The Kaiser Rocket Effect in Cosmology

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Cosmology from Home

What is the Kaiser Rocket?

Surveys observe angular positions and redshifts, but observer moves

Often, not all of it is accounted for

⇒ Systematic shifts in redshift space (e.g. Davis, Hinton, Howlett & Calcino 2019)

$$z = \bar{z} - (1 + \bar{z}) v \cos \theta$$

The Kaiser Rocket Effect 🚀

- Observer's motion wrt rest frame causes v and LOS dependent radial selection function:

$$\hat{N}(z,\Omega) = \frac{\bar{N}(z,\Omega) + \left.\frac{\mathrm{d}\bar{N}}{\mathrm{d}\bar{z}}\right|_{\bar{z}=z} (\bar{z} - z)}{1 - v\cos\theta}$$

- Assuming isotropic $\bar{N}(\bar{z})$ results in spurious density fluctuation:

$$\delta_{\mathrm{rocket}}(z,\theta) = \frac{\hat{N}(z,\Omega) - \bar{N}(z,\Omega)}{\bar{N}(z,\Omega)} = v\cos\theta + (1+z)\frac{\mathrm{d}\ln\bar{N}(z)}{\mathrm{d}z} v\cos\theta$$

Impact on Measurements

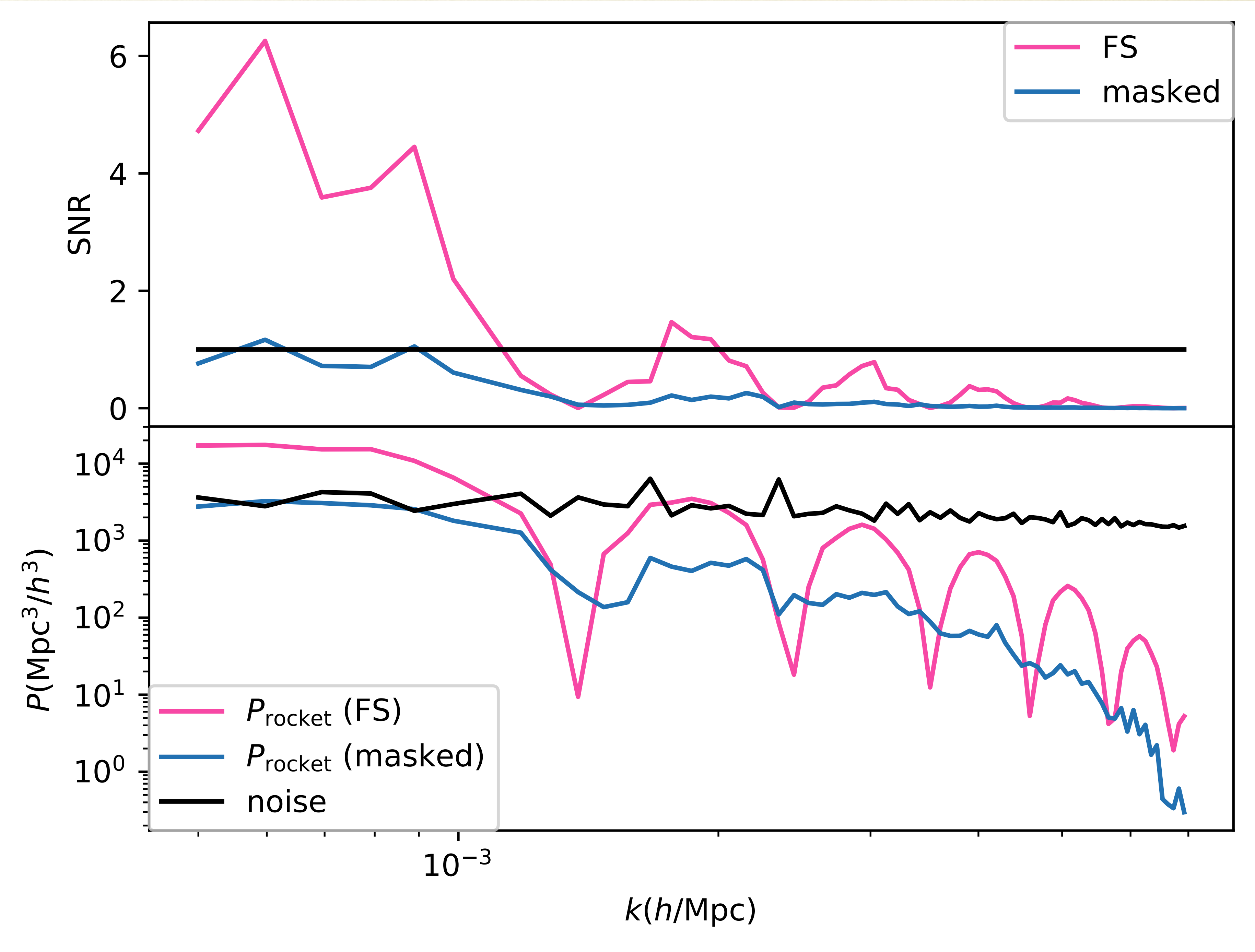
- Cartesian 3D power spectrum widely used:

$$P_{\text{rocket}}(k) \propto v^2 \int_{-1}^{1} \mathrm{d}\,\mu \int_0^\infty \mathrm{d}\,s' \int_0^\infty \mathrm{d}\,s'' \frac{\mathrm{d}\ln \bar{N}}{\mathrm{d}\,s}(s') \frac{\mathrm{d}\ln \bar{N}}{\mathrm{d}\,s}(s'') \ldots (s', s'', k, \mu)$$

- $\hat{P}(k) = P_{\text{cosmo}}(k) + P_{\text{rocket}}(k)$

- We make predictions using random catalogues (i.e. w/o clustering) where we shift redshifts to the values observed by observer in motion

Planck dipole, Euclid-like selection



Should Cosmologists Care?

