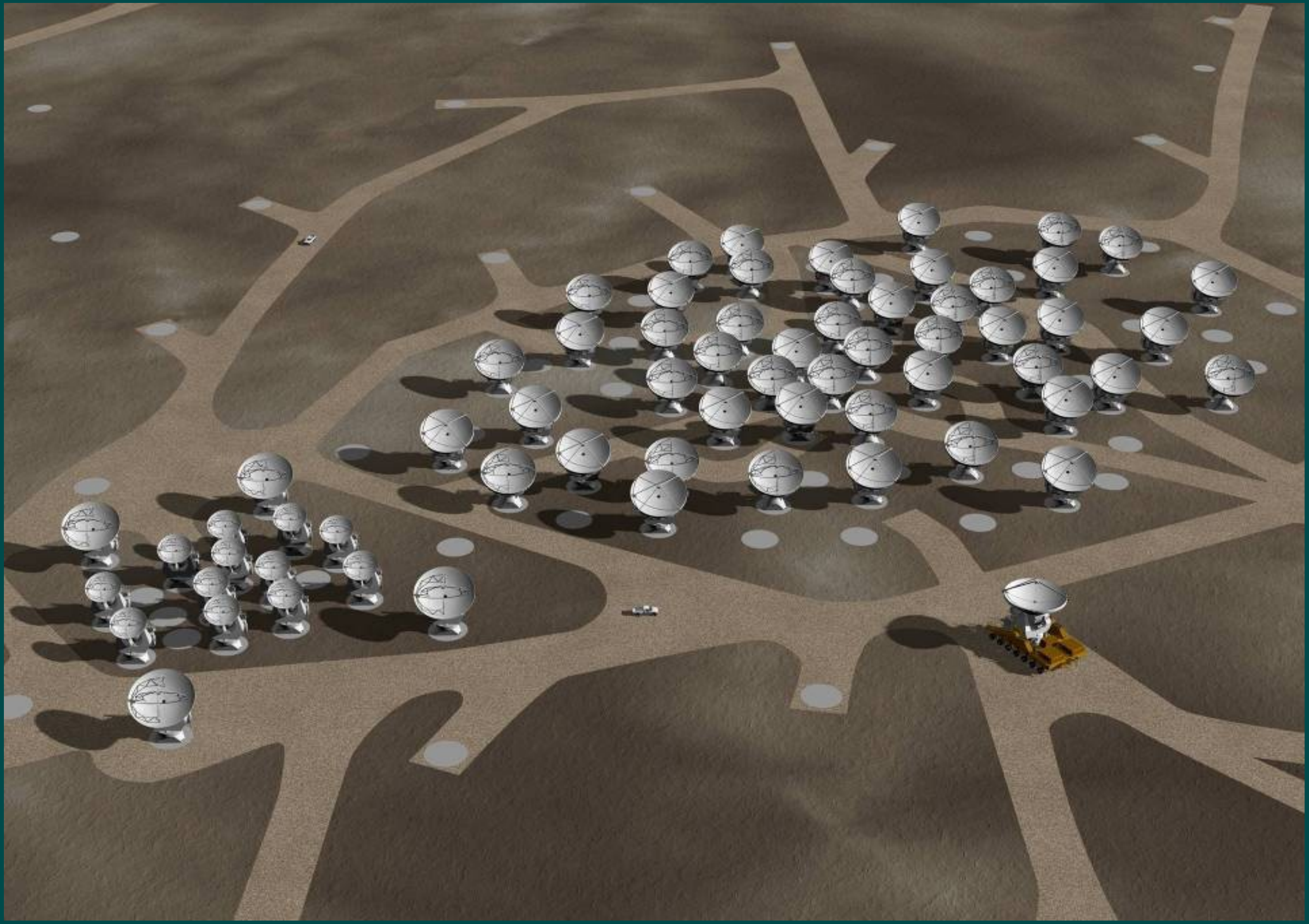
SZ Effect with ALMA



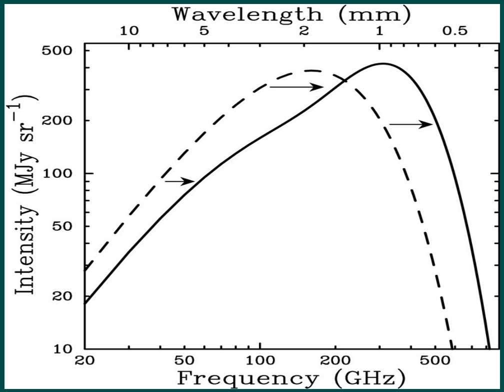
Kaustuv moni Basu (MPIfR / Universität Bonn)

with Martin Nord, Frank Bertoldi, Florian Pacaud
APEX-SZ collaboration, X-ray cluster cosmology group at AIfA

The Sunyaev-Zel'dovich Effect

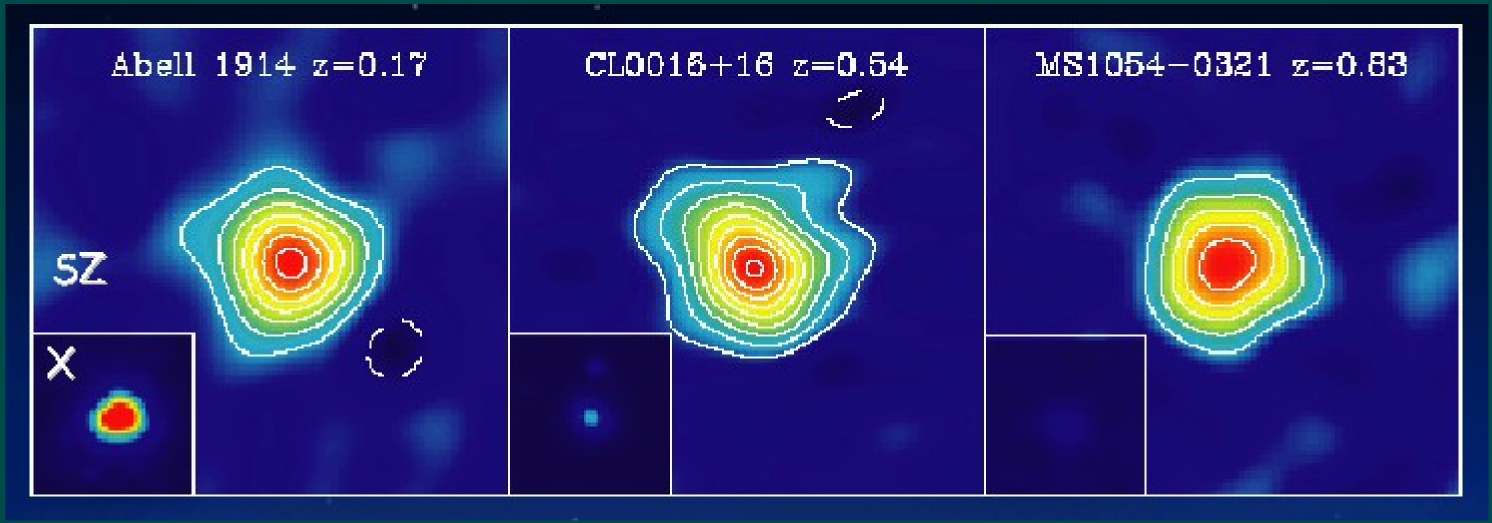
Thermal SZE is a small (<1 mK) distortion in the CMB caused by inverse Compton scattering of 1-2% of the CMB photons that passes through the clusters

$$\frac{\Delta T}{T_{\rm CMB}} = g(x) \int n_e(l) \, \frac{k_{\rm B} T_e(l)}{m_e c^2} \, dl$$



