Title: Studying Cluster Physics with SPT

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Abstract:

Studying Clusters with the South Pole Telescope (SPT)

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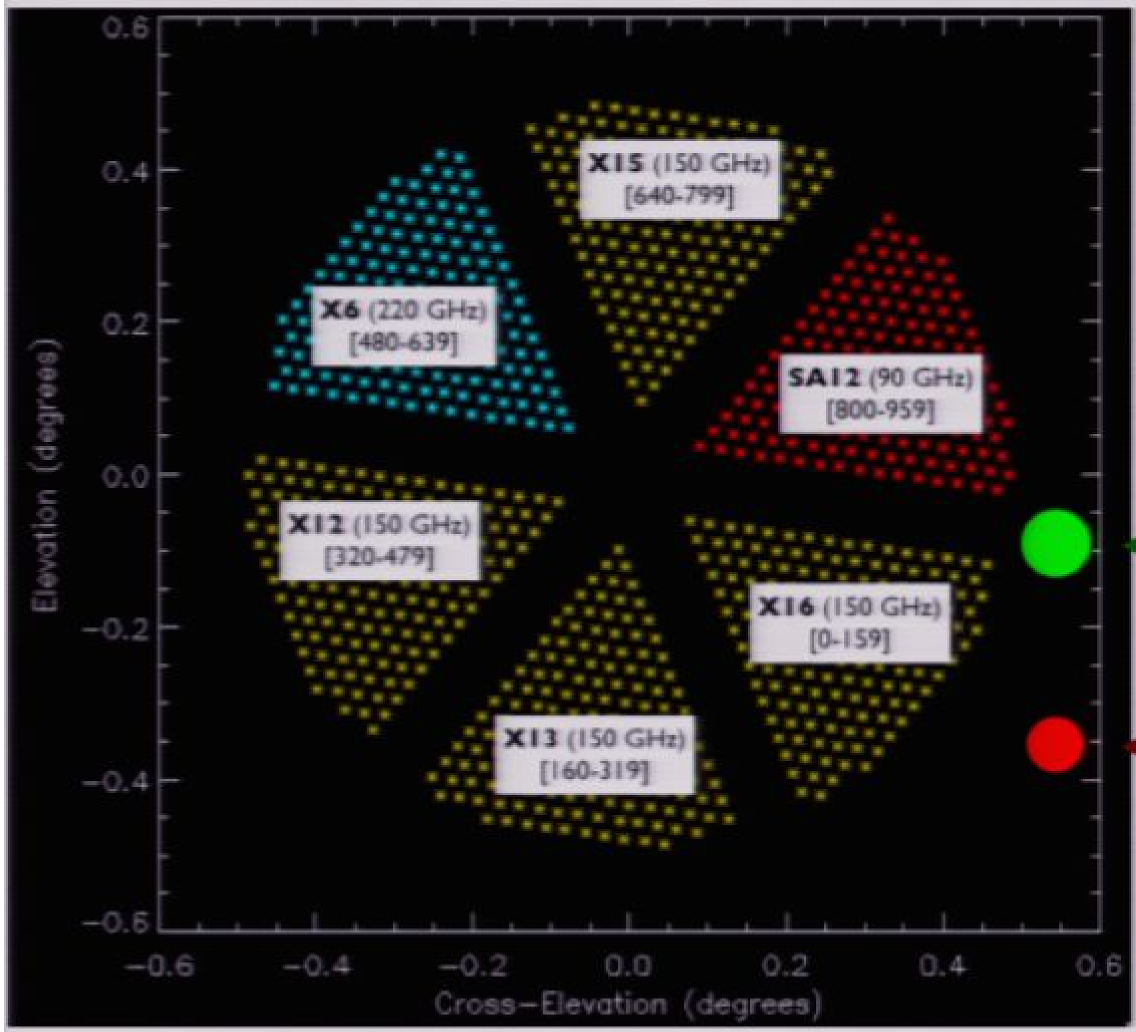
Outline

1) Cluster Observations with SPT
2) Targeted/Pointed Cluster Program
   - -example clusters/maps/profiles
   - -science goals
3) How this relates to Blind Cluster Program

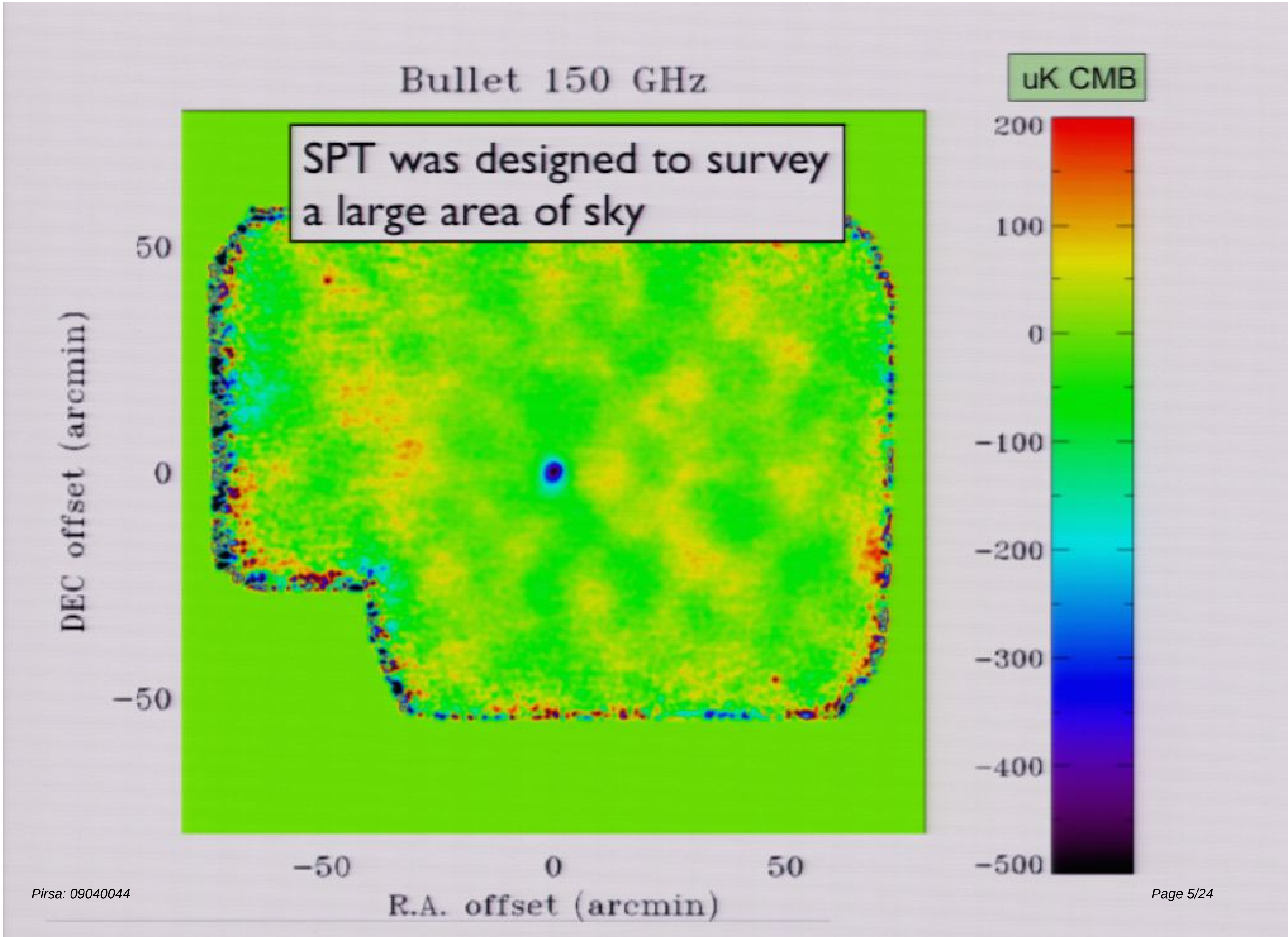
SPT Field of View (FOV)



