公募研究「ボイド構造の精密モデリングと宇宙論検証への応用」

# Precise Modeling of cosmic voids and application to cosmology

Atsushi J. Nishizawa (Nagoya, IAR)

Accelerated Universe Symposium @ KEK, Mar. 8-10, 2017

# VOIDER

## Collaborators (連携研究者)

Y. Urakawa

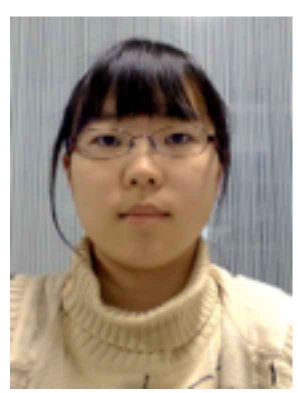
K. Ichiki

K. Hasegawa

T. Ishiyama (Chiba)

## Ph.D students involved

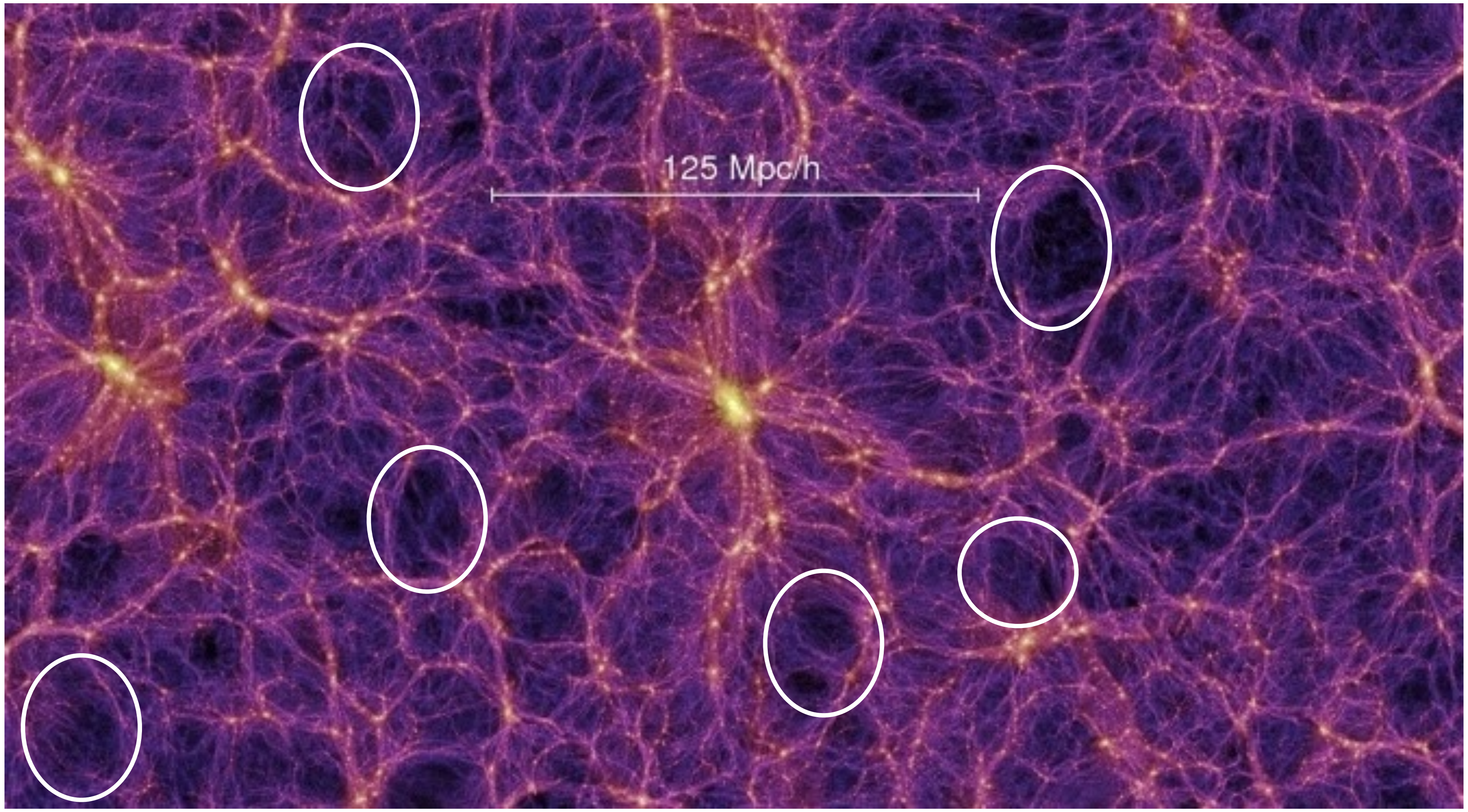
T. Endo (M2)



M. Minoguchi (M1)

c.f.

# Void in large-scale structure




- Low-density regions in large-scale structure enclosed (typically) by high-density shell.
- can be described in LINEAR to Quasi-LINAER regime
- use void as a tool to constrain cosmological models
- systematic due to the void finding algorithm

# Project overview

## Theory

**N-body simulations w/ standard model**

- Large (Np=4096^3)
- Construct theory template
- Covariance
- Evaluate Systematics