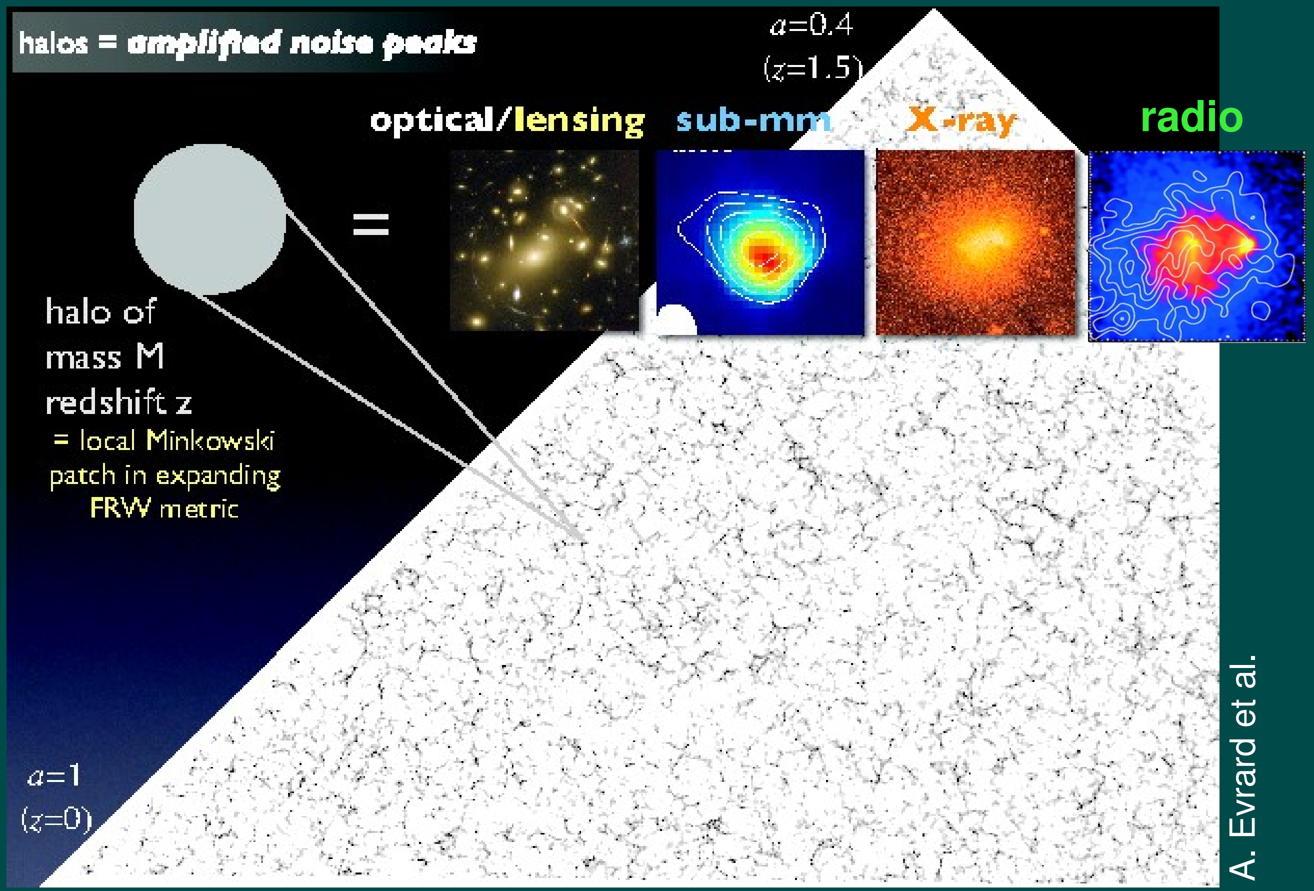
Total flux density is independent of redshift!

$$\Delta S_\nu = \int \Delta I_\nu \, d\Omega \propto \frac{\int n_e T_e \, dV}{D_{\rm A}^2} \propto \frac{f_{\rm gas} M_{\rm tot} T_e}{D_{\rm A}^2}$$



Carlstrom et al.

Galaxy clusters and cosmology

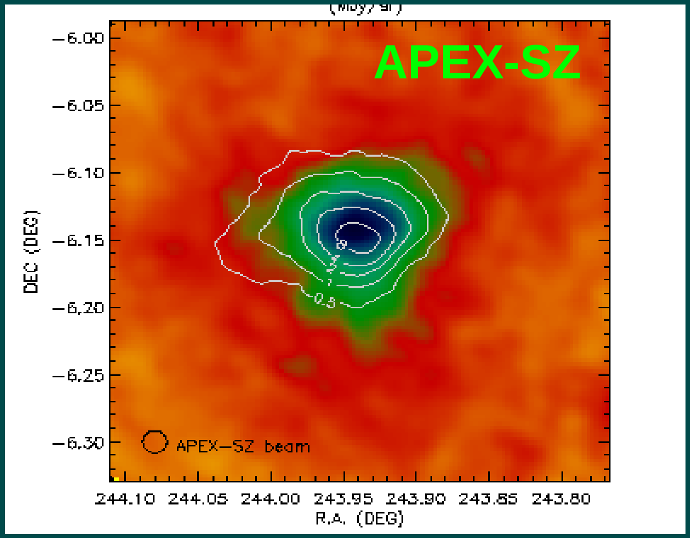


Clusters = collapse of density peaks → most massive, well-differentiated structures

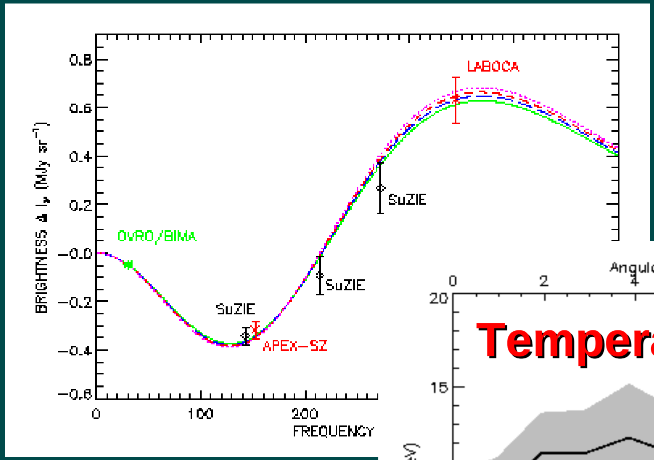
Formation = huge amount of energy conversion → visible in many wavebands

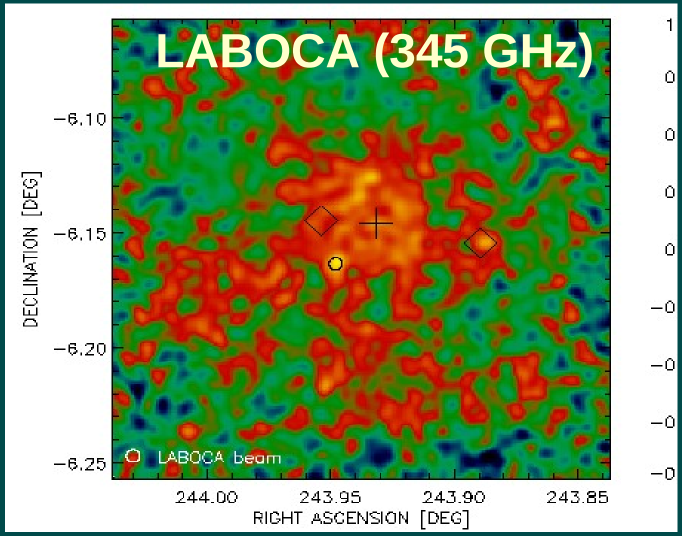
Scaling relations = relating observables to total mass

