After Bicep2

A theorist's perspective on CMB experiments

Rishi Khatri

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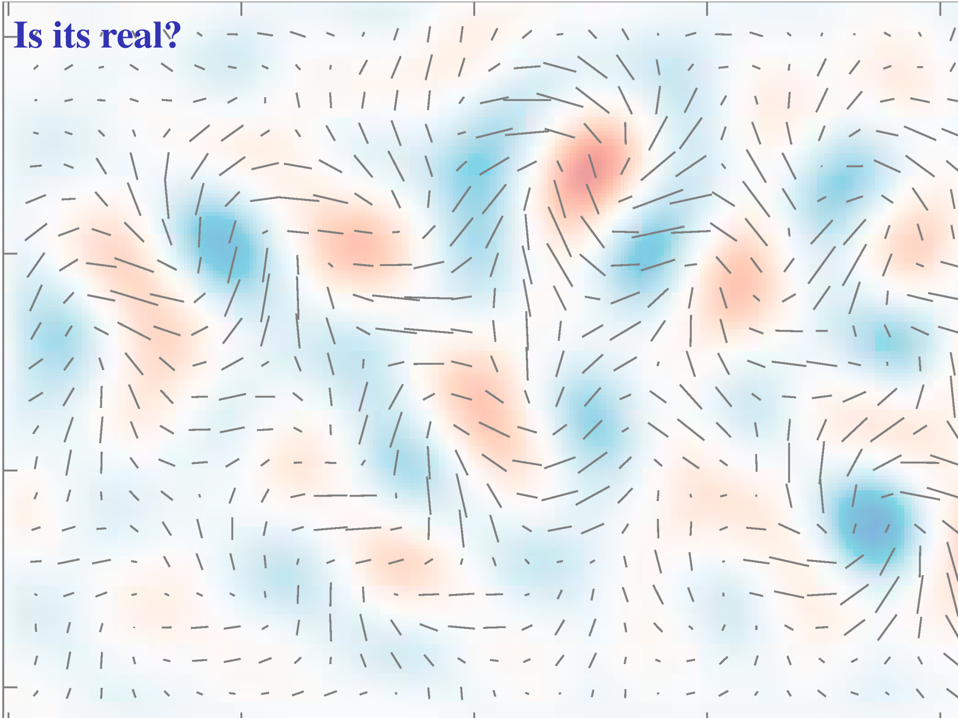
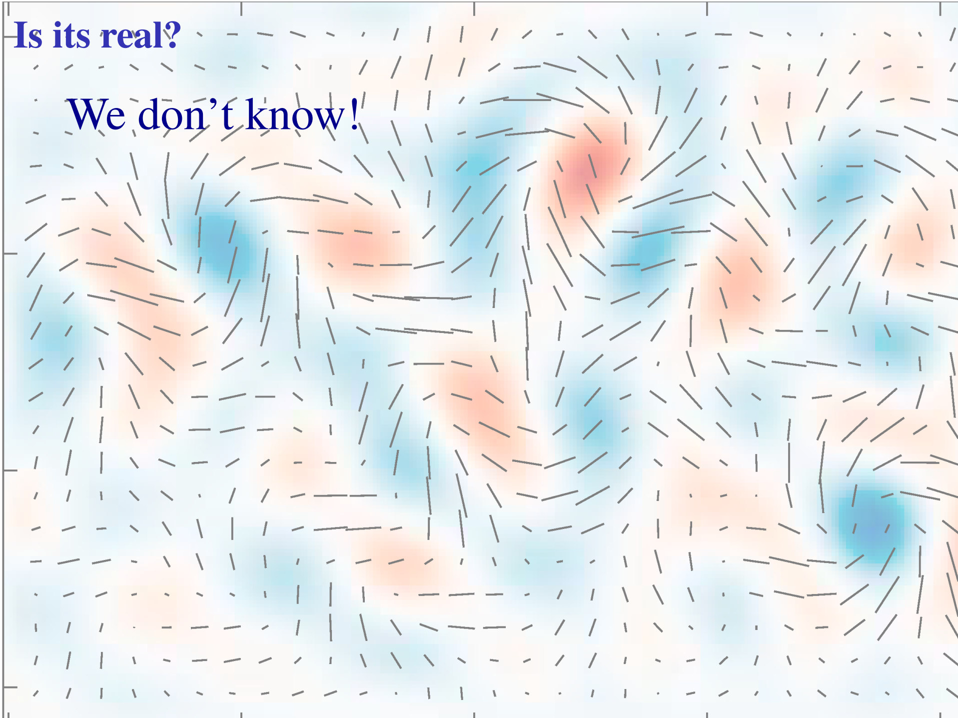
MAX-PLANCK-GESELLSCHAFT

Is its real?



Is its real?

We don’t know!



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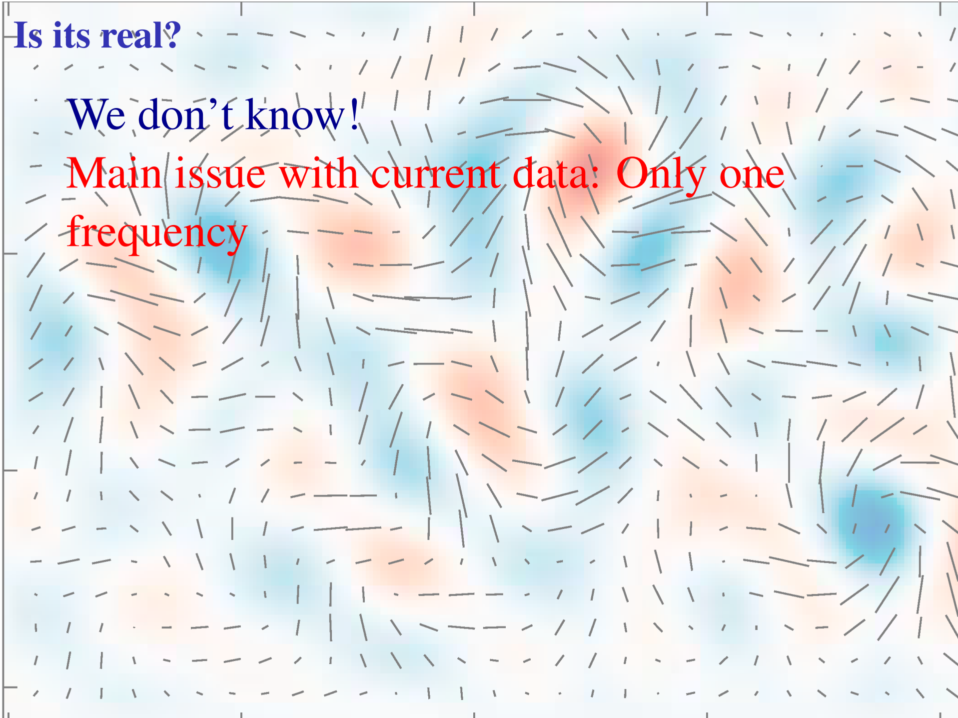

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Main issue with current data: Only one frequency

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- Foregrounds (Dust/Synchrotron)
- Temperature leakage
- E-B leakage

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Solution:

- More frequencies
- Different instruments/experiments

Ground vs Balloon vs Space

Atmosphere is bright → adds noise

Atmosphere is opaque

Water vapor and atmospheric transmission

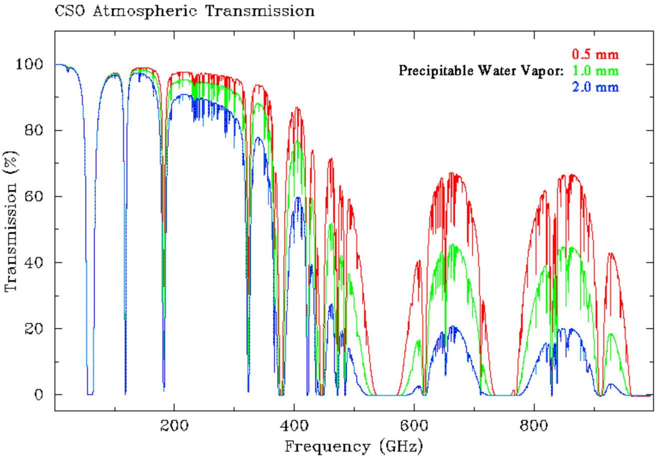


Figure from John Carlstrom's CMB lecture

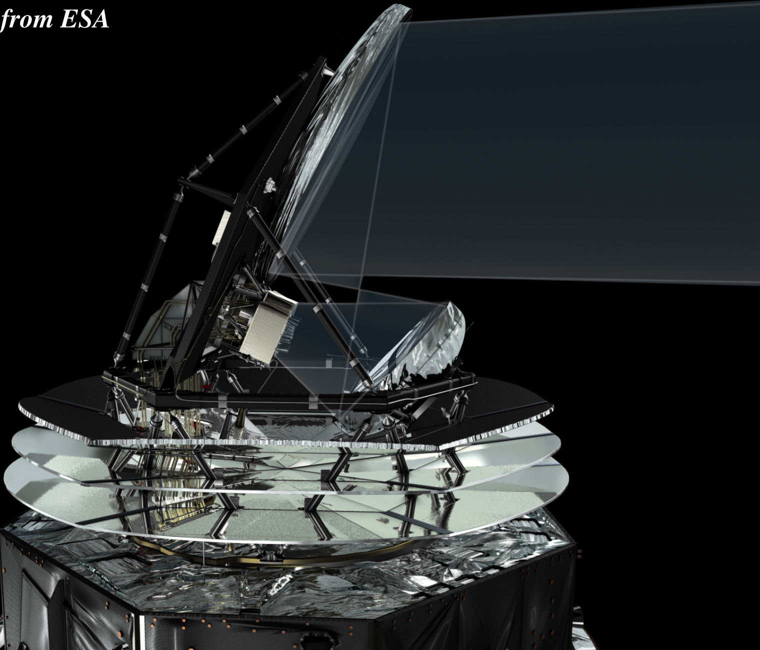
Instrumental effects

Violation of rotational symmetry $\rightarrow$ T to B leakage

Rotation of polarization angle $\rightarrow$ E to B leakage

What's next

Background Fig from ESA



What's next

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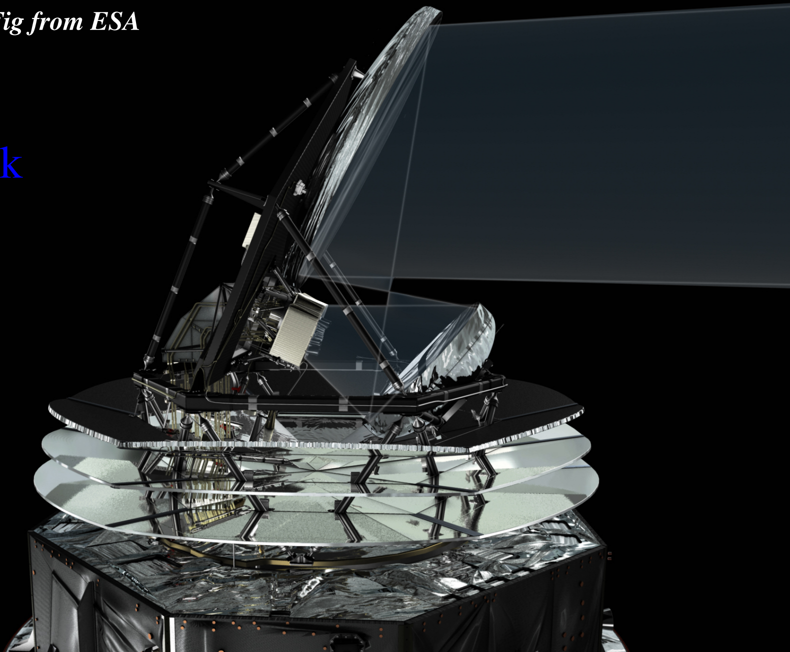
Planck



What's next

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- LFI: 30, 44, 70 GHz
- HFI: 100, 143, 217, 353 GHz

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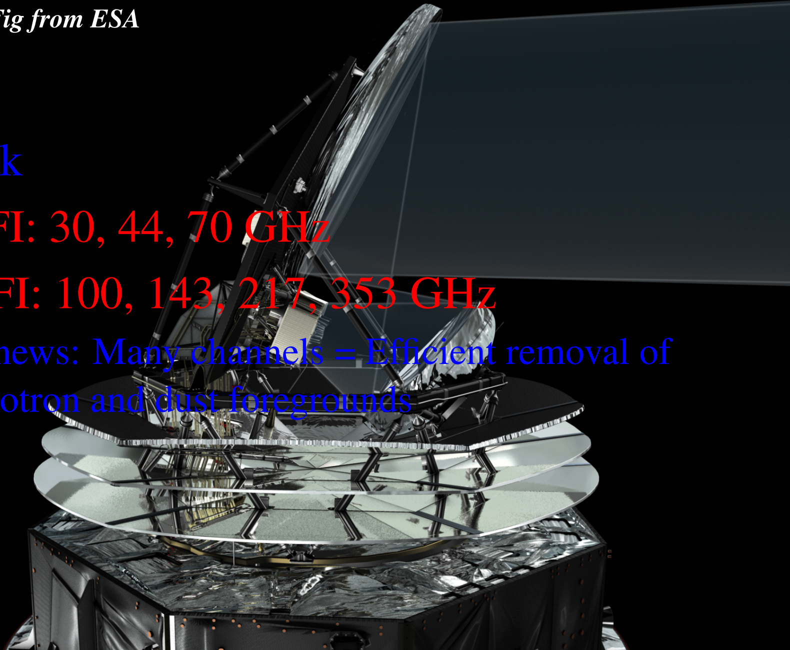

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Good news: Many channels = Efficient removal of synchrotron and dust foregrounds

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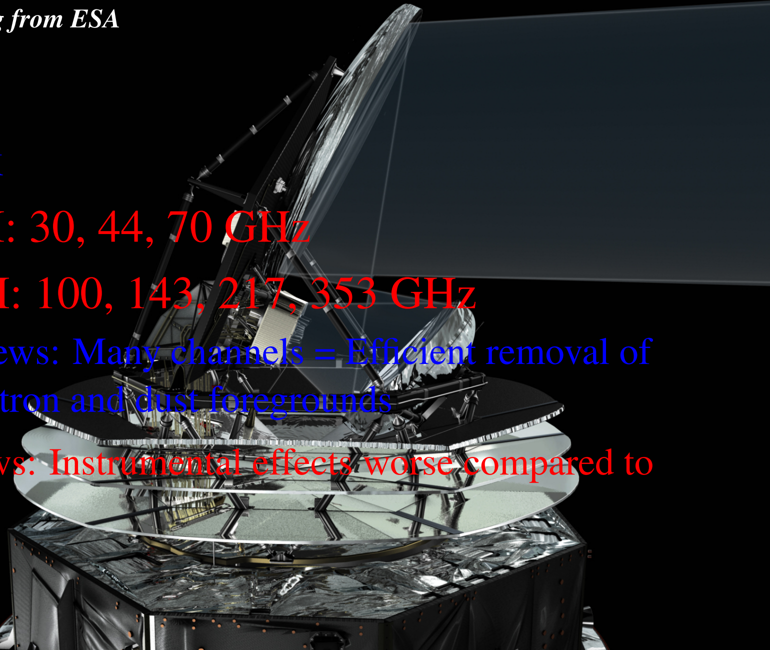

