The Diabolo photometer and the future of ground-based millimetric bolometer devices

Désert, F.–X. [*], Benoît, A., Camus, Ph.[†], Giard, M., Pointecouteau, E.[**], Aghanim, N., Bernard, J.–P., Coron, N., Lamarre, J.–M., Marty, Ph.[‡], Delabrouille, J.[§] and Soglasnova, V.[¶]

[*] *Laboratoire d'Astrophysique de l'Observatoire de Grenoble, 414 rue de la Piscine, BP53, F–38041 Grenoble Cedex 9, France*
[†] *Centre de Recherche sur les Très Basses Températures, 25 Avenue des Martyrs BP166, F–38042 Grenoble Cedex 9, France*
[**] *Centre d'Étude Spatiale des Rayonnements, 9 avenue du Colonel Roche, BP 4346, F–31029 Toulouse Cedex France*
[‡] *Institut d'Astrophysique Spatiale, Bât. 121, Université Paris XI, F–91405 Orsay Cedex, France*
[§] *Physique Corpusculaire et Cosmologie, College de France, 11 pl. Marcelin Berthelot, F-75231 Paris Cedex 5*
[¶] *Space Research Institute, Astrospace Center, Academy of Science of Russia, Profsoyuznaja St. 84/32 117810 Moscow, Russia*

Abstract. The millimetric atmospheric windows at 1 and 2 mm are interesting targets for cosmological studies. Two broad areas appear leading this field: 1) the search for high redshift star-forming galaxies and 2) the measurement of Sunyaev–Zel'dovich (SZ) effect in clusters of galaxies at all redshifts. The Diabolo photometer is a dual-channel photometer working at 1.2 and 2.1 mm and dedicated to high angular resolution measurements of the Sunyaev–Zel'dovich effect towards distant clusters. It uses 2 by 3 bolometers cooled down to 0.1 K with a compact open dilution cryostat. The high resolution is provided by the IRAM 30m telescope. The result of several Winter campaigns are reported here, including the first millimetric map of the SZ effect that was obtained by Pointecouteau et al. (2001) [13] on RXJ1347-1145, the non-detection of a millimetric counterpart to the radio decrement towards PC1643+4631 and 2 mm number count upper limits. We discuss limitations in ground-based single-dish millimetre observations, namely sky noise and the number of detectors. We advocate the use of fully sampled arrays of (100 to 1000) bolometers as a big step forward in the millimetre continuum science. Efforts in France are briefly mentionned.

INTRODUCTION

The atmospheric windows at 1 and 2 mm wavelengths constitute a large opening for ground–based cosmological studies. Continuum observations on large single–dish telescopes (IRAM 30 m, JCMT, CSO, SEST, ...) have already provided outstanding results in that respect. Whereas the search for high redshift galaxies has proved very successful in the near past mostly at 1.2 and 0.8 mm (this conference), we would like here to also emphasize the usufulness of millimetre SZ measurements in the 2.1 mm window by showing the results that have been achieved with the Diabolo instrument[1]. The IRAM 30 m millimeter telescope at Pico Veleta (Spain) provides the highest angular resolution on SZ effect with the combination of the size of the telescope and the operating wavelength, namely about 20 arcsecond at 2 mm. This can be very important for the study of high redshift clusters of galaxies which may not be fully virialized.

One can note that both (sub)millimetric flux of galaxies and the SZ effect brightness (although not for the same reason) share the property of being rather insensitive to their redshift. Hence, number counts can be much more

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[1] More details on the experiment can be found at http://www-laog.obs.ujf-grenoble.fr/desert/diabolo/diabolo.html

sensitive to the luminosity function than to distance effect. The high redshift population of objects can stick out more easily than in other wavelength domains. In particular, when confusion is close, this can be a very important positive leverage to extract the early population from the low redshift crowd.

THE DIABOLO INSTRUMENT

FIGURE 1. One of the 2 arrays of 3 bolometers used in Diabolo. The Winston cones are arranged in a close-packed triangular configuration.

