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The energy spectra of distant metagalactic sources: 1739+522 and 3c454.3

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Abstract: 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 gamma-astronomical researches are carrying out with SHALON mirror telescope at the Tien-Shan high-mountain observatory since 1992. The redshifts of SHALON very high energy gamma-ray sources range from z=0.0179 to 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(z=0.0179) $k_\gamma = -2.25 \pm 0.10$, $k_{on} = -2.13 \pm 0.09$, $k_{off} = -1.72 \pm 0.09$; for Mkn 421 (z=0.031) $k_\gamma = -1.87 \pm 0.11$, $k_{on} = -1.85 \pm 0.10$, $k_{off} = -1.76 \pm 0.09$; for Mkn 501 (z=0.034) $k_\gamma = -1.85 \pm 0.11$, $k_{on} = -1.83 \pm 0.06$, $k_{off} = -1.72 \pm 0.06$; for 3c454.3 (z=0.859) $k_\gamma = -0.99 \pm 0.10$, $k_{on} = -1.13 \pm 0.08$, $k_{off} = -1.71 \pm 0.08$; for 1739+522 (z=1.375) $k_\gamma = -0.93 \pm 0.09$, $k_{on} = -1.10 \pm 0.08$, $k_{off} = -1.71 \pm 0.08$. 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 $F(> E_\gamma) \propto E_\gamma^{-1.2 \pm 0.1}$. 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?

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. 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 [2 - 9]. Our method

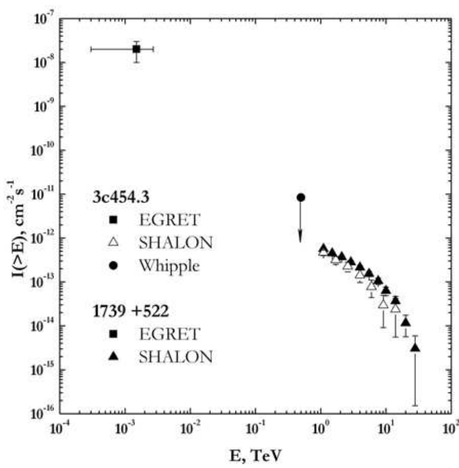

Figure 1: The 3c454.3 and 1739+522 gamma - quantum ($E > 0.8$ TeV) integral spectra by SHALON in comparison with EGRET and Whipple data.

Table 1: 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}

of the data processing is described in [1], [2], [4] and [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. 3 (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 1, 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 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. 2) [2 - 14].

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].

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, $k_{ON} = -1.85 \pm 0.10$ and $k_{ON} = -1.83 \pm 0.06$ 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 spec-

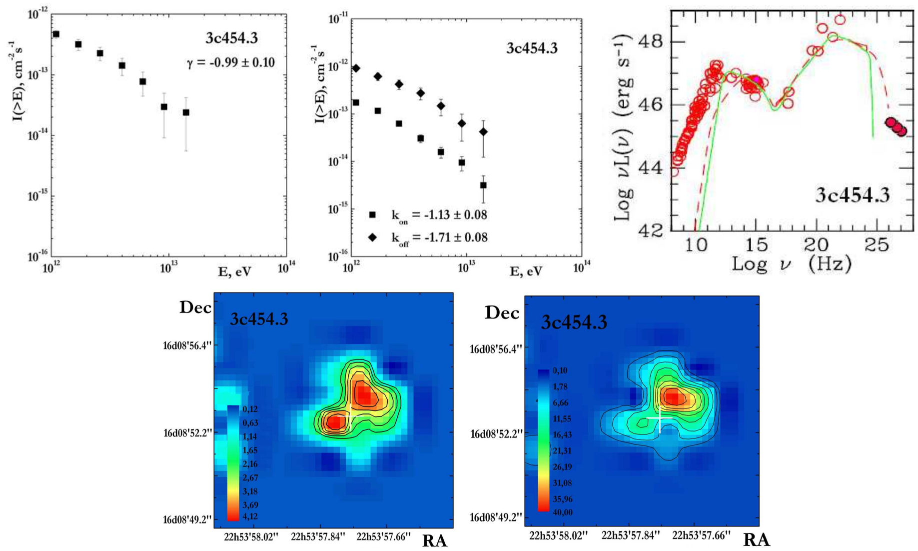

Figure 2: **top:** left – The 3c454.3 gamma-quantum integral spectrum with power index $k_\gamma = -0.99 \pm 0.10$; right – The event spectrum from 3c454.3 with background with index of $k_{ON} = -1.13 \pm 0.08$ and spectrum of background events observed simultaneously with 3c454.3 with index $k_{OFF} = -1.71 \pm 0.08$; and Spectral energy distributions of 3c454.3. Red circles is SHALON data. The data marked with open red circles; solid and dashed lines refer to the synchrotron self-Compton (SSC) and external Compton (EC) model described in [15]. **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.

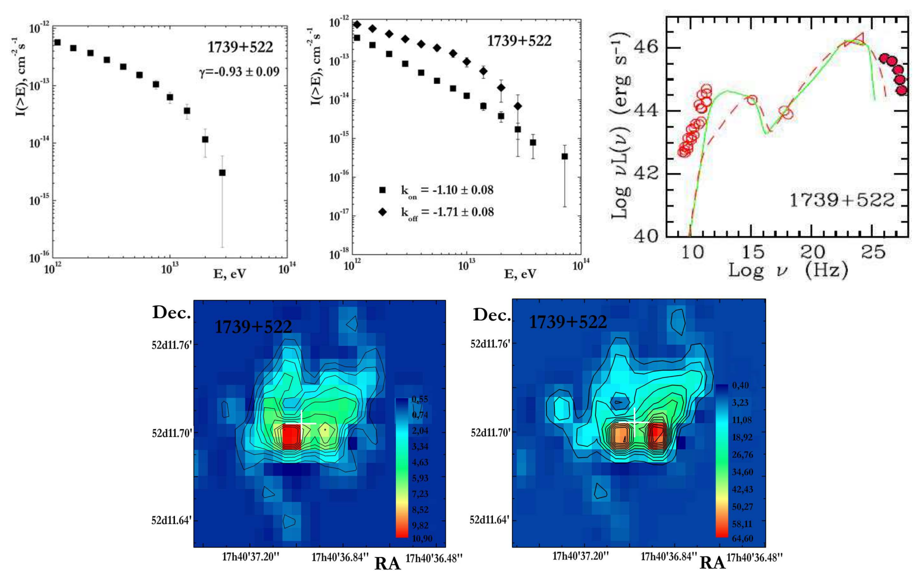

Figure 3: **top:** left – The 1739+522 gamma-quantum integral spectrum with power index of $k_\gamma = -0.93 \pm 0.09$; right – the event spectrum from 1739+522 with background with index of $k_{ON} = -1.10 \pm 0.08$ and spectrum of background events observed simultaneously with 1739+522 with index $k_{OFF} = -1.71 \pm 0.08$; and Spectral energy distributions of 1739+522 with curves and data same as fig. 2. **bottom:** left – The image of gamma-ray emission from 1739+522; right – The energy image of 1739+522 by SHALON.

Table 2: 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
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

tra 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 $F(> E_\gamma) \propto E_\gamma^{-1.2\pm0.1}$.

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 1). 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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