Dark Quest II project and halo shapes

Takahiro Nishimichi (YITP, Kyoto U / Kavli IPMU, U of Tokyo)

w/ **Satoshi Tanaka**, and many others in HSC weak lensing working group

See also:

TN+ ApJ ***884*** *(2019) 29*

Kobayashi+ PRD ***102*** *(2020) 063504*

Kobayashi+ PRD ***105*** *(2022) 083517*

Miyatake+ PRD ***106*** *(2022) 083519*

Miyatake+ PRD ***106*** *(2022) 083520*

Cuesta-Lazaro+ arXiv:2208.05218

for DQ I and its main applications

“New Frontiers in Cosmology with the Intrinsic Alignments of Galaxies”, YITP Kyoto U, 9 Dec. 2022

Disclaimer!

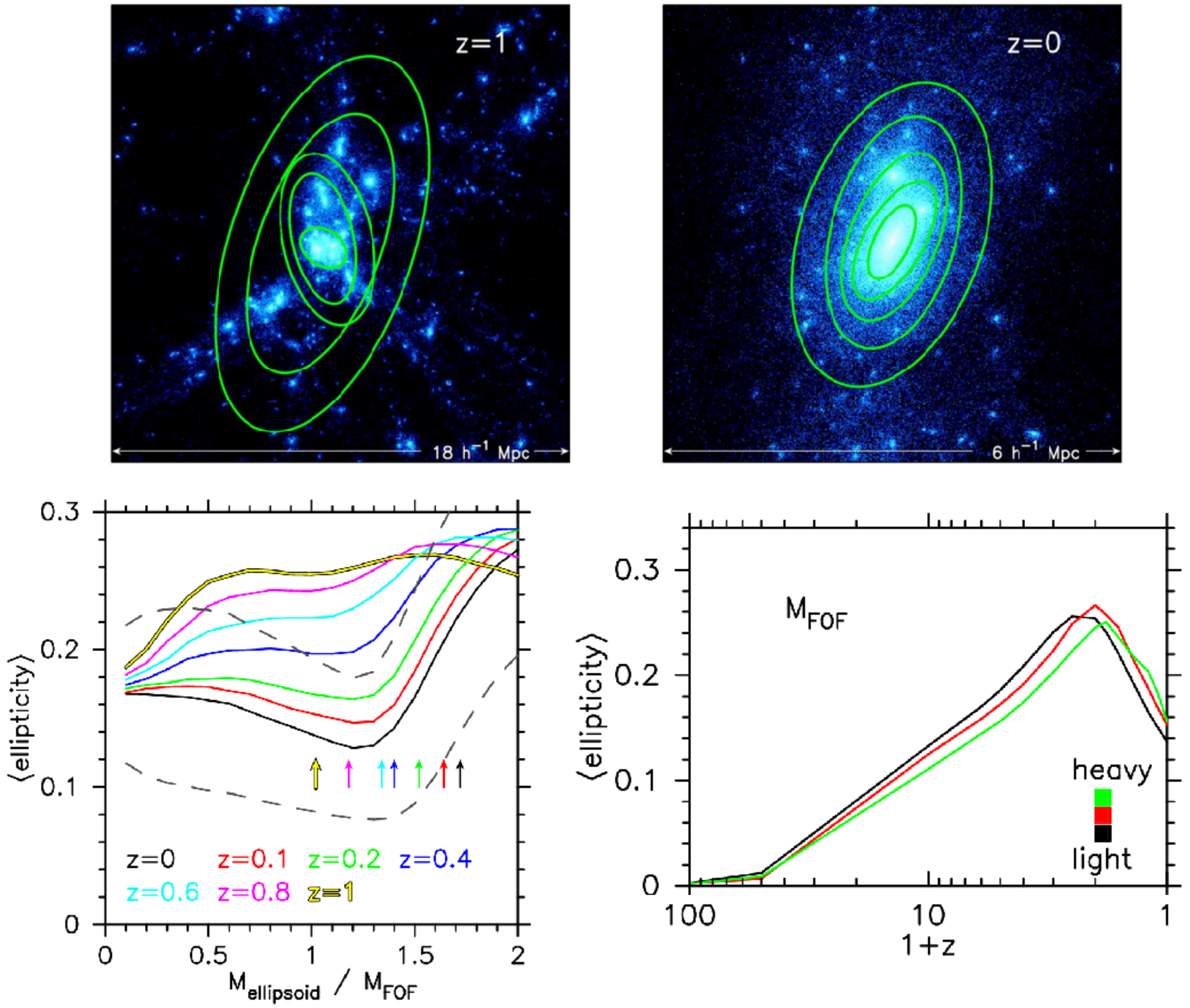
- I am not really seriously working on IA myself !
- But had the opportunities for some fruitful collaborations on shapes of halos and galaxies thanks to many (mostly young) people
  - w/ D. Suto/T. Okabe (U Tokyo) on halo shapes (pre DQ1) arXiv:1608.06494, arXiv:1611.05192, arXiv:1804.08843, arXiv:1911.04653, arXiv:2005.11469
  - w/ Ken Osato on projection effects (DQ1 data)
  - w/ Teppei Okumura on the configuration-space IA signal (DQ1 data)
  - w/ Toshiki Kurita on the Fourier-space counterpart (DQ1 data)
    - (see also Kazu Akitsu on non-Gaussianity)
  - w/ Shogo Ishikawa on cluster shapes traced by subhalos (DQ2 data)

Already covered

Disclaimer!

- The “Dark Quest” simulation campaign was originally planned for
  - BAO, RSD, weak lensing (2x2 or 3x2 pt analyses)
- Given the many interesting science cases from galaxy (halo) shapes, I now am seriously thinking of adding them as a part of the standard outputs of the DQ2 products
- Super preliminary results on halo shapes are at the very end of the talk (I have to thank **Satoshi Tanaka** for his hard work!)

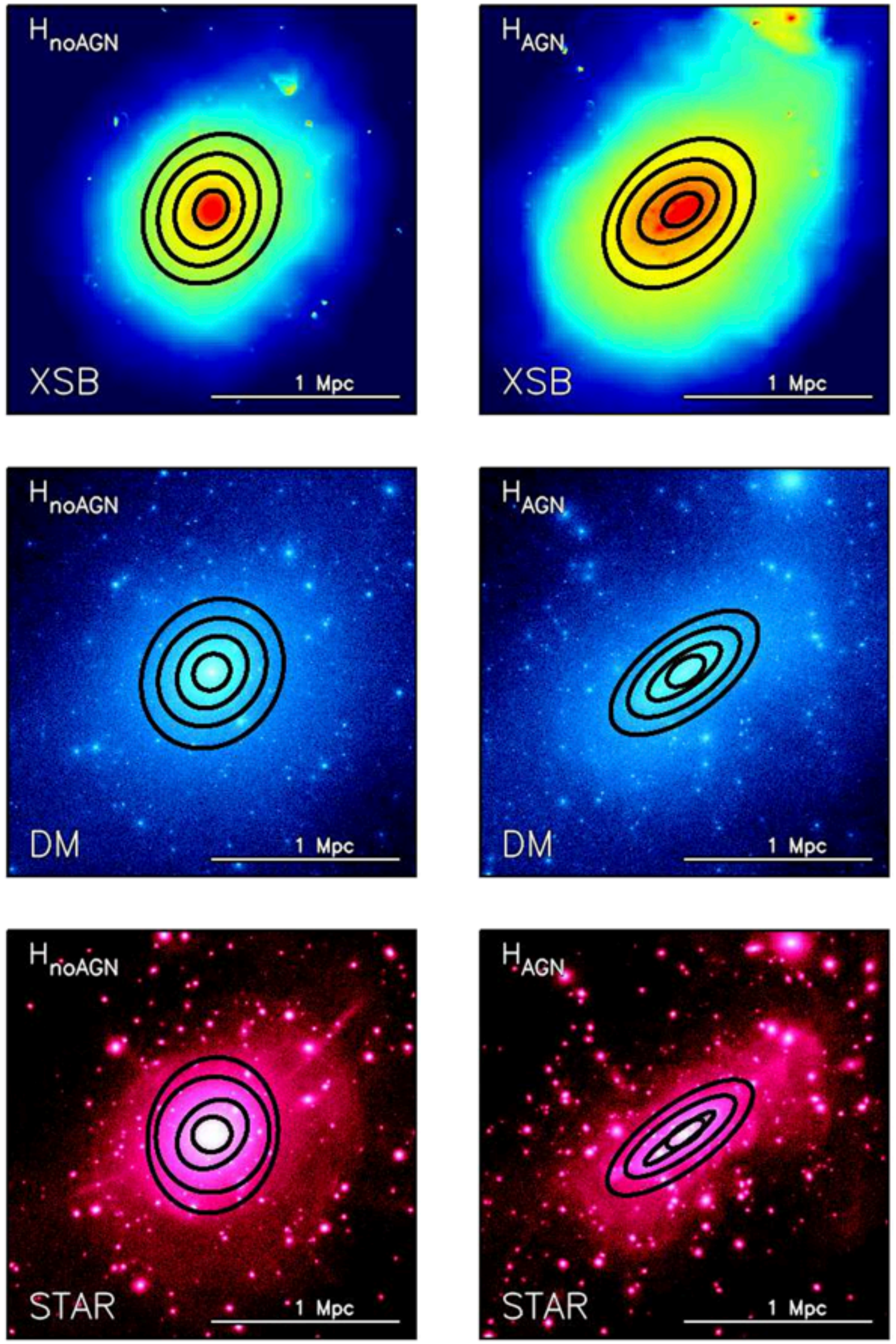
Halo shapes (groups — clusters)

