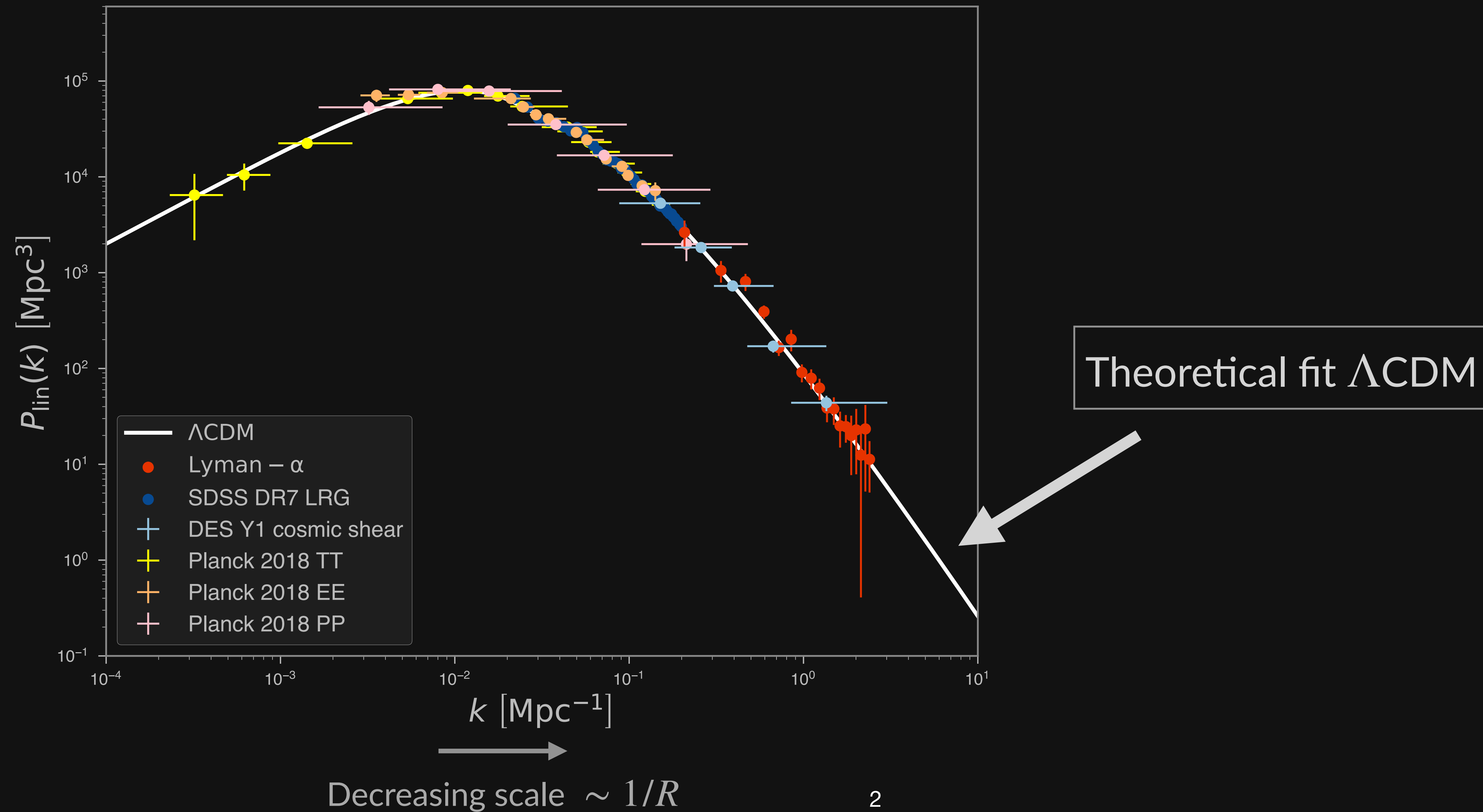


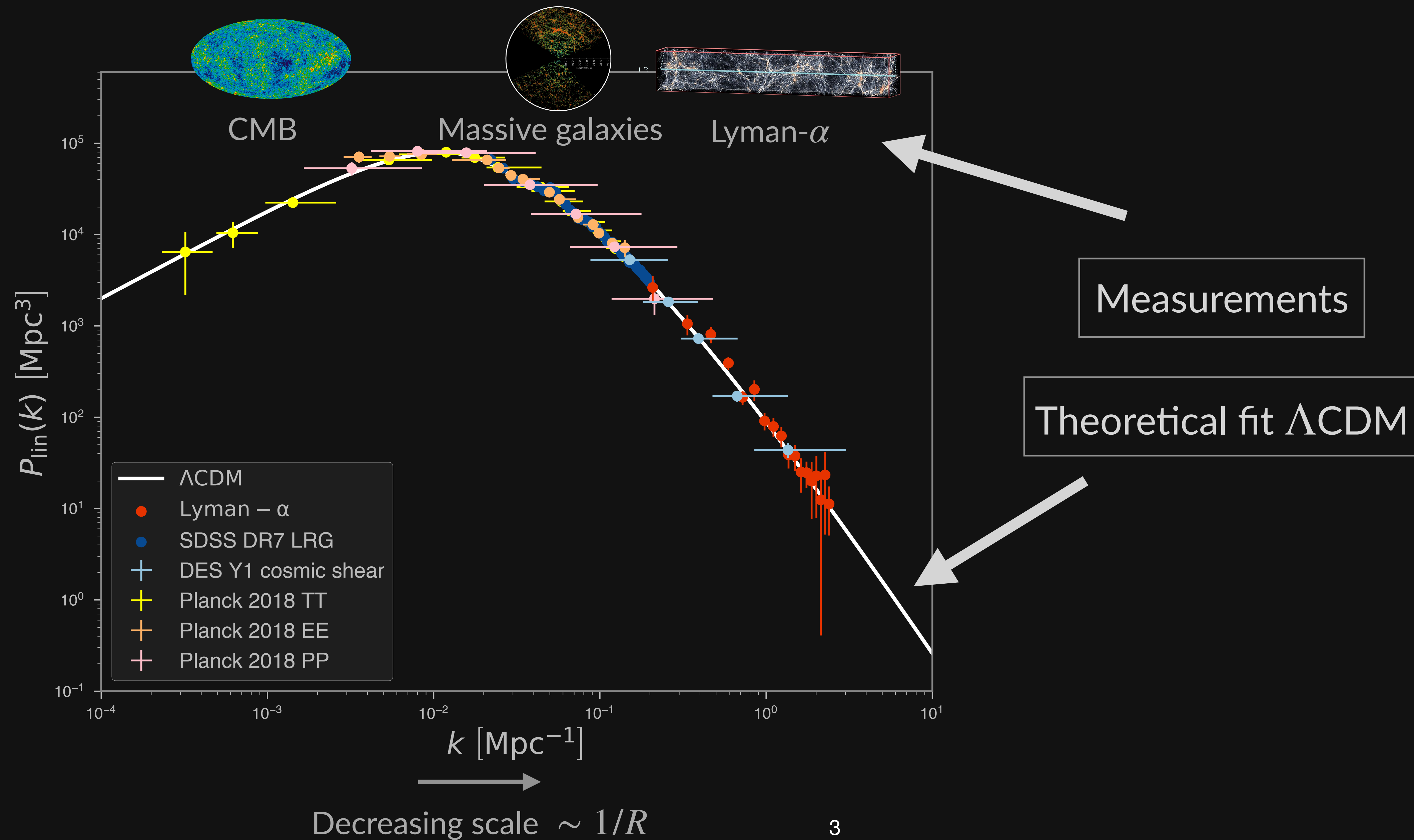
Constraining dark matter models using dwarf galaxy size and luminosity

Ariane Dekker
KICP Fellow

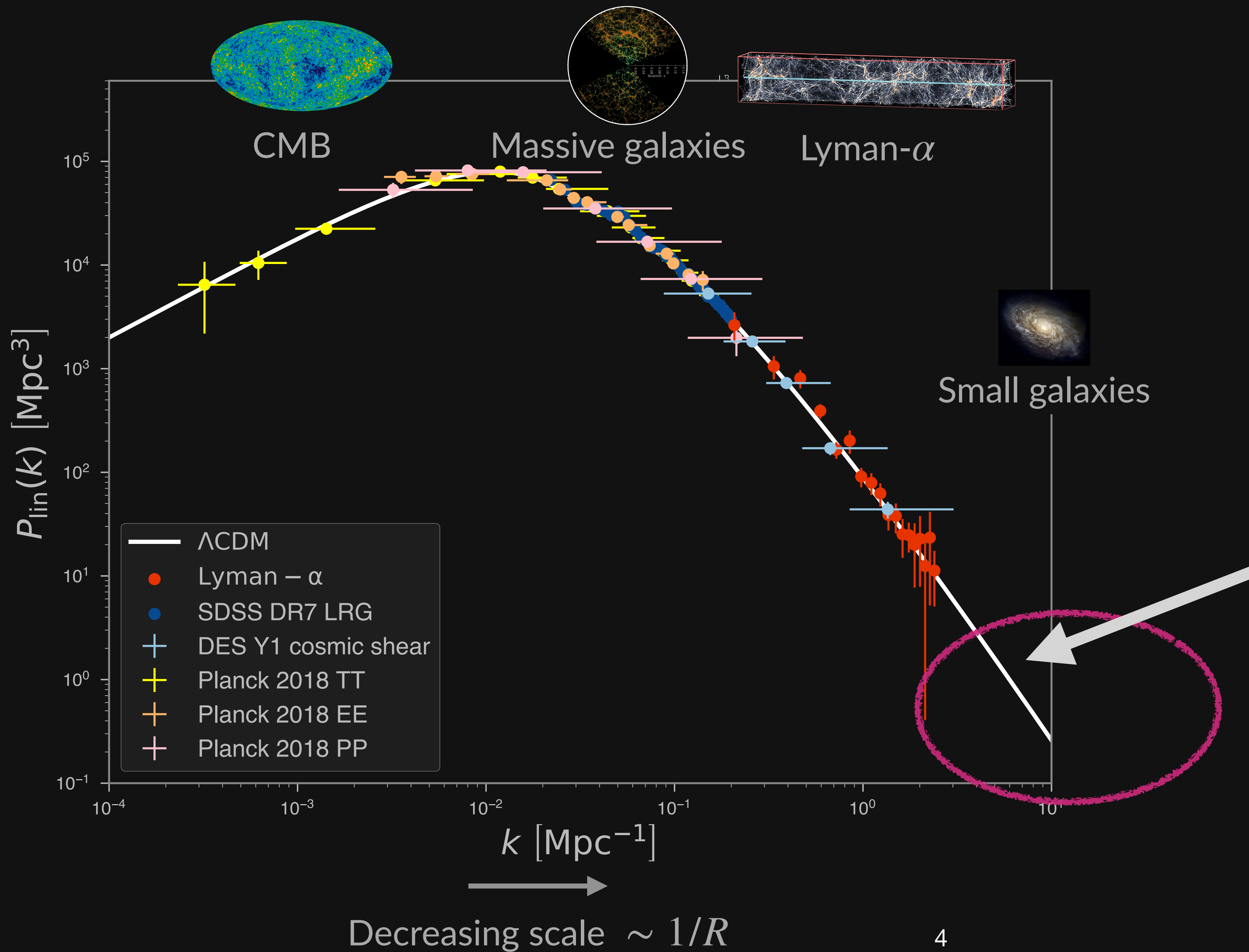
Matter power spectrum



Matter power spectrum



Matter power spectrum



??
 Various models predict deviations at small scales, impacting galaxy observations

