LETTERS TO NATURE

PHYSICAL SCIENCES

X-rays from the Coma Cluster of Galaxies

THE Coma cluster of galaxies is usually considered to contain insufficient matter in the form of galaxies to be gravitationally bound, but the high degree of symmetry of the cluster, and the presumed age of its galaxies, suggest that the cluster is, in fact, gravitationally bound. It is possible that the missing mass takes the form of ionized intracluster gas, and Woolf[1] has used radio, visible light and X-ray observations to set upper limits for the amount of such matter and, more recently, Turnrose and Rood[2] have discussed the problems of heating and supporting such a gas against gravitational collapse. We present here new observational evidence of X-ray emission which limits the amount of hot intracluster gas to less than 2% of that required for gravitational binding.

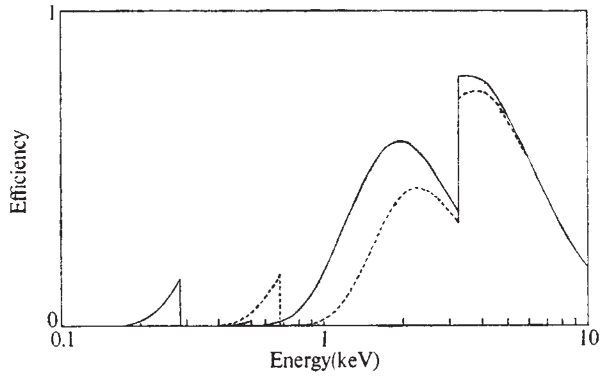

Fig. 1 The efficiency of the X-ray proportional counters as a function of photon energy. The solid curve is for the 'Mylar' window detector and the dashed curve is for the 'Teflon' window detector.

On March 14, 1969, at 0530 UT an Aerobee 150 was launched from White Sands Missile Range, New Mexico. Aboard the rocket were two proportional counters filled to about 800 mm Hg with 10% methane in argon. The windows of the two proportional counters were 'Teflon' (3.2 µm) and 'Mylar' (3.8 µm) with open areas of 234 cm^2 and 326 cm^2, respectively. The quantum efficiencies of the two detectors are shown in Fig. 1. During the flight, the rocket performed a slow scan, such that the detector field of view moved at a rate of approximately 0.35° s^{-1} over the Coma cluster and adjacent sky. Each detector had a cylindrically symmetrical field of view of about 10° full width at half maximum and about 20° full width at cutoff.

Table 1 lists the results of three observations each lasting 27 s; one observation was centred approximately on the Coma cluster, and the two adjacent positions gave background data. The data shown are tne count totals from the detectors for the approximate bandwidths indicated and are uncorrected for instrumental field of view, area, and quantum efficiency.

Table 1 Count Rates near Coma Cluster

Position	Observed counts per 27 s 'Teflon' 18–24 Å	'Teflon' 1–12 Å	'Mylar' 44–60 Å	'Mylar' 1–17 Å	Total
Before Coma	169	1,821	242	2,732	4,964
Coma	202	1,900	259	3,092	5,453
After Coma	208	1,872	248	2,865	5,193

Fig. 2 shows the result of a pulse height analysis of the data, corrected for field of view and area; the mean of the count totals from the two background intervals has been subtracted from that obtained from the region which includes the Coma cluster. It is clear from Table 1 and Fig. 2 that only upper limits of the flux in the 44–60 Å and 18–24 Å bands from the Coma cluster can be specified, but the flux measured from 3–17 Å is statistically significant. The last column in Table 1 shows the sum of the other columns and indicates an approximately 5σ X-ray enhancement over the sky background from the direction of the Coma cluster.

The 'Teflon' counter taken separately indicates an enhancement of only 1σ, although the 'Mylar' counter shows a 4.5σ increase above background. Almost all this increase occurs in

