

Final Report of the Cosmic Microwave Background Task Force*

B. Winstein (for Rai Weiss)

- Membership
 - The Task Force Recommendations
 - Science & Technology
 - This rapid fly-through no substitute for the report
 - Meetings; many telecons; external readers
-
- Perspectives on the Field
 - How and why DOE/HEP might contribute

*Commissioned by NSF, NASA, and DOE

MEMBERS OF THE CMB TASK FORCE

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Recommendation S1

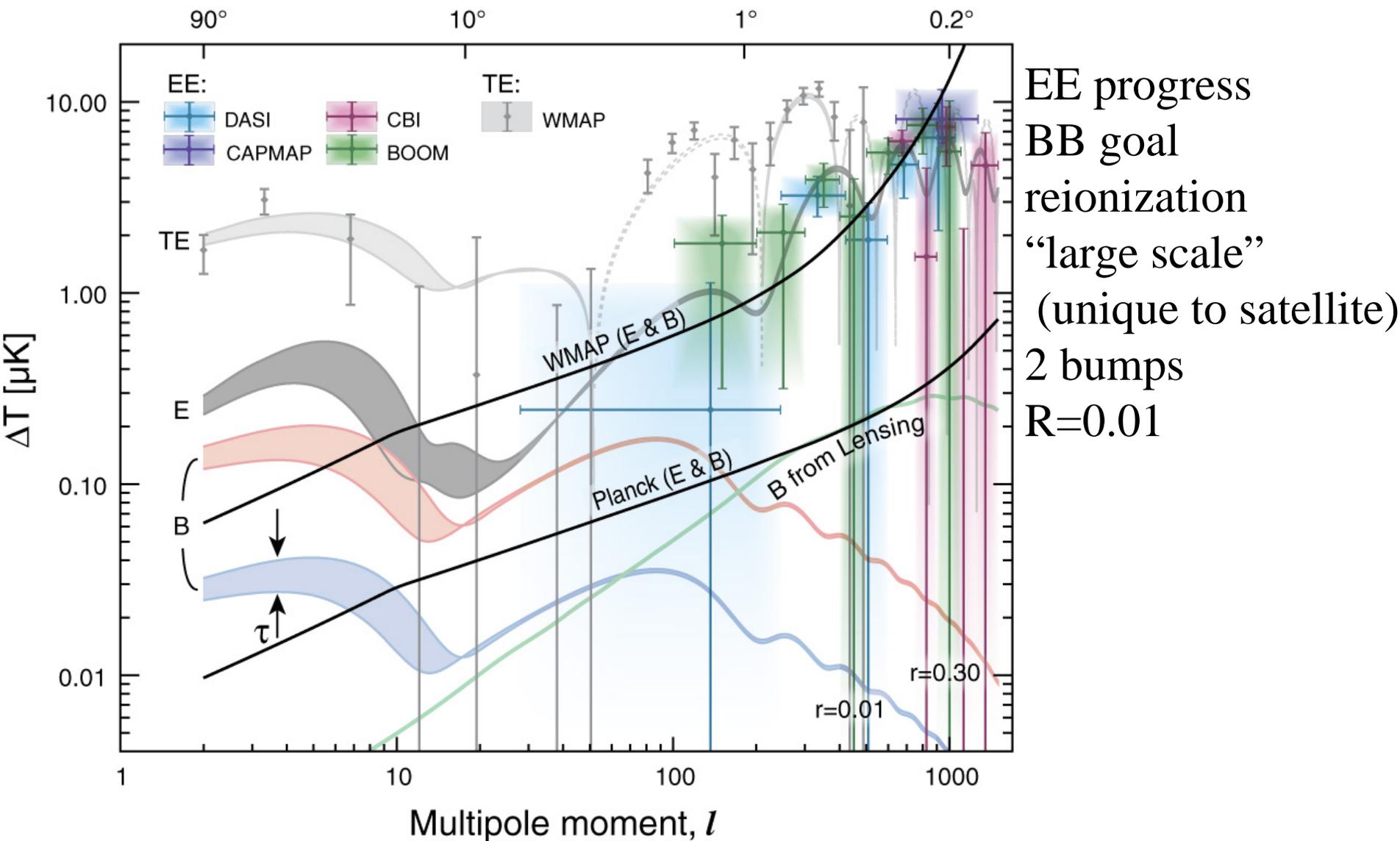
- **Finding**: A unique CMB polarization signal on **large angular scales** directly tests inflation and probes its energy scale.
- **Recommendation**: As our highest priority, we recommend a phased program to measure the large-scale CMB polarization signal expected from inflation. The primary emphasis is to test whether GUT-scale inflation occurred by measuring the signal imprinted by gravitational waves to a sensitivity limited only by our ability to remove the **astrophysical foregrounds**.

