Optimizing the Search for Features in the Primordial Power Spectrum

Julius Wons

In Collaboration with Jan Hamann

The University of New South Wales

UNSW SYDNEY

ΛCDM Summary

- Cosmological constant + cold dark matter

→Explains cosmological events (BBN, recombination, …)

ΛCDM Summary

- Cosmological constant + cold dark matter

→ Explains cosmological events (BBN, recombination, …)

- Discovery of CMB

→ Problems for ΛCDM

Initial value problems no addressed (Horizon, Flatness, …)

ΛCDM Summary

- Cosmological constant + cold dark matter

→ Explains cosmological events (BBN, recombination, …)

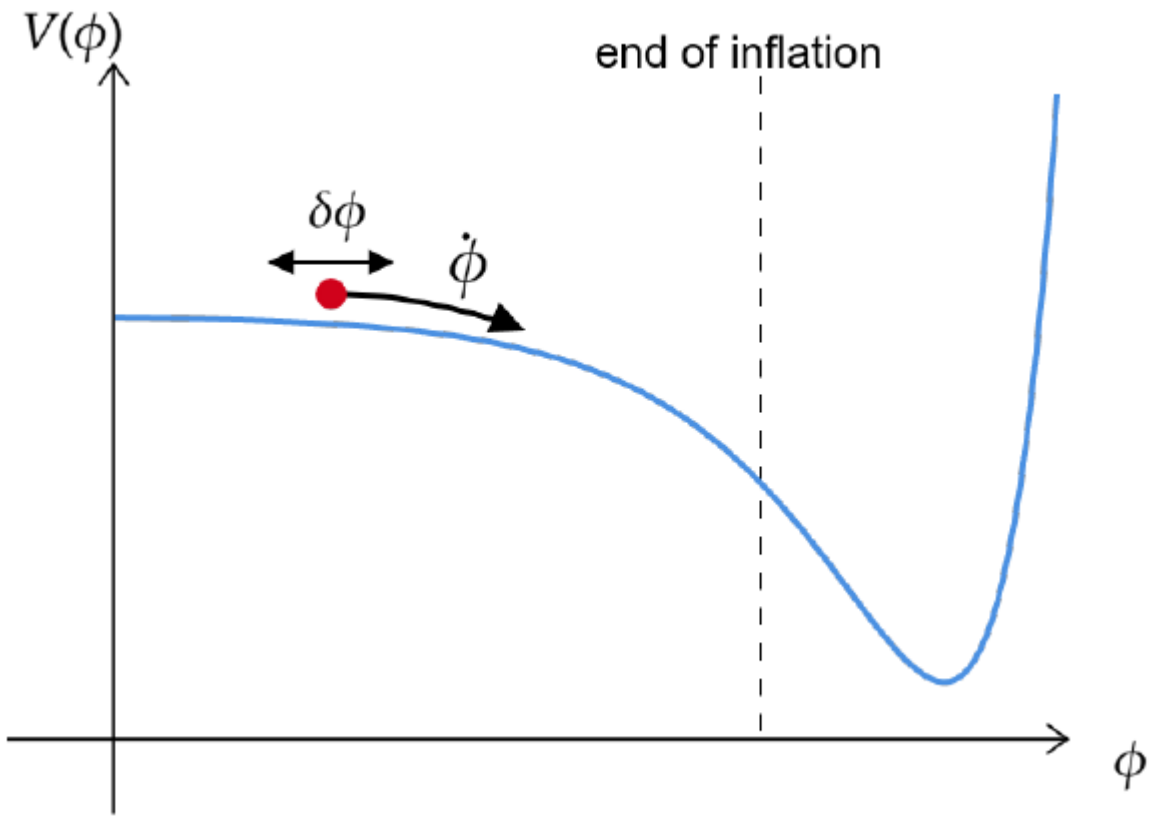
- Discovery of CMB

→ Problems for ΛCDM

Initial value problems no addressed (Horizon, Flatness, …)

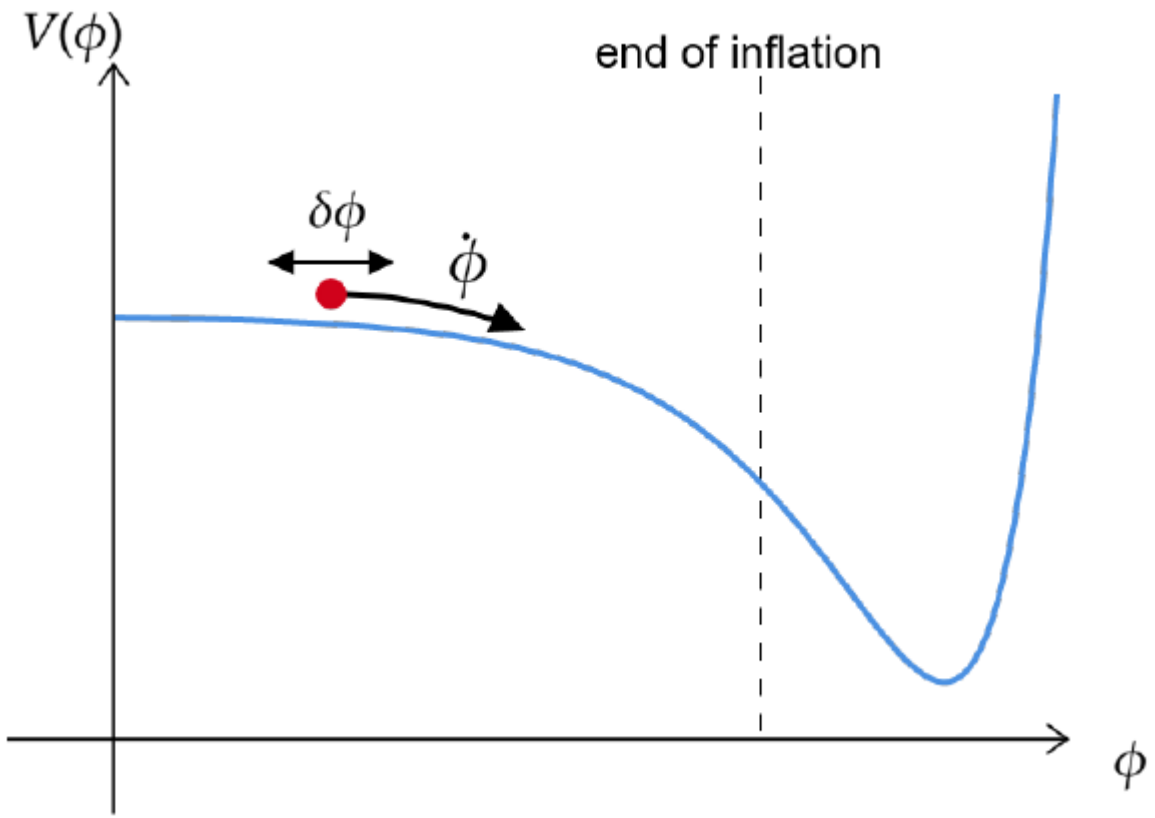
Inclusion of Inflation into Standard Model

