SZ/X-ray Joint Analysis of the ICM with APEX-SZ Data

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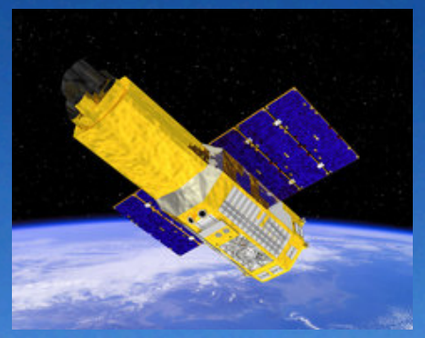
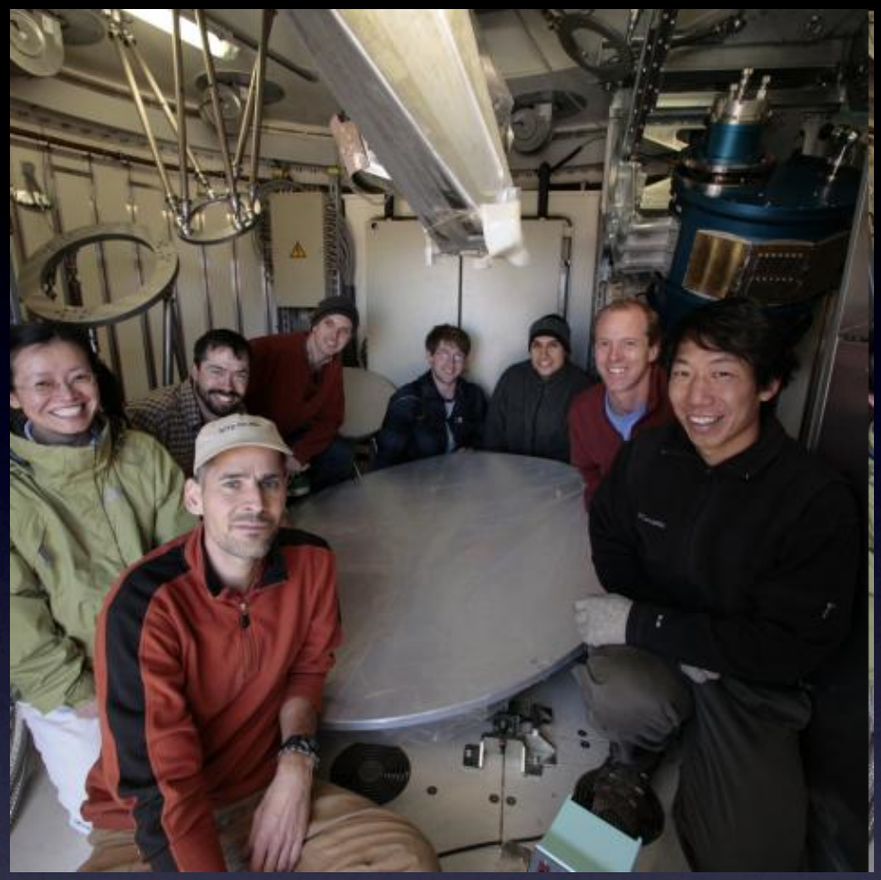


Collaboration

Martin Sommer

Yu-Ying Zhang

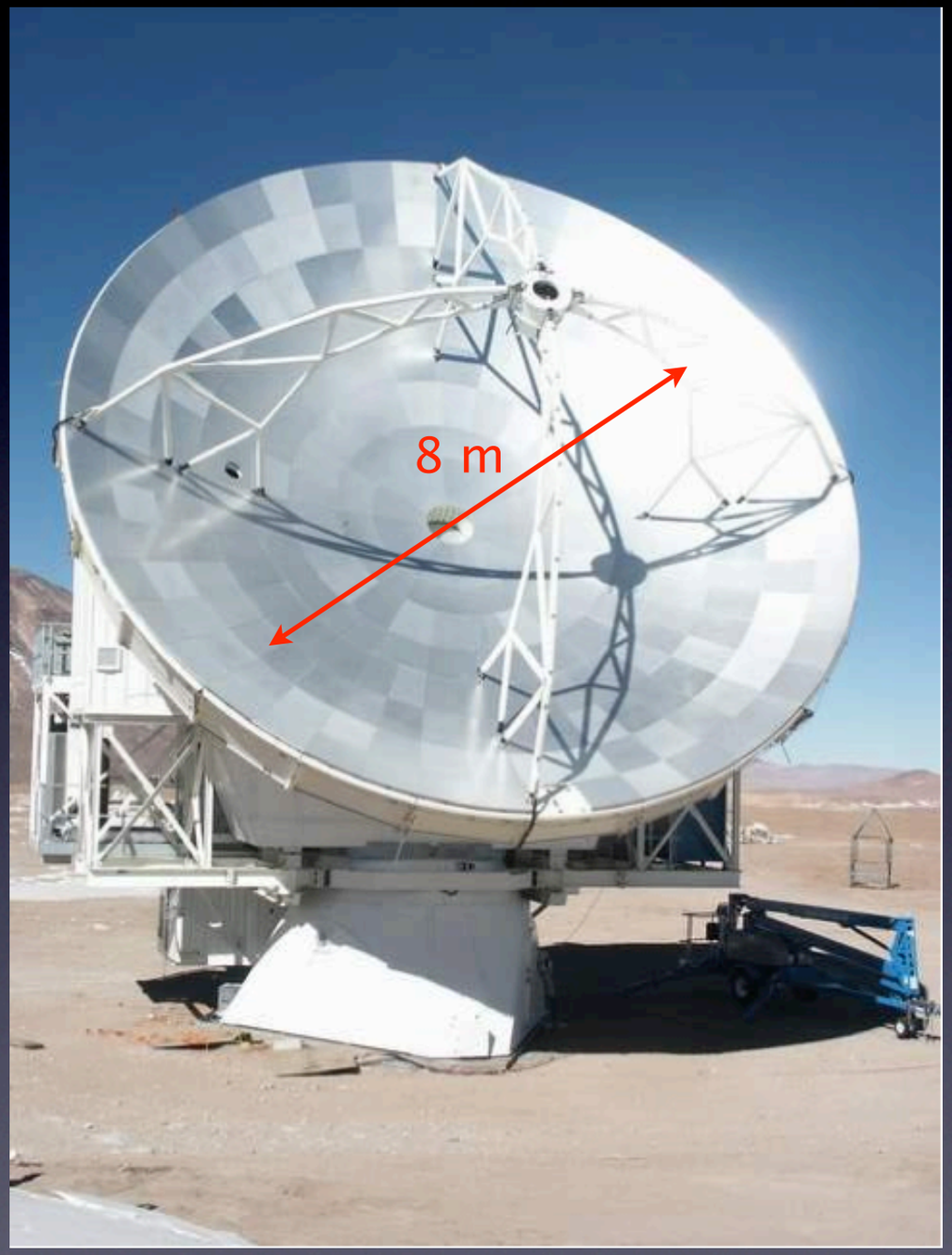
FLorian Pacaud



APEX-SZ collaboration:
(PI Adrian Lee)

- UC Berkeley
- MPIfR Bonn
- University of Bonn
- Onsala
- MPE
- ESO

The APEX-SZ Experiment

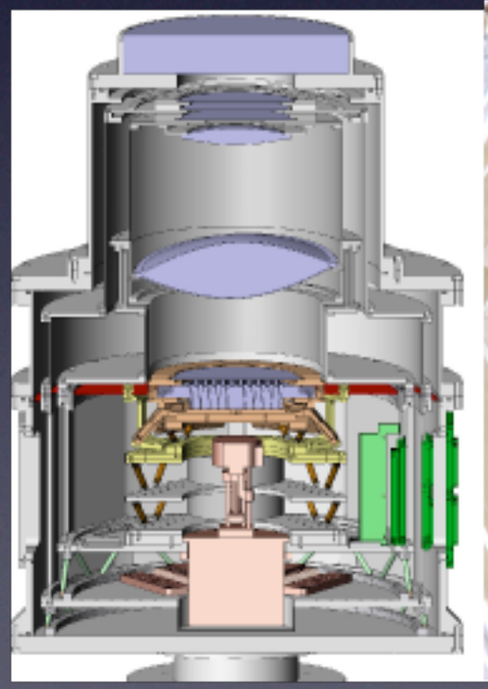


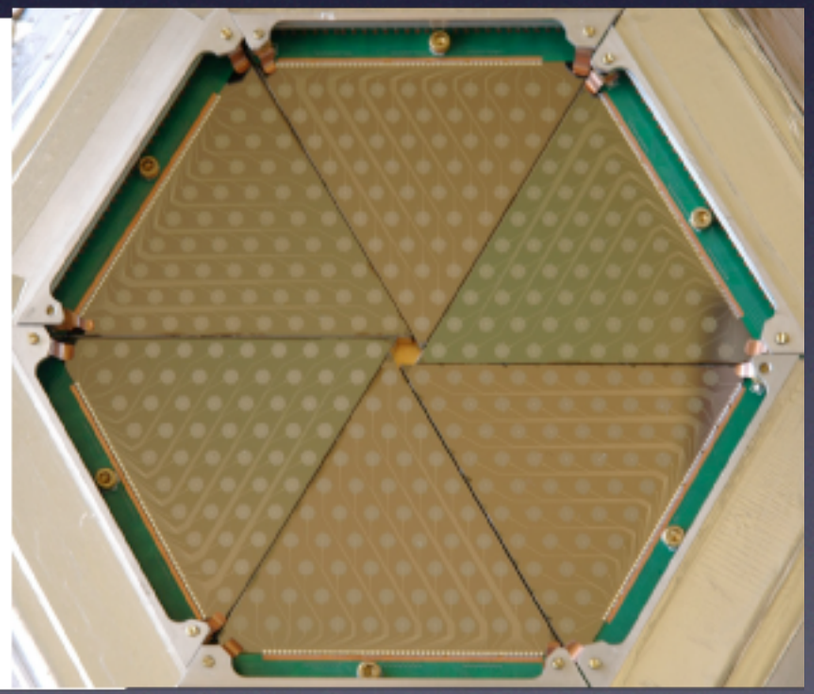
Telescope

- 12 m ALMA prototype, located at 5100 m altitude in the Chilean Altiplano

Receiver

- 300 pixel TES bolometer, PI instrument on APEX, **de-commissioned in Dec 2010**
- 1′ resolution, 0.4 deg FoV @ 150 GHz
- *About 7% sky time compared to SPT/ACT (often in bad weather!)*



