MEDIUM-DISTANT CLUSTERS OF GALAXIES SEEN BY ISO

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ABSTRACT

We present a comprehensive study of ISO cluster galaxies in connection with other wavelengths. First results show that infrared galaxies detected by ISO-CAM concentrate on the edge of clusters. Surprisingly, they are not emission lines galaxies but very luminous elliptical, merging or interacting ones, which suggests non-trivial connections between star formation rate, optical and mid-IR properties. However, no correlation has been found between the MIR/optical star formation properties of the galaxies, so that the exact origin of the IR emission remains unclear.

Key words: ISO; infrared astronomy; galaxy clusters.

1. INTRODUCTION

Until recently, detailed cluster studies were restricted to nearby clusters ($z < 0.1$). Nowadays, new imaging as well as spectroscopic capabilities (visible, X-ray, IR, radio) have considerably improved our view of the distant universe. In this context, we have selected a sample of ten bright objects, expected to be rich clusters, from the ROSAT All Sky Survey (RASS) in the $z = 0.15 - 0.3$ range in order to investigate issues ranging from cluster formation and evolution down to a local phenomenon such as the enrichment of the ICM (Pierre et al. 1994). We have undertaken a detailed high-resolution multi-wavelength follow-up including ROSAT HRI and PSPC, ASCA pointings, radio images at 3, 6, 13, 20 and 36 cm and extensive photometry and spectroscopy in the optical. Seven of them were included in the ISO Central Program (DEEPXSRC, 30 hours, P.I.: C.J. Cesarsky; Collaborator: M. Pierre), in order to study the influence of the environment on the galaxy evolution. We present here the analysis which allowed us to statistically determine properties of IR emitting galaxies in our clusters.

2. OBSERVATIONS

Seven objects extracted from the RASS have been observed by ISO, at 6.75 and 15 $\mu$m with ISO-CAM and at 90 $\mu$m with ISOPHOT. From our X-ray/radio/optical, four clusters turned out to be very rich objects ranging from $z = 0.165$ (Abell 1111) to $z = 0.307$ (Abell 1300), and three objects appeared to be small groups with a central AGN (see Table 1 (Lmonon 1999, hereafter L99). All observations were made with a pixel size of 6 arcsec, and each sky position as observed four times. The various environmental conditions are represented in those seven objects, fully described in several papers, and can be summarized as follow:

- Abell 1300: a post merging cluster containing a radio halo and a relic radio source (Lmonon et al. 1997, Reid et al. 1998)
- RXJ1104-2330: a strong AGN of BL-Lac type possibly embedded in a small cluster or a large group of galaxies (L99)
- Abell 1732 and Abell 1111: two cooling flow clusters respectively large and small (L99)
- RXJ1032-2607: probably a strong AGN in a small group of galaxies (L99)
- RXJ1314-2516: a new very interesting merging cluster of galaxies, containing probably a relic radio source (L99)
- RXJ1315-4236: a more nearby ($z = 0.105$) AGN of BL-Lac type, in a group of galaxies (L99)

3. IR EMISSION IN ISOCAM FILTERS

As discussed by Fadda & Elbaz (1999), the k-correction for distant clusters is a very important point when we look in the mid-IR wavelength. In our redshift range ($0.165 < z < 0.307$), LW2 always includes only the 6.2 $\mu$m Unidentified Infrared Band (UIB) feature, but is more and more (with the redshift) contaminated by the rayleigh-jeans tail of red stars. The LW3 filter is less and less sensitive to the warm dust but is always contaminated by the 11.3$\mu$m UIB feature and the 9.7$\mu$m silicate absorption. Unfortunately, the interpretation of mid-IR properties

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is turning into a maze by this mixity of IR contributions.

4. RESULTS

4.1. What Kind Of Objects Did We Detect ?

First, two third of the objects detected by ISOCAM are optically identified as stars. On about 70 remaining galaxies, since we had optical spectra for 35 of them, we were able to evaluate the contamination by field galaxies. One third of the 35 appeared not to belong to the clusters, so by extrapolation, we expect that some 50 out of 70 are really clusters members. At our depth, 20 fields galaxies on the total area covered by our ISOCAM observation are in a good agreement with deep 15 µm count at 1 mJy from ELAIS (Rowan-robinson et al. 1999). We detect as many galaxies at 6.75 µm as at 15 µm although very few of them are detected in both filters (about 15%). Detected galaxies are bluer (V-I ∼ 1.2) than the mean cluster galaxy (V-I ∼ 1.5, which corresponds to "normal" early-type galaxies at those redshifts) but their spectrum look like elliptical galaxies.

4.2. Radial Distribution Of ISOCAM Galaxies In Clusters

Figure 1 shows the radial distribution of a composite cluster made of all detected galaxies in each cluster. Solid and dotted lines show 6.75 and 15 µm galaxies, respectively, dashed line shows galaxies detected in both bands.

