4.The Future

Bruce Partridge

Outline

Planck

Some Ground-based Programs

Improved Accuracy of Cosmological Parameters

E Mode Polarization

Value in breaking degeneracies

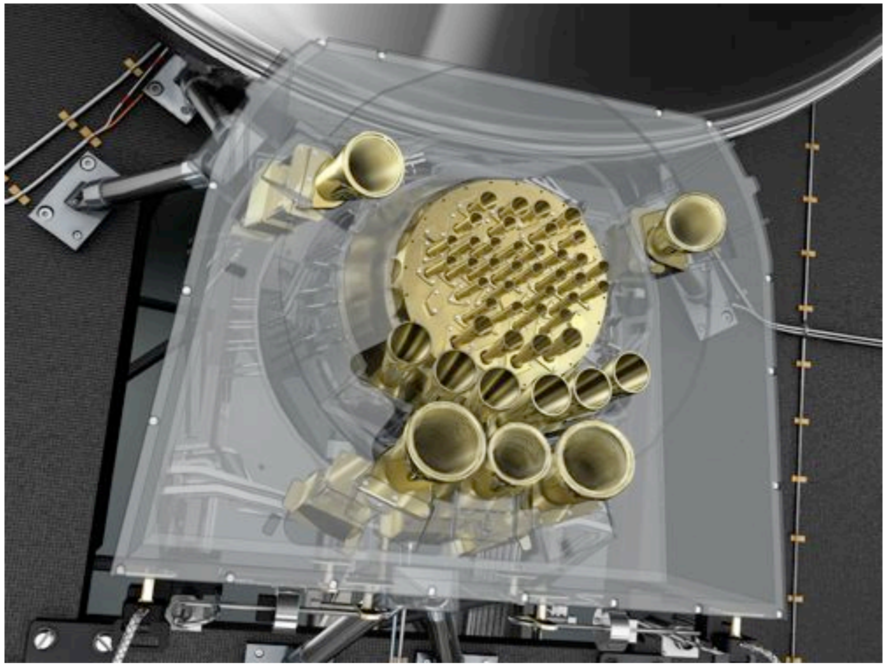
The Search for B Modes

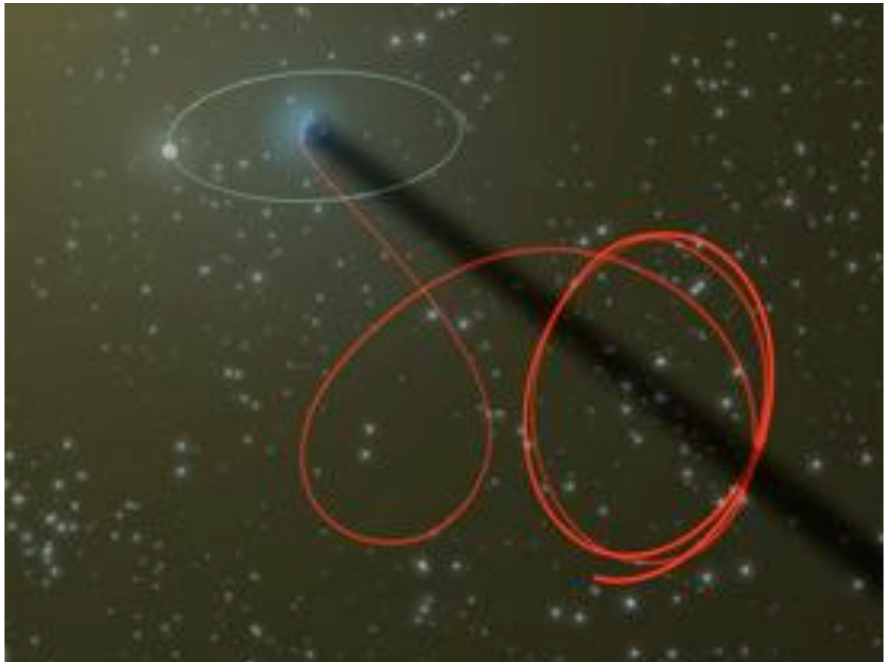
Direct test of inflation

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	~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 ($\times10^{-6}$) units, relative to the average temperature of the CMB (2.73 K), achievable after two sky surveys (14 months).

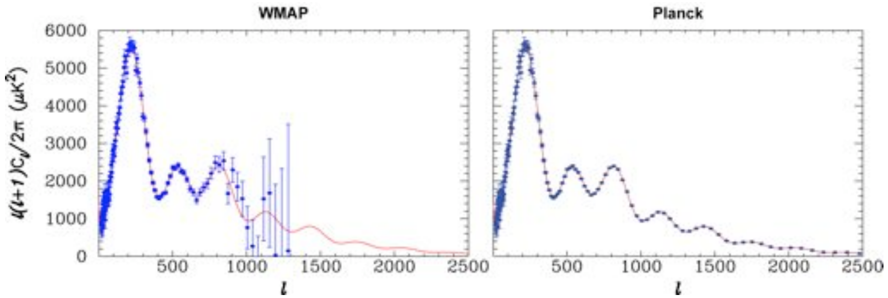
\# A pixel is a square whose side is the FWHM extent of the beam.

