Sunyaev-Zel’dovich Effect

Karisa Zdanky
ASTR 8400

Moving Cluster

Trigonometric Parallax

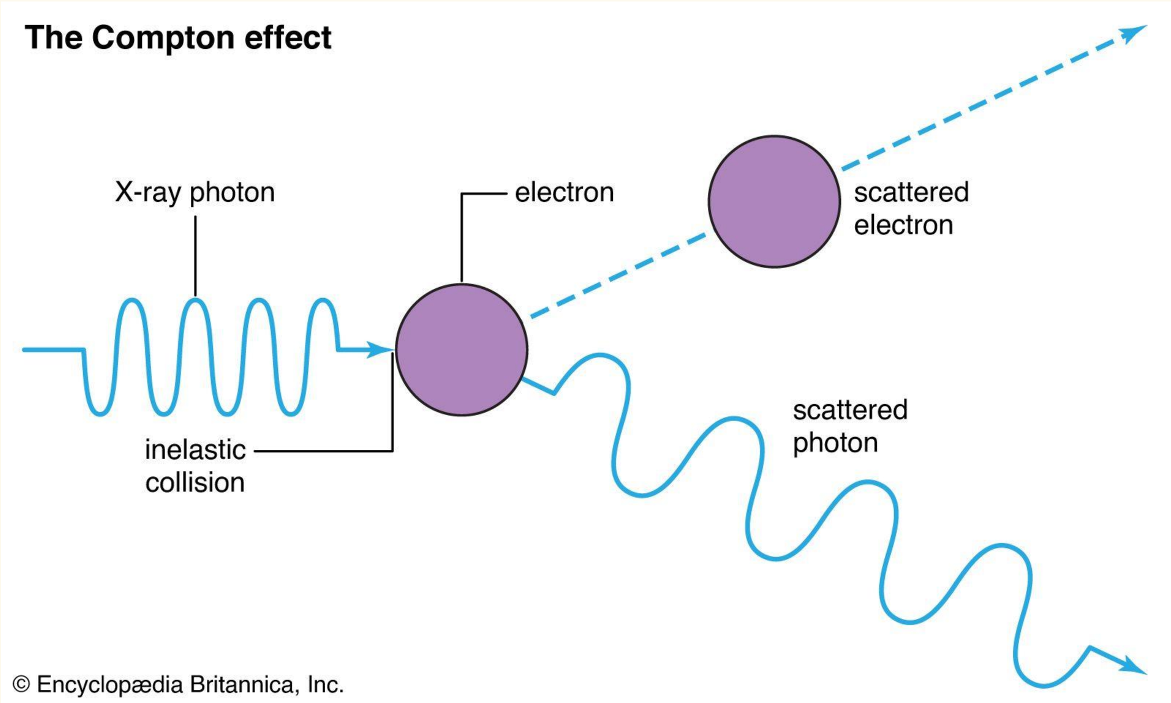
What IS the SZ Effect?

