X-RAY IMAGING STUDIES OF NGC 1275 AND THE CORE OF THE PERSEUS CLUSTER

J. Grindlay, G. Branduardi
Harvard-Smithsonian Center for Astrophysics
Cambridge, Massachussetts, USA.
A. Fabian
Institute of Theoretical Astronomy
Cambridge, UK.

The EINSTEIN X-ray Observatory has been used to study the X-ray emission from the center of the Perseus cluster, including the active galaxy NGC 1275. Both a point source and extended (∿ 6') source are observed from NGC 1275. The central 40' x 40' region of the Perseus cluster around NGC 1275 displays an interesting temperature and surface brightness distribution. Simple hydrostatic isothermal sphere models do not well describe the cluster emission. The surface brightness of the high resolution image of NGC 1275 can be fit with a constant-pressure but centrally-cooling (i.e., temperature increases with radius) gas which suggests a radiative cooling accretion flow onto NGC 1275.

I. INTRODUCTION

The Perseus cluster of galaxies is the brightest, and one of the most extensively studied, galaxy cluster X-ray sources. The most recent of these studies have had X-ray spatial resolution of a few arcmin (Helmken et al. 1978; Gorenstein et al. 1978) and X-ray spectral resolution of ∿ 20% (Mushotzky et al. 1978); other important earlier studies are cited in these papers. We shall report some of the first observations of the Perseus cluster and its central galaxy, NGC 1275, obtained with the EINSTEIN Observatory (see Giacconi et al. 1979 for a description of the Observatory and instruments). These are imaging results, and have spatial resolutions of ∿ 1 arcmin (IPC images) and ∿ 2 arcsec (HRI images). Coarse spectral data for Perseus are available from the IPC and will be discussed briefly; high resolution spectra of Perseus from the EINSTEIN SSS and FPCS experiments are reported in accompanying papers in this volume.

II. THE CENTRAL REGION OF THE PERSEUS CLUSTER

The central 40' x 40' of the Perseus cluster was observed for 7544 sec with the IPC. These imaging data are discussed in some detail by

Patrick A. Wayman (ed.), Highlights of Astronomy, Vol. 5, 741–745.

Branduardi et al. (1979) and will only be summarized here. The most prominent feature is a compact source, or halo, surrounding NGC 1275. The apparent radius of the compact source is 6', although this is dependent on the model assumed for fitting the surface brightness distribution of the underlying diffuse emission from the cluster. The 6' value is in fact appropriate for a hydrostatic isothermal sphere (see Gorenstein et al. 1978) with core radius $r_c = 8'$ and ratio $\beta = 0.65$ of specific kinetic energy of the galaxies to that of the gas. Whereas this is the core radius measured (Bahcall, 1974) for the distribution of bright galaxies in Perseus, the corresponding best-fit β value gives a velocity dispersion which is a factor of ~ 1.5 smaller than the value measured by Tifft (1978). Conversely, using the measured velocity dispersion would require a cluster core radius of $r_c = 22'$ and a larger apparent radius for the compact source around NGC 1275. These values for r_c and β, and the discrepancy with the hydrostatic isothermal sphere model, are very similar to those found by Gorenstein et al. (1978) for Perseus. However, the EINSTEIN IPC data, with higher resolution and much better statistics, may resolve this paradox.

The data suggest that in fact the gas is *not* isothermal but that there is at least a pronounced East-West asymmetry in the gas temperature and possibly large radial temperature gradients as well. Branduardi et al. (1979) show intensity contour maps in two energy ranges (0.4 - 1.8 keV and 1.8 - 3.9 keV) which indicate that the cluster core is most elongated E-W at the lowest energies and that the soft emission is distinctly peaked East of NGC 1275. It is not yet clear whether this is entirely a temperature gradient (with the hottest diffuse cluster emission to the West of NGC 1275, or near the optical cluster center derived by Bahcall 1974) or due to variable low energy absorption in the field. Indeed, the HRI image to be discussed below suggests there is absorption NW of NGC 1275 at approximately the position of the supposed intervening galaxy responsible for the 8000 km s^{-1} velocity system.

