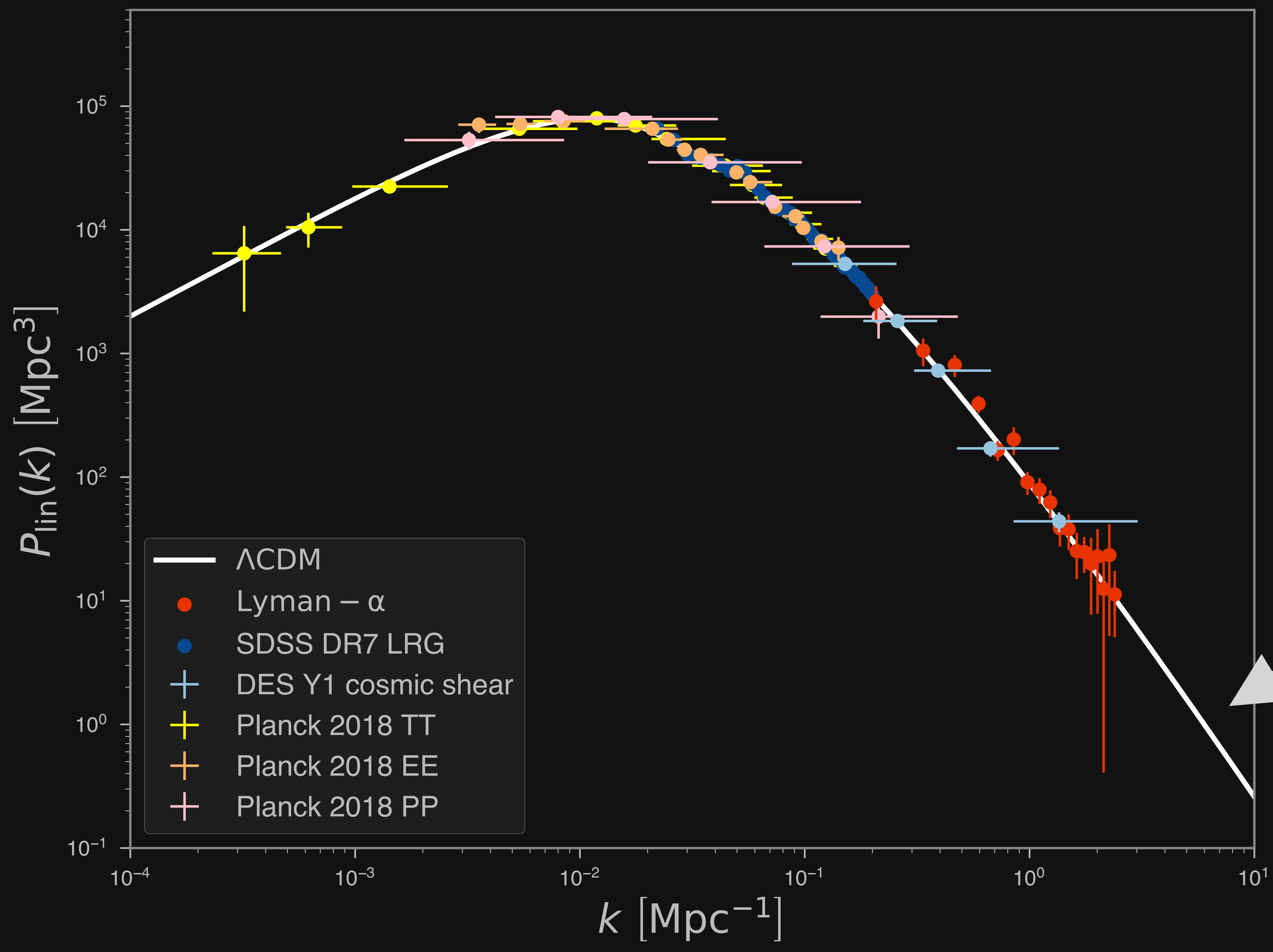
THE UNIVERSITY OF CHICAGO

Constraining dark matter models using dwarf galaxy properties

Ariane Dekker
KICP Fellow

arXiv: 2407.04198

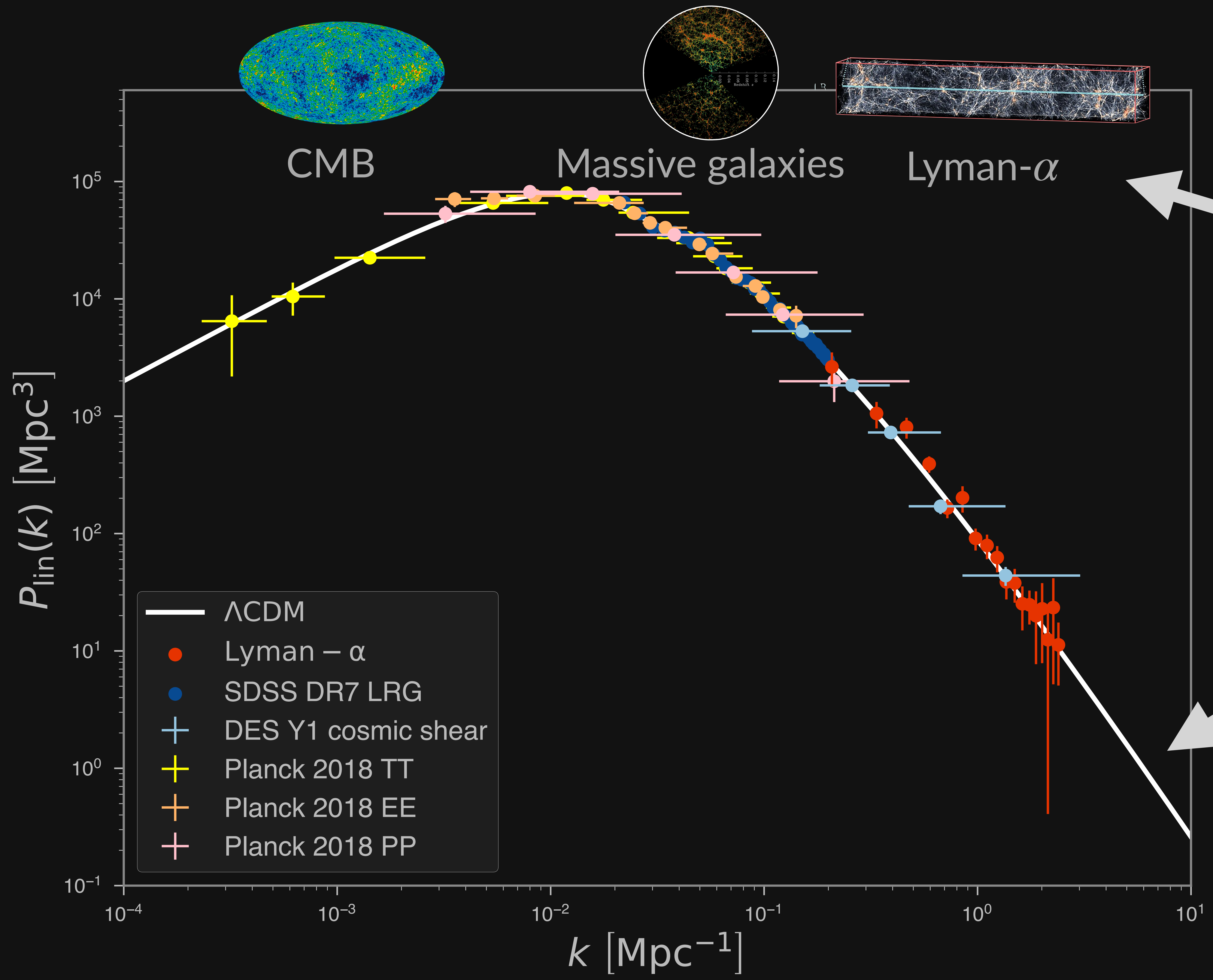
Matter power spectrum



Decreasing scale $\sim 1/R$

Theoretical fit ΛCDM

Matter power spectrum

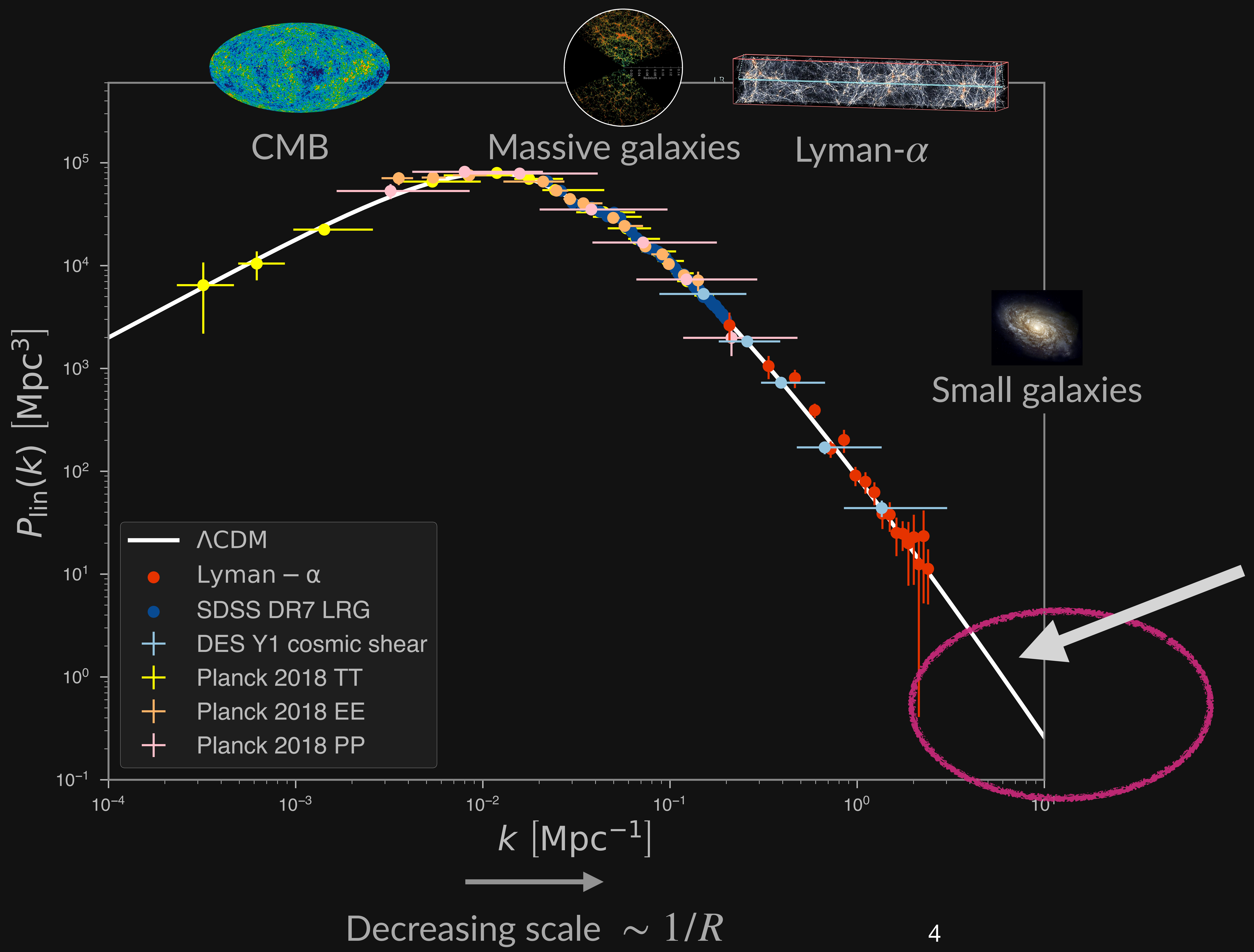


Measurements

Theoretical fit ΛCDM

Decreasing scale $\sim 1/R$

Matter power spectrum



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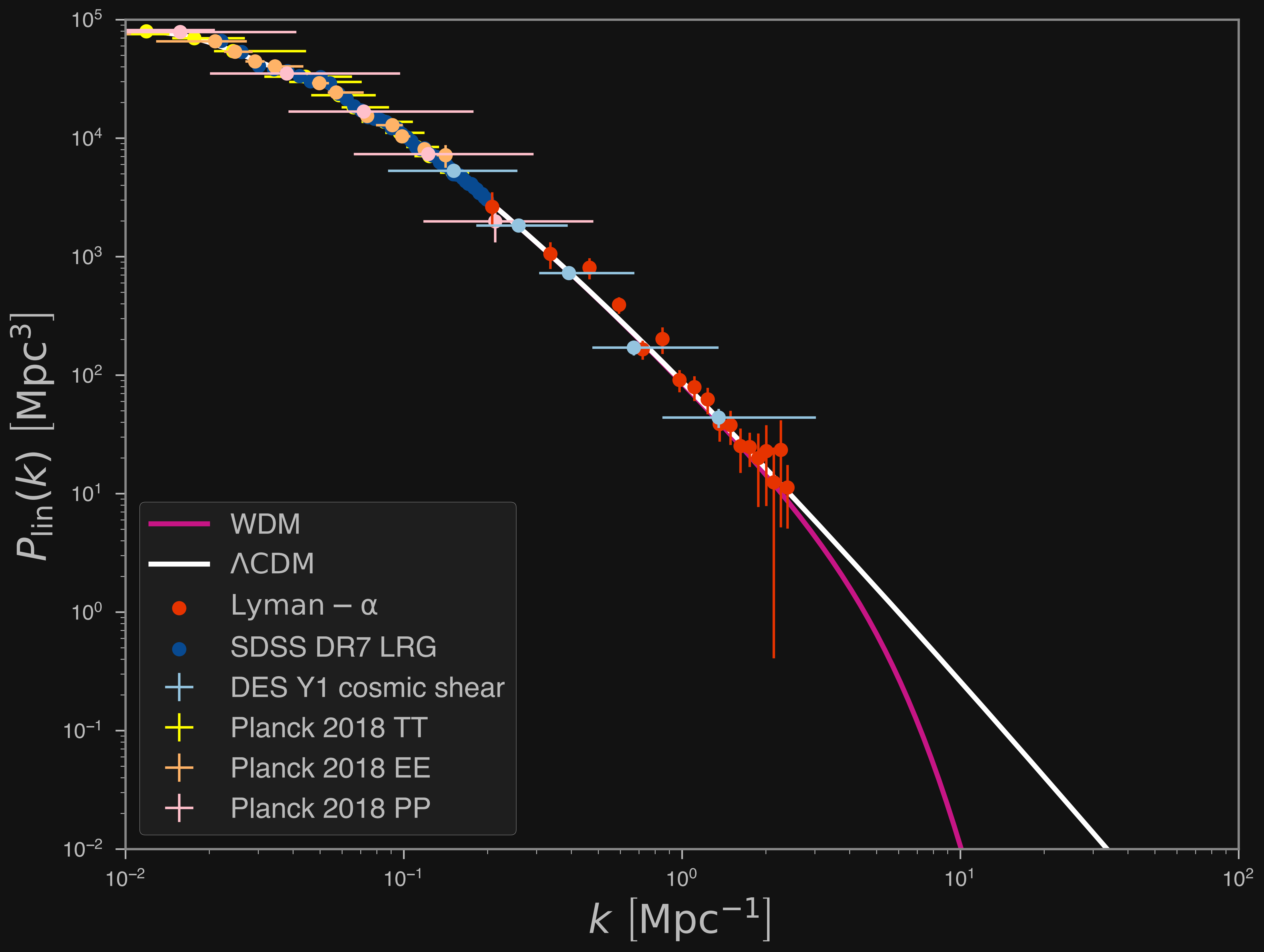
Various models predict deviations at small scales, impacting galaxy observations

Outline

Enhancements and suppressions in MPS → Impacts formation of DM halos & galaxies → Constrain MPS shape at small scales

