

Constraining Single Field Inflation with the SKA

Lennart Röver

2112.09148: Tanmoy Modak, Tilman Plehn, Lennart Röver and Björn Malte Schäfer

Contents

- Parameters considered
 - HSR parameters
 - Primordial power spectrum
- Observations
 - 21cm Intensity Mapping
 - SKA forecasting
- Results

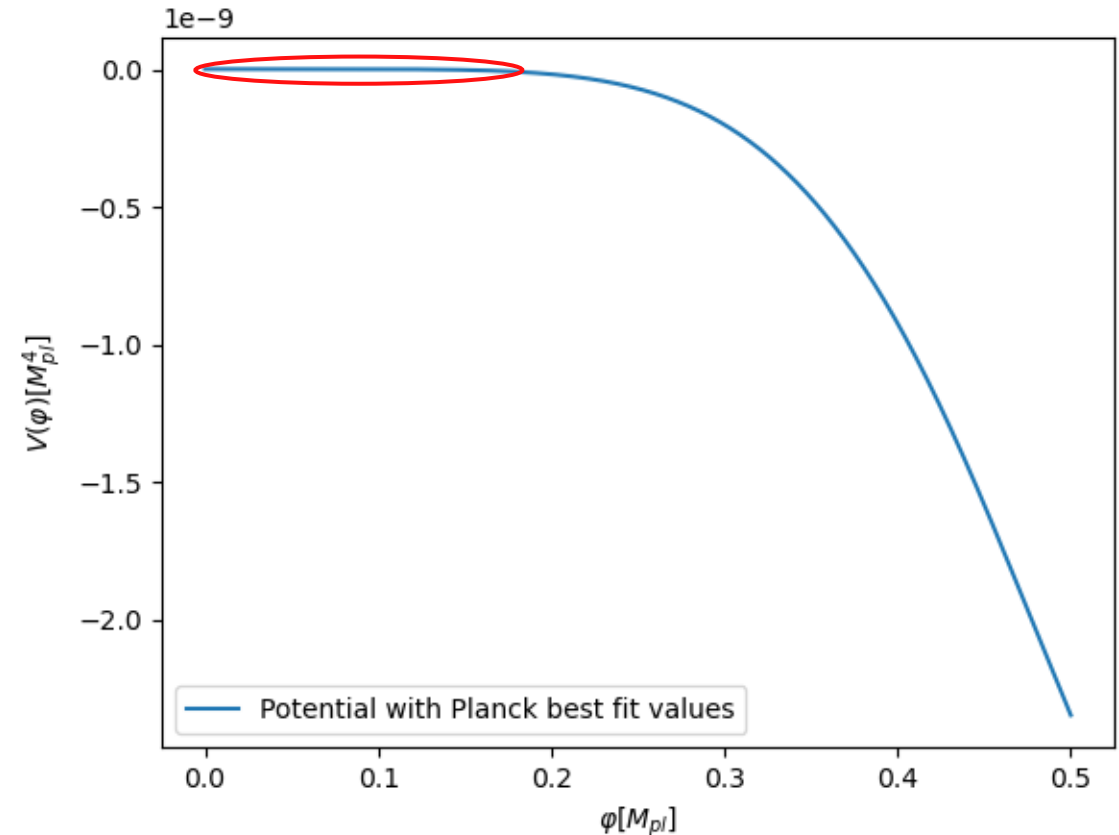
Single field slow-roll

- Single field inflation

$$S = \int d^4x \sqrt{-g} \left(\frac{1}{2} g^{\mu\nu} \nabla_\mu \varphi \nabla_\nu \varphi - V(\varphi) \right)$$

- Perfect slow-roll $\dot{\varphi}^2 \ll 2V(\varphi)$
- Deviations from perfect slow-roll

$$\varepsilon_H = \frac{m_{pl}^2}{4\pi} \left(\frac{H'}{H} \right)^2 \quad \dots \xi_H^2, \omega_H^3$$
$$\eta_H = \frac{m_{pl}^2}{4\pi} \left(\frac{H''}{H} \right)$$



Inflation: Perturbations

$$\varphi \rightarrow \varphi(t) + \delta\varphi(\mathbf{x}, t)$$



$$\mathcal{R}(\delta\varphi)$$



$$P_{\mathcal{R}}(k)$$



$$P_{\mathcal{R}}(k; n_s, \alpha, \beta)$$



$$P_{\mathcal{R}}(k; \varepsilon_H, \eta_H, \xi_H^2, \omega_H^3)$$

Hubble slow-roll (HSR) parameters

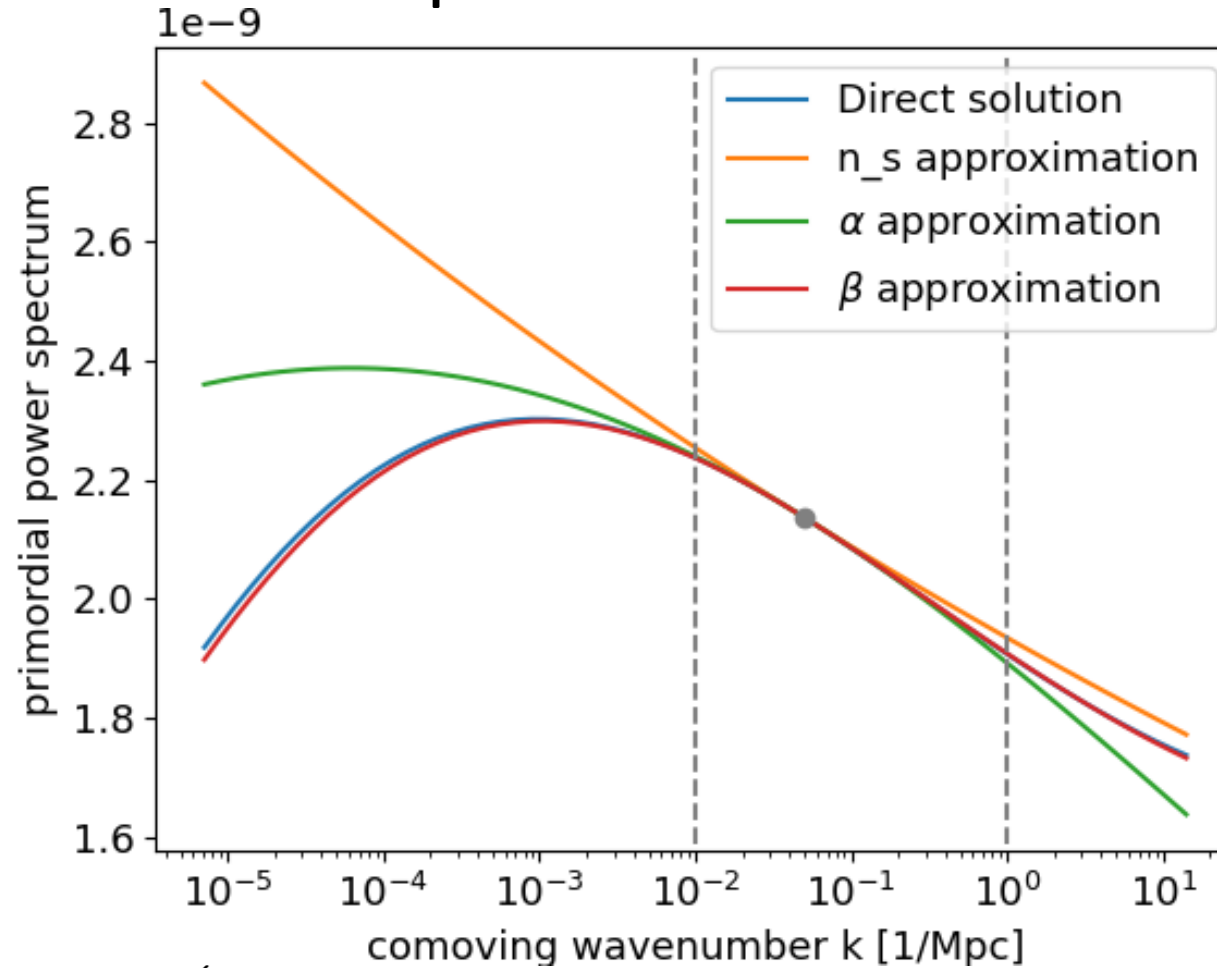
- Hierarchy of slow-roll parameters

$$\lambda_H^{(n)} = \left(\frac{m_{pl}^2}{4\pi} \right)^n \left(\frac{(H')^{n-1}}{H^n} \frac{d^{n+1}H}{d\varphi^{n+1}} \right)$$