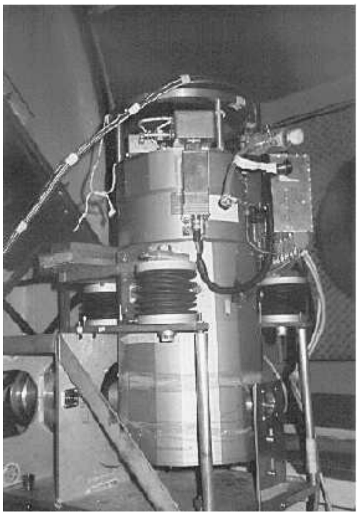

FIGURE 2. Diabolo cryostat in the Nasmisth cabin of the 30m. One can see shock absorbers (black springs) around the cryostat to damp vibrations coming from cryocoolers in the same cabin. The electronics box is on the upper right.

Diabolo is a dual-channel photometer with 0.1 K bolometers cooled by a space-compatible dilution fridge of the same type as what will be flown on Planck-HFI (Lamarre et al. , this conference). It is described in length by Benoît et al. (2001) [2]. The AC square bias electronics to read the bolometers is described by Gaertner et al. (1997) [6].

It now contains two small arrays of 3 bolometers each of which has a Winston cone at its entrance aperture (Fig. 1). With a beam splitter, both arrays simultaneously measure the sky brightness resp. at 1.2 mm and at 2.1 mm. This is essential to spectrally separate sky noise from the SZ effect (see below). The FWHM of the beam is 22 arcseconds when the photometer is installed on the IRAM 30m telescope at Pico Veleta (Spain). Fig. 2 shows the cryostat at the Nasmith focus.

In 1995 and 1996, we performed ON-OFF (target) along with ON-OFF (blank-sky) on selected clusters of galaxy (Désert et al. 1998 [3]) to make first detections and to check for systematics. Since then, we have done small raster maps where the telescope is held fixed in local coordinates and the Earth rotation makes a drift subscan at constant declination. A map is made by repeating those subscans at different declination.

The sensitivity is below 1×10^{-4} (about 1 mJy/beam) for the comptonisation parameter y at 1σ in one hour of integration and after sky noise is subtracted (see below).

