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ASTRONOMY AND ASTROPHYSICS

BeppoSAX observation of Hercules A and MRC 0625-536

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Abstract. We present BeppoSAX observations of the two FR I type radio galaxies Hercules A (3C 348) and MRC 0625-536 in the energy range $0.2-200$ keV. Data analysis shows that the X-ray flux from Hercules A is consistent with a diffuse thermal plasma emitting at $T \approx 4-5$ keV with a possible, but somewhat uncertain, contribution of a softer component at $T \approx 3$ keV. The non thermal emission from the active nucleus must be significantly smaller than the thermal one, and no indication of relevant core obscuration by a surrounding torus was detected. The flux from MRC 0625-536 originates form an extended region and has been fitted to a thermal law with $T \approx 5.7$ keV and with a column density consistent with the galactic absorption. A spatially resolved spectral analysis does not show a relevant variation of the temperature and the metallicity across the diffuse emission zone. A non thermal spectral component, related to the nuclear activity, may be present in the innermost region with some possible amount of local obscuration, contributing $\lesssim 10\%$ to the total luminosity. Hard X-ray emission from MRC 0625-536 has been detected in the PDS (15 - 200 keV) that may be related either to its galactic core or to the intracluster region.

Key words: galaxies: active - galaxies: clusters: individual: A 3391 - galaxies: individual: Hercules A; MRC 0625-536 - galaxies: nuclei - X-rays: galaxies

1. Introduction

The two sources Hercules A (3C 348) and MRC 0625-536 are radio galaxies classified as Fanaroff-Riley I (FR I) type objects, although Hercules A has indeed the morphology of a FR I radio galaxy, but with a much higher radio luminosity, typical of a FR II object. The galaxy associated with MRC 0625-536 is the main member of the cluster A 3391, while Hercules A lies in a group.

Recent spectral and morphological analyses of X-ray data, collected by ROSAT and ASCA (Otani et al. 1998, Siebert et al. 1999, Gliozzi et al. 2000), have provided information on the physical and dynamical properties of the environment surrounding these objects and of their active nuclei. Both radio galaxies are embedded in diffuse clouds of X-ray emitting hot plasma of size larger than the extended, radio emitting, regions. The active nucleus may also contribute to the X-ray flux, as observed in several FR I radio galaxies, and this emission is likely related to the inner region of the relativistic jet (Worrall & Birkinshaw 1994, Trussoni et al. 1999, Hardcastle & Worrall 1999).

In this paper we present BeppoSAX observations of Hercules A and MRC 0625-536. This analysis provides new information on the structure of these radio galaxies and their associated clusters. In fact, the instrumentation on board of BeppoSAX allows us to collect data, during the same pointing, that range from the soft band up to ≈ 200 keV. We will also examine the variation of the spectral parameters of the X-ray emission across the clusters, relying upon the smoother (with respect to the ASCA detectors) radial behavior of the Point Spread Function of the BeppoSAX MECS detectors.

In Section 2 we summarize the known properties of the two sources, in Section 3 we outline the details of the observations and of the data analysis while in Section 4 we report the results of the spectroscopic analysis. Their implications on the structure of the two sources are discussed in detail in Section 5, taking into account also previous observations, and in Section 6 we summarize our results. A value of $H_0 = 50$ km s^{-1} Mpc^{-1} is assumed throughout.

2. The sources

We list in Table 1 the main properties of Hercules A and MRC 0625-536 and recall in the following the available literature.

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Table 1. Main data on the targets

Source	RA (J2000)	DEC (J2000)	z	$m_{\rm V}$	$P^{\rm a}_{\rm tot}$	$P^{\rm a}_{\rm core}$	Galaxy	Environment
Hercules A	$16^h\ 51^m\ 08.1^s$	04° 59′ 34″	0.154	16.9	150	0.12	Giant cD	Group
MRC 0625-536	$06^h\ 26^m\ 15.4^s$	-53° 40′ 52″	0.054	15.4	2.50	0.056	Pair/Dumbbell	A 3391

[a] $\times 10^{25}$ W Hz^{-1} at 5 GHz

Table 2. Observational details

Source	Obs. date	$t_{\rm exp,MECS}$	$t_{\rm exp,LECS}$	$t_{\rm exp,PDS}$	Source cts$^{\rm a,b}_{\rm MECS}$	Source cts$^{\rm b}_{\rm LECS}$	count rate$^{\rm b}_{\rm PDS}$
Hercules A	28/3/1997	18790 s	9875 s	8550 s	1477 ± 48	432 ± 30	-
MRC 0625-536	8/11/1996	13386 s	3588 s	5136 s	4213 ± 70	368 ± 29	0.43 ± 0.13

[a] merging the counts of the three instruments
[b] Source - background $\pm 1\sigma$

