4.The Future

Bruce Partridge

Outline

Planck

Some Ground-based Programs

Improved Accuracy of Cosmological Parameters

E Mode Polarization

- Value in breaking degeneracies

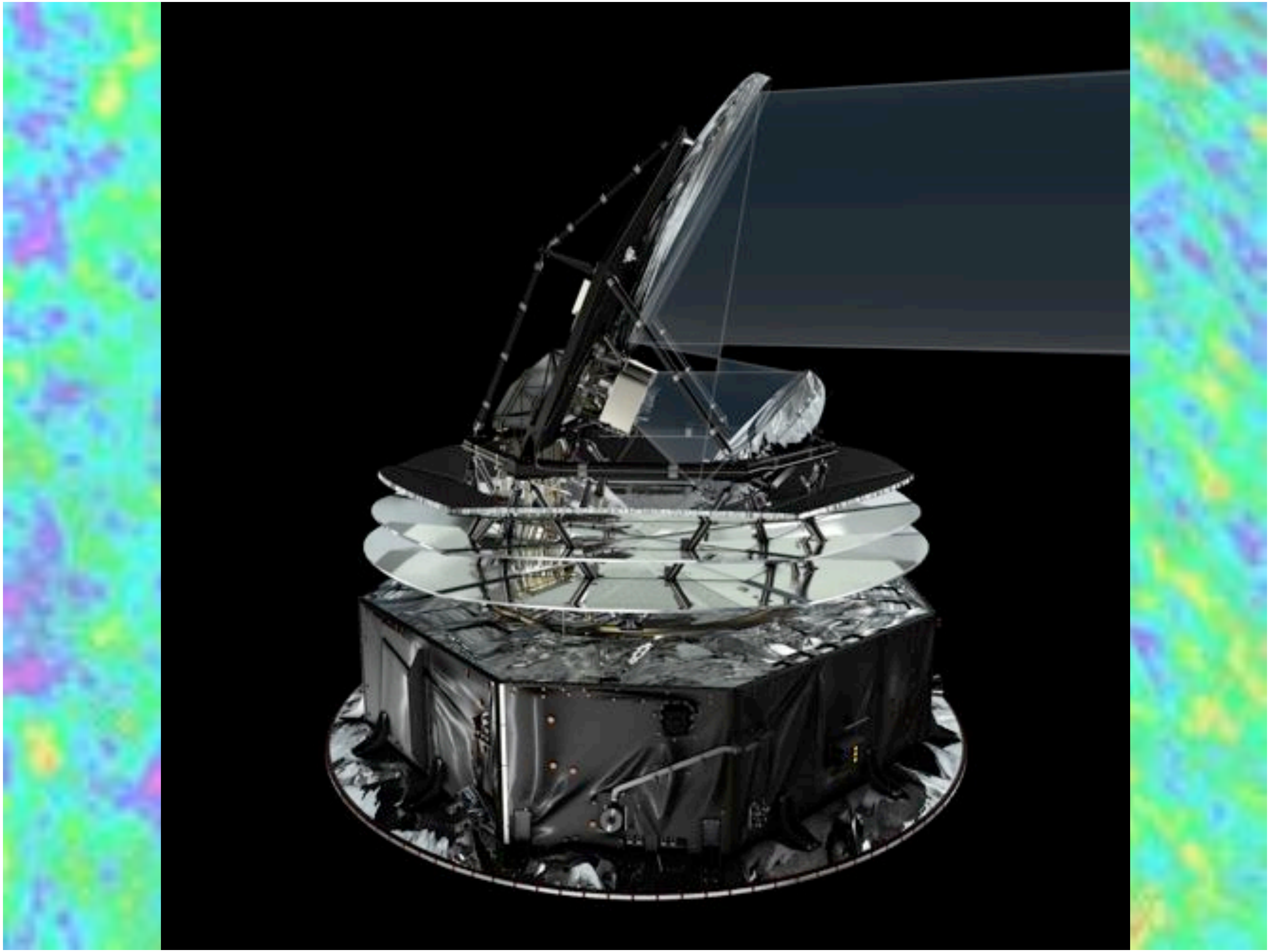
