Constraining Single Field Inflation with the SKA

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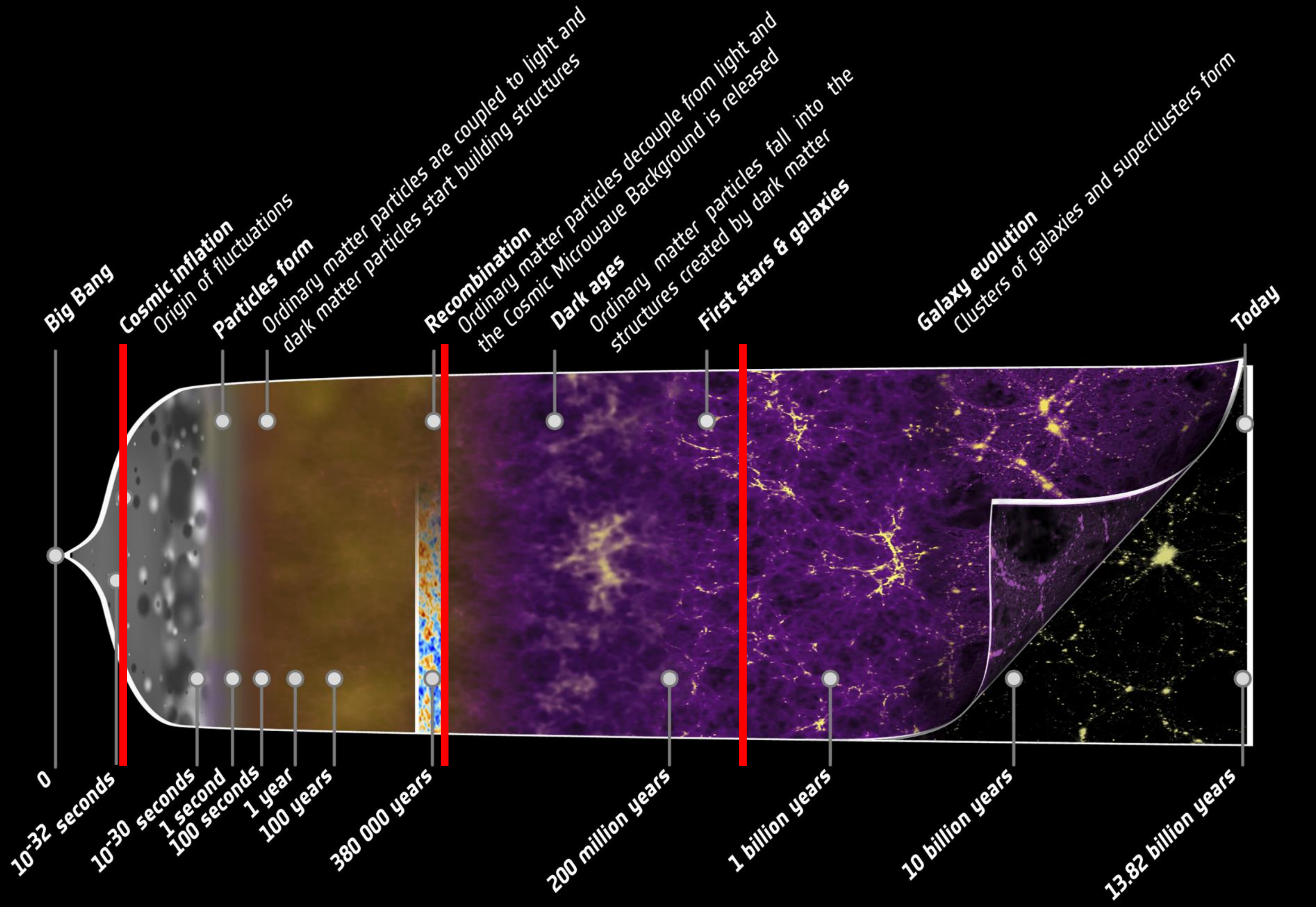


History of the Universe [1] ESA

Inflation

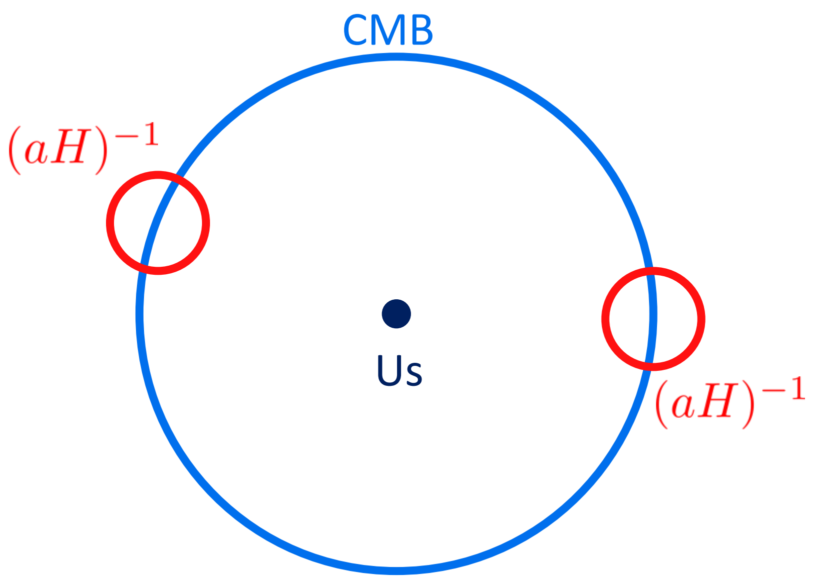
- Horizon problem
- Flatness problem
- Exotic relics

} accelerated expansion

- 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 $\varphi = \varphi(t)$



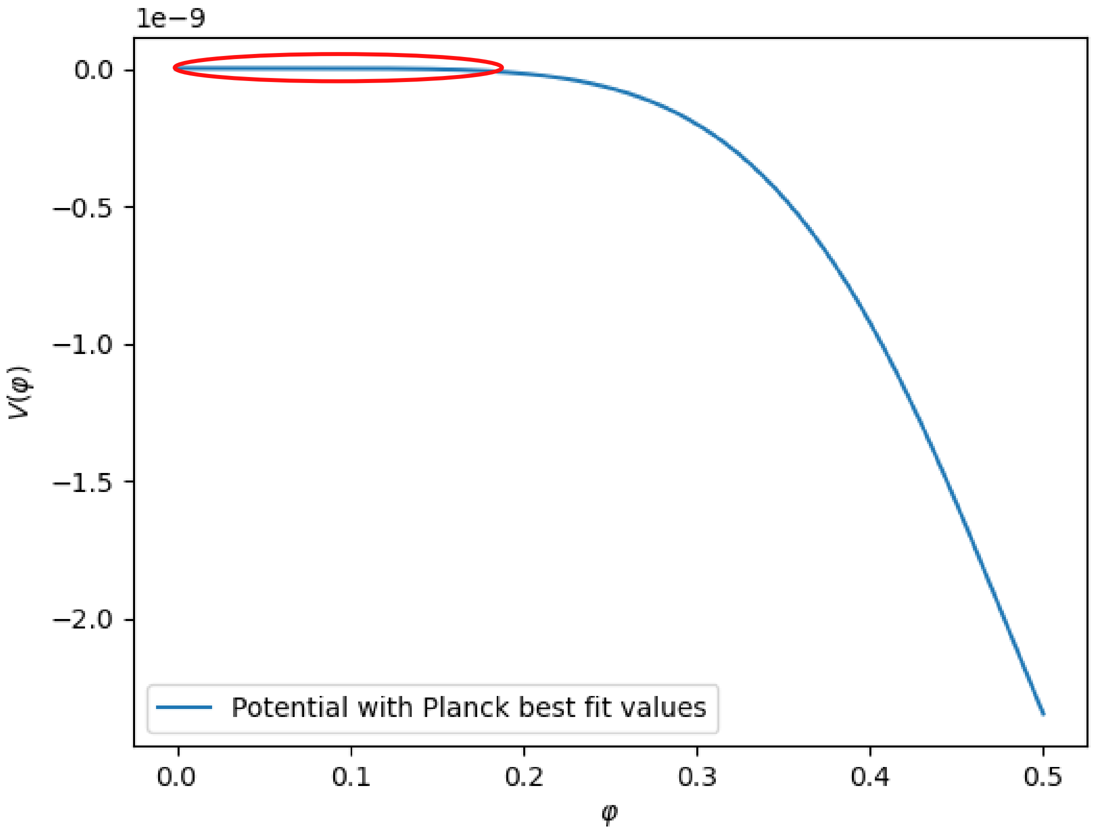
Slow-roll inflation

- Expansion needs to last long enough
- Perfect slow-roll $\dot{\varphi}^2 \ll 2V(\varphi)$
- Deviations from slow-roll

