B02 Subaru spectroscopy
status report of FY2022

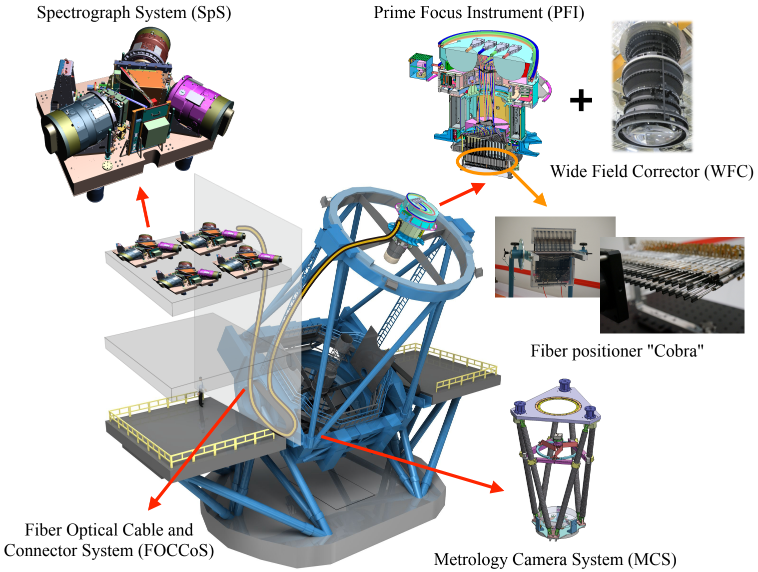
Masahiro Takada
(Kavli IPMU)

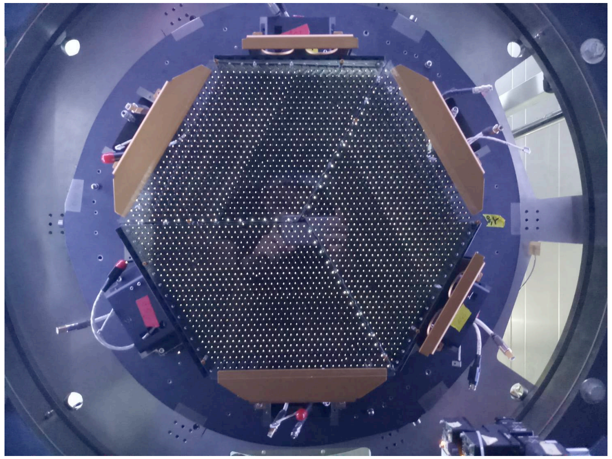
KAVLI IPMU INSTITUTE FOR THE PHYSICS AND MATHEMATICS OF THE UNIVERSE

東京大学 THE UNIVERSITY OF TOKYO

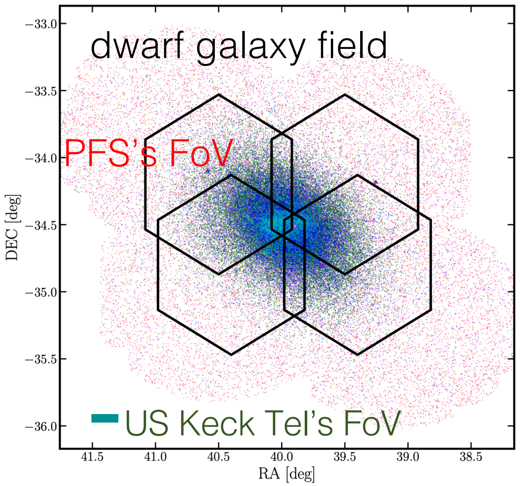
wpi

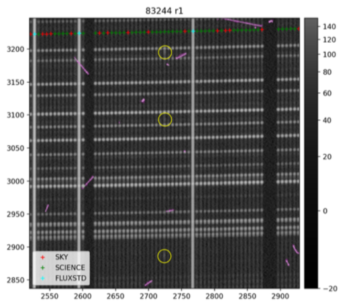
Subaru Prime Focus Spectrograph (~$100M) (see Naoyuki's talk)



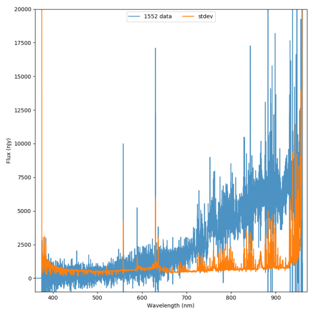


Prime Focus Instrument hosts 2394 robotic fibers on the focal plane

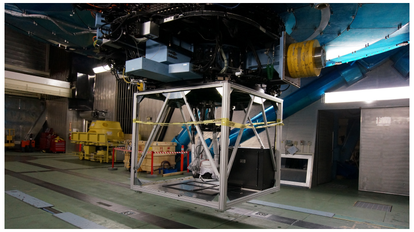




2D spectrum



1D spectrum



Metrology camera at Cassegrain focus of Subaru

Spectrograph module

imaging (galaxy shapes by HSC) + spectroscopy (distances to galaxies by PFS)

