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A STRONG X-RAY SOURCE IN THE COMA CLUSTER OBSERVED BY *UHURU*

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ABSTRACT

X-rays have been observed from a source in the Coma cluster of galaxies. The source is extended, with a size of about 45′. Its X-ray luminosity is 2.6×10^{44} ergs s^{-1}, and its spectrum is consistent with thermal bremsstrahlung at 7.3×10^{7} ° K or a power law. If the source is hot gas, its mass is 3×10^{13} $M_{\odot}$, which is about 1 percent of the mass required to stabilize the cluster.

I. INTRODUCTION

We have observed a strong source of X-rays (2.4–20 keV) close to the center of the Coma cluster, and we report here on its location, size, and spectrum as observed on five different days. The *Uhuru* instrumentation has been described by Giacconi *et al.* (1971). In accordance with earlier practice we suggest that this source be designated Coma X-1.

The Coma cluster at a distance of 90 Mpc contains about 800 galaxies within a 100 × 100 arc-min area of the sky. Its brightest members, NGC 4874 and NGC 4869, lie close to the kinematically determined center of the cluster. Some members of the cluster are radio sources with nonthermal spectra, somewhat analogous to the situation in the Virgo and the Perseus clusters. If in fact the source is at the Coma cluster, then its X-ray luminosity exceeds 10^{44} ergs s^{-1}. Furthermore, we have indications that the source is extended, which argues against the possibility that a single galaxy is responsible for the emission.

II. SOURCE LOCATION AND SIZE

The region of the Coma cluster was scanned on 5 days by the *Uhuru* instruments, and we have analyzed about 20 percent of the data obtained on 1971 January 6.9, 8.9, 12.3, 12.9, and 13.9, representing an exposure of about 40 s in the 0°.5 full width at half-maximum (FWHM) collimator and 380 s in the 5° FWHM collimator.

We combined the position data from each day's observation to obtain our best estimate of the location of R.A. (1950) = $12^{h}56^{m} \pm 2^{m}$ ($1\ \sigma$), decl. (1950) = $28°6' \pm 12'$ ($1\ \sigma$). The kinematically determined center of the Coma cluster (Abell 1965) lies within the location uncertainty. In addition to obtaining the source location, we have found that the source is extended. The weighted mean of the values for the width over the five days is $43' \pm 7'$ ($1\ \sigma$). Also, we combined the 0°.5 data from the 5 days, and fit the summed data using the technique described above. The combined data and the fit are shown in Figure 1*a*. The resulting width is $45' \pm 6'$ ($1\ \sigma$), which agrees with the weighted average as expected.

In order to check this result, we performed a test on similar data from Cas A. We expect the size of the X-ray source in Cas A to be no larger than in optical or radio, that is, about 4′. The resulting fit, illustrated in Figure 1*b*, gives a width of $\leq 15'$ ($1\ \sigma$).

We conclude that Coma X-1 is extended by about 45′. Figure 2 (Plate L1) shows a *Palomar Sky Survey* print of the region of the Coma cluster with a circle 45′ in diameter superposed in order to illustrate the extent of the X-ray source in relation to the galaxies of the cluster.

