Submillimeter detection of the Sunyaev - Zel'dovich effect toward the most luminous X-ray cluster and its cosmological implications

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Contents

1 Breaking the cosmological degeneracy

Many cosmological models are known to be more or less successful in reproducing the structure at redshift $z \sim 0$ *by construction*.

$$\Downarrow$$

This is because the models have still several degrees of freedom or *cosmological parameters* which can be appropriately *adjusted* to the observations at $z \sim 0$ $(\Omega_0, \sigma_8, h, \lambda_0, b(r, z))$.

How to break the degeneracy
among the viable models ?

$$\Downarrow$$

Wider: increase the statistics from wide-field surveys (SDSS, PLANCK, ...)

Deeper: observe higher redshifts

Different bands: cm, mm and submm bands in addition to the optical and X-ray bands.

(Viana & Liddle 1996; Eke, Cole, & Frenk 1996; Barbosa, Bartlett, Blanchard, & Oukbir 1996; Fan, Bahcall, & Cen 1997; Kitayama, Sasaki & Suto 1998; Bahcall, & Fan 1998)

$\star$ The Sunyaev-Zel'dovich effect

Inverse Compton scattering of the CMB photon by the high temperature electron gas in clusters

$\star$ thermal SZ flux

$$\Delta I_\nu^{\rm th} = i_0 y \frac{x^4 e^x}{(e^x-1)^2}\left(x \coth\frac{x}{2} - 4\right) = i_0 y \; g(x)$$

$$i_0 \equiv 2\frac{k^3 T_{\rm CMB}^3}{h^2 c^2} = 2.6\times 10^{-15} \mathrm{erg/s/cm^2/Hz/str}$$

$$= 2.2\times 10^4 \mathrm{mJy/arcmin^2}$$

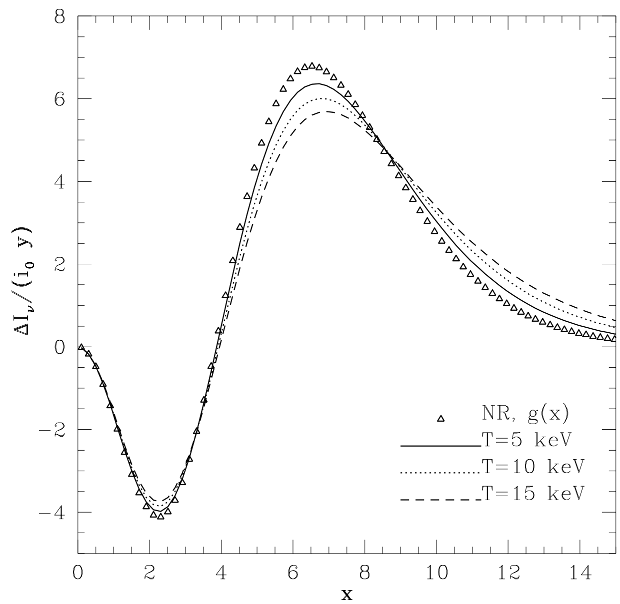

Figure 1: Spectral feature of the Sunyaev-Zel'dovich flux. Independent of sources nor z !

Negative source for $\lambda > 1.38$mm ($\nu < 218$GHz)

Positive source in submm band

⋆ Breaking the degeneracy in soft X-ray number counts using the SZ number counts (CDM models)

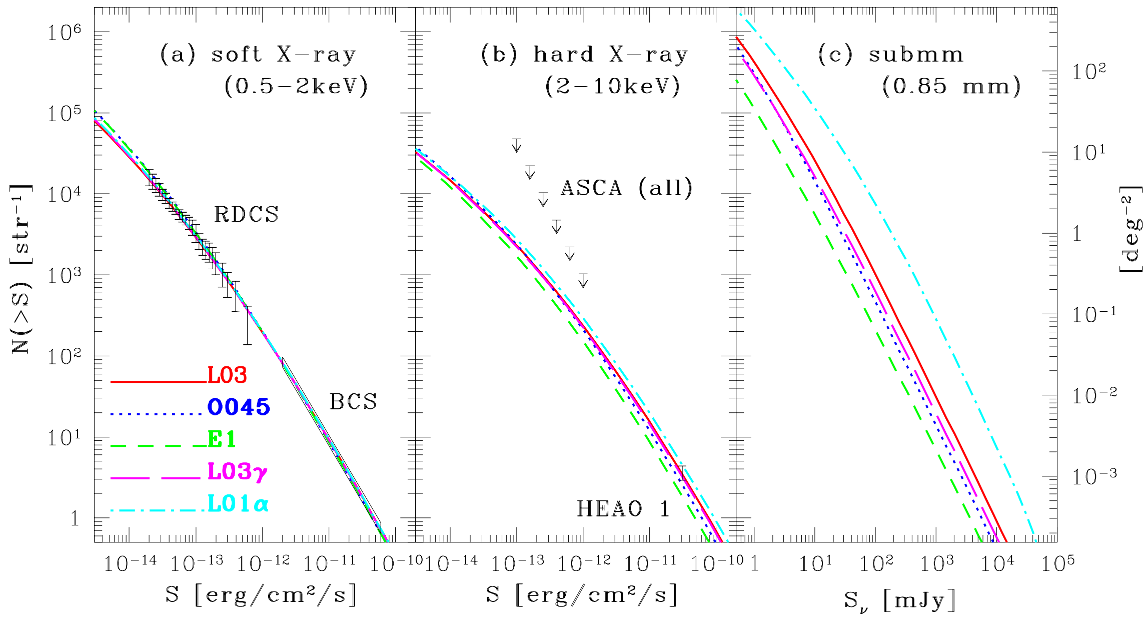

Figure 2: (a) soft X-ray (0.5-2.0 keV), (b) hard X-ray (2-10 keV), and (c) submm (0.85 mm) bands. (Kitayama, Sasaki & Suto, PASJ, 1998, 50, 1).

