Probing Galaxies in Galaxy Clusters with Dense Spectroscopy

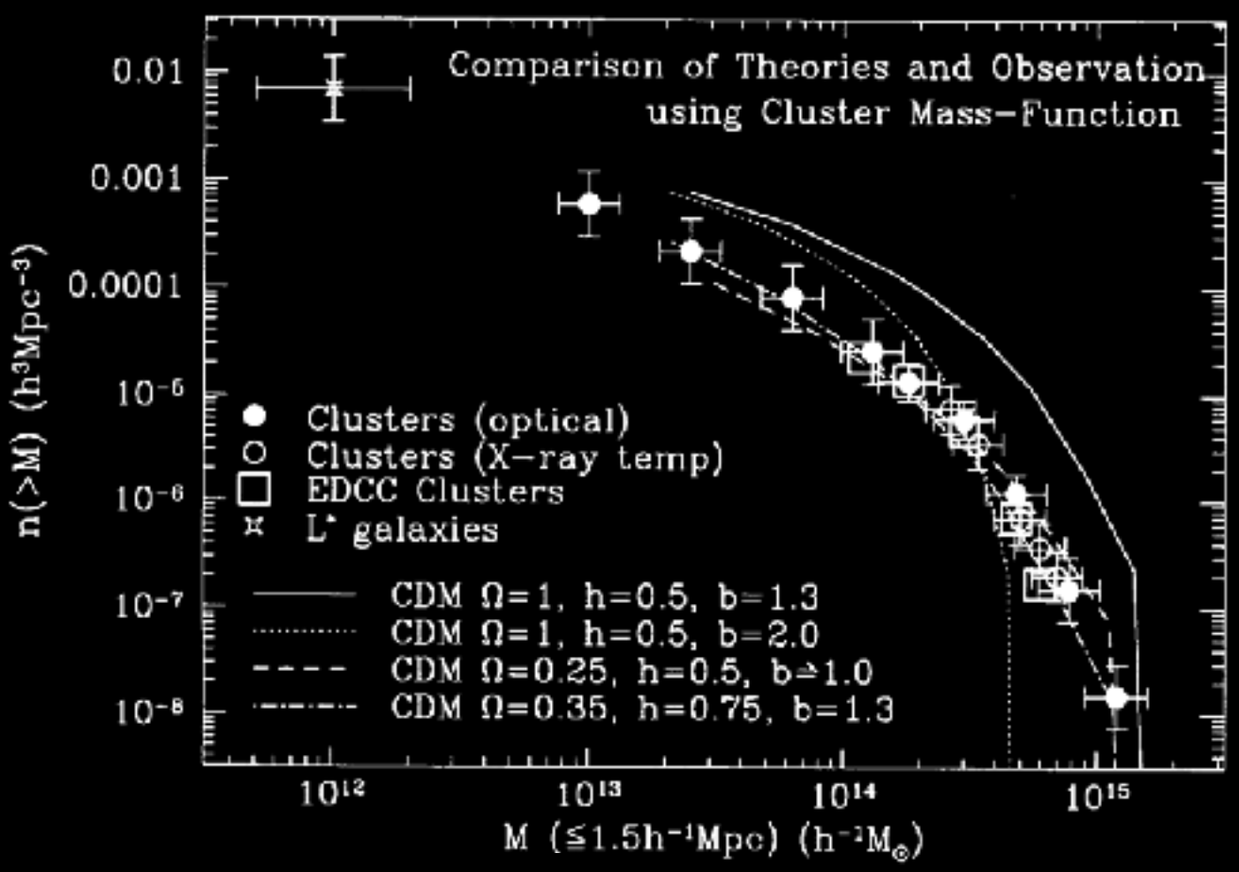
Jubee Sohn
(Seoul National University)



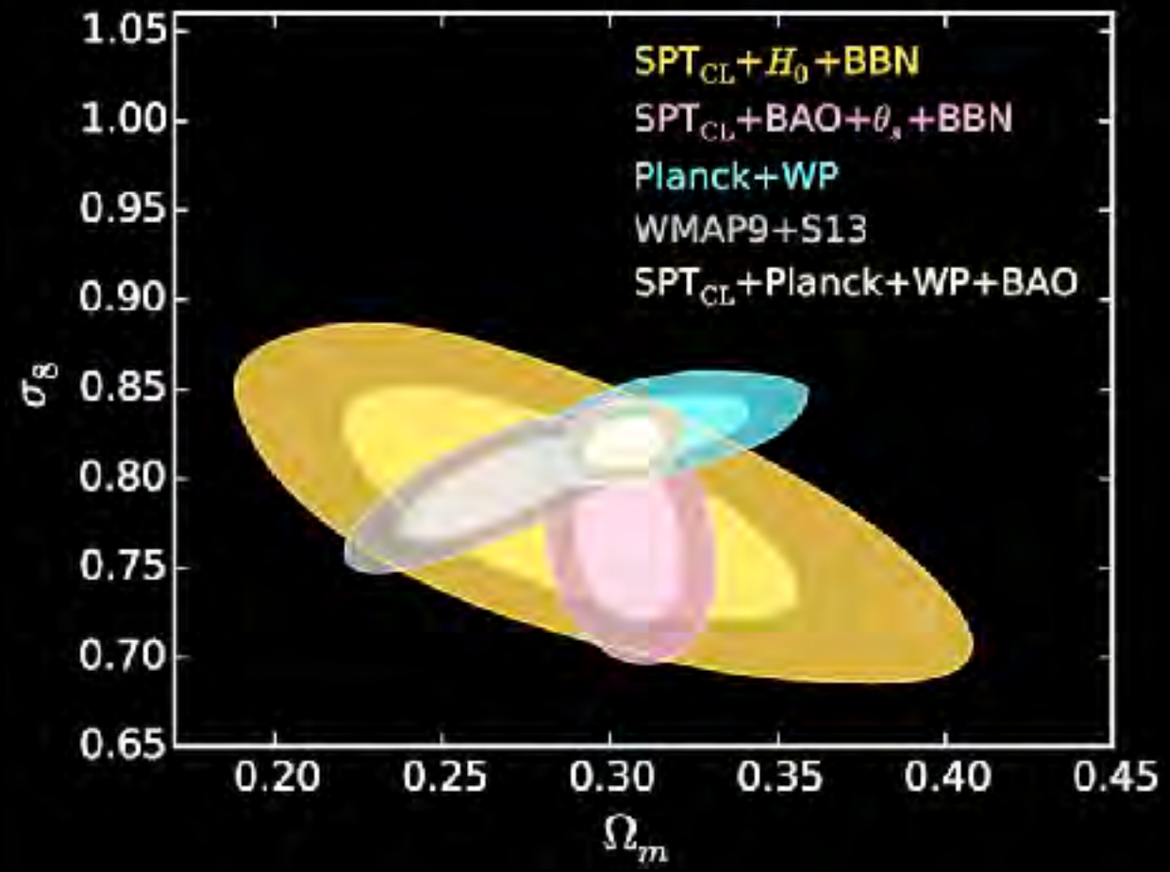
Why Galaxy Clusters?

- **Tools for studying dark matter & dark energy**
  - Most massive gravitationally bound structures
  - Cosmological structure formation

De Hann et al. (2016)

