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HEAO 1 HIGH ENERGY X-RAY OBSERVATIONS OF THE VIRGO CLUSTER AND A2142

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ABSTRACT

We report observations of the Virgo cluster and Abell 2142 taken with the UCSD/MIT hard X-ray and low energy γ-ray instrument (A-4) on board the *HEAO 1* spacecraft, during 1977 and 1978. We observe a mean flux from the Virgo cluster of $(1.3 \pm 0.3) \times 10^{-3}$ photons cm^{-2} s^{-1} between 20 and 100 keV. We also present the complete spectrum for this cluster from 0.2 to 100 keV, using data from both the A-2 and A-4 detectors on *HEAO 1*. Our data are best fitted by a two component model, a thermal with $kT = 2$ keV and a power law. We derive a limit of EM $\leq 1.2 \times 10^{65}$ cm^{-3} for the emission measure of any moderate temperature ($kT \sim 6$ keV) gas. For A2142 we obtain a marginally significant (15–40) keV flux of $(2 \pm 0.8) \times 10^{-3}$ photons cm^{-2} s^{-1} and a 2 σ upper limit to the 40–150 keV flux of $< 2 \times 10^{-4}$ photons cm^{-2} s^{-1}. We use our results to derive limits to the intracluster magnetic field of $B \gtrsim 5 \times 10^{-7}$ gauss and $B \gtrsim 5 \times 10^{-8}$ gauss in the Virgo cluster and A2142, respectively. We also discuss our results in terms of possible variability of the hard X-ray emission in these two clusters.

Subject headings: galaxies: clusters of — galaxies: intergalactic medium — magnetic fields — X-rays: sources

I. INTRODUCTION

It has been realized for some time that clusters of galaxies form a class of X-ray emitting objects (see, e.g., Gursky and Schwartz 1977). It is by now well accepted that the bulk of the emission at photon energies lower than 10 keV is due to thermal emission from a hot gas contained in the potential well of the cluster as a whole, the individual galaxies, or both. Recently, however, new data have complicated our original simple picture for these cluster sources. Many clusters are observed to have at least two components to their spectra (Mitchell and Mushotzky 1980; Reichert *et al.* 1981). X-ray pictures taken with the *Einstein* Observatory show several different morphologies, ranging from smooth, centrally peaked X-ray distributions to "clumpy" distributions (Jones *et al.* 1979). Many clusters of galaxies contain one or more active galaxies. Since these galaxies constitute another class of known X-ray emitters, we may expect that they would also contribute to the X-ray spectra of the clusters. In addition, since most clusters also contain sources of radio emission, inverse Compton X-ray emission due to scattering of the radio emitting electrons off the microwave background must be present at some level; the intensity of this emission is determined by the magnetic field strength in the radio source (e.g., Harris and Romanishin 1974; Lea and Holman 1978). Since the spectra of both active galaxies and inverse Compton emission are fairly hard, we expect these sources to dominate the thermal emission at energies $\geq$ a few times kT. For most clusters, $kT \lesssim 10$ keV.

Both the Perseus and Virgo clusters should have observable inverse Compton (IC) emission if the magnetic field in the cluster radio sources is $\lesssim 10^{-7}$ gauss. This magnetic field strength is less than the equipartition field for these sources which is typically $\sim 10^{-6}$ gauss, but is not an unreasonable value for the field strength in a cluster. Previous limits and theoretical arguments suggest $B \lesssim 10^{-7}$ gauss in intergalactic matter (see Lea 1974 for a review). In addition, the Virgo cluster is known to have a complex spectrum, requiring at least two emitting components (Mushotzky *et al.* 1978*b*) one of which is

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either a high temperature thermal or a power law, and might be due to inverse Compton emission. The *OSO 8* data for A2142 indicate a hard X-ray spectrum, with $T \gtrsim 50$ keV or a photon spectral index roughly equal to 1.4. We have chosen these three clusters for observation with the UCSD/MIT hard X-ray and low-energy γ-ray instrument (A-4) on board the *HEAO 1* spacecraft. In this paper we report observations of the Virgo cluster and A2142. Our results for the Perseus cluster have been reported elsewhere (Primini *et al.* 1981).