Outline

Enhancements and
suppressions in MPS

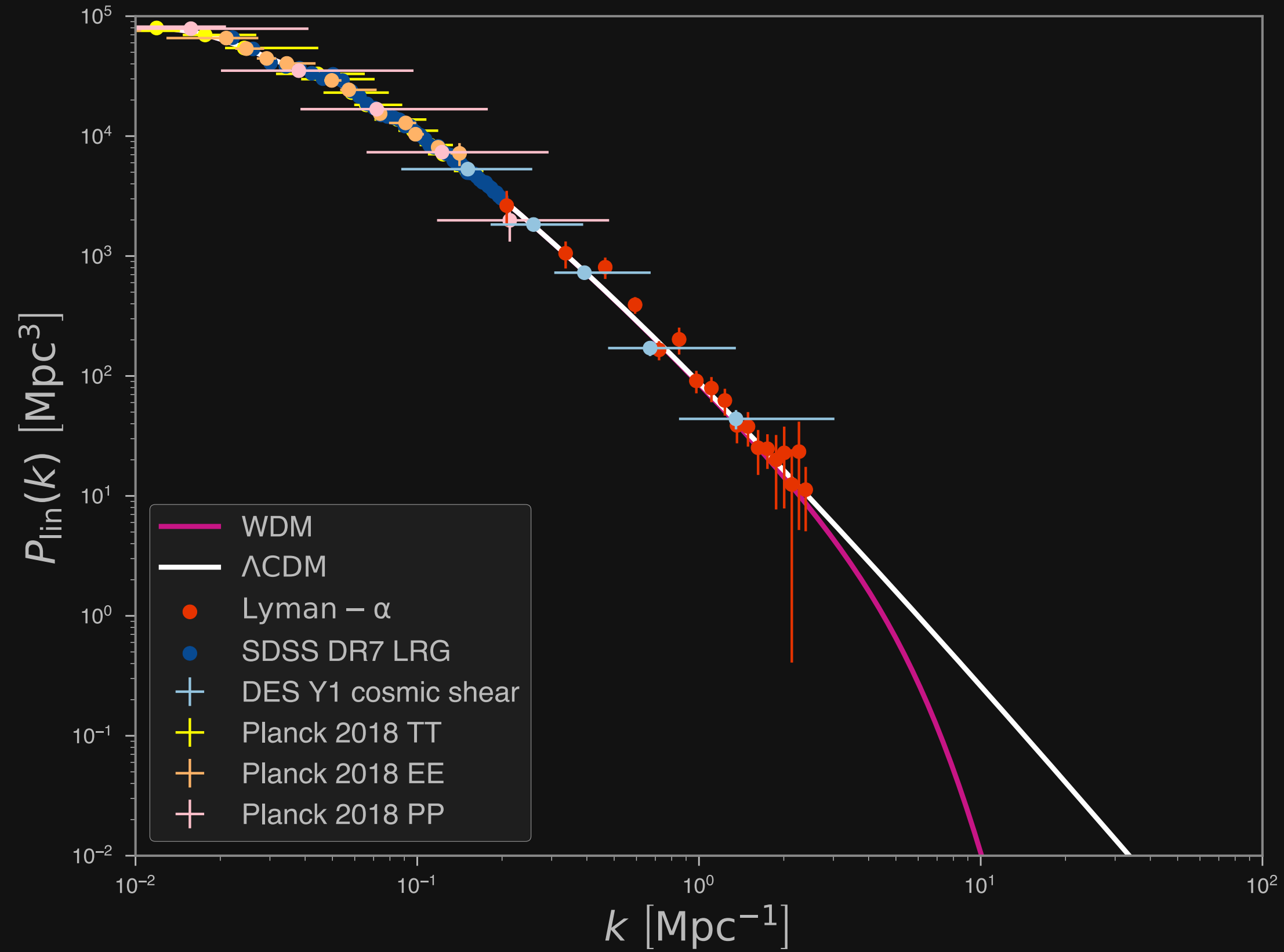


Impacts formation of
DM halos & galaxies



Constrain MPS shape
at small scales

Predictions for suppressed MPS

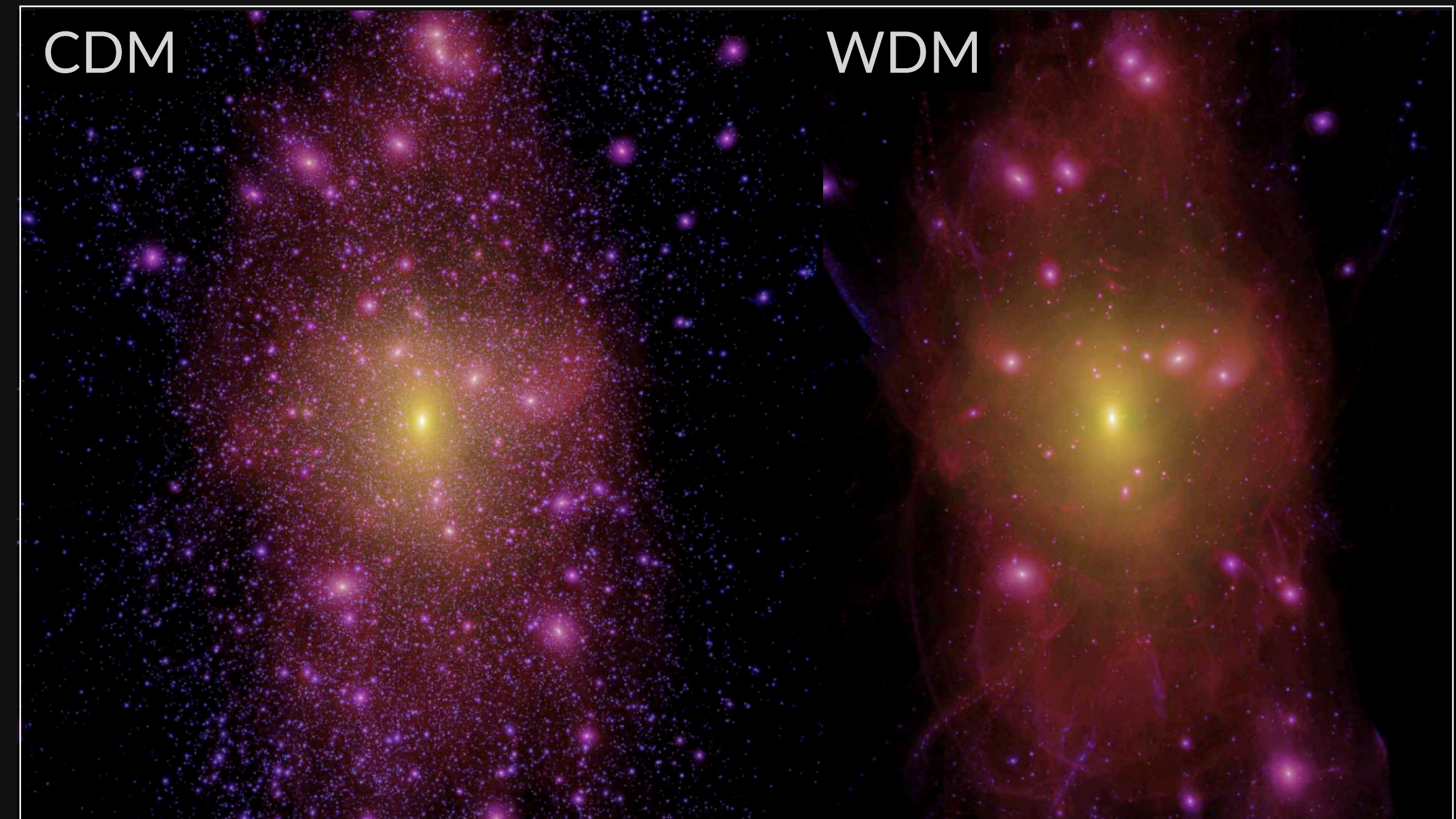


Examples

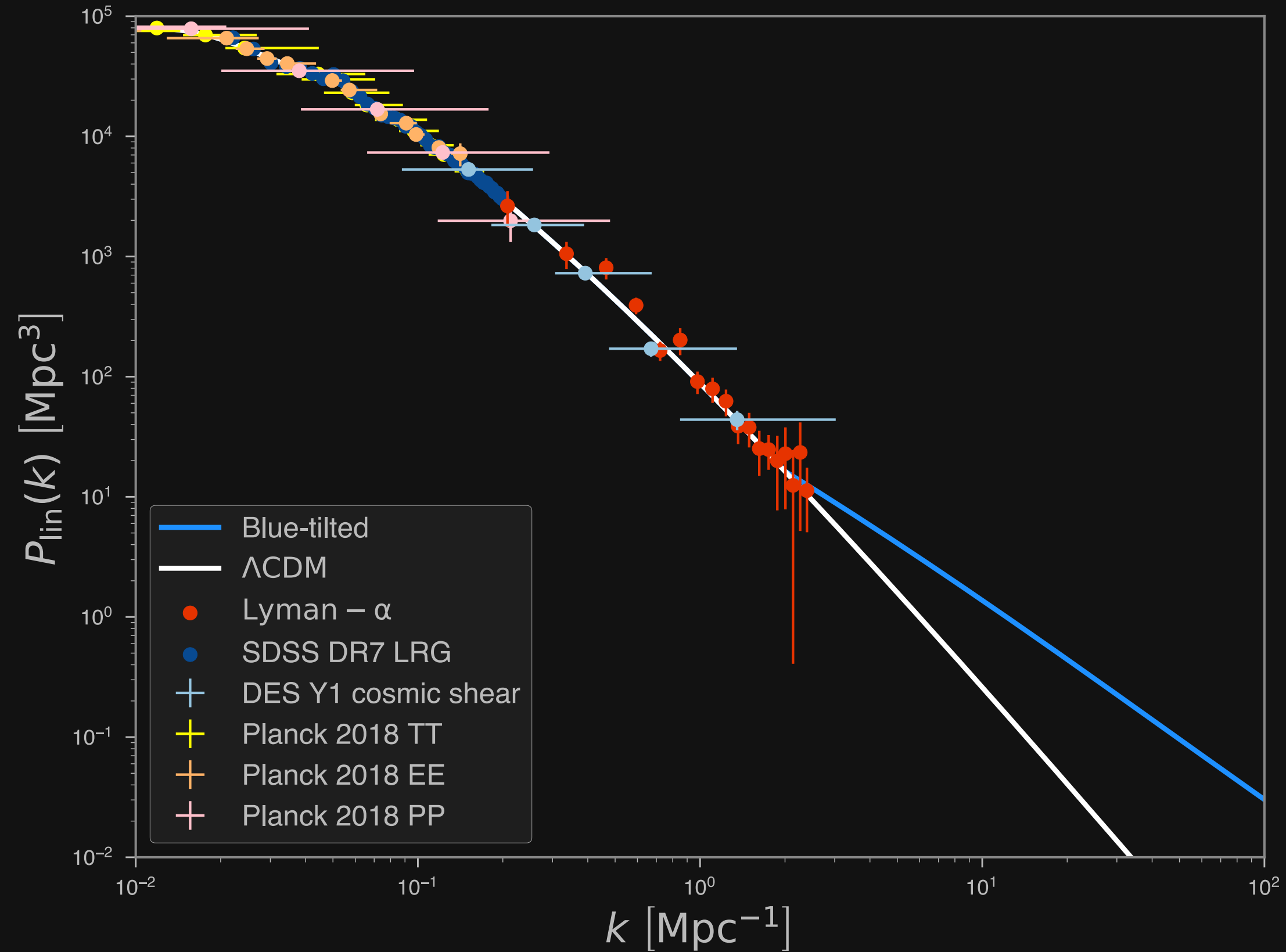
Warm dark matter (Lovell 2023)

Ultra-light axion DM (Marsh 2016)

Self-interactions (Berryman+2022)



Predictions for enhanced MPS

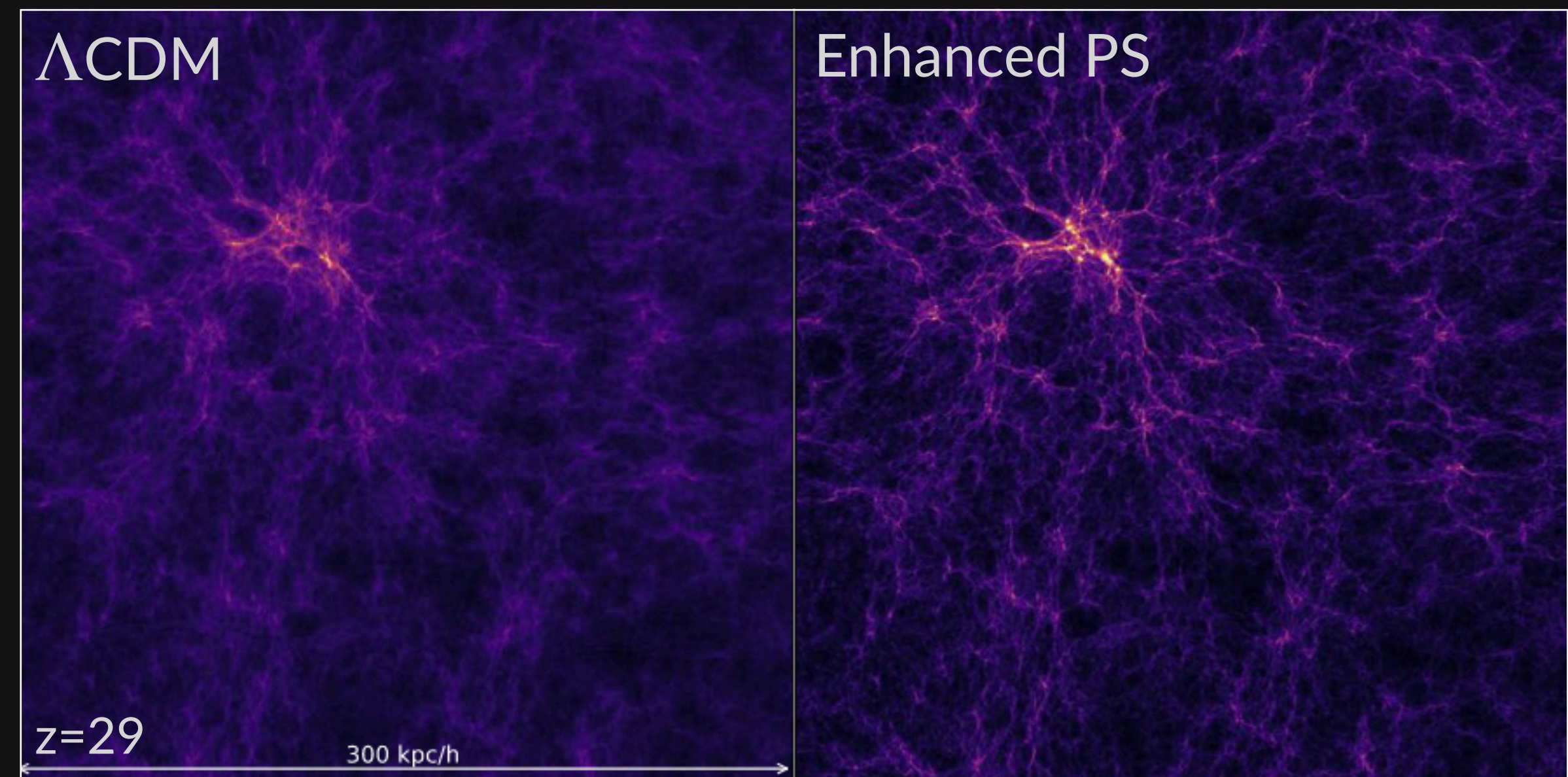


Examples

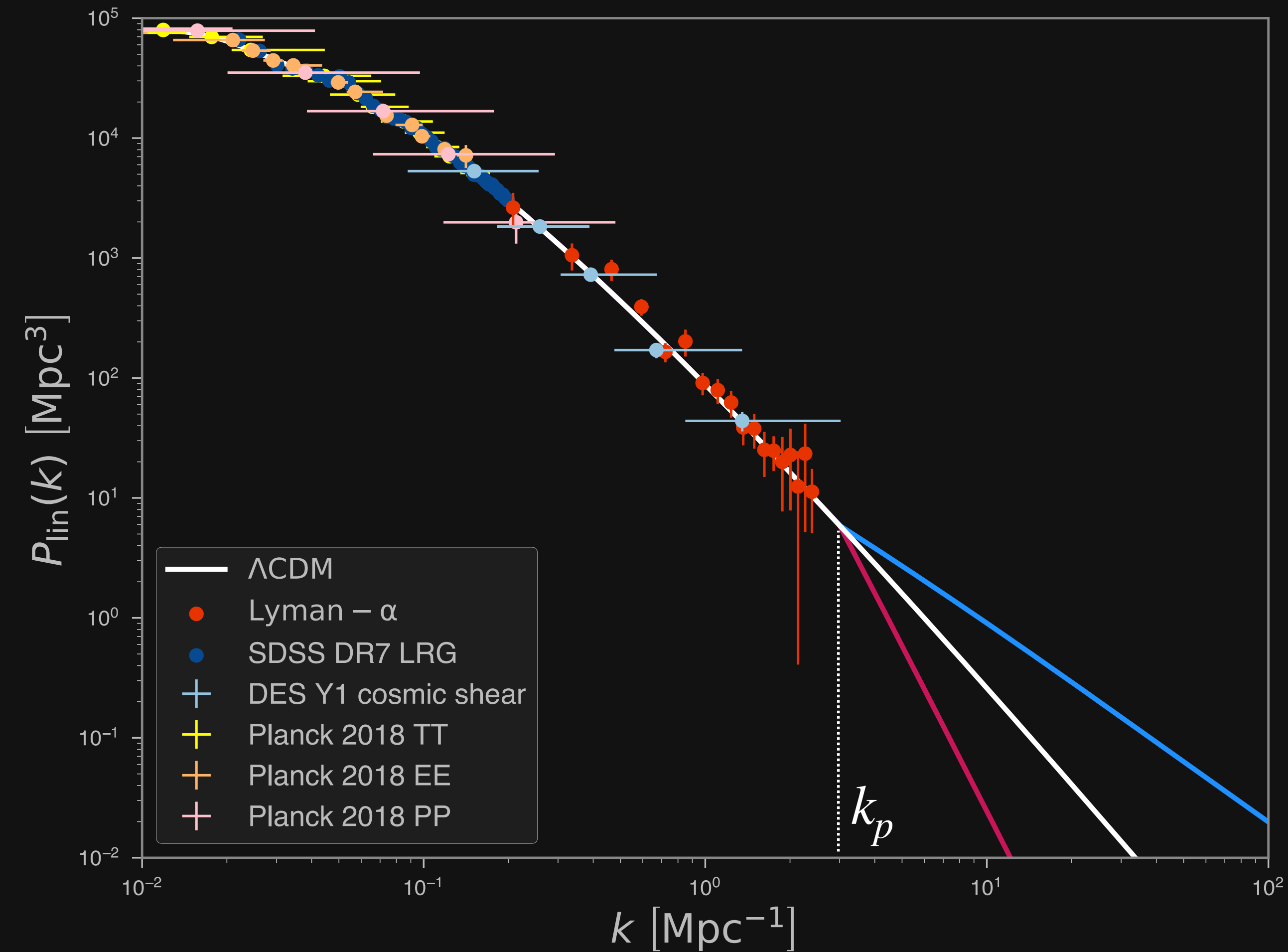
Massive vector boson DM (Graham+2015)

