HIGH RESOLUTION X-RAY SPECTROSCOPY OF THE GAS SURROUNDING M87 AND NGC1275: EMISSION LINE DETECTION AND EVIDENCE FOR RADIATIVELY REGULATED ACCRETION

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I. INTRODUCTION

The topic of this paper really falls somewhere between this session on active galaxies and the session on clusters. What I will report is really a cluster phenomenon but one which depends on the presence of a dominant, massive galaxy in the cluster. Specifically, we have detected several X-ray emission lines from the vicinity of M87 in the Virgo Cluster and NGC1275 in Perseus. The lines are indicative of material which is cooler than the bulk of the intracluster gas. This material is most likely accreting onto the central galaxy with the accretion rate controlled by the rate of radiative cooling.

The observations I am reporting were made with the Focal Plane Crystal Spectrometer (FPCS) on the Einstein Observatory. The instrument is a Bragg crystal spectrometer which has a resolving power ($E/\Delta E$) of 50 to 500 over the energy range of 0.2 to 3 keV. It operates much like an optical scanner in that it has a narrow passband which is swept over some restricted spectral range containing an emission line. Detailed descriptions are given elsewhere (Canizares et al. 1977, 1979, Giacconi et al. 1979).

II. M87 IN THE VIRGO CLUSTER

M87 is the better studied of the two sources. Some of our results have been reported by Canizares et al. (1979). Recall that the X-ray emission from the Virgo Cluster has a large component which extends throughout most of the cluster and another which is concentrated around M87 (with a core radius of 12 - 15 arc min; Malina et al. 1976, Gorenstein et al. 1977, Lawrence 1978, Davison 1978, Lea et al. 1979) and which is probably due to an increased concentration of the intracluster gas in the local gravitational potential well of the massive galaxy (cf. Bahcall and Sarazin 1977, Mathews 1978, Mathews and Bregman 1978). Emission lines from ionized iron have been detected with proportional

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counters at 6.7 keV (Serlemitsos et al. 1977, Mushotsky et al. 1978) and at ∿ 1.1 keV (Fabricant et al. 1978, Lea et al. 1979). Fabricant et al. (1978) also showed that the 1.1 keV iron emission was spread over at least ∿ 25 arc minutes.

Our observations were made with a 3 x 30 arc min aperture (19 x 190 kpc at 21.9 Mpc; Sandage and Tamman 1976) centered on M87. The aperture contains ∿ 25% of the M87 "halo" source and ∿ 10% of the total Virgo cluster source. We have detected the Lyman α line of hydrogenic oxygen (O VIII) at 0.65 keV and set upper limits on several iron lines, as reported by Canizares et al. (1979). Since that paper was sent to press, further analysis on a larger data set has resulted in the detection of at least one of the iron lines, the Fe XXIV line at 1.164 keV. This analysis is not complete so the result is still preliminary. Table 1 summarizes the line strengths.

Table 1

M87 Line Strengths

Ion	Rest Energy (keV)	Flux (10^{-3} photons $cm^{-2}s^{-1}$)	Strength* at M87 10^{41} erg s^{-1}
O VIII	0.654	13 ± 3	12
Fe XXIV	1.164	2.3 ± 0.7	2.7
Fe XXIII	1.127	< 2.9	< 3.3
Fe XVII	0.826	< 2.5	< 2.2

* Within 3 x 30 arc min aperture; corrected for absorption in the Galaxy; see Canizares et al. 1979.

The properties of the emitting gas can be determined from the line strengths using the emissivities calculated by Raymond and Smith (1977 and 1979), for emission from a thin plasma. The Fe XXIV line at 1.16 keV and the Fe XXV, XXVI lines around 6.7 keV together determine an effective ionization temperature. The flux of the higher energy line is 0.0021 ± 0.0006 photons $cm^{-2}s^{-1}$ (Serlemitsos et al. 1977) for the whole Virgo Cluster. For a preliminary result we assume that this emission is distributed as the cluster continuum so that only 10% of this flux would be included within the region sampled by our aperture. In Figure 1 we show how the iron line ratio constrains the effective temperature to be 2.1 - 2.6 x 10^7K, consistent with the continuum temperature determined by OSO-8 (Serlemitsos et al. 1977, Mushotzky et al. 1978).

