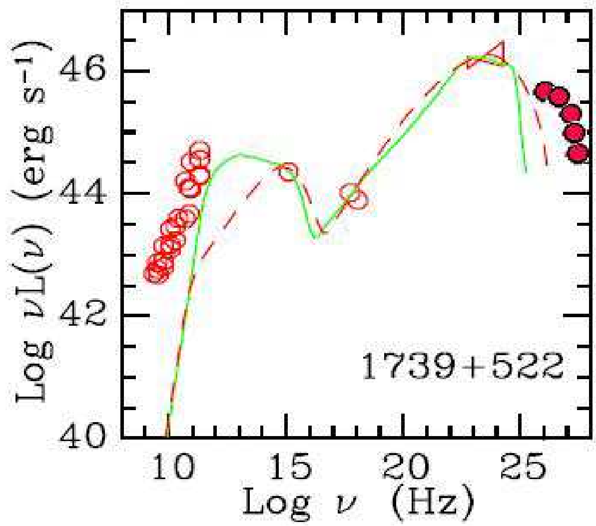


Fig. 4. **left** – Spectral energy distributions of 3c454.3. Black circles (at TeV energies) are SHALON data. The data marked with open circles; solid and dashed lines refer to the synchrotron self-Compton (SSC) and external Compton (EC) model described in [15]; **right** – Spectral energy distributions of 1739+522 with curves and data same as top

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	-2.25 ± 0.10	-2.13 ± 0.09	-1.72 ± 0.09
SN2006 gy	0.019	-3.13 ± 0.27	-2.54 ± 0.16	-1.73 ± 0.11
Mkn 421	0.031	-1.87 ± 0.11	-1.85 ± 0.10	-1.76 ± 0.09
Mkn 501	0.034	-1.85 ± 0.11	-1.83 ± 0.06	-1.72 ± 0.06
3c4543	0.859	-0.99 ± 0.10	-1.13 ± 0.08	-1.71 ± 0.08
1739+522	1.375	-0.93 ± 0.09	-1.10 ± 0.08	-1.71 ± 0.08

remote objects 1739+522 and 3c454.3 within the energy range $10^{12} - 10^{13}$ eV. This observation does not contradict to unified energy spectrum $F(> E_\gamma) \propto E_\gamma^{-1.2\pm0.1}$.

CONCLUSION

The average energy spectrum of these two metagalactic sources differs from spectra of remote objects 1739+522 and 3c454.3 within the energy range $10^{12} - 10^{13}$ eV. This observation does not contradict to unified energy spectrum $F(> E_\gamma) \propto E_\gamma^{-1.2\pm0.1}$.

The observed energy gamma-quantum spectra for four sources in our Galaxy and for five Metagalactic sources do not contradict to a averaged energy gamma-quantum spectrum of all sources in the energy range of 0.8-50 TeV, $f(E_\gamma)dE_\gamma \sim E_\gamma^{-2.25\pm0.10}dE_\gamma$. Meanwhile, the differential spectrum of protons and nuclei of cosmic radiation is $f(E)dE \sim E^{-2.72\pm0.01}dE$ in the energy interval of $1 - 3 \times 10^7 TeV$.

Thus, the energy spectrum in the interval $10^{12} - 10^{14}eV$ for most of detected gamma-sources is harder than the hadron cosmic ray spectrum. This makes the following known problem even sharper: what are processes in the Universe that result in the uniform cosmic-ray spectrum over many orders of magnitude in the energy?

A new problem arises after comparing the power of sources of gamma-quanta generated in our Galaxy (supernova remnants) and the power of metagalactic gamma-sources (active galactic nuclei, quasars). The power of the metagalactic g-sources exceeds the power of gamma-sources in our Galaxy by the factor of $\sim 10^6$. Moreover, the most distant of the currently known sources, 1739+522 (see Table I), has the power 10^{11} times more than the total power of all known gamma-sources in our Galaxy.

As was metioned above, the average energy-spectrum of gamma-quanta from local sources, $F(> E_o) \sim E_o^{-1.25}$, does not coincide with the energy spectrum of cosmic radiation, $F(> E) \sim E^{-1.72}$, which has a different spectral index. So, the development of gamma-astronomy raises two questions: (i) are there any grounds to divide cosmic radiation into two parts: of galactic and of metagalactic origin, and (ii) what processes make the cosmic-ray spectrum $\propto {E_k}^{-2.72\pm0.01}$ as a uniform spectrum in the wide energy range $10^{11} - 10^{19}$ eV with the index so different from that of a harder energy spectrum of metagalactic sources, $\propto {E_\gamma}^{-2.25\pm0.10}$. The total volume of intergalactic space is nearly thousand times more than the total volume of all galaxies in the Metagalaxy. The unlimited number of small energy losses by protons and nuclei of cosmic rays in elastic collisions with relict photons eventually results in the Napiers constant 2.718..., i.e. the number more than close to the index of the observational energy-spectrum of primary protons in the energy ranges $10^{12} - 10^{16}$ eV and

$3 \times 10^{17} - 10^{20}$ eV and reconstructed from the EAS spectrum. A weak manifestation of the relict cutoff of protons and hard fission of primary nuclei can be considered as a confirmation of the suggestion made.

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