Resuts from the APEX Sunyaev-Zel'dovich Experiment

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on behalf of the
APEX-SZ collaboration

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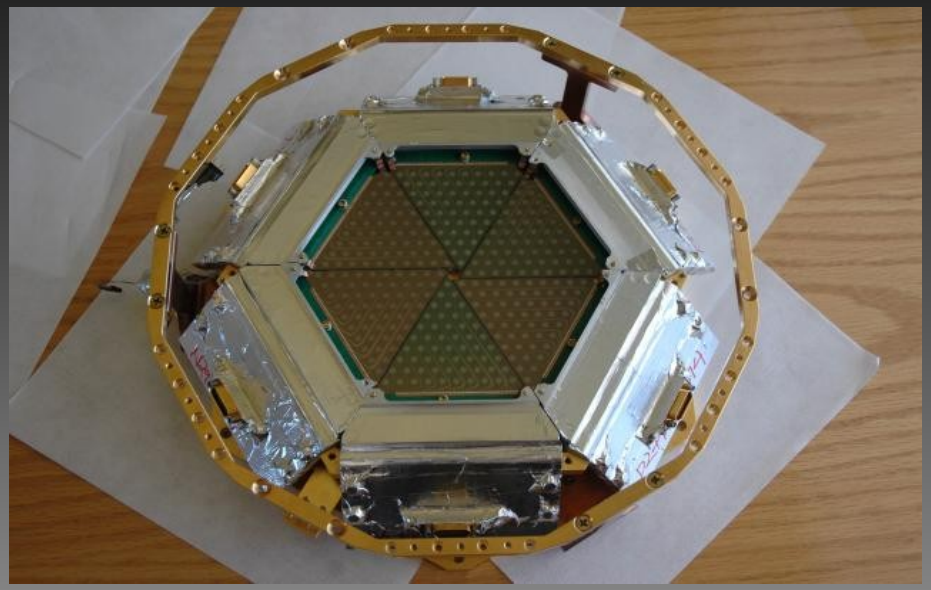
Telescope and Instrument

- 12-m on-axis ALMA prototype
- Located at the Chilean altiplano, elevation 5100 m
- 1 arcmin reolution @ 150 GHz 0.4 deg FoV
- Surface accuracy 18 μm

Telescope and Instrument

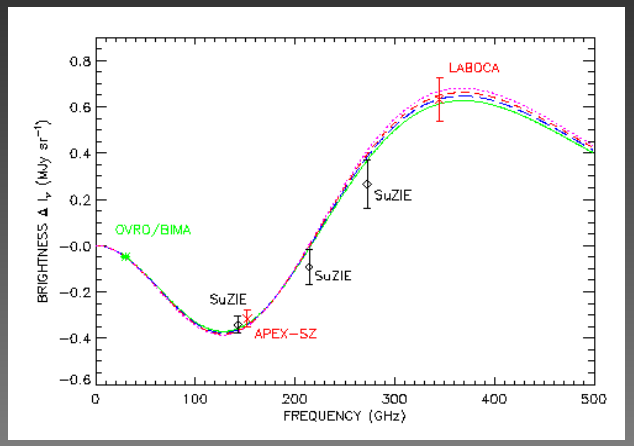


- PI instrument on APEX, commissioned Spring 2007, approx 300 hours of data
- Demonstrates new technologies for SZ experiments:
  - TES bolometers
  - Multiplexed readout electronics
  - Pulse tube cooler (no cryogen loss)
- Can track sources in RA-Dec, powerful camera for targeted cluster observation

The beauty of the SZ Effect

Thermal SZE is a small (<1 mK) distortion in the CMB caused by inverse Compton scattering of the CMB photons

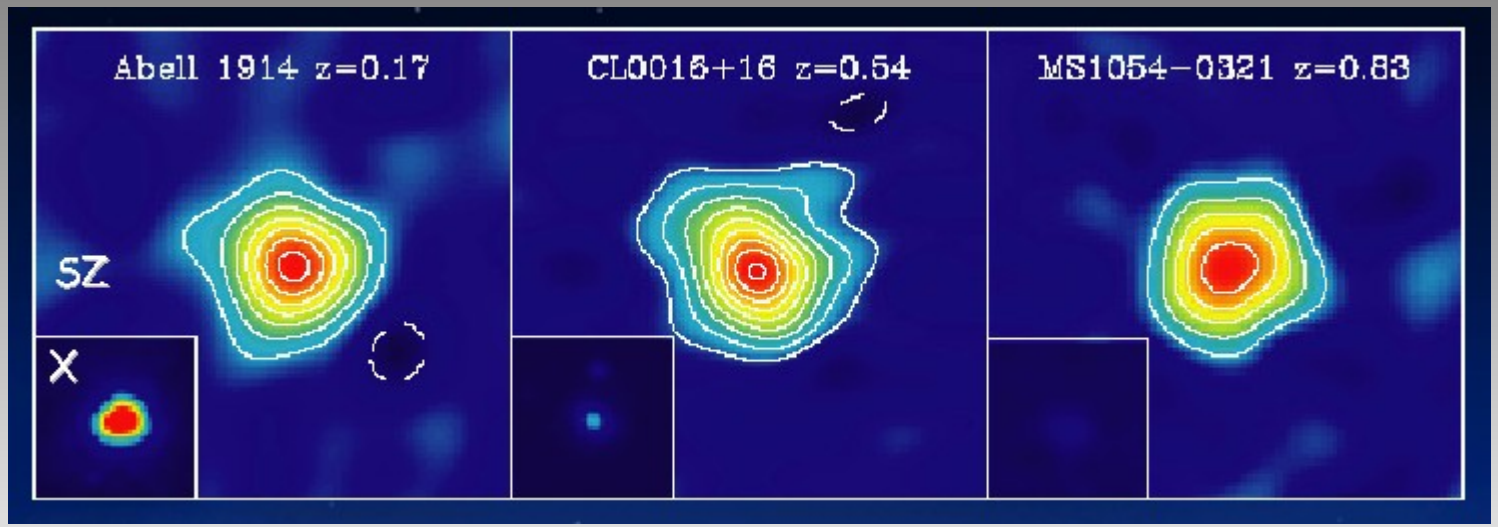
$$\frac{\Delta T}{T_{\rm CMB}} = g(x) \int n_e(l) \frac{k_{\rm B} T_e(l)}{m_e c^2} \, dl$$



Nord, Basu, Pacaud et al, 2009

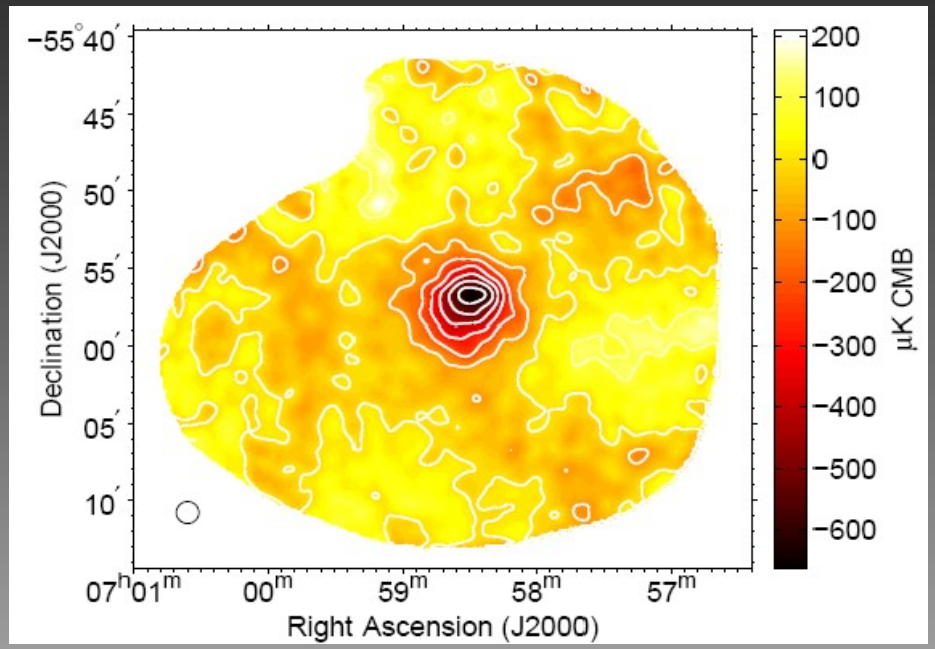
Total cluster flux density is independent of redshift!