II. OBSERVATIONS

Our observations were taken with the low-energy $1^\circ.5 \times 20^\circ$ slat detectors of the A-4 experiment which have been described in detail by Matteson (1978). These detectors are sensitive from approximately 15 to 150 keV. The observations were taken in a scanning mode, with background observations taken both shortly before and after the source passed through the field of view, and in a pointing mode when the detectors pointed alternatively at the source and at a nearby background region containing no known X-ray sources.

a) *The Virgo Cluster*

This source was scanned during 1977 December, 1978 June, and 1978 December. In addition two points were performed during June of 1978. We obtained a total of 4000 seconds of on source data during 1977 December 17–31, 2000 seconds of data during 1978 June 13–26, plus 10,000 seconds of data from pointings, and 2000 seconds of data during 1978 December 16–1979 January 1. A flux above background was seen during each of the observations. The results are shown in Table 1. These results are suggestive of variability. We obtain a value of $\chi^2 = 10.6$ for 2 degrees of freedom for the assumption of a constant source, which is significant at the 99.5% confidence level. We have simultaneously obtained data with the A-2 experiment[3] on board the *HEAO 1* spacecraft.

In Figure 1 we present the composite spectrum of the Virgo cluster from 0.2 to 100 keV. This spectrum clearly shows the excess above the 2 keV thermal spectrum at energies above about 8 keV.

It is clear that a two component model is necessary to fit the data. If both components are thermal, the *HEAO* A-2 data require $kT > 9$ keV for the high temperature component. The source was also observed by *OSO 8* in 1975–1976 (Mushotzky *et al.* 1978*b*), and a two component fit to the *OSO 8* data requires $kT_{\mathrm{HIGH}} > 15$ keV. Further, the A-4 data show emission out to at least 40 keV, requiring $kT_{\mathrm{HIGH}} > 10$ keV; inclusion of the datum at 60–100 keV implies $kT_{\mathrm{HIGH}} > 20$ keV. Such high temperatures are improbable for a cluster like Virgo. A thermal hard component is also unlikely if the variability discussed below is real. For these reasons, we have fitted a thermal plus power law model to the data. The best fit model of this type requires a thermal spectrum with $kT = 2.05$ keV and a power law of photon index ~ 2.4, although the slope of the hard component is not well constrained by the A-2 data, which require only that the index be $\gtrsim 1.4$. The χ^2 for this fit is 1.36 per degree of freedom. The A-4 data are also consistent with this power

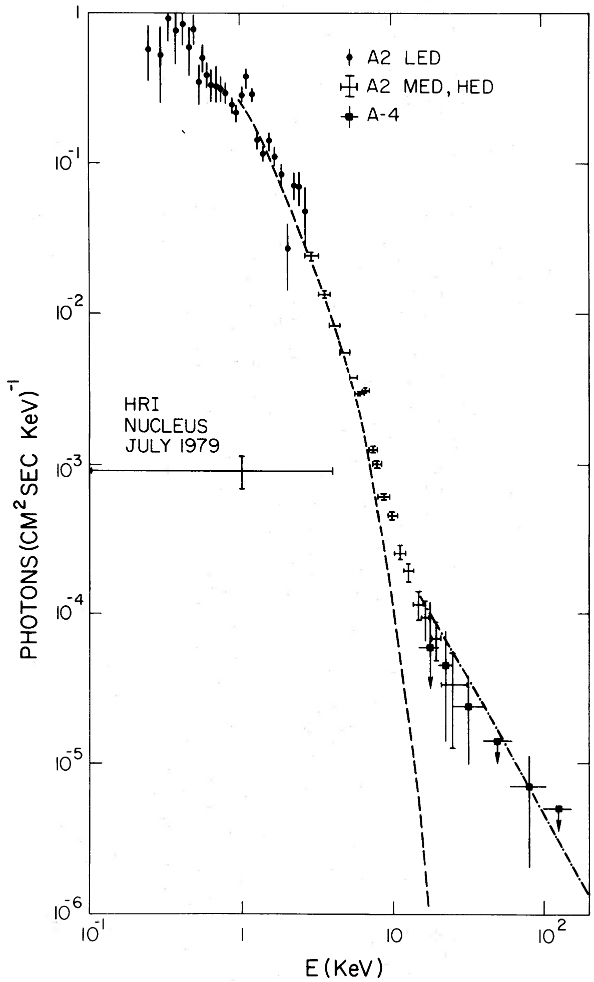

FIG. 1.—X-ray spectrum of the Virgo cluster in 1978 June. The dashed line shows a 2.05 keV thermal bremsstrahlung spectrum, for reference. The excess above this spectrum at energies $\gtrsim 8$ keV is clear. The dot-dash line shows the predicted IC spectrum for a 5×10^{-7} gauss field. The iron lines at 1.1 keV and 6.7 keV are also evident. The 1 keV line is discussed in Lea *et al.* (1979). The 6.7 keV line equivalent width is the same as measured by *OSO 8* (Mushotzky *et al.* 1978*b*; Smith, Mushotzky, and Serlemitsos 1979).