Single-Field Slow-Roll (SFSR) Inflation



- Scalar field slowly rolling down potential

Single-Field Slow-Roll (SFSR) Inflation

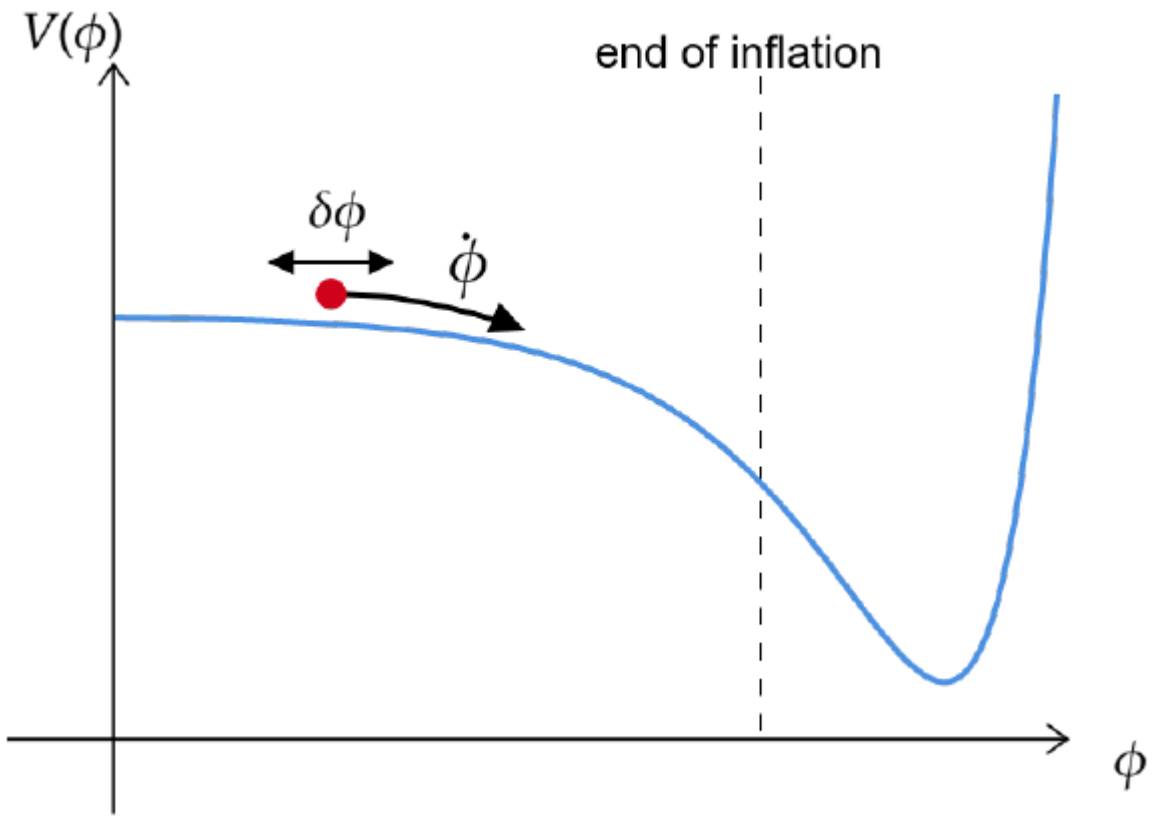


- Scalar field slowly rolling down potential

→ Exponential expansion

→Solution to initial value problems

Single-Field Slow-Roll (SFSR) Inflation



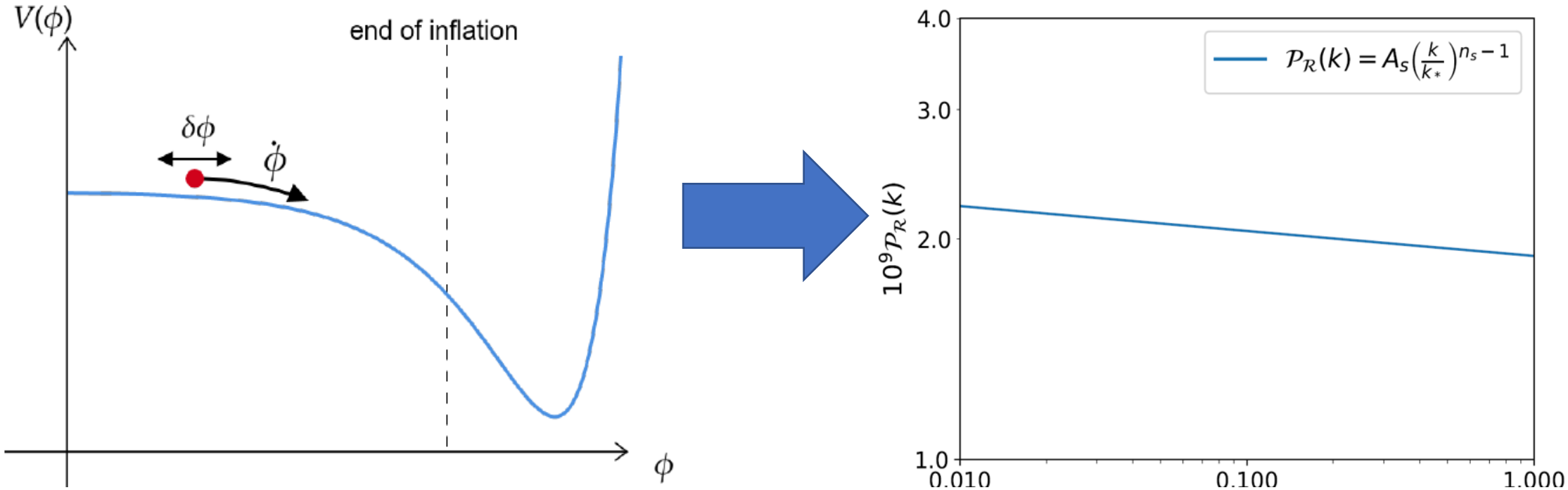
- Scalar Field slowly rolling down potential

→ Exponential expansion

→Solution to initial value problems

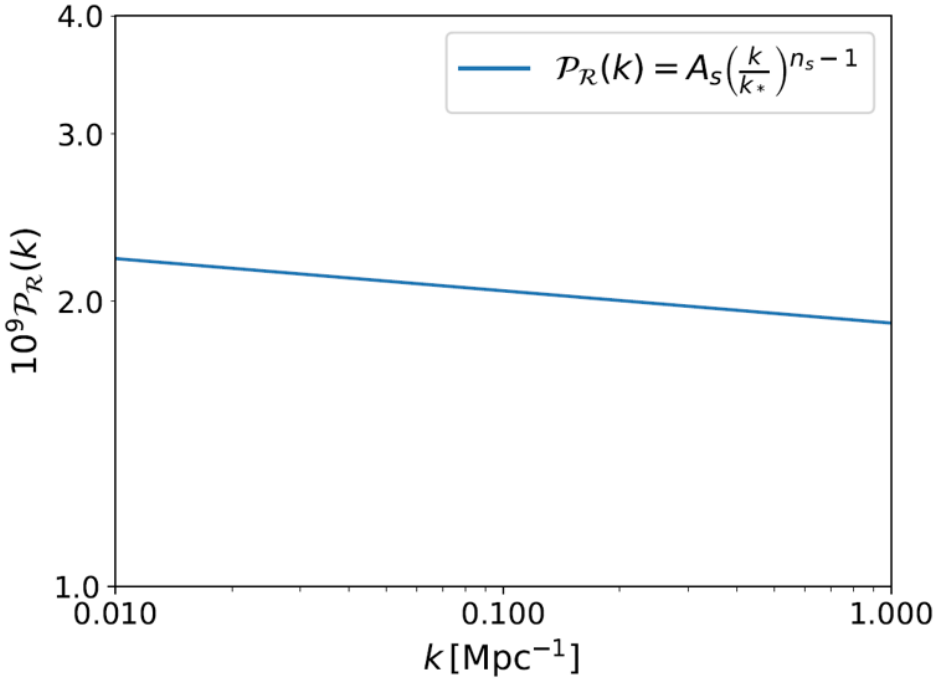
- Quantum fluctuations of scalar field predicted inhomogenities in CMB

Simple Prediction from SFSR Inflation



Primordial Power Spectrum to CMB

End of Inflation

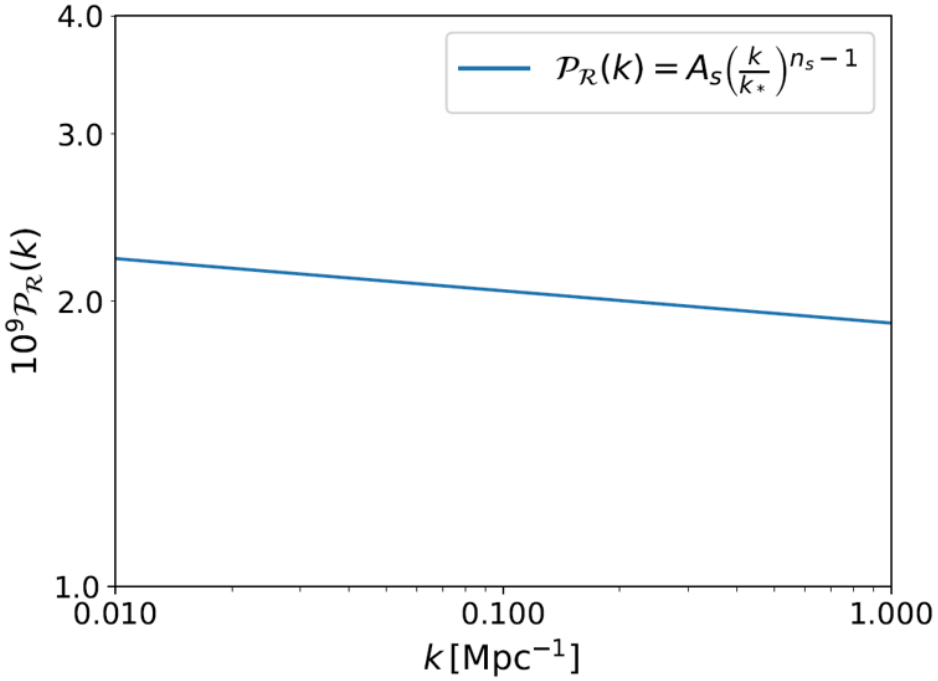


Primordial Power Spectrum

Today?

