Recent SZ observations and prospects for cluster surveys

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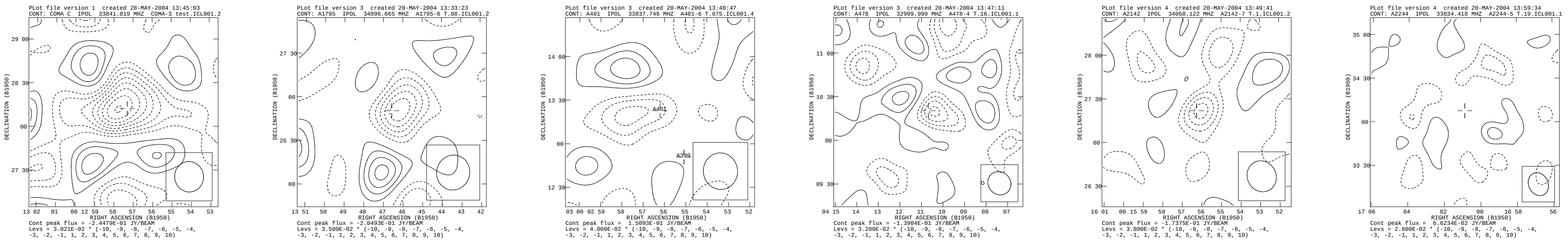
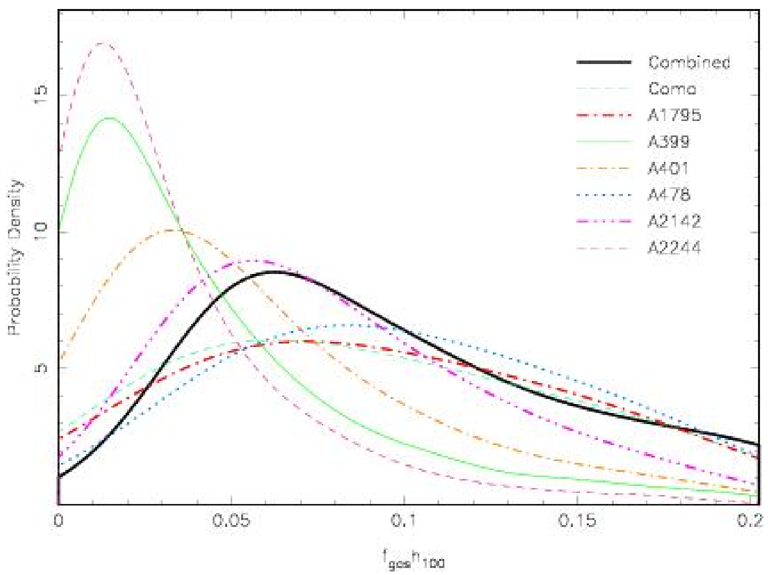
Distant cluster workshop, Schloss Ringberg, 27 October 2005

- Examples of recent SZ cluster observations
  - Baryon fraction and M-T relation from the VSA sample
  - High sensitivity SZ observations (first AMI targets)
- Cluster searches
  - Interferometer technique: AMI
  - Multi-bolometer arrays: APEX-SZ
  - Satellite by-product: Planck
- Outlook

The VSA cluster sample: Coma, A1795, A399+A401, A478, A2142, A2244

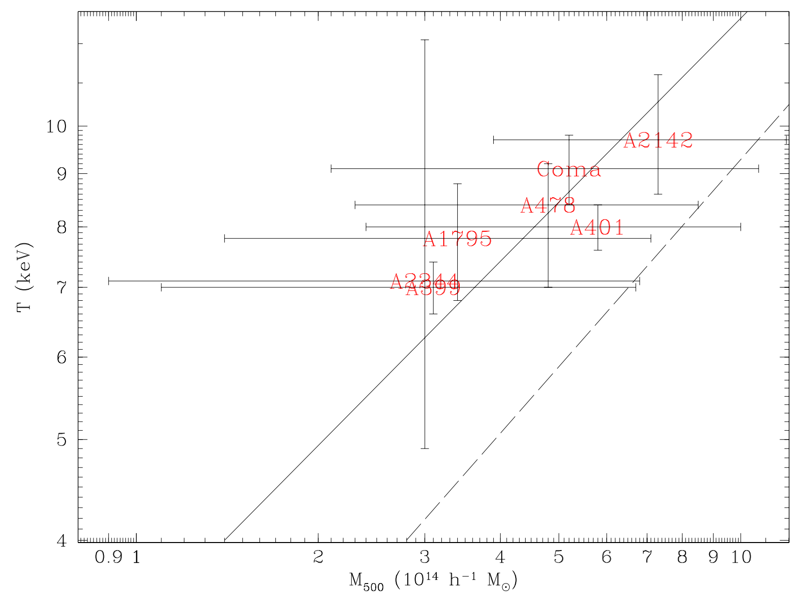


Gas fraction measurement



Combined constraint:
$f_g = 0.08^{+0.06}_{-0.04} h^{-1}$ (Lancaster et al., astro-ph/0405582)

A mass - temperature relation



Agrees with X-ray determinations

Understanding L_{SZ} - M relation, ie. M-T and f_g, will be essential for the SZ surveys.

Analysis

Cluster model: assume gas density King-profile with HSE giving total mass, eg. M_{200},

$$M_r = \frac{3\beta r^3}{r_c^2 + r^2}\frac{kT}{\mu G}$$

and gas mass $M_g = 4\pi\rho_g(0)r_c^3\int_0^{r/r_c}(1+x^2)^{-3\beta/2}x dx$, $x = r/r_c$. Therefore

$$f_g = \frac{M_g}{M_r} \qquad \text{and also} \qquad A = M_r T^{-3/2} = \frac{3\beta r^3}{r_c^2 + r^2}\frac{kT^{-1/2}}{\mu G}$$

Radio sources: 41 radio source ($400 > S_\nu > 20$mJy; $\sim 3\sigma$) simultaneously observed and subtracted from the data; preselecting all NVSS and GB6 sources with predicted fluxes > 50mJy within 2° radius and raster-scanning one square-degree with the Ryle telescope to $S_{15\mathrm{GHz}} > 20$mJy.

Bayesian Inference: $P(\Theta|\mathrm{data}, H) = P(\mathrm{data}|\Theta, H)P(\Theta|H)/P(\mathrm{data}|H)$; characterisation of posterior PDF with Monte-Carlo approach; typically 10 Markov chains running in parallel using BayeSys, evaluation in visibility (Fourier) space; weak priors on r_c, β, M_g, strong prior on T_e.

The Arcminute Micro-Kelvin Imager

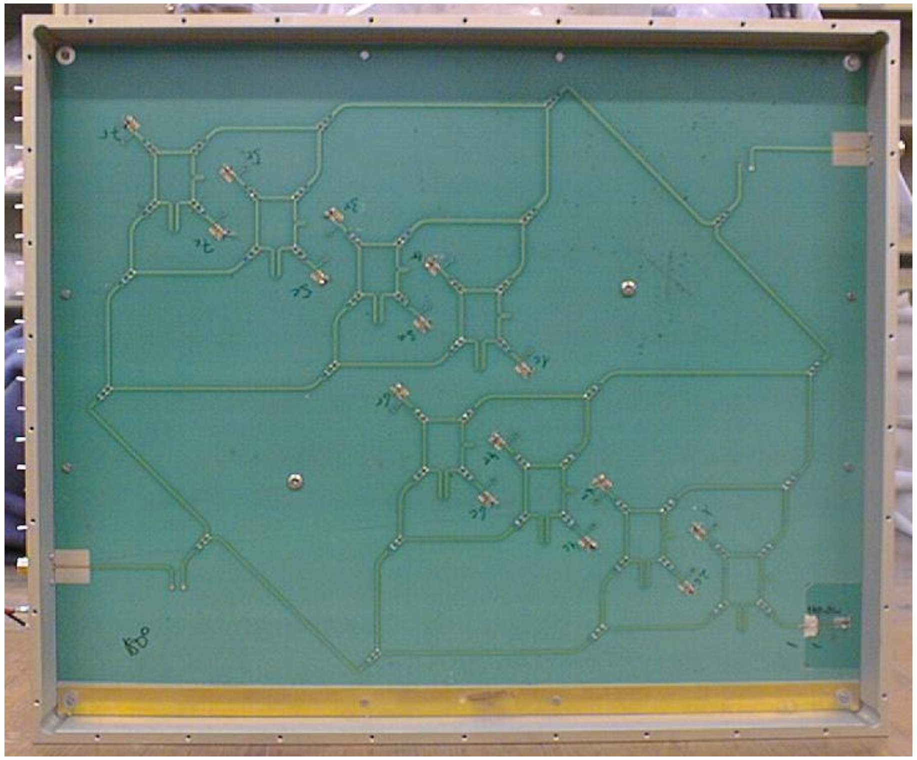
10 3.7m (200 $\lambda \sim$ 3') & 8 13m antennae, 12-18 GHz, $T_{sys} = 25K$

