INVERSE COMPTON SCATTERING AS THE SOURCE OF DIFFUSE EXTREME-ULTRAVIOLET EMISSION IN THE COMA CLUSTER OF GALAXIES

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Received 1997 December 17; accepted 1998 May 29

ABSTRACT

We have examined the hypothesis that the majority of the diffuse EUV flux in the Coma Cluster is due to inverse Compton scattering of low-energy cosmic-ray electrons \((0.16 < \epsilon < 0.31 \text{ GeV})\) against the 3 K blackbody background. We present data on the two-dimensional spatial distribution of the EUV flux and show that these data provide strong support for a nonthermal origin for the EUV flux. However, we show that this emission cannot be produced by an extrapolation to lower energies of the observed synchrotron radio emitting electrons and that an additional component of low-energy cosmic-ray electrons is required.

Subject headings: cosmic microwave background — diffuse radiation — galaxies: clusters: individual (Coma) — intergalactic medium — ultraviolet: galaxies

1. INTRODUCTION

Diffuse EUV emission has been detected in five clusters of galaxies: Virgo (Lieu et al. 1996a), Coma (Lieu et al. 1996b), Abell 1795 (Mittaz, Lieu, & Lockman 1997), and Abell 2199 and Abell 4038 (Bowyer, Lieu, & Mittaz 1997). These clusters were detected with a statistical significance varying from 8 to 50 \(\sigma\). The diameter of the diffuse emission in these clusters ranges from 20' to 40'.

Some diffuse EUV emission in clusters of galaxies would be expected from the well-studied X-ray cluster emission. However, in all cases examined to date, the EUV emission is far greater than the expected emission from the X-ray-emitting gas. Marginal signatures of this “soft excess” are sometimes present in the lowest energy resolution band of the ROSAT Position Sensitive Proportional Counter (PSPC), where they produce less than a 20% enhancement over the emission expected from the X-ray cluster gas. In contrast, the excesses found with the Extreme Ultraviolet Explorer (EUVE) range from 70% to 600% above that expected from the X-ray gas. A variety of instrumental and Galactic interstellar medium absorption effects have been suggested as alternative explanations for the EUVE data, but these have all been found wanting (for a discussion of these issues, see Bowyer et al. 1997.)

In the original reports of diffuse EUV cluster emission, the data were interpreted in terms of additional thermal gas components in the clusters. In these analyses, the known X-ray emission from the hot cluster gas was first fitted to the EUV data, and the excess EUV emission was computed. This excess was then fitted by additional components of thermal gas. Because of the low energy of the EUV emission, much lower temperature thermal gases \((-10^6 \text{ K})\) are required. The concept that additional components of lower temperature gas are present in these clusters has not received wide support, primarily because gas at these temperatures is near the peak of the radiative cooling curve and hence cools rapidly, requiring a substantial energy input to sustain the gas at these temperatures. In addition, it is difficult to understand how different components of gas at grossly different temperatures could retain their separate identity. For example, the Coma Cluster has been shown to be formed by merging of distinct subunits, in both X-ray (White, Briel, & Henry 1993) and optical (Colless & Dunn 1996) studies. This produces variations less than a factor of 3 in temperatures of the X-ray-emitting gas (Honda et al. 1996). Deiss & Just (1996) have shown in a general analysis, and with specific application to the Coma Cluster, that turbulent mixing timescales are only a few times \(10^9 \text{ yr}\), which argues against the coexistence of major quantities of gas at two vastly different temperatures. However, Cen et al. (1995) have argued that a warm \((-10^6 \text{ K})\) thermal gas is widely distributed throughout the universe, as a direct product of the growth of structure leading, eventually, to clusters of galaxies. In their scenario, the energy required to sustain the warm gas is provided by gravitation.

Hwang (1997) has examined the hypothesis that the source of the diffuse EUV flux is inverse Compton scattering by electrons that are a low-energy extrapolation of electrons producing the observed synchrotron emission; these electrons are scattered against the 3 K blackbody background radiation. The magnetic field he derived for the cluster was 0.2–0.4 \(\mu\text{G}\), which is consistent with the range of estimates for the cluster field. In this work he considered only the constraints imposed by the total EUV flux.

