EXTENDED SZ EMISSION OF THE MOST LUMINOUS X-RAY CLUSTER, RXJ1347-1145

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We have mapped the most luminous X-ray cluster, RXJ1347-1145 at 2.1mm using the DIABOLO spectrophotometer working on the 30m IRAM radiotelescope over a 4 by 4 arcmin field. We have detected the strongest Sunyaev-Zel'dovich (SZ hereafter) decrement known to date and mapped the SZ extended signal of this cluster. The SZ map shows a structure, which is quite different from the X-ray ray map. We have measured a gas mass of $M_{gas}(r < 0.6\,\mathrm{Mpc}) = 5.3 \times 10^{14}$ $M_{\odot}$ in 0.6 Mpc assuming an isothermal temperature of 9.3 keV for the gas (value deduced from the X-ray data). Our data argue in favor of a higher gas temperature. We estimate it to 16 keV.We have also recomputed the gas mass, $M_{gas}(r < 0.6\,\mathrm{Mpc}) = 3.0 \times 10^{14}$ $M_{\odot}$. This result suggests the gas producing the SZ effect is probably very hot and not virialized.

1 Introduction

The study of very distant galaxy clusters is a very powerful tool in cosmology. The cluster redshift and mass distributions are strongly dependent of the universe geometry.

As their X-ray observations, their submillimeter to centimeter observations allow to detect the intra-cluster gas through the Sunyaev-Zel'dovich effect[1]. This effect is due to a spectral distortion of the cosmic microwave background (CMB hereafter) radiation, induced by the inverse Compton scaterring of the CMB photons by the hot intra-cluster electrons.

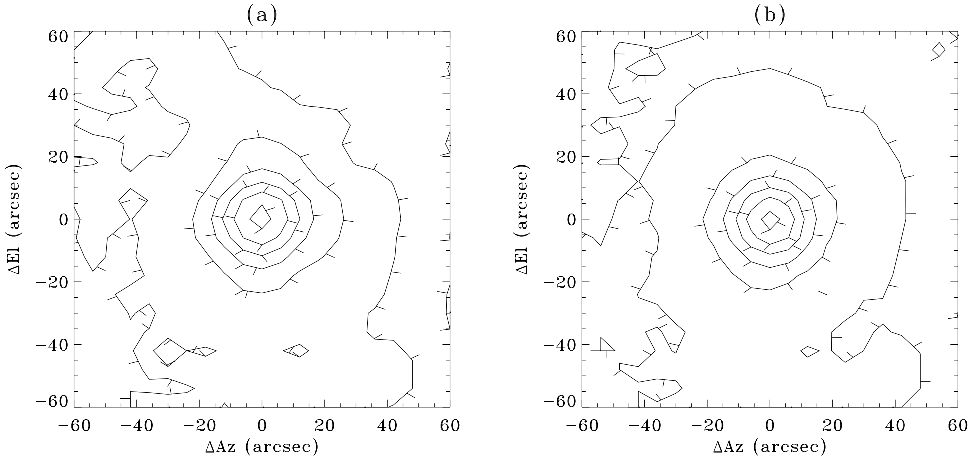

Figure 1: The DIABOLO beams obtained from the Mars observations at 1.2 mm (a) and 2.1 mm (b).

2 Observations

2.1 DIABOLO

DIABOLO is a multiwavelengths photometer, working at 1.2 and 2.1 mm. Its detectors are bolometers. They are cooled down to 0.1 K using an open dilution cycle of ^{3}He inside ^{4}He [2]. Each channel is constituted by a mini matrix of three bolometers, organized in such a way that each bolometer of the 1.2 mm channel is coaligned with a bolometer of the 2.1 mm channel. This configuration allows to observe simultaneously the same region of the sky in the two channels[3].

DIABOLO is commonly installed at the focus of the 30 m IRAM telescope at Pico Veleta, Spain. This association is needed to achieved a very high angular resolution. In fact, we reach a 22 arcsec resolution since 1997. We used the secondary wobbling mirror of the 30 m to operate a spatial modulation of the signal. DIABOLO is specially designed to observed the SZ effect. Some detections have allready been achived with it[3].