- Kaiser rocket effect at same scales as scale-dep bias $b_{\rm NL}(k) = b_0 \left[1 + f_{\rm NL}\frac{A}{k^2}\right]$ due to local PNG
- We estimate BF param shifts of ΛCDM+$f_{\rm NL}^{\rm (loc)}$ (Euclid-like selection, Planck dipole)
- No significant shifts in standard ΛCDM params, but **Kaiser rocket biases measurement of $f_{\rm NL}^{\rm (loc)}$ by 2.2 (0.23 σ)**

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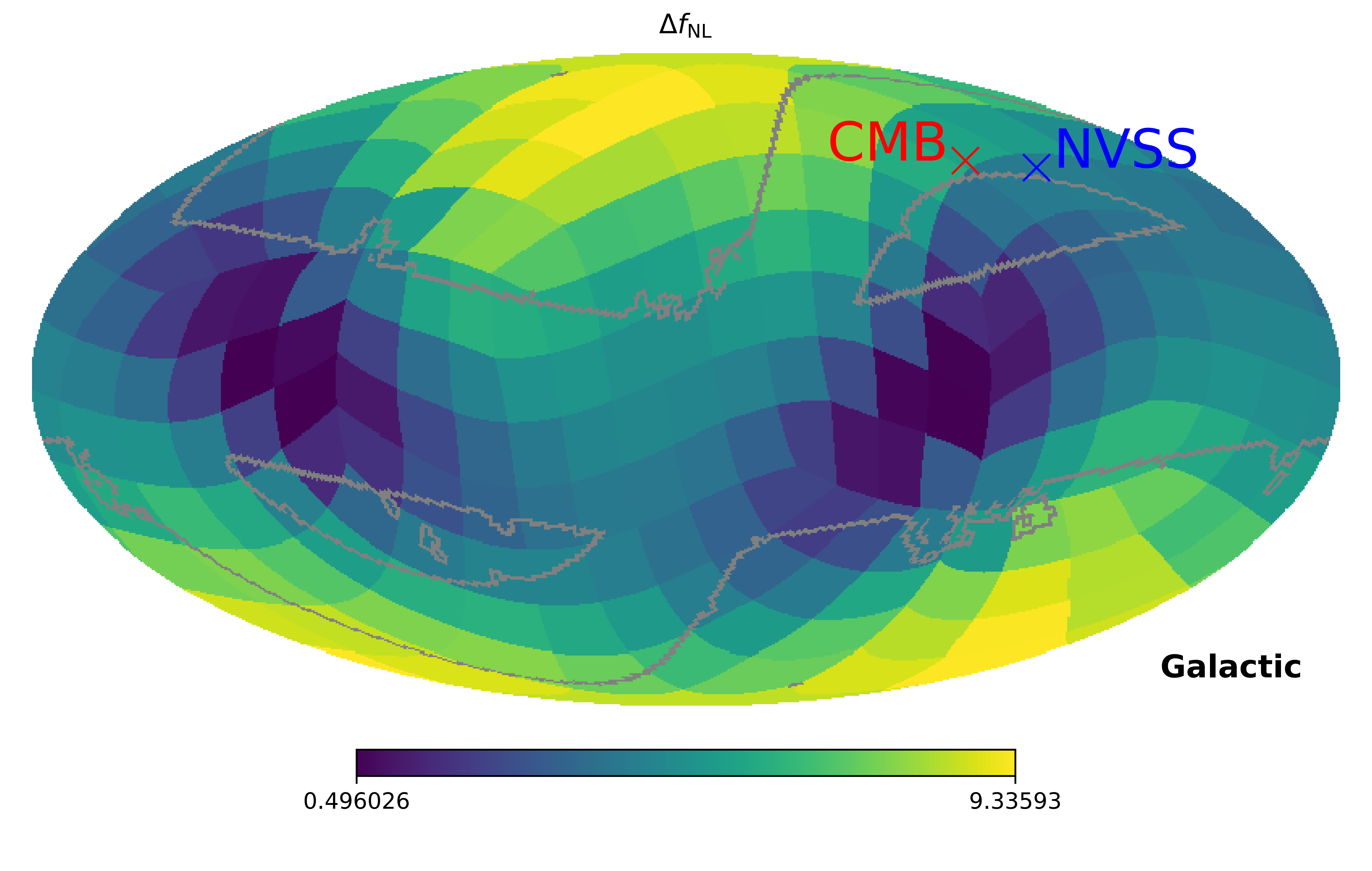
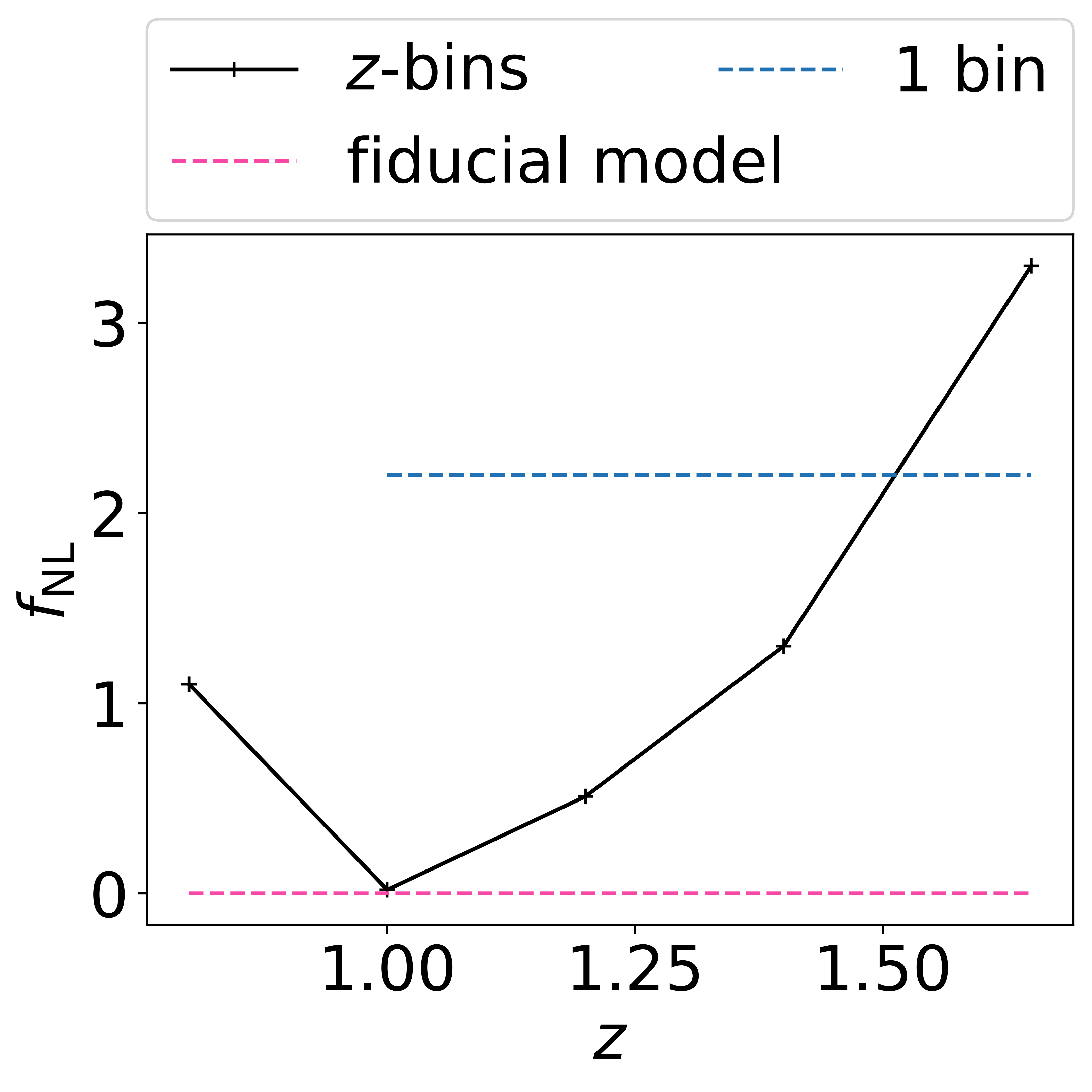
Not the worst case!