Planck

- LFI: 30, 44, 70 GHz
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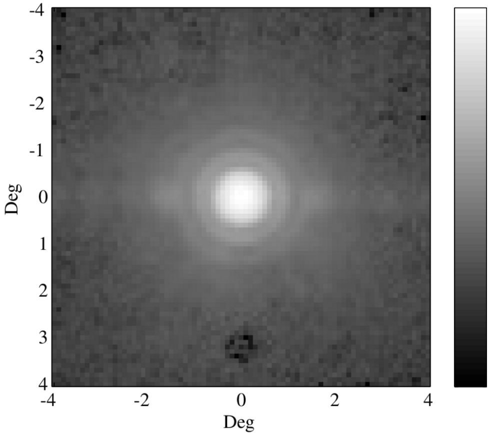
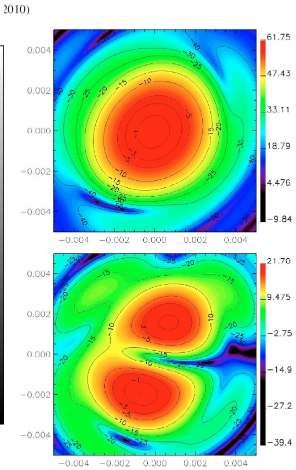
Good news: Many channels = Efficient removal of synchrotron and dust foregrounds

Bad news: Instrumental effects worse compared to BICEP

Planck

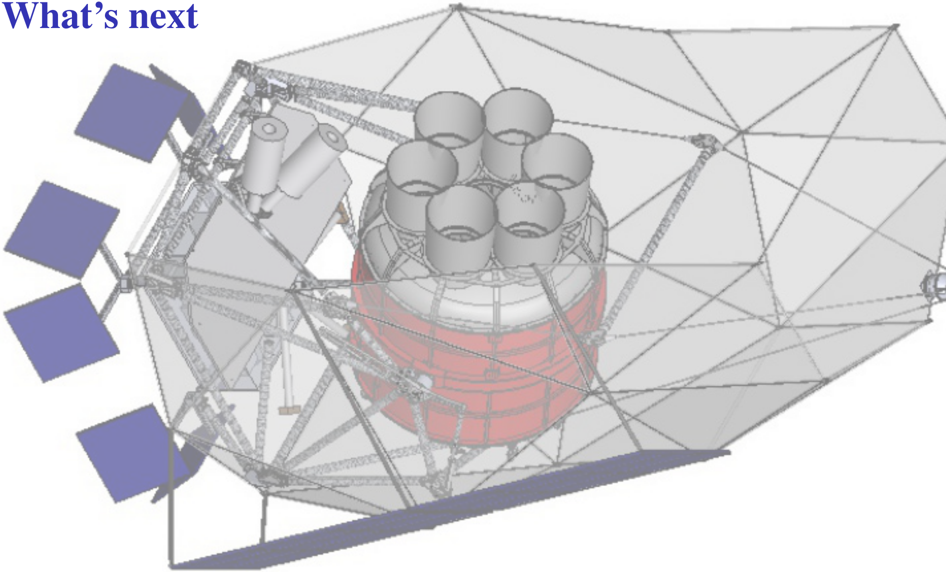


Bicep2 *arXiv:1403.4302*



Planck *Rosset et al. 2010*

What's next



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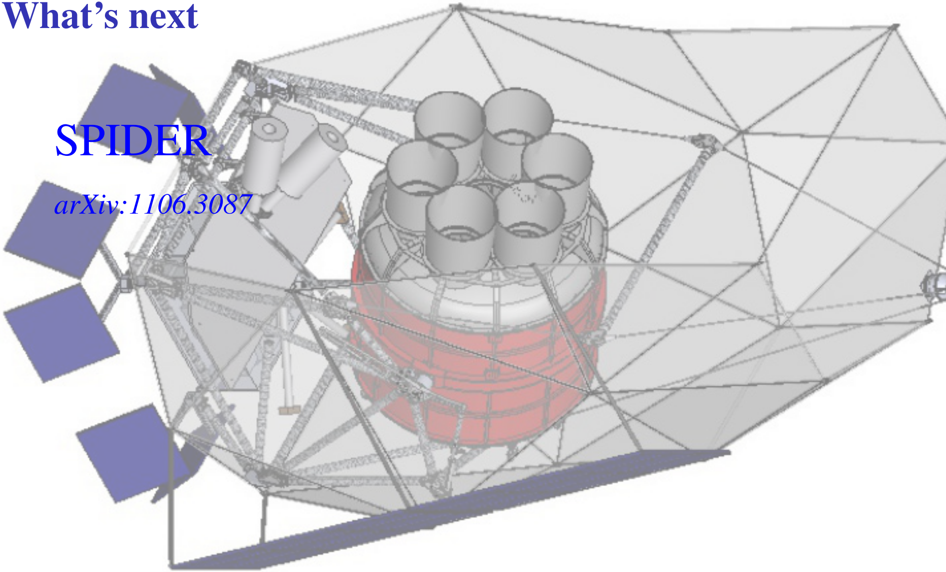
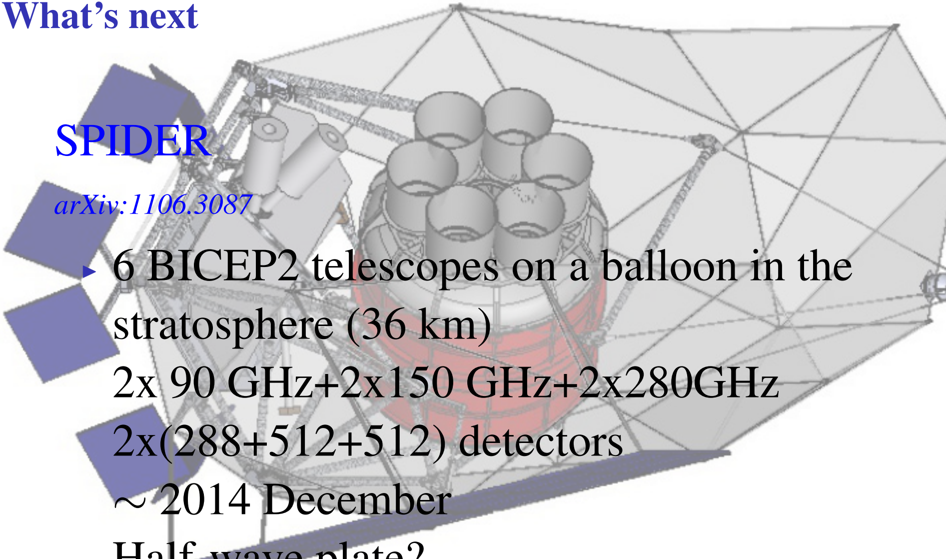


SPIDER

arXiv:1106.3087

What’s next



SPIDER

arXiv:1106.3087

- 6 BICEP2 telescopes on a balloon in the stratosphere (36 km)
  2x 90 GHz+2x150 GHz+2x280GHz
  2x(288+512+512) detectors
  ∼ 2014 December
  Half-wave plate?