AMI Collaboration: R. Barker, P. Biddulph, D. Bly, R. Boysen, A. Brown, C. Clementson, M. Crofts, T. Culverhouse, J. Czeres, R. Dace, R. D'Alessandro, P. Doherty, P. Duffett-Smith, K. Duggan, J. Ely, M. Felvus, W. Flynn, J. Geisbuesch, K. Grainge, W. Grainger, D. Hammet, R. Hills, M. Hobson, C. Holler, R. Jilley, M. Jones, T. Kaneko, R. Kneissl, K. Lancaster, A. Lasenby, P. Marshall, F. Newton, O. Norris, I. Northrop, G. Pooley, V. Quy, R. Saunders, A. Scaife, J. Schofield, P. Scott, C. Shaw, A. Taylor, D. Titterington, M. Velic, E. Waldram, S. West, B. Wood, G. Yassin, J. Zwart

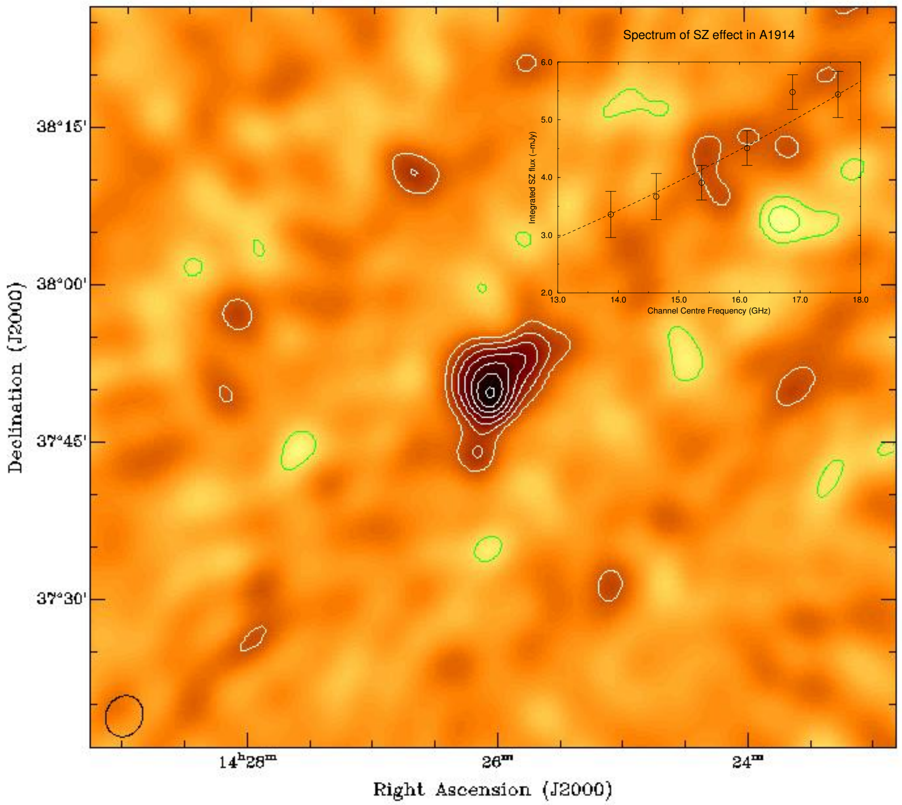
IF system: downconverters, amplifiers, filters, path compensator, gain control units for 6–12 GHz.

Correlator:

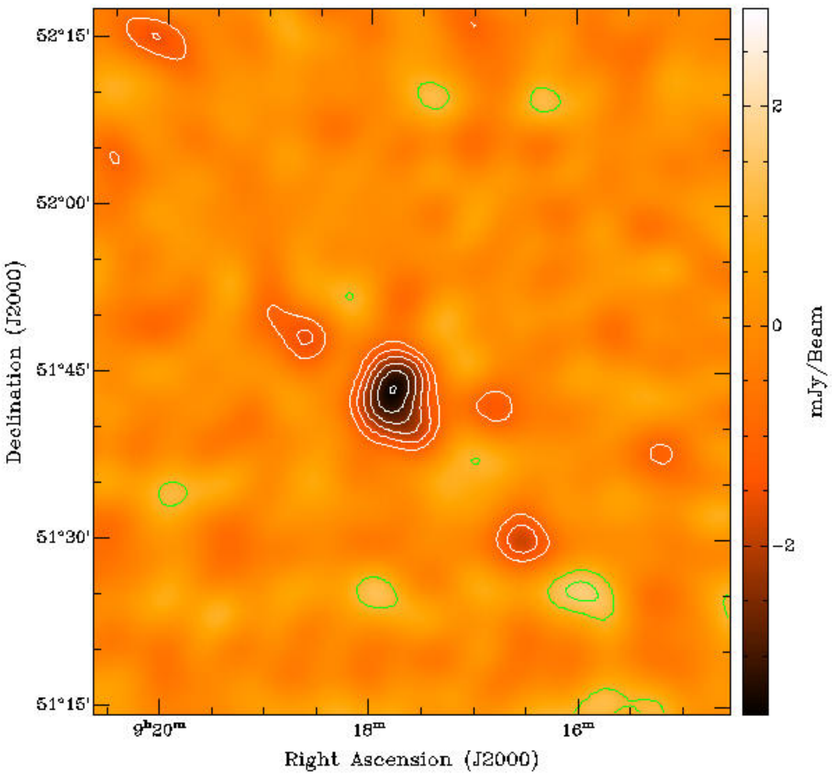
- 16-lag analogue correlator $\rightarrow$ 8 complex frequency channels
- detect phase-switched power with Schottky diodes



