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COULD A LOCAL GROUP X-RAY HALO AFFECT THE X-RAY AND MICROWAVE BACKGROUNDS?

RACHEL A. PILDIS
Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, MS 83, Cambridge, MA 02140; rpildis@cfa.harvard.edu

AND

STACY S. MCGAUGH
Department of Terrestrial Magnetism, Carnegie Institution of Washington, 5241 Broad Branch Road, NW, Washington, DC 20015; ssm@dtm.ciw.edu
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ABSTRACT

Suto et al. have suggested that an X-ray halo in the Local Group might explain both the observed low-energy excess in the X-ray background and the quadrupole anisotropy in the cosmic microwave background. Recent observations of poor groups of galaxies by the *ROSAT* PSPC set reasonable limits on how extensive and dense such a halo could be. The poor groups most similar to the Local Group do not have a detectable halo, and the upper limits of these observations suggest that any Local Group halo would be nearly 2 orders of magnitude too tenuous to produce the effects that Suto et al. discuss. In particular, the Sunyaev-Zeldovich effect cannot contribute significantly to the quadrupole anisotropy measured by *COBE*.

Subject headings: cosmic microwave background — galaxies: clusters: general — Local Group

1. INTRODUCTION

Hot, X-ray–emitting gas is an important component of the gaseous content of the universe. It usually dominates the interstellar medium of elliptical galaxies (Fabbiano 1989; Bregman, Hogg, & Roberts 1992). It also accounts for most of the baryonic mass of rich clusters of galaxies and up to 30% of their total gravitating mass (White et al. 1993; Elbaz, Arnaud, & Böhringer 1995). Such observations led Suto et al. (1996, hereafter SMIO) to suggest that the Local Group of galaxies might have a substantial X-ray halo of its own.

This hypothesized hot intragroup medium (IGM) could contribute much of the excess in the soft (~1 keV) X-ray background. Recent measurements have shown that this excess is well fitted by a thermal model with solar metallicity and a temperature of 0.16 keV (Gendreau et al. 1995). Determining the contributors to the X-ray background is crucial to understanding it. Furthermore, SMIO point out that such a Local Group X-ray halo would produce a significant quadrupole anisotropy in the microwave background through the Sunyaev-Zeldovich (SZ) effect (Zeldovich & Sunyaev 1969). This quadrupole signature, Q_{SZ}, could in principle account for the entirety of the quadrupole signal observed by *COBE*: $Q_{COBE} \approx 6\ \mu$K (see, e.g., Górski et al. 1994; Bennett et al. 1994).

The *COBE* measurement provides a critical constraint on cosmological models. The power spectrum of primordial density fluctuations is usually parameterized as $P(k) = Ak^n$. The spectral index n is a primary component of any cosmological model, with the scale-invariant value $n = 1$ being the preferred "natural" value of inflationary models. The *COBE* observations provide both the normalization A and powerful constraints on n. The *COBE* normalization on large angular scales is far too high relative to the power on smaller (galaxy to cluster) scales for the predictions of the "standard" $n = 1$ cold dark matter model (see, e.g., Fisher et al. 1993). The need for relatively more power on large scales as indicated by *COBE* is a primary motivation for considering contrived models with admixtures of hot as well as cold dark matter. A significant local contribution to Q_{COBE} through the SZ effect would alter the range of viable cosmological models significantly, perhaps even reviving standard cold dark matter. It is therefore very important to place limits on the potential Q_{SZ} of the putative Local Group hot IGM.

Since we are embedded in the hot interstellar medium of the Galaxy, it is exceedingly difficult to disentangle the possible contribution of a hot IGM to the diffuse X-ray background from other, more local sources. However, the Local Group can be placed in the context of observations of other groups of galaxies. While the suggestion of a significant Local Group IGM was made as a parallel to the highly luminous intracluster media of rich clusters, groups provide a more enlightening comparison. With the advent of the *ROSAT* PSPC, many observations of galaxy groups of varying richness have been obtained, so such comparisons can be made.

