Towards the analysis of the redshift-space bispectrum

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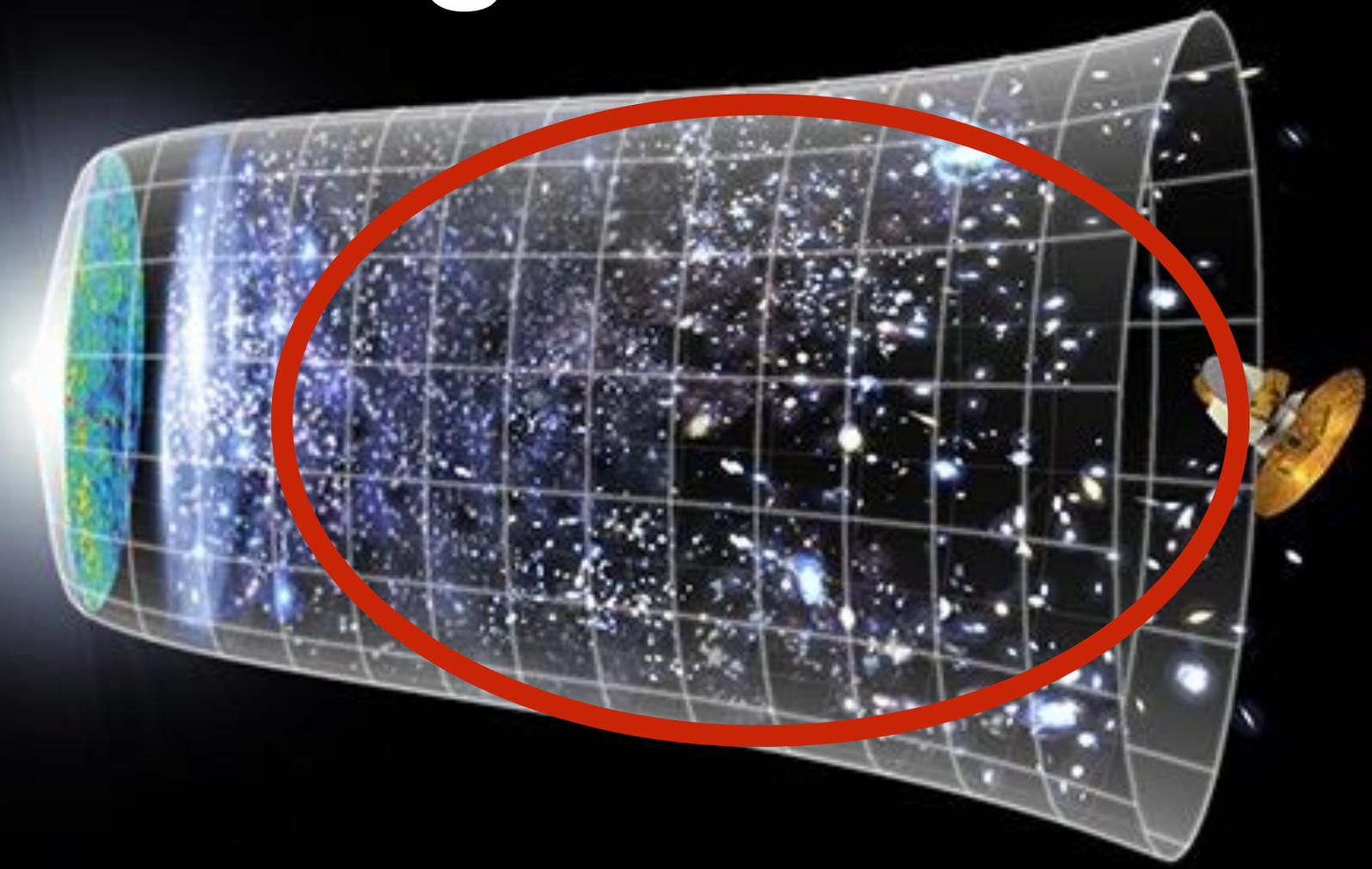
Accelerating Universe in the Dark @ Yukawa Institute (Match 4-8, 2019)

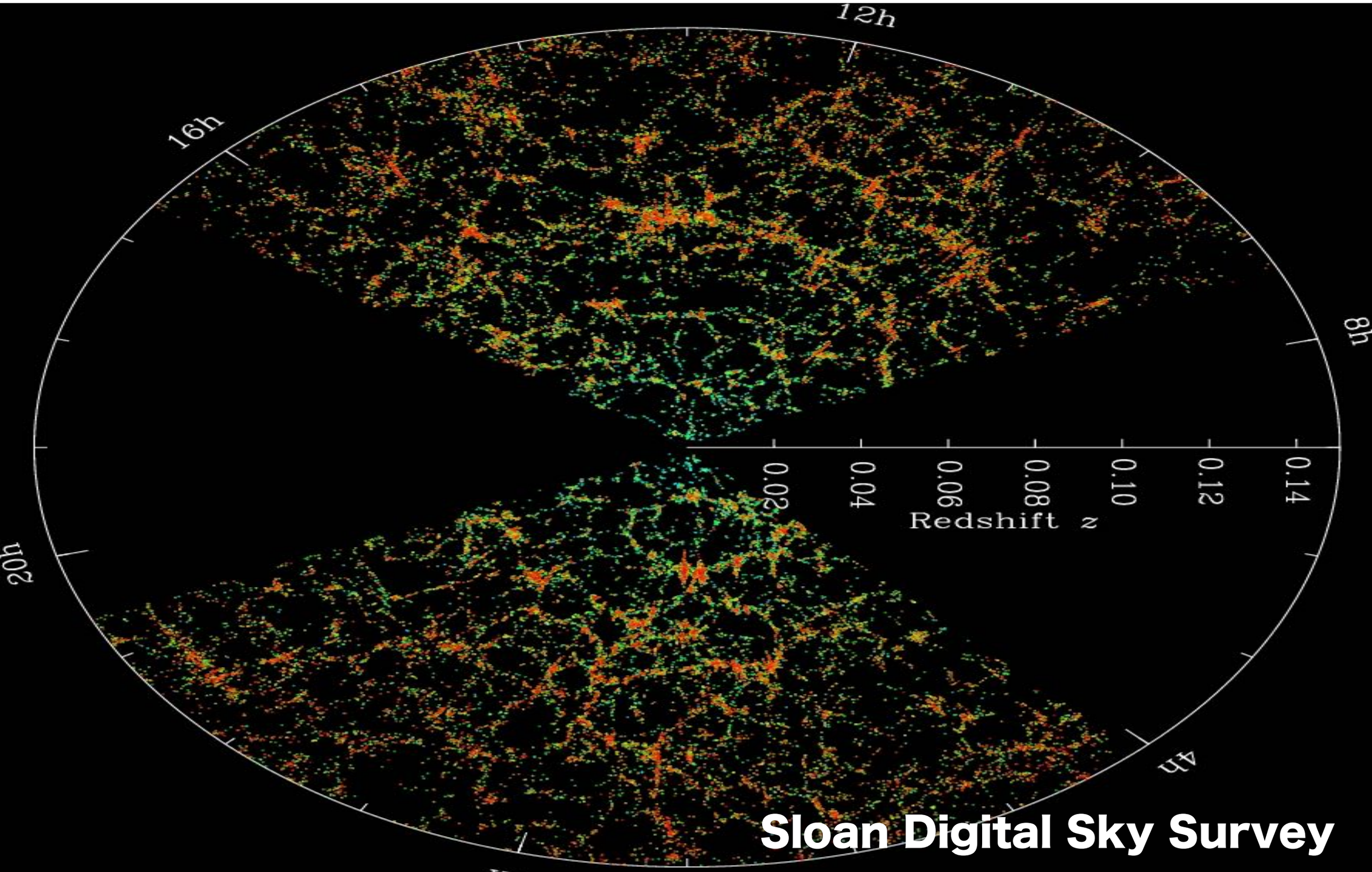
What can we know from the Large scale structure?



