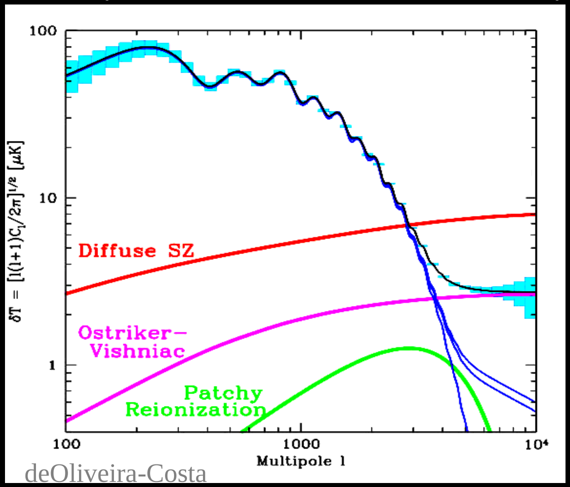
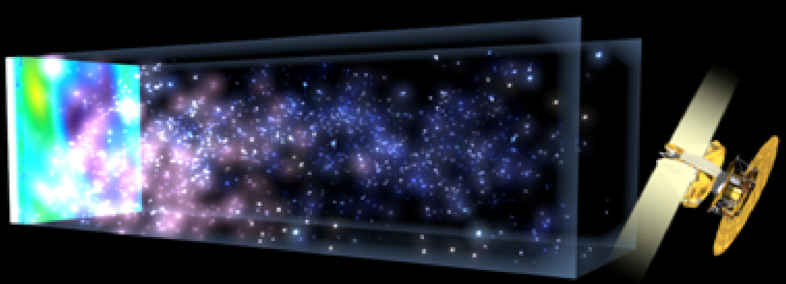
Ground-based CMB
Where are we going?

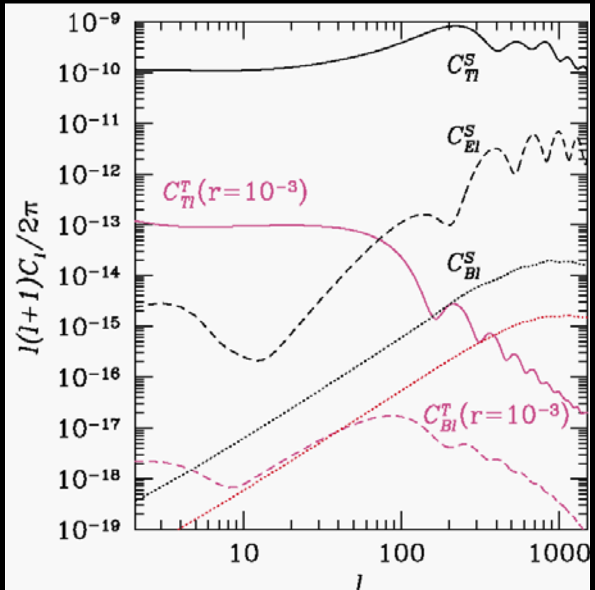
Small-Scale CMB Temperature anisotropy



The Sunyaev-Zel'dovich Effect



CMB Polarization Anisotropy



Small Scale CMB Anisotropy/SZE

Interferometers

o Very stable so long integrations possible

o Each field observed with many detectors, high angular resolution → deep, detailed images

o Simultaneous point source observations separable – long baselines used for point source removal, short baselines give cluster sensitivity

o Brightness sensitivity is limited

Will yield early survey results (100s of clusters), detailed cluster observations