S1

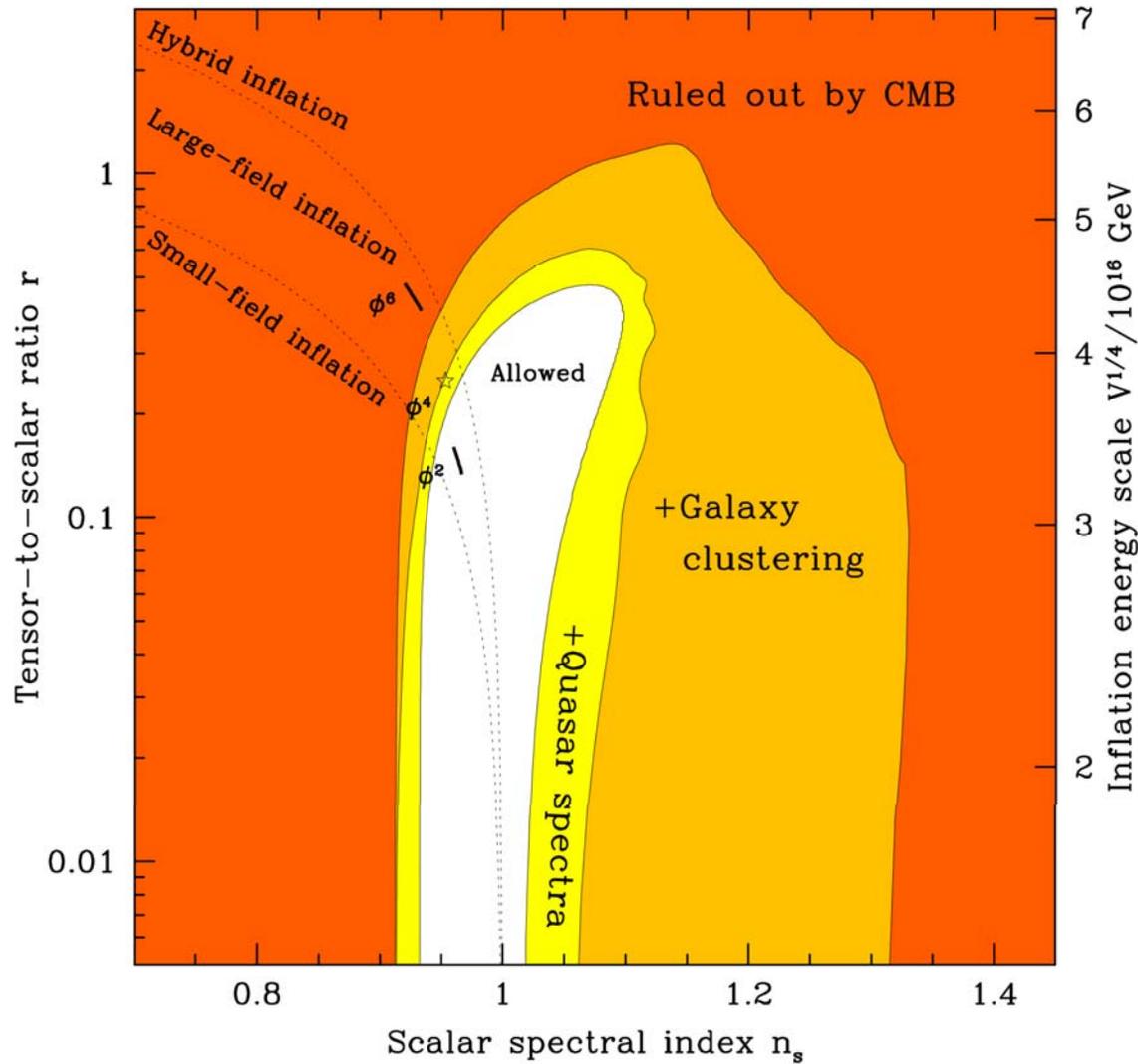
- The phased program ...begins with a strong ground- and balloon-based program that will make polarization measurements on small and medium angular scales and culminates in a space mission for larger angular scales ($\theta > 1^\circ$) specifically optimized, for the first time, to measure CMB polarization to a sensitivity limited only by our ability to remove the astrophysical foreground emission. We estimate that limits at or below $r = 0.01$ can be set on the amplitude of primordial gravitational waves; to reach this level a sensitivity at least 10 times that of Planck will be required. The new mission is known as “CMBPOL” and is a candidate *Beyond Einstein* Inflation Probe.