Primordial magnetic fields (Ralegankar+2024)

Non-standard inflation (Seleim+2020)



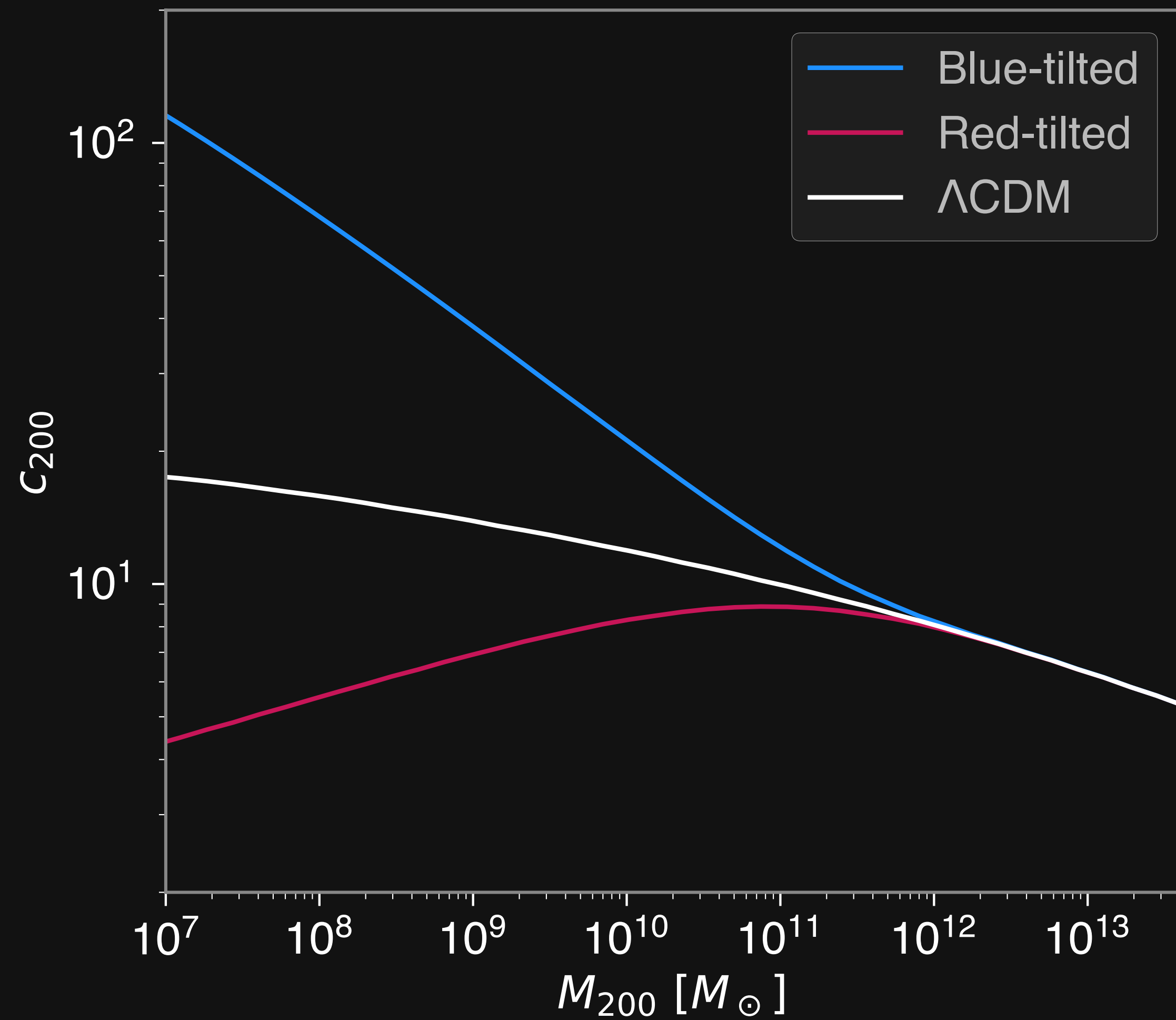
Blue and red tilted power spectra



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

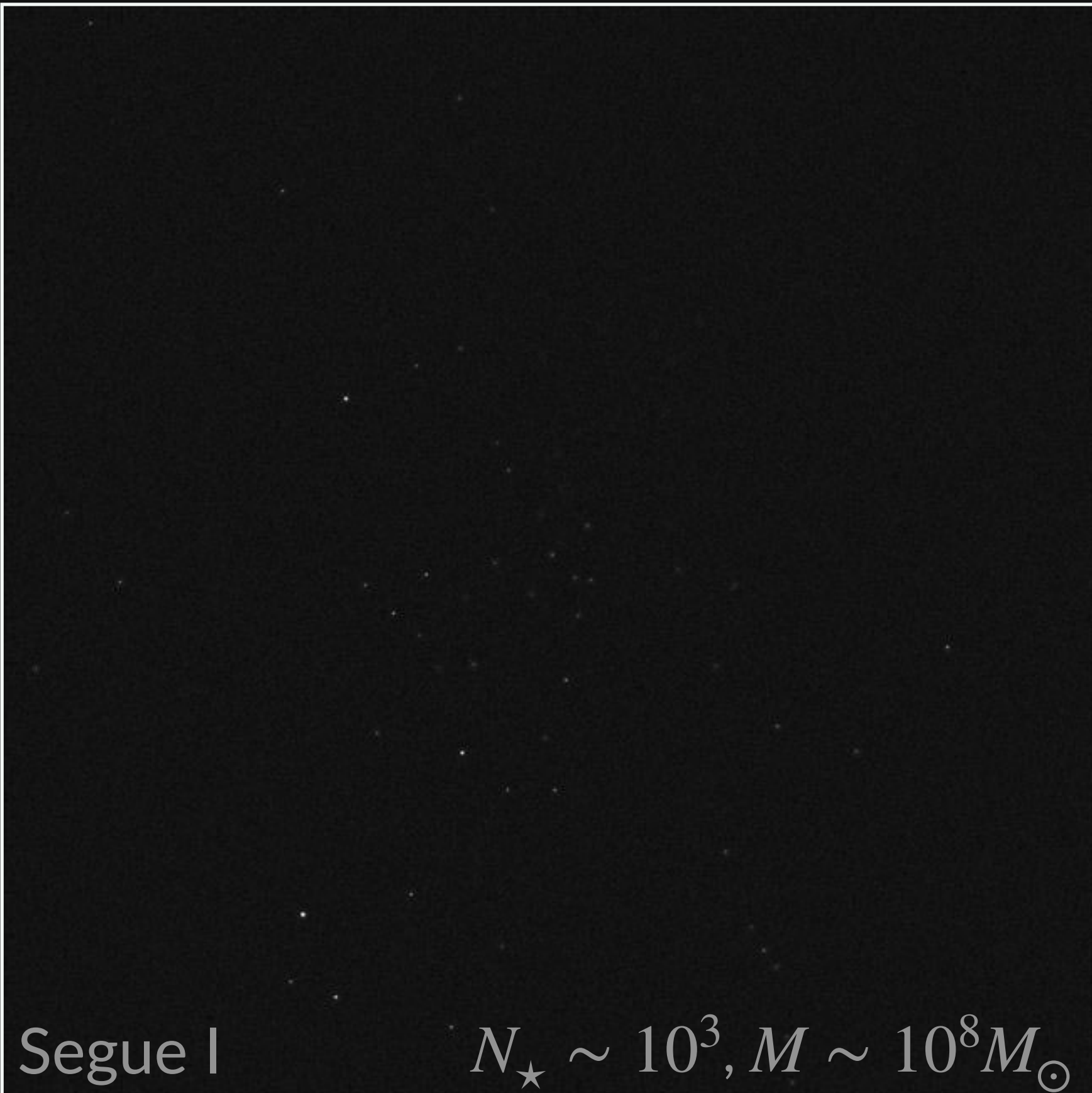
$$c(M, z) = R_{vir}(M, z)/r_s$$



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

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

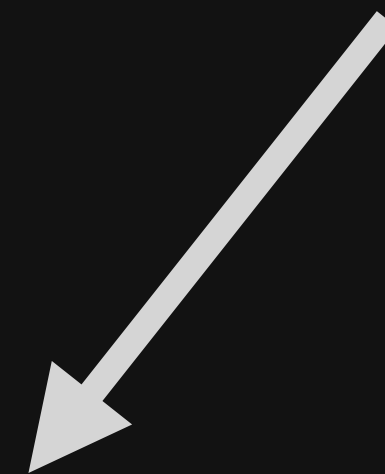
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Observable with kinematic data ($\sigma_{los}, R_{1/2}$)

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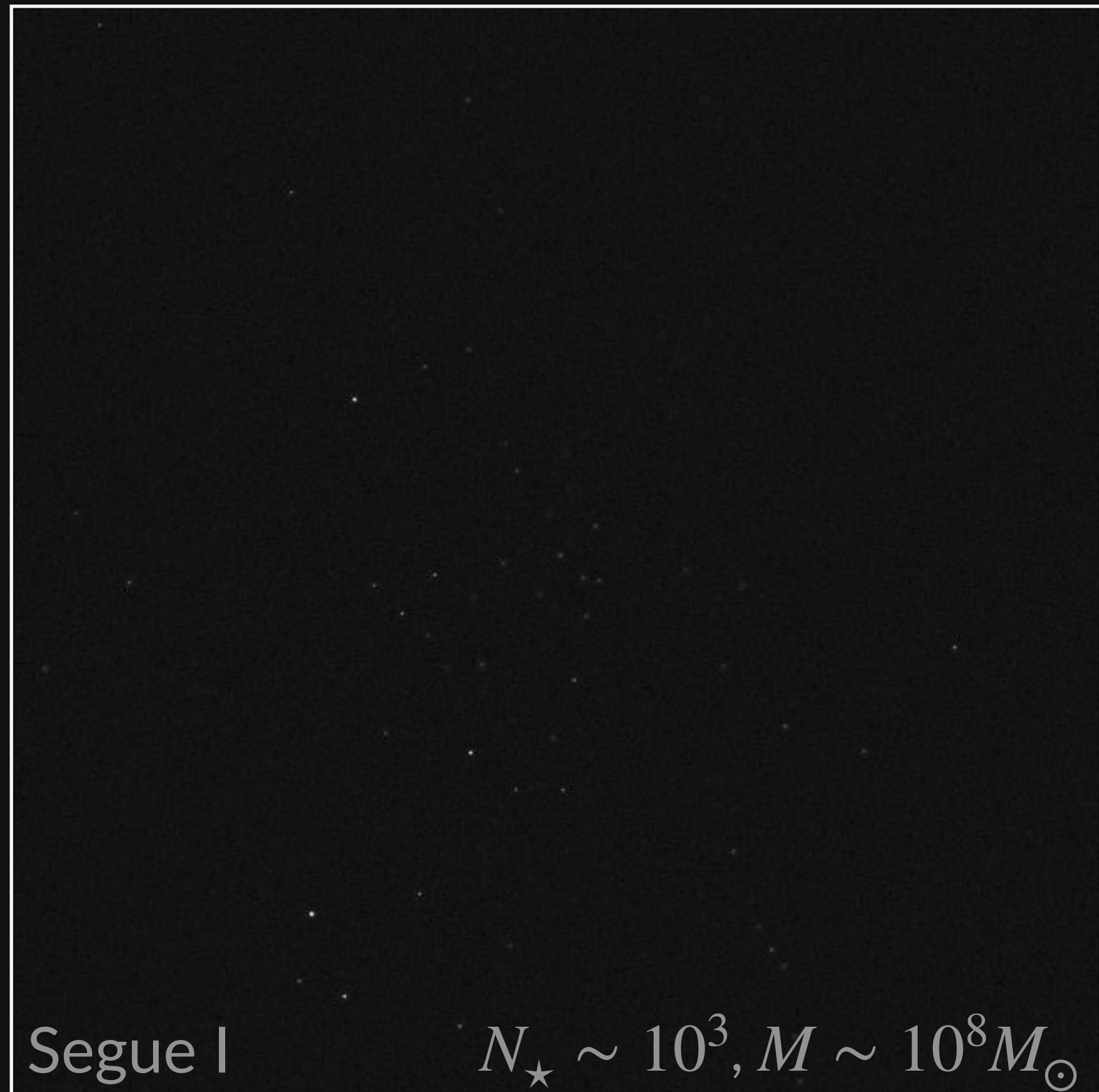
$$M_{tot}(< r_{1/2}) = M_{dm}(< r_{1/2}) + 0.5M_{\star}$$

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

Model for each cosmological model

Inner mass of galaxies

Small galaxies are dark matter-dominated!



Concentration impacts inner mass of galaxies

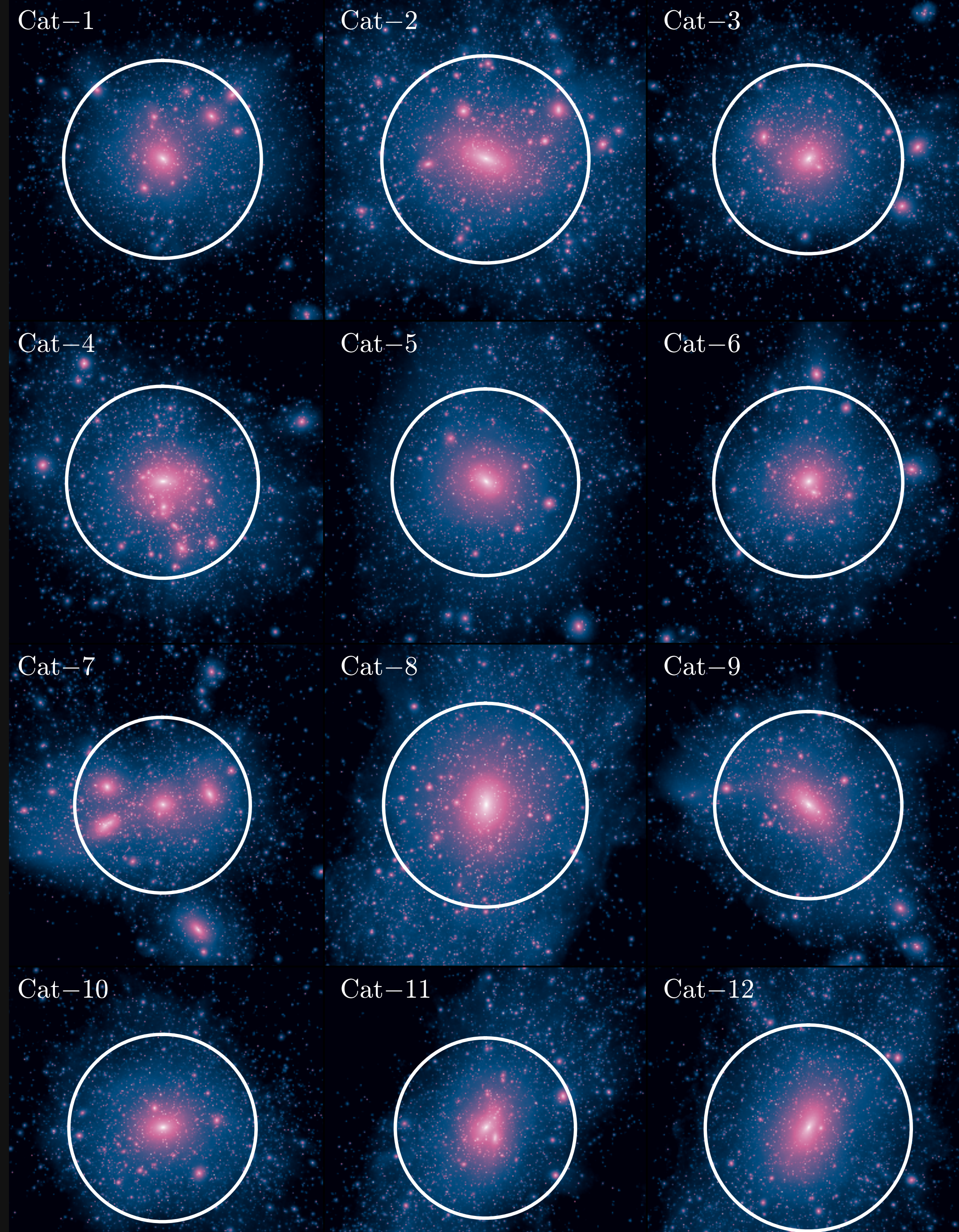
$$M_{tot}(< r_{1/2}) = M_{dm}(< r_{1/2}) + 0.5M_{\star}$$

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

= ?

