Bayesian reconstruction of the inflaton's speed of sound using CMB data

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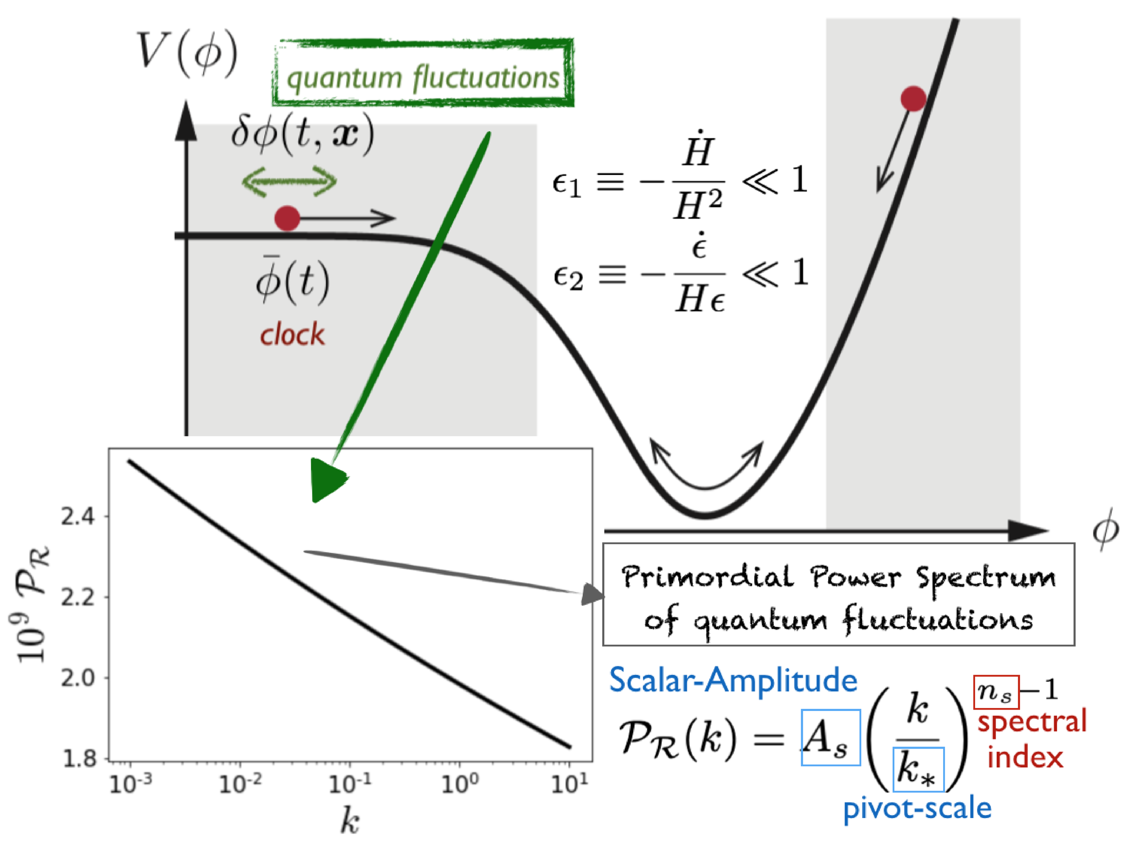
1. The Standard Model of Cosmology

- **ΛCDM**: our universe contains Cold Dark Matter and Dark Energy Λ, and is compatible with the simplest inflationary scenario: canonical Single-Field slow-roll inflation.
- **Slow-roll Single-field inflation**: period of accelerated expansion in the early universe $\to d^2a/dt^2 > 0$, with one degree of freedom ϕ, and slow-roll parameters ϵ_1 and $\epsilon_2 \ll 1$. .

