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COMPTEL observation of the flaring quasar PKS0528+134

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Abstract. With a direct demodulation method, we have reanalyzed the data from the COMPTEL observation of PKS0528+134 during the 1993 March flare in γ-rays. Our results show that during the flare γ-rays were detected at a level approximately 2.4-3.8 times higher than the observed intensity in two earlier COMPTEL observations VP 0 and VP 1 in the energy range 3 MeV to 30 MeV. The 3-30 MeV time variability of the flux follows well the trend as observed by EGRET at higher energies. No convincing excess can be found around the position of PKS0528+134 in the energy range 0.75 MeV to 3 MeV, which indicates a spectral break around 3 MeV. The detections and non-detections in the four standard COMPTEL energy bands are consistent with the earlier reports given by Collmar et al., while the feature that γ-rays of the quasar still kept on flaring at energies down to 3 MeV is clearly found.

Key words: galaxies: active – gamma rays: observations – quasars: individual: PKS0528+134

1. Introduction

The quasar PKS0528+134 was first detected at γ-ray energies by EGRET aboard the Compton Gamma-Ray Observatory (CGRO)(Hunter et al. 1993). Before this, it had been known as a bright radio source with a flat radio spectrum, a optical source with a mean brightness of m_v=20 and little polarization (Fugmann & Meisenheimer 1988) and also an X-ray source (Bregman et al. 1985). It has a redshift of z=2.07 (Hunter at al. 1993) and, along with the strong γ-ray sources Crab and Geminga, is located near the Galactic anticenter. Following the detection of PKS0528+134 by EGRET, the COMPTEL data were analyzed and PKS0528+134 was discovered at soft γ-rays (0.75-30 MeV) by Collmar et al. (1993a). Collmar et al. (1993b) also reported the preliminary result from COMPTEL viewing periods 0 and 1 that spectral breaks were found at energies around 10 MeV when comparing with the spectra detected by EGRET. PKS0528+134 was seen to flare during viewing period (VP) 213 by EGRET and γ-rays ($\geq$ 100 MeV) were detected at a level approximately three times higher than the observed intensity in earlier observations VP 0 and VP 1 (Mukherjee et al. 1996). The quasar was also detected by EGRET in its 'low' states during the other observations include viewing periods 2.1, 36.0 , 36.5, 39, 221, 310, 321, and 337 (Nolan et al. 1993). Comparisons of the results from COMPTEL VP 213 with those from EGRET were carried out by Collmar et al. (1997) in their analyses of PKS0528+134 using the first 3.5 yr of COMPTEL observational data (VP 0 to VP 337). They subdivided the data into two parts according to the luminosity of the source: viewing periods 0, 1 and 213 as high states, and all the other observations as low states. They found that during the low states the combined spectra can be fitted by a single power-law representation, while a spectral break at energies around 10 MeV exists for the combined spectra of the high states. However, their results for the flux show that PKS0528+134 had high luminosity in the 3-10 MeV band and, at the upper COMPTEL energy band (10-30 MeV), the quasar only had normal luminosity during VP 213. This feature is odd and stimulates us to reanalyze the flaring quasar.

Considering the poor statistics of the data from COMPTEL VP 213 which covered only 6 days, we adopt the direct demodulation method which owns the capability of reconstructing objects from incomplete and noisy data to make a spatial analysis upon the flaring quasar. We introduce the instrument and the analysis method in Sect. 2 and give our results in Sect. 3. The results show clearly the detection of PKS0528+134 in the energy range 3 MeV to 30 MeV. We also compare the intensity ratios and the light curves with those derived from EGRET and give our flaring spectrum. In Sect. 4, we give a discussion and draw the conclusion that the quasar kept on flaring in the energy range 3 MeV to 30 MeV during COMPTEL VP 213.