$$\Delta S_\nu = \int \Delta I_\nu \, d\Omega \propto \frac{\int n_e T_e \, dV}{D_{\rm A}^2} \propto \frac{f_{\rm gas} M_{\rm tot} T_e}{D_{\rm A}^2}$$

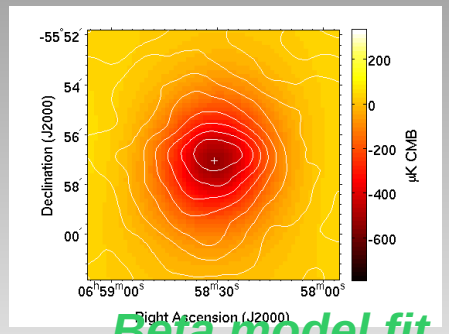


Carlstrom et al.

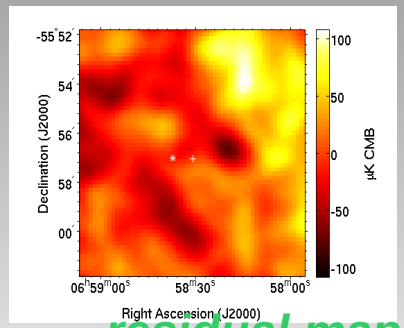
Results from the APEX-SZ Experiment



23 sigma detection, 10.7 ± 0.8 keV



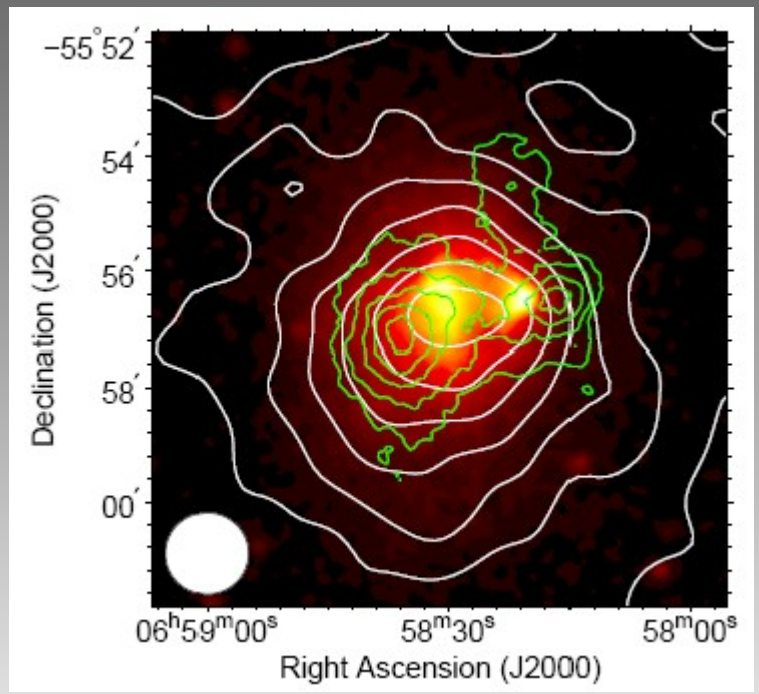
Beta model fit



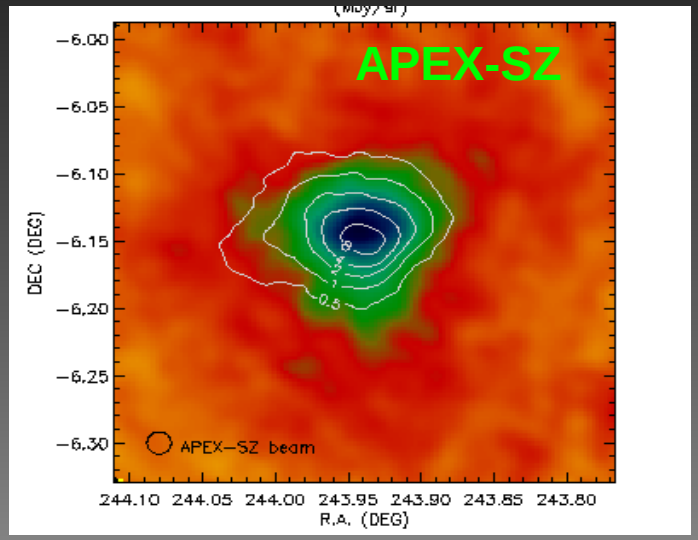
residual map

The Bullet cluster (1E 0657-56)
Halverson, Lanting et al. (arXiv:0807.4208v1)

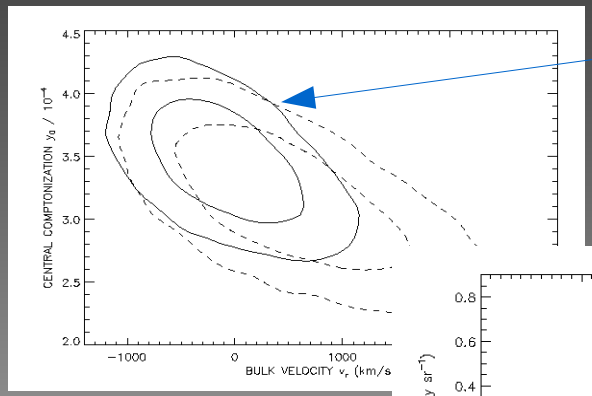
X-ray image with APEX-SZ (white contours) and weak-lensing (green contours)