First AMI cluster detections - high sensitivity SZ observations

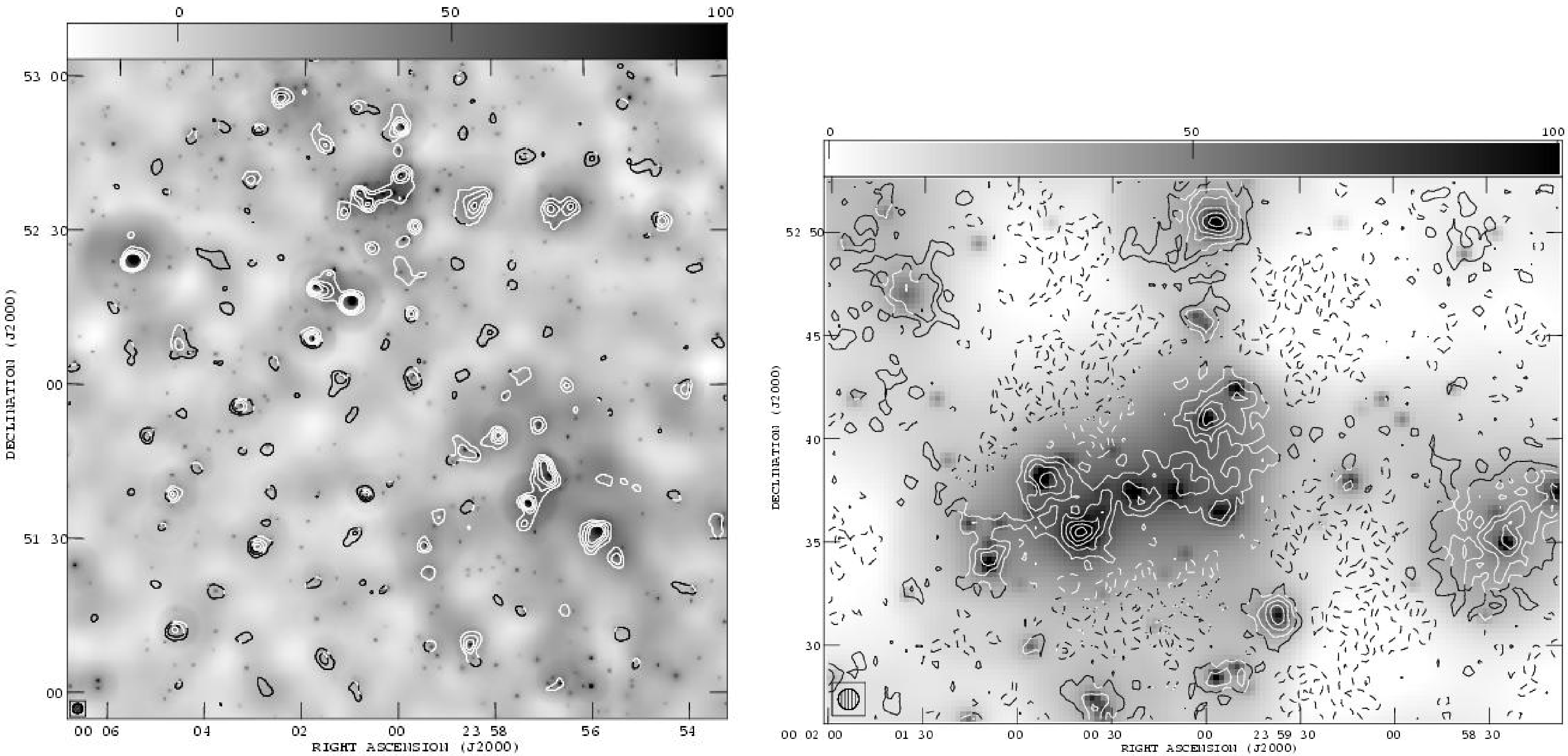


A1914 (astro-ph/0509215; Accepted for publication in MNRAS Letters)
S = -8.6 mJy, noise = 0.2 mJy/beam



A773 (6h observation)

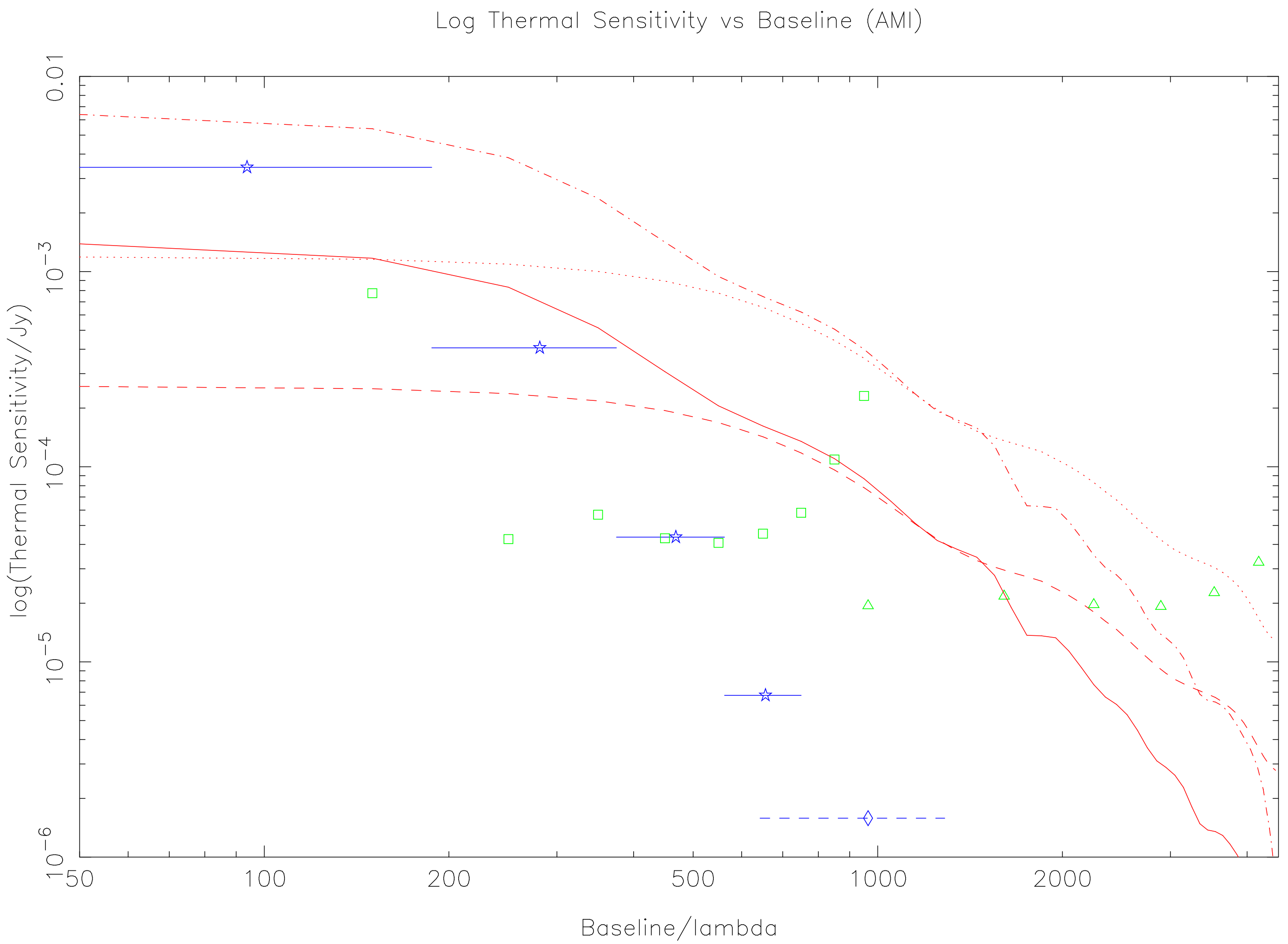
Cluster survey in the presence of primordial CMB



Grayscale image: Virgo cluster positions with scaled β model clusters, plus CMB

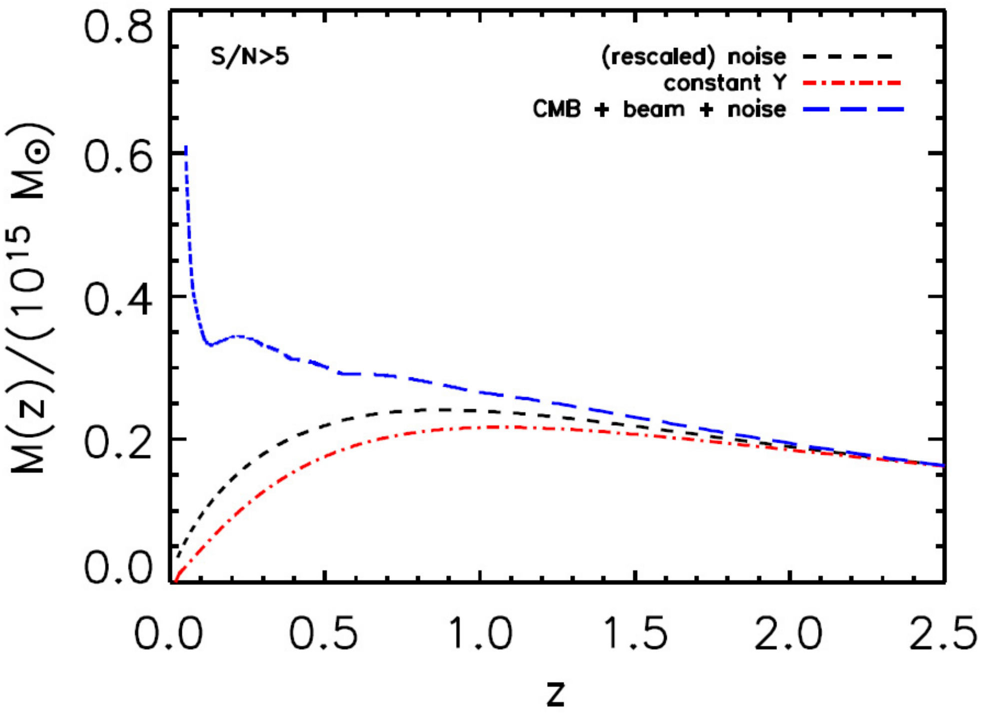
Contour overlay: 6 months survey, 2 arcmin resolution. Sources subtracted!

