Atacama Cosmology Telescope SZE Cluster Survey: XMM-Newton X-ray Follow-up

John P. Hughes
(Rutgers University)
for the ACT Collaboration

Atacama Cosmology Telescope

P.I.: Lyman Page (Princeton)

A New Generation Temperature Experiment

ACT with Unfinished Ground Screen

D. Swetz at the site with ACT Receiver

ACT aims to make high-resolution (1'), low-noise (1μK) maps of the CMB

- The emergence of structure manifests itself as non-Gaussian features in a map, with both compact and diffuse components.

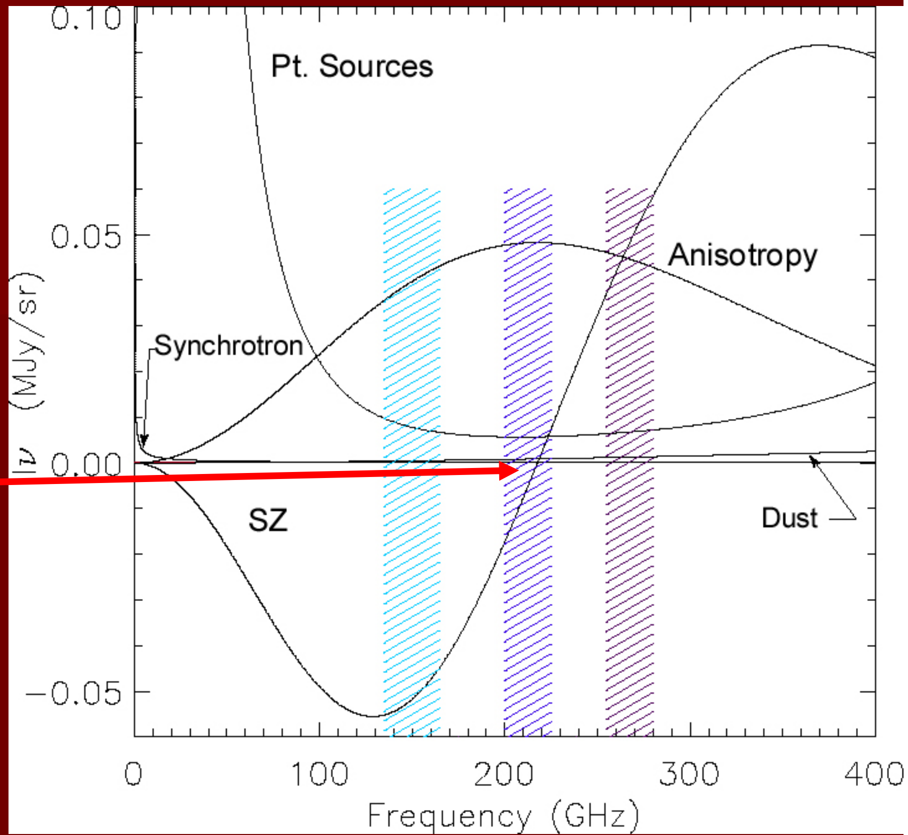
- The detail to which these are understood depends directly on the *quality* of the map.

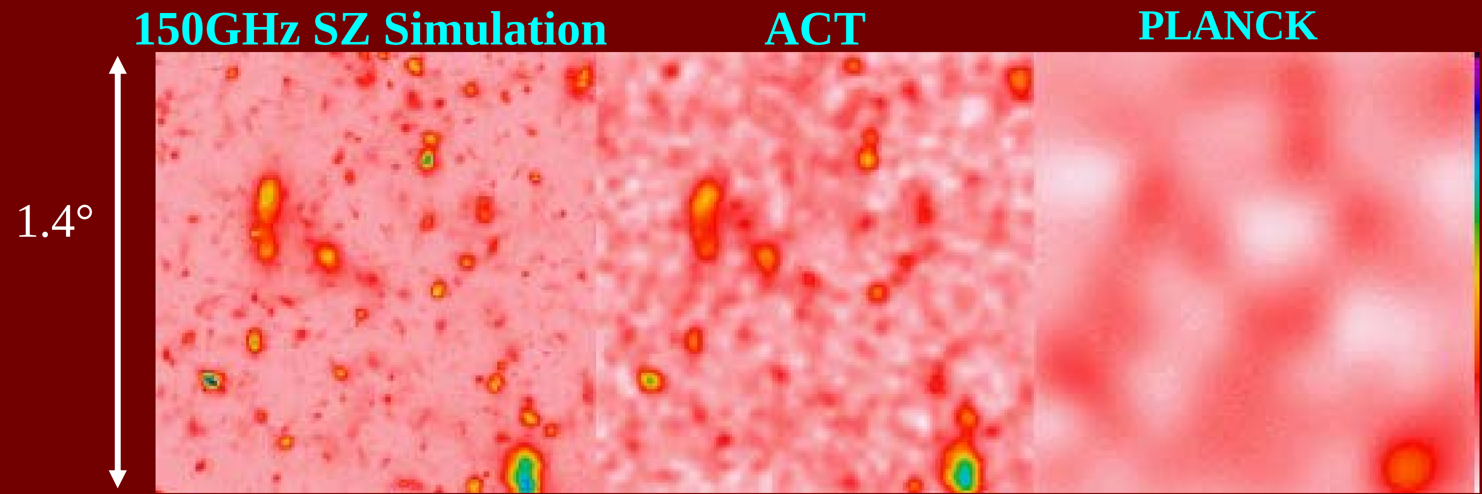
- High fidelity maps facilitate direct comparisons to other surveys e.g., PLANCK, Spitzer, HST, GALEX, XMM-LLS, ...

- Allow calibration with WMAP anisotropy.

Thermal SZ effect

- Inverse Compton Scattering
  Hot cluster electrons boost energy of CMB photons
- Spectral Signature
  ACT bands bridge SZ null
- Redshift independent
  “clean” cluster selection
- tSZ Effect proportional to $n_e T$
  probes cluster pressure