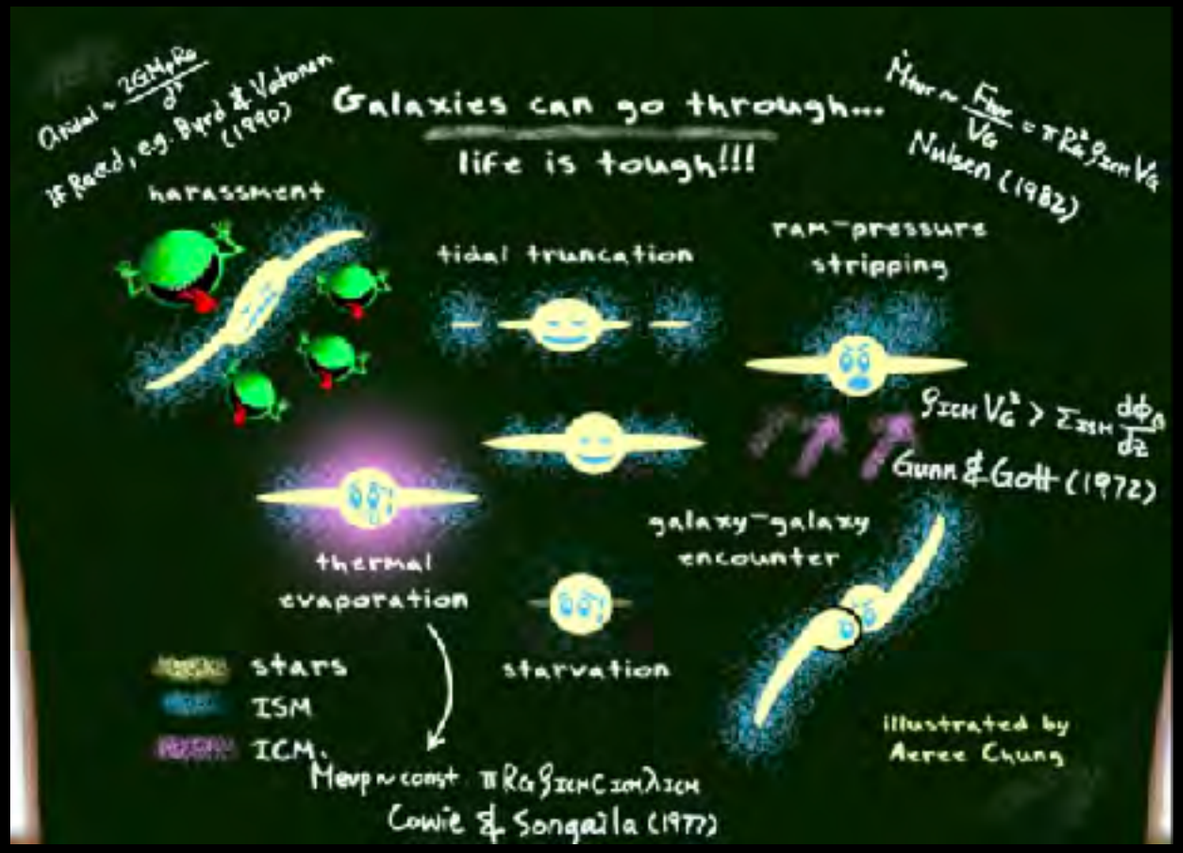


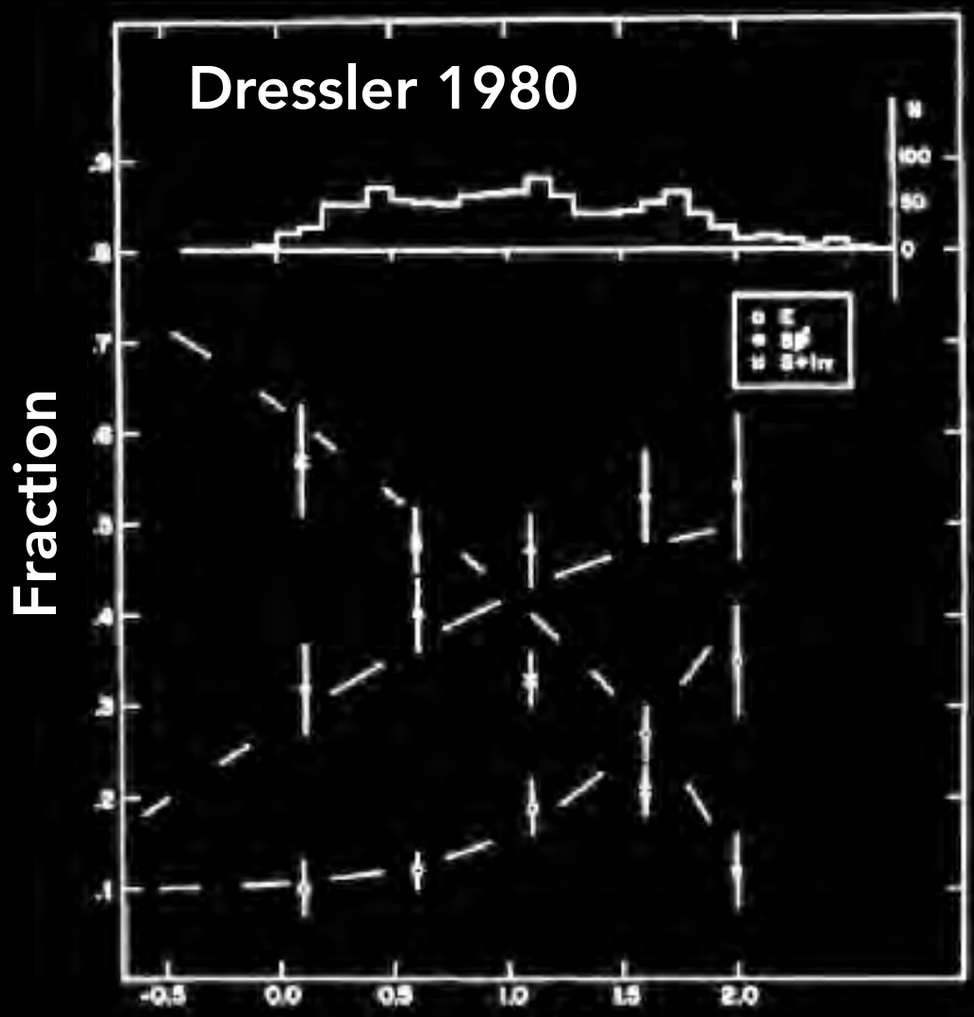
Bahcall & Cen (1993)



Why Galaxy Clusters?

- **Evolution of galaxies**
  - Environmental effects on galaxy evolution
  - Preferential presence of massive galaxies
  - The role of DM





Ingredients for Cluster Studies

- **Clusters** → X-ray, SZ, Galaxy overdensity
- **Cluster members** → color, photo-z, spec-z