- Dark energy
- Modified gravity
- Neutrino

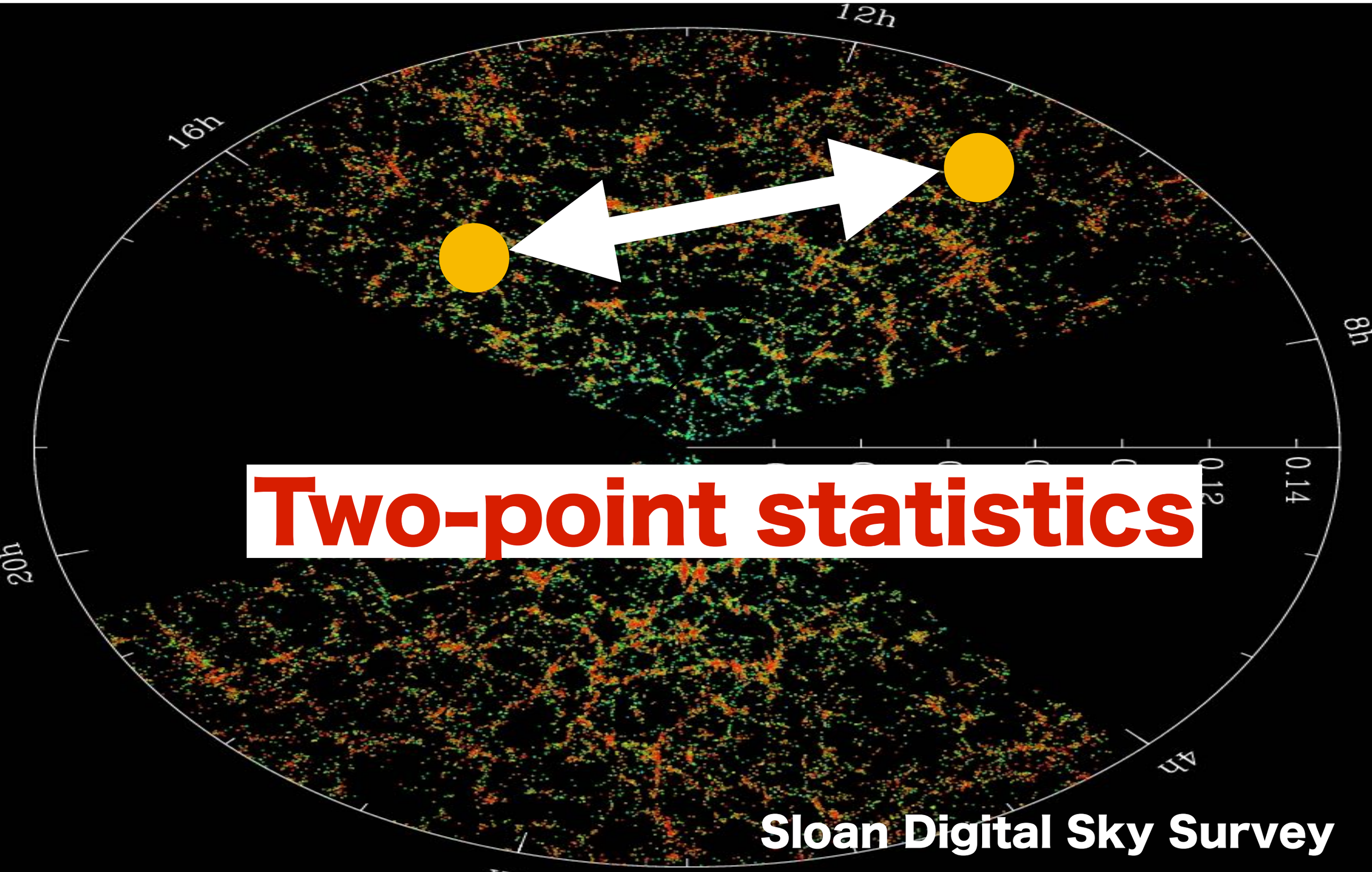
NASA/WMAP Science Team

3D galaxy map



Sloan Digital Sky Survey

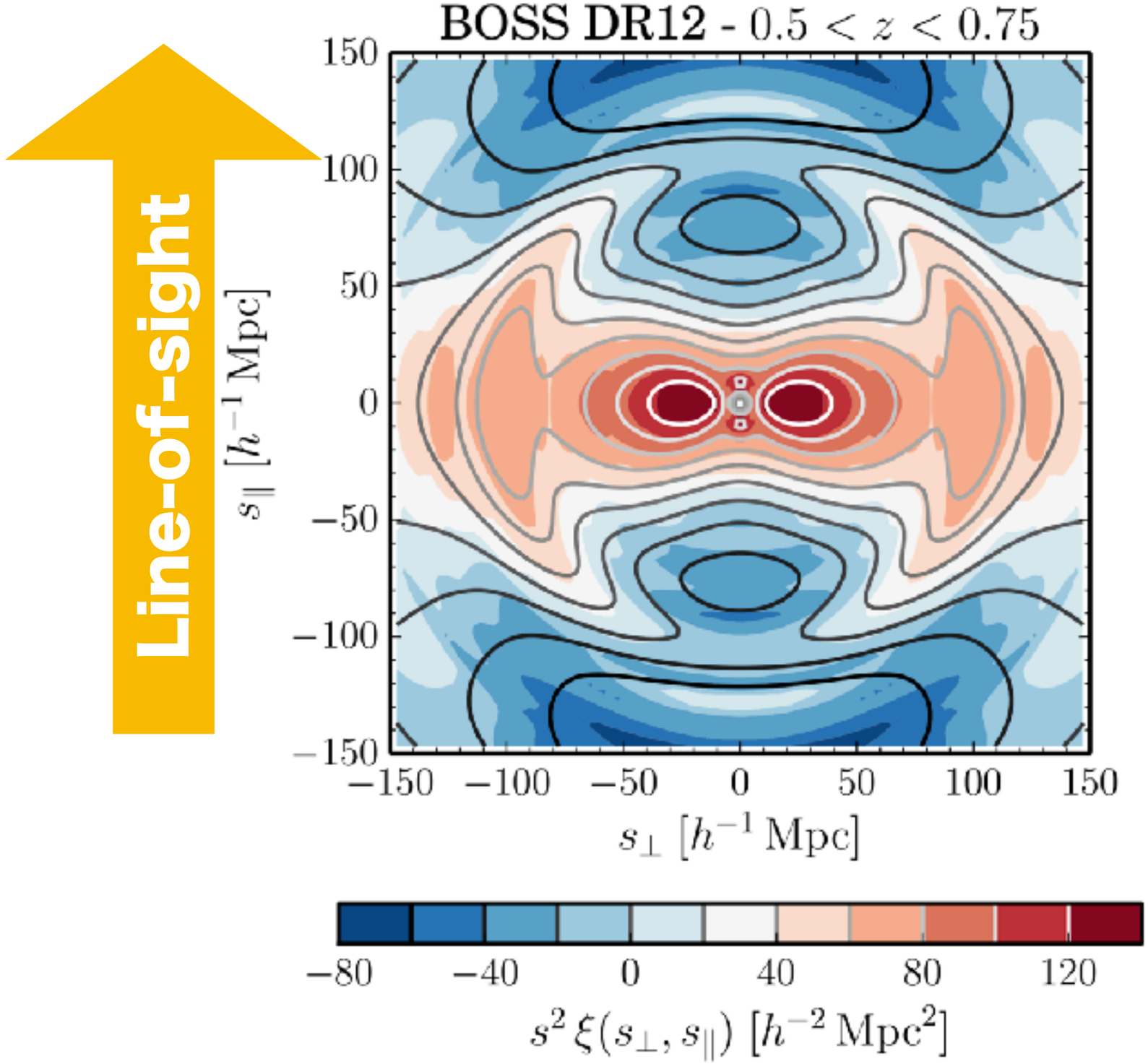
3D galaxy map



Two-point statistics

Sloan Digital Sky Survey

Anisotropic signals



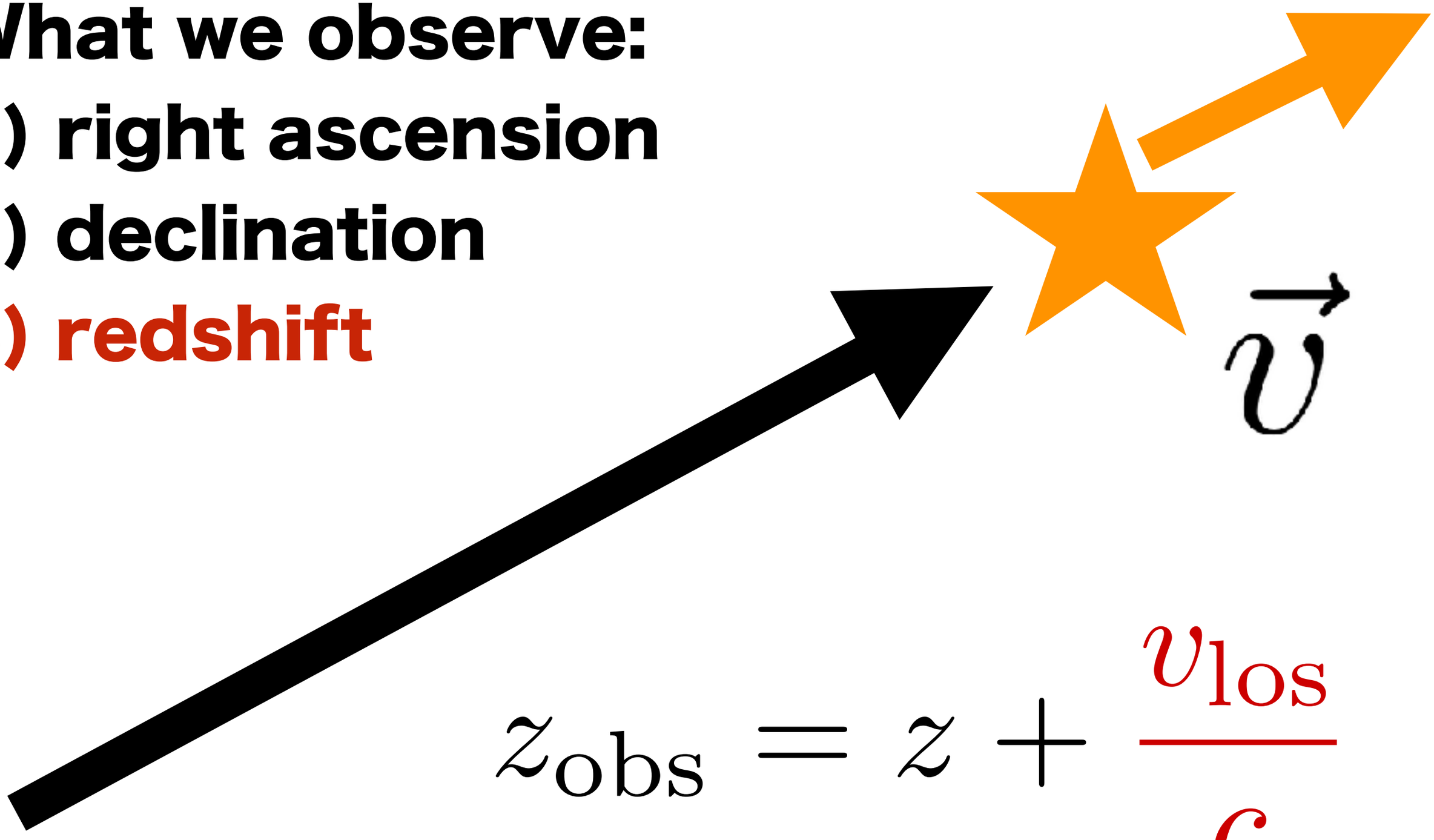
Redshift space distortions

What we observe:

1) right ascension

2) declination

3) redshift



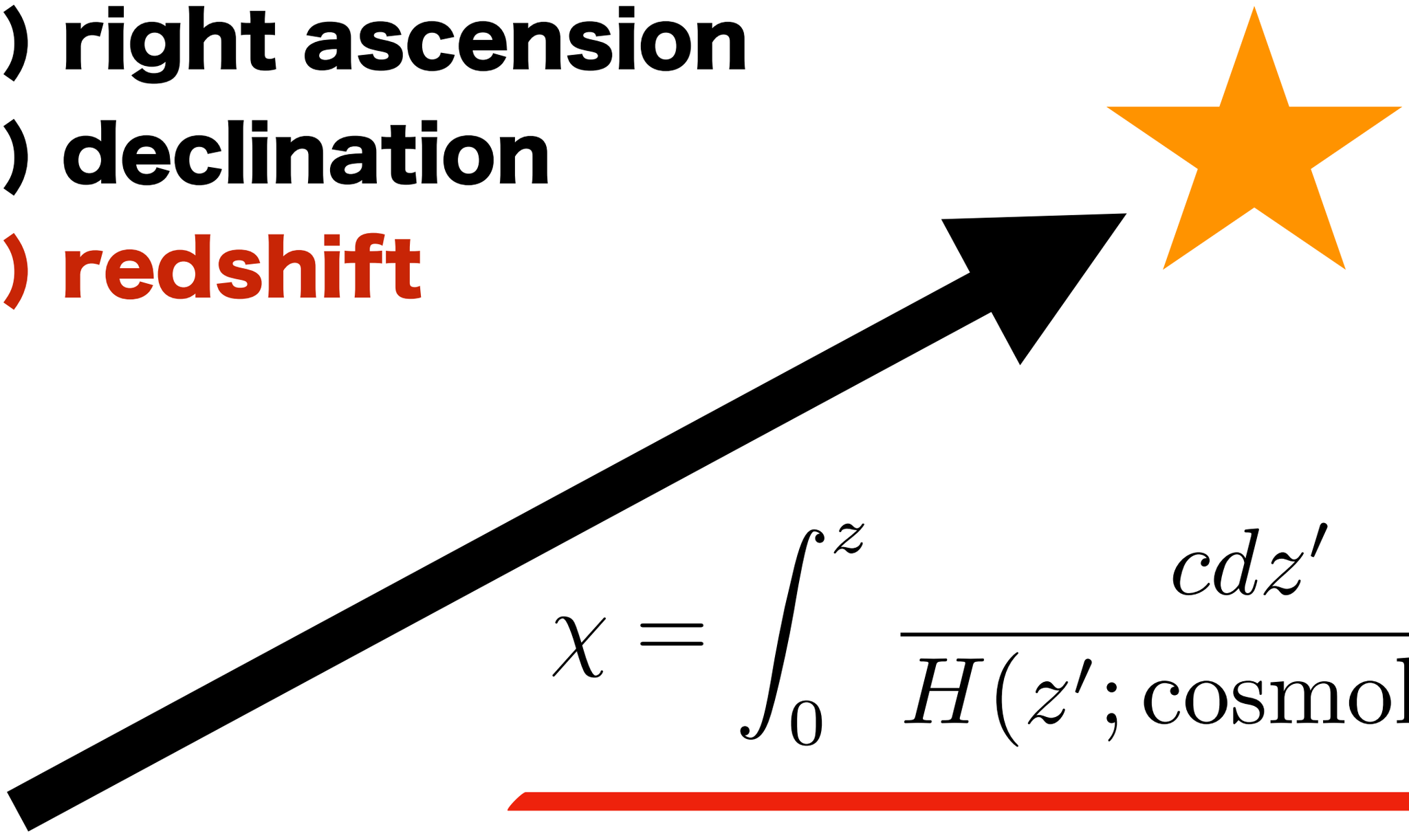
Alcock-Paczyn´ski effect

What we observe:

1) right ascension

2) declination

3) redshift



$$\chi = \int_0^z \frac{c dz'}{H(z'; \text{cosmology})}$$

Radial distance

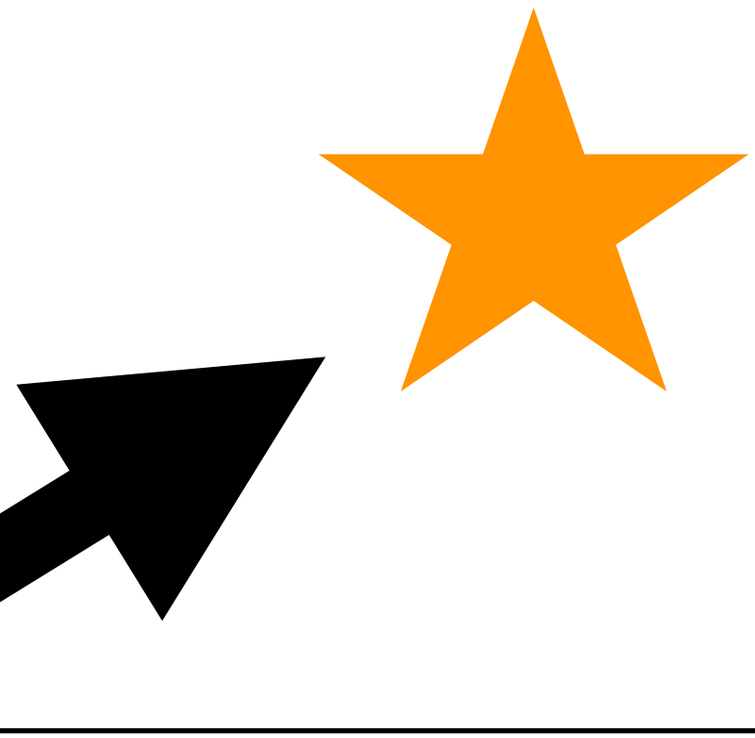
Anisotropic signals

What we observe:

1) right ascension

2) declination

3) redshift

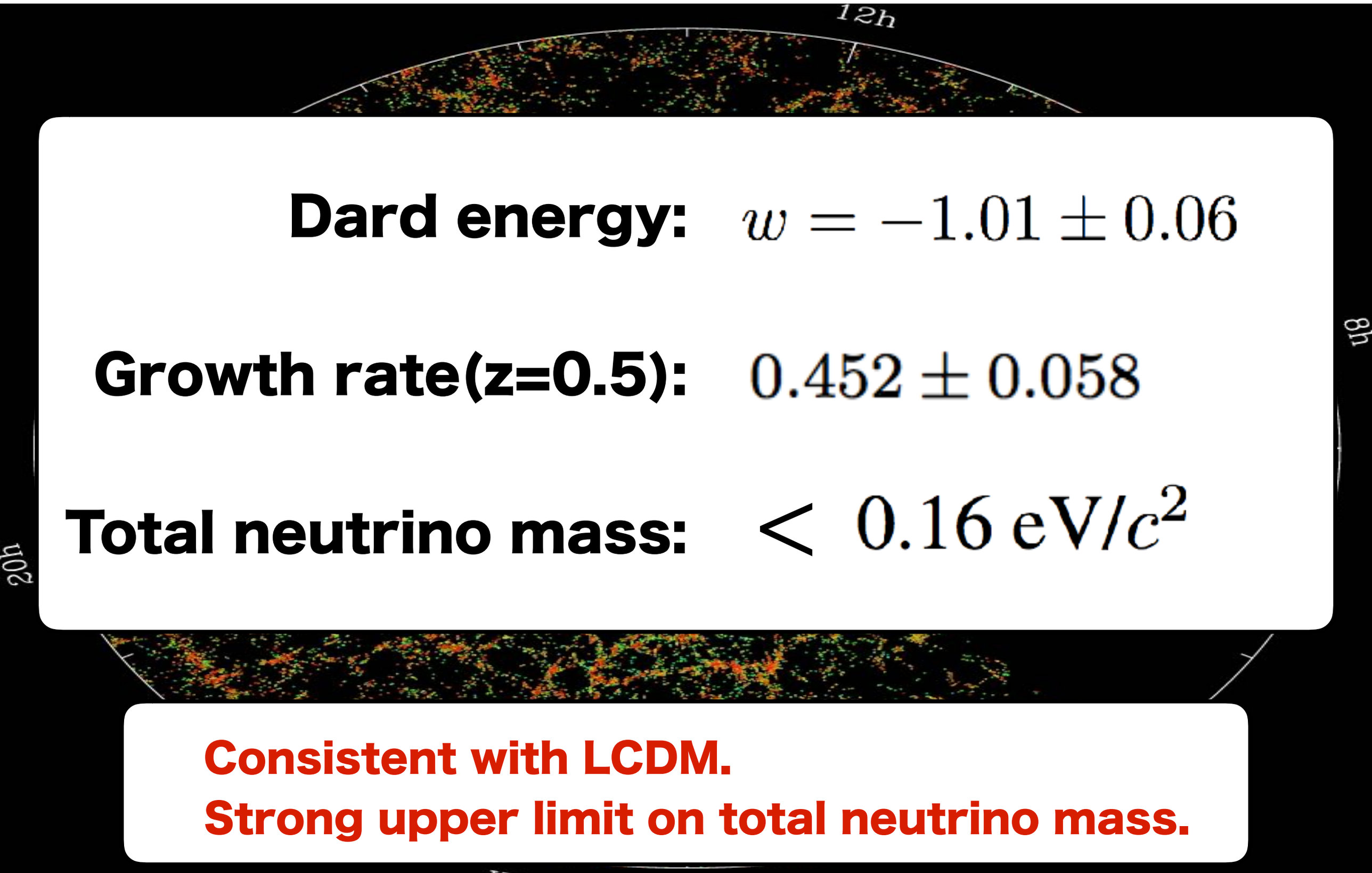


The anisotropic signal provides additional information,

velocity field and Hubble parameter

beyond spherically averaged measurements.

SDSS DR12 BOSS (2016)



Dard energy: $w = -1.01 \pm 0.06$

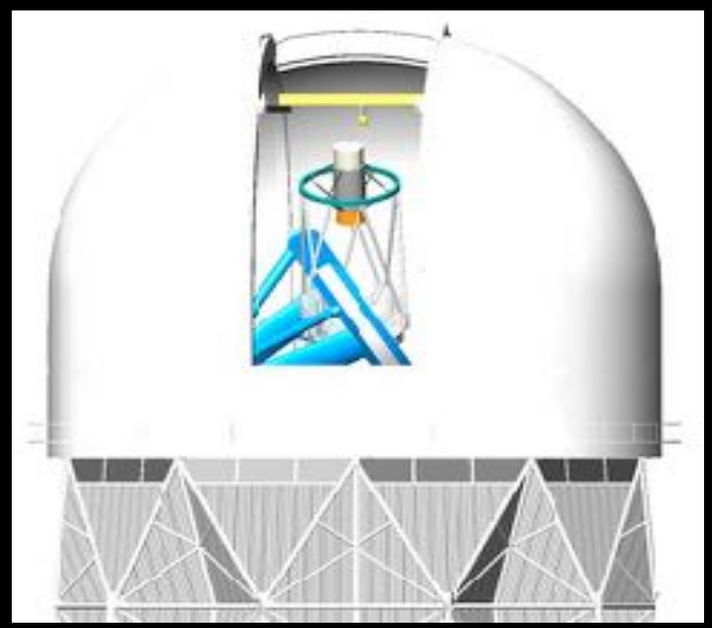
Growth rate(z=0.5): 0.452 ± 0.058

Total neutrino mass: $< 0.16\,\mathrm{eV}/c^2$

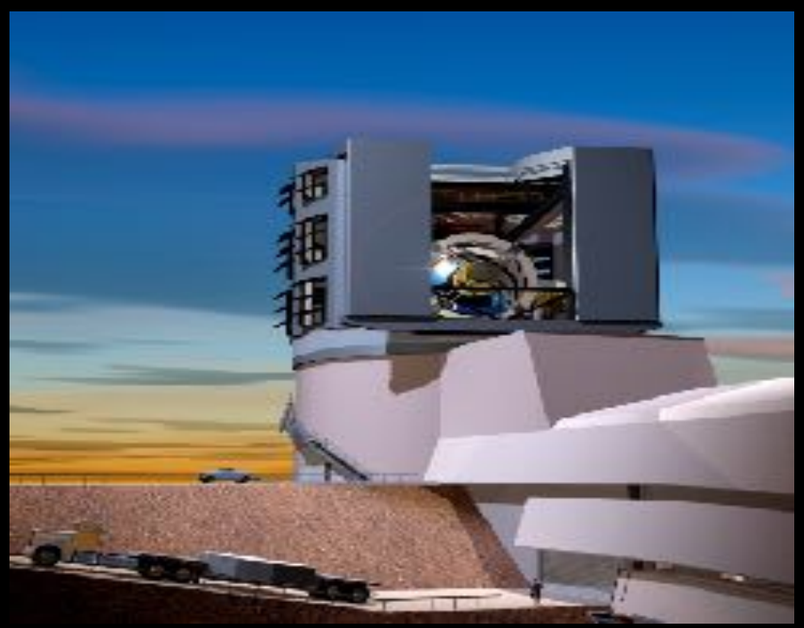
Consistent with LCDM.
Strong upper limit on total neutrino mass.

