大規模宇宙論的シミュレーション群を用いた宇宙大規模構造の精密理論テンプレートの構築

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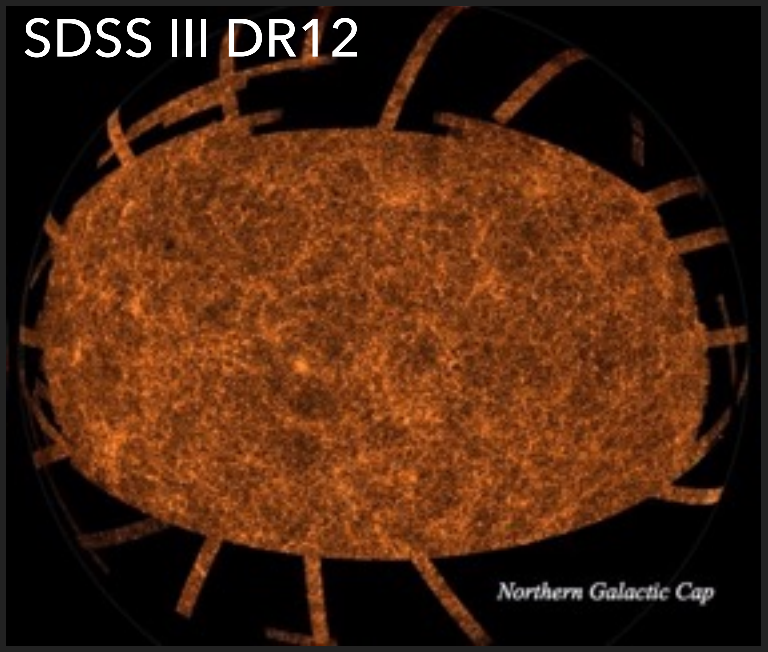
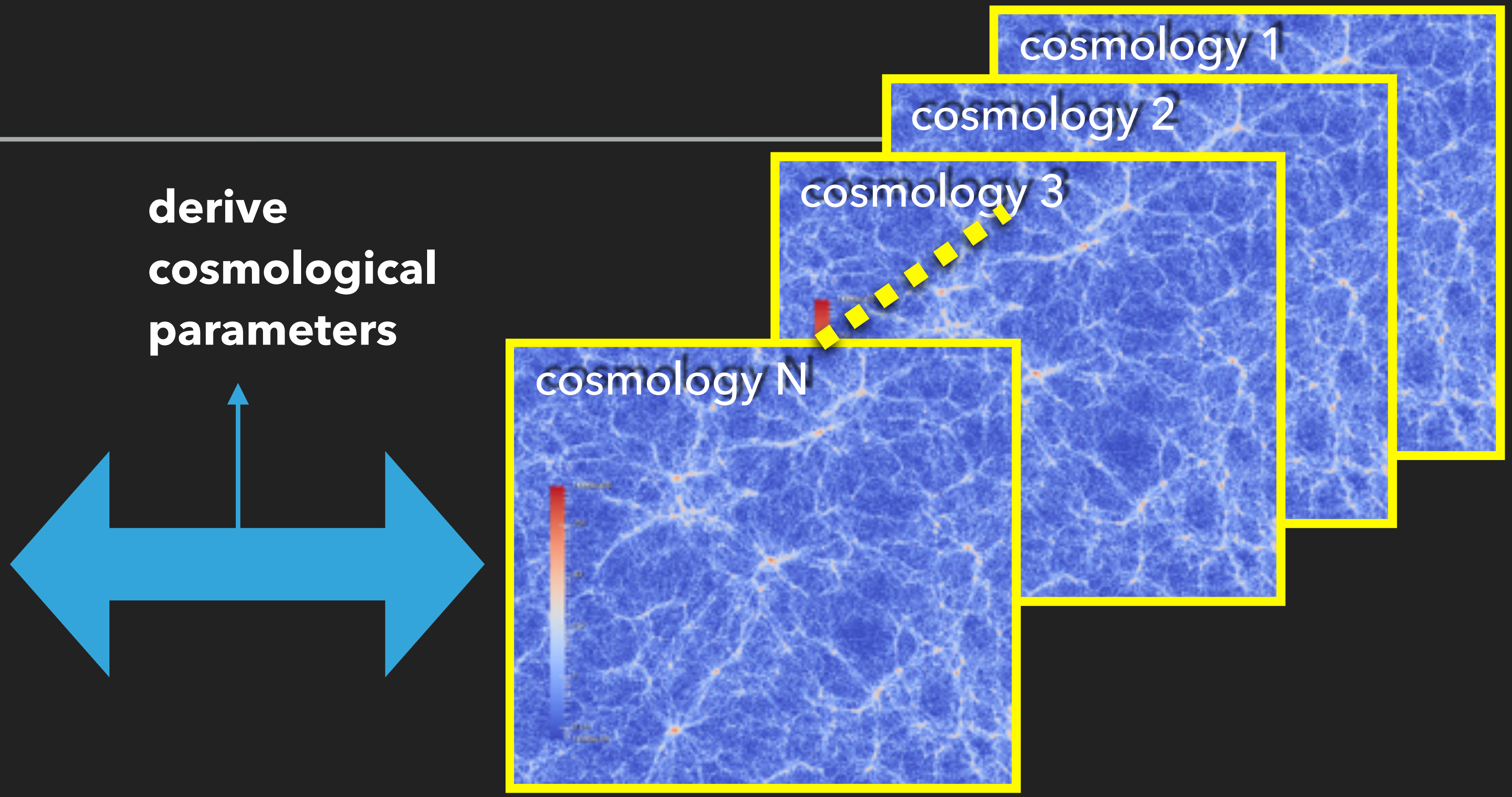
2016/01/29 CfCA users meeting @ Mizusawa

THE ULTIMATE GOAL





Establishment of Numerical Cosmology

- ✓ Direct comparison btwn simulation and observation to draw cosmological information
- ✓ N-body method kind of established for mock large scale structures by solving gravitational system

- ✓ "Scan" multi-D cosmological parameter space?
  - ✓ feasibility questionable given the high dimensionality and required accuracy for future programs
  - ✓ **Efficient sampling scheme and use of machine learning techniques**
  - ✓ **Quick simulations with new algorithm**