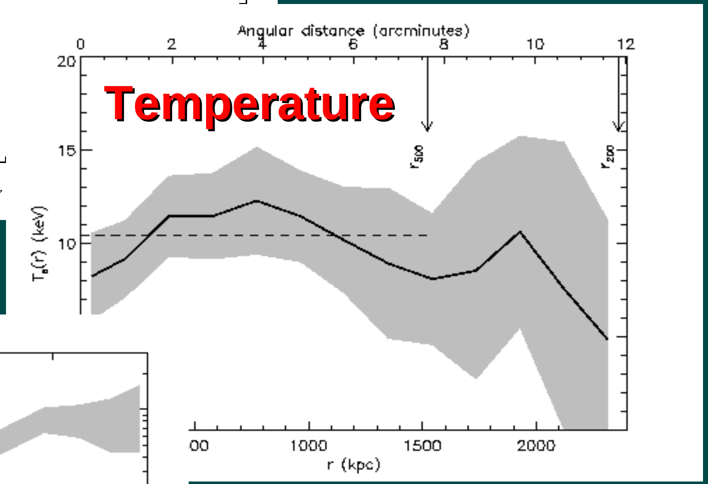
SZE observation state-of-the-art

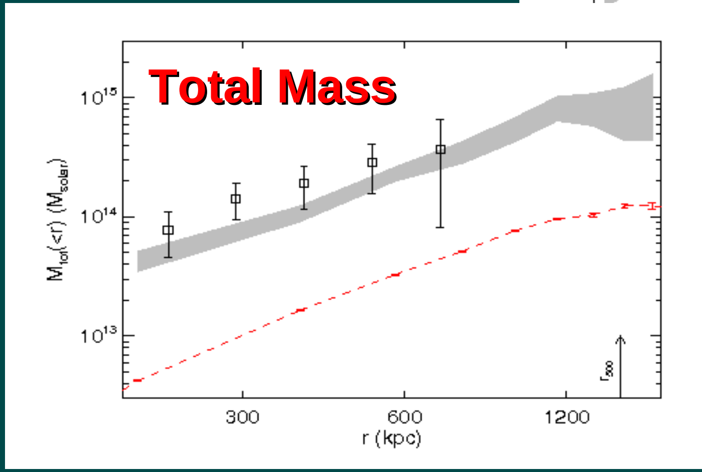


APEX-SZ + LABOCA imaging of Abell 2163
Nord, Basu, Pacaud et al., *A&A in press*
(arXiv: 0902.2131)





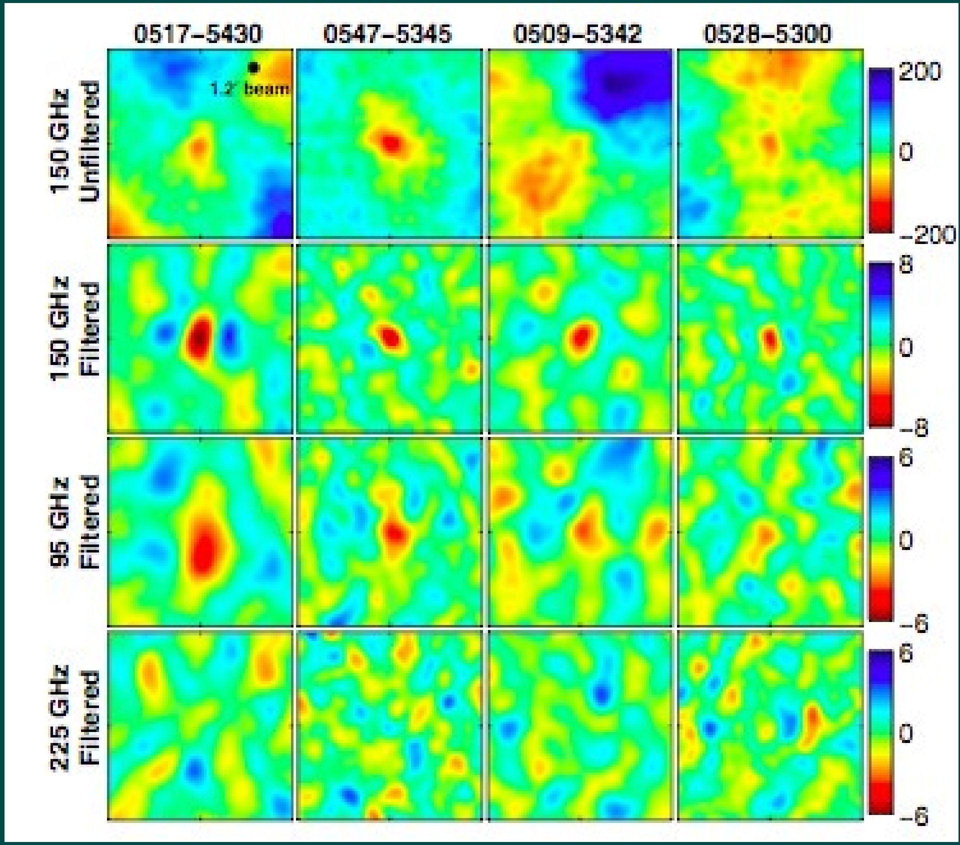




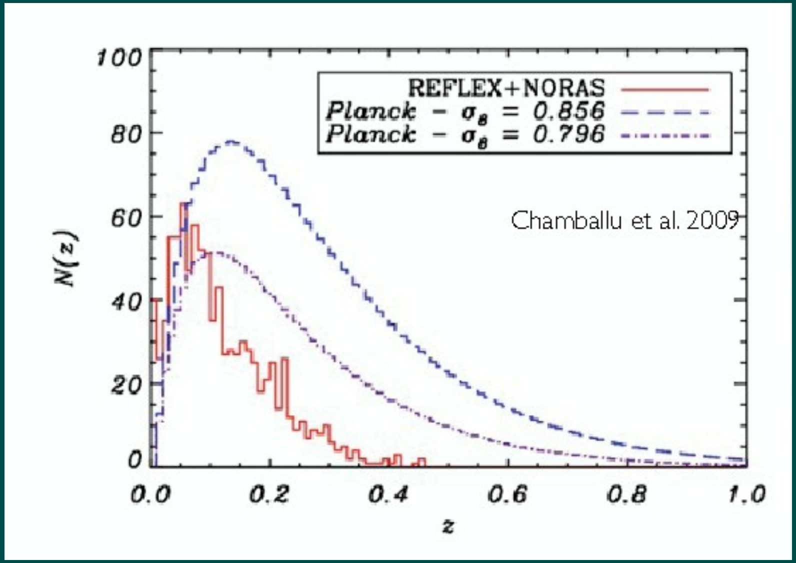
Non-parametric Temperature modeling

SZE observation state-of-the-art

The four most significant SPT 150 GHz detections in region overlapping 40 deg^2 BCS5h30m field