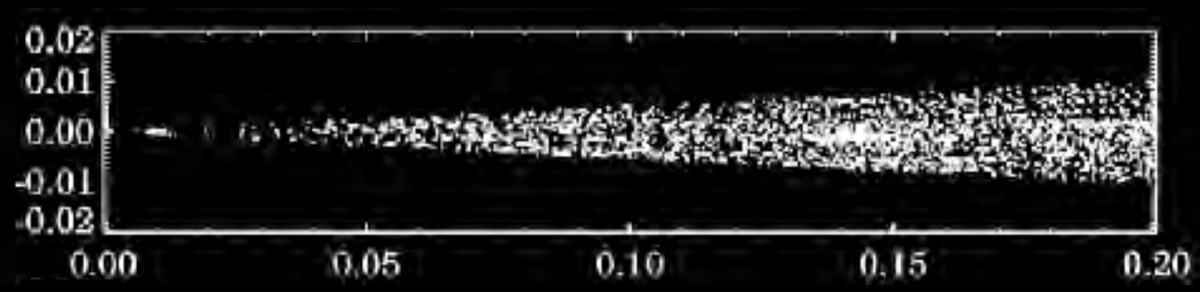
Cluster spectroscopy

Spec-z



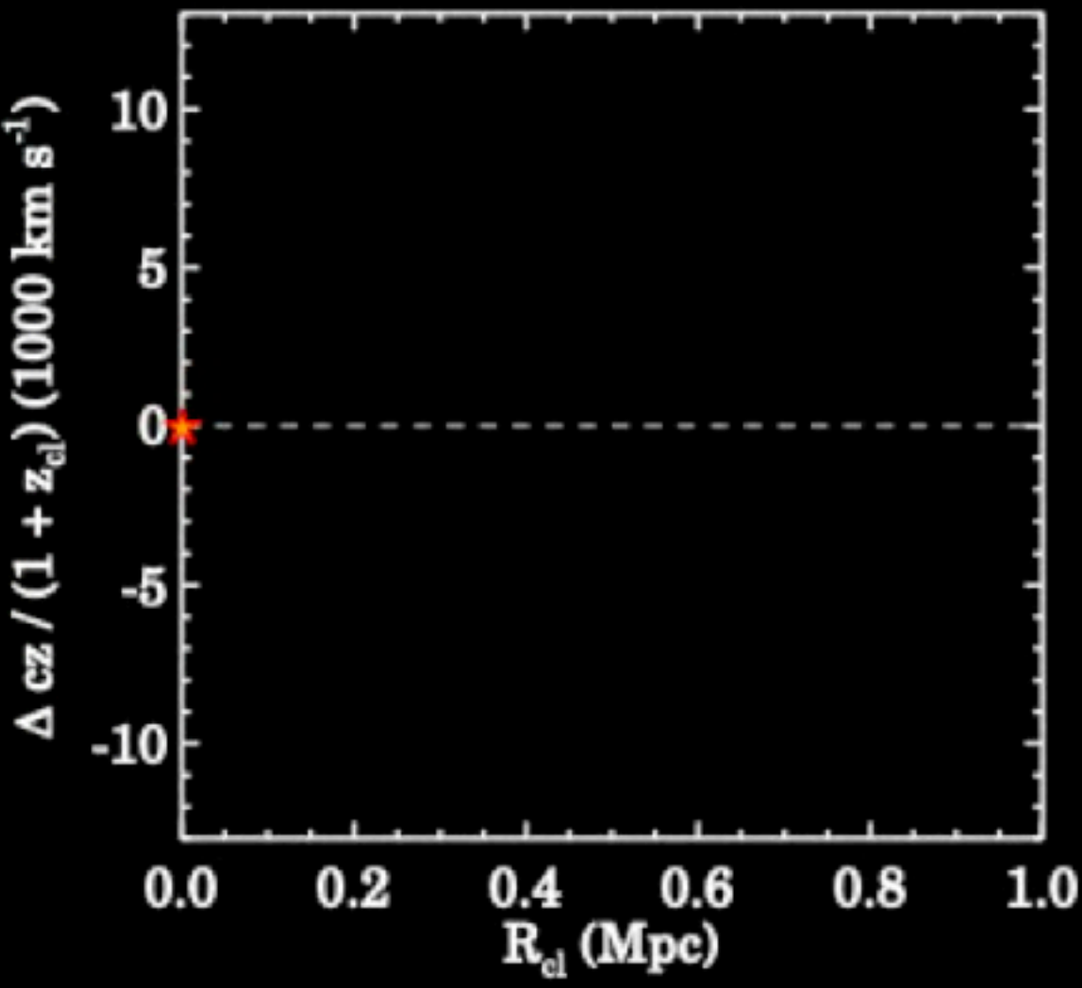
Redshift

Phot-z



Redshift

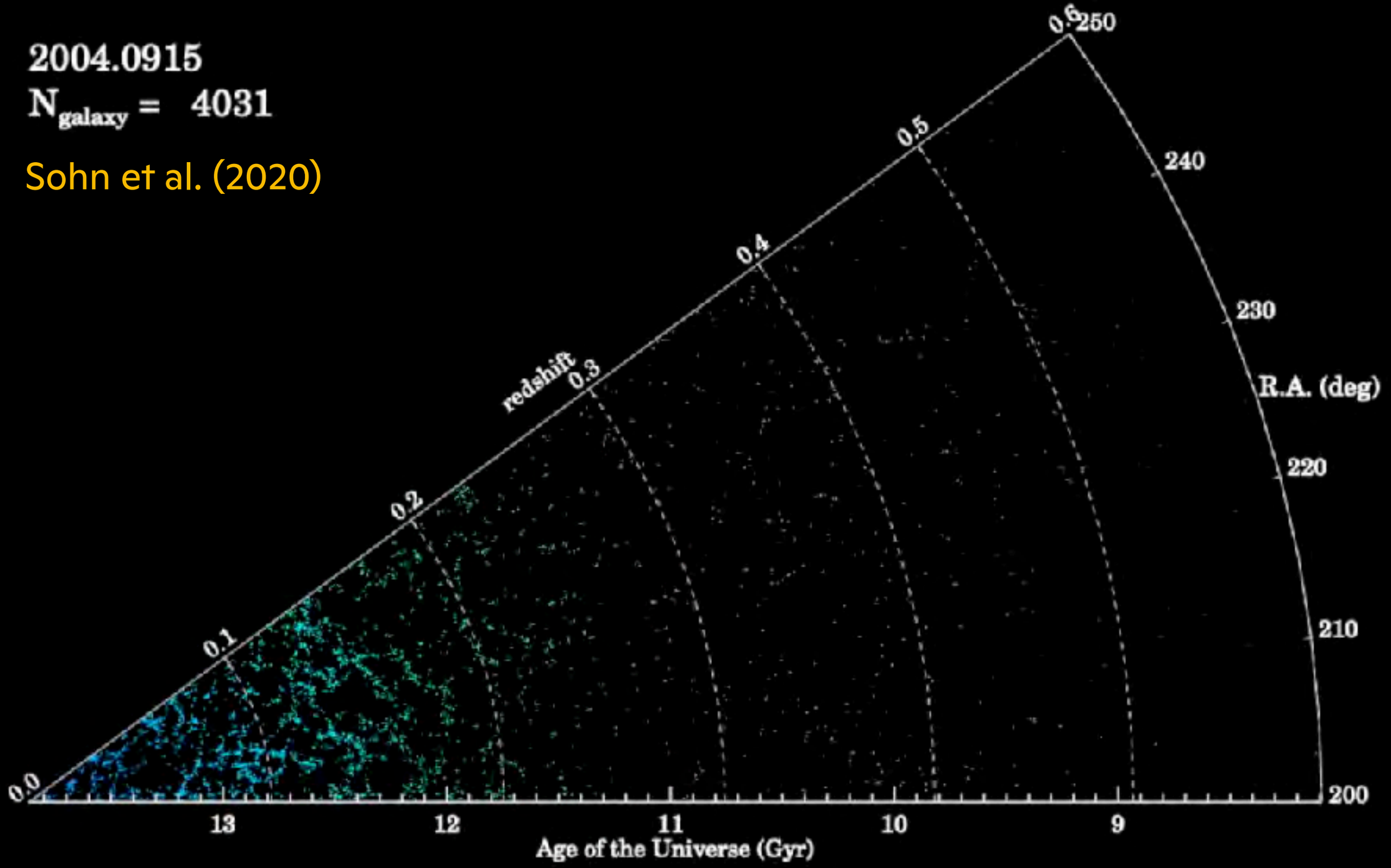




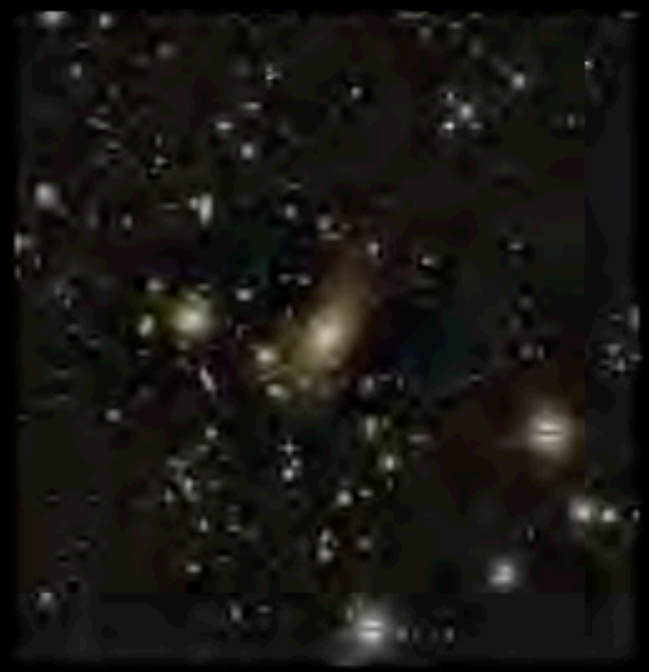
The HectoMAP Redshift Survey

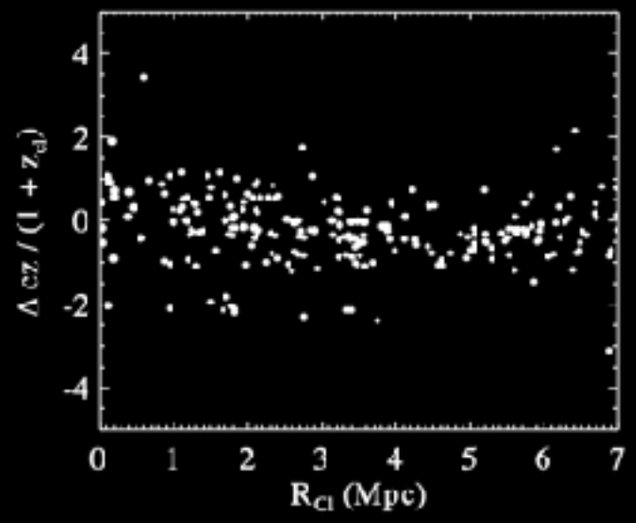
2004.0915
$N_{galaxy} = 4031$

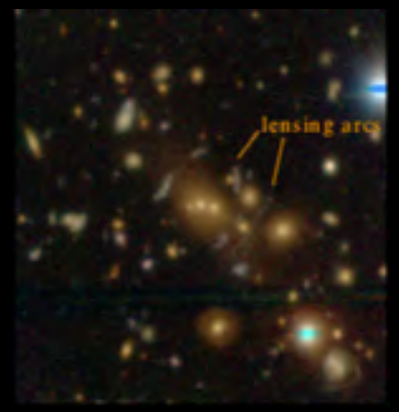
Sohn et al. (2020)



Sohn et al. 2018a,b, 2020c, 2023a







Applications of Dense Spectroscopy

- **Cluster Galaxy Evolution with spectroscopy**
  - Quiescent Galaxy Evolution (Sohn et al. 2019b)
  - **The Velocity Dispersion Functions** (Sohn et al. 2017a,b, 2020b)
    - Comparison with **IllustrisTNG** (Sohn et al. 2024a,b)
  - **Co-evolution of clusters and BCGs** (Sohn et al. 2020a, 2021b)
    - Comparison with **IllustrisTNG** (Sohn et al. 2022a,b)
- **Cluster Evolution**
  - Spectroscopic Tomography (Dell'Antonio, Sohn et al. 2020)
  - Mass accretion of Galaxy Clusters (Pizzardo, Sohn et al. 2020, 2021)

DM subhalos

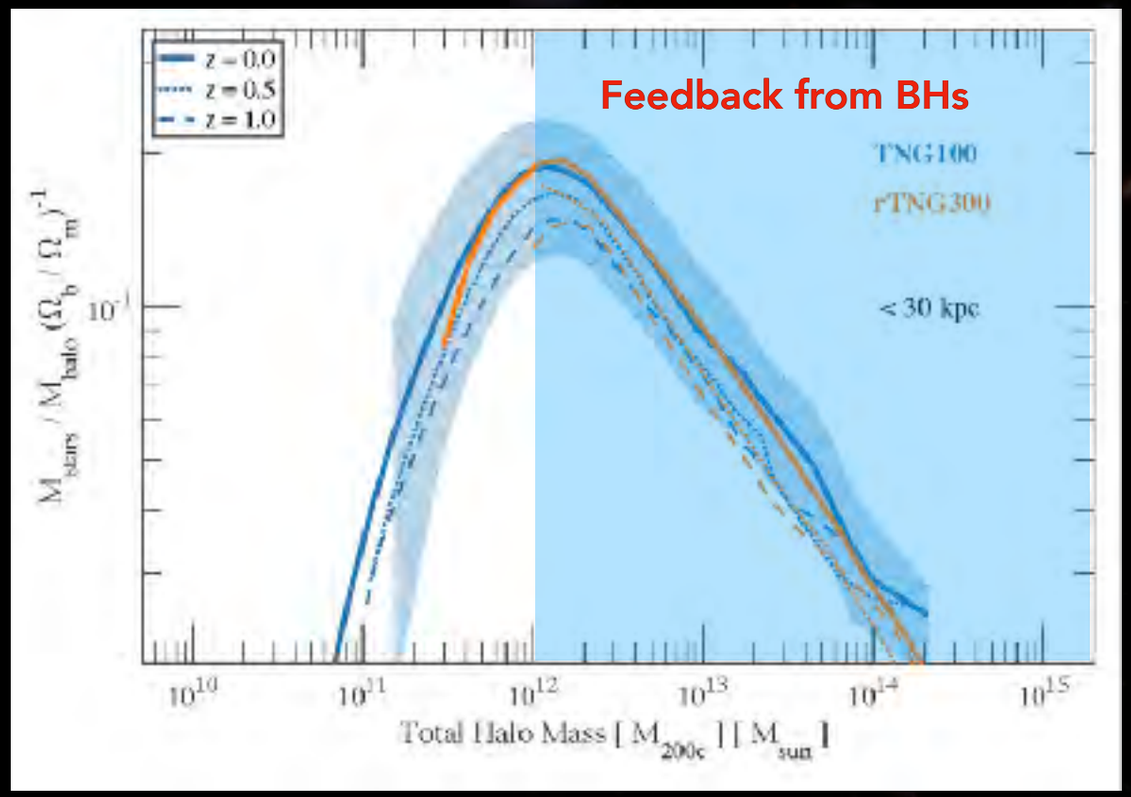


Mass evolutions of galaxies and underlying DM subhalos?



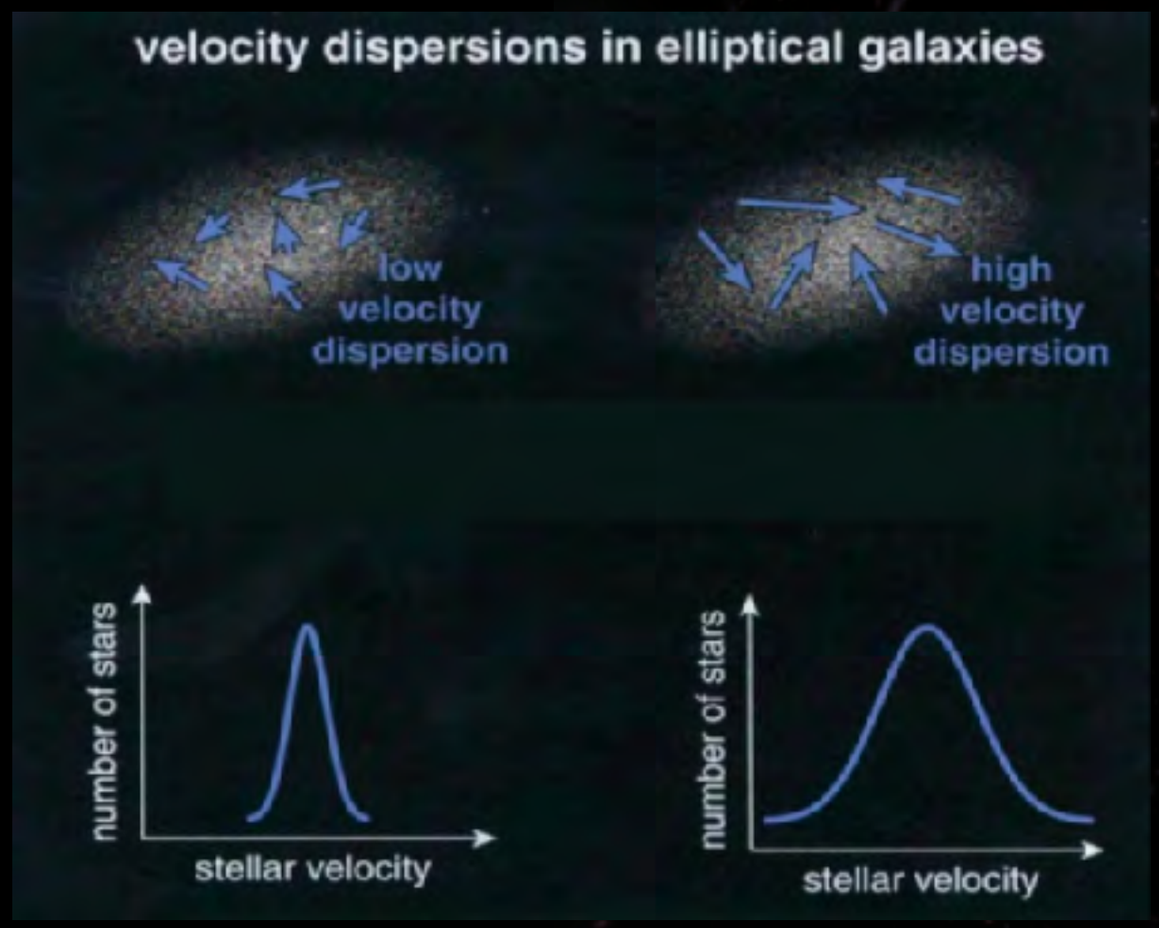
Connecting observables to DM

- Luminosity / Stellar Mass
- Issues
  - Determination of galaxy boundaries
  - Complexity in baryonic physics
  - Various feedback models



Connecting observables to DM

- Velocity dispersion!
  - Relatively straightforward to measure with fibers
  - Less sensitive to baryonic physics?