TABLE 1

A-4 OBSERVATIONS OF THE VIRGO CLUSTER

Date	Flux, 20–100 keV (photons cm^{-2} s^{-1})
1977 December	$(3 \pm 1) \times 10^{-3}$
1978 June	$(0.79 \pm 0.36) \times 10^{-3}$
1978 December	$(3.9 \pm 1.1) \times 10^{-3}$
Mean	$(1.3 \pm 0.3) \times 10^{-3}$

[3] The A-2 experiment of *HEAO 1* is a collaborative effort led by E. Boldt of GSFC and G. Garmire of CIT with collaborators at CIT, GSFC, UCB, and JPL.

law. The 1978 December A-2 spectrum is fitted by a similar thermal component with $kT = 2.04$ keV, together with a power law index 2.6, and a power law normalization of $N = 0.14$ as compared with $N = 0.07$ for the June data. Again, $\chi^2 = 1.36$ per degree of freedom for this fit. These data are also consistent with the A-4 results (see Fig. 2). The statistical errors in the A-2 data are very small, but we estimate systematic errors of $\sim 10\%$. The 1978 December *HEAO* A-4 data are also in good agreement with the 1975–1976 *OSO 8* data at 15–20 keV, and an extrapolation of their best fit power law component fits the A-4 data throughout our bandpass. These data points lie above the A-2 data points at 10–15 keV, however, which could mean that the spectrum was flatter in 1978 December than in 1975–1976. There is some suggestion (primarily from the A-4 data) that the hard component was also higher in 1977 December than in 1978 June.

b) A2142

We obtained a total of 3000 seconds of scanning data across A2142 during the period 1978 January 31–February 13. The measured flux for this source is $(2 \pm 0.8) \times 10^{-3}$ photons cm^{-2} s^{-1} in the 15–40 keV

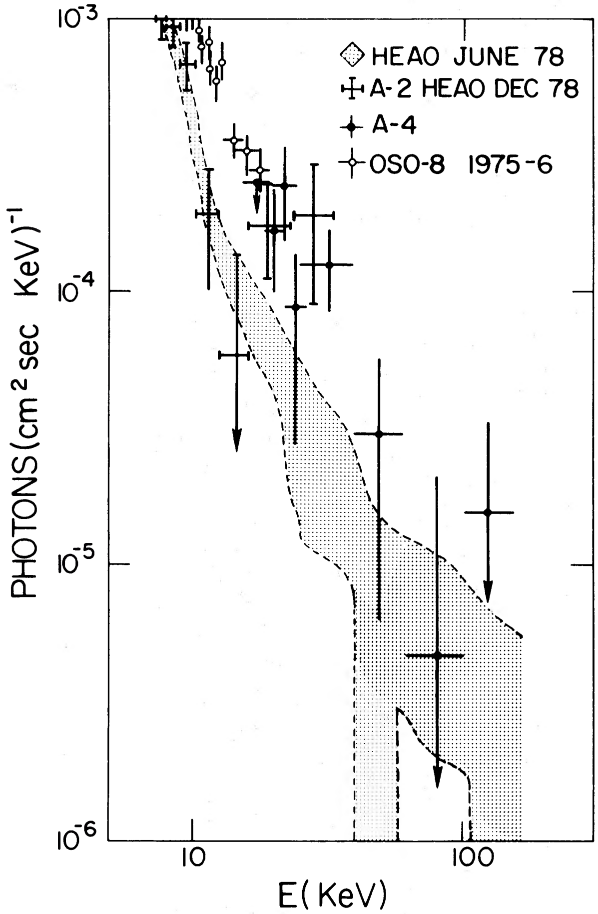

FIG. 2.—The hard X-ray tail of M87 at different epochs. The shaded band is equivalent to the data shown in Fig. 1.

