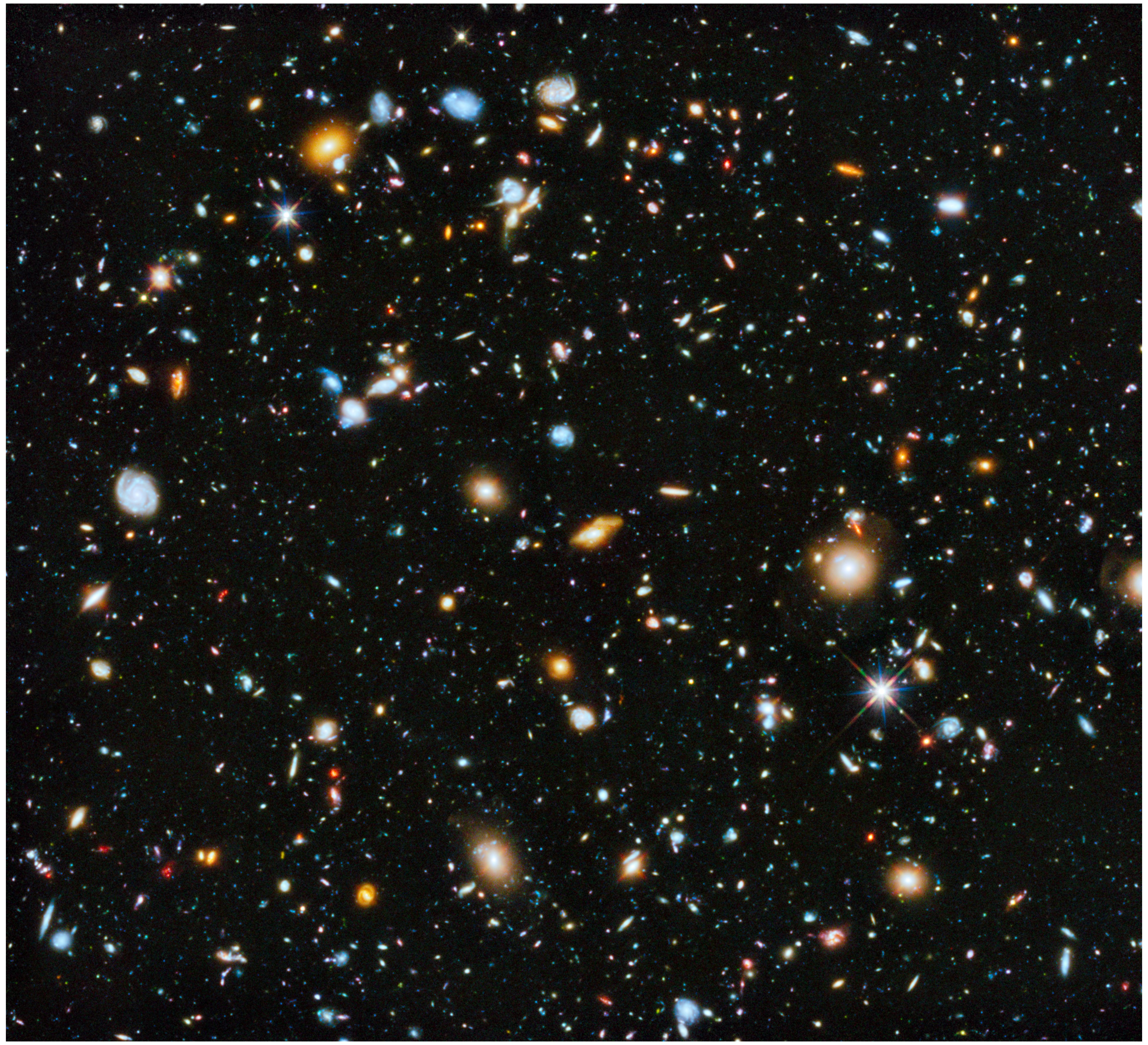
Dark matter halo properties of intermediate-z star-forming galaxies

B. Ciocan, N. Bouché, **R. Bacon, J. Fensch, J. Blaizot, T. Buchert, A. Jeanneau, L. Michel-Dansac, Richard, J. Rosdahl, T. Contini, W. Mercier, B. Épinat, E. Emstellen, D. Krajnovic**