Polarbear

http://bolo.berkeley.edu/polarbear/

- Single Frequency 150 GHz
- Polarbear2 upgrade 2014 +95 GHz, new detectors
- Simons array +2 telescopes $\sim$ 2015

SPTpol

Background from Stephen Hoover's talk

What Has Come Before

arXiv:1210.4970

- SPTpol $\Delta r \sim 0.03$ in 3 years (end of 2015)
- 90 GHz and 150 GHz
- SPT-3G 2016+ $\Delta r \sim 0.03$

More..

Balloon borne:
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90,150,250 GHz

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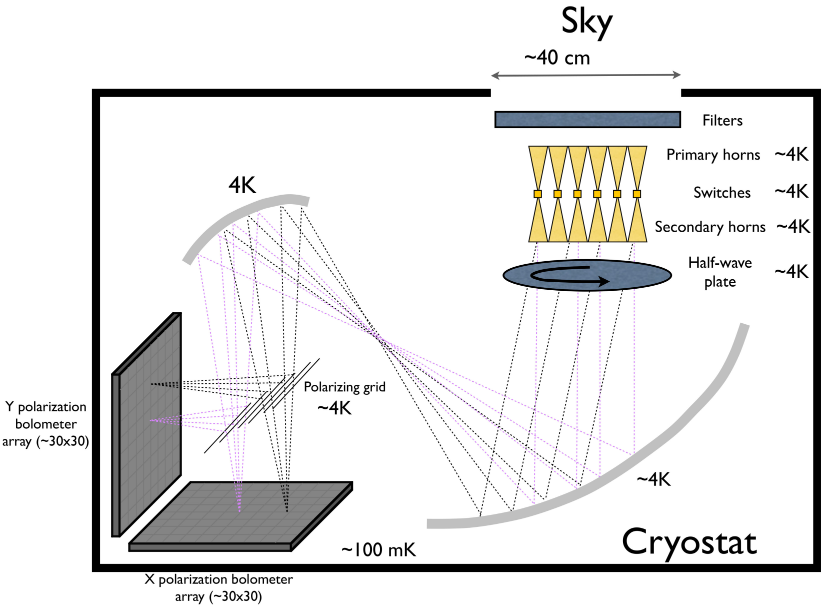
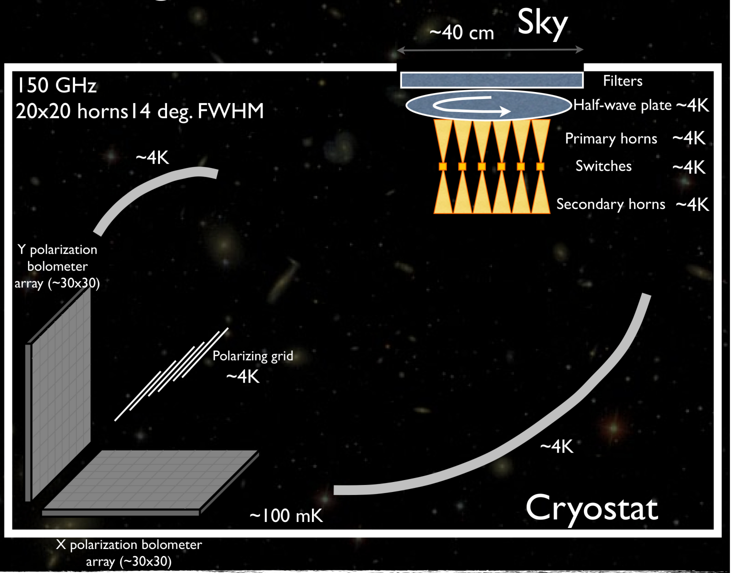
Litebird - Japanese satellite mission - low resolution 6 frequency channels (60-280 GHz) - $r \sim 10^{-3}$
CoRE - European mission - $r \sim 10^{-4}$ - high resolution 6-7 frequency channels - status unknown

The future: New concepts

QUBIC arXiv:1010.0645



QUBIC design



J.-Ch. Hamilton - Aug. 2012
hamilton@apc.univ-paris7.fr

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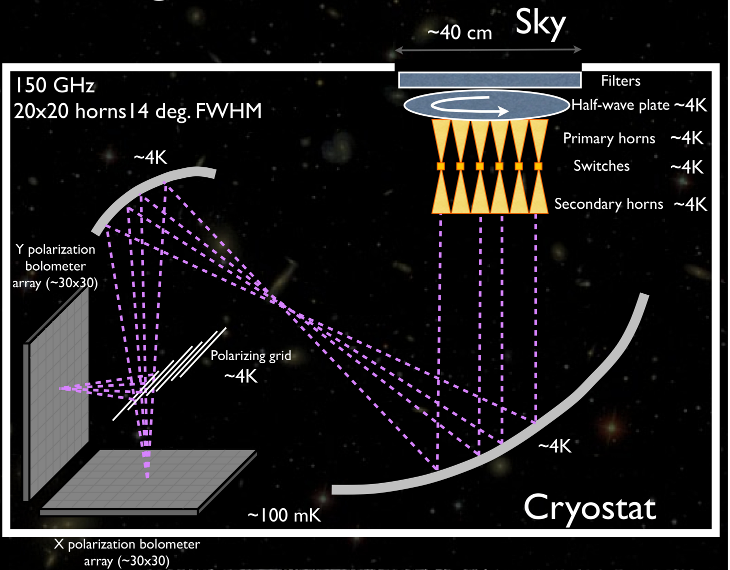

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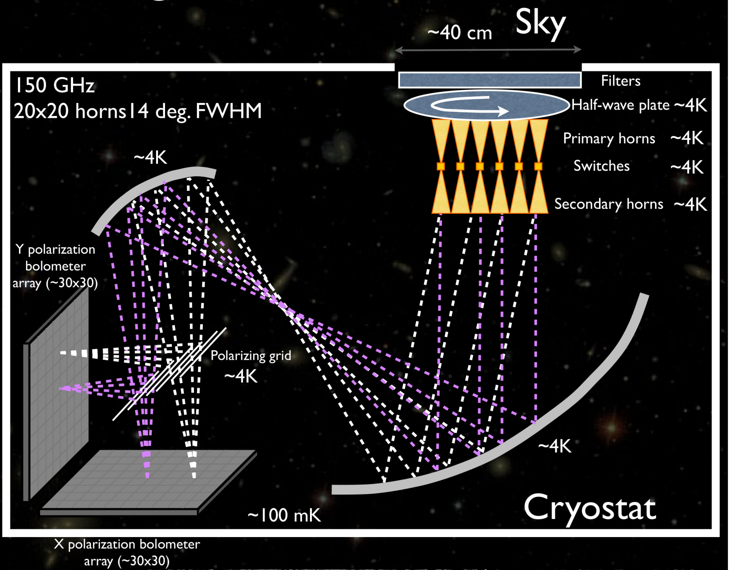