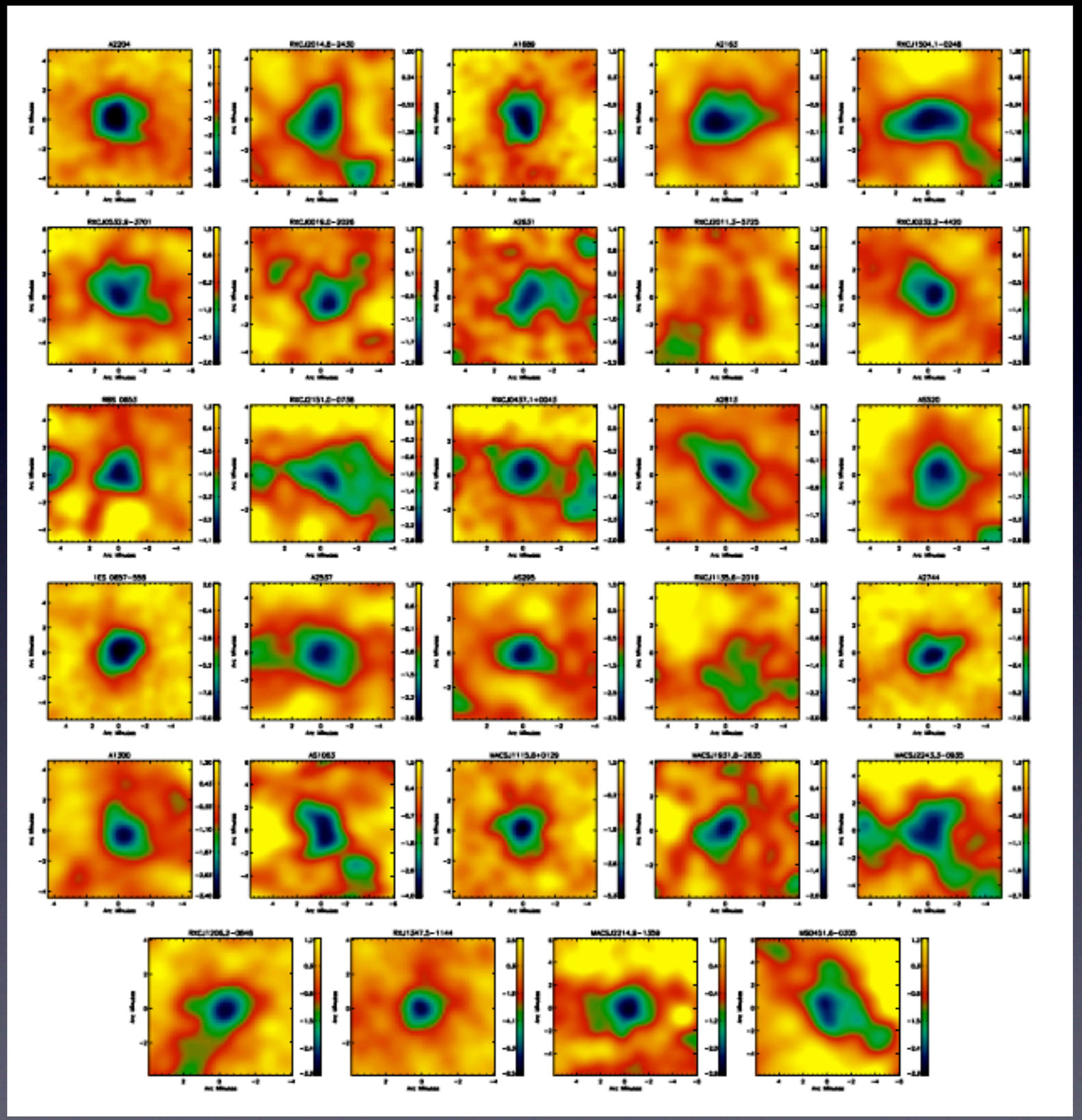


APEX-SZ Observations

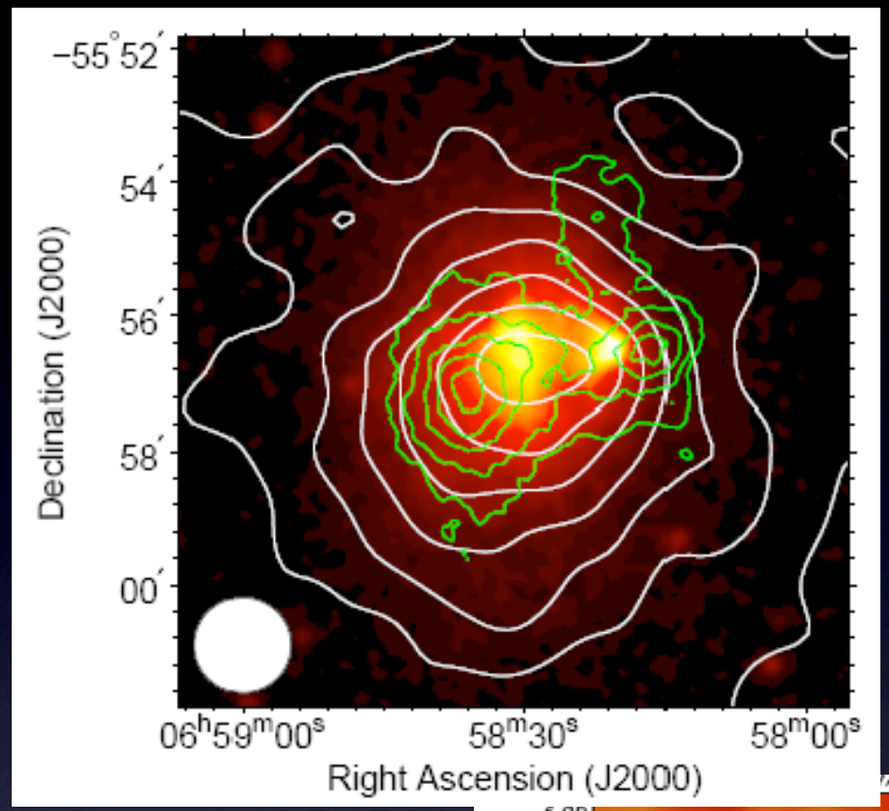
Name	R.A.	Dec.	z	M_{200}	APEX	X-ray	Cont.	Dist.
-	J2000	J2000	-	$10^{14}\,M_{sun}$	h	X/Ch	mJy	′
*** Complete X-ray selected sample ***								
** Low-z sub-sample **								
A2204	16:32:45.7	+05:34:43	0.152	-	20.3	100/100	69.3	0.32
RXCJ2014.8-2430	20:14:49.7	- 24:30:30	0.161	-	10.1	25/20	229.2	0.48
A1689	13:11:29.5	- 01:20:17	0.183	-	17.8	40/190	59.6	0.86
A2163	16:15:45.8	- 06:08:55	0.203	-	12.7	25/80	21	0.98
RXCJ1504.1-0248	15:04:07.7	- 02:48:18	0.215	-	10.4	40/50	60.5	0.05
** Intermediate z sub-sample **								
RXCJ0532.9-3701	05:32:55.9	- 37:01:35	0.2708	6.9	21.4	8.2/0	9.8	0.42
RXCJ0019.0-2026	00:19:07.8	- 20:27:21	0.2773	6.7	8.1	**0/0**	31.6	0.84
RXCJ2337.6+0016	23:37:39.7	+00:17:37	0.2779	8.3	9.0	9.3/25	107.0	0.87
RXCJ2011.3-5725	20:11:23.1	- 57:25:39	0.2786	6.9	22.5	**0/24**	N/A	-
RXCJ0232.2-4420	02:32:18.7	- 44:20:41	0.2836	8.0	8.7	9.3/23	N/A	-
RXCJ0528.9-3927	05:28:52.5	- 39:28:16	0.2839	9.6	19.5	7.1/22	18.3	3.65
RXCJ2151.0-0736	21:51:01.2	- 07:36:03	0.2841	6.5	8.0	**0/0**	7.5	0.49
RXCJ0437.1+0043	04:37:09.8	+00:43:37	0.2842	7.9	10.6	6.3/40	11.6	0.86
A2813	00:43:24.4	- 20:37:17	0.2924	7.2	7.9	8.3/20	105.8	0.42
RXCJ0516.6-5430	05:16:38.0	- 54:30:51	0.2952	9.8	27.2	9.7/10	N/A	-
Bullet	06:58:31.1	- 55:56:49	0.2965	12.3	11.5	20.6/550	N/A	-
A2537	23:08:23.2	- 02:11:31	0.2966	8.5	15.5	8.5/75	13.9	0.60
RXCJ0245.4-5302	02:45:27.7	- 53:02:10	0.3018	6.7	13.1	28/20	N/A	-
RXCJ1135.6-2019	11:35:36.8	- 20:19:42	0.3045	7.0	16.0	**0/0**	213.5	0.60
A2744	00:14:18.8	- 30:23:00	0.3066	9.4	21.8	12.2/125	15.8	0.95
A1300	11:32:00.7	- 19:53:34	0.3075	9.6	17.4	9.7/14	42.0	1.77
** High-z sub-sample **								
RXCJ2248.7-4431	22:48:54.3	- 44:31:07	0.3475	13.8	17.8	5.1/24	N/A	-
MACSJ1115.8+0129	11:15:52.1	+01:29:53	0.3499	9.4	16.1	0/56	16.2	0.57
MACSJ1931.8-2635	19:31:48.0	- 26:35:00	0.3520	11.1	9.4	0/110	216.5	1.11
MACSJ2243.3-0935	22:43:20.8	- 09:35:18	0.4400	9.4	7.0	130/20	6.0	1.67
RXCJ1206.2-0848	12:06:12.2	- 08:48:22	0.4414	10.6	14.7	30/23	160.9	0.34
RXJ1347.5-1144	13:47:30.6	- 11:45:12	0.4516	15.2	10.2	38/90	45.9	0.27
MACSJ2214.9-1359	22:14:59.0	- 13:59:41	0.4830	9.8	7.3	**0/40**	58.0	4.95
MS0451.6-0305	04:54:11.4	- 03:00:52	0.5390	9.9	8.3	45/60	14.4	3.62

Over 900 hours of science data

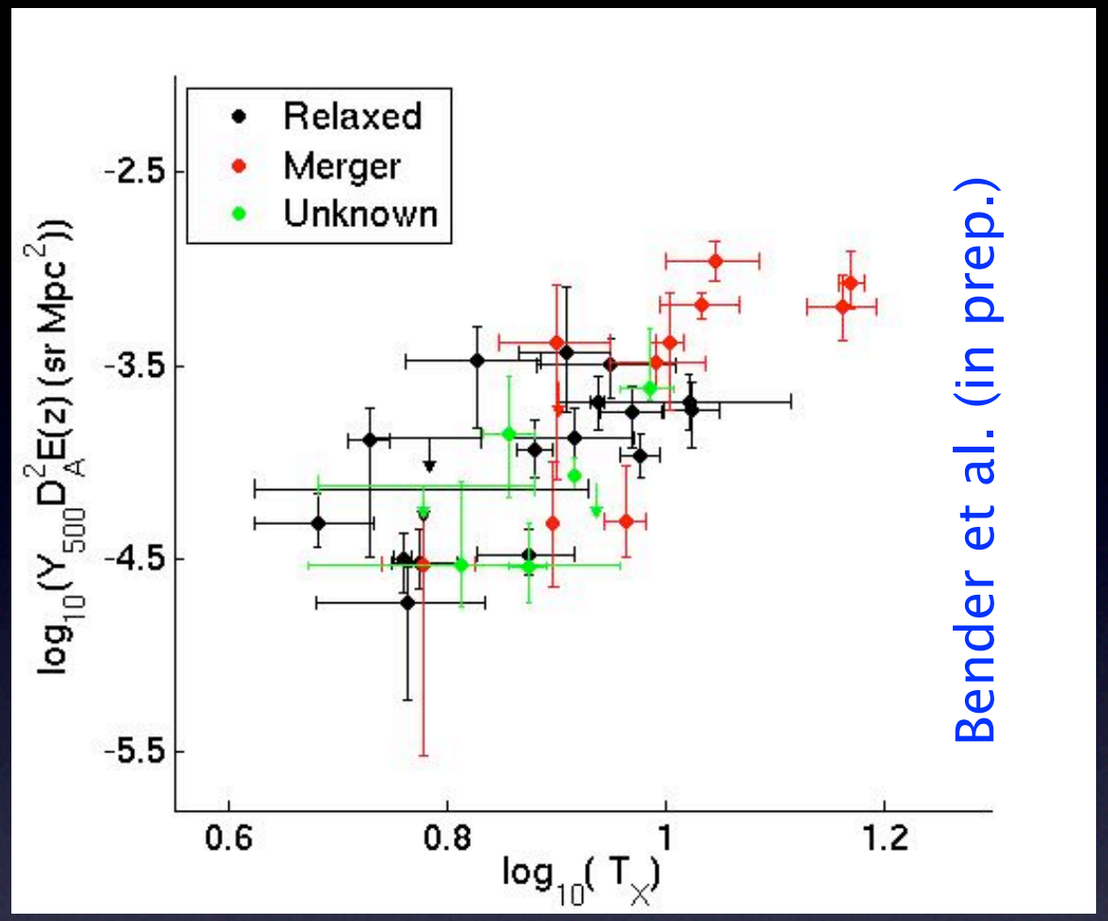
APEX-SZ Observations



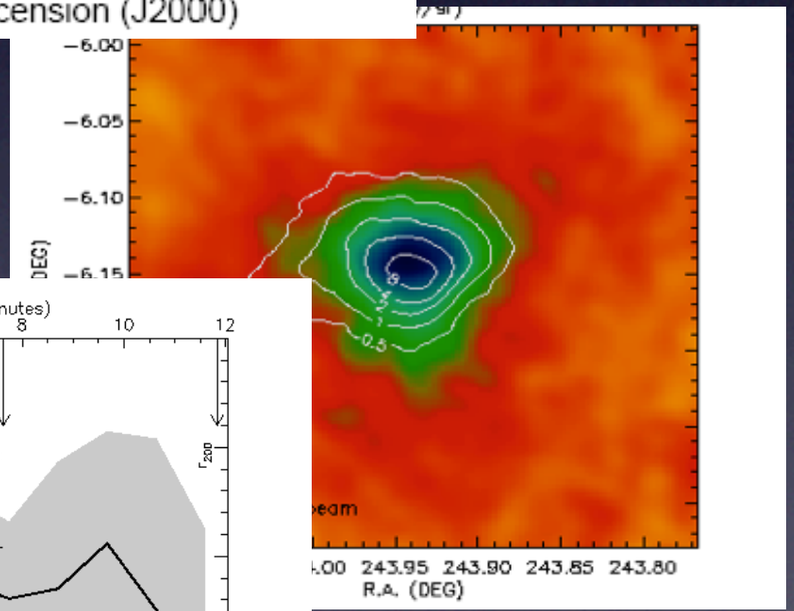
APEX-SZ past & future results

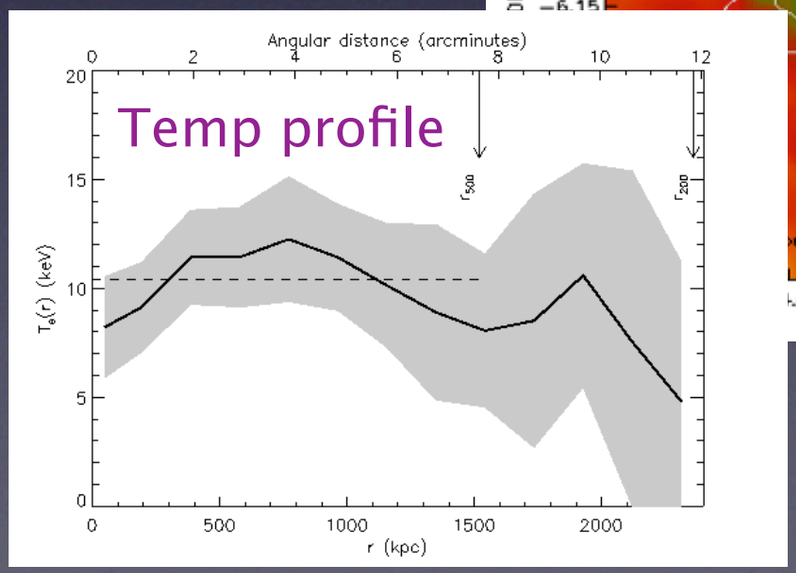


Halverson, Lanting et al. 2009

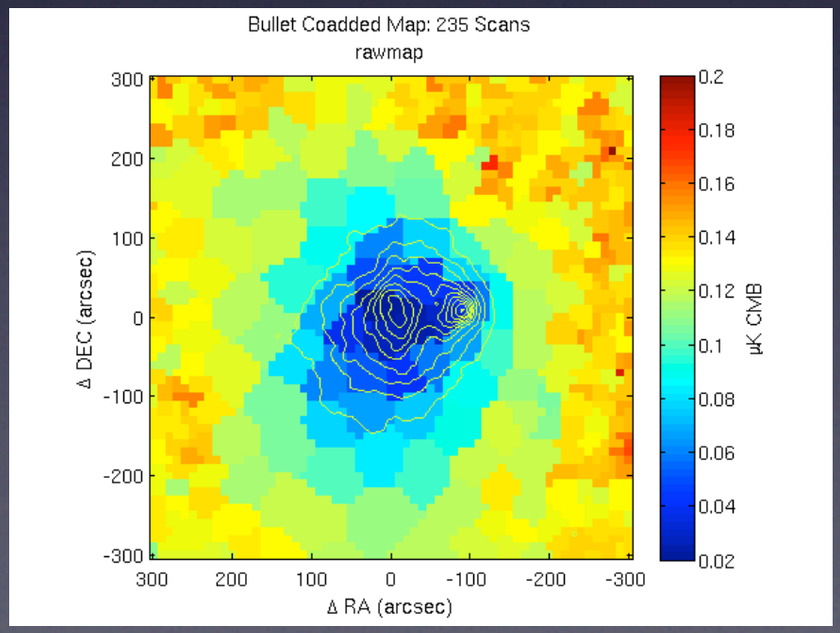


Bender et al. (in prep.)



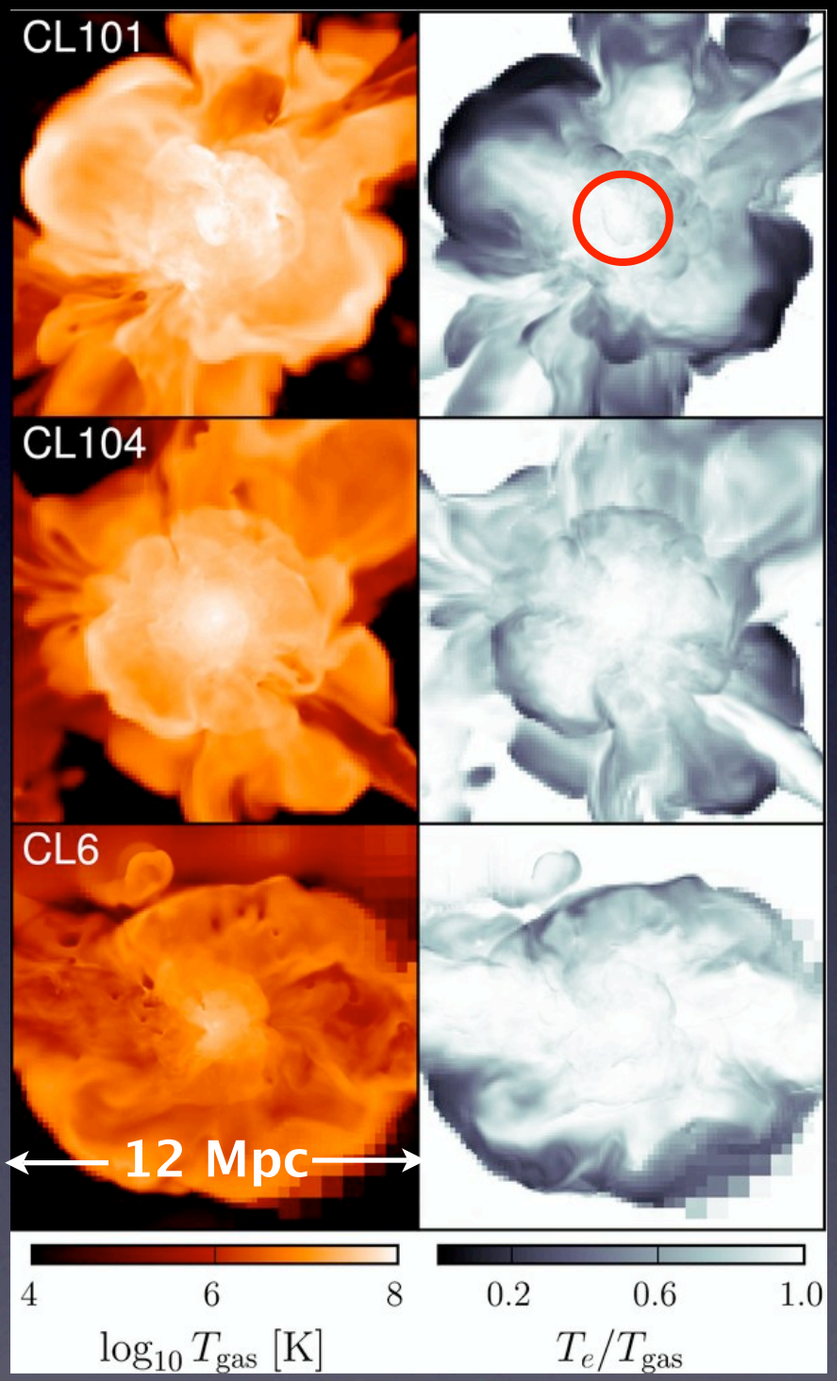


Nord, Basu, Pacaud et al. 2009



Kennedy, Basu et al. (in prep)