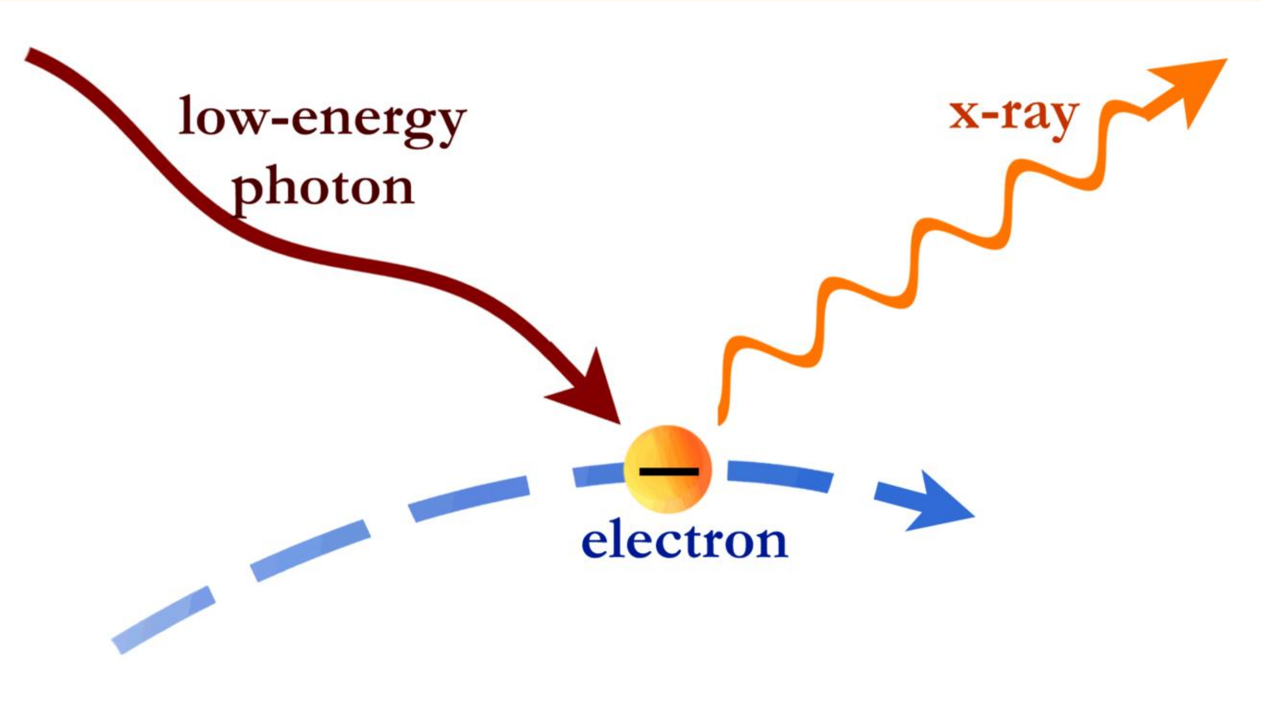
The Namesake

Rashid Sunyaev

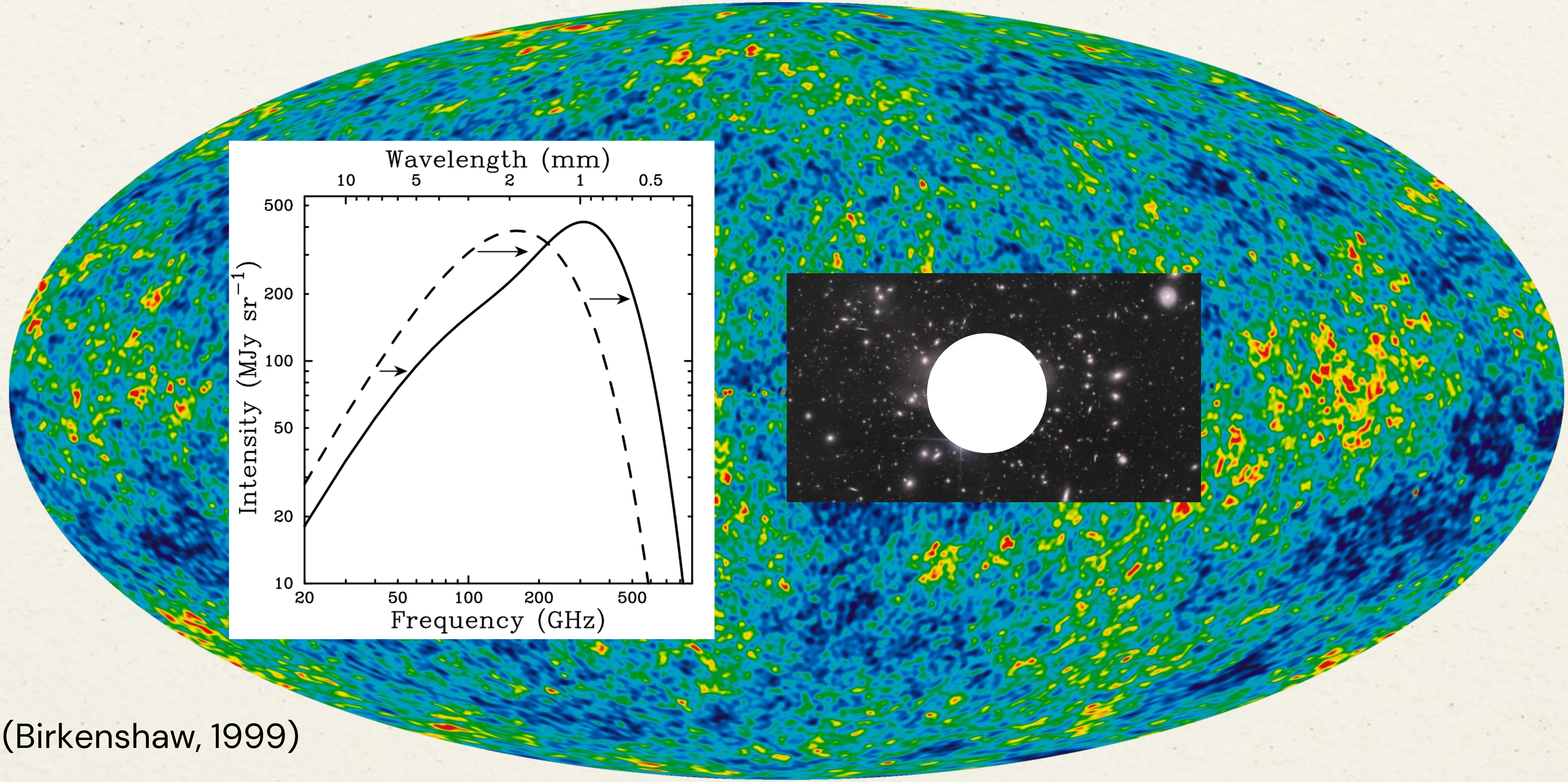
Yakov Zel'dovich

Compton Scattering





The SZ Effect in Action



(Birkenshaw, 1999)

(Sunyaev and Zel'dovich, 1970, 1972, 1980)

ALMA (ESO/NAOJ/NRAO)/T. Kitayama (Toho University, Japan)/ESA/Hubble & NASA

Two Main Types of SZ Effects

Thermal Effect

High energy in electrons is due to **temperature**

Kinetic Effect

High energy in electrons is due to **bulk motion**

Both play a part in finding the distance!

(Reese, 2004)
