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PKS 0208-512 detected at MeV energies by COMPTEL: A new "MeV-Blazar" candidate

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Abstract. We report evidence for intense MeV emission of the blazar-type AGN PKS 0208-512 from two COMPTEL observations in May-June 1993. No significant indication was seen during a series of earlier observations performed in the second half of 1991. EGRET detected high-energy γ-rays during both periods, with similar average fluxes in both (and a short flare in September 1991). We argue that the MeV emission from PKS 0208-512 seems to represent a distinct spectral component, characterized by either a bumped shape or strong time variability, or possibly both. This might be a valuable clue in our understanding of "MeV Blazars" (i.e. blazars that are exceptionally bright at MeV energies), suggesting a possibly transient nature of the MeV-blazar phenomenon. As a consequence, essentially all γ-ray blazars might contribute to the MeV bump in the diffuse cosmic background radiation during certain epochs rather than any specific sub-class.

Key words: gamma rays: observations – galaxies: active – galaxies: quasars: individual: PKS 0208-512–galaxies: general

1. Introduction

The COMPTEL instrument aboard the Compton Gamma Ray Observatory (CGRO) is an imaging γ-ray telescope capable of detecting photons with energies between about 0.75 MeV and 30 MeV. This energy range has turned out to be of particular interest for the study of blazars. These are active galactic nuclei (AGNs) that show intense core-dominated radio emission with flat spectra ($\alpha \lesssim 0.5$ between 2.7 and 5 GHz, with flux density $F \sim \nu^{-\alpha}$), rapid optical variability, and strong optical polarisation (e.g. Dermer & Schlickeiser 1992). Superluminal motion has been observed for a number of blazars, lending support to the generally accepted idea that this type of AGNs emits beamed radiation at small angles to the line of sight.

About 35 blazars have been detected at high γ-ray energies ($\gtrsim 100$ MeV) by the EGRET telescope, coaligned with COMPTEL on board CGRO (Fichtel et al. 1994; von Montigny et al. 1995). For a subset (~ 17) spectra have been derived, which can each be fitted by a single power-law ($S \sim E^{\alpha_\gamma}$) with a spectral index ranging from $\alpha_\gamma = -1.5$ to $\alpha_\gamma = -2.6$ (Fichtel et al. 1994). Several blazars have been seen by COMPTEL at lower MeV energies (Bloemen et al. 1995; Blom et al. 1995; Collmar et al. 1995; Hermsen et al. 1993; Williams et al. 1995a). These COMPTEL detections indicate breaks (and possibly bumps) in the power-law spectra at MeV energies, as discussed in Section 4.

In this paper the COMPTEL observations of PKS 0208-512 ($z = 1.003$) are presented. This AGN is a flat-spectrum, radio-loud quasar with $\alpha_{2.7GHz-5GHz} = 0.17$ (e.g. Véron-Cetty & Véron 1991). The radio emission of PKS 0208-512 is compact, core dominated and exhibits variability on timescales of years (Preston et al. 1989). According to Impey & Tapia (1988), PKS 0208-512 is a high-polarisation quasar with a linear optical polarisation of 11.5%. At soft X-ray energies (0.1–2.4 keV) ROSAT has detected PKS 0208-512 during its all-sky survey (Brinkmann et al. 1994).

The EGRET telescope has observed PKS 0208-512 above 30 MeV on 6 occasions during the CGRO observing Phases I and II (Bertsch et al. 1993; Michelson et al. 1994). For the interpretation of the results presented in this paper, it is important to note that the average flux measured by EGRET during the Phase I observations (second half of 1991) was similar to the average flux during the Phase II observations (May-June 1993), although a distinct flux increase was observed during a short period in September 1991.

2. Instrument and Data Analysis

COMPTEL is designed to detect γ-ray photons with energies between about 0.75 and 30 MeV with an energy resolution better than 10% FWHM. It has a FOV of ~ 1 steradian, which enables the instrument to monitor several objects simultaneously. The location accuracy is about 0°.5 for a strong source. A detailed description of the detection principle and instrument is given by Schönfelder et al. (1993). Ideally, incoming γ-ray photons are first Compton scattered in an upper detector layer and then completely absorbed in a lower detector layer. The

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Table 1. COMPTEL observations of PKS 0208-512 (observation numbers in CGRO notation). The angular distance refers to the angle between the instrument pointing direction and the source location.

