Chandra and SZA Observations of Galaxy Clusters at z≥1

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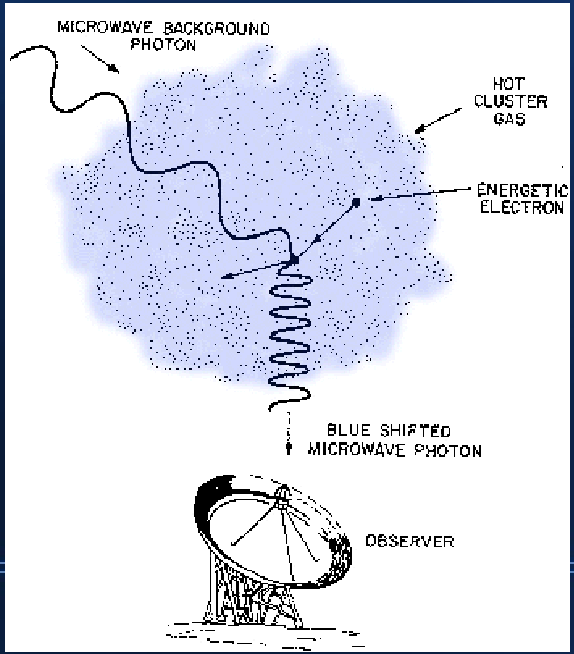
The Sunyaev-Zeldovich Effect

- CMB photons inverse compton scatter off keV e^- in cluster gas
- Net increase in photon energy

- Spectral shift to higher frequency
- Secondary CMB temp. anisotropy on ~1' scales
- **decrement** below ~220 GHz

L.P. Van Speybroeck



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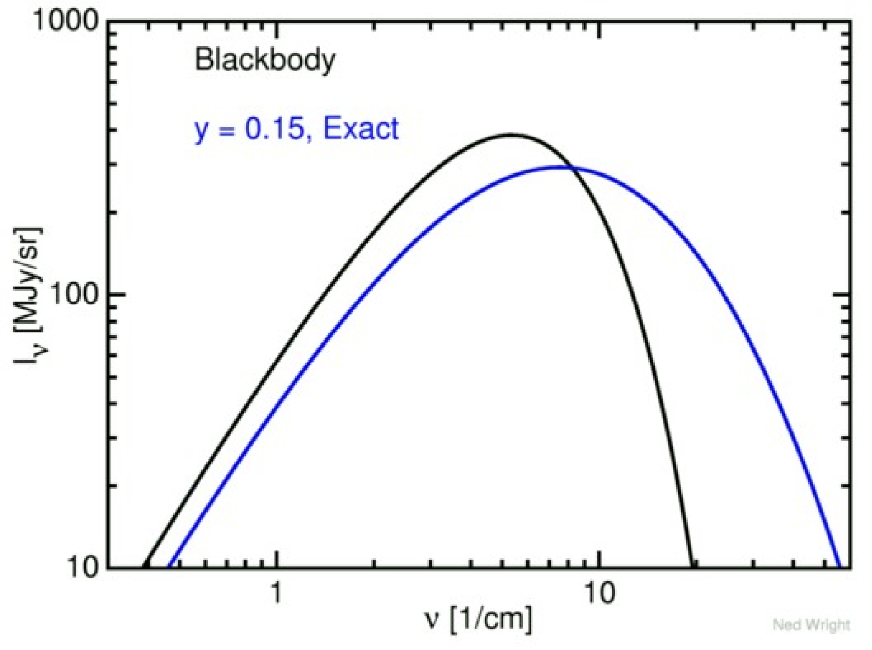


The Sunyaev-Zeldovich Effect

- Quantify by compton y-parameter; brightness indept. of redshift:

$$y \equiv \frac{k_B \sigma_T}{m_e c^2} \int n_e T_e \, d\ell$$

$$\Delta I_{\mathrm{T}} = I_0 y f(x)(1 + \delta_{\mathrm{T}})$$

- Integral of y prop. to thermal energy content:

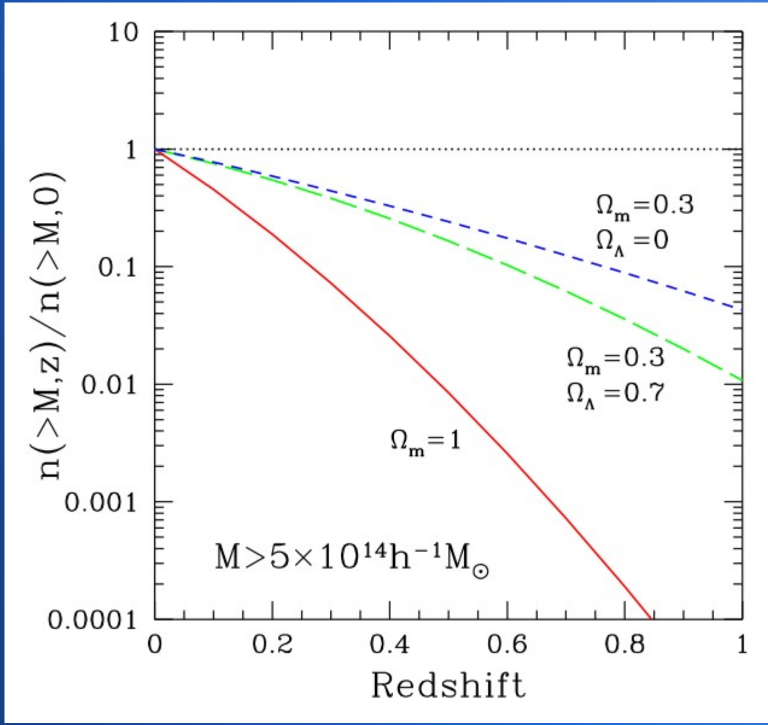
$$Y = \int y \, d\Omega \propto \frac{1}{D_\theta^2} \int n_{\mathrm{e}} T_{\mathrm{e}} dV$$

- $Y_X \equiv M_g T_e$ derived; SZE measures Y directly
- Self-similar scaling:

$$Y D_\theta^2 \propto M_{gas}^{5/3} E(z)^{2/3}$$

Motivation for z≥1

- Scaling relationships not well studied - implications for structure formation and evolution
- Useful for cosmology – difference between expectation of different models more pronounced at high redshift
- X-rays + SZE → calibrate mass-observable relationship (SPT, ACT, APEX...)



The Sunyaev-Zeldovich Array

- Eight 3.5m diameter telescopes
- Six close-packed – sensitive to typical cluster scales
- Two 'outriggers' to remove radio sources
- 30 and 90 GHz, 8 GHz bandwidth

High-z Sample

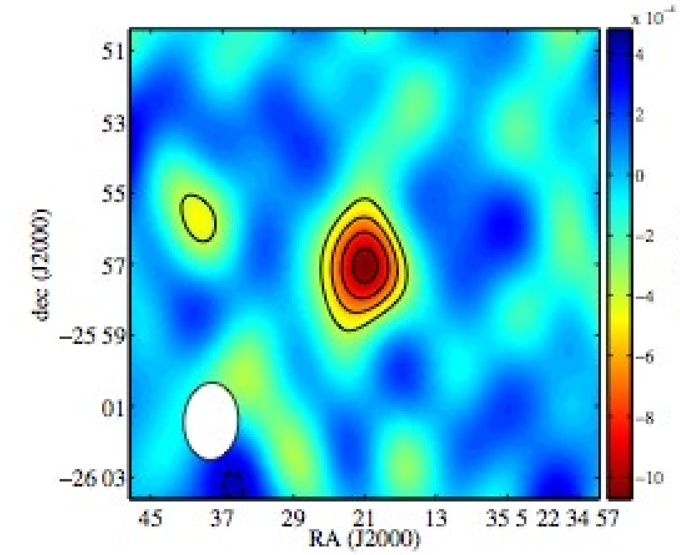
- Ad-hoc 11-cluster sample in available dec range
- Most massive cluster candidates from recent IR surveys
- Massive serendipitous detections with confirmed redshifts
- Observe at 30GHz; detections for clusters with $M_{g,X\text{-ray}} > 10^{13} M_{sun}$

Cluster	*z*	*R.A.*	*decl.*	Discovery	X-ray Data	SZE Constraint
JKCS 041[a]	1.90	02 26 44	-04 41 37	IR	Yes	Upper Limit
2XMM J083026.2+524133[b]	0.99	08 30 26	+52 41 33	X-ray	Yes	Yes
RX J0848+4453[c]	1.27	08 48 35	+44 53 49	IR	Yes	Upper Limit
RX J0849+4452[d]	1.26	08 49 58	+44 51 55	X-ray	Yes	Upper Limit
RX J0910+5422[e]	1.11	09 10 44	+54 22 09	X-ray	Yes	Upper Limit
RX J1252-2927[f]	1.24	12 52 54	-29 27 17	X-ray	Yes	Upper Limit
Cl J1415.1+3612[g,h]	1.03	14 15 11	+36 12 03	X-ray	Yes	Yes
ISCS1438.1+3338[i]	1.41	14 38 09	+34 14 19	IR	No	Upper Limit
SpARCSJ1638 [j]	1.20	16 38 52	+40 38 43	IR	No	Upper Limit
XMMU J2235-2557[k]	1.39	22 35 21	-25 57 42	X-ray	Yes	Yes
XMMXCS J2215.9-1738[l]	1.46	22 15 58	-17 38 03	X-ray	Yes	Upper Limit

Culverhouse et al 2009 (in prep.)

