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Calibrating photometric redshifts with the galaxy-IM cross-bispectrum

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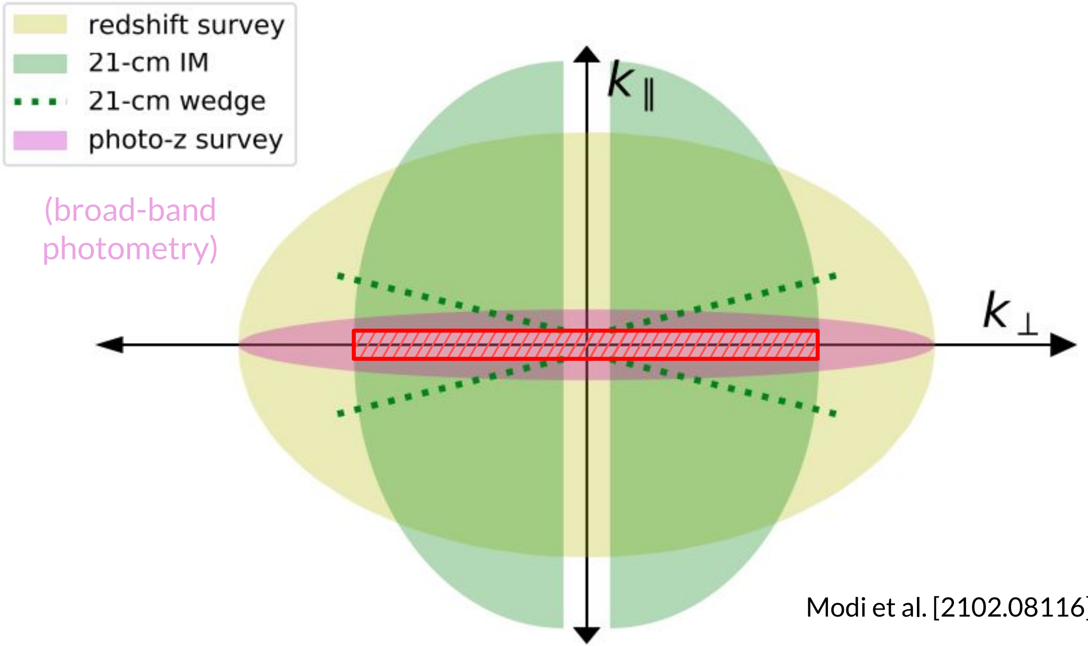
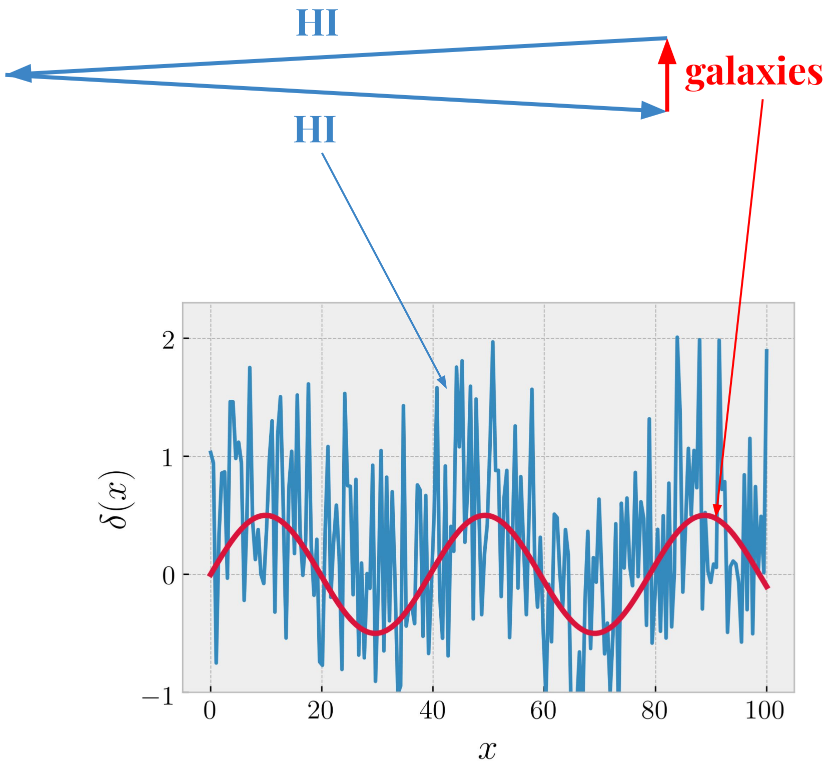
Problem of cross-correlating photometric galaxies with HI IM