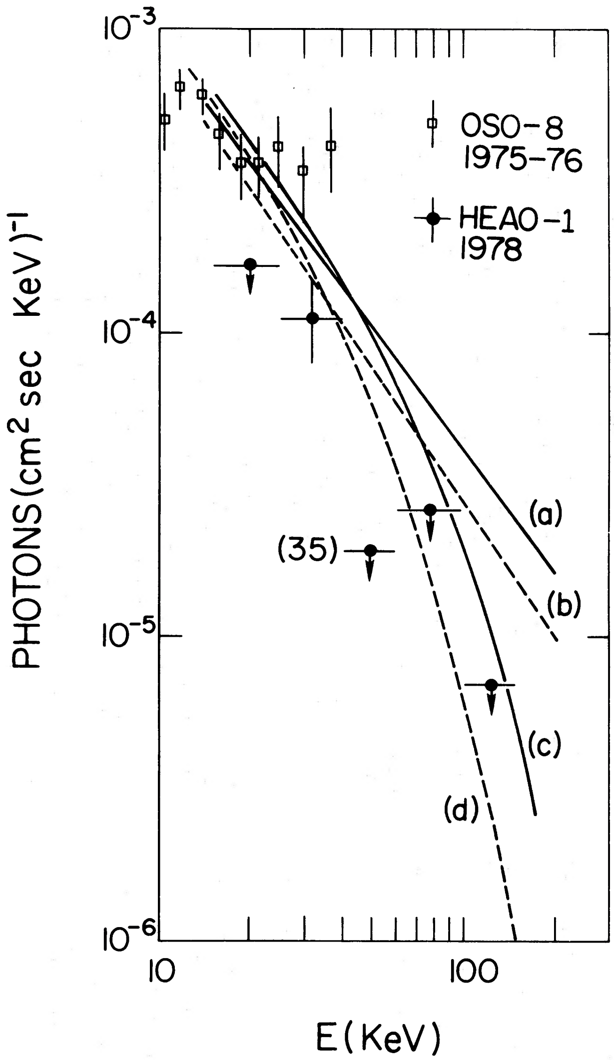

FIG. 3.—X-ray spectrum of A2142. Error bars are 1 σ, upper limits 2 σ except where noted. The solid lines are extrapolations of the (*a*) best fit power law and (*c*) thermal models to the *OSO 8* data (Mushotzky *et al.* 1978*b*). The dashed lines show the steepest power law (*b*) and lowest temperature thermal (*d*) spectra which are consistent with the *OSO 8* data.

energy band and the source was not detected above 40 keV. Our observed spectrum is shown in Figure 3. We have also plotted the published "best fits" to the *OSO 8* data (Mushotzky *et al.* 1978*b*). Our data are inconsistent with these fits. The model which gives the closest approach to the data is the lowest temperature thermal model allowed by the *OSO 8* data (at 90% confidence), $T = 33$ keV. A fit of our data to this model gives a χ^2 of 60 for 4 degrees of freedom, so that we can rule out this fit at a very high degree of confidence. We conclude that the source decreased in intensity by a factor of $\gtrsim 1.5$ between the time of the *OSO 8* observations (1975–1976) and our own (1978). This conclusion is supported by data taken simultaneously by the HED of the A-2 experiment.

III. DISCUSSION

a) *Limits on the Magnetic Field Strength in Clusters*

i) *General Considerations*

Both the Virgo cluster and Abell 2142 have been identified with steep spectrum, low frequency radio sources (Viner and Erickson 1975; Erickson, Matthews, and Viner 1978). We expect that inverse Compton (IC) scattering off the 3 K background photons of the electrons responsible for the radio emission will give rise to X-ray emission. The expected X-ray spectrum is a power law with photon index $1 + \alpha$, where α is the radio spectral index, defined as $F_\nu(\text{Jy}) \propto \nu^{-\alpha}$. The intensity of the X-ray emission depends on the magnetic field strength and the radio source flux, $F_x \propto F_R B^{-(\alpha+1)}$ (Lea and Holman 1978). The energy of the emitted X-ray photons also depends indirectly on the magnetic field strength. If the field is weak, higher energy electrons are required to produce the observed radio emission, and these electrons produce higher energy X-ray photons via the IC process. Since the radio spectrum is observed down to a minimum frequency ν_{min}, typically ~ 20 MHz; this is equivalent to observing the relativistic electron spectrum down to a minimum γ, $\gamma_{\text{min}} \sim 1.2 \times 10^{-3} B^{-1/2} \nu_{\text{min}}{}^{1/2}$, where B is in gauss and ν in Hz. These electrons then produce X-rays at $E_{\text{min}} \sim 1.65 \times 10^{-12}(\nu_{\text{min}}/B)$ keV, ~ 330 keV for typical values of $\nu_{\text{min}} \sim 20$ MHz and $B \sim 10^{-7}$ gauss. Thus in general we must assume an extrapolation of the electron spectrum below γ_{min} to make a comparison with the observed X-ray data.