Ensslin & Biermann (1998) also considered this mechanism as the source of the EUV flux in the Coma Cluster. They assumed that the relativistic energy density of the synchrotron emitting electrons scales radially with the same profile as the X-ray producing gas. This assumption can be questioned, since the nonthermal relativistic electrons may well be independent of the thermal X-ray gas. These authors cite as the best support for this assumption the data given in Figure 3 of Deiss et al. (1997), which compares the X-ray and radio radial emission profiles. Unfortunately, the results in this figure are incorrect, as has been confirmed by B. M. Deiss (private communication, 1998). These authors find a magnetic field of 1.2 \(\mu\text{G}\) is required. Given their assumptions, this field is also consistent with the range of estimates of the magnetic field for the cluster.

Sarazin & Lieu (1998) have explored the possibility that EUV radiation in clusters of galaxies could be produced by inverse Compton scattering by a population of very low energy cosmic-ray electrons. They showed that the one-dimensional EUV spatial profile for the cluster A1795, a radio-quiet cluster, was consistent with this hypothesis. A potential problem with this hypothesis as a universal expla-
nation for the EUV emission in clusters of galaxies is that the electrons they proposed have an energy density and pressure that are 1%–10% of that of the thermal gas in clusters. If one includes the ratio of the pressure of cosmic-ray ions to the pressure of the electrons, as proposed by Sarazin & Lieu, using the ratio expected on theoretical grounds (Bell 1978) and measured at Earth orbit (see, e.g., Weber 1983), the total cosmic ray pressure is substantially larger than that of the X-ray–emitting gas.

In this work we reconsider the hypothesis that the EUV emission in the Coma Cluster is the result of inverse Compton emission. We first consider the constraints imposed by the total EUV flux. We review the existing radio data and obtain a different, and we argue more appropriate, spectral index than that employed by Hwang (1997) and Ensslin & Biermann (1998). We then derive results that are generally consistent with the inverse Compton hypothesis. We then consider the two-dimensional spatial distribution of the EUV flux; the data provide substantial support for a nonthermal origin for this flux. We find that the spatial distribution of the magnetic field required by Ensslin & Biermann to produce the EUV emission profile is unrealistic. We show that the difference in spatial extent between the EUV and radio halos cannot be explained using an electron distribution that is an extrapolation of the known synchrotron-emitting electrons and that an additional population of low-energy cosmic-ray electrons are required to explain these data.

2. THE TOTAL INVERSE COMPTON EMISSION

Assuming that relativistic electrons produce the radio emission by synchrotron radiation, the observed power-law radio spectrum can be used to derive the number spectrum of the electrons in the cluster, which is normally characterized by a power-law spectrum of the form:

\[ N(\gamma) = N_0 \gamma^{-\alpha} \].

Following Pacholczyk (1970), the synchrotron emissivity of such an ensemble of relativistic electrons is

\[ \varepsilon_r = c_1(\gamma)N_0B^{(\gamma+1)/2} \left( \frac{\gamma}{2c_2} \right)^{(1-\gamma)/2}, \]

where \( \gamma \) is the radio frequency, \( B \) the magnetic field strength perpendicular to the line of sight, \( c_1 \) is a function of the spectral index of the electron spectrum \( \gamma \) (see Pacholczyk 1970), and \( c_2 \) is a constant. The observed radio flux is related to the emissivity by \( S_r = \varepsilon_r/D^2 \), where \( D \) is the cluster distance. (In this work we assume \( H = 50 \text{ km s}^{-1} \text{ Mpc}^{-1} \). For the same population of electrons, the total inverse Compton flux (see Blumenthal & Gould 1970; Ginzburg & Syrovatskii 1964) is

\[ F_{\text{IC}} = \frac{1}{4\pi D^2} \frac{8\pi^2 e^4}{h^3 m_e^2 c^5} f_1(\gamma)N_0(m_e c^2)^{-\gamma+1} \times (k_B T)^{(\gamma+5)/2} E \text{IC}^{(\gamma-1)/2}, \]

where \( E_{\text{IC}} \) is the energy of the comptonized photons, \( T \) the temperature of the microwave background, \( k_B \) Boltzman’s constant, and \( f_1 \) a function of \( \gamma \). The observed radio flux can be related to the inverse Compton flux by inserting \( N_0 \) from equation (2), which leads to the following relation

\[ F_{\text{IC}} \propto f(\alpha)F_{\text{sync}} B^{-(\alpha+1)}(k_B T)^{\alpha+3} E_{\text{IC}}^{-\alpha}, \]

where \( \alpha = (\gamma - 1)/2 \) is the photon number index, \( S \) is the radio flux, and \( f \) is a function of \( \alpha \).

