Constraints of Extragalactic Background Light expected from observation of distant metagalactic sources 1739+522 (z=1.375) and 3c454.3 (z=0.859) (by SHALON Cherenkov telescopes)

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As the TeV gamma rays can be absorbed due to interaction of low-energy photons of Extragalactic Background Light (EBL), the observations of active galactic nuclei can also be used to study the background light from UV to far infrared and even cosmic microwave background. Extragalactic diffuse background radiation blocks the propagation of TeV gamma-rays over large distances ($z > 0.1$) by producing e^+e^- pairs. As a result, the primary spectrum of gamma-source is changed, depending on the spectrum of background light. So, hard spectra of Active Galactic Nuclei with high red shifts of 0.03 - 1.8 allow to determine an absorption by Extragalactic Background Light and thus spectrum of EBL. The redshifts of SHALON very high energy gamma-ray sources range from z=0.0183 to z=1.375. Among them are bright enough AGNs of BLLac type: Mkn421 (z=0.031), Mkn501 (z=0.034) and FSRQ type: 3c454.3 (z=0.895), 1739+522 (z=1.375) those spectra are resolved in the TeV energy band from 1 to $\sim 20-30$ TeV. Spectral energy distributions and images of distant AGNi are presented. Spectral energy distribution of EBL constrained from observations of Mkn421, Mkn501, 3c454.3 and 1739+522 together with models and measurements are presented.

1. 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 have been carried out with the SHALON [1] mirror telescope at the Tien-Shan high mountain station since 1992. Our method of data processing is described in [1–4]. Some representative results are shown in [2–8] and in these proceedings. During the period 1992 - 2010 SHALON has been used for observations of extragalactic sources. Among them are active galactic nuclei Mkn 421, Mkn 501, Mkn 180, NGC 1275, OJ 287, 3c 382, 3c454.3, 1739+522 and extragalactic supernova SN2006 gy (table I).

The active galactic nuclei (AGNi) detected in high and very high energy gamma-rays are radio-loud sources with the radio emission arising primarily from a core region rather than from lobes. These types of AGNi are often collectively referred to as "blazars" and include BL Lacertae (BL Lac) objects, flat spectrum radio-loud quasars (FSRQs), optically violent variables, and superluminal sources. The emission characteristics of blazars include high polarization at radio and optical wavelengths, rapid variability at all wavelengths, and mainly non-thermal emission at most wavelengths.

Table I The catalogue of metagalactic gamma-quantum sources, observed by SHALON;

Sources	Observable flux ($\times 10^{-12} cm^{-2} s^{-1}$)	Distance, (Mpc)
Mkn 421	(0.63 ± 0.14)	124
Mkn 501	(0.86 ± 0.13)	135
Mkn 180	(0.65 ± 0.23)	182
NGC 1275	(0.78 ± 0.13)	71
SN2006 gy	(3.71 ± 0.65)	83
3c 382	(0.95 ± 0.33)	230
OJ 287	(0.32 ± 0.11)	1070
3c454.3	(0.43 ± 0.13)	4685
1739+522	(0.53 ± 0.10)	7500

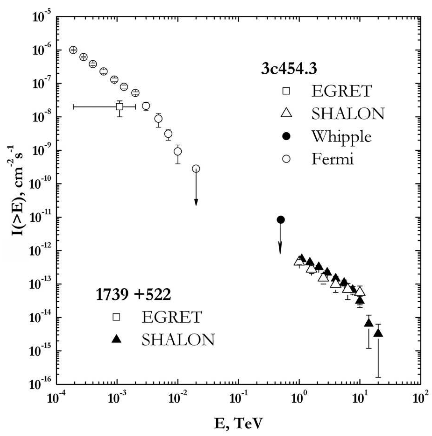

Figure 1: The 3c454.3 and 1739+522 γ - quantum ($E > 0.8$ TeV) integral spectra by SHALON in comparison with Fermi LAT [15], EGRET and Whipple [9, 10] data.