Observational Samples

- SDSS Field galaxies
- MACH (MAssive Cluster survey with Hectospec)
  - 10 most massive clusters at 0.06 < z < 0.12
  - > 3,500 redshifts / cluster

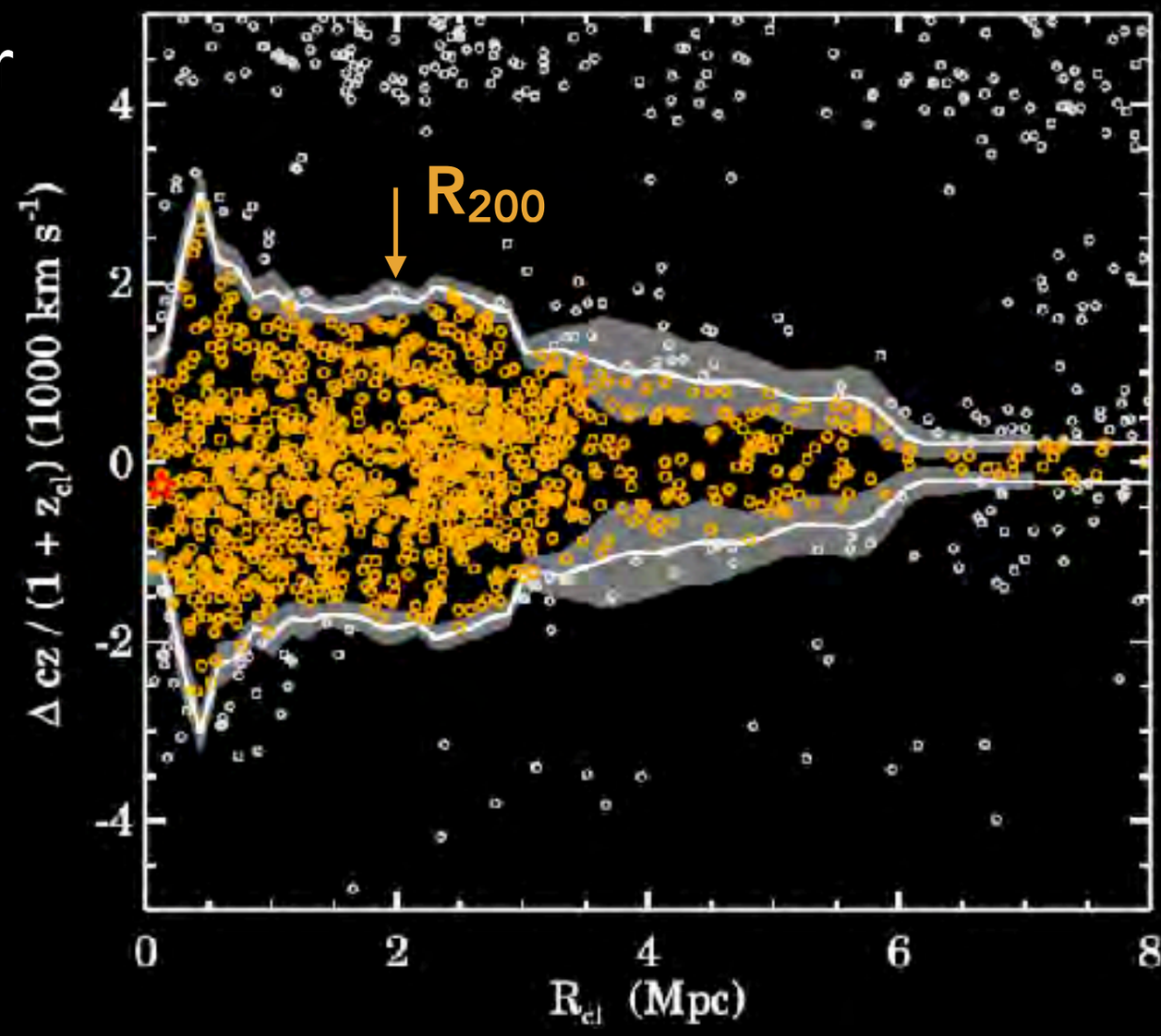
MMT



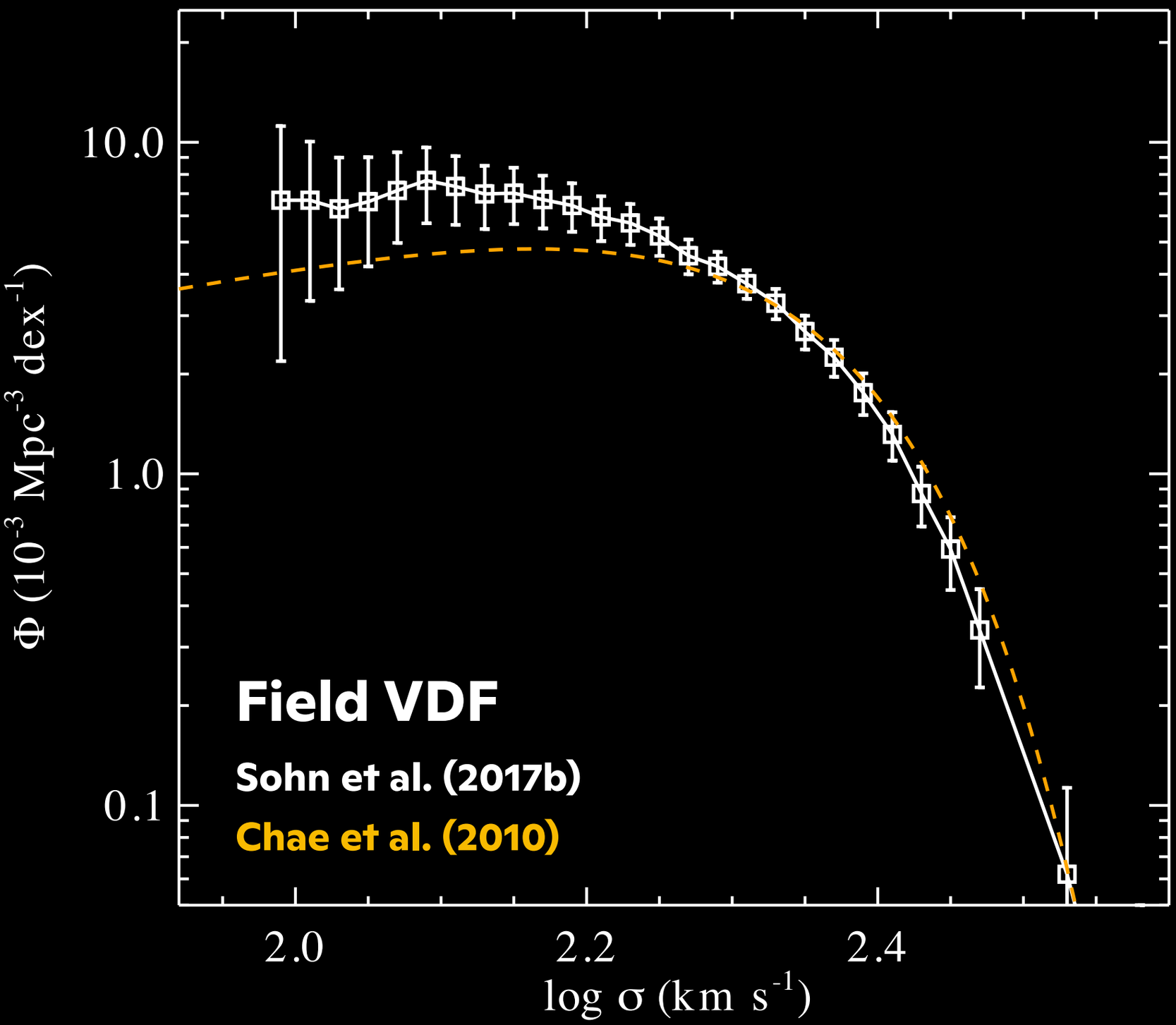
Hectospec



A2029 (Sohn et al. 2019a) : 1215 spec. members

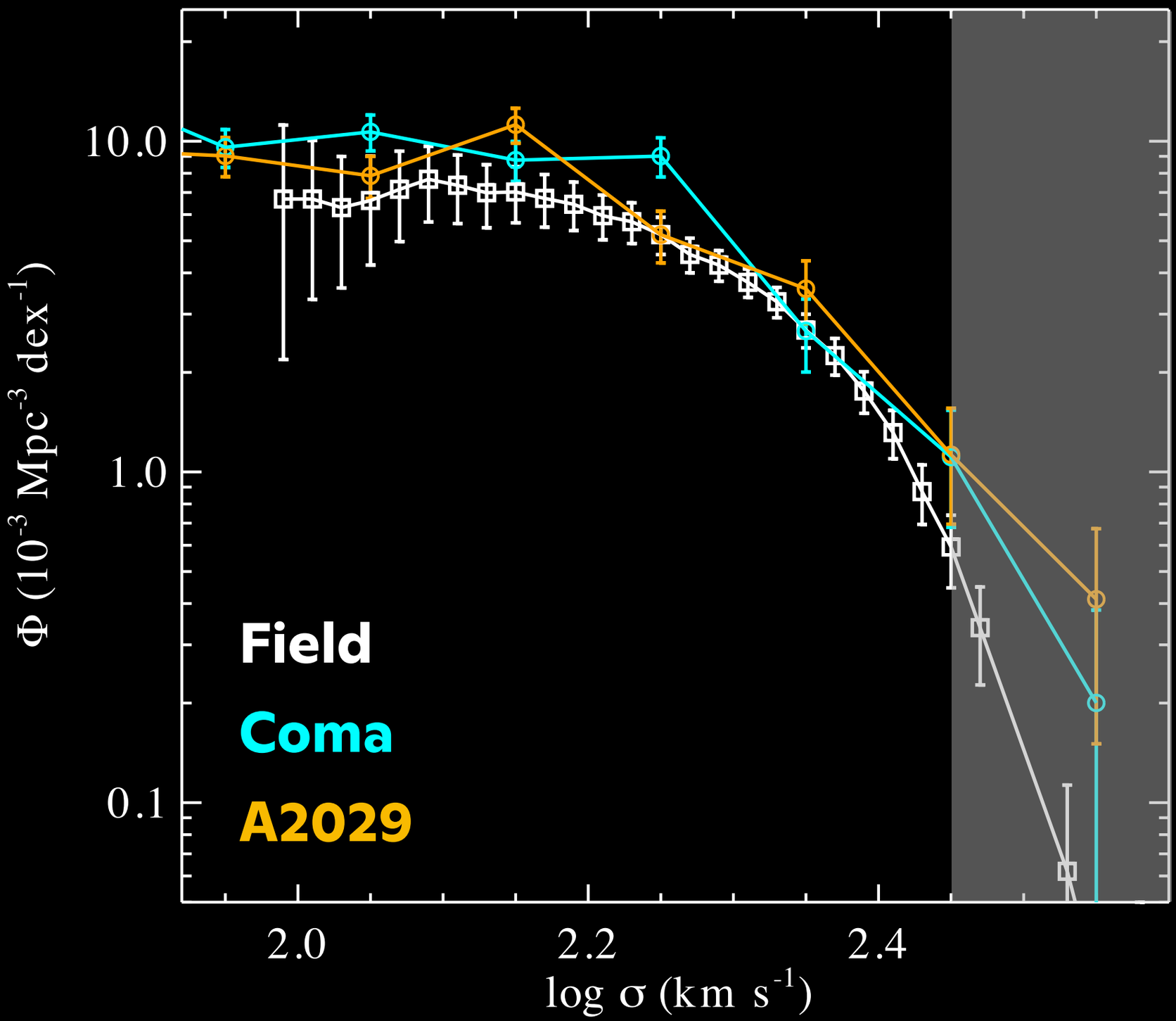


Velocity Dispersion Functions

