



# Measurements of CMB Polarization Anisotropy and Searches for Galaxy Clusters with Bolometer Arrays

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# Outline

- CMB Polarization Science
- Galaxy Cluster Survey Science
- Development of Bolometer Arrays
- Experiments
  - POLARBEAR
  - APEX-SZ
  - South Pole Telescope



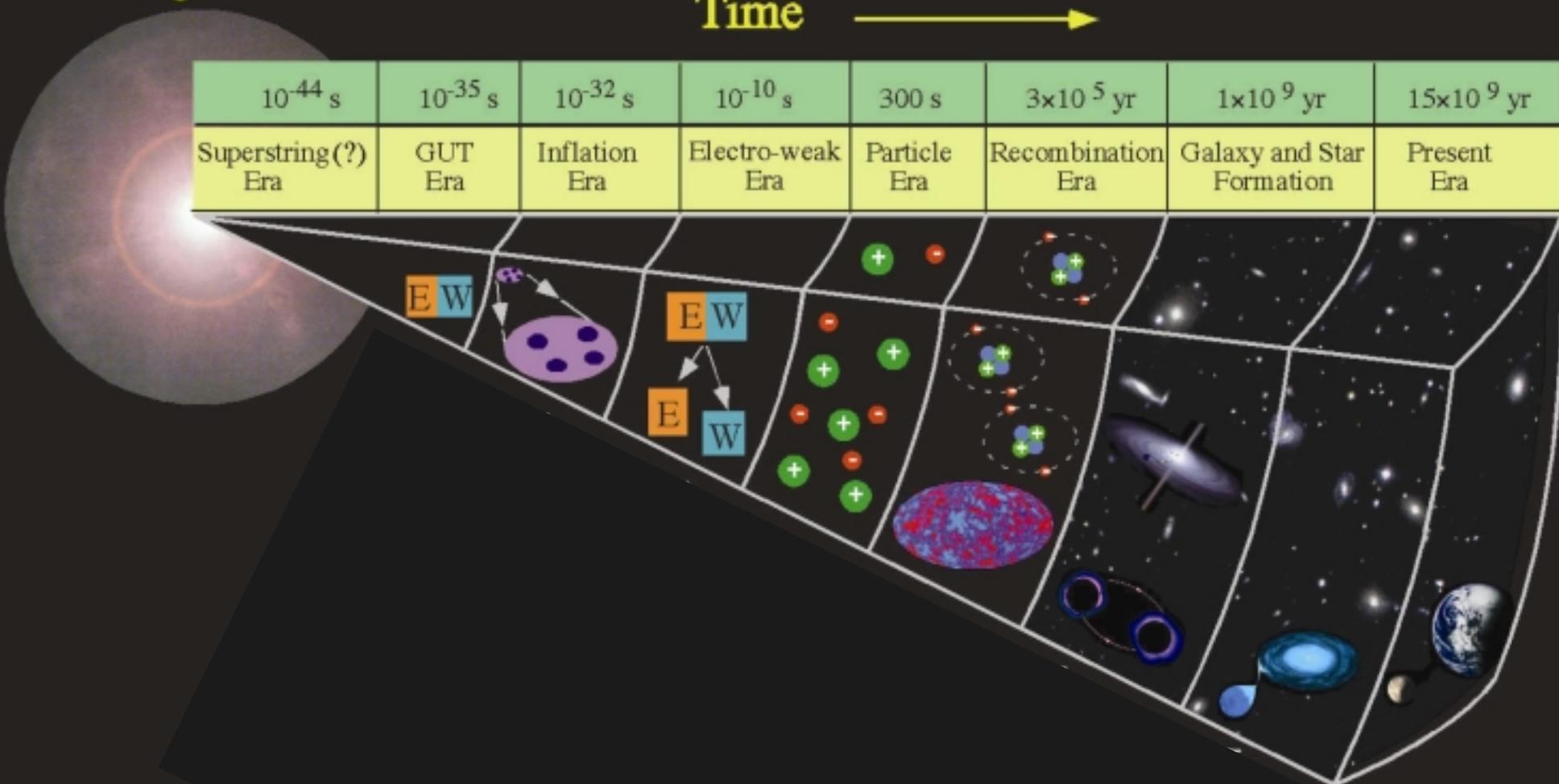
# Polarization Science

# Big Bang

Time



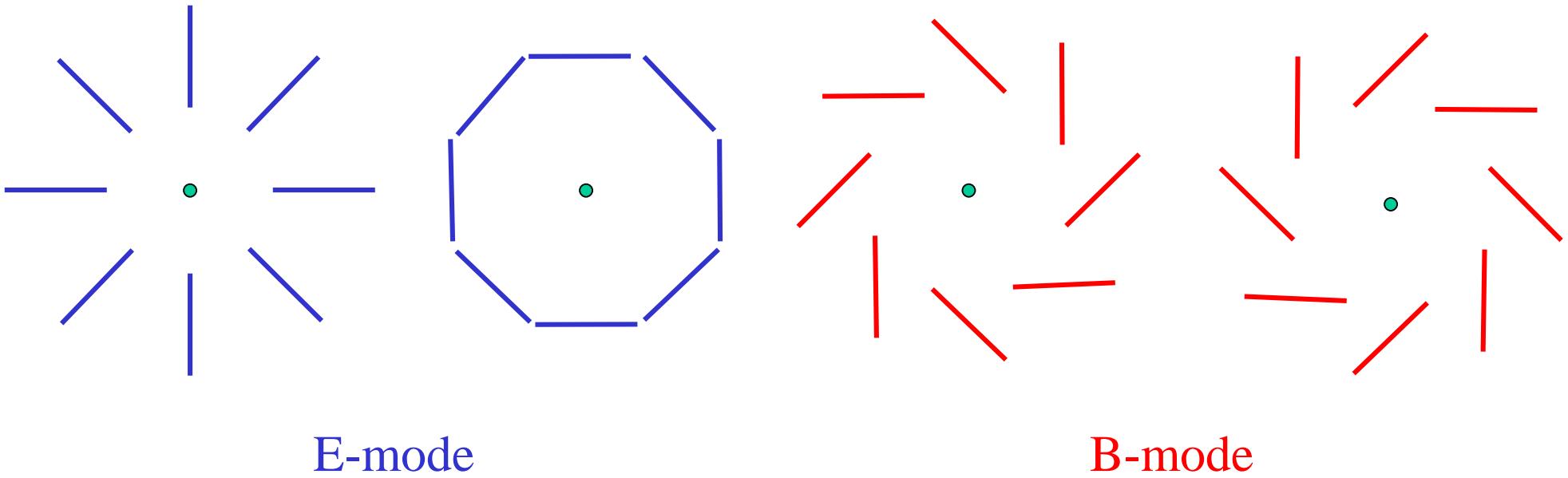
$10^{-44}$ s	$10^{-35}$ s	$10^{-32}$ s	$10^{-10}$ s	300 s	$3 \times 10^5$ yr	$1 \times 10^9$ yr	$15 \times 10^9$ yr
Superstring(?) Era	GUT Era	Inflation Era	Electro-weak Era	Particle Era	Recombination Era	Galaxy and Star Formation	Present Era