\+ Sensitivity (1σ) to polarised intensity (Stokes U and Q) fluctuations observed on the sky, in thermodynamic temperature ($\times10^{-6}$) 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

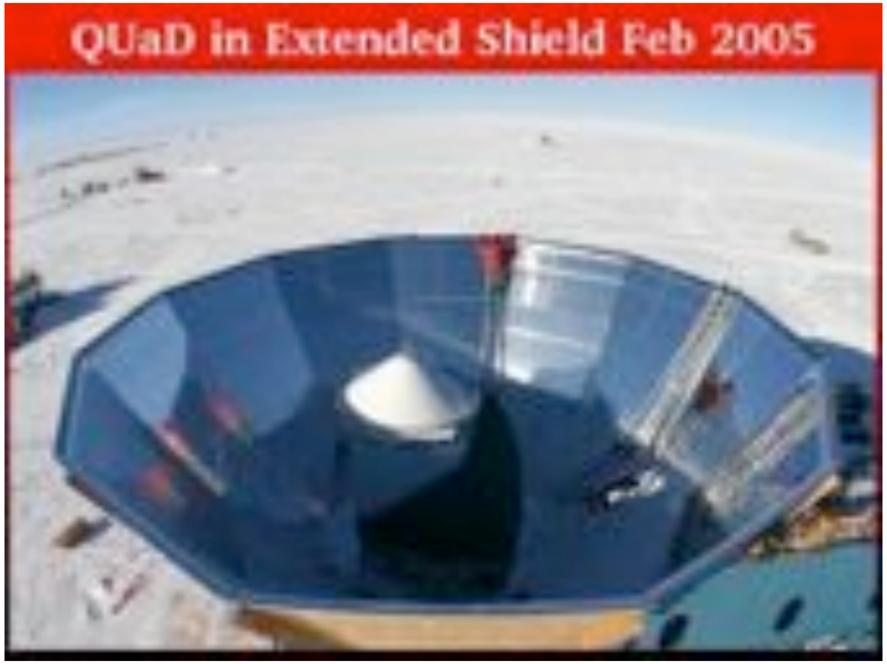
Primary goal -- SZ effect (and high-l anisotropy)

- 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



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:

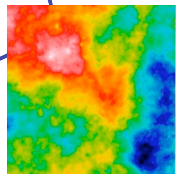
- ★Growth of structure
- ★Eqn. of state
- ★Neutrino mass
- ★Ionization history
- ★Power spectrum

Observations:

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

X-ray

Optical

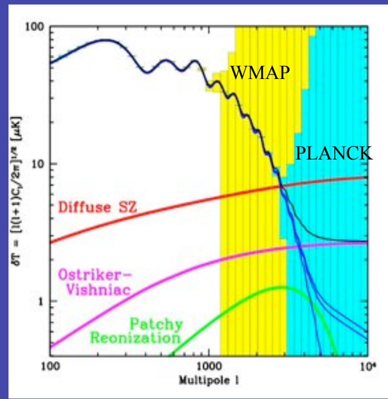


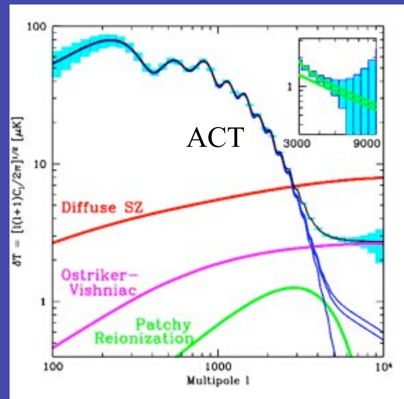
Theory

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

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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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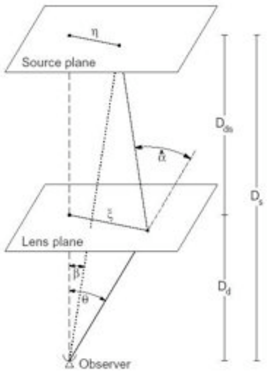
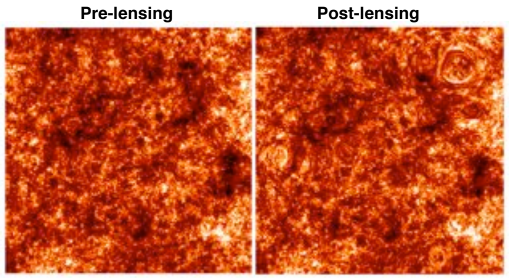
Gravitational Lensing of CMB

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



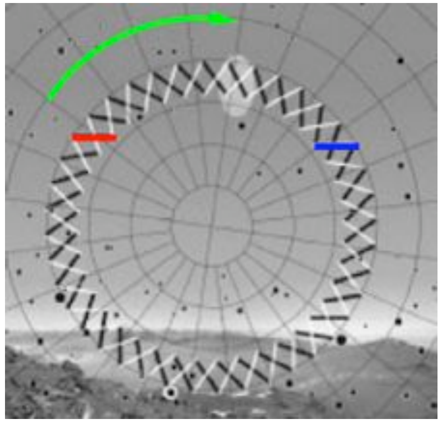
(Bartelmann and Schneider 1999)



(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