SEARCHING FOR DUST IN THE INTRACLUSTER MEDIUM FROM REDEENING OF BACKGROUND GALAXIES

S. MULLER, 1 S.-Y. WU, 1,2 B.-C. HSIEH, 1 R. A. GONZÁLEZ, 3 L. LOINARD, 3 H. K. C. YEE, 4 AND M. D. GLADDEES 5

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ABSTRACT

We report a search for the presence of dust in the intracluster medium based on the study of statistical reddenning of background galaxies. Armed with the Red-sequence Cluster Survey data, from which we extracted (1) a catalog of 458 clusters with \( z_{\text{clust}} < 0.5 \) and (2) a catalog of \( \sim 90,000 \) galaxies with photometric redshift \( 0.5 < z_{\text{ph}} < 0.8 \) and photometric redshift uncertainty \( \delta z_{\text{ph}} / (1 + z_{\text{ph}}) < 0.06 \), we have constructed several samples of galaxies according to their projected distances to the cluster centers. No significant color differences \( \langle E(B - R) \rangle = 0.005 \pm 0.008 \) and \( \langle E(U - z) \rangle = 0.000 \pm 0.008 \) were found for galaxies in the background to the clusters compared to the references. Assuming a Galactic extinction law, we derive an average visual extinction of \( (A_V) = 0.004 \pm 0.010 \) toward the inner \( R_{200} \) of clusters.

Subject headings: dust, extinction — galaxies: clusters: general — intergalactic medium

1. INTRODUCTION

Zwicky (1951) was the first one to observe a weak and diffuse intracluster light in the Coma Cluster, suggesting the presence of material in the intracluster medium (ICM). The jump in sensitivity of the CCD detectors later allowed intracluster light to be studied more quantitatively (see, e.g., Bernstein et al. 1995; Feldmeier et al. 2002; Zibetti et al. 2005). The existence of an intracluster stellar population has further been clearly established with the detection of planetary nebulae (Arnaud et al. 1996; Feldmeier et al. 1998), red giant stars (Ferguson et al. 1998), and supernovae (Gal-Yam et al. 2003) in the ICM. In parallel, X-ray spectroscopic observations revealed the presence of heavy metals in the ICM (Mitchell et al. 1976; Mushotzky et al. 1996). This ICM matter is commonly believed to originate from stripping and/or disruption of cluster galaxies, and one can then naturally wonder about the existence of dust in the ICM.

It is true that the ICM is a harsh medium, where strong X-ray radiation and gas temperatures of \( \sim 10^7 \) K may impose severe restrictions on the presence of dust. However, the survival time-scale for dust grains in this environment is still of the order of a few \( \times 10^8 \) yr (Draine & Salpeter 1979). Besides, many mechanisms, such as tidal or ram pressure stripping, galactic winds, mass loss from ICM red giants and supergiants, or possible accretion of primordial dust, may contribute to the release or replenishment of dust in the ICM (see, e.g., Popescu et al. [2000], Schindler et al. [2005], and Dominko et al. [2006] for predictions on the efficiency of the different mechanisms).

While there have been many attempts, using various methods, to detect the existence of dust in the ICM (see Table 1), the debate is still open. The methods are mostly twofold, based either on a direct search for dust thermal emission, typically peaking in the far-infrared to submillimeter range, or on an indirect search for extinction and reddenning of background sources.