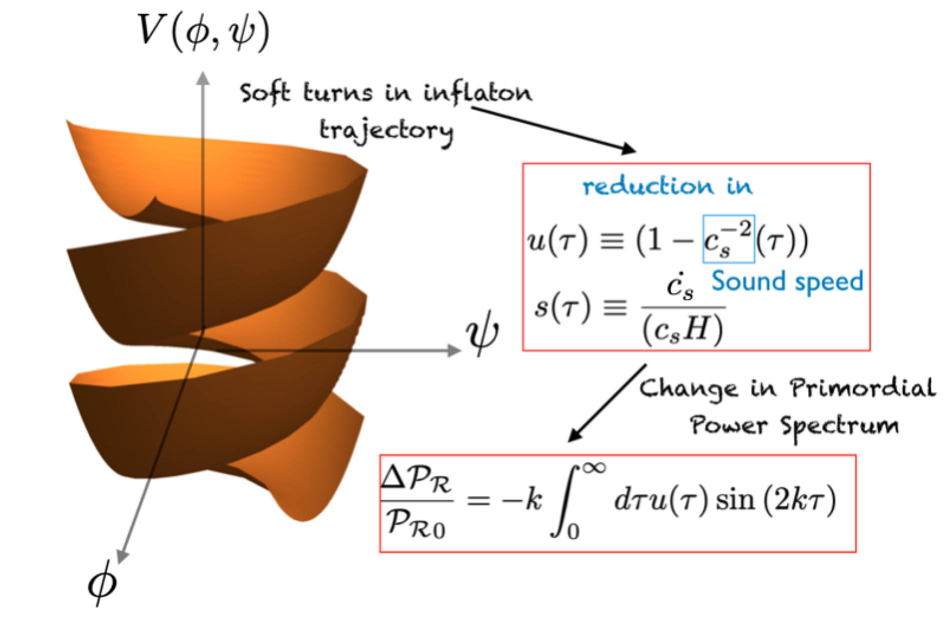


2. Effective Field Theory of inflation

EFT of inflation is used to describe the comoving curvature perturbations $\mathcal{R}$. The effective quadratic action (when c_s is small, transient and mild) is: $S_2 =$