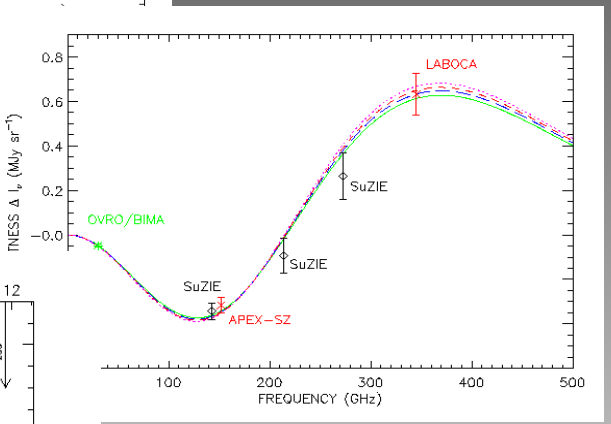
Results from the APEX-SZ Experiment

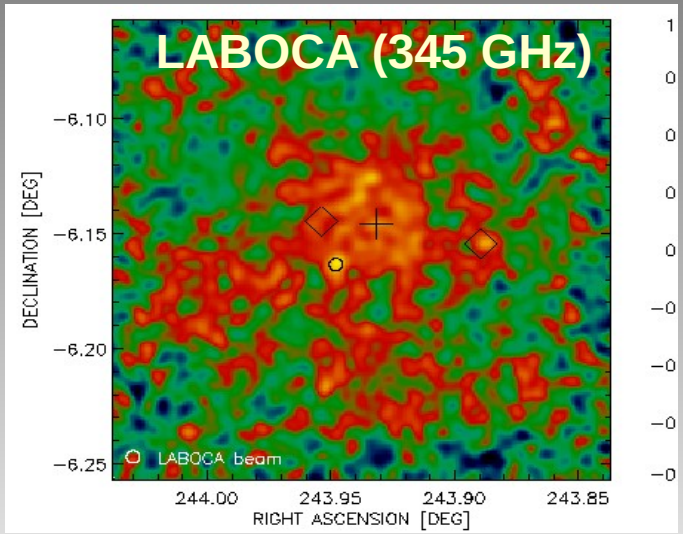


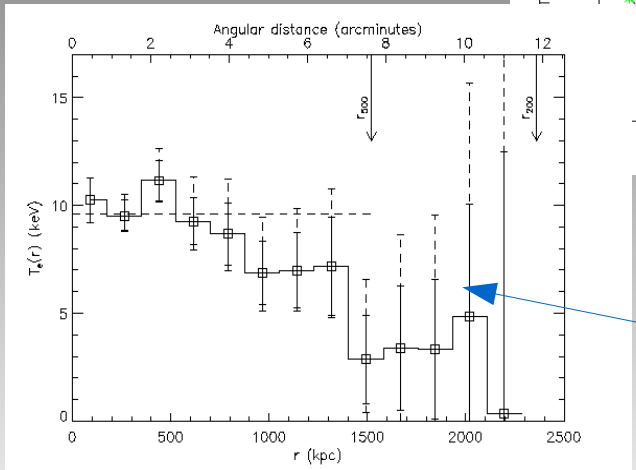
APEX-SZ + LABOCA imaging of Abell 2163
Nord, Basu, Pacaud et al.
(arXiv:0902.2131v1)



With new data

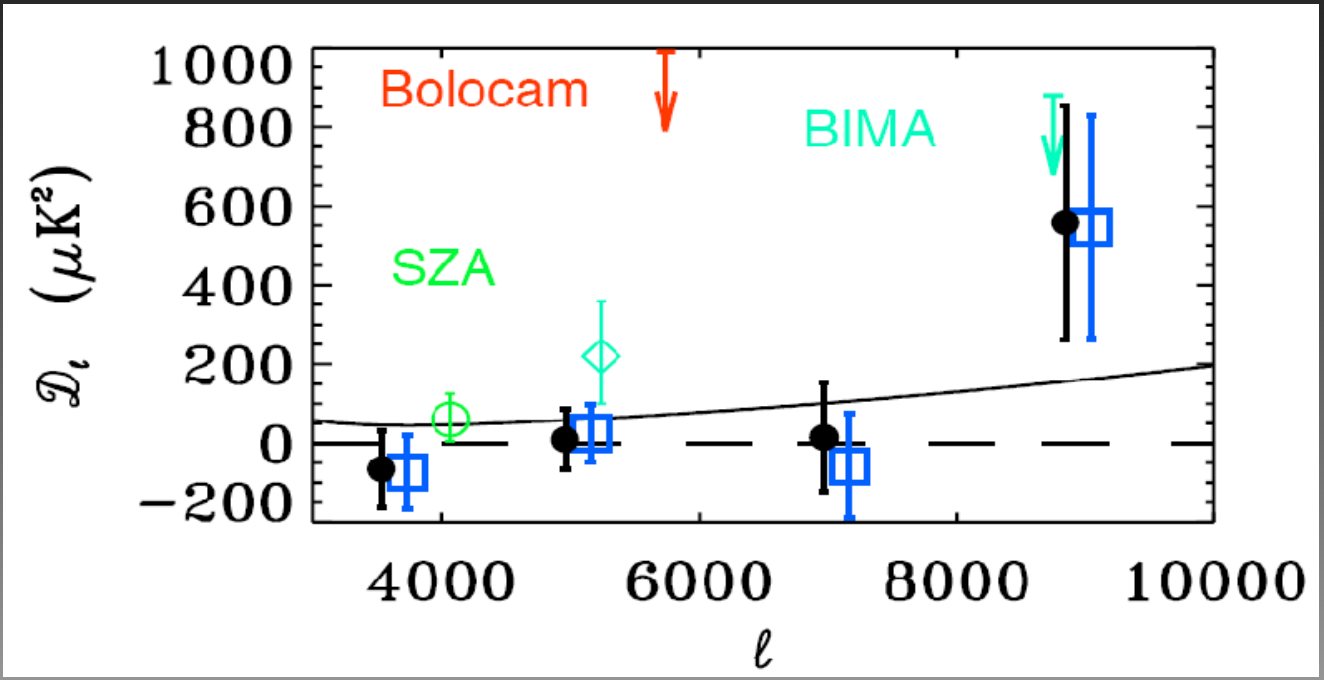






Non-parametric Temperature modeling

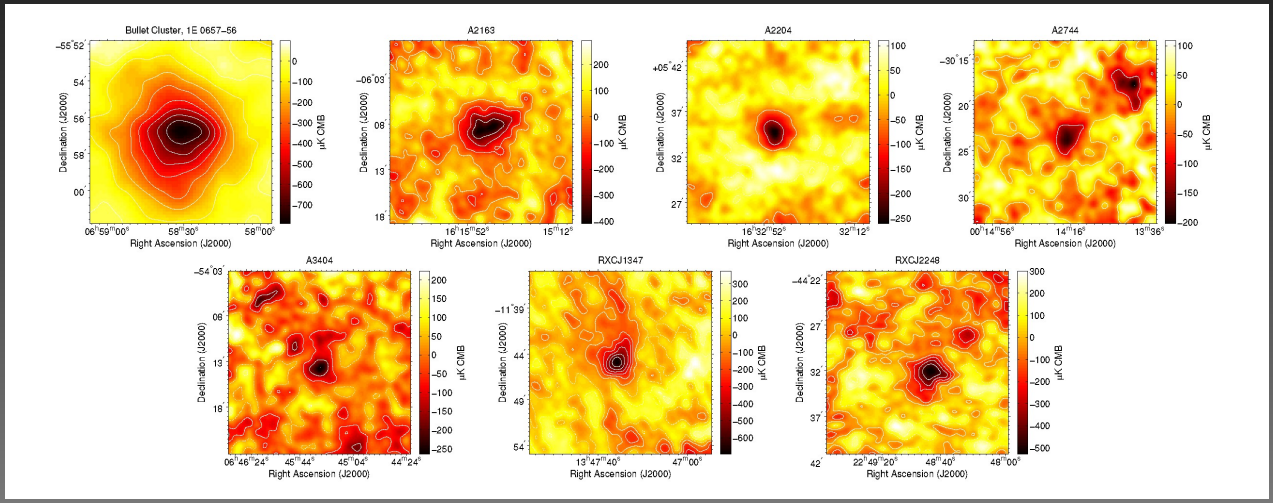
Results from the APEX-SZ Experiment



150 GHz Power Spectrum
Reichardt, Zahn et al.
(arXiv:0904.3939v1)

- Map 0.8 sq degrees with 1' resolution, 10 nights in Aug-Sep 2007
- 12 μK rms noise per 1' pixel
- Total anisotropy < 105 μK^2 at 95% CL
- $\sigma_8 < 1.15$ at 95%
- Power at 150 GHz dominated by dusty sub-mm galaxies
- Power from radio sources 20 times less
- Prediction of point source power (in absence of clustering) agrees well with APEX-SZ measurement

