THE ASTROPHYSICAL JOURNAL, 429:554–556, 1994 July 10

OSSE SEARCH FOR HIGH-ENERGY X-RAY EMISSION FROM THE COMA CLUSTER

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Received 1993 October 18; accepted 1994 January 11

ABSTRACT

Nonthermal emission of high-energy X-rays from the Coma Cluster is predicted from the presence of diffuse intracluster radio synchrotron emission. We have observed the Coma Cluster with the OSSE experiment, onboard the *Compton Gamma-Ray Observatory*, for a total on-source time of 4.4 days. No significant emission was detected. The flux upper limit, combined with the known radio flux, leads to a lower limit of $\sim 1 \times 10^{-7}$ G on the mean intracluster magnetic field in the central region of the Coma Cluster.

Subject headings: galaxies: clusters of (Coma) — intergalactic medium — magnetic fields — radiation mechanisms: nonthermal — X-rays: galaxies

1. INTRODUCTION

Sensitive measurements of clusters of galaxies at high X-ray energies will yield qualitatively new insight on phenomena in the intracluster (IC) space. At energies well above 20 keV, thermal emission from the hot IC gas is weak; Compton scattering of relativistic electrons by the cosmic microwave background (CMB) radiation is likely to be the leading mechanism of X-ray emission. The Compton scattered radiation, in conjunction with radio measurements, will readily yield definite information about magnetic fields and the density and energy spectrum of relativistic electrons in the IC space. Diffuse radio emission from some clusters clearly reveals the presence of such electrons in these clusters (see, e.g., Kim et al. 1990 and references therein). This emission has been detected in eight clusters in the frequency range 0.04–2.7 GHz; the measured indices are in the range 1.2–1.7. That diffuse radio emission was detected in only a relatively small number of clusters may be due to the difficult observational task of separating out discrete galactic radio emission from IC emission. It is therefore possible that IC radio emission is a more common phenomenon than implied by these observations (Rephaeli 1988).

Few attempts to detect clusters at energies above $\sim$20 keV have been made (see references in Rephaeli, Gruber, & Rothschild 1987, hereafter RGR). At present, the only claimed detection of cluster high-energy X-ray (HEX) emission is that of the Coma Cluster by the MIFRASO experiment (Bazzano et al. 1990). However, as has been argued by Rephaeli & Goldshmidt (1992), it is doubtful whether this detection is indeed of diffuse IC emission from the Coma Cluster. Until recently, the *HEAO 1* A-4 was the only relevant, all-sky HEX database. A-4 data from six clusters (of the eight with diffuse radio emission) were analyzed (RGR; Rephaeli & Gruber 1988). Thermal emission—at energies of up to 25 keV—from two clusters (Coma and A2319) was clearly detected by the A-4 experiment. Upper limits were set on the emission at higher energies from these six clusters. The bounds on the nonthermal emission from all the clusters resulted in interesting lower limits on the mean magnetic field $B \sim 0.1$ μG, and upper limits on the electron energy densities.

In our continuing attempt to detect diffuse IC emission, we have recently observed the Coma Cluster region with the OSSE experiment aboard the *Compton Gamma-Ray Observatory* (*CGRO*). The results of this observation and its immediate implications are briefly discussed in the following two sections.

2. OSSE MEASUREMENTS OF THE COMA CLUSTER REGION

The Coma Cluster region was observed during 15 days in 1993 June (19–27) and August (10 and 12–16), for a total on-source time of about 4.4 days. The OSSE instrument (Johnson et al. 1993) consists of four separate, nearly identical detectors. The primary detecting element of each detector is a large area NaI(Tl)-CsI(Na) phoswich crystal which provides spectral information over the energy range 0.04–10 MeV. The instrument has an effective area of $\sim$400 cm^2 for each detector at 50 keV. Tungsten slat collimators provide a field of view which is $3.^\circ8 \times 11.^\circ4$ full width at half-maximum. During the Coma observations, periodic background measurements were performed offset-pointing the detectors from the region centered on Coma by $\pm 4.^\circ5$. Source and background observations were about 2 minutes in length, with the observations alternating between source and background measurements.

