

# Monodromy, Modulated Power Spectra and the CMB

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# Theoretical Background and Motivation

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- Monodromy inflation
  - Silverstein and Westphal: [arXiv:0803.3085](#)
  - Flauger, McAllister, Pajer, Westphal and Xu: [arXiv:0803.3085](#)
  - Flauger and Pajer: [arXiv:1002.0833](#)
- Key features
  - Large field range, wrapped around a compact direction
  - High scalar, detectable tensors, theoretical “control”
  - Wrapping provides extra scale: modulated spectrum?

# Approximation to the potential...

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$$V(\phi) = \mu^3 \left( \phi + bf \cos \frac{\phi}{f} - c \right)$$

- Amplitude of perturbations set by  $\mu$ 
  - $\mu$  fixed by amplitude of perturbations
- Axion decay constant  $f$ : sub-Planckian,  $f > \text{few} \times 10^{-4}$
- Modulations:  $0 \leq b < 1$  to prevent trapping

# Analysis

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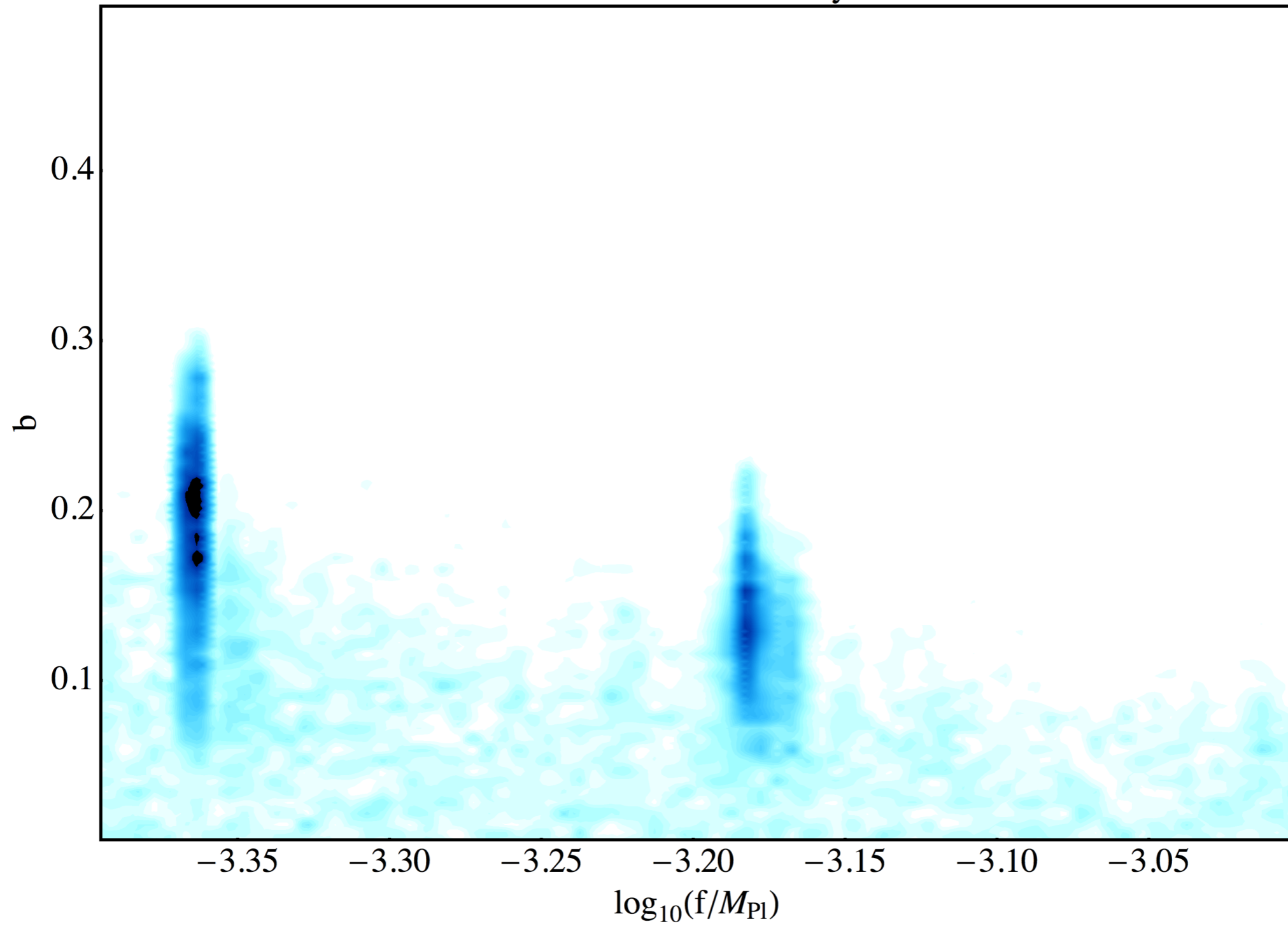
- Uses ModeCode (Easther, Peiris and others)
  - Directly solves perturbation equations
  - There is also a good approximate solution
- CAMB slowed down by oscillatory spectrum
  - Uses interpolation when it can; not safe here
  - Boosted accuracy settings in CAMB (checked convergence)
- Sampling done by MultiNest
  - Massively parallel; samples prior not posterior