GALAXY-GALAXY LENSING SIMULATION EFFORT

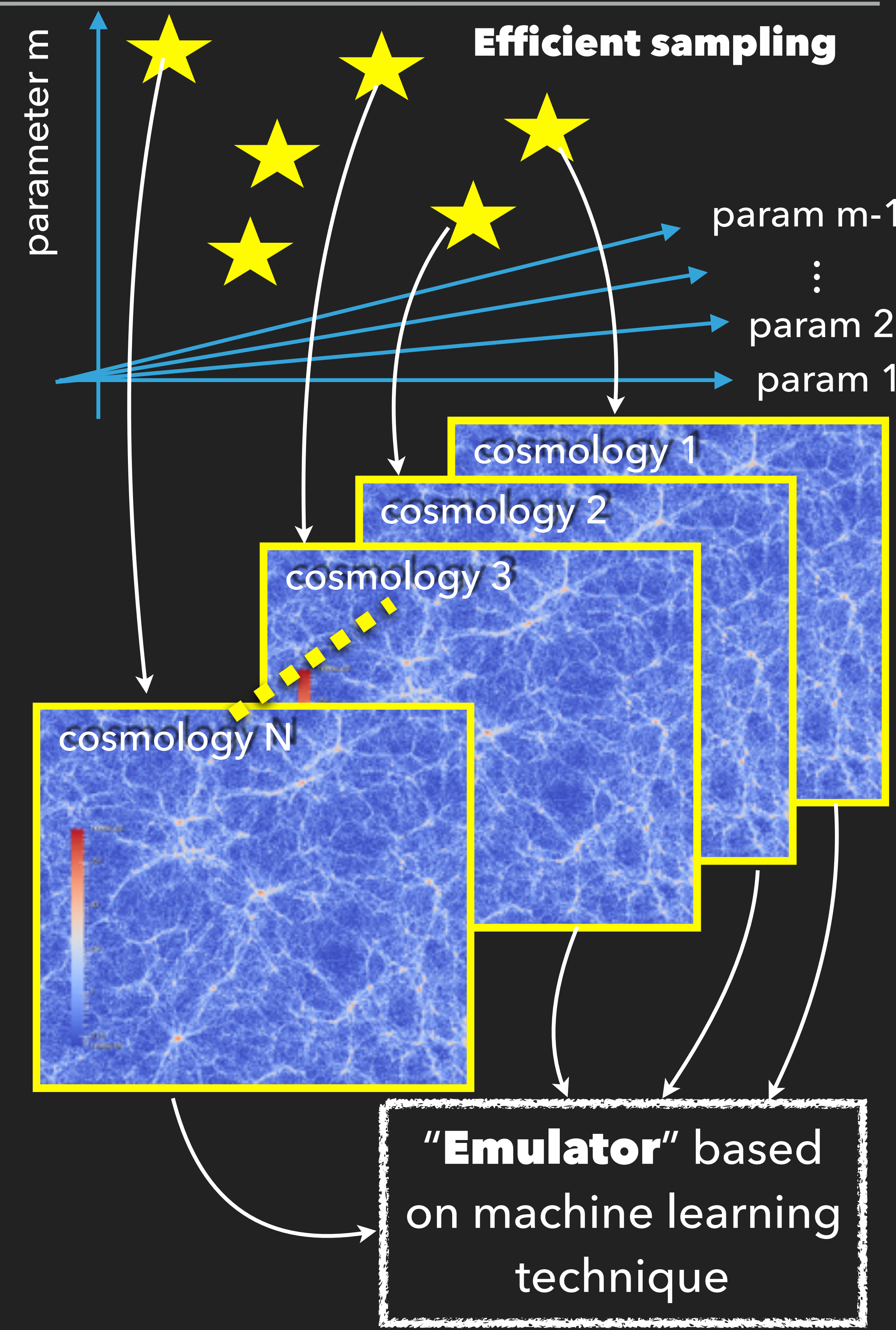
Simulations for Subaru HSC

✓ accurate theoretical templates

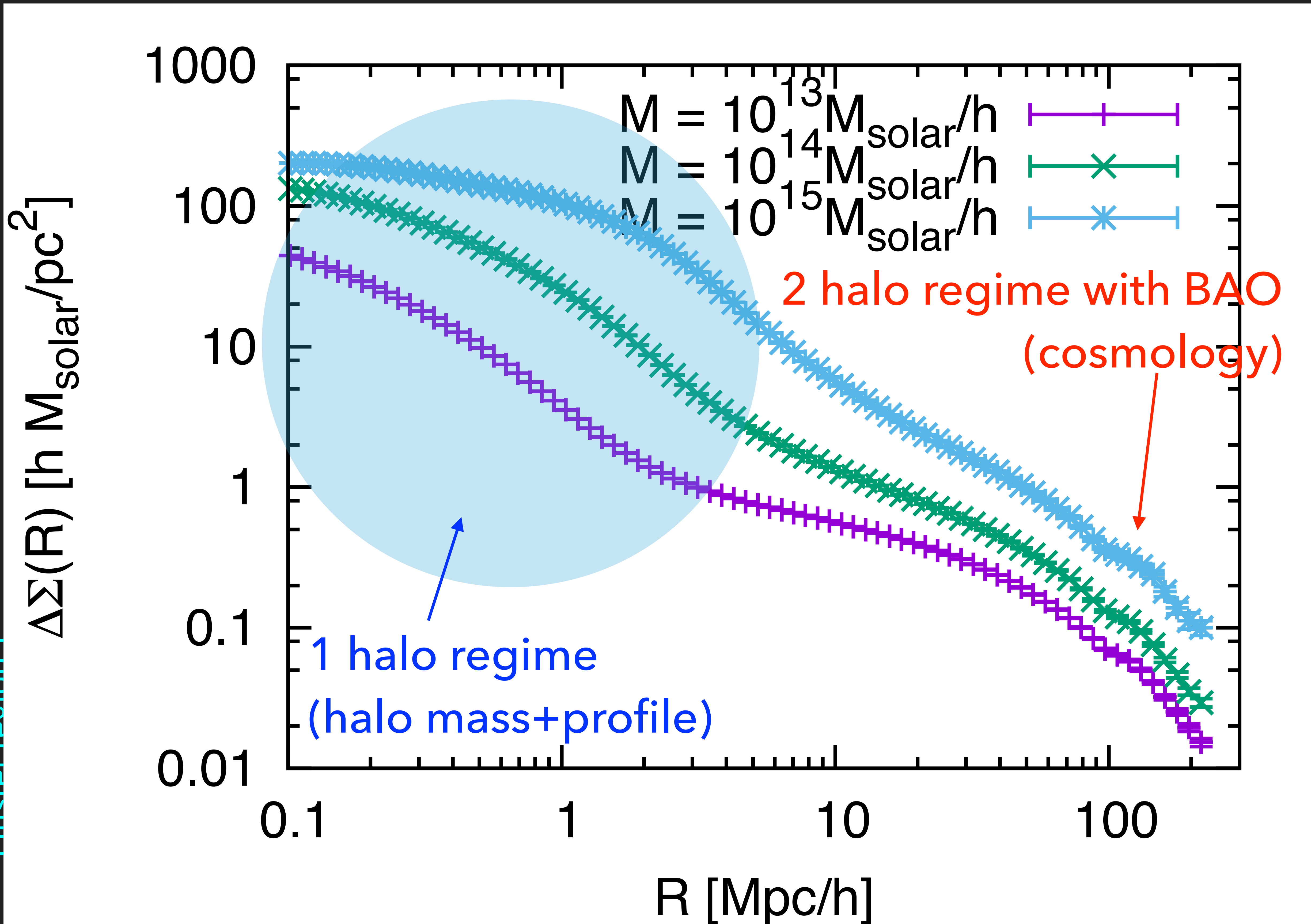
- ✓ Galaxy (cluster)-galaxy lensing
- ✓ Galaxy-3D spatial clustering

