SKA Cosmo Meetings x Snow in Manchester

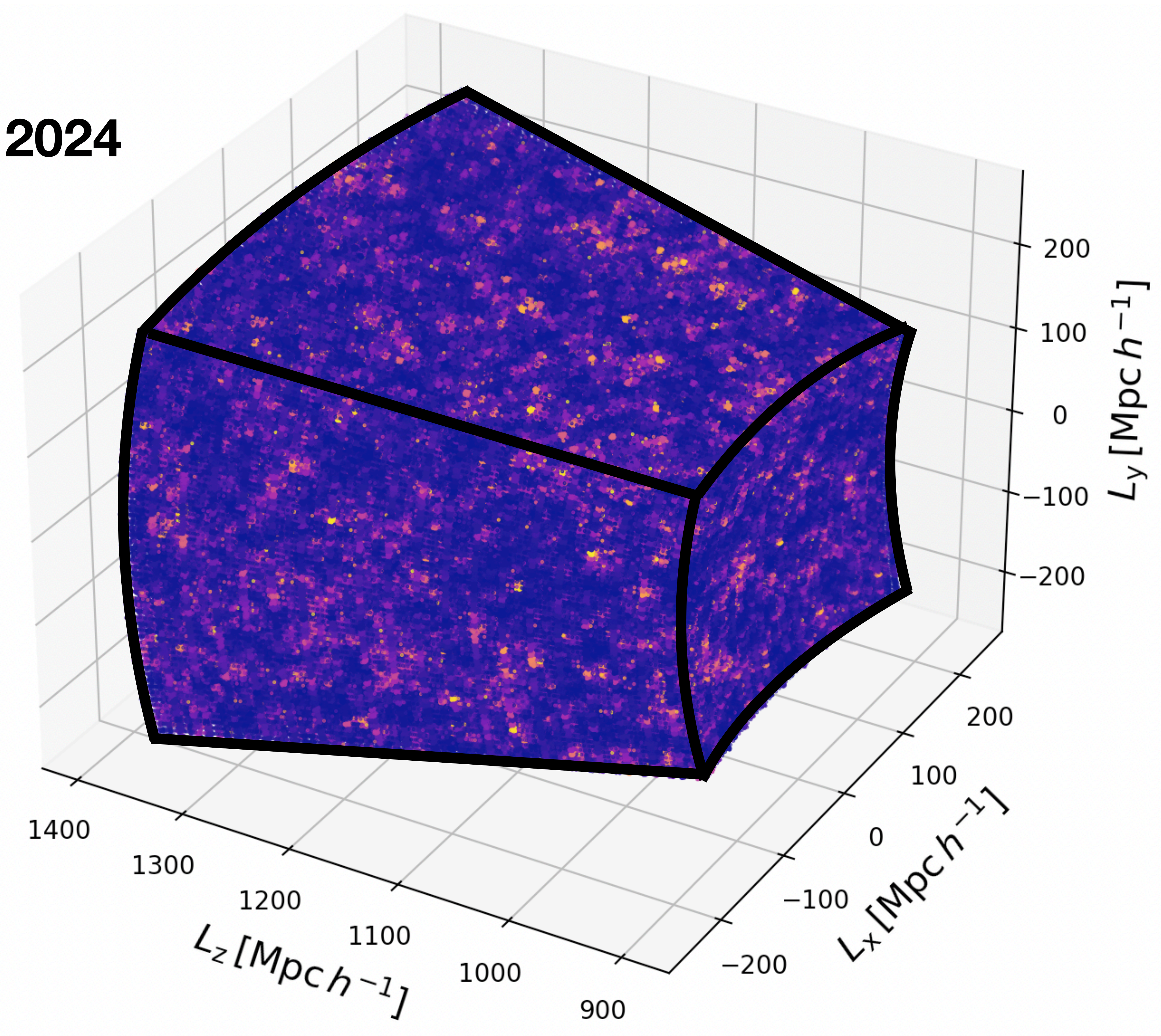
19th Jan 2023

16th Jan 2024

Accurate Fourier-space statistics for line intensity mapping

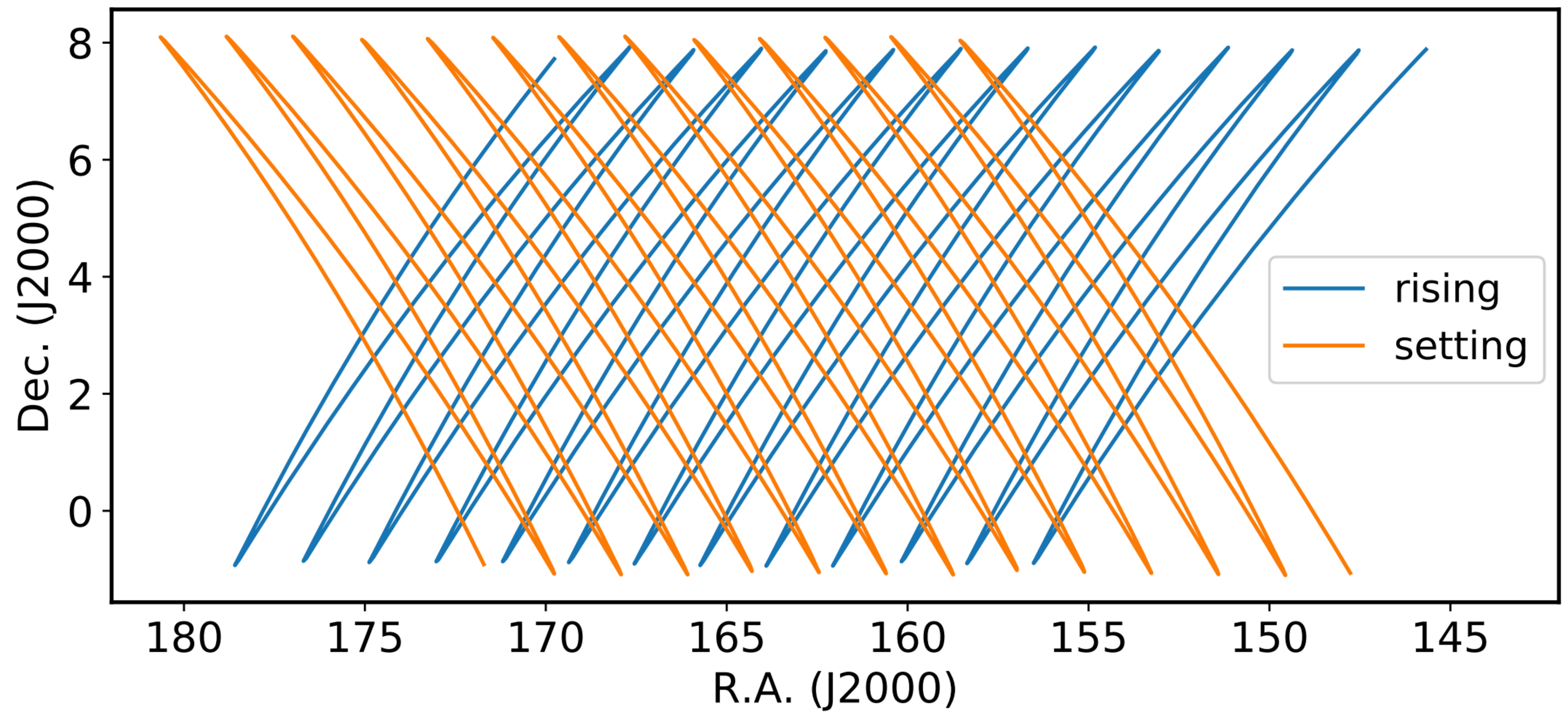
Steve Cunnington
Jodrell Bank Centre for Astrophysics - The University of Manchester

Cosmology SWG Annual Meeting
Centro de Astrofísica da Universidade do Porto - 16th January 2024

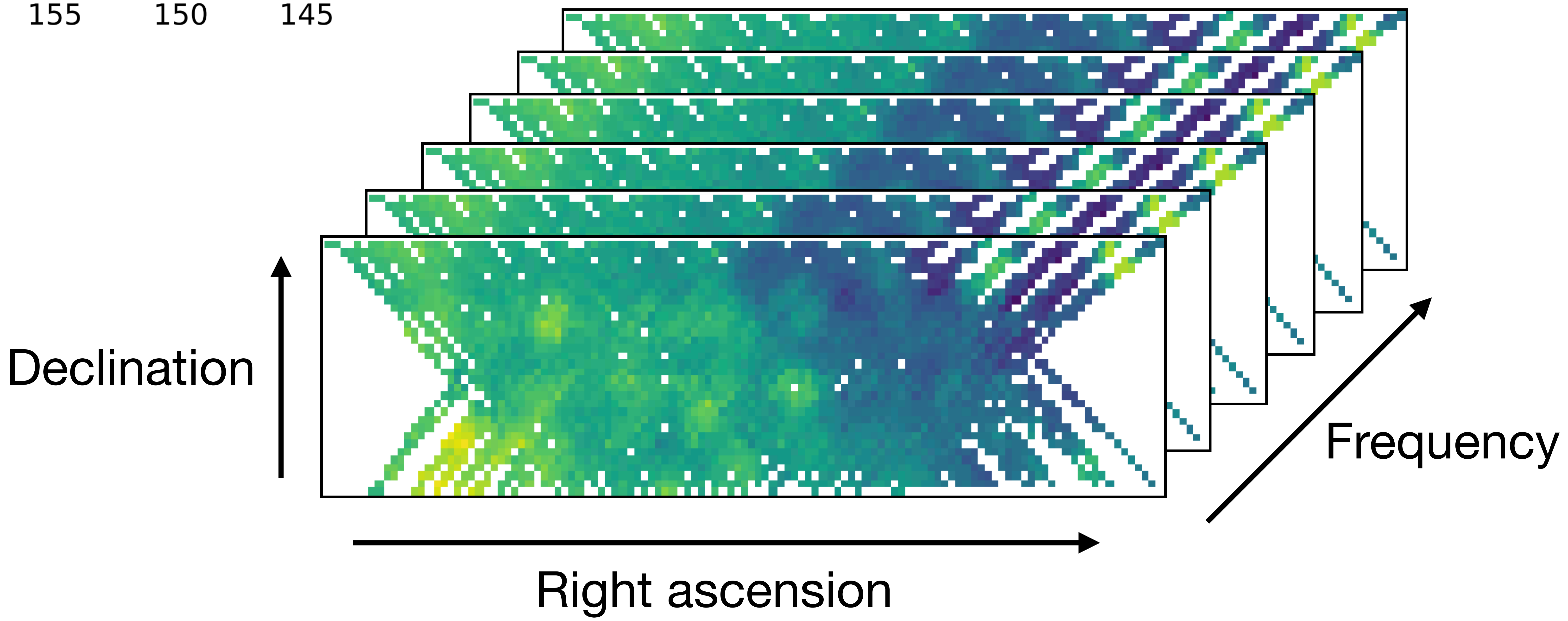


arXiv:2312.07289
Steve Cunnington [steven.cunnington@manchester.ac.uk]

Observations on the sky



MeerKAT 2019 pilot survey scanning strategy
Wang+21 [arXiv:2011.13789]



