Structure of the ICM and its Evolution with Redshift: Status from SZE Observations

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Outline

- Existing SZE analyses
- Cluster selection in the SZE

SZE Data and Analyses

- The instruments
  - Bolocam, BIMA/OVRO, Ryle, SuZIE, ACBAR
  - AMI, AMIBA and SZA
  - ACT, APEX and SPT
- The science
  - Distance measurements
  - Gas masses
  - SZE scaling relations
  - SZE cluster surveys

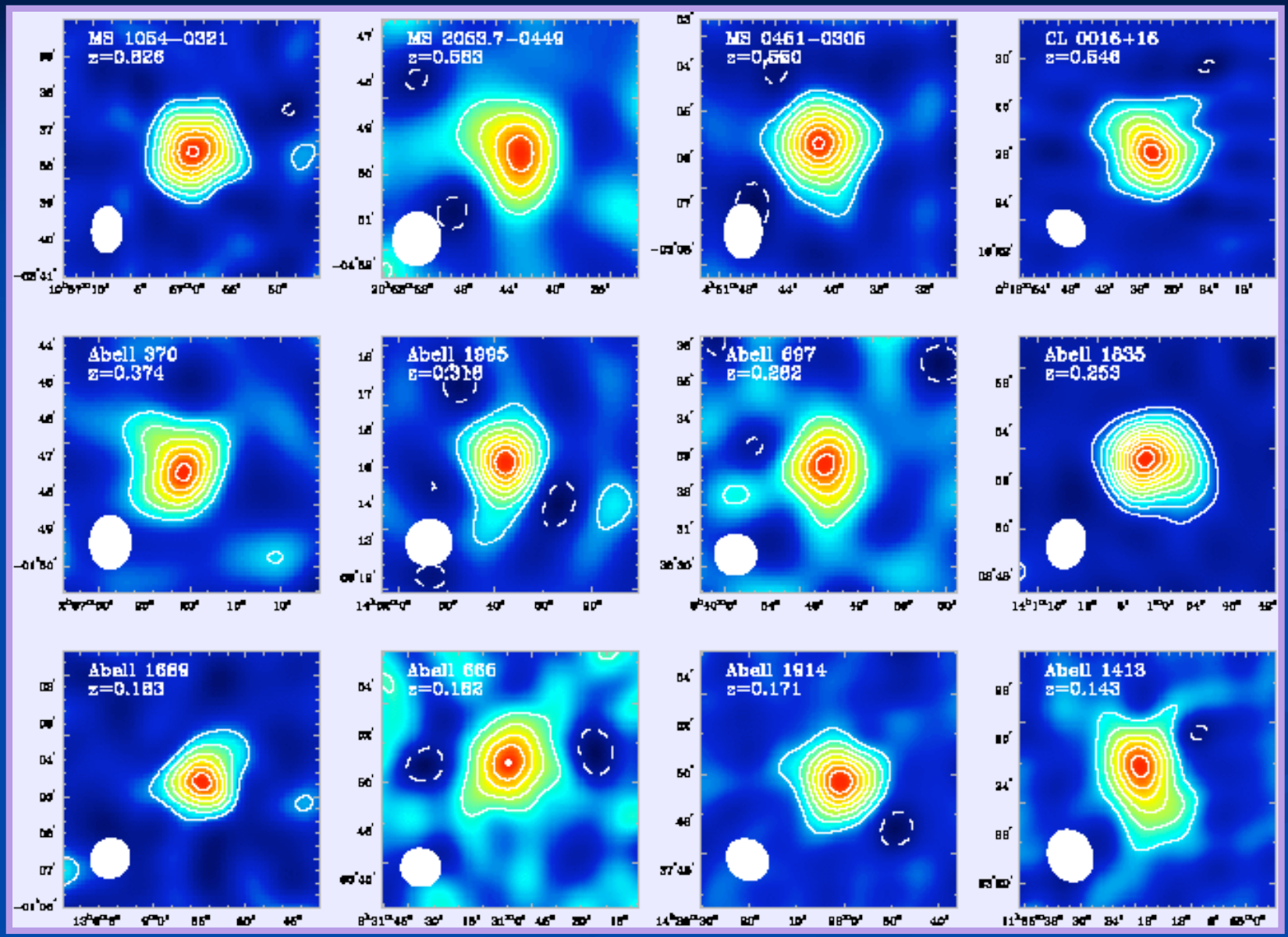

OVRO


CSO


BIMA


AMI/Ryle

Sample from 60 OVRO/BIMA imaged clusters, 0.07 < z < 1.03



Measuring Cluster Sizes and Distances

- X-ray surface brightness I_x

$$I_x(R) = \frac{1}{4\pi(1+z)^4}\frac{\mu_e}{\mu_H}\int dl\, n_e^2(l,R)\Lambda(T_e)$$

