D01:
Ultimate Physics Analysis
Summary of Achievements
2015–2020

Eiichiro Komatsu
(Max-Planck-Institut für Astrophysik / Kavli IPMU)
"*Cosmic Acceleration*" Symposium, Kavli IPMU
February 19, 2020

Goals of the D01 team [1]

- To develop and provide necessary analysis tools for the “B-teams” (experiments) of the proposal
  - B01: **CMB** (Simons Array, LiteBIRD)
  - B02: **Weak gravitational lensing survey** (HSC)
  - B03: **Galaxy redshift survey** (PFS)
  - B04: **Redshift drift** (TMT)

Science Goals

- The main scientific motivations for the “ultimate physics analysis” are three-folds:

B02,03,04 Falsify the ΛCDM model by **ruling out Λ**

B01,02,03 Detect, or rule out, the inverted mass hierarchy of the neutrino mass by **measuring $\sum m_\nu < 0.1$ eV** [95% CL]

B01 Find definitive evidence for inflation by **measuring primordial gravitational waves in the CMB**

「宇宙の加速膨張」：領域代表　村山　斉
領域事務　片山伸彦

[X00]総括班 村山 (IPMU)	[A01]Inflation 佐々木 (京都)	[A02]構造と揺らぎ 高橋 (東北)	[A02]dark energy 杉山 (名古屋)
[B01]CMB偏光 羽澄 (KEK)	$\delta\rho/\rho$, r, n_s 直接検証	CMB lensing isocurv, m_ν	cosm. params CMB lensing
[B02]imaging 宮崎 (NAOJ)	b(k)測定→ $P_{primord}(k)$	weak lensing m_ν	weak lensing SNe-Ia, γ
[B03]spectroscopy 高田 (IPMU)	*primord. NG*, n_s, α_s, Ω_k	dSph, isocurv $P(k)$, m_ν	BAO $\Omega_\Lambda(z)$, γ
[B04]将来計画 臼田 (NAOJ)	varying α	Lyman α	加速直接測定
[C01]究極理論 大栗 (Caltech/IPMU)	mod. grav $>M_{Pl}$? BD?	non-Std DM	models mod. grav.

[D01]データ解析班　小松 (MPA/IPMU)

Summary of Achievements

- Over the last 4.5 years of the grant period, we have made fundamental contributions to the progress of B01, B02, B03, and B04

  - **Many of them were not possible without this grant. We should make sure to let the reviewers know this!**

Requests to the coordinators of B0X

- *In the final report,* ***please include the description of the D01 achievements relevant to your group***

- In this way, we can communicate efficiently to the reviewers that the cross-experimental D01 activities have achieved the goal

B01: **CMB**

- New microwave sky simulator "**GM100**"
- New foreground removal method "**Delta-map Method**"
- New way of calibrating miscalibrated polarisation angle of detectors
  - ***Simultaneous*** determination of miscalibrated angles and the cosmic birefringence
- "**Power spectrum reconstructor**" for the tensor power spectrum from CMB B-mode polarisation

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Gave a talk

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PTEP

Prog. Theor. Exp. Phys. **2019**, 033E01 (30 pages)
DOI: 10.1093/ptep/ptz009

Delta-map method of removing CMB foregrounds with spatially varying spectra

D01xB01

Kiyotomo Ichiki[1,2,*], Hiroaki Kanai[3], Nobuhiko Katayama[4] Eiichiro Komatsu[4,5]

$$-2\ln P(\bar{p}^{I},\vec{s}_f^{\,\mathrm{ML}},\boldsymbol{S}|\vec{m}) = \vec{m}^{\mathrm{T}}\left(\boldsymbol{S}^{\mathrm{CMB}}+\boldsymbol{N}\right)^{-1}\vec{m}$$
$$-\left[\tilde{\boldsymbol{D}}^{\mathrm{T}}(\boldsymbol{S}^{\mathrm{CMB}}+\boldsymbol{N})^{-1}\vec{m}\right]^{\mathrm{T}}\left[\tilde{\boldsymbol{D}}^{\mathrm{T}}(\boldsymbol{S}^{\mathrm{CMB}}+\boldsymbol{N})^{-1}\tilde{\boldsymbol{D}}\right]^{-1}\tilde{\boldsymbol{D}}^{\mathrm{T}}(\boldsymbol{S}^{\mathrm{CMB}}+\boldsymbol{N})^{-1}\vec{m}$$
$$+\ln\left|2\pi(\boldsymbol{S}^{\mathrm{CMB}}+\boldsymbol{N})\right| - 2\ln P(\vec{s}_f^{\,\mathrm{ML}},\boldsymbol{S}^{f}) + \text{constant}. \qquad (60)$$

- New foreground removal method "**Delta-map Method**"
  - Accounting for spatially-varying SED of foregrounds is considered as the most important issue in the field