It is very unlikely that the O VIII line comes from the same gas

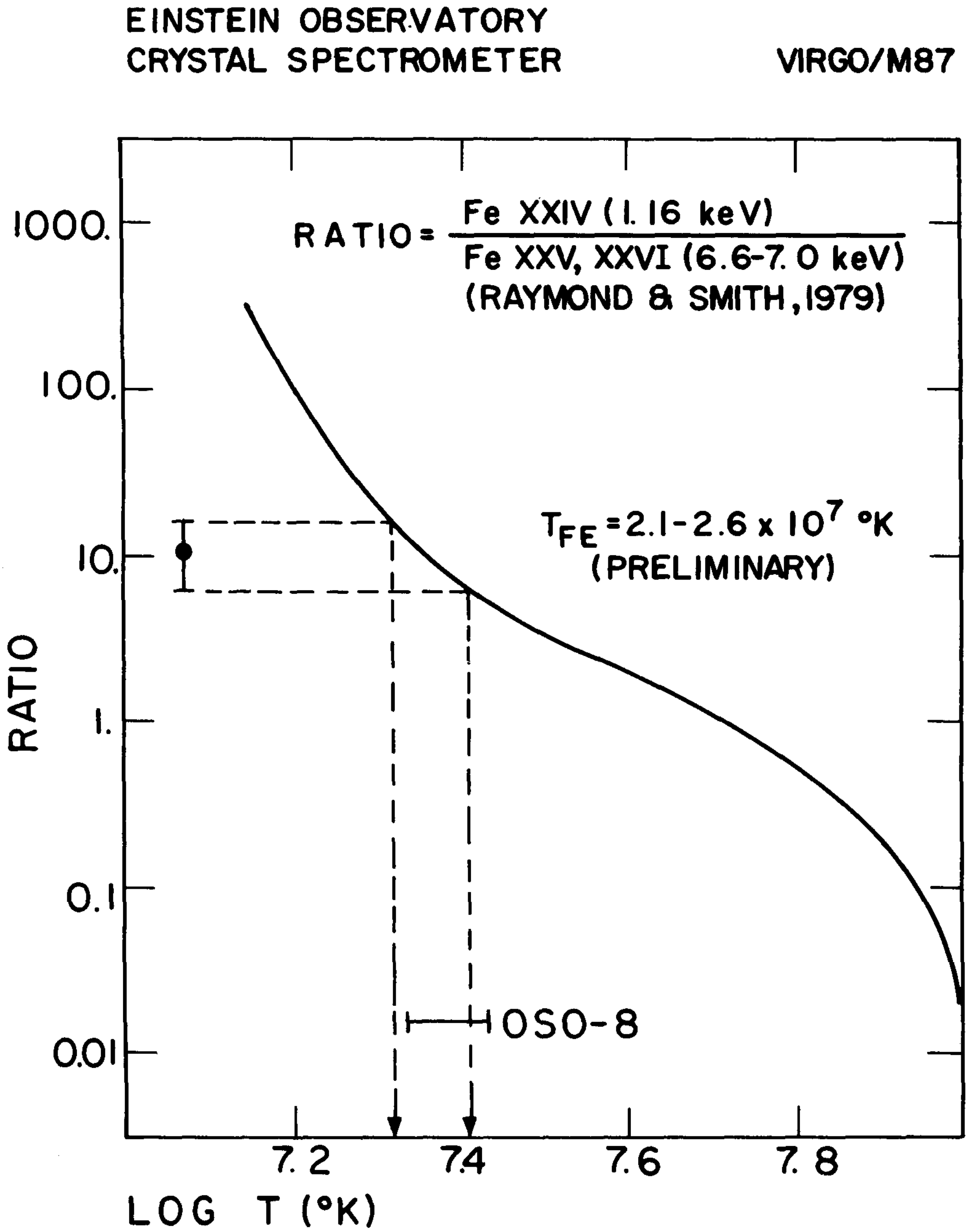

Fig. 1. Ratio of photon fluxés for two iron lines vs. temperature. The solid curve is the theoretical ratio of Raymond and Smith (1977, 1979) and the point is preliminary result from the measured values (see text).

