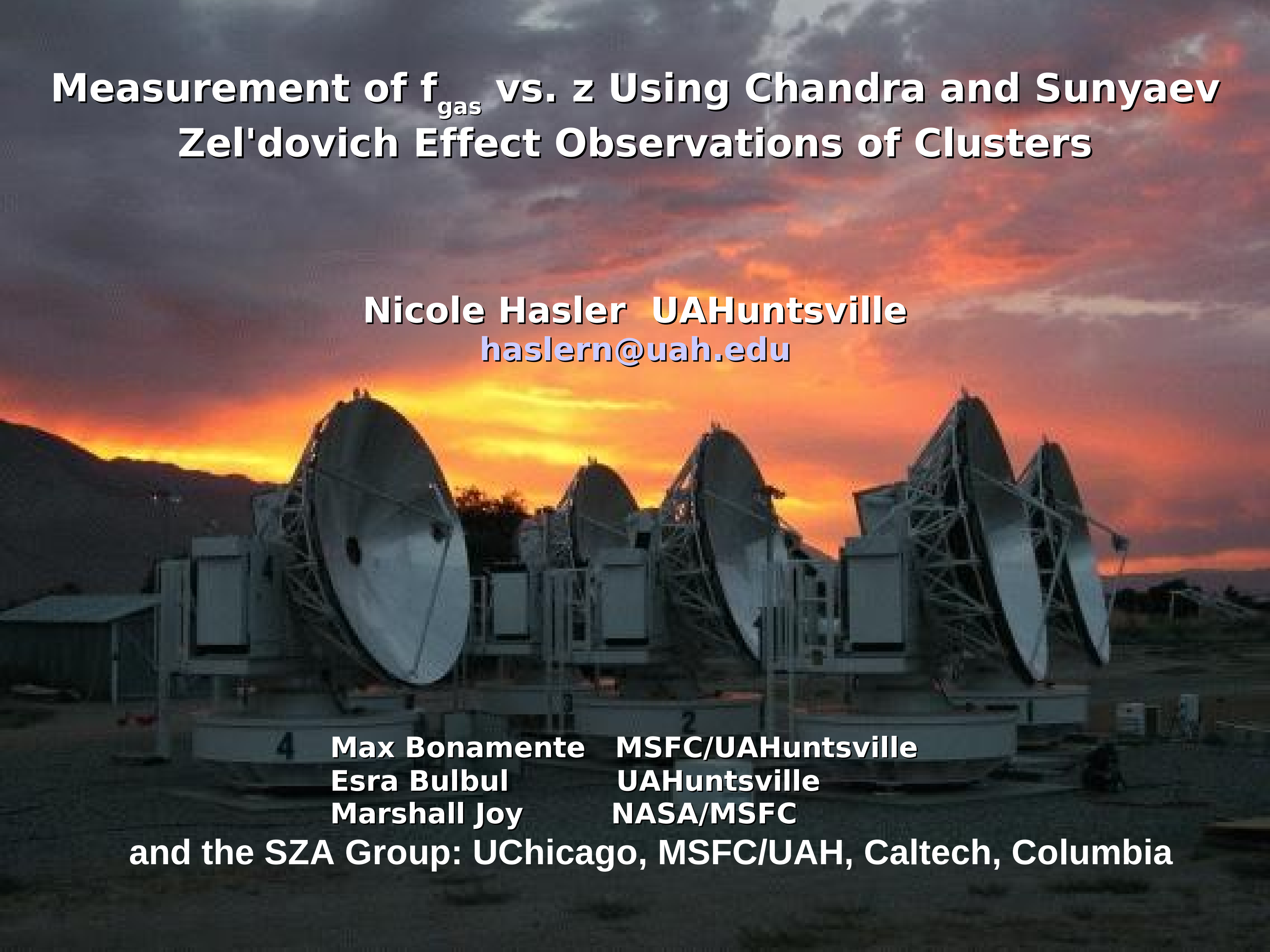

Measurement of f_{gas} vs. z Using Chandra and Sunyaev Zel'dovich Effect Observations of Clusters

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Overview

1. Introduce new physically motivated models of the Intra-Cluster Medium which incorporates a generalized Navarro,Frenk, and White (1997) dark matter distribution. These models will be used to:

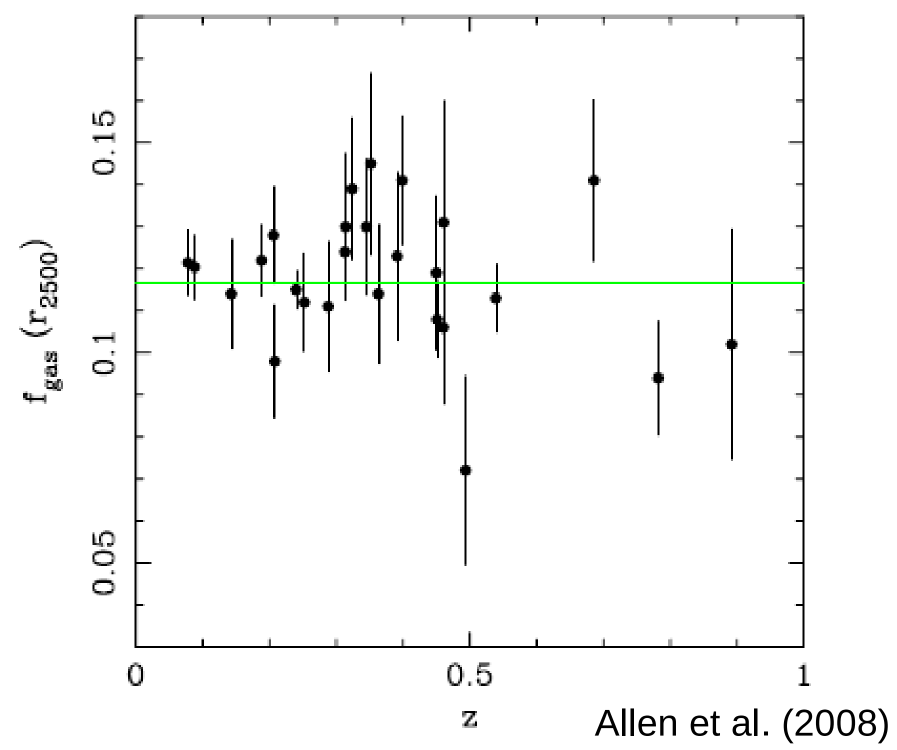
2. Measure the asymptotic slope of the dark matter density
   - Currently applied to the highest S/N clusters

