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COMPTEL observations of the Virgo region

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Abstract. The analysis of all available COMPTEL data collected from the Virgo region of the sky between the beginning of the Compton Gamma-Ray Observatory mission in April 1991 and the end of its observational Phase III in October 1994 is currently in progress. During this period COMPTEL was pointed for in total 15 weeks directly towards the Virgo region of the sky.

In the sum of all data, the quasar 3C 273 is detected with a significance of $\sim 9\sigma$ in the energy band 1 to 10 MeV. There is evidence for the quasar 3C 279 at a significance level of $\sim 3.4\sigma$ in the 1-3 MeV band. In addition, there are indications for additional (new) MeV γ-ray sources in the Virgo region. The most significant new source was detected at a level of $\sim 4.5\sigma$ by COMPTEL in one of the four energy ranges. Another candidate source is spatially consistent with the higher-energy EGRET source 2EG J1224+2155, and reaches a $\sim 3\sigma$ significance level at the EGRET source position.

Key words: gamma rays: observations - galaxies: active - quasars: 3C 273, 3C 279

1. Introduction

The COMPTEL experiment aboard the Compton Gamma-Ray Observatory (CGRO) measures γ-rays in the energy range between 0.75 MeV and 30 MeV. Within its $\sim$1 steradian field-of-view COMPTEL has an energy resolution between 5% and 10% and an angular resolution of $\sim 1^o$-2^o. For a detailed description of the COMPTEL instrument see Schönfelder et al. (1993).

Between April 1991 and October 1994 (Phase I, II, and III of the CGRO mission) COMPTEL was pointed towards the Virgo region of the sky several times. The data of these Virgo observations are currently being analysed in detail. The main objectives of the analysis are to study the MeV properties of the prominent Virgo region quasars 3C 273 and 3C 279 over a long time span, and to search for new, previously unknown MeV gamma-ray sources using the large exposure collected.

In this paper we concentrate on "time-averaged" results which have been derived from the complete set of Virgo data (more than 15 weeks of observation time collected over a time span of 3.5 years). The results presented here should be considered as preliminary. Detailed temporal and spectral studies on individual sources are currently in progress.

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2. Data analysis

So far the data have been analysed following the COMPTEL standard analysis procedures. Significance maps have been generated by applying a maximum-likelihood method (de Boer et al. 1992) with a background modelling technique which eliminates any source signature but preserves the general background structure (Bloemen et al. 1994). For this initial analysis point-spread functions (PSFs) assuming an E^{-2} power-law spectrum for potential sources have been used. The maximum-likelihood analysis provides various source parameters, such as fluxes and error regions. The quantity -2lnλ (where λ is the maximum-likelihood ratio of source + background versus background) follows a χ^2_3 distribution (3 degrees of freedom) in a search for sources. A χ^2_1 distribution applies when the possible detection of *a priori* selected sources is considered. To cross check the resulting maximum-likelihood maps, corresponding maximum-entropy images have also been generated.

This standard analysis procedure was applied to the sum of all Virgo observations in each of the four COMPTEL standard energy bands (0.75 - 1 MeV, 1 - 3 MeV, 3 - 10 MeV, and 10 - 30 MeV) to derive time-averaged results.

3. Observations

Up to October 1994 (end of CGRO Phase III) COMPTEL had been pointed for 13 observation periods directly (within 15^{o}to 3C 273) to the Virgo region of the sky. In addition, there is about an equal number of CGRO pointings which surround the Virgo sky region. To enhance the COMPTEL efficiency near the edge of the field-of-view of the direct Virgo observations, pointings up to 50^o from 3C 273 have been included in the analysis. Overall a net observation time (including efficiency corrections and data losses) of ~35 days was collected by COMPTEL on Virgo. Table 1 lists the details of the COMPTEL pointings with the highest effective exposure toward the Virgo region.

Table 1. COMPTEL observations of the Virgo region during CGRO Phases I-III. The last column gives the angular separation between the location of 3C 273 and the COMPTEL pointing direction.