CGRO Viewing Period		Date start	Date end	Pointing direction $l(°)$	$b(°)$	Angular distance (°) to PKS 0208-512	Flux in 1–3 MeV (10^{-4} ph cm^{-2} s^{-1})
Phase I	6.0	Jul 27 '91	Aug 08 '91	278.0	−29.3	32.6	2.1 ± 0.9
	9.0	Sep 05 '91	Sep 12 '91	338.6	−83.6	25.7	< 2.6
	10.0	Sep 19 '91	Oct 03 '91	287.8	−54.3	9.7	< 1.5
	13.5	Nov 07 '91	Nov 14 '91	338.8	−83.6	25.7	< 1.8
	17.0	Dec 27 '91	Jan 10 '92	283.2	−31.6	30.6	< 2.3
Phase II	220.0	May 08 '93	May 13 '93	298.1	−44.6	21.5	3.5 ± 1.2
	224.0	Jun 03 '93	Jun 14 '93	298.1	−44.6	21.5	4.4 ± 0.9

Table 2. COMPTEL flux measurements for the combined Phase II data (viewing periods 220+224) as plotted in Figure 2.

Standard energy interval	Flux or 2σ upper limit (10^{-4} ph cm^{-2} s^{-1})
0.75–1 MeV	< 1.2
1–3 MeV	4.1 ± 0.7
3–10 MeV	< 0.7
10–30 MeV	< 0.3

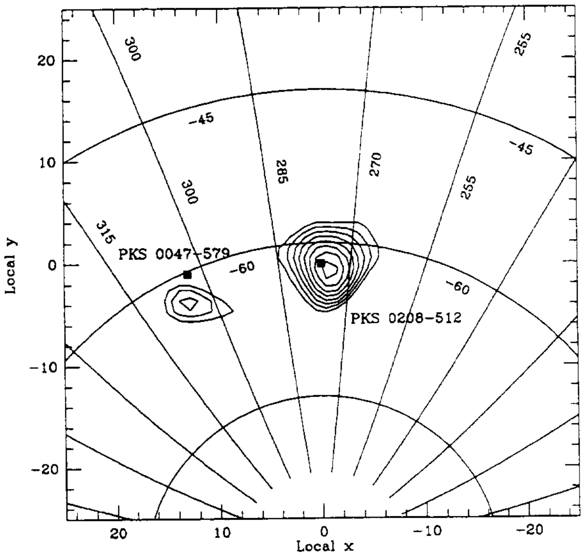

Fig. 1. Maximum-likelihood ratio map (1–3 MeV) of observations 220 and 224. The contour levels start at $-2\ln\lambda = 20$, with steps of 3. The filled squares mark the positions of the blazars. An (l,b) grid is superimposed. See text for details.

measured energy deposits and locations in these layers determine the scatter direction, scatter angle, and total energy of each photon. The telescope events are binned in a 1° × 1° × 2° 3D data space, which consists of two scatter direction coordinates and a Compton scatter angle coordinate. The source response function of the instrument in this 3D data space has a cone-like shape and depends on the actual source spectrum. In the present work we have adopted an E^{-2} power-law input spectrum, although our findings are not sensitive to this specific choice.

Skymaps are generated by applying a maximum-likelihood method (de Boer et al. 1992), which provides flux estimates and statistical significances of sources that may be present. A quantity $-2\ln\lambda$ is defined, where λ is the ratio of the likelihood L_{max}(background) and the likelihood L_{max}(source+background). This quantity follows a χ^2 distribution with 1 degree of freedom for known source locations. Confidence regions of the source locations can be derived from the likelihood maps as well. In this case a χ^2_2 distribution should formally be used; the 99% and 95% confidence contours can then be drawn at $-2\ln\lambda$ values of respectively 9.2 and 6.0 below the local peak value.

On average, more than 95% of the number of events tagged by the instrument as Compton-scattered γ-rays should be attributed to the background (instrumental and isotropic). The likelihood analysis requires a careful estimate of this background for which a variety of methods has been studied. The results shown in this paper are based on a method of background determination in which a running-average filter technique is applied to the 3D data space. This method is described by Bloemen et al. (1994), although we applied here an improved algorithm. The filter smooths the distribution of measured events and eliminates (to first order) any source signature present. A corresponding modification of the instrument response function accounts for this filtering in the subsequent likelihood analysis.

3. Observations and results

The observation programme of the Compton Observatory consists of four phases (see e.g. Gehrels et al. 1994). This work uses observations from Phases I and II, during which PKS 0208-512 was 7 times in the FOV of COMPTEL (see Table 1).

3.1. *Phase I observations*

We have generated maximum-likelihood ratio maps in four standard energy intervals (0.75–1 MeV, 1–3 MeV, 3–10 MeV, and 10–30 MeV) for the combined Phase I observations (all obtained in the second half of 1991). None of these maps shows evidence for emission from PKS 0208-512. The maps created for the *individual* Phase I observations yield a 2.8σ hint (for a single trial) in the 1–3 MeV energy range from viewing period 6.