- Model independent
- Reconstruct Hubble function from HSR parameters

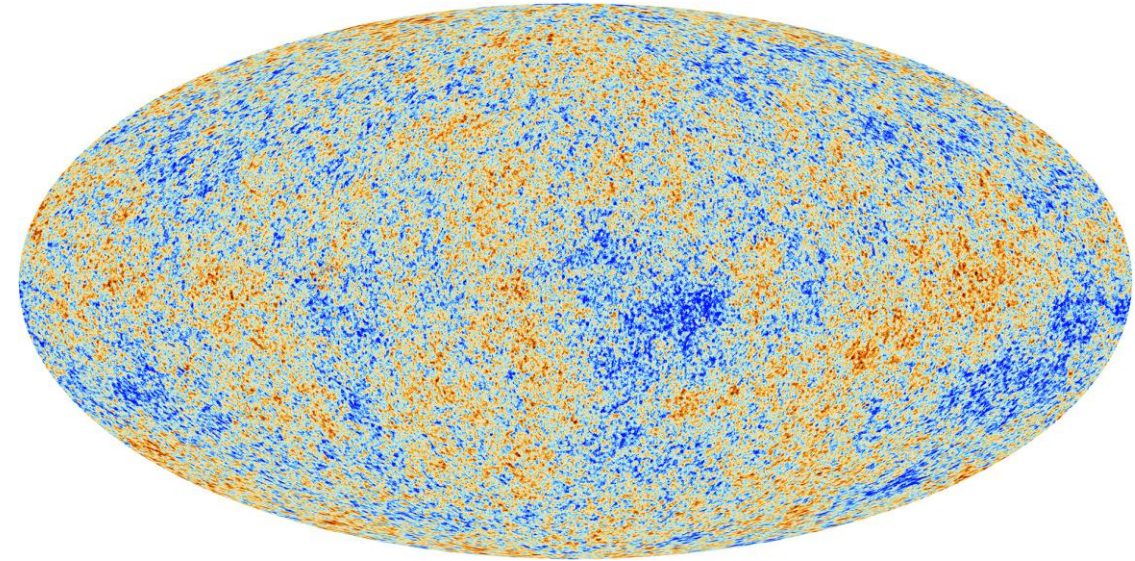
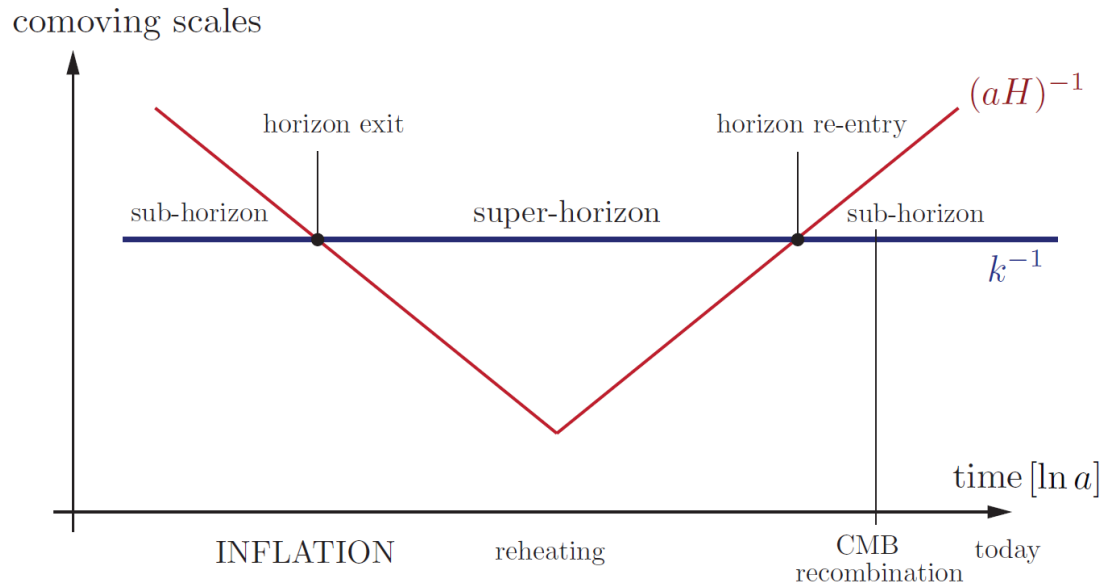
$$H(\varphi) = \sum_{n=0}^N \frac{1}{n!} \frac{d^n H}{d\varphi^n} \Big|_{\varphi_*} (\varphi - \varphi_*)^n$$

Primordial Power Spectrum



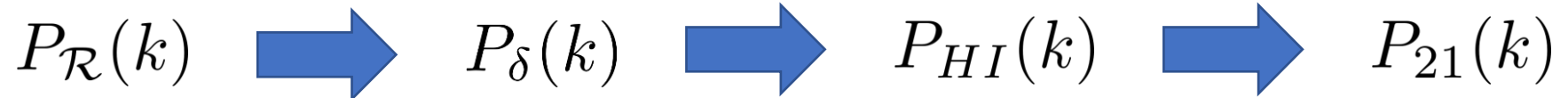
$$P_{\mathcal{R}}(k) = A_s \exp \left((n_s - 1) \ln \left(\frac{k}{k_*} \right) + \frac{\alpha}{2} \ln \left(\frac{k}{k_*} \right)^2 + \frac{\beta}{6} \ln \left(\frac{k}{k_*} \right)^3 \right)$$

Connection to Observations



Baumann ICTS 2011 [2]

Cosmic Microwave Background [1] ESA



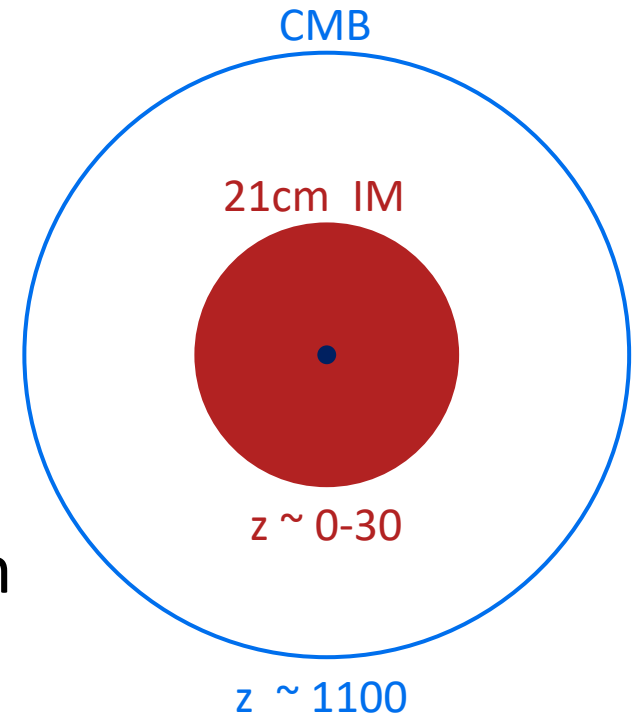
21cm Intensity Mapping

- Matter distribution at high redshifts
- Measure 21cm hyperfine transition
- Find power spectrum

$$\langle \Delta T_{21}(\mathbf{k}) \Delta T_{21}(\mathbf{k}') \rangle = P_{21}(\mathbf{k}, z) (2\pi)^3 \delta(\mathbf{k} - \mathbf{k}')$$

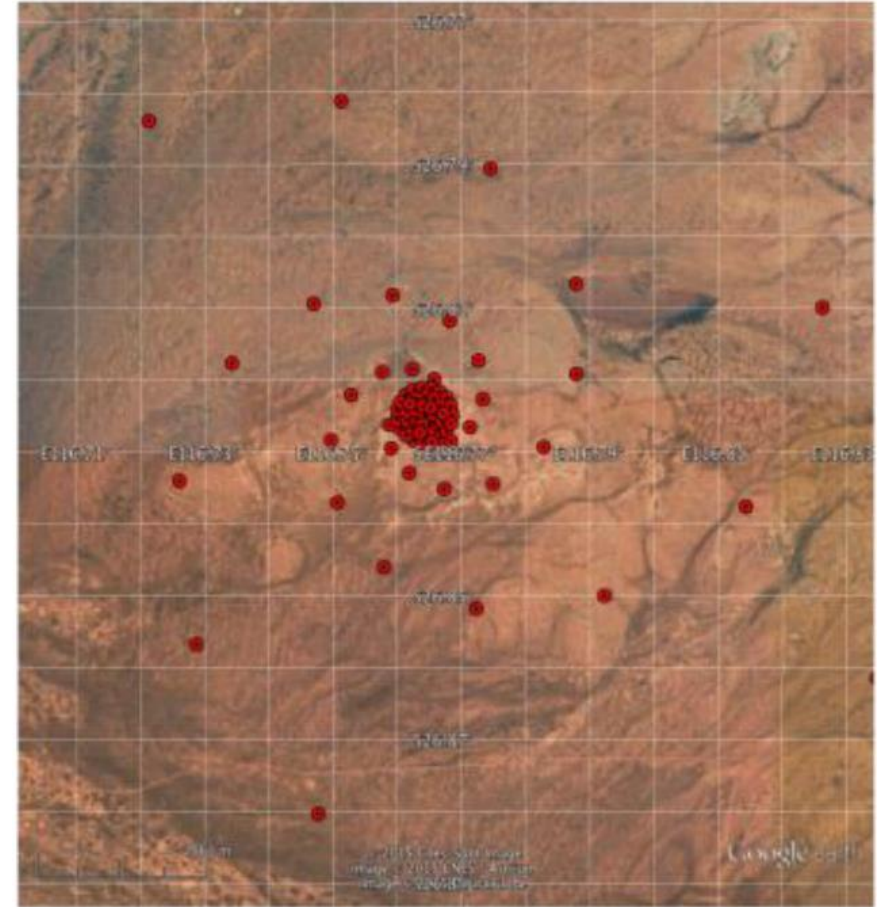
- 21cm power spectrum traces DM power spectrum

$$P_{\delta}(k) \quad \longrightarrow \quad P_{HI}(k) \quad \longrightarrow \quad P_{21}(k)$$



Square Kilometer Array

- Measures 21cm during EoR
- Large maximum baseline
- Many small baselines
- Sites: South Africa, Australia
- Data in the late 2020s



Antenna placement of SKA-LOW [4]