$$\varepsilon_H = \frac{m_{pl}^2}{4\pi}\left(\frac{H'}{H}\right)^2$$

$$\eta_H = \frac{m_{pl}^2}{4\pi}\left(\frac{H''}{H}\right)$$

$$\ldots\xi_H^2, \omega_H^3$$



Inflation: Perturbations

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

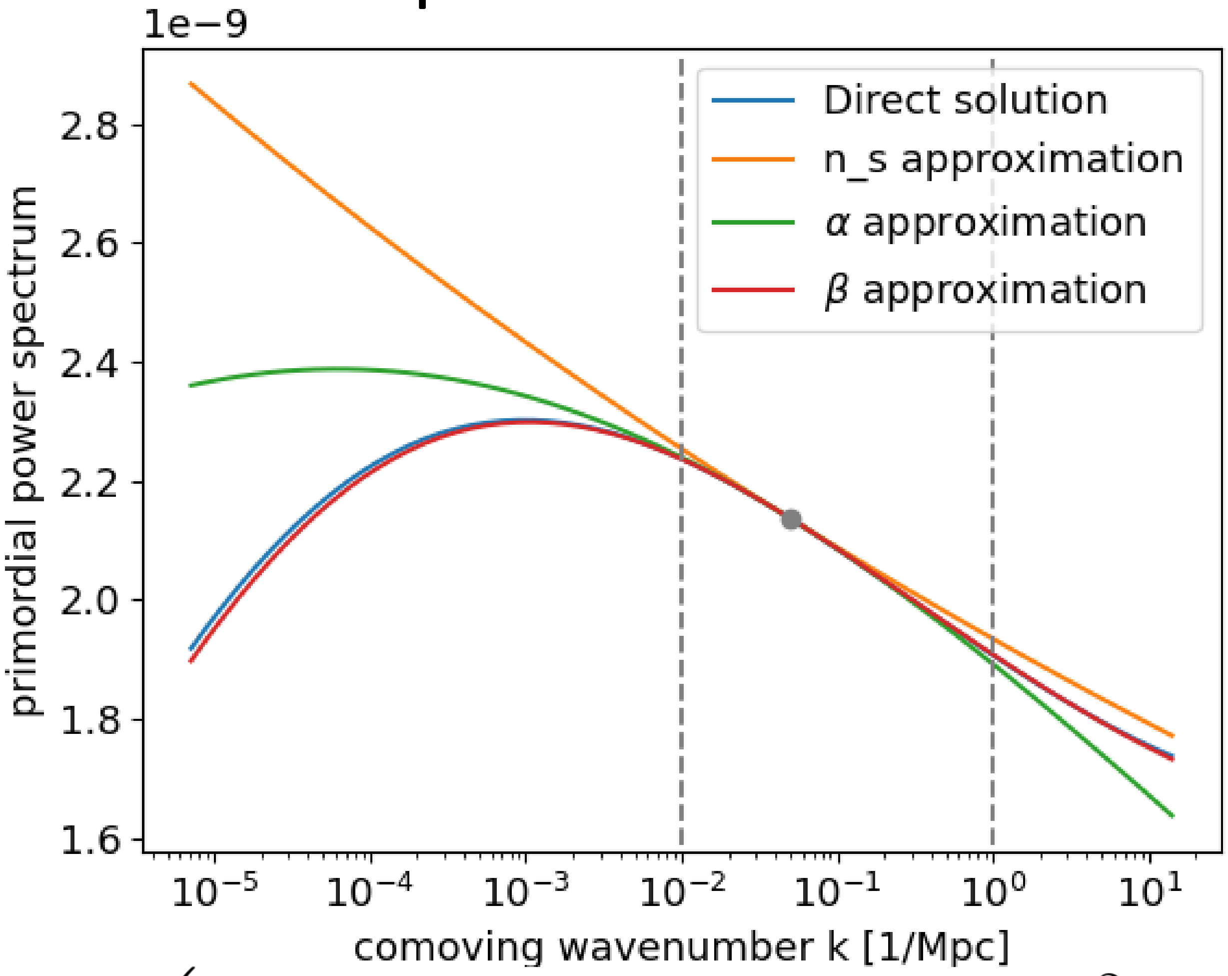
$$\mathcal{R}(\delta\varphi)$$

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

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

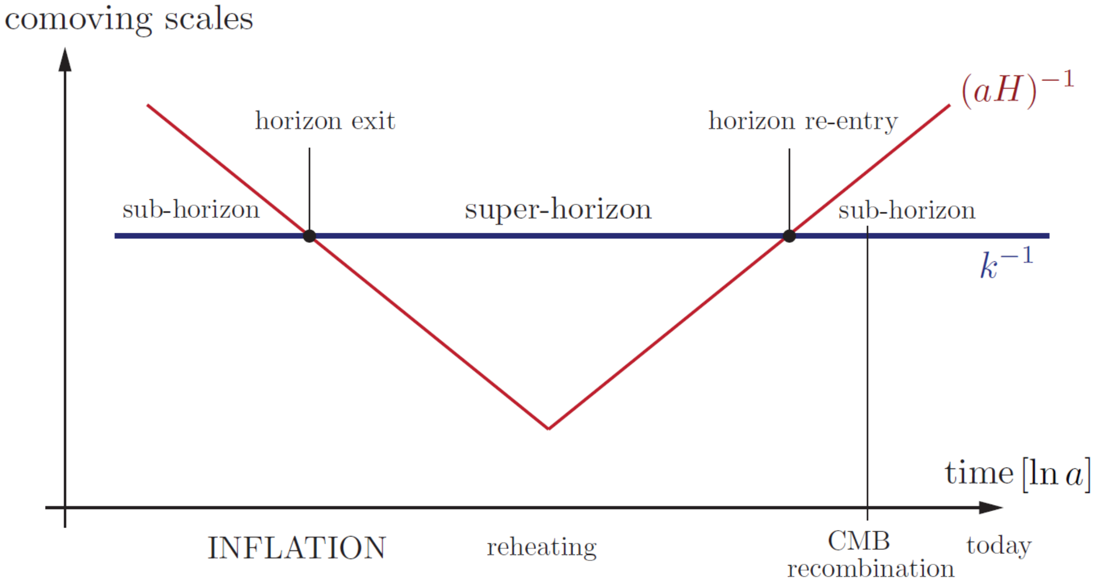
$$P_{\mathcal{R}}(k; \varepsilon_H, \eta_H, \xi_H^2, \omega_H^3)$$

Primordial Power Spectrum

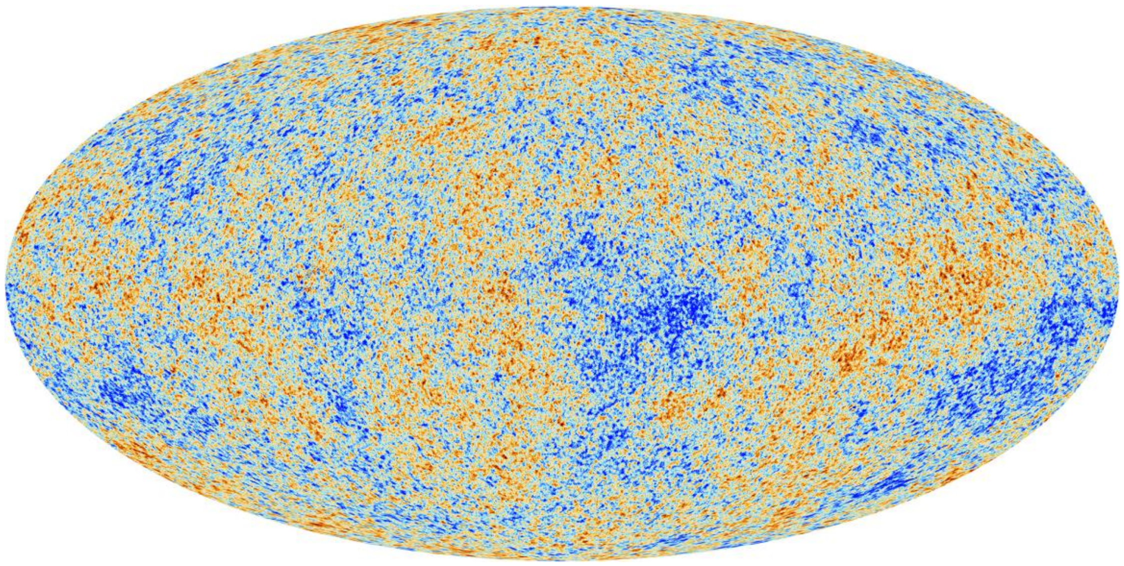


$$P_{\mathcal{R}}(k) = A_s \exp\left((n_s - 1)\ln\left(\frac{k}{k_*}\right) + \frac{\alpha}{2}\ln\left(\frac{k}{k_*}\right)^2 + \frac{\beta}{6}\ln\left(\frac{k}{k_*}\right)^3 \right)$$

Connection to Observations

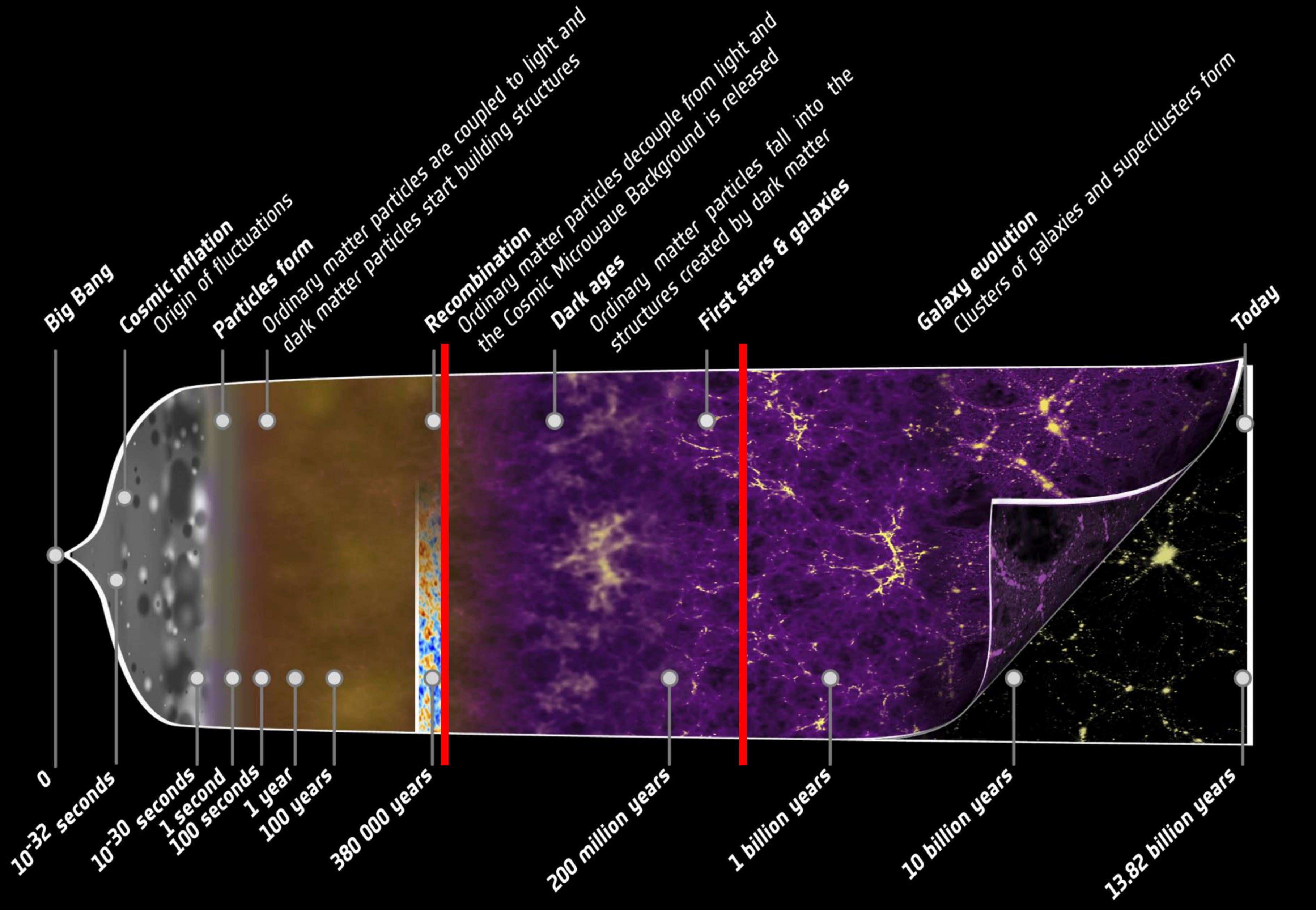


Baumann ICTS 2011 [2]



