Progress of the Sunyaev-Zel'dovich effect observation in Japan

Hajime Ezawa

National Astronomical Observatory of Japan

+ *Japanese SZ observation team*

Outline

- Introduction
- Nobeyama Radio Observatory
- Results and on going observations in Japan
- Future Prospects

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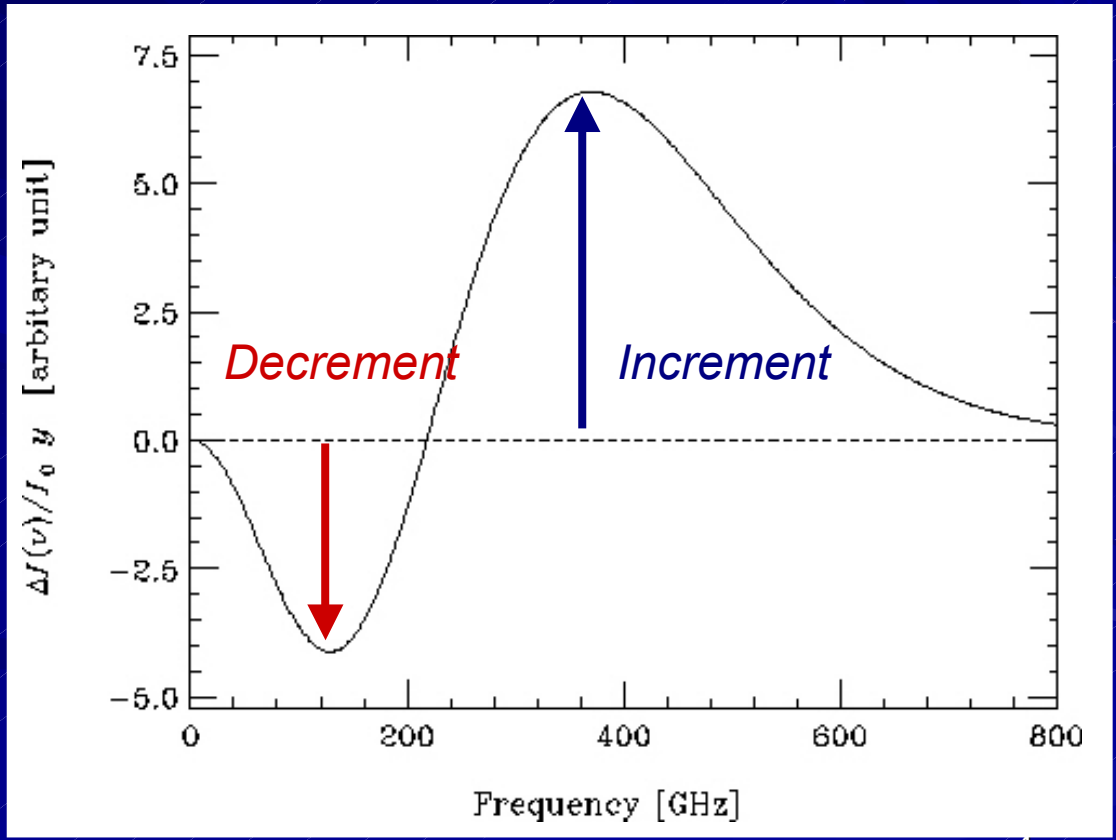
Sunyaev-Zel'dovich Effect

- Inverse Compton scattering of CMB with hot plasma in clusters of galaxies
- Decrement
  for $\nu < 220$ GHz
- Increment
  for $\nu > 220$ GHz



SZ observations in Japan

- Mainly single dish millimeter observations with NRO 45-m Radio telescope.
- 20 GHz – 150 GHz at NRO
- Utilizing multi-beam receivers
- Submillimeter observation with JCMT/SCUBA
- Several future projects
  - High resolution imaging with ALMA ACA

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Nobeyama Radio Observatory

NRO 45m RT

45 m single dish telescope
(largest millimeter telescope)
20 GHz – 150 GHz

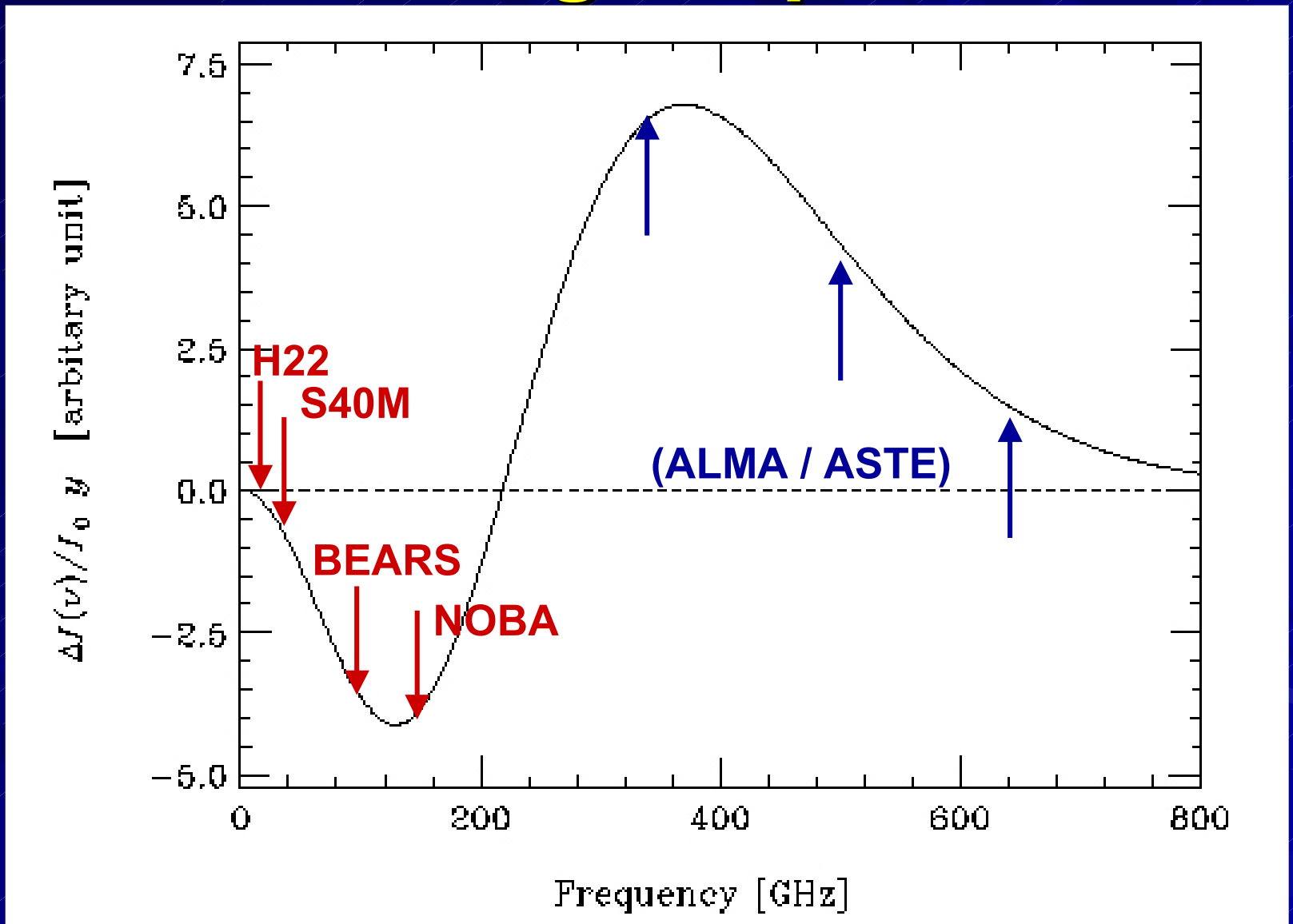
NMA (Nobeyama Millimeter Array)
10 m x 6, 100 GHz – 230 GHz

ASTE (in Atacama, Chile)
10 m: 100 GHz – 800 GHz

Receivers on NRO 45 m

- Multi beam receivers
  - **S40M** : SIS 6 beams at 40 GHz
  - **NOBA** : Bolometer array at 150 GHz
  - BEARS : SIS 25 beams at 100 GHz
- Single beam receivers
  - HEMT: **20 GHz**, 30 GHz, 40 GHz
  - SIS: 40 GHz, 80 GHz, 100 GHz