The Search for B Modes

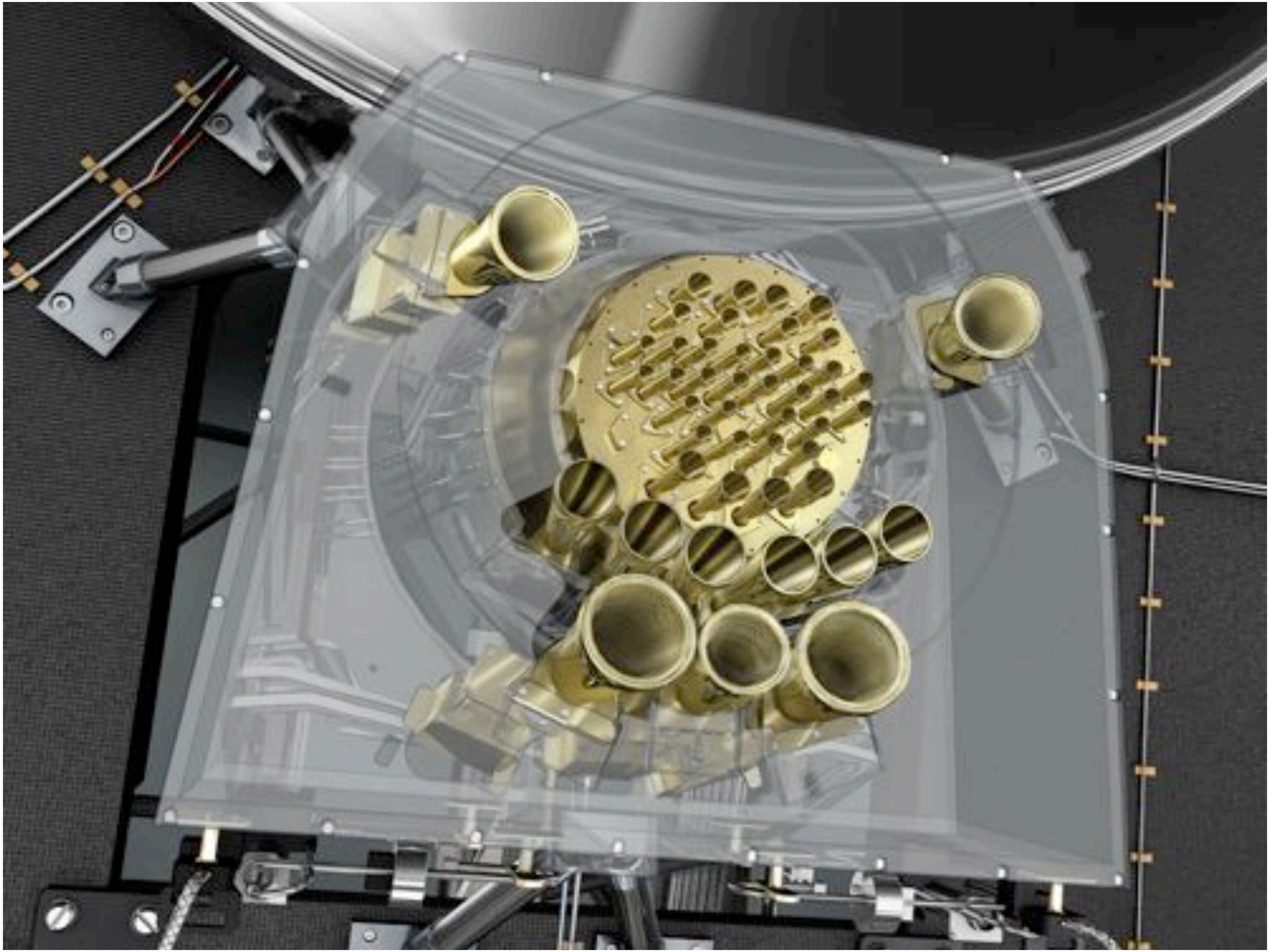
- Direct test of inflation

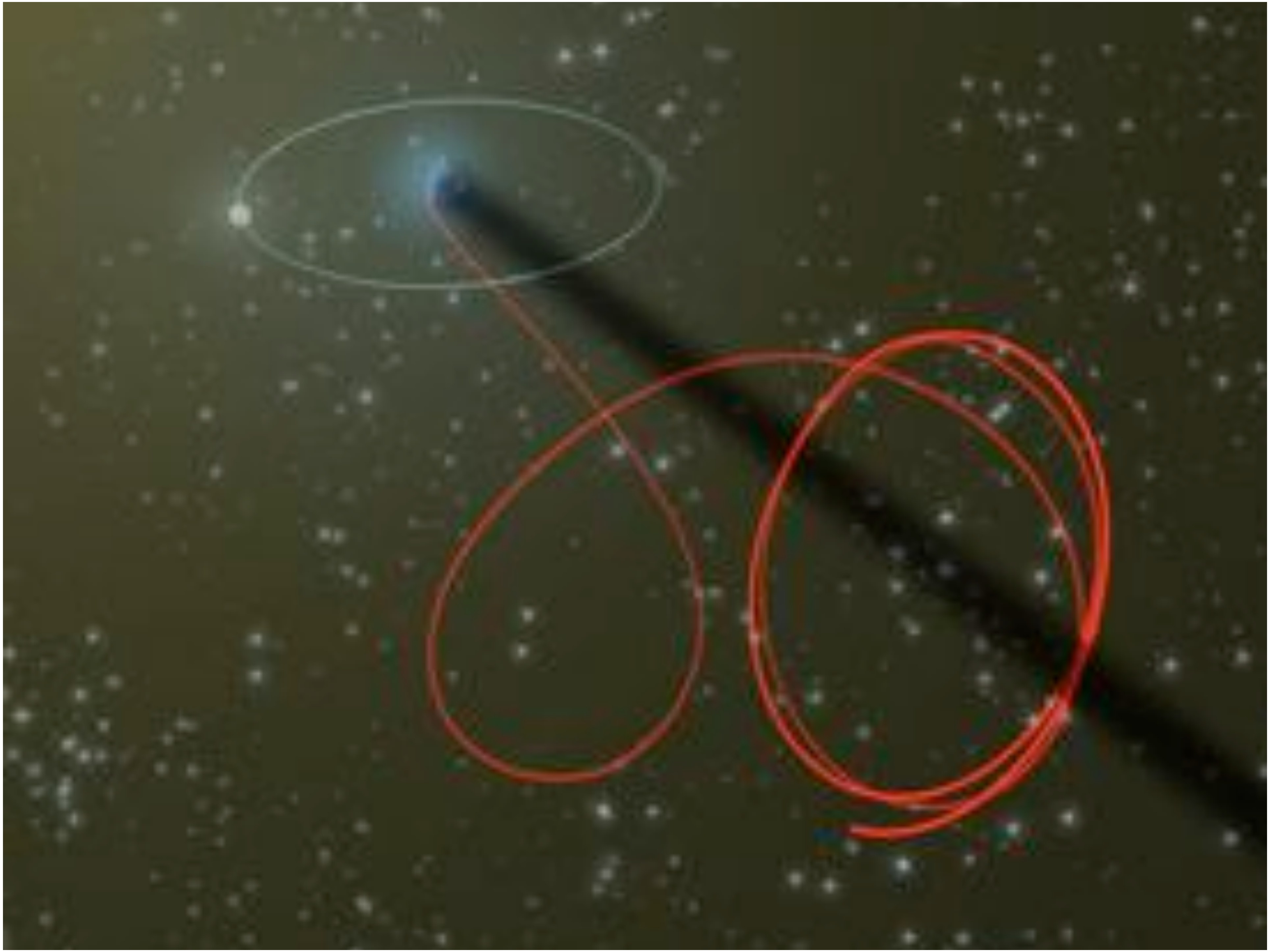
Observational and Instrumental Difficulties