**N-body simulations w/ non-std. model**

- Medium (Np=1024^3)
- multi-parameters

**modified gravity**

WL sims

## Observation

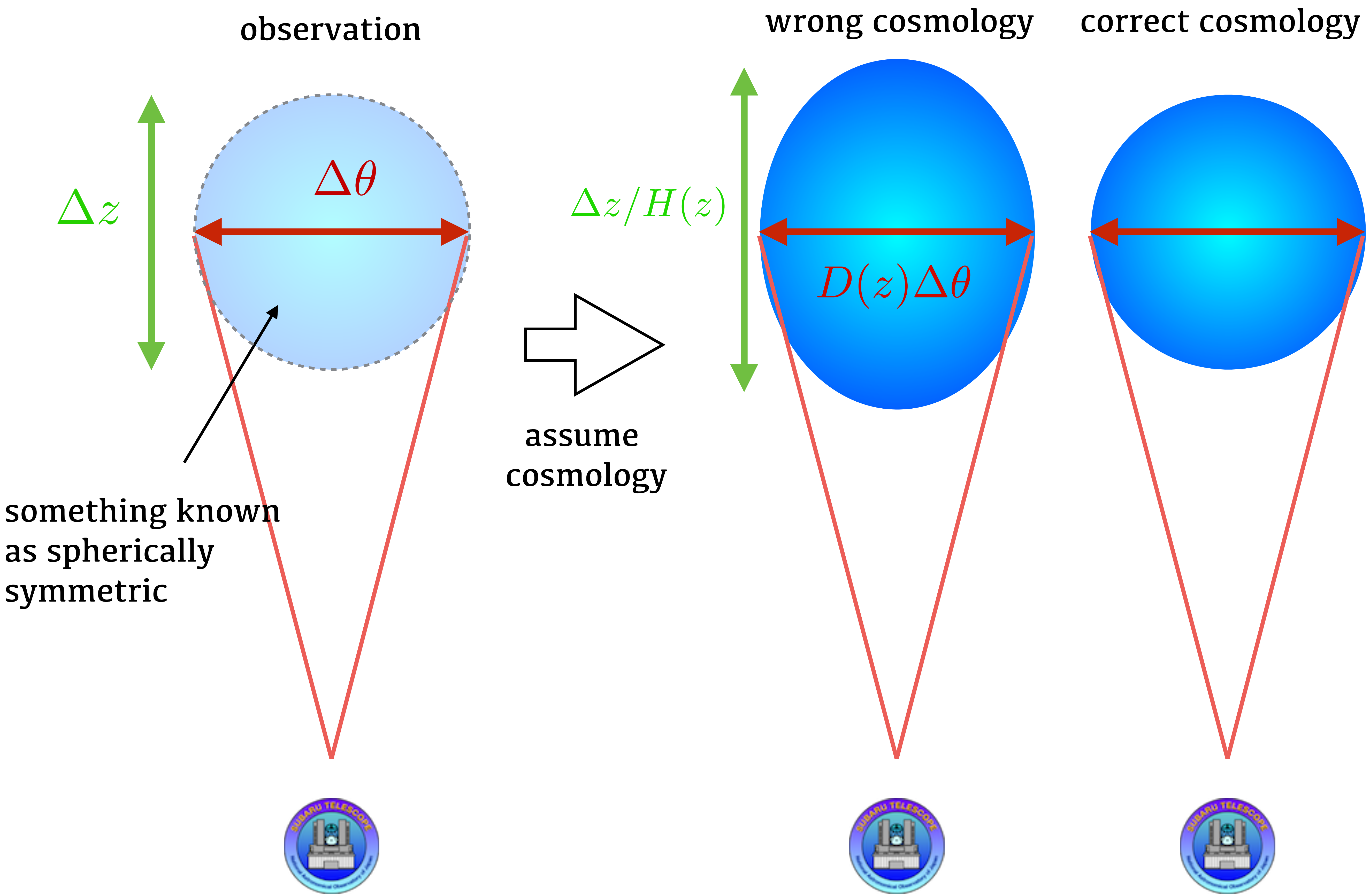
**BOSS - 3D void**

- gal-void x-corr.
- RSD
- AP test

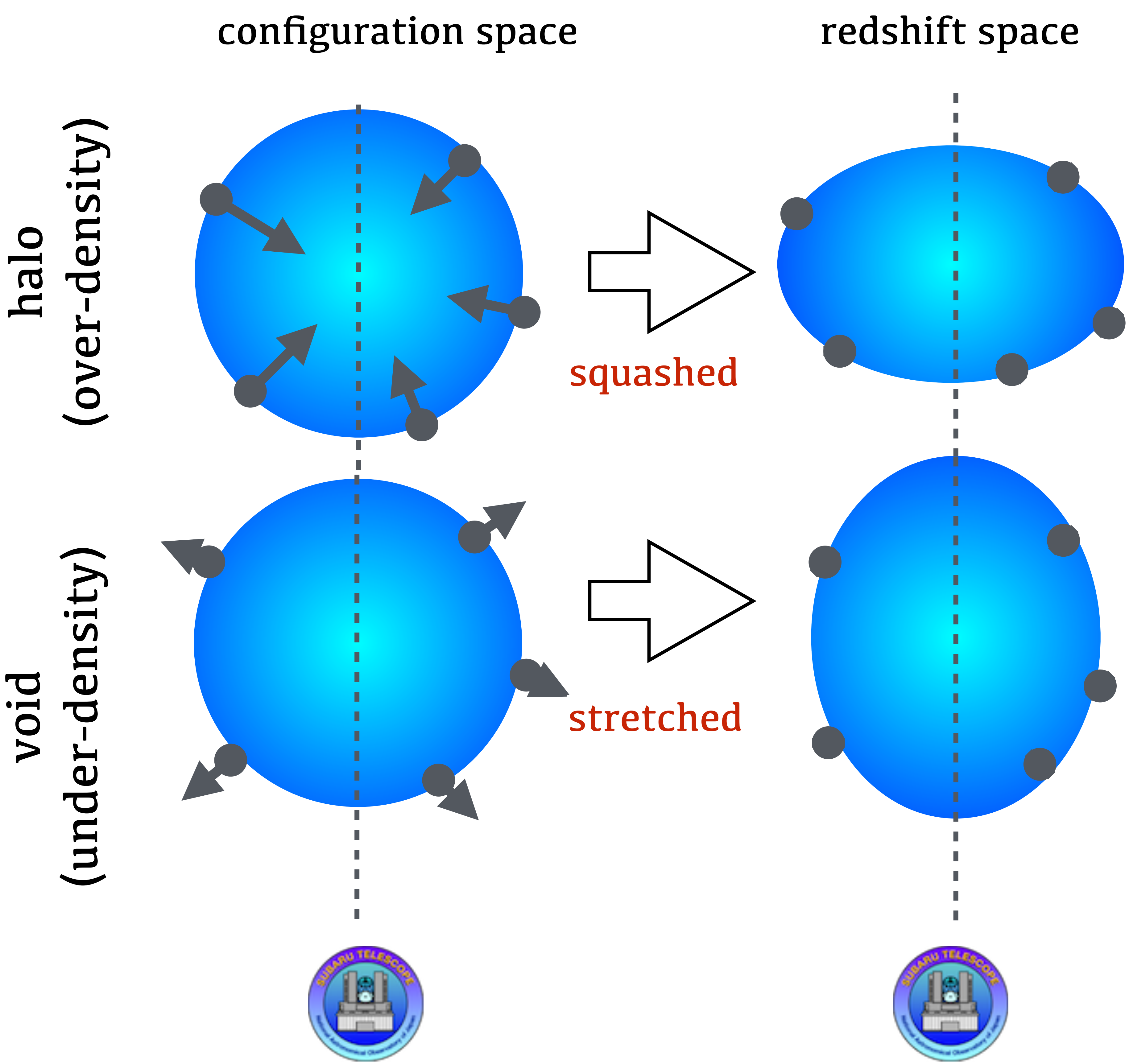
**HSC - 2D void**

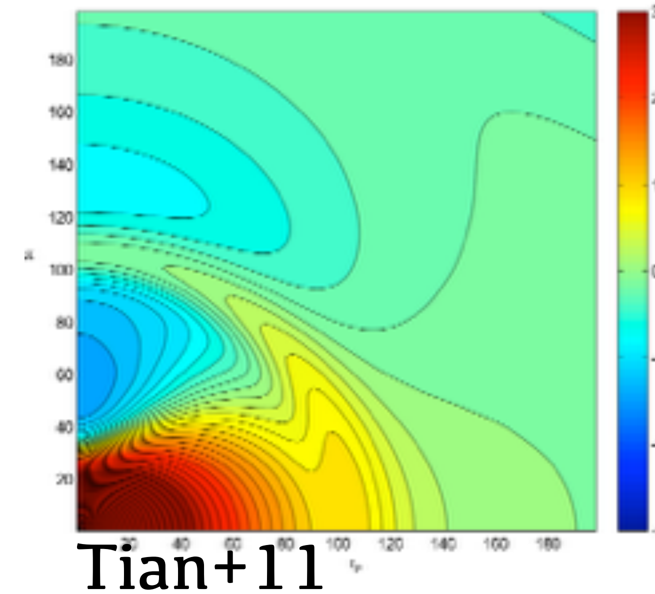
- void profile by lensing
- CMB x-corr.
- CMB anomaly

