LOW-ENERGY X-RAY EMISSION FROM THE ABELL 2199 CLUSTER OF GALAXIES

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ABSTRACT

In a recent Letter, Berghöfer & Bowyer rediscussed the analysis of BeppoSAX LECS data of the cluster of galaxies Abell 2199 as presented by Kaastr et al., in particular the detection of a soft X-ray excess. Berghöfer & Bowyer stated that their analysis method is better suited and does not show evidence of a soft X-ray excess. Here we find it necessary to publish a rebuttal because it can be demonstrated that the method used by Berghöfer & Bowyer is oversimplified, leading to an erroneous result. As a consequence, their statement that our initial analysis is incorrect is invalid, and the detection of a soft X-ray excess in A2199 is still confirmed.

Subject headings: galaxies: clusters: general — galaxies: clusters: individual (Abell 2199) — X-rays: galaxies

1. INTRODUCTION

The X-ray spectrum of the cluster of galaxies Abell 2199 has been studied using many instruments. The detection of a soft X-ray excess in this cluster was first claimed by Bowyer, Lieu, & Mittaz (1998), based on Extreme Ultraviolet Explorer (EUVE) data, although they do not represent any analysis work. Kastra et al. (1999) analyzed the BeppoSAX data of this cluster of galaxies and found evidence of both a soft and a hard X-ray excess at radii larger than 300 kpc. This last analysis was based on spatially resolved spectroscopy with data from the BeppoSAX, EUVE, and ROSAT missions.

However, in a recent Letter, Berghöfer & Bowyer (2002, hereafter BB) made categorical statements that the analysis of Kastra et al. (1999) is flawed. BB say explicitly that “Unfortunately, the telescope sensitivity profile used is likely to be incorrect,” that “BeppoSAX LECS does not detect an EUV excess when the data are analyzed correctly,” that “using a procedure better suited to the analysis of extended sources we have already been presented in our earlier work (Kaastra et al. 1999).” Unfortunately, the telescope sensitivity profile used is likely to be incorrect,” that “BeppoSAX LECS does not detect an EUV excess when the data are analyzed correctly,” that “using a procedure better suited to the analysis of extended sources we have already been presented in our earlier work (Kaastra et al. 1999).”

For a clear discussion of this controversy, we focus on the data analysis method used previously by us and that hereafter we will refer to as the “BB” method. We do not address the question of the existence of a soft X-ray excess in Abell 2199, since this has already been presented in our earlier work (Kaastra et al. 1999).

2. SUMMARY OF THE DATA ANALYSIS BY KAASTRA ET AL.

The data analysis method used previously by us has been described by Kastra et al. (1999). Briefly, the cluster was divided into seven concentric annuli, centered around the bright cD galaxy, with outer radii of 3', 6', 9', 12', 15', 18', and 24'. Background-subtracted spectra for these regions were obtained from the BeppoSAX Low and Medium Energy Concentrator Spectrometers (LECS and MECS, respectively), High Pressure Gas Scintillator Proportional Counter, and Phoswich Detection System as well as from the ROSAT Position Sensitive Proportional Counter (PSPC) and the EUVE Deep Survey (DS). The background for the BeppoSAX LECS and MECS instruments was obtained from the standard blank-sky observations, and it was verified that the background level during our observation was not enhanced because of a higher level of particle activity.

For the study of the soft excess, the most important instruments are the LECS, PSPC, and DS, but the data of all instruments in the entire 0.1–100 keV range were used and fitted simultaneously.

The instrumental point-spread function (PSF) of the LECS instrument is a strong function of energy (Parmar et al. 1997). For example, at 0.28 keV, the energy resolution is 32% (FWHM), and the angular resolution is 9.7' (FWHM). Both scale approximately with the incoming photon energy E as E~0.5. Moreover, the wings of the PSF are strongly non-Gaussian. Thus, at low energies, a significant fraction of the flux generated in a given annulus extends to the neighboring annuli, so that the annular spectra are coupled and need to be fitted simultaneously.