(Birkenshaw, 1999)

How do we find the distance?

$$\Delta T_{SZE} \sim \int d\ell n_e T_e$$

- ΔT_{SZE}: SZE spectral distortion of the CMB
- $\int d\ell$: along the line-of-sight
- n_e: electron density
- T_e: electron temperature

$$d\ell = D_A d\zeta$$

- D_A: angular-diameter distance!

But wait! There's more...

(Reese, 2004)

We need the X-Ray emission too!

$$S_x \sim \int d\ell n_e^2 \Lambda_{e\mathrm{H}}$$

X-Ray emission

electron density

X-Ray cooling function

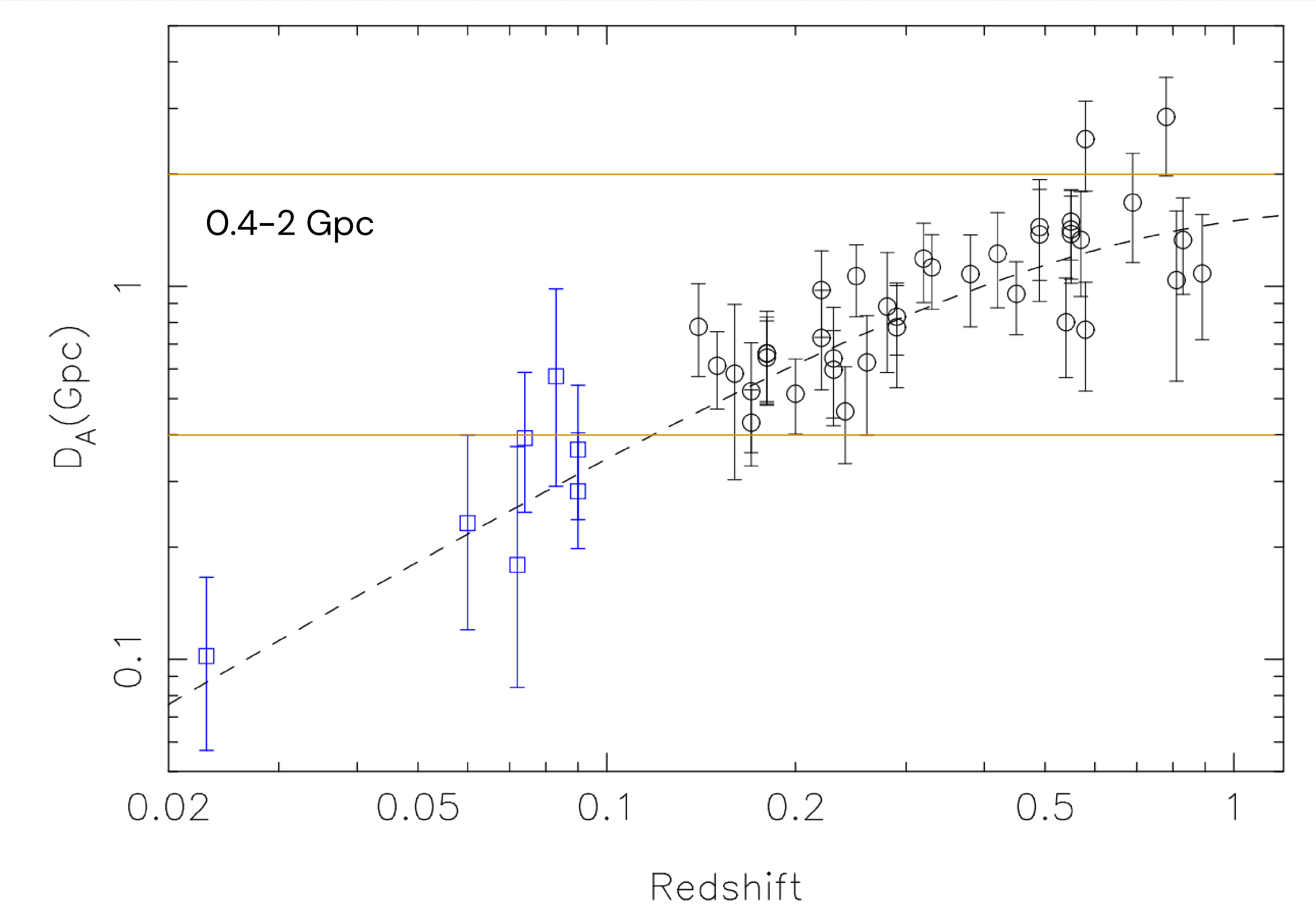
(Bonamente, 2006)