Physics at the Cluster Outskirts

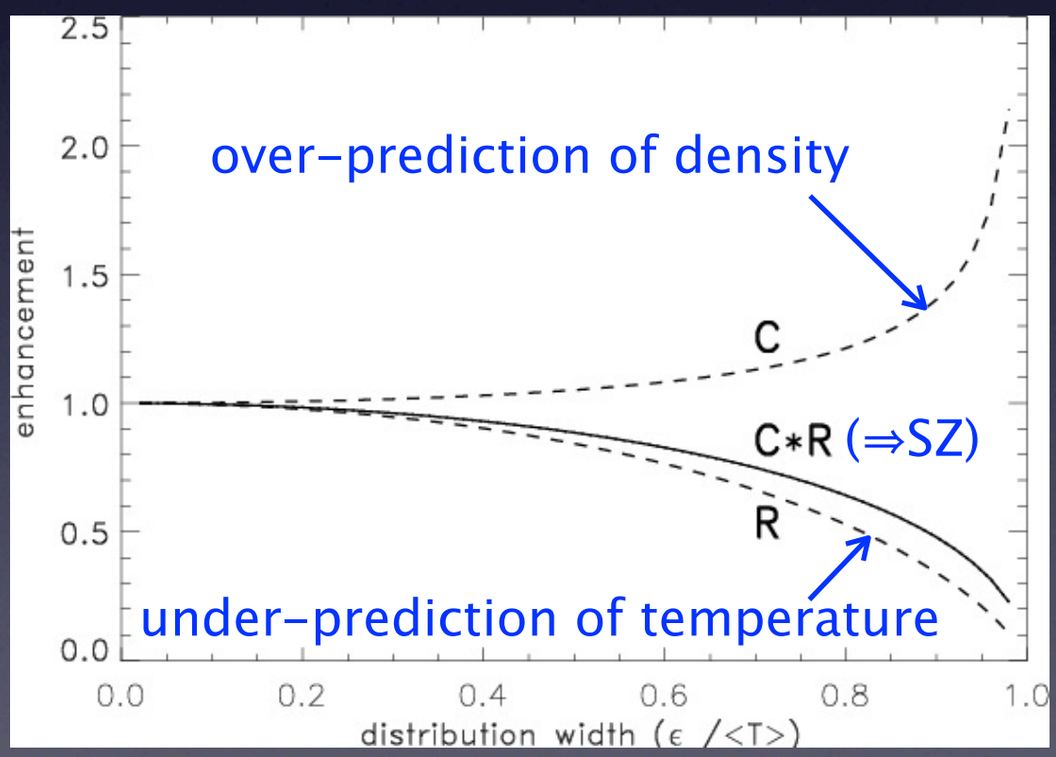


Departure from thermodynamic equilibrium in the cluster outskirts ($T_e < T_{gas}$)

Rudd & Nagai 2009

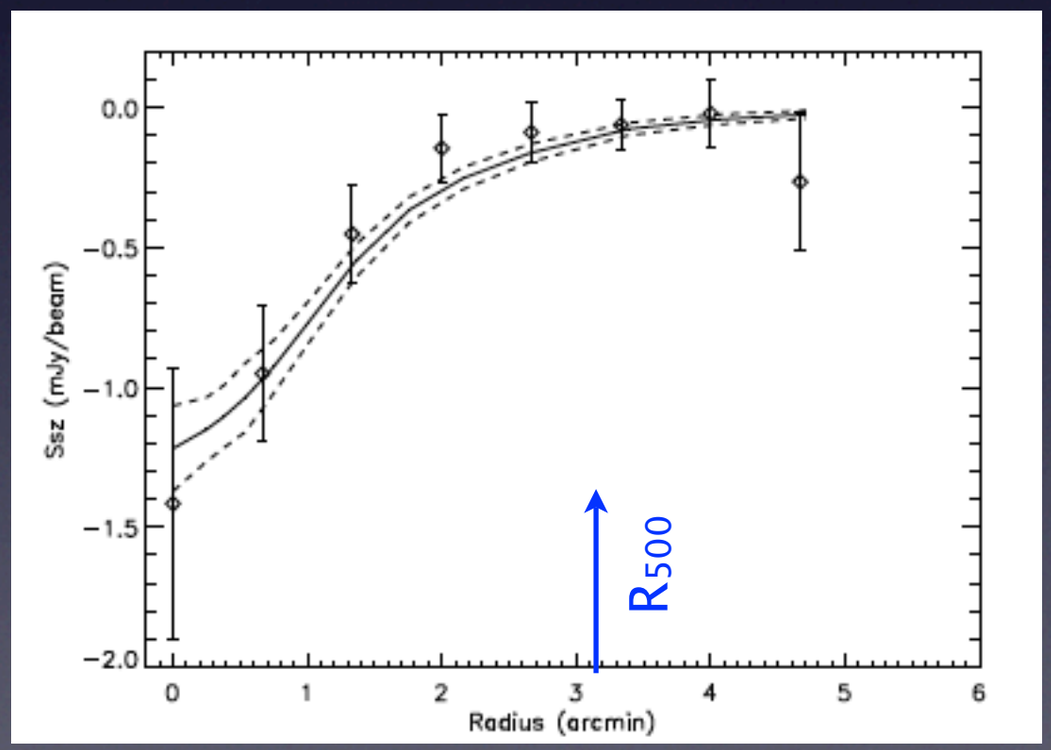
Gas clumping creates opposite biases for the X-ray spectroscopic and SZ temperatures

RXC J2228.6: Jia, Boehringer et al. 2008



Physics at the Cluster Outskirts

SZ measurement with NRO
(From Pointecouteau et al. 2002)



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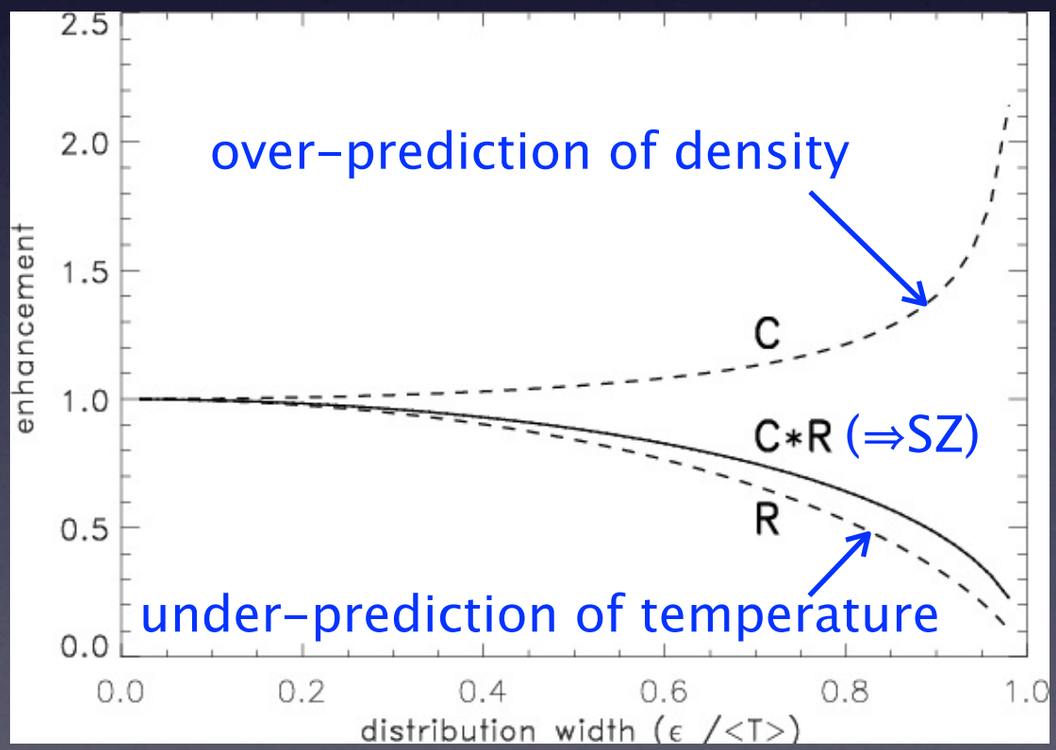
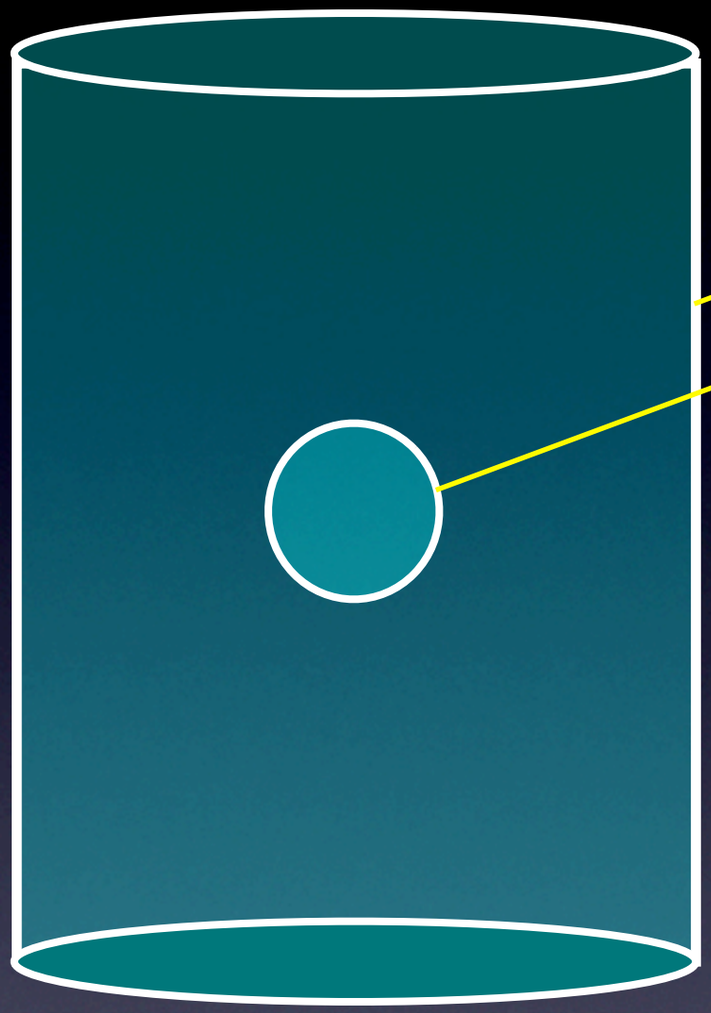
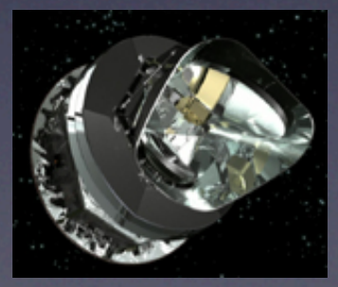


Modeling the cluster outskirts

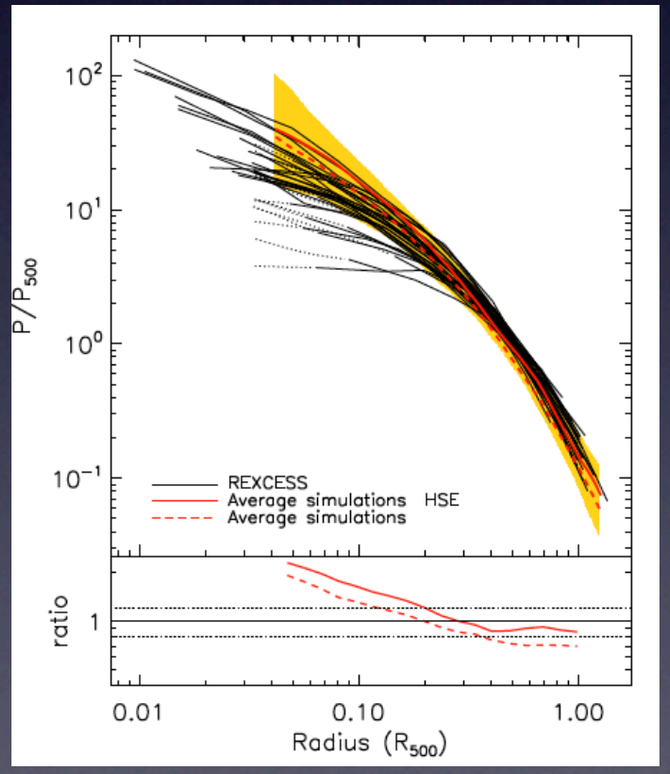


Measured Y_{SZ} in a cylinder

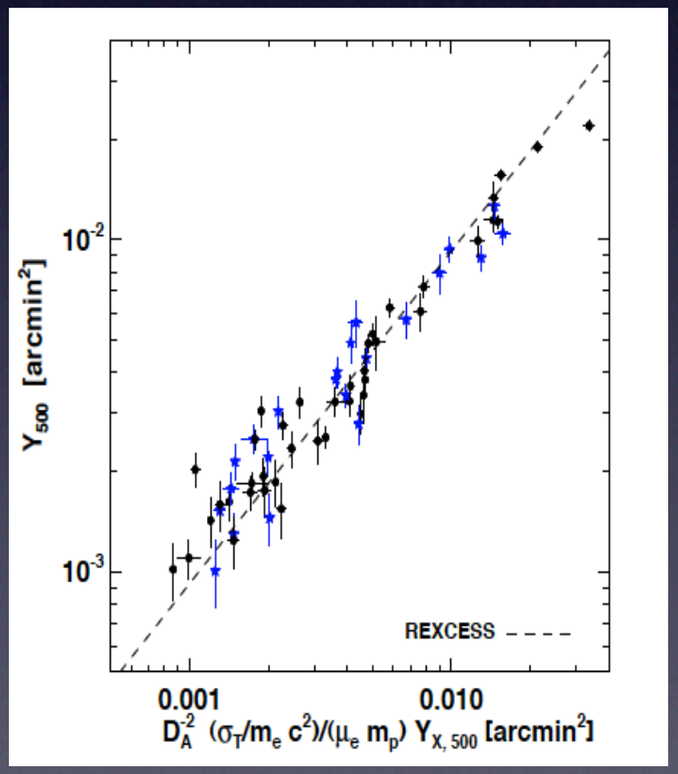
Y_{SZ} / Y_X comparison in R_{500} sphere