# Alcock-Paczynski (AP) Test

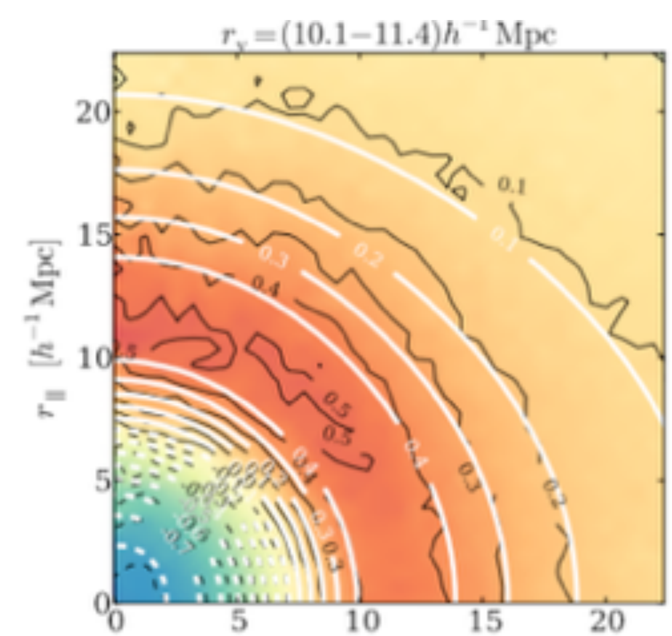


# Redshift Space Distortion for void



Tian+11



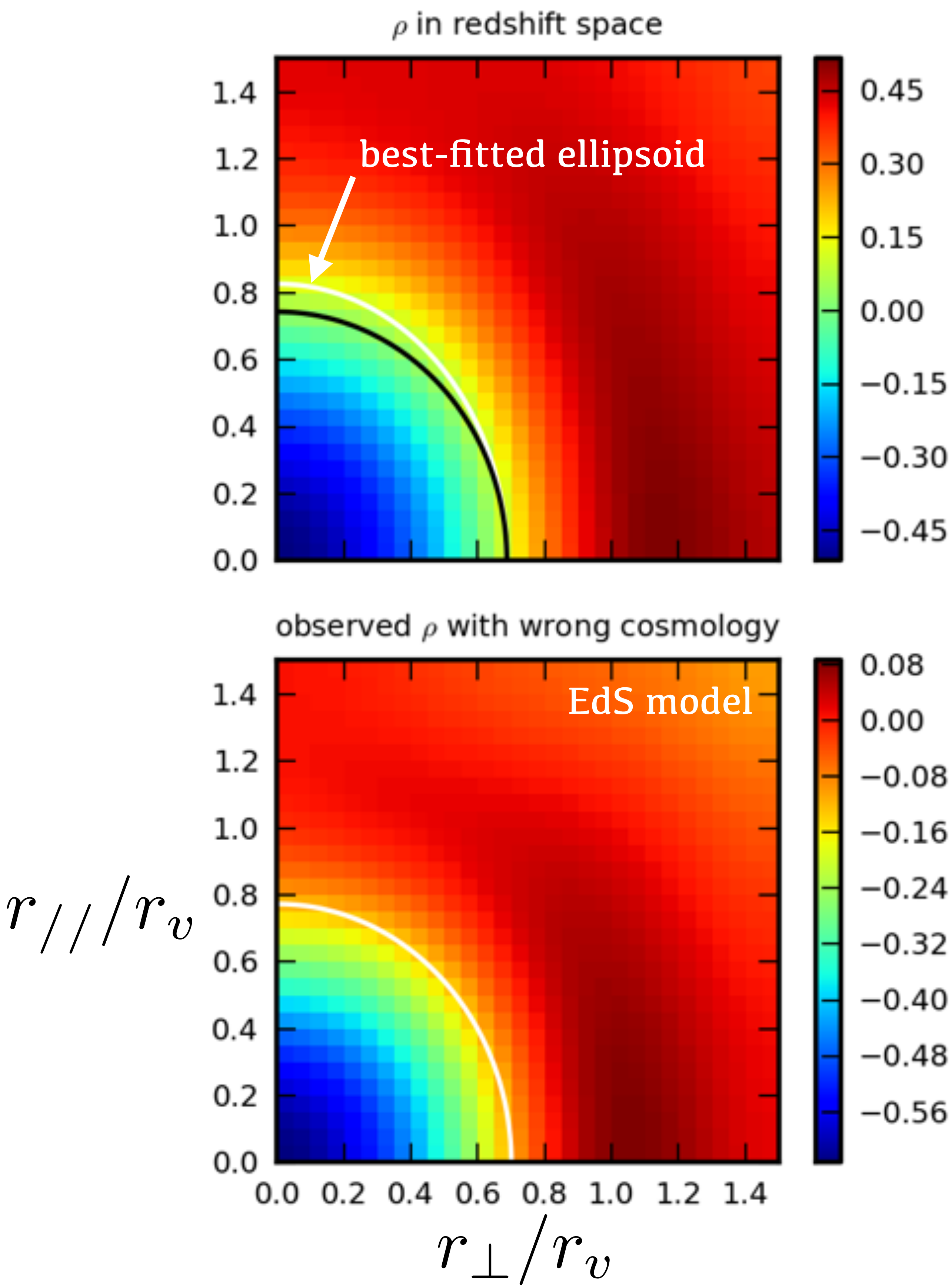

Hamaus+15

# Test Simulation

- Initial Condition
  - 2LPT (z_init=99)
- N-body simulation
  - code = GreeM (Ishiyama et al.) : fast up to Large Np (4096)
  - resources = XC30 (NAOJ) + 250 cores cluster (Nagoya)
  - Lbox = 500 Mpc/h
  - N_particles = $128^3$
  - Mass_particle = $1.9 \times 10^{12}$ Msun/h
  - Planck Cosmology (1 realization so far)
- Void finding
  - Void IDentification and Examination (VIDE: Sutter 2014)