Model for each cosmological model

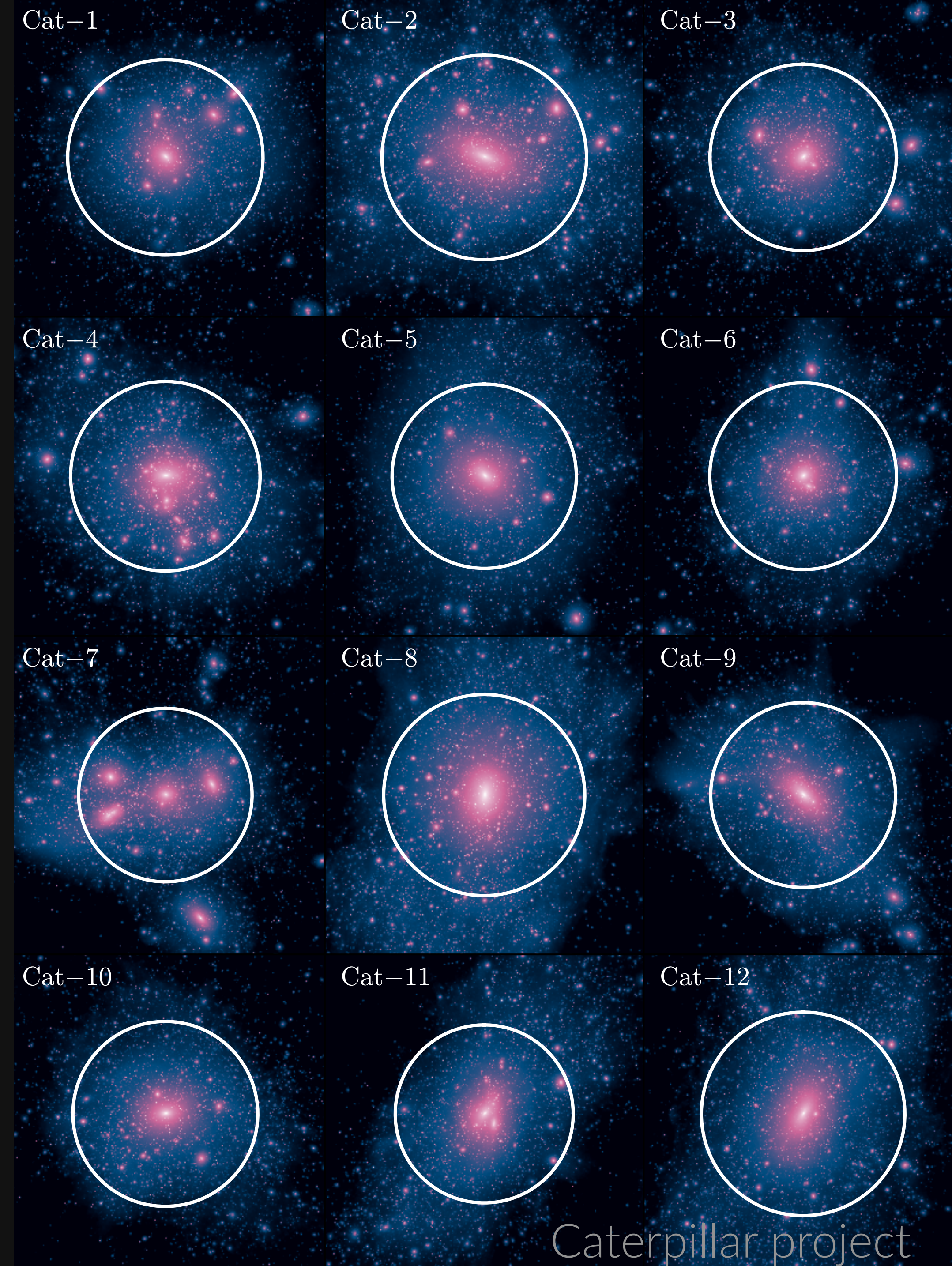
Model dwarf galaxies



Model dwarf galaxies

1) High-resolution Caterpillar simulations of 32 Milky-Way sized halos in Λ CDM.

Griffen et al. (2016)



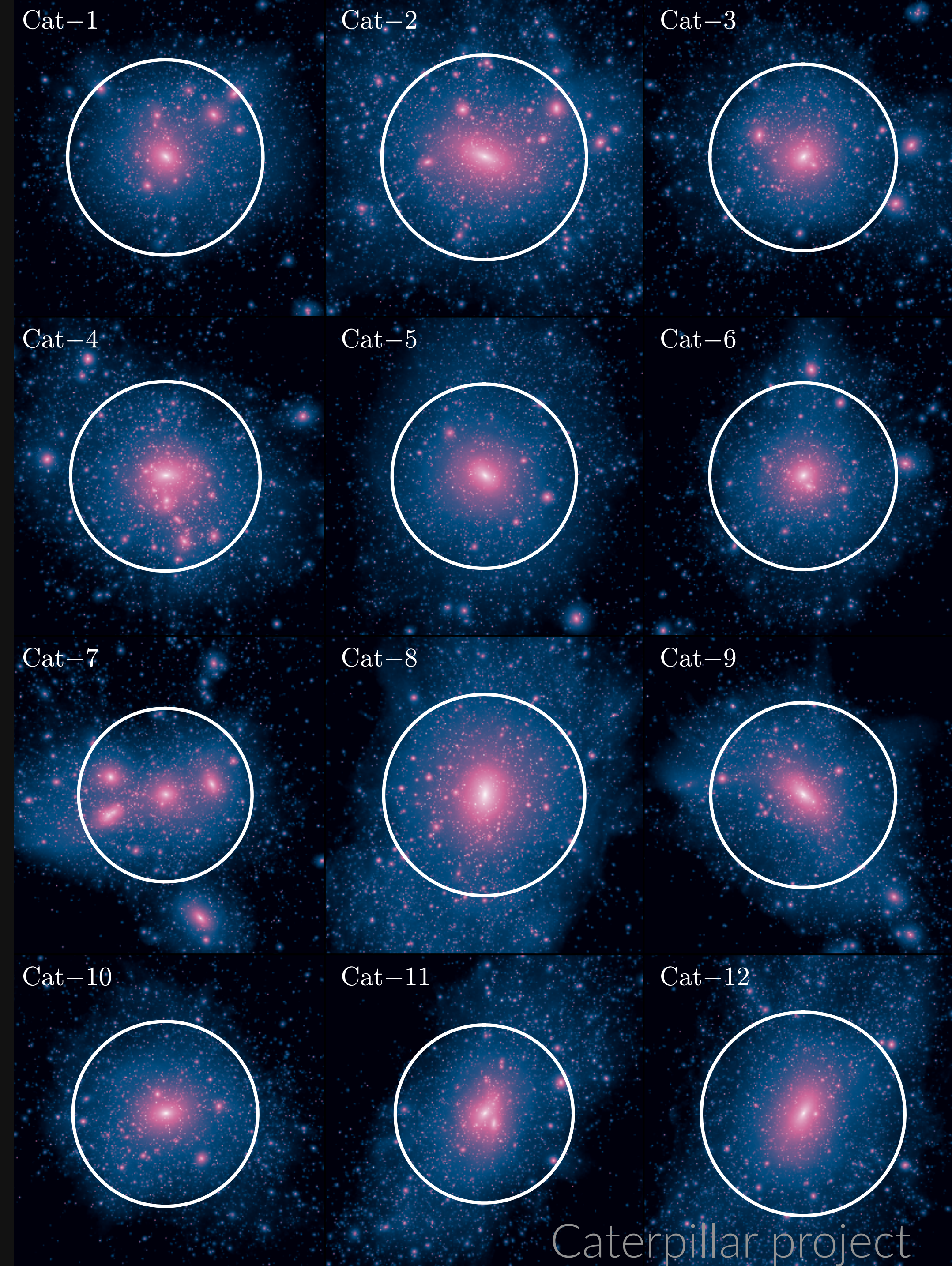
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Griffen et al. (2016)

- 2) Populate halos and subhalos with galaxies using GRUMPY.

Manwadkar & Kravtsov 2023



Model dwarf galaxies

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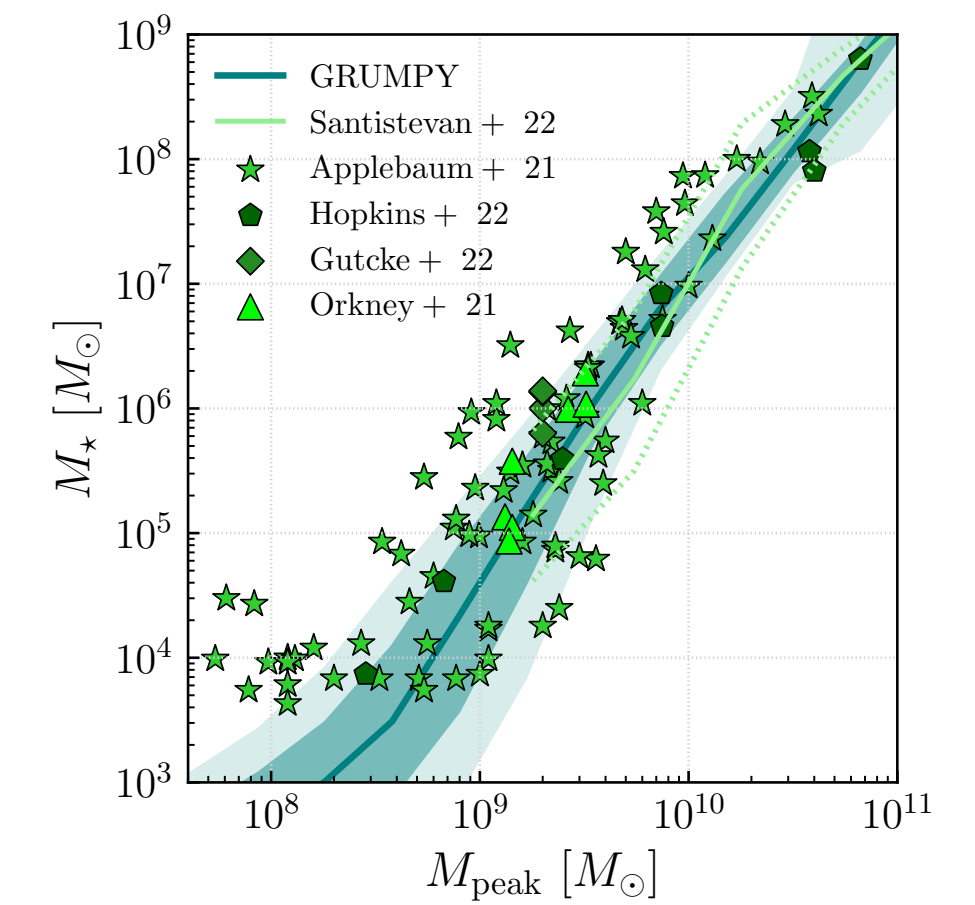
Griffen et al. (2016)