2. Instrument and analysis method

COMPTEL is one of the four instruments aboard CGRO and is sensitive to γ-rays in the energy range 0.75 MeV to 30 MeV. COMPTEL consists of two detector arrays. An incident γ-ray photon is first Compton scattered in the upper detector and then interacts with the lower detector. Two orthogonal coordinates (χ,ψ) which describe the direction of the scattered γ-ray can be obtained from the positions of interaction occurring in the two detectors and the Compton scattering angle $\bar{\varphi}$ in the upper detector can be calculated from the measured energy deposits of the photon in the two detectors. The incident direction of the photon is then known to lie on a projected circle (with its center

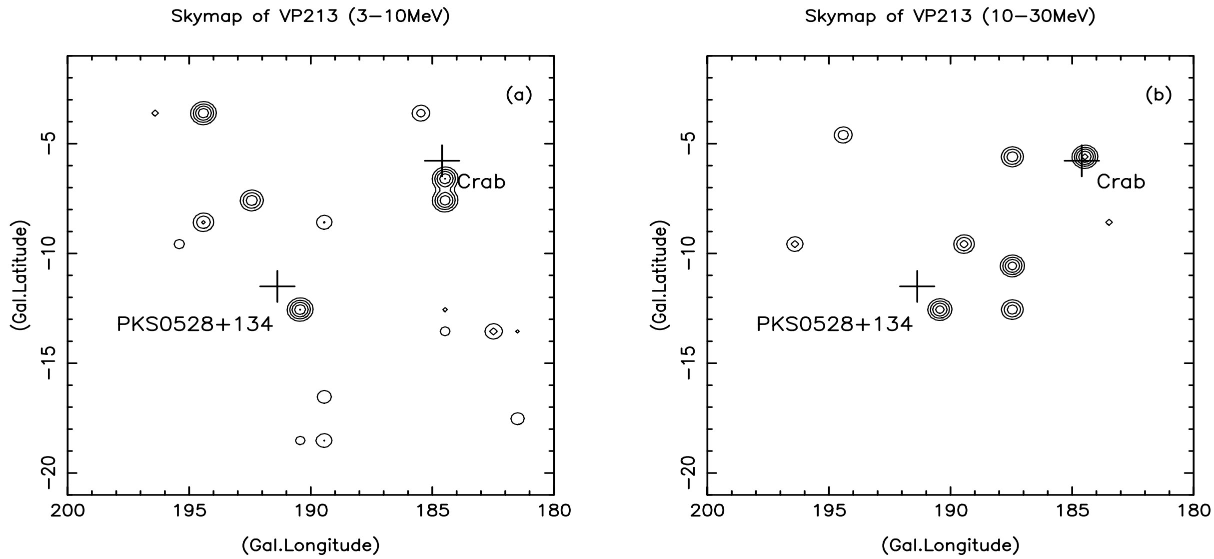

Fig. 1. a The direct demodulation map of VP 213 in the 3-10 MeV band. **b** The direct demodulation map of VP 213 in the 10-30 MeV band. Apart from Crab and PKS0528+134, the other source features emerged in these two maps are generally insignificant and most of their statistical significances are below 2σ.

Table 1. Fluxes of PKS0528+134 measured by COMPTEL and EGRET in three high states.

VP	EGRET	COMPTEL	
	$\geq$ 100 MeV	10-30 MeV	3-10 MeV
	($\times 10^{-7}$ph/cm^{-2}s^{-1})	($\times 10^{-5}$ph/cm^{-2}s^{-1})	($\times 10^{-5}$ph/cm^{-2}s^{-1})
0	12.9±0.9	3.2±1.0	4.4±2.5
1	8.5±0.8	3.0±1.0	$\leq$ 7.2
213	30.8±3.5	7.71±3.03*	16.60±5.95*

at (χ,ψ) and with radius $\bar{\varphi}$, called 'event circle') on the sky for the ideal case of total absorption in the lower detector. The scattering direction (χ,ψ) and the Compton scattering angle $\bar{\varphi}$ constitute a three-dimensional data space in which the spatial response of the instrument is cone-shaped. For the details about COMPTEL see Schönfelder et al. (1993).