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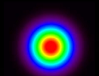
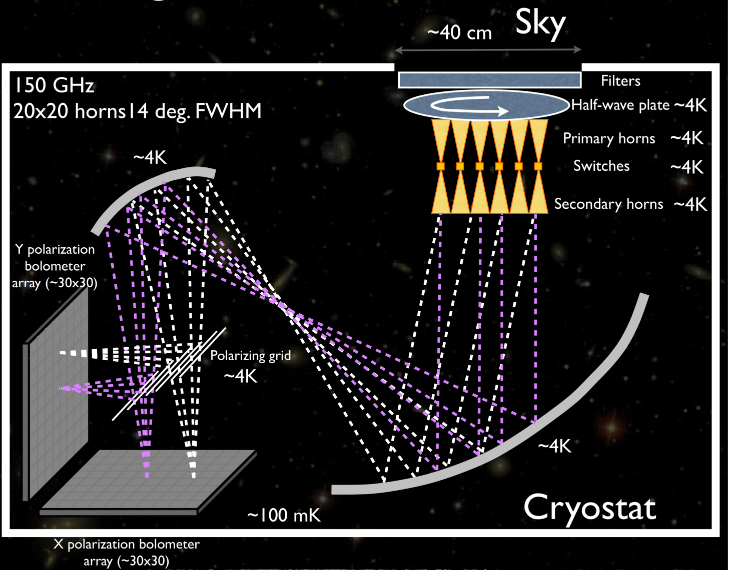


1 horn open



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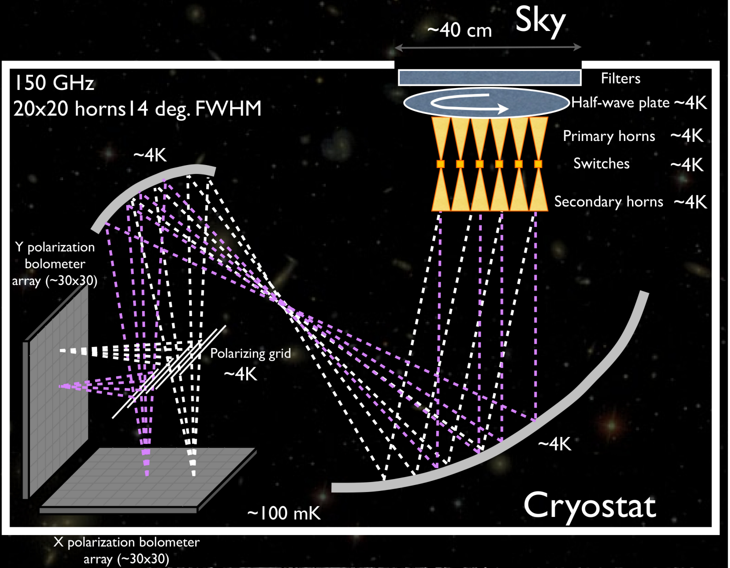

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PIPER - slides from Dale Fixsen's talk

Goddard Space Flight Center

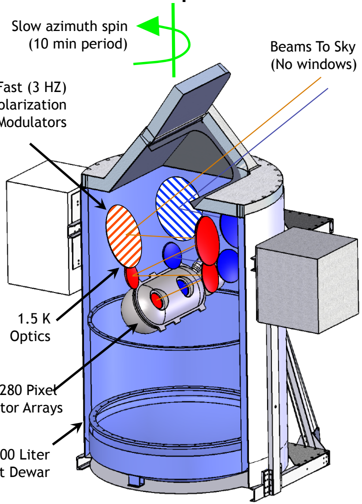
Primordial Inflation Polarization Explorer

Sensitivity
- 5120 TES bolometers in four 32 x 40 arrays
- 1.5 K Optics with no warm window
- Background-limited performance

Systematics
- Front-End VPM polarization modulator
- Twin cryogenic telescopes

Foregrounds
- 1500, 1100, 850, and 500 μm
- Single frequency band per flight

Sky Coverage
- Balloon payload, conventional flight
- 8 flights, North and South hemisphere



Goal: Detect Primordial B-Modes with r < 0.01

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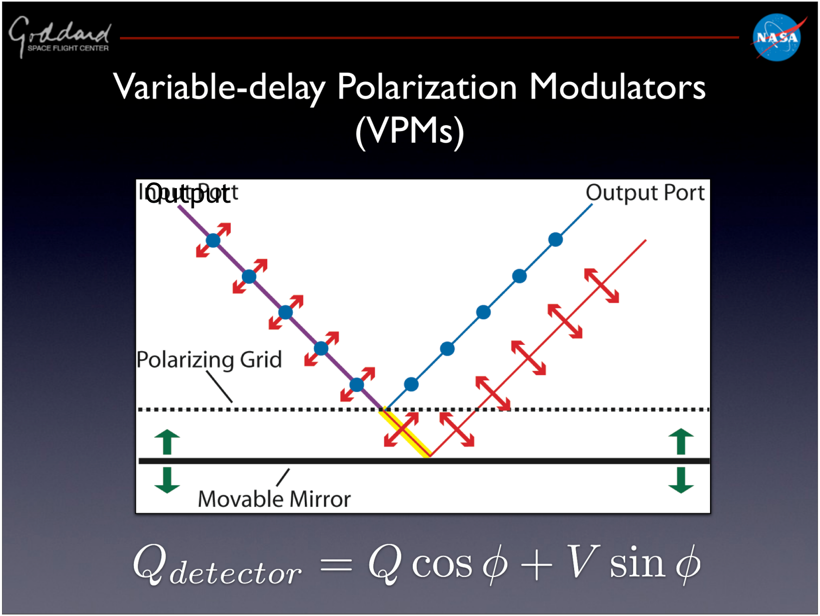

Tuesday, June 4, 13

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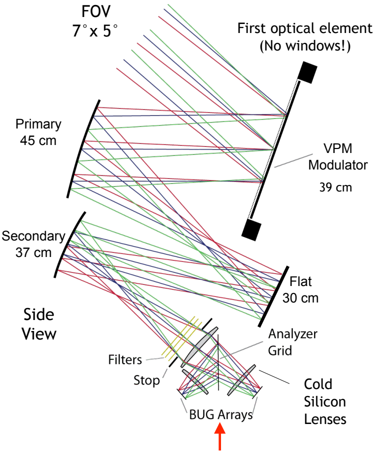
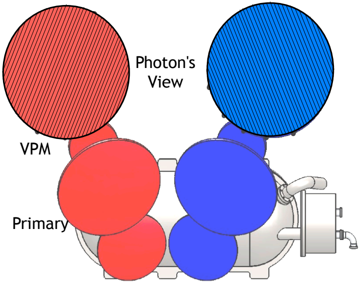
Catadioptric Telescope Design



Two detector arrays for each telescope, opposite phase for polarization signal

Frequency (GHz)	200	270	350	600
Wavelength (mm)	1500	1100	850	500
FWHM (arc-min)	21	15	14	14



Two mirror-image telescopes (IQV and IUV) cooled to 1.5 K with superfluid LHe

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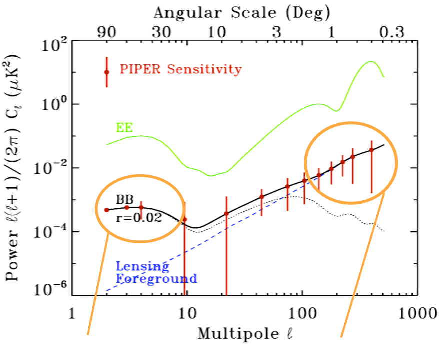
Result: Sensitivity + Sky Coverage



Large angular scales: Amplitude of primordial signal

Small angular scales: Amplitude of lensing foreground

Detect primordial signal
Begin to map power spectrum

Detect signal on largest scales using conventional ballooning

Limits r < 0.03 (one flight)
r < 0.007 (8 flights)

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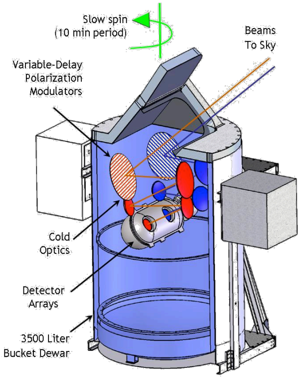
Systematic Error Mitigation