ii) *The Virgo Cluster*

This cluster has been observed to have a flux of 4341 Jy at 26.3 MHz by Viner and Erickson (1975), and 7940 Jy at 10 MHz by Bridle (quoted by Clark 1967). The radio spectral index is $\alpha = +0.79$ (e.g., Erickson, Matthews, and Viner 1978). We have used our 1978 June X-ray spectrum to compare with the predicted IC spectrum. Because of its variability, the higher flux detected in 1978 December cannot be due to the IC process. There is some indication that the radio source is extended, with a size of $\sim 6'$ at 26.3 MHz (Viner 1973). The size can be measured more reliably at higher frequencies; the total extent is $16' \times 12'$ at $\nu \gtrsim 80$ MHz (Costain *et al.* 1976; Kotanyi 1980). There are no direct measurements of the X-ray source size at energies above 20 keV, although at lower energies A-2 data indicate that there are several components, the largest being at least 1° in size (Lea *et al.* 1979). Lawrence (1978) also observed a size $\gtrsim 1°$ in the 2–18 keV band. Since for this source, the inverse Compton model implies that we are observing radiation from the same electrons in the X-ray as in the radio (see below), the size of the inverse Compton X-ray source must be $\sim 10'$ also, and this large size implies that the IC X-ray emission cannot be variable.

We have used our data to construct limits to the electron spectrum in the radio source region, as described in Harris and Romanishin[4] (1974) (see Fig. 4). We use the

[4] The procedure described by these authors has been corrected as noted in Primini *et al.* (1980).

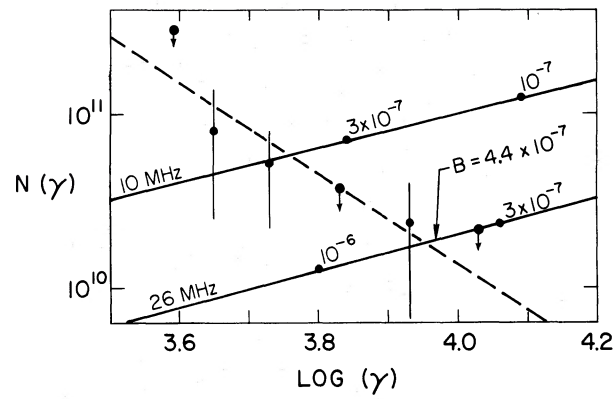

FIG. 4.—Inferred electron spectrum for the Virgo cluster, based on the 1978 June X-ray observation. The solid lines are the loci of the $[N(\gamma), \gamma]$ points defined by the radio data, as B varies. Values of B are noted on these lines. The dashed line is a line of the correct slope (as defined by the radio data) fitted to the X-ray data. The intersection of the dashed line with the solid line indicates the magnetic field strength.

radio spectral index to define the spectral index $p = 2\alpha + 1$ of the electron spectrum, $N(\gamma) \propto \gamma^{-p}$, and our X-ray data points to define upper limits to $N(\gamma)$ at $\gamma = 950 E_x{}^{1/2}$ where E_x is the photon energy in keV at the center of each X-ray band. The dashed line is of slope $p = 2\alpha + 1 = 2.58$ and is normalized to fit the X-ray data points. The radio data at frequency ν_R define a value of $N_{\nu_R}(\gamma)$ at an energy γ_{ν_R} where both N_{ν_R} and γ_{ν_R} depend on the magnetic field strength B. Each solid line in Figure 4 is a locus of the $[N(\gamma), \gamma]$ point as the magnetic field varies. Each line corresponds to one radio datum. Note that some X-ray data points lie between the solid lines in Figure 4. The 10 MHz datum should be regarded as much less certain than the 26.3 MHz datum. It is included here to emphasize that for this cluster the X-ray and radio data give information about the same electrons, which is somewhat unusual for clusters, as discussed in § III*a*(i) above.