Observing frequencies

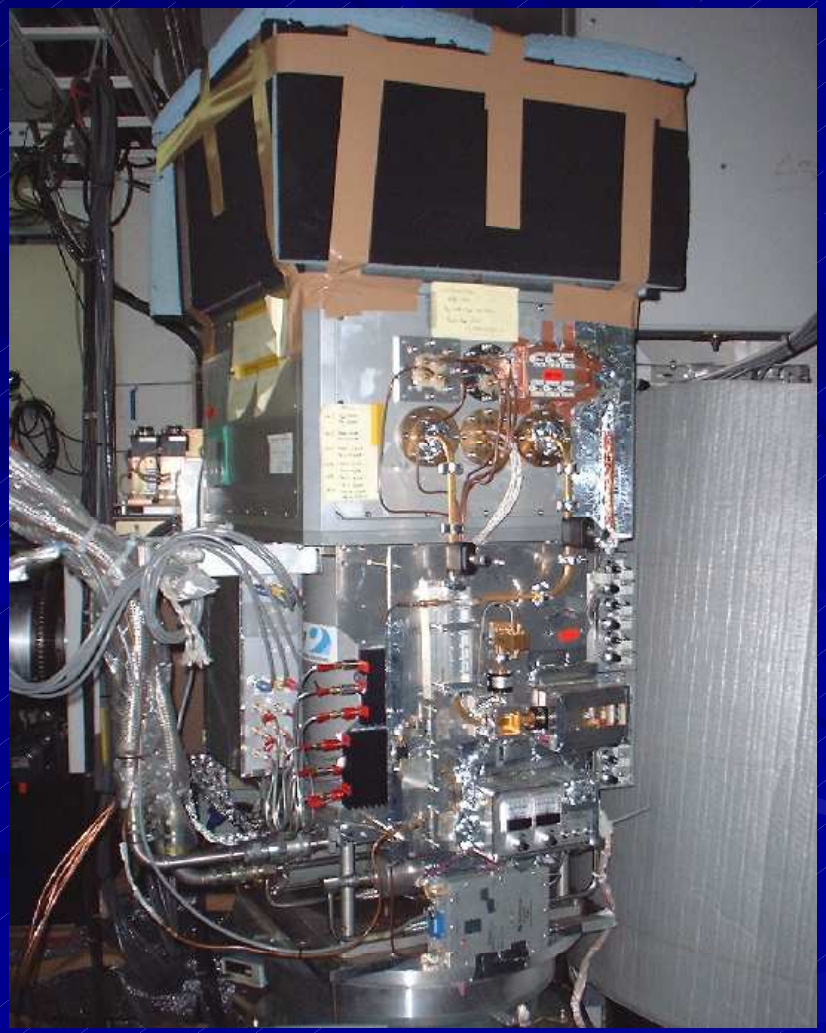


S40M receiver

- Main RX for our SZ obs.
- 6 beams SIS at 43 GHz
- Beam size 40 arcsec.
- Separation 80 arcsec.
- 20 mJ/s$^{1/2}$ / beam

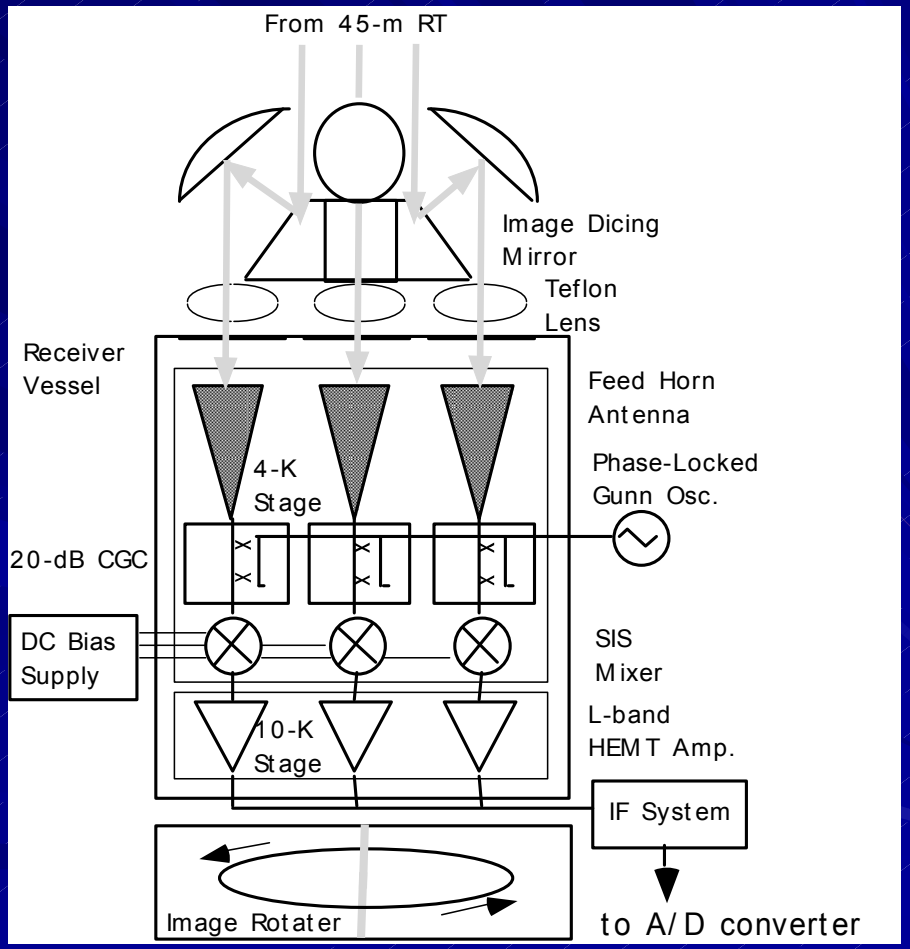
Developed in collaboration among
NRO + Ibaraki Univ.+ Hosei Univ.

Tsuboi et al. 2000
Proc.SPIE 4015, 278-286



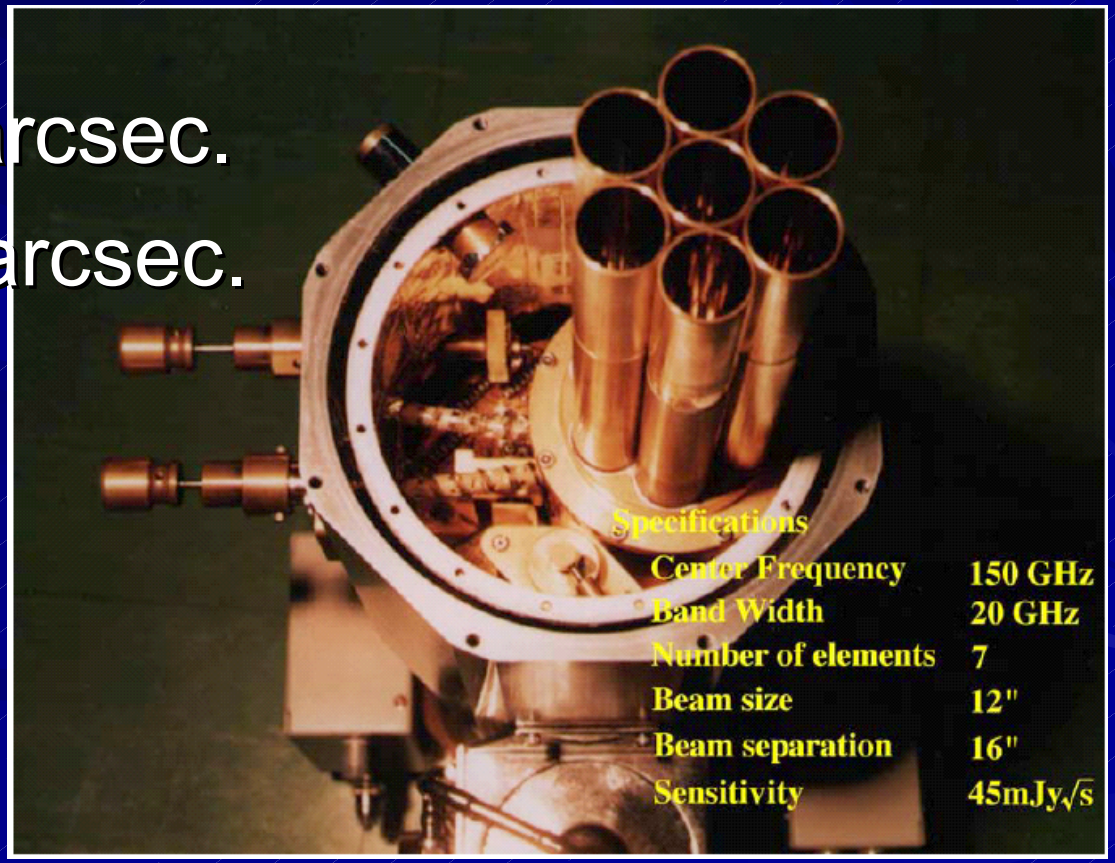
S40M receiver

Internal view of S40M RX
Operated at 4 K



NOBA
Nobeyama Bolometer Array

- ν=150 GHz, $\Delta\nu$ = 30 GHz
- 7 beam,
- Beam size 12 arcsec.
- Separation 16 arcsec.
- 45 mJ/s$^{1/2}$
- Op. @ 0.3 K



Kuno et al. 1993
Kuno et al. 2000

H22 receiver

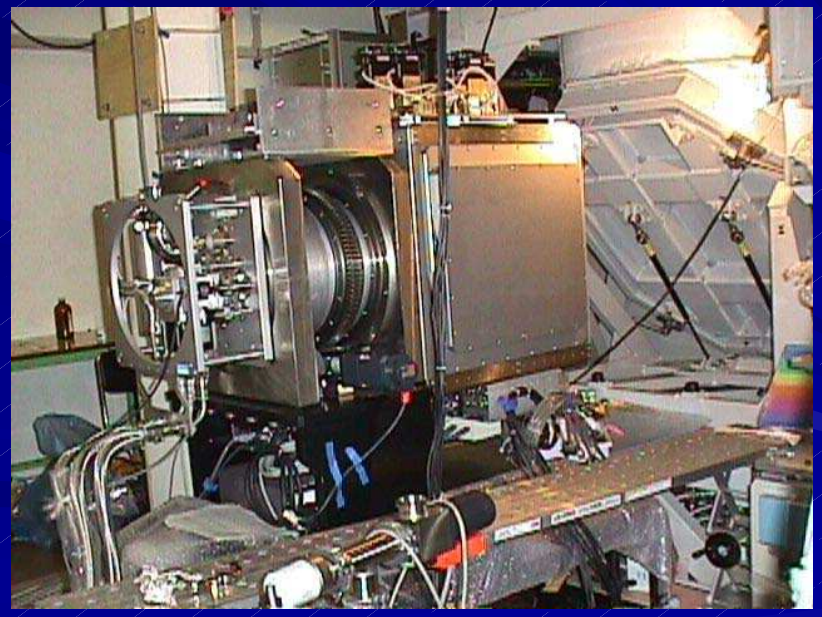
- HEMT receiver at 22 GHz
- Sensitivity of 30-40 mJy/s$^{1/2}$
- $\Delta\nu$ = 2 GHz, dual polarization
- Beam size 80 arcsec.

