First Millimeter Detection of the X-Ray Cluster RXJ1347-1145

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ABSTRACT

We report here the first Sunyaev-Zeldovich (hereafter SZ) effect detection of the most luminous X-ray distant cluster, RXJ1347-1145. This measurement has been achieved with the DIABOLO photometer running on the 30 meters IRAM radiotelescope. We have mapped the central region of RXJ1347-1145 with a resolution better than 25". The SZ decrement we have measured is the deepest observed up to know. The comptonization parameter range between 5.1×10^{-4} to 7.0×10^{-4}.

1. Introduction

The hot intracluster gas ($T_{gas} \sim 10^6 - 10^8$ K) can be observed at X-ray wavelengths via the bremmstrahlung emission or from submillimeter to centimeter wavelengths via the Sunyaev-Zeldovich (SZ) effect. The SZ emission is a distorsion of the cosmic microwave background (CMB) spectrum, due to the inverse Compton scattering of the CMB photons by the hot intracluster gas electrons (). It is observed in the direction of galaxy clusters. The CMB photons are shifted to higher energies, so that the spectral shape of the SZ spectrum present an flux increment at submillimeter wavelengths and a flux decrement at millimeter wavelengths. (eg: result spectrum of the difference between the CMB spectrum in a cluster direction and in a empty fied direction). For more details on the SZ effect see se review by Birkinshaw (). The thermal SZ spectra is plotted on Fig 1 and the expression of the two effect are detailed in Sect **??**.

The cluster RXJ1347-1145 is the most luminous X-ray cluster discover up to know. It has been observed at X-ray wavelengths with ROSAT/PSPC, ROSAT/HRI and ASCA/GIS. Its X-ray properties have been derived by Schindler et al. (1995, 1997) from those observations. They derived a bolometric luminosity of $L_X(bol) = 2 \times 10^{46}$ erg/s, a core radius of $r_c = 57 \pm 12$

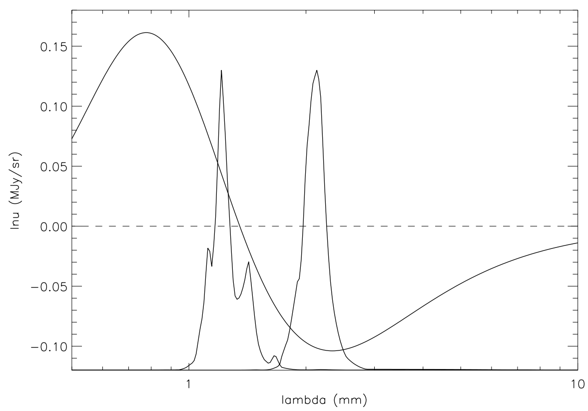

Fig. 1.— Spectrum of the thermal SZ effect for a 9.3keV cluster (eg: RXJ1347 gas temperature) plotted with respect to the DIABOLO passbands at 1.2 and 2.1mm

kpc, a beta parameter of $\beta = 0.57 \pm 0.04$ and a gas temperature of $T_e = 9.3 \pm 1.0$ keV. They have calculated a total binding mass of $M(R < 1.7Mpc) = 9.8 \times 10^{15}$ $M_\odot$. This object is very attractive for observers and it has also been observed at optical wavelengths (,). We report here the detection of this cluster at 2.1 mm with the DIABOLO photometer. In Sect 2 we detail the observations performed in December 1997. In a third part, we present the data analysis and then we discuss in Sect **??** our results.

2. Observations

DIABOLO is a dual-channel photometer working at the IRAM 30 meters radiotelescope. The two central wavelengths are 1.2 and 2.1 mm. The detectors are bolometers cooled at 0.1 K with an open $^4He -^3 He$ cycle dilution refrigerator (). There are 3 bolometers per channels and two monitoring thermometers are used to regulate the temperature of the cooling bath.