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Manwadkar & Kravtsov 2023

Halo-stellar mass

Manwadkar, Kravtsov 2022



Model dwarf galaxies

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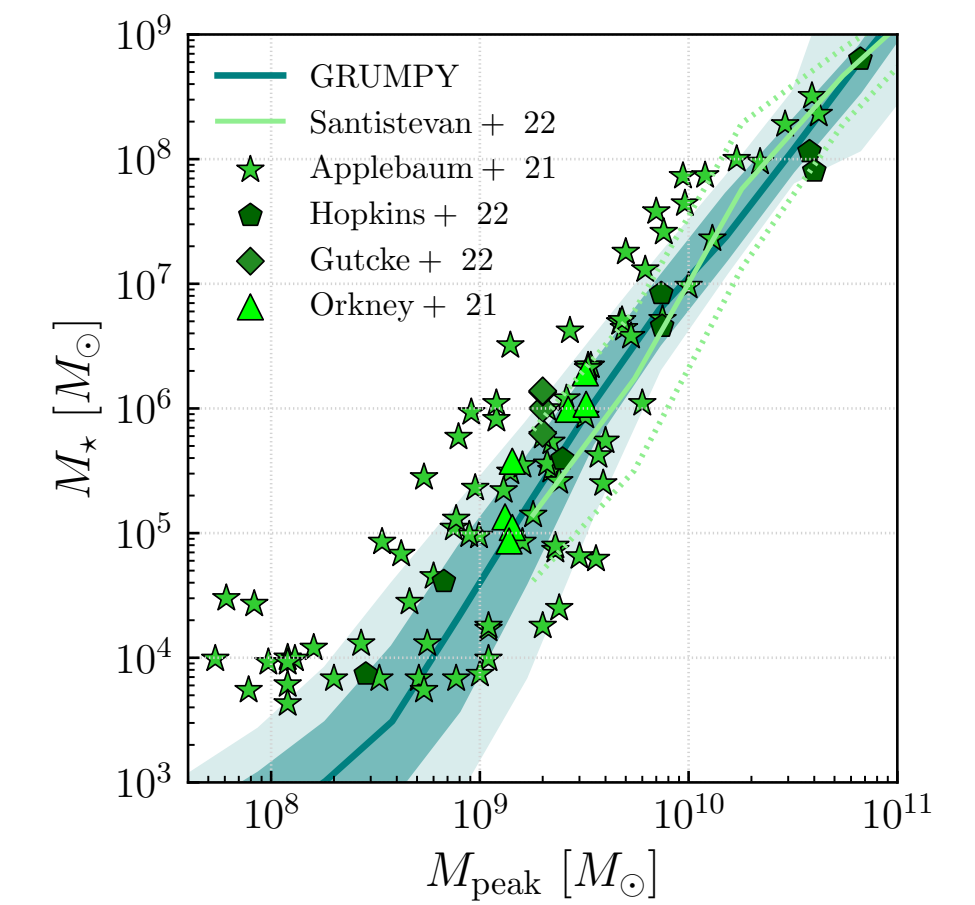
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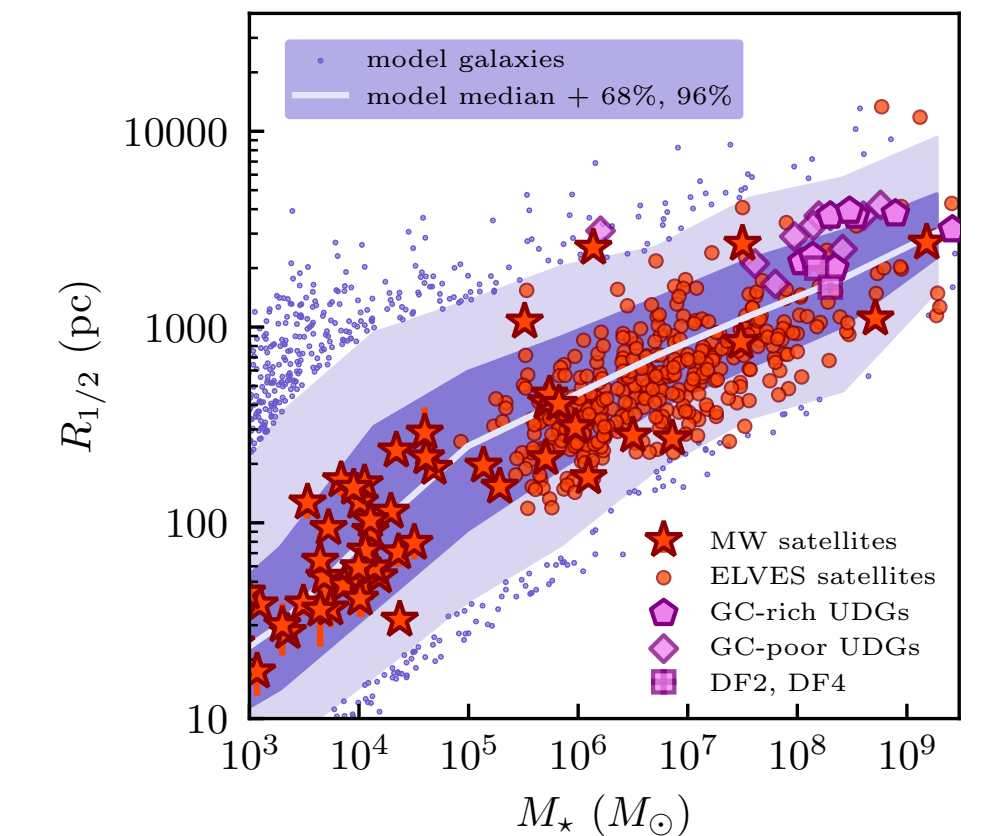
Halo-stellar mass

Manwadkar, Kravtsov 2022



Radius-stellar mass

Kravtsov 2024



Model dwarf galaxies

1) High-resolution Caterpillar simulations of 32 Milky-Way sized halos in Λ CDM.

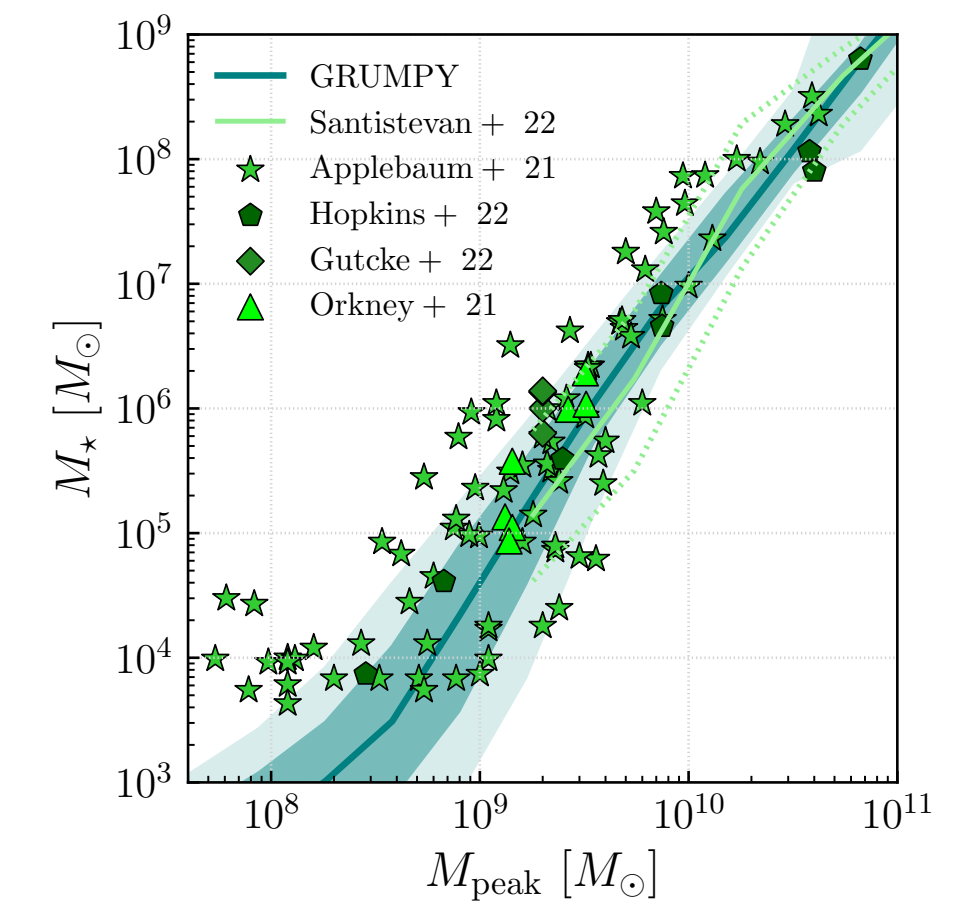
Griffen et al. (2016)

2) Populate halos and subhalos with galaxies using GRUMPY.