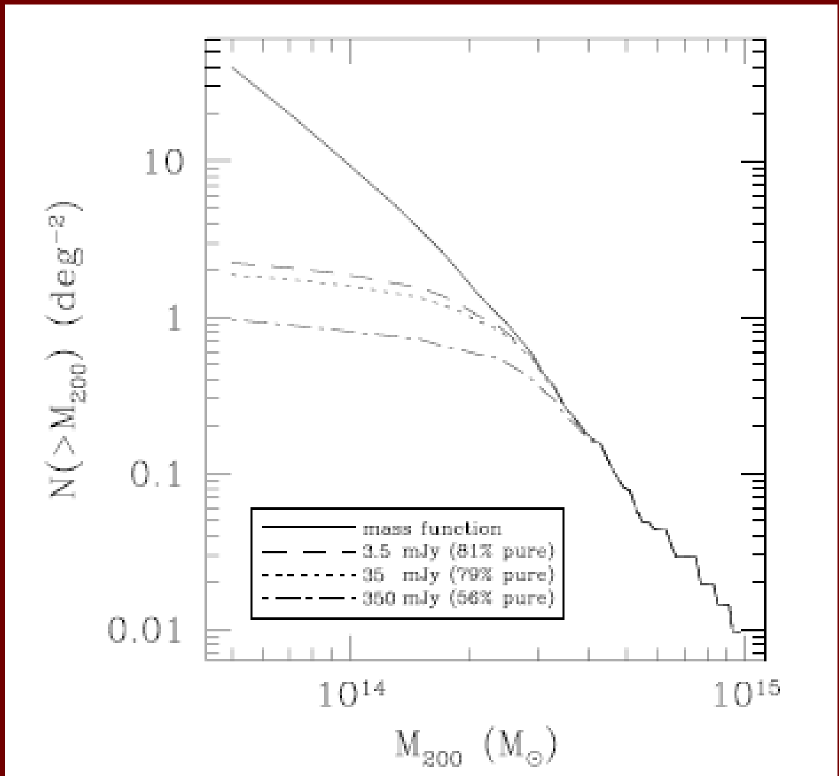




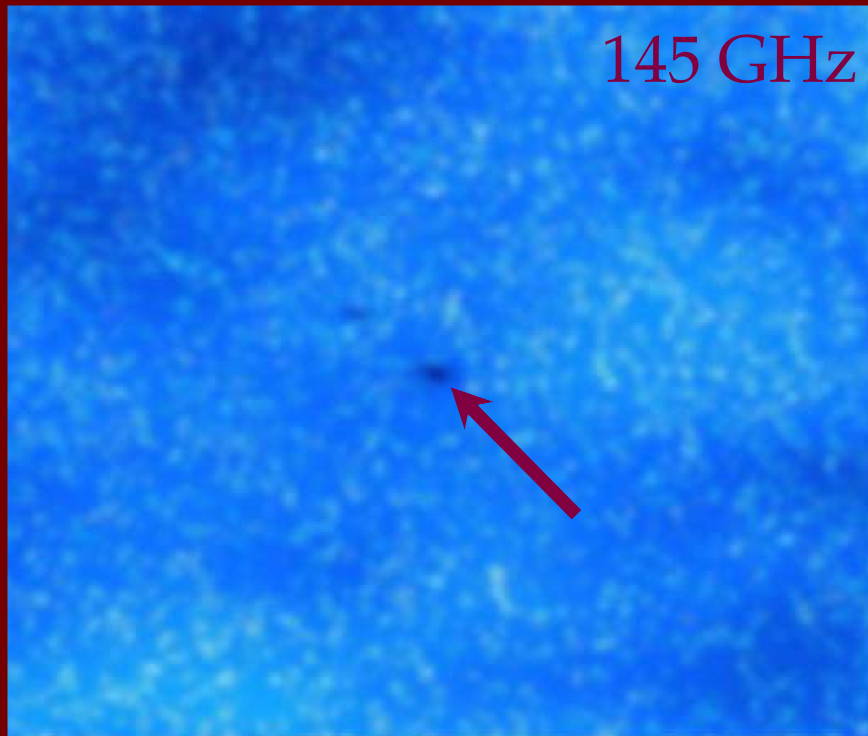
(Seljak and Burwell 2000)

From ACT simulations

Cluster detection in presence of point sources (3-bands combined)