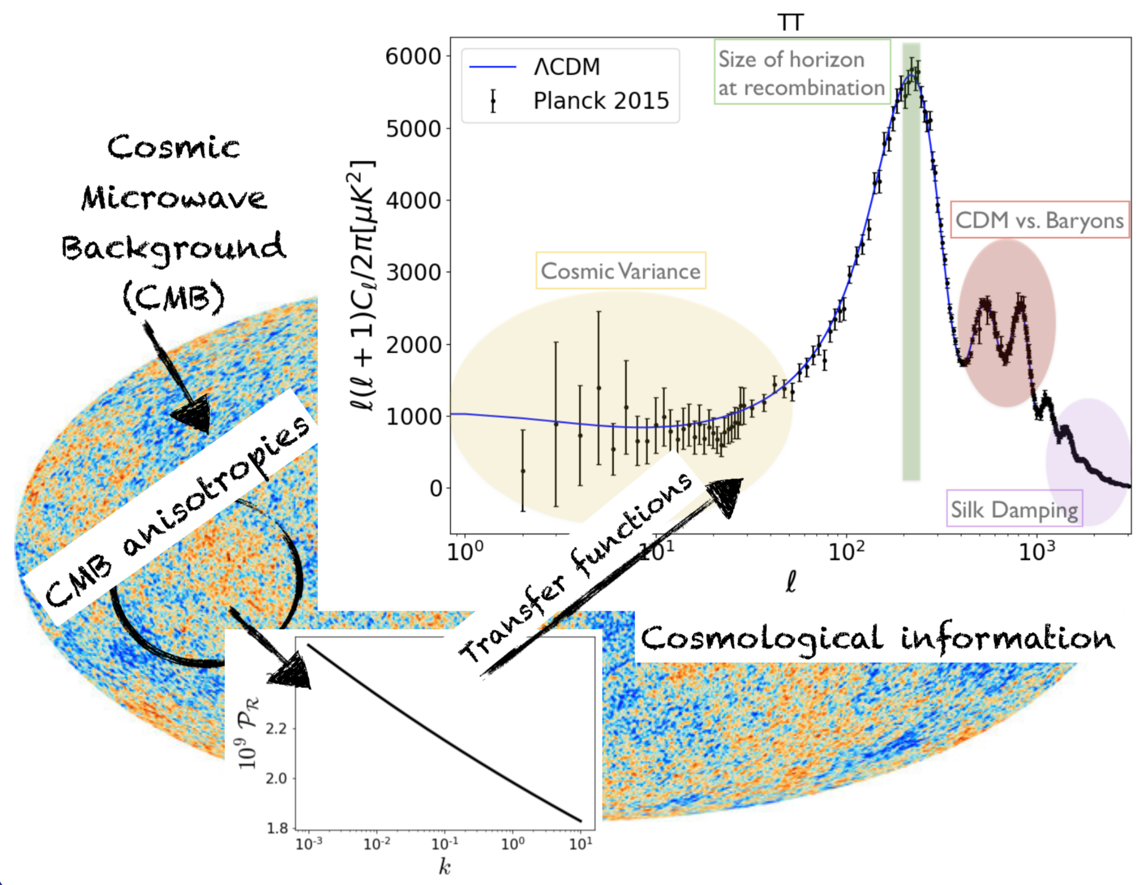
$$= \underbrace{\int d^4x a^3 M_P^2 \epsilon H^2 \left[\dot{\mathcal{R}}^2 - \frac{(\partial_i \mathcal{R})^2}{a^2}\right]}_{S_0 \text{ (Single-Field Inflation)}}$$

