BAYESIAN MODEL SELECTION OF INFLATIONARY MODELS USING THE CONNECT EMULATION FRAMEWORK

Based on the article

"Calculating Bayesian evidence for inflationary models using CONNECT"

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CONTENT

- A short introduction to inflation and Bayesian Model Selection
- Setup and Workflow
- Comparison of a computation with and without a neural network
- Comparison of different inflationary models
- Conclusion

A SHORT INTRODUCTION TO INFLATION

- Takes place in the very early universe
- Universe expands with speed faster than light
- Multiple possible theoretical models

BAYESIAN MODEL ESTIMATION

- Based on Bayes Theorem
- Prior, likelihoods, posteriors, and evidence
- Bayes Factor and Jeffrey's Scale

$$P(\theta|d,\mathcal{M}) = \mathcal{L}(\theta)\frac{P(\theta|\mathcal{M})}{P(d|\mathcal{M})}$$

$$\mathcal{Z} = P(d|\mathcal{M}) \equiv \int_{\Omega_M} P(d|\theta,\mathcal{M})P(\theta|\mathcal{M})\mathrm{d}\theta$$

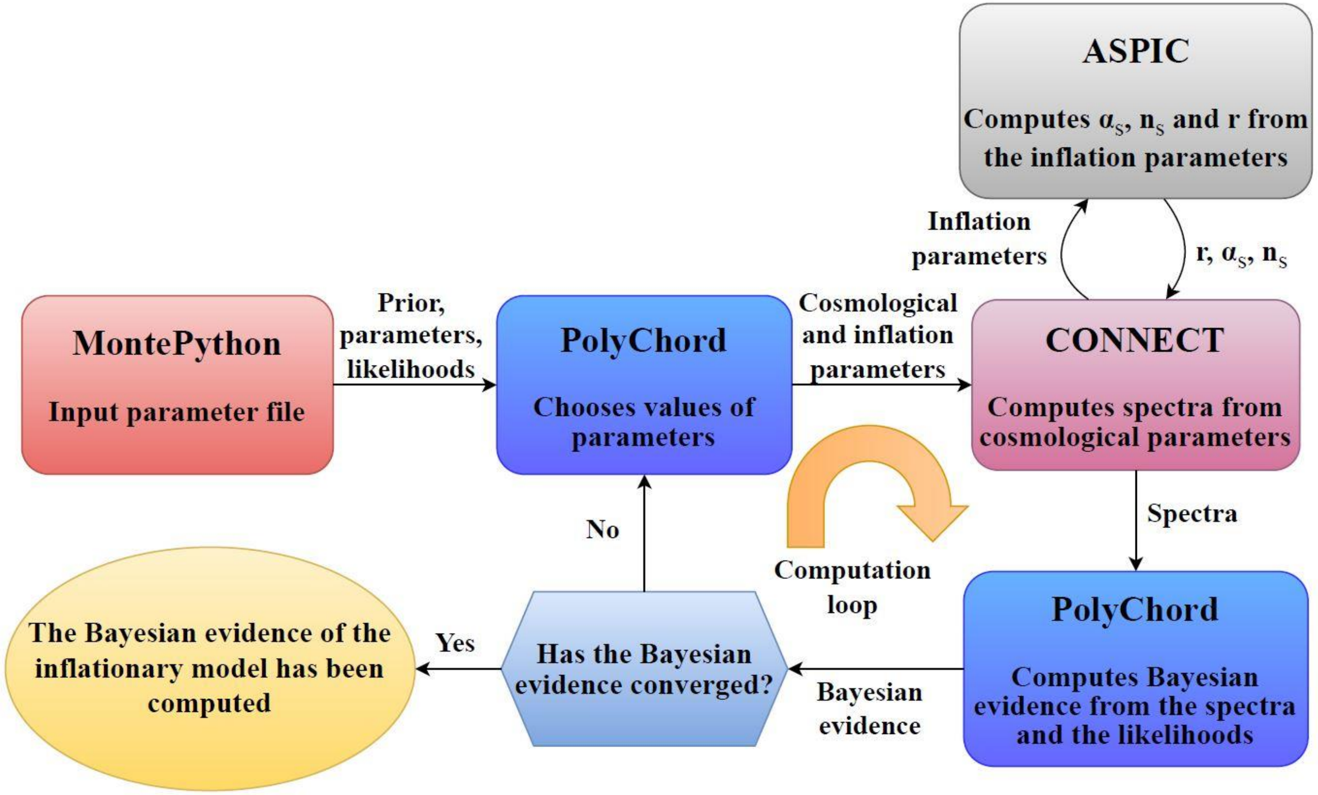
BAYESIAN MODEL ESTIMATION

- Based on Bayes Theorem
- Prior, posteriors, and evidence
- Bayes Factor and Jeffrey's Scale

