THE ABELL 2163 SPECTRUM FROM INFRARED TO MILLIMETRE WAVELENGTHS

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ABSTRACT

We have compiled far infrared to millimetre observations of the Abell cluster A 2163. The signal is essentially composed by two astrophysical components. The Sunyaev-Zel'dovich (SZ) effect emission due to the inverse comptonization of the cosmic microwave background photons by the hot intracluster gas and the dust emission due to galactic, intracluster or background point sources dust. The SZ effect has been detected at submillimetre wavelengths for the first time with the PRONAOS telescope. We compiled this measurement with millimetre wavelengths measurements achieved with the SuZIE and the DiaBolo photometers. The dust component has been observed with ISOPHOT at 90 and 180 μm. The whole data set has been homogenized to the PRONAOS observations to draw for the first time the spectrum of a galaxy cluster from far infrared to millimetre wavelengths. It appears that the far infrared measurements were needed to constraint the dust emission and to remove its residual contribution from the signal at longer wavelengths. This allows us to determined the peculiar velocity of the cluster with a better accuracy than previous works.

Key words: cosmology: observation; galaxy: clusters; ISOPHOT.

1. INTRODUCTION

The inverse Compton scattering of the cosmic microwave background (hereafter CMB) by the electrons of the hot intracluster gas produces a shift of the CMB photons at higher energies. This effect, called the Sunyaev-Zel'dovich effect (hereafter SZ effect, Sunyaev & Zel'dovich 1972), makes the CMB spectrum decreasing at centimetre and millimetre wavelengths and increasing at submillimetre wavelengths.

We have selected five clusters as targets for multi-wavelengths observations. We planed to observed them from far infrared to millimetre wavelengths. These clusters have been selected according to their X-ray properties. They are all distant, hot and extended sources (see table 1).

The far infrared observations have been carried out with the ISO satellite, the submillimetre one with the balloon borne experiment PRONAOS and the millimetre one using the DiaBolo spectrophotometer.

2. ISO OBSERVATIONS

We have obtained 24 ksec observing time within two programs (GSERRA.SZCLUSTS and MGIARD. SZCLUSTS) with the PHOT instrument on board the ISO satellite. This has provided us the maps at 90 μm and 180 μm of each five clusters. The data reduction was performed with the PIA-7.01 software.

Because the targets have not been selected according to the dust emission level in their direction, some of them present a strong dust emission with strong gradients (see Figure 1).

The first goal of this program was to characterize the dust emission in the direction of these clusters to remove it from the signal at submillimetre and millimetre wavelengths. This should allow us to perform a better analysis of the SZ data. Nevertheless, we have use these data to look for a possible far infrared emission intrinsic to the intracluster medium. We have roughly subtracted the galactic component by fitting a five order polynomial to the ISO map. We have subtracted the eventual sources (as in the case

Table 1. Galaxy cluster targets

	A478	A2142	A2218	A2163	CL0016 +16
z	0.088	0.089	0.171	0.201	0.545
T_g (keV)	6.6	8.7	7.0	13.0	9.9
θ_c (′)	1.9	4.2	1.0	1.2	0.8

"ISO Beyond Point Sources: Studies of Extended Infrared Emission", Madrid, Spain, 14-17 Sep 1999 (ESA SP-455, April 2000)