Current and Near-Term Polarization Measurements

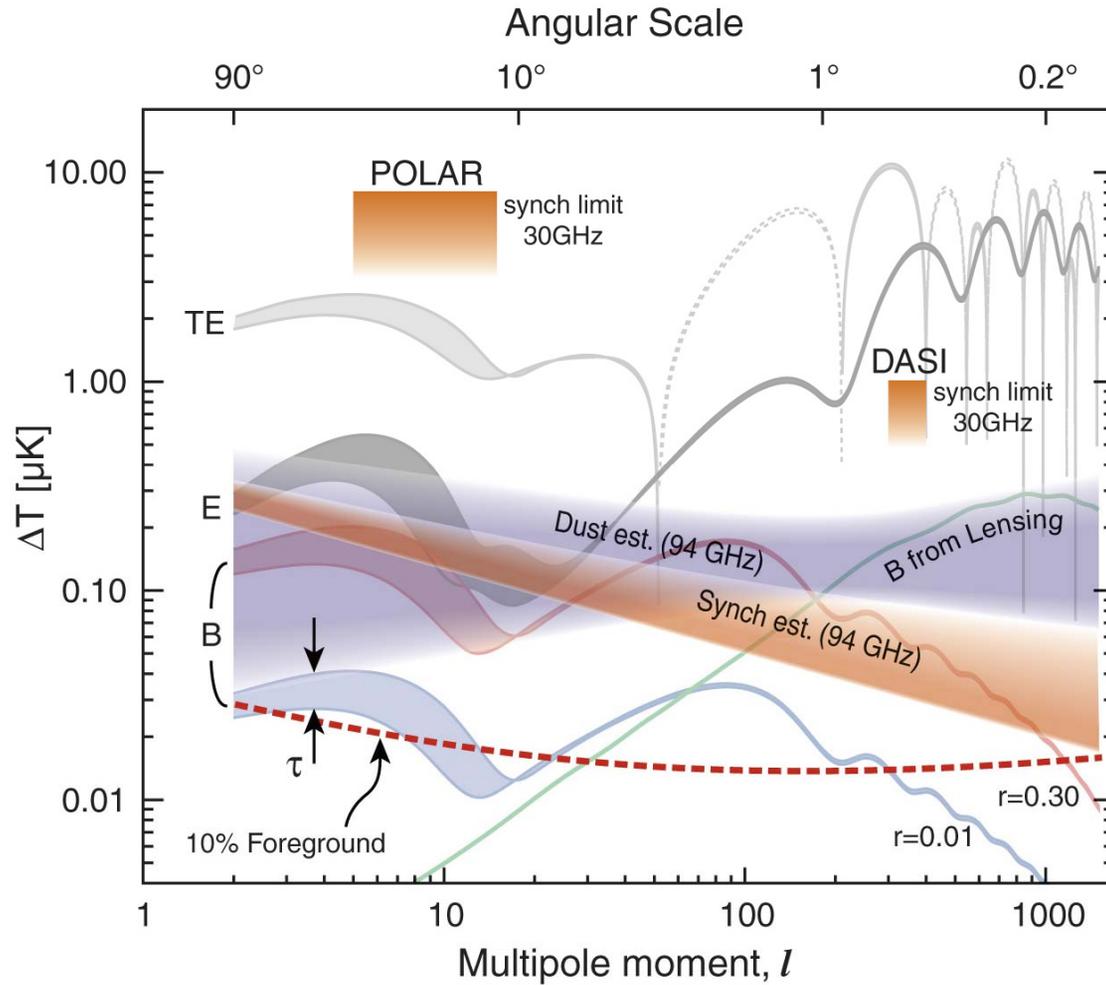
Angular Scale



Testing Inflationary Models



Polarized CMB and Foreground Spectra



Recommendation S2

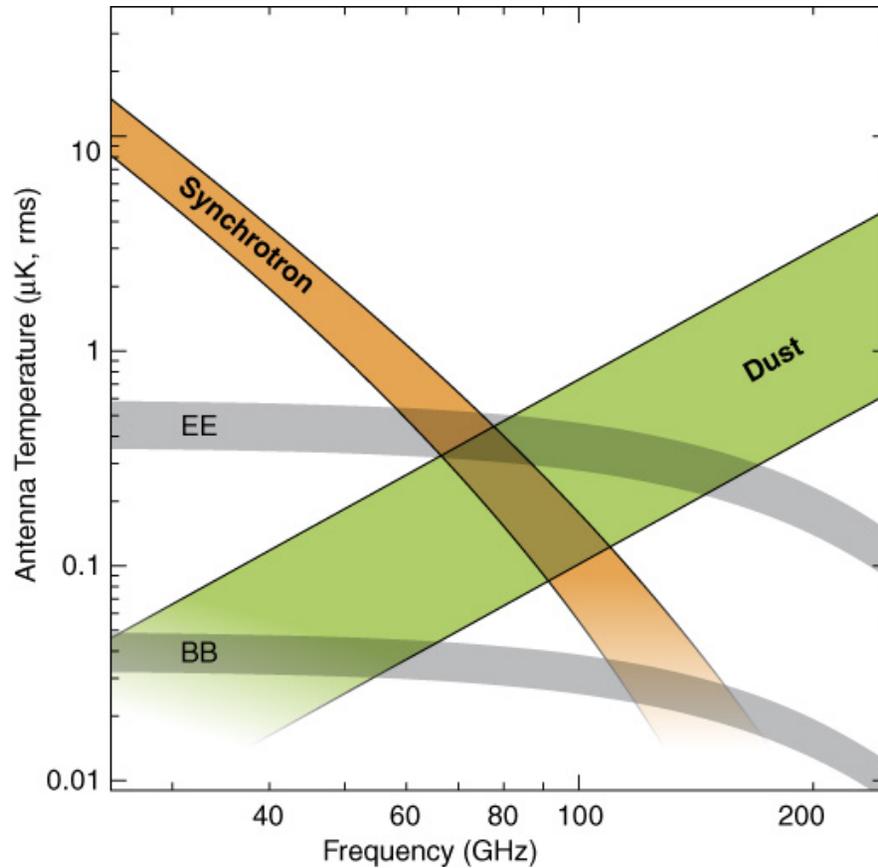
- **Finding**: The CMB temperature anisotropy on **small angular scales** contains a wealth of additional information about inflation and the evolution of cosmic structure.
- **Recommendation**: We also recommend a program to measure the temperature and polarization anisotropy on small angular scales, including the signals induced by gravitational lensing and by the Sunyaev-Zeldovich effect.

Recommendation S3

- **Finding**: Foreground signals, particularly emission from our Galaxy will limit measurements of polarized fluctuations in the CMB.
- **Recommendation**: We recommend a systematic program to study polarized astrophysical foreground signals, especially from our Galaxy.