Sorry for no photo of RX…

BEARS Beam Array Receiver System

- 100 GHz, array of 5x5 SIS receivers
- Beam size = 17 arcsec.
- Currently operated for spectroscopy

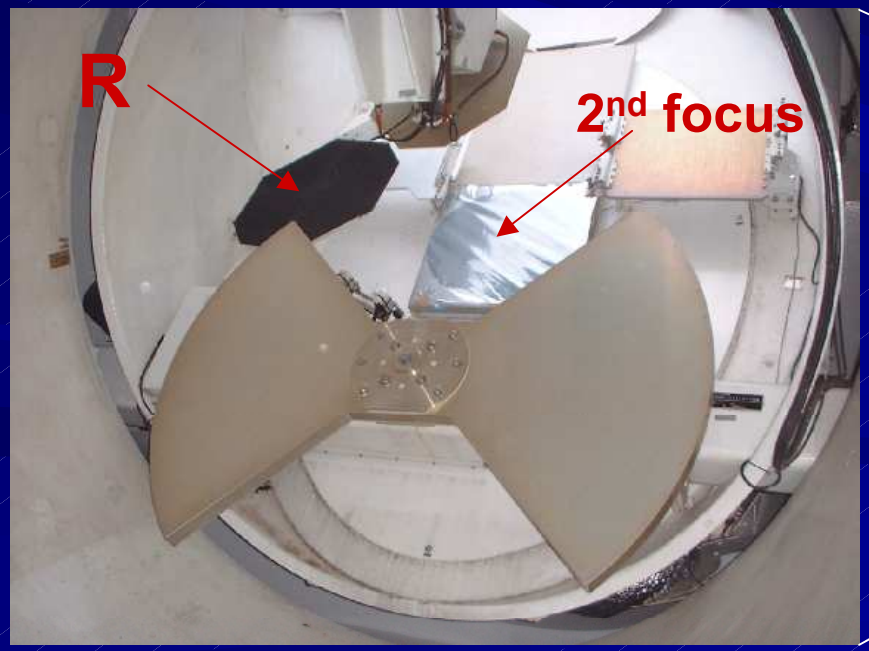
  → Operation for continuum obs. will start this year!



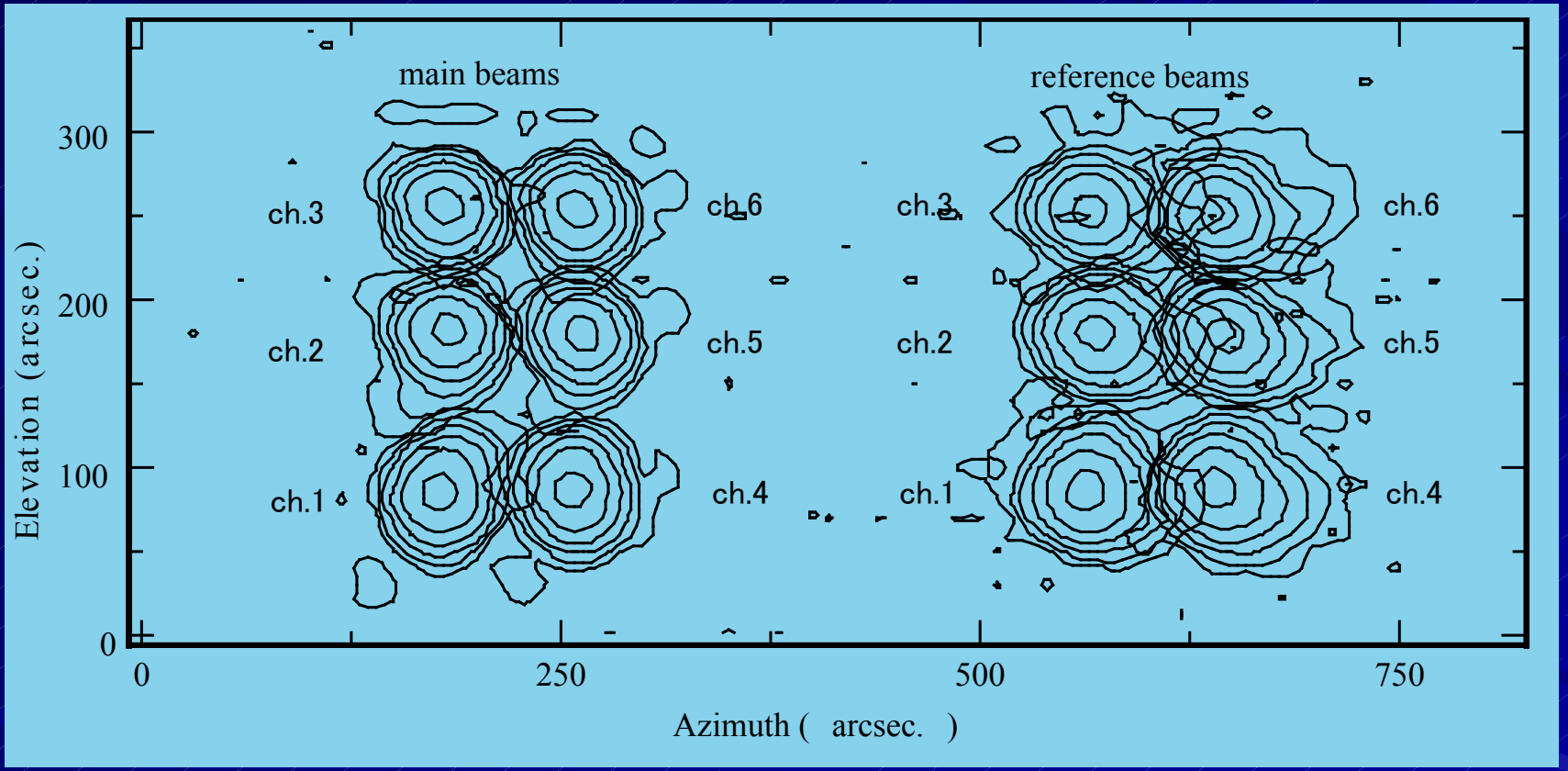
Sunada et al. 2000, Proc. SPIE 4015, 237

Beam switching

- Compensate atmospheric variation of SKY
- Beam throw = 6 arcmin.
- 15 Hz switching
- Also for R-SKY calibration