SCIENTIFIC RESULTS

The SZ effect

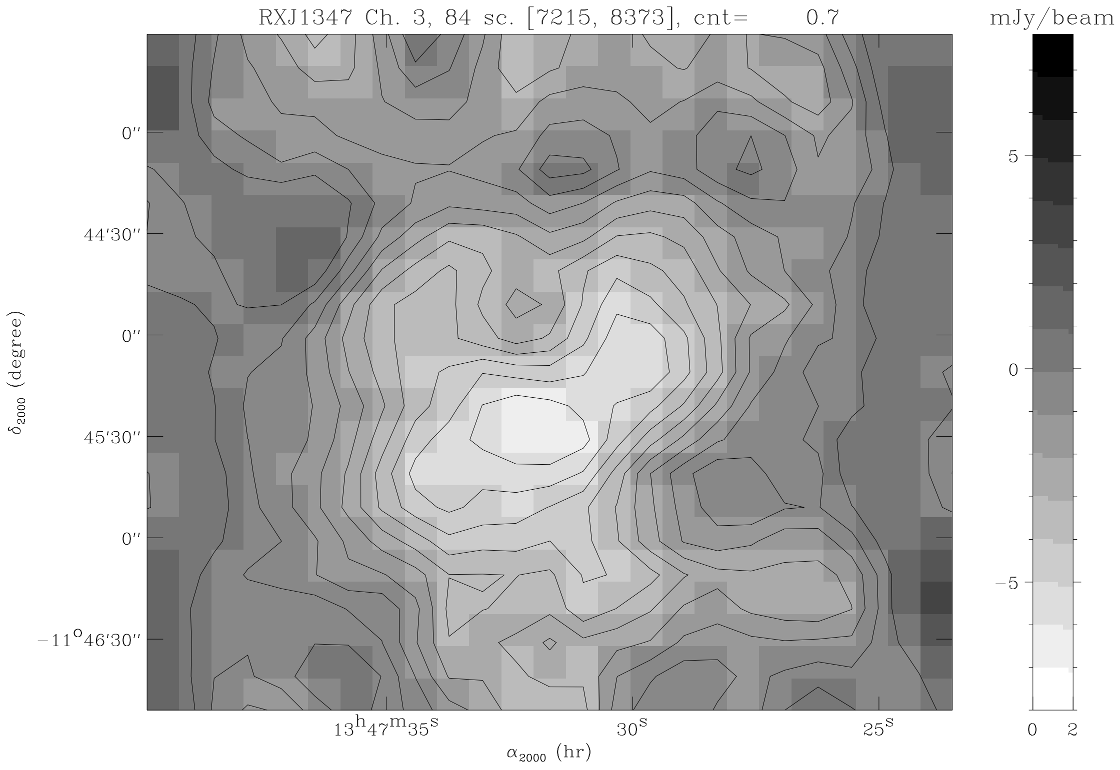

FIGURE 3. 2.1 mm map obtained with the Diabolo instrument in 1999 of the cluster of galaxies RXJ1347-1145. It corresponds to the coaddition of 84 independant rasters. The grey scale is from white (negative brightness) to black (positive brightness). Contours are in units of 0.7 mJy per beam (1σ level) from -9 to 0. Pixel size is 10 arcseconds. A smoothing by 3 pixels was applied.

The SZ effect is clearly detected in one of the most X-ray luminous clusters, RXJ1347-1145, at a redshift of 0.45. The map shown in Fig. 3 is obtained after coadding 16 hours of rasters taken in January 1999. First results were described by Pointecouteau et al. (1999) [12] and these observations are analysed at length by Pointecouteau et al. (2001) [13]. A new mapping algorithm is used here in order to deal with the effect of wobbling (Marty et al. 2001) [11]. A projected gas mass can be almost directly deduced from these observations $1.1 \pm 0.1 \times 10^{14} M_{\odot}$ within an angular radius of $\theta = 74''$ in agreement with X-ray expected gas mass. The SZ effect is the strongest ever detected ($y = 7 \times 10^{-4}$). This is accomplished with a high signal to noise (about 20).

Other clusters have been mapped with the same experiment and will be reported by Marty et al. (2001) [11].