# Priors

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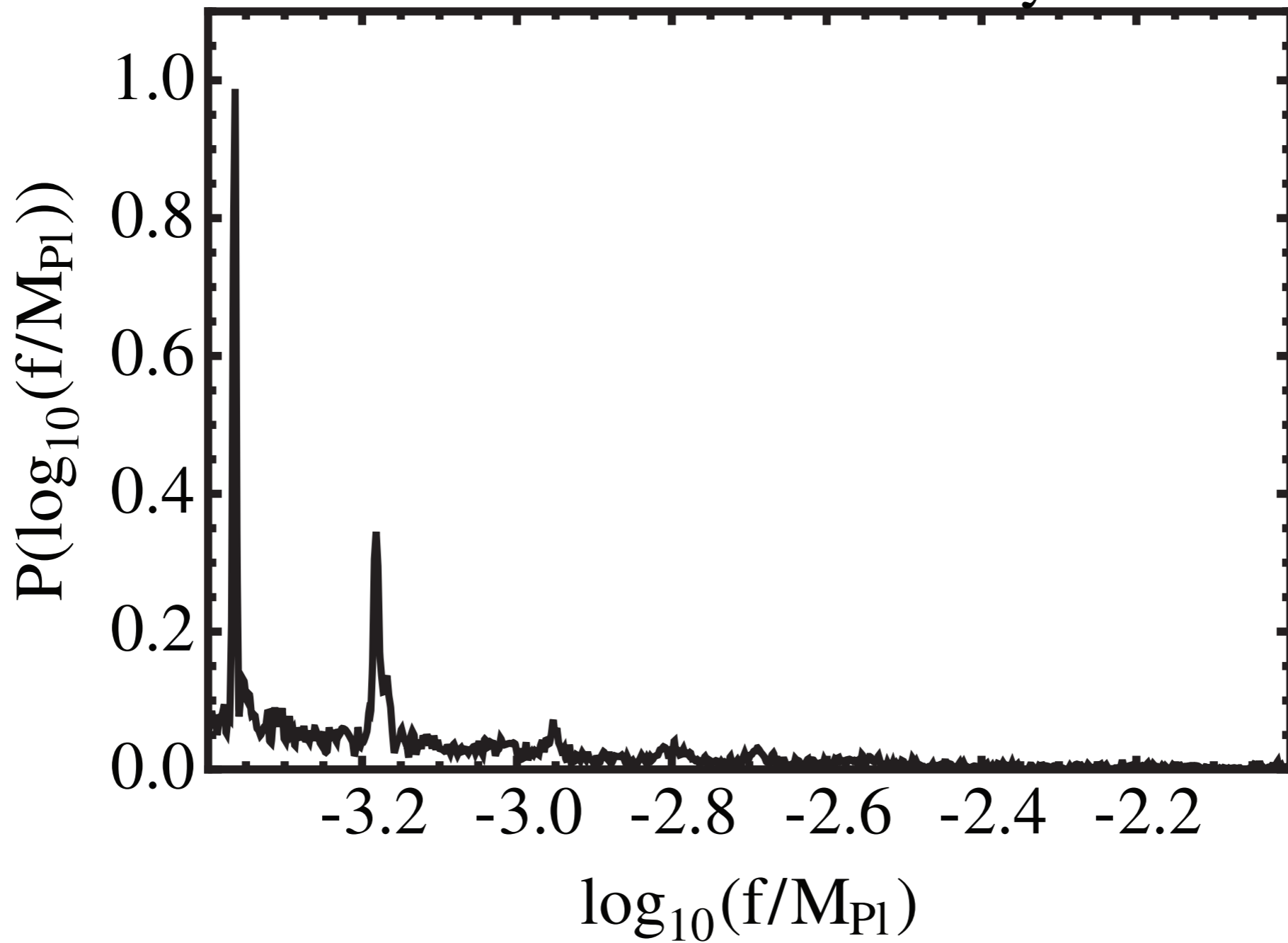
Inflation	
Mass scale	$-3.615 < \log_{10}(\mu/M_{\text{Pl}}) < -3.015$
Axion coupling	$-3.4 < \log_{10}(f/M_{\text{Pl}}) < -2.0$
Oscillation amplitude	$0 < b < 0.9$
Phase	$-\pi < \psi < \pi$
Matching	
$e$ -foldings	$N = 55$
Astrophysics	
Baryon fraction	$0.0218859 < \Omega_b h^2 < 0.02378859$
Dark matter	$\Omega_{\text{dm}} h^2 = 0.1145$
Reionization	$\tau = 0.0874$
Projected acoustic scale	$\theta = 1.040$
Sunyaev-Zel'dovich Amplitude	$A_{\text{SZ}} = 0.10078$