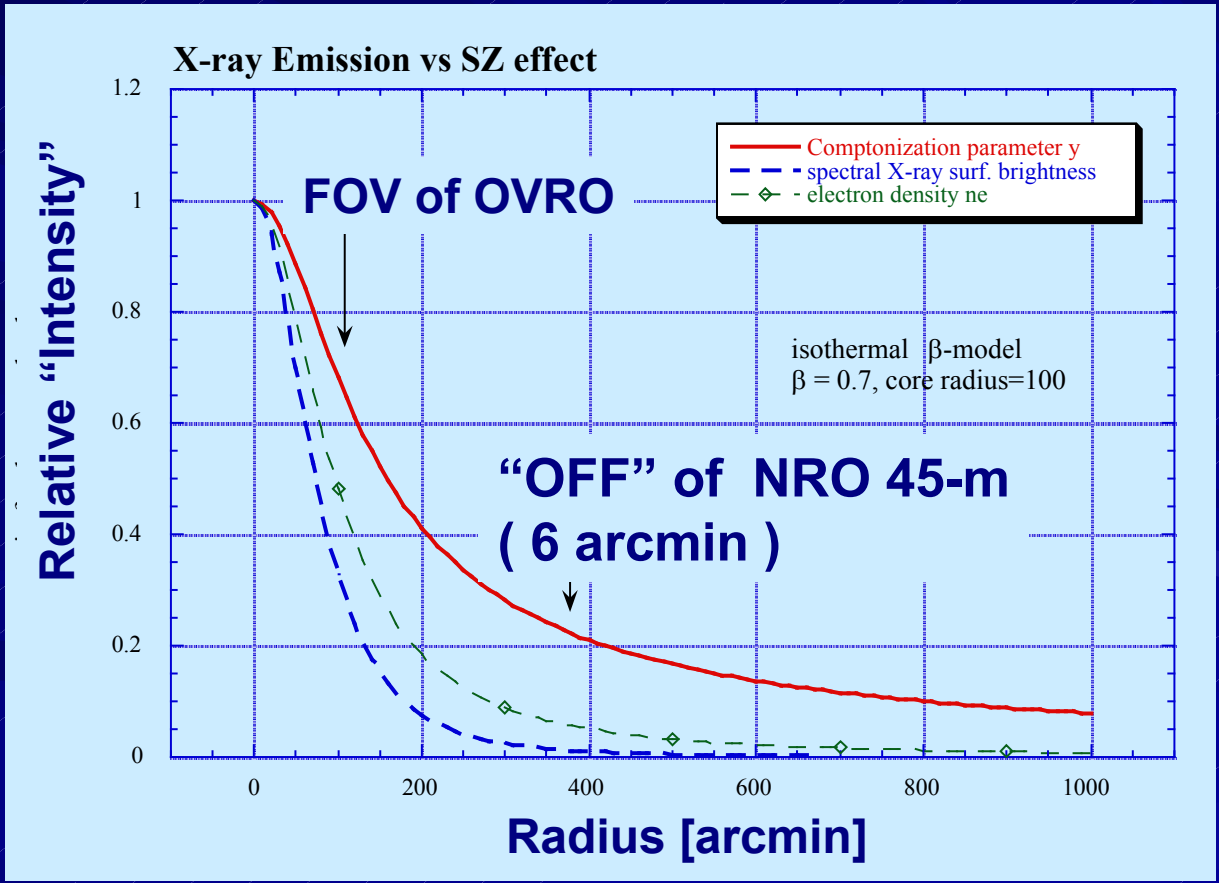
Beam switching



Beam size =40”, low sidelobe level (the lowest cotour is 2.5%).

SZ obs. with NRO single dish

- High resolution imaging
- Far “OFF” (reference) point



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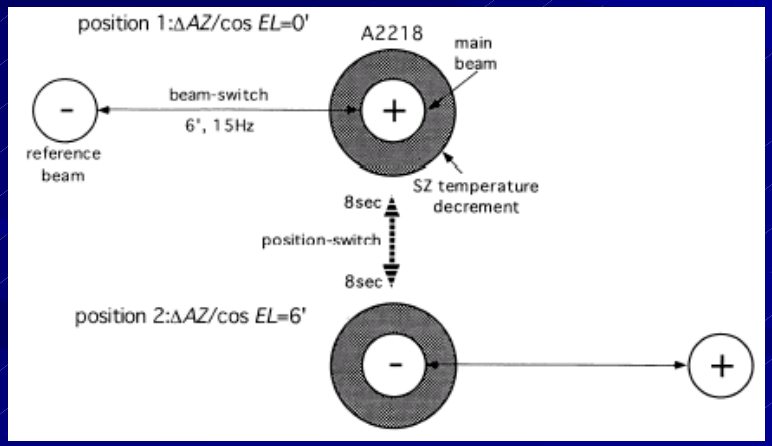
Physics from SZ observation

- Constraint to H_0
  - Combining X-ray data with SZ image
- Physical properties of the ICM
  - Measure T_e *without* X-ray spectroscopy
  - Confirm high-T_e values

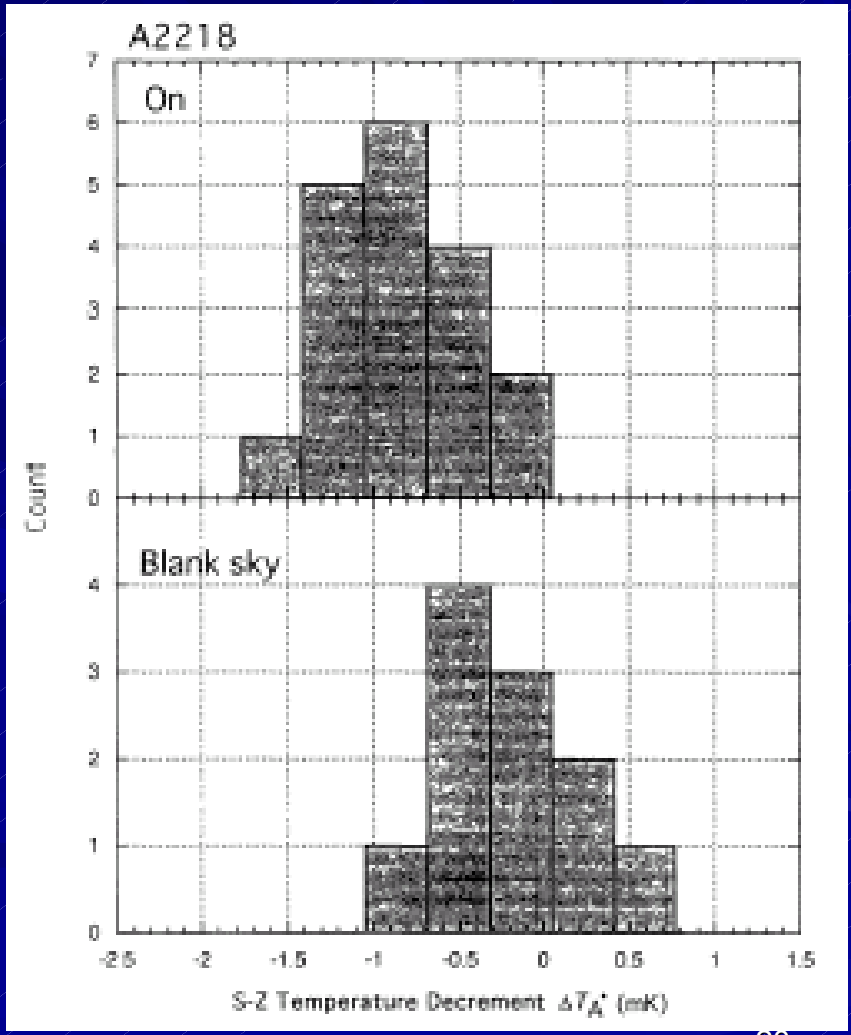
First SZ obs. with NRO 45 m

- NRO 45 m + S40M
- Abell 2218 at 36 GHz
- SZ + X (Einstein IPC)