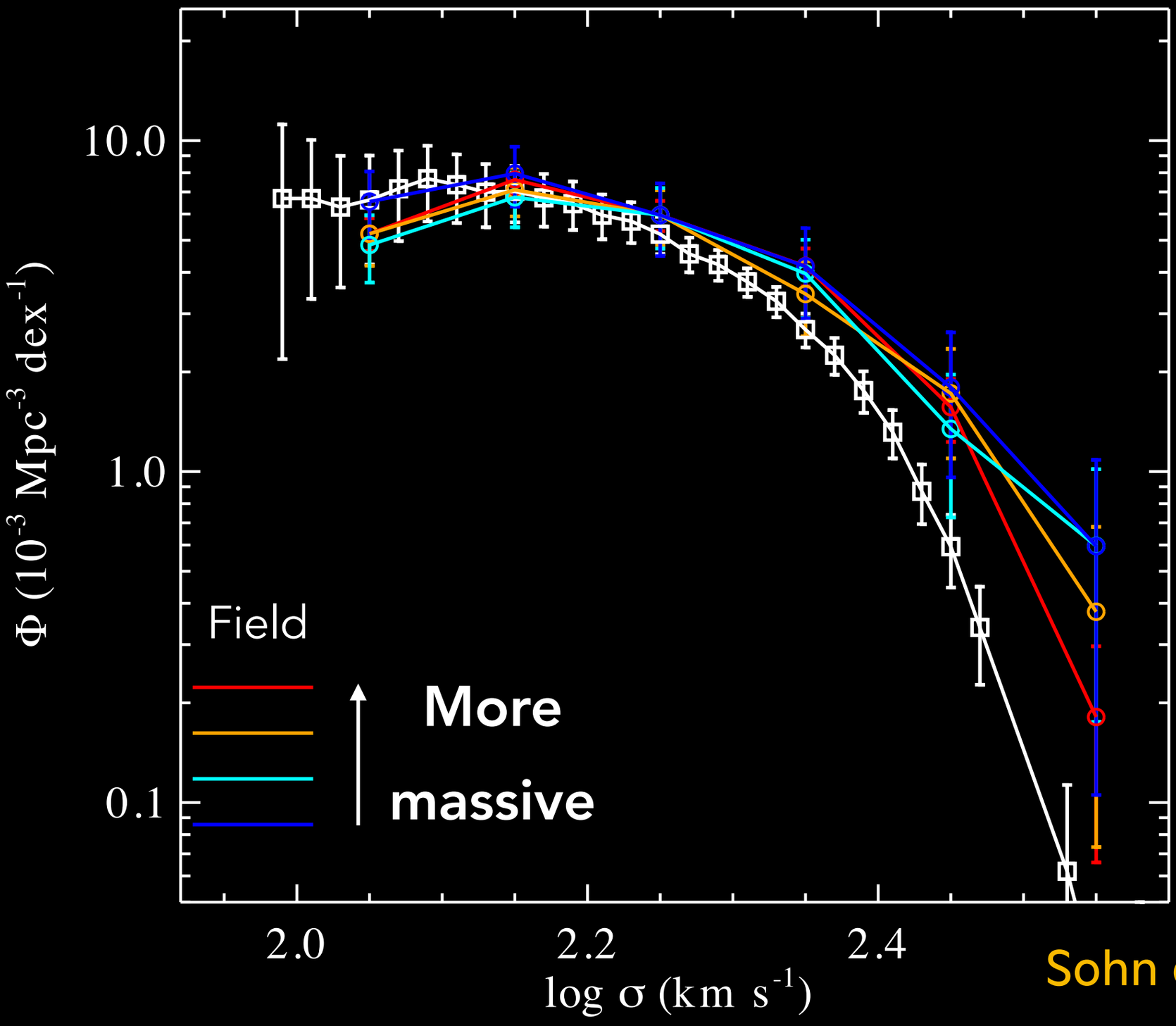


Velocity Dispersion Functions

An excess at σ > 250 km/s



Velocity Dispersion Functions



Sohn et al. (2020b)

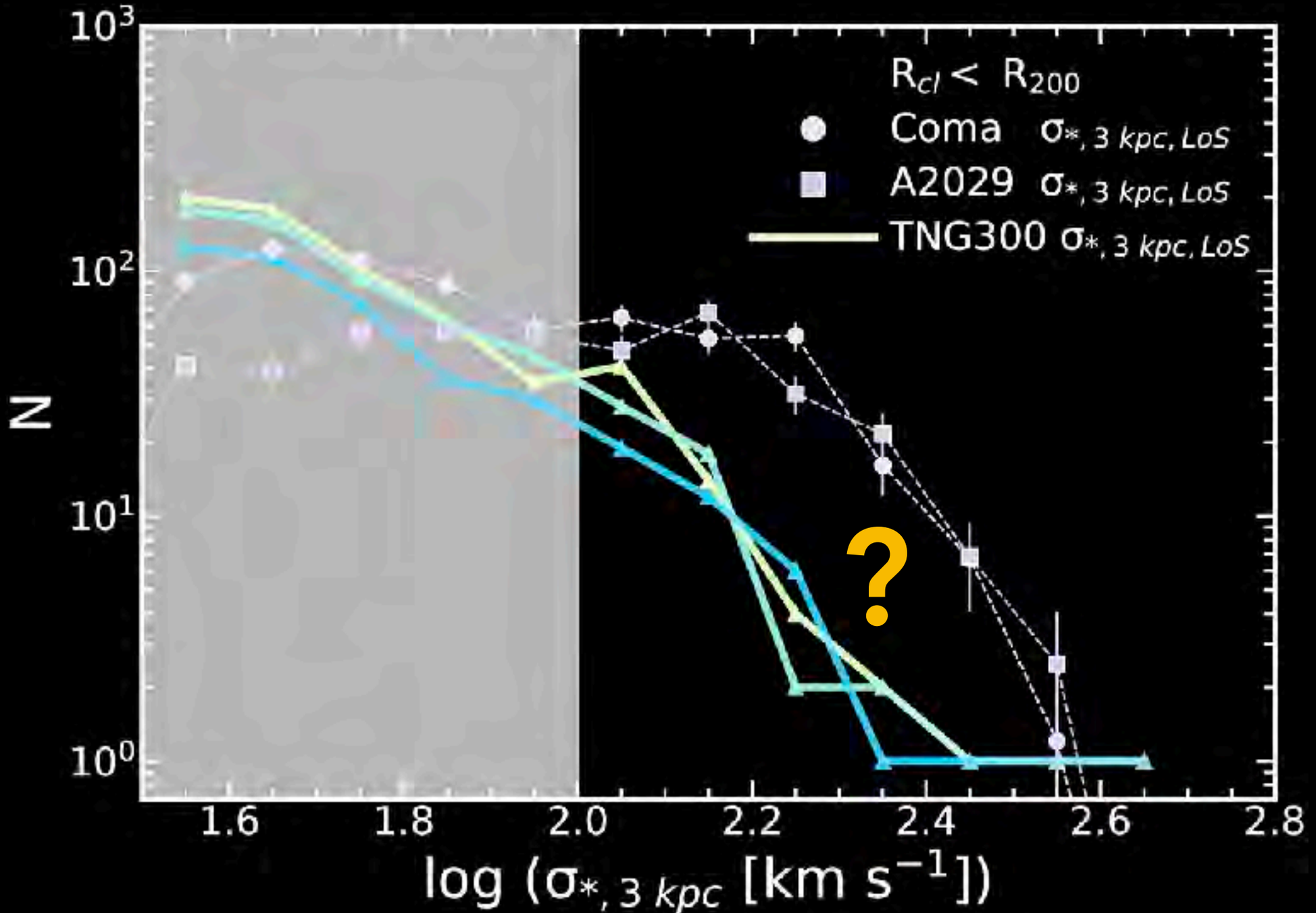
Velocity Dispersion in Simulations

- Numerical simulations (IllustrisTNG, EAGLE, ...)
  - Stellar velocity dispersion measurements with the similar manner with observations