Predictions for suppressed MPS

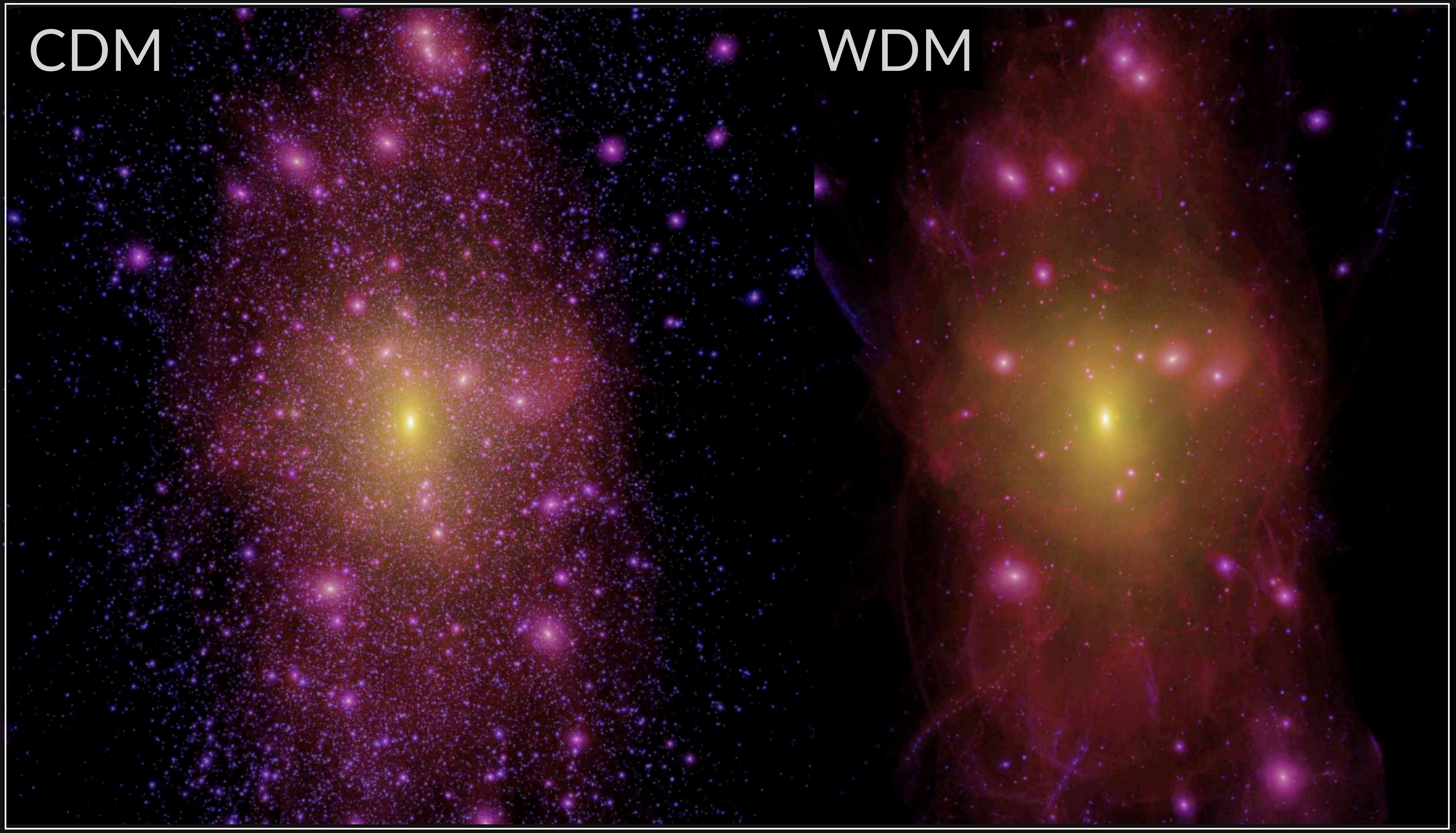


Examples

Warm dark matter (Lovell 2023)

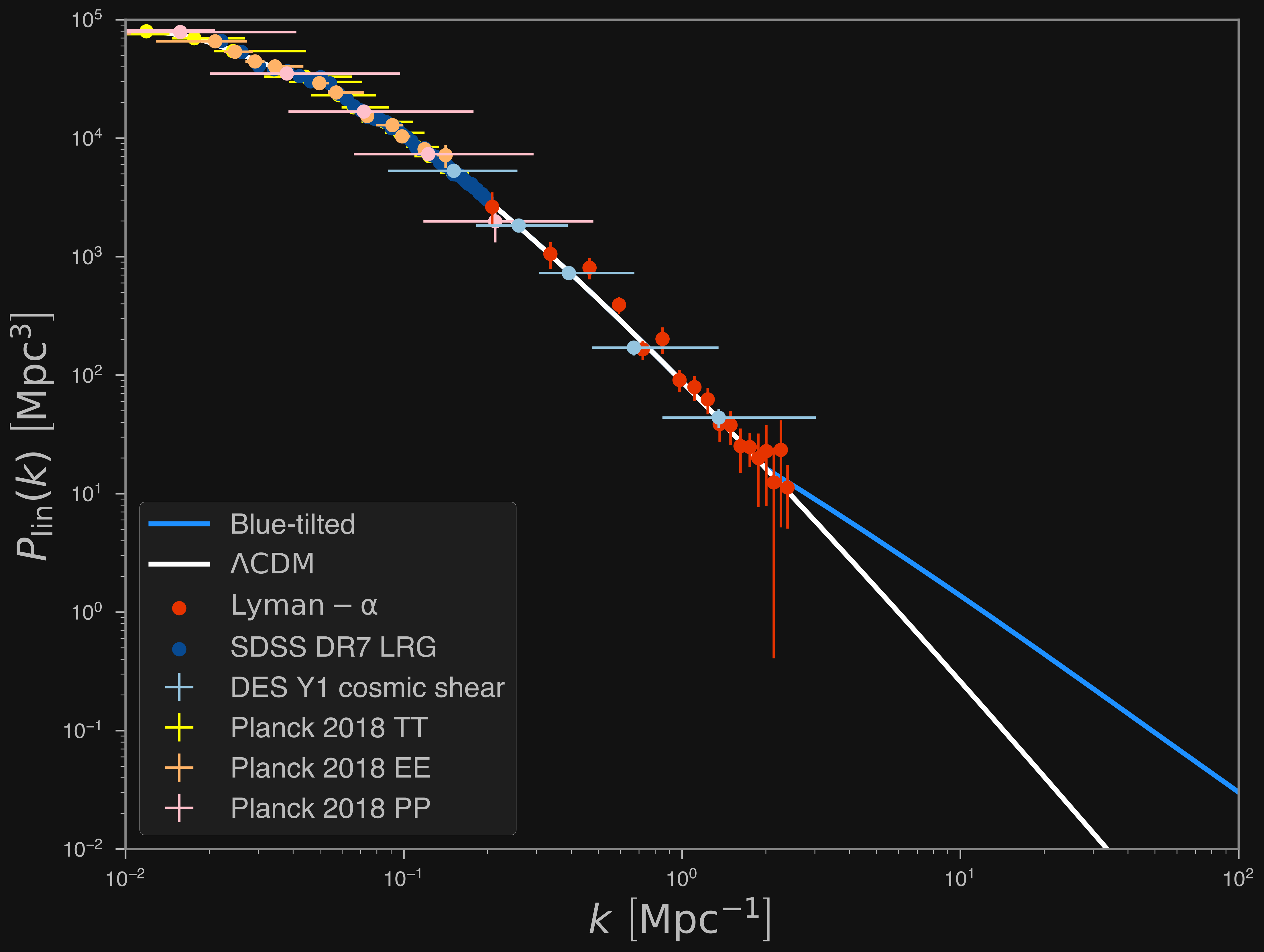
Ultra-light axion DM (Marsh 2016)

Self-interactions (Berryman+2022)



Lovell+2014

Predictions for enhanced MPS

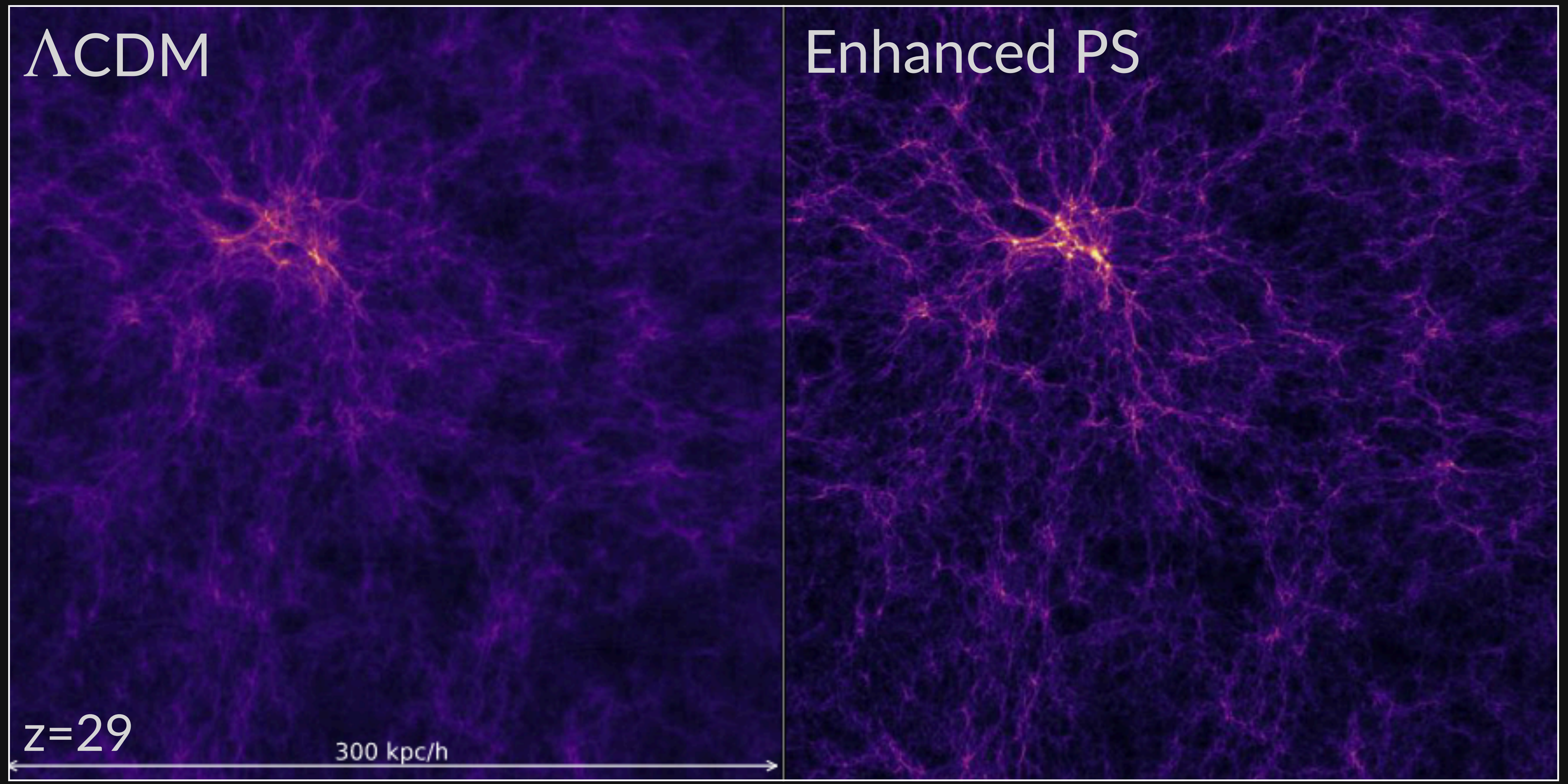


Examples

Massive vector boson DM (Graham+2015)

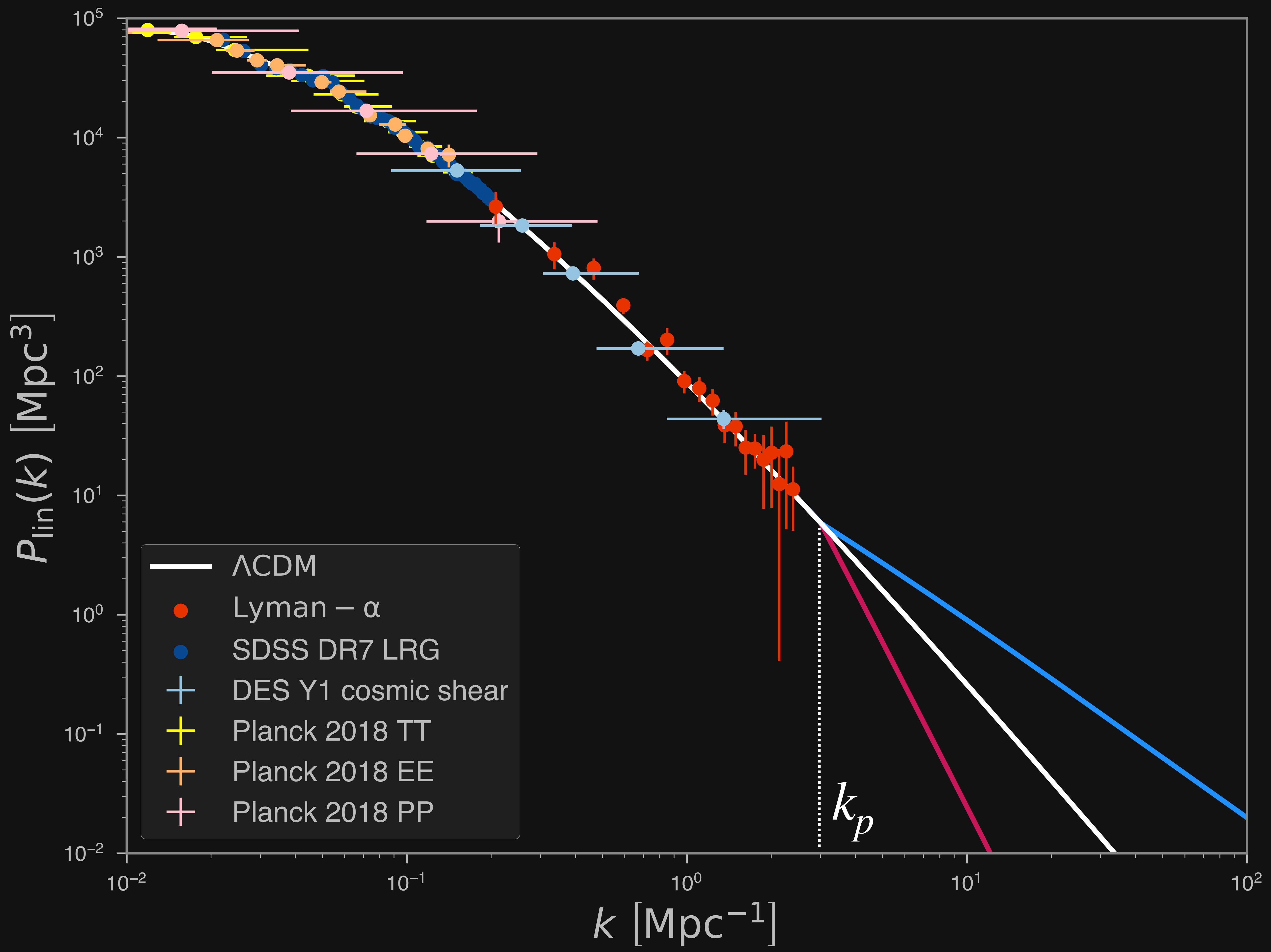
Primordial magnetic fields (Ralegankar+2024)

Non-standard inflation (Seleim+2020)