# WMAP9 Monodromy

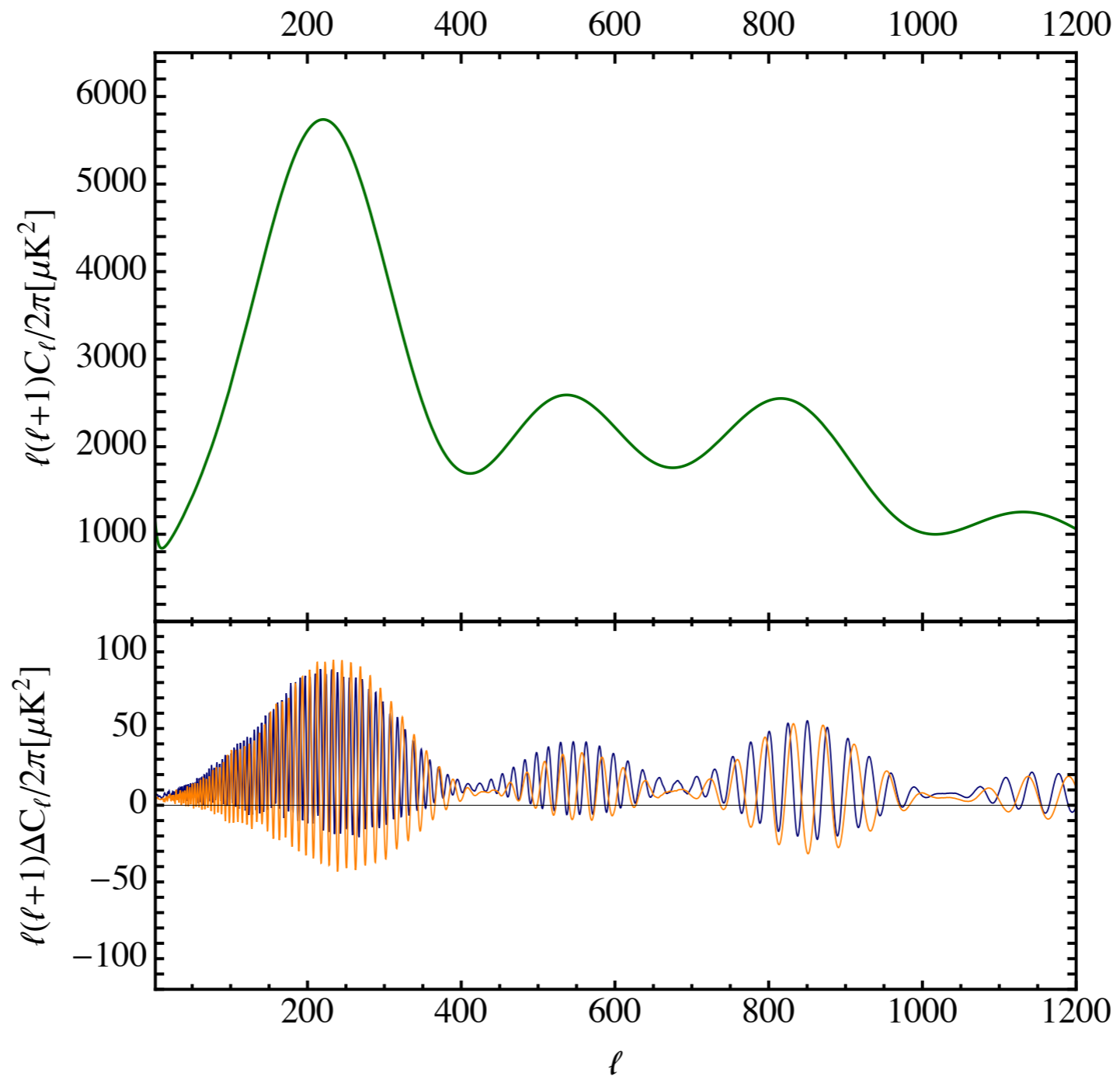


•  $\mu$  fixed

# WMAP9 Monodromy



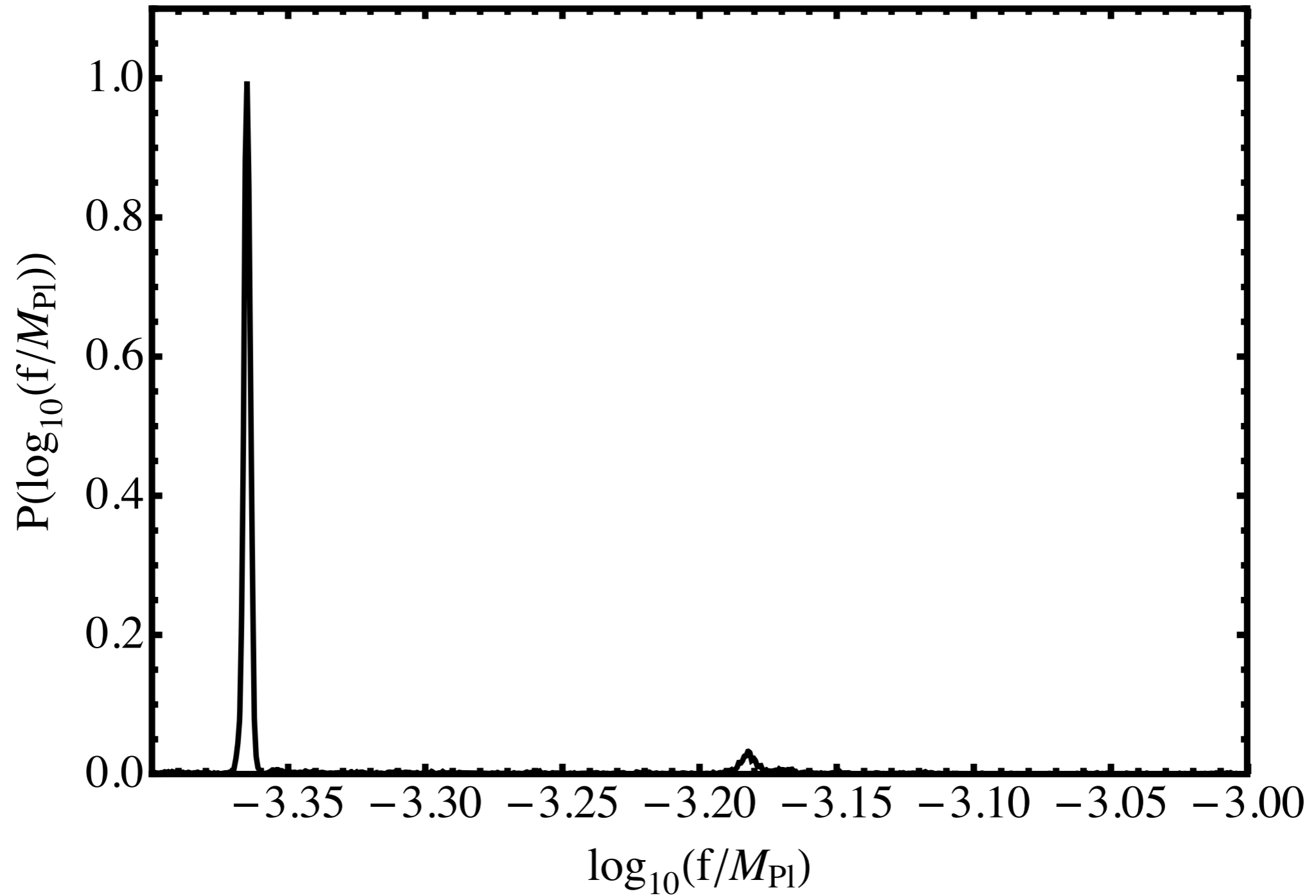