The Planck Mission

- ESA mission with support from NASA
- Launch second half of 2008 to L2
- 1.5 m primary
- Two instruments
  - LFI -- at 30, 44, 70 GHz; a total of coherent receivers; all polarization-capable
  - HFI -- at n = 100-857 GHz; bolometric detectors;100,   key CMB frequencies; many bolometers are polarization-sensitive
- Will sharply improve accuracy of many cosmological parameters
- Will accurately characterize the E mode polarization
- May (barely) detect the B mode signal







Estimated Instrument Performance Goals

Telescope	1.5 m (proj. aperture) aplanatic; shared focal plane; system emissivity 1%								
	Viewing direction offset 85° from spin axis; Field of View 8°								
Instrument	LFI			HFI					
Center Freq. (GHz)	30	44	70	100	143	217	353	545	857
Detector Technology	HEMT LNA arrays			Bolometer arrays					
Detector Temperature	$\sim$20 K			0.1 K					
Cooling Requirements	H_2 sorption cooler			H_2 sorption + 4 K J-T stage + Dilution cooler					
Number of Unpol. Detectors	0	0	0	0	4	4	4	4	4
Number of Linearly Polarised Detectors	4	6	12	8	8	8	8	0	0
Angular Resolution (FWHM, arcmin)	33	24	14	9.5	7.1	5	5	5	5
Bandwidth (GHz)	6	8.8	14	33	47	72	116	180	283
Average $\Delta T/T_I$ * per pixel #	2.0	2.7	4.7	2.5	2.2	4.8	14.7	147	6700
Average $\Delta T/T_{U,Q}$ * per pixel #	2.8	3.9	6.7	4.0	4.2	9.8	29.8		

* Sensitivity (1σ) to intensity (Stokes I) fluctuations observed on the sky, in thermodynamic temperature ($\times 10^{-6}$) units, relative to the average temperature of the CMB (2.73 K), achievable after two sky surveys (14 months).

\# A pixel is a square whose side is the FWHM extent of the beam.

* Sensitivity (1σ) to polarised intensity (Stokes U and Q) fluctuations observed on the sky, in thermodynamic temperature ($\times 10^{-6}$) units, relative to the average temperature of the CMB (2.73 K), achievable after two sky surveys (14 months).

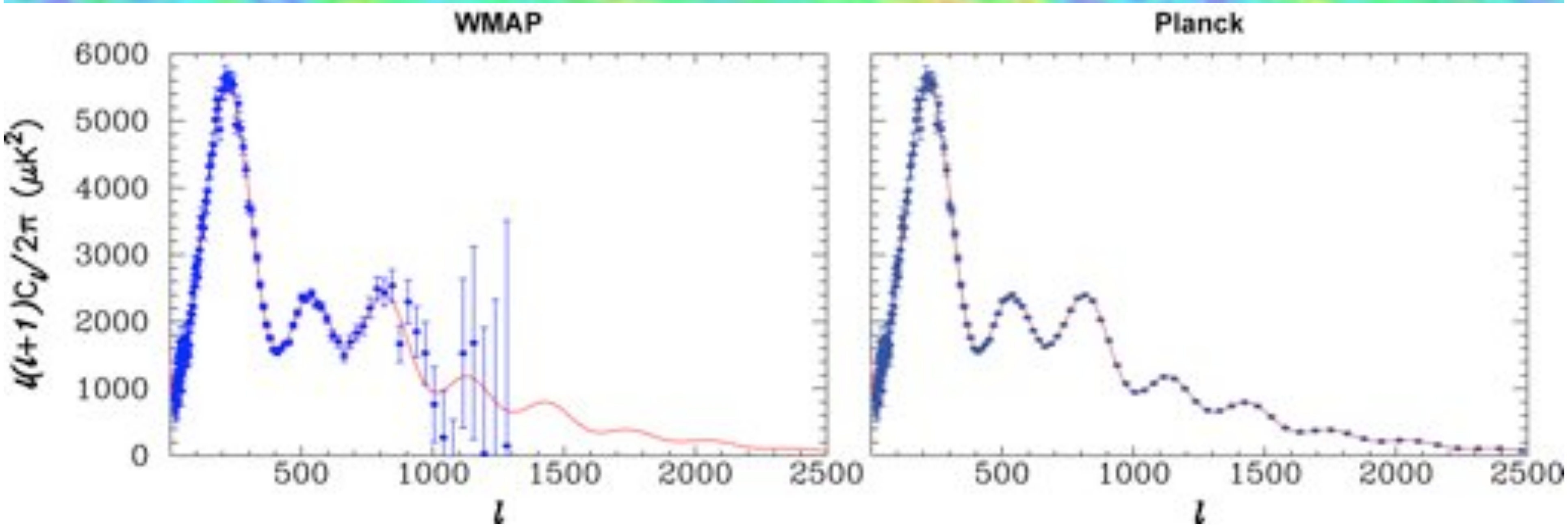
PLANCK

Table last updated Feb. 2004

esa ASTROPHYSICS

Comparing WMAP and Planck

- Wider (and higher) frequency range
  - “Wider” gives better control over foregrounds, esp. Galaxy
  - “Higher” controls dust emission AND gives…
- Better angular resolution
- Higher sensitivity
  - Should detect 5-6 peaks
  - Will detect ~1000 radio sources ~10,000 dusty galaxies