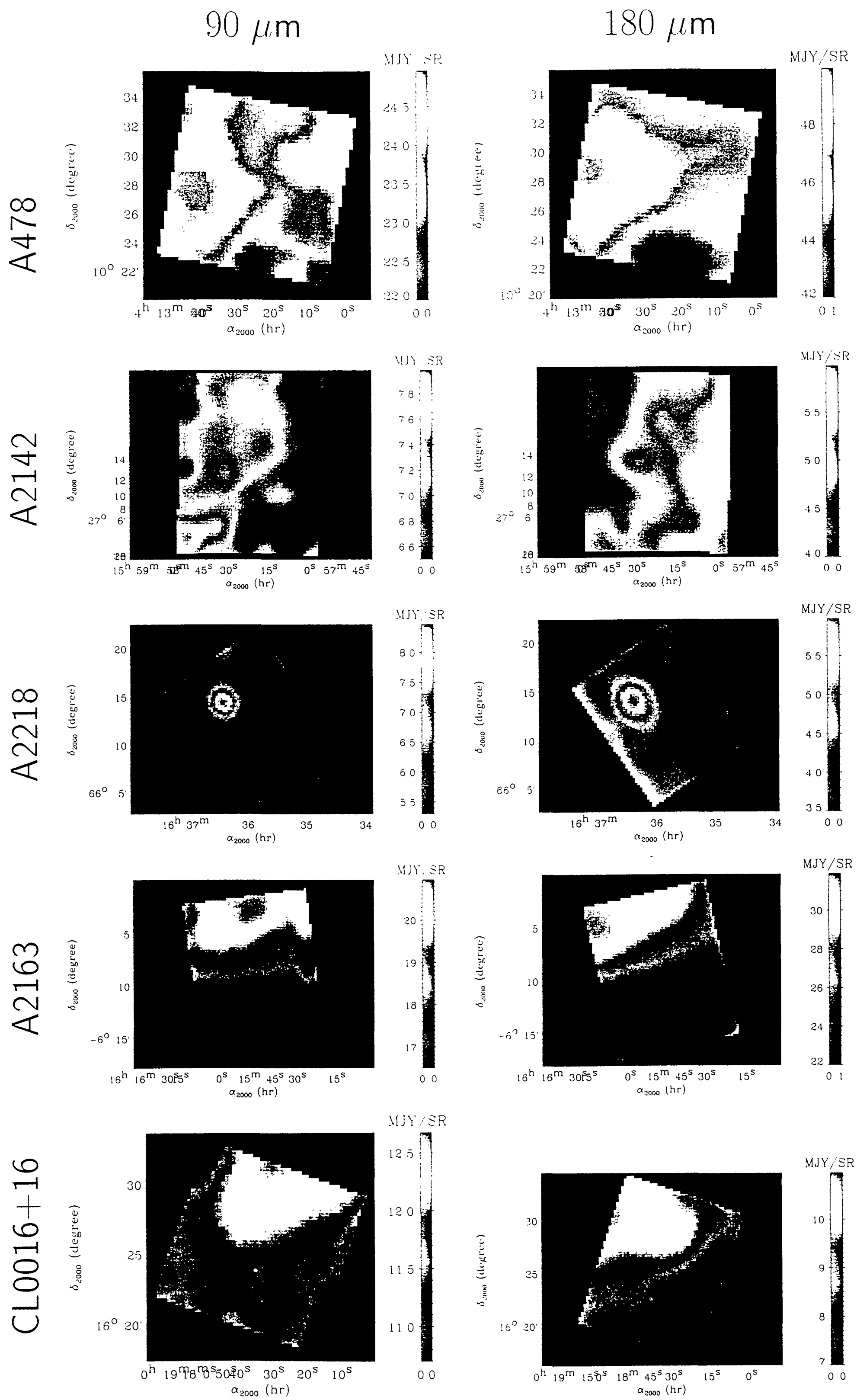

Figure 1. 90 μm and 180 μm ISOPHOT maps of the selected clusters.