Photo Credit: Leitch

Bolometer Array Instruments

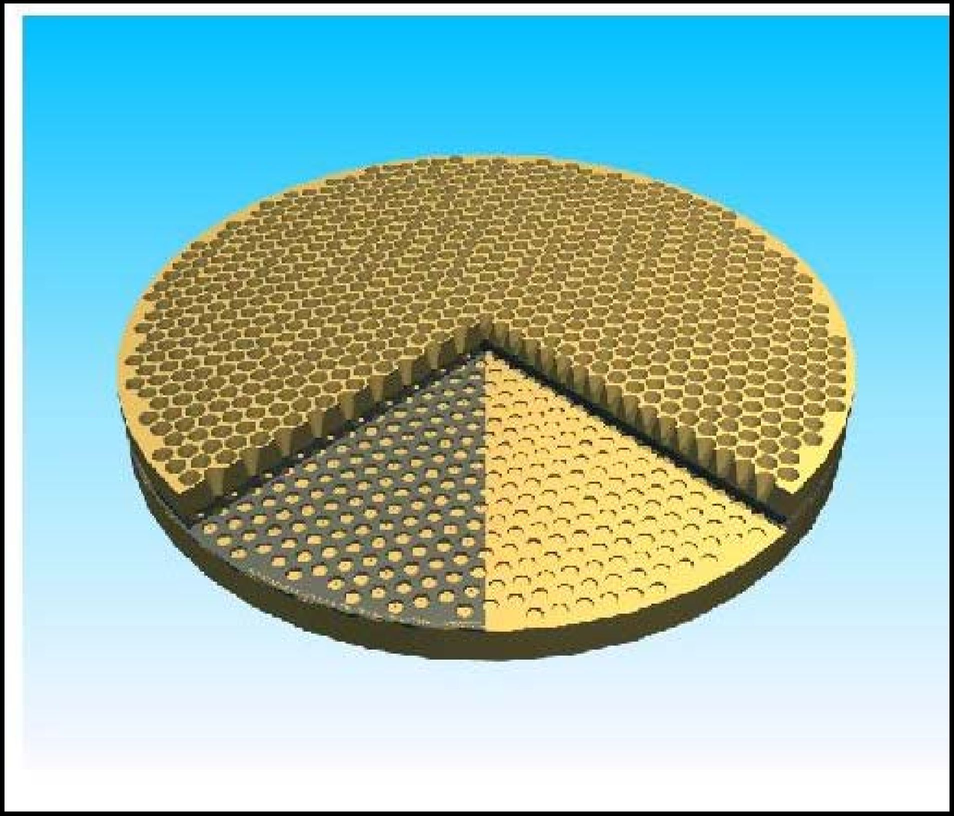
Very sensitive → short integrations required

Many detectors across the sky → Fast, large scale mapping

Single filled aperture → high sensitivity to low surface brightness objects

Angular resolution is limited

Will yield surveys containing 1000s to tens of 1000s of clusters



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Future SZE Survey/Small Scale CMB Anisotropy Instruments

SZA (Sunyaev-Zel'dovich Array) – first light this summer (N. Hemisphere, Owens Valley, CA)
- Chicago, Coumbia, OVRO, MSFC
- 8 element interferometric array of 3.5 m dishes (30, 90 GHz)
- 100s of clusters survey, detailed imaging, small scale anisotropy (l~1000-2000)

AMI (Arcminute Microkelvin Imager) – first light achieved (N. Hemisphere, Cambridge, England)
- MRAO/Cavendish/Cambridge group
- 10 element interferometric array of 3.7 m dishes (15 GHz)
- 100s of clusters survey, detailed imaging, small scale anisotropy (l~1000-2000)

AMIBA (Array for MIcrowave Background Anisotropy) (N. Hemisphere, Mauna Loa, Hawaii)
- ASIAA, Physics Dept of National Taiwan University, ATNF
- 19 element interferometric array of 1.2m and 0.31m dishes (95 GHz)
- SZE, missing baryons, polarization anisotropy

