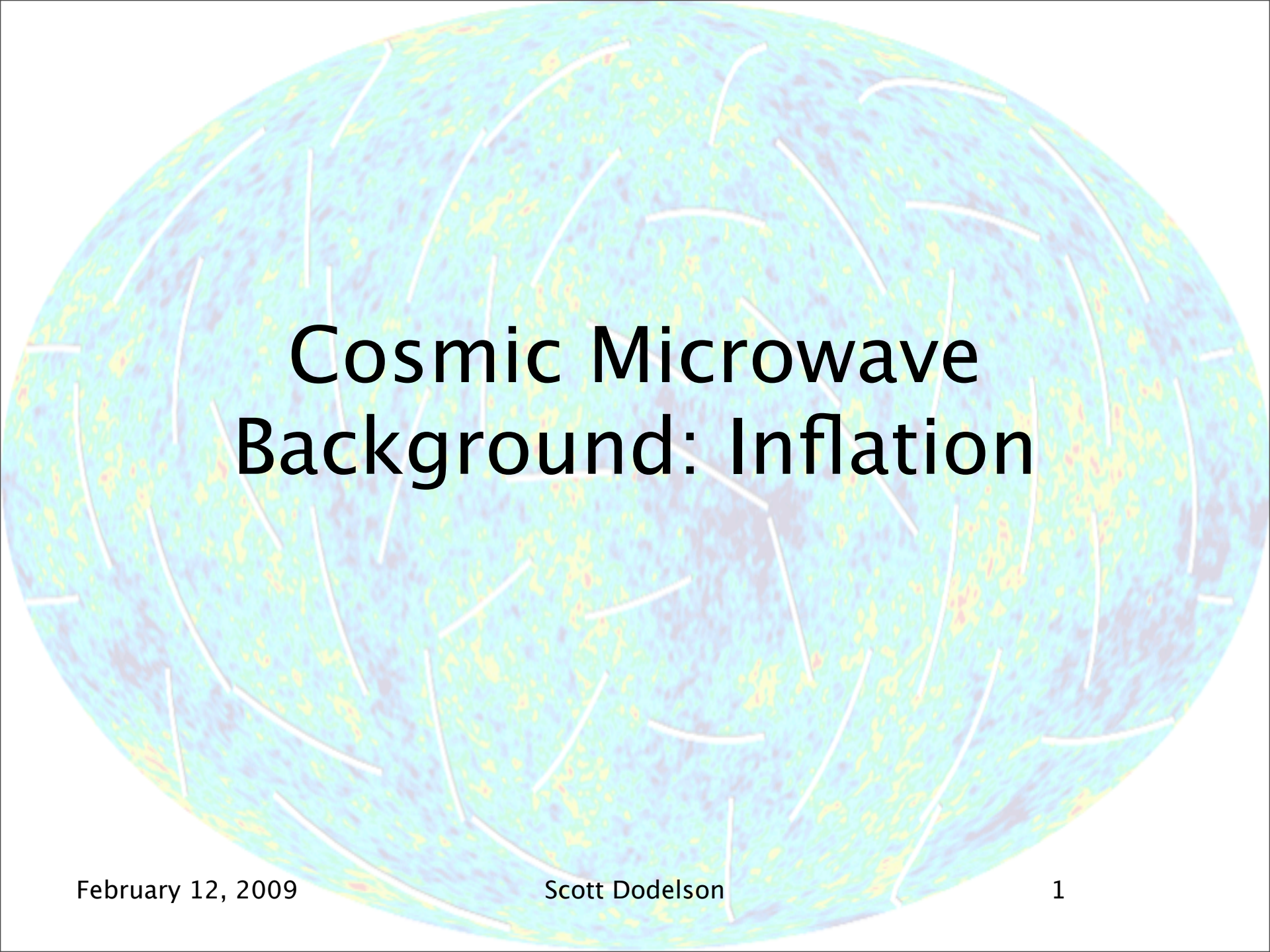


Cosmic Microwave Background: Inflation

Astronomy's Decadal Survey

- Prioritizes Projects for the coming Decade
- Billions of Dollars at Stake
- The Fundamental Physics community should be heard

Astronomy's Decadal Survey

- Prioritizes Projects for the coming Decade
- Billions of Dollars at Stake
- The Fundamental Physics community should be heard

If you agree with the contents of this talk, go to
http://cmbpol.uchicago.edu
Look at the inflation paper and sign up. Your endorsement will be appear on the White Paper sent to the Decadal Committee and your name will appear on the paper submitted to the `arxiv`.

Astronomy's Decadal Survey

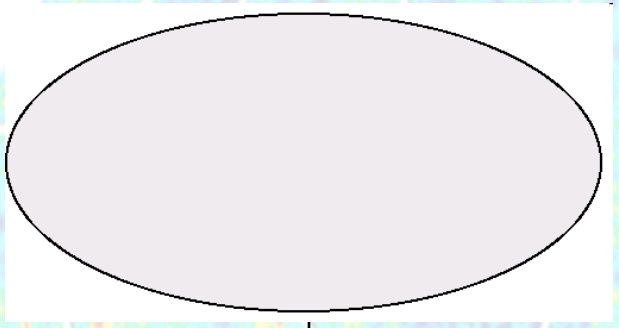
- Prioritizes Projects for the coming Decade
- Billions of Dollars at Stake
- The Fundamental Physics community should be heard

If you agree with the contents of this talk, go to
http://cmbpol.uchicago.edu
Look at the inflation paper and sign up. Your endorsement will be appear on the White Paper sent to the Decadal Committee and your name will appear on the paper submitted to the `arxiv`.

Deadline: Tomorrow!
Tell your friends!