Inversion methods are needed for source reconstruction in three-dimensional data space and a direct demodulation method is chosen by us. The direct demodulation method has already been successfully applied to imaging analysis of scan observation data of slat collimator telescopes, e.g. the scan imaging of CygX-1 by the balloon-borne hard X-ray collimated telescope HAPI-4 (Lu Z.G. et al. 1995) and reanalyzing the EXOSAT-ME galactic plane survey (Lu F.J. et al. 1996). It can also be applied to analyze observational data from a coded-mask aperture telescope (Li 1995), rotating modulation telescope (Chen et al. 1998) and Compton telescope (Zhang et al. 1997).

The principle of direct demodulation (Li & Wu 1994) is to perform a deconvolution from the following correlation equation under proper physical constraints:

$$P'f = c \tag{1}$$

where $P' = P^T P$, $c = P^T d$, P is the point spread function matrix of COMPTEL and P^T its transpose, d is the observational data and f the intensity distribution of the unknown sky and background. The physical constraints can be the upper and lower limits of intensity. The process of direct demodulation consists of two main steps. The diffuse background is derived first by iteratively solving the correlation equation under constraints of continuity. Then, the intensity distribution of the object sky is obtained by solving the correlation equation again under constraints of the produced diffuse background as a lower limit. After subtracting the diffuse background, the true intensity distribution of the sources in the object sky and the non-uniform component of the background are left. In this work iteration calculations are carried out by using the Gauss-Seidel algorithm and error estimates derived by the bootstrap technique.

3. Results

From the beginning of the all-sky survey of COMPTEL PKS0528+134 has been in the field of view several times. During observation VP 213 (March 23 – 29, 1993) the source was located about 9.0° off the COMPTEL pointing direction. With the direct demodulation method, we have analyzed the data from VP 213 in the four standard COMPTEL energy bands.

Images of PKS0528+134 were obtained only in the 3-10 MeV and 10-30 MeV bands (see Fig. 1a and Fig. 1b). In the 0.75-1 MeV and 1-3 MeV bands, no convincing excess around the position of PKS0528+134 was found. Fig. 1a and