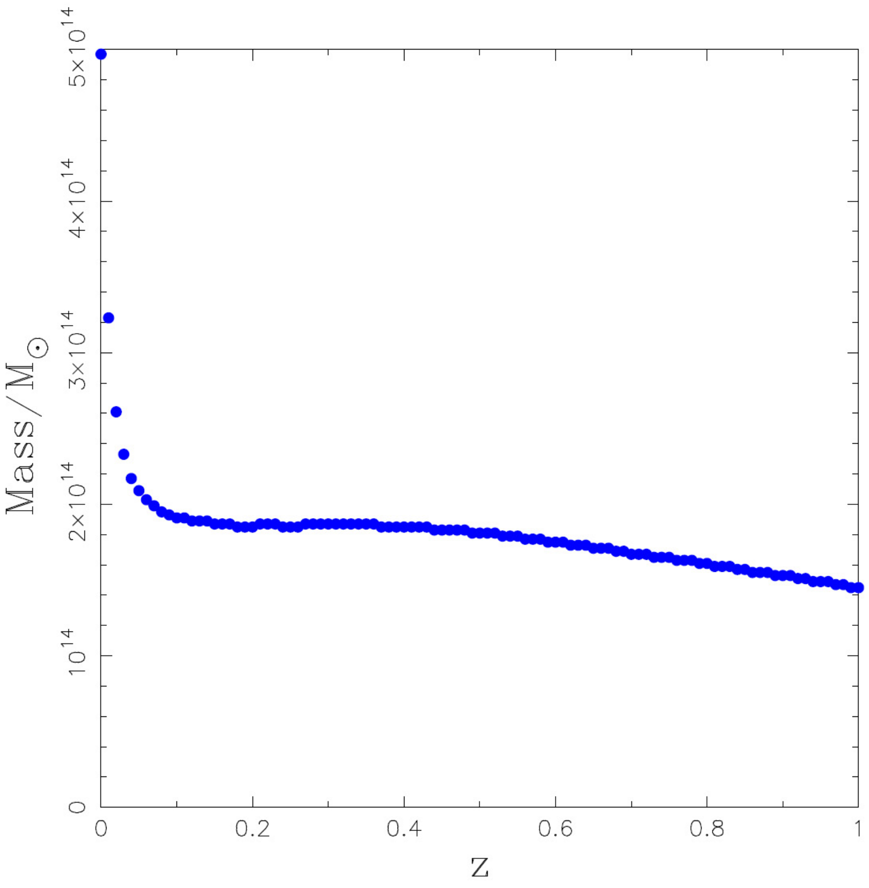
Sensitivity and CMB Confusion



Thermal flux sensitivity (6 $\times$ 8-hours; within a 21 arcmin aperture) of the compact array 3.7-m and large array 13-m dishes compared to primordial CMB and 4 clusters with masses of $M =$ 2 / 5 $\times 10^{14} M_{\odot}$ and at redshifts $z = 0.15/0.8$.

SZ selection function

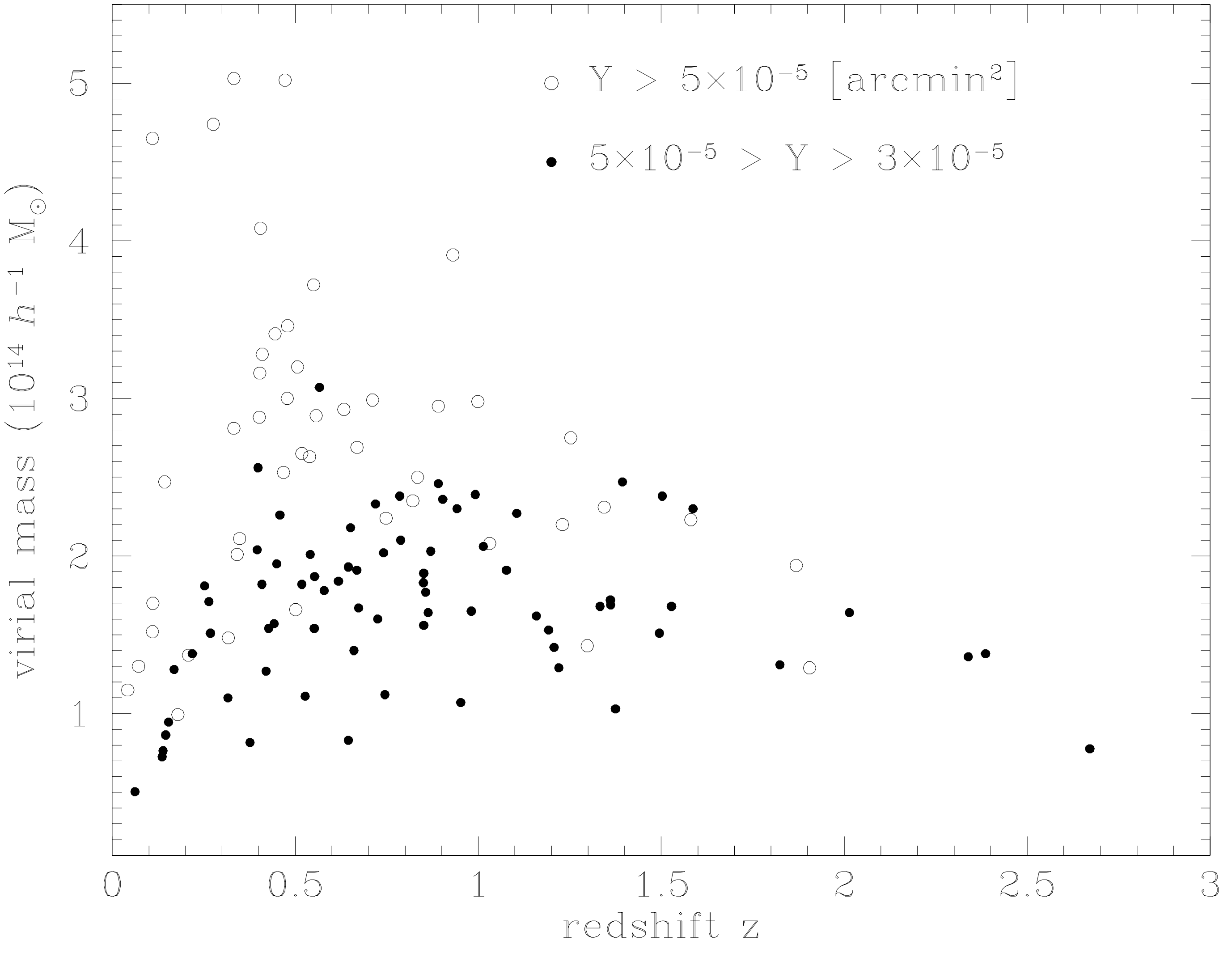




Melin, Bartlett, Delabrouille
2005, A&A 429, 417

Culverhouse
(Moriond 2004)

