Can We See Planck/Stringy Physics in the CMB?

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Dimensional Analysis

- Two scales in this problem:
  - H - Hubble scale during inflation
  - M - mass scale of new physics

- Optimistically: H ~ 10^{15} GeV, M ~ 10^{17} GeV

- New effects from fundamental length scale
  - $\sim(H/M)^p$
  - $H/M < .01$; $p = ??$

Cosmological Scales

- Inflation occurs at GUT scale (or lower)
- Final temperature: T_{reheat} ~10^{15} GeV
  - Assumed efficient (p)reheating.
- T_{Planck} =10^{19} GeV, l_{Planck} = $1/T_{Planck}$
  - 1 GeV= 10^{13}K, 1 ly = 10^{18} cm
- Today: visible universe is
  - 10^{10} ly = 10^{61} l_{Planck}, T=2.7 K
- a_{today}/a_{end} = T_{today}/T_{reheat} = 10^{28}

Scales....

- Longest perturbations grow
  - $>e^{60} = 10^{26}$ during inflation, 10^{28} afterward
  - Total growth at least 10^{54}
- Long scales almost always subplanckian
- Small scales always subplanckian
- Does this have observational consequences?

Possible Models

- New physics will change either
  - initial state (p~1)
  - evolution of mode (p~2)
- Don’t understand string/Planck physics well
  - Can’t do a first principles calculation
  - Always need an ansatz introducing new scale

One Mechanism

- One model (Easther, Greene, Kinney and Shiu)
- Normalize modes to Minkowski vaccuum
  - When wavelength exceeds fundamental scale
  - Not in the infinite past; k-dependent time.
  - Evolution unchanged; same solution(s)
  - Initial conditions rotated relative to standard solution

