Clusters Of Galaxies – The EGRET Observations between 1991 and 2000

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Abstract. Various emission mechanism suggest clusters of galaxies to exhibit high-energy gamma-ray radiation. Galaxy clusters are predicted to be at the edge of the instrumental sensitivity currently accessible with gamma-ray telescopes. It is suggested that galaxy clusters contribute to the extragalactic diffuse background and, in few individual cases, they might be already detectable as individual sources. On the assumption that a flux limited sample of X-ray bright clusters will suit as a reasonable selection, gamma-ray fluxes (E > 100 MeV) are determined using EGRET data throughout the entire CGRO mission. In order to investigate beyond the case of the individual X-ray bright cluster, the gamma-ray data of individual clusters are cumulative stacked in a cluster-centered coordinate system and the resulting images have been analyzed. The results from EGRET are given and discussed in the light of predictions already found in the literature as well as in perspective of upcoming gamma-ray mission like INTEGRAL and, primarily, GLAST

INTRODUCTION

Clusters of galaxies are excellent representatives for formation and evolution of structures in the universe and extensively studied at radio, optical and X-ray wavelengths. Within the last decade, radio, EUV and X-ray observations revealed emission features, which also gave rise to predict galaxy clusters as emitters of high-energy gamma-rays: the discovery of diffuse radio halos, the controversially discussed EUV excess emission, and the evidence for a distinct nonthermal emission component in X-rays. Various scenarios are suggested: pp interactions of high-energy cosmic rays with intracluster gas (Berezinsky et al. 1997), relativistic electrons, which scatter background photons to higher energies (Enßlin & Biermann, 1998), electrons generated as secondaries in cosmic ray interactions in the intracluster medium (Blasi & Colafrancesco 1999), heating of cluster gas with injected cosmic-ray protons and magnetic field densities (Enßlin et al. 1997, Völk & Atoyan 1999, Atoyan & Völk 2000), and bow shocks of supersonically moving galactic halos (Bykov et al. 2000).

Generally, all of these models predict galaxy clusters to contribute to the extragalactic diffuse gamma-ray background. Rather different estimates of the quantity of such contribution could be found in the literature, comparable to the situation of the contribution of AGN to the extragalactic gamma-ray background (Dar & Shaviv 1996). In contrast to the well-observable population of Active Galactic Nuclei by EGRET, so far no galaxy cluster has been discovered in high-energy gamma-rays. Nevertheless, for several individual clusters flux predictions at EGRET energies (30 MeV - 10 GeV) exist (i.e. Dar & Shaviv 1995, Enßlin et al. 1997, Colafrancesco & Blasi 1999). However, the predicted gamma-ray fluxes are close to or even below the sensitivity of the EGRET telescope. The only existing study of galaxy clusters in high energy gamma-rays by McGlynn et al. 1994 was performed on earliest EGRET data only, and one upper limit has been determined for the Coma-cluster only (Sreekumar et al. 1996). Here we have expanded the analysis of Reimer 1999 into the relevant data throughout the entire CGRO mission from 1991 to 2000 in order to determine the currently best observational estimates on the high-energy emission of clusters of galaxies.

THE SELECTED SAMPLE OF GALAXY CLUSTERS

For analyzing 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 consists of the X-ray flux limited cluster detections from 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 existing gamma-ray telescopes justify the attempt to analyze clusters of galaxies as point-like excesses in gamma-rays. For 58 individual X-ray bright galaxy clusters within $z < 0.14$ gamma-ray data from the Compton GRO high-energy telescope EGRET were analyzed (see table in Reimer 1999). Although additional cluster surveys are on the way or have been recently completed (NORAS, REFLEX, HIFLUGCS, MACS) the chosen selection adequately represents the more energetic side of the log N- log S distribution from galaxy clusters in X-rays. Almost all clusters extensively discussed in individual papers due to evidence of nonthermal X-ray emission, EUV-excess features and/or characteristic radio halos are among this sample chosen to analyze for high-energy gamma-ray emission.