Simulated maps in 3 bands

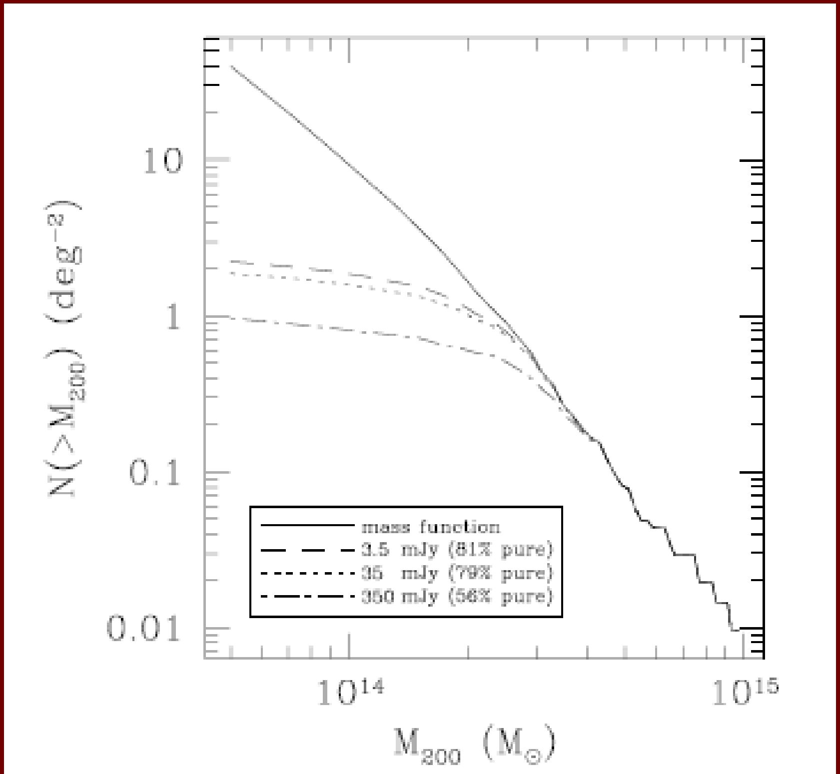


Expect ~ 1-2 cluster/deg^2

Sehgal et al. 2007

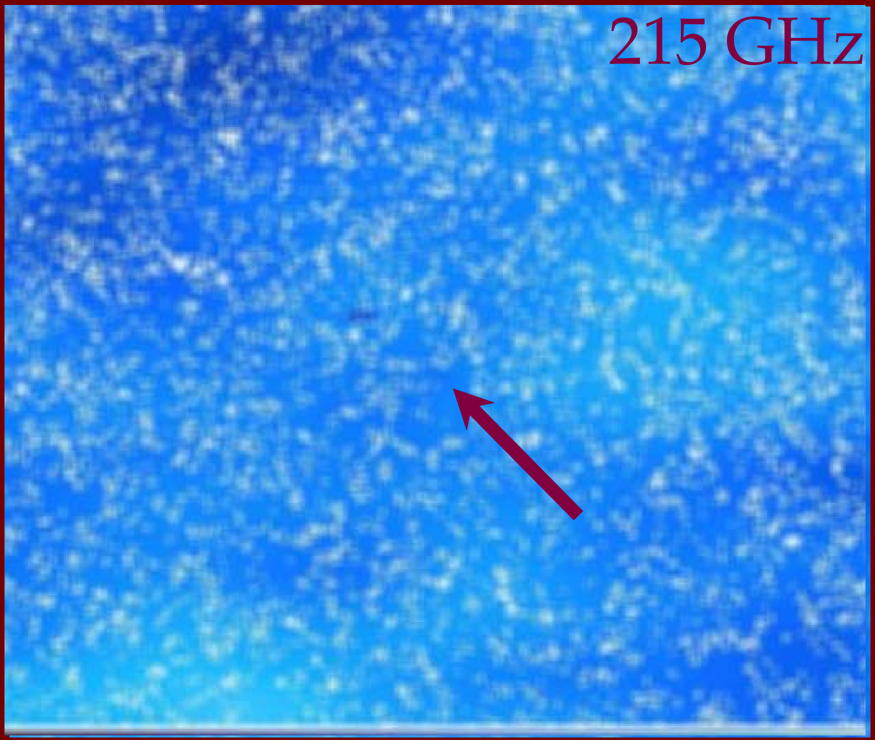
From ACT simulations

Cluster detection in presence of point sources (3-bands combined)



Expect ~ 1-2 cluster/deg^2

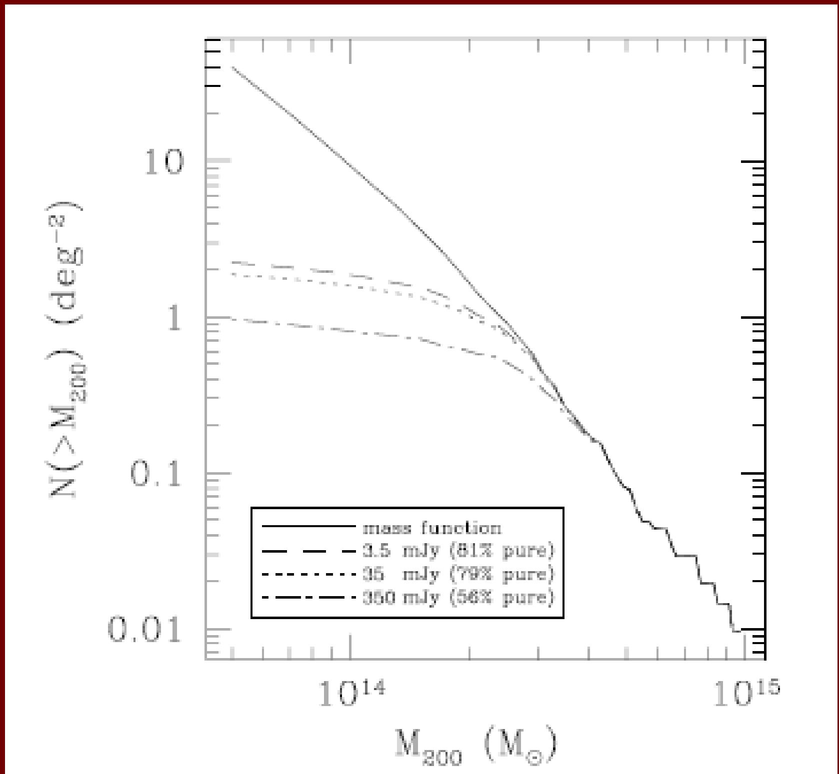
Simulated maps in 3 bands



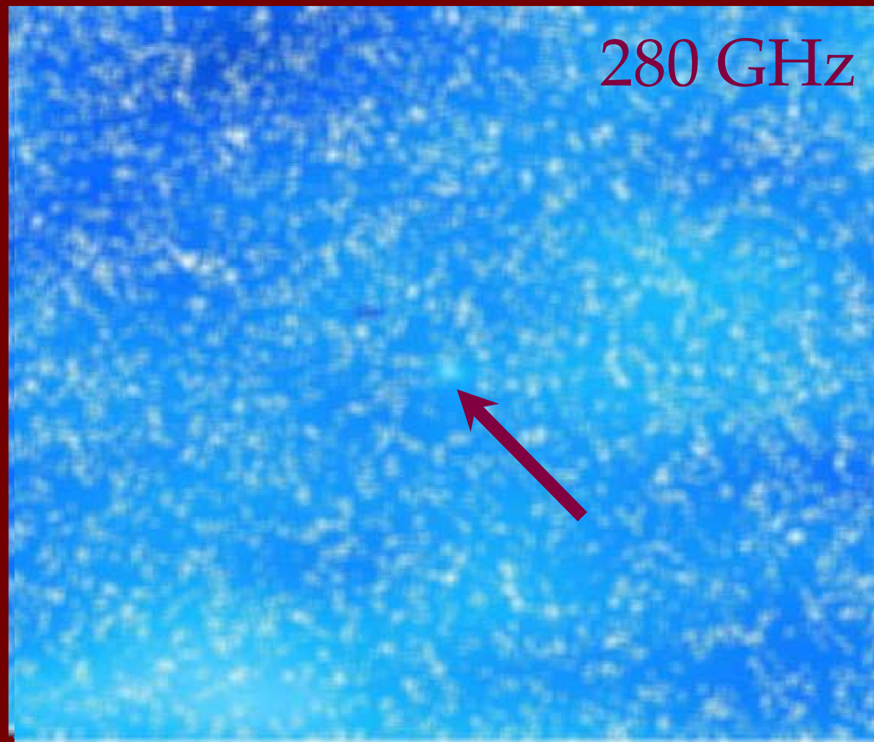
Sehgal et al. 2007

From ACT simulations

Cluster detection in presence of point sources (3-bands combined)