Primordial Power Spectrum to CMB

End of Inflation

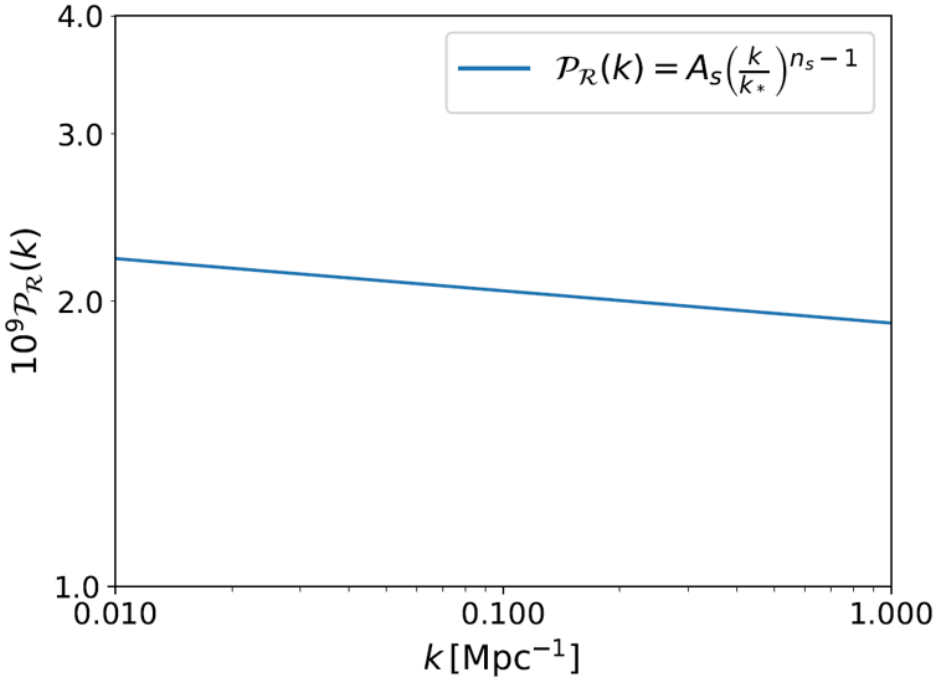


Primordial Power Spectrum

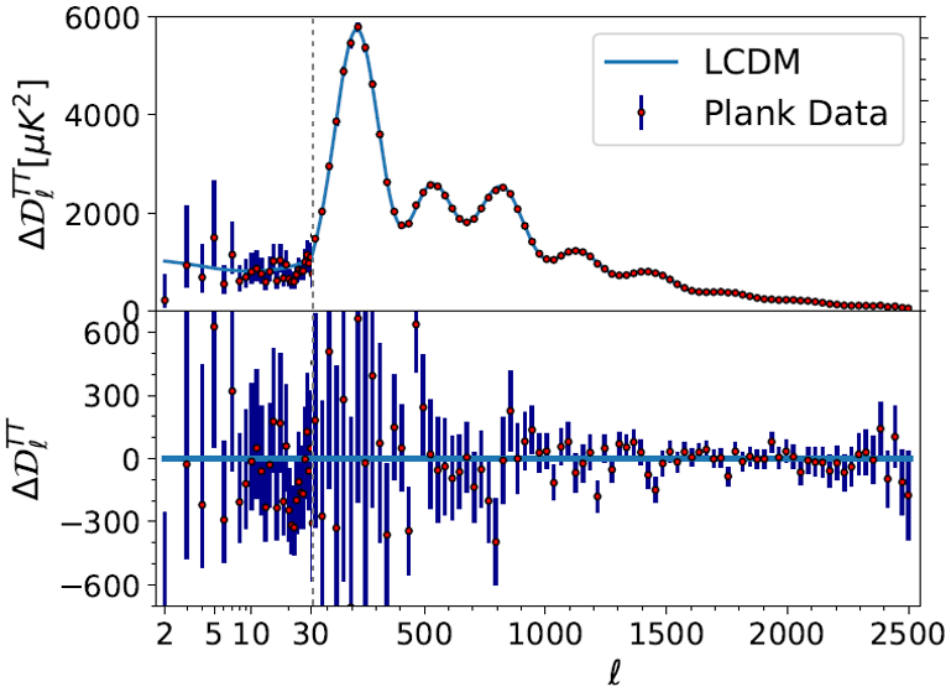
Transfer Function

Today?

Primordial Power Spectrum to CMB



Transfer Function



Primordial Power Spectrum

CMB Spectrum (Temperature)

Going Beyond Single-Field Slow-Roll

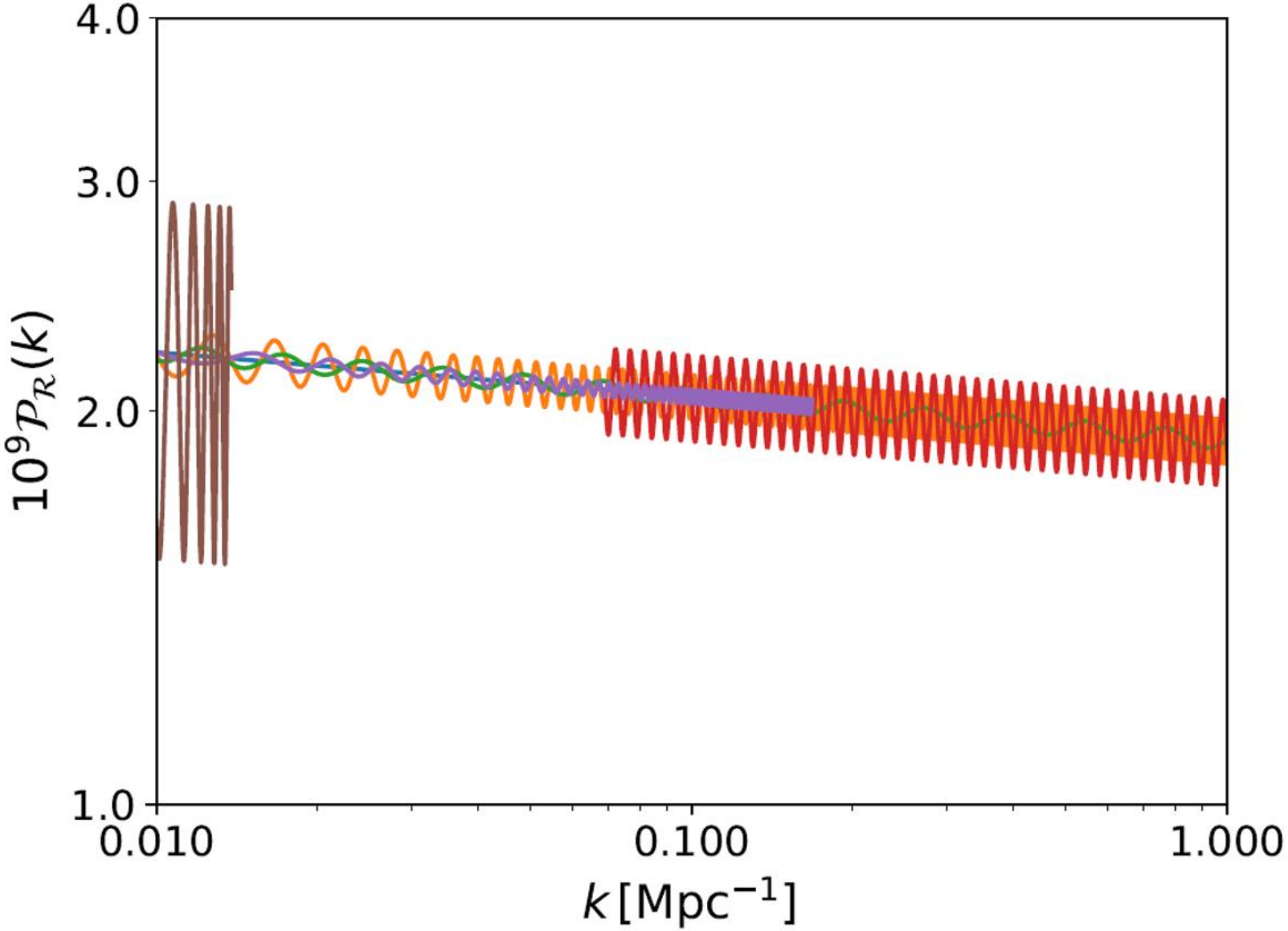
- What if there are multiple fields?
- What if the potential is more complicated?