The intersection of the dashed line and the solid, 26.3 MHz line gives a magnetic field strength of $B = 4.7 \times 10^{-7}$ gauss. The predicted IC spectrum for this field strength is shown as the dot-dash line in Figure 1. This value should be regarded as a lower limit to the field strength, because some or all of the emission may be due to other processes. Because of the overlap between the X-ray and radio data, when translated into (N, γ) space, this is a reasonably firm lower limit to B. The only possible alternative is $B \ll 1.5 \times 10^{-7}$ gauss *and* the electron spectrum turns over at γ_0 where

$$10^4 < \gamma_0 < 10^4[B/(1.5 \times 10^{-7})]^{-1/2} ,$$

which we regard as unlikely.

The equipartition field for this radio source is $B_{\text{eq}} \sim 2 \times 10^{-6}$ gauss (assuming that the particle energy is not dominated by the protons), so that our data require $B \gtrsim B_{\text{eq}}/4$.

iii) *A2142*

The electron spectrum for this cluster is shown in Figure 5. The radio spectrum is quite steep, $\alpha = 1.52$ (Erickson, Matthews, and Viner 1978), implying a steep electron spectrum with index $p = 4.04$. The dashed lines are of slope $p = 4.04$ and have the highest normalization consistent with the X-ray upper limits (*a*) over the whole spectrum and (*b*) at $\gtrsim 100$ keV. The intersections of these lines with the 26.3 MHz radio datum locus imply magnetic fields of 5×10^{-8} gauss and 3.2×10^{-8} gauss, respectively. The source has not been observed below 26.3 MHz. There is a fairly large gap between the part of the electron spectrum defined by the X-ray data and that defined by the radio data, so that the electron spectrum could turn over in the unobserved region between the two data sets. We conclude that $B \gtrsim 5 \times 10^{-8}$ gauss, *or* $B \gtrsim 3 \times 10^{-8}$ gauss *and* $\gamma_0 \gtrsim 6300$, *or* $\gamma_0 \gtrsim 10^4$. The equipartition field for this radio source is $B_{\rm eq} \sim 10^{-6}$ gauss, but is somewhat uncertain because of our lack of knowledge of the source size.

b) Source Variability

There is some evidence for variability of the hard X-ray emission in all those clusters for which good X-ray data exist above 20 keV (Perseus, Virgo, and A2142). A comparison of *OSO 7* and *HEAO 1* data indicates possible variability of the Perseus cluster above 20 keV (Rothschild *et al.* 1981). Comparison of *HEAO 1* and *OSO 8* data for A2142 indicates variability by more than a factor of 1.5, while the *HEAO 1* data for Virgo indicate variability by a factor of 2–3 (at 99.5% confidence) over 6 months. In light of this evidence, it seems likely that at least some of the hard X-ray emission from clusters may be due to a point source of emission within the cluster, rather than from an extended region. Active galaxies are characterized by hard X-ray spectra having photon power law indices 1.3–2.0 (Mushotzky *et al.* 1980). In addition, some of these objects are variable in intensity over time scales ranging from days to months. The obvious candidate galaxies are NGC 1275 in the Perseus cluster and M87 in the Virgo cluster. NGC 1275 is discussed elsewhere (Primini *et al.* 1981). If the hard X-ray flux we have observed from the Virgo cluster is due to M87, then this galaxy has a luminosity of 4×10^{42} to 2×10^{43} ergs s^{-1} in the 20–100 keV band. This luminosity is comparable to that of other active galaxies. This source is distinct from the thermal source due to hot gas in the potential well of M87, which has been observed at lower energies.