Manwadkar & Kravtsov 2023

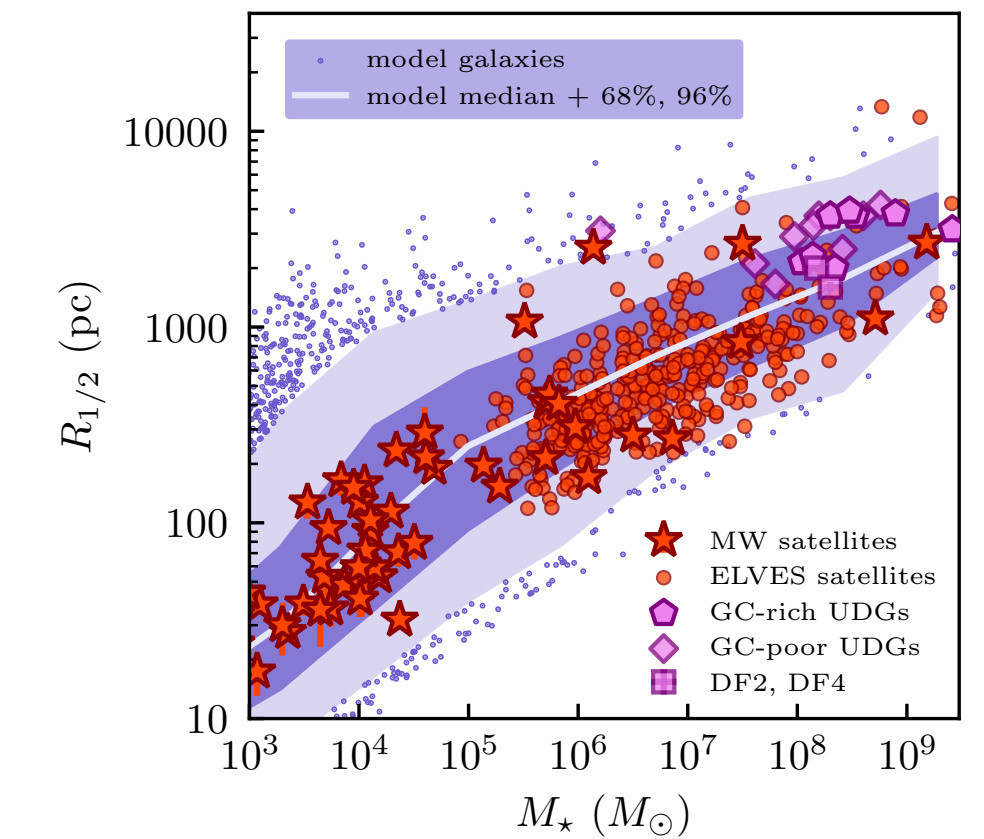
Halo-stellar mass

Manwadkar, Kravtsov 2022



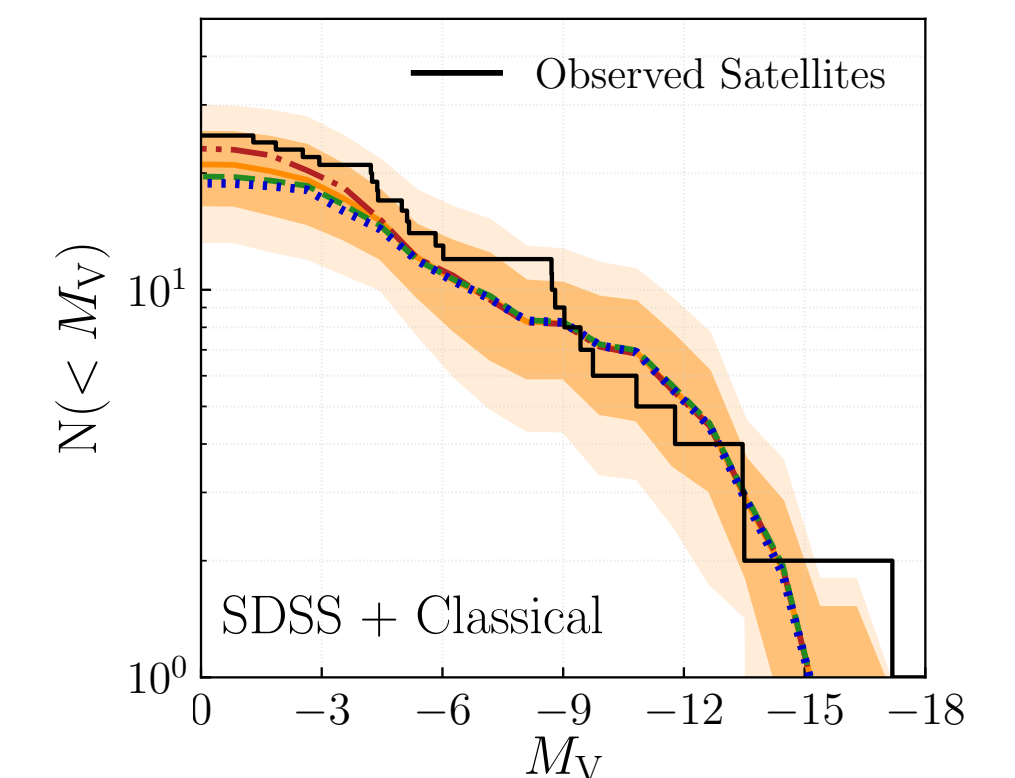
Radius-stellar mass

Kravtsov 2024

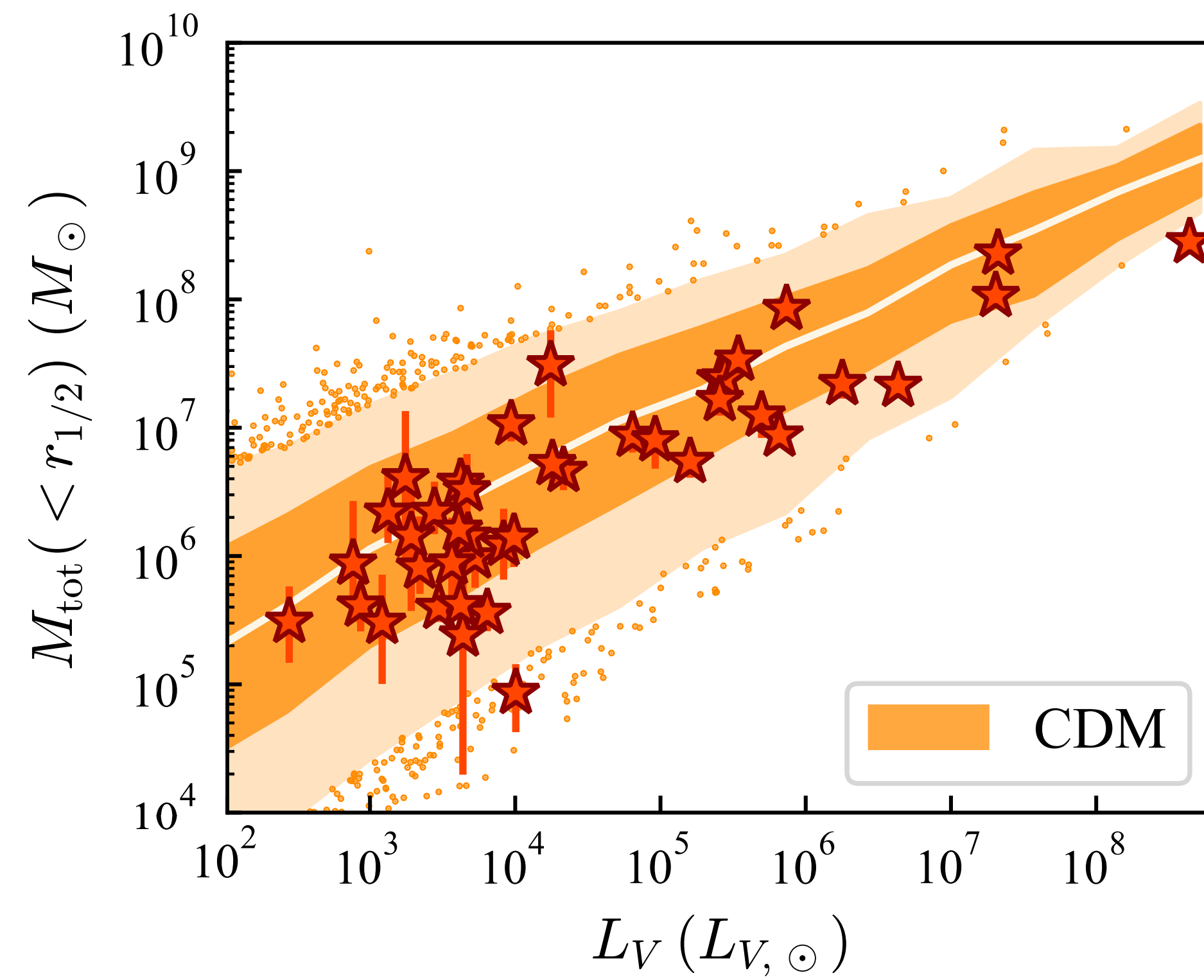


Luminosity function

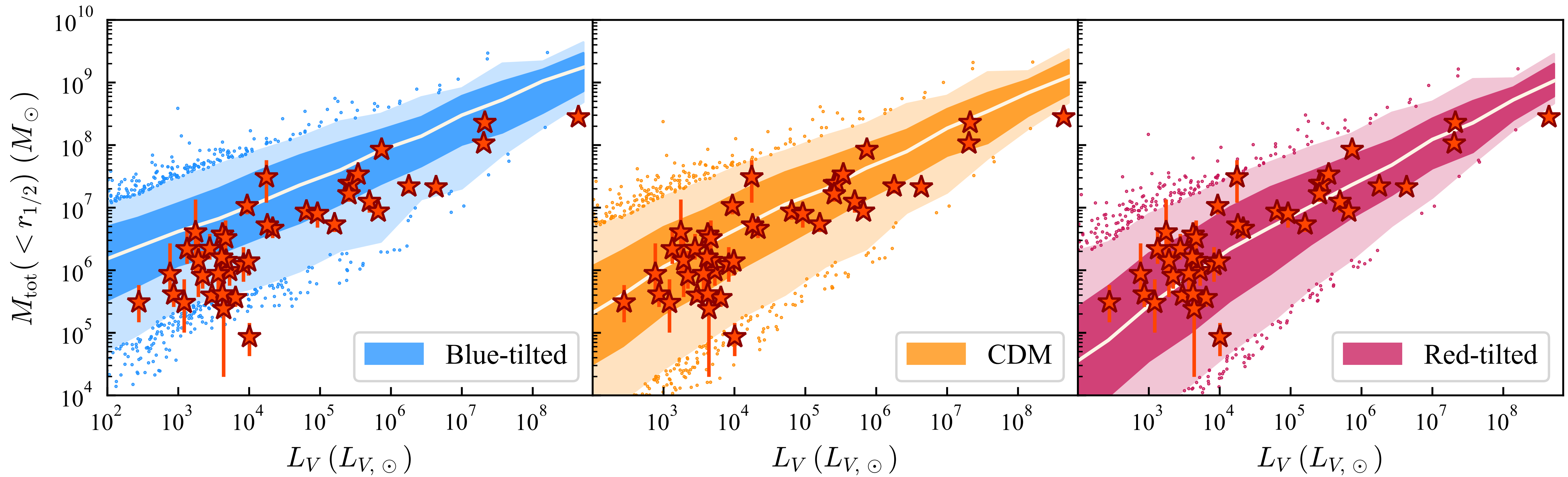
Manwadkar, Kravtsov 2022



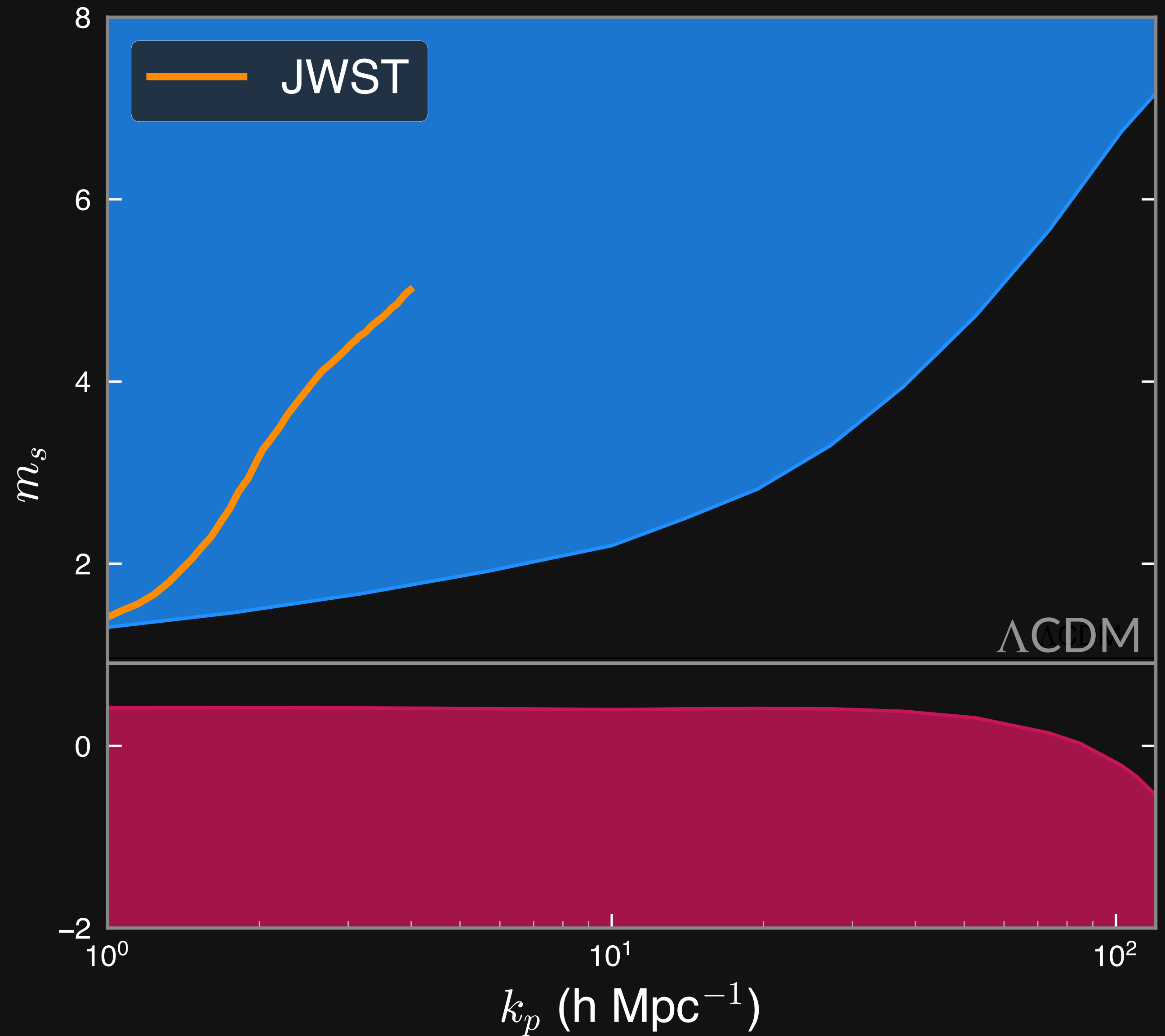
Model galaxies in Λ CDM agree with observations



