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# Sunyaev-Zeldovich effect measured towards Abell cluster A 2218

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**Abstract.** We report a new measurement of the cosmological Sunyaev-Zeldovich (SZ) diminution of $\Delta T \simeq -(750 \pm 200)\ \mu K$ at 10.55 GHz with the Effelsberg 100-m radio telescope towards the A 2218 cluster of galaxies. We also report and analyse the X-ray observations of the A 2218 cluster of galaxies with the *ROSAT* satellite. The position and the strength of the measured SZ diminution are in excellent agreement with the expectations calculated from the X-ray analysis.

**Key words:** cluster of galaxies: A 2218 – plasmas – radiative transfer – cosmology: diffuse radiation

## 1. Introduction

It has been predicted (Sunyaev and Zeldovich 1972, 1980) that as a result of the passage through a hot electron cloud of pressure $p_e = n_e k_B T_e$ the brightness temperature $T_R$ of the cosmic microwave background radiation in the Rayleigh-Jeans part of the spectrum decreases by $\Delta T_R \simeq -2yT_R$, where $y = \frac{\sigma_T}{m_e c^2} \int_{-\infty}^{\infty} d\ell\ p_e$ is the Comptonization parameter. The measurement of this so-called Sunyaev-Zeldovich (SZ) effect is of extreme astrophysical and cosmological interest (Sunyaev and Zeldovich 1980; Rephaeli 1995) since it is one of the few possible tests to verify the cosmological origin of the isotropic 2.7 K microwave background radiation. For a review of the data see Raphaeli (1995). It is also an important diagnostic tool of observational cosmology since it offers a determination of the Hubble constant $H_0$ and, in case of very distant clusters, of the deceleration parameter $q_0$ (see e.g. Birkinshaw and Hughes 1994; Inagaki, Suginohara and Suto 1995).

Very deep $\lambda$1.2 cm ($\nu$24.5 GHz) measurements of the SZ diminution towards the cluster of galaxies A 2218 with the Effelsberg 100 m telescope have been reported by our group before (Klein et al. 1991), employing the double beam observing method to minimize atmospheric fluctuations. Their measured diminution of $600 \pm 200 \mu K$ peaked at a position off-set by $1'.6$ from the peak of the *EINSTEIN HRI* brightness profile (Boynton et al. 1982). This serious positional discrepancy between the observed and the expected (from modelling the SZ effect with the known X-ray brightness profile) diminution is not removed by any possible influence of the thermal bremsstrahlung emission from a central cooling flow (Schlickeiser 1991), and has limited the credibility of that result.

During the last three years new sensitive radio (Jones et al. 1993) and ROSAT X-ray data on A 2218 have become available. The purpose of this contribution is twofold:
(i) to report on a new measurement of the SZ diminution at 10.55 GHz with the Effelsberg 100m telescope (section 3), and
(ii) to compare the measured diminution with the expected signal, as calculated from an analysis of the public ROSAT data on A 2218 presented in section 2.

As we shall demonstrate the strength and the location of the measured SZ diminution are in reasonable agreement with the new X-ray data.

## 2. ROSAT observations of A 2218

In this section we present the X-ray observations of A 2218, processed using the EXSAS package (Zimmerman et al. 1994) in the MIDAS environment and compare our results with the full treatment of Snowden's approach (Snowden 1995).

The optical HEASARC catalog classifies this cluster as a richness class $R$ = 4 and distance class $D$ = 4 cluster with visual magnitude $V$ = 17.7 and redshift $z$ = 0.171. The cluster has been observed with the ROSAT PSPC detector in 1991 for a duration of 44530 s. Although there exists also the HRI data of the cluster due to its low background we have analysed only PSPC data. The ROSAT detectors pointed towards the coordinates $\alpha_{2000} = 16^h35^m51.^s31$ and $\delta_{2000} = 66°12'33.2''$.

### 2.1. Spatial analysis

For the purpose of spatial analysis we have constructed a 30 × 30 binned image from PSPC data using only channels 42 - 201 corresponding to a $\sim$ 0.4 - 2 keV energy range. The omission of low energy data increases the signal to noise ratio of the map and also avoids the very soft X-ray photons which give rise to the extension of the image (ghost image problem). This effect is not evident above channel 20, i.e. above $\sim$ 0.2 keV (Nousek & Lesser 1993).