Cluster masses and redshifts

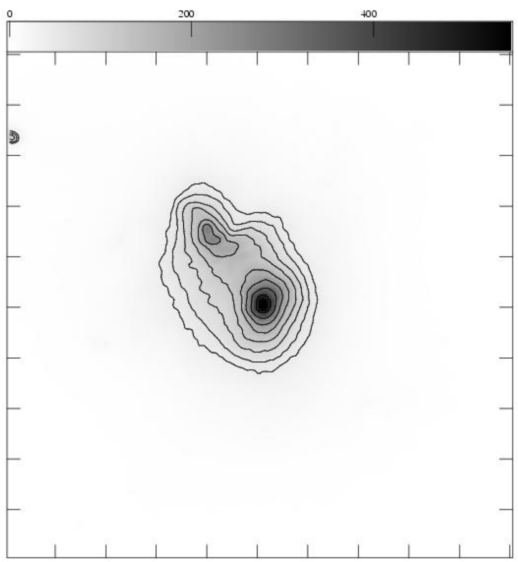


RK et al. 2001

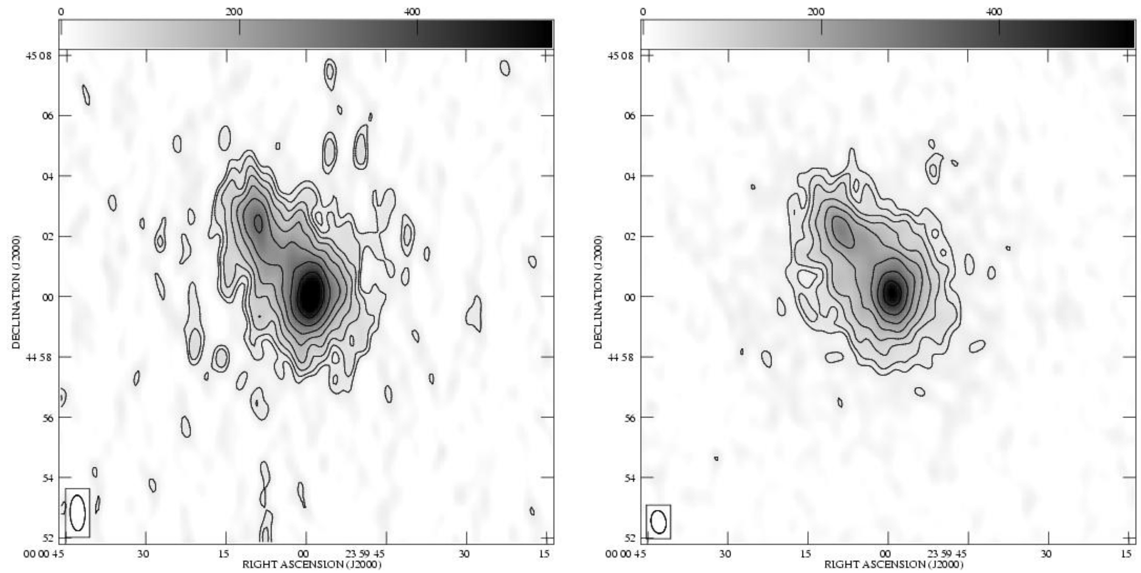
Imaging cluster substructure

Construction phase 3: Compactifying the Ryle telescope

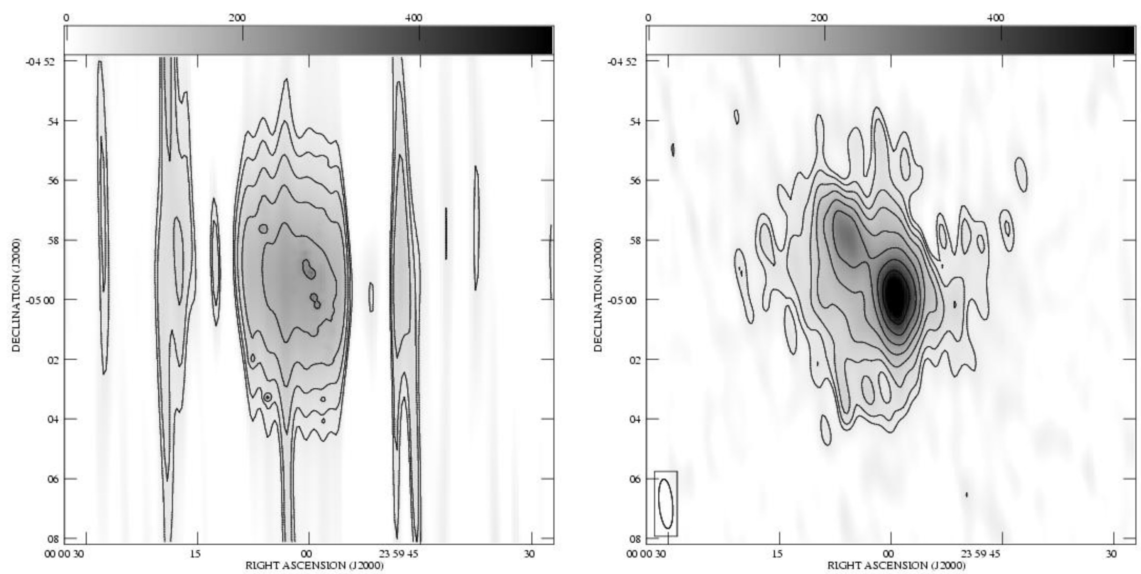
current wide East-West alignment



Hydrosimulation: 5×10^{14} $M_{\odot}$ merging cluster at $z = 0.155$.



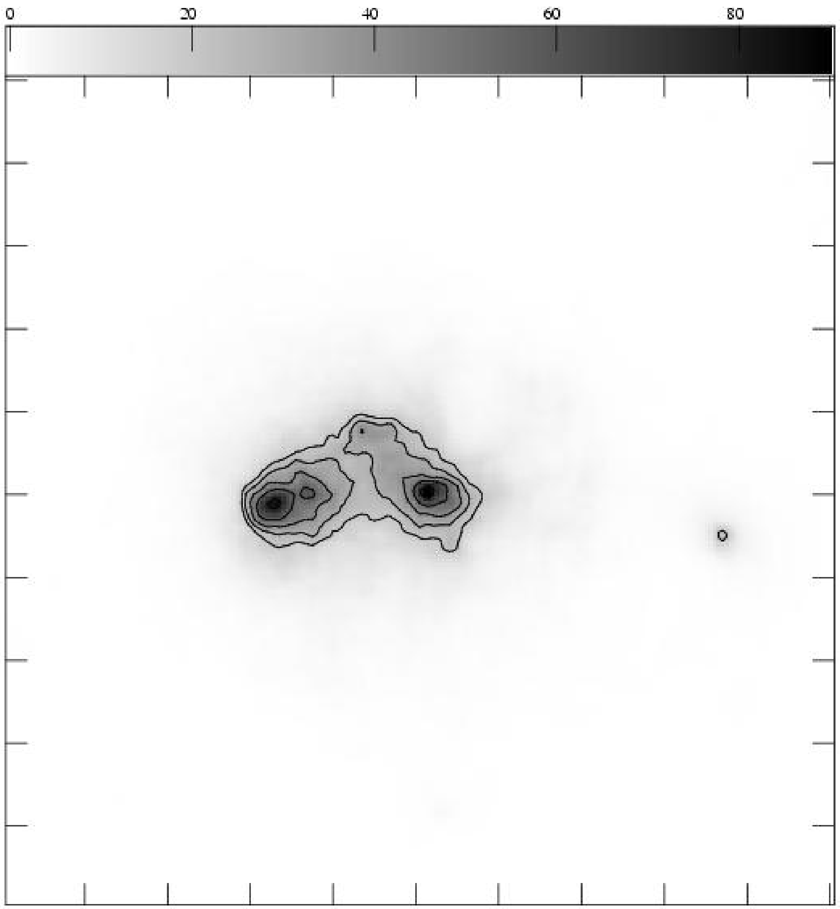
high declination (45 deg)



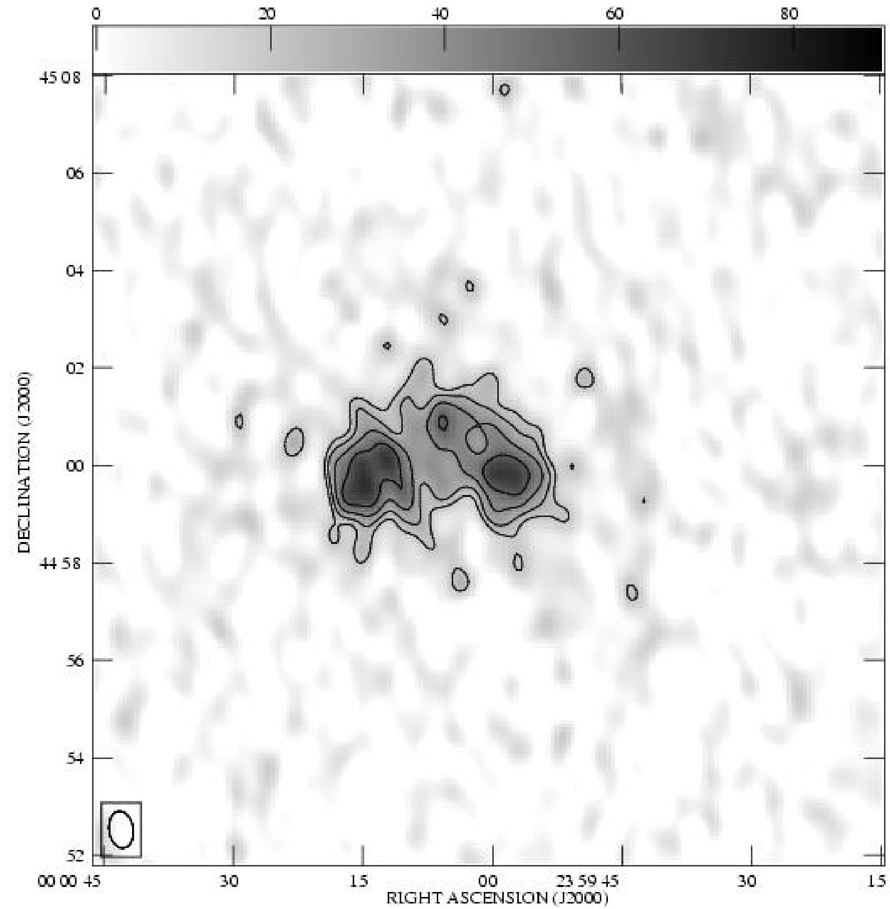
low declination (-5 deg)