Staniszewski et al. 2009, ApJ, 701



Massive clusters are rare and thus most constraining for cosmology

Known X-ray distant clusters

~50-60 with $z > 0.5$

~6 with $z > 0.6$ & $kT > 6$ keV

Expected new distant clusters with Planck

100-200 with $z > 0.6$, $kT > 6$ keV

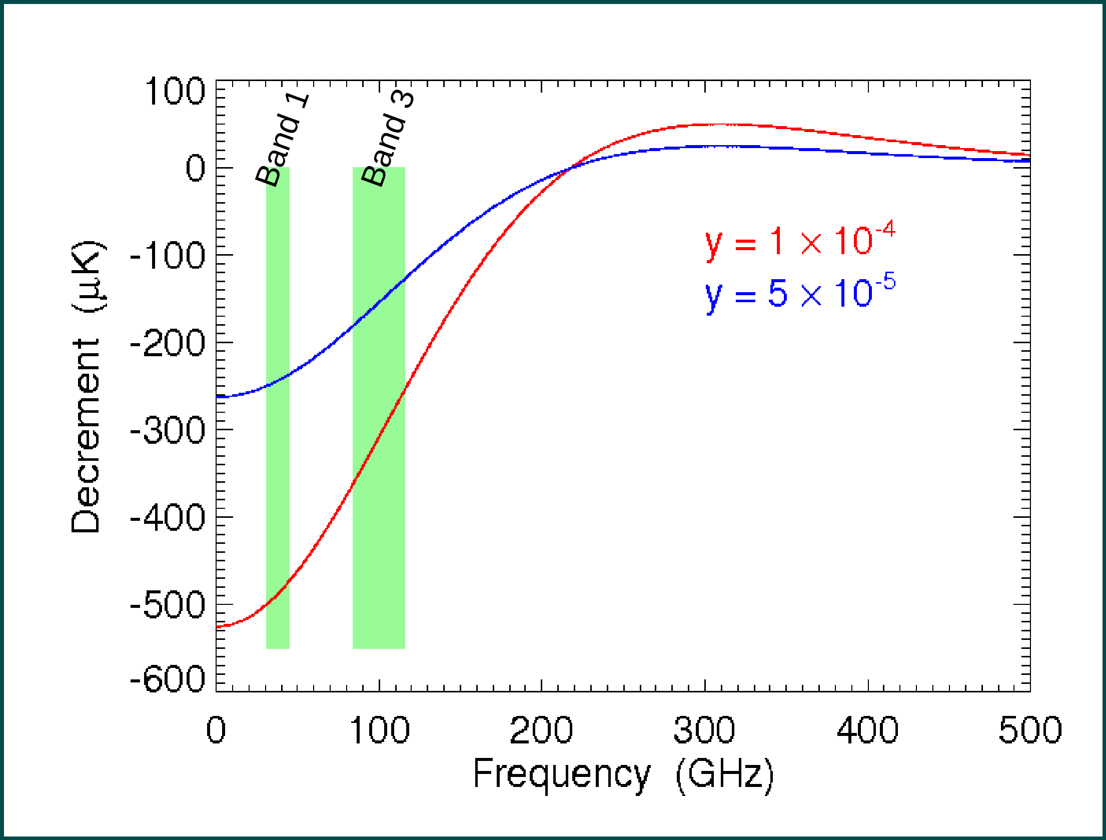
~20-50 fold increase

ALMA band(s) for SZ

1 31.3 – 45 GHz
2 67 - 90 GHz
3 84 - 116 GHz HIA
4 125 – 163 GHz
5 163 – 211 GHz
6 211 – 275 GHz NRAO
7 275 – 373 GHz IRAM
8 385 – 500 GHz
9 602 – 702 GHz SRON
10 787 – 950 GHz

Under construction (NA/Europe)
Under construction (Japan)
Passed PDR (Japan)
EU FP6 (6 antennas)
Not yet funded

Thermal SZE brightness temperature



Primary beam / arcsec (12 m dish) = 17 (λ / mm)

Band 3 (90 GHz) can combine with bolometric maps!

ALMA Band 1 specifications

Fiducial at 34 GHz, 8 GHz bandwidth, dual polarization, T_{rec} < 17 K

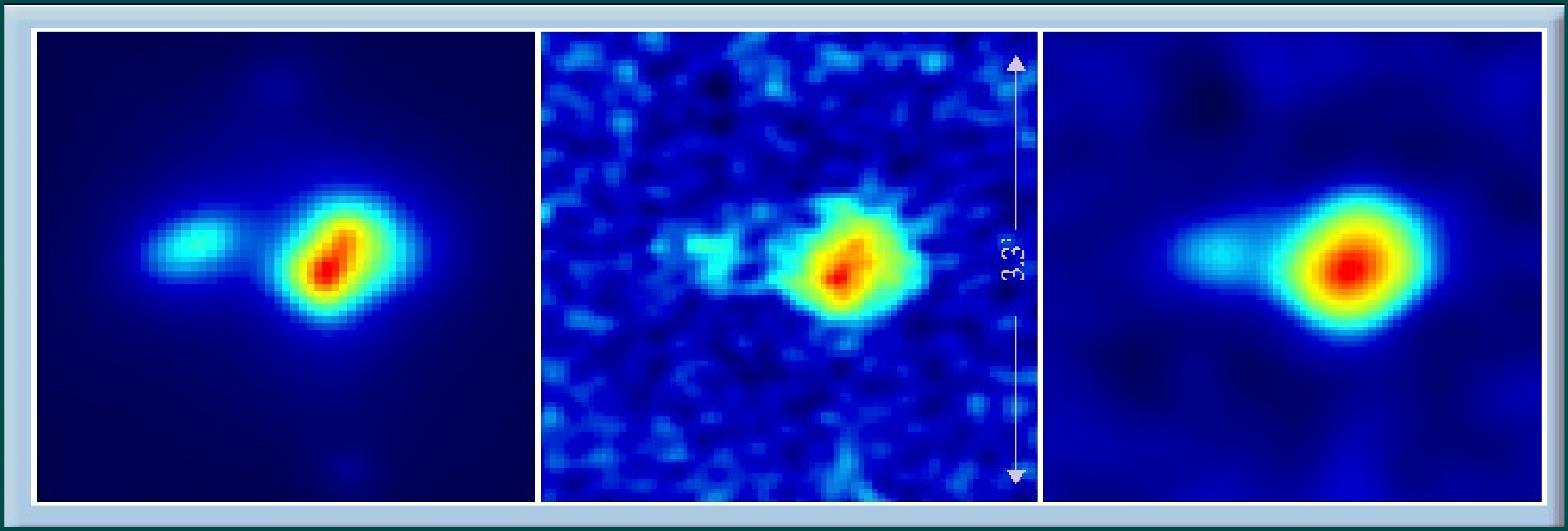
50 x 12m antennas: 13 µJy in 5 min, 1.7 µJy in 6 hr
150 µK in 5 min, 20 µK in 6 hr
(compact configuration; 10 arcsec beam)

12 x 7m antennas: 170 µJy in 5 min, 20 µJy in 6 hr
55 µK in 5 min, 6 µK in 6 hr

Numbers taken from R. Laing's slide

ν (GHz)	λ/D (arcsec)					
	Primary beam		**Shortest spacing**		**Resolution**	
	12m array *(compact)*	ACA	12m array	ACA	12m array	ACA
35	170	291	116	199	10	60
110	56	99	37	64	3.1	19

SZ simulations for Band 1



SZ simulation (Carlstrom et al.)

2×10^{14} M_{sun} at $z = 1$

Slide from S.T. Myers

ALMA 12m array (4 hours)
34 GHz in compact config.

