Towards robust LSS cosmology: how to mitigate uncertainties in small-scale nonlinearities

Masahiro Takada (Kavli IPMU)
Hyper Suprime-Cam

- largest camera
- 3m high
- weigh 3 ton
- 104 CCDs (~0.9G pixels)
Subaru HSC = superb image quality

6 fields (~140 sq. deg. in total): HSC-Y1 data

Subaru HSC typically 0.6” seeing FWHM (spatial resolution)
⇔ DES: ~0.9”
HSC-Y1 cosmic shear cosmology

Hikage, Oguri+ 19

Planck CMB

DES (~1300 deg$^2$)

KiDS (400 deg$^2$)

HSC (140 deg$^2$)
HSC-SDSS joint probe cosmology

- HSC (140 sq. deg.): background galaxies, g-g lensing
- SDSS (~10000 sq. deg.): spec-z galaxies (3D distribution) + RSD

Subaru HSC (8.2m)

SDSS (2.5m)

Huang et al. 18
HSC-SDSS joint probe cosmology

- Use a single population of source HSC galaxies for 3 lens samples of SDSS galaxies at 3 z-bins → this allows us to calibrate photo-z uncertainties (Oguri & Takada 11)
- S/N~50 in total for g-g lensing
- We are performing the blind analysis

Hironao Miyatake (Nagoya/IPMU)
Lensing + Clustering complementarity

IF $\xi_{gm} \sim b\sigma_8^2, \xi_{gg} \sim b^2\sigma_8^2, b \sim b(M)$

$z \sim 0.55$

Clustering amplitude

decreasing $\Omega_{m0}$

Weak lensing

More, Miyatake, Mandelbaum, MT+15
How to extract cosmology against galaxy bias?

- Linear theory or PT: DES approach (see Elisabeth’s talk)
  - Pros: robust, simple theory
  - Cons: has to be restricted to large scales

\[ P_{gm}(k) \simeq b P_{mm}^{NL}(k), \quad P_{gg}(k) \simeq b^2 P_{mm}^{NL}(k) \]

- Method filtering out the small-scale information (SDSS; Mandelbaum et al. 2013)
  - Pros: robust against small-scale NL’s
  - Cons: conservative

\[ \gamma_{gm}(R) = \Delta \Sigma(R) - \frac{R_0^2}{R^2} \Delta \Sigma(R_0) \]

- Halo Emulator approach (HSC; Miyatake+ in prep.)
  - Pros: could use the small-scale information
  - Cons: need to introduce a sufficient number of paras to model 1-halo term uncertainties, assembly bias ….
Dark Quest & Dark Emulator

Nishimichi, MT, Takahashi et al.

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DARK QUEST. I. FAST AND ACCURATE EMULATION OF HALO CLUSTERING STATISTICS AND ITS APPLICATION TO GALAXY CLUSTERING

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ABSTRACT

We perform an ensemble of cosmological N-body simulations with 2048$^3$ particles for 101 cosmological models within a flat wCDM cosmology framework, which are sampled based on a maximin-distance Sliced Latin Hypercube Design. By using the outputs of N-body simulations and the halo catalogs extracted at multiple redshifts in the range of $z = [0, 1.48]$, we develop an emulator, Dark Emulator, which enables fast and accurate computations of halo clustering quantities, the halo mass function, halo-matter cross-correlation, and halo auto-correlation as a function of halo masses, redshift, separations and cosmological models, based on the Principal Component Analysis and the Gaussian Process Regression for the large-dimensional input and output data vector. We use a validation set of N-body simulations for cosmological models, which are not used in training the emulator, to assess the performance of the emulator. We show that, for typical halos hosting CMAS galaxies in the Sloan Digital Sky Survey, the emulator reproduces halo-matter cross-correlation, relevant for galaxy-galaxy weak lensing, with an accuracy of 0.1% and halo auto-correlation for galaxy clustering correlation, with an accuracy better than 1% of the emulator. For instance, the emulator outputs can be combined with other catalogs of halos, such as the mass-concentration relation and splashback radius, for galaxy growth and redshift evolution. We also show that the emulator outputs can be combined with other information such as the halo occupation distribution at the equation of state parameters, weak lensing constraints, and cosmic shear correlation function for any model within the wCDM framework.

Keywords: large-scale structure of the universe — numerical simulations

1. INTRODUCTION

Cosmic large-scale structures are promising avenues to fundamental questions in cosmology. Various wide-area imaging or spectroscopic surveys of galaxies are ongoing and being

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R. Takahashi (B03)
M. Shirasaki (NAOJ: solicited)
Y. Kobayashi (IPMU: D2)
M. Oguri (B02)
H. Miyatake (Nagoya: solicited)
Towards an accurate modeling of nonlinear structure formation

Specify wCDM model

\[ p_\alpha = \{ \omega_c, \omega_b, \Omega_{de}, \ln(10^{10} A_s), n_s, w_{de} \} \]

Run N-body sim.

