SC 2059-247 - No evidence for cluster evolution or extreme X-ray properties

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Astron. Astrophys. 192, 77–80 (1988)

ASTRONOMY AND ASTROPHYSICS

SC 2059-247: no evidence for cluster evolution or extreme X-ray properties

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Received October 24, 1986; accepted August 21, 1987

Summary. The southern cluster SC 2059–247 has been observed by the X-ray satellite EXOSAT. The cluster has a high luminosity and cooling mass flow and a small core radius, but it has neither exceptional properties compared to other clusters, nor does it show signs of evolution effects, as was concluded from earlier Einstein observations.

Key words: clusters of galaxies – X-rays

1. Introduction

The southern cluster SC 2059–247 has been classified as a very distant, extremely luminous cluster (White et al. 1981, here after WSQJ). The redshift of the nucleus of the central cD galaxy is 0.188 (obtained by Spinrad *et al.*, quoted in a note added in proof in WSQJ), resulting in a total cluster X-ray luminosity as determined by the IPC on the Einstein observatory of $7\,10^{37}$ W between 0.5 and 4.5 keV for $H_0 = 50\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$ (WSQJ). These authors concluded that the luminosity is too large with respect to the relative soft X-ray spectrum however, comparing the cluster with other, nearby clusters. WSQJ concluded therefore that the cluster gas is either in an early, cool stage of evolution, or that the X-rays originate from an unresolved non-thermal source at the center of the cD galaxy, probably a quasar or BL Lac like object.

In this paper we present EXOSAT observations of this cluster which show that it is a very compact, hot and luminous, but not unusual cluster of galaxies.

2. Observations

SC 2059–247 was observed for nearly 5 hours by the X-ray satellite EXOSAT on October 30, 1984. Data obtained by two instruments were used: the low-energy (LE) imaging instrument with the 3000 Å Lexan filter (de Korte et al., 1981), and the medium energy (ME) spectrometer (Turner et al., 1981).

The LE experiment detected SC 2059–247 and the quasar discovered by WSQJ.

The quasar (WSQJ) has a net count rate of 0.0009 $\pm 0.0004\,\mathrm{cts\,s^{-1}}$ in the LE, some 10% of the cluster count rate. This is consistent with the Einstein data (WSQJ), which yielded a net flux between 0.5 and 3 keV of 10% of the cluster flux. The redshift of the quasar is 0.96 (John Stocke, private communication to WSQJ). If the quasar spectrum is a power law with photon index between 1.4 and 2.0, our LE flux corresponds to an intrinsic 2–10 keV luminosity between 1.1 resp. $0.5\,10^{39}$ W, comparable to 3C 273.

The background subtracted LE map of the central part of SC 2059–247 is shown in Fig. 1. The count rate in the outer parts is small compared to the noise level and is discernable only after radial integration (Figs 2, 3). The background was determined in an annulus with inner radius 4′ and outer radius 5′.3, centered at the cD galaxy. These radii were chosen in order to be as close to the cluster as possible (but excluding cluster contributions of course), with sufficient area in the annulus to provide an accurate background determination. The total cluster count rate does not