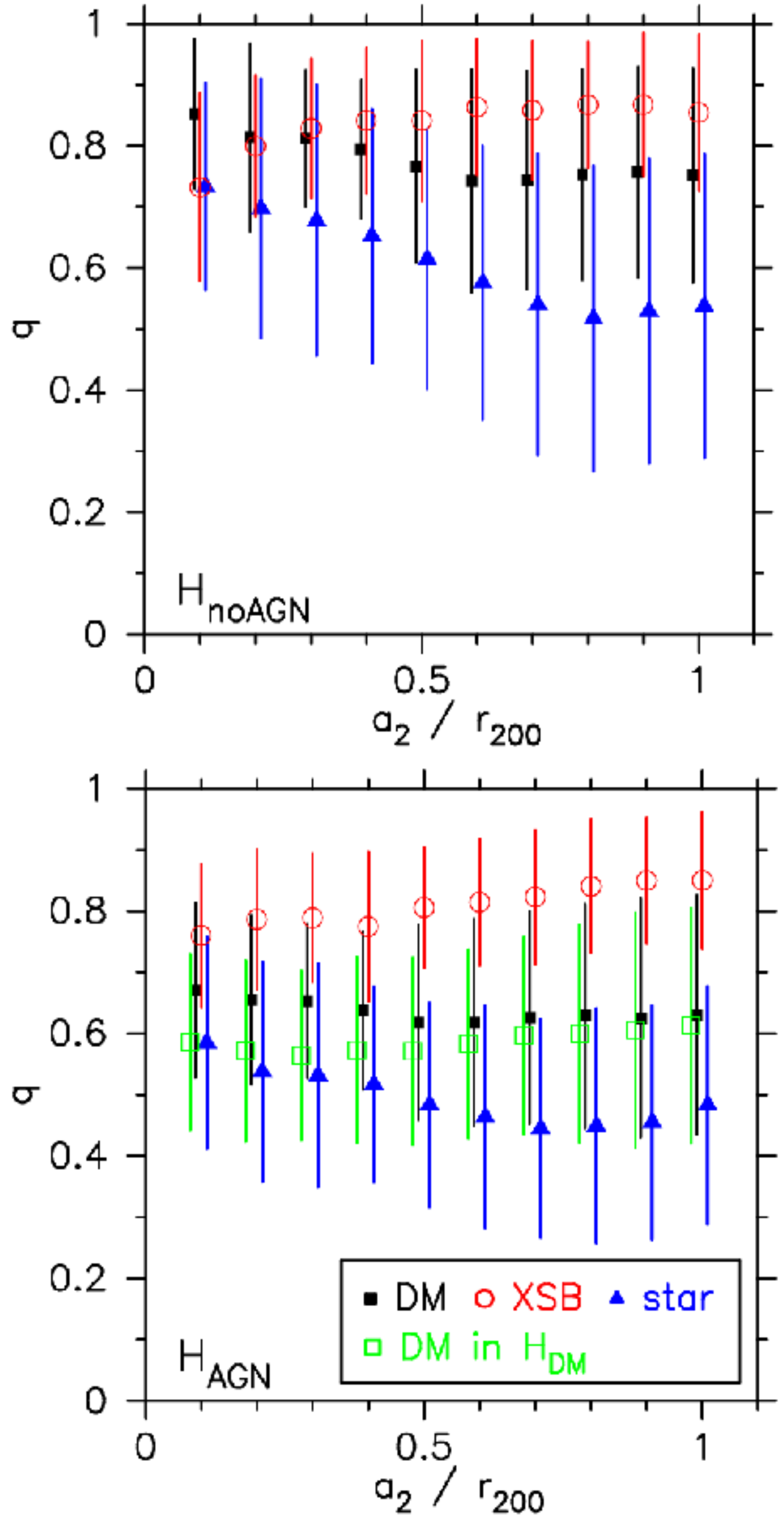


Suto+ arXiv:1608.06494

- Halos acquire the current shape in a complicated manner
  - Time dependence
  - Radial dependence
  - Mass dependence
  - Weighting scheme

Halo shapes (groups — clusters)