cross-correlation analysis w/ BOSS CMASS

dark matter (sub)-halos as a simplest representative of galaxies



- **Kavli IPMU**
  Takahiro Nishimichi*
  Masahiro Takada
  Naoki Yoshida
- **U. Tokyo**
  Ken Osato*
  Masamune Oguri
- **NAOJ**
  Masato Shirasaki*
  Takashi Hamana
- **Hirosaki U.**
  Ryuichi Takahashi*



cluster region 1

da '11

ffect

(with z)

can probe the mean dark matter distribution around halos

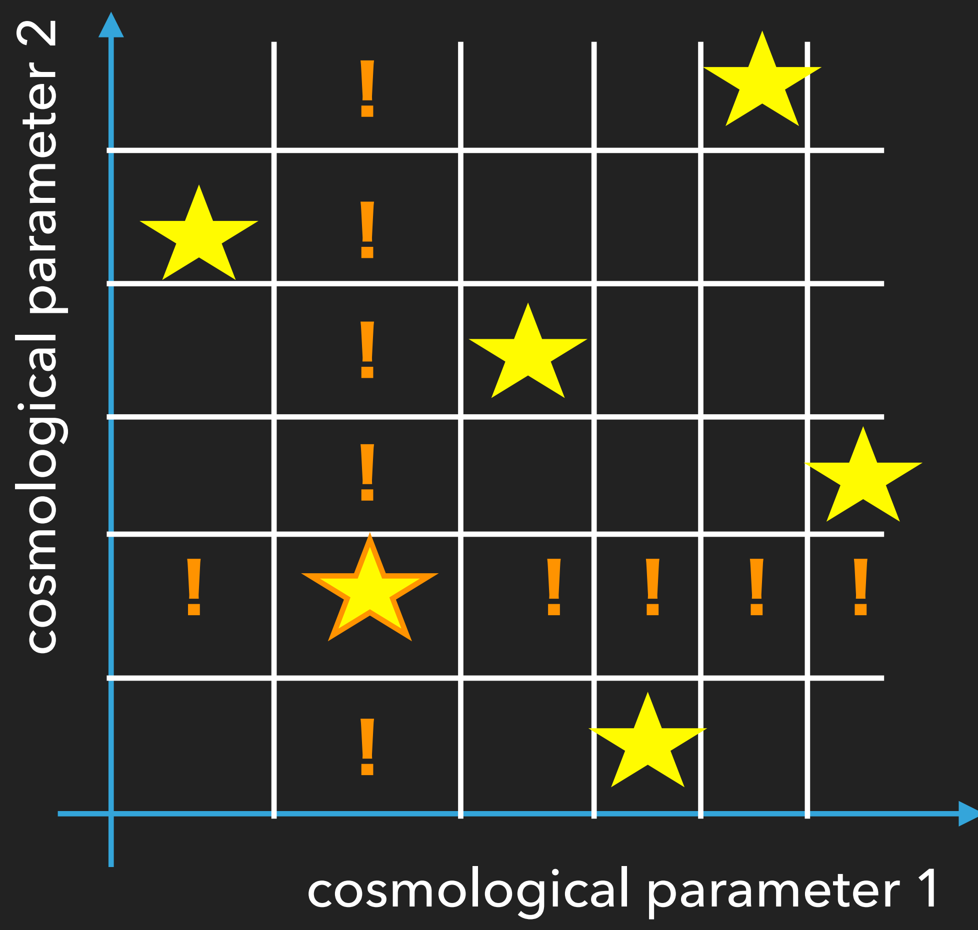
SIMULATION SPECIFICATIONS

- ✓ N of particles: 2048^3
- ✓ box size: $1h^{-1}$Gpc
  resolve a $10^{12}\ h^{-1}M_{solar}$ halo with ~100 particles
- ✓ 2nd-order Lagrangian PT initial condition @ z_{in}=59
  (vary slightly for different cosmologies to keep the RMS displacement about 25% of the inter-particle separation)
- ✓ Tree-PM force by L-Gadget2
  (w/ 4096^3 PM mesh)
  - ✓ ~2days/run using 27 nodes on XC30 after parameter optimization
- ✓ 21 outputs in $0 \leqq z \leqq 1.5$
  (equispaced in linear growth factor)