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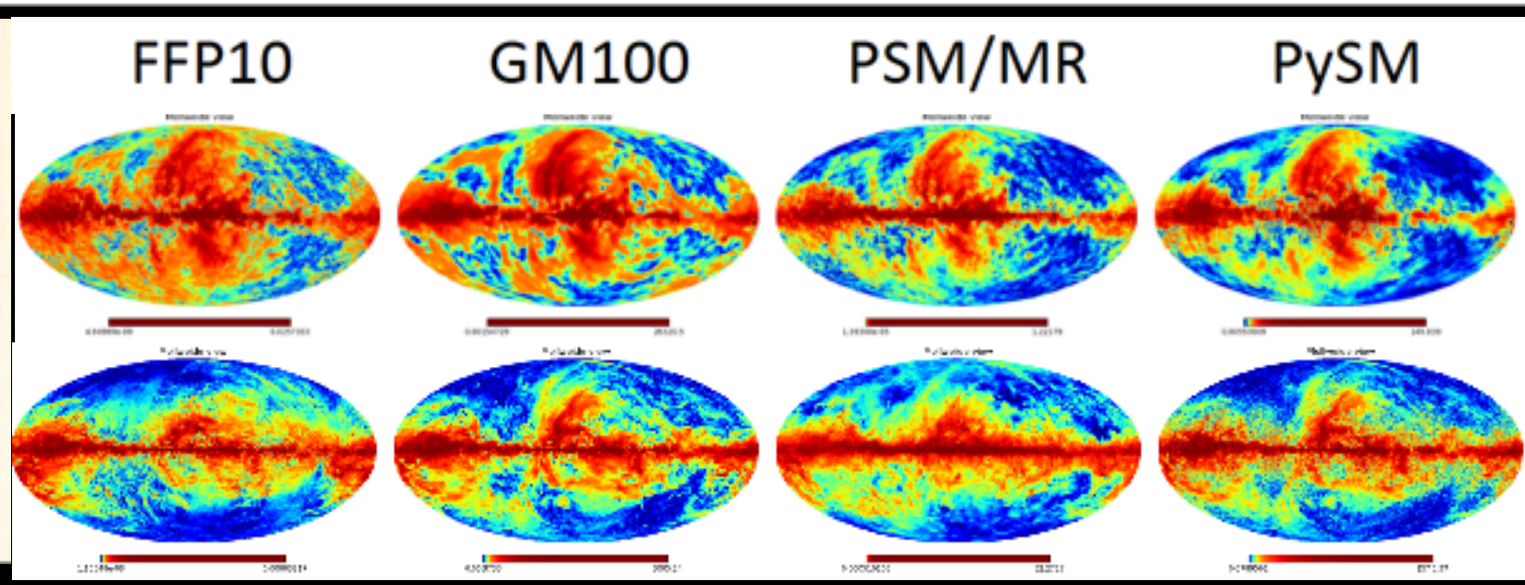
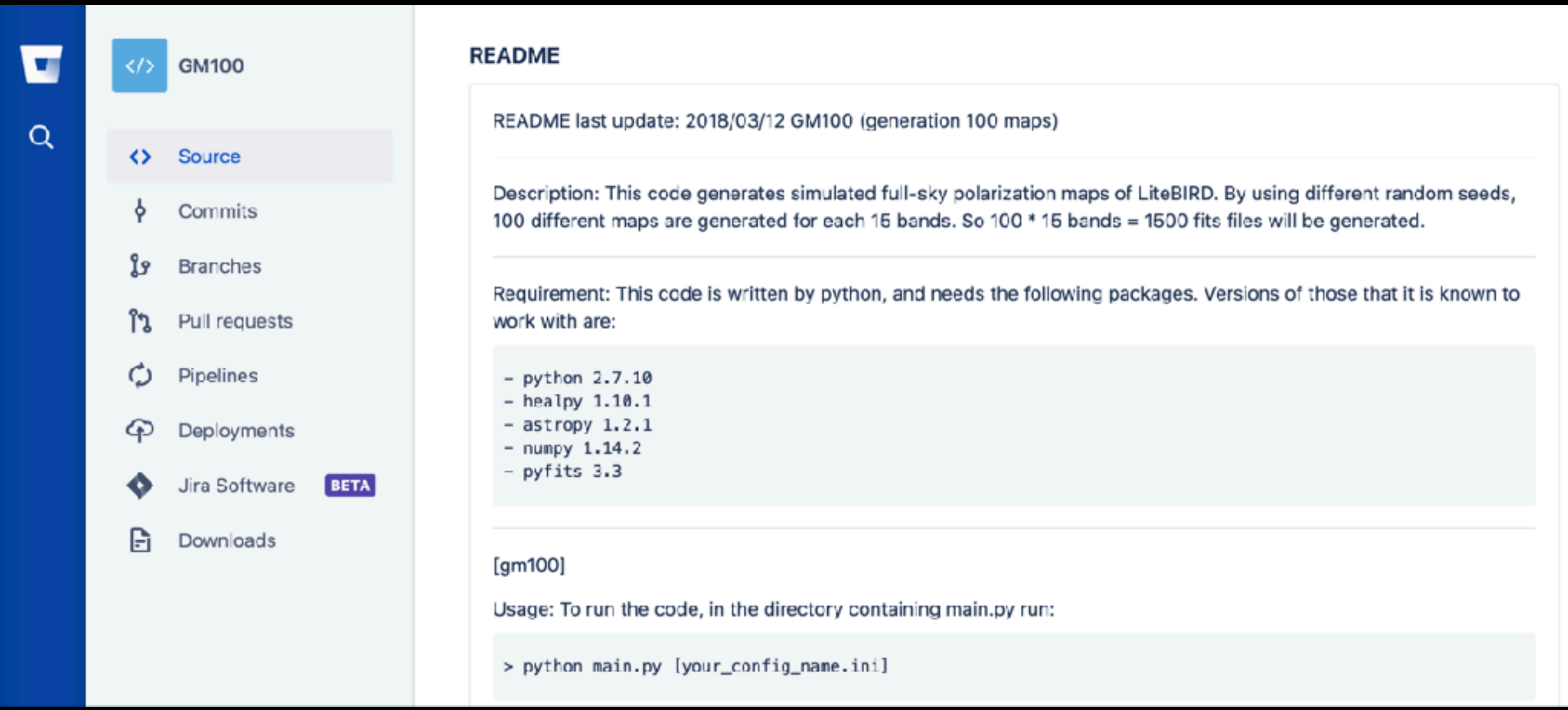


- New microwave sky simulator "**GM100**"
  - This sky model simulation played the fundamental role in this paper

GM100 in bitbucket



PTEP

Prog. Theor. Exp. Phys. **2019**, 083E02 (13 pages)
DOI: 10.1093/ptep/ptz079

Simultaneous determination of the cosmic birefringence and miscalibrated polarization angles from CMB experiments D01xB01

Yuto Minami[1,*], Hiroki Ochi[2], Kiyotomo Ichiki[3,4], Nobuhiko Katayama[5], Eiichiro Komatsu[5,6], and Tomotake Matsumura[5]

- **Game-changing results!**
  - Foreground is not an issue for the angle calibration using the EB correlation
  - We can determine simultaneously the angle miscalibration and the intrinsic EB

PHYSICAL REVIEW D
covering particles, fields, gravitation, and cosmology

Highlights Recent Accepted Authors Referees Search Press About

Reconstruction of primordial tensor power spectra from B-mode polarization of the cosmic microwave background