2.2 Data processing

Here follows the different steps using to reconstruct an astrophysical map from the DIABOLO raw data: (1) The impact of cosmic rays has been removed. (2) A synchronous demodulation is performed on the data, tacking into account the wobbling frequency and amplitude. (3) The two channels signal are correlated. The correlated part corresponds to the atmospherical noise. This part is subtracted from the 2.1 mm signal. (4) The signal is corrected from the atmosphere opacity. (5) A baseline is subtracted to remove the low-frequency detector noises. It is a one degree polynomial fitted to 60% of the data points (30% on each side). (6) Each map is resampled on a regular right ascension / declination grid. (7) An average map is computed for each bolometer and finely a single final map is produced for each channel by coaddition of the previous three bolometers average map.

The pointing verifications have been performed throughout the run in the direction of planets and quasars. Mars has been used to characterize the DIABOLO beams. The shapes of the 1.2 and the 2.1 mm beam is shown on Fig. 1. The corresponding full width half maximum at 2.1 mm is 22”.

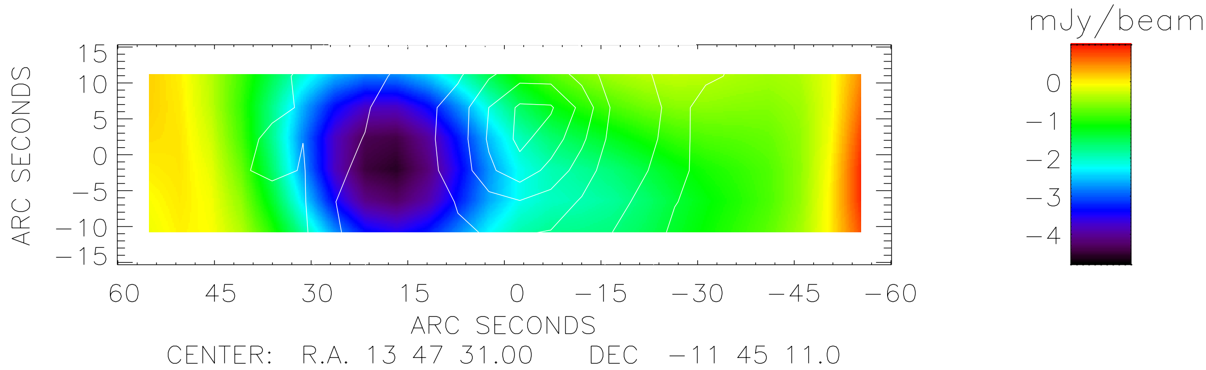

Figure 2: RXJ1347-1145 central region has seen by DIABOLO at 2.1 mm during the 1997 campaign. The map has been smoothed with a 25" FWHM Gaussian filter. The sensitivity achieved on the map is 1 mJy / beam at a 1 σ level. The X-ray (ROSAT-HRI) contours have been overplotted.

3 Analysis and results

3.1 *RXJ1347-1145*

This cluster is the most luminous X-ray cluster know to date, $L_{bol} = 21 \times 10^{45}$ erg / s, and one of the most massive ($M_{X-ray}(r < 1 \text{ Mpc}) = 5.8 \times 10^{14}$ M$_\odot$). It is a distant cluster with a redshift of $z = 0.45$. It is also a very hot cluster with a gas temperature of $T_g = 9.3 \pm 1.0$ keV. The central electronic density is $n_{e0} = 0.094 \pm 0.004$ cm^{-3}. The maximum of the X-ray emission is located at $\alpha = 13^h 47^m 31^s$ and $\delta = -11°45'11''$. Additionally, this cluster presents a very strong cooling flow in its center. All those results are taken from the X-ray analysis by Schindler et al.[4,5].

3.2 *The 1997 campaign*

During the 1997 DIABOLO run we have only mapped the central region of RXJ1347-1145 (2×1 arcmin) for a total integration time of 16 hours. The resulting map, obtained after all the data processing, is presented on Fig. 2.