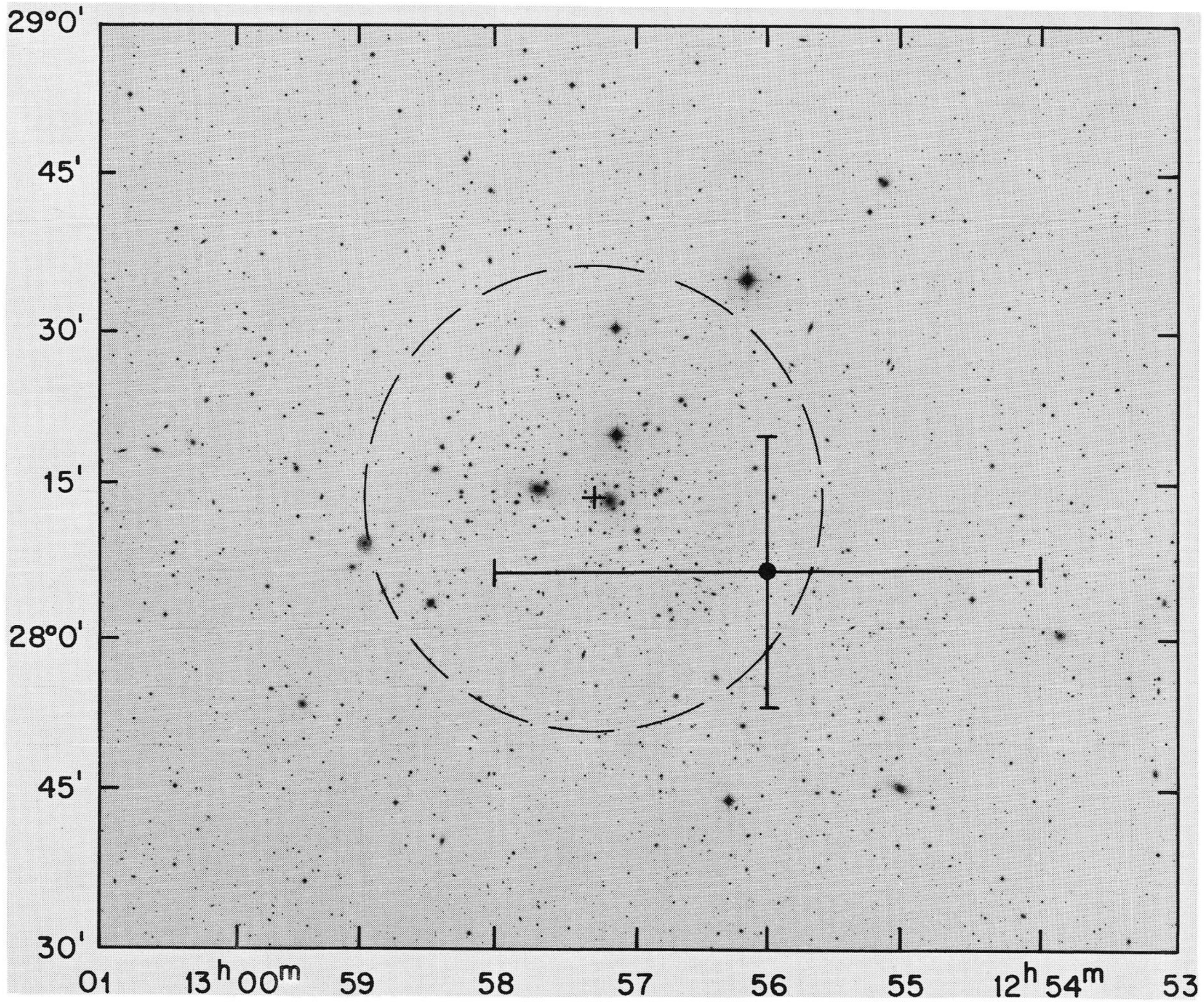

FIG. 2.—The X-ray source in Com X-1. Broken circle is drawn centered on the kinematic center of the Coma cluster, and indicates the approximate extent of the X-ray source. Error bars show the centroid of the source as determined from the data with the 1 σ uncertainties.

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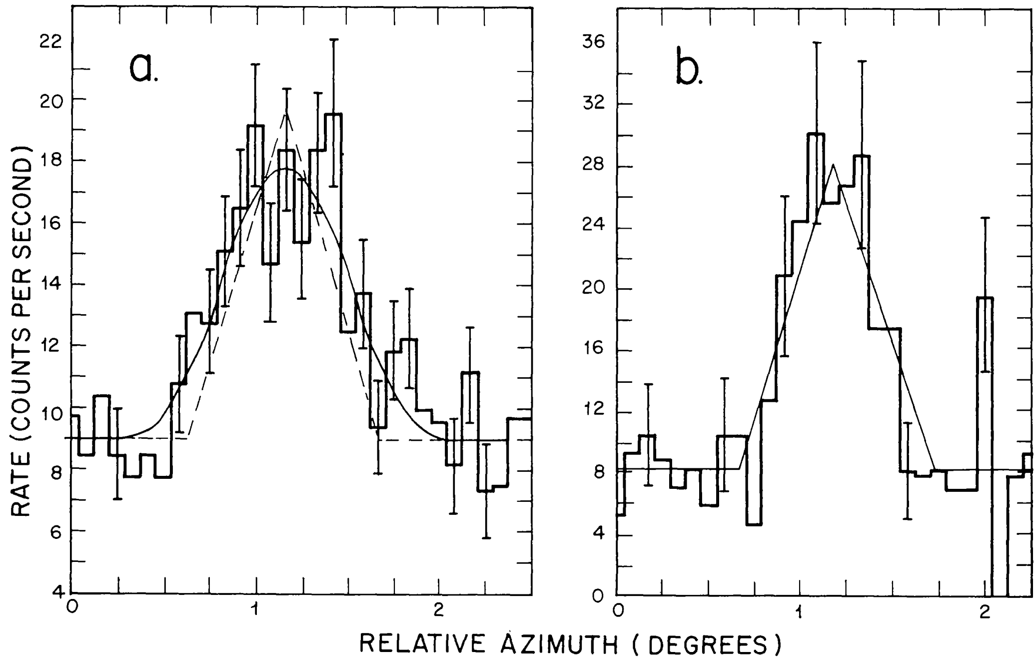