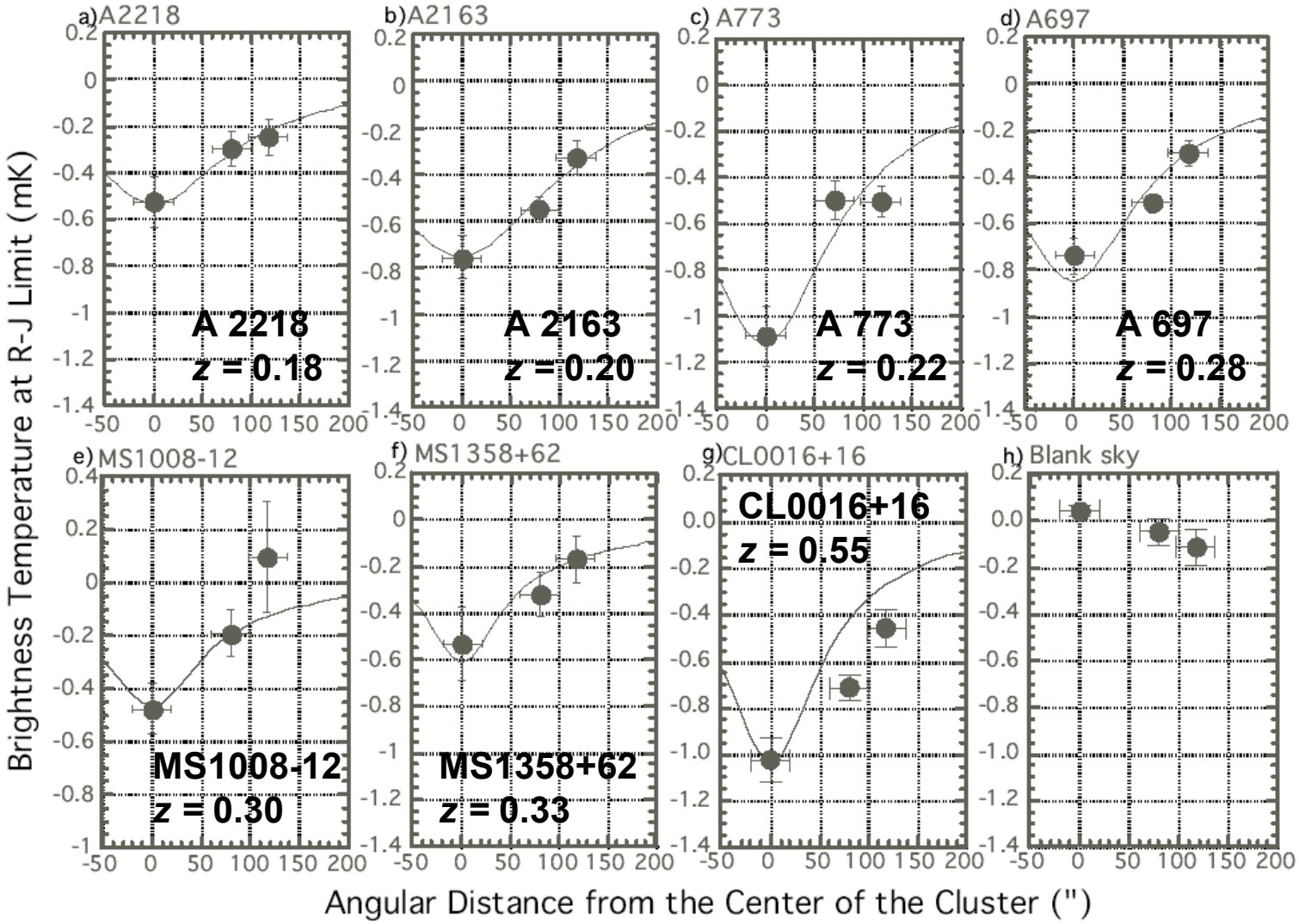
  → H_0=54 $^{+24}_{-13}$ km/s/Mpc



Tsuboi et al. 1998, PASJ 50, 169



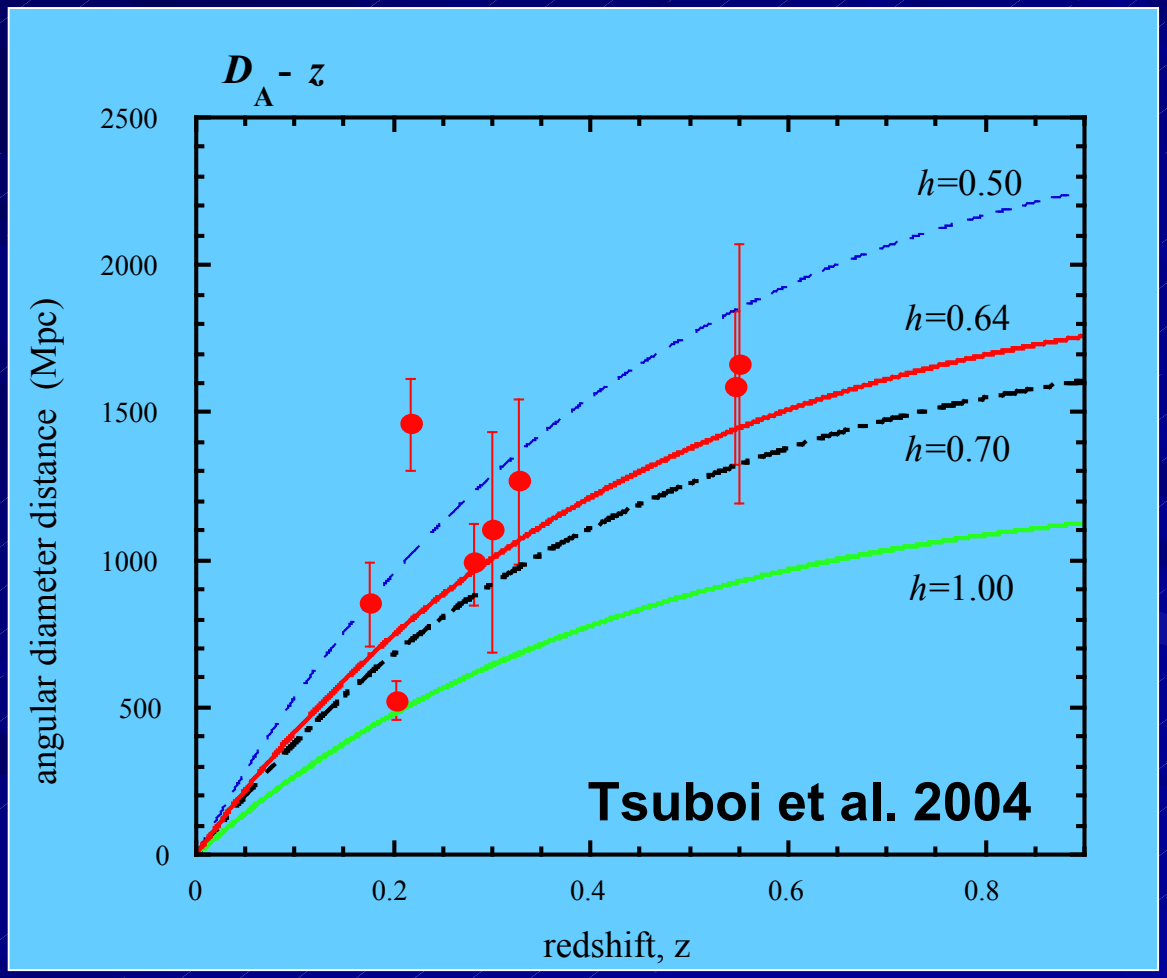
1-dim profile with S40M



Tsuboi et al. 2004, PASJ 56, 771-721

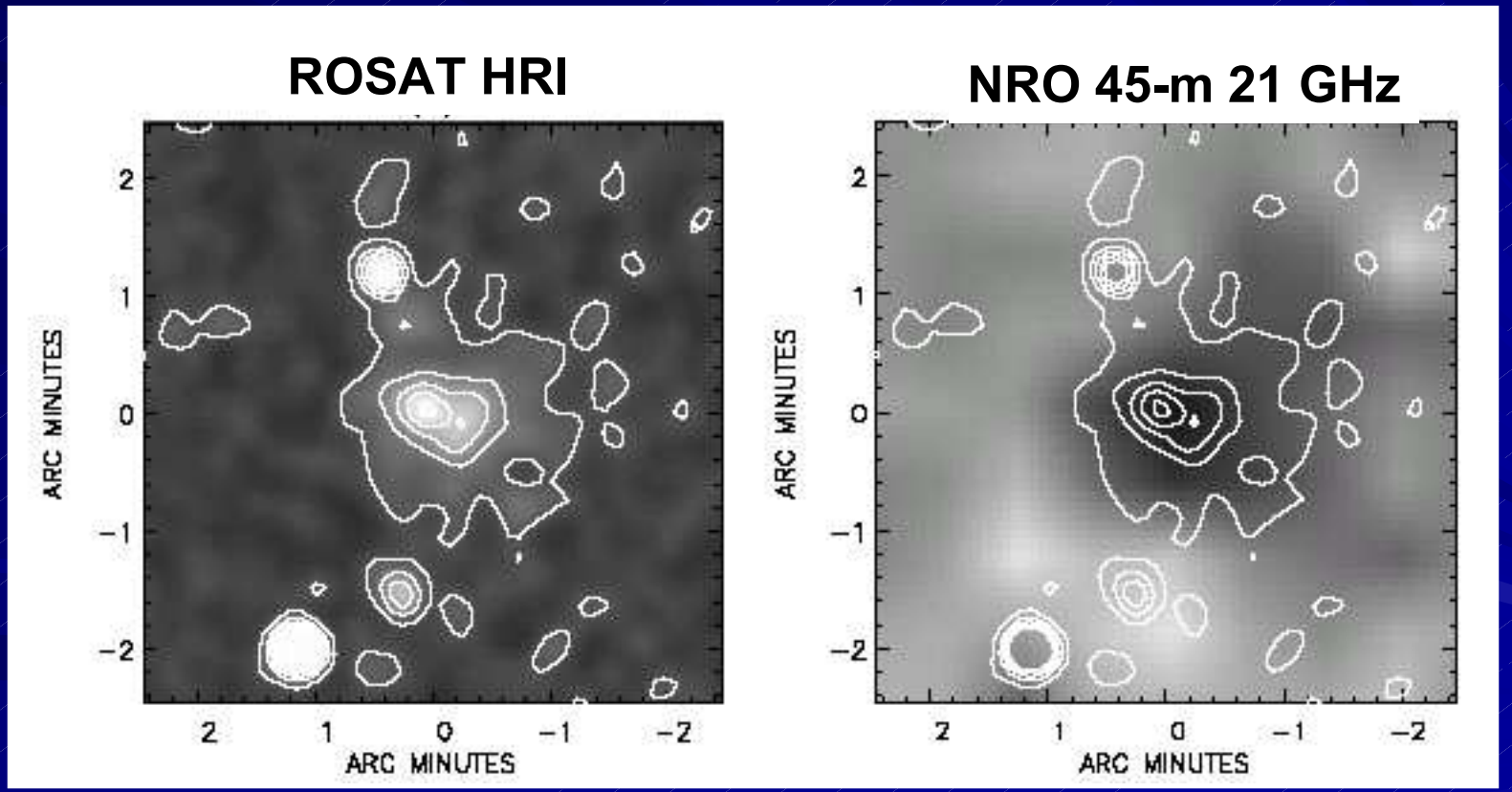
1-dim profile with S40M

- H_0 = 64±17 km/s/Mpc for flat ΛCDM



RX J2228+2037 (21 GHz)