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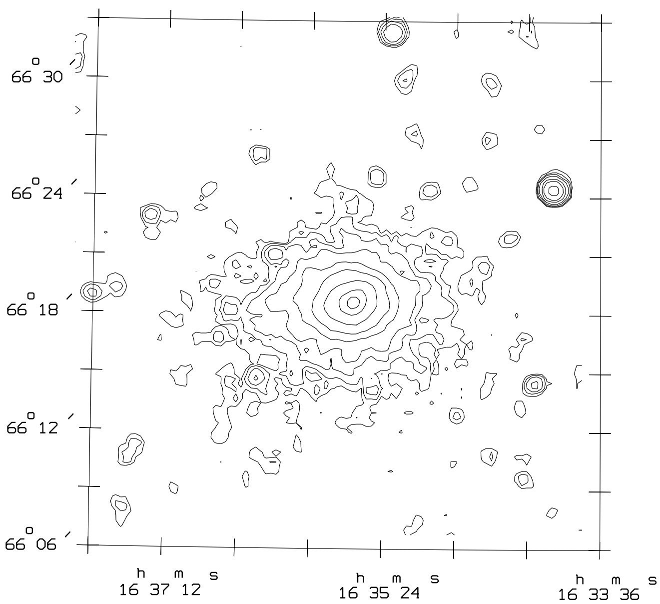


**Fig. 1.** ROSAT PSPC map of A 2218. This map is produced from the vignetting corrected image after background subtraction and exposure correction. Contour levels 5,7,10,15,30,50,100,200,270 are in units of $10^{-5}$ counts/sec/pixel$^2$. Coordinates are for the epoch 1950.

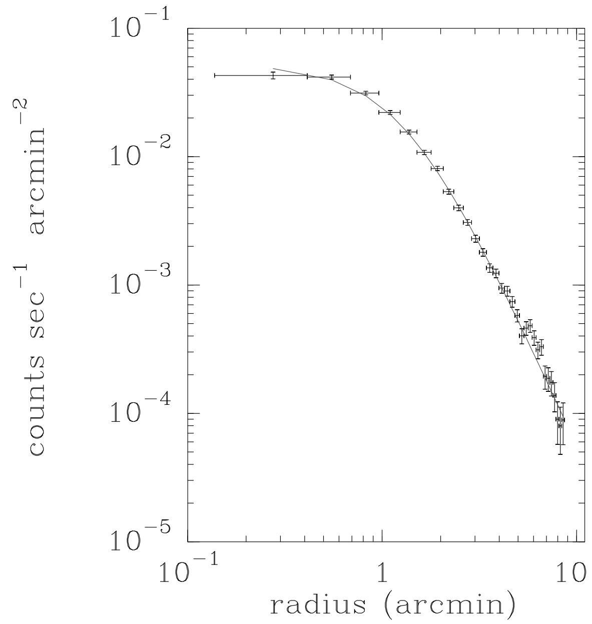


**Fig. 2.** Radial profile of the data, obtained from the raw image, divided by the exposure image before subtracting the background. The background is left as a free parameter in the fit to be determined. The solid line indicates the best fit corresponding to $\theta_c$ = 1.31′ and $\beta$ = 0.73. The reduced $\chi^2_{min}$ is 1.29.

In addition it has been reported that scattered solar X-rays have a strong influence on the 1/4 keV band, corresponding to channels 11-41 (Snowden & Freyberg 1993). Because of this we have first cleaned the light curve from the sharp count rate enhancements, erratic peaks etc., and then selected only the 42 to 201 pulse height channels. The poor attitude solutions are also excluded from the data, so that our final data set has a total effective exposure of 26699 seconds. We have prepared a mask showing the window support structure of the PSPC, and by means of rotation and translation we have fitted this mask to the actual position of the support structure. In order to exclude the background emission from the analysis we prepared a background image in the same energy range as the raw image by cutting out the regions around sources which are 8 $\sigma$ above the mean local background and then applying a spline fit to the obtained background image.

The raw data were then corrected for the mirror efficiency and the absorption by the window structure by means of subtracting the background from the raw image and dividing by the exposure map. The exposure map is generated by taking into account the energy response of the detector and weighting the instrument maps in the energy range 0.4 - 2 keV with the source spectrum in various channels. Thus we have obtained a “count-clean” image.