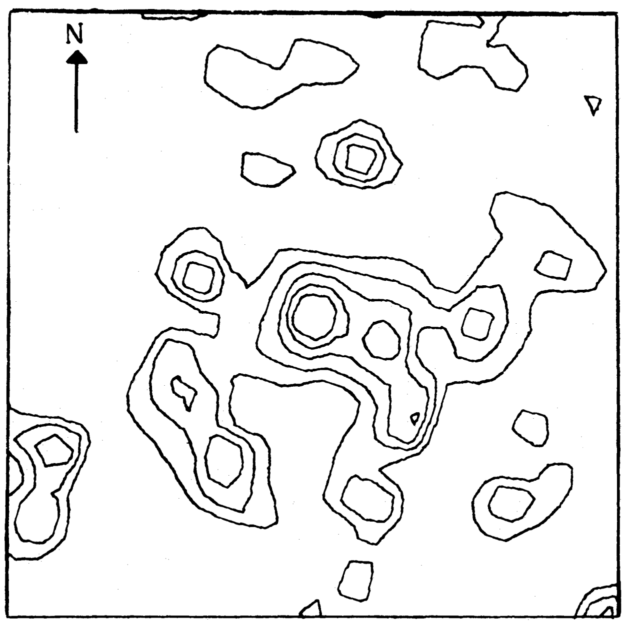

Fig. 1. EXOSAT background subtracted LE-map of the central 2′ × 2′ of SC 2059-247. The map is centered around the X-ray nucleus (the cD galaxy). Contours are shown at levels of 1,2,3,4 and 5 times the background count rate of 7.3 $\mathrm{cts\,s^{-1}}$ square $\mathrm{degree^{-1}}$, corresponding to significance levels of 2.3, 2.8, 3.2, 3.6 and 4.0σ. The spatial resolution of the image is 18″ (FWHM)

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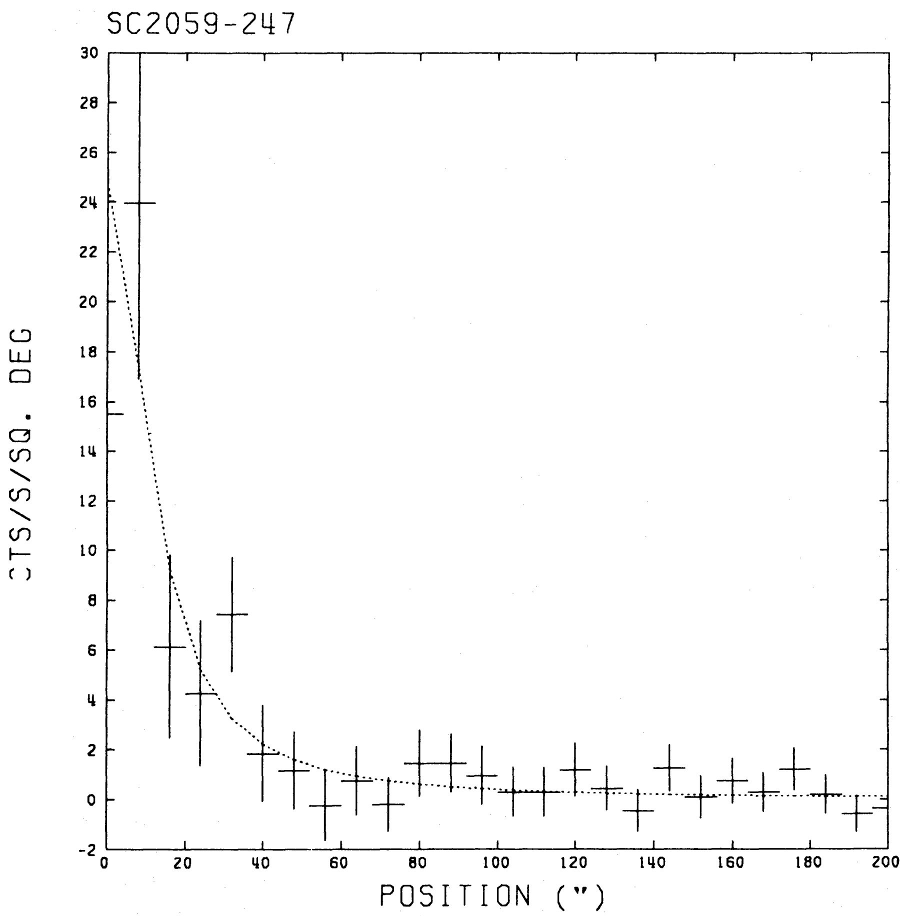

Fig. 2. Differential LE surface brightness distribution, centered around the maximum brightness position for SC 2059-247. The first, central datapoint coincides with the axis and has a value of 15.5 ± 11 cts s^{-1} square degree. The dashed line indicates the best fit to Eq. (1)

depend (within its error bounds) on the precise choice of these radii. The background determined this way is accurate to within 2.5%. Its value is 7.3 cts s^{-1} square degree^{-1}. Systematic variations in the LE detector background are known to exist from e.g. deep field observations with EXOSAT. Small scale structures in the background are known to be not present in the part of the detector where we determined the source and background. Large scale gradient (on a scale of 1°) are also known, and we estimated that this leads to differences in the background from one part of the annulus to the opposed side of at most 1–2% of the raw background. Since the gradient is orientated in one specific direction, and our background estimate is the average over an annulus, the role of possible systematic effects is reduced even more to a level of less than 0.1%, which is completely negligible compared to the statistical uncertainty in the background of 2.5%. The effective exposure time of the LE detector was 17995 s.