# Gravity Waves from Inflation

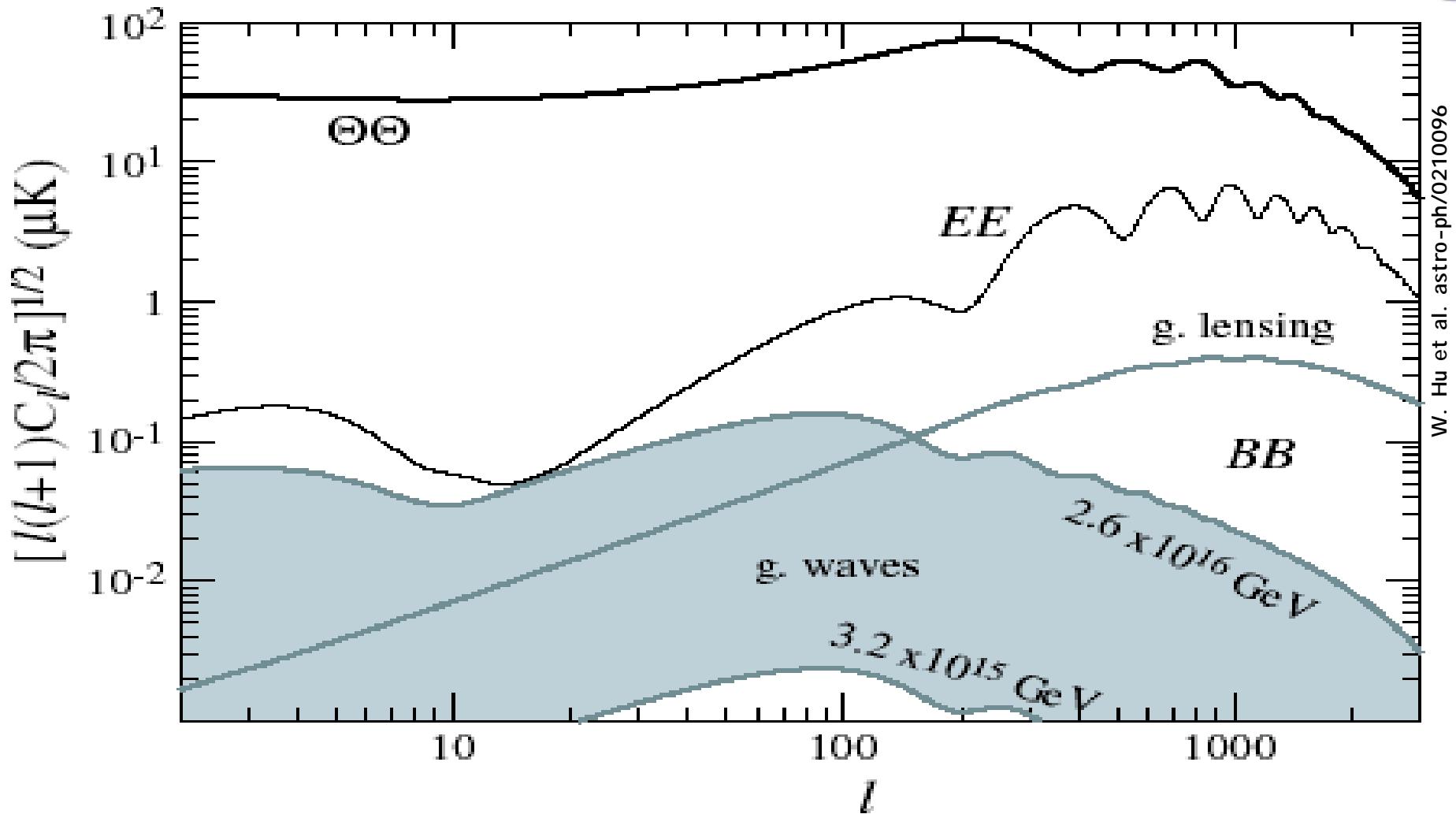
- Gravity waves put stress on photon-baryon fluid
  - Generation of B-mode polarization
- Detection => “smoking gun” of inflation
- Amplitude of B-mode gives Energy Scale
  - One possibility: GUT level  $10^{16}$  GeV
  - 12 orders of magnitude higher energy than accelerators!
- Observable evidence of String Theory?

# E-modes and B-modes



- Density fluct. give **scalar** perturbations => E-mode
- Gravity Waves give **tensor** perturbations=> B, E modes
- Defects and strings give **vector** perturbations => B-mode

# CMB Polarization Spectra



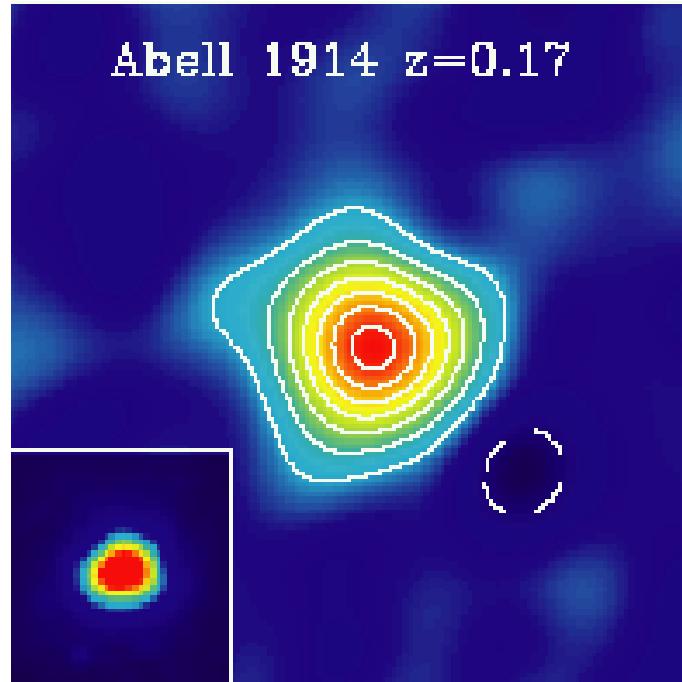
We need a large increase in sensitivity!



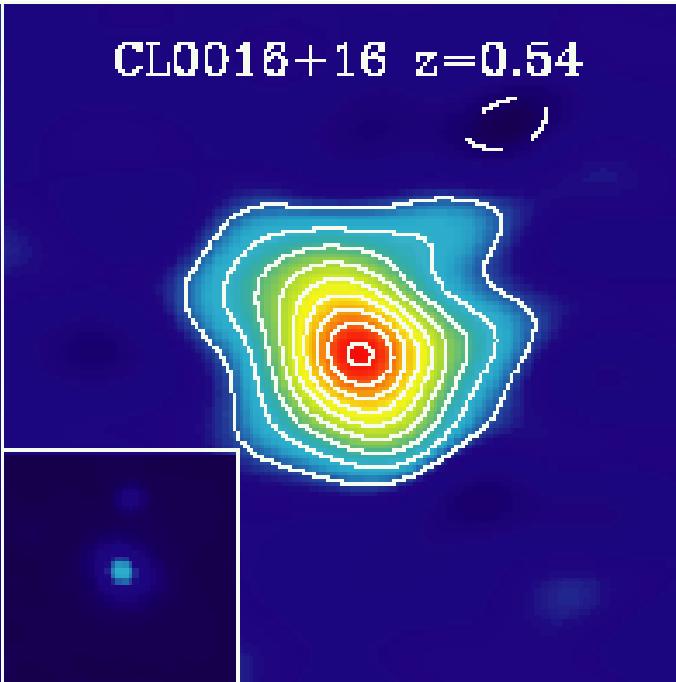
# Galaxy Cluster Survey using SZ Effect Science Case

