Cosmology Dependence of the Transition Mass of Dark Halo Spins

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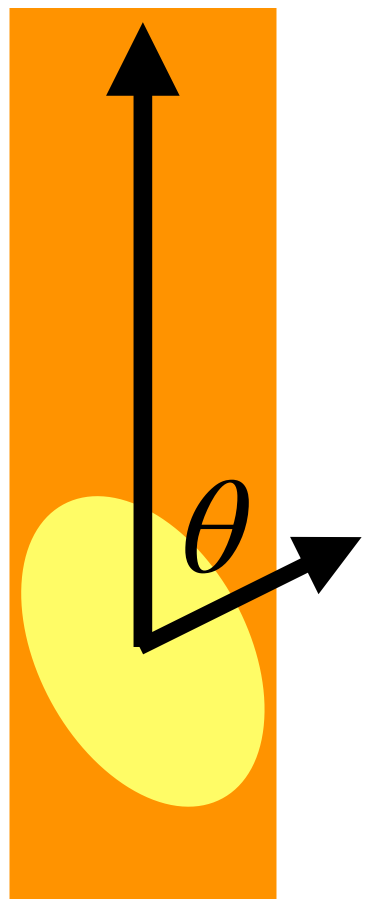
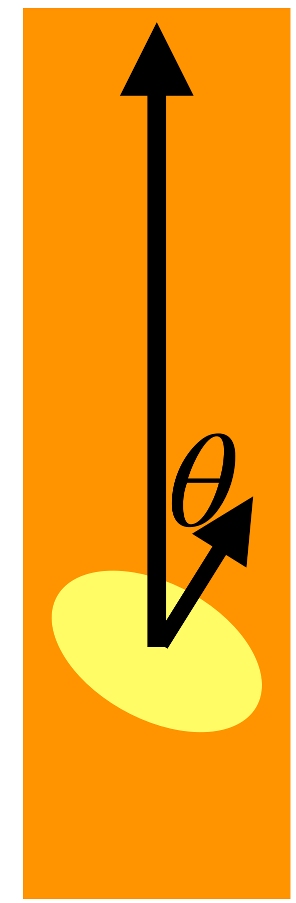
- Lee & Libeskind (ApJ, 2020, 902, 22)
- Lee et al. (ApJ, 2021, 922, 6)
- Lee, Moon, & Yoon (submitted to ApJ, arXiv:2111.13831)

Halo Spin Transition (HST)



If $M > M_t$, then

$\langle \cos\theta \rangle < 0.5$



If $M \leq M_t$, then

$\langle \cos\theta \rangle \geq 0.5$

Previous Results

- Numerically, the occurrence of HST confirmed.
  - Sensitive dependence of M_t on how the filaments are identified (e.g., Kraljic et al. 2020).
  - Its occurrence in the sheet environments (e.g., Lee et al. 2020)
- Observationally, a weak signal of the morphology-dependent transition (e.g., Tempel & Libeskind 2013).
- Theoretically, no consensus established.
  - It should be closely linked with the evolution of the halo angular momentum in the cosmic web (Codis et al. 2015).

Directions of Improvements

- Considering all of 3 tidal principal directions.
- Finding a more rigorous definition of M_t
- Testing M_t as a cosmological diagnostics.
- Exploring the galaxy stellar spin transitions.

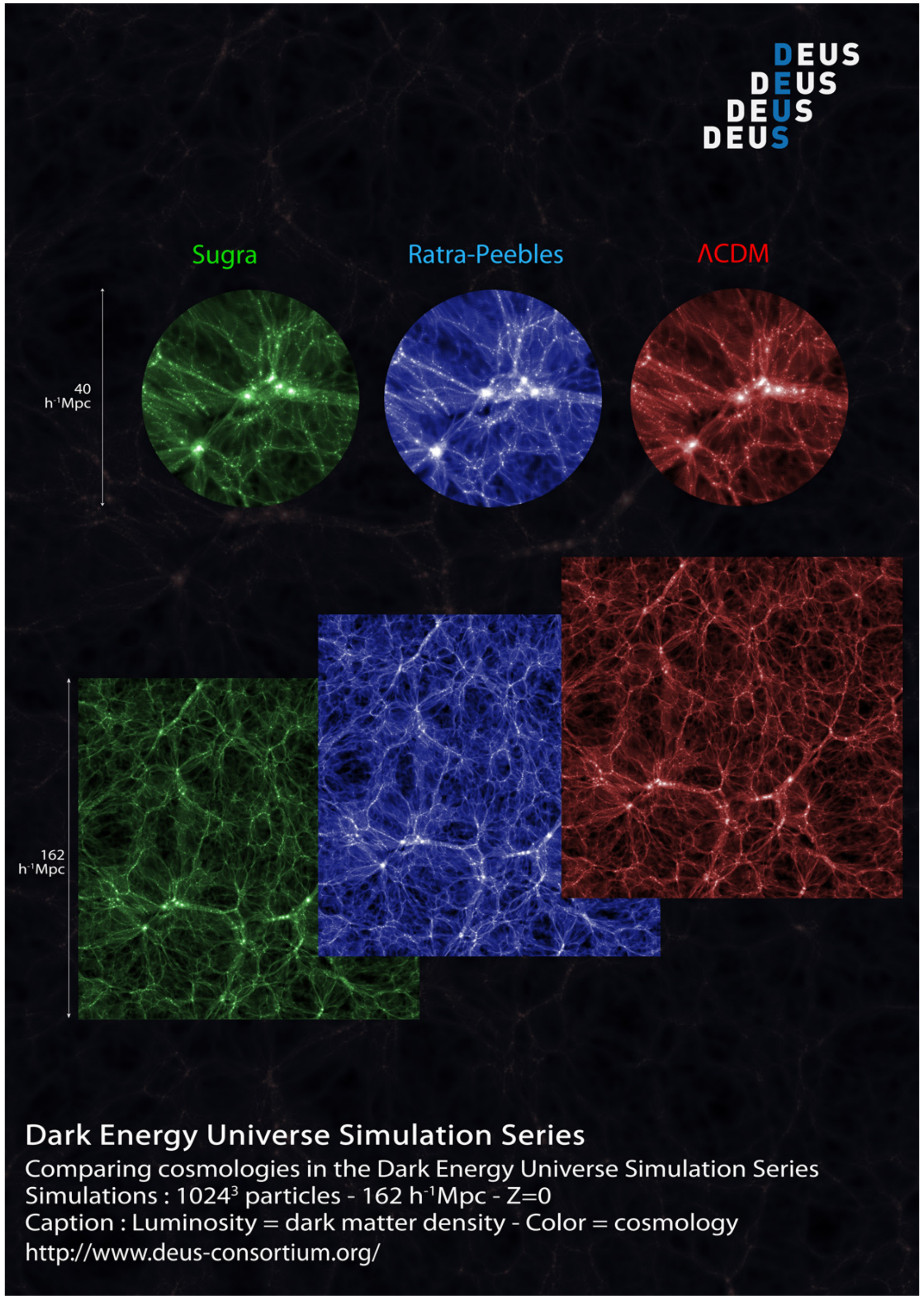
Simulation Data

LARGE SET OF UNIVERSE VOLUMES (+ 25 SIMULATIONS)

HIGH SPATIAL RESOLUTION AND MASS: 2.5 h^{-1} kpc to 10.4 h^{-1} Gpc, 2.5 10^{8} h^{-1} M⊙ to 10^{16} h^{-1}M⊙

INITIAL REDSHIFT DEEP IN LINEAR REGIME

Box Size	Force Resolution	Mass Resolution	Number of Particles	Initial Redshift	Cosmological Models	Supercomputer (Nb of Proc)
162 h^{-1} Mpc	2.5 h^{-1} kpc	~2. 10^{9} h^{-1} M⊙	512^3	~90	ΛCDM, SUCDM, RPCDM	Titane (64)
162 h^{-1} Mpc	2.5 h^{-1} kpc	~2.5 10^{8} h^{-1} M⊙	1024^3	~130	ΛCDM, SUCDM, RPCDM	Blue Gene/P(4096)
648 h^{-1} Mpc	20 h^{-1}kpc	~1.5 10^{11} h^{-1} M⊙	512^3	~55	ΛCDM, SUCDM, RPCDM	-
648 h^{-1} Mpc	10 h^{-1}kpc	~1.75 10^{10} h^{-1} M⊙	1024^3	~90	ΛCDM, SUCDM, RPCDM	Blue Gene/P(4096)
648 h^{-1} Mpc	5 h^{-1}kpc	~2. 10^{9} h^{-1} M⊙	2048^3	~90	ΛCDM, RPCDM	Blue Gene/P(32768)
1296 h^{-1} Mpc	40 h^{-1}kpc	~1. 10^{12} h^{-1} M⊙	512^3	~40	ΛCDM, SUCDM, RPCDM	-
2592 h^{-1} Mpc	40 h^{-1}kpc	~1. 10^{12} h^{-1} M⊙	1024^3	~55	ΛCDM, SUCDM, RPCDM	Blue Gene/P(4096)
2592 h^{-1} Mpc	20 h^{-1}kpc	~1.5 10^{11} h^{-1} M⊙	2048^3	~55	ΛCDM, RPCDM	Blue Gene/P(24576)
5184 h^{-1} Mpc	40 h^{-1}kpc	~1. 10^{12} h^{-1} M⊙	2048^3	~40	ΛCDM, RPCDM	Blue Gene/P(24576)
10368 h^{-1} Mpc	40 h^{-1}kpc	~1. 10^{12} h^{-1} M⊙	4096^3	~40	ΛCDM	Curie Fat Nodes (9728)



