Probing primordial non-Gaussianity with Fast Radio Bursts

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arXiv:2007.04054

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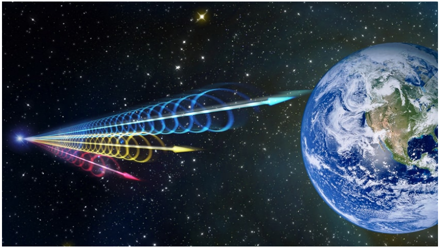
Fast Radio Bursts (FRBs)

- Short radio transients, $T \sim$ ms, $\nu \sim 10^{11-12}$ Hz
- Delay in arrival time $\sim \nu^{-2}$
- Dispersion measure (DM) probes electron distribution

$$\mathrm{DM} \sim \int n_e \, \mathrm{d}l$$

- Expect $\sim 10^4$ FRBs per decade up to cosmological distances



Jingchuan Yu, Beijing Planetarium

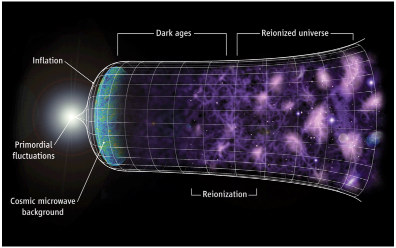
Primordial non-Gaussianity (PNG)

- Many models of inflation predict small PNG
- Local models parametrized by $f_{\rm NL}$

$$\phi_{\rm NG} = \phi_{\rm G} + f_{\rm NL}\,\phi_{\rm G}^2 + \mathcal{O}(\phi_{\rm G}^3)$$

- CMB constraint from Planck-18 is $f_{\rm NL} = 0.9 \pm 5.1$

$\Longrightarrow$ Probe inflation by tightening the constraint using LSS



Faucher-Giguère et al., Science 31 (2008) 5859

Large-scale bias from PNG

- Long ϕ_{NG}-modes couple to small-scale δ-fluctuations

$\Longrightarrow$ Scale-dependent bias contribution

$$b \longrightarrow b + \Delta b^{\mathrm{NG}}(k, z)$$

- Peak-background split approach predicts

$$\Delta b^{\mathrm{NG}}(k, z) = f_{\mathrm{NL}}\,(b-1)\,\frac{1}{k^2}\,\frac{3\delta_{\mathrm{c}}\Omega_{\mathrm{m}0}H_0^2}{aT_\phi(k, z)c^2}$$

$\Longrightarrow$ Distinct large-scale feature in spectrum of biased tracers

Dispersion measure sources

- DM splits into three contributions

$$\mathrm{DM}_{\mathrm{tot}}(\hat{\boldsymbol{x}}, z) = \mathrm{DM}_{\mathrm{MW}}(\hat{\boldsymbol{x}}) + \mathrm{DM}_{\mathrm{host}}(z) + \mathrm{DM}_{\mathrm{LSS}}(\hat{\boldsymbol{x}}, z)$$

- Subtract model for $\mathrm{DM}_{\mathrm{MW}}(\hat{\boldsymbol{x}})$
- Approximate $\mathrm{DM}_{\mathrm{host}}$ by mean plus Gaussian scatter

$$\langle \mathrm{DM}_{\mathrm{host}} \rangle(z) \approx \sigma_{\mathrm{DM,host}}(z) \approx 50\ \mathrm{pc\,cm}^{-3}\,(1+z)^{-1}$$

- LSS contribution dominates and depends on electron bias

$$\begin{aligned}\mathrm{DM}_{\mathrm{LSS}}(\hat{\boldsymbol{x}}, z) &= \langle \mathrm{DM}_{\mathrm{LSS}} \rangle(z) + \mathcal{D}(\hat{\boldsymbol{x}}, z) \\ &= \frac{3 H_0 \Omega_{\mathrm{b}0} c}{8\pi G m_{\mathrm{p}}} \int_0^z \mathrm{d}z'\, \frac{1+z'}{E(z')}\, F(z') \left[1 + b_{\mathrm{e}}(\boldsymbol{x}, z')\, \delta_{\mathrm{m}}(\boldsymbol{x}, z')\right]\end{aligned}$$

Electron bias

- Feedback pushes electrons out of halos
- Hydrodynamical simulations suggest on large scales

$$b_{\rm e}(z) \approx \begin{cases} b_{\rm e}^0 + \left(1 - b_{\rm e}^0\right) \frac{z}{z_{\rm fb}} & \text{for } z \leq z_{\rm fb} \\ 1 & \text{for } z > z_{\rm fb} \end{cases}$$

$$b_{\rm e}^0 \approx 0.75\,,\ z_{\rm fb} \approx 5$$

$\Longrightarrow$ Large-scale bias due to PNG in $\langle \mathcal{D}\mathcal{D} \rangle$

Tomographic analysis

- Project $\mathrm{DM}_{\mathrm{LSS}}$ fluctuations for given FRB distribution $n(z)$

$$\mathcal{D}(\hat{\boldsymbol{x}}) = \int \mathrm{d}z\, n(z)\, \mathcal{D}\big(\hat{\boldsymbol{x}}, z\big)$$

- FRB redshifts via host identification or estimated from DM

$$n(z) \approx \int \mathrm{dDM}\; n(\mathrm{DM})\; \mathcal{N}\big(\langle \mathrm{DM}\rangle(z), \sigma^2_{\mathrm{DM}}(z)\big)$$