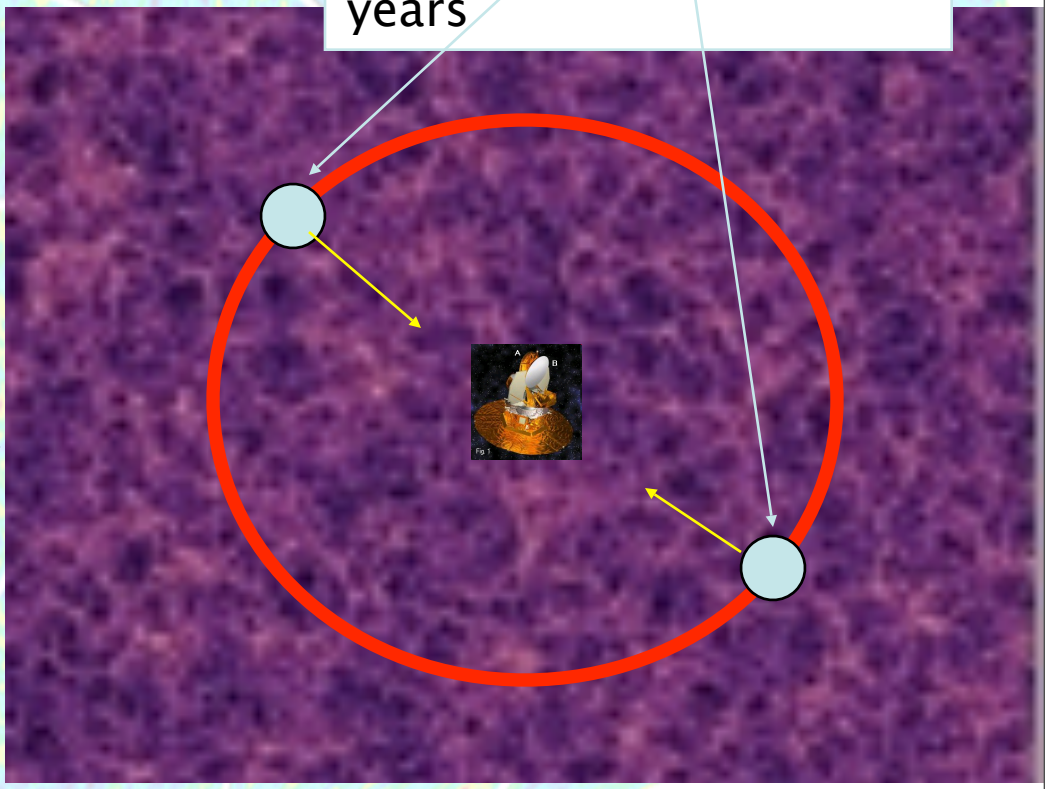
Motivation for Inflation

Uniform CMB Sky



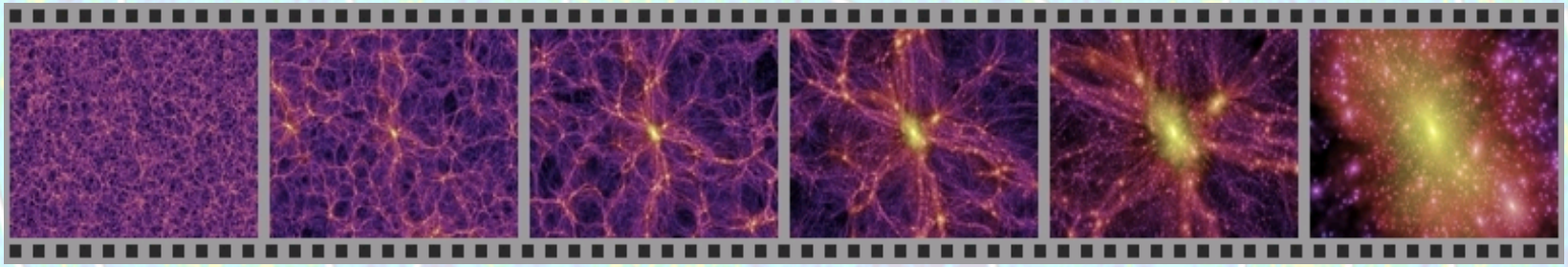
Homogeneous Universe at t=380,000 years

Causally connected regions at t=380,000 years



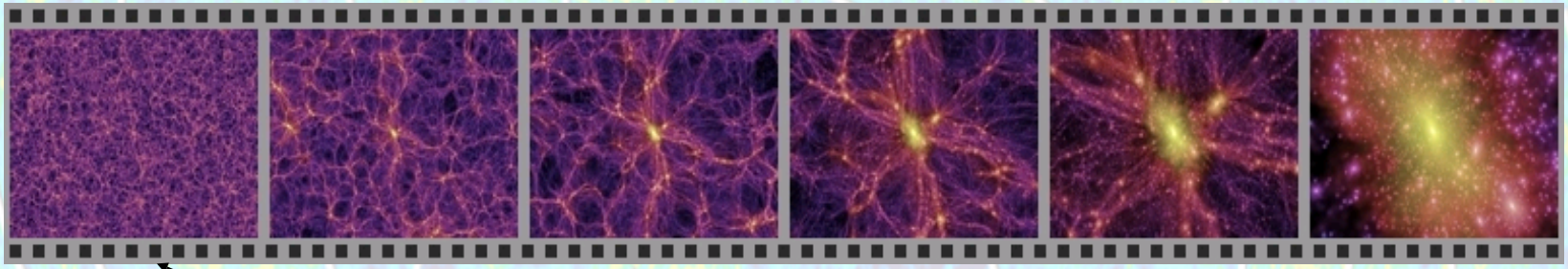
Motivation for Inflation

We have a coherent picture of cosmic evolution



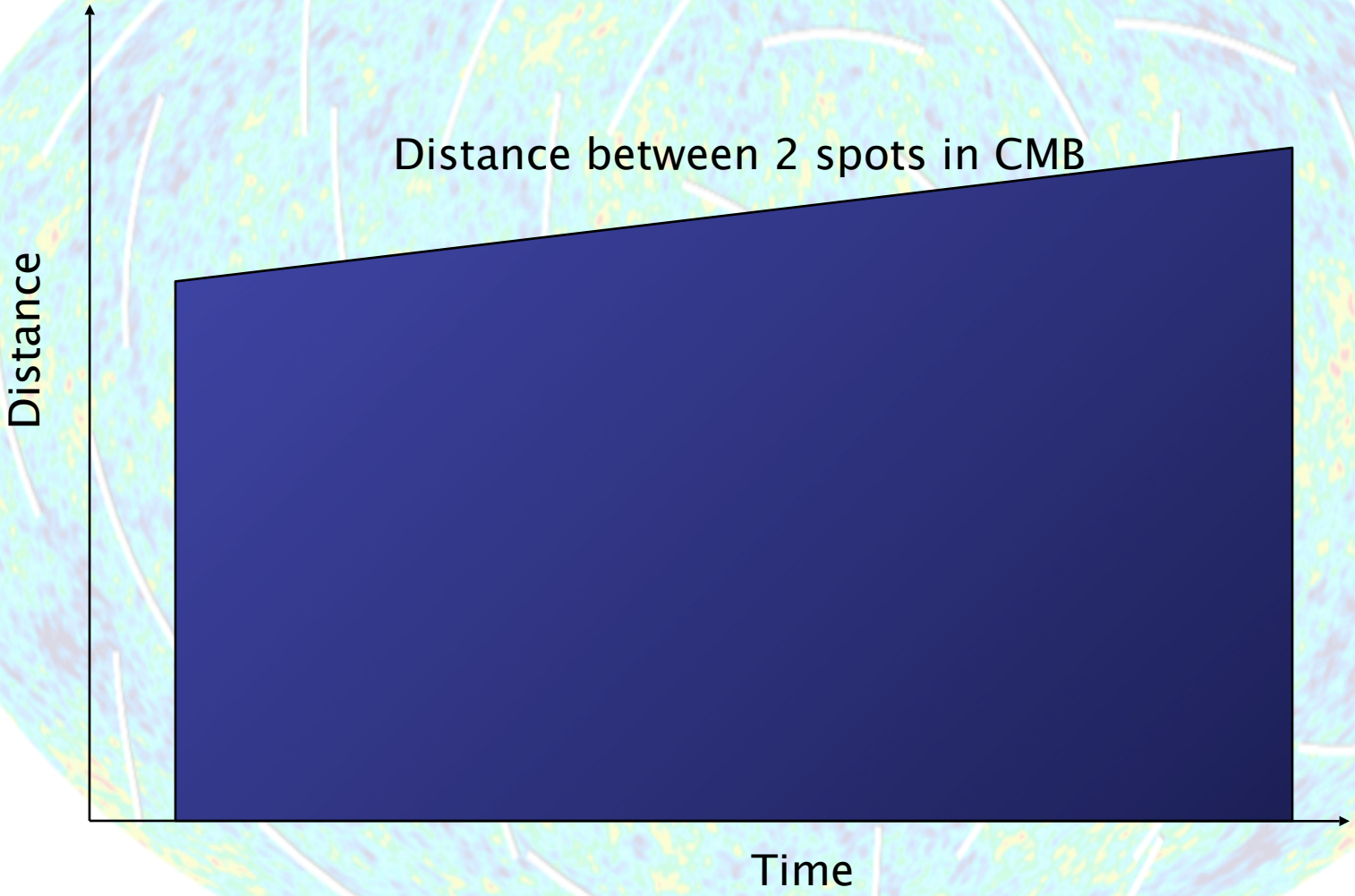
Motivation for Inflation

We have a coherent picture of cosmic evolution

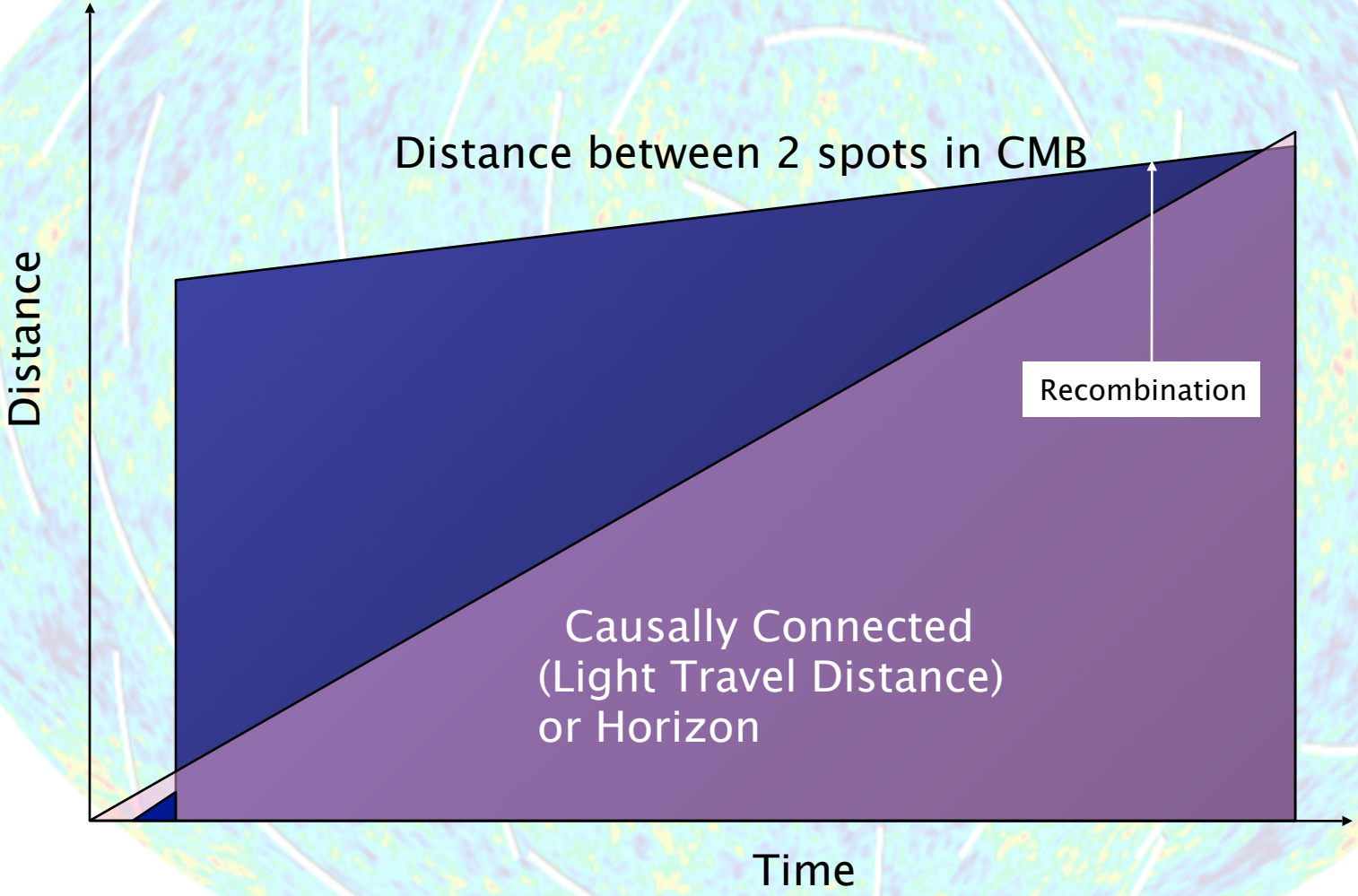


Where did the seeds of structure come from?

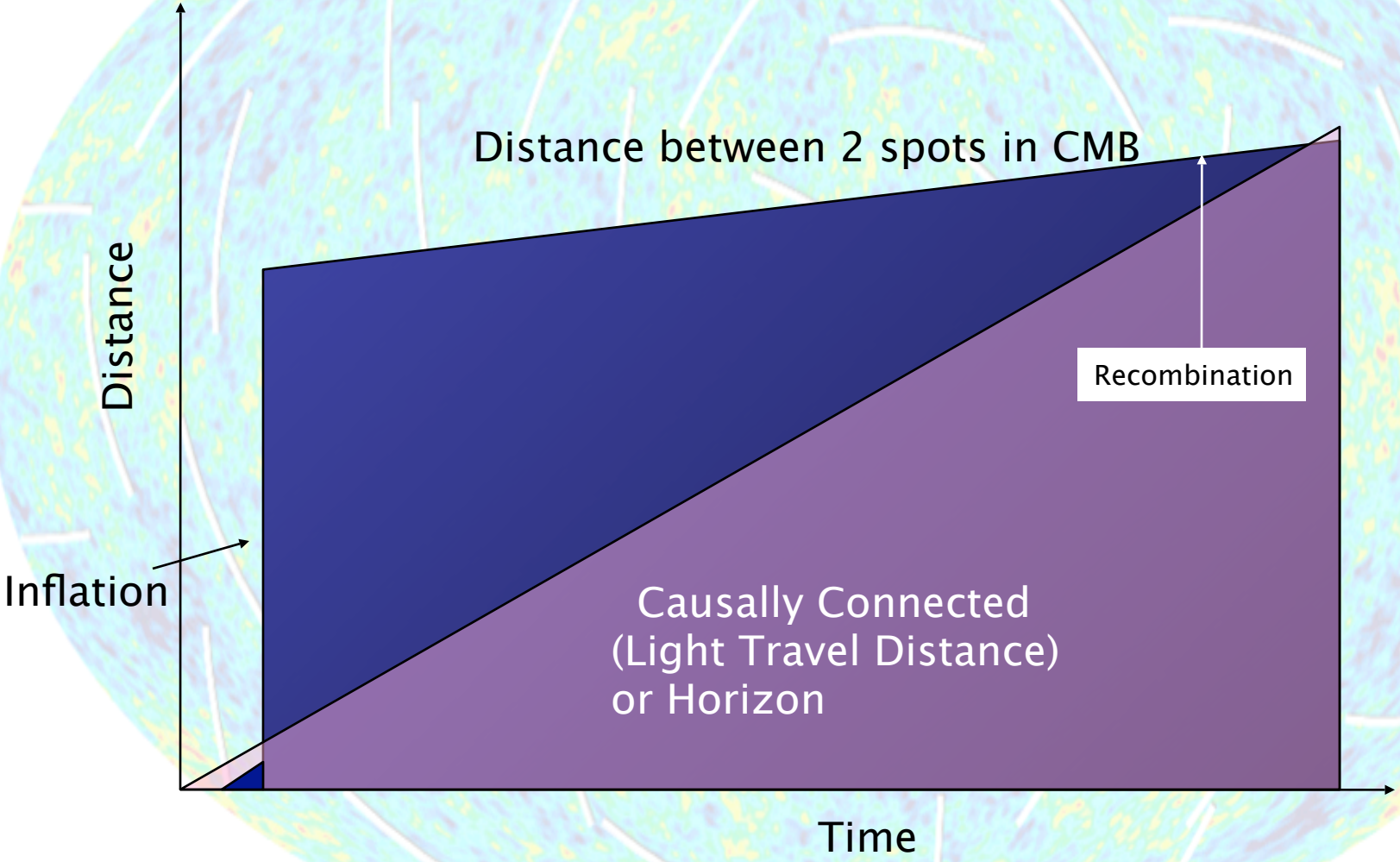
Inflation: Early Dark Energy & Acceleration



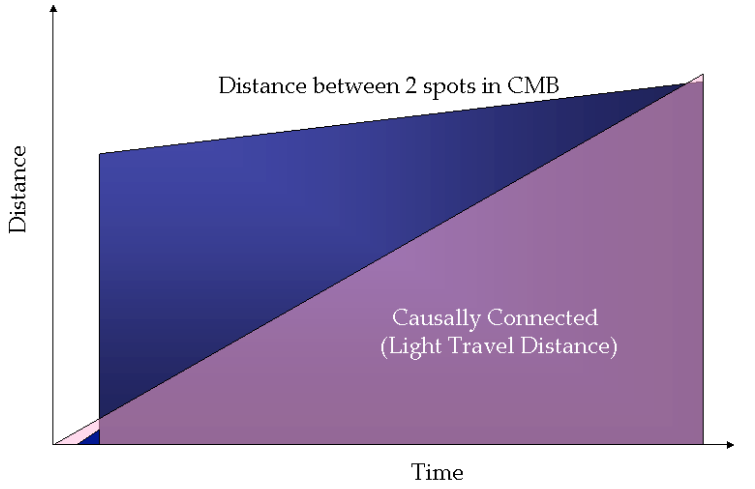
Inflation: Early Dark Energy & Acceleration



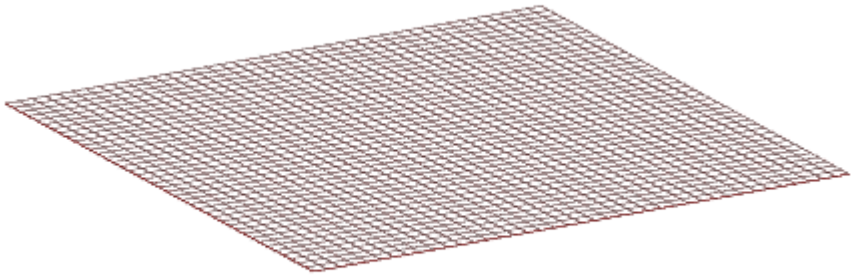
Inflation: Early Dark Energy & Acceleration