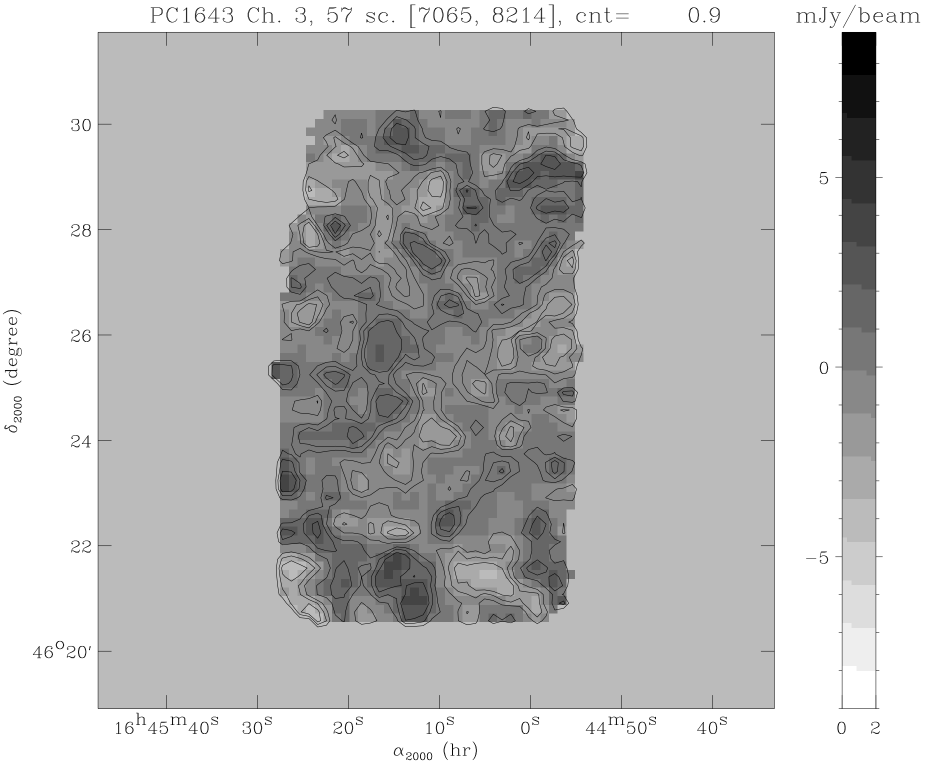

FIGURE 4. 2.1 mm Diabolo map in the field of PC1643+4631. The grey scale is from white (negative brightness) to black (positive brightness). Contours are in units of 0.9 mJy per beam (1σ level for the applied 30 arcsecond smoothing). The center of the Ryle decrement is at 16h45m11.2+46d24’56"

A strong SZ effect has been detected with the radio Ryle interferometer at a position near the pair of quasars PC1643+4631 by Jones et al. (1997) [10]. This brightness decrement observed at 15 GHz could not be confirmed by other experiments like BIMA at 28.5 GHz [9] or SuZie at 2 mm [7]. Here we wanted to map a sufficiently large map so as not to miss any decrement that could have been mispositioned, especially in declination, and have high resolution as well so as not to miss any relatively compact source. About 18 hours were spent in January 1999 providing our deepest field ever observed at 2.1 mm. 57 maps of 1200 seconds each can be coadded in order to have a typical sensitivity of 1.5 mJy (1σ) for each of the 20 arcsecond pixel making up the final 4 by 9 arcmin map. Fig. 4 shows this final map. No strong SZ effect is detected in this map. To set a preliminary upper limit, we have computed the integrated flux inside varying radii for a given central position. Fig. 5 shows that the absolute flux is never larger than 15 mJy in the 1 to 2 arcminute radius range (the optimum range for our 2.5 arcmin wobbling amplitude), whatever the center declination is chosen. We can safely exclude sources with an absolute flux larger than 20 mJy. The SZ effect expected with the minimum parameters advocated by Jones et al. [10] (core radius of 1 arcmin, $\Delta T/T = 2\times10^{-4}$) is -35 mJy at 2.1 mm, which is not observed. If the Ryle decrement were due to a kinetic SZ effect, as would arise, for example, from a bubble of matter ionized by early quasars (Aghanim et al. [1]), then our spectral leverage implies a flux twice larger (-70 mJy) which is clearly not observed. Analysis of the PC1643 field in terms of CMB anisotropies should also be reported soon.