# SZ Observations

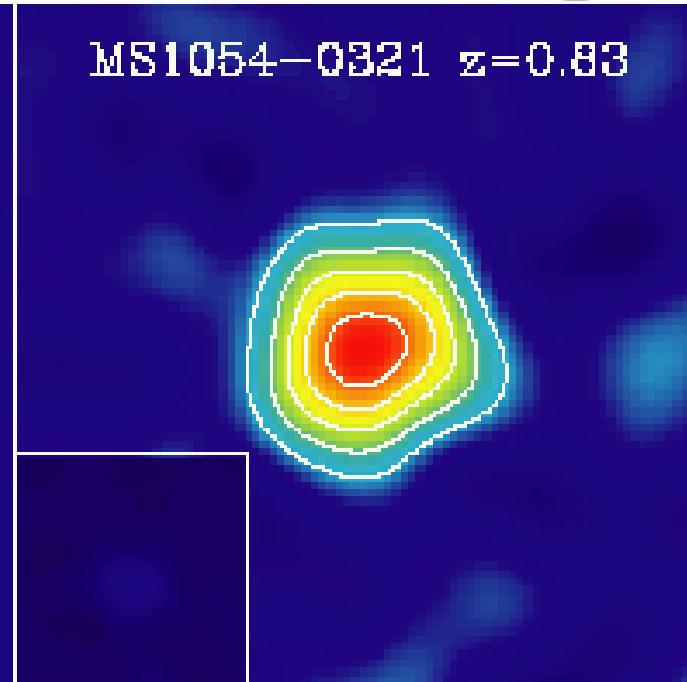
Abell 1914  $z=0.17$



CL0016+16  $z=0.54$



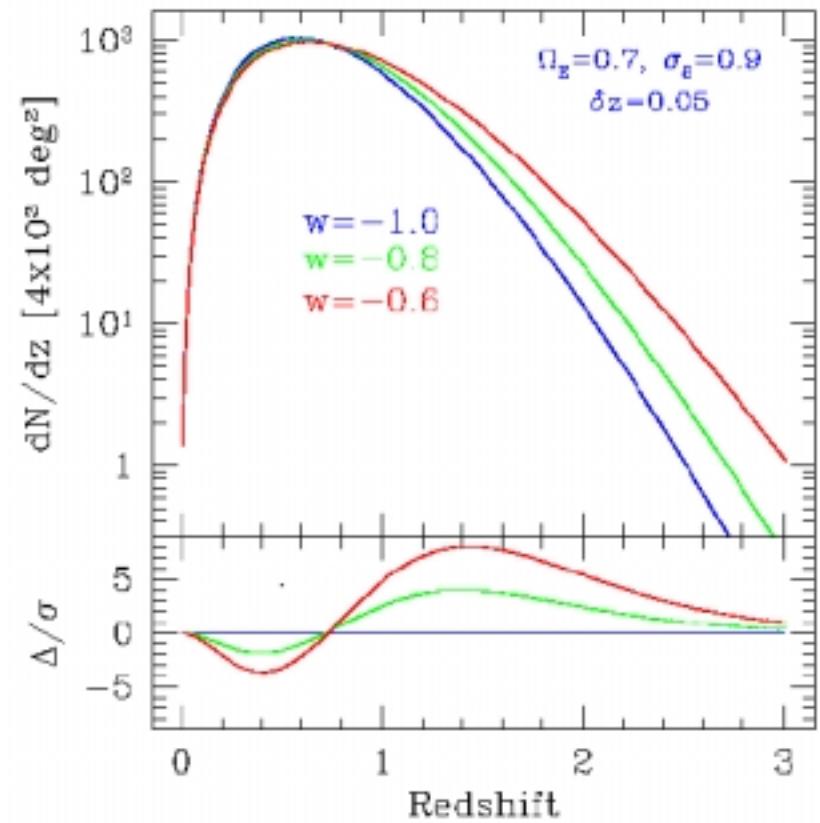
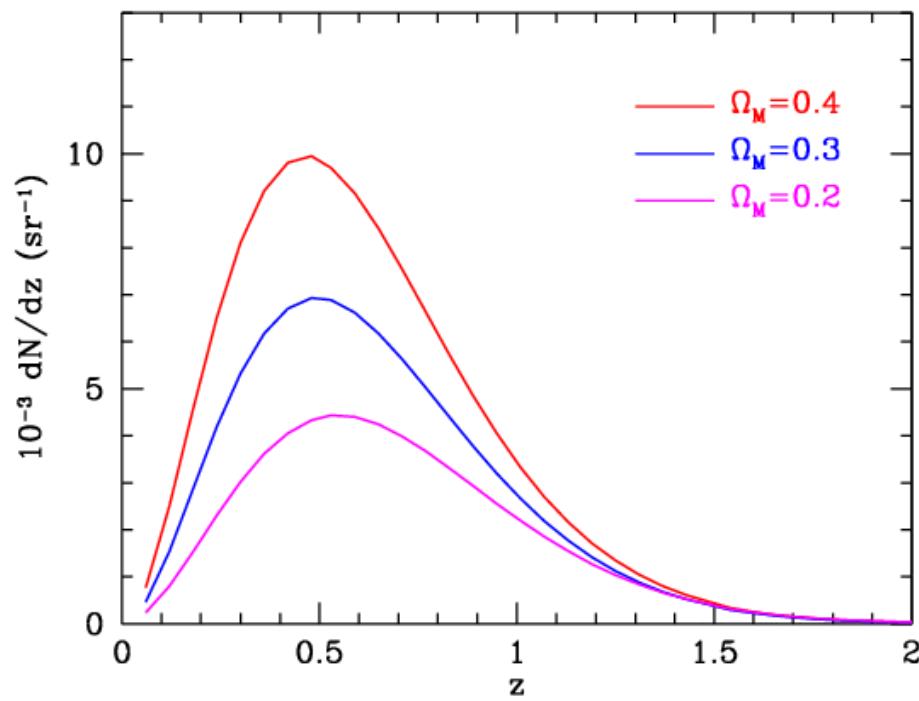
MS1054-0321  $z=0.83$



In contrast to X-ray emission, SZ surface brightness is independent of cluster redshift, clusters can be seen at any distance!

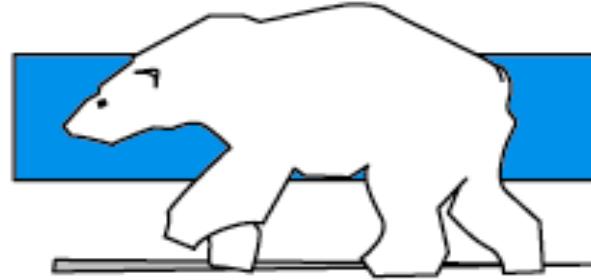
# Galaxy Cluster Surveys Probe Dark Energy

Cluster surveys probe (1) volume-redshift relation, (2) abundance evolution, (3) structural evolution



# Large Focal Plane Bolometer-Arrays

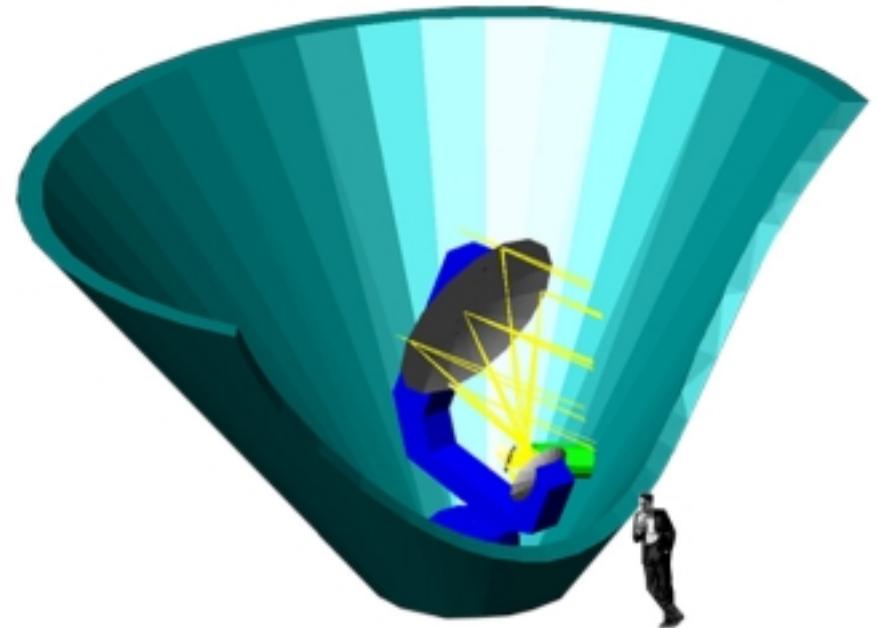
- Approaching single pixel photon noise limit
  - Next Step: Large format bolometer arrays
- Transition-edge Sensor Bolometer
  - Entire fabrication is by optical photolithography
  - Multiplexed readout in development