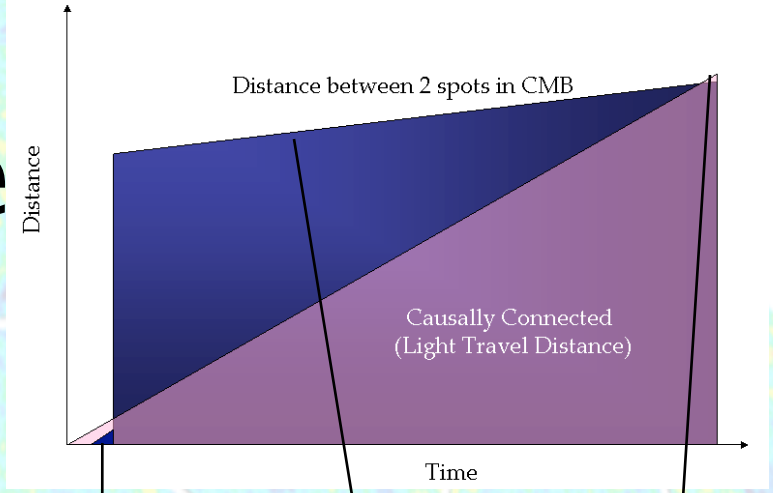


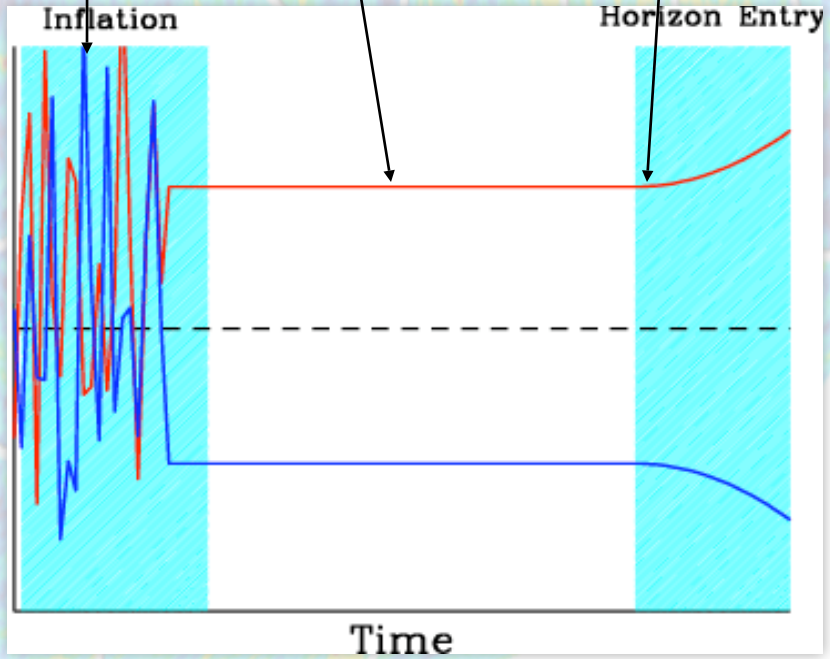
Seeds of Structure



Seeds of Structure

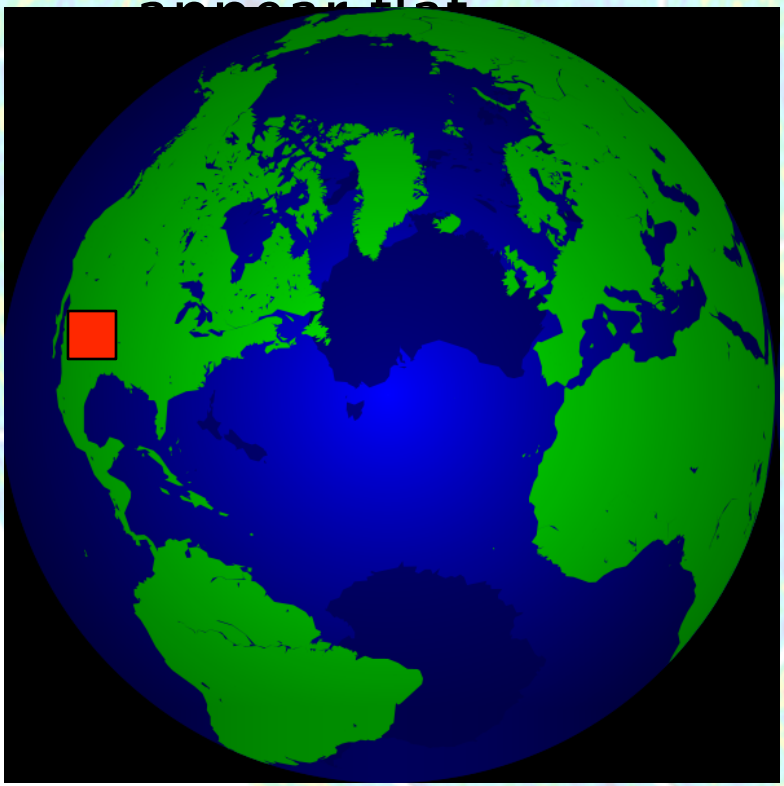


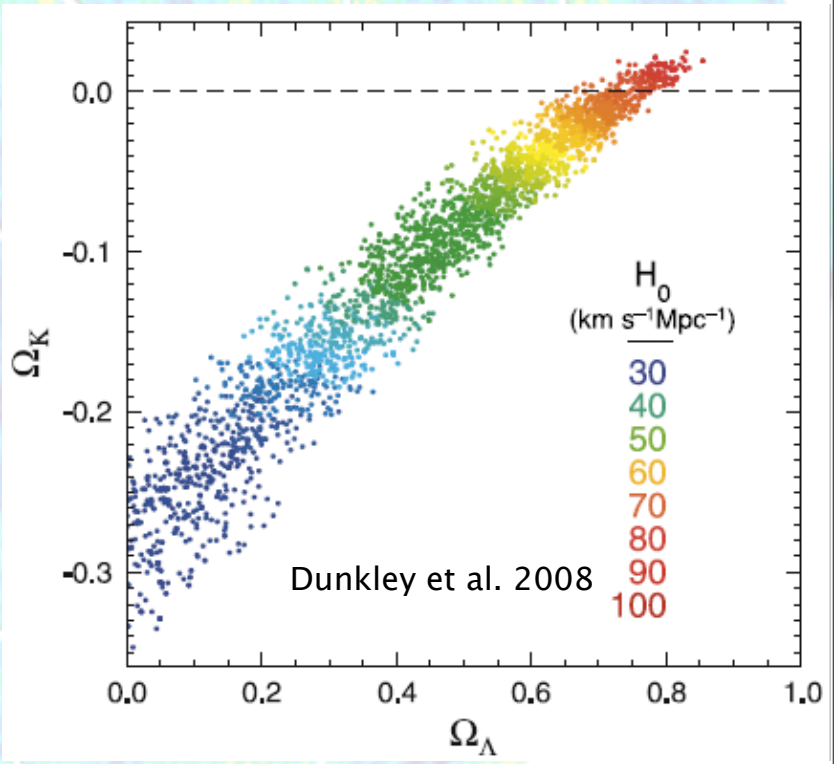




Evidence for Inflation: Flatness

Inflation makes the universe so big that curvature is irrelevant, so the universe should appear flat.



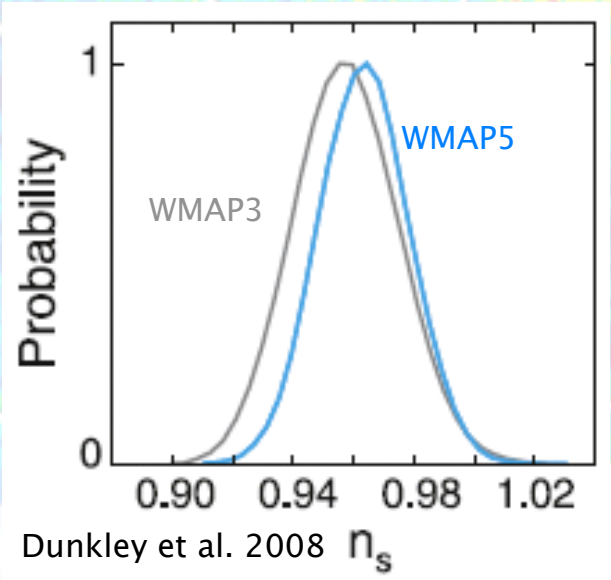


Evidence for Inflation: Scale Invariance

Perturbations should be close to scale invariant

$$\Phi^2{}_{rms} \propto \int d^3k\, P_\Phi(k) \propto \int d\ln(k)\, k^{n_s - 1}$$

with n close to 1



Dunkley et al. 2008

Evidence for Inflation: Coherence

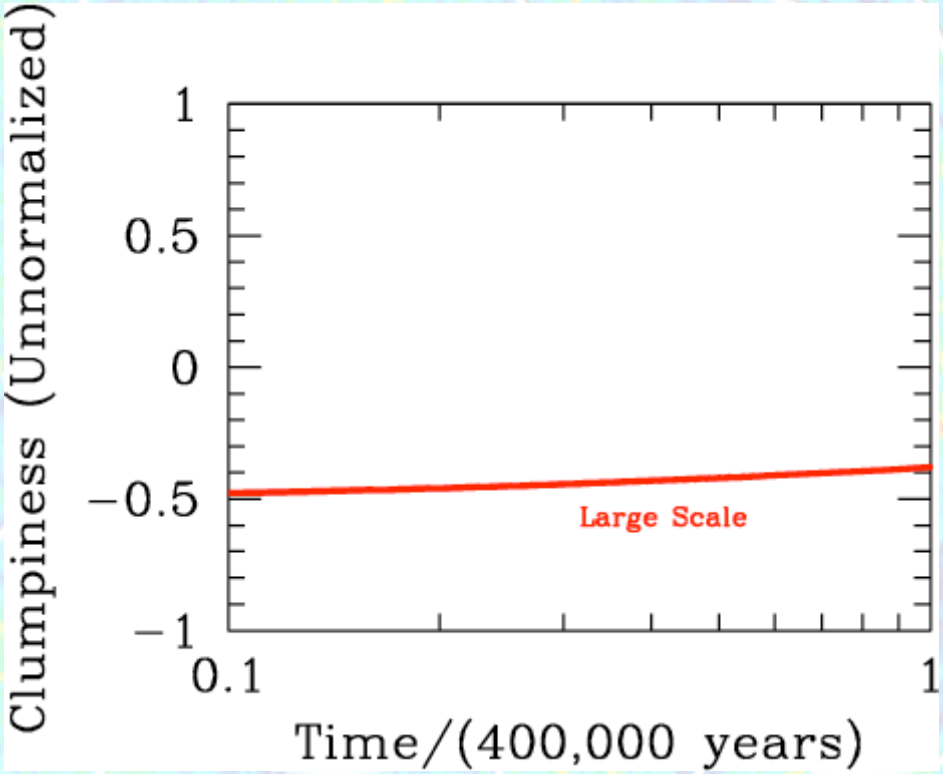
- Pressure of radiation acts against clumping
- If a region gets overdense, pressure acts to reduce the density: **restoring force**

Evidence for Inflation: Coherence

- Pressure of rad clumping
- If a region gets re acts to reduce the density: **res**

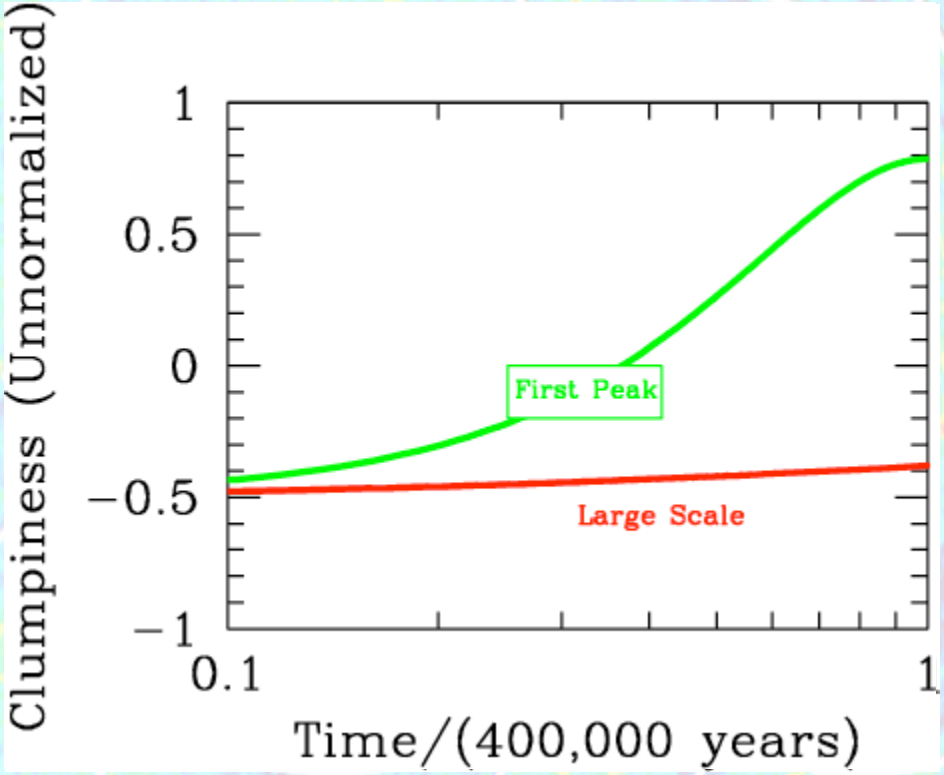
Evidence for Inflation: Coherence

- Vibrating String: Characteristic frequencies because ends are tied down
- Temperature in the Universe: Small scale modes begin oscillating earlier than large scale modes



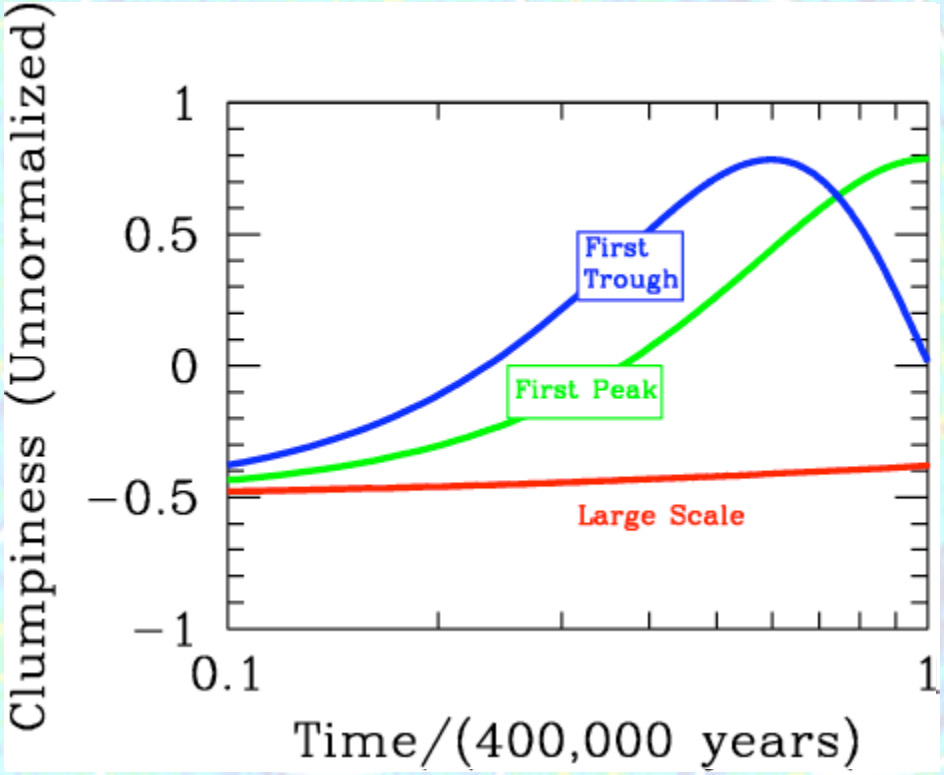
Evidence for Inflation: Coherence

- Vibrating String: Characteristic frequencies because ends are tied down
- Temperature in the Universe: Small scale modes begin oscillating earlier than large scale modes