Cosmological Models

Initial Conditions and the Particle Mass Resolution

Model	Ω_m	h	σ_8	w_0	w_a	m_p $(10^9\ h^{-1}M_\odot)$
ΛCDM	0.257	0.72	0.80	−1.0	0.0	2.3
*w*CDM	0.275	0.72	0.852	−1.2	0.0	2.4
RPCDM	0.230	0.72	−0.66	−0.87	0.08	2.0

Lee & Libeskind 2020, ApJ, 902, 22

- wCDM: a phantom DE model with negative kinetic energy.
- RPCDM: a quintessence model with Ratra-Peebles scalar field dark energy.
- All of the three models satisfy the same WMAP7 constraints.

Calculations

- Constructing the tidal fields smoothed on the scale R_f:
  - Finding three eigenvectors, $\{\hat{\mathbf{e}}_1, \hat{\mathbf{e}}_2, \hat{\mathbf{e}}_3\}$, at the positions of the selected halos with 300 or more particles
  - Calculating the cosines of the angles between the halo spin axis, $\hat{\mathbf{j}}$, and each of $\{\hat{\mathbf{e}}_1, \hat{\mathbf{e}}_2, \hat{\mathbf{e}}_3\}$: $cos\theta_i \equiv |\hat{\mathbf{j}} \cdot \hat{\mathbf{e}}_i|$
  - Ensemble averages, $\langle cos\theta_i \rangle$, as a function of the halo mass M_h

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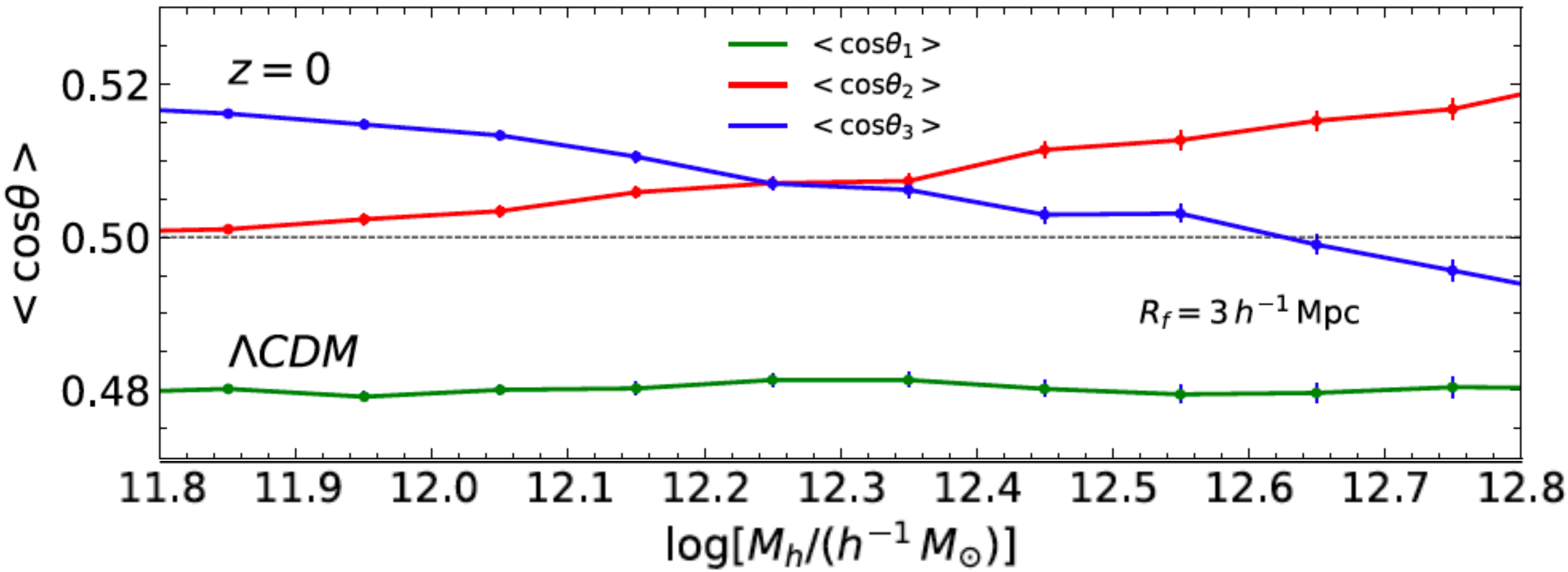

- Transition of the preferential direction of $\hat{\mathbf{j}}$ from $\hat{\mathbf{e}}_2$ to $\hat{\mathbf{e}}_3$, as M_h decreases.

- The preferential direction of $\hat{\mathbf{j}}$ being perpendicular to $\hat{\mathbf{e}}_1$, regardless of M_h .

A New Definition of M_t

- Setting up a null hypothesis, H_0 :

$$p(\cos\theta_2) \sim p(\cos\theta_3)$$

- Performing a KS test of H_0 :
  - Finding the mass bin at which the KS test rejects H_0 at the C.L. below 99.9%.
  - Defining the bin as the spin transition zone, M_t

$$D_{\max} \equiv \mathrm{Max}_{\theta}\{\,|\,P(\cos\theta \geq \cos\theta_2) - P(\cos\theta \geq \cos\theta_3)\,|\,\}$$

$$\sqrt{\frac{n_h}{2}}D_{\max} \leq 1.99 \quad \longleftrightarrow C.L. \leq 99.9\,\%$$