Inman+ 2022

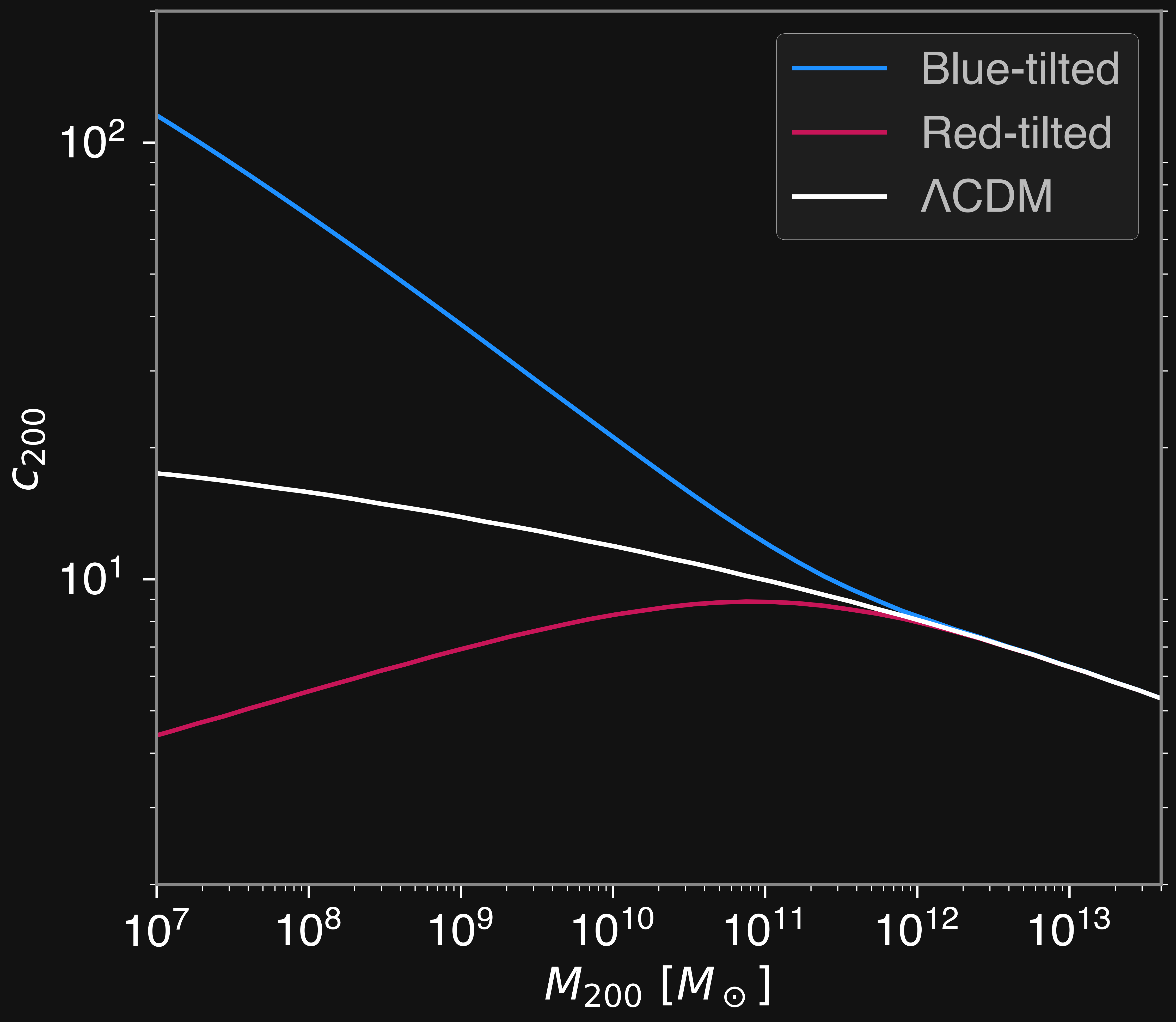
Blue and red tilted power spectra



Model-independent continuous tilt beyond pivot scale k_p with spectral index m_s ($m_s = n_s \approx 0.97$ in ΛCDM).

Concentration of dark matter halos

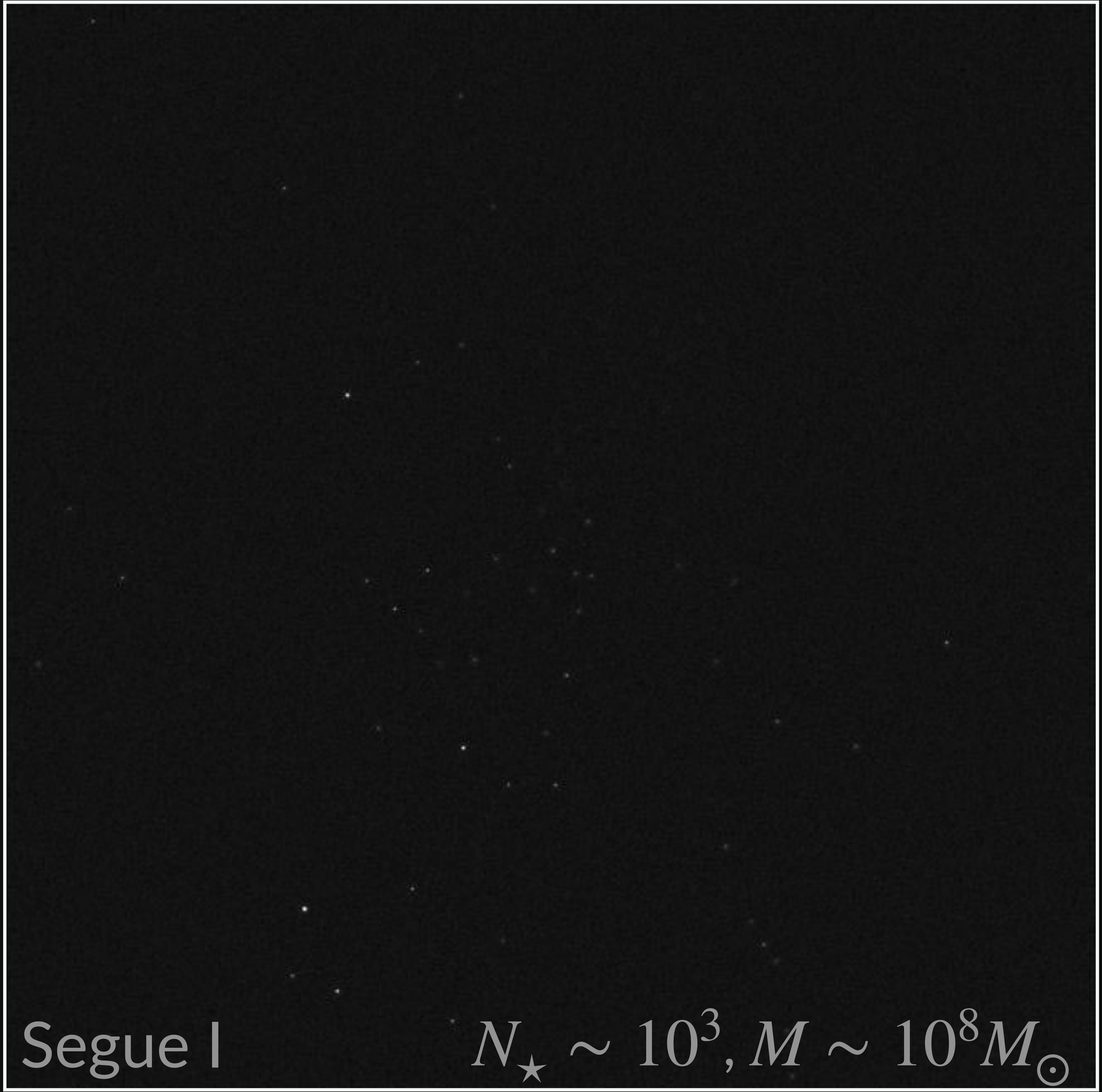
$$c(M, z) = R_{vir}(M, z)/r_s$$



Models that enhance (suppress) the formation of structure form DM halo's at earlier (later) time with higher **concentration**.

Inner mass of galaxies

Small galaxies are dark matter-dominated!



Concentration impacts inner mass of galaxies

$$M_{tot}(< r_{1/2}) = M_{dm}(< r_{1/2}) + 0.5M_\star$$

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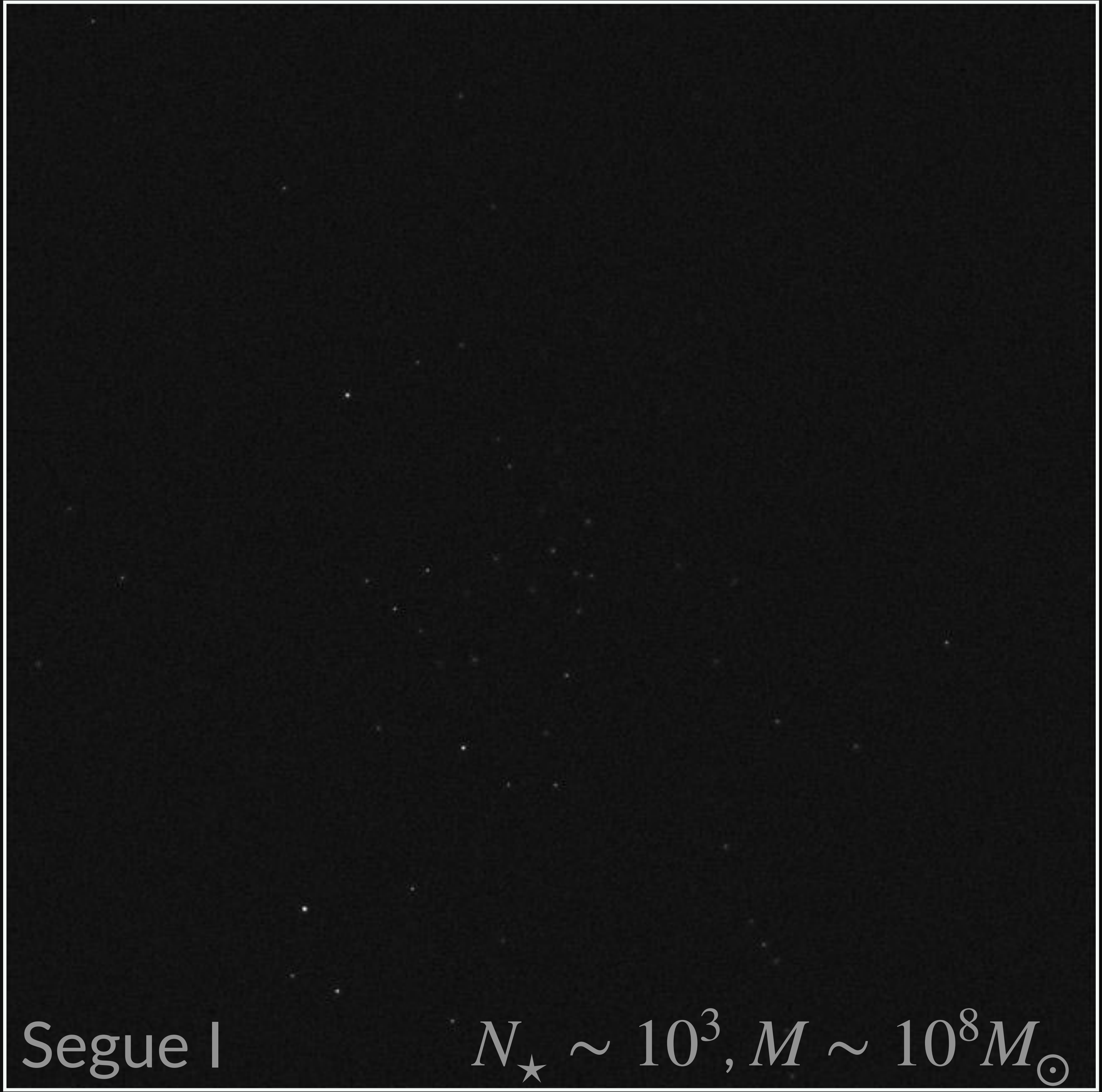

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Observable with kinematic data ($\sigma_{los}, R_{1/2}$)

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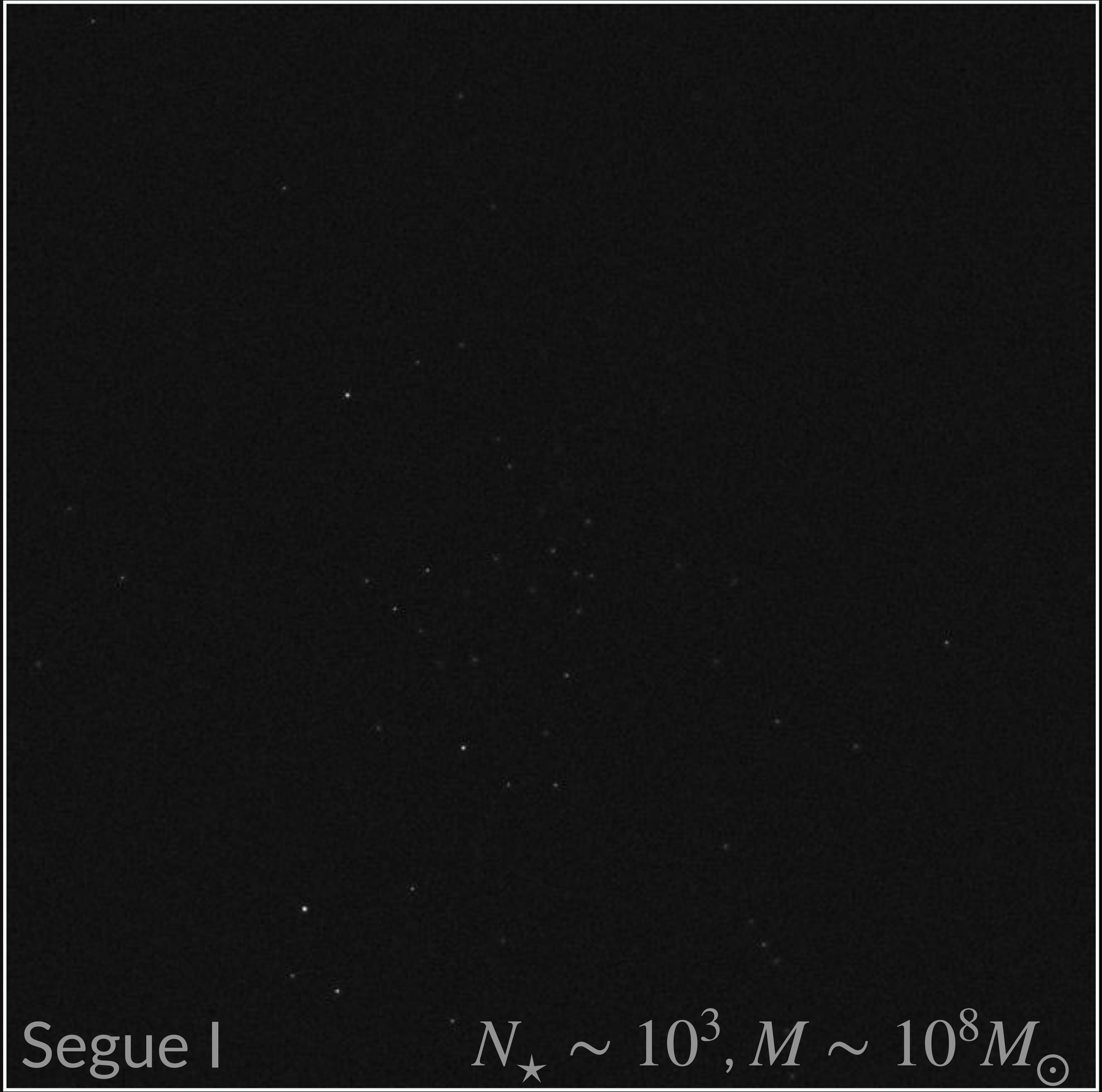

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Model for each cosmological model

