Redshift Space Distortion of 21cm line at $1 < z < 5$
with Cosmological Hydrodynamic Simulations

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21-cm線観測における赤方偏移空間歪み

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Outline

motivation

21cm line as a probe of large-scale structure

method

cosmological hydrodynamic simulations

results

Redshift Space Distortion of HI

SKA survey

motivation

Future surveys probe the large-scale structure

by detecting the 21-cm line.

Theory		observation
matter in real space	⟷	neutral hydrogen (HI) in redshift space

connect theoretical predictions with observables

measure the HI power spectrum in redshift space

Redshift Space Distortion (RSD)

redshift ← cosmological recession velocity + **peculiar velocity of the object**

distance in redshift space differs from that in real space

↓

geometric shape and 2D-power spectrum are distorted

RSD of HI at 1<z<5

this work

- measure the 2D power spectra P_{2D} in redshift space

- fit theoretical models with results and
  explore the HI bias and velocity dispersion

method

using the cosmological hydrodynamic simulation

Osaka simulation

Box size：$(85\mathrm{Mpc}/h)^3$

Particle Number (DM and gas)：$2{\times}512^3$

cosmological parameter：WMAP-9

Osaka simulation

N-body/SPH code GADGET-3 (Springel 2005)

Aoyama et al. 2017, Shimizu et al. 2018 (submitted)

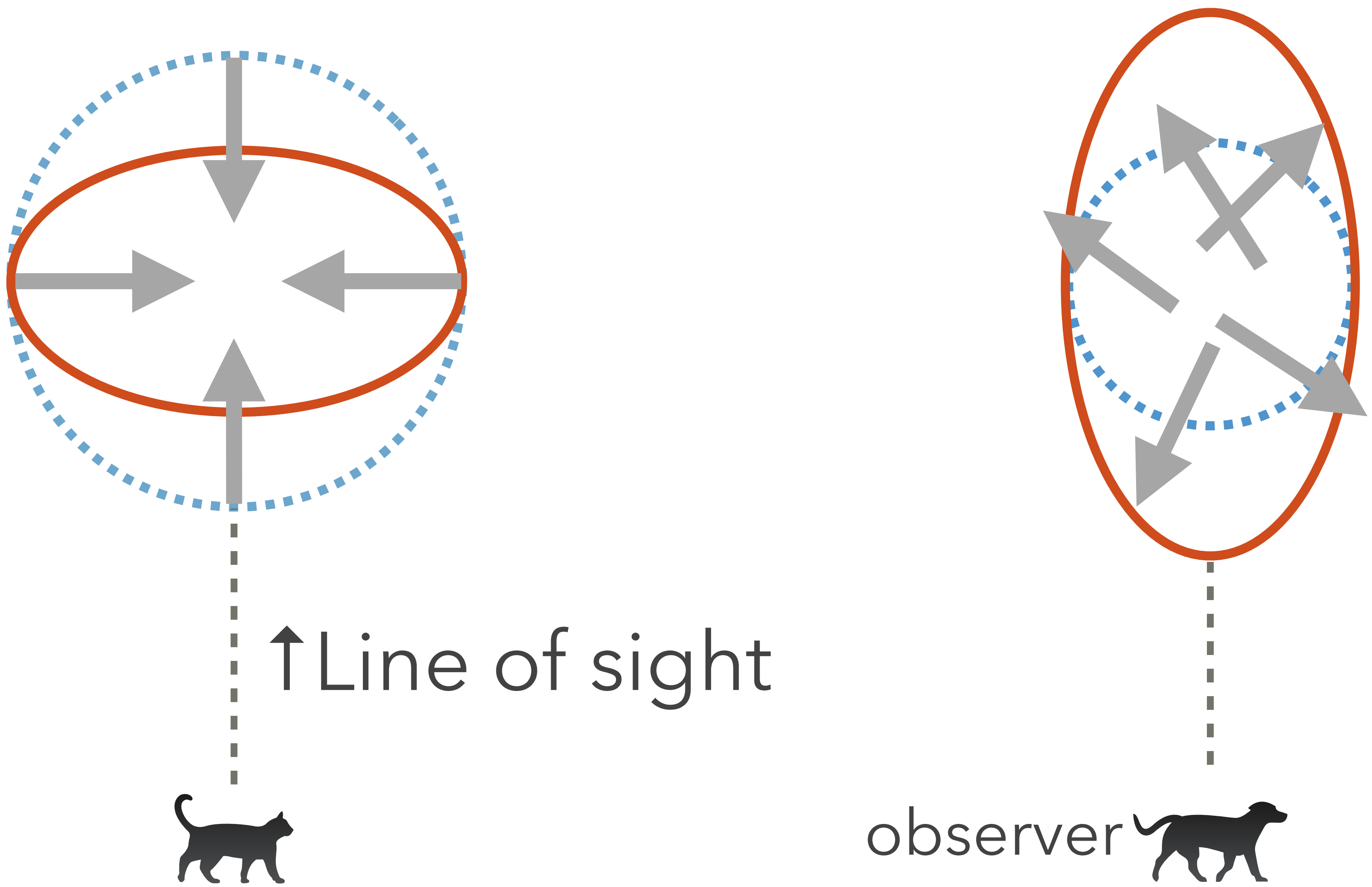
- star formation・supernova feedback
- uniform UV background