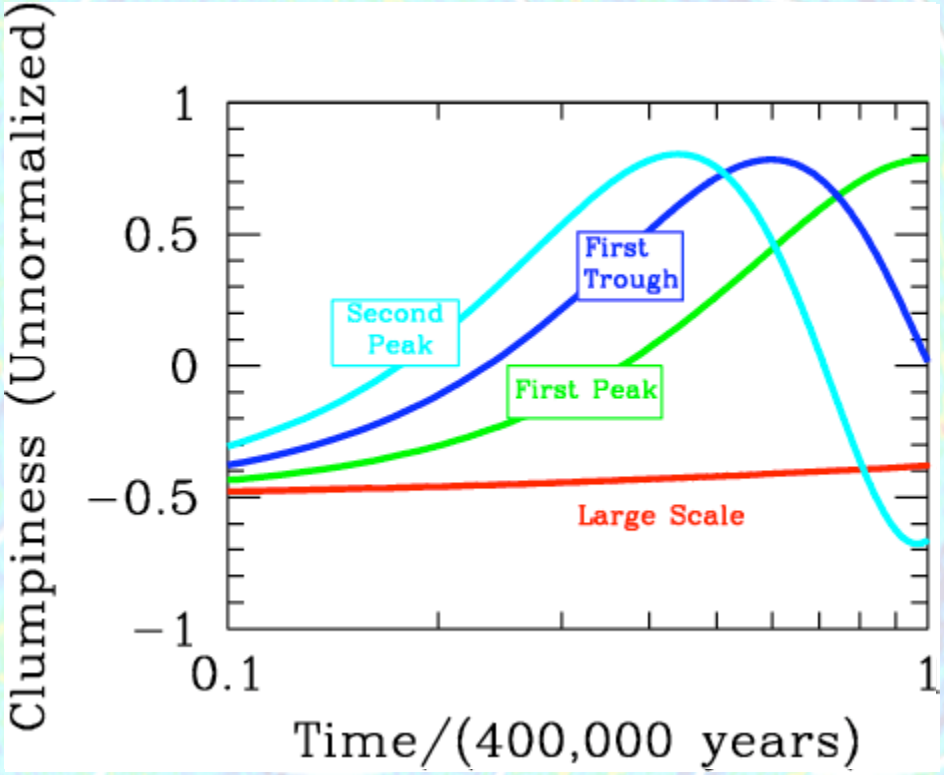
Evidence for Inflation: Coherence

- Vibrating String: Characteristic frequencies because ends are tied down
- Temperature in the Universe: Small scale modes begin oscillating earlier than large scale modes



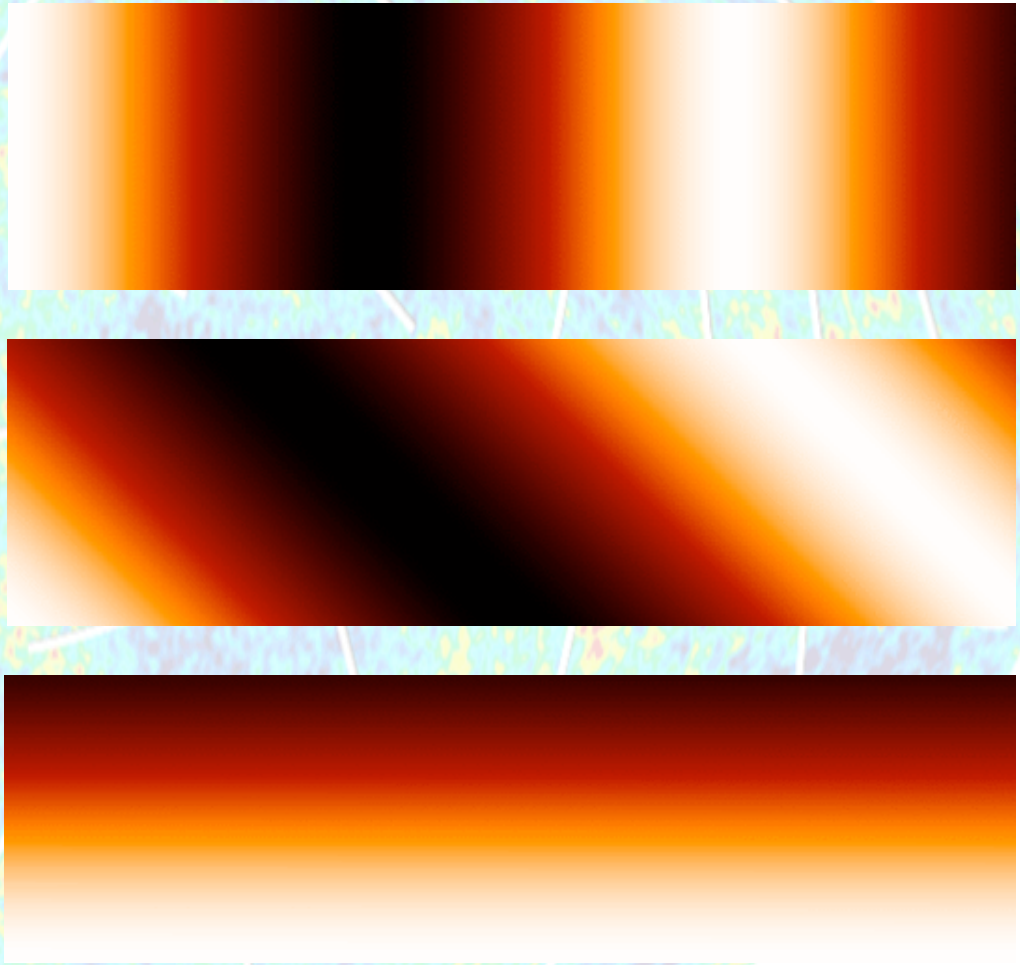
Evidence for Inflation: Coherence

- Vibrating String: Characteristic frequencies because ends are tied down
- Temperature in the Universe: Small scale modes begin oscillating earlier than large scale modes



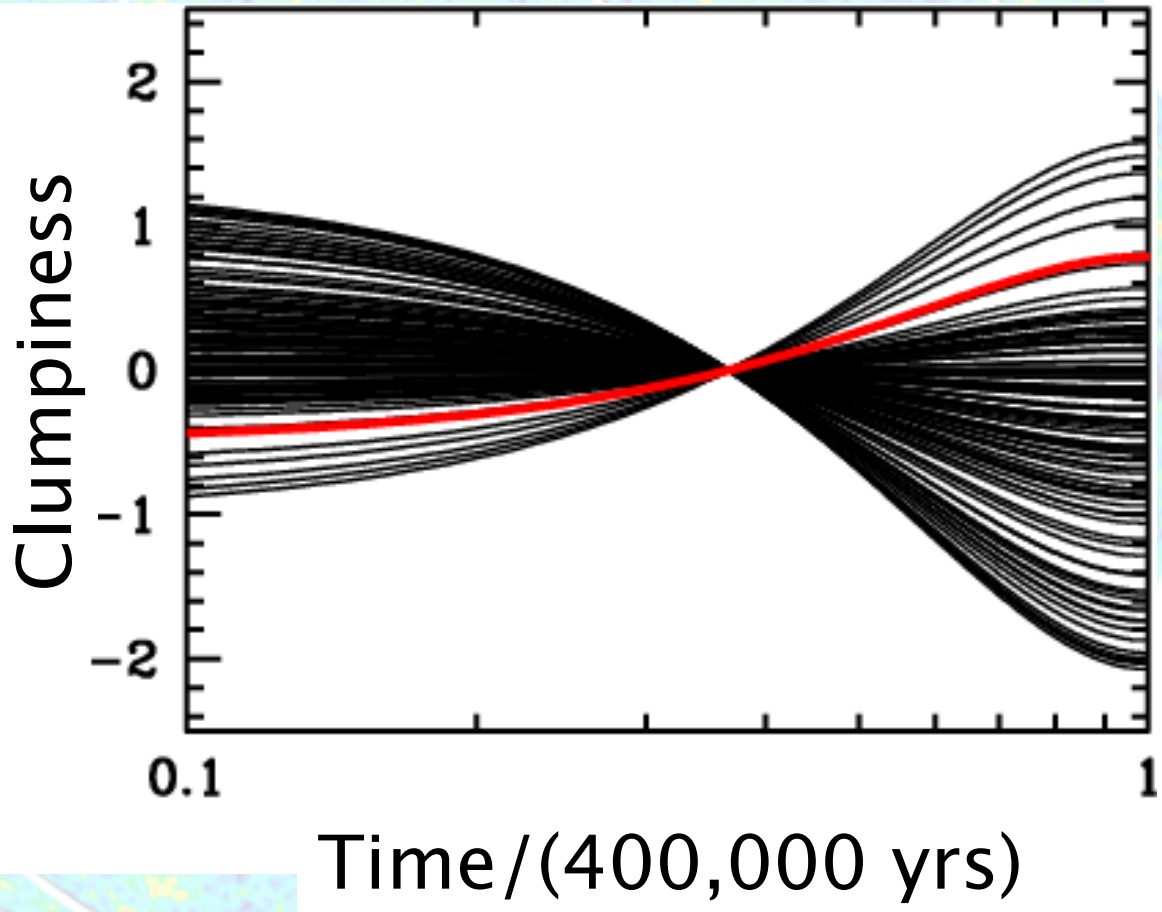
Evidence for Inflation: Coherence

At any wavelength, we are averaging over many modes with different direction.