4.3. Galaxies Detected Only At 6.75 µm

This population may be the signature of the rayleigh-jeans tail of an old stars population, as:

1. all cD galaxies are detected, and they are the most luminous galaxies of each clusters,
2. there is likely a correlation between LW2 and I flux (see Figure 3),
3. the mean V-I color (∼ 1.4) is closer of "normal" elliptical galaxy than others detected objects,
4. regarding our 15 µm completeness, we can be sure that most of galaxies detected at 6.75 µm have a 15 µm flux below the 6.75 µm one, excluding intense star formation activity.

Even if many galaxies seen only at 6.75 µm are detected beyond 750 kpc where elliptical galaxy density is much lower than in center, the low total number of them is fully compatible with the statistically normal density of early-type in outskirt regions.

4.4. Galaxies Detected At 15 µm

It is well known that spiral galaxies in clusters are more concentrated in the external regions (Dressler 1984). Figure 1 shows that galaxies detected at 15 µm are preferentially seen beyond 750 kpc, and much more than 6.75 µm ones. Half of them are detected also at 6.75 µm with flux ratio typical of photo-dissociation regions or star formation activity. Their optical colors are bluer than mean cluster galaxies.

Table 1. DEEPXSRC ISOCAM observations. The column are: (1) the object name from the ACO catalogue (Abell et al. 1989) when existing or the ROSAT All Sky Survey number. (2) the redshift of the object. (3) the size of the side of the maximum sensitivity box area. (4) the sensitivity in the LW2 (6.75 µm) CAM filter. (5) the sensitivity in the LW3 (15 µm) CAM filter (RXJ1314-2516 was not observed in the LW3 band).

| Object name | z     | Field of View | LW2  | LW3  |
|-------------|-------|---------------|------|------|
| Abell 1300  | 0.307 | 6.4'          | 500  | 1400 |
| RXJ1104-2330| 0.187 | 6.4'          | 450  | 1000 |
| Abell 1732  | 0.193 | 6.4'          | 400  | 1000 |
| Abell 1111  | 0.165 | 6.4'          | 500  | 1300 |
| RXJ1032-2607| 0.247 | 4.8'          | 750  | 1500 |
| RXJ1314-2516| 0.244 | 4.8'          | 500  | -    |
| RXJ1315-4236| 0.105 | 9.6'          | 750  | 1100 |
Figure 2. The 6.75 µm (µJy) luminosity in function of the I absolute magnitude for objects detected only at 6.75 µm. Four galaxies are well outside the general trend, they must be field galaxies or dusty/star-forming objects.

4.5. Effects Of The Environmental Conditions

It could be a correlation between the number of detect galaxies at 6.75 µm and the X-ray luminosity in the [0.1-2.4 keV] band (L99). Since the X-ray luminosity is related to the richness of the clusters, this corroborates the suggestion of section 4.3, as most LW2 galaxies are luminous early-type galaxies. Other effects of environmental conditions are very hard to point out because of our low statistic (between 4 and 15 galaxies detected by ISOCAM per cluster).

4.6. Optical Correlations With Star-Forming Galaxies

In the course of our optical follow-up, we have discovered that detected ISOCAM galaxies in medium distant clusters (at a sensitivity of ~ 1 mJy) are not emission lines galaxies but very luminous elliptical, merging or interacting ones, which suggests non-trivial connections between star formation rate, optical and mid-IR properties (see Figure [3]). However, the spectral resolution at which the redshift of these galaxies were measured (15 Å) does not allow us to identify any peculiar signature in the optical spectra of these objects, so that the exact origin of the IR emission remains unclear. This observation became a very scheming subject since IR deep surveys claim the existence of a population of galaxies with great IR fluxes in the past (0.6 < z < 1) with no peculiar optical signature (Elbaz et al. 1998, Aussel et al. 1998) and could be a new starting point to the comprehension of the stars formation history.

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Figure 3. Abell 1300, a post-merging cluster [Lemonon et al. 1997, Reid et al. 1998]. On the R band image taken on the CFHT are overlaid in red contours X-ray [0.1-2.4 keV] PSPC levels (8.3×10^{-4}, and 1.8×10^{-3} to 6×10^{-2} by step of 5.76×10^{-3} counts/s/arcmin^2) and in green radio (1.4 GHz) ATCA levels (0.2, 0.3, 0.5, 0.9, 1.6, 3.2 and 6 mJy/beam). It confirms that detected ISOCAM galaxies (in magenta and blue for respectively 6.75 µm and 15 µm bands, circle for galaxies and squares for point-like objects, with size proportional to emitting fluxes) in clusters above a limited flux are not galaxies with emission lines but very luminous elliptical, merging or interacting galaxies [Pierre et al. 1996]. Line-emitting galaxies are pointed by the "RAIES" label. Abell 1300 contains the most distant radio halo known (A4) and a relic radio source (B3). This is one out of our seven objects, others are available in L99.