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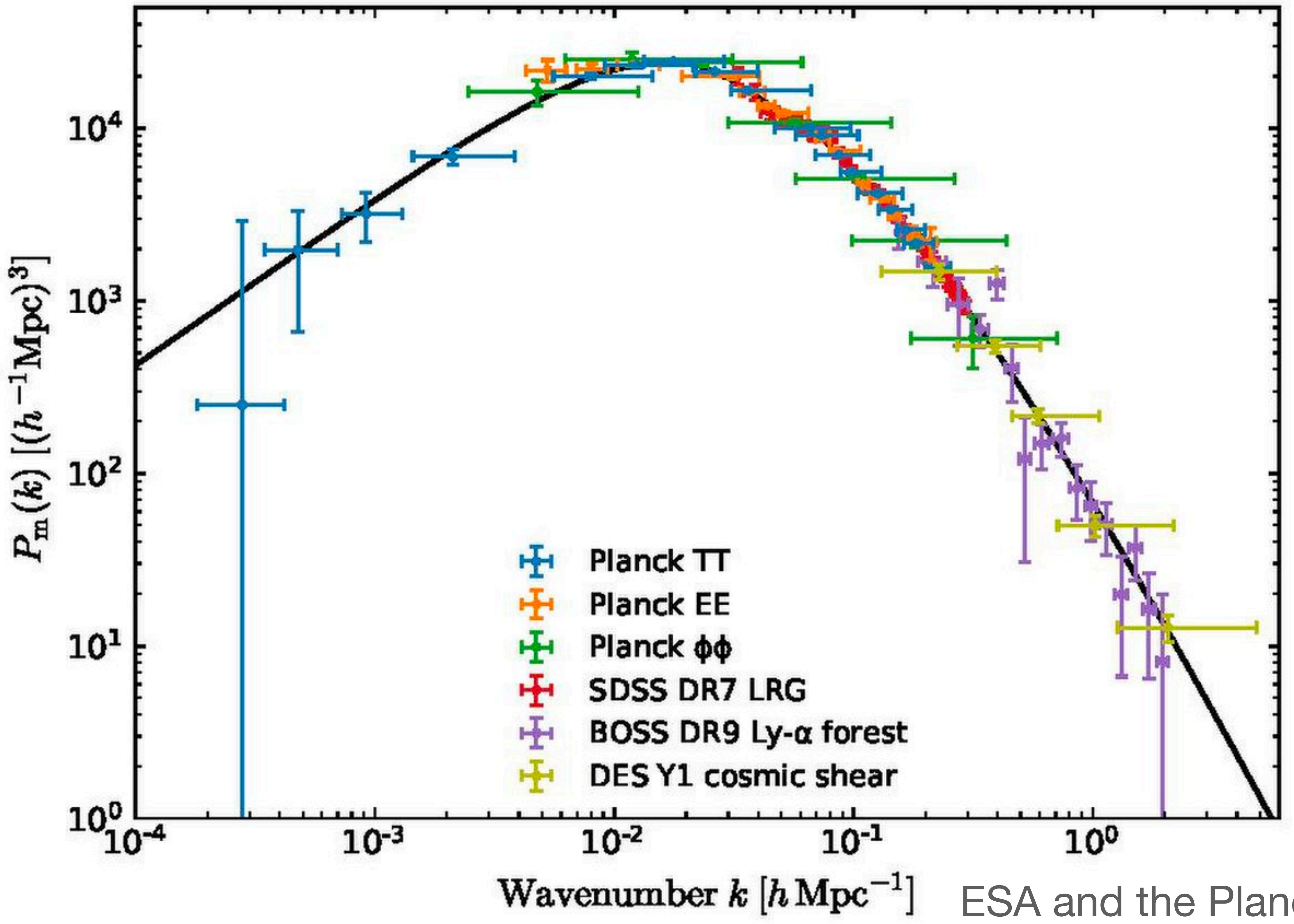
Observations on the sky

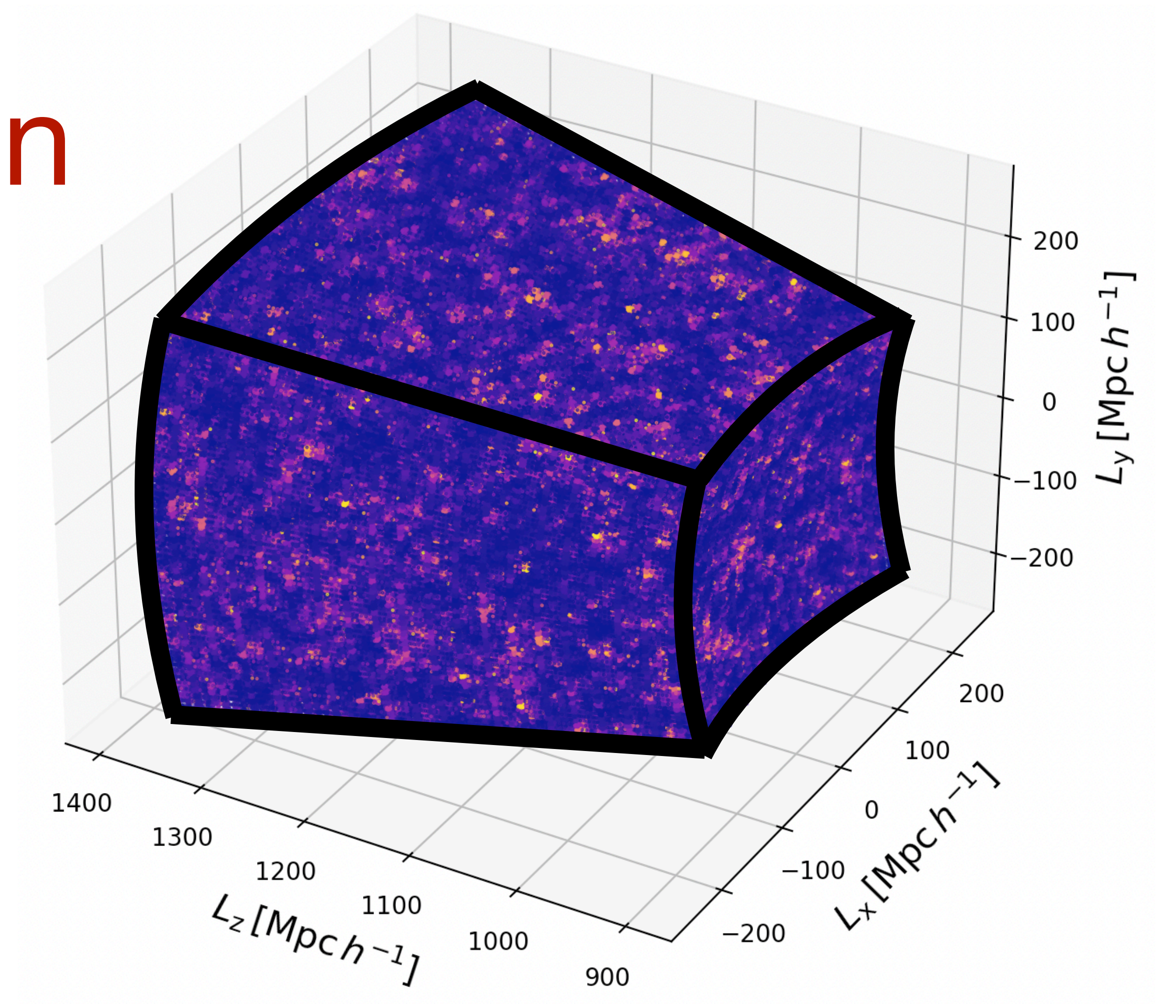
Analysis in Cartesian space



ESA and the Planck Collaboration

3D **Fourier-space** clustering analysis require observations in **Cartesian** *comoving* (Mpc/*h*) space

➡ Require transformation of voxel intensities



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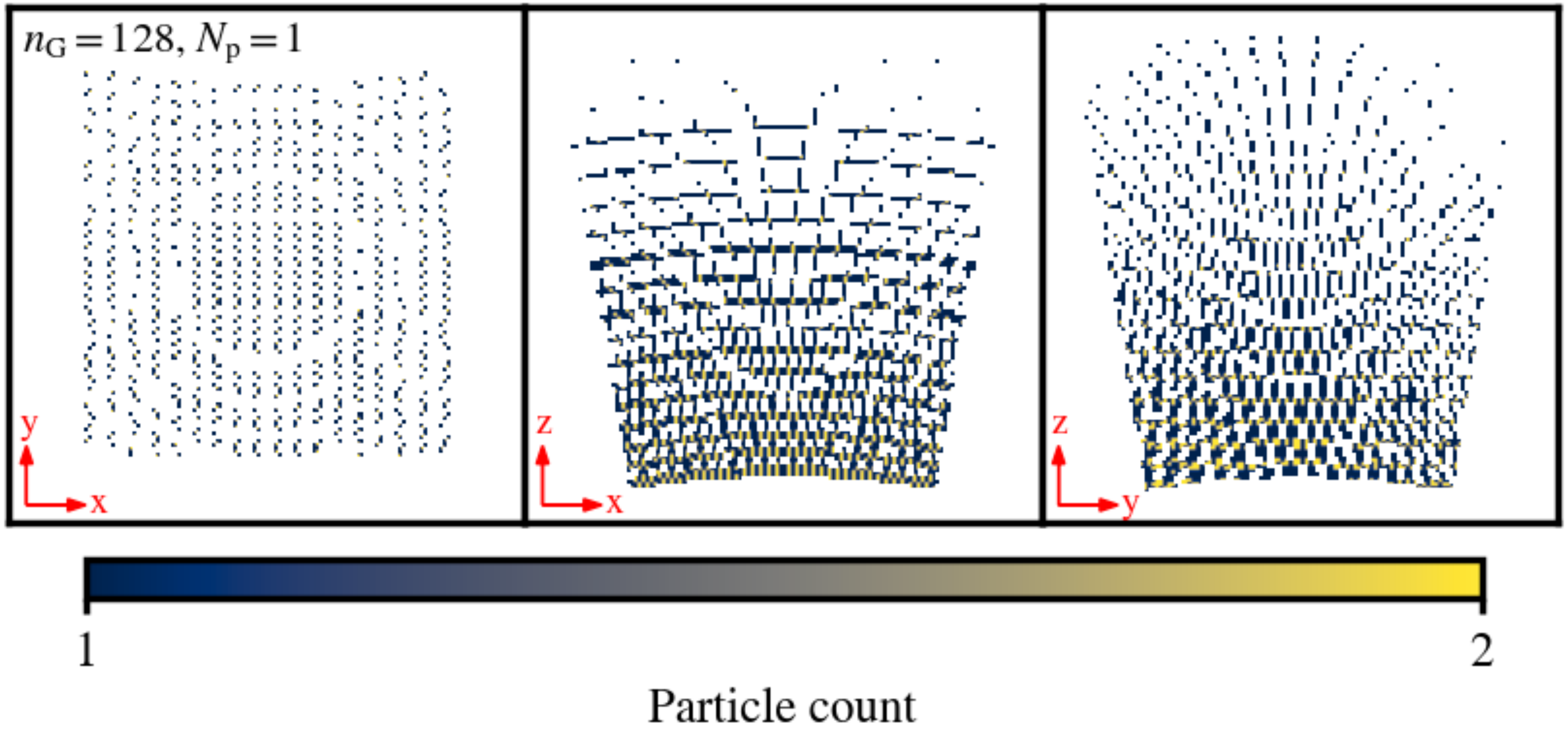
Transforming each voxel's sky coordinate into Cartesian space is trivial but **holes in the coverage** will arise unless very corse grid is chosen