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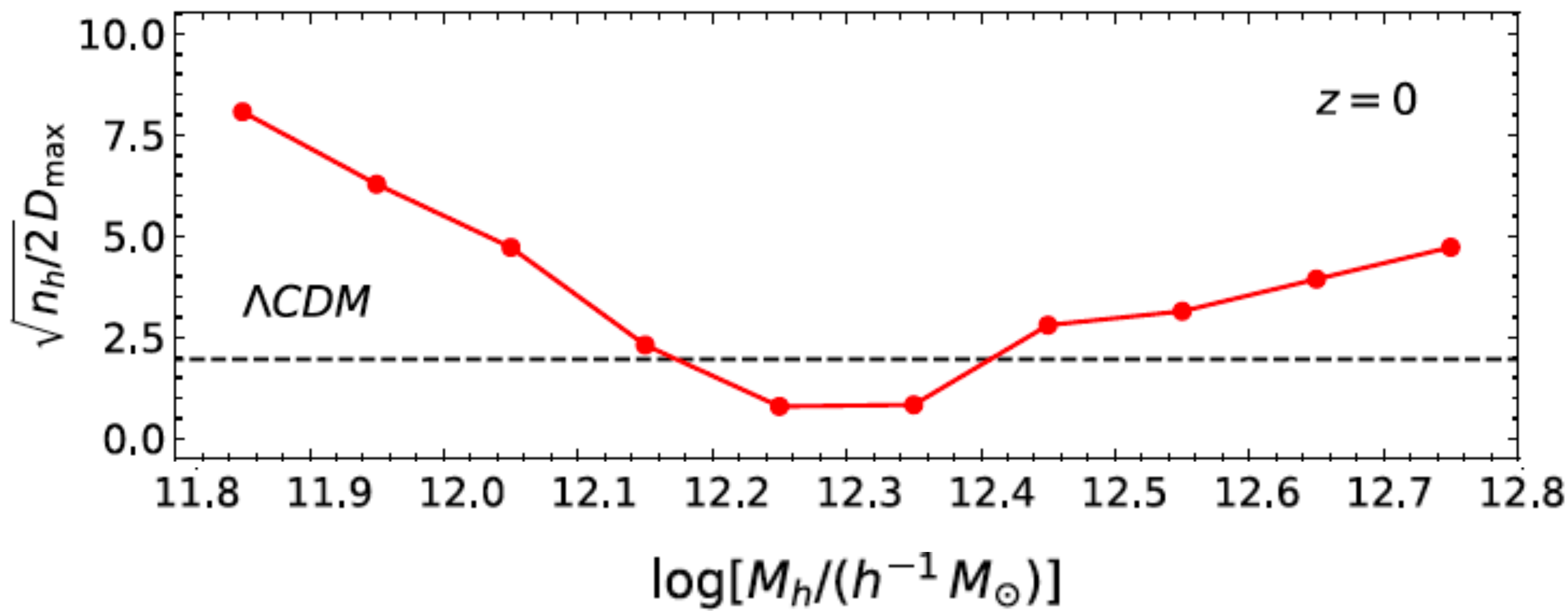
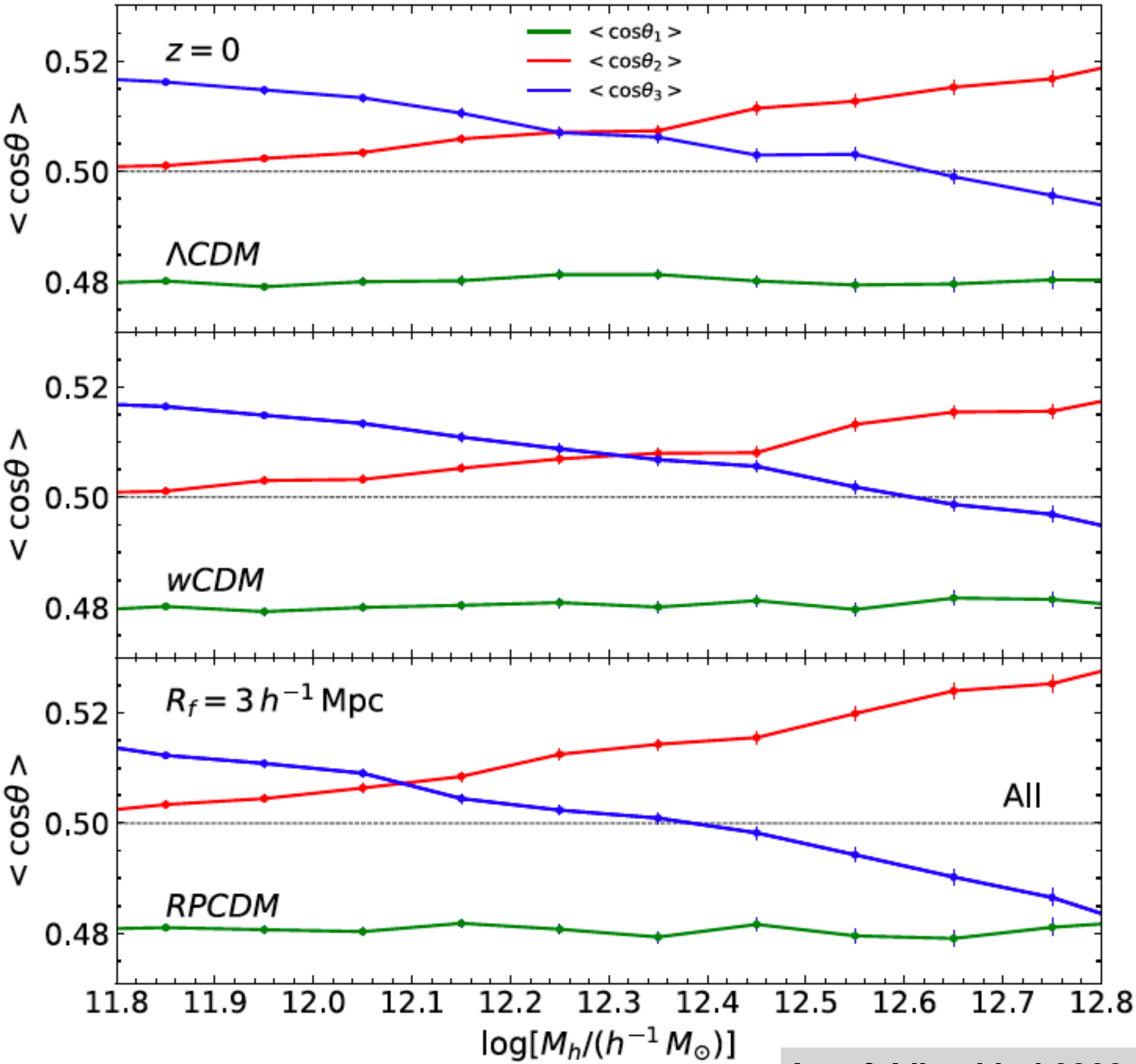


Variation of M_t with Cosmology



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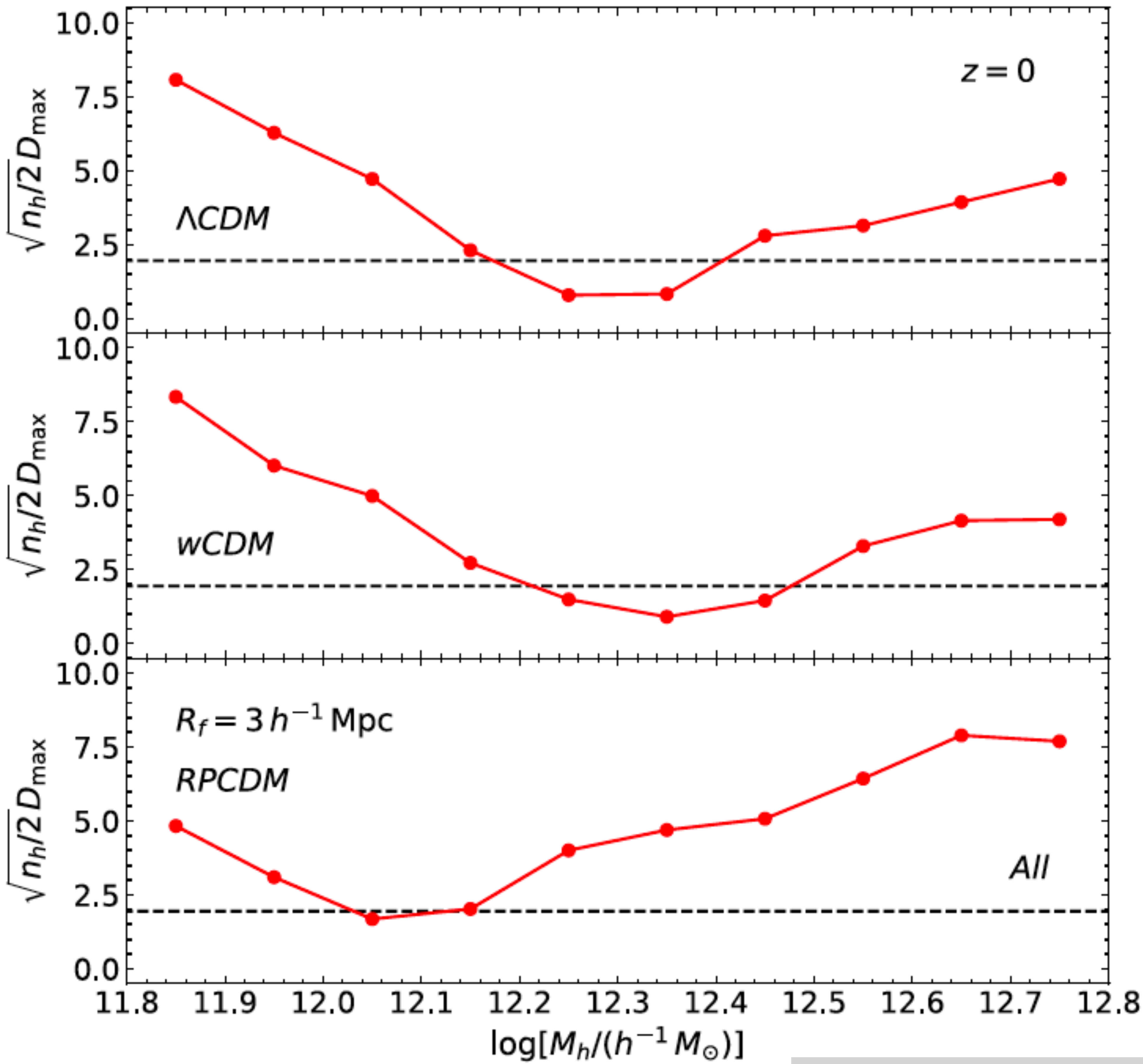