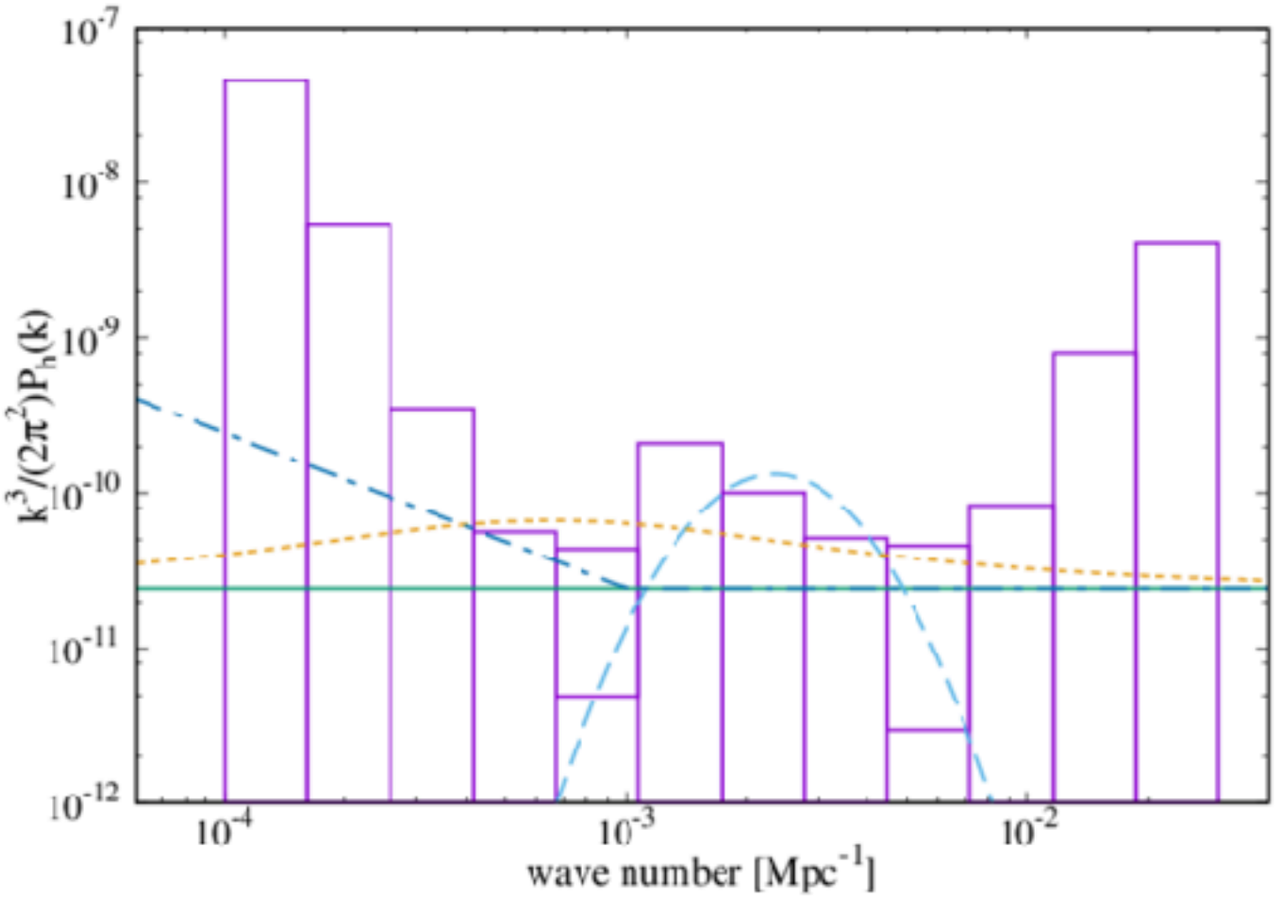
Takashi Hiramatsu, Eiichiro Komatsu, Masashi Hazumi, and Misao Sasaki
Phys. Rev. D **97**, 123511 – Published 11 June 2018

A01xB01xD01

Q: How can we distinguish between different inflation models using the B-mode polarisation power spectrum?

A: Reconstruct the underlying tensor power spectrum!

Web tool: Tensor Power Spectrum Reconstructor



MAKE PLOT

Basic | Drawing | Built-in models | Custom models

Basic parameters

Error-bar type	(F^-1)_ll	
Tensor-to-scalar ratio	0.01	
Spectral index	0.0	
bin type	log	
k_{min}	0.0001	Mpc^{-1}
k_{max}	0.03	Mpc^{-1}
Number of bins	12	
Noise level	1.0	μK·arcmin
Beam size	30	arcmin
l_{max}	1000	$l_{max} \leq 1000$
Delensing factor λ	1.0	denominator of $\Gamma_{ij} \supset \lambda C_l^{lens}$
With cosmic variance ?	yes	

NOTE : Hovering over parameter names shows pop-up information on each parameter.

Fisher & covariance matrices

	χ^2	σ^2	PTE
fiducial	2.826e+2	4.573e+0	2.056e-53
SU(2)-axion	1.429e+2	8.019e+0	1.547e-24
Massive	1.086e+2	7.099e+0	1.128e-17
Red-tilted	1.618e+1	5.494e-1	1.832e-1

PTE = Probability to exceed, given as 1-F(χ) with F(χ) being the cumulative chi-squared distribution function.

JAXA

+ participations from USA, Canada, Europe

LiteBIRD 2028–

Selected!

May 21: JAXA has chosen LiteBIRD as the strategic large-class mission.

The D01 activity played a major role

B03: **Galaxy Redshift Survey**

- Work horse: "**lognormal_galaxies**" simulator
- **The D01 activity has been absolutely essential for the preparation of the cosmology program of the PFS project**

- **Ryu Makiya**, appointed by this grant, became one of the leaders in formulating the science case and the observing proposal of the PFS project