  http://www.cosmicvoids.net/algorithm

# stacked void density profile

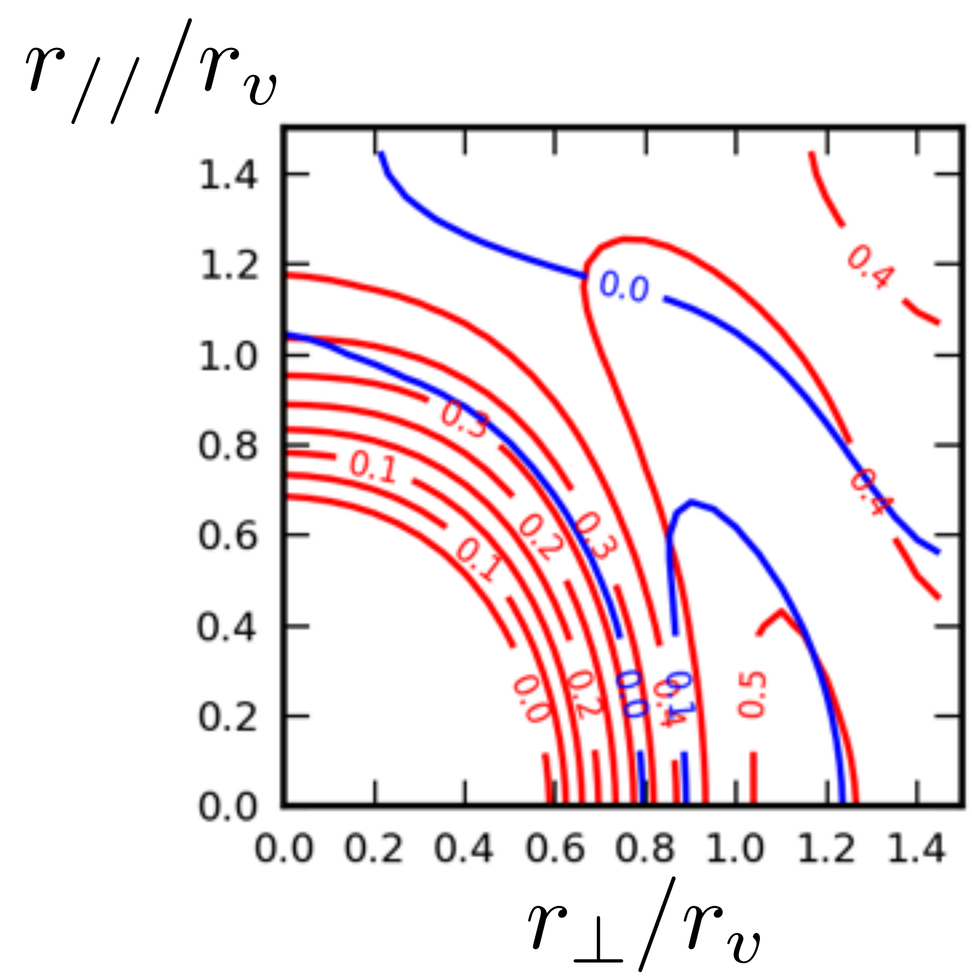



$$n_v(r_{//}, r_\perp) = \min\left\{ n_0 + \left[\left(\frac{r_{//}}{a_{//}}\right)^2 + \left(\frac{r_\perp}{a_\perp}\right)^2\right]^2, n_{\max} \right\}$$

$$\chi^2 = \sum_{i,j} \frac{[n_v(r|a_{//}, a_\perp) - n_{ij}]^2}{\sigma^2_{n,ij}}$$

Sutter et al. 2012

σ_nij are measured by 100 JackKnife sampling



# procedures

- run N-body dark matter simulation with Planck ΛCDM
- get (sub-)halo catalog (not yet implemented)
- add displacements to particles according to the velocity
- place simulation box at distance corresponding to the redshift and convert it in coordinate (ra, dec, z)
- void finding (associate particles to each void)
  - assume cosmology ($\Omega_{m0}$, $H_0$) to derive the physical size of the void and stack all the voids in the box
  - obtain the stretch, $e(r):=\Delta s_\sigma/\Delta s_\pi$ as a function of distance from void center
  - fit e with model obtained from $\xi_s^{mv}(s,\mu)$ to get Likelihood
- Find the optimal solution

# stacked void density profile

- Can extend the usual RSD formula for galaxies
- Cross-Correlation Function btwn. void and galaxies,

$$\xi^s_{\rm gv}(\mathbf{s}) = \sum_\ell \xi^{s,(\ell)}_{\rm gv}(\mathbf{s})\mathcal{P}_\ell(\mu)$$

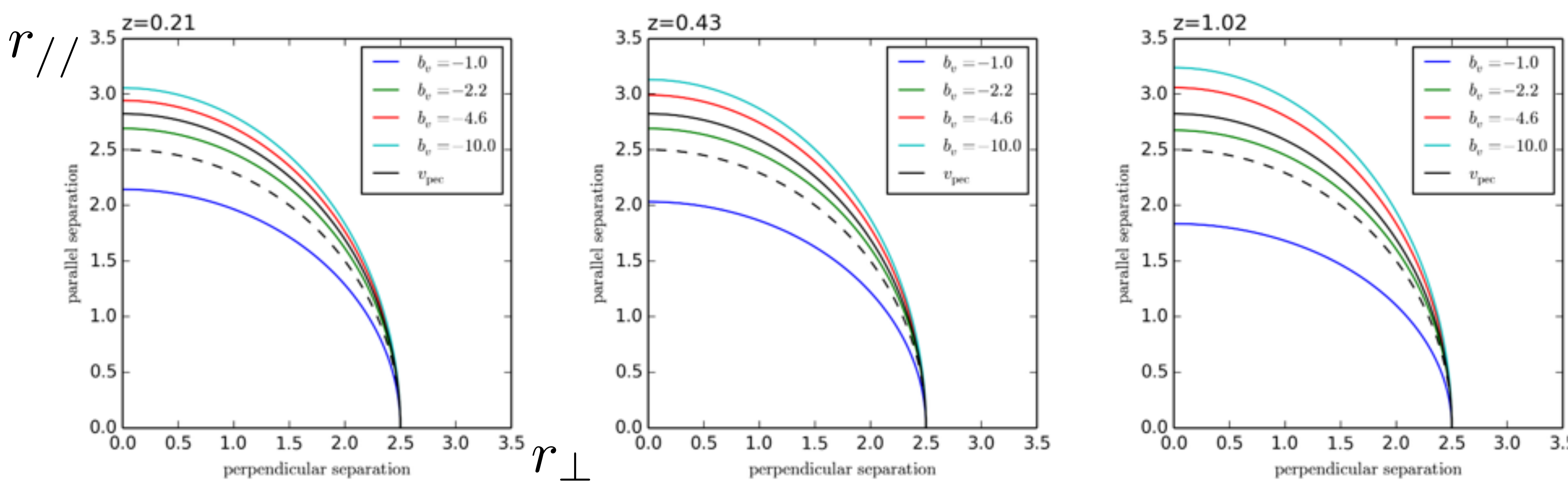
$$\xi^{s,(0)}_{\rm gv}(\mathbf{s}) = \left[1+\frac{1}{3}(\beta_{\rm g}+\beta_{\rm v})+\frac{1}{5}\beta_{\rm g}\beta_{\rm v}\right]\xi_{\rm gv}(r)$$

$$\xi^{s,(2)}_{\rm gv}(\mathbf{s}) = \left[\frac{2}{3}(\beta_{\rm g}+\beta_{\rm v})+\frac{4}{7}\beta_{\rm g}\beta_{\rm v}\right]\left[\xi_{\rm gv}(r)-\frac{3}{r^3}\int_0^r r'^2\xi_{\rm gv}(r')dr'\right]$$

$$\xi^{s,(4)}_{\rm gv}(\mathbf{s}) = \left[\frac{8}{35}\beta_{\rm g}\beta_{\rm v}\right]\left[\xi_{\rm gv}(r)+\frac{15}{2r^3}\int_0^r r'^2\xi_{\rm gv}(r')dr'\,\frac{35}{2r^5}\int_0^r r'^4\xi_{\rm gv}(r')dr'\right]$$

