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THE DETECTION OF HOT INTERGALACTIC GAS IN THE NGC 3607 GROUP OF GALAXIES WITH THE *EINSTEIN* SATELLITE

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ABSTRACT

We have detected extended X-ray emission around the galaxies NGC 3607, NGC 3605, and NGC 3608 in the group TG 39a = G49 using the IPC aboard the *Einstein* satellite. We argue that this emission is due to thermal bremsstrahlung from a hot, intergalactic gas; this gas sits in the potential well of the group, around the dominant galaxy NGC 3607. We thus confirm the prediction made earlier that hot, intergalactic gas should be there to keep galaxies clear of gas, since previous sensitive H I observations of this group did not show evidence of neutral hydrogen (Biermann, Clarke, and Fricke). The gas has a density of about 4×10^{-3} cm^{-3}, a temperature of about 5×10^{6} K, a mass of about 6×10^{9} $M_{\odot}$, and a cooling time of about 5×10^{9} yr. The spatial structure of the X-ray emission around NGC 3607 suggests that the dominant galaxy is being stripped at present (cf. Lea and De Young). The X-ray luminosity and velocity dispersion of the galaxies in the group place it on the relation predicted by Silk and Tarter for groups and clusters of galaxies. We discuss the cosmological implications of this detection.

Subject headings: cosmology — galaxies: clusters of — galaxies: evolution — galaxies: intergalactic medium — X-rays: general

I. INTRODUCTION

Very sensitive H I observations with the Arecibo telescope showed that there is no neutral hydrogen in or around the galaxies NGC 3607, NGC 3605, and NGC 3608 in the group TG 39a (Turner and Gott 1976) to very low limits. This group is also designated G49 by de Vaucouleurs (1975). Using the stripping model for the evolution of S0 galaxies, Biermann, Clarke, and Fricke (1979, hereafter BCF) predicted then that there should be hot, intergalactic gas, observable in X-rays, around these galaxies. In this *Letter* we report the detection of such emission with the *Einstein* satellite, thus providing strong support for the relevance of the stripping process for the evolution of galaxies in some groups and clusters. In § II we describe the observations, and in § III we discuss possible implications for galactic evolution, for our understanding of groups and clusters, and for the X-ray background.

The five central galaxies of the group TG 39a have a mean redshift of 835 ± 190 km s^{-1} corresponding to a distance of 16.7 Mpc ($H_0 = 50$ km s^{-1} Mpc^{-1}). They are NGC 3599, NGC 3605, UGC 6296, NGC 3607, and NGC 3608. For all 11 galaxies in TG 39a with known redshift, the mean redshift is 1040 ± 251 km s^{-1}, and the overall three-dimensional velocity dispersion is 435 km s^{-1}. By comparison, the local velocity dispersion around NGC 3607 is only 327 km s^{-1}.

II. THE X-RAY OBSERVATIONS

The observations were carried out on 1979 December 7 and contain 19,496 s in the processed image (dead time correction 1.05) within a span of 58,409 s real time. The data are displayed in Figure 1 in the form of smoothed maps with background subtracted. Crosses indicate the position of galaxies in the field. There are no SAO or AGK 3 stars in this field. The large-scale maps, on the left-hand side, have been smoothed with a 60″ Gaussian beam. They show extended emission around NGC 3607, 3605, and 3608. This emission is centered on the dominant galaxy NGC 3607 and is generally extended in the direction of the other two galaxies, but extends clearly beyond them, showing two possible "point" sources northeast of NGC 3608 and southwest of NGC 3605. NGC 3608 is of second rank and there is some X-ray emission centered on this