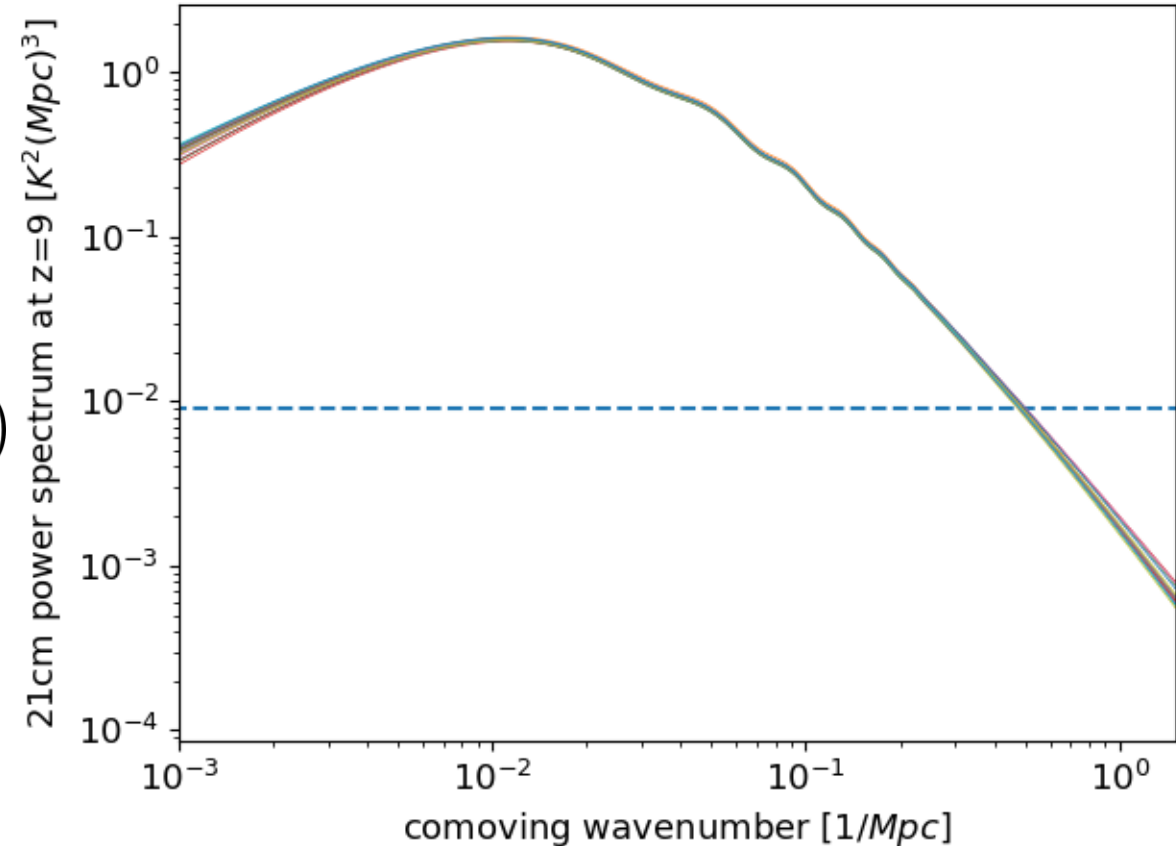
SKA forecasting

- Neutral fraction $z > 8$
- Spin temperature $z < 10$
- Signal

$$P_{21}(\mathbf{k}) = [\mathcal{A}(z) + \bar{T}_{21}(z)\mu^2]^2 P_{HI}(\mathbf{k}, z)$$

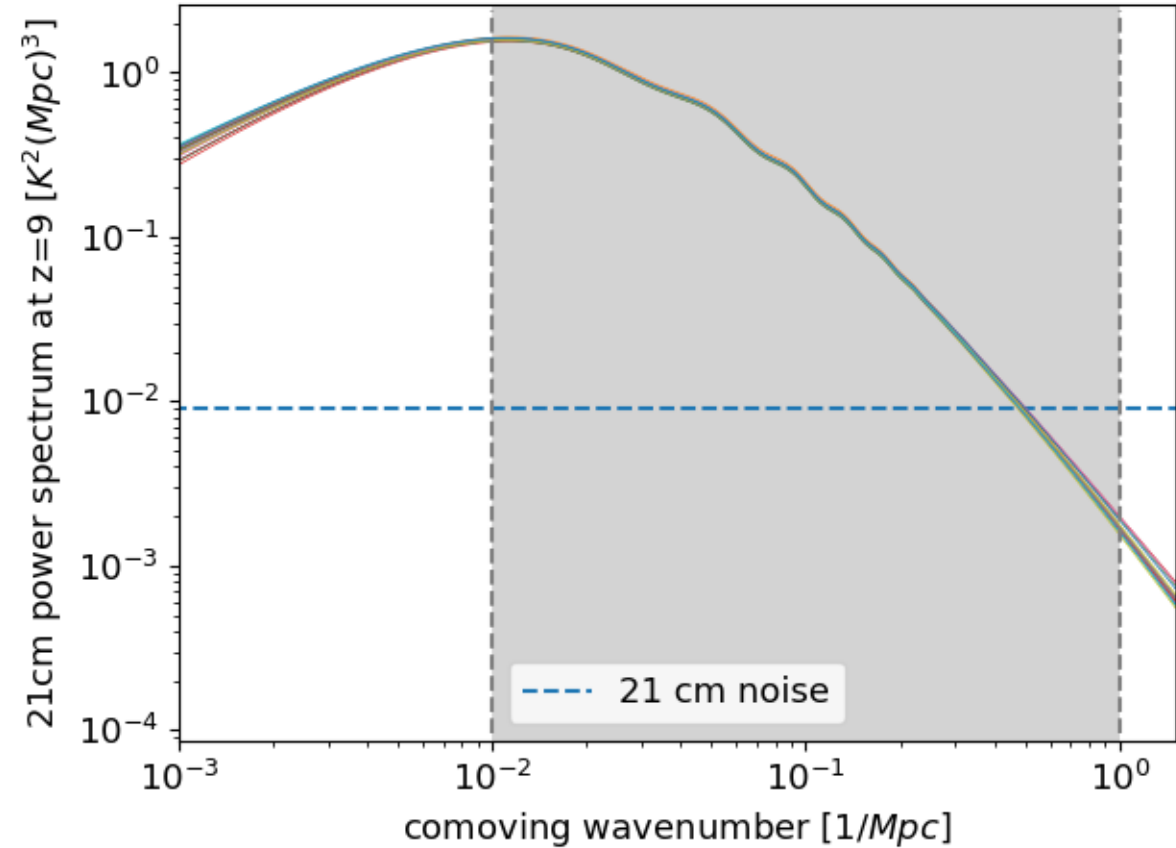
- Noise:

$$P_{21}^N = \frac{\pi T_{sys}^2}{t_{of_{cover}}^2} d_A^2(z) y_\nu(z) \frac{\lambda^2(z)}{D_{base}^2}$$



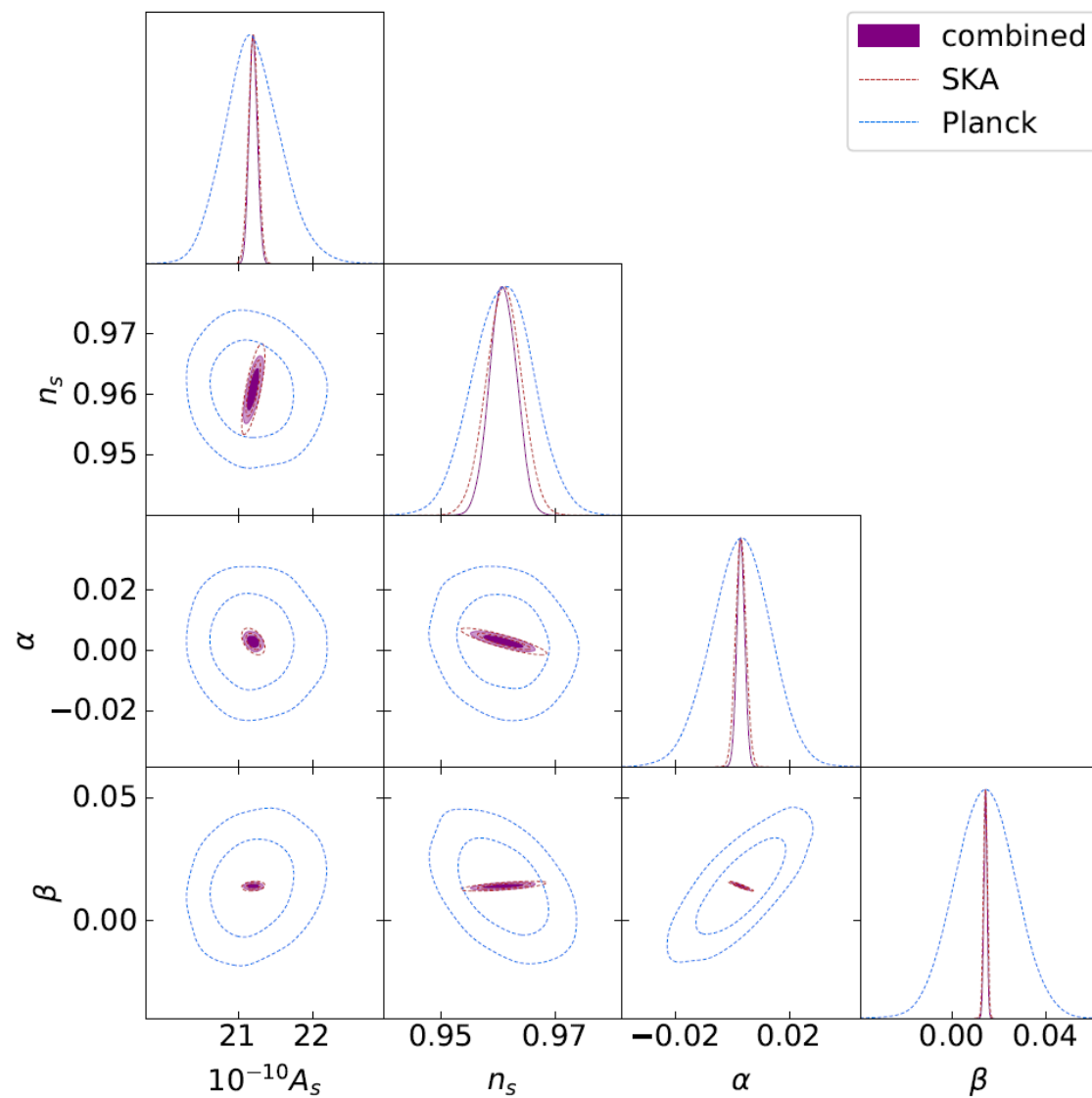
SKA forecasting

- Foregrounds
 - Galactic emissions, large scales
- Non-linear structure formation

