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EGRET Observations of Clusters of Galaxies

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Abstract

EGRET data from CGRO observation cycles 1 to 4 were analysed for gamma-ray emission from individual candidates of an X-ray flux limited sample of clusters of galaxies. The gamma-ray fluxes determined above 100 MeV at the positions of these clusters are given and are discussed. In order to investigate further individual gamma-ray images of a suitable sample of galaxy clusters has been co-added and analysed. The results are presented and will be compared with recent models and predictions of the gamma-ray emission from galaxy clusters.

1 Introduction

Clusters of Galaxies are excellent representatives for formation and evolution of structure in the universe, and are extensively studied at radio, optical and X-ray wavelength. From realistic modelling of the distribution of the intergalactic medium within galaxy clusters it is suggested that a fraction of the extragalactic diffuse gamma-ray background could well be originated from galaxy clusters. About the quantity of the suggested contribution rather different estimations could be found in the literature, therefore the situation appears similar to the contribution of AGN to the extragalactic gamma-ray background. In contrast to the well-observable population of Active Galactic Nuclei with EGRET, so far no galaxy cluster has been discovered in the high-energy gamma-rays. Nevertheless, for several individual galaxy clusters precise flux predictions for the EGRET energy regime already exsist (i.e. Enßlin et al. 1997, Colafrancesco and Blasi 1999), but predict gamma-ray fluxes close to the sensitivity limit of the EGRET telescope. A discovery of galaxy clusters as a new class of observable gamma-ray sources would directly improve our understanding of the Cosmic Rays (see i.e. Dar and Shaviv 1996, Berezinsky et al. 1997, Völk et al. 1996).

2 The selected sample of Galaxy Clusters

For analysing the emission characteristics of Galaxy Clusters in the high-energy gamma-rays a sample of X-ray emitting Clusters of Galaxies has been compiled. This sample is based on X-ray flux limited Cluster samples from the EINSTEIN (Edge et al., 1990), EXOSAT (Edge and Steward, 1991) and ROSAT surveys (XBACs: Ebeling et al. 1996, BCS north: Ebeling et al. 1998, BCS south: De Grandi et al. 1999). Cluster selections in X-rays currently provide the best way to obtain complete samples without introducing biases (i.e. projection effects). Appearing as extended sources with radii (r_{VTP}) of several arcminutes in X-rays, the limited angular resolution of exsisting gamma-ray telescopes justify the attempt to analyse Clusters of Galaxies as point-like excesses in the high-energy gamma-rays. For 58 individual X-ray bright galaxy clusters within $z < 0.18$ gamma-ray data from the Compton GRO high-energy telescope EGRET were analysed.

3 The gamma-ray analysis of Galaxy Clusters

So far, no galaxy cluster has been found positional coincident with gamma-ray point sources in exsisting EGRET source catalogues. Only for the Coma cluster a result of an EGRET analysis has been published, based on observations within CGRO cycle 1 and 2 (Sreekumar et al. 1996). In the analysis described here

EGRET-data from CGRO observation cycles 1-4 were used for the analysis of individual clusters. All individual galaxy clusters were analysed by means of standard EGRET analysis procedures. The same all-sky counts, exposure and intensity maps were used as described in the recently published 3EG catalogue of gamma-ray point sources (Hartman et al. 1999). The advantage ot that procedure is the possibility of an adequate usage of results from the already performed extensive data processings for the EGRET catalog. Therefore the maps from the 3EG catalogue ($E > 100$ MeV) could be correctly used in conjunction with the exsisting 3EG catalogue source list and a more expanded, but less reliable determination of each gamma-ray excess above a lower, but uniform $3.5\,\tau$ detection threshold. The maps are searched for residual sources after modelling and subtracting of already catalogued and determined gamma-ray point sources by using the maximum-likelihood technique. At the positions of the considered clusters the gamma-ray intensity is determined. Applying the same detection criterium like already used and described for the EGRET source catalogues, none of the 58 galaxy clusters could be detected in the EGRET data. Special care has taken into account (and is indicated in Table 1) when exsisting EGRET sources are close to the considered cluster. The strongest gamma-ray excess for the candidates in Table 1 is a $1.9\,\tau$ excess in the case of A3532, but not considered as a detection. Therefore for all galaxy clusters only $2\,\tau$ confidence upper limits were found.