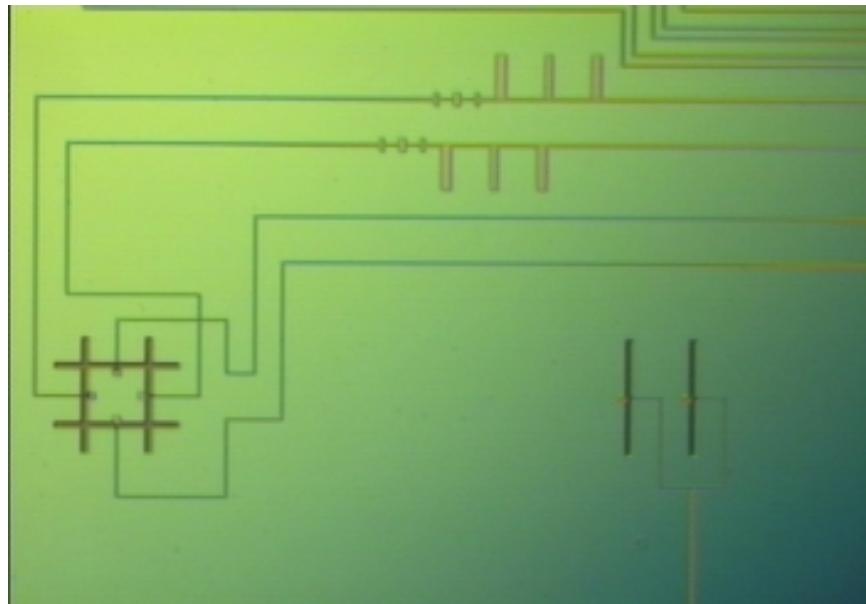
# POLARBEAR

J. Borrill, S. Cho, J. Clarke, Matt Dobbs, N. Halverson, W. Holzapfel, A.H. Jaffe, Z. Kermish, T. Lanting, A.T. Lee, M. Myers, R. O'brient, P.L. Richards, H. Spieler, R. Stompor, H. Tran, M. White

- Ground-Based 3 meter Telescope at White Mountain CA
  - Characterize E-modes
  - Search for B-modes
- First Light 2004-2005
  - LDRD seed funding



# New Detector Technology: Antenna Coupled Bolometer



1 mm

- Fabricated in UCB Microlab by  
M.Meyers

1739

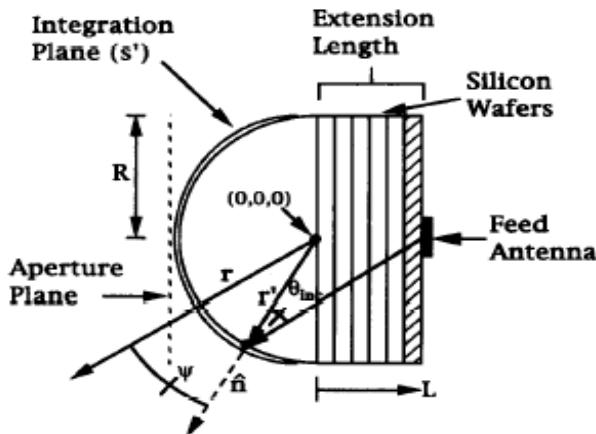


Fig. 1. The extended hemispherical lens and the ray-tracing/field-integration technique.

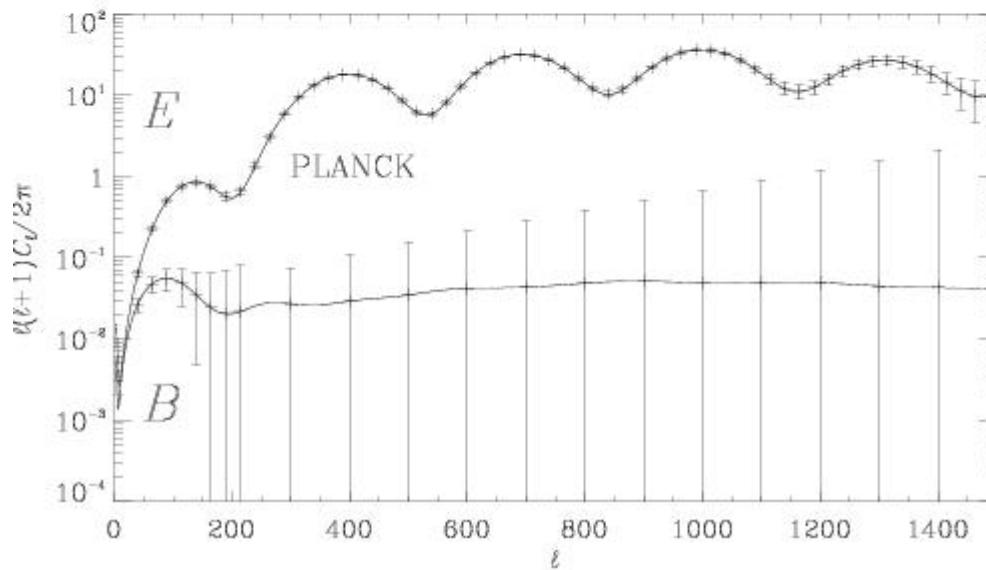
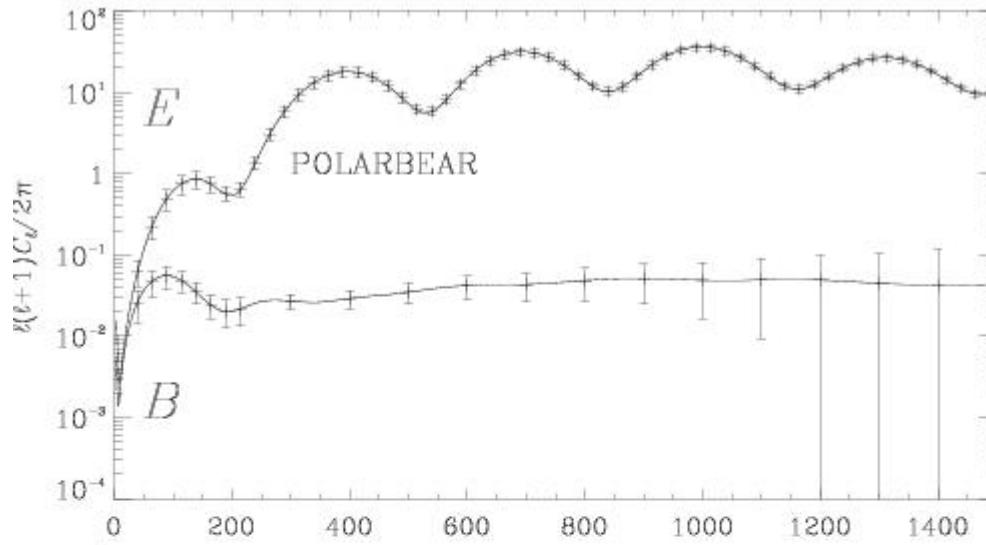
Silicon Lens used to focus the beam

Filipovic et. al. 1993

SEE TALK Y08 BY MIKE MYERS

# POLARBEAR-I Performance

A.H. Jaffe



- 15 x 15 deg. observed
- 1.2  $\mu\text{K}$  rms per 5' pixel
- 200 nK rms per 30' pixel  
(re-pixelized map)
- T/S = 0.35 assumed



# CMB Polarization Satellite

- One of three NASA “Einstein Probes” in roadmap is for CMB Polarization
- Study Proposed of mission named **Experimental Probe of Inflationary Cosmology “EPIC”** (JPL, CIT, UCB, LBNL, Minn, NIST, UColo, Stanford, CMU, Cardiff, Chicago, Dartmouth, Fermilab, Davis)

# ALMA Pathfinder Experiment (APEX)



## Telescope Specifications:

- 12 m on-axis ALMA prototype.
- *45'' resolution* at 150 GHz.
- Located at 16,500 ft in the *Chilean* Andes.
- Assembly near complete in Chile!
- Berkeley Component NSF funded
- **First light late 2004**

### MPIfR

Frank Bertoldi  
Rolf Guesten  
Ernst Kreysa  
Karl Menten  
Dirk Muders  
Andrea Racanelli  
Peter Schilke