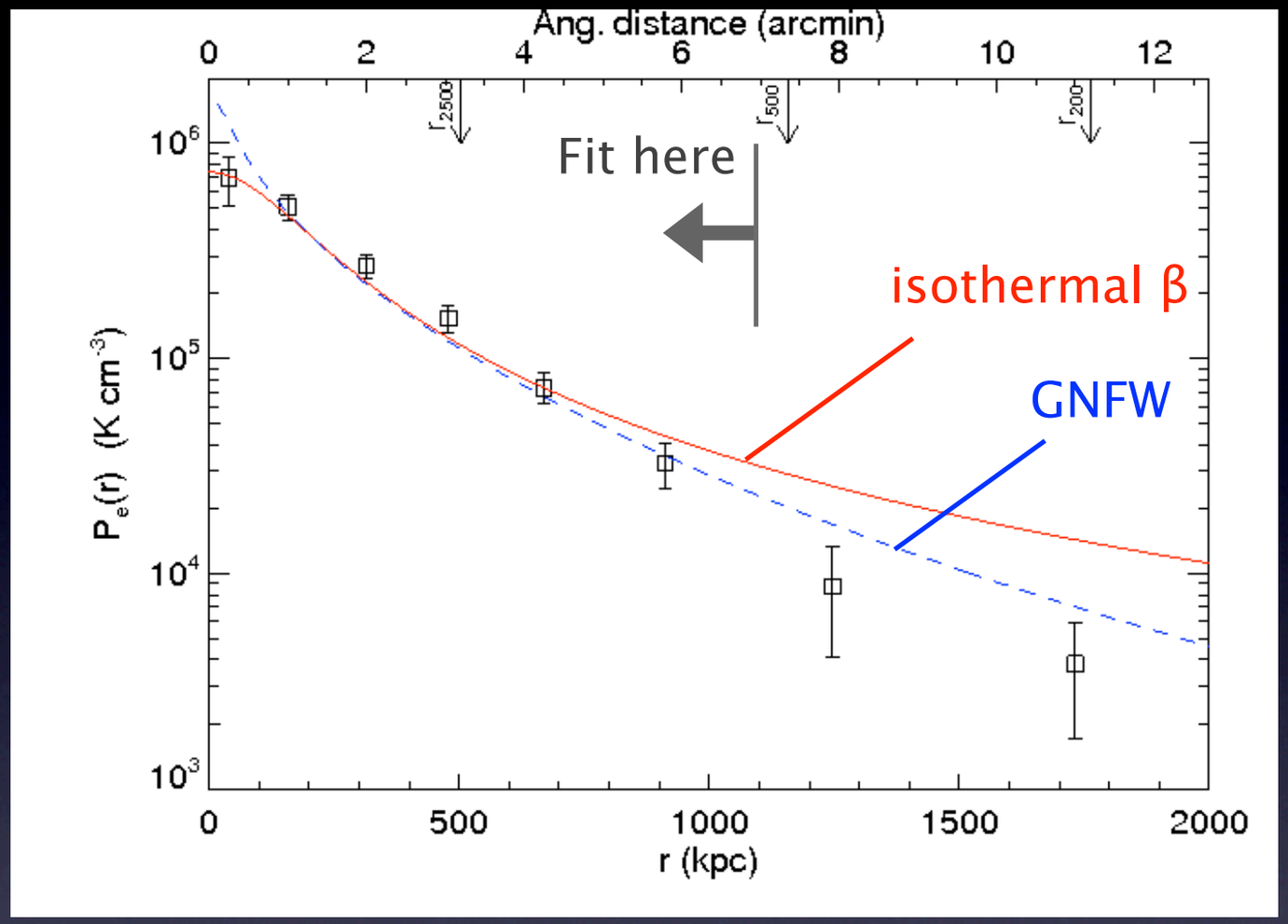
Arnaud et al.2010



Planck collaboration 2011

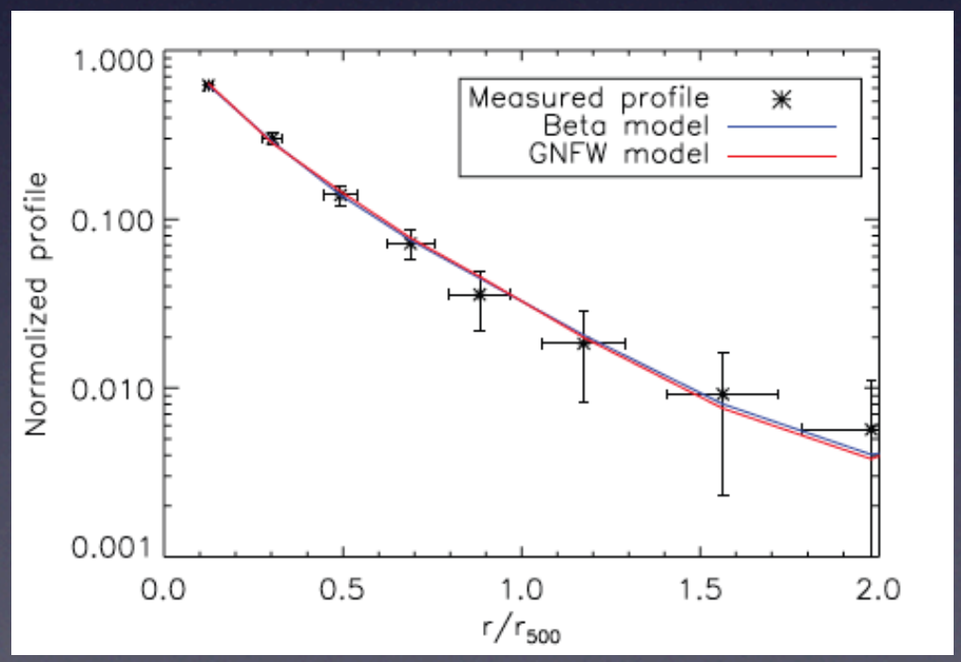


De-projecting without parametric models



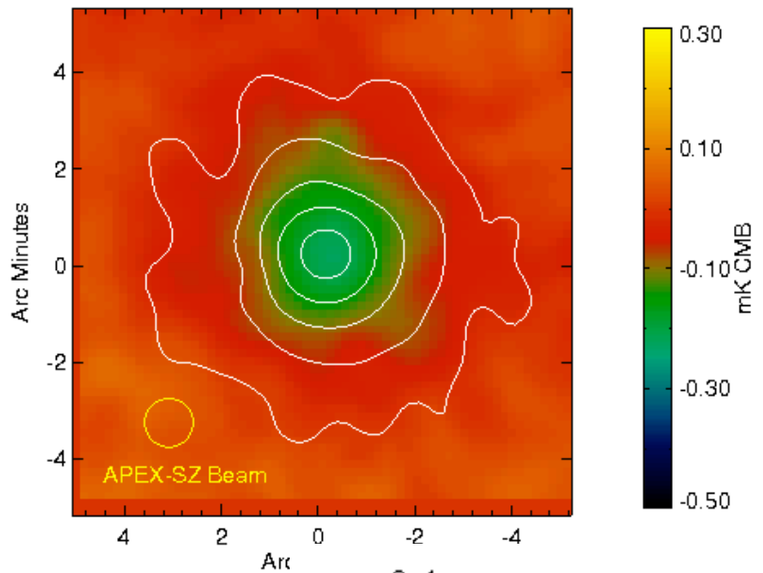
A2204: Basu et al. 2010

De-projection of the SZ map
=
the radial pressure profile

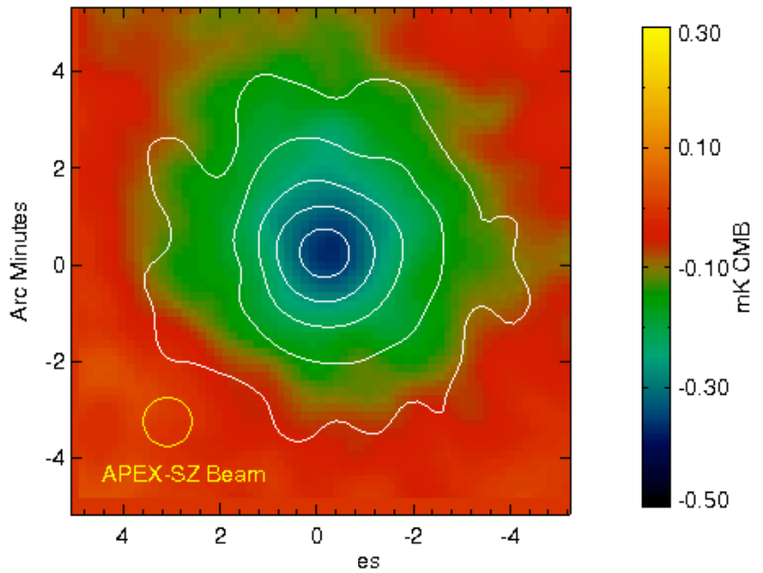


SPT measurement
(Plagge et al. 2010)

“True” SZ map/profile

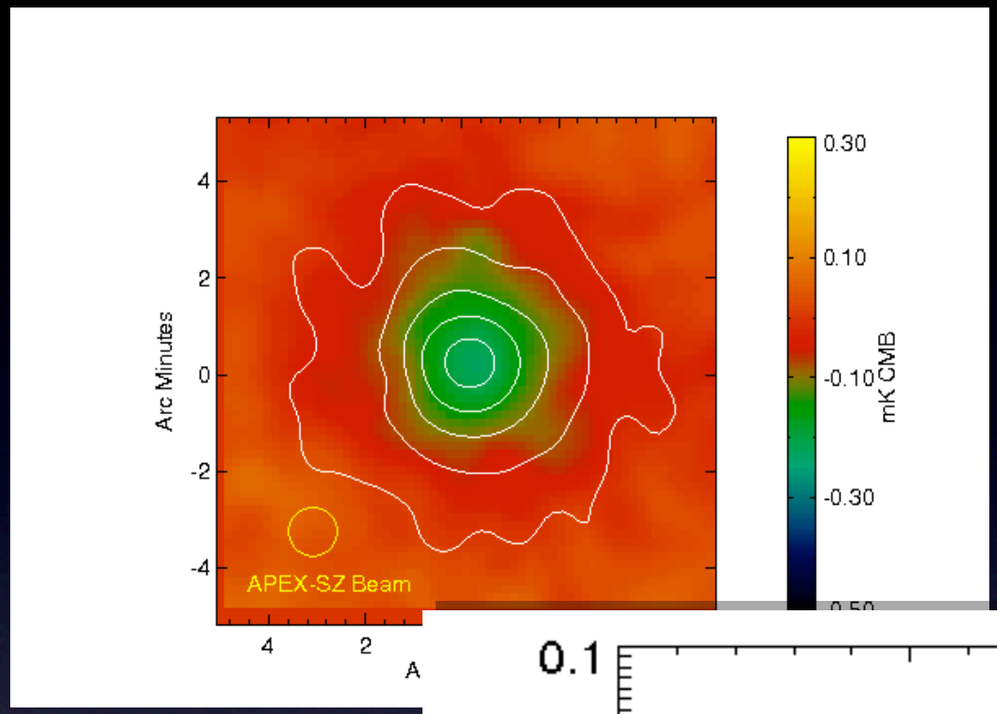


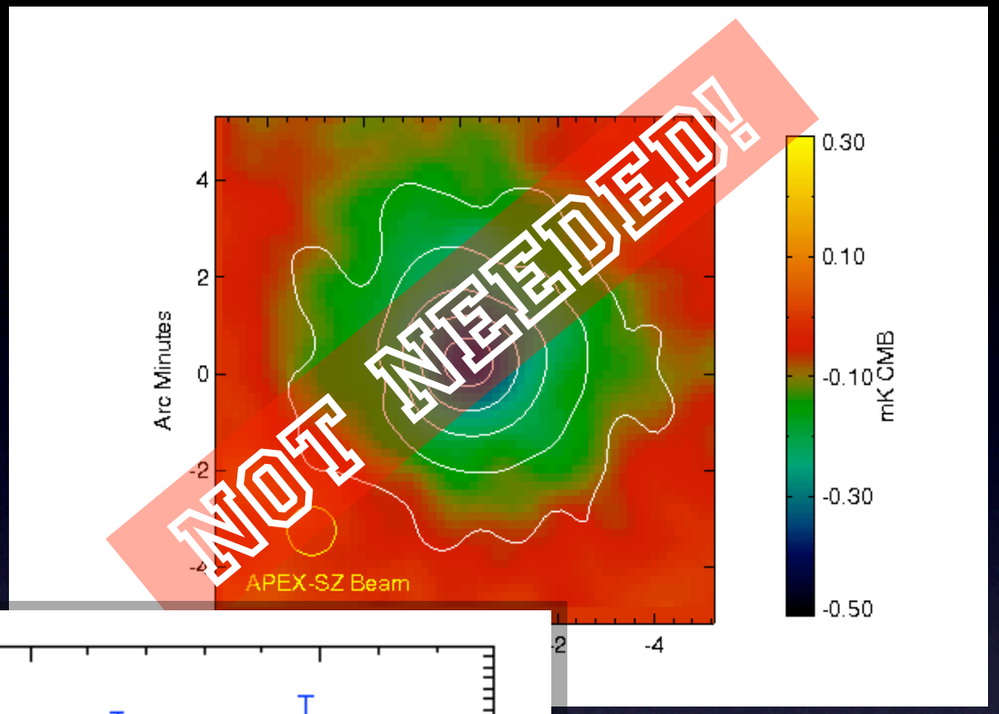
Filtered (observed) map



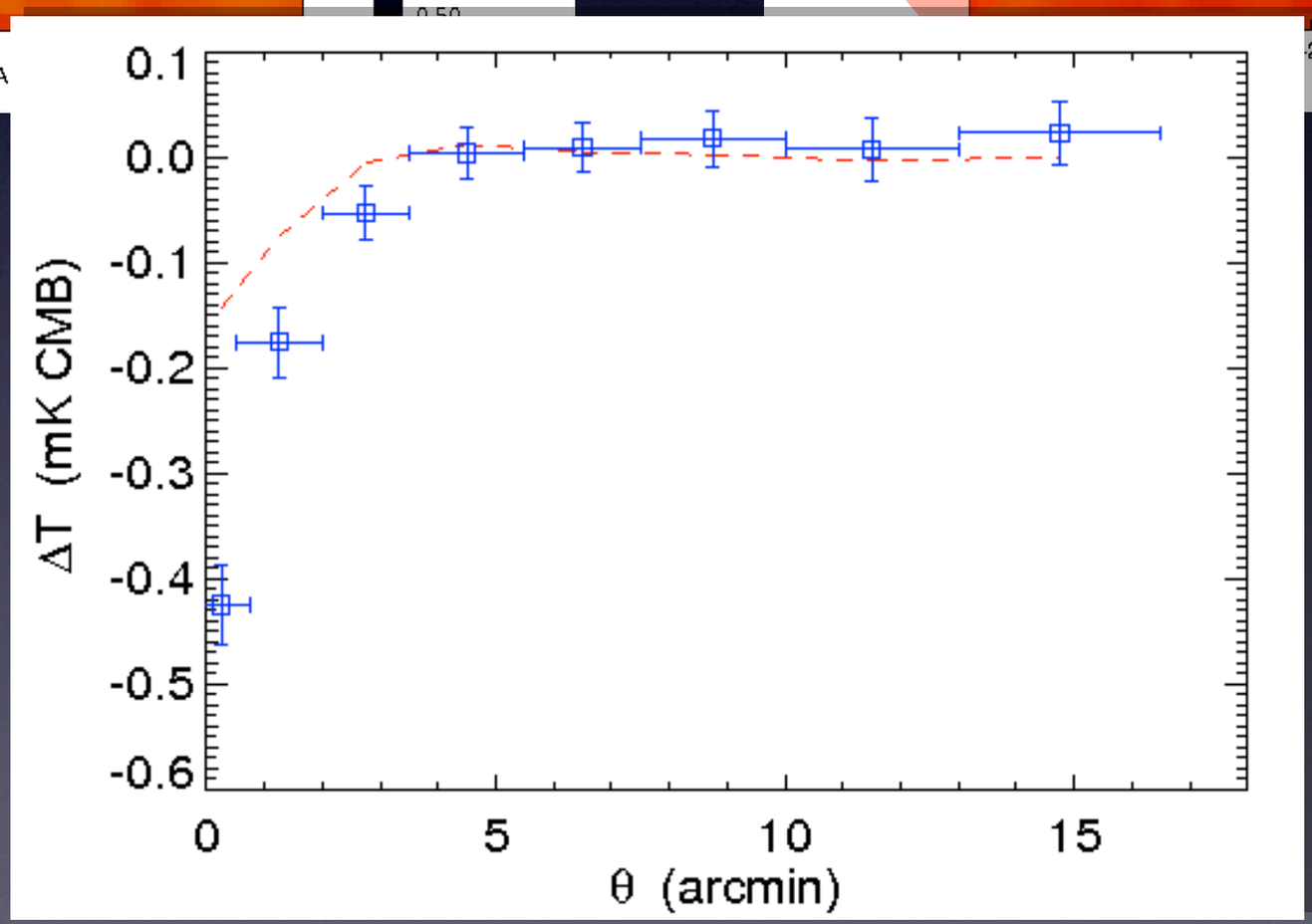
De-convolved map

“True” SZ map/profile





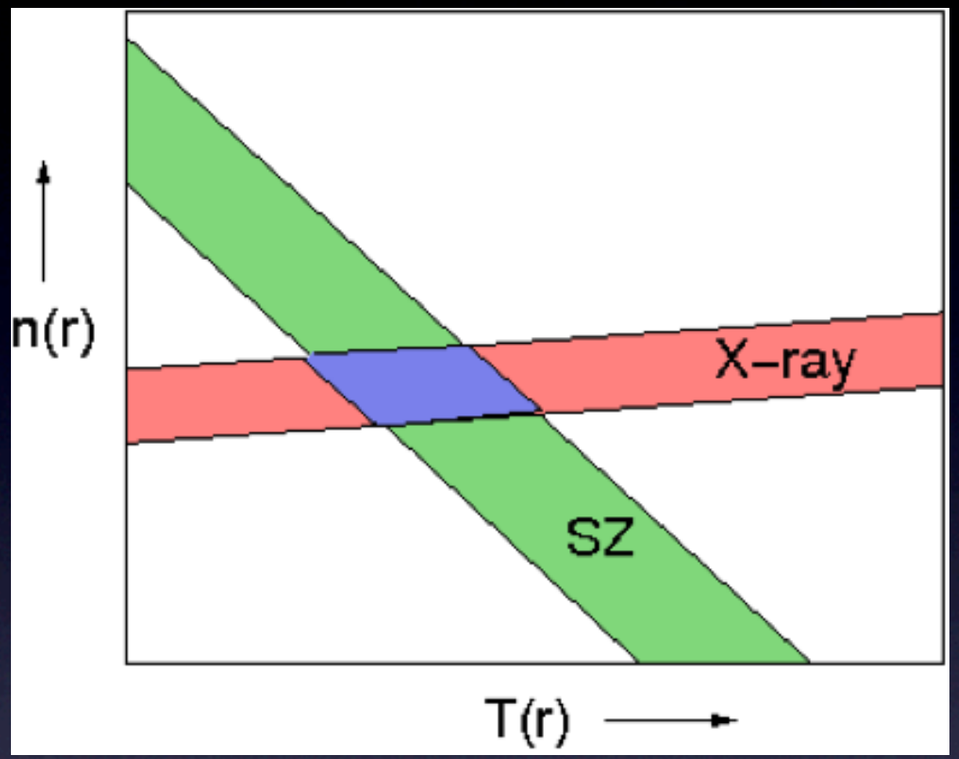
NOT NEEDED!