2. THE IGM IN OTHER GROUPS

While poor groups of galaxies tend to be somewhat more populated and more dense (in projection) than the Local Group, they provide a much better comparison for the X-ray properties of the Local Group than rich clusters. The *ROSAT* PSPC has provided the necessary sensitivity and angular resolution to make a detailed study of the diffuse X-ray emission seen in some galaxy groups. PSPC observations reveal that, in general, X-ray–luminous groups contain more elliptical galaxies than spirals and that the first-ranked galaxy in these groups is an elliptical (Pildis, Bregman, & Evrard 1995; Mulchaey et al. 1996). Very few groups with a spiral majority (the Local Group has no bright ellipticals) have detected X-ray emission, perhaps because of their not being sufficiently compact to contain an IGM or because of the temperature of the IGM being too low for the PSPC to detect.

Since over two dozen galaxy groups have been detected with the PSPC, their properties can be used to constrain models of the possible IGM of the Local Group. The relevant quantities are T, the temperature of the plasma; the column density, which one can parameterize as $n_0 r_c$ (where n_0 is the central

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TABLE 1

DENSITY AND TEMPERATURE PARAMETERS FOR MODEL AND OBSERVED GROUPS

Group	Type	r_c (kpc)	n_0 (cm^{-3})	kT (keV)	x_0/r_c	$n_0 r_c T_{\mathrm{keV}}$ (cm^{-2})
Suto et al.	...	150	1×10^{-4}	1	2.3	4.6×10^{19}
HCG 12	E	45	5.7×10^{-3}	0.72	7.8	5.7×10^{20}
HCG 62	E	60	1.5×10^{-3}	1.1	5.8	3.1×10^{20}
HCG 68	E	33	1.3×10^{-3}	0.98	10.6	1.3×10^{20}
HCG 97	E	8	6.0×10^{-3}	0.97	43.8	1.4×10^{20}
N2300 group	E/S	27	2.8×10^{-4}	0.93	13.0	2.2×10^{19}
HCG 2..............	S	33	$<3.8 \times 10^{-4}$	1	10.6	$<3.9 \times 10^{19}$
HCG 10	S	33	$<4.4 \times 10^{-4}$	1	10.6	$<4.5 \times 10^{19}$
HCG 44	S	33	$<2.2 \times 10^{-4}$	1	10.6	$<2.2 \times 10^{19}$
HCG 79	E	33	$<3.5 \times 10^{-4}$	1	10.6	$<3.6 \times 10^{19}$
HCG 93	S	33	$<5.4 \times 10^{-4}$	1	10.6	$<5.5 \times 10^{19}$

NOTE.—Data from Pildis et al. 1995, and model from SMIO. For the purposes of this comparison, we retain the value of x_0 (Milky Way to group center distance) assumed by SMIO. Group type indicates whether the group is spiral or elliptical dominated; the NGC 2300 group contains one bright galaxy of each type. Groups with upper limits have their core radius and temperature fixed, as discussed in the text.

electron density and r_c is the core radius); and the distance of the Milky Way from the center of the Local Group, x_0. SMIO assumed a Local Group IGM with $T = 1$ keV, $n_0 = 10^{-4}\ \mathrm{cm}^{-3}$, and $r_c = 150$ kpc and assumed $x_0 = 350$ kpc. Table 1 lists the values for these quantities for the groups analyzed by Pildis et al. (1995), as well as the values that SMIO assumed. For the purposes of this comparison, we retain the value of x_0 used by SMIO, as if one were to replace the Local Group IGM with that of the other groups. Three groups in the sample of Pildis et al. (1995) are not included in Table 1 because they are not spatially resolved in the PSPC observations: HCG 4, HCG 92, and HCG 94 (see Pildis et al. 1995 for details). The upper limits assume the typical core radius (33 kpc) and temperature (1 keV) observed in the X-ray–luminous groups and use a calculated central density determined from the 3 σ upper limit on the number of counts within the group radius in their PSPC observations (Pildis et al. 1995). Mulchaey et al. (1996) do not list central densities but find average temperatures of ~1 keV and core radii ranging from 9 to over 300 kpc, with a median value of 43 kpc (excluding the groups from Pildis et al. 1995). Note that the observed groups tend to have smaller values of r_c and greater values of n_0 than SMIO assumed for the Local Group IGM, while the values for T are similar.