The X-ray map of A 2218 in coordinates of epoch 1950.0 is shown in Fig. 1. The first contour in the figure has a value 8 $\cdot\ 10^{-4}$, and the innermost contour circumferencing the cluster center is 4.32 $10^{-2}$ counts sec$^{-1}$ arcmin$^{-2}$. The center coordinates of the cluster, defined as the peak of the X-ray intensity after the source detection task, are found to be $\alpha_{1950}$ = $16^{\rm h}35^{\rm m}$ $39^{\rm s}.27$ and $\delta_{1950}$ = 66° 18′ 30″.8. In $\alpha_{1950}$ this differs by $2.^{\rm s}73$ = 16.32″ from the peak of the Einstein HRI image (Boynton et al. 1982) and $3.^{\rm s}53$ = 21.11″ from the Einstein IPC peak (Birkinshaw & Hughes 1994). Furthermore the difference from the Jones et al. (1993) values are $4.^{\rm s}27$ = 25.7″ in right ascension and 19.2 ″ in declination.

Next we have plotted an azimuthally averaged surface brigthness profile and determined the best fit parameters for an isothermal King profile of the form

$$S_x = S_0\ [1 + (\frac{\theta}{\theta_c})^2]^{-3\beta+1/2}\ . \qquad (1)$$

A Levenberg - Marquardt nonlinear least-squares fitting scheme (Press et al. 1992), modified to check also the goodness of the fit by means of calculating $\chi^2$-probability of the distribution, is used.

We obtain for the angular core radius $\theta_c$ = 1.31′ ± 0.15′ and the kinetic energy ratio $\beta$ as 0.73 ± 0.06. In Fig. 2 we display the radial profile obtained and its best $\chi^2_{min}$-fit. Confidence intervals of the fit are plotted in Fig. 3. In order to see the possible smoothing of the radial profile by the point spread function (PSF) we have calculated the PSF with an updated version of the subroutine (kindly supplied by S. Döbereiner). Deconvolution of the profile with this PSF affected the fit parameters insignificantly. This is mainly because we are dealing with the brightest part of the cluster. Regarding the value of $\beta$ the resulting radial profile is comparable to the mean of the $\beta$ values obtained from the same data by Squires et al. (1996).

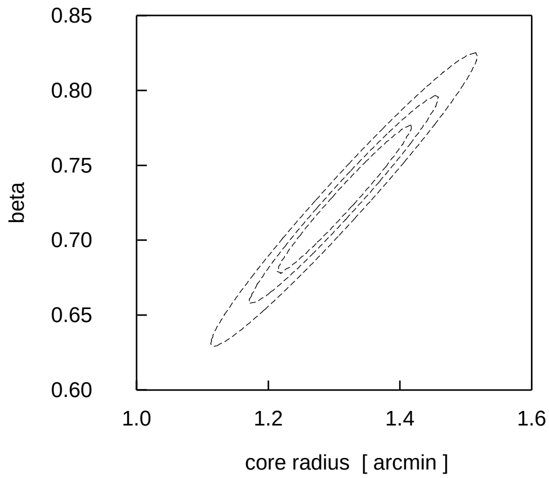


**Fig. 3.** Error ellipses for the parameters $\beta$ and $\theta_c$. Contours correspond to the confidence intervals of the parameters, derived from the covariance matrix, with probabilities 68 %, 90 % and 99 %, respectively.

Moreover we have also applied the code of Snowden (1995) to the data and prepared a background subtracted and exposure corrected image free from particle and non-cosmic X-ray background, for R4-R7 bands. The upper limit of the allowed master veto rate was 170 counts sec$^{-1}$. For this energy range 2001 particle background counts and 11514 background counts are modelled. No sign of strong long term enhancement contamination has been seen. Note that the coordinates of X-ray peaks from this analysis and the previous one are perfectly in agreement. Meanwhile using the final image (background subtracted) obtained with the Snowden's code another radial profile is plotted and the King profile parameters are determined as above. No significant variation in the fit parameters between the two methods have been seen.

### *2.2. Spectral analysis*

The X-ray spectra of the cluster are prepared by means of subtracting a background, about $3{\cdot}10^{-4}$ counts sec$^{-1}$ arcmin$^{-2}$, from the raw spectra. The particle background of the spectra is modelled as explained by Plucinsky et al. (1993). The allowed limit of the master veto rate was 170 counts sec$^{-1}$. Fitting the obtained spectra with the theoretical model spectra obtained with the Raymond-Smith code including galactic absorption and normal galactic chemical abundances, yielded a gas temperature of $k_BT_e$= 5.7 $\pm$ 1.2 keV, and within the errors no statistical significant evidence for any temperature variation over the cluster (see below) has been seen. This value is a little bit higher than the one obtained by Squires et al. (1996) and consistent with the 6.7 keV GINGA value (McHardy et al. 1990). However, the central electron density obtained from our analysis is smaller than obtained by Squires et al. (1996) . This may be due to their use of a temperature of 8 keV from ASCA instead of their fitted 3-5 keV, in order to calculate the central electron density.