3. Determine Cluster Masses and the gas mass fraction (f_{gas}) without assuming underlying cosmology using Joint X-ray/SZE observations
   - Goals: 1. Application to Allen et al. (2008) sample for determining the distribution of f_{gas} vs. z.

     2. Measurement of Ω_M
   - Currently applied to the highest S/N clusters

Use of f_{gas} vs. z for cosmology

- Sasaki (1996), Pen (1996), Allen et al. (2008), Ettori et al. (2009) and others assumed that the gas mass fraction is constant with redshift.
- This allowed constraints to be placed on the cosmological parameters.
- This assumption has never been observationally verified.



Allen et al. (2008)

- **GOAL:** Determine the distribution of the gas mass fraction as a function z without prior knowledge about cosmology.

1. Physically Motivated Models Based on Dark Matter Density

- Generalized NFW Dark Matter Density:
  - -Suto et al. (1998) investigated models of this type
  - - Can be simplified to the NFW profile when β=2

$$\rho = \frac{\rho_i}{r/r_s(1+r/r_s)^{\beta}}$$

- Assume a polytropic gas for the hot plasma at large radii:

$$\frac{\rho_{gas}(r)}{\rho_{g,0}} = \left[\frac{T(r)}{\tau_0}\right]^n$$

- Following Ascasibar & Diego (2008) approach, we solve the HSE equation and discover an **analytical solution** of the temperature profile.

$$T_{poly}(r) = \tau_0 \left(\frac{1}{(\beta-2)} \frac{(1+r/r_s)^{\beta-2}-1}{r/r_s(1+r/r_s)^{\beta-2}} \right)$$

- For *cool core clusters*, we introduce a Vikhlinin et al. (2006) cooling function

$$T(r) = T_{poly}(r)\frac{\alpha + (r/r_{cool})^{\gamma}}{1 + (r/r_{cool})^{\gamma}}$$

- Solve the HSE with the temperature profile to obtain an analytical solution for the gas density

$$\rho_{gas}(r) = \rho_{poly}(r)\frac{1 + (r/r_{cool})^{\gamma}}{\alpha + (r/r_{cool})^{\gamma}}$$

