On a new method to constrain primordial non-Gaussianity with galaxy surveys

Shintaro Nakano (Kavli IPMU),
Masahiro Takada (Kavli IPMU),
Toshiki Kurita (MPA)



Shintaro Nakano
中野新太郎
(2nd year grad student, Kavli IPMU)

KAVLI IPMU INSTITUTE FOR THE PHYSICS AND MATHEMATICS OF THE UNIVERSE

東京大学 THE UNIVERSITY OF TOKYO

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Primordial non-Gaussianity (PNG) – the key to the physics of inflation (the early universe)

- Local-type PNG

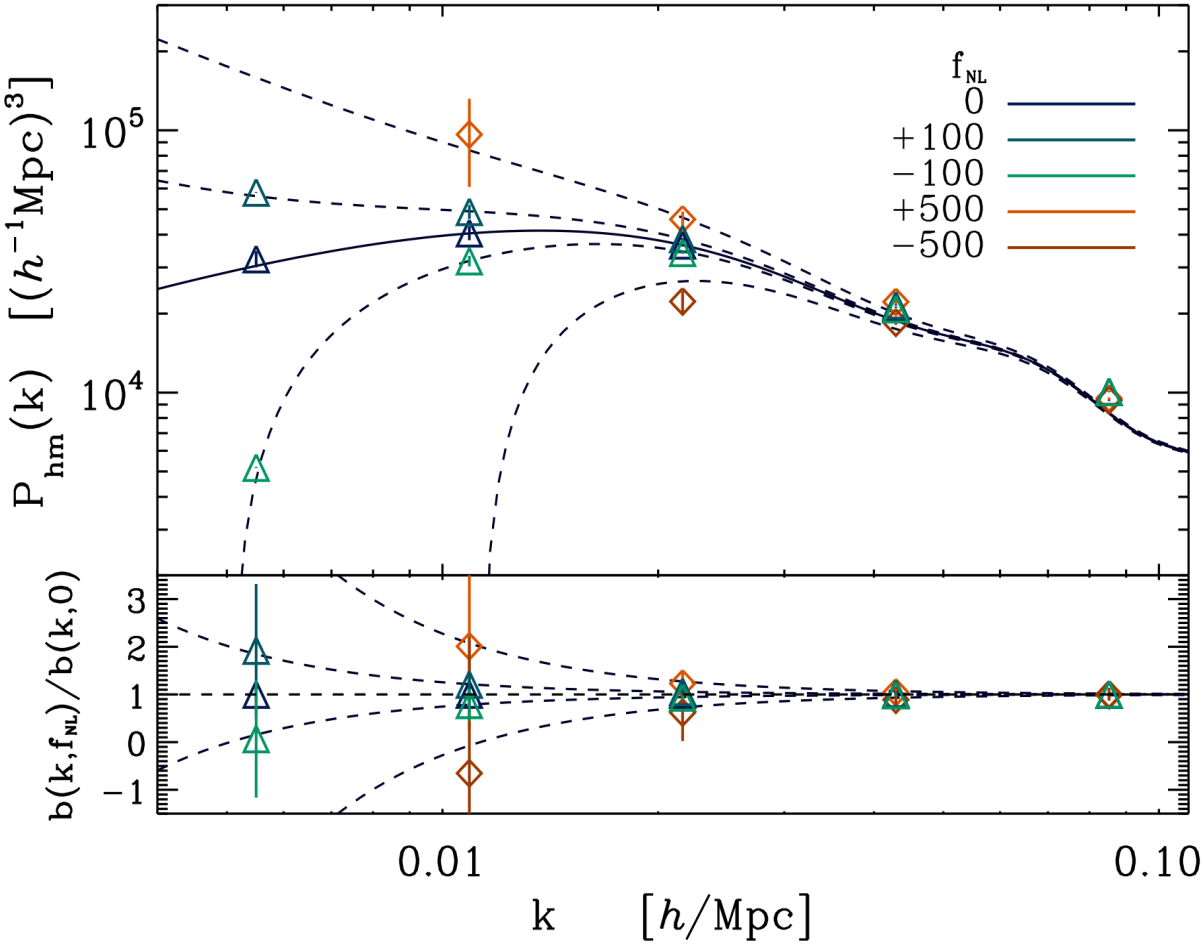
$$\zeta = \zeta_{\rm g} + f_{\rm NL}(\zeta_{\rm g}^2 - \langle\zeta_{\rm g}^2\rangle)$$

- PNG induces a scale-dependent bias in the linear regime

$$b_1^{\rm PNG} = b_1 + \underbrace{f_{\rm NL} b_\phi \mathcal{M}^{-1}(k,a)}_{\propto f_{\rm NL} k^{-2}}$$

- Also see Desjacques, Jeong, Schmidt 18 for a review

Dalal et al 08



Primordial non-Gaussianity (PNG) – the key to the physics of inflation (the early universe)

- Pajer, Schmidt & Zaldarriaga (13) showed that the *observable* squeezed bispectrum should have a negligible amplitude for a single-field inflation

$$B_{\zeta\zeta\zeta} \sim -(n_s - 1) P_\zeta(k_L) P_\zeta(k_S)$$

$$B_{\bar{\zeta}\bar{\zeta}\bar{\zeta}} \sim 0$$

- Therefore, any detection of f_NL rules out a single-field inflation scenario
- So very important to observationally pursue

Pajer, Schmidt & Zaldarriaga 13

$$B_{\bar{\zeta}\bar{\zeta}\bar{\zeta}}(\mathbf{k}_L, \mathbf{k}_1, \mathbf{k}_2) = P_\zeta(k_L) P_\zeta(k_S) \frac{\partial \ln(k_S^3 P_\zeta(k_S))}{\partial \ln k_S} + B_{\zeta\zeta\zeta}(\mathbf{k}_L, \mathbf{k}_1, \mathbf{k}_2), \quad (27)$$

where $B_{\zeta\zeta\zeta}$ is the three-point function calculated in co-moving gauge. As shown in [4, 24], this is in the squeezed limit given by

$$B_{\zeta\zeta\zeta}(\mathbf{k}_L, \mathbf{k}_1, \mathbf{k}_2) = -[n_s - 1] P_\zeta(k_L) P_\zeta(k_S)\,, \quad (28)$$