- ✓ Halo (subhalo) catalogs by
  - ✓ FOF + Subfind
  - ✓ Rockstar (+ merger tree by consistent-trees)
  - ✓ consistent central/satellite separation
- ✓ Data compression (256GB -> 48GB par snapshot)
  - ✓ positions -> displacement (16 bits par dimension; accuracy ~$1h^{-1}$kpc)
  - ✓ velocity: discard after halo identification
  - ✓ ID: rearrange the order of particles by ID and then discard
  - ✓ already consuming ~200TB (100TB for DM, 100TB for halos) in half a year

EFFICIENT SAMPLING IN MULTI DIMENSIONAL SPACE: LATIN HYPERCUBE

- Each sample is the only one in each axis-aligned hyperplane containing it
  - One can find many realizations of such design (ex. diagonal design)
  - Impose additional condition such as "the sum of the distances to the nearest design point is maximal"
- **Useful technique to efficiently cover parameter space when the dimensionality is high but many simulations are not realistic**



EFFICIENT SAMPLING IN MULTI DIMENSIONAL SPACE: LATIN HYPERCUBE

fiducial model

- ✓ PLANCK15 flat ΛCDM
- ✓ 24 realizations done
- ✓ assess statistical error
- ✓ check the accuracy of the emulator

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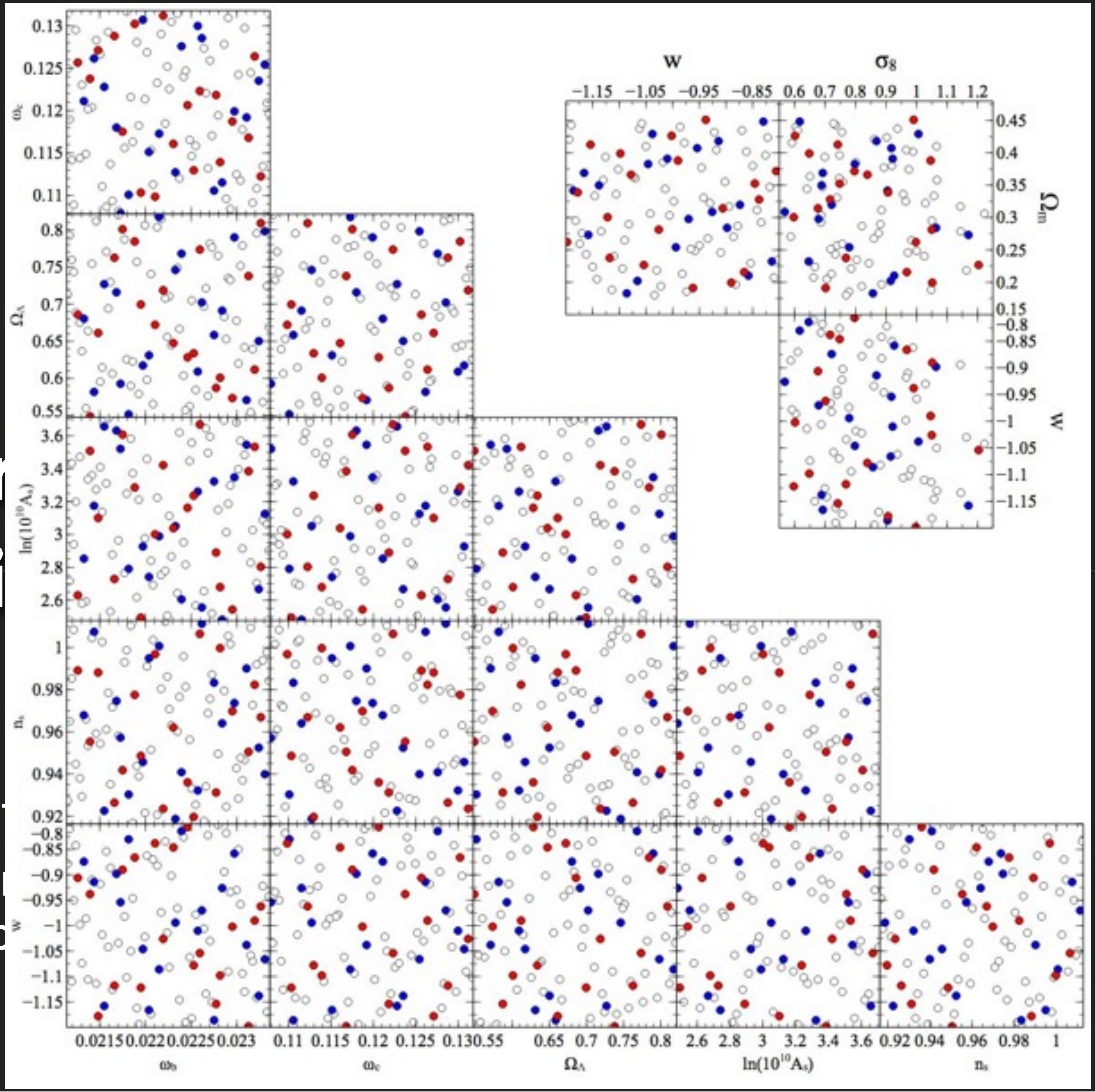
avai