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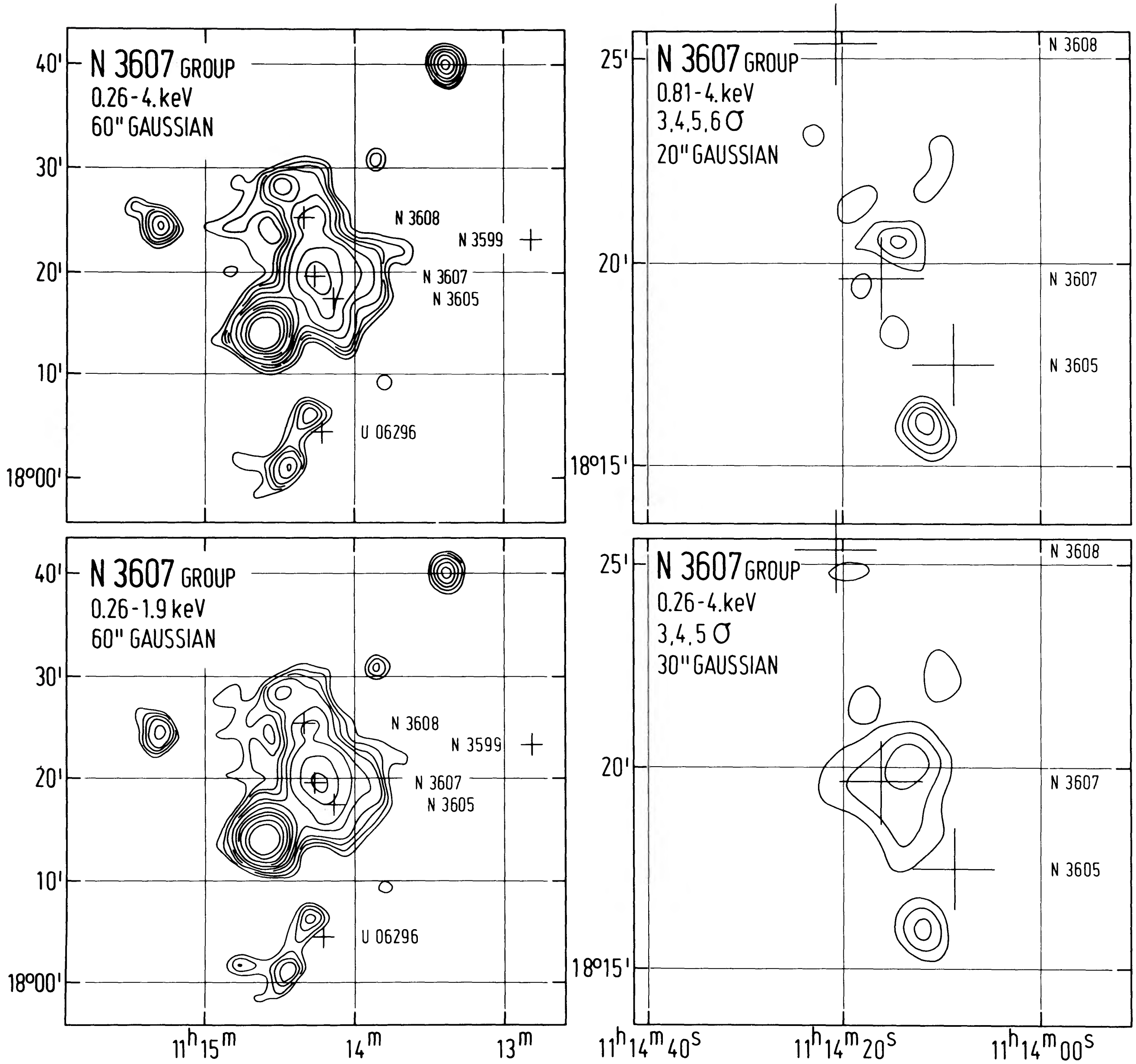

FIG. 1.—*Einstein* IPC X-ray maps of the group TG 39a containing NGC 3607. On the left-hand side the data have been smoothed with a 60″ Gaussian beam, on the right-hand side with a 20″ and 30″ Gaussian, as indicated. The contour levels are 0.2, 0.4, 0.6, 0.8, 1.2, 1.6, 2.4, 3.2, 4, 5.6, and 7.2 counts per 32″ × 32″ pixel (*left*). On the right-hand side the graphs show maps of the central region with the strong serendipitous source removed. The contour levels are 0.193, 0.269, 0.350, and 0.435 counts per 8″ × 8″ pixel, corresponding to 3, 4, 5, and 6 sigma for the 0.81–4 keV map; and 0.140, 0.193, and 0.247 counts per 8″ × 8″ pixel, corresponding to 3, 4, and 5 sigma for the 0.26–4 keV map. The galaxy positions are indicated by crosses with a length of 2′, showing the absolute positional uncertainty of X-ray sources of $\lesssim 1'$ for strong sources, and about 90″ for weak sources.

