Cluster Surveys with SZE & X-rays

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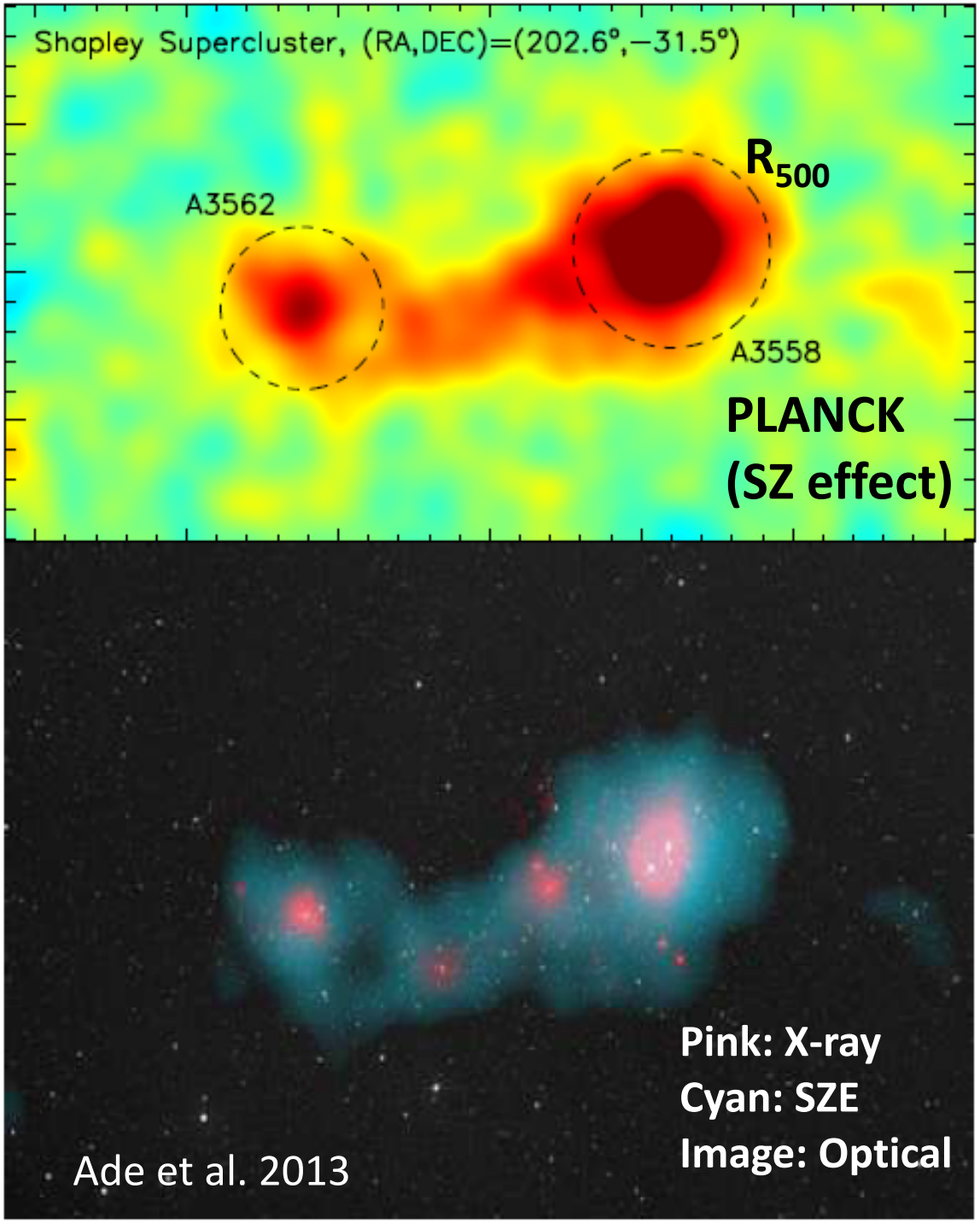
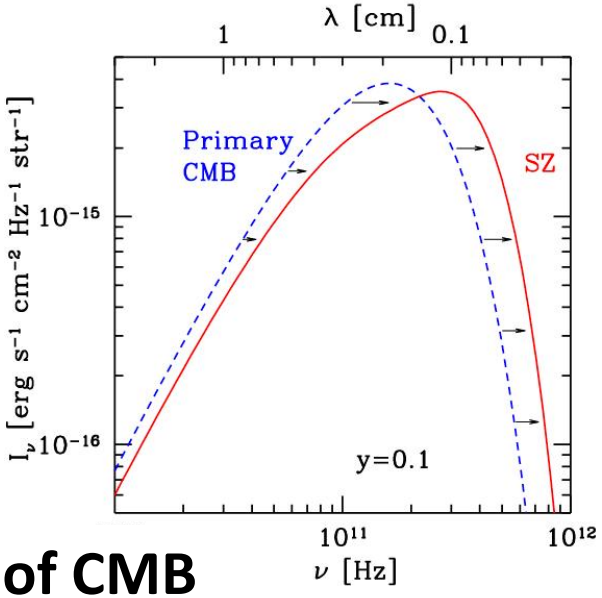