more compact array with improved North-South resolution

Pointed high redshift cluster observations



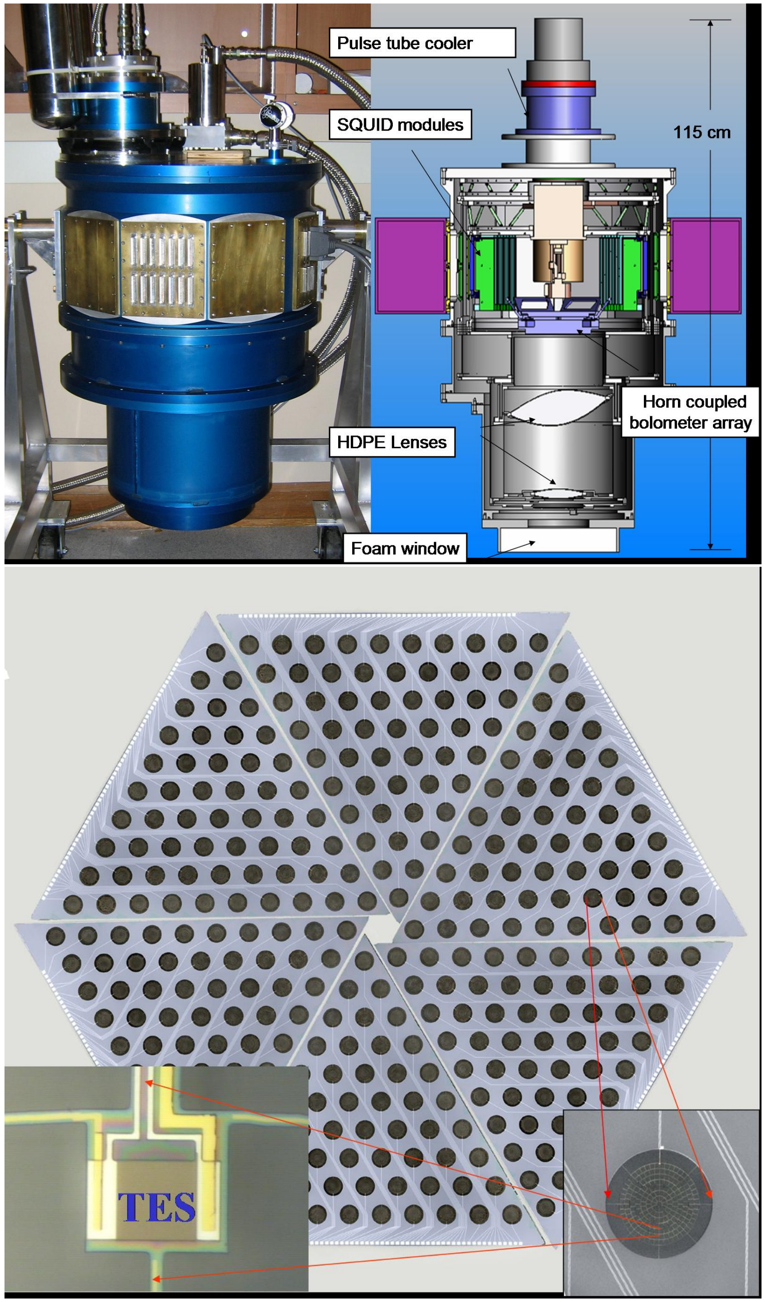
Cluster merger at redshift 1.5 of total mass 2×10^{14} $M_{\odot}$ from a hydrodynamical simulation (G. Tormen); in y-units of 10^{-6}.



Simulated $14 \times 8{-}$h observation with compact array and Ryle mosaic; in μJy beam^{-1}.

The SZ receiver for the APEX telescope

MPIfR Bonn & UC Berkeley



People:

Max Planck Institute for Radioastronomy:

K. Basu, F. Bertoldi (U Bonn), R. Güsten, E. Kreysa, K. Menten, D. Muders, P. Schilke

MPE: H. Böhringer

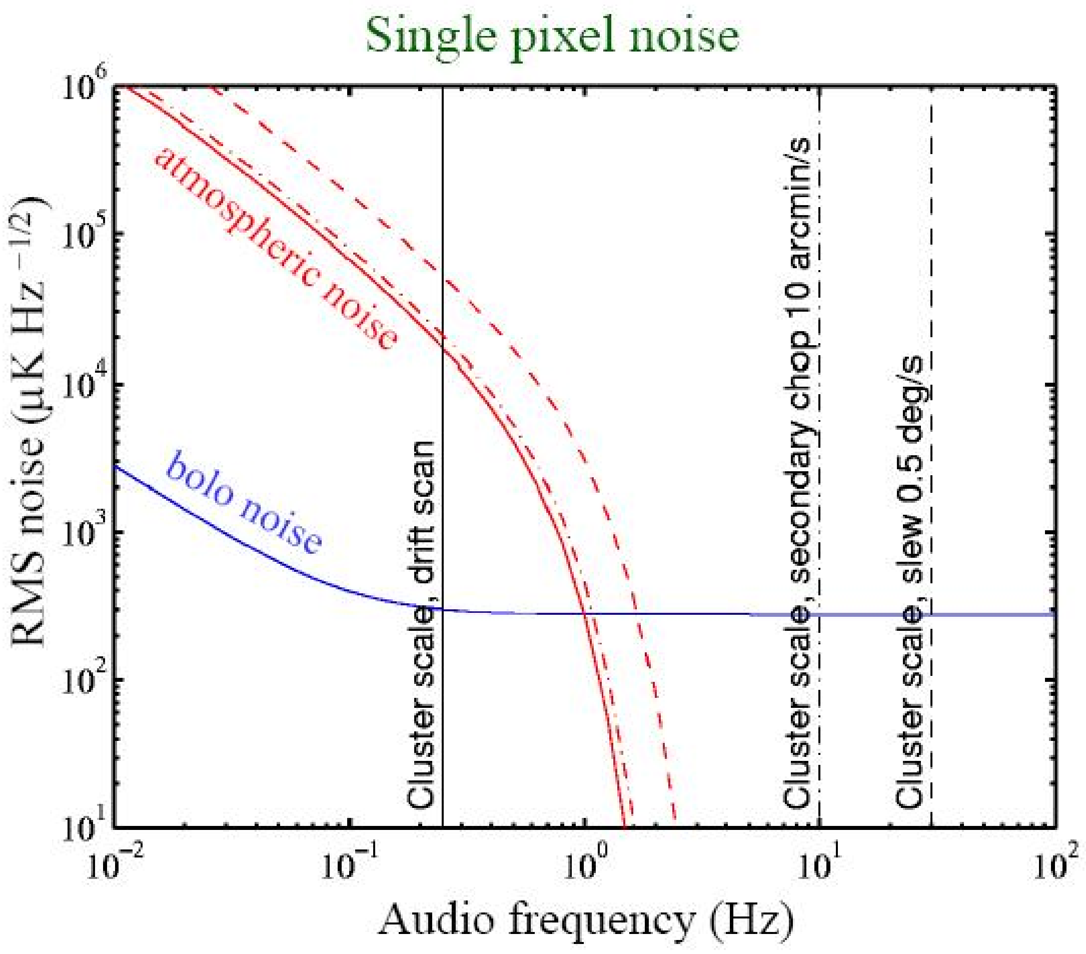
University of California, Berkeley

Physics Department: H.-M. Cho, N. W. Halverson (U Colorado), W. L. Holzapfel, R. Kneissl, T. M. Lanting, A. T. Lee, M. Lueker, J. Mehl, T. Plagge, P. L. Richards, D. Schwan, M. White

LBNL: M. Dobbs (U McGill), H. Spieler

- 12 m Atacama Pathfinder Experiment telescope, on-axis Cassegrain
- 0.75 m secondary, tertiary optics, 0.4 degree field-of-view
- Spiderweb Transition-Edge Sensor bolometer array with 330 elements
- SQUID readout, frequency multiplexing for SPT
- dry ($\tau = 0.061$ at 225 GHz), high elevation (5000 m) site, 23°S latitude
- observing frequencies (90) 150 (217) GHz
- 100-200 deg^2, several months integration, 10 μK, 60” FWHM (150 GHz) resolution