### MPI Munich

Hans Bohringer

### Berkeley

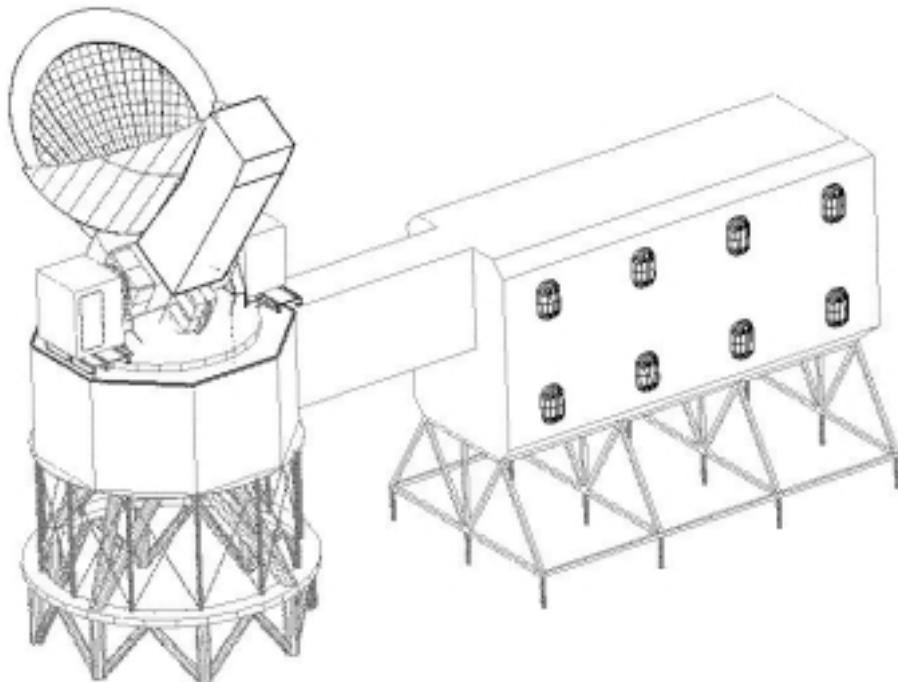
Sherry Cho  
Matt Dobbs  
Nils Halverson  
Bill Holzapfel  
Paul Richards  
Tom Plagge  
Adrian Lee

Trevor Lanting  
Martin Leuker  
Jared Mehl  
Mike Myers  
Dan Schwan  
Helmuth Spieler  
Martin White



# South Pole Telescope

S. Cho, J. Carlstrom, P. Cheimets, J. Clarke, T. Crawford, Matt Dobbs, C. Greer, N. Halverson, W. Holzapfel, T. Lanting, A.T. Lee, E. Leitch, S. Myer, J. Mohr, S. Padin, C. Pryke, P.L. Richards, J. Ruhl, M. Runyan, H. Spieler

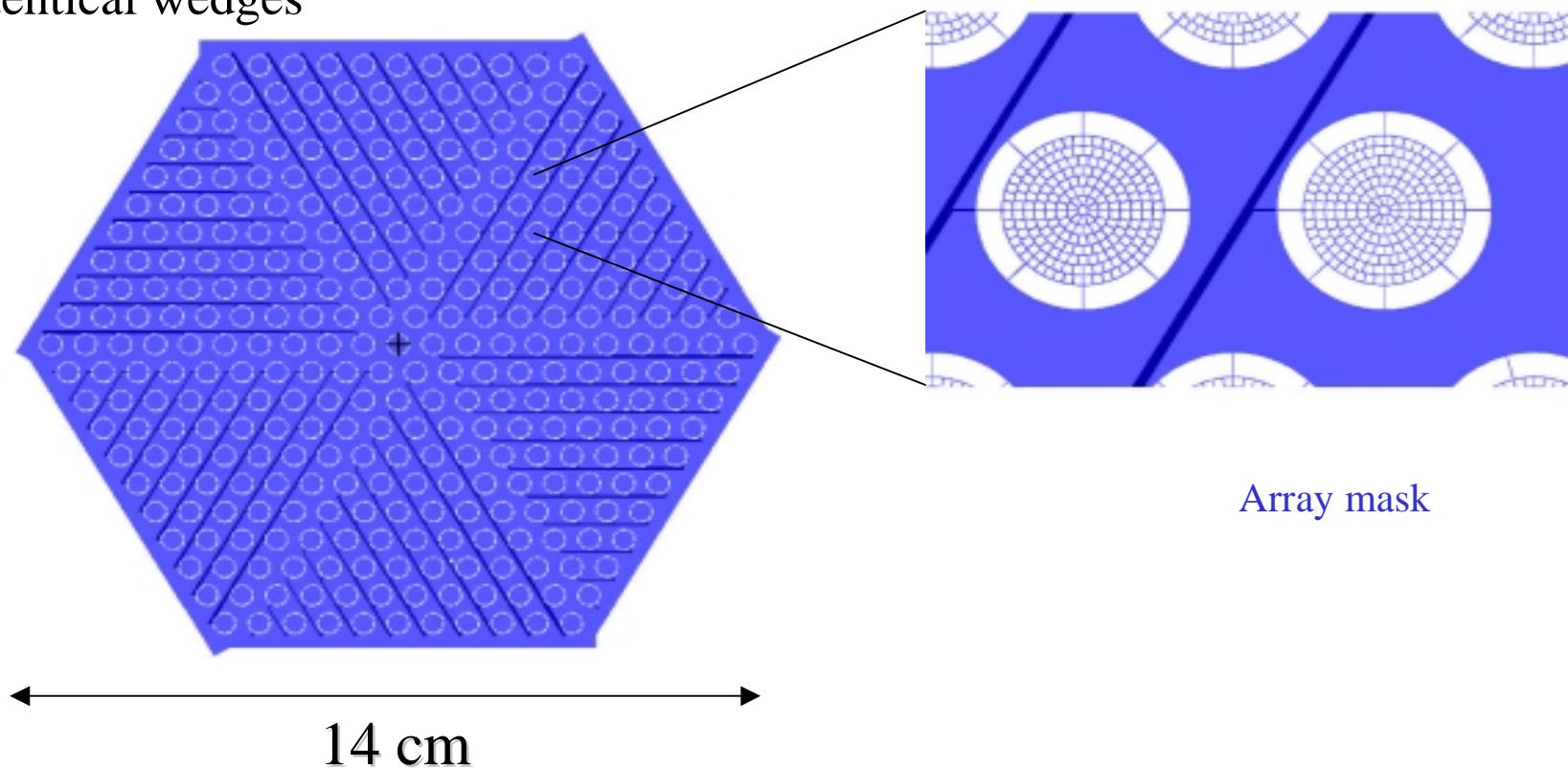


- 8m, off-axis design
- 1.3' resolution
- 100% time SZ observations
- Best mm-wave site
- First light 2006-2007
- NSF Funded: Chicago, Berkeley, CWRU, SAO

