High-resolution SZE observations of RX J1347.5-1145 as a case study for ALMA

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Outline
Obs. of the most X-ray-luminous cluster at 150 & 350GHz
- Highest resolution (〜15") SZE images
  Implications on cluster physics
Prototype of high resolution/frequency studies by ALMA
Collaborators


References

Komatsu et al. (2001) PASJ 53, 57
Kitayama et al. (2004) PASJ 56, 17
Why RX J1347.5-1145?

The most X-ray luminous galaxy cluster known

ROSAT & R-band (Schindler et al. 1997)

$z = 0.451$

$<kT> = 9.3$ keV

$y_0 = 8.0 \times 10^{-4}$

Model SZE profile 150GHz

Model SZE profile 350GHz

Strongest & very compact SZE
“best” target for high resolution studies
SZE maps of RX J1347.5-1145 (1)

28.5GHz, BIMA/OVRO
40”x50” beam
(Carlstrom et al. 2002; Reese et al. 2002)

143GHz, Diabolo on IRAM 30m
22” beam, 20” smoothing
Contours: ROSAT X-ray
(Pointecouteau et al. 1999; 2001)

Point source-subtracted images
SZE maps of RX J1347.5-1145 (2)

150GHz, NOBA on Nobeyama 45m
13” beam, 16” smoothing
1 $\theta = 0.6$ mJy/beam in the smoothed image
(Komatsu et al. 2001)
Contours: Chandra X-ray (Allen et al. 2002)

350GHz, SCUBA on JCMT 15m
15” beam, 16” smoothing
1 $\theta = 2.5$ mJy/beam in the smoothed image
(Komatsu et al. 1999)

Highest resolution SZE images, point sources un-subtracted
Hot substructure at $\sim 20''$ (120 kpc) off center, discovered by SZE
SZE signals of RX J1347.5-1145

150GHz

350GHz
Applications of high resolution SZE data (1) (Kitayama et al. 2004)

- Can **mask** point sources & inhomogeneous regions
- Probe of **temperature** structures even for clusters with **no X-ray spectroscopy**

Temperature deprojection by imaging data only

\[ I_{SZ} \propto n(r)T(r) \, dl \]
\[ I_X \propto n^2(r)T^{1/2}(r) \, dl \]
assuming \( V=0 \), spherical symmetry

\[ \text{SZE & X-ray surface brightness} \]
\[ \text{X-ray spectroscopy} \]
Applications of high resolution SZE data (2)
(Kitayama et al. 2004)

Unique tool to spatially resolve very hot gas with $kT>20\text{ keV}$

cf. current X-ray imagers $E<10\text{ keV}$

Properties of hot substructure:

$n_{ex} = (1.45 \pm 0.58) \times 10^{-2} \text{ cm}^{-3}$

$L_{ex} = 250 \pm 190 \text{ kpc (l.o.s. extent)}$

$kT_{ex} = 28.5 \pm 7.3 \text{ keV}$

cf. X-ray spectra: $kT_{ex}>21.5 \text{ keV}$

- merger shock?
- Mach number $\sim 2.1$
  
  $v_{\text{preshock}} \sim 3900 \text{ km/s,}$
  
  $v_{\text{postshock}} \sim 1600 \text{ km/s (shock frame)}$
Simulations of sub-cluster mergers  
(Takizawa 2005)

Temperature maps at the central surface

- Eulerian mesh
- N=400³
- L=0.8 Mpc

\[ kT_{\text{max}} \sim 30 \text{ keV} \]
\[ V_{\text{max}} \sim 4000 \text{ km/s} \]
\[ \square \quad \square \sim 0.1 \text{ Gyr} \]
Simulations of sub-cluster mergers (Takizawa 2005)

$I_{SZ} \propto n_e T_e \, dl$

$I_X \propto n_e^2 T_e^{1/2} \, dl$

SZE image is highly disturbed, while X-ray remains compact.

better tracer of shock front
Feasibility simulations for ALMA by GILDAS (Tsutsumi et al. 2005)

INPUT based on 150GHz data (13” FWHM) of RX J147.5-1145

ALMA 64 arrays
longest baseline 150m
13 mosaics, 18 min

with ACA
longest baseline 30m
13 mosaics, 72 min

1 □ = 0.03 mJy/beam
peak = -0.22 mJy/beam
FWHM = 2.4”
ALMA imaging Simulations

INPUT:
Snapshot from cluster merger simulations (Takizawa 2005). Place it at z=1, Dec= -23 deg.

Output:
ALMA 64 arrays + ACA
13 field mosaic, 90min total
no thermal noise (preliminary!)

FWHM=2.4”@150GHz

14” FWHM

60” FWHM
Impacts of high resolution

X-rays: drastic progress in understanding of ICM

Perseus

ROSAT/PSPC contour + optical image FWHM\(\sim 25''\) (Ettori et al. 1998)

Most of current SZE images

FWHM \(\sim\) arcmin

\(\square 50\)

Chandra/ACIS-S image FWHM\(\sim 0.5''\) (Fabian et al. 2003)

ALMA: FWHM \(\sim 2'' \) @ 150GHz
Conclusions

High resolution SZE + X-ray images
- Powerful probe of cluster physics
  e.g. RX J1347.5-1145 at z=0.45
  strongest SZE & most X-ray luminous

- Temperature profile solely from imaging data
  high z clusters with no X-ray spectroscopy
- Unique tracer of very hot gas with kT>20 keV
  cf. current X-ray imagers: E<10 keV

Applicable to a larger number of clusters by ALMA!