SZE & X-rays from galaxy clusters



For the same thermal plasma,

$I_{SZ} \propto \int n_e T_e \, dl$ indep. of z : Inv. Compton of CMB

$I_X \propto \int n_e^2 \Lambda(T_e) \, dl / (1+z)^4$: Bremsstrahlung + lines

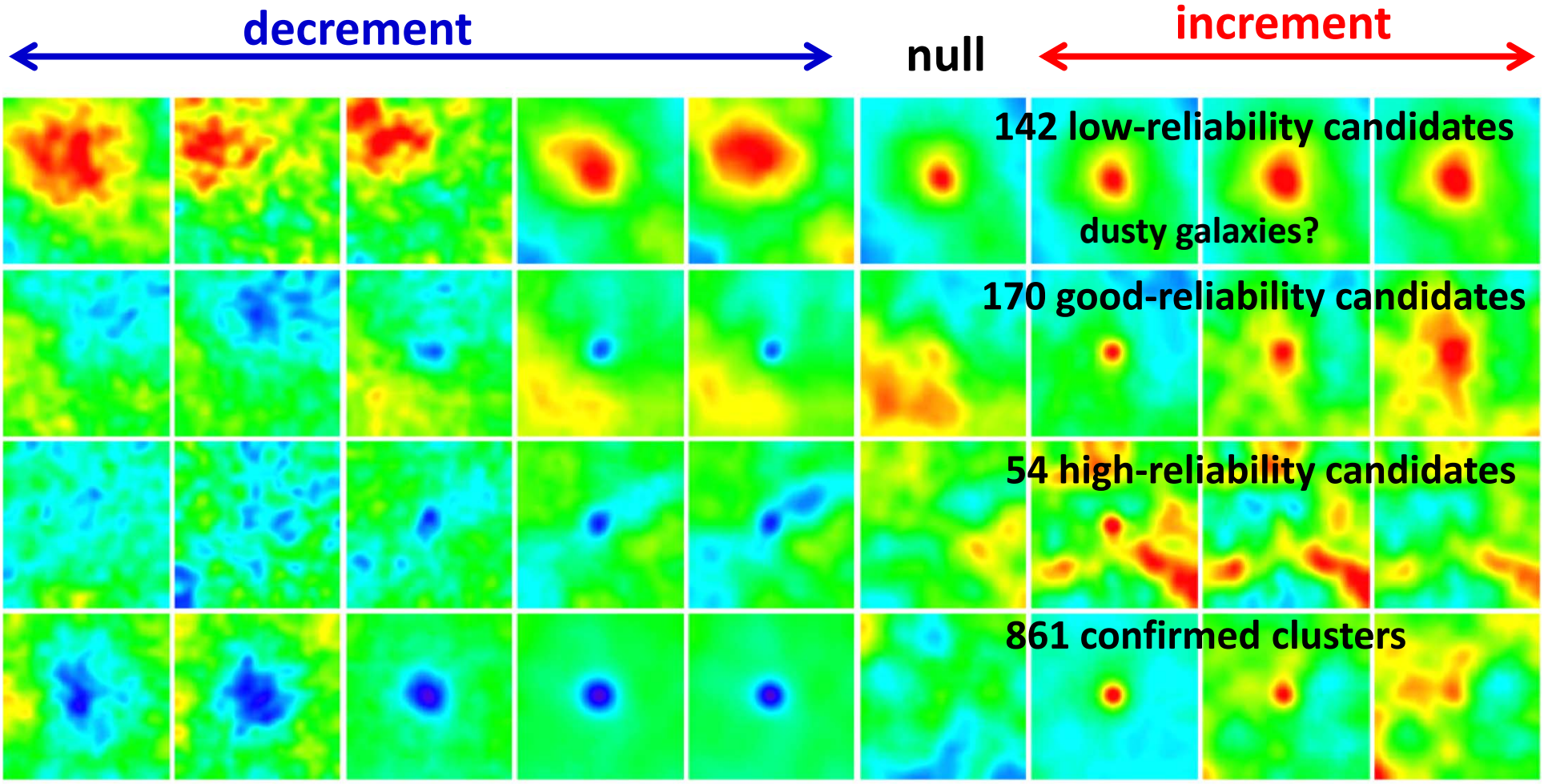
$\Lambda(T_e)$: weaker than $T_e^{1/2}$

- **X-ray :**
  - High contrast against BGD
  - Bulk of radiation energy
  - Detailed spectroscopy (continuum＋lines)

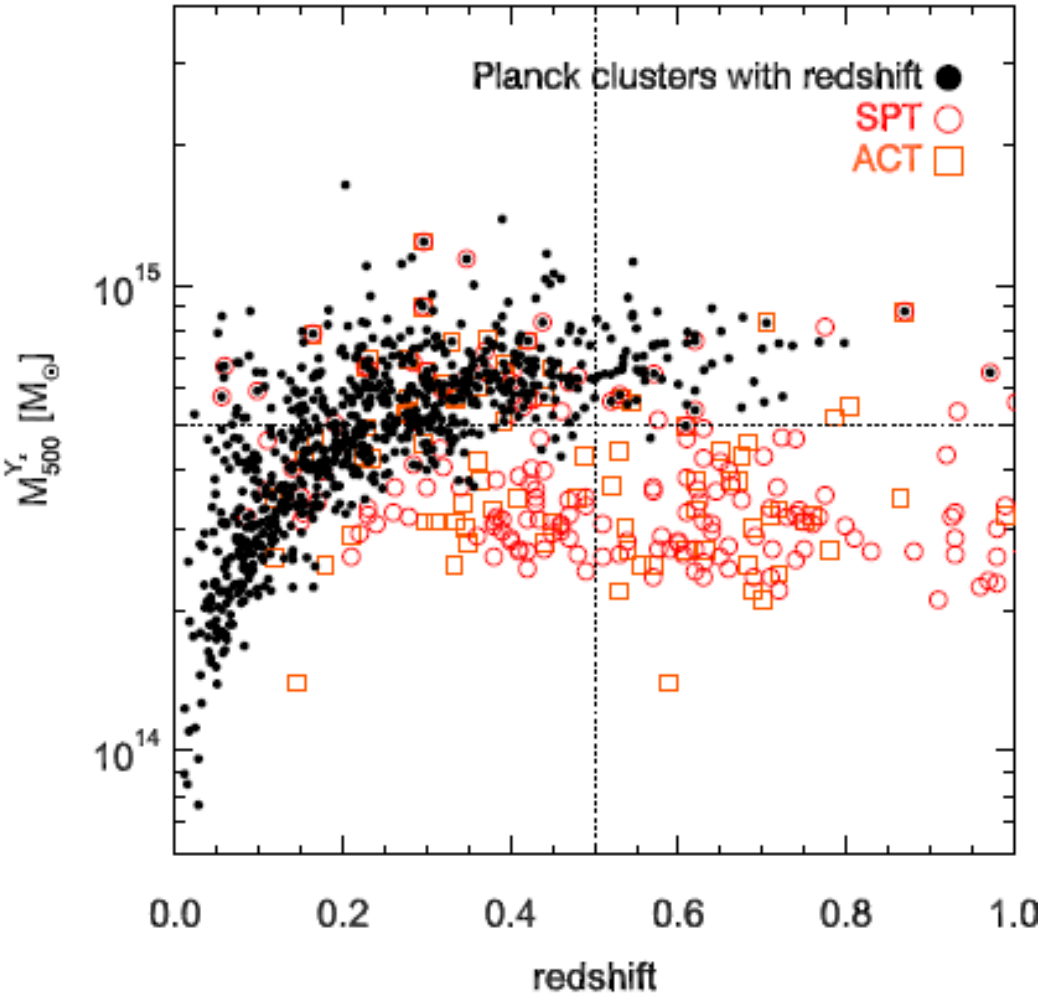
- **SZ effect**
  - Brightness constant with z ∝ P（e.g., shock）
  - Unique spectral shape （decrement + increment）

Complementary!