Triggered from this negative result on individual Clusters of Galaxies, an approach has been made to study whether or not galaxy clusters radiate in gamma-rays as a population. For this purpose EGRET count, exposure, and intensity maps from CGRO observation cycles 1-8 were used, whenever an EGRET pointing was within 25° of the considered cluster position. After co-adding of those individual maps a coordinate transformation into a clustercentered coordinate system has been applied. The following step of further co-adding of individual maps in clustercentered coordinates into the final superposition required the exclusion of eigth galaxy clusters due to poor angular separation from the Galactic disk or strong EGRET sources within the center region of the 25° by 25° map for each individual cluster. This assures that the central region of the final superpositioned map is not dominated from already known gamma-ray point sources or Galactic disk gamma-ray emission. The homogeneity of the superposition is indicated from the underlaying exposure (Figure 1). The central bin in the exposure map is $2.5 \cdot 10^{10}$ cm^2 s, the lowest values in the map about $5 \cdot 10^9$ cm^2 s. Figure 2 shows the resulting intensity map from the final superposition of all available EGRET data within 8 years of the CGRO mission on 50 individual Clusters of Galaxies. The result is that no excess at all is indicated in the cental bin or even the central region of the constructed image. When individual exposure fractions and weighted intensity contributions are determined, a quantitative result on the superpositioned cluster sample will be given.

4 Discussion and Conclusion

The negative results from the gamma-ray analysis of EGRET data above 100 MeV at positions of individual Clusters of Galaxies as well as from the superposition of galaxy clusters might provoke some suspections. Categorically, the question of an appropriate selected sample of galaxy clusters might arise. The strong assumption has been made that nearby X-ray bright clusters do have a good chance to radiate in the gamma-rays also, supported from various models of multifrequency emission properties of galaxy clusters. Due to the different distances and sizes of the various candidates in the cluster sample an be revised and better sample might be constructed in the future. And an application of any more sophisticated analysis method for the superpositioned cluster sample is far from being trivial, it would incorporate detailed and precise modelling of the Galactic diffuse emission, should be able to deal with extended gamma-ray emission features etc. Despite that a recent modelling of the gamma-ray emission from galaxy clusters only predict values below the sensitivity of EGRET (Colafrancesco and Blasi 1998), some upper limits from individual Clusters of Galaxies are already sensitiv enough to restrict other model predictions on the gamma-ray emission found in the literature, for instance on A426 (Ensslin et al. 1997).

#	clustername	flux ($E > 100$ MeV) [10^{-8} cm^{-2} s^{-1}]	comment	excluded from superposition due to
1	A426 (PER Cluster)	< 3.73		
2	OPH Cluster	< 7.49		Galactic Plane nearby
3	VIR Cluster	< 2.20		
4	A1656 (COMA Cluster)	< 3.26		
5	A2319	< 3.80		Galactic Plane nearby
6	A3571	< 5.17		
7	A3526 (CEN Cluster)	< 5.30		
8	TRA Cluster	< 8.13		
9	3C 129 (3A 0446+449)	< 5.28		Galactic Plane nearby
10	AWM 7 (2A 0251+413)	< 3.60		
11	A754	< 7.43		
12	A2029	< 6.36		
13	A2142	< 5.24		
14	A2199	< 10.43	only 1.9° of 3EG J1635+38	
15	A3667	< 3.38		
16	A478	< 6.10		
17	A85	< 6.77	only 0.8° of 3EG J0038-09	source contamination
18	A3266	< 3.28		
19	A401	< 4.97		
20	3A 0745-191	< 8.28		Galactic Plane nearby
21	A496	< 8.92		
22	A1795	< 5.50	3° of 3EG J1347+29	
23	A2256	< 4.28		
24	CYG A Cluster	< 6.24		Galactic Plane nearby
25	2A 0335+096	< 9.20		
26	A1060	< 13.66		
27	A3558	< 3.71		
28	A644	< 9.80	only 1.4° of 3EG J0812-06	
29	A1651	< 4.00	only 1.8° of 3EG J1255-05	source contamination
30	A3562	< 3.51		
31	A1367	< 2.65		
32	A399	< 5.18		
33	A2147	< 7.45	only 0.7° of 3EG J1605+15	source contamination
34	A119	< 4.84		
35	A3158	< 2.35		
36	HYD A Cluster	< 6.95		
37	A2065	< 5.48		
38	A2052	< 5.50		
39	A2063	< 5.25		
40	A1644	< 3.33		
41	Klem 44 (A4038)	< 3.38		
42	A262	< 4.25		
43	A2204	< 8.74		
44	A2597	< 7.83		
45	A1650	< 2.78		
46	A3112	< 5.75		
47	A3532	< 8.39		
48	A4059	< 3.00		
49	A3395	< 6.51		
50	MKW 3s	< 5.07		
51	A1689	< 3.50		
52	A576	< 3.38		
53	A2244	< 9.43		
54	A2255	< 5.44		
55	A1736	< 3.86		
56	A400	< 5.63		
57	A2657	< 7.93		
58	A1775	< 4.42		