Next Generation Galaxy Surveys

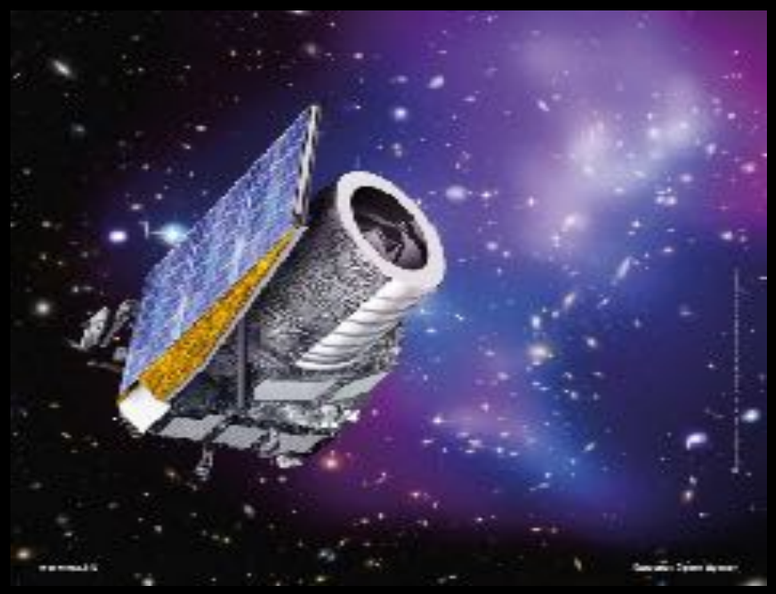
SuMIRe HSC/PFS (2015-25)



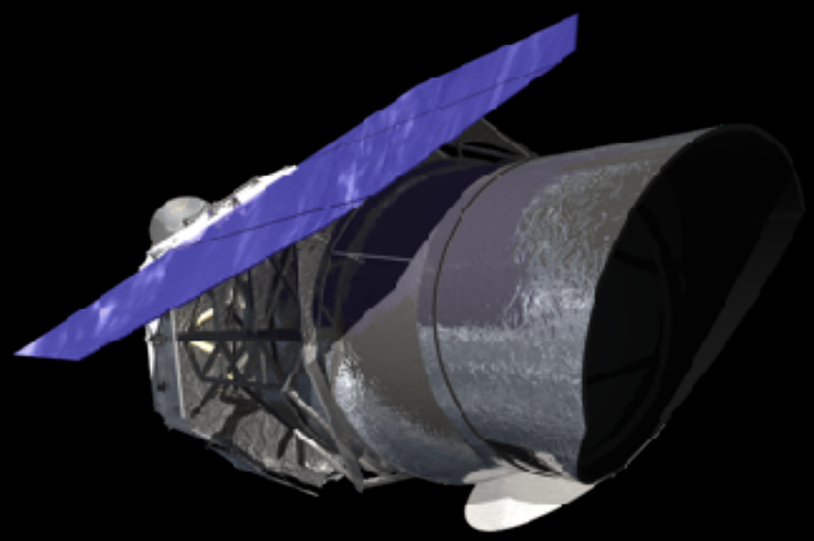
DESI (4m, LBL, 2020-)



LSST (6.5m, SLAC,2022-)

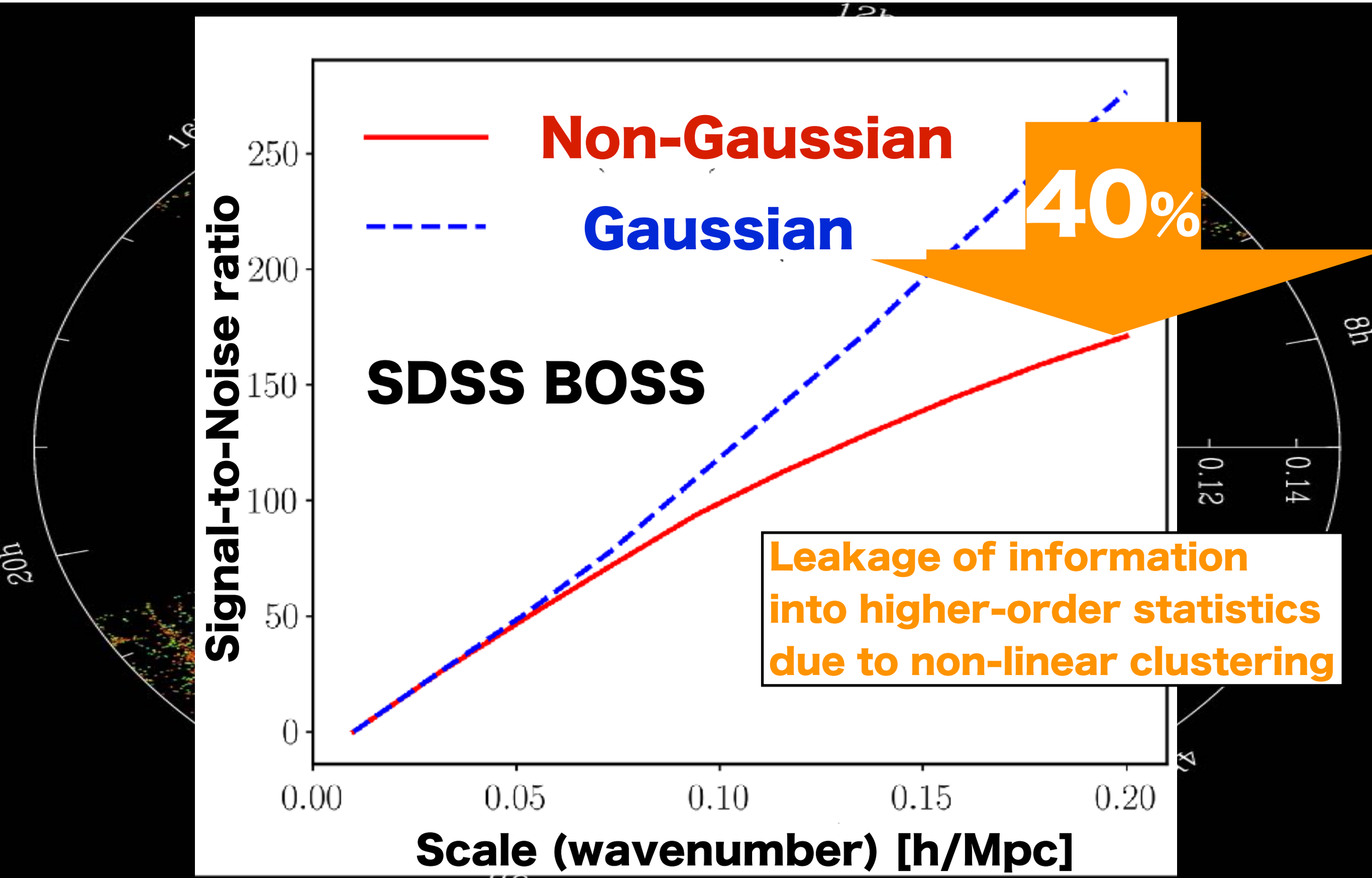


Euclid (ESA, 2022-)

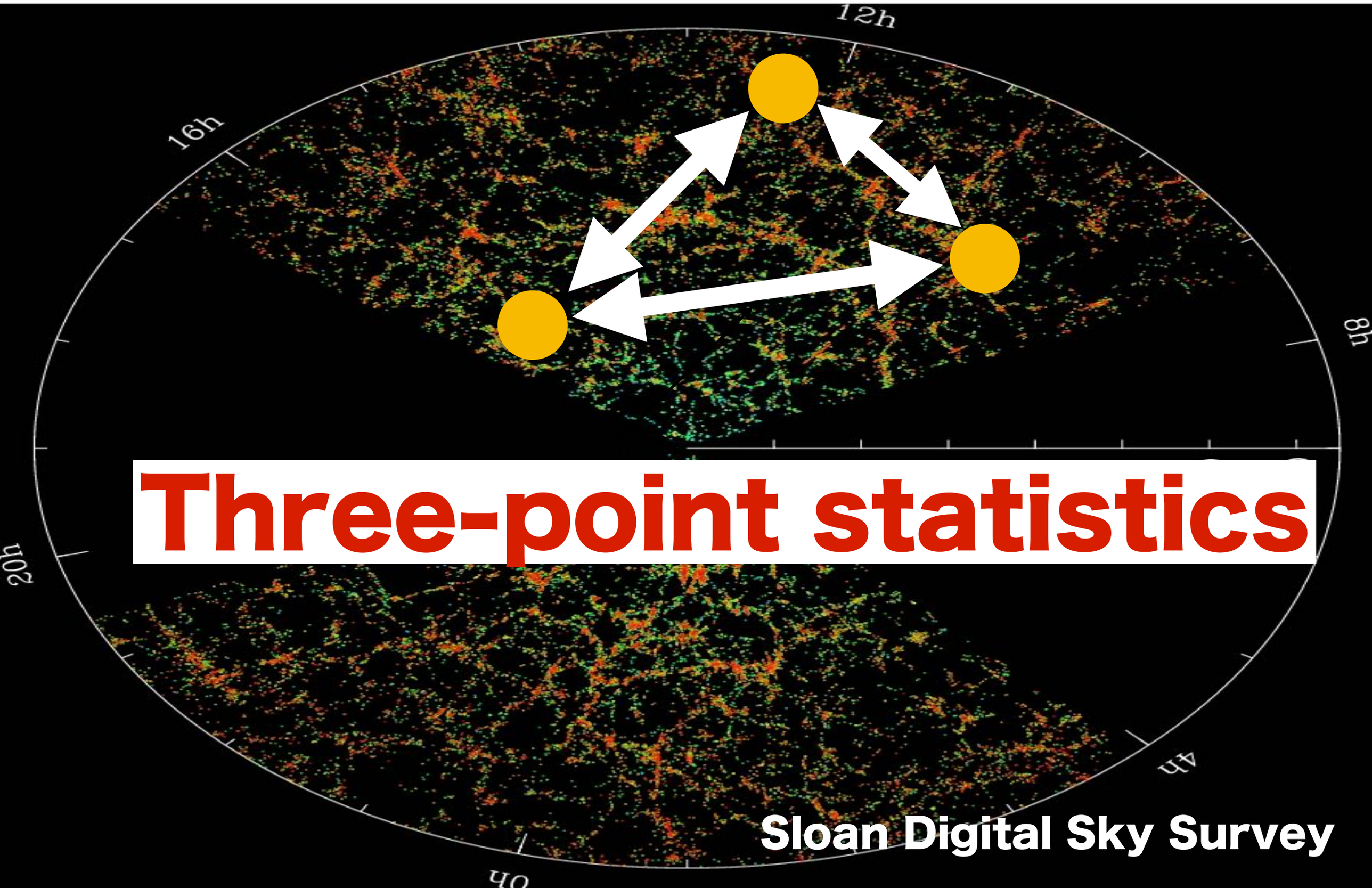


WFIRST (NASA,2025-)