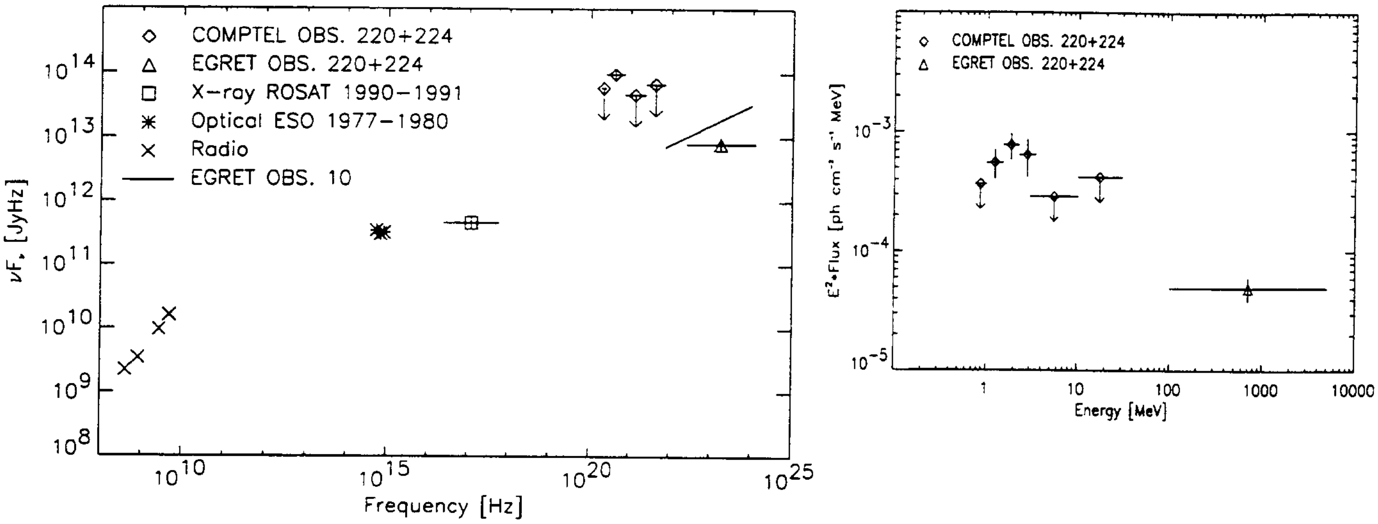

Fig. 2. *Left:* Spectrum of the radiated power per decade of energy for PKS 0208-512, showing the COMPTEL and EGRET results derived from a combination of observations 220 and 224 (May-June 1993), together with a compilation of observations at other frequencies. COMPTEL observations are indicated by 2σ upper limits and by a flux with a $\pm 1\sigma$ error bar; explicit values are given in Table 2. The observations at lower frequencies were not obtained simultaneously. The radio data were taken from Brinkmann et al. (1994), Campbell-Wilson et al. (1994), Mavrides & Mutus (1984) and Véron-Cetty & Véron (1991), the optical data from Adam (1984) and the ROSAT X-ray flux from Brinkmann et al. (1994). The EGRET spectrum obtained in September 1991 (observation 10) is shown for comparison. ***Right:*** Blow-up of the simultaneous COMPTEL and EGRET measurements. Instead of the flux value in the 1–3 MeV range, flux estimates of three sub-intervals (1–1.5, 1.5–2.25 and 2.25–3.4 MeV) are shown.

By contrast, EGRET has detected PKS 0208-512 during all viewing periods of Phase I except for observation 6 (Bertsch et al. 1993). An extrapolation to lower energies of the relatively hard EGRET power-law spectrum ($\alpha_\gamma = -1.7 \pm 0.1$) of PKS 0208-512 (available for viewing period 10 only) is consistent with our non-detections. This extrapolation predicts a flux at medium γ-ray energies which is far below the sensitivity limit of COMPTEL.

3.2. Phase II observations

The combined Phase II data (obtained in May-June 1993) show clear evidence for emission ($\sim 6\sigma$) from PKS 0208-512 in the 1–3 MeV range (see Figure 1 and Table 2). This source significance is calculated again for a single trial (we searched specifically for PKS 0208-512) and remains a significant detection if we take into account that we examined four energy intervals for both Phases I and II. Nothing is seen in the maps for the other three standard energy intervals. The individual Phase II observations, 220 and 224, both show evidence for PKS 0208-512 in the 1–3 MeV range, at 3.2σ and 5.5σ respectively, in spite of a rather low exposure during observation 220 (see Table 1). EGRET detected PKS 0208-512 in both viewing periods of Phase II, however with lower significance than during Phase I (Michelson et al. 1994).

Fig. 1 also shows a second (4.6σ) source feature (at $l \approx 305°$, $b \approx -63°$) near the radio loud quasar PKS 0047-579, although it is located outside the 99% confidence contour. A catalogue search did not yield any other candidate counterpart. The significance drops to $\lesssim 3\sigma$, if we properly consider all trials (i.e. number of independent source locations in the map and energy intervals). Interestingly, hints for this second source are seen in the likelihood maps of both Phase II observations, but further confirmation is needed.