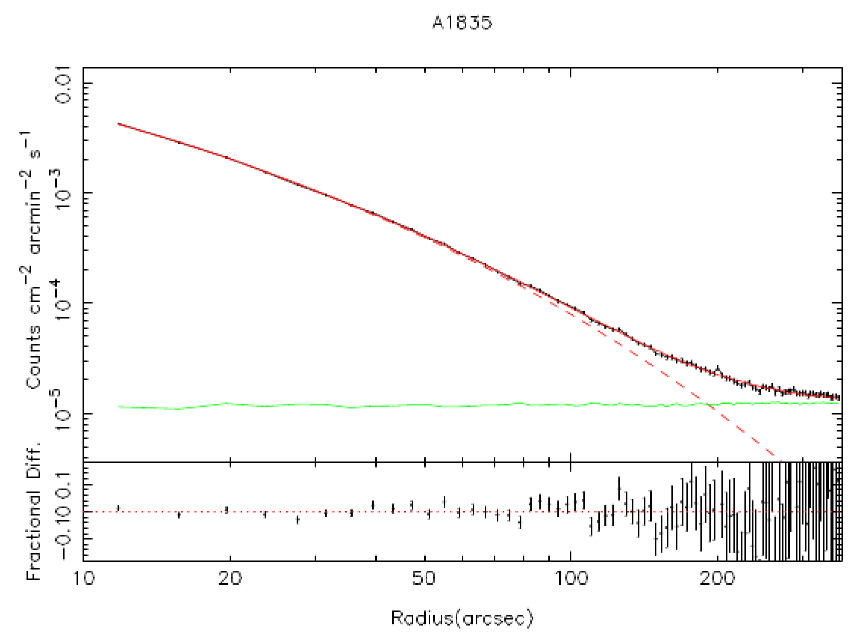
Bulbul et al. (2009) in prep

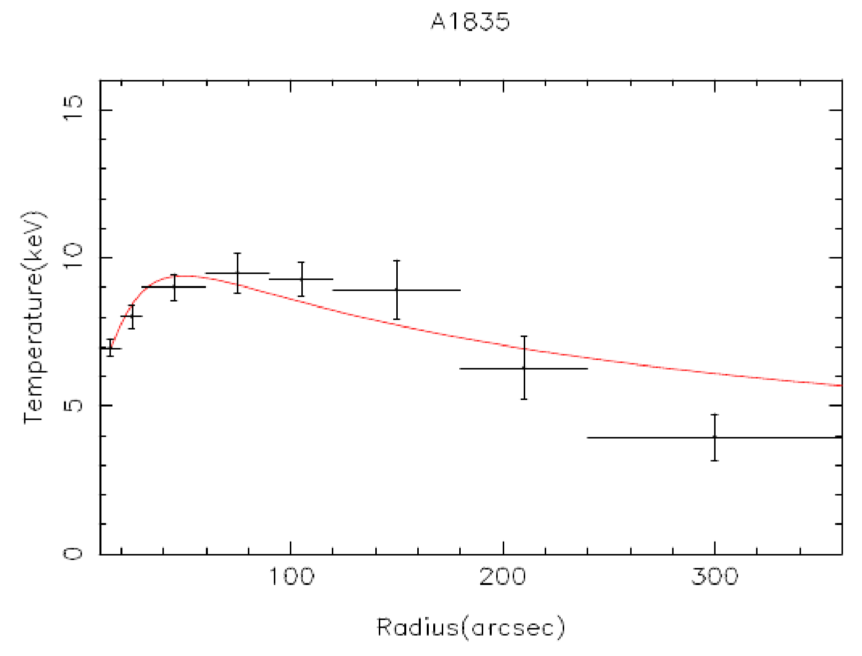
- Our models also provide an analytical model for the gas pressure

$$P_e(r) = P_{e0}\left(\frac{1}{\beta - 2}\frac{(1 + r/r_s)^{\beta-2} - 1}{r/r_s(1 + r/r_s)^{\beta-2}}\right)^{n+1}$$

- This model can be used for analysis of SZ data
- For details refer to poster number 6.1 by Esra Bulbul

Model Validation with Abell 2204 and Abell 1835



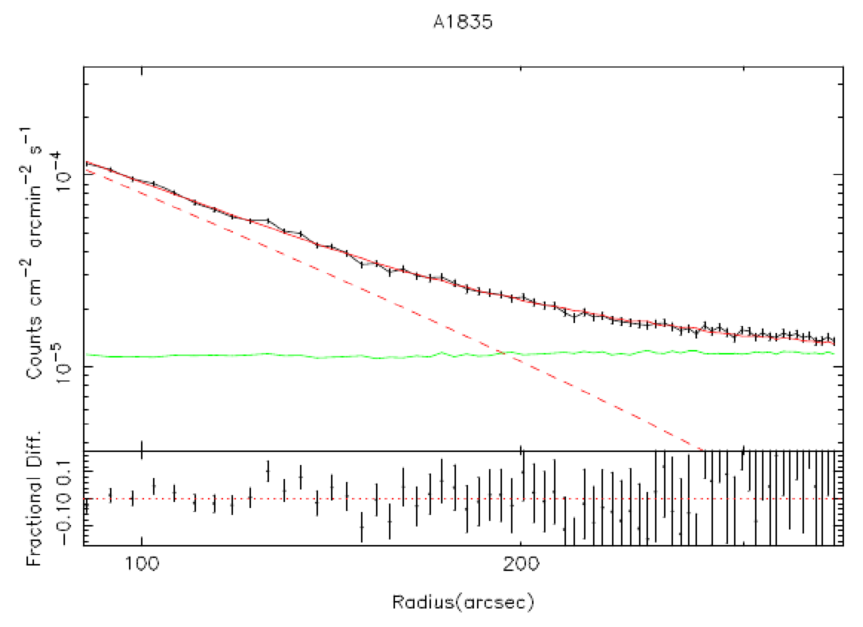


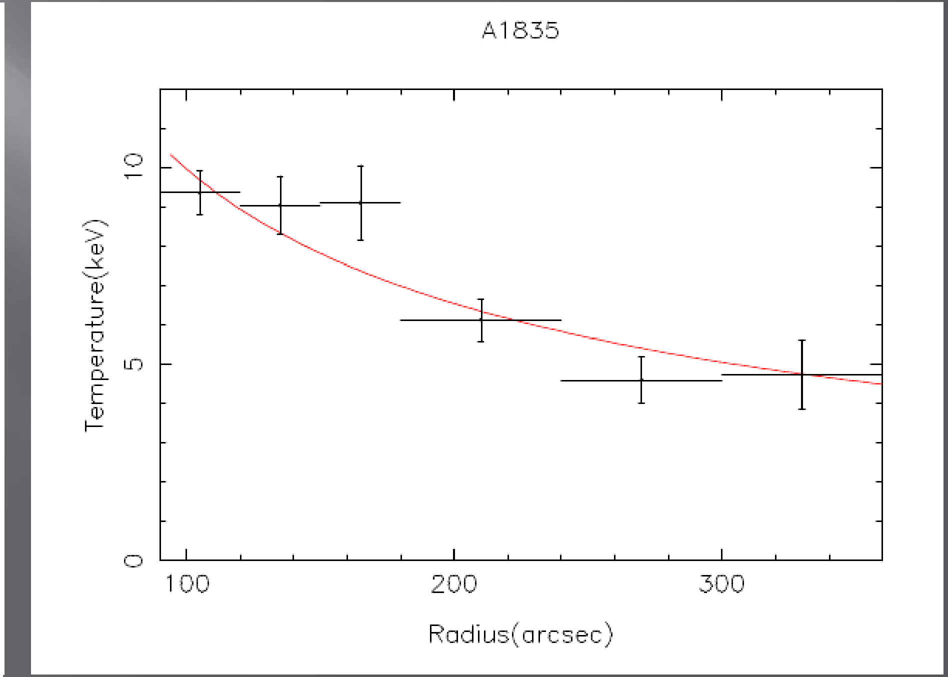
$\chi^2 = 234$ for 140 dof

$\chi^2 = 116$ for 88 dof

Model Fits at Large Radii

- For the rest of the talk we are focused on measurement of f_{gas} at large radii and exclude the cool core region
- Exclude the correction function in the temperature and density profiles