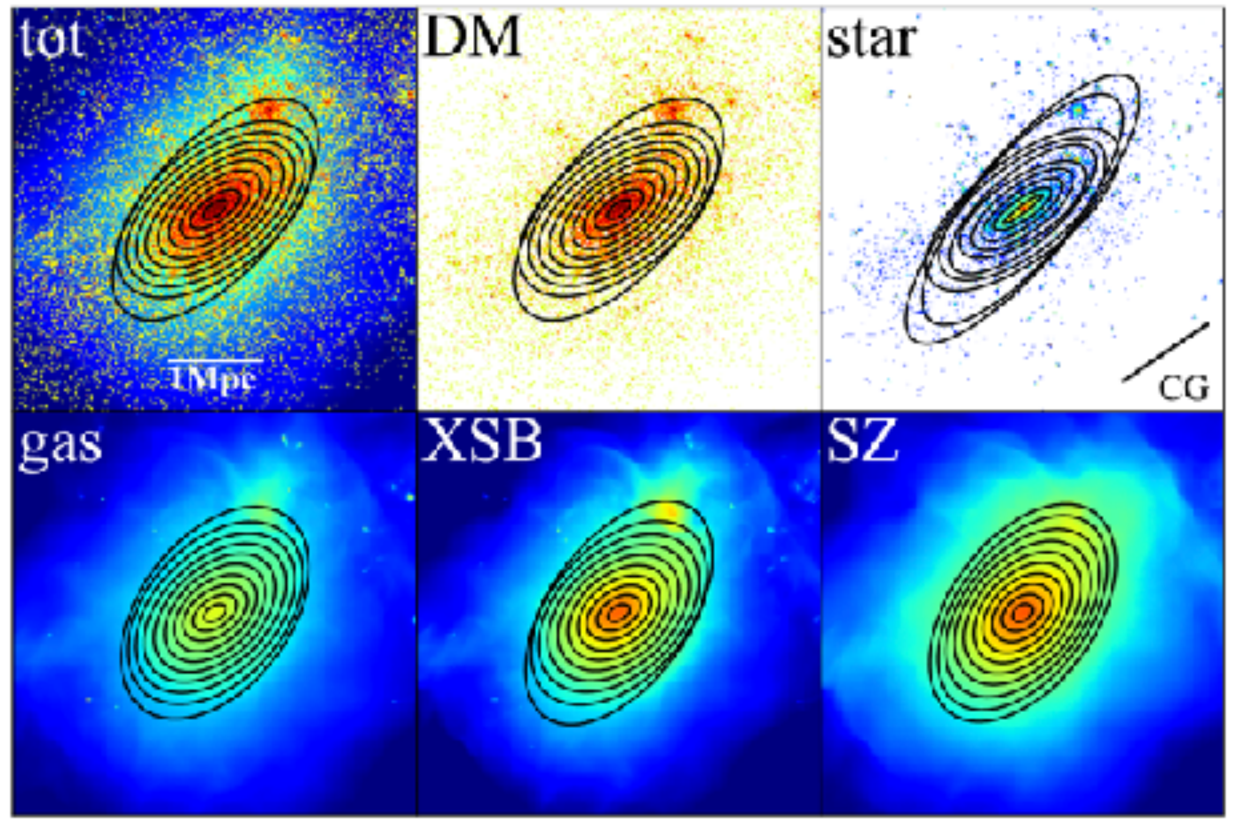


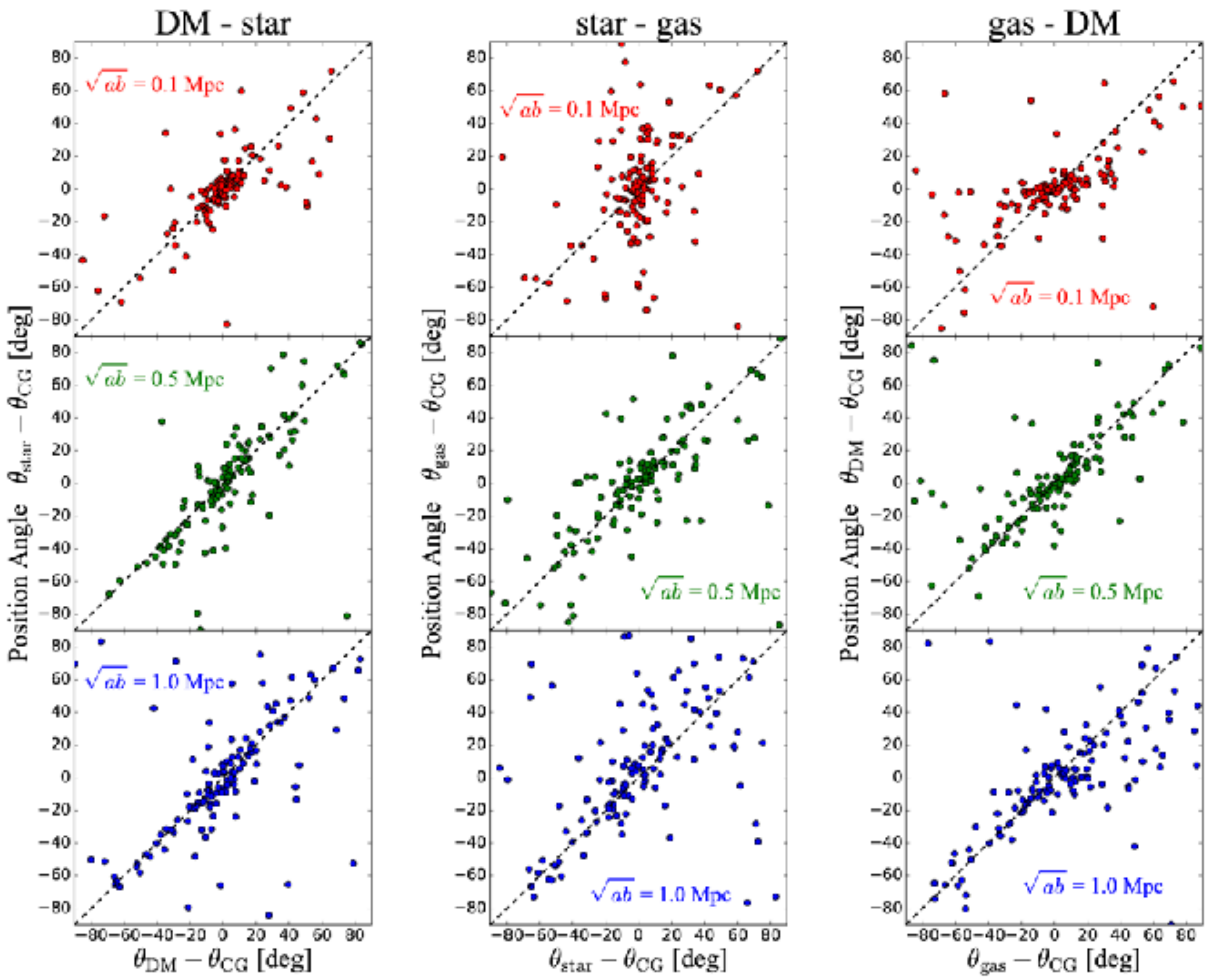
Suto+ arXiv:1611.05192

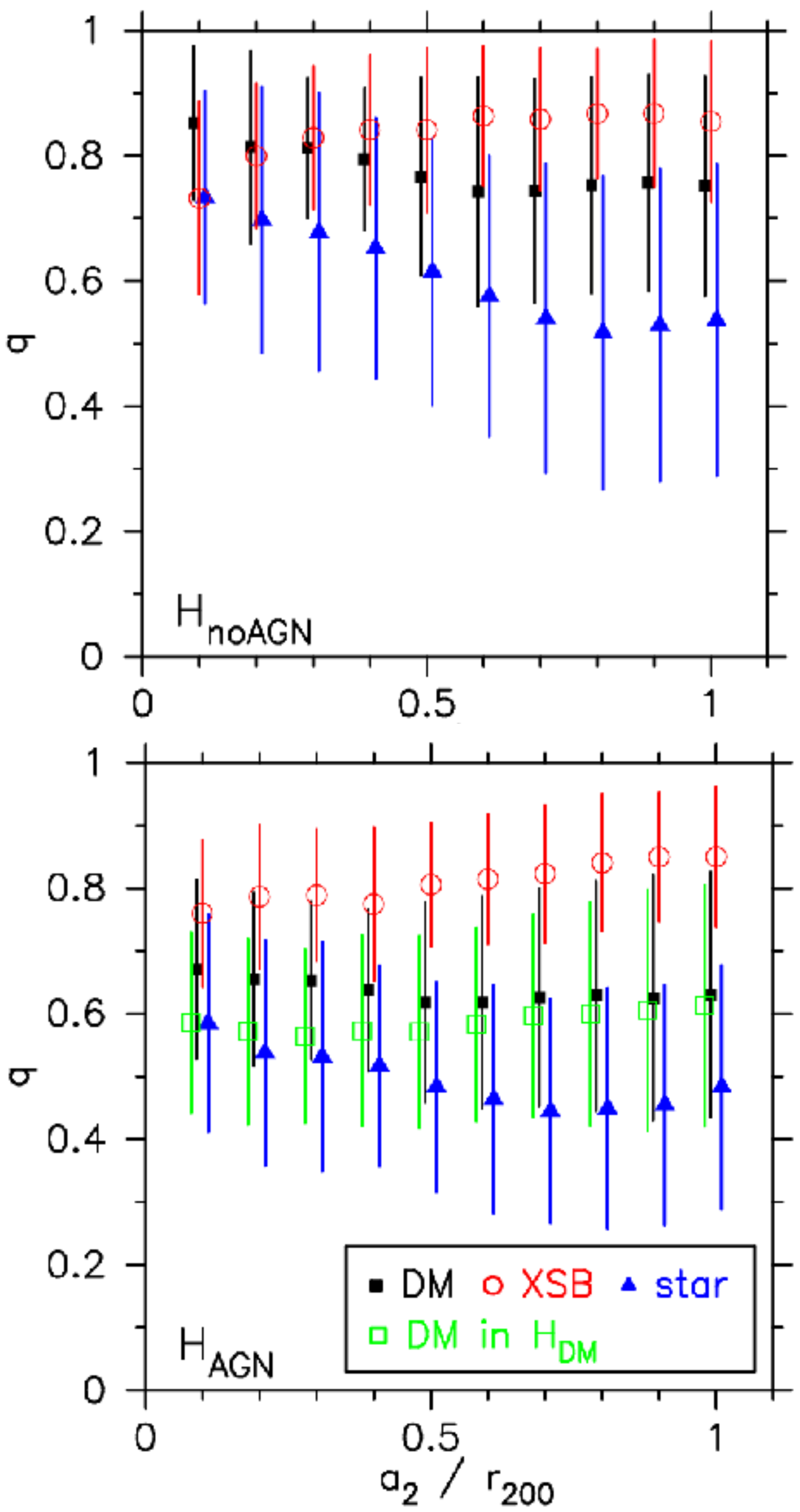
Horizon AGN simulation

- Halos acquire the current shape in a complicated manner
  - Impact of baryonic physics
  - Dependence on what we actually observe

Halo shapes (groups — clusters)







Suto+ arXiv:1611.05192

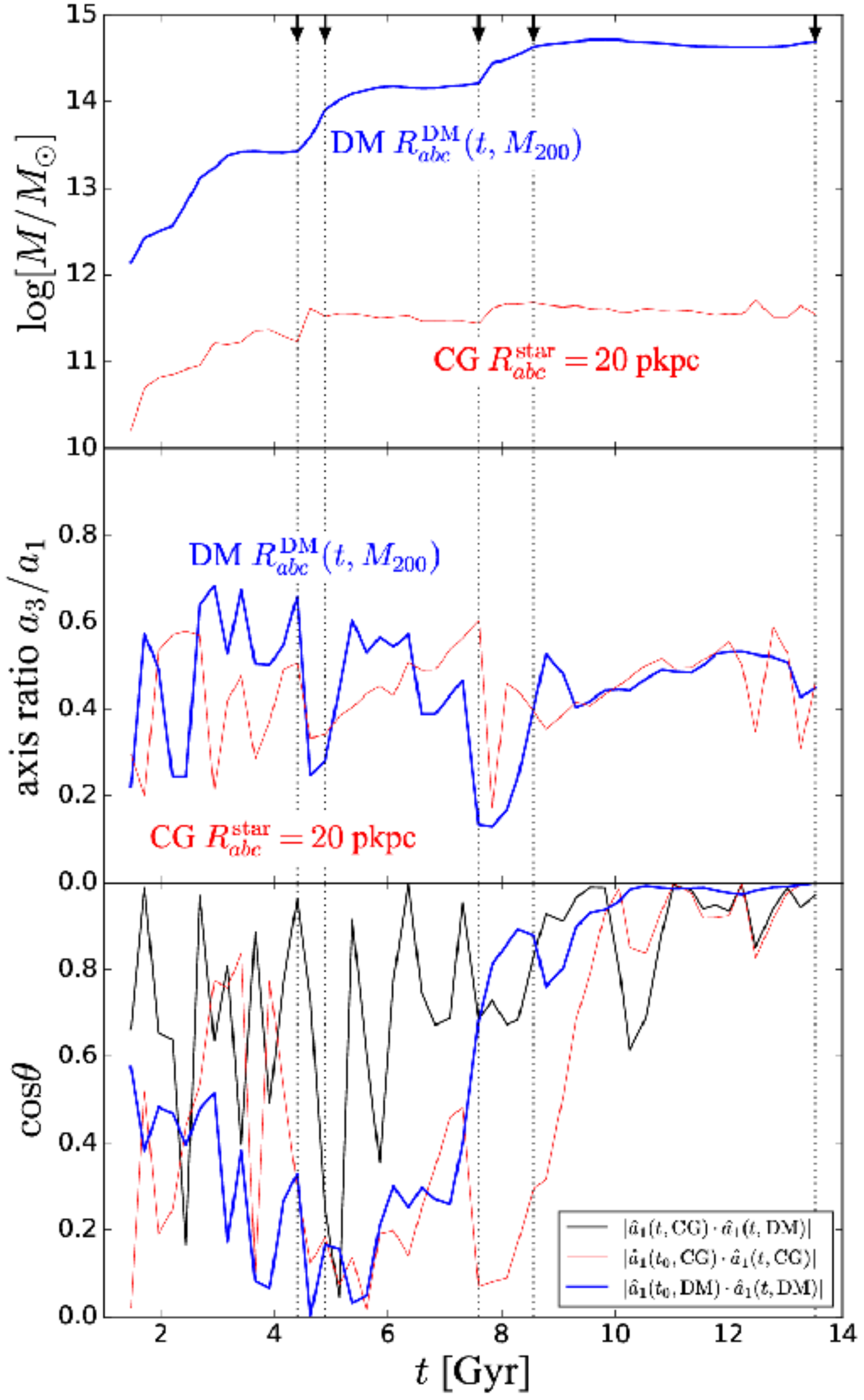
Okabe+ arXiv:1804.08843

Horizon AGN simulation

- Halos acquire the current shape in a complicated manner
  - Impact of baryonic physics
  - Dependence on what we actually observe

T. Nishimichi (YITP, Kyoto U)

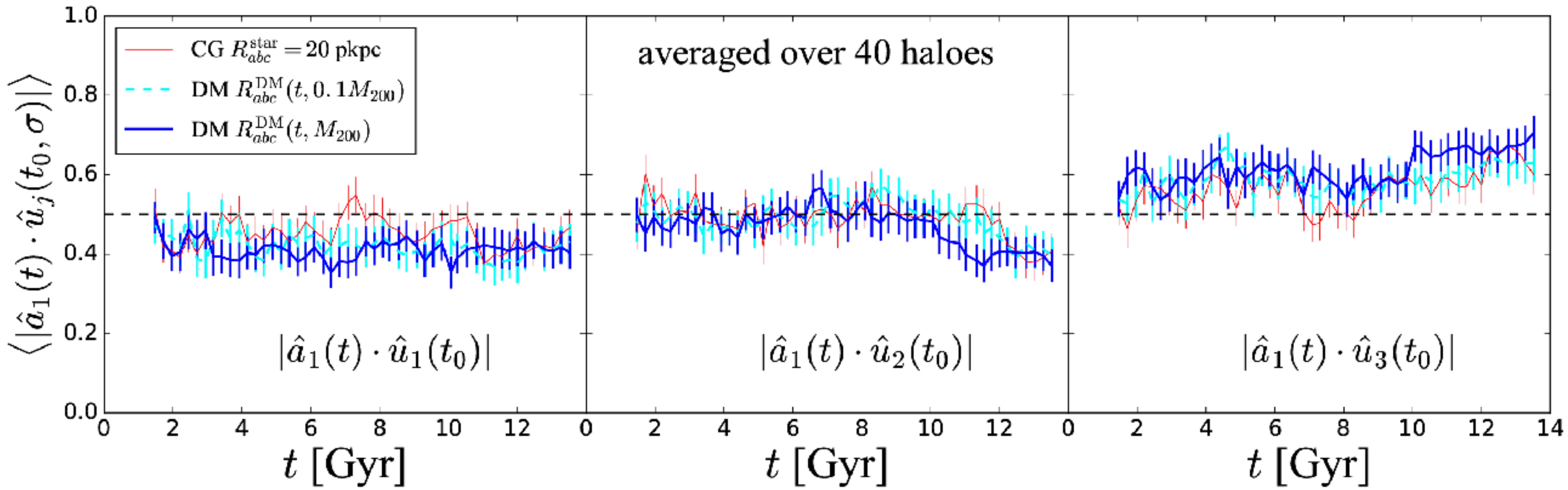
Halo shapes (groups — clusters)