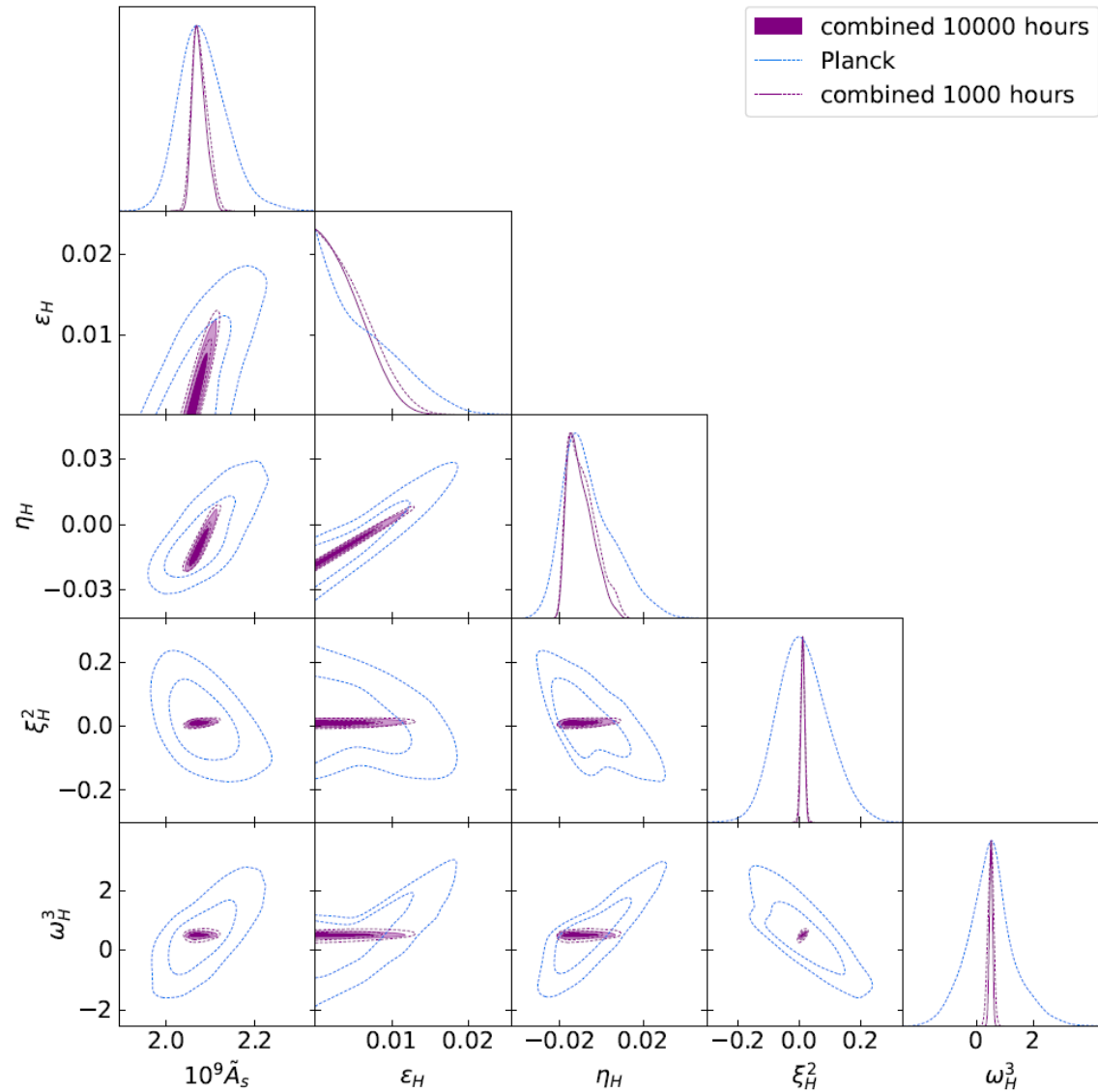


Primordial Power Spectrum

$$P_{\mathcal{R}}(k; n_s, \alpha, \beta)$$



HSR parameters combined $P_{\mathcal{R}}(k; \varepsilon_H, \eta_H, \xi_H^2, \omega_H^3)$

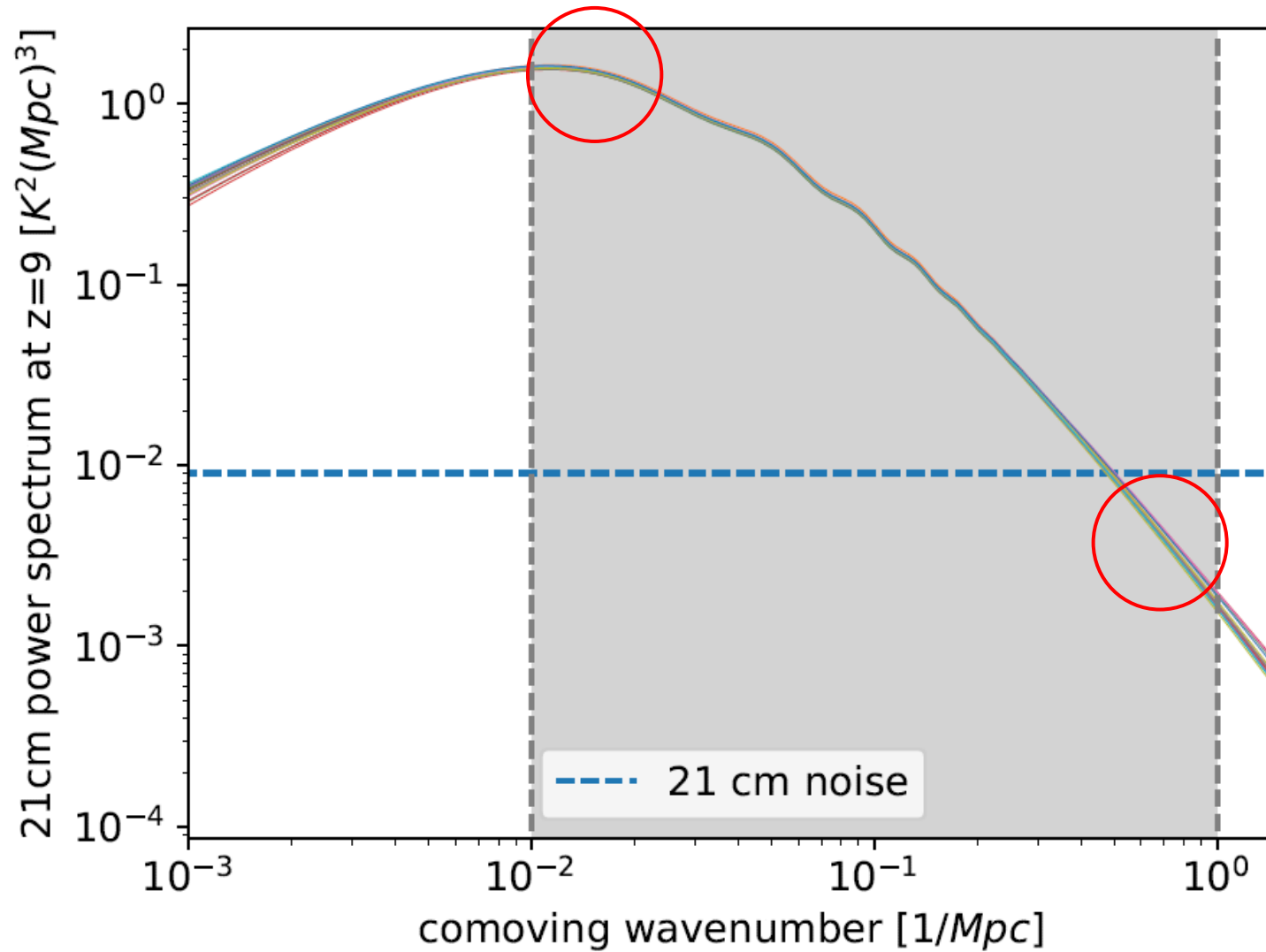


Combined results

- Higher order parameters strongly constrained by SKA
- Primordial power spectrum

$$P_{\mathcal{R}}(k) = A_s \exp \left((n_s - 1) \ln \left(\frac{k}{k_*} \right) + \frac{\alpha}{2} \ln \left(\frac{k}{k_*} \right)^2 + \frac{\beta}{6} \ln \left(\frac{k}{k_*} \right)^3 \right)$$

Combined results



Conclusion

- We can constrain single field inflation with the SKA
- Slow-roll parameters constrained at scales away from the pivot scale
- Extension of the redshift and wavenumber ranges

Sources

[1] <https://www.esa.int>

[2] <https://www.icts.res.in/program/focg2011/talks>

[3] Y. Akrami et al. Planck 2018 results. X. Constraints on inflation. *Astron. Astrophys.*, 641:A10, 2020.

[4] Dewdney, Peter. SKA1 SYSTEM BASELINEV2 DESCRIPTION, 2015.

[5] Benjamin Audren, Julien Lesgourgues, Karim Benabed, and Simon Prunet. Conservative constraints on early cosmology with montepython. *Journal of Cosmology and Astroparticle Physics*, 2013.

[6] Thejs Brinckmann and Julien Lesgourgues. Montepython 3: boosted mcmc sampler and other features, 2018.

[7] Diego Blas, Julien Lesgourgues, and Thomas Tram. The cosmic linear anisotropy solving system (class). part ii: Approximation schemes. *Journal of Cosmology and Astroparticle Physics*, 2011.