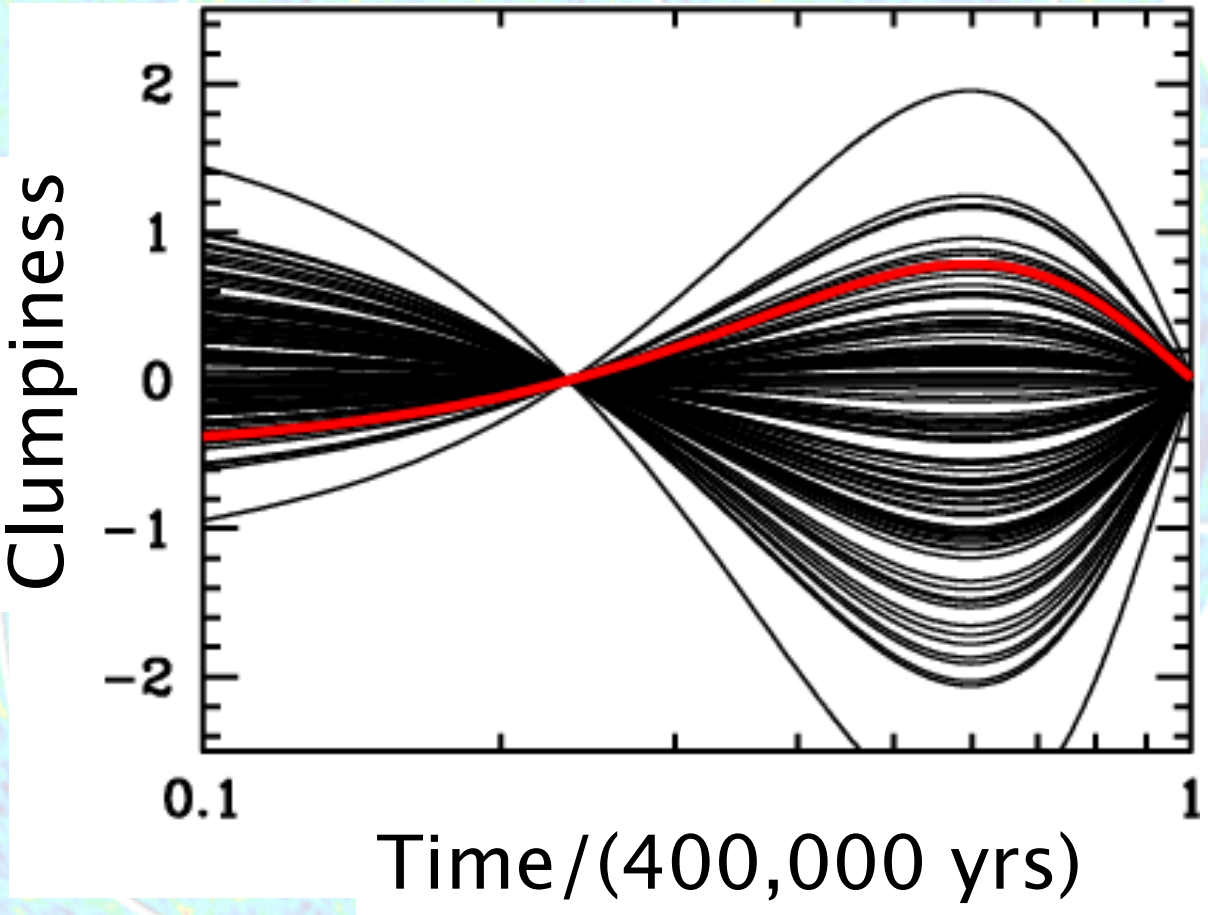
Evidence for Inflation: Coherence

If they do all start out with the same phase …
first peak will be well-defined



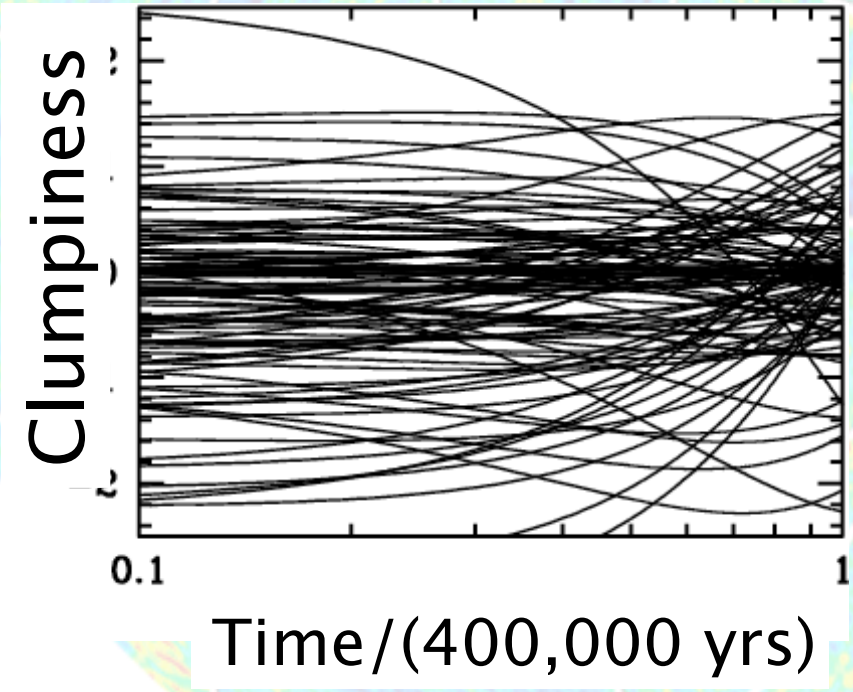
Evidence for Inflation: Coherence

As will first trough ... and all subsequent peaks and troughs

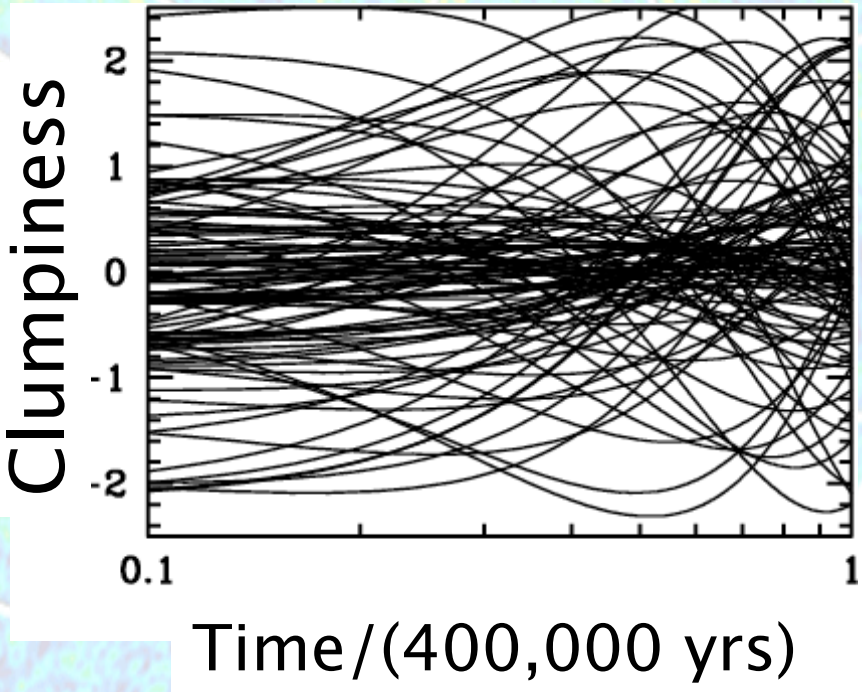


If all modes are **not** synchronized though

First "Peak"



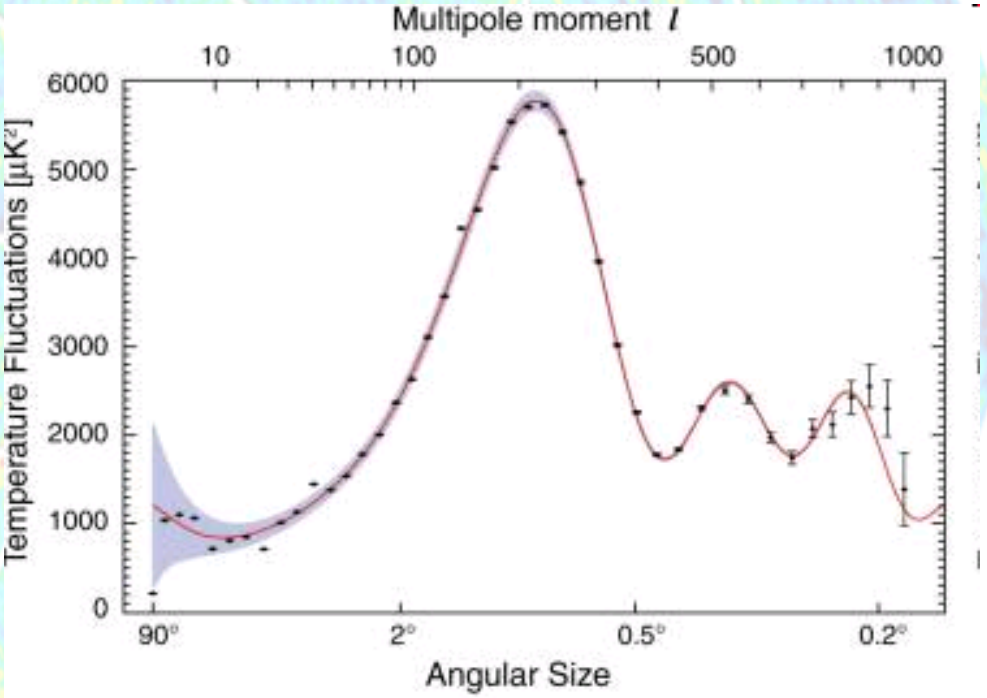
First "Trough"



We will NOT get series of peaks and troughs!

Evidence for Inflation: Coherence

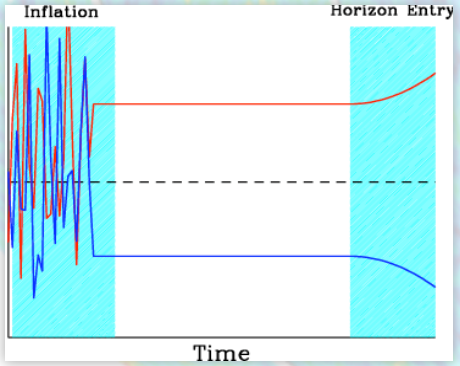
Observed pattern of peaks and troughs point to early synchronization of all Fourier modes: this happens naturally in inflation!

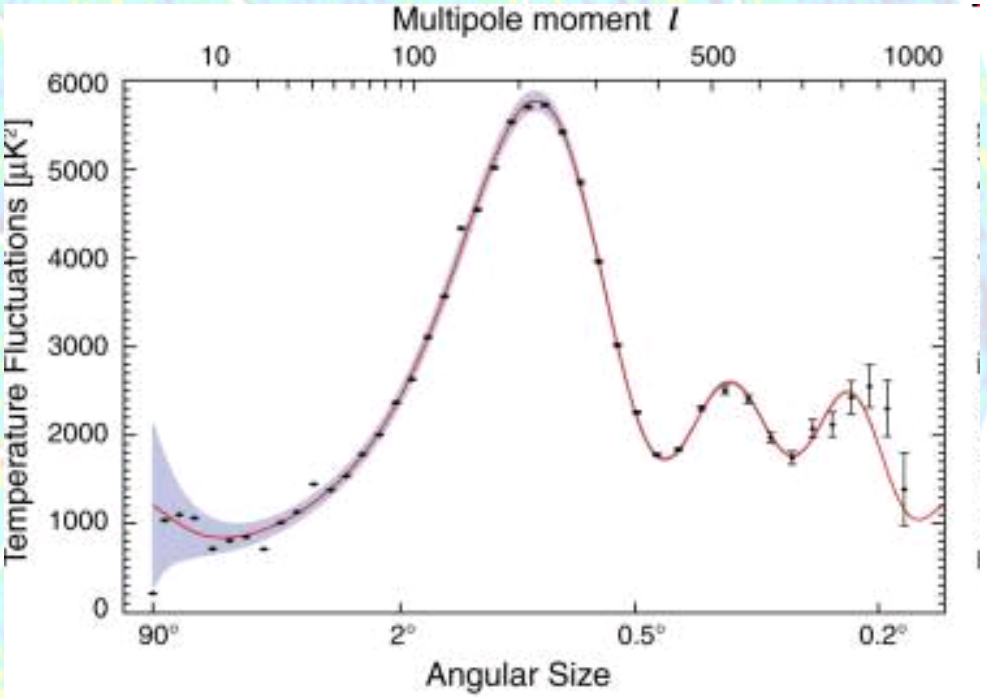


WMAP5

Evidence for Inflation: Coherence

Observed pattern of peaks and troughs point to early synchronization of all Fourier modes: this happens naturally in inflation!





WMAP5

Evidence for Inflation

- Position of first peak
- Temporal phases set early on as evidenced by peak structure
- Shape of primordial spectrum close to scale-invariant

Evidence for Inflation

- Position of first peak
- Temporal phases set early on as evidenced by peak structure
- Shape of primordial spectrum close to scale-invariant

Can we obtain more direct evidence for inflation and the dark energy which drives it?

Evidence for Inflation

Gravity waves are also produced during inflation. These are detectable with upcoming CMB experiments.

Quantum mechanical fluctuations during inflation are stretched to astronomical scales

$$g_{\mu\nu} = \begin{pmatrix} -1+2\Phi & 0 & 0 & 0 \\ 0 & a^2(1+2\Phi+h_+) & a^2 h_\times & 0 \\ 0 & a^2 h_\times & a^2(1+2\Phi-h_+) & 0 \\ 0 & 0 & 0 & a^2(1+2\Phi) \end{pmatrix}$$

Inflation produces perturbations to scalar potential Φ and these grow to be majestic structure we see today… but also tensor perturbations h

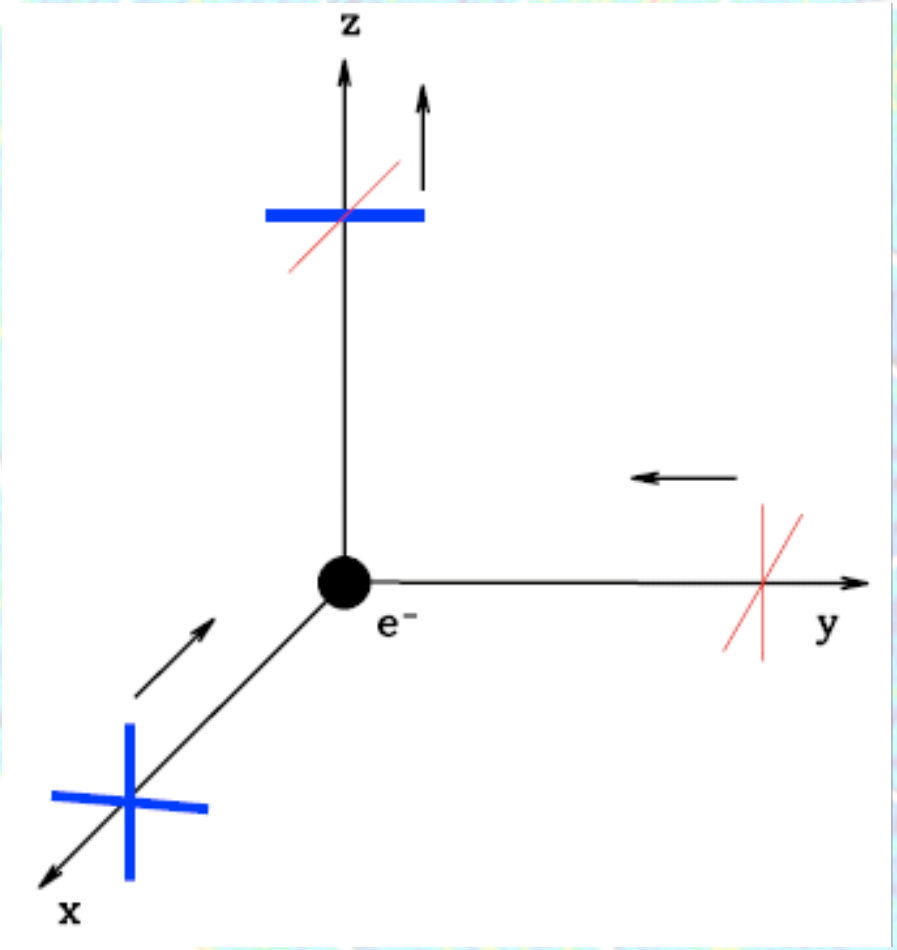
Quantum mechanical fluctuations during inflation are stretched to astronomical scales

$$g_{\mu\nu} = \begin{pmatrix} -1+2\Phi & 0 & 0 & 0 \\ 0 & a^2(1+2\Phi+h_+) & a^2 h_\times & 0 \\ 0 & a^2 h_\times & a^2(1+2\Phi-h_+) & 0 \\ 0 & 0 & 0 & a^2(1+2\Phi) \end{pmatrix}$$