Dark matter search with Subaru

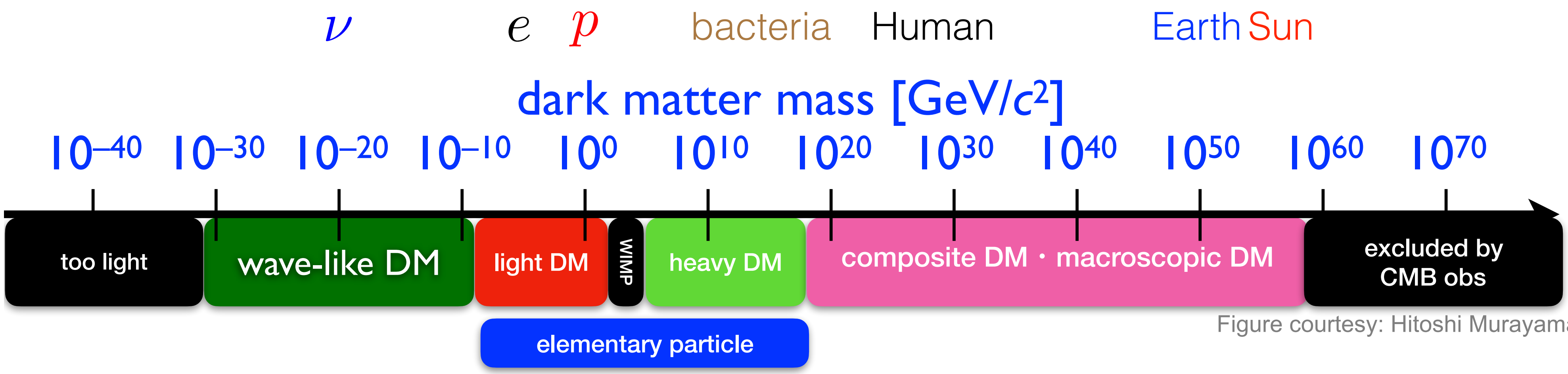


Figure courtesy: Hitoshi Murayama

Subaru spectroscopy
(axions, FDM, SIDM, WIMP; dSphs, MW streams …)
see Jowett, Ando-san, Horigome-san, Chiba-san, Hayashi-san's … talks!

Subaru microlensing
(axion stars, PBHs, …)

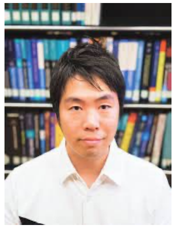
1 Subaru PFS night = ~50 Keck nights (even $10B JWST can't do it)

Team members

- Masahiro Takada (Kavli IPMU: PFS Science WG co-chair)
- Naoyuki Tamura (Kavli IPMU: PFS Project Manager/System Engineer)
- Collaborator: Kiyoto Yabe (Kavli IPMU: Survey planning coordinator)
- Collaborator: Yuki Moritani (IPMU⇒NAOJ: Commissioning observation coordinator)
- Yue Nan (Cosmology/LSST), since April 2022
- Tomomi Sunayama (Nagoya U.: PFS Cosmology WG co-chair)
- Ryuichi Takahashi (Hirosaki U.: Cosmological simulations)
- Miho Ishigaki (NAOJ: PFS Galactic Archaeology)
- Sakurako Okamoto (NAOJ: PFS Galactic Archaeology)
- New faculty members at Kavli IPMU: Collaborators, Jia Liu (neutrino mass), Elisa Ferreira (fuzzy DM)
- Collaborators: Youngsoo Park, Jingjing Shi, …
- Students: Sunao Sugiyama, Toshiki Kurita, Tian Qiu, Akira Tokiwa, Takanori Taniguchi, Ryo Terasawa, Kota Hayashi, Kanmi Nose, …
- Colleagues in PFS collaboration including Chiba-san, Hayashi-san, … colleagues at Princeton, JHU, Caltech, ASIAA, …

N.Tamura (IPMU⇒NAOJ)

Tomomi Sunayama (Arizona/Nagoya)



K. Yabe (IPMU⇒NAOJ)

Y. Moritani (IPMU⇒NAOJ)

Miho Ishigaki (NAOJ)

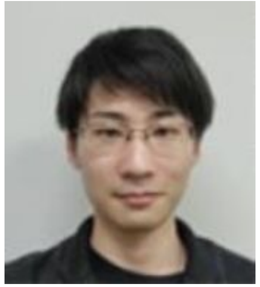
Y. Nan (Hiroshima U. ⇒ IPMU)

Sakurako Okamoto (NAOJ)