Modification

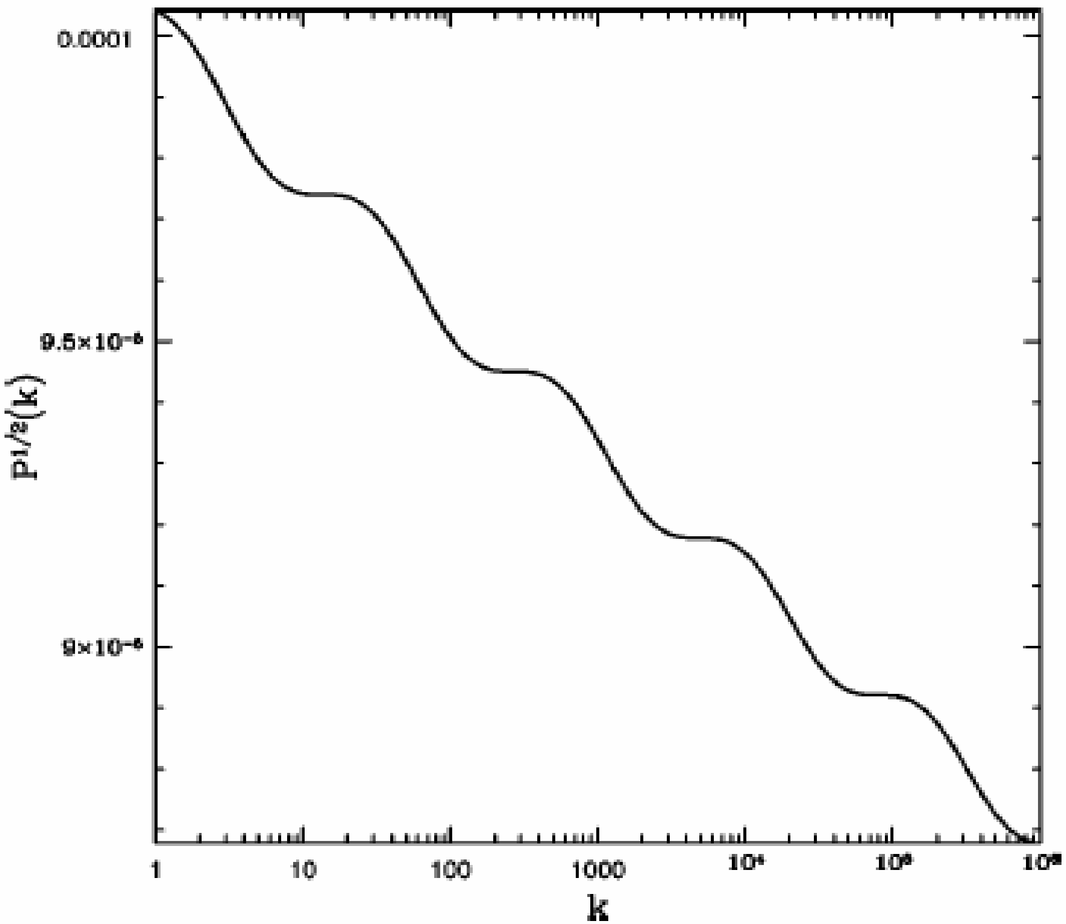
Tensor to scalar ratio: 16ε

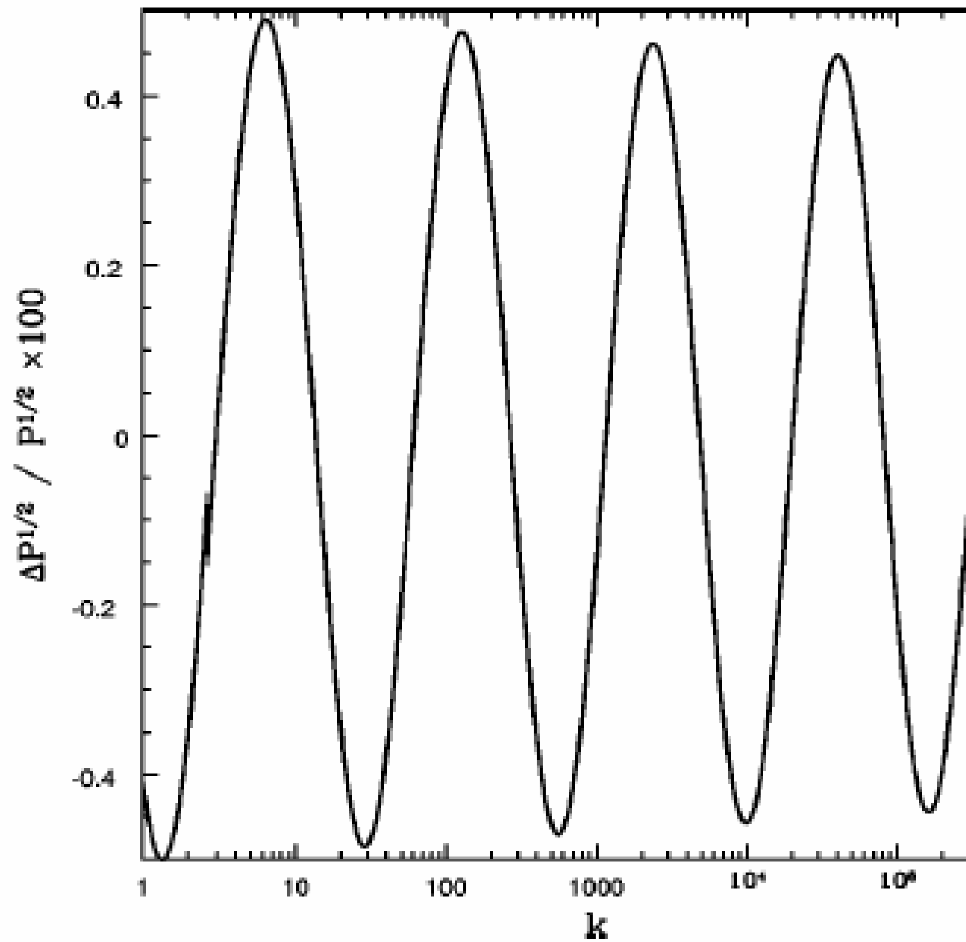
$$P_{TP} = \left\{ 1 + \left(\frac{H_*}{M}\right)\left(\frac{k}{k_*}\right)^{-\varepsilon} \sin\left[\frac{2}{1-\varepsilon}\left(\frac{M}{H_*}\right)\left(\frac{k}{k_*}\right)^{\varepsilon} + \phi \right] \right\} P$$