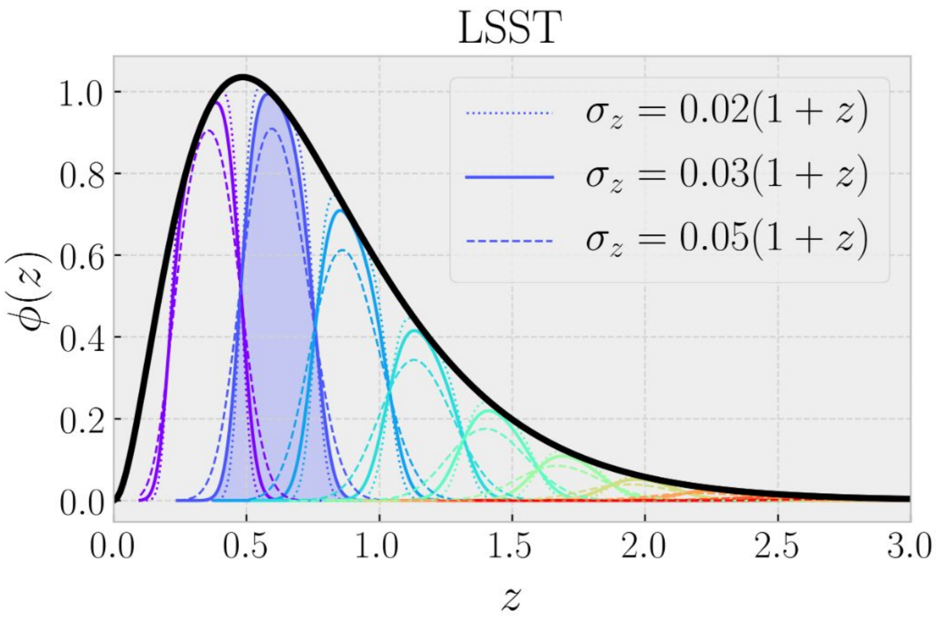
(broad-band photometry)

Modi et al. [2102.08116]

Our goal: reconstruct long-λ modes



Practical application: photometric redshift surveys



$$\Delta_g(\boldsymbol{r}_\perp) = \int \mathrm{d}r_\parallel \; \phi(r_\parallel)\, \delta_g(r_\parallel, \boldsymbol{r}_\perp)$$

$$\phi_i(z) = n_g(z) \int_{z^i_{\rm ph}}^{z^{i+1}_{\rm ph}} \mathrm{d}z_{\rm ph} P(z_{\rm ph}|z)$$

$$P(z_{\rm ph}|z) = \frac{1}{\sigma_z\sqrt{2\pi}} \exp\left[-\frac{1}{2}\frac{(z_{\rm ph}-z)}{\sigma_z^2}\right]$$

Clustering-z to calibrate the redshift distribution

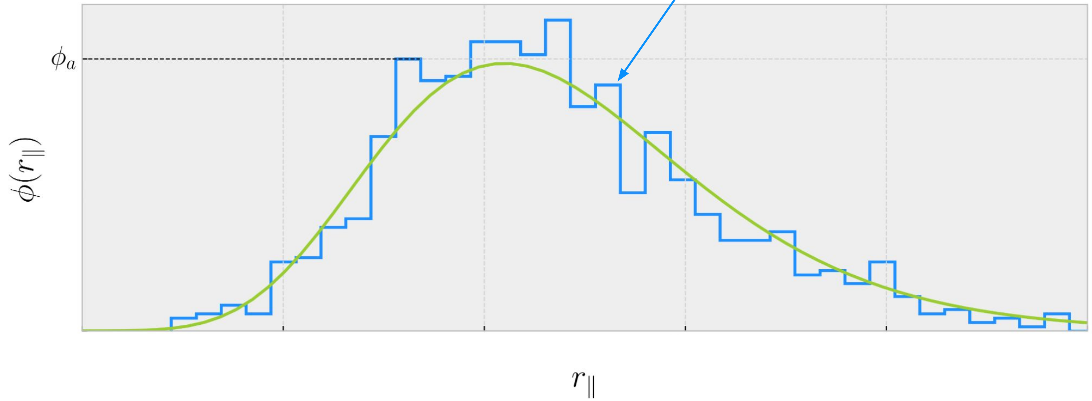
$$\phi(r_\parallel) \propto \exp\left[-\frac{(r_\parallel - r_\parallel^*)^2}{2\sigma_\parallel^2}\right]$$