We first review the observational data on the intensity and spectral index of the synchrotron emission in the Coma Cluster. We note that observations of synchrotron emission in clusters are quite difficult. Major problems include the difficulty of detecting low surface brightness diffuse radiation in regions containing blended point sources of emission, and a variety of technical difficulties, including problems in obtaining adequate integration volumes and correct intensity offsets. A number of authors have provided summaries of quality observations of synchrotron emission in the cluster, measured at frequencies ranging from 10.3 MHz to 4.85 GHz.

We are especially interested in lower frequency radio observations, since the electrons producing this emission are closer to the energies that will produce the inverse Compton EUV flux. With a magnetic field in the range of \( \approx 0.1–7 \mu \text{G} \) (as discussed in the following), electrons with energies in the range 0.16–0.31 GeV will produce EUV inverse Compton emission. The corresponding synchrotron emission will range from 4 to 15 MHz for a 0.1 \( \mu \text{G} \) field and from 0.4 to 0.15 MHz for a 1 \( \mu \text{G} \) field.

The lowest reported detection of radio flux from the Coma Cluster was by Bridle & Purton (1968), who carried out transient scans of 124 radio sources at 10.3 MHz using the Dominion Radio Astrophysical Observatory Low Frequency Array. Ionospheric effects were substantial at this frequency. The major thrust of this work was simply to detect the total low-frequency flux from sources in the Revised Third Cambridge Catalogue of Radio Sources, and detailed studies of individual sources were not carried out. The ratio of measured flux to expected flux for these sources varied by a factor of 10; the extent to which this was an observational effect or was due to true low-frequency cutoffs in the sources is not known. We believe this measurement to be sufficiently uncertain that we will not consider it further.

The next lowest frequency observation was made by Henning (1989). She used the Maryland Clark Lake telescope to obtain a detailed map of the Coma Cluster at 30.9 MHz. She then derived the total diffuse flux after subtraction of the contributions of discrete sources.

A substantial number of workers have measured this flux at frequencies above 30.9 MHz (see, e.g., the summaries in Kim et al. 1990; Giovannini et al. 1993, and Deiss et al. 1997). At high frequencies, measurements at 2.7 and 4.85 GHz fall below a simple extrapolation of the photon number spectral index derived from data at lower frequencies. Schlickeiser et al. (1987) have suggested that this may indicate a break in the photon number spectral index at higher frequencies, and Deiss et al. (1997) provide evidence that this is an instrumental effect. In either case, we believe it is most reasonable to use only the measurements at or below 1.4 GHz to derive a spectral index for the cluster.

The data between 30.9 MHz and 1.4 GHz are well fitted with \( \alpha = 1.16 \). We will use this value hereafter, although we note that many authors, and specifically Hwang (1997) and Ensslin & Biermann (1998), use the spectral index derived from the entire dataset that is best fitted with \( \alpha = 1.36 \).

We turn now to the question of the magnetic field in the cluster. A number of estimates of this field have been made. The simplest approach is to assume equipartition between
the energy in the magnetic field and the relativistic electrons. This approach has been used by Giovannini et al. (1993), who obtained a magnetic field of 0.5 μG.

Kim et al. (1990) measured the Faraday rotation of background radio sources shining through the cluster with background sources outside of the cluster region. This provided an estimate of the excess rotation through the cluster, which is due to free electrons produced by the thermal X-ray gas in the cluster. These workers obtained a value of 1.7 ± 0.9 μG in the cluster. Feretti et al. (1995) measured the depolarization of the radio emission from an active galaxy near the core of the cluster and obtained a magnetic field of 6 ± 1 μG. Each of these methods has its own set of difficulties; the existing data and theoretical arguments suggest the field is between 0.1 and 7 μG.

Calculations of the inverse Compton emission from gas in clusters of galaxies typically assume a spherical source and a spatially constant spectral index for the electrons as derived from the integrated flux density of the synchrotron emission at different frequencies. Using equation (4) and a model of this type, we have calculated the expected count rates in the Lexan/boron filter of the Deep Survey Telescope of the Extreme Ultraviolet Explorer (Bowyer & Malina 1991) as a function of magnetic field in the cluster for a spectral index of α = 1.16. The results are shown in Figure 1 as a solid line. In this figure we also show as a dotted horizontal line the excess EUV count rate above that expected from the X-ray-emitting cluster gas as obtained by Lieu et al. (1996b); the shaded region shows the 1 σ statistical errors in the measurement. These data suggest that the magnetic field in the cluster is B ≈ 0.2 μG. A spectral index which we have argued above is inappropriate) is shown as a dotted line. This would suggest B ≈ 0.4 μG.