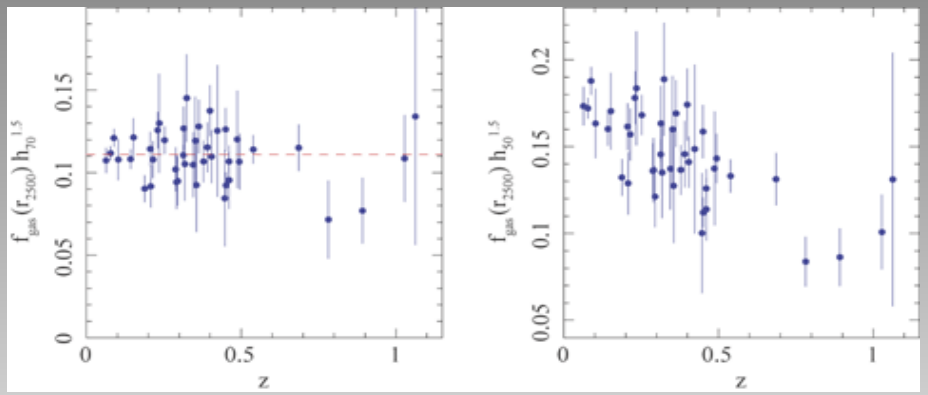
Upcoming science highlights



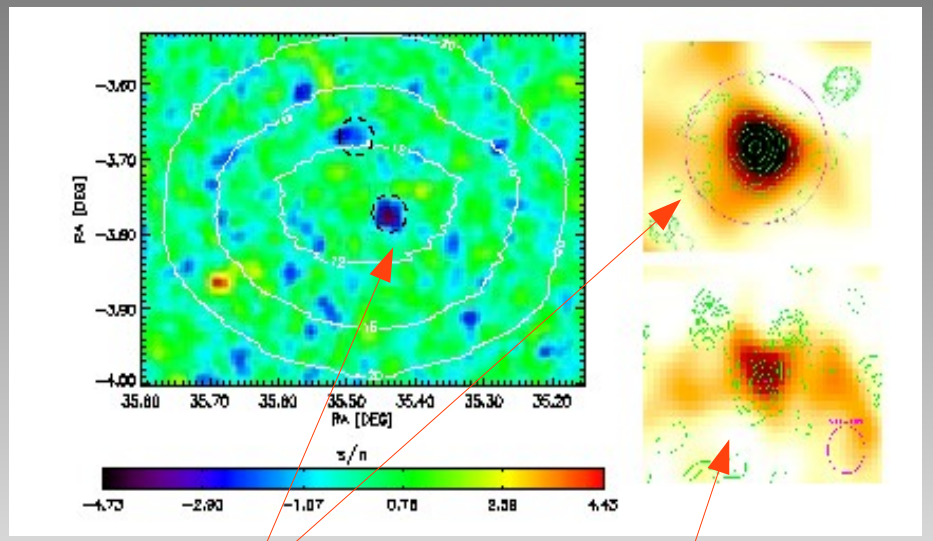
Cluster SZE scaling relations (Bender et al.)

XMM-LSS map analysis (Pacaud et al.)

Cluster SZ/X-Ray comparison (Kneissl et al.)



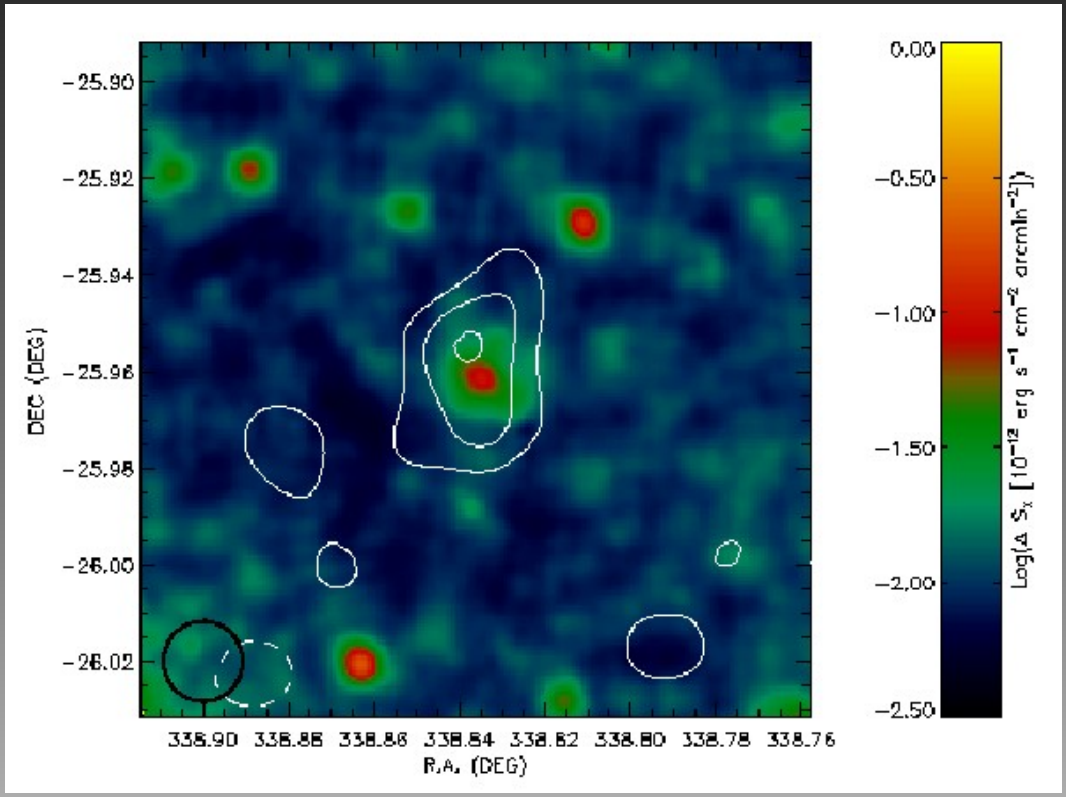
Cosmology from X-ray gas mass fraction, Allen et al. 2009



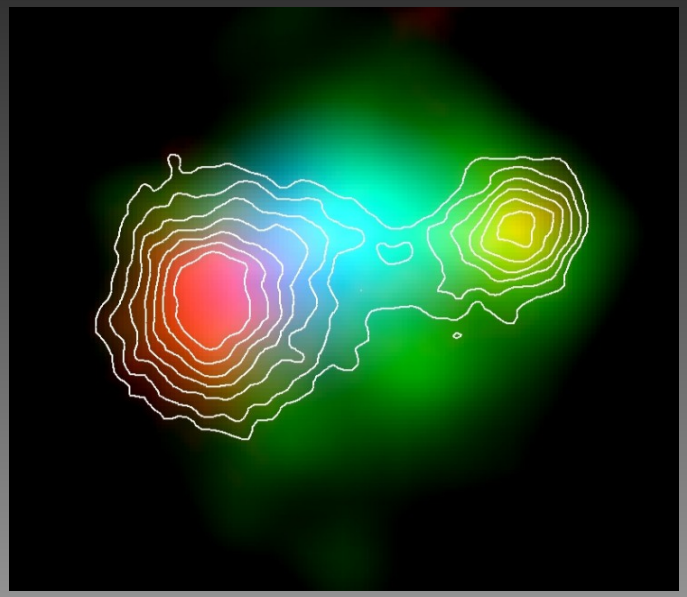
XLSSC-006 (T_X=5 keV)

T_X~4 keV

Upcoming science highlights



z=1.39 cluster **XMM J2235** (Johnson et al.)



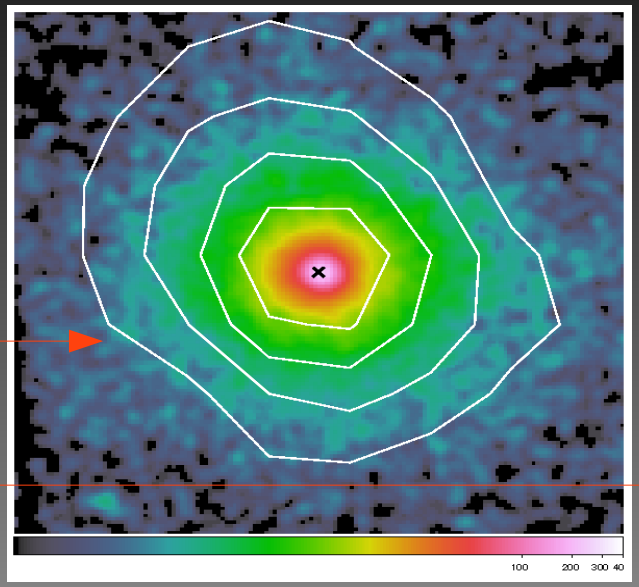
Modeling merging systems
(Johansson/Kennedy et al.)