Okabe+ arXiv:1911.04653

Horizon AGN simulation

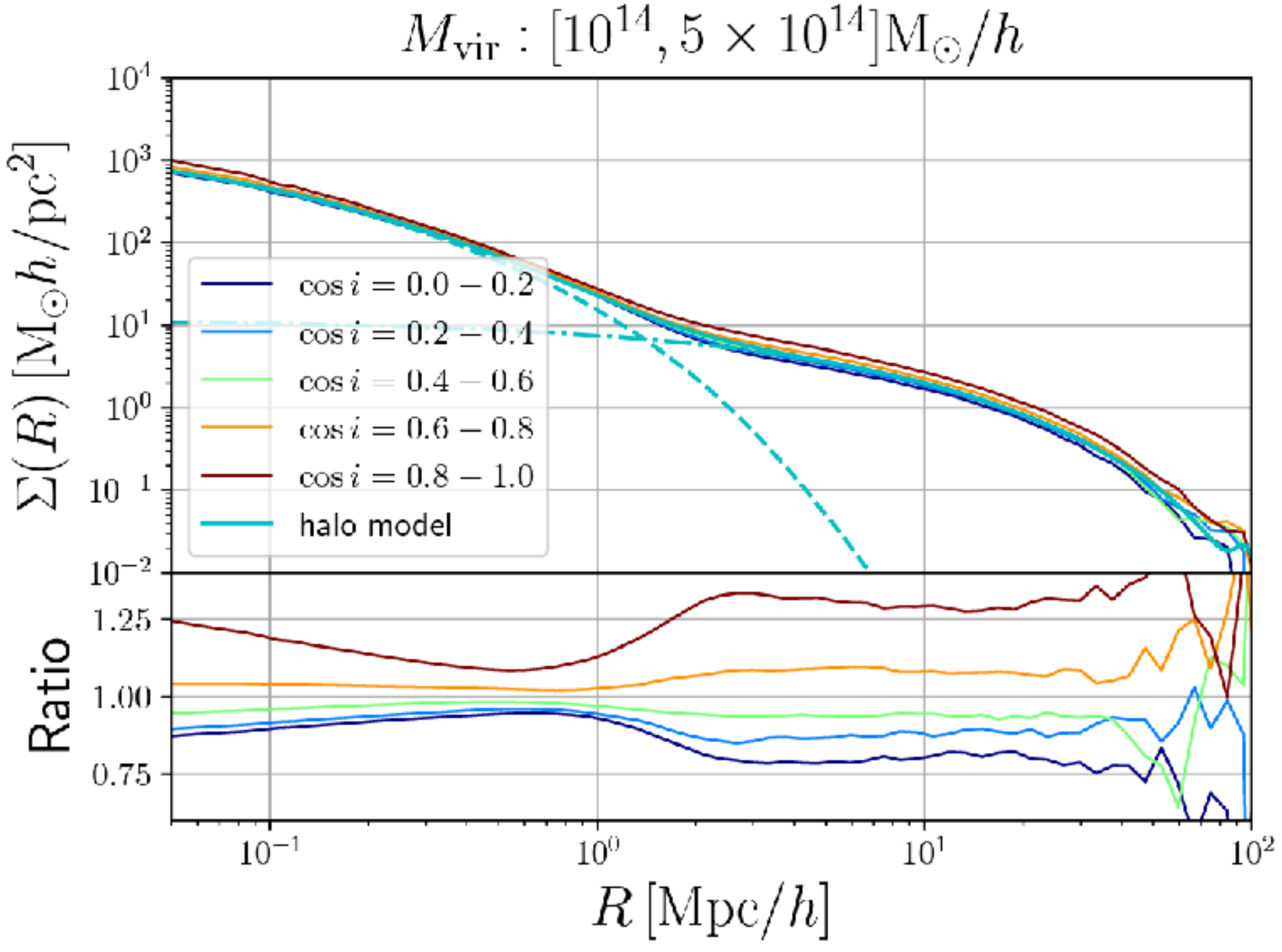
- Halos acquire the current shape in a complicated manner
  - Time evolution is like a random process due to mergers
  - Large scale tides are the attractor



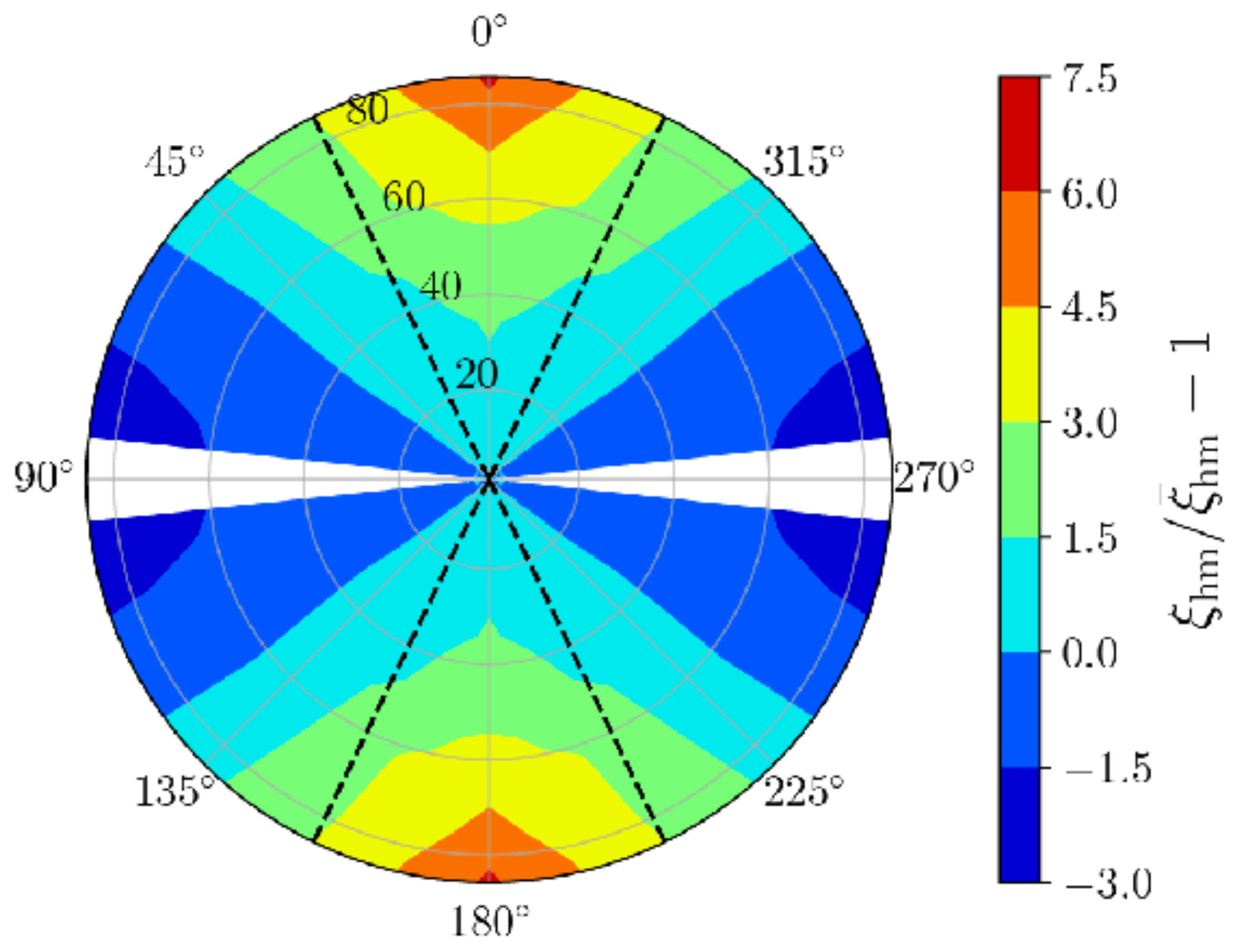
Orientation dependence of clustering

Osato+ arXiv:1712.00094

DQ1 simulations



- Angular clustering could be affected if clusters elongated along the line of sight are preferentially detected
  - Nothing but the IA signal
    - ξ_{g+}
    - Quadrupolar

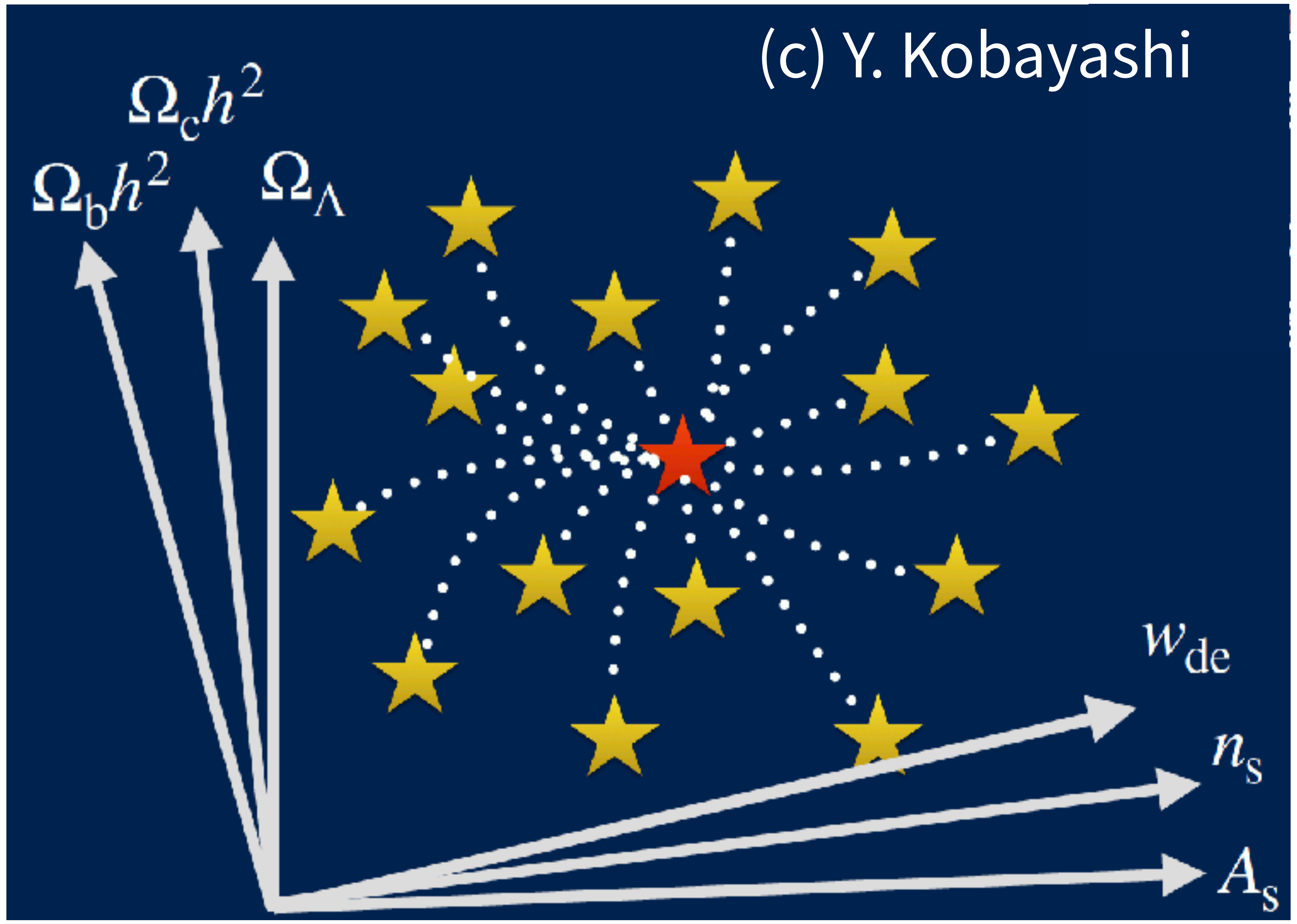


See also Sunayama *et al.* `20 (and Jingjing's talk)