Research activities in FY2022

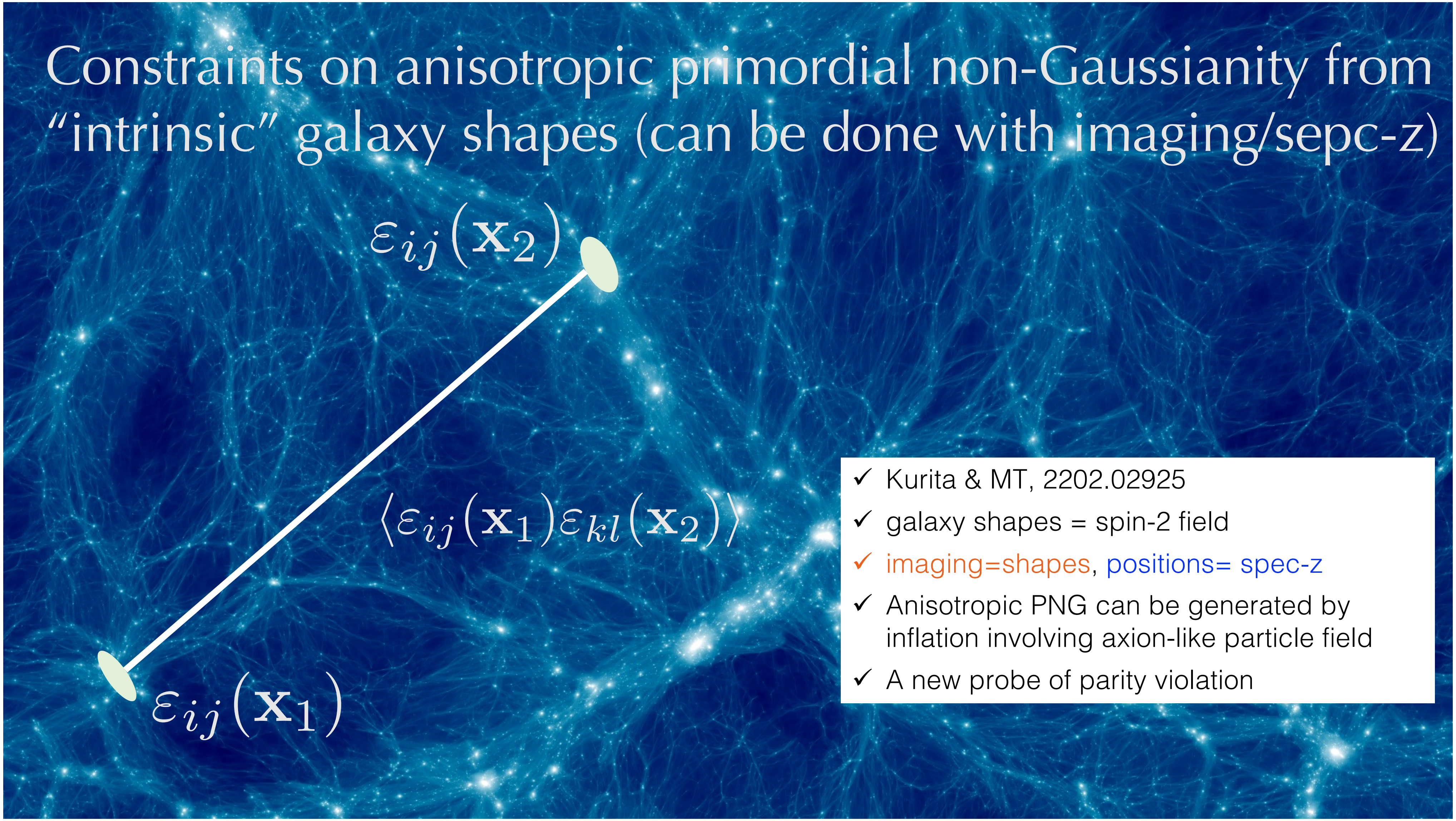
Sunao Sugiyama
(IPMU⇒ UPenn)

- PFS instrumentation ⇒ see Naoyuki's talk
- 24 publications (published ones)
  - Subaru Year 3 Hyper Suprime-Cam Cosmology papers: 5 papers, announced soon (the early April) ⇒ Sunao Sugiyama's talk, just received the excellence award for his PhD thesis from U. Tokyo (please congratulate him!). Sunao made a major role in all the 5 cosmology papers
  - Constraints on anisotropic PNG from galaxy shape correlations: Toshiki Kurita & Takada, arXiv:
- Workshop/Conference
  - Joint workshop with A02 (Kohta Murase-san's group), at Tohoku U. in May 2022
  - Observational cosmology WS, Dec 2022
  - Dark Matter conference (Kohei Hayashi & Nagisa Hiroshima), Sep 2022



Toshiki Kurita
(IPMU⇒MPA)

Constraints on anisotropic primordial non-Gaussianity from "intrinsic" galaxy shapes (can be done with imaging/sepc-z)



- ✓ Kurita & MT, 2202.02925
- ✓ galaxy shapes = spin-2 field
- ✓ imaging=shapes, positions= spec-z
- ✓ Anisotropic PNG can be generated by inflation involving axion-like particle field
- ✓ A new probe of parity violation

