



The interplay between self-interacting dark matter and baryons: the case of cosmological simulations

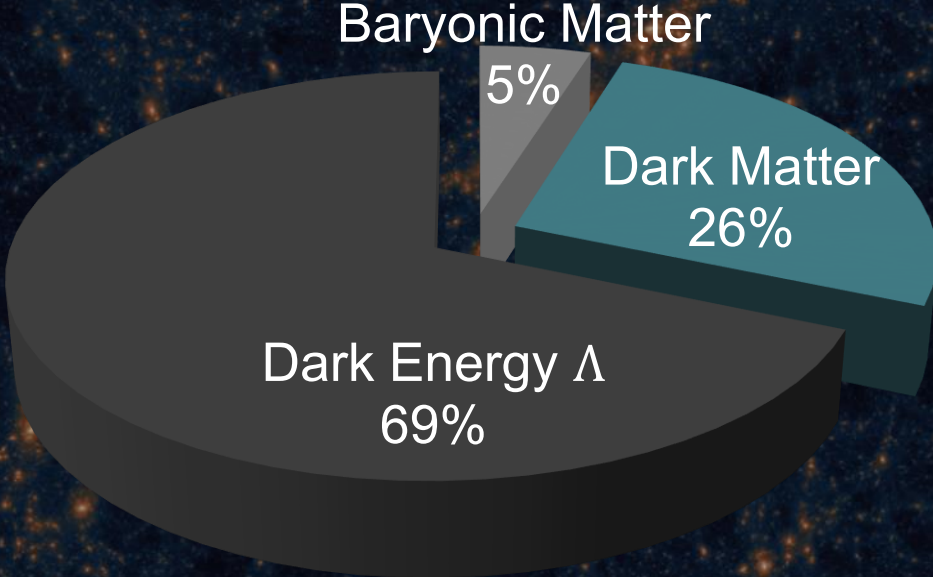
Giovanni Yehoshua Ferron

Collaborators:

A. Ragagnin, L. Pizzuti, M. S. Fischer, G. Bordogna

Dark matter and structure formation

Λ CDM



Dark matter and structure formation

Λ CDM

Baryonic Matter

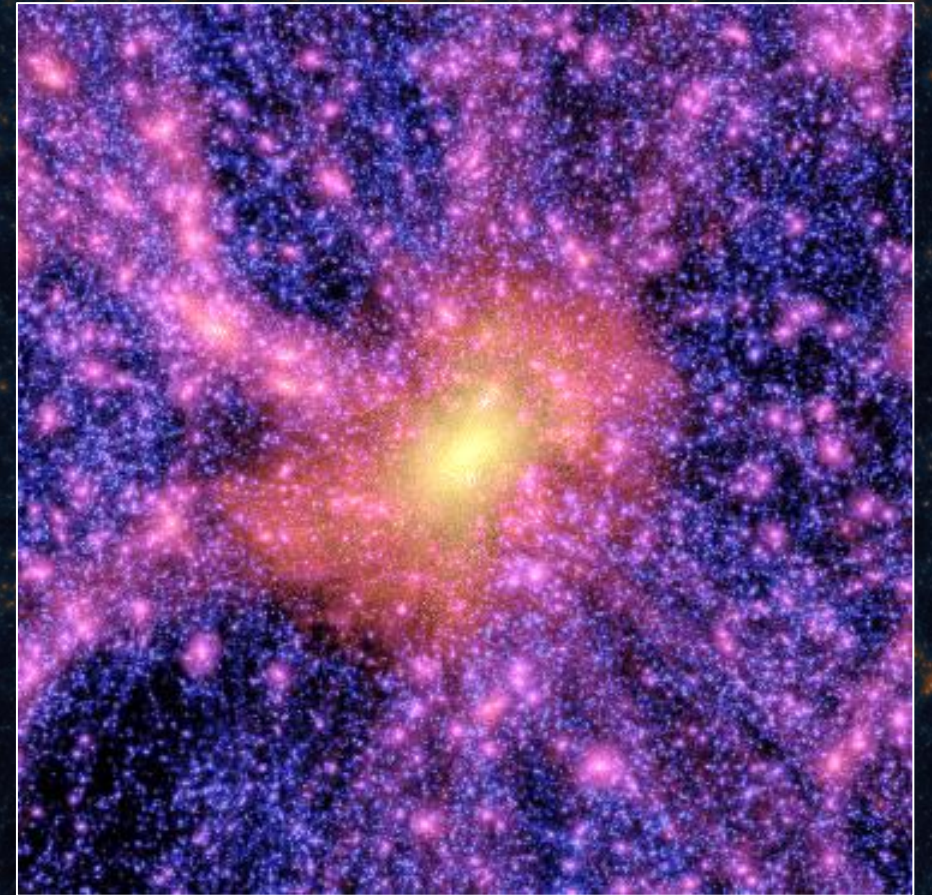
5%

Dark Matter
26%

Dark Energy Λ
69%



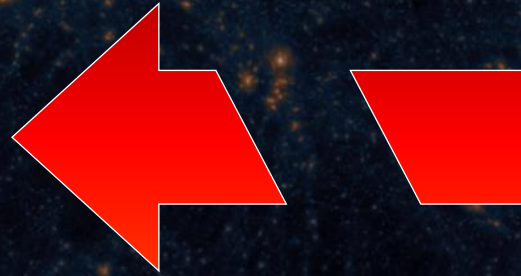
CDM halos



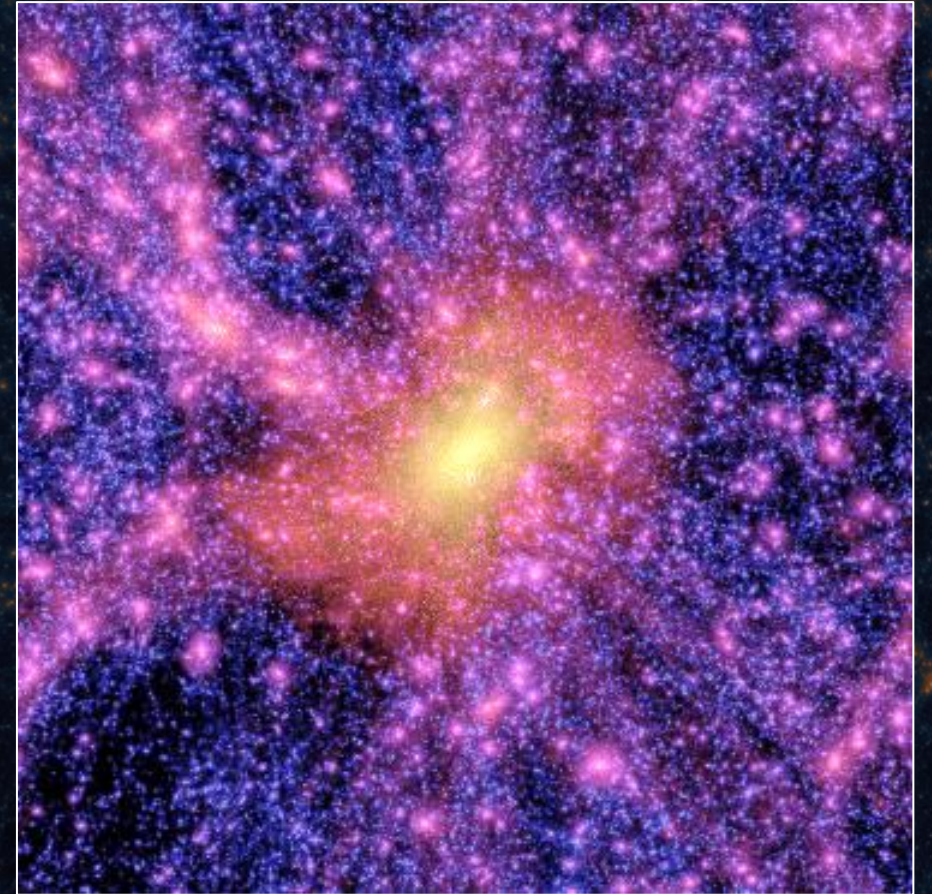
Biermann et al. 2012

Dark matter and structure formation

- Core-cusp problem
- Missing satellites
- Nature of dark matter



CDM halos



Biermann et al. 2012

Self-interacting dark matter

- Core-cusp problem
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**Self-interacting
dark matter
(SIDM)**

Aims of this work

How does SIDM affect the dark matter distribution inside of simulated galaxy groups and clusters?

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Can cluster weak lensing and kinematic mass reconstructions allow for detection of SIDM in view of future optical survey data (e.g. Euclid, DESI)?

Aims of this work

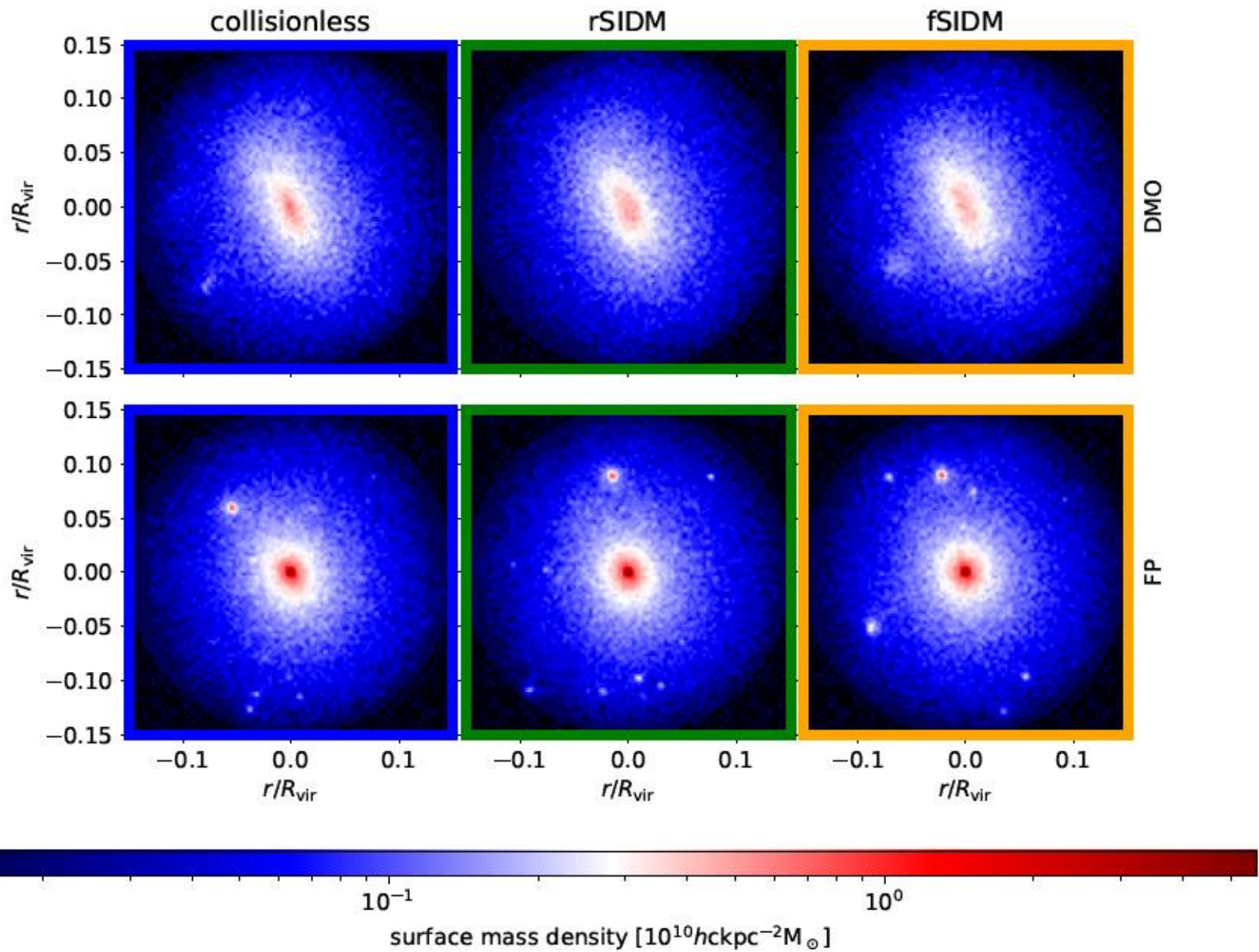
How does SIDM affect the dark matter distribution inside of simulated galaxy groups and clusters?