Going Beyond Single-Field Slow-Roll

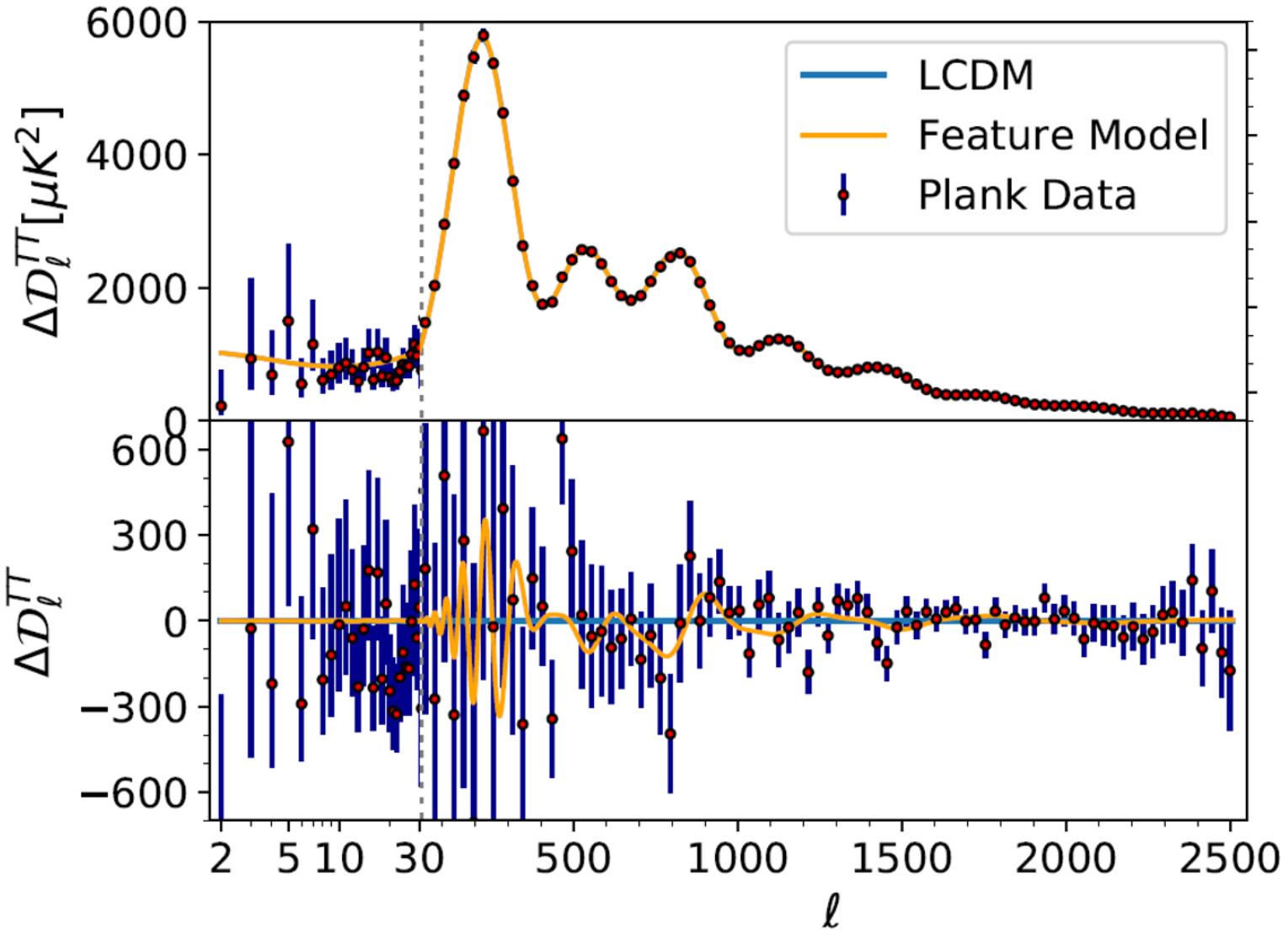
- What if there are multiple fields?
- What if the potential is more complicated?

→Study of Features in the Power Spectrum / Beyond SFSR Inflation

Features in the Primordial Power Spectrum



Features in the CMB Spectrum



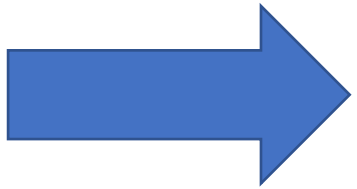
Transfer Function

- Transfer function smooths features out
- Fast oscillation in primordial power spectrum,

  But slower oscillation in CMB

Transfer Function

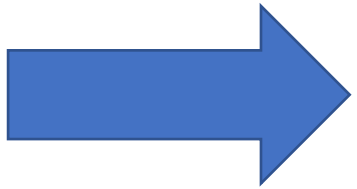
- Transfer function smooths features out
- Fast oscillation in primordial power spectrum,
  But slower oscillation in CMB



Features have “reduced” imprint on CMB Spectrum

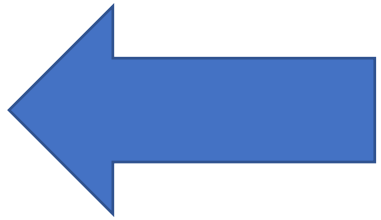
Transfer Function

- Transfer function smooths features out
- Fast oscillation in primordial power spectrum,
  But slower oscillation in CMB



Features have “reduced” imprint on CMB Spectrum

More difficult to identify feature models from CMB



Data Analysis

Data Analysis

Bottom-Up or Top Down?

Data Analysis

Bottom-Up or **Top Down**?

$$\mathcal{P}_{\mathcal{R}}^{X}(k) = \mathcal{P}_{\mathcal{R}}^{0}(k)[1 + \mathcal{A}_X \cos(\omega_X \Xi(k) + \varphi_X)]$$

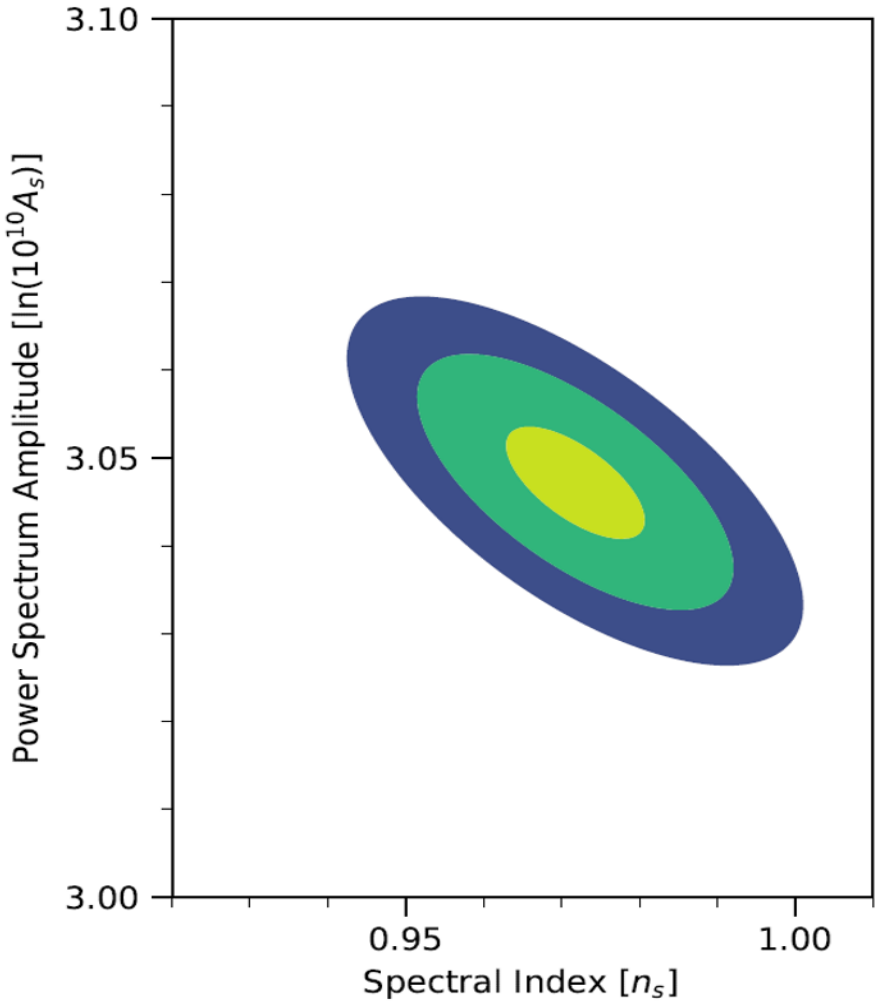
Example: $\Xi_{\log} \equiv \ln \frac{k}{k_*}$