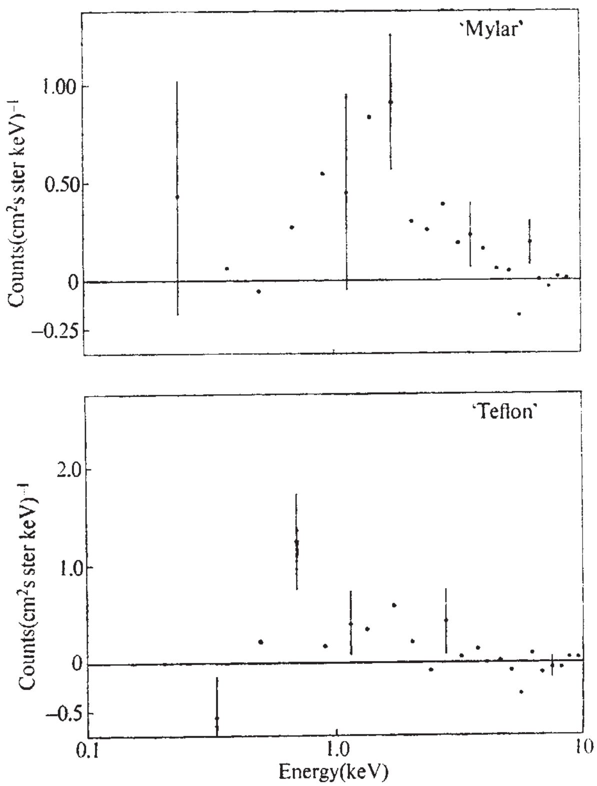

Fig. 2 Spectra from the two detectors of the Coma cluster region after subtraction of the diffuse background. Vertical error bars are 2σ in length and represent the combined uncertainty in the background and Coma cluster data. The solid angle assumed is that of the detector (0.024 ster).

the energy band 0.7–4 keV (centred at 8 Å) in which the efficiency of the 'Mylar' counter is considerably higher than that of the 'Teflon' counter (Figs. 1 and 2). Over the entire 0.7–4 keV bandwidth, the Coma X-ray flux is approximately 0.03 counts cm^{-2} s^{-1}, a factor of ten below the upper limit (at the 3σ confidence level) set by Friedman and Byram[3] in a similar energy band.

From the data shown in Fig. 2, and because the Coma cluster subtends a solid angle of about 2.5×10^{-3} steradians, upper limits have been placed on the flux in the three bands of 44–60 Å (from the 'Mylar' detector), 18–24 Å (from the 'Teflon' detector) and 1–3 Å (from both detectors). The flux from the 3–17 Å (0.7–4 keV) band is a positive detection. The values are listed in Table 2.

Table 2 Photon Flux from Coma

Wavelength band (Å)	Flux (photons cm^{-2} s^{-1} $ster^{-1}$ keV^{-1})
44–60	450 (upper limit)
18–24	250 (upper limit)
3–17	11 (observed)
1–3	20 (upper limit)

We can use the X-ray data to test the hypothesis that the cluster is gravitationally bound by an optically thin, hot intracluster gas, as was done by Woolf[1]. From the observed flux (3–17 Å) and the upper limit in the longest wavelength band (44–60 Å) we obtain a minimum temperature of 8×10^{6} K. At this temperature, the mass of gas required to bind the cluster ($\sim 3 \times 10^{48}$ g) would radiate much more intensely than the observations permit. Only if the total mass is less than 6×10^{46} g or about 2% of that required for gravitational binding can the X-ray observations in the various wavelength bands be reconciled. This estimate assumes a uniform distribution of gas. Concentration in clouds would decrease the mass still further. Taking the diameter of the cluster to be about 4°, or 5 Mparsec, gives a density upper limit of about 2×10^{-5} cm^{-3}, which is close to the critical density for intergalactic gas in a closed universe.

The possibility that individual galaxies within the Coma cluster are responsible for the observed X-rays has been shown to be unlikely[4]. We will assume that the population of X-ray sources in our galaxy is typical of all galaxies of similar optical luminosity and compare the X-ray emission of our galaxy with that of the Coma and Virgo clusters. (The following gross comparison does not take into account that both the Virgo and Coma clusters include a great number of elliptical galaxies, whereas ours is a spiral galaxy.) The Virgo and Coma clusters contain of the order of 100 and 1,000 galaxies, respectively, at least as bright as our own. The estimated power of our galaxy from discrete X-ray sources is about 7×10^{39} erg s^{-1} for the 1–10 Å region[5]. At a distance of 70 Mparsec the expected X-ray flux from the 1,000 bright galaxies in the Coma cluster would be about 5×10^{-3} photons cm^{-2} s^{-1} or about a factor of twenty below that observed. Byram, Chubb, and Friedman[6] found that the X-ray power of the Virgo cluster (minus M-87) is about 1.6×10^{43} erg s^{-1} in the 1–10 keV range and suggested that it could be accounted for as the integral of all galaxies in a field of view of approximately 30 square degrees. It was an oversimplification, however, to treat each of 2,000 galaxies in Virgo as equivalent to our galaxy in X-ray power. For the approximately 100 bright galaxies in Virgo, the X-ray flux from discrete sources would be only 7×10^{41} erg s^{-1} (assuming 7×10^{39} erg s^{-1} $galaxy^{-1}$), again a factor of twenty below that observed. The X-ray fluxes from both the Virgo and Coma clusters thus seem to be proportional to the optical luminosity of the cluster.