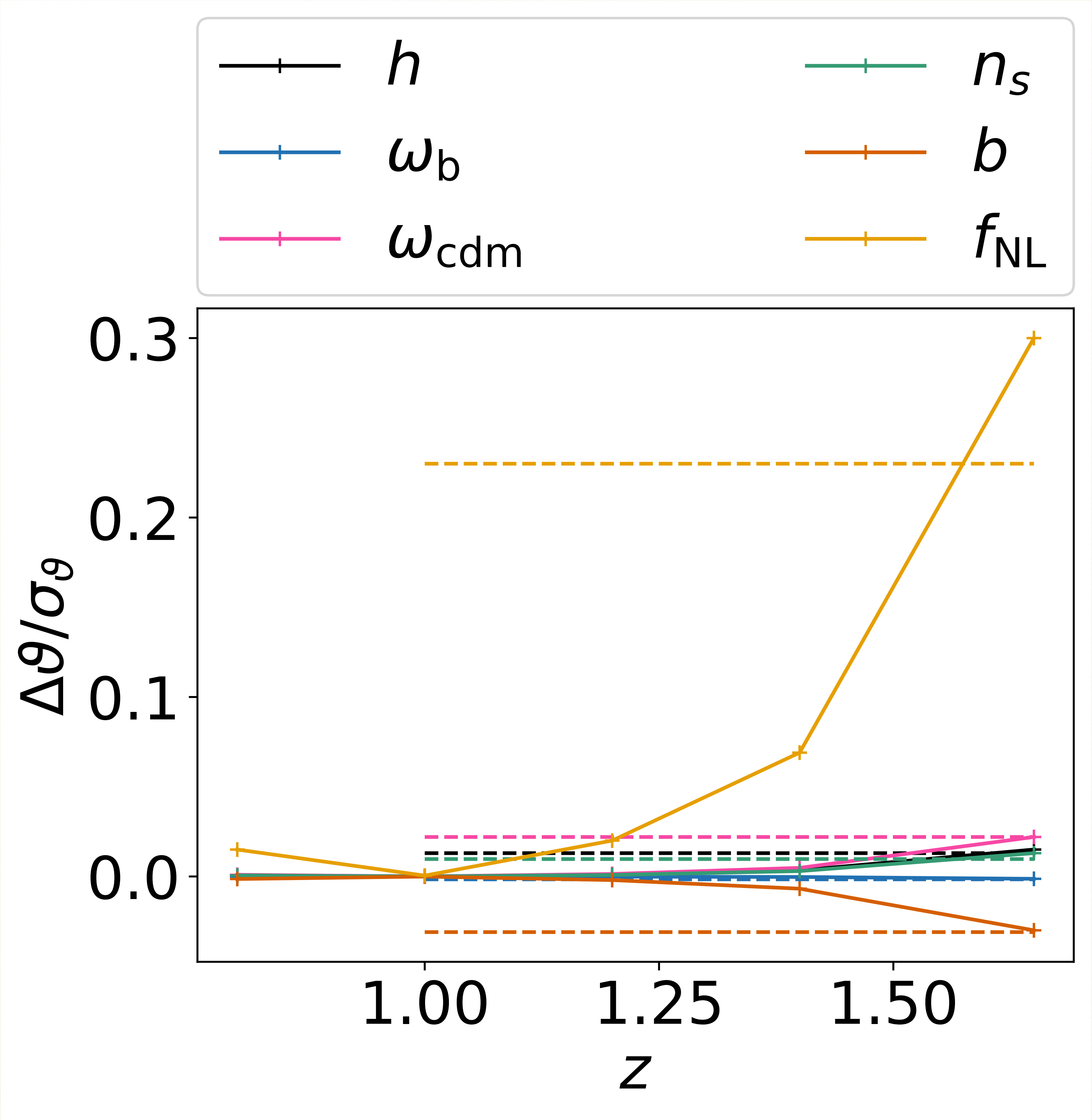
What if direction of Motion is different?