Therefore, in our analysis, we fitted the spectra of all eight annuli and all instruments (26 spectra in total) simultaneously. In the response matrices, the position- and energy-dependent vignetting factors were taken into account as well as the effects of the (energy-dependent) overlapping PSF for the different annuli.

The spectral model that we used consists of a thermal plasma in collisional ionization equilibrium for each annulus. For the inner regions, the possible effects of resonance scattering have also been taken into account for the iron Kα complex. In addition, a cooling-flow model with partial absorption has been included in the central annulus.

After applying this model to the data, we found evidence at the 99.99% confidence level of the soft excess as described by Kastra et al. (1999). In particular, in the 6'–12' range, the 0.1–0.3 keV excess luminosity above the thermal component is 25%. In this region, the subtracted background is smaller than 15% of the cluster signal, while the large-scale variations of the background in this region of the sky are less than 10% of this background.
3. SUMMARY OF THE DATA ANALYSIS BY BB

3.1. Background Subtraction

BB focus much of their attention on the background subtraction. However, as we noted above, this is not really a matter of concern for the observed cluster signal since (1) the background in the relevant radial range is relatively small and (2) its level during the A2199 observation was of average level and not enhanced.

BB attempted to divide the background into a flat, time-dependent particle background plus an X-ray background. Much earlier, Parmar et al. (1999a, 1999b) already showed that the particle contribution in the 0.1–0.5 keV band is small, less than 13% of the total, and that it even decreased by about 15% over 2 yr (our A2199 observation is in the middle of this period). Also, a study of the MECS background (see F. Fiore, D. Ricci, & P. Giommi 1997)† indicates that the particle background does not vary in time by more than 30% of the total background. The remaining background is the cosmic X-ray background. Since the LECS only operates during satellite night time, any contribution to the background from scattered solar X-rays is negligible (Parmar et al. 1999b).

However, BB scaled the remaining nonparticle background for A2199 and A1795 by a factor of 4.4 and 3.9, respectively, and explained the magnitude of the scaling factor by time-variable–scattered solar X-rays. This is grossly inconsistent with the negligible level of solar X-ray photons mentioned above. Moreover, BB did not at all explain quantitatively how they arrived at this scaling factor. BB attempted to divide the background into a flat, time-dependent particle background plus an X-ray background. Much earlier, Parmar et al. (1999a, 1999b) already showed that the particle contribution in the 0.1–0.5 keV band is small, less than 13% of the total, and that it even decreased by about 15% over 2 yr (our A2199 observation is in the middle of this period). Also, a study of the MECS background (see F. Fiore, D. Ricci, & P. Giommi 1997)† indicates that the particle background does not vary in time by more than 30% of the total background. The remaining background is the cosmic X-ray background. Since the LECS only operates during satellite night time, any contribution to the background from scattered solar X-rays is negligible (Parmar et al. 1999b).

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3.2. Radial Profiles

BB questioned the reliability of the low-energy calibration of the LECS. The low-energy response used by us is based on ray-trace simulations. This is what is available to the general observer. BB quote Parmar et al. (1997) regarding a discrepancy by a factor of 1.5 at low energies (0.18 and 0.28 keV) between ray-trace simulations and ground measurements. However, Parmar et al. suggested that the discrepancy may be caused by the scattered X-ray photons during the ground calibration measurements, that there is yet no convincing explanation, and that in-flight measurements are needed to resolve this. Since BB did not offer an improved in-flight calibration or ray-trace model, they essentially use the same calibration data as we did, and therefore if our analysis would contain flaws as a result of this effect, so the same will be true of theirs.

