Radio-optical synergies to constrain primordial non-Gaussianity

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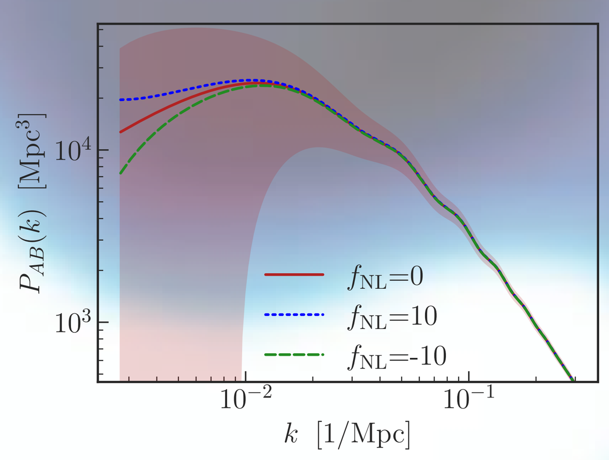
Primordial non-Gaussianity

Why Primordial non-Gaussianity (PNG)? Expected in many scenarios of inflation, it would be a direct proof of the inflation and would give a hint about the right model.
How to measure the PNG? The deviation from the perfect Gaussianity is quantified by the PNG parameter $f_{\rm NL}$, which enters the power spectrum of a tracer A of the matter distribution as an additional scale dependent bias term. The main issue is that PNG is a large scale effect, and large scales are limited by the cosmic variance.



$$b_A \to b_A + f_{\rm NL}\Delta b_A(k,z) \qquad \Delta b_A(z) = 3\left[b_A(z)-1\right]\frac{\delta_c \Omega_{m,0} H_0^2}{k^2 T(k) D(z)}$$

Auto-correlation, cross-correlation, multi-tracer

Observables and analysis:

- **Galaxies** auto power spectrum P_{gg} → Stage IV spectroscopic survey (flux limit of $F_c = 2\times 10^{-16}\,{\rm erg\,s^{-1}\,cm^{-2}}$, H$\alpha$ galaxies as main target, and Hβ, OIII and OII galaxies as interloper samples)
- **HI** auto power spectrum $P_{\rm HIHI}$ → SKAO-like radio intensity mapping survey (including beam damping at small $k_\perp$ and foreground avoidance at large $k_\parallel$)
- **Galaxies** × **HI** cross power spectrum $P_{g\rm HI}$
- **Multi-tracer** $P_{\rm MT} = \{P_{gg}, P_{g\rm HI}, P_{\rm HIHI}\}$

Given two tracers A and B of the matter distribution, the auto (A = B) and cross (A ≠ B) power spectra and the associated variance read as

$$P_{AB} = \left[b_A + \Delta b_A f_{\rm NL} + f\mu^2\right]\left[b_B + \Delta b_B f_{\rm NL} + f\mu^2\right] P_m$$

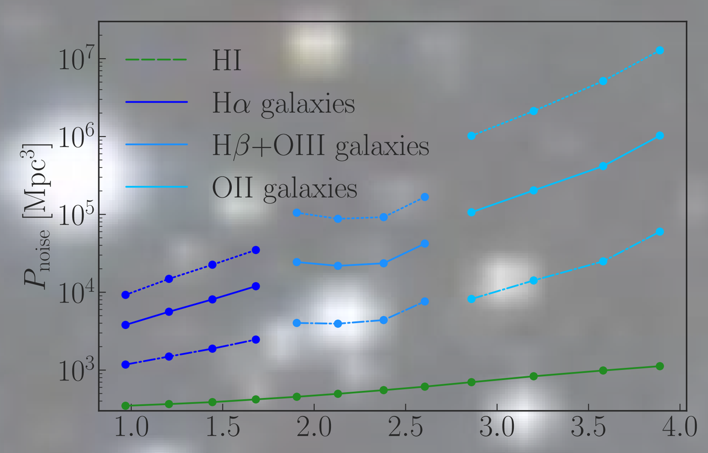
$$\left[\Delta P_{AB}\right]^2 = \frac{\tilde P_{AB}\tilde P_{AB} + \tilde P_{AA}\tilde P_{BB}}{N_{\rm modes}}$$

where $\tilde P_{AB} = P_{AB} + P^{\rm noise}_{AB}\,\delta^K_{AB}$, $P^{\rm noise}_{AB}$ is the (scale independent) noise and δ^K_{AB} is the Kroneker delta:

- **Galaxies** auto power spectrum ($A = B = g$) → **Shot noise**
- **HI** auto power spectrum ($A = B = $ HI) → **Thermal noise** of the antennas
- **Galaxies** × **HI** cross power spectrum ($A = g$, $B = $ HI) → No noise term: the noise is not correlated between independent tracers

$$P^{\rm shot}_{gg}(z) = \frac{1}{\bar n_g(z)} \qquad P^{\rm thermal}_{\rm HIHI}(z) = \frac{2\pi f_{\rm sky}}{N_d\,\nu_{21\rm cm}\,t_{\rm tot}}\frac{(1+z)\,\chi(z)^2}{H(z)}\left[\frac{T_{\rm sys}}{T_{\rm HI}}\right]^2 \qquad P_{g\rm HI} = 0$$

The multi-tracer covariance matrix ${\rm Cov}(\boldsymbol{P}_{\rm MT}, \boldsymbol{P}_{\rm MT})$ is a 3 × 3 matrix.

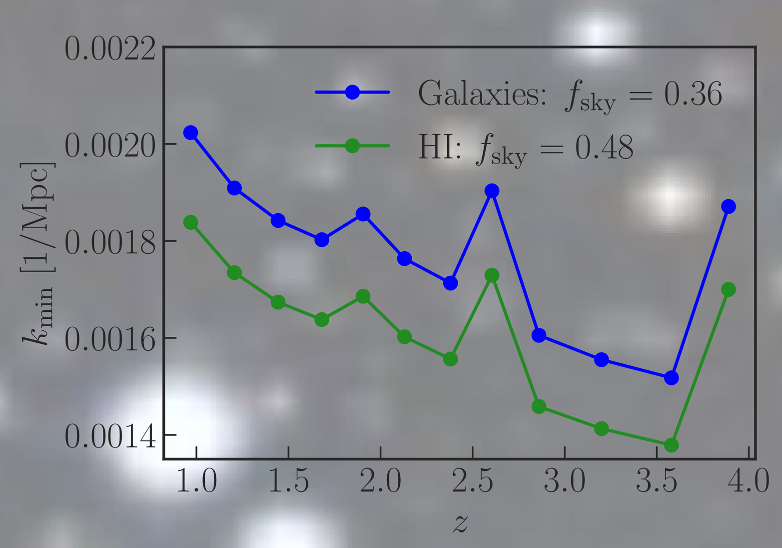


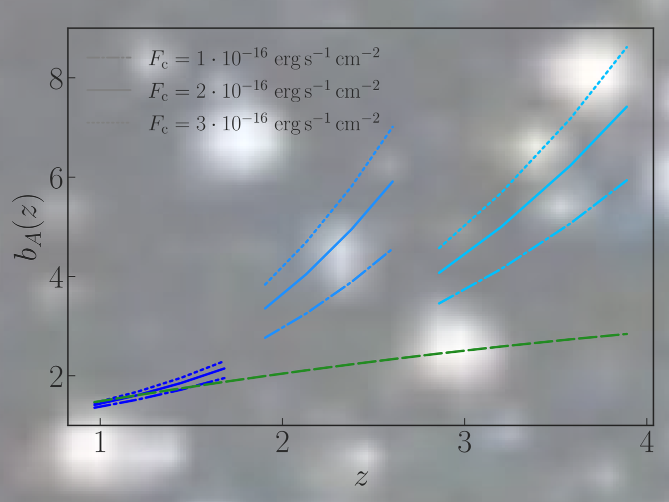
Dataset

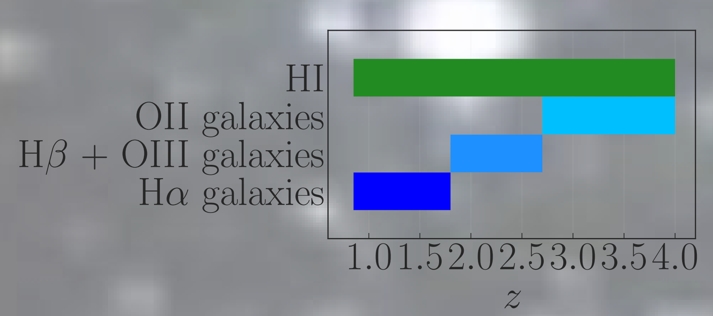
Model sampled in:

- 12 z bins → $z \in [0.85, 4.0]$
- 50 k bins → $k \in [k_{\rm min}(z), k_{\rm max}(z)]$ where

$$k_{\rm min}(z) = 2\pi V_{\rm sky}^{-1/3}(z) \qquad k_{\rm max}(z) = 0.08\,(1+z)^{2/(2+n_s)}\,h\,{\rm Mpc}^{-1}$$







Multivariate analysis

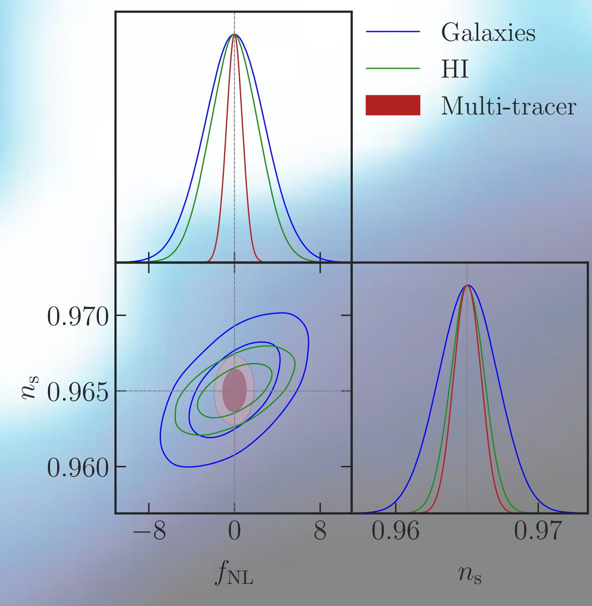
MCMC chains were used to sample the likelihood aiming to recover not only the **PNG parameter** $f_{\rm NL}$ but also the **primordial spectral index** (n_s) and the **bias parameters** of the tracers (b_g and $b_{\rm HI}$).

- **Full data set** → Global constraint on $f_{\rm NL}$ exploiting the whole redshift range avaliable
- **2 redshift bins** at a time → Study of the trend of the results with respect to the redshift
- **Redshift grouped per ELG type** in the spectroscopic survey → More information available; study of the impact of the observed galaxy number density and the of the tracer's bias

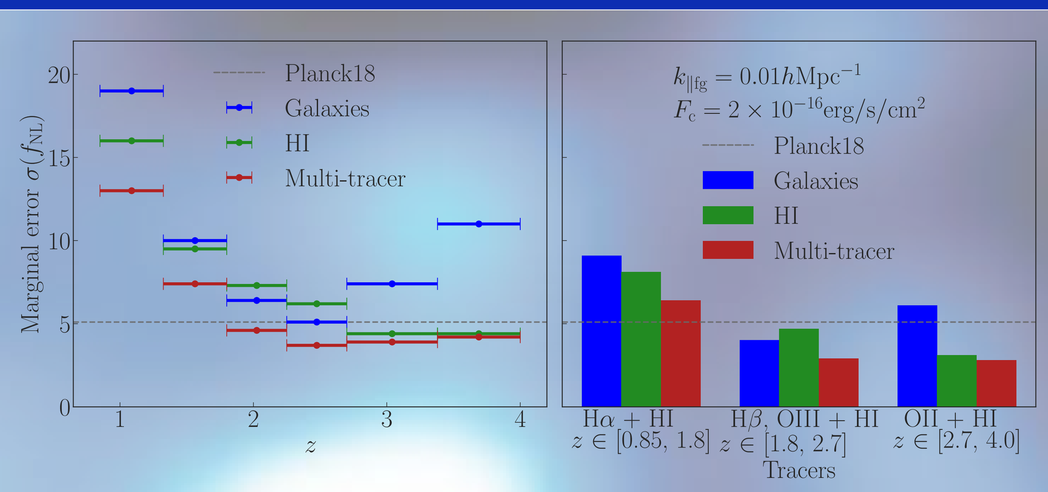
$$\ln\mathcal{L}(\boldsymbol{d}|\boldsymbol{\theta})^{\rm MT}_{\rm tot} = \ln\mathcal{L}(\boldsymbol{d}|\boldsymbol{\theta})^{\rm MT}_{\rm overlap} + \ln\mathcal{L}(\boldsymbol{d}|\boldsymbol{\theta})^{AA}_{\rm no\text{-}overlap} + \ln\mathcal{L}(\boldsymbol{d}|\boldsymbol{\theta})^{BB}_{\rm no\text{-}overlap}\,,$$