The point-like substructures visible 0′.5 from the nucleus may be caused by statistical fluctuations in the enhanced cluster emission. The probability of finding one point source by chance at the third contour level somewhere in the displayed cluster frame is about 5%. The cluster consists of an unresolved nucleus (radius smaller than 8″) and extended emission up to 3′ from the nucleus. The measured X-ray position of the nucleus is 22″ East of the optical nucleus. The nucleus contains 11 net counts only, however, while the FWHM of the point spread function of the LE is 18″ and systematic position errors may be as large as 15″. Therefore the present data do not exclude that the unresolved X-ray nucleus coincides with the optical and radio nucleus of the cD galaxy. The orientation of the extended emission close to the nucleus at a position angle of 110″ (North to East) coincides approximately with the orientation of the optical cD galaxy on the plates of WSQJ. There is some indication of either a lack of emission at 20″ from the nucleus, near the outer boundary of the cD galaxy, or extra emission at 30″ (Fig. 1).

The total count rate for the cluster is 0.0084 ± 0.0021 cts s^{-1}, and for the nucleus only 0.0011 ± 0.0004 cts s^{-1}. We fit the observed radial count rate distribution (Fig. 2) by the surface distribution function of Cavaliere and Fusco–Femiano (1981) using a χ^2 analysis:

$$S(r) = S(0)\{1 + (r/a)^2\}^{-3\beta + 0.5} \quad (1)$$

where

$$\beta = \mu m_p \sigma_{los}^2 / 3kT_{gas} \quad (2)$$

Here μ is the mean molecular weight, m_p the proton mass, σ_{los} the line-of-sight velocity dispersion and T_{gas} the (isothermal) temperature of the X-ray emitting gas. We obtain an acceptable fit for $\beta = 0.5 \pm 0.2$, $a = 12''(-8, +24)$ and $S(0) = (8 \pm 3)\, 10^4$ cts s^{-1} sr^{-1}, with a χ^2 value of 15 for 23 degrees of freedom. The errors quoted for β and a are combined 1σ errors for 2 strongly correlated parameters, ($\Delta\chi^2 = 4$, e.g. Lampton et al., 1976) while the error on $S(0)$ is a simple 1σ error.

The ME count rate of the cluster is very low. Uncertainties in the background count rate for the inner four Argon detectors of the ME experiment may result in an erroneous spectrum. Therefore we only used the data of the four outer counters. The total