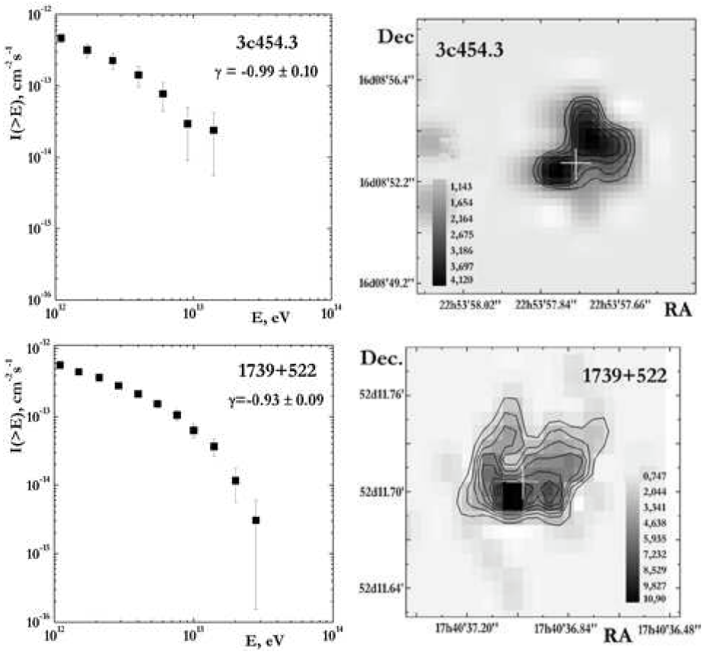

Figure 2: **from left to right:** The 3c454.3 gamma-quantum integral spectrum with power index $k_\gamma = -0.99 \pm 0.10$; The 3c454.3 image at energy range of more then 0.8 TeV by SHALON; The 1739+522 gamma-quantum integral spectrum with power index of $k_\gamma = -0.93 \pm 0.09$; The image of gamma-ray emission from 1739+522 by SHALON.

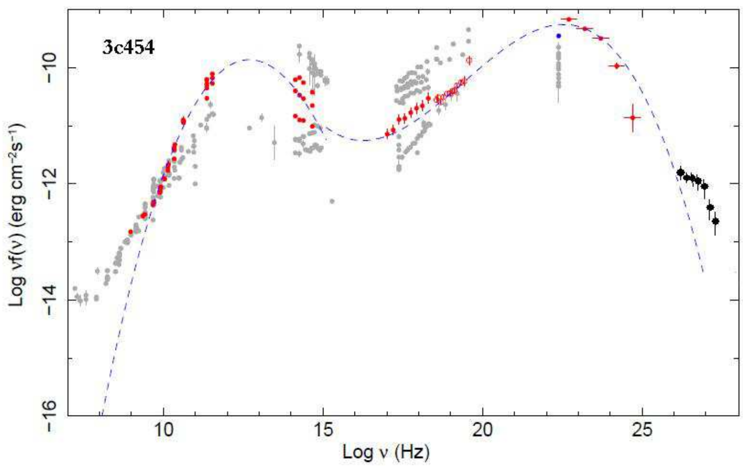

Figure 3: Spectral energy distributions of 3c454.3. Black circles (at TeV energies) are SHALON data. The circles (at MeV - GeV energies) are Fermi LAT data [15]. The dashed lines represent the best fits to the Synchrotron and Inverse Compton part of the SED [15]

2. 3c454.3

In 1998 a new metagalactic source 3c454.3 of FSRQ type with redshift z=0.859 was 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, Figs. 1, 2, 3). It is consistent with the upper limit $0.84 \times 10^{-11}\ cm^{-2}s^{-1}$ obtained by the Whipple telescope at energies more than 0.5 TeV [9, 10], 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 $E^{-1.2}$ [11].