RSD

real space
redshift space
peculiar velocity

large scales
Kaiser

small scales
Finger of God

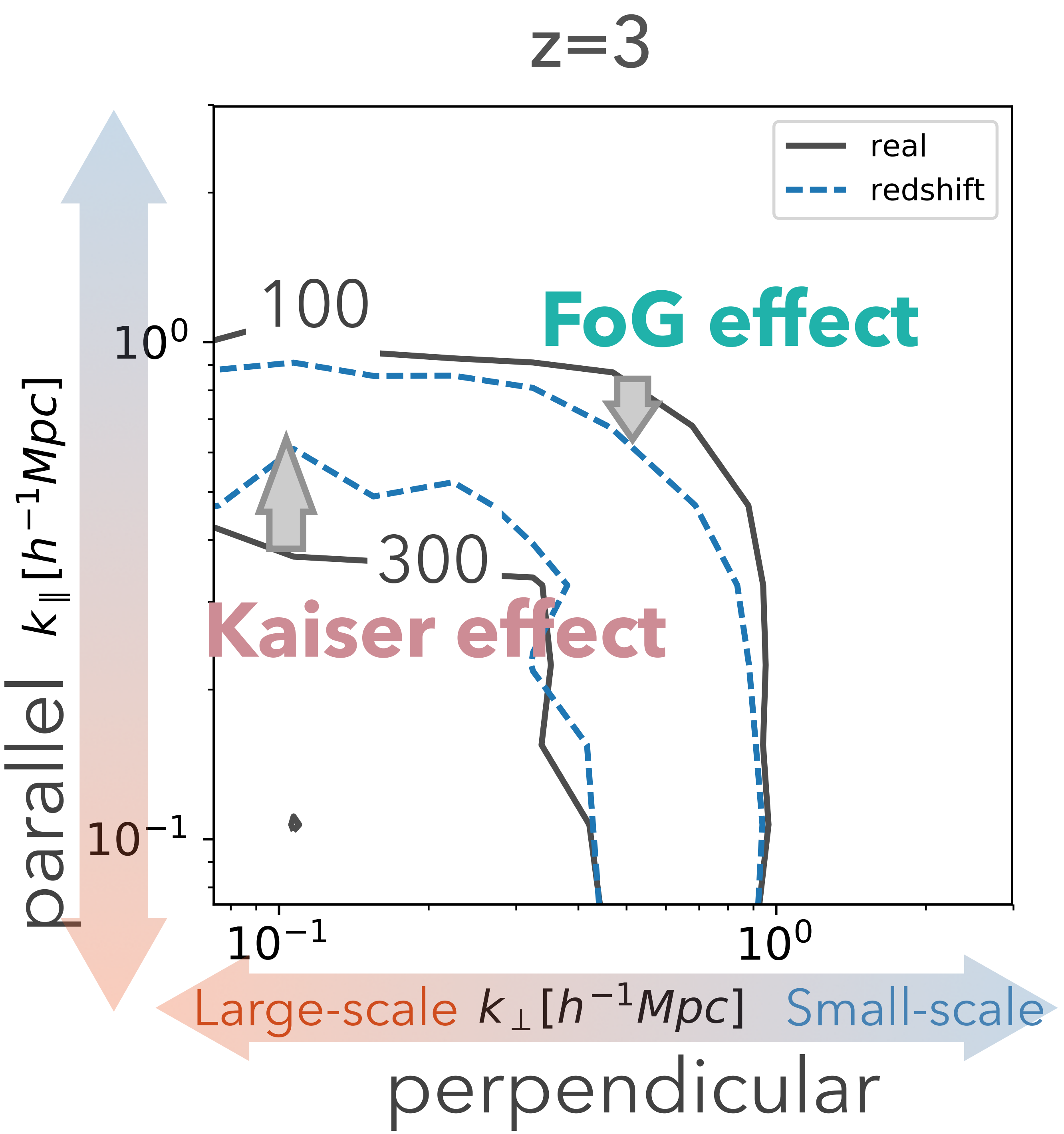


coherent motion
toward the overdensity

non-linear
random motion

2D HI power spectra

real space
redshift space



contour of 2D HI power spectra $P_{\mathrm{HI}}(k_\perp, k_\parallel)$