Marginalized posterior  
 $\mu$  fixed



Fixed  $\mu$ :  $C_l$  rises with  $b$

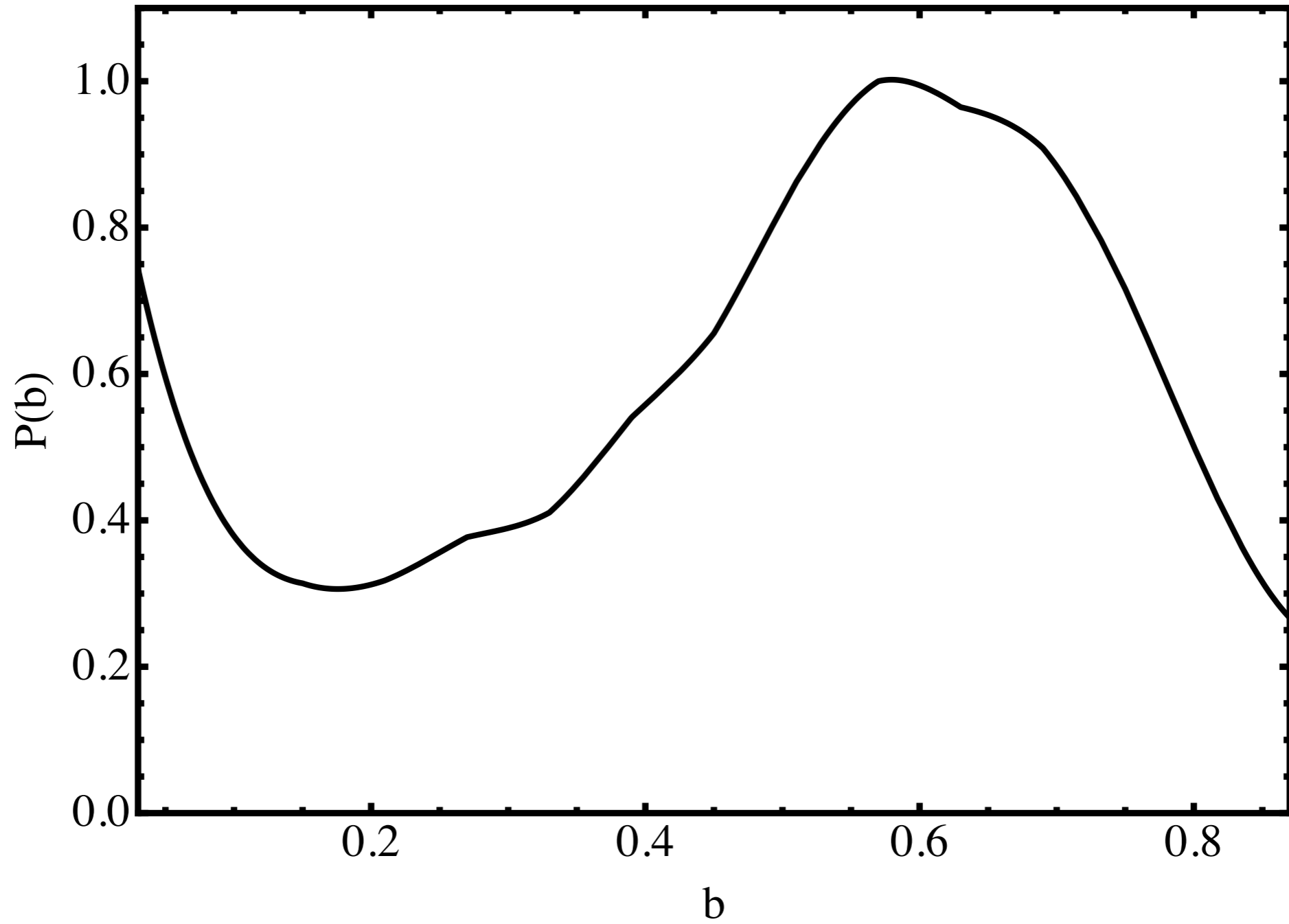


# WMAP9 monodromy