Can cluster weak lensing and kinematics mass reconstructions allow for detection of SIDM in view of future optical survey data (e.g. Euclid, DESI)?

Extract halo profiles from **dark-matter-only (DMO) and full-physics (FP) SIDM simulations** and compare with real kinematic data

The DIANOGA-SIDM simulation suite (Ragagnin et al. 2024)

Simulations of galaxy clusters in SIDM at $z = 0.4$



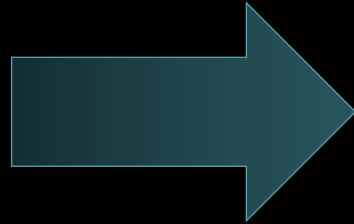
region	$M_{\text{vir}} [10^{14} h^{-1} M_{\odot}]$
D3	4.8
D4	2.7
D5	1.2
D10	11.2
D15	11.5
D16	12.3

Ragagnin et al. 2024

SIDM angular dependence: rare SIDM and frequent SIDM

Interaction through Yukawa potential:

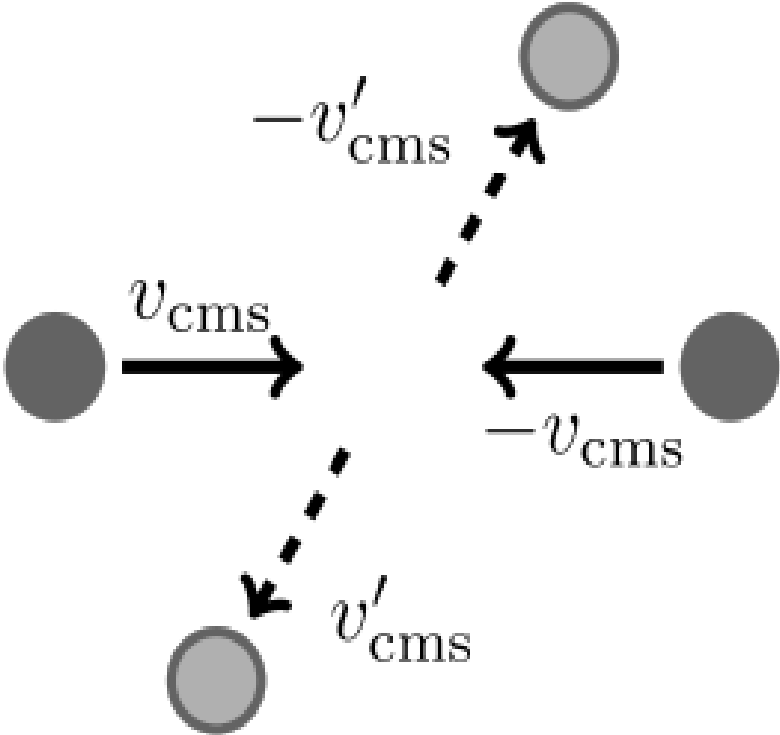
$$V(r) = -\frac{\alpha_{\text{DM}}}{r} e^{-m_\phi r}$$



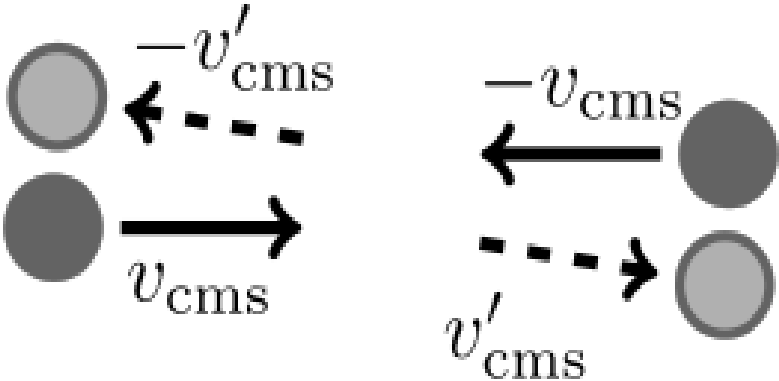
$$\frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\Omega}(\theta, v_{\text{rel}})$$

SIDM angular dependence: rare SIDM and frequent SIDM

Large-angle scattering



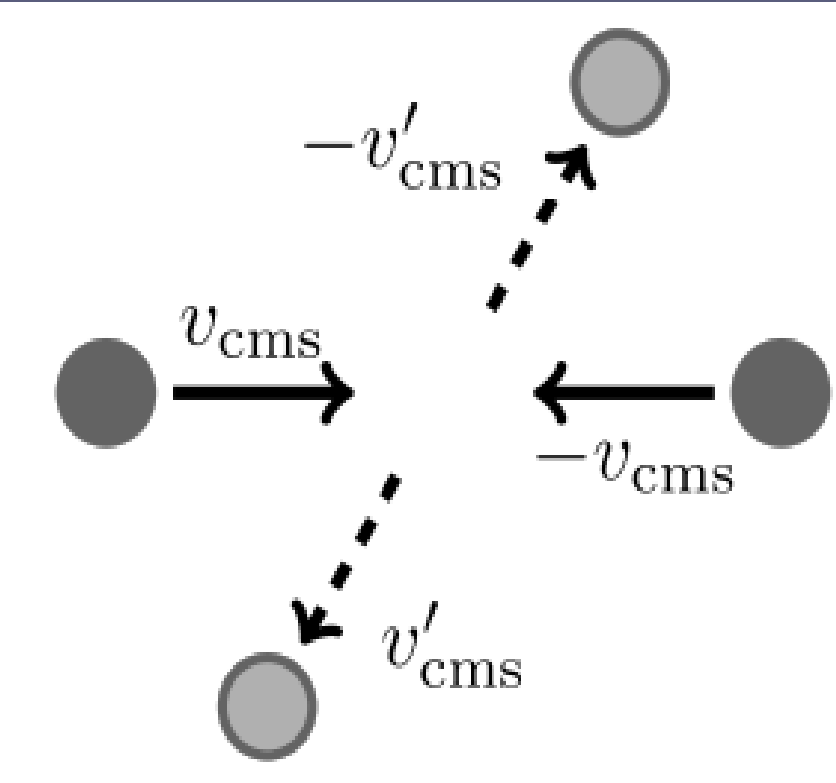
Small-angle scattering



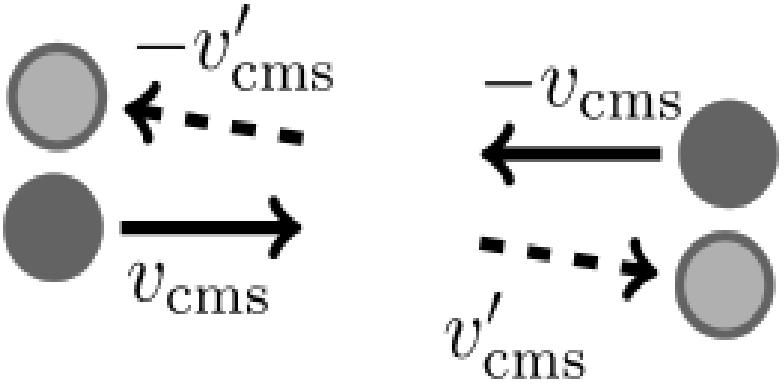
M. S. Fischer – SIDM workshop 2023

SIDM angular dependence: rare SIDM and frequent SIDM

Large-angle scattering



Small-angle scattering

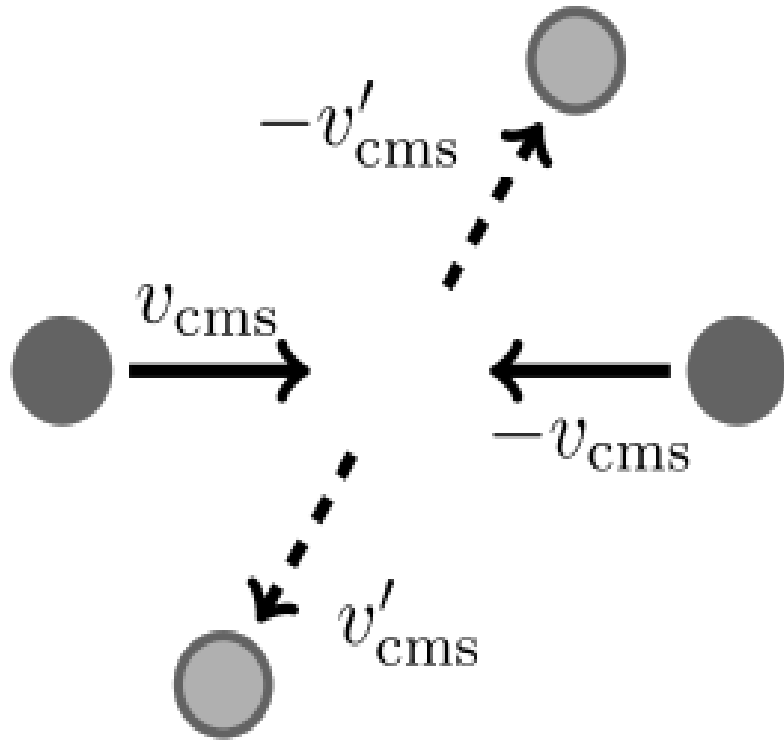


M. S. Fischer – SIDM workshop 2023

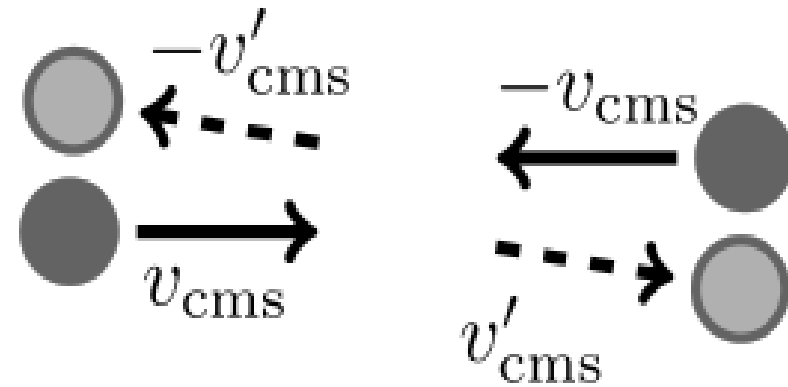
rSIDM (large angle):
low DM collision rate