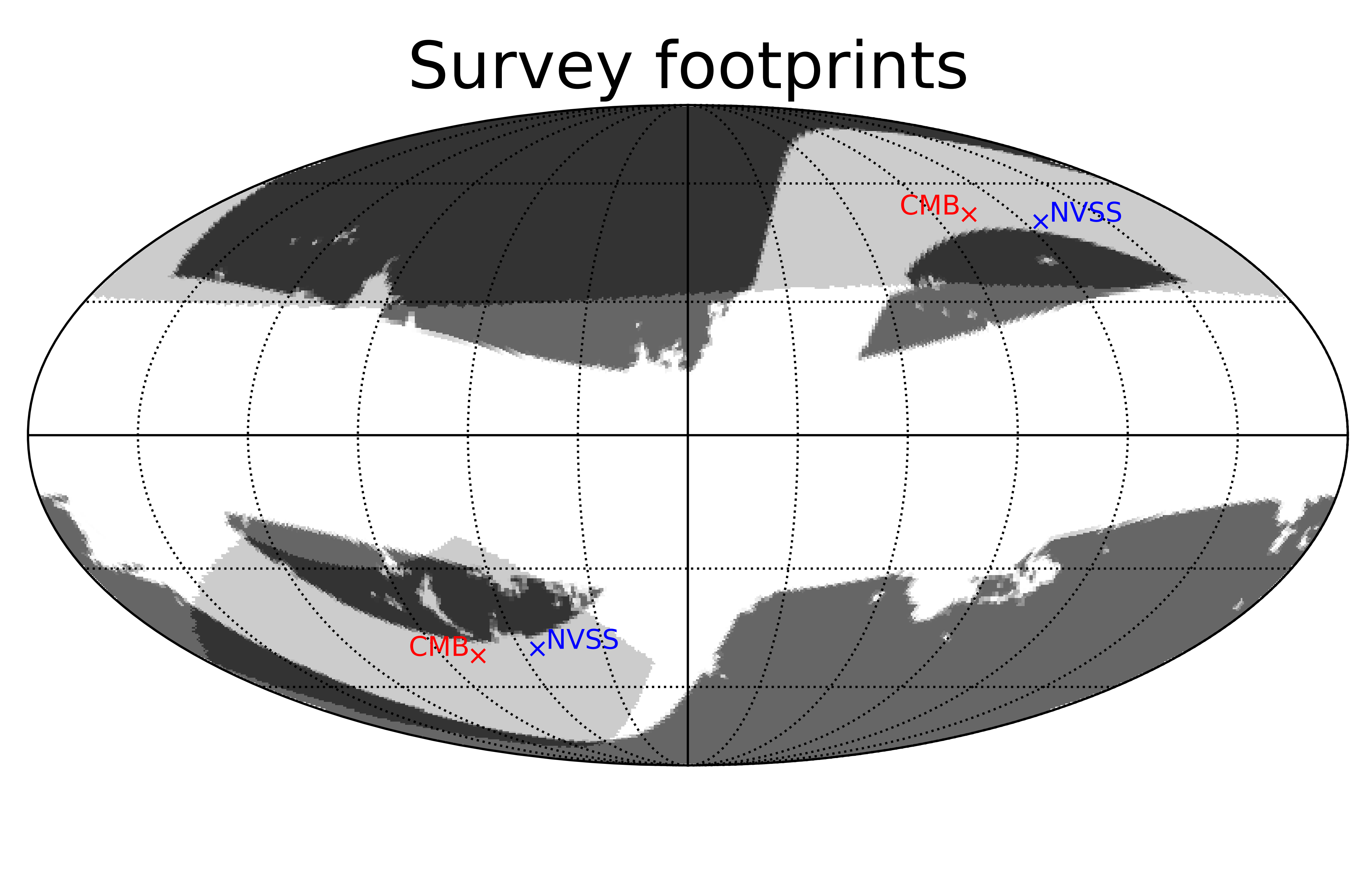
Can You Check For Unaccounted Velocity Dipoles?