**Table 1.** Derived parameters from X-ray analysis $^\star$

| Parameter | with 90 % confidence |
|---|---|
| $r_c$ | $(1.31\,' \pm 0.15\,')h_{75}^{-1}$ |
| | $(207 \pm 24)h_{75}^{-1}$ kpc |
| $\beta$ | 0.73 $\pm$0.06 |
| Temperature | 5.7 $\pm$ 1.2 keV |
| Luminosity | $(1.67 \cdot 10^{44})h_{75}^{-2}$ erg/sec |
| Luminosity distance | $742h_{75}^{-1}$ Mpc |
| Central electron density | $(4.3 \pm 1.7)\cdot 10^{-3}h_{75}^{1/2}$ cm$^{-3}$ |

$^\star$ Hubble parameter $H_0 = 75h_{75}$ km Mpc$^{-1}$s$^{-1}$, $q_0 = 0$.

In Fig. 4 we display the spectral fit to the data, which was extracted from a region of 10 arcmin in size about the cluster center. The best fit has a $\chi^2_{min}$ of 143 with 134 degrees of freedom. It is worth to note that exclusion of the channels below 42 affects the value of temperature obtained from the spectral fit by about 10 %. The hydrogen column density is found as $N_H$=$1.6{\cdot}10^{20}$ cm$^{-2}$, which is lower than the galactic value $3{\cdot}10^{20}$ cm$^{-2}$ (Dickey & Lockman 1990). Note that if we fix the $N_H$ to the galactic value together with a metallicity (relative to cosmic abundances) the temperature drops to 4.6 keV. On the contrary if we fix the temperature to the 8 keV ASCA value we still get $N_H$ values lower than the galactic one.

Integrating the detected flux, and using a Hubble parameter of $H_0 = 75h_{75}$ km Mpc$^{-1}$s$^{-1}$, and a deceleration parameter of $q_0$ =0, we obtain the luminosity distance of $D_L$=742 $h_{75}^{-1}$ Mpc, resulting in a luminosity of $L_x = 1.67 \cdot 10^{44}h_{75}^{-2}$ erg s$^{-1}$ in the 0.4-2.0 keV energy band. Using the angular diameter-redshift relation (Lang 1980)

$$\theta = \frac{\ell(1+z)^2}{D_L}, \tag{2}$$

where $\ell$ is the linear radius we obtain for the core radius $r_c$ =(0.207$\pm$ 0.024) $h_{75}^{-1}$ Mpc.

The total count rate of the detector is then found to be 0.308 counts s$^{-1}$. The energy flux in the 0.4 - 2.0 keV range is determined as $3.74 \cdot 10^{-12}$ erg cm$^{-2}$ s$^{-1}$, with a photon flux of 2.61 $\cdot$ $10^{-3}$ photons cm$^{-2}$ s$^{-1}$. We interpret the radiation coming from the cluster gas as thermal plasma emission with emission measure

$$EM = \int_V n_e^2 \; dV \; = \; \pi^{3/2} n_{e,o}^2 r_c^3 \frac{\Gamma(3\beta - 3/2)}{\Gamma(3\beta)}, \tag{3}$$

and express the electron density as a King profile (see Sect. 4). The central electron density then results as $n_{e,o}$ =(4.3 $\pm$ 1.7)$\cdot$ $10^{-3}h_{75}^{1/2}$ cm$^{-3}$ . This value is smaller than the Squires et al. value of $6.8{\cdot}10^{-3}$ cm$^{-3}$ (average of their four quadrants and scaled to our Hubble constant) because of the temperature value that they have used. In Table 1 we summarize all derived parameters. Even at 90 % confidence our parameter values for the core radius, central electron density and $\beta$ are not in accord

