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# Gamma-ray probe of the dense QSO environment ⋆

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**Abstract.** We report the very first detection of $\gamma$-ray resonant absorption along the line of sight toward $\gamma$-ray bright quasars (QSOs), like 3C273, 3C279, PKS0528+0134 and BL Lacertae. These detections resulted from the analysis of COMPTEL and EGRET data that were collected during monitoring campaigns of the Virgo and galactic anticenter regions by the Compton Gamma Ray Observatory (CGRO), or during ToO observations of QSOs flares. At least two absorbers are detected on the sight lines towards $\gamma$-ray bright QSOs, one at the QSO rest frame redshift, and another at the redshift that has an ≈0 value. The latter we tentatively identify with the absorber in the galactic halo, while the former is undoubtedly caused by the photon absorption in the host galaxy of the QSO.

**Key words.** Spectral energy distribution – QSO – Gamma-ray absorption

## 1. Introduction

The detection absorption lines in the spectral energy distribution (SED) of the bright QSOs is the most useful tool to study the intervening matter between the QSO and the observer. The $\gamma$-ray absorption is potentially sensitive to higher column densities than those accessible for the longer wavelengths, like Opt, UV, or X-rays, and can be used to study the heavily absorbed systems.

It is known that both high-energy attenuation processes, Compton scattering and pair production, have a rather smooth functional dependence of the cross section on the photon energy at the photon energies above ≈100 keV (Hubbell 1971).

It is also known that the total absorption cross-section of photons by nuclei have at least three resonant-like peaks in the cross section, namely at energies of ∼7 MeV ("pygmy" dipole resonance (PDR)), 20-30 MeV (giant dipole resonance (GDR)), and ∼325 MeV (Δ-resonance) (Ahrens 1985). The best studied of these three processes are GDR, and Δ-isobar resonance (Ahrens 1985).

The resonant photo-absorption processes on nuclei contribute to the total photon atten-

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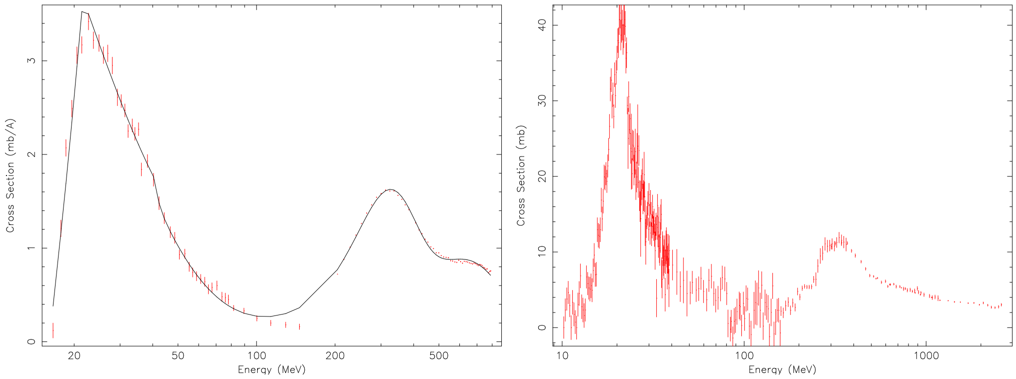


**Fig. 1.** Left: Gamma-ray absorption cross section on the $^4$He (MacCormick et al. 1997). Right: the absorption cross section on the $^{27}$Al (Ahrens et al. 1975; Bianchi et al. 1996; Muccifora et al. 1999) in the regions of GDR, and of Δ resonance.

uation varies from 2% to 9% for the GDR, depending on the nuclei mass number and nuclear structure (Hubbell 1971). We note that the Δ-resonance cross section peaks at the same photon energy of $E_{\gamma 0}$==327±5 MeV for all nuclei (Ahrens 1985).

## 2. Instruments and analysis technique

Our results are based on the data acquired by COMPTEL and EGRET gamma-ray telescopes on-board CGRO.

COMPTEL was the first generation $\gamma$-ray imaging telescope operating in the 0.75 to 30.0 MeV energy range with a field-of-view (FoV) of about 1 steradian, a source location accuracy of $\sim 1^o$, and an energy resolution of 5-10% FWHM. A detailed description of the instrument and COMPTEL data analysis in the 3-dimensional data space is given by Schönfelder et al. (1993).