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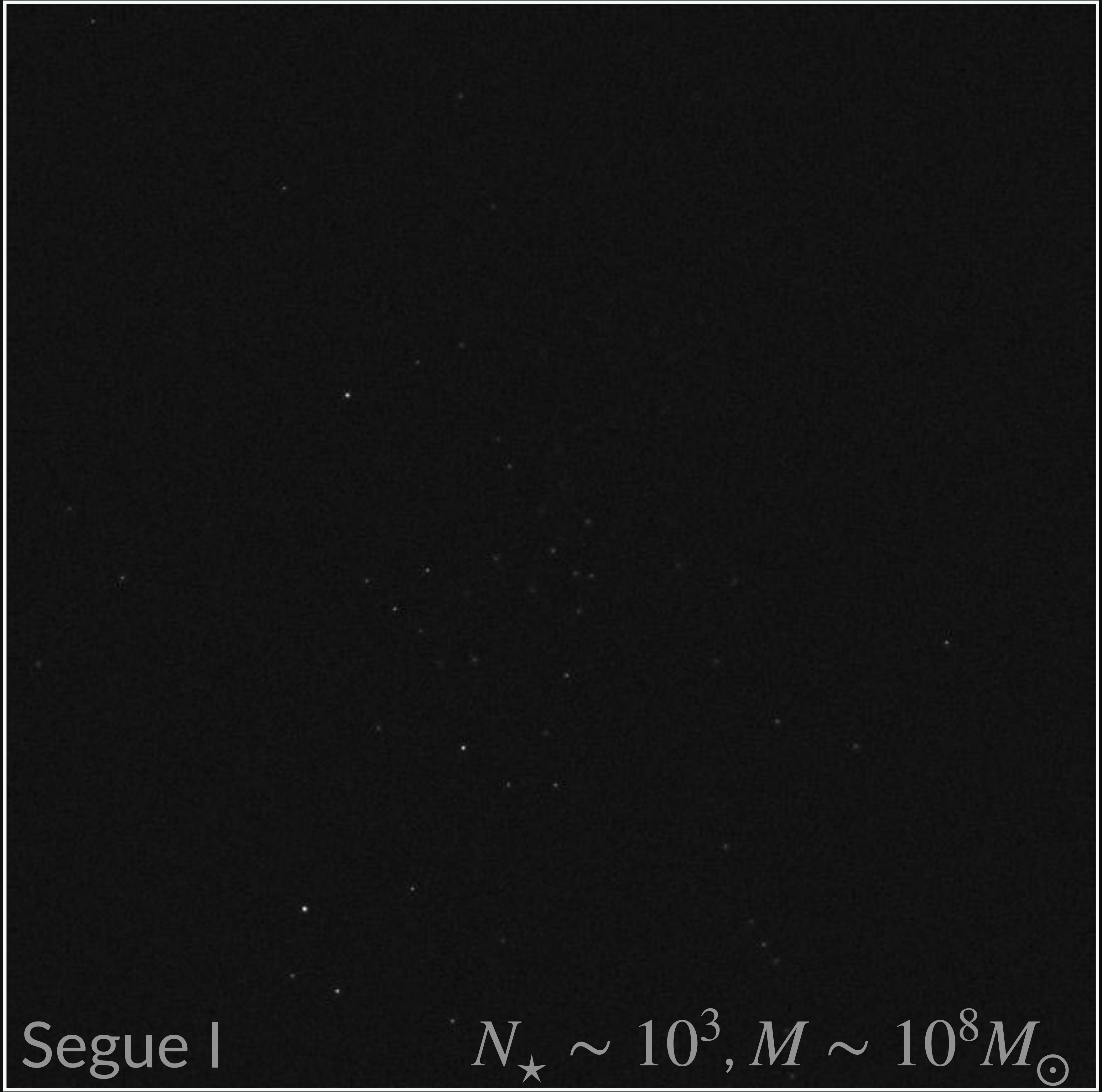

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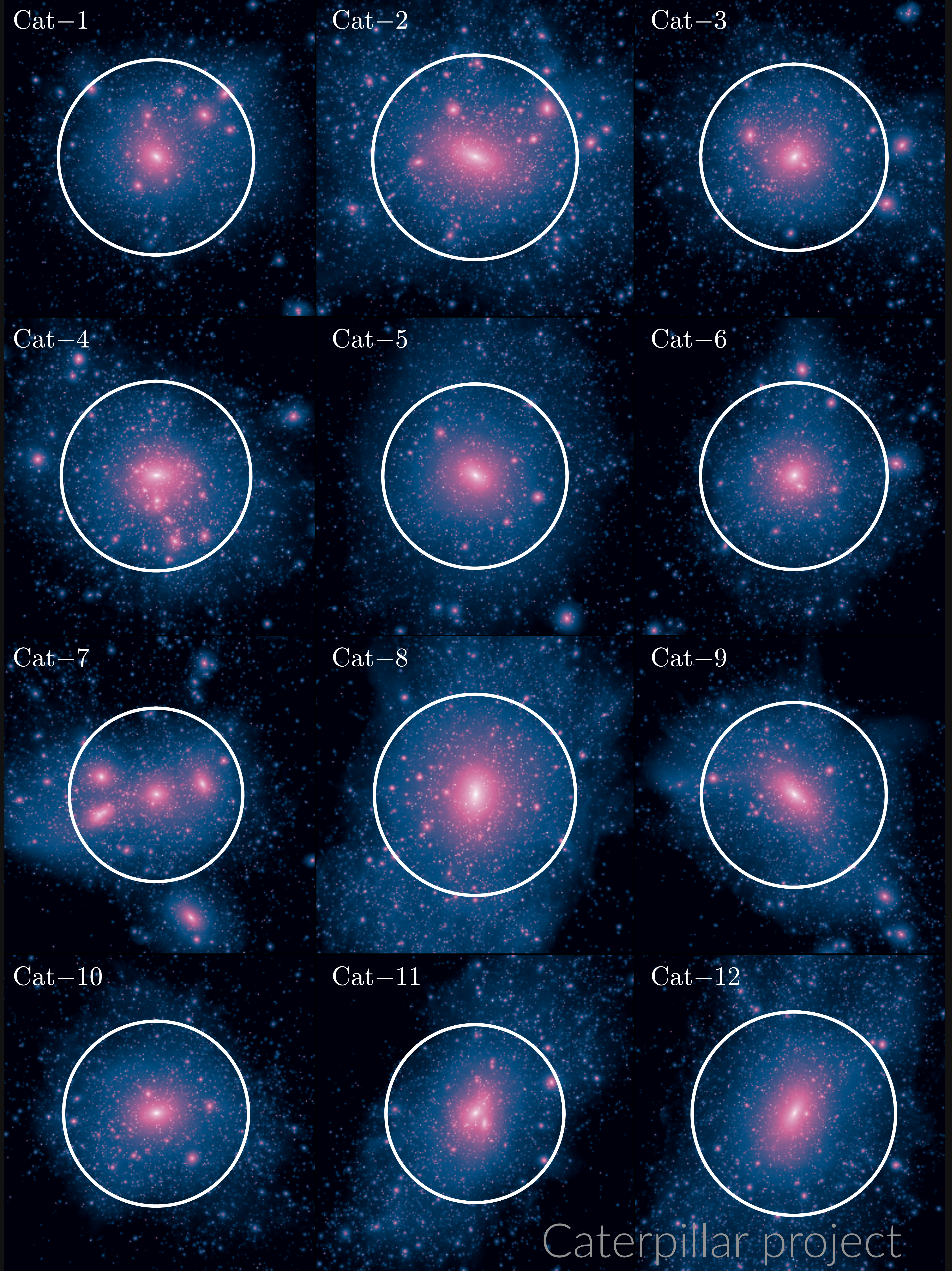
$$= ?$$

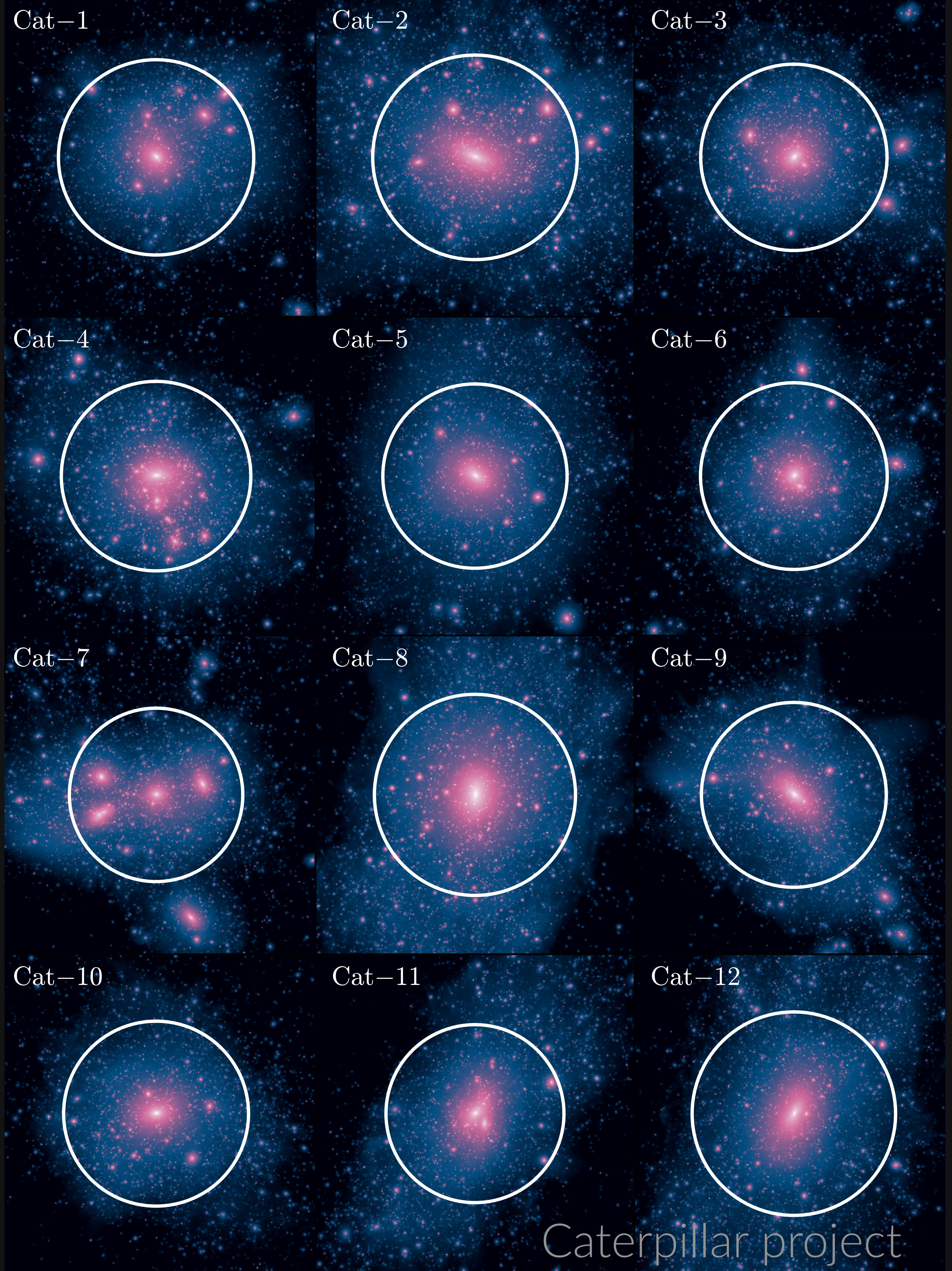
Model for each cosmological model

Model dwarf galaxies



Model dwarf galaxies

1) High-resolution Caterpillar simulations of 32 Milky-Way sized halos in ΛCDM.
   Griffen et al. (2016)



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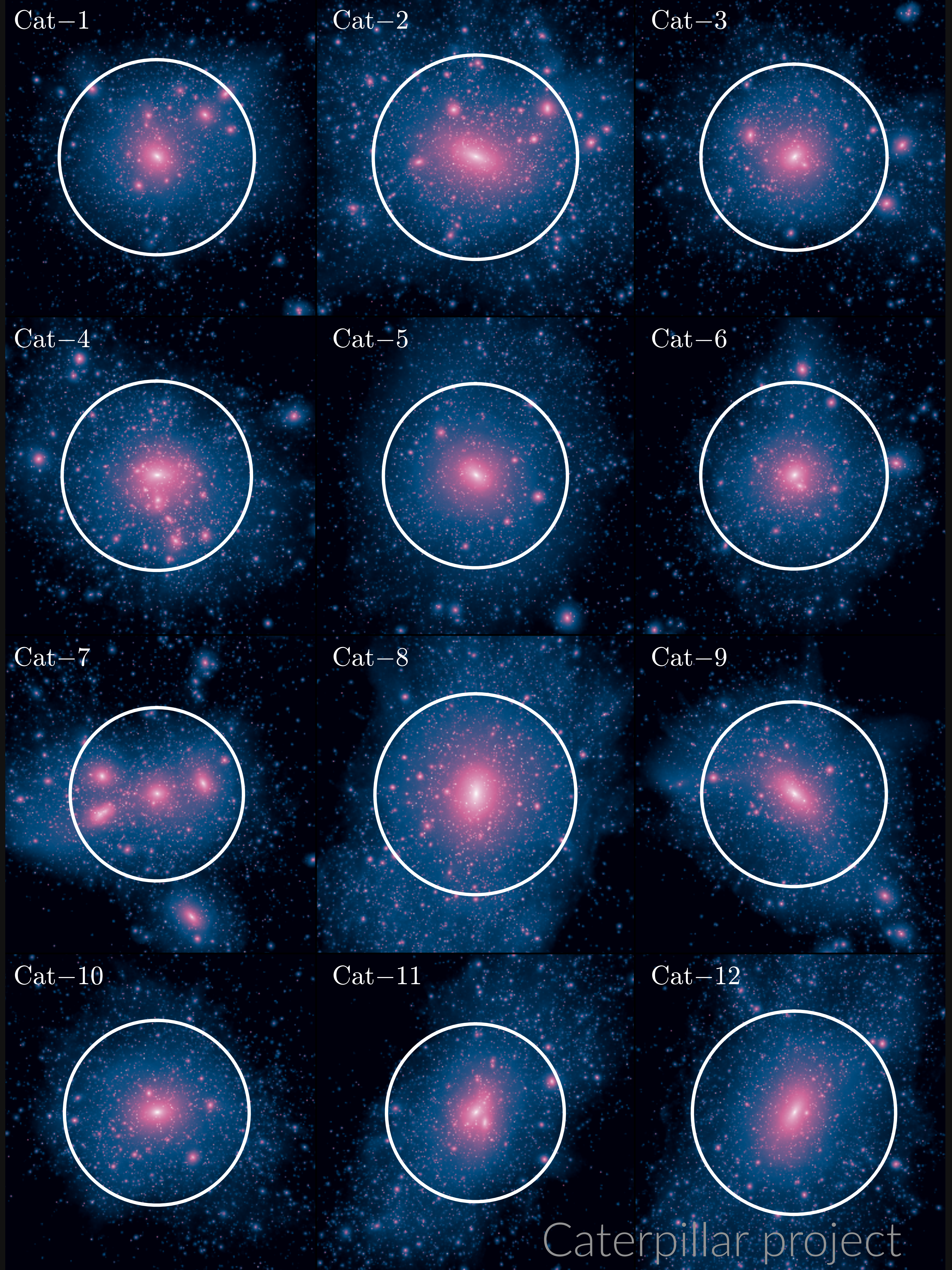
2) Populate halos and subhalos with galaxies using GRUMPY.
   Manwadkar & Kravtsov 2023



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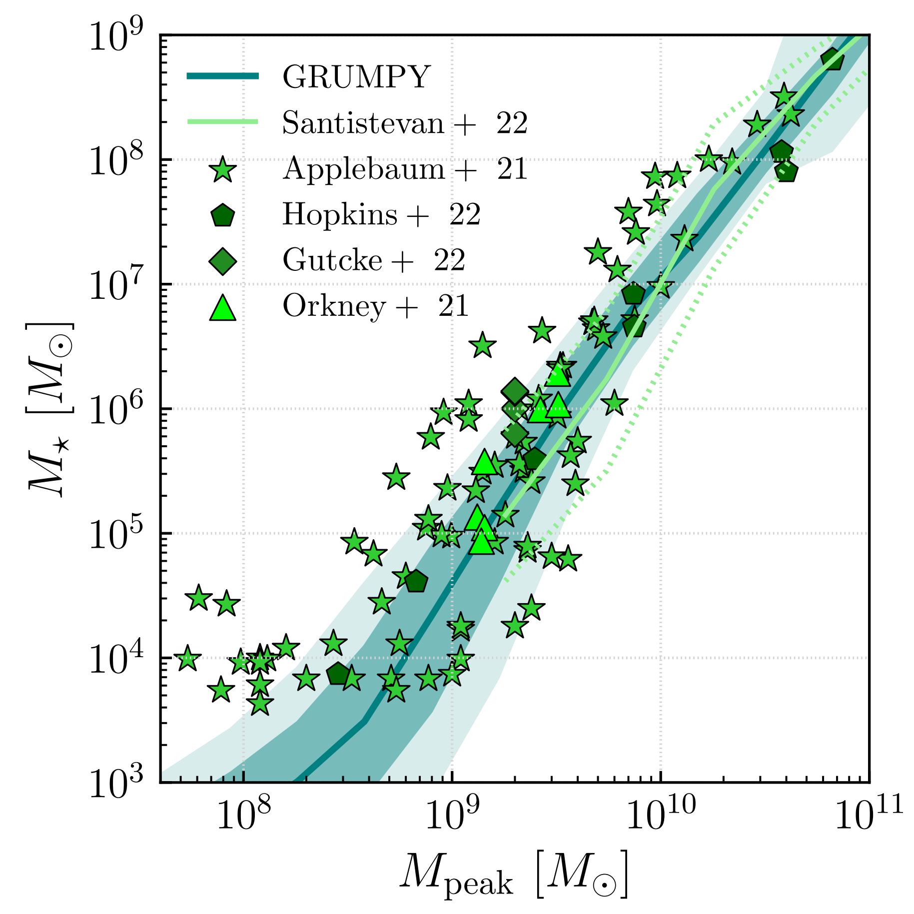
Halo-stellar mass