- ~1 degree diameter FOV
- ~700 live detectors
- 3x frequency bands: 100, 150, and 220 GHz
- FWHM of ~1.6, 1.1, 0.8 arcminutes

d500 = 2x r500 = 6 arcmin for a 5.5 x 10^14 Msun cluster at z = 0.5

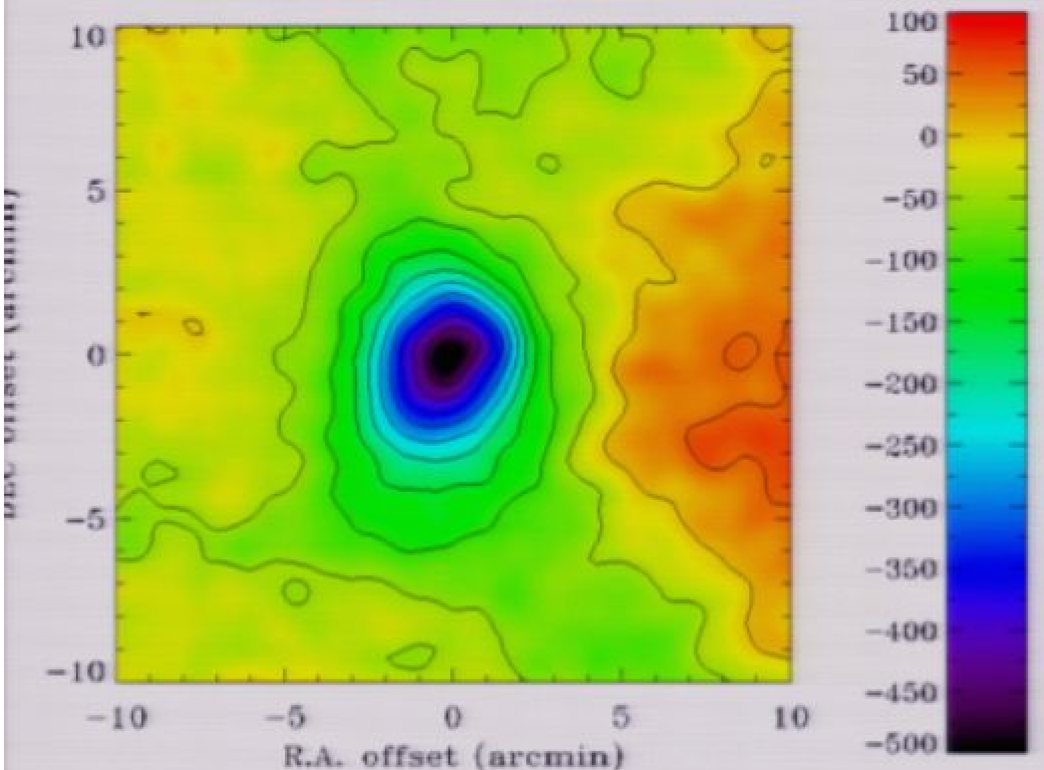
d500 = 2x r500 = 3.6 arcmin for a 5.5 x 10^14 Msun cluster at z = 1.0

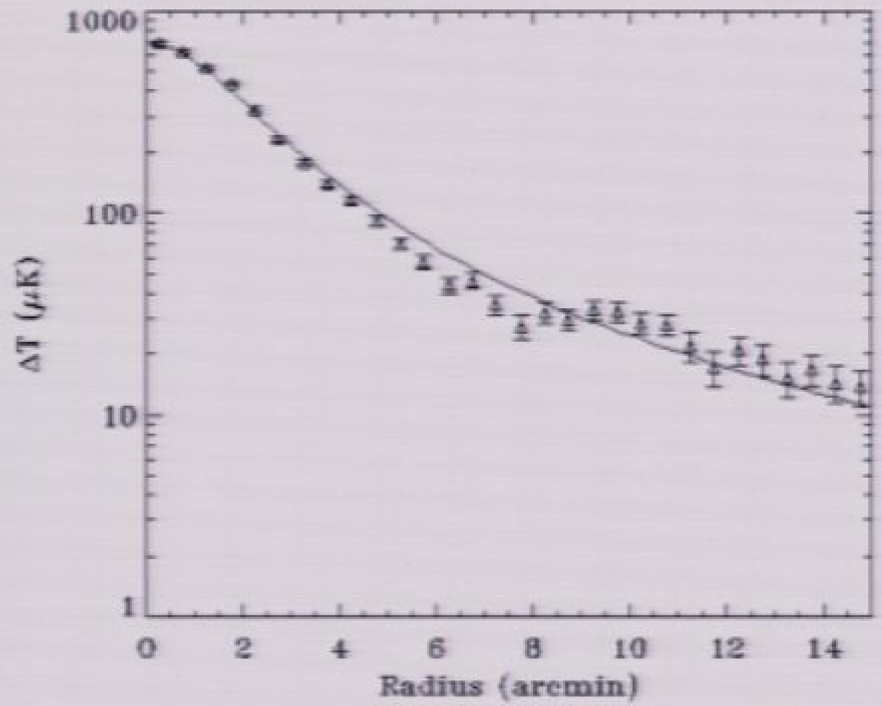

Bullet 150 GHz
uK CMB
SPT was designed to survey
a large area of sky
200
100
0
−100
−200
−300
−400
−500
50
0
−50
DEC offset (arcmin)
−50
0
50
R.A. offset (arcmin)

SPT Bullet Cluster Observation

13 hour 150 GHz SPT observation
~12 uK noise -> 50 sigma detection!