Recently, 3c454.3 has been observed with Fermi LAT at energies 200 MeV - 300GeV [14]. The spectrum observed by Fermi is fitted with a a broken power-law with photon indices $\gamma_{low} = 2.27 \pm 0.3$, $\gamma_{high} = 3.5 \pm 0.05$ with an average flux of $\sim 3 \times 10^{-6} photons\ cm^{-2}s^{-1}$, for energies $> 100 MeV$.

Figure 3 shows the spectral energy distributions of 3c454.3. Black circles are SHALON data. The circles (at MeV - GeV energies) are Fermi LAT data [15].

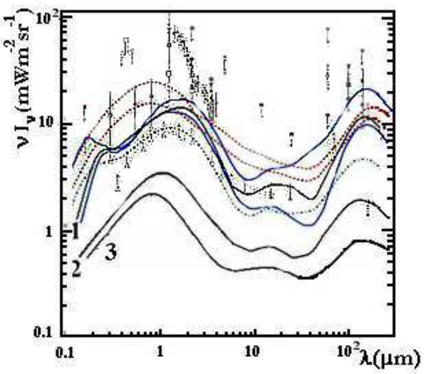

Figure 4: Spectral energy distribution of Extragalactic Background Light: models [17, 19] and measurements [18]; 1 - averaged EBL shape from best-fit model and Low-SFR model [19], 2 - EBL shape from constrained observations of 3c454.3 (z=0.859); 3 - 2 - EBL shape from constrained observations of 1739+522 (z=1.375)

The dashed lines represent the best fits to the Synchrotron and Inverse Compton part of the quasi-simultaneous SED [15].

3. 1739+522

One more remote metagalactic gamma - source was detected by SHALON in 1999 and has been intensively studied since then. This object was identified with the active galactic nucleus 1739+522 (fig. 1) also of FSRQ type; its image is shown in fig. 2. 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 > 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. 2). The average gamma-flux measured by the EGRET telescope of the Compton Observatory (CGRO)in the range $\sim$ 30 MeV to 50 GeV is about 2×10^{-8} $cm^{-2}s^{-1}$ with an integral spectrum index about -1.2 [11].

According to our analysis, the energy spectra of the distant quasars 3c454.3 and 1739+522 differ from those of the known blazars of BL Lac type Mkn 421 (z=0.031) and Mkn 501 (z=0.034) (table II): $F_{Mkn\ 421}(> E_\gamma) \propto E_\gamma^{-1.87\pm0.11}$ and $F_{Mkn\ 501}(> E_\gamma) \propto E_\gamma^{-1.85\pm0.11}$. Hence, the average energy spectrum of these two metagalactic sources differs from the spectra of the remote objects 1739+522 and 3c454.3 within the energy range $10^{12} - 10^{13}$ eV. This observation does not contradict to a unified energy spectrum $F(> E_\gamma) \propto E_\gamma^{-1.2\pm0.1}$.

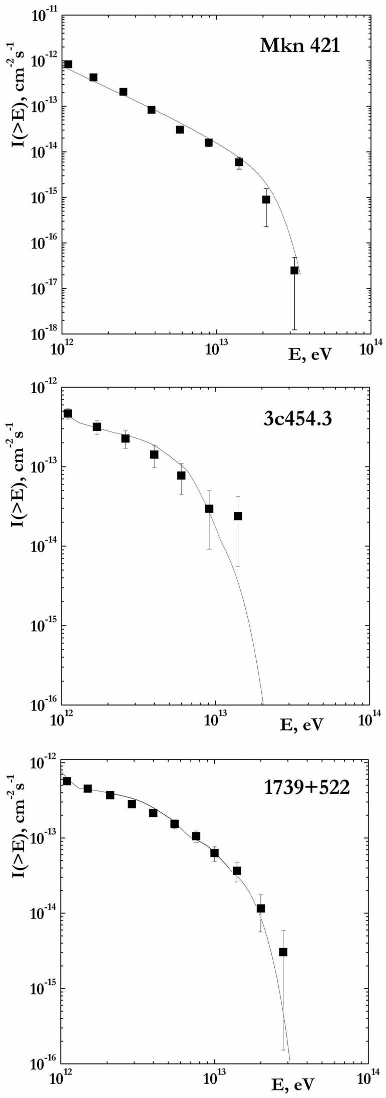

Figure 5: The measured spectra for Mkn 421, 3c454.4 and 1739+522 (black squares) together with spectra attenuated by EBL (see text)