RXJ1347-1145 has been observed in December 1997 for a total integration time of 16 hours. The center of our observation is the ROSAT-HRI X-ray emission center, reported by Schindler et *al.* (), as pointing position: $\alpha = 13h47mn31s$, $\delta = -11°45'11$". The observations have been performed using the wobbling secondary mirror of the IRAM telescope at a frequency of 1Hz and with a modulation amplitude of 150 arcsec. We have scanned the cluster central region over a length of 120 arcsec. The scans have directly been performed in right ascension direction using the Earth rotation so that the telescope is kept fixed during the measurements. So, the scrolling speed was $15 \times \cos\delta$, where δ is the pointing declination. The wobbling is horizontal, thus not aligned with the scan direction. However, the amplitude is enough so that the reference field should be in all cases far out of the cluster. In order to remove systematic signals produced for instance by far side lobes pickup, we use alternatively the positive and negative beams to map the cluster. Observations have been performed in a mapping mode. Each map was constituted by independent scans. We spent an average time of 285 seconds per map for a total of 200 maps performed.

3. Data Analysis

3.1. Results

The data procedure reduction of the DIABOLO data has been performed as described by Désert et *al.* (). The maps are reconstructed from the data tempotal sequence. Each map is constituted from scans (eg: lines of the map). The signal is cleaned from the cosmic ray impacts. A synchronous demodulation alghorithm is applied taking into account the wobbling secondary characteristics. The 1.2mm correlated signal due to the atmospheric emission, is substracted to the 2.1mm signal. The signal is corrected from the atmosphere absorption taking into account the source elevation and the scan observation time. All the maps are recentered with respect to their elevation and the bolometer position on the sky at the observing time. A baseline is substracted to each scan (eg: the map lines): a 1 degree polynom is fitted to 50% of the data and supported by the (0.1,0.3) and (0.7,0.9) intervals with respect to a relative scan length of 1. The final map is computed at each wavelength from the cube of maps.

We have performed our calibrations on Mars. Because of its apparent angular diameter, 5”, Mars is a point source for the DIABOLO resolution. The observing Mars sequences have been reduced as described previously. The calibration coefficients set has been computed for each bolometer by averaging all the Mars sequences. The uncertainty that remains from those calibrations did not exceed 25% and 15% at 1.2mm and 2.1mm respectively. These errors have been reported on the final cluster error map at each wavelengt. The Mars observations are used to characterized the Diabolo’s beam too. The best gaussian fit performed on the average normalize Mars map led to a 12” and a 11” FWHM at 1.2mm and 2.1mm.

Fig **??** shows the maps of the cluster central region at 1.2mm and 2.1mm.

3.2. SZ analysis

Expending the SZ effect to first and second order in the electron’s velocity and integrating over the thermal distribution yields respectively to the so called kinetic and thermal SZ effects:

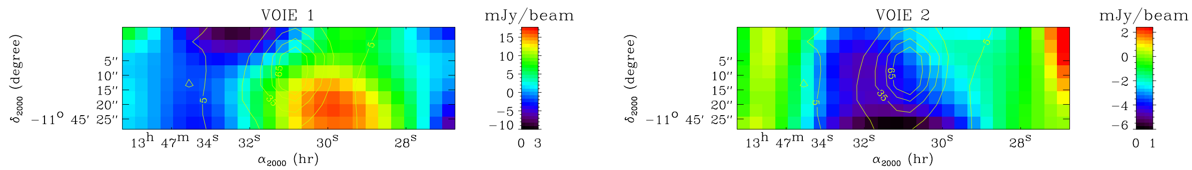

Fig. 2.— 1.2mm (“VOIE 1”) and 2.1mm (“VOIE 2”) DIABOLO maps of RXJ1347-1145 central region. The images have been smoothed with a gaussian filter of $\sigma = 10''$. The ROSAT/HRI X-ray contours have been overplotted (numbers on the contours are percentages of the total flux.).

$$\frac{\Delta I_\nu}{I_\nu}|_{th} = y_c SZ_{th}(\nu, T_e) \quad (1)$$

$$\frac{\Delta I_\nu}{I_\nu}|_{kin} = -\frac{y_c v_p}{T_e} SZ_{kin}(\nu, T_e) \quad (2)$$

where $y_c = \frac{kT_e}{m_e c^2}\sigma_T \int n_e(l)dl$, is the Comptonisation parameter, T_e is the electronic gas temperature, v_p is the cluster peculiar velocity. $SZ_{th}(\nu, T_e)$ and $SZ_{kin}(\nu, T_e)$ are numerical functions of ν and T_e. $n_e(r)$ is the electronic density integrated along the line of sight. k, m_e, c and σ_T are respectively the Bolzmann constant, the electron mass, the ligh velocity and the Thompson cross section.