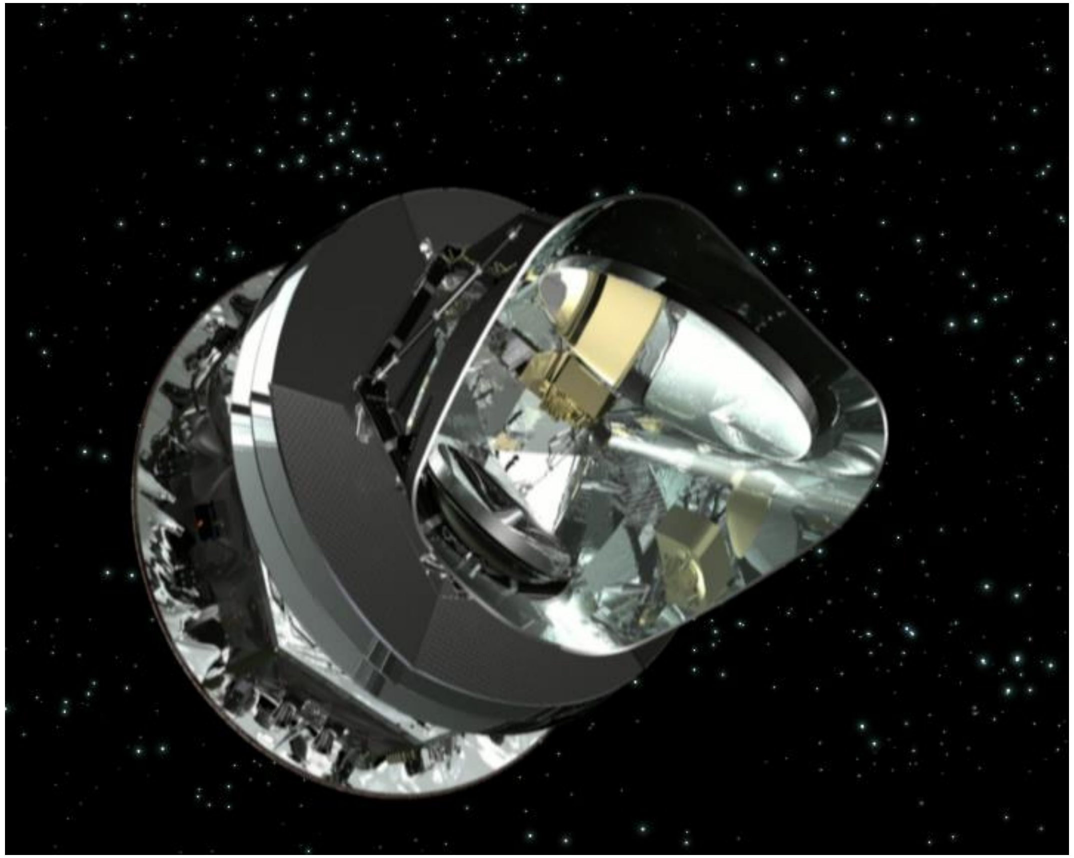
Cosmic Microwave Background [1] ESA

$P_{\mathcal{R}}(k)$ → $P_{\delta}(k)$ → $P_{HI}(k)$ → $P_{21}(k)$

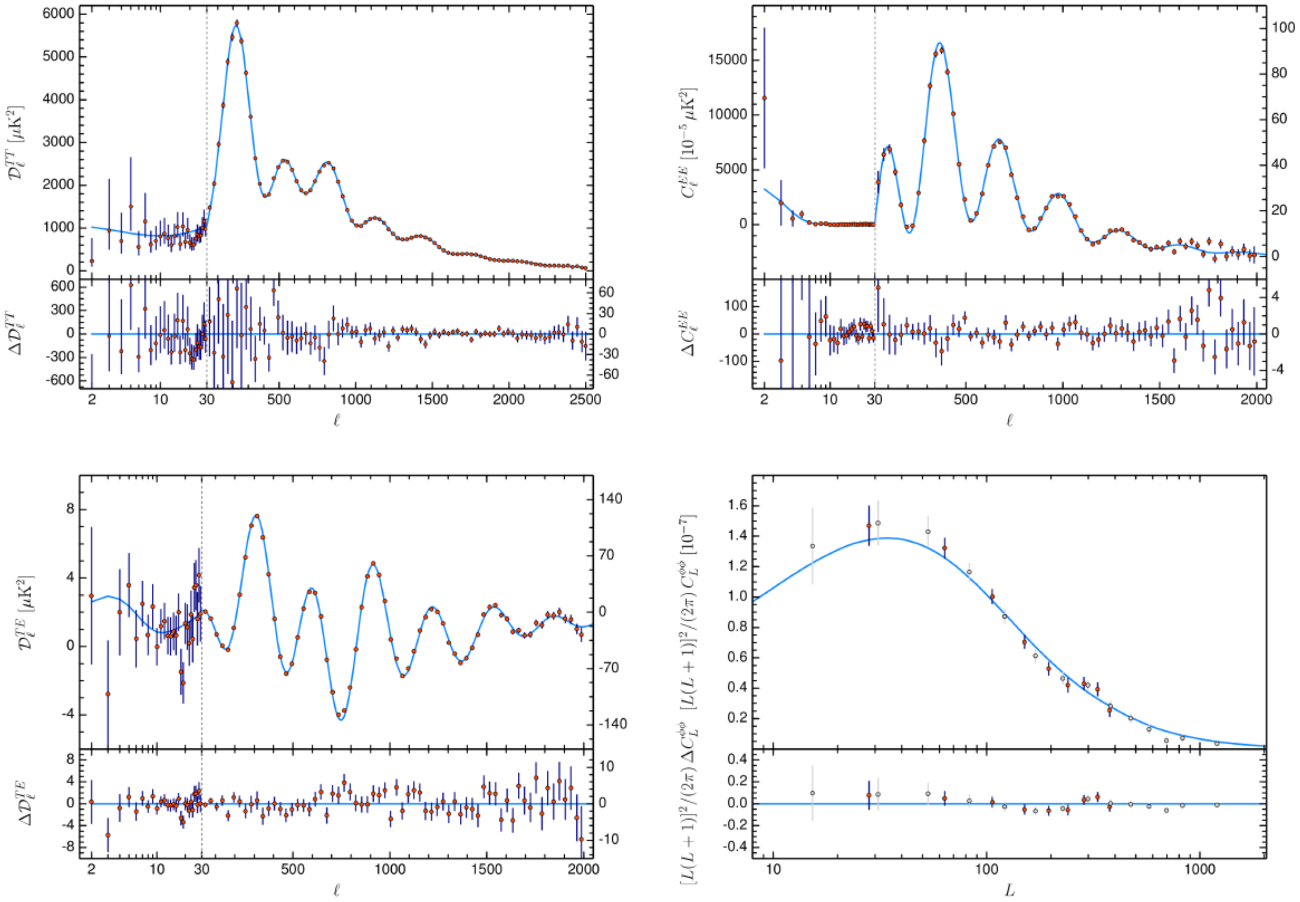


History of the Universe [1] ESA

Planck



Front view of the Planck satellite [1] ESA



Planck 2018 results X. Constraints on Inflation [3]

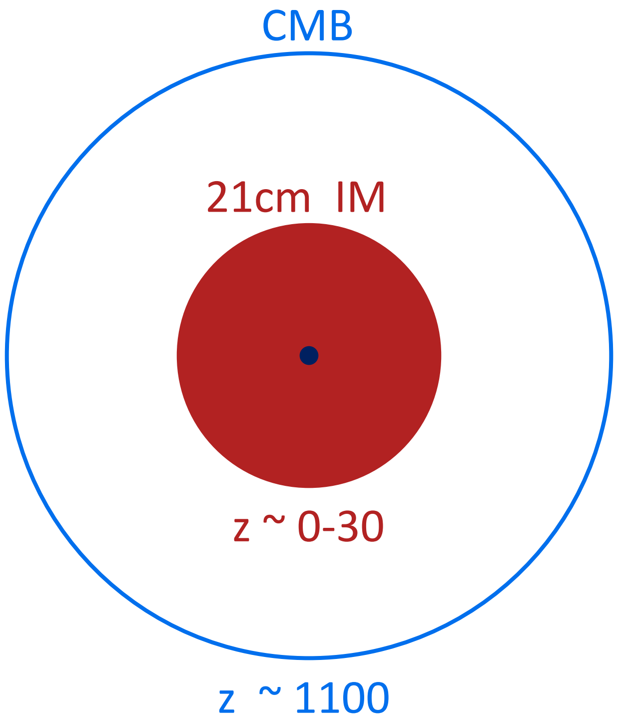
21cm Intensity Mapping

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

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

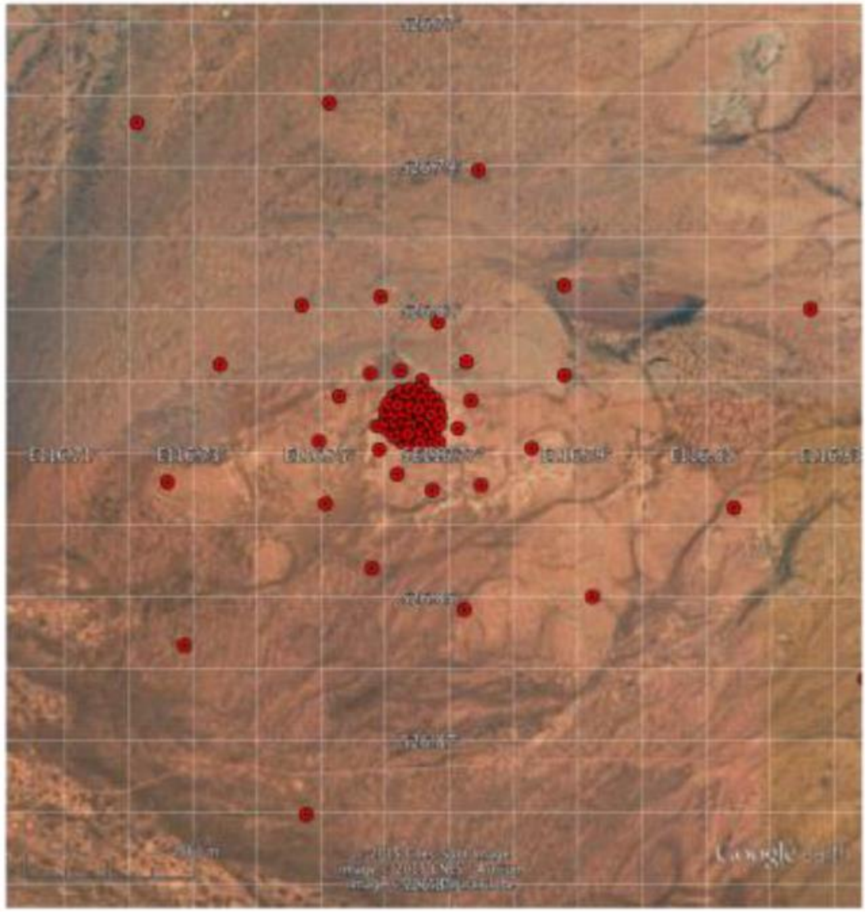
- 21cm power spectrum traces DM power spectrum

$$P_\delta(k) \Rightarrow P_{HI}(k) \Rightarrow P_{21}(k)$$



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]