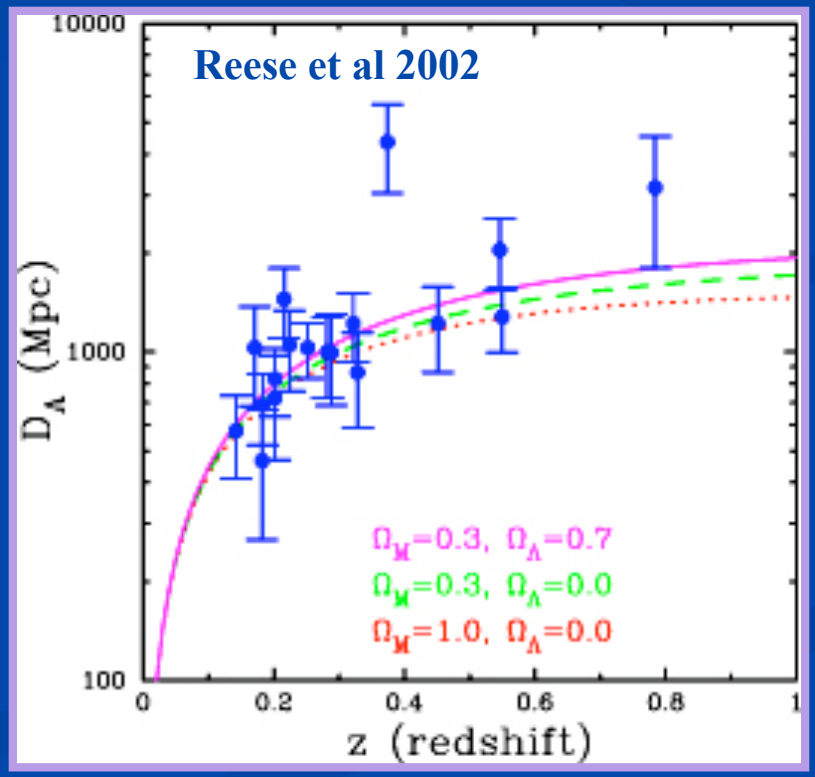
- SZE Decrement ΔT

$$\frac{\Delta T(R)}{T_{cmb}} = -2\frac{\sigma_T}{m_e c^2}\int dl\, n_e(l,R)\, k_B T_e(l,R)$$