All optical elements 1.5 K or colder
VPM measures I,Q,V every 0.5 sec
Dual telescopes, each with 2 arrays



Parameter	Effect	RMS (nK)	Notes
Calibration	ΔT→B	0	VPM
Beam Shape	ΔT→B	0	VPM
Instrumental Polarization	ΔT→B	0	VPM
Differential Pointing	ΔT→B	0	VPM
Cross-Polar Response	E→B	< 1	VPM
Polarization Angle	E→B	< 3	Measure
Differential Pointing	E→B	< 3	Telescope Alignment
Differential Beam Shape	E→B	< 2	Worst Case e ~ 0.1
Stray Light	T→B	< 1	Cold Optics

Maximize sensitivity, minimize systematics

CLASS: Cosmology Large Angular Scale Surveyor

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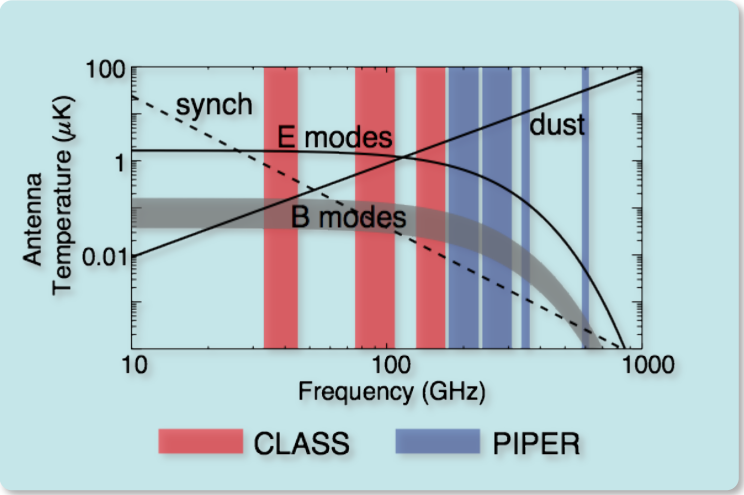
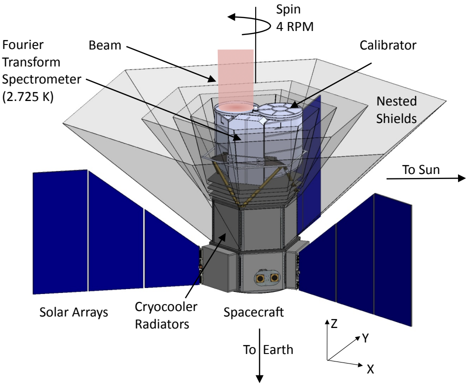
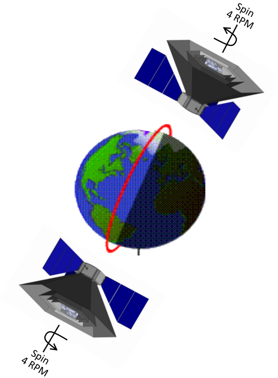
Frequency Coverage/Foreground Removal

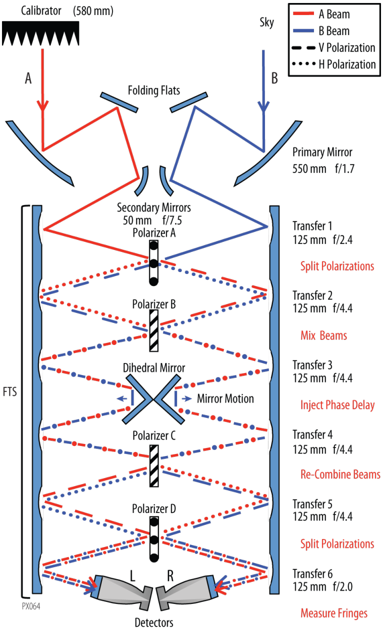


Pixie will also measure the spectrum *(Kogut et al. 2011)*





Pixie: Fourier transform spectrmeter *(Kogut et al. 2011)*



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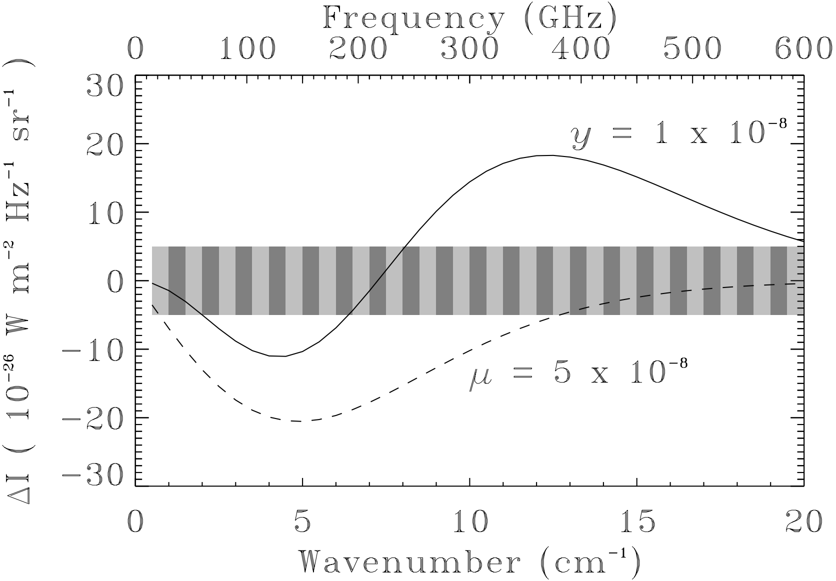


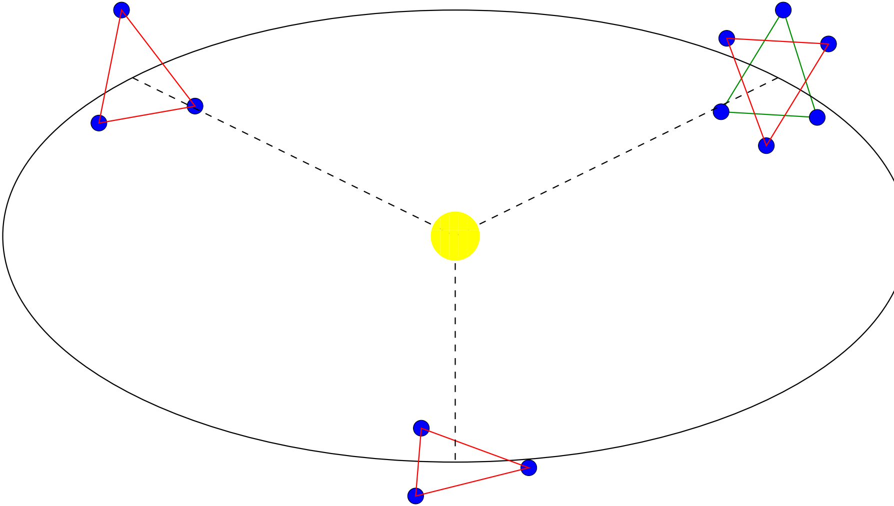
If r is really ~ 0.2

It is possible to measure the tensor spectral index n_T and test the inflationary consistency relation $r = -8n_T$