Separate universe picture (peak-background split)

Baldauf+ 11; Li, Hu & MT 14

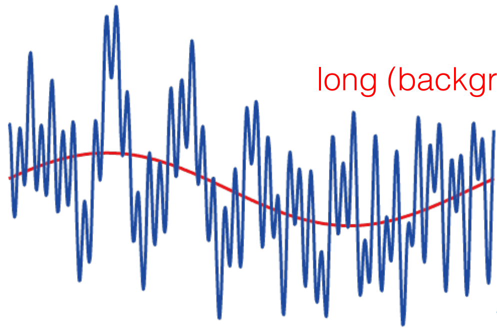
- Cosmological Newtonian metric

$$\mathrm{d}s^2 = -\left[1+2\Phi(\mathbf{x},t)\right]\mathrm{d}t^2 + a(t)^2\left[1-2\Phi(\mathbf{x},t)\right]\mathrm{d}\mathbf{x}^2$$

here $\nabla^2\Phi = 4\pi G a^2\left[\bar{\rho}_\mathrm{c}\delta_\mathrm{c} + \bar{\rho}_\mathrm{b}\delta_\mathrm{b} + \cdots\right]$

- Long- and short-wavelength mode splits

$$\Phi(\mathbf{x},t) \simeq \Phi^{(l)}(\mathbf{x},t) + \Phi^{(s)}(\mathbf{x},t)$$



- Taylor expansion …

$$\begin{aligned}
\Phi^{(l)}(\mathbf{x},t) &\simeq \Phi^{(l)}(\mathbf{x}_0,t) + \partial_i\Phi^{(l)}\Big|_{\mathbf{x}_0}(x-x_0)^i + \frac{1}{2}\,\partial_i\partial_j\Phi^{(l)}\Big|_{\mathbf{x}_0}(x-x_0)^i(x-x_0)^j + O(\partial^3\Phi) \\
&= \Phi^{(l)}(\mathbf{x}_0,t) + \partial_i\Phi^{(l)}\Big|_{\mathbf{x}_0}x^i + \frac{1}{6}\,\nabla^2\Phi^{(l)}\Big|_{\mathbf{x}_0}x^i x_i + \frac{1}{2}\left[\partial_i\partial_j - \frac{\nabla^2}{3}\delta^K_{ij}\right]\Phi^{(l)}\Big|_{\mathbf{x}_0}x^i x^j + O(\partial^3\Phi) \\
&= \Phi^{(l)}(\mathbf{x}_0,t) + \partial_i\Phi^{(l)}\Big|_{\mathbf{x}_0}x^i + \underbrace{\frac{1}{6}\,\nabla^2\Phi^{(l)}}_{\text{isotropic}}\Big|_{\mathbf{x}_0}r^2 + \frac{1}{2}\underbrace{\left[\partial_i\partial_j - \frac{\nabla^2}{3}\delta^K_{ij}\right]\Phi^{(l)}\Big|_{\mathbf{x}_0}}_{\text{trace-less anisotropic (tide)}}x^i x^j + O(\partial^3\Phi)
\end{aligned}$$

Separate universe picture (cont'd)

Baldauf+ 11; Li, Hu & MT 14

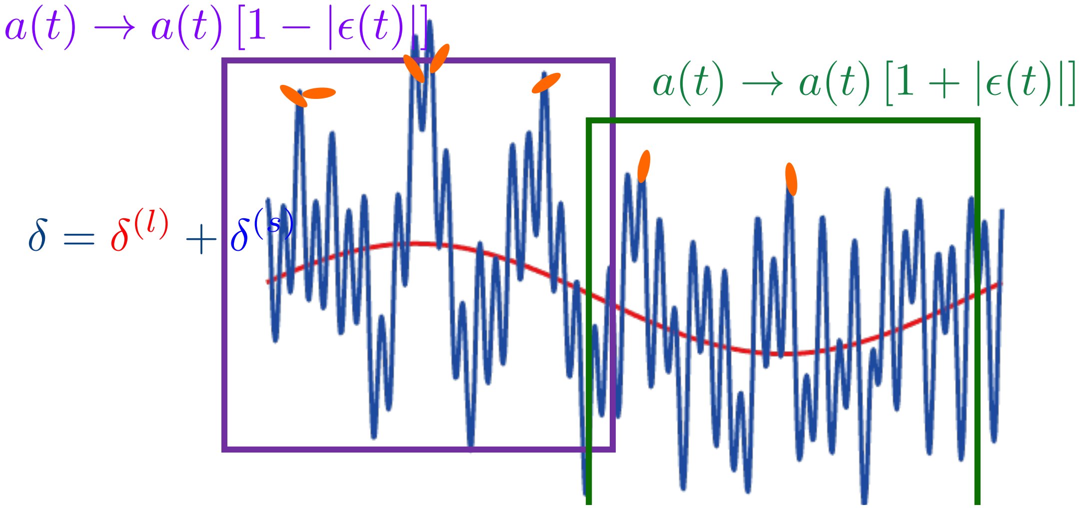
- The effect of isotropic long-wavelength mode