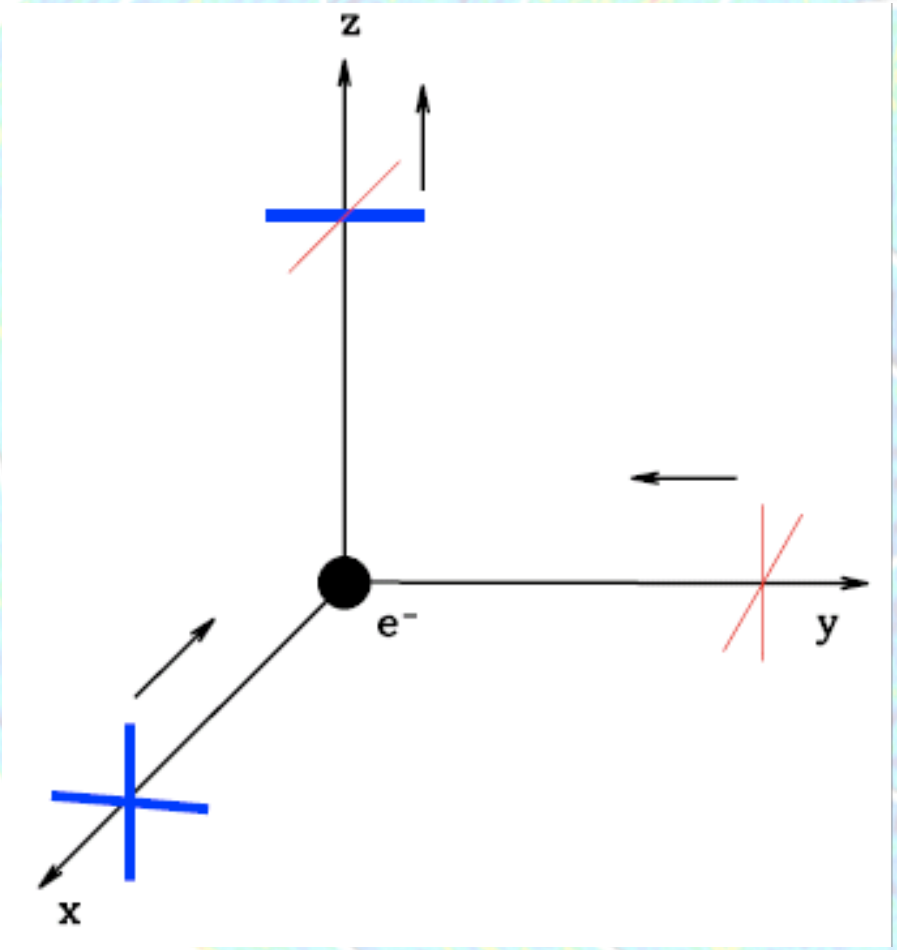
Inflation produces perturbations to scalar potential Φ and these grow to be majestic structure we see today… but also tensor perturbations h

What is the best way to detect these?

Compton scattering of unpolarized anisotropic radiation produces

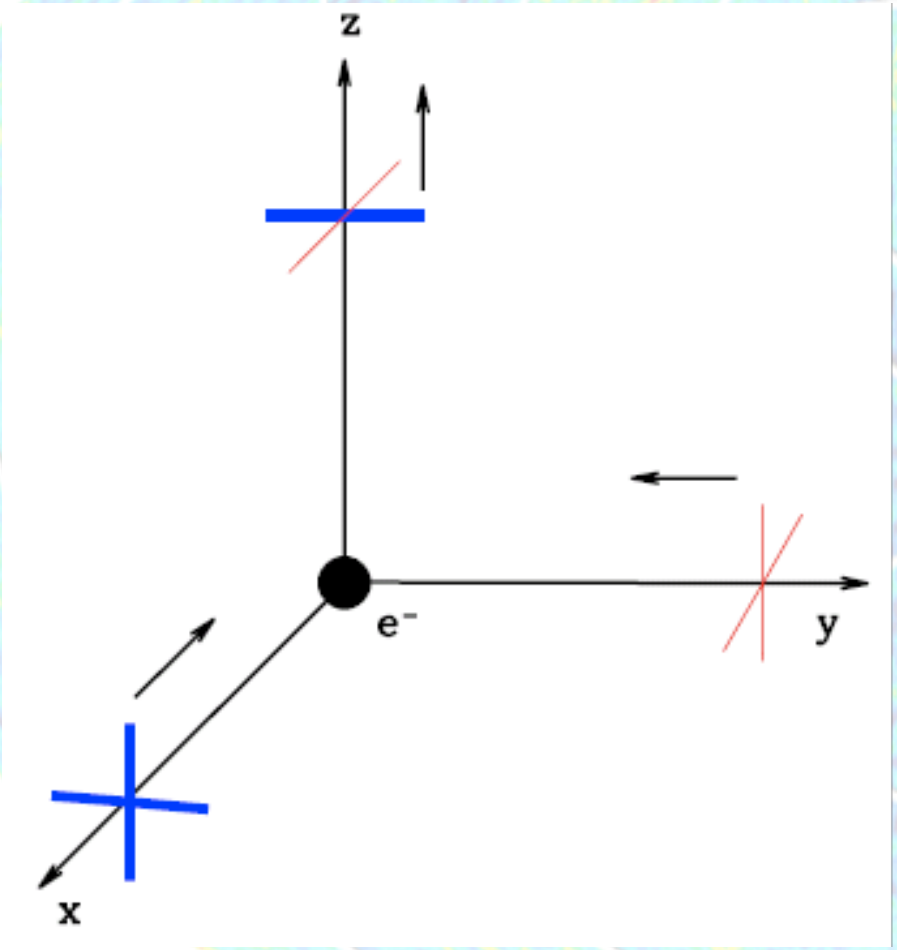


Compton scattering of unpolarized anisotropic radiation produces



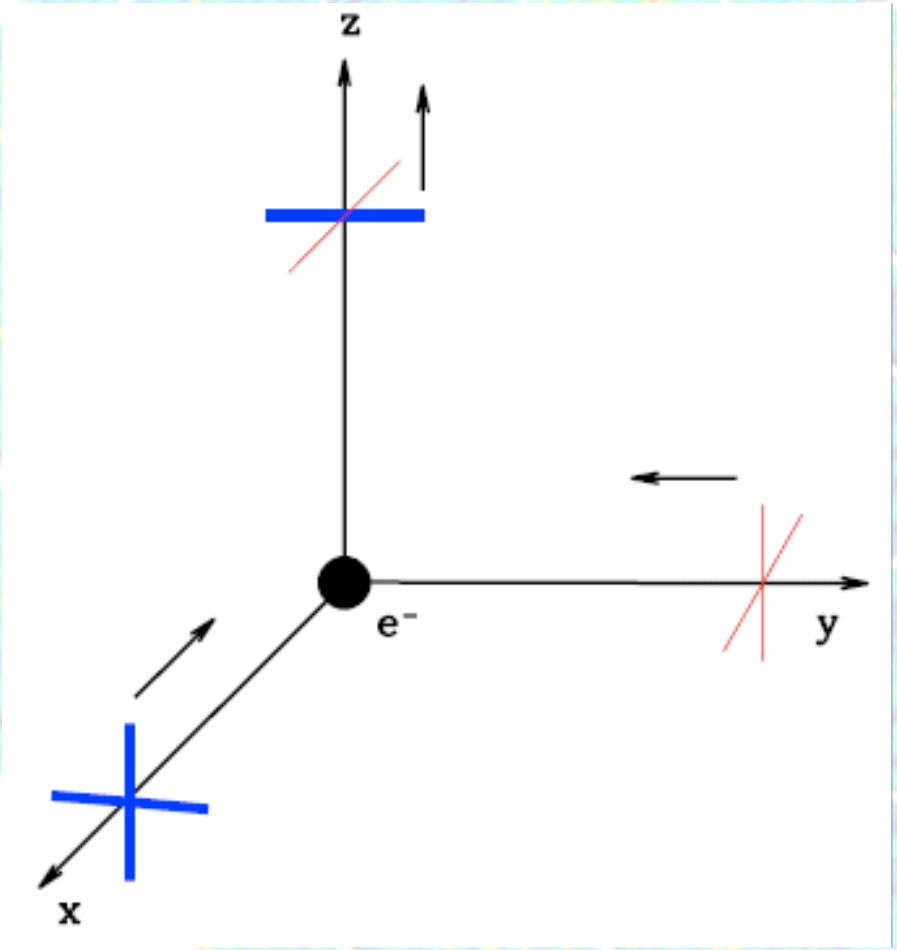
- Require Quadrupole (small before recombination)

Compton scattering of unpolarized anisotropic radiation produces



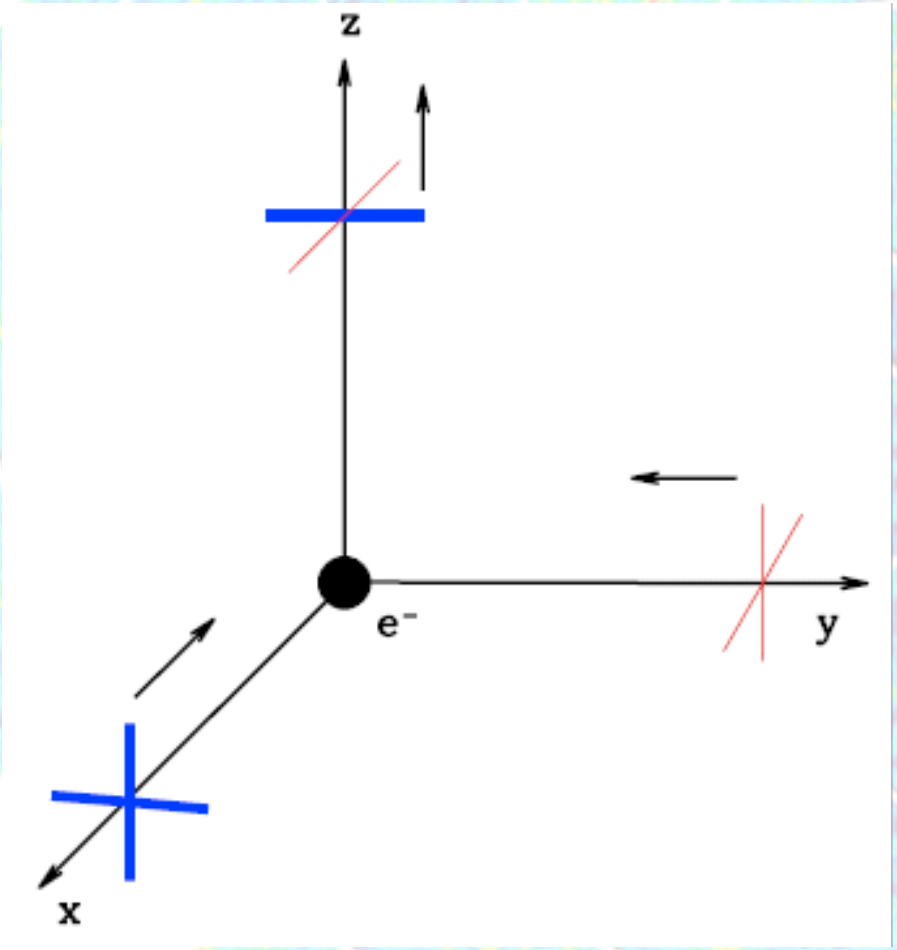
- Require Quadrupole (small before recombination)
- Require Compton scattering (rare after recombination)

Compton scattering of unpolarized anisotropic radiation produces



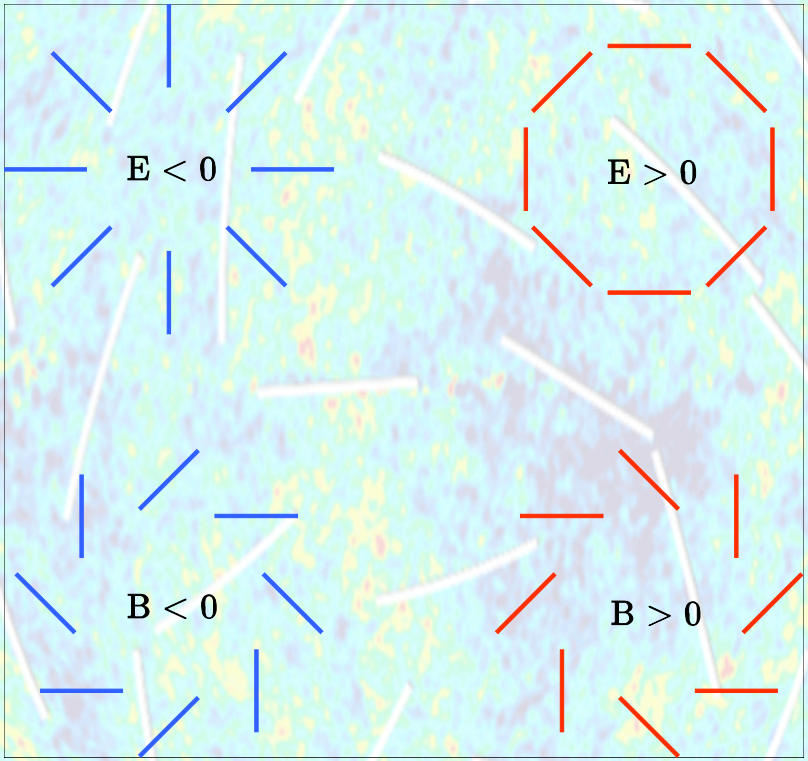
- Require Quadrupole (small before recombination)
- Require Compton scattering (rare after recombination)
- Signals factor of 10 smaller than temperature anisotropies