The Power of Planck

- Better control of foregrounds
- More sensitivity
- Higher angular resolution

- Consequences:
- More precise measurements of cosmological parameters
  - Ho to better than 1%
  - r to 0.3 or 0.03 under some circumstances

Some Ground-based Programs

Primary goal -- SZ effect (and high-l anisotropy)

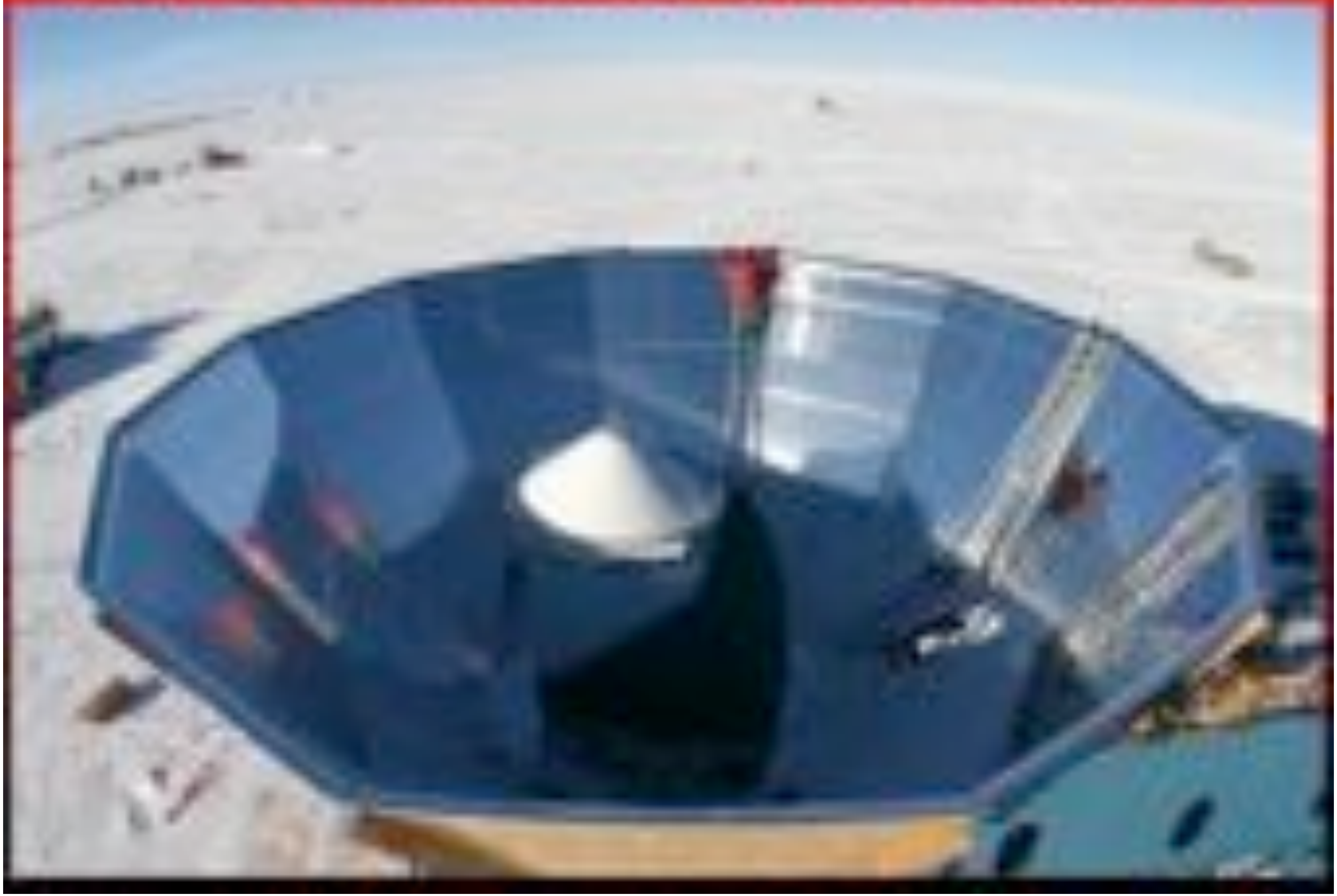
- AMI (Arcminute Microwave Imager)
- SPT (South Pole Telescope)
- ACT (Atacama Cosmology Telescope)