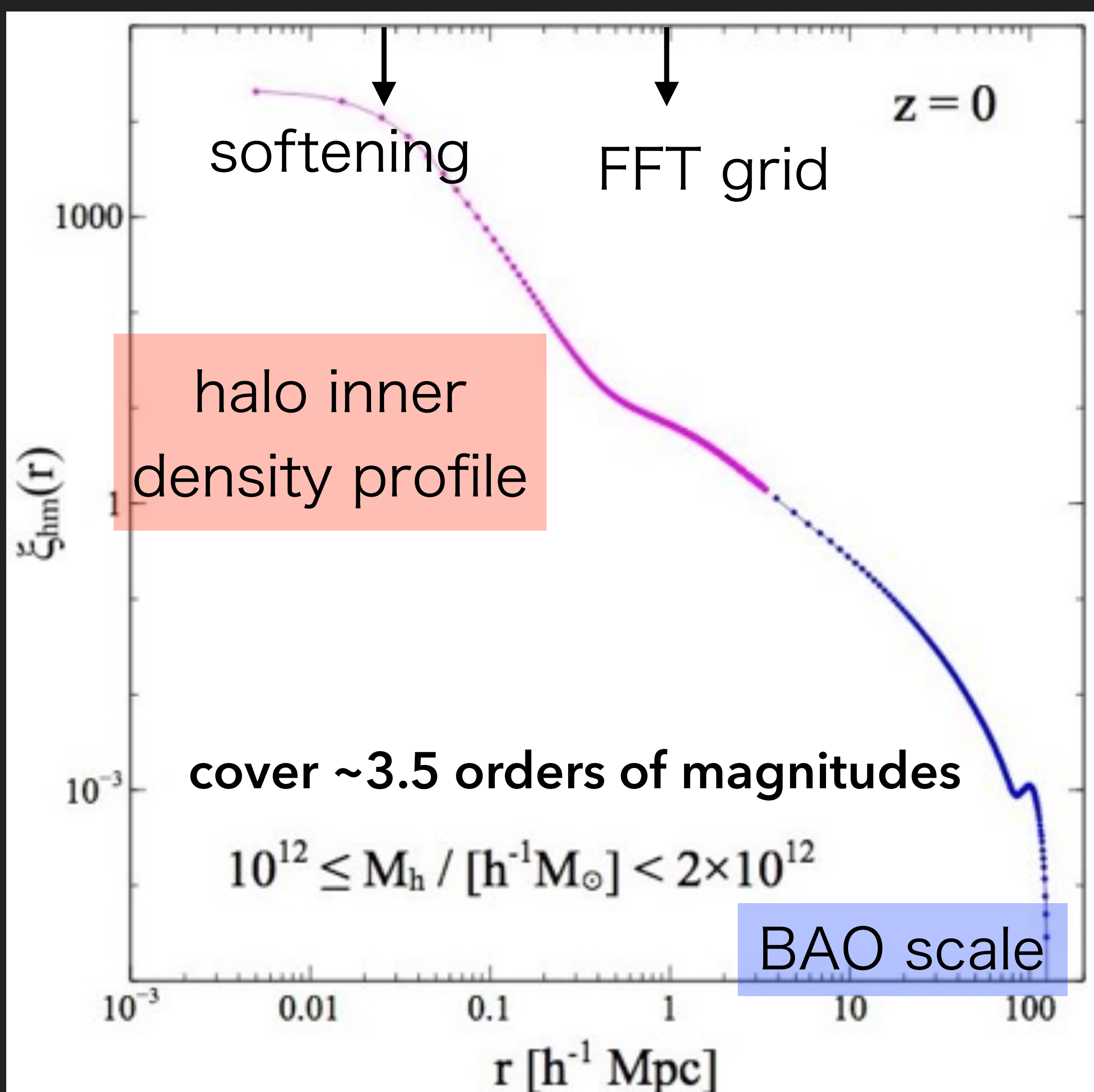
varied cosmology

- ✓ “sliced” LH design (Ba, Brenneman & Myers ’15)
- ✓ generate 100 samples event
- ✓ maxi-min distance LH desig every 20 models (e.g., red/b points)
- ✓ 2 types of sims



MEASURING G-G LENSING SIGNAL

- ✓ Work in 3D (c.f., 2D nature of lensing)
- ✓ And then projection on 2D
- ✓ **Hybrid Fourier-direct scheme**



3D cross spectrum in Fourier space

$P_{\rm hm}(\vec{k})$ (on 1024^3 mesh by FFT)

Inverse FFT to real space and take the spherical average

$$\xi_{\rm hm}(\vec{r}) \xrightarrow[\text{spherical avg.}]{} \xi_{\rm hm}(r)$$

ξ_{hm} on small scale from direct pair count

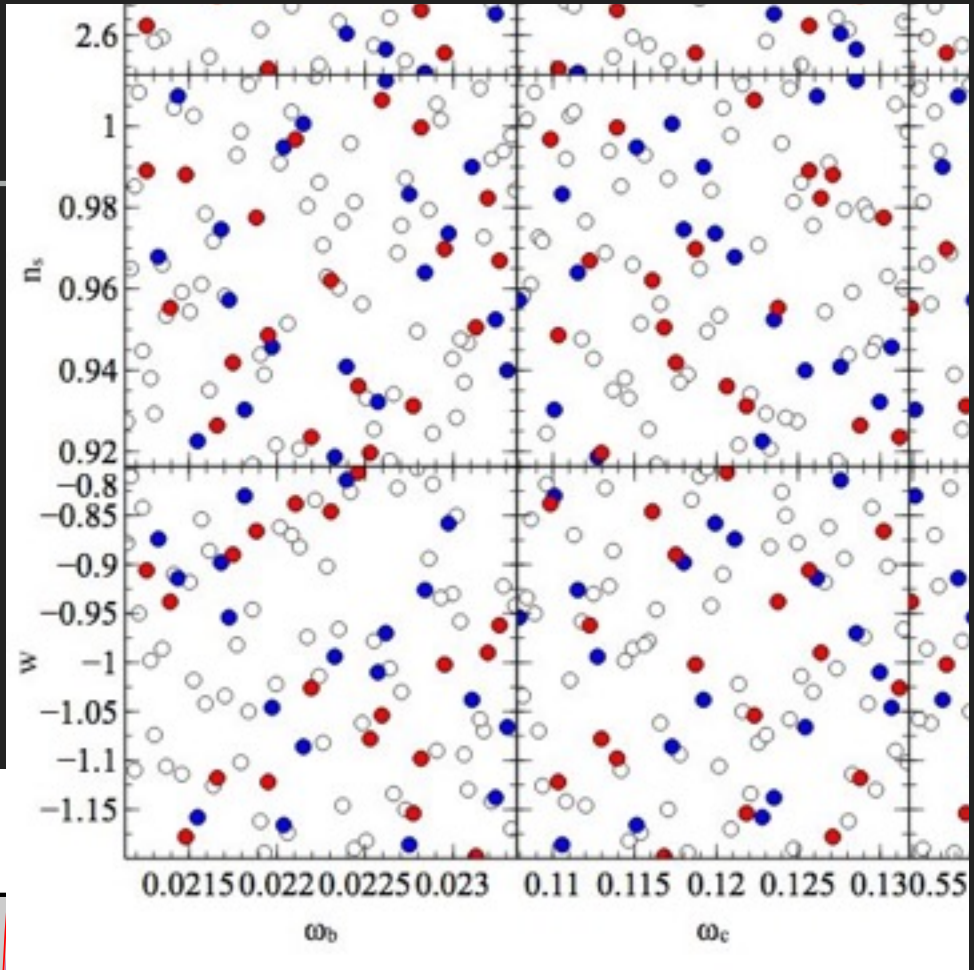
Finally project onto 2D to have $\Sigma(R)$ and then $\Delta\Sigma(R)$