BB attempt to avoid potential calibration problems (without solving them) by switching to a radial profile analysis. First they noted that at low energies, the FWHM of the instrument is large, in particular in the 0.1–0.3 keV band. Such a non-uniform resolution is undesirable if radial profiles in different energy bands are compared. Therefore, they convolved the radial profile in the high-energy band (0.5–2.2 keV) with a Gaussian of 9.7 FWHM. Using a spectral model for the cluster, they then compared this scaled, convolved 0.5–2.2 keV profile with the observed, unconvolved 0.1–0.3 keV band. The comparison shows no soft excess, not even a small soft X-ray deficit in the center, and this leads BB to the conclusion that our analysis is wrong.

There are several reasons why this simplified approach by BB is unacceptable. Specifically:

1. Convolving the 0.5–2.2 keV image with a Gaussian does not render it compatible with the resolution of the 0.1–0.3 keV image. This is mainly due to the strong, non-Gaussian tails of the instrumental PSF, as we show in the next section.

2. Degradation of the images by smoothing destroys essential information.

3. The radial profile in the 0.1–0.3 keV band is also significantly affected by the low-energy response of higher energy photons (32% FWHM at 0.28 keV). Thus, the radial profile in this band is sensitive to spectral variations as a function of radius.

4. The effective vignetting corrections to be made are dependent on both energy and position, and these have been apparently neglected by BB.

5. The 0.5–2.2 keV band contains the Fe-L complex, which can be quite strong in moderately cool clusters such as A2199. In particular, the strength of this complex depends on both the amount of central cool gas as well as metallicity. Since both components vary strongly with position, this biases the 0.5–2.2 keV flux.

In particular, item 1 is very important for the analysis of the soft X-ray excess, as we show below.

4. RADIAL PROFILES

In order to understand what really happens in the analysis of BB, we present here some simulated radial profiles. First, we generated a cluster emission profile, for which we have chosen for demonstration purposes a simple $\beta$-model, with a core radius $r_c$ of 2.6 and $\beta = \frac{3}{4}$, parameters that approximately describe the structure of the A2199 cluster of galaxies. This image is then convolved with the monochromatic instrumental PSF of the LECS. A sufficiently accurate parameterization for the present purpose, based on the publicly available calibration data, is given by

$$F(r) = 1 - [1 + (x/a)^2]^{-\frac{1}{2}},$$

where $F(r)$ is the encircled energy fraction of the instrument. For energies of 0.19, 0.277, and 0.93 keV, the scale height $a$ is 16.27, 14.70, and 5.50, and $b$ is 10.57, 13.32, and 5.12, respectively. Finally, we then convolve the high-energy image with a Gaussian for which $F(r) = 1 - \exp(-r^2/2\sigma^2)$, with $\sigma = 4.12$, corresponding to the FWHM of 9.7 as used by BB.

In Figure 1, we show the results of our analysis. In all but one case, we have chosen an effective energy of 0.19 keV for the low-energy band (around the center of the soft 0.1–0.3 keV band of BB) and 0.93 keV for the high-energy band (around the effective center of the 0.5–2.2 keV band of BB). In all cases, we plotted the ratio of the soft to hard band, for an equal number of photons.

Case A in Figure 1 shows the profile ratio for an isothermal cluster, without convolving the high-energy band with a Gaussian, thus reflecting purely the instrumental PSF. The strong drop in the center demonstrates the effect of the broader PSF at low energies. It is evident that even for a cluster without spectral variations, the radial profile ratio varies strongly and is nowhere equal to unity.

† SDC Report on LECS and MECS Dark Earth Background (http://bepposax.gsfc.nasa.gov/bepposax/software/cookbook/rep_dark_497.html).
Case B in Figure 1 is similar to case A, but now we convolved the high-energy band with a Gaussian as BB did. Again, for an isothermal cluster, the ratio varies strongly as a function of $r$, but now with opposite signatures compared with the previous case. Apparently, the hard band has been smoothed too much. Adopting the approach of BB, a soft flux deficit around 10$^\circ$ would indeed have been inferred, despite the fact that the cluster is isothermal. Taking one step further, if BB would have corrected their profile with a curve like case B, they would have found the soft excess reported by us!