- On large scales
  clustering is enhanced
- On small scales
  power is suppressed

Future SKA survey

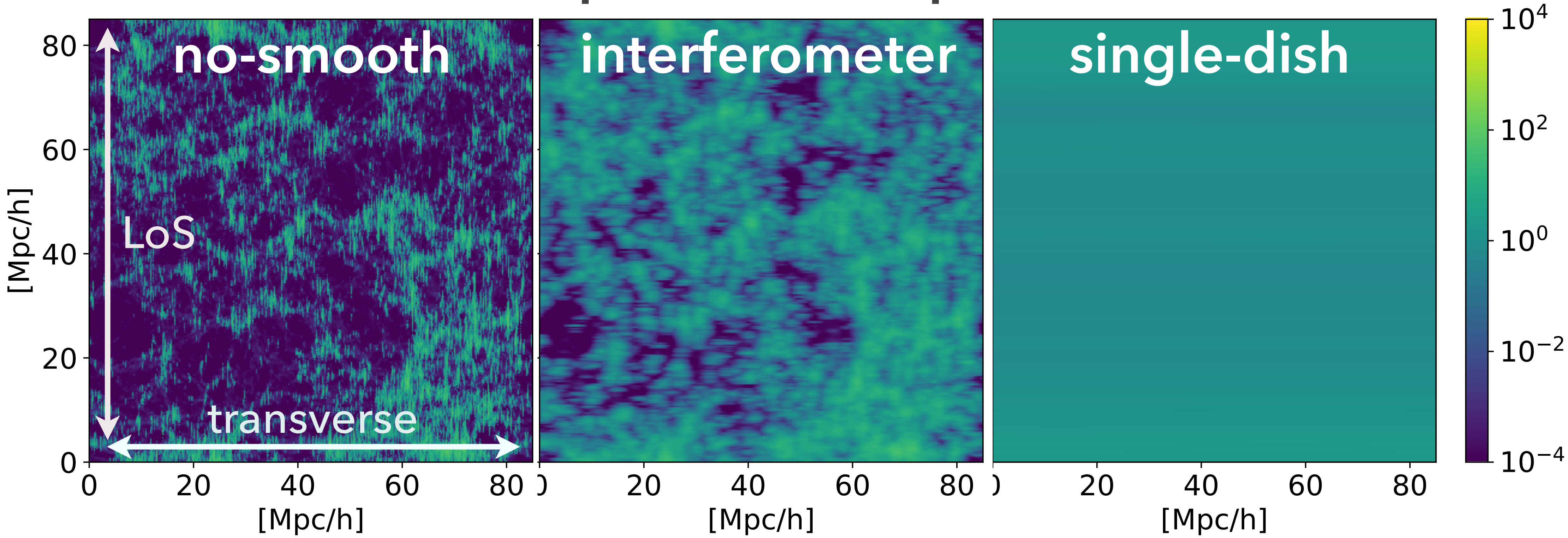
0<z<3

frequency resolution : 50kHz

the transverse density fluctuation is smoothed out

	interferometer	single-dish
angular resolution	high ~2Mpc/h @z=1	low ~65Mpc/h @z=1
field of view	small	large

