Extragalactic Background Light expected from photon-photon absorption on spectra of Active Galactic Nuclei at distances from $z=0.018$ to $z=1.375$

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Abstract. Extragalactic background radiation blocks the propagation of TeV gamma-ray over large distances by producing $e^+e^-$ pairs. As a result, primary spectrum of gamma-source is changed, depending on spectrum of background light. So, hard spectra of Active Galactic Nuclei with high red shifts allow the determination of a EBL spectrum. The redshifts of SHALON TeV gamma-ray sources range from 0.018 to 1.375 those spectra are resolved at the energies from 800 GeV to about 50 TeV. Spectral energy distribution of EBL constrained from observations of Mkn421, Mkn501, Mkn180, OJ287, 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 detection of the very high energy $\gamma$-ray sources at the redshifts $z=0.0179$ to $z=1.375$ with SHALON telescope gives an opportunity to constrain extragalactic background light (EBL) density, based on modification to gamma-ray spectra and thus it will help to reconstruct the the cosmological history of the EBL.

2. SHALON telescope
The $\gamma$-astronomical researches are carrying out with SHALON [1, 2, 3, 5, 6, 7, 8] mirror Cherenkov telescope at the Tien-Shan high-mountain observatory. The SHALON mirror telescopic system consists of composed mirror with area of $11.2 \, \text{m}^2$. It is equipped with 144 photomultipliers receiver with the pixel of 0.6° and the angular resolution of the experimental method of $< 0.1\degree$. It is essential that our telescope has a large matrix with full angle $> 8\degree$ 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.
An additional selection of electron-photon showers among the net cosmic rays EAS becomes possible through an analysis of a light image which, in general, emerging as an elliptic spot in light receiver matrix. The selection of gamma-initiated showers from the background of proton showers is performed by applying the following criteria:

- $\alpha < 20^\circ$;
- $\text{length/width} > 1.6$;
- the ratio $INT_0$ of Cherenkov light intensity in pixel with maximum pulse amplitude to the light intensity in the eight surrounding pixels exceeds $> 0.6$;
- the ratio $INT_1$ 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 $> 0.8$;
- $\text{distance}$ is less than 3.5 pixels.

Our analysis of the distributions of listed shower image parameters suggests that the background is rejected with 99.92% efficiency (see Refs. [2, 3, 5, 6, 7, 8]), whereas the amount of background showers to the selected gamma-showers does not exceed of 10%.

The $\gamma$-astronomical researches are carrying out with SHALON [1] mirror Cherenkov telescope since 1992. During the period 1992 - 2012 SHALON has been used for observations of extragalactic sources of different type. Among them are known BLLac-type sources Mkn 421, Mkn 501, Mkn 180; Seyfert Galaxy NGC 1275; Broad Line Radio Galaxy 3c 382; and Flat Spectrum Radio Qusars: 3c 454.3; 1739+522 (4c+51.37). Some representative results on fluxes, spectra are shown in Table 1 and also in [2, 3, 5, 6, 7], and Figures in these proceedings.

### 3. Extragalactic Background Light

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 for the study background light from UV to far infrared and even cosmic microwave background. TeV gamma-rays, radiated by distant sources, interact with photons of background via $\gamma + \gamma \rightarrow e^+e^-$ resonant process, then relativistic electrons can radiate gamma-ray with energies less than of primary gamma-quantum. As a result, primary spectrum of gamma-source is changed, depending on spectrum of background light. So, a hard spectra of AGNi with high red shifts of 0.03 - 1.8 allow the determination an absorption by EBL and thus its spectrum.