Journal of Cosmology and Astroparticle Physics
An IOP and SISSA journal

Generating log-normal mock catalog of galaxies in redshift space

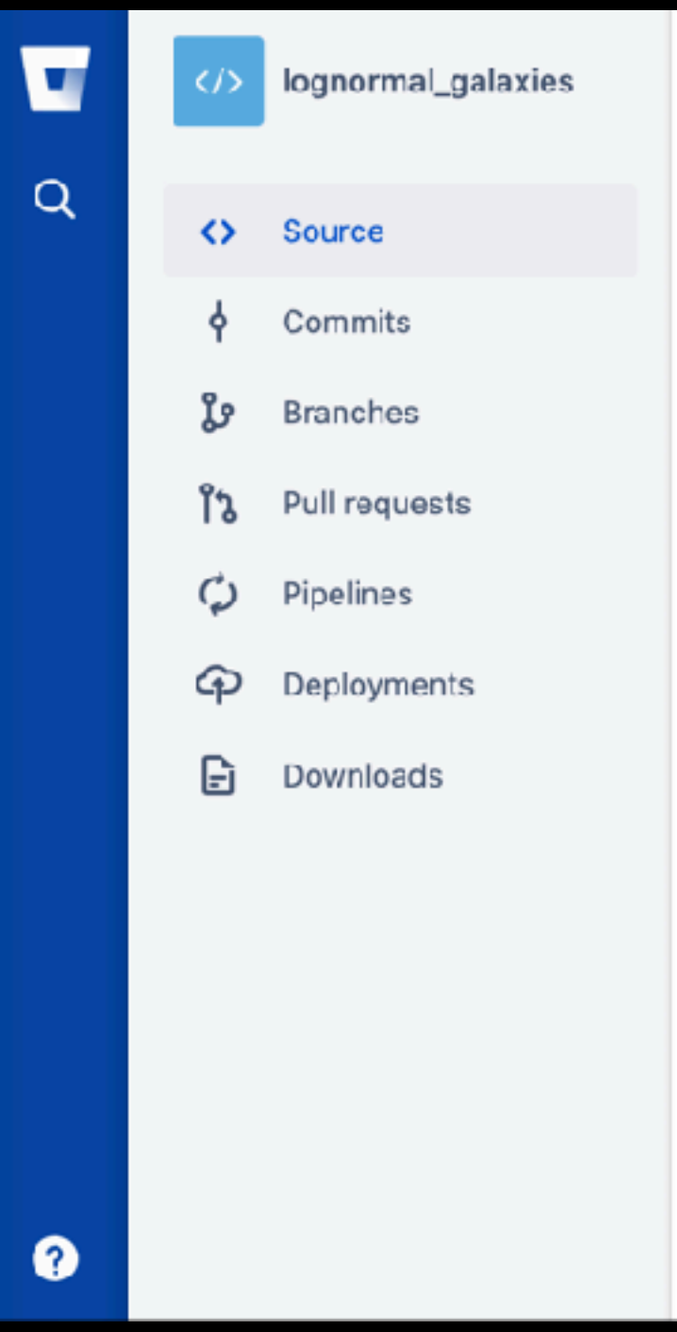
JCAP10(2017)003

Aniket Agrawal,[a] Ryu Makiya,[a,b] Chi-Ting Chiang,[c]
Donghui Jeong,[d,e] Shun Saito[a] and Eiichiro Komatsu[a,b]

- Fast and reasonably accurate algorithm to generate the distribution of galaxies

- **Innovation:** First time to include **peculiar velocities.** We can generate galaxies in redshift space

lognormal_galaxies in bitbucket



README.md

Log-normal galaxies

Codes for generating log-normal realisations of galaxies in redshift-space, and computing the monopole, quadrupole, and hexadecapole power spectra.

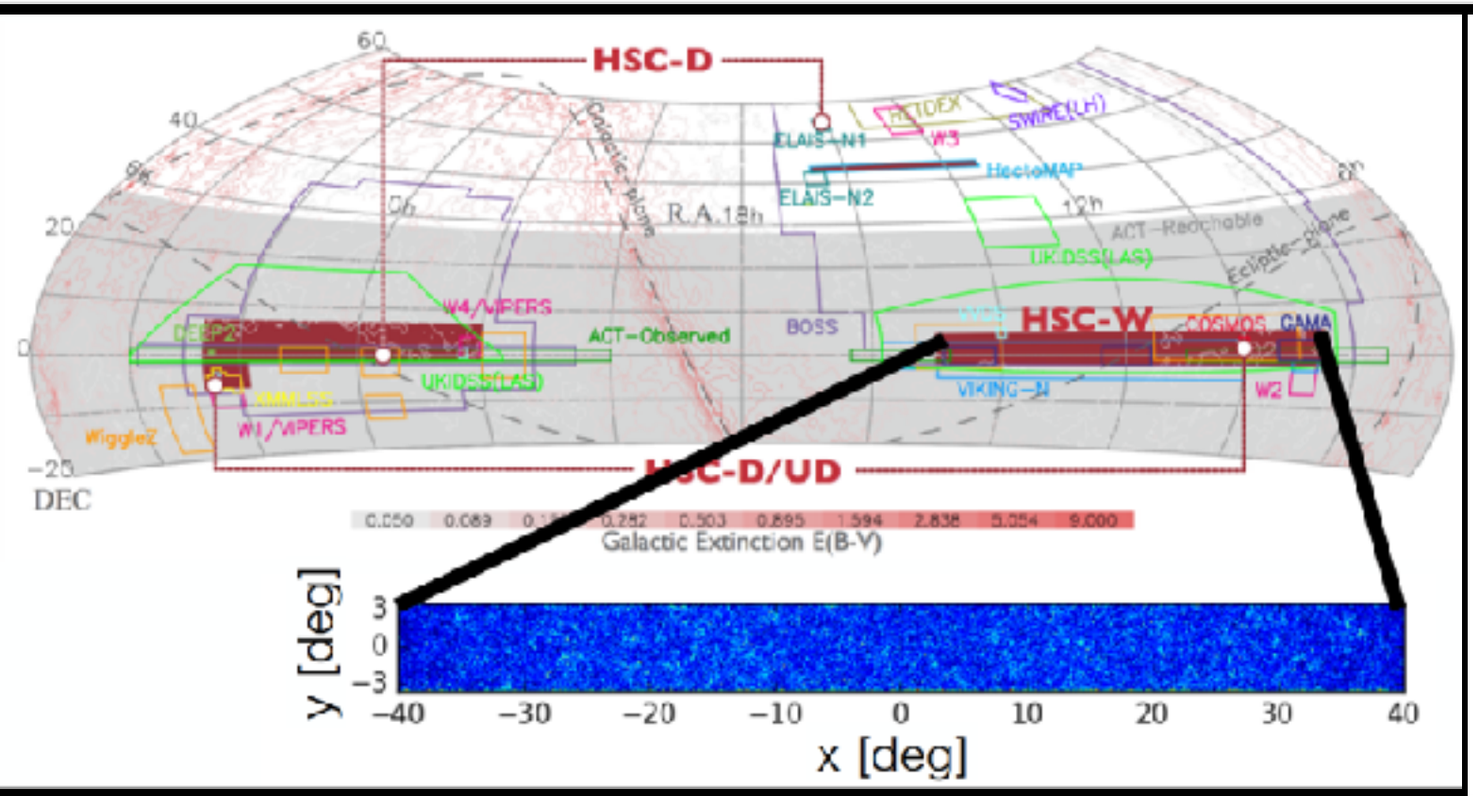
Reference: A. Agrawal, R. Makiya, C.-T. Chiang, D. Jeong, S. Saito, and E. Komatsu, arXiv:1706.09195