The direct detection of extended thermal emission in the intracluster medium would constitute the best evidence for the presence of ICM dust. Theoretical predictions of the IR emission have been made (see, e.g., Dwek et al. 1990; Yama1 & Kitayama 2005); taking into account dust injection by galaxies, sputtering, and heating by the hot ICM plasma, they yield a mean dust temperature \( \sim 20–30 \) K and a dust-to-gas ratio \( \sim 10^{-6} \). Annis & Jeffry (1993) could not detect significant emission from a submillimeter search toward 11 clusters with cooling flows, up to a limit of \( \sim 10^8 \) \( M_\odot \). Wise et al. (1993) observed with the Infrared Astronomical Satellite (IRAS) a larger sample of 56 clusters, from which only two may show evidence for extended diffuse emission. Further Infrared Space Observatory (ISO) observations revealed far-infrared (FIR) excess emission toward Coma (Stickel et al. 1998), possibly due to a dust mass of \( \sim 10^7–10^9 \) \( M_\odot \) in the inner 0.4 Mpc region, but none toward five other Abell clusters (Stickel et al. 2002). More recently, Montier & Giard (2005) adopted a statistical approach and co-added IRAS maps of a large number (>11,000) of clusters and detected a significant emission in all four IRAS bands (12, 25, 60, and 100 \( \mu \)m). The origin of the emission, tentatively attributed to ICM dust, is, however, questionable. Indeed, in addition to the challenging detection of low surface brightness and extended emission, IR observations of ICM dust might be affected by contamination from Galactic cirrus (e.g., Wise et al. 1993; Bai et al. 2007), as well as from cluster members (Quillen et al. 1999), dusty star-forming galaxies in clusters (Geach et al. 2006), dust associated with the central dominant galaxies or the presence of a cooling flow (Bregman et al. 1990; Grabelsky & Ulmer 1990; Cox et al. 1995; Edge et al. 1999), or even from background (possibly magnified) galaxies.

The first claim for ICM dust was, nevertheless, historically made by Zwicky (1962), based on the extinction of light from distant clusters by nearby ones. He estimated \( A_V \sim 0.4 \) for Coma. Karachentsev & Lipovetskii (1969) derived a similar value of \( A_V \sim 0.3 \) mag for Coma and found a mean cluster extinction of \( A_V \sim 0.20 \pm 0.05 \) mag by averaging over 15 clusters. Bogart & Wagoner (1973) measured that distant Abell clusters appear to be inversely correlated on the sky with nearby ones. To account for this effect, they argued for an extinction corresponding to \( A_V \sim 0.4 \) mag and extending to \( \sim 2.5 \) times the optical radii of the nearby clusters. However, these first results were probably severely affected by the difficulties of identifying background clusters.
Obvious background sources to search for dust extinction and reddening are quasars. Boyle et al. (1988) measured a value of $A_B = 0.2$ mag ($A_V \sim 0.15$ mag) from a deficiency of ultraviolet-excess-selected objects behind clusters of galaxies. Similarly, Romani & Maoz (1992) concluded that an area-averaged extinction of $A_V \sim 0.5$ mag was required to explain the anticorrelation between quasars and Abell clusters. On the other hand, Maoz (1995) could not measure a significant difference $E(B - V) \leq 0.05$ between the color distribution of radio-selected quasars located within 1° of a foreground Abell cluster, and quasars with no cluster in their line of sight. He reached the conclusion that the apparent deficiency of optically discovered quasars in the background of clusters could be attributed to selection effects, reflecting the difficulty of identifying quasars in crowded fields.

More recently, Nollenberg et al. (2003) proposed what is to our knowledge the first and only search so far of ICM dust based on extinction and reddening of background galaxies. They used a catalog of $\sim 140$ nearby ($z < 0.08$) clusters with $B$ and $R$ photometric data, complete to $B \sim 20.5$ mag and $R \sim 19.5$ mag. For each cluster, they constructed two samples. The cluster sample includes all galaxies lying in a circular region centered on the cluster with an angular radius equivalent to the physical radius of 1.3 Mpc at the distance of the cluster. The second sample, namely, the control sample, contains galaxies projected within a ring of inner radius 1.3 Mpc and of outer radius such that the area covered by the cluster and control samples are identical. The cluster and control samples for all clusters were then, respectively, merged to increase the number of galaxies and improve the statistics. The cluster sample inevitably suffers from contamination of cluster members and foreground galaxies, although Nollenberg et al. (2003) estimate that these latest amount to less than 10% contamination. The cluster and control group galaxies were then distributed in two color-magnitude diagrams (CMDs), and any extinction and reddening of the cluster group was searched by shifting the cluster CMD both in magnitude and color with respect to the control CMD until the two CMDs matched. The pixel resolution (in magnitude and color) of the CMD is constrained by the number of galaxies in each pixel, which should be high enough. Given the number of galaxies in each of their samples ($< 10^5$), Nollenberg et al. (2003) fixed the smallest reasonable pixel size for $\Delta(B - R)$ and $\Delta R$ at 0.025. They could not detect a significant difference between the cluster and control samples, thus yielding upper limits of $A_R < 0.025$ and $E(B - R) < 0.025$ mag ($A_V < 0.044$) for ICM dust.