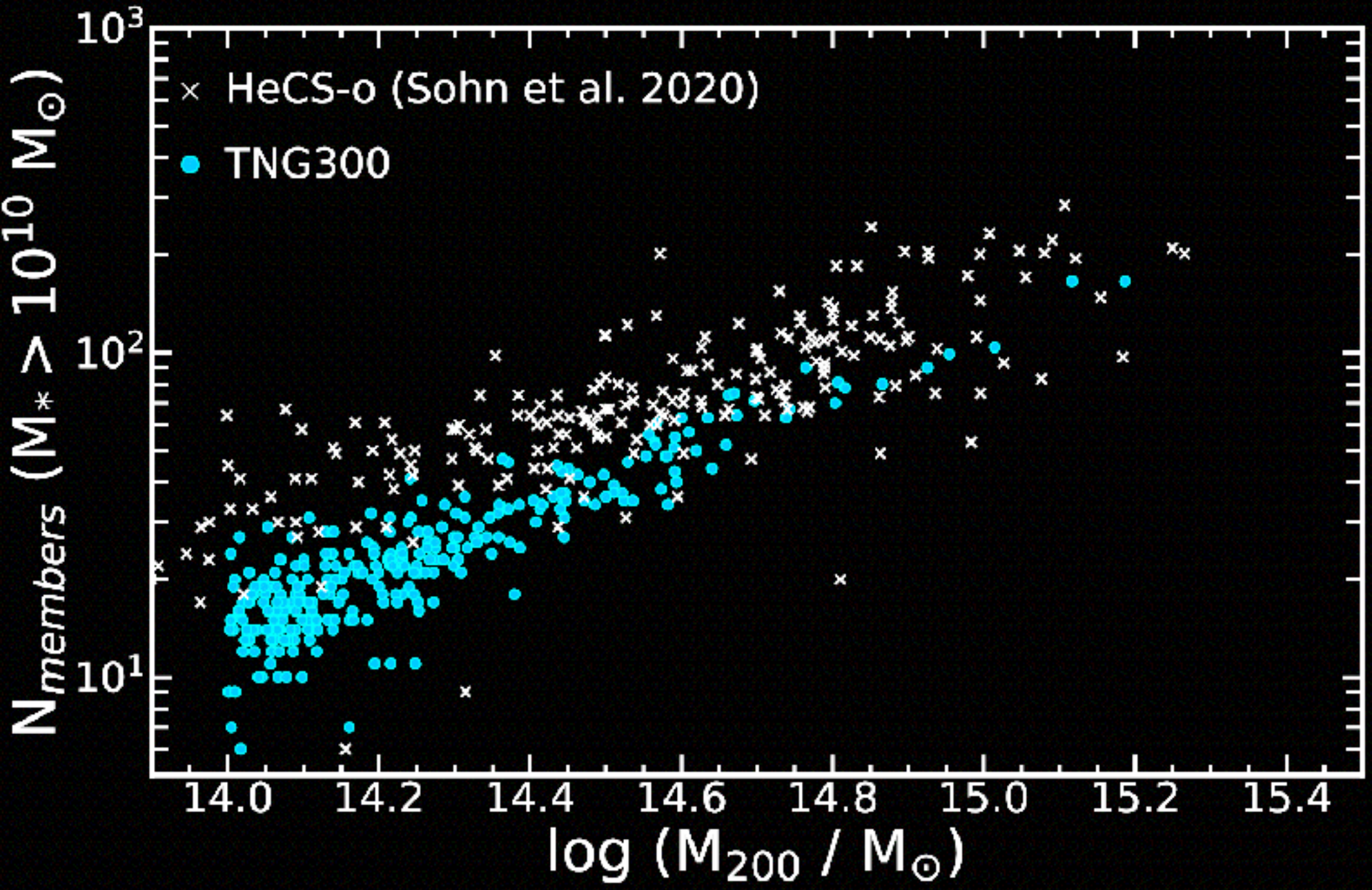




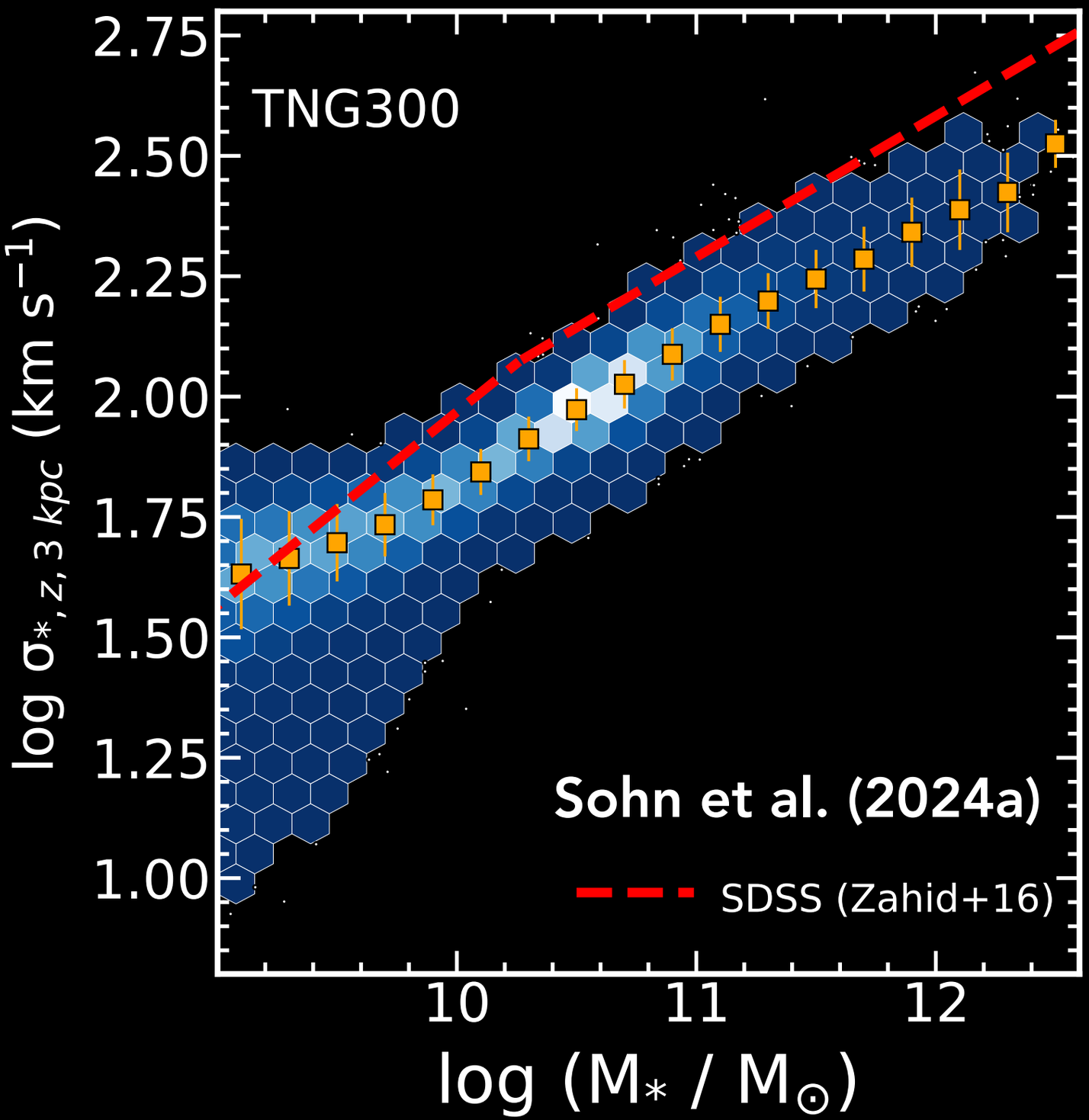
VDFs in Simulations



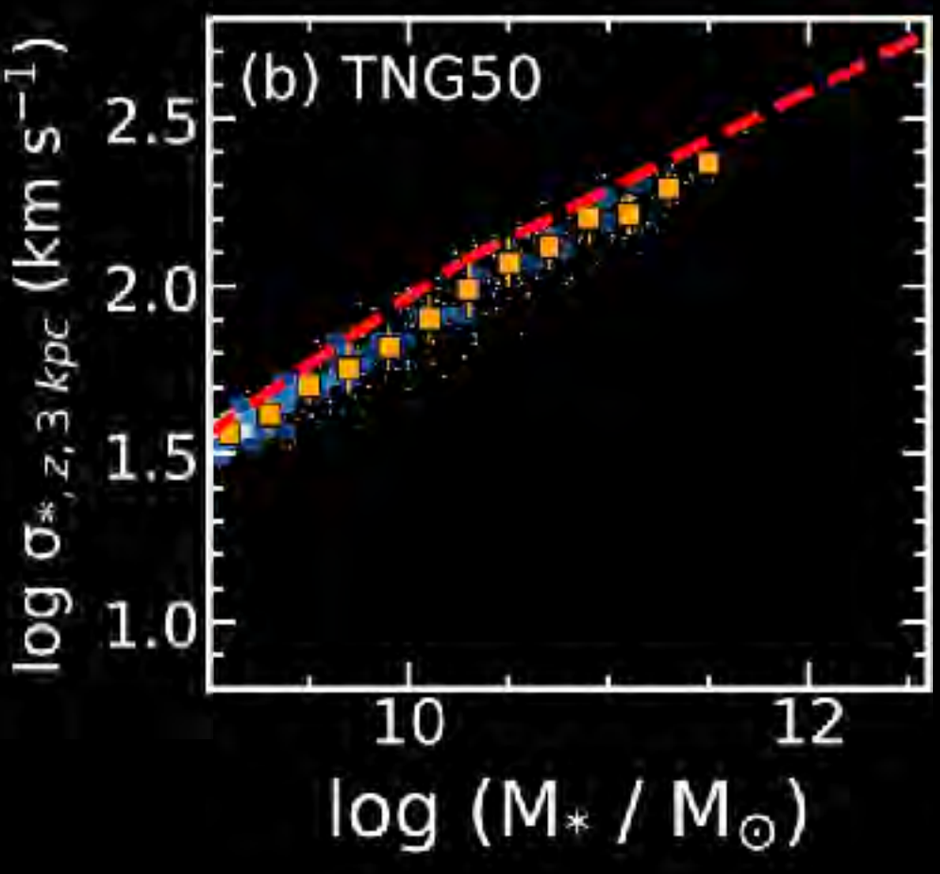
- What causes the offsets?
  - TNG300 contains less number of subhalos?
  - Not enough…



- Comparison between TNG and SDSS



- Line : SDSS galaxies
- Contour : TNG 300 quiescent galaxies
- Squares : TNG 300 median



- Resolution matters! What about AGN feedback?

Impact of AGN feedbacks



Jungwon Choi

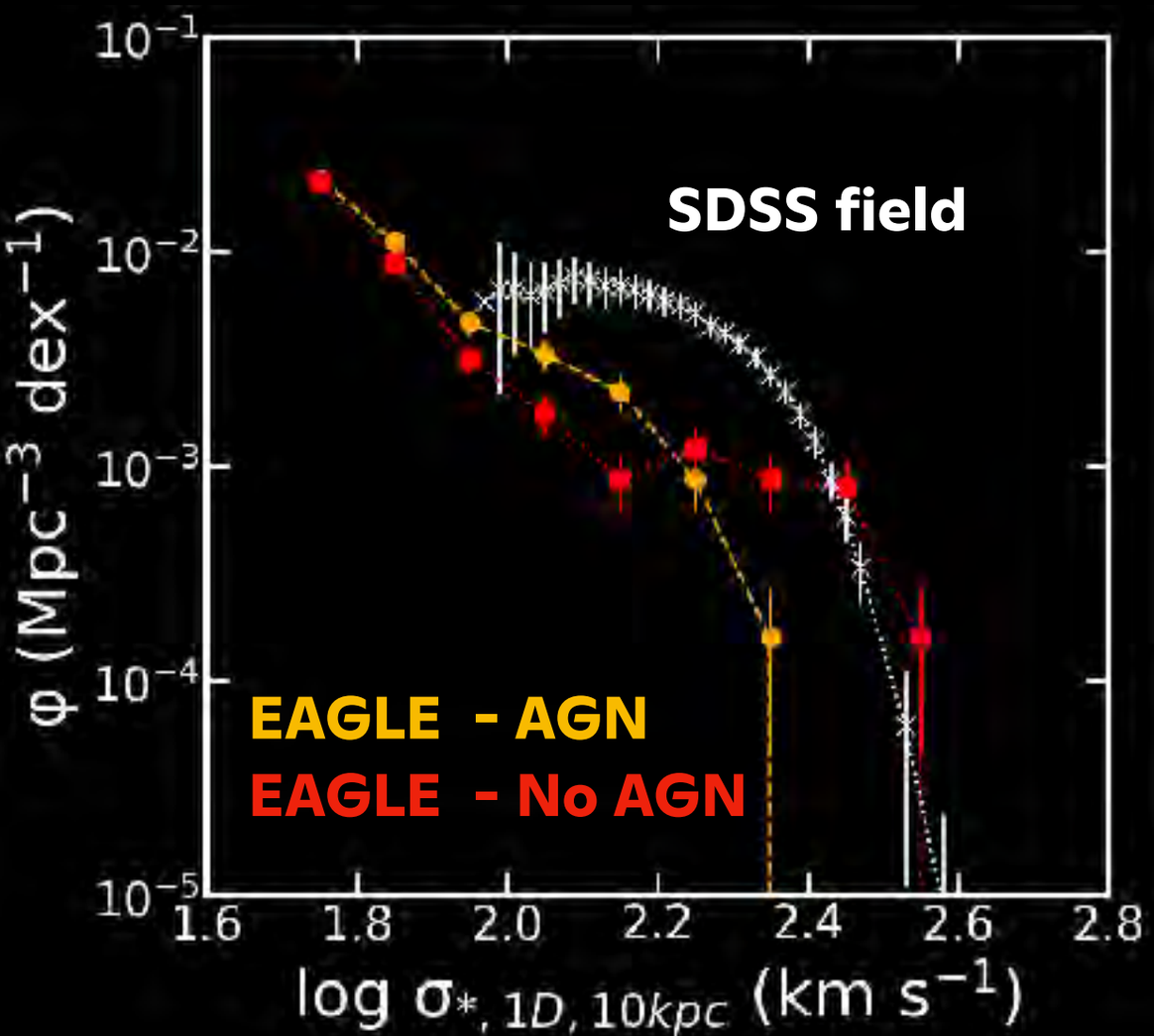
- EAGLE simulations
  - 50 Mpc with a similar mass a with TNG100
  - EAGLE50 - Normal
  - EAGLE-wAGN - weak
  - EAGLE-noAGN - no AGN feedback