$1+\delta_{HI}$ map in redshift-space at $z=3$

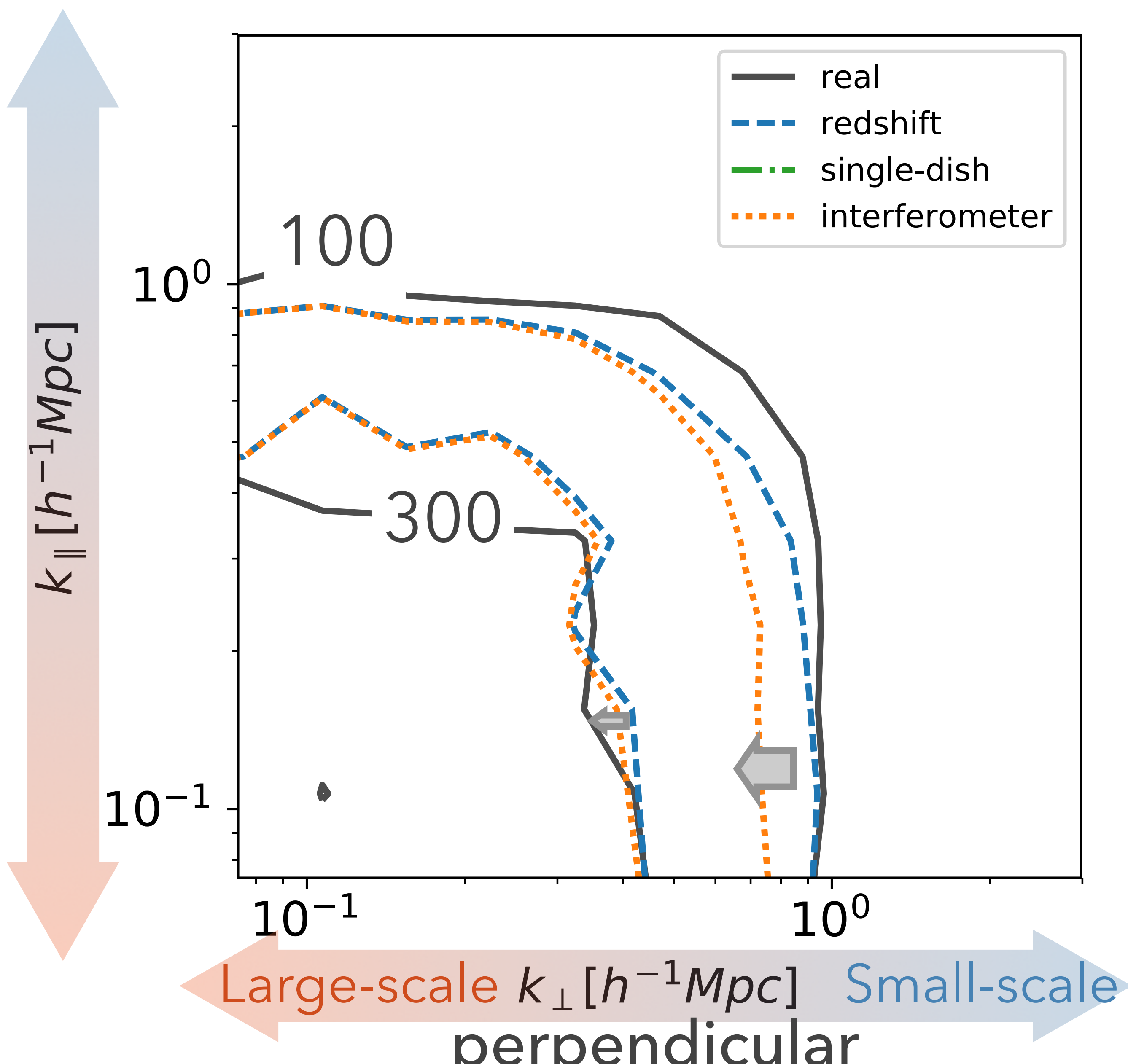


2D HI power spectra

real space
redshift space
interferometer

the power spectrum is suppressed

contour @ z=3



interferometer

power is slightly suppressed

single-dish

since angular resolution is low,

fluctuations in

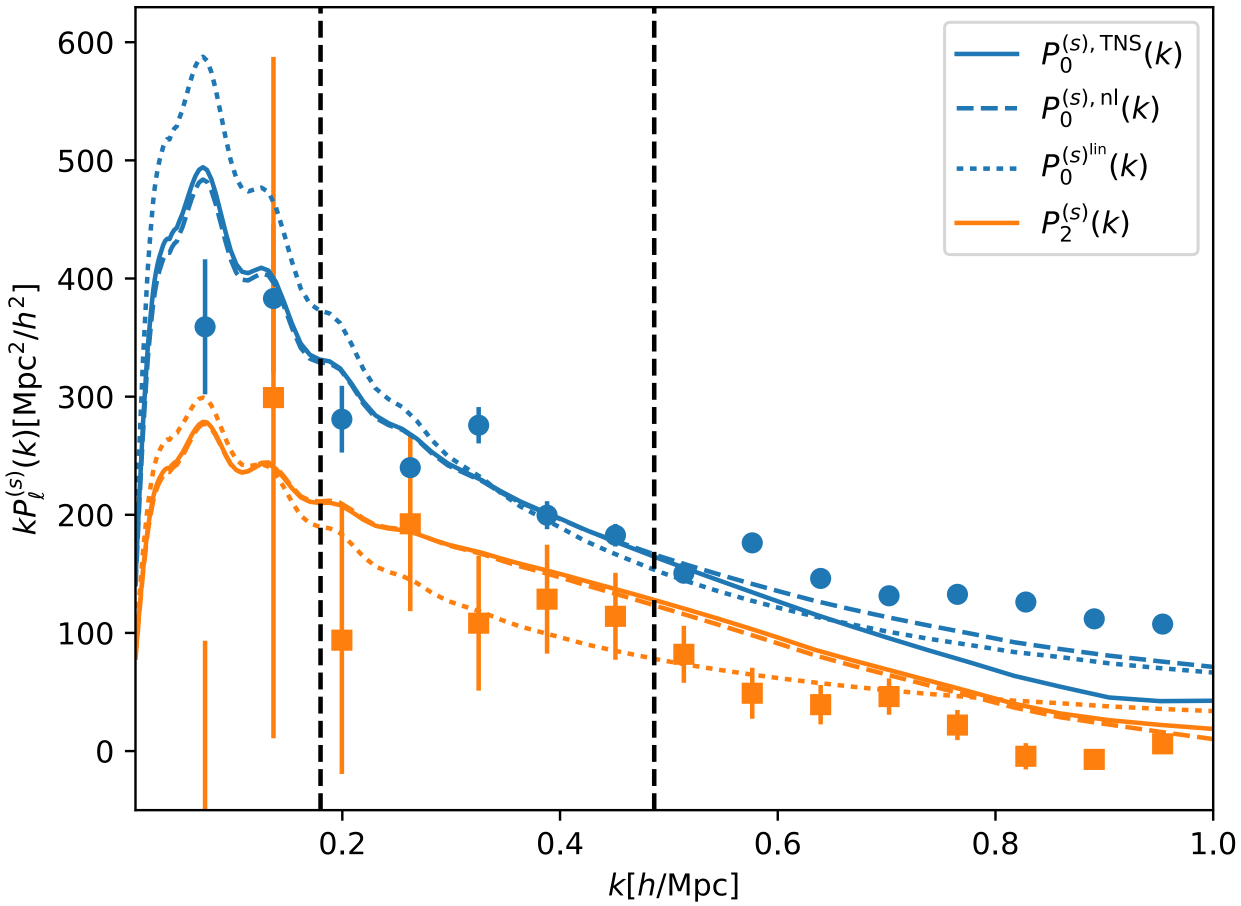
transverse direction

are smoothed out

multipole $P_l^{(s)}(k)$

symbols: Osaka simulation
curves: best-fitting models
solid : TNS
bashed: non-linear empirical
dotted : linear theory
• • • ℓ=0 : monopole
▪▪▪ ℓ=2 : quadrupole

$$kP_l^{(s)}(k)$$



anisotropic 2D power spectrum

$$P(k,\mu)\,(\,\mu = \cos\theta = k_{\parallel}/k\,)$$

Legendre expand

$$P_l^{(s)}(k) = \frac{2l+1}{2}\int_{-1}^{1} d\mu\, P^{(s)}(k,\mu)\,\mathcal{L}_l(\mu)$$

$\mathcal{L}_l(\mu)$: l-th Legendre polynomial

models for anisotropic power spectrum

$$P_{\rm HI}(k,\mu) = e^{-(k\mu f\sigma_v)^2} b_{\rm HI}^2(1+\beta\mu^2)^2 P_{\rm dm}^{\rm lin}(k)$$

HI	Finger of God	Kaiser	matter
redshift space	suppressed	enhanced	real space

take angular resolution into account

$$W_{\rm beam} = \exp\left(-\frac{k^2(1-\mu^2)\sigma_{\rm smooth}^2}{2}\right)$$

$1-\mu^2=\sin^2\theta$

$$\delta_{\rm obs} = W_{\rm beam}(k,\mu)\delta \ , \ P = \langle\delta\delta\rangle$$