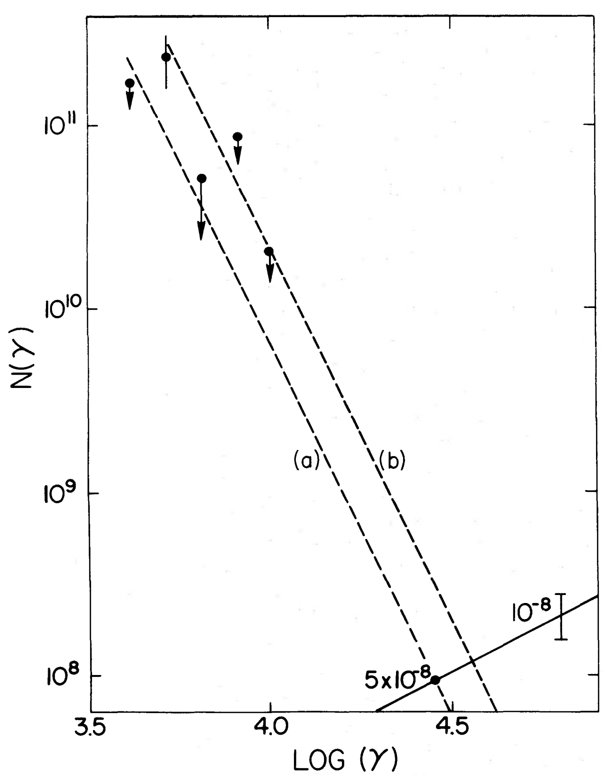

FIG. 5.—Inferred electron spectrum for A2142. Symbols are as in Fig. 3. The radio [$N(\gamma)$, γ) locus is for the 26.3 MHz radio datum. The uncertainty in the radio measurement is shown by the error bar in the lower right of the figure.

The nucleus of M87 has been detected as an X-ray source by the high-resolution imager on board the *Einstein* Observatory (Schreier *et al.* 1979; Gorenstein *et al.* 1980). The flux was 6×10^{-7} janskys in the HRI (0.1–4 keV) in 1979 July (Schreier, private communication). This flux lies well below the extrapolation of the hard X-ray spectrum, even for our lowest flux (1978 June). However, absorption by gas in the M87 nucleus will reduce the observed HRI flux substantially. Data from the solid state spectrometer on the *Einstein* Observatory indicate a neutral hydrogen column for the nucleus region, $N_{\rm H} > 6 \times 10^{20}$, with a best fit almost 10 times this limit. This is sufficient to reduce the HRI flux by as much as a factor of 3. Any remaining discrepancy could be due to even larger variations in the nuclear flux, or to a spectrum which is not a single power law. It is also possible that inverse Compton emission from Virgo A dominates the nucleus at energies above 10 keV when the nucleus is in its lowest state.

We stress that because of the large field of view of our detectors, we cannot prove that M87 is the source of the hard X-ray emission. It is, however, the most reasonable candidate. The fact that the A-2 and A-4 spectra agree very well in the region of overlap (see Fig. 1) implies that the emission observed in 1978 June must come from an object contained in the overlapping field of view of these two detectors. This region is almost the same as the A-2 field alone. This field contains essentially the whole Virgo cluster. Many of the cluster galaxies have been observed to be X-ray sources by the *Einstein* Observatory (Forman *et al.* 1979); however, any reasonable extrapolation of their spectra would not produce enough flux to account for the source we have observed.

The variability depends both on data from the A-4 experiment alone, and on a comparison of A-2, A-4, and *OSO 8* data. The higher *OSO 8* flux could be explained if the hard X-ray source were very extended. However, the size of the radio source leads us to believe that an inverse Compton source would not be sufficiently large to cause this effect. Also, an extended source should produce a higher flux in the A-4 detectors than in the A-2 detectors at all times, and this was not the case in 1978 June. We can further constrain the source size by noting that the hard X-ray flux for a given date was the same in each of the two fields of view ($3° \times 3°$ and $3° \times 1°.5$) of the A-2 detectors. If the variability is real, then a source size $\lesssim 6$ light-months is implied, and the M87 nucleus seems a logical candidate for such a source.

If M87 is the source of the emission, then a possible source model can be constructed using the synchrotron self-Compton (SSC) process (e.g., Marscher *et al.* 1979). From equation (6) of Marscher *et al.*, with the values $\theta \sim 1.3$ milli-arcsec, $\nu_m \sim 2$ GHz (Kellermann *et al.* 1973), $S_m = 2$ Jy (Turland 1975), and $\alpha = 0.55$ (Graham 1970) for the compact nuclear radio source in M87, we find fluxes and spectra in rough agreement with our observations. The SSC flux is, however, very dependent on the parameters (particularly ν_m, the frequency of the spectral turnover) which are not well defined for this source. We would also expect that variability in the X-ray would be accompanied by corresponding variations in the radio. Variations of up to 30% have been reported for the M87 nucleus (Graham 1971) which could result in factors of 2 in the X-ray (Mushotzky *et al.* 1978*a*).