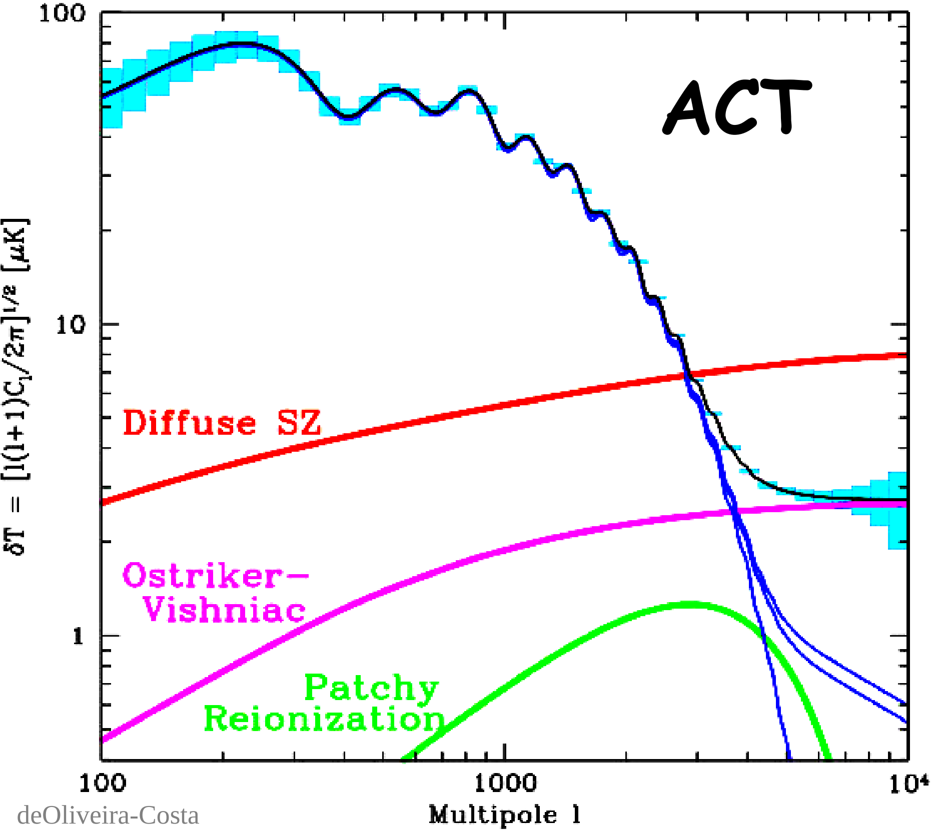
Bolocam (currently operating) (N. Hemisphere (Hilo, Hawaii)
- Caltech 150 element array for the CSO ← EXISTS
- UMASS Bolocam-2 array on the 50-m LMT in Mexico
- Blank-field cluster survey, other astrophysics

APEX (Atacama Pathfinder Experiment) 2006 (S. Hemisphere, Atacama Desert, Chile)
- U.C. Berkeley 300 element array on the Max Planck prototype ALMA 12 m telescope at Atacama
- 1000s of SZ clusters, small scale anisotropy

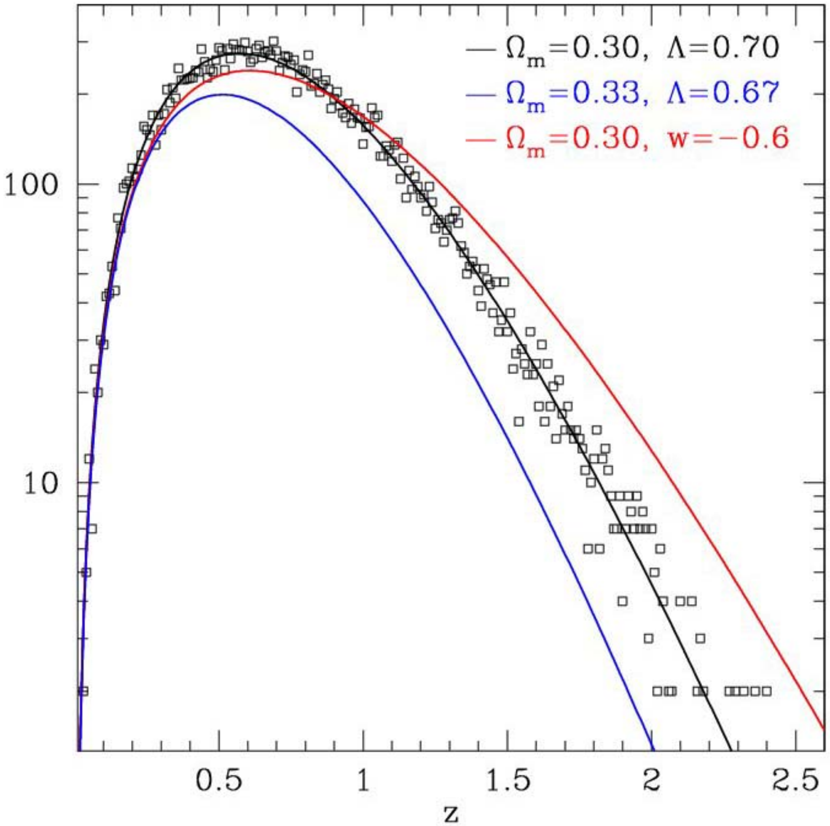
SPT (South Pole Telescope) 2007 (S. Hemisphere, South Pole)
- Large team – PI J. Carlstrom at U. Chicago
- with 1000 element array being developed at U.C. Berkeley
- Optimized for detecting tens of thousands of clusters, also measure small-scale anisotropy