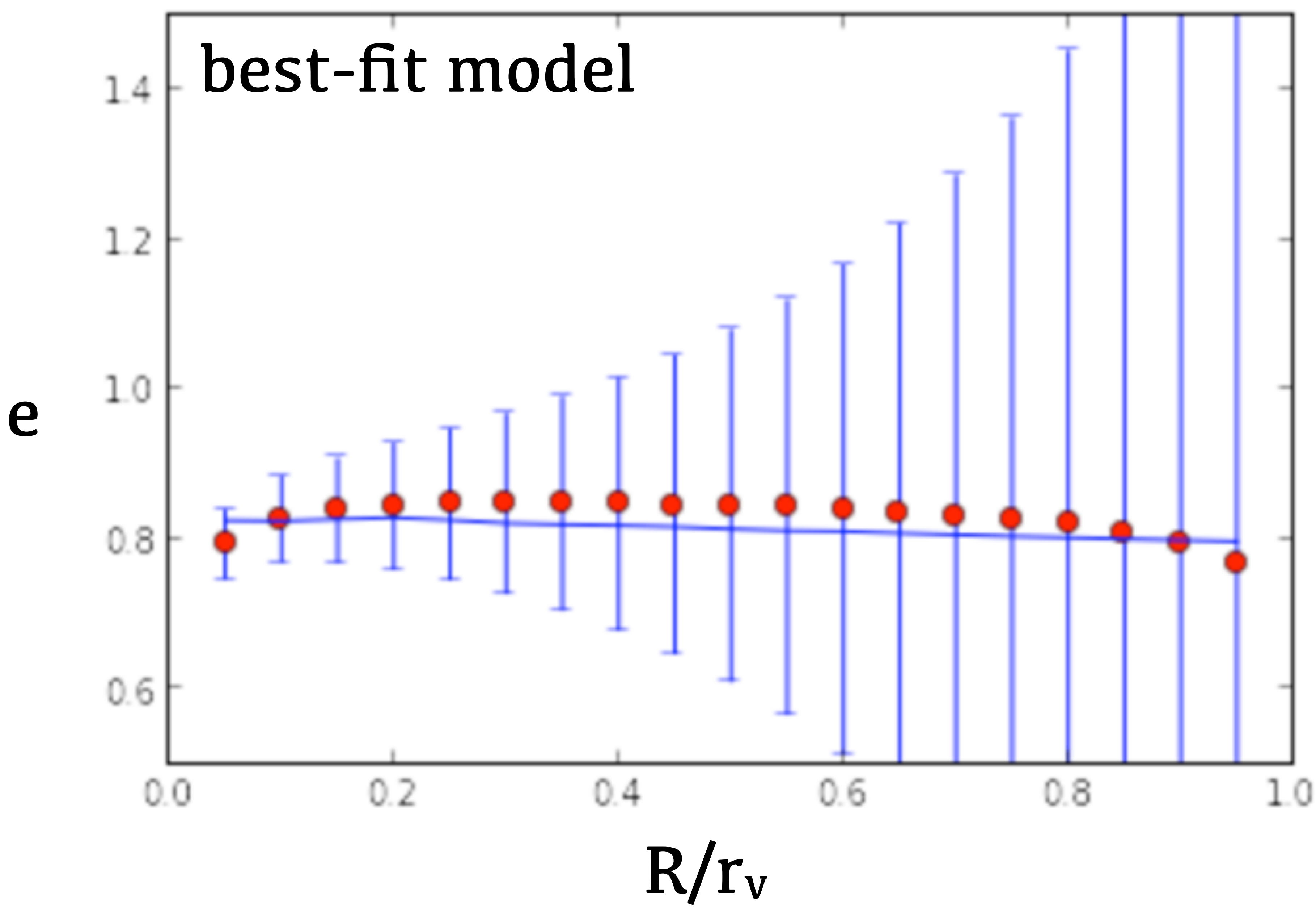
Hamilton 1992
e.g. Mountrichas+ 2009

- Halo model based approach (Endo et al. in prep)



# stretching estimator

$$e(r) = \left.\frac{r_\perp}{r_{//}}\right|_{n(r_{//},0)=n(0,r_\perp)} \qquad e^{\rm th}(r) = \left.\frac{r_\perp}{r_{//}}\right|_{\xi_s^{\rm mv}(r_{//},0)=\xi_s^{\rm mv}(0,r_\perp)}$$



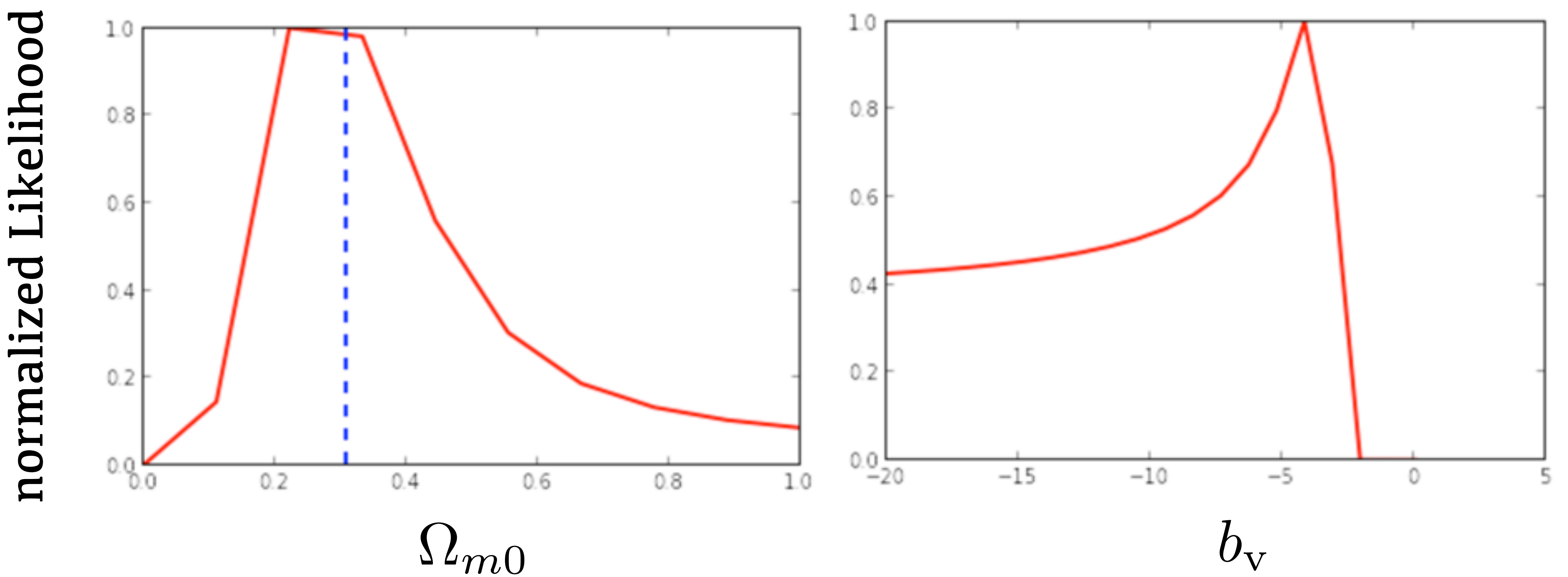

- insensitive to the absolute value of the density profile
- direct measure of the distortion of the void shape
- discard higher order info. (i.e., hexadecapole…)

