Constraining primordial non-Gaussianity by combining photometric galaxy and 21cm intensity mapping surveys

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Cosmic Roy and the General Roylativitis: Arxiv:2409.19383

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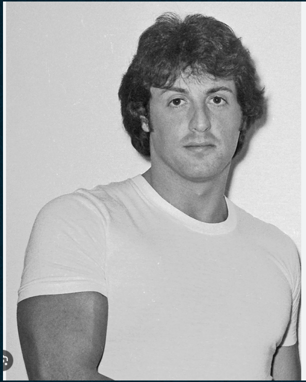
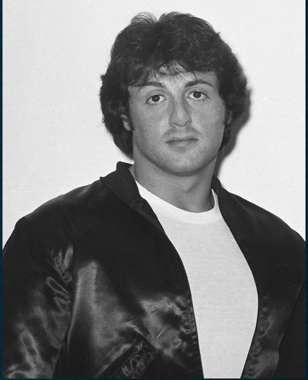
UNIVERSITY *of the* WESTERN CAPE

National Research Foundation

SARAO South African Radio Astronomy Observatory

Sylvester Stallone on “Rocky/Rambo”, 1976

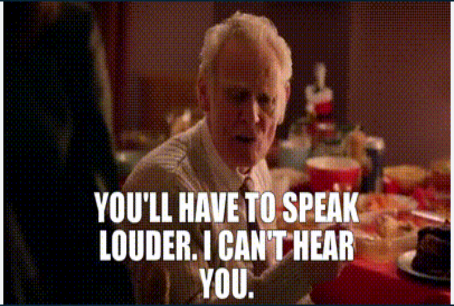




"I thought we had Sylvester’s long-lost brother at UWC, fighting in the field of cosmology!"

Rambo in Cosmology: The Roy Maartens Edition

"At UWC, we don't just have a cosmologist—we have a fighter. A true warrior in the battle against cosmic mysteries. You might know Rambo, but we have our own: Roy, the fearless fighter of the large-scale structure!"



"Who told the women to speak softly and in a low tone?"

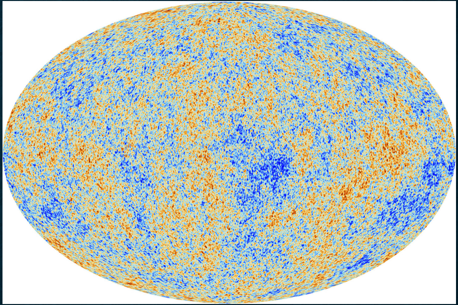
Primordial non-Gaussianity

Primordial non-Gaussianity (PNG) is a key probe of Inflation.

$$\Phi(\mathbf{x}) = \Phi_{\mathrm{G}}(\mathbf{x}) + f_{\mathrm{NL}}\left[\Phi_{\mathrm{G}}^2(\mathbf{x}) - \langle\Phi_{\mathrm{G}}^2(\mathbf{x})\rangle\right]$$

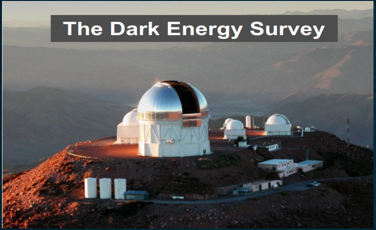
- The local type of PNG, f_{NL}.
- if $f_{\mathrm{NL}} \neq 0$, will rule out the simplest Inflation models
- if $0 < |f_{\mathrm{NL}}| \leq 1$, many other models can also be ruled out
- Current best constraint (1σ) from *Planck* survey

$$f_{\mathrm{NL}} = -0.9 \pm 5.1$$



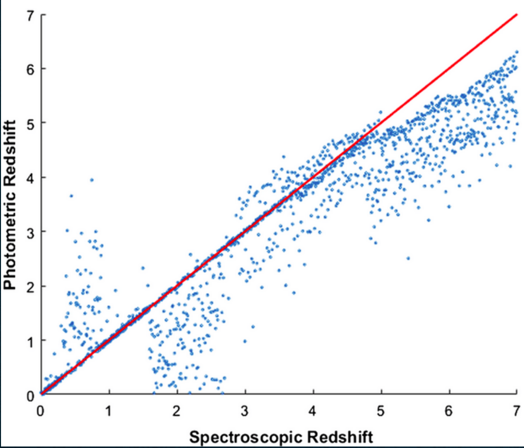
Temperature Map

3D tracer surveys to use



In the future, data will be incredible, but theory and analysis still have room for improvement.

