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A SEARCH FOR X-RAY EMISSION FROM RICH CLUSTERS, EXTENDED HALOS AROUND CLUSTERS, AND SUPERCLUSTERS

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ABSTRACT

The all-sky data base acquired with the HEAO A-2 experiment has been searched for X-ray emission on a variety of metagalactic size scales which had either been predicted or previously detected. We present results in the 0.2-60 keV energy range. The optically richest clusters, including those from which a microwave decrement has been observed, appear to be relatively underluminous in X-rays. Observations of Abell 576 show its luminosity to be less than earlier estimates, and moreover less than the luminosity predicted from its microwave decrement, unless the intracluster gas is a factor of ∿ 10 hotter than in typical clusters.

Extended halos around clusters were not detected in our data, and weak sources appear to be responsible for the apparent effect around several clusters. Near SC0627 there are two X-ray sources, and the identification of the dominant source with SC0627 is probably incorrect.

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New spectral observations of Abell 401 and 2147, possible superclusters, reveal that they have typical cluster spectra with iron line emission. Our substantially lower intensities for the 4U supercluster candidates indicate that there is no requirement for supercluster X-ray emission above the contribution of the member clusters.

I. INTRODUCTION

Clusters of galaxies have been identified as sources of large-scale X-ray emission (e.g. Gursky et al. 1971; Cash, Malina, and Wolff 1976; Gorenstein et al. 1977). Nine clusters are classified by Abell (1958) as richness class 4 or 5 out of the > 2700 clusters in his catalogue. They each contain more than 200 member galaxies which are no more than 2 magnitudes fainter than the third brightest member. Both the suggested correlation between Abell richness class and X-ray luminosity (Jones and Forman 1977; McHardy 1978), and the observations of significant "cooling" of the microwave background (e.g. Birkinshaw et al. 1978) suggest that that at least some of the optically richest clusters are luminous X-ray sources. We present the results of HEAO 1 A-2 observations of these clusters (see Table 1).

The centroids of the X-ray emission associated with the clusters Abell 2147 (part of the optically defined Hercules Supercluster--see Cooke et al. 1978) and Abell 401 (Maccagni et al. 1978; Ulmer et al. 1978) are offset from the optical cluster centers. This has suggested the possibility that the X-rays arise from a hot intercluster gas. Positional and spectral information for these two sources are examined as a test of this hypothesis. Extended halos around clusters (Forman et al. 1978a), superclusters containing at least 6 member clusters (Murray et al. 1978), and the two preceeding supercluster candidates might contain ~ 10 times more X-ray emitting mass in the intercluster medium than that observed in the visible galaxies. Thus, as has been pointed out in the references above, the hot intercluster gas could represent a significant part of the mass required to close the universe. We discuss the results of our search for these extended X-ray sources.

II. THE EXPERIMENT AND THE ANALYSIS

The A-2[+] experiment (see Rothschild et al. 1979 for details) performs

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

great circle scans of the sky and data have now been processed for nearly two complete sky views. Positional and intensity results are obtained using rectangular collimators that are 1.5^o (FWHM) along the scan direction and 3^o (FWHM) in the perpendicular direction. Scanning data are superposed for a particular source during days of the year for which the peak detection efficiency is greater than ½ its maximum value. These "summed" scans are then modelled with an X-ray intensity distribution containing an isotropic background and a number of either point or extended sources (Marshall et al. 1979). The χ^2 test (Avni 1976) is used to discriminate among models and to determine confidence limits for various parameters.

Our exposure to selected X-ray sources is significantly increased for spectral studies by long pointed observations. Abell 401 was observed in this mode for 3 hours starting 16^h UT on February 8, 1978 and Abell 2147 was observed for 6 hours starting 5^h UT on August 25, 1978. Spectral information is obtained in 64 PHA channels from a medium energy detector (MED 1.7 - 18 keV) and a high energy detector (HED 3. -

60. keV). The method of spectral analysis is discussed elsewhere (Pravdo et al. 1978).

The intensities of sources discussed herein are sometimes presented in counts s^{-1} for a particular combination of rates from the MED and HED3, termed R15 by Marshall et al. (1979). These units are roughly equal to UHURU counts (Forman et al. 1978b) although the comparison is affected by the source spectrum (Marshall et al.). For source temperatures higher than $\sim 10^8$ K the R15 count rate is larger than either UHURU or Ariel 5, while for a source with $T < 10^7$ K the count rate would be less than that obtained with the comparison detectors. However, the A-2 experiment includes soft X-ray detectors (LED 0.2 - 3 keV) in addition to the hard X-ray detectors (Rothschild et al.). These detectors are more efficient than UHURU for sources with $T \lesssim 10^7$ K so that HEAO A-2 is at least as sensitive as UHURU for any source temperature.

III. RICH CLUSTERS

Figures 1-3 show the summed scans for the 9 rich clusters. Abell 576, 401, and 2147 (Her Cls) will be discussed later. The cluster named in the upper left corner is positioned in the center of each intensity plot which covers 25^o in scan angle ($\frac{1}{4}^o$ per tick mark). For comparison purposes the source near scan angle 208^o in the Abell 545 plot, is $\sim$ 3.0 aspect-corrected UHURU counts. The days of the year (1977) between which the data were obtained are shown in the upper right.

Of these 9 only Abell 1146 was detected at the 3σ level at an intensity consistent with that reported by McHardy (1978). Table 1 indicates the upper limits to the intensity and bolometric luminosity, assuming a typical cluster X-ray spectrum, thin thermal bremsstrahlung with kT = 6.8 keV (Mushotzky et al. 1978). For Abell 1146 lower limits are included in parenthesis. We assume H_0 = 50 km sec^{-1} Mpc^{-1}. The limits in Table 1 are similar to but up to a factor ∿ 5 lower than those reported by Ricketts (1978a). These clusters were also not detected with HEAO 1 as soft X-ray sources (Table 1). The isotropic background intensity level is independently determined from each 25^0 source scan. Weak unresolved sources could introduce some uncertainty in the background determination but would significantly ($\lesssim$ 50%) effect only the lowest limits in Table 1 (e.g. Rowan-Robinson and Fabian 1974).

The correlation between cluster richness and luminosity (Jones and Forman 1978; McHardy 1978) appears to fail for the richest clusters. We note that 6 of the 20 clusters discussed by Mushotzky et al. (1978) have higher bolometric luminosities than 4 of the 9 upper limits for the rich clusters (Table 1). These 6 clusters have average richness class 2.2 and are in the high end of the X-ray luminosity distribution of their richness class. However, our results demonstrate that many of the richest clusters have lower luminosities and that the other rich clusters can not be much more luminous. It may be difficult to understand why the richest clusters are underluminous on physical grounds, but the explanation could lie in the approximate classification scheme of Abell (1958). The detailed optical analysis of Dressler (1978b), for example, shows that the richness parameter can be revised based on cluster core properties (e.g. A665 is richness 3.2 using this method rather than 5).

IV. ABELL 576

Abell 576 is only of richness class 1 but is of particular interest because 1) microwave cooling is observed in its direction (Birkinshaw, Gull, and Northover 1978a) and 2) it is reported to have an extended X-ray halo (Forman et al. 1978a). The HEAO A-2 X-ray intensity distribution centered at A576 is shown in Figure 3. There is a broad intensity enhancement near the cluster which can be modelled equally well by a superposition of weak "point" sources or an extended source of uniform surface brightness. In the former model the intensity of A576 is 0.6 $\pm$ 0.2 cts sec^{-1} which is a factor $\sim$ 4 less than that measured with UHURU (Forman et al. 1978b) and a factor $\sim$ 2 less than the Ariel 5 result (Ricketts 1978). An additional source or sources (< 0.4 cts sec^{-1}) is located from 1^{o} to 3^{o} from A576. The second model consists of a single uniform extended source centered at A576 with radius $3\overset{o}{.}6 \pm 0\overset{o}{.}8$. In this case the integrated source intensity of A576 is about twice that obtained with the first model. The inconsistency by at least a factor 2 between the A-2 and UHURU intensities can not be reconciled with the assumption of a low temperature source spectrum, since A576 is not seen with the LED with a 3σ upper limit of 2.5×10^{-11} erg cm^{-2} sec^{-1} (assuming $T = 10^{7}$ K).

Table 1 of Forman et al. (1978a) indicates that A576 has the largest ratio of intensities derived from the large and small collimators in their cluster sample. The HEAO A-2 results show that a point source at A576 is relatively weak but that the X-ray background near A576 is enhanced. This demonstrates some consistency between the two observations. We can not distinguish between the two models for this X-ray distribution on the basis of goodness-of-fit. However, note that the extended source model indicates an X-ray radius for A576 of 15 ± 4 Mpc, apparently with constant surface brightness. This is a factor ~ 60 larger than the observed radii (e.g. Lea 1975; Gorenstin et al. 1977) within which most of the X-rays from other clusters arise. Hence, the indication is that the broad X-ray enhancement near A576 is due to unrelated weak X-ray sources. Section VI presents a further search for extended cluster X-ray emission which is not limited by statistics since it concerns an ensemble of clusters (including A576).