Model galaxies in Λ CDM agree with observations

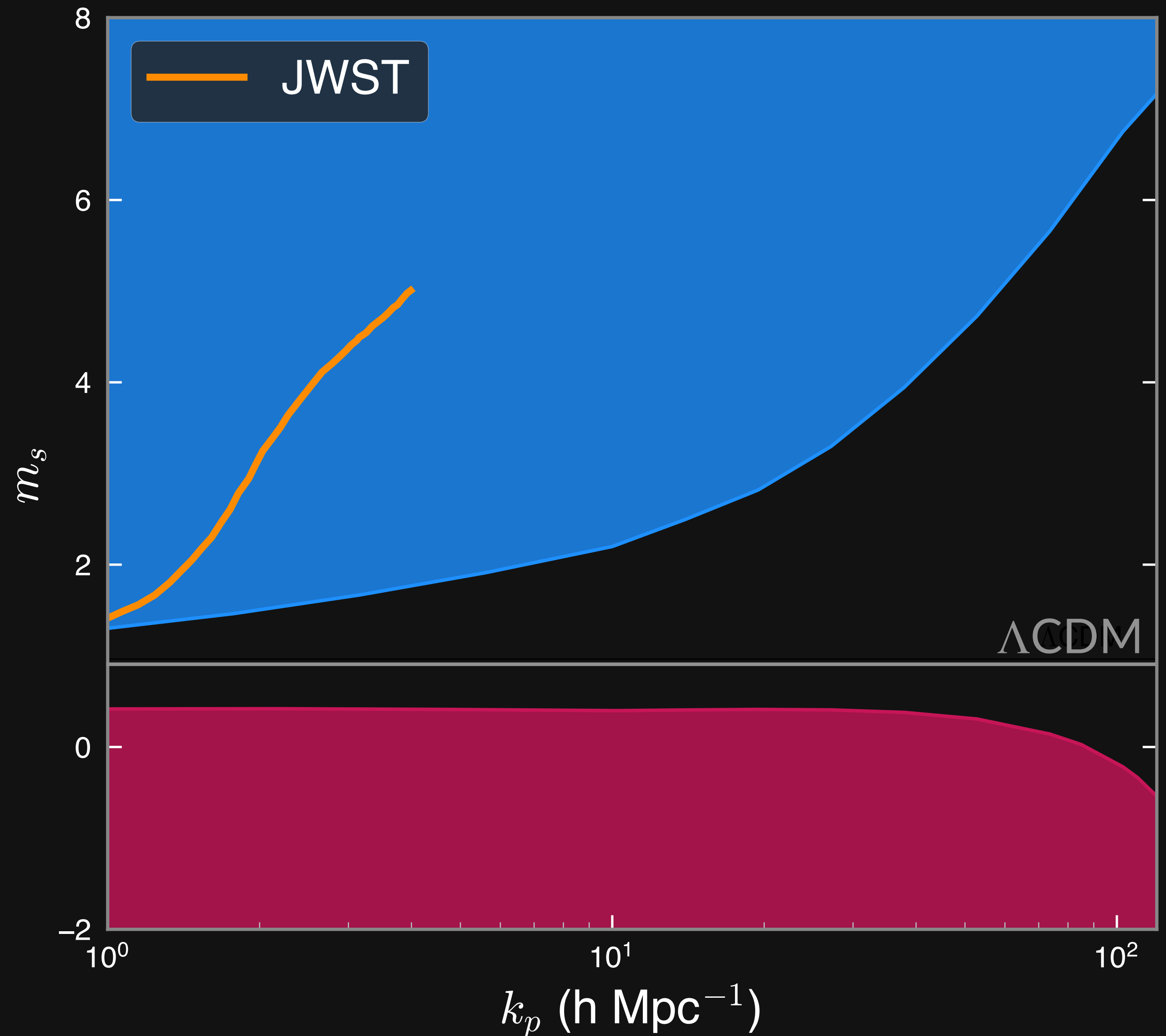


Exclude (m_s, k_p) that deviate too much from Λ CDM at 95% CL

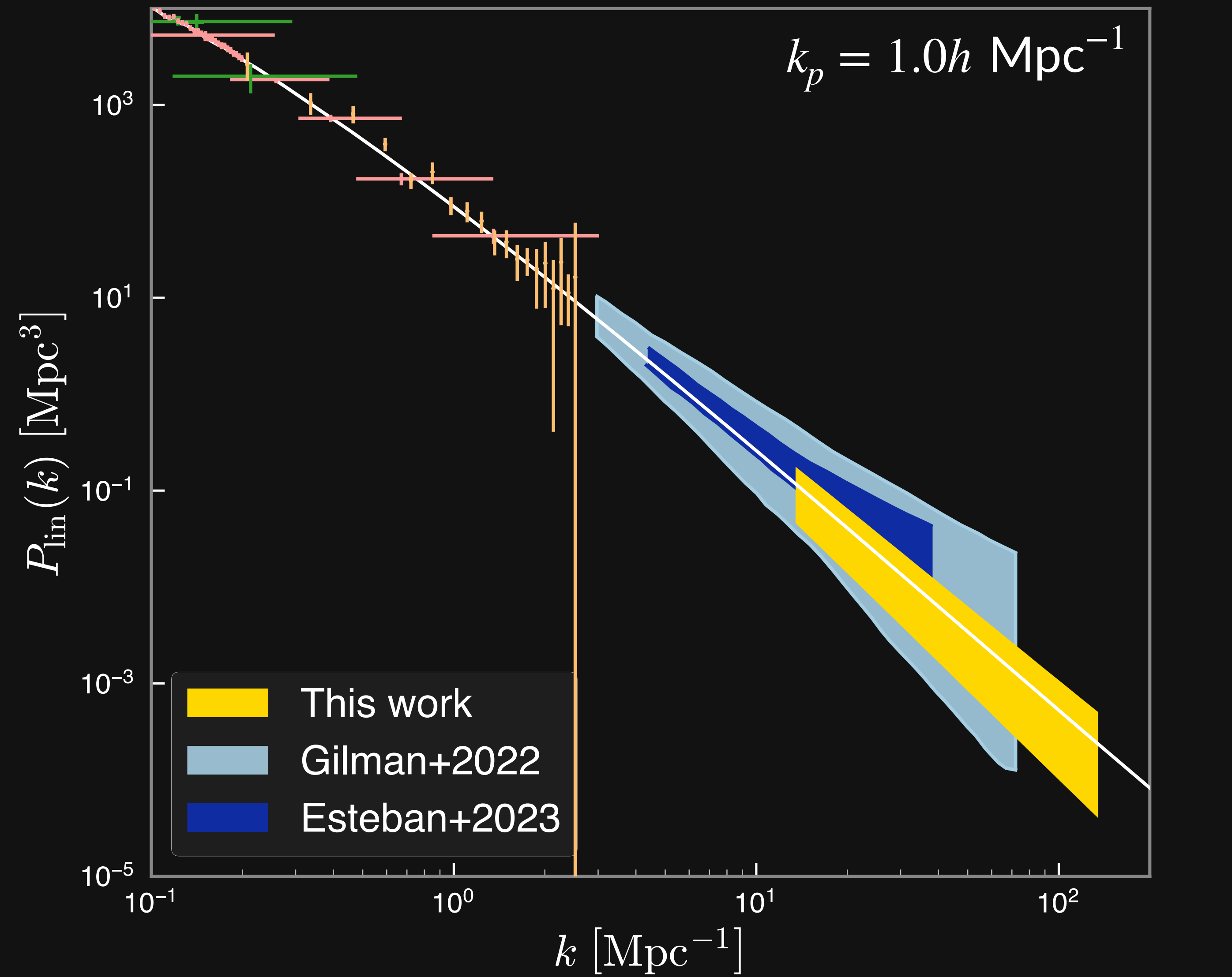


Exclude (m_s, k_p) that deviate too much from Λ CDM at 95% CL

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



Matter power spectrum



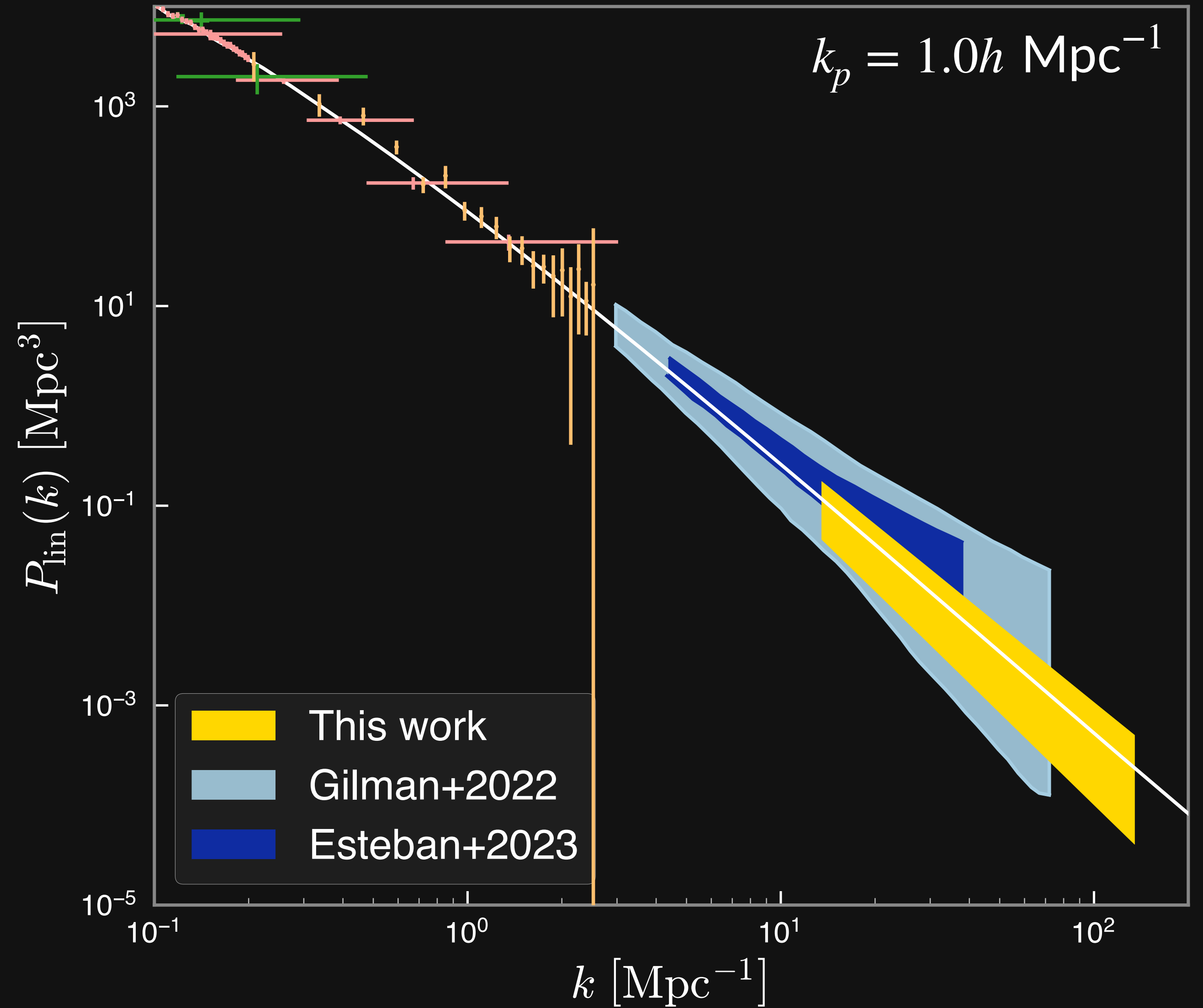
Excluded at 68% CL

Matter power spectrum

Effective wavelength of DM halo concentration

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

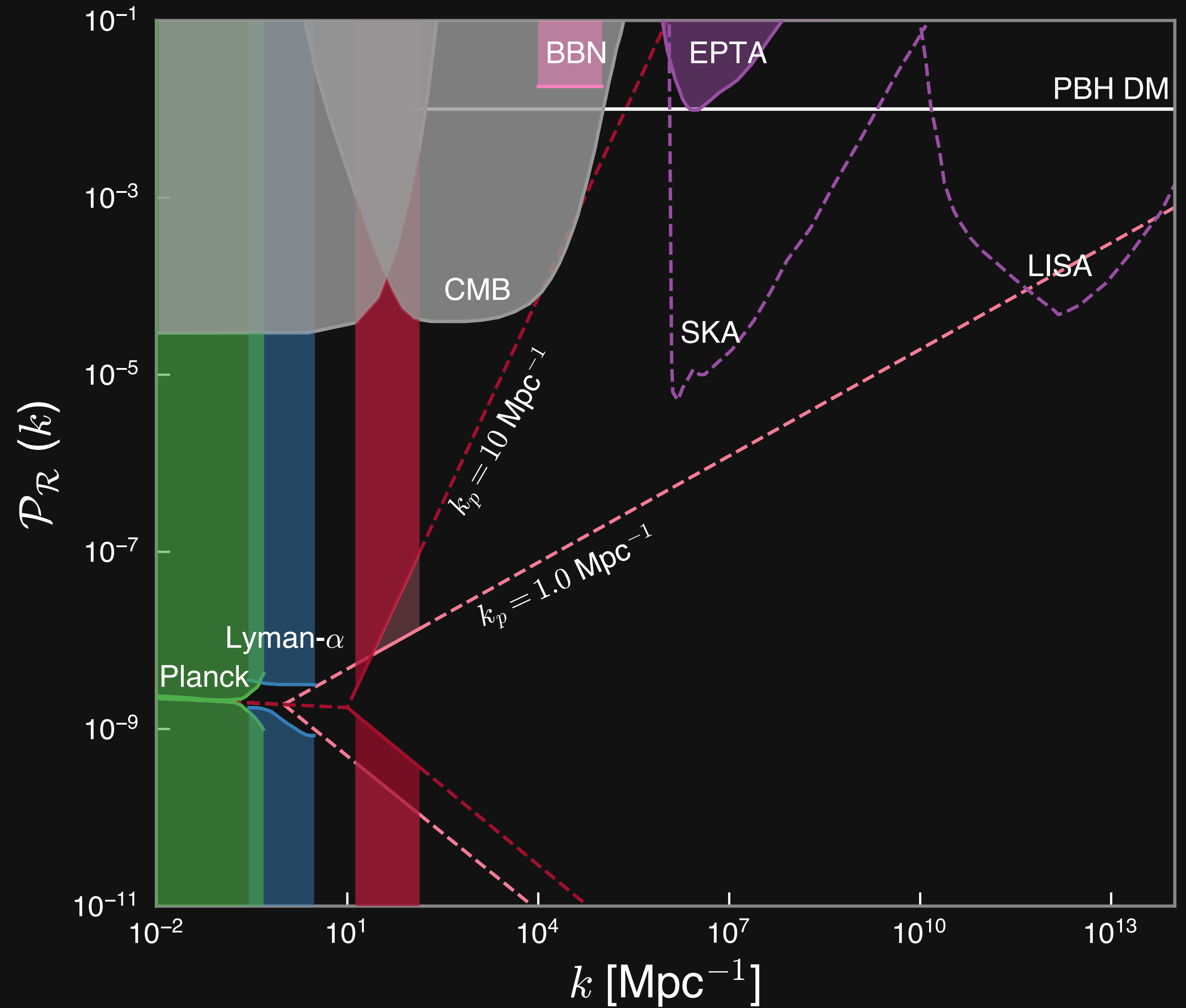
Smallest & largest galaxies in MW corresponds
to $k \sim 130, 13 \text{ Mpc}^{-1}$.



Excluded at 68% CL

Primordial power spectrum

Amplitude of primordial fluctuations

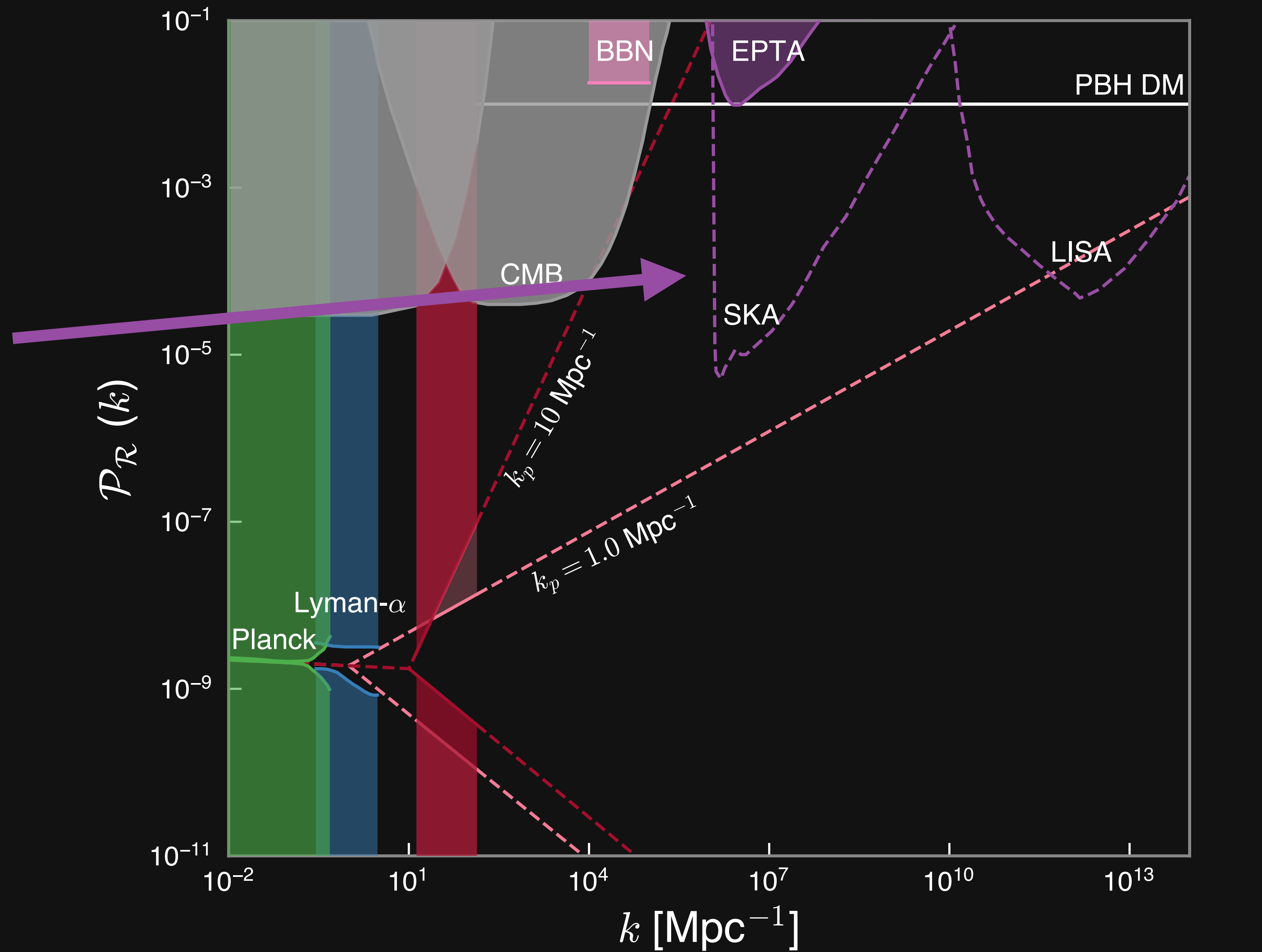


Primordial power spectrum

Significant large primordial fluctuations
can induce GW signal.

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

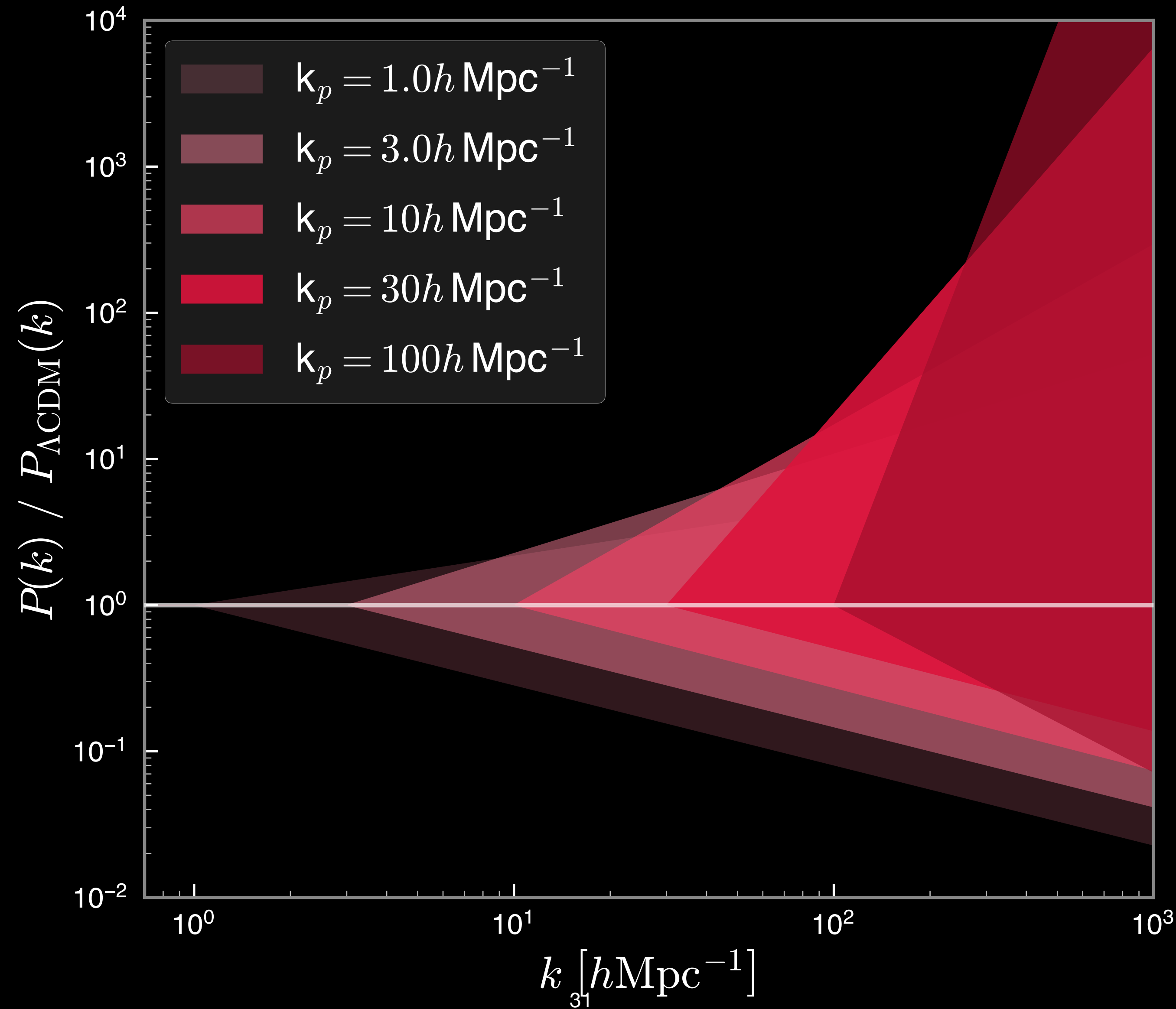
SMBH or blue-tilt?
(Afzal+2023)



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 $13 \text{ Mpc}^{-1} \lesssim k \lesssim 130 \text{ Mpc}^{-1}$.

