OPTICAL OBSERVATIONS OF SERENDIPITOUS EXOSAT SOURCES IN THE COMA CLUSTER

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ABSTRACT. A ~7 hour observation of the central part of the Coma Cluster of galaxies has been performed with the EXOSAT LE telescopes and CMA detectors. Five serendipitous sources are detected within the inner 35 arcmin radius of the field. Optical spectroscopy demonstrates that at least three of these are background AGN not associated with the cluster. At the sensitivity level of the EXOSAT exposure, we would have expected to see only 0.01 background sources based on the Einstein Medium Sensitivity Survey. The EXOSAT and Einstein results may be reconciled if these AGN have a much softer average X-ray spectrum than previously assumed.

1. X-RAY OBSERVATIONS

A ~15 hour observation of the central part of the Coma Cluster of galaxies was carried out with EXOSAT during the performance verification phase of the mission. We report here the results of a 6.6 hour exposure taken with both the LE telescopes, using the CMA detectors and a Lexan 3000 Å filter, centred at RA = $12^h 57^m 29^s$, DEC = $+28^o$ 11' 24". For a description of the instrumentation see de Korte et al. (1981). Figure 1 shows the LE2 CMA image: within the central 35 arcmin radius 5 serendipitous sources are clearly visible. The central diffuse emission is due to the Coma Cluster. The LE1 CMA image is essentially identical and shows the same sources. Table 1 lists coordinates, countrates and fluxes for the 5 sources derived from the LE2 telescope which is slightly more sensitive than LE1 and had a longer exposure time on the field. Given the high galactic latitude of the region ($b_{II} = 88^o$) we expect most of the serendipitous sources to be extragalactic objects. In order to compare our results with those of the Einstein Medium Sensitivity Survey we convert from countrates to fluxes assuming a power-law spectrum of photon index 1.4 and an equivalent Hydrogen column

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Table 1. Parameters of the EXOSAT CMA serendipitous sources discovered in the Coma Cluster field.

No.	Name EXO-	RA 12h	DEC +28°	CMA counts min^{-1}	0.02-2.5 keV flux erg cm^{-2} s^{-1}
1	125653+2809.9	$56^m53.2^s$	09'54"	.31±.10	$2.3x10^{-12}$
2	125757+2840.3	57 57.5	40 20	.91±.09	$6.6x10^{-12}$
3	125905+2807.0	59 05.1	06 59	.26±.08	$1.9x10^{-12}$
4	125921+2828.2	59 21.9	28 12	.34±.07	$2.5x10^{-12}$
5	125938+2803.1	59 38.8	03 05	.31±.07	$2.3x10^{-12}$