VP #	Obs. Time yy/mm/dd - yy/mm/dd	Dur. [days]	Separ. [°]
3	91/06/15 - 91/06/28	13	4.3
11	91/10/03 - 91/10/17	14	2.0
204	92/12/22 - 92/12/29	7	3.2
205	92/12/29 - 93/01/05	7	3.4
206	93/01/05 - 93/01/12	7	3.2
304	93/10/19 - 93/10/25	6	5.4
305	93/10/25 - 93/11/02	8	5.8
306	93/11/02 - 93/11/09	7	8.1
307	93/11/09 - 93/11/16	7	9.7
308	93/11/16 - 93/11/19	3	10.5
308.6	93/11/23 - 93/12/01	8	10.5
311	93/12/13 - 93/12/15	2	10.4
311.6	93/12/17 - 93/12/20	3	10.4
312	93/12/20 - 93/12/27	7	7.2
313	93/12/27 - 94/01/03	7	14.3

4. Results

4.1. Combined Virgo skymaps

Combined (sum of all data) skymaps have been generated in a circular fashion (radius 25°) around the exposure maximum on Virgo which roughly coincides with the location of 3C 273. The 1-3 MeV and 3-10 MeV skymaps (detection significances) are shown in Figure 1. The likelihood ratios near the center of the 3-10 MeV map are a superposition of the individual likelihood ratios of two sources. Therefore the individual detection significances for these two sources are smaller than is indicated by the contour lines shown in Figure 1 (the contribution of the other source has to be subtracted off). The 0.75-1 MeV and 10-30 MeV maps do not show excesses which clearly exceed the 3σ-threshold level.

Both maps of Figure 1 show clear evidence for the quasar 3C 273. Taking into account the known position of the object (i.e. 1 degree of freedom (dof) in the likelihood fit) and the contribution of neighboring sources, the quasar is detected with $\sim 7.6\sigma$ (1-3 MeV) and $\sim 4.7\sigma$ (3-10 MeV). Additionally, 3C 273 is detected in the 10-30 MeV energy range with $\sim 2.5\sigma$. Due to the larger number of observations, the total significance

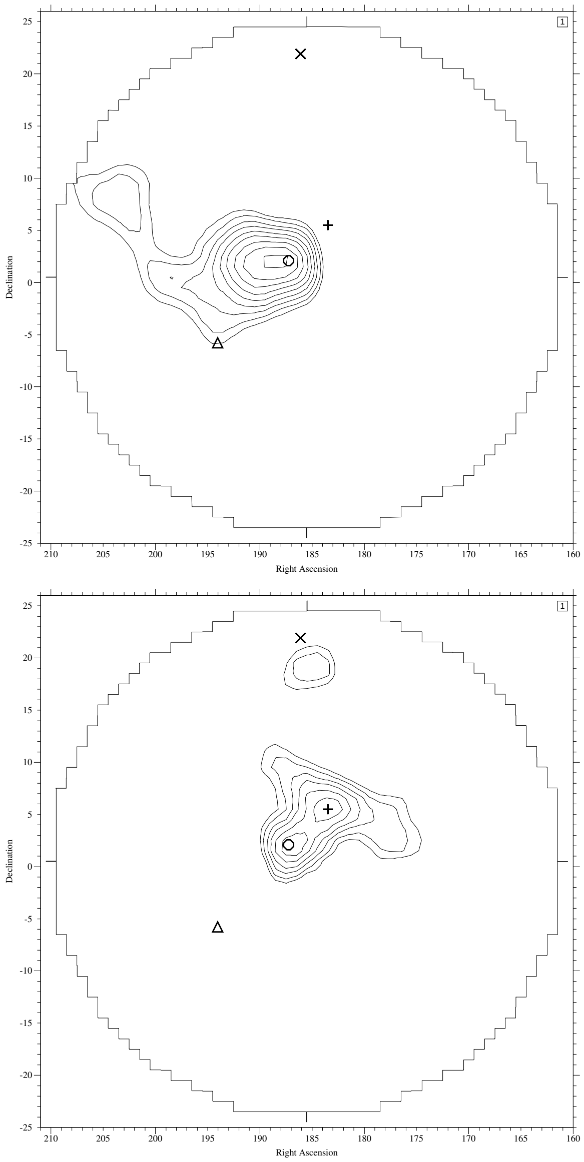

Fig. 1. COMPTEL skymaps (detection significances) of the Virgo region for the sum of all data (~35 days net observation time). The contour lines start at a detection significance of 2.5σ for one energy band with a step of 0.5σ (3 dof for an unknown source). The maps are generated in the 1-3 MeV (upper), and the 3-10 MeV band (lower). The locations of 3C 273 (**o**), 3C 279 (Δ) and 2EG J1224+2155 (**x**) are indicated. The most likely position of the new MeV source GRO J1214+06 (**+**) is also marked.

of the detection of this source has increased substantially with respect to its discovery in early COMPTEL analyses (Hermsen et al. 1993; Williams et al. 1995).

In the 1-3 MeV skymap there is evidence for the quasar 3C 279 at the 3.4σ-level (again for 1 dof). This is not obvious from the map shown in Figure 1 because the detection significance contours are for a search for unknown sources (3 dof). Additional support for the presence of 3C 279 at this energy range is given by the corresponding maximum-entropy map which shows a weak spot at the location of 3C 279. At energies above 10 MeV there is evidence for 3C 279 at about the 2.5σ-level.