Foreground Estimates

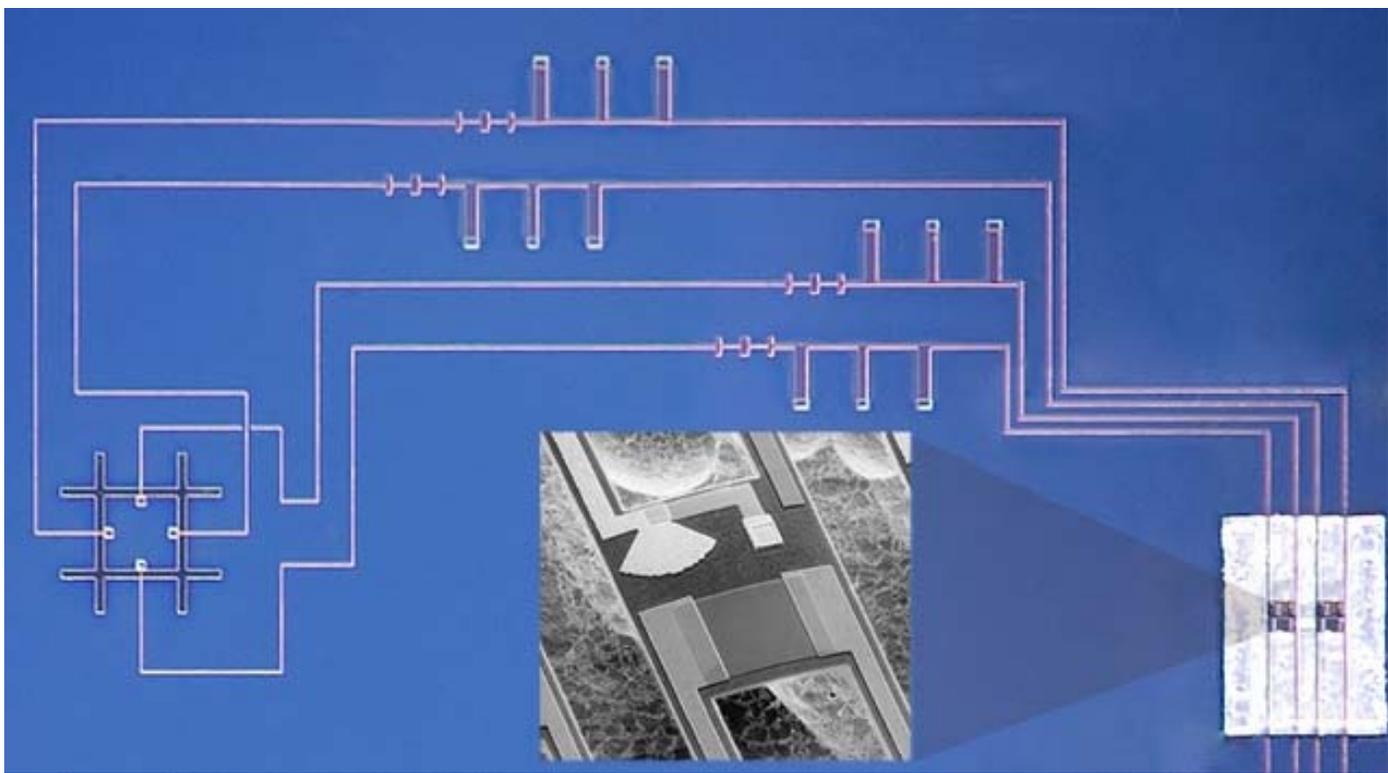
$2 < l < 20$



Multi-frequencies

Recommendation T1

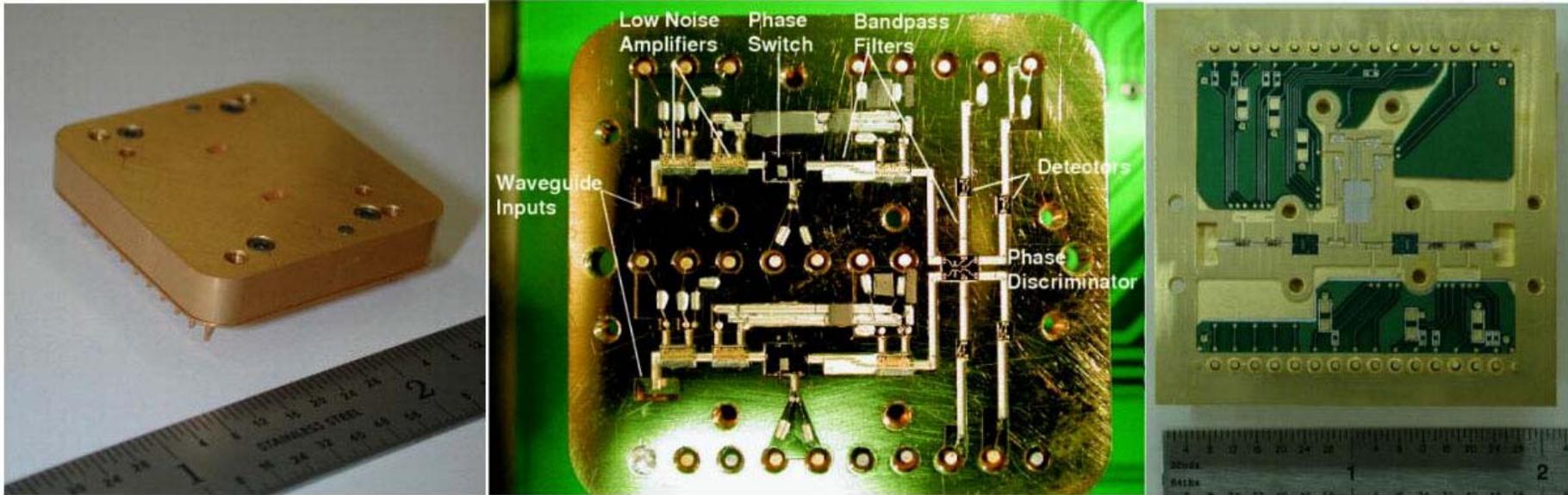
- **We recommend technology development leading to receivers that contain a thousand or more polarization sensitive detectors, and adequate support for the facilities that produce these detectors.**
- To meet the timeline outlined in this report there is a need to fund the development of polarization sensitive detectors at a level of \$7M per year for the next 5 to 6 years. This would roughly restore the pre-2003 level of funding for the field, which has been especially hard-hit by the shift in NASA's priorities toward exploration. It is important to keep open a variety of approaches until a clear technological winner has emerged. *Nevertheless, highest priority needs to be given to the development of **bolometer-based polarization sensitive receivers**.*