Limitation of two-point statistics



Towards full information extraction



Three-point statistics

Sloan Digital Sky Survey

History

Angular catalogues:

Peebles & Groth (1975)

Groth & Peebles (1977);
Fry & Slender (1982)

Spectroscopic surveys in configuration-space

Kayo et al. (2004);

Jing & Boerner (2004);
Wang et al. (2004);
Gaztanaga et al. (2005);
Nichol et al. (2006);
Kulkarni et al. (2007);
Gaztanaga et al. (2009);
McBride et al. (2011a, b);
Marin (2011);
Marin et al. (2013);
Guo et al. (2013);
Slepian et al. (2017a,b);

Spectroscopic surveys in Fourier-space

Scoccimarro et al. 2001;
Feldman et al. 2001;
Verde et al. 2002;
Gil-Marin et al. 2015a,b;

Gil-Marin et al. 2017 (SDSS BOSS analysis)

Pearson & Samushia 2017;

Joint analysis of P + B will become the standard method for future galaxy surveys.

Is there anything else we should do?

Anisotropic bispectrum analysis has not been done yet.

Bispectrum Project

[1] NS, Saito, Beutler and Seo 2018

- A new decomposition formalism
- Detection of the quadrupole bispectrum (14σ)

[2] In progress

- Modeling the bispectrum
- Modeling the bispectrum covariance
- Fisher analysis

[3] Future works

- Analysis using BOSS data

Final goal

- Applying the pipeline to future galaxy surveys, PFS

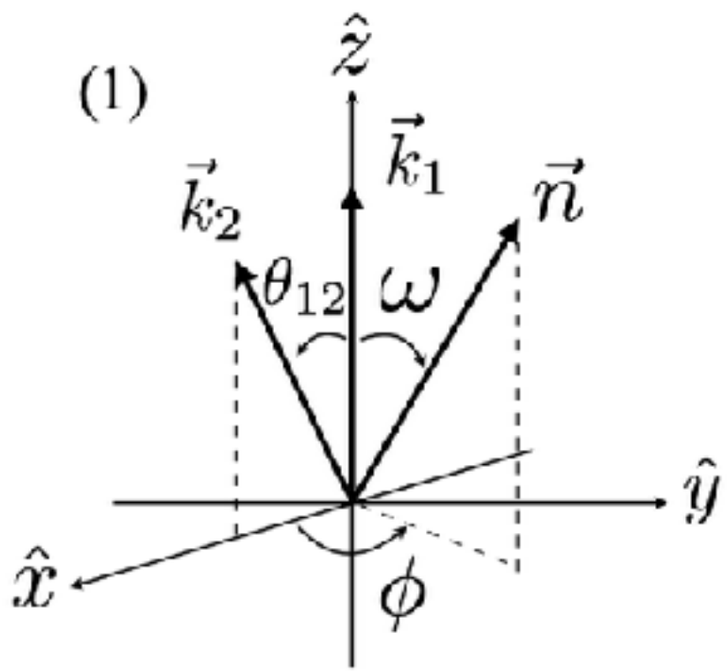
Decomposition formalism

$$B(k_1, k_2, \hat{n})$$

Wavevectors **Line-of-sight**

k1 is the z-axis

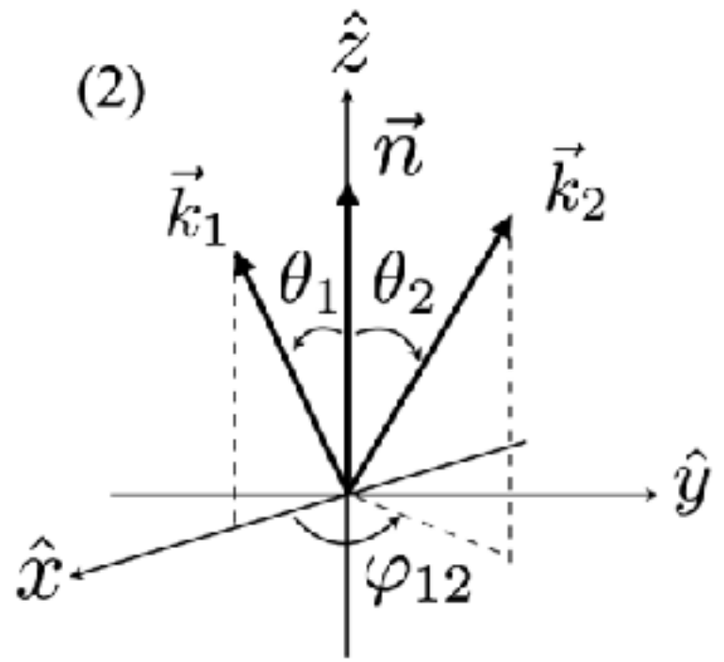
$$B = B_{LM}\, Y_{LM}(\hat{n})$$



Scoccimarro et al. (1999)

LOS is the z-axis

$$B = B^m_{\ell_1\ell_2}\, Y^m_{\ell_1}(\hat{k}_1)\, Y^{m*}_{\ell_2}(\hat{k}_2)$$



Slepian et al. (2017)

New decomposition formalism not depending on coordinate systems

1)Expand the bispectrum in three spherical harmonics

$$B^{m_1 m_2 M}_{\ell_1 \ell_2 L}(k_1, k_2) = N_{\ell_1 \ell_2 L} \int \frac{d^2\hat{k}_1}{4\pi} \int \frac{d^2\hat{k}_2}{4\pi} \int \frac{d^2\hat{n}}{4\pi}$$
$$\times \quad y^{m_1 *}_{\ell_1}(\hat{k}_1) y^{m_2 *}_{\ell_2}(\hat{k}_2) y^{M *}_{L}(\hat{n}) B(\boldsymbol{k}_1, \boldsymbol{k}_2, \hat{n}),$$

2) Sum up over all m-modeswith wigner 3j symbol.

$$B_{\ell_1 \ell_2 L}(k_1, k_2) \propto \sum_{m_1 m_2 m_3} \begin{pmatrix} \ell_1 & \ell_2 & \ell_3 \\ m_1 & m_2 & m_3 \end{pmatrix} B^{m_1 m_2 M}_{\ell_1 \ell_2 L}(k_1, k_2)$$

3) Restrict the allowed multipoles to l1+l2+L=even

New Bispectrum Multipoles

Three multipole indexes

Two wavenumber

$$B_{\ell_1 \ell_2 L}(k_1, k_2)$$

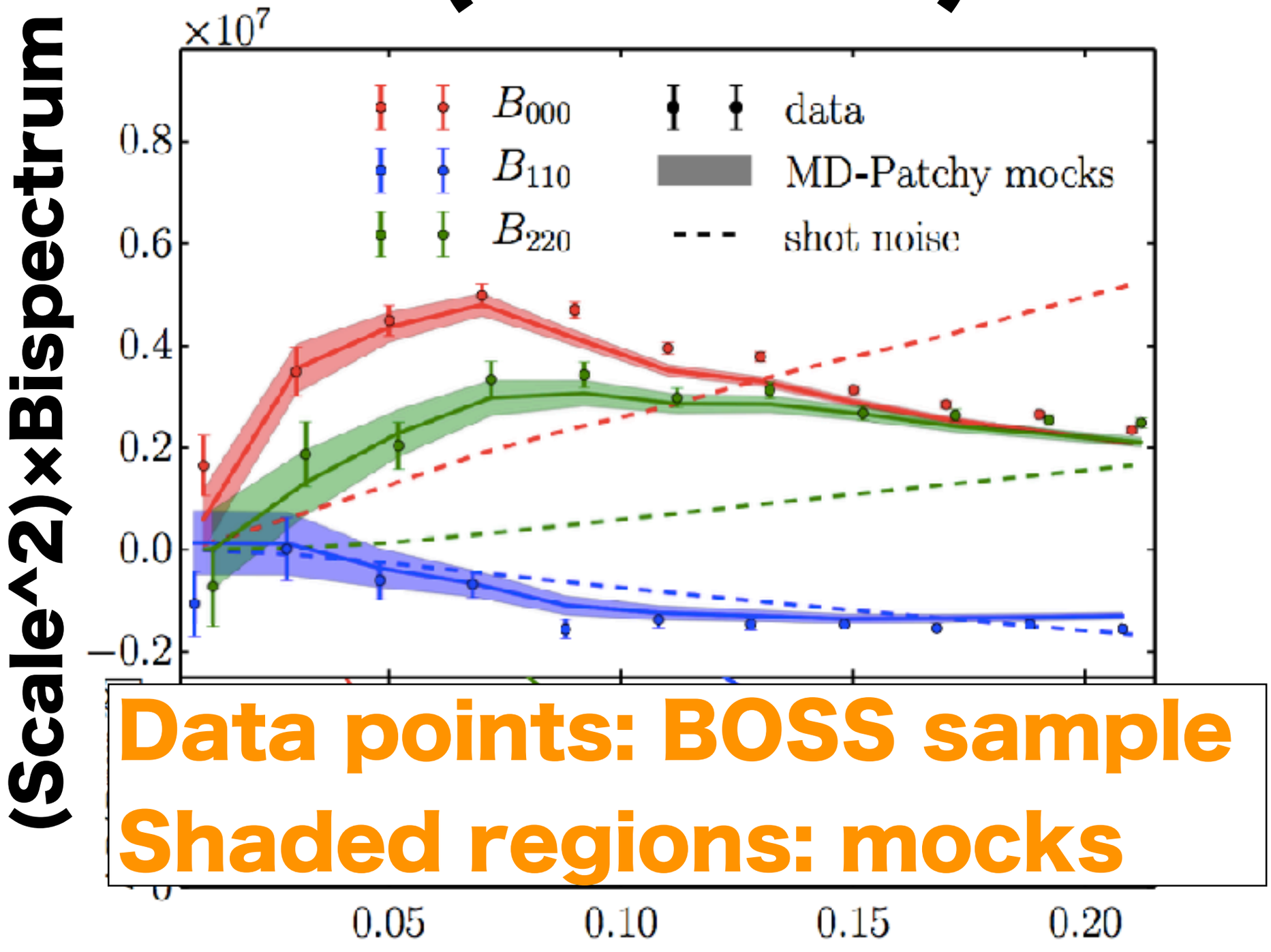
k1 , k2 **LOS**

L = 0: monopole

L = 2: quadrupole

Measurements of Monopole (L=0)