Manwadkar, Kravtsov 2022



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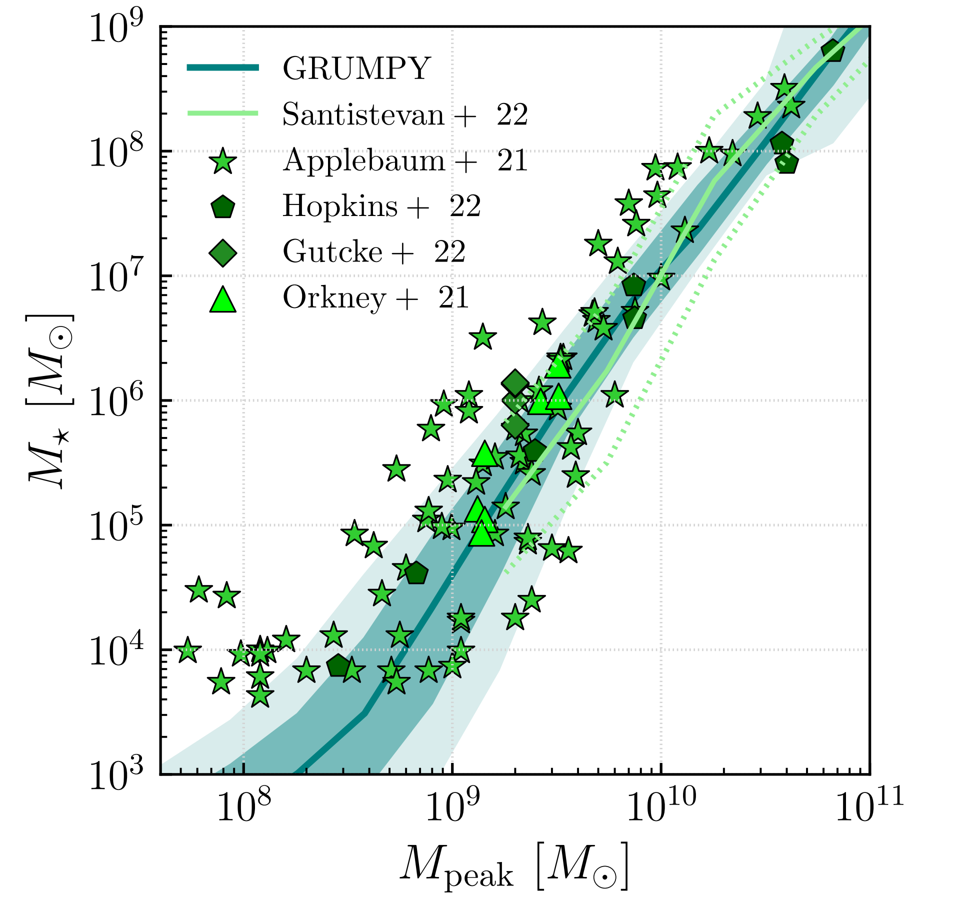
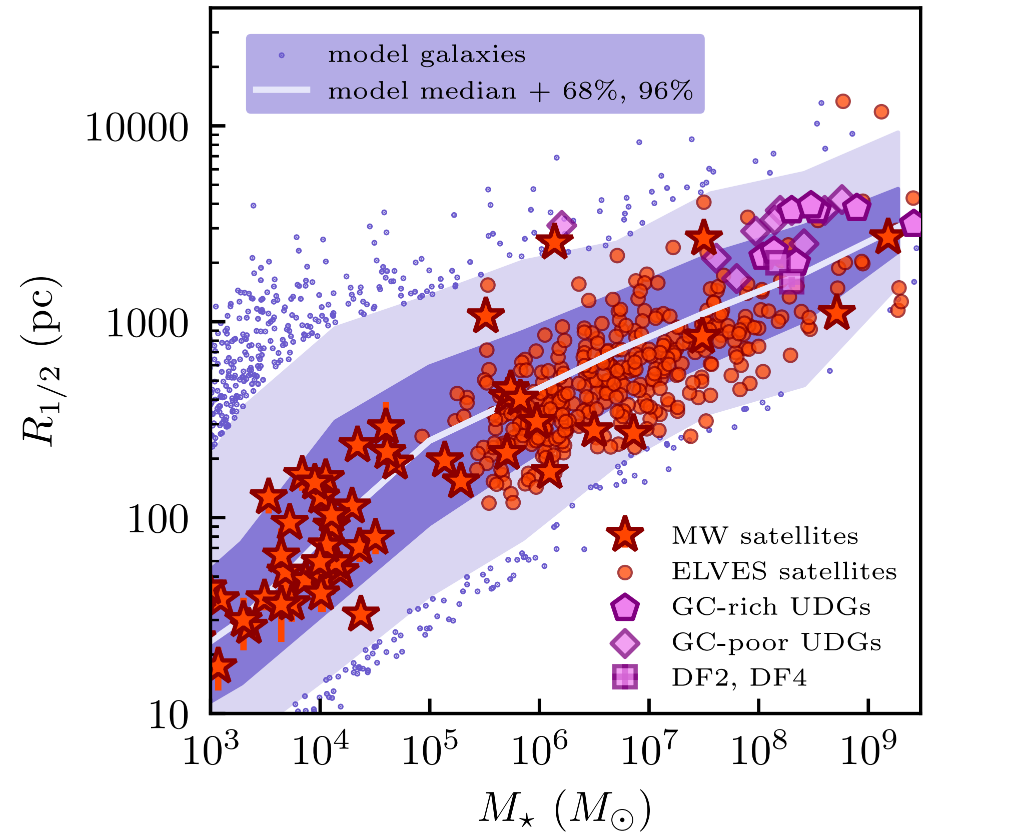


Radius-stellar mass
Kravtsov 2024



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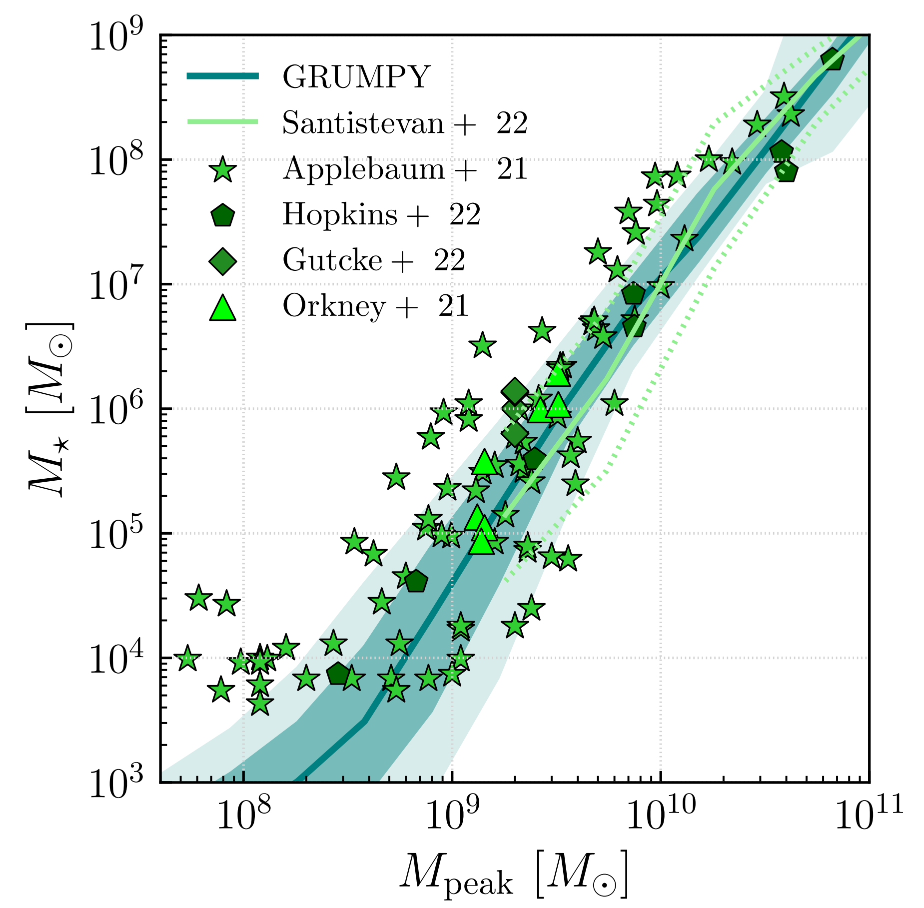

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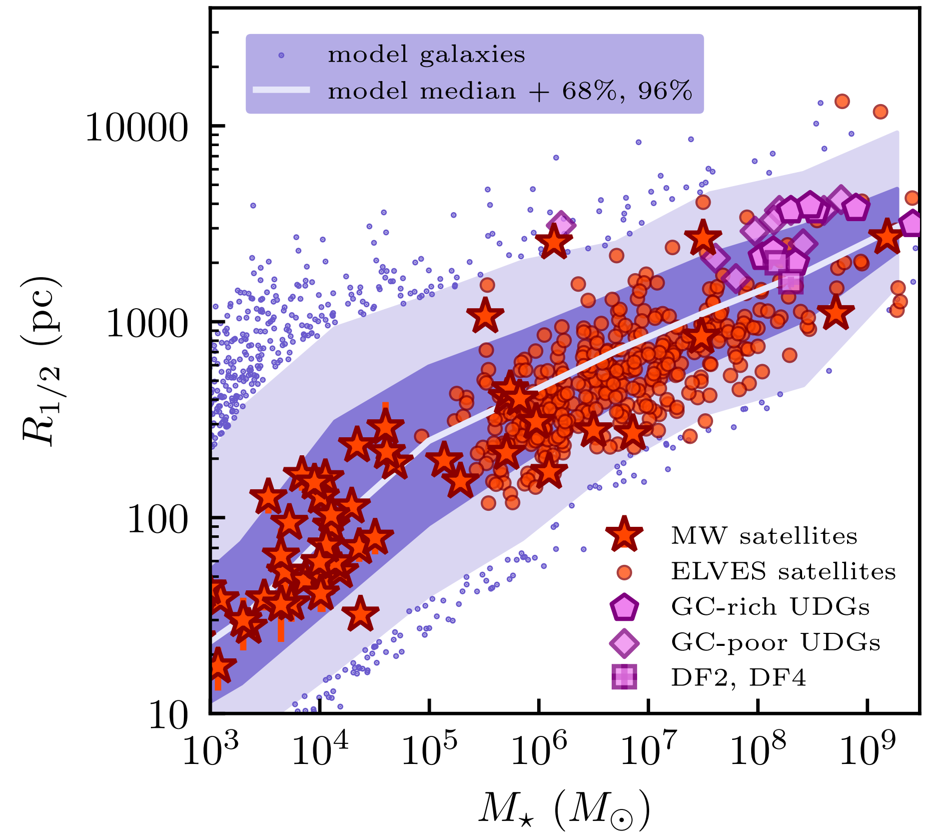
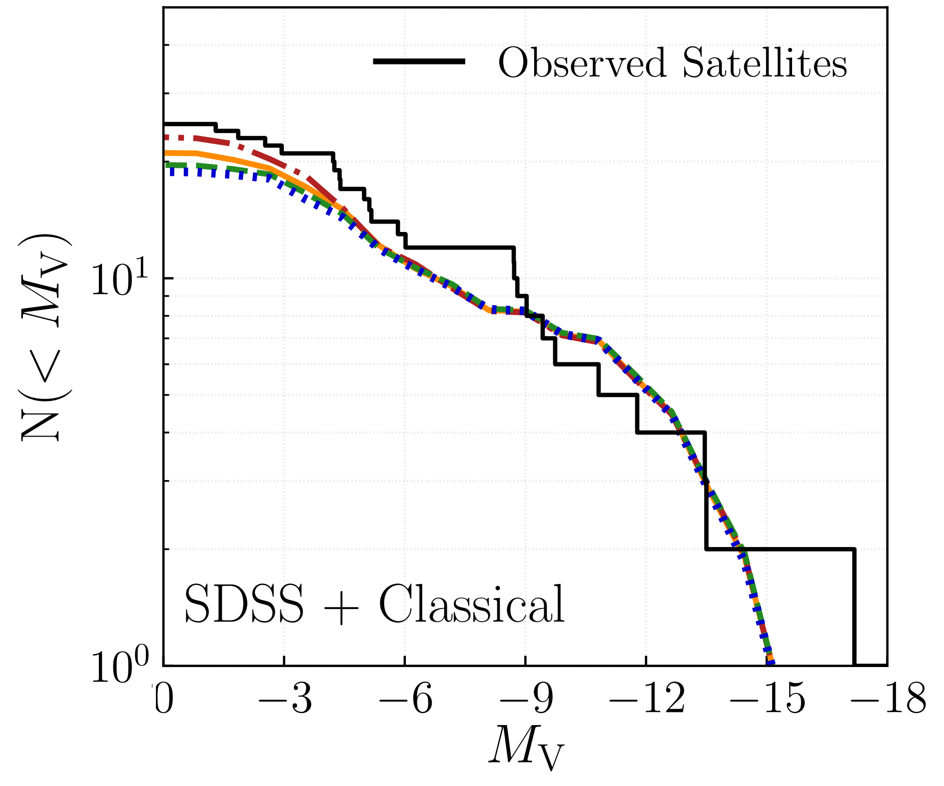
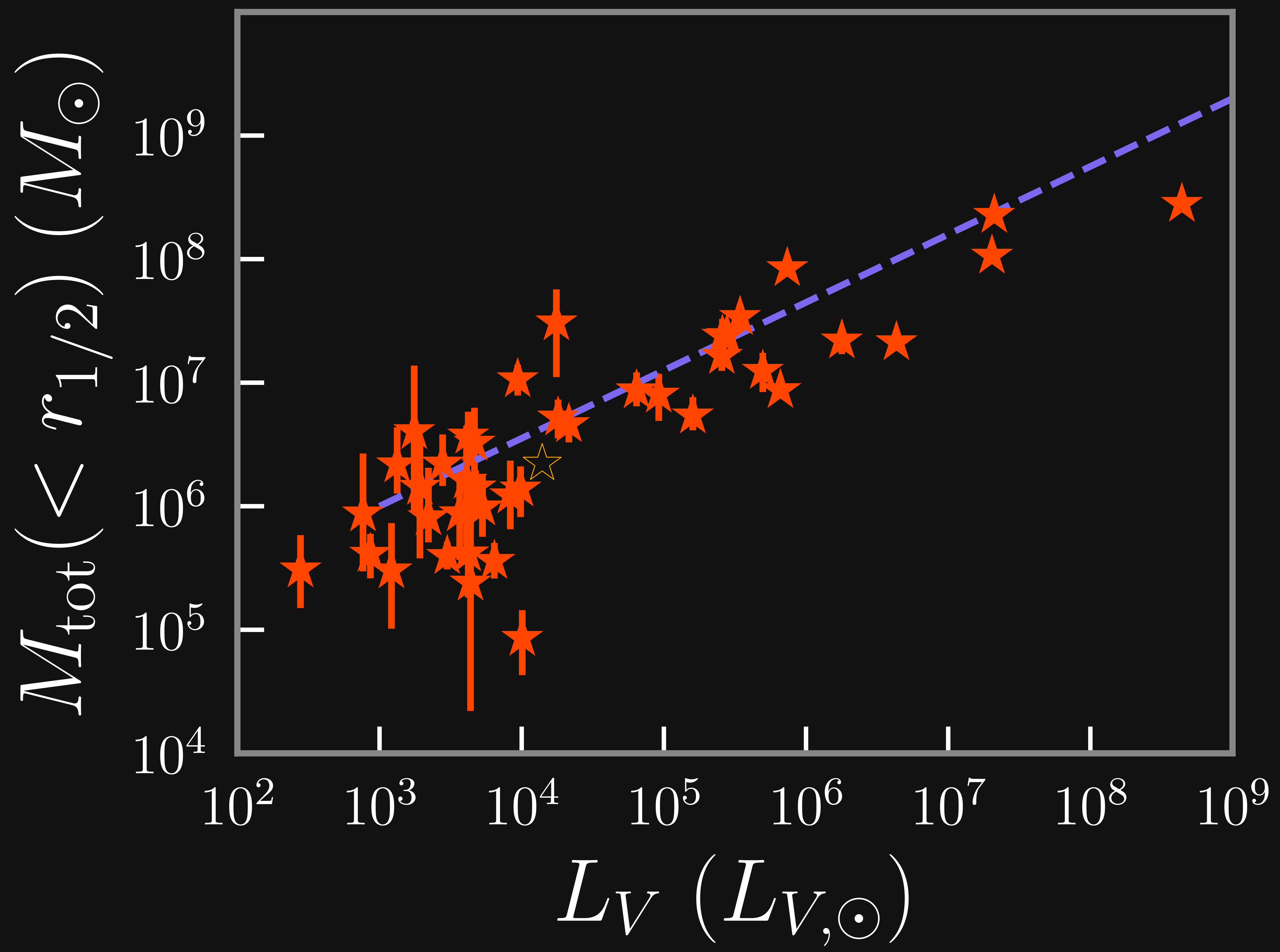