Clusters as Isothermal, Constant Density Spheres

$$I_{xo} \approx 2Rn^2\Lambda(T_e)$$

$$\Delta T_o \approx T_{cmb} 2RnT_e$$

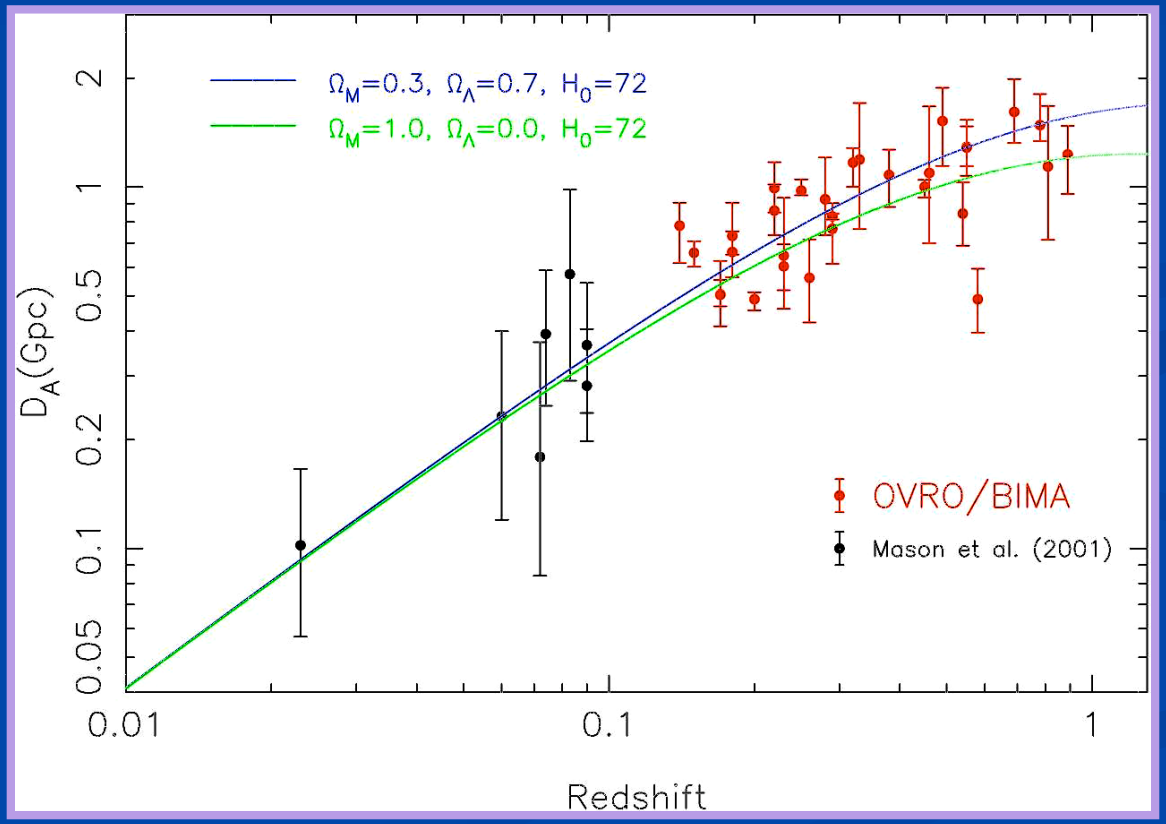


Mason et al 2001 (7 distances)
Udomprasert et al 2004 (7 distances)
Jones et al 2005 (5 distances)
Reese et al 2002 measured distances to 18 clusters (BIMA/OVRO+ROSAT), constraining Hubble parameter to

$$H_o = 60^{+4\,+13}_{-4\,-18}\ \mathrm{km/s/Mpc}$$

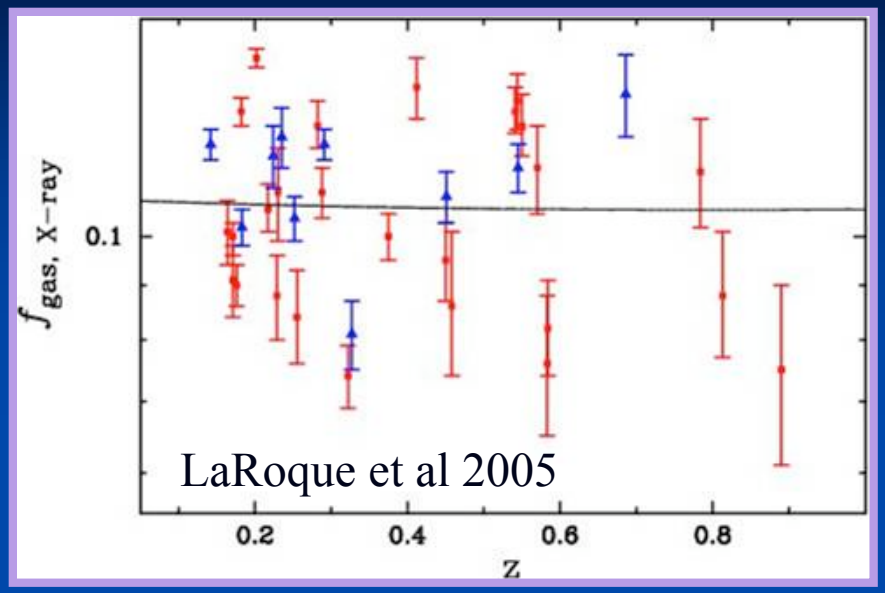
The SNe Ia Experiment with Clusters?

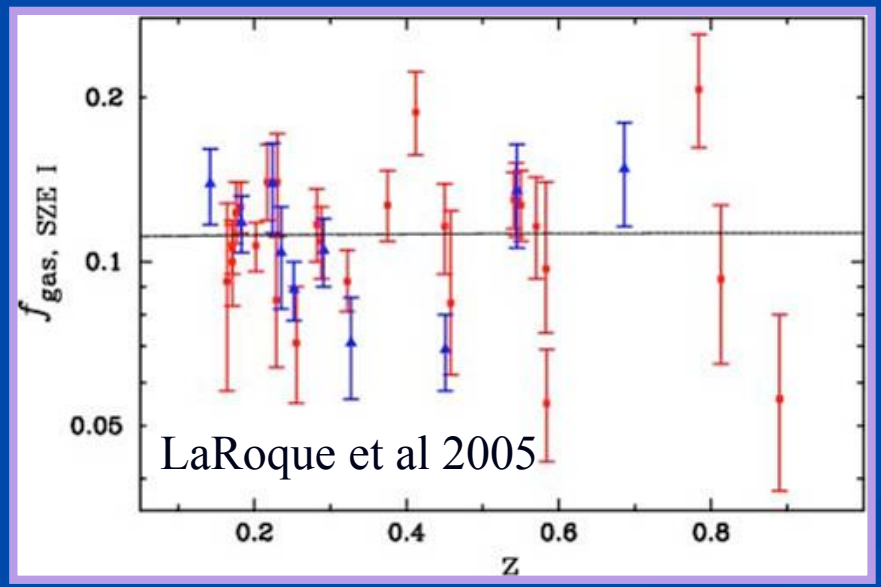
They have recently expanded their sample to 28 and are using Chandra X-ray data to measure distances. In combination with local distance measurements of Mason et al (2001), they can begin to probe the dark energy.