We analysed COMPTEL data using the maximum-likelihood method (SRCFIX), that evolved from the work on diffuse emission modeling (van Dijk 1996). The display of the maximum-likelihood ratios over the FoV is referred to as the maximum-likelihood (ML) map. Such maps allow the determination of the excess significance, flux, error region, etc., as well as to produce SED of QSOs in the COMPTEL energy range.

EGRET was the high-energy $\gamma$-ray telescope on-board of CGRO. It covers $\gamma$-ray energies from about 20 MeV to over 20 GeV, with a broad maximum of the effective area of 1500 cm$^2$ in the range 500 MeV to 1 GeV. Description and capabilities of the instrument are given by Thompson et al. (1993a).

The detection of QSO by EGRET is also based on the maximum likelihood analysis of the observed region (Mattox et al. 1996). To determine the background-subtracted $\gamma$-ray spectrum of the source of interest, the EGRET energy band of 30 MeV -10 GeV was divided into 10 bins.

*Analysis of SEDs*

The analysis of the QSO $\gamma$-ray spectra usually performed assuming that the spectrum emitted by the astrophysical object smooth, even if the change of the power-law slopes in different energy bands can be observed. In reality, the photon flux from AGN is a function of the photon energy and of redshift: $\frac{dN}{dE} = (\frac{dN}{dE})_{unabsorbed} \cdot e^{-\tau(E,z)}$ .

The dependence of $\tau$ on $E$ and $z$ is quite complex. To first order we assume that we have a SED modified by absorbers at two redshifts, one in the QSO host galaxy, and second absorber in Milky Way.

In a first step of a SED analysis, we fit a smooth function to the spectrum, which we choose to be the so-called "Band"-function

(Band et al. 1993), which describes not only power-law spectra, but also spectra with a break. In the second fit we use the sum of the "Band"-function and a gaussian as a fit function. Which means, that we add another three free parameters to the fit. From this fit we derive the value of $\chi^2_{band+gauss}$ as a quality descriptor of the SED fitting by the more complex model.

The significance of the fit improvement was evaluated using the probability for the spurious improvement of the fit based on the value of $\Delta\chi^2$=$\chi^2_{band}$-$\chi^2_{band+gauss}$ for 3 d.o.f. as a test for such an improvement (see Freeman et al. (1999)).

*3C279*

Below we report results derived with the use of subtractive profiles for 3C279. Results for the larger sample of $\gamma$-ray bright QSOs are presented in the paper by Iyudin et al. (2004). Figure 3 presents 3C279 time-averaged spectrum, measured by COMPTEL and EGRET, with the GDR and $\Delta$-resonance absorption fit, as well as the January 1996 3C279 flare SED. We notice that all spectra of 3C279, time-averaged (Fig. 2), or flare spectra (Fig. 2 (right)) show notable absorption features. Note that SED of January 1996 3C279 flare does not show a prominent GDR absorption trough because three low energy bins of EGRET, namely 30-50 MeV, 50-70 MeV and 70-100 MeV, were combined into one energy bin of 30-100 MeV in this particular case (Fig. 2).

The improvement of the fit to SEDs of 3C279 of Jan. 1996 flare has the value of $\Delta\chi^2$=17.3, which corresponds to the probability of the spurious fit improvement of $P_{spurious}$=7×10$^{-4}$. For other SEDs of 3C279 the value of $P_{spurious}$ is much smaller. The ratio of the peak value of the depression in the continuum due to the $\Delta$- or giant dipole resonance absorption, to the continuum fit above the trough can be used to estimate the column density of the absorber in the QSO environment, or locally in the galactic halo.

