Observations of Sunyaev-Zel'dovich Effect with Nobeyama 45-m telescope

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ABSTRACT

We have three focal plane array receiver systems at 40, 100, and 150 GHz for the Nobeyama 45-m telescope. These array receivers cover the wide frequency range of Rayleigh-Jeans region of the Sunyaev-Zel'dovich (S-Z) effect. We have performed systematic observations the S-Z effect since 1997. From the pilot ON-OFF observations toward 8 X-ray bright galaxy clusters at 40 GHz, the Hubble constant was estimated to be H_0 = 64±17 km/s/Mpc for a flat Λ-CDM cosmology, which shows good agreement with the values by other SZ effect observations. Mapping observations toward 6 galaxy clusters have been performed. The overall distribution of the hot plasma observed by S-Z effect roughly follow the spherical isothermal β-model, while there are some possible deviations from the model especially in the central core region.

INTRODUCTION

The Sunyaev-Zel'dovich (S-Z) effect is a phenomenon whereby photons of the Cosmic Microwave Background (CMB) are scattered through inverse-Compton process by electrons of hot plasma in a galaxy cluster [1][2]. The effect makes a brightness temperature decrement of the CMB under 216 GHz and an increment over 216 GHz independently of the galaxy cluster's red shift. The effect gives information about the structure and the origin of hot gas in galaxy clusters, of which mass is heavier than the total mass of galaxies in a cluster. The effect is a robust and reliable probe for cosmology and astrophysics of galaxy clusters. Although the SZ effect is as faint as the order of 100 μK and are extended over several arc minutes, it yields important information about the structure of intergalactic hot plasma. The effect is also a probe for the cosmology parameters.

In this paper, we will present the present status of observation of S-Z effect using the 45-m radio telescope at Nobeyama Radio Observatory. The 45-m radio telescope is the most precise and large single-dish telescope in the frequency range of 40 - 150 GHz.

TELESCOPE AND FOCAL PLANE INSTRUMENTS

As mentioned in the previous section, the S-Z effect expected by isothermal β-model and X-ray observation is as faint as $\Delta T \approx 0.1$-1 mK, and has widely extended radial distribution of $\theta >> 100''$. The side lobes level and the background level of the telescope limit the reliability of the S-Z effect observation. The surrounding temperature distributions and radio sources picked up by the side lobes would contaminate the S-Z effects. The 45-m radio telescope has small beam sizes, for example 39" at 43 GHz and 17" at 100 GHz. The beam sizes are usually smaller than those of interferometer observations at cm wavelengths[3]. A small beam size is important in observations to avoid beam-dilution of the S-Z effect. Because the foreground and background radio sources steeply decrease at the mm wavelengths [4], the observations of the S-Z effect at mm wavelength enforce tolerance for radio source contamination. The 45-m radio telescope have pure Cassegrain optics. The optics, in comparison with shaped Cassegrain optics, provides wider field of view and lower side lobe level. In addition, this telescope has a beam switch system with large beam throw angle of 390" and fast switching frequency of 15 Hz. The zero level of brightness temperature is defined by that at a reference position of 390" apart from the beam center. These performances should be superior to those of interferometer observations at cm wavelengths. Thus the 45-m radio telescope is suitable for S-Z effect observation (see figure 1).

Figure 1. The 45-m radio telescope at Nobeyama Radio Observatory (left panel) and a beam switch system of the telescope (right panel). The beam switch system is located at the Cassegrain focus. The beam throw angle is 390" and the switching frequency is 15 Hz.

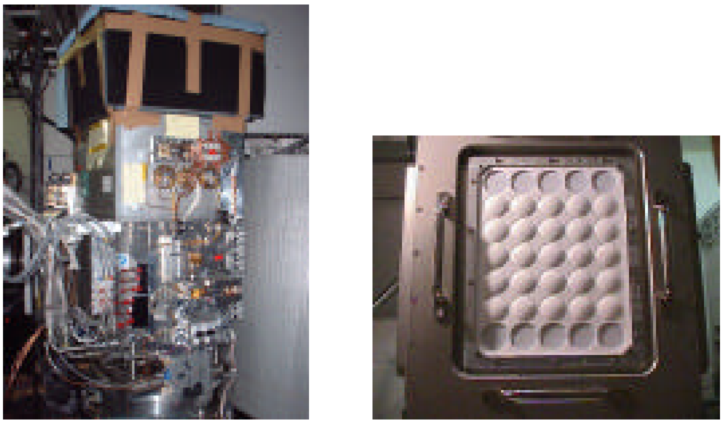

Figure 2. Array receiver systems in the Nobeyama 45-m telescope. S40M (left panel) is a 2×3-array SIS receiver of 40 GHz band and BEARS (right panel) is 5×5-array SIS receiver at 100GHz.