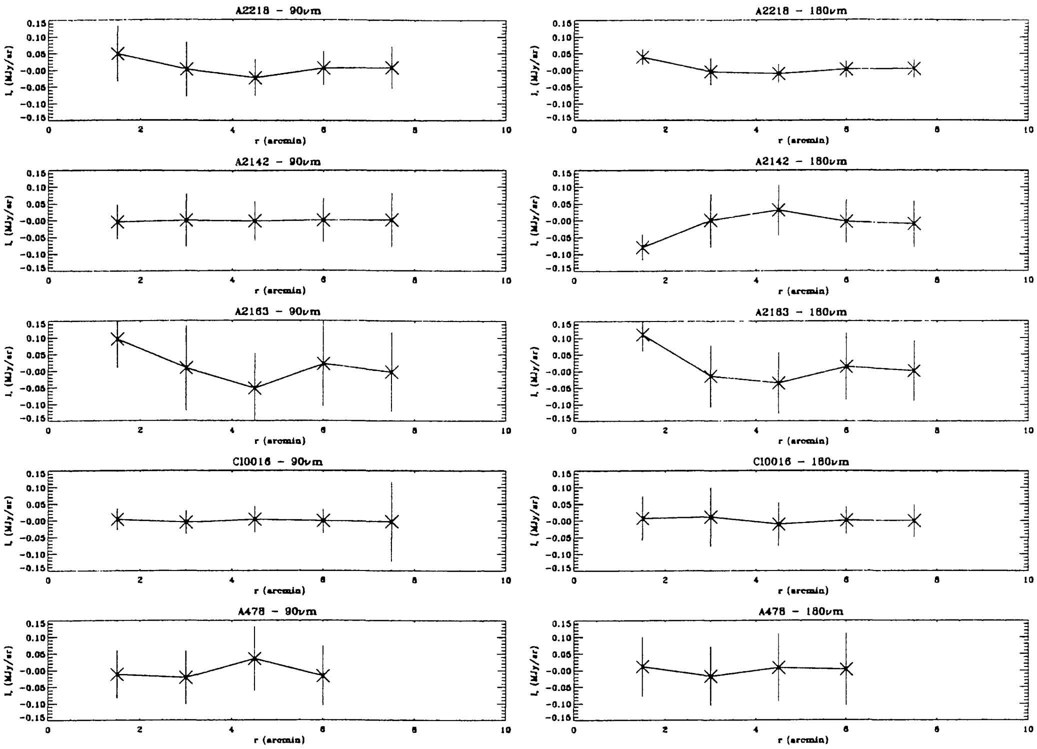

Figure 2. radial profiles at 90 μm and 180 μm obtained from the ISOPHOT maps after the subtraction of the galactic dust emission and of the point sources contribution (see test.). The 68% confidence level error bars have been overplotted on each profile.

of A 2218). We have finally computed a radial profile of each cluster at 90 and 180 μm (see Figure 2).

As shown on Figure 2, the profiles of A 2163 and A 2218 exhibit a small excess of signal at the two wavelengths. Unfortunately, taking into account the uncertainties that remains on the PHOT data analysis, and despite of this two marginal but uncertain detections, we have not detected any significant intracluster dust emission in the direction of these five clusters.

3. MULTI-WAVELENGTH ANALYSIS

We have attempted to detect the SZ effect in the direction of the five clusters using the PRONAOS submillimetre telescope. Unfortunately we have only detected an SZ effect signal in the direction of A 2163. We will now focus on this detection. All the results presented bellow have already been published by Lamarre et al. (1998).

A 2163 is a well studied massive cluster located at $z = 0.201$, which has one of the hottest known intracluster gas temperature ($T_e = 12 - 15keV$, Elbaz et al. 1995 and Markevitch et al. 1996). This cluster is a very attractive candidate for measurements of the SZ effect.

3.1. The PRONAOS measurements

The SZ effect measurements on the A 2163 line of sight at submillimetre wavelengths have been achieved with the balloon borne stratospheric telescope PRONAOS during a stratospheric flight from Fort Sumner (NM, USA) on September the 22nd and 23rd, 1996 and correspond to 2 hours of observing time. PRONAOS has a 2-metre 6-elements segmented primary mirror. SPM is the detector on board. It is a four channels photometer which uses bolometers cooled to 0.3 K (^{3}He coolers inside a liquid ^{4}He cryostat). The optical scheme uses dichroics so that a single direction on the sky is observed in the four channels simultaneously. The warm optics provide the sky modulation and internal regulated black-body calibrators. The SPM characteristics are gathered in Table 2 (Lamarre et al. 1994).