We note briefly that dust extinction and reddening of background galaxies have been successfully detected in galactic disks (see, e.g., González et al. 1998; Holwerda et al. 2005), in galactic halos (Zaritsky 1994), and recently in the intergalactic medium toward the M81 group (Xilouris et al. 2006). This simple method should become more and more popular with the advent of wide-field cameras on board large telescopes.

Finally, in a very recent paper, Chelouche et al. (2007) claim the detection of reddening of background quasars behind $0.1 < z < 0.3$ galaxy clusters using the Sloan Digital Sky Survey (SDSS) photometric and spectroscopic data. They report $E(g - i)$ of $0.003 \pm 0.002$ from photometry analysis, on one hand, and $0.008 \pm 0.003$ from spectroscopic extinction curve, on the other hand, toward the central $\sim 1$ Mpc of clusters. Assuming a Galactic

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**Table 1: Previous Searches for ICM Dust**

| Method | Targets | Results | Reference |
|--------|---------|---------|-----------|
| Infrared Emission | | |
| Submillimeter (James Clerk Maxwell Telescope) | 11 clusters | No detection | 1 |
| FIR (IRAS) | 56 clusters | Two clusters with some extended | 2 |
| FIR (ISO) | Coma | $0.01 < A_V < 0.2$ | 3 |
| FIR (ISO) | 5 Abell clusters | $A_V \ll 0.1$ | 4 |
| Co-addition of IRAS data | 11,507 clusters | Statistical detection | 5 |

| Extinction and/or Reddening of Background Sources | |
|---------------------------------|--------|
| Background clusters................. | Coma |
| Background clusters................ | 15 clusters |
| Background QSR .................. | Abell clusters |
| Background UVX objects.......... | Rich Abell clusters |
| Background QSR .................. | Abell clusters |
| Background SDSS QSR ........... | $\sim 10^4$ SDSS clusters |
| Background galaxies ................ | 140 APM clusters |
| Background galaxies ................ | 458 RCS clusters |

| Other Methods | |
|------------------|--------|
| Redshift asymmetry and color-velocity correlation | Nearby galaxy groups |
| Ly$\alpha$/H$\alpha$ ratio | 10 cooling flow clusters |
| $Mg_2$ vs. $B - V$ correlation | 19 nearby clusters |

**References**—(1) Annis & Jewitt 1993; (2) Wise et al. 1993; (3) Stickel et al. 1998; (4) Stickel et al. 2002; (5) Montier & Giard 2005; (6) Zwicky 1962; (7) Karachentsev & Lipovetskii 1969; (8) Bogart & Wagoner 1973; (9) Romani & Maoz 1992; (10) Boyle et al. 1988; (11) Maoz 1995; (12) Chelouche et al. 2007; (13) Nollenberg et al. 2003; (14) this work; (15) Girardi et al. 1992; (16) Hu 1992; (17) Ferguson 1993.
extinction curve (Schlegel et al. 1998), this converts to \( A_V \sim 0.005 \pm 0.003 \) and 0.013 \pm 0.004, respectively. The reference quasars were taken at large projected distances (>7 Mpc) from the cluster centers. Their measurement of average reddening at different radial annuli seems to indicate both a large covering factor and a large-scale distribution of dust, up to 5–6 Mpc.

In the present paper, we propose to address the question of the presence of dust in the ICM by studying the statistical reddening of galaxies located in the background of clusters, as compared to a reference sample of galaxies located away from the line of sight to clusters. We have constructed the samples based on the cluster and galaxy catalogs from the Red-sequence Cluster Survey (RCS; Gladders & Yee 2005) using galaxy photometric redshifts. In § 2, we briefly describe the RCS data and present our galaxy sample selection and analysis. Our results are discussed in § 3, and a summary is given in § 4.