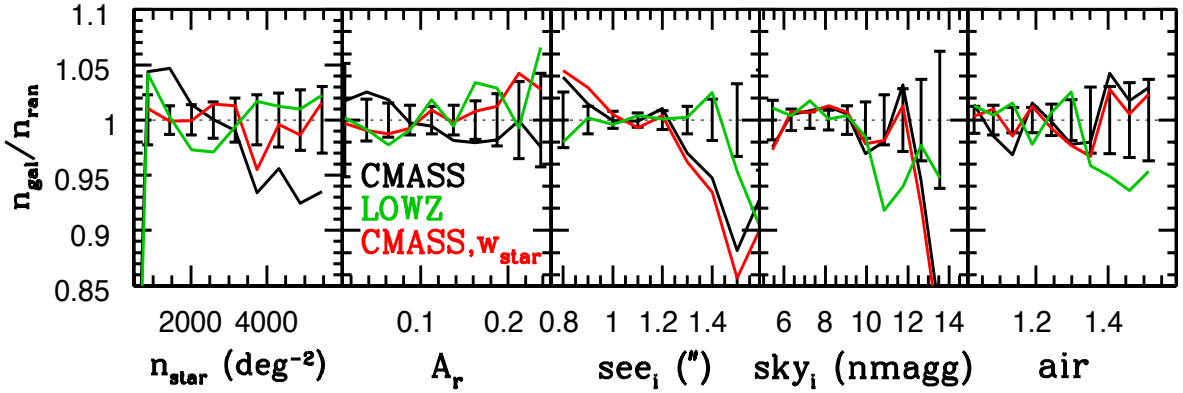
where n_s is defined through $P_\zeta(k) \propto k^{-4+n_s}$. Eq. (28) is usually referred to as the *consistency relation*. We now see that the first term in Eq. (27) exactly cancels the contribution from $B_{\zeta\zeta\zeta}$, leading to

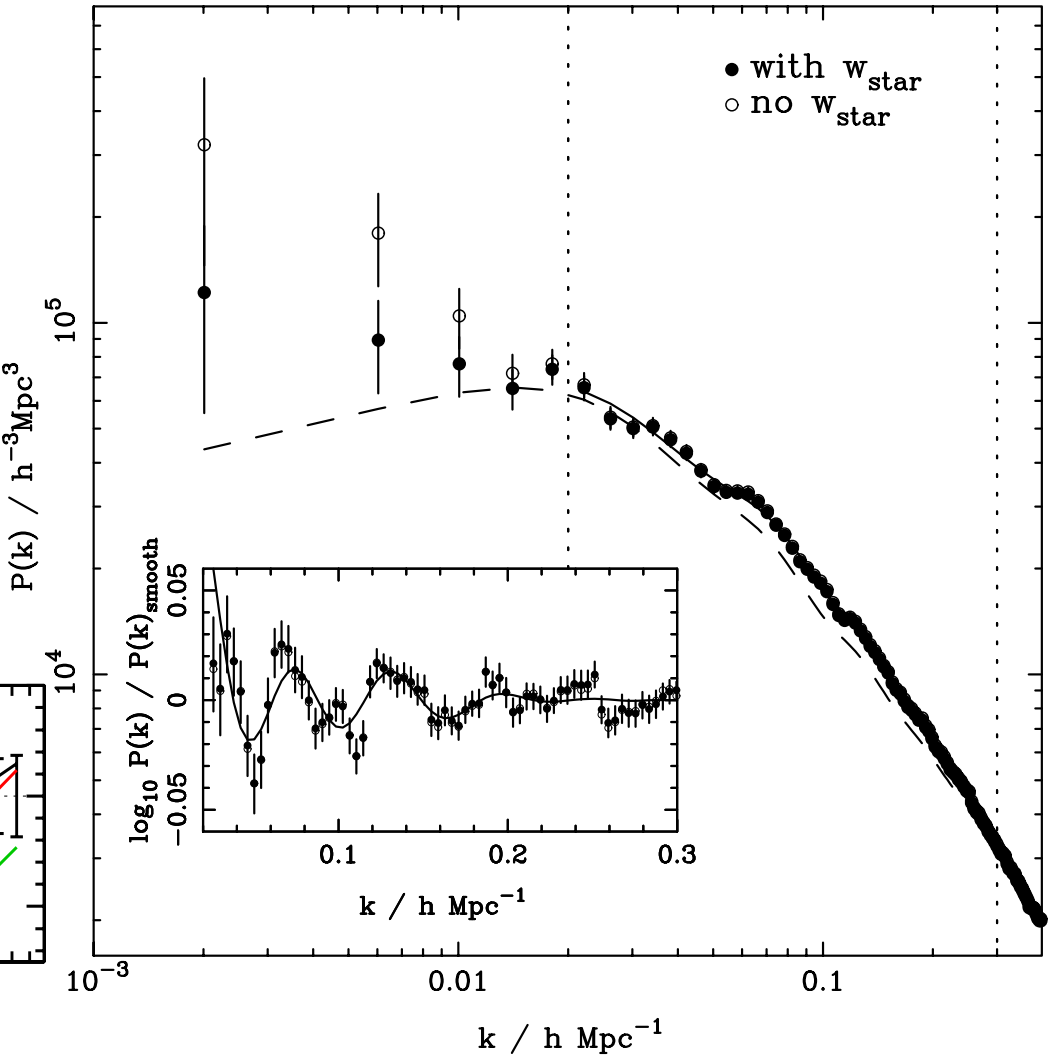
$$B_{\bar{\zeta}\bar{\zeta}\bar{\zeta}}(\mathbf{k}_L, \mathbf{k}_1, \mathbf{k}_2) = \mathcal{O}\left(\frac{k_L}{k_S}\right)^2 . \quad (29)$$