$$\mathrm{d}\ell^2 = a(t)^2 \left[1 - \frac{1}{3}\nabla^2\Phi^{(l)}\Big|_{\mathbf{x}_0} r^2 - 2\Phi^{(s)}(\mathbf{x},t)\right] \mathrm{d}\mathbf{x}^2$$

$$\simeq a(t)^2 \left[1 - \frac{1}{3}\nabla^2\Phi^{(l)}\Big|_{\mathbf{x}_0} r^2\right]\left[1 - 2\Phi^{(s)}(\mathbf{x},t)\right] \mathrm{d}\mathbf{x}^2$$

$$\mathrm{d}\ell^2_{\mathrm{FRW}} = a(t)^2 \left[\frac{\mathrm{d}r^2}{1 - Kr^2} + \mathrm{d}\Omega^2\right]$$

- The effect can be absorbed into the change of scale factor



Galaxy bias for LCDM

$$\delta_g = b_g \delta_{\mathrm{m}}^{(l)}$$

$$b_g \sim \frac{\partial \ln n_g}{\partial \delta^{(l)}} \sim \frac{\partial \ln n_g}{\partial \Omega_K}$$

Anisotropic separate universe picture

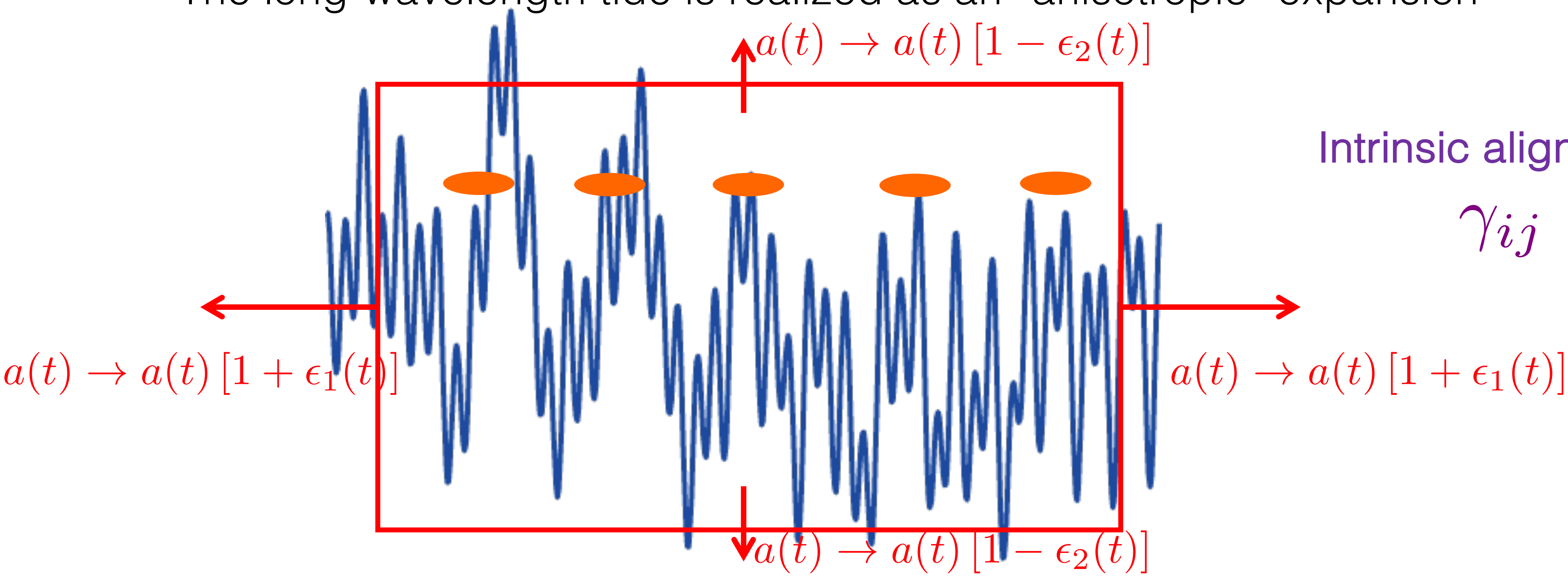
- The effect of anisotropic long-wavelength mode (tide)

Ip & Schmidt 17; Akitsu & MT 17; Schmidt+18; Masaki+20

$$\tau_{ij} \equiv \left[\partial_i\partial_j - \frac{\delta^K_{ij}}{3}\nabla^2\right]\Phi^{(l)}\Big|_{\mathbf{x}_0}$$

$$\begin{aligned} d\ell^2 &= a(t)^2\left[1-\tau_{ij}x^ix^j - 2\Phi^{(s)}(\mathbf{x},t)\right]d\mathbf{x}^2 \\ &\simeq a(t)^2\left[1-\tau_{ij}x^ix^j\right]\left[1-2\Phi^{(s)}(\mathbf{x},t)\right]d\mathbf{x}^2 \end{aligned}$$