The data were analyzed using the standard methods described in Johnson et al. (1993). First, the raw 2 minute spectra were screened for known systematic and transient effects. Background estimation was then performed for each 2 minute source spectrum by fitting the nearest three or four background spectra, channel by channel, using a quadratic function in time. Finally, the background estimate was subtracted from the source spectrum, and the resulting difference spectra were summed separately for each detector. When summing the difference spectra, the propagation of the uncertainties included the correlation terms introduced by using the same offset-pointed background observation for multiple source spectra. Several screening methods were used to search for low-level residual systematic effects in the 2 minute difference spectra, but no statistically significant residual effects were found.

No statistically significant signal was detected, so we used a standard conversion from counts to a photon spectrum based on the instrument response model and assuming the (predicted) spectrum $\propto E^{-2.3}$. (The conversion of counts to

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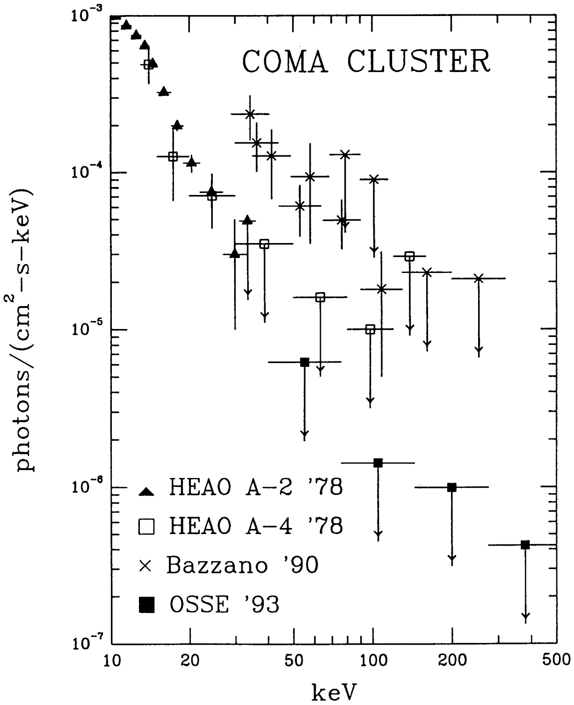

FIG. 1.—High-energy X-ray spectrum of the Coma Cluster: black squares are OSSE measurements discussed in the text; open squares denote *HEAO 1* A-4 (LED) measurements analyzed by RGR. Black triangles are *HEAO 1* A-2 data, and crosses are MIFRASO data (Bazzano et al. 1990; the inconsistency of these data with the other measurements is discussed by Rephaeli & Goldshmidt 1992). Error bars are 1 σ; upper limits are 2 σ.

photons is insensitive to the input spectrum—less than 10% effect in the ~50–500 keV range—for a wide range of spectra.) For improved statistics, we have binned the photon spectra into broader energy channels than those intrinsic to the instrument. The 2 σ upper limits on the photon flux in the energy band 40–300 keV are shown in Figure 1.

3. DISCUSSION

Radio measurements imply that electrons with energies in the (approximate) range 1–100 GeV (for magnetic fields in the range 0.1–1 μG) are present in the IC space of some clusters. The scattering of these electrons by the CMB results in radiation in the few keV to tens of MeV range. The predicted nature of HEX emission from clusters has been extensively explored (Rephaeli 1977a, b, 1979). The level of the HEX emission depends strongly on the value of the mean, volume-averaged magnetic field. Specifically, based on calculations in these papers, it was concluded that unless B assumes the relatively high value of few μG (i.e., a typical *Galactic* value), HEX emission in the 30–60 keV range would be expected at the 10^{-6} cm^{-2} s^{-1} keV^{-1} level.

Diffuse radio emission from the Coma Cluster was detected by many observers, most recently by Kim et al. (1990; see this paper for references to previous observations), who measured the emission at 408 and 1420 MHz. Their best-fit power-law spectrum to 21 data points yields

$$F_\nu \simeq (8.3 \pm 1.5) \times 10^{-12} \nu^{-1.34 \pm 0.06} \text{ ergs cm}^{-2} \text{ s}^{-1} \text{ Hz}^{-1} , \quad (1)$$

for the energy flux in the 10–1420 MHz band. Thus, the predicted electron power-law spectrum in the IC space of Coma has an index $p = 3.68$. Due to its small relative value (< 5%), as compared to other more appreciable uncertainties in our estimates below, we will here ignore the 1 σ uncertainty in the value of the power-law exponent.