Global constraints

- **Galaxies** auto power spectrum → $f_{\rm NL} = 0.0 \pm 2.8$
- **HI** auto power spectrum → $f_{\rm NL} = 0.0 \pm 2.3$;
- **Multi-tracer** → $f_{\rm NL} = -0.01 \pm 0.76$

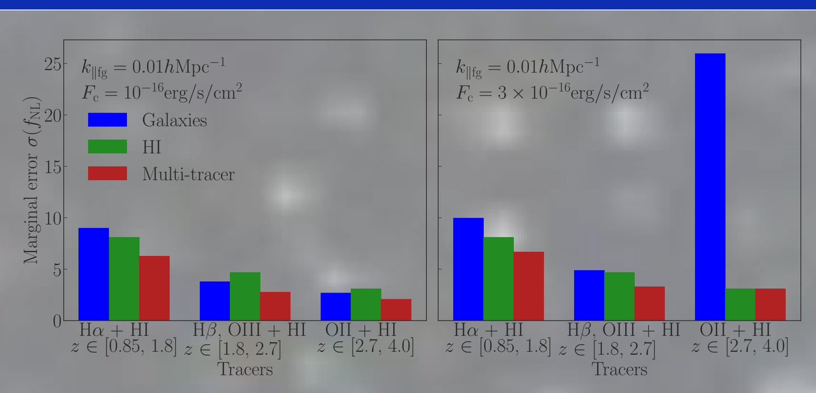


$\sigma(f_{\rm NL})$ vs redshift and tracers



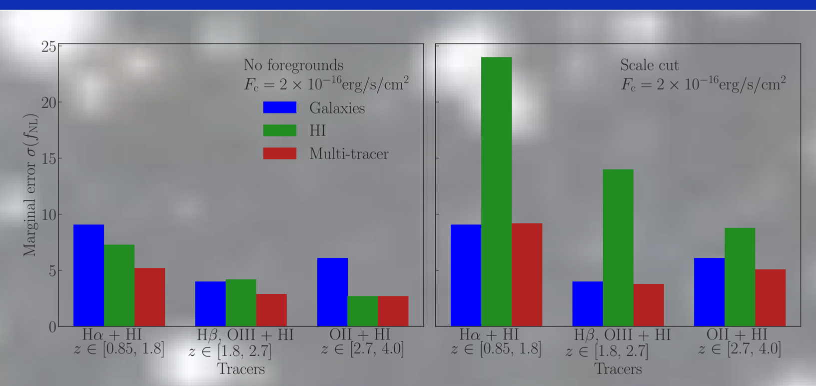
- Better constraints at **higher** z, except for the galaxies auto power spectrum at $z > 2.7$ (the sample is too sparse) and at low redshift (the bias term $b_g - 1$ is too close to unity)
- **Improvement** of a factor 2 when grouping more redshift bins
- The **multi-tracer technique is more powerful** (up to 30%) than the simple auto-correlation of a tracer; it is robust to the lower galaxy number density, to the low galaxy bias and to the effect of 21cm foregrounds.

Impact of the flux limit



- Analysis of the galaxy sample with **different F_c**
- **Bias terms** evaluated according to the flux limit: a lower flux limit implies a lower bas and viceversa
- **Variation of the galaxy number densities** and of the shot noise
- Strong impact at high z, mild effects at low z
- Differences mitigated in the multi-tracer analysis

Impact of foregrounds



- Analysis of the HI data set with **different approaches for foregrounds**
- **Improvement** of 15% for the ideal case **without foregrounds**
- **Strong degradation** of the constraints in the largest scales are cut away to simulate a more **severe signal loss**
- Multi-tracer technique stable

Conclusion

- The multi-tracer method performs better than the autocorrelation of a single tracer in every configuration analysed
- The multi-tracer methods provides $\sigma(f_{\rm NL}) \le \mathcal{O}(1)$, the threshold required to **discriminate different inflationary models**
- Including **high redshift** data sets also for a spectroscopic survey (exploitation of interloper galaxies) leads to tighter constraints, which might be improved if a survey can look at a **lower flux limit**
- Improvement from the HI intensity mapping can be provided if **foregrounds** are well understood