The 1.2mm filtered map presents a positive excess of signal, which is confirm by the right ascension average scan (see Fig **??**, “VOIE 1”). We considered this signal as a point source emission. Due to the center of its emission it may correspond to a radio source known from the NVSS (eg: NRAO VLA Sky Survey,) near the cluster center. Following this hypothesis, we have fitted its flux assuming the 1.2mm DIABOLO beam as the source profile. We have found $F_\nu = 12.9 \pm 3.0$ mJy/beam . Because of variations existing from one radio spectrum to an other, it seems difficult to estimate the contribution of the radio flux at 1.2mm. However, due to the very strong flux we have found at 1.2mm we suggest that this emission may be due to dust emission. Assuming a dust spectrum with a spectral index of $n = 1$ (eg: $\propto \nu^3$, a quite flat dust spectrum), we are able to estimate the contribution of this point source at 2.1mm and to substract it from the 2.1mm map.

For the 2.1mm SZ analysis, we used the physical parameters derived by Schindler et *al.* (): $r_c = 8.4$ arcsec, $\beta = 0.56$ and $T_e = 9.3$ keV. We assumed that the intracluster gas is isothermal and that its distribution follows a β-model:

$$n_e(r) = n_{e0} \times (1 + (\frac{r}{r_c})^2)^{-3\beta/2} \tag{3}$$

The 2.1mm map shows clearly a signal decrement centered on RXJ1347 position. We have fitted a simple SZ model on the 2.1mm map:

$$I(\bar{\nu}, \Omega) = y_c \int SZ(\nu, T_e) d\nu \int P(\Omega) L(\Omega - \Omega') d\Omega' \tag{4}$$

The SZ effect has been integrated over the DIABOLO passband and express for the central passband wavelength, $\bar{\nu}$, using exact SZ spectra computed by Pointecouteau et *al.* (). $P(\Omega)$ is the projected gas distribution on the sky. We have choosed an arbitrary cut off of $15r_c$ for the gas distribution. This gas density profile is convolved with the DIABOLO beam, $L(\Omega)$ We have fitted this model with y_c as only free parameter in two cases: (1) we performed the fit on the decorrelated map (see Fig **??**, "VOIE 2"). We found $y_c = (5.1 \pm 0.35) \times^{-4}$. (2) We substract the point source contribution from the 2.1 mm map assuming a ν^3 dust spectrum. We obtained $y_c = (7.0 \pm 0.7) \times 10^{-4}$. From the X-ray parameter it is possible to estimate the expected value of y_c. It yield a $y_c = (7.2^{+2.2}_{-2.5}) \times 10^{-4}$. This value is in good agreement with the both values we derived. Those two values give the range of the comptonization parameter for RXJ1347.

4. Conclusion

We have mapped with a very high resolution the deepest SZ decrement in the direction of the most luminous X-ray cluster RXJ1347-1145. The corresponding comptonisation parameter lies in the interval $[5.1, 7.0] \times 10^{-4}$. We have detected a point source at 1.2mm, which seems to correspond to a NVSS radiosource. This detection has to be confirm and its flux to be better determine. In terms of SZ detection, we need to cover a bigger area arround RXJ1347 to look for extended SZ emission and to map its gas distribution. At both wavelengths the results we obtained have to be compared with other "SZ wavelengths": Submillimeter (SCUBA) and radio (Nobeyama Radio Observatory, OVRO) observations (Suto et *al.* , private communication). Nevertheless, this detection of a massive distant (z=0.45) cluster, both at X-ray and millimeter wavelengths, argues in favour of high redshifts massive clusters. The case of RXJ1347-1145, illustrates the kind of X-ray and millimeter measurements combination that should be done with futur data sets that will be provided by very sensitive spaceborne experiments as XMM and Planck Surveyor.

All these results are gathered and more detailed in a paper from Pointecouteau et *al.* (1999, in preparation).

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