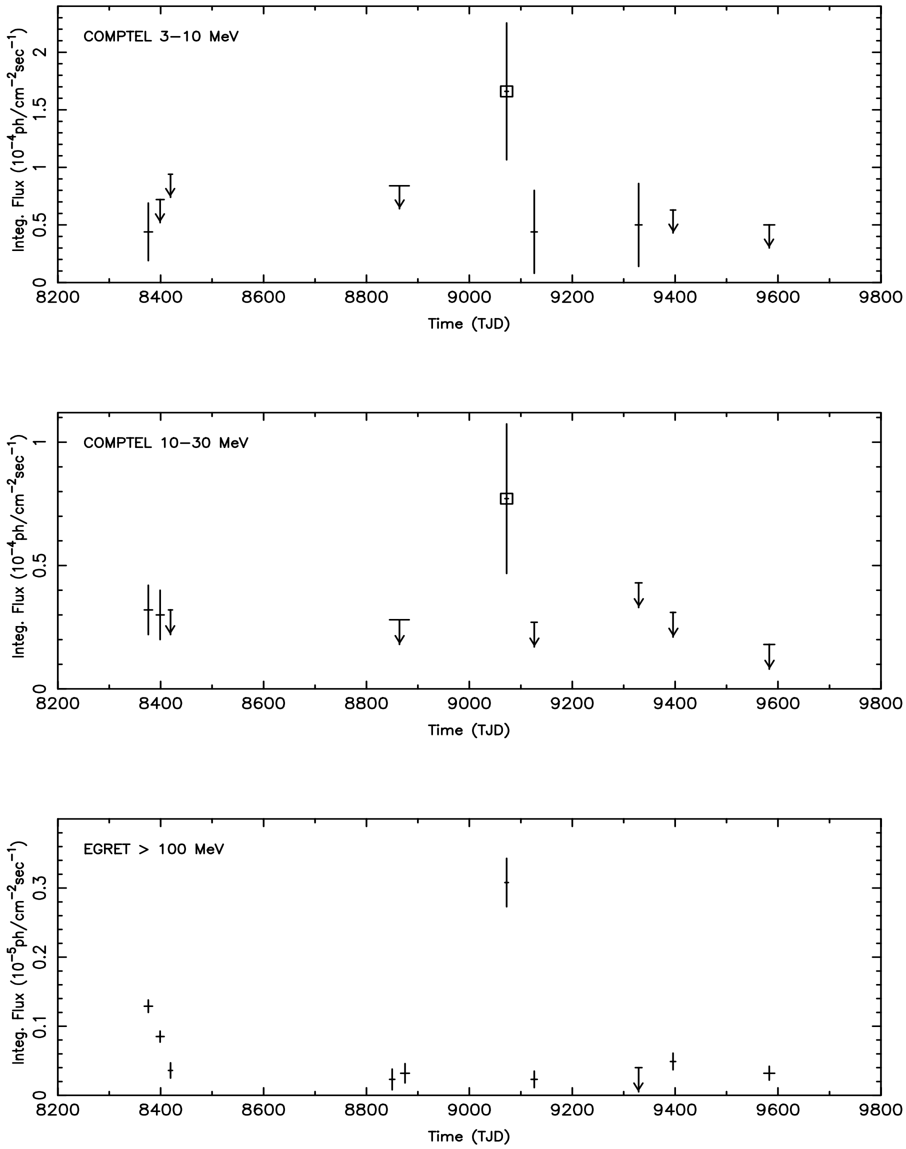

Fig. 2. Time history of PKS0528+134 as measured by COMPTEL in the 3-10 MeV and 10-30 MeV bands and by EGRET above 100 MeV (Mukherjee et al. 1996). Data points with square symbol are our results and all other COMPTEL data points are from Collmar et al. (1997). The error bars are 1σ and the upper limits are 2σ.

Table 2. Intensity ratios of PKS0528+134 measured by COMPTEL and EGRET.

Intensity ratio	EGRET	COMPTEL	
	$\geq$ 100 MeV	10-30 MeV	3-10 MeV
VP 1/VP 0	0.66±0.08	0.94±0.43	$\leq$ 1.64
VP 213/VP 0	2.39±0.32	2.41±1.21	3.77±2.53
VP 213/VP 1	3.62±0.54	2.57±1.32	$\geq$ 2.31

Fig. 1b show clearly the existence of a source at the position of PKS0528+134. In addition to the quasar, the Crab nebula and pulsar also exist in the two skymaps and these two γ-ray sources are resolved exactly. The flux density values of PKS0528+134 are found to be (16.6±5.95)×10^{-5} ph cm^{-2} s^{-1} in the 3-10 MeV band and (7.71±3.03)×10^{-5} ph cm^{-2} s^{-1} in the 10-30 MeV band. The relative statistical significance is about 2.79σ and 2.54σ. The flux values of the Crab in the two skymaps are (3.57±0.68)×10^{-4} ph cm^{-2} s^{-1} in Fig. 1a and (9.57±2.57)×10^{-5} ph cm^{-2} s^{-1} in Fig. 1b. Therefore, although the quasar became the brightest γ-ray source during its flare at energies above 100 MeV, it was still weaker than the Crab at MeV energies. The flux values of PKS0528+134 obtained by Collmar et al. (1997) are (15.2±4.7)×10^{-5} ph cm^{-2} s^{-1} in the 3-10 MeV band and (3.3±1.7)×10^{-5} ph cm^{-2} s^{-1} in the 10-30 MeV band. Our 3-10 MeV flux is close to their result and 10-30 MeV flux is about 2.3 times higher. Both the 10-30 MeV fluxes, nevertheless, are consistent with each other within the error bars. Collmar et al. (1997) also gave an upper limit of the 0.75-1 MeV flux and a very marginal 1-3 MeV flux, which indicates that PKS0528+134 was very weak and could hardly be detected at energies below 3 MeV. Our non-detection of PKS0528+134 in the 0.75-1 MeV and 1-3 MeV bands confirms this indication. The other structures in both skymaps reflect the non-uniform background from the instrument and the statistical fluctuations of the observational data.