SIDM angular dependence: rare SIDM and frequent SIDM

Large-angle scattering



Small-angle scattering

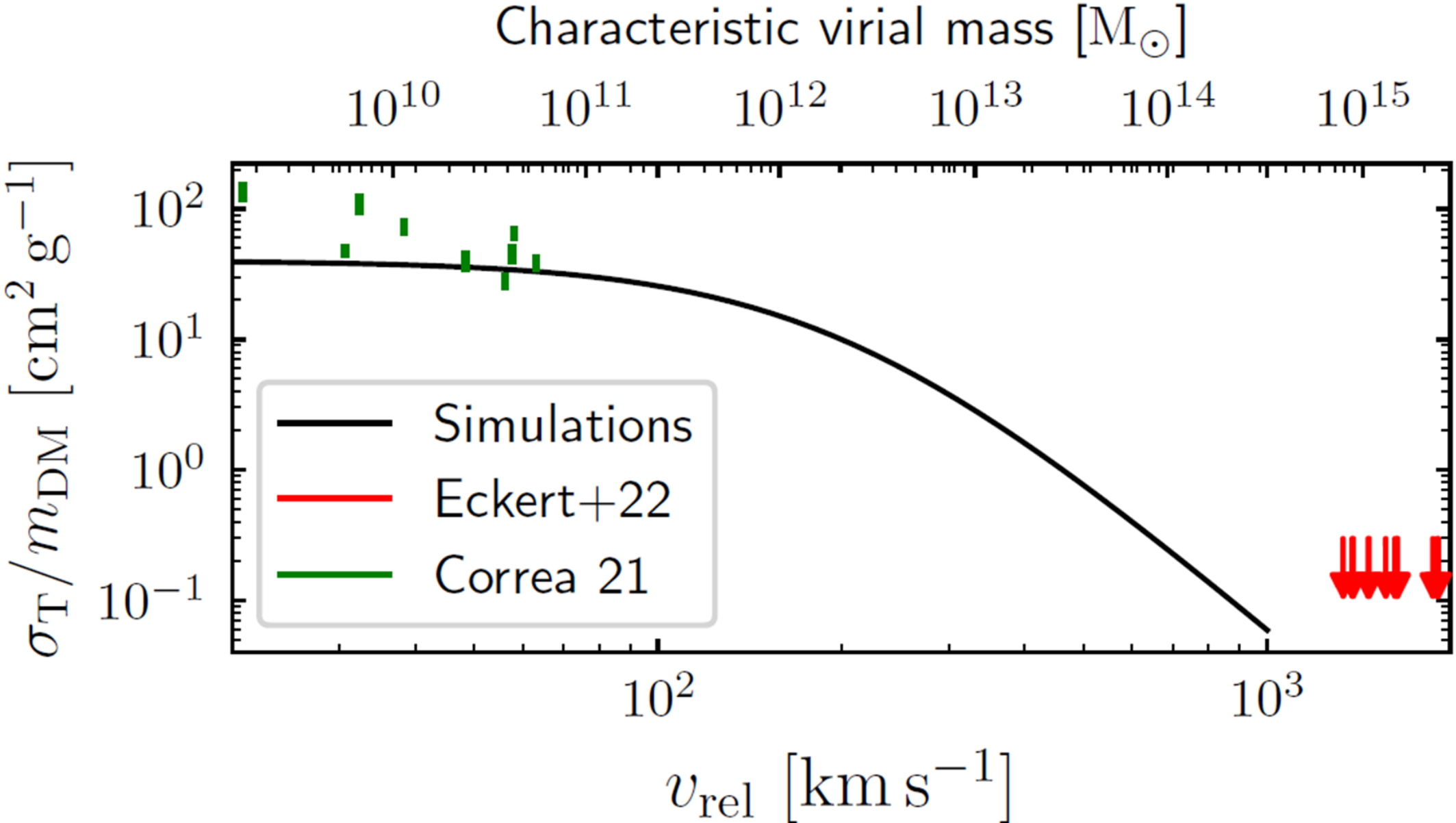


M. S. Fischer – SIDM workshop 2023

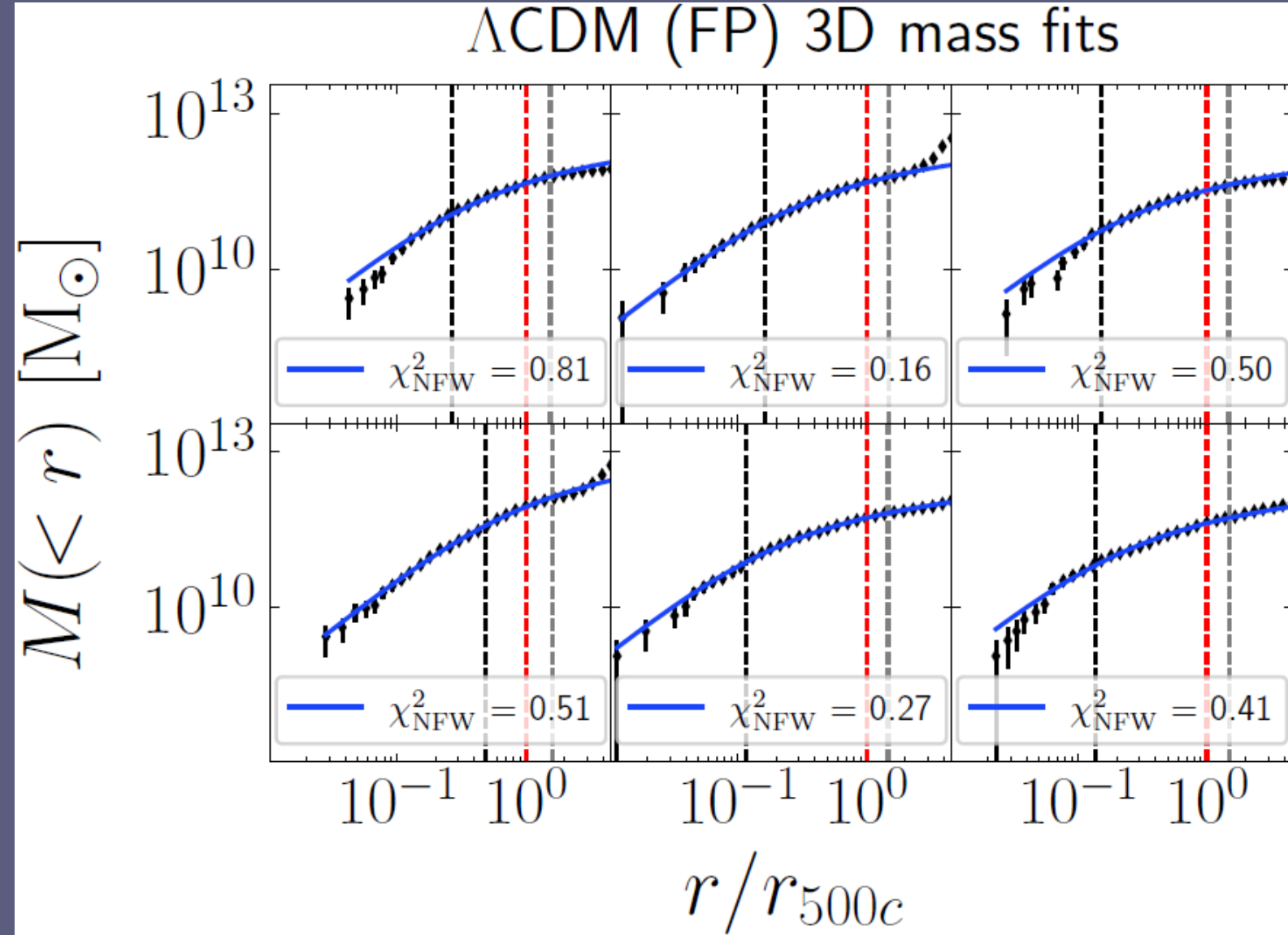
rSIDM (large angle):
low DM collision rate

fSIDM (small angle):
high DM collision rate

SIDM velocity dependence



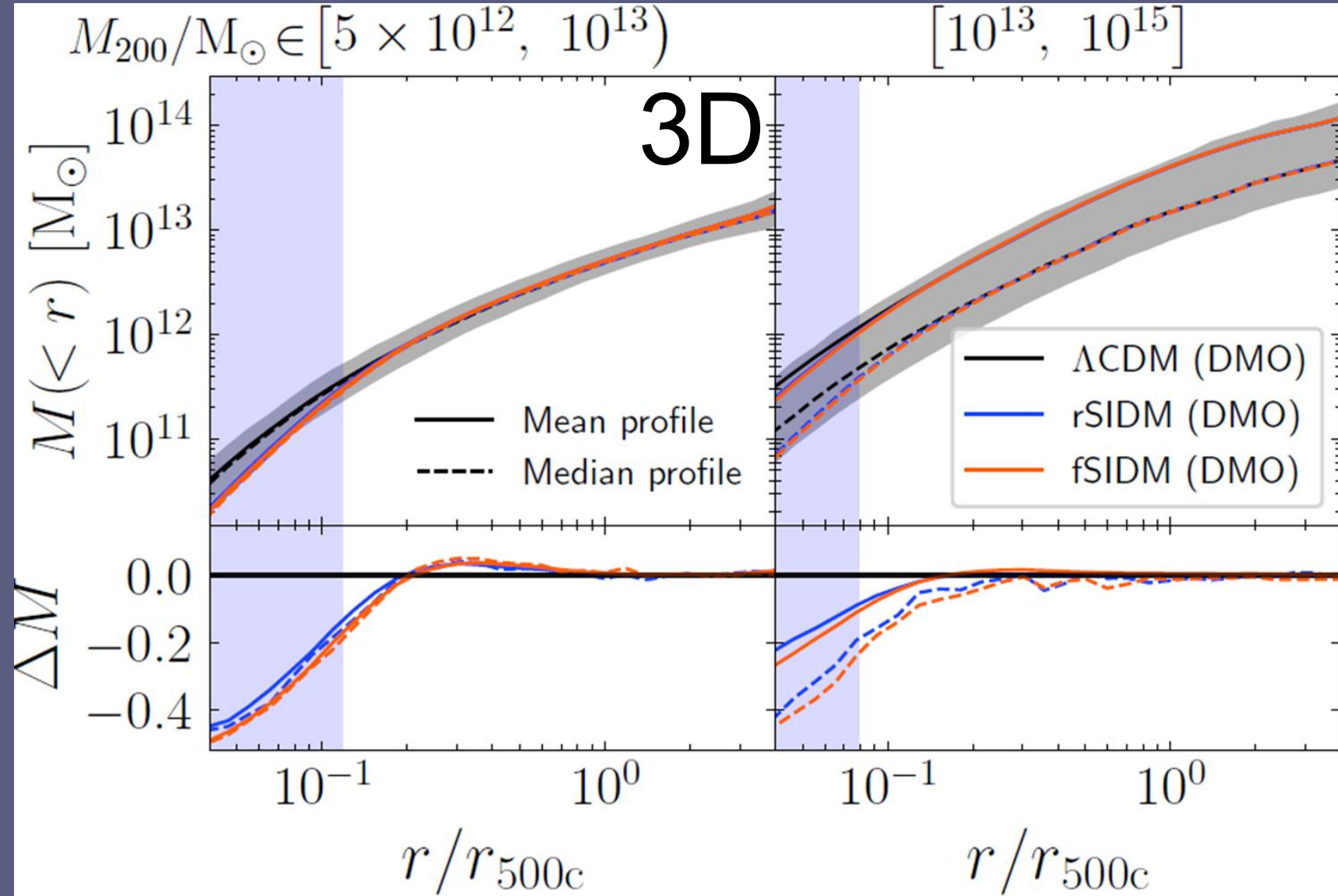
Fits 3D and 2D halo mass and density profiles using NFW model:



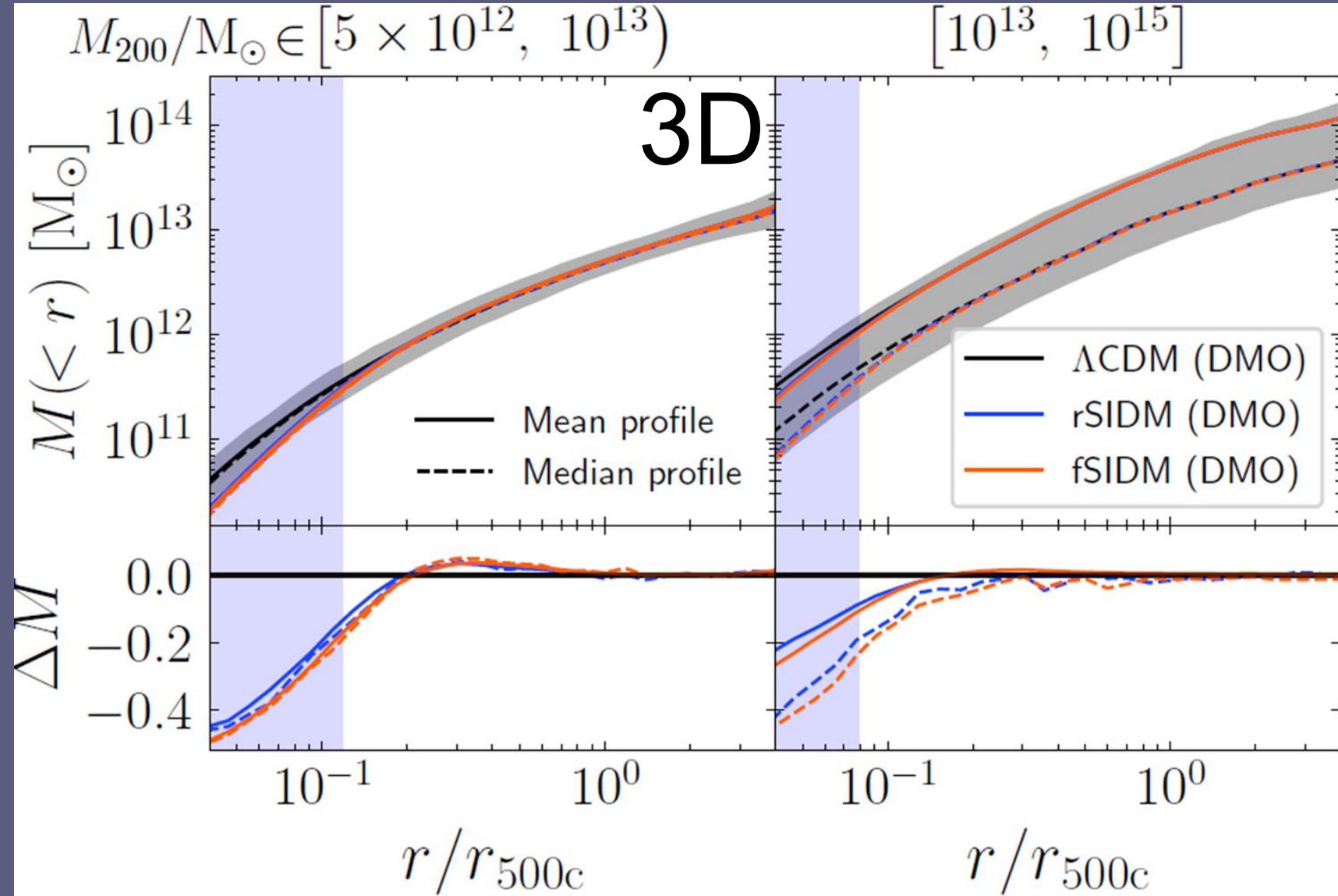
$$\rho_{\text{NFW}}(x) = \frac{\rho_0}{x(1+x)^2}$$

$$x \equiv \frac{r}{r_s}$$

Example of 3D NFW mass fits of random CDM halos



Stacking analysis of 3D and 2D halo profiles: statistically robust estimators of SIDM effects

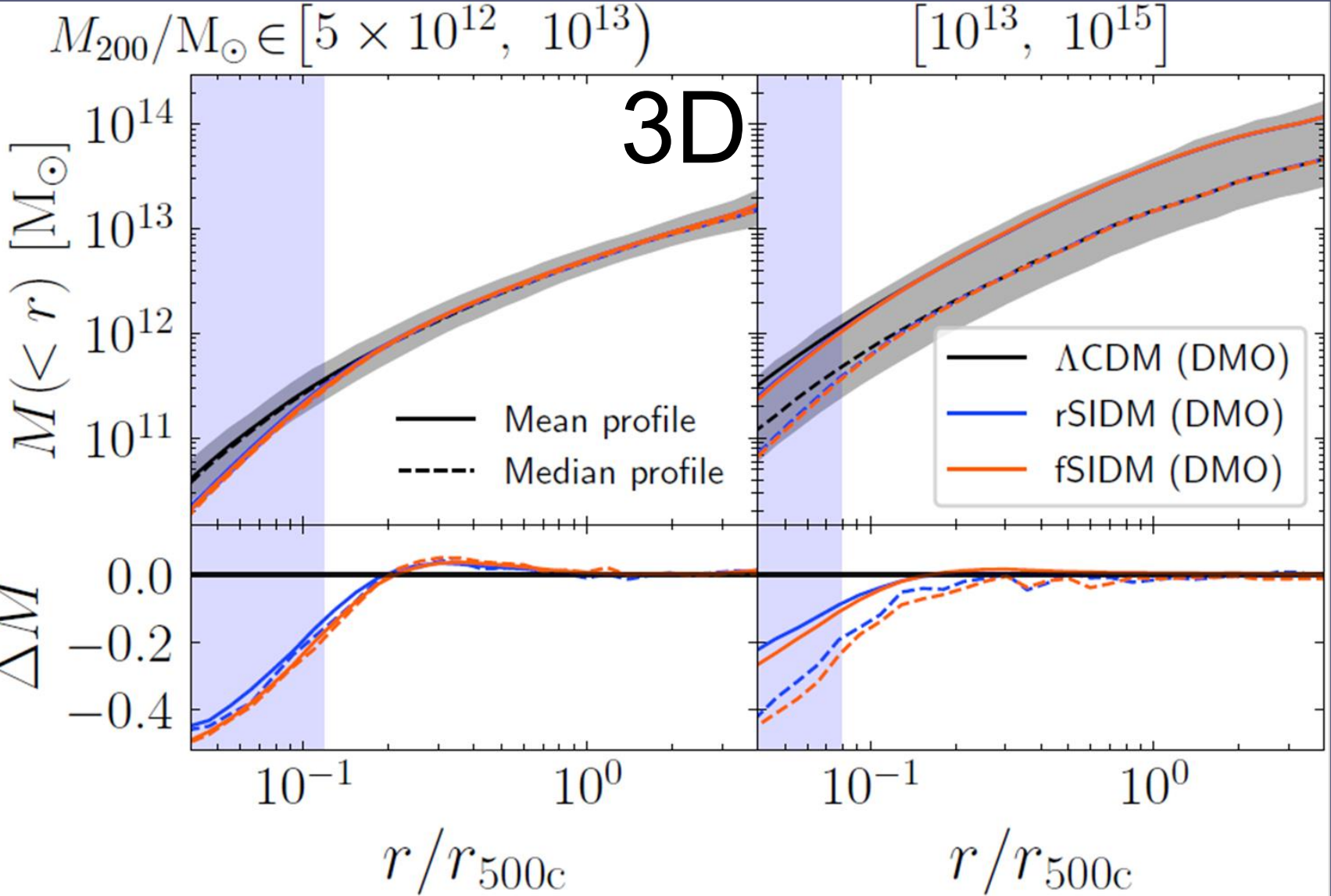


Shaded regions are Λ CDM 68% uncertainties

Stacking analysis of 3D and 2D halo profiles: statistically robust estimators of SIDM effects

Resolution limit: profiles are only resolved above convergence radius (Power et al. 2003)