⋆ Why submm number counts

New: no unambiguous detection yet

Feasible: new facilities (SCUBA, BIMA, PLANCK, LMSA)

Complementary: orthogonal information to radio/optical/X-ray data → distance indicator, H_0, Ω_0, λ_0, peculiar velocity field

$\star$ σ_8 vs. Ω_0 in CDM models ($n = 1$, $h = 0.7$)

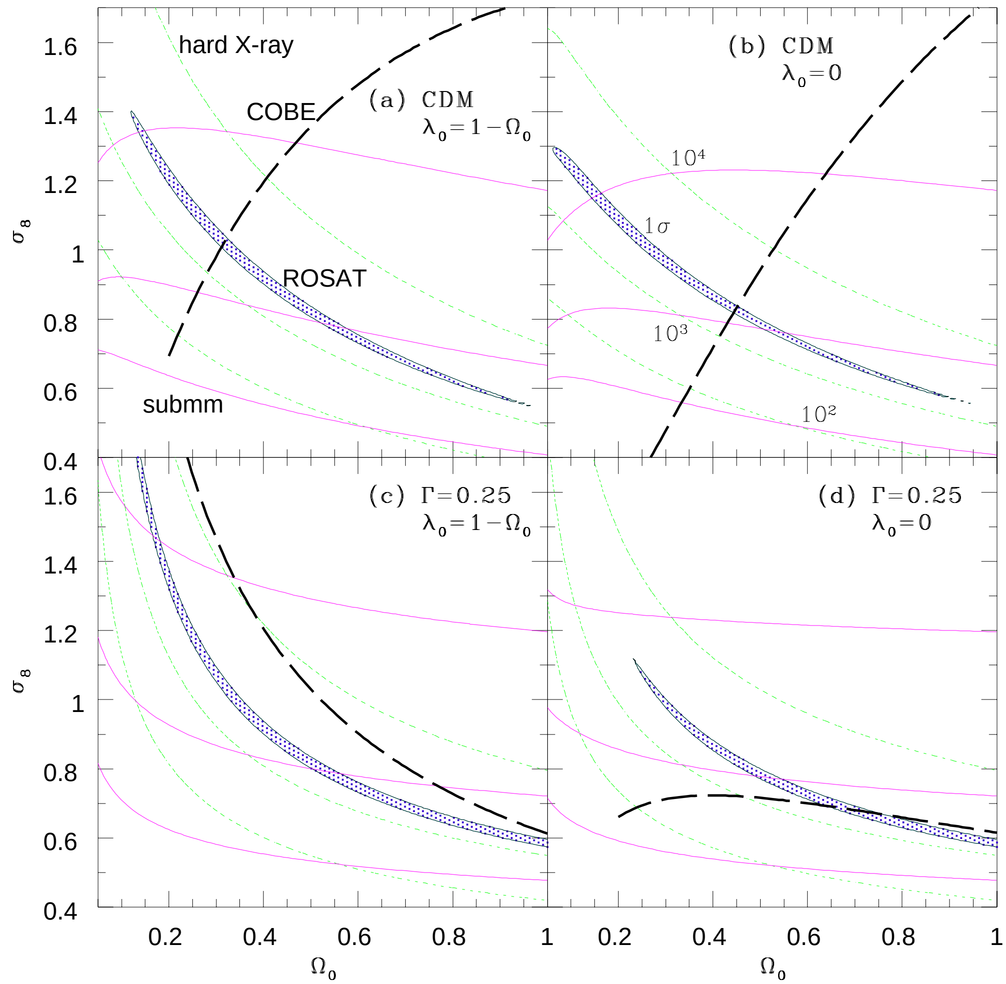

Figure 3: Shaded regions represent the 1σ significance contours derived in KS97 from the soft X-ray (0.5-2 keV) Log N - Log S. Dotted and solid lines indicate the predicted contours of the number of clusters in the hard X-ray (2-10 keV) band at $S = 10^{-13}$ erg cm^{-2} s^{-1} in the submm (0.85 mm) band at $S_\nu = 10^2$mJy. (Kitayama, Sasaki & Suto, PASJ, 1998, 50, 1).

2 SZ observation of RXJ1347

1998 March 4-14, May 19-21 at Nobeyama, Japan
1998 May 30-31 at JCMT/SCUBA, Hawaii

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cluster	z	θ_c [arcsec]	$\Delta I_\nu(0)$ at 350GHz
RXJ1347–1145	0.45	8.4 ± 1.8	$7.1 \pm 1.7 [h_{50}^{-1/2}$mJy/beam]
CL0016+16	0.555	51	$1.9^{+0.3}_{-0.1}$
A2163	0.201	72 ± 3	4.5 ± 0.3
A2218	0.171	60 ± 12	1.2 ± 0.3
Coma	0.0235	630 ± 36	1.1 ± 0.1

detector	frequency	FWHM	integ. time	noise [mJy/beam]
Nobeyama	21GHz	$76''$	25min	1.9
Nobeyama	43GHz	$40''$	30min	4.0
Nobeyama	150GHz	$12''$	50min	3.0
SCUBA	350GHz	$14''$	150min	8.0