- Joint analysis of X-ray and SZ image

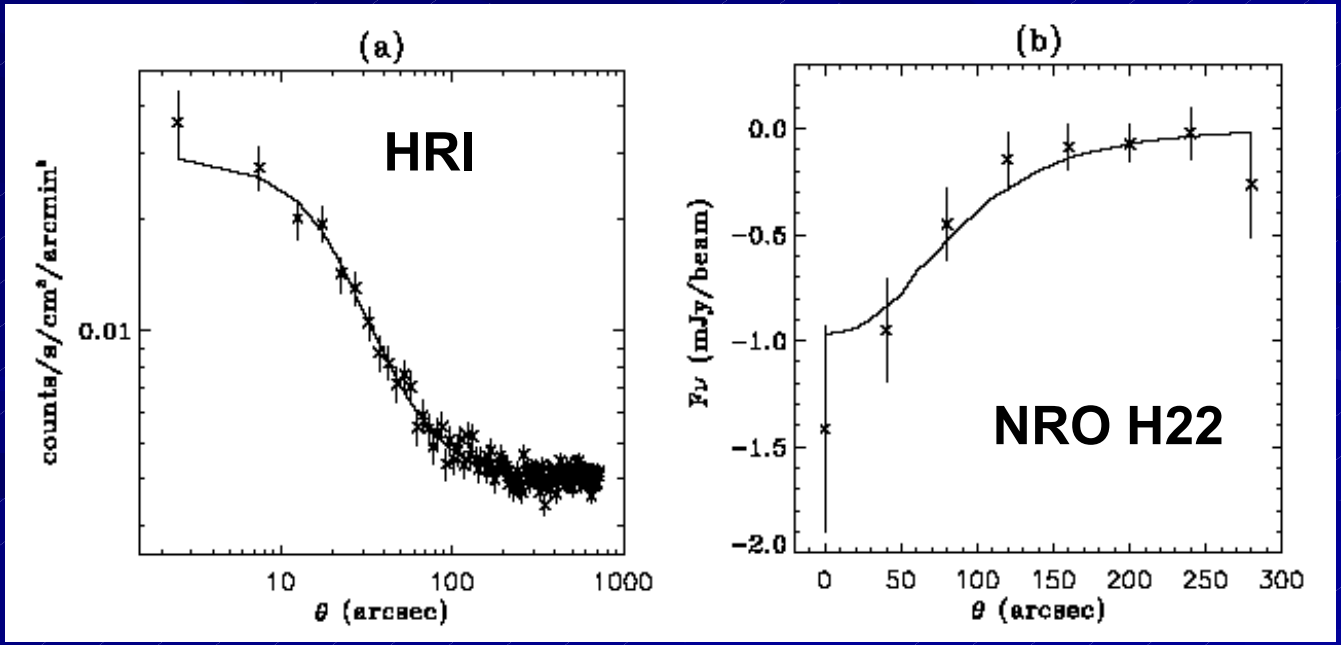


Pointecouteau et al. 2002, A&A 387, 56-62

RX J2228+2037 (21 GHz)

- Modeling the data with β-model
- SZ (β, r_c) compatible with X-ray (β, r_c)
- Derive T_e by SZ + X-ray *without* X-ray spectroscopy

  → T_e=10 keV; consistent with L_x-kT relation



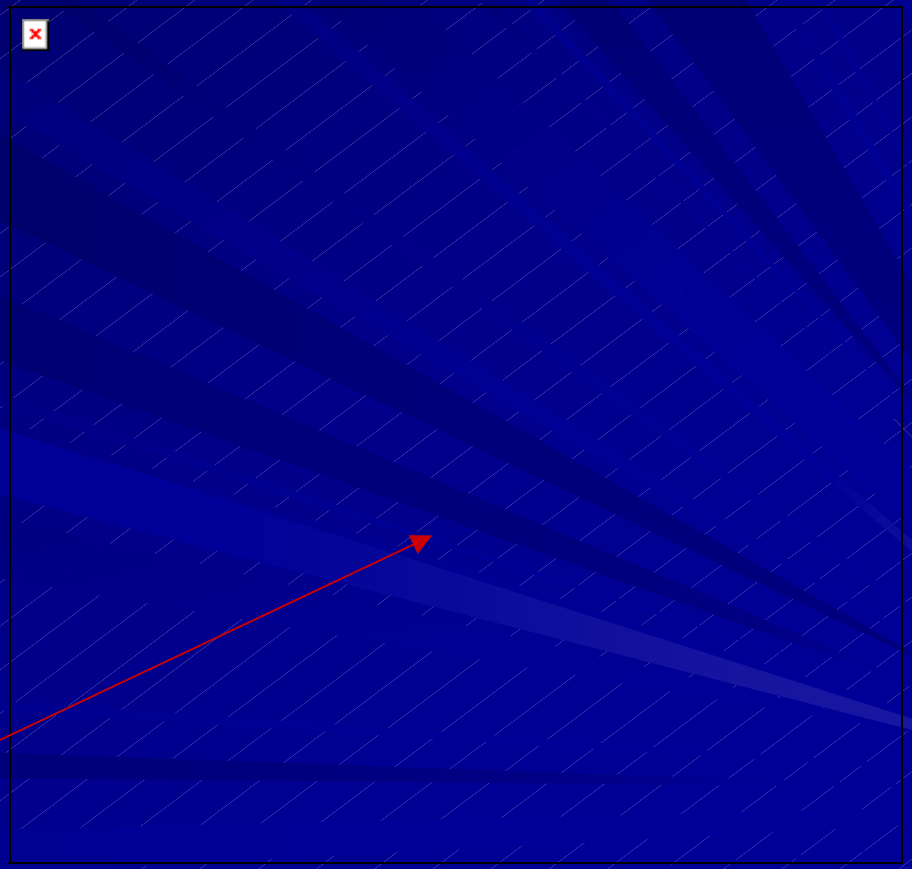
Pointecouteau et al. 2002, A&A 387, 56-62

RX J1347-1145

- X-ray brightest cluster at z = 0.45
- kT = 9.3 keV (*ASCA*)
- NRO 45 m + **NOBA** at 150 GHz
- SZ image with highest resolution (20 arcsec.)

→Inhomogeneous structure first found by SZ observation!

SZ peak at 20'' offset From the X-ray

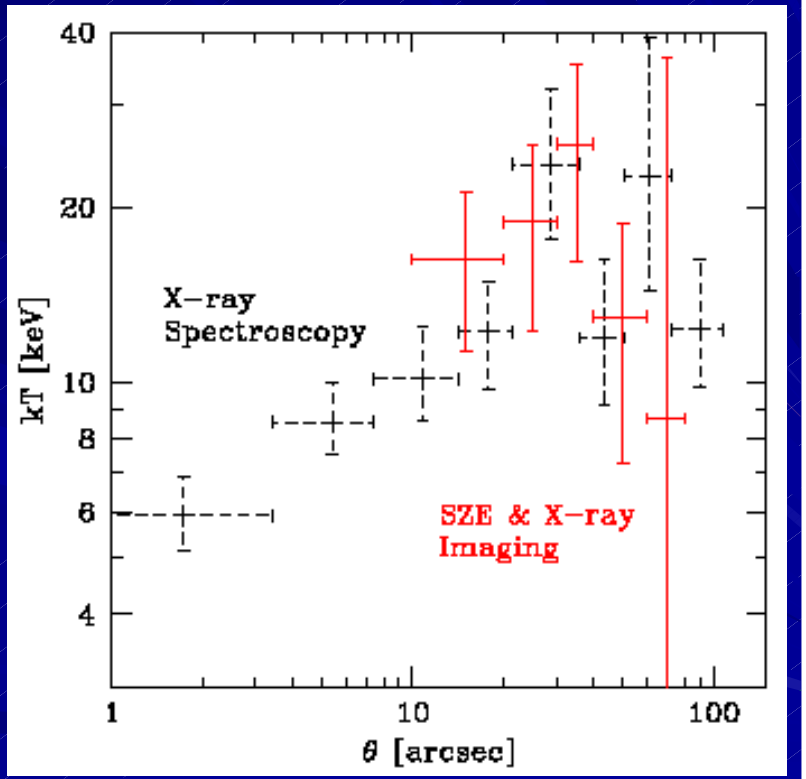


Komatsu et al. 2001, PASJ 53, 57-62

High res. SZ + X-ray image

- SZ image (150 GHz @ NRO, 350 GHz @JCMT)
- X-ray image (*Chandra*)
  → Temperature distribution

- Angular res. of 10 arcsec. essential to resolve irregular morphology (eg. merger)
- Unique probe for temperature structure in distant clusters