$$\sigma_z = \sigma_{z,0}(1+z)$$

$$\phi(r_\parallel) = \sum_a \phi_a \, w_a(r_\parallel)$$

$$\Delta_g(\boldsymbol{r}_\perp) = \sum_a \phi_a \, \delta_g^a(\boldsymbol{r}_\perp), \quad \delta_g^a(\boldsymbol{r}_\perp) \equiv \int \mathrm{d}r_\parallel \; w_a(r_\parallel) \, \delta_g(r_\parallel, \boldsymbol{r}_\perp)$$

e.g. HI slices [Alonso et al., 1704.01941]
Also explained by Giulio Scelfo



Summary

- We will combine photometric galaxies with 21-cm intensity mapping in the clustering redshifts approach;
- We will use the **galaxy-HI bispectra** to recover the large radial scales lost by foreground contamination in 21-cm intensity mapping experiments;
- I will present the forecasts we did, at a **Fisher matrix** level, using a **HIRAX-like interferometer** and a **SKA-like single-dish** survey to see how well we can constrain the centre and width of the redshift distribution of photometric galaxies.

Clustering redshifts with 2-point statistics

$$F^P_{\alpha\beta} = \sum_{XX'} \frac{A}{4\pi} \int_0^\infty \mathrm{d}k_\perp \, k_\perp \, \partial_\alpha \mathcal{P}^{XY}(k_\perp) \, \partial_\beta \mathcal{P}^{X'Y'}(k_\perp) \, \mathcal{I}^{XX'}(k_\perp) \, \mathcal{I}^{YY'}(k_\perp)$$

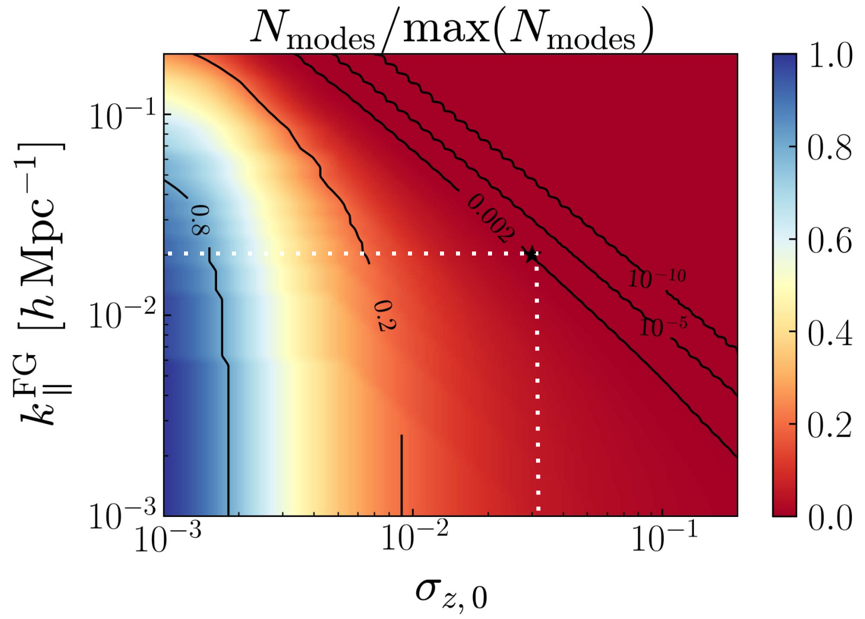
$$\sigma_P^{-1}(\theta) \propto \int \frac{\mathrm{d}k_\parallel}{2\pi} \, \mathcal{K}^2_\theta(k_\parallel, \sigma_\parallel) \, \mathrm{e}^{-k_\parallel^2 \sigma_\parallel^2} \frac{P^2_{gh}(\boldsymbol{k}_\parallel, k_\perp)}{P_{hh}(k_\parallel, k_\perp)}$$

$$\phi(r_\parallel) \propto \exp\left[-\frac{(r_\parallel - r^*_\parallel)^2}{2\sigma^2_\parallel} \right]$$