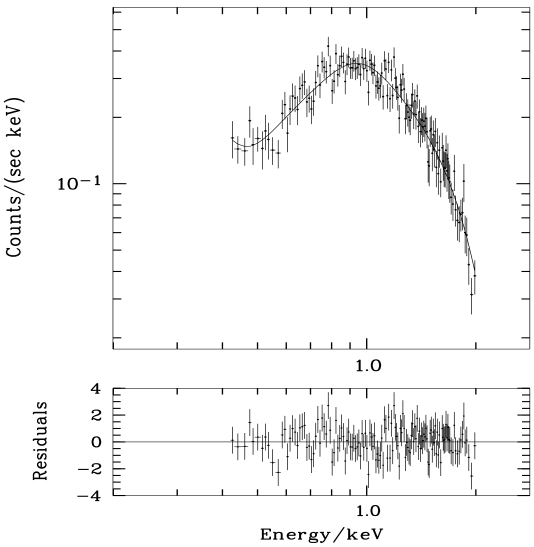


**Fig. 4.** Spectral fit of the data with Raymond-Smith model within 10 arcmin.

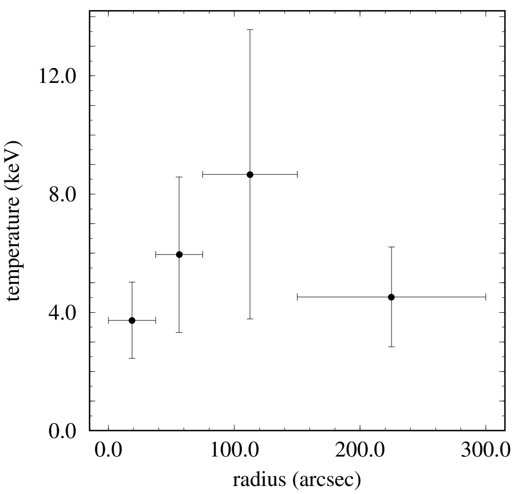


**Fig. 5.** Temperature profile of the data, obtained by fitting plasma model to the rings selected with various radius intervals.

with the earlier estimates of $0.15 h_{75}^{-1}$ Mpc for the core radius, 0.6 for $\beta$ and $6.3 \cdot 10^{-3} h_{75}^{1/2}$ $\mathrm{cm}^{-3}$ for the density, from Boynton et al. (1982) and Mc Hardy et al. (1990), which we have rescaled to our value of the Hubble constant.

To test the isothermality of the cluster gas we have divided the data into four radial rings between 0 - 75, 75 - 150, 150 - 300 and 300 - 600 skypixels with respect to the center of the cluster, and fitted the same X-ray spectrum as above, for each of the sectors seperately. The resultant temperature variation as a function of radius is displayed in Fig 5. No significant variation of the temperature as a function of radius is found.

## 3. Radio measurements

We used one feed of the 10.55 GHz multi-feed receiving system that has been installed in the secondary focus cabin of the Effelsberg 100-m telescope at two perfectly clear nights in 1993 to observe the cluster of galaxies A 2218. Technical details of the 10.55 GHz system and the data reduction technique are described by Schmidt et al. (1993). This system relies on the application of the "software beam switching technique" (Morsi and Reich, 1985), which requires the highest possible total power stability of the individual receiver channels. The data have been calibrated in respect to 3C286 assuming a flux density of 4.5 Jy. The angular resolution of the Effelsberg 100-m telescope is $69''$ (HPBW) and the conversion of main beam brightness temperature $T_B$ and flux density S is $T_B/S$ = 2.4 K/Jy at 10.55 GHz. The aim of the observations of A 2218 where thus two-fold: firstly to check on the receiver stability, whose results have been already published by Reich (1995), and secondly to search for the SZ effect.

Briefly, we have mapped two $2' \times 10'$ large fields centered on the cluster A 2218. The two fields were arranged orthogonally in declination and right ascension (see Figure 6) covering the maximum of the ROSAT X-ray emission. The field elongated in declination was mapped 53 times, the field elongated in right ascension 25 times. Each of these maps had seven $10'$ long scans separated by $20''$. The integration time for each scan was exactly one minute. We corrected for linear baseline effects and averaged the left-hand and right-hand circularly polarized channel from all coverages. Each gridpoint in the sum of all declination maps had 212 s of integration time. With a system temperature of 50 K, a bandwidth of 300 MHz and an aperture efficiency of 42% we calculate a theoretical rms-noise of about 166 $\mu$Jy/beam in the case of no confusion and in the absence of any limitation of the receiver stability. Due to the smaller number of coverages of the right ascension field, the noise is larger than in the declination field.