Dark Quest I

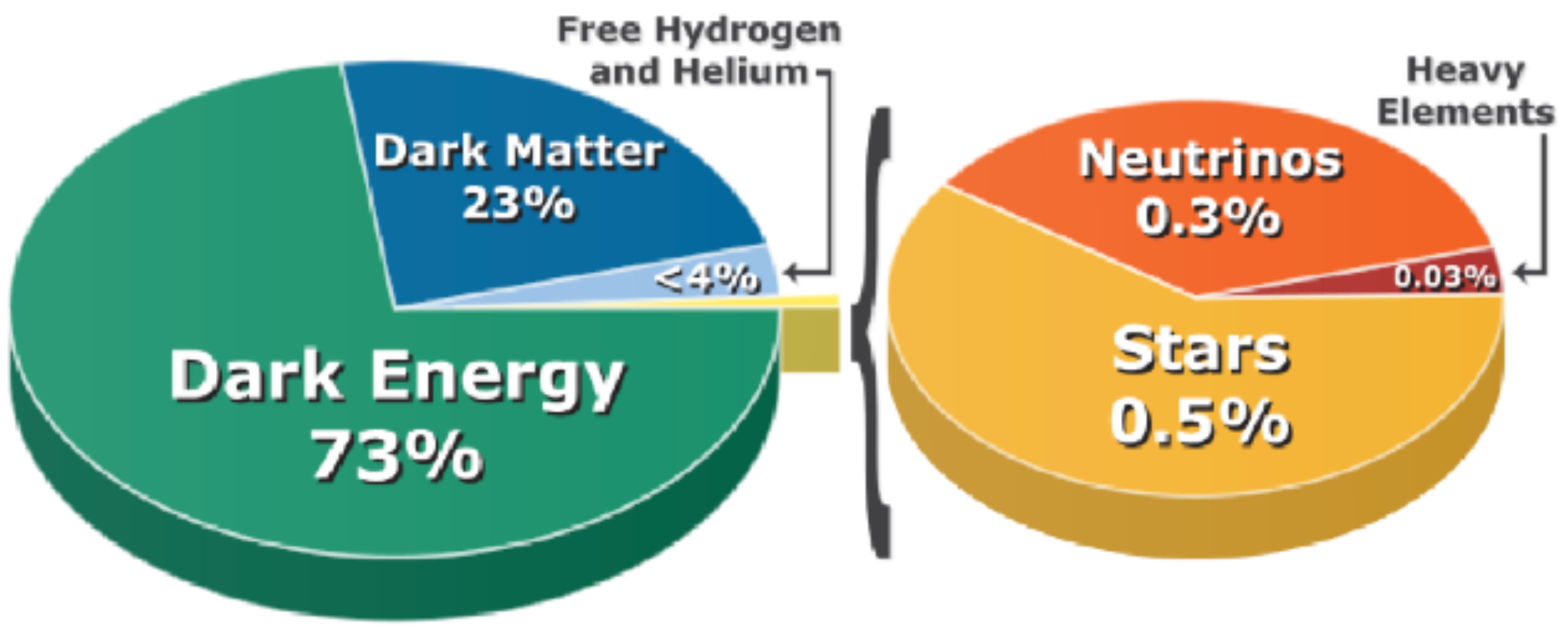
Our solution: Emulation

- Replace costly numerical simulations with a cheap statistical model making *"simulation-based inference"* possible
  - Multi-input regression problem
  - Key challenge: *curse of dimensionality*
  - Introduced to cosmology by Heitmann+`06 (ApJL; "Cosmic calibration")
    - Early studies focused on the matter power spectrum (not biased tracers)



Dark Quest Project (2015~)

Observational data (**Galaxies**)



ω_b, ω_c, H_0, A_s, n_s, w_0, …

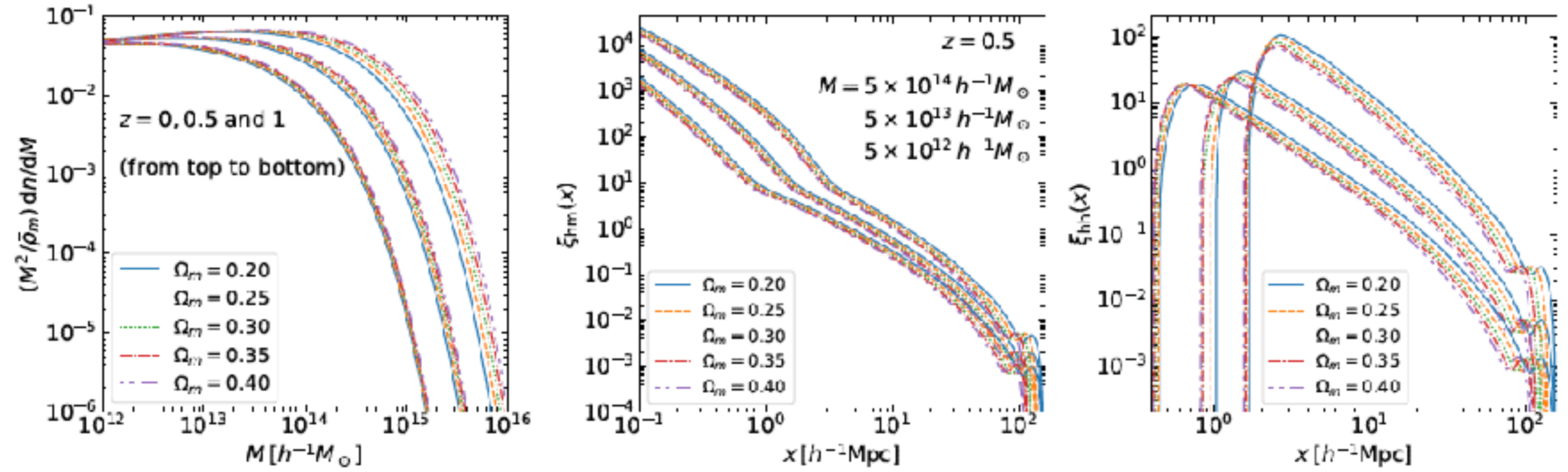
Flexible galaxy-halo connection model (analytical)