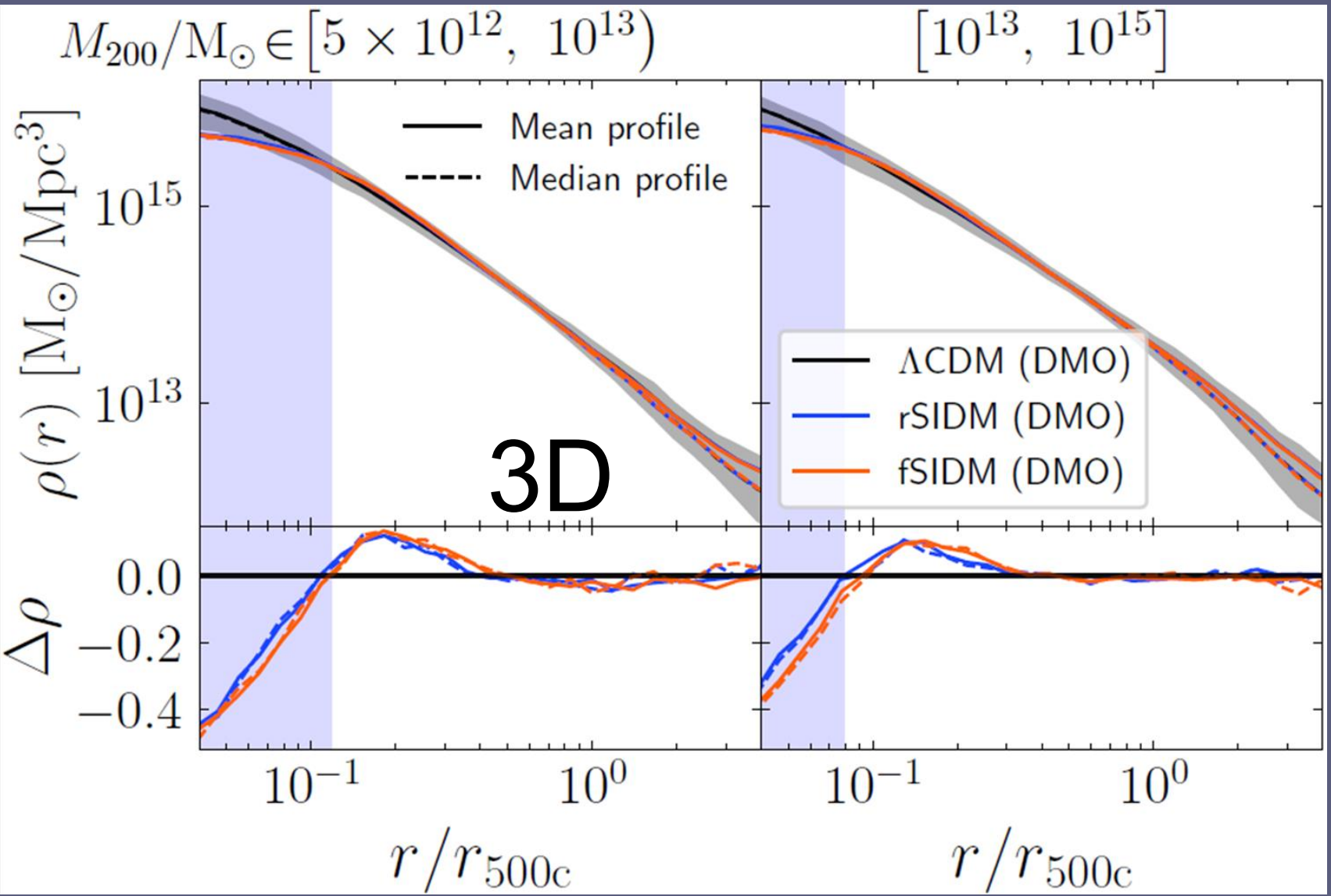
3D mass and density profiles: DMO



Flattened cores
in DMO SIDM
profiles

Shaded regions are Λ CDM 68% uncertainties

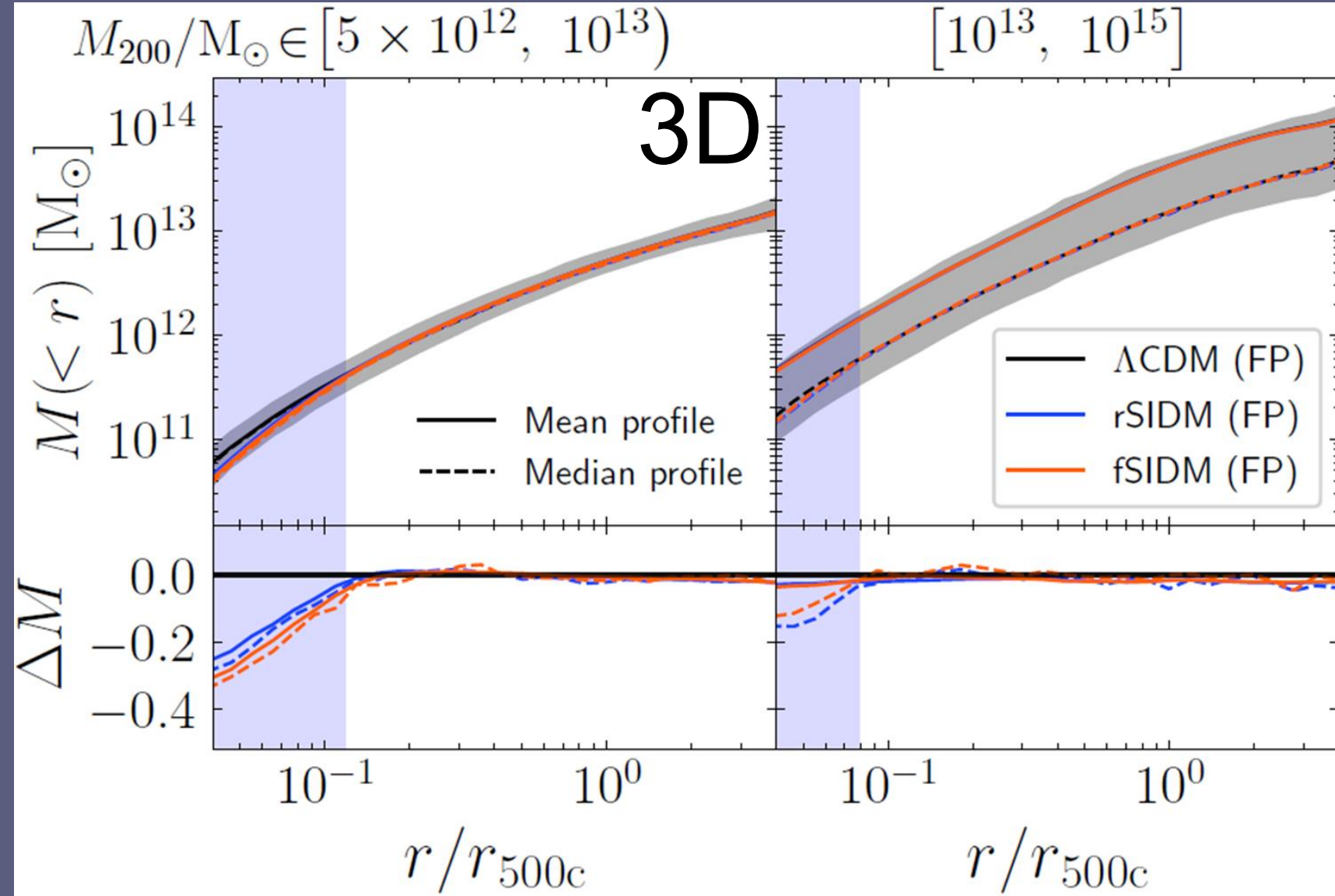
3D mass and density profiles: DMO



Shaded regions are ΛCDM 68% uncertainties

Flattened cores
in DMO SIDM
profiles

3D mass and density profiles: FP



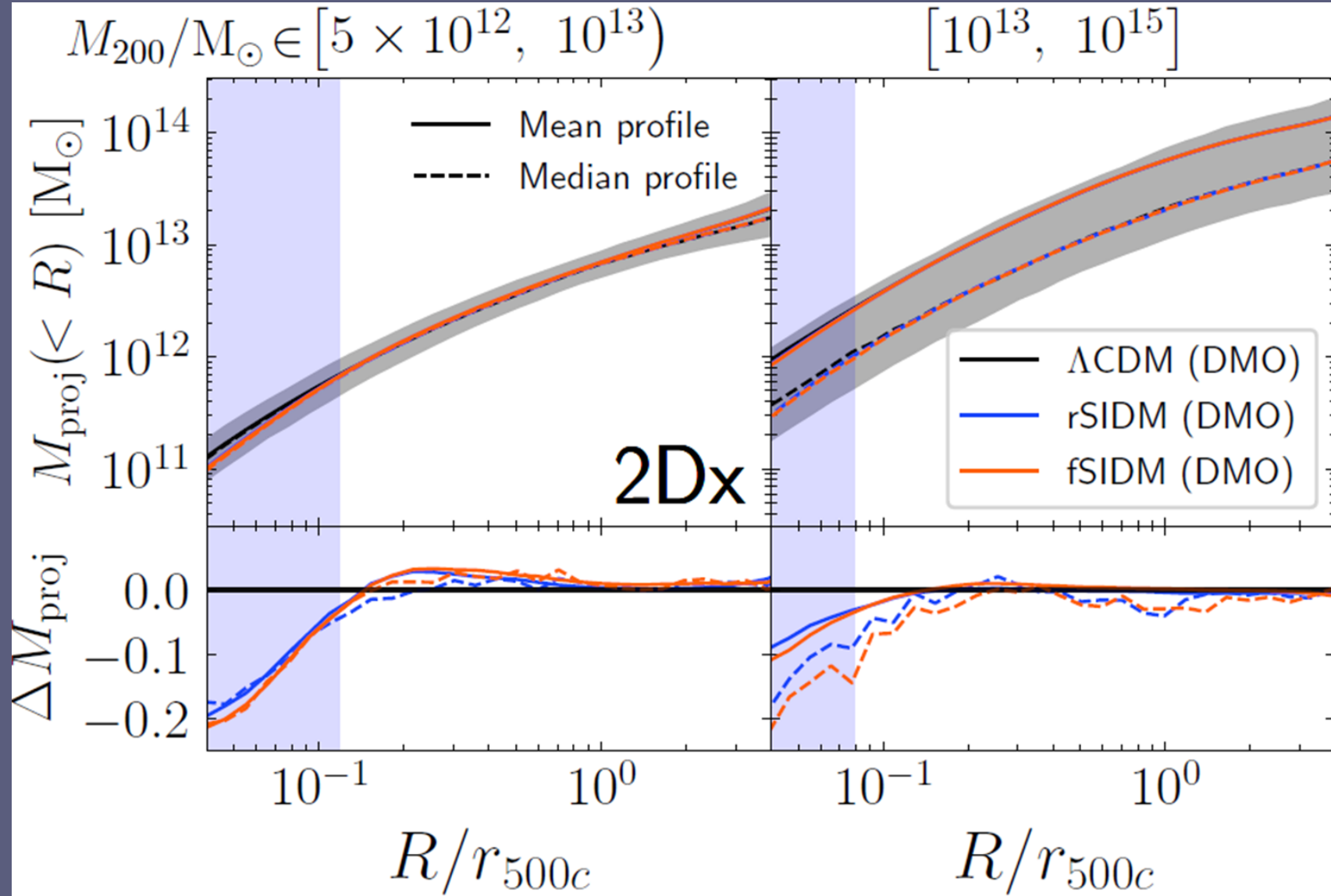
Shaded regions are Λ CDM 68% uncertainties