Fields not suitable for Fourier transform

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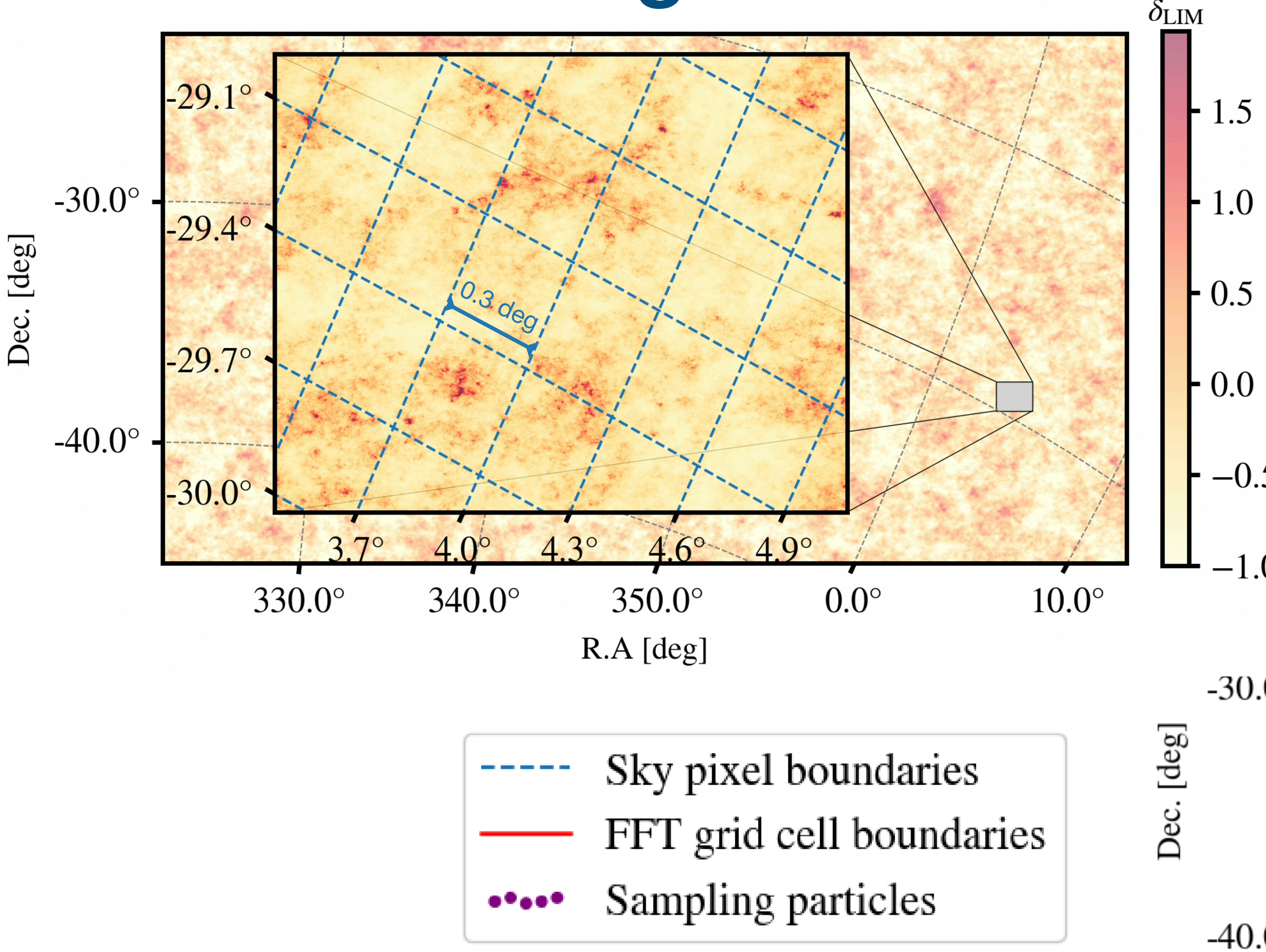
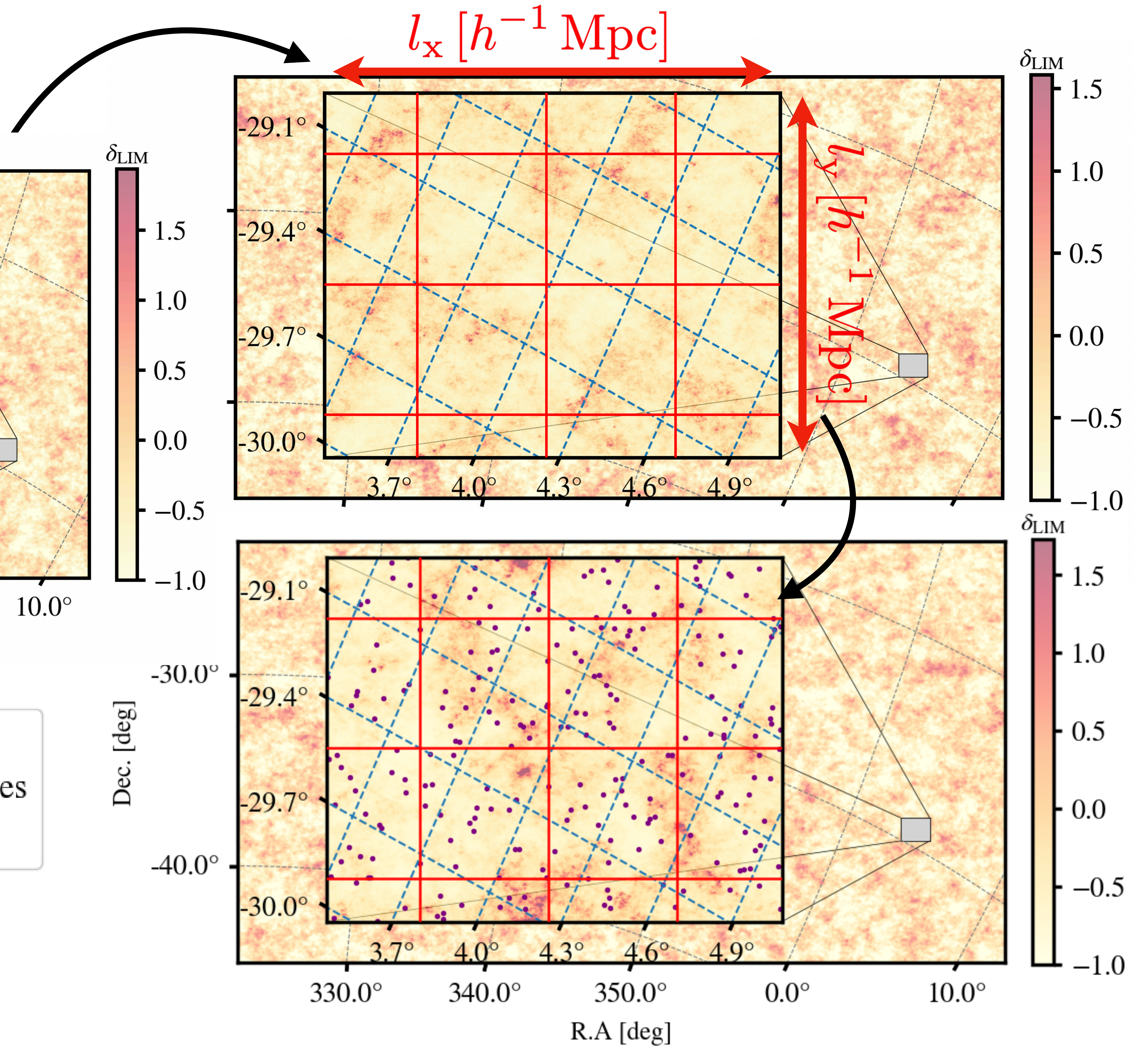
Monte Carlo sampling to a Cartesian grid





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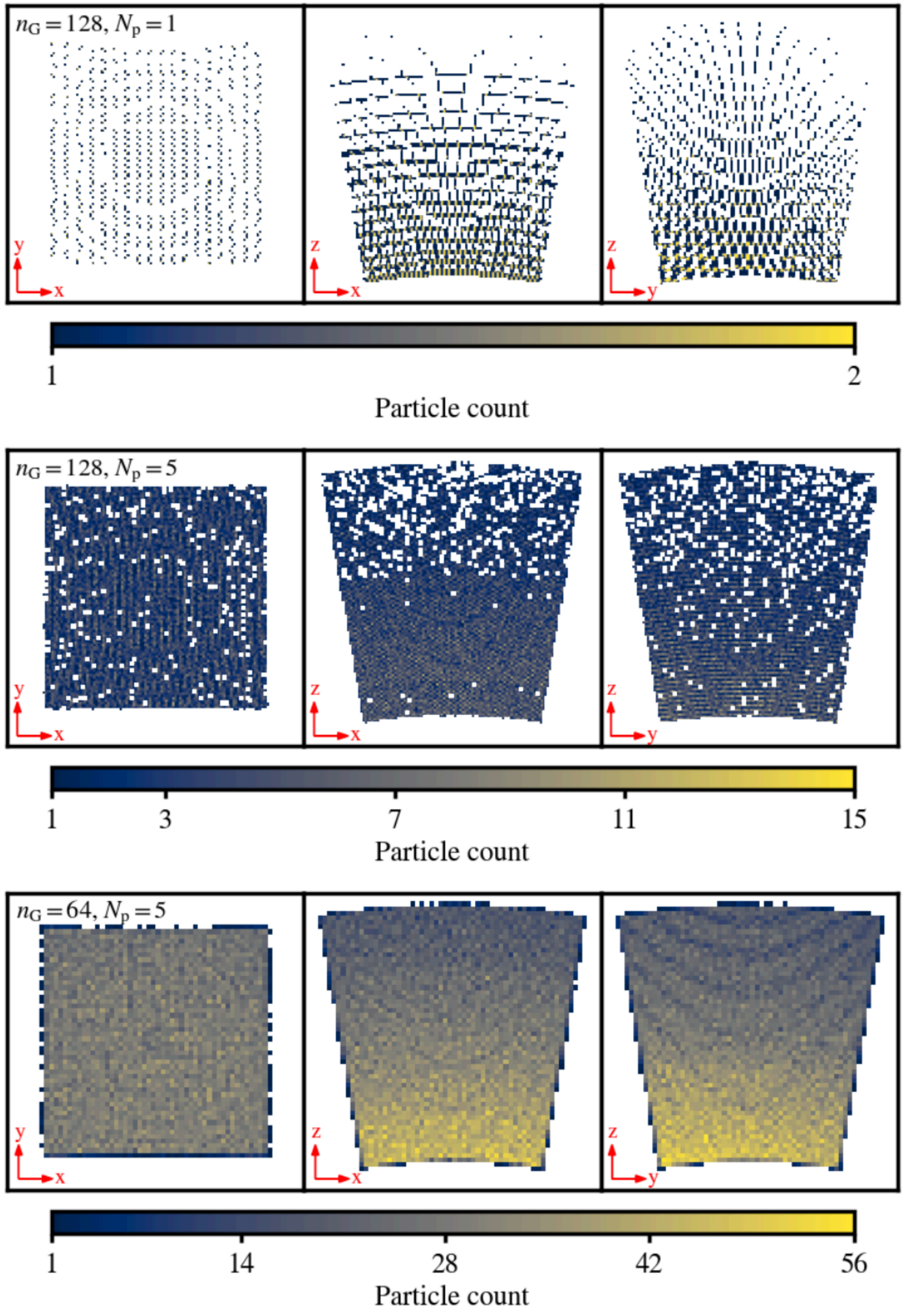