10 arcsec FWHM
22 microK rms

4 kλ taper

22 arcsec FWHM
5 microK rms

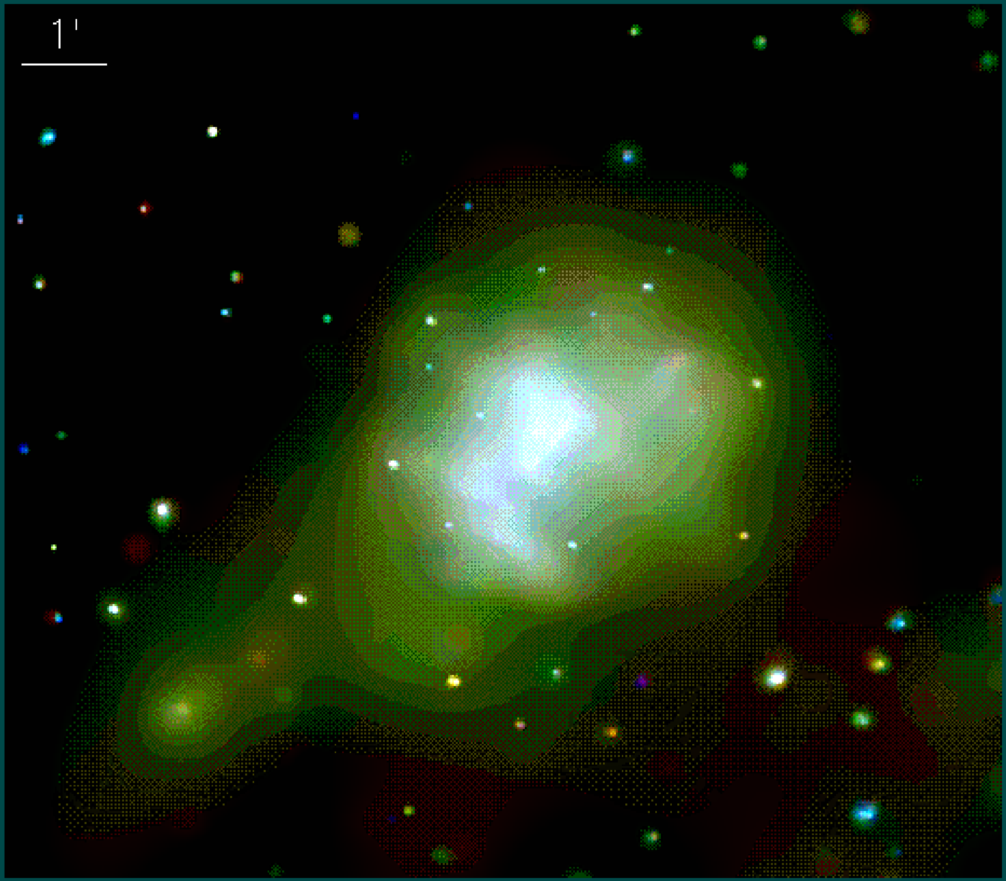
high-res SZ: Cluster morphology

J0717.5+3745

at z = 0.548

Clearly disturbed, shock-like substructure, filament

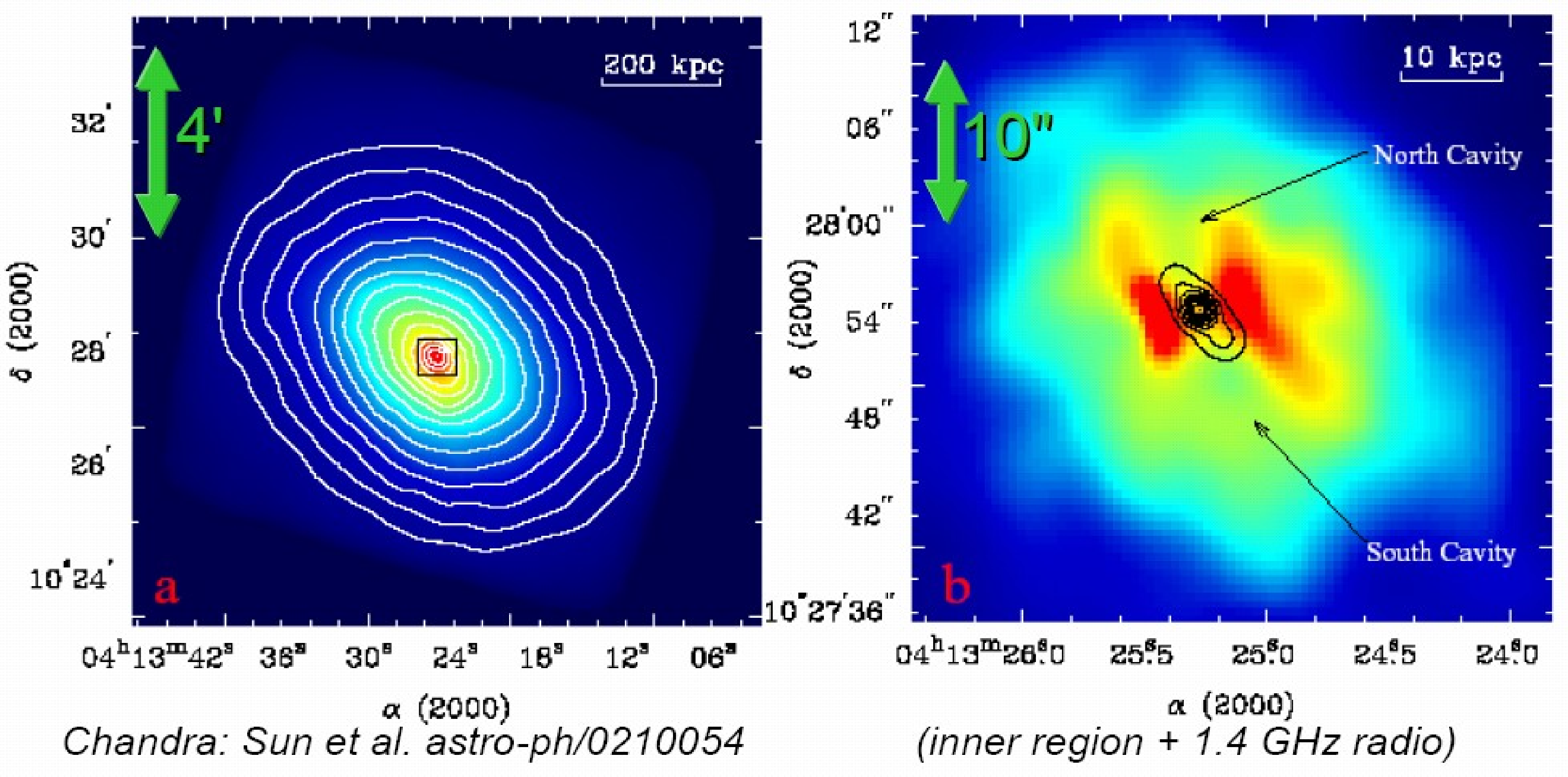
What will SZ image look like?



(Slide from M. Birkinshaw)