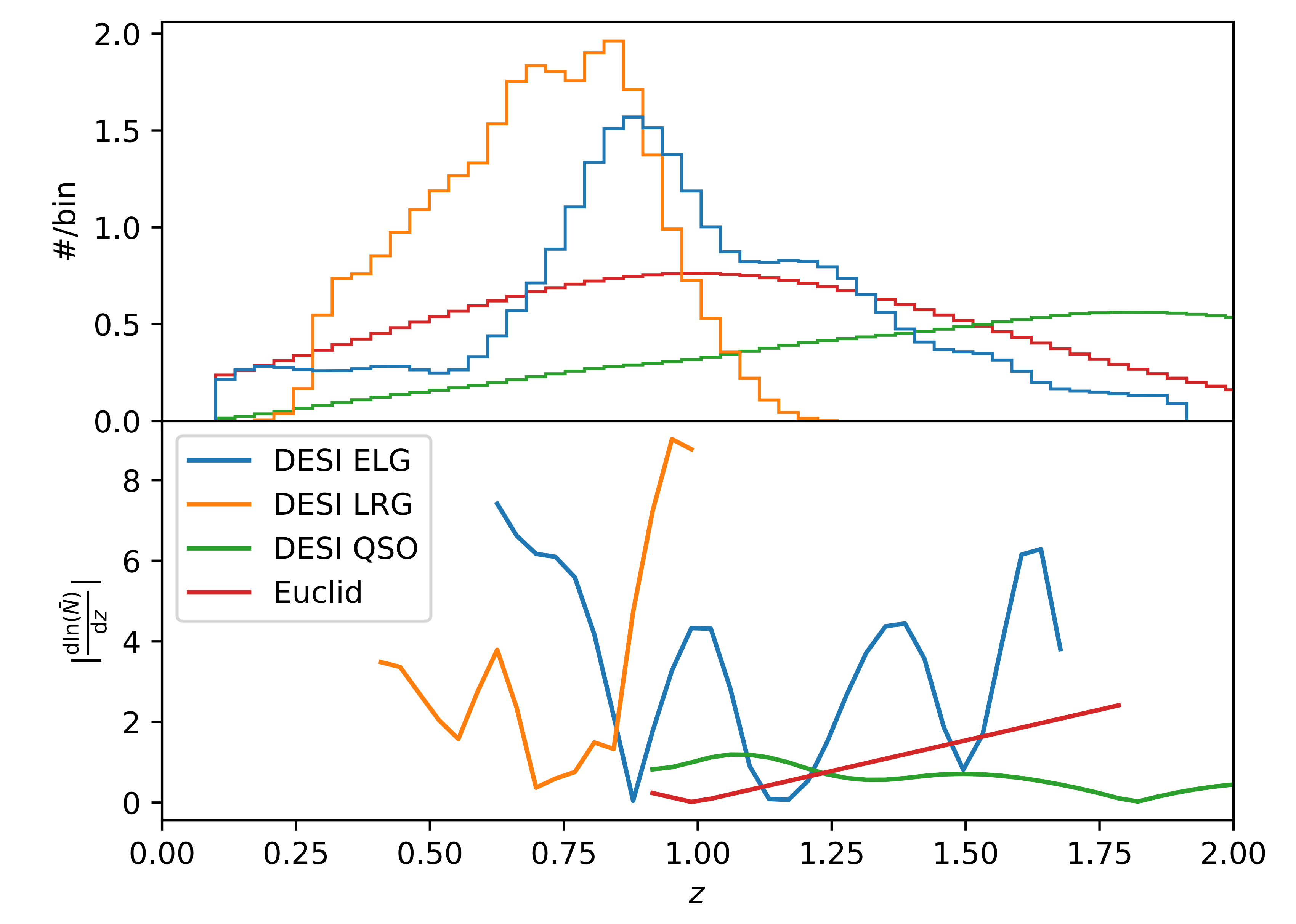
Redshift tomography: Params have extrema at peak of $\bar{N}(z)$!