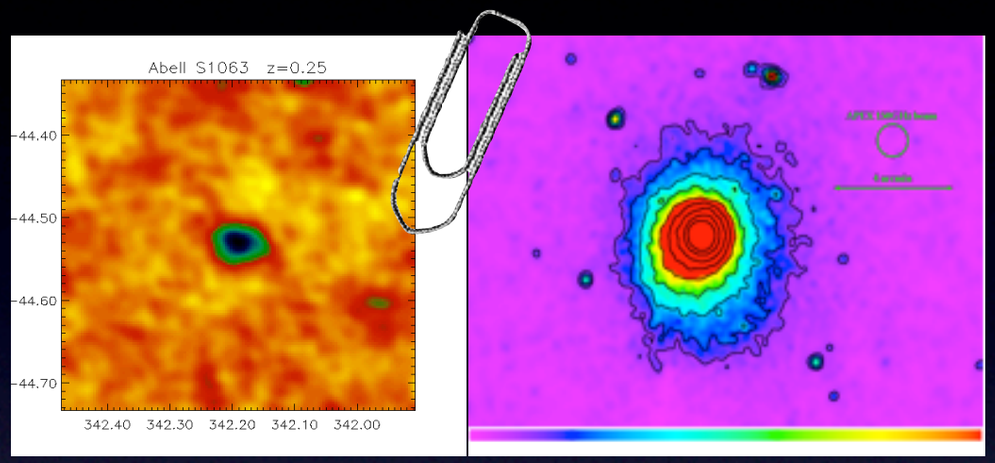


Direct de-projection with MCMC method

(see Ameglio, Borgani et al. 2007)

ICM Temperature De-projection





X-ray $\propto n_e^2 \Lambda(T_e)$

SZE $\propto n_e T_e$

(SZE) observed $\Delta T(\theta)$ (SZE) $n_e(r)\, T_e(r)$

$$f(\theta) = \int_{-\infty}^{\infty} g(r)dl = 2\int_{d_A\theta}^{\infty} g(r)\frac{rdr}{\sqrt{r^2 - d_A^2\,\theta^2}},$$

$$g(r) = \frac{1}{\pi d_A}\int_{\infty}^{r/d_A} \frac{df(\theta)}{d\theta}\frac{d\theta}{\sqrt{\theta^2 - r^2/d_A^2}}.$$

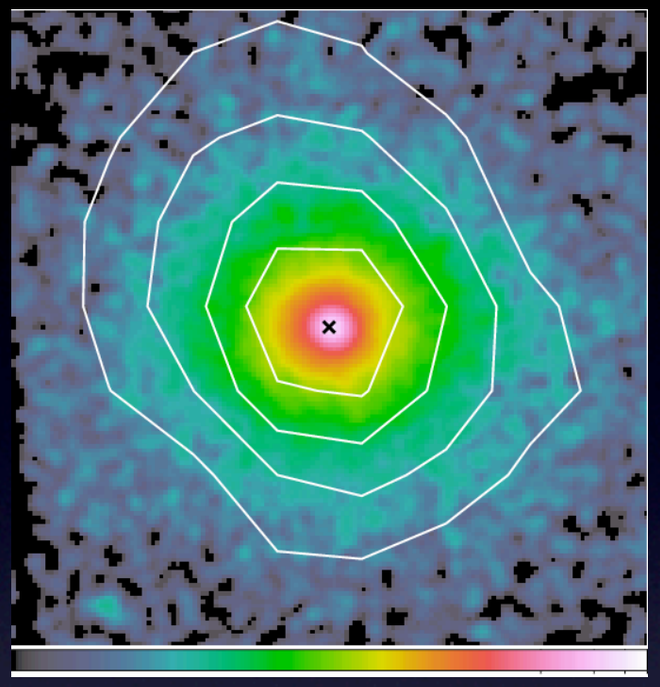
ICM Temperature De-projection

Abell 2204

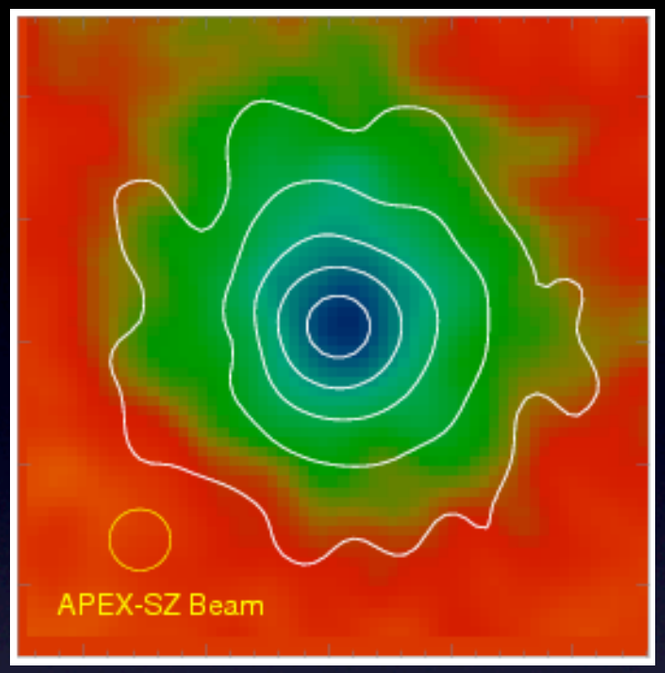
Archetypal
relaxed cluster

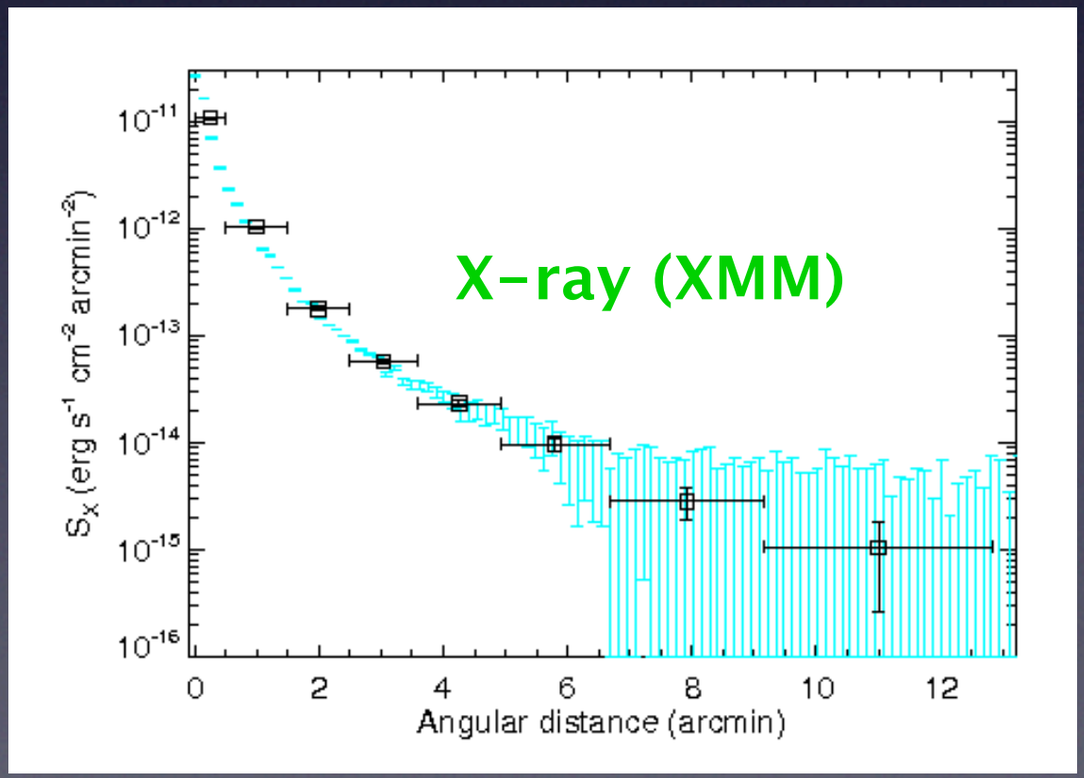
Basu, Zhang at el. 2010

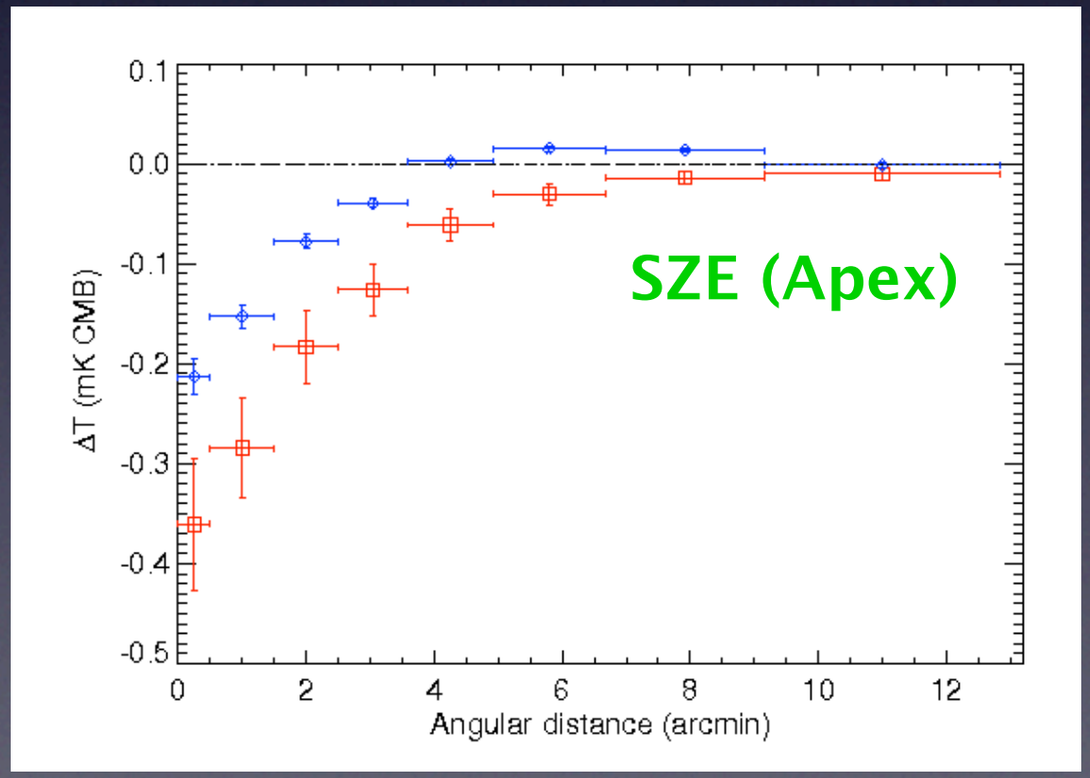
X-ray image with
SZ contours



SZ image with
X-ray contours







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X-ray image with
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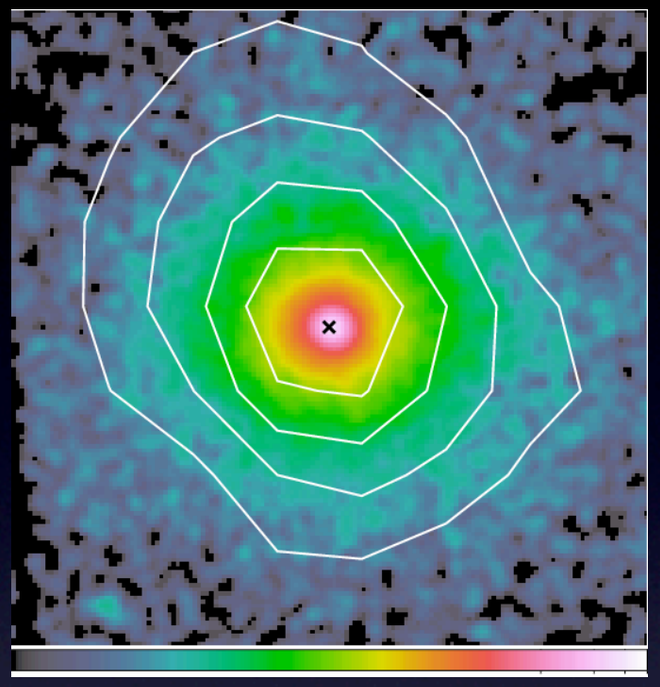
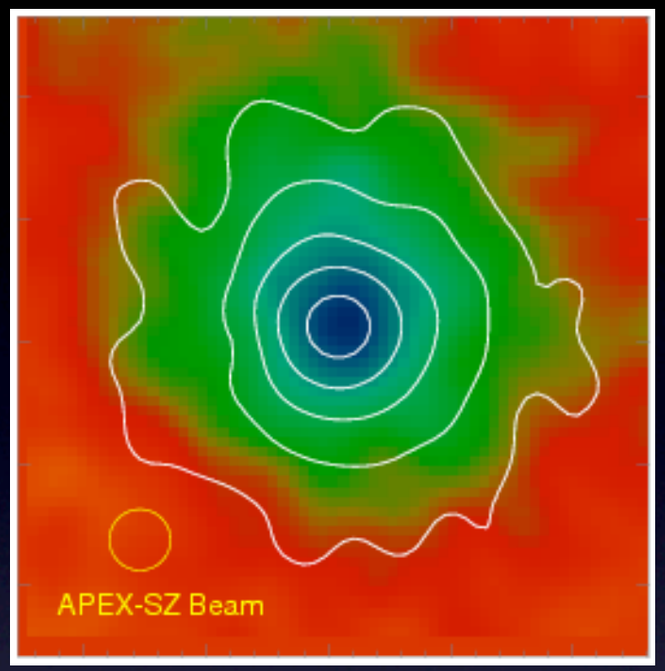
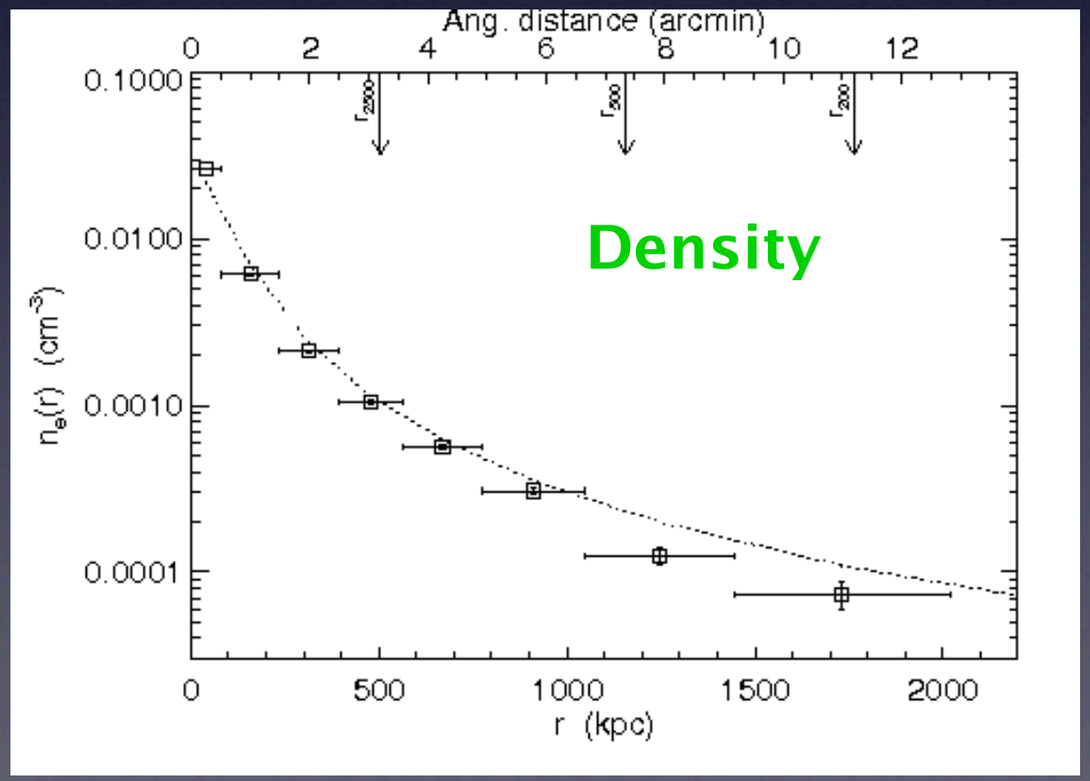
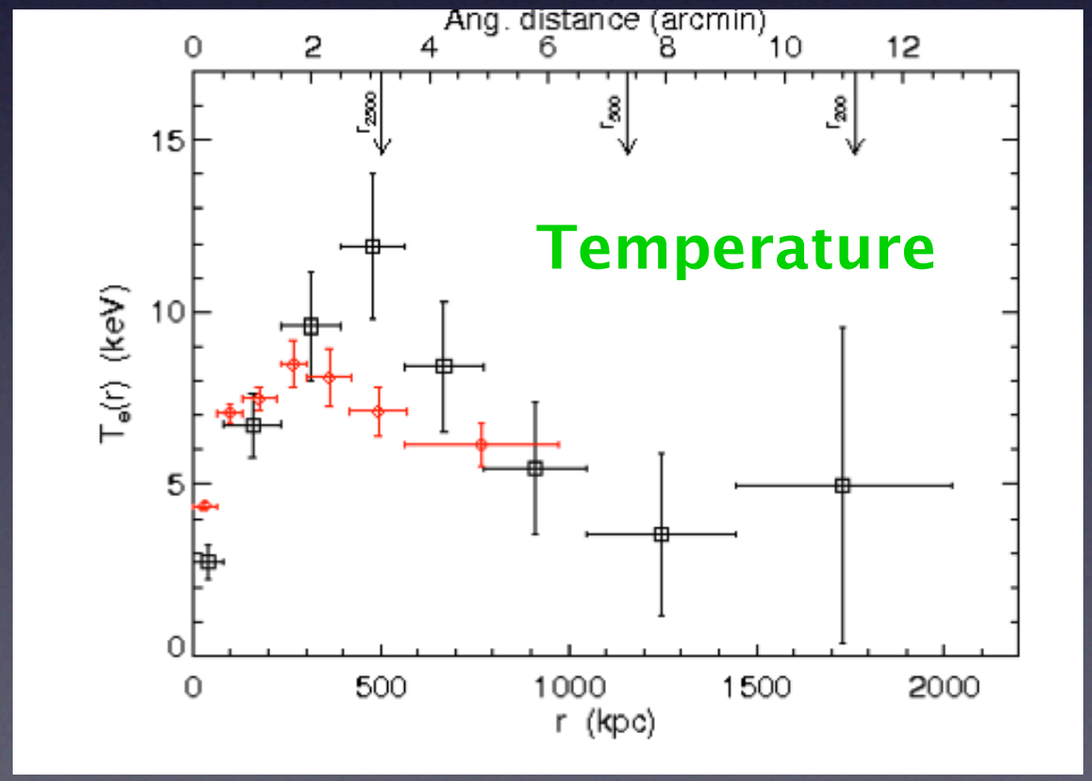