$\lvert \ln B \rvert$	Odds	Probability	Strength of evidence
<1.0	<3:1	<0.750	Inconclusive evidence
1.0	~3:1	0.750	Weak evidence
2.5	~12:1	0.923	Moderate evidence
5.0	~150:1	0.993	Strong evidence

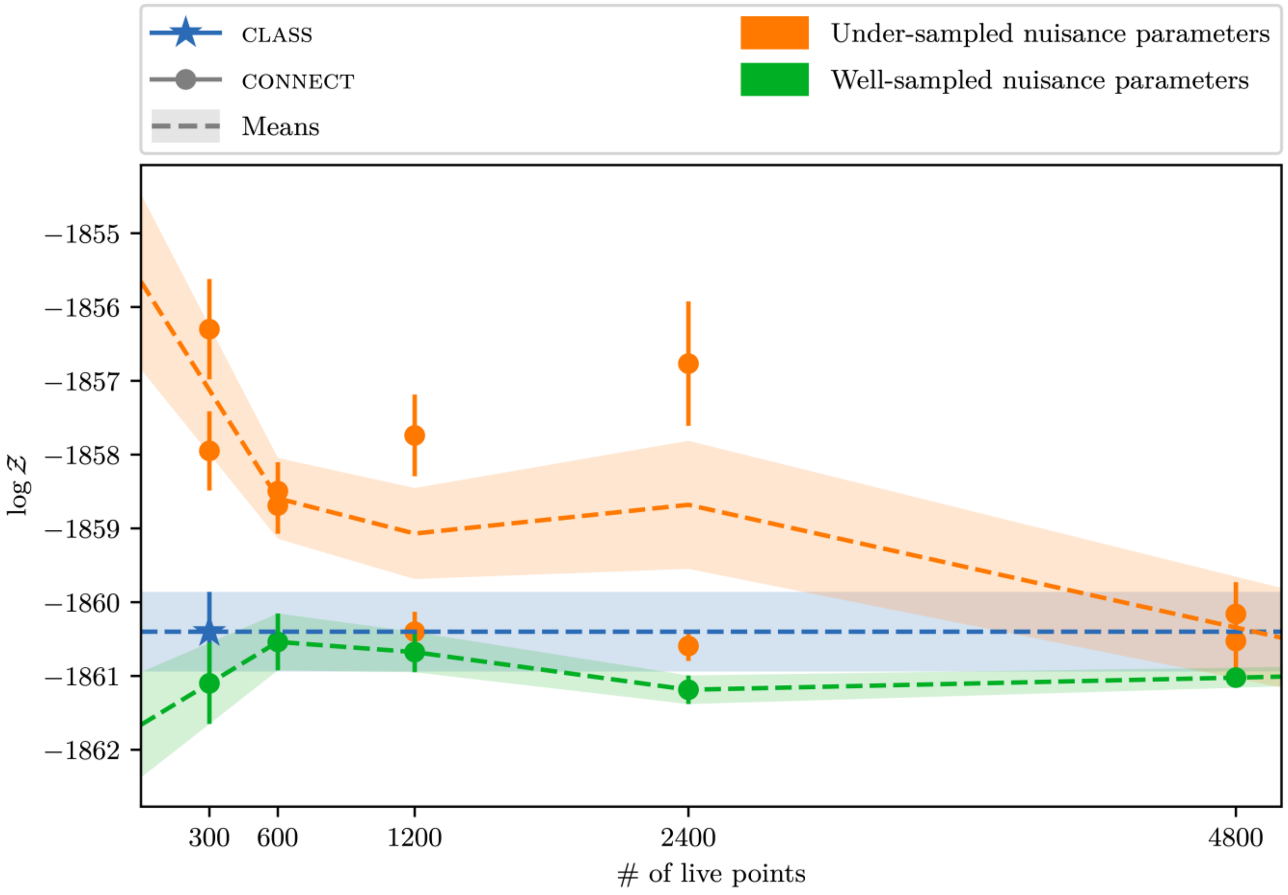
$$B = \frac{P(d|\mathcal{M}_0)}{P(d|\mathcal{M}_1)}$$