ACT (Atacama Cosmology Telescope) 2007 (S. Hemisphere (Atacama Desert, Chile)
- Large team – PI L. Page, Princeton
- with 1000 element array being developed at NASA/Goddard
- Optimized to measure small-scale CMB anisotropy, also measure 1000s of clusters

What we plan to know…



deOliveira-Costa



The SZE/Small-Scale CMB

- Thermal SZE
  - Cluster Abundance dN/dz ➔ Ω_M , Ω_Λ, w, w(t)?
  - Determine σ_8
  - Tests of Non-Gaussianity
  - Small-Scale CMB Angular Power Spectrum
  - Spatial power spectrum, P(*k*)
  - Cluster gas mass fraction ➔ Ω_b
  - with X-ray observations
    - Angular Diameter distance/Hubble Constant
    - Scaling Relations, ΔS_ν-T_x, θ-T_x, T_x- ΔS_ν
    - Scatter in scaling relations

Cluster Astrophysics

- cluster evolution
- cooling cores, cold fronts, shock fronts, evacuated cavities
- merger history, current dynamical state, relationship of intra-cluster gas to stellar population

- Kinetic SZE/OV Effect
  - Reionization epoch
  - Peculiar velocities at high z
- Small-Scale CMB Anisotropy
  - n_s, $dn/d\ln(k)$