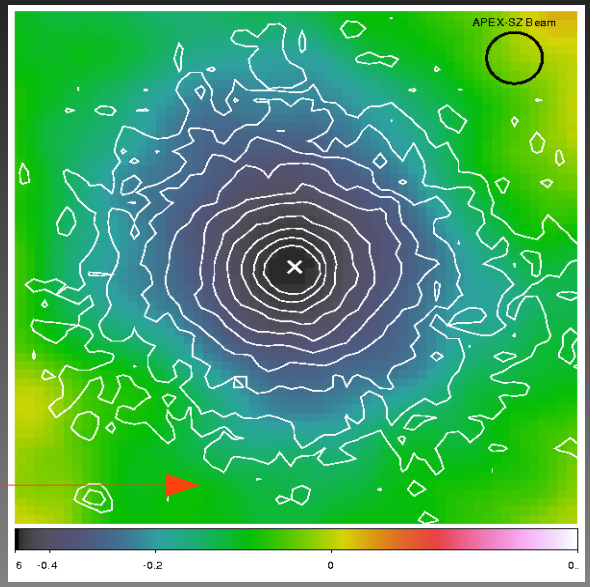
ICM temperature de-projection

Abell 2204:
Prototypical relaxed Cluster

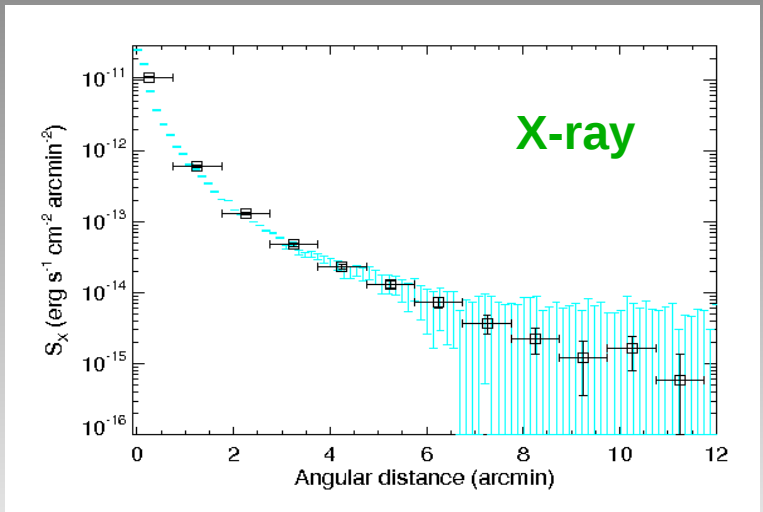
X-ray image with SZ contours

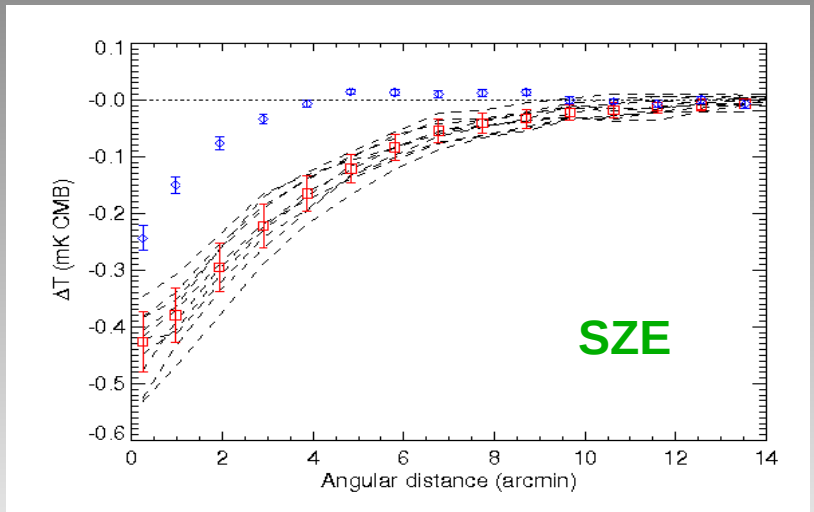
SZ image with X-ray contours





Abell 2204, Basu, Zhang, Nord et al.





ICM temperature de-projection

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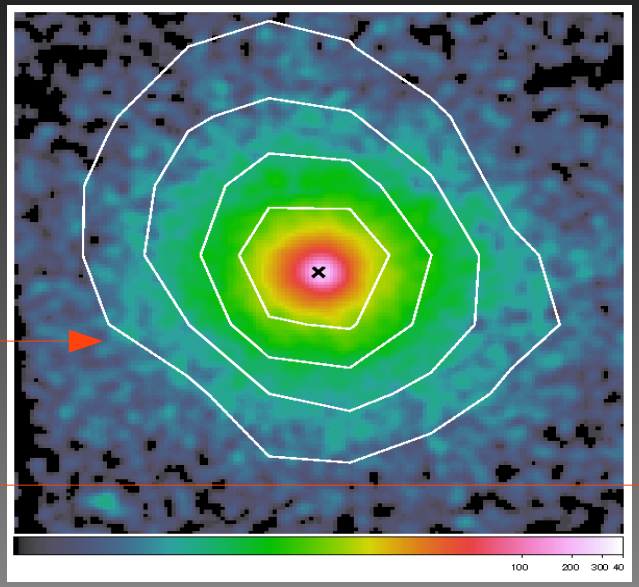
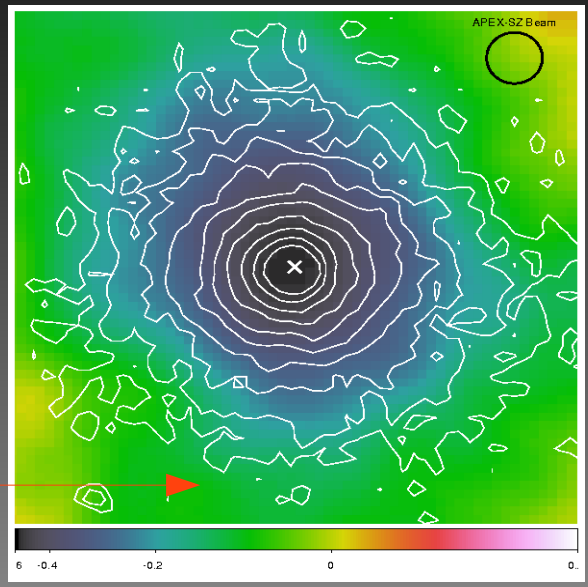
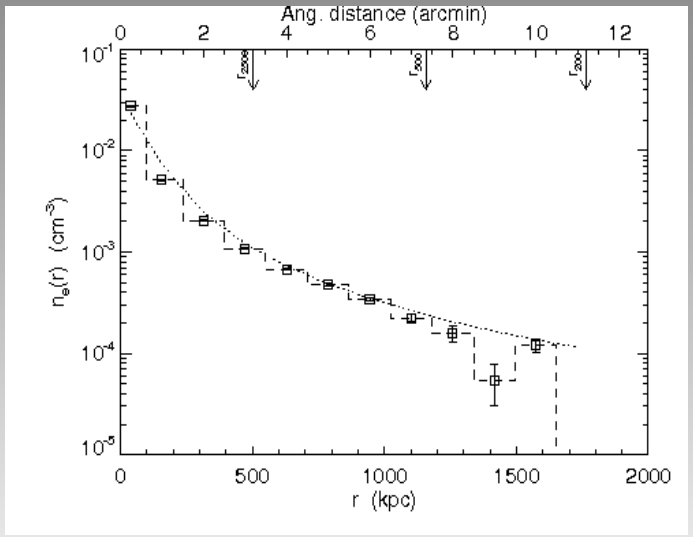
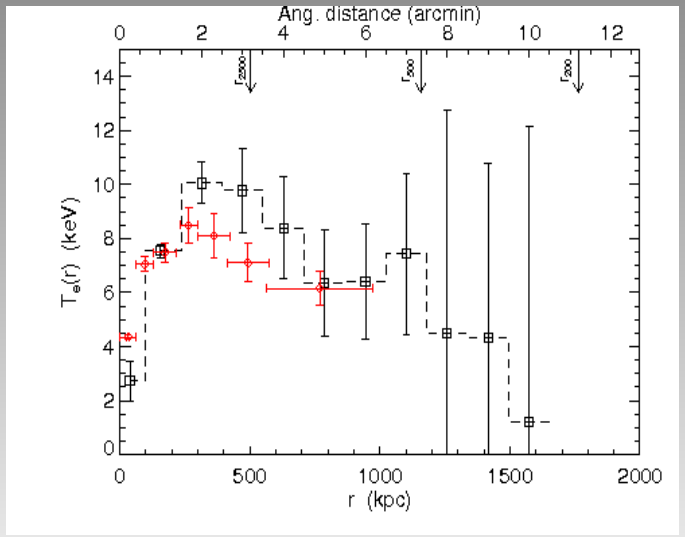