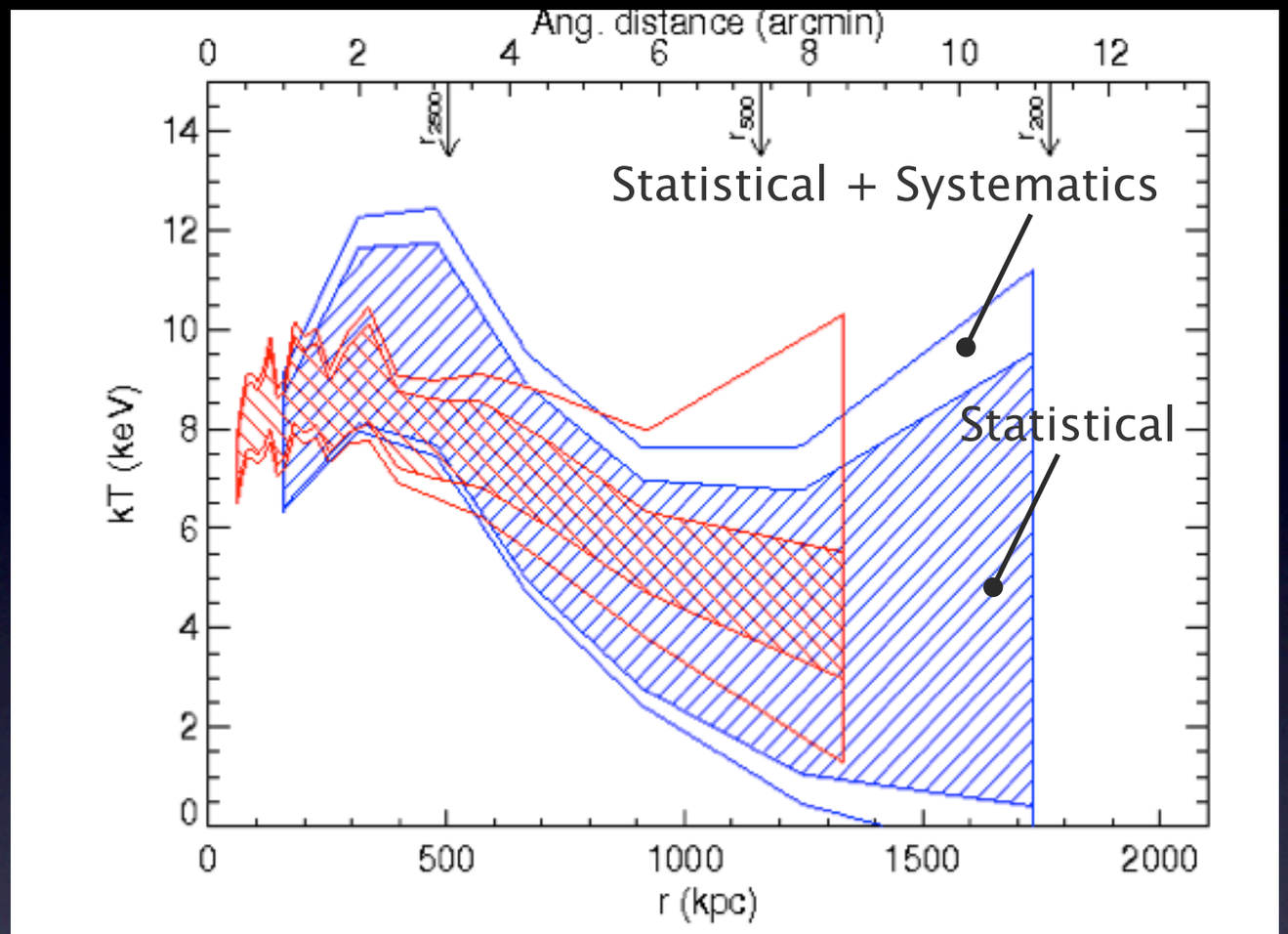
SZ image with
X-ray contours



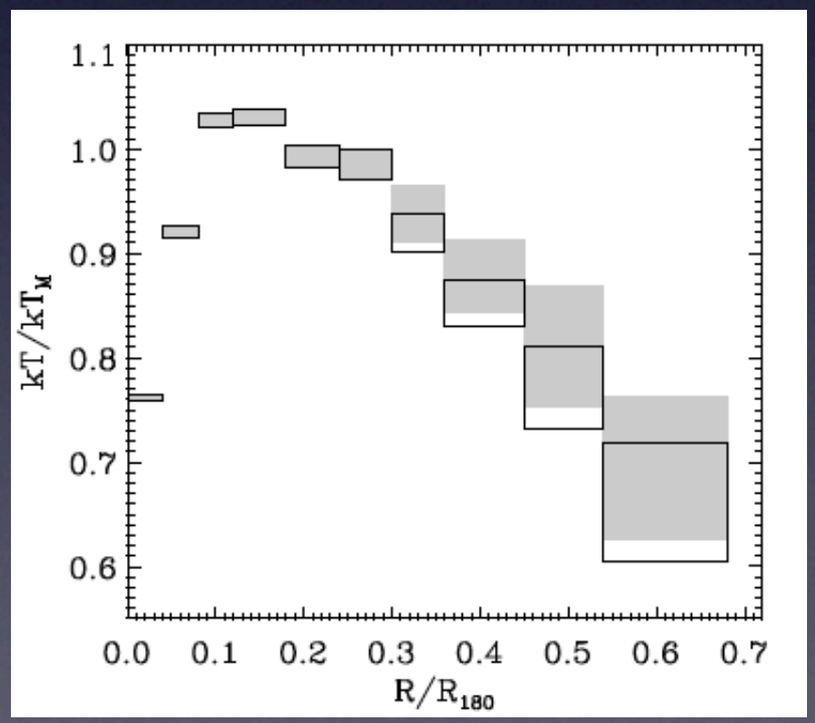




SZ/X and X-ray spec. systematic errors



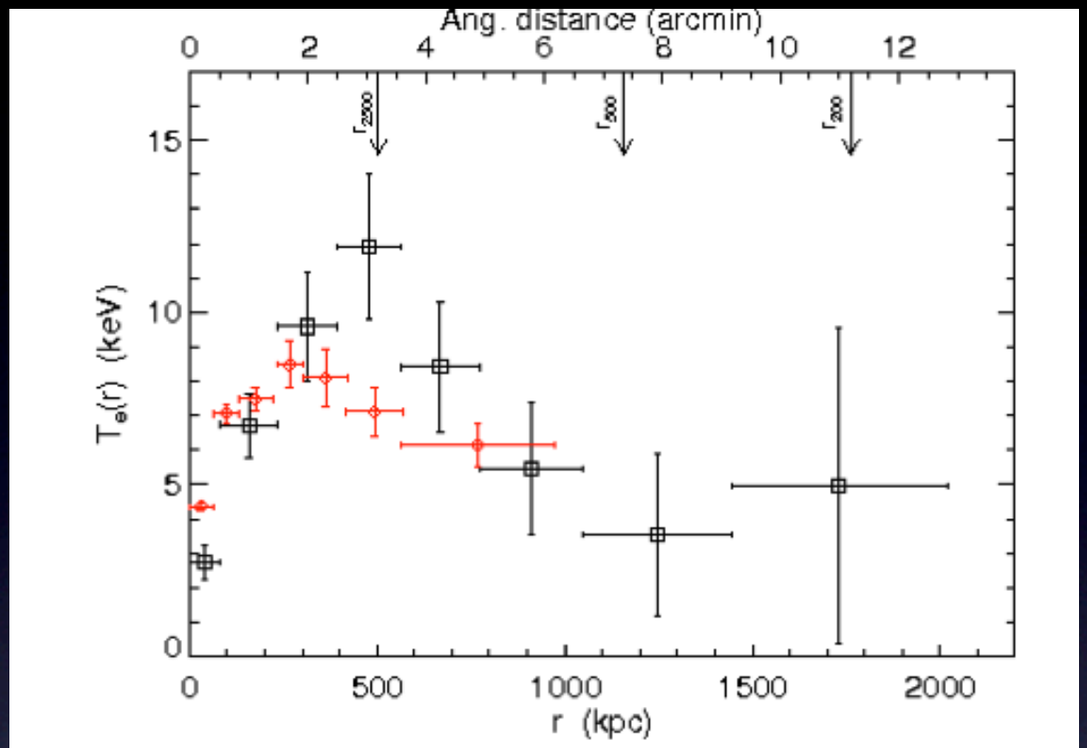
Projected ("spectroscopic-like") temperature and re-calibrated *Chandra* (88 ks) measurement



XMM temperature profile of ~50 clusters, including systematic errors

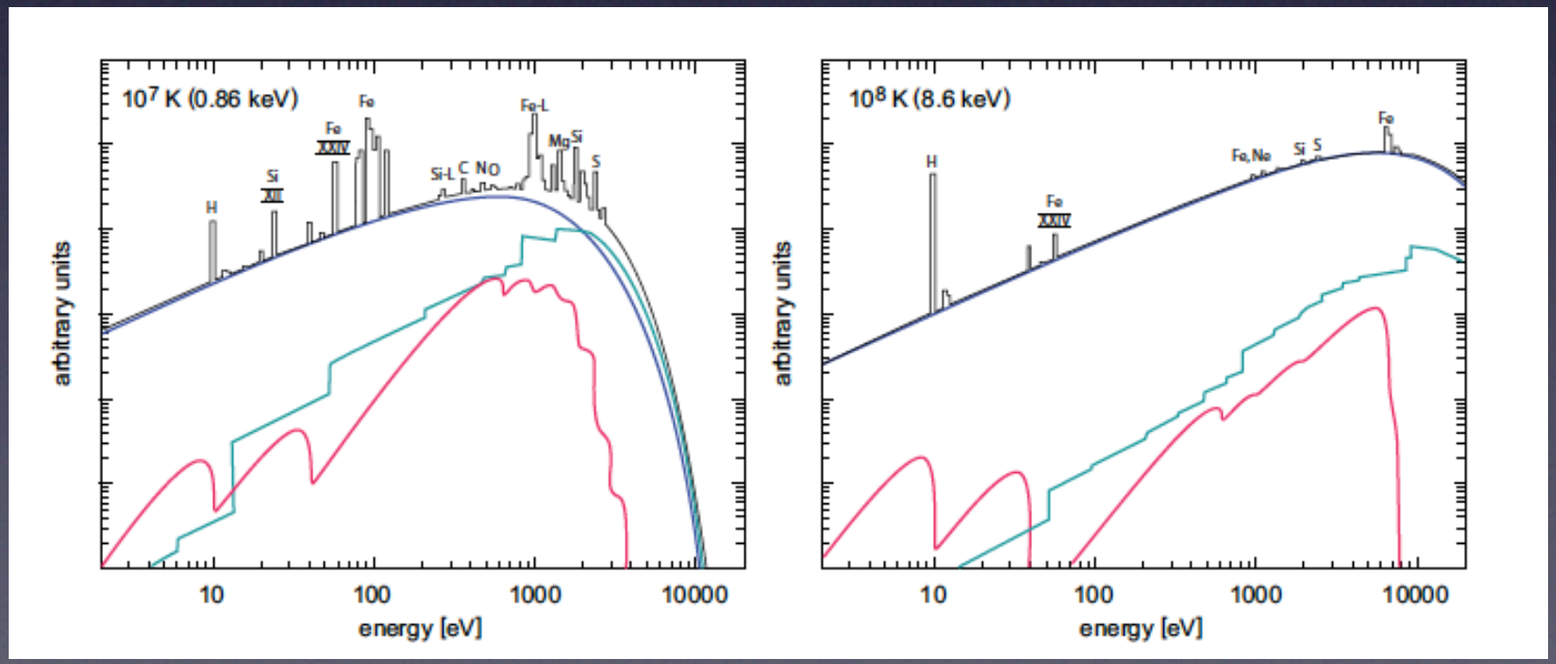
(Leccardi & Molendi 2008)

Biases in SZ/X-ray joint modeling



Since density profile is almost fully constrained by X-ray, the SZ-derived temperature will carry the opposite bias

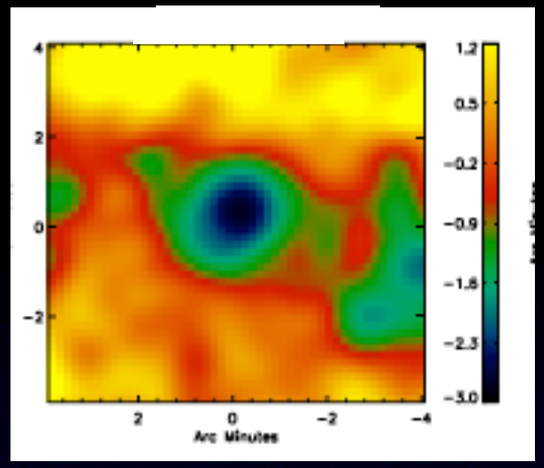
Boehringer & Werner 2009

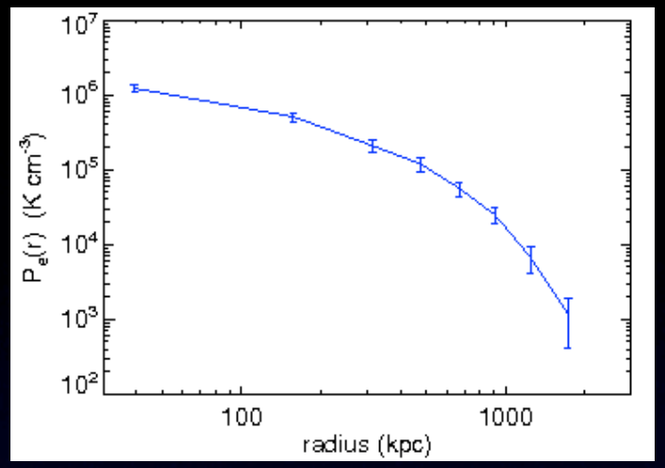


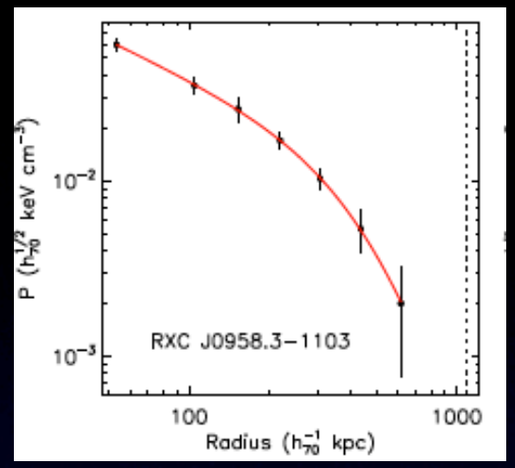
In the soft X-ray band (0.5-2 keV) the surface brightness is almost independent of gas temperature