Flattened cores
in DMO SIDM
profiles

Baryons heavily
suppress SIDM
core formation

Projected mass and density profiles: DMO

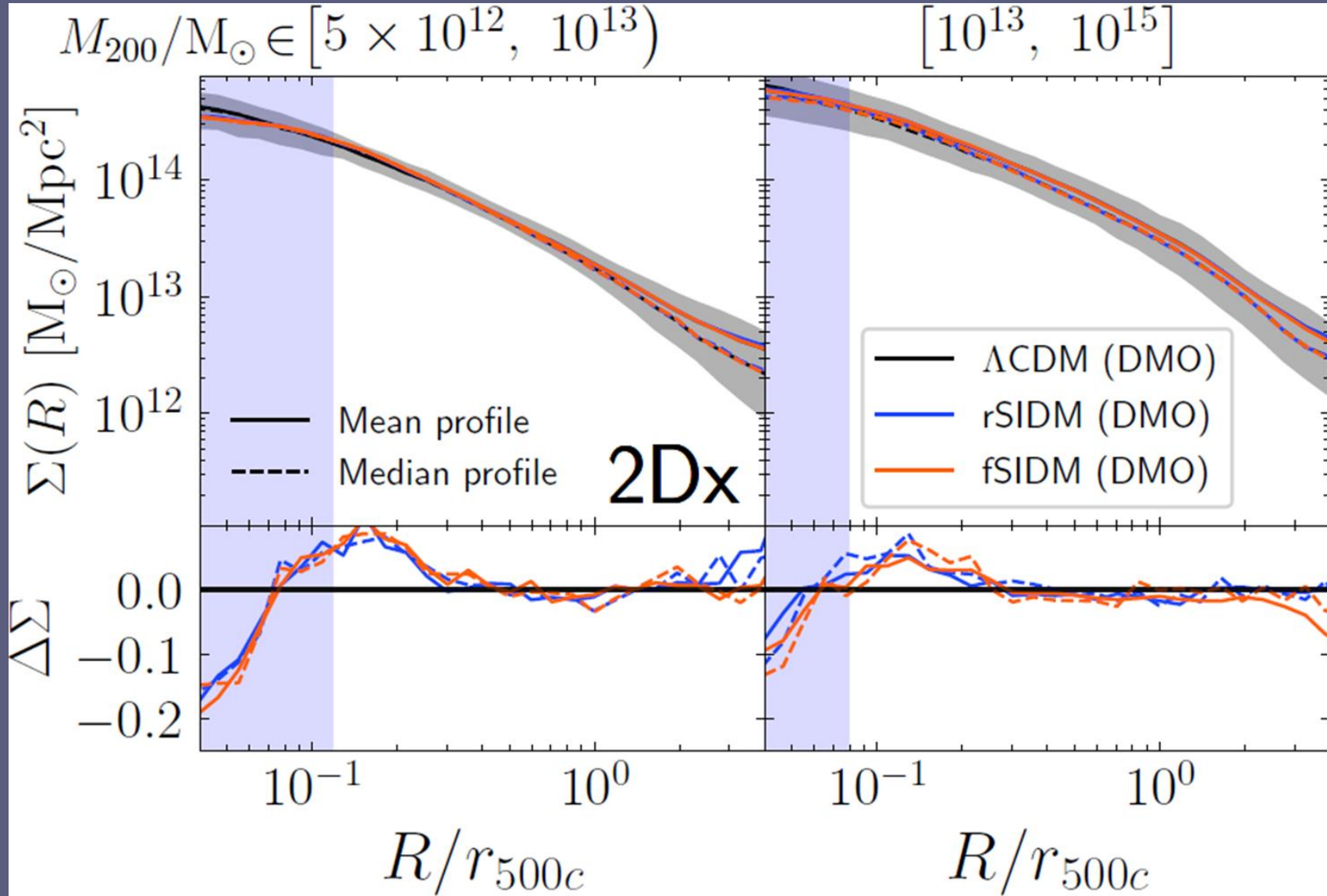
Projection also suppresses SIDM effects



Shaded regions are Λ CDM 68% uncertainties

Projected mass and density profiles: DMO

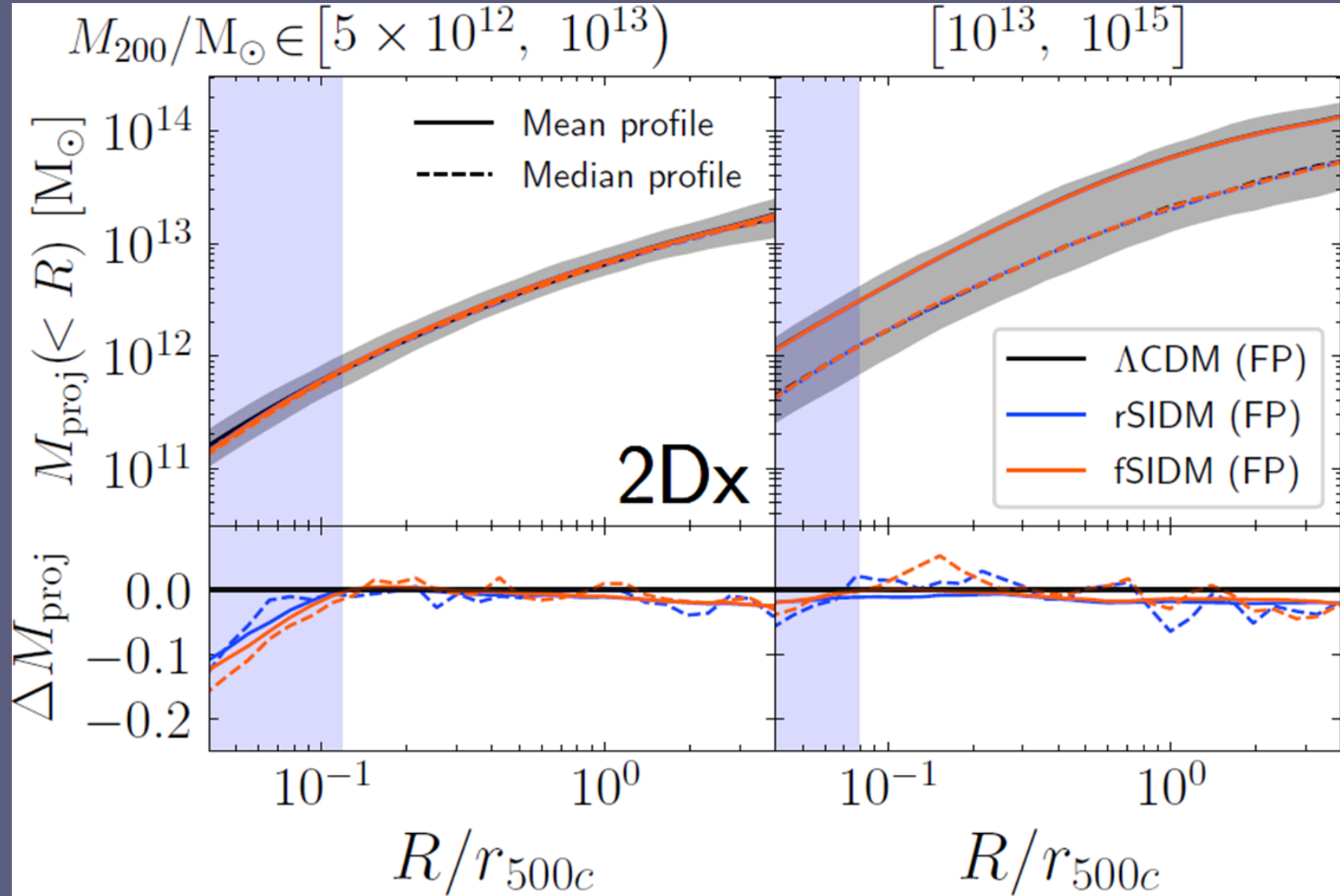
Projection also suppresses SIDM effects



Shaded regions are ΛCDM 68% uncertainties

Projected mass and density profiles: FP

Very small effects
when baryons +
projection
($< 5\%$)



Shaded regions are ΛCDM 68% uncertainties

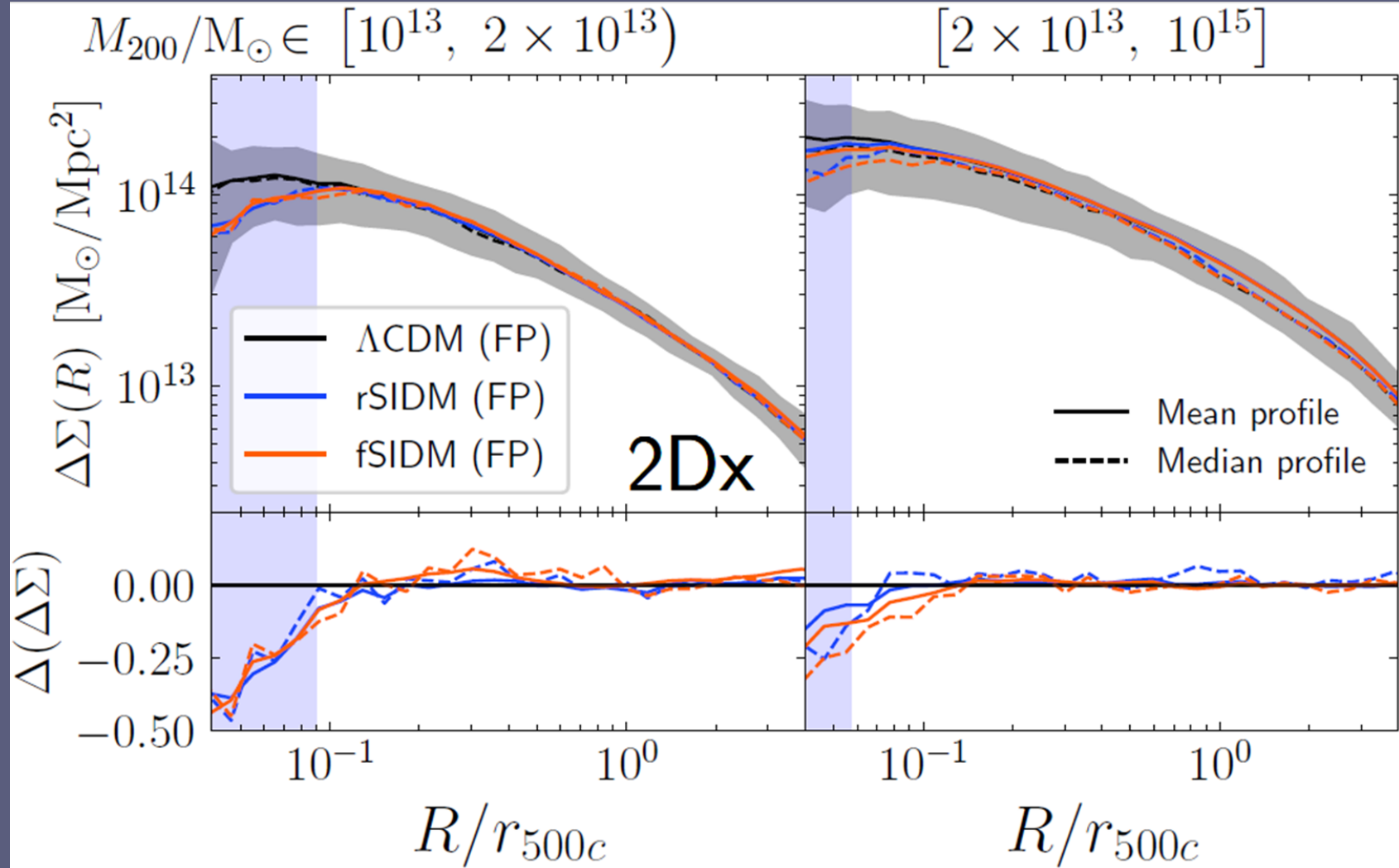
Surface density excess $\Delta\Sigma$

Proportional to halo weak lensing tangential shear

Surface density excess $\Delta\Sigma$

Proportional to halo weak lensing tangential shear

Greater SIDM effects than 2D mass and density profiles ($\sim 10\% - 20\%$)