Primary goal -- characterization of polarized fluctuations

- QUAD
- Continuation of programs like DASI, CBI, BOOMERanG…

Useful discussion in recent report of the Task Force on CMB Research

QUaD in Extended Shield Feb 2005



AMI (Arcmin. Microwave Imager) Parameters

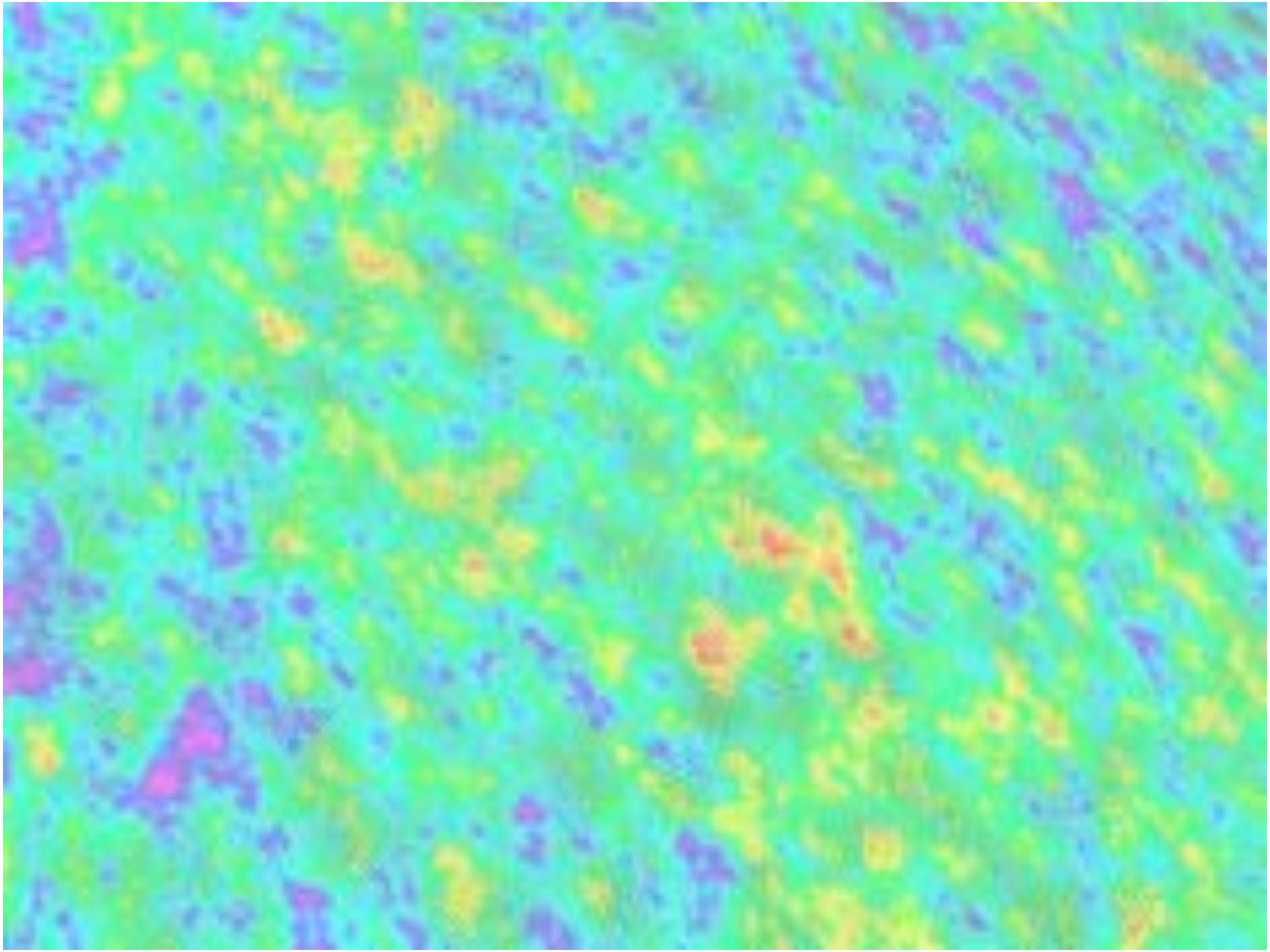
Sub-array	AMI-SA	AMI-LA
Primary dish diameter	3.7 m	12.8 m
Antenna efficiency	0.75	0.67
Number of antennas	10	8
Range of baseline lengths	4–20 m	18–120 m
Primary beam (FWHM at 15 GHz)	18'	5.5'
Observing frequency	13.5–18 GHz	
Effective Bandwidth	4.5 GHz	
Flux sensitivity	30 mJy s-1/2	3 mJy s

AMI

Paired arrays

Located in Cambridge

Large array to find and remove foreground sources



ACT

Science:

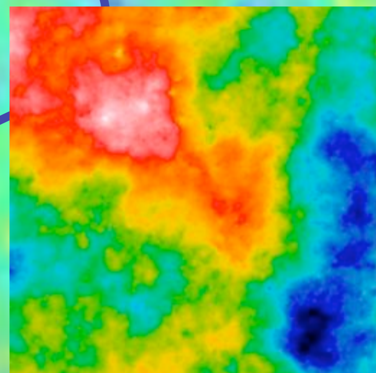
- ★Growth of structure
- ★Eqn. of state
- ★Neutrino mass
- ★Ionization history
- ★Power spectrum

Observations:

- ★CMB to l 10,000
- ★Cluster (SZ, KSZ X-ray, & optical)
- ★ Diffuse SZ
- ★ OV
- ★ Lensing