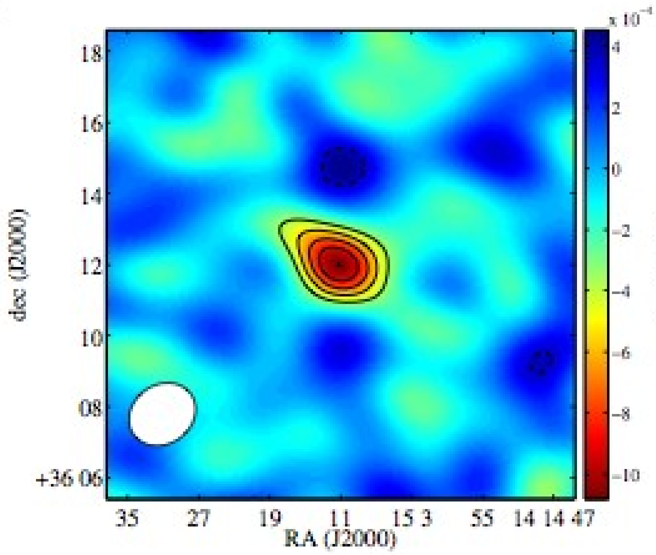
Detected Clusters

XMMU J2235-2557



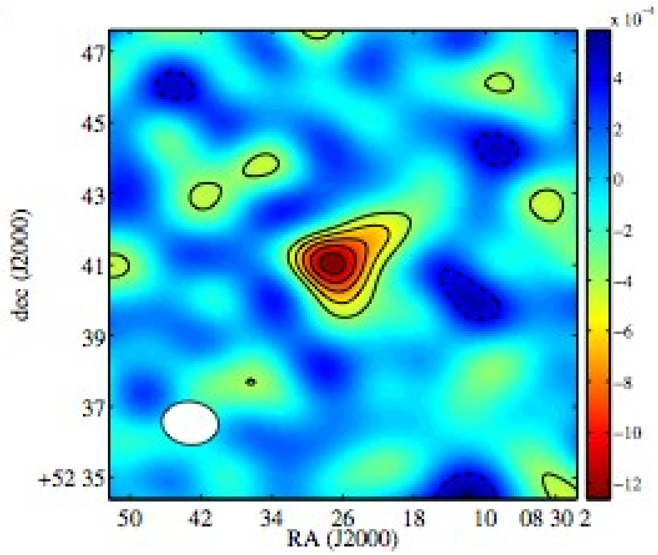
- $z = 1.39$
- $M_g = 0.95 \pm 0.1 \times 10^{13}\ M_{sun}$
- $YD_A^2 = 1.7 \pm 0.4 \times 10^{-5}\ Mpc^2$

CL J1415.1+3612



- $z = 1.03$
- $M_g = 1.1 \pm 0.1 \times 10^{13}\ M_{sun}$
- $YD_A^2 = 1.3 \pm 0.4 \times 10^{-5}\ Mpc^2$

2XMM J0832+5241



- $z = 0.99$
- $M_g = 1.4 \pm 0.2 \times 10^{13}\ M_{sun}$
- $YD_A^2 = 2.0 \pm 0.4 \times 10^{-5}\ Mpc^2$