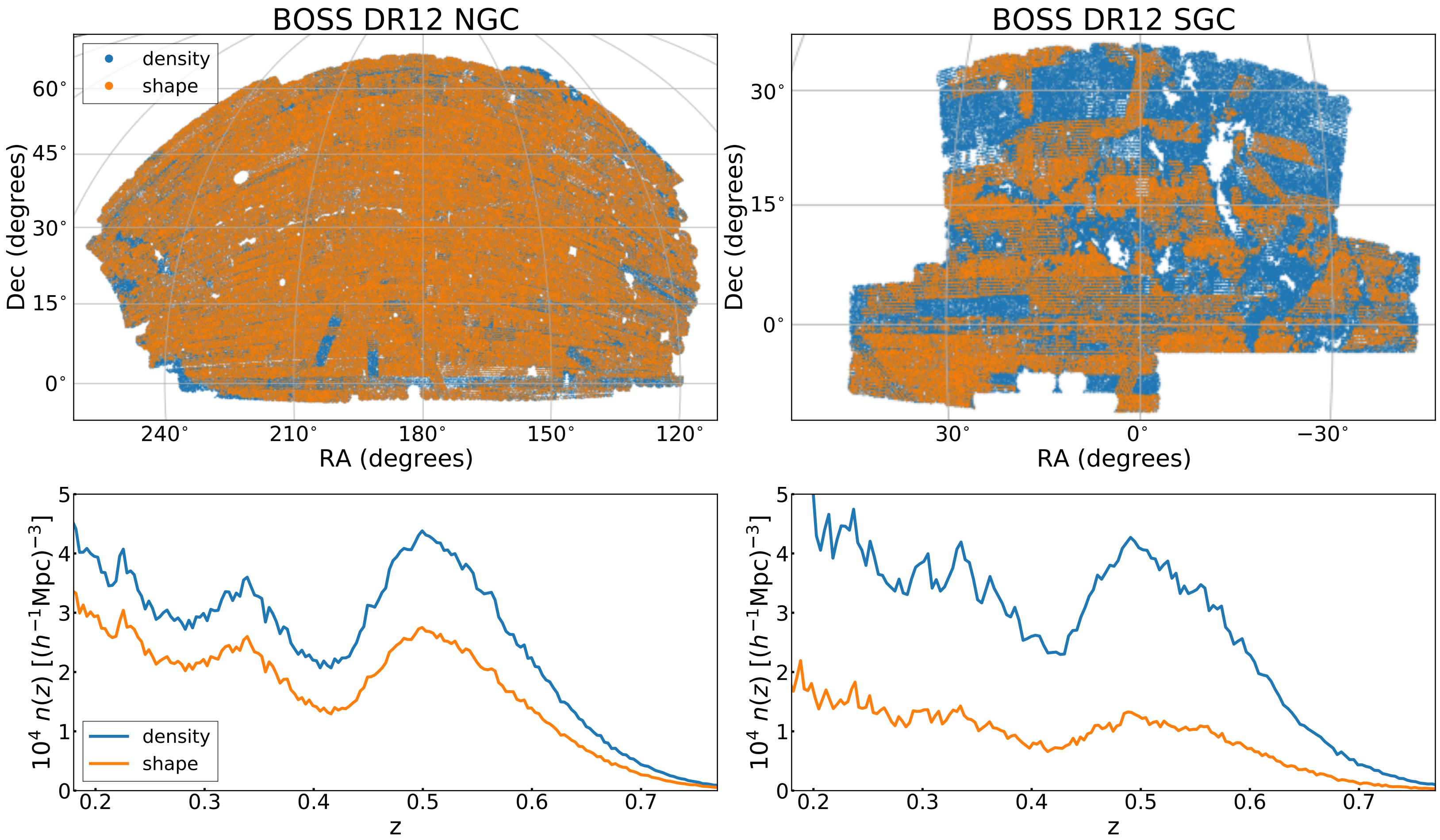
- The long-wavelength tide is realized as an “anisotropic” expansion