2.1. Hercules A (3C 348)

This source is a giant cD elliptical (Spinrad et al. 1985, Zirbel 1997) embedded in an environment that Zirbel (1997) has classified as a group of the first Bautz-Morgan class, with Hercules A as the main member. At radio frequencies, 3C 348 shows two large and symmetric lobes connected by twin jets and without the presence of any hot spot (Dreher & Feigelson 1984). The radio emission originates in the extended lobes mainly, with a weak contribution of a compact core ($S_{\rm c,\,4.8\,GHz} = 10$ mJy, corresponding to $< 0.1\%$ of the total emission, Morganti et al. 1993). Polarization maps show a strong asymmetry in the fractional polarization, with the most prominent jet lying in the more strongly polarized lobe (Harvanek & Hardcastle 1998, Gizani & Leahy 1999). This fact can be interpreted as due to the Laing-Garrington effect (Laing 1988, Garrington et al. 1988) and is consistent with the existence of a cluster/group environment around the source.

The X-ray properties of 3C 348, derived by ROSAT and ASCA observations, are discussed by Siebert et al. (1999). The flux detected by ASCA is fit to a thermal model with temperature $T \approx 4.6$ keV and metallicity $\mu \approx 0.38$ (with respect to the standard cosmic values). The presence of an additional non thermal component, with a flat slope (photon index $\Gamma \sim 1.7$), is also consistent with the data. The ROSAT/PSPC data are consistent with a plasma emitting at temperature $T \sim 2.4$ keV, suggesting that a two temperature gas may be present around Hercules A, without any significant temperature gradient up to an outer radius of $3'$. The total luminosity in the energy band 0.1 - 2.4 keV turns out to be 4.4×10^{44} erg s^{-1}.

The brightness profile obtained by the ROSAT/HRI data analysis is consistent with a β-model with $r_c \approx 35''$ (≈ 120 kpc) and $\beta \approx 0.63$, with the diffuse emission extending up to $\approx 3'$ from the center. A point-like structure, coincident with the nucleus of the galaxy, is detected as well and contributes for a fraction of $\approx 8\%$ to the total emission. The luminosity in the soft X-ray band (0.1 - 2.4 keV) results in 3.4×10^{43} erg s^{-1} for the nucleus (assuming a power law spectrum with $\Gamma = 1.7$).

2.2. MRC 0625-536

This radio source is associated with the eastern component of a pair of galaxies (also classified as a dumbbell galaxy) and is the brightest member at the center of the cluster A 3391. The radio morphology shows a wide-angle tail structure (Morganti et al. 1999, and references therein), with a compact core of flux $S_{\rm c,\,4.8\,GHz} = 42$ mJy, which contributes only $\approx 2\%$ to the total emission.

X-ray studies are presented by Otani et al. (1998) and by Gliozzi et al. (1999). The ASCA and ROSAT/PSPC data are consistent with a thermal spectrum with $T \sim 6 - 6.5$ keV and $\mu \approx 0.35$. The PSPC observations also show that the flux from the innermost $2'$ is consistent with a power law spectrum.

The region of X-ray emission is extended (radius of $\approx 15'$) and, from ROSAT/HRI data, its brightness profile is fit to a β-model with core radius $\approx 2.5'$ (≈ 220 kpc) and $\beta \approx 0.56$, typical of a cluster. The central nucleus can contribute to the flux only up to $\approx 3\%$, with a luminosity (0.1 - 2.4 keV) of $\approx 4.1 \times 10^{42}$ erg s^{-1} (power law with $\Gamma = 1.67$), while the luminosity of the extended region is $\approx 1.5 \times 10^{44}$ erg s^{-1}.

3. The observations and data analysis

The BeppoSAX observation plan, covering the energy range 0.2 - 200 keV, is reported in Table 2 (for details on the BeppoSAX instrumentation see Boella et al. 1997). The event files of the three MECS and of the LECS have been processed with the packages FTOOLS 4.2 and SAXDAS 2.0.2. The adopted matrices for the instrument response and the effective areas were released in September 97. The spectral analysis has been performed with the XSPEC package (ver. 9.0) rebinning the counts in order to have at least 20 events in each energy channel. For the thermal fits the MEKAL model for an optically thin plasma has been employed. We have adopted the HI measurements, reported in Dickey & Lockman (1990), for the values of the galactic column density ($N_{\rm H,gal}$) used in the spectral fits. The errors for the parameters are at 68% of uncertainty (1σ).

The background, extracted from the public BeppoSAX archive, consists of different merged exposures of blank fields with the same extent as the source. We have limited the spectral fits to the energy ranges 0.2 - 4 keV for the LECS, and 1.5 - 9.5 keV for the MECS.

The analysis of extended sources requires the correction of the Point Spread Function (PSF) for the vignetting effects. This correction can be performed for the MECS observations through the command *effarea* of the SAXDAS package that provides the suitable auxiliary response matrices (Molendi 1998, D'Acri et al. 1998). This command requires an 'a priori' estimate of the radial distribution of the counts: we have generated the corrected matrices using the brightness profile derived from the HRI observations (see Section 2). The photons have been extracted, for both sources, from a region with radius of $8'$: this choice is satisfactory for Hercules A, while it includes only the central region of the more extended MRC 0625-536. In order to analyze the spectral properties of different regions of the diffuse emission, we have also carried out spectral fits to photons extracted from the inner region (radius $2'$) and external concentric annuli, with size dependent on the count statistics.