Simulated maps in 3 bands



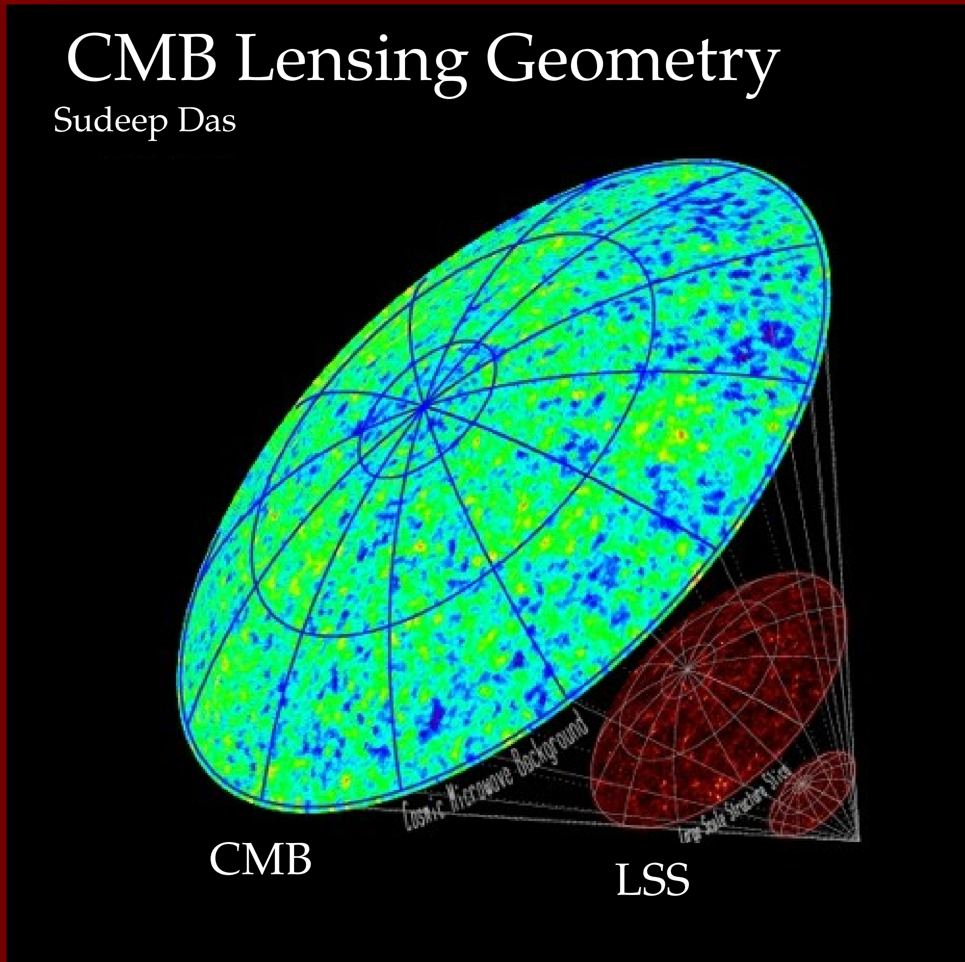
Expect ~ 1-2 cluster/deg^2

Sehgal et al. 2007

Lensing measurements of structure growth

- CMB lensing measures the integral mass distribution to z = 1100.

- CMB Lensing with multifrequency estimates of LSS at later epochs can better determine growth of structure.



ACT Site

5200 Meters high in the Atacama desert in the Andes of northern Chile

ACT Site

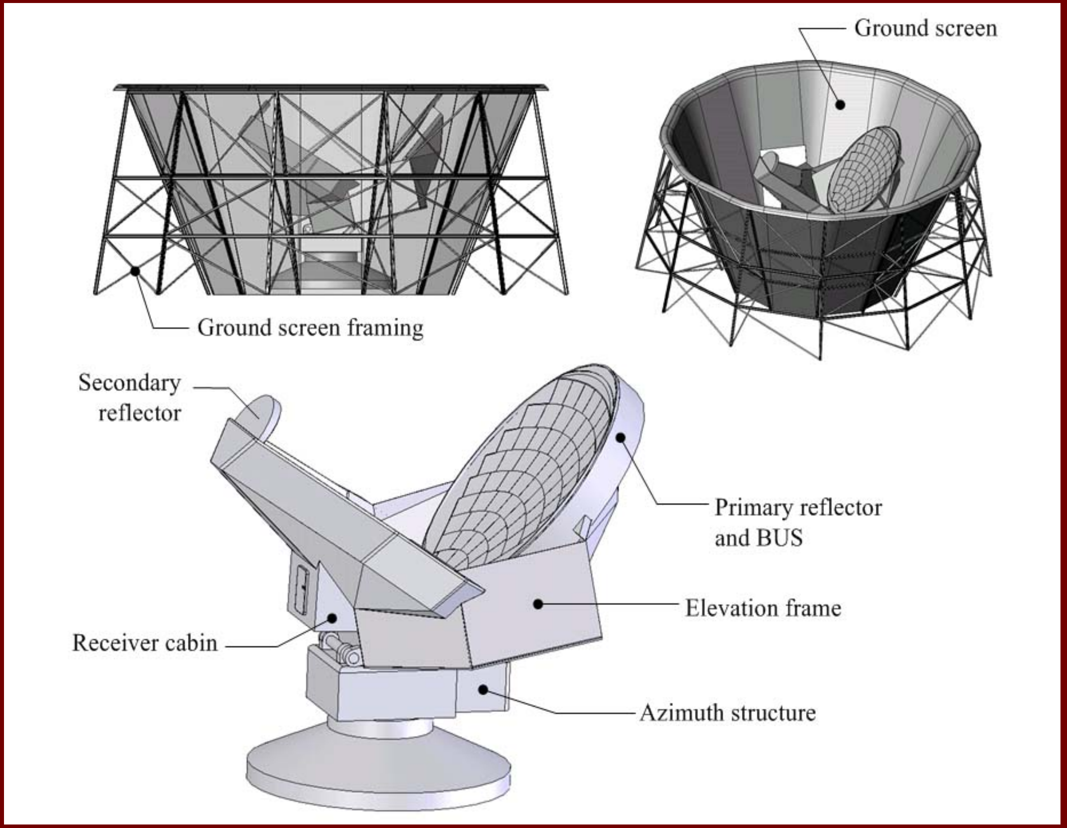
5200 Meters high in the Atacama desert in the Andes of northern Chile

Telescope

Telescope Lead: M. Devlin (UPenn)

- 6 Meter Aperture (F~1)
- Low Ground Pickup (< 20μK dc)
- No Moving Optics
- Scan in azimuth by 5^{o} in 5-6 s

- Remote Controlled
- Flexible Focal Plane
- Near the ALMA Site
- Highly rigid structure



No existing telescope incorporates the features required for these measurements.

Extreme control of potential systematic errors.

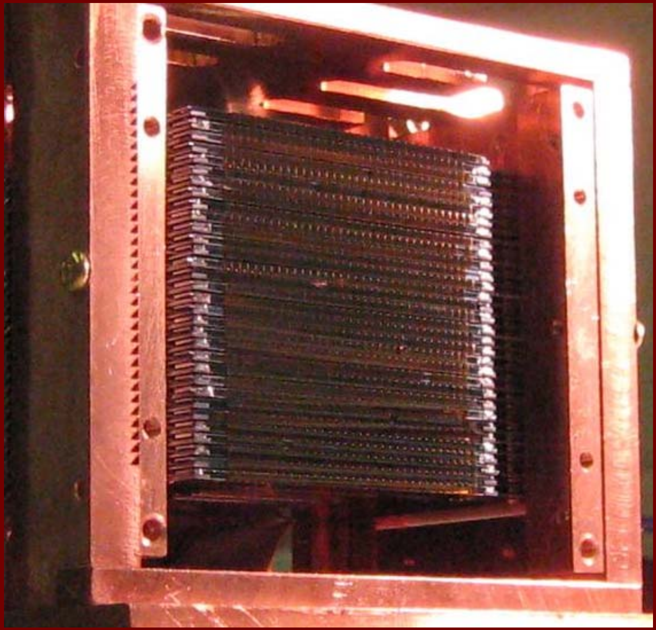
Installation of telescope

Chile, March/April 2007
Chile, May 2007

Photos by Site Coordinator: M. Limon (Columbia)