V. X-RAY SOURCES AND MICROWAVE COOLING

A number of authors have recently pointed out that measurements of both the X-ray emission and the microwave decrement (Sunyaev and Zel'dovitch 1972) from clusters of galaxies can lead to determinations of H_o and q_o which are largely model-independent (Cavaliere, Danese, and DeZotti 1978; Silk and White 1978). The detections of the microwave effect in the directions of several clusters (Gull and Northover 1976; Lake and Partridge 1977) have focused interest on the X-ray evidence from these objects. Based on the microwave result and the pre-HEAO upper limit to the X-ray emission from Abell 2218, Cavaliere et al. deduced an upper limit to $H_c < 80$ km sec^{-1} x $(T/3 \times 10^8\ K)^{3/2}$ where T is the gas temperature. Substituting the new HEAO A-2 X-ray intensity and a new value for the decrement toward this cluster (Birkinshaw, Gull, and Northover 1978b) into equation 4 of Cavaliere et al. yields $H_o < 30$ km sec^{-1} Mpc^{-1} x $(T/3 \times 10^8\ K)^{3/2}$. This would imply an anomalously high temperature for the cluster gas (see also below) if this limit for H_o is to be consistent with the higher value determined with independent means (e.g. Sandage and Tamman 1975).

We can also compare the observed X-ray luminosity limit for A2218 with the luminosity predicted from the microwave decrement. Unfortunately we can not independently determine the X-ray temperature of this source since it is too weak. Table 2 shows this comparison for a number of gas temperatures using the model calculations of Sarazin and Bahcall (1977). Since the predicted X-ray intensity scales as $\sim T^{-2.5}$ for a constant microwave decrement, the low temperature models, $T < 6 \times 10^8$K, are strongly ruled out. And, since the predicted luminosities scale as the square of the microwave decrement, the result of Schallwich and Wielebinski (1979), which suggests that this decrement has been underestimated, reinforces this conclusion.

A strong microwave cooling has also been seen from A576 (Birkinshaw, Gull, and Northover 1978a). Table 2 shows that high temperatures are also required for this cluster gas. The isothermal model would be consistent for $T \sim 6 \times 10^8$ but the adiabatic model requires $T \gtrsim 10^9$ K. Note that an intracluster gas at this temperature would worsen the inconsistency between the HEAO and UHURU intensities. If the X-ray and microwave measurements are to be reconciled with such an intracluster gas (a factor $\sim$ 10 hotter than the typical cluster--see Mushotzky et al. 1978) then future measurements of anomalously high velocity dispersions between the member galaxies would be an important test. However, if velocity dispersion measurements and/or more sensitive X-ray spectral measurements show that these clusters have typical temperatures, then the X-ray and microwave results are clearly inconsistent in these models. We note that the microwave measurements are subject to intrepretive uncertainty (Tarter 1978) and observational inconsistency (Partridge 1978). Nevertheless the theoretical promise of these combined observations is encouragement for further investigations.

VI. EXTENDED HALOS

Cavaliere and Fusco-Femiano (1978) have suggested that extended gas halos may exist around clusters of galaxies. By comparing the intensities determined with different size UHURU collimators, Forman et al. (1978a) have reported detection of large X-ray halos. A similar analysis using HEAO A-2 data by Nulsen et al. (1979), has ruled out X-ray extensions of $\sim$ 1^{o} for 26 clusters, including those of Forman et al. These results are in apparent contradiction.

In order to further investigate this question, we have superposed the summed scans of many clusters and modelled the X-ray distribution. Figure 4a, d illustrates these superpositions for two sets of data. The first data set is comprised of the 8 clusters from which Forman et al. (1978a) observed halos. The following one-dimensional models were tested: 1) point source, 2) extended source with uniform surface brightness, and 3) King model for the cluster gas (King 1972; Lea et al. 1973). For the 8 clusters a uniform extended source model with radius $0\overset{\circ}{.}73 \pm 0\overset{\circ}{.}20$ provides a better fit than the point source model at the 3σ confidence level (however see below). A comparison superposition of sources was created which consists of the 18 Seyfert galaxies listed by Tananbaum et al. (1978). IC4329A has been removed since there is a strong unrelated X-ray source nearby. The best fitting model for this data has a radius of $0^\circ.35 \pm 0^\circ.23$ which is somewhat larger than but consistent with the expected smearing effects of $0^\circ.1$ due to aspect uncertainties and $0^\circ.13$ due to data digitization. The King model yielded a core radius of $0^\circ.28 \pm 0^\circ.22$ for the Seyfert superposition.

Figures 4b,c show the summed scans for SC0627 and Ab2666, two clusters in the sample of Forman et al. There is evidence for an asymmetric X-ray distribution within $\sim 1^\circ$ of each of the cluster centers. A new HEAO A-2 source, H0624-555, with intensity 0.80 ± 0.15 cts sec^{-1} is seen near SC0627 during both the first and second sky views. Figure 5 shows the position contours determined for these sources and the 4U and Ariel 5 (Maccagni et al. 1978) results. The dominant source, H0630-541, is offset from the line of clusters (Duus and Newell 1977) as shown in Figure 5 and exhibits evidence for day-to-day variability in the A-2 observations. While the weaker source could be associated with the clusters in this region, the source usually identified with SC0627 is probably unrelated to the clusters.

Similarly the only available observation of A2666 indicates the presence of a ~ 0.6 ct sec^{-1} source offset from the cluster. When these two clusters are removed from the sample of 8, the resultant superposition has a maximum radius consistent with the Seyfert superposition. This smaller sample, however, contains A576 which as discussed above probably has nearby sources with lower intensity.

We next enlarge the sample of clusters. The final plot in Figure 4 shows the superposition of 21 clusters of galaxies including the 8 clusters discussed above. The additional clusters are 3C129, A2256, SC2009, A2319, A754, K44, A1367, A85, A1795, A2029, A2199, A478, and A496. These sources have about the same intensity (Nulsen et al. 1979) and the same average and r.m.s. richness class (1 ± 1) and distance class (3 ± 1) as the first 8 clusters. The radius of extent in the uniform model for the combined data is $0^{\circ}.30 \pm 0^{\circ}.18$, while the King model yields a core radius of $0^{\circ}.27 \pm 0^{\circ}.22$. This is the same result as was obtained for the superposition of Seyfert galaxies.

An additional test was made to detect a low level of diffuse X-ray emission near the clusters. The average diffuse background intensity within 4° of the 21 clusters was compared to the intensity within 4° of the 17 Seyfert galaxies. We find a small increase near the clusters which corresponds to $1.1 \pm 0.5\%$ of the diffuse background intensity. If we assume that the excess surface brightness is uniformly distributed within X° of the cluster centers then this indicates a diffuse X-ray source with a 2-6 keV surface brightness of $2.9 \times 10^{-12}\ X^{-2}$ erg $cm^{-2} sec^{-1} deg^{-2}$, or a factor 20 less than the intensity of the point component. A scaling of the angular sizes of nearby clusters, Virgo and Coma (e.g. Lea et al. 1973), to the larger distances of the clusters considered here, implies an angular radius of $\approx 0^{\circ}.1$ for the point component. Therefore, this result still allows a factor 9 $X^{3/2}$ more mass in an extended halo than in the core X-ray emission (uniform densities assumed in each component).

Forman et al. state that the extended halos are significant only when their cluster sample is considered as a group and not for individual clusters. However, it appears that at least 3 of the 8 clusters should be excluded because: two have nearby sources; and Abell 401 (see below) is not an isolated cluster source. We note that there is a Poisson probability of $\sim$ 0.2 for finding two unrelated X-ray sources with intensities $\gtrsim$ 0.6 ct sec^{-1} within 1^{o} of the 21 clusters (e.g. Schwartz 1979). Therefore, we conclude that there are no intrinsic differences in the X-ray distributions around these 8 clusters and the other clusters in our larger sample.

The average X-ray halo as measured by HEAO 1 has radius < $0\overset{o}{.}5$. At this upper limit to size our measurements of the nearby background indicate that the luminosity in the halo is $\lesssim$ 1/20 the core luminosity and that it contains at most an equal mass of gas. This result is inconsistent with the model of Forman et al. in which an extended halo luminosity dominates the core emission and the mass in the halo is 10-400 times larger than the mass within 0.5 Mpc of the cluster center.

VII. ABELL 401 AND THE HERCULES CLUSTERS

The summed scan for Abell 401 is shown in Figure 3. A measured 2-6 keV intensity of $(6.2 \pm 0.5) \times 10^{-11}$ erg cm^{-2} sec^{-1} is consistent with previous results (McHardy 1978; Mushotzky et al. 1978; Forman et al. 1978b). Figure 6 shows one model fitted to the Abell 401 scan. Low intensity (< 0.5 cts sec^{-1}) unidentified sources are included to improve the fit. An extended source (radius $0\overset{o}{.}8 \pm 0\overset{o}{.}3$) centered $0\overset{o}{.}1$ from Abell 401 or two point sources centered on Abell 401 and 399 (Figure 6) fit the data significantly better ($\sim$ 90% confidence) than a single source at Abell 401. In the two point source model the ratio of luminosities is 3 to 1, with Abell 401 larger. This is consistent with the result of Ulmer et al. (1978).