PLANCK: stacked images (Ade+13)



Current status of SZE surveys



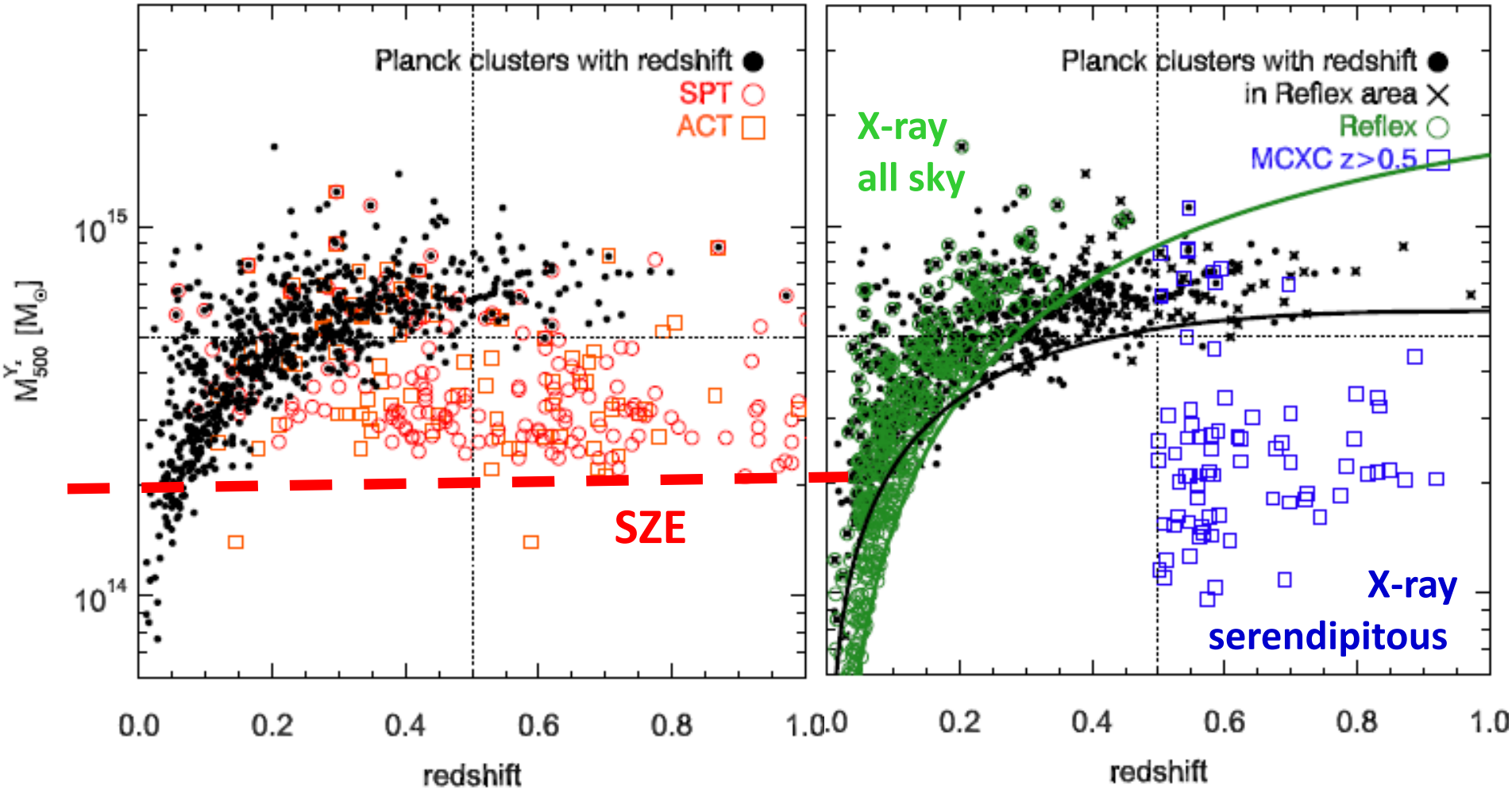
Mass estimated by $Y_z = \int y\, dA$

- **Planck** (1.5m at L2)
  - 30-860GHz , >5' beams
  - 861 confirmed + 366 candidates
  - 178 new, up to z=1
  - (Ade et al. 2013)

- **SPT** (10m at South Pole)
  - 95, 150, (220) GHz, 1.1' beam
  - 224 candidates in 720 deg^2
  - 144 new, up to z=1.5
  - (Reichardt et al. 2013)