⋆ R-band and X-ray image of RXJ 1347-1145

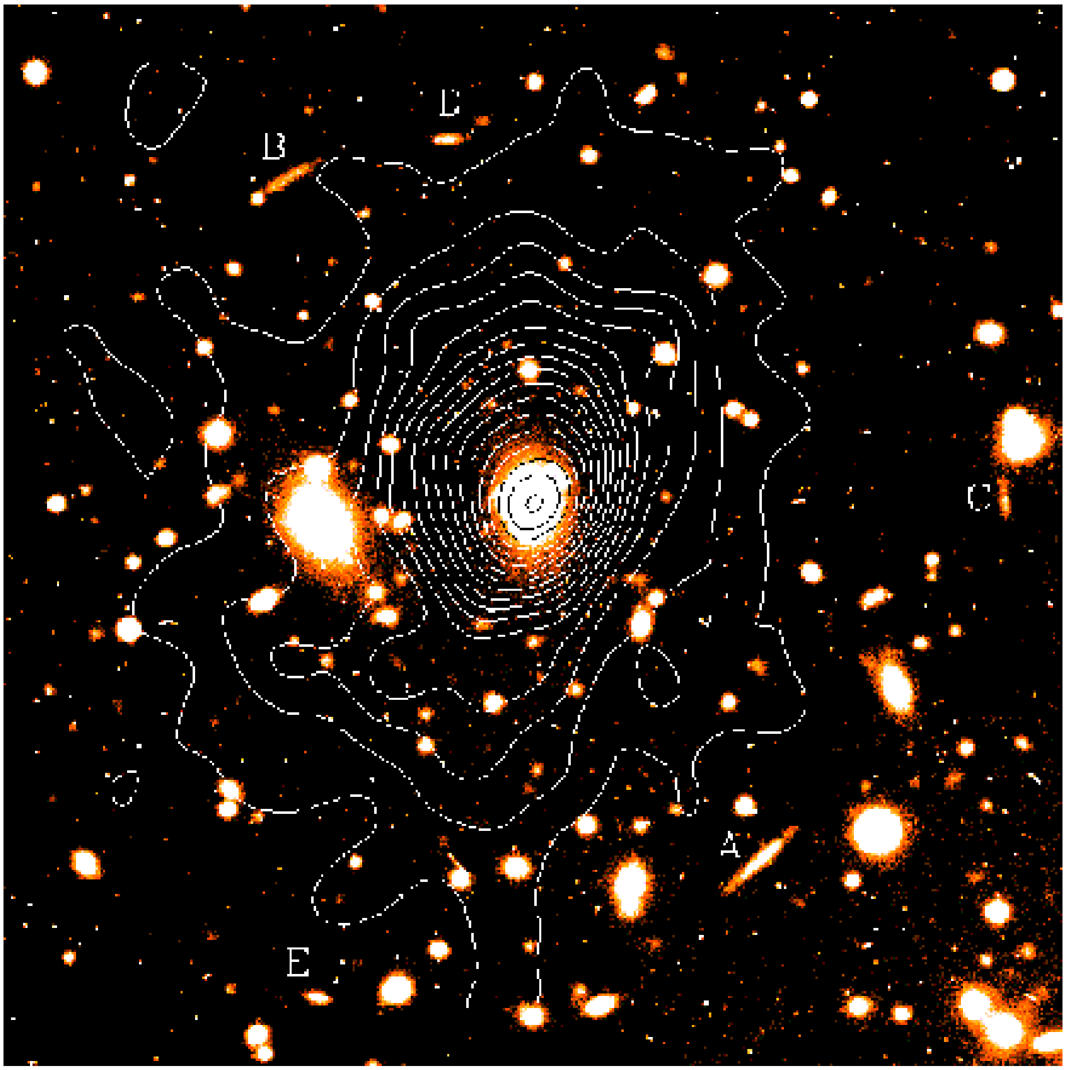

Figure 4: X-ray flux contour (ROSAT/HRI) is overlaid on the R-band image (ESO NTT). (Schindler et al. A&A 1997, 317, 645.)

⋆ Radial profile of RXJ1347-1145 at 21GHz and 43 GHz

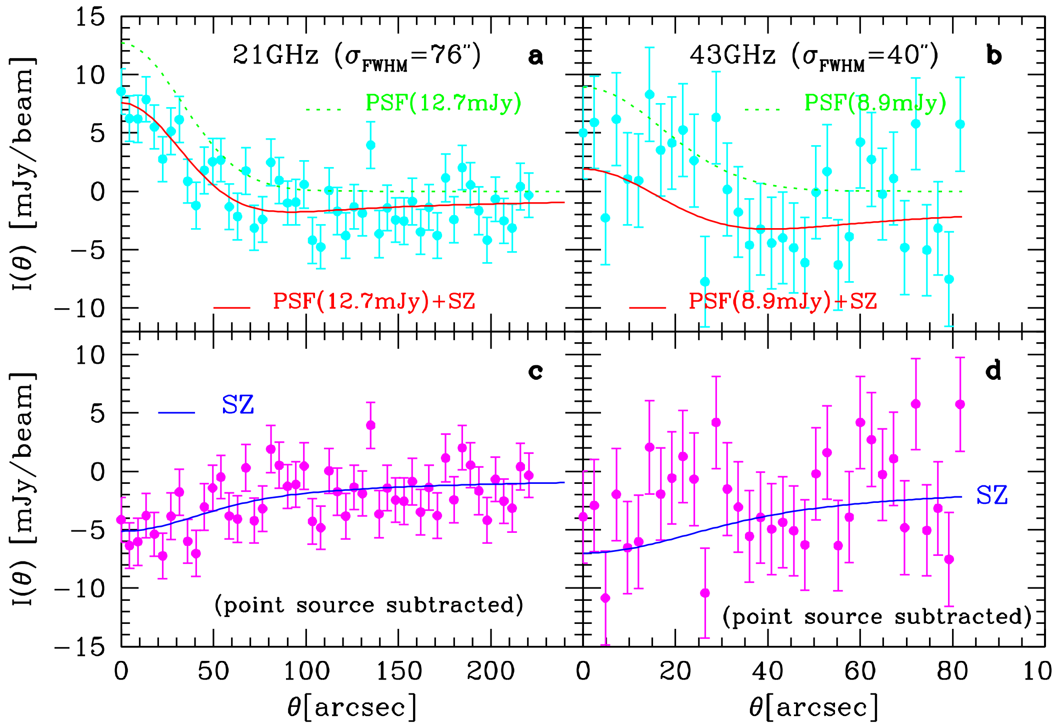

Figure 5: Radial intensity profile towards RXJ1347 at 21 (left panels) and 43 (right panels) GHz observed at NRO. (Komatsu et al. 1999, ApJ, 561, L1)