Three focal plane array mm-wave receiver systems are on board the 45-m radio telescope: 6-beam SIS receiver at 40 GHz (S40M) [5][6], 25-beam SIS receiver at 100 GHz (BEARS)[7], and 7-beam bolometer at 150 GHz (NOBA) [8]. The receivers cover a wide frequency range of Rayleigh-Jeans region of the S-Z effect. Although there is the difficulty of the beam-to-beam calibration, focal plane array receivers are superior to single beam receivers in terms of its total sensitivity and the capability of reducing the effect from atmospheric turbulence. They are suitable especially for mapping observations of faint astronomical sources. The 45-m telescope with array and wideband receivers is one of most powerful tool for the observation of the S-Z effect.

S40M is a 6-beam array SIS receiver of 40 GHz band (see figure 2), which was built by Ibaraki university and Hosei university. The receiver has 2×3-grid beams with 80" interval on the celestial sphere. Each beam has three IF channels with BW=1 GHz. The total bandwidth is 3 GHz per beam. The beam size is $FWHM$ = 40" at 43 GHz. The side lobe level is lower than 2.5% of the peak. The aperture and the main-lobe efficiencies are measured to be 0.6 and 0.8, respectively. Moon efficiency is the coupling efficiency between the beam pattern and the flat disk distribution with the radius of Moon, $\theta = 16'$. This efficiency is typically 0.9. Typical sensitivity is 25 mJy /1sec at 43 GHz in a bestweather condition in winter. BEARS is 25-beam array SIS receiver at 100GHz(also see figure 2). The receiver has 5×5-grid beams with 40" interval on the celestial sphere. IF band width is BW=0.5 GHz. The beam size is $FWHM$ = 17" at 100 GHz. The aperture and the main-lobe efficiencies are measured to be 0.4 and 0.6, respectively. The receiver was built mainly for line observation, but will be a powerful tool for sensitive continuum observation by improving of DC stability. NOBA is a 7-beam bolometer array at 150 GHz. The bolometer is operated at 0.3 K and has low *NEP* of 2× 10^{-16} $WHz^{-1/2}$. The beam size is *FWHM* = 12" at 150 GHz. The total bandwidth is 50 GHz per beam. The sensitivity strongly depends on weather condition. The first 150 GHz map of S-Z Effect toward a most X-ray bright cluster, RXJ1347-1145 was obtained by the bolometer and found a negative peak is 20" offset from the center of the cluster [9].

OBSERVATION AND RESULTS

We started systematic observations with Nobeyama 45-m telescope of the SZ effect from 1997. We have performed the ON-OFF observation of the S-Z effect toward eight X-ray bright galaxy clusters from z = 0.18 to 0.55 at 43 GHz using S40M receiver as a pilot survey[6]. The S-Z effects were detected for all clusters as temperature decrement of $\Delta T_B = -0.5$-1mK at the center. Although most of the observed profiles are roughly described by the isothermal spherical β−model density distribution, the deviation from the model seems to be large for the clusters with the irregularity in the X-ray image rather than those without it. The combination of the S-Z effect and the X-ray measurements provides a method for estimating the Hubble constant. From the pilot observations, the Hubble constant was estimated to be H_0 = 64±17 km/s/Mpc for a flat Λ-CDM cosmology (Ω_m=0.3,Ω_Λ=0.7), which shows good agreement with the values by previous S-Z effect observations for nearby clusters. (Cf. Ho= 66±20 km/s/Mpc[10]). On the other hand, this is slightly smaller than the values by other methods.