Luminosity function

Manwadkar, Kravtsov 2022

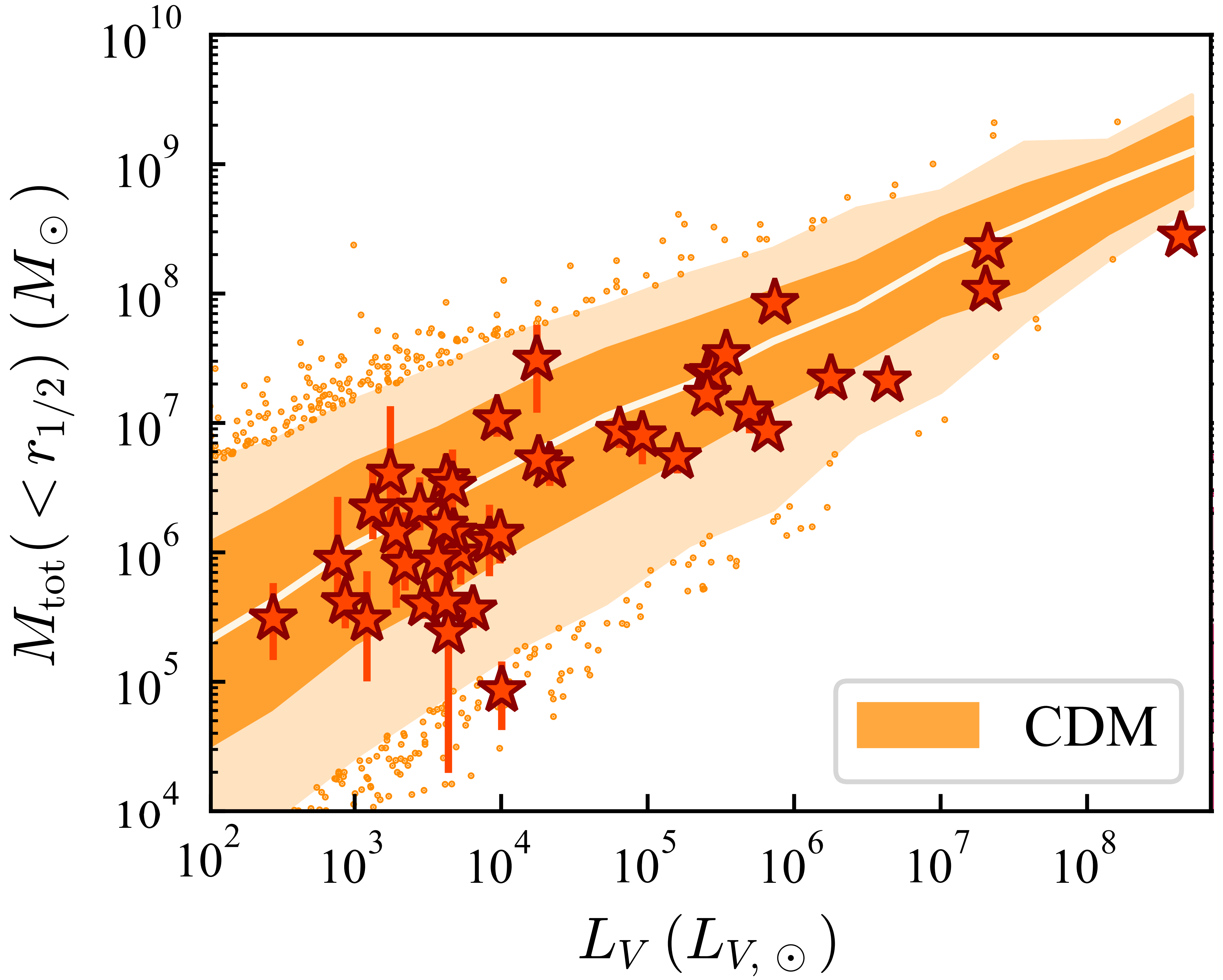


Milky Way dwarf galaxy observations



42 dwarf galaxies with kinematic data

Model galaxies in ΛCDM agree with observations



Dekker & Kravtsov 2024

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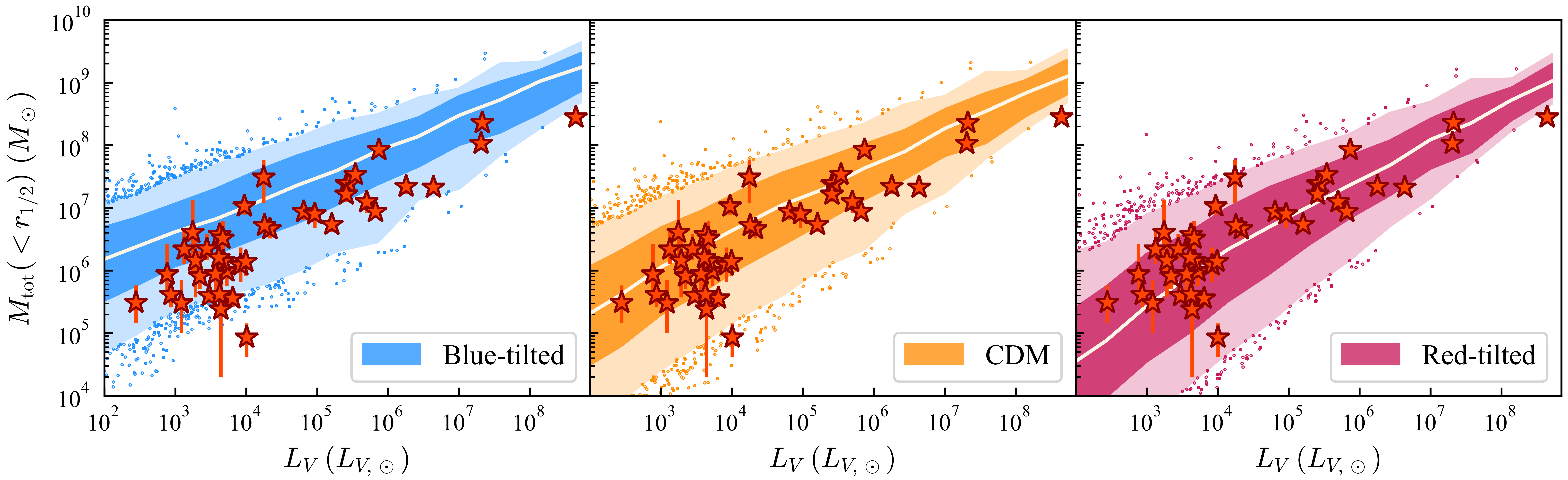
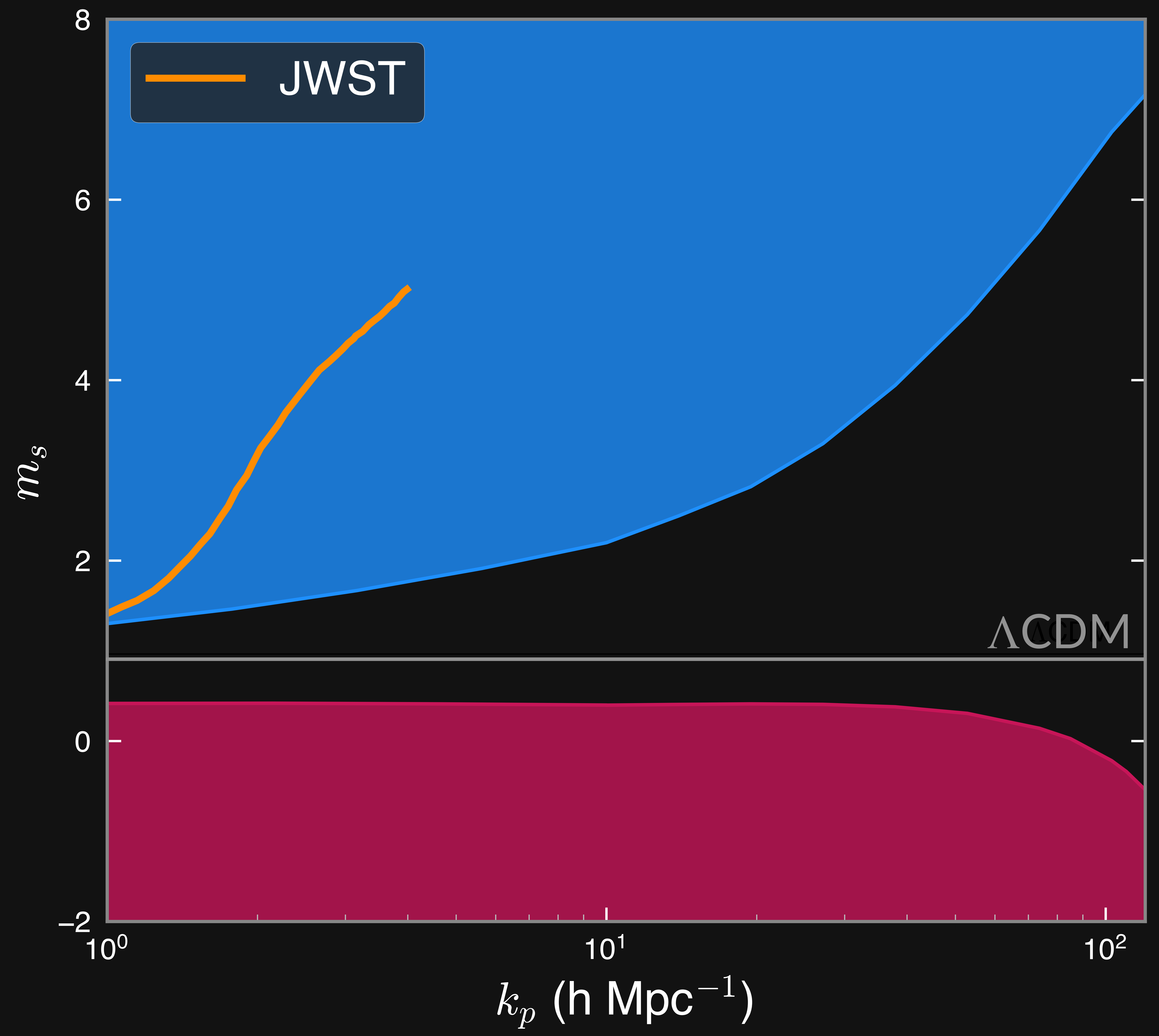


Dekker & Kravtsov 2024

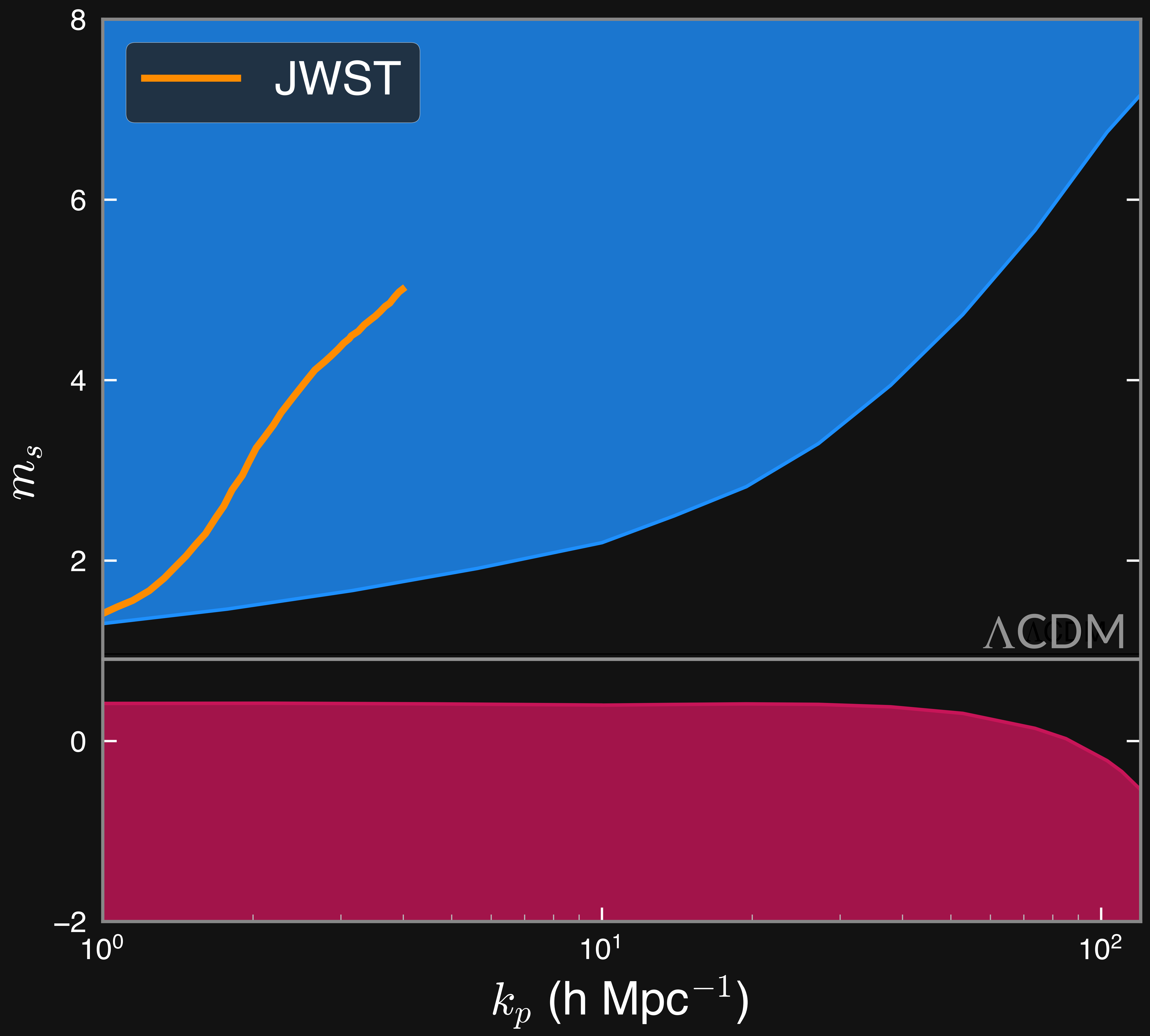
Exclude (m_s, k_p) that deviate too much from ΛCDM at 95% CL