- *A planar-antenna-coupled bolometer. A dual-polarization antenna is on the left. Each double-slot dipole antenna coherently adds the signal from two slot dipoles to form a relatively symmetric antenna pattern. The slots in this chip are lithographed in a superconducting Nb ground plane. They are ~1 mm long and have a resonant response centered at 220 GHz. Microstrip transmission lines and transmission line filters are used. The filter combination at the top of the photograph includes a low pass filter (left) and a band pass filter (right). The design bandpass is centered at 220 GHz with a 30% bandwidth. These filters have been tested in an end-to-end receiver optical measurement which shows 20% receiver efficiency. The transmission lines terminate in the matched loads on the leg-isolated TES bolometers at the lower right.*

Recommendation T2

- **We recommend a strategy that supports alternative technical approaches to detectors and instruments.**
- Advances in CMB science have been based on a variety of technologies. Though we expect that bolometers will be the clear choice for CMBPOL, it is premature to shut down the development of alternatives. We recommend the continued development of **HEMT-based detectors** as they might lead to an alternative space mission and will certainly be used in ground-based measurements. ...these relatively inexpensive enhancements would lower risk by keeping a wider set of technology channels open until an accepted best method has emerged.



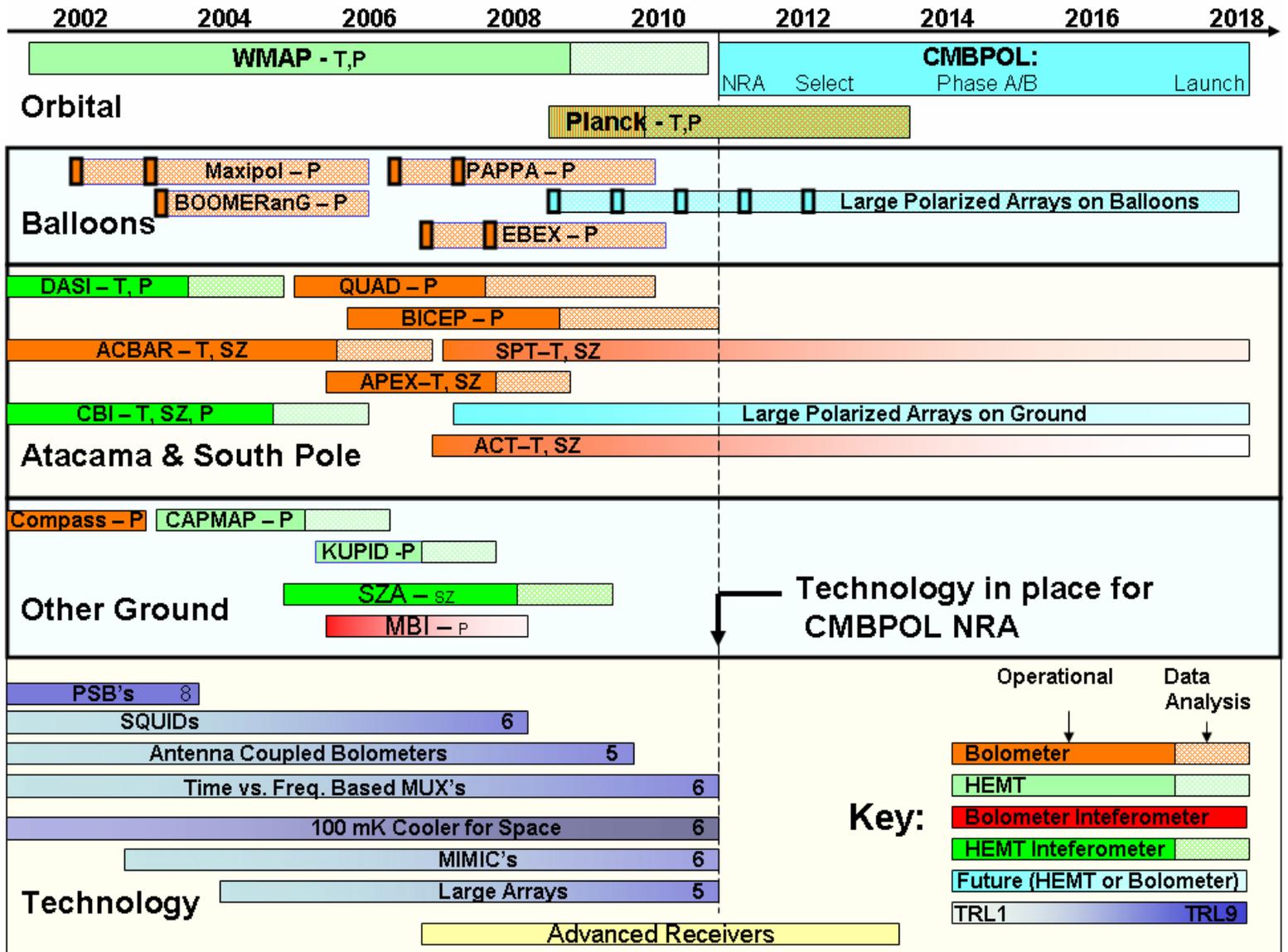
Left: Photograph of a prototype HEMT polarimeter with cover on and input waveguides shown. Center: The complete 90 GHz Q/U module shown with cover off. Right: The 40 GHz Q/U module shown with lid off. Photographs courtesy of Todd Gaier.