Compton scattering of unpolarized anisotropic radiation produces



- Require Quadrupole (small before recombination)
- Require Compton scattering (rare after recombination)
- Signals factor of 10 smaller than temperature anisotropies
- Generated during 2 epochs: pre-recombination (z~1000) and after reionization (z~10)

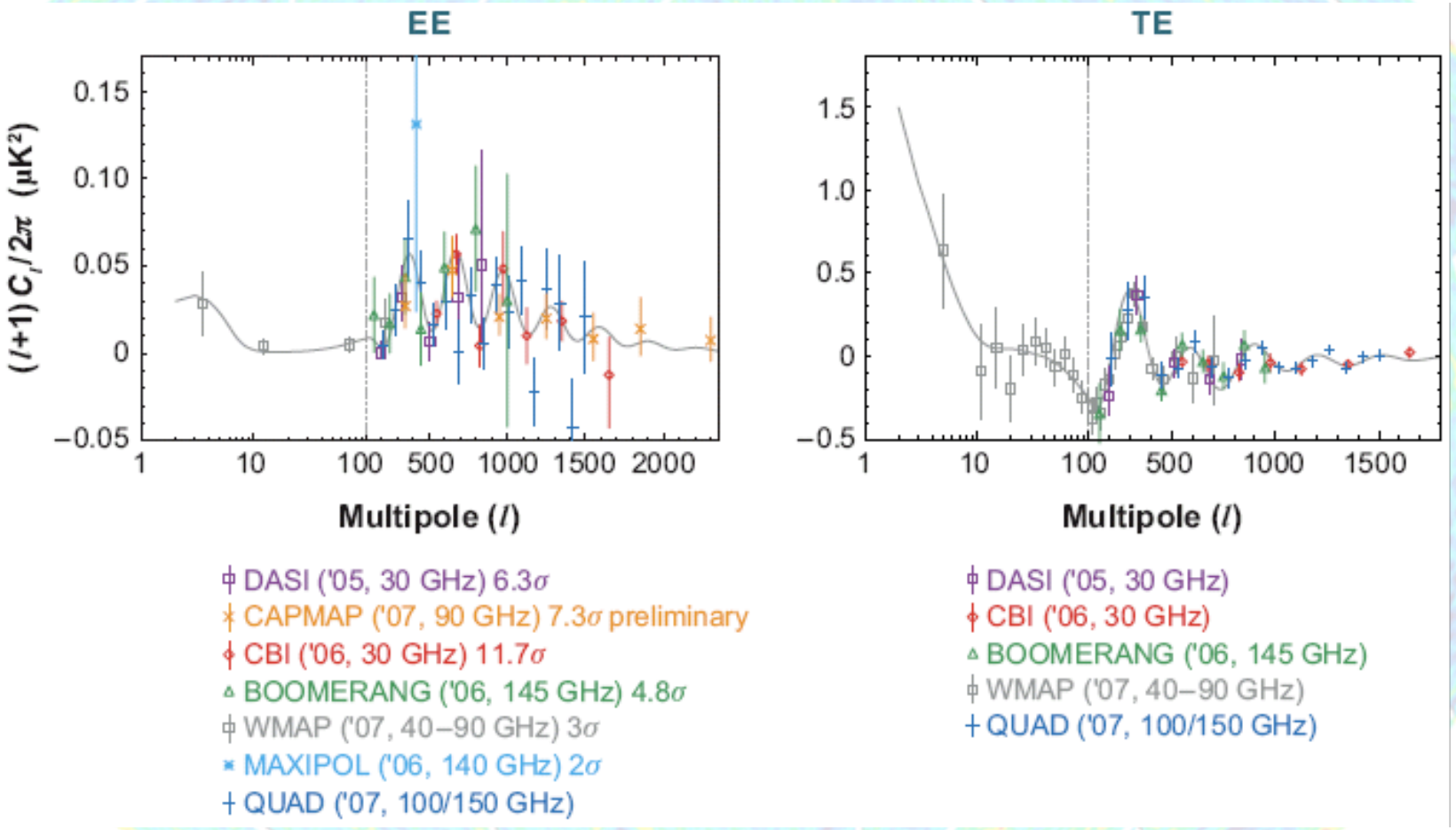
Polarization field decomposed into E- and B- modes



Mission Concept Study: Theory 2008

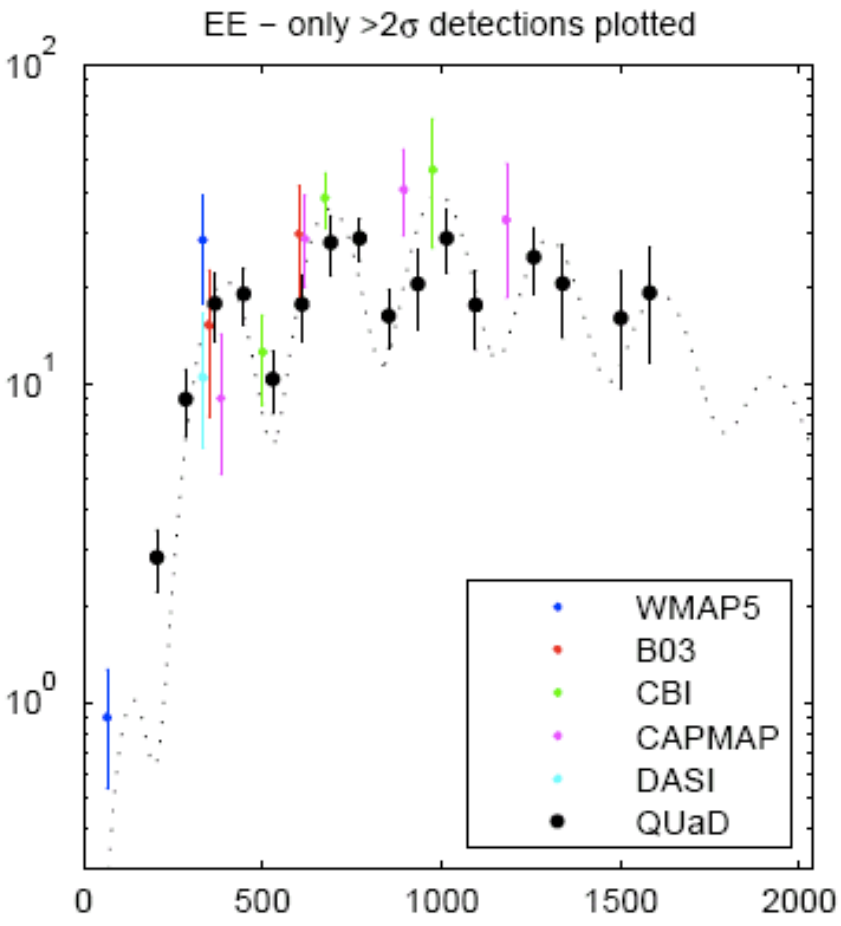
Scalar perturbations (Φ) source E but not B. Tensor perturbations (h) source (E,B), so **B-mode detection would be clear signal of inflation-produced gravity waves**.

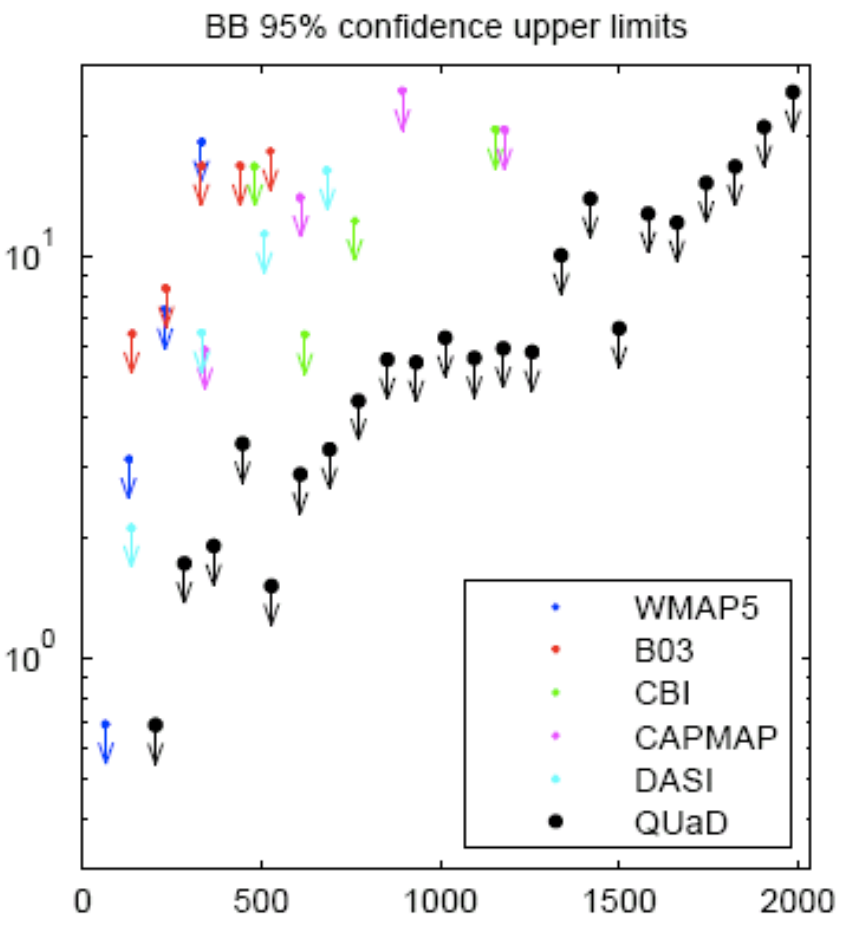
Results



Samtleben, Staggs, & Winstein 2008

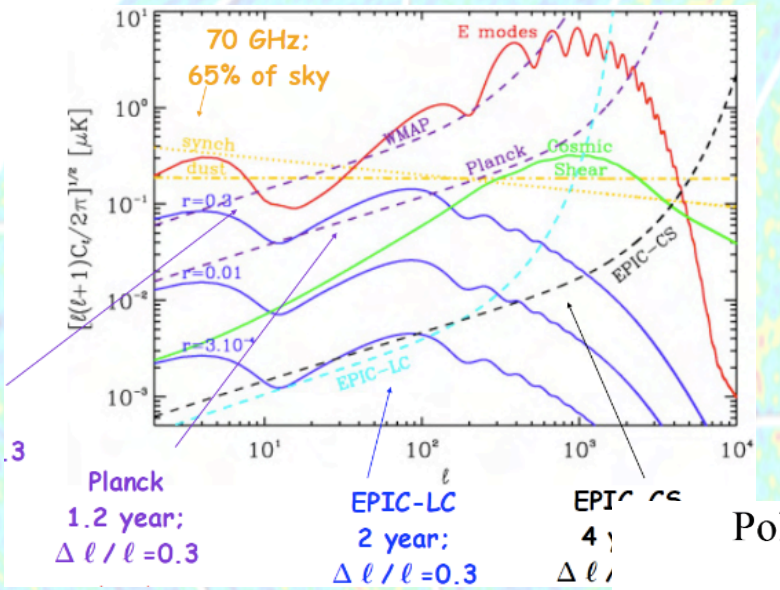
New QUAD Results

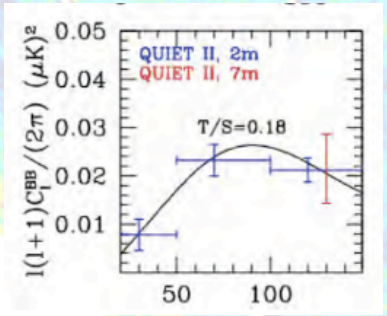


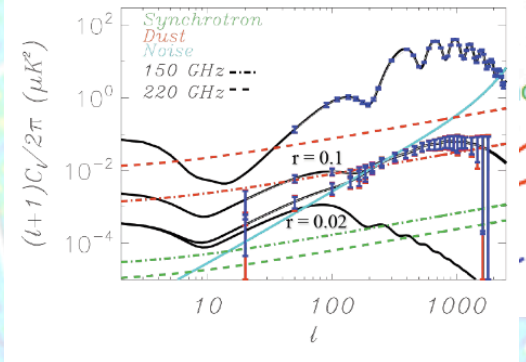


Pryke et al. 2008

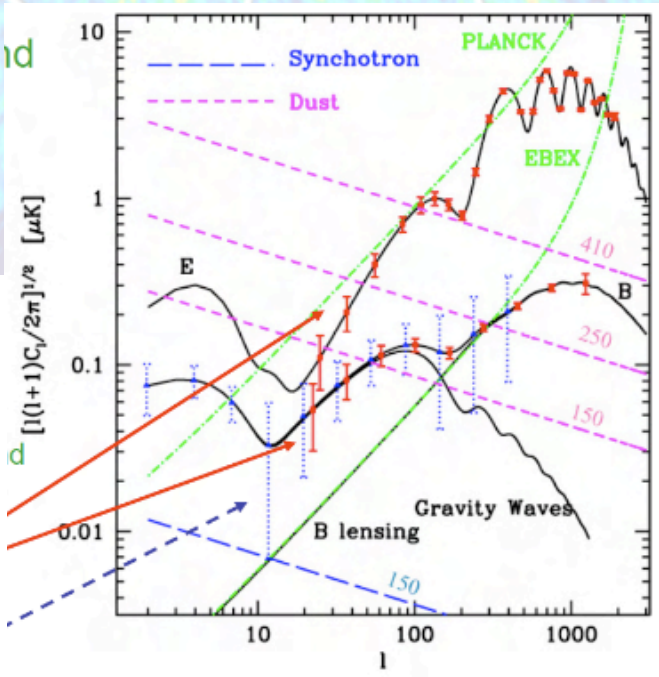
Ambitious (But Realistic) Plans to Detect B-Modes