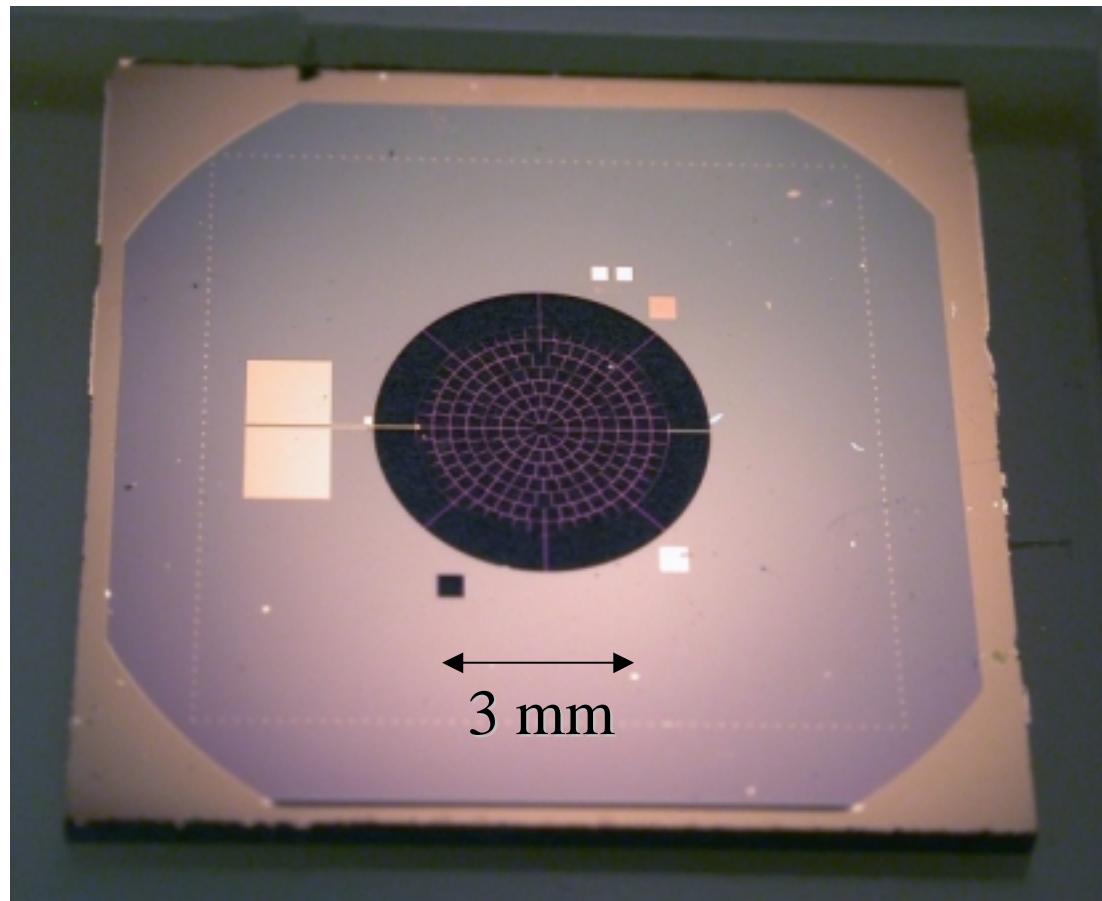
APEX/SPT Complementarity: APEX will be operational 2-3 years before SPT, but SPT will have ~5x faster cluster finding rate.

# TES Bolometer Array

- 6 identical wedges



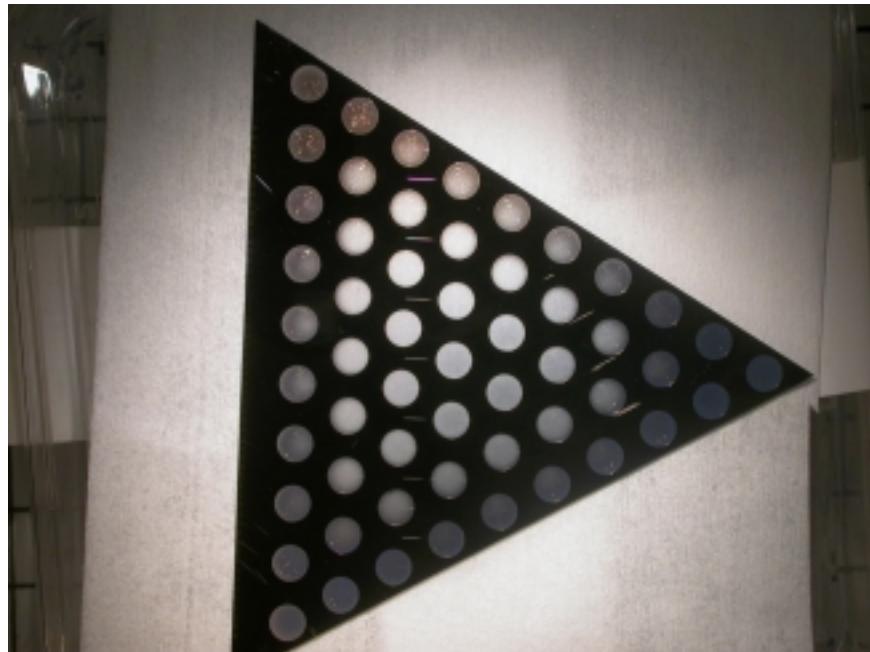
# Horn Antenna Coupled Bolometers Sunyaev-Zel'dovich Effect Surveys