Amplitude

Modulation

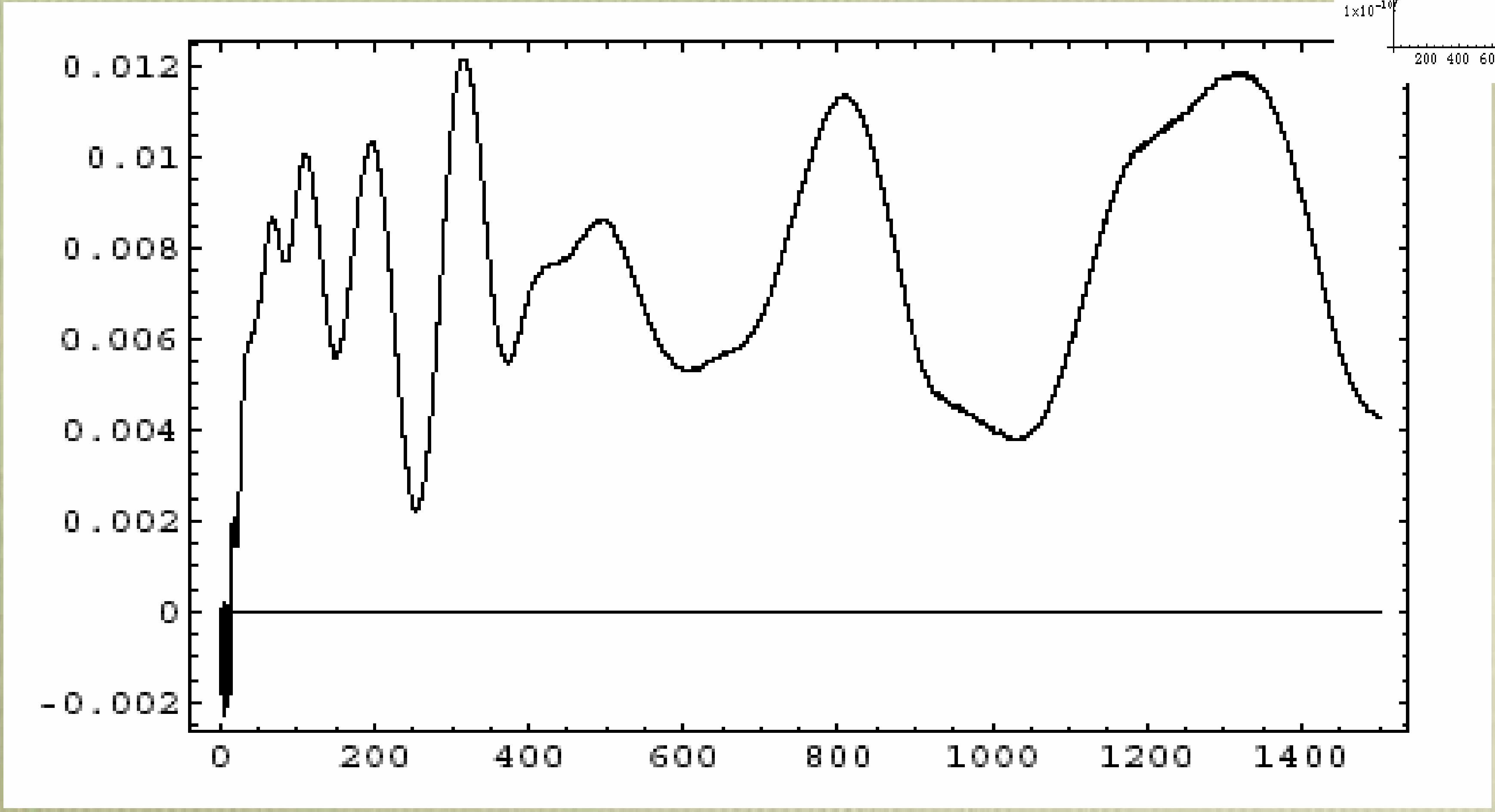
Modulated Spectrum

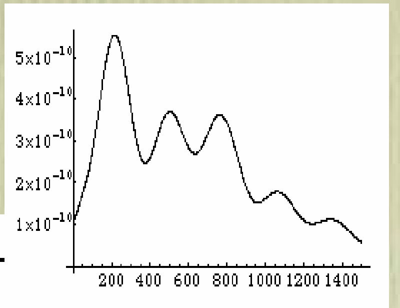




- p=1.00, ε = 0.01, H/M = 0.01

Impact on Observations





Observational Constraints

- Working on this....
- Precise modulation depends on ansatz
- Must include a phase
    - Okamoto & Lim
        - Fix “late-time” cosmological parameters
        - Look for general modulation
        - Detectable if $H/M > 0.005$ ($l < 2000$)
        - Weak constraint from WMAP 1 year
        - Likelihood complex function; local maxima.