However, systematics, systematics, …

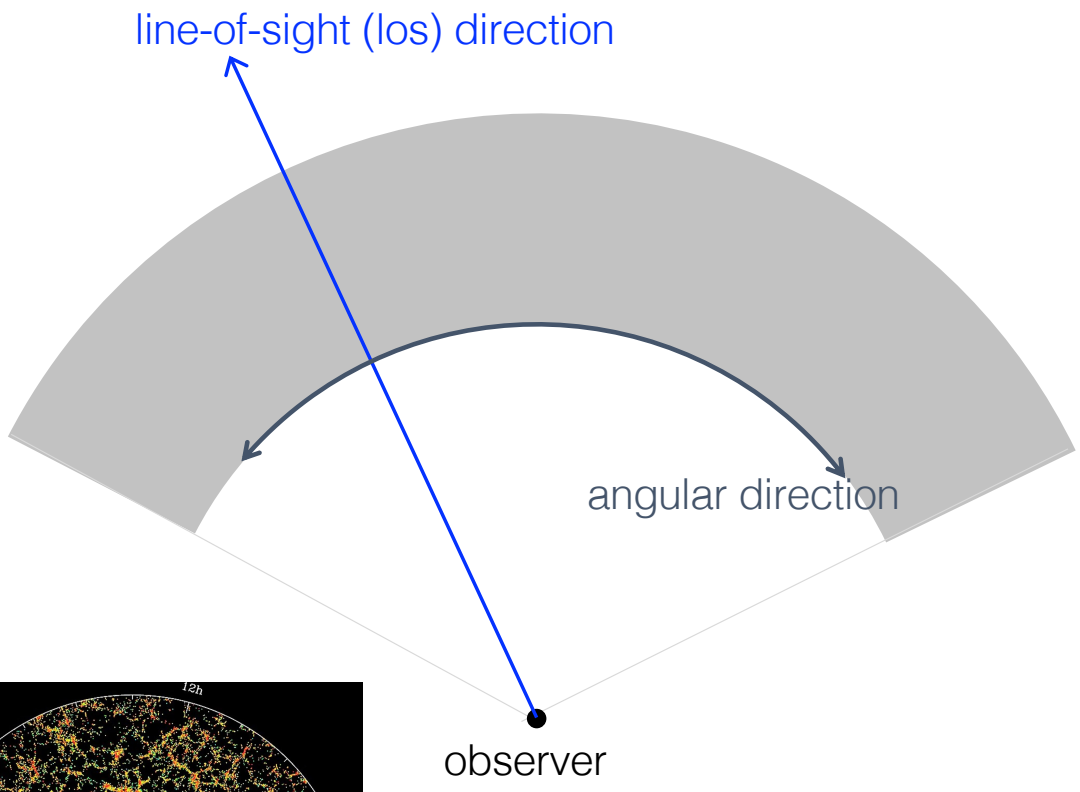
- Residual systematics: non-zero correlations of galaxy density with star density, seeing, …
- Most previous analyses constraining f_NL used the data at k>0.01 h/Mpc (even if the measurements are down to k~0.001h/Mpc) (e.g., Kurita & Takada 23)

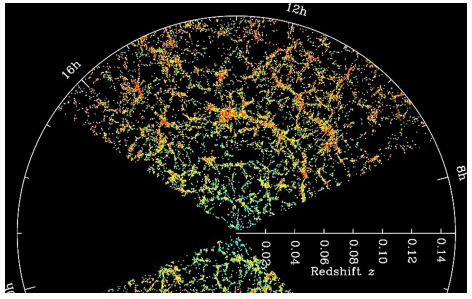
Ross+(BOSS collab.)12





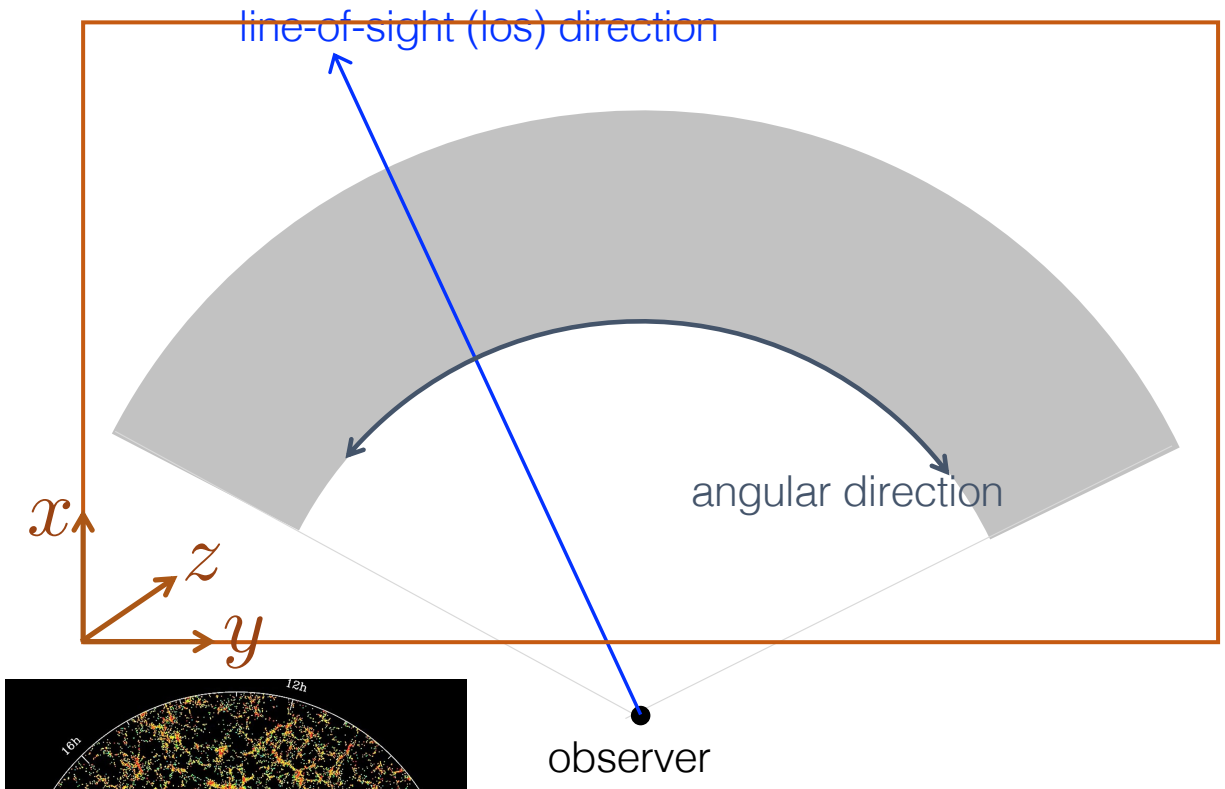
Angular direction ≠ Fourier mode directions