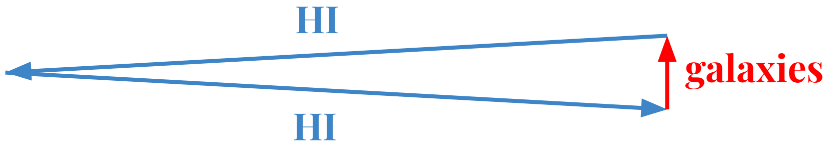
Zé's talk for Fisher matrices

Clustering redshifts with 2-point statistics

$$\sigma_P^{-1}(\theta) \propto \int \frac{\mathrm{d}k_\parallel}{2\pi}\, \mathcal{K}_\theta^2(k_\parallel, \sigma_\parallel)\, \mathrm{e}^{-k_\parallel^2 \sigma_\parallel^2} \frac{P_{gh}^2(\color{red}{k_\parallel}, k_\perp)}{P_{hh}(k_\parallel, k_\perp)}$$



Clustering redshifts with the 3-point statistics



$$F^B_{\alpha\beta} = \sum_{\boldsymbol{XX'}} \frac{A}{4\pi}\frac{1}{6}\int_0^\infty \mathrm{d}k_\perp\,\mathrm{d}q_\perp\,\mathrm{d}p_\perp\,\frac{k_\perp q_\perp p_\perp}{\pi^2 A_T}\,\partial_\alpha \mathcal{B}^{XYZ}(k_\perp,p_\perp,q_\perp)\,\partial_\beta \mathcal{B}^{X'Y'Z'}(k_\perp,p_\perp,q_\perp)\,\mathcal{I}^{XX'}(k_\perp)\,\mathcal{I}^{YY'}(q_\perp)\,\mathcal{I}^{ZZ'}(p_\perp)$$

$$\sigma_B^{-1}(\theta) \propto \int \frac{\mathrm{d}p_\parallel}{2\pi}\frac{\mathrm{d}k_\parallel}{2\pi}\,\mathcal{K}^2_\theta(k_\parallel,\sigma_\parallel)\,\mathrm{e}^{-k_\parallel^2\sigma_\parallel^2}\,\frac{B^2_{ghh}(k_\parallel,p_\parallel,-k_\parallel-p_\parallel;k_\perp,p_\perp,q_\perp)}{P_{hh}(p_\parallel,q_\perp)P_{hh}(-k_\parallel-p_\parallel,p_\perp)}$$

We can avoid the foreground-dominated region!

Forecast specifications

Power spectrum modelling

$$P_{xy}(k) = \mathcal{K}_{xy}\, P_{\rm nl}(k) + N_{xy}\,\delta_{xy}$$

$$P_{gg}(k,z) = b_g^2(z) P(|\boldsymbol{k}|, z) + \bar{n}_g^{-1}(z)$$

$$P_{hh}(z, k_\parallel, k_\perp) = b_h^2(z)\, \bar{T}_h(z)^2\, P(z,k)\, [\mathcal{S}_b^2(|\boldsymbol{k}_\perp|)\, \mathcal{S}_{\rm FG}^2(k_\parallel)] + P_{hh}^{\rm noise}$$

$$P_{gh}(z, k_\parallel, k_\perp) = b_g(z) b_h(z)\, \bar{T}_h(z)\, P(k,z) [\mathcal{S}_b(k_\perp)\, \mathcal{S}_{\rm FG}(k_\parallel)]$$

$$b_h(z) = 1.307\left(0.66655 + 0.17765\, z + 0.050223\, z^2\right)$$

$$\bar{T}_h(z) = (0.055919 + 0.23242\, z - 0.024136\, z^2)\ [\rm mK]$$

Santos et al. [1709.06099]
Ballardini et al [1906.04730]

Bispectrum modelling

$$B_{ghh}(\boldsymbol{k},\boldsymbol{p},\boldsymbol{q}) = \bar{T}_h^2(z)\mathcal{S}_b(p_\perp,q_\perp)\mathcal{S}_{\rm FG}(p_\parallel,q_\parallel)\times \left[b_{g,1}b_{h,1}^2 B(\boldsymbol{k},\boldsymbol{p},\boldsymbol{q}) + b_{g,1}b_{h,1}b_{h,2}P(k)P(p) + b_{g,1}b_{h,2}b_{h,1}P(k)P(q) + b_{g,2}b_{h,1}^2 P(p)P(q)\right]$$

$$b_2(b_1) = 0.412 - 2.143\,b_1 + 0.929\,b_1^2 + 0.008\,b_1^3$$

Lazeyras et al. [1511.01096]

$$B(\boldsymbol{k}_1,\boldsymbol{k}_2,\boldsymbol{k}_3) = 2\,F_2^{\rm eff}(\boldsymbol{k}_1,\boldsymbol{k}_2)\,P_{\rm nl}(\boldsymbol{k}_1)\,P_{\rm nl}(\boldsymbol{k}_2) + \text{ perms}$$