BIMA/OVRO SZE team, 2005

Recent Gas Mass Fractions





Gas mass fractions can be used to constrain Ω_m (SZE: Mason et al 2001, Grego et al 2001, Lancaster et al 2005)

Comparison between X-ray and SZE derived gas mass fractions allows one to constrain clumping in the gas.

This sample of 28 shows good agreement- no evidence for clumping

f_g(X-ray) = 0.109±0.003

f_g(SZE) = 0.115±0.005

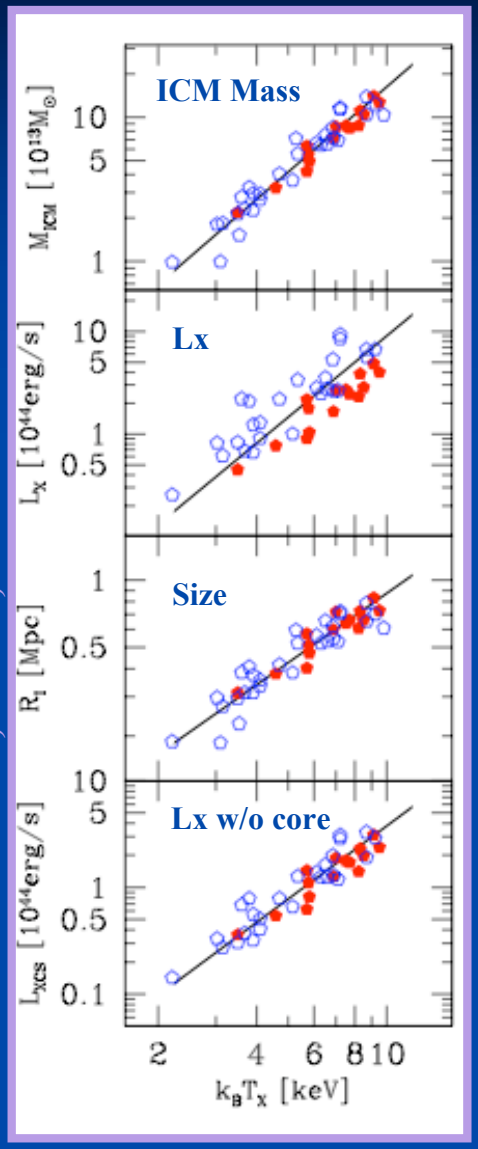
Cluster Scaling Relations

- The relationships among crude cluster observables like luminosity, temperature, isophotal size, mass, and galaxy number provide a wealth of information
  - Slopes of scaling relation reveal departures from self-similarity (preheating, cooling, galaxy processing, etc)
  - Amplitudes and redshift evolution of scaling relations are critically important for analyses of clusters and surveys
  - Scatter about scaling relations provides quantitative measure of similarity of galaxy, gas and dark matter properties for a cluster of a given mass
  - Clusters are, to a large degree, a one parameter family where mass is the fundamental parameter