Matter power spectrum

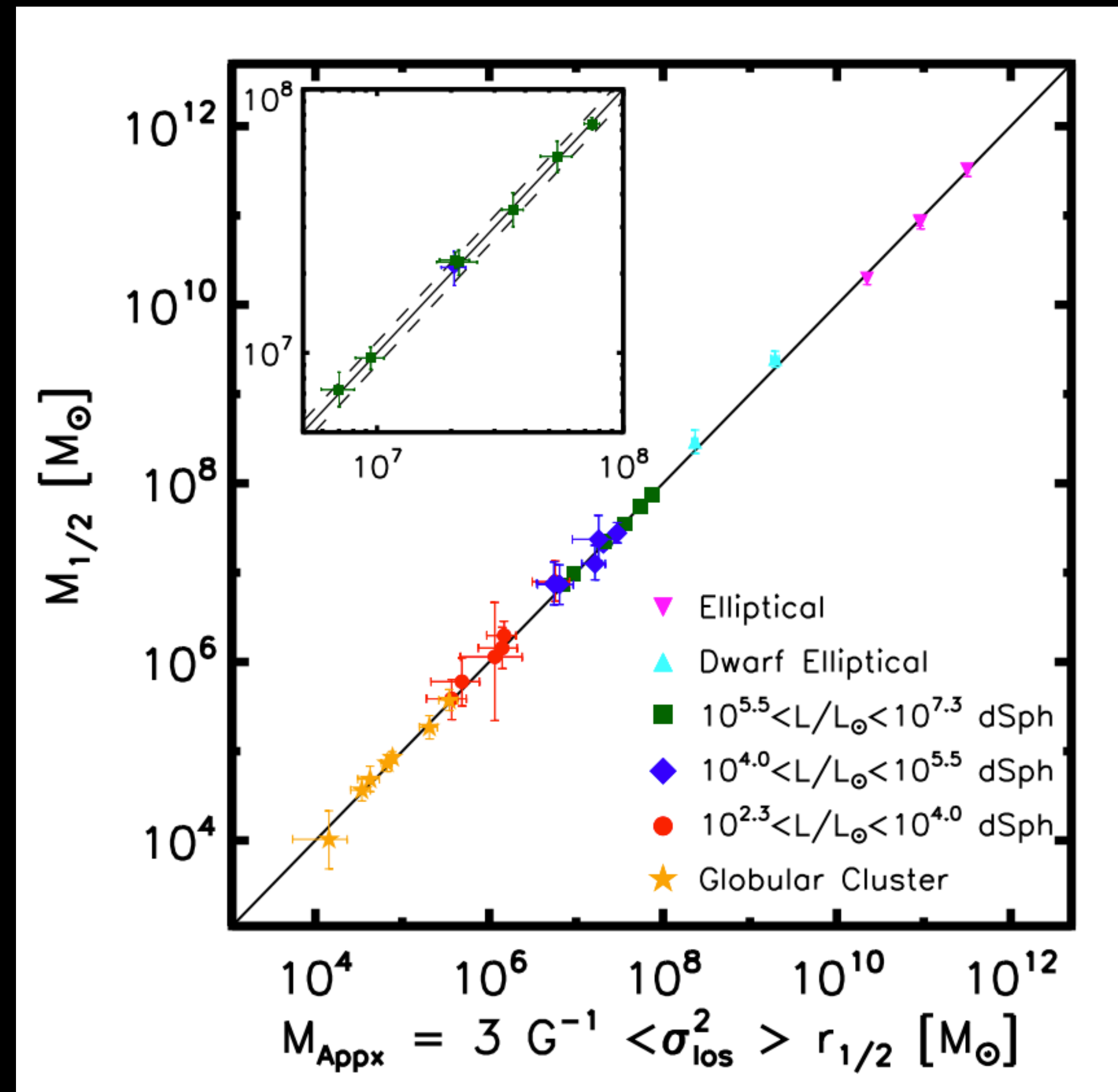


Excluded at 95% CL

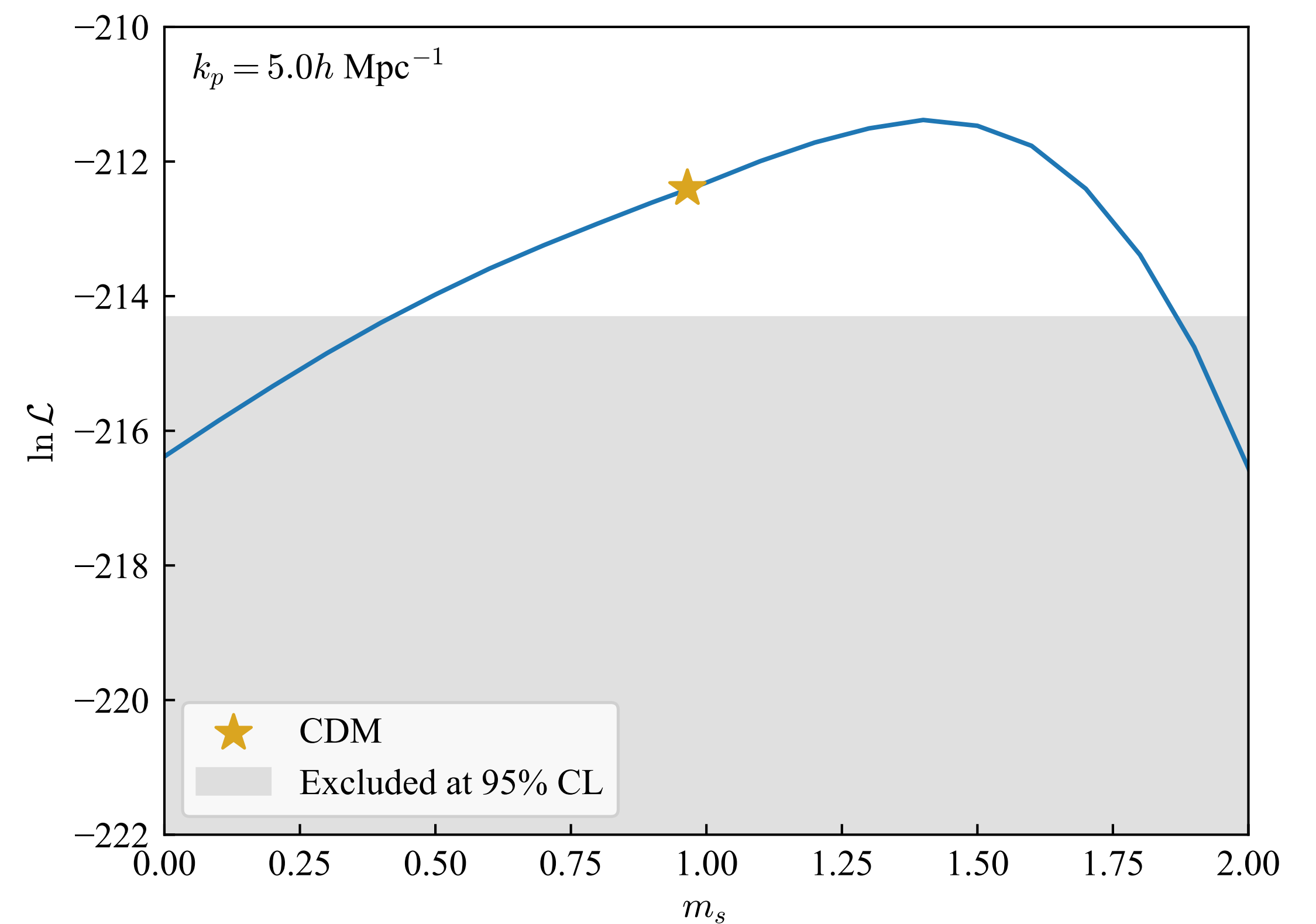
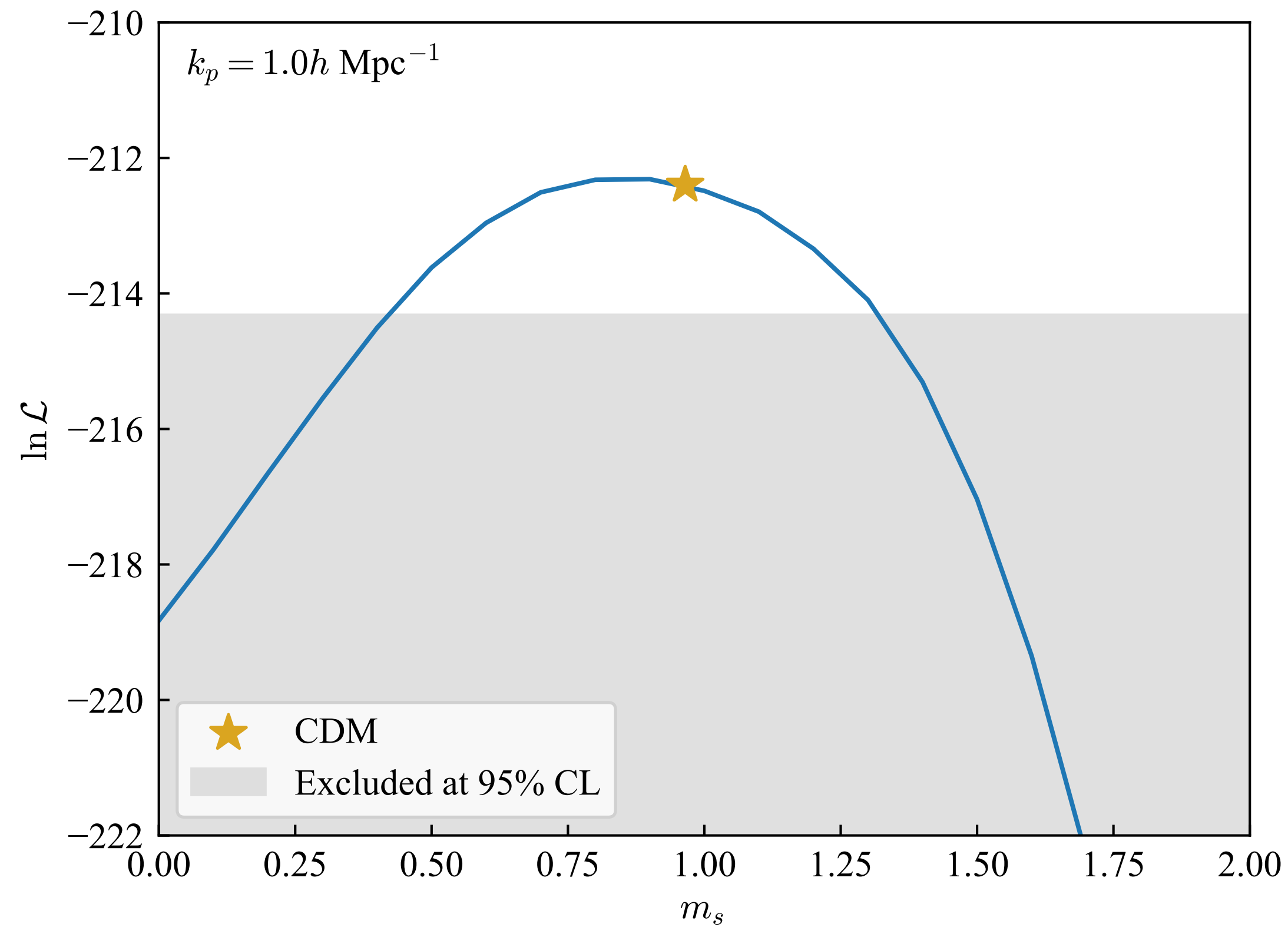
Milky Way satellite galaxy observations

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

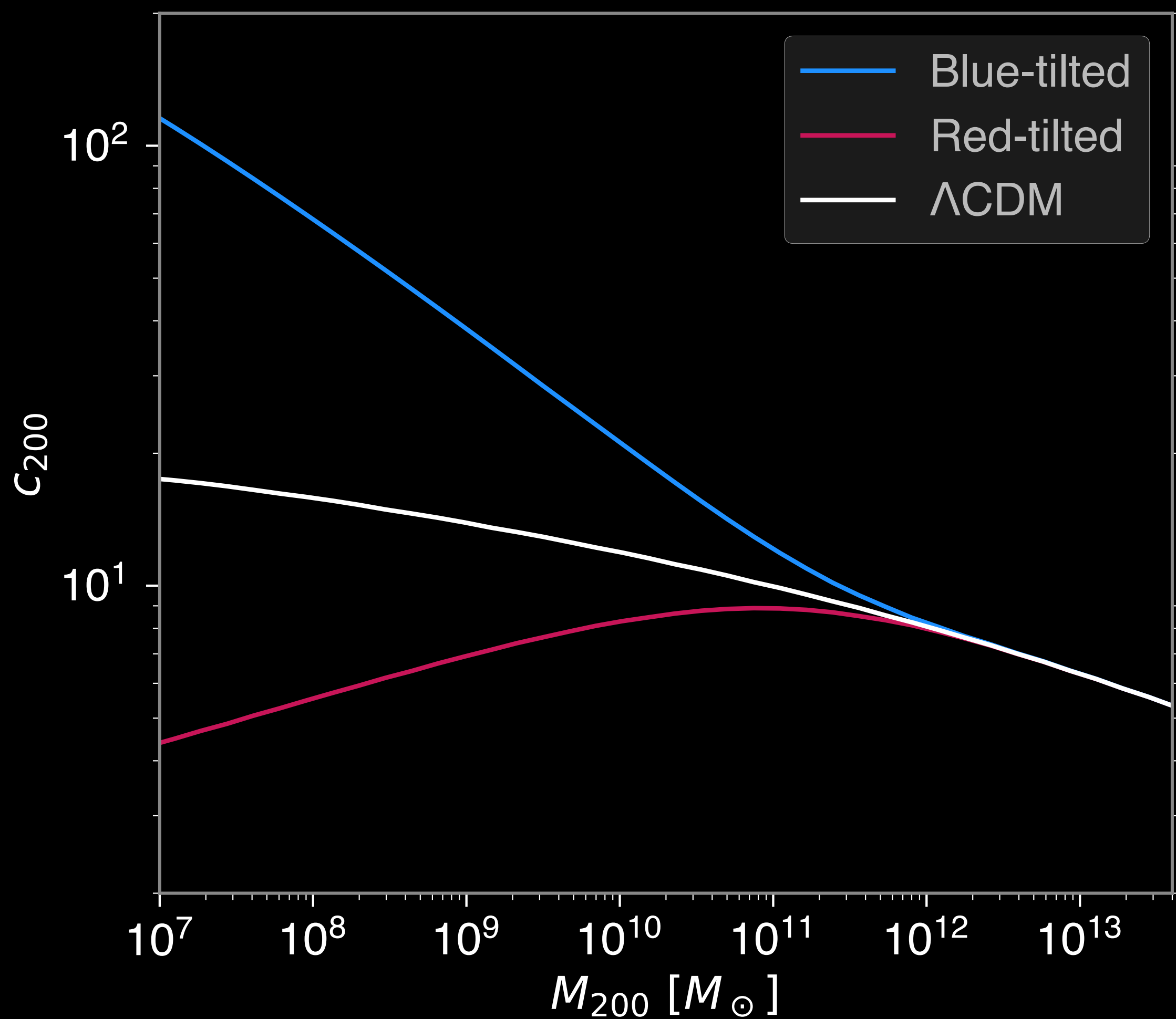
$$M_{tot} = 930 \sigma_{\star, los}^2 R_{1/2} M_{\odot}$$



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



Concentration of dark matter halos



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

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

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 $k \sim 100 \text{ Mpc}^{-1}$

Concentration of dark matter halos

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