galaxy as well. We note that the optical ellipticity of NGC 3607 is nearly perpendicular to the line connecting NGC 3605 and NGC 3608. There are several further sources in the field. The strong one is at about $11^h14^m40^s$, $+18°14'$; it has 800 counts, is not associated with TG 39a, and will be discussed elsewhere. The source at $11^h13^m20^s$, $+18°40'$ is also strong and has no optical counterpart on the Palomar Observatory Sky Survey (POSS). The weak emission north of UGC 6296 and the other weak sources in the field also cannot readily be identified with objects on the POSS. The total number of counts in the emission around the galaxies NGC

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3607, 3605, and 3608 is 500 ± 100. This corresponds to a luminosity of $\sim 2 \times 10^{40}$ ergs s^{-1}. If there is significant emission beyond the lowest contour shown, not visible because of the background variations in the IPC, then the luminosity could be higher by up to a factor of 2. The contribution of any point source near NGC 3607 is at most about 10% of the total emission. Unfolding the distribution of emission near NGC 3607 with a point-source response function yields an average Gaussian width of 4′.7 (22 kpc), considerably larger than the isophotal radius $D(0)/2$ of 1′.8. The higher resolution maps on the right-hand side of Figure 1 show only the central parts of the field. The source at $11^h14^m40^s$, $+18°14'$ has been removed from these graphs. There is no significant emission near the faint galaxy NGC 3605 (the lowest contour here is 3σ), and only soft, weak emission is detected near NGC 3608. The structure of the emission around NGC 3607 is not centered on the optical center of the galaxy and has the shape of a tail with an opening angle of about 40°. The tail has the harder X-ray emission near its tip (see the 0.81–4 keV map) and embraces the galaxy at lower energies (see the 0.26–4 keV map). There is an additional point source about 90″ south of N3605 which is stronger in the higher energy map. Its identification is at present uncertain.

Using a spectral-fitting program we have explored possible fits to the X-ray spectrum of the source around NGC 3607. Adopting the column density of hydrogen from Heiles (1975) as 5.6×10^{20} to determine the X-ray absorption cutoff, we obtain 0.65(+0.3, −0.2) keV for the temperature of hot gas producing the emission. This corresponds well to the motions of the galaxies in the entire group, which corresponds to 0.7 keV. At such temperatures, emission lines contribute most to the cooling, if the abundances are normal.

III. DISCUSSION

Using a recent review of *Einstein* observations of normal galaxies by Long and van Speybroeck (1981) as the basis of our comparison with other galaxy types, we note the following properties: Out of approximately 50 S0 galaxies, only three have L_X/L_V larger than or comparable to the value of 2×10^{-4} for NGC 3607, namely NGC 1316 and NGC 5532 (both well-known radio galaxies) and NGC 1332. If the X-rays in NGC 1316 and NGC 5532 are associated with their nuclear activity, then NGC 3607 may be similar to NGC 1332 in that both have high L_X/L_V and neither has nonthermal radio emission at 21 cm (Bieging and Biermann 1977; Hummel 1980).

Since the emission near NGC 3607 goes much beyond the optical image, we conclude that the extended X-ray emission in the NGC 3607 group is best explained as coming from hot, intergalactic gas. We note, that its X-ray luminosity, $L_X = 2 \times 10^{40}$ ergs s^{-1}, and its velocity dispersion, $\sigma = 430$ km s^{-1}, place it on the predicted L_X-σ relation of Silk and Tarter (1973). The group also fits the extrapolation of the L_X-σ relation of Faber and Dressler (1976). It does not fit the theoretically derived L_X-σ relation by Quintana and Melnick (1981) which is valid only for higher temperatures.