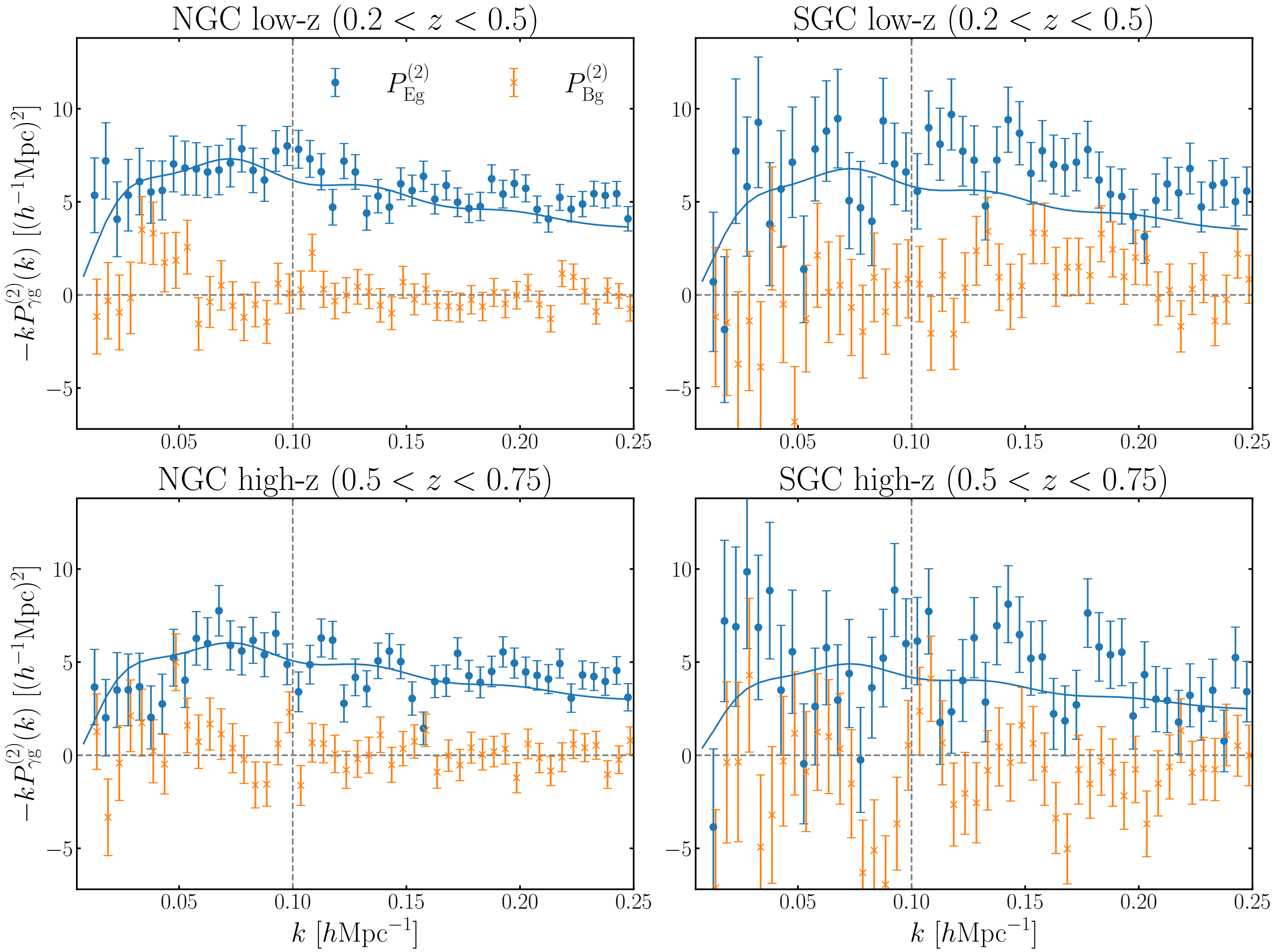
Intrinsic alignments

$$\gamma_{ij} \sim b_K \tau^{(l)}_{ij}$$

Kurita & MT: IA measurements from SDSS



First measurements of 3D IA power spectrum



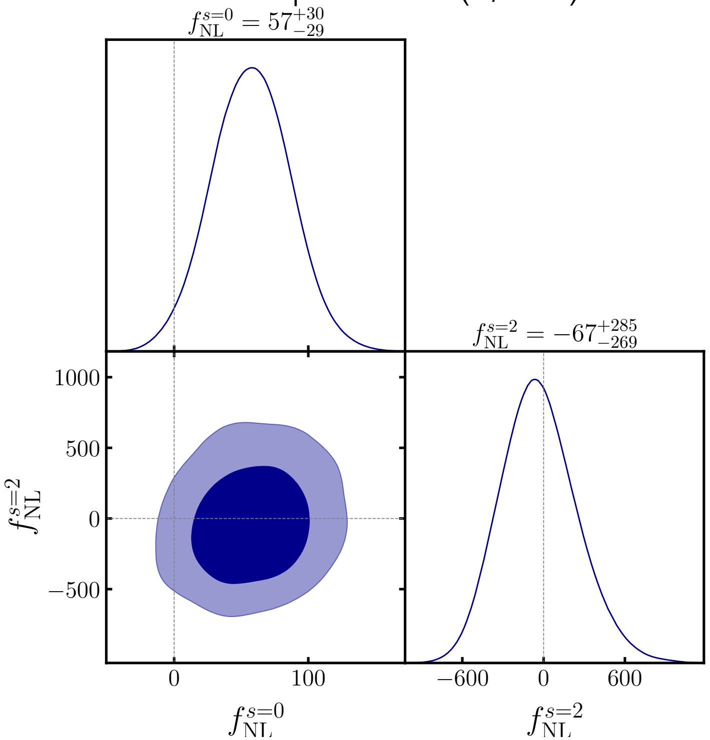
Isotropic and anisotropic primordial non-Gaussianity