⋆ Energy spectrum of the central point source

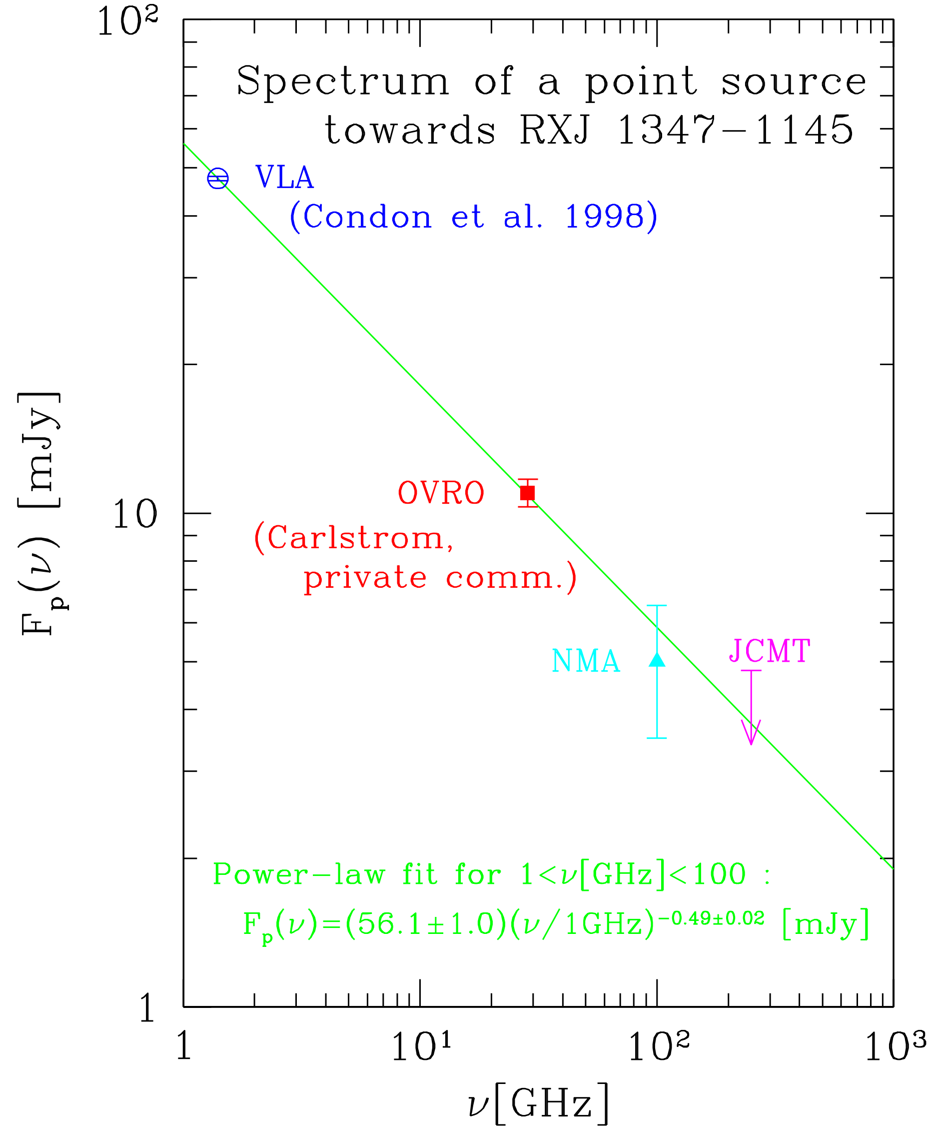

Figure 6: Energy spectrum of the central point source at the position of RXJ 1347-1145.(Komatsu et al. 1999, ApJ, 561, L1)