THE GAMMA-RAY ANALYSIS OF GALAXY CLUSTERS

So far, no galaxy cluster has been reported being positional coincident with gamma-ray point sources in existing EGRET source catalogues.[1] Only for the Coma cluster the result of an EGRET analysis has been published, based on observations from CGRO cycle 1 and 2 (Sreekumar et al. 1996). In the analysis described here, EGRET data of individual viewing periods from CGRO observation cycles 1- 9 were used for

[1] At this conference, S.Colafrancesco suggested a positional correlation between unidentified EGRET sources and Abell clusters. Despite the fact that there are 2712 clusters listed in the catalog (Abell 1958), and therefore *several* chance coincidences expected, the fact has not been explained why Coma, Virgo, and Perseus, the most obvious candidates for detectable gamma-ray emission still avoid their detection, and therefore do not coincide with any known yet unidentified gamma-ray source.

the analysis of 58 individual clusters. The latest and probably final improvements in the efficiency correction of EGRET have been fully implemented. Each galaxy cluster has been individually analyzed by means of standard EGRET data reduction procedures (likelihood source finding algorithm and subsequent flux determination at the X-ray position of the cluster center). This goes beyond the work presented by Reimer 1999, where four years of EGRET observations have been analyzed in strict congruence with the 3EG catalog of gamma-ray point sources (Hartman et al. 1999). The cumulative stacked maps are searched for residual sources after modeling and subtracting cataloged (and therefore well-known) gamma-ray point sources by using the maximum-likelihood technique. At the positions of the cluster center the gamma-ray flux has been determined.

Applying the same detection criteria as used and described in the EGRET source catalogs, none of the 58 galaxy clusters could be detected in the EGRET data. Special attention has been taken when existing EGRET sources are close to a considered cluster position. Four of these sources are identified blazar-class AGN. Only one of the remaining two cases shows considerable interference at the position of the analyzed cluster (A85 with the unidentified source 3EG J0038-09). Keeping in mind that the EGRETs instrumental point spread function has a width of 5.85° at 100 MeV, that the 3EG catalog contains about 170 unidentified sources, and also that our cluster sample consists of 58 candidates, such occurrence is perfectly in agreement with pure chance coincidence. The strongest gamma-ray excess for any cluster in the sample is a 1.6ó excess in the case of A3532, but this is well below the threshold of seriously being considered as a detection. Therefore for all galaxy clusters upper limits have been determined.

Triggered from this negative result on individual clusters, an approach has been made to study whether or not galaxy clusters radiate in gamma-rays as a population. For this purpose EGRET counts, exposure, and intensity maps from CGRO observation cycles 1- 9 were used, whenever an EGRET pointing has been within 30° of the considered cluster position for standard field-of-view observations or 19° for narrow field-of view observations, respectively. Before co-adding of individual maps a coordinate transformation into a cluster-centered system has been performed. The subsequent step in co-adding of individual maps in cluster-centered coordinates into the final stacked image required the exclusion of 8 galaxy clusters due to poor angular separation from the Galactic disk or dominant EGRET sources within the center region of the 40° by 40° map for each individual cluster. This assures that the central region of the final stacked image is not dominated from already identified gamma-ray sources or diffuse emission from the Galactic bulge. The central bin in the exposure map is $3.4 \cdot 10^{10}$ $cm^2 s$ ($E > 100$ MeV), the lowest values in the map about $1.4 \cdot 10^{10}$ $cm^2 s$.

No excess at all is indicated in the central bin or even the central region of the constructed intensity image. Only after the individual gamma-ray intensities at the center position of the X-ray bright galaxy clusters have been weighted corresponding to their individual exposure and are analyzed on a adapted diffuse emission model, a final quantitative result on galaxy clusters as population will be given.