SETUP AND WORKFLOW



POLYCHORD

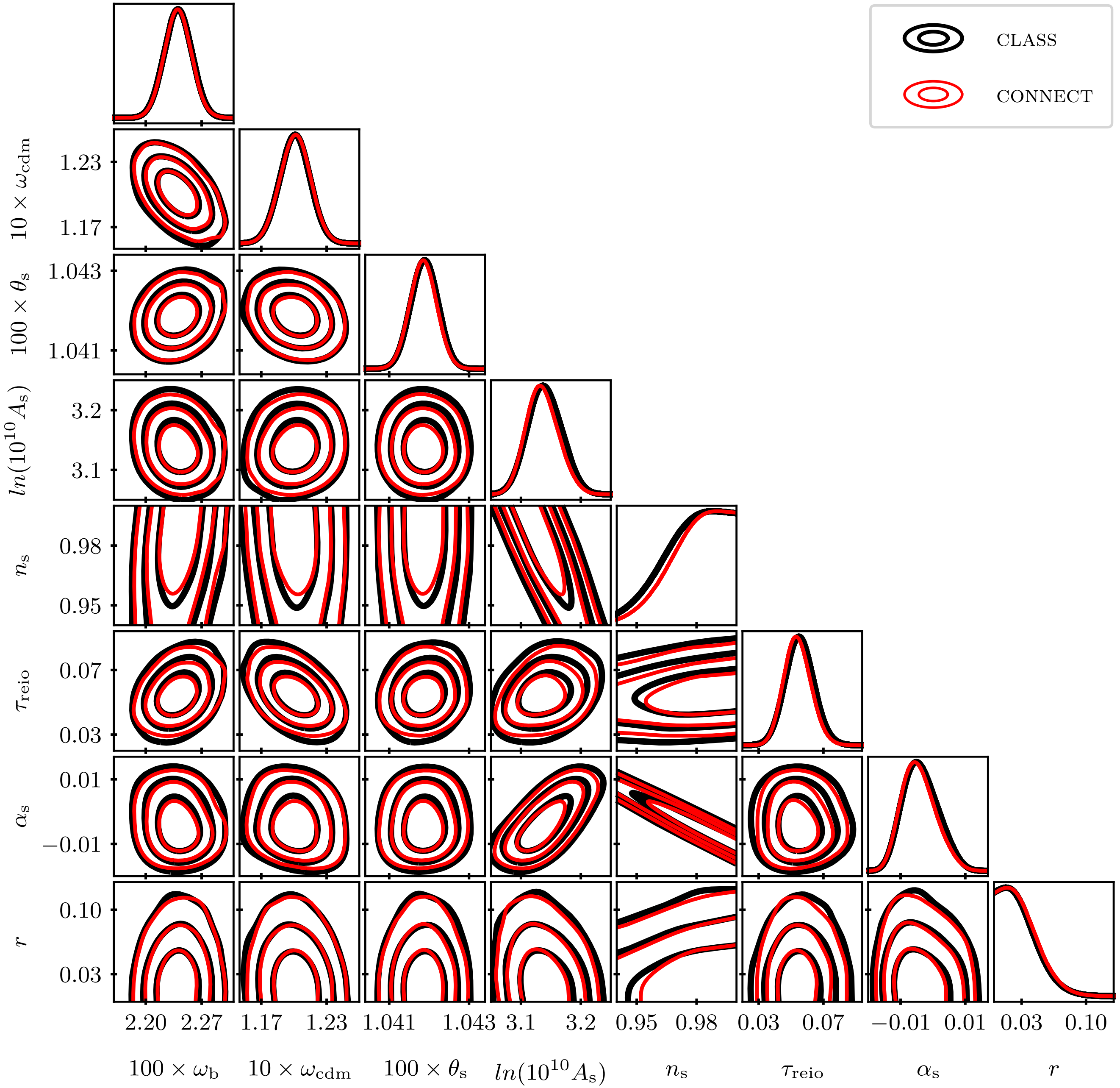
- "Slow" (cosmological) vs "fast" (nuisance) parameters
- Considerations when using a neural network