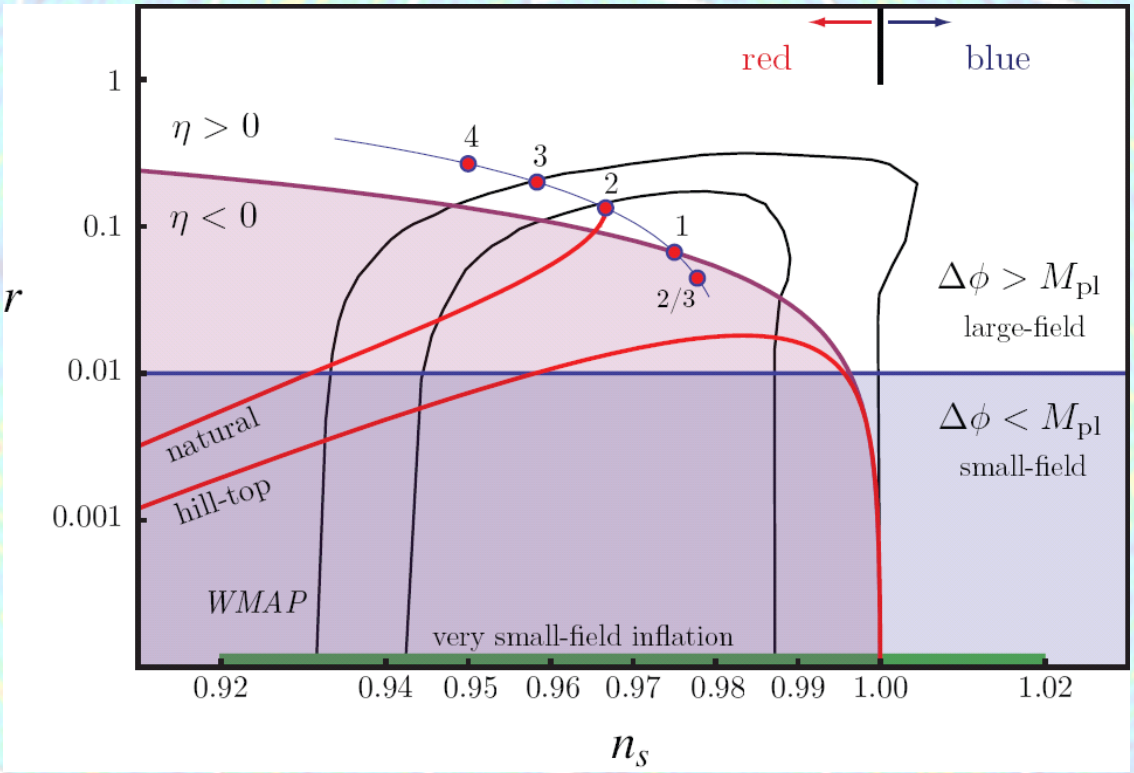




Polarbear Sensitivity



Amplitude of B-mode signal tied to physics of inflation

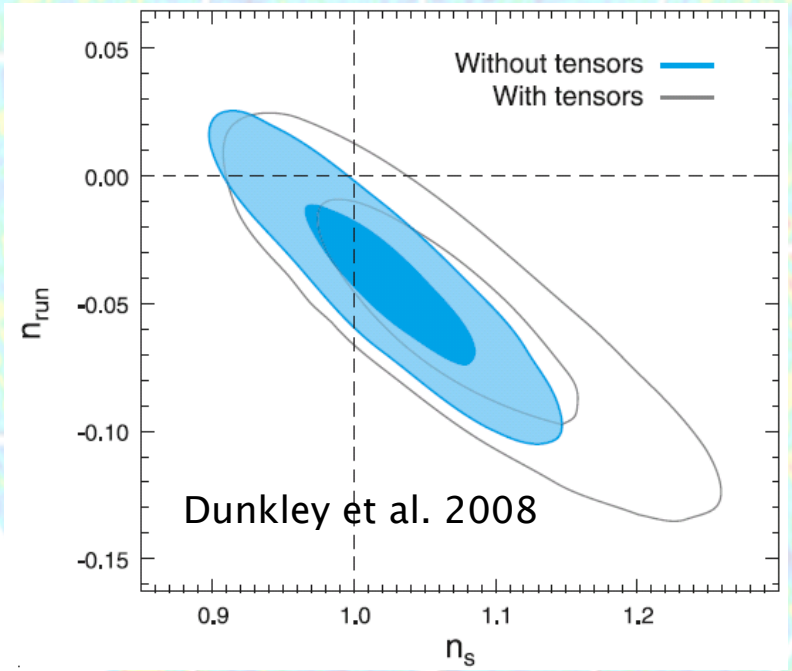


Mission Concept Study: Theory 2008

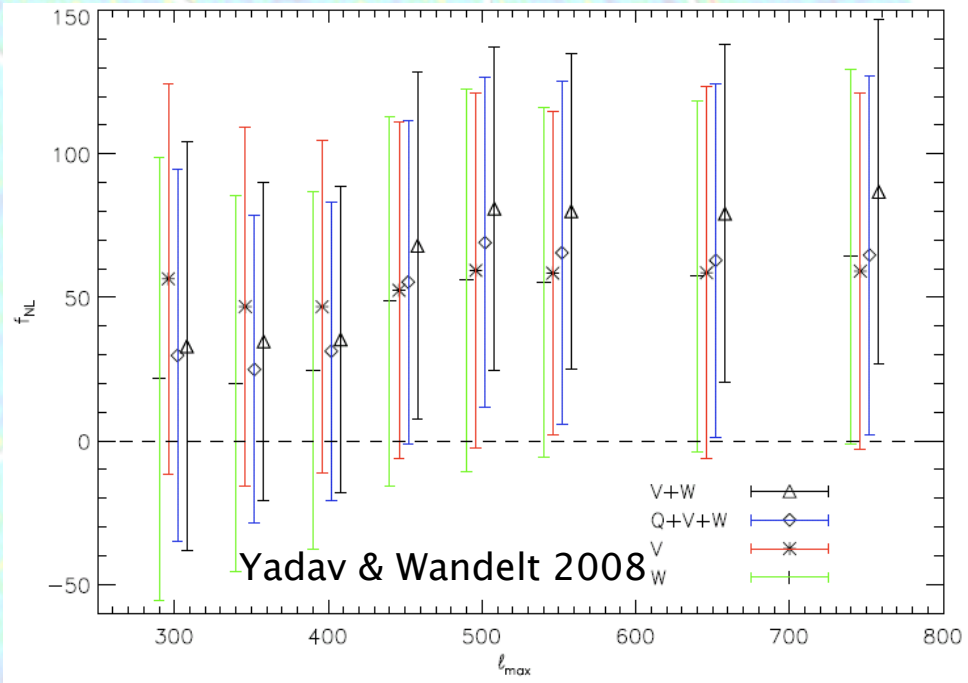
Tensor/scalar ratio teaches us about the high energy physics driving inflation.

Beyond Gravity Waves

Running of the Spectrum



Non-gaussianity

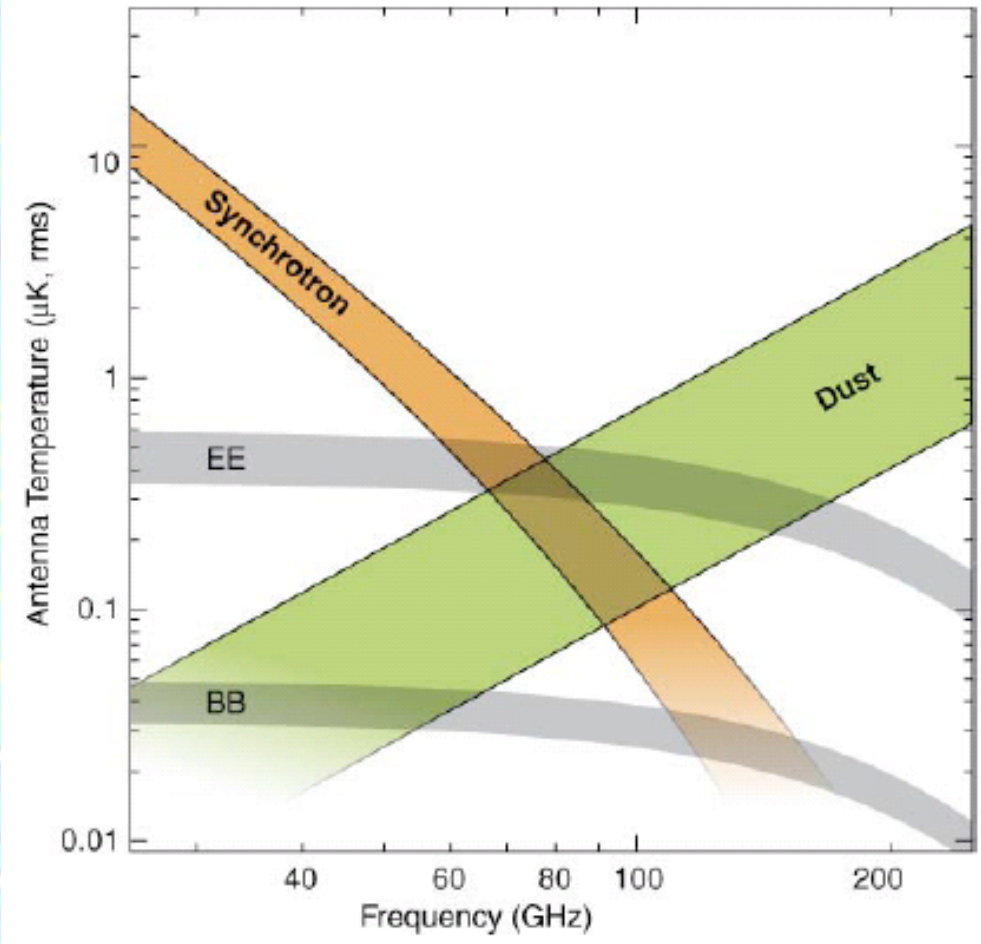


Conclusions: If B-modes are detected …

- Alternatives to inflation will be ruled out
- Pin down the energy scale driving inflation
- Prove Symmetries of the UV-complete theory

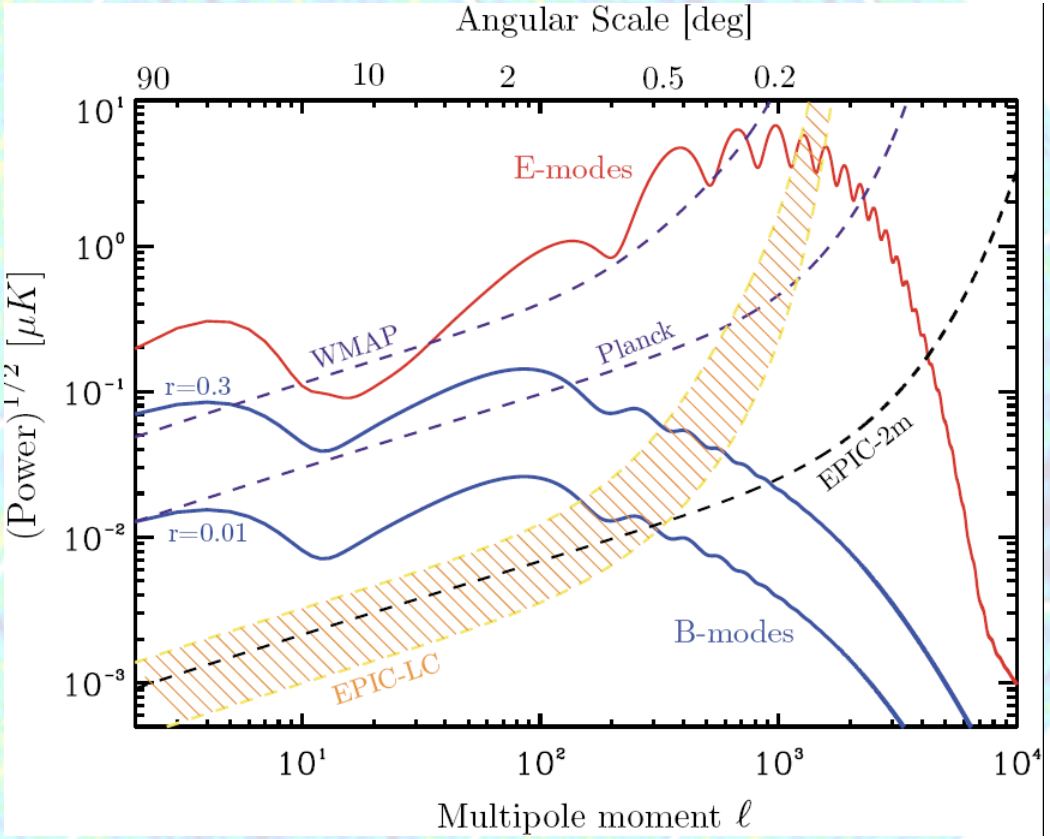
Remember http://cmbpol.uchicago.edu

Foregrounds



Challenges

- B signal is unknown but < 0.1 microK
- Characteristic double peaked (l=6 and l=100) signature
- Foregrounds will likely be limiting factor
- r=0.01 (E_{inf}~10^{16} GeV) might be best we can do



Mission Concept Study: Theory 2008