From the L_X, shape, and temperature, we derive a density at the center of 4×10^{-3} cm^{-3}, a total mass of 5×10^9 $M_\odot$ in hot gas, and a cooling time of 5×10^9 yr. The uncertainty about the dominant radiation mechanism (which depends on abundance ratios and the possibility of low-level emission on larger scales) produces an uncertainty of about a factor of 2 in the density and other derived quantities (cf. Cox and Daltabuit 1971). The density and cooling time depend only weakly on the distance assumed, but the mass in gas is more strongly distance dependent. Comparing with large clusters of galaxies, it is evident that the fraction of the virial mass in groups and clusters which is in hot gas is not a constant but decreases for groups. For this group it is 10^{-3}. Although the average velocity in groups is smaller than in clusters, the central intragroup gas density is slightly higher—at least in TG 39a. Stripping might therefore occur, and thus may be the main process for keeping the galaxies clean of gas.

The morphology of the higher resolution X-ray map of TG 39a (Fig. 1) can be understood in terms of the calculations of Lea and De Young (1976). If we assume that the increased emissivity to the northwest of NGC 3607 is due to a post–bow-shock increase in temperature, and that the open tail occurs at a Mach number of approximately unity, then NGC 3607 appears to be moving in position angle −40° (projected) with a velocity of ~ 400 km s^{-1}. Equating the ram pressure force at Mach number 1 to the restoring force for gas in the disk of NGC 3607 at the upper limit for H I derived by BCF, leads to an upper limit for the extent of gas possibly present near the nucleus of NGC 3607. This extent is at most about 1 kpc, and thus it would be of interest to check for optical emission lines.

Silk and Tarter (1973) have shown that, if all groups have X-ray emission similar to clusters, but reduced, then they contribute to the X-ray background. Our results emphasize the need for further data on X-ray emission from small groups. If TG 39a is typical of other similar groups, they may make a substantial contribution to the soft X-ray background.

Given that the density of small groups like that containing NGC 3607 is 10^5–10^7 times that of massive clusters (cf. Bahcall 1980), it is of further interest to consider whether such groups may produce absorption lines or Faraday rotation in background QSOs. For a luminosity of $\sim 2.5 \times 10^{10}$ $L_\odot$, the density of such systems (cf. Bahcall 1980) should be of the order of 0.03 Mpc^{-3}. To estimate the possible occurrence rate of

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TG 39a-like clusters, we have used a sample of 54 nearby groups from de Vaucouleurs (1975) which has been analyzed by one of us (B. F. M.). Six of these have first ranked S0 galaxies and a further 17 have S0s as the second or third brightest galaxy. Using these numbers suggests a density of $n(0) \sim 0.01$ Mpc^{-3} for TG 39a-like groups at $z = 0$. If such groups do not collectively evolve over look-back times of up to $z \approx 2.5$, then $n(z) = n(0)(1 + z)^3$, which, combined with a radius of 22 kpc (that of the TG 39a X-ray source), implies an intersection probability of ~ 1 ($H_0 = 50$) for the ray path from a QSO at $z \approx 2.5$. (It is also similar to the probability of an intervening galaxy halo.) Thus, it is conceivable that some high-excitation absorption-line systems in QSOs might be due to gas in a group like that of NGC 3607. Similarly, the excess Faraday rotation of some QSOs, which Kronberg and Perry (1982) have found to be associated with some strong-absorption QSOs, may be due to such systems. All this presumes that all S0-dominated groups have intergalactic hot gas.

In a similar vein, one can estimate the effect on the microwave background (see, e.g., Sunyaev and Zeldovich 1980). Since we measure the spatial fluctuation of the fractional decrease in temperature of the microwave background, here we again have to consider the random fluctuations of electron temperature of the hot, intergalactic gas, its number density, its scale, and its total cross section to interception. For the relevant numbers of the NGC 3607 group, a comparison with massive clusters shows that groups are likely to have an effect similar to clusters, but on smaller angular scales. Again, this presumes that most groups are like the group considered here.

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