Significant signal out to ~15 arcmin
r_200 is ~8.5 arcmin for this cluster



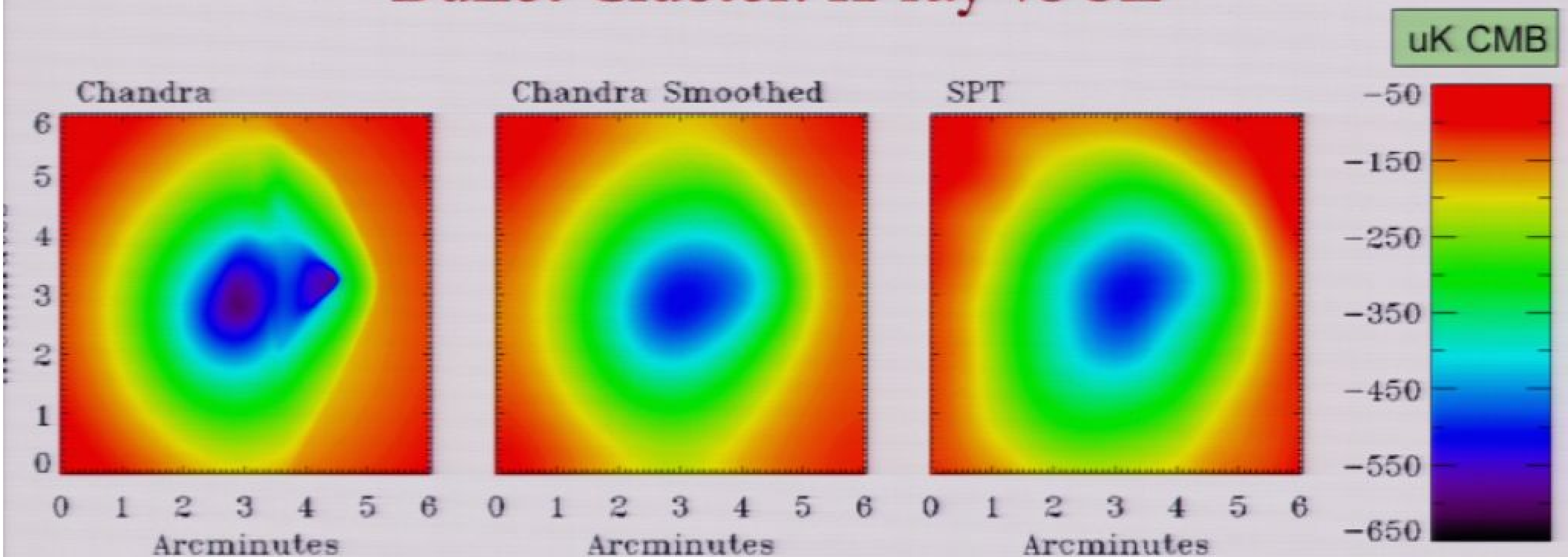


T. Plagge et al, in prep

Chandra
40 hrs obs
Markevitch)

ame scale
s SPT image

Bullet Cluster: X-ray vs SZ

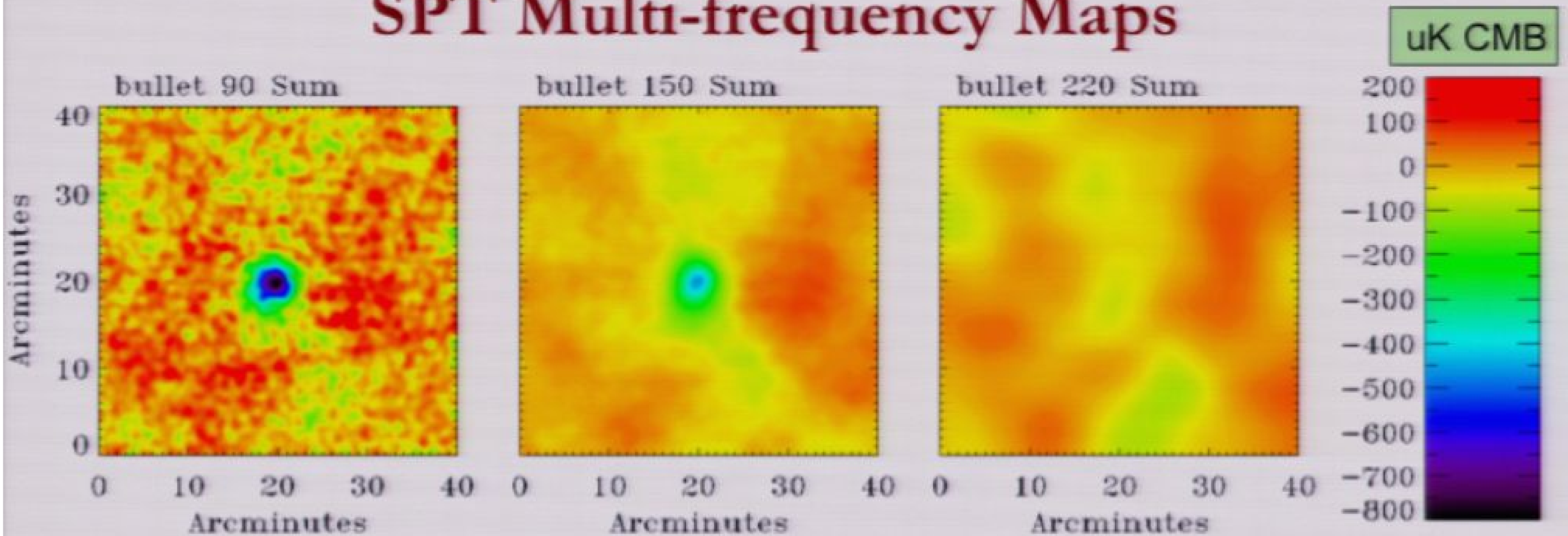


Markevitch et al 2006 surface density map (assume isothermal temperature to predict SZ flux)

Smoothed to SPT beamsize

SPT 150 GHz map

SPT Multi-frequency Maps

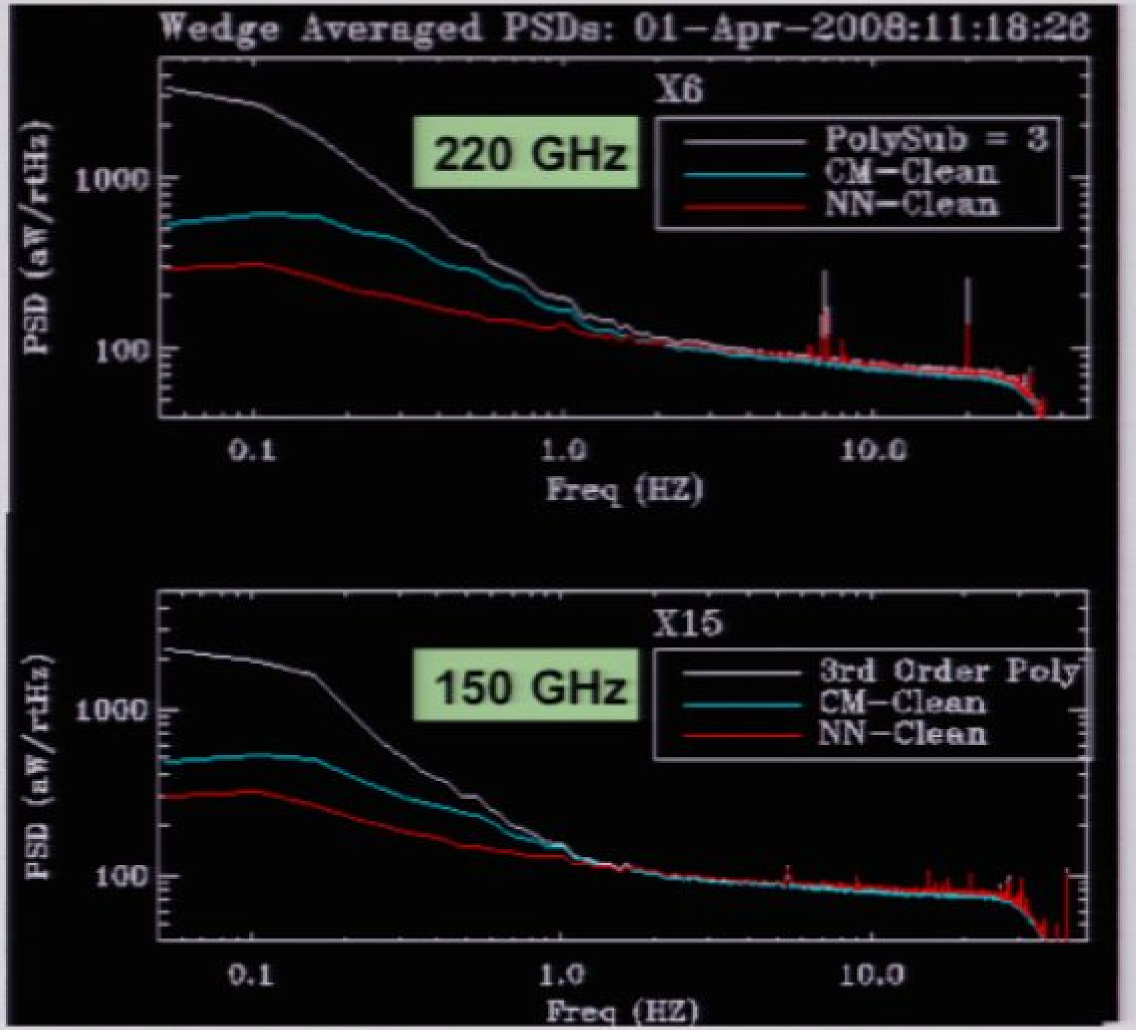


Bullet cluster at 90, 150, and 220 GHz, ~2, 13, 13 hours integration, respectively

