Celestial Origin of the Extended EUV Emission from the Abell 2199 and Abell 1795 Clusters of Galaxies

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Abstract

Several authors (S. Bowyer, T. Berghöfer, and E. Korpela, hereinafter abbreviated as BBK) recently announced that the luminous extended EUV radiation from the clusters Abell 1795 and Abell 2199, which represents the large scale presence of a new and very soft emission component, is an illusion in the EUVE Deep Survey (DS) detector image. Specifically BBK found that the radial profile of photon background surface brightness, for concentric annuli centered at a detector position which has been used to observe cluster targets, shows an intrinsic ‘hump’ of excess at small radii which resembles the detection of extended cluster EUV. We accordingly profiled background data, but found no evidence of significant central excess. However, to avoid argument concerning possible variability in the background pattern, we performed a clincher test which demonstrates that a cluster’s EUV profile is invariant with respect to photon background. The test involves re-observation of A2199 and A1795 when the photon background was respectively three and two times higher than before, and using a different part of the detector. The radial profiles of both clusters, which have entirely different shapes, were accurately reproduced. In this way the BBK scenario is quantitatively excluded, with the inevitable conclusion that the detected signals are genuinely celestial.

1. Introduction

Since the original EUVE discovery (Lieu et al 1996a) of the CSE effect, substantial development in the field has taken place, including the ROSAT and BeppoSAX confirmatory detection of soft X-ray (0.1 - 0.4 keV) excesses (Lieu et al 1996a,b; Bowyer, Lampton and Lieu 1996; Fabian 1996; Mittaz, Lieu and Lockman 1998; Bowyer, Lieu and Mittaz 1998; Kaastra 1998, Kaastra et al 1999) from Virgo, Coma, A1795, A2199, and A4038, and the proposition of theoretical ideas which relate the CSE to other new radiation components (in particular the hard excess (HEX) emission recently found from some clusters; details and references may be found in Ensslin and Biermann 1998, Sarazin and Lieu 1998, Rephaeli et el 1999, Kaastra 1998 and Fusco-Femiano et al 1998).

Despite the exciting progress, some researchers continue to question the reality of CSE. In a recent workshop on clusters of galaxies (Ringberg 1999) BBK suggested that the detection of spatially extended EUV emission from the clusters A1795 and

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A2199 (Mittaz, Lieu, and Lockman 1998, Lieu, Bonamente, and Mittaz 1999), which implies a radially increasing importance of the CSE, results from an error in the photon background subtraction procedure.

The original authors of the CSE detection determined the background level from a large outer annulus (typically between 15 and 30 arcmin cluster angular radii) of the EUVE Deep Survey (DS) Lex/B (69 - 190 eV) image, a region where the radial profile of the cluster surface brightness has reached asymptotic flatness (i.e. the brightness no longer falls with radius). BBK, on the other hand, asserted that the photon background radial profile is enhanced from the asymptotic level within a circle of radius \( \sim 15 \) arcmin centered at a position of the detector where observations of clusters were performed (the enhancement is in the form of a ‘hump’ which peaks at \( \sim 5 \) arcmin radius); outside this circle the profile does not flatten, but gradually decreases with radius. Thus the original usage of an asymptotic background would have led to an undersubtraction effect in the central 15 arcmin region, and hence a false detection of cluster EUV.

BBK then applied the forementioned photon background profile as a ‘template’ (i.e. the shape remains unchanged and the ‘normalization’ is adjusted to obtain agreement with the measured photon background of a cluster field at large radii) in a ‘revised’ background subtraction procedure which led to the removal of all previously detected cluster signals from A1795 and A2199 at radii beyond \( \sim 5 \) arcmin. Moreover within 5 arcmin the CSE was turned into an intrinsic cluster absorption effect, with the detected brightness being \textit{smaller} than the amount of EUV expected from the hot intracluster medium (ICM).

![Figure 1: A2199 surface brightness profile in the 0.1 - 0.2 keV band as observed by the EUVE/DS and SAX/LECS detectors; the solid and dashed lines give the respective expected DS and LECS brightness had the soft emission been due only to the hot ICM gas radiation, thereby revealing CSE at the outer portions of the cluster.](image-url)
2. No CSE for A1795 and A2199?

The results of BBK raise several perplexing questions.

(a) The CSE effect was confirmed by the LECS instrument aboard BeppoSAX (Kaastra et al 1999, see also Figure 1). The radially rising trend of the CSE, as detected by LECS, is commensurate with that found by EUVE/DS (Figure 1) when instrument effective areas are taken into account. Moreover the LECS soft excess was noted to exist only below 0.2 keV, again in agreement with the conclusion obtained from simultaneous modeling of the EUVE/DS and ROSAT/PSPC data of this cluster.