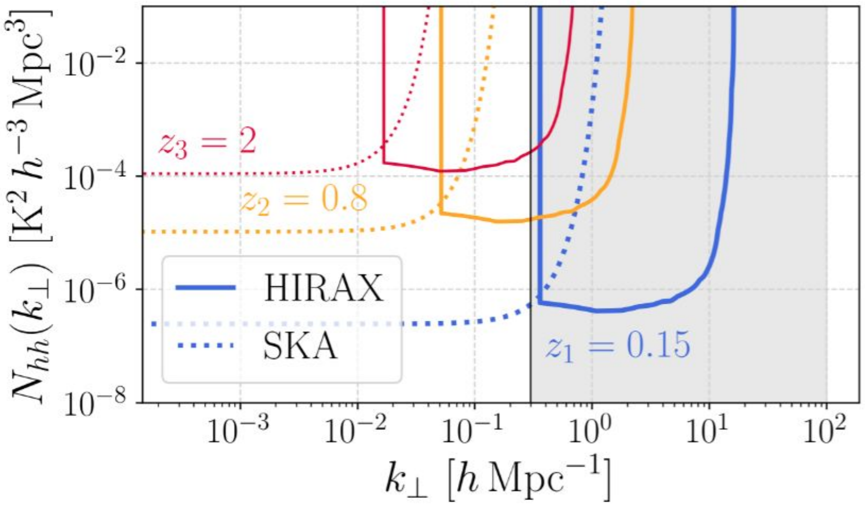
$$F_2^{\rm eff}(\boldsymbol{k}_i,\boldsymbol{k}_j) = \frac{5}{7}\,\tilde{a}(k_i)\,\tilde{a}(k_j) + \frac{1}{2}\cos(\theta_{ij})\left(\frac{k_i}{k_j}+\frac{k_j}{k_i}\right)\tilde{b}(k_i)\,\tilde{b}(k_j) + \frac{2}{7}\cos^2(\theta_{ij})\,\tilde{c}(k_i)\,\tilde{c}(k_j)$$

Gil-Marín et al. [1111.4477]