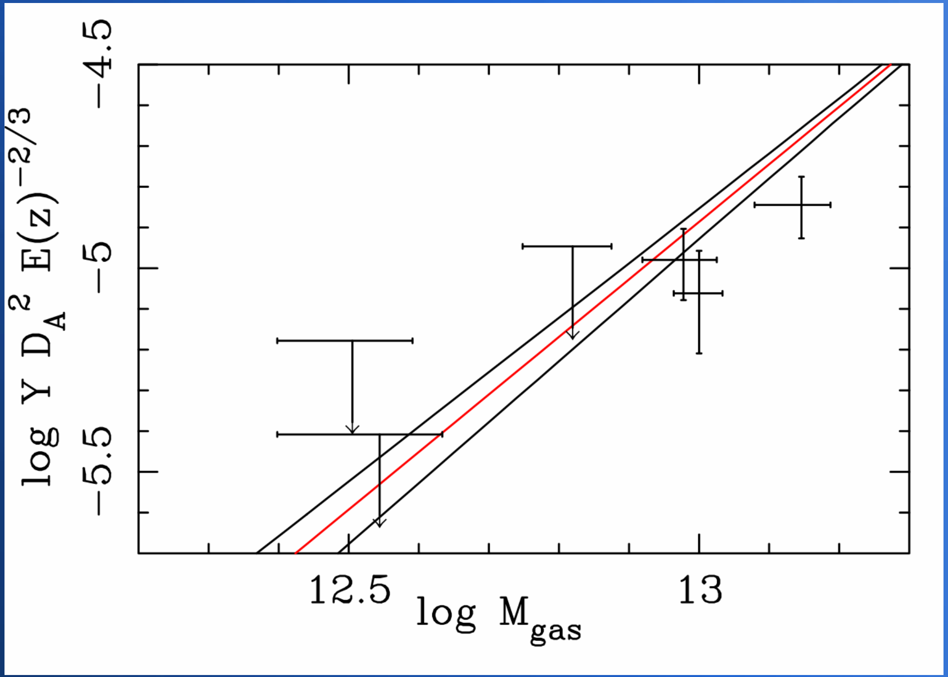
(M_g, Y within r_{2500} to compare to previous measurements)

Scaling Relation Comparison

- Compare to low-z sample of Bonamente et al 2008

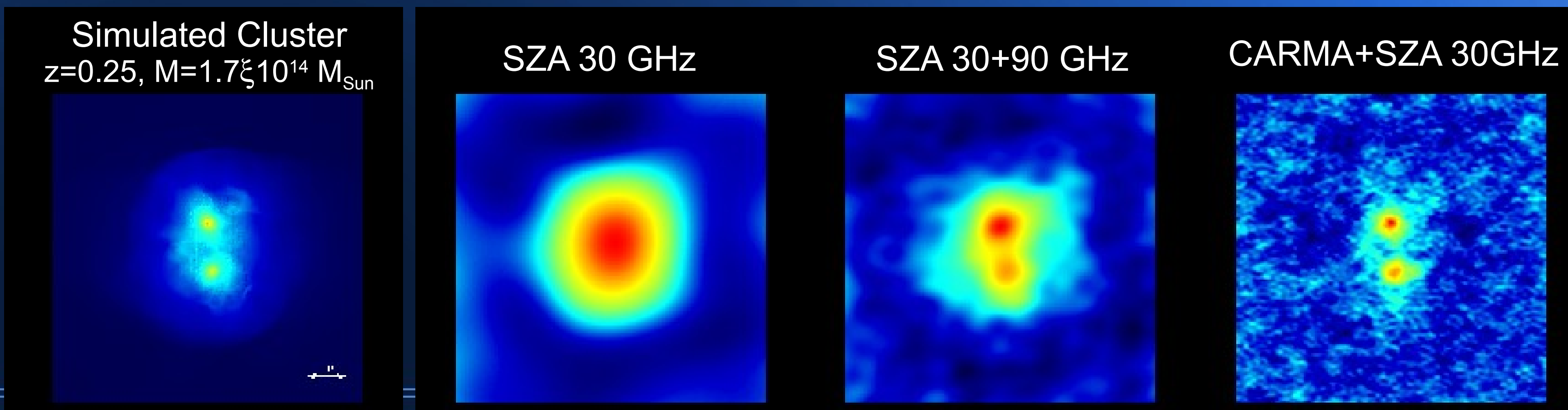
$$Y D_A^2 \propto M_{gas}^{5/3} E(z)^{2/3}$$

- 6 clusters with enough X-ray photons for M_g constraint
- Upper limits for clusters with no SZ detection
- Mild tension with low-z, though intrinsic scatter not included
- Larger sample required to make stronger statement



Current/Future Directions

- Combine with CARMA 6x10m telescopes at 30GHz → 10-45” angular resolution in SZE
- Study cluster gas morphology
- Insights into cluster evolution, mergers



Nagai et al 2007

Simulated observations: Erik Leitch

Conclusions

- SZA an excellent follow-up instrument for cluster candidates with $M_g > 10^{13}\ M_{sun}$ – public proposal time
- similar Y constraints in few 10s of hrs for clusters of equal gas mass regardless of distance
- No detections of IR-selected clusters – bias towards high f_g ?
- Mild tension with low-z - larger cluster sample needed (evolution, intrinsic variance) → work in progress
- High resolution SZE imaging soon