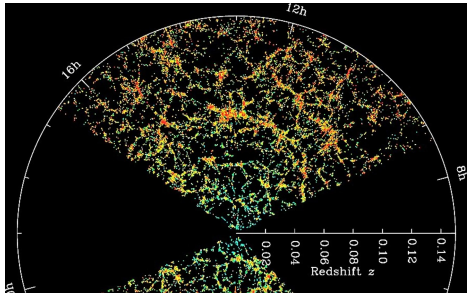




- A galaxy redshift survey observes galaxies in the past light cone
- Systematics of stars, seeing, … are all in the angular direction
- Fourier analysis, used for the power spectrum measurement, is done in the xyz-coordinates
- angular directions ≠ xyz-coordinates

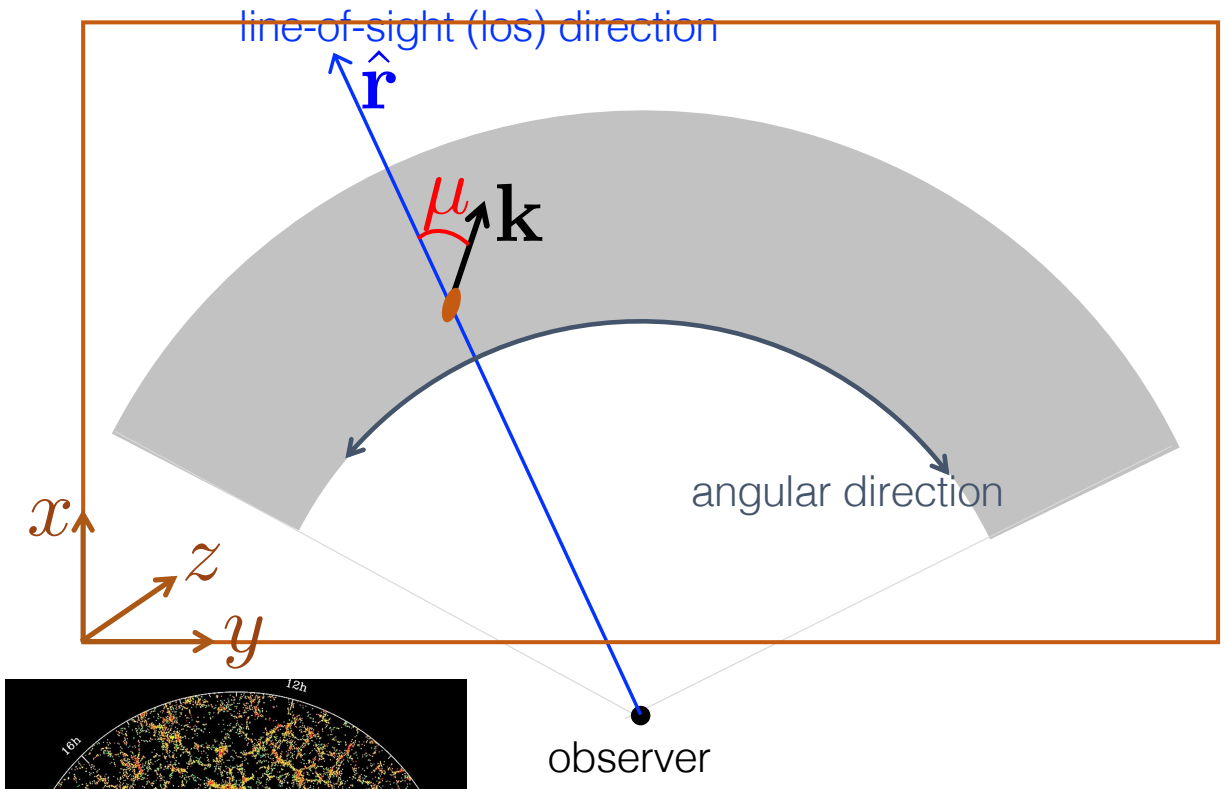
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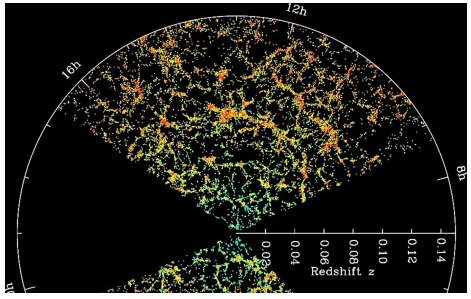




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Angular direction ≠ Fourier mode directions