$$\Sigma(R) = \bar{\rho} \int \left[1 + \xi_{\rm gm}\left(\sqrt{R^2 + \Pi^2}\right)\right] d\Pi$$

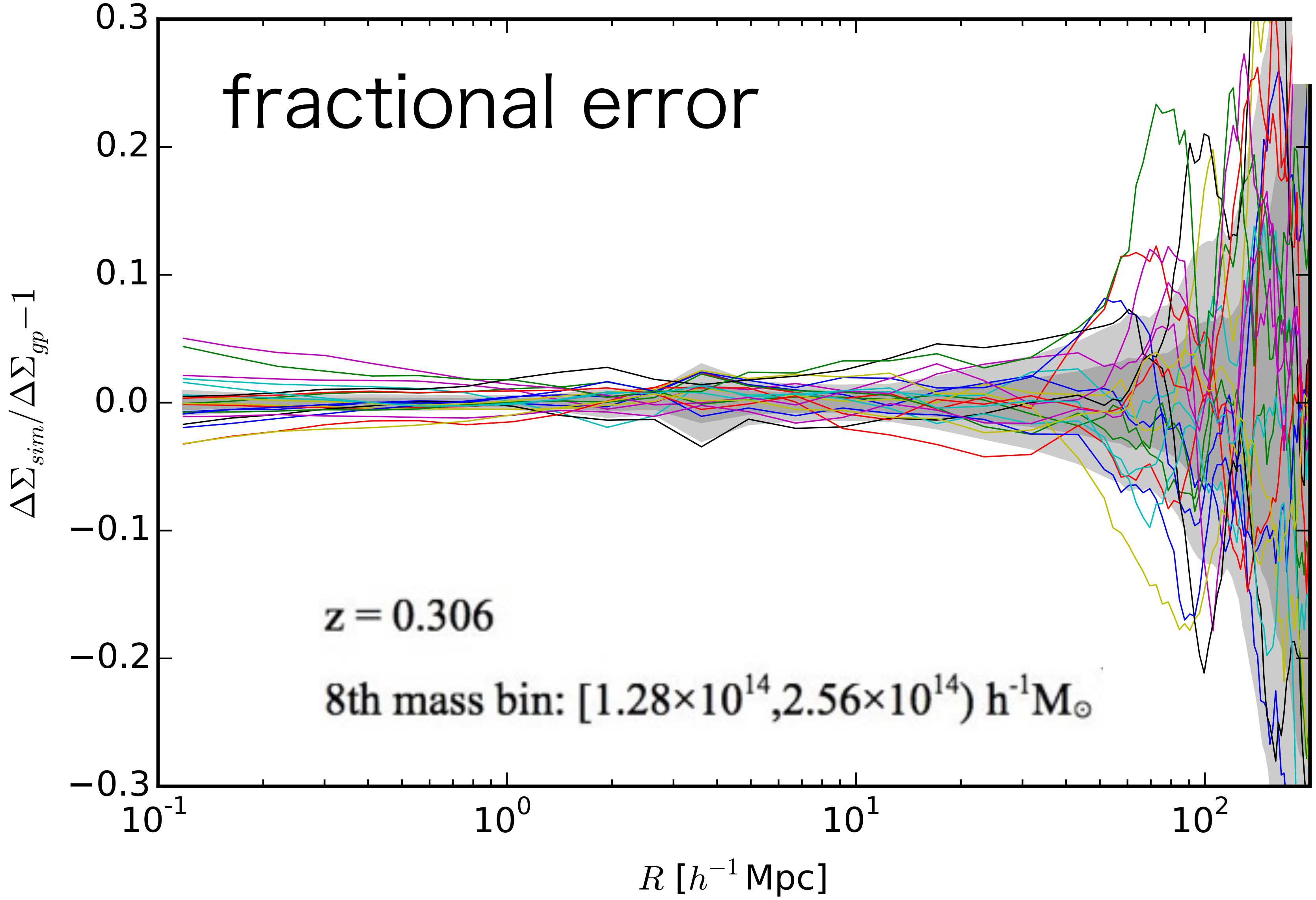
Easier accuracy control than working in 2D, and quicker than direct pair counting alone

GAUSSIAN PROCESS

validation at 20 other models
(blue points)