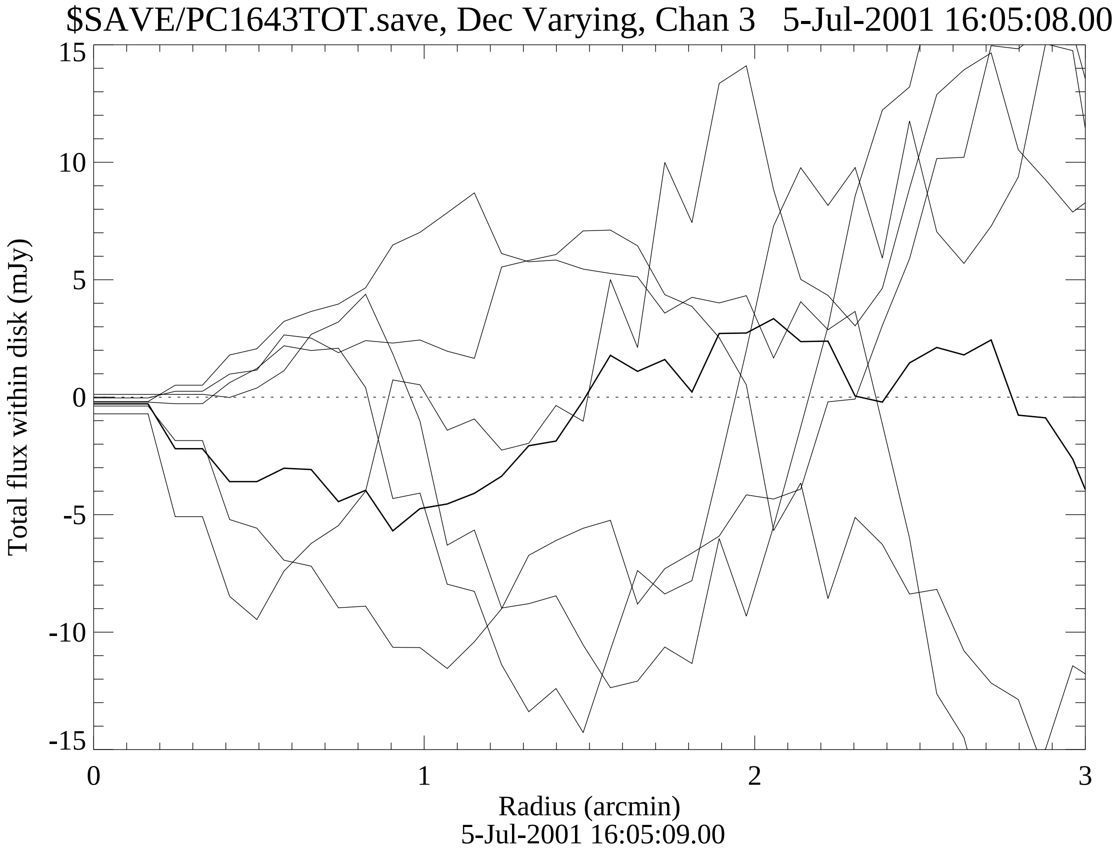

FIGURE 5. Integrated 2.1 mm flux radial profile obtained from the previous map. Each line corresponds to a central position with a constant right ascension but a declination varying by steps of 1 arcminute across the map.

2 mm source counts

From the previous deep survey, we also analysed the map for the presence of point sources. No sources could be detected at the level of 6 mJy in an area of 34 arcmin^2. A 2σ upper limit on integral number counts is thus $400\,\mathrm{deg}^{-2}$ at the flux limit of 6 mJy. This limit, which is above 850 μmand 1.2 mm counts, could be improved with a larger observing time and/or next generation of bolometer instrument (see below). These constraints may prove very useful for the knowledge of high redshift galaxies.

Sky noise

One of the main limitations in ground-based (sub)millimeter observations is sky noise. This is due to inhomogeneous water vapour layers travelling above the telescope. This fluctuating emission produdes a spatially and temporally variable noise degrading the performance of millimetre continuum measurements. Two methods are used to counteract this noise. The spatial method is used when one wants to observe point sources with an array of bolometers, thereby one subtracts the average signal from neighbouring pixels (Kreysa, this conference). For extended sources this is insufficient. With a dual channel instrument like Diabolo we were able to perform the spectral method, whereby the SZ signal having a spectrum very different from the water vapour emission, a simultaneous measurement at 2 wavelengths (namely 1.2 and 2.1 mm) allows one to subtract the sky noise induced map at all spatial scales. Fig 6 illustrates this method. In this case, the gain in signal to noise has proven not to be dramatic (30 to 50%). However the statistics of the signal is much improved in that the remaining (hopefully) detector noise is closer to Gaussian, hence improving the quality of SZ detections (*e.g.* [3]).