The spectrum of Abell 401 obtained with the MED is shown in Figure 7. It is fitted by a thin thermal bremsstrahlung model, $T = 7.6 \pm 1.2 \times 10^7$ K, with 380 ± 100 eV equivalent width of 6.7 keV iron line emission or $2.6 \pm 0.7 \times 10^{-4}$ line photons cm^{-2} sec^{-1} corresponding to Fe/H ratio of 1.5×10^{-5}. The measured neutral hydrogen column density (Fireman 1974) in the line of sight is $7.2 \pm 3.6 \times 10^{21}$ cm^{-2}. The HED result confirms the existence and strength of the iron line emission feature. The spectrum is consistent with that determined with OSO-8 and is similar in all respects to the average cluster spectrum of Mushotzky et al.

The X-ray emission from the vicinity of Abell 2147 (Hercules CLS-Figure 2) also appears to be more complex than a single point source. The total 2-6 keV X-ray intensity from the region is $3.7 \pm 0.7 \times 10^{-11}$ erg cm^{-2} sec^{-1} in good agreement with previous results (Cooke et al. 1978; Mushotzky et al. 1978; Forman et al. 1978b). Again, statistically indistinguishable fits are obtained for an extended source (ES) model or a two point source (TPS) model. The extended source is consistent with an area of uniform surface brightness with an angular radius of $1^\circ.4 \pm 0^\circ.2$ corresponding to 5.6 Mpc. Figure 8 illustrates the 90% source confidence boxes for these models. The dominant (by factor of 2) point source can be associated with Abell 2147 in agreement with the 4U position, while the other source box in the TPS model (not shown in the Figure) includes Abell 2152. The intersection of the ES model box and the confidence contour obtained with Ariel 5 (Cooke et al. 1978) excludes all of the clusters.

Figure 9 shows the X-ray spectrum of the Hercules clusters. Again significant iron line emission is detected at 6.7 keV with an equivalent width of 1. $\pm$ 0.3 keV or 7.1 $\pm$ 1.8 x 10^{-4} line photons cm^{-2} sec^{-1}. All three detectors (one MED and two HEDs) indicate that a two-component thermal model fits significantly better than a single temperature model (see Figure 9). This result is confirmed with the LED observation of soft X-ray emission with a 0.2-3 keV intensity of (5.8 $\pm$ 1.1) 10^{-11} erg cm^{-2} sec^{-1}. The ratio of bolometric luminosities in the low temperature component ($T = 2 \pm 1 \times 10^7$ K) to the high temperature component ($T > 1.5 \times 10^8$ K) is between 0.6 - 1.1. It is difficult, however, to come to a conclusion from this result since the X-ray spatial distribution is not known. If both components come from a single cluster, this spectrum is similar to that of Virgo (Mushotzky et al.). There is no apparent low energy absorption with an upper limit of 5 x 10^{21} cm^{-2}, consistent with the OSO-8 result.

The Hercules Supercluster and Abell 401-399 are typical of the smallest scale of the optically-defined superclusters (Karachentsev, Tsarevskaya, and Scherbanovski 1975). They contain $\sim$ 2 member clusters and are $\sim$ 20 Mpc in size. We confirm with HEAO A-2 the results of previous observers (Cooke et al. 1978; Maccagni et al. 1978; and Ulmer et al. 1978) that the centroids of the X-ray emission from the vicinity of these objects are offset from any cluster center. However, we are unable to distinguish whether the X-ray emission is diffuse or composed of two "point" components located at two cluster centers.

Our spectral results indicate that with regards to luminosity, temperature, and iron abundance, these X-ray sources have typical cluster spectra (Mushotzky et al. 1978). Since the mass of iron in a gas with radius R increases as $R^{3/2}$ for fixed line and continuum intensity, it is unlikely that Abell 401 or 2147 could provide enough iron (e.g. DeYoung 1976) to fill a much larger region than that of, for example, the Perseus cluster (Smith, Mushotzky, and Serlemitsos 1979) with a "cosmic" ratio of Fe/H. This evidence implies either the presence of two size scales of X-ray emission with differing elemental abundances or that the X-ray emission is confined to cluster and not supercluster dimension.

VIII. THE X-RAY SOURCES IDENTIFIED WITH MORE DISTANT SUPERCLUSTERS

The superclusters defined by Abell (1961) and Murray et al. (1978) each contain at least 6 member clusters with distant class $\geq$ 5, and have an angular radius of $\sim 1^{\circ}$. These sources would be individually detected by HEAO A-2 at their 4U PST intensities. However, our limits on X-ray emission from these candidates are inconsistent (Table 3) with the previously determined intensities for the three 4U sources, at the 2σ level (see also Pravdo et al. 1977; Ricketts 1978). Note that if these sources are variable on time scales of years, this would rule out a supercluster identification. There are two weak X-ray sources near the position of the supercluster candidate A1018+49 (Ricketts 1978) which are however offset by $\sim 1^{\circ}$ from the associated supercluster center (Murray et al.). One of these as been tentatively identified as the Seyfert galaxy MK142 by Marshall et al. (1979).

The 0.2-3 keV intensity results are also presented in Table 3. There is no evidence for soft X-ray emission from two of the candidates, but a weak source is detected near 4U0443-09. However, the spectrum of this source, based on our results over the entire A-2 energy range, is too soft to be consistent with the 4U intensity. An identification of the soft X-ray source is not possible from these data.

Perrenod (1978) has suggested that X-rays from the member clusters could provide most and perhaps all of the emission which had been associated with the superclusters. By superposing the HEAO A-2 data for the three 4U candidates we detect a statistically significant average intensity of 0.44 ± 0.10 cts sec^{-1} which is a factor 2-6 below the individual 4U PST intensities. This result strengthens the conclusion that supercluster emission is not required to explain the X-ray luminosities.

IX. SUMMARY

This work is one part of the continuing study of the X-ray sky with HEAO A-2. We have found that:

1) The richest Abell clusters are relatively underluminous in X-rays compared to extrapolations from lower richness classes,

2) The X-ray and microwave measurements for some of the rich clusters and for Abell 576 can be used to meaningfully constrain intracluster gas parameters and H_0,

3) Extended X-ray halos around clusters are not present at the level discussed by Forman et al. (1978a), and

4) Spectral observations of Abell 401 and 2147, and intensity measurements of the sources observed by Murray et al. (1978) indicate that supercluster X-ray emission is not required.

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TABLE 1

RICH ABELL CLUSTERS

CLUSTER	Z*	INTENSITY 0.2 - 3 keV+	INTENSITY 2-6 keV++	BOLOMETRIC LUMINOSITY+++
A545	0.153	3.6	1.7	48
A665	0.180**	3.6	0.53	21
A777	0.194	7.3	0.88	40
A910	0.19	2.2	0.43	19
A1146	0.137***	15.	2.4 (1.1)	56 (25)
A1689	0.207	7.3	0.32	17
A2125	0.241	6.5	0.83	59
A2218	0.1641**	1.1	0.92	30
A2645	0.267	18.	0.27	23

* Leir and van den Bergh 1977 except where noted

** Bruzual and Spinrad 1978

*** Dressler 1978a

\+ 10^{-11} erg cm^{-2} sec^{-1} with $T = 10^7 K$, 3σ upper limit

++ 10^{-11} erg cm^{-2} sec^{-1} with $T \sim 10^8 K$, 90% upper limit

+++ 10^{44} erg sec^{-1} with $T \sim 10^8 K$, 90% upper limit

TABLE 2

X-RAY OBSERVATIONS AND PREDICTIONS FROM MICROWAVES

ABELL CLUSTER	GAS TEMPERATURE(K)	$I^{+}_{OBSERVED}$	$I^{+ADIABATIC}_{PREDICTED}$	$I^{+ ISOTHERMAL*}_{PREDICTED}$
A2218**	6×10^7	11.	2800	500
	10^8	13.	1700	310
	2×10^8	9.3	520	95
	6×10^8	8.4	50	9.3
	10^9	7.4	15	2.7
A576	6×10^7	7.1 ± 2.4	2000	360
	10^8	8.6 ± 2.9	1200	220
	2×10^8	6.2 ± 2.1	370	68
	6×10^8	5.6 ± 1.9	36.	6.6
	10^9	4.9 ± 1.6	11.	1.9

+ Spectral Intensity Units 10^{-4} keV cm^{-2} sec^{-1} keV^{-1} at 10 keV

* Sarazin and Bahcall 1977 for $\beta \equiv \frac{\mu V^2 M_H}{kT} = 1$

**"Observed" intensity is 90% upper limit for A2218

TABLE 3

INTENSITIES* OF SUPERCLUSTER CANDIDATES

SOURCE	4UPST	HEAO A-2 10^7K	HEAO A-2 10^8K
4U0134-11	2.8 ± 0.9	0.45**	0.39 ± 0.39
4U0443-09	1.64 ± 0.3	0.27 ± 0.14	$0.37^{+0.13}_{-0.37}$
4U1456+22	1.0 ± 0.2	0.45**	0.56 ± 0.30

*Converted to Uhuru flux units for either 10^7 or 10^8 K incident spectrum

**3σ upper limits

REFERENCES

Abell, G. 1958, Ap. J. Supple No. 31, 3, 211.

Abell, G. 1961, A. J. 66, 607.

Avni, Y. 1976, Ap. J. 210, 642.

Birkinshaw, M., Gull, S.F., and Northover, K.J.E. 1978a, MNRAS 185, 245.

Birkinshaw, M., Gull, S.F., and Northover, K.J.E. 1978b, Nature 275, 40.

Bruzual, G. and Spinrad, H. 1978, Ap. J. 220, 1.