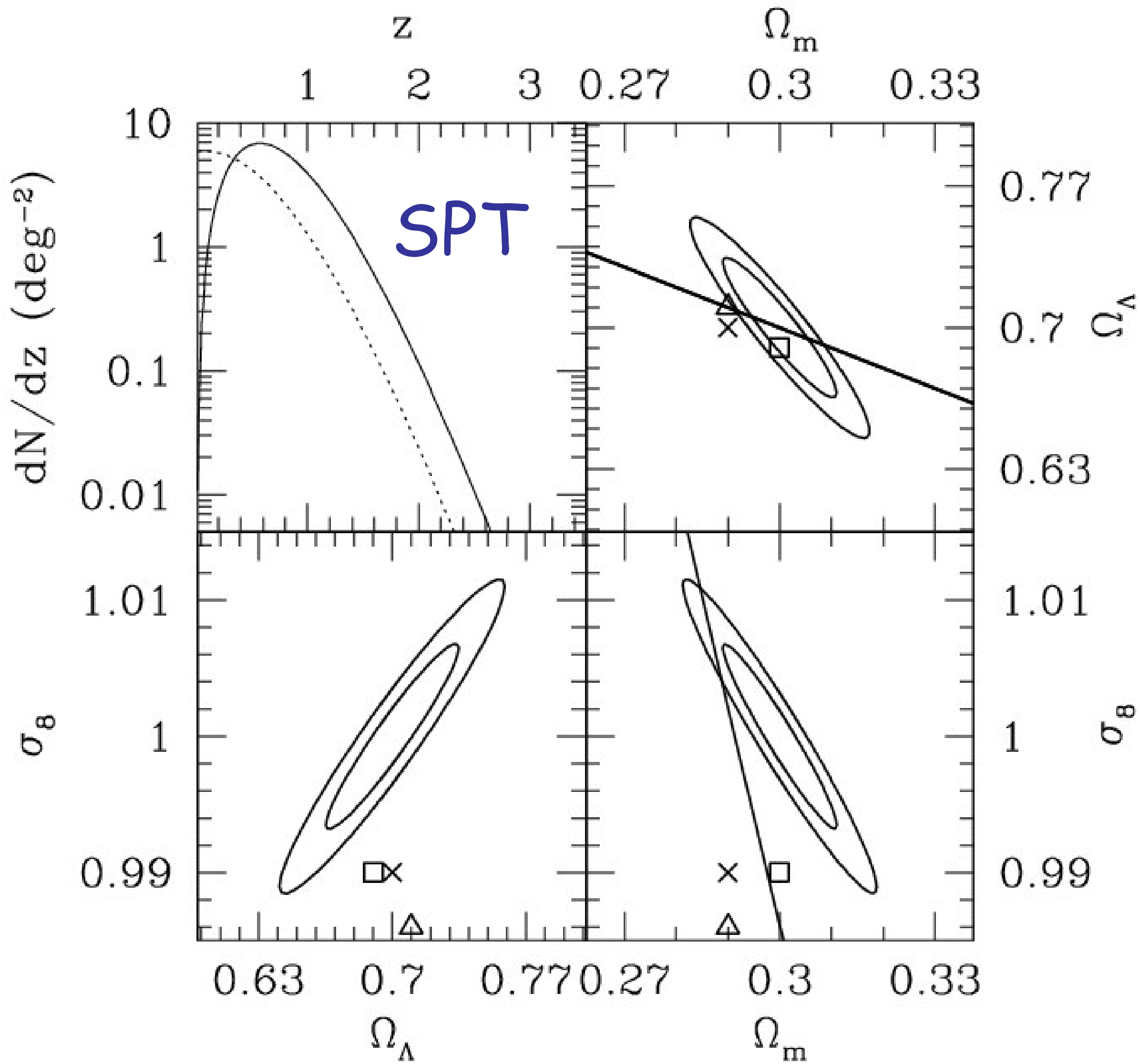
Cosmological Parameter Constraints

4000 sq deg
~17,000 clusters

□ : systematic tilt in the mass function $\sigma(M)^{0.1}$

△ : 10% reduction in mass function amplitude

x : +5% offset in limiting mass



Holder, Haiman & Mohr 2001, astro-ph/0105396

What we will certainly learn…

Better control of Instrumental Systematics (sidelobes, offsets, pickup, loading, etc etc etc.)

Small-scale foregrounds at many frequencies at sub μK levels (dust, free-free, synchrotron, point sources, ?)

Lots of things about galaxy clusters (can they be used as standard candles at all – self calibration, fitting functions, etc? Do we learn only astrophysics and no cosmology?)

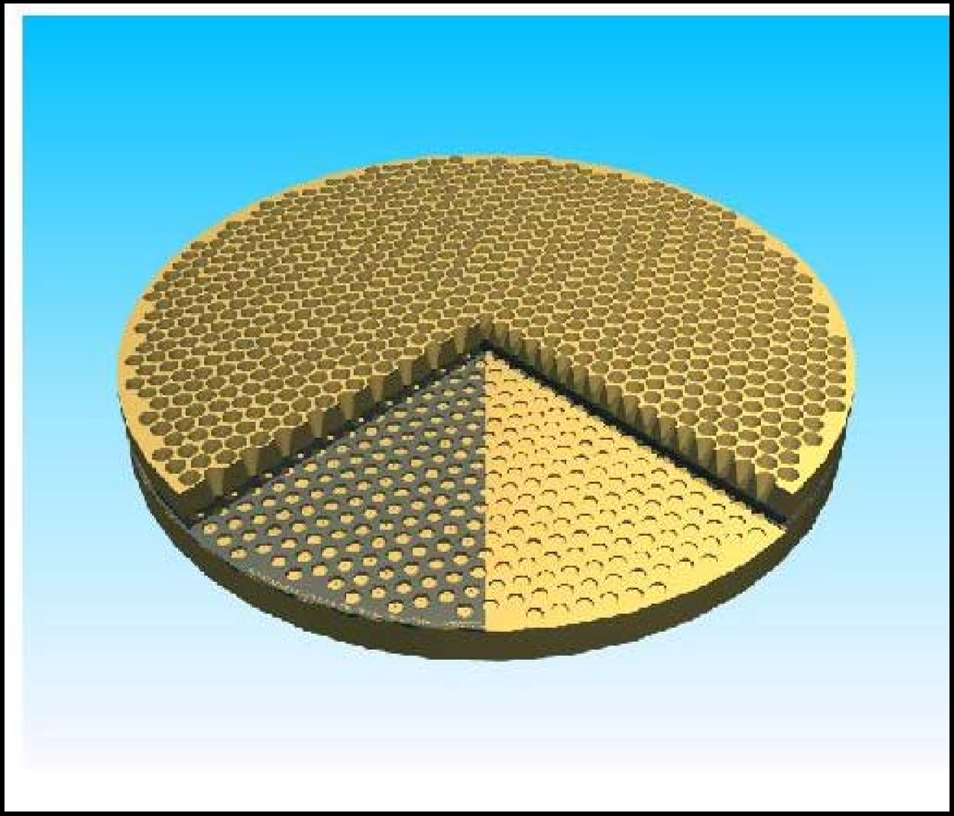
σ_8, small-scale primary CMB anisotropy, small-scale secondary CMB anisotropy