χ^2=115 for 112 dof

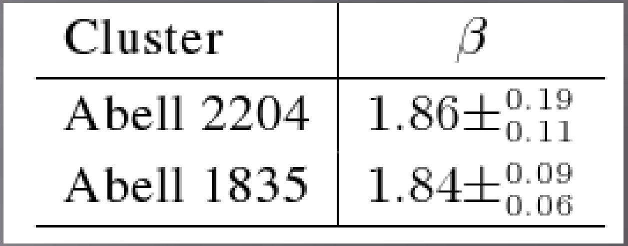
χ^2=71 for 64 dof

2. Measuring the Dark Matter Density

- We can use the physically motivated models and measure the asymptotic slope of the dark matter density in Abell 2204 and Abell 1835.

$$\rho = \frac{\rho_i}{r/r_s(1+r/r_s)^\beta}$$

- Let all 5 parameters be free in the gas density and temperature profiles.



Cluster	β
Abell 2204	$1.86\pm^{0.19}_{0.11}$
Abell 1835	$1.84\pm^{0.09}_{0.06}$

- We measure an asymptotic slope ~ 3, consistent with the NFW dark matter profile.

3. Joint X-ray/SZE Analysis

- Surface Brightness:

$$S_X = \frac{1}{4\pi(1+z)^4} D_A \int n_e^2 \Lambda(T_e, A) d\theta$$

- SZE Decrement:

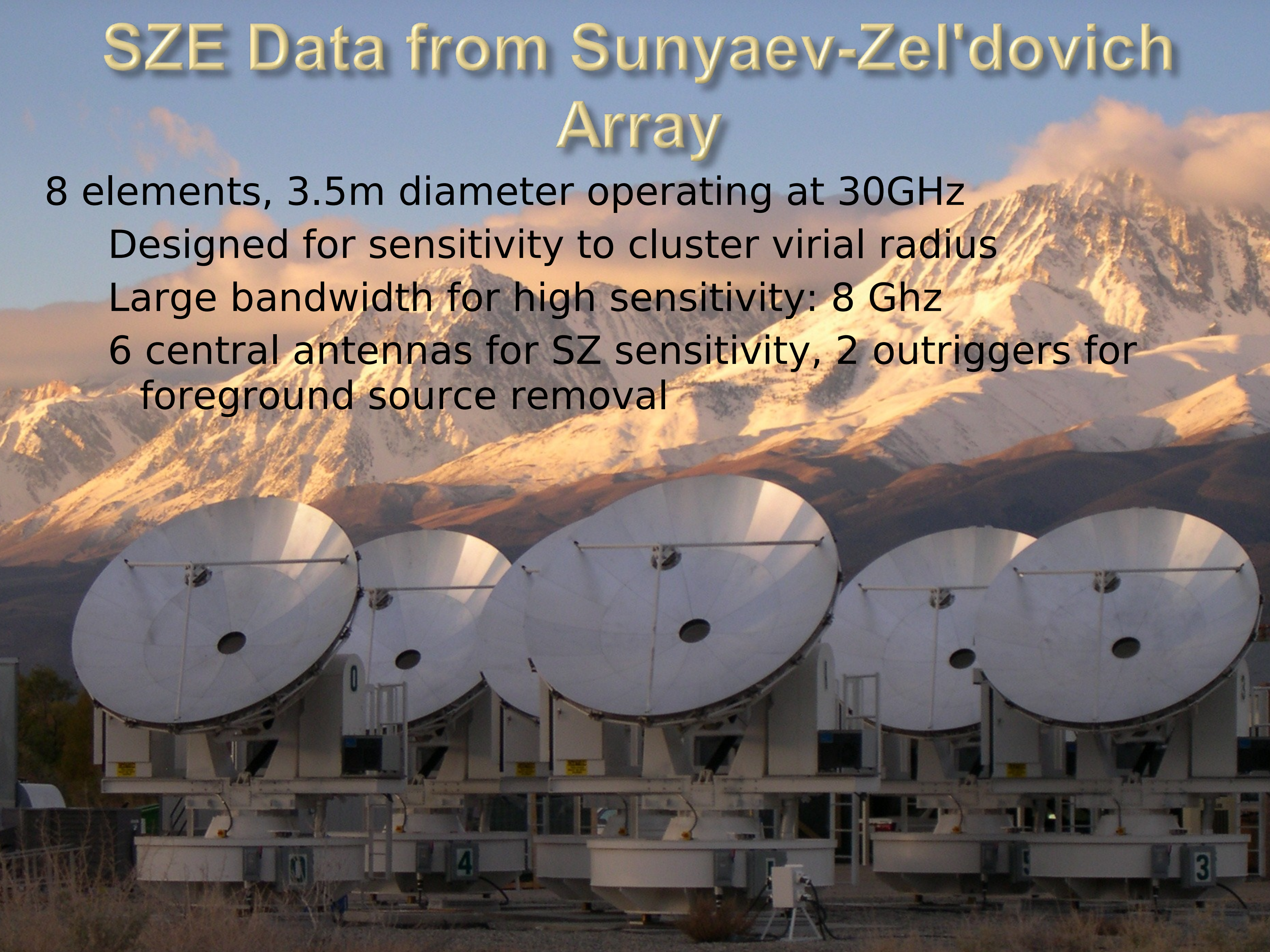
$$\Delta T_{SZ} = T_{CMB} f(x) D_A \int \sigma_T n_e \frac{kT_e(\theta)}{m_e c^2} d\theta$$

- Combined X-ray and SZE observations provide a direct measurement of the angular diameter distance, D_A, the electron number density, $n_e(r)$, and the temperature profile, $T_e(r)$ (Birkinshaw et al. 1991, Reese et al. 2002).