The final map is shown in Figure 6, where also a section of a 1.4 GHz VLA map of Moffet & Birkinshaw (1989) is included to indicate known individual confusing sources, whose properties are summarized in Table 2. We clearly detect source A and B. Source B is the brightest source in our map and has a flux density of 3.8 mJy in agreement with the previous measurements of Andernach et al. (1988). Source A has a flux density of about 2.6 mJy which is a factor of 2 smaller as measured by Andernach et al. (1988). Variability is typical for compact flat spectrum extragalactic radio sources. We measured south of the weak sources at declination $66^o16'$ a rms-noise of 180 $\mu$Jy/beam. The difference to the expected rms-noise can be almost completely attributed to the source confusion component of 80 $\mu$Jy/beam. This value for confusion is in excellent agreement with the expectation for a 100-m telescope at 10.55 GHz based on the work of Condon et al. (1989).

We used the declination strip from the map shown in Fig. 6 and applied the unsharp masking technique of Sofue and Reich (1979) with a convolving beam size of $2'$. This method is included in the data reduction package for continuum mapping ob-

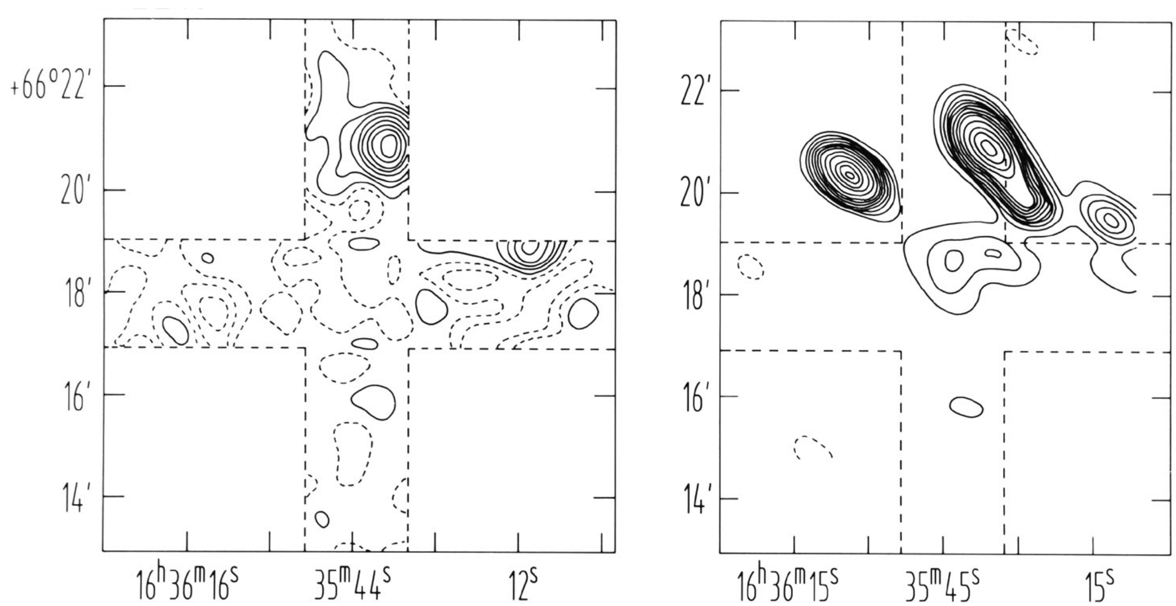


**Fig. 6. a** 10.55 GHZ single feed observations of two 2′ × 10′ strips in declination and right ascension across A 2218. Contours are 0.4 mJy/beam (2.2×rms-noise) apart. The zero level and the negative contours are shown dashed. **b** Section of the 1.4 GHz map of A 2218 (beam of 59″ × 33″) as observed by Moffet & Birkinshaw (1989). The two cross-like oriented strips observed at 10.55 GHz are marked. Contours are 0.2 mJy/beam apart.

**Table 2.** Radio sources close to the microwave diminution center ⋆

| Source | $\alpha_{1950}$ h m s | $\delta_{1950}$ ° ′ ″ | $S_{1.44}$ mJy | $S_{4.86}$ mJy | $S_{10.55}$ mJy | $S_{10.7}$ mJy | $S_{15}$ mJy | Identification |
|---|---|---|---|---|---|---|---|---|
| A | 16 35 08 | 66 19 22 | 1.25[a] | 2.82[a] | 2.6[d] | 5.0[b] | 1.69[c] | 12[a], A 2218.1a[b], 1a[c] |
| B | 16 35 35 | 66 20 46 | 8.12[a] | 3.66[a] | 3.8[d] | 3.8[b] | 0.91[c] | 16[a], A 2218.1b[b], 1b[c] |
| C | 16 36 03 | 66 20 26 | 7.61[a] | 4.21[a] | – | 1.5[b] | 1.83[c] | 21[a], A 2218.1c[b], 1c[c] |