X-ray

Optical

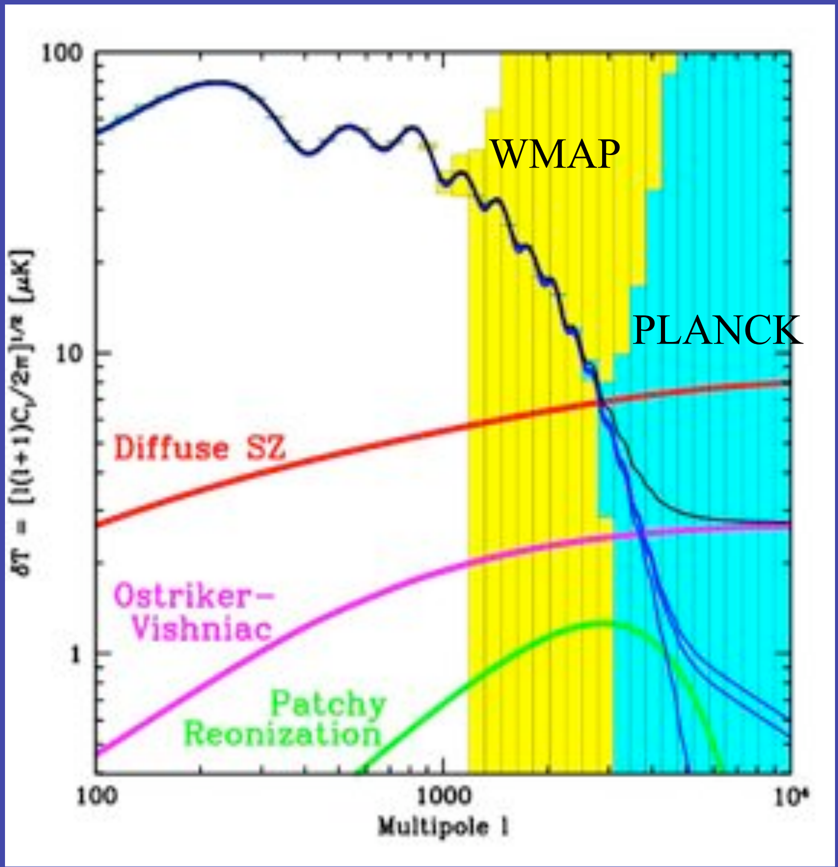


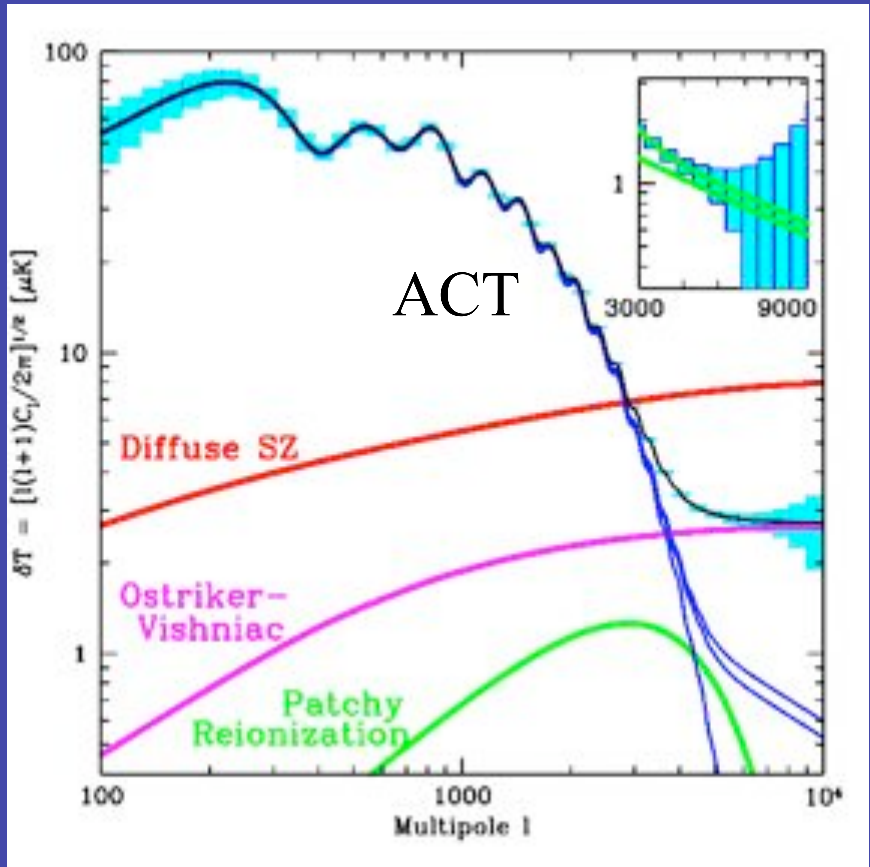
Theory

Collaboration:

Cardiff	Columbia	CUNY	Haverford	INAOE	NASA/GSFC	NIST	Princeton
Rutgers	UBC	U. Catolica	U. KwaZulu-Natal	UMass	UPenn	U. Pittsburgh	U. Toronto

CMB Temperature Power Spectrum





(Tegmark and Oliveira-Costa)

- Measure the linear regime and the transition to the non-linear
- Overlap with WMAP for calibration

SZ Studies

Cluster physics, evolution of structure

Follow-up redshifts + mass estimates

(optical – SALT) (x-ray, lensing, or velocity dispersions)

Þ $N_{cluster}\ (m,z)$

Sensitive to both *w* and neutrino mass

$w \rightarrow 0$, earlier dark energy domination

$\Rightarrow$ fewer low-z clusters relative to high-z

$m_{\upsilon}\ \uparrow \Rightarrow$ suppression of growth of structure

KSZ – Baryon evolution (Shirley Ho, last week)