Dalal+08

$$\Phi^{(l)} = \phi + f_{\rm NL}^{s=0}(\phi^2 - \langle \phi^2 \rangle)$$

$$\Phi^{(l)} = \phi + \frac{2}{3}\left[(\psi_{ij})^2 - \langle (\psi_{ij})^2 \rangle\right] \qquad \psi_{ij} \equiv \left(\frac{\partial_i \partial_j}{\partial^2} - \frac{\delta^K_{ij}}{3}\right)\phi$$

This causes a "scale-dependent" (1/k^2) bias of the number or IA fields of galaxies on very large scale



The first constraint on anisotropic PNG from galaxy surveys

So many things can be done (test of parity-violation, ….)

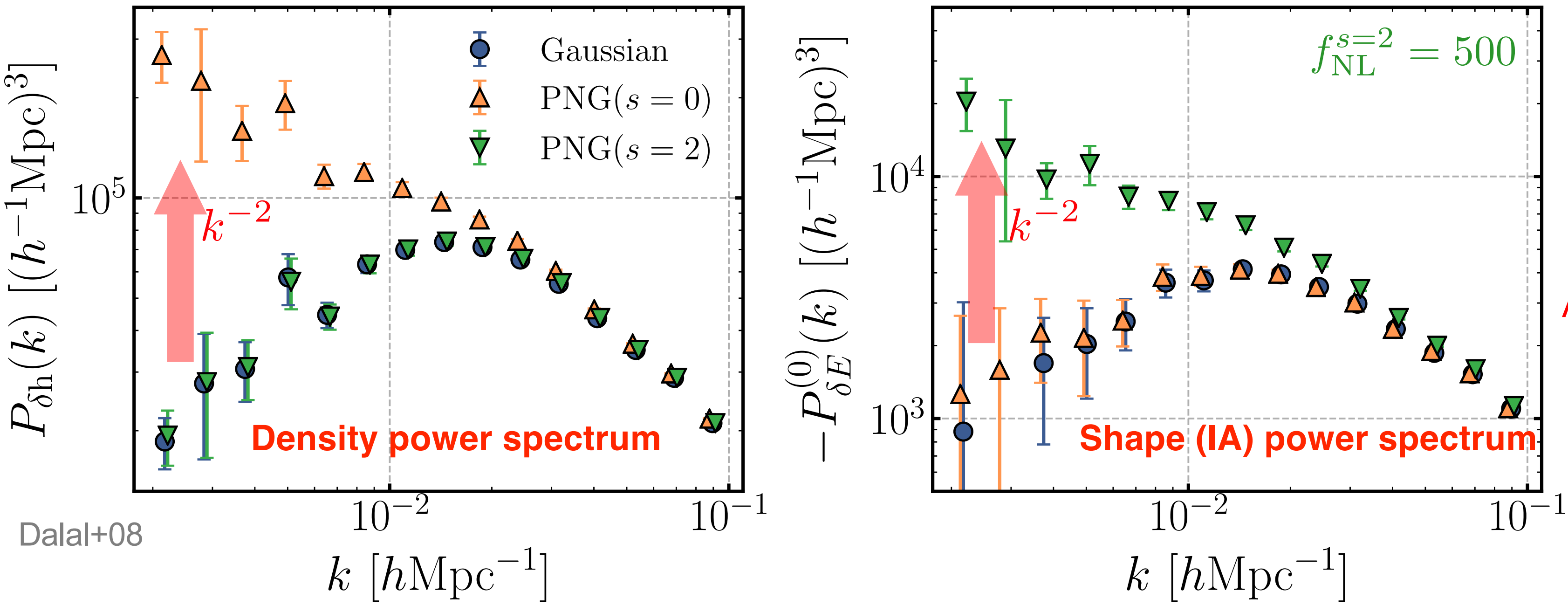
Kurita & MT 23

IA: a new probe of anisotropic PNG

- Tests of different types of primordial non-Gaussianity (ΛCDM predicts f_NL<1)

$$\zeta^{\rm NG}(\mathbf{x}) = \zeta(\mathbf{x}) + f_{\rm NL}\left[\zeta(\mathbf{x})^2 - \langle\zeta^2\rangle\right]$$

$$\zeta^{\rm NG}(\mathbf{x}) = \zeta(\mathbf{x}) + f_{\rm NL}^{s=2}\left[(\psi_{ij})^2 - \langle(\psi_{ij})^2\rangle\right] \qquad \psi_{ij}(\mathbf{x}) \equiv \nabla^{-2}\left(\partial_i\partial_j - \frac{\delta^K_{ij}}{3}\nabla^2\right)\zeta$$



Akitsu, Kurita+21