SPT also observes in 3-frequencies

- allows spectral discrimination between SZ, CMB, and point sources
- NET CMB sensitivity of ~ 60, 25, 140 uK rt(hrs)/rt(sq degs) at 90, 150, and 220 GHz (2009 focal plane)

SPT Time-stream Filtering



- 1.0 Hz corresponds to 15 arcminute scales
- 1/f knee of detector timestream PSDs are ~1.0 Hz at 150 GHz and ~1.5 Hz at 220 GHz
- Below these frequencies noise rises like ~1/freq^2.7 and is dominated by correlated atmosphere
- Atmospheric noise gets progressively worse from 90 to 150 to 220 GHz

SPT Cluster Time-stream Filtering

"Masked" Time-stream filtering procedure

1) De-convolve detector time constants
2) Low-pass filter data (at frequency above detector time constant)
3) Remove long-timescale drifts with a low-order polynomial
4) For a given frequency, remove a common spatial mode across the array, masking region centered on the cluster
5) Fit cluster map to gas model

"Un-Masked" Time-stream filtering procedure

1) Steps 1-3 the same
2) For a given frequency, remove a common spatial mode across the array
3) Simultaneously calculate transfer function of time-stream filtering by running a point source convolved with the SPT beam thru the filtering pipeline
4) Estimate noise covariance by jack-knife noise map realizations (differencing observations)
5) Add CMB noise to jack-knife noise covariance matrix
6) Fit map in fourier space. (Assuming the time-stream noise is stationary, then the fourier transform of the covariance matrix is diagnol)

SPT Targeted Cluster Observations

Targeted Cluster Program

1) Measure known massive clusters with existing optical and X-ray data

2) Measure pressure profiles out to the virial radius

3) Combine with X-ray data

- measure density, temperature, mass profiles
- measure baryon fraction vs radius
- measure SZ scaling relations

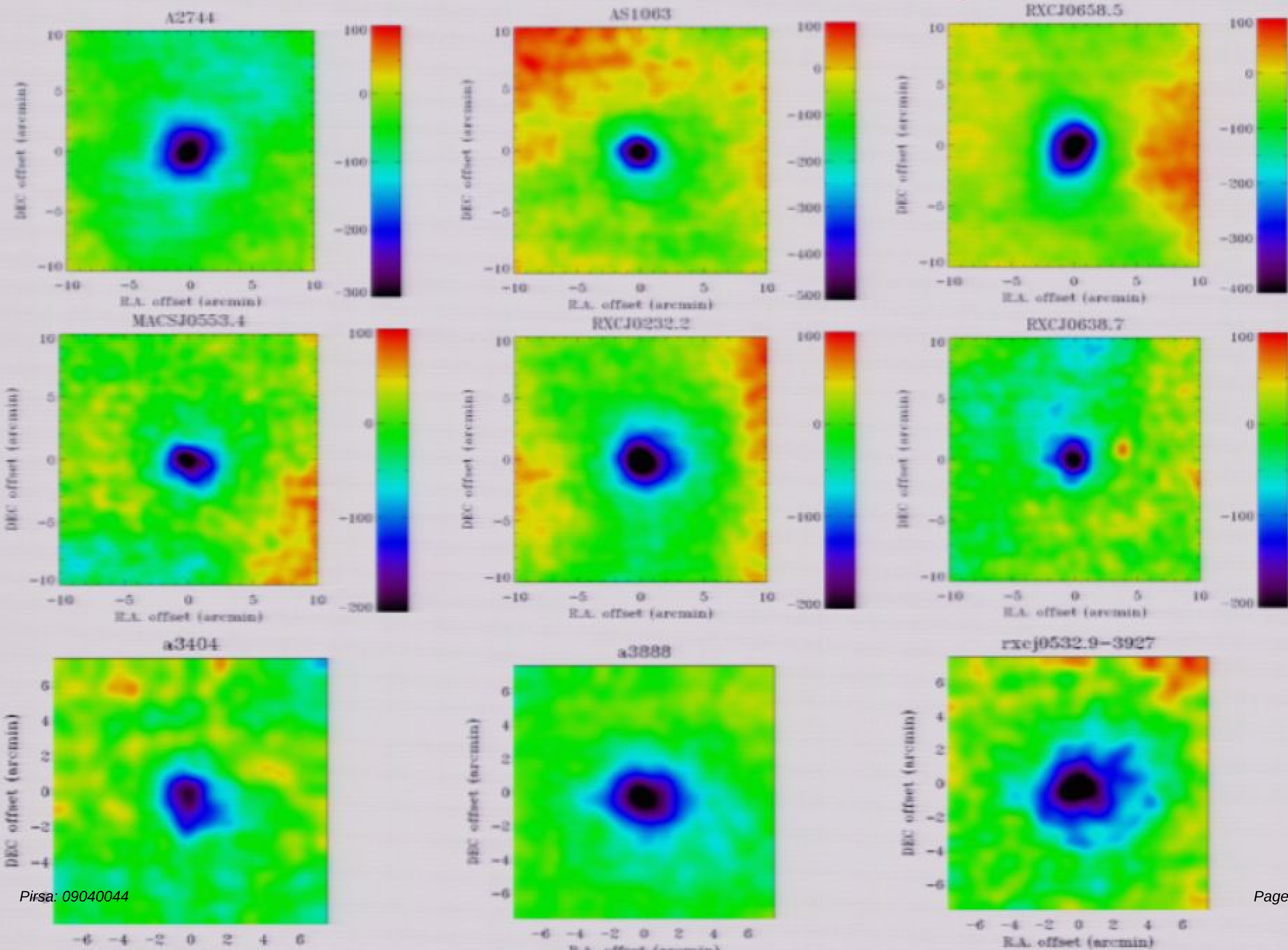
4) Deep integrations on massive clusters could allow detection of kinematic SZ in a handful of clusters