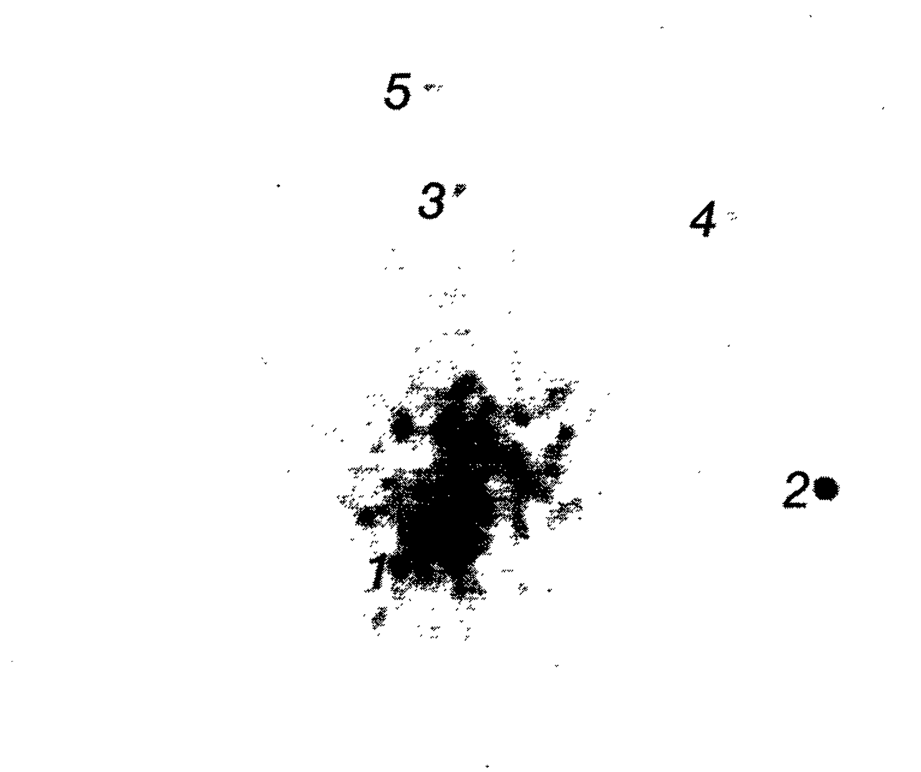

Figure 1. The EXOSAT CMA exposure centred on the Coma Cluster (its diffuse emission is visible on the lower left). The 5 serendipitous sources are clearly marked. The cross-type feature through the image is due to the 'central channel distortion' of the CMA, which has not been corrected for in this early picture.

density in the line of sight equal to the galactic contribution (3×10^{20} cm^{-2}; Burstein and Heiles, 1982). We treat the minimum flux observed (2.2×10^{-12} erg cm^{-2} s^{-1}, .02–2.5 keV) as our sensitivity limit because we have not as yet performed an exhaustive statistical search for sources in the field. The expected 5σ sensitivity limit is close to 10^{-12} erg cm^{-2} s^{-1}.

Of the 5 sources in Table 1 only the brightest (no. 2) was previously known to be an X-ray emitter from Einstein observations (Helfand et al., 1980); this source is identified with the type 1 Seyfert galaxy X Comae. At a redshift of 0.092 ± 0.002 (Bond and Sargent, 1973) this is a background object with respect to the Coma Cluster ($z = .0232$).

2. OPTICAL OBSERVATIONS

We have examined blue and red POSS prints in order to select candidates for identification with the serendipitous CMA sources. In each case we have taken an error circle of 20" radius around the X-ray position. The optical nucleus of X Comae is only 11" away from the CMA position. Three of the remaining error circles (sources 1, 3 and 4) contain or just overlap a point-like object which is found to be bluer than average on the POSS plates. Source 5's error circle is empty, although the POSS plate shows 2 objects just outside it.

We have obtained optical spectra of stars in and around the error circles of sources 1, 4 and 5. In addition, we have obtained a high quality spectrum of X Comae. The observations were made at the Observatorio del Roque de los Muchachos during three nights in early July 1984. We used the RGO Image Photon Counting System attached to the RGO Cassegrain spectrograph on the 2.5 m Isaac Newton Telescope. The exposure times on each star were between 2000 s and 4000 s. The spectra covered the wavelength range 3500 to 7500 Å at a dispersion of 130 Å/mm.

In the case of sources 1 and 4, the optical spectroscopy shows that the blue object within the X-ray error cicle on the POSS prints is a quasar. The redshifts are $.384 \pm .003$ and $.86 \pm .02$ respectively. Of the two objects nearest to the error circle of source 5, only one, which appears spatially extended, yielded an interesting spectrum, with Balmer absorption lines and [OIII] and [NII] emission lines; these features suggest that activity, for instance star formation, is taking place in its nucleus and make it a likely candidate as the source of the X-ray emission. At the redshift of $.023 \pm .001$ it is a member of the Coma Cluster. The spectra of the two quasars and the emission line galaxy are illustrated in Figure 2. Particulars of these identifications and their offsets from the X-ray positions are given in Table 2, together with approximate visual magnitudes estimated from the spectra by comparison with that of a standard star. The X-ray luminosities have been computed for $q_o = 0.$ and $H_o = 50$ km s^{-1} Mpc^{-1}. The spectrum of X Comae is also presented in Figure 2: it shows strong Balmer and forbidden emission lines; the [OIII] $\lambda5007$ to H_β ratio of ~1 is typical of type 1 Seyfert galaxies. We measure its redshift to be 0.091 ± 0.001.