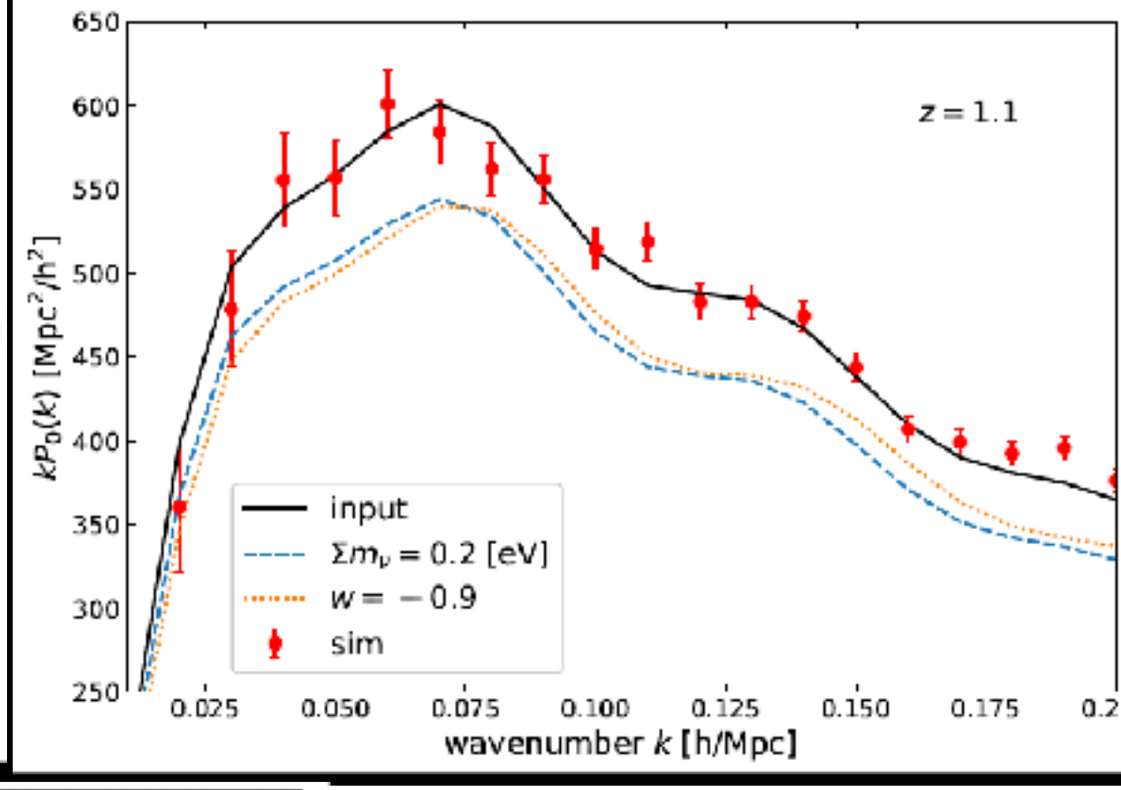
History

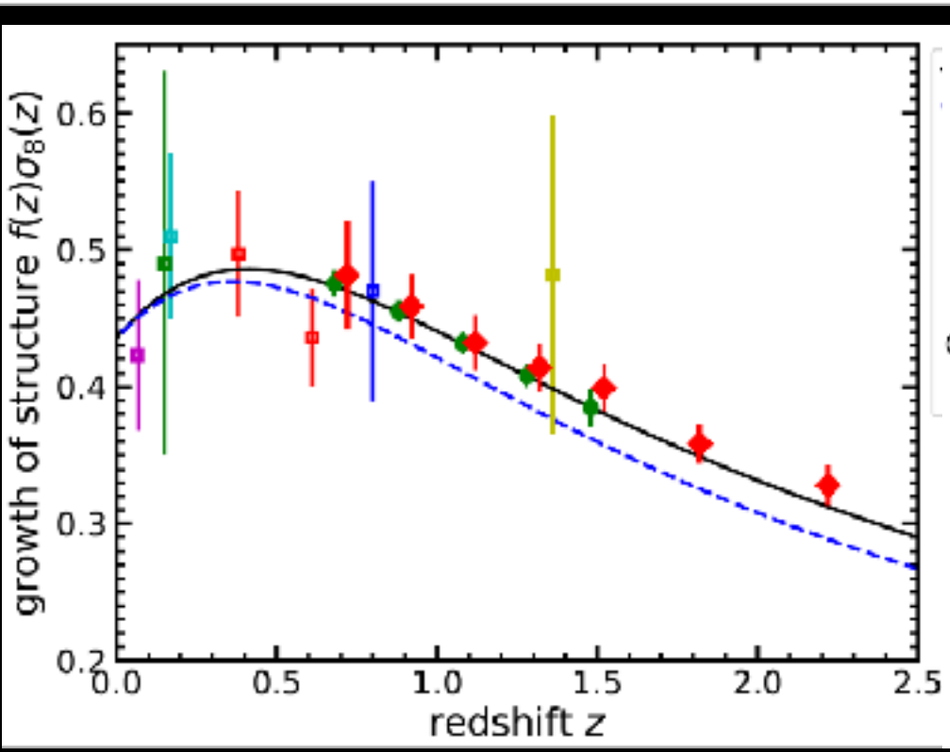
- Originally developed by Donghui Jeong (Penn State Univ.) in 2011
- Enhanced by Chi-Ting Chiang (Stony Brook Univ.) through 2015 (arXiv:1308.4157 is based on this code)
- Packaged by Eiichiro Komatsu on December 28, 2015
- (v2) includes a fix in "calc_pk_const_los_ngp" by Issha Kayo, Jan 12, 2016
- (v3) Added cross-power spectrum code by Donghui Jeong, February 8, 2016
- (v4) Generate velocities from the matter density field, instead of the galaxy density field divided by the linear bias, by Aniket Agrawal, March 4, 2016
- (v4.1) New Makefile [by Ryu Makiya], making it easier to change compilers etc, and re-packaged with cleaned python scripts, March 30, 2016
- (v5) By Ryu Makiya, Sep 04, 2016.
  - Added new python script, run.py, enabling to execute the all steps of the simulation all at once
  - Includes a new option for the estimation of the power spectrum, in which the Pk is estimated in the cubic box which is large enough to encompass the whole survey region. (set calc_mode_pk = 1 in .ini file to use it)