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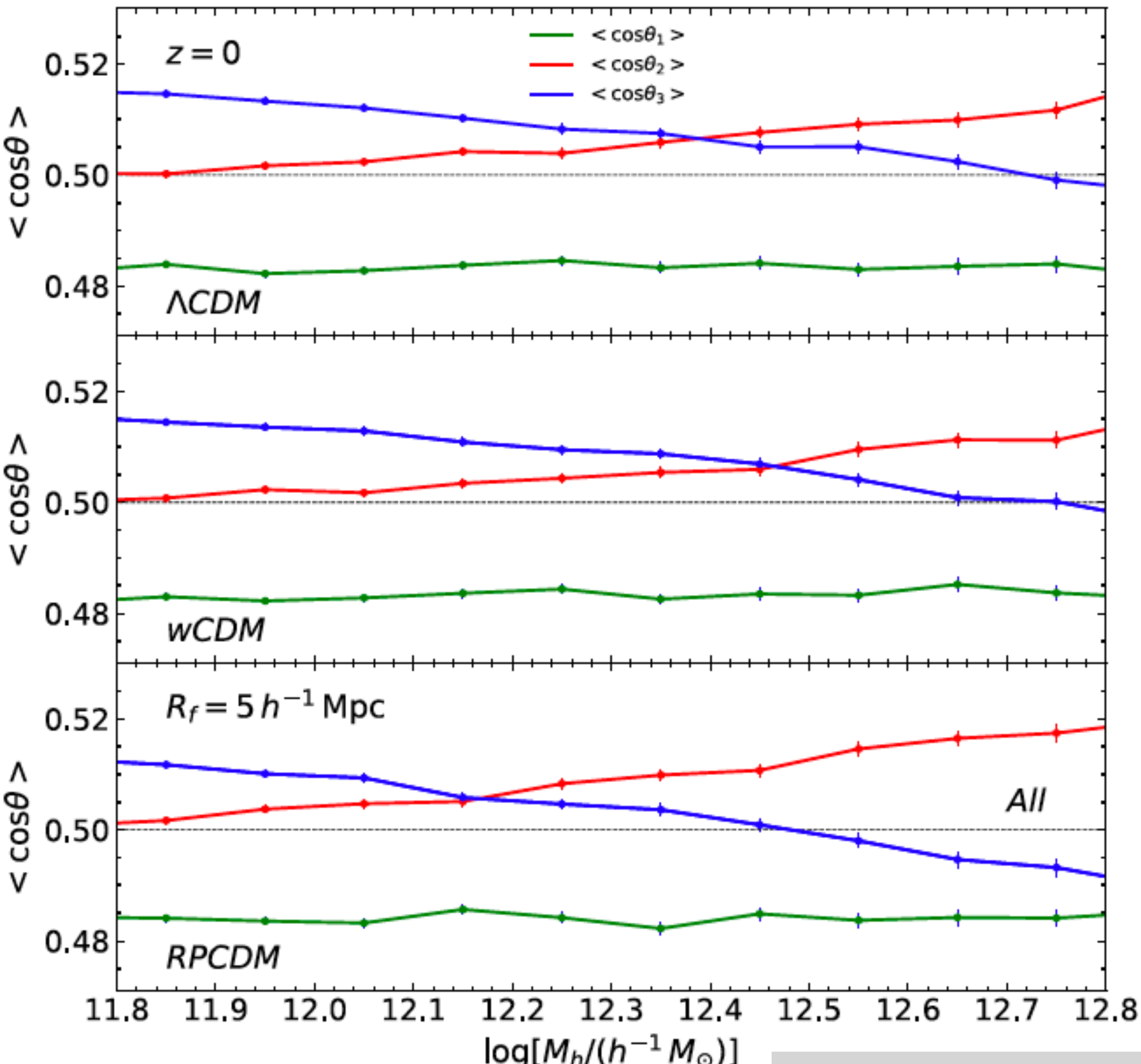
Variation of M_t with Smoothing Scale



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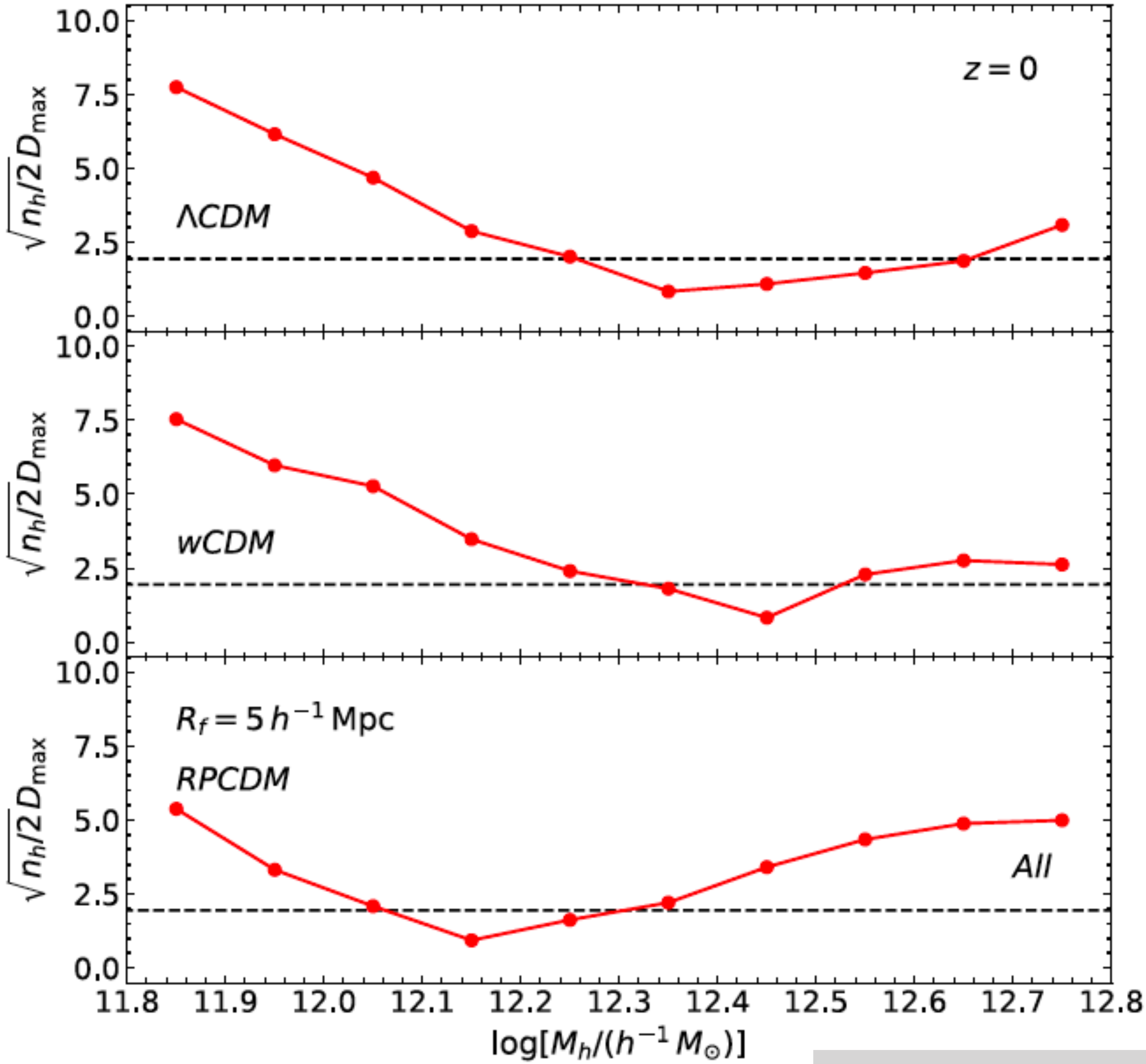