In addition to the prominent Virgo quasars there are two candidate MeV γ-ray sources which we discuss briefly in this paper. In the 3-10 MeV map there is an excess visible at α~183.5^o, δ~+5.5^o(GRO J1214+06) which has a detection significance of $\sim 4.5\sigma$. Apart from the maximum at the location of 3C 273, this is the most significant feature in all four maps, and its significance remains above 4σ taking the four trials (energy ranges) into account. In the same map another excess shows up at α~185^o, δ~+19.5^{o}with a marginal detection significance of 3.4σ. However, this excess is spatially consistent (at the 2σ error location contour) with the γ-ray source 2EG J1224+2155 (α:186.1^o; δ:+21.9^o), which was detected at hard γ-ray energies by the EGRET telescope aboard CGRO and identified with the quasar PKS 1222+216 (Thompson et al. 1995; v. Montigny et al. 1996). The significance of the COMPTEL detection at the EGRET position is $\sim 3\sigma$.

The main parameters of the four (candidate) sources discussed here are compiled in Table 2. Detailed investigations on each object as well as searches for possible counterparts of the yet unknown candidate source are currently underway.

Table 2. Locations and detection significances of the (candidate) sources discussed in the text for their most significant COMPTEL energy intervals. The significances were calculated for 1 degree of freedom (dof) or 3 dof whether the source position was known or not, respectively.

Object	RA/Decl. [^{o}]	Significance [σ]	Energy [MeV]
3C273	187.3/2.1	9.0(1dof)	1 - 10
3C279	194.1/-5.8	3.4(1dof)	1 - 3
GRO J1214+06	183.5/5.5	4.5(3dof)	3 - 10
2EG J1224+2155	186.1/21.9	2.9(1dof)	3 - 10

4.2. Energy Spectra

Flux values for each of the four sources in the four standard COMPTEL energy bands are given in Table 3. The corresponding energy spectra are shown in Figures 2 and 3 (differential flux multiplied by the square of the energy). A positive flux measurement is shown if the spectral point has a significance of at least 2σ. Otherwise an upper limit is drawn.

The COMPTEL spectrum for 3C 273 is plotted in Figure 2 together with published spectral results from OSSE and EGRET in neighbouring energy bands. Note, that the OSSE, COMPTEL and EGRET measurements are not contemporaneous. For OSSE we show two spectral shapes (drawn between 50 keV and 600 keV), which have been derived by Johnson et al. (1995) during high- and low-intensity states of 3C 273. The two shapes are shown to indicate the variability range of 3C 273 in hard X-/soft

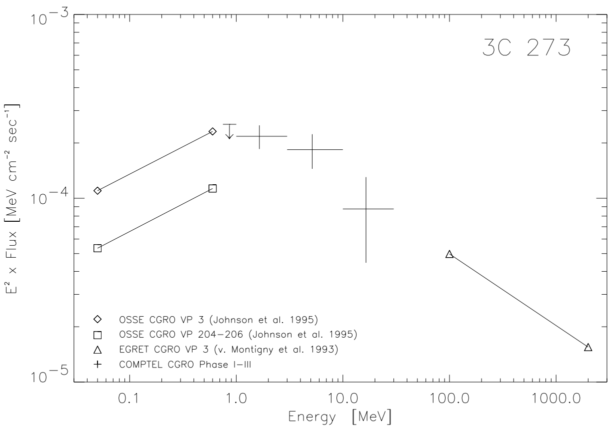

Fig. 2. Combined OSSE, EGRET and COMPTEL spectrum of 3C 273, plotted as differential flux * E^2, which represents a power per decade of energy plot. The spectra are not measured contemporaneously. The measured OSSE spectral shapes (Johnson et al. 1995) for a high- and a low-intensity observation are drawn between 50 keV and 600 keV. The COMPTEL error bars are 1σ and the upper limit is 2σ. The spectral turnover at a few MeV is evident.