Abell 2204, Basu, Zhang, Nord et al.

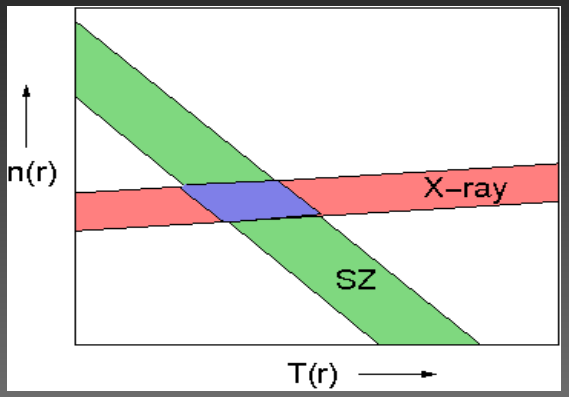


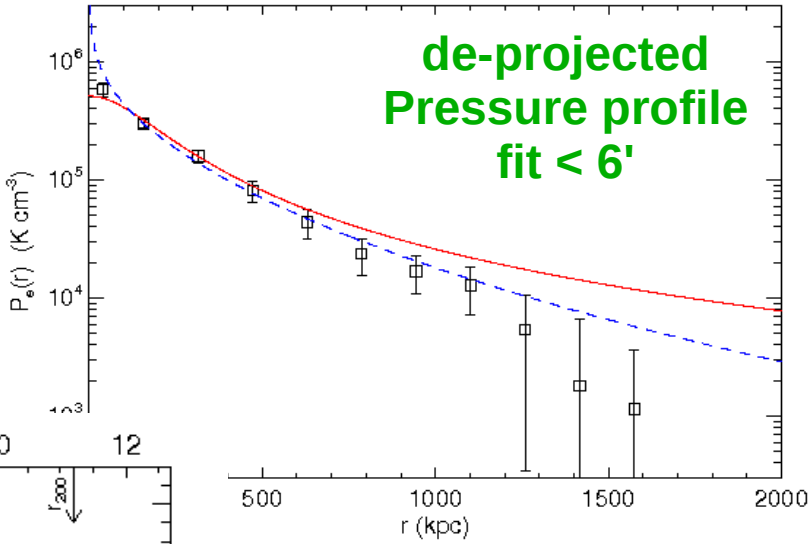


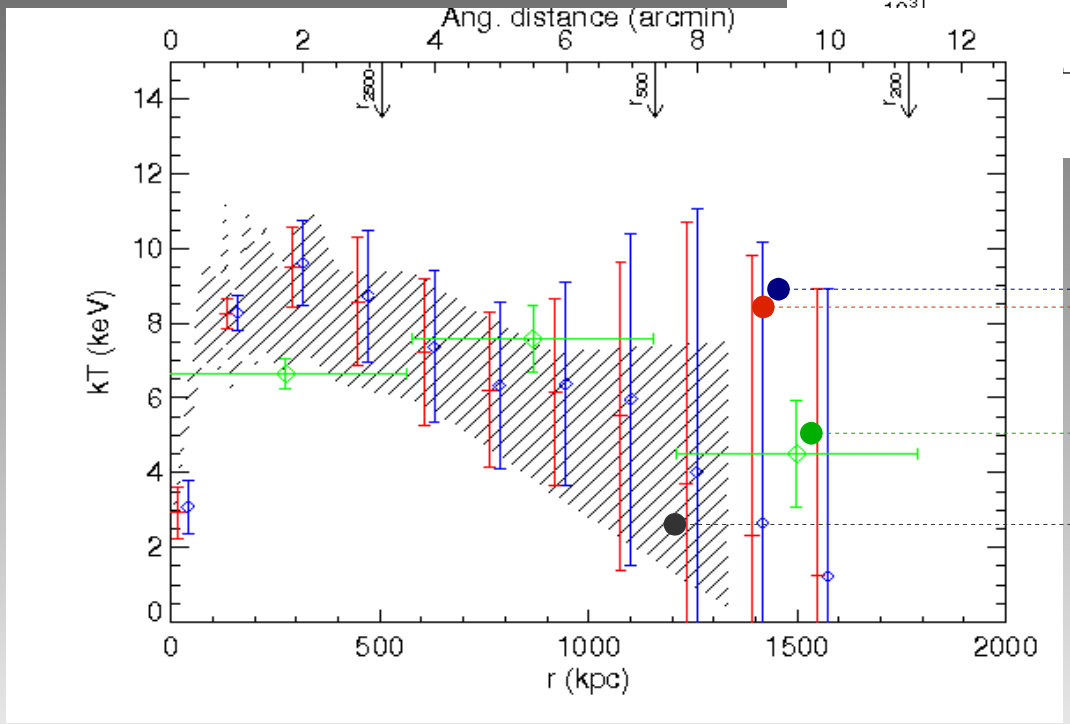
Direct de-projection of density and temperature with Abel's inversion

No parametric modeling!