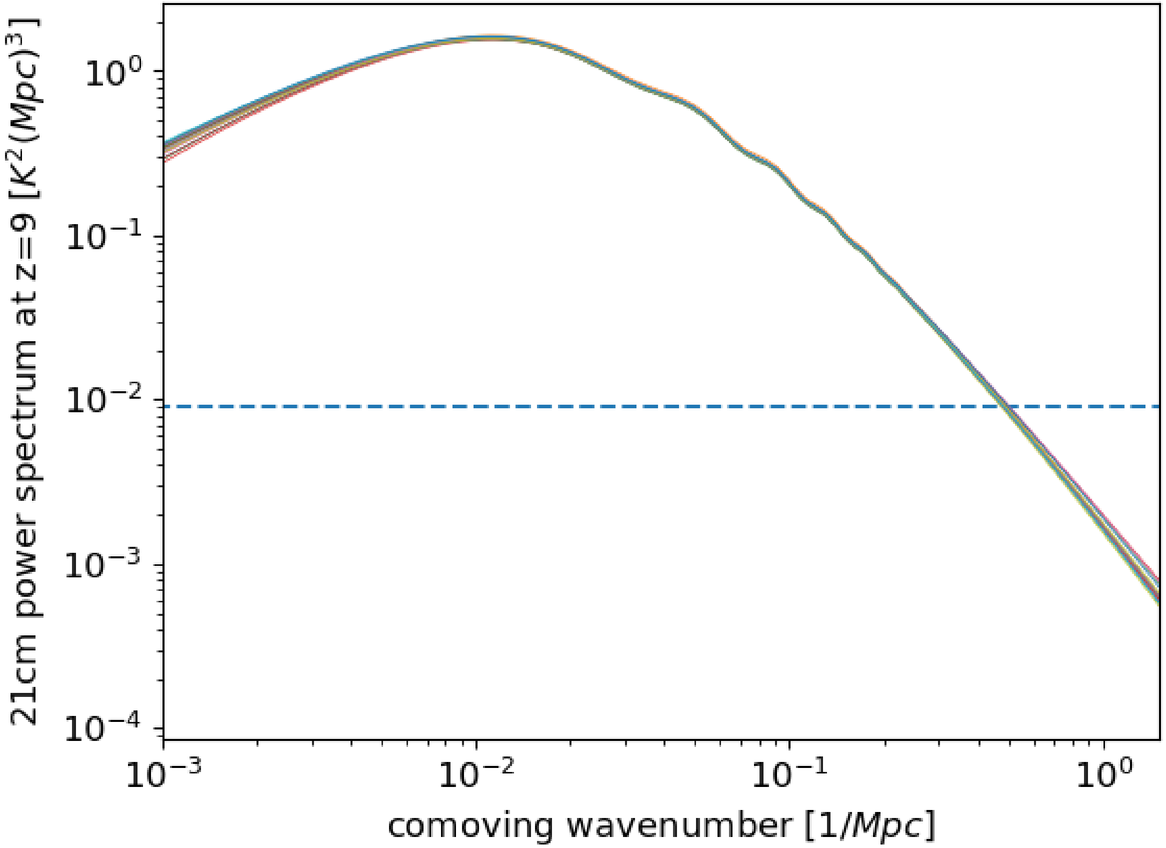
SKA forecasting

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

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

- Noise:

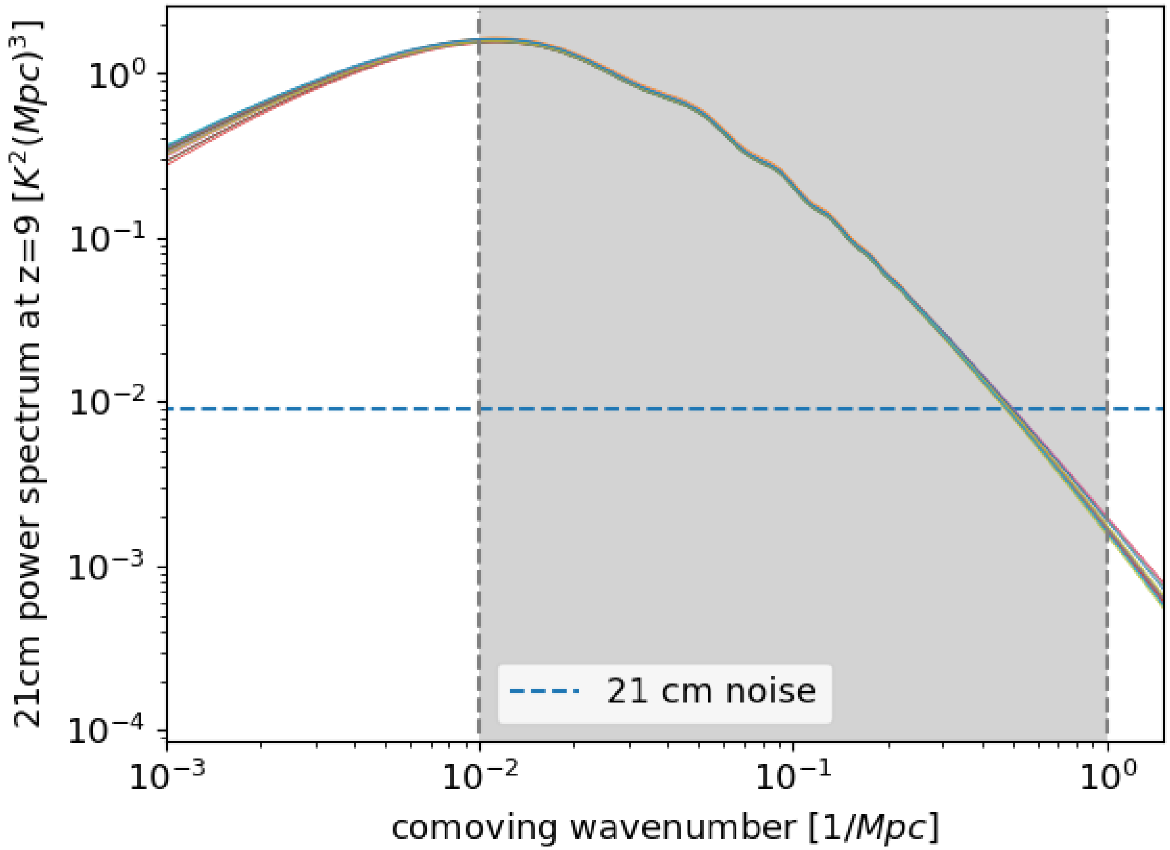
$$P_{21}^N = \frac{\pi T_{sys}^2}{t_o f_{cover}^2} d_A^2(z) y_\nu(z) \frac{\lambda^2(z)}{D_{base}^2}$$



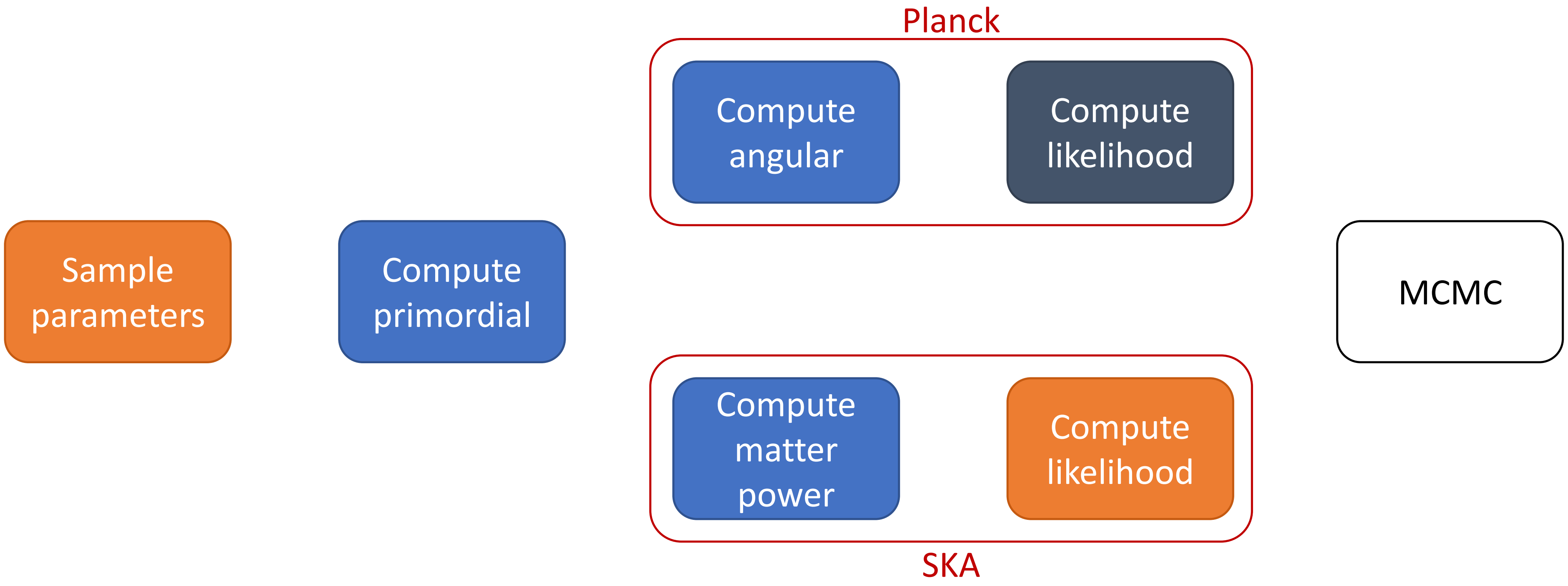
[Munoz et al., 2017], [Tegmark, Zaldarriga 2009]