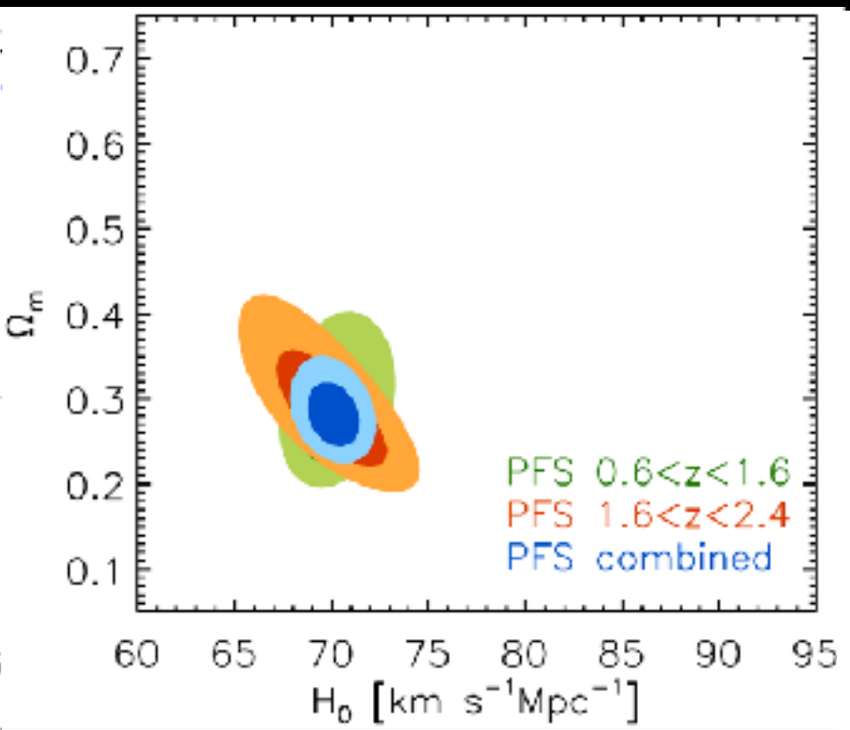
PFS SSP: COSMOLOGY PROGRAM

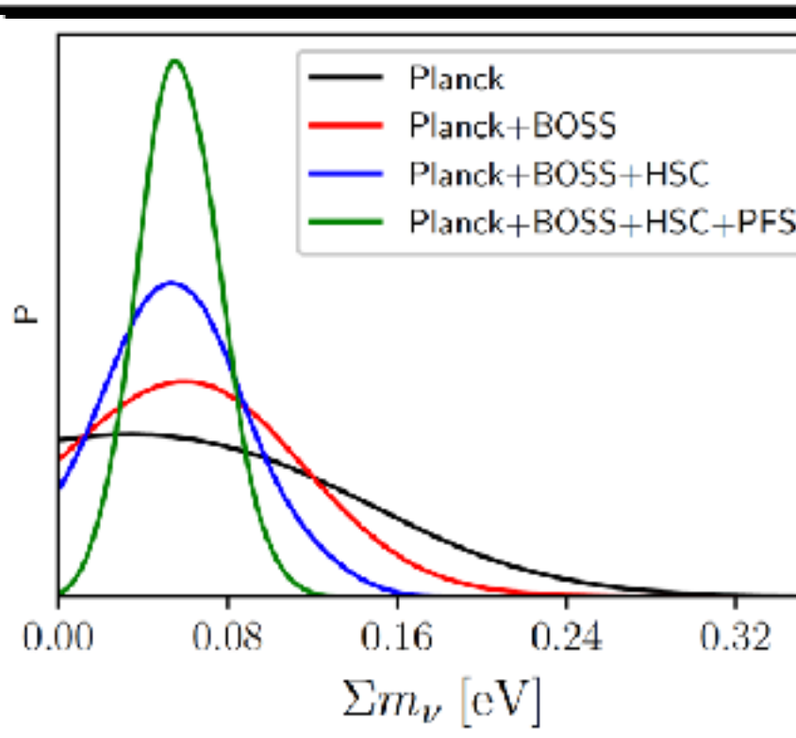
A. Boyle,[1] C. L. Bennett,[2] S. de la Torre,[3] R. de Putter,[4] O. Doré,[4,5] C. Hikage,[6] Y.-P. Jing,[7,8] I. Kayo,[9] E. Komatsu,[1,6] R. Makiya,[1,6] T. Okumura,[10] A. Pisani,[11] A. G. Sánchez,[12] S. Saito,[1] F. Schmidt,[1] M. A. Strauss,[11] T. Sunayama,[6] N. S. Sugiyama,[6] M. Takada,[6] P. Zhang,[13,8] and G.-B. Zhao[14,15]











Prepared for submission to JCAP

Mitigating the impact of fiber assignment on clustering measurements from deep galaxy redshift surveys

D01xB03

Tomomi Sunayama,[a,1] Masahiro Takada,[a] Martin Reinecke,[b] Ryu Makiya,[a] Takahiro Nishimichi,[c,a] Eiichiro Komatsu,[b,a] Shun Saito,[d] Naoyuki Tamura,[a] Kiyoto Yabe[a]

gave a talk

- "lognormal_galaxies" was used to generate many realisations of the galaxy distribution to study the impact of fiber assignment

B02: **Weak Grav. Lensing**

- Work horse: "**lognormal_lens**" simulator
- **<u>Target</u>: Synergy between HSC and PFS!**
  - This is essential to exploit the uniqueness of two SSPs on Subaru