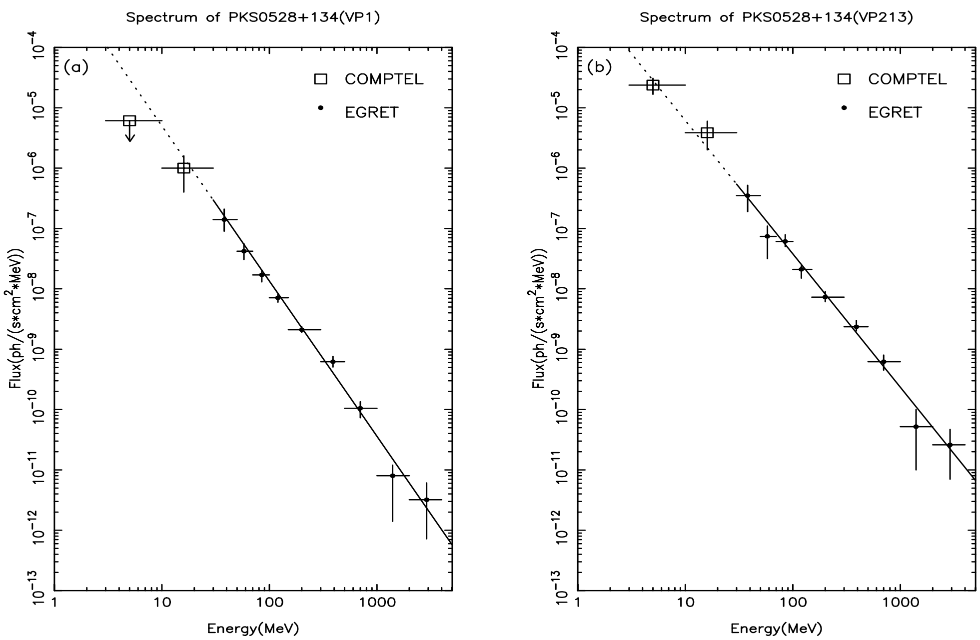

Fig. 3. a Energy spectrum of PKS0528+134 measured by COMPTEL and EGRET during VP 1. **b** Energy spectrum of PKS0528+134 measured by COMPTEL and EGRET during VP 213.

We list in Table 1 the fluxes detected by EGRET and by COMPTEL at energies above 3 MeV during three high states of PKS0528+134. Fluxes marked (*) are our results and fluxes of PKS0528+134 for COMPTEL VP 0 and VP 1 are from Collmar et al. (1997). All the EGRET results in Table 1 are from Mukherjee et al. (1996). With these fluxes, we have calculated the intensity ratios for every two high states observed by EGRET and by COMPTEL respectively, and the results are listed in Table 2. We can see from Table 2 that the 10-30 MeV intensity ratios are close to those detected by EGRET at energies above 100 MeV and the intensity ratios of VP 213/VP 1 and VP 213/VP 0 in the 3-10 MeV band are also high, which suggest that the flaring of PKS0528+134 was in phase in both the energy intervals 3-30 MeV and $\geq$ 100 MeV. The non-detections in the lower energy bands show its cessation. The COMPTEL 3-10 MeV and 10-30 MeV light curves together with the EGRET one (Mukherjee et al. 1996) are shown in Fig. 2. In Fig. 2 our fluxes of PKS0528+134 for VP 213 are used and all other data points in the COMPTEL 3-10 MeV and 10-30 MeV light curves are from Collmar et al. (1997). From Fig. 2 one can see that the COMPTEL 3-10 MeV and 10-30 MeV energy bands follow well the intensity trend as observed by EGRET above 100 MeV.