# marginalized Likelihood

$$2\ln\mathcal{L} = \sum_{i}^{r/r_v \in 1.5} \left[\frac{e(r_i) - e^{\rm th}(r_i)}{\sigma_e(r_i)}\right]^2$$

$$\mathcal{L}(\Omega_{m0}) = \int \mathrm{d}b_{\rm v}\ \mathcal{L}(\Omega_{m0}, b_v)$$

- other cosmological parameters are fixed
- particle bias (halo-bias) is assumed to 1 which in reality can be measured directory from ξhh

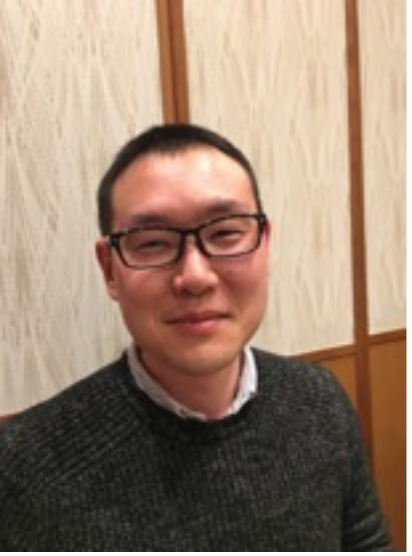


# summary

- RSD is modeled by Kaiser's formula with linear theory xi
- Halo model approach to model xi (Endo+)
- pairwise velocity distribution (as Hamaus+2015)

- Run real simulation
- Construct halo catalog (w/ Nishimichi, Oogi+)

- Modify N-body code for some modified gravity theory (w/ Ishiyama, Tsujikawa+)



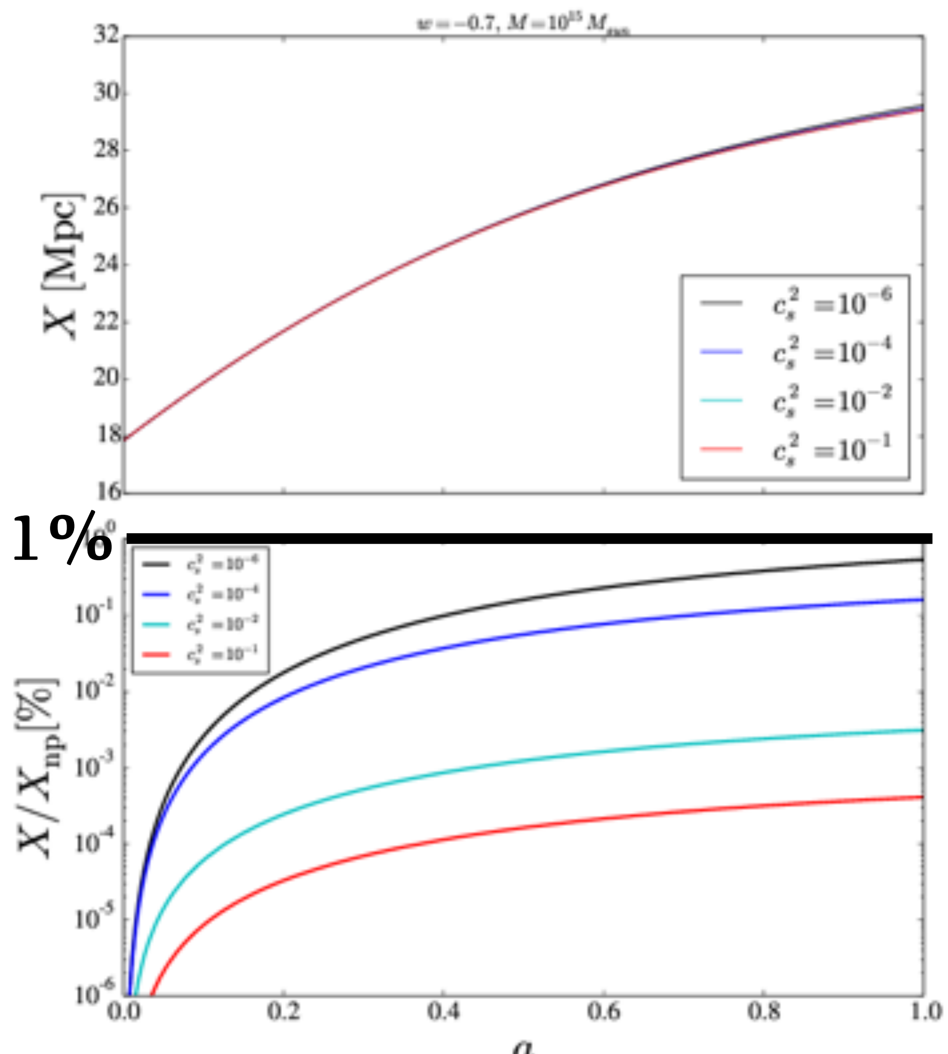
# Endo et al. 2017

- Effect of DE perturbation (DEP) on the void formation is studied
- negligible impact on the size of spherically collapsed voids
- But it affects the size distribution through "$\sigma_R$" in the PS formalism