- Therefore gas mass, total mass, and the gas mass fraction can be measured **without assuming any underlying cosmology**.

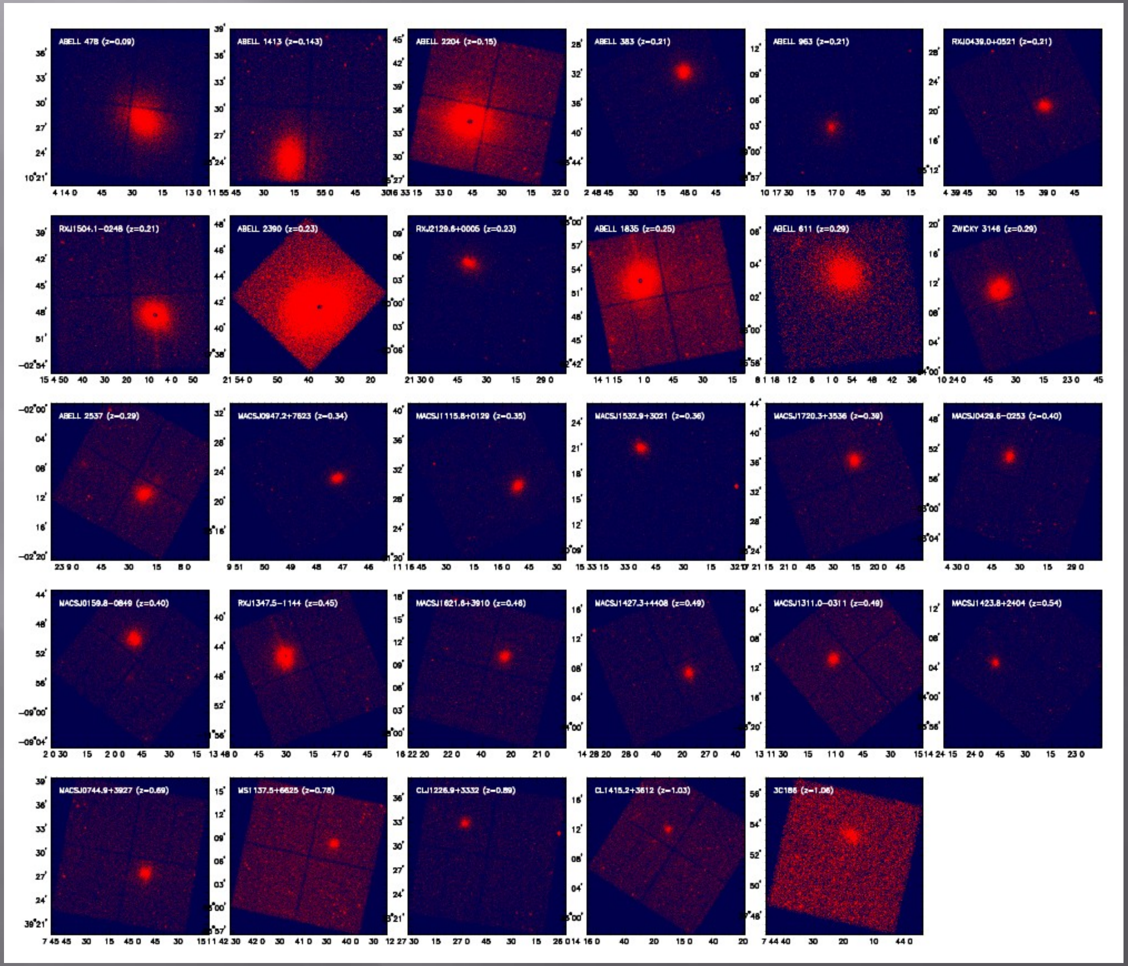
SZE Data from Sunyaev-Zel'dovich Array

- 8 elements, 3.5m diameter operating at 30GHz
  - Designed for sensitivity to cluster virial radius
  - Large bandwidth for high sensitivity: 8 Ghz
  - 6 central antennas for SZ sensitivity, 2 outriggers for foreground source removal