Cash, W.C., Malina, R.F., and Wolff, R.S. 1976, Ap. J. (Letters) 209, L111.

Cavaliere, A. and Fusco-Femiano, R. 1978, Astr. and Ap. 70, 677.

Cavaliere, A., Danese, L., and De Zotti, G. 1979, Astr. and Ap., in press.

Cooke, B.A., Maccacaro, T., Perola, G.C., Tarenghi, M., and Valentijn, E.A. 1977, Astr. and Ap. 58, L17.

De Young, D.S. 1978, Ap. J. 223, 47.

Dressler, A. 1978a, Ap. J. 223, 765.

Dressler, A. 1978b, Ap. J. 226, 55.

Duus, A. and Newell, B. 1977, Ap. J. Supple 35, 209.

Fireman, E.L. 1974, Ap. J. 187, 57.

Forman, W., Jones, C., Murray, S., and Giacconi, R. 1978a, Ap. J. (Letters) 225, 1.

Forman, W., Jones, C., Cominsky, L., Julien, P., Murray, S., Peters, G., Tananbaum, H., and Giacconi, R. 1978b, Ap. J. Supple 38, 357.

Gorenstein, P., Fabricant, D., Topka, K., Tucker, W., and Harnden, F.R. Jr. 1977, Ap. J. (Letters) 216, L95.

Gull, S.F. and Northover, K.J.E. 1976, Nature 263, 572.

Gursky, H., Kellogg, E., Murray, S., Leong, C., Tananbaum, H., and Giacconi, R. 1971, Ap. J. (Letters) 167, L81.

Jones, C. and Forman, W. 1978, Ap. J. 224, 1.

Karachentsev, I.D., Tsarevskaya, R.L., and Shcherbanovskii, A.L. 1975, Astron. Zh. 52, 999 (transl. Sov. Astr. 19, 606).

King, I.R. 1972, Ap. J. (Letters) 174, L123.

Lake, G. and Partridge, R.B. 1977, Nature 270, 502.

Lea, S.M. 1975, Ap. Letters 16, 141.

Lea, S.M., Silk, J., Kellogg, E., and Murray, S. 1973, Ap. J. 184, L105.

Leir, A.A. and van den Bergh, S. 1977, Ap. J. Supple 34, 381.

Maccagni, M., Tarenghi, M., Cooke, B.A., Maccacaro, T., Pye, J.P., Ricketts, M.J. and Chincarini, G. 1978, Astr. and Ap. 62, 127.

Marshall, F.E., Boldt, E.A., Holt, S.S., Mushotzky, R.F., Pravdo, S.H., Rothschild, R.E., and Serlemitsos, P.J. 1979, Ap. J. Supple, in press.

McHardy, I. 1978, MNRAS 184, 783.

Murray, S.S., Forman, W., Jones, C., and Giacconi, R. 1978, Ap. J. 219, L39.

Mushotzky, R.F., Serlemitsos, P.J., Smith, B.W., Boldt, E.A., and Holt, S.S. 1978, Ap. J. 225, 21.

Nulsen, P.E.J., Mushotzky, R.F., Boldt, E.A., Holt, S.S., Marshall, F.E., and Serlemitsos, P.J. 1979, submitted to MNRAS.

Partridge, R.B. 1978, private communication.

Perrenod, S.C. 1978, Nature 274, 39.

Pravdo, S.H., Bussard, R.W., Becker, R.H., Boldt, E.A., Holt, S.S., and Serlemitsos, P.J. 1978, Ap. J. 225, 988.

Pravdo, S.H., Mushotzky, R.F., Becker, R.H., Boldt, E.A., Holt, S.S., Serlemitsos, P.J., and Swank, J.H. 1977, Nature 270, 158.

Ricketts, M.J. 1978 , MNRAS 183, 51p.

Rothschild, R., Boldt, E., Holt, S., Serlemitsos, P., Garmire, G., Agrawal, P., Riegler, G., Bowyer, S., and Lampton, M. 1979, Sp. Sci. Instr., in press.

Rowan-Robinson, M. and Fabian, A. 1974, MNRAS 167, 419.

Sandage, A.R. and Tammann, G.A. 1975, Ap. J. 196, 313.

Sarazin, C.L. and Bahcall, J.N. 1977, Ap. J. Supple 34, 451.

Schallwell, D. and Wielebinski, R. 1979, Astr. and Ap. 71, L15.

Schwartz, D.A. 1979, Proceedings of the Symposium on X-Ray Astronomy, XXI COSPAR/IAU, Pergamon Press, Oxford, in press.

Silk, J. and White, S.D.M. 1978, Ap. J. (Letters) 226, L103.

Smith, B.W., Mushotzky, R.F., and Serlemitsos, P.J. 1979, Ap. J. 227, 37.

Sunyaev, R.A. and Zel'dovich, Y.B. 1972, Comm. Ap. Space Sci. 4, 173.

Tananbaum, H., Peters, G., Forman, W., Giacconi, R., Jones, C., and Avni, Y. 1978, Ap. J. 223, 74.

Tarter, J.C. 1978, Ap. J. 220, 749.

Ulmer, M.P., Kinzer, R., Cruddance, R.G., Wood, K., Evans, W., Byram, E.T., Chubb, T.A., and Friedman, H. 1978, preprint.

FIGURE CAPTIONS

Figure 1 - The summed scans (as defined in the text) which show R15 counts versus scan angle for the clusters named in the upper left corner of each plot. The cluster would appear centered in the plot. Since the collimator is rectangular, $1^{\circ}\!.5 \times 3^{\circ}\!.0$, the response to a point source would appear approximately triangular. Each tick mark is $\frac{1}{4}^{\circ}$. The upper right corner contains the days of year (1977) over which the data have been summed.

Figure 2 - Same as Figure 1.

Figure 3 - Same as Figure 1.

Figure 4a - The superposition of the summed scans for the eight clusters discussed by Forman et al. (1978). The scan angle has an arbitrary starting value.

4b - Same as Figure 1.

4c - Same as Figure 1.

4d - Same as 4a but for the 21 clusters listed in the text.

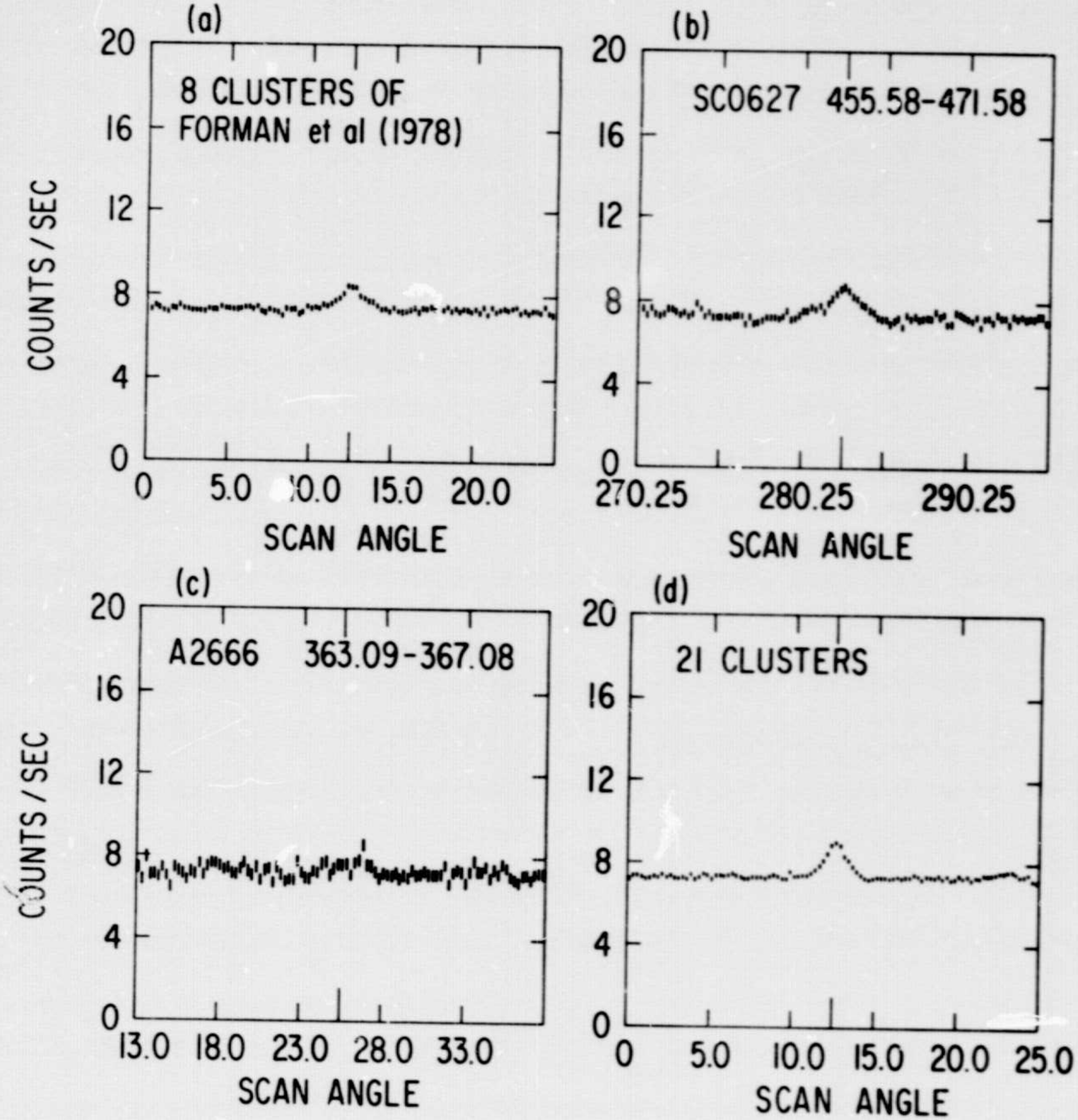
Figure 5 - The clusters of galaxies (*) identified by Duus and Newell (1977), the X-ray source position contours of Forman et al. 1978 (4U) and Maccagni et al. 1978 (2A), and the new HEAO A-2 source contours for H0630-541 and H0624-555.