(b) A multi-scale wavelet analysis of the EUVE/DS data of A1795 (Durret et al 1999) shows clear signatures of cluster emission out to a radius of at least 8 arcmin with the isophot levels rising radially to reach a factor of \( \sim 4 \) above those expected from the hot ICM (see Figure 2). The same technique as applied to a background field of comparable exposure (see next section for details of this field) revealed no statistically significant features at \( \geq 3 \sigma \) level around detector areas where clusters were normally observed by the DS. To facilitate direct appreciation by the reader of these points, FITS images of A1795 (90 ksec exposure), A2199 (48 ksec) and background (85 ksec) can be downloaded via anonymous ftp to [ftp://cspar.uah.edu/input/max](http://cspar.uah.edu/input/max) (the README.TXT file contains further information). These images are raw data (for precise meaning see section 3) which underwent only one stage of additional processing: they were smoothed with a constant gaussian filter (size commensurate with the DS point spread function) to enhance larger features. Each image has equal spatial scale, and the central portion corresponds to the same part of the DS detector. It will immediately be obvious to the viewer that the cluster fields exhibit a luminous extended glow (with A2199 particularly sprawling) which is not reproduced in the background field.

(c) The additional background subtracted by BBK did not lead to the removal of CSE.
from the Virgo and Coma cluster data. A natural puzzle is why these two clusters exhibit CSE but not the others (in fact the rest suffer from the opposite effect: they are strongly intrinsically absorbed). We note in this regard that the presence of CSE in Virgo and Coma excludes the possibility of a simple correlation or anti-correlation between the CSE on one hand, and cooling flow or merging/subclustering on the other.

(d) The strong intrinsic absorption of A1795 and A2199 within cluster radii of $\sim 5$ arcmin should have measurable effects in the ROSAT/PSPC 0.25 keV band and in the LECS data at energies $\geq 0.2$ keV, yet it is not immediately obvious why such effects are totally absent from the PSPC and LECS data of A1795 and A2199.

At the request of workshop participants, including some of the scientific organizers, we are circulating this memo to address the BBK criticism of the CSE. In particular we shall demonstrate that the EUVE/DS photon background does not exhibit a template radial distribution involving excess counts at small radii. In fact the integrity of the original method of asymptotic background subtraction is assured by pairs of observations of the same clusters, under conditions of very different photon background levels, yielding the same radial brightness dependence which varies only from cluster to cluster.

3. Background radial profiles from blank fields

Public domain EUVE DS data are accessible from HEASARC, and standard data products (hereinafter referred to as raw data) are obtained by running routine pipeline software packages which accept satellite telemetry as input. The raw data (with a background that includes photons, particles, and detector intrinsic noise) can further be processed in any number of ways, some of which could lead to artifacts. The CSE results published so far are, however, based on the analysis of raw data. We show in Figure 3 the radial profiles of the DS background, obtained with the center at $\sim 3$ arcmin.

Figure 3: Left: Radial profile of EUVE/DS background with center at $\sim 3$ arcmin off-axis. Right: same as left panel, except center is now at $\sim 10$ arcmin off-axis. In each case the dotted line represents the average brightness between 15 and 30 arcmin (a region typically chosen to determine the background of cluster fields).
and \( \sim 10 \) arcmin off-axis along the detector x-axis, i.e. the direction parallel to the long side of the relevant (Lex/B) filter. The data were gathered by merging three blank field pointings which took place in July 1994 and December 1996, with a total exposure of \( \sim 85 \) ksec, comparable to the longest cluster observation by EUVE. It can be seen from Figure 3 that the profiles reveal no significant central enhancement - there are no signatures of extended emission resembling those of A1795 (Figure 1 of Mittaz et al 1998) or A2199 (Figure 1 of Lieu, Bonamente and Mittaz 1999). Specifically for the left plot the average 0 - 15 arcmin background is \( 1.75 \pm 0.50 \) \% higher than the 15 - 30 arcmin value, and for the right plot the same comparison yields \( 0.9 \pm 0.5 \) \%.

A technique often applied to reduce the raw background by removing its particle component in the cluster signal is pulse height (PH) thresholding. It has the positive effect of lowering the Poisson noise in the cluster signal. In brief, one first constructs a PH histogram of all detected counts, which consists of a normally distributed peak of photon events superposed upon an underlying (pseudo power-law) continuum of particle events. By suitably setting the PH thresholds to select only events within the photon peak, it is possible to reject the majority of the particle background without compromising the cluster signal. The precise fractional reduction of the particle component varies from one dataset to the next. As an example, for the first observation of A2199 at least \( \sim 62 \) \% of the background was due to particles, and was removed by PH thresholding. The resulting product, from which BBK derived the photon background, is no longer a raw dataset. However, if proper processing is performed the integrity of the PH thresholded data may still be maintained, as demonstrated by Figure 4 where there is close resemblance between the radial profiles of the raw and PH thresholded data (with no extra features in the latter) for the clusters A1795 and A2199. We also

\[ \text{Figure 4: Left: Background subtracted radial profiles of raw and photon (PH thresholded) data from an EUVE/DS observation of A1795. Right: same as left, now for A2199. Point sources and detector artifact contributions were removed. Note in each case the excellent agreement between the profiles.} \]

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\[ \text{the former is the position where clusters centroids were located during the cycle 4 and 5 observations, while the latter is the position for the cycle 6 re-observations of, e.g., A2199.} \]

\[ \text{3Defined as fields which do not contain bright sources. The three specific datasets correspond to the targets 2EUVE J1100+34.4, 2EUVE J0908+32.6, and M15.} \]
note in passing that, like the raw profile and unlike the BBK template, the thresholded photon background is flat - it does not exhibit BBK’s downward slope from 10 arcmin outwards (Fig. 4, left). Thus such a pattern, even if it were to exist, is not the norm of behavior, and certainly does not have to be be present in every observation.

