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Observations of the Sunyaev–Zel'dovich effect in the $z = 0.78$ cluster MS 1137.5+6625

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ABSTRACT

We have observed the $z = 0.78$ cluster MS 1137.5+6625 with the Ryle Telescope (RT) at 15 GHz. After subtraction of contaminating radio sources in the field, we find a Sunyaev–Zel'dovich flux decrement of $-421 \pm 60\,\mu$Jy on the $\approx 0.65\,\mathrm{k}\lambda$ baseline of the RT, spatially coincident with the optical and X-ray positions for the cluster core.

For a spherical King-profile cluster model, the best fit to our flux measurement has a core radius $\theta_{\mathrm{C}} = 20$ arcsec, consistent with previous X-ray observations, and a central temperature decrement $\Delta T = 650 \pm 92\,\mu$K.

Using this model, we calculate that the cluster has a gas mass inside a $500\,h_{65}^{-1}$ kpc radius of $2.9 \times 10^{13}\,\mathrm{M}_{\odot}$ for an $\Omega_M = 1$ universe and $1.6 \times 10^{13}\,\mathrm{M}_{\odot}$ for $\Omega_M = 0.3$, $\Omega_\Lambda = 0.7$. We compare this model with existing measurements of the total mass of the cluster, based on gravitational lensing, and estimate a gas fraction for MS 1137.5+6625 of ≈ 8 per cent.

Key words: galaxies: clusters: individual: MS 1137.5+6625 – cosmology: observations.

1 INTRODUCTION

The cluster MS 1137.5+6625 was discovered in the *Einstein* Extended Medium Sensitivity Survey (EMSS; Gioia et al. 1990). It lies at redshift $z = 0.785$ and has an X-ray temperature $T_{\mathrm{X}} = 6.0$ keV and a 2–10 keV rest-frame luminosity of $L_{\mathrm{X}} = 2.8 \times 10^{37}$ W (Gioia & Luppino 1994; Donahue et al. 1999). It is the second most distant cluster in EMSS, and is representative of the population of massive high-redshift clusters which is beginning to be discovered by X-ray selection and other means. Because the Sunyaev-Zel'dovich (SZ; Sunyaev & Zel'dovich 1972) effect is dependent on cluster gas mass, but is close to independent of redshift, we observed MS 1137 with the Ryle Telescope (RT) to attempt an SZ detection and constrain the cluster gas mass.

2 OBSERVATIONS AND DATA ANALYSIS

RT observations totalling 460 h were made over 21 d in 1998 July and August and 18 d in 1999 March–May. The telescope was in Cb configuration (Grainge et al. 1996), resulting in the aperture-plane coverage shown in Fig. 1. For each day, observations of the target field were interleaved with observations of a phase calibrator about every 20 min, and a primary flux calibrator (3C 286 or 3C 48) was observed at either the start or end of the run.

The entire 39-d visibility data were concatenated and analysed to measure the cluster SZ signal. First, we made a map using only visibilities from projected baselines longer than $1.5\,\mathrm{k}\lambda$. First inspection of the dirty long-spacing map revealed two sources, the first lying close to the map centre, the second, about 30 arcmin to the south, is 3C 263 (Fig. 2). The long-spacing map was then CLEANed and the positions and fluxes of these sources measured with the task MAXFIT in the Astronomical Image Processing System (AIPS; http://www.cv.nrao.edu/aips/). Details of the sources are given in Table 1; The central source is clearly identified with the 2-mJy 20-cm source observed by Stocke et al. (1999). Two model point sources with the measured positions and fluxes were removed from all the visibilities using UVSUB in AIPS, and a new long-baseline map was made. This revealed only one further source close to the centre of the map with flux greater than 3.5 times the map rms. This source was removed from the visibility data using the same procedure. Then, a map was made using only the visibilities in the range 0.65–$1.0\,\mathrm{k}\lambda$, corresponding to the shortest baseline. The dirty maps showed a clear negative feature at the centre, but also some residual flux from 3C 263. This map was CLEANed and the residual flux was measured and subtracted from the visibilities using MAXFIT and UVSUB. We then made a final short-spacing map in which the only feature is the SZ decrement of the cluster; the CLEANed version of this map is shown in Fig. 3. The decrement in the map has a minimum flux of $-422 \pm 60\,\mu$Jy, a 7σ detection (we take the noise to be the map RMS well outside the primary beam), and is centred at RA $11^{\mathrm{h}}\,40^{\mathrm{m}}\,20\overset{\mathrm{s}}{.}0$, Dec. $66^{\circ}\,07'\,53''$ (J2000). Finally, we phase-rotated the source-subtracted visibilities