Finding Distance

$$D_A \propto \frac{(\Delta T_0)^2 \Lambda_{eH0}}{S_{x0} T_{e0}^2} \frac{1}{\theta_c}$$

Characteristic scale along line-of-sight (depends on chosen density model)

Evaluated along line-of-sight through center of cluster



(Bonamente, 2006)

Pros and Cons

Pros

- Distances are independent of the rest of the extragalactic distance ladder (no standard candles necessary!)
- Because independent of distance, can locate very distant clusters!
- Redshift independent (works for any redshift)
- Can make many other observations as well (mass, H_0, etc.)

(Reese, 2004)
(Myers, NRAO, 2005)

Cons

Cluster Asphericity

Most clusters aren't spherical in X-Ray/radio.
- Assuming it is gives about 15% standard dev.

New data suggests that most galaxy clusters
- are elliptical! (Colaço, 2024)

Small Scale Clumps (Unlisted)

Can be left out of data (why it's unlisted).
However, clumpiness in intracluster
- medium smaller than Chanda res. can effect high-redshift clusters, giving a smaller distance.

Table 3. Sources of uncertainty in the measurement of D_A

Source	Effect on D_A	Reference
STATISTICAL CONTRIBUTIONS		
Galactic N_H	$\leq \pm 1\%$	(1)
Cluster asphericity	$\pm 15\%$	(2)
SZE point sources	$\pm 8\%$	(3)
Kinetic SZE effect	$\pm 8\%$	(4)
CMB anisotropy	$\leq 1\%$	(4)
X-ray background	$\pm 2\%$	(5)
SYSTEMATIC CONTRIBUTIONS		
Presence of radio halos	$+3\%$	(4)
X-ray absolute flux calibration (S_X)	$\pm 5\%$	(6)
X-ray temperature calibration (T_e)	$\pm 7.5\%$	(7)
SZE calibration	$\pm 8\%$	(4)

(1) This paper, Section 3.3.1.
(2) Sulkanen (1999).
(3)La Roque et al. (2006).
(4)Reese et al. (2002).
(5) This paper, Section 3.3.7.
(6) http://asc.harvard.edu/cal/.
(7) This paper, Section 3.3.8.

(Bonamente, 2006)

Cons

SZE Point Sources

Undetected radio point sources can create an underestimate of the cluster distance.

Kinetic SZE

Kinetic SZ effect comes into play. With typical assuming numbers, kinetic SZ effect is ~4% of thermal, creating 8% uncertainty.