☑ Enough sampling particles

☑ Well chosen grid resolution

➡ footprint in Cartesian space with no holes

Testing with simulations

➡ https://github.com/stevecunnington/gridimp

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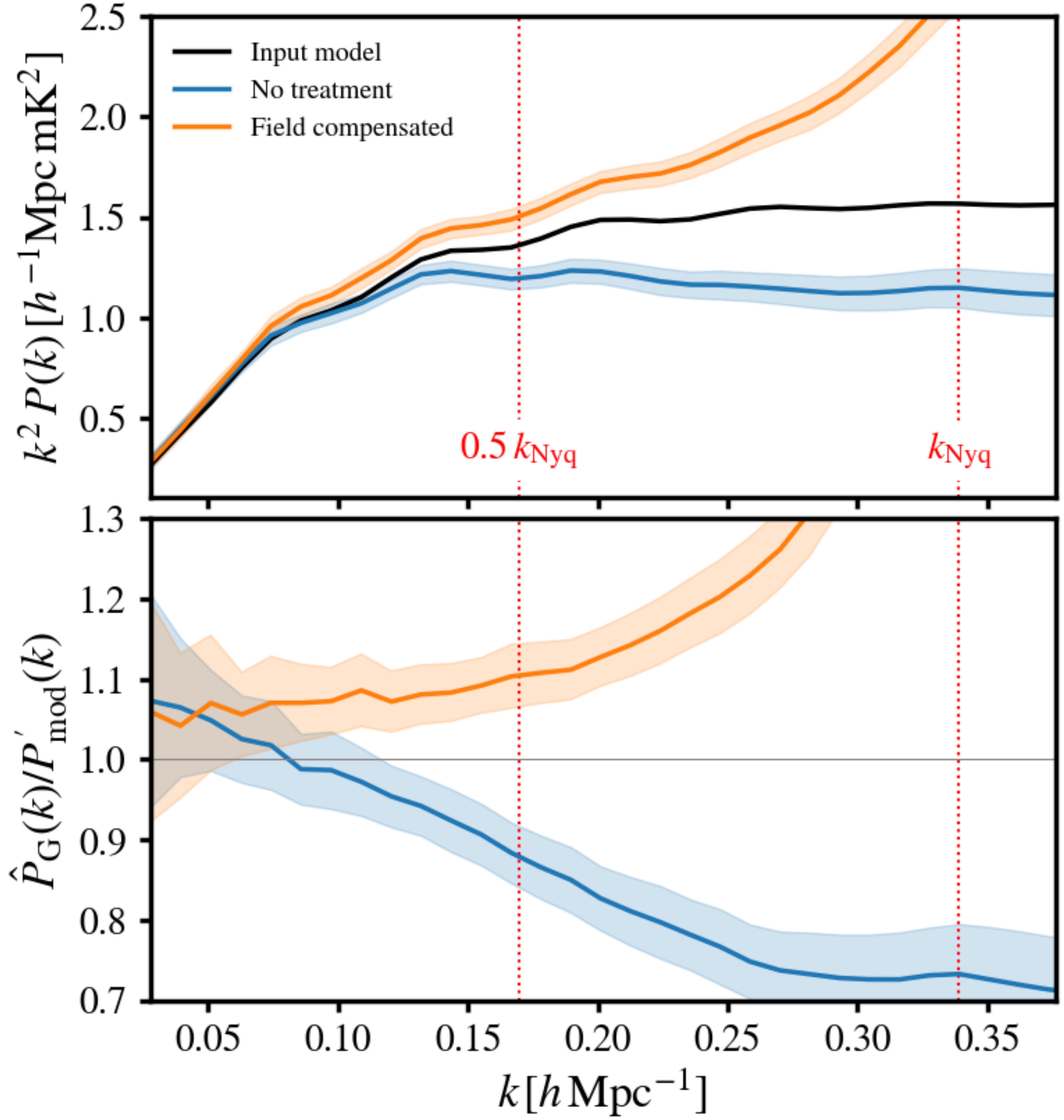

To **compensate** for smoothing from resampling, the Cartesian field is deconvolved with the Fourier transform of **top-hat** functions

$$\tilde{W}_{\mathrm{ngp}}(\boldsymbol{k}) = \mathrm{sinc}\left(\frac{k_{\mathrm{x}}H_{\mathrm{x}}}{2}\right)\mathrm{sinc}\left(\frac{k_{\mathrm{y}}H_{\mathrm{y}}}{2}\right)\mathrm{sinc}\left(\frac{k_{\mathrm{z}}H_{\mathrm{z}}}{2}\right)$$

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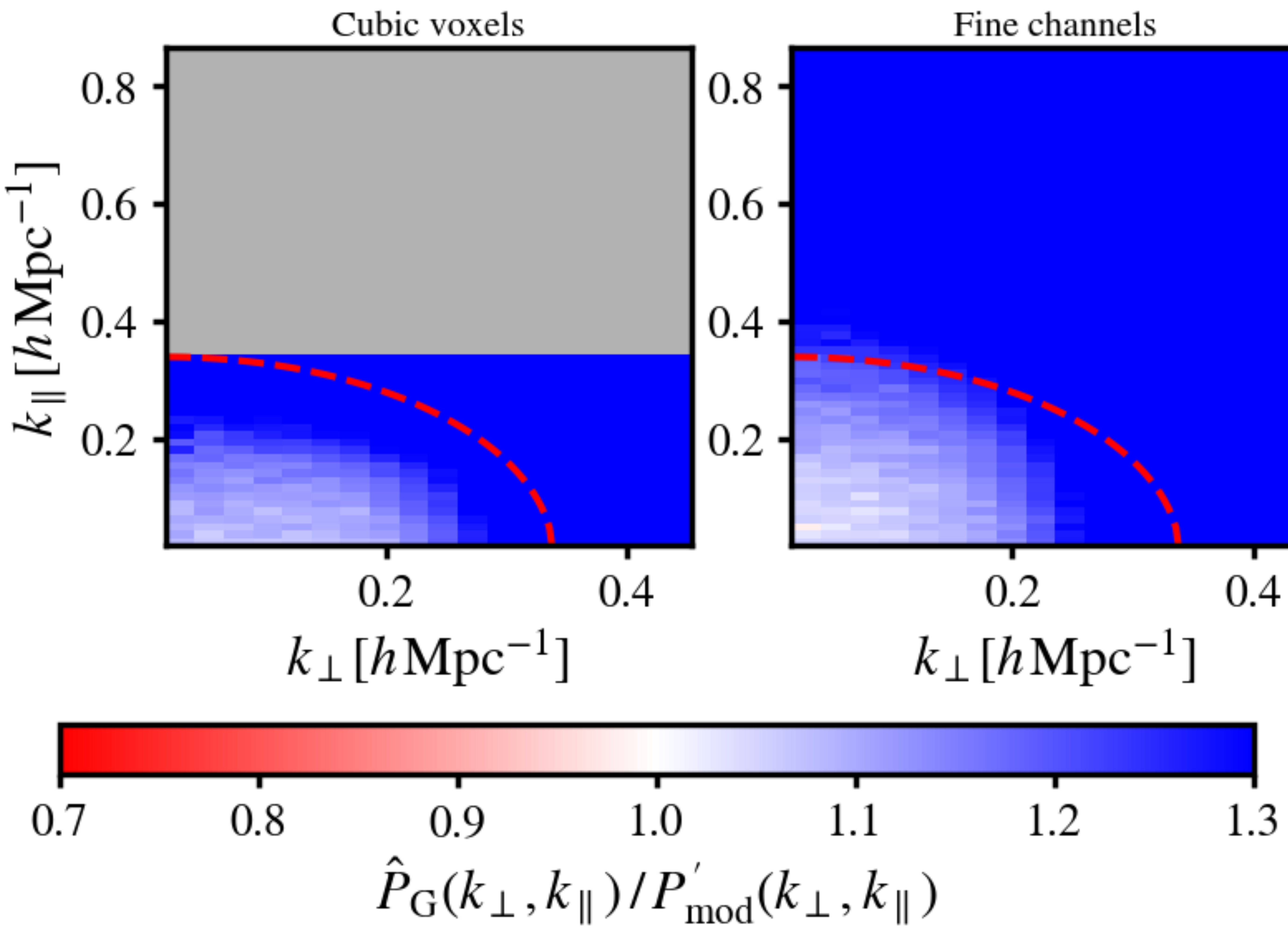
High resolution channels



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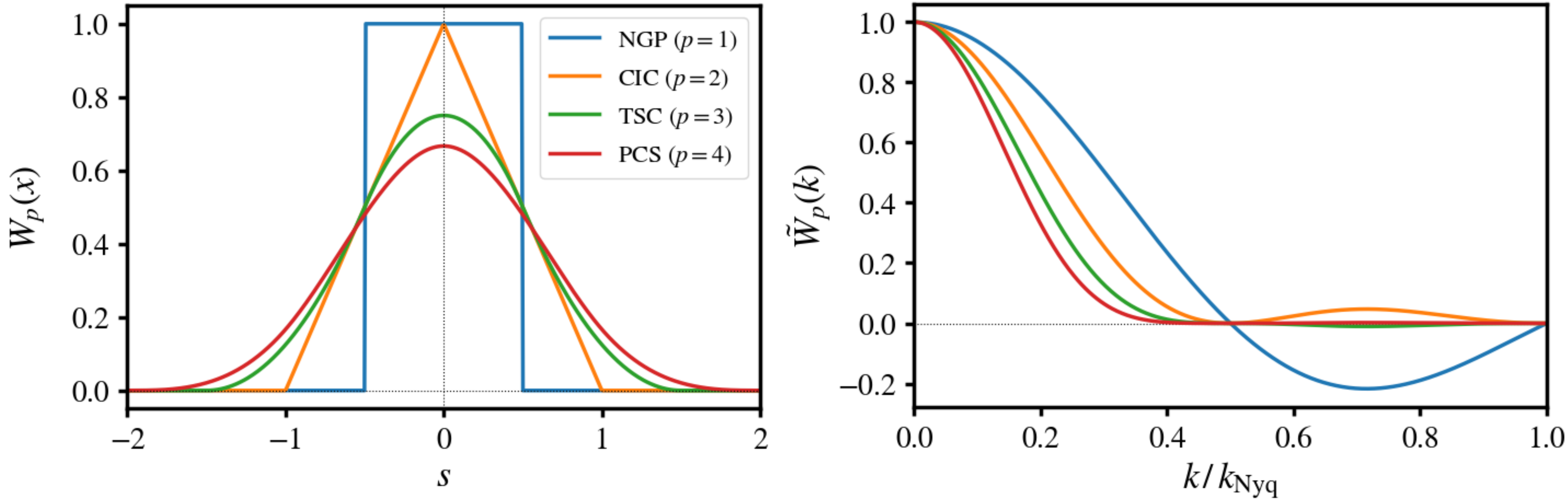
Can we mitigate aliasing with higher-order assignment schemes



$$\tilde{W}_p(\boldsymbol{k}) = \left[\mathrm{sinc}\left(\frac{k_{\rm x}H_{\rm x}}{2}\right)\mathrm{sinc}\left(\frac{k_{\rm y}H_{\rm y}}{2}\right)\mathrm{sinc}\left(\frac{k_{\rm z}H_{\rm z}}{2}\right)\right]^p$$

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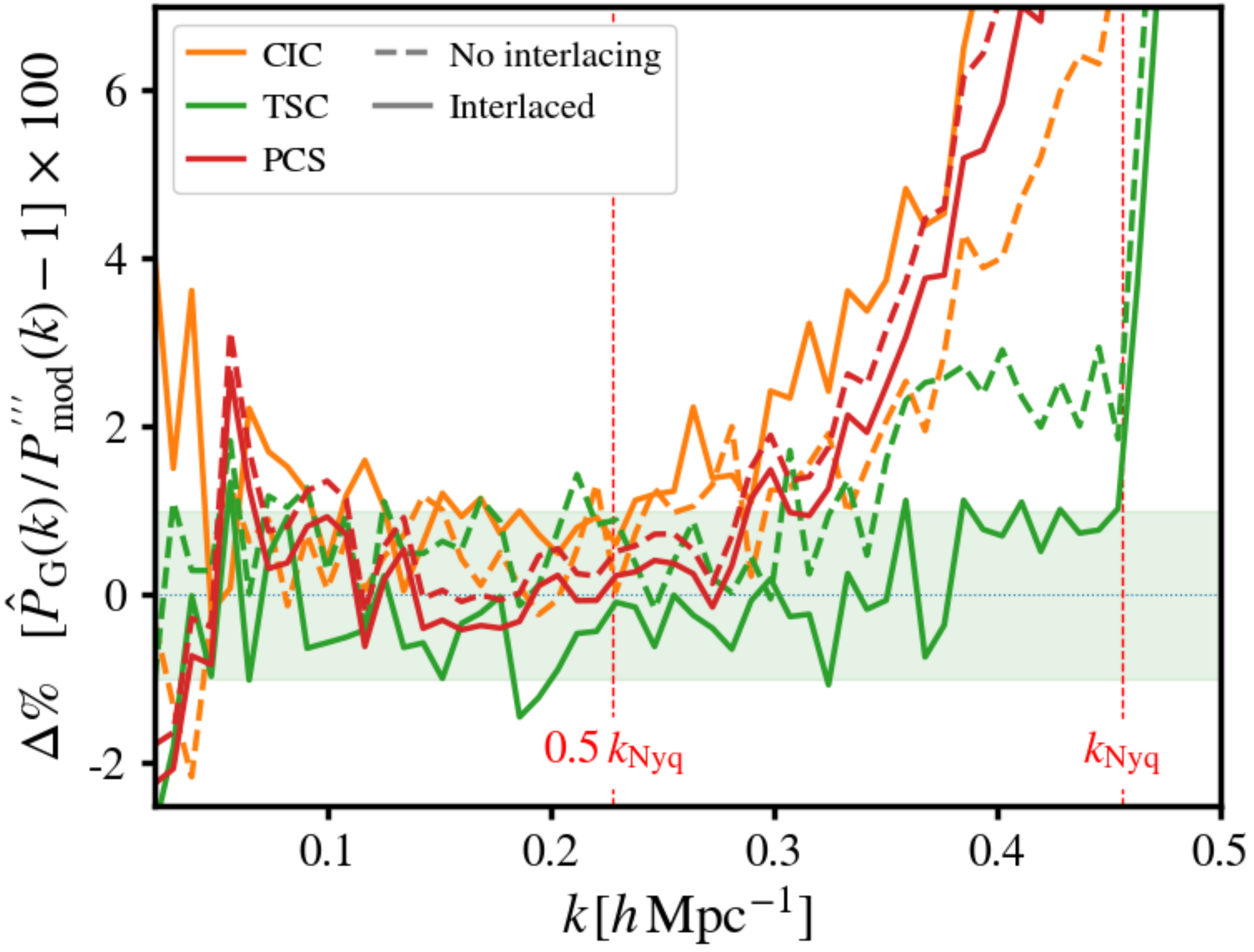
Can we mitigate aliasing with higher-order assignment schemes