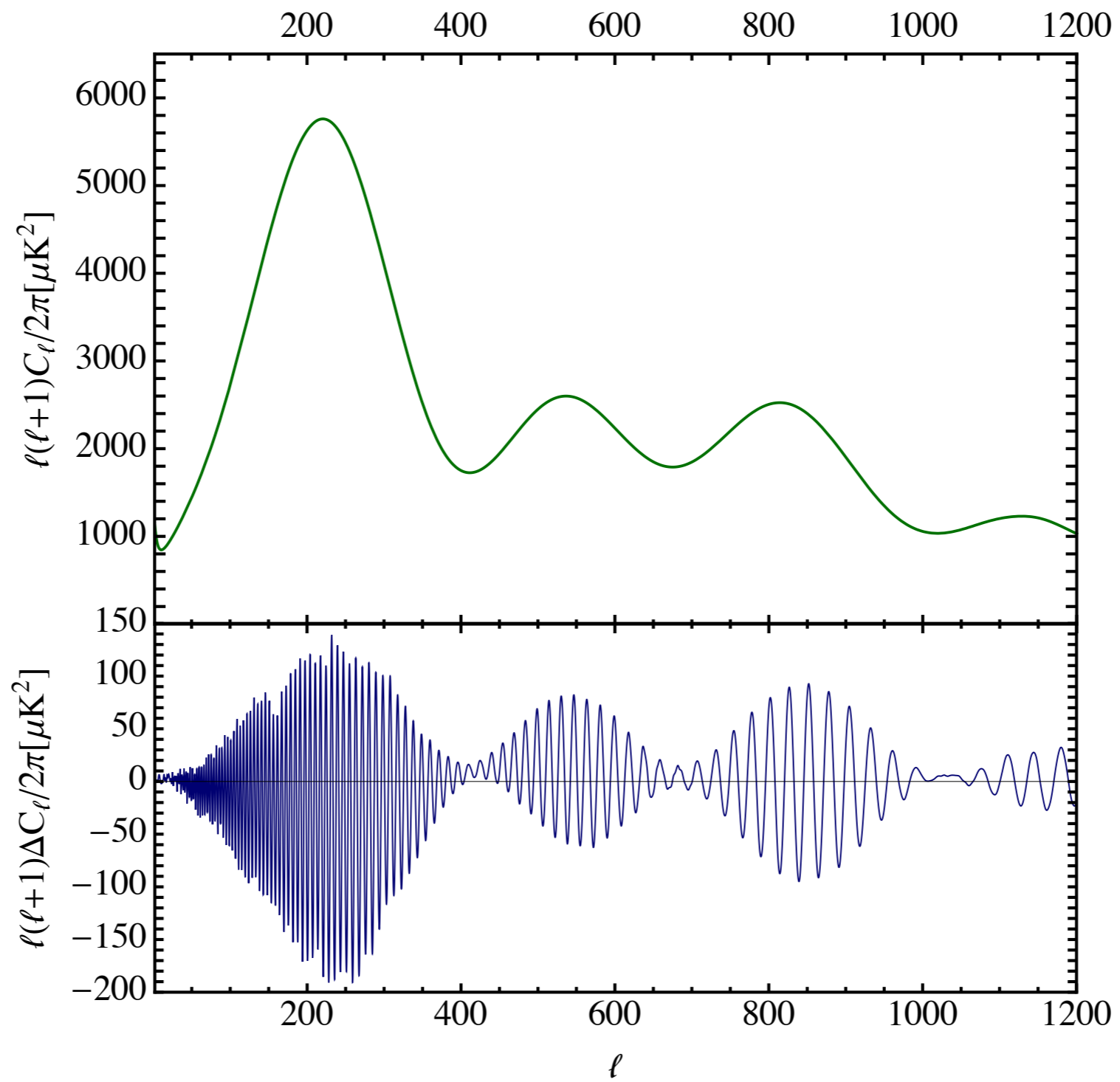


Marginalized posterior  
 $\mu$  varies

# WMAP9 Monodromy



Marginalized posterior

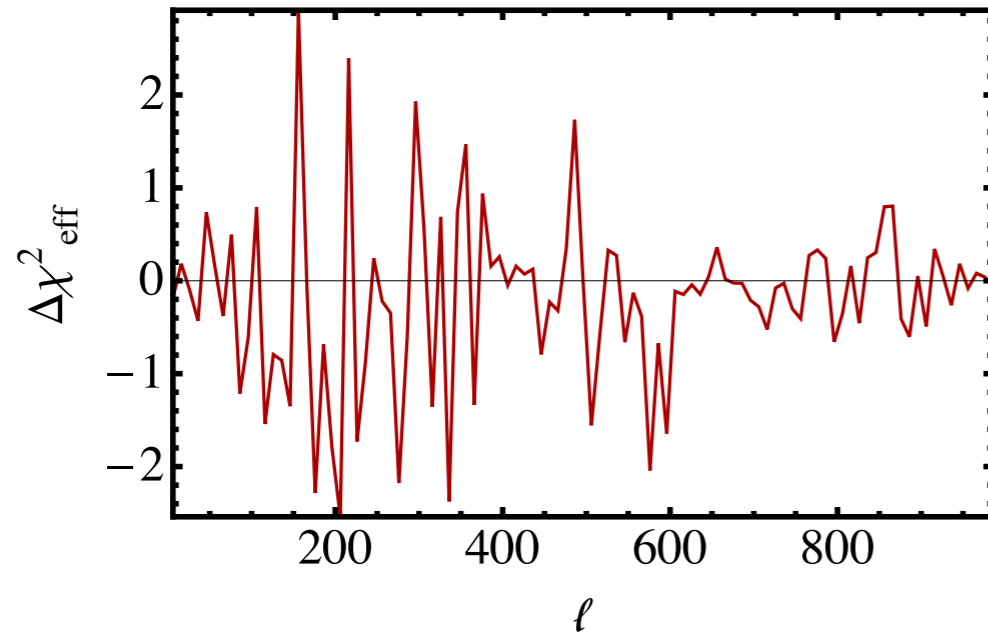