Kitayama et al. 2004, PASJ 56, 17-28

Systematic SZ imaging with S40M

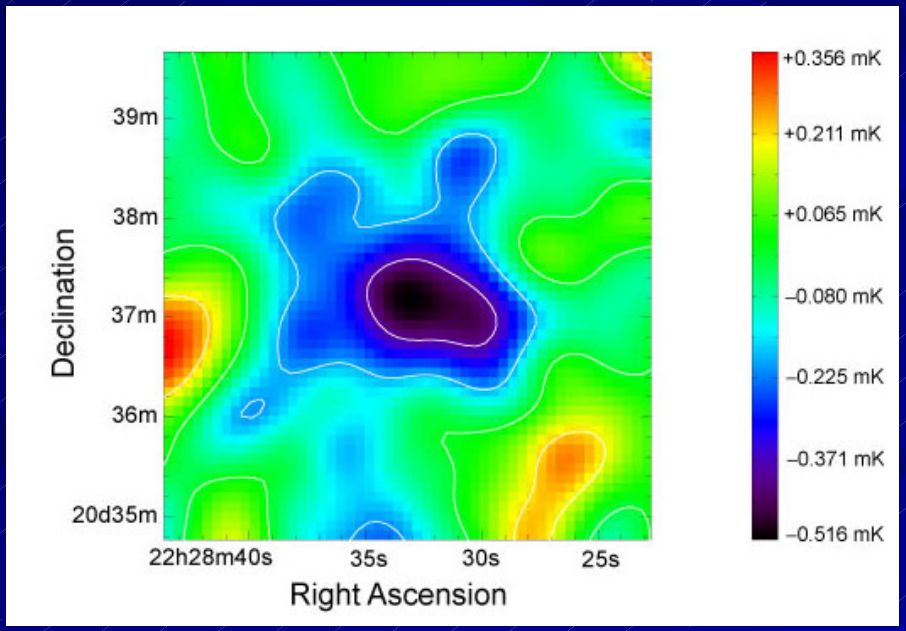
- On-going with NRO 45 m+S40M (or H22)
- Imaging SZ by raster scanning over CLG
- Collaborators:

NAOJ:	H. Ezawa, H. Matsuo, A. Miyazaki, M. Tsuboi, N. Sugiyama, Y. Fujita, et al.
Hosei Univ.:	T. Kasuga
RIKEN:	N. Ota
Univ. of Tokyo:	T. Kuwabara, Y. Suto, et al.
Toho Univ.:	T. Kitayama
Tohoku Univ.:	M. Hattori

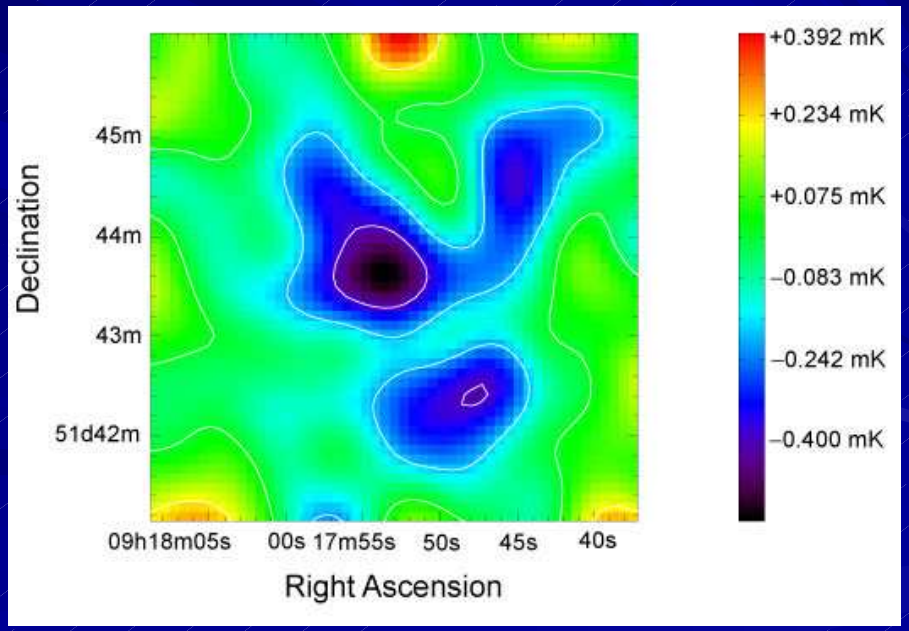
SZ images by S40M

- Combining 6 beams into one 6'x6' image
- SZ decrement clearly detected from several clusters of galaxies

RX J2228+2037



Abell 773



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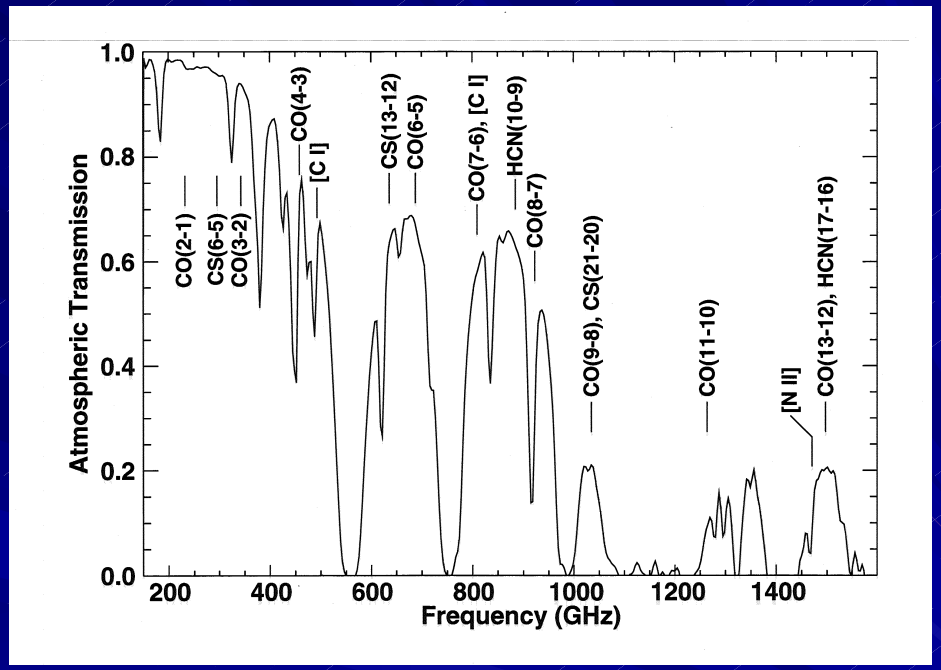
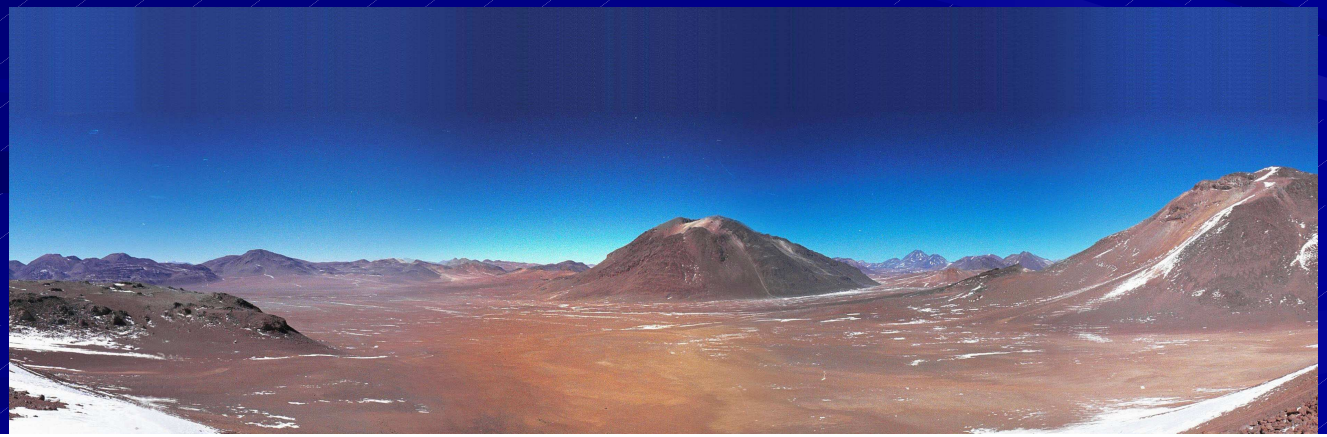
Future prospect - ALMA

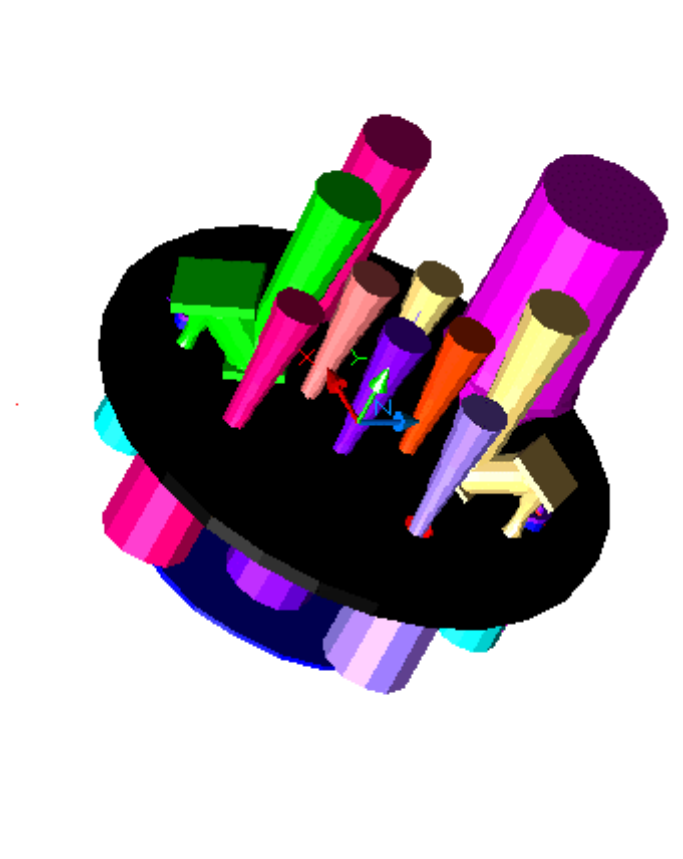
Atacama Large Millimeter/Submillimeter Array