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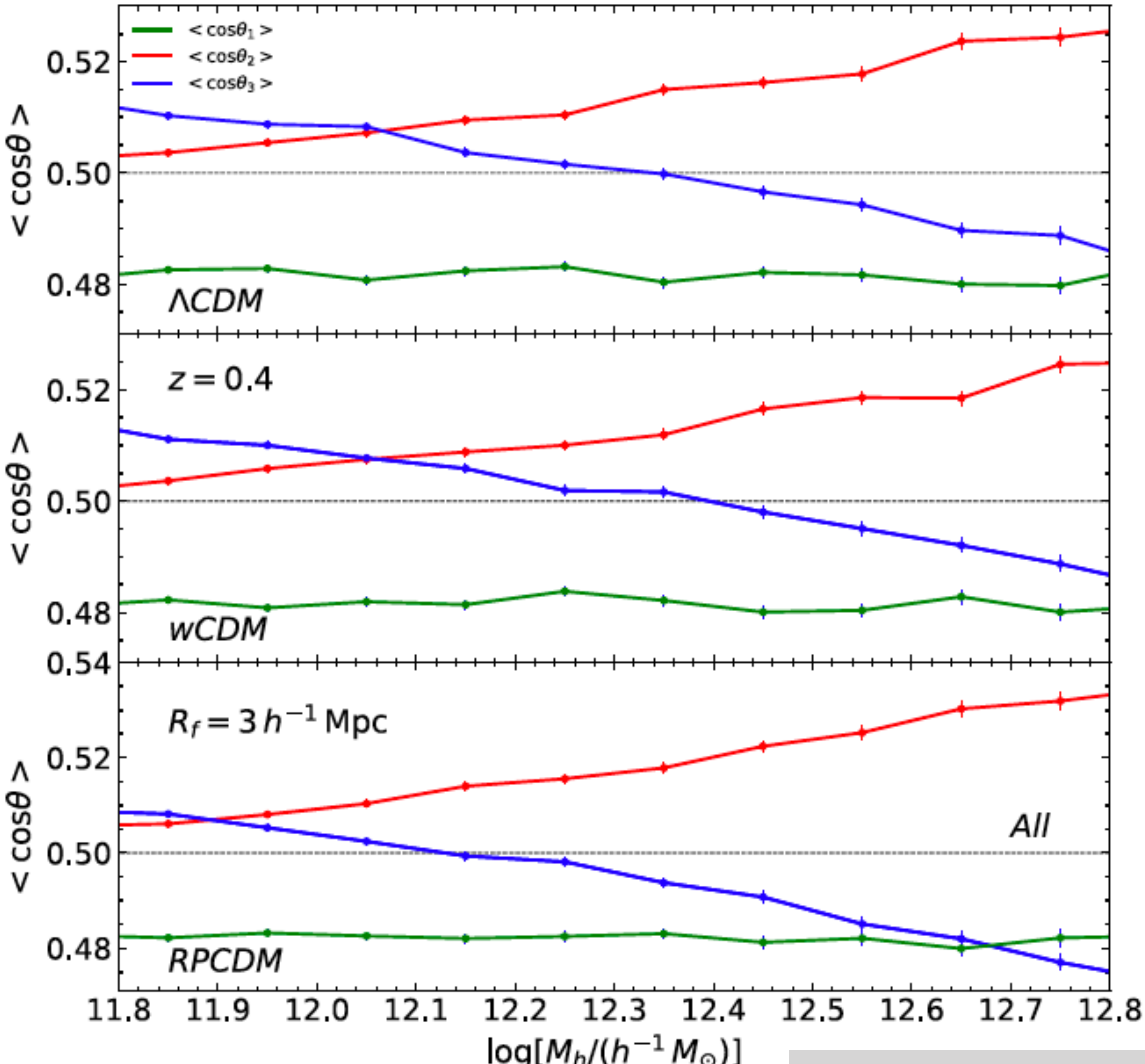
Variation of M_t with Redshifts



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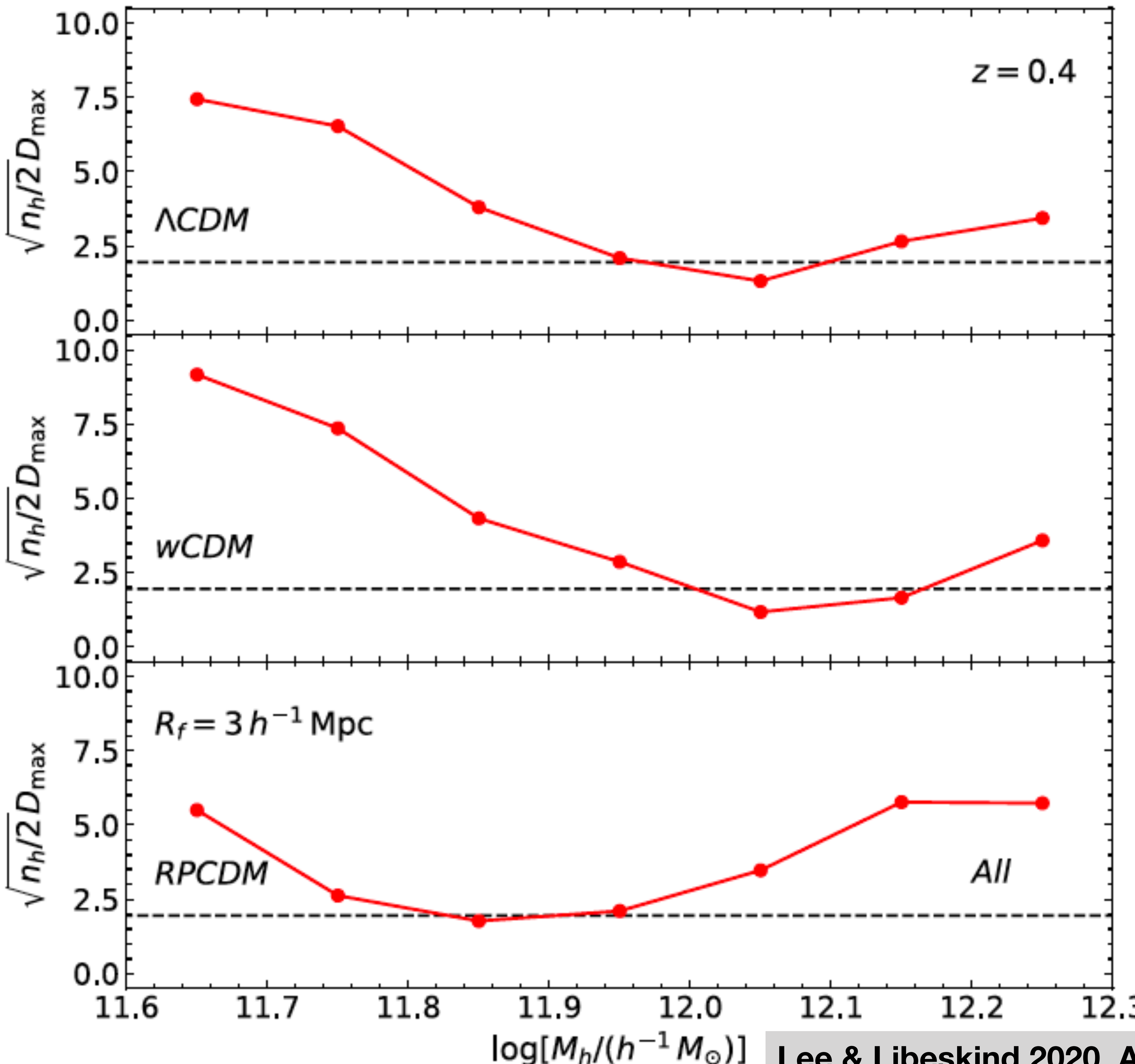

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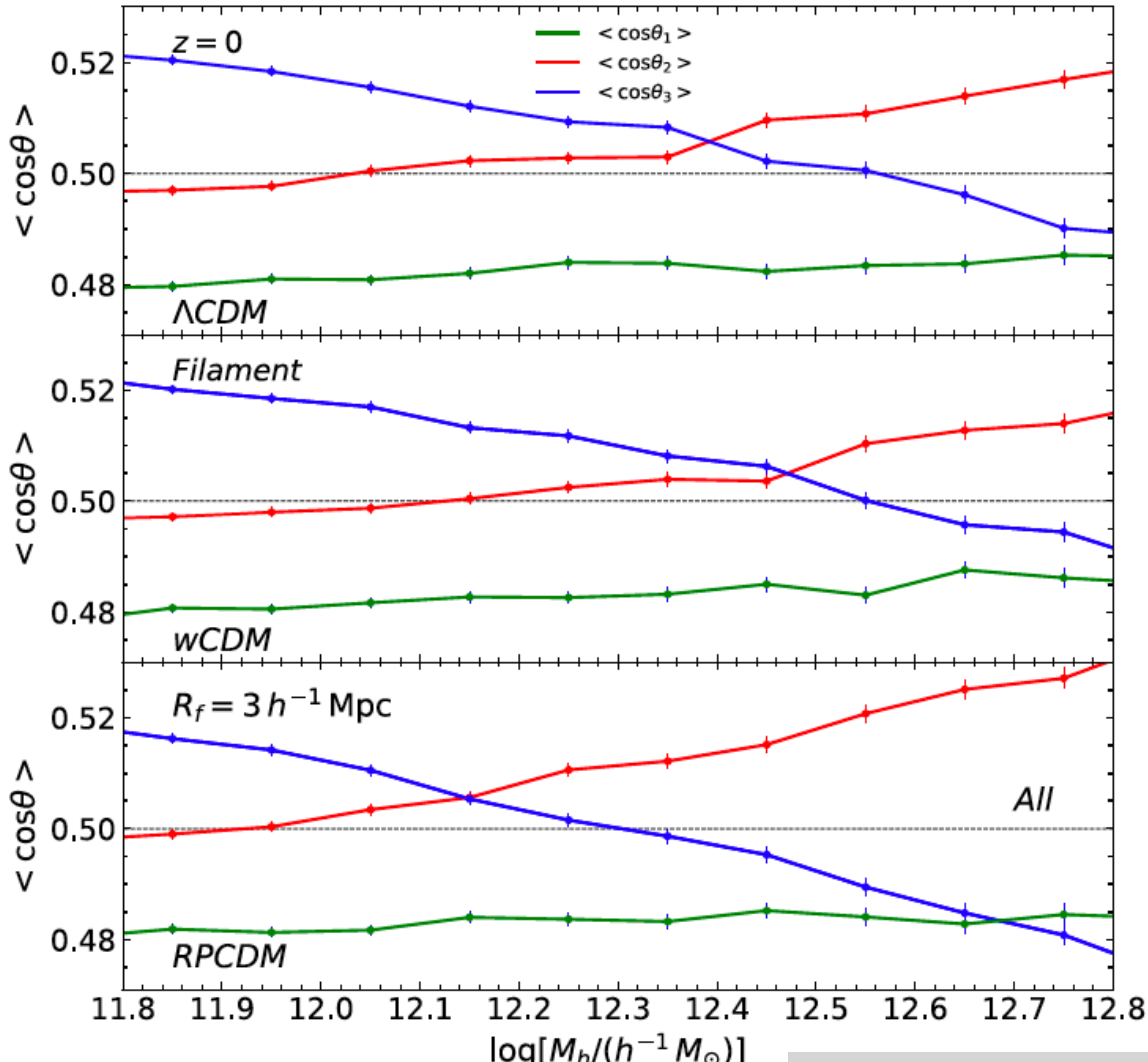
Variation of M_t with Web Type