### Table 1. The catalogue of metagalactic $\gamma$-ray sources observed by SHALON

| Sources     | Observable flux$^a$ | $k_\gamma$ $^b$ | Distance $^c$ | $z$  | Type   |
|-------------|---------------------|-----------------|--------------|------|--------|
| NGC 1275    | (0.78 ± 0.05)       | -2.24 ± 0.09    | 71           | 0.018| Seyfert|
| SN2006 gy   | (3.71 ± 0.65)       | -3.13 ± 0.27    | 83           | 0.019| SN     |
| Mkn 421     | (0.63 ± 0.05)       | -1.87 ± 0.11    | 124          | 0.031| BL Lac |
| Mkn 501     | (0.86 ± 0.06)       | -1.87 ± 0.13    | 135          | 0.034| BL Lac |
| Mkn 180     | (0.65 ± 0.09)       | -2.16 ± 0.15    | 182          | 0.046| BL Lac |
| 3c382       | (0.95 ± 0.20)       | -1.08 ± 0.11    | 247          | 0.0578| BLRG   |
| OJ 287      | (0.26 ± 0.07)       | -1.43 ± 0.18    | 1070         | 0.306| BL Lac |
| 3c454.3     | (0.43 ± 0.07)       | -0.85 ± 0.07    | 5489         | 0.859| FSRQ   |
| 1739+522    | (0.49 ± 0.05)       | -0.93 ± 0.09    | 9913         | 1.375| FSRQ   |

$^a$ Integral flux at energy $> 800$ GeV in units of $10^{-12} \text{cm}^{-2} \text{s}^{-1}$

$^b$ Power index in case of power fit of observable data

$^c$ Distance in Mpc
**Figure 1.** Spectral energy distribution of EBL: measurements [9] and models [10, 11, 12, 13] and EBL shape constrained from observations of the extragalactic sources by SHALON: 1 - Mkn 421 (z=0.031), Mkn 501 (z=0.034); 2 - OJ287 (z=0.306); 3 - 3c454.3(z=0.859); 4 - 1739+522 (z=1.375)

**Figure 2.** The measured spectra for Mkn 421, Mkn 501, OJ287, 3c454.4 and 1739+522 (black points) together with spectra attenuated by EBL (lines, see text)
The redshifts of SHALON very high energy gamma-ray sources range from $z=0.018$ to $z=1.375$. Among them bright enough AGNi of BLLac type Mkn421, Mkn 501 and FSRQ type 3c454.3, 1739+522 (4c+51.37) those spectra are resolved in the TeV energy band from 800 GeV up to $\sim 20-50$ TeV. The fit of a simple power law function to the observational data presented in Table 1. Also, the measured spectra can be fitted by a power law with an exponential cutoff: $F(E) \propto E^{-\gamma} \times \exp(-E/E_{\text{cutoff}})$ 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 $E_{\text{cutoff}}$ ranges from $11 \pm 2$ TeV for Mkn 421, Mkn 501 and to $7 \pm 2$ TeV for distant sources.

It has mentioned that the observed spectra are modified by $\gamma$-ray attenuation, i.e. $F_{\text{observed}}(E) = F_{\text{intrinsic}}(E) \times \exp(-\tau(E, z))$ 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 on the primary source spectrum at $\tau \geq 1$, but for $\tau < 1$ the medium is transparent, so the measuring of source spectrum in the both range of $\tau$ can give the intrinsic spectrum of the source to constrain the EBL density. The optical depth for sources at redshifts from 0.031 to 1.375 was calculated with assumption of EBL shapes shown in Fig. 1. We used the EBL shape from Best-fit model and Low-SFR model [12] (see Fig. 1 thick black line 1 corresponds to Low-SFR model) to calculate the attenuated spectrum of Mkn 421 and Mkn 501 in assumption of simple power low intrinsic spectrum of the source with spectrum index of $\gamma = 1.5$, taken from the range of $\tau < 1$. The result is shown at Fig. 2 with line; the black squares are observational data for Mkn 421 and Mkn 501. The shapes of EBL density constrained from the spectra of high redshift sources OJ287 ($z=0.306$), 3c454.3 ($z=0.859$) and 1739+522 (1.375) are shown in Fig. 1 with curves 2, 3 and 4, respectively. For these sources the slope of intrinsic spectrum is taken $\gamma = 0.9-1.2$. The attenuated spectra for OJ287, 3c454.3 and 1739+522 are also presented at Fig. 2 (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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