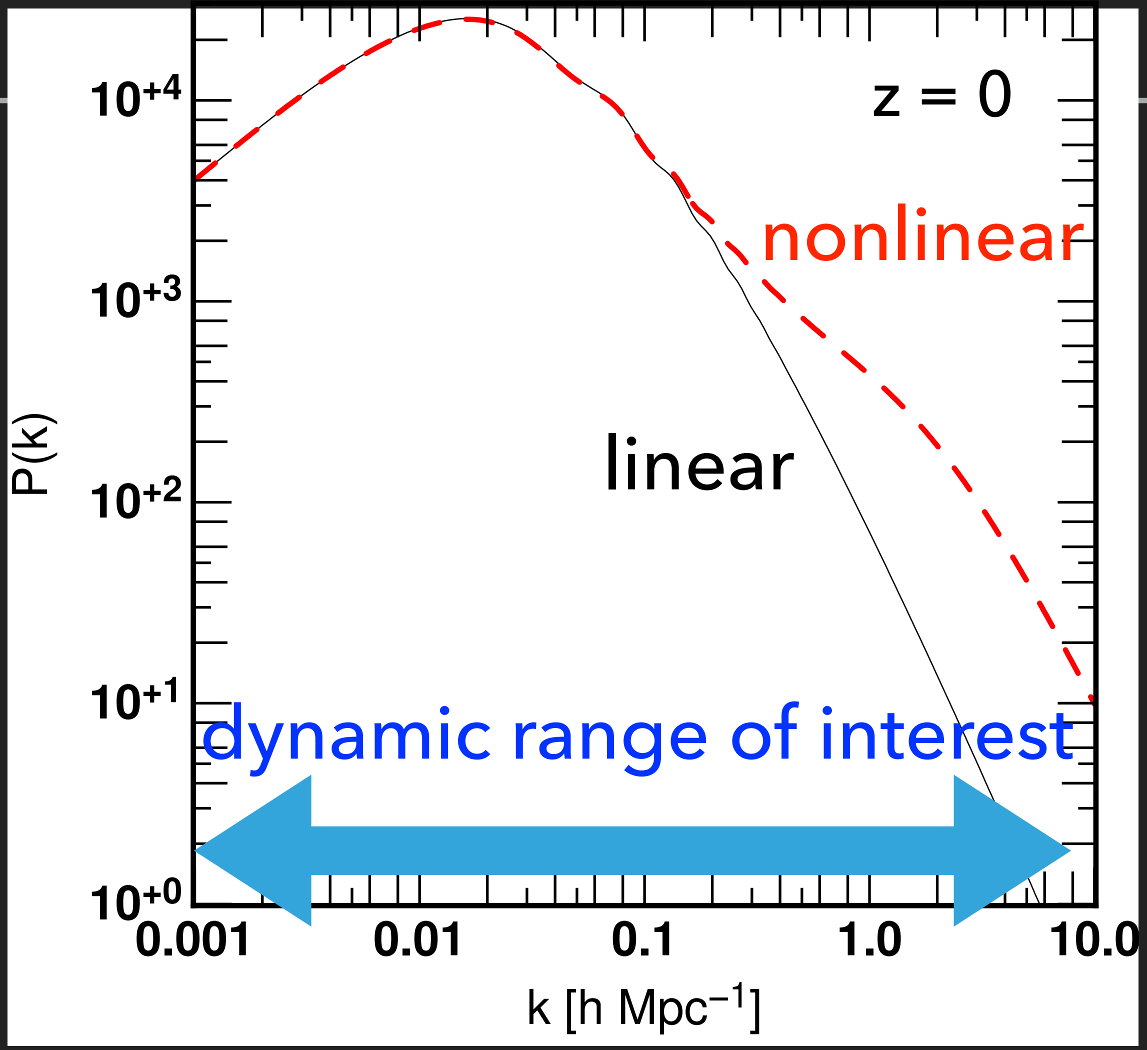
random number varied



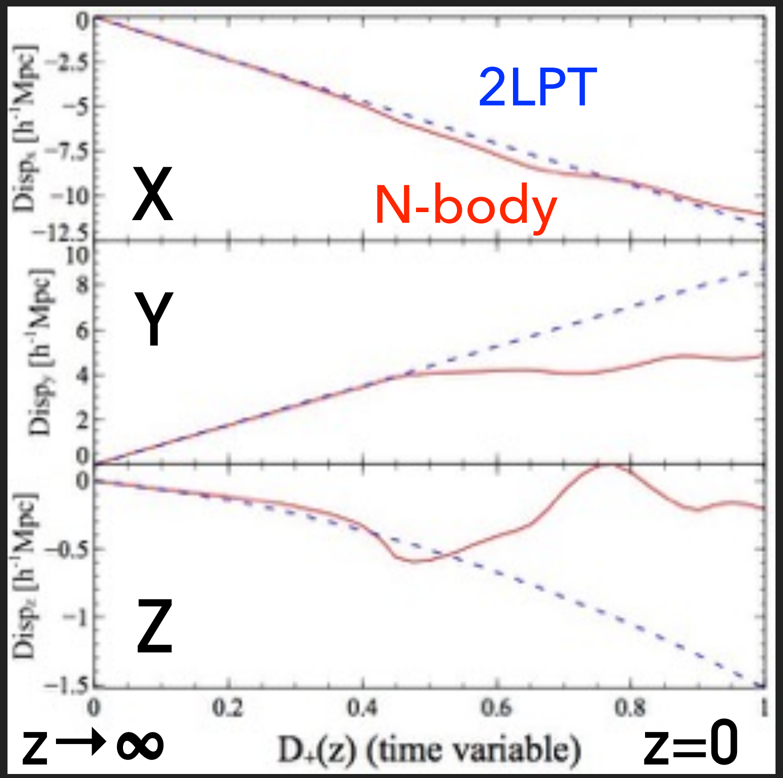
COMBINING PT WITH N-BODY

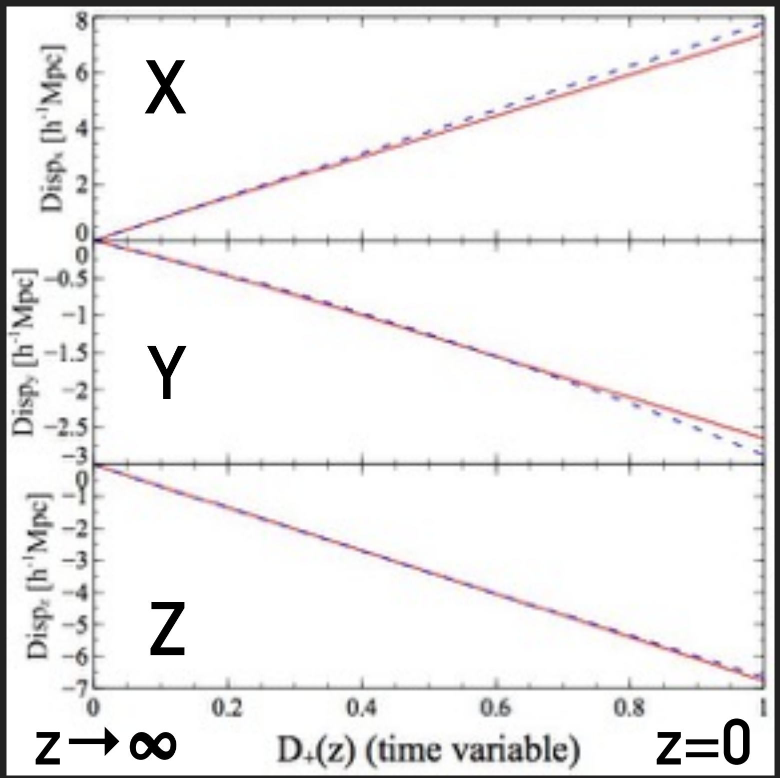
- Full-sky light cone simulation for future surveys (+ covariance)?
  - Need a very large N to keep the resolution
  - scalable?
  - just solving linear dynamics on large scales
- Let us combine perturbative solution with N-body !