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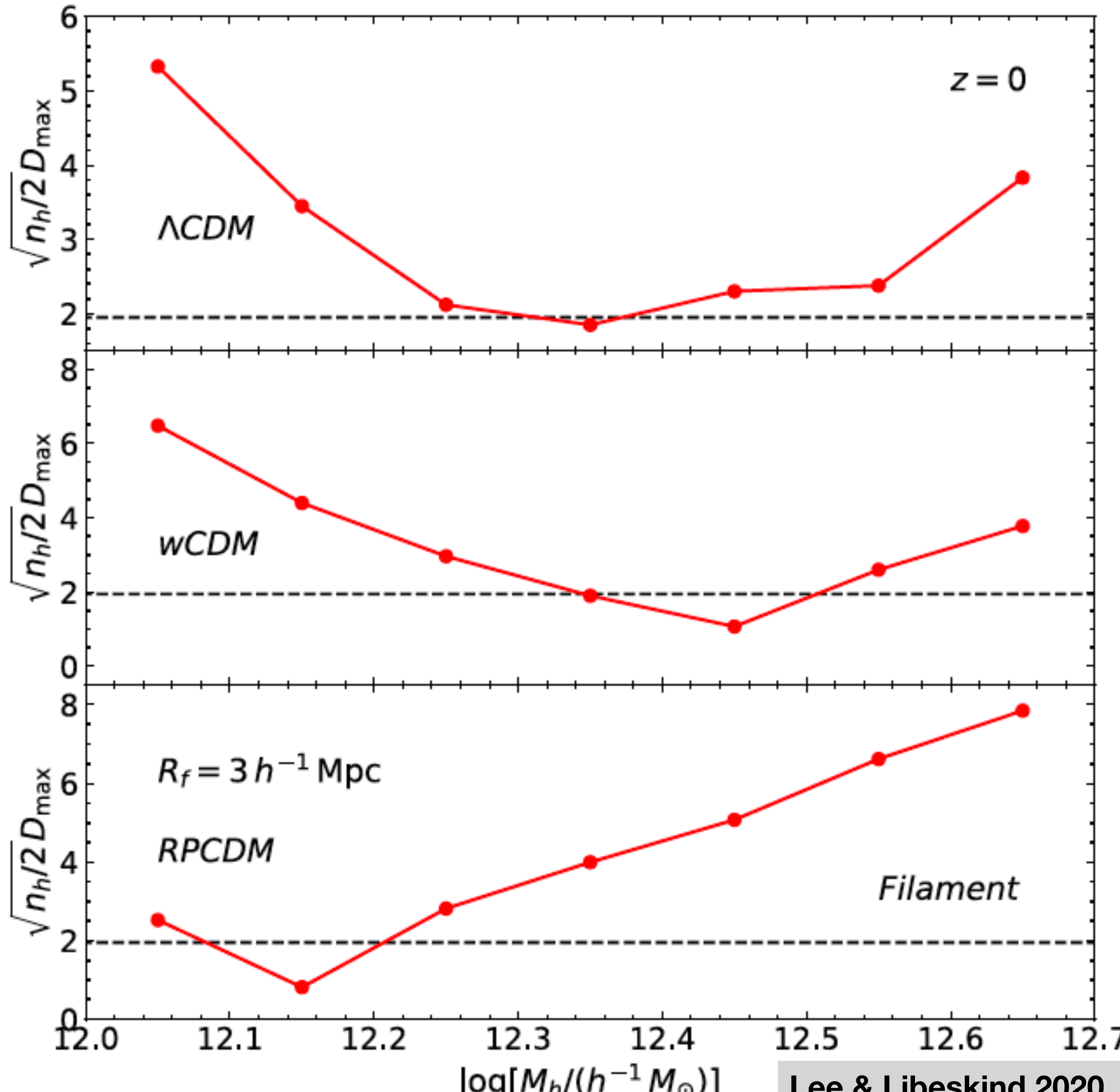

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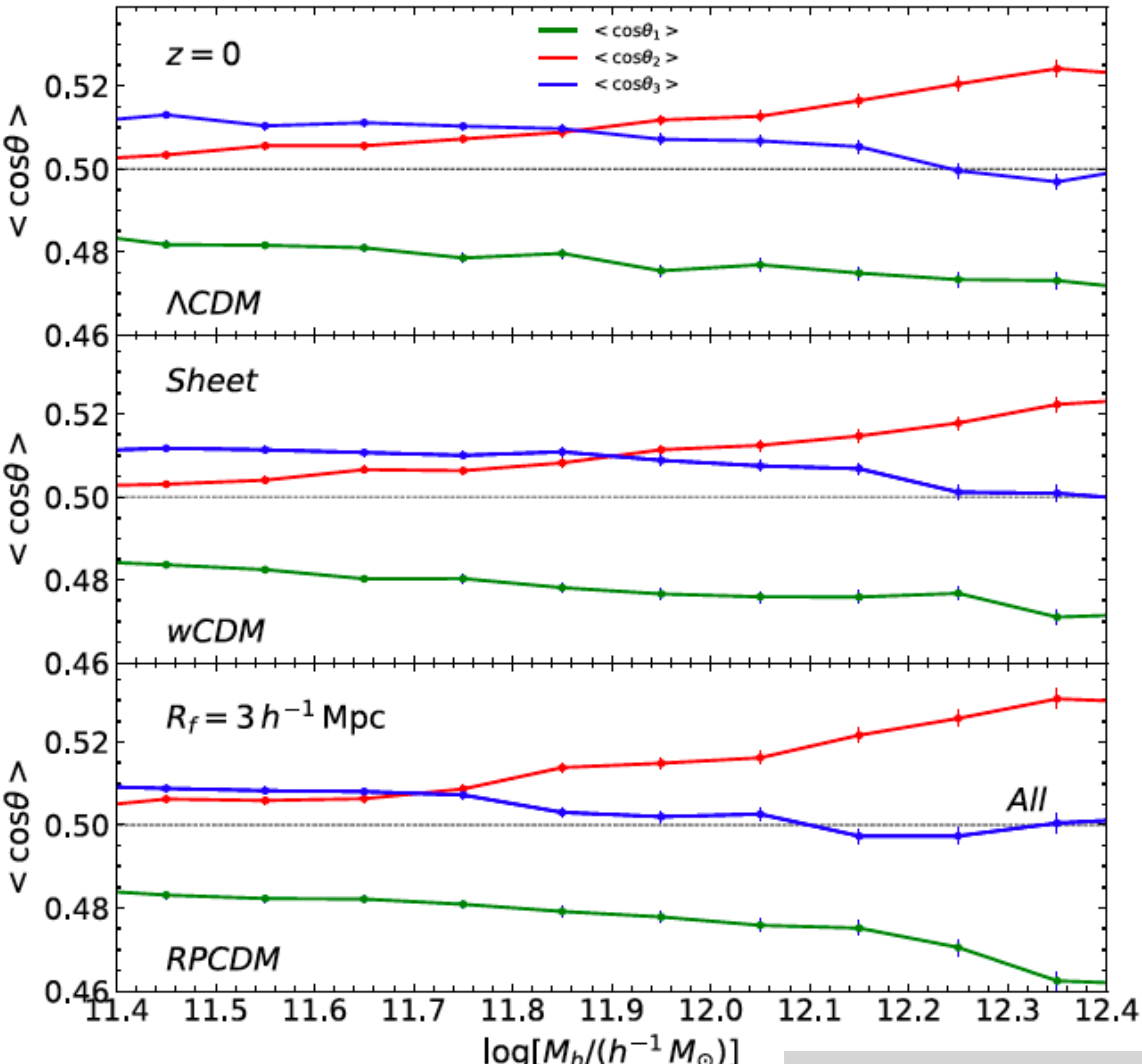