Figure 1 shows an expanded version of Figure 4 of SMIO, with the addition of the data presented in Table 1 and SMIO's own model for the Local Group IGM. The theoretical curves follow from equation (9) of SMIO,

$$n_0 r_c = \frac{4f}{\sqrt{5}\pi} Q_{\mathrm{SZ}} \frac{m_e c^2}{\sigma_{\mathrm{T}} kT} \left(\frac{x_0}{r_c}\right) \times \left[\tan^{-1}\left(\frac{x_0}{r_c}\right) - 3\left(\frac{x_0}{r_c}\right)^{-1} + 3\left(\frac{x_0}{r_c}\right)^{-2} \tan^{-1}\left(\frac{x_0}{r_c}\right)\right]^{-1}, \quad (1)$$

where m_e is the electron mass, c is the speed of light, σ_{T} is the Thomson scattering cross section, and k is the Boltzmann constant. There is also a numerical fudge factor f owing to the spherical harmonic multipoles (see eqs. [4] and [5] of SMIO) that SMIO calculate numerically but do not explicitly state. We have adopted $f = 8.7$ to match their curve for $Q_{\mathrm{SZ}} = 6\ \mu\mathrm{K}$. One detected group, HCG 97, does not appear on the graph because of its large value of x_0/r_c. Note that the NGC 2300 group, which is dominated by neither spirals nor ellipticals, has the lowest value of $n_0 r_c T$ of all the detections.

Even the brightest elliptical-dominated groups in the Pildis et al. (1995) sample fall well short of producing the observed

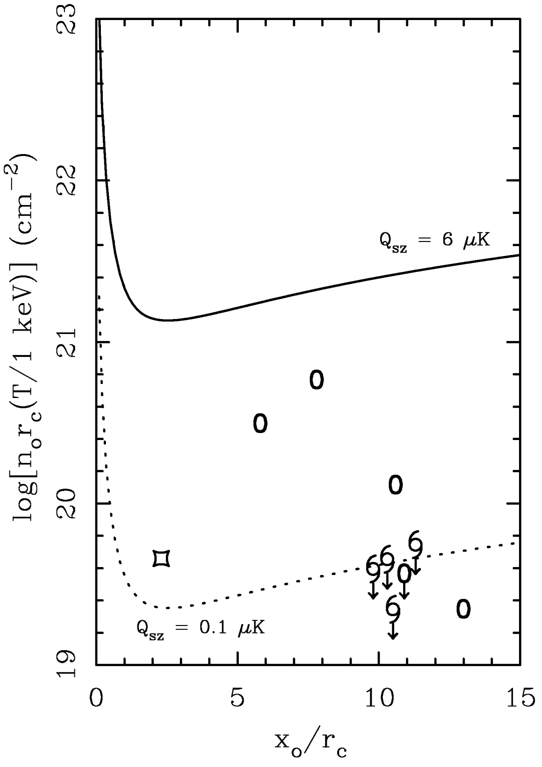

FIG. 1.—The density, size, and temperature of the IGM of poor groups of galaxies analyzed in Pildis et al. (1995) compared to quadrupole anisotropies of the microwave background, after Fig. 4 of SMIO. The 6 μK anisotropy curve is taken from SMIO, and the 0.1 μK curve is a scaled version of the 6 μK curve. Ovals mark elliptical-dominated groups, spirals mark spiral-dominated groups, and downward-pointing arrows indicate upper limits. For clarity, the groups with upper limits are scattered around the assumed value of 10.3 for x_0/r_c. Also shown, as a square, is the Local Group X-ray halo model assumed by SMIO. Note that no groups—even the model of Suto et al.—come close to the 6 μK curve, including those that are richer and more elliptical dominated than the Local Group.