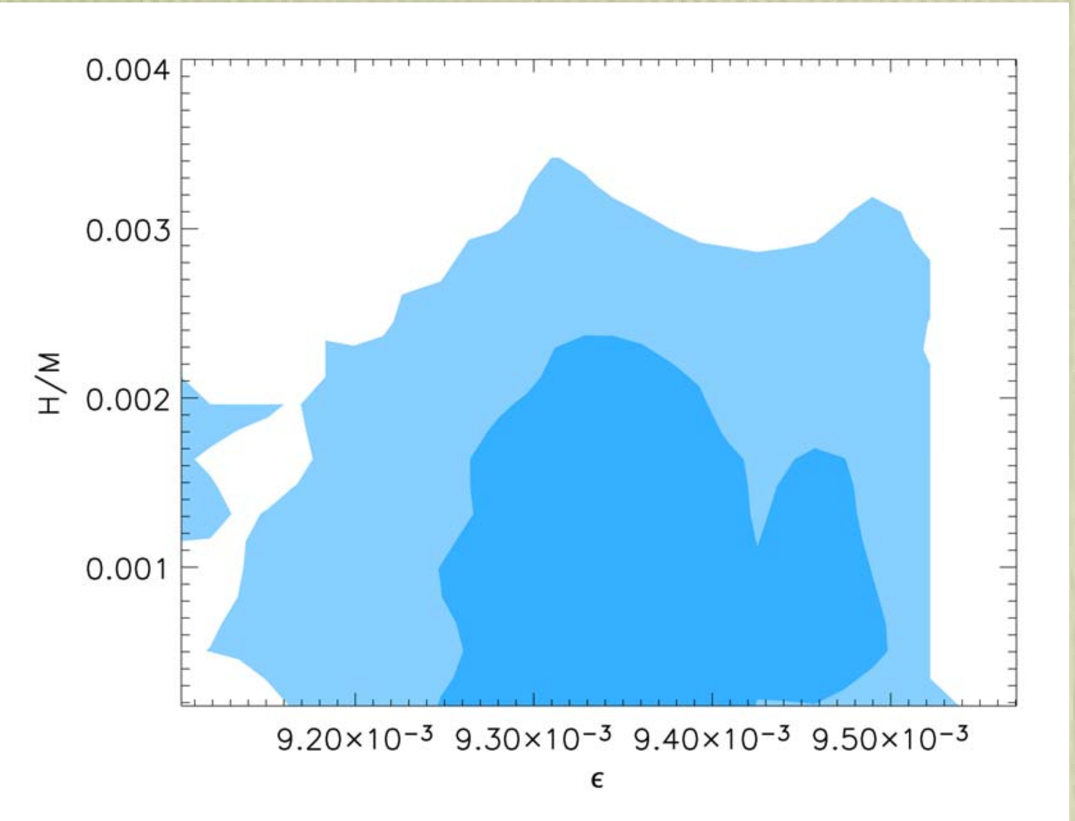
Our work...

- Looking at specific model
  - Not because we believe it...
  - Modulation could arise in other ways
    - Need theoretical prediction to test
  - Fewer parameters in modulation
    - Tighter constraint
    - Modulation a function of ε
  - Modulation and tensor detection coupled
    - Generic for any changed initial condition?
- Markov chains running as I speak....

Preliminary Markov Results

• Cosmic-variance-limited, noiseless experiment, weak lensing included, {TT, TE, EE, BB} measured to l=2000

• 4 "late-time" parameters + n_s + running + amplitude + (H/M) + ε + ϕ varied in the chains, fiducial model r=0.15, no TP oscillations



$r = 16\,\varepsilon$

Summary

- Feasibility study only
- Significant theoretical uncertainties
- Needs favorable piece of parameter space

Don't spend millions of dollars doing an experiment to test this!

But if you are spending millions of dollars to look at the CMB (or the power spectrum) keep this in mind...