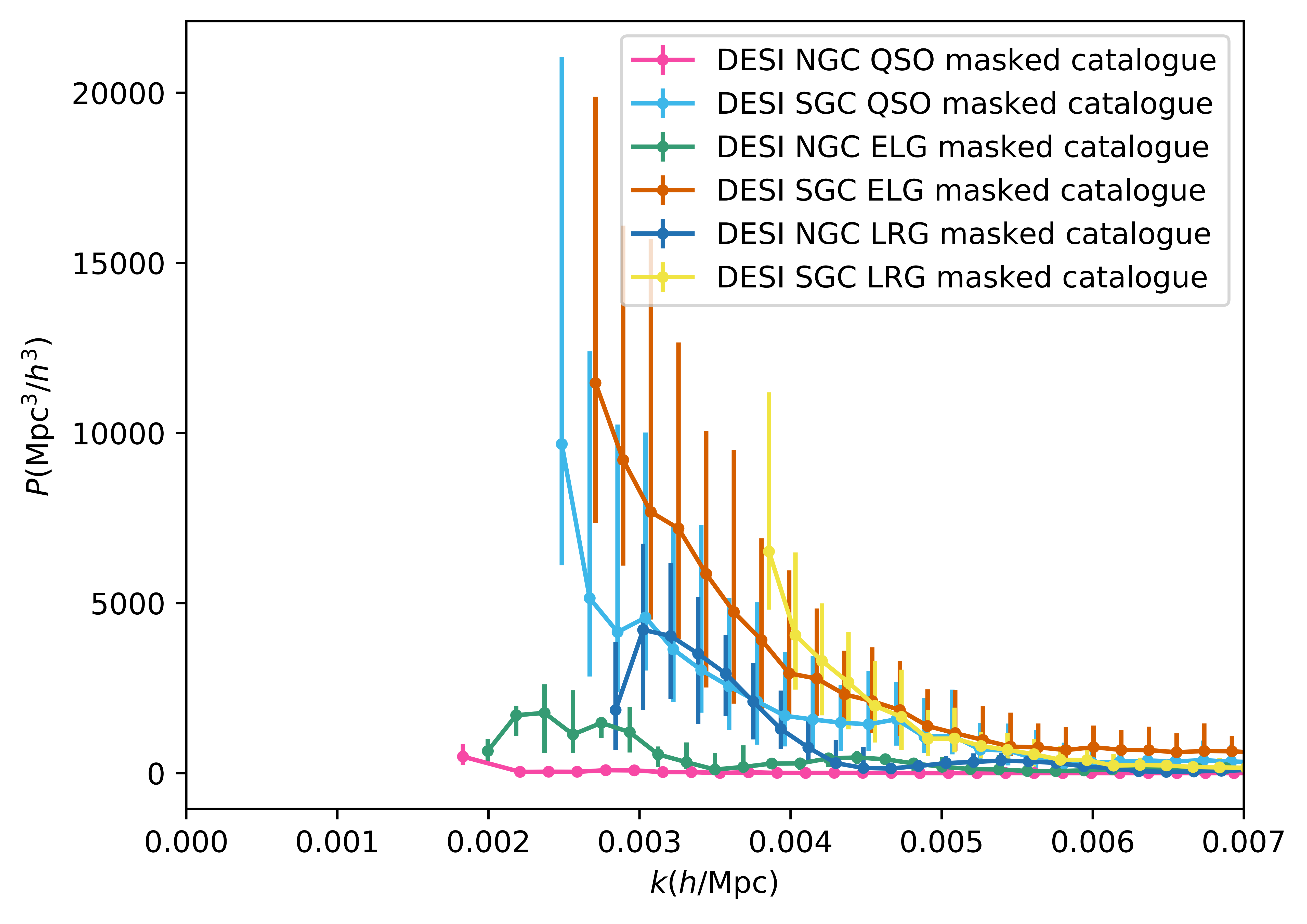
What about DESI?





Light grey: DESI,
Darker grey: Euclid,
Dark grey: overlap

Forecasts for DESI



	Δf_{NL}	σ
NGC QSO	3.8	0.19
SGC QSO	14	0.65
NGC ELG	5.5	0.25
SGC ELG	71	2.1
NGC LRG	4.9	0.13
SGC LRG	13	0.21

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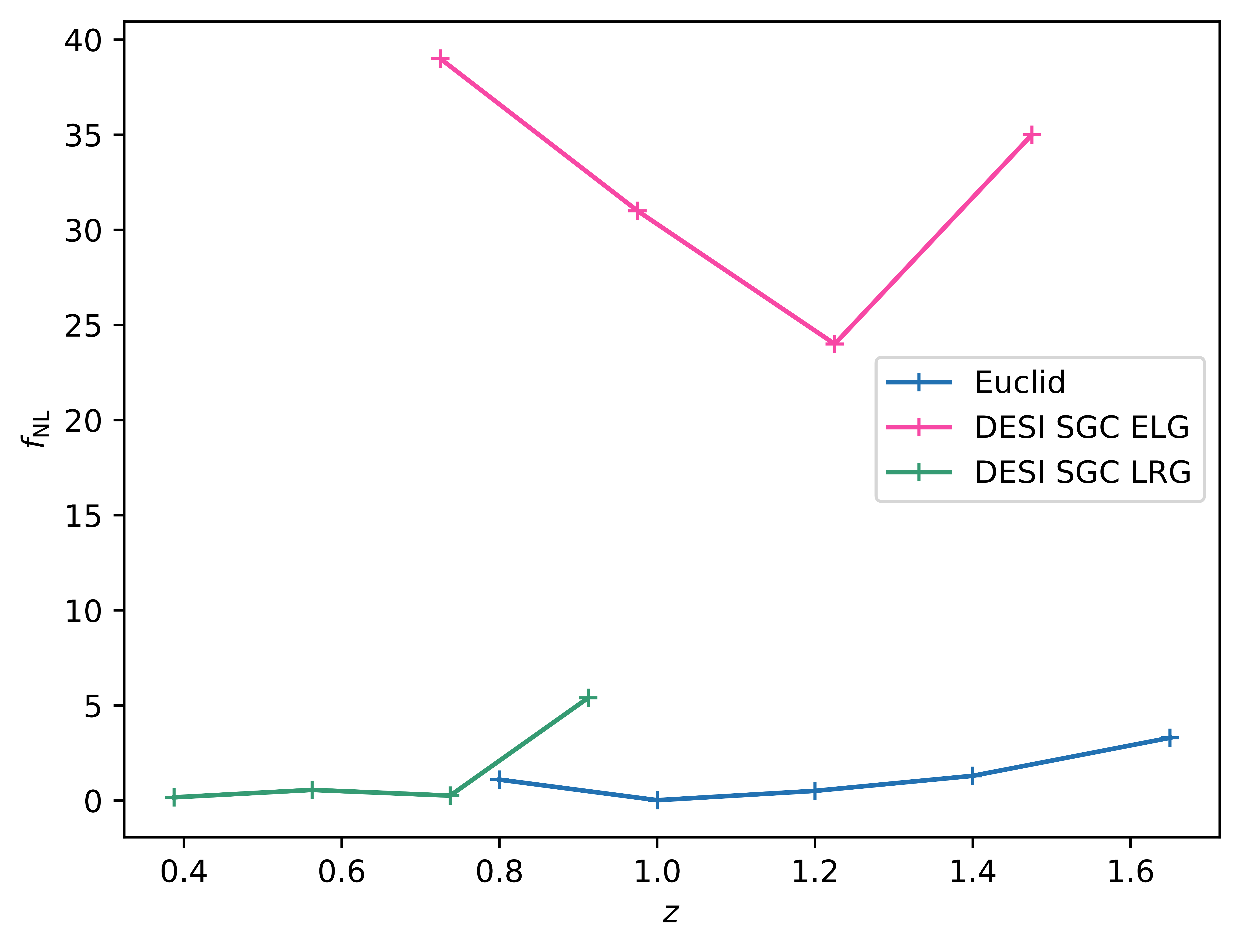