ICM temperature de-projection





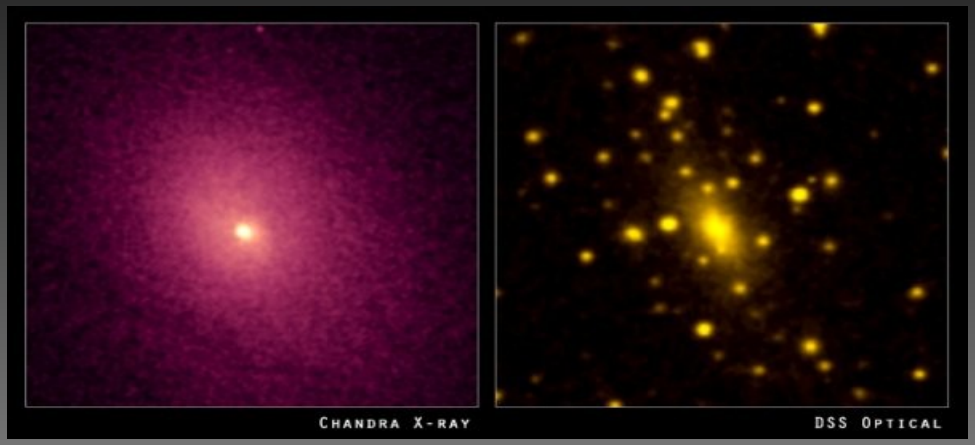


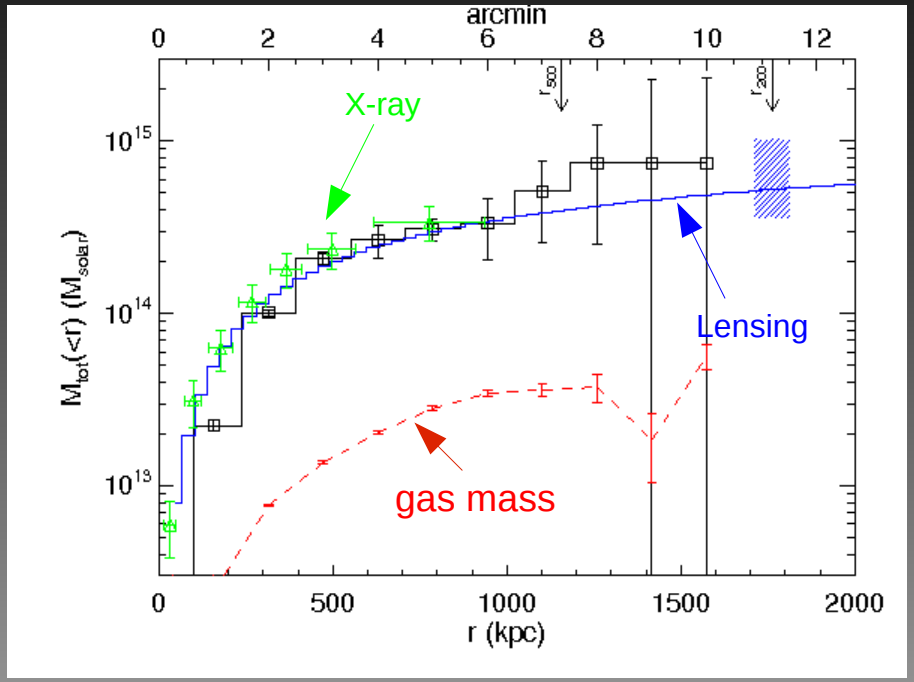
Projected SZE-derived temperature profile

Suzaku observation

88 ks Chandra re-calibrated

Mass and Entropy profiles



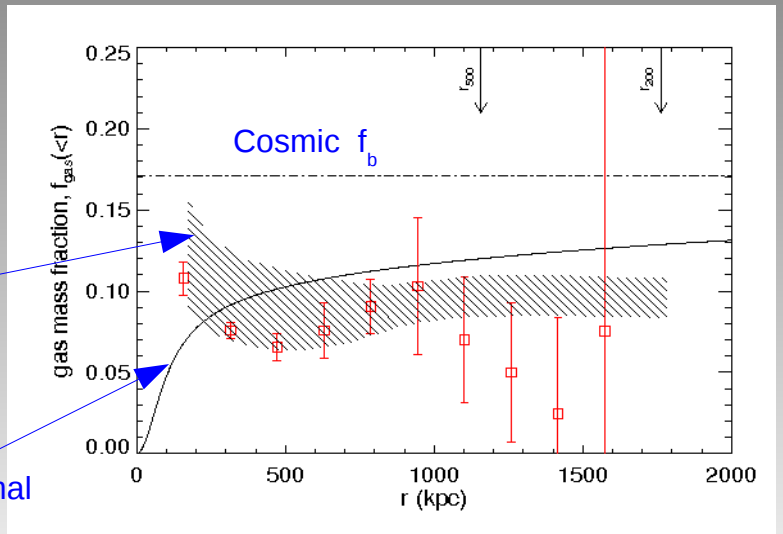


Gas in hydrostatic equilibrium inside the dark matter potential well

$$\frac{1}{\rho_g}\frac{dP}{dr} = -\frac{d\phi}{dr} = -\frac{GM(<r)}{r^2}$$

$$M_{tot}(<r) \propto -T_e(r)\left[\frac{d\ln n_e(r)}{d\ln r} + \frac{d\ln T_e(r)}{d\ln r}\right]$$

Abell 2204
Basu, Zhang, Nord et al.

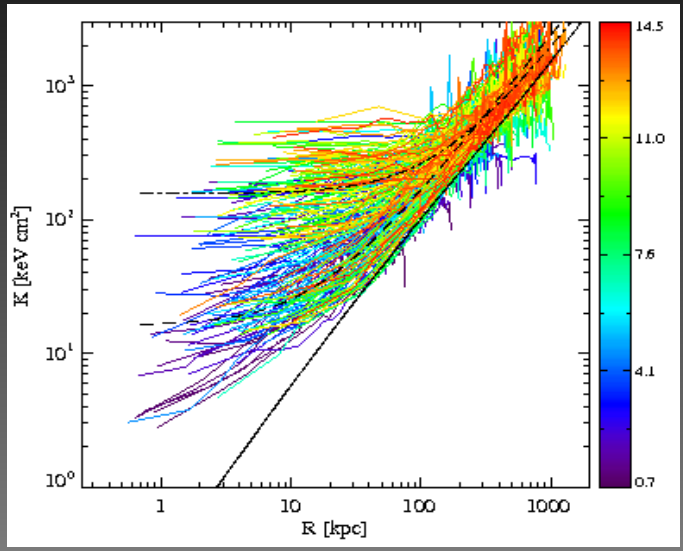


Mass and Entropy profiles

Entropy is a fundamental property of the ICM, describing its history of heating and cooling

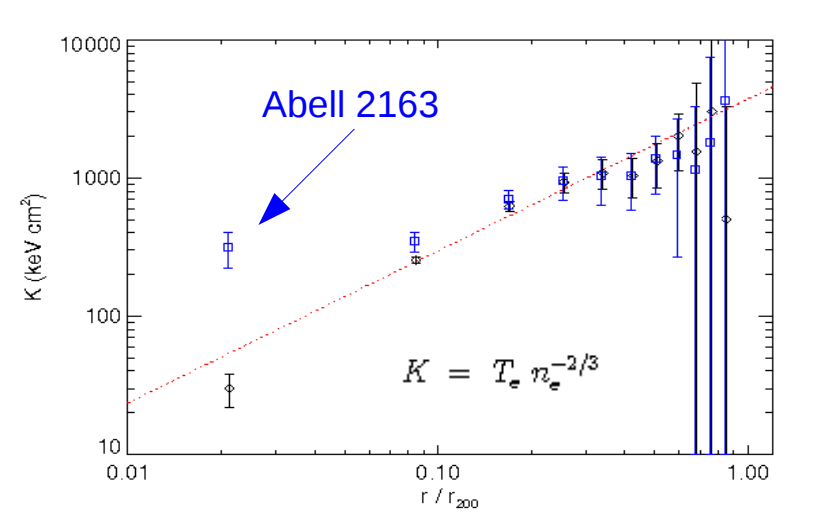
Slope of the entropy profile near the cluster center determines the extent of non-gravitational heating

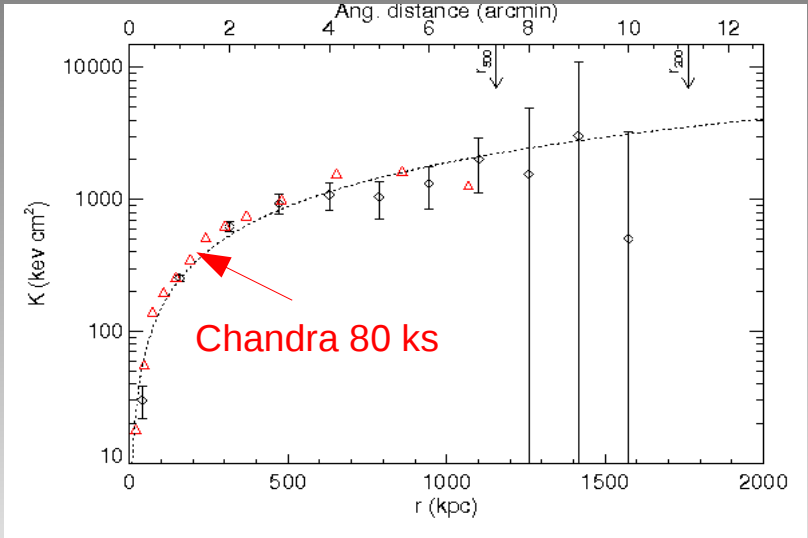
Low entropy near the virial radius indicates missing baryons from the ICM!