## 2. DATA AND DATA ANALYSIS

### 2.1. The Red-Sequence Cluster Catalog

The Red-sequence Cluster Survey (RCS; Gladders & Yee 2005) made use of both the Canada-France-Hawaii Telescope (CFHT) and the Cerro Tololo Inter-American Observatory to cover a total sky area of \( \sim 90 \text{ deg}^2 \) in the \( R_C \) (6500 Å) and \( z' \) (9100 Å) bands. We hereby consider only the CFHT RCS data that overlap the CFHT follow-up observations in the \( B \) and \( V \) bands presented in Hsieh et al. (2005), briefly described below in 2.2. The intersection of the \( B, V, R_C, \) and \( z' \) data results in a total of \( 33.6 \text{ deg}^2 \) over 10 different fields (see Table 2), located at high Galactic latitude (\( > 40^\circ \)) to minimize Galactic extinction.

The RCS was originally designed to obtain a large sample of galaxy clusters up to redshift \( z \sim 1.4 \), using the cluster red-sequence method (Gladders & Yee 2000). In this method, clusters are identified as density enhancements in the four-dimensional space of position, color, and magnitude. Red-sequence models provide cluster photometric redshifts for which a comparison with spectroscopic data shows that the accuracy is typically better than 0.05 over the redshift range \( 0.2 < z < 1.0 \).

In total, the RCS cluster catalog includes \( \sim 4000 \) identified clusters with redshift \( 0.2 < z < 1.4 \), each listed with position, redshift, size, and richness (see Gladders & Yee 2005). The cluster size is defined by the \( R_{200} \) radius, within which the average galaxy density is 200 times the critical density. The cluster richness is estimated through the amplitude of the cluster galaxy correlation function Bgc. This parameter basically traces the excess galaxy counts around a reference point (e.g., the center of a cluster), giving a luminosity function and a spatial distribution for galaxies, and is known to be a robust quantitative measurement of the cluster richness (see Yee & Lopez-Cruz [1999] for a detailed discussion of the Bgc parameter). For this study, we extracted only clusters with \( z_{\text{clust}} < 0.5 \) and \( \text{Bgc} > 200 \), the typical uncertainty in Bgc for RCS clusters is 150–200, and the average Bgg (i.e., the galaxy-galaxy correlation amplitude computed by picking any random galaxy) is about 60.

The RCS cluster catalog is not complete for nearby clusters (i.e., \( z < 0.2 \)), due to the choice of the \( R_C \) and \( z' \) filters, optimized to find clusters at higher redshift. We have used the MaxBCG cluster catalog issued by the SDSS, recently published by Koester et al. (2007), to check the apparent surface covered by SDSS nearby clusters (0.05 \( < z < 0.35 \)) with respect to RCS data. Seven out of the 10 RCS patches overlap the SDSS, and we found a total of 41 SDSS clusters within these limits. By fixing a typical size of \( 5' \) (in radius) for each cluster, we estimate that the coverage of these nearby clusters represents a surface area less than 4% of the corresponding RCS data. We therefore neglect the contamination by nearby \( (z < 0.2) \) clusters in our study.

### 2.2. Photometric Redshifts

Additional photometric data were obtained in the \( V \) and \( B \) bands with the CFHT for some part of the RCS fields. The intersection of \( B, V, R_C, \) and \( z' \) data covers a total \( \sim 33 \text{ deg}^2 \), with limiting magnitudes of 23.9 in \( z' \) (AB), 25.0 in \( R_C \) (Vega), 24.5 in \( V \) (Vega), and 25.0 in \( B \) (Vega). The four-band photometry data, corrected for Galactic extinction, were used by Hsieh et al. (2005) to derive photometric redshifts for \( \sim 1.2 \) million galaxies, using an empirical quadratic polynomial-fitting technique with spectroscopic redshifts for 4924 galaxies in the training set. However, since then more spectroscopic data became available for the RCS fields, which can be added to the training set. In particular, the DEEP2 DR2\(^6\) provides 4297 matched spectroscopic redshifts in the range 0.7 \( < z < 1.5 \). The new training set not only contains almost twice as many objects compared to the original one, but also provides a much larger sample for \( z > 0.7 \), i.e., a better photometric redshift solution for high-redshift objects. Besides having a larger training set, we also used an empirical third-order