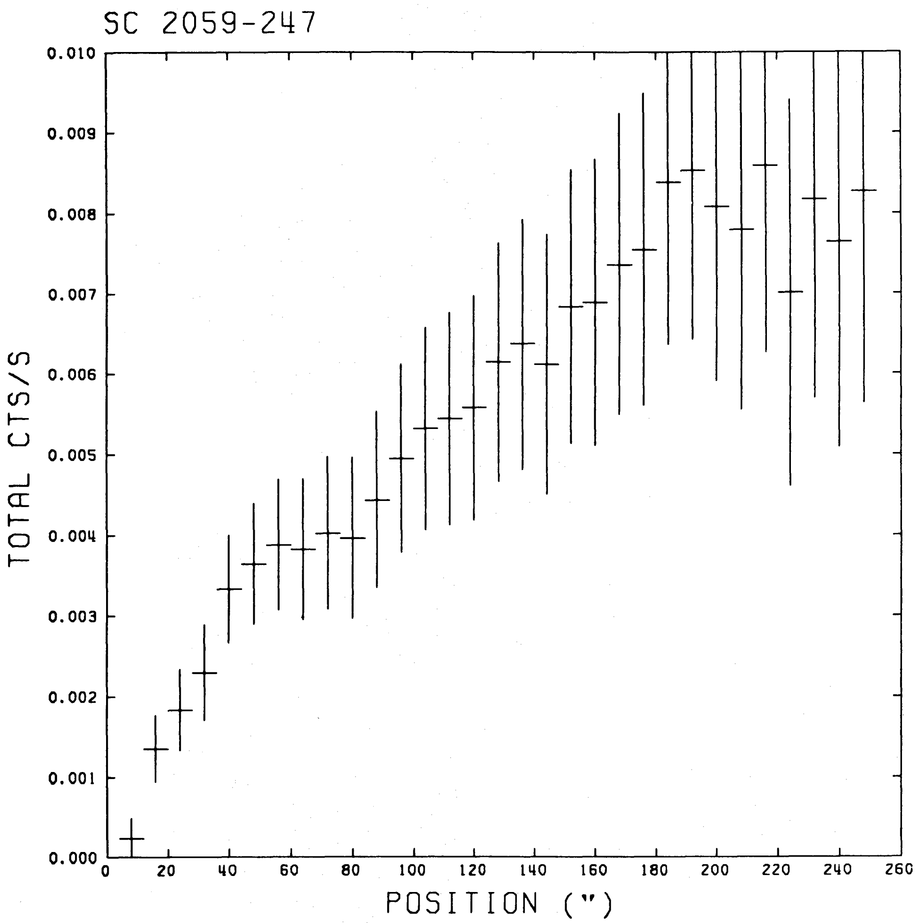

Fig. 3. Cumulative distribution of the total LE count rate within circles of radii as indicated, centered around the maximum brightness position for SC 2059–247. Note the boundary of the cluster at 180″

cluster count rate in these counters is 0.71 ± 0.10 cts s^{-1} which is too low to obtain a reliable spectrum. Given a theoretical source spectrum however, it is possible to constrain some of the spectral parameters.

We fitted the spectrum by a thermal bremsstrahlung model which includes free-bound and bound-bound transitions (Mewe and Gronenschild, 1985). Standard solar abundances and the standard absorbing neutral hydrogen column density due to our galaxy of $6\ 10^{24}\ \mathrm{m}^{-2}$ was adopted (Heiles, 1975). We used the opacity function of Morrison and McCammon (1983). The ME and LE were fitted simultaneously. The temperature is larger than $7\ 10^{7}$ K with 95% confidence while the corresponding emission measure (for $H_0 = 50\ \mathrm{km\ s^{-1}\ Mpc^{-1}}$, $q_0 = 0.5$) as used throughout this paper is $(1.4 \pm 0.2)\ 10^{74}\ \mathrm{m}^{-3}$. These values do not depend much upon uncertainties in the adopted column density. The extrapolated 0.5–4.5 keV luminosity of the source is $(1.4 \pm 0.2)\ 10^{38}$ W.

3. Discussion

Based upon the Einstein IPC data, WSQJ concluded that the X-ray source of SC 2059–247 is either

1. a nonthermal unresolved source, with characteristics of a quasar or BL Lac object, or

2. it is thermal emission from the intracluster gas, which is relatively cool compared to its large luminosity, indicating probably cluster evolution.

The present data clearly exclude the first possibility: most of the low energy emission originates from an extended source.

In analysing the present data for SC 2059–247, we use the surface density distribution (1). We put $\beta = 0.5$, consistent with the fit to the LE data. The hot gas density distribution in that case is

$$n_{\mathrm{gas}} = n_0 \{1 + (r/a)^2\}^{-0.75} \tag{3}$$

As usual in such models the gas is assumed to be isothermal. In the density distribution (3) a cut-off at a certain radius R has to be assumed. From our present data (Fig. 3) we obtain a cluster radius of 1 Mpc.