3.3. Spectral results

From our Phase II observations, flux values were derived for each standard energy band by simultaneously fitting two source models in the likelihood analysis; one for PKS 0208-512 and a second model for the unidentified source. Figure 2 presents the fit results for PKS 0208-512 in a flux spectrum that is multiplied by E^2, i.e., the quantity shown is the radiated power per decade of energy.

The spectrum of PKS 0208-512 shows a pronounced maximum in the 1–3 MeV energy interval, comparing our results with the flux measured simultaneously by EGRET and the flux estimates at lower frequencies (although those were not obtained simultaneously). An extrapolation of the hard EGRET power-law spectrum derived from observation 10 is clearly well below the COMPTEL flux estimate.

4. Discussion and conclusions

Although no spectral information on the EGRET observations during Phase II is available yet, the spectral characteristics of PKS 0208-512 implied by the findings above are already remarkable. There are two possible scenarios:

- First, if the hard power-law spectrum observed by EGRET (>30 MeV) during observation 10 (September 1991) can be extrapolated to the few-MeV regime, then PKS 0208-512 must have brightened at MeV energies by at least an order of magnitude between September 1991 and May-June 1993, whereas the integrated flux in the 100-MeV regime is unchanged within a factor of two.
- Second, if the time variability is less severe (i.e. in case the MeV flux in September 1991 was not far below the upper limit given in Table 1), then the spectrum of PKS 0208-512 shows a distinct bump in the MeV range also during the September 1991 observation.

In conclusion, one way or another, both scenarios imply that the MeV emission from PKS 0208-512 represents a distinct spectral component, characterized by either a bumped shape or strong time variability, or possibly both.

A spectral analysis of the EGRET observations obtained in May-June 1993 is potentially of great value for the interpretation of the γ-ray emission from PKS 0208-512 (and other blazars). In this respect it is important to realize that COMPTEL is finding increasing evidence for sources at high Galactic latitudes that can be associated with EGRET blazar detections which are marginal or have no EGRET counterpart at all (Bloemen et al. 1995; Williams et al. 1995b). Until recently, the reported COMPTEL blazar detections could all be expected on the basis of a simple extrapolation of the EGRET power-law spectra. The existence of a class of blazars exceptionally bright at MeV energies (dubbed "MeV blazars" by Bloemen et al.) can have important implications. Particularly, the indication for a distinct variable MeV component may be a valuable clue in our understanding of the link between the "classical" blazar γ-ray sources and MeV blazars. Our findings indicate that γ-ray blazars might be only temporarily in a MeV-blazar phase.

Several models have been proposed that attribute the γ-ray emission from blazars to inverse-Compton scattering of low-energy photons (Dermer & Schlickeiser 1993; Blandford 1993; Sikora, Begelman & Rees 1994; Baring 1994). Although characteristics like a MeV spectral break and time variability can generally be understood in the framework of these models, neither of the two observational scenarios given above is a priori expected. The second scenario (involving a MeV bump) sets the strongest constraint if indeed applicable: any spectral upturn from the 100-MeV regime into the few-MeV regime is not a feature of inverse-Compton models. The first scenario (strong MeV variability not accompanied by a significant flux change at higher energies) might be explained by detailed geometry considerations, such as varying contributions from emission regions at different distances from the central engine and small changes in the orientation of the jet.

Alternative models that have been proposed are the proton-initiated cascade model of Mannheim & Biermann (1992) and the $e^{\pm}$ annihilation models of Henri, Pelletier & Roland (1993) and Böttcher & Schlickeiser (1995) (all in addition to inverse-Compton emission). Only the latter models predict a distinct spectral bump due to a broad blue shifted $e^{\pm}$ annihilation line that is Doppler boosted in a relativistic beam. Roland & Hermsen (1995) and Böttcher & Schlickeiser (1995) have discussed the observations of the MeV-blazar GRO J0516-609 (Bloemen et al. 1995) in the framework of these models.

The γ-ray emission from blazars may play an important role in our understanding of the diffuse cosmic γ-ray background. Padovani et al. (1993) and Salamon & Stecker (1994) have already shown that blazars may be responsible for at least a substantial fraction of the diffuse background in the 100-MeV regime. The break in blazar spectra at MeV energies approximately coincides with the well known MeV bump in the diffuse background radiation. MeV blazars would be particularly good candidates for this bump (Bloemen et al. 1995). Since our findings for PKS 0208-512 suggest a temporal nature of the MeV-blazar phenomenon, it cannot be excluded that essentially all γ-ray blazars contribute during certain epochs rather than any specific sub-class.

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