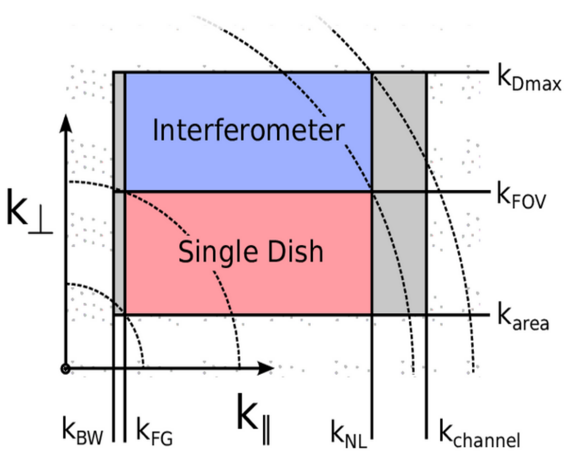
Photometric surveys



Photometric redshift versus spectroscopic redshift before postprocessing

- Like LSST: $0.1 < z < 3.0$ with sky coverage 20000deg^2
- DES: $0.1 < z < 2.0$ with sky coverage 5000deg^2
- Detect numerous galaxies, reducing shot noise
- But have limited radial resolution.

21cm Intensity mapping with Practical Challenges



Schematic of the ranges of radial and transverse wavenumbers

- Like MeerKAT (5000 deg^2) and SKA (2000 deg^2):
  Operating in Single-dish modes, targeting low and high redshifts.

- HIRAX (15000 deg^2) and PUMA (20000 deg^2):
  Operate in Interferometer mode covering very high redshifts.

Specifications of mock surveys used

HI single-dish ⊗ Photometric	z	$\Omega_{\rm sky}$ [deg^2]	$t_{\rm tot}$ [hr]
M ⊗ D	$0.4 - 1.45$	$5,000$	$4,000$
S ⊗ D	$0.35 - 2.0$	$5,000$	$2,500$
S ⊗ L	$0.35 - 2.9$	$10,000$	$5,000$
HI interferometer ⊗ Photometric			
H ⊗ D	$0.8 - 2.0$	$5,000$	$5,833$
H ⊗ L	$0.8 - 2.5$	$10,000$	$12,000$
P ⊗ L	$0.3 - 2.9$	$10,000$	$19,000$

Here D, L, M, S, H, P have properties similar to DES, LSST, MeerKAT (UHF Band), SKA (Band 1), HIRAX, PUMA respectively.

Power spectrum Estimation

HI intensity mapping survey using Single dish (SD) or Interferometer(IF) mode

- The observed HI IM auto-power spectrum is: $\tilde{P}_{\rm HI}(z, \mathbf{k}) = P_{\rm HI}(z, \mathbf{k}) + P_{\rm HI}^{\rm therm}(z, \mathbf{k})$
  - $P_{\rm HI}$ includes the effect of beam and foreground avoidance
  - $P_{\rm HI}^{\rm therm}$ is the thermal (instrumental) noise.