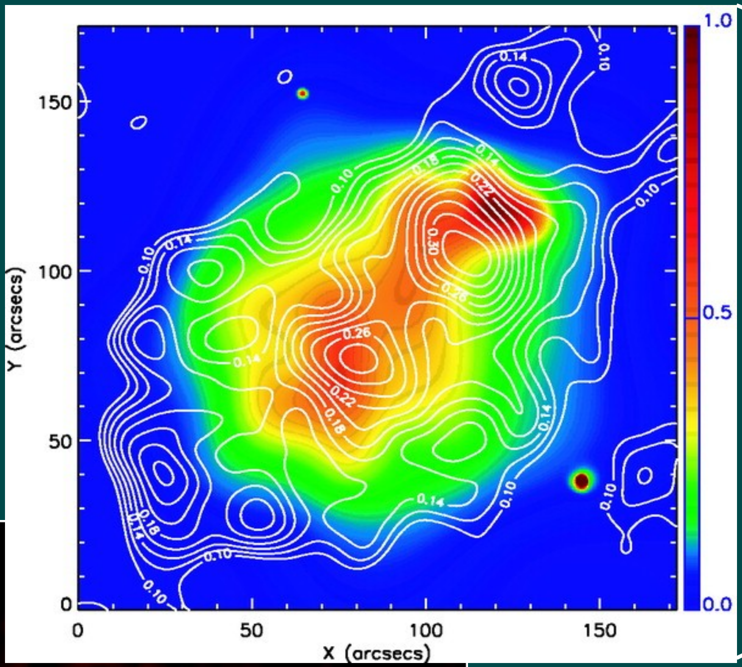
high-res SZ: Cluster morphology

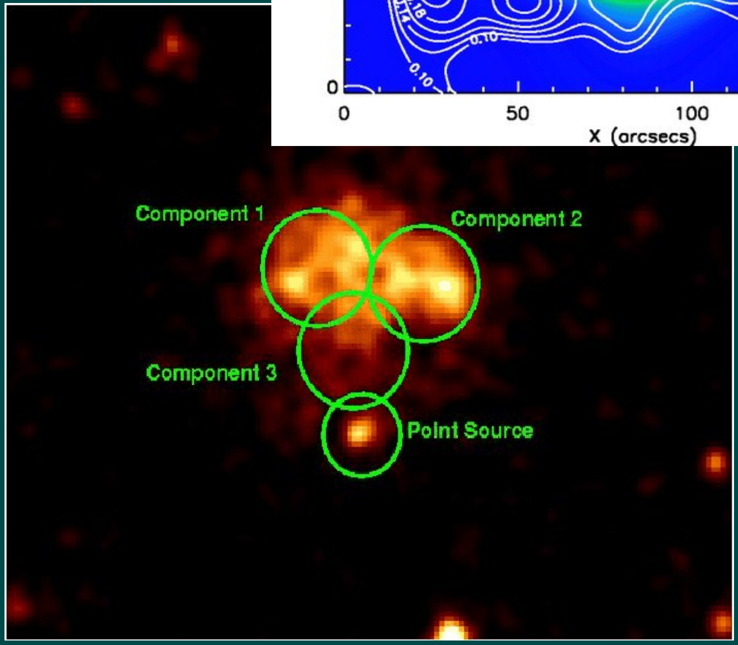
Abell 478: relaxed cooling flow cluster at z=0.09, X-ray cavities

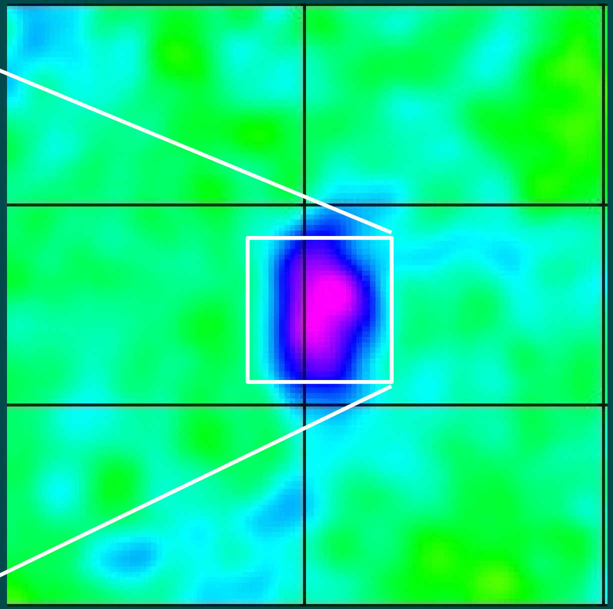


high-res SZ: Cluster morphology

X-ray + lensing

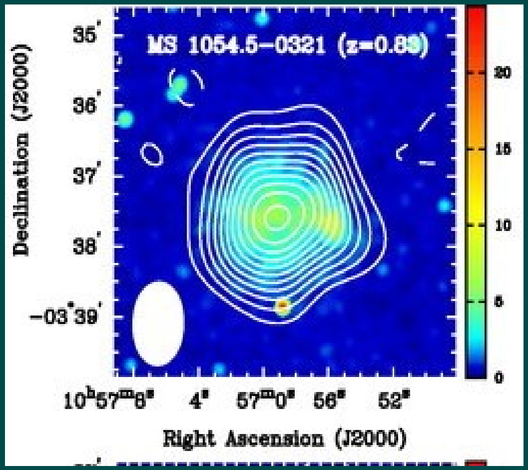






APEX-SZ imaging (D. Johansson / M. Nord)