CMB Polarization Anisotropy

Bolometric Receivers

Highest sensitivity CMB detectors above ~150 GHz

Required to understand dust foregrounds



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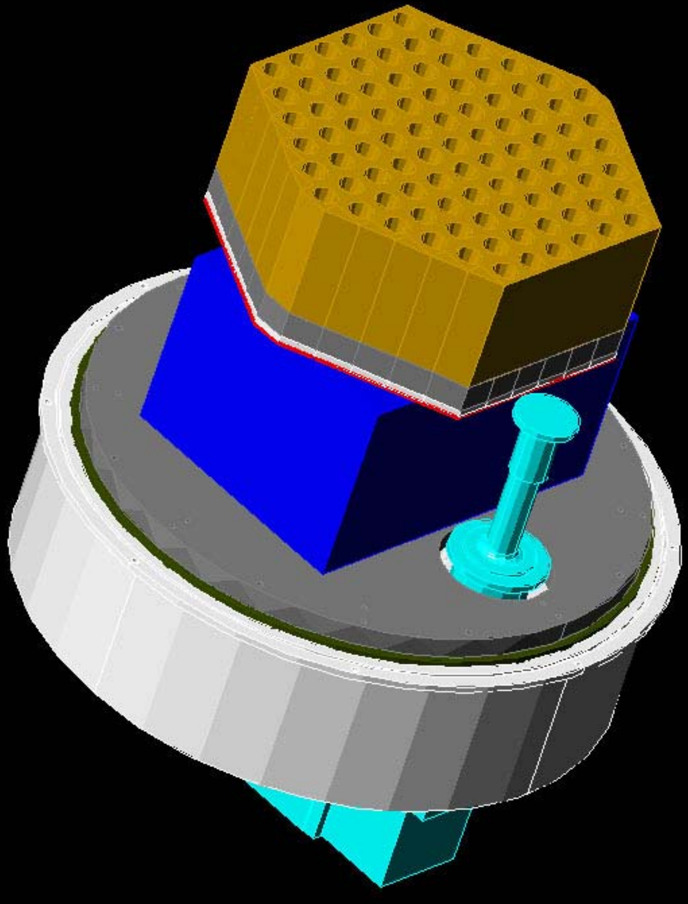
Coherent Radiometers

Best detectors at frequencies lower than ~100 GHz

Required to understand Synchrotron, free-free, possible spinning dust



Muchovej (Columbia)

Future CMB Polarization Anisotropy Instruments (Ground-Based Only)

Currently operating or already have data in hand

- CAPMAP (HEMT) – N. Hemisphere (New Jersey, USA)
  - Princeton, Chicago, Miami, JPL
- DASI (HEMT – Interferometer) – S. Hemisphere (South Pole)
  - Chicago, Caltech, JPL
- CBI (HEMT – Interferometer) – S. Hemisphere (Atacama Desert, Chile)
  - Caltech, Chicago, JPL

Upcoming – tens of detectors

- QUEST (bolometer) – S. Hemisphere (South Pole)
  - Stanford, Cardiff, Chicago, Caltech, JPL, IPAC
- BICEP (bolometers) – S. Hemisphere (South Pole)
  - Caltech, JPL, Cardiff, San Diego
- AMIBA (HEMTs)
  - ASIAA, Physics Department of National Taiwan University, ATNF

Upcoming – hundreds to thousands of detectors

- QUIET (HEMTs) – S. Hemisphere (Atacama Desert, Chile)
  - Caltech, Chicago, Columbia, JPL, Miami, Princeton, Berkeley, Harvard, GSFC
- PolarBear (bolometers) – N. Hemisphere (White Mountain, CA)
  - Berkeley, ?
- clover (bolometers) S. Hemisphere (Dome C, Antarctica)
  - Cardiff, Cavendish Astrophysics Group