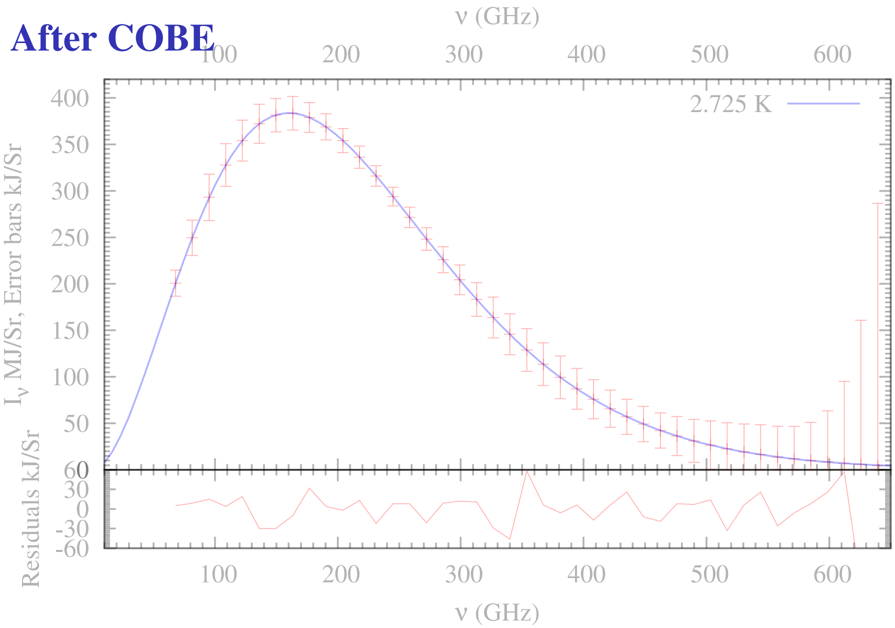
Dodelson arXiv:1403.6310, Caligiuri and Kosowsky arXiv:1403.5324

Beyond future: The Big Bang Observer

Crowder& cornish 2005 arXiv:gr-qc/0506015



After COBE



ν (GHz)
100
200
300
400
500
600
2.725 K
400
350
300
250
200
150
100
50
0
I_ν MJ/Sr, Error bars kJ/Sr
60
30
0
-30
-60
Residuals kJ/Sr
100
200
300
400
500
600
ν (GHz)

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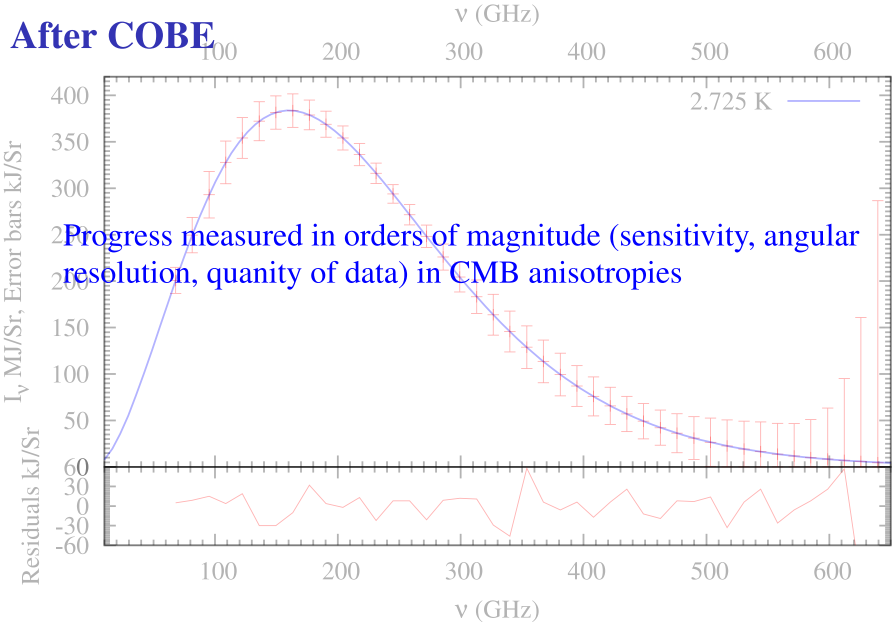
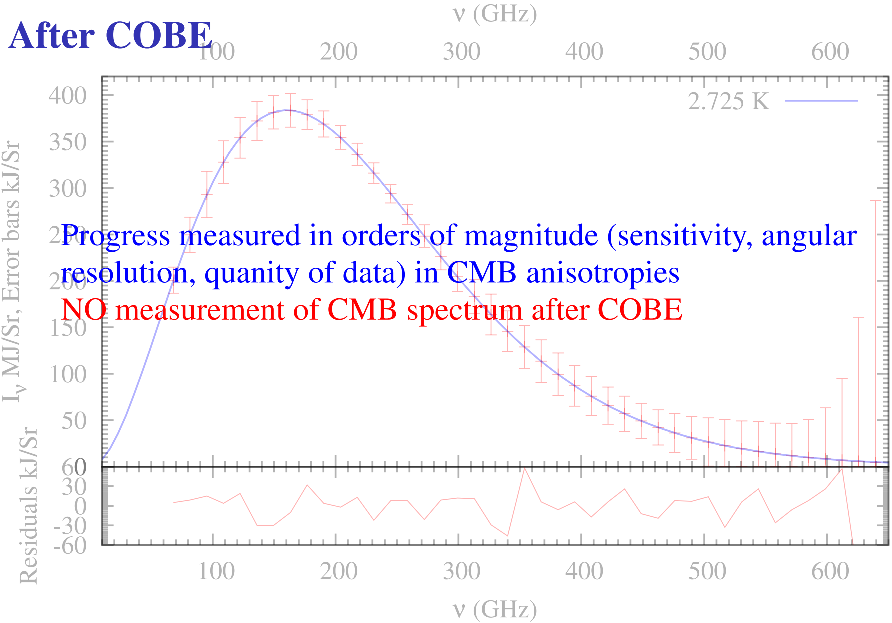


Progress measured in orders of magnitude (sensitivity, angular resolution, quanity of data) in CMB anisotropies

After COBE



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NO measurement of CMB spectrum after COBE

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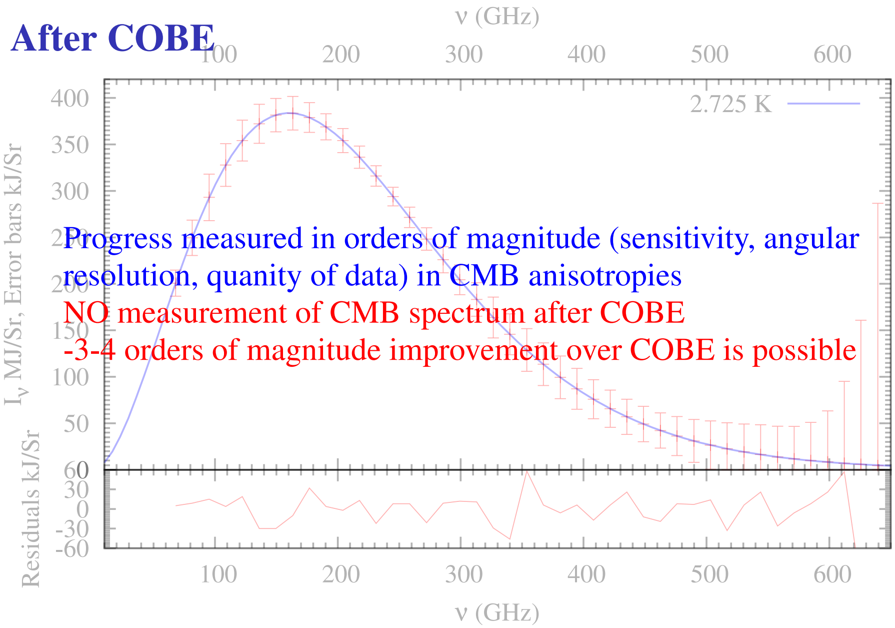