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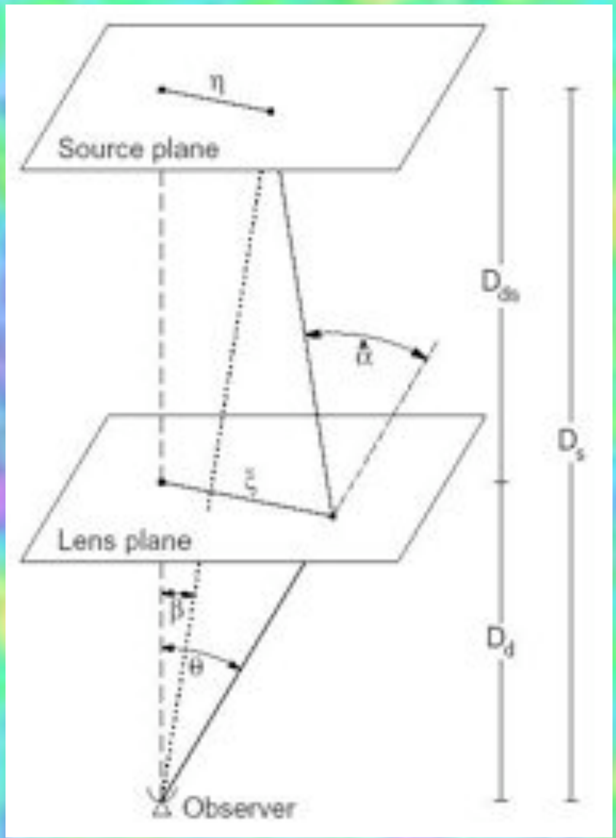
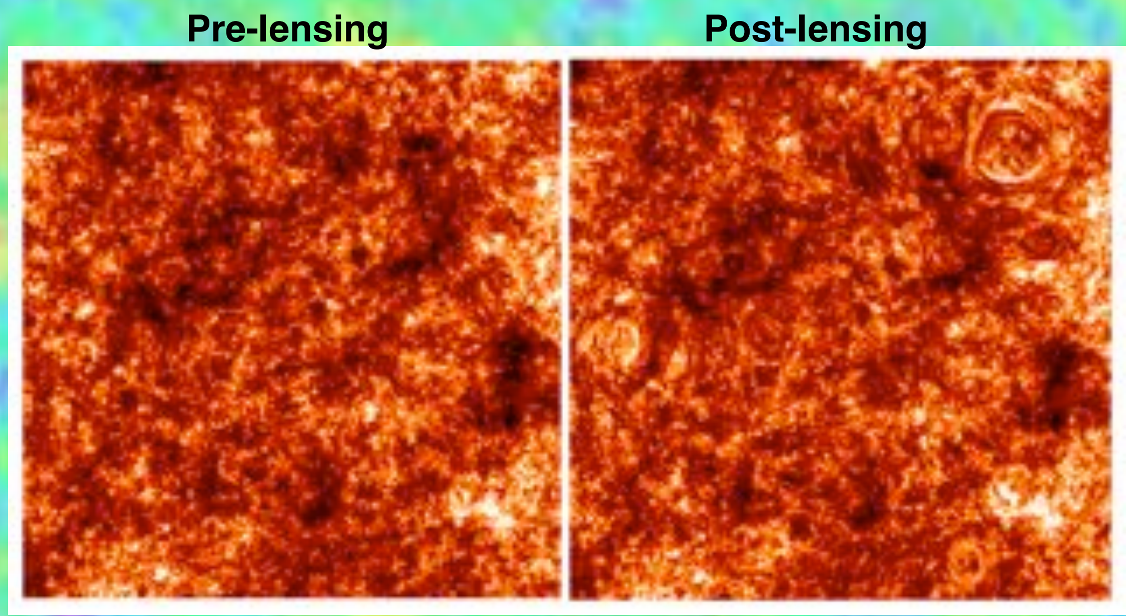
Gravitational Lensing of CMB

- Remapping of source by intervening mass
- Conserves surface brightness
- CMB as the source has a well known redshift



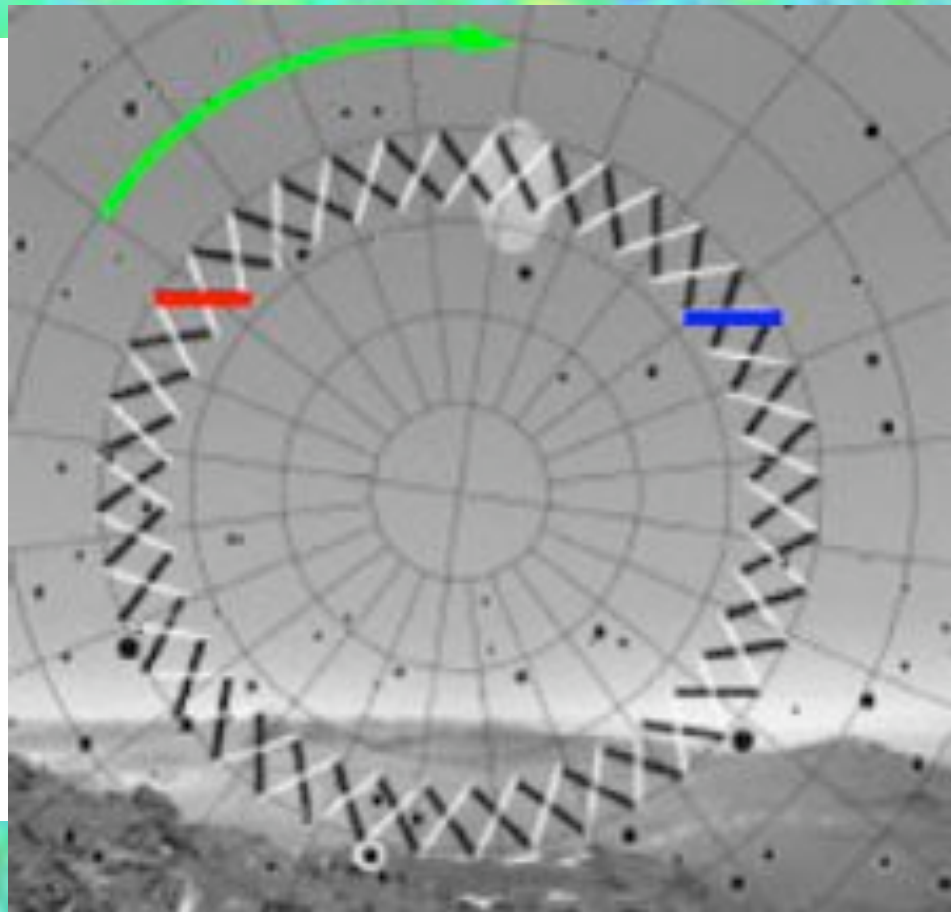
(Bartelmann and Schneider 1999)



(Ryan Scranton – website)