- μ: cosine angle between the wavevector and the los direction

$$\mu = \cos(\hat{\mathbf{r}} \cdot \hat{\mathbf{k}})$$

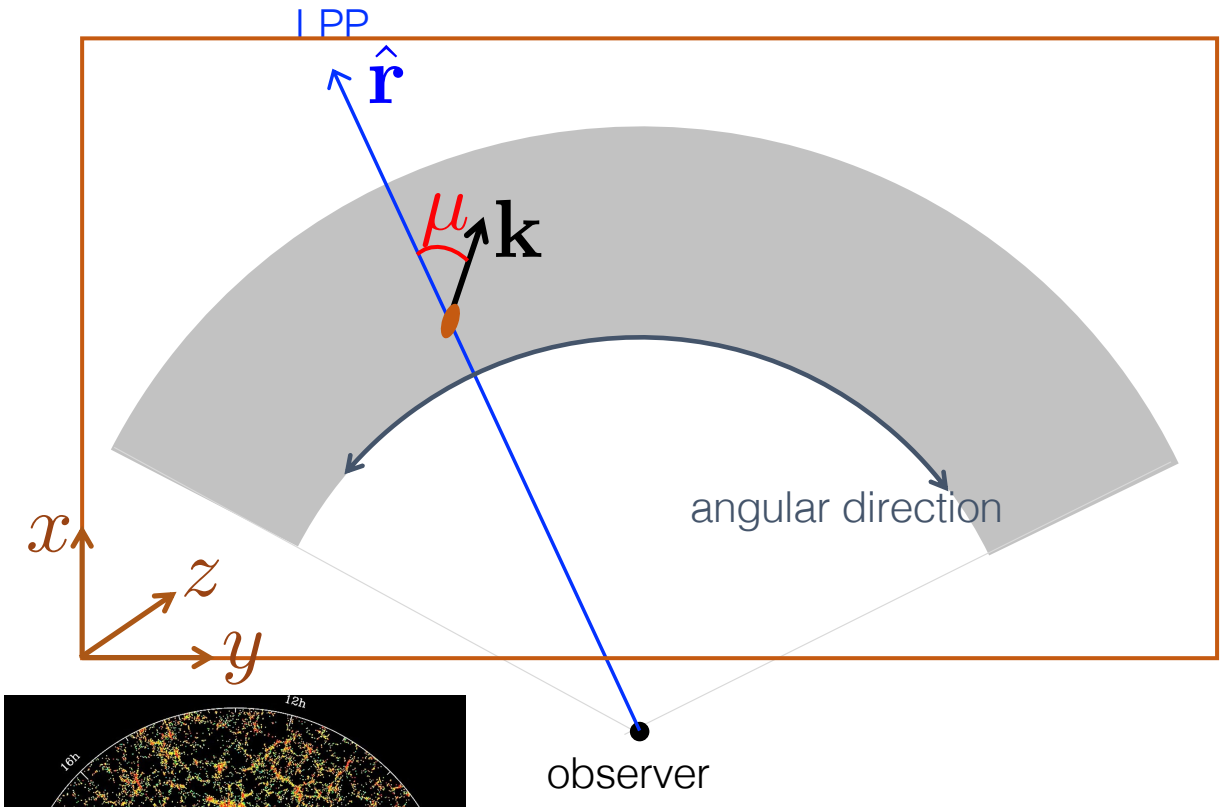
- Systematics due to stars …(angular modes) should be expressed as (also see Hand et al. 07)

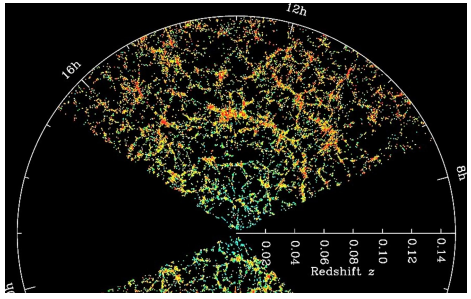
$$P_{\rm sys}(\mathbf{k})\delta_D(\mu)$$

- Difficulties lie in the fact that mu varies with galaxy position

Local plane parallel (LPP) approx. (Yamamoto estimator)

Yamamoto+06, Bianchi+15, Scoccimarro 15





- The 2D power spectrum estimated based on the LPP app.

$$P(k,\mu) = \sum_{\ell=0}^{\infty} P_\ell(k)\mathcal{L}_\ell(\mu)$$

$$P_\ell(k) = (2\ell+1)\int \frac{\mathrm{d}\Omega_{\mathbf{k}}}{4\pi}\,\delta_\ell(\mathbf{k})\delta_0(\mathbf{k})$$

where

$$\delta_\ell(\mathbf{k}) = \frac{4\pi}{2\ell+1}\sum_{m=-\ell}^{\ell} Y_{\ell m}(\hat{\mathbf{k}})\int \frac{\mathrm{d}\mathbf{r}}{V}\,\delta(\mathbf{r})Y_{\ell m}(\hat{\mathbf{r}})e^{i\mathbf{k}\cdot\mathbf{r}}$$

- This multipole-moment field can be read as

$$\delta_\ell(\mathbf{k}) \sim \sum_{i,j,\cdots}\hat{k}_i\hat{k}_j\cdots\int\frac{\mathrm{d}\mathbf{r}}{V}\,\delta(\mathbf{r})e^{i\mathbf{k}\cdot\mathbf{r}}\hat{r}_i\hat{r}_j\cdots$$

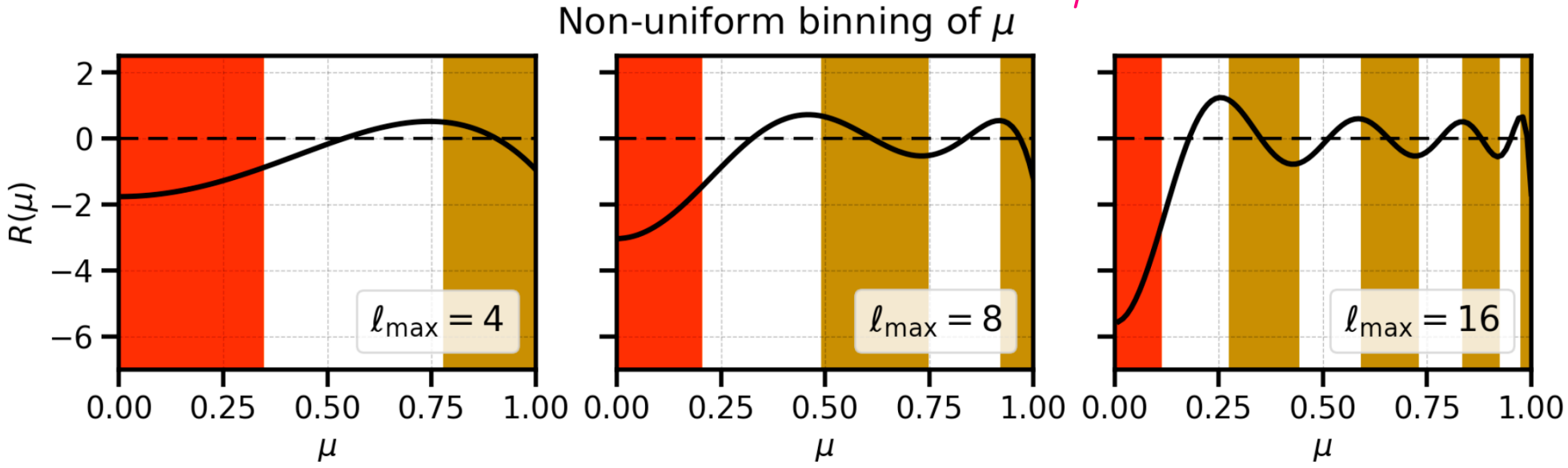
we can use FFT!