⋆ Coordinates and fluxes of sources at different GHz frequencies and corresponding spectral indices. Identification of the sources are according to the original designations of the given references.
[a] Moffet & Birkinshaw, 1989. [b] Andernach et al., 1988. [c] Jones et al., 1993. [d] This work.

servations with the Effelsberg telescope and often applied when comparing these maps with those from synthesis telescopes with missing zero spacings. The method results in a decomposition of the data into low and high spatial frequencies. Jones et al. (1993) have demonstrated that it is essential for measuring the SZ effect with great accuracy to separate the high spatial frequency components from the low spatial frequency data, which show the SZ diminution. This method is suitable to separate the total emission map into one map containing the small scale contributions from unresolved point sources and noise and a second map showing some underlying large scale emission. The sum of both decomposed maps is the original map. From each of these three maps we calculate 40″ wide central cuts in declination at fixed right ascension $16^h35^m44^s$ which are shown in Figs. 7a,b and c. The declination cuts from the original map (Fig. 7a) and the small scale map (Fig. 7b) have lower (by a factor 1.7) rms-noise of 106 $\mu$Jy/beam, or 205 $\mu$K/beam, than the corresponding maps due to the integration over 40″ in right ascension. The declination cut calculated from the large scale map shown in Fig. 7c clearly reveals the SZ radio flux density diminution in A 2218, with the minimum of about $-280$ $\mu$Jy, corresponding to a radiation temperature diminution of $-680$ $\mu$K, reflecting in width and position (within the determination uncertainties) exactly the center of the X-ray emission from A 2218. Smoothing by the 69″ beam results in a decrease of the measured amplitudes by about 10 percent. We therefore quote for the radiation temperature diminution $-750$ $\mu$K. The applied unsharp masking method does not give formal errors that can be applied for the derived SZ diminution. We have therefore varied the input parameters used for decomposition covering the convolving beam size between 1.8′ and 2.2′, and the number of iterations between 3 and 10. The SZ diminution then is measured between $-670\,\mu$K and $-820\,\mu$K. Therefore a conservative estimate of the error is about $\pm 200\,\mu$K, and predominantly due to uncertainties to determine the zerolevel at

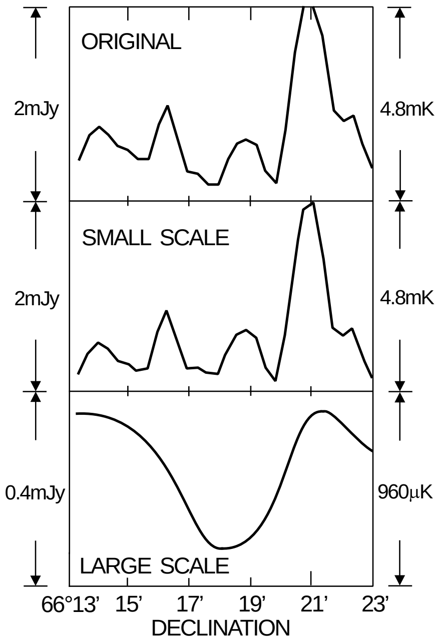


**Fig. 7a–c.** $40''$ wide declination cuts central cuts in declination at fixed right ascension $16^h35^m44^s$ calculated **a** from the original 10.55 GHz map shown in Fig. 6, **b** from the small scale map, and **c** from the large scale map, after applying the unsharp masking technique of Sofue and Reich (1979) with a convolving beam width of $2'$.

the edges of the cut and the parameters of the decomposition method.

We have clearly detected a SZ diminution towards the cluster of galaxies A 2218 at a frequency of 10.55 GHz with a strength of $\Delta T = -(750 \pm 200)$ $\mu$K at the position of the maximum of the ROSAT X-ray emission.

The size and the location of the diminution are in excellent agreement with those reported by Jones et al. (1993) using the Ryle telescope at 15 GHz. They report a strength of the central diminution based on model fits between 1.1 mK and 0.6 mK.