- Observe angular power spectrum in n_{tomo} tomographic bins

$$\underbrace{C_{ij}^{\mathcal{D}\mathcal{D}}(\ell)}_{\mathcal{D}\text{ spectrum}} + \underbrace{n_{\mathrm{tomo}} \frac{\sigma^2_{\mathrm{DM,host}}(z_i)}{\bar{n}} \delta_{ij}}_{\text{shot noise}}$$

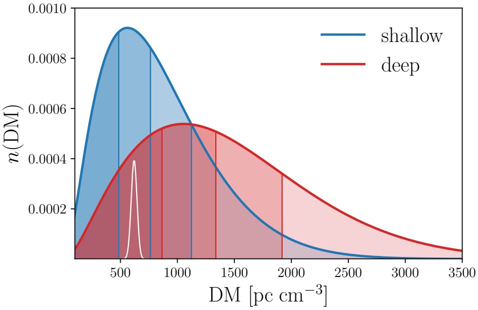
$\Longrightarrow$ Limited by cosmic variance for only a few 10^3 FRBs

Survey characteristics

- Consider two survey models

$$n(z) \propto z^2 \exp(-\alpha z)$$

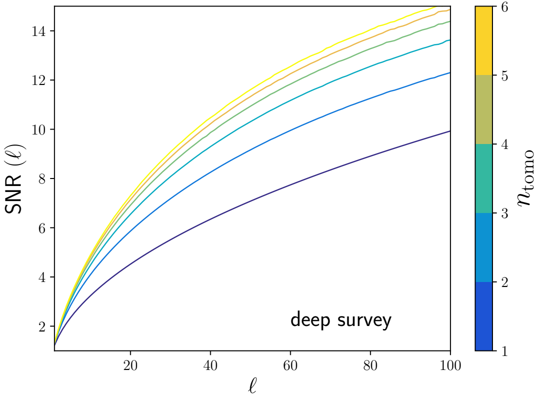
$$\text{shallow: } \alpha = 3.5\,,\ N_{\rm FRB} = 5\times 10^3$$
$$\text{deep: } \alpha = 2\,,\quad N_{\rm FRB} = 5\times 10^4$$



Reischke, Hagstotz, RL, arXiv:2007.04054

Signal-to-noise ratio (SNR)

- SNR for different tomographic bin numbers



Reischke, Hagstotz, RL, arXiv:2007.04054

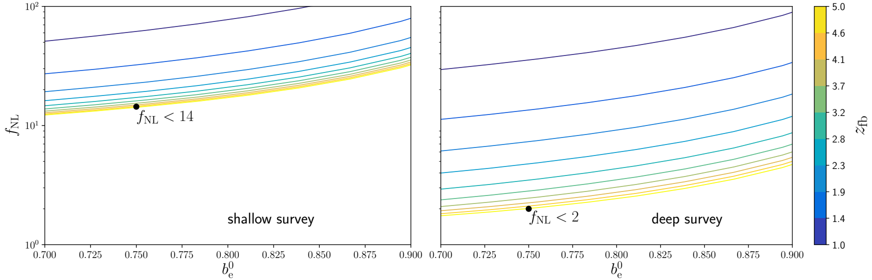
$\Longrightarrow$ Saturates for $n_{\rm tomo} \gtrsim 4$, as bins become increasingly correlated

Forecast assumptions

- Gaussian likelihood of observed $\{\mathcal{D}_{lm,i}\}$
- Fixed fiducial ΛCDM Planck-18 cosmology without PNG
- Constrain deviation from $f_{\mathrm{NL}} = 0$ by Fisher analysis
- Flat prior on f_{NL}
- Observed sky fraction $f_{\mathrm{sky}} = 0.9$
- Maximal multipole $l_{\mathrm{max}} = 100$

Constraints on $f_{\rm NL}$

- Constraints for different feedback models



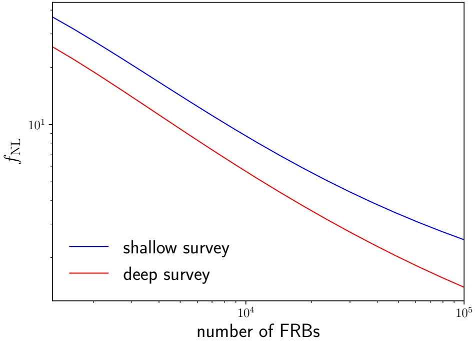
Reischke, Hagstotz, RL, arXiv:2007.04054

$\Longrightarrow$ Deep survey constraints tighter by up to an order of magnitude

$\Longrightarrow$ Constraints weaker for higher b_e^0 or lower $z_{\rm fb}$

Constraints on $f_{\rm NL}$

- Constraints for different FRB numbers



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$\Longrightarrow$ Current LSS constraints surpassed for $\sim 10^3$ FRBs

$\Longrightarrow$ CMB constraints surpassed for $\sim 10^4$ FRBs in deep survey

Conclusion

Summary

- Large-scale PNG feature in DM spectrum due to electron bias
- Tomographic analysis possible even without host identification
- Large volume, low shot noise, small foreground contamination

  $\Rightarrow f_{\rm NL} \sim \mathcal{O}(1)$ reachable with only a few 10^4 FRBs
- Largest uncertainty is feedback strength

Outlook

- Measure bias directly by cross-correlation with weak lensing

$\Longrightarrow$ FRBs are promising tool to test inflation with complementary systematics to galaxy clustering