⋆ Submm and X-ray image of RXJ 1347-1145

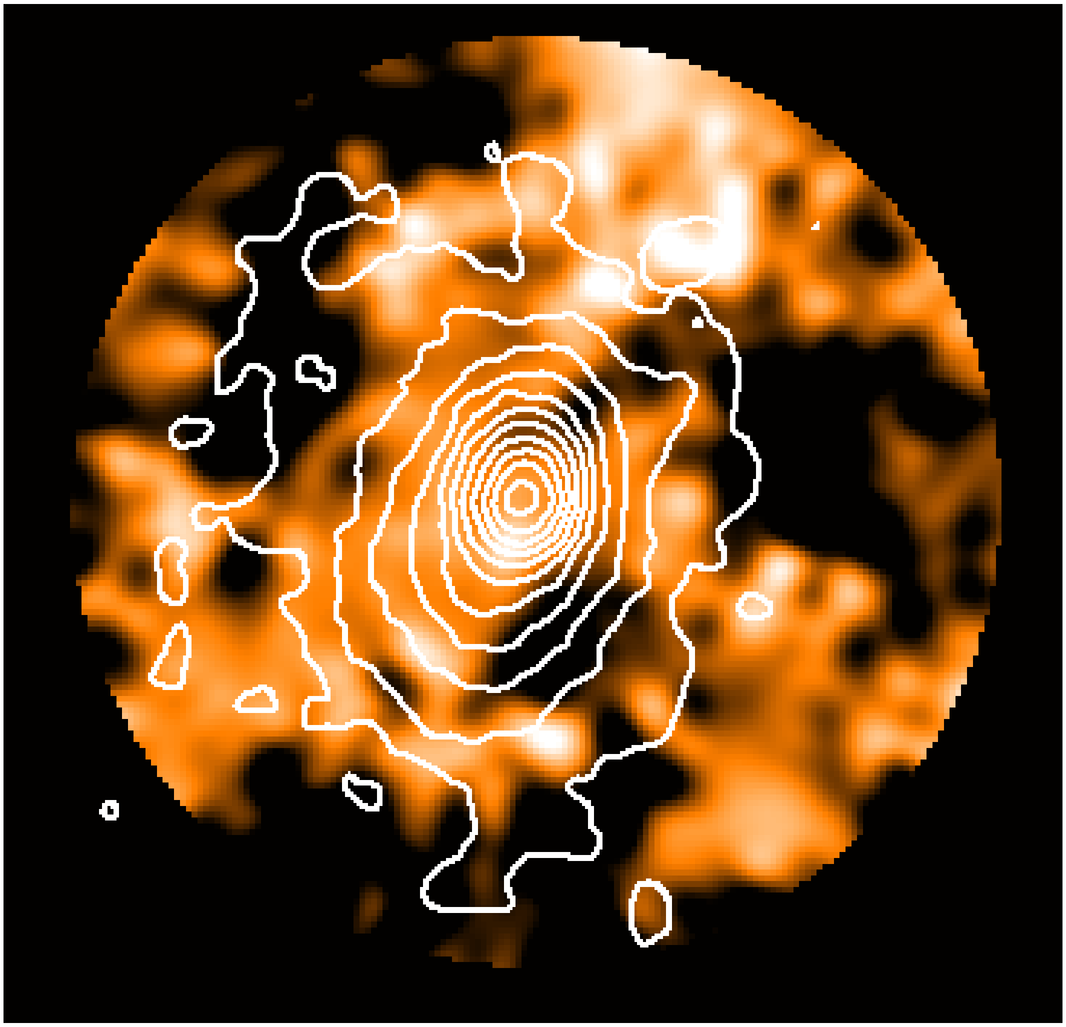

Figure 7: 350 GHz SCUBA map of RXJ1347-1145, which is overlaid by X-ray contours of the ROSAT-HRI data. SCUBA and HRI image is smoothed with a Gaussian filter of $\sigma_{\rm FWHM} = 6$ and $5''$, respectively. (Komatsu et al. 1999, ApJ, 561, L1)

⋆ Radial profile of RXJ1347-1145 at 350 GHz

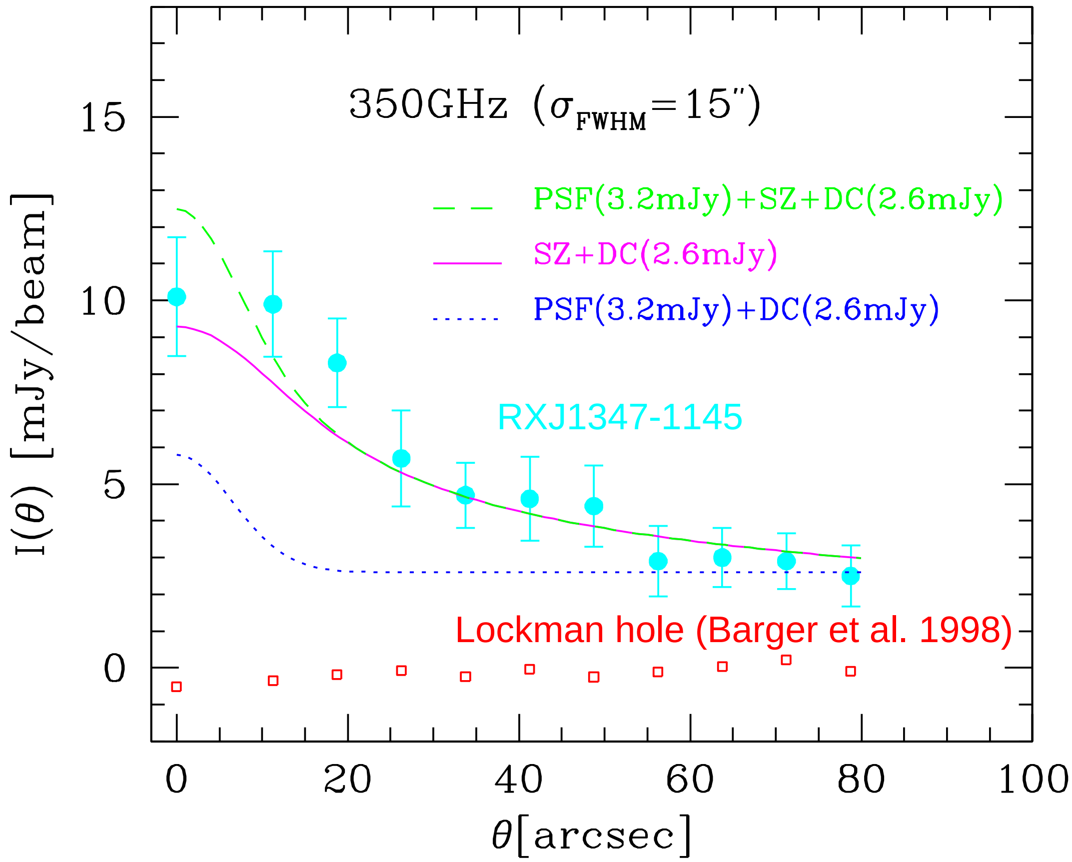

Figure 8: Radial intensity profile towards RXJ1347 at 350GHz observed at JCMT/SCUBA. (Komatsu et al. 1999, ApJ, 561, L1)