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(Bonamente, 2006)

Cons

X–Ray Calibration

Typical X-ray calibration (from Chandra) gives about 7.5% uncertainty via calculations.

SZE Calibration

Typical SZE calibration gives about 8% uncertainty via calculations.

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(Bonamente, 2006)

Modern Use of the Sunyaev–Zel'dovich Effect

A Hubble Constant Estimate from Galaxy Cluster and type Ia SNe Observations

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[3] *Departamento de Física, Universidade Federal de Sergipe, São Cristóvão, SE 49100-000, Brazil*
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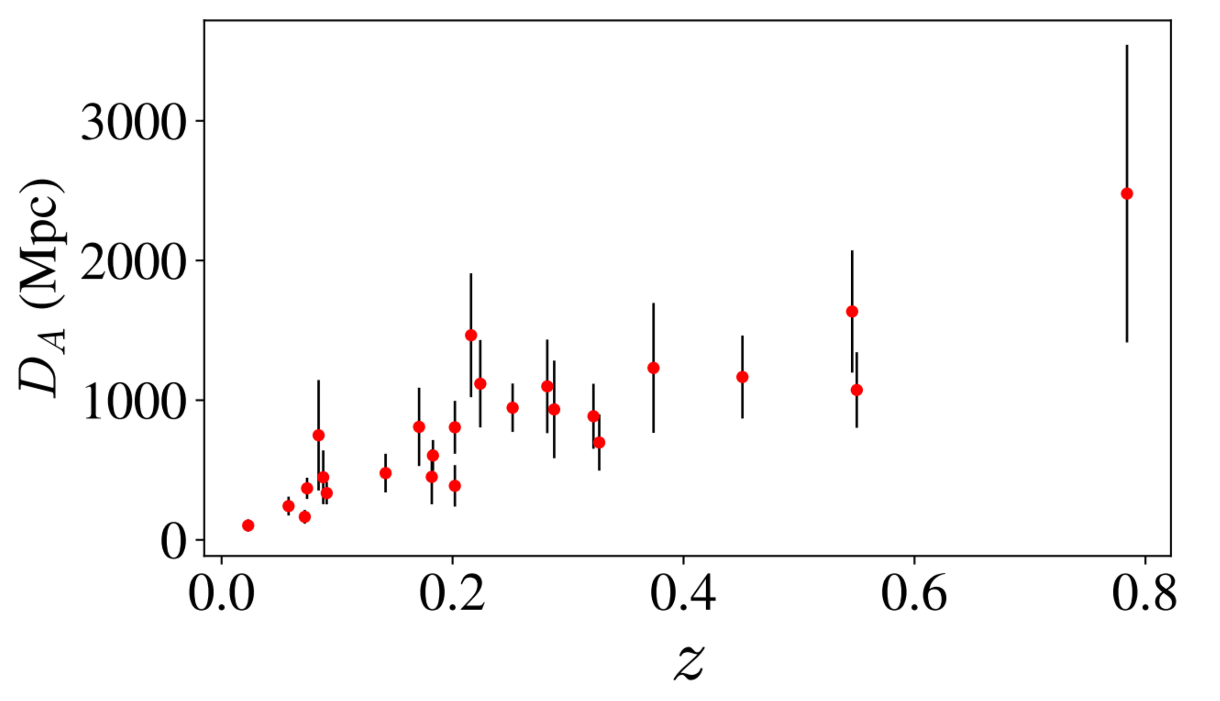
(2024!)

- "However, the usually assumed spherical geometry for galaxy clusters has been severely questioned… clusters exhibit preferably an elliptical surface brightness."
- "Additionally, galaxy cluster angular diameter distance data… has also been rejected in several tests of the CDDR (cosmic distance duality relation)."
- "Moreover… it was predicted that dark matter halos show axis ratios typically of the order of ≈ 0.8."

