Cosmological Constraints with HIRAX and Spectroscopic Galaxy Surveys

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UNIVERSITY of the WESTERN CAPE

CRC Centre for Radio Cosmology

HIRAX

ICTP The Abdus Salam International Centre for Theoretical Physics

Modelling Large-scale Structure formation

Large scale structure (LSS)

- Tiny fluctuations in the number count of sources lead to the formation of large scale structure.
- The nature and amplitude of these fluctuations can be understood from correlation functions.
- Fourier transform of the 2-point correlation function (2PCF) is the power spectrum.
- Understanding the growth of LSS can help to constrain cosmological parameters.

Multiple Tracer Surveys

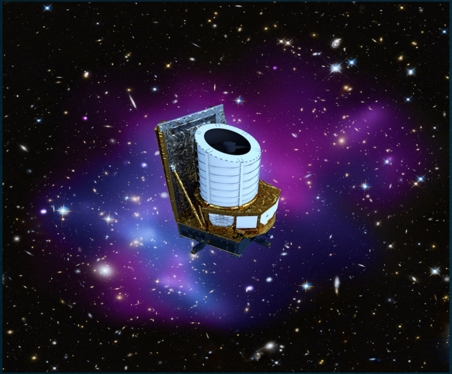
We use the multi-tracer (MT) technique of Jose, Stefano, Mario, Roy (2015) for the following reasons:

- We look at two different spectroscopic surveys - galaxy and HI IM.
- We want to overcome cosmic variance.
- In the cross-power spectrum, the noise and foregrounds vanish.

Papers to recommend

- Viljoen et al(2021).
- Jolicoeur et al(2023).
- Karagiannis et al(2023).

Two tracer surveys to use



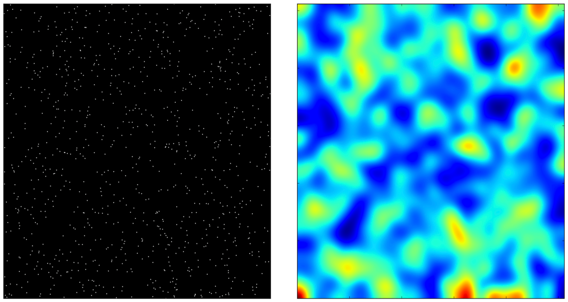
$Euclid\ range: 0.9 < z < 1.8$

Sky area: 15 000 deg^2

$HIRAX\ range: 0.8 < z < 2.5$

Sky area: 15 000 deg^2 with $[t_{tot} : 17.5 \times 10^3 \mathrm{hr}]$

How MT Surveys works



Villaescusa-Navarro et al.

- Both the galaxy and HI IM surveys should overlap perfectly in redshifts and sky area.
- Additional information can be obtained from the non-overlapping regions of the individual surveys.

$$\delta_g \approx b_g \delta_m \qquad \delta_{HI} \approx b_{HI} \delta_m$$

$$\nwarrow \quad \nearrow$$

$$\delta_g / \delta_{HI} \approx b_g / b_{HI}$$

- We can directly measure the ratio free from cosmic variance

$$\delta_g / \delta_{HI} = \frac{b_g}{b_{HI}} + \text{correction terms}$$

Power spectrum for Multi tracer

- We consider Euclid and HIRAX with the following overlapping information:
  - Redshift range: $0.9 < z < 1.8$
  - Sky area $10000\,\mathrm{sq.deg}$ with observation time of $11700\mathrm{hrs}$

power spectra from combining 2 different dark matter tracers

$$\boxed{\left\langle \Delta_A(z,k)\Delta_B(z,k')\right\rangle = (2\pi)^3 P_{AB}(z,k)\delta^{\mathrm{D}}(k+k')} \longrightarrow P_{AB}(z,k) = \left(\hat{b}_A + f\mu^2\right)\left(\hat{b}_B + f\mu^2\right)\mathcal{P}\,.$$

Here, $\mu = \hat{k}\cdot\hat{n}$, where $\hat{n}$ is the unit vector in the line-of-sight direction.

f is the linear growth rate parameterized as: $\boxed{f(z) \approx \Omega_m(z)^{\gamma},\ \gamma = 0.55}$

We constrain the primordial non-Gaussianity parameter via:

$$\boxed{\hat{b}(z,k) = b_i(z) + b_\phi(z)\frac{f_{\mathrm{NL}}}{\mathcal{M}(z,k)}}\,.$$

Power spectrum for Multi tracer

We define a row vector for the power spectra as follows:

$$P = \begin{bmatrix} P_{HH} & P_{gH} & P_{gg} \end{bmatrix}$$

where

$$\begin{aligned} P_{HH}(z,k) &\rightarrow \mathcal{D}_{\mathrm{b}}(z)^2\, P_{HH}(z,k)\,, \\ P_{gH}(z,k) &\rightarrow \mathcal{D}_{\mathrm{b}}(z)\, P_{gH}(z,k)\,. \\ P_{gg}(z,k) &\rightarrow P_{gg}(z,k)\,. \end{aligned}$$

Power spectrum Estimation

HI intensity mapping survey using interferometer(IF) mode: HIRAX

- The observed HI IM auto-power spectrum is: $\tilde{P}_{HH}(z,k) = P_{HH}(z,k) + P_{HH}^{\mathrm{therm}}(z)$
  - P_{HH} includes the effect of beam (typically a damping Gaussian function).
  - P_{HH}^{therm} is the thermal (instrumental) noise.