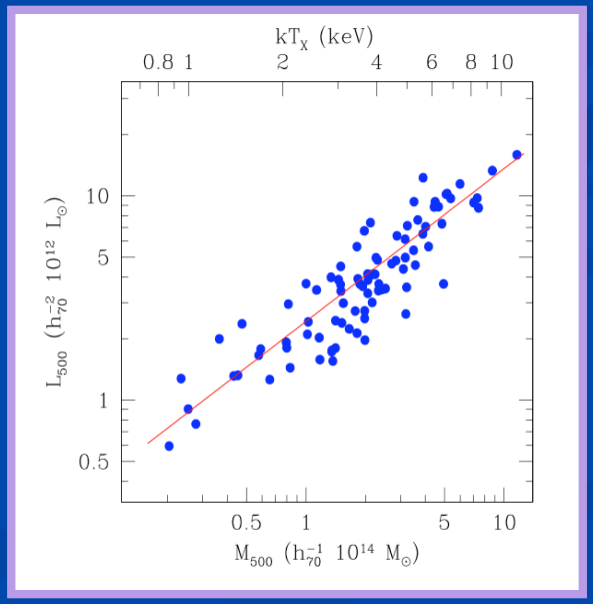
Observed Scaling Relations

- X-ray scaling relations are well established
- Optical and NIR scaling relations are being established (I am pleased that people are focusing on the virial region rather than fixed metric regions- *It's time to retire Sir Abell and his Radius*)
- But what about SZE scaling relations?