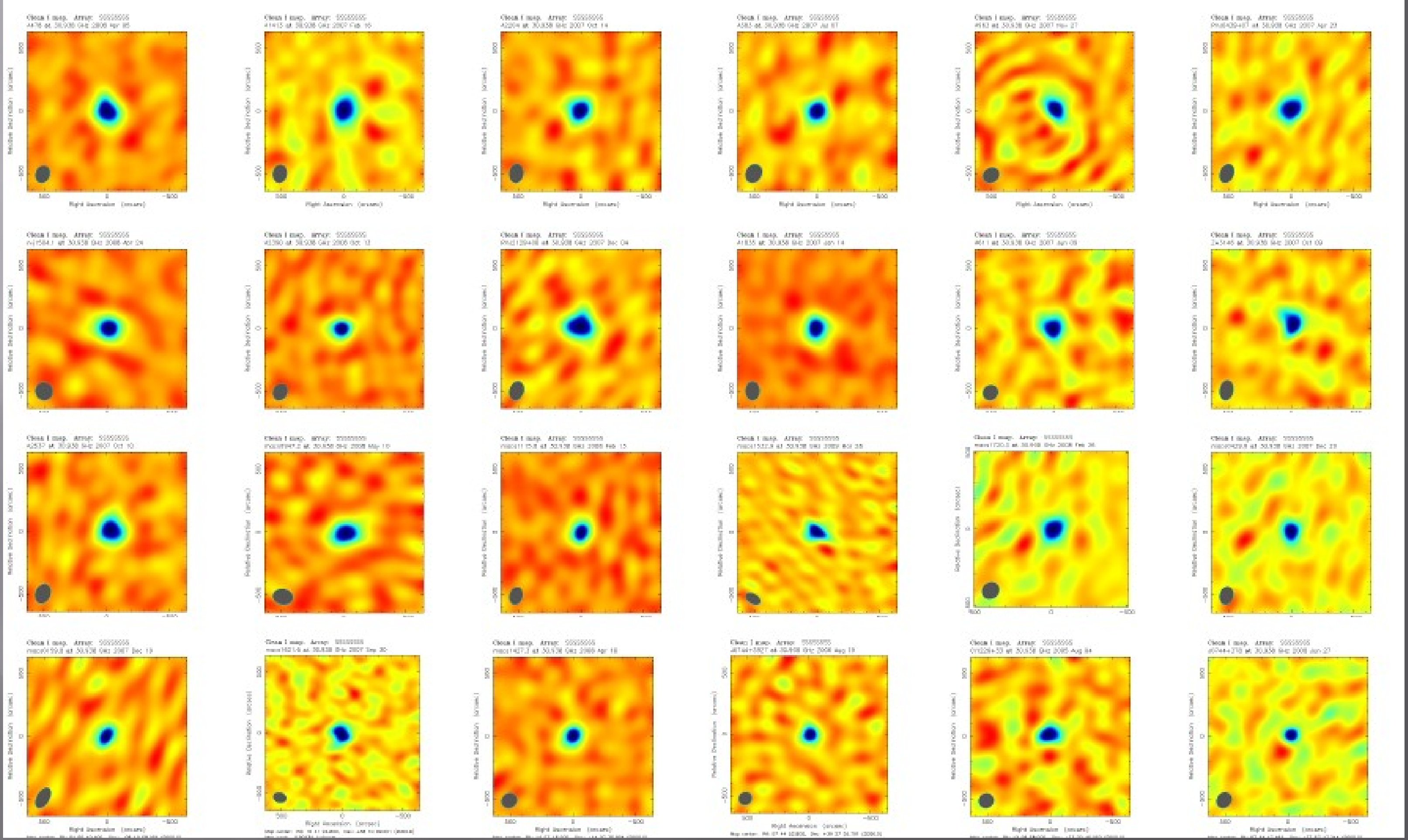
X-ray Images

- Clusters in the Allen et al. (2008) sample which are observable in the northern hemisphere with the SZA.



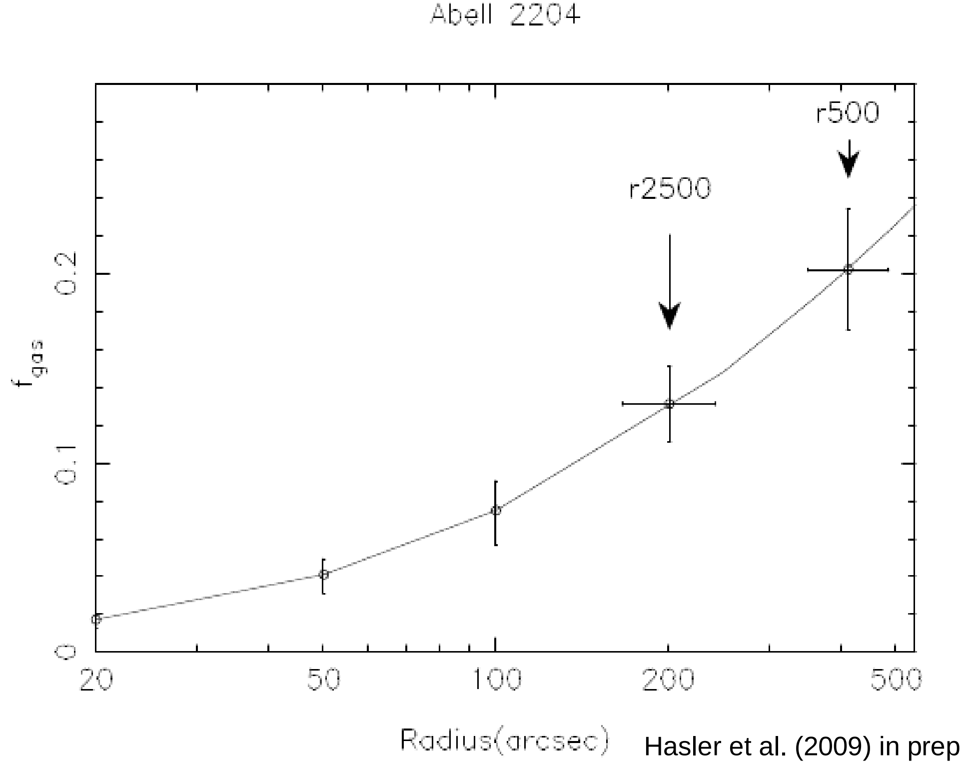
SZ Images

- Clusters observed with the SZA.
- We have proposed for SZA observation time for the remaining 5 clusters



f_{gas} Measurement From X-ray/SZE Observations

- We obtained a measurement of the f_{gas} from joint X-ray and SZE observations without any assumptions about the underlying cosmology
- We want to determine f_{gas} vs. z which can be used as a template instead of relying on numerical simulations for the Allen et al. (2008) method.



Hasler et al. (2009) in prep

D_A=684.8±70 Mpc

$f_{gas}(r_{2500})$ = 0.123±0.025

$f_{gas}(r_{500})$ = 0.250±0.042

- r_Δ is calculated using a ΛCDM model with large uncertainties to determine the critical density

Summary

- Developed physically motivated models of cluster density and temperature based on the underlying dark matter distribution.

- We are able to obtain analytical models of the density and temperature profiles and obtain good fits to the Chandra data for Abell 2204 and Abell 1835.