Other SPT Pointed Cluster Observations

SPT Hours Observed	Name	J2000 RA	J2000 Dec	z	LCDM, h=0.7 Lx(0.1-2.4) *(1e44 ergs/s)*
12	A2744	00:14:19	-30:23:00	0.3066	12.92
6	RXJ0217	02:17:13	-52:44:49	0.3432	12.0
6	RXJ0220.9	02:20:57	-38:28:48	0.228	5.82
12	RXJ0232.2	02:32:17	-44:20:51	0.2836	9.65
6	A3084	03:04:04	-36:56:27	0.219	4.68
6	RXJ0336.3	03:36:16	-40:37:45	0.1729	5.3
6	A3292	04:49:57	-44:40:24	0.150	3.29
bcs + 6	RXJ0516	05:16:38	-54:30:51	0.2952	13.87
6	RXJ0528	05:28:56	-39:27:46	0.2839	13.12
12	RXJ0532	05:32:55.5	-37:01:28	0.2708	6.94
6	CLJ0542.8	05:42:50	-41:00:02	0.634	9.9
6	A3364	05:47:38	-31:52:25	0.148	4.67
6	MACSJ0553	05:53:27	-33:42:53	0.407	32.68^{bolo}
9	RXJ0638	06:38:46.5	-53:58:18	0.2266	10.62
6	A3404	06:45:29	-54:13:08	0.1644	7.360
7 (+ 6)	Bullet	06:58:31	-55:56:49	0.297	23.03
12 (+4)	MACS1931	19:31:49.6	-26:34:34	0.352	
6	RXJ2011	20:11:23	-57:25:39	0.279	7.23
9	A3667	20:12:24.3	-56:49:49	0.053	5.41
6	RXJ2031	20:31:52	-40:37:14	0.3416	12.04
15	MACS2046	20:46:00.5	-34:30:17	0.423	
6	RXJ2218.6	22:18:40	-38:53:51	0.141	3.78
6	A3888	22:34:31	-37:44:06	0.151	8.46
9 (+ 6)	AS1063	22:48:43.5	-44:31:44	0.348	30.78

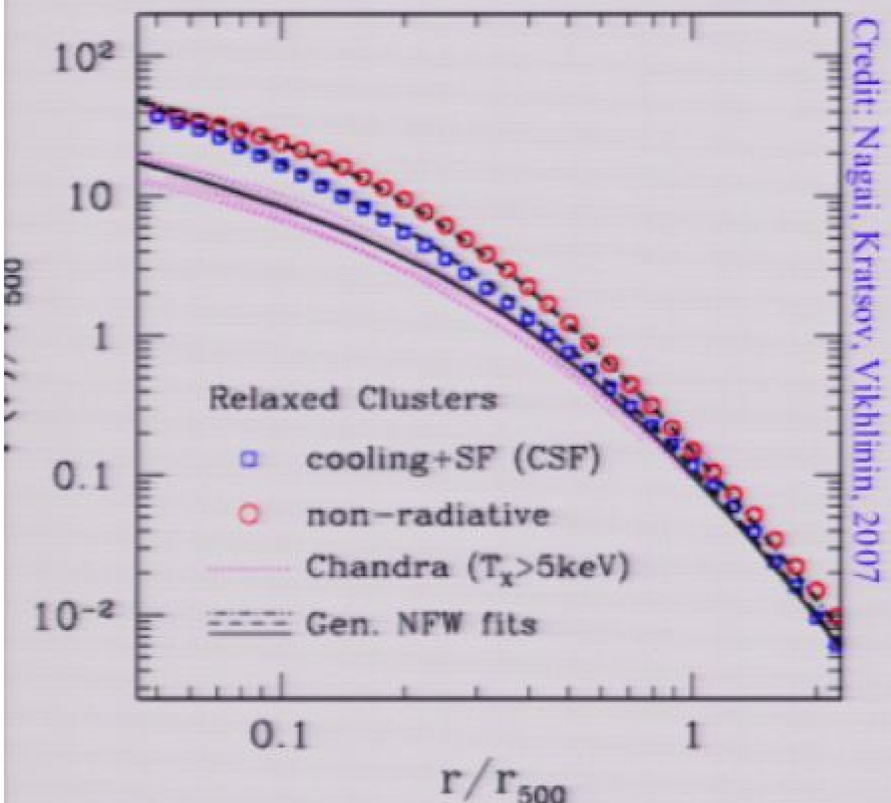
- 24 known clusters measured and detected with SPT, most selected by their X-ray luminosity
- Fairly massive well-studied clusters
- Almost all have Chandra or XMM data
- All between $0.05 < z < 0.65$, most between $0.15 < z < 0.35$
- Lensing data? Nine in LoCuSS sample (Graham Smith et al.), which combines X-ray + lensing, hopefully can give us some insight into HSE mass bias (along with SZA results)

More SPT Cluster Maps



Pressure Profiles at Large Radii

Simulated Pressure Profiles vs Chandra measurements



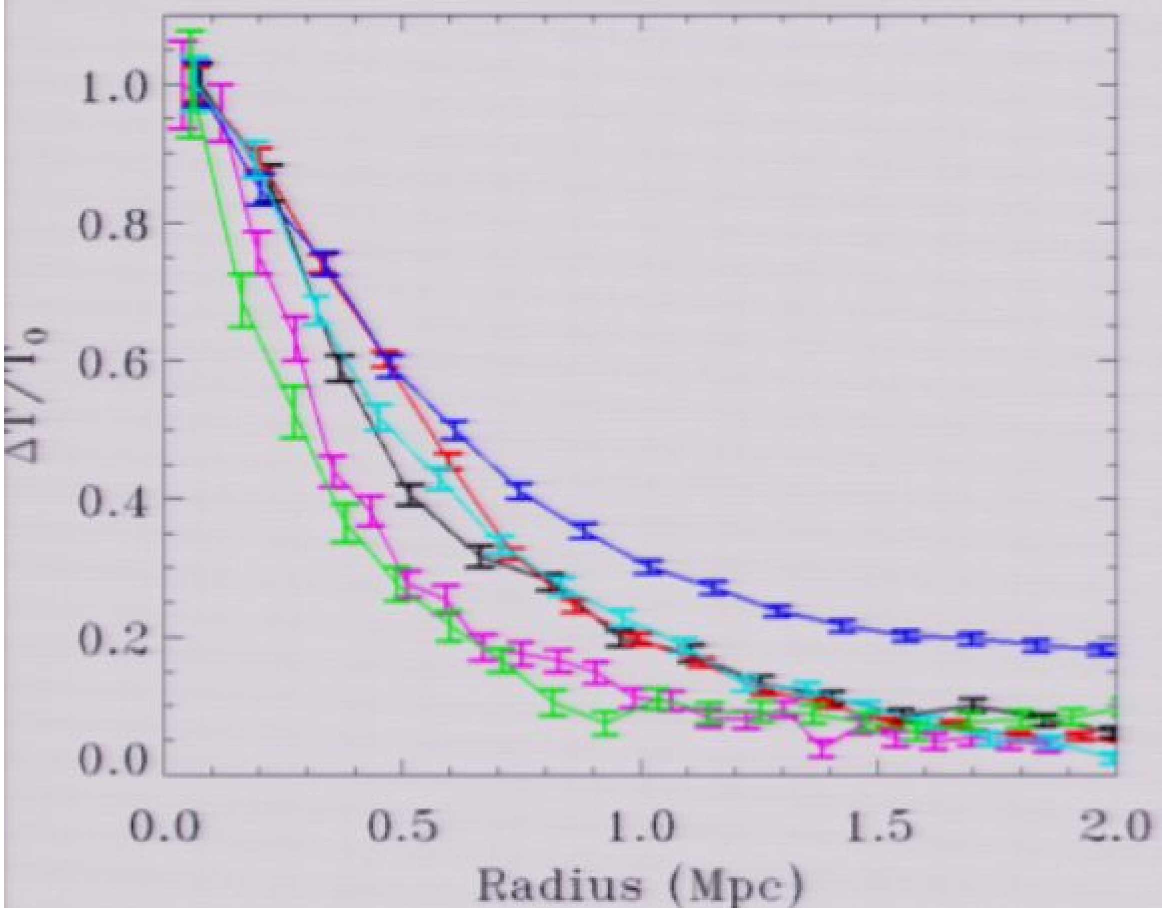
- SZ measurements are directly measuring the cluster pressure profile
- measurements of the pressure profile can distinguish between thermal feedback processes and physics in clusters