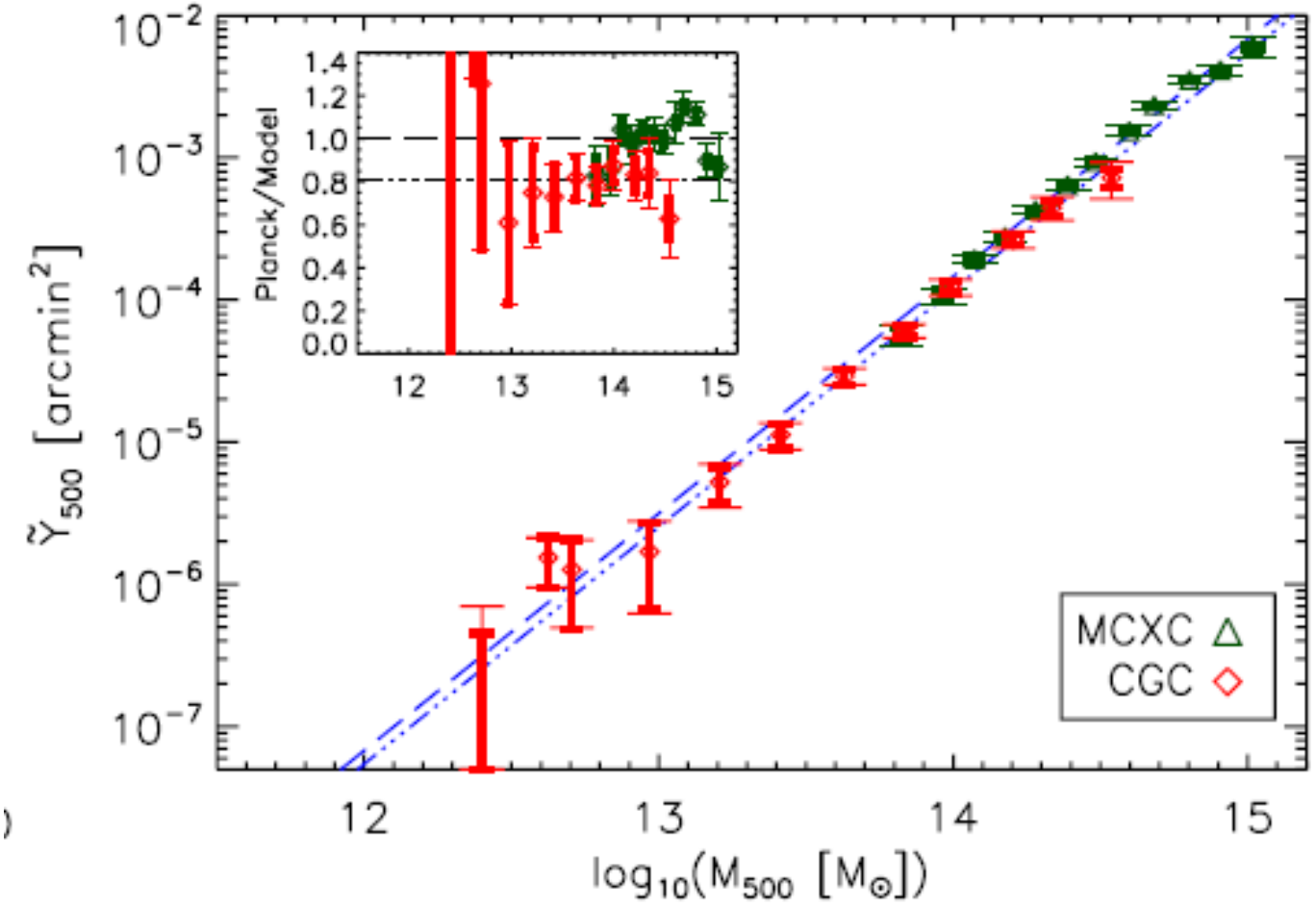
- **ACT** (6m at Atacama)
  - 148, (218, 277) GHz, 1.4' beam
  - 68 clusters in 504 deg^2
  - 19 new
  - (Hasselfield et al. 2013)

Current status of SZE & X-ray surveys



Current SZ surveys are nearly mass-limited at M_{500}>2e14 M_{sun}

SZE from groups/galaxies



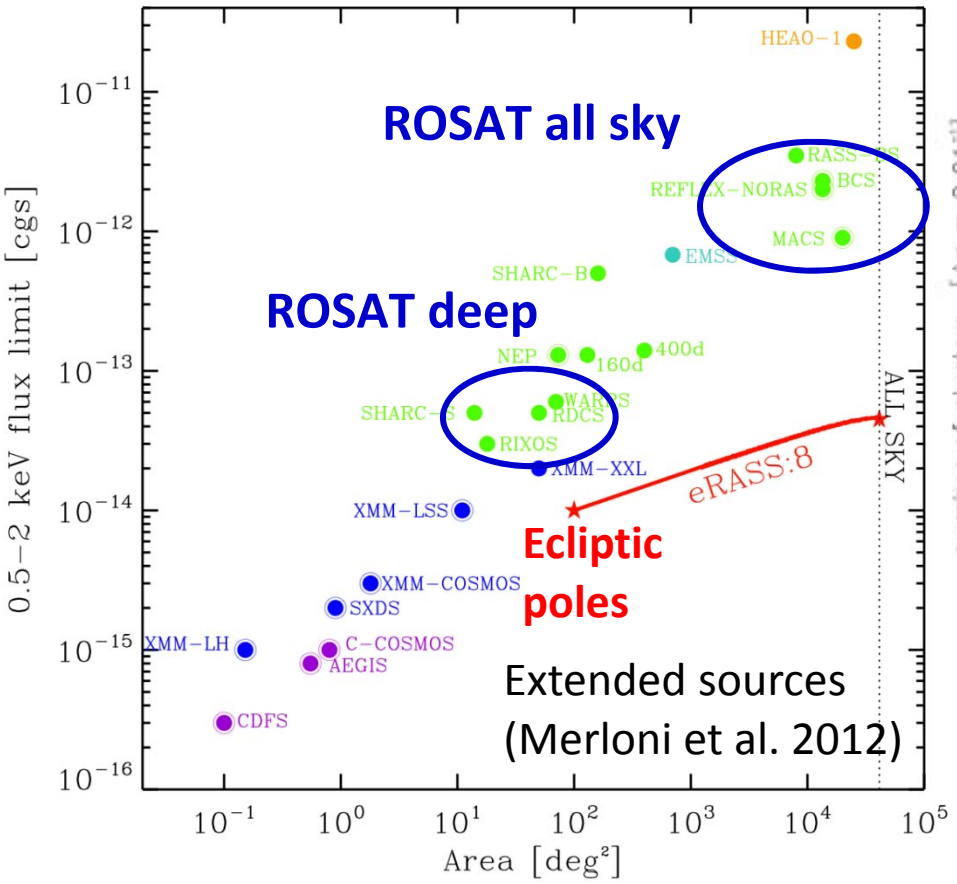
Planck (Ade+13)

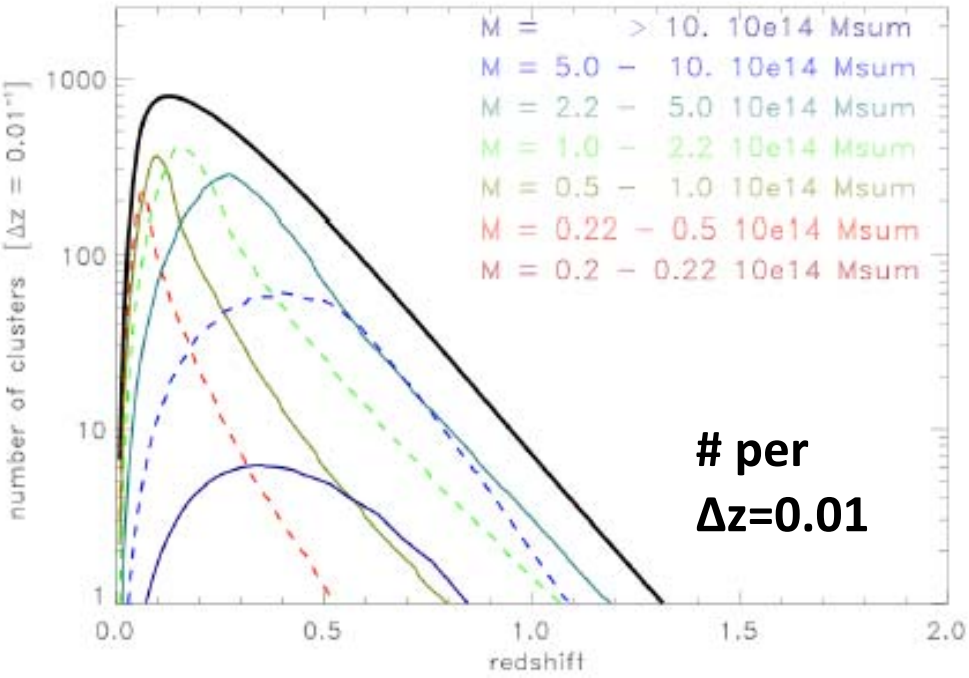
Stacked SZE around 260,000 "locally brightest galaxies" (LBG) within Δr=Mpc & cΔz=1000km/s