At present, no analogous procedure exists for processing the data of LECS observations of extended sources. To reduce the vignetting effects in this case, we have extracted the photons from a smaller region (radius of $6'$), even though the PSF of the LECS is wider than that of the MECS. Considering this limitation, we have not carried out simultaneous fits of the spectra of the two instruments. The LECS data at softer energies have therefore been considered as a consistency test of the MECS results and for comparison with the previous ROSAT observations.

The background subtracted spectra of the PDS have been extracted from the public BeppoSAX archive. For the positive detection of MRC 0625-536, and in order to have a significant statistics for a useful analysis, the counts have been rebinned to 4 energy channel bins in the energy range 15 - 200 keV.

4. Results

4.1. Hercules A

The results of the spectral analysis are given in Table 3. The spectrum obtained from the whole emitting region and detected in the MECS, with the column density fixed to its galactic value ($N_{\rm H,gal} = 6.3 \times 10^{20}$ cm^{-2}), is consistent with thermal emission (see Fig. 1). The fit yields a temperature $T \approx 4.2 - 5.4$ keV and metallicity $\mu \approx 0.2 - 0.5$. The resulting unabsorbed flux (2 - 10 keV) is $f = 3.5 \times 10^{-12}$ erg cm^{-2} s^{-1}, corresponding to a luminosity of 4.3×10^{44} erg s^{-1}, and of 4.7×10^{44} erg s^{-1} in the ROSAT energy band (0.1 - 2.4 keV).

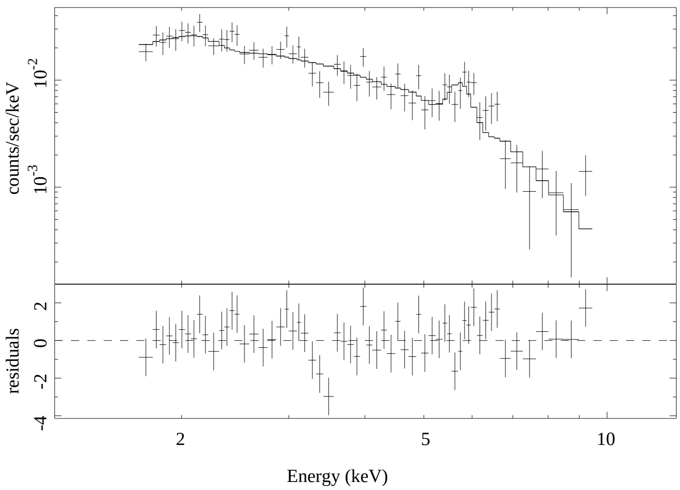

Fig. 1. Thermal spectrum (MECS) of the whole region of Hercules A (radius $8'$) assuming $N_{\rm H} = N_{\rm H,gal}$.

We have then divided the whole region in concentric annuli extending up to $8'$ (Table 3). We have obtained from the thermal fits $T \approx 4 - 5$ keV and $\mu \approx 0.5 - 0.6$. These values are all consistent, within 1σ fluctuations, with emission from a homogeneous and isothermal gas (see Table 3). In the external zone $4' - 8'$, we were only able to derive the flux, after setting $T = 5$ keV and $\mu = 0.4$, since only $\approx 15\%$ of the total counts are emitted in this outer region. We thus conclude that the present data do not show any significant variation of the spectral parameters across the intragroup plasma.

Some contribution to the flux emitted from the central region (of $2'$ radius, ≈ 700 photons) originates from the galactic nucleus. This emission is quite low: from the parameters derived for the power law emission from ASCA and ROSAT ($\Gamma = 1.7$, $f = 3.3 \times 10^{-13}$ erg cm^{-2} s^{-1}) we expect in the MECS a count rate about ten times lower than the thermal component. Consistently a single power law spectrum does not fit with the emission from this region ($\chi^2 \approx 1.5$). Performing a fit with a composite model (thermal + power law) by fixing $T = 4$ keV, $\mu = 0.4$ and $\Gamma = 1.7$ we found for the non thermal emission an upper limit ≈ 2.5 times larger than the luminosity detected in Siebert et al. (1999). This confirms that no strong X-ray variability occurred in the nucleus of Hercules A between the observations of August 1993 (ROSAT/PSPC), August/September 1996 (ROSAT/HRI), March 1997 (BeppoSAX) and August 1998 (ASCA).