O'Hara, Mohr, Bialek & Evrard 2005

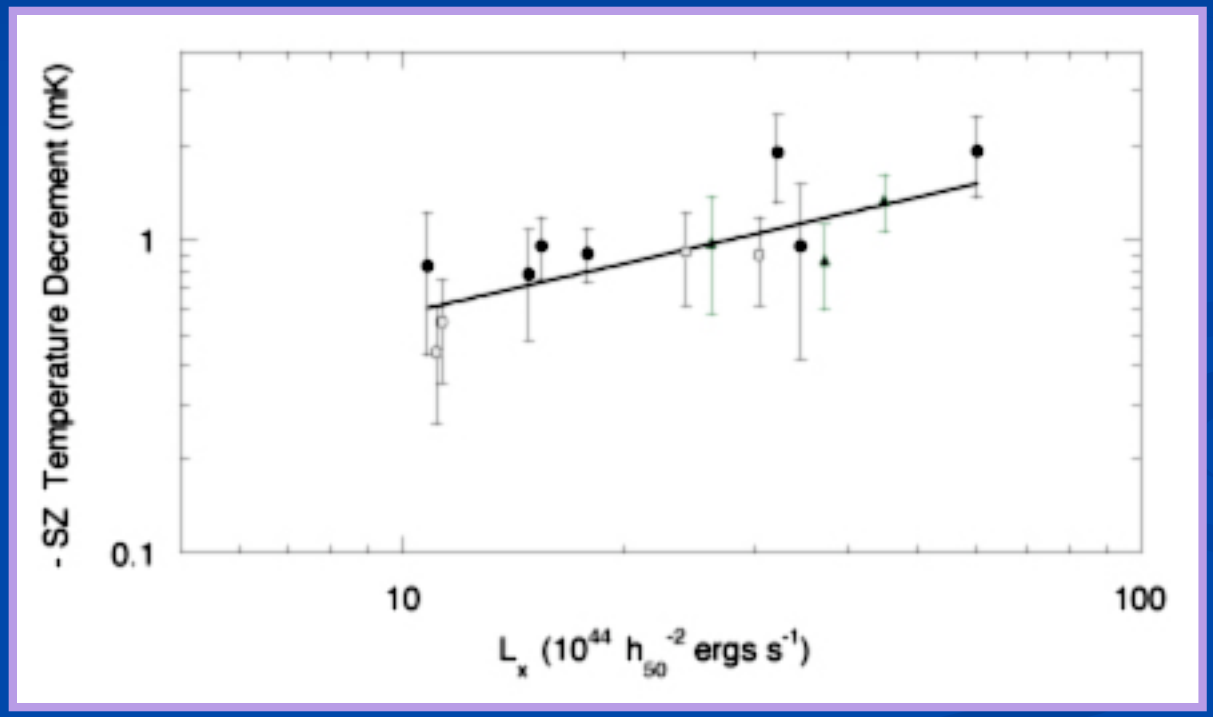


Lin, Mohr & Stanford 2004



Cluster SZE Scaling Relations

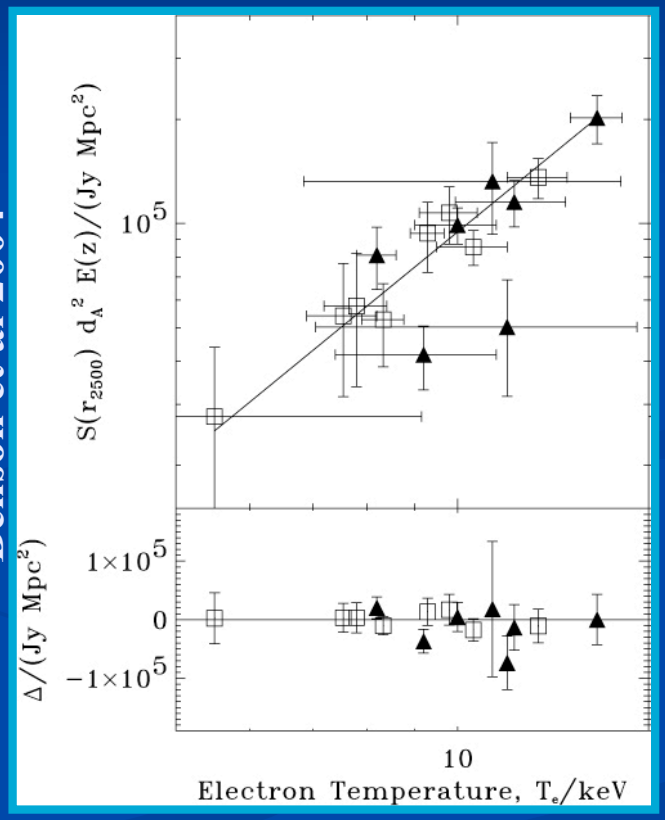
- Asantha Cooray published the first SZE scaling relation
  - Central SZE decrement versus X-ray luminosity for 14 clusters, where data are culled from the literature from a variety of sources



Cooray 2001

Cluster SZE Scaling Relations

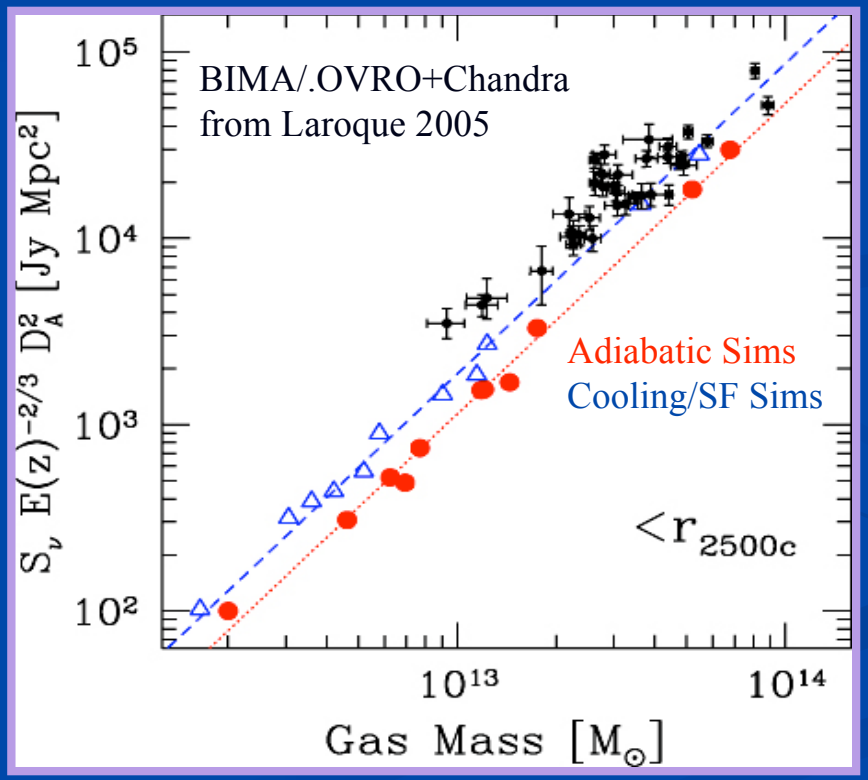
- SuZIE II observations of 15 clusters by Sarah Church's group have yielded the second SZE scaling relations
- Slope is consistent with self-similar expectation, and redshift evolution is *detected* with 90% confidence. Also claim to see CC related effects (?)
- Signal to noise is still an issue, but with instruments like the SZA and AMI it should be possible to examine the intrinsic scatter in SZE-X-ray scaling relations starting very soon



Cluster SZE Scaling Relations

- BIMA/OVRO observations also provide a scaling relation, which has been compared to scaling relations in hydrodynamical simulations
  - Integrated SZE within R_{2500} versus M_{icm} within r_{2500}
  - Expectation is that the intrinsic SZE luminosity- mass relation will have very small scatter and be rather insensitive to the thermodynamic history of the ICM…