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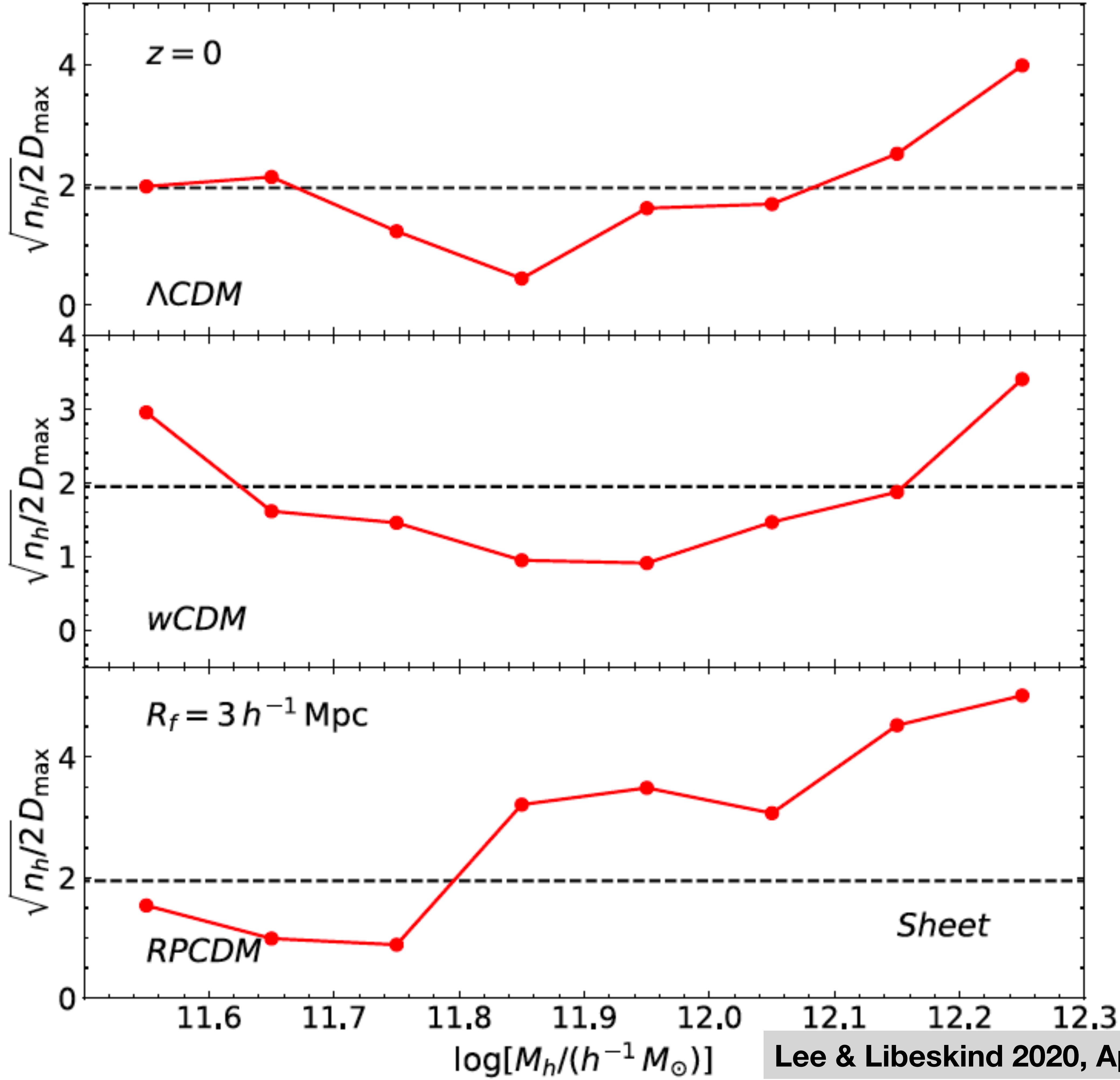

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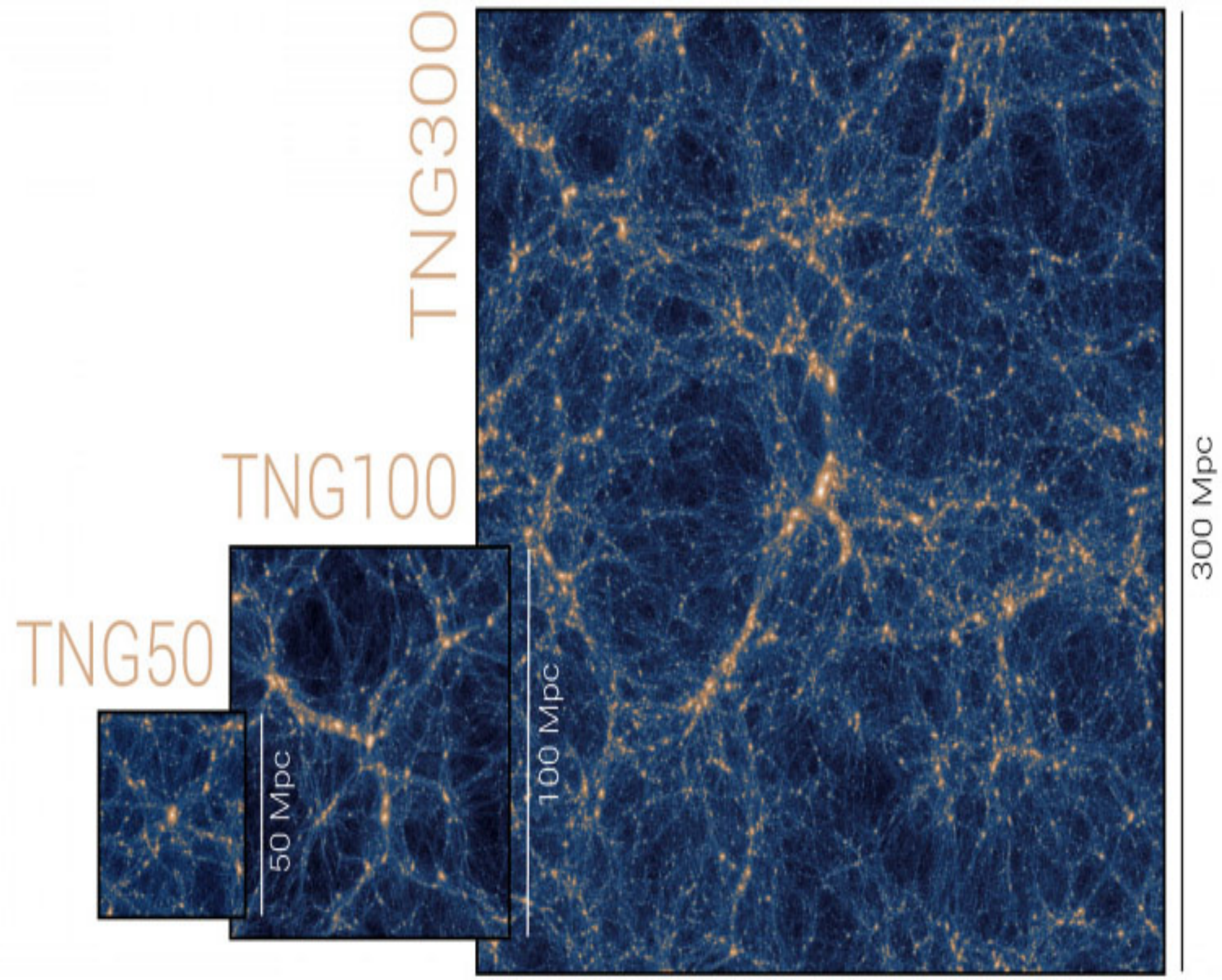
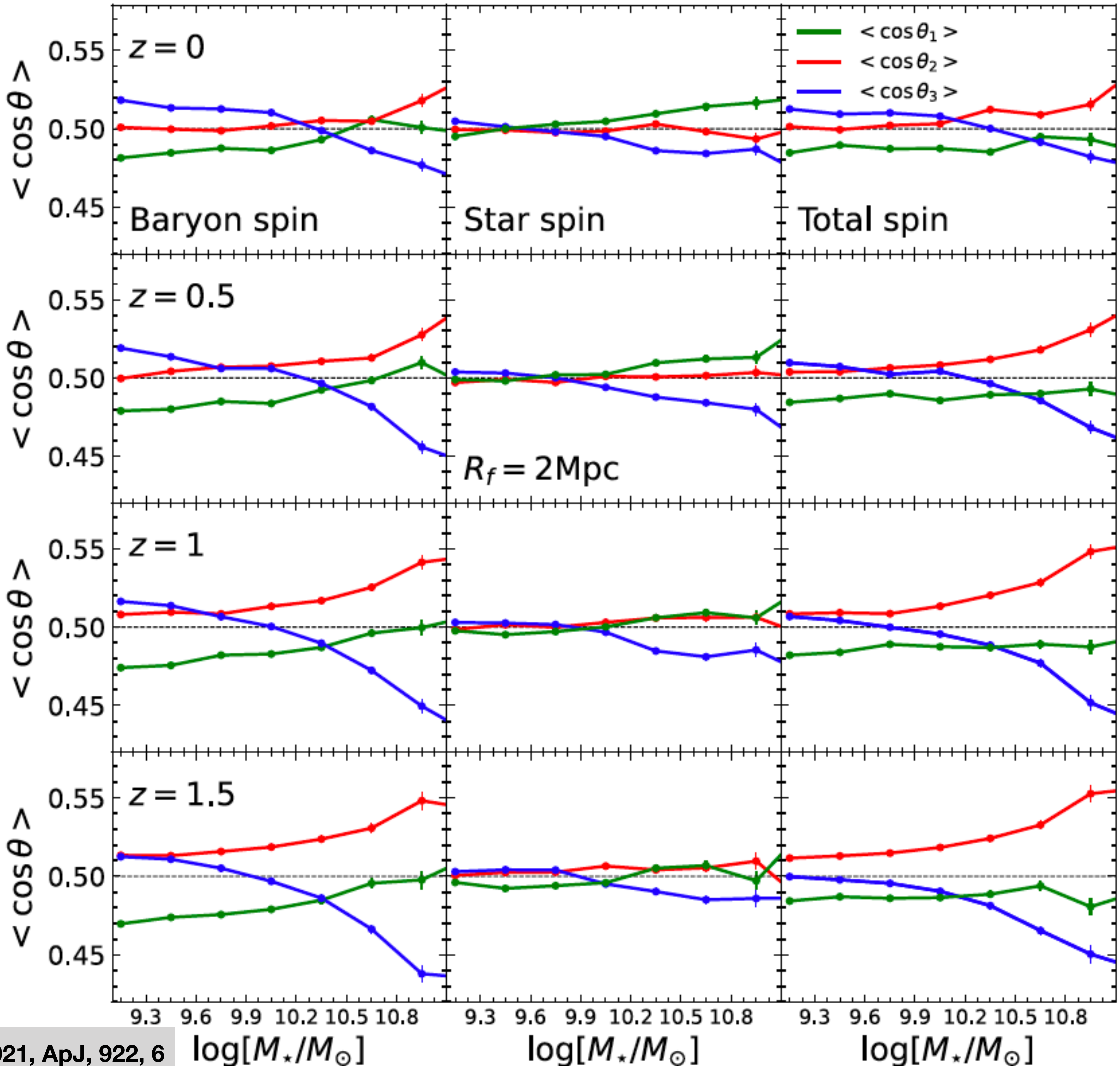
A Different Type of Transition of the Galaxy Stellar Spins