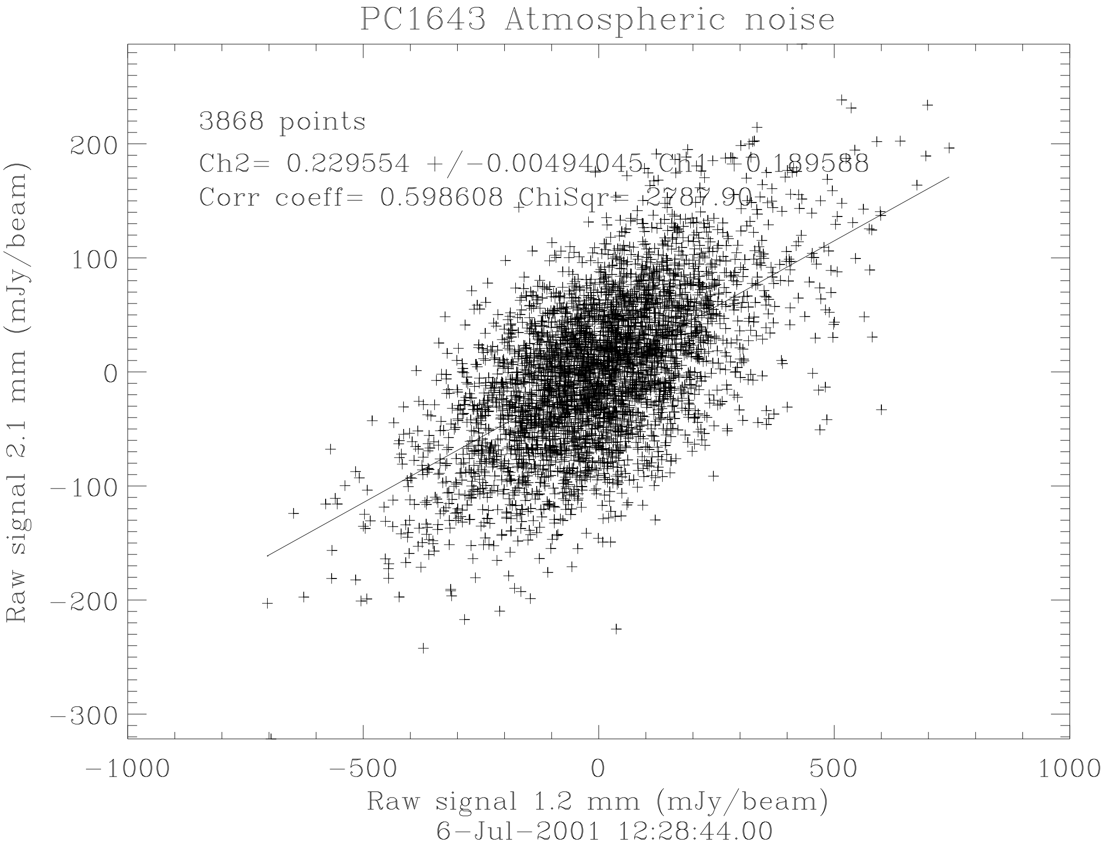

FIGURE 6. Illustration of millimetre sky noise. Raw signal correlation between two bolometers during one scan made on the "empty" field PC1643. The signal at 1.2 mm (containing almost no SZ effect) provides a template on which the 2.1 mm (SZ) signal can be decorrelated. The slope is compatible with the spectrum expected from water vapour emission.

THE STEP FORWARD IN MILLIMETER CONTINUUM ASTROPHYSICS

The previous results have shown examples of the importance of the large surveys at 1.2 but also 2.1 mm wavelengths with high resolution. The 4 most important (extragalactic) reasons at 2.1 mm are the study of the SZ effect in conjontion with X-ray observatory data, the study of secondary anisotropies (the CMB is flat on these small angular scales), the detection of primordial galaxies, and the mapping of external galaxies. To achieve that goal, this conference has seen many projects and realisations of cameras with many bolometers packed together with individual horns. On the other hand, we wish to advocate the use of filled arrays of bolometers fully sampling the available focal plane of large millimetre dishes (see details in [4]). Indeed, there are three reasons for this new design to be competitive: the sky noise may be better handled (no instanteneous holes in the observed field of view), the confusion noise, nearly reached even with large telescopes, can be better tackled and the efficiency of photon gathering is optimised. The challenge is clearly the optical behaviour of such new cameras (the background is a million time larger than the objects to be detected), adapting a multiwavelength operation (should we keep dichroic or use wavelength sensitive piled up arrays?), multiplexing arrays of several thousand pixels. Such cameras can be the workhorse for the ground-based follow-up of large surveys made by the next generation space instruments like SIRTF, Herschel and Planck. Developments in France follow from the CEA/Leti design of a submillimeter camera for Herschel (initially for SPIRE [8] and now for PACS) and other advance in NbSi technology [5]. Prototypes are currently being built and tested to qualify these new designs.

ACKNOWLEDGMENTS

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