void size evolution

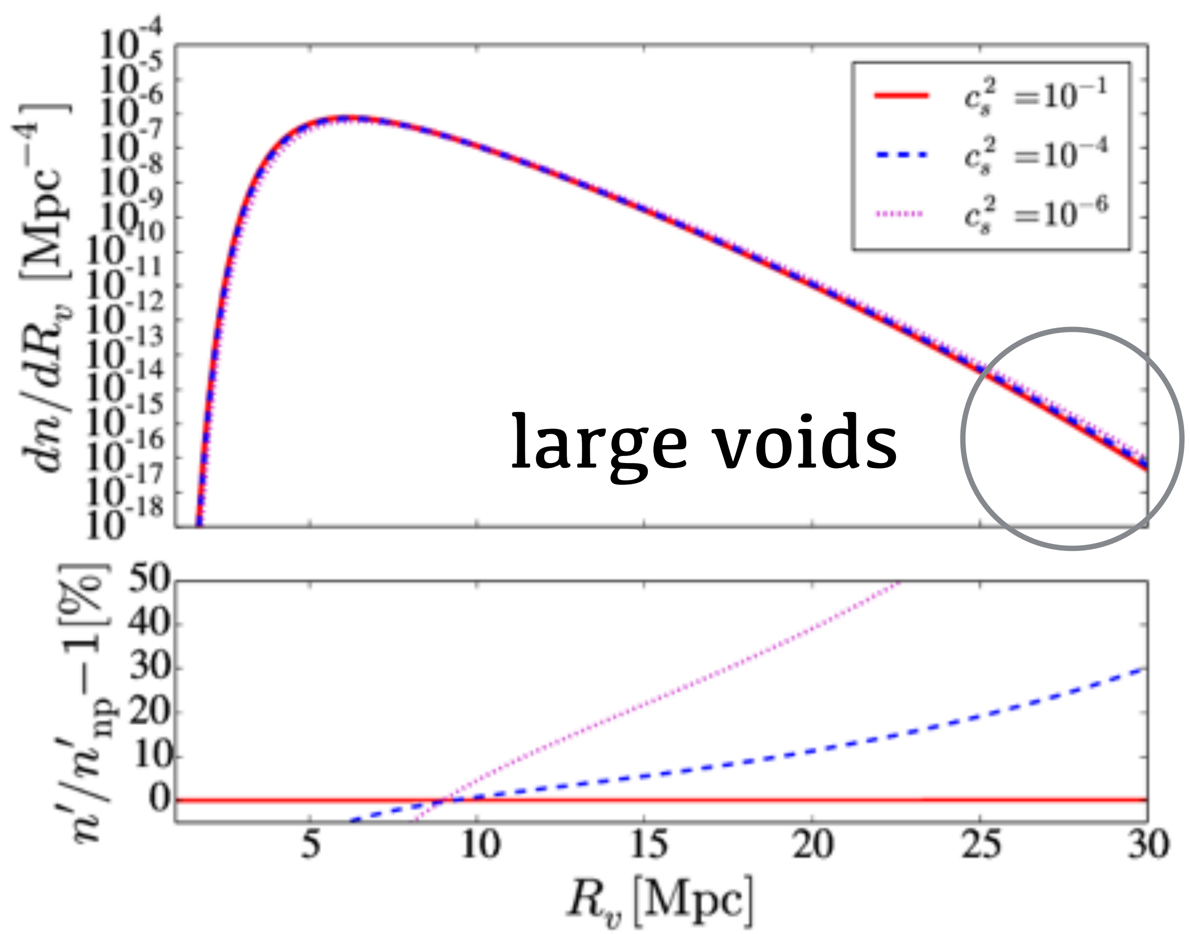
void size [Mpc]

diff (%)