Figure 5: PH thresholded and background subtracted A2199 radial profiles as obtained by the original observation (Fig. 4) and another observation which took place approximately one year later; all point sources and detector artifact contributions were removed. Note again the consistency of the two profiles.

4. Still, does this mean Lieu et al were right?

At the very least, therefore, it is clear that the DS background profile is not a template which carries features reminiscent of a cluster detection, as advocated by BBK. On the other hand, BBK did prompt an intriguing question, viz. given that the EUVE/DS background (like that of most satellite detectors) is a complex function of many parameters, how can one *guarantee* that the original asymptotic subtraction procedure is correct, short of actually measuring the background underlying each cluster at the time of every observation (an impossible task)?

Fortunately there is a clear answer to even this question. The test is essentially an extension of the approach depicted in Figure 4.

5. Clincher test of background subtraction - the reproducibility of cluster EUV signals

The longevity of EUVE made it possible for repeated observations of the same clusters - indeed some of these took place within cycle 6. The DS background of the re-observations is in general considerably higher (typically by a factor of ∼ 2) than that of the original data, *mainly due to an increase in the photon background*. Further, to explore the effects of detector uniformity the clusters were usually re-observed in a different detector position, some 10 arcmin off-axis as described earlier. Thus, e.g.,
in the case of A2199 a comparison using PH thresholded data reveals that during re-observation the photon background was $\sim$ three times higher than before.

New data for three bright clusters: A2199, A1795, and Coma are available, and in every case the signals peter out to a flat background with a radial profile which is consistent with that of the original observation. As an example, we show in Figure 5 the PH thresholded and background subtracted profiles of A2199.

The significance of this agreement, however, lies in the fact that the large difference in the photon background level between each pair of observations clinches any scenario which attributes cluster signals to a centrally enhanced template profile of the photon background. To prove our statement, Figure 6 shows the radial profiles in the form of percentage above this background.

It is clear that within the context of the BBK scenario the photon background must assume two templates, suitably correlated with each other as to produce the same absolute brightness profile (Figure 5)! In particular, if the 5 - 15 arcmin signals were to be a background variation effect (as advocated by BBK) this variation will have to form templates (Figure 6) which are statistically distinct, and which conspired to

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4 Data for Coma and A1795 only reinforce the same points made by Figures 5 & 6. They are therefore not shown here, except to add that for A1795 BBK also noted the reproducibility of the radial profile, and that the re-observation photon background is twice as high as before, again quantitatively excluding any part of the cluster detection as a background effect.

5 The conspiracy could exist in a ‘relatively simple’ form if the higher re-observational background is due primarily to an increase in the level of a ‘flat profile’ component, such as particles, superposed upon a photon component which is constant, and which carries an intrinsic enhancement at the inner radii where cluster EUV were reported. However, this scenario is not viable because Figures 5 and 6 refer to thresholded background, which consists principally of photons (see earlier discussion). Certainly particles cannot be responsible for the 3-fold increase of the background in the new A2199 data.
yield Figure 5.

6. Another cosmic conspiracy

Finally, suppose we do accept the last two statements of the previous section as truth, do we need even more cosmic coincidences to explain any ‘loose ends’ that may still exist? If yes, then perhaps one can safely declare that the premise of CSE as a background variation effect has been given sufficient ‘benefit of the doubt’, and exclude it as a sensible, viable approach?

The answer is indeed yes, for if there exists highly contrived ‘multiple templates’ which correspond to a single absolute brightness profile irrespective of the background level (the ‘beyond BBK’ scenario described in section 4), one will be forced to conclude that such a profile must apply to every cluster observed by EUVE, i.e. all clusters must appear in the EUV like A2199. That this is not the case is immediately revealed by a comparison of the brightness profiles of A2199 and A1795. As Figure 7 clearly shows, they are not consistent with each other.

The evidence presented are sufficient to secure a firm conclusion. The radial profiles of blank sky and pairs of cluster fields provided stringent tests of the integrity of the background subtraction procedure used by the original authors who announced the CSE discovery. The verdict is favorable: while it is always possible to interpret the data in a less straightforward way, any attempt to attribute genuine cluster signals to illusions created by substantial deviations from flatness of the underlying background profile must invoke several very artificial arguments. In fact, the only premise upon which one can sensibly explain all the data is that for the clusters in question the underlying background were reasonably flat, and the correct cluster EUV profiles are the published ones.
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