III. HIGH RESOLUTION IMAGE OF NGC 1275

An exposure of 12339 sec centered on NGC 1275 was obtained with the HRI detector. The contour map of the HRI image is shown in Figure 1 superposed on the optical photograph of NGC 1275 as published by Lynds (1975). The peak of emission at the center of NGC 1275 is well fit as a point source with an upper limit on angular size of $\lesssim 1''$ ($\lesssim 500$ pc diameter at the 110 Mpc distance of NGC 1275). The point source is coincident (to within the $\sim 5''$ uncertainty) with the optical (Cohen, 1972) and radio (Wade and Johnston, 1977) positions for the galaxy nucleus. The point source luminosity is $L_x \simeq 6 \times 10^{43}$ erg s^{-1} in the energy range $\sim$ 0.5-4.5 keV. This is about 10% of the total in the $\sim 6'$ compact source surrounding the nucleus and about 6% of the total emission within the central 40'x40' of the Perseus cluster. Although the HRI observations extended over $\sim$2 days, no evidence for variability was found (any variations were $\leq 10\%$) on time scales $\sim$200 sec-1 day.

https://doi.org/10.1017/S1539299600004676 Published online by Cambridge University Press

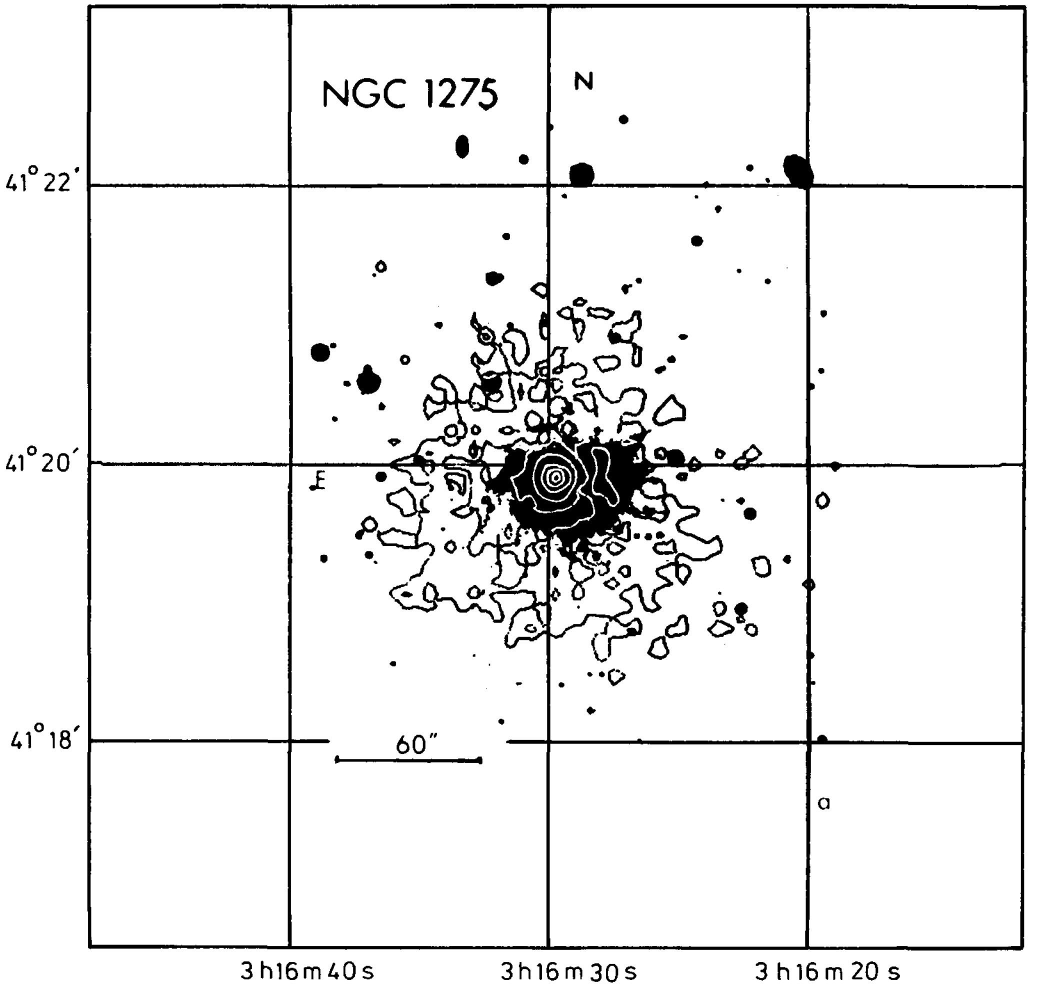

Figure 1. Superposition of X-ray contours (levels 10, 16, 26, 38, 64, 128, 256, 512, 1024 counts/pixel) from the HRI image of NGC 1275 on the Hα photograph of Lynds (1970). The SW extension of the X-ray image may be related to a loop structure whereas the relative deficiency of X-rays to the NE of the NGC 1275 nucleus may be due to absorption by the intervening ∿ 8000 km s^{-1} galaxy (see text).

https://doi.org/10.1017/S1539299600004676 Published online by Cambridge University Press