$$- \underbrace{\int d^4x a^3 M_P^2 \epsilon H^2 \left[\dot{\mathcal{R}}^2 (1 - c_s^{-2})\right]}_{S_{\text{pert}} \text{ (perturbation)}} .$$



The information of the background is encoded in primordial functions: $\epsilon_1(t), c_s(t), s(t)$...

3. Cosmological Data: CMB



4. Bayes' Theorem

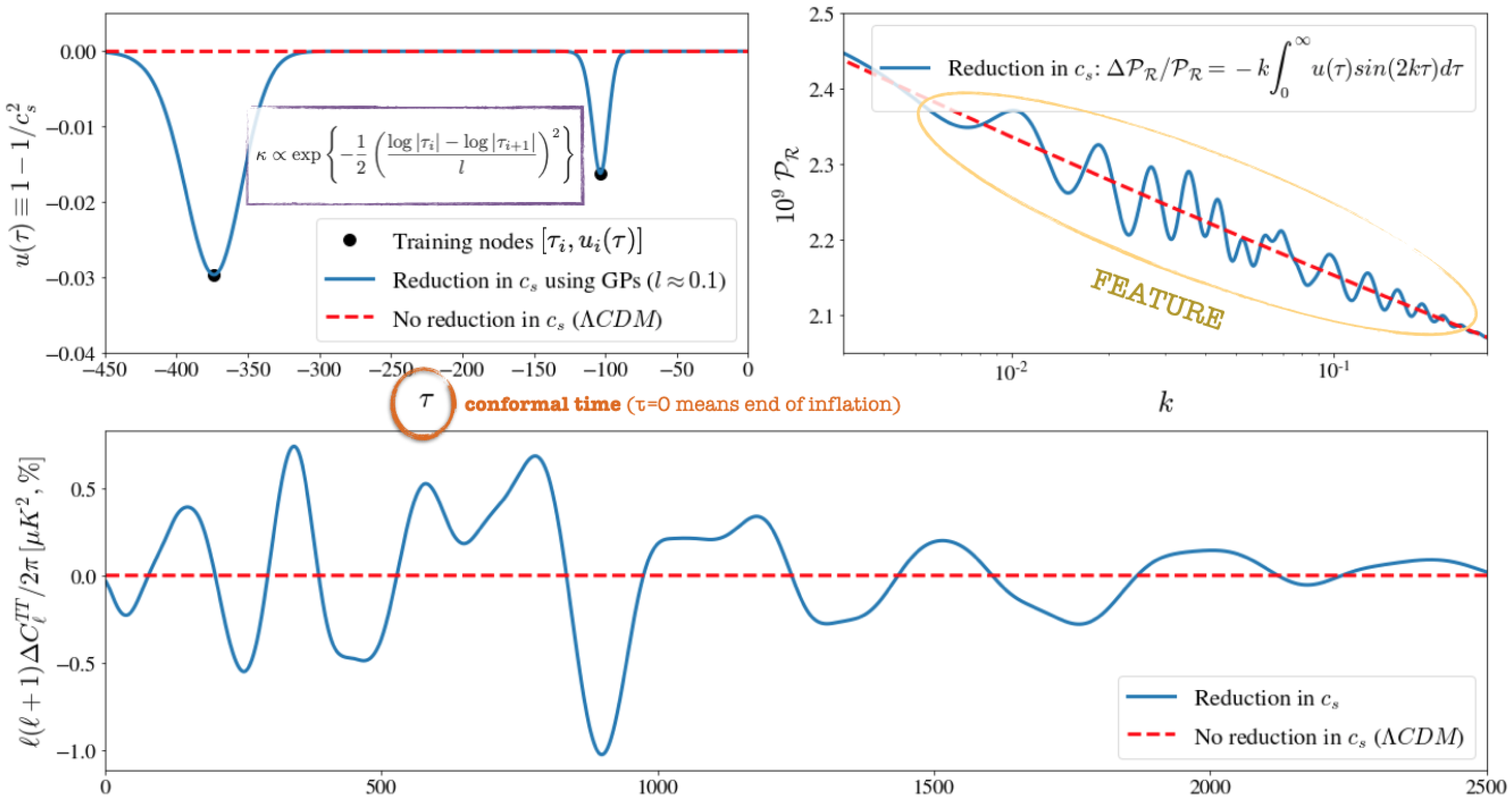
The probability distribution (***posterior***) of the parameters θ given the observed data d and a given model M:

$$P(\theta|d, M) \propto \mathcal{L}(d|\theta, M)\Pi(\theta|M). \quad (1)$$

- $\mathcal{L}(d|\theta, M)$ (***likelihood***): probability of observing the data d given the set of parameters θ and the model M.
- $\Pi(\theta|M)$ (***prior***): probability distribution of the parameters θ given some external information.

5. Reconstruction of the reduction in c_s using Gaussian-Processes

Gaussian Processes (GPs): non-linear and non-parametric **regression technique** based on a collection of random variables indexed by time or space, whose distribution is defined by a kernel.