- We are able to measure the asymptotic slope of the dark matter density in Abell 2204 and Abell 1835 and found that it is consistent with the NFW profile.

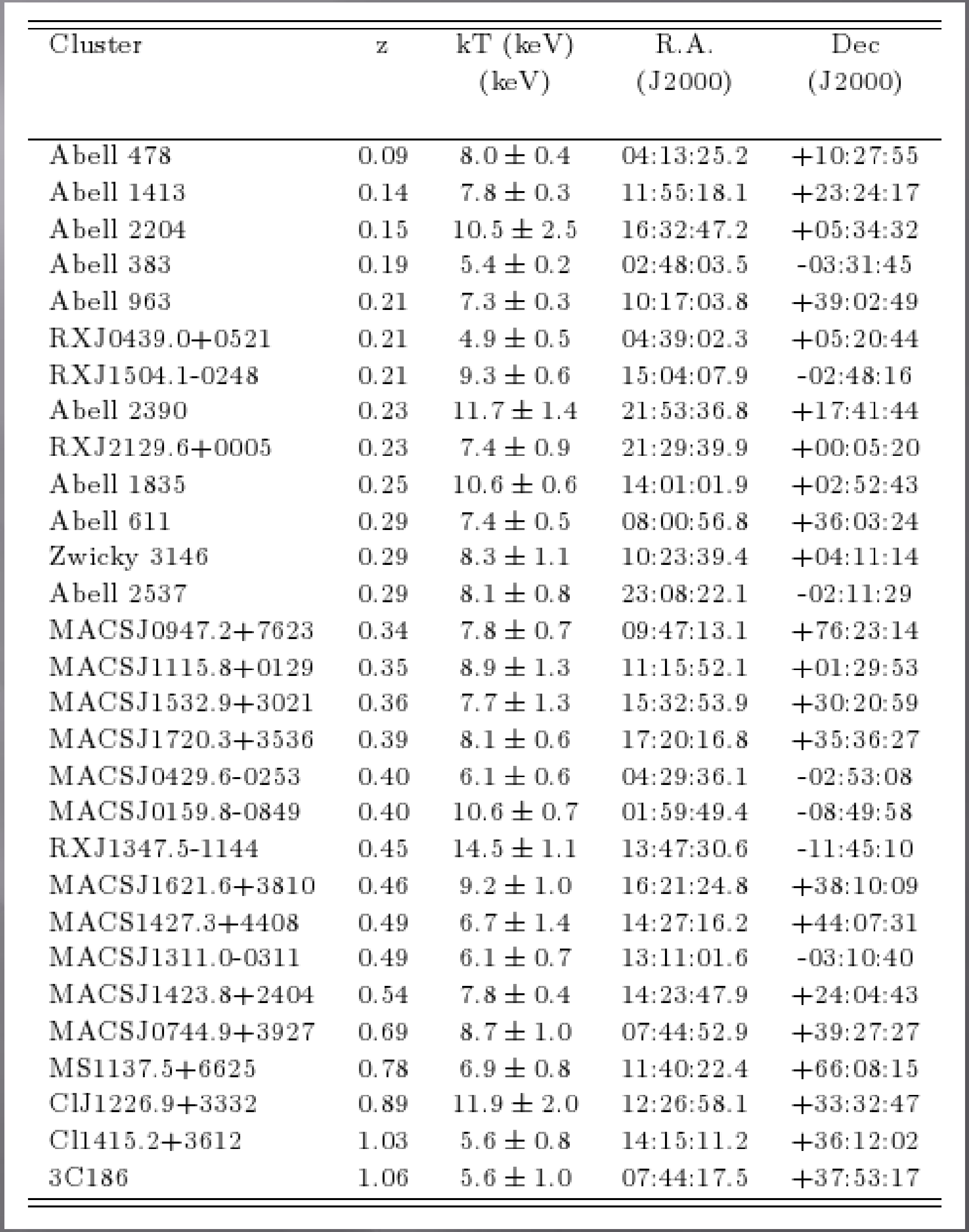
- We combined X-ray and SZE observations to measure the gas mass fraction without any prior knowledge of the underlying cosmology.

- Future Work:

1. Plan to apply the method discussed in this talk to our entire sample and determine the gas mass fraction as a function of redshift.
2. Measure Ω_M from the entire sample