Photometric galaxy survey

- The observed galaxy auto-power spectrum is:: $\tilde{P}_g(z, k) = P_g(z, k) + P_g^{\rm shot}(z)$

Cross-power spectrum

In the cross-power spectrum, the cross shot noise is 0.

$$\tilde{P}_{gH}(z, k) = P_{gH}(z, k)$$

Marginalised errors on f_{NL} using single-dish HI

Parameters we have considered: $f_{\mathrm{NL}},\ A_s,\ n_s,\ b_{g0},\ b_{\mathrm{H0}}$

M ⊗ D	
Survey A, $A \otimes B$	
D	13.0
M	22.5
M ⊗ D	10.3

S ⊗ D	
Survey A, $A \otimes B$	
D	6.89
S	10.9
S ⊗ D	5.78

S ⊗ L	
Survey A, $A \otimes B$	
L	2.28
S	4.15
S ⊗ L	2.15

Marginalised 68% CL errors on from galaxy surveys D (DES-like), L (LSST-like) and HI IM single dish-mode surveys A = M (MeerKAT UHF-like), S (SKA Band 1-like).

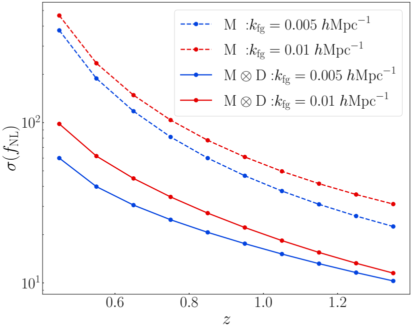
Marginalised errors on f_{NL} using Interferometer HI

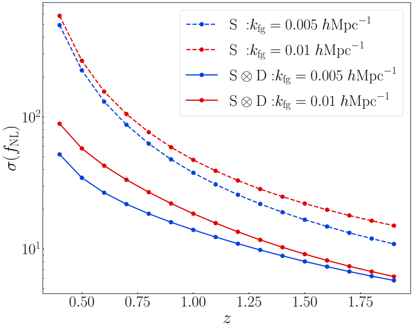
H ⊗ D	
Survey A, $A \otimes B$	
D	7.00
H256	11.40
H1024	9.09
H256 ⊗ D	5.70
H1024 ⊗ D	5.40

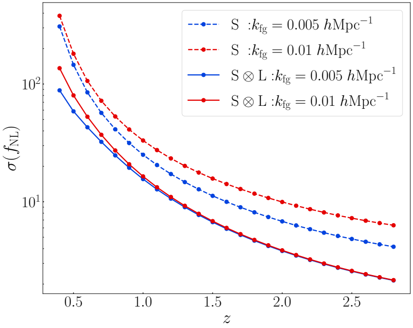
H ⊗ L	
Survey A, $A \otimes B$	
L	2.92
H256	5.15
H1024	4.03
H256 ⊗ L	2.61
H1024 ⊗ L	2.51

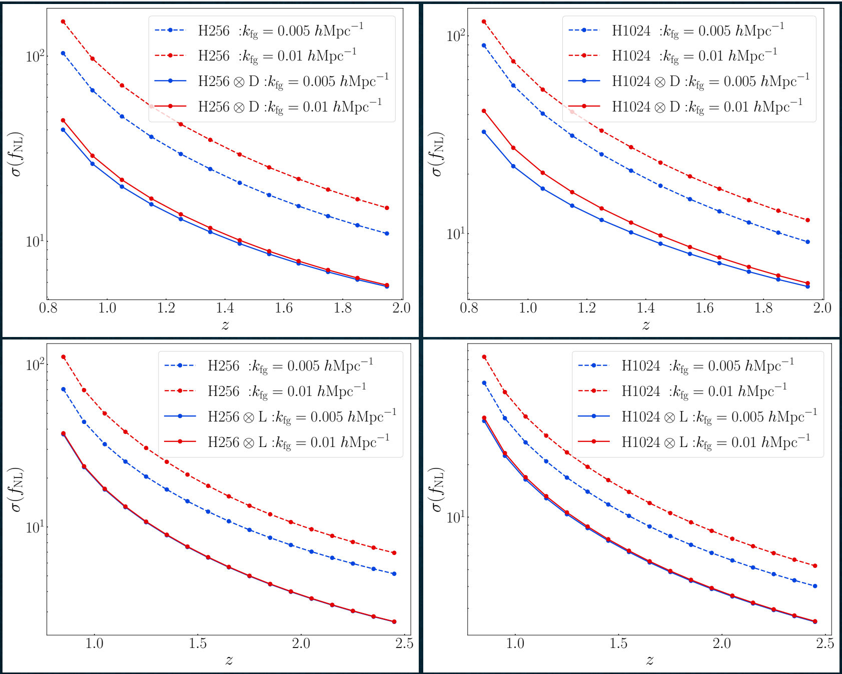
P ⊗ L	
Survey A, $A \otimes B$	
L	2.22
P5k	2.48
P32k	2.28
P5k ⊗ L	1.85
P32k ⊗ L	1.81