### Table 2

| Patch      | R.A. (J2000.0) | Decl. (J2000.0) | Area\(^a\) (deg\(^2\)) | Number of Selected Clusters\(^b\) | Number of Selected Galaxies\(^c\) |
|------------|----------------|----------------|------------------------|-------------------------------|-------------------------------|
| RCS 0226   | 02 26 07.0     | +00 40 35      | 3.99                   | 64                            | 11,119                        |
| RCS 0351   | 03 51 20.7     | −09 57 41      | 4.30                   | 52                            | 1,679                         |
| RCS 0926   | 09 26 09.6     | +37 10 12      | 4.85                   | 70                            | 18,731                        |
| RCS 1122   | 11 22 22.5     | +25 05 55      | 4.72                   | 74                            | 9,154                         |
| RCS 1328   | 13 27 41.9     | +29 43 55      | 1.34                   | 24                            | 1,023                         |
| RCS 1416   | 14 16 35.0     | +53 02 26      | 3.04                   | 40                            | 12,056                        |
| RCS 1449   | 14 49 26.7     | +09 00 27      | 2.01                   | 21                            | 5,913                         |
| RCS 1616   | 16 16 35.5     | +30 21 02      | 4.16                   | 48                            | 14,142                        |
| RCS 2153   | 21 53 10.8     | −05 41 11      | 2.96                   | 38                            | 9,573                         |
| RCS 2318   | 23 18 10.7     | −00 04 55      | 2.23                   | 27                            | 6,940                         |
| Total      |                |                | 33.60                  | 458                           | 90,330                        |

\(^{a}\) Area with data in the \( B, V, R_C, \) and \( z' \) filters.

\(^{b}\) Clusters with \( z_{\text{clust}} < 0.5 \) and \( \text{Bgc} > 200 \).

\(^{c}\) Galaxies with \( 0.5 < z_{\text{ph}} < 0.8 \) and \( z_{\text{ph}}/(1+z_{\text{ph}}) < 0.06 \).
polynomial-fitting technique with 16 Kd-Tree cells for the photometric redshift estimation, allowing a higher redshift accuracy and giving a rms scatter less than 0.05 for \( \delta z_{\text{ph}} \) within the redshift range 0.2 < \( z < 0.5 \) and less than 0.09 for galaxies at 0.0 < \( z < 1.2 \). The refined calibration procedure and photometric redshift method will be described in detail elsewhere (B. C. Hsieh et al. 2008, in preparation).

2.3. Sample Selection and Analysis

The goal of our study is to measure any statistical color difference between a sample of galaxies seen in the background of clusters and a reference sample of galaxies presumably not affected by intervening dust. We first extracted only the galaxies with 0.5 < \( z_{\text{ph}} < 0.8 \) (i.e., at redshift larger than that of selected clusters) and \( \delta z_{\text{ph}}/(1 + z_{\text{ph}}) < 0.06 \) (i.e., with good photometric redshift accuracy). A total of \( \sim 90,000 \) galaxies satisfied these criteria. Each galaxy of our RCS subset is defined by its photometric redshift \( z_{\text{ph}} \) and \( B, V, R_C \), and \( V-z' \) magnitudes (with the associated uncertainties \( \delta z_{\text{ph}}, \delta B, \delta V, \delta R_C \), and \( \delta z' \)).

Our samples were built by using a Monte Carlo method, to take into account the redshift and photometric uncertainties. We repeated the process explained hereafter 100 times. Before checking its line of sight, we replaced any given galaxy by a “new” galaxy with

\[
\begin{align*}
z_{\text{ph}} & \rightarrow z_{\text{ph}} + G(\delta z_{\text{ph}}), \\
i - j & \rightarrow [i + G(\delta i)] - [j + G(\delta j)],
\end{align*}
\]

where \( i \) and \( j \) are any two filters taken from \( B, V, R_C, \) and \( z' \) and \( G(x) \) is a random value following a Gaussian distribution with standard deviation \( x \). Two independent colors, \( B - R_C \) and \( V - z' \), were derived.