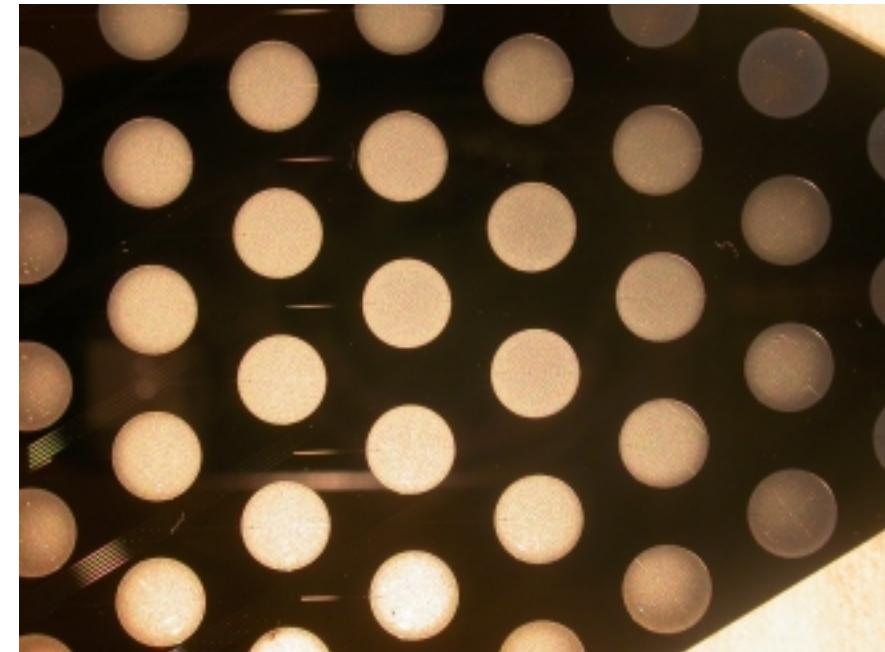
TES Spider Absorber Bolometer



# APEX-SZ 54-Bolometer Wedge

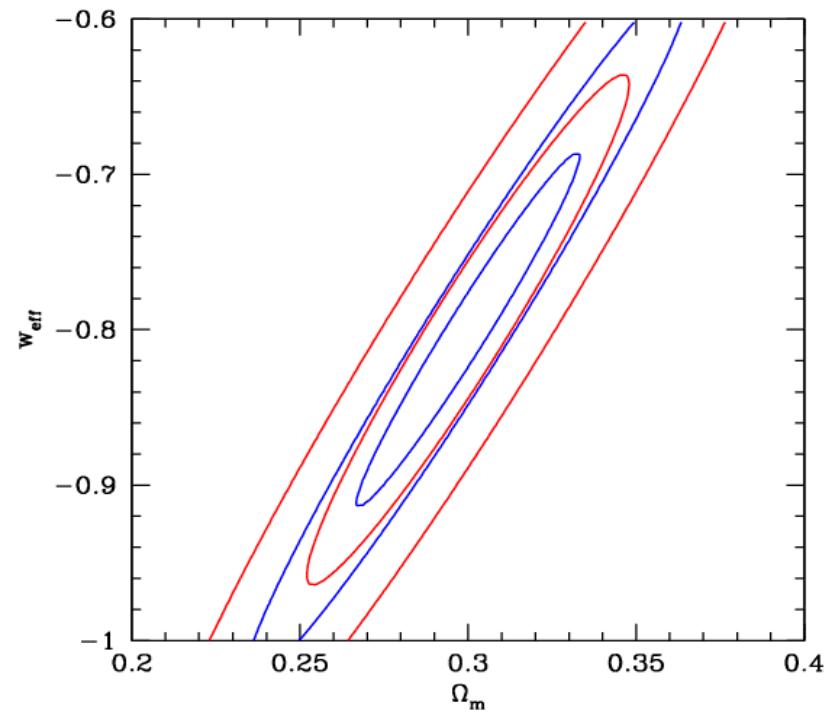
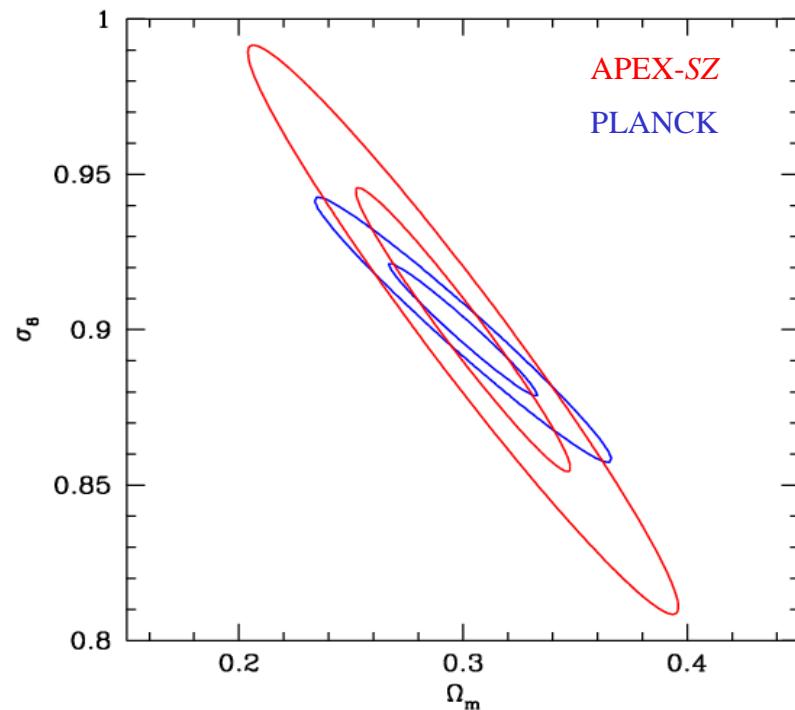


7 cm



Jared Mehl

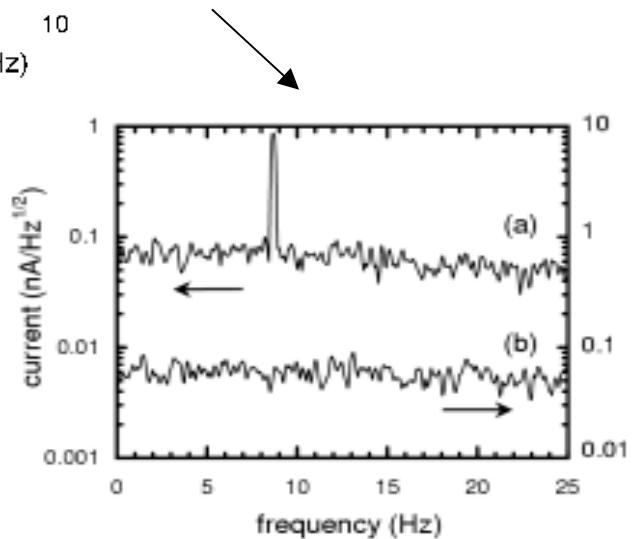
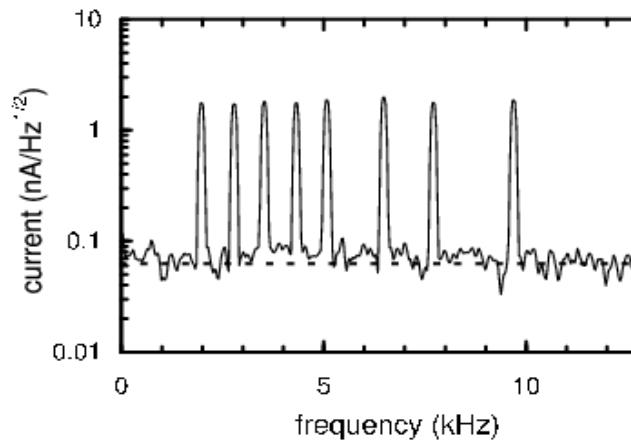
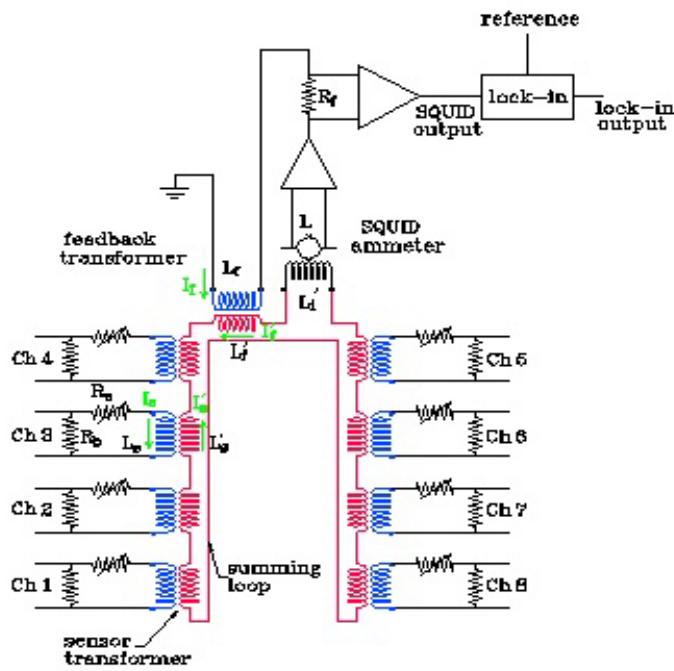
# Cosmology with APEX-SZ



courtesy M. White

# Single SQUID multiplexer

- One SQUID per row
- AC-bias => sum signals => demodulate



- 8-ch prototype tested with resistors
- Bolometer test

SEE TALK E02 BY TREVOR LANTING

# Conclusion

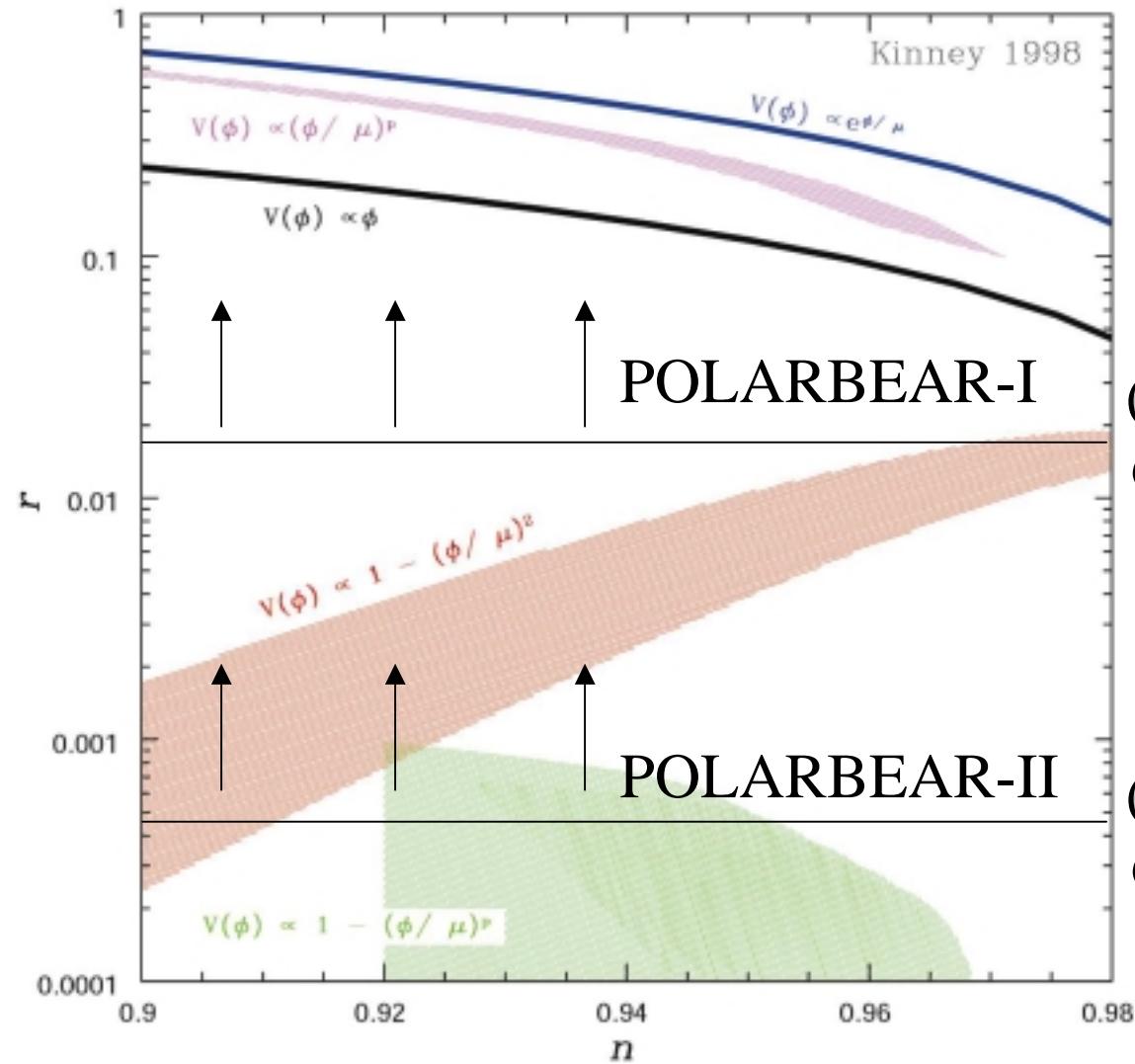
- Much more to learn from CMB photons!
  - Polarization: Probe of physics at  $10^{16}$  GeV
  - Galaxy Clusters: Characterize Structure Formation, Dark Energy
- Needed step in instrumentation is imminent
- Control of systematic errors will be critical



