ELEMENTAL ABUNDANCES AND TEMPERATURE DISTRIBUTIONS IN THE INTRA-CLUSTER MEDIUM OF THE PERSEUS CLUSTER

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ABSTRACT. Temperatures and iron abundances in two distinct regions of the Perseus Cluster, based on X-ray observations made with SPARTAN 1, are reported. Iron abundance values relative to solar are $0.81^{+0.26}_{-0.16}$ and $0.41^{+0.41}_{-0.25}$, and the temperatures are $4.2^{+0.2}_{-0.1} \times 10^7$ K and $7.1^{+0.8}_{-0.6} \times 10^7$ K, for the regions 0′ to 5′ and 6′ to 20′ from the cluster center, respectively. The uncertainties are 90% confidence.

1. INTRODUCTION

Determination of the elemental abundances and temperatures of the intra-cluster medium (ICM) of rich clusters of galaxies provides important cosmological information relating to the formation and evolution of large-scale structure, dark matter, and scenarios of the generation of the heavy elements in clusters. The Perseus cluster has long been recognized as an X-ray source, the primary emission mechanism being thermal bremsstrahlung from an optically thin plasma. Iron line emission was detected from the cluster, but, until now, these measurements could not distinguish between two hypotheses: (1) the iron line emission is spread throughout the cluster, and much of the intra-cluster medium has been processed through stars; or, (2) the iron line emission in concentrated in the cluster core, and much of the ICM is mainly made up of primordial gas. We report here the first definitive evidence for spatially varying temperature and abundance in the ICM of the Perseus cluster. Details of the analysis and interpretation of our data can be found in Ulmer et al. (1986).

OBSERVATIONS AND RESULTS

The observations were made with two nearly identical systems, each consisting of a proportional counter and a passive collimator, on board SPARTAN 1. Figure 1 shows the SPARTAN 1 instrument prior to deployment with the remote manipulator arm of the space shuttle. The field of view defined by the collimators was about 5′x 3°. After deployment, the SPARTAN 1 scanned the sky in the narrow field of view direction.

A. Hewitt et al. (eds.), Observational Cosmology, 523–526.

Figure 1. The SPARTAN 1 instrument just prior to deployment.

Figure 2 shows the counts versus time for a typical scan across the Perseus Cluster. Due to limited statistics, we binned the data into two regions, inner and outer. The inner region includes data obtained when the field of view of the detectors was with ~5′ of the peak emission; the outer-region data was accumulated when the instrument was ~6′ to 20′ from the peak emission.

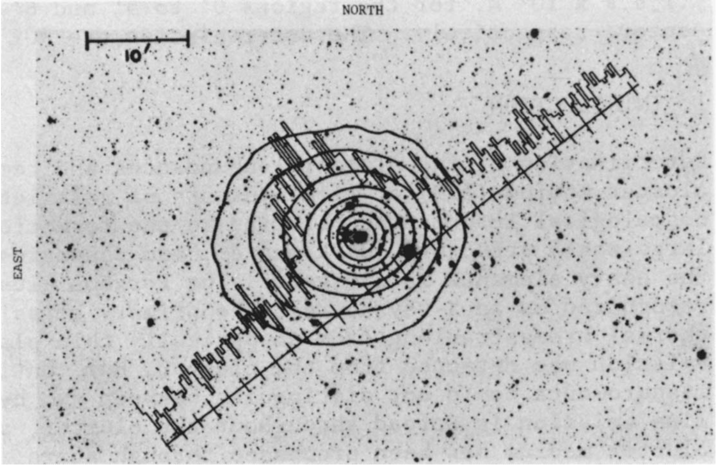

Figure 2. Counting rate as a function of time (the histogram) for a typical SPARTAN 1 scan superposed on an optical print of the cluster. The contours are from the Einstein Observatory X-ray image of the cluster (Branduardi-Raymont et al. **1978).**

The complex spectrum for the inner region is shown in Figure 3. A power law is needed in addition to a thermal spectrum to produce a good fit to the data. We note that the best-fit spectral index is 2.05 ± .10 (photons cm^{-2} s^{-1}) and that the absorption derived from the best fit is consistent with the interpretation that the X-ray source is the nucleus of NGC 1275. Details of the fitting procedure and spectra for the outer region are given in Ulmer et al. 1986.