Dekker & Kravtsov 2024

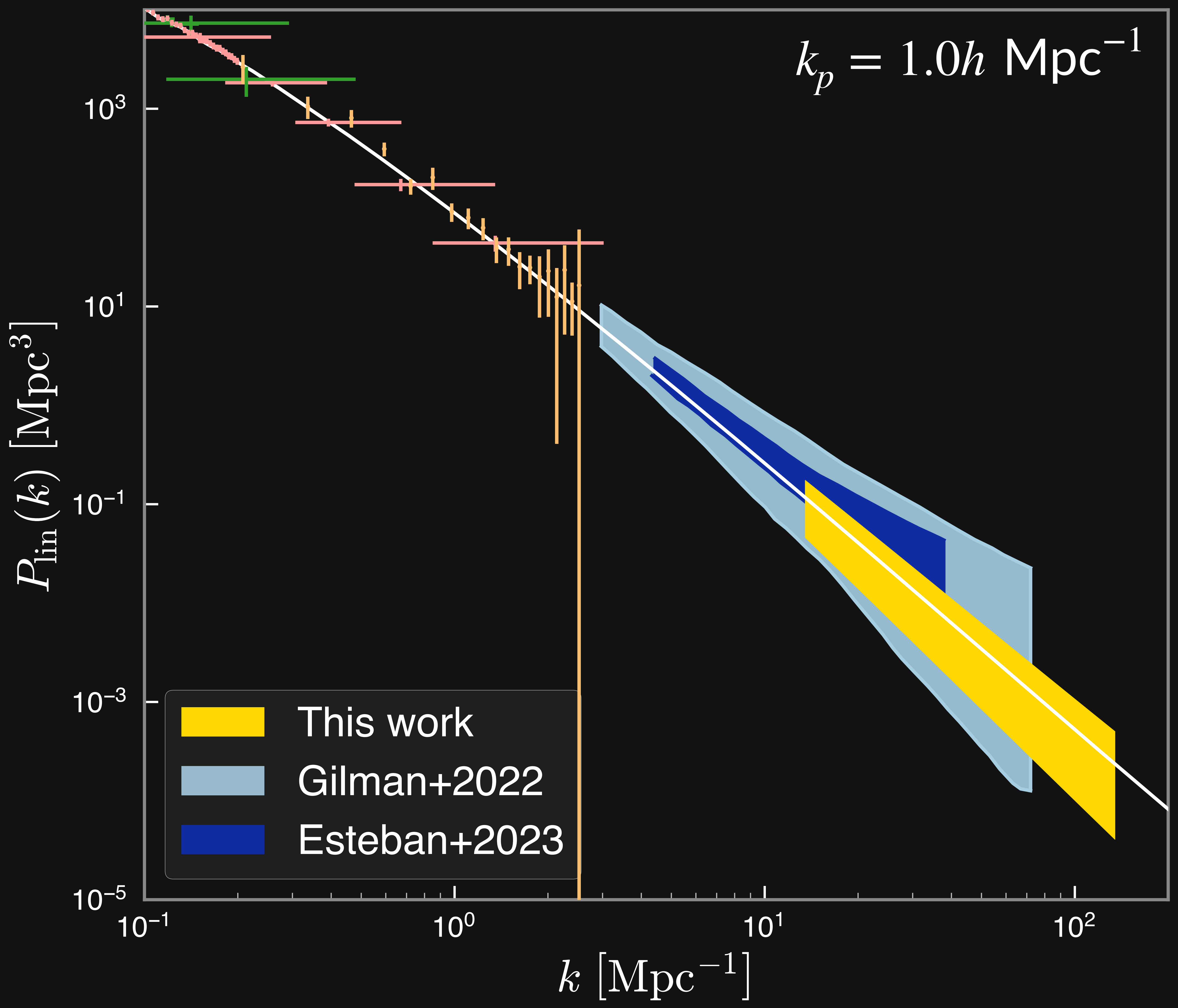
Exclude (m_s, k_p) that deviate too much from ΛCDM at 95% CL

Rule out blue-tilt explanation early JWST observations of high-z massive galaxies.
(Labbé+2023, Parashari+2023)



Dekker & Kravtsov 2024

Matter power spectrum



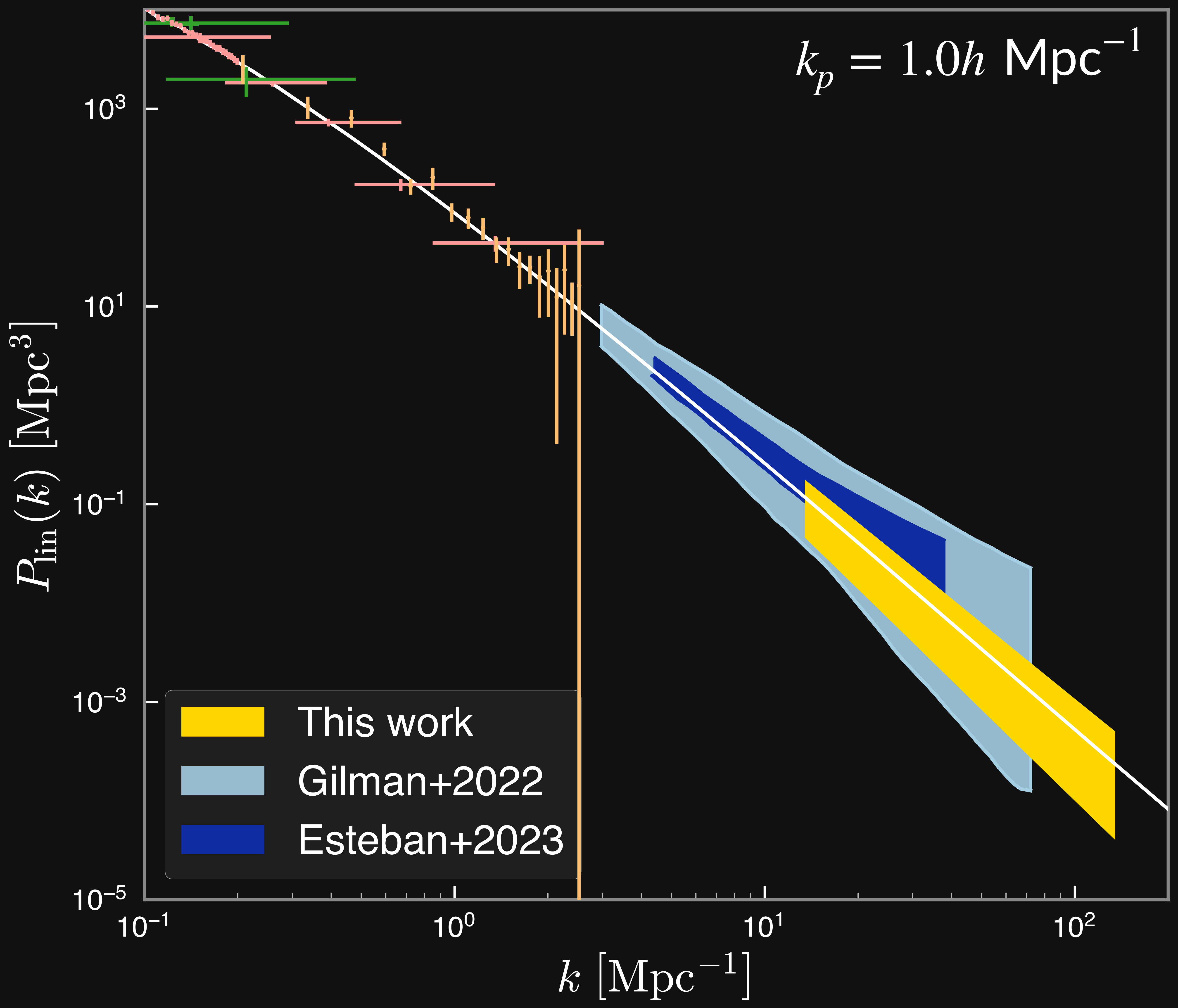
Excluded at 68% CL

Matter power spectrum

Effective wavelength of DM halo concentration

$$k \approx 134.5\ \text{Mpc}^{-1} \left(\frac{M}{10^8 M_\odot}\right)^{-1/3}$$

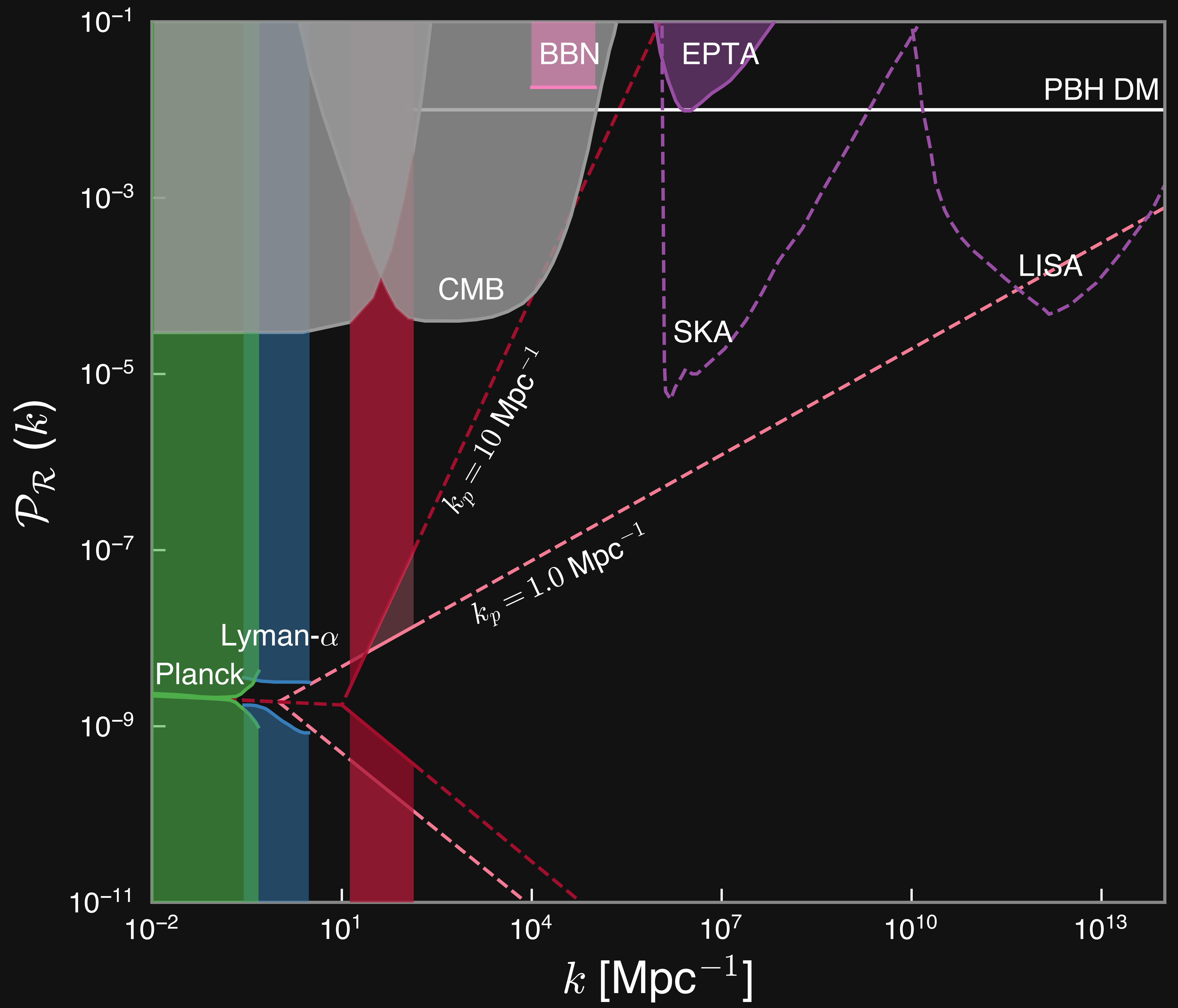
Smallest & largest galaxies in MW corresponds to $k \sim 130, 13\ \text{Mpc}^{-1}$.



Excluded at 68% CL

Primordial power spectrum

Amplitude of primordial fluctuations



Excluded at 95% CL

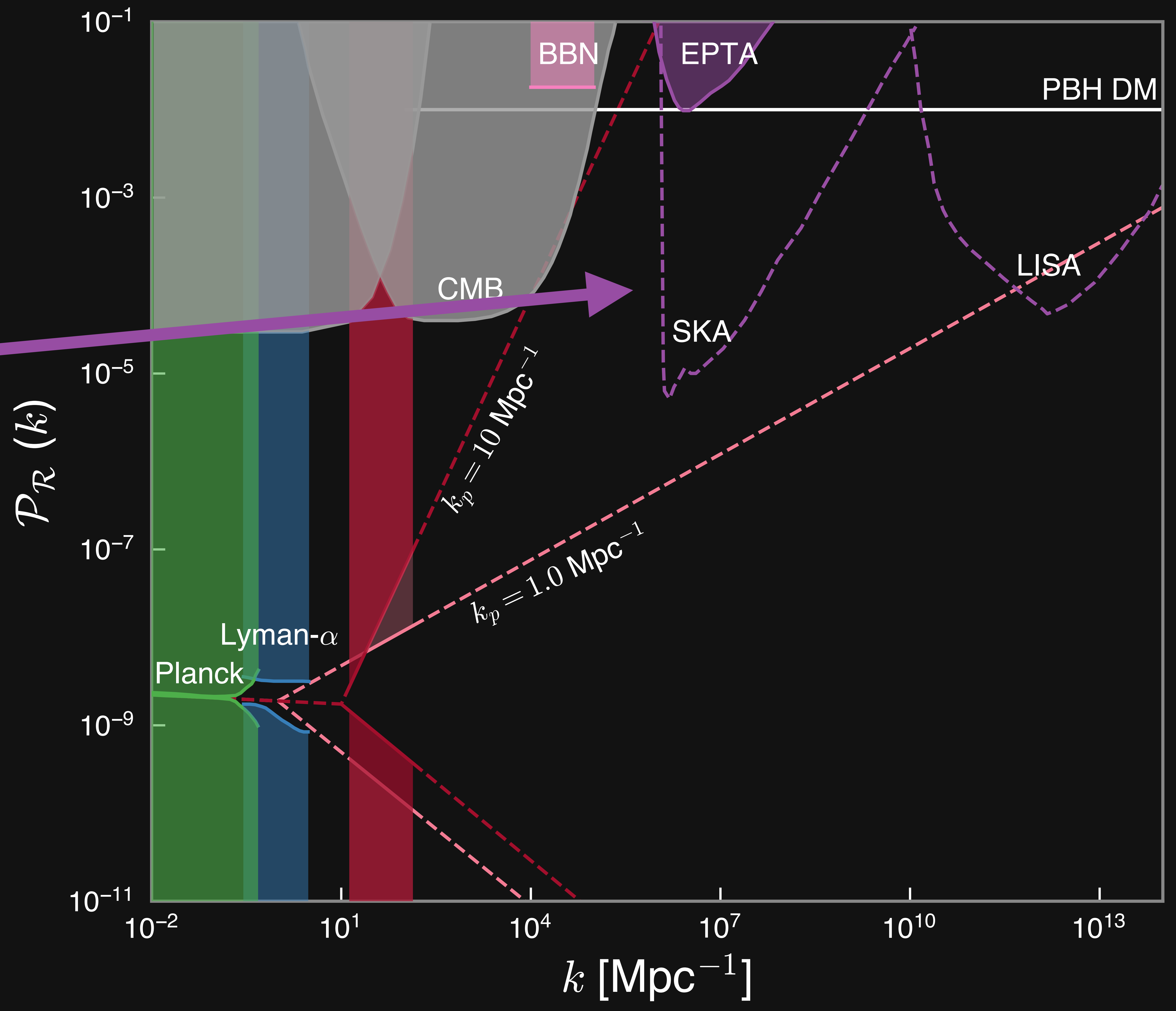
Primordial power spectrum

Significant large primordial fluctuations can induce GW signal.

NANOGrav evidence for SGWBG between $k \sim 10^6, 10^7$ Mpc^{-1}.

SMBH or blue-tilt?