The X-ray contours (Figure 1) show a general, though not a detailed, correspondence, with the optical filaments and diffuse emission around NGC 1275. In particular, the X-ray contours extend asymmetrically to the SE from the galaxy nucleus where a loop structure is visible in the Lynds photograph as well as that of Arp (1979). This may be a region of higher density gas in which star formation is occurring; the more diffuse X-ray emission could arise in a cooling accretion flow down to the filament structure as suggested by Fabian and Nulsen (1977). Before further comparing the HRI data with this model, we note also that there is a region of lower X-ray surface brightness ∿1-2 arcmin NW of the galaxy nucleus. This may be due to absorption by the intervening galaxy with velocity ∿8000 km s^{-1} inferred to be $\lesssim$ 40 arcsec from NGC 1275 (Rubin et al. 1977). The apparently greater radial offset (from NGC 1275) of the X-ray absorption feature could suggest an extended absorbing halo with column density $N_H \simeq 3 \times 10^{21}$ cm^{-2} (vs. the "normal" X-ray value towards the Perseus cluster of ∿ 1.6×10^{21} cm^{-2} (Mushotzky et al. 1978)).

IV. DISCUSSION AND CONCLUSIONS

Although the HRI data have no energy resolution, we may infer the temperature profile from the intensity distribution if we assume constant pressure for the emitting gas. This would be justified for the cooling accretion flows of Fabian and Nulsen (1977). We have fit the HRI data to derive the radial variation of temperature and density for (various) constant pressure values and cooling functions including both bremsstrahlung and line cooling, for which approximations to the results of Raymond and Smith (1977) were used. The observed surface brightness was de-projected by assuming spherical shells and subtracting the fractional contributions from overlying shells. Space does not permit a full discussion of these results here (instead see Grindlay et al. 1979), but the temperature was found to decrease (and the density to increase) as the radius decreases within a few arcminutes of the nucleus. Models with pressures of ∿ 2×10^{-10} dyne cm^{-2} , or ambient cluster densities of ∿ 1×10^{-3} cm^{-3} in fact give central (NGC 1275) temperatures of $\lesssim$ 1 keV (vs. the ∿ 7 keV cluster ambient temperature).

Such low central temperatures inferred from the HRI brightness distribution are strictly suggested by both the EINSTEIN SSS and PFCS spectra (see the papers by Smith and Canizares in this volume) which show Si,S and Fe XVII emission lines at ∿ 1.8,2.4 and 0.8 keV,respectively. However either of these experiments has the spatial resolution to test the temperature gradients inferred from the HRI image.This can be done(though with only ∿ 1'resolution) with the IPC.The IPC spectral analysis is not yet complete, but examination of the hardness ratio (= F(2.1-2.9 keV)/F(0.8-1.4 keV)) as a function of radius shows a significant dip (of ∿ 10%) within 4' of the nucleus. Since de-projection effects have not yet been included (i.e., the foreground cluster gas contribution at ∿ 7 keV is present), only qualitative agreement with the central cooling inferred from the

HRI data can be claimed. A complete discussion of these results, which suggest that radiative accretion onto NGC 1275 is indeed occurring in the Perseus cluster, will be given by Grindlay et al. (1979).

REFERENCES

Arp, H.C.: 1979, IIIaj plate of NGC1275 to be scanned at IOA.
Brànduardi, G., Fabricant, D., Feigelson, E., Gorenstein, P., Grindlay, J., Soltan, A., and Zamorani, G.: 1979, submitted to Ap.J. (Letters).
Bahcall, N.A.: 1974, Ap.J. 187, 439.
Fabian, A.C., and Nulsen, P.E.J.: 1977, M.N.R.A.S. 180, 479.
Giacconi, R. et al.: 1979, Ap.J. 230, 540.
Gorenstein, P., Fabricant, D., Topka, K., Harnden, F.R. Jr., and Tucker, W.H.: 1978, Ap.J. 224, 718.
Grindlay, J. et al.: 1979, in preparation.
Helmken, H., Delvaille, J.P., Epstein, A., Geller, M.J., Schnopper, H. W., and Jernigan, J.G.: 1978, Ap.J. (Letters) 221, L43.
Lynds, R.: 1975, Ap.J. (Letters) 159, L151.
Mushotzky, R.F., Serlemitsos, P.J., Smith, B.W., Boldt, E.A., and Holt, S.S.: 1978, Ap.J. 225, 21.
Raymond, J., and Smith, B.: 1977, Ap.J. Suppl. 35, 419.
Rubin, V.C., Ford, W.K. Jr., and Peterson, C.J.: 1977, Ap.J. 211, 693.
Tifft, W.G.: 1978, Ap.J. 222, 421.
Wade, C.M., and Johnson, K.J.: 1977, Astron. J. 82, 791.