SKA forecasting

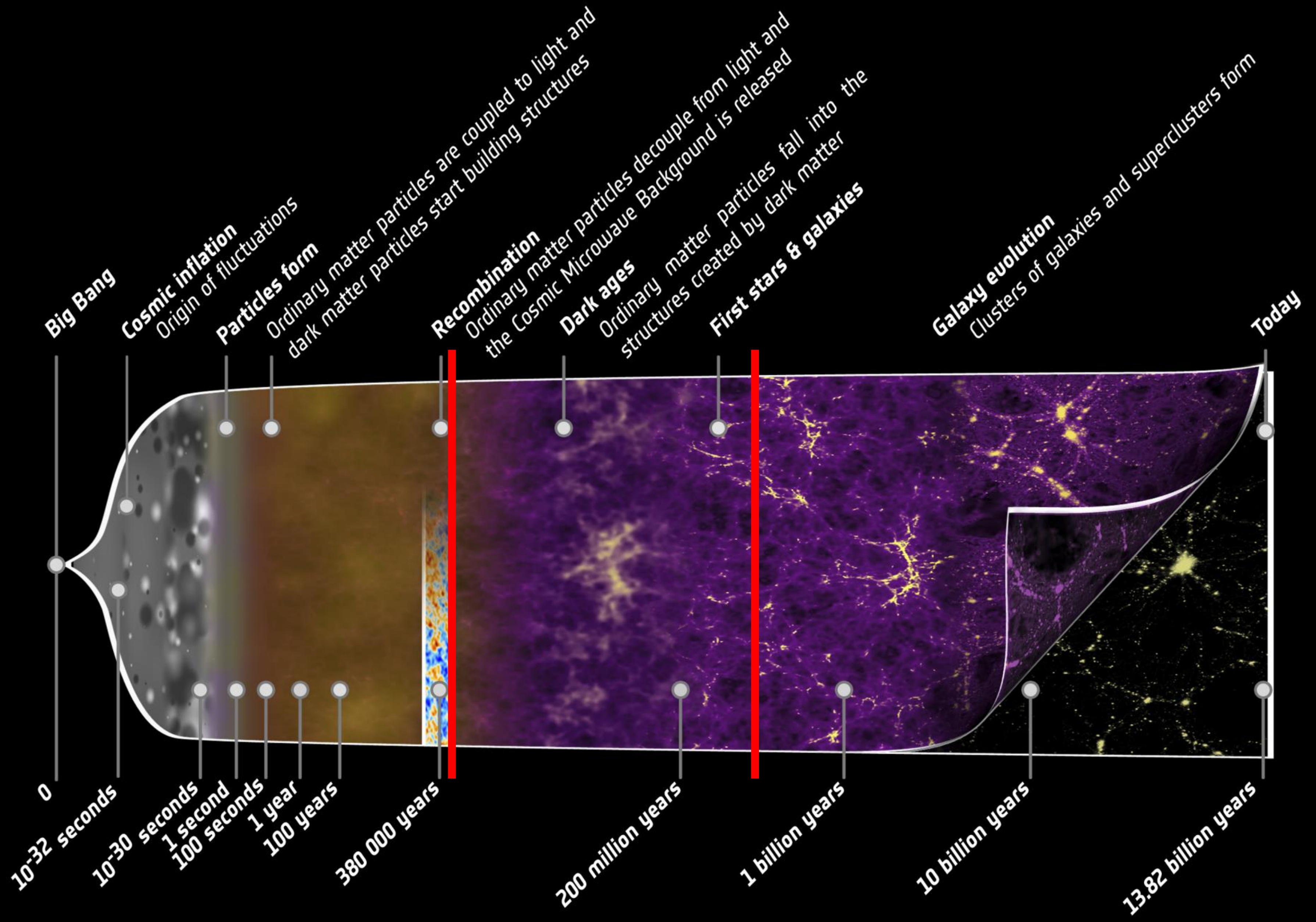
- Foregrounds
  - Galactic emissions, large scales
- Non-linear structure formation



Data analysis



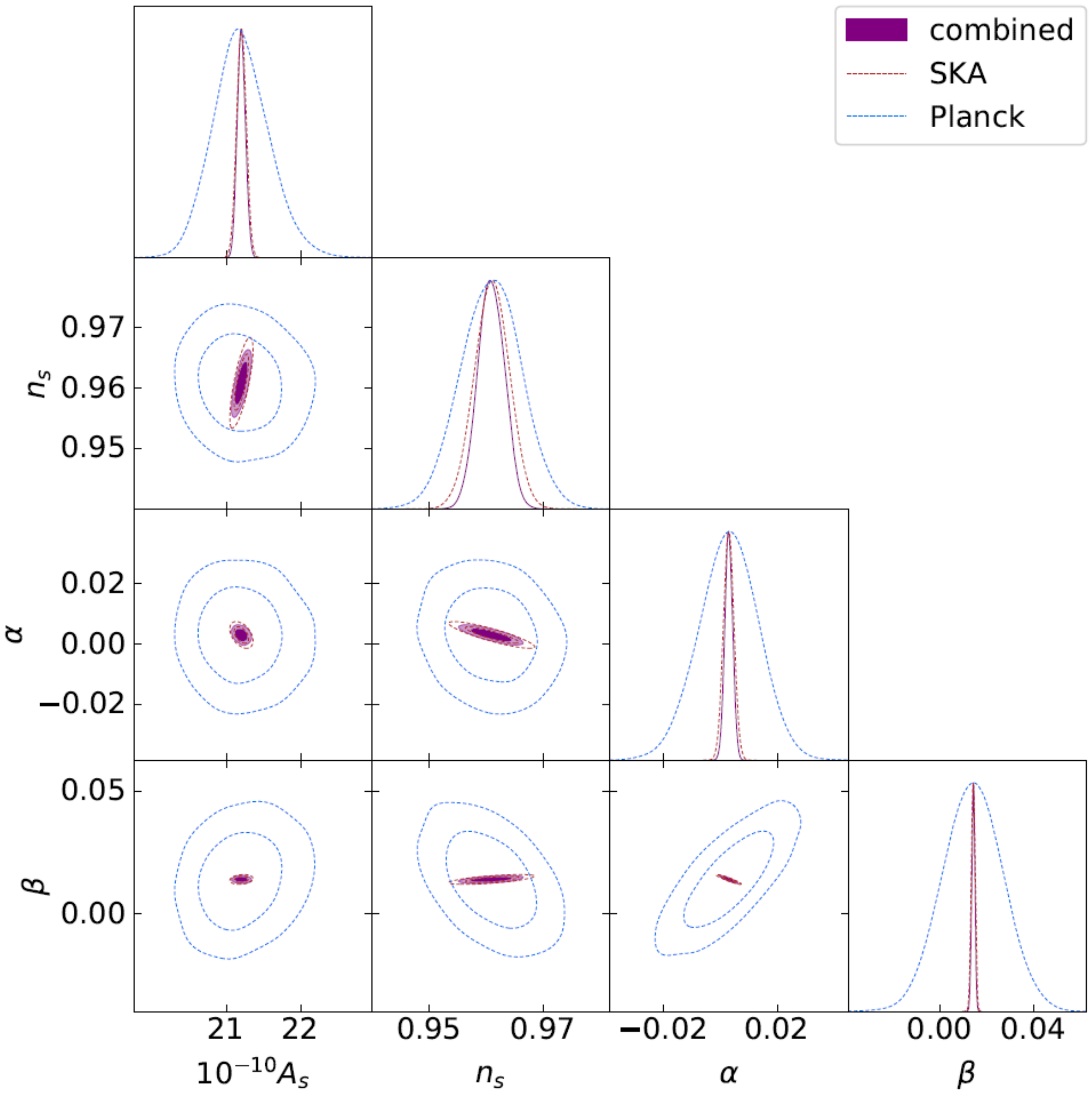
MontePython [5], [6], CLASS [7]