Combinations of lower magnetic fields and steeper power law indices produce inverse Compton flux above the actual detected EUV flux. A straightforward conclusion is that the EUV data limit these parameters to the values indicated. However, an alternative possibility is that a mechanism is present that reduces the inverse Compton flux to the level actually observed.

The only mechanism we have identified that could reduce the EUV flux from this cluster is absorption by an extended neutral hydrogen halo. Such a halo would be extremely difficult to detect by its 21 cm emission. However, M. Urry (private communication, 1998) has obtained Hubble Space Telescope spectra of QSO 1258 + 285, which is in the line of sight of the cluster. This spectrum includes the redshifted wavelengths corresponding to Lyα absorption from neutral hydrogen in the cluster. The absorption observed is unsaturated and shows that N(H) ≲ 3 × 10¹³, which is clearly insufficient to absorb any appreciable EUV radiation.

3. THE SPATIAL DISTRIBUTION OF THE INVERSE COMPTON EMISSION

The EUVE data provide more information than simply the total EUV flux from the Coma Cluster; they also provide information on the spatial distribution of this flux. In Figure 2 we show an isophotal map of this flux. The emission is clearly not spherically distributed but is elongated in the east-west direction. We note that a fraction of the EUV flux is produced by the high-temperature X-ray-emitting plasma. This portion of the flux is almost spherical (White et al. 1993), and hence the asymmetric distribution of the total flux is the result of whatever process is producing the excess EUV flux.

We have quantified the distribution of the excess EUV flux. We first subtracted the EUV flux produced by the X-ray-emitting gas with T = 8.2 keV (Hatsukade 1990), a central electron density of 2.89 × 10⁻³ cm⁻³, and the best-fit King profile provided by Briel, Henry, & Böhringer (1992). We then fitted a two-dimensional Gaussian to the excess. The fit is reasonable (reduced χ² = 1.4 for 40 × 40 pixels of 1’ × 1’ size). The excess flux has a FWHM of 19.3 × 12.6 ± 1.5.

A number of studies of the spatial distribution of the Coma radio halo at different frequencies have been carried out. These all show an east-west elongation. In Table 1 we provide results from some of the more detailed radio investigations in which the authors have fitted a two-dimensional Gaussian to their data. As stated previously, the X-ray emission is almost spherical, and previous workers have not cited parameters for an asymmetric profile. For this work, we have quantified the X-ray distribution by fitting a two-dimensional King profile to the X-ray map of White et al. (1993). The FWHM of the X-ray emission derived from this fit is 17’ by 15’.

In Table 1 we also show an “aspect ratio” for the results obtained. This parameter is defined as the FWHM size of the larger dimension divided by the FWHM of the smaller dimension. The asymmetry of the EUV emission more nearly resembles the radio emission than the gravitationally bound, X-ray thermal gas emission. This is compelling evidence that the production mechanism for the EUV flux in the Coma Cluster is related to nonthermal processes and is not the result of a gravitationally bound thermal gas.

In Figure 3 we show the azimuthally averaged excess EUV count rate as a function of distance from the cluster.
Fig. 2.—Spatial distribution of the EUV emission from the Coma Cluster in excess of that expected from that produced by the high-temperature X-ray-emitting gas. The contour levels are counts s\(^{-1}\) deg\(^{-2}\). The image was created by convolving the raw data with a Gaussian with a FWHP equal to the on-axis point-spread function of the Deep Survey telescope (37'' and then subtracting a mean background estimated far from the cluster center. The data are well fitted by a Gaussian with a size of FWHP = 15.8 (reduced \(\chi^2 = 1.16\), which is shown as a solid line. The 1 \(\sigma\) error of the fit is shown as a gray shaded region. Within the errors, the EUV excess emission shows the same spatial azimuthally averaged distribution as the radio emission at 1.4 GHz (FWHP = 15.2).