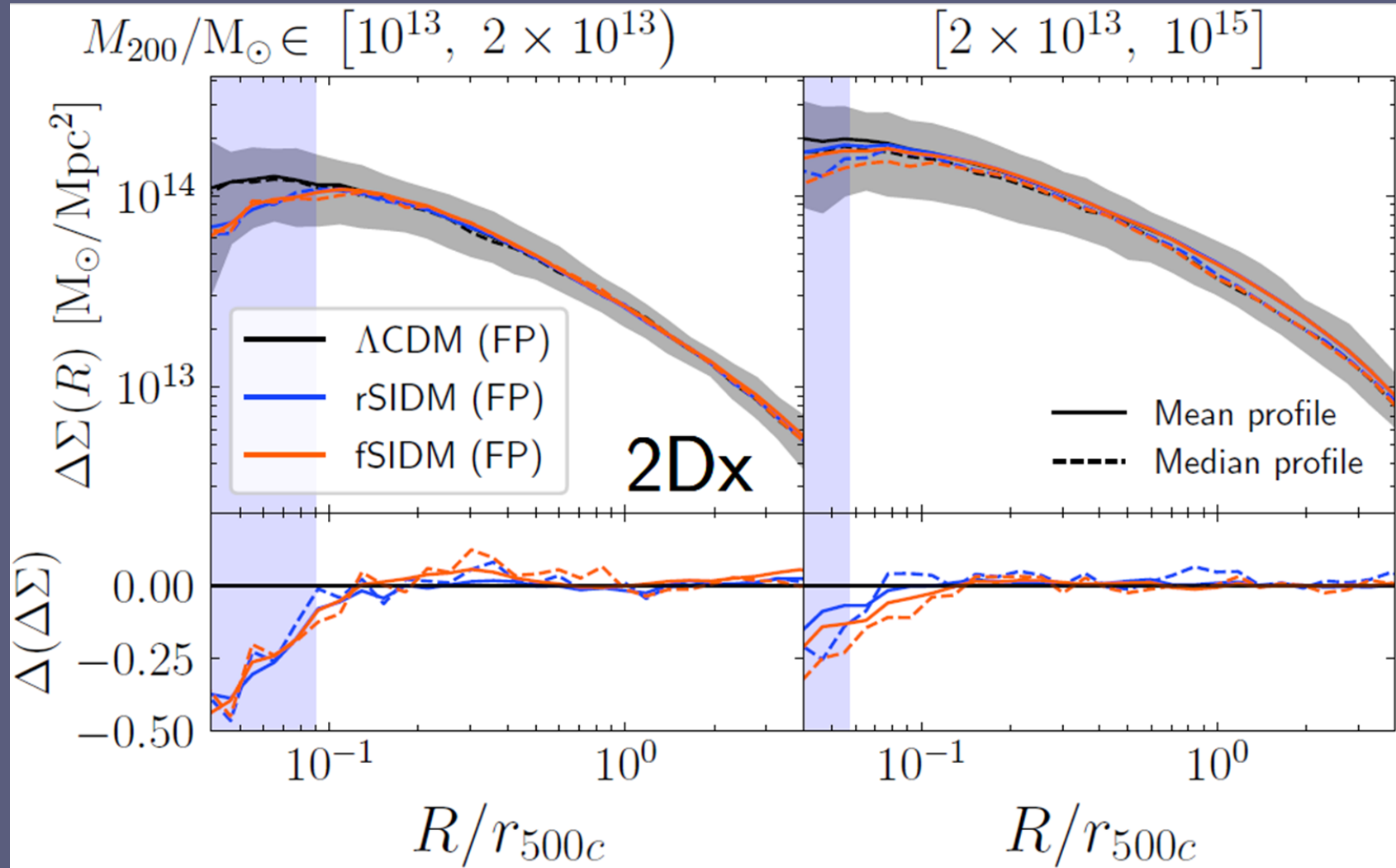
Shaded regions are ΛCDM 68% uncertainties

Surface density excess $\Delta\Sigma$

Proportional to halo weak lensing tangential shear

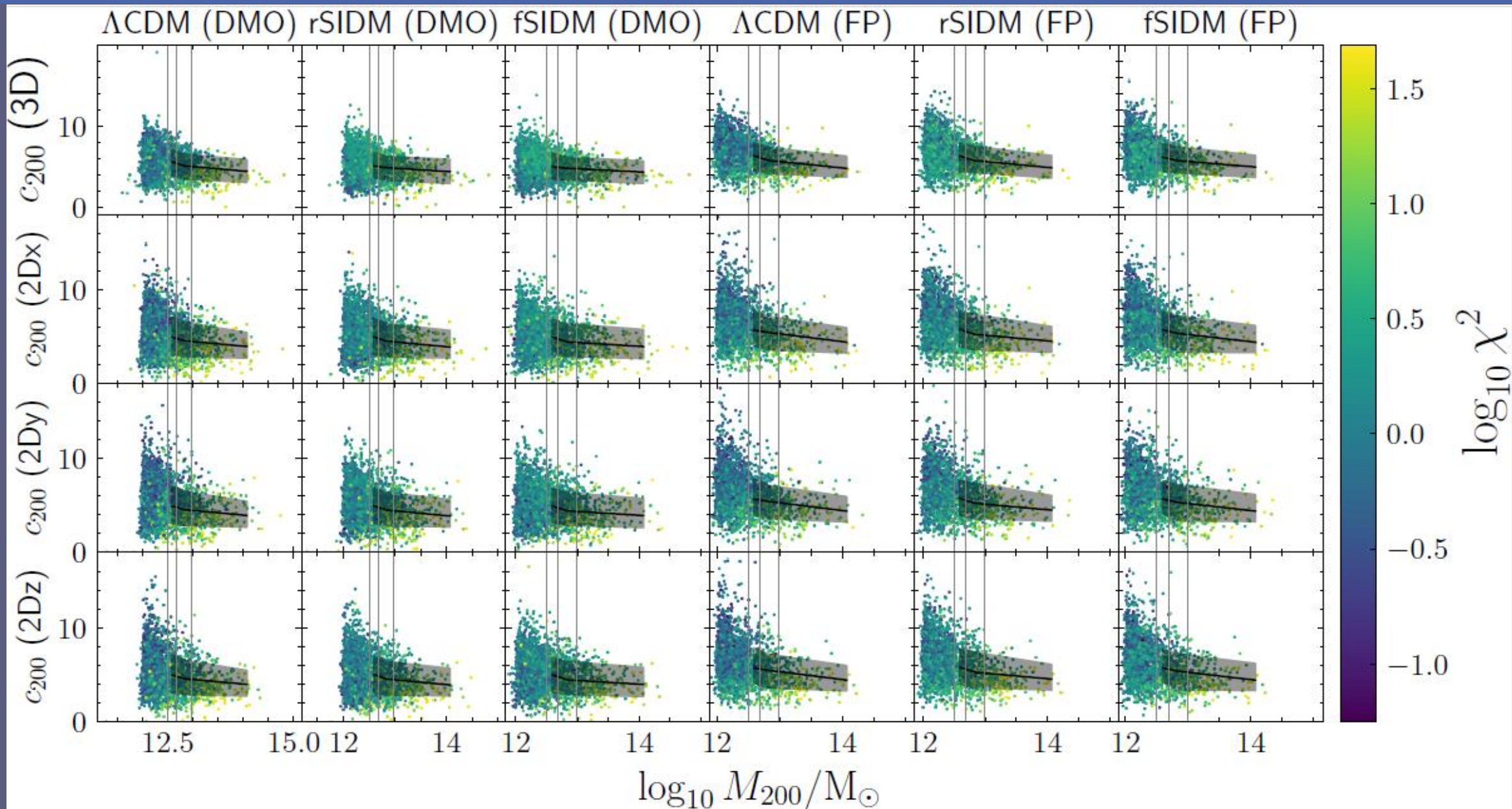
Greater SIDM effects than 2D mass and density profiles ($\sim 10\% - 20\%$)