FIG. 1.—Counting-rate distributions from 0°.5 collimator. (*a*) Coma cluster showing fit to 45′ extended source, and (*broken lines*) the expected response to a point source. (*b*) Data from Cas A, as an example of a set of data which can be fitted well to a point source.

III. SOURCE SPECTRUM AND INTENSITY

Spectra were obtained for the source by using a seven-channel on-board pulse-height analysis of the output from the proportional counters, in a pulse-height range corresponding to 1.8–10 keV. The technique of Gorenstein, Gursky, and Garmire (1968) was used to analyze the data by comparison with assumed input spectra of three types: power law plus photoelectric absorption, exponential (thermal bremsstrahlung) plus photoelectric absorption, and a blackbody. The first two cases gave distinctly better fits as determined by χ^2 than blackbody, with the following results for the differential-power-spectral densities (f_ν):

$$f_\nu = (1.26 \pm 0.24) \times 10^{-10} E^{(-0.87\pm 0.14)} \text{ ergs cm}^{-2} \text{ s}^{-1} \text{ keV}^{-1},$$

$$f_\nu = (0.69 \pm 0.13) \times 10^{-10} \exp [- E/(6.3 \pm 1.1)] \text{ ergs cm}^{-2} \text{ s}^{-1} \text{ keV}^{-1}.$$

The difference in χ^2 is not sufficient to allow a choice between a power-law and an exponential spectral shape. No significant low-energy cutoff is observed in the spectrum for either fit. The fit of these two to the spectral data is shown in Figure 3. The intensity of the source was found by integrating the above power law to be

$$I = (2.6 \pm 0.5) \times 10^{-10} \text{ ergs cm}^{-2} \text{ s}^{-1}$$

between 1.8 and 10.0 keV, averaged over 5 days, and was constant to ± 20 percent on each of those days. Within the quoted energy range this figure is sensibly independent of the assumed spectral shape. The primary sources of error are the uncertainty of the elevation of the X-ray source in the detector field of view and spin-axis drift during the superposition interval. The above differential and integral intensities could be as much as 20 percent higher due to a fixed uncertainty in the effective area of the detectors.