Several groups (Giovannini et al. 1993; Deiss et al. 1997) have shown that at higher frequencies the spectral index of

| TABLE 1 |
| --- |
| **COMA HALO SHAPES** |

| size (FWHP) | aspect ratio | \(\nu\) | Reference |
| --- | --- | --- | --- |
| Radio | 31 \(\times\) 15 | 2.1 | 30.9 MHz | Henning (1989) |
| | 28 \(\times\) 20 | 1.4 | 326 MHz | Giovannini et al. (1993) |
| | 19 \(\times\) 14 | 1.4 | 14 GHz | Kim et al. (1990) |
| X-ray | 17 \(\times\) 15 | 1.1 | | White et al. (1993) |
| EUV | 19.3 \(\times\) 12.6 | 1.5 | | This work |
the synchrotron emission near the core of the cluster is substantially flatter than that farther out. Deiss et al. (1997) and Deiss (1997) have developed formalisms that relate the distribution of the spectral indices to the surface brightness distribution. In addition, they have developed a semi-empirical relationship between the radio halo size and spectral index distribution at two different frequencies. They show that the variation of the photon number spectral index is interrelated with the increasing cluster size at lower frequencies. This follows from the requirement that a larger halo size at lower frequencies requires a flux redistribution from the cluster center to larger radii. This effect is observed for the Coma Cluster in the frequency range 326 MHz–1.4 GHz.

However, at frequencies ≤ 326 MHz the radio halo size is essentially independent of frequency; the average FWHP at 30.9 MHz (~23') is about the same as observed at 326 MHz (~24'). Following Deiss et al. (1997), the α distribution will be constant. The existing data therefore imply a spectral index distribution at low frequencies that is almost constant throughout the cluster. Further, a decreasing halo size at lower frequencies would require a spectral index distribution that is steeper near the cluster center than at larger radii.

The radio halo size in the frequency range 30.9–326 MHz is significantly larger than the size of the EUV excess emission. This has far-reaching consequences for the interpretation of the Coma EUV excess. As can be seen from equation (4), the magnetic field distribution in the intracluster medium is related to the inverse Compton and synchrotron emission by

$$B^{-α-1}(r) ∝ \frac{F_{IC}(r)}{F_{sync}(r)}.$$  

For simplicity we use the azimuthally averaged halo sizes of \(FWHP_{IC} = 15.8\) and \(FWHP_{sync} = 24'.\) Assuming the electron distribution is radially independent, the magnetic field strength distribution \(B(r)\) is defined by the ratio \(F_{IC}/F_{sync}\) and must increase toward larger radii. Figure 4 shows the radial distribution of the magnetic field strength for this case. However, a radially increasing magnetic field appears to be unphysical, since this field must soon meld with the cluster field at larger radii.

We conclude that there is no straightforward way to produce the EUV halo with an electron population that is an extrapolation of the observable synchrotron-producing electrons.

In order to explain the EUV halo as inverse Compton emission from a population of electrons with reasonable properties, we must postulate an additional population of low-energy relativistic electrons in the central part of the cluster. These electrons will, by necessity, have an asymmetric distribution defined by the EUV emission profile, but for simplicity we use the azimuthally averaged Gaussian profile in the following. R. Lieu (1998) has made a power-law fit to the excess EUV flux using data from somewhat different bandpasses of EUVE and the ROSAT PSPC. He obtained a spectrum with a photon number index of \(≈ 1.75.\) If our scenario is correct, the photon number spectral index of the EUV emission and the electron number distribution will be the same, hence we use this index for our additional population of electrons. The only other observational constraint is imposed by the fact that these electrons cannot produce observable synchrotron emission. Accordingly, we use the 1 σ error in the 30.9 MHz observation (10 Jy) as an upper limit for the radio emission of this component.

The EUVE count rate for this population of electrons is shown as a function of magnetic field strength in Figure 1.

For clarity we use the azimuthally averaged halo sizes of \(FWHP_{IC} = 15.8\) and \(FWHP_{sync} = 24'.\) Assuming the electron distribution is radially independent, the magnetic field strength distribution \(B(r)\) is defined by the ratio \(F_{IC}/F_{sync}\) and must increase toward larger radii. Figure 4 shows the radial distribution of the magnetic field strength for this case. However, a radially increasing magnetic field appears to be unphysical, since this field must soon meld with the cluster field at larger radii.