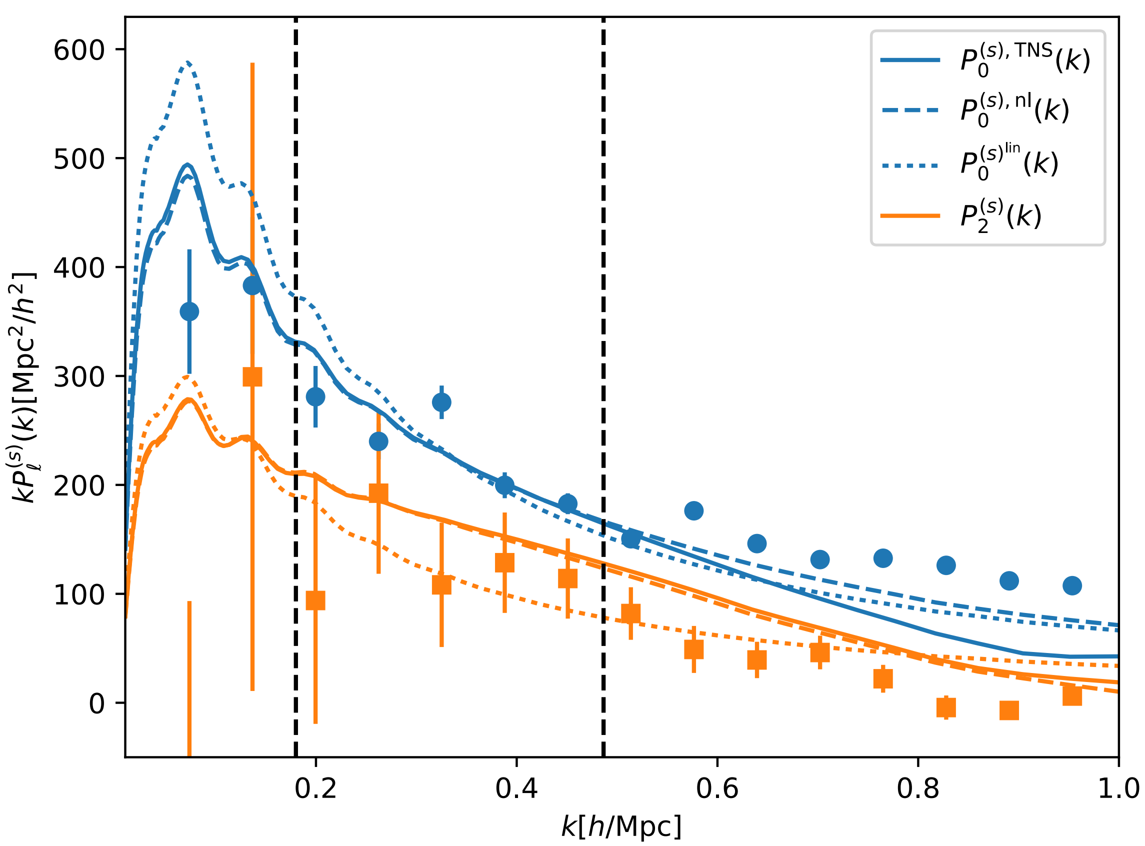
$$P_{\rm HI,obs}^{(s)}(k,\mu) = W_{\rm beam}^2(k,\mu)\, P_{\rm HI}^{(s)}(k,\mu)$$