Bayesian inference

Fast emulation
~100 millisecs

Cosmological model/params

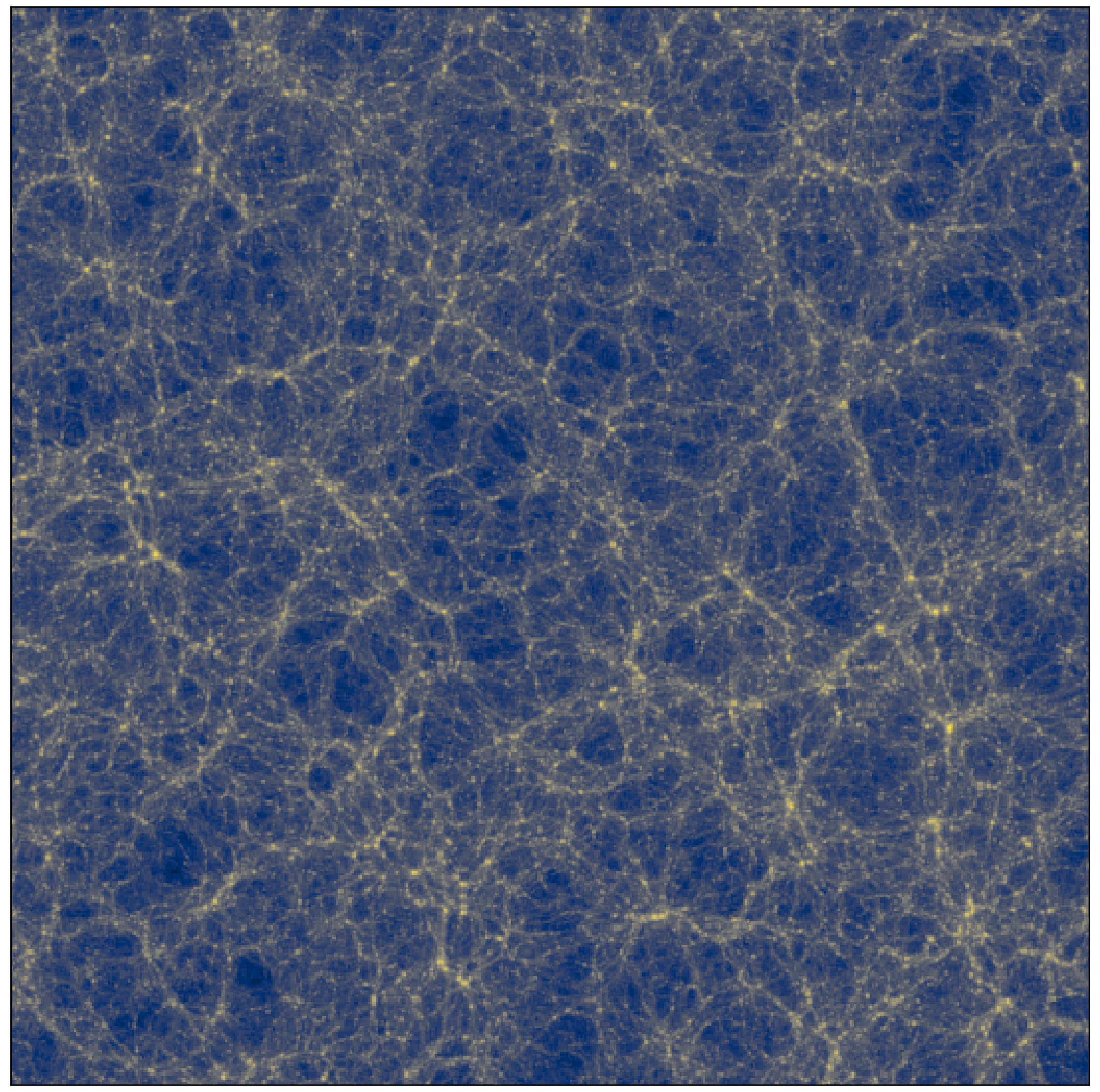
Halo clustering statistics



Statistical analysis

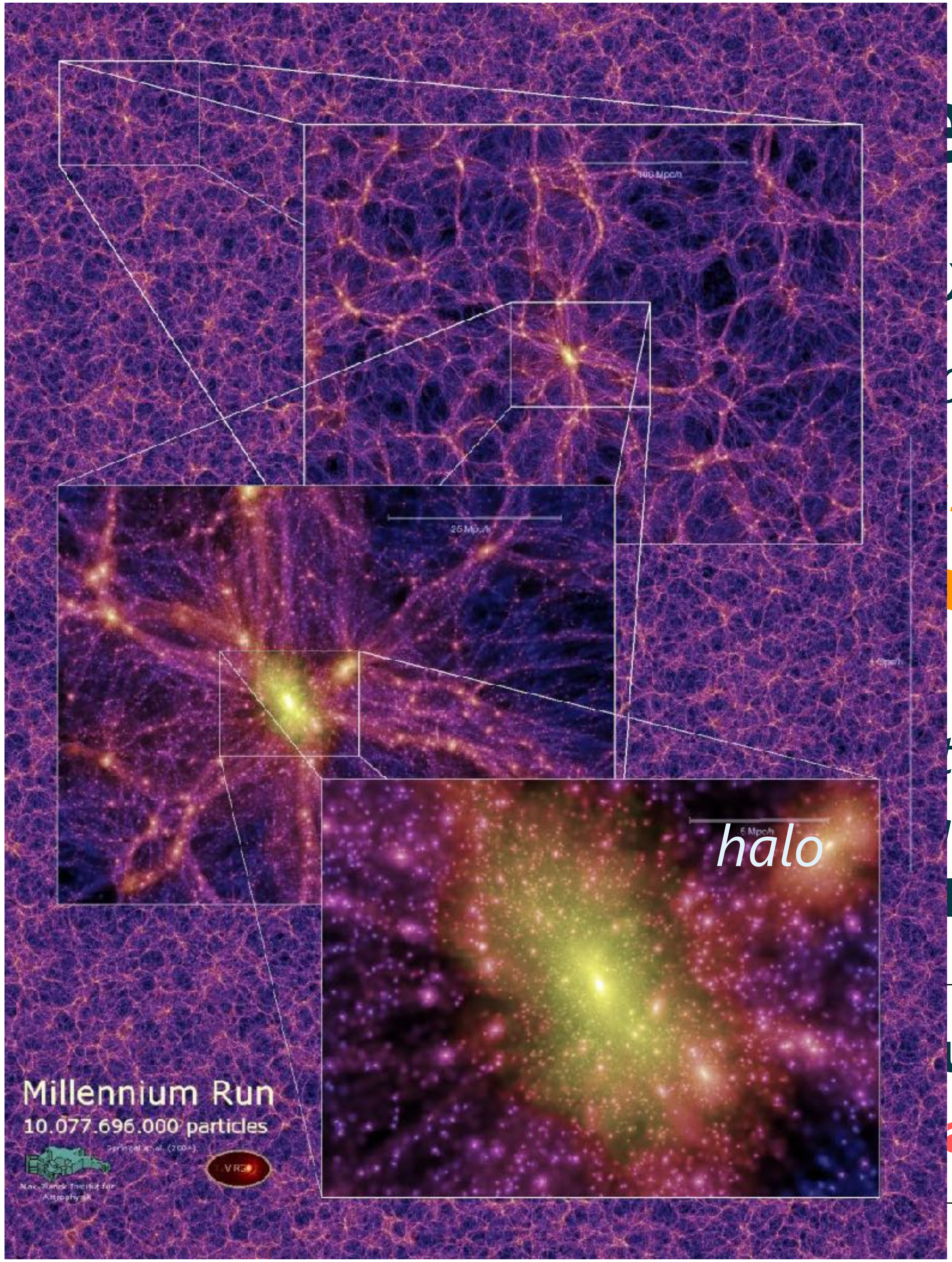
Simulation

~days



Fully investigate basic statistical properties of halos as a function of cosmological parameters

T. Nishimichi (YITP, Kyoto U)



ect (2015~)

Observational data (**Galaxies**)

$_c$, H_0, A_s,

$_0$, …

Flexible galaxy-halo connection model (analytical)