⋆ Corrected radial profile at 350 GHz

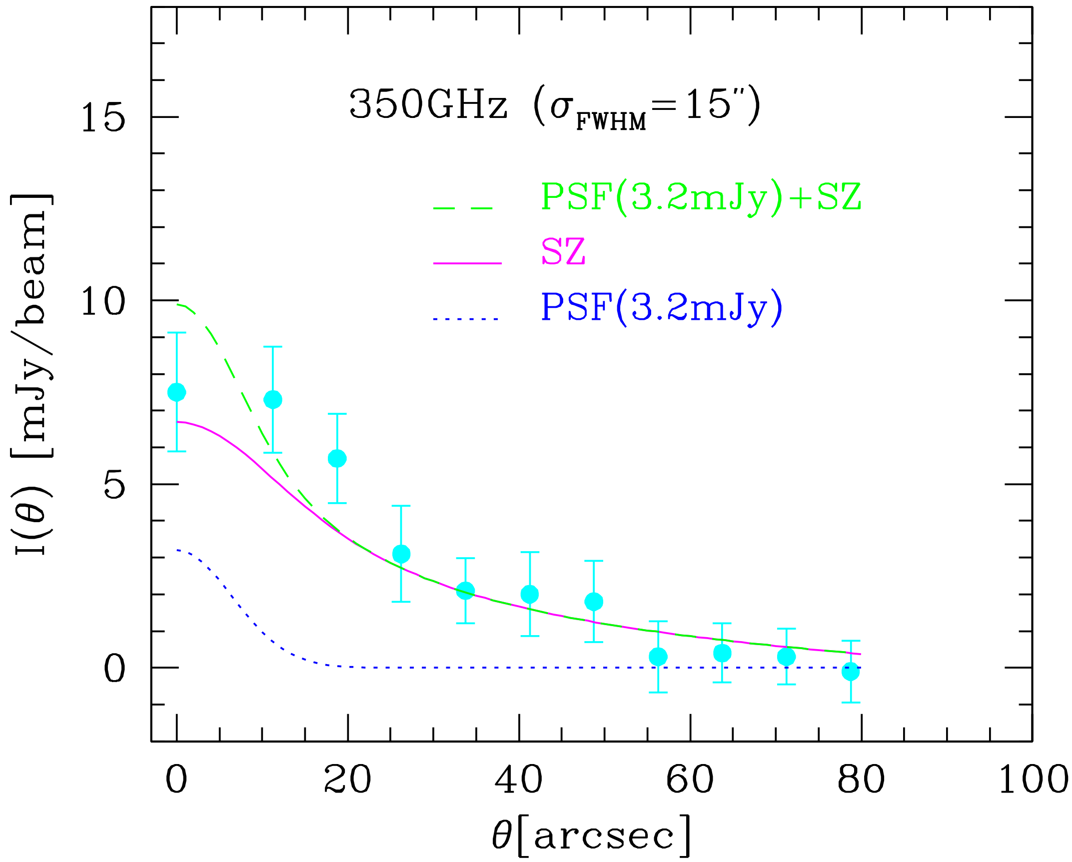

Figure 9: Radial intensity profile towards RXJ1347 at 350GHz observed at JCMT/SCUBA.(Komatsu et al. 1999, ApJ, 561, L1)

⋆ Confidence level contour ($T_e - \theta_c$)

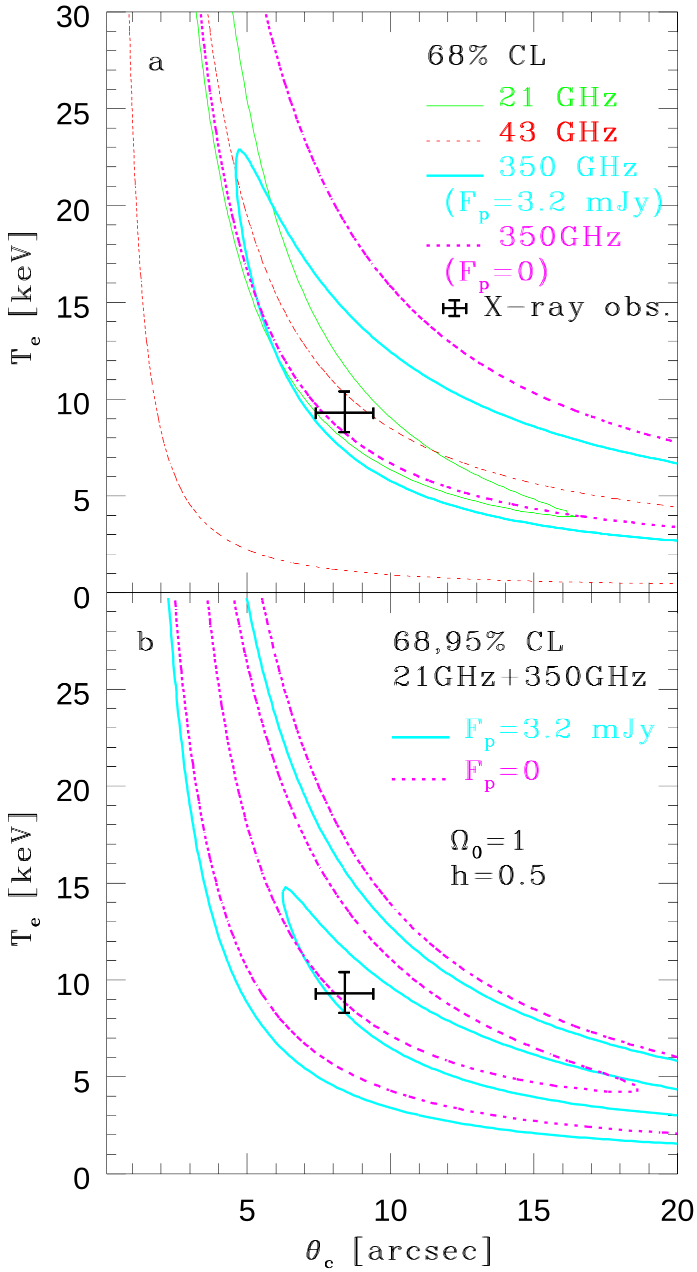

Figure 10: Confidence contours on the gas temperature T_e and the core radius θ_c from data analysis at 21, 43, and 350 GHz. (Komatsu et al. 1999, ApJ, 561, L1)