The flux in the LECS was fitted to a thermal spectrum without a satisfactory estimate of the parameters, the column density only could be constrained yielding $N_{\rm H} = 6.75^{+3.3}_{-2.3} \times 10^{20}$ cm^{-2} ($\chi^2 = 1.13$, 15 d.o.f.), in agreement with the galactic hydrogen column density. Thus setting $N_{\rm H} = N_{\rm H,gal}$ and $\mu = 0.4$ we derived $A_{th} = 4.60^{+0.31}_{-0.32}$ cm^{-5} and a temperature $T = 3.12^{+0.70}_{-0.49}$ keV, with an up-

Table 3. Spectral fits for Hercules A[a]

Region	T (keV)	μ	$A_{\rm th}$ (cm^{-5})	χ^2 (d.o.f.)
$0'$ - $8'$	$4.78^{+0.67}_{-0.55}$	$0.36^{+0.16}_{-0.14}$	$5.49^{+0.44}_{-0.40} \times 10^{-3}$	0.94 (70)
$0'$ - $2'$	$4.31^{+0.57}_{-0.48}$	$0.64^{+0.24}_{-0.20}$	$3.90^{+0.37}_{-0.33} \times 10^{-3}$	1.07 (28)
	$4.55^{+0.56}_{-0.46}$	0.4	$4.08^{+0.35}_{-0.32} \times 10^{-3}$	1.09 (29)
$2'$ - $4'$	$5.20^{+1.12}_{-0.83}$	$0.55^{+0.31}_{-0.26}$	$9.52^{+0.98}_{-1.04} \times 10^{-4}$	0.89 (23)
	$5.39^{+1.09}_{-0.79}$	0.4	$9.68^{+0.96}_{-0.86} \times 10^{-4}$	0.87 (24)
$4'$ - $8'$	5	0.4	$3.88 \pm 0.67 \times 10^{-4}$	0.92 (29)

[a] $N_{\rm H} = N_{\rm H,gal}$; quantities without errors are fixed

per limit (at 2σ level) $T \leq 4.45$ keV ($\chi^2 = 1.01$). Apparently the temperature in this softer band results lower.

The lack of any detected flux in the PDS is in agreement with the extrapolation of the thermal (from the cluster) and non thermal (from the core) spectra to the 15 - 200 keV energy band. We expect in the energy range of the PDS a flux from the cluster of $\sim 10^{-13}$ erg cm^{-2} s^{-1} and from the non thermal component (allowing some amount of local absorption, as discussed below) $\approx 2 \times 10^{-12}$ erg cm^{-2} s^{-1}. Both these fluxes are well below the detection threshold of the PDS.

The value of the temperature obtained in the MECS is in excellent agreement with the ASCA observation, while the lower value deduced from the LECS data seems to confirm the PSPC results. Concerning the non thermal nuclear emission, the comparison of the flux detected in the HRI with the upper limit found in the MECS implies also an upper limit for the local column density: $\lesssim 4 \times 10^{21}$ cm^{-2} (90% of confidence). Then the obscuration of the core by an edge-on projected disk is not relevant. This is also consistent with the very high luminosity detected by the HRI in the soft band, higher by a factor ≈ 10 than expected from the correlation between the radio and X-ray core luminosities in FR I radio galaxies (and ≈ 3 times larger than its 90% upper confidence limit; Canosa et al. 1999, Hardcastle & Worrall 1999).

We will discuss these points further in Section 5.1.

4.2. MRC 0625-536

The flux detected in the MECS in the whole region ($8'$ in radius) is fit to a thermal emission model with $T \approx 5.7$ keV and $\mu \approx 0.3$, assuming $N_{\rm H} \equiv N_{\rm H,gal} = 5.4 \times 10^{20}$ cm^{-2} (see Fig. 2). The total unabsorbed flux is $f = 1.7 \times 10^{-11}$ erg cm^{-2} s^{-1}, with luminosity of 2.2×10^{44} erg cm^{-2} s^{-1}, in both the 2 - 10 keV and 0.1 - 2.4 keV bands.

After selecting four concentric circular regions with spacing $\Delta r = 2'$ we carried out fits to the emitted fluxes deriving values of the temperature and metallicity basically consistent with the 'average' values obtained analyzing the whole cluster region (see Table 4 and Fig. 3). We obtain a similar value for the temperature T setting $\mu = 0.33$ in the fit. In the innermost region we can notice an increase in temperature and a decrease in metallicity,

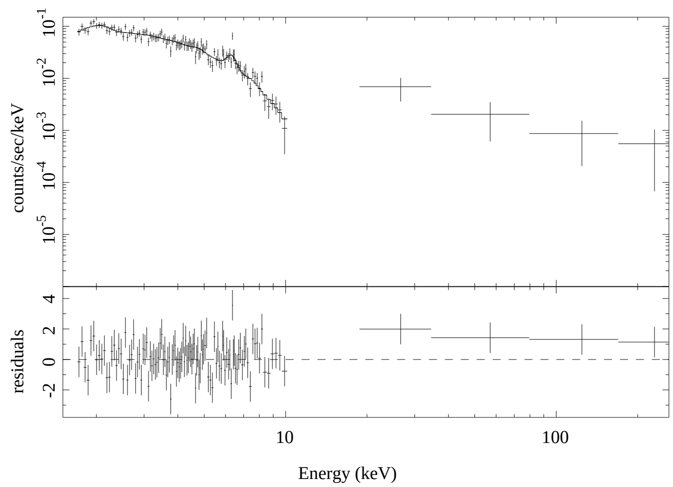

Fig. 2. Thermal spectrum (MECS + PDS) of MRC 0625-536 assuming $N_{\rm H} = N_{\rm H,gal}$. The fit has been performed only to the MECS data.

that may be a signature of non thermal emission from the active nucleus.