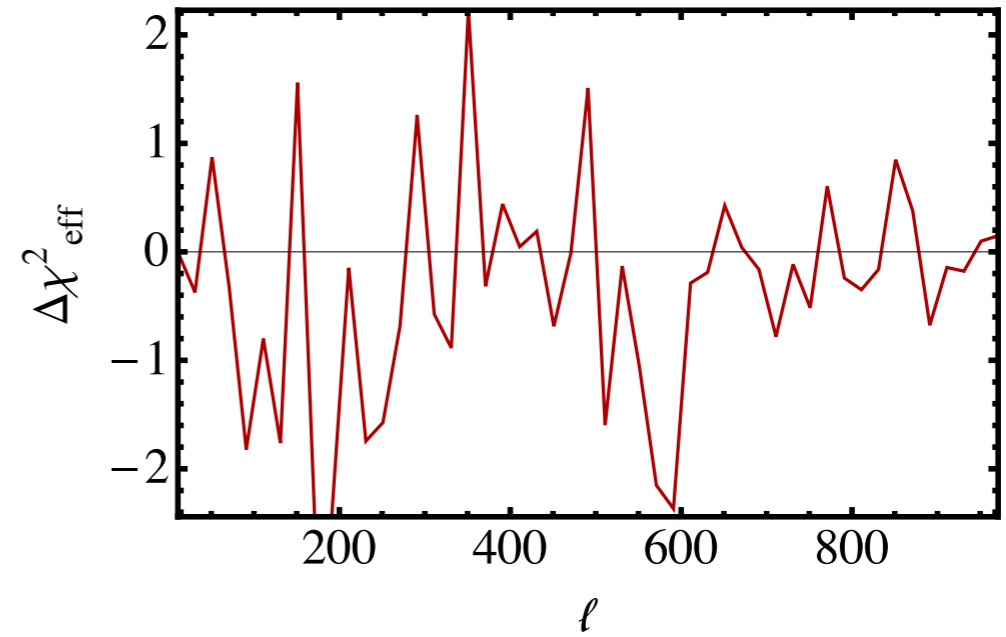
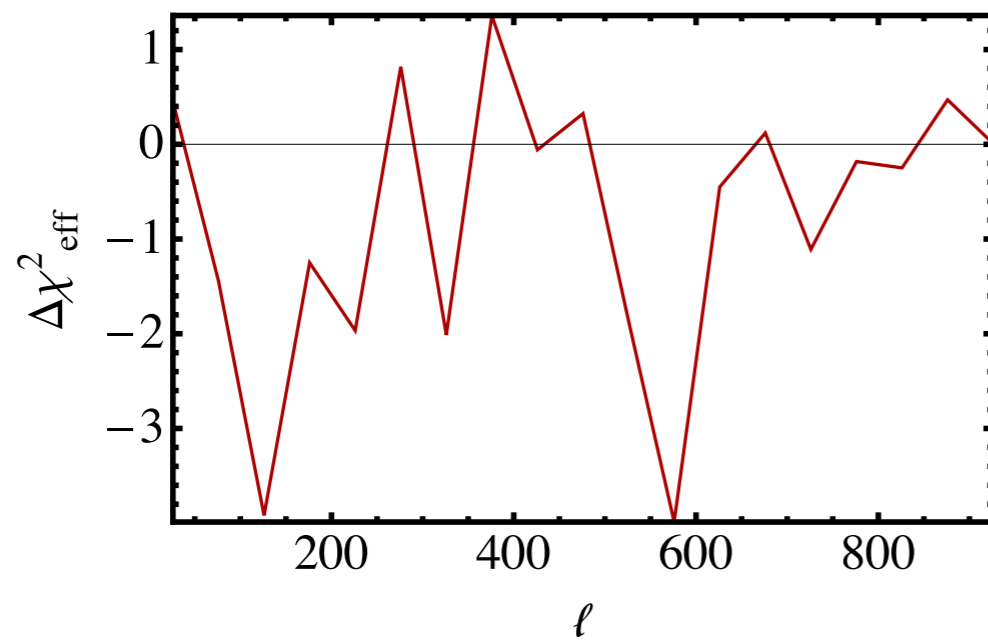
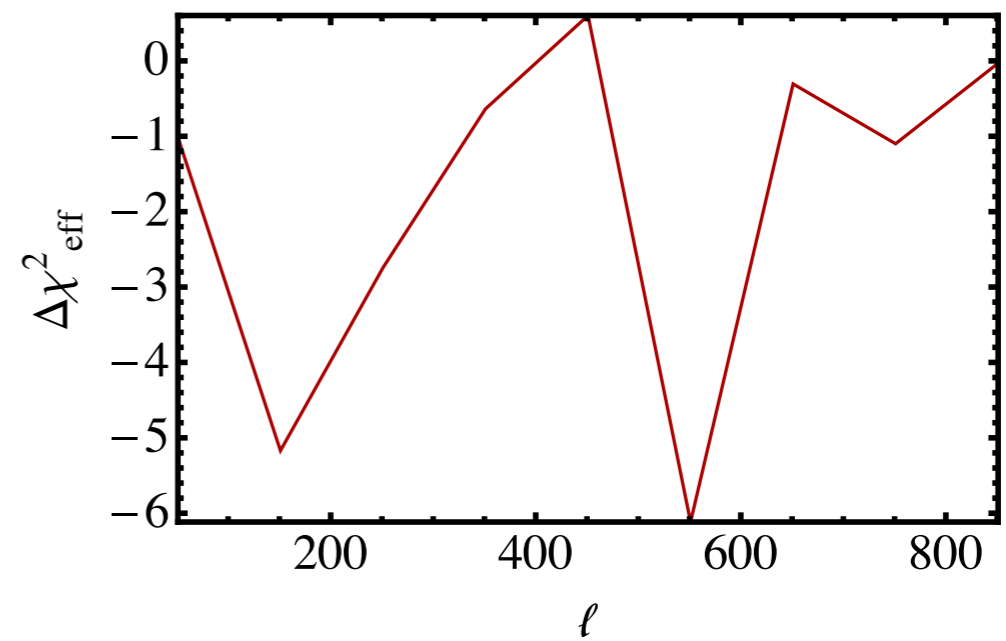