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The EUVE count rate for this population of electrons is shown as a function of magnetic field strength in Figure 1.
We have normalized the result to the total energy, of metric Gaussian distribution to the EUV surface brightness profile. From the EUV emission profile assuming a spherically symmetric distribution of the relativistic electron population we have introduced to explain the EUV flux profile. The pressure of the relativistic electrons depends upon the energy, the pressure distribution for this population is given by the dashed line.

\[ P_{\text{electrons}}(r) = \int E_{\text{tot}} N_0 E^{-\gamma} dE = \frac{1}{\gamma-2} N_0 E_{\text{low}}^{2-\gamma} . \]  

The magnetic field that is required if the total EUV excess flux is produced by this population of relativistic electrons is \( \sim 0.35 \mu G \). This field is constant throughout the EUV emitting-region; we show this as a dotted line in Figure 4. Halo sizes with FWHP\(_{\text{sync}}\) less than this value lead to decreasing values of \( B(r) \) toward larger radii. A decreasing radio halo size at lower frequencies also implies a different distribution of electrons across the cluster showing an electron spectrum flattening with cluster radius. This results in a somewhat flatter, but nonetheless decreasing, magnetic field distribution across the cluster.

We have computed the pressure of the additional relativistic electron population we have introduced to explain the EUV flux profile. The pressure of the relativistic electrons is one-third of the energy density of these electrons; as a first-order approximation we used a spatial distribution with a FWHP of 15.8, which is the average value obtained from the EUV emission profile assuming a spherically symmetric Gaussian fit to the EUV surface brightness profile. We have normalized the result to the total energy, \( E_{\text{tot}} \), of the relativistic electrons. \( E_{\text{tot}} \) can be obtained by an integration of the electron energy spectrum given by equation (1), which leads to

\[ E_{\text{tot}} = \int_{E_{\text{low}}}^{\infty} N_0 E^{-\gamma} dE = \frac{1}{\gamma-2} N_0 E_{\text{low}}^{2-\gamma} . \]

The magnetic field in the cluster is constant throughout the EUV emitting-region; we show this as a dotted line in Figure 4. Halo sizes with FWHP\(_{\text{sync}}\) less than this value lead to decreasing values of \( B(r) \) toward larger radii. A decreasing radio halo size at lower frequencies also implies a different distribution of electrons across the cluster showing an electron spectrum flattening with cluster radius. This results in a somewhat flatter, but nonetheless decreasing, magnetic field distribution across the cluster.

We have computed the pressure for the X-ray-emitting gas (electrons and ions) as a function of cluster radius for a cluster temperature of \( kT = 8.2 \) keV (Hatsukade 1990), a central electron density of \( 2.89 \times 10^{-3} \) cm\(^{-3} \), and the best-fit King profile provided by Briel, Henry, & Böhringer (1992). We display these results in Figure 5 as a solid line.

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4. CONCLUSIONS

We have examined the hypothesis that the EUV radiation from the Coma Cluster is due to inverse Compton scattering of low-energy cosmic-ray electrons against the 3 K blackbody background radiation. The total integrated EUV emission produced by cosmic-ray electrons that are a low-energy extrapolation of higher energy electrons, known to be present from their synchrotron emission, gives results that are consistent with the range of estimates of the magnetic field in the cluster.

We next consider the two-dimensional spatial distribution of the EUV emission. This emission does not follow the distribution of the gravitationally bound X-ray gas but rather exhibits an asymmetric distribution similar to that exhibited by the radio emission. This suggests a nonthermal origin for the EUV emission rather than a gravitationally constrained thermal gas.

We show from a comparison of the size of the EUV halo and the radio halo that the EUV emission cannot be produced by inverse Compton radiation from electrons that are an extrapolation of the distribution that produces the observed radio emission. We develop a model for the EUV emission that is self-consistent and fits the existing data. This model requires an additional component of low-energy cosmic rays.

Inverse Compton EUV emission is surely present at some level in clusters of galaxies with radio halos. However, it may well be masked by emission from some other more dominant source mechanism. A test of the inverse Compton scattering hypothesis as the source of the EUV flux in the Coma Cluster would be provided by a measurement of the size of the radio halo at \( \sim 1 \) MHz. Unfortunately, this is a challenging measurement because of instrumental limitations and ionospheric effects. In addition, at these low frequencies, self-absorption could affect the surface brightness profile by reducing the flux near the cluster center while increasing the halo size; this effect would have to be considered carefully when interpreting such a measurement.

We thank Bruno Deiss, Philipp Kronberg, Hans Böhringer, Thorsten Ensslin, Peter Biermann, Michael Lampton, Richard Lieu, Greg Sarazin, and Chorng-Yuan Hwang for useful discussions and suggestions. We thank Martin Sirk for the isophot map of the EUV emission. T. W. B. acknowledges the support from the Alexander-von-Humboldt-Stiftung (AvH) by a Feodor-Lynen Fellowship. This work has been supported by NASA contract NAS 5-30180.
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