# STOP

# PolarBeaR Performance

$r$  = tensor to scalar ratio

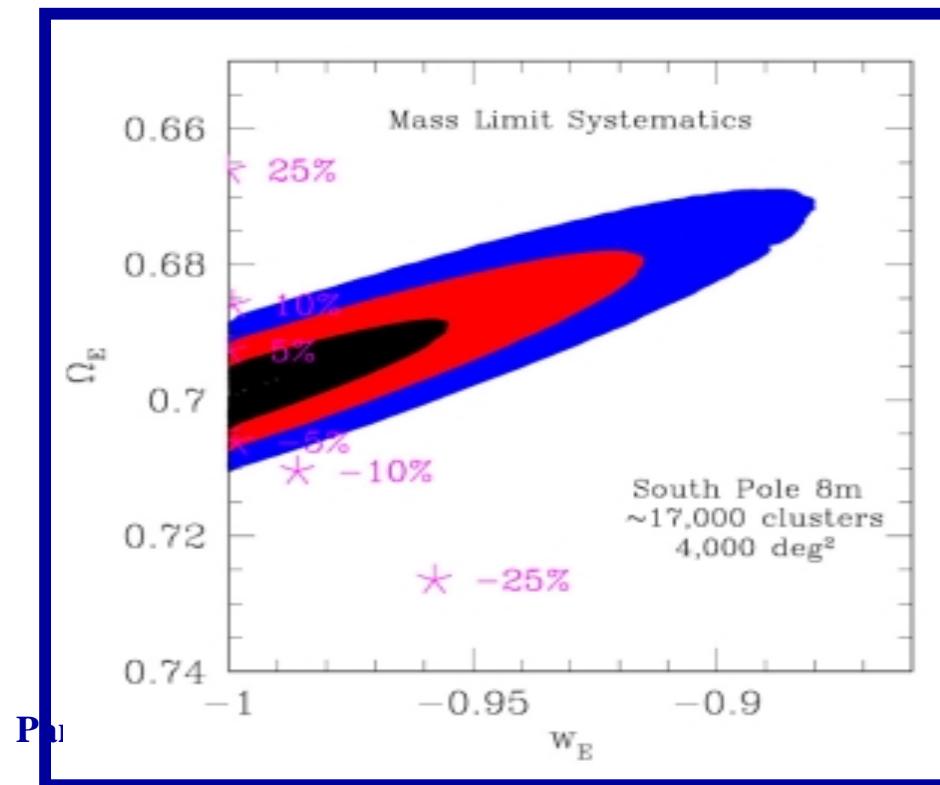


(300 Bolometers  
@ 300 mK)

(3000 Bolometers  
@ 100 mK)

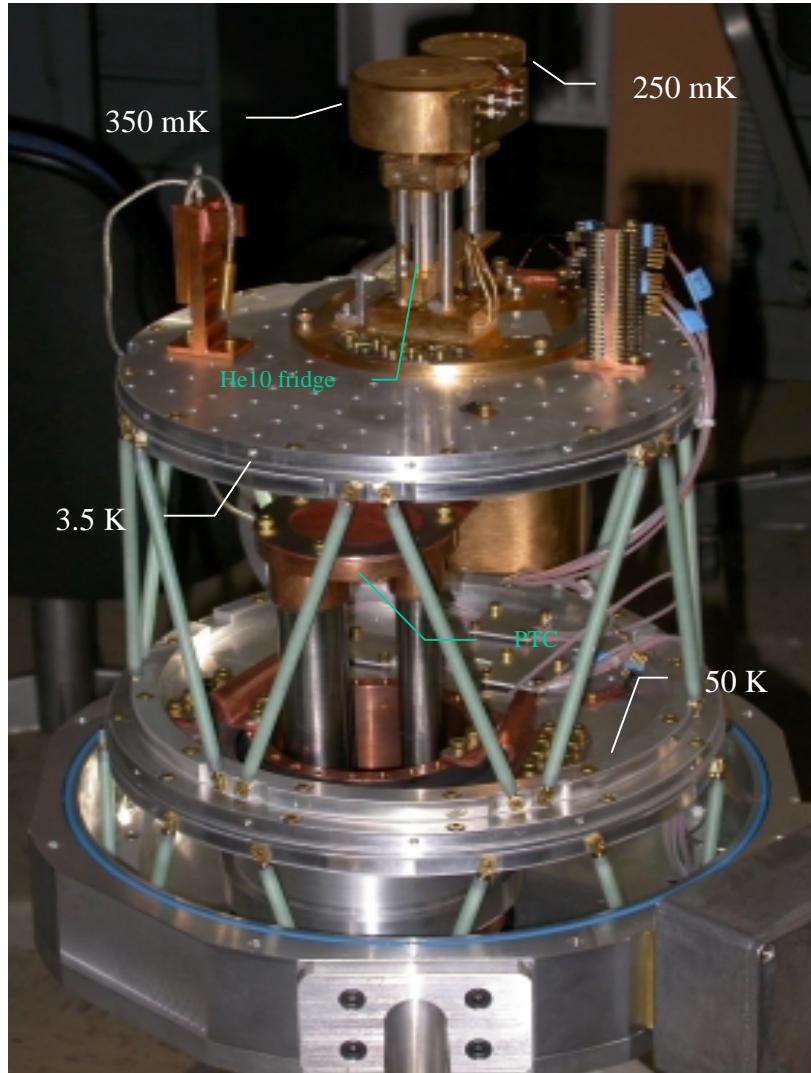
$n$  = tilt of primordial spectrum

# Dark Energy and Mass Limit Systematic Errors



$\Delta \log M$	$\Omega_E$	$\langle w \rangle$	$\sigma_8$
+25%	0.6661	-1.0000	0.9539
+10%	0.6859	-0.9991	0.9231
+5%	0.6927	-0.9998	0.9124
0%	0.700	-1.0000	1.000
-5%	0.7061	-0.9985	0.8894
-10%	0.7105	-0.9860	0.8749
25%	0.7265	-0.9579	0.8305

# Pulse-Tube Cooler Testing



- Closed He gas cycle
  - No cryogens
  - Reduces logistical and personnel demands
- 250 mK for 50 hours
- Microphonics tests underway

Dan Schwan