Also includes some modelling of:

- power damping from HEALPix pixelisation
- power damping from frequency channels

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https://github.com/stevecunnington/gridimp

stevecunnington / gridimp

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stevecunnington added arXiv number · 93260b9 · last month · 26 Commits

data	param file update	2 months ago
examples	axes labels	2 months ago
gridimp	removed CAMB option	last month
scripts	fixed some path inconsistencies	last month
README.md	added arXiv number	last month
environment.yml	.yml file	2 months ago
setup.py	fixing setup.py steps	2 months ago

README

gridimp

gridded intensity mapping power

Getting started:

Cartesian lognormal mock:

Generate a fast cubic lognormal mock over n=128^3 cells with size l=500^3(Mpc/h)^3:

```
from gridimp import cosmo
from gridimp import mock

cosmo.SetCosmology(z=1) # set cosmology
Pmod = cosmo.GetModelPk(z=1) # obtain matter power spectrum

l = 500 # length of box down one side [Mpc/h]
n = 128 # number of cells down one side
dims = [l,l,l,n,n,n,0,0,0] # lengths,cells,origins for each dimension

delta_0 = mock.Generate(Pmod,dims) # generate LIM mock (default b=1,T=1)
```

- **HEALPix sky maps for simulated survey:**

By defining input simulated survey parameters, a lognormal mock can be generated onto a Cartesian grid calculated to fully enclose the survey footprint.

```
### Define survey parameters:
ramin,ramax = 10,30 # [deg]
decmin,decmax = 10,30  # [deg]
numin,numax = 900,1110 # [MHz]
nnu = 60 # number of frequency channels
nside = 128 # HEALPix resolution: determines pixel size
n0 = 256 # n0^3 will be number of cells for input grid cube

### Initialise healpix and get sky coordinates for voxels covering survey:
from gridimp import grid
ra,dec,nu,dims_0 = grid.init_healpix(nside,ramin,ramax,decmin,decmax,numin,numax,nnu,n0)

delta_0 = mock.Generate(Pmod,dims_0) # generate LIM mock (default b=1,T=1)

# Create healpy sky maps for each frequency channel:
m = grid.lightcone_healpy(delta_0,dims_0,ra,dec,nu,nside)
```


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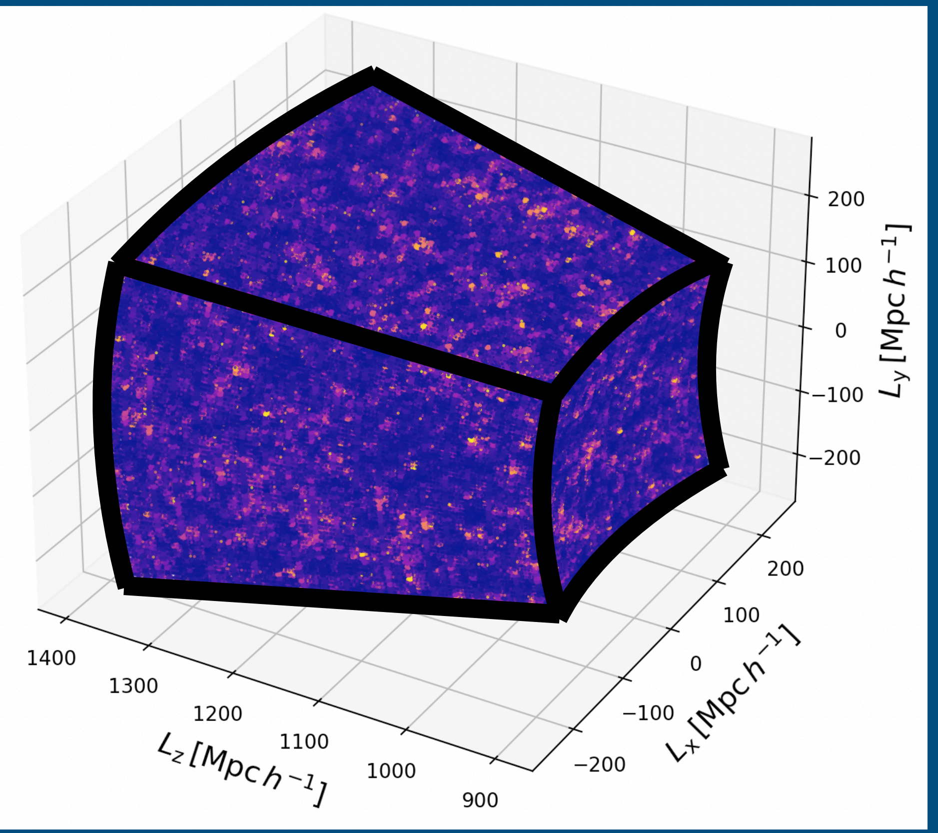
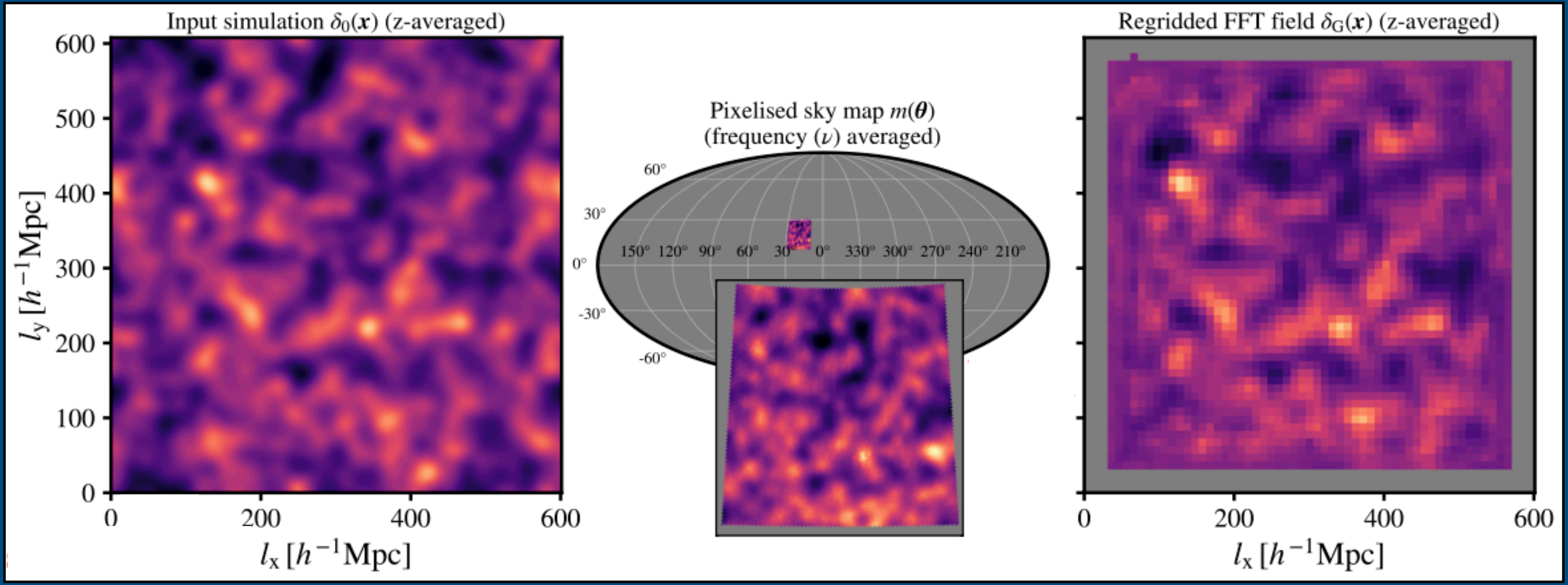
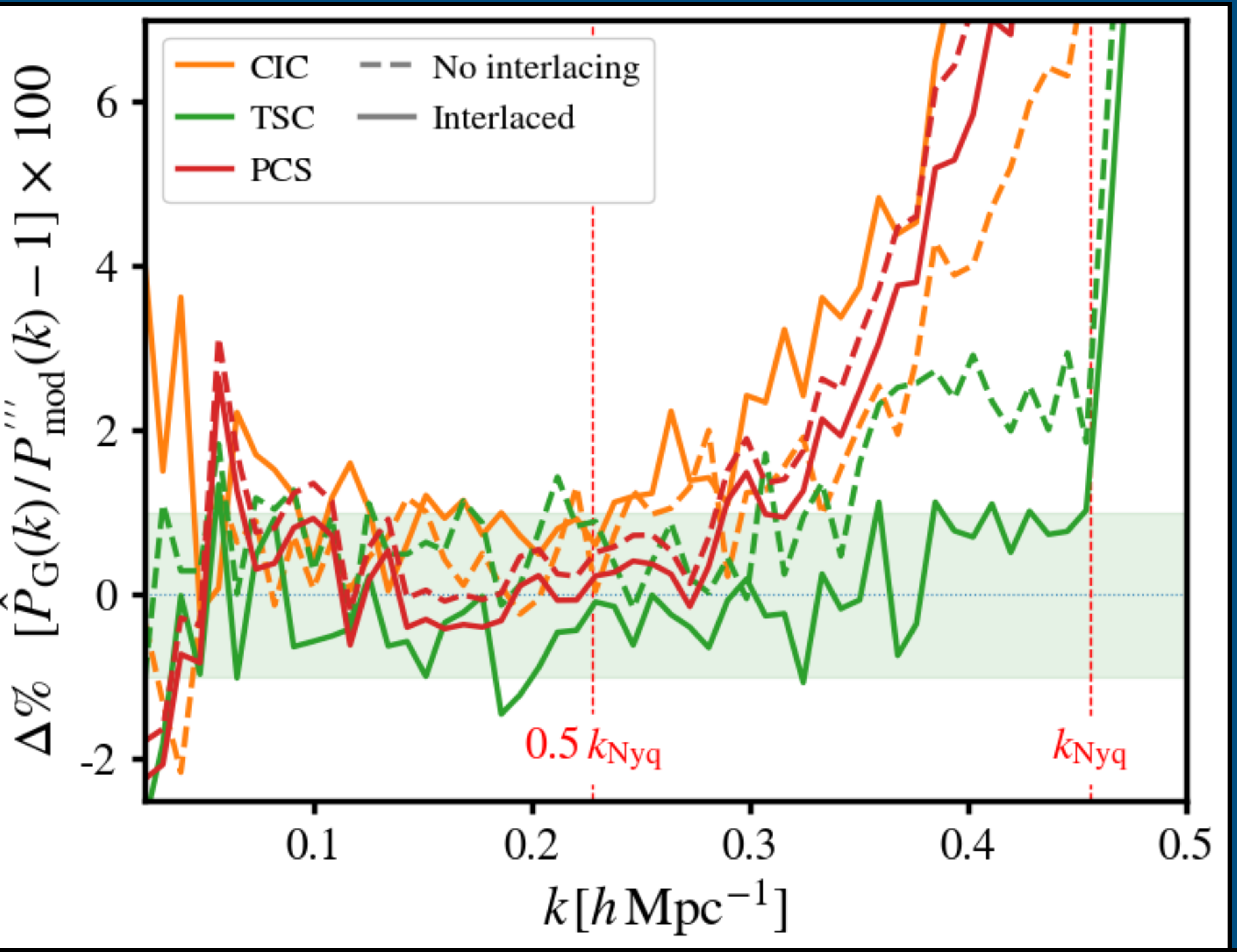
In Summary…