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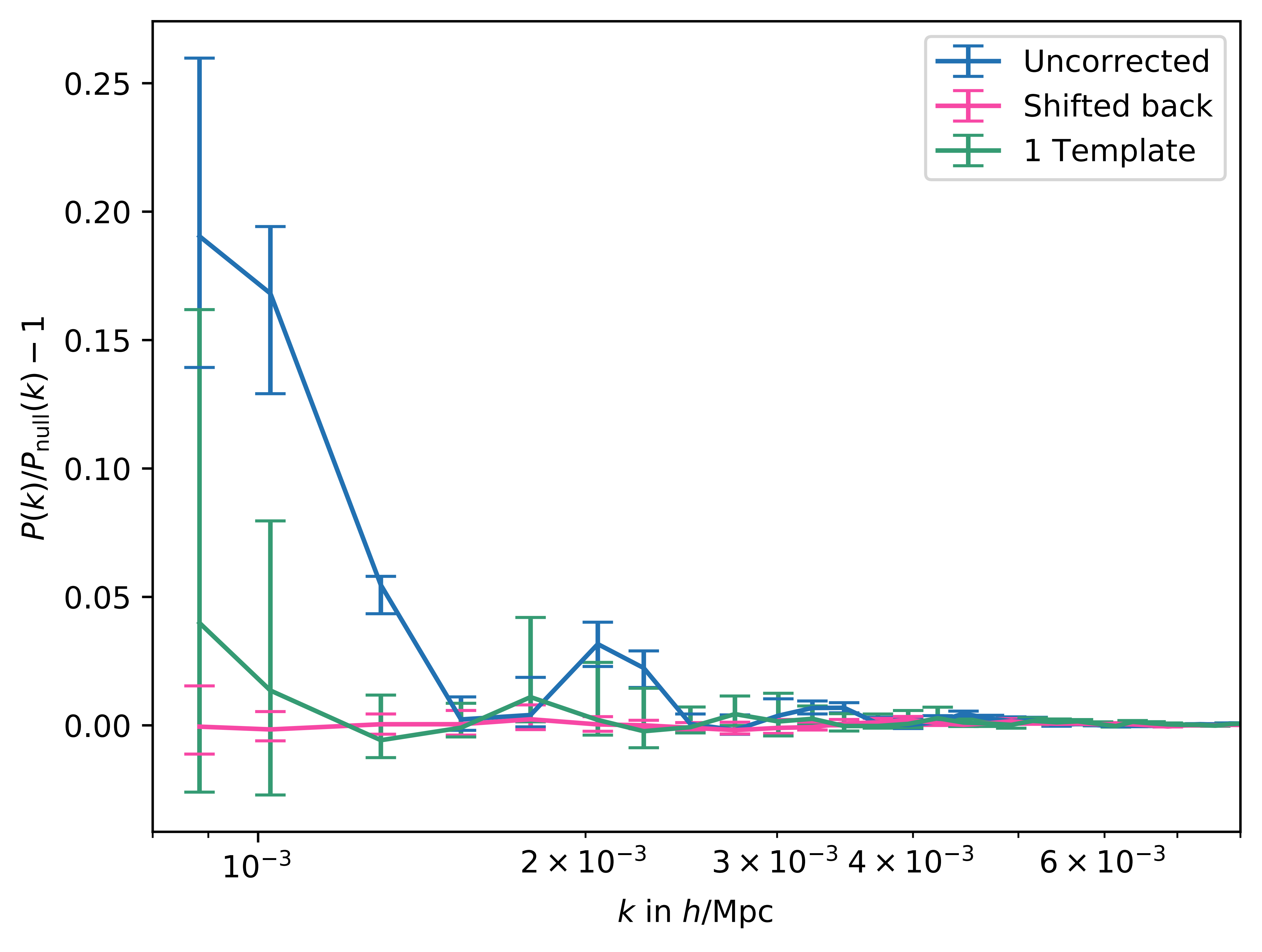
Tests on Gaussian Random Fields

- We test the following using Gaussian random fields:
  - Kaiser rocket mitigation techniques
  - Are cosmological and Kaiser rocket power really independent?