3.2. Far-infrared measurements

We have had to the 90 μm and the 180 μm ISOPHOT the IRAS 100 μm measurements. To obtained a consistent data set, we have homogenized this data to the 630 μm PRONAOS measurements with a 3.′5 beam and a 6′ beamthrow. The PRONAOS observing sequences have also been reproduced on the ISO and the IRAS-ISSA maps to correct from the difference of beam sizes and from the modulation amplitude effects (see Figure 3).

Table 2. Technical characteristics of the multiwavelengths spectrophotometer, SPM, on board the PRONAOS telescope.

λ_c (μm)	205	290	390	630
λ μm	170-240	240-340	340-540	540-1050
θ (arcmin)	2.0	2.0	2.5	3.5
NEB (MJy sr^{-1}) (1σ, 1 hour)	1.0	0.58	0.17	0.06

3.3. Millimetre data

A 2163 was already observed at millimetre wavelengths by two experiments. The SuZIE instrument on the CSO telescope is working at 1.1, 1.4 and 2.1 mm with a 1.′9 beam and a 4.′6 modulation amplitude (Holzapfel et al. 1997). The DiaBolo photometer on the 30 m IRAM telescope is working at 2.1 mm with a 0.′5 beam and a 3′ beamthrow (Désert et al. 1998). The Diabolo and SuZIE data have been corrected for the differences of beam sizes and modulation amplitudes, to be compared with PRONAOS data, assuming a King profile for the intracluster gas density:

$$n_{gas} = n_e \times \left[1 + \left(\frac{r}{r_c}\right)^2\right]^{-\frac{3}{2}\beta} \qquad (1)$$

where r_c, the cluster core radius, corresponds to a projected angle $\theta_c = 1.2'$ and $\beta = 0.62$ according to Elbaz et al. (1995).

4. MODELLING THE SIGNAL

Figure 4 shows the A 2163 spectrum from far infrared to millimetre wavelengths. This spectrum shows clearly the two different components of the signal. The dust emission from far-infrared to submillimetre wavelengths is traced by the ISO, the IRAS

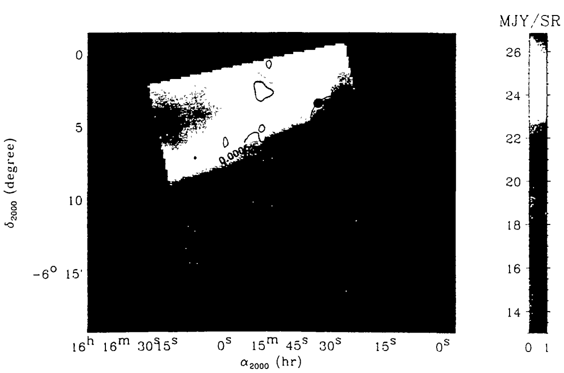

Figure 3. Positions observed with PRONAOS overlaid on the 180 µm ISOPHOT map and the X-ray ROSAT PSPC contours. The dots show the centers of the 5 observed positions (Cluster plus left and right beams at the same elevation), and the circles show the PRONAOS 3.′5 beam FWHM at 630 µm.

and the 390μm PRONAOS measurements. The positive SZ effect signal has been detected in the 630μm PRONAOS and in the 1.1 mm SuZIE bands. The negative side has been measured at 2.1 mm by SuZIE and DiaBolo. The kinetic SZ effect is dominant at 1.4 mm in the SuZIE band, where the thermal SZ effect level is close to zero. The whole data set has been fitted with a simple SZ plus dust spectrum:

$$\begin{aligned} I_{\nu_i} &= F(180\mu m)\nu_i^{n_d} B_{\nu_i}(T_d) \\ &+ y f_i \times \left(SZ_{th}(T_e, \nu_i) + \frac{v_p}{T_e} SZ_{kin}(\nu_i)\right) \end{aligned} \qquad (2)$$

The four free parameters are : y the comptonization parameter in the direction of the cluster center; v_p the peculiar velocity of the cluster; $F_{dust}(180\mu m)$ the level of dust emission at 180 μm: and T_d the dust temperature (The dust emissivity index being fixed to $n_d = 2$ according to Boulanger et al. 1996). We have assumed an intracluster gas temperature of 13 keV (Elbaz et al. 1995, Markevitch et al. 1996) and used an exact relativistic thermal SZ spectrum as calculated by Pointecouteau et al. (1998). f_i is a dilution factor which takes into account the cluster brightness distribution on the sky and the beam profile.