cosmic matter power spectrum



trajectories of particles





TREE-PM ALGORITHM

w/ Naonori Sugiyama

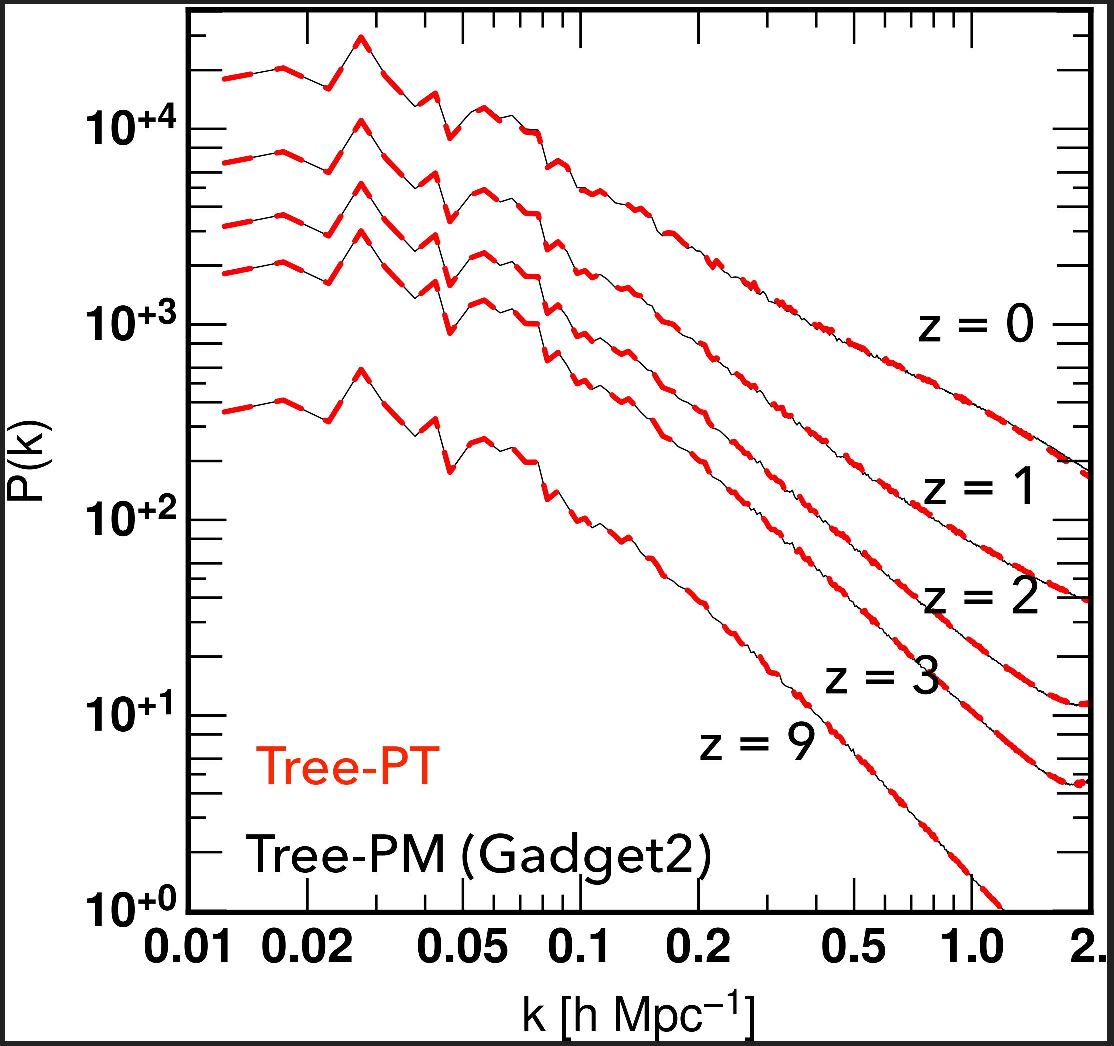
- Reinterpret PT solution as "PT force"

$$\vec{x}(\vec{q};t) = \vec{q} + D_1(t)\vec{\Phi}^{(1)}(\vec{q}) + D_2(t)\vec{\Phi}^{(2)}(\vec{q})$$

  - PT solution: displacement field
  - Need to compute this just once
  - "Force" can be defined as the time derivative of this
    - can be done analytically
  - just solving linear dynamics on large scales
- Smooth out small scale contribution, replace the PM part in Gadget 2 to have Tree-PT
  - Still working on the "optimal" splitting scheme of the 2 forces
  - Speed is still an issue
- Developing a Tree-PM-PT code!

$L = 512\ h^{-1}$Mpc, $N = 256$^3

$R_{split} = 10\ h^{-1}$Mpc **~15% speed up**



SUMMARY

- Modeling galaxy-galaxy lensing signal over a wide parameter/dynamic range
    - a suite of cosmological simulations with Latin hypercube design
    - halo catalogs with density profile
    - Emulator based on Gaussian process (20 learning sets)
    - currently ~5% accuracy (20 validation sets) and hopefully this gets better
- Quick simulation
    - perturbative solution can be used as the long range force
    - Tree-PT code was developed based on Gadget2
    - Still need more work on the accuracy/speed optimization
    - Tree-PM-PT code under development