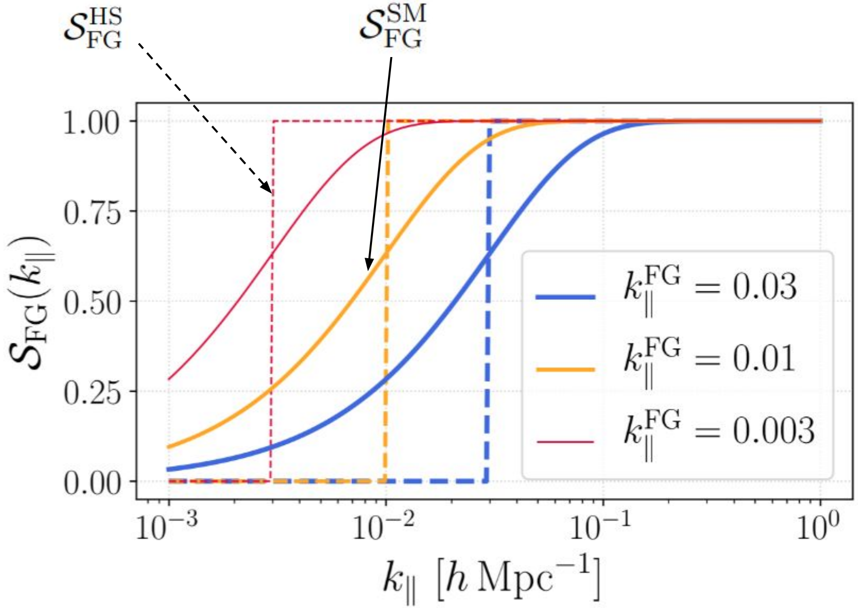
Beam and noise

Single-dish mode
Area: 20000 deg²
Redshift coverage: 0-3

Interferometer mode
Area: 2000 deg²
Redshift coverage: 0.8-2.5



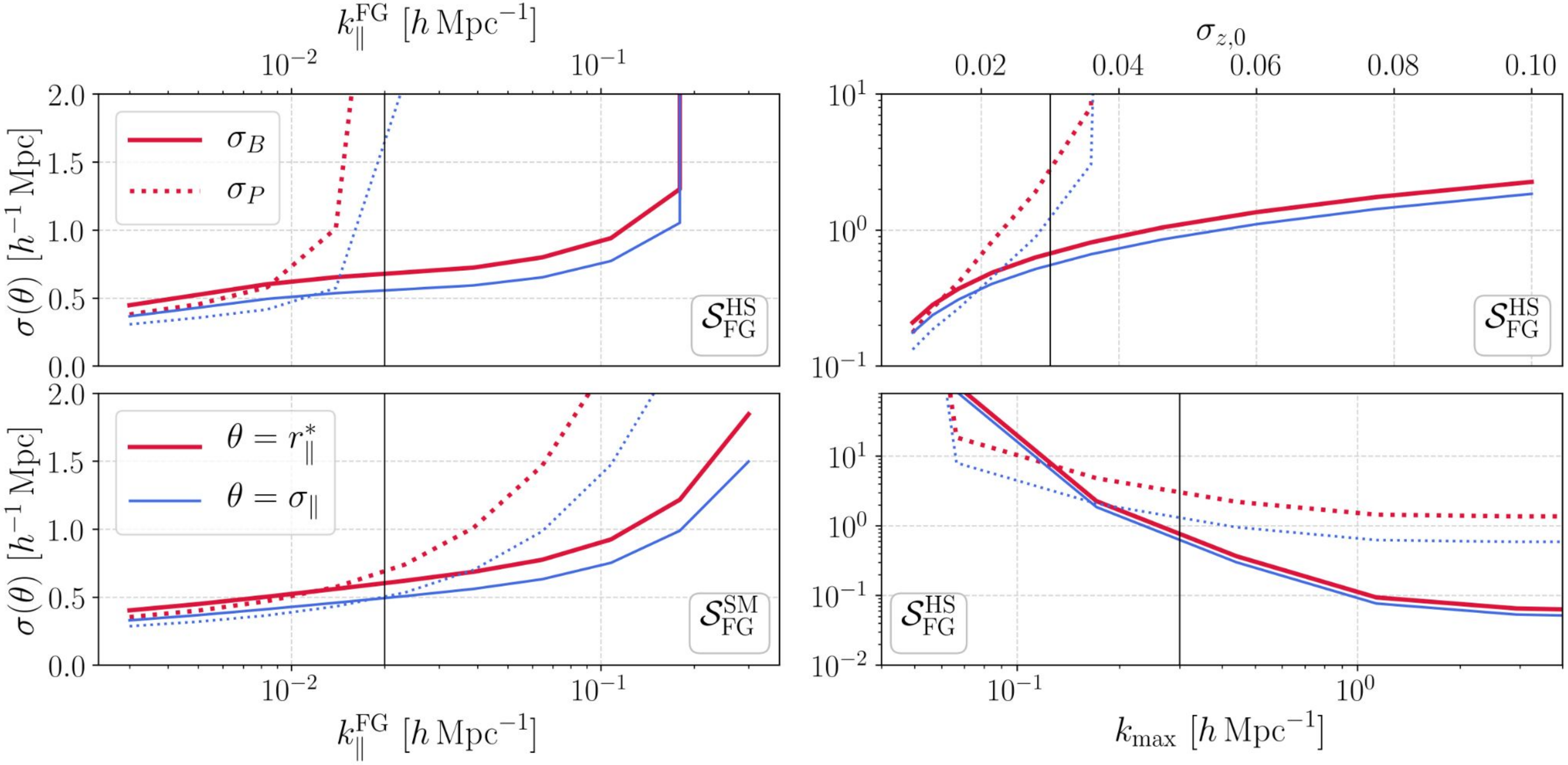
Alonso et al. [1704.01941]