(Afzal+2023)



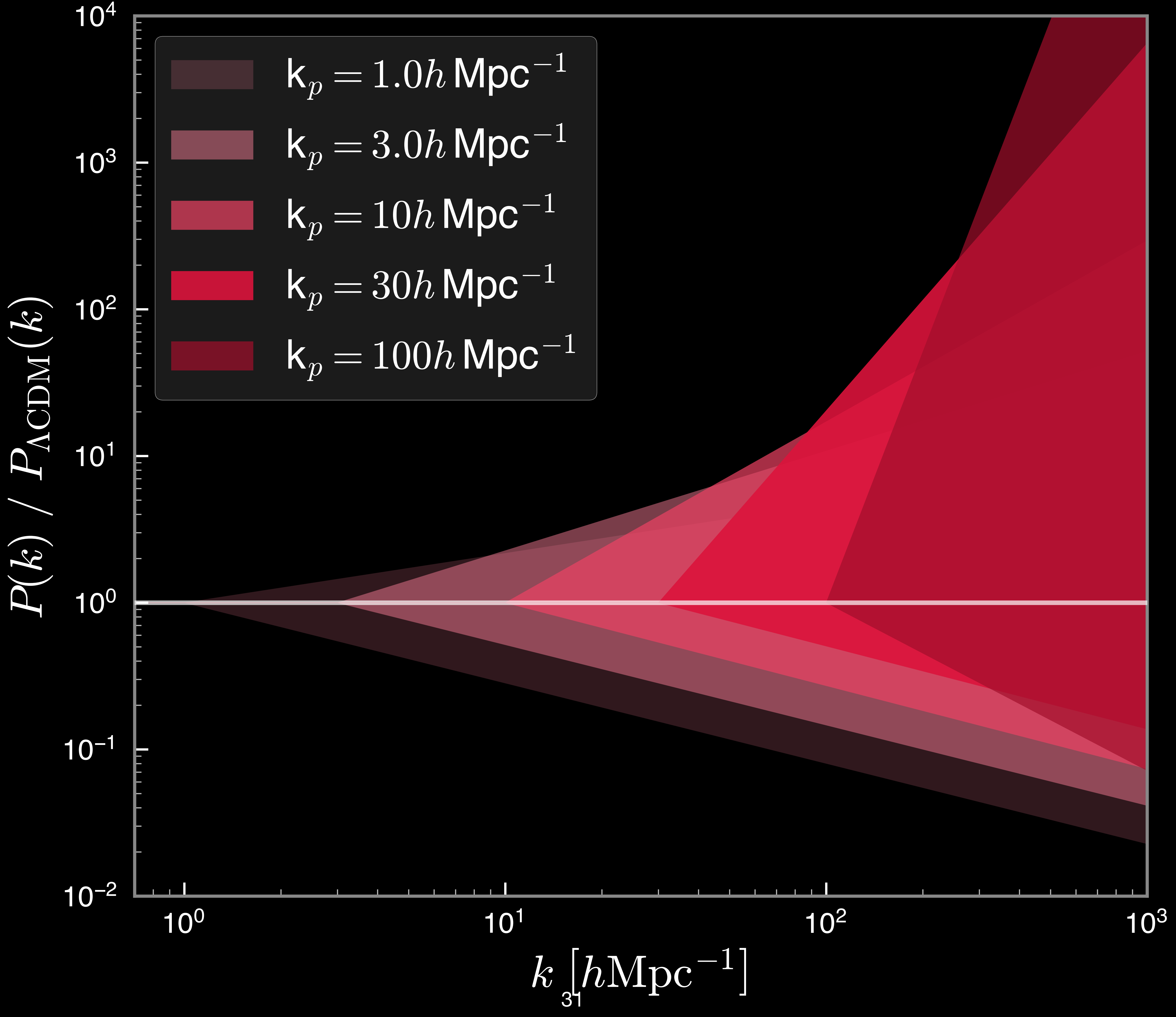
Excluded at 95% CL

Take away

- **Correlation between galaxy inner mass and luminosity** sensitive to the amplitude of the power spectrum.
- Leading constraints on power spectrum at small scales.
- Analysis can be applied to any model that produce any feature in the range of $13\ \mathrm{Mpc}^{-1} \lesssim k \lesssim 130\ \mathrm{Mpc}^{-1}$.

arXiv: 2407.04198

Matter power spectrum

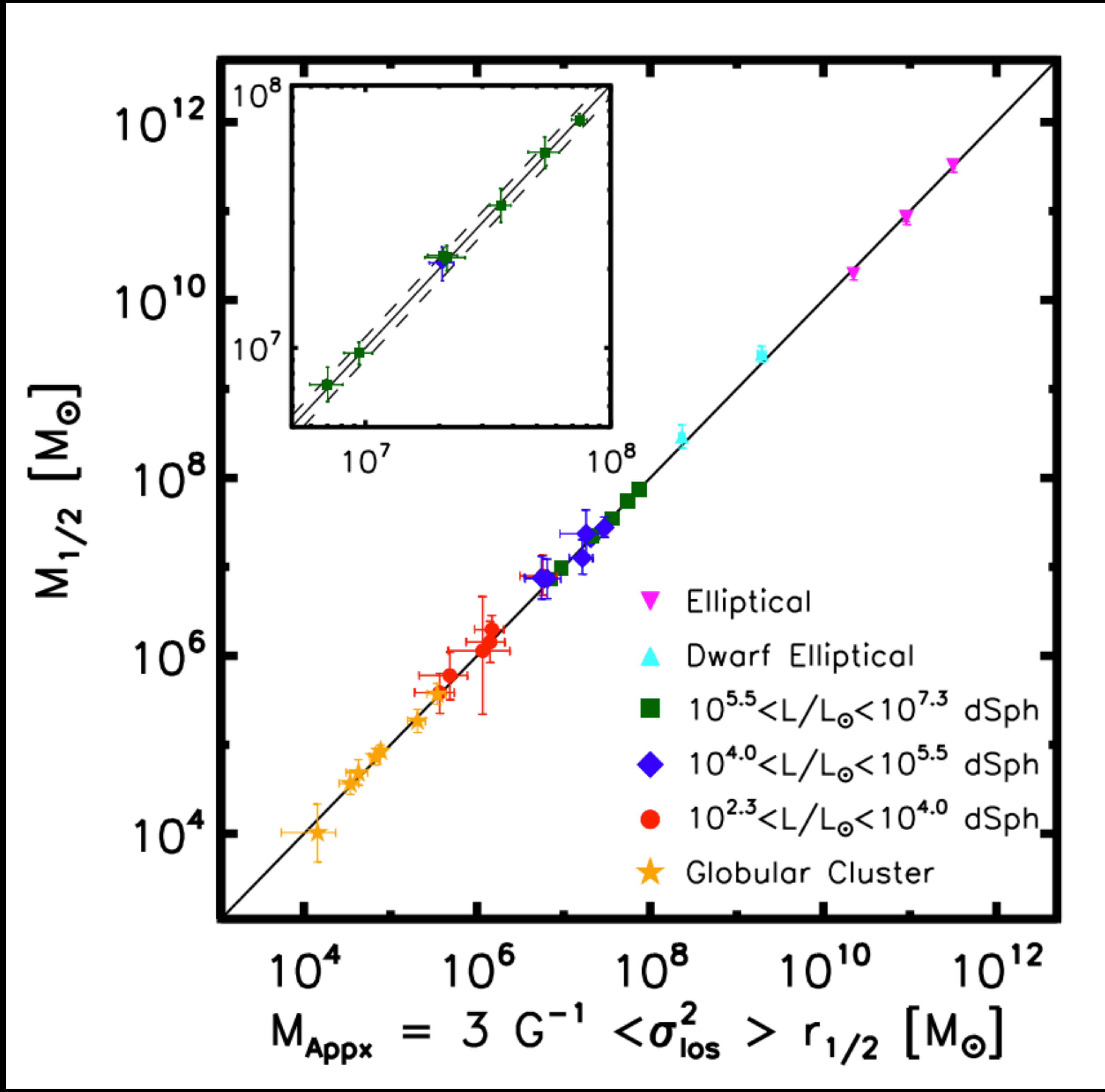


Excluded at 95% CL

Milky Way satellite galaxy observations

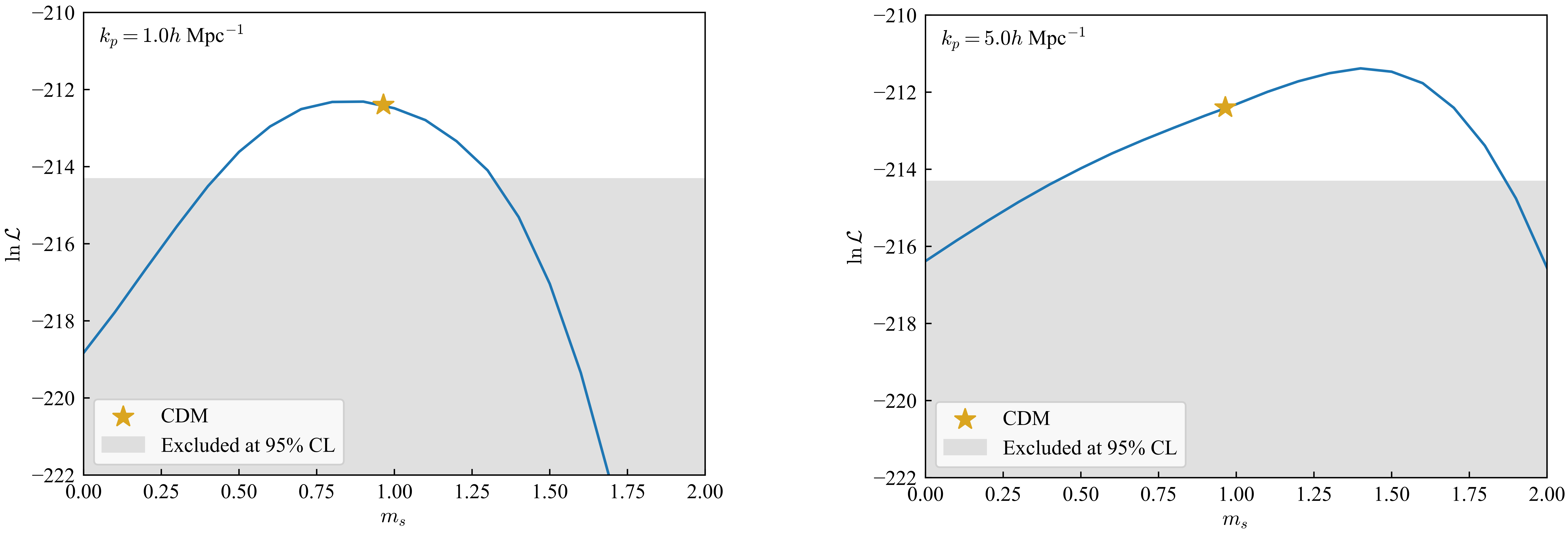
42 dwarf galaxies observations: velocity dispersion (σ_{los}), V-band luminosity (L_V) and half-light radii $R_{1/2}$.

$$M_{tot} = 930\sigma^2_{\star,los}R_{1/2}M_\odot$$

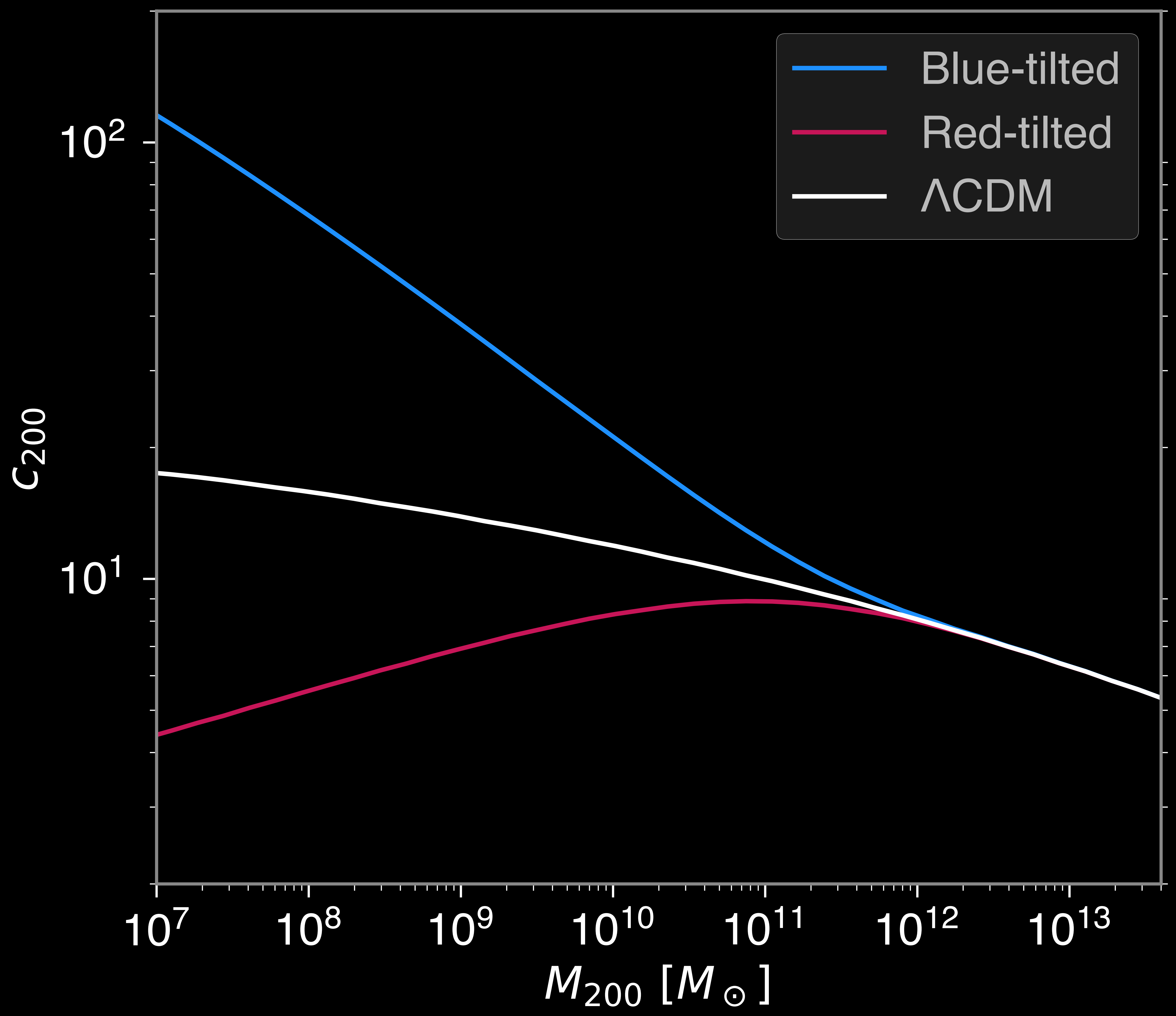


Wolf+2010

$$\ln \mathcal{L}(\theta) = \sum_{i,\mathrm{obs}} \ln \left[\int \int \mathcal{P}(M_{\mathrm{tot}}, L_V | , \theta) \frac{1}{\sqrt{2\pi}\sigma_{M_{\mathrm{tot},i}}} \exp\left(-\frac{(M_{\mathrm{tot}} - M_{\mathrm{tot},i})^2}{2\sigma^2_{M_{\mathrm{tot},i}}} \right) \right.$$
$$\left. \times \frac{1}{\sqrt{2\pi}\sigma_{L_{V,i}}} \exp\left(-\frac{(L_V - L_{V,i})^2}{2\sigma^2_{L_{V,i}}} \right) dM_{\mathrm{tot}} dL_V \right]$$



Concentration of dark matter halos



Fourier transform of radius R collapsing into a halo (Chan+2017)

Effective wavelength $k \approx \frac{4.5}{0.4}/R$

Effective scale determining halo concentration (Diemer+2019)

Smallest galaxies in MW hosted by

$$M = \frac{4\pi R^3 \bar{\rho}_m}{3} \sim 10^8\ M_\odot$$

corresponds to $k \sim 100\ \mathrm{Mpc}^{-1}$

Concentration of dark matter halos

$$c(M,z) = R_{vir}(M,z)/r_s$$