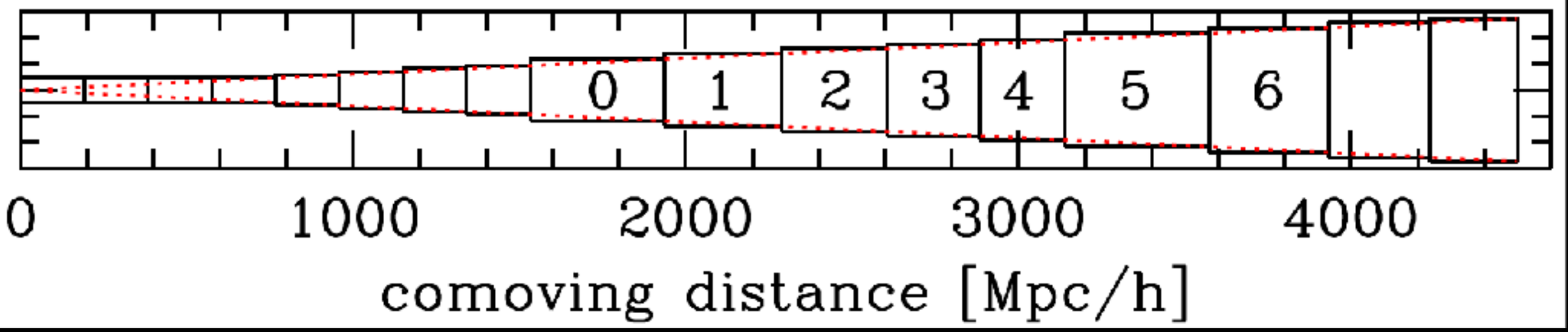
Will give a talk after me

Prepared for submission to JCAP

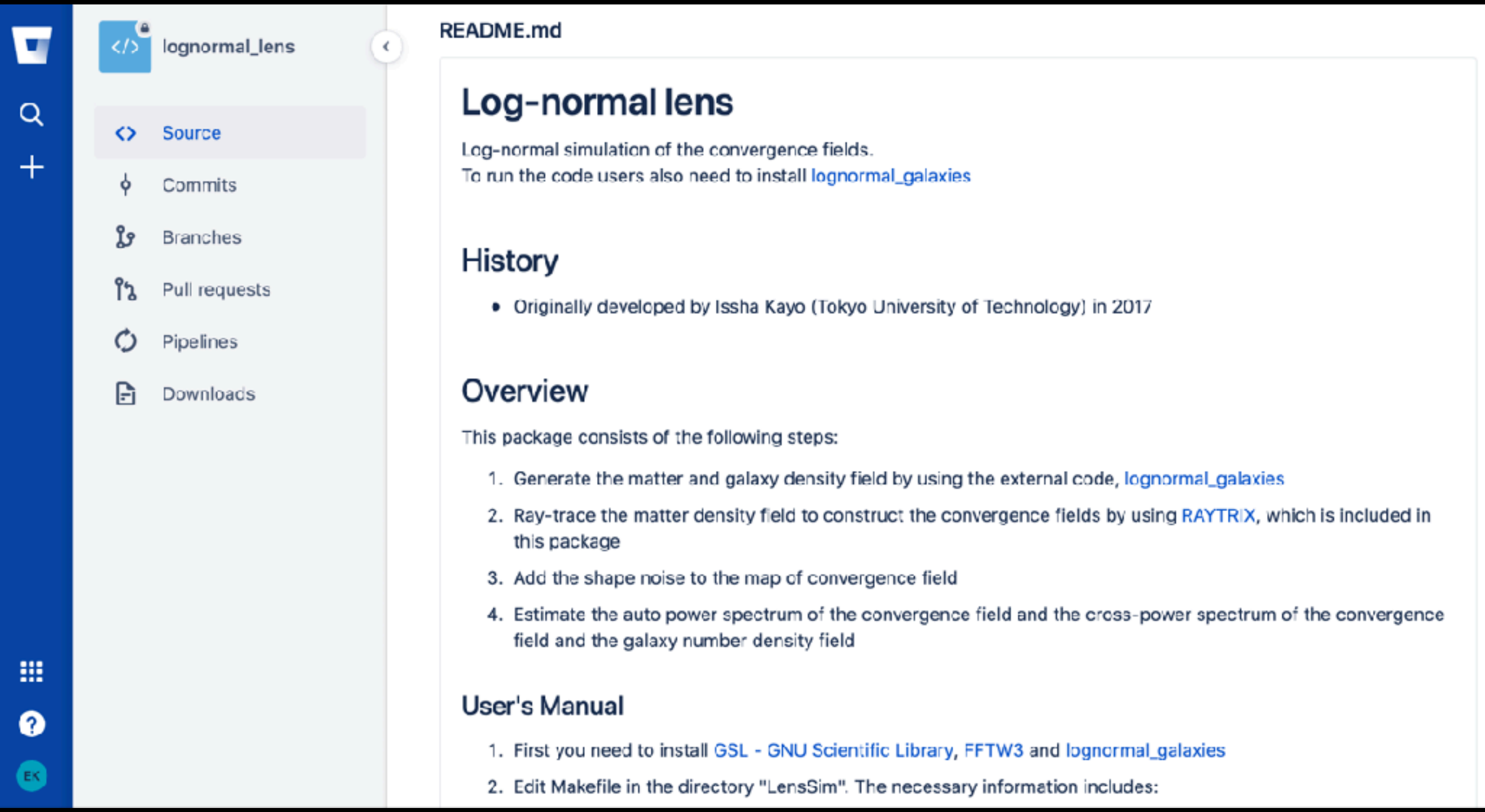
To be submitted soon...!!

Log-normal simulation for weak gravitational lensing: application to the cross-correlation with galaxies

Ryu Makiya,[a,b] **Issha Kayo,**[c] **Eiichiro Komatsu**[a,b]



lognormal_lens in bitbucket



B02: **Weak Grav. Lensing**

- **<u>New science result:</u>** Constraints on the hydrostatic mass bias of galaxy clusters from **HSC** **and the thermal Sunyaev-Zeldovich effect**

D01 x **B02**

Will give a talk later

B04: **Redshift Drift**

- **<u>Goal</u>**: To measure the expansion of space directly by measuring a change in redshifts over many years. "Sandage-Loeb Test"

$$\frac{\Delta z}{\Delta t_0} = H_0(1+z) - H(z)$$

$$\Delta v = c\Delta z/(1+z)$$

$$\Delta t_0 = 10\,\mathrm{yr}$$

$$\approx -2.5\,\mathrm{cm\,s^{-1}} \text{ for } z = 3$$

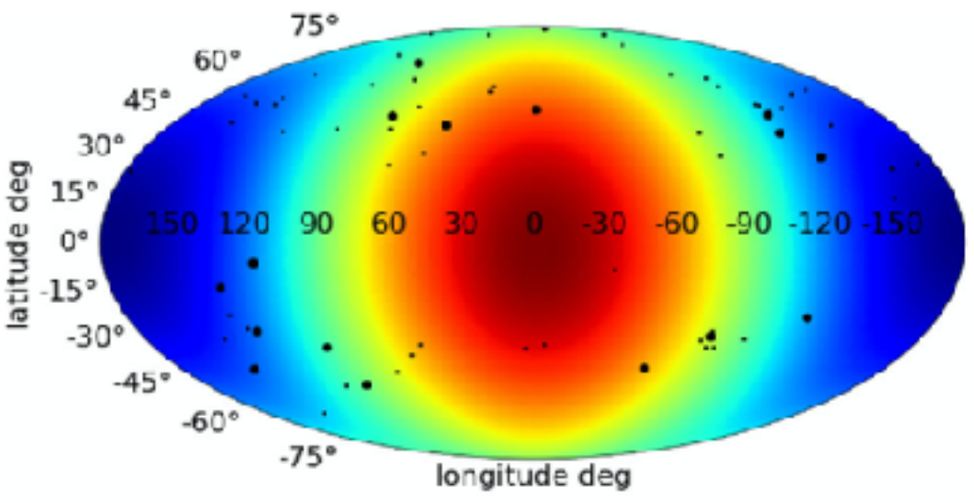
- **However, the local acceleration of Solar System contaminates the cosmological effect**
  - We have produced, for the first time, **the full-sky map of spurious redshift drifts due to the local motion**