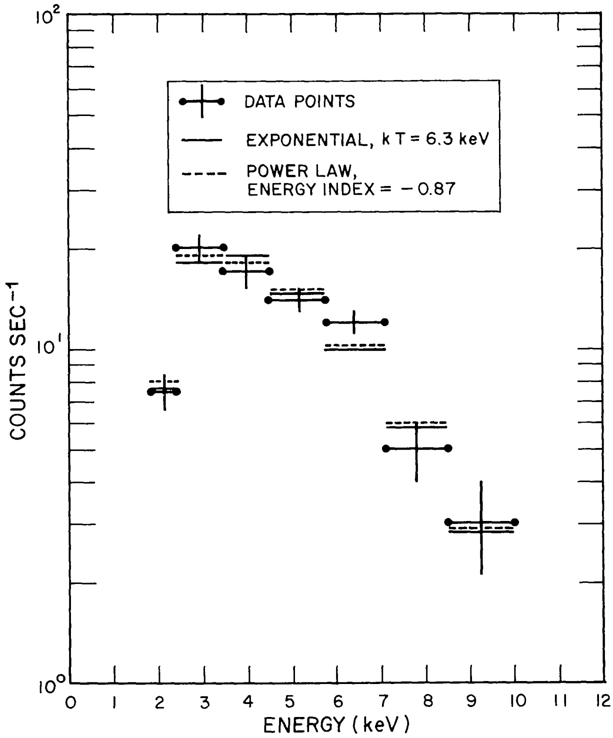

FIG. 3.—Spectral data on Com X-1. *Crosses,* data from the *Uhuru* pulse-height analyzer, with $\pm 1\ \sigma$ error bars. *Dashed lines,* comparison distribution if the best-fit power-law input spectrum is assumed. *Solid lines,* best-fit exponential.

Our result disagrees with that of Boldt *et al.* (1966). They claimed a source of strength about 10^{-2} photons $cm^{-2}\ s^{-1}\ keV^{-1}$ at 25 keV, and a size of 5°. The spectrum we observe would give no greater than about 10^{-3} photons $cm^{-2}\ s^{-1}\ keV^{-1}$ at 25 keV if it were a power law, or about 3×10^{-5} photons $cm^{-2}\ s^{-1}\ keV^{-1}$ for the exponential fit. Our result is consistent with the upper limit given by Friedman and Byram (1967) in the range 1–15 Å, since our flux is roughly one-half of their 2 σ upper limit.

IV. DISCUSSION

Because of the good location accuracy and high galactic latitude it is natural to assume that the source is in fact associated with the Coma cluster, in which case the X-ray luminosity is 2.6×10^{44} ergs s^{-1} (1.8–10 keV). However, in contrast to other strong X-ray sources at high galactic latitude that we or others have reported, there is no single galaxy with peculiar optical characteristics consistent with our location. The X-ray luminosity of the source is comparable to that reported for NGC 1275 (Fritz *et al.* 1971; Gursky *et al.* 1971), and both are substantially more luminous than any reported extragalactic source other than 3C 273. We cannot make a clear-cut choice among the several possible origins for the X-ray source on the basis of the present data. Among these are:

1. The source is due to several of the single galaxies near the center of the cluster, which for some reason (e.g., local obscuration) do not manifest peculiar optical characteristics. This is consistent with the measured angular size of this source and is similar to what we have observed in the Virgo cluster (Kellogg *et al.* 1971).

2. A large number of individual galaxies in the cluster comprise the source. This

would require an average galactic luminosity of 10^{41}–10^{42} ergs s^{-1}, which is at variance with observations of the Virgo cluster (Byram, Chubb, and Friedman 1971).

3. The source is thermal bremsstrahlung from a hot intergalactic gas in the cluster (see Felten *et al.* 1966). There is some evidence to support the hot-gas interpretation. First, the temperature we have obtained from our thermal bremsstrahlung fit, 73×10^6 ° K, implies particle velocities of 1050 ± 90 km s^{-1}, on a uniform-temperature assumption, which is close to the rms velocity of 1470 km s^{-1} for galaxies in the cluster (see Peebles 1970). This suggests a picture of some kind of kinetic equilibrium between the gas and the galaxies. Second, the measured source size agrees well with that expected if the gas-density function follows that of the galaxies as determined by Omer, Page, and Wilson (1965). In the approximation that the gas distribution is a Gaussian with characteristic width 100′, then the thermal source whose intensity distribution is proportional to the square of the density would have a width of 50′, which agrees with our value of 45′ ± 6′.

If the source is due to hot gas at 73×10^6 ° K, we calculate the mass to be $M(\text{gas}) = 3 \times 10^{13} M_\odot$, which is about 1 percent of the mass needed to stabilize the cluster. It is possible that the optical emission from such a hot intracluster medium might be barely detectable, but we expect that it would be extremely faint. It is interesting to note that several observers "have suggested a faint luminous background in the central region of the Coma cluster" (Abell 1965), but it is so faint, if it exists, that the observers cannot be sure whether it is due to intergalactic matter or to the outer faint parts of observed galaxies.

Note added in proof.—Meekins *et al.* (1971) have reported the detection of an excess of X-rays from the region containing the Coma cluster of about the same strength as the source reported here.

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