DISCUSSION

The negative results from an analysis of the final gamma-ray data from EGRET at positions of 58 individual galaxy clusters as well as from a superposition of 50 galaxy clusters might provoke some suspicion. Categorically, the question of an appropriate selected sample of galaxy clusters might arise. The assumption has been made that the brightest and closest clusters detected at X-ray wavelengths should be the best candidates to radiate in the gamma-rays, supported from various models of multifrequency emission properties. Because almost all clusters which show unusual multifrequency emission characteristics (EUV-excess emission, nonthermal X-ray emission and/or a radio halo) are naturally included here, the above assumption is certainly not artificially. To determine a quantitative results from the cumulative image is far from being trivial, it will incorporate detailed and precise modeling of the Galactic diffuse emission, should reflect the different cluster sizes and distances as well as the individual exposure histories. Despite that a recent modeling of the gamma-ray emission from galaxy clusters predicts values below the sensitivity of EGRET (Colafrancesco and Blasi 1998), some upper limits from individual galaxy clusters are already sensitive enough to restrict earlier model predictions found in the literature, for instance on Abell 426 (Enßlin et al. 1997, Dar & Shaviv 1995) or Virgo (Dar & Shaviv 1995). At this point, considering the combined exposure of $3.4 \cdot 10^{10}$ $cm^2 s$ by EGRET for 50 galaxy clusters without any hint of gamma-ray emission from the population as well, chances for INTEGRAL to detect clusters in the soft gamma rays are rather moderate due to the modest continuum sensitivity of SPI and IBIS-ISGRI, their limited field-of-view (i.e. limited long-term accumulation of required exposure time) and an observation strategy dominated by Galactic Plane observations. However, the nonthermal emission of some clusters might be observable by JEM-X beyond energies currently accessible. Speaking of gamma-rays, the (predicted) detection of galaxy clusters has to await the GLAST mission, which will combine the resolution and sky coverage required to go well below theoretical predictions on the high-energy emission of galaxy clusters.

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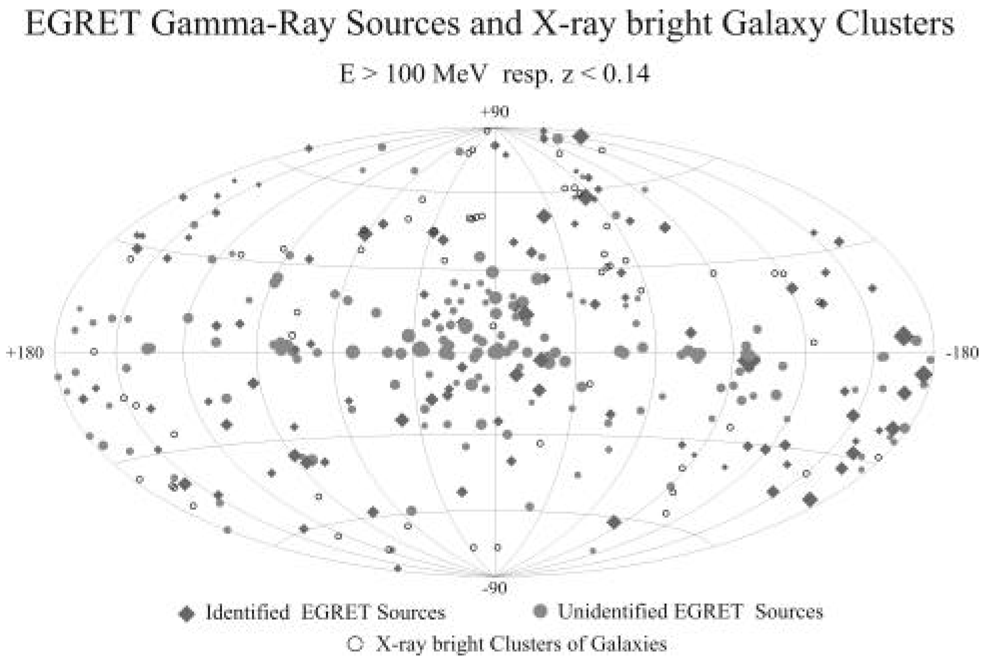

FIGURE 1. Positional arrangement of the studied 58 X-ray brightest clusters and gamma-ray sources detected by EGRET (E > 100 MeV)

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