Other Instruments about which I know little

- BRAIN, MBI, SPTPOL, ACTPOL

CMB Polarization Anisotropy

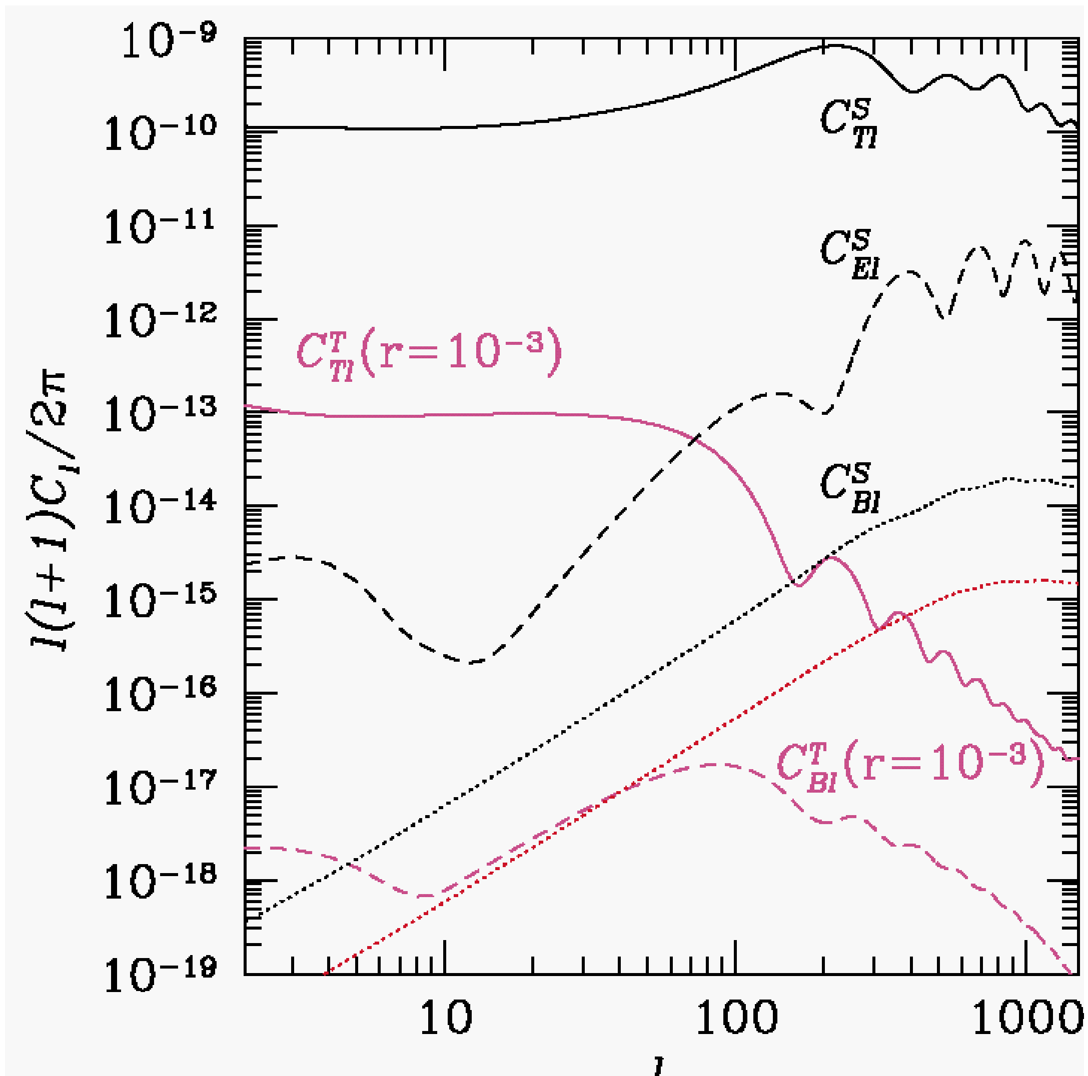
E-mode polarization

- Generated only by scattering (most direct probe of physics at recombination)
- Probe epoch of reionization by first stars (WMAP result)
- Serves as a consistency check on interpretation of temperature anisotropy as signature of gravitational instability model
- Remove degeneracies in cosmological parameters inferred from primary anisotropies and enhance precision with which cosmological parameters are measured

B-mode polarization

- Generated by perturbations in the spacetime metric – gravitational waves
- The amplitude of polarization from Inflation is proportional the square of the inflaton potential
- Detection of this signal may yield a measurement of the energy scale of inflation
- Yields clues to quantum gravity
- Separable from E-modes by "curl" signature

What we plan to know…



What we will certainly learn...

Better control of Instrumental Systematics
(sidelobes, offsets, pickup, loading, instrumental polarization, E/B mixing, etc etc etc.)

polarized foregrounds at many frequencies at nK levels
(dust, free-free, synchrotron, point sources, atmosphere, etc.)