To test this point further, we have verified that the central flux also fit a power law model with $\Gamma = 1.84^{+0.08}_{-0.08}$ ($\chi^2 = 0.77$). The total number of photons from this zone (≈ 900) does not allow a complete analysis with a composite spectrum. Setting $T = 5.7$ keV, $\mu = 0.33$ and $\Gamma = 1.7$ we obtain acceptable fits ($\chi^2 = 0.72$) with fluxes of the two components (2 - 10 keV, with large errors; see Table 4) $f_{\rm th} \approx 2.5 \times 10^{-12}$ erg cm^{-2} s^{-1} and $f_{\rm pl} \approx 2.0 \times 10^{-12}$ erg cm^{-2} s^{-1}, respectively. This corresponds to a nuclear luminosity of $L_{\rm pl} \approx 2.6 \times 10^{43}$ erg s^{-1} (a similar value of $L_{\rm pl}$ is obtained in the softer band 0.1 - 2.4 keV).

Little useful information can be obtained from the LECS observation: setting $\mu = 0.33$ we derive $T = 5.09^{+5.60}_{-1.76}$ keV and $N_{\rm H} = 1.71^{+0.95}_{-0.74} \times 10^{21}$ cm^{-2} ($\chi^2 = 1.09$, 12 d.o.f.). This value is larger than the galactic column density by a factor $\sim 2 - 3$, however its lower limit (at 2σ level), 5.5×10^{20} cm^{-2}, is coincident with $N_{\rm H,gal}$.

The flux detected in the high energy band by the PDS (at $\approx 3\sigma$ level) is well above the extrapolated thermal emission from the cluster and from the active nucleus, assuming the parameters derived from the MECS observa-

Table 4. Spectral fits for MRC 0625-536[a]

Region	T (keV)	μ	$A_{\rm th}$ (cm^{-5})	χ^2 (d.o.f.)	Γ	$A_{\rm pl}^{\rm b}$
0′ - 8′	$5.66^{+0.40}_{-0.35}$	$0.33^{+0.08}_{-0.07}$	$1.98^{+0.07}_{-0.06} \times 10^{-2}$	1.02 (108)		
0′ - 2′	$7.60^{+1.54}_{-1.13}$	$0.13^{+0.16}_{-0.13}$	$4.81^{+0.31}_{-0.31} \times 10^{-3}$	0.75 (34)		
	$7.10^{+1.32}_{-0.97}$	0.33	$4.64^{+0.30}_{-0.28} \times 10^{-3}$	0.75 (35)		
2′ - 4′	$5.50^{+0.68}_{-0.56}$	$0.47^{+0.15}_{-0.14}$	$6.11^{+0.37}_{-0.36} \times 10^{-3}$	0.95 (50)		
	$5.72^{+0.67}_{-0.55}$	0.33	$6.24^{+0.35}_{-0.32} \times 10^{-3}$	0.95 (51)		
4′ - 6′	$4.79^{+0.69}_{-0.55}$	$0.49^{+0.19}_{-0.17}$	$4.96^{+0.37}_{-0.34} \times 10^{-3}$	1.03 (42)		
	$5.05^{+0.67}_{-0.55}$	0.33	$5.06^{+0.36}_{-0.33} \times 10^{-3}$	1.03 (43)		
6′ - 8′	$6.75^{+1.88}_{-1.19}$	$0.42^{+0.26}_{-0.24}$	$3.29^{+0.29}_{-0.28} \times 10^{-3}$	0.69 (32)		
	$6.97^{+1.81}_{-1.17}$	0.33	$3.32^{+0.27}_{-0.24} \times 10^{-3}$	1.03 (43)		
0′ - 2′	5.7	0.33	$2.93^{+1.08}_{-1.43} \times 10^{-3}$	0.72 (35)	1.7	$5.00^{+3.35}_{-2.53} \times 10^{-4}$
0′ - 2′	5.7	0.33	$4.18^{+0.58}_{-0.52} \times 10^{-3}$	0.74 (35)	1.2	$1.10^{+0.54}_{-0.73} \times 10^{-4}$

[a] $N_{\rm H} = N_{\rm H,gal}$; quantities without errors are fixed
[b] photons cm^{-2} s^{-1} keV^{-1} (at 1 keV)