APEX-SZ pressure profiles

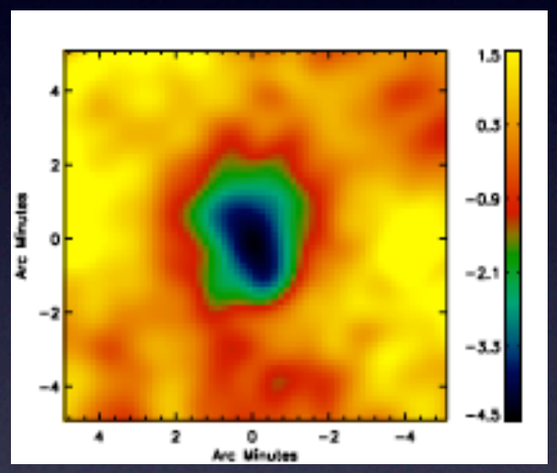
A907

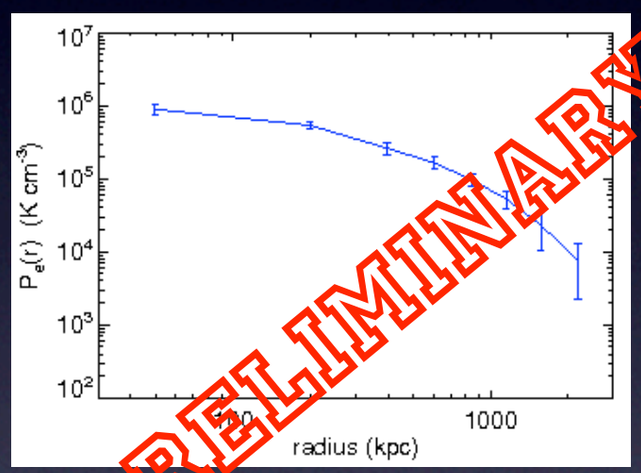


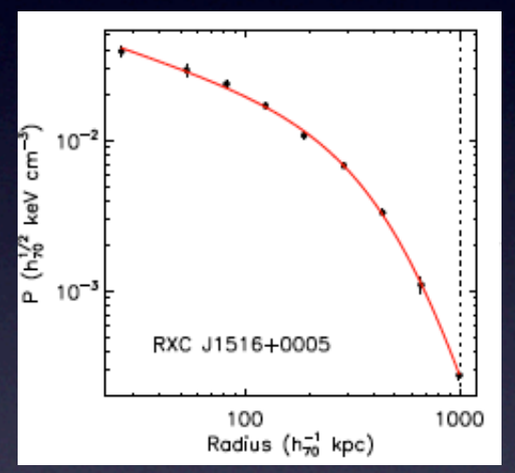




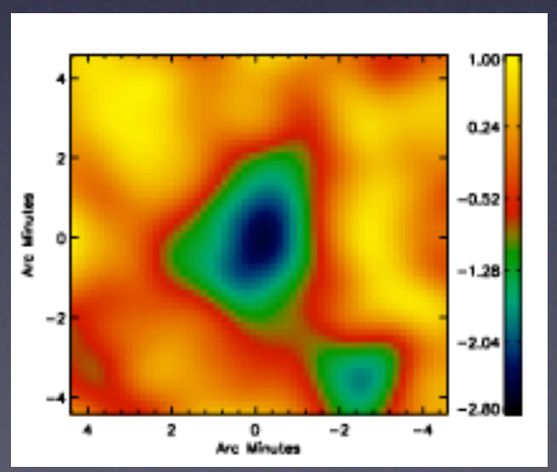
A1689

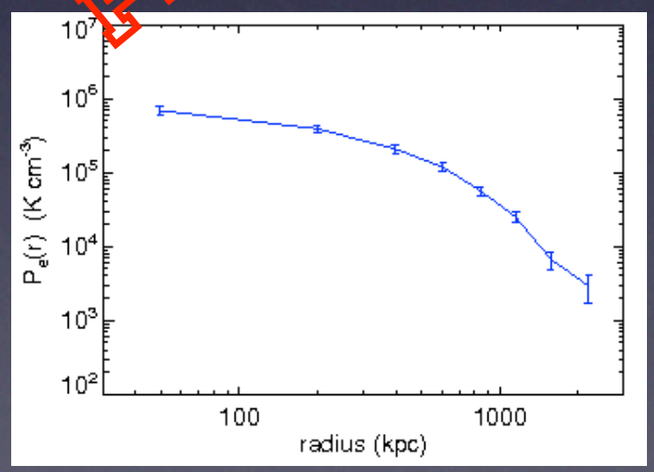


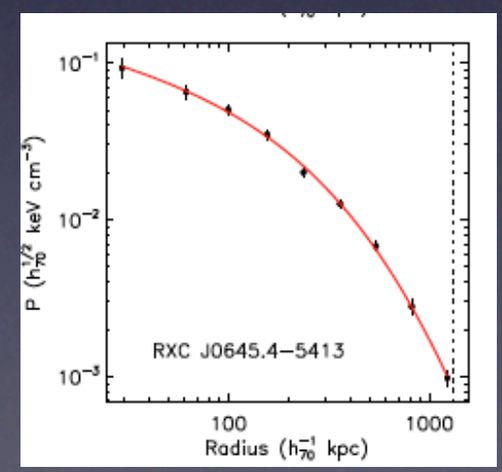




A3404

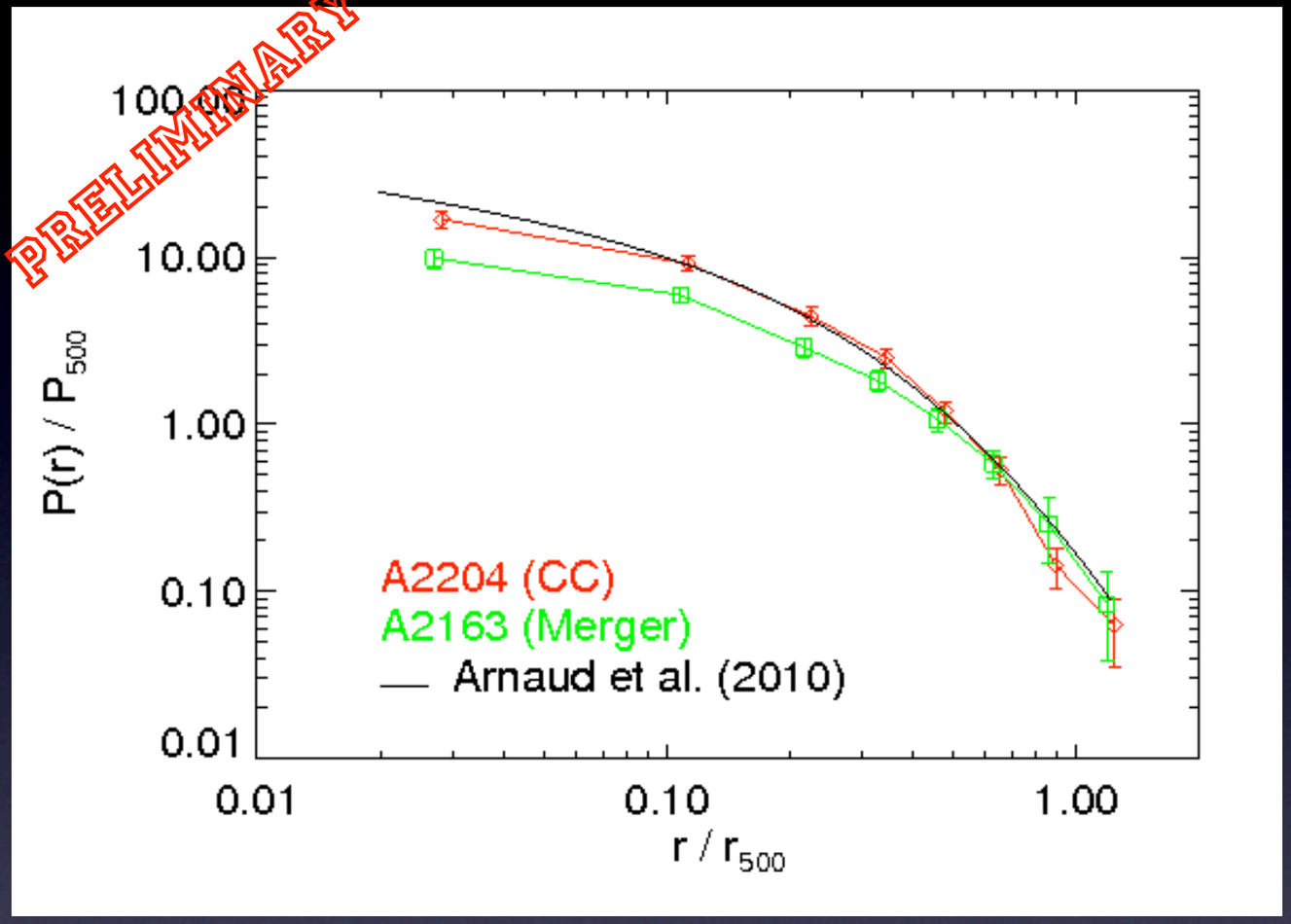






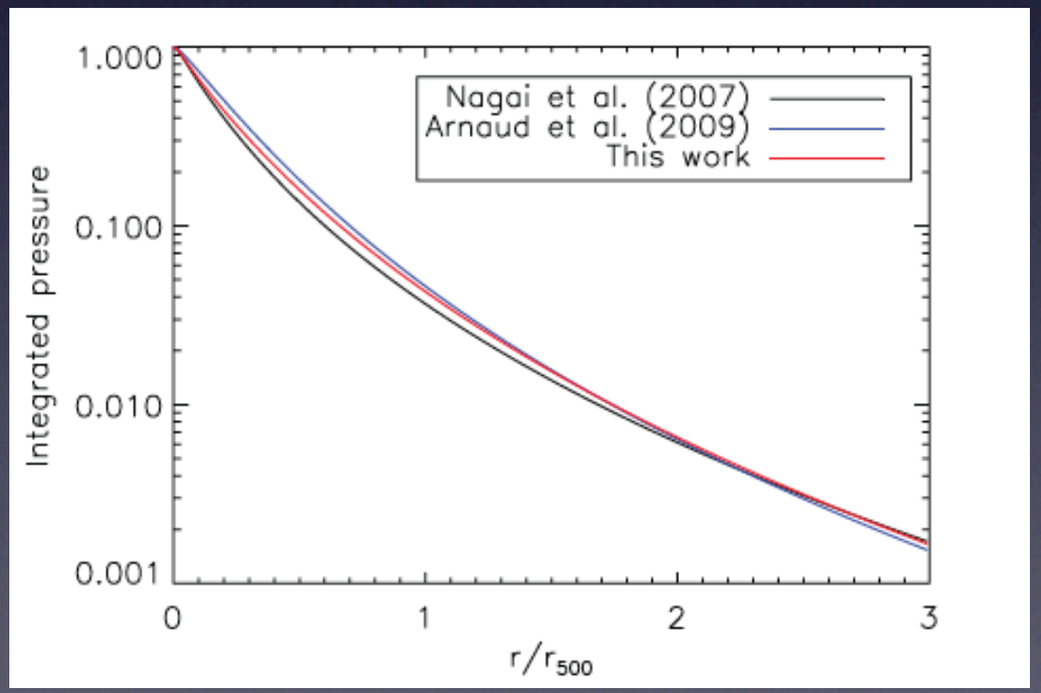
PRELIMINARY

APEX-SZ pressure profiles



APEX-SZ measurement
(Basu et al., in prep.)

SPT measurement
(Plagge et al. 2010)

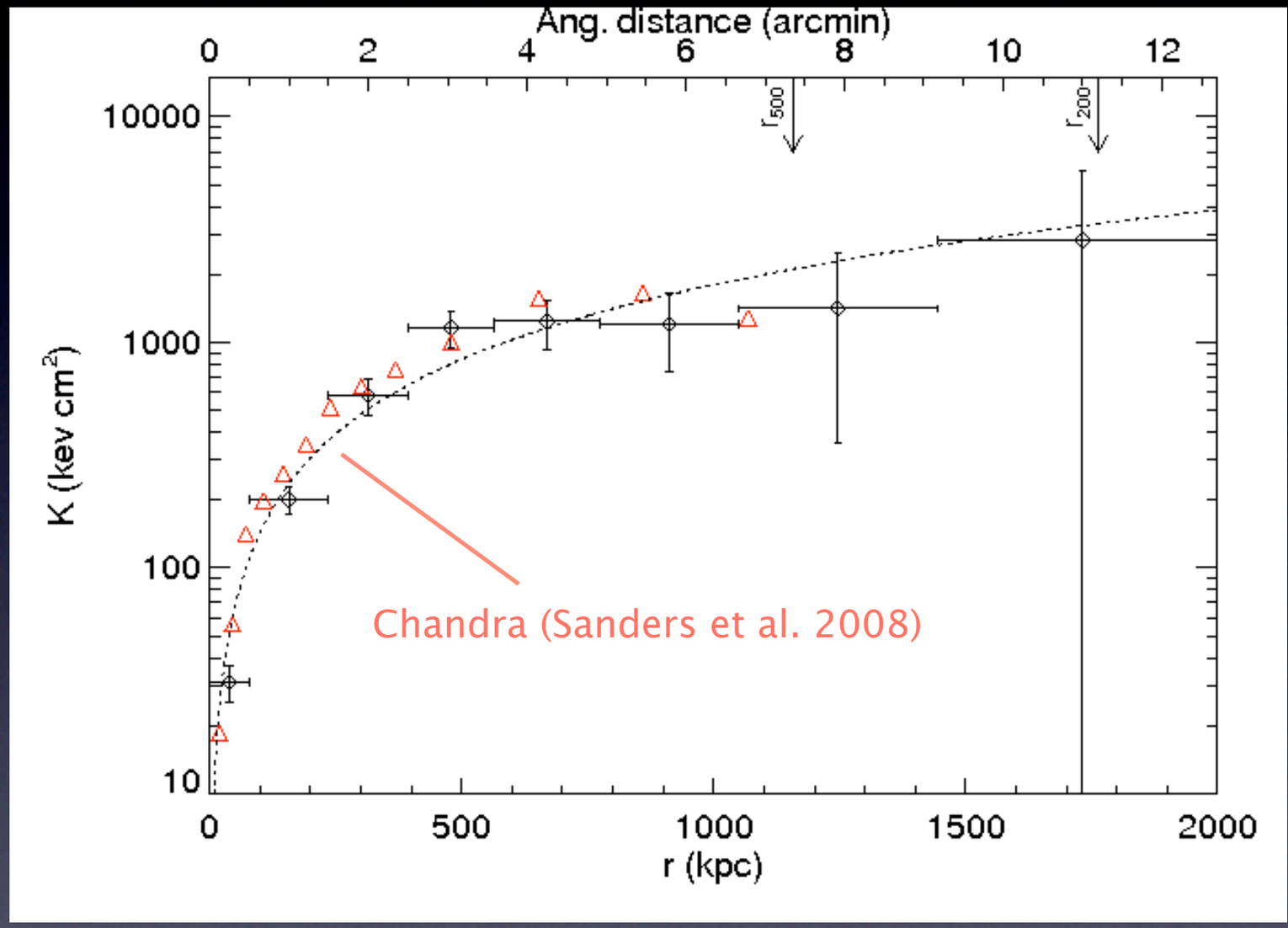


ICM Entropy profiles

$$K = T_e \, n_e^{-2/3}$$

Entropy is a fundamental indicator of heating/cooling in the ICM (it remains unchanged during adiabatic processes)