Other models are possible, of course, particularly if the nucleus of M87 contains a black hole (e.g., Young *et al.* 1978). We can use our results to constrain the mass of such a black hole, if it is the sourse of the X-ray emission. Since most of the X-ray emission originates at $r \sim 10\ GM/c^2$ (e.g., Liang 1979) and this radius must be less than 6 light-months, then $M_H < 3 \times 10^{11}\ M_\odot$.

On the other hand, there is no obvious candidate for a hard X-ray source in A2142 from previous studies. The two brightest galaxies in the cluster are D galaxies, and the cluster is B-M type II. The radio source was unresolved (size $\lesssim 5'$) by Owen (1973) at 1400 MHz. Harris, Baheall, and Strom (1977) have observed several sources at 610 MHz, one a head-tail galaxy, and several others which may be associated with galaxies in the cluster, as well as several clumps of emission not obviously associated with galaxies. No diffuse radio halo has been detected (Jaffe and Rudnick 1979). Observations with the imaging proportional counter on the *Einstein* Observatory (Ku 1980) have shown that a Seyfert galaxy 5′ NE of the cluster peak seems to be an X-ray source. There is another Seyfert 20′ SE of the cluster center. Since both the *OSO 8* and A-4 detectors had large fields of view, the variable component in A2142 could be associated with either of these Seyferts or, indeed, some object unrelated to the cluster.

c) Further Comments on the M87/Virgo Cluster Source

In § II we have discussed two component fits to the Virgo cluster spectrum. We see no evidence for a third spectral component. This suggests that emission from hot gas (2 keV $< kT <$ 10 keV) in the Virgo cluster (as distinct from M87) must be very weak. We obtain an upper limit of 1.2×10^{65} cm^{-3} for the emission measure of a 6 keV plasma, which is 0.02 of the emission measure of the gas around M87. For a simple model of a sphere of radius 260 kpc, this implies $n_e < 2 \times 10^{-4}$ for any gas at 6 keV. This limit is inconsistent with the value of $\sim 6 \times 10^{-4}$ cm^{-3} determined by Forman *et al.* (1979). For a uniform sphere of radius 2 Mpc, we find $n_e < 1.15 \times 10^{-5}$ cm^{-3}. This limit is close to the value 10^{-5} cm^{-3} estimated by Fabian, Schwarz, and Forman (1980) in their model of galactic wind confinement applied to M86. A nonuniform sphere is of course more realistic; and such a sphere, having a density of 10^{-5} at a radius of 2 Mpc, would have an emission measure greater than that allowed by our spectral measurements. We are unable to determine the spatial locations of our spectral components, however. Further observations of this cluster with a detector capable of spatially resolved spectral observations will be needed to fully determine the nature of the X-ray sources in this cluster.

IV. CONCLUSIONS

We have presented observations of the Virgo cluster and A2142 in the energy range 15–150 keV. We have detected the Virgo cluster at a mean flux of $(1.3 \pm 0.3) \times 10^{-3}$ photons cm^{-2} s^{-1} in the 20–100 keV band, and we have a marginal detection of A2142 at a flux of $(2 \pm 0.8) \times 10^{-3}$ photons cm^{-2} s^{-1} in the 15–40 keV band. A2142 is not detected above 40 keV. Since we have not yet unambiguously detected inverse Compton emission in these clusters, we may use our data to place lower limits to the intracluster magnetic field of $B \gtrsim 5 \times 10^{-7}$ gauss in the Virgo cluster and $B \gtrsim 5 \times 10^{-8}$ gauss in A2142. Together with the results for the Perseus cluster, published elsewhere (Primini *et al.* 1981), these results indicate that the magnetic fields in cluster radio sources must be close to the equipartition values.

There is some evidence for variability in these sources, which would imply that the hard X-ray emission originates in a relatively compact object or region rather than from the cluster as a whole. Our limits to the magnetic field strength are independent of the origin of the X-ray emission, with the equality holding only if the observed flux is due to the IC process.

We note also that most cluster X-ray sources are both hotter and more luminous than the Virgo cluster. A hard component such as we have detected here would be much more difficult to detect in such clusters. Hard X-ray emission from galactic nuclei may be a common feature of clusters of galaxies, detectable only with sensitive detectors at energies $\gtrsim 10$ keV.

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