If the estimated X-ray power of our galaxy is integrated over all galaxies within a Hubble radius to obtain their contribution to the diffuse background, the result is a factor ten to fifty times lower than the observed background. Because the total X-ray flux observed from Coma and Virgo is about an order of magnitude greater than might be expected from discrete sources, every cluster may well contain a mass of hot intracluster gas proportional to the number of bright galaxies in the cluster. The integral over a Hubble radius could then give sufficient X-ray flux in the 0.7–4 keV range to make up most of the diffuse background observed in that portion of the spectrum by Henry, Fritz, Meekins, Chubb, and Friedman[7]. It would still be possible to attribute the flux observed near $\frac{1}{4}$ keV to intergalactic gas at a temperature close to 10^{6} K and the critical density of about 10^{-5} cm^{-3}.

We thank A. F. Davidsen for helpful discussions. R. C. H. received a US National Science Foundation grant.

JOHN F. MEEKINS
GILBERT FRITZ
TALBOT A. CHUBB
H. FRIEDMAN

E. O. Hulbert Center for Space Research,
Naval Research Laboratory,
Washington, DC 20390

RICHARD C. HENRY

E. O. Hulbert Center for Space Research, and
The Johns Hopkins University,
Baltimore, Maryland 21218

Received April 5, 1971.

1 Woolf, N. J., *Nature*, **229**, 544 (1971).
2 Turnrose, B. E., and Rood, H. J., *Astrophys. J.*, **159**, 773 (1970).
3 Friedman, H., and Byram, E. T., *Astrophys. J.*, **147**, 399 (1967).
4 Felten, J. E., Gould, R. J., Stein, W. A., and Woolf, N. J., *Astrophys. J.*, **146**, 955 (1966).
5 Friedman, H., Byram, E. T., and Chubb, T. A., *Science*, **156**, 374 (1967).
6 Byram, E. T., Chubb, T. A., and Friedman, H., *Nature*, **229**, 544 (1971).
7 Henry, R. C., Fritz, G., Meekins, J. F., Chubb, T. A., and Friedman, H., *Astrophys. J. Lett.*, **163**, L73 (1971).

Optical Identification of PKS 0320–37

LÜ[1] has suggested that the large extended radio source PKS 0320–37 (Fornax A), identified for many years with the tenth magnitude SO galaxy NGC 1316 (ref. 2), should really be identified with a seventeenth magnitude blue stellar object. We propose to show here why this new identification should not be accepted.

The structure and scale of the radio source are typical of a radio galaxy and not of any known QSO. The total intensity and linear polarization distributions at a wavelength of 6 cm (F. F. G. and J. B. W., work in preparation) are shown in Fig. 1. They were obtained with the Parkes 64 m telescope and a resolution of 4.0′. The distribution consists basically of two highly polarized components (up to 50% linearly polarized) with centres separated by 32′. They straddle the galaxy NGC 1316, which is centred at 03 h 20 m, 47 s, −37° 23.1′ (ref. 3). The broken lines represent the outer limits of the optical nucleus as shown on a limiting exposure at visual wavelengths with the 48 inch Palomar Schmidt telescope[4]. The 6 cm radio distribution is similar to that found at 75 cm with similar resolution[5]. The apparent dimensions are typical of a radio galaxy located at the distance of NGC 1316 (about 20 mparsec) but exceeds by two orders of magnitude those of any known QSO.

For the galaxy NGC 1316, evidence of an association of optical and radio continuum has been provided by Arp[4]. Using a faint photography technique, he showed that the galaxy had outer extensions which bend into the two radio components.