Post processing (identify halos ~ place where galaxies form)

Make a mock of galaxy survey (gals, lensing fields, …)

A measurement from the mock

~a few days

Nishimichi et al.
Dark Emulator

- Stored all data (~200TB)
- Gauss process & ML
- Make an “emulator” from the tabulated data

Allow a fast computation of galaxy clustering observables (<1sec)
my office is very hot…

PC1 (500GB memory, 20+400TB)

PC1 (1.5TB memory, 200+80TB)

For me
validation test

$\xi_{hm}(r; M, z)$

$z = 0.549$ halo-matter cross correlation function

$n_h = 3.16e - 04 h^3\text{Mpc}^{-3}$

vs 40 training sets $M_{\text{min, fid}} = 1.18e + 13 h^{-1}\text{M}_\odot$

$\sim$ a few % at $x<30\text{Mpc}/h!!$

vs 20 validation sets

vs 24 fiducial runs
\[ \xi_{hh}(r; M, M', z) \]

Validation test

Halo auto correlation function

\( z = 0.549 \)

\( n_h = 3.16 \times 10^{-4} \, h^3 \text{Mpc}^{-3} \)

\( M_{\text{min, fid}} = 1.18 \times 10^{-13} h^{-1} M_\odot \)

Vs 40 training sets

Vs 20 validation sets

Vs 14 fiducial runs
Clustering observables form Halo Emulator

- The abundance of SDSS galaxies; we don’t use for cosmology though (sensitive to masks, obs. systematics, …)

\[ \bar{n}_g = \sum_M \frac{dn}{dM} [\langle N \rangle_c (M) + \langle N \rangle_s (M)] \]

- g-g lensing

\[ P_{gm}(k) = \frac{1}{\bar{n}_g} \sum_M \frac{dn}{dM} [\langle N \rangle_c \mathcal{H}_{off}(k) + \langle N \rangle_s u_s(k)] P_{hm}(k; M) \]

\[ \Delta \Sigma(R) \]

\( \text{FFTlog} \)

- g-g clustering

\[ P_{gg}(k) = P_{gg}^{1h}(k) + \frac{1}{\bar{n}_g^2} \sum_{M,M'} [\langle N \rangle_c \mathcal{H}_{off}(k) \langle N \rangle_s u_s(k)] \ldots P_{hh}(k; M, M') \]

\[ w_{gg}(R) \]

\( \text{FFTlog} \)
HSC cosmology challenges

- Populating sim halos with galaxies using different gal recipes with many variants
  - Diff HOD paras
  - Sat gals distribution
  - Off-centering
  - Baryonic effects
  - Assembly bias

- MCMC parameter inference
  - Use the fiducial HOD/gal paras
  - Address whether to recover the underlying cosmo paras
Stochasticity in galaxy clustering

- Scale-dependent bias
- Stochasticity

\[
\langle N_g(N_g - 1) \rangle \neq \langle N_g \rangle^2
\]

\[
r(r) \equiv \frac{\xi_{gm}(r)}{\sqrt{\xi_{gg}(r)\xi_{mm}(r)}} \neq 1
\]

Seljak 00
Scoccimarro + 01
conservation laws for baryonic effects

- (red) galaxy bias not changed: galaxies form from the same initial peaks
- mass conservation around each galaxy -- baryonic effects causes a redistribution of total matter around each galaxy

Van Daalen et al. 13

Schneider & Teyssier 15; Leautahud+17
Results: HSC cosmology challenges

- ~8 galaxy parameters (for each sample)

Miyatake, Kobayashi, in prep

- **fid**
- **sat_dm_dist**
- **nonfid_nsat**
- **off-cent**
Used HSC+BOSS mocks for covariance
We expect ~3% accuracy in $S_8$
galaxy parameters are nuisance
we don’t care any bias in galaxy parameters

Miyatake, Kobayashi+
Against baryon effects …

Gals parameters can absorb baryon effects

Miyatake, Kobayashi+
$P_{gm}(k) = b_1 P_{mm}^{NL}(k) + b_2 A^{PT}(k)$

$P_{gm}(k) = (b_1)^2 P_{mm}^{NL}(k) + 2b_1 b_2 A^{PT}(k) + \frac{b_2}{2} B^{PT}(k)$

Mocks very useful!

testing/validation of PT-based approach

See Sunao’s poster
summary

• Galaxy bias so annoying (except for Nick’s linear bias!)

• The community NEEDS a good, practical method (valuable data there)
  – Give us a good method
  – Linear theory: are you satisfied? Loose a lot of small-small info
  – PT: looks great, but useful?
  – Halo-model approach (our HSC approach): are you convinced?

• Want to impose conservation laws
  – Mass/momentum conservation laws
  – Small-scale stochasticity backreaction, $P(k) \sim k^4$ (Peebles 1980)