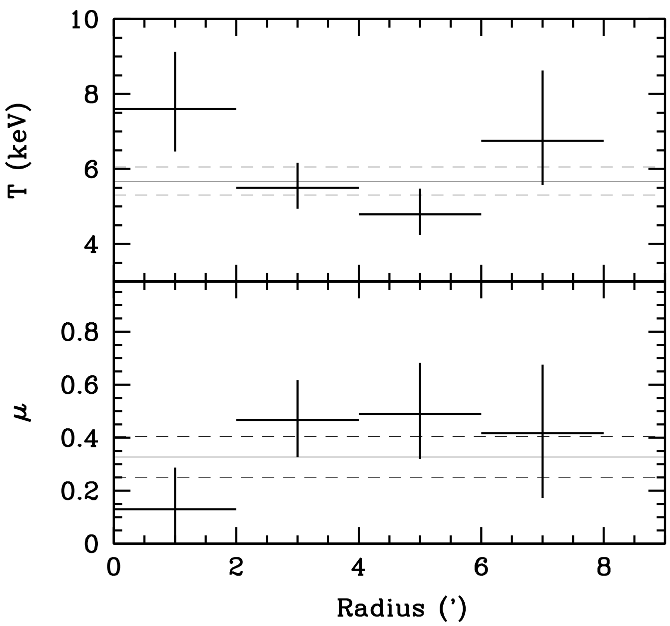

Fig. 3. Temperature (upper panel) and metallicity (lower panel) vs the radial distance in MRC 0625-536. The thin horizontal lines indicate the values of T and μ (solid) $\pm 1\sigma$ (dotted) deduced from the fit to the whole region ($r = 8'$).

tion. In fact, the fluxes expected in the 15 - 200 keV energy range are $\approx 1.1 \times 10^{-12}$ erg cm^{-2} s^{-1} and $\approx 2.0 \times 10^{-12}$ erg cm^{-2} s^{-1}, respectively, below the detection capability of the PDS (see Fig. 2).

The values of the temperature and metallicity obtained by the BeppoSAX observations are fully consistent with those of ASCA and PSPC (Otani et al. 1998) within 1σ statistical fluctuations. The total luminosity from the cluster in the 2 - 10 keV range is $\approx 90\%$ lower than derived from ASCA consistently with the slightly smaller region of photon extraction assumed for the MECS.

The nuclear luminosity derived from the HRI observation (Gliozzi et al. 1999) exceeds by a factor ≈ 3 the one predicted by the correlation of Canosa et al. (1999), but is still within 90% of uncertainty. This would suggest the absence of heavy local absorption in the nucleus of this radio galaxy. However, the MECS data indicate a much higher luminosity (by a factor ≈ 6) with respect to HRI, but, due to the large statistical fluctuations, the lower limit of the luminosity in the MECS is $\sim$ three times the one in the HRI. Assuming no variability, this discrepancy could be ascribed to a local column density of $\sim 5 \times 10^{21}$ cm^{-2} surrounding the core. This point will be discussed further in the next Section, considering also the results of the PDS observation.

5. Discussion

We outline the main implications of the BeppoSAX observations considering also previous observations from other satellites.

5.1. Hercules A

Our results confirm the discrepant value of the temperature of the thermal diffuse emission obtained from the ASCA and ROSAT observations and support the possibility that a two temperature plasma is present in Hercules A. However, since both MECS and PSPC data are consistent with emission from an isothermal medium, it is difficult to gain some insights about the origin of these two thermal components. Unfortunately it is not possible to merge the LECS and MECS data to perform a spectral fit with a two temperature model (see Section 3).

Some clues for the interpretation of this phenomenology may be provided by the HRI image (Siebert et al. 1999), that shows peculiar morphologies, unrelated to the extended thermal gas and suggested to originate from the interaction of the expanding radio lobes with the hot medium. We can then argue that this processed gas has physical conditions far from those of a plasma in ionization equilibrium. On the other hand, the extent of this irregular structure is smaller but comparable with the size of the diffuse region modeled with a β profile ($\sim 2'$, see Fig. 4 of Siebert et al. 1999), such that the imaging capability of the MECS does not allow to spatially disentangle these different regions.

It is worth noticing that the luminosity and temperature of the thermal plasma detected in Hercules A are consistent with the correlation found for the galaxy clusters (Wu et al. 1999). Therefore, the X-ray properties of this object are typical of rich clusters, despite the fact that Hercules A has been associated with a group of galaxies, which would be expected to show a lower temperature and luminosity (Zirbel 1997, Ponman et al. 1996).