MCMC Plots: Antony Lewis. GetDist: a Python package for analysing Monte Carlo samples. 2019

Inflation

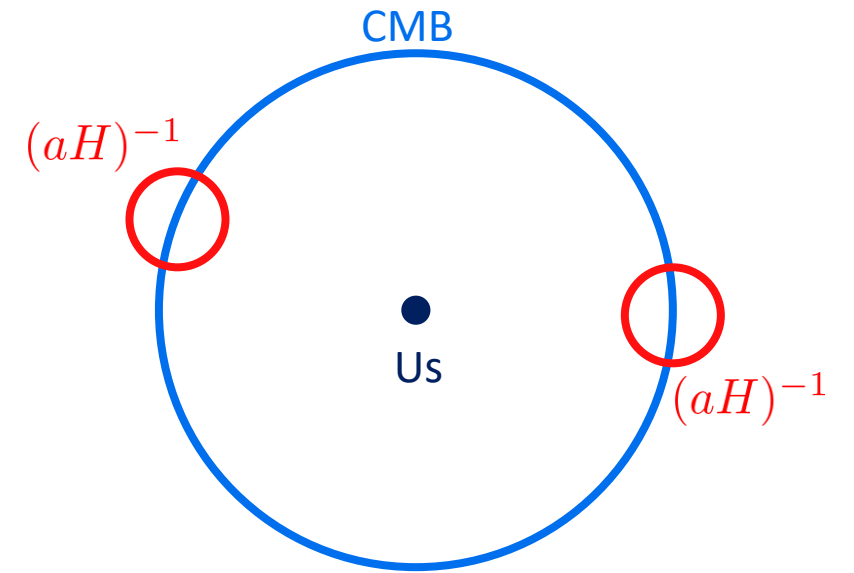
- Horizon problem
- Single field inflation

$$S = \int d^4x \sqrt{-g} \left(\frac{1}{2} g^{\mu\nu} \nabla_\mu \varphi \nabla_\nu \varphi - V(\varphi) \right)$$

- Background evolution:

$$\dot{\varphi} = -\frac{m_{pl}^2}{4\pi} H'(\varphi)$$

$$V(\varphi) = -\frac{m_{pl}^4}{32\pi^2} [H'(\varphi)]^2 + \frac{3m_{pl}^2}{8\pi} H^2(\varphi)$$



Inflation: Perturbations

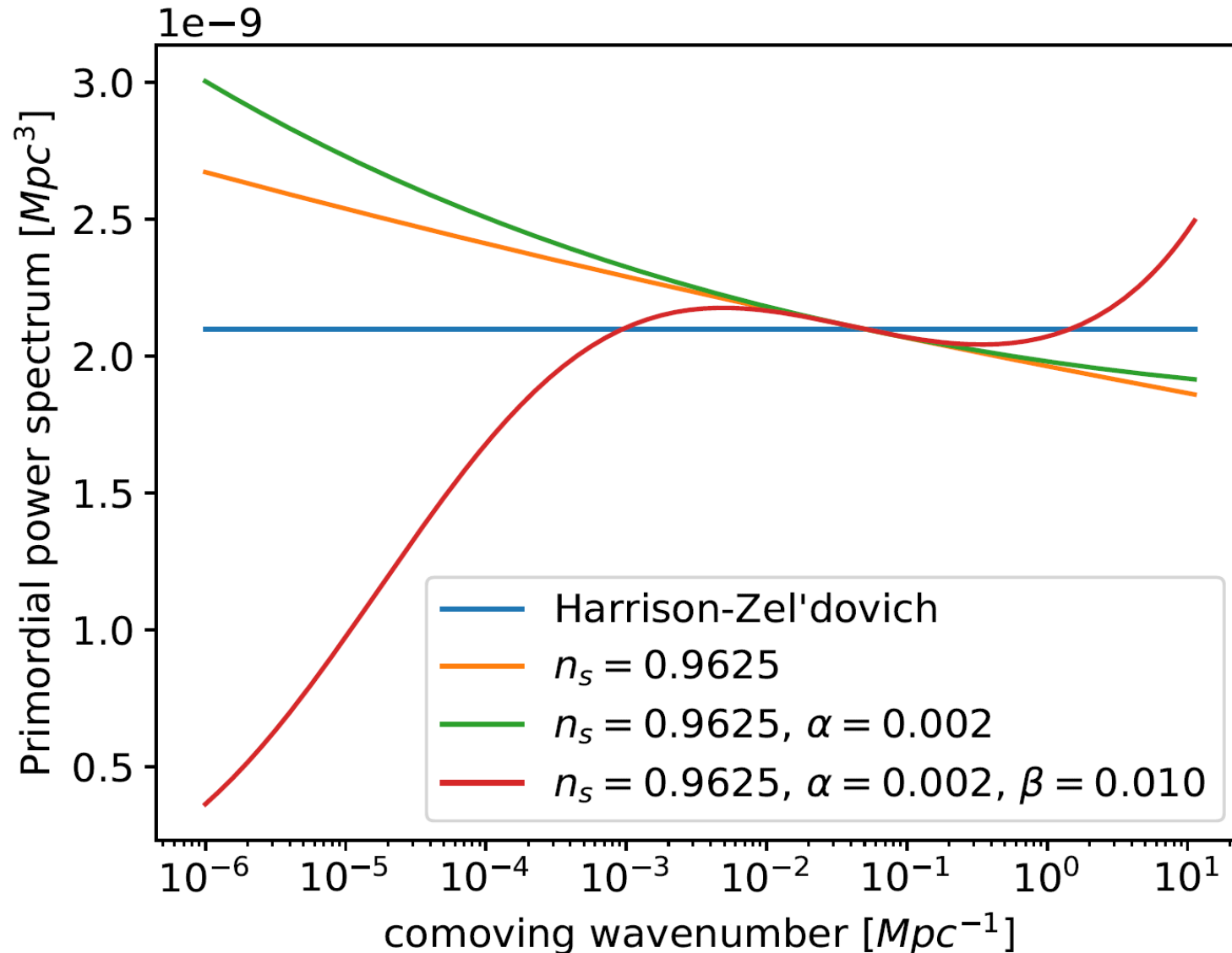
- Perturb inflaton field $\varphi(t) \rightarrow \varphi(t) + \delta\varphi(\mathbf{x})$
- Gauge invariant quantity $u = z\mathcal{R}(\delta\varphi, \Psi)$
- Mode equation

$$\frac{d^2}{d\eta^2} u(k) + \left[k^2 - \frac{1}{z} \frac{d^2 z}{d\eta^2} \right] u(k) = 0 \quad z = a\dot{\varphi}/H$$

- Bunch-Davies vacuum as initial conditions
- Spectrum of curvature perturbations