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

$$I_{Xray} \propto n_e^2 \Lambda(T_e)$$

- because of linear dependence on electron density SZ measurements can in principle probe further than X-rays
- for this reason, SPT can in principle probe regions not necessarily accessible to other experiments

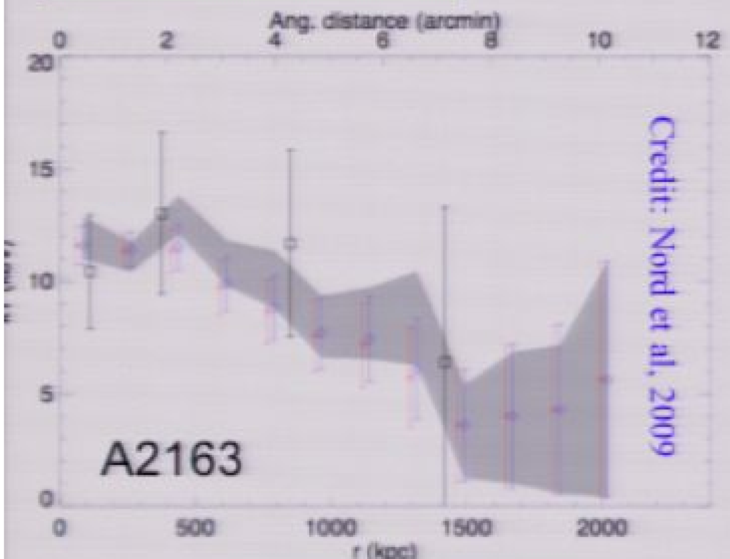
SPT 150 GHz CMB Temperature Profiles



- Significant signal seen in many clusters out to ~1.5-2.0 Mpc (typical value of r500 for these clusters is ~1.2 Mpc)
- How much of this is CMB?
- Multi-frequency SZ data will be important to disentangle this
- We need to finalize a satisfactory multi-frequency SZ pipeline

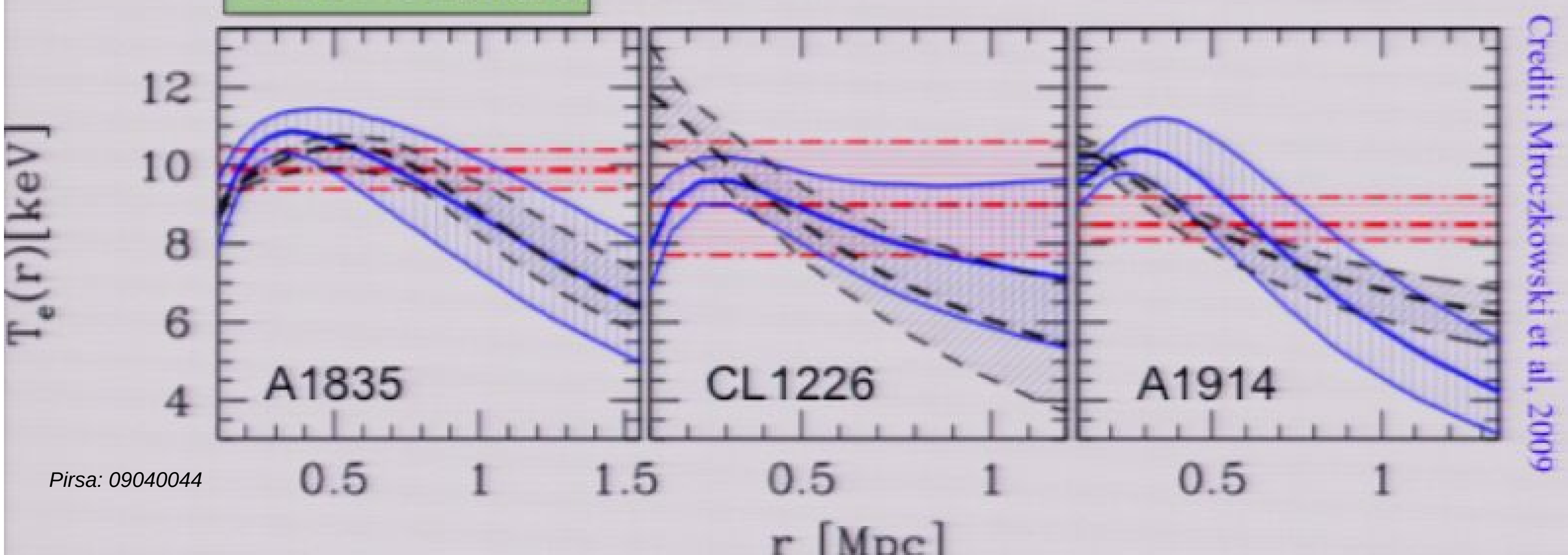
Combining SZ + X-ray data

APEX-SZ + XMM



- SZ in combination with X-ray data provides more information about thermodynamic state of IC gas
- the combination of SZ + X-ray imaging data can recover density and temperature profiles to larger radii without X-ray spectroscopy