Note:

M_{halo} is estimated from M_{star} of LBG by simulations.

X-ray survey by SRG on eROSITA (2015?)





All sky in 4yrs:

～10^5 clusters（×100 ROSAT）

& 3×10^6 AGNs

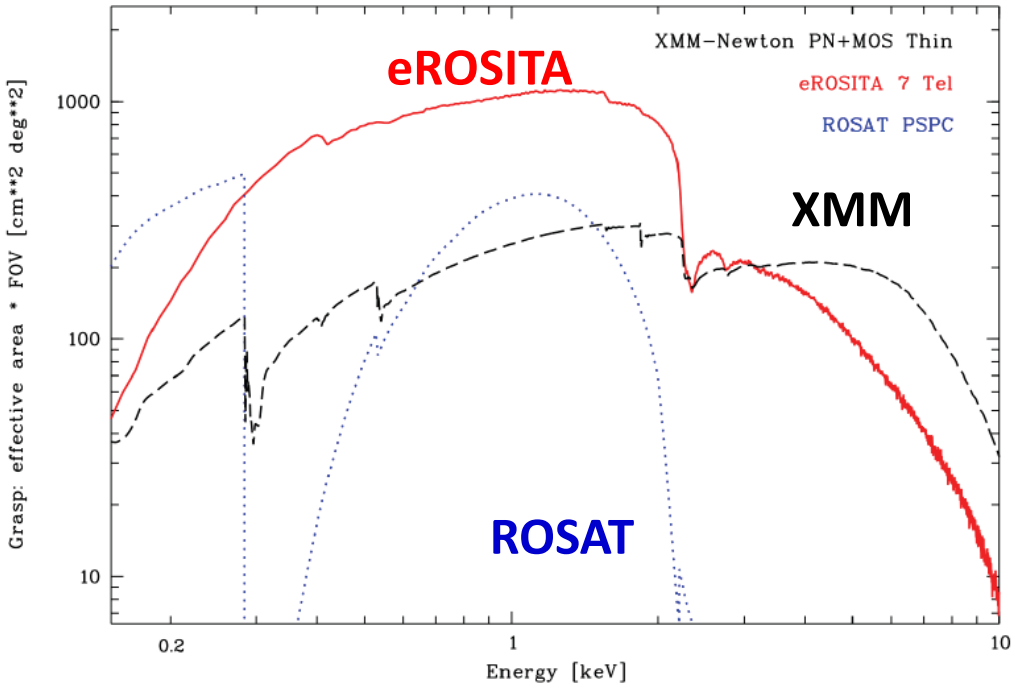
Mean spatial resolution 30”

Follow-up needed for z (as for SZE surveys)

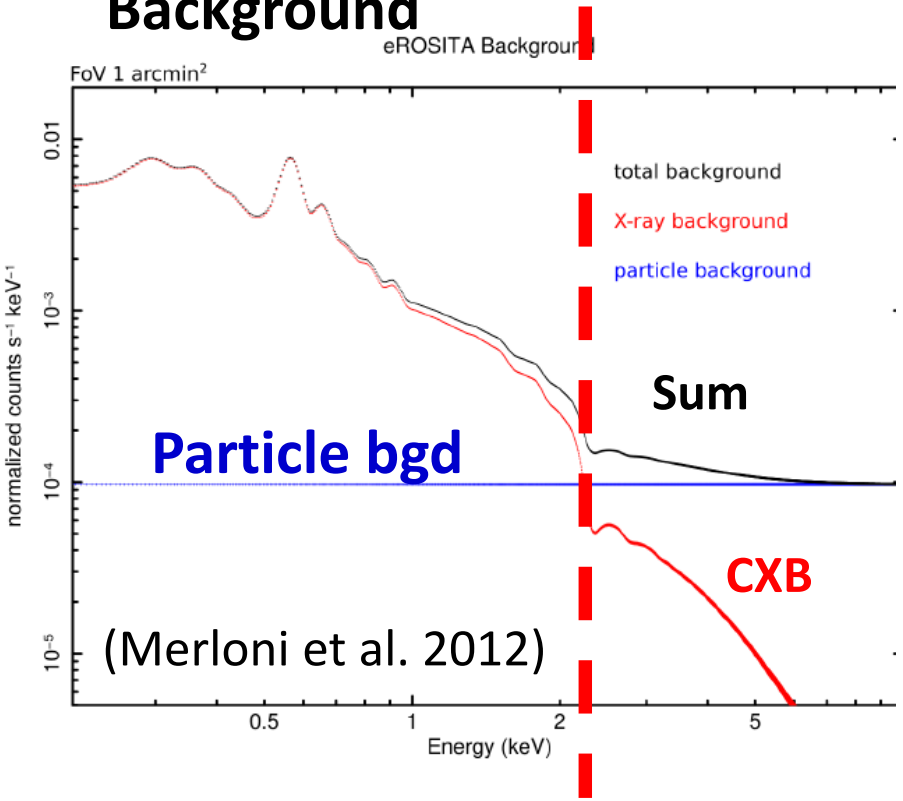
Data rights?

eROSITA: Background

Grasp (survey efficiency)