⋆ Confidence level contour ($y_0 - \theta_c$)

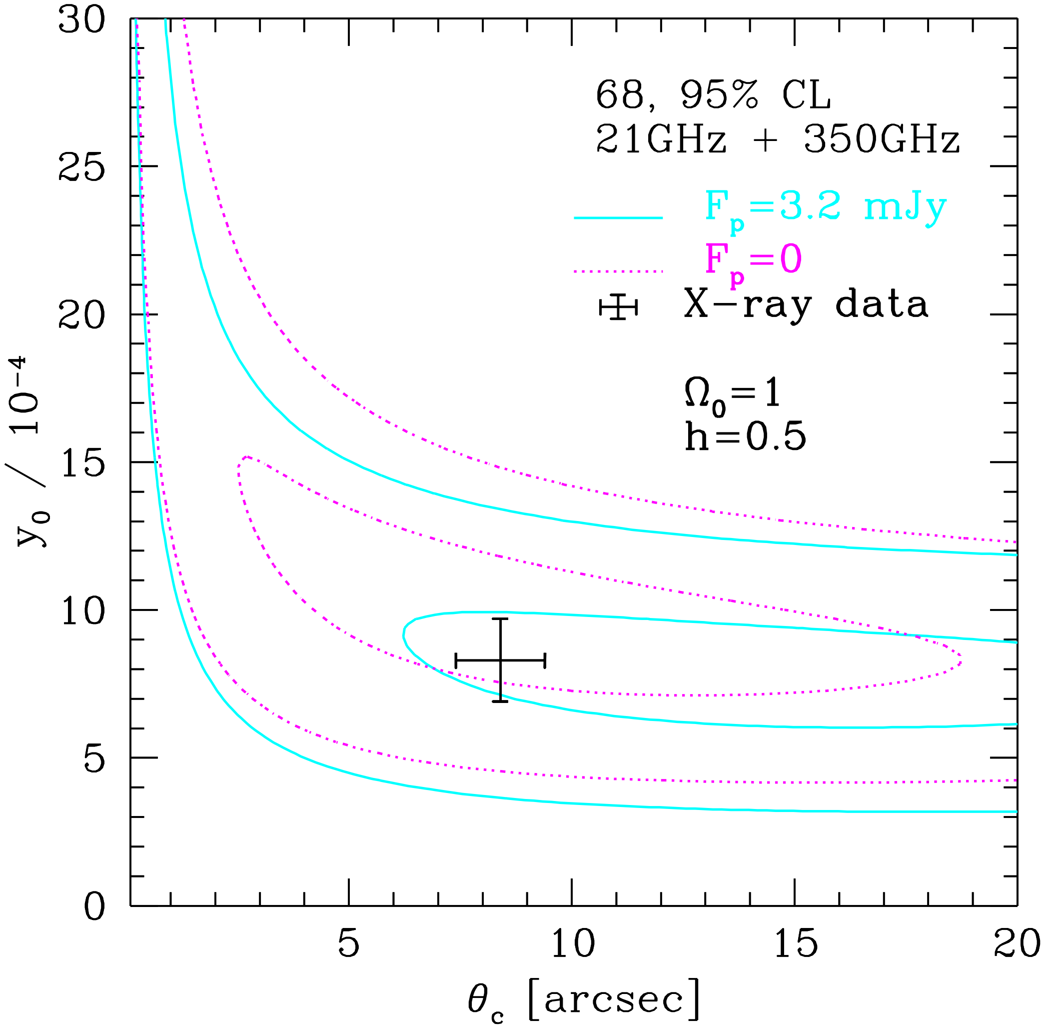

Figure 11: Confidence contours on the central y-parameter y_0 and the core radius θ_c from combined data analysis at 21 and 350 GHz. (Komatsu et al. 1999, ApJ, 561, L1)

3 Cosmological implications

⋆ H_0 from the SZ effect toward RXJ1347 [Preliminary]