Cavagnolo et al. 2009

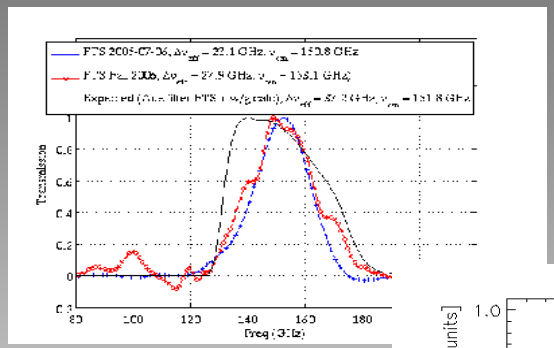
Abell 2204, Basu, Zhang, Nord et al.



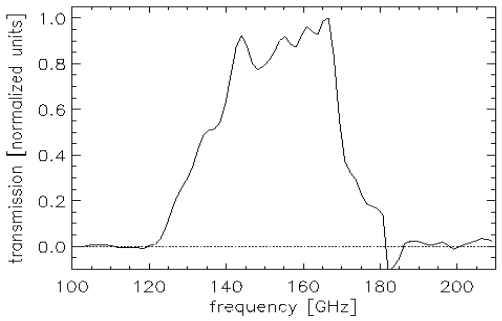


What's next for APEX-SZ?

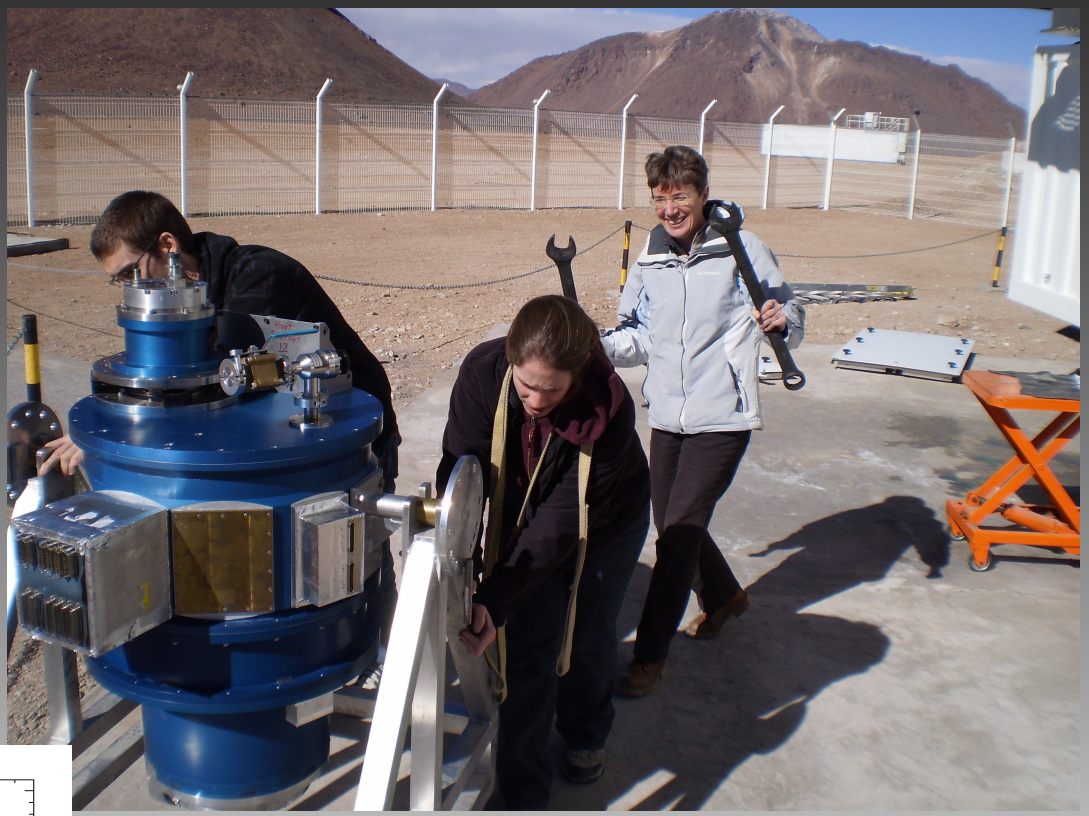
- 40% improvement in bandwidth has been achieved
- Full array upgrade by Dec 2009, factor 4 improvement in mapping speed
- Dual array: half detectors at 150 GHz, half at 90 GHz



(before)



(Apr 2009)



APEX-SZ is on its way home for upgrade!

Summary

First results from APEX-SZ are coming out, many more at works!

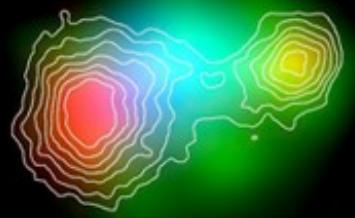
Couple of dozen clusters already detected, and also deep exposure of XMM-LSS and COSMOS sub-fields

Possible to reconstruct gas density and temperature profiles in combination with X-ray imaging data

Current systematics limit the ability to reach the virial radius (will be widening scans), but temperature and mass constraints at r_{500} are already comparable to X-ray and lensing results

Aiming to combine with *Suzaku* imaging data, as well as perform stacking analysis of relaxed clusters

SZ @ Bonn 2009: A multi-wavelength look at galaxy clusters



- Overview
- Program
- Participants
- Venue for Workshop
- Travel Information
- Organisers and Contact

SZE workshop in Bonn (July 15-17, 2009)

The last few years have seen tremendous growth in our understanding of the physics of galaxy clusters and their relation to cosmology. One of the latest and most interesting tools in this analysis has been the availability of large-area imaging of galaxy clusters using the Sunyaev-Zel'dovih Effect (SZE), with the help of state-of-the-art multi-pixel bolometer arrays. Several such experiments with new generation of bolometer receivers are now collecting data and producing their first results. The APEX-SZ instrument, commissioned in Spring 2007, is one of the first such experiments and is in the process of announcing its first scientific results.

One particular strength of such large-area SZE maps is to use them in combination with X-ray and weak-lensing data to extend our understanding of the physical and dynamical properties of the intra-cluster gas (ICM) out to a large fraction of the cluster virial radius. The aim of the workshop will be to bring together experts of such multi-wavelength ICM analysis and discuss the recent results from new SZE experiments as well as their combination with other observational probes. Since APEX-SZ is unique in its sensitivity, resolution and ability to track sources, resulting in detailed SZE maps of known galaxy clusters, it is our aim to put current and future APEX-SZ time to its best possible use by developing a joint plan for observation and target selection with a broader community.

As mentioned above, we aim to focus on cluster physics rather than surveys, so the topics will include: cluster ICM modeling combining SZ, X-ray, and possibly weak lensing data; cluster SZE scaling relations; cosmology from cluster baryon fractions; etc. We aim to make possible for every participant to present their latest works.