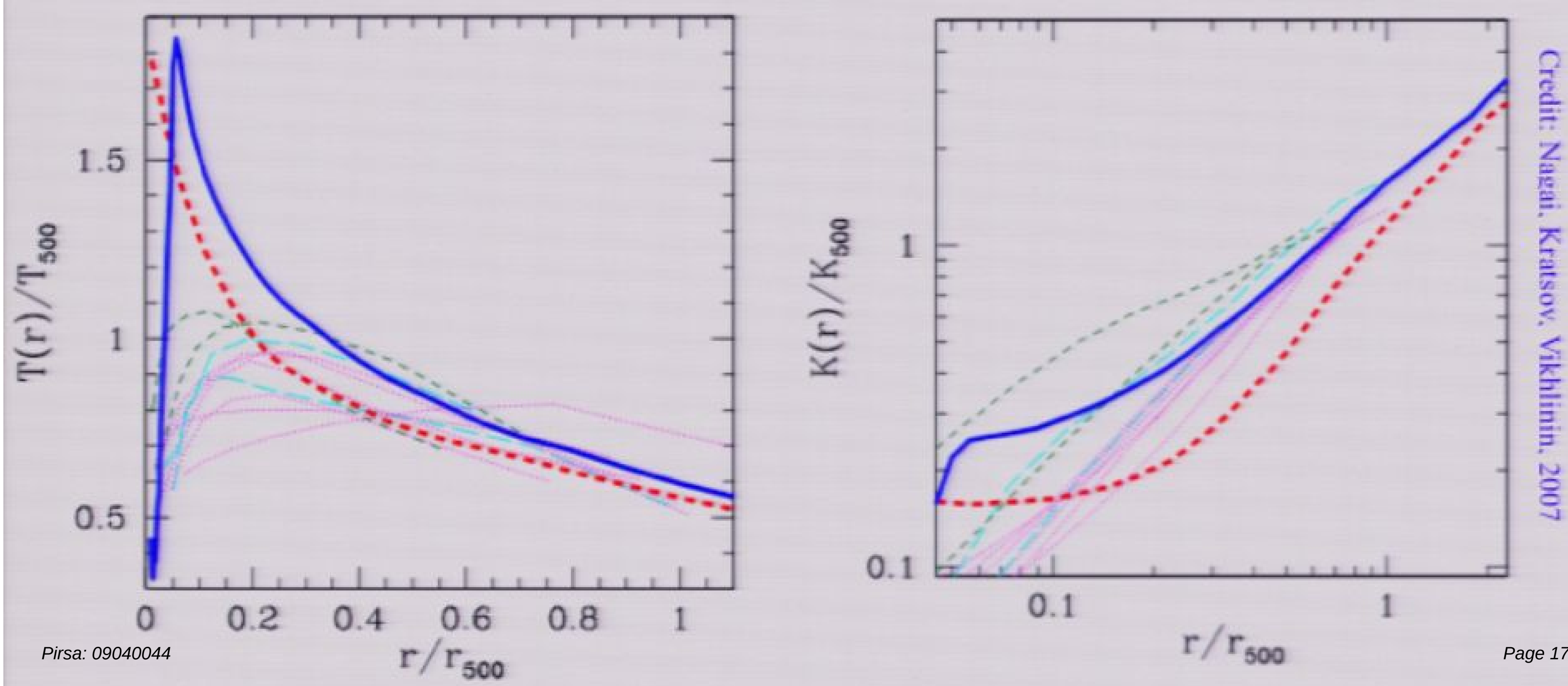
SZA + Chandra



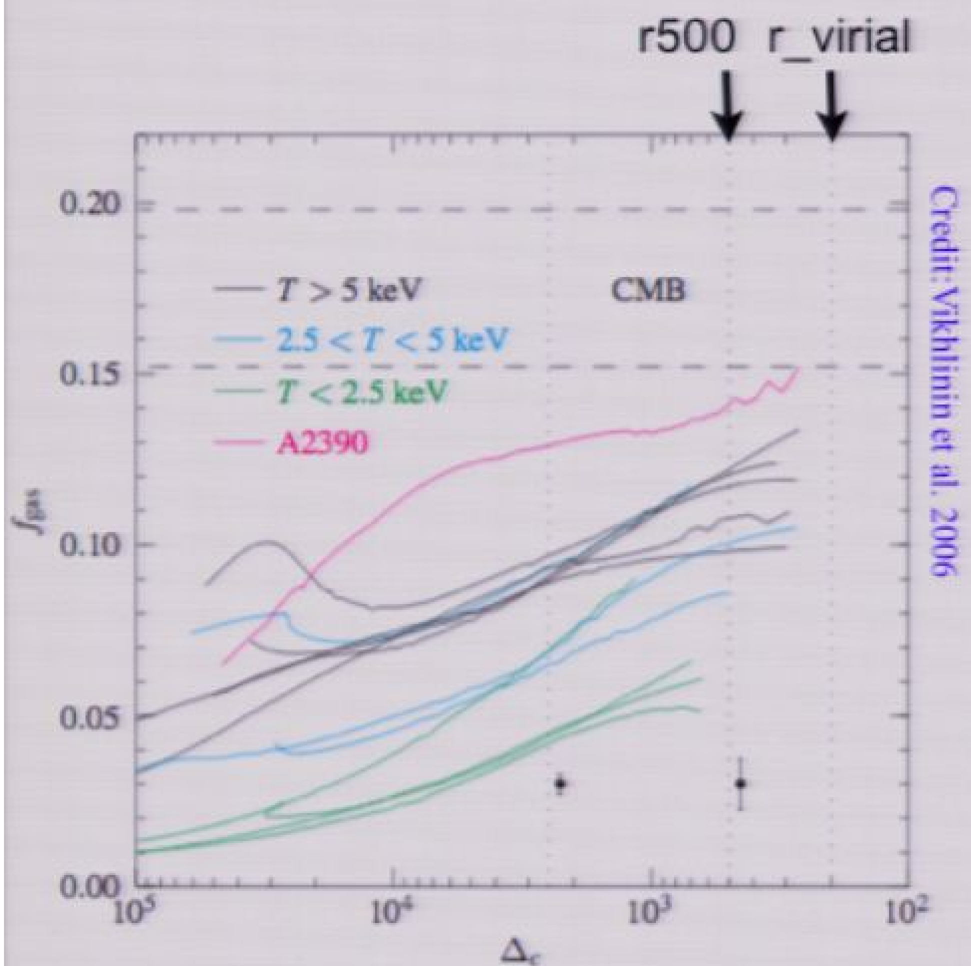
Blue = X-ray spectroscopy
Black = SZ + X-ray imagin

Constraining Physics from Cluster Profiles

- As Daisuke showed yesterday, agreement is good in outer regions, but most X-ray studies at best extend to ~ r500 (~ 0.5 r_virial)
- Extending measurements to larger radii might reveal surprises that tell us about the thermodynamics of the intra-cluster gas at large radii



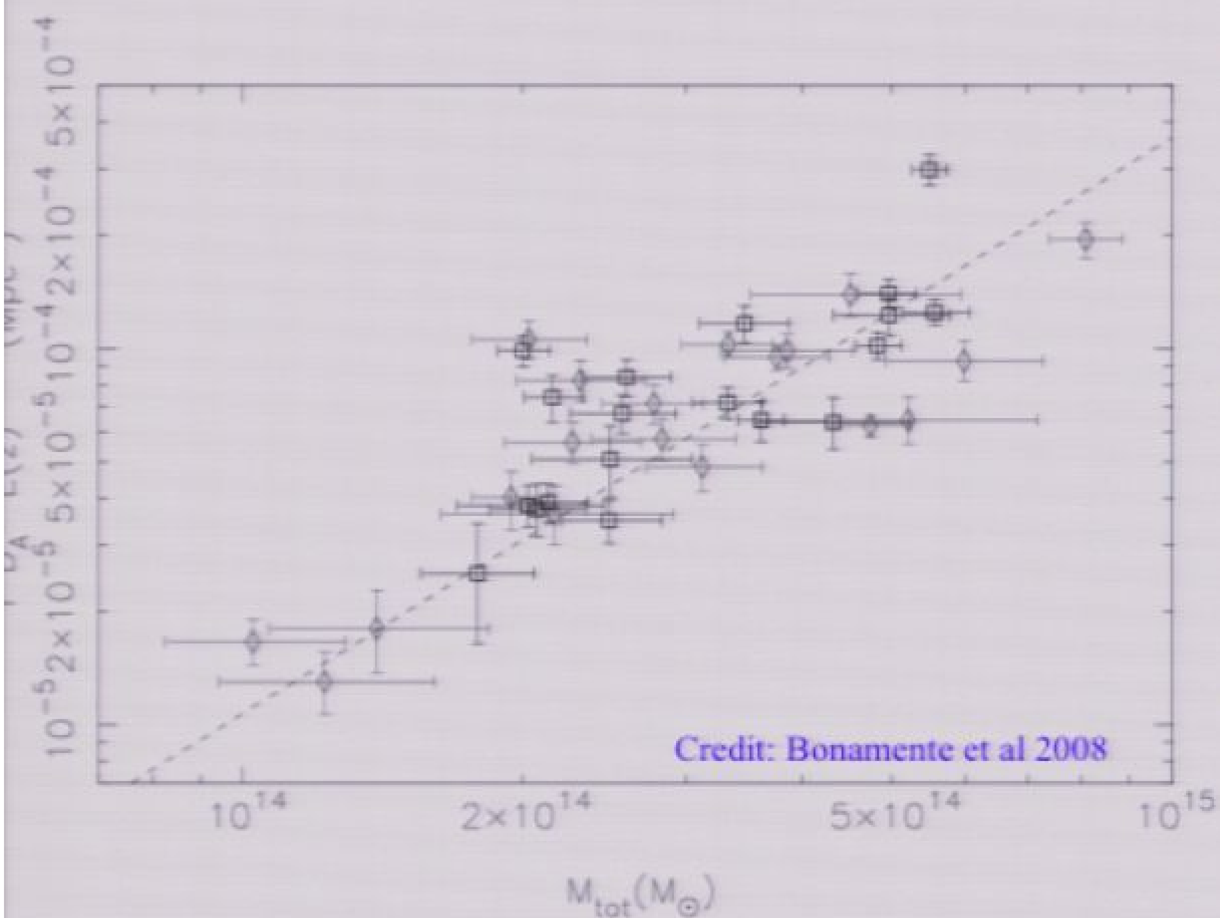
Gas Mass Fraction vs Radius



IG. 20.— Enclosed gas fraction as a function of overdensity, defined with spect to the critical density at the cluster redshift. Dashed lines show the nge $\Omega_b/\Omega_m = 0.175 \pm 0.023$ constrained by CMB observations. Points with or bars show typical measurement uncertainties at two radii.