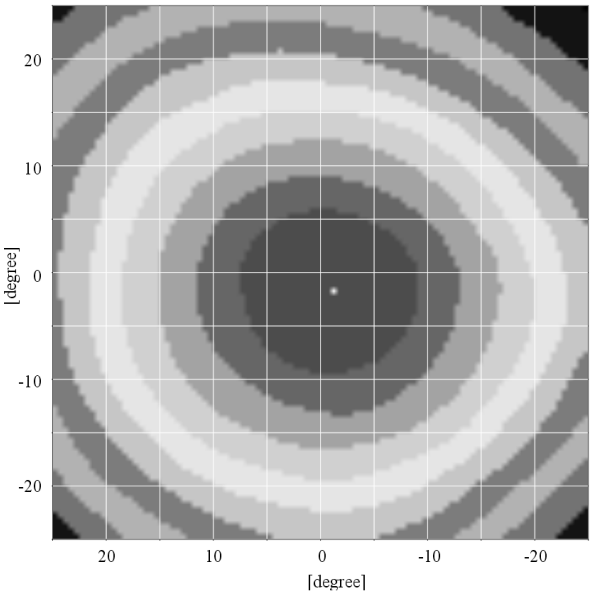

Figure 1: EGRET exposure map of the co-added galaxy clusters. The coordinate system used here is a clustercentered system where the origin corresponds to the X-ray position of each of the respective galaxy clusters. The homogeneous symmetry in respect to the center region of the total exposure map is easily seen. This is a premise for an interpretation of the intensity map.

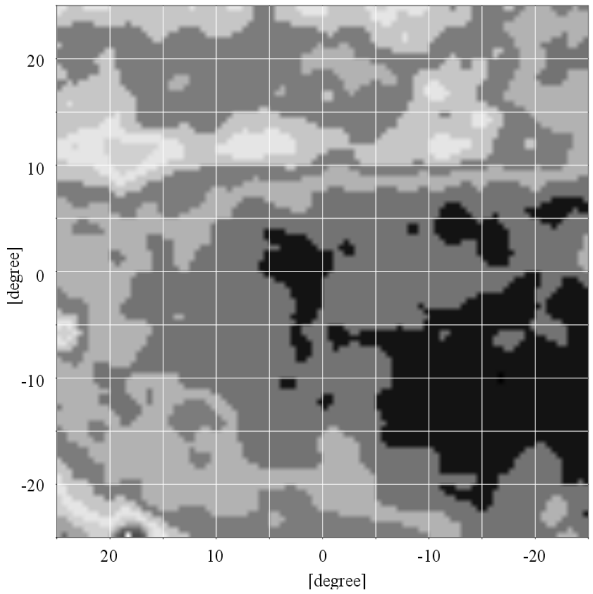

Figure 2: EGRET intensity map of the co-added galaxy clusters. The darker grey colours correspond to lower gamma-ray intensity. If the collective sample of galaxy clusters radiates gamma-rays, an excess should be seen at the center of the image. The rather flat region at the very center of the map indicates, that neither single galaxy clusters nor their superposition could currently be considered as observable gamma-ray sources.

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