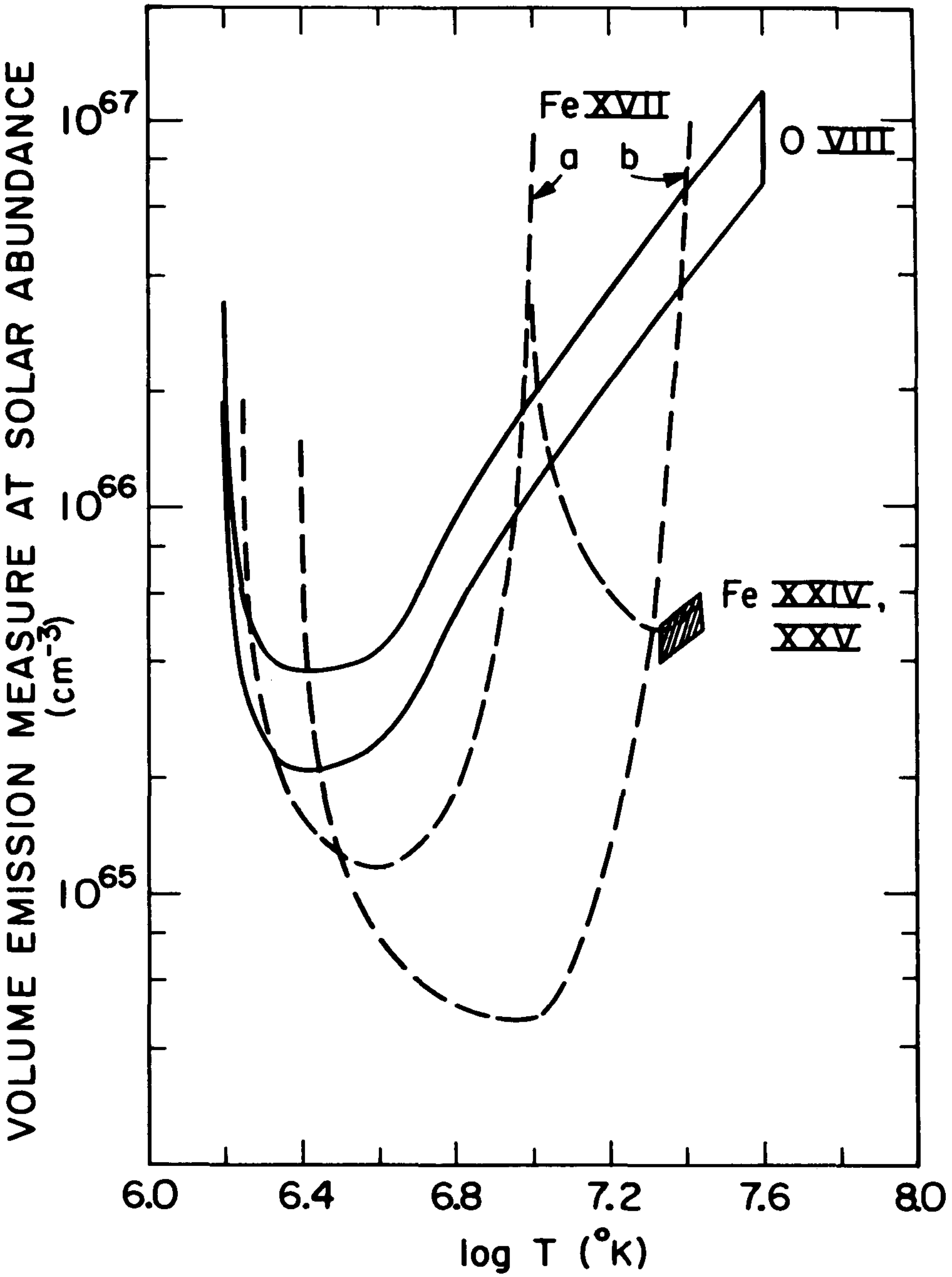

Fig. 2. The volume emission measure at cosmic abundance vs. temperature using Raymond and Smith (1977, 1979). The solid curves are measured values, the dashed curves are upper limits. For Fe XVII the true limit lies between curve a and b but closer to a (see Canizares et al. 1979).

which is emitting the iron lines. In Figure 2 we plot the volume emission measure of the emitting gas required to account for the various detected lines and upper limits as a function of temperature assuming solar abundances. The O VIII curve does not intersect the region defined by the iron lines. If the plasma is isothermal with the temperature deduced above then the O VIII line can be explained only if the oxygen to iron abundance is ∿ 7 times its solar value. Current models of nucleosynthesis fall far short of accounting for such an extreme enhancement (Arnett 1978, DeYoung 1978).

The most likely explanation of our data is that the central portion of the M87 "halo" source contains a cooler component which, to be consistent with our upper limits on the presence of Fe XVII and XXIII lines, must have a temperature near 10^7 K or below ∿ 2 x 10^6 K. All the hydrostatic, adiabatic models reviewed by Bahcall and Sarazin (1978) are *hotter*, not *cooler* in the interior and therefore do not apply to this source.

On the other hand, several authors have explored the likely situation that the gas surrounding M87 is accreting onto the central galaxy and that the rate of accretion is in fact controlled by the rate of radiative cooling in the central region (Silk 1976, Cowie and Binney 1977, Fabian and Nulsen 1977, Mathews and Bregman 1978). We have used the detailed model of Mathews and Bregman (1978) for an accretion rate of 30 M_o yr^{-1} to estimate an O VIII line luminosity of ∿ 2 x 10^{42} erg s^{-1} which is remarkably close to our value of 1.2 x 10^{42} erg s^{-1}. A more complete comparison of the detected and predicted line luminosities could well narrow considerably the range of allowed model parameters.

III. NGC1275 IN THE PERSEUS CLUSTER

We have studied only one line in this source, the Fe XVII line at 0.826 keV, and have detected it at a flux of 0.0020 ± 0.0004 photons cm^{-2} s^{-1}. This observation was again made with a 3 x 30 arc min aperture (90 x 900 kpc). Jernigan et al. (1979) give the details of this measurement.

The Perseus cluster X-ray source has a continuum temperature of ∿ 8 x 10^7 K, and the 7 keV Fe line strength is consistent with a plasma at this temperature (Serlemitsos et al. 1977, Mushotzky et al. 1978). However, Fe XVII cannot exist at such high temperatures, so again we must conclude that some cooler gas exists in the region around NGC1275. Without any further information we can only say that the temperature of this cool component must be between 2.5 and 25 x 10^6 K. A cooler central region was already suggested by Ulmer and Jernigan (1978) from broadband measurements.

Radiatively regulated accretion may again explain the presence of the cooler gas. However, as Grindlay shows in his contribution to the cluster session, the structure of the Perseus source is complex (see also Helmken et al. 1978) and so we should not yet rule out the possibility that some other mechanism is operating here.

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