Impact on power spectrum

# Tests...

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- Bayesian evidence: 0.6 in favor of modulated model
  - Not significant
- Maximum likelihood:  $-2 \Delta L \sim 19$  for high peak; 11 for low peak
  - Relative to both  $b=0$  and  $\Lambda$ CDM
  - Significant improvement, but not compelling
  - Both peaks:  $-2 \Delta L \sim 11$  with  $\mu$  fixed

$\Delta\ell=10$  $\Delta\ell=20$  $\Delta\ell=50$  $\Delta\ell=100$ 

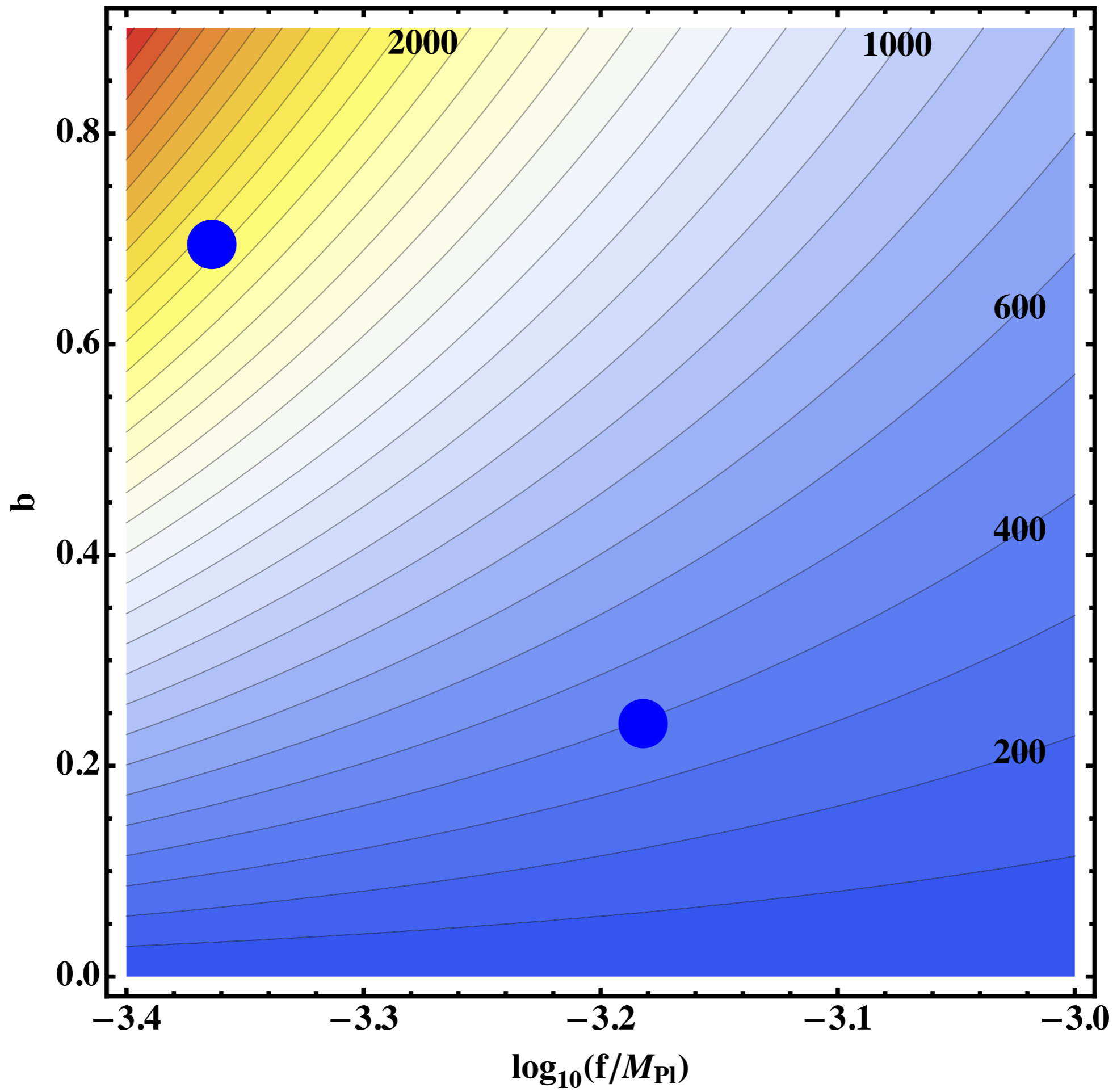
Locating the improvement...