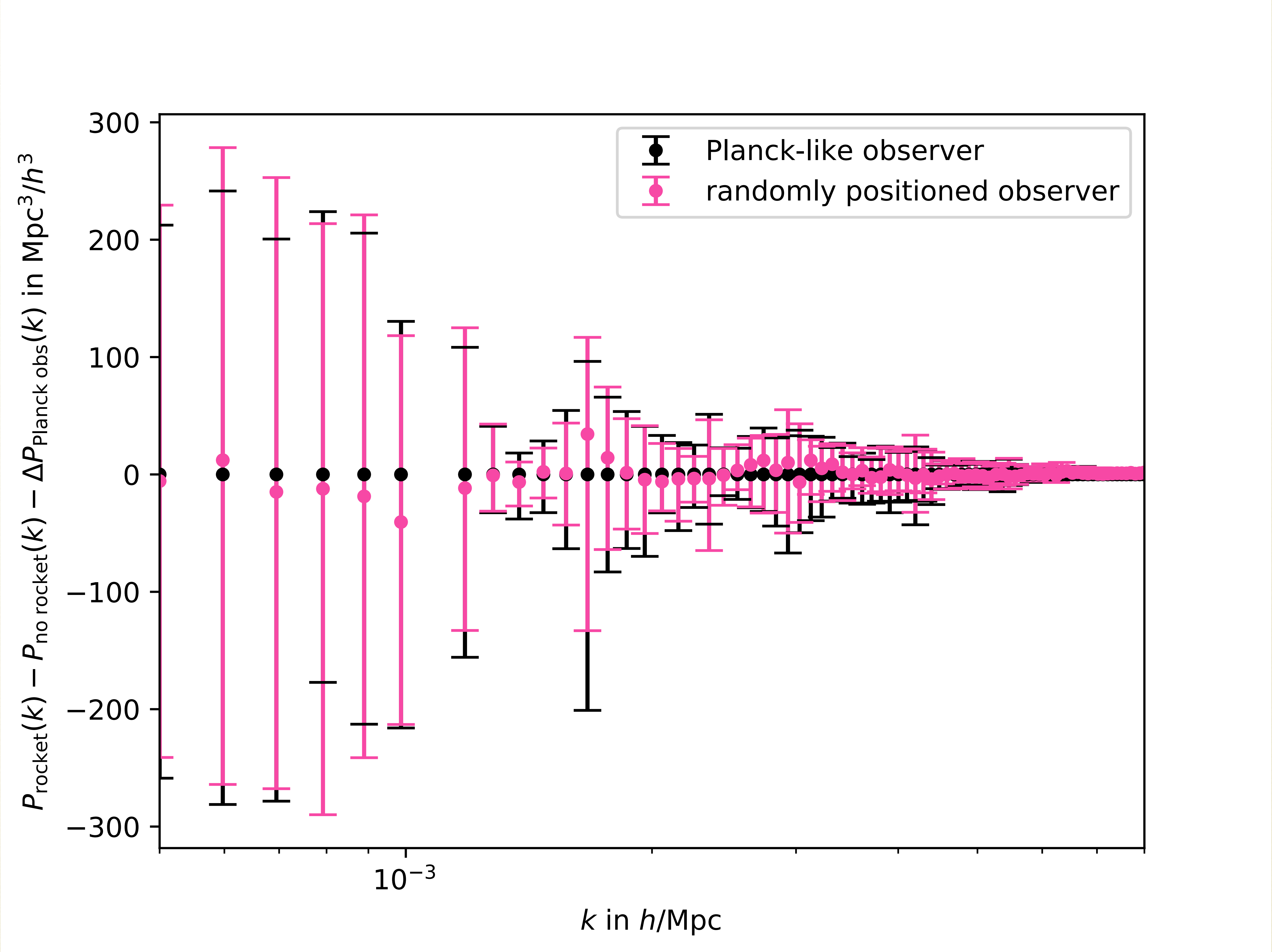
How to get rid of effect

- Simplest: Shift galaxies "back" to their expected redshift
- What if other redshift corrections have been applied? What if our motion not entirely described by CMB dipole?
- We can model $\delta_{\text{true}} = \delta_{\text{obs}} + v\delta_{\text{rocket}}$, thus can use $f(\mathbf{k}) = \delta_{\text{rocket}}(\mathbf{k})$ as template in mode deprojection $C_{\alpha\beta} \to C_{\alpha\beta} + \lim_{\sigma\to\infty} \sigma f(\mathbf{k}_\alpha) f^*(\mathbf{k}_\beta)$ or mode subtraction (1607.02417, 1806.02789)
- Can marginalise out direction by considering several templates, i.e. $\delta_{\text{true}} = \delta_{\text{obs}} - \sum_{i=1}^{N} v_i \delta_{\text{rocket},i}$



Independence Test

- Use continuity equation for velocity field corresponding to GRF
- Place two observers: 1. At position where v-field ~ CMB dipole, 2. At random position
- Apply selection functions and measure power spectrum
- Apply Kaiser rocket shifts for both observers and measure power again
- If assumption correct, differences between power before and after Kaiser rocket shift must be consistent



Conclusions

- Peculiar motion of observer introduces spurious clustering signal (Kaiser rocket effect)
- Spurious signal can mimic f_{NL}
- Depending on survey mask and selection, Kaiser rocket can dominate measurement
- Effect easy to model and therefore easy to mitigate