The Compton photon flux, at energy ϵ, expected from the same electrons which emit the above radio synchrotron radiation is (e.g., Rephaeli 1979)

$$f_C \simeq (3.4 \pm 0.6) \times 10^{-18} B^{-2.34} \epsilon^{-2.3} \text{ cm}^{-2} \text{ s}^{-1} \text{ keV}^{-1} , \quad (2)$$

where B is the mean volume-averaged IC magnetic field in the central ~1 Mpc region of Coma (roughly the size of the radio source).

Using the standard Compton-synchrotron formulae and the 2 σ upper limits on the Compton flux, we compute a lower limit on the value of B: $B \geq 0.1$ μG. Note that the level of thermal emission at even the first OSSE energy channel is below 10% of the flux upper limit. (We have estimated this emission based on the best-fit spectrum [Hughes et al. 1993] from *Ginga* measurements of Coma.) The previous lower limit on B was obtained by RGR from A-4 measurements. Due to the revised, steeper radio spectrum (of Kim et al. 1990), our present limit on B is essentially identical to that obtained by RGR, $B \geq 1.1 \times 10^{-1}$ μG, even though the OSSE upper flux limit (in the lowest energy band in Fig. 1) is about a factor of ~2.5 lower than the corresponding A-4 limit.

Field values in the cores of clusters have been determined from Faraday rotation of the plane of polarization of radio waves from sources seen through clusters (Kim, Tribble, & Kronberg 1991). These authors deduced values which are generally around 1 μG, significantly higher than our lower limit. In comparing these results, however, it has to be remembered that rotation measures are essentially weighted averages of the field and gas density along the line of sight, whereas radio synchrotron emission depends on volume averages of the field. The specific relations between field values obtained from these very different observables strongly depend on the field morphology. For a general discussion and illustrative numerical examples, see Goldshmidt & Rephaeli (1993a).

While the limit on the mean value of the magnetic field is independent of the source size and distance (when it is assumed that the radio and HEX sources have the same size), the upper limit on the relativistic electron energy density does depend on these quantities. Taking a radio size of 40′ and a distance of 138 Mpc (assuming a Hubble constant of 50 km s^{-1} Mpc^{-1}), we compute an upper bound of 3.5×10^{-13} ergs cm^{-3} on the energy density of electrons with energies ≥ 500 MeV.

The basic conclusion from our result is that a total of 4.4 day (on-source) observation of Coma with OSSE is insufficiently sensitive for the detection of emission from this cluster. It can therefore be definitely concluded that the detection of the IC HEX emission necessitates an overall sensitivity better than a few times 10^{-6} cm^{-2} s^{-1} keV^{-1} in the 40–80 keV band. OSSE's inability to detect Coma is largely due to its high level of internal background, and large (3°.8 × 11°.4 full width at half-maximum) field of view. These two instrumental characteristics reflect the fact that OSSE was designed for measurements in the MeV, rather than the tens of MeV range. To reduce source confusion, detectors optimized specifically for HEX measurements of clusters should have ~1° × 1° fields of view. A level of internal background more than a factor of 10 lower than that of OSSE is quite realistic. Obviously, another very desirable feature of any future experiment is wide energy coverage, starting near (or below) 15–20 keV, in order to independently measure the tail of the thermal emission. Planned balloon (LLNL/UCSB) and satellite (XTE) missions will provide opportunities to continue the search for cluster HEX emission; however, long observing times will be required.

In at least one additional sense, our result yields a conservative lower limit on B, because we have not taken account of other sources of HEX emission which were in the OSSE field centered on Coma. In particular, the radio relic source 1253+275, which is roughly 70′ (~3 Mpc) from the Coma center, contributes significantly to the total HEX emission from this region, even if its mean magnetic field is as high as 1 μG (Goldshmidt & Rephaeli 1993b).

We are grateful to Bill Purcell for his help in the OSSE data reduction.

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