Need to robustly validate methods for transforming intensity maps to Cartesian spaces for clustering analysis



Using a suite of lognormal simulations we tested a Monte Carlo field sampling technique as a means for regridding the observational data



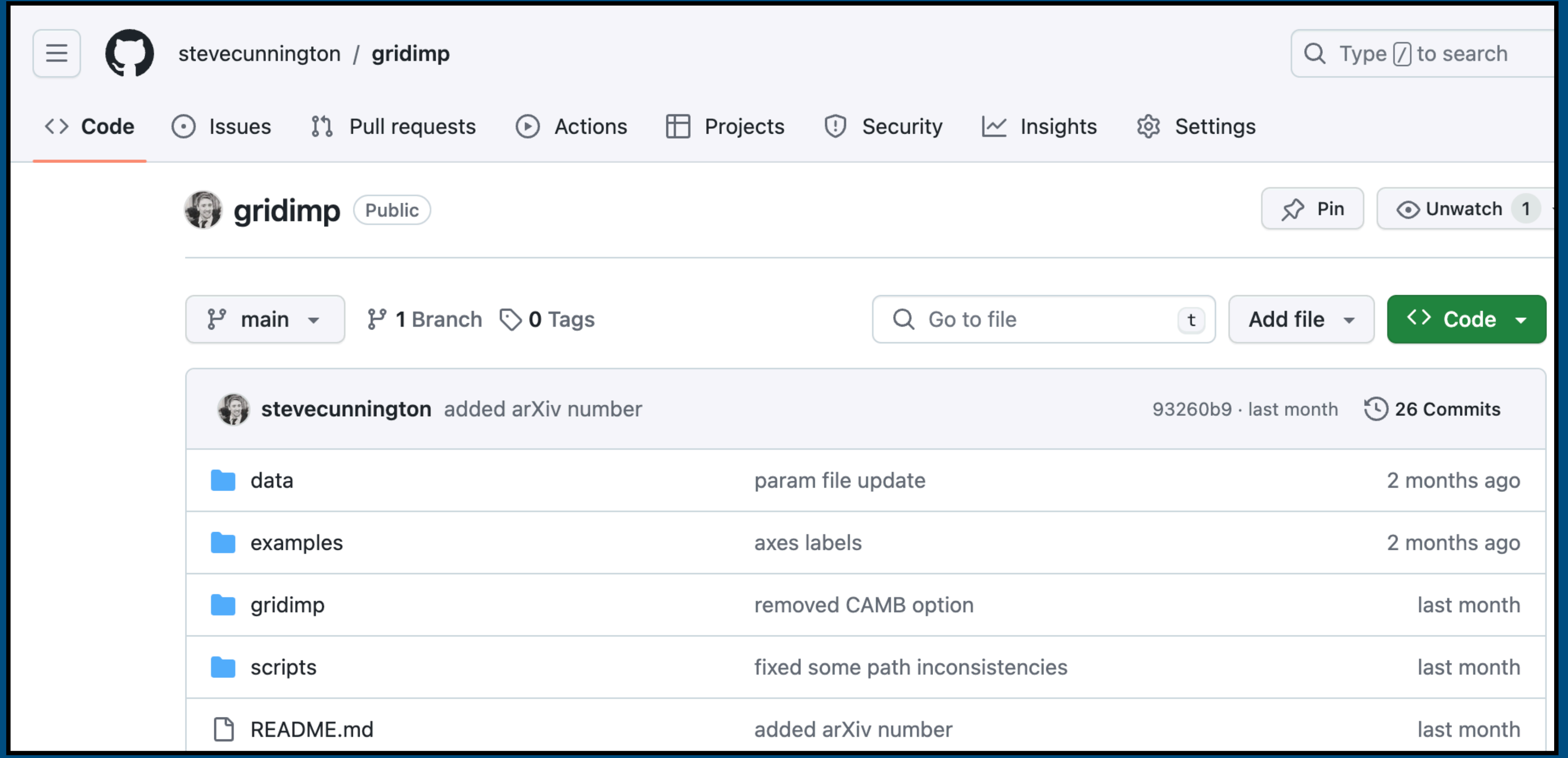
Thank you

With additional modelling, good accuracy is achieved.

Higher-order particle assignment can also help control aliasing

Public code available to generate intensity maps with survey geometry and correct for the distorting effects

github.com/stevecunnington/gridimp



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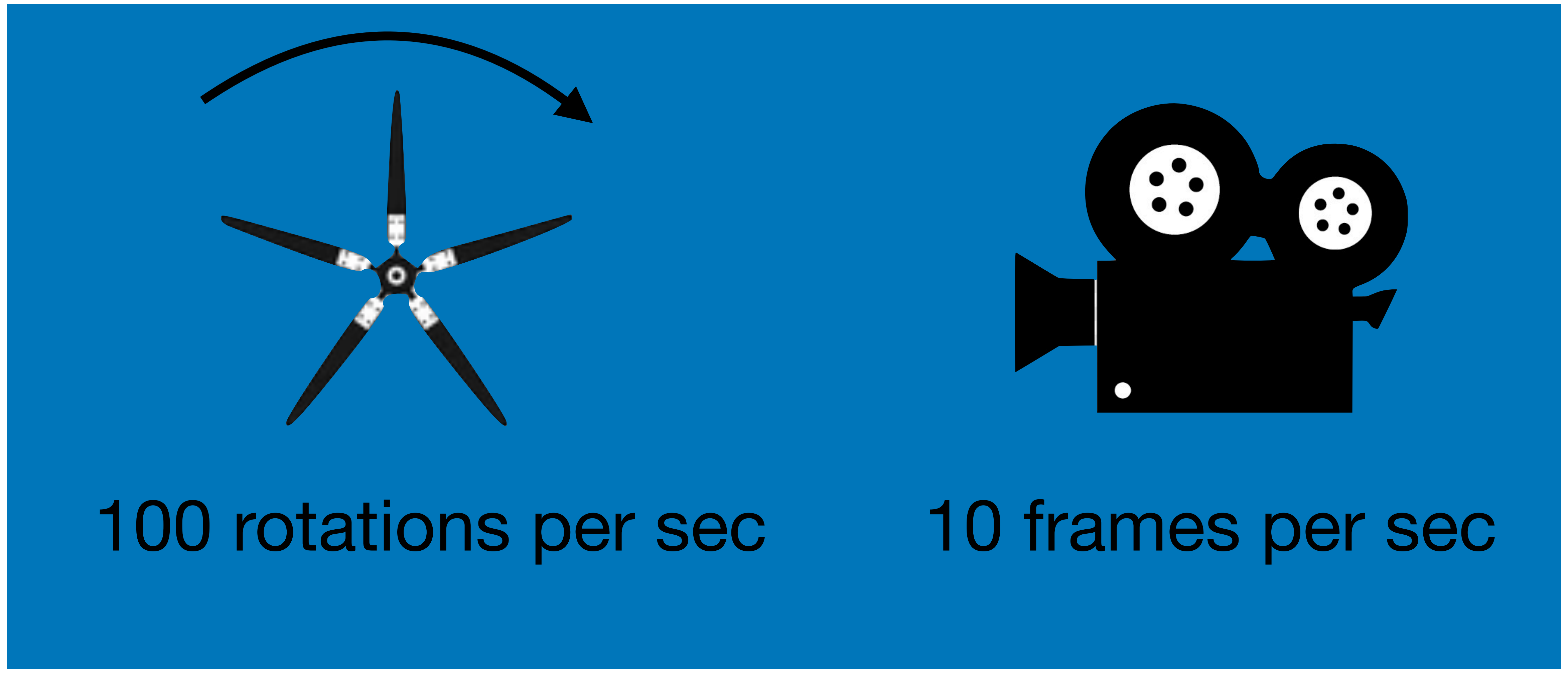
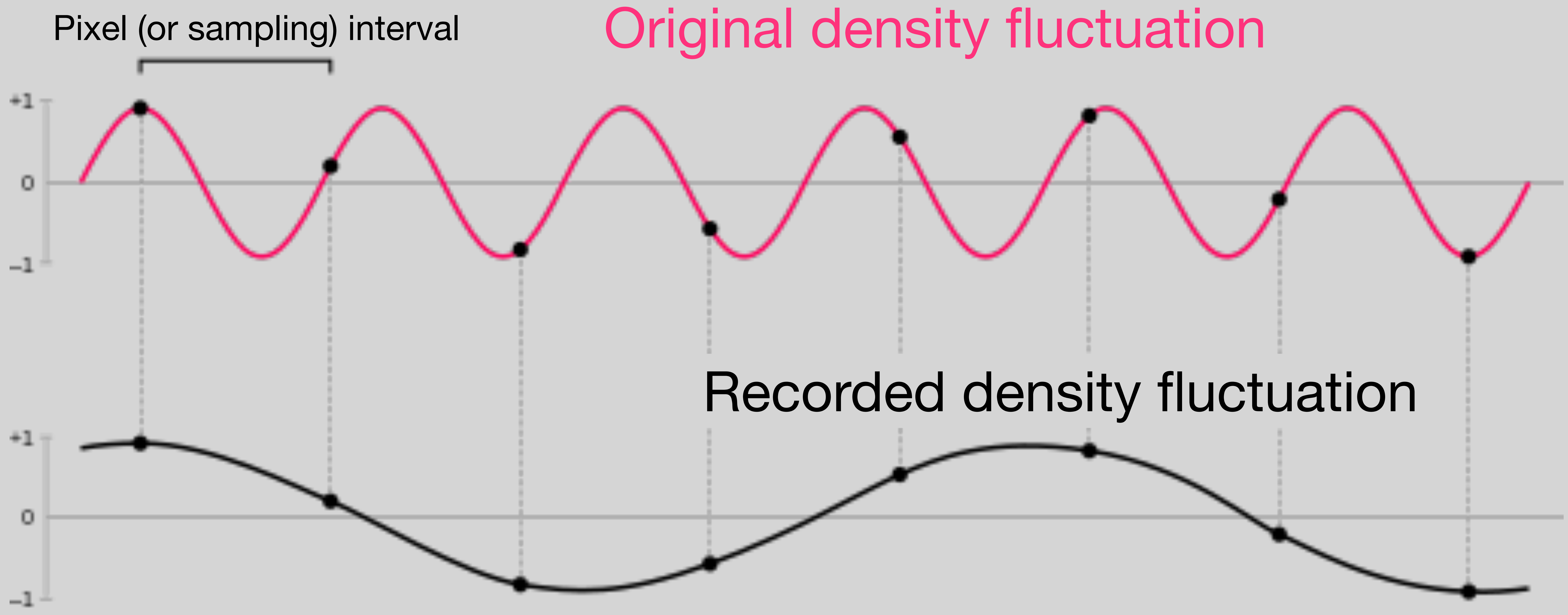
Backup Slides