$$P_{\mathcal{R}}(k) = \frac{k^3}{2\pi^2} \left| \frac{u(k)}{z} \right|^2$$

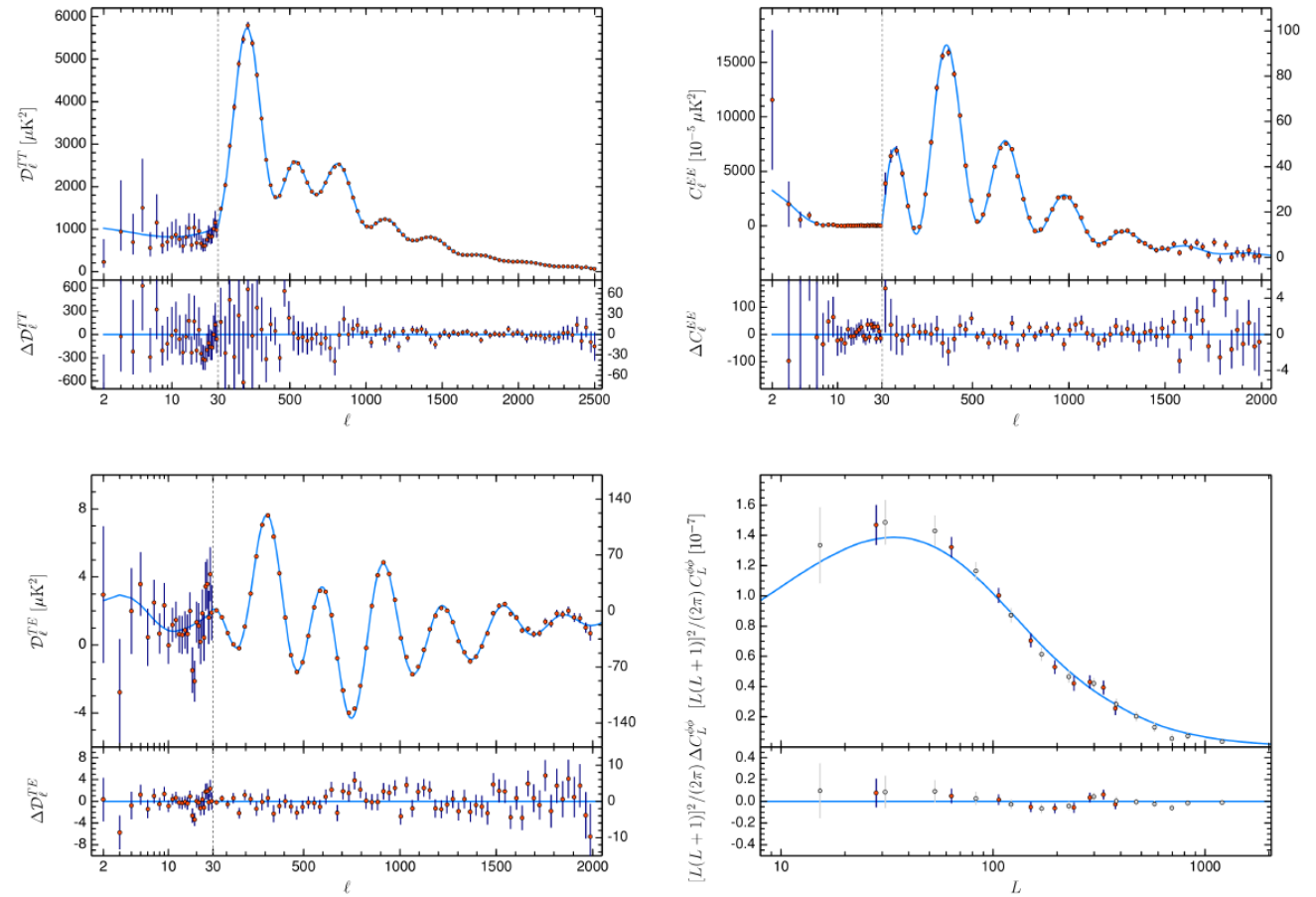
Primordial Power Spectrum



Planck



Front view of the Planck satellite [1] ESA



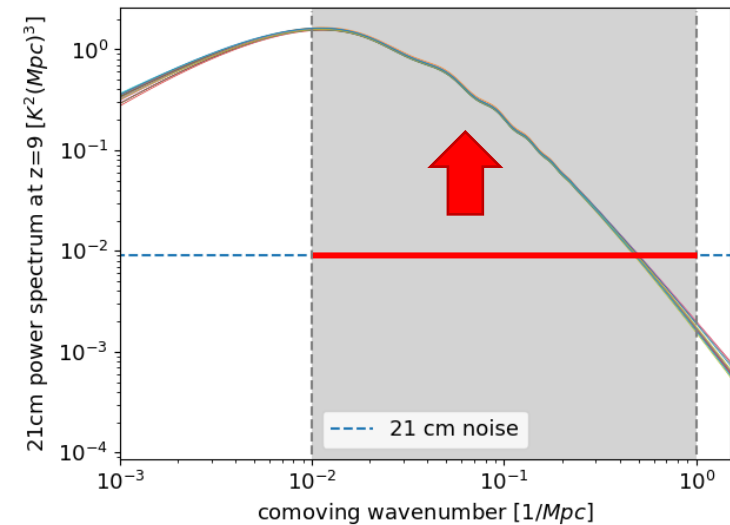
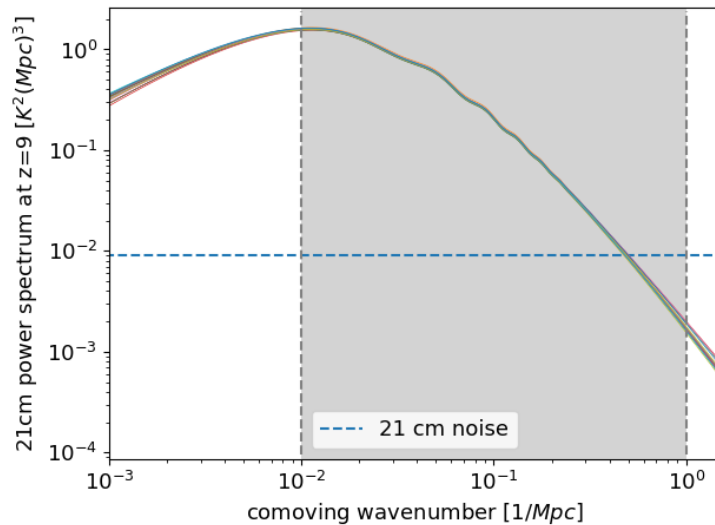
Planck 2018 results X. Constraints on Inflation [3]

Foreground subtraction

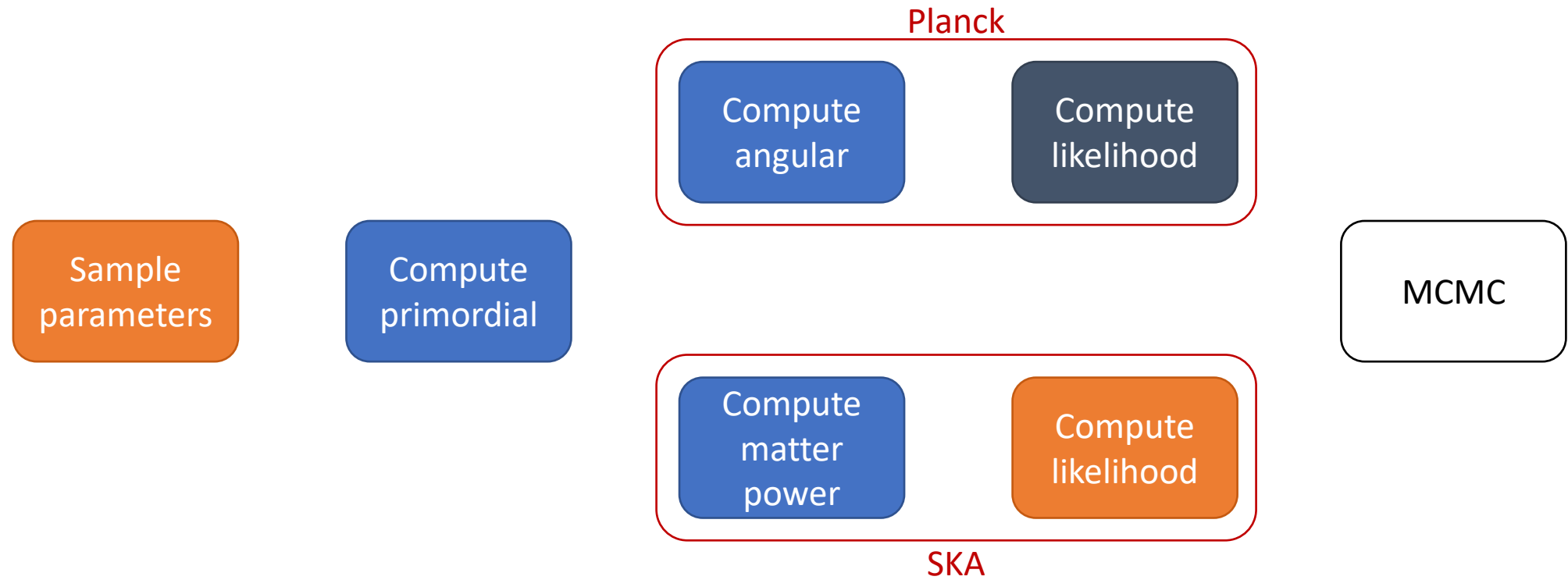
Signal + foregrounds

Great foreground
removal

Model errors,
missestimated
parameters, mode
mixing...



Data analysis

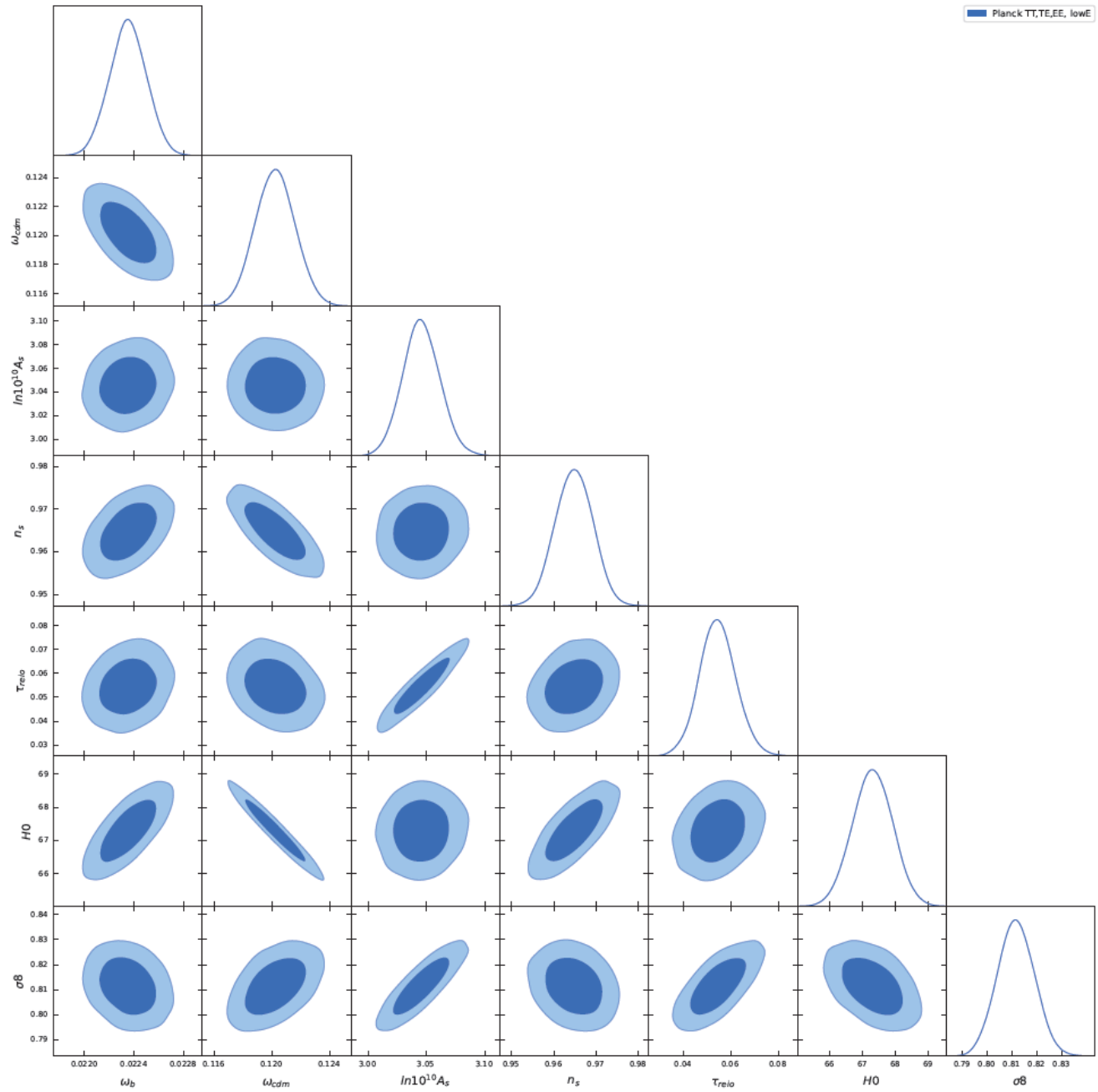


MontePython [5], [6],
CLASS [7]