Bayesian inference

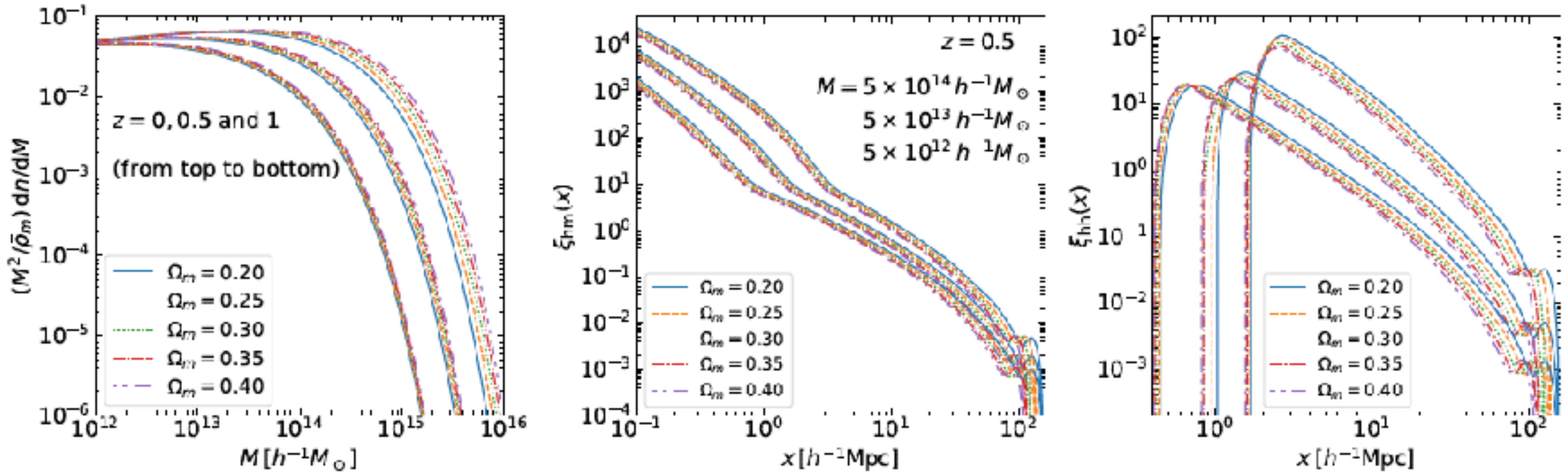
st emulation

~100 millisecs

Halo clustering statistics

tistical

lysis



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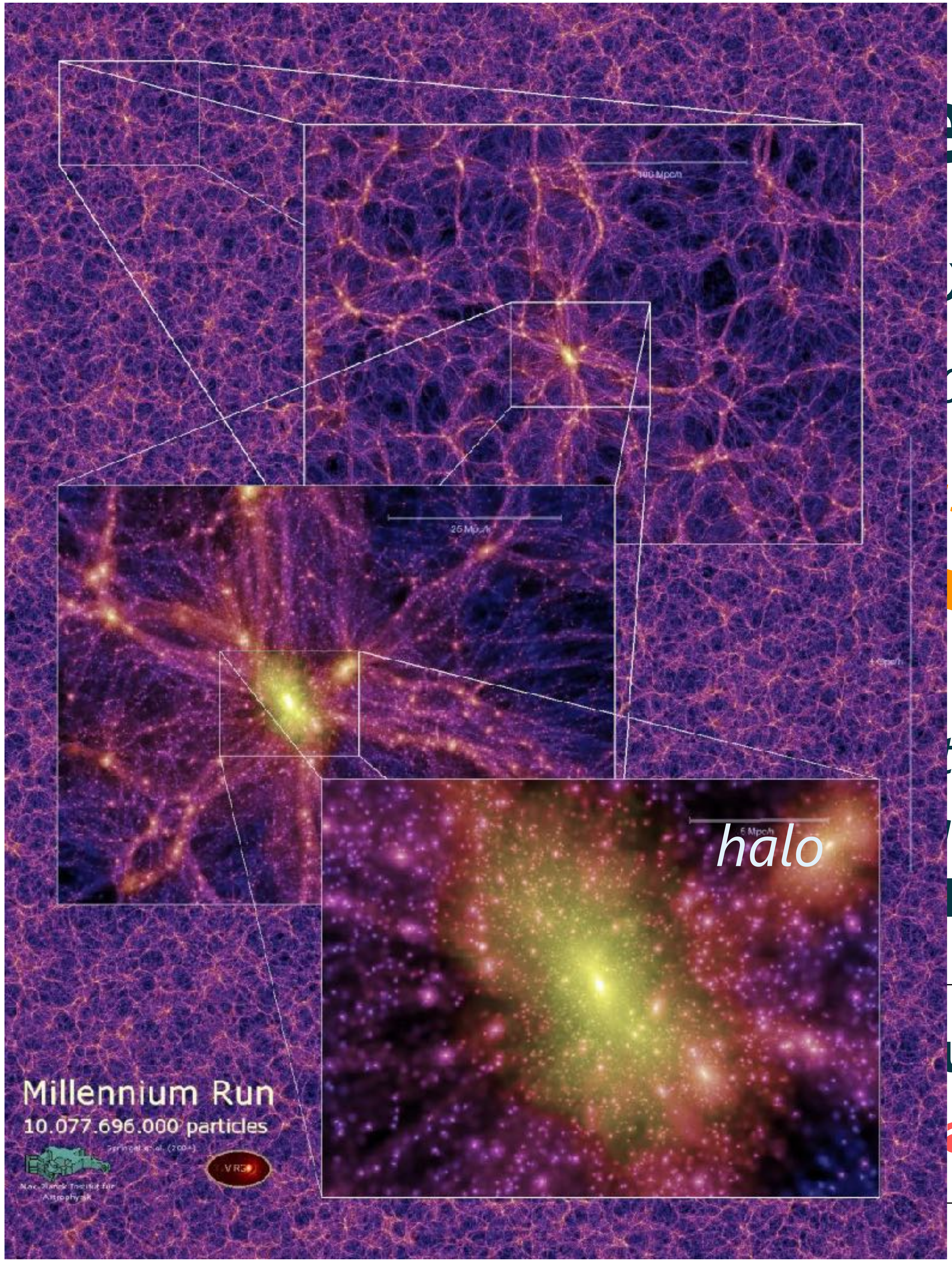
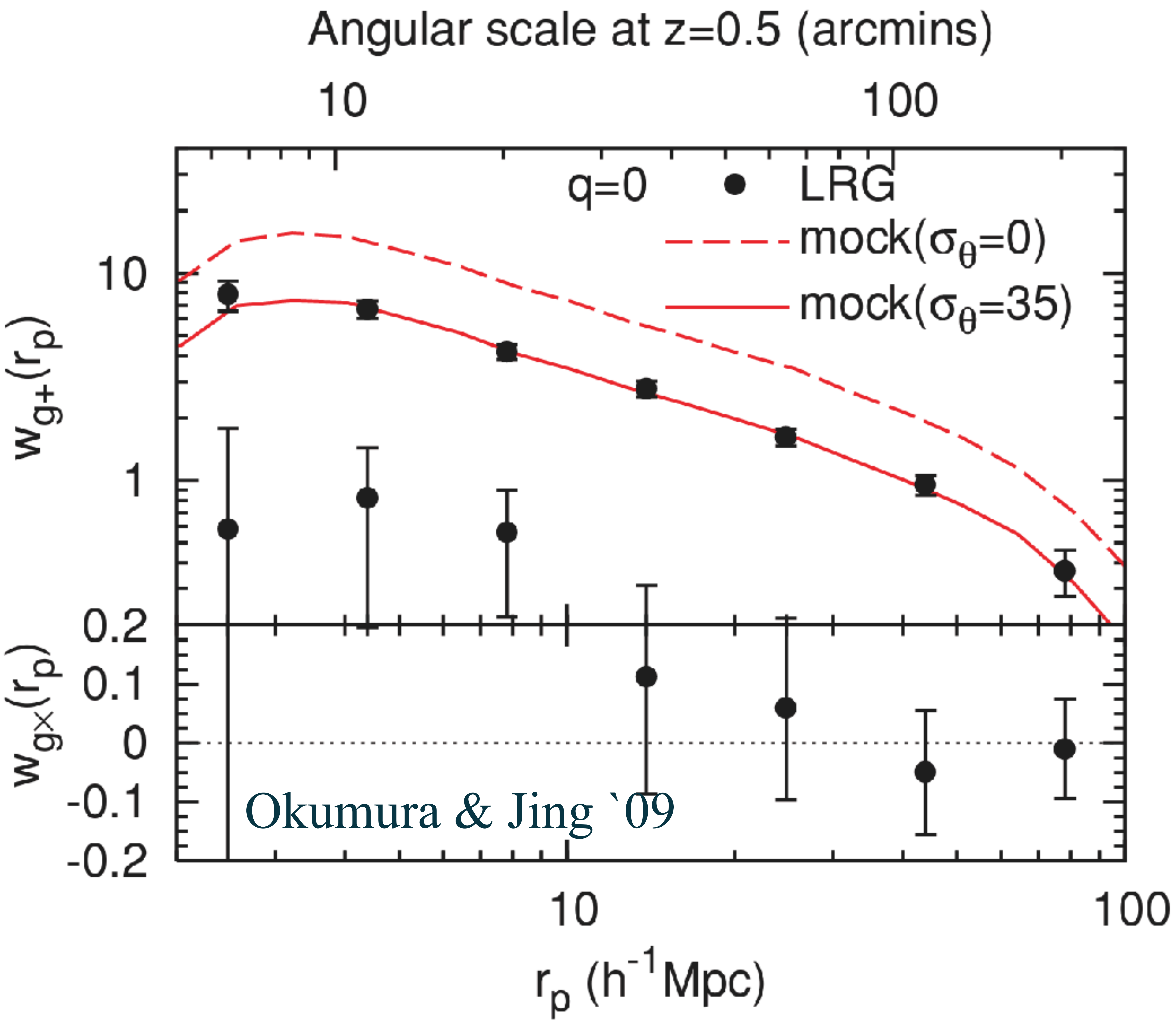