CosmoMC

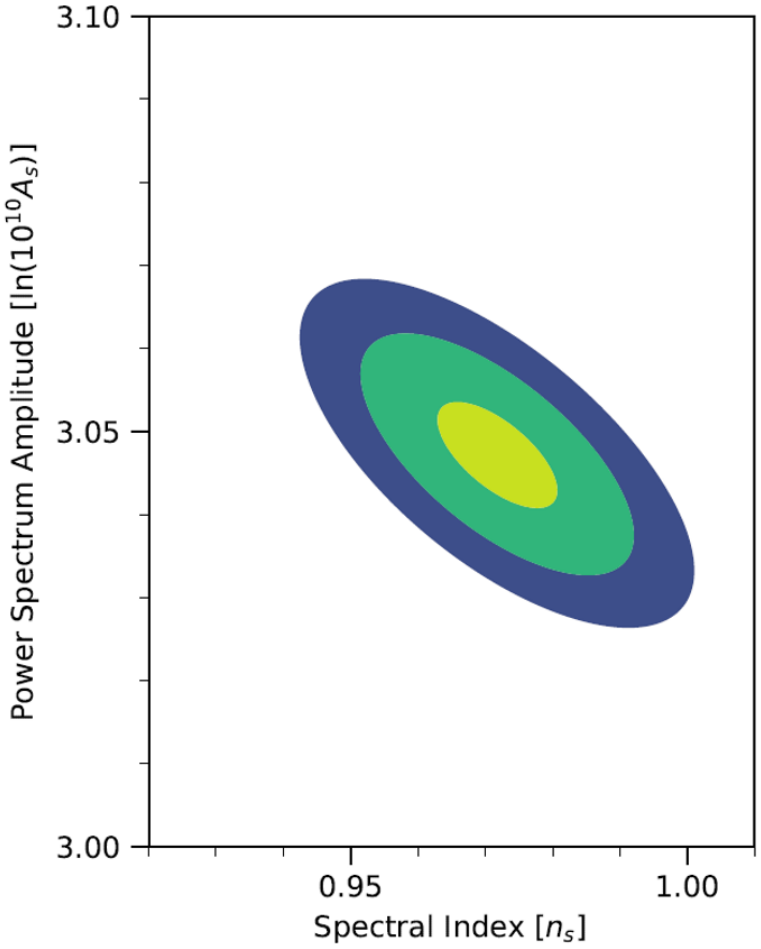
- Markov-Chain Monte-Carlo (MCMC) Sampler
- Powerful algorithm to interfer large dimensional parameters space
- Struggles with likelihoods with mutliple maxima

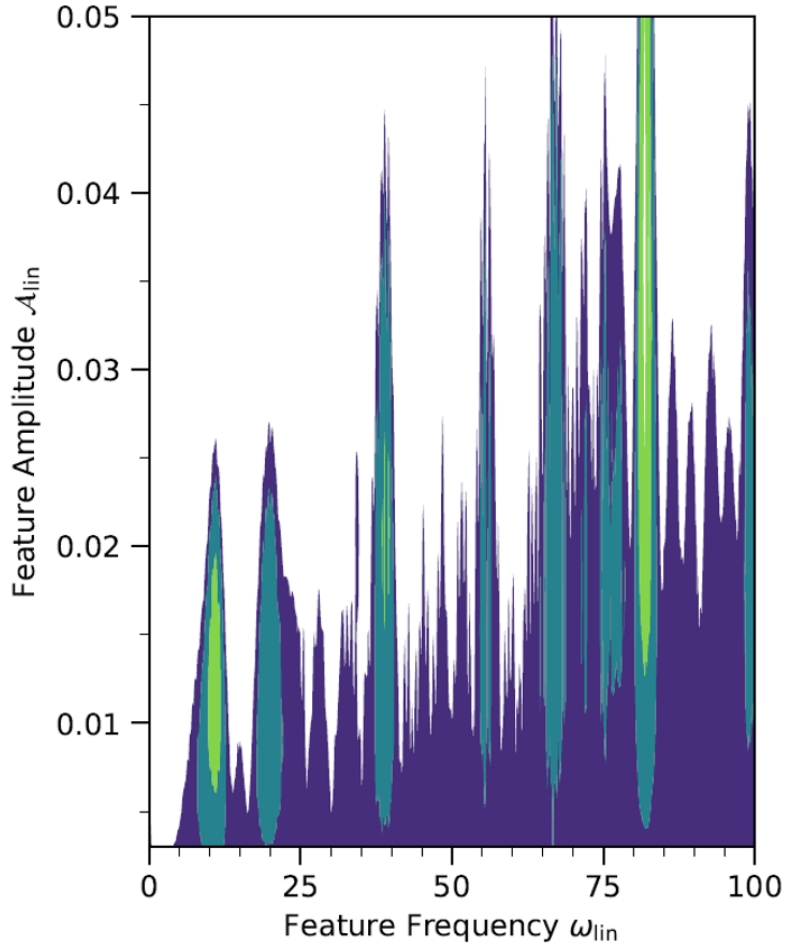
Likelihood profile of two standard cosmology parameters

- One maximum
- Convex



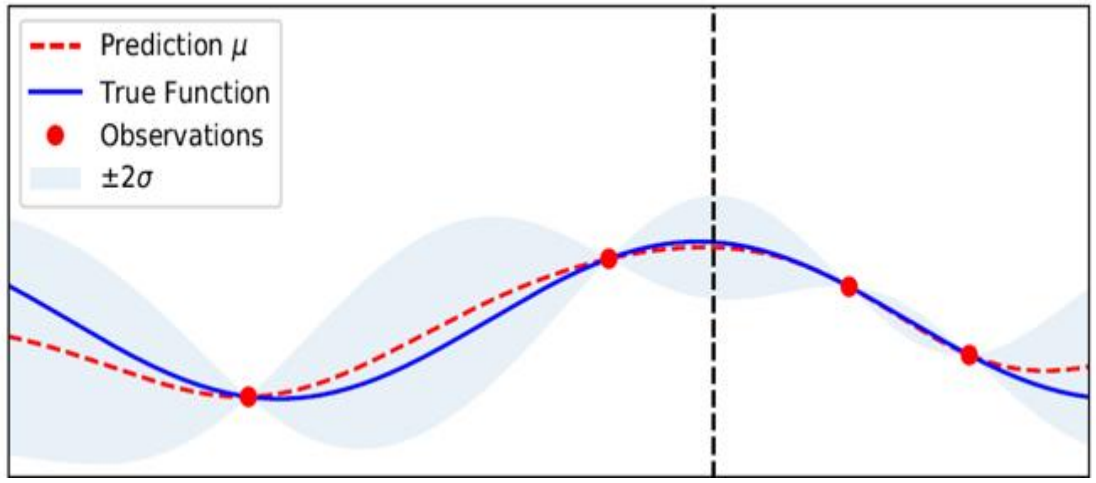
Likelihood profile of Feature Parameters