HI bias, velocity dispersion

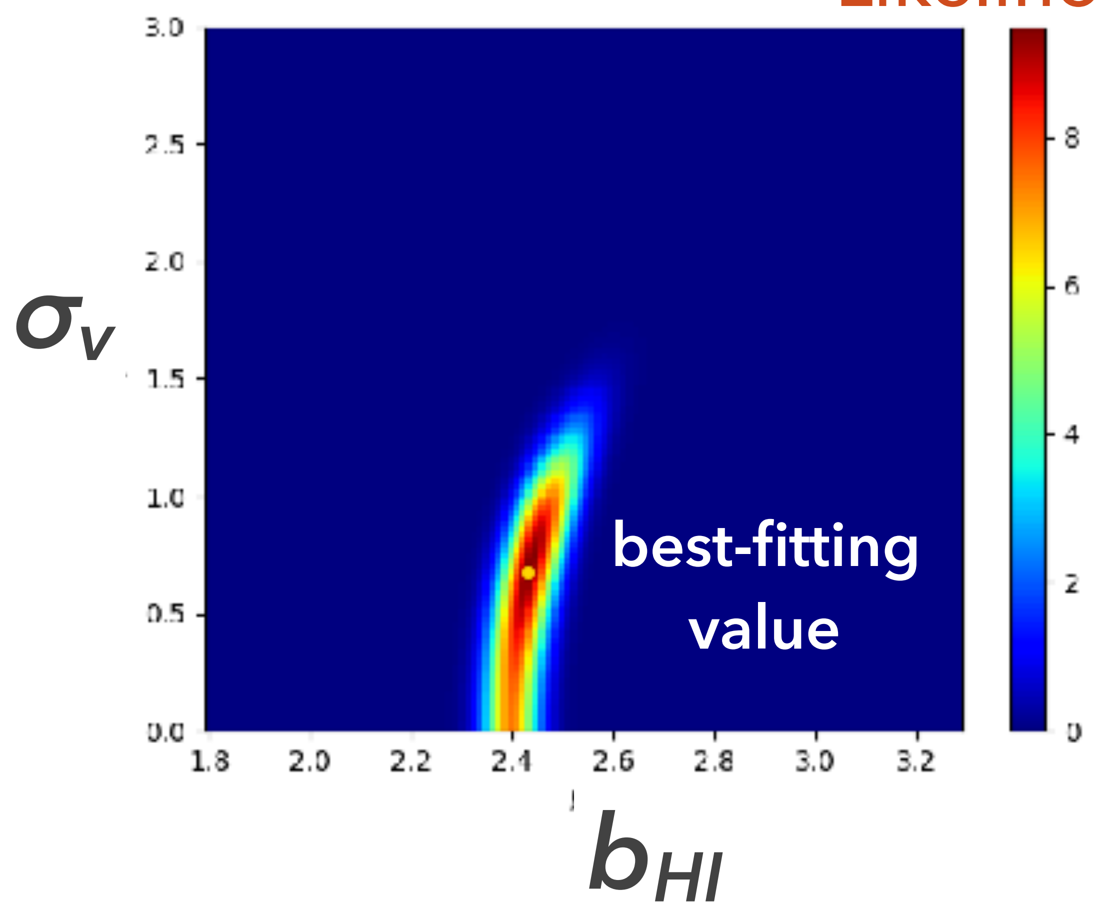
model: $P_{\rm HI}(k,\mu) = W^2_{\rm beam}(k,\mu)\, e^{-(k\mu f \sigma_v)^2}\, b^2_{\rm HI}(1+\frac{f}{b_{\rm HI}}\mu^2)^2\, P_{\rm m}(k)$