For the inner and outer regions, our derived best-fit iron abundance values relative to solar are, respectively, $0.81^{+0.26}_{-0.16}$, and $0.41^{+0.41}_{-0.25}$, and the temperatures are $4.2^{+0.2}_{-0.1}$ x 10^7 K and $7.1^{+0.8}_{-0.6}$ x 10^7 K. The uncertainties are 90% confidence values. The abundance values being nearly solar, we conclude that a substantial fraction of the ICM has been processed through stars.

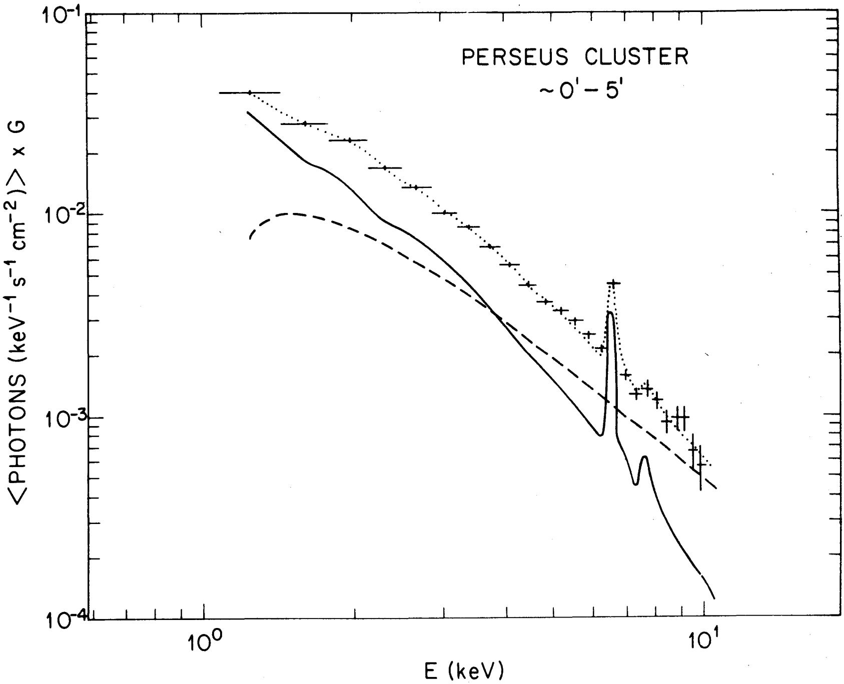

Figure 3. The best fit for spectra for the inner region.

It is difficult to determine whether or not there is an abundance gradient. Our derived abundances for the inner region being higher than that derived previously for the entire cluster (e.g. Mushotzky et al. 1978) may be taken as evidence for an abundance gradient in the cluster. We caution, however, that there are several uncertainties both in our derived abundances as well as those published elsewhere. Some uncertainties introduced by the models can be more important than the statistical errors. For example, the effect of the power-law continuum on the computed elemental abundances has been ignored by previous workers. Also, iron line emission being temperature-dependant, some uncertainty is introduced by assuming an average temperature for the entire cluster, as has been done prrviously, or for the selected regions here. We conclude that any evidence from our results for an abundance gradient in the Perseus cluster is marginal, at best.

The lower gas temperature we derive in the central region of Perseus is consistent with the high density and resultant short cooling time (less than a Hubble time) in the cluster core (Fabian et al. 1978 ; Sarazin 1986 and references therein).

REFERENCES

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Ulmer, M. P., et. al. submitted to Ap. J. Letters, October 1986.

DISCUSSION

AUDOUZE: What are the other chemical elements that you expect to see with your observational device?

ULMER: The instrumental energy resolution did not permit us to directly detect other species. The other most prominent lines in the theoretical spectrum are from Mg, Si and S.