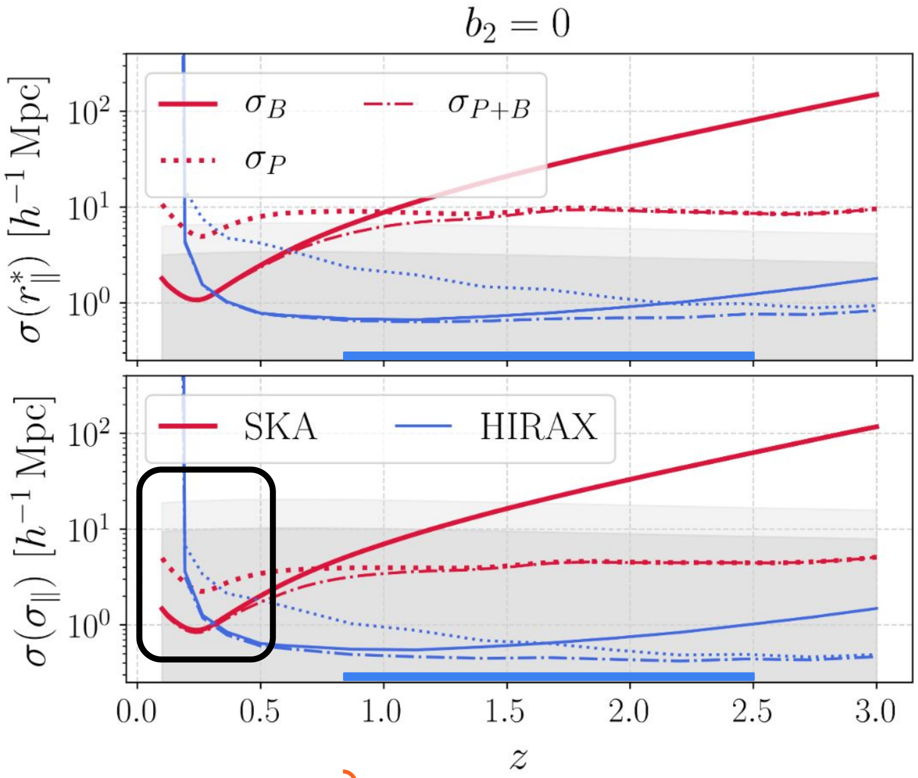
Cunnington et al. [2007.12126]

Forecast results

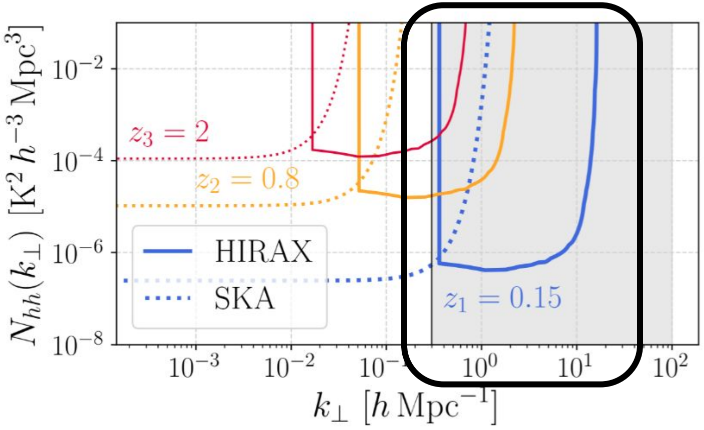
Intuition: behaviour with characteristic scales



Forecast for Stage-IV surveys: single-dish vs. interferometer



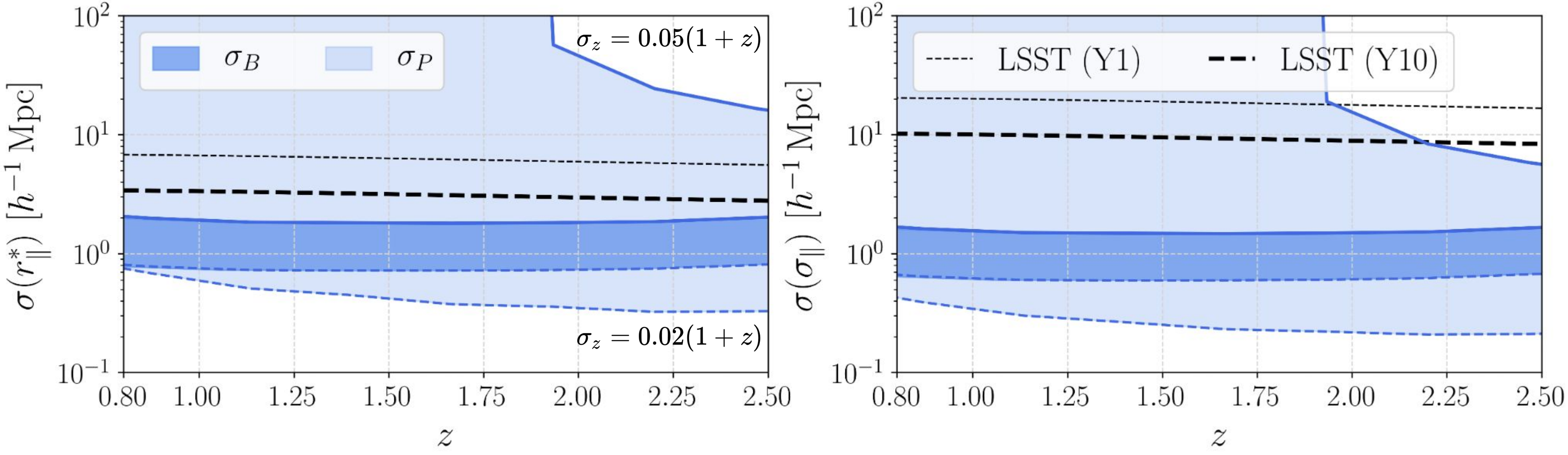
$\sigma_{z,0} = 0.03,\ k_\parallel^{\mathrm{FG}} = 0.02\,h\,\mathrm{Mpc}^{-1},\ k_{\mathrm{max}} = 0.3\,h\,\mathrm{Mpc}^{-1}$