Background

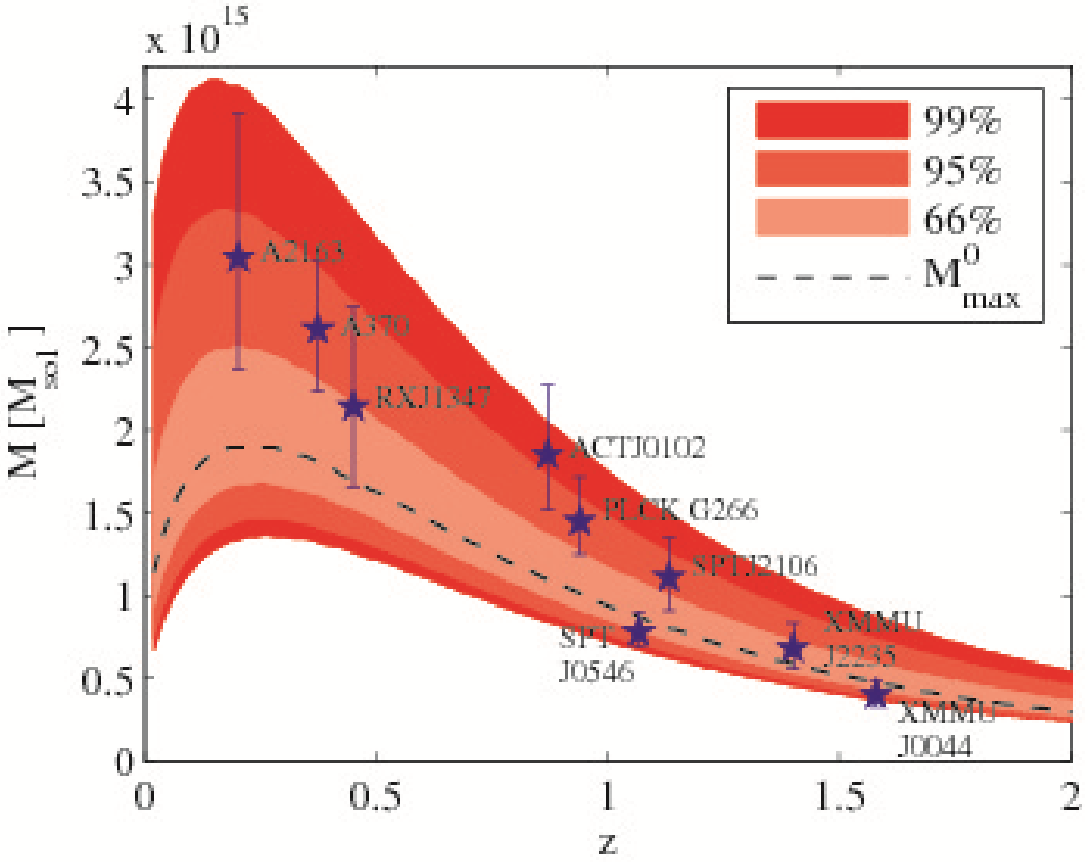


First X-ray observatory @L2

Particle background exceeds CXB at E>2 keV

& average exposure 2.5 ksec/position (4yrs)

Testing Standard Cosmology



Harrison & Coles (2012)
Extreme value statistics
cf. Mortonson et al. (2011)

Galaxy clusters
= highest σ objects

Even a single massive cluster can challenge ΛCDM+Gaussian.

Accurate mass is crucial.

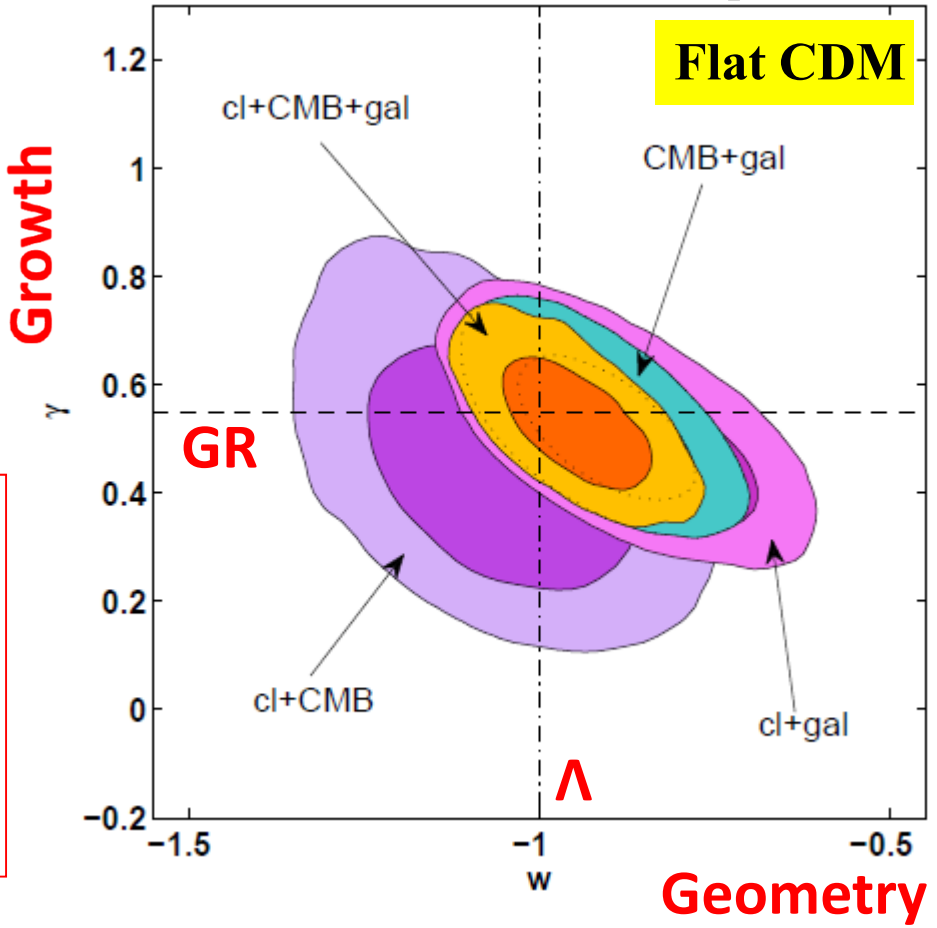
Testing Standard Cosmology

Generalized linear growth rate
(Linder & Cahn 2007)