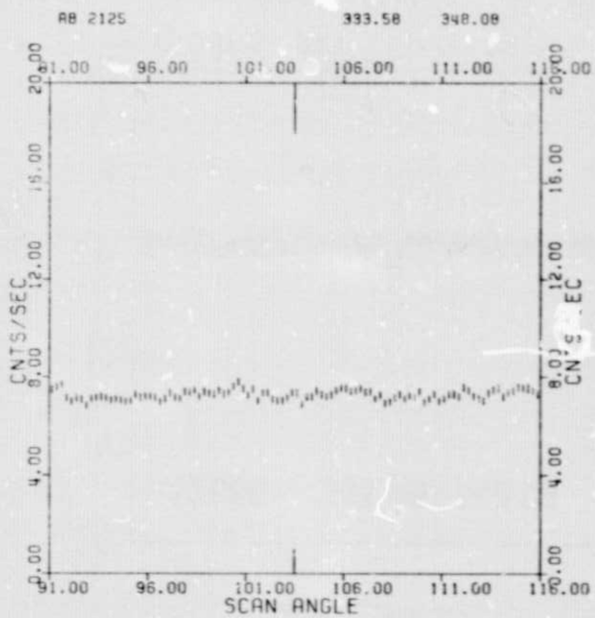
Figure 6 - The summed scan for Abell 401 which illustrates one model fit to the data. This model includes sources at Abell 401, Abell 399, and three low intensity (< 0.5 ct sec^{-1}) unidentified sources.

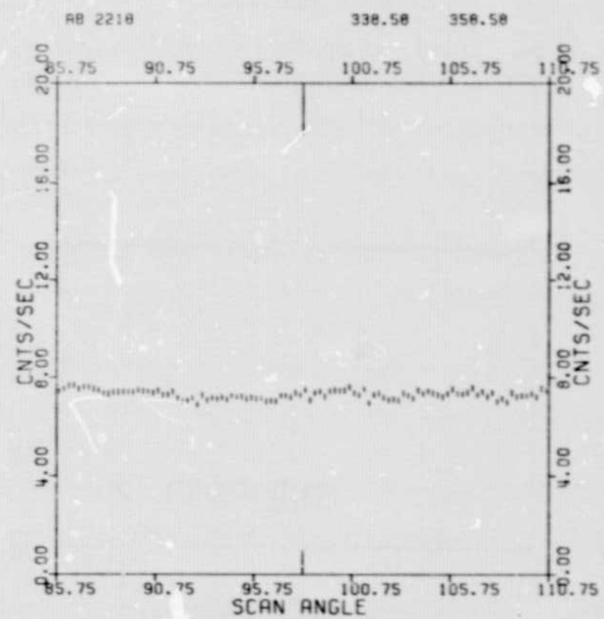
Figure 7 - The pulse-height-analyzed (PHA) count distribution and the inferred incident spectrum for Abell 401.

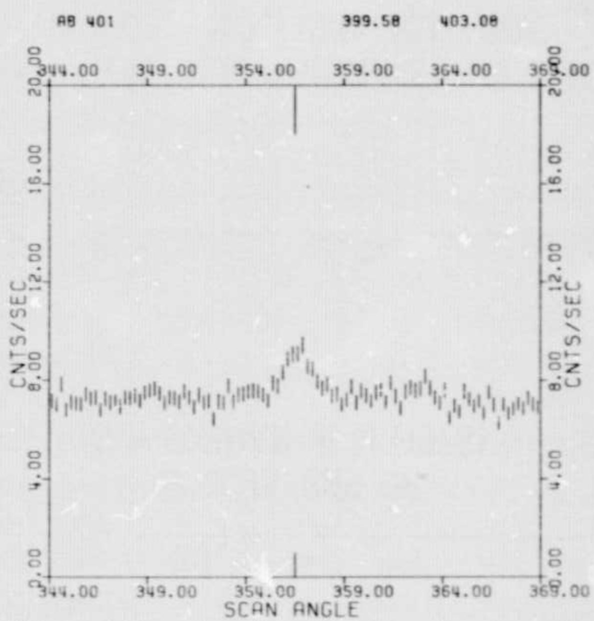
Figure 8 - The Hercules clusters (*) and the X-ray source position contours (hatched region) determined by Cooke et al. (1978) and Forman et al. (1978)--(4U). HEAO A-2 source contours are shown for an extended source (ES) model and a two point source (TPS) model. The contour for the weaker source in the TPS model is not shown, but it includes A2152.

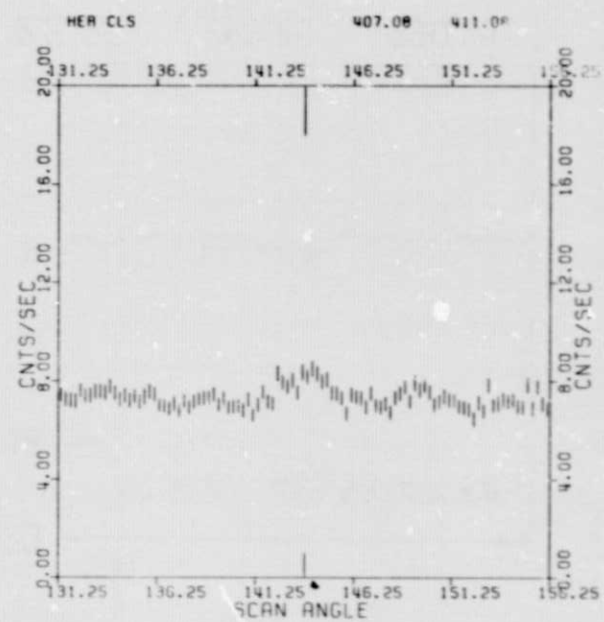
Figure 9 - The PHA count distributions (left side) and inferred incident spectrum (right side) for the Hercules clusters as determined with MED (upper) and HED (lower).

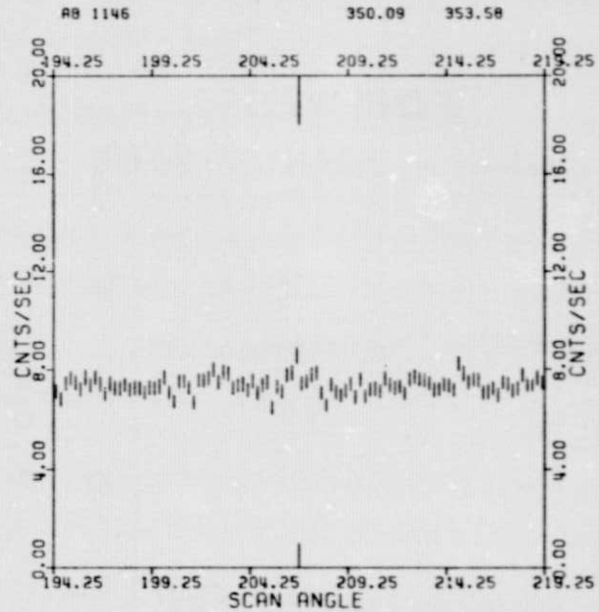

(a)
8 CLUSTERS OF
FORMAN et al (1978)
COUNTS / SEC
20
16
12
8
4
0
0
5.0
10.0
15.0
20.0
SCAN ANGLE
(b)
SC0627 455.58-471.58
20
16
12
8
4
0
270.25
280.25
290.25
SCAN ANGLE
(c)
A2666 363.09-367.08
COUNTS / SEC
20
16
12
8
4
0
13.0
18.0
23.0
28.0
33.0
SCAN ANGLE
(d)
21 CLUSTERS
20
16
12
8
4
0
0
5.0
10.0
15.0
20.0
25.0
SCAN ANGLE