The line of sight to each galaxy was investigated by checking against the positions of all clusters in our RCS cluster subset. We constructed five samples, containing all galaxies with redshifts such that \( z_{\text{ph}} < 0.3 \) and located at projected distances \( l < R_{200} \) (sample \( a \)), \( l \in (1 - 2)R_{200} \) (sample \( b \)), \( l \in (2 - 3)R_{200} \) (sample \( c \)), \( l \in (3 - 4)R_{200} \) (sample \( d \)), and \( l \in (6 - 7)R_{200} \) (sample \( e \)), respectively, from a cluster center. A bootstrap technique ([Efron 1979]) was applied to rebuild each sample by randomly picking out \( N \) times a galaxy among the \( N \) galaxies of the sample. Each “new” sample was further binned in each color with a bin resolution of \( \delta = 0.05 \) mag. Figure 1 illustrates the redshift and color distributions obtained for one given Monte Carlo + bootstrap realization. We finally checked any color difference between two samples by progressively shifting the color distribution of one relative to the other by a bin offset \( \Delta \) (where \( \Delta \) is an integer) and calculating the value

\[
\chi(\Delta) = \sum_i \left[ \text{sample1}(i - \Delta) - \text{sample2}(i) \right]^2.
\]

The color difference \( \Delta_{\text{col}} \) between the two samples was then assumed to be the minimum value for \( \chi(\Delta) \) (i.e., that for which the two samples are most similar), calculated as

\[
\Delta_{\text{col}} = \frac{\sum \Delta \delta / \chi(\Delta)}{\sum \Delta^2 / \chi(\Delta)}.
\]

In practice, we limited the shifts \( \Delta \) between -10 to +10 bins, thus exploring a color difference range -0.5 to +0.5 mag. For each Monte Carlo realization, we performed a total of 100 bootstrap runs, which allowed us to derive a statistical dispersion associated with \( \Delta_{\text{col}} \).

The combination of Monte Carlo + bootstrap techniques allowed us (1) to take into account the redshift and photometric uncertainties and (2) to derive the average color differences between the samples, with their associated dispersion. To give some numbers, we counted \( \sim 8000 \) galaxies in sample \( a \), \( \sim 23,000 \) in sample \( b \), \( \sim 36,000 \) in sample \( c \), \( \sim 47,000 \) in sample \( d \), and \( \sim 73,000 \) in sample \( e \). The final results for the color differences between the various samples are presented in Table 3.
3. DISCUSSION

Our results indicate that there is statistically no color difference between the samples of background galaxies seen behind the inner part of clusters (within $R_{200}$) and in the periphery up to $(6–7)R_{200}$. We emphasize that while the color differences are derived from independent filter pairs with independent calibration, the results in columns (2) and (3) of Table 3 are all consistent with no reddening, given the uncertainties. Assuming a Galactic extinction law, we convert the $E(B - R_C)$ and $E(V - z^*)$ values into visual extinction, $A_V$, from the following relations: $A_V = 1.9E(B - R_C)$ and $A_V = 1.9E(V - z^*)$ (taking the coefficients from Schlegel et al. 1998) and calculate the weighted average of the two independent values (col. [4] in Table 3). We end up with a visual extinction of $\langle A_V \rangle = 0.004 \pm 0.010$ when comparing the sample of galaxies projected within $R_{200}$ and the reference sample of galaxies projected at $(3–4)R_{200}$ away from the cluster centers.

The relation between the total mass of intracluster dust, $M_d$, and average visual extinction, $A_V$, within a radius $R_{\text{clus}}$ can be expressed as (Whittek 1992)

$$ M_d = \frac{16\pi}{9} \frac{A_V}{1.086 Q_{\text{ext}}} \rho_d R_{\text{clus}}^2, $$

where the dust grains are characterized by their radius $r_d$ ($\sim 0.1 \mu m$), mass density $\rho_d$ ($\sim 1$ g cm$^{-3}$), and extinction efficiency factor $Q_{\text{ext}}$ ($\sim 2$). The values given in parentheses are characteristic of standard silicate grains (Hildebrand 1983). There is, however, no guarantee that ICM dust grains have similar properties. Should there be dust with such properties uniformly distributed within $R_{\text{clus}} \sim 1.5$ Mpc (roughly corresponding in average to $R_{200}$) from the cluster center, the $3 \sigma$ upper limit on $A_V$ would yield a dust mass of $M_d \sim 8 \times 10^7 M_\odot$.