Bayesian Optimisation

Gaussian Process Regression



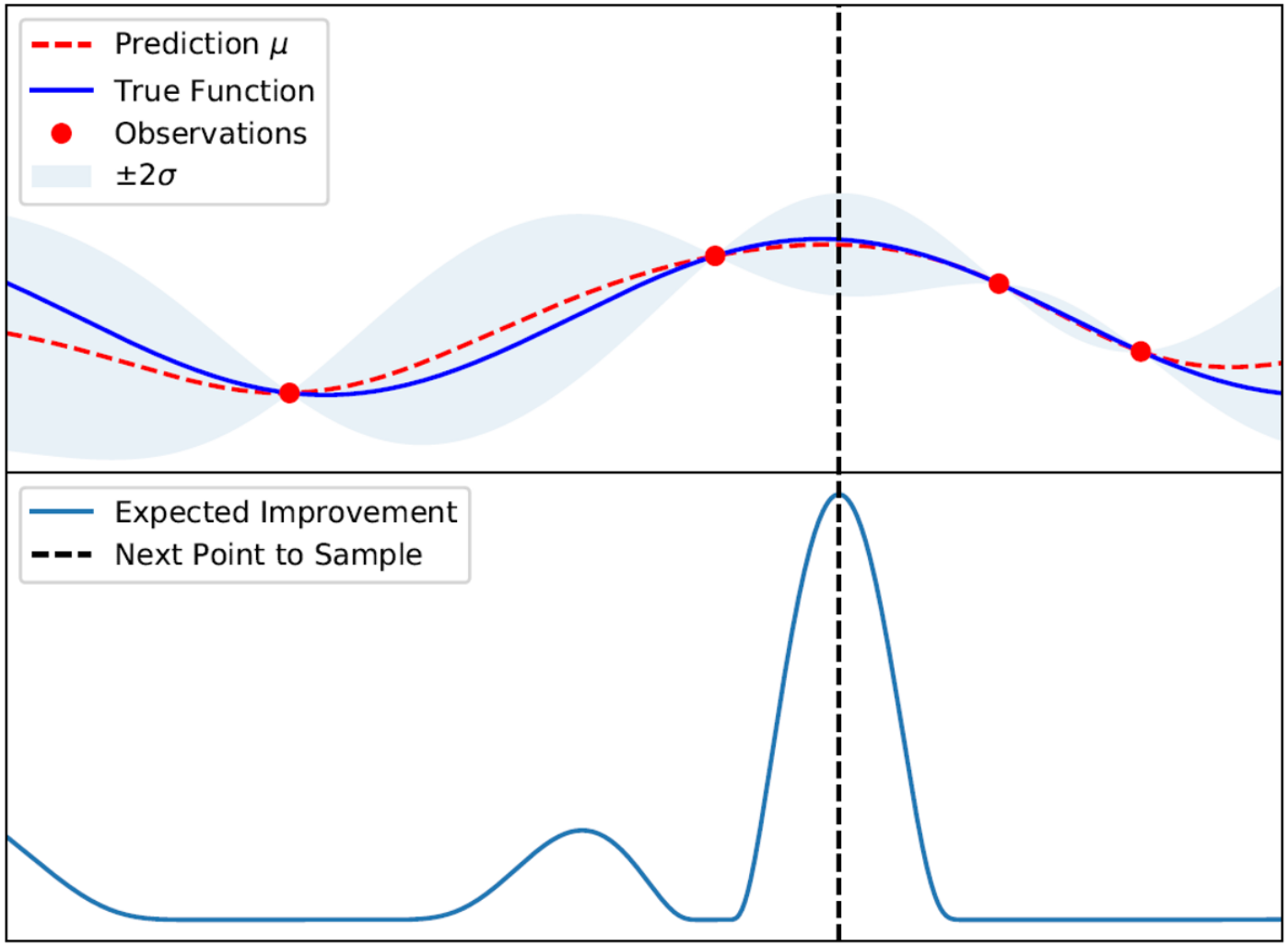
- Non-parametric regression

→No template for function needed

Returns:

Expectation value

+ Uncertainty

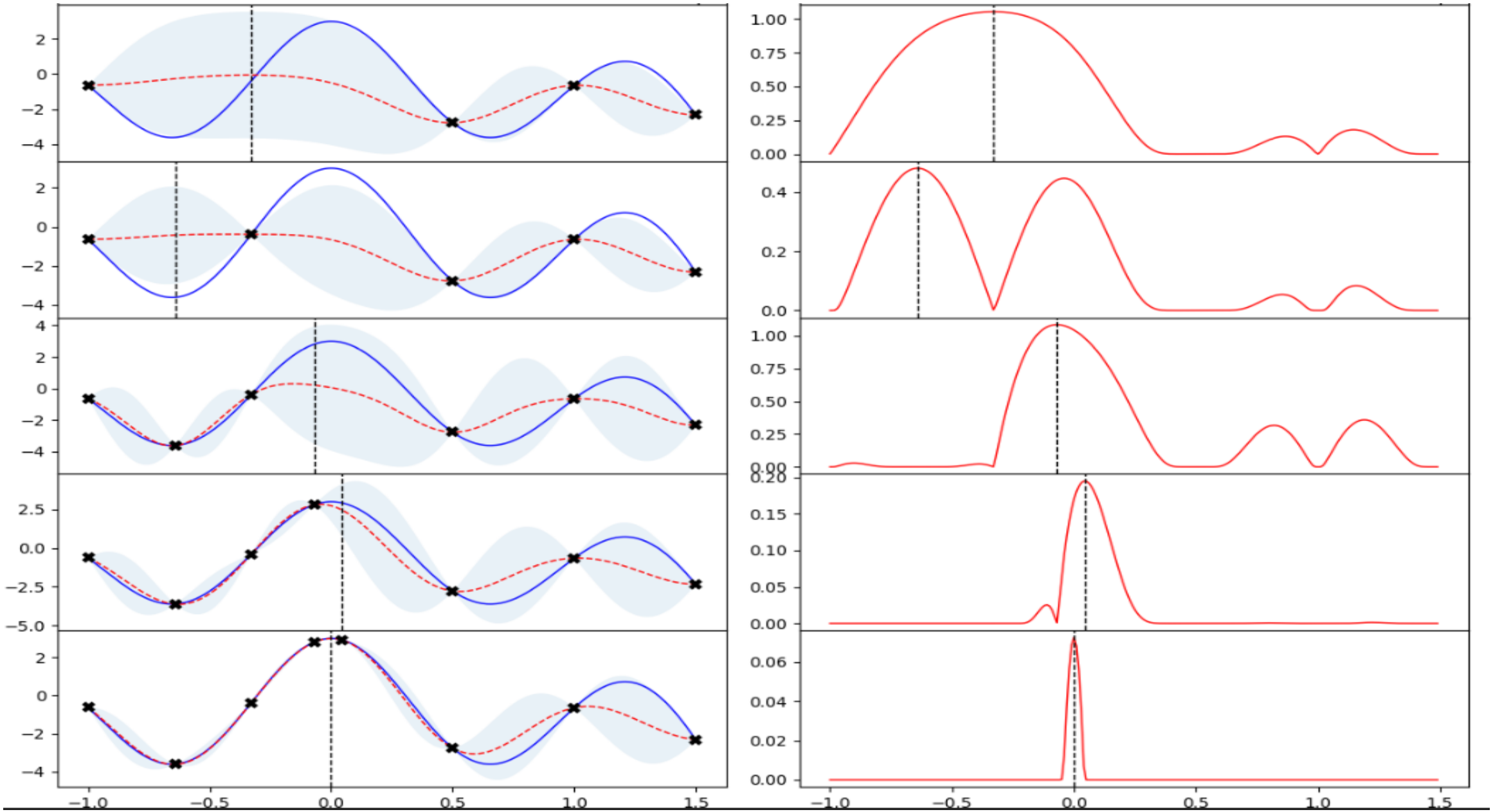


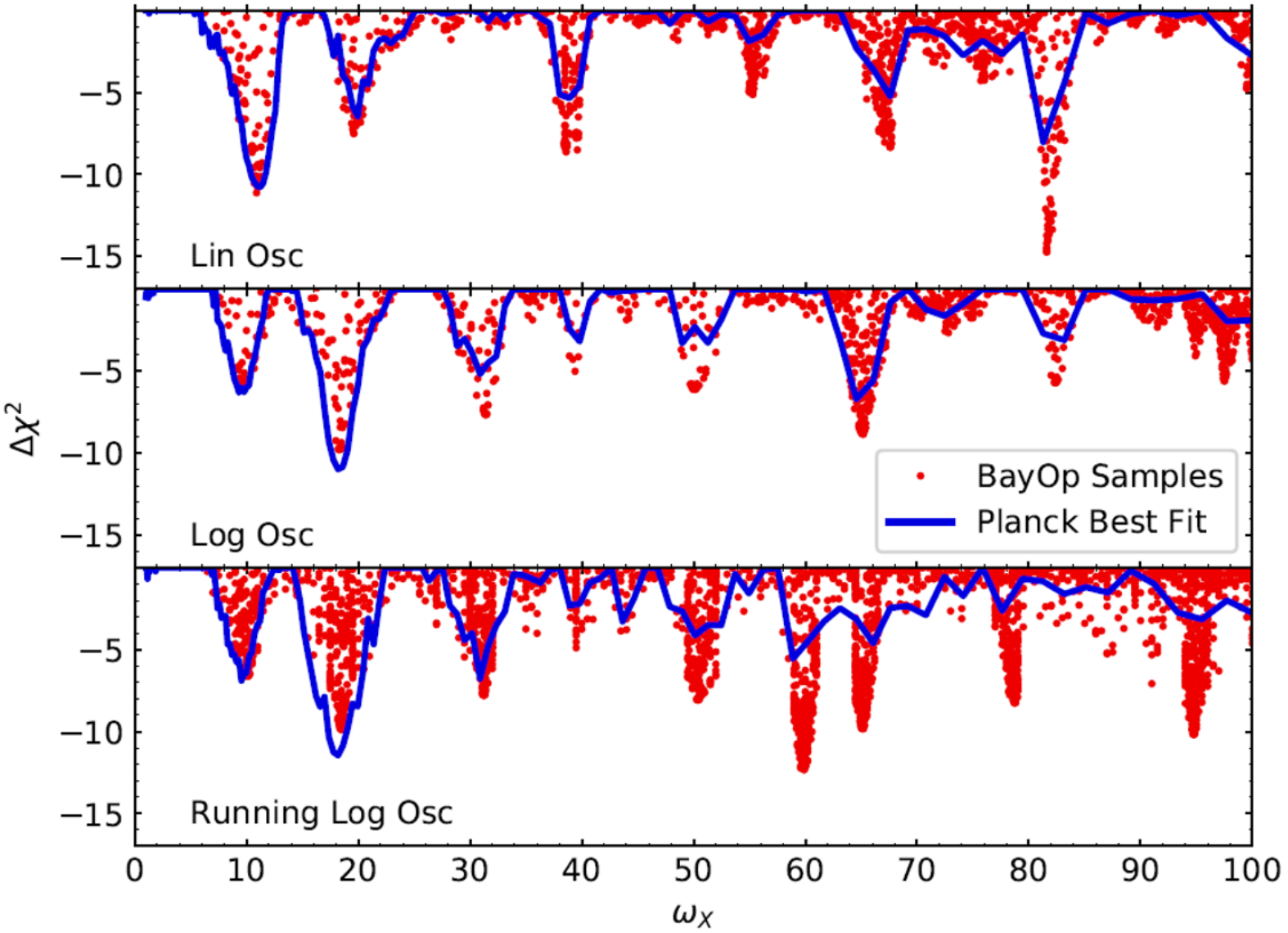
Expected Improvement

- Compare expectation value and uncertainty to best data point
- If grey area is above best point, we expect improvement

Gaussian Process Regression

Expected Improvement





Comparison of Likelihood Profile for different Feature Models

CosmoMC vs. BayOp

- MCMC not reliable
- Global Maximum not found in 2 out of 3 cases

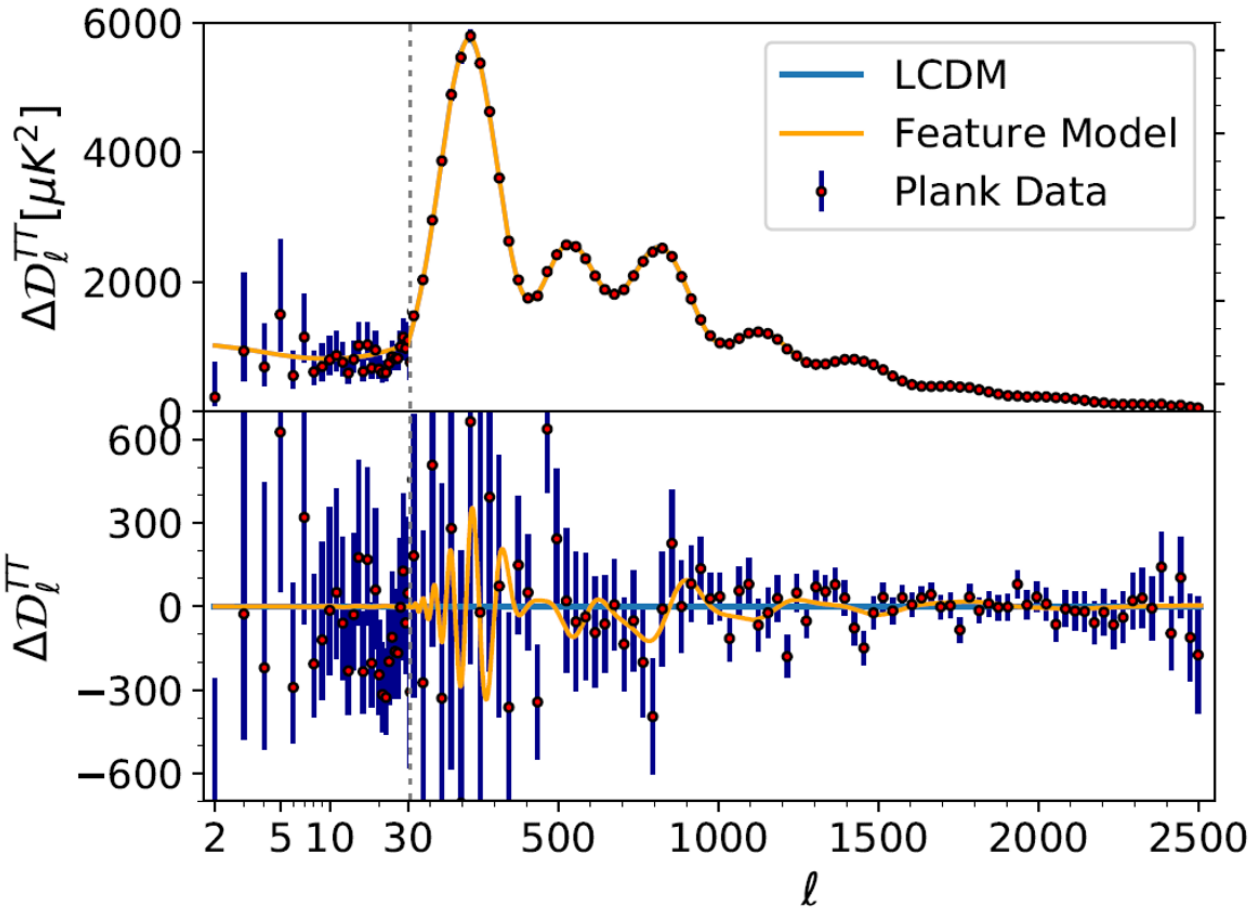
Advantages & Disadvantages of BayOp

+ Analyses complicated parameter directions
+ Fast and confident results
+ More complicated models can be analysed

Advantages & Disadvantages of BayOp

+ Analyses complicated parameter directions
+ Fast and confident results
+ More complicated models can be analysed

- Bad scaling for higher dimension (like all global optimisation schemes)



- Scale of Effect of Feature Parameter small compared to scale of ΛCDM parameter effect
- Baryonic Acoustic Oscillation scale a lot smaller than feature oscillations

 Analyse parameters separately

- Paper will be on the Arxiv soon
- Code will be available publicly soon (implemented into CosmoMC)
- Your model of inflation can be compared to the data fast and easy