A way to mitigate the angular modes in P(k) measurement

In practice, we cannot measure the infinite-order multipole moments, but rather can measure only a finite order of multipoles

$$P_{\rm sys}(\mathbf{k})\delta_D(\mu) = \sum_{\ell=0}^{\infty} P_{{\rm sys},\ell}(k)\mathcal{L}_\ell(\mu) \simeq \sum_{\ell=0}^{\ell_{\rm max}} P_{{\rm sys},\ell}(k)\mathcal{L}_\ell(\mu)$$

$$\propto P_{\rm sys}(k)\frac{\ell_{\rm max}+1}{\mu}\mathcal{L}_{\ell_{\rm max}}(\mu=0)\mathcal{L}_{\ell_{\rm max}+1}(\mu)$$

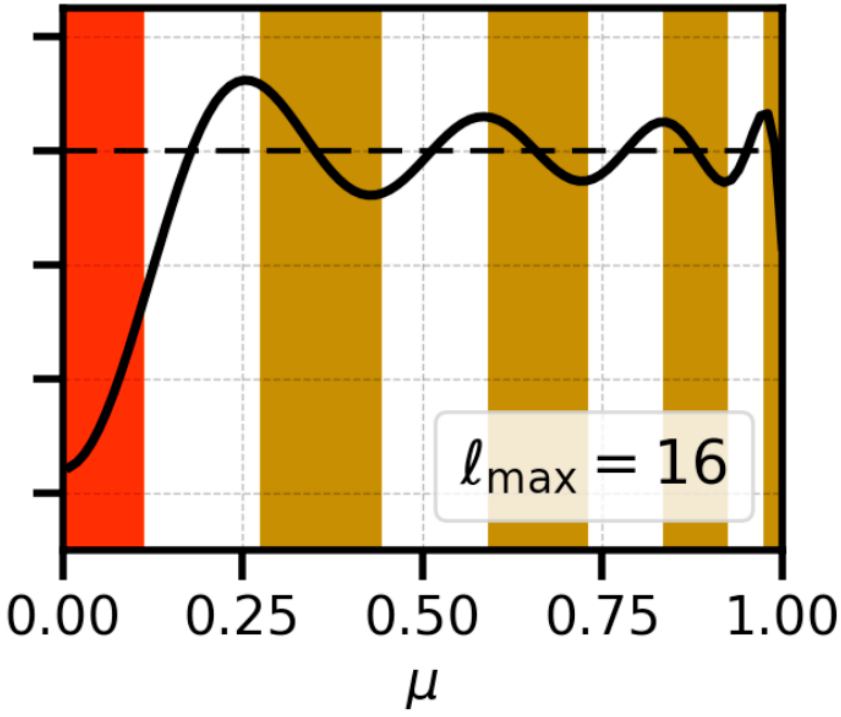


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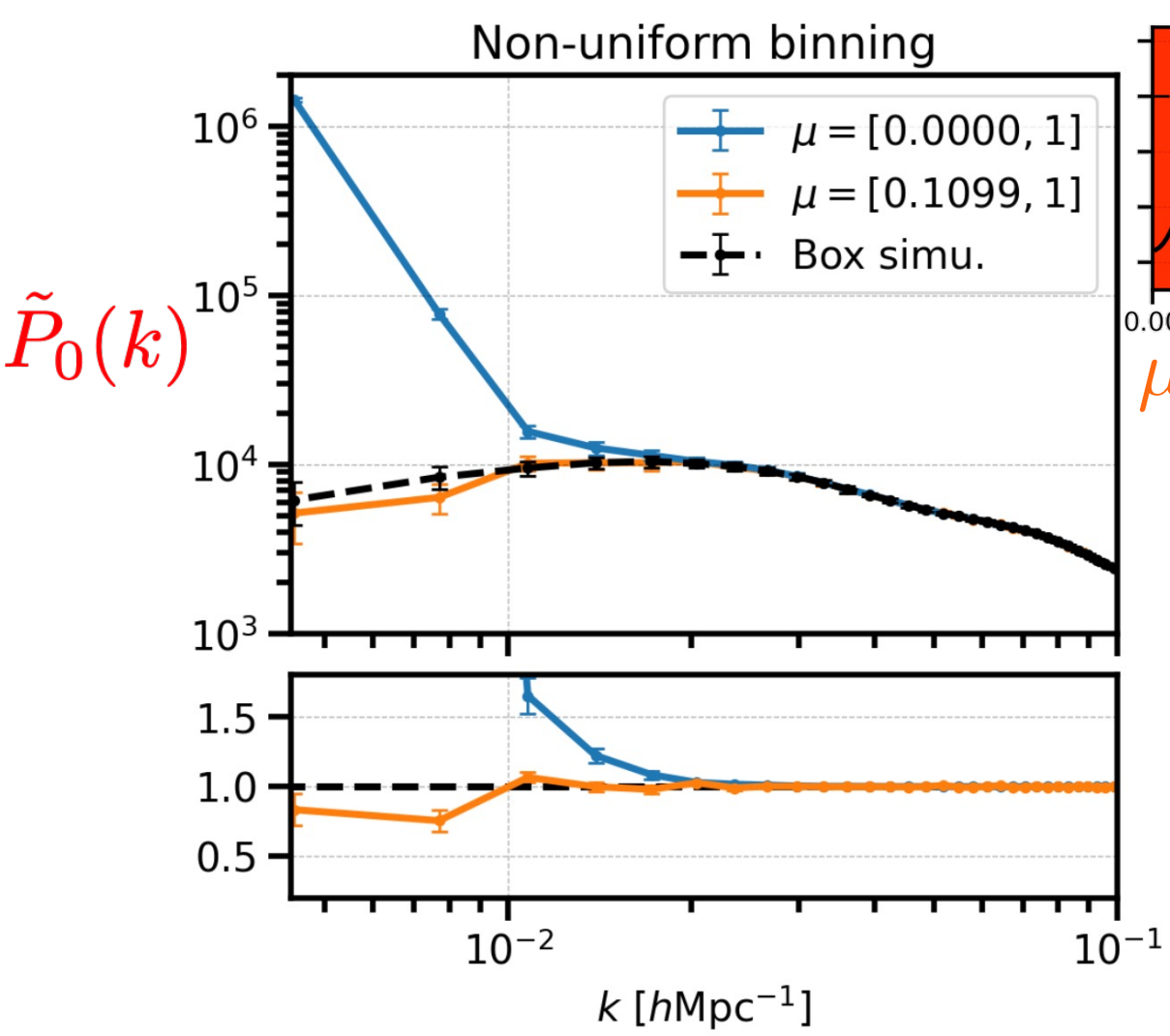
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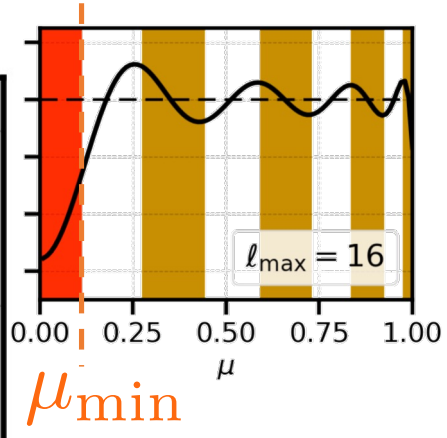
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Result: A way to mitigate the angular modes in P(k)