Chelouche et al. (2007) have recently claimed the detection of ICM dust by studying both the photometric and spectroscopic properties of background quasars at different projected distances from galaxy clusters, using SDSS data. They report reddening of a few $10^{-3}$ mag over large scales up to $(6–7)R_{200}$. The slight difference with respect to our results could be attributed either to systematic errors or to the fact that they used relatively closer clusters $0.1 < z < 0.3$. Despite a larger number of background sources in our data, our error bars are about 2–3 times larger. This could be explained by the fact that the color distribution of quasars is narrower than that of galaxies. Indeed, under a Gaussian probability distribution, the uncertainty on the mean can be expressed as $\sigma/\sqrt{N}$, where $\sigma$ is the dispersion of the distribution and $N$ is the number of elements. The dispersion in color is $\sim 0.5$ for SDSS quasars (see, e.g., Richards et al. 2001) and $\sim 2$ for our galaxy sample (Fig. 1). Therefore, with $N = 8000$ background galaxies in our sample a and $N = 3000$ background quasars in the Chelouche et al. (2007) study, we naturally end up with uncertainties $\sim 2.5$ times larger in our case. The one way to improve our results would then be to significantly increase the number of background galaxies, for example, with a larger survey. We note that, within $R_{200}$, we get about 20 background galaxies per cluster, whereas Chelouche et al. (2007) count a total of about 3000 quasars for their sample of $10^4$ clusters, i.e., on average, less than one background quasar per cluster.

Given the uncertainties associated with those measurements, it is still difficult to reach a definite conclusion about the presence of dust in the intracluster medium. All the studies based on the measurement of reddening of background sources (cf. Maoz 1995; Nollenberg et al. 2003; Chelouche et al. 2007; this work) agree with null or very small average reddening, in contrast to previous counts of background clusters or quasars (Table 1), which were probably severely affected by selection effects. At infrared or submillimeter wavelengths, on the other hand, only the combination of high angular resolution and sensitivity might help to clarify the claimed detection by Stickel et al. (1998) and Montier & Giard (2005). Still, the task will not be eased by the large angular size of galaxy clusters, as, e.g., emission from diffuse and extended ICM dust might be filtered out by interferometers.

4. SUMMARY AND CONCLUSIONS

In this paper, we report a search for the presence of dust in the intracluster medium. Our method relies on the statistical measurement of the color differences between galaxies located in the background of a cluster and reference galaxies. We take advantage of data acquired with the CFHT in the frame of the Red-sequence Cluster Survey, providing us with deep and homogeneous catalogs of galaxies and galaxy clusters. For our purpose, a major asset of these RCS data is the availability of photometric redshifts for more than a million galaxies. We extracted 458 clusters up to a redshift of 0.5 and a total of $\sim 90,000$ galaxies, selected for their photometric redshift 0.5 $< z_{ph} < 0.8$ and with photometric redshift uncertainty $\delta z_{ph}/(1 + z_{ph}) < 0.06$. In particular, our selection criteria ensure low contamination by foreground galaxies and cluster members. Special attention was given to the propagation of photometry and photometric redshift uncertainties, which were taken into account by a combination of Monte Carlo and bootstrap methods.

A sample of about 8000 galaxies projected within $R_{200}$ of a cluster is compared to different reference samples composed of galaxies projected at distances 1–2, 2–3, 3–4, and 6–7 times $R_{200}$ from a cluster center. We do not detect significant color differences between the first sample and the different references. Unless intracluster dust extends over scales larger than $\sim 10$ Mpc in radius, we therefore conclude that the dust extinction is statistically low, with visual extinction $\langle A_V \rangle = 0.004 \pm 0.010$ for the 458 RCS clusters with $z < 0.5$, corresponding to an upper dust mass limit of $8 \times 10^7 M_\odot$ within $R_{200}$. Given the uncertainties, our results are consistent with the recent measurements of reddening of background quasars by galaxy clusters from Chelouche et al. (2007).

The ongoing RCS2 survey, extending the RCS coverage to $\sim 1000$ deg$^2$ in four photometric bands with the CFHT MegaCam, will soon be available. The observed sky surface will be multiplied by a factor of 30, providing a much larger number of background galaxies. These new data could allow us to improve our measurements and compare the dust reddening toward clusters with different properties, such as richness, X-ray brightness, or merging activity.

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