Recommendation T3

- **We recommend funding for development of technology and for planning for a satellite mission to be launched in 2018.**
 - We recommend funding for both development of technology and planning for a satellite mission to be launched in 2018. Background (CMB) noise limited receivers with thousands of elements and the sub-Kelvin cryogenics, required for these detectors, are part of the technical development required for the satellite mission. Another need is for modeling the mission based on improved knowledge of foreground emissions, to decide on the optimal spatial scale and frequency bands to separate the *B*-mode signals from the polarized foreground emission and to control systematic effects. As detailed in §10, preparation for a 2011 AO and a 2018 launch requires adequate funding, starting at \$1M in 2007 and rising to \$5M per year in 2011, for systems planning and technology development and assessment leading to CMBPOL.

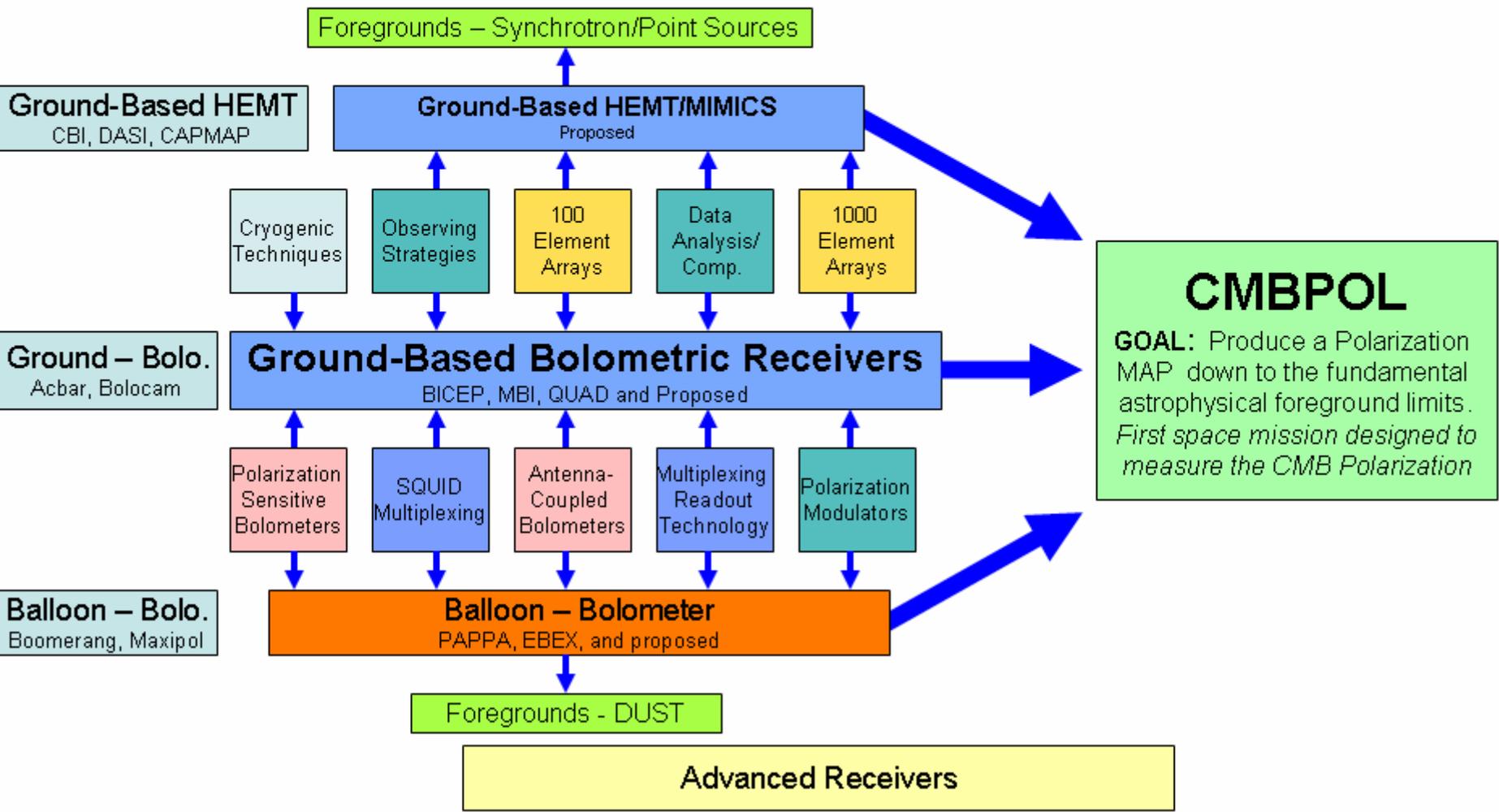
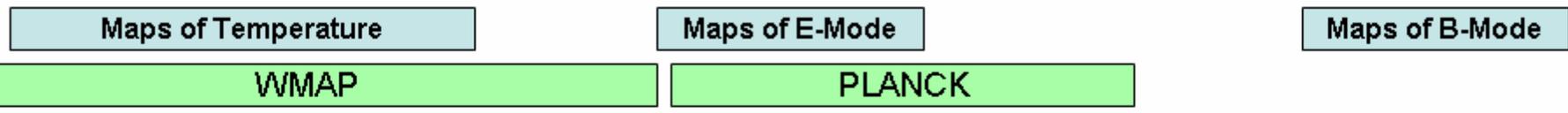
Recommendation T4