This map presents the strongest SZ decrement observed up to know. We can easily observed a discrepancy between the X-ray emission and the SZ signal distributions. We know from Komatsu et al.[6] that a radio point source lays near the X-ray emission center. They have characterized its spectrum from radio observations: $F(\nu) = (55.7 \pm 1.0)(\nu/1\,\text{GHz})^{-0.47 \pm 0.02}$ mJy. The corresponding extrapolated flux at 1.2 and 2.1 mm are respectively 3.7±0.4 mJy / beam and 4.9±0.5 mJy / beam.

To analyze our data we have build a combined model including an SZ component and a radio point source component. For the SZ component, we have used the X-ray parameters for the gas distribution ($\beta = 0.56$ and $\theta_c = 8.4$ arcsec)and we have computed an exact SZ spectrum for a 9.3 keV gas[7]. The radio source has been considered as a point source with respect to the DIABOLO beam. Its exact coordinates are $(\alpha, \delta) = (13^h 47^m 30.67^s, -11°45'8.6'')$. We have performed simulations of DIABOLO observations on the SZ and the point source model, which reproduced exactly the observed data (those simulations includes the wobbling effect and the sky rotation at the Nasmyth focus). The simulated data have been processed through the same pipeline as the observed data.

We have simultaneously fitted the combined SZ and radio point source models to the data with two free parameters: the comptonization parameter to manage the SZ effect amplitude and the radio point source flux. The best-fit parameters are $y = 12.7^{+2.9}_{-3.1} \times 10^{-4}$ and $F(\nu) = 6.1^{+4.3}_{-4.8}$ mJy / beam. Results are given at a 68% confidence levels. The best fit is presented with

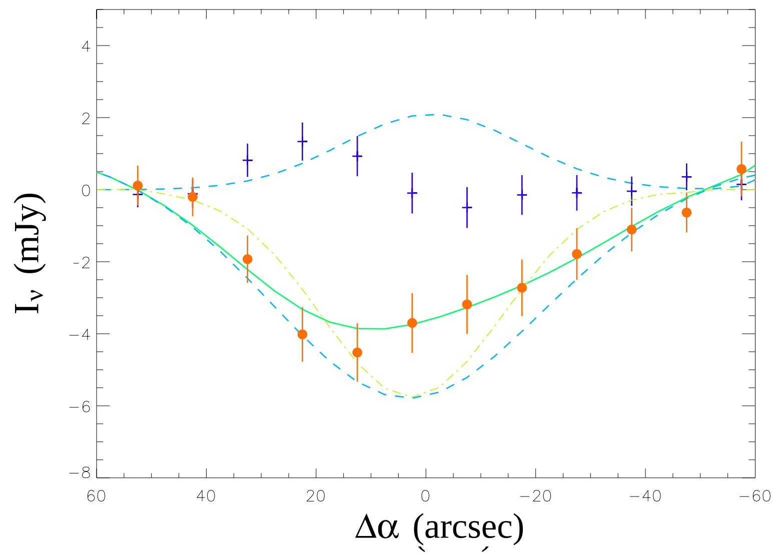

Figure 3: RXJ1347-1145 right ascension profile at 2.1 mm computed from the map presented on Fig. 2. The data points are presented as diamonds with their 1σ associated errors bars. The best fit model is overplotted (solid line). It corresponds to the sum of an SZ component (dotted line) and a radio point source component (dashed line). The triangles shows the sensitivity level (those data points have been obtained in the direction of a blank field for the same integration time).

respect to the data on Fig.3.

Our y value is quite twice the X-ray estimation ($y_{X-ray} = 7.3 \times 10^{-4}$). Our result corresponds to a mass larger than the X-ray mass, despite of the large uncertainties on the Comptonization parameter determination. Following the hypothesis of Allen & Fabian[8], that the effect of cooling flows in galaxy clusters decrease the gas temperature, we have recomputed the value of T_g from our y value. We assumed that the core radius and the β parameter values remain unchanged from the X-ray values. We deduced $T_g = 16.2 \pm 3.8$ keV, which is in good agreement with the value of $26.4^{+7.8}_{-12.3}$ keV derived by Allen & Fabian for RXJ1347-1145. With this new value of the gas temperature, we can recompute the cluster total mass (under the hydrostatic equilibrium hypothesis): $M_{X-ray}(r < 1\text{ Mpc}) = 1.0 \pm 0.3 \times 10^{15}\ M_\odot$.