A COMPUTATION WITH AND WITHOUT A NEURAL NETWORK

- Model ΛCDM + α_s + r
- CLASS: 30.000 CPU hours
- CONNECT: 100 CPU hours
- Done with 300 livepoints and 24 tasks

Case	Bayesian evidence ($\log \mathcal{Z}$)
PolyChord with class	-1860.4 ± 0.54
PolyChord with connect	-1861.1 ± 0.55



CLASS
CONNECT
1.23
1.17
1.043
1.041
3.2
3.1
0.98
0.95
0.07
0.03
0.01
−0.01
0.10
0.03
$10 \times \omega_{\rm cdm}$
$100 \times \theta_{\rm s}$
$ln(10^{10} A_{\rm s})$
$n_{\rm s}$
$\tau_{\rm reio}$
$\alpha_{\rm s}$
r
2.20 2.27
1.17 1.23
1.041 1.043
3.1 3.2
0.95 0.98
0.03 0.07
−0.01 0.01
0.03 0.10
$100 \times \omega_{\rm b}$
$10 \times \omega_{\rm cdm}$
$100 \times \theta_{\rm s}$
$ln(10^{10} A_{\rm s})$
$n_{\rm s}$
$\tau_{\rm reio}$
$\alpha_{\rm s}$
r

RESULTS

- Done with 1200 live points, 24 tasks, and 1 CPU per task
- Computation time was 3500 CPU hours in total

ASPIC model	Model name in Ref. [28]	Potential
Higgs Inflation (HI)	$R + R^2/(6M^2)$	$M^4\left(1 - e^{-\sqrt{2/3}\phi/M_{\rm pl}}\right)^2$
Large Field Inflation (LFI_2)	Power-Law Potential	$M^4\left(\frac{\phi}{M_{\rm pl}}\right)^2$
Large Field Inflation (LFI_4)	Power-Law Potential	$M^4\left(\frac{\phi}{M_{\rm pl}}\right)^4$
Natural Inflation (NI)	Natural Inflation	$M^4\left[1 + \cos\left(\frac{\phi}{f}\right)\right]$
Loop Inflation (LI)	Spontaneously broken SUSY	$M^4\left[1 + \alpha \ln\left(\frac{\phi}{M_{\rm pl}}\right)\right]$
Colemann-Weinberg Inflation (CWI)	Not in the reference	$M^4\left[1 + \alpha\left(\frac{\phi}{Q}\right)^4 \ln\left(\frac{\phi}{Q}\right)\right]$

[28] **Planck** Collaboration, Y. Akrami *et al.*, "Planck 2018 results. X. Constraints on inflation," *Astron. Astrophys.* **641** (2020) A10, arXiv:1807.06211 [astro-ph.CO].

RESULTS

- All Bayes factors were computed with respect to Higgs Inflation
- The reference used 512 livepoints
- Same strength brackets as the reference

ASPIC model	$\ln \mathcal{B}$	$\ln \mathcal{B}$ in Ref. [28]
Large Field Inflation (LFI_2)	-8.8 ± 0.9	-11.5
Large Field Inflation (LFI_4)	-51.2 ± 0.9	-56.0
Natural Inflation (NI)	-4.6 ± 0.9	-6.6
Loop Inflation (LI)	-4.7 ± 0.9	-6.8
Colemann-Weinberg Inflation (CWI)	-19.7 ± 1.0	Not in the reference

[28] **Planck** Collaboration, Y. Akrami *et al.*, "Planck 2018 results. X. Constraints on inflation," *Astron. Astrophys.* **641** (2020) A10, arXiv:1807.06211 [astro-ph.CO].

RESULTS

- All Bayes factors were computed with respect to Higgs Inflation
- Comparison with a new article using a neural network trained on an effective likelihood

$$\ln \mathcal{B}_{\mathrm{LFI}_2} = -7.35$$

$$\ln \mathcal{B}_{\mathrm{NI}} = -4.74$$

[31] J. Martin, C. Ringeval, and V. Vennin, "Cosmic Inflation at the Crossroads," arXiv:2404.10647 [astro-ph.CO].

CONCLUSION

- Succesfully computed Bayesian evidence of inflationary models with a neural network
- Agrees with earlier computations both with and without a neural network
- Be careful when using PolyChord from MontePython

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