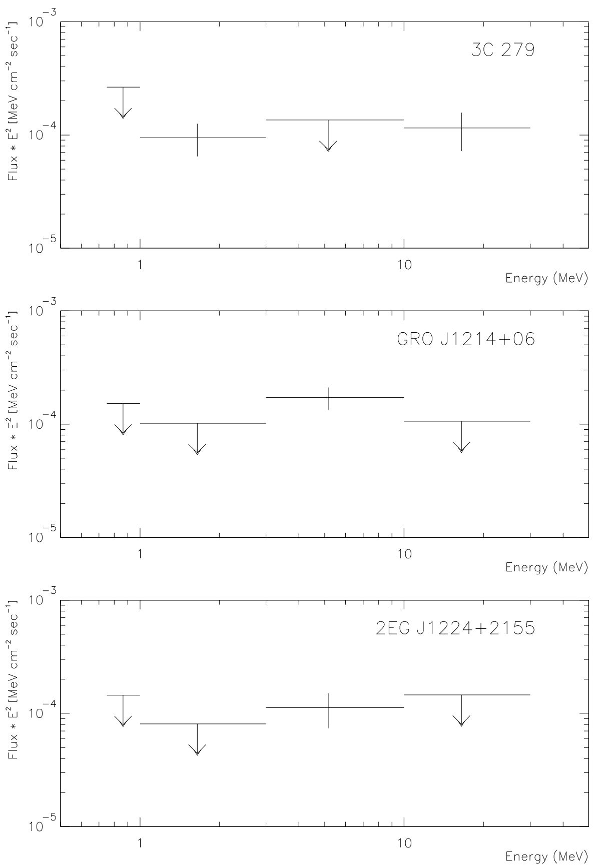

Fig. 3. COMPTEL spectral points of the three (candidate) γ-ray sources discussed in the text. The error bars are 1σ and the upper limits (down arrows) are 2σ.

γ-rays during the time span of the observations discussed. The COMPTEL time-averaged measurement fits well overall with the OSSE and EGRET measurements. The well known bending of the 3C 273 spectrum at MeV energies (e.g. Lichti et al. 1995) is already indicated by the COMPTEL points themselves.

The COMPTEL spectral points of the other three (candidate) sources are shown in Figure 3. Earlier in the CGRO mission 3C 279 was detected by COMPTEL during VP 3 only at energies above 3 MeV (Williams et al. 1995, Hermsen et al. 1993), while it showed a major flare in the EGRET band (Kniffen et al. 1993). The weak detection now in the 1-3 MeV band was reported already by Collmar et al. (1995) analysing eight weeks of Virgo observations carried out between October 1993 and January 1994 (CGRO viewing periods (VP) 304 to 313 in Table 1), which is a subset of the data analysed for this paper.

The derived energy spectrum of the candidate MeV source GRO J1214+06 seems to peak in the 3-10 MeV band (Figure 3) similar to what we have seen so far from most AGN detected by COMPTEL. Due to the high upper limit in the 10-30 MeV range, a spectral peaking is not obvious for 2EG J1224+2155 but can not be excluded either. Note, that the flux values given for 2EG J1224+2155 (Figure 3, Table 3) are derived for the location of the EGRET source, not for the maximum of the COMPTEL skymap.

Table 3. Preliminary time-averaged fluxes and upper limits for the four (candidate) sources. The fluxes are given in units of $10^{-5}\text{cm}^{-2}\text{s}^{-1}$. The errors are 1σ. The upper limits are 2σ. The errors and upper limits are statistical only. We estimate systematical errors to be of the order of 30%.

Source	Energy band (MeV)	Fluxes ($10^{-5}\text{cm}^{-2}\text{s}^{-1}$)
3C273	0.75 - 1	<8.5
	1 - 3	14.5±2.2
	3 - 10	3.9±0.9
	10 - 30	0.6±0.3
3C279	0.75 - 1	<8.8
	1 - 3	6.3±2.0
	3 - 10	<3.2
	10 - 30	0.8±0.3
GRO J1214+06	0.75 - 1	<5.1
	1 - 3	<6.8
	3 - 10	4.0±0.9
	10 - 30	<0.7
2EG J1224+2155	0.75 - 1	<4.8
	1 - 3	<5.4
	3 - 10	2.6±0.9
	10 - 30	<0.9

5. Summary and outlook

During the first 3.5 years of its mission COMPTEL has accumulated a very high exposure of the Virgo sky region. A detailed analysis of these data has begun. In this paper we report first and as yet preliminary results from an analysis of the sum of all COMPTEL Virgo data, gathered up to October 1994. Apart from the quasar 3C 273, which is - at least in this time-averaged analysis - the strongest MeV source of the Virgo region, there is evidence for further MeV γ-ray sources in this sky region. In particular, there is evidence for emission from 3C 279 at energies above 1 MeV, and there are indications for emission from two additional sources at energies between 3 and 10 MeV. A more detailed analysis for each candidate source is in progress, including spectral and temporal studies analysing the individual Virgo observations. Counterpart searches for the yet unknown source candidate GRO J1214+06 are underway.

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