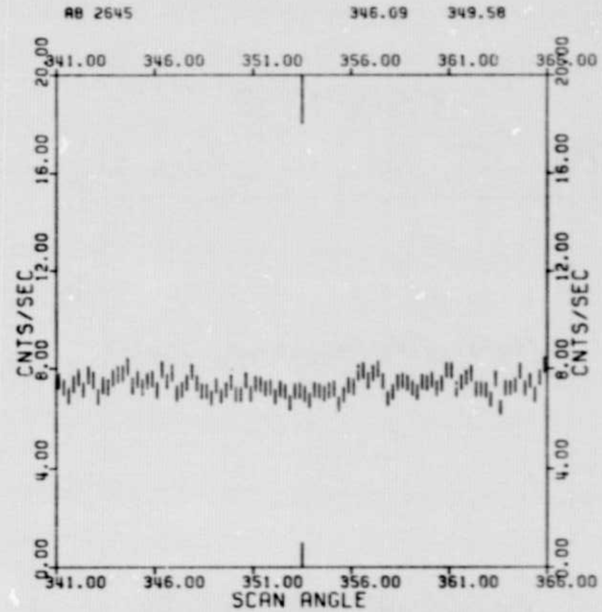

AB 2125
333.58
348.08
CNTS/SEC
SCAN ANGLE

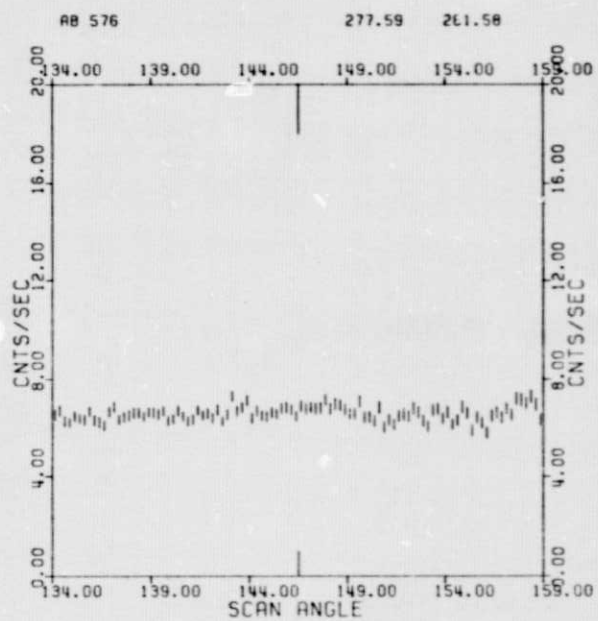

AB 2218
338.58
358.58
CNTS/SEC
SCAN ANGLE

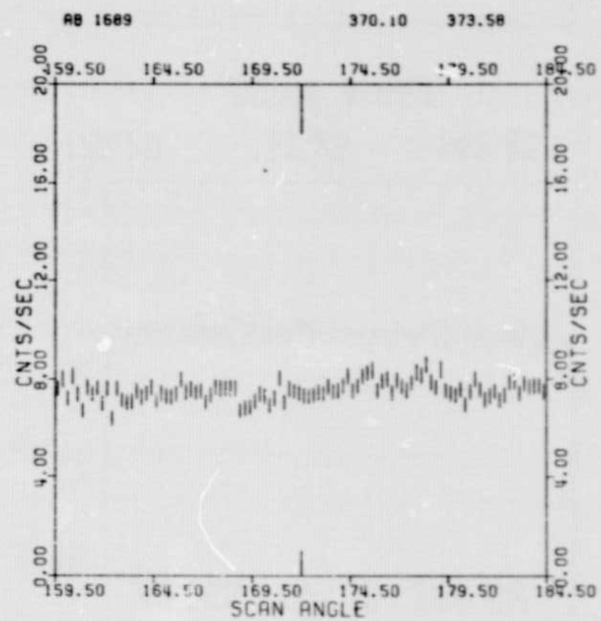

AB 401
399.58
403.08
CNTS/SEC
SCAN ANGLE

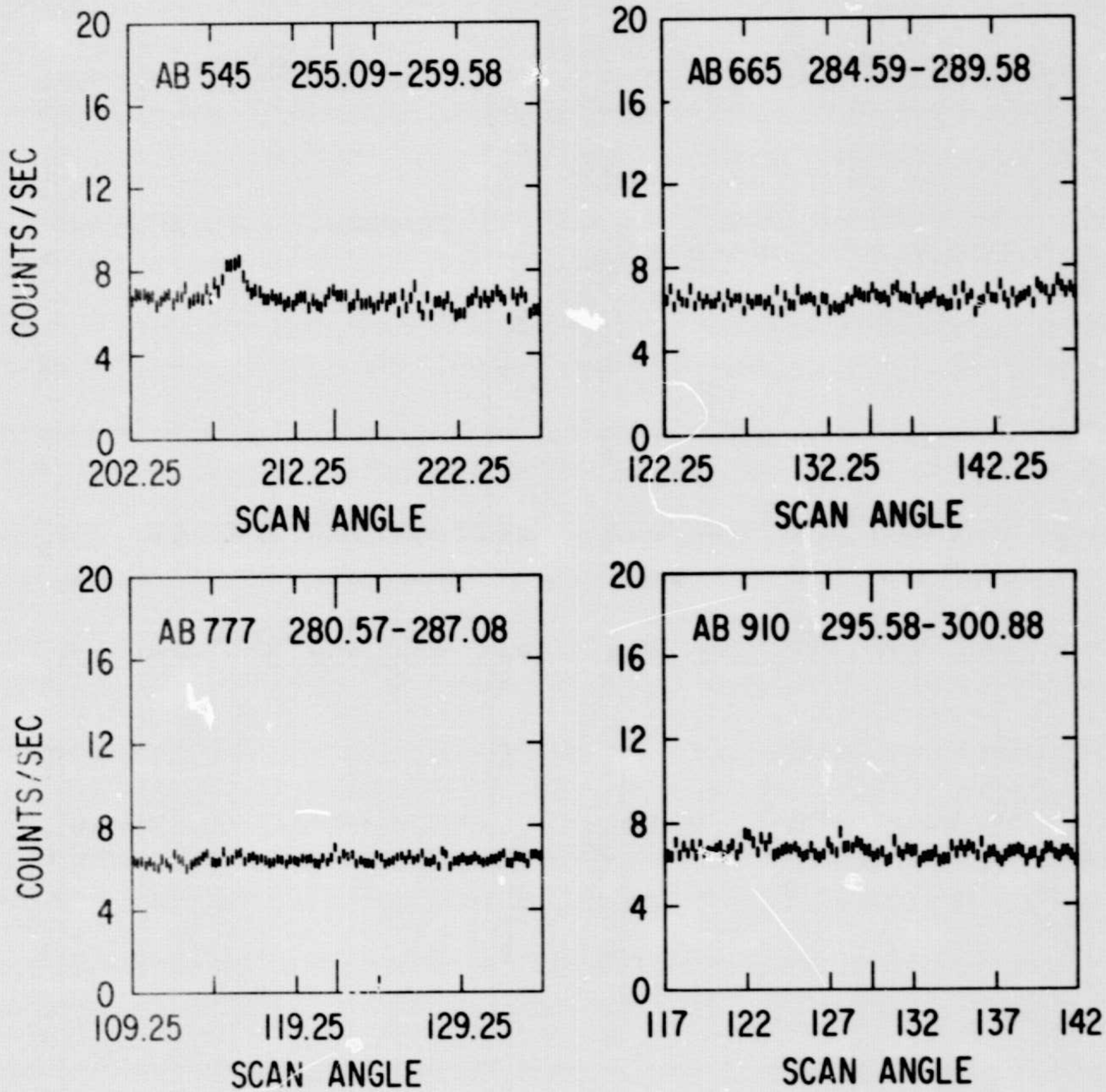

HER CLS
407.08
CNTS/SEC
SCAN ANGLE


AB 1146
350.09
353.58
194.25
199.25
204.25
209.25
214.25
219.25
0.00
4.00
8.00
12.00
16.00
20.00
CNTS/SEC
SCAN ANGLE


AB 2645
346.09
349.58
341.00
346.00
351.00
356.00
361.00
366.00
0.00
4.00
8.00
12.00
16.00
20.00
CNTS/SEC
SCAN ANGLE