$$\frac{d\ln\delta}{d\ln a} = \Omega_M(a)^{\gamma}$$

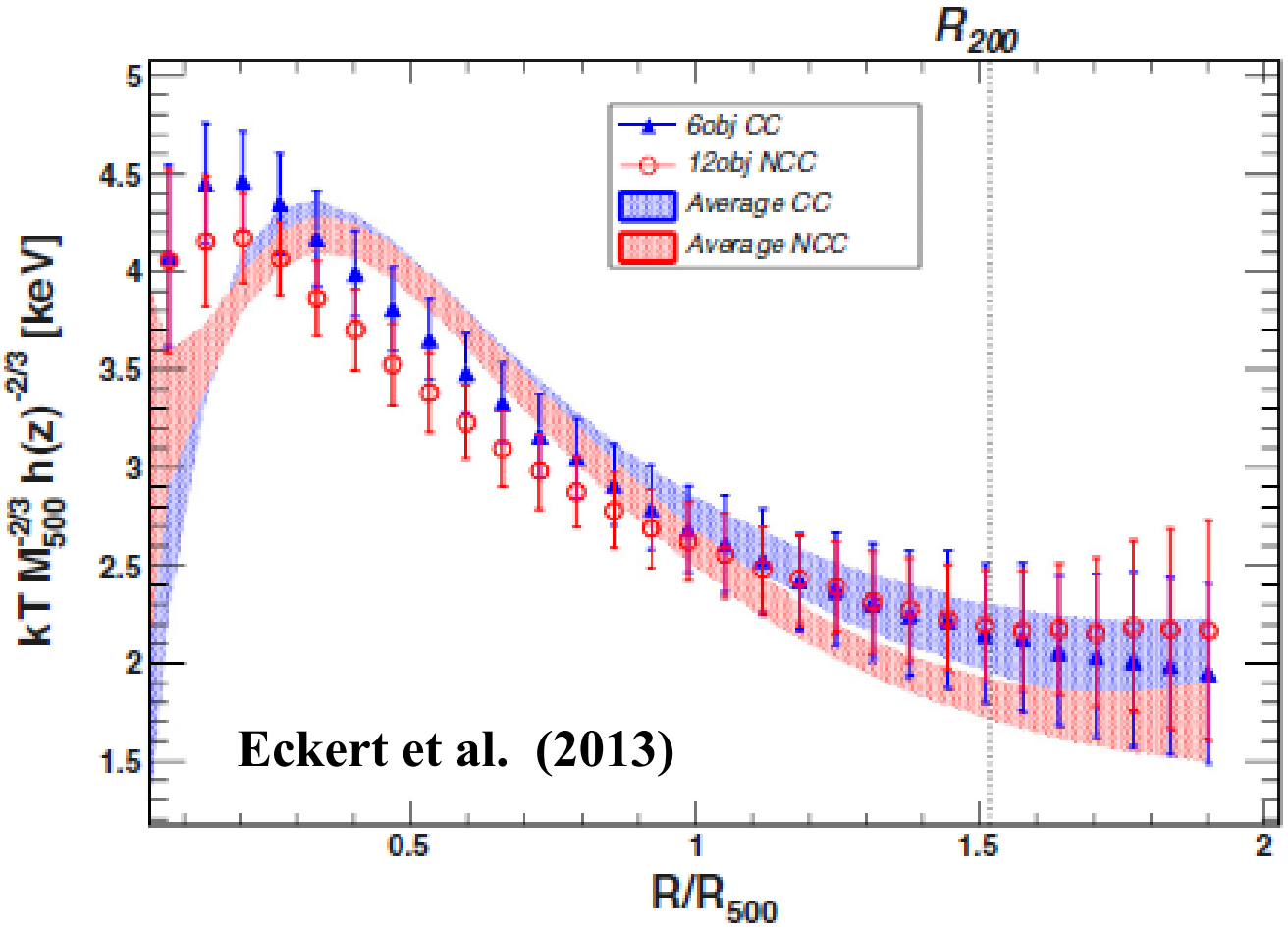
γ=0.55: **GR, ΛCDM, w=−1**
(accuracy <1%)
0.57: **GR, wCDM, w=−1/3**
0.68: **DGP (braneworld) gravity**
z, scale-dependent: **f(R) gravity**

Limits from current data（Rapetti+12）



Complementary to geometrical tests.
Data at z>1 and z<1 are both important.

Mass at z>>1 ?



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

$I_X \propto \int n_e^2\ \Lambda(T)\ dl$

↓

n(r), T(r) from imaging data only

↓

Hydrostatic mass at high z, large r

ROSAT X-ray + Planck SZE stacked, 18 low-z clusters

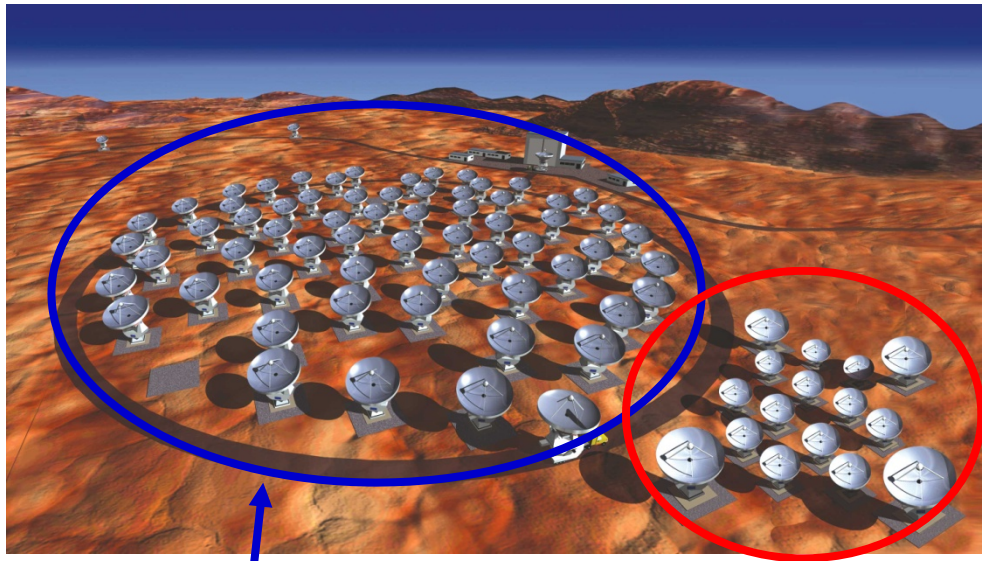
→ Continuous T(r) including outskirts.

Tension with Suzaku results?