The MECS data confirm also that only a small fraction of emission from the central region can originate from the core, that however it is very bright when compared with similar objects. It turns out that in fact that the X-ray luminosity of the nucleus of Hercules A is typical of that of FR II narrow lines radio galaxies (4×10^{17} W Hz^{-1} sr^{-1}, see Fig. 6 in Hardcastle & Worrall 1999). This may mean that extra contributions to the core emission could come from other components, e.g. from an thick accretion disk (we cannot exclude also that the inner nucleus is actually obscured by the torus and the non thermal X-ray emission originate from the jet on much larger scales). On the other hand, the optical and radio core luminosities are consistent with the properties of FR I radio galaxies where obscuration does not play a relevant role and no thick accretion disks appear to be present (Chiaberge et al. 1999). However the above argument implies that in this radio galaxy the low value of the core radio luminosity, with respect to the total one, may not be a reliable indicator of local absorption in the nucleus.

In conclusion, Hercules A appears very peculiar at X-ray energies on large and small scales: observations from the new generation telescopes (Chandra) will provide new insights on this interesting object.

5.2. MRC 0625-536

The MECS data confirm the spectral properties obtained by the previous observations with ASCA and ROSAT. The values of the temperature and metallicity are typical for a cluster, and the luminosity is again consistent with the L_X-T correlation (Wu et al. 1999). The lack of any variation of the temperature across the region of emission confirms that this cluster has very likely undergone a merging process (see also Otani et al. 1998).

The detection of hard X-ray flux in the PDS, even though weak, may have important implications on the interpretation of this radio galaxy. X-ray emission above 20 keV is commonly observed in Seyfert galaxies (see e.g. Matt 1998). Among clusters, hard X-ray emission has been found so far only in Coma and A 2256 with good significance, and in A 2199 with marginal significance (Fusco-Femiano et al. 1999, 2000, Kaastra et al. 1999)

As stated in Sect. 4.2, the high energy emission cannot be the extrapolation of the thermal emission from the intracluster plasma, detected from the MECS. Should this emission originate from a hotter thermal component, the fit to the PDS data would require a temperature $T \geq 80$ keV. We can reasonably exclude the presence in this cluster of a plasma with these extreme physical conditions.

For investigating the origin of the hard emission, we have first looked for possible contamination by a different source in the PDS field of view. The nearby cluster A 3395 falls within the PDS field of view, but its thermal emission could not increase the flux by more than a factor ~ 2 (Henriksen & Jones 1996). A BL-Lac object, MS 0622.5-5256, is present in the PDS field, at the position RA$_{2000}$ = $06^h\ 23^m\ 39.1^s$, DEC$_{2000}$ = -52° 57′ 49″, i.e. at about 49′ from the field center. The flux of this source in the 0.3 - 3.5 keV energy band is 3.7×10^{-13} erg cm^{-2} s^{-1}, estimated assuming a power-law spectrum with a photon index Γ=2 (Stocke et al. 1991). Extrapolating this flux to the PDS energy band, and correcting for the attenuation due to the distance of the BL-Lac from the field center, it turns out that it is about 100 times lower than the flux detected in the PDS and therefore cannot be responsible for it, unless an unusually strong variability in the flux of the BL-Lac object has occurred.

Thus, it seems reasonable to consider that the PDS flux is of non-thermal origin, and actually originating from the target itself. We consider in the following three main possibilities : 1) it is related to the nucleus of the radio galaxy MRC 0625-536; 2) it is related to the radio lobes of MRC 0625-536; 3) it is associated to the cluster A 3391.

1) In this case, the hard X-ray emission would originate from the core of radio galaxy MRC 0625-536. A similar case is represented by the radio galaxy NGC 1275 (3C 84), in the Perseus cluster, where hard non thermal emission has been detected by OSO7 (Rothschild et al. 1981). BeppoSAX observations have confirmed the existence of X-ray emission at energies exceeding 20 keV, with flux of $\sim 4 \times 10^{-11}$ erg cm^{-2} s^{-1} in the 20 - 100 keV band (Molendi 1998). According to the MECS analysis and to the results of previous observations, the emission from the core of MRC 0625-536 is not detectable in the PDS energy range. One might, however, speculate on the existence of a component with a much flatter spectral index: for $\Gamma = 1.2$ one would derive a (15 - 200 keV) flux of $7.2 \pm 4.6 \times 10^{-11}$ erg cm^{-2} s^{-1}, corresponding to a luminosity of $\approx 9.0 \times 10^{44}$ erg s^{-1}. Fitting the MECS flux from the central region (radius 2′) to a composite spectrum with the same parameters as in Table 3 for the thermal component, and with $\Gamma = 1.2$ for the power law spectrum, one obtains for the latter a flux $1.3^{+0.7}_{-0.9} \times 10^{-11}$ erg cm^{-2} s^{-1} in the 15 - 200 keV band, ≈ 5 times less than detected in the PDS.

However, considering the large statistical fluctuations, the difference between the upper limit of the MECS flux and the lower limit of the PDS flux (90% of confidence) reduces to a factor ≈ 1.3. A larger discrepancy is found with the HRI data on the nuclear emission, that is ≈ 3 times less than the lower limit of the PDS flux. This difference disappears if some amount of obscuration is present with $N_{\rm H} \approx 5-6\times10^{21}$ cm^{-2}, as deduced in Section 4.2. In this case the intrinsic core luminosity in the soft band would increase by a factor ~ 2.