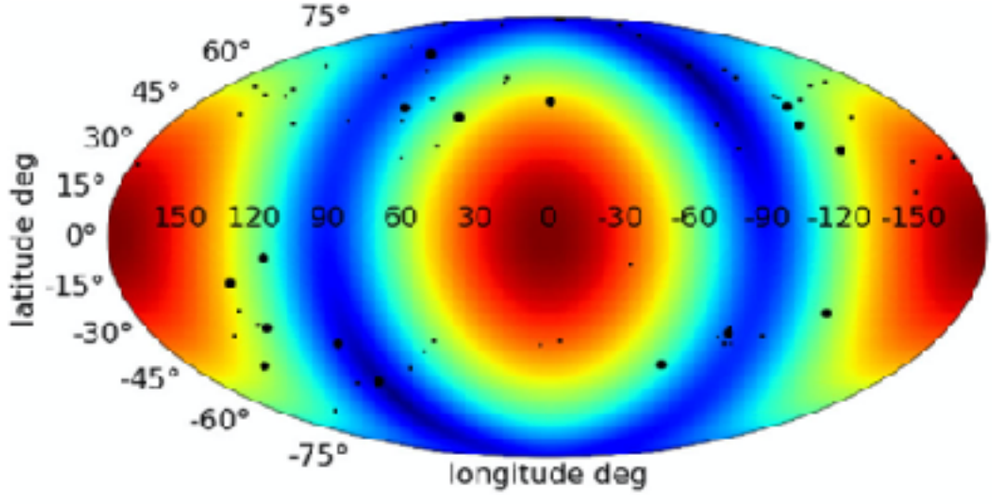
Publ. Astron. Soc. Japan (2020) 72 (1), L1 (1–6)
doi: 10.1093/pasj/psz131
Advance Access Publication Date: 2019 December 23
Letter

Letter D01xB04

The effect of our local motion on the Sandage–Loeb test of the cosmic expansion

Takuya INOUE,[1,2,3,*] Eiichiro KOMATSU,[3,4,*] Wako AOKI,[5,6] Takeshi CHIBA,[7] Toru MISAWA,[8] and Tomonori USUDA[5,6]





We go beyond BOX!

Goals of the D01 team [2]

- To develop **<u>novel analysis tools</u>** that go **<u>beyond</u>** B01–04:
  - Tomography of **hot gas** in the Universe: SZ-galaxy cross-correlation
  - **Intensity mapping**
    - Lyman-alpha and 21-cm lines, cross-correlated with galaxies and CMB

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Will give a talk later

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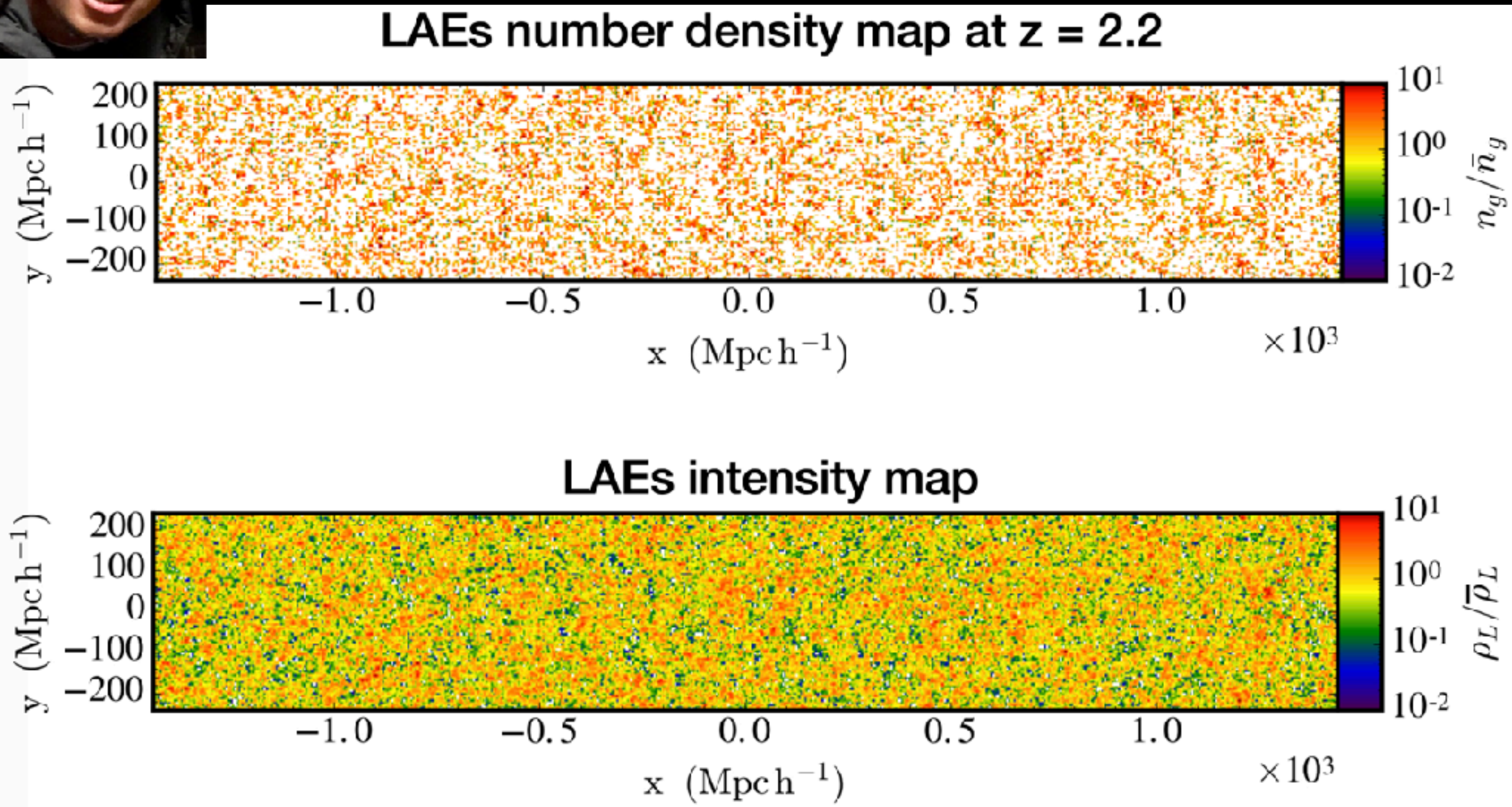
Shun Saito

lognormal_im



- The code is basically done. The paper in preparation…

Summary: 2015–2020

- **Fundamental contributions** to all of **B01**/**02**/**03**/**04**
  - Major contribution to the selection of **LiteBIRD**
  - Leading roles in shaping the **PFS cosmology** program; Synergy between **HSC** and **PFS**
  - First full-sky map of **the local acceleration**

Summary: 2015–2020

- **New tools have been developed and made available**

wwwmpa.mpa-garching.mpg.de/~komatsu/codes.html

  - *lognormal_galaxies, lognormal_lens, lognormal_im*
  - *GM100, Delta-map, New angle calibration method*
  - *Tensor spectrum reconstructor*

- **New science:** Tomography of hot gas in the Universe