MS 1054.5–0321
a rich merger
at z=0.83

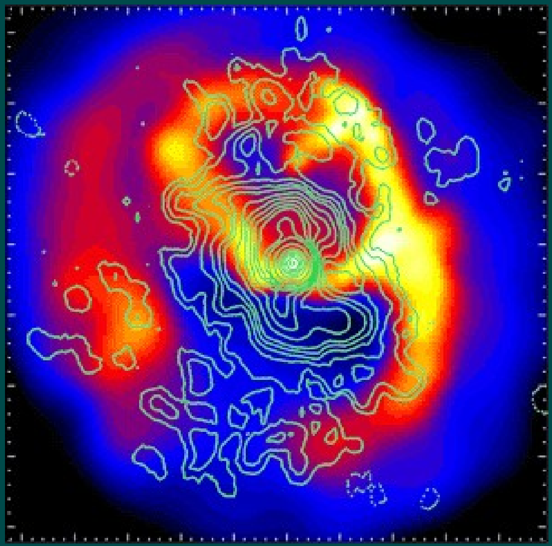


OVRO/BIMA
Bonamente et al. 2006

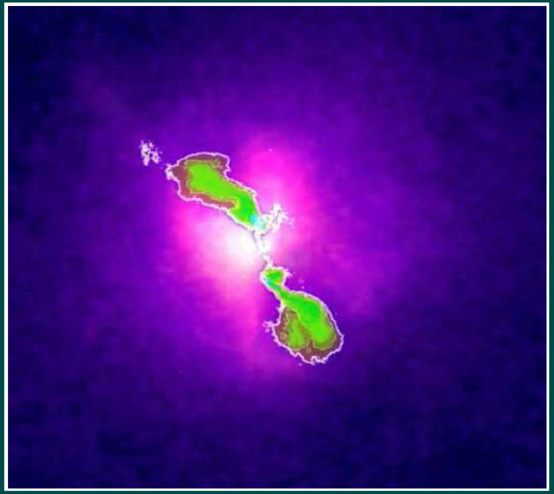
high-res SZ: Bubbles and filaments

X-ray + radio

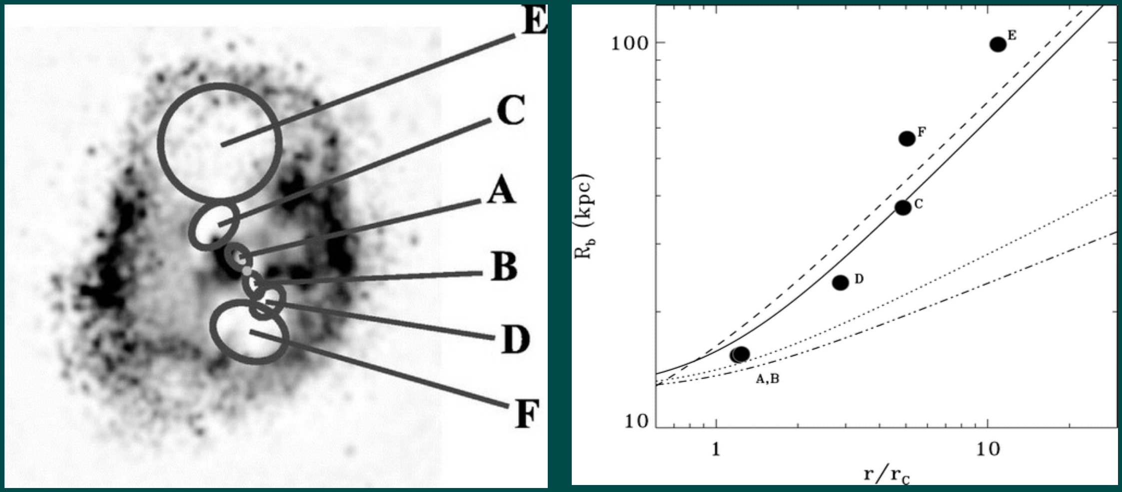
Abell 2052



Abell 478



Hydra A: Diehl et al. 2008



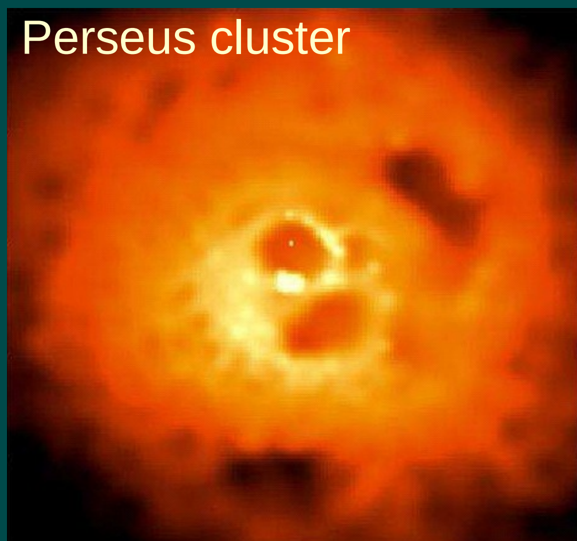
Are ICM bubbles in pressure equilibrium?
(lack of shocked gas surrounding them)

Higher pressure near the center will naturally explain bubble expansion (but sound crossing times much smaller than bubble ages)

What provides the stability of bubbles?
– tangential magnetic fields?
– viscosity?

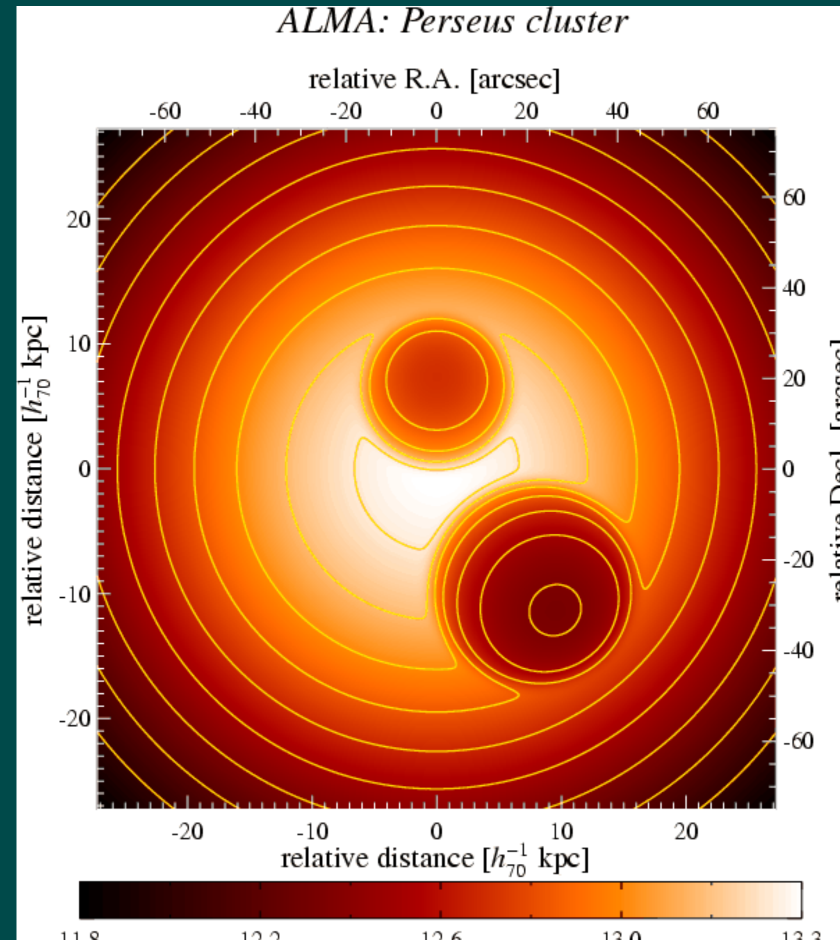
high-res SZ: Bubbles and filaments

Pfrommer, Ensslin & Sarazin
(2005, A&A, 430, 799)



the difference!

Telescope: cluster	I_A [mJy amin^{-2}]	I_B [mJy amin^{-2}]	exposure [hours]
ALMA: Perseus	13.25	12.70	5.1
ALMA: Abell 2052	3.930	3.698	38
GBT: Perseus	11.31	10.85	2.1
GBT: Abell 2052	3.272	3.138	31