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-3-4 orders of magnitude improvement over COBE is possible

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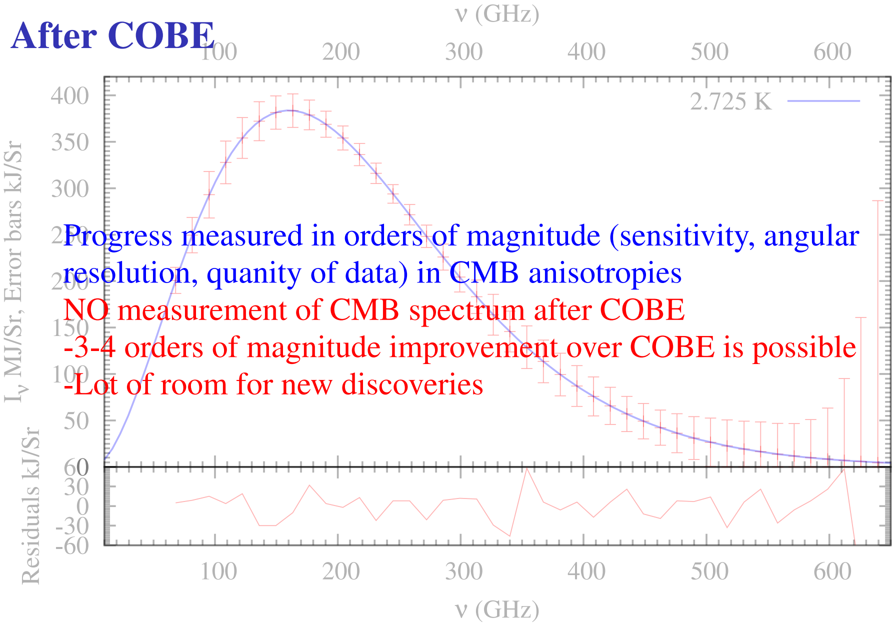

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-Lot of room for new discoveries

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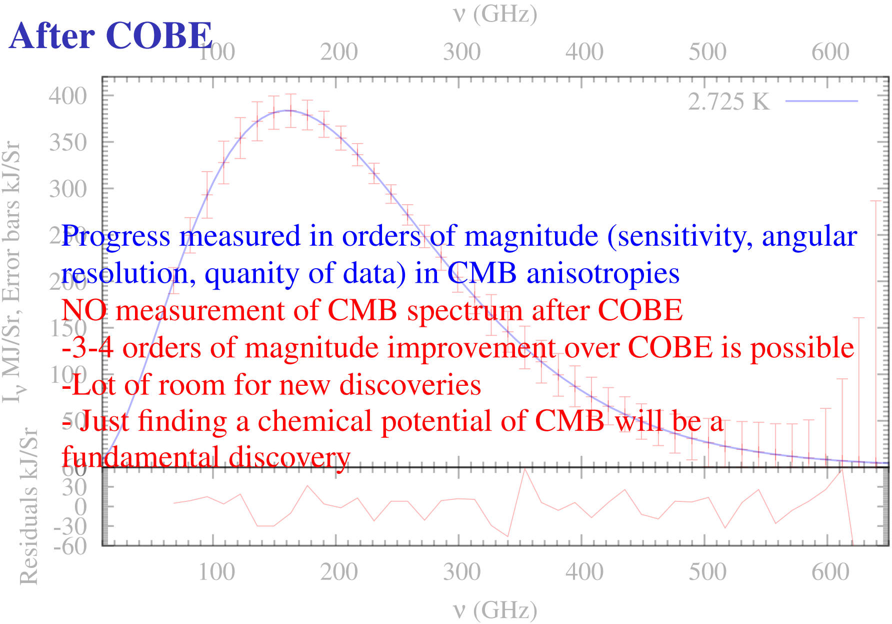

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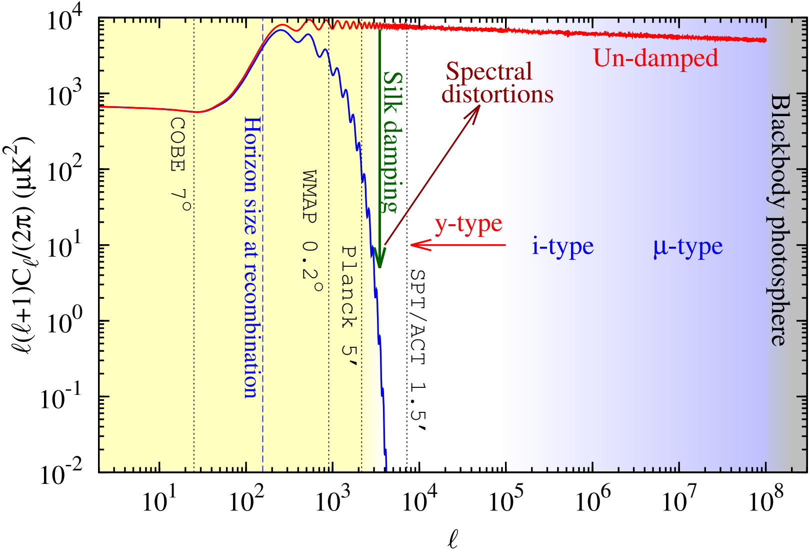
-3-4 orders of magnitude improvement over COBE is possible

-Lot of room for new discoveries

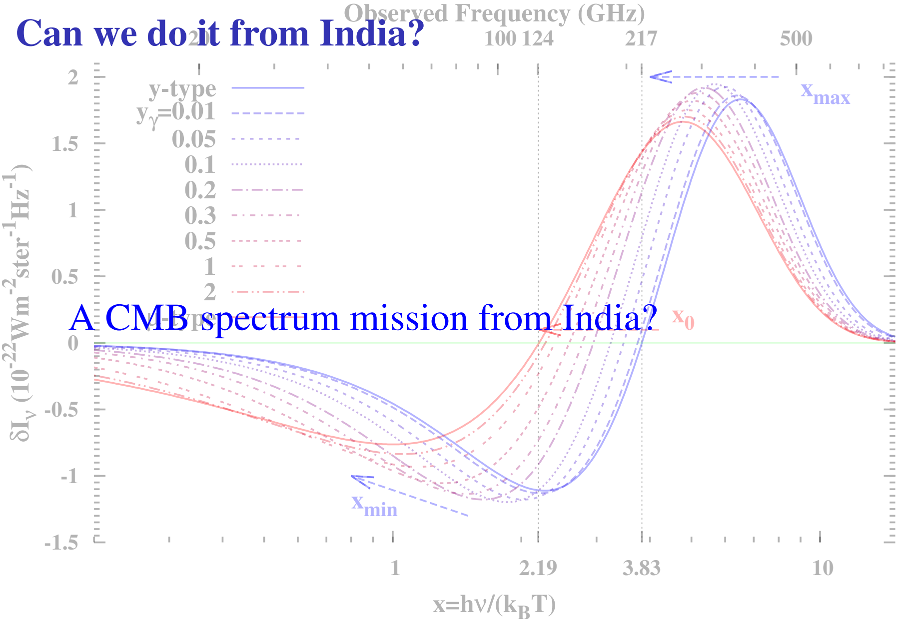
- Just finding a chemical potential of CMB will be a fundamental discovery

Going from 7 e-folds to 17 e-folds of inflation



Can we do it from India?

A CMB spectrum mission from India?



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