- Most current X-ray measurements of gas fraction extend nearly to virial radius
- Pushing this measurement further could help us estimate the total baryon budget and the amount of missing baryons or ...
- Disentangling effects of non-thermal pressure support will make total mass estimates difficult

SZ Scaling Relations



- State of the art is Bonamente et al. 2008 from OVRO/BIMA sample
- SZA results coming soon
- SPT should push scaling relations closer to virial radius, might reduce scatter, but could increase bias
- This sample will at least help us understand how to better estimate masses from SPT multi-frequency data

Kinematic SZ

- Some clusters might have detectable kSZ, especially the merging clusters
- For Bullet cluster

$$\Delta T_{kSZ} = \tau T_{CMB} \frac{v_{pec}}{c} \sim 0.015 \times 2.725 \times \frac{1000km/sec}{c} \sim 140\mu K$$

- 220 GHz Bullet maps have ~40 uK noise per arcmin pixel
- SPT is at an interesting depth to make make cluster kSZ maps
- Potentially can do other interesting physics (our A3667 maps are crazy!)

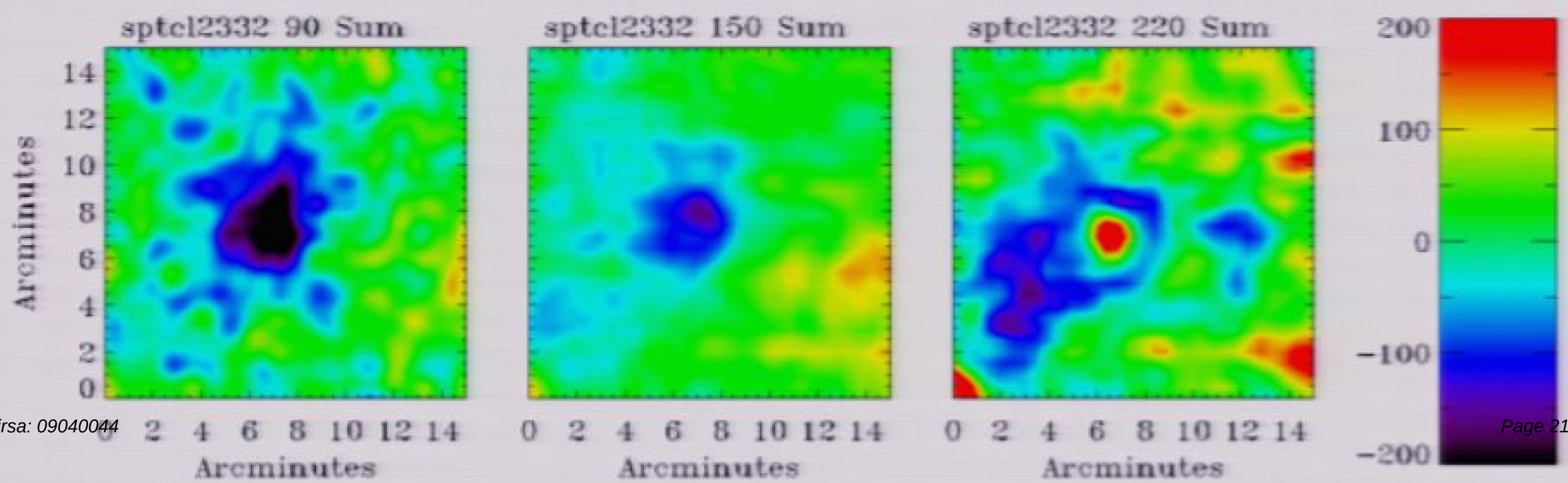
SPT Blind Clusters

Blind Clusters

1) Targeted clusters can provide intermediate scaling relations for interpreting cosmology

2) Will want to measure scaling relations from them from targeted X-ray follow-up, and understanding of HSE mass estimates from stacked lensing comparison

3) Point source confusion population needs to be better characterized, especially sources that are correlation with clusters



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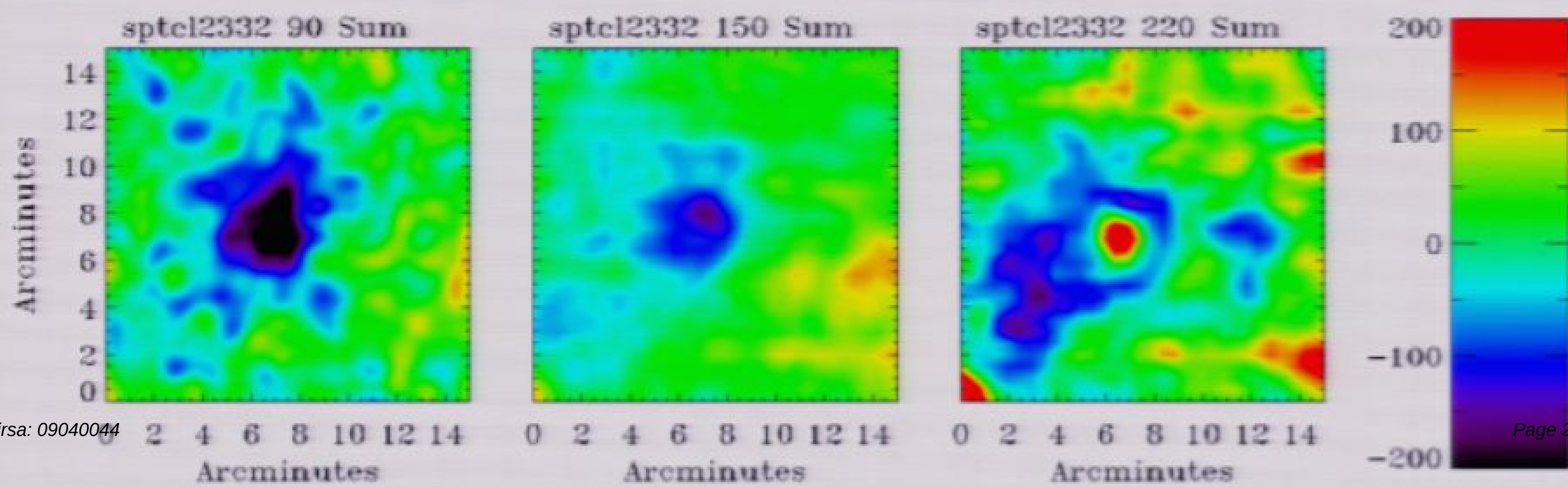

Summary

1) SPT is working and can make deep multi-frequency maps of clusters

2) Massive well-studied clusters will be an interesting sample to constrain:

- thermodynamics of outer regions of clusters
- will motivate more accurate intra-cluster gas models to larger radii
- SZ scaling relations near out to virial radius
- other interesting science (kSZ, cluster physics, ...)

3) Related to blind clusters, hopefully we learn more about SZ scaling relations and develop a joint SZ + X-ray pipeline