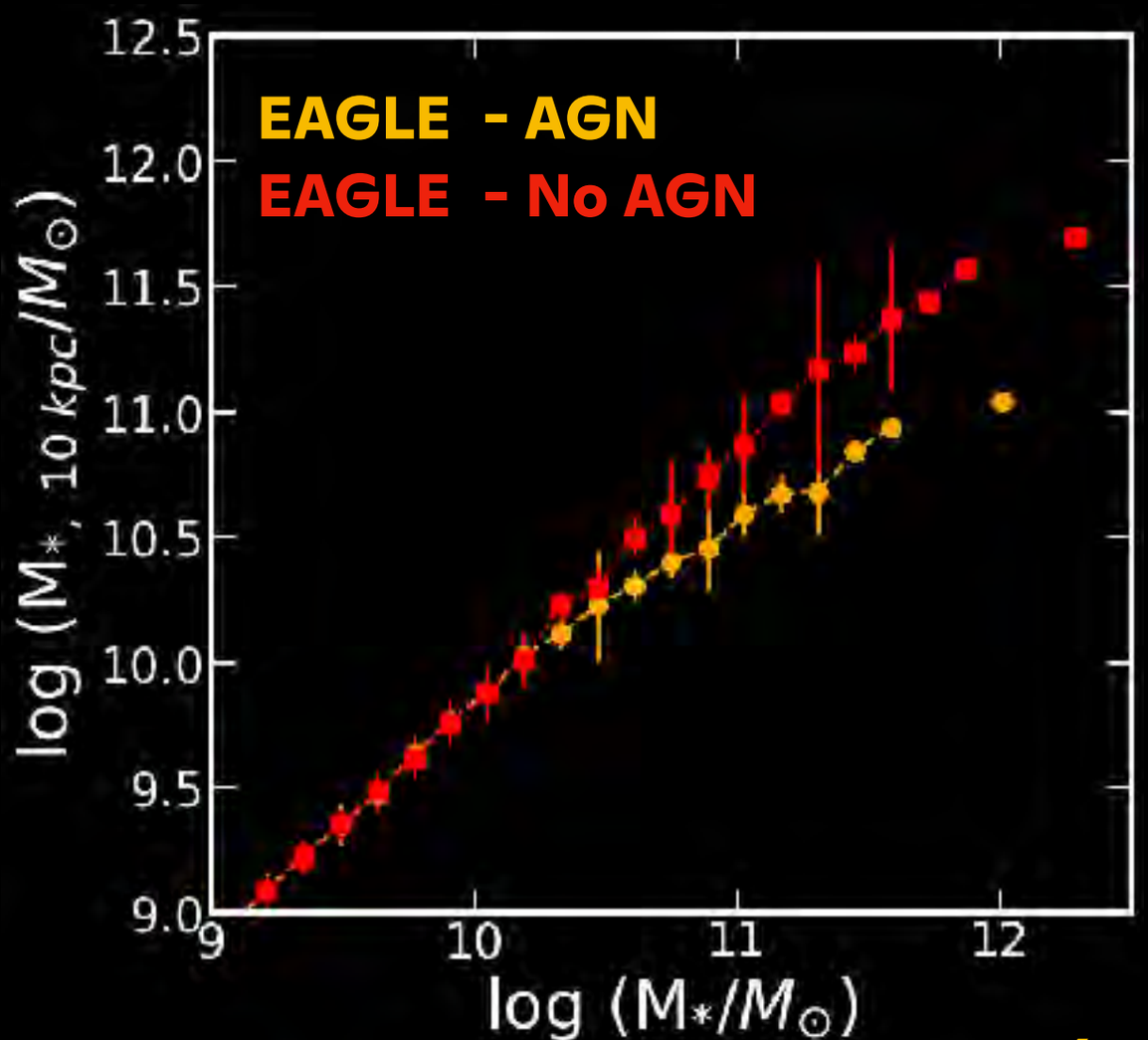
	ΔT_{AGN} [K]	C_{visc}
EAGLE50	$10^{8.5}$	2π
EAGLE-eAGN-dT	10^{9}	2π
EAGLE-eAGN-Visc	$10^{8.5}$	$2\pi \times 10^{-2}$
EAGLE-wAGN	10^{8}	2π
EAGLE-noAGN		

- Enhanced AGN
  - eAGN-dT : more energetic feedback
  - eAGN-visc : BHs accrete more matter

EAGLE Velocity Dispersion Functions

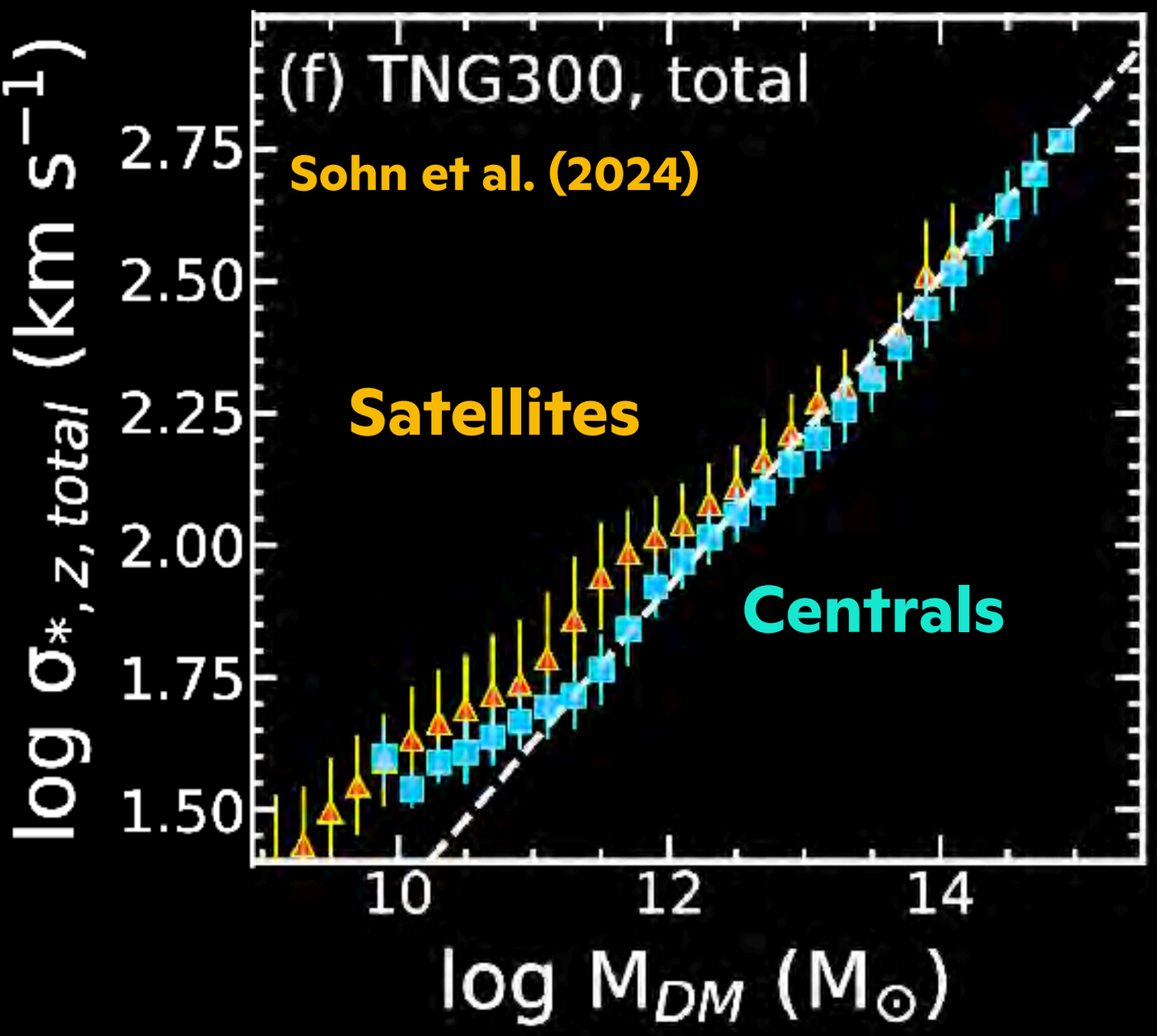
- No AGN feedback predicts more number of massive galaxies!
- AGN feedback : explains the shape of VDF
- AGN feedback : changes the mass profile of galaxies





Choi & Sohn (2025)

Tracing underlying DM distribution



- σ traces DM mass well
- Separation between central and satellites?

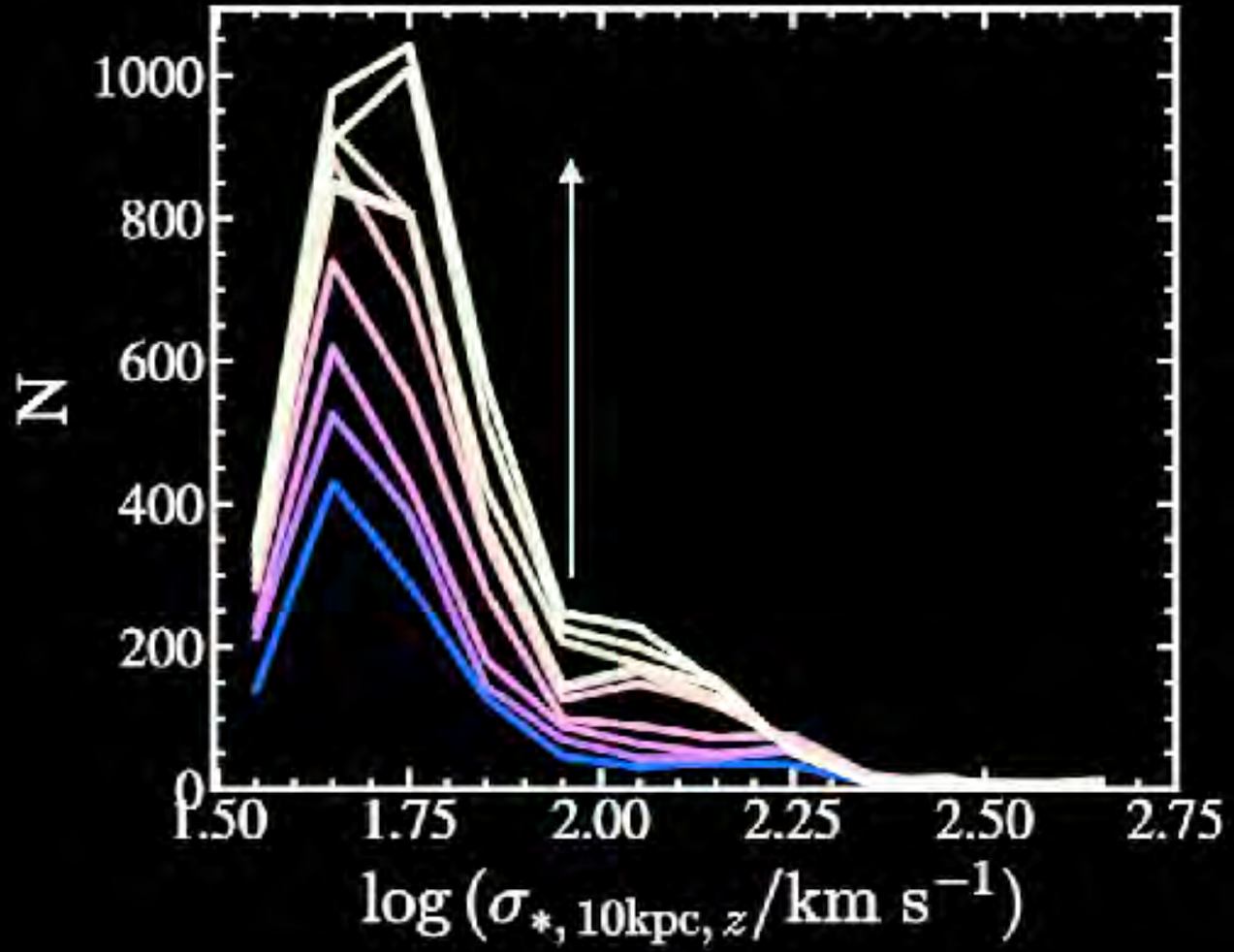
→ Connected to galaxy accretion history

→ DM subhalo evolutions in massive cluster halos

→ Dynamical mass functions of cluster galaxies with future spectroscopy!

Redshift evolution of VDFs

- Example VDF evolution
  - Key to understand the accretion of cluster galaxies
  - Internal vs. accreted populations



Evolution of TNG VDFs
from z = 1 to 0
(Seo et al. in prep.)

Observational evidence
from PFS?