Table II The integral spectrum indices of the SHALON spectra of AGNi

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
3c454.3	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

4. Extragalactic Background Light

As the TeV gamma rays can be absorbed due to the interaction of low-energy photons of Extragalactic

Background Light (EBL), the observations of active galactic nuclei can also be used to study the background light from UV to far infrared and even cosmic microwave background. The EBL spectrum contains information about star and galaxy formation in early stages of Universe evolution. TeV gamma-rays, radiated by distant sources, interact with photons of the background via $\gamma + \gamma \rightarrow e^+ + e^-$ resonant process, then relativistic electrons can radiate gamma-rays with energies less than of primary gamma-quantum. As a result, the primary spectrum of the gamma-source is changed, depending on the spectrum of the background light. So, hard spectra of Active Galactic Nuclei with high red shifts of 1 - 1.8 allow to determine an absorption by Extragalactic Background Light and thus spectrum of EBL.

The redshifts of SHALON very high energy gamma-ray sources range from z=0.0179 to z=1.375. Among them are bright enough AGNs of BLLac type (Mkn421, Mkn 501) and FSRQ type (3c454.3, 1739+522) whose spectra are resolved in the TeV energy band from 1 to ~20-30 TeV. The fit of a simple power law function to the observational data is presented in table II and discussed above. As is seen from fig. 2 and from [16] the measured spectrum can be fitted by a power law with an exponential cutoff: $F(>E) \propto E^{-\gamma} \times exp(-E/E_{cutoff})$ with hard power indices of about $\gamma \sim 1.55$ for Mkn 421 and Mkn 501 and $\gamma \sim 0.6$ for 3c454.3 and 1739+522. The value of E_{cutoff} ranges from 11 ± 2 TeV for Mkn421, Mkn 501 to 7 ± 2 TeV for distant sources.

It has mentioned that the observed spectra are modified by gamma-ray attenuation, i.e. $F_{observed}(E) = F_{intrinsic}(E) \times exp(\tau(E,z))$ where $\tau(E,z)$ is optical depth for pair creation for a source at redshift z, and at an observed energy E. According to the definition of the optical opacity the medium influences the primary source spectrum at $\tau \geq 1$, but for $\tau < 1$ the medium is transparent, so measuring the source spectrum in both ranges of τ can give the intrinsic spectrum of the source to to constrain the EBL density. The optical depth for sources at redshifts from 0.031 to 1.375 was calculated assuming the EBL shapes shown in fig 4. We used the averaged EBL shape from the best-fit model and Low-SFR model [19] (see fig. 4 upper black curve) to calculate the attenuated spectrum of Mkn 421 assuming a simple power law intrinsic spectrum of the source with spectrum index of $\gamma = 1.5$, taken from the range of $\tau < 1$. The result is shown in fig. 5 by the thin line; the black squares are observational data for Mkn 421. The shapes of EBL density constrained from the spectra of the high redshift sources 3c454.3 (z=0.859) and 1739+522 (1.375) are shown in fig 4 with curves 2 for and 3, respectively. For these FSRQ sources the slope of intrinsic spectrum is taken $\gamma = 0.4$. The attenuated spectra for 3c454.3 and 1739+522 are also shown in fig. 5 (thin lines) together with observational data. Observations of distant metagalactic sources have shown that the Universe is more transparent to very high-energy gamma-rays than previously believed.

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