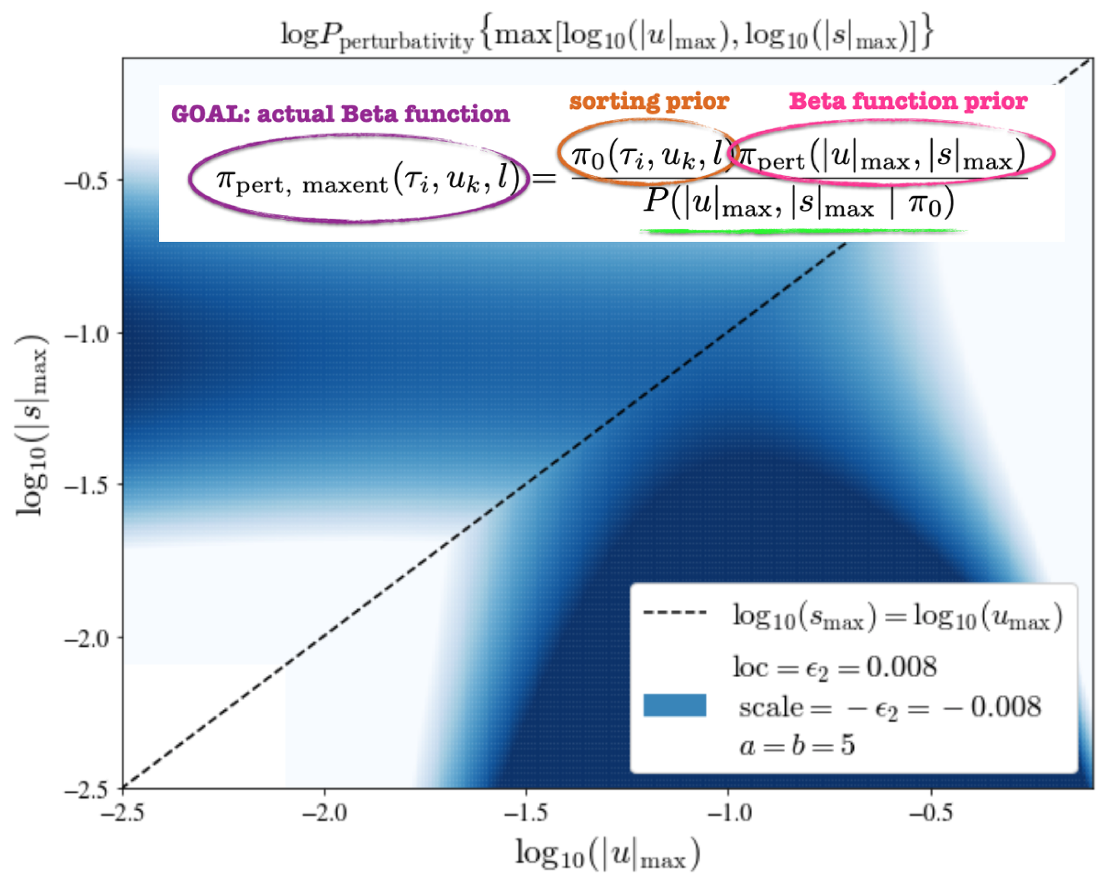


Upper-left: reconstruction of $u(\tau)$ using GPs with 2 training nodes and a Gaussian kernel κ with correlation length l.
Upper-right: corresponding feature in the primordial power spectrum $\mathcal{P}_\mathcal{R}$ from the reconstruction.
Bottom: difference in the CMB angular power spectrum of temperature anisotropies due to the feature.