All the results presented up to know in this paper are described in details by Pointecouteau et al.[9].

3.3 The 1999 campaign

We have also mapped RXJ1347-1145 during the 1999 DIABOLO run. We have performed a 4×4 arcmin map of the extended emission of the cluster. The resulting map after 17 hours integration time is presented on Fig. 4.

As in 1997, we have detected a very strong SZ signal in the direction of the cluster center. We have also detected an extended emission in the south direction. We confirm that some differences remain between the X-ray and the SZ signal distributions. For the extended map, it seems quite difficult to explain those discrepancies only with the presence of the central point source. Now, we need to perform an exact modelisation of the observing method.

Nevertheless, without any modeling, we can directly estimate the gas mass we have measured. In fact the SZ effect is directly proportional to the projected gas mass. Using the 1999 map, we can estimate the gas mass in 0.6 Mpc to $5.3 \times 10^{14}\ M_\odot$ for a gas temperature of 9.3 keV and $3.0 \times 10^{14}\ M_\odot$ for a gas temperature of 16 keV.

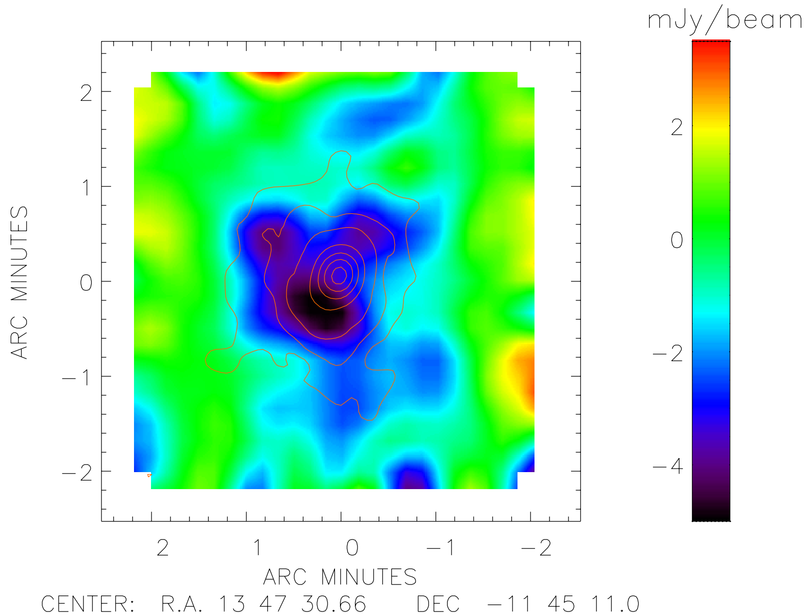

Figure 4: Extended map of RXJ1347-1145 has seen by DIABOLO at 2.1 mm. The X-ray contours have been overplotted. The corresponding level are 3%, 5%, 10%, 30%, 50% 70% and 90% of the X-ray maximum.

The detailed results and analysis of the 1999 DIABOLO campaign will be presented in a future paper[10].

4 conclusion

We have detected the strongest SZ effect to date in the direction of the most luminous X-ray cluster. We have presented an extended map of this cluster, RXJ1347-1145, obtained at 2.1 mm with the DIABOLO spectrophotometer.

We need now to modelise properly the results of the 1999 DIABOLO campaign. All those forthcoming analysis will be presented in a future paper by pointecouteau et al.[10]. Nevertheless, the DIABOLO spectrophotometer installed at the 30 m IRAM telescope focus allows to achieved a very high angular resolution. This resolution is needed to map the SZ emission of very distant clusters. During the 2000 DIABOLO run we have also mapped two $z = 0.83$ galaxy clusters : MS1054-03 (Desert et al.[11]) and CL0152-13 (Giard et al.[12]).

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