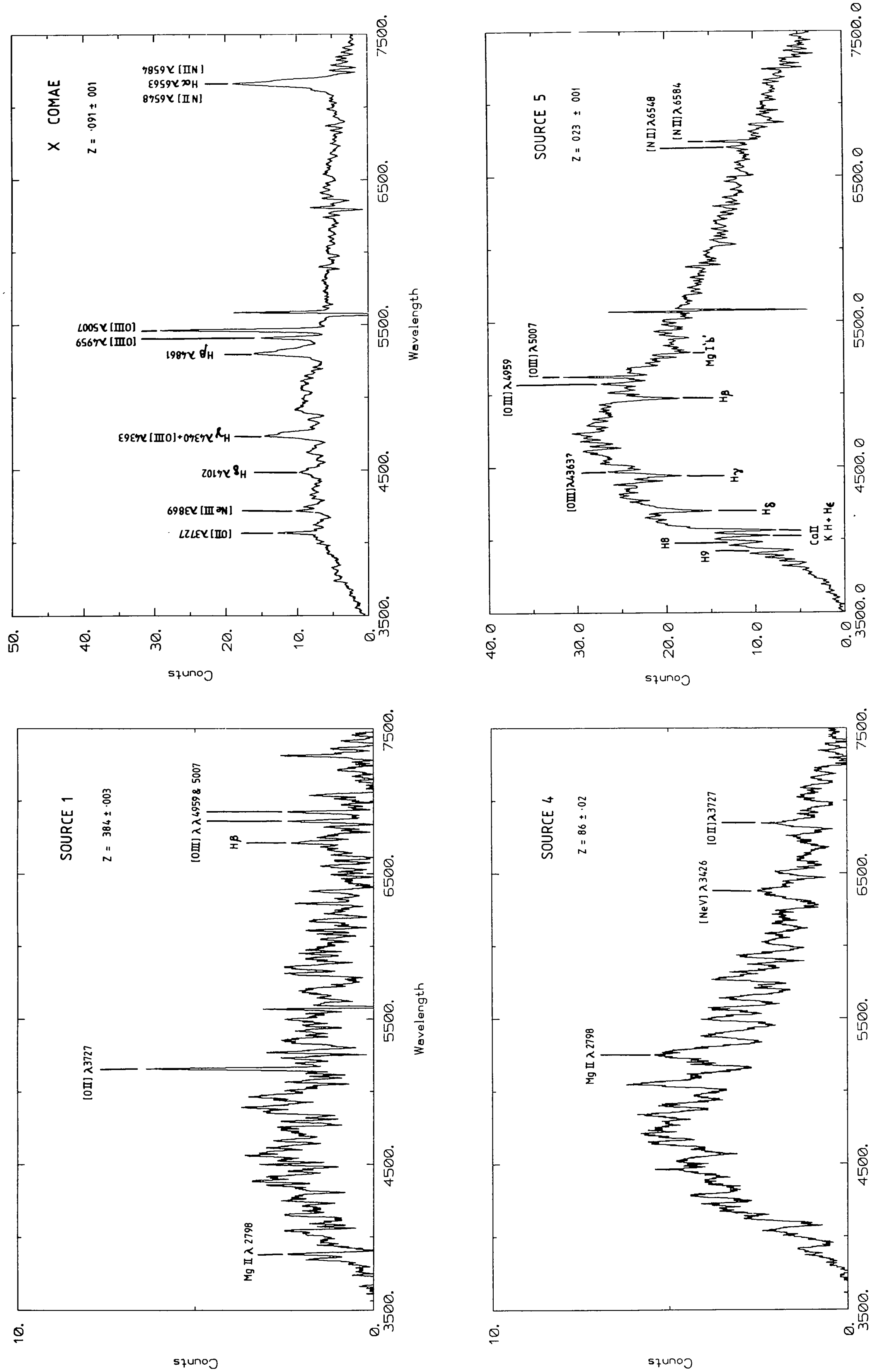

Figure 2. INT spectra of the objects identified with the EXOSAT CMA serendipitous sources. The data are displayed in the observed wavelength frame and are not corrected for the spectrograph's response. The features occasionally present at 5577 and 6300 Å are night sky lines improperly subtracted.

Table 2. Optical identifications of the EXOSAT serendipitous sources.