History of the Universe [1] ESA

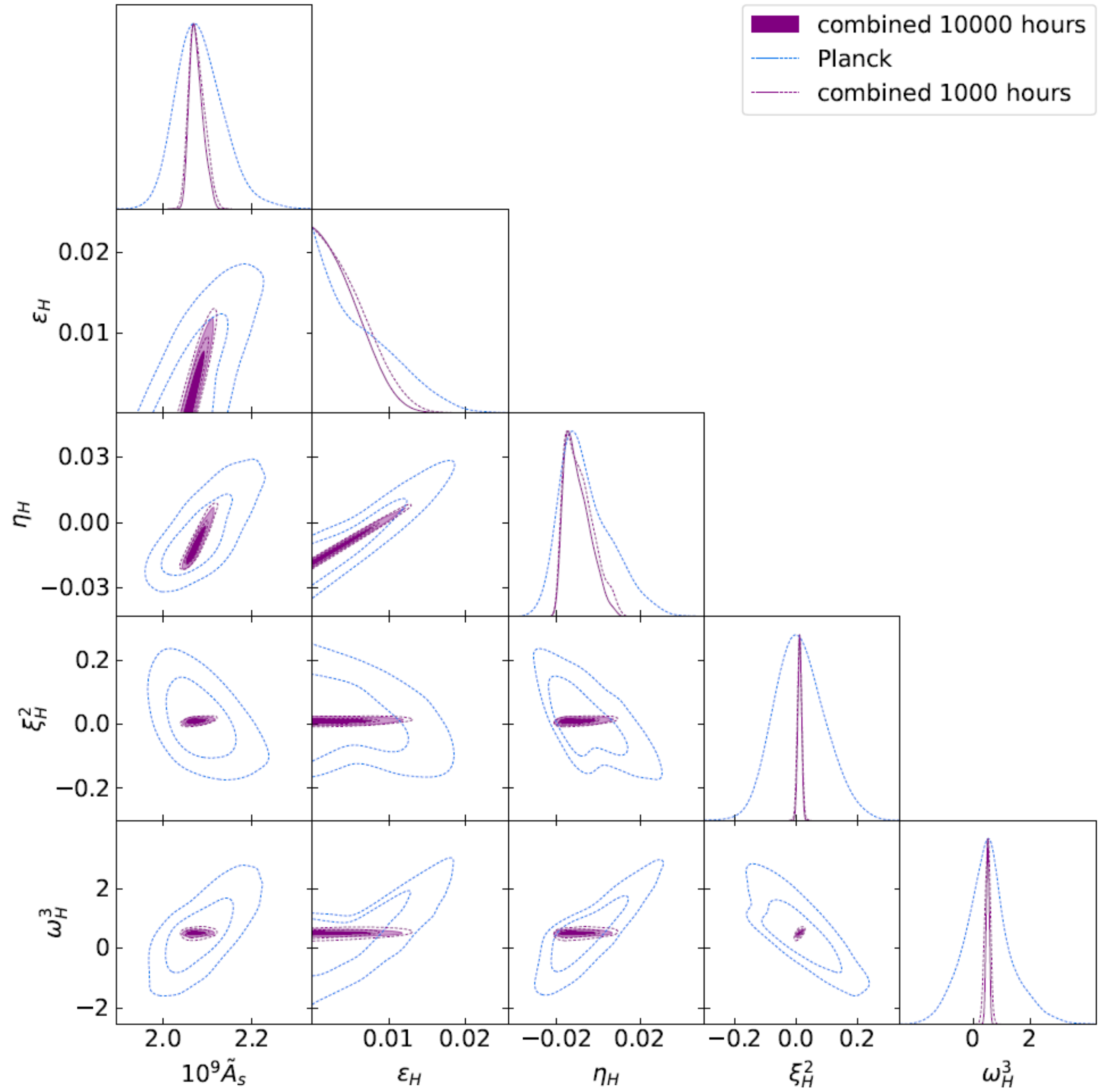
Primordial Power Spectrum

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



HSR parameters combined

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



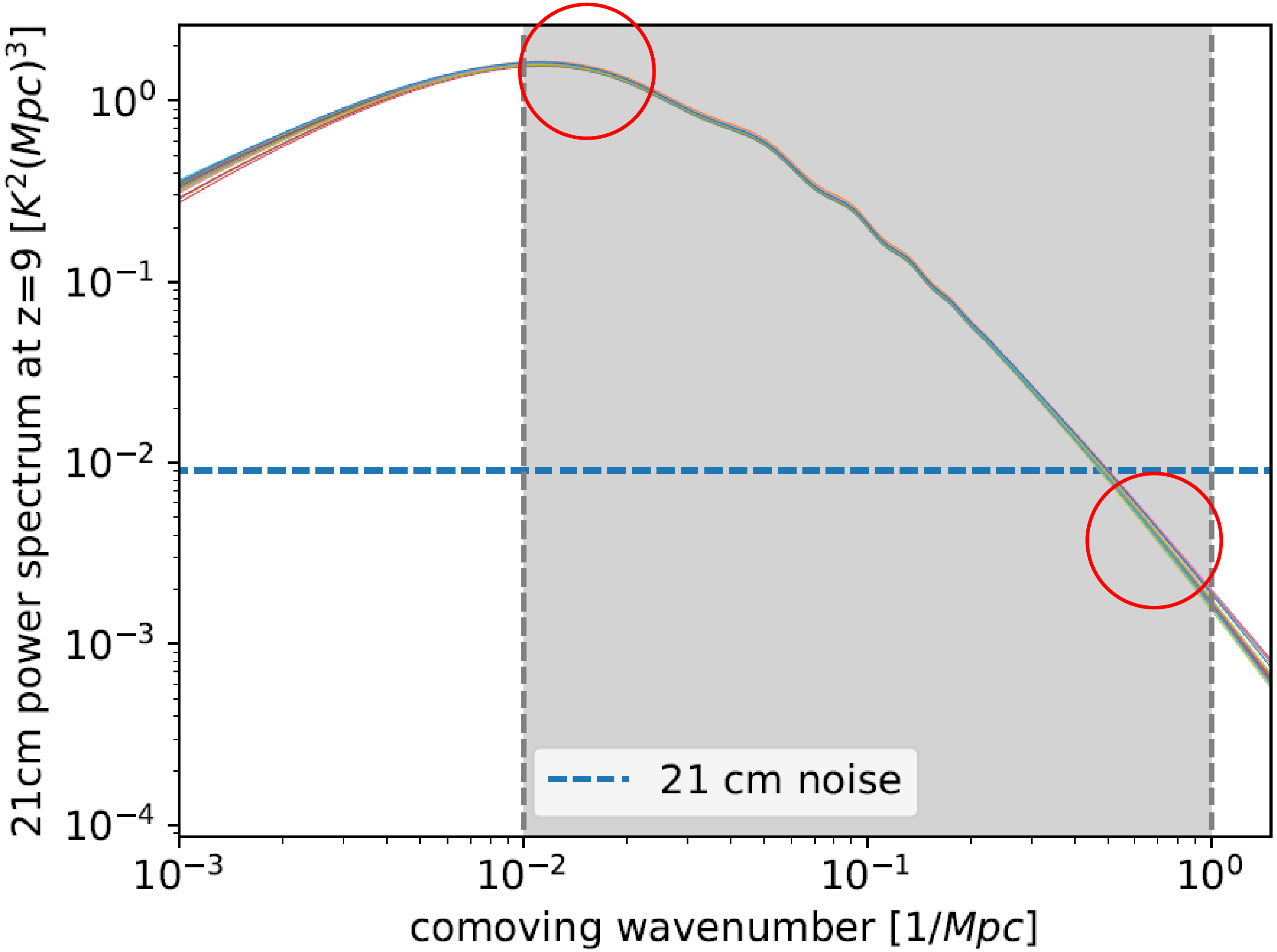
Combined results

- 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
- Deviation from slow-roll measured 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: Perturbations

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

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

- Bunch-Davies vacuum as initial conditions
- Spectrum of curvature perturbations $P_{\mathcal{R}}(k) = \frac{k^3}{2\pi^2}\left|\frac{u(k)}{z}\right|^2$

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

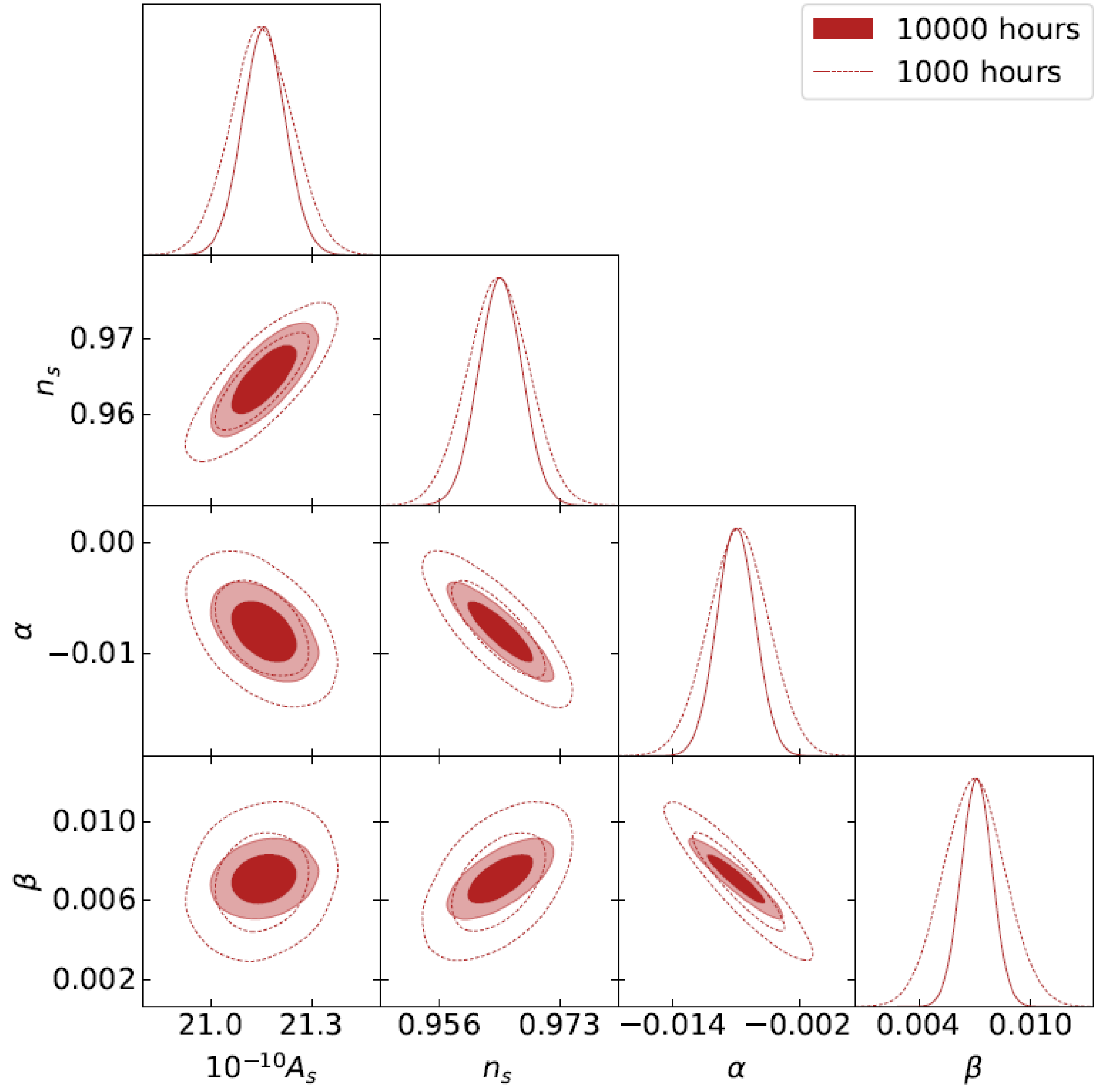
$$H(\varphi) = \sum_{n=0}^{N} \frac{1}{n!}\frac{d^n H}{d\varphi^n}\Big|_{\varphi_*}(\varphi - \varphi_*)^n$$