Potential for SIDM detection

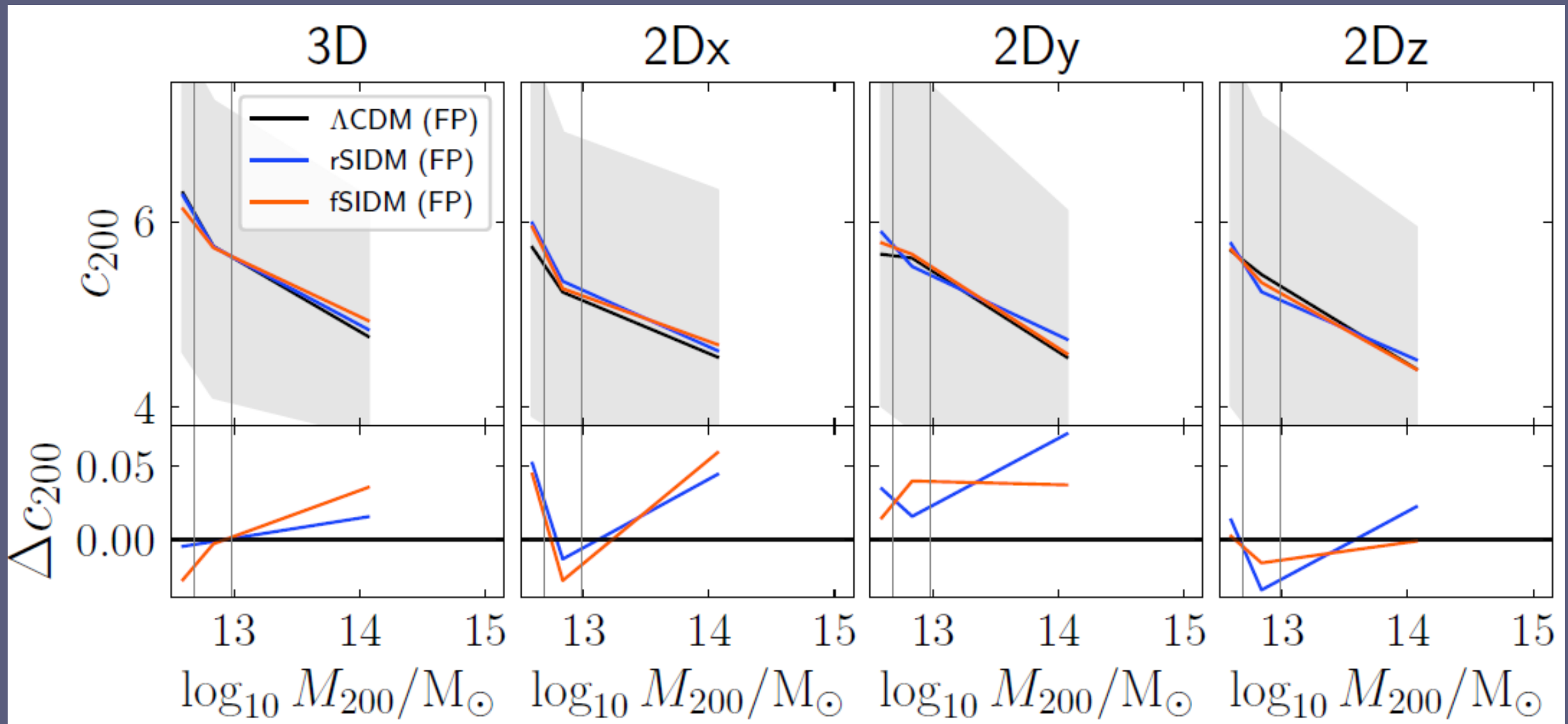


Shaded regions are ΛCDM 68% uncertainties

Concentration-mass relation



Concentration-mass relation

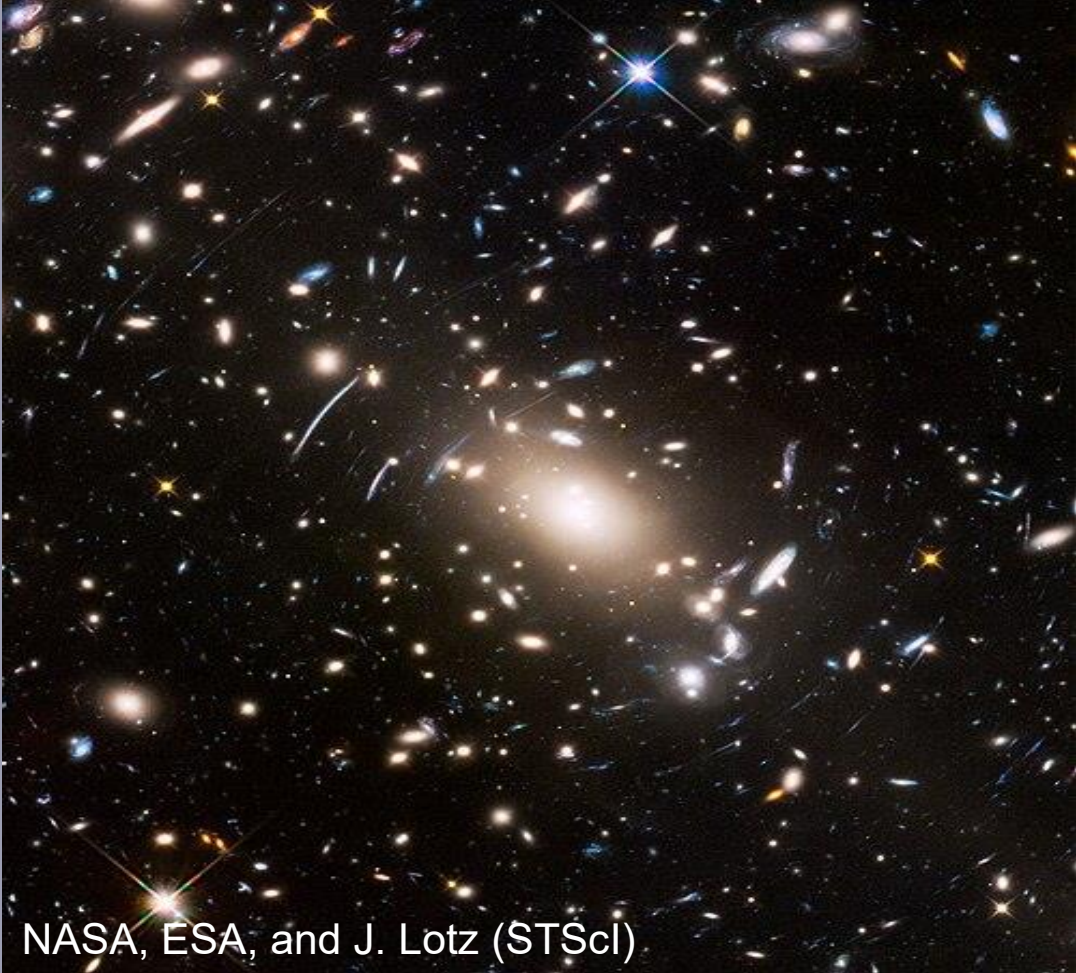


Shaded regions are Λ CDM 68% uncertainties

Observational comparison with CLASH clusters

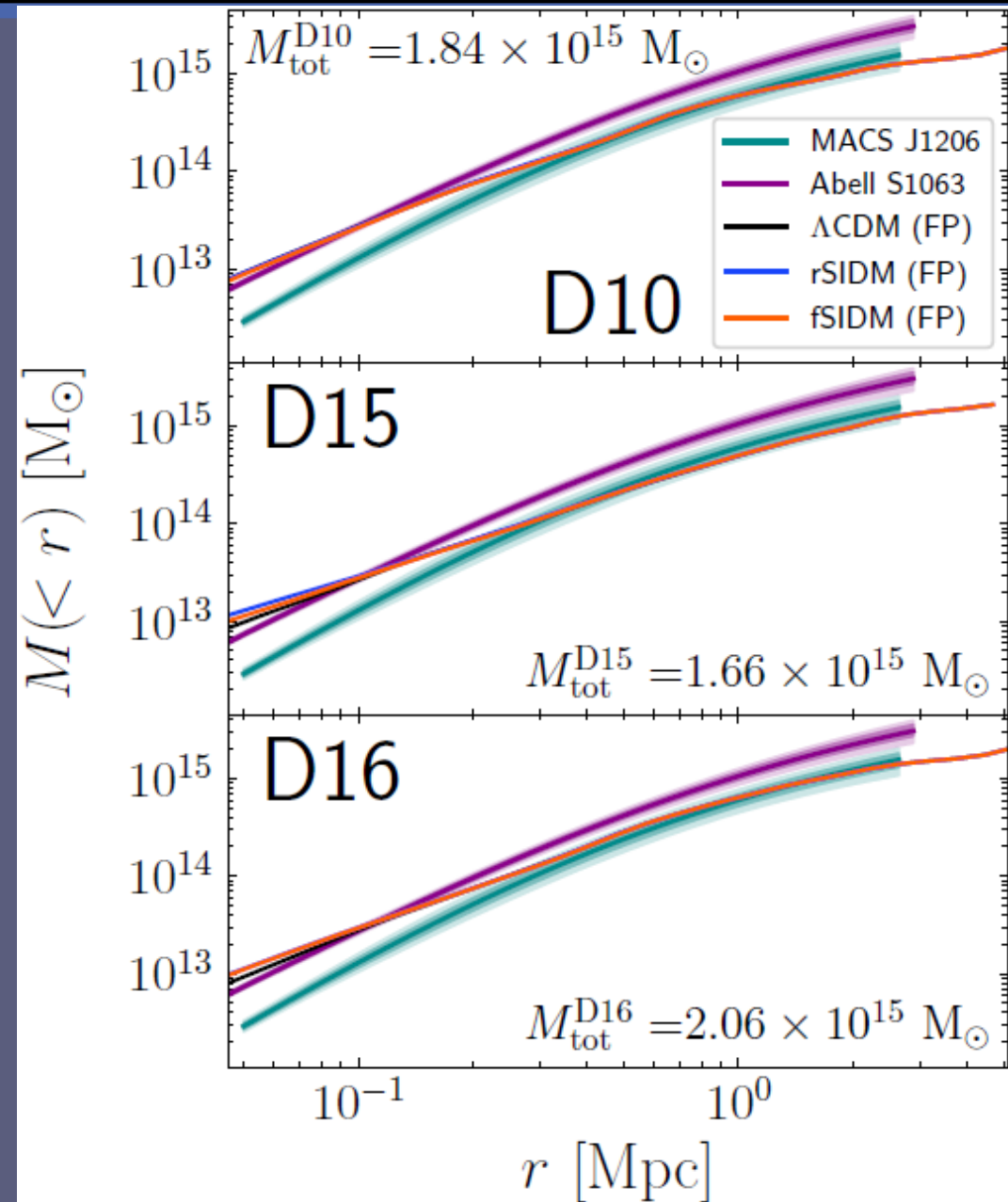


MACS J1206



Abell S1063

Observational comparison with CLASH clusters



Dark matter mass profiles
computed with MG-MAMPOSSt
from **galaxy kinematics**
(profiles used are by Biviano et al. 2023,
Sartoris et al. 2020)

MACS J1206: $M_{\text{tot}} = 1.56 \times 10^{15} M_\odot$

Abell S1063: $M_{\text{tot}} = 3.08 \times 10^{15} M_\odot$

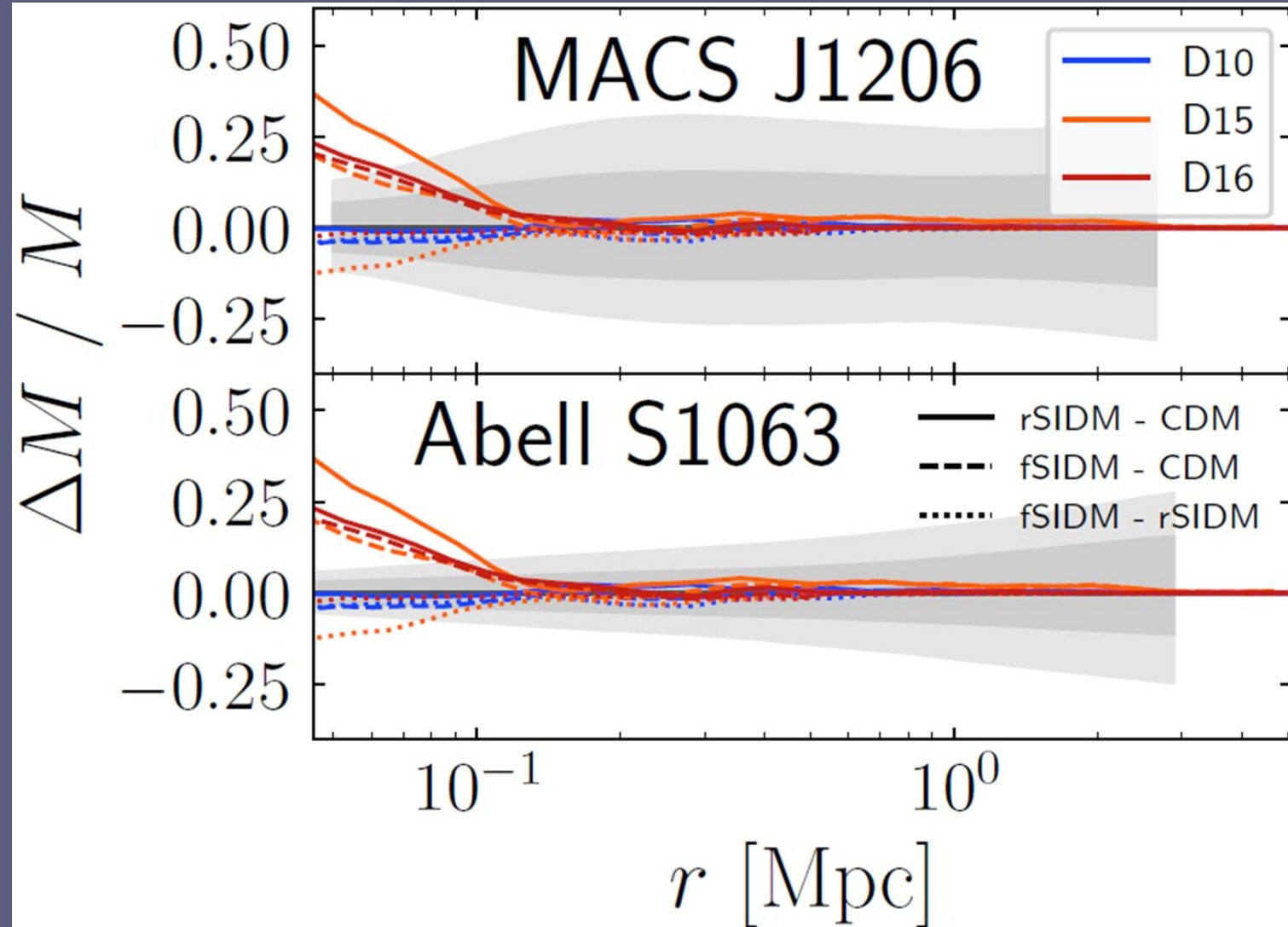
Observational comparison with CLASH clusters

Central SIDM enhancement:
potential detectable SIDM
signatures in cluster core
profiles

Solid lines: rSIDM – CDM

Dashed lines: fSIDM – CDM

Dotted lines: fSIDM – rSIDM



Shaded regions are kinematic mass profiles uncertainties

Conclusions and future prospects

This work provides an analysis of SIDM dark matter halo profiles of simulated groups and clusters of galaxies

Although **baryons and projection reduce the impact of SIDM (< 5% deviations)**, weak lensing shear and kinematic mass profiles in galaxy clusters may offer robust SIDM detection

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Possible follow-ups:

- Robust sample of halo core: **higher resolution** simulations
- Increased cluster statistical sample: **larger volume** simulations + bigger observational catalogue
- Study of **velocity anisotropy profiles and merging systems**: viable for SIDM detection?

Searching for signatures of self-interacting dark matter in halos from full-physics simulations: From 3D structure to projected observables

G. Y. Ferron¹, A. Ragagnin², L. Pizzuti¹, M. S. Fischer³, and G. Bordogna¹

Thank you