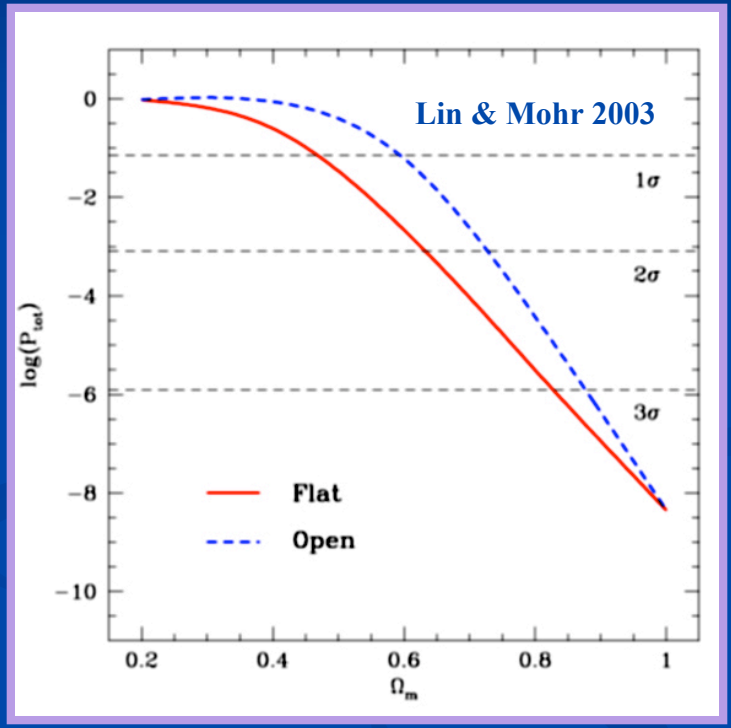
Nagai 2005



SZE Surveys

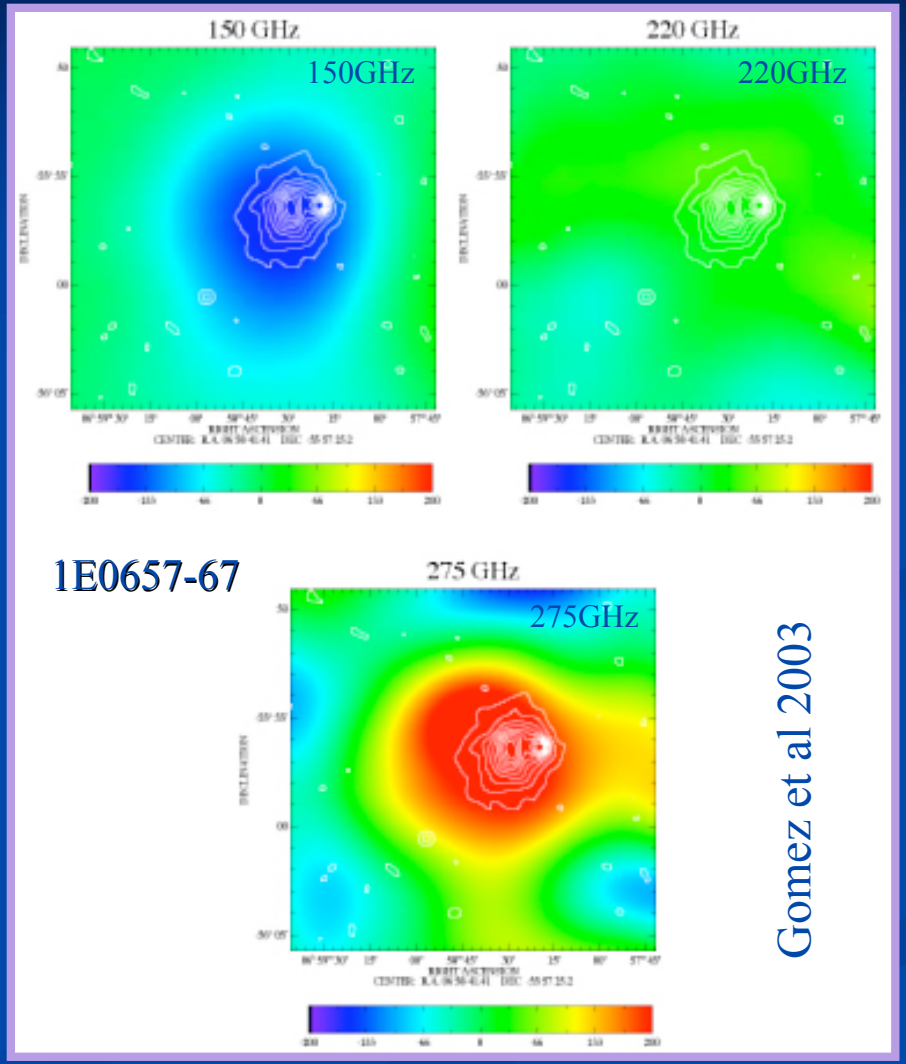
- SZE "Blind surveys" have so far been aptly named