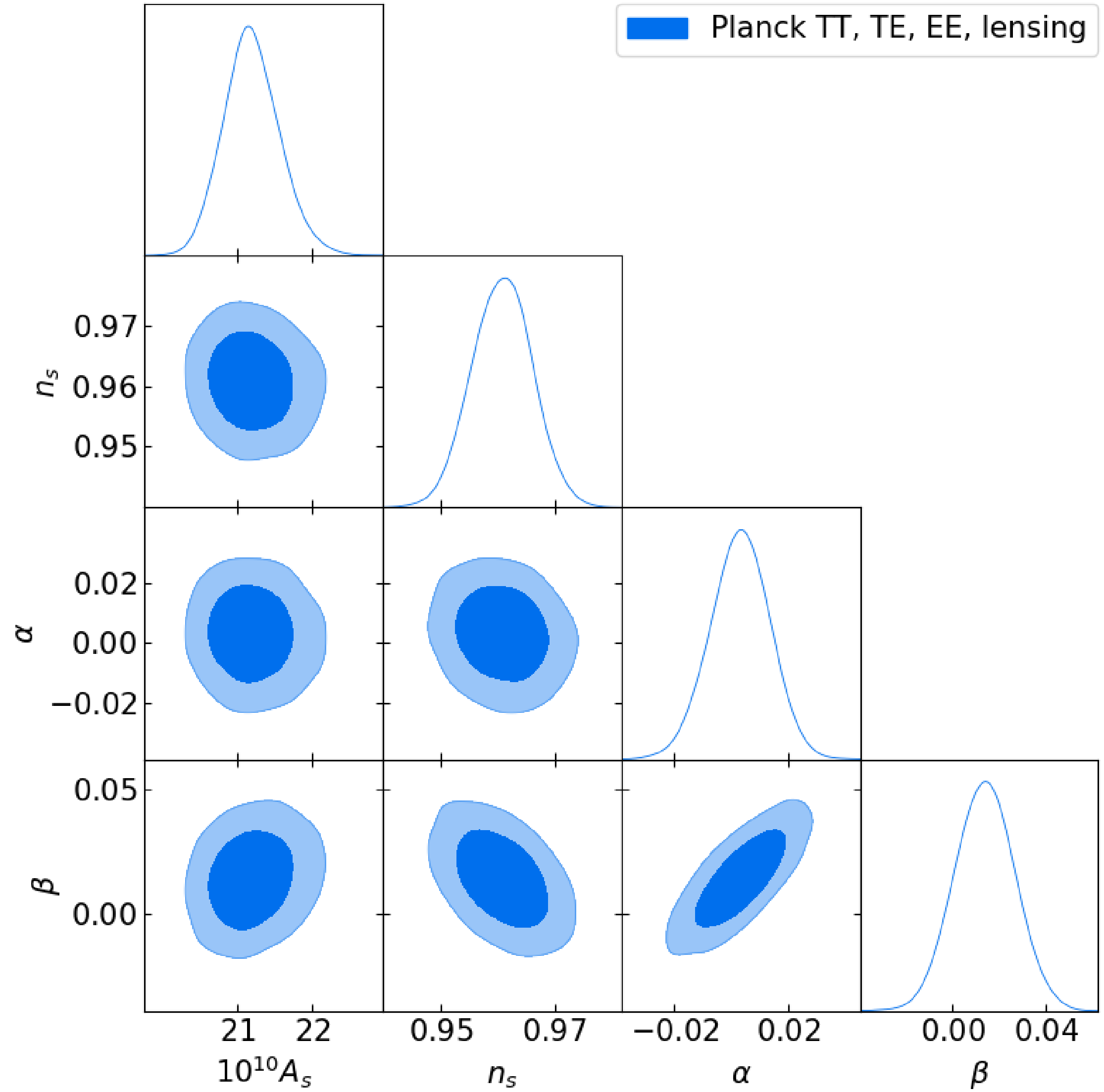
SKA likelihood

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

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

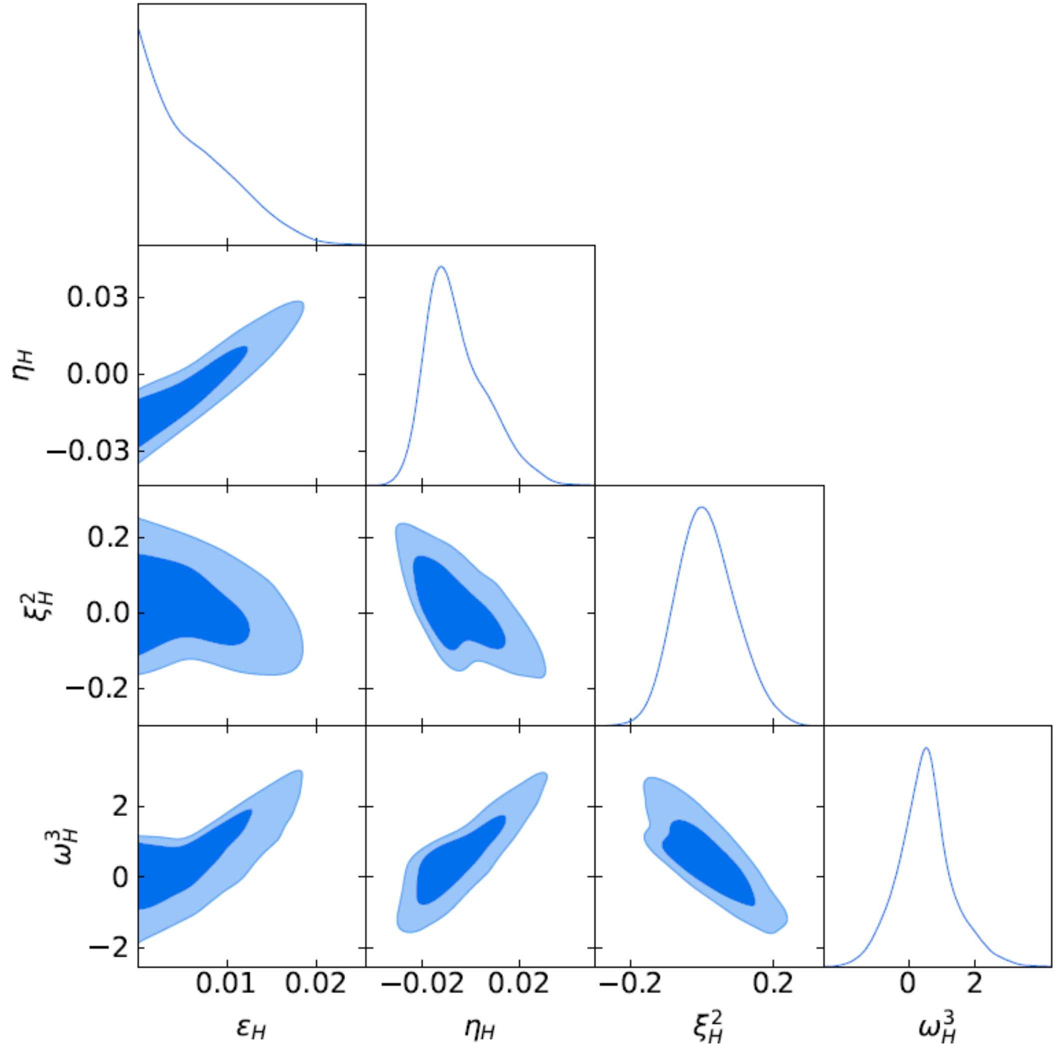
Primordial Power Spectrum $P_{\mathcal{R}}(k; n_s, \alpha, \beta)$