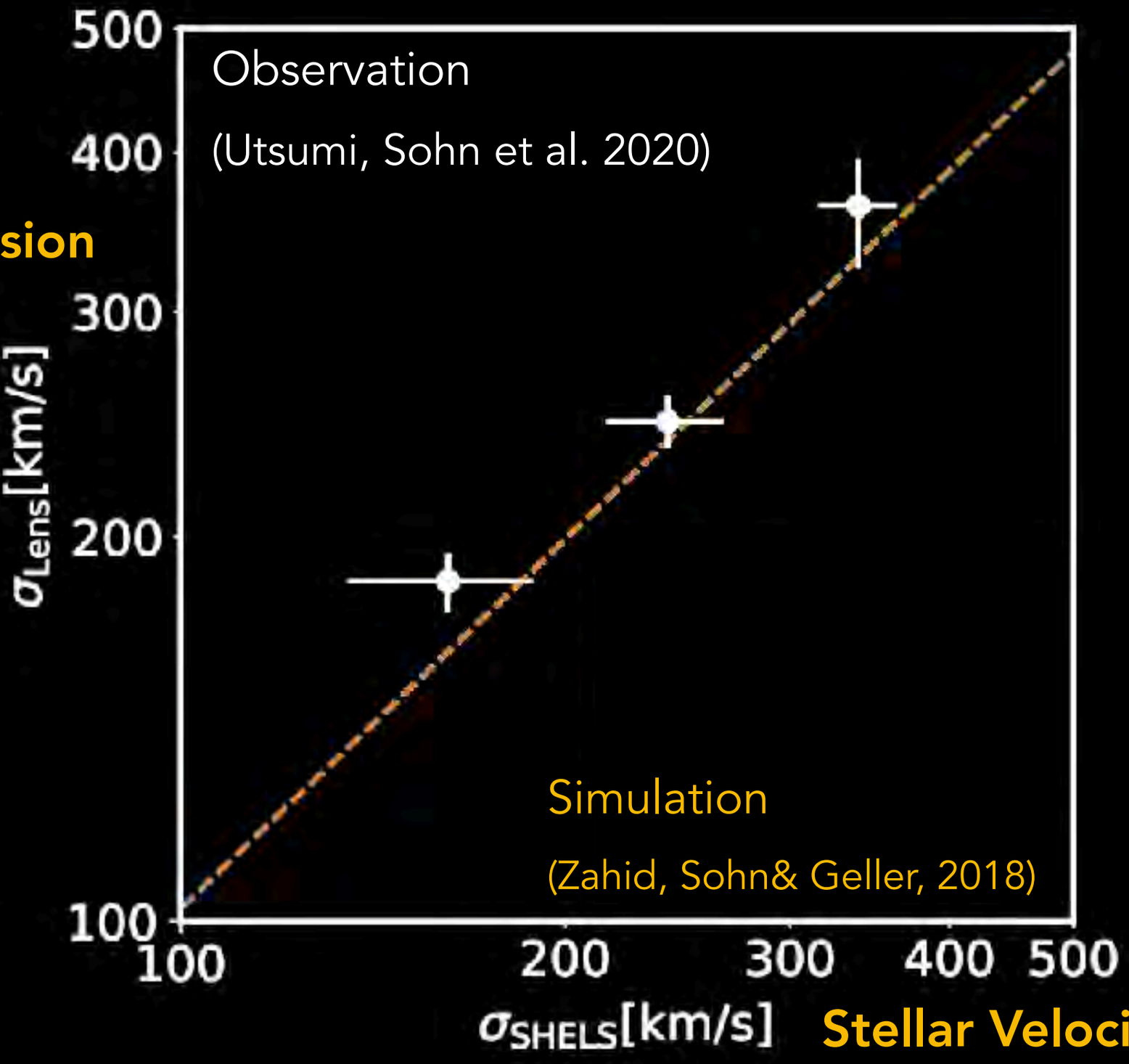
Future Directions & Summary

- Tracing cluster galaxy evolutions with dense spectroscopy
  - Less biased sample
  - Spectroscopic measures including σ_* , metallicity, etc
- Direct connection between VDF and M_{dyn} functions
  - Better understanding for connection between σ_* and DM subhalos
- Stay tune for future dense spectroscopic surveys
  - DESI, 4MOST, Subaru/PFS...

Thank you

Velocity Dispersions

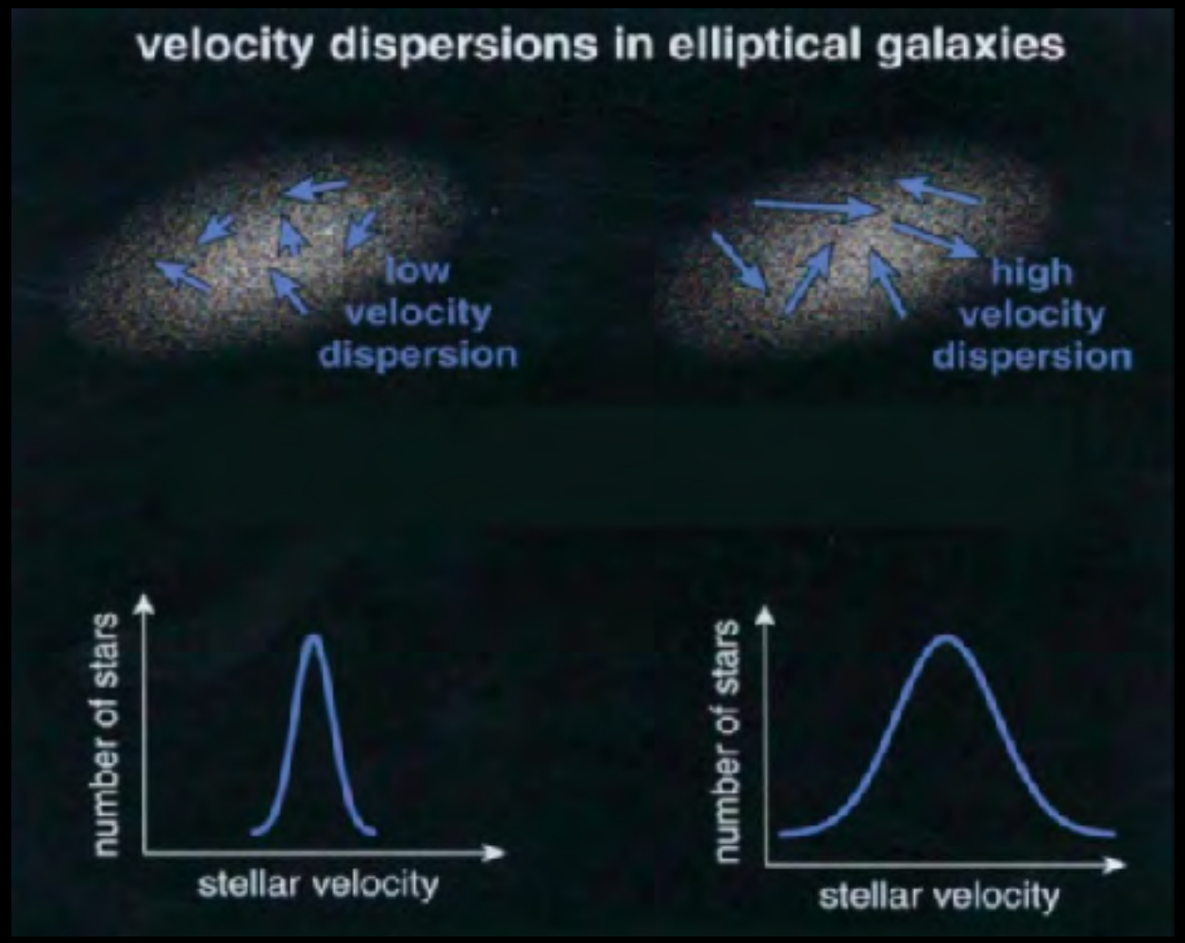
Dark Matter Velocity Dispersion



Stellar Velocity Dispersion

Stellar Velocity Dispersions

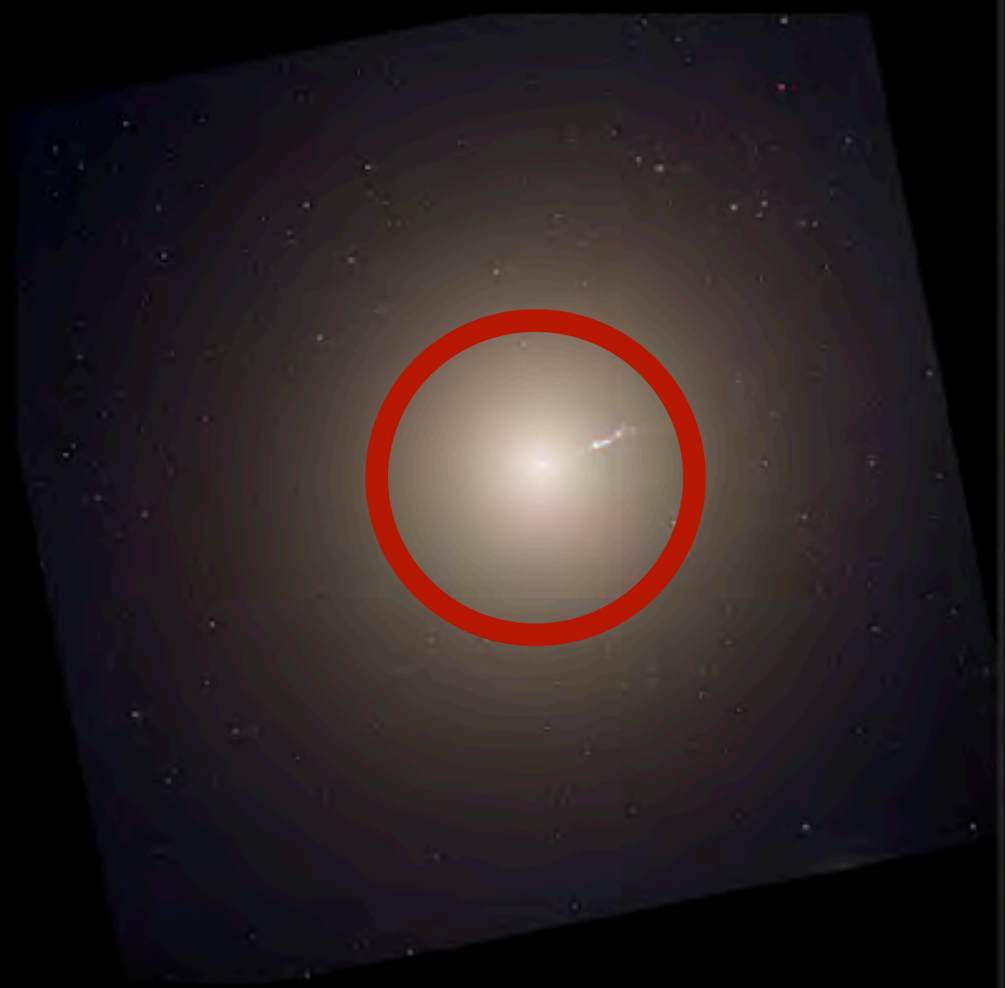
- Stellar velocity dispersion
  - Ideal proxy for DM determined by gravity (only/mainly)
- Measurable from spectroscopy
- Test this idea?



Courtesy from GARRETT E. POLACK's slides

Measuring σ* in Simulations

- Measuring σ*s in simulations with the same manner with observations



HUBBLE PHOTO OF M87



3D ILLUSTRATION OF M87