Nakano, MT, Kurita in prep.



Shintaro Nakano

$$P(k,\mu) = P_{\Lambda\rm CDM}(k,\mu) + P_{\rm sys}(\mathbf{k})\delta_D(\mu)$$

We can significantly reduce the contamination of the systematic errors, by using the proper mu_min for the monopole moment measurement

Next steps forward …

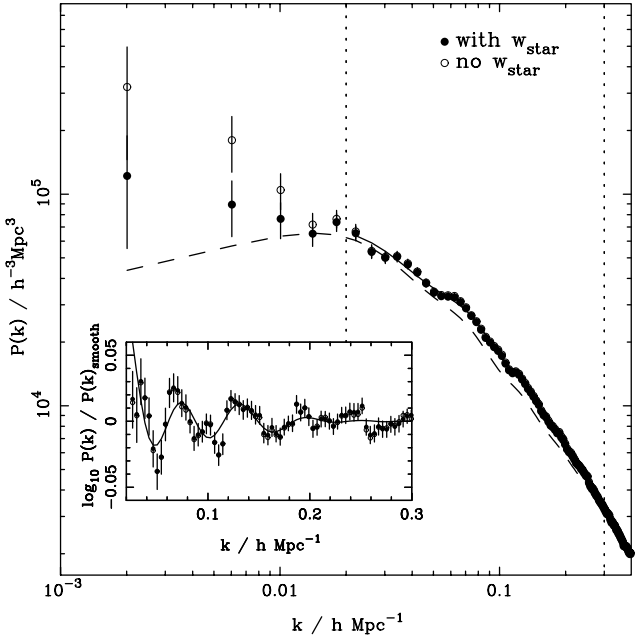
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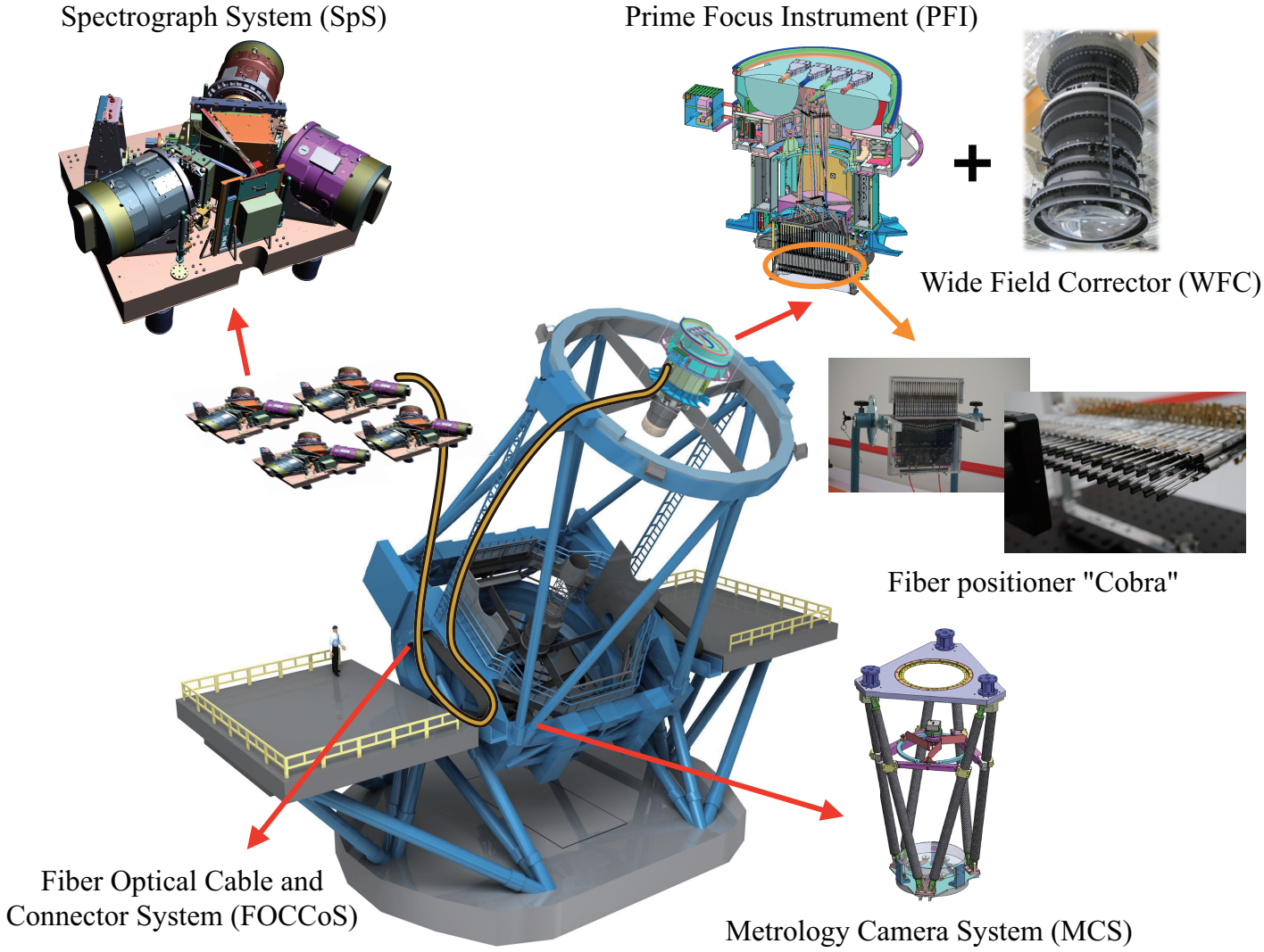
Shintaro Nakano