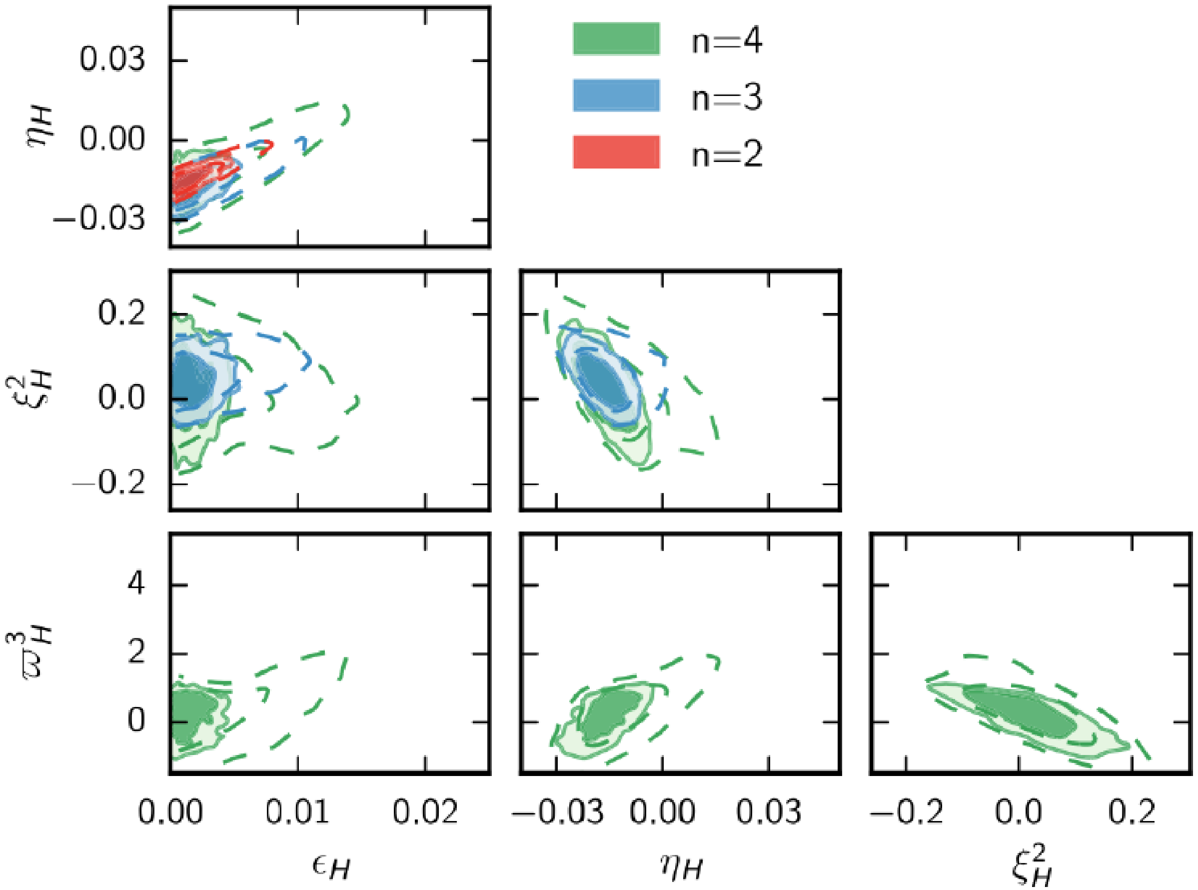




HSR parameters Planck

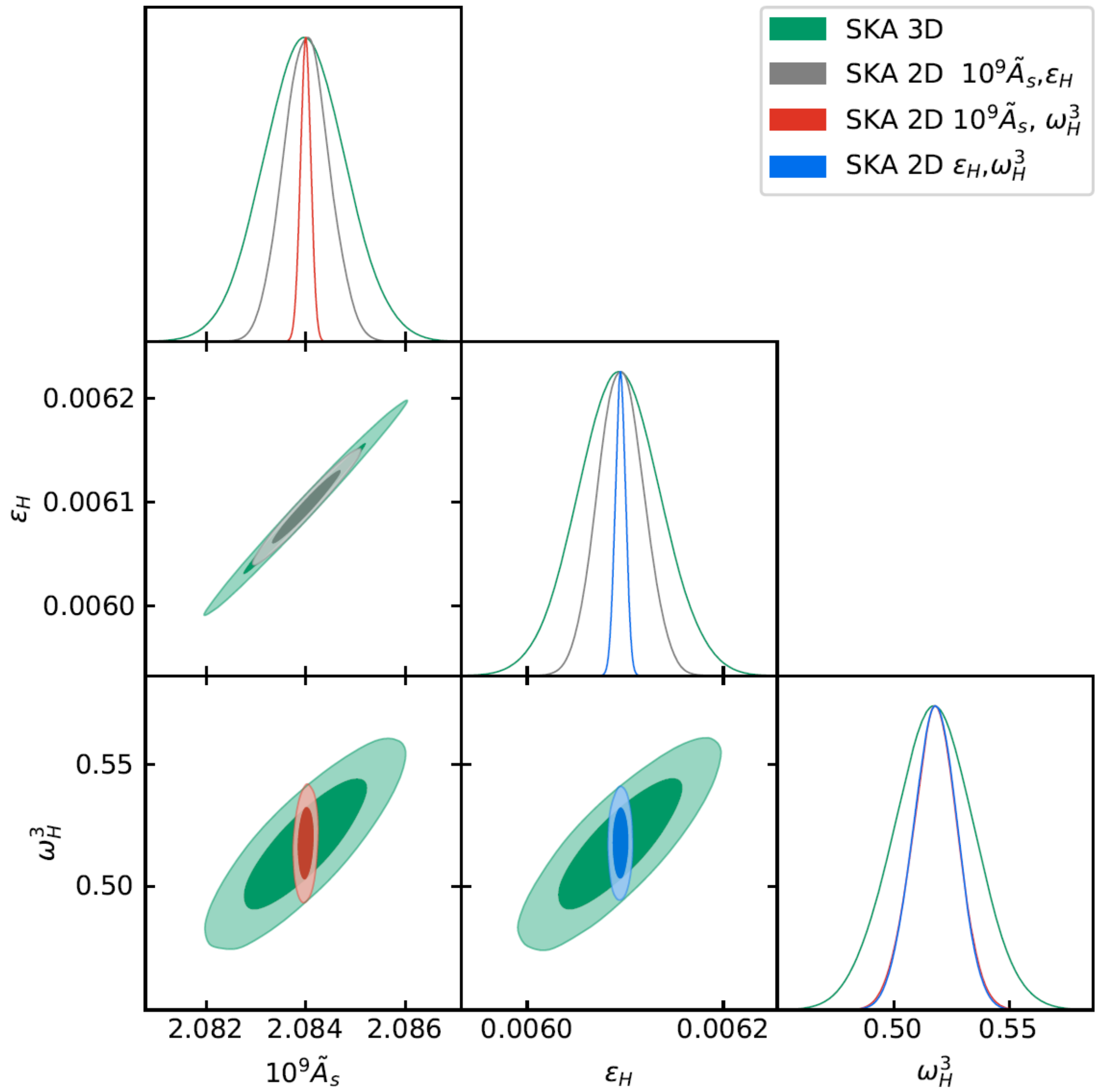
$$P_{\mathcal{R}}(k; \varepsilon_H, \eta_H, \xi_H^2, \omega_H^3)$$

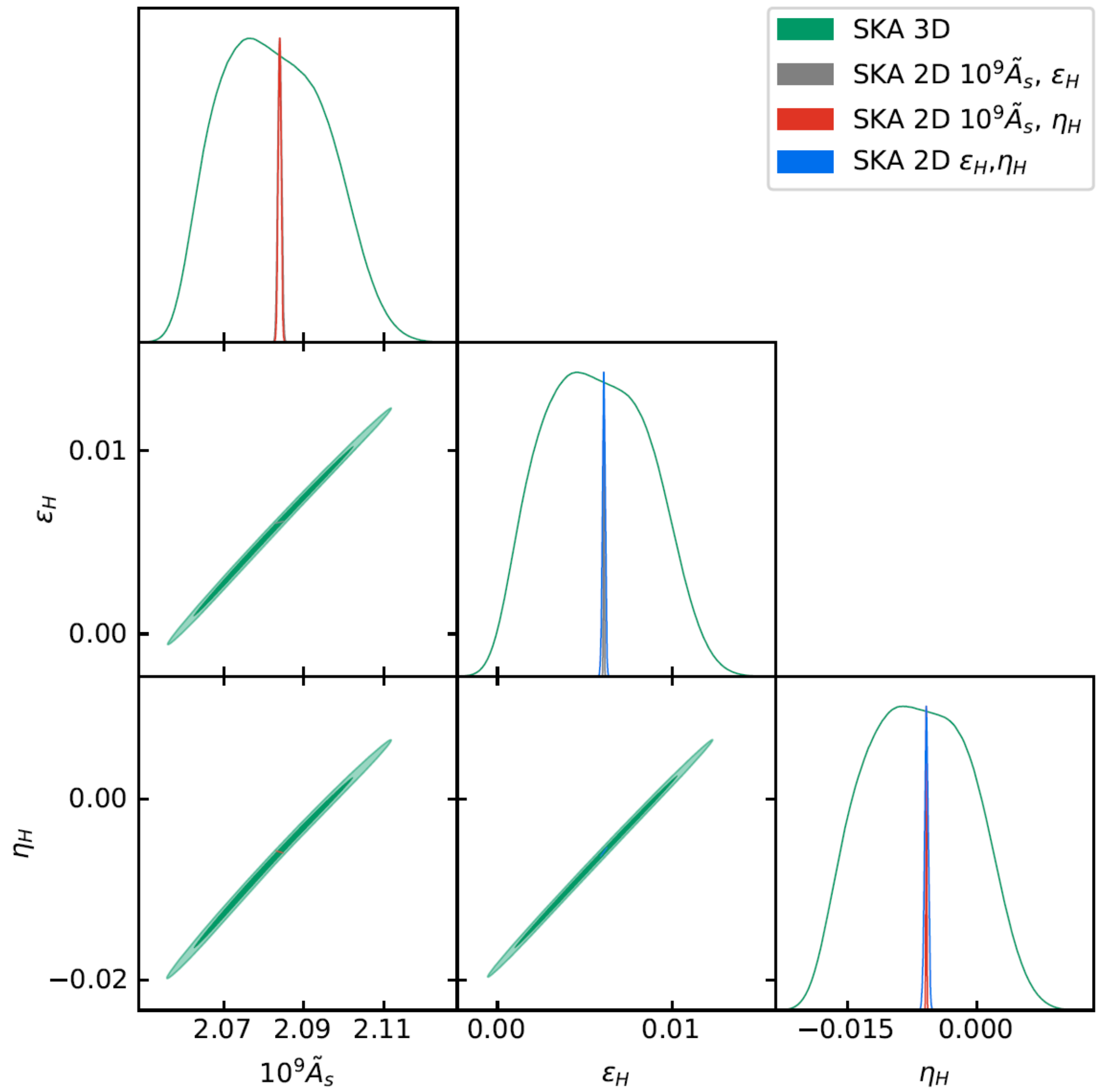


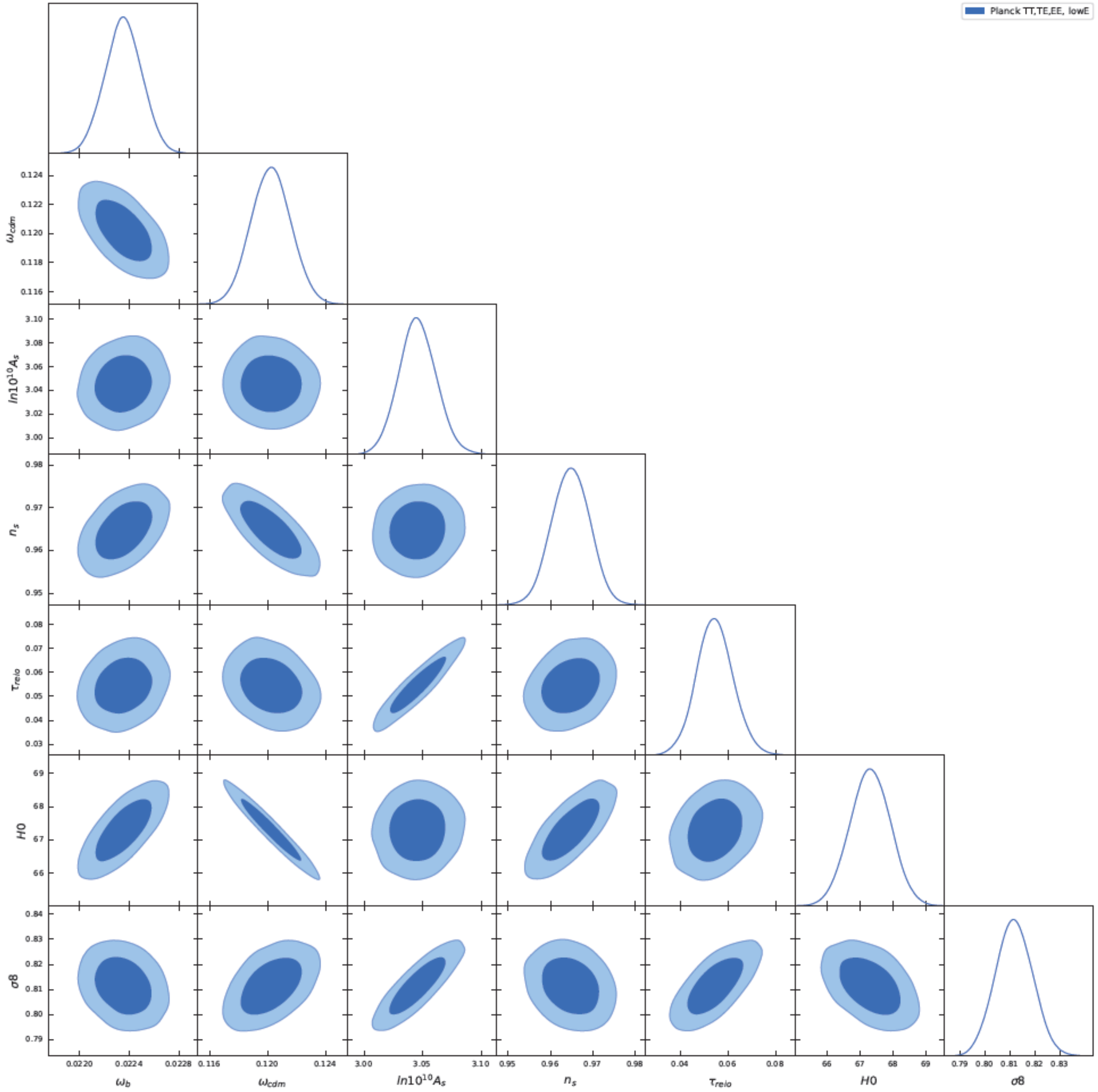


Planck 2018 results X. Constraints on Inflation [3]

HSR parameters SKA







Planck TT,TE,EE, lowE
ω_b
ω_{cdm}
$ln10^{10}A_s$
n_s
τ_{reio}
$H0$
$\sigma8$

HSR parameters SKA