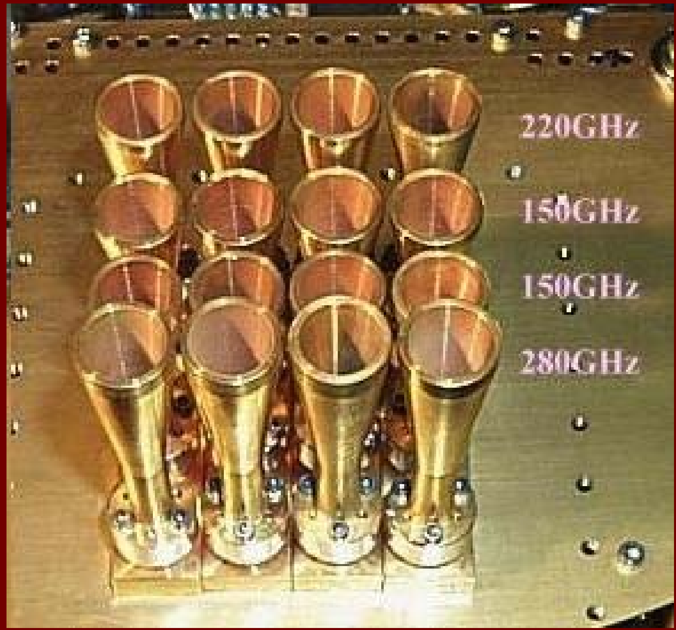
Focal Plane Evolution

ACT



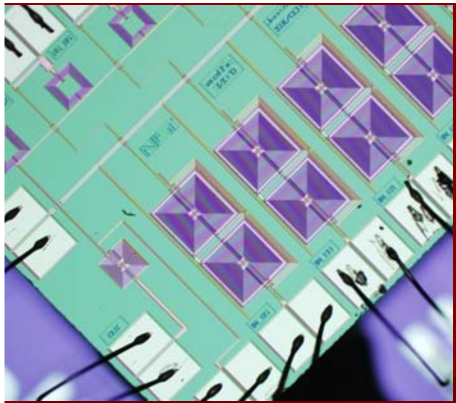
2007: 1000 x 145 GHz

ACBAR

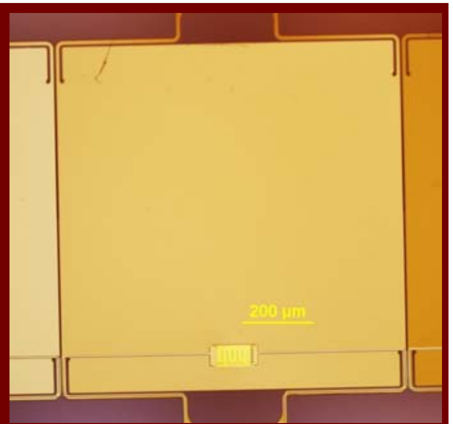


2005: 16 x 150 GHz

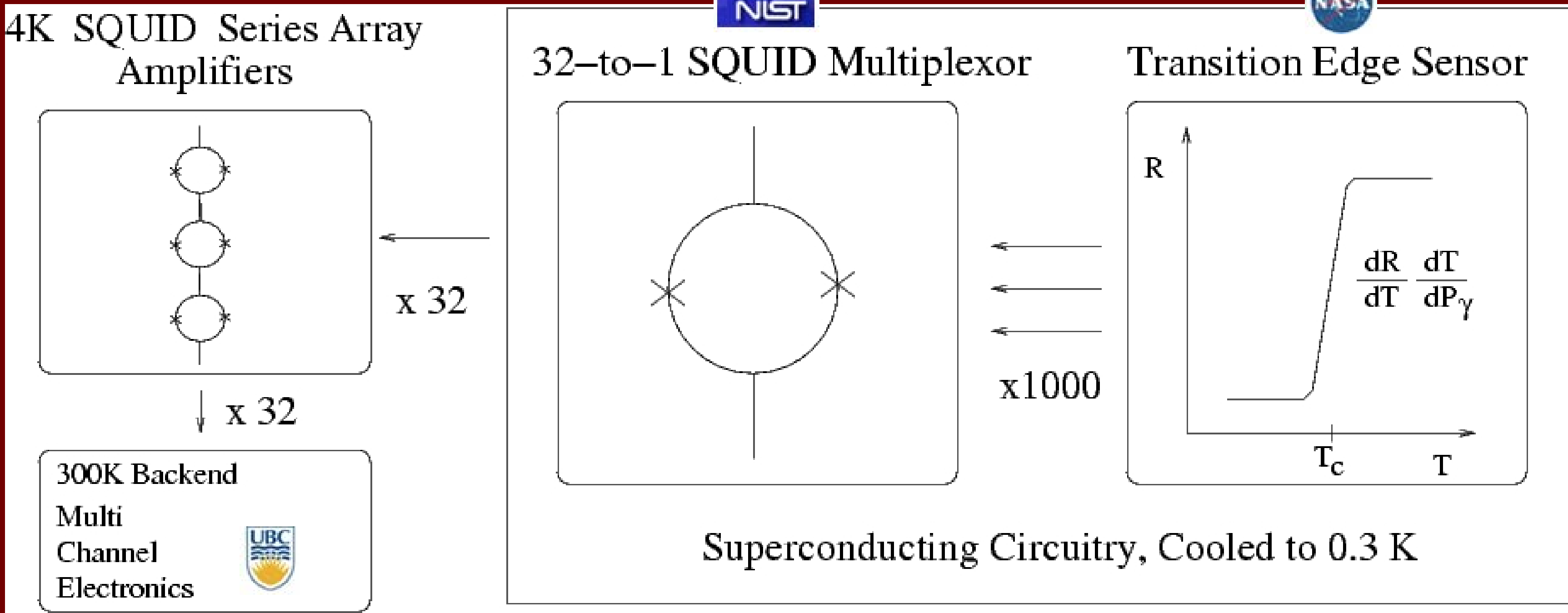
(ACT 2008: 1000 x 145 GHz, 1000 x 215 GHz, 1000 x 280 GHz)



ACT Detectors



Detector Lead: S. Staggs (Princeton)