$$\Delta\chi^2_{\text{eff}} \approx -19$$

# Non-Gaussianity

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- Resonant non-Gaussianity
  - Chen, Easther and Lim - arXiv:0801.3295
  - Generated *inside* the horizon
  - Considered generic interaction terms for 3-point function
- Monodromy
  - Flauger, McAllister, Pajer, Westphal and Xu
  - Detailed look at non-Gaussianity (also Flauger and Pajer)
  - Little “overlap” with standard shapes; not constrained



# Summary...

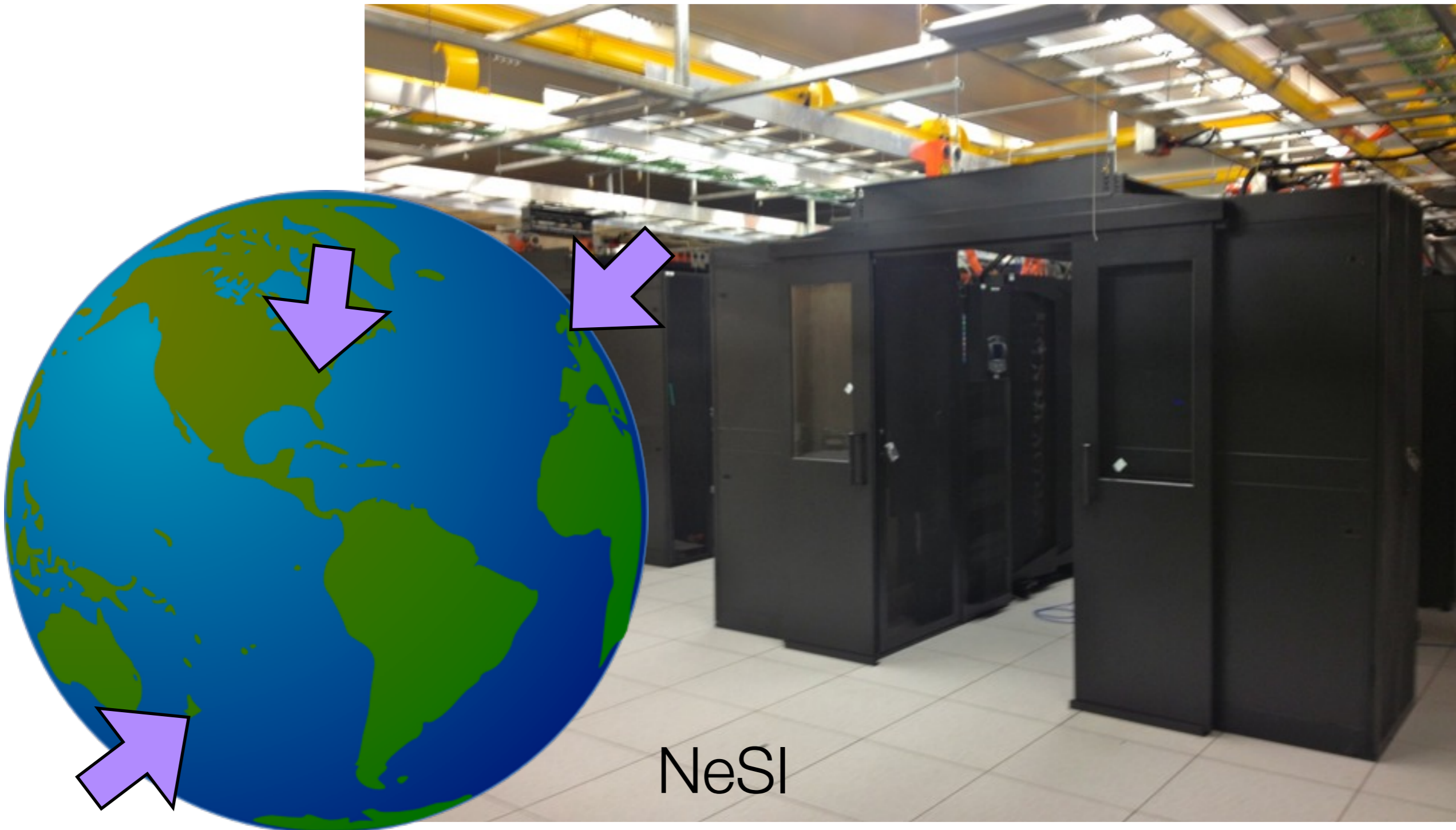
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- Large, high frequency oscillation seen in WMAP9
  - Similar analysis by Planck; but not at this frequency
- Larger than most “anomalies”
  - But not compelling
  - And even if it is “real”, it could be a systematic
- Interesting model, interesting problem...



# Thanks

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