- Internationalcollaboration
  - North America
  - Europe
  - ASIA
- Altitude 5000 m
- Freq. range
  - 100 GHz – 800 GHz





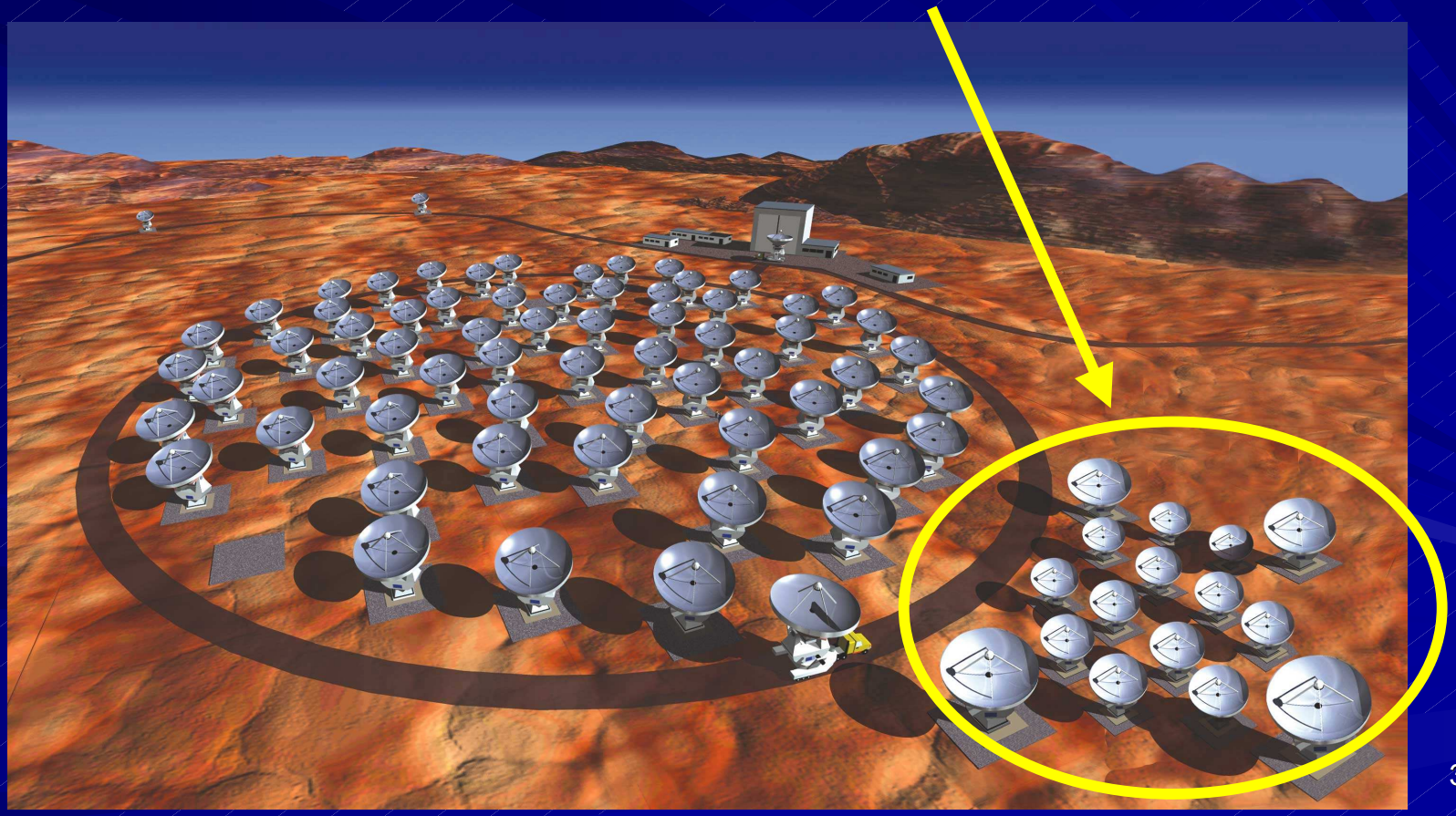
Planned RX bands



Band	Freq. [GHz]
1	30-40
2	67-90
3	84-116
4	125-163
5	163-211
6	211-275
7	275-370
8	385-500
9	602-720
10	787-950

Future prospect – ALMA

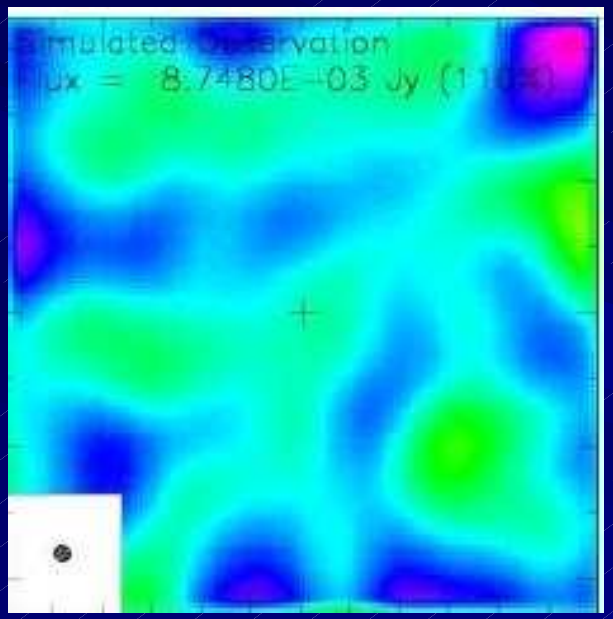
- ACA – Atacama Compact Array
  Enhancement to baseline ALMA by Japan



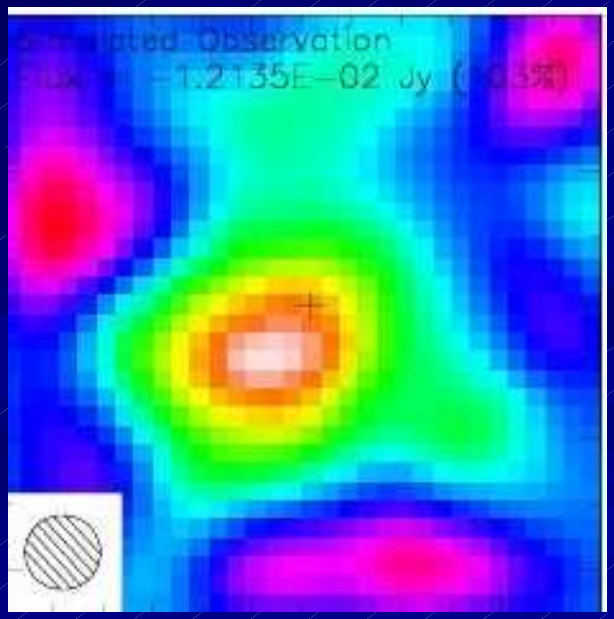
SZ observation with ACA

- Case for RX J1347-1145 at 150 GHz (Band4)
- Contribution of ACA is essential

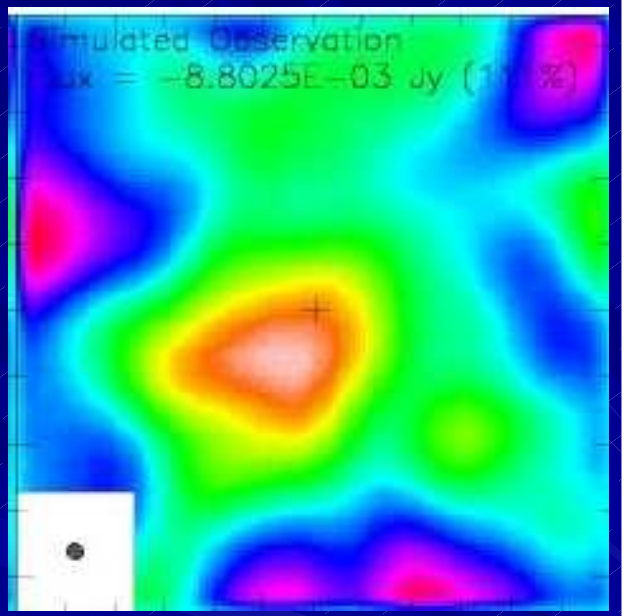
90 arcsec.



ALMA-B
64 antennas C1 config
(longest BL=150 m)
13 mosaics, 18 min



ACA + SD
12 antennas Spiral config.
(longest BL=30 m)
13 mosaics, 72 min



ALL

Tsutsumi, Kitayama 2004

Summary

- SZ observation in Japan is currently focused on high resolution imaging with NRO 45-m.
- Currently we have performed SZ observations at 21 GHz, 43 GHz, and 150 GHz (+345 GHz).
- Combined analysis of X-ray and SZ image is essential to explore the physical condition of high-z clusters
- Future ALMA with ACA will be a powerful tool to observe high-z clusters even with short observing time.