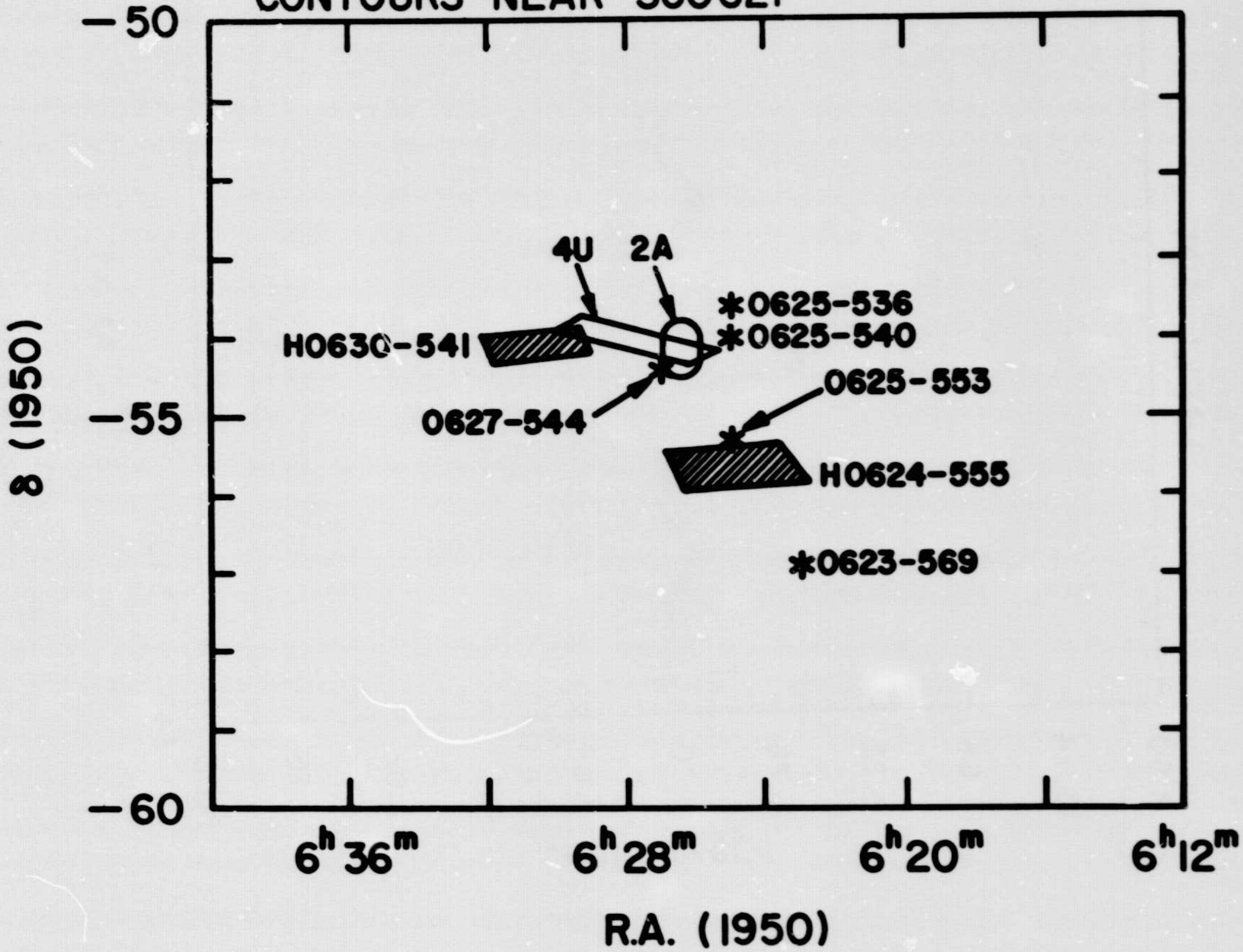

AB 576
277.59
281.58
134.00
139.00
144.00
149.00
154.00
159.00
0.00
4.00
8.00
12.00
16.00
20.00
CNTS/SEC
SCAN ANGLE

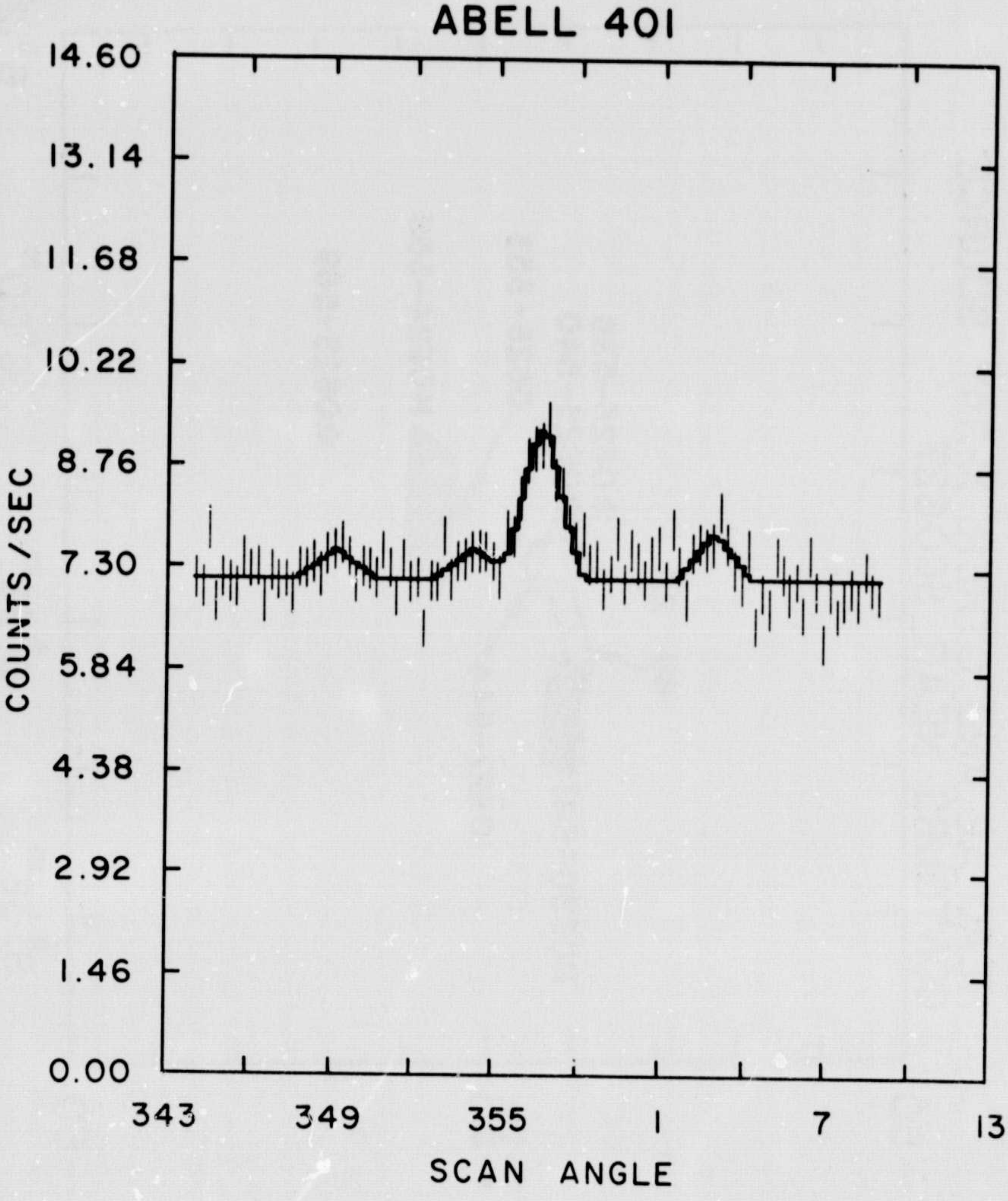

AB 1609
370.10
373.58
159.50
164.50
169.50
174.50
179.50
184.50
0.00
4.00
8.00
12.00
16.00
20.00
CNTS/SEC
SCAN ANGLE



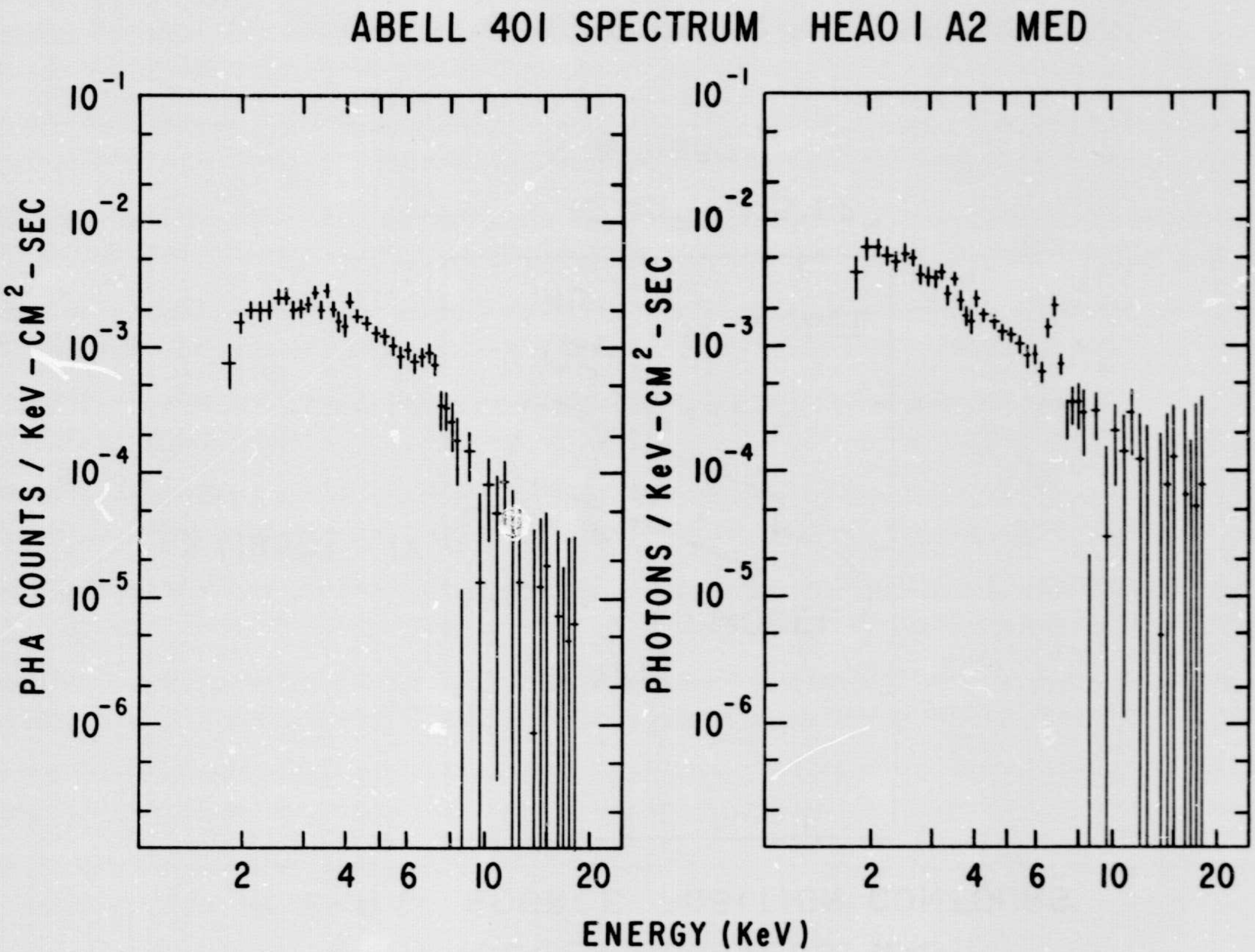
AB 545 255.09-259.58
AB 665 284.59-289.58
AB 777 280.57-287.08
AB 910 295.58-300.88
COUNTS/SEC
SCAN ANGLE
0
4
8
12
16
20
202.25
212.25
222.25
122.25
132.25
142.25
109.25
119.25
129.25
117
122
127
132
137
142