Galaxy survey: Euclid like

- The observed galaxy auto-power spectrum is:: $\tilde{P}_{gg}(z,k) = P_{gg}(z,k) + P_{gg}^{\mathrm{shot}}(z)$

Cross-power spectrum

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

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

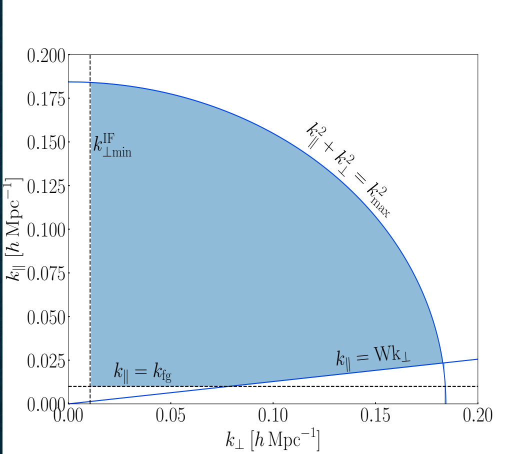
Multi-tracer Fisher Matrix

Region of interest in k-space is defined as:

$$k_{\min}(z) = \max\{k_{\rm f}(z),\, k_{\rm fg},\, k^{\rm IF}_{\perp\min}(z)\}$$
$$k_{\max}(z) = \min\{k^{\rm NL}_{\perp}(z),\, k^{\rm IF}_{\perp\max}(z)\},$$

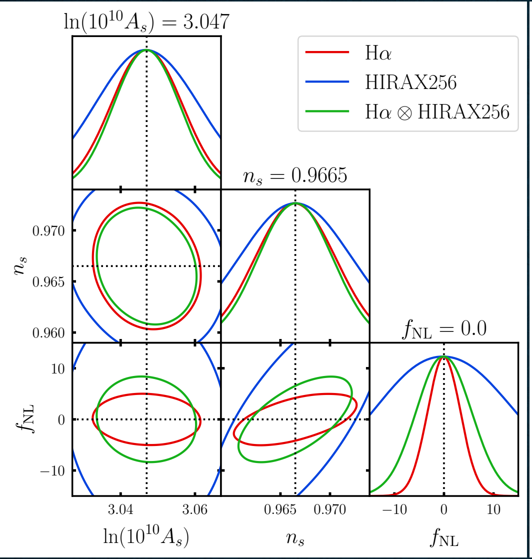
$$F^{P}_{\alpha\beta} = \sum_{\mu=-1}^{+1} \sum_{k=k_{\min}}^{k_{\max}} \partial_\alpha P \cdot {\rm Cov}(P,P)^{-1} \cdot \partial_\beta P^{\rm T}$$

$${\rm Cov}(P,P) \propto \begin{pmatrix} \tilde{P}^2_{gg} & \tilde{P}_{gg}\tilde{P}_{gH} & \tilde{P}^2_{gH} \\ \tilde{P}_{gg}\tilde{P}_{gH} & \frac{1}{2}\left[\tilde{P}_{gg}\tilde{P}_{HH} + \tilde{P}^2_{gH}\right] & \tilde{P}_{HH}\tilde{P}_{gH} \\ \tilde{P}^2_{gH} & \tilde{P}_{HH}\tilde{P}_{gH} & \tilde{P}^2_{HH} \end{pmatrix}$$

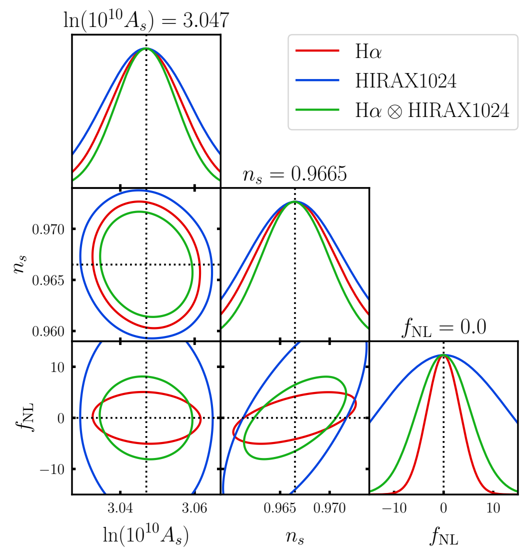


Scales for HIRAX $\sim H$

Results



$\ln(10^{10}A_s) = 3.047$
$n_s = 0.9665$
$f_{\rm NL} = 0.0$
Hα
HIRAX256
Hα ⊗ HIRAX256
n_s
0.970
0.965
0.960
$f_{\rm NL}$
10
0
−10
3.04
3.06
0.965
0.970
−10
0
10
$\ln(10^{10}A_s)$
n_s
$f_{\rm NL}$



$\ln(10^{10}A_s) = 3.047$
$n_s = 0.9665$
$f_{\rm NL} = 0.0$
Hα
HIRAX1024
Hα ⊗ HIRAX1024
n_s
0.970
0.965
0.960
$f_{\rm NL}$
10
0
−10
3.04
3.06
0.965
0.970
−10
0
10
$\ln(10^{10}A_s)$
n_s
$f_{\rm NL}$

Conclusion & Future Work

- We find improvement on the constraints for the power spectrum amplitude parameter A_s and tilt parameter n_s from MT.
- We do not gain much improvement on f_{NL} constraint from MT. This is because HIRAX (IF) cannot probe the large scale mode of f_{NL} due to its long baseline.
- We are working on a similar parallel project using the angular power spectrum in harmonic space. This will include cross-correlations between redshift bins which is omitted in Fourier space calculations.
- We are writing a paper.