$Q_{COBE} \approx 6$ μK. Also well below the curve, puzzlingly enough, are the IGM parameters assumed by SMIO. It is rather mysterious why they explicitly suggest that "the LG X-ray halo can potentially have a significant effect on the quadrupole of the CMB anisotropies" when their own optimistic estimate of the Local Group parameters give $Q_{\rm SZ} \ll Q_{COBE}$. The maximum quadrupole anisotropy consistent with the spiral-dominated groups appears to be 0.1 μK, a factor of 60 less than Q_{COBE}. So, unless the Local Group is extremely unusual, any hot IGM that it may contain is simply not relevant to the *COBE* quadrupole anisotropy measurement.

3. DISCUSSION

While it is clear that many systematic effects come into play in determining the characteristics of an IGM from an X-ray observation (notably the assumed metallicity of the gas and the background level of the observation; see Mulchaey et al. 1996 for an enlightening discussion), these effects could change the core radius and central density fitted to these groups by no more than a factor of a few and likely much less. The temperatures of galaxy groups are well determined to be close to 1 keV on average. With the further observation that the Local Group is less populated and more diffuse than even the average *undetected* spiral-dominated group, it appears extremely unlikely that a Local Group IGM could produce a significant fraction of the *COBE* quadrupole anisotropy.

Perhaps a more plausible source for the soft excess in the X-ray background is a combination of the probable X-ray halo of the Milky Way plus emission from the Local Superbubble. Previous studies of the 1/4 and 3/4 keV X-ray backgrounds point toward their origination in the Galaxy rather than the Local Group (McCammon & Sanders 1990). Recent observations of X-ray shadowing by high-latitude molecular clouds demonstrate that the 3/4 keV background is dominated by emission from the Local Superbubble, while the 1/4 keV background is likely to arise from a patchy hot halo surrounding the Milky Way (Snowden et al. 1991; Burrows & Mendenhall 1991; Snowden, McCammon, & Verter 1993). A significant fraction of spiral galaxies considered to be similar to our own Galaxy are also seen to have patchy soft X-ray halos (Bregman & Pildis 1994; Vogler, Pietsch, & Kahabka 1996). Since the X-ray emission in spiral-dominated groups is due solely to the component galaxies, there is no reason to expect that a Local Group IGM would be an important component of the local X-ray background.

4. CONCLUSION

In light of the possibly substantial effect a Local Group X-ray–emitting halo could have on the local soft X-ray and microwave backgrounds, as suggested by SMIO, we have considered the X-ray properties of poor groups of galaxies. Sparse, spiral-dominated groups like the Local Group have yet to be detected in X-rays, and even elliptical-dominated groups have low luminosities relative to rich clusters. We therefore conclude the following:

1. Unless the Local Group is exceedingly unusual for groups of its type, it does not have a significant 1 keV X-ray halo.
2. The contribution of any hot gas in the Local Group IGM to the soft (1 keV) X-ray background is negligible. A more important contributor might be hot gas associated with the Milky Way itself.
3. The contribution of a Local Group X-ray halo to the *COBE* quadrupole anisotropy measurement through the Sunyaev-Zeldovich effect is completely negligible: $Q_{\rm SZ} < 0.1\ \mu{\rm K} \ll Q_{COBE} \approx 6\ \mu{\rm K}$.

Since spiral-dominated groups as yet have only upper limits rather than actual detections of their IGM, this upper limit on $Q_{\rm SZ}$ is quite hard unless the Local Group IGM is very exceptional (e.g., comparable to that of a rich cluster of galaxies). Thus, the quadrupole anisotropy measured by *COBE* must represent the true cosmic signature. The level at which this places the normalization of the primordial power spectrum remains an uncomfortable fact that cosmological models must fit.

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