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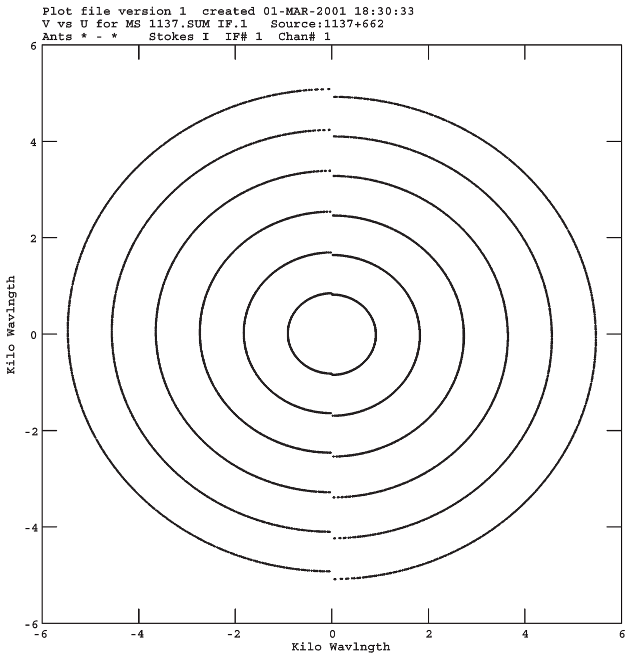

Figure 1. Aperture-plane coverage for the RT observations of MS 1137.5+6625 field. Two physical baselines contribute to the shortest baseline in this figure, three to the second shortest, two to the third shortest, and one to each of the three longest baselines.

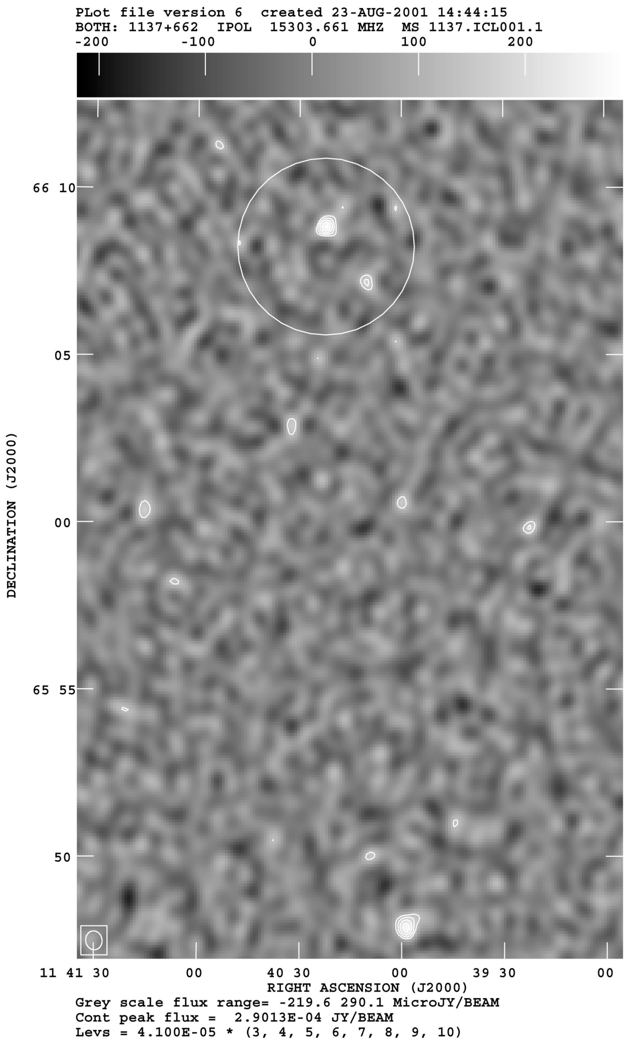

Figure 2. 1.5–5.4 kλ map of MS 1137 before source subtraction. The large circle at the centre of the map shows the FWHM of the RT primary beam; the FWHM of the synthesized beam is at lower left. We include enough of the map to show 3C 263 to the south. Contour levels are -3, 3, 4, 5, 6, $\ldots \times 41\,\mu$Jy, the rms of the map well outside the primary beam.

to the decrement centre and azimuthally averaged them (Fig. 4). The mean flux on the shortest baseline is $-421\,\mu$Jy. The 1σ positional error is roughly the beamwidth divided by the signal-to-noise ratio (e.g. Kenderdine, Ryle & Pooley 1966), i.e. about 20 arcsec. Thus the position of the SZ decrement is coincident with the optical and X-ray core of the cluster (e.g. fig. 2 of Donahue et al. 1999). The position and size of the decrement are also consistent with those measured by Grego et al. (2001) using the OVRO and BIMA arrays at 30 GHz.