Several parameters for the cluster derived by using (3) among others, are listed in Table 1. The total cluster mass is derived by assuming pressure equilibrium of the hot gas with the cluster potential at the outer border of the cluster. The galaxy line-of-sight velocity dispersion was obtained from (2). The cooling mass flow (Fabian and Nulson, 1977) was derived from (3) by assuming energy balance between radiative cooling and convective heat transport, the enthalpy flux being $5vnkT$ where v is the local cooling velocity. The kinetic energy flux $\frac{1}{2}nm_pv^3$ can be neglected compared to the enthalpy flux in the present case.

The emission is more extended than WSQJ found: while they claimed that at least 80% of the flux originates from within a circle of radius 45″, we find that within that radius only 45% of the flux is produced, and that emission can be found up to 180″ from the cD galaxy (1 Mpc).

Table 1. Parameters for SC 2059-247

Parameters	Value
Distance	1.2 Gpc
Core radius	70 kpc
Cluster radius	1.0 Mpc
X-ray luminosity	$2.8\,10^{38}$ W
X-ray temperature	$7\,10^{7}$ K
Emission measure	$1.4\,10^{74}$ m^{-3}
Central gas density	$2.3\,10^{4}$ m^{-3}
β	0.5
Gas mass	$1.4\,10^{44}$ kg
Total mass	$8\,10^{44}$ kg
Line-of-sight vel. disp.	1200 km s^{-1}
Cooling velocity	13 km s^{-1}
Cooling mass flow	800 $M_{\odot}$ yr^{-1}
Central cooling time	1.4 Gyr
Cluster crossing time	0.5 Gyr

If we compare SC 2059–247 with the sample of clusters given by Jones and Forman (1984a), we find that the total gas mass and the total cluster mass are quite normal. The core radius is small, corresponding to a high central density, but there are other clusters with similar properties. The large luminosity and the temperature of more than $7\,10^{7}$ K, combined with the small core radius give evidence for classification as an evolved, XD (X-ray dominant) cluster. A property of this class of clusters is the presence of cooling flows. The mass flow derived for SC 2059–247 (Table 1) is very large, but other clusters with similar mass flows exist, e.g. PKS 0745–191 (Fabian et al., 1985) with a flow at 100 solar masses/year; this last cluster shows optical line emitting gas up to 10 kpc from the nucleus; it would be interesting to look for similar line emission in the present cluster. The accretion time scale for SC 2059–247 (the time needed to accrete as much gas as is observed to be present now) is of the order of the Hubble time scale, showing that the cluster is not in a rapidly changing stage of evolution, as suggested by WSQJ. Also the temperature shows no evidence for evolution effects, since it fits well within the luminosity-temperature relation as given by Jones and Forman (1984b).

There are three large discrepancies between our data and those of WSQJ: the spatial extension of the emission, the temperature and the luminosity. The difference in spatial distribution is probably caused by the small angular size of the core of the cluster, which is comparable to the pointspread function of the IPC, combined with confusion by the quasar. The spatial resolution of the LE on the other hand is sufficient to resolve the core. The lack of a proper calibration of the IPC at the publication date of WSQJ may cause the discrepancy in temperature which exists between the EXOSAT and Einstein data.

The 0.5–4.5 keV luminosity is $1.4\,10^{38}$ W, two times larger than the value quoted by WSQJ ($7\,10^{37}$ W, note an error of a factor 10 in their value in the note added in proof). The difference arises because WSQJ assumed the spectrum to be a power law with photon index 2; a thermal bremsstrahlung spectrum with a temperature of $7\,10^{7}$ K as we obtained is relatively harder at higher energies (our ME) than the power law, which was fitted at lower energies (IPC).

4. Conclusion

SC 2059–247 is a cluster of the evolved, XD type. The emission has an extension to 1 Mpc from the center, showing that a pointsource can be excluded. It has a very small core radius and a large central density; both values are not unusual for similar clusters however. The cluster temperature is quite normal for the present large luminosity; therefore no indication of temperature evolution on short timescales is present for this cluster.

Acknowledgement. The Laboratory for Space Research Leiden is supported financially by ZWO, the Netherlands Organisation for the Advancement of Pure Research.

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