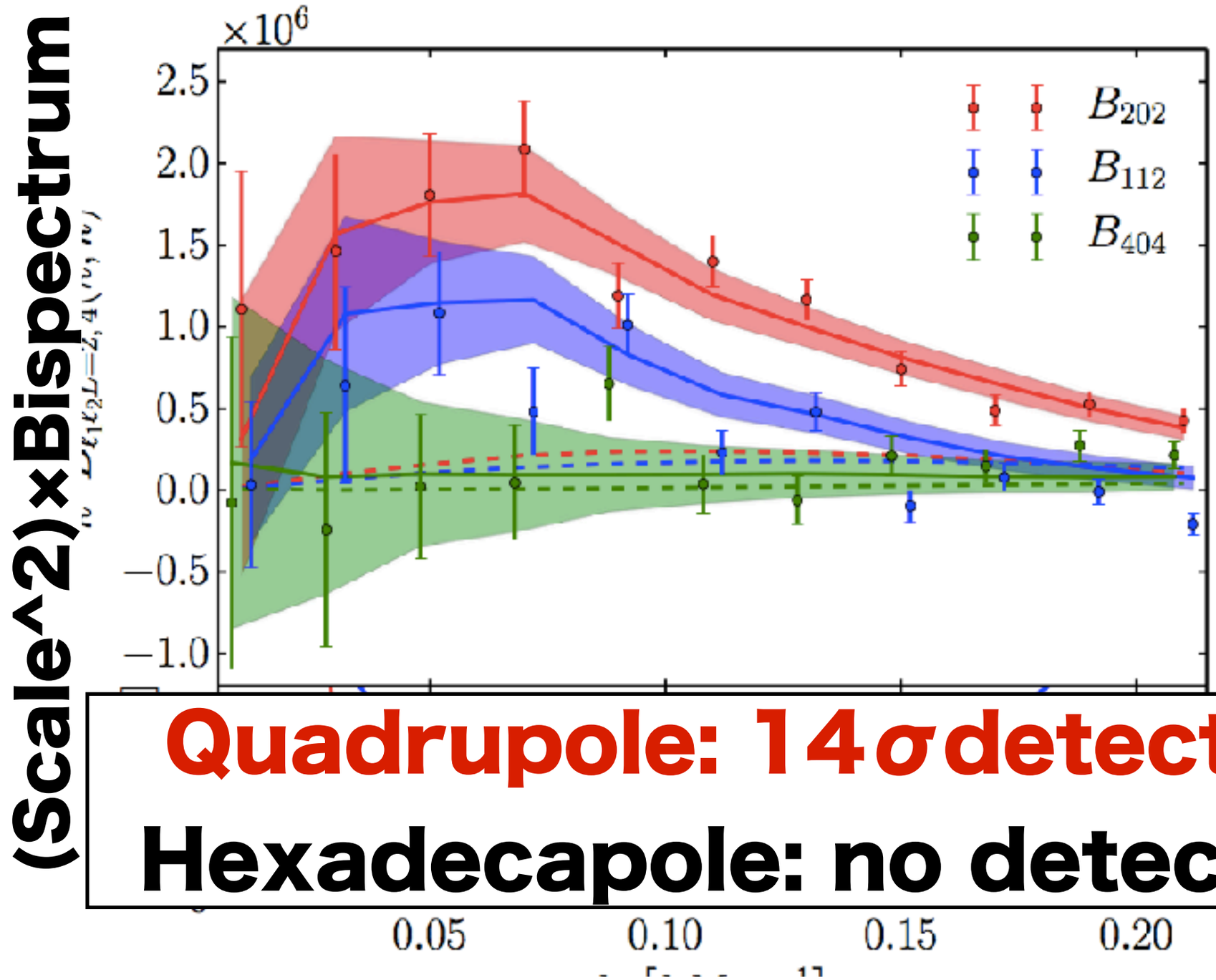
(k1 = k2)



Data points: BOSS sample

Shaded regions: mocks

Quadrupole (L=2)
and Hexadecapole (L=4)



Quadrupole: 14σ detection

Hexadecapole: no detection

How do anisotropic bispectrum measurements improve constraints on cosmological parameters? (Preliminary results)

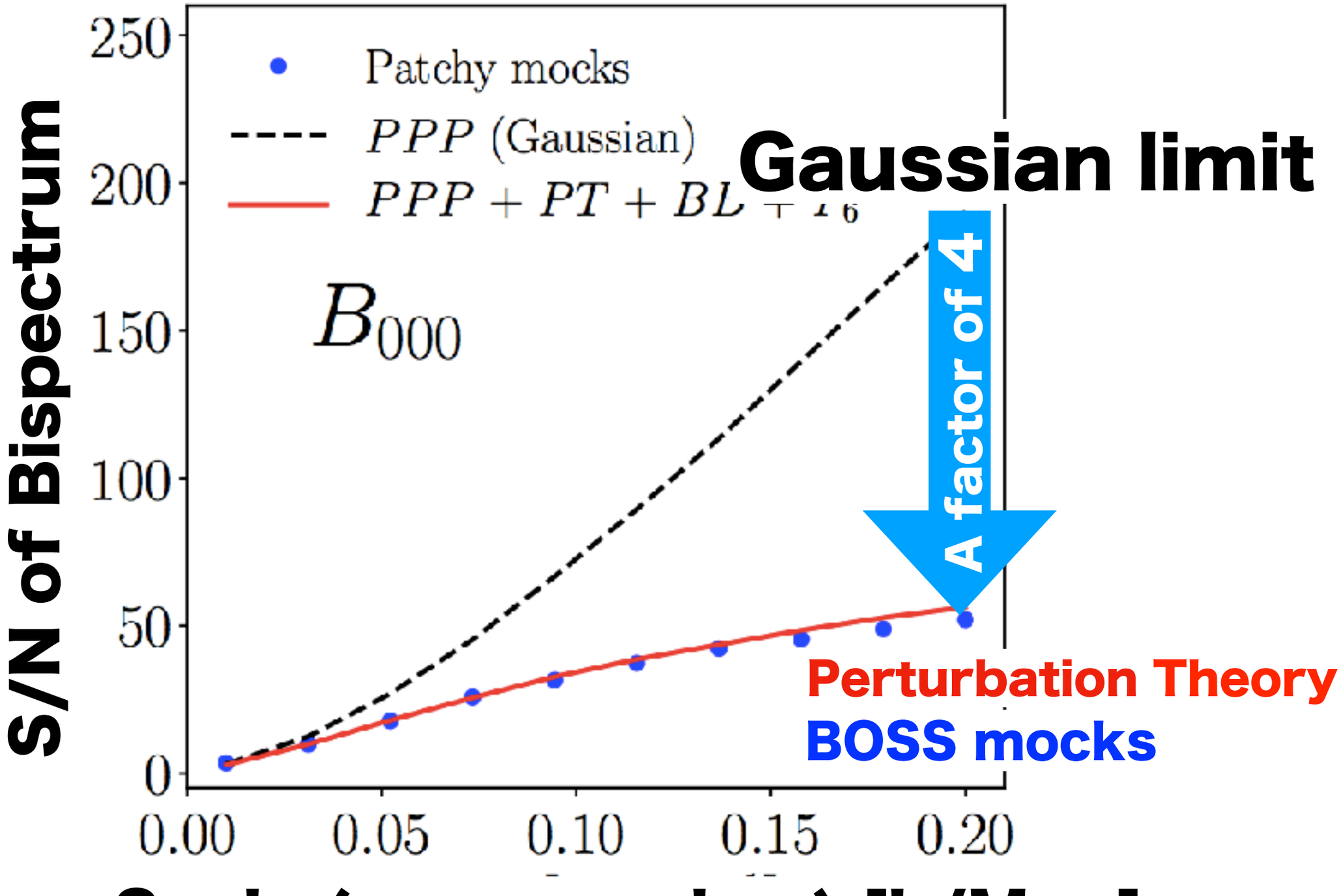
Fisher analysis

Correct error estimates

[non-Gaussian covariance]