Marginalised 68% CL errors on from galaxy surveys A = D (DES-like), L (LSST-like) and HI IM inteferometer-mode surveys A = H (HIRAX-like) and P (PUMA-like). H and P have phases 1 and 2 with the initial and final number of dishes.


M :k_{fg} = 0.005 hMpc^{-1}
M :k_{fg} = 0.01 hMpc^{-1}
M ⊗ D :k_{fg} = 0.005 hMpc^{-1}
M ⊗ D :k_{fg} = 0.01 hMpc^{-1}
$\sigma(f_{NL})$
10^2
10^1
0.6
0.8
1.0
1.2
z


S :k_{fg} = 0.005 hMpc^{-1}
S :k_{fg} = 0.01 hMpc^{-1}
S ⊗ D :k_{fg} = 0.005 hMpc^{-1}
S ⊗ D :k_{fg} = 0.01 hMpc^{-1}
$\sigma(f_{NL})$
10^2
10^1
0.50
0.75
1.00
1.25
1.50
1.75
z


S :k_{fg} = 0.005 hMpc^{-1}
S :k_{fg} = 0.01 hMpc^{-1}
S ⊗ L :k_{fg} = 0.005 hMpc^{-1}
S ⊗ L :k_{fg} = 0.01 hMpc^{-1}
$\sigma(f_{NL})$
10^2
10^1
0.5
1.0
1.5
2.0
2.5
z



H256 : $k_{\rm fg} = 0.005\ h{\rm Mpc}^{-1}$
H256 : $k_{\rm fg} = 0.01\ h{\rm Mpc}^{-1}$
H256 ⊗ D : $k_{\rm fg} = 0.005\ h{\rm Mpc}^{-1}$
H256 ⊗ D : $k_{\rm fg} = 0.01\ h{\rm Mpc}^{-1}$
$\sigma(f_{\rm NL})$
z
H1024 : $k_{\rm fg} = 0.005\ h{\rm Mpc}^{-1}$
H1024 : $k_{\rm fg} = 0.01\ h{\rm Mpc}^{-1}$
H1024 ⊗ D : $k_{\rm fg} = 0.005\ h{\rm Mpc}^{-1}$
H1024 ⊗ D : $k_{\rm fg} = 0.01\ h{\rm Mpc}^{-1}$
H256 ⊗ L : $k_{\rm fg} = 0.005\ h{\rm Mpc}^{-1}$
H256 ⊗ L : $k_{\rm fg} = 0.01\ h{\rm Mpc}^{-1}$
H1024 ⊗ L : $k_{\rm fg} = 0.005\ h{\rm Mpc}^{-1}$
H1024 ⊗ L : $k_{\rm fg} = 0.01\ h{\rm Mpc}^{-1}$

Conclusion

- We focused on estimating the precision gains possible through multi-tracer analyses, deliberately excluding non-overlapping survey pairs.
- For the first time we examined the performance of multi-tracer combinations with interferometric mode surveys.
- The best single-tracer and multi-tracer $f_{\rm NL}$ precision is delivered by SKA $\otimes$ LSST and PUMA $\otimes$ LSST.
- These combinations surpass the latest Planck constraints.
- We plan to enhance forecast accuracy by moving beyond the plane-parallel approximation, incorporating wide-angle effects for a more complete large-scale structure analysis.

Thank You!