HEAO-A2 AND OTHER X-RAY SOURCE CONTOURS NEAR SCO627



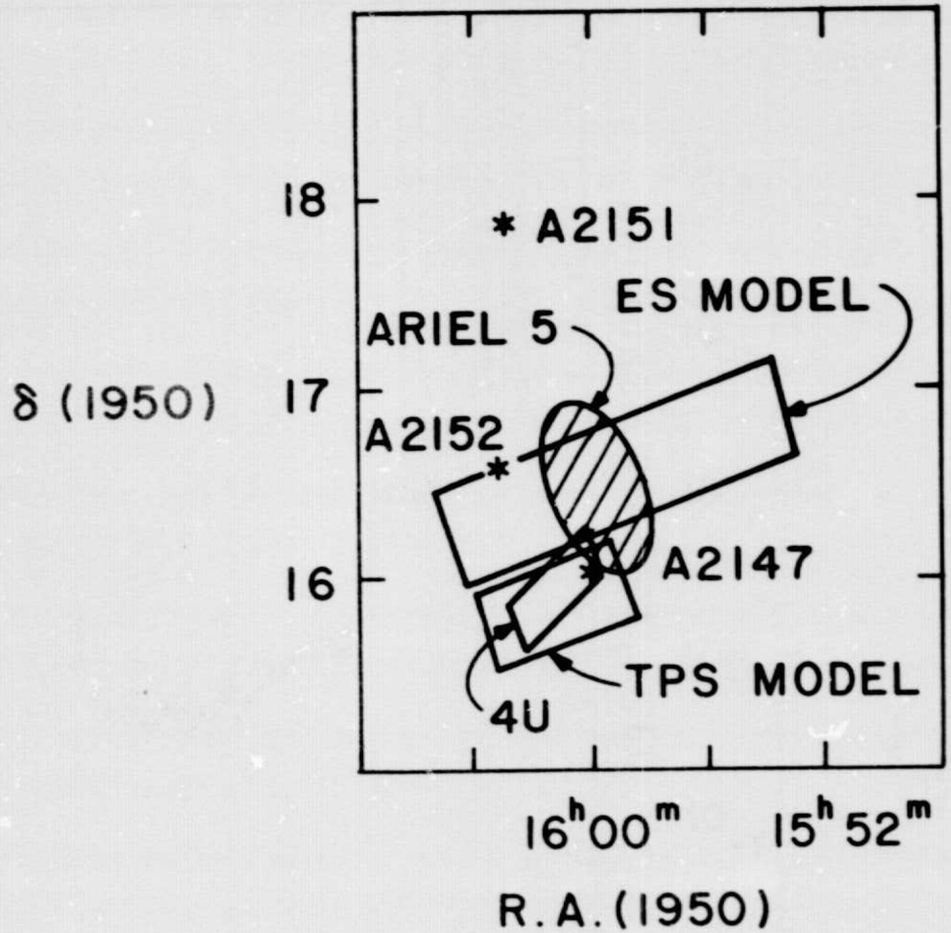


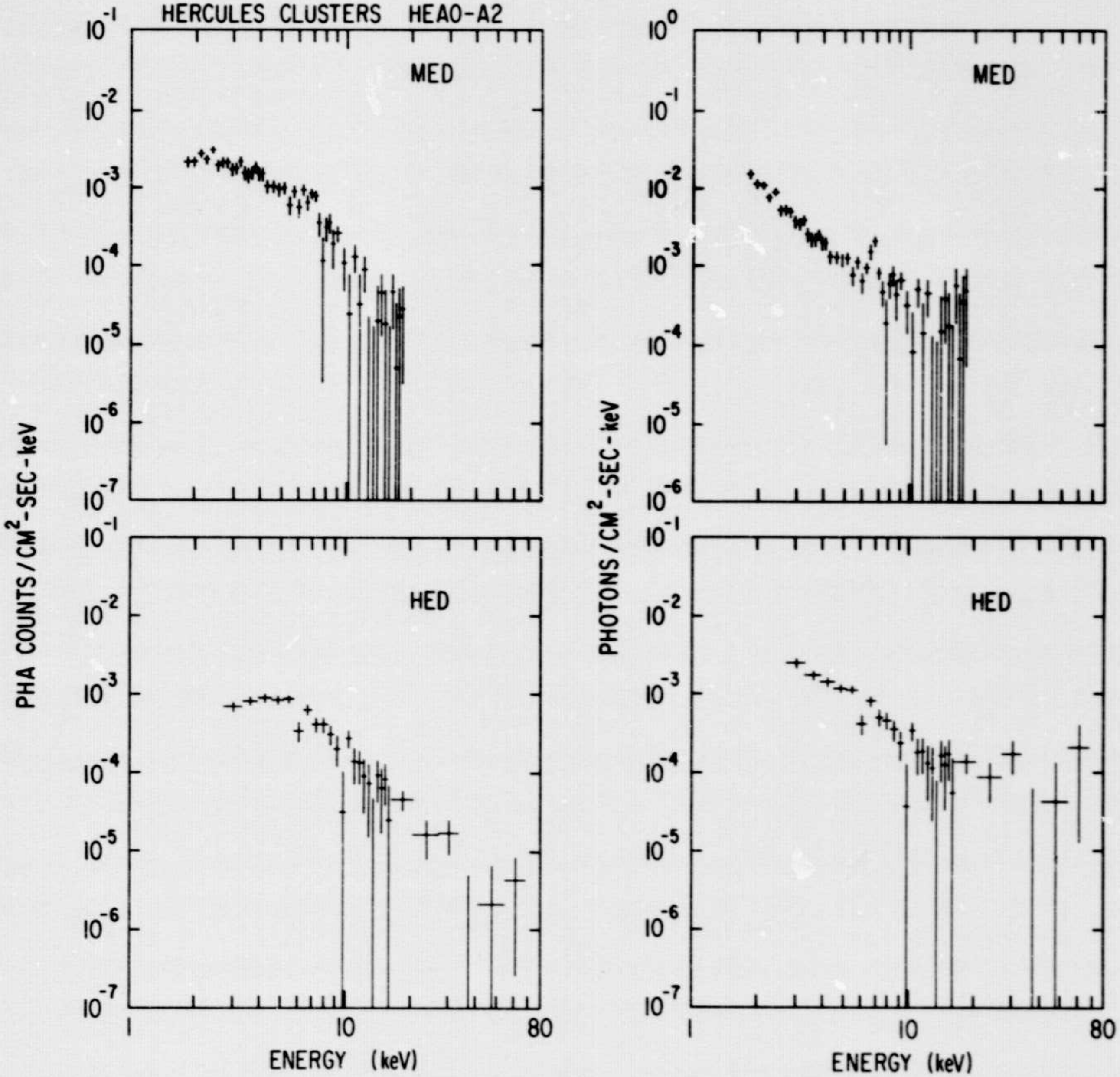
ABELL 401
14.60
13.14
11.68
10.22
8.76
7.30
5.84
4.38
2.92
1.46
0.00
COUNTS / SEC
343
349
355
1
7
13
SCAN ANGLE



ABELL 401 SPECTRUM HEAO I A2 MED
PHA COUNTS / KeV - CM^2 - SEC
PHOTONS / KeV - CM^2 - SEC
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
2
4
6
10
20
ENERGY (KeV)

HERCULES CLUSTERS AND
X-RAY SOURCE POSITION CONTOURS




HERCULES CLUSTERS HEAO-A2
MED
HED
PHA COUNTS/CM^2-SEC-keV
PHOTONS/CM^2-SEC-keV
ENERGY (keV)

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7. Author(s) S.H. Pravdo, E.A. Boldt, F.E. Marshall, R.F. Mushotzky, B.W. Smith, J. McKee and G. Reichert	8. Performing Organization Report No.
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16. Abstract

The all-sky data base acquired with the HEAO A-2 experiment has been searched for X-ray emission on a variety of metagalactic size scales which had either been predicted or previously detected. We present results in the 0.2-60 keV energy range. The optically richest clusters, including those from which a microwave decrement has been observed, appear to be relatively underluminous in X-rays. Observations of Abell 576 show its luminosity to be less than earlier estimates, and moreover less than the luminosity predicted from its microwave decrement, unless the intracluster gas is a factor of $\sim$ 10 hotter than in typical clusters.

Extended halos around clusters were not detected in our data, and weak sources appear to be responsible for the apparent effect around several clusters. Near SC0627 there are two X-ray sources, and the identification of the dominate source with SC0627 is probably incorrect.

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