Case C in Figure 1 is similar to case B (i.e., an isothermal cluster with the BB approach of smoothing the high-energy band), but now for a low-energy band of 0.277 keV instead of 0.19 keV. The oversmoothing of the high-energy band is more evident here. The comparison of curves B and C shows that if radial profiles are used for this kind of analysis, the spectral/spatial energy distribution should be known and modeled appropriately. This has not been done by BB.

Case D in Figure 1 simulates the effect of the presence of a cooling flow or an abundance gradient. It shows the theoretical hardness ratio in case the core radius of the hard component is 0.8 times smaller than that of the soft component. This mimics, e.g., the case when the Fe-L complex (in the hard band) is centrally concentrated, because of either an abundance gradient or a cooling flow. The profiles have not been convolved with the instrument or the Gaussian. It also has an ~20% excess beyond ~6$'$, thereby mimicking approximately the soft excess as found by us in A2199.

Finally, case E in Figure 1 corresponds to the case presented in case D, but now the profiles are convolved with the instrument and the hard band convolved with the Gaussian. A comparison of curve E with curve D shows that the convolved profile is completely different from the original profile, and comparing curve E with curve B shows that the differences due to a different cluster model are partially washed out, thus confirming that the method of BB tends to destroy information by oversmoothing.

All these effects are completely neglected by BB. They simply compare their results with the expected—scaled—softness ratio of 1 rather than the appropriate curve. That curve can only be obtained by a full spatial/spatial analysis as, e.g., done by our team. But then the procedure of BB is obsolete since our spectral modeling already gave the correct answers.

5. CONCLUSIONS

We have shown in this Letter that the analysis method of BB for assessing the soft excess in A2199 is inadequate and leads to erroneous conclusions regarding the presence of a soft excess.

In fact, the method of BB is oversimplified since it neglects the intricacies associated with the position and energy dependence of the effective area as well as the spatial/spectral dependence of the LECS PSF.

As a consequence of their inadequate analysis, the results presented by BB are misleading, in the sense that a simple method that makes use of radial profile ratios is purported to be better than a full, sophisticated spatial/spectral analysis, without assessing both methods in a controlled experiment. As we have shown here, their method leads to unpredictable, erroneous results.

The discussion of BB is also misleading because they claim that the finding of a soft excess by Kaastra et al. (1999) is due to calibration problems, while BB neither established this nor used a better LECS calibration.

Finally, we have shown that the method of BB is also wrong because of a misunderstanding of the BeppoSAX background and corresponding background subtraction errors.

In conclusion, we have shown in this Letter that our previous results on the soft X-ray excess in A2199 are still valid within the uncertainties related to the spectral and spatial sensitivity of the BeppoSAX LECS detector. It is clear that a further investigation of the presence of the soft excess in A2199, confirming or refuting it, can only come either from a thorough recalibration of the BeppoSAX instruments or from forthcoming observations with other satellites with higher sensitivity, such as the XMM-Newton satellite.

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REFERENCES

Berghöfer, T. W., & Bowyer, S. 2002, ApJ, 565, L17 (BB)
Bowyer, S., Lieu, R., & Mittaz, J. 1998, in IAU Symp. 188, The Hot Universe, ed. K. Koyama, S. Kitamoto, & M. Itoh (Dordrecht: Kluwer), 185
Kaastra, J. S., Lieu, R., Mittaz, J. P. D., Bleeker, J. A. M., Mewe, R., Colafrancesco, S., & Lockman, F. J. 1999, ApJ, 519, L119
Parmar, A. N., Guainazzi, M., Oosterbroek, T., Orr, A., Favata, F., Lumb, D., & Malizia, A. 1999a, A&A, 345, 611
Parmar, A. N., et al. 1997, A&AS, 122, 309
Parmar, A. N., Oosterbroek, T., Orr, A., Guainazzi, M., Shane, N., Freyberg, M. J., Ricci, D., & Malizia, A. 1999b, A&AS, 136, 407