- Implement the survey window of the northern-cap BOSS LOWZ and CMASS distribution (dndz, masks, …)
- Apply the angular-mode mitigation method to the real BOSS data to see whether it changes the measured P_0(k) at k<0.01h/Mpc (no one has done this!)
- Include the modes at k<0.01h/Mpc to obtain improved constraints on the local PNG from the BOSS data
- Extend this method to the bispectrum, IA, ….

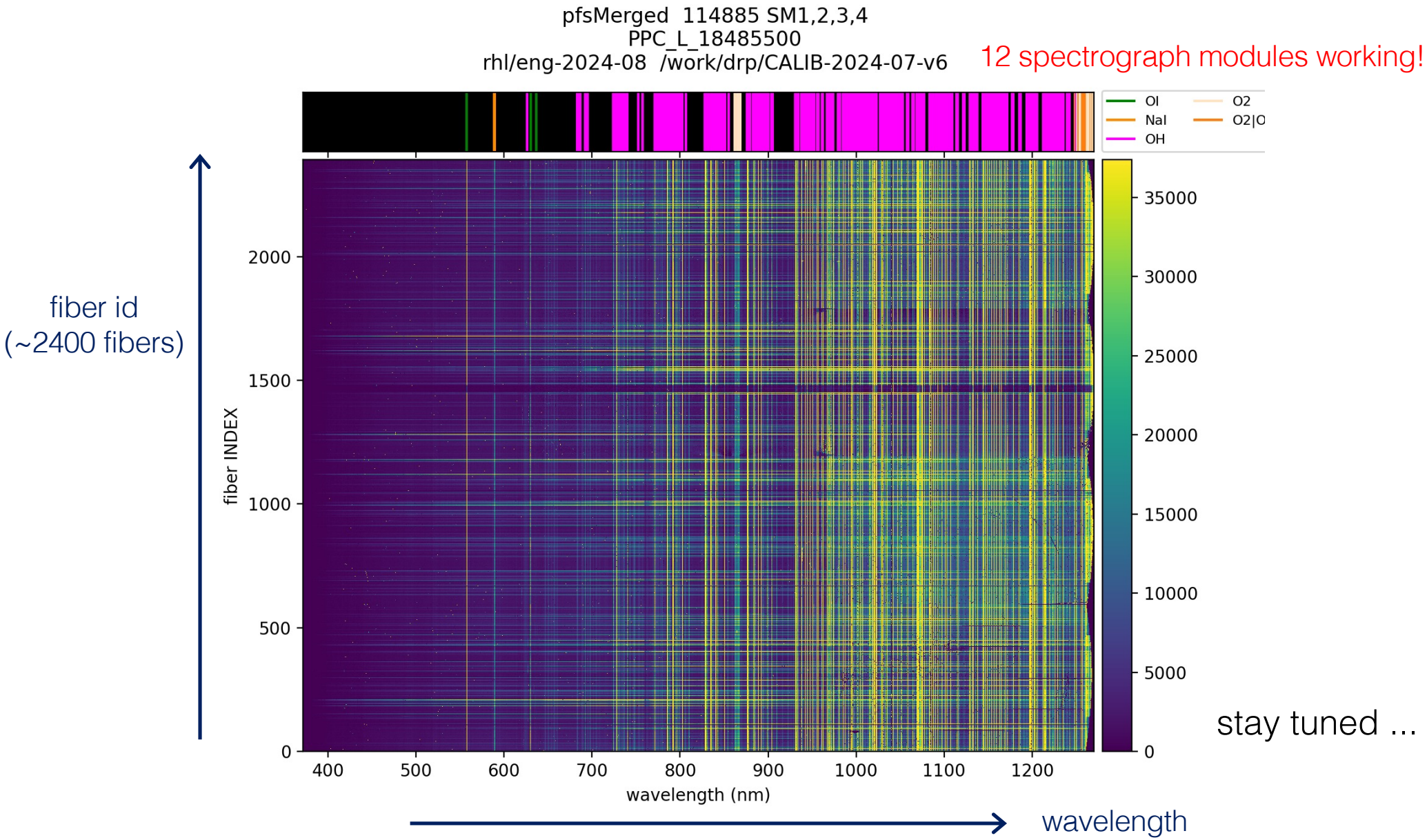
Ross+ 12



Subaru Prime Focus Spectrograph (PFS)



- Being led by Kavli IPMU (PI: Hitoshi Murayama, PM: Naoyuki Tamura, PS: MT)
- Institutes in 6 countries are involved (US, France, Taiwan, Brazil, Germany, China)
- Mentioned in several places of US Astro2020
- 2394 fibers, wide field-of-view, [0.38,1.26]nm, 8.2m collecting power
- We will start our large-scale surveys, from early 2025
- https://pfs.ipmu.jp
- PFS blog: https://pfs.ipmu.jp/blog/ja/


pfsMerged 114885 SM1,2,3,4
PPC_L_18485500
rhl/eng-2024-08 /work/drp/CALIB-2024-07-v6
12 spectrograph modules working!
OI
NaI
OH
O2
O2|O
fiber id
(~2400 fibers)
fiber INDEX
0
500
1000
1500
2000
400
500
600
700
800
900
1000
1100
1200
wavelength (nm)
35000
30000
25000
20000
15000
10000
5000
0
wavelength
stay tuned ...

summary

- Primordial non-Gaussianity is the key to the physics of the early universe (e.g. inflation), so its observational exploration is very important
- New method to mitigate the systematics due to the angular modes (stars, seeing, …)
- PFS is coming, FINALLY!!! We will start our survey program from S25A