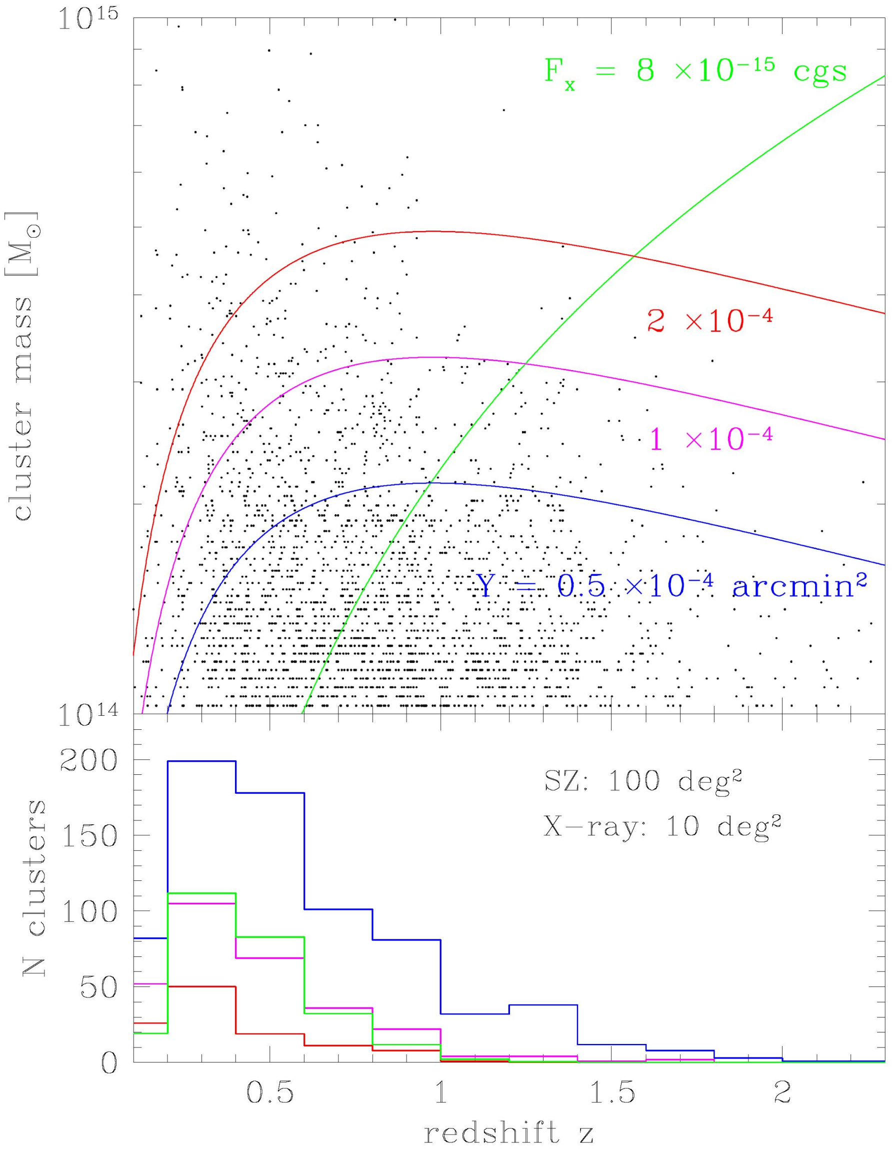
Observing strategy



Optimise scanning speed, cross-linking, field size, geometry, etc.

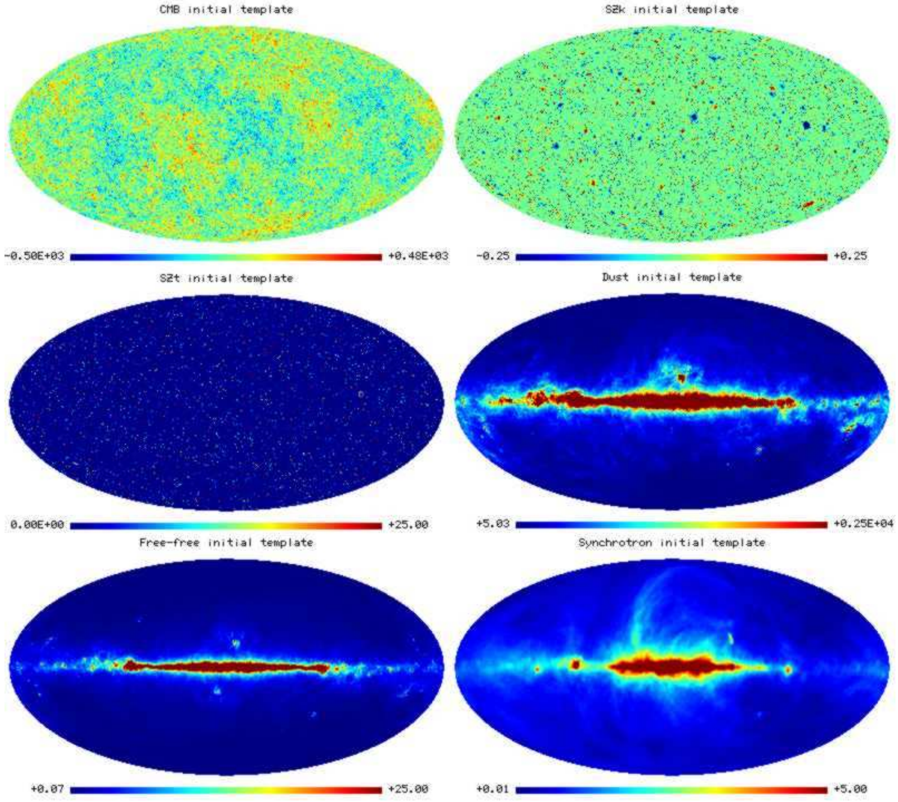
Science goals / cluster yield with APEX-SZ

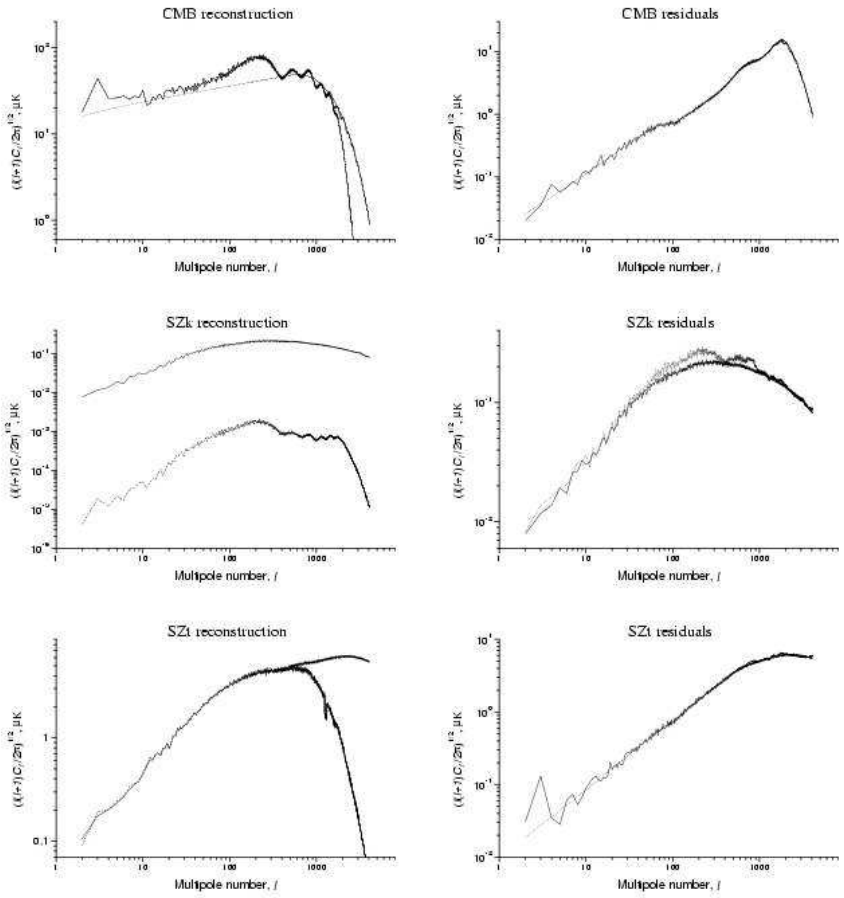
- Evolution of cluster mass function
- Cluster correlation function
- Evolution of gas fraction and M-T relation
- Dark matter density and distribution
- Dark energy equation of state
- Population of inverted spectrum radio sources
- High redshift star forming galaxies
- Density-velocity field correlations
- Lensing of the cosmic microwave background