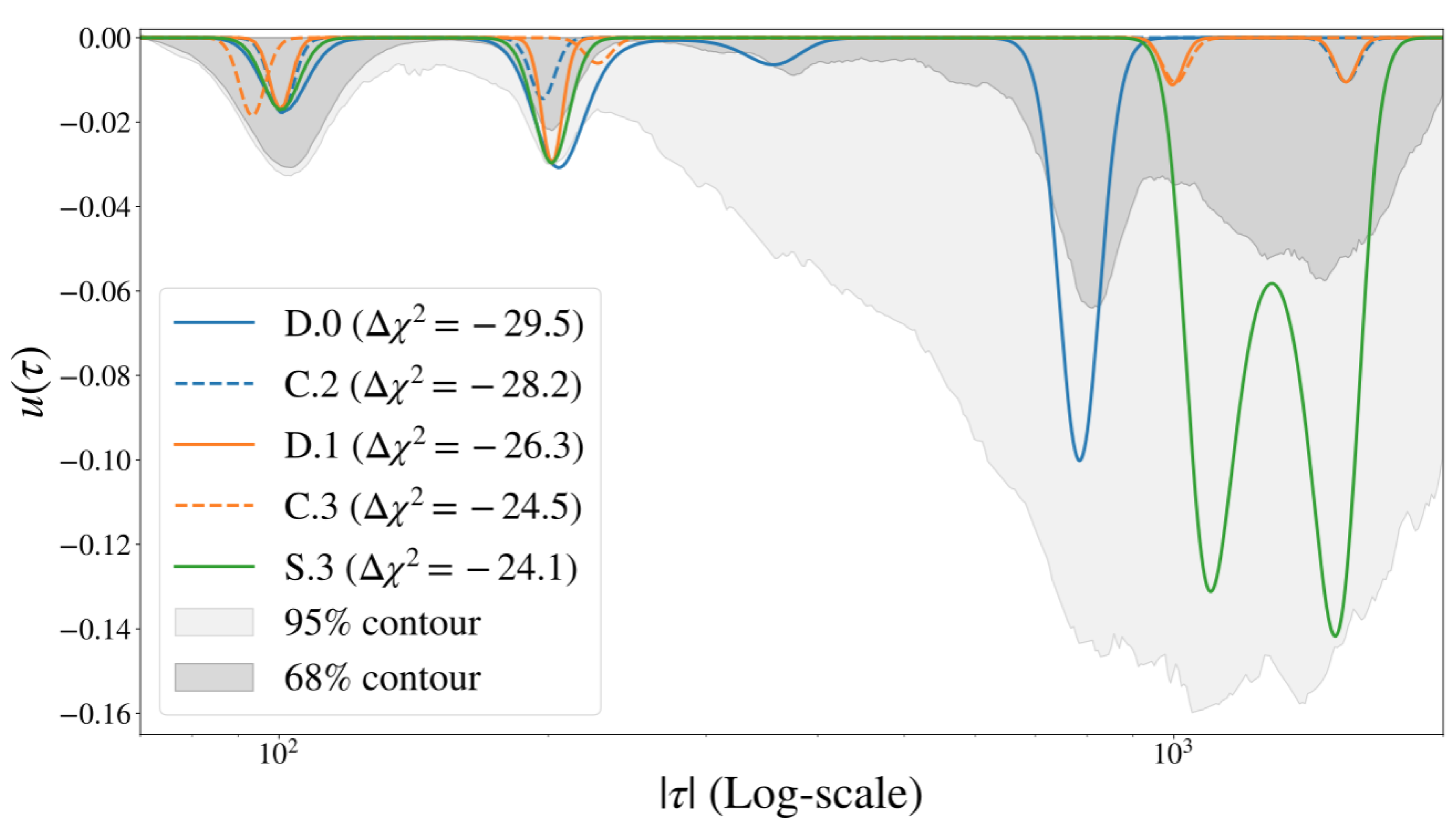
6. Priors

Parameters of the reconstruction of the inflaton's speed of sound profile $u(\tau)$ need to verify theoretical conditions:

1. Sorting condition on the number i of training nodes (uniform):
   $1.8 < \log_{10}(|\tau_i|) < \log_{10}(|\tau_{i+1}|) < 3.3$;
   $-4 < \log_{10}(|u_i|) < 0$.
2. Correlation length l (uniform):
   $-2 < \log_{10} l < 2$.
3. Theoretical prior on EFT parameters:
   $max(\epsilon_1, \epsilon_2) \ll max(|u|_{max}, |s|_{max}) \ll 1$.
4. Impose a Beta distribution on $(|u|_{max}, |s|_{max})$ as prior using Maximum Entropy principle:



7. Methodology



1. **Goal**: Sample the posterior distribution of the parameters of interest.
2. **Parameters**: Cosmological and perturbativity ones $(\tau_i, u_i(\tau), s)$.
3. **How**: Bayesian tool COBAYA and the sampling algorithm POLYCHORD.
4. **Theory Code**: CAMB (modified accordently).
5. **Data**: Planck Release 3 (2018) likelihoods `lowℓ` + `plikHM_TTTEEE_unbinned` + `lensing`.
6. **Computation**: 16 MPI processes and 8 cores each.

8. Conclusions

- Tested feature templates not analyzed by Planck Collaboration. Interesting reductions are found but not significative.
- Analysis pipeline is modular, flexible and robust. Easily extendable to other observables (i.e: Large Scale Structure).
- Possible reductions of the inflaton's speed of sound are crucial to give a prediction of the whole bispectrum (3-point correlation function) and increase statistical significance.