No.	Offset	Type of identification	m_V	z	L_x (0.02–2.5 keV) erg cm^{-2} s^{-1}
1	20"	QSO	19.5	.384±.003	$1.8x10^{45}$
2	11	X Comae, type 1 Seyfert galaxy	18.1	.091±.001	$2.5x10^{44}$
4	20	QSO	19.0	.86±.02	$1.2x10^{46}$
5	40	Star-burst galaxy	17.1	.023±.001	$5.4x10^{42}$

3. DISCUSSION

In the previous sections we have shown that at least 3 out of 5 serendipitous sources detected with the EXOSAT CMAs in an area of sky of 1 square degree centred on the Coma Cluster are associated with background AGN. Using the Log N – Log S function of Gioia et al. (1984) from the Einstein Medium Sensitivity Survey, and correcting our sensitivity limit to the Einstein IPC energy range (.3 – 3.5 keV), we calculate that the probability of chance coincidence of an X-ray AGN at least as bright as our faintest detection being included in a 20" radius area of sky is only $1.1x10^{-6}$. Expressed in another way, the same calculation shows that in the 35' radius CMA field under examination we would expect to find only 0.01 serendipitous sources to be associated with AGN at our 'MSS equivalent' sensitivity level of 2.9×10^{-12} erg cm^{-2} s^{-1}, while we see 3! Another 4 AGN are known to be present in the field: 2 radio-loud QSOs (5C04.105 and .127), the quasar W61972 (Hewitt and Burbidge, 1980) and a type 2 Seyfert galaxy. The latter is the proposed counterpart of a serendipitous Einstein IPC source (Reichert et al., 1982). The three quasars were part of the Einstein IPC survey of Ku et al. (1980) and are too weak (by an order of magnitude) to be detected in the EXOSAT observations. The same is true for the Seyfert galaxy.

We can also ask whether, other than X Comae, the relatively bright EXOSAT serendipitous sources were detected in the Einstein observations of this region of sky. As far as we can tell from the list of Einstein pointings, EXOSAT sources 3, 4 and 5 were not included in any of the Einstein fields, or were just at the edges or under the 'ribs' of the IPC, so it is not surprising that they are not reported in the literature. Source 1 is only ~6' away from the pointing position of an Einstein HRI observation centred on the Coma Cluster: visual examination of the HRI image confirms the presence of a weak source at the EXOSAT position with a countrate 3 to 4 times lower than that in the CMA (K.Arnaud, private communication). For a 'typical' AGN power-law spectrum with photon index 1.6 and $N_H = 3x10^{20}$ cm^{-2}, however, we predict at least 3 times more counts per second in the HRI than in the CMA.

The energy bandpass of the EXOSAT CMA (effective energy ~0.15 keV) is considerably lower than that of the Einstein IPC and HRI (effective energy 0.7 and 0.26 keV respectively). We thus consider whether an erroneous assumption of the spectral parameters of the AGN could cause both the discrepancy in the number of serendipitous sources seen with EXOSAT compared to that expected from the MSS, and the discrepancy between the CMA and Einstein HRI countrates of source 1. We first examine the possibility that a 'hole' in the Galactic absorption in the direction of the Coma Cluster could cause X-ray AGN to be more easily detected in the EXOSAT CMA than in the Einstein IPC and HRI. However, even with no absorption in the line of sight we would only expect 0.14 AGN detections if their power-law spectrum extrapolates unchanged down to the low-energy end of the CMA bandpass, and we would then expect about the same countrate for source 1 in the CMA and HRI.

The EXOSAT and Einstein results can only be reconciled if the spectrum of AGN is steeper than that considered 'typical'. For a photon index of 3 a 'modified' MSS Log N - Log S function (taking into account the difference in the spectrum) predicts 3 AGN detections in the EXOSAT field, as observed, when the absorbing column density is of the order of 3×10^{18} cm^{-2}. We note that the expected number of sources is strongly dependent on the N_H value: for the same slope and a column of 10^{20} cm^{-2} the number of sources expected is about 0.2 (so we still require a very low column in the direction of Coma). We note that cases of AGN spectra with a 'low-energy excess' have already been discovered with the joint analysis of EXOSAT ME and LE data (see e.g. Branduardi-Raymont et al., 1984, for the Seyfert galaxy NGC5548). This would also provide a natural way to explain the 'turn-up' of some AGN spectra at short UV wavelengths.

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