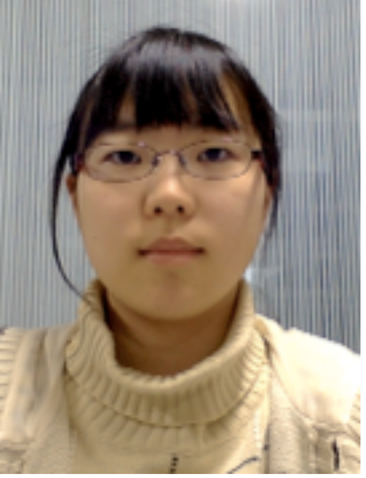



scale factor a

void size distribution

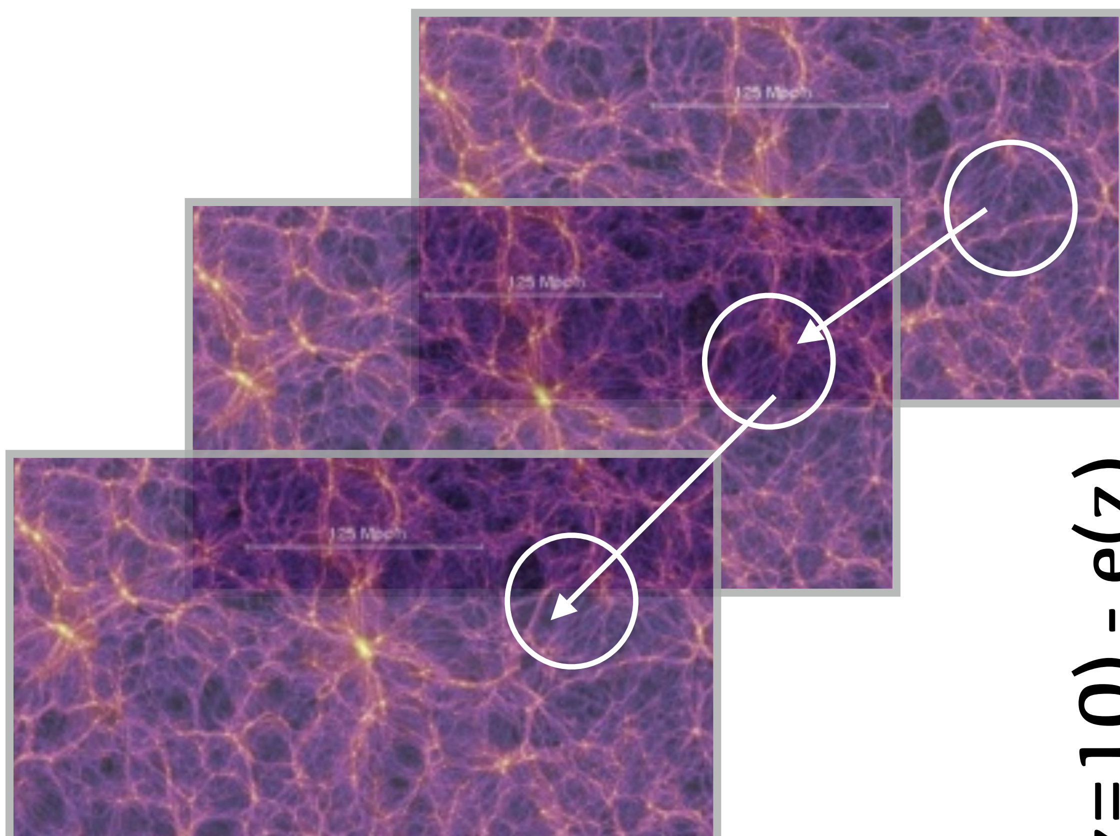


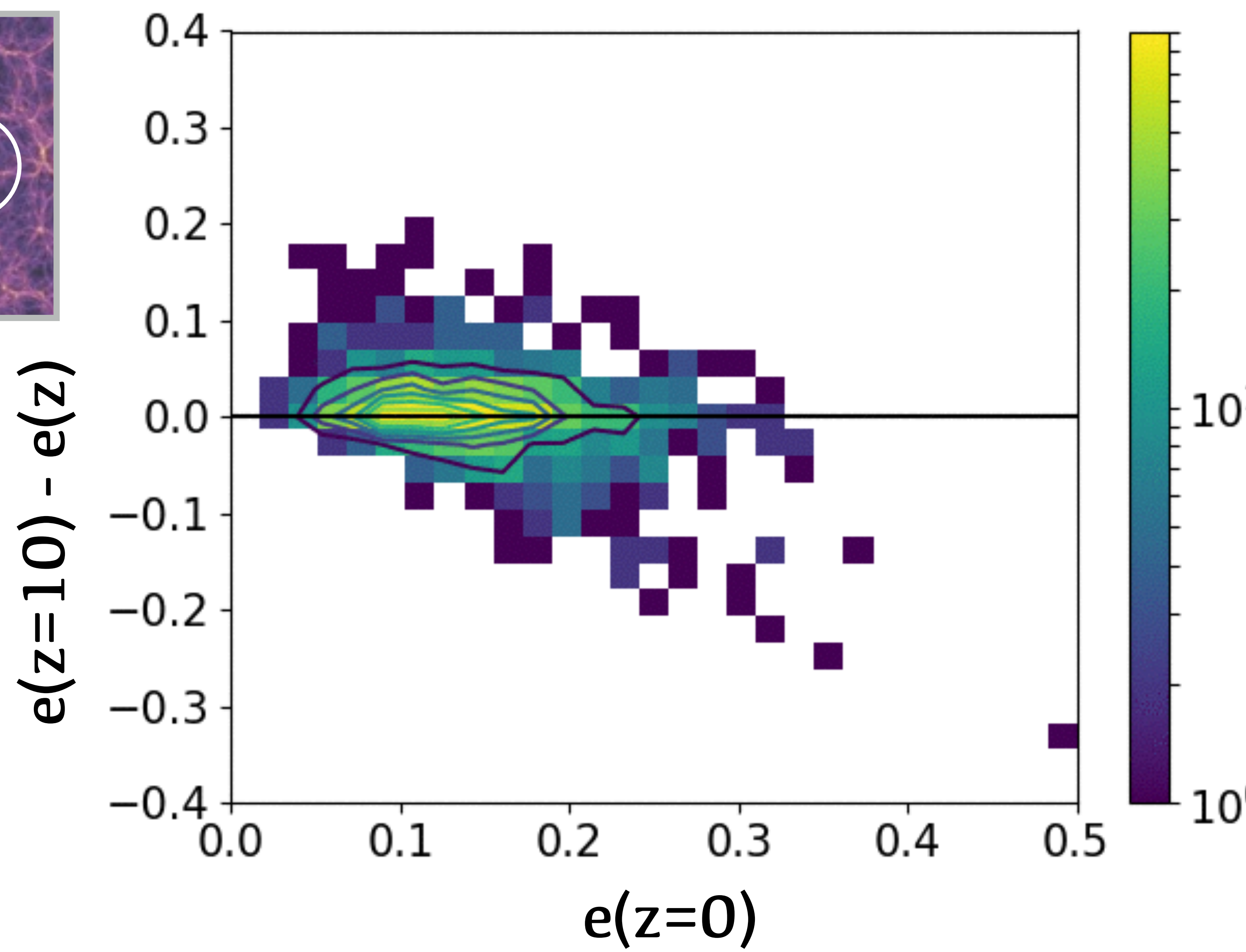

void size



# Minoguchi et al. in prep.

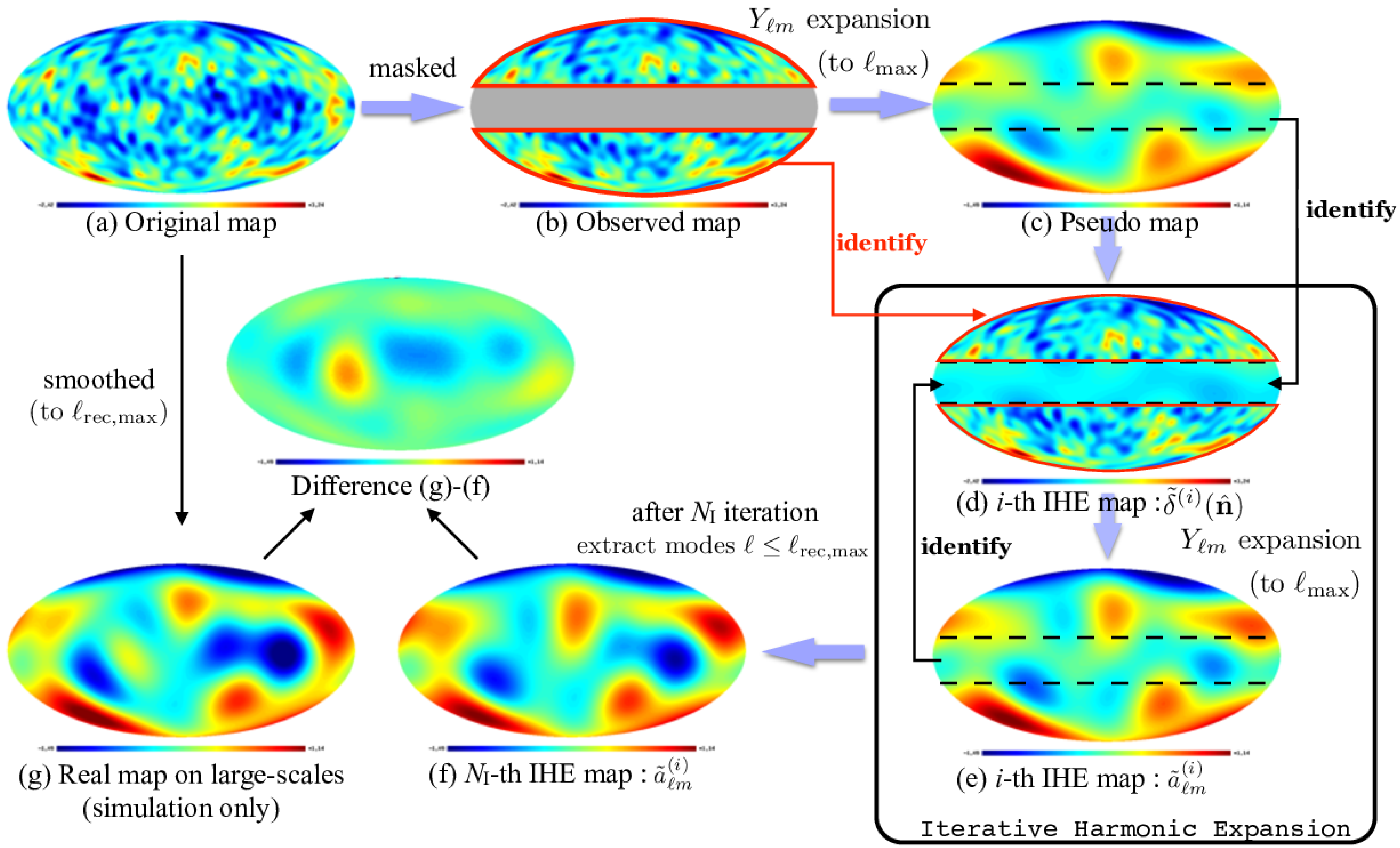
- Construct Void merger tree to track the evolution of voids
- How the ellipticity of void evolves in the cosmic time
- Comparison to analytic solution (axially symmetric collapse model)





# Map Reconstruction Method

AJN, K.T. Inoue 2016 MNRAS 462(1), 588




- Basically no assumptions on the underlying map
- can apply to highly non-gaussian map
- can apply not only to 2D map (e.g. CMB) but 3D (galaxy survey)