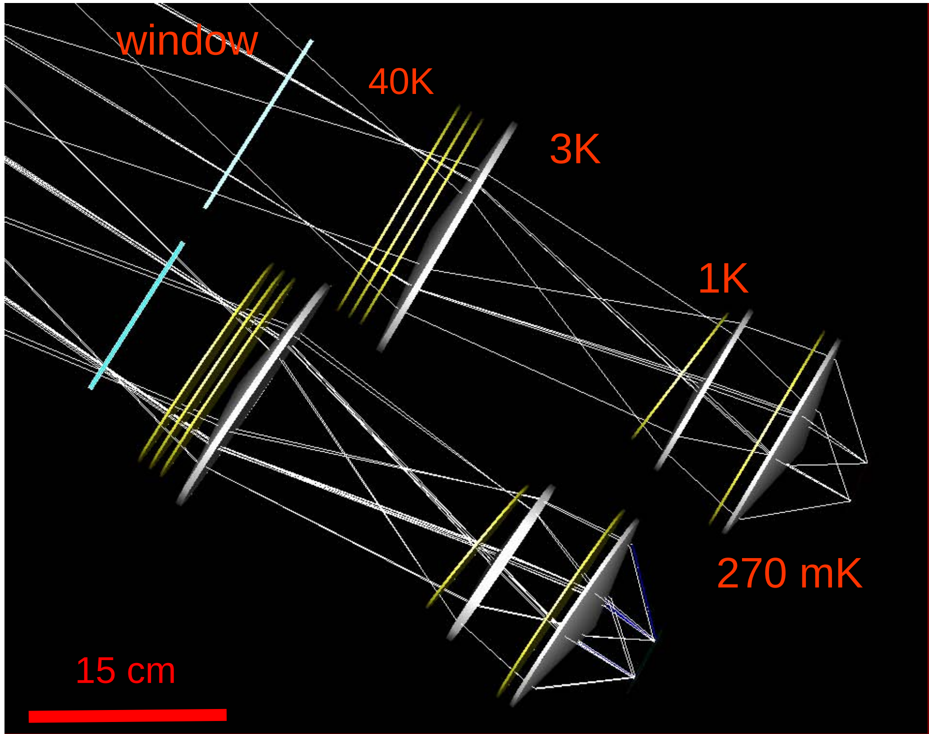


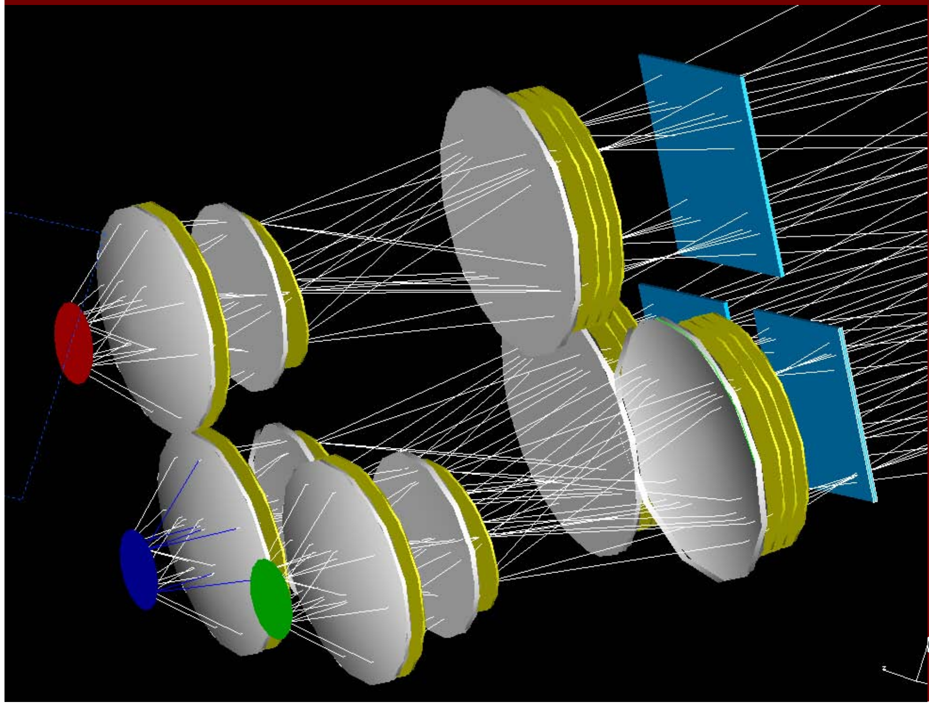
Bolometer: H. Moseley (NASA Goddard)
SQUID Multiplexing: K. Irwin (NIST Boulder),
MCE: M. Halpern (UBC, SCUBA2).

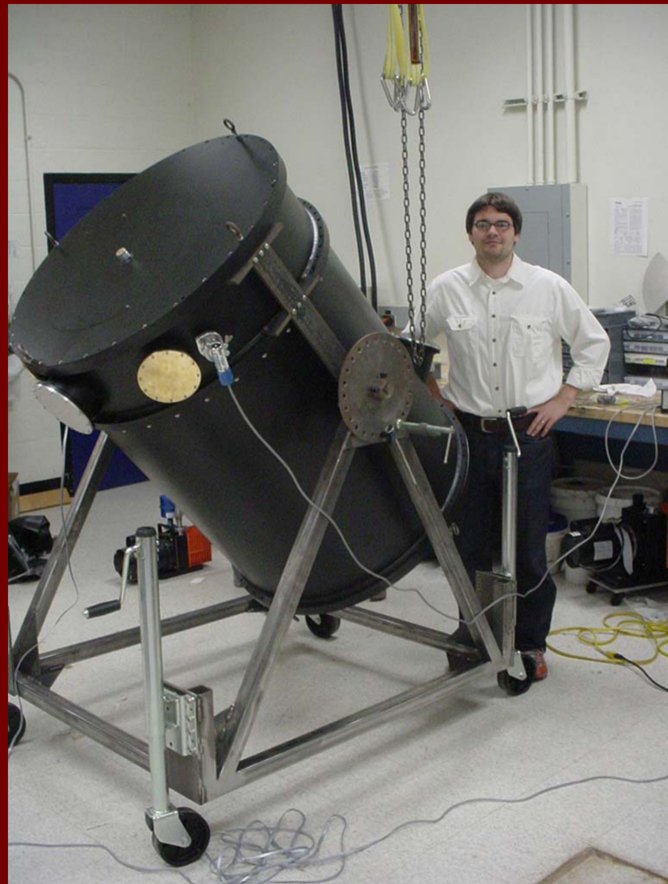
Optical Design

3 separate optics assemblies for each beam (145, 215, 280 GHz)