- **We recommend strong support for CMB modeling, data analysis and theory.**

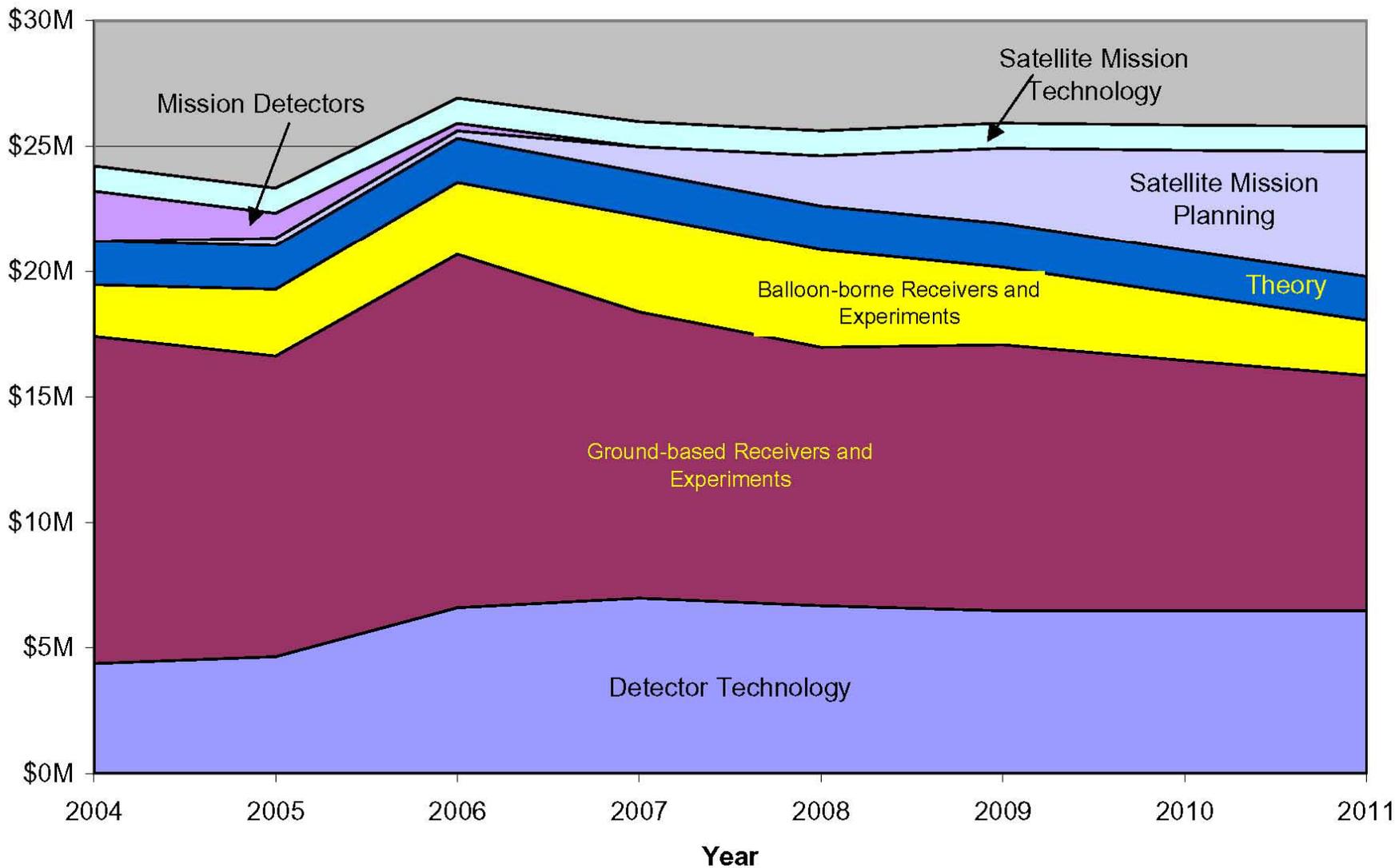


Schematic timeline of research programs observing CMB small-scale temperature fluctuations, CMB polarization, and the Sunyaev-Zel'dovich effect. The projects included in technology development are needed for ground-based, balloon and space

100 $\mu\text{K}\cdot\text{s}^{1/2}$	Polarization Sensitivity	10 $\mu\text{K}\cdot\text{s}^{1/2}$	1 $\mu\text{K}\cdot\text{s}^{1/2}$
10 μK	Polarization Systematic Limit	1 μK	0.1 μK
10 μK	Polarization Map Sensitivity 1 x 1 degree	1 μK	0.1 μK