The COMPTEL spectral results together with the simultaneously measured EGRET spectra of PKS0528+134 for VP 1 and VP 213 are shown in Fig. 3a and Fig. 3b. The spectrum of the quasar in Fig. 3a is from Collmar et al. (1993b). The spectrum at energies above 30 MeV in Fig. 3b is from Mukherjee et al. (1996) and the other two data points in this figure are our results. The COMPTEL spectral results shown in Fig. 3b are consistent with a simple extrapolation of the measured EGRET spectrum. The spectral break in the 10-30 MeV band for COMPTEL VP 1 (see Fig. 3a) does not appear in the flaring spectrum for VP 213 (see Fig. 3b) even down to the energy of 3 MeV. The non-detection of PKS0528+134 at energies below 3 MeV implies that a spectral break may occur around 3 MeV in Fig. 3b. Such a spectral break is also required by the results of Collmar et al. (1997).

4. Discussion and conclusion

We have carried out an imaging analysis upon the quasar PKS0528+134 during its flare with the direct demodulation method. All our results agree with those given by Collmar et al. (1997) except for a difference in the 10-30 MeV flux. The 3-10 MeV flux obtained by us is close to that by Collmar et al. (1997) and our 10-30 MeV flux is about a factor of 2.3 higher. Taking into account, however, the significance of the detections and the errors of the derived fluxes, one can see that the two values for the 10-30 MeV flux are in agreement. The flux difference may result from the different treatment of the background when analyzing the data. In our analysis, we search for the diffuse background only from the data and use them as lower limit when solving again the modulation equation. The non-uniform instrumental background and the intensity distribution of the real sources are left in the final map. In this way, we need no longer consider the background prior to estimating intensities of the sources because both of them can be derived from the data simultaneously. We note that there is some structure near PKS0528+134 in Fig. 1b and no other structures around PKS0528+134 in Fig. 1a, which imply that the background around PKS0528+134 is relatively clean in the 3-10 MeV band but dirty and noisy in the 10-30 MeV band. The complicated background in Fig. 1b may therefore lead to the difference in the 10-30 MeV flux when using different analysis methods.

Although PKS0528+134 has been fully studied by Collmar et al. (1997), some important features for the flaring quasar are found by us in our reanalyzing COMPTEL data of VP 213 with the direct demodulation method. The flaring quasar PKS0528+134 was detected with high luminosity in the energy range 3 MeV to 30 MeV and not detected in the lower COMPTEL energy bands; The intensity ratios and the light curves measured by COMPTEL at energies above 3 MeV are consistent with those by EGRET; A spectral break at energies around 3 MeV is required from the combined spectrum measured simultaneously by COMPTEL and EGRET during VP 213. These features suggest that PKS0528+134 still kept on flaring in the 3-30 MeV band at similar level as measured by EGRET above 100 MeV and no flaring below 3 MeV. The inverse Comptonization (IC) models, which can be subdivided into the self generated synchrotron Compton model (SSC model; e.g. Maraschi et al. 1992, Bloom & Marscher 1993) and the external radiation Compton model (ERC model; e.g. Dermer & Schlickeiser 1993, Sikora et al. 1994, Blandford & Levinson 1995) according to the origin of low-energy photons scattered to γ-energies by the relativistic jet electrons, are generally used to explain the production of high energy γ-rays from quasars. To explain the spectral break for the flaring spectrum of PKS0528+134, however, we need a combined ERC / SSC model (Böttcher & Collmar 1998) which introduces a high-energy electron pair population with a low-energy cutoff in its Lorentz-factor distribution (Böttcher et al. 1997). Our result for the flaring spectrum is consistent with this model. Our detections and non-detections of the flare at MeV energies put hard constraints on the relative low-energy cutoff, thus helping to further understand the emission process that produces the flare.

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