Correct theoretical model

Importance of Non-Gaussian errors



Non-Gaussian covariance

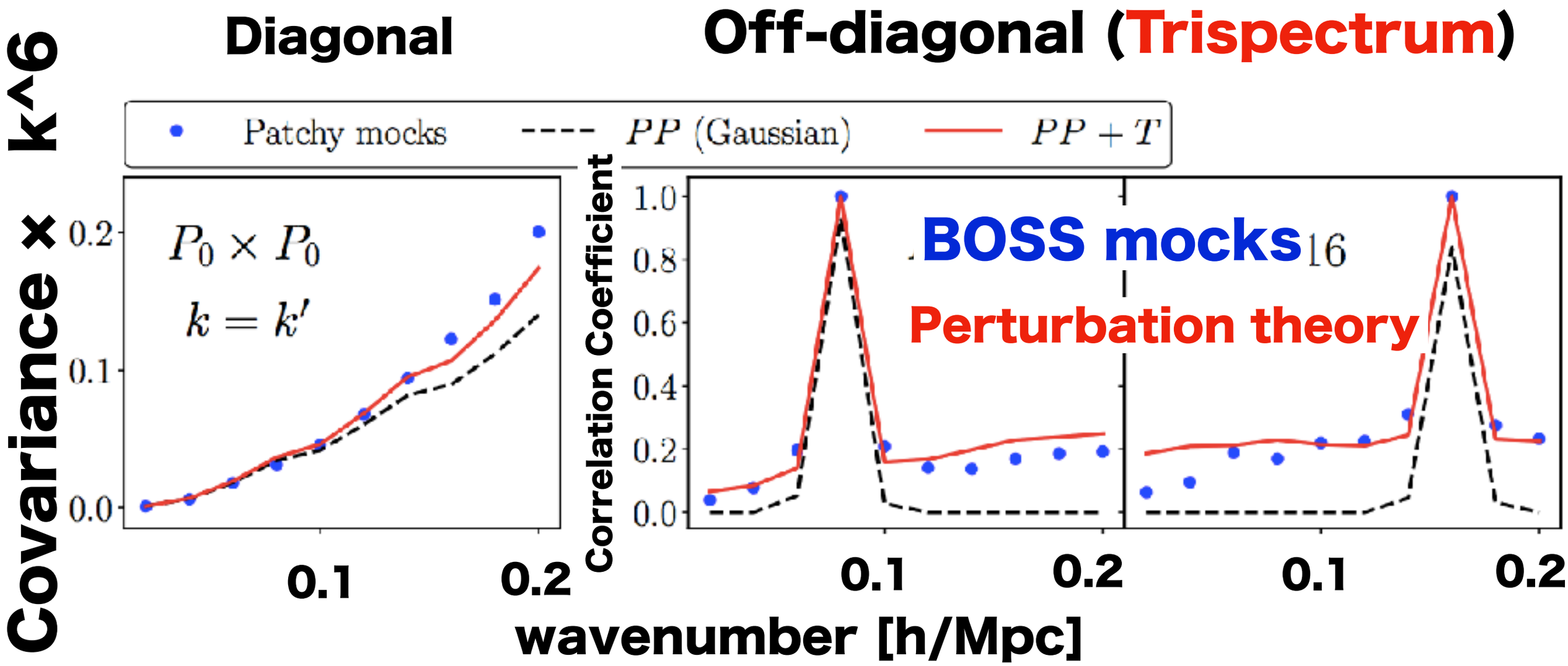
P-P covariance -> tri-spectrum

P-B covariance -> 5-point spectrum

B-B covariance -> 6-point spectrum

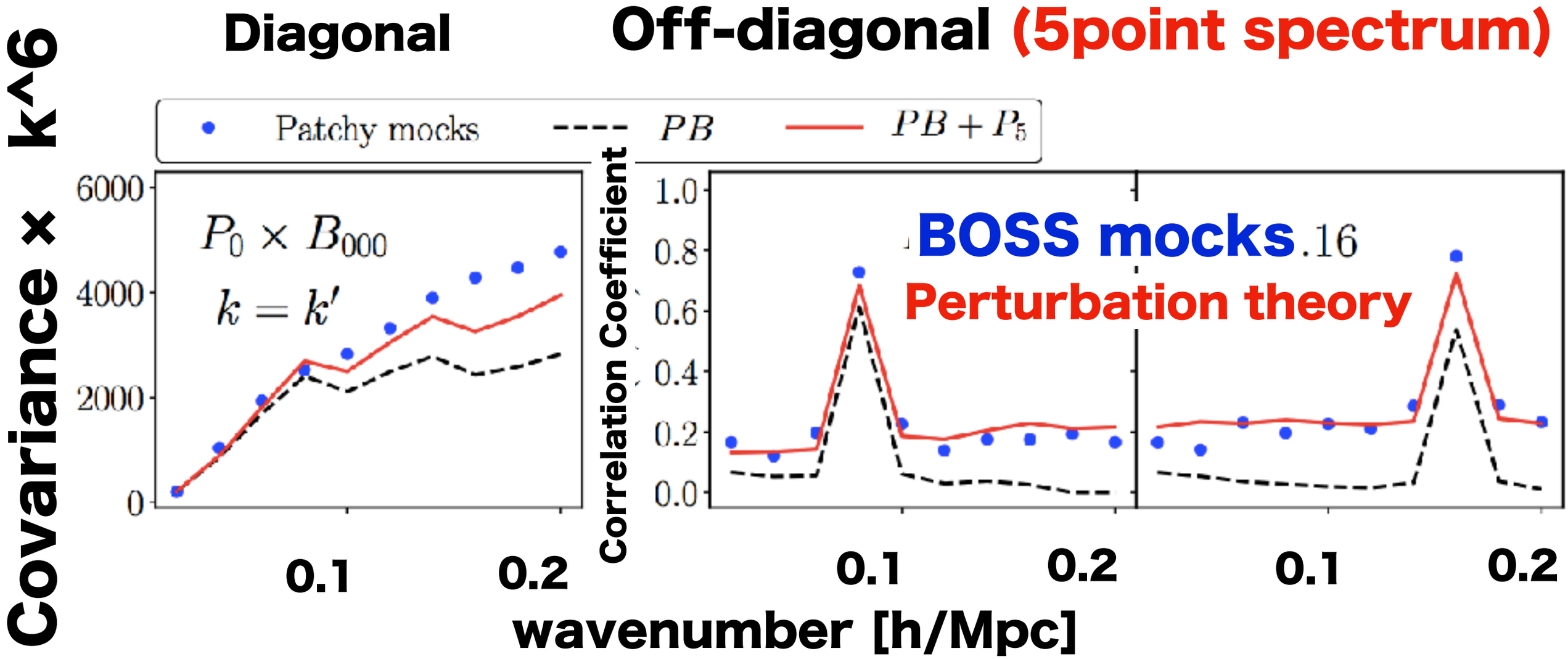
RSD + linear bias + shot noise

Cov [P0, P0]



Cov[P,P] = PP + T

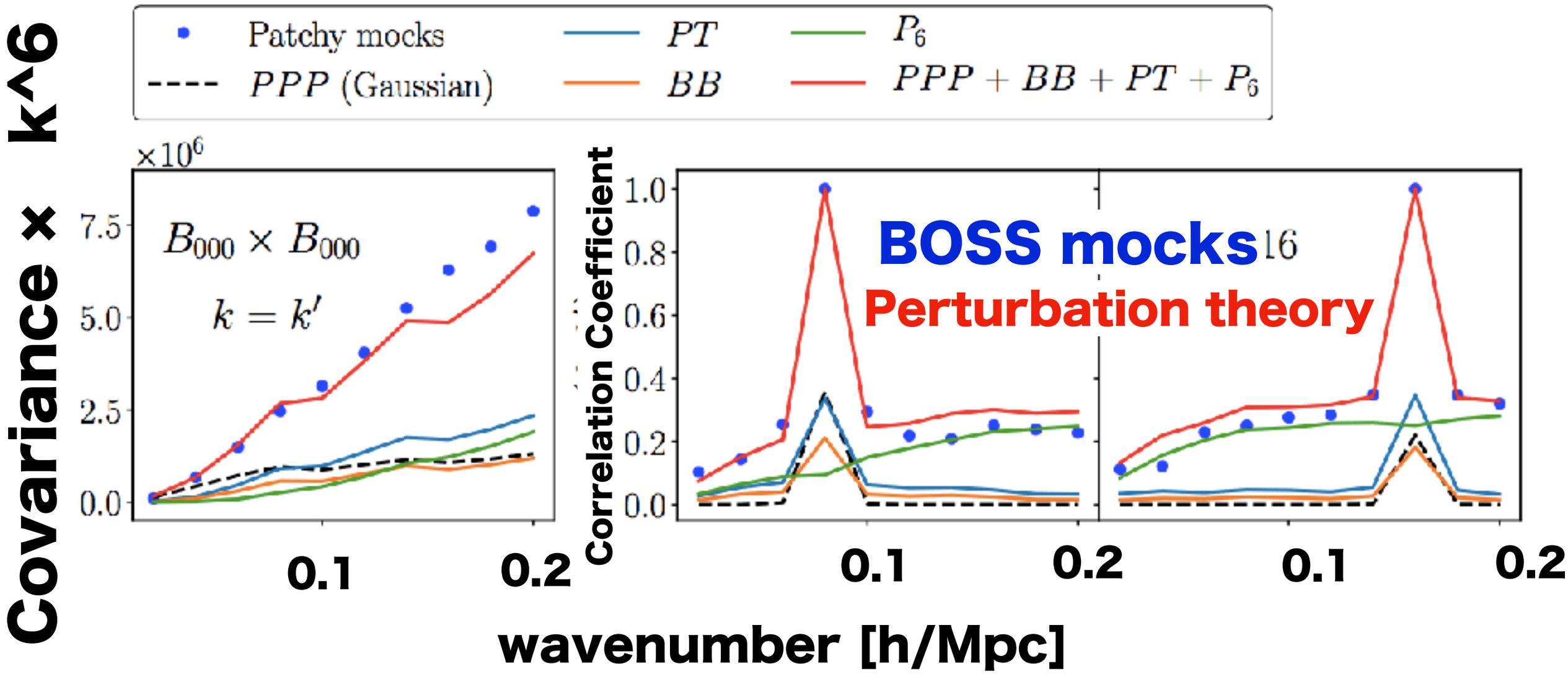
Cov [P0, B000]



Cov[P,B] = PB + P5

Cov [BOOO, BOOO]

Diagonal **Off-diagonal (6point spectrum)**



Cov[B,B] = PPP + PT + BB + P6

Bispectrum model

We need the model that explains the anisotropic galaxy power spectrum and bispectrum simultaneously.