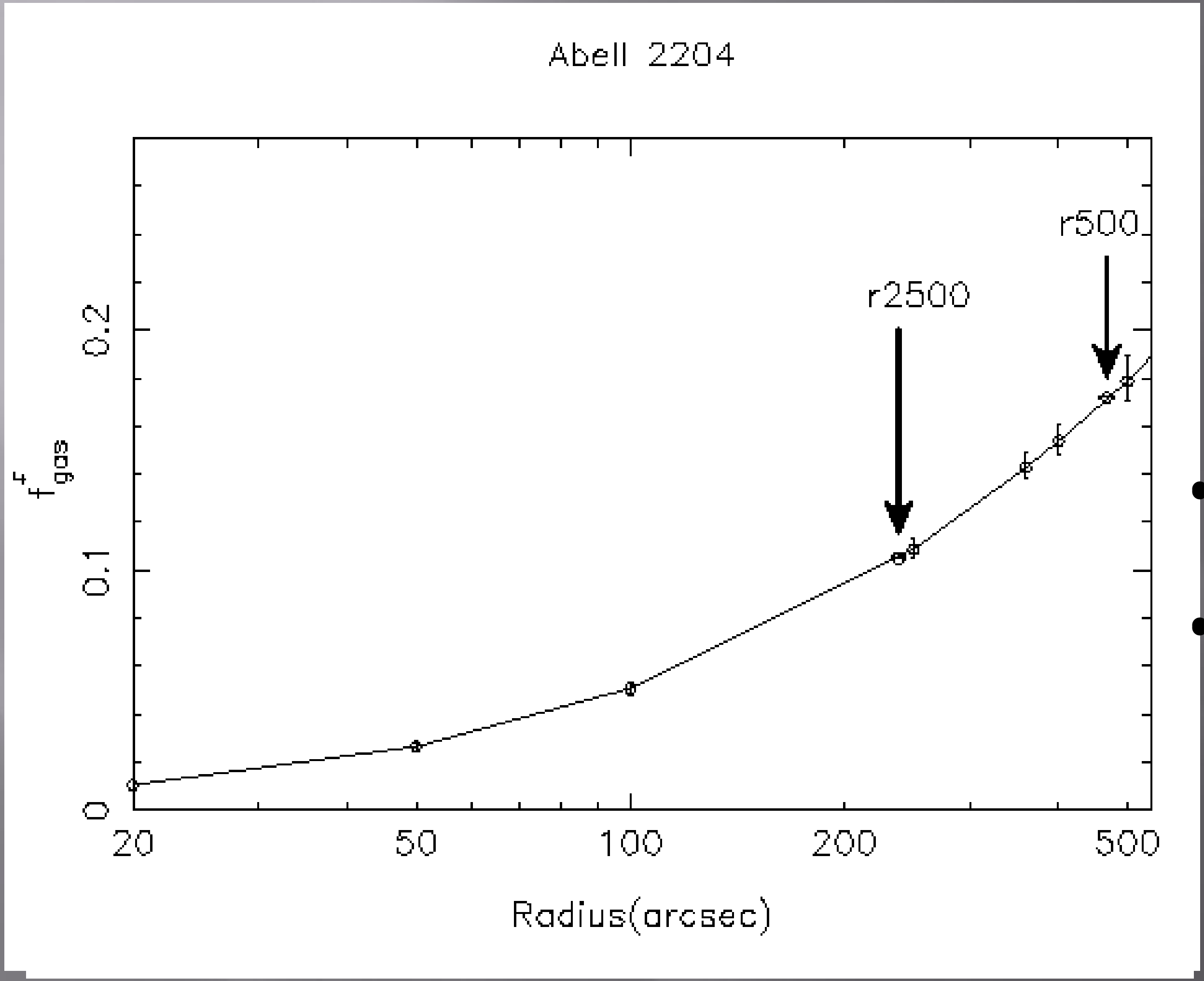
Thank You

Sample List



Cluster	z	kT (keV) (keV)	R.A. (J2000)	Dec (J2000)
Abell 478	0.09	8.0 ± 0.4	04:13:25.2	+10:27:55
Abell 1413	0.14	7.8 ± 0.3	11:55:18.1	+23:24:17
Abell 2204	0.15	10.5 ± 2.5	16:32:47.2	+05:34:32
Abell 383	0.19	5.4 ± 0.2	02:48:03.5	-03:31:45
Abell 963	0.21	7.3 ± 0.3	10:17:03.8	+39:02:49
RXJ0439.0+0521	0.21	4.9 ± 0.5	04:39:02.3	+05:20:44
RXJ1504.1-0248	0.21	9.3 ± 0.6	15:04:07.9	-02:48:16
Abell 2390	0.23	11.7 ± 1.4	21:53:36.8	+17:41:44
RXJ2129.6+0005	0.23	7.4 ± 0.9	21:29:39.9	+00:05:20
Abell 1835	0.25	10.6 ± 0.6	14:01:01.9	+02:52:43
Abell 611	0.29	7.4 ± 0.5	08:00:56.8	+36:03:24
Zwicky 3146	0.29	8.3 ± 1.1	10:23:39.4	+04:11:14
Abell 2537	0.29	8.1 ± 0.8	23:08:22.1	-02:11:29
MACSJ0947.2+7623	0.34	7.8 ± 0.7	09:47:13.1	+76:23:14
MACSJ1115.8+0129	0.35	8.9 ± 1.3	11:15:52.1	+01:29:53
MACSJ1532.9+3021	0.36	7.7 ± 1.3	15:32:53.9	+30:20:59
MACSJ1720.3+3536	0.39	8.1 ± 0.6	17:20:16.8	+35:36:27
MACSJ0429.6-0253	0.40	6.1 ± 0.6	04:29:36.1	-02:53:08
MACSJ0159.8-0849	0.40	10.6 ± 0.7	01:59:49.4	-08:49:58
RXJ1347.5-1144	0.45	14.5 ± 1.1	13:47:30.6	-11:45:10
MACSJ1621.6+3810	0.46	9.2 ± 1.0	16:21:24.8	+38:10:09
MACS1427.3+4408	0.49	6.7 ± 1.4	14:27:16.2	+44:07:31
MACSJ1311.0-0311	0.49	6.1 ± 0.7	13:11:01.6	-03:10:40
MACSJ1423.8+2404	0.54	7.8 ± 0.4	14:23:47.9	+24:04:43
MACSJ0744.9+3927	0.69	8.7 ± 1.0	07:44:52.9	+39:27:27
MS1137.5+6625	0.78	6.9 ± 0.8	11:40:22.4	+66:08:15
ClJ1226.9+3332	0.89	11.9 ± 2.0	12:26:58.1	+33:32:47
Cl1415.2+3612	1.03	5.6 ± 0.8	14:15:11.2	+36:12:02
3C186	1.06	5.6 ± 1.0	07:44:17.5	+37:53:17

3.1 Measure of fgas
X-ray constraints



- $f_{gas}(r_{2500})=0.132\pm0.005$
- $f_{gas}(r_{500})=0.206\pm0.006$

- Assumed a ΛCDM model for D_A.