LSST Y1
LSST Y10
} requirements for 3x2 analyses

Impact of photo-z width

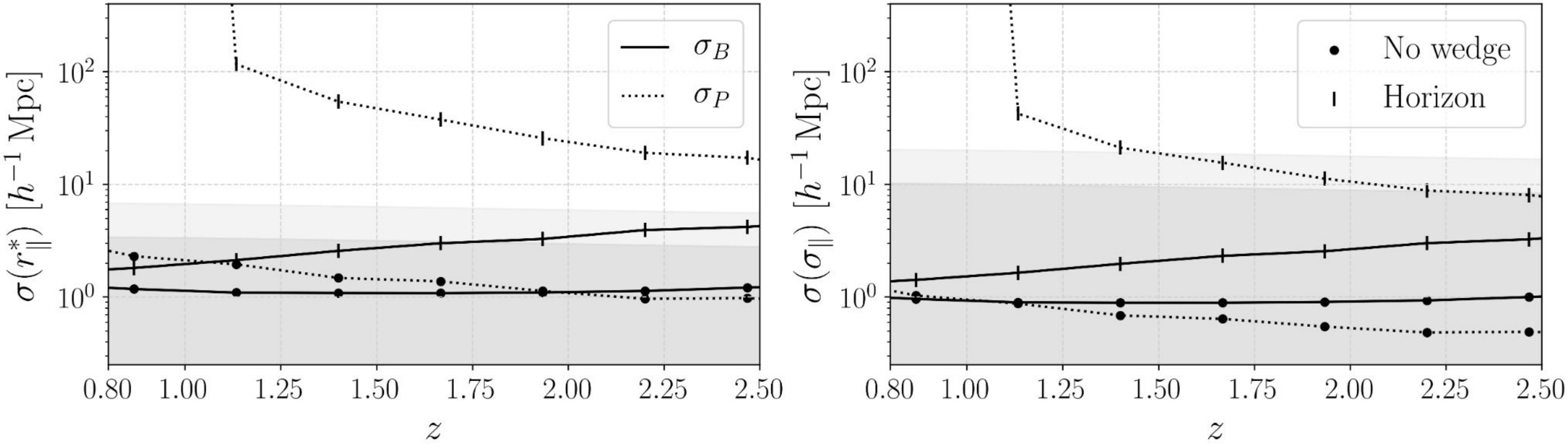
$$k_{\parallel}^{\rm FG} = 0.02\,h\,{\rm Mpc}^{-1},\ k_{\rm max} = 0.3\,h\,{\rm Mpc}^{-1}$$



Impact of horizon wedge

Junaid's talk for a nice explanation of the wedge

$$k_{\parallel} < k_{\parallel}^{\rm hor} \equiv \frac{\chi(z)\,H(z)}{c\,(1+z)} k_{\perp}$$



Conclusions & future prospects

Summary:

- We presented a novel method, based on the **galaxy-HI bispectra**, to recover the large radial scales lost by foreground contamination in 21-cm intensity mapping experiments;
- As shown with a **HIRAX-like interferometer** survey, the ability to **access non-linear perpendicular modes** (where the bispectrum amplitude is larger) improves the photo-z calibration;

Main message:

- **The bispectrum is capable of calibrating the redshift distribution in situations where the two-point function is not** due to foreground contamination.
- It is important to reach scales **$k \gtrsim 0.3$ h/Mpc**, with the constraints saturating at around **$k \sim 1$ h/Mpc** for next-generation experiments.

Future prospects:

- Apply this idea to data (MeerKAT x WiggleZ) to see if we can mitigate the impact of foreground removal;
- Study bias degeneracies and generic photo-z distributions;