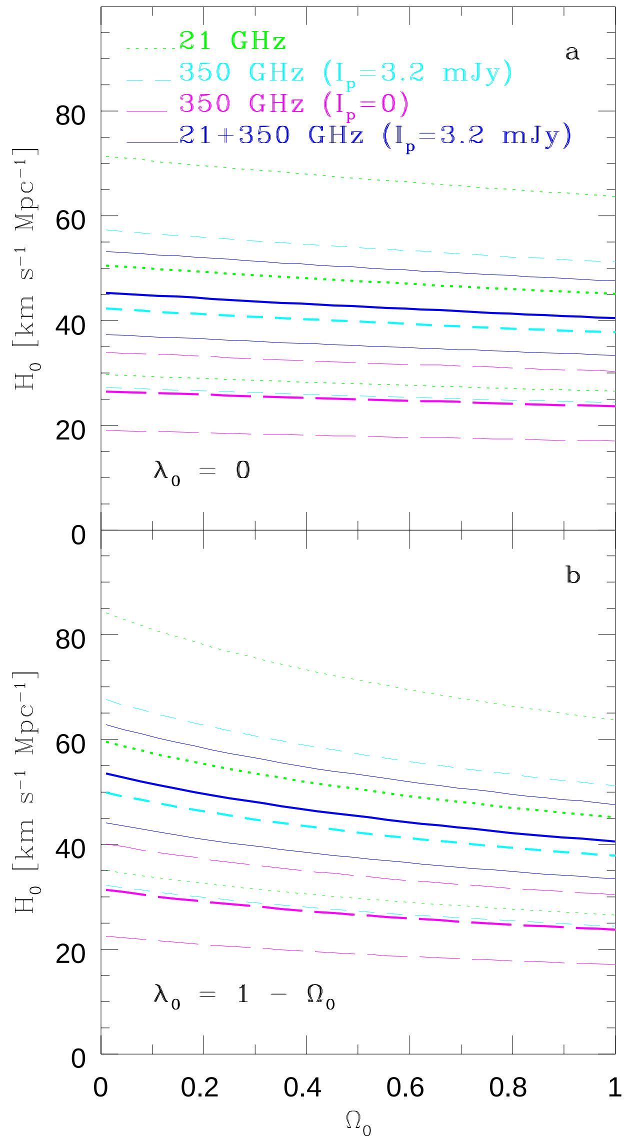

Figure 12: The Hubble constant estimated from RXJ1347 observation at 21 and 350 GHz as a function of Ω_0. Thick and thin curves indicate the best fit value and its 1σ uncertainty, respectively. (Komatsu et al. 1999, ApJ, 561, L1)

⋆ Peculiar velocity of RXJ1347 [Preliminary]

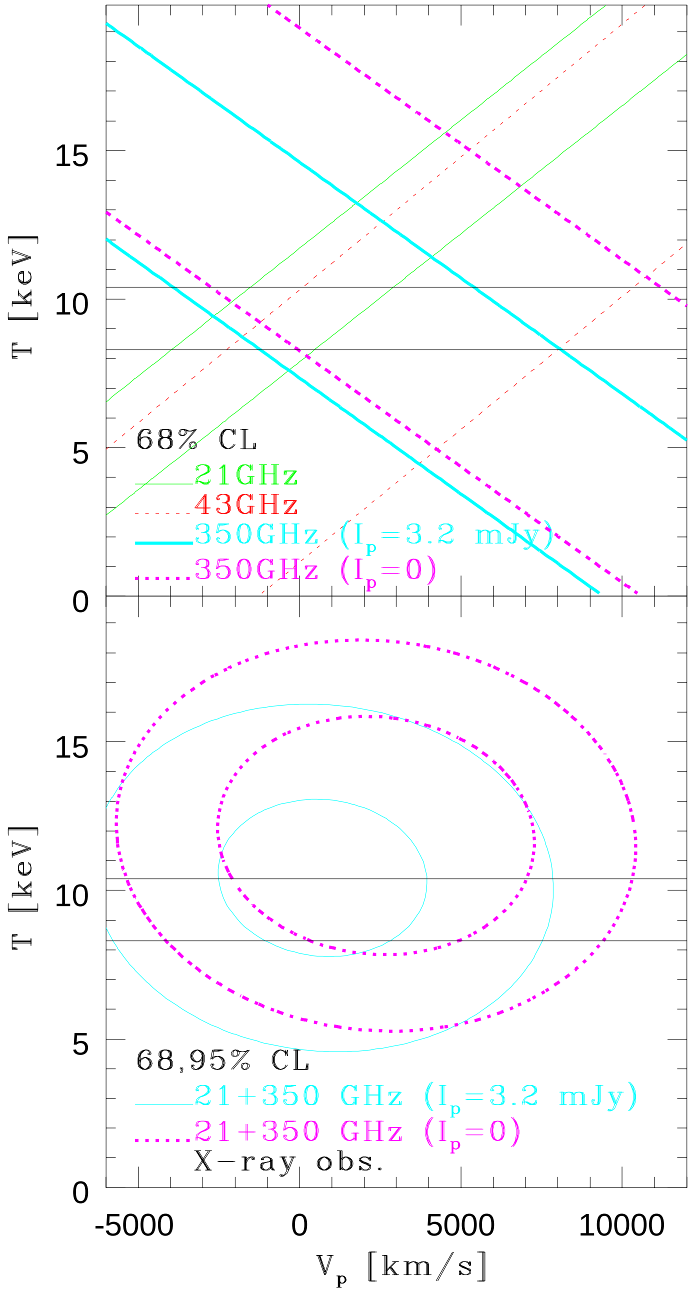

Figure 13: The peculiar velocity of RXJ1347 estimated from the combined analysis of the kinematic and thermal SZ effect at 21 and 350 GHz. (Komatsu et al. 1999, ApJ, 561, L1)

4 Conclusions

⋆ Previous claims of the SZ temperature increment were based on the measurement of the total flux alone.

→ might be seriously contaminated by the dust in our Galaxy and by submm sources in the field, and thus difficult to identify the SZ signal from the total flux.

⋆ We have sucessfully detected the intensity profile of the cluster RXJ 1347-1145 at 350 GHz (0.85 mm) band with SCUBA/JCMT, which provided an unambiguous case for the detection of the submm SZ temperature increment for the first time.

⋆ Preliminary combined analysis of X-ray, 21 GHz and 350 GHz of RXJ1347 yielded

$$d_{\mathrm{A}}(z = 0.451) = 1730 \pm 300 \pm 370\mathrm{Mpc}$$

assuming $I_{\mathrm{p}} = 3.2$ mJy and the spherical symmetry. This is translated to

$$h = 0.41 \pm 0.07 \pm 0.09 \quad \text{for} \quad (\Omega_0, \lambda_0) = (1.0, 0.0)$$

$$h = 0.48 \pm 0.08 \pm 0.10 \quad \text{for} \quad (\Omega_0, \lambda_0) = (0.3, 0.7)$$