1) Non-linear clustering
2) Non-linear RSDs
3) Non-linear bias

Bispectrum model

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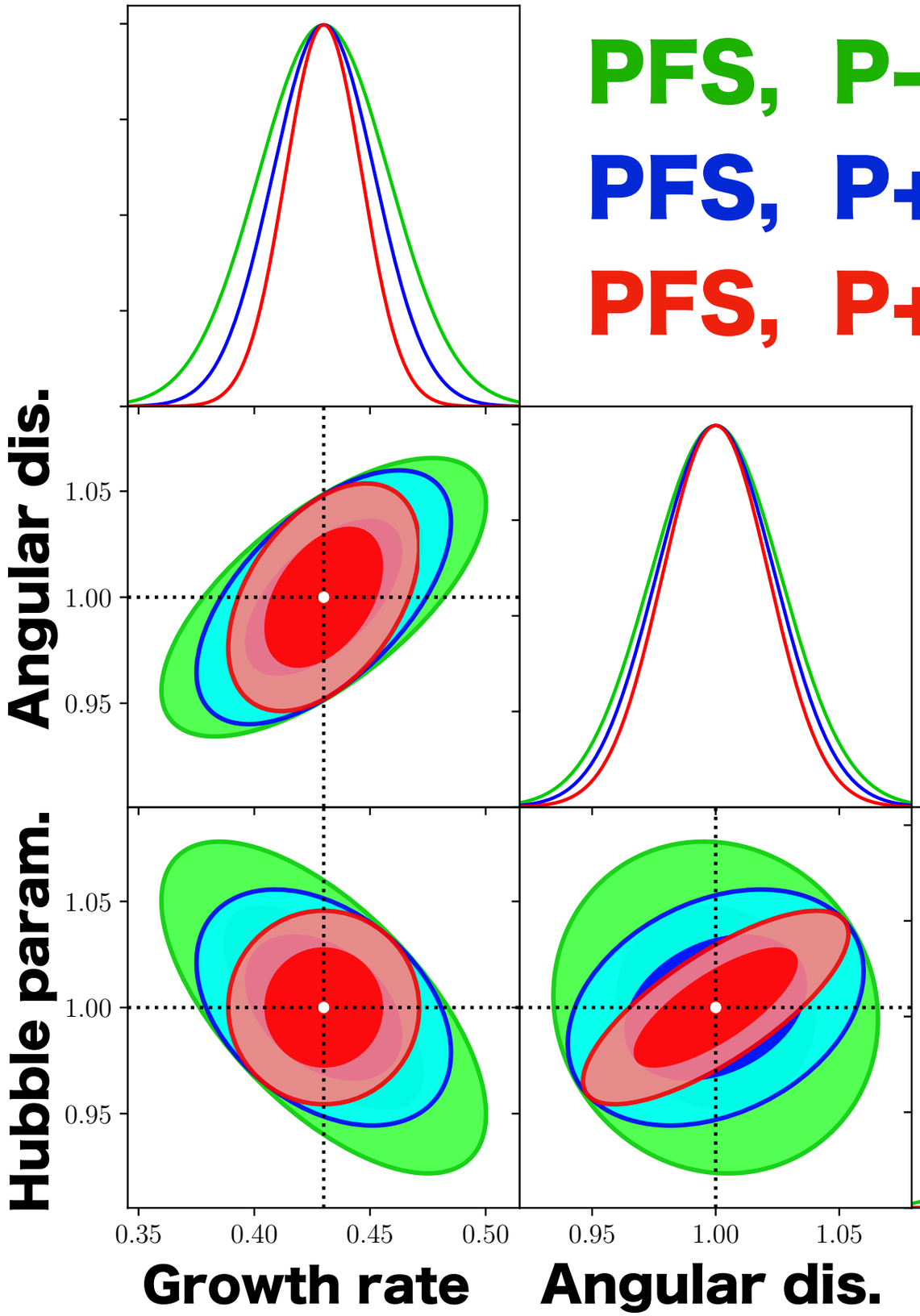
Bispectrum model

Power spectrum and bispectrum:
tree-level solution
+ finger-of-god ← **non-linear RSDs**
+ local bias (b1, b2) ← **non-linear bias**
+ residual shot-noise terms

Fisher analysis for PFS



PFS, P-only

PFS, P+ B (mono.)

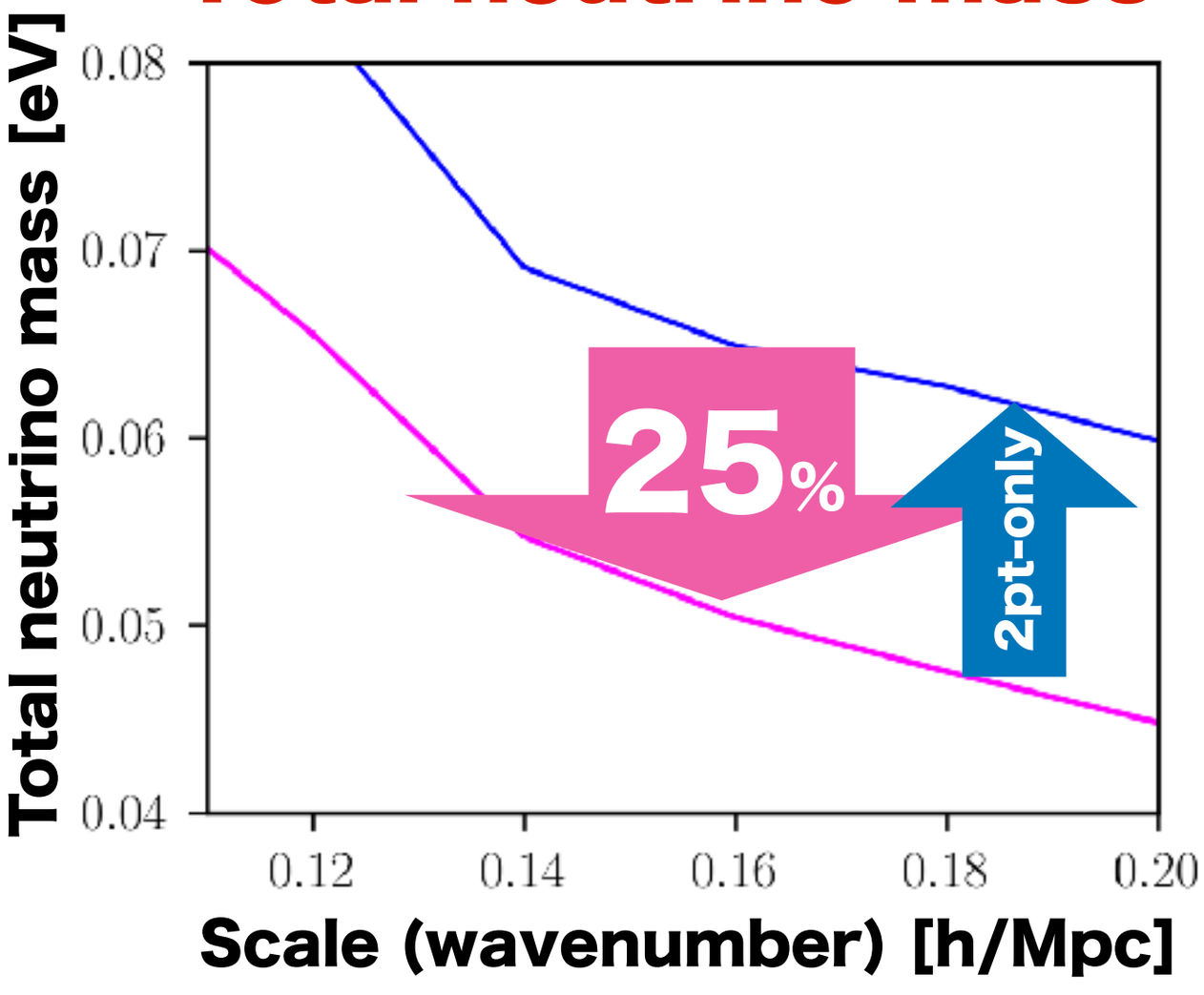
PFS, P+B (mono.+quad.)

redshift = 1.1

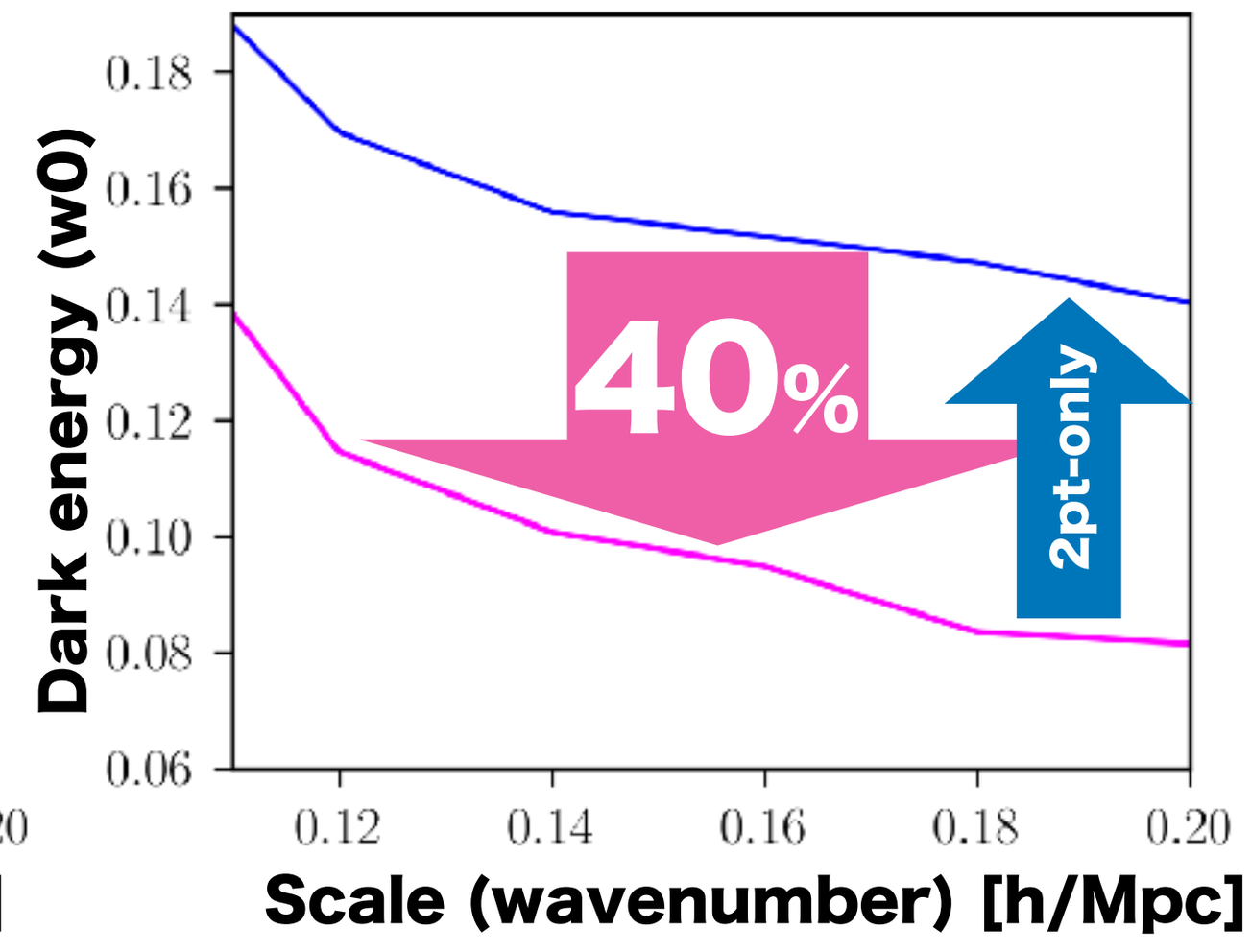
- **b1 and b2**
- **FOGs**
- **residual shot noises**

PFS Project
(0.6 < z < 2.2)

Total neutrino mass



Dark energy



Bispectrum Project

[1] NS, Saito, Beutler and Seo 2018

- A new decomposition formalism
- Detection of the quadrupole bispectrum (14σ)

[2] In progress

This talk

- Modeling the bispectrum covariance
- Fisher analysis
- Modeling the anisotropic bispectrum

[3] Future works

- Analysis using BOSS data

Final goal

- Applying to future galaxy surveys, PFS