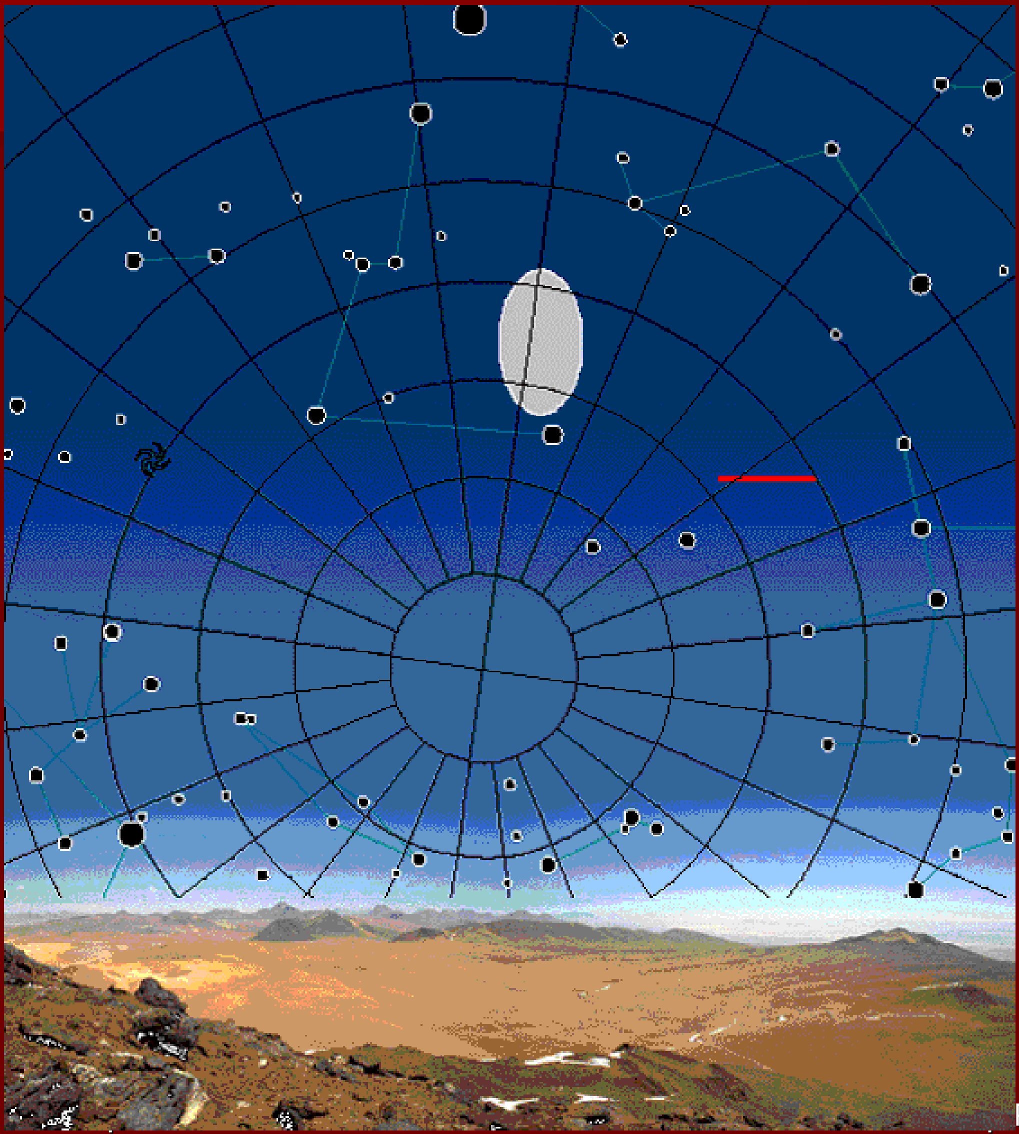
Incomplete frequency coverage at scan edges





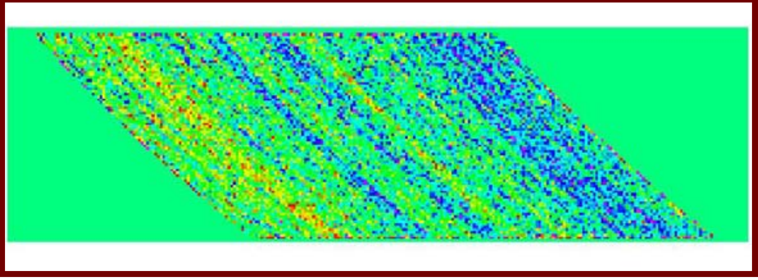


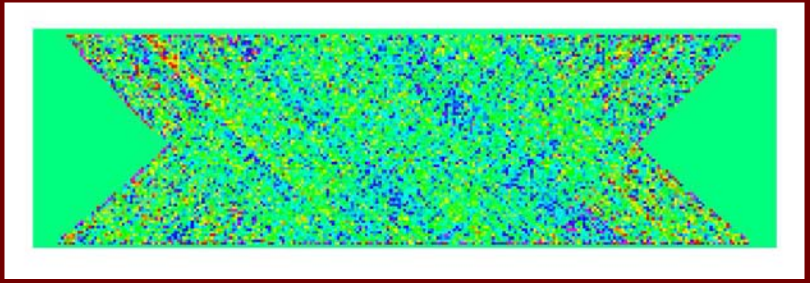
Observing Strategy: Cross Linked Scans



- 240 square degrees in circle
- 100 square degrees for CMB
- Connect to MAP satellite for calibration