Modern Use of the Sunyaev–Zel'dovich Effect



(Colaço et al, 2024)

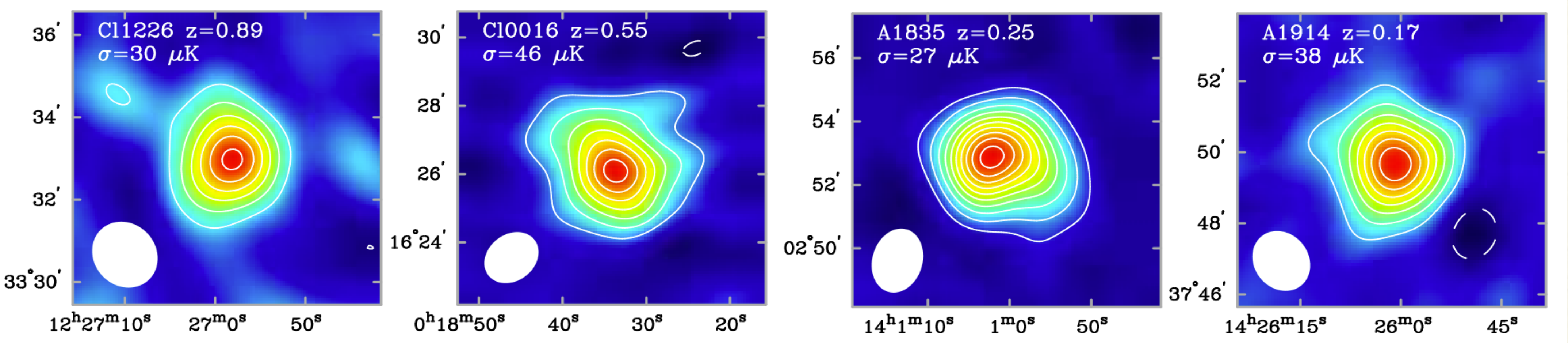
"...the galaxy cluster angular diameter determined from their SZE + X-ray observations provides an alternative method for determining direct cosmological distance. Our results further underscore the importance of actively pursuing observational efforts to obtain new galaxy cluster angular diameter distance samples through SZE and X-ray observations."

Angular Diameter Distance

Cluster	$D_c\|_{cosm}$ [a] (Mpc)	$D_c\|_{exp}^{circ}$ [b] (Mpc)	$D_c\|_{exp}^{ell}$ [c] (Mpc)
MS 1137.5+6625	1537^{+71}_{-91}	3179^{+1103}_{-1640}	2479 ± 1023
MS 0451.6−0305	1322^{+58}_{-76}	1278^{+265}_{-299}	1073 ± 238
Cl 0016+1609	1318^{+58}_{-76}	2041^{+484}_{-514}	1635 ± 391
RX J1347.5−1145	1189^{+52}_{-68}	1221^{+368}_{-343}	1166 ± 262
A370	1063^{+46}_{-61}	4352^{+1388}_{-1245}	1231 ± 441
MS 1358.4+6245	974^{+41}_{-55}	866^{+248}_{-310}	697 ± 183
A1995	964^{+41}_{-54}	1119^{+247}_{-282}	885 ± 207
A611	893^{+38}_{-50}	995^{+325}_{-293}	934 ± 331
A697	880^{+37}_{-49}	998^{+298}_{-250}	1099 ± 308
A1835	811^{+37}_{-45}	1027^{+194}_{-198}	946 ± 131
A2261	743^{+31}_{-41}	1049^{+306}_{-272}	1118 ± 283
A773	722^{+30}_{-40}	1450^{+361}_{-332}	1465 ± 407
A2163	686^{+29}_{-38}	828^{+181}_{-205}	806 ± 163
A520	686^{+29}_{-38}	723^{+270}_{-236}	387 ± 141
A1689	634^{+27}_{-35}	688^{+172}_{-163}	604 ± 84
A665	632^{+26}_{-35}	466^{+217}_{-179}	451 ± 189
A2218	601^{+25}_{-33}	1029^{+339}_{-352}	809 ± 263
A1413	515^{+21}_{-29}	573^{+171}_{-151}	478 ± 126
A2142	349^{+14}_{-19}	187^{+212}_{-97}	335 ± 70
A478	340^{+14}_{-19}	406^{+237}_{-135}	448 ± 185
A1651	327^{+14}_{-18}	373^{+202}_{-122}	749 ± 385
A401	289^{+12}_{-16}	610^{+593}_{-254}	369 ± 62
A399	282^{+12}_{-16}	107^{+85}_{-41}	165 ± 45
A2256	232^{+10}_{-13}	296^{+127}_{-90}	242 ± 61
A1656	96^{+4}_{-5}	235^{+218}_{-98}	103 ± 42

(Flippis, 2006)

(Reese, 2004)



Questions?