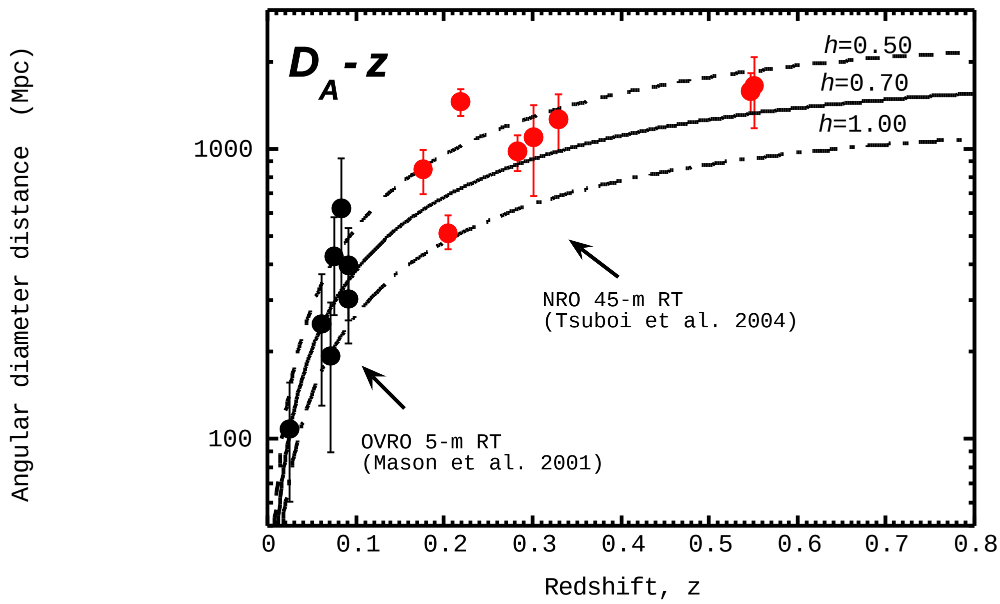

Figure 3 The relation between red shift of clusters and angular diameter distance derived by our data (red filled circles) and the comparison with the previous data (black filled circles).

Second, mapping observation project by S40M and other receivers is on-going. Images of S-Z effect for several clusters have been obtained. Figure 4 shows an example of the preliminary result, the brightness temperature distribution and the radial profile of A773 at 43 GHz. The images reveal a single negative peak near the center of the cluster. The deconvolved negative peak is $\Delta T_B = -1.0$ mK. There is no contamination point source within 1′ from the center position according to the NVSS survey[11] The overall distribution of the hot plasma observed by SZ effect roughly follows the spherical isothermal β-model, while there are some possible deviations from the model especially in the central core region.

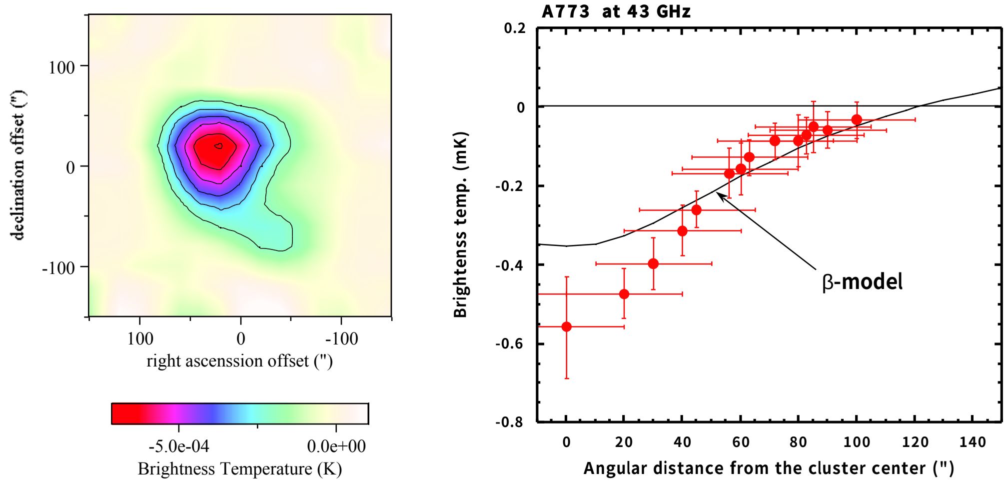

Figure 4. The brightness temperature distribution and the radial profile of S-Z effect toward A773

SUMMARY

We have three focal plane array receiver systems in Nobeyama 45-m radio telescope. These are S40M at 40 GHz, BEARS at 100 GHz, and NOBA at 150 GHz. The telescope and these array receivers cover the wide frequency range of Rayleigh-Jeans region of the Sunyaev-Zel'dovich (S-Z) effect. The 45-m telescope is one of most powerful tool for the observation of S-Z effect. We have performed the ON-OFF observation of the S-Z effect toward X-ray bright galaxy clusters using S40M as a pilot survey. The Hubble constant is estimated to be H_0 = 64±17km/s/Mpc for a flat Λ-CDM cosmology, which shows good agreement with the values by other S-Z effect observations. The mapping observations of S-Z effect are on-going. Although most of the observed S-Z effects are roughly described by the isothermal spherical β–model density distribution, the deviation from the model seems to be also detected.

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