SZ / X-ray cluster selection

Planck all-sky CMB (and cluster) component separation
(Stolyarov et al. 2002)





Input component maps

Recovered power spectra

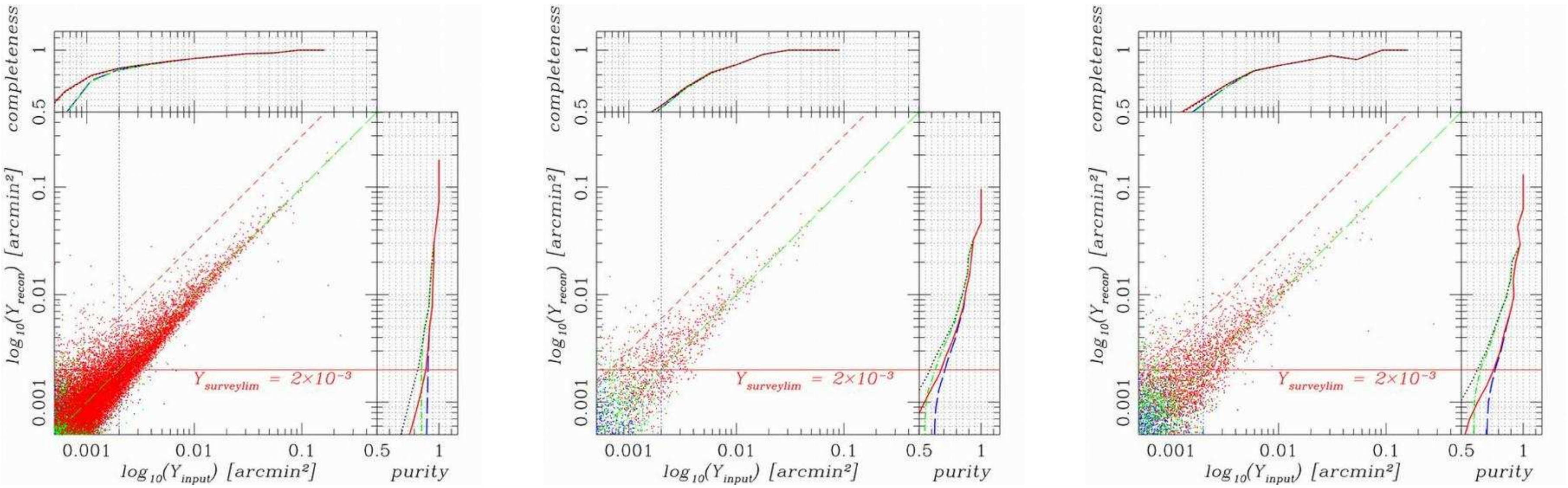
Towards a complete and pure Planck cluster sample

Geisbüsch, RK, Hobson, 2005, MNRAS 360, 41

- Virgo HVLC catalogues (Sphere, Octants, 'Evrard mass function')
- ΛCDM and τCDM cosmologies
- rescaling of cluster catalogue with σ_8
- $M - T$ relation with different normalisation (virial $+$ 'X-ray')
- analytic isothermal gas profile truncated at r_v (90 % unresolved clusters)
- assume constant gas fraction f_g
- assume NFW profile to rescale dark matter mass definitions
- fix total cluster flux, 'adjust' central density and r_c/r_v

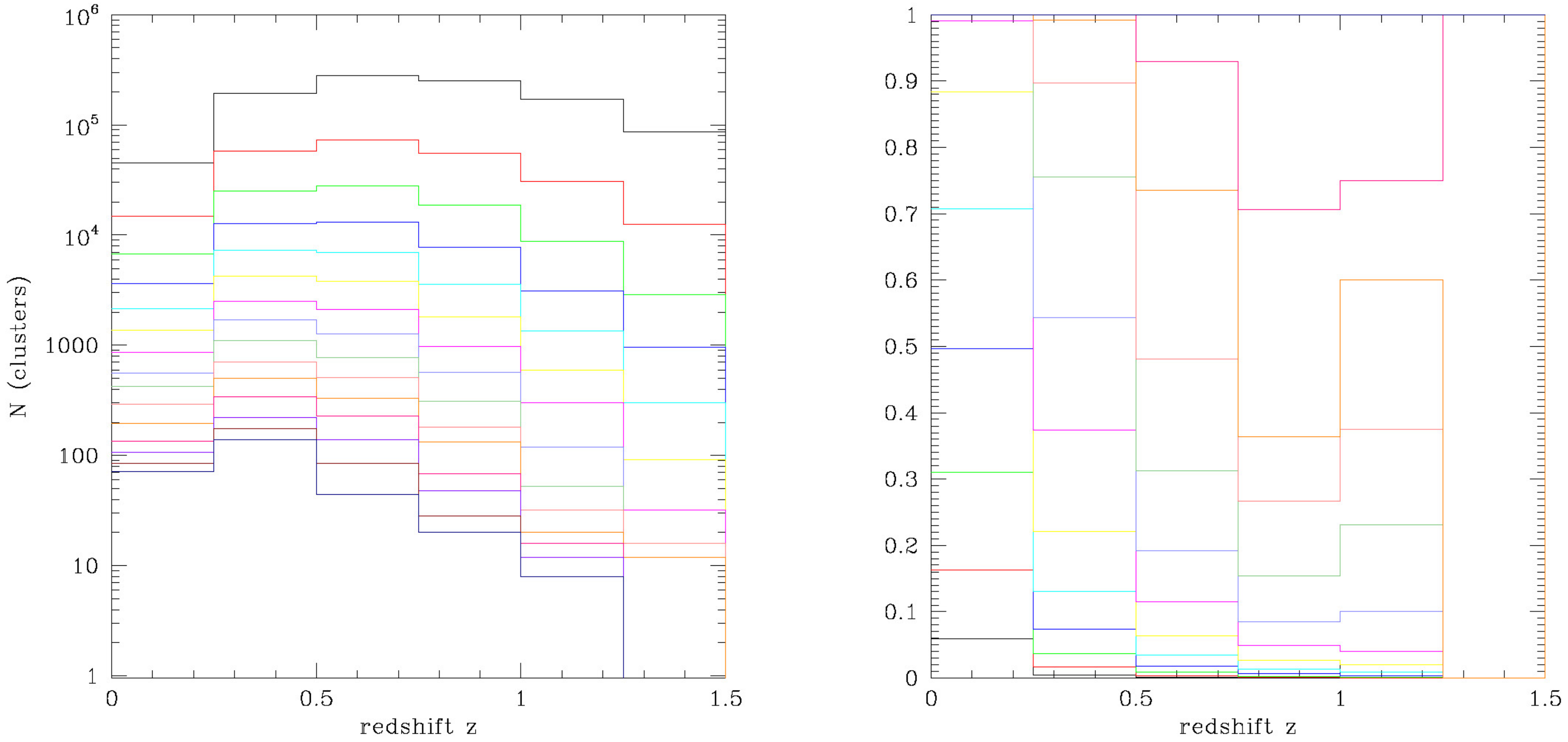
Recovered cluster fluxes

ΛCDM: $\sigma_8 = 1$ (virial) ΛCDM: $\sigma_8 = 0.7$ (virial) ΛCDM: $\sigma_8 = 0.7$ (xnorm)



Scatter, completeness and purity for a variety of cosmological SZ realisations.

Mass function and completeness in redshift bins



Outlook

- First generation (testing) SZ survey instruments (interferometers) beginning to take data: SZA, AMI (known clusters until spring 2006, surveys from summer), limited by radio source confusion until large telescopes, e.g. Ryle array, become available.

- Second generation (fast surveying), large bolometer arrays on single telescope, starting soon, e.g. APEX-SZ engineering run this year, full commissioning spring 2006.

- High sensitivity SZ cluster data are very interesting to explore gas physics

- SZ will provide high-z clusters to study evolution and large samples to constrain cosmology, hopefully with advantageous selection

- Multi-wavelength (optical,IR,X-ray,radio,sub-mm) (pre-)follow-up important

- Third generation (digesting) SZ instruments (high resolution imaging, SZ spectroscopy)