- Nevertheless, there have been some scientific successes
  - Subha Majumdar carried out the first SZE survey analysis (Majumdar and Subrahmanyan 2000)
    - Result: Ω_m must be low given 1) ATCA upper limits on arcminute scale anisotropy + 2) COBE anisotropy constraints
  - Lin and Mohr (2003) carried out second SZE survey analysis
    - Result: Ω_m must be low given 1) non-detections in 0.1 deg^2 *deep* BIMA anisotropy fields (Holzapfel et al 2001) + 2) COBE anisotropy constraints
  - Dawson et al have pursued even deeper BIMA/OVRO fields and some optical followup, but no solid cluster candidates have emerged



ACBAR Survey

- ACBAR (led by Bill Holzapfel) is a multifrequency, 4 arcminute beam bolometer deployed on the 2.5m Viper telescope at the South Pole
  - Beam scale (similar to Planck high frequency) has made it challenging to separate cluster signal from the primary CMB anisotropy
  - Have targeted known clusters
  - Observations of a new ACBAR deep field are just now ending

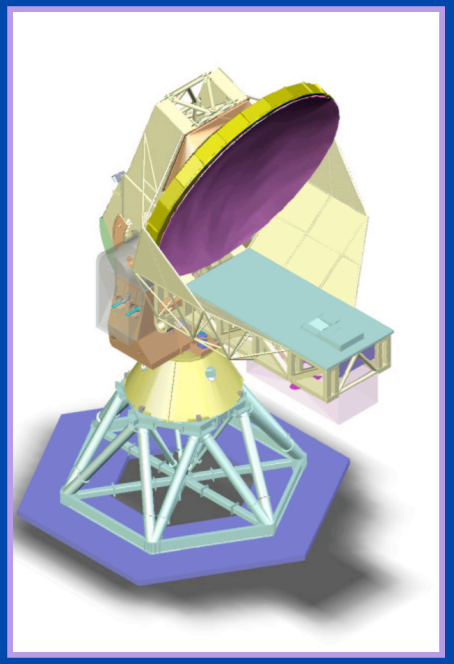


New Generation of SZE Interferometers

- SZA and AMI are online (first results in review talk by Clem Pryke tomorrow)
  - 100X more sensitive than BIMA/OVRO
- AMiBA expected by the end of the year
  - Even more sensitive than SZA and AMI

Arcminute Resolution, Multi-frequency CMB Mapping Telescopes

- Atacama Pathfinder Experiment (APEX)- 12m w/150 bolometers
  - MPIfR + UC Berkeley, engineering run Dec '05, science Spring '06
- Atacama Cosmology Telescope- 6m w/10^3 bolometers
  - Led by Lyman Page, 2007 deployment
- South Pole Telescope (SPT)- 10m w/10^3 bolometers
  - Led by John Carlstrom, Nov '06-Jan'07 deployment



(SZE) Cluster Survey Cosmology

- Precision cosmology with samples of 10^4 clusters requires new approaches
  - Cluster redshifts using photo-z's
  - Cluster mass-observable scaling relations must be calibrated
    - from within: dN/dz + P(k) + dN/dM(z) (self-calibration)
    - from without: crude (but unbiased) weak lensing mass measurements
    - Scatter about relations must be measured to 10% accuracy (Lima & Hu 2005)
  - Cluster selection must be well understood (1% to 5% level)
    - Require moderate solid angle, medium-depth X-ray survey to calibrate SZE selection
- Multiwavelength approach required

Overview

SZE observations with available instruments have been used successfully to study the ICM and cosmology

- X-ray+SZE distances measured
- SZE gas mass fractions
- SZE scaling relations
- SZE surveys have been attempted

New generation of interferometers are online now

- AMI and SZA are approximately 100 times more sensitive than BIMA/OVRO
- Cluster science and targeted surveys imminent

Large scale SZE Survey Cosmology has arrived before the instruments!

- APEX, ACT and SPT will all come on line within 1.5yrs…
- Cluster radio galaxies may be a challenge even for the high frequency experiments- Yen-Ting Lin is leading a multi-frequency survey of a sample of ~200 known cluster radio galaxies to better constrain their spectra up to 43GHz. Obs at 90GHz with SZA are likely. Observations with APEX, ACT and SPT guaranteed (unfortunately!)
- Preparations underway for coordinated, multiwavelength survey fields where cluster selection can be measured (X-ray component very important)