The best fit values for the four parameters with 68% confidence errors, are: $y_c = (3.42^{+0.41}_{-0.46}) \times 10^{-4}$; $v_p = 975^{+812}_{-971}$ km s^{-1} (cluster moving away from us): $F_{dust}(180) = 1.00^{+0.09}_{-0.16}$ MJy sr^{-1}: and $T_{dust} = 14.8^{+1.0}_{-1.0}$ K.

First of all, the three SZ measurements are performed with different beam sizes (0.′5, 1.′9 and 3.′5). They are consistent with the density profile derived from X-ray data for angular scales ranging from 0.4 to 5 core radii. In a second time, we have obtained an estimation of the cluster peculiar velocity. The large error bars associated to this determination can be explained by the difficulty to extract the SZ kinetic signal from the whole signal. Our value of v_p can be compared to the value derived by Holzapfel et al. (Holzapfel et al. 1997) from the analysis of the SuZIE data: $v_p = 490^{+910}_{-730}$ km s^{-1}. Our value is two times the SuZIE value despite of the However in their analysis the authors assumed a zero dust emission level. The hight level and the strong gradient of the dust emission in the direction of A 2163 do not argue in favor of this hypothesis. Some galactic dust emission is present at millimetre wavelengths and must be subtracted before to determine the peculiar velocity of the cluster.

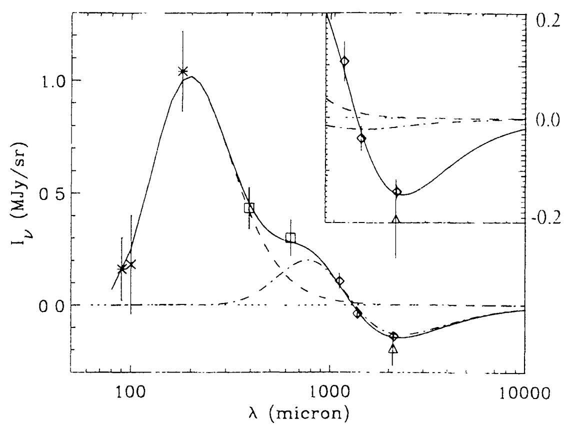

Figure 4. Far infrared to millimetre brightness difference between the cluster of galaxies A 2163 and its surroundings, using data from ISOPHOT (∗). IRAS (×), PRONAOS (□), SuZIE (◇). Diabolo (△). All values have been corrected to be homogeneous with the PRONAOS dilution (3.'5 beam, 6' beamthrow). The solid line shows the best fit of the model including dust (dash line), positive and negative parts of the thermal S.Z. effect (dash-dot line), and kinetic S.Z. effect (dash-dot line in the insert).

5. CONCLUSION

We have looked for far infrared dust emission from the intracluster medium in the direction of five galaxy clusters. We have not detected any significant signal. Nevertheless, we have pointed out the need of far infrared and submillimetre measurements to constraint the dust emission and to subtract its residual component at millimetre wavelengths. Taking into account the dust emission at millimetre wavelengths is crucial when measuring the kinetic SZ effect. The determinations of the peculiar velocity are strongly dependent of this condition.

We have also presented the first detection of the submillimetre SZ effect in the direction of A 2163, which is a very massive cluster at low galactic latitude. Its case illustrates the kind of problems that will be faced in the near future by the space borne missions such as Planck Surveyor with data sets on more standard clusters (eg: Comptonization parameter $\sim 10^{-5}$) at higher galactic latitudes. Nevertheless, concerning the peculiar velocity, fundamental limitations are induced by the CMB, because it has the same spectrum as the kinetic SZ effect (Haehnelt & Tegmark 1996). Anyway, the constraint put on the dust emission by submillimetre data are needed for CMB data sets analysis too.

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FUTURE PROSPECTS