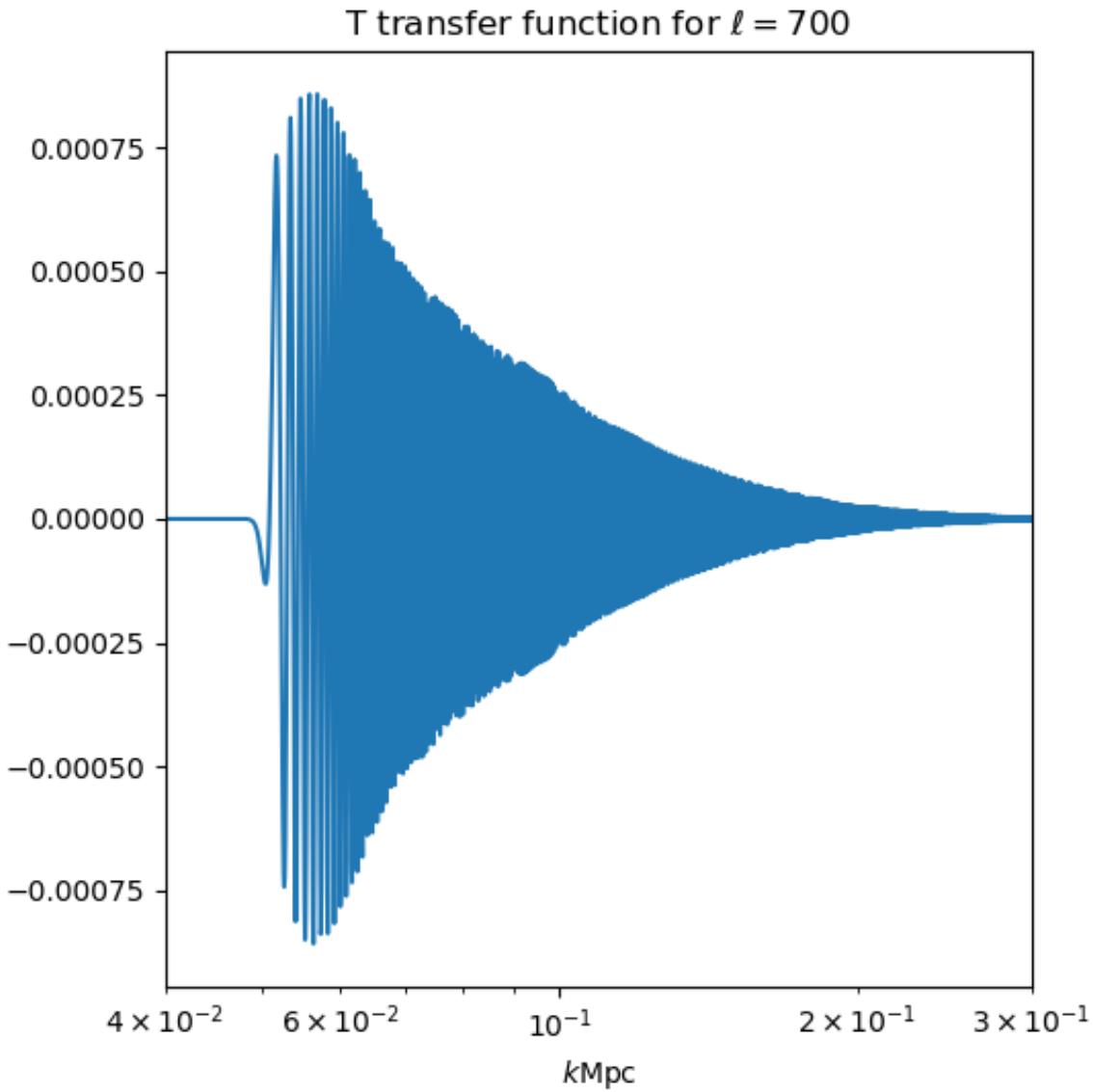
Future of Features

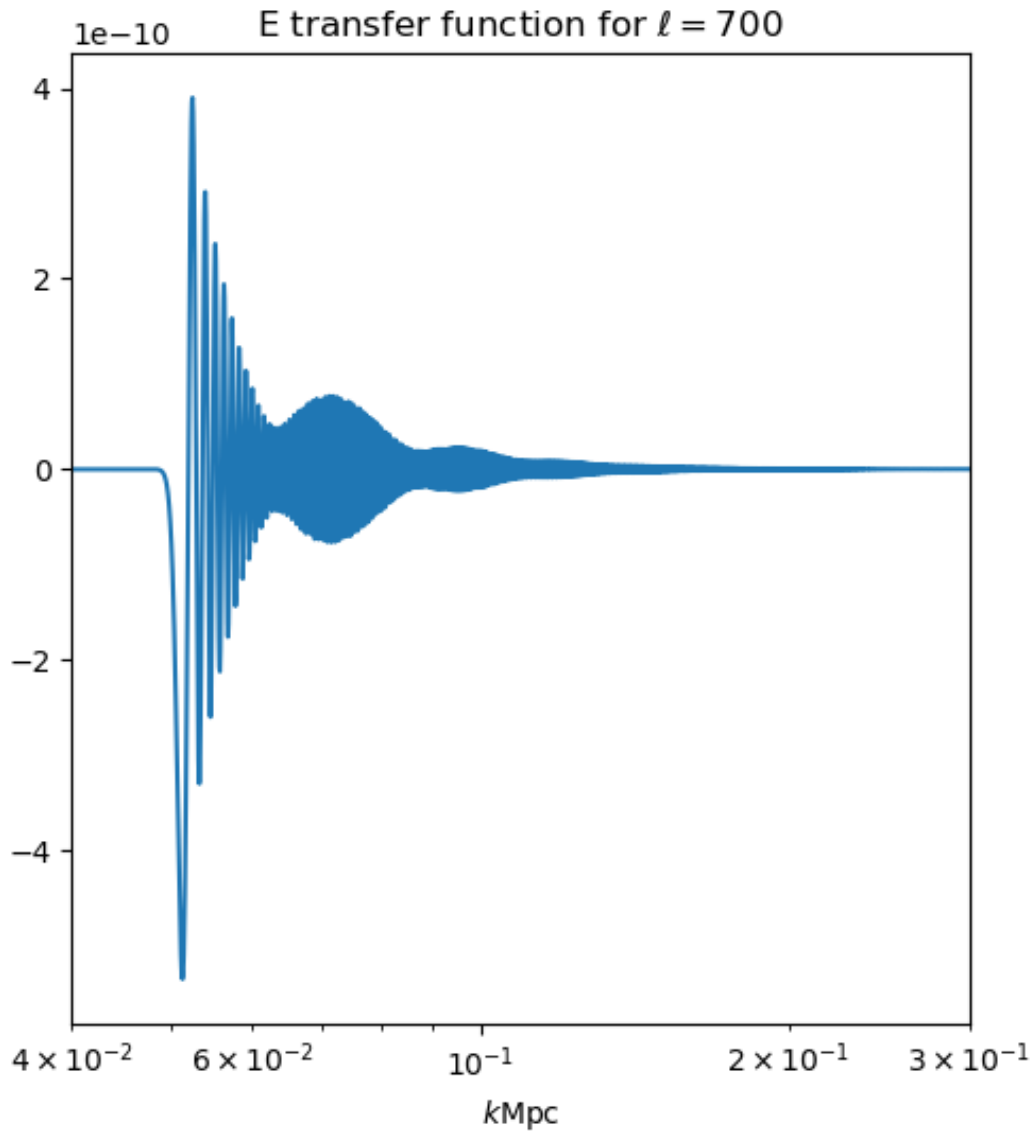
- Simple power law is still best guess for primordial power spectrum
  → Need better data, smaller error bars

- Temperature data is at cosmic Variance limit,
  but Polarization Data can be improved (LiteBird, CMB S4)
  → Polarization data more sensible to features

- Large scale structure surveys also improve sensitivity (LSST, Euclid)

Back Up Slides


T transfer function for $\ell = 700$
0.00075
0.00050
0.00025
0.00000
−0.00025
−0.00050
−0.00075
4×10^{-2}
6×10^{-2}
10^{-1}
2×10^{-1}
3×10^{-1}
kMpc


E transfer function for $\ell = 700$
1e−10
4
2
0
−2
−4
4×10^{-2}
6×10^{-2}
10^{-1}
2×10^{-1}
3×10^{-1}
kMpc

Expected Improvement

$$\mathrm{EI}(x) = \left(\mu(x) - \mu_+ - \xi\right)\Phi(Z) + \sigma(x)\phi(Z)$$

$$Z = \begin{cases} \frac{\mu(x)-\mu_+-\xi}{\sigma(x)} & \text{if} \quad \sigma(x) > 0\,, \\ 0 & \text{if} \quad \sigma(x) = 0\,, \end{cases}$$

- Expectation value and uncertainty are used to find best point to sample next