From the fitted $\Delta$-resonance troughs of 3C279 we derived the weighted mean energy of the $\Delta$-resonance trough in the observer coordinate system as $E_\Delta^{measured}$=203.5±3.5 MeV. By using known redshift of 3C279 we recalculated the energy of trough to the QSO rest frame as $E_\Delta^{restframe}$=313±10 MeV. Which is close to the expected value of the peak position in the absorption cross section of the $\Delta$-isobar resonance, and therefore supports our interpretation of the trough as an absorption in the QSO host galaxy. The time-averaged SED of 3C279, clearly show another trough at the energy of ~25 MeV, that correspond to the peak position of the giant dipole resonance (GDR) with the trough strength that is dependent on the use of the EGRET flux correction coefficients. For 3C279 SEDs this low energy trough does not dissappear even if the usual EGRET flux corrections are applied (Fig. 2, left). We suggest that this lower energy trough in SED of 3C279 was produced via the GDR type absorption at the redshift z≈0. Indeed, the calculated weighted mean value of the GDR related trough positions derived from SEDs of 3C279, 3C273, PKS0528+0134, PKS1622-297 has a value of $<E>_{GDR}$=25.1±2.5 MeV, and is consistent with the position of GDR absorption on $^4$He (Fig. 1).

*Absorbing columns in AGNs*

For the extinction values of $A_V$>500, or equivalently at $N_H$>10$^{25}$ cm$^{-2}$ the AGN nucleus is hidden from the direct view even for 10 keV X-ray photons. Such opaque matter is optically thick to Compton scattering, and the central source is only detectable via scattering of X-ray photons by material out of the line of sight. In such cases only $\gamma$-rays can probe the column density towards the central engine.

From the ratio of the typical absorption cross sections in the $\gamma$-ray and X-ray regimes follows that $\gamma$-rays will deliver information on the column densities of the order of $\sigma_\Delta{}^{-1}$, for the $\Delta$-resonance trough, or of the order of $\sigma_{GDR}{}^{-1}$, for the giant dipole resonance absorption, while in the X-ray regime a Thompson cross section, $\sigma_T$ defines an absorption. To quantify these ratios we use values of $\sigma_T$~0.7 barn, $\sigma_\Delta$~0.5 mb, and $\sigma_{GDR}$~3.6 mb. Clearly we can probe the optical depth of the QSO environment up to $N_H$ values of ~10$^{26}$ cm$^{-2}$ via the resonant $\gamma$-absorption, while in X-ray regime we are limited to column densities of the order of ≤10$^{25}$ cm$^{-2}$.

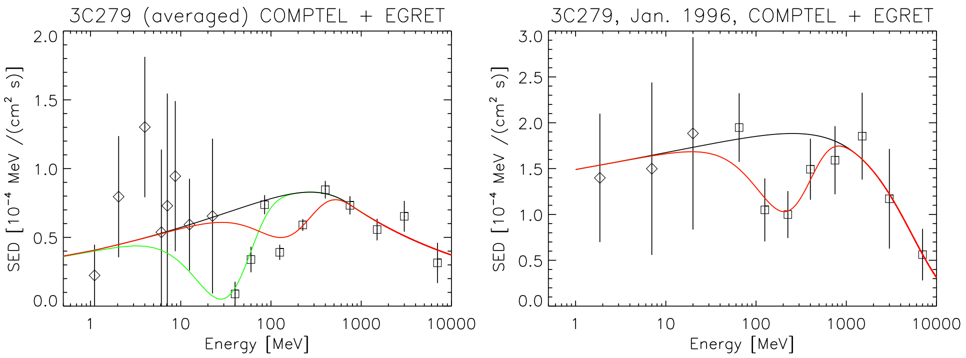


**Fig. 2.** Left: A fit to the 3C279 time-averaged spectral energy distribution measured during CGRO Phases I-IV (1991-1997), that includes the Δ resonance photon absorption in the QSO environment (red line) and the GDR resonance photon absorption in the local galactic environment (galactic halo) shown by blue line. Green line shows "Band"-function fit to the SED. Right: A fit to the 3C279 power spectrum measured during the flare of January 1996, that includes the Δ resonance photon absorption (red line) in the QSO circumnuclear environment. Green line shows "Band"-function fit to the flare SED.

In contrast to the X-ray or UV-absorption studies where the ionization state of the absorber is very important in the derivation of the absorbing column, the $\gamma$-ray absorption method is completely independent of the ionization, or of the chemical state of the absorber, and capable to derive the metallicity of absorber.

A monitoring of the $\gamma$-ray bright QSOs bright can be used to perform a survey of the baryonic matter distribution in Milky Way, as well as in the QSO host galaxies. Such survey can be extended to quite high redshifts by observations with GLAST.

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