No cross-linking





Single cross-linked scan

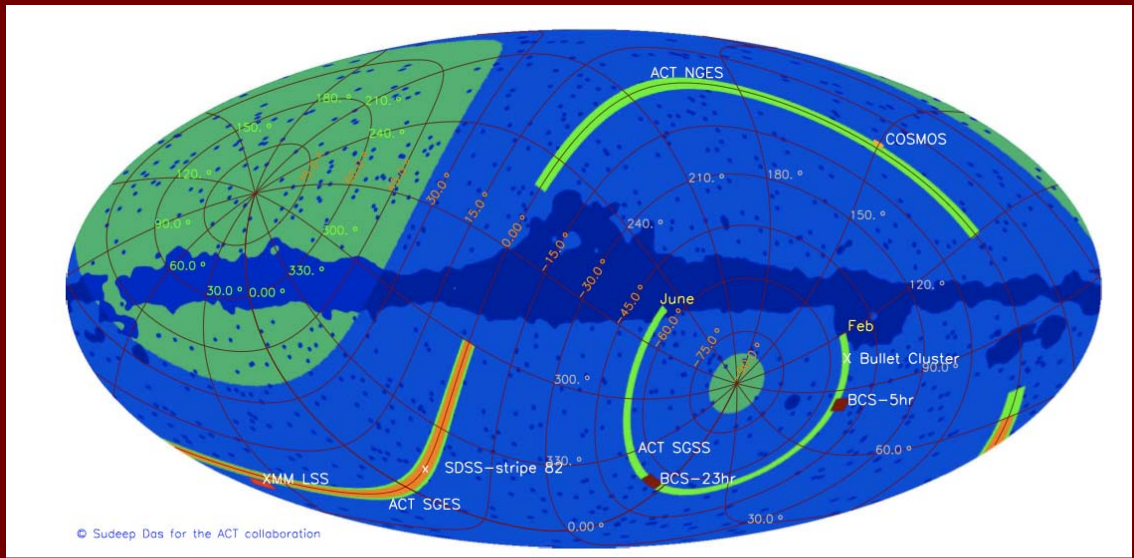
Simulations by Tobias Marriage

Observing

- 2007 Season Complete:
  30 Days with 1000-element 145 GHz detector array

- 2008 Season to commence in June for 6 months with 145, 215, and 280 GHz arrays

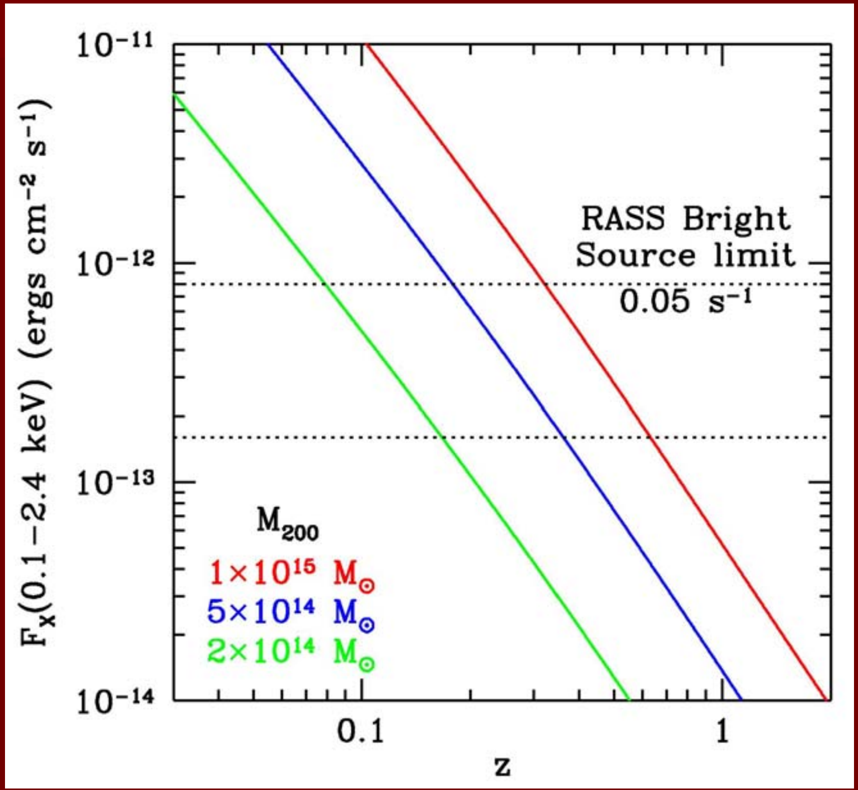
- 2009 Season:
  Another 6 months
  with three arrays



X-ray Follow-up

X-rays

- Mass limit from ACT SZE maps
  - 145 GHz band: approx. 0.5×10^{15} M_{sun}
  - 145, 215, 280 GHz bands: 0.3×10^{15} M_{sun}
- Convert M_{200} to T_X
  - $M_{200} = 4.42 \times 10^{13}\, T_X^{1.5}\, h^{-1}\, M_0$ (Evrard, Metzler, & Navarro, 1996, ApJ, 469, 494)
- Convert T_X to L_X (bol)
  - L_X (bol) $= 10^{45.06}\, (T_X/6\ \text{keV})^{2.88}\, h_{50}^{-2}$ ergs s^{-1} (Arnaud & Evrard 1999, MNRAS, 305, 631)
- Convert from bolometric L_X to band-limited L_X(0.1-2.4 keV)
- Plot F_X vs. Redshift
  - Most z>1 clusters $F_X < 10^{-14}$ ergs cm^{-2} s^{-1}



ACT 2008 Survey Strategy

Use both Wide and Deep Approaches

- Wide: few 1000 sq-deg
  - Enables accurate calibration to WMAP
  - Discover rare objects (e.g., high mass clusters)
  - Likely survey region: SDSS Stripe 82
- Deep: few 100 sq-deg
  - Reach ultimate noise level of ACT camera
  - Detect clusters to mass limit (2-3 x 10^{14} M_{sun})
  - Likely survey region: ACT strip (δ ~ -55°)
- Team making decisions now
  - 2008 survey begins in June (runs for 6 months)
  - Funding approved for 2009 observing season
- ACT is highly flexible
  - Can reach much of southern sky (from -70° to +20°)
  - "Minimum" size patch to survey δ~3°, α~1 hr

XMM Survey of ACT Clusters

Target SZE clusters with XMM

- Relate SZE-selected cluster sample to existing samples, specifically, X-ray ones
  - Correlate Y_X and Y_{SZ} using observations of clusters – currently done with simulations
- Critical issue for cosmology: relate cluster mass observable to mass
  - “Calibrate” a subsample of SZE-detected clusters with X-ray, weak lensing, galaxy velocity data
- Measure cluster peculiar velocities
  - Based on the kinetic SZ (kSZ) effect due to cluster’s motion with respect to CMB frame (faint signal: only 5-10 μK)
  - In principle 3-band SZE data allows extraction of τ, T, v_{pec}
  - In practice (ACT) only 2 quantities can be measured accurately
    - Addition of T_X estimate breaks degeneracy

XMM Survey of ACT Clusters

Advantages

- Cluster targets obtained for "free"
- Exposure times tuned to individual clusters for specific observation goals (e.g., temperature, metallicity, morphology)
  - Estimate M_{200} from SZE (will introduce some uncertainty)
- Can select subsamples of SZE clusters for specific science goals, such as
  - High redshift clusters
  - Evolution of mass function
- Minimum sample size ~100 clusters (depends on science goals)

High Impact Science

XMM Survey of ACT Clusters

Proposed survey does not address

- Differential selection function (SZE vs. X-ray)
  - Addressed by Boehringer's survey in the 6.5 sq-deg Common SZE Survey (ACT, SPT, ...) area, where there is optical and IR data already
  - ACT can scan the XMM-LSS region to double the sky area for assessing the selection function for clusters

Other Issues

- SZ cluster target lists do not yet exist
  - Soon (autumn) we will have samples of SZE-selected "blobs"
    - Likely quite secure (decrement, null, increment)
  - ACT to access photo-z estimates available in SDSS (100 's of sq-deg) and BCS (~100 sq-deg)
    - Good up to moderate redshifts z~0.5 to 0.8
  - ACT longer term: spectroscopic redshifts from SALT, IR observations from Chile

Conclusion

- Blind SZE cluster surveys
  - Long anticipated, now close to fruition
  - ACT obtained single-band (145 GHz) maps in Nov 2007
  - Ready for three-band survey beginning June 2008
  - Expect ~1-2 cluster/deg^2
- XMM survey
  - Best done as cluster by cluster follow-up program
    - Areal density of SZE clusters not high enough
    - Tune exposure times for science goals
  - Selection function can be studied with ACT surveys of current and existing XMM survey regions