CMB Funding Summary



Predicted Future Satellite Sensitivities

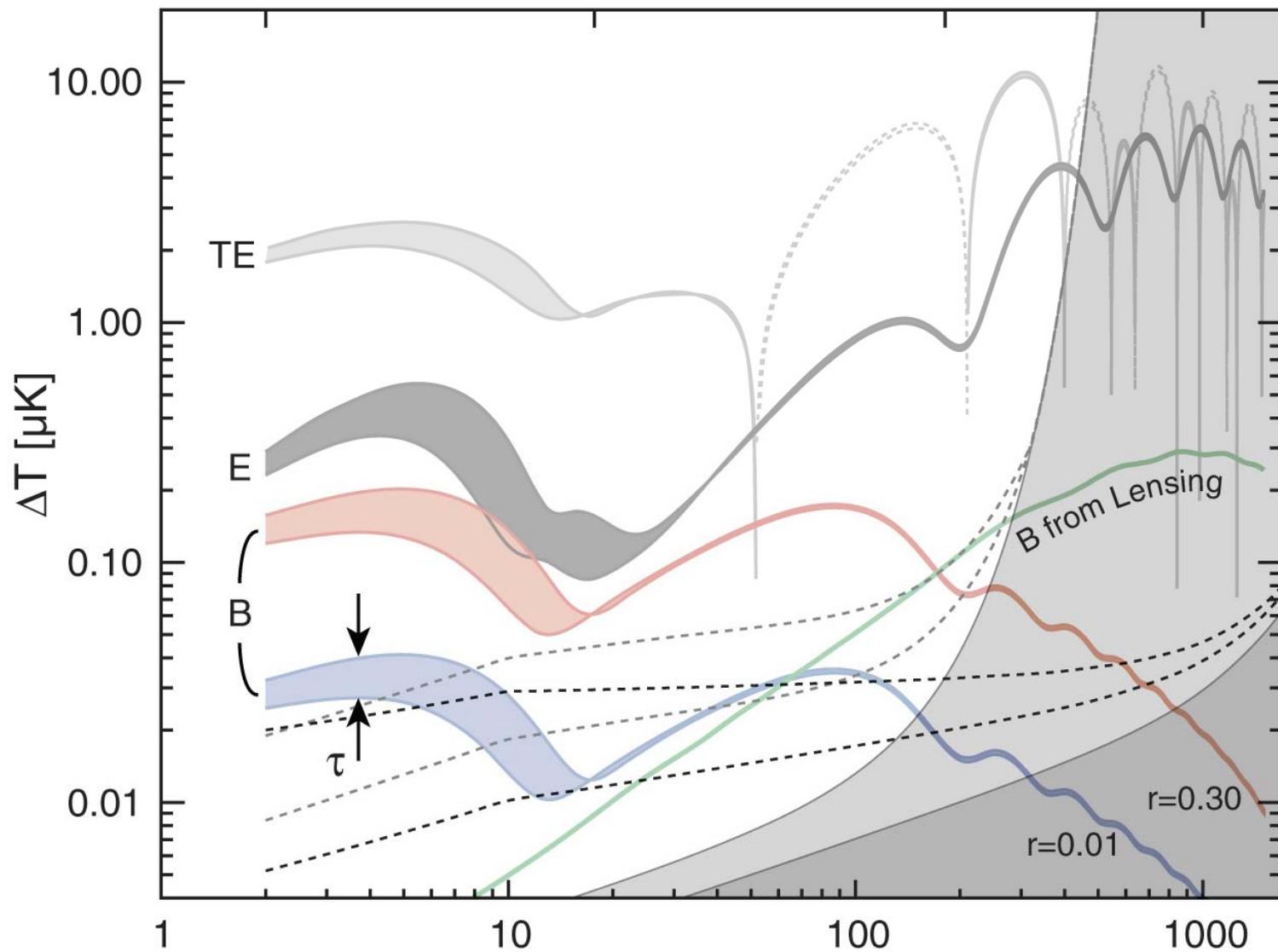
Angular Scale

90°

10°

1°

0.2°



Systematic Challenges for the Ultimate Mission

Table 6.1: Instrument Performance Goals

Parameter	Effect	Goal	Method
Cross-Polar Beam response	$E \rightarrow B$	< 0.003	Rotate Instrument, Wave Plate
Main lobe ellipticity (0.5° beam)	$dT \rightarrow B$	$< 10^{-4}$	Rotate Instrument, Wave Plate
Polarized sidelobes (response at Galaxy)	$dT \rightarrow B$	$< 10^{-6}$	Baffles/shielding/measure
Instrumental polarization	$dT \rightarrow B$	$< 10^{-4}$	Rotate Instrument, Wave Plate
Polarization angle	$E \rightarrow B$	$< 0.2^\circ$	Measure
Relative pointing (of differenced samples)	$dT \rightarrow B$	$< 0.1''$	Dual-polarization pixels
Relative calibration	$dT \rightarrow B$	$< 10^{-5}$	Modulators
Relative calibration drift (scan synchronous)	$T \rightarrow B$	$< 10^{-9}$	Modulators
Lyot Stop Temperature (10% spill, scan synch.)	$dT_{\text{opt}} \rightarrow B$	$dT_{\text{opt}} < 30 \text{ nK}$	Measure
Cold stage T drifts (scan synch.)	$dT_{\text{CS}} \rightarrow B$	$dT_{\text{CS}} < 1 \text{ nK}$	Improve uniformity, measure

Perspectives on the Field

- Science is “fundamental”
- Scientists are first rate
- Field is really starved for resources
 - manpower funding tied to projects
 - researchers on multiple projects
 - Intense competition; some getting disillusioned
 - Not sure agencies really know the funding situation
- No one body reviewing proposals/progress
- Collaborations are often not smooth
- Very little open discussion of progress/problems
- Phase transition underway
 - 100, 1000 element arrays
 - More expense, larger groups, need for engineering & management
 - The kind of planning in the Task Force report

Role for DOE/HEP?

- Science
 - Inflation: extraordinary idea outside Standard Model!
 - Very rich phenomenology
- Agency Problems
 - Crunch at NSF
 - NASA on the ground?
- Contributions to Experiments
 - The challenge of the instrumentation
 - Extremely low noise requirements
 - The regime of $S/N=10^{-8}$
 - (warm) Electronics
 - Data analysis, large scale computing
 - Engineering; Management

From the Executive Summary ..

- The search for CMB polarization offers an ideal arena for DoE, NASA, NIST and NSF interagency co-operation. Indeed, given the need for receiver development, ground-based observations, foreground characterization, and a space mission, the road map requires such cooperation.