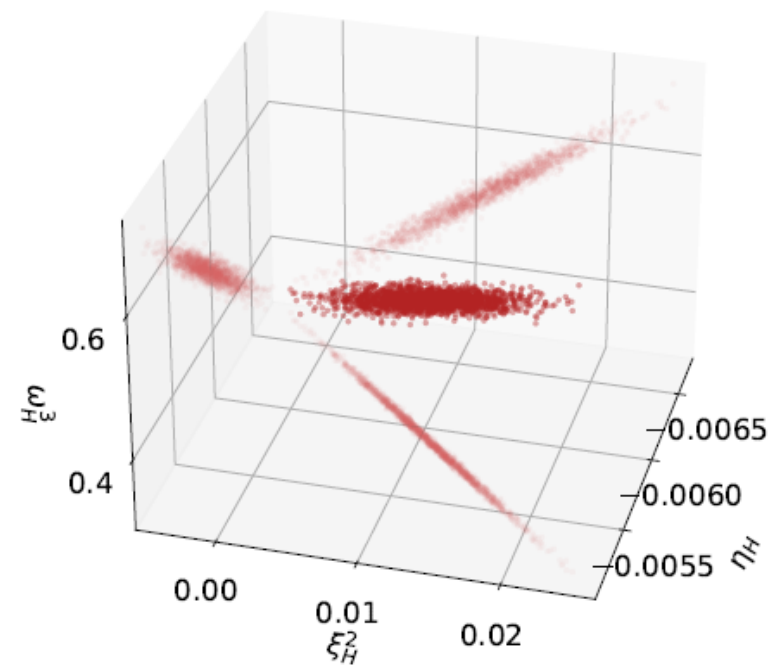
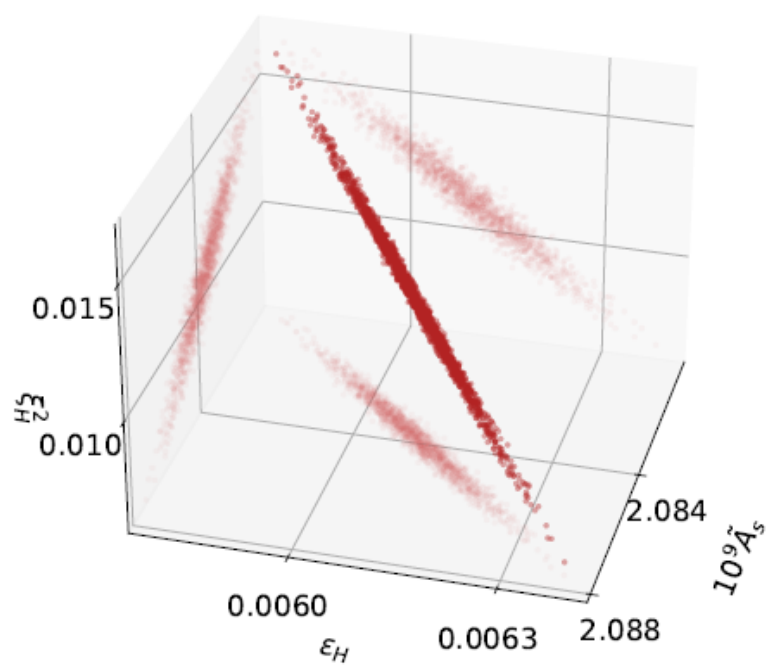
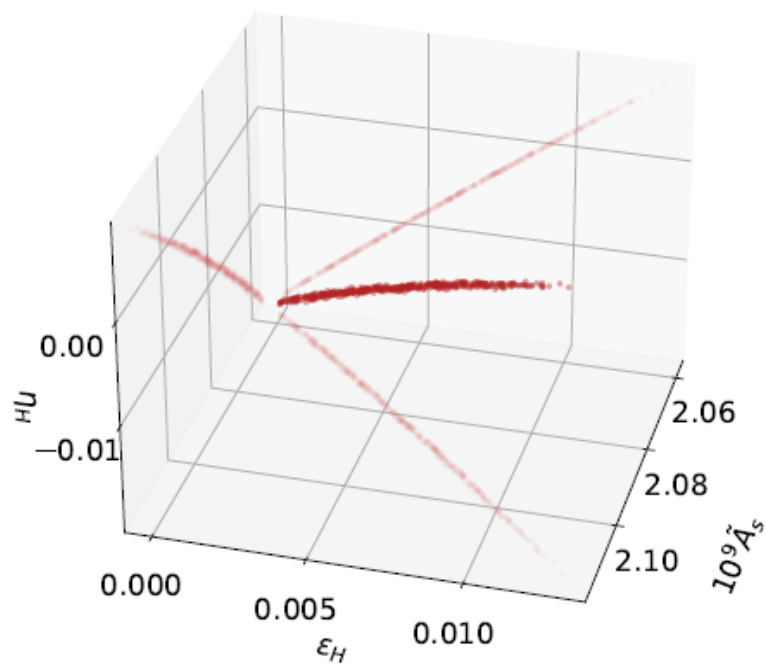
SKA likelihood

- Construct a χ^2 for 22 non overlapping redshift bins

$$\chi_i^2 = \frac{f_{sky}}{2} \frac{Vol_i}{(2\pi)^3} \int_{k_{min}}^{k_{max}} dk (2\pi k^2) \int_{-1}^1 d\mu \frac{[P_{21}(\mathbf{k}, z, \theta) - P_{21}^{fid}(\mathbf{k}, z, \theta_{fid})]^2}{[P_{21}(\mathbf{k}, z, \theta) + P_{21}^N(z)]^2}$$

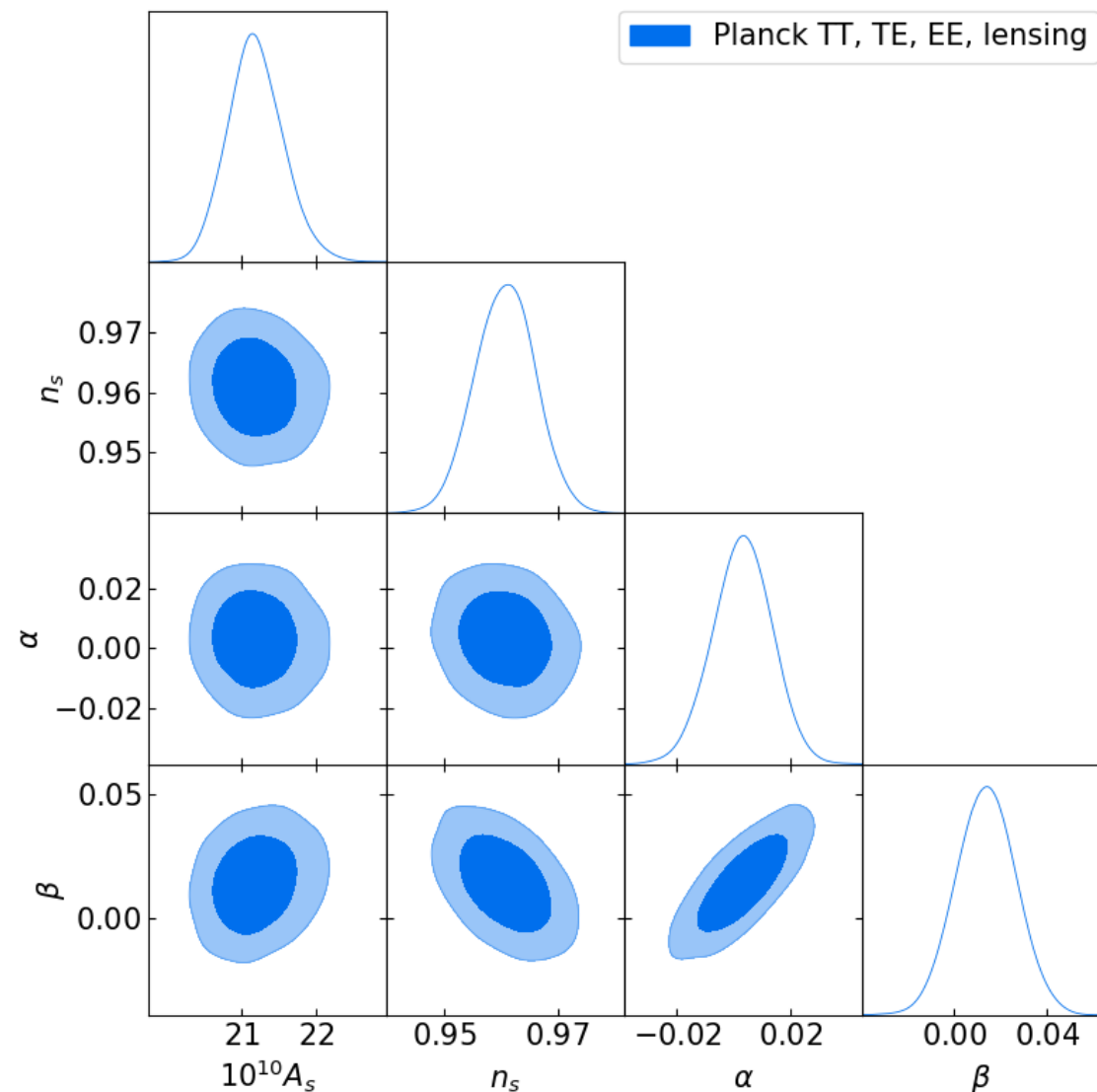
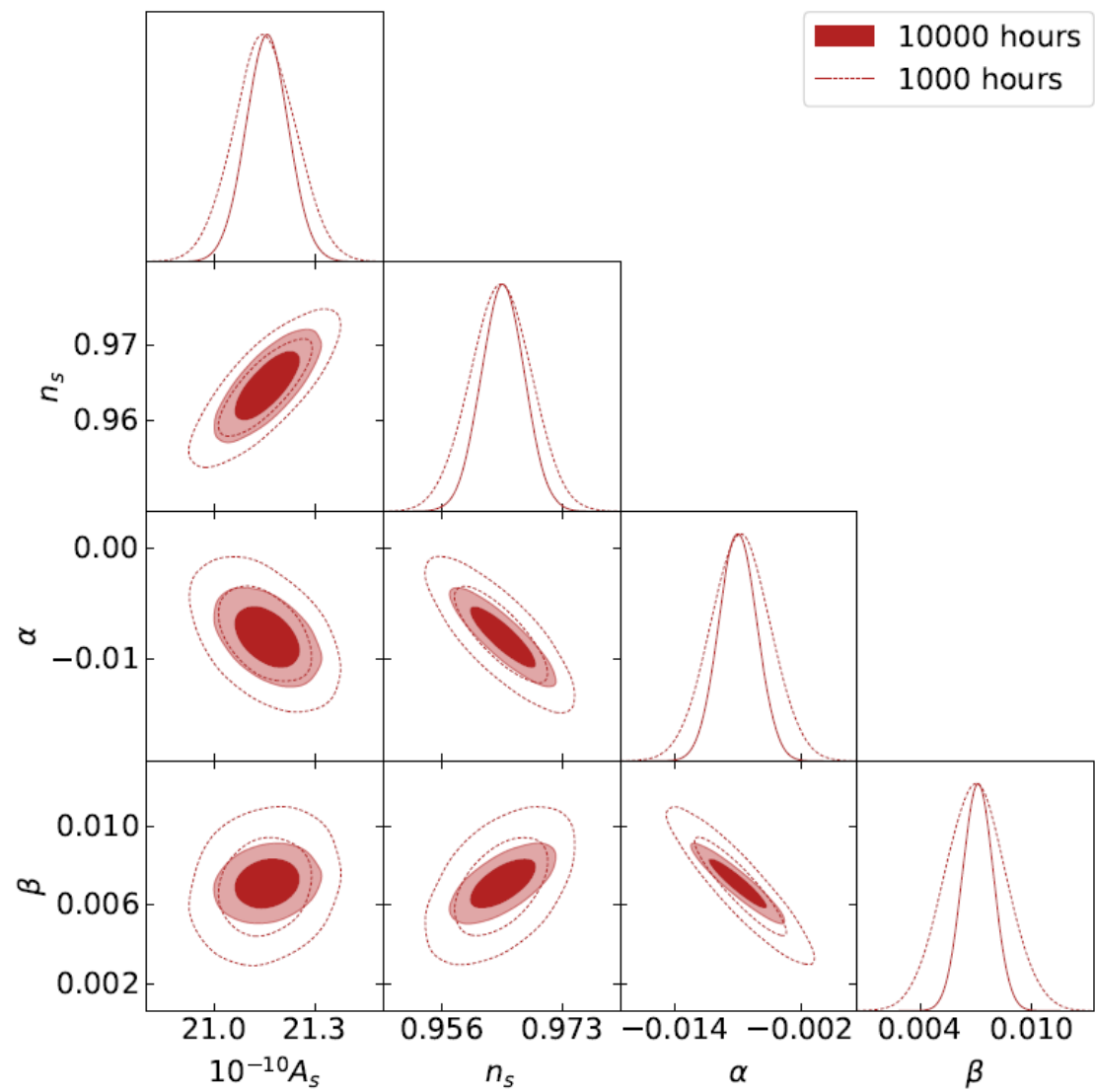