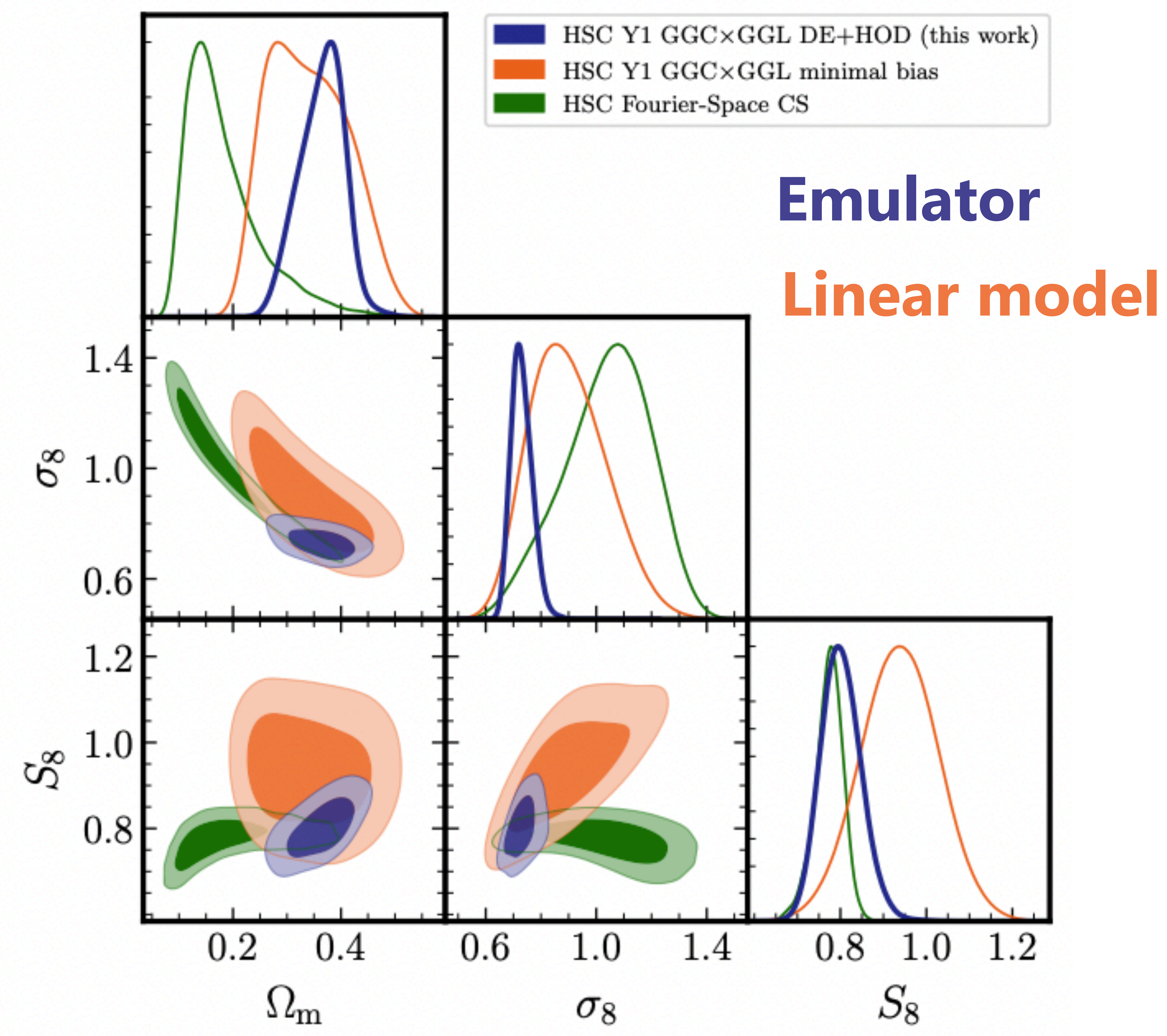
Observational data



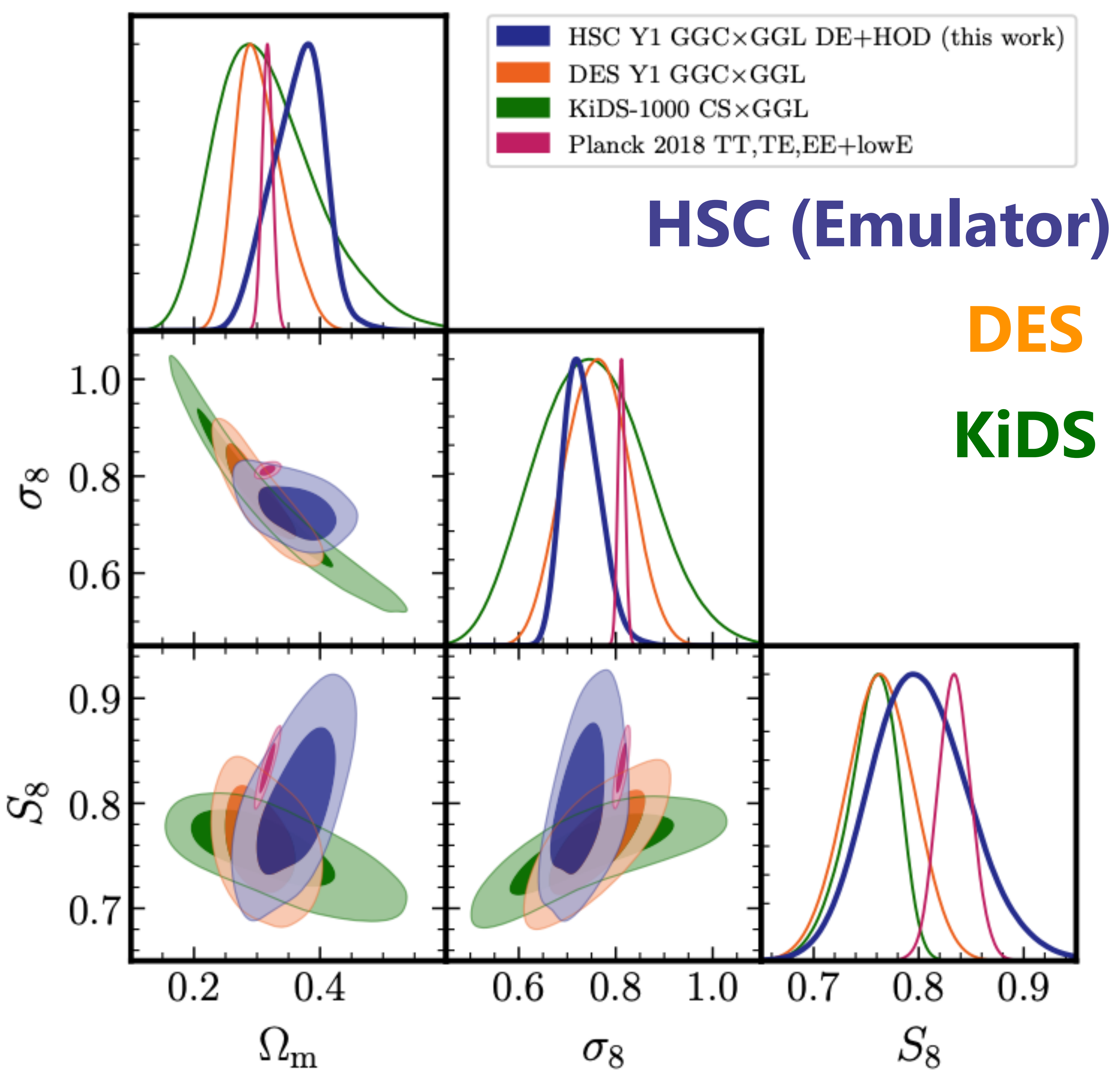
DarkEmulator vs Subaru HSC

Miyatake+ PRD **106** (2022) 083520

Internal consistency within HSC



Comparison with other WL surveys



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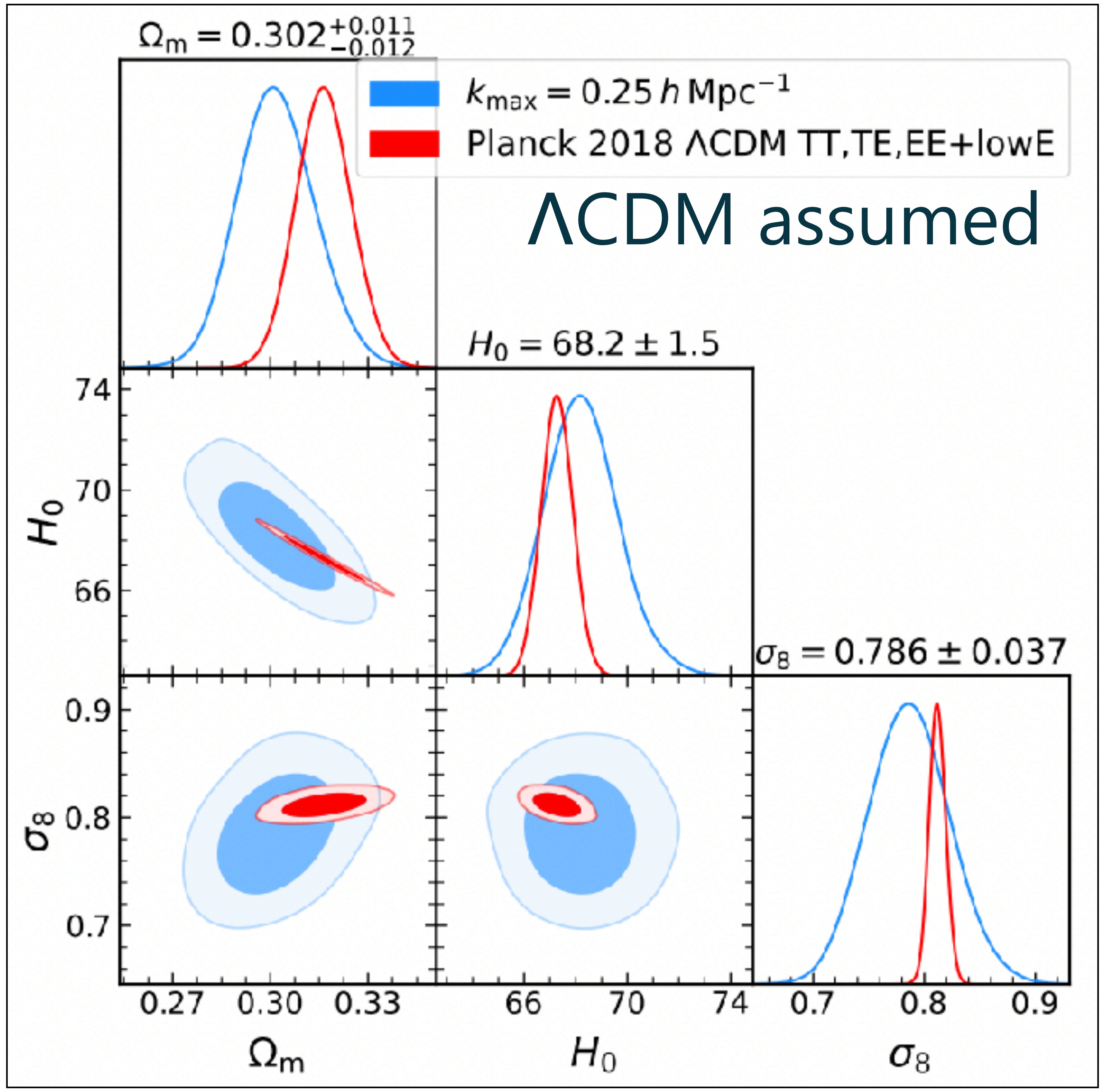
SDSS BOSS “full shape”

Kobayashi, TN+, PRD **105** (2022) 083517

Full-shape cosmology analysis of SDSS-III BOSS galaxy power spectrum using emulator-based halo model: a 5% determination of σ_8

Yosuke Kobayashi[1,2,*] Takahiro Nishimichi[3,2], Masahiro Takada[2,†] and Hironao Miyatake[4,2]



Comparison with competitors (EFTofLSS)

Analyses on exactly the same power-spectrum data

Kobayashi+ (Emulator) :	$\sigma_8 = 0.786^{+0.036}_{-0.037}$	$\Omega_m = 0.301^{+0.012}_{-0.011}$	$H_0 = 68.2 \pm 1.4$
Princeton (Philcox+21):	$\sigma_8 = 0.737^{+0.040}_{-0.044}$	$\Omega_m = 0.312^{+0.011}_{-0.012}$	$H_0 = 68.5^{+1.1}_{-1.3}$
Berkeley (Chen+21):	$\sigma_8 = 0.738 \pm 0.048$	$\Omega_m = 0.305 \pm 0.01$	$H_0 = 68.5 \pm 1.1$

- Roughly consistent with EFT-based analyses
  - Better determination of σ_8
- No tension with Planck! (σ_8 = 0.812±0.0073)

T. Nishimichi (YITP, Kyoto U)

Philosophy

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- Gain cosmological info from the 2-halo term
  - Our emulator is an update of the classical halo model
  - Our model automatically deals with
    - Nonlinear gravitational growth
    - Complicated bias relation
      - nonlinear bias
      - tidal bias …
    - Halo exclusion effect

Parameter	Prior
Cosmological parameters	
ω_b	$\mathcal{N}(0.02268, 0.00038)$
ω_c	$\mathcal{U}(0.10782, 0.13178)$
Ω_Λ	$\mathcal{U}(0.54752, 0.82128)$
$\ln(10^{10}A_\mathrm{s})$	$\mathcal{U}(2.4752, 3.7128)$
n_s	$\mathcal{N}(0.9649, 0.0042)$
HOD parameters	
$\log M_\mathrm{min}$	$\mathcal{U}(12.0, 15.0)$
$\sigma^2_{\log M}$	$\mathcal{U}(0.0001, 2.0)$
$\log M_1$	$\mathcal{U}(12.0, 16.0)$
α_sat	$\mathcal{U}(0.01, 5.0)$
κ	$\mathcal{U}(0.01, 5.0)$
Other nuisance parameters	
c_vel	$\mathcal{U}(0.01, 10.0)$
P_shot	$\mathcal{U}(-10^4, 10^4)\,h^{-3}\,\mathrm{Mpc}^3$
Derived parameters	
Ω_m	–
H_0	–
σ_8	–

Philosophy

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- We can try adding/reducing complexity in the 1-halo term, which is anyway marginalized
  - Non-standard HOD parameterization (beyond Zheng's 5 parameter model)
  - Non-standard central/satellite distribution both for positions and velocities
    - (off-centering, modified c-M relations, velocity bias …)

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H_0	–
σ_8	–

Philosophy

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Kobayashi, TN+, PRD **105** (2022) 083517

$$P_{\rm gg}^{\rm S,1h}(\mathbf{k}) = \frac{1}{\bar{n}_{\rm g}^2}\int {\rm d}M\, \frac{{\rm d}n}{{\rm d}M}(M)\,\langle N_{\rm c}\rangle(M)\left[2\lambda_{\rm s}(M)\,\tilde{\mathcal{H}}^{\rm S}(\mathbf{k};M) + \lambda_{\rm s}(M)^2\,\tilde{\mathcal{H}}^{\rm S}(\mathbf{k};M)^2\right], \quad (20)$$

and

$$P_{\rm gg}^{\rm S,2h}(\mathbf{k}) = \frac{1}{\bar{n}_{\rm g}^2}\int {\rm d}M_1\, \frac{{\rm d}n}{{\rm d}M}(M_1)\left[\langle N_{\rm c}\rangle(M_1) + \langle N_{\rm s}\rangle(M_1)\,\tilde{\mathcal{H}}^{\rm S}(\mathbf{k};M_1)\right] \times \int {\rm d}M_2\, \frac{{\rm d}n}{{\rm d}M}(M_2)\left[\langle N_{\rm c}\rangle(M_2) + \langle N_{\rm s}\rangle(M_2)\,\tilde{\mathcal{H}}^{\rm S}(\mathbf{k};M_2)\right] \times P_{\rm hh}^{\rm S}(\mathbf{k};M_1,M_2), \quad (21)$$

with the mean number density of galaxies, defined as

$$\bar{n}_{\rm g} = \int {\rm d}M\, \frac{{\rm d}n}{{\rm d}M}(M)\left[\langle N_{\rm c}\rangle(M) + \langle N_{\rm s}\rangle(M)\right]. \quad (22)$$

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Derived parameters	
$\Omega_{\rm m}$	–
H_0	–
σ_8	–

Dark Quest II

Sorry, please just wait until we post papers on arXiv…

Summary

- Emulation is an efficient way to prepare theoretical templates in cosmological inference
  - Quick and accurate
  - **DarkEmulator** from DQ1 successfully applied to real data!!
  - Use 2-halo term, discard 1-halo term
- Halo shapes complicated and interesting
  - Trying to incorporate in DQ2 as a standard entry of the halo catalog
  - "*Emulator for IA*" in the near future (?)