This interpretation has two major difficulties. First, the nucleus would result, in the X-ray band, overluminous with respect to its radio power (see Sec. 4.2). The second problem is the extreme flatness of the spectrum. In blazars, where the hard X-ray emission is related to the inverse Compton process in the relativistic jet, it is generally found that $\Gamma \gtrsim 1.5$ for luminosities $\sim 10^{44-45}$ erg s^{-1} (and steeper spectra in the γ energy band; see Fossati et al. 1998). It has been alternatively proposed that advection dominated disks (ADAF) could contribute to the X-ray core emission of low power radio galaxies (Sambruna et al. 1999), with a very flat spectral emission (see e.g. Allen et al. 2000), but with a luminosity much lower (a factor < 0.01) than appropriate for our target.

2) The hard X-ray emission might be produced by Inverse Compton scattering of relativistic electrons within the radio lobes with the photons of the Cosmic Microwave Background (CMB), as detected in a few radio galaxies (e.g., Feigelson et al. 1995, Tsakiris et al. 1996). A non-thermal power law model with $\Gamma = 2$, gives for the present source a flux $\sim 4\times10^{-11}$ erg cm^{-2} s^{-1} in the 15-200 keV band. Using the total radio flux at 4.8 GHz of 1.85 Jy (Morganti et al. 1993) and the radio spectral index $\sim$1 (Otani et al. 1998), the detected X-ray flux would imply a magnetic field of about 0.25 μG, i.e. more than an order of magnitude lower than the equipartition value derived from the data published by Otani et al. (1998). With this low magnetic field, the relativistic electrons emitting in the radio domain up to 8.87 GHz (frequency to which the radio spectrum extends, Otani et al. 1998) would have very high energy, largely sufficient to account for the 15-200 keV Inverse Compton emission. Although there is no firm evidence in the literature that radio sources should be in equipartition conditions, there is also no evidence of such large deviations from it. Therefore, this interpretation seems unlikely.

3) Non thermal X-ray emission from the cluster A 3391 would be expected if relativistic electrons present in the intergalactic medium undergo Inverse Compton scattering with the photons of the CMB. This kind of emission has been detected by BeppoSAX in the two clusters Coma (Fusco-Femiano et al. 1999) and A 2256 (Fusco-Femiano et al. 2000), where the presence of ultra-relativistic electrons in the intracluster medium is directly demonstrated by the existence of diffuse radio halos. Conversely, no diffuse radio emission is detected in the cluster A 3391, so the presence of ultra-relativistic electrons in the intergalactic medium remains questionable. In any event, if the hard X-ray emission is of Inverse Compton origin, the magnetic field must be very weak in order to avoid producing an observable radio halo. A similar conclusion is reached for the cluster A 2199, where a marginal detection of hard X-rays above the expected thermal emission is reported by Kaastra et al. (1999), and no diffuse radio halo is observed. For the cluster A 2199, Kempner & Sarazin (1999) suggest the alternative possibility that the X-ray emission above 20 keV could be due to non thermal bremsstrahlung by a population of suprathermal electrons. The same interpretation might apply to the present case.

We conclude that, even though reasonable, none of the possibilities that we have analyzed for the interpretation of the PDS emission is fully convincing. More data would be needed to clarify this issue.

6. Summary

We summarize the main results obtained from the BeppoSAX observations and their implications on the properties of these two radio galaxies and their environment.

Hercules A. No relevant variation of temperature and metallicity occurs between the inner and outer regions of the cluster. However a plasma with two different temperatures seems to be present, perhaps related to the interaction of the radio components with intracluster gas. It must be borne in mind anyway that the structure of this object is quite peculiar: at optical wavelengths it is classified as a group but its X-ray properties are typical of clusters.

The non thermal emission from the active nucleus appears unabsorbed, as expected for this class of radio galaxies, but brighter than expected by its core radio emission. This could be related to the peculiar nature of Hercules A that shows properties of both FR I and FR II radio galaxies.

MRC 0625-36. The X-ray luminosity and the values of T and μ are consistent with those expected for this kind of clusters. The lack of strong variation of the temperature and metallicity across the emitting region suggests that no cooling flow is present, while it could be related to a recent merging process. The nuclear non thermal emission detected in the MECS and in previous missions is consistent with that expected from radio data, without excluding however some amount of local obscuration.

Concerning finally the high energy flux detected in the PDS, it seems unlikely that it is related to the cluster or to the radio lobes. On the other hand, a nuclear origin for this emission would imply a luminosity of some units of 10^{44} erg s^{-1} in the hard band. Either this emission is completely independent of the flux detected at lower energies, or, to fit the ROSAT, ASCA and BeppoSAX (MECS) data, it must have an very flat spectrum.

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