SZE with ALMA

- Spatial resolution < 5”
- Well-controlled systematics & point-source free

Band	ν [GHz]	resolution[”]	FOV[”]
(1)	31-45	13-0.1	140
(2)	67-90	6.0-0.05	80
3	84-116	4.9-0.038	62
4	125-163	3.3-0.027	43
5	163-211		33
6	211-275	2.0-0.016	27
7	275-373	1.5-0.012	19
8	385-500	1.1-0.009	14
9	602-720	0 68-0.006	9
(10)	787-950	0.52-0.005	7



12m × 50
Higher resolutions

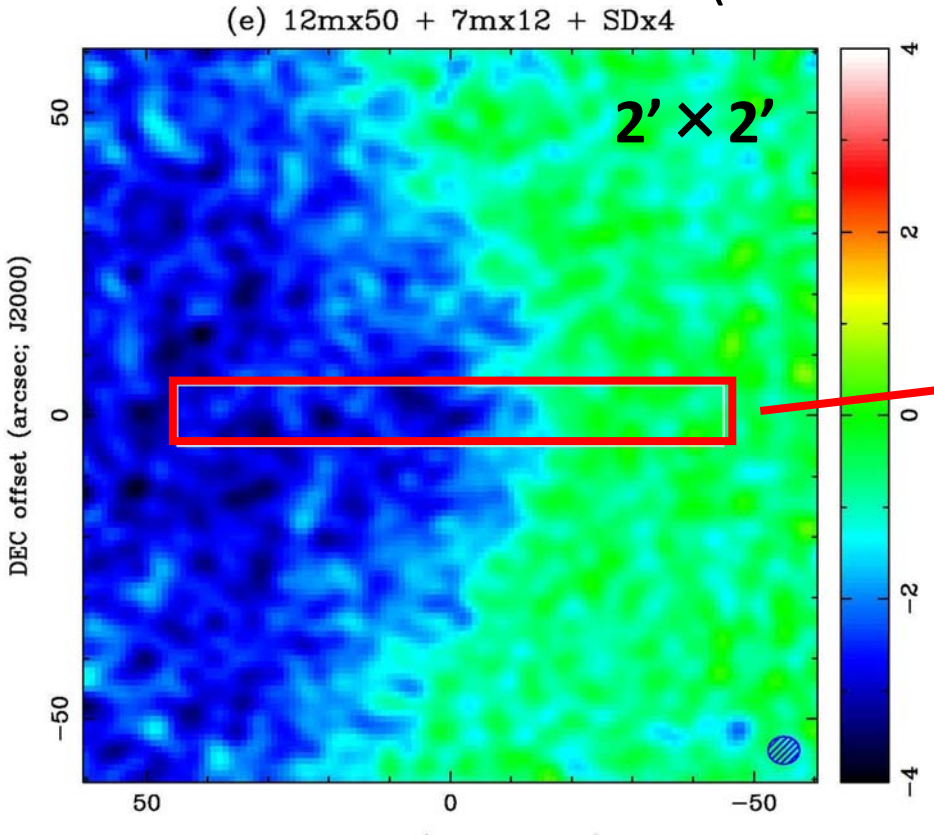
ACA
7m × 12 &
12m SD × 4
Lower resol.

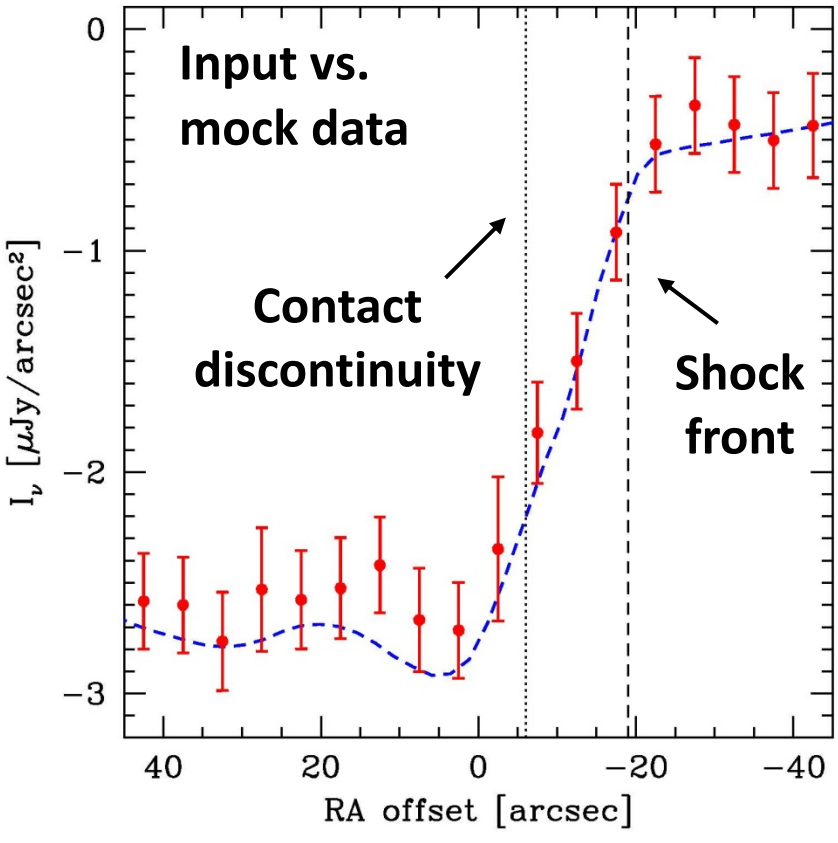
※12m × 34 + 7m × 9
available in 2014 (Cycle 2).

※Bands 1, 2 & 10 will be added in the future.

ALMA Imaging simulations: Bullet cluster

(Yamada, TK+ 2012)





Mock Image at 90GHz

12m × 50, 10hr, 19 mosaics

+ACA, 40 hr, 7 mosaics

FWHM=4.8" σ= 0.3μJy/arcsec2

(Input: mesh sim. by Takizawa 2005)

15"～60kpc@z=0.3

Only ALMA can resolve ICM into 5" in ～2020.

Summary

1) SZE & X-ray: complementary probes of intracluster medium.

2) SZE sample is now comparable to ROSAT X-ray sample
and will keep growing; e.g. SPT3G from 2016 may reach z>2.

3) X-ray sample will be enhanced by two orders of magnitude
with eROSITA by 2020.

4) Issues:

- Follow-up for z (and T_e ?).
- Determination of M at z>>1.
- Low spatial resolution (>30")

after Chandra/XMM (201?) before ATHENA+ (>2028).