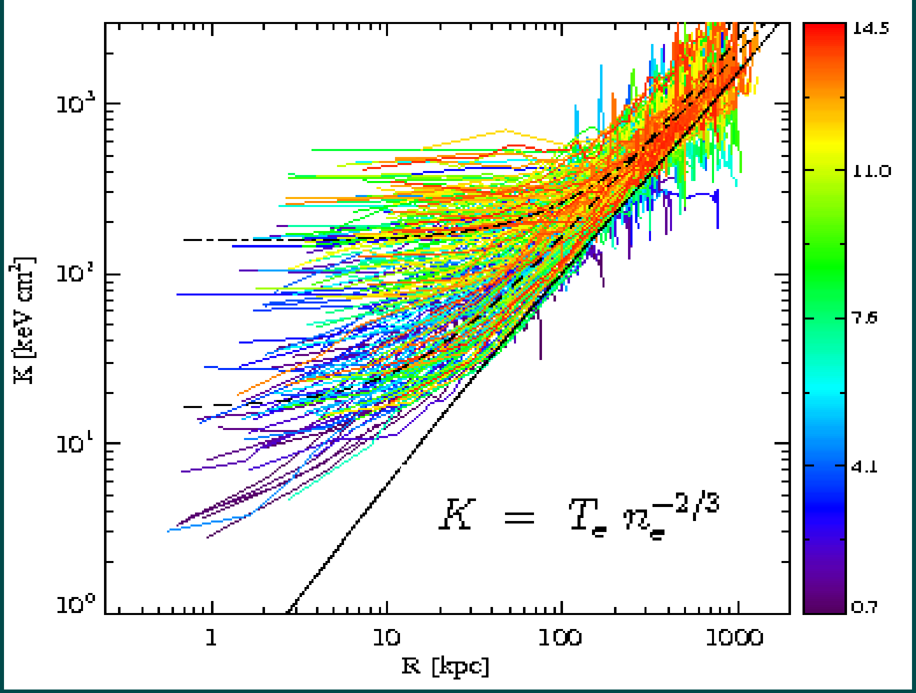


ALMA band 4 (144GHz)
FoV 36´´, FWHM 3´´

high-res SZ: Gas entropy

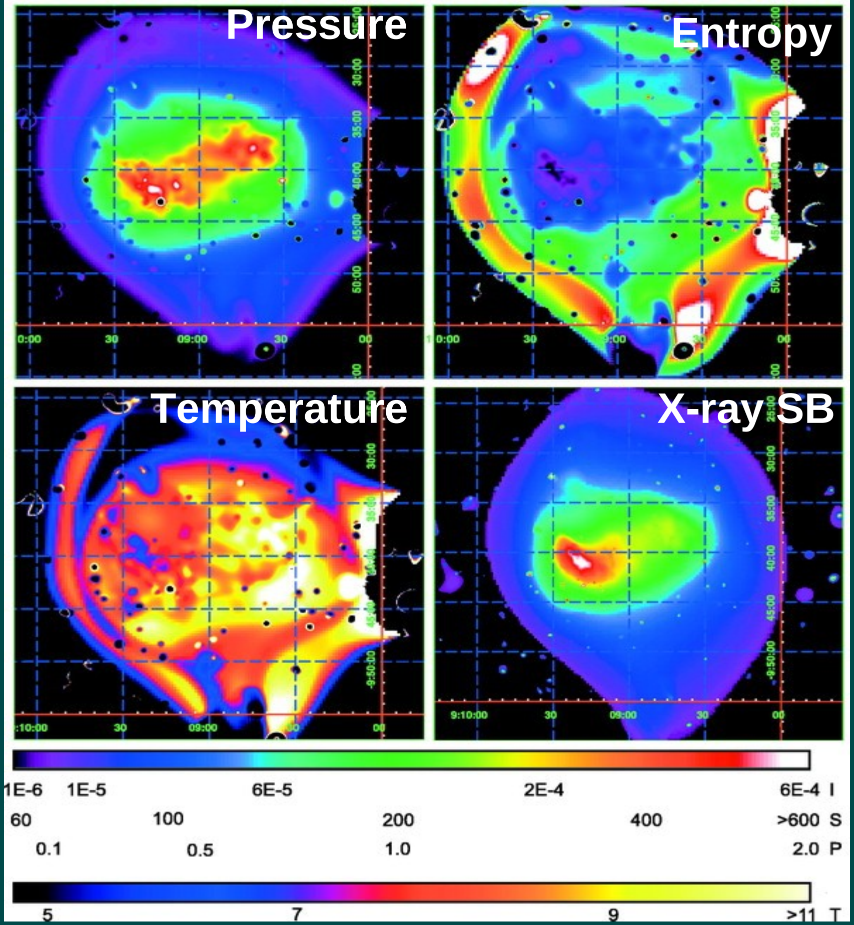
Entropy is a fundamental property of the ICM, describing its history of heating and cooling

Slope of the entropy profile near the cluster center determines the extent of non-gravitational heating



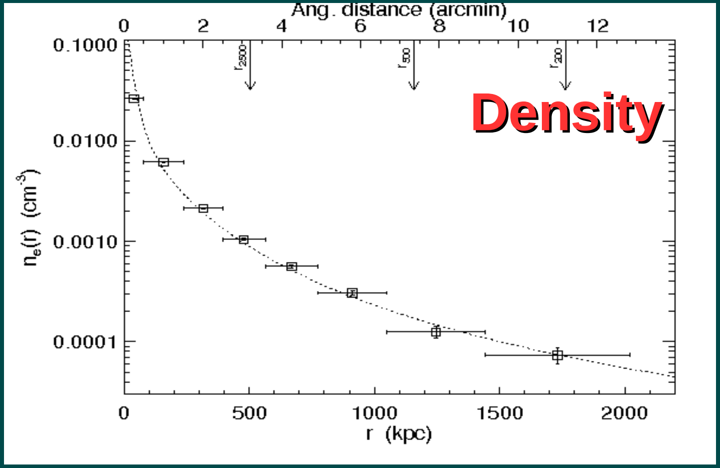
Cavagnolo et al. 2009

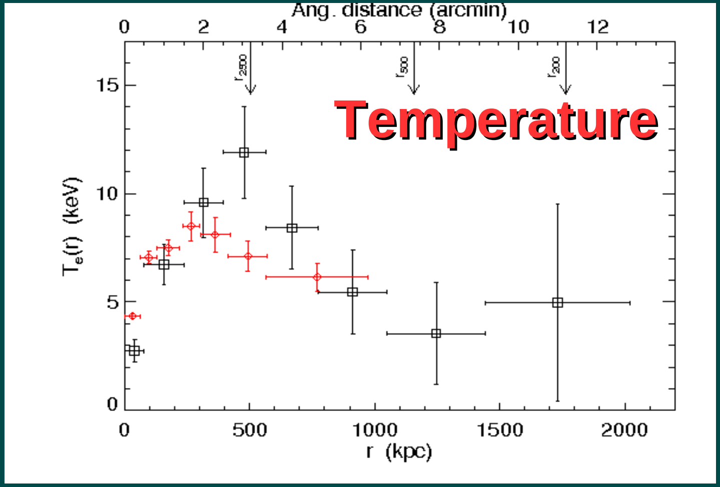
X-ray spectral mapping of A754
(Henry, Finoguenov & Briel 2004)

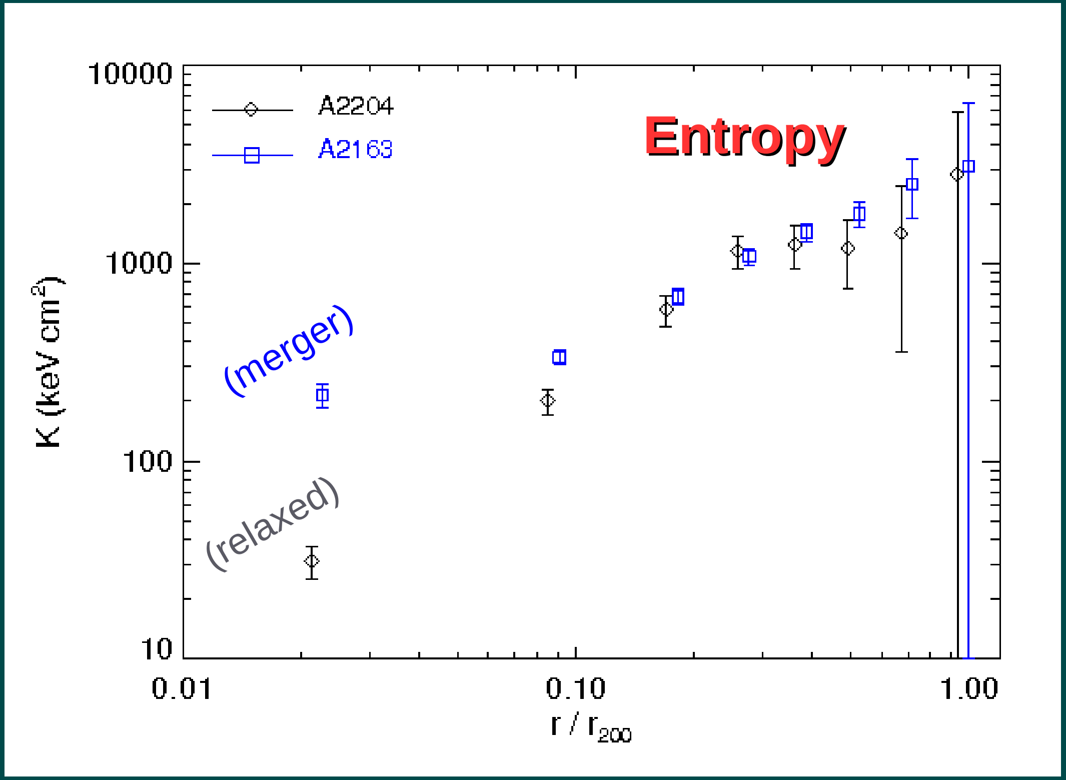


high-res SZ: Gas entropy

Abell 2204, Basu, Zhang, Nord et al. (Submitted)







Summary: SZ with ALMA

- SZ science provides one of the strongest scientific case for ALMA band 1. Southern hemisphere (location of bolometric surveys) and larger FoV than EVLA.
- Early science can commence with Band 3, in particular with the Compact Array. Band 3 also provides the opportunity to combine with 90 GHz bolometer maps (APEX-SZ).
- Strong scientific return in following-up all high-z clusters detected through X-ray & SZE: merging activity at high-z, evolution of thermal feedback, etc.
- ALMA might do to SZ science what *XMM-Newton* and *Chandra* did to X-ray, in understanding ICM physics.