## 4. Discussion

Using the physical parameters from the analysis of the ROSAT X-ray observation of A 2218 we calculate the expected SZ diminution. Schlickeiser (1991) has shown that the free-free emission from a possible cooling flow in A 2218 is negligibly small. Apart from the disturbing influence of individual radio sources in the field the brightness temperature at 10.55 GHz is given by

$$T_b = -2yT_R \quad (4),$$

with the Comptonization parameter

$$y = \frac{\sigma_T}{m_e c^2}\int_{-\infty}^{\infty} d\ell \; p_e = \frac{\sigma_T k_B T_e}{m_e c^2}\int_{-\infty}^{\infty} d\ell \; n_e(\ell) \quad (5)$$

calculated in the last step for an isothermal cluster electron gas. We calculate the expected SZ diminution (4)-(5) by assuming an isothermal King profile for the cluster electron gas, i.e.

$$n_e = n_{e,o}[1 + (\frac{R}{r_c})^2]^{-3\beta/2} \quad (6),$$

with

$$R = \sqrt{x^2 + \ell^2} \quad (7)$$

where

$$x(\alpha,\delta) = \sqrt{225(\alpha_0 - \alpha)^2\cos^2(\delta_0) + \; (\delta - \delta_0)^2} \quad \text{arcmin} \quad (8)$$

denotes the angular distance from the cluster center $(\alpha_0, \delta_0)$. We use the parameter values $(n_{e,0}, r_c, \beta, T_e)$ determined from the fit to the ROSAT X-ray measurement (see Table 1).

Integration of the density profile (6) used in Eq. (5) along the line of sight ($\ell$) yields for the Comptonization parameter

$$2y = Y_0[1 + (\frac{x}{r_c})^2]^{-3\beta/2+1/2} \quad (9)$$

with

$$Y_0 = \frac{2\pi^{1/2}\sigma_T k T_e n_{e,0} r_c}{m_e c^2}\frac{\Gamma(\frac{3\beta-1}{2})}{\Gamma(\frac{3\beta}{2})}$$

$$= (1.29 \pm 1.08)\cdot 10^{-4} {h_{75}}^{-1/2} \quad (10),$$

The 90 percent confidence error on the value of $Y_0$ is calculated by the sum of the relative 90 percent confidence errors in the X-ray parameters given in Table 1. The maximum expected SZ dip thus is

$$T_{b,max} = -Y_0 T_R = -(349 \pm 293){h_{75}}^{-1/2} \; \mu\,\text{K} \quad (11).$$

The difference between the measured signal ($-750 \pm 200$ $\mu$K) and the modelled signal is about a factor of 2 but within two 90 % confidence errors. Note that, using the ASCA temperature value of 8 keV and the corresponding central electron density roughly doubles the amplitude of the modelled SZ dip, which is still consistent with our radio determination of $\Delta T = -(750 \pm 200)\mu K$.

Calculating the ratio between the expected and our measured maximum SZ diminution

$$f_U \equiv \frac{T_{b,max}}{\Delta T_{10.55\;GHz}} \quad (12),$$

we obtain values between

$$\frac{0.059}{h_{75}^{1/2}} \le f_U \le \frac{1.167}{h_{75}^{1/2}} \quad (13).$$

As the range of ratio values (13) shows, at a significance level of 90 percent the ROSAT X-ray and our radio measurements are consistent. Moreover, neglecting any other systematic uncertainties (see the discussion in Inagaki, Suginohara and Suto 1995) the restriction (13) indicates that with 90 percent confidence any value of the Hubble constant between $0.0035 \le h_{75} \le 1.36$, corresponding to 0.3 km Mpc$^{-1}$ s$^{-1}$ $\le$ H$_0$ $\le$ 102 km Mpc$^{-1}$ s$^{-1}$, is consistent with the measurements.

## 5. Conclusions

We have reported new measurements of the SZ diminution of $-(750 \pm 200)$ $\mu$K towards the cluster of galaxies A 2218 performed at 10.55 GHz with the Effelsberg 100-m radio telescope and used ROSAT X-ray measurements for the analysis. Analysing the ROSAT data we determine the X-ray parameters of the cluster such as core radius, $\beta$, luminosity, distance and central electron density. We find that an isothermal King distribution for the cluster gas fits the radial distribution of the X-ray surface brightness well. The assumption of isothermality is in accord with the spectral analysis of the X-ray data. Our parameters differ significantly from previous X-ray studies. The ROSAT data analysis implies a SZ dip of $-(349 \pm 293) {h_{75}}^{-1/2}$ $\mu$K. The width and position of the measured SZ diminution are in excellent agreement with the expectations calculated from the X-ray analysis. At the 90 percent confidence level the measured strength of the diminution is consistent with the expected diminution calculated from the X-ray parameters. Our measurements confirm the cosmological origin of the isotropic 2.7 K microwave background radiation. A 90 percent confidence upper limit to the Hubble constant of $H_0 \leq 102$ km Mpc$^{-1}$ s$^{-1}$ is derived.

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