find the best-fitting HI bias
and velocity dispersion parameters

free parameters
$0.1 < b_{HI} < 10$
$0 < \sigma_V < 5\sigma_{v\text{-}lin}$

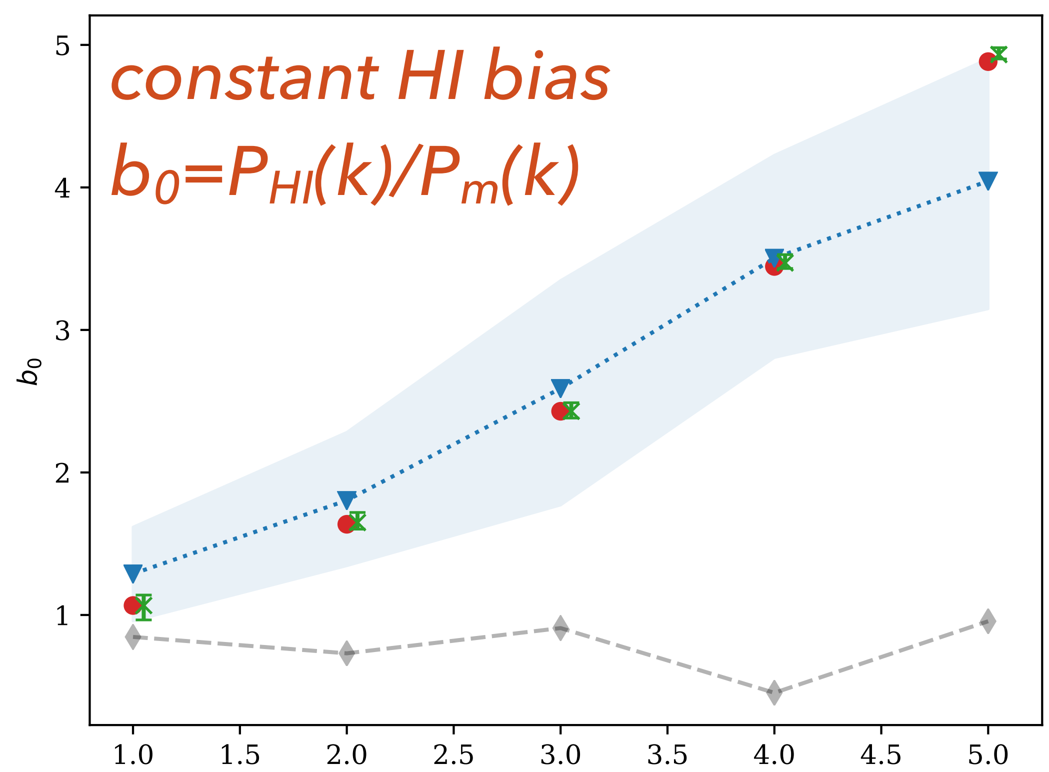


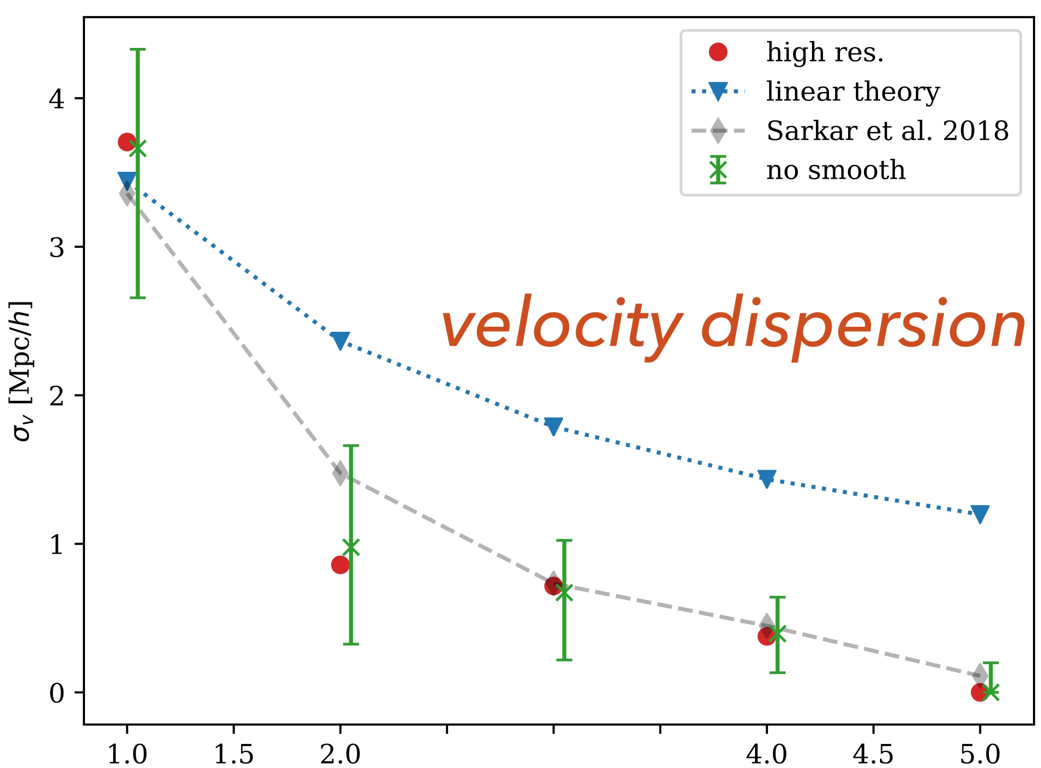
Likelihood



best-fitting values

- ● interferometer
- ▼ real space
- × no smooth





redshift

- bias is consistent with direct measurement ($b_{HI}=P_{HI,m}/P_m$)
- velocity dispersion is smaller than the linear theory prediction @z>1
- Since box size ~ angular resolution we cannot measure the parameters for single-dish

summary

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We measured the Redshift space distortion of HI

for future 21cm surveys (SKA)

method

using the full cosmological hydrodynamic simulation

assuming the SKA-like observation

result

- we need to develop a more sophisticated model for HI power
- the best-fit values for interferometer is almost same as no-smooth
- we need the simulations with larger box-size for single-dish