HSR parameters SKA

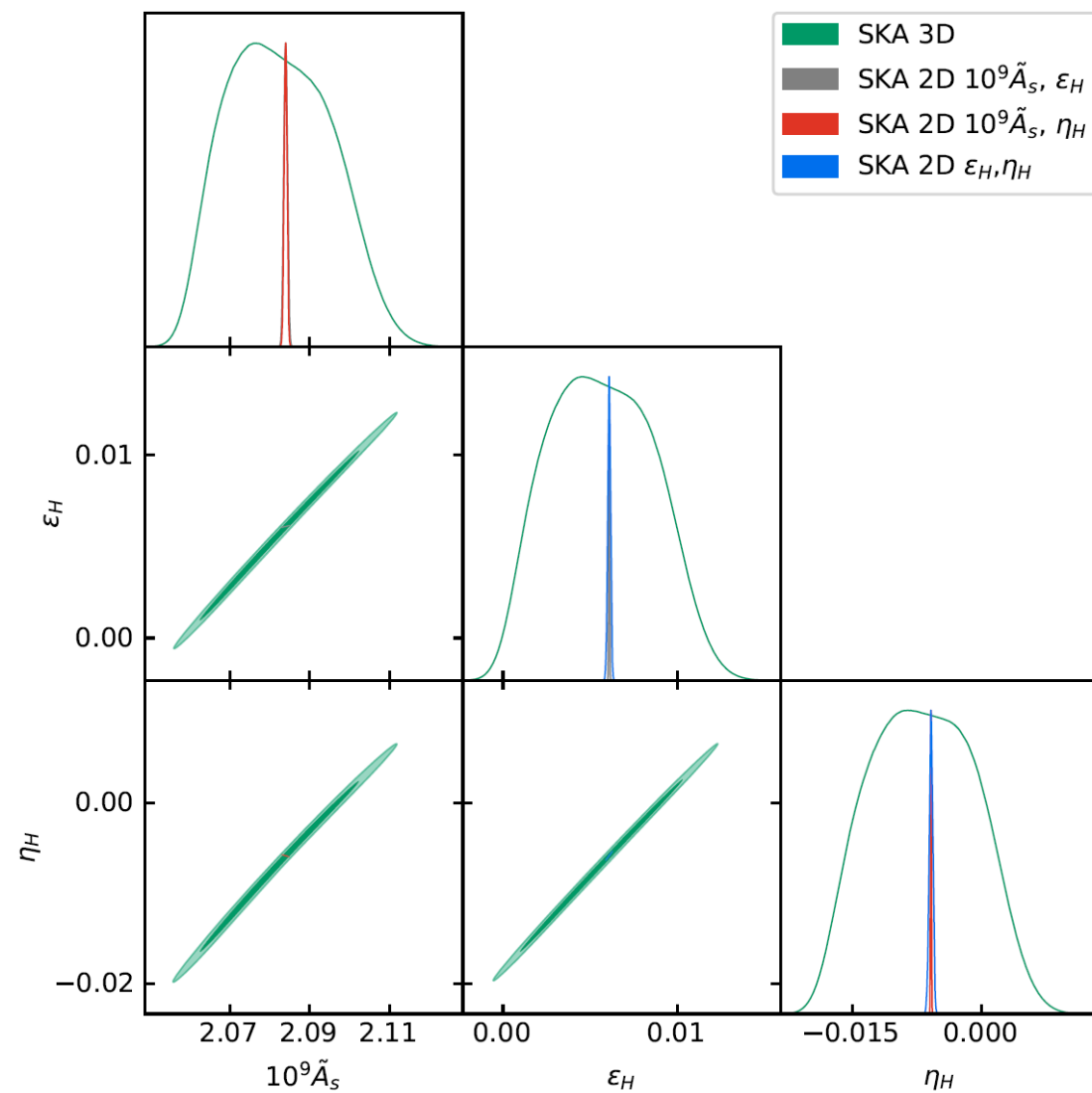
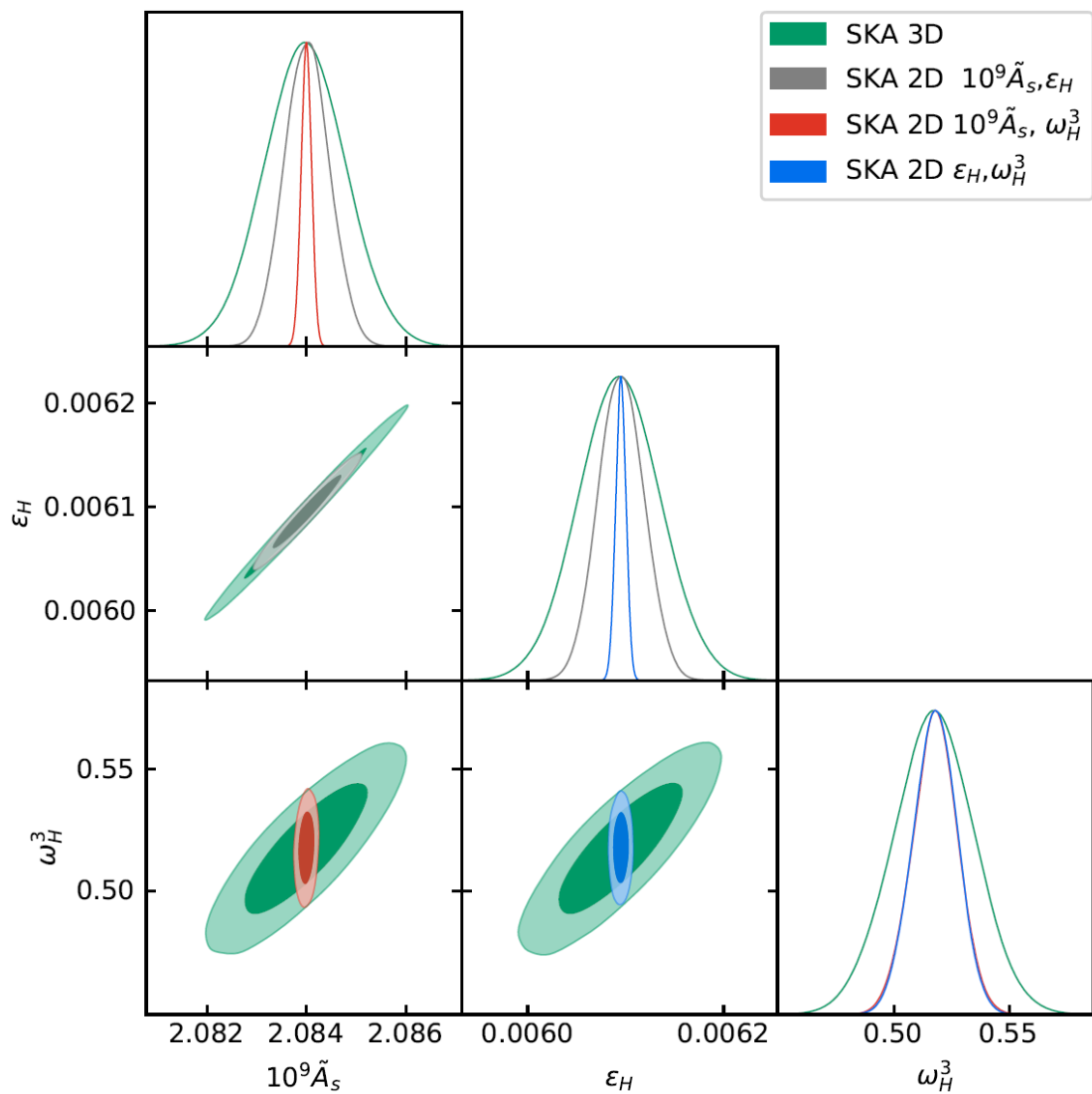


Primordial Power Spectrum

$$P_{\mathcal{R}}(k; n_s, \alpha, \beta)$$



HSR parameters SKA



HSR parameters Planck

$$P_{\mathcal{R}}(k; \varepsilon_H, \eta_H, \xi_H^2, \omega_H^3)$$