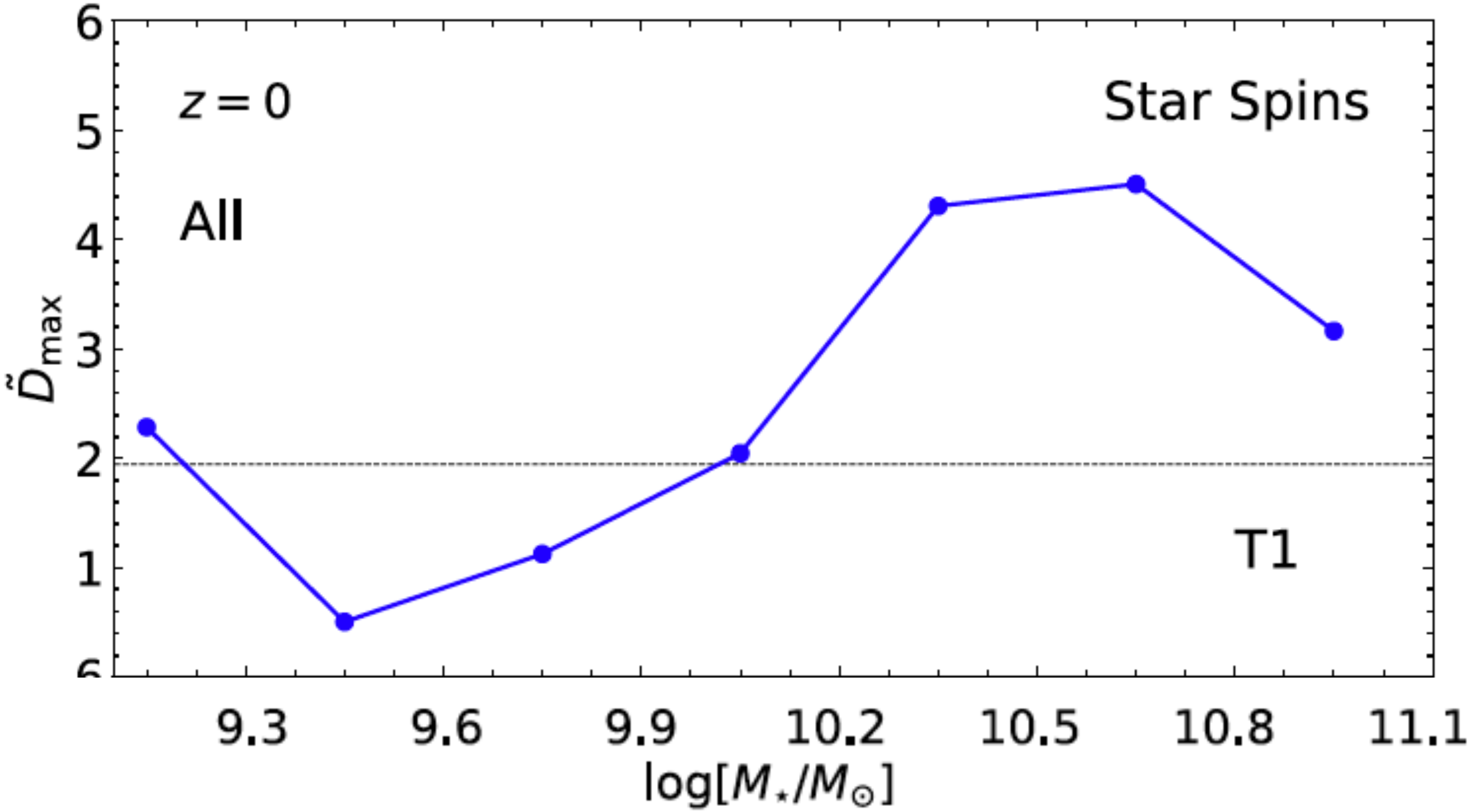
Hydrodynamic Simulation Dataset

- IllustrisTNG 300-1
  - Full baryon physics
  - Planck cosmology
  - $m_{gas} = 1.1 \times 10^7 \, M_\odot$
  - $L_{\mathrm{box}} = 302 \, \mathrm{Mpc}$
  - Subhalos with 300 or more stellar cells





Lee et al. 2021, ApJ, 922, 6



Lee et al. 2021, ApJ, 922, 6

Summary

- The halo spin directions transit between the tidal intermediate and minor principal axes in the spin transition zone, M_t
  - A new algorithm based on the KS test is developed to rigorously determine M_t .
- The range of M_t varies with redshift, smoothing scale, web-type and background cosmology as well.
  - It becomes narrower at higher redshifts, on the smaller scales, in the filamentary environments, and for dynamical DE models.
  - It can distinguish among ΛCDM, wCDM and RPCDM.
- The galaxy stellar spins transit between the tidal major and minor principal directions.

Discussion

- The halo spin transition may be related to the nonlinear growth of the tidal fields:
  - Retarded nonlinear growth of the tidal fields can induce smaller values of M_t.
- The galaxy spin transition might be induced by anisotropic occurrence of discharge of stellar materials by the galactic winds (Lee et al. 2021, arXiv:2111.13831)