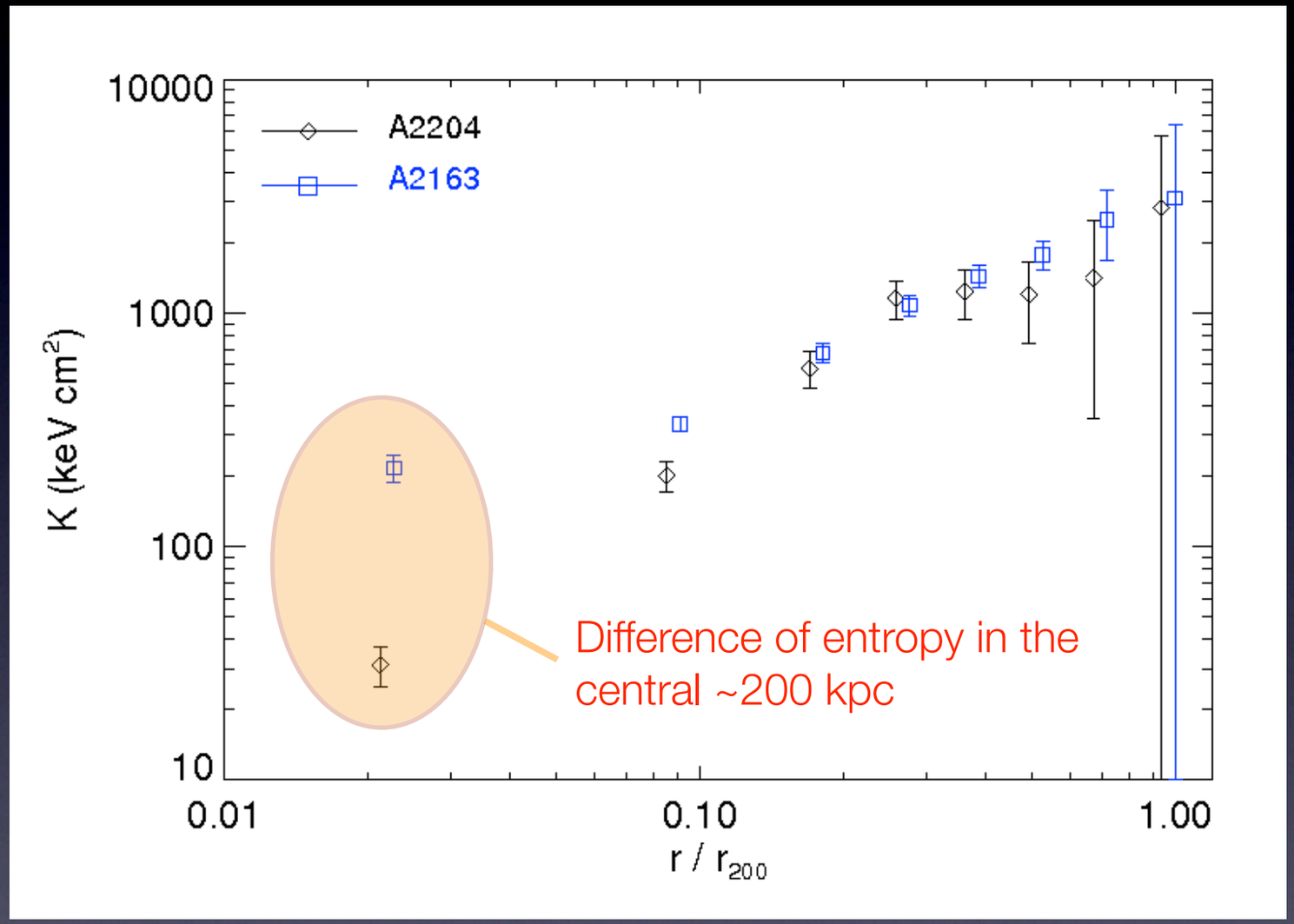
Entropy at the cluster outskirts with **Suzaku**: George et al. 2009, Bautz et al. 2009, Kawaharada et al. 2010, ..



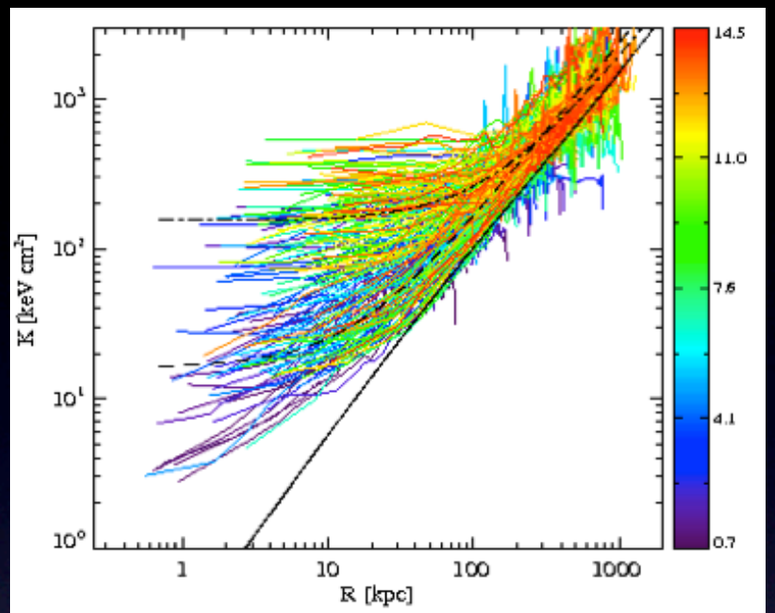
Entropy profile in A2204
Basu, Zhang et al. 2010

SZ confirmation of "Entropy Floor"

Entropy comparison from SZ/X-ray imaging data

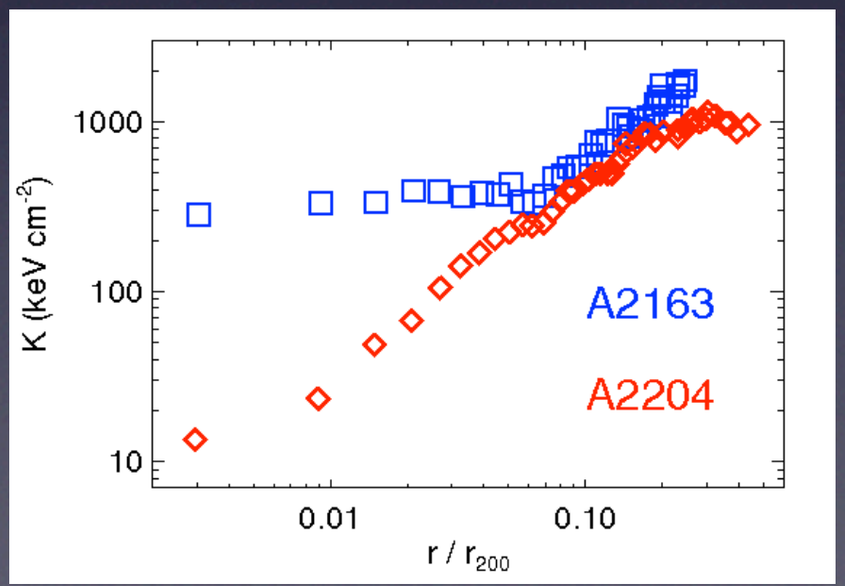


Basu, Zhang et al. 2010

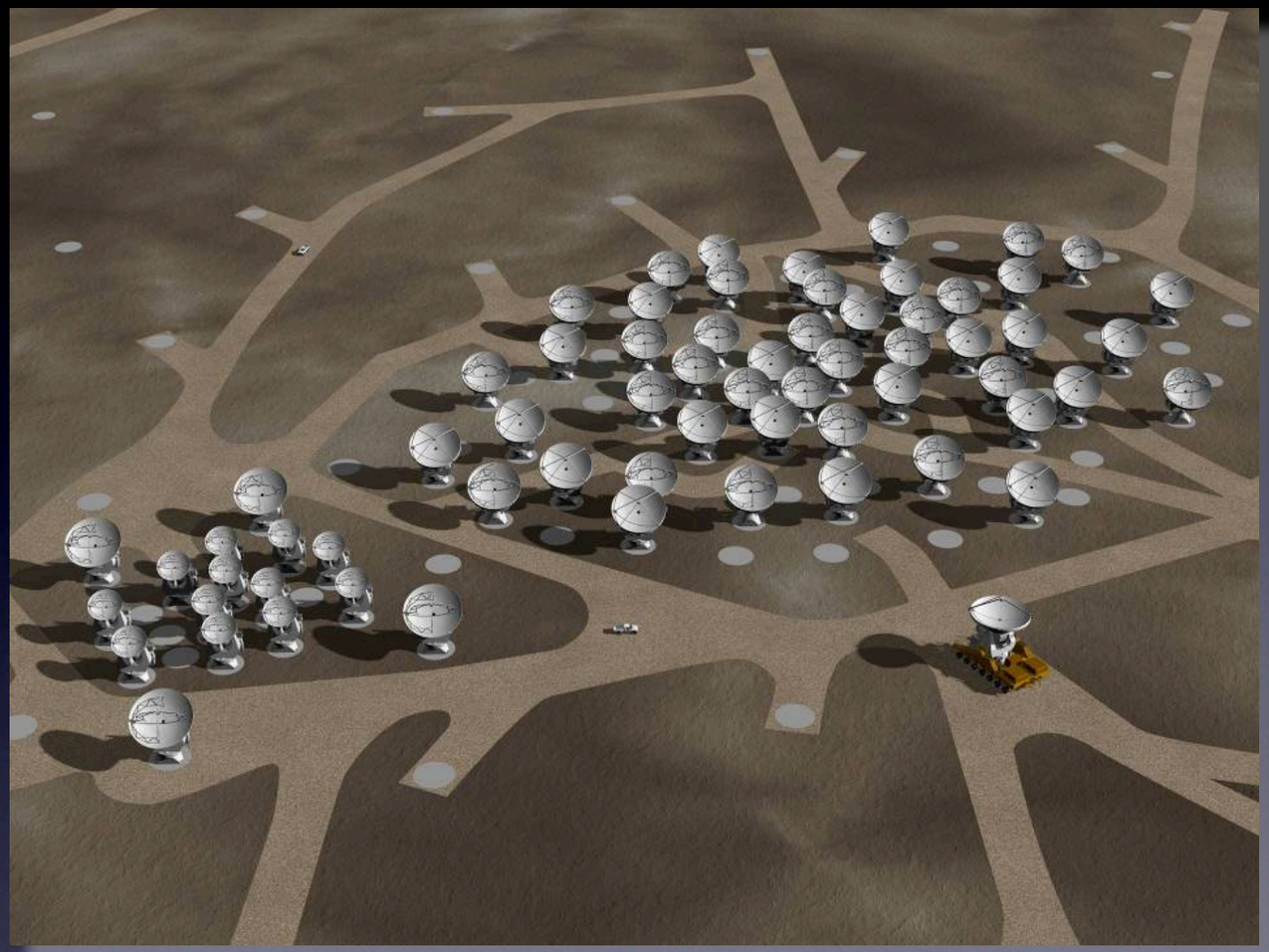


Cavagnolo et al. 2009

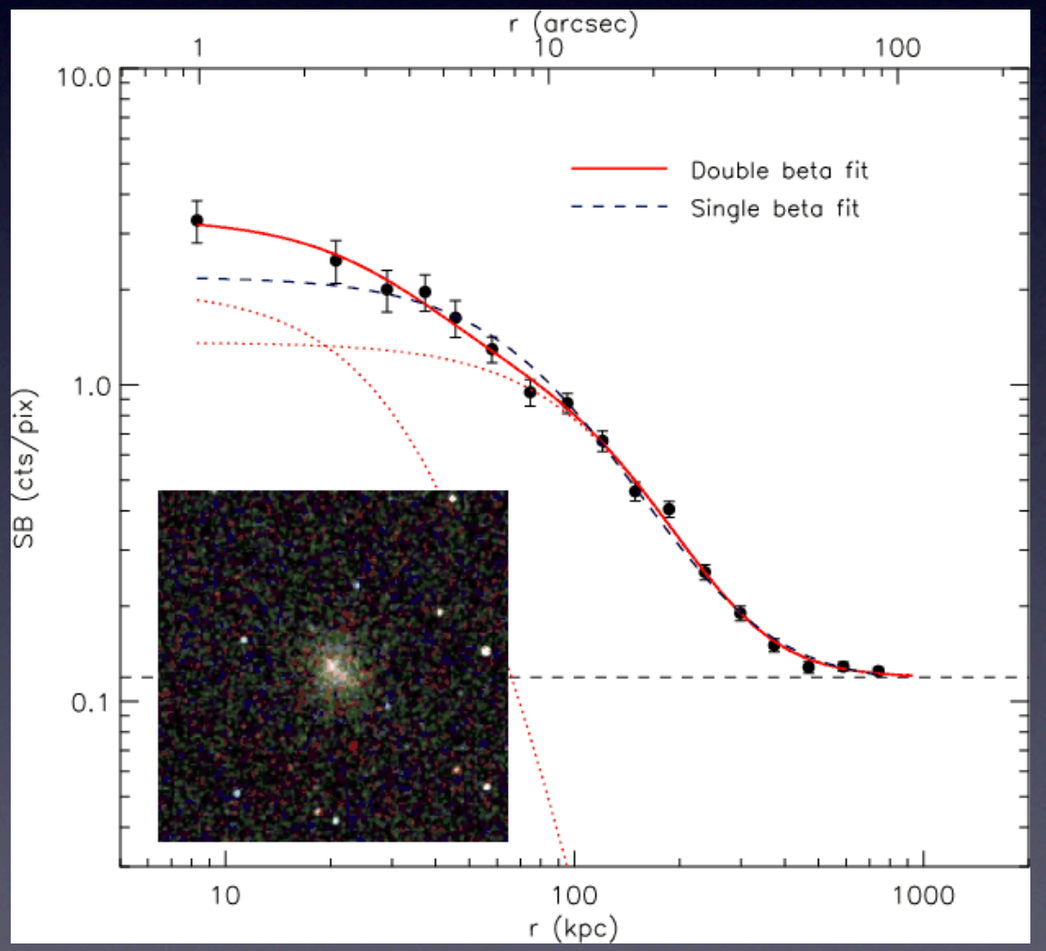
Central entropies from *Chandra* data, taken from K. Cavagnolo's ACCEPT site



High-Res SZ Imaging with ALMA



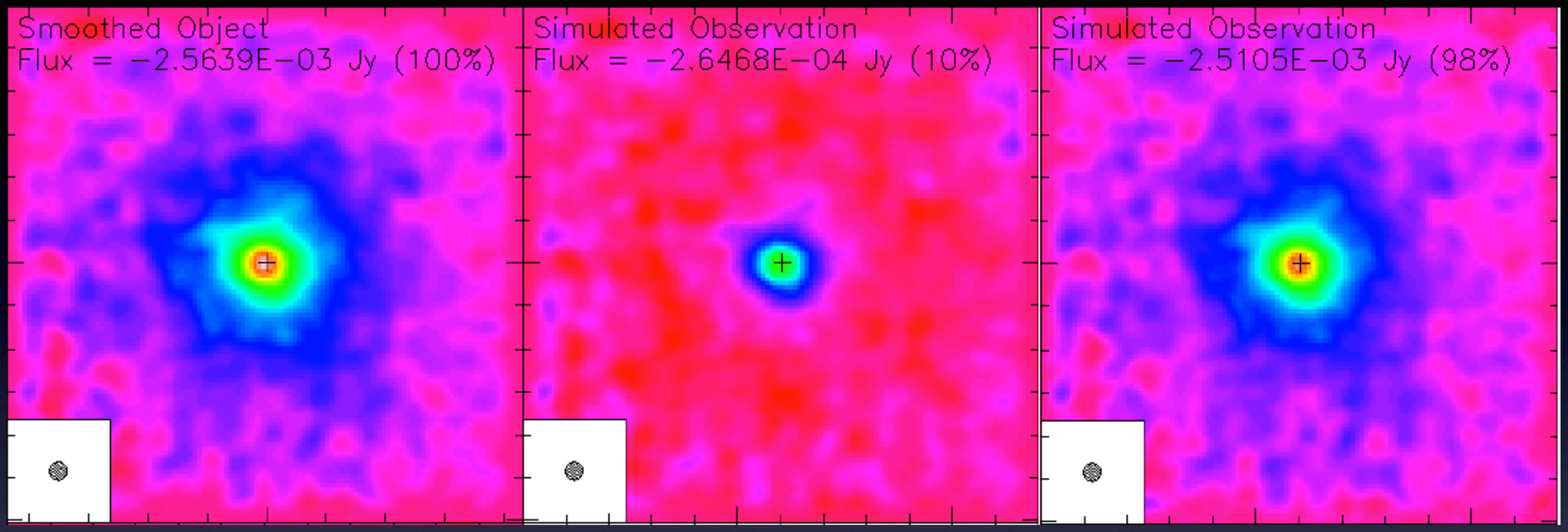
XMM J2235.3-2557 (z=1.39)
Rosati et al. 2009



J. Santos' talk

(apparently you *can* get temperature profile at z=1 with ~400 ks Chandra time!)

High-Res SZ Imaging with ALMA



Model XMMU J2235 with white noise (16h integration)

Simulation of ALMA-only observation

ALMA plus idealized single dish observation

Simulated ALMA observation at 90 GHz, Band 3 (Basu & Salomé, in prep)

In a nutshell..

Analysis of the intra-cluster medium (ICM) with resolved SZE maps have become a reality (some way to catch up with the sophistication and depth of the X-ray spectral analysis).

We have performed non-parametric X-ray/SZE modeling of ICM properties in two clusters out to r_{200}. Stacking analysis in progress.

Using APEX-SZ and XMM imaging data we were able to verify the existence of “entropy floors” in clusters, and also measure the decreasing gas temperature at the cluster outskirts (independently of X-ray spectroscopy).