We next estimate the gas mass required to produce this SZ signal. We used PROFILE (Grainge et al. 2002) to model the cluster as a spherical King-profile gas distribution. Initially we used an $\Omega_M = 1$ world model with $H_0 = 65\,h_{65}\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$, taking the X-ray core radius $\theta_C = 15$ arcsec, $T_X = 6$ keV, and central electron density $n_0 = 1.6 \times 10^4\,h_{65}^{1/2}\,\mathrm{m^{-3}}$ values measured by Donahue et al. (1999). In this model, the SZ flux on the shortest RT spacing would be $-339\,\mu$Jy, $1.4\,\sigma$ different from our SZ measurement. The best-fitting model to the SZ data has $n_0 = 1.3 \times 10^4\,h_{65}^{1/2}\,\mathrm{m^{-3}}$ and $\theta_C = 20$ arcsec, and a central temperature decrement of $\Delta T = 650 \pm 92\,\mu$K. For this model, we find a total gas mass enclosed inside a $500\,h_{65}^{-1}$ kpc radius of $2.9 \times 10^{13}\,\mathrm{M_\odot}$; in an $\Omega_M = 0.3$, $\Omega_\Lambda = 0.7$ universe, the best-fitting model has $n_0 = 1.0 \times 10^4\,h_{65}^{1/2}\,\mathrm{m^{-3}}$ and $\theta_C = 20$ arcsec, giving a gas mass enclosed inside $500\,h_{65}^{-1}$ kpc of $1.6 \times 10^{13}\,\mathrm{M_\odot}$.

Clowe et al. (1998) have used a gravitational lensing analysis to estimate estimated the total mass of MS 1137, for an $\Omega_M = 1$ universe. Comparing our best-fitting King-profile model with Clowe et al.'s total mass estimate, we calculate a gas fraction inside a $500\,h_{65}^{-1}$ kpc radius of 0.08 ± 0.026.

Finally, we note that the RT image shows essentially no substructure in MS 1137. This is consistent with the X-ray core radius measured by Donahue et al. (1999) and the compact mass distribution measured by Clowe et al. (1998). However, the distribution of galaxies in MS 1137, as noted by Clowe et al., has clear east–west extensions; Clowe et al. propose that the apparent compactness of MS 1137 may be because we are observing several merging filaments, with one pointing along the line of sight. Unfortunately, the imaging capabilities of the RT are insufficient, in terms of both sensitivity and aperture coverage, to detect any gas associated with the proposed filaments. Targets such as MS 1137, where there may be gas filaments too faint for X-ray detection, will

Table 1. Sources subtracted from the observations MS 1137. Fluxes are those measured in the map, uncorrected for primary beam attenuation. (1) 3C 263; (2) Extended flux from 3C 263 visible on short baseline map only.

RA (J2000)	Dec. (J2000)	$S_{15\,\mathrm{GHz}}$/mJy
11 40 22.302	66 08 49.94	0.290
11 39 58.738	65 47 53.02[1]	0.271
11 40 10.260	66 07 10.57	0.178
11 40 00.547	65 47 51.60[2]	0.424