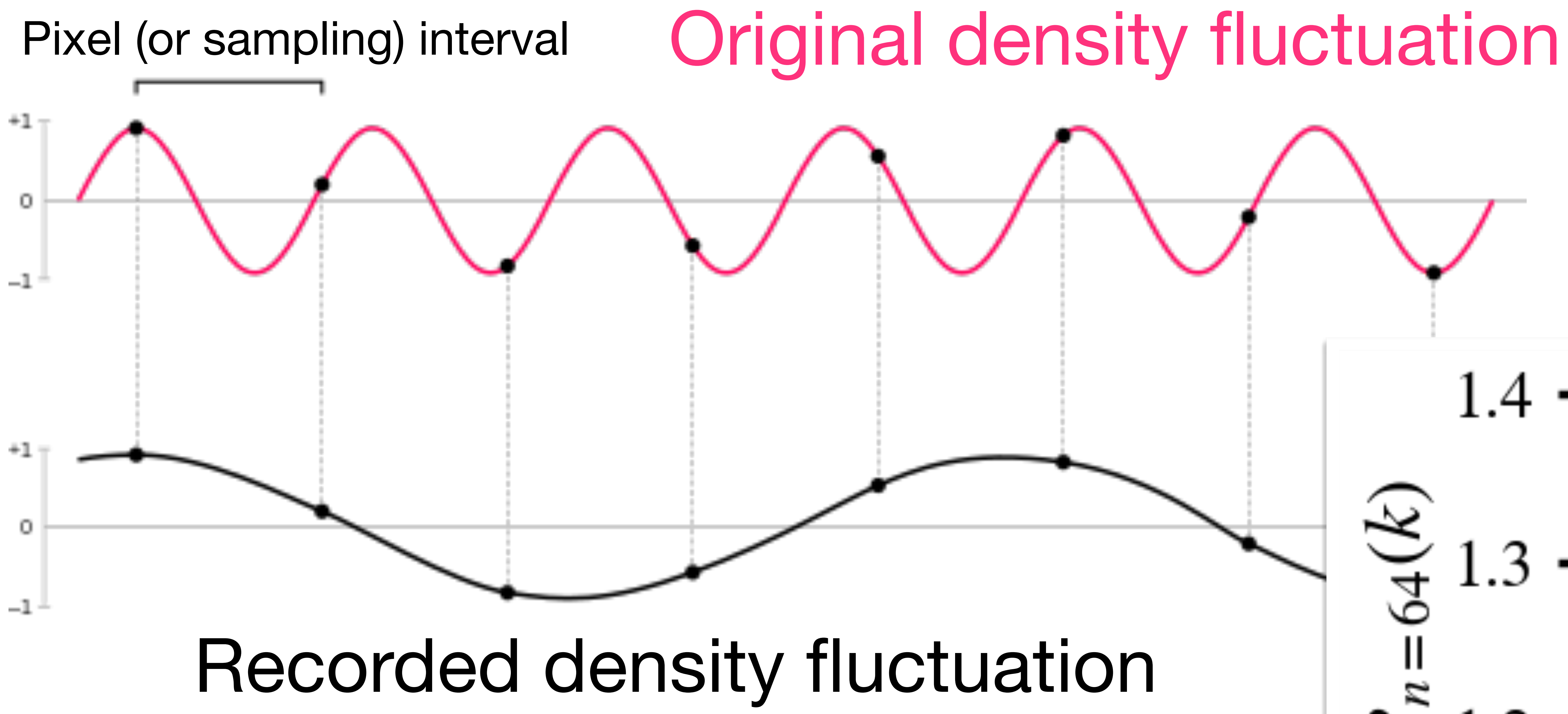
Aliasing from resampling

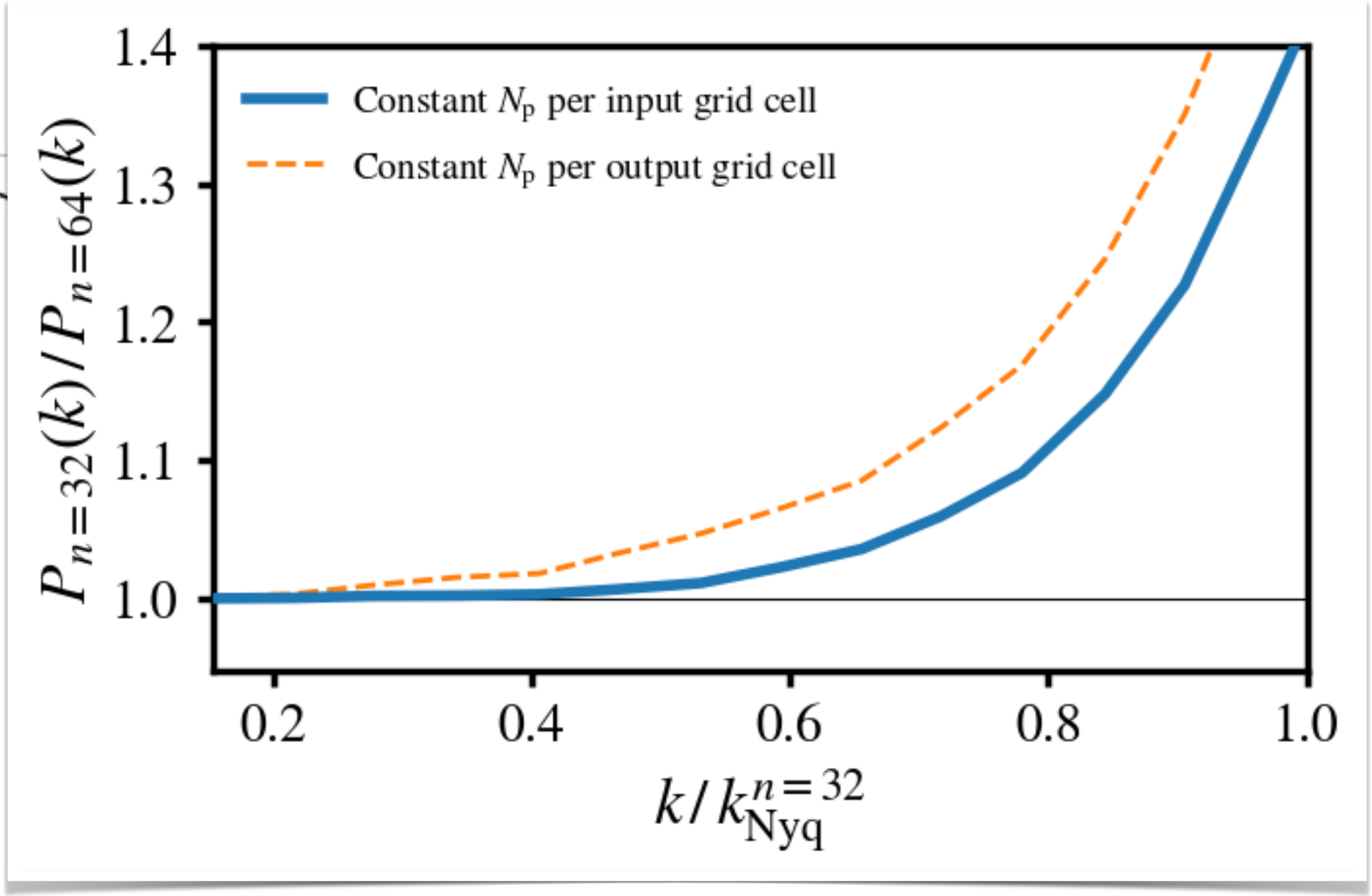


In Cosmology:

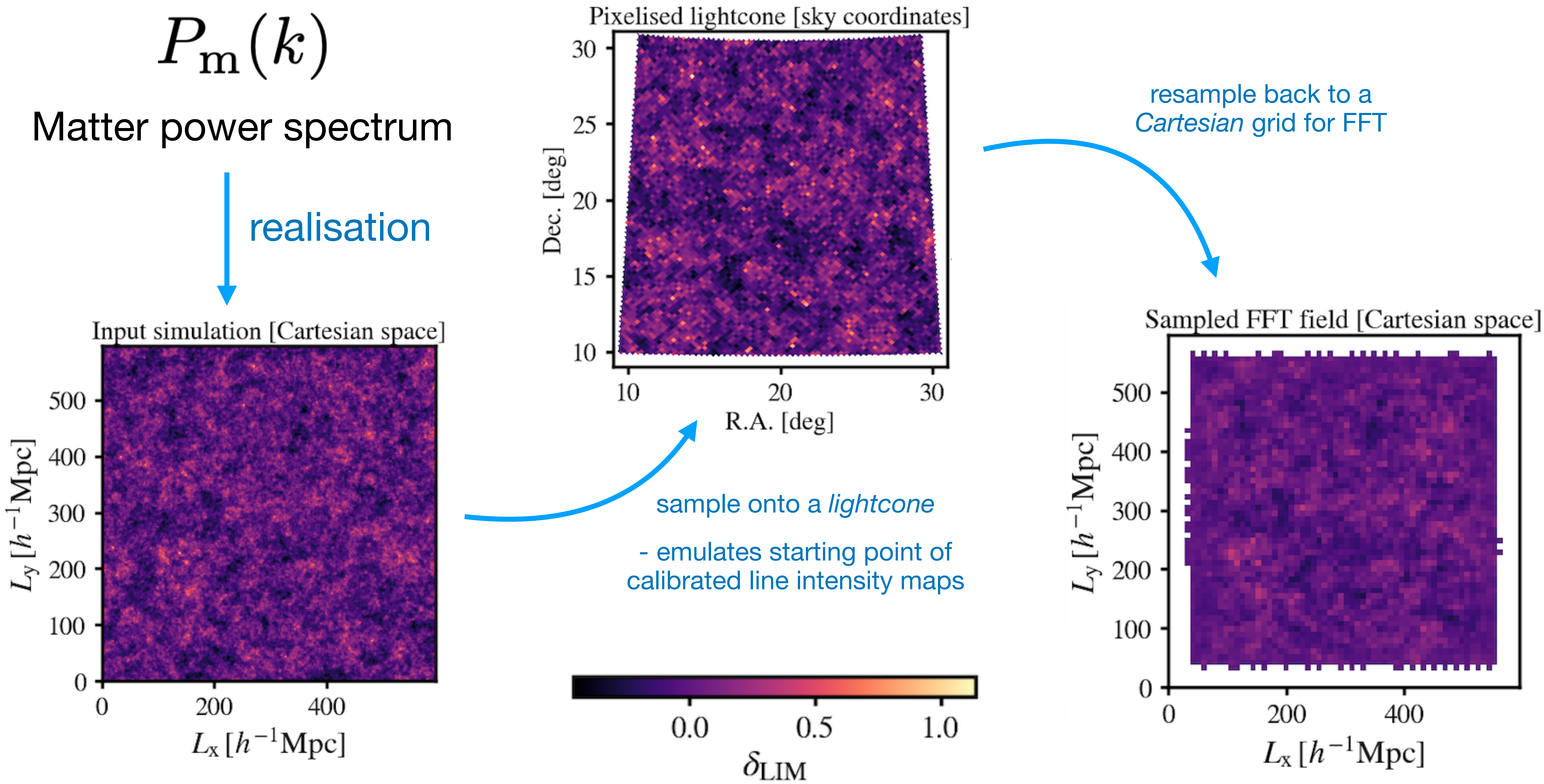


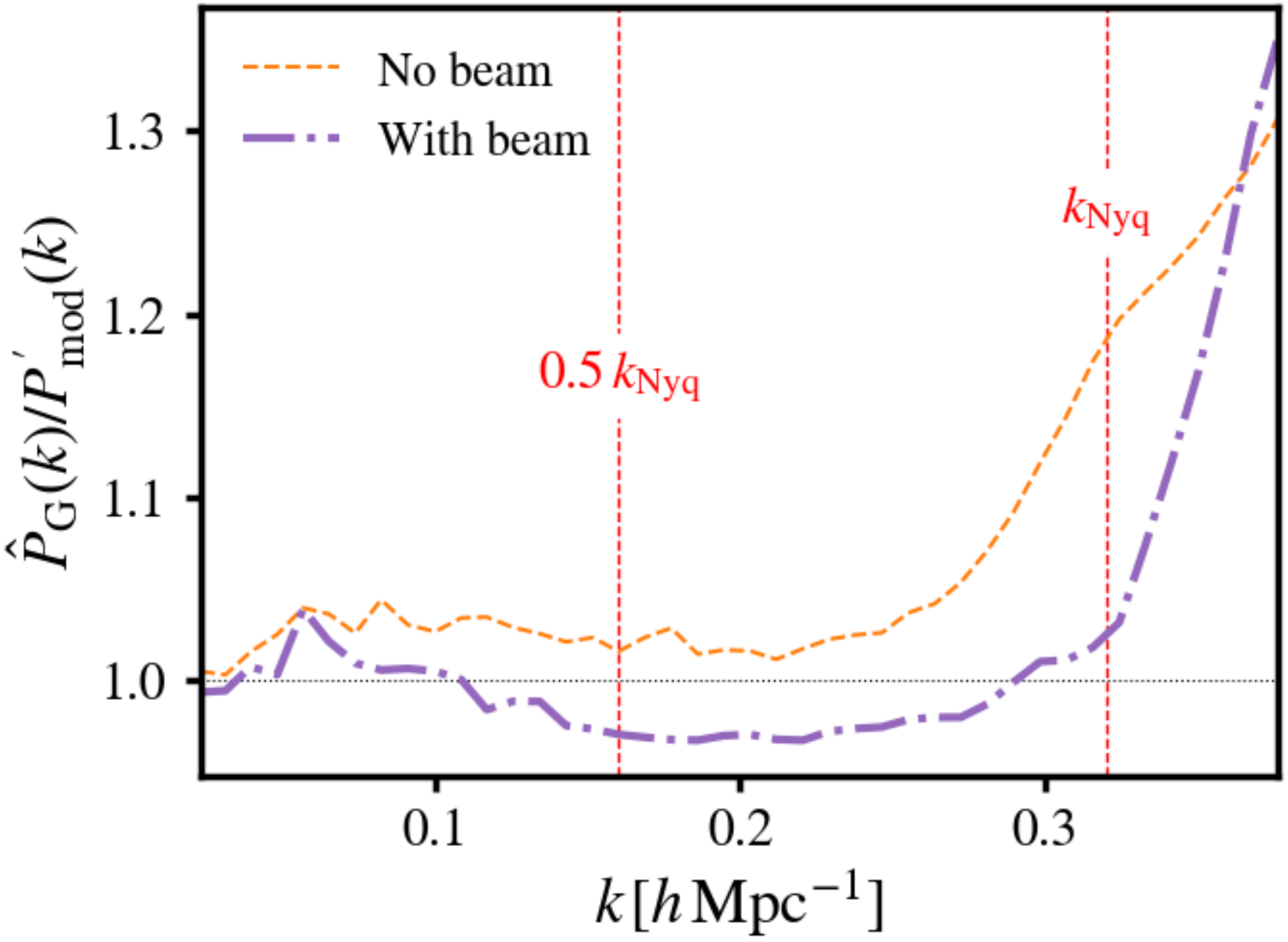
Aliasing from resampling





Simulating the mapping/regridding scenario





No beam
With beam
$0.5\,k_{\rm Nyq}$
$k_{\rm Nyq}$
1.3
1.2
1.1
1.0
0.1
0.2
0.3
$\hat{P}_{\rm G}(k)/P'_{\rm mod}(k)$
$k\,[h\,{\rm Mpc}^{-1}]$

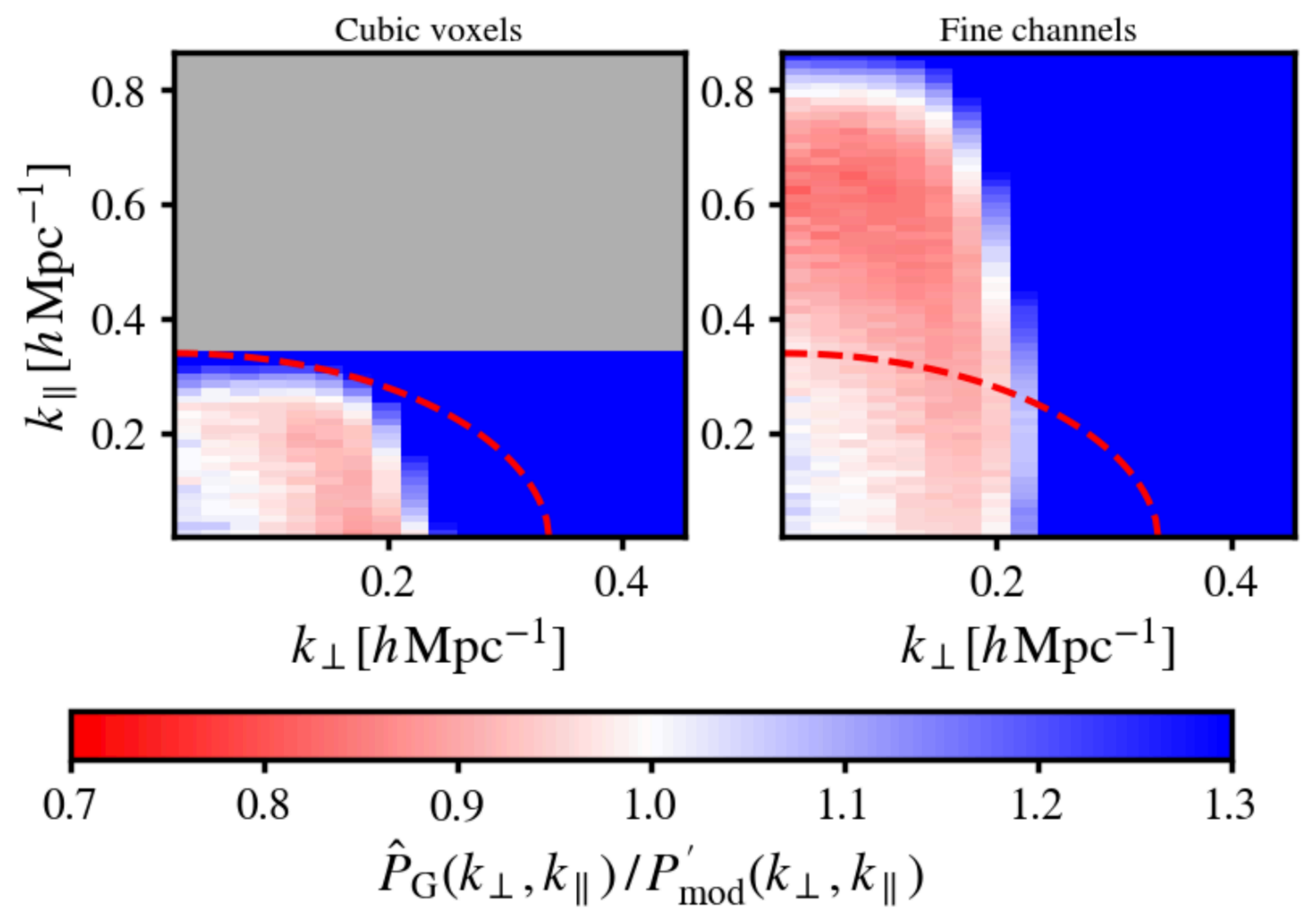


Figure C1. Cylindrical ($k_\perp$, $k_\parallel$) power spectrum comparison to model for two simulation versions. Same as Figure 5 but with smoothing effects from the telecope beam. The red dashed line shows the *minimum* Nyquist frequency calculated from the cell resolution along one of the dimensions in the perpendicular directions. Colour-bar range is fixed to avoid saturation.

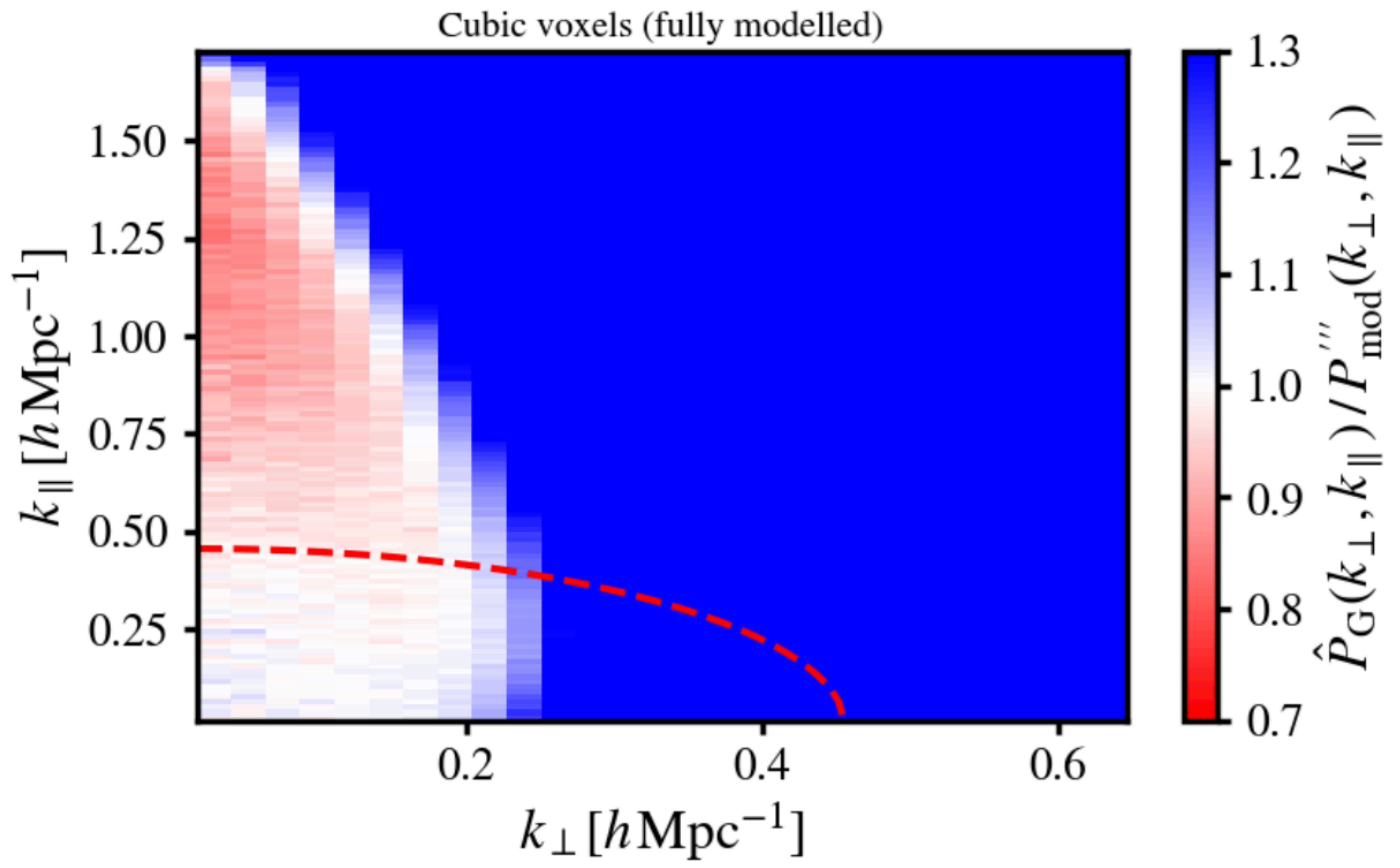


Figure C2. Cylindrical ($k_\perp$, $k_\parallel$) power spectrum for the Cubic voxels simulation (with the beam) relative to the final full model P'''_mod (Equation 15) including the treatments for discretisation and aliasing from the sky map voxels. This shows the 2D version of Figure 9 where PCS and interlacing has been used in the regridding of the data. The red dashed line shows the *minimum* Nyquist frequency calculated from the cell resolution along one of the dimensions in the perpendicular directions. Colour-bar range is fixed to avoid saturation.

Higher-order interpolation schemes

- Nearest Grid Point (NGP):

$$W_{\mathrm{ngp}}(s) = \begin{cases} 1 & \text{for } |s| < \frac{1}{2} \\ 0 & \text{otherwise} \end{cases}$$

- Cloud-in-Cell (CIC):

$$W_{\mathrm{cic}}(s) = \begin{cases} 1 - |s| & \text{for } |s| < 1 \\ 0 & \text{otherwise} \end{cases}$$

- Triangular-Shaped Cloud (TSC)

$$W_{\mathrm{tsc}}(s) = \begin{cases} \frac{3}{4} - s^2 & \text{for } |s| < \frac{1}{2} \\ \frac{1}{2}\left(\frac{3}{2} - |s|\right)^2 & \text{for } \frac{1}{2} \leqslant |s| < \frac{3}{2} \\ 0 & \text{otherwise} \end{cases}$$

- Piecewise Cubic Spline (PCS)

$$W_{\mathrm{pcs}}(s) = \begin{cases} \frac{1}{6}\left(4 - 6s^2 + 3|s|^3\right) & \text{for } 0 \leqslant |s| < 1 \\ \frac{1}{6}(2 - |s|)^3 & \text{for } 1 \leqslant |s| < 2 \\ 0 & \text{otherwise} \end{cases}$$