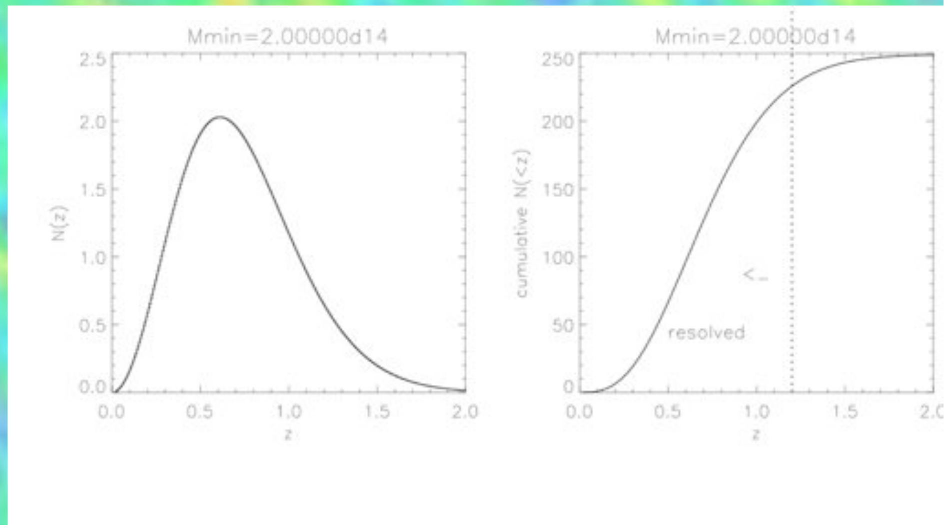
How are we doing it?

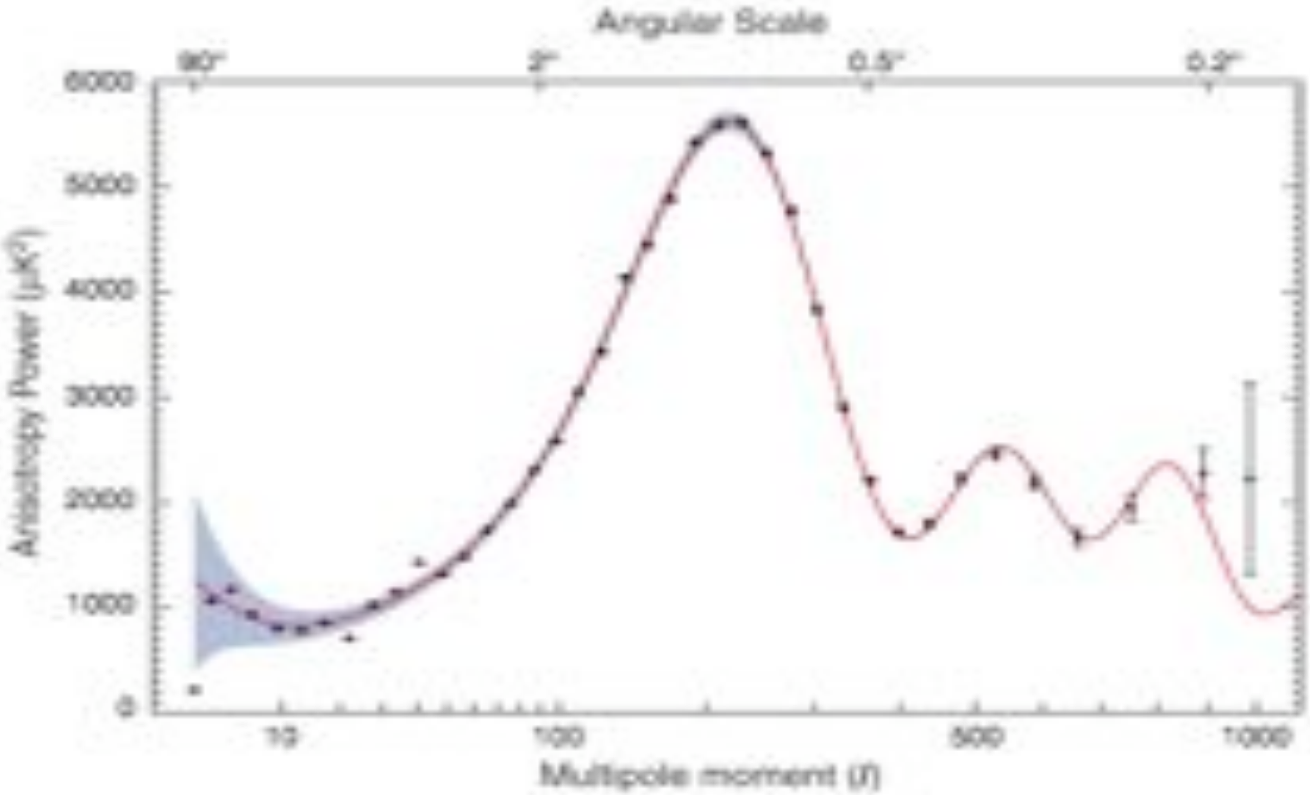
- Atacama Plateau
- Careful Optical Design
- Crosslinked, simultaneous 3 band observations
- Close-packed kilopixel TES arrays (GSFC)
- Time-domain SQUID Multiplexing (NIST)



Equation of State of Dark Energy

- A major goal of ACT (and SPT)
- Derived from study of evolution of number density of SZ clusters
- Parameterize eqn. of state using w: w = P/u, where P is pressure and u the energy density
  - w = 1/3 for photons and -1 for a pure cosmological const. form of Dark Energy
  - But other (negative) values of w are possible; so is w(t)
- WMAP already limits w to close to -1





Angular Scale
90°
2°
0.5°
0.2°
6000
5000
4000
3000
2000
1000
0
Anisotropy Power (μK²)
10
100
500
1000
Multipole moment (l)