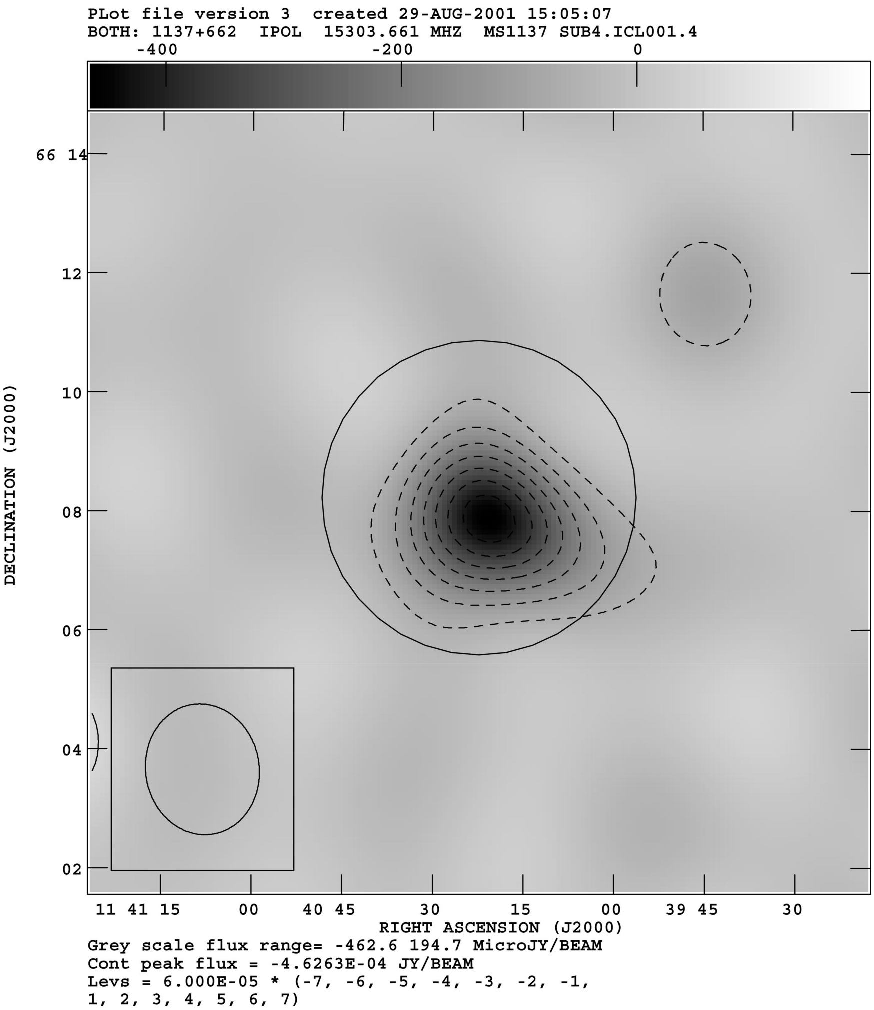

Figure 3. CLEANed 0.65–1.0 kλ map of MS 1137 after subtraction of the remaining flux from 3C263. Contour levels are $-6, -5, -4, -3, -2, -1, 1 \times$ the map rms away from the primary beam, 60 μJy. Primary and synthesized beams are shown as in previous figures.

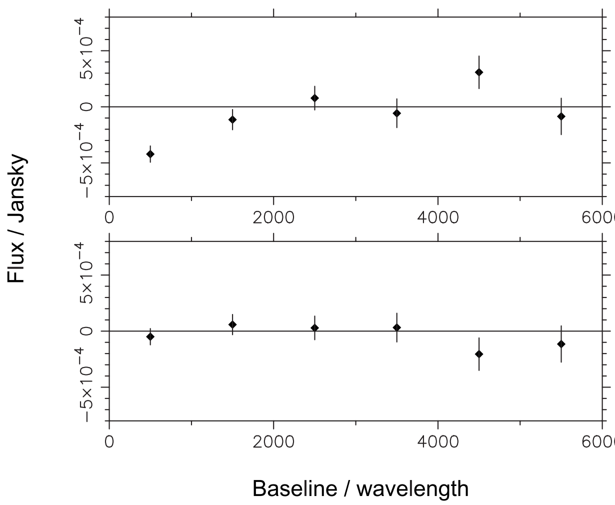

Figure 4. Real (top) and imaginary (bottom) parts of the visibilities, azimuthally averaged about the centre of the decrement after source subtraction. The baseline scale ranges from 0 to 6000 wavelengths, and the flux scale in each plot ranges from -0.8 to 0.8 mJy. The visibilities indicate a single extended negative source at the centre of the field.

be ideal targets for next-generation SZ telescopes (e.g. Holder et al. 2000, Kneissl et al. 2001).

3 CONCLUSIONS

(i) MS 1137.5+6625 is detected in SZ by the Ryle Telescope at 7σ.

(ii) We estimate that the minimum gas mass required produce the observed SZ flux is $\approx 1.6\text{–}2.9 \times 10^{13}\,\mathrm{M}_{\odot}$ inside a $500\,h_{65}^{-1}$ kpc radius.

(iii) The SZ image shows no spatial substructure; higher fidelity imaging, as provided by the proposed new generation of SZ telescopes, may allow us to determine if the extensions to the galaxy distribution in MS 1137.5+6625 are associated with significant gas masses.

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