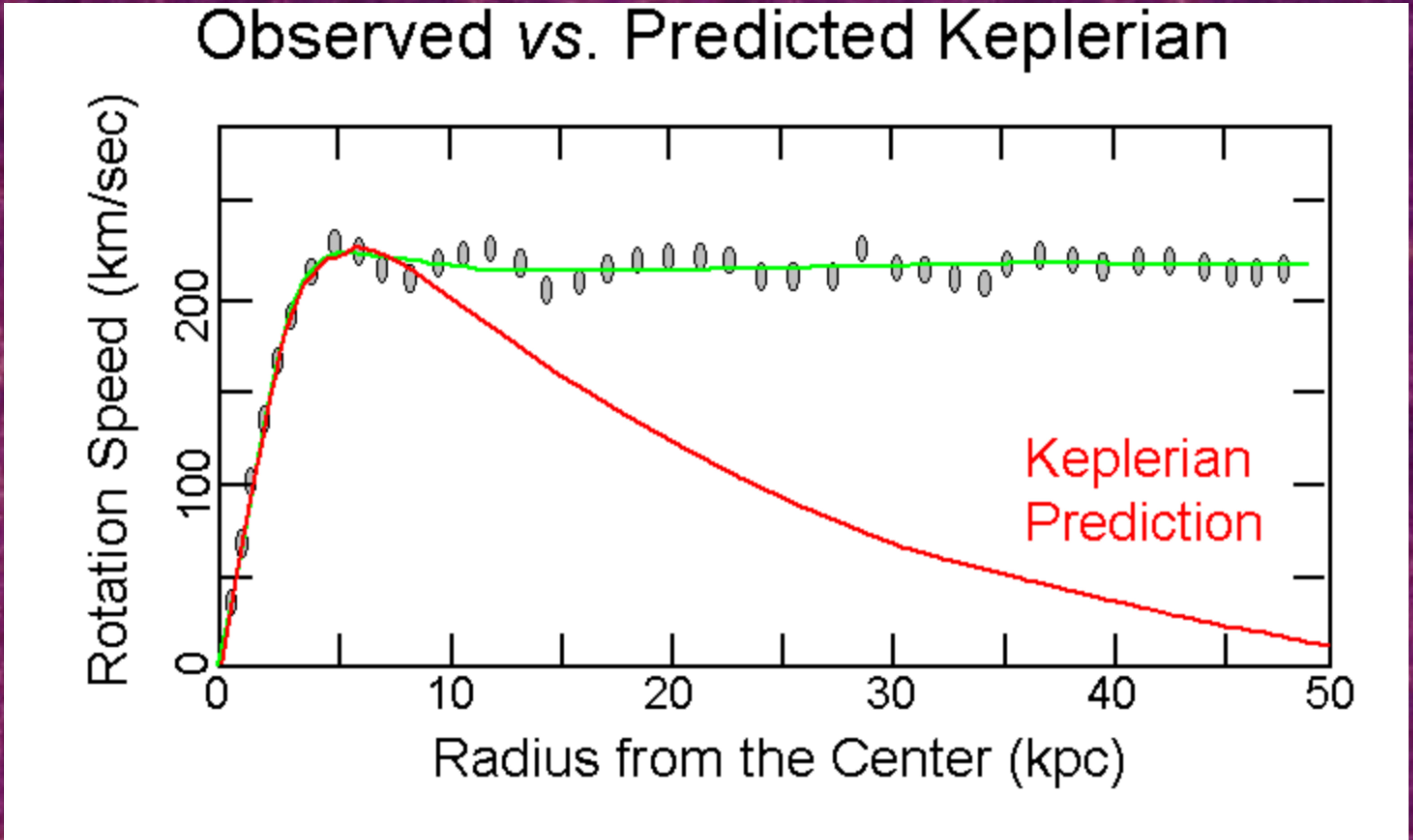
HUBBLE ULTRA DEEP FIELD

CRAL
CENTRE DE RECHERCHE ASTROPHYSIQUE DE LYON

cnrs

Motivation:

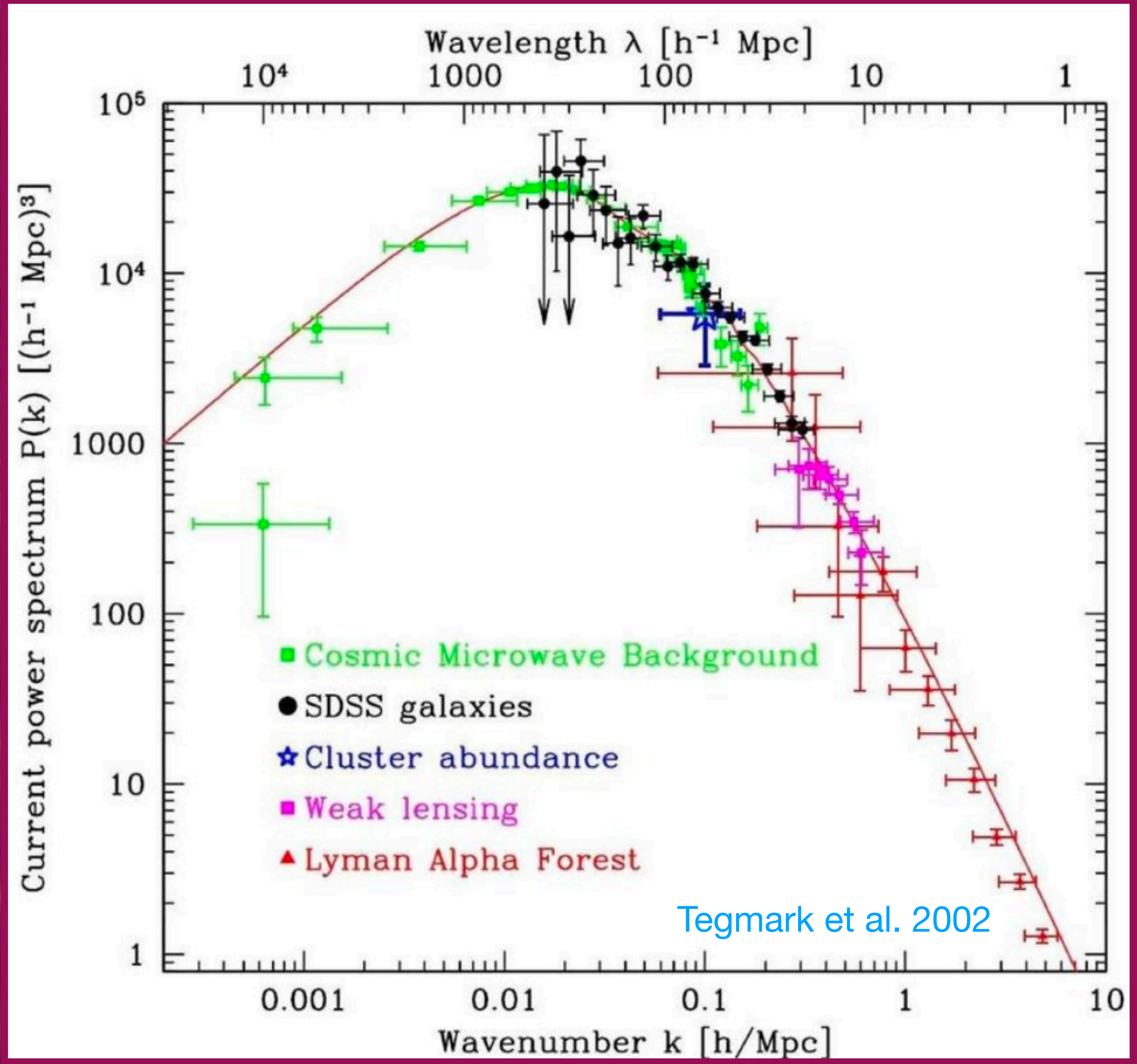
➡Evidence for dark matter from rotation curves of disk galaxies (van de Hulst+1957)



➡Rotation curves represent fundamental tools to study the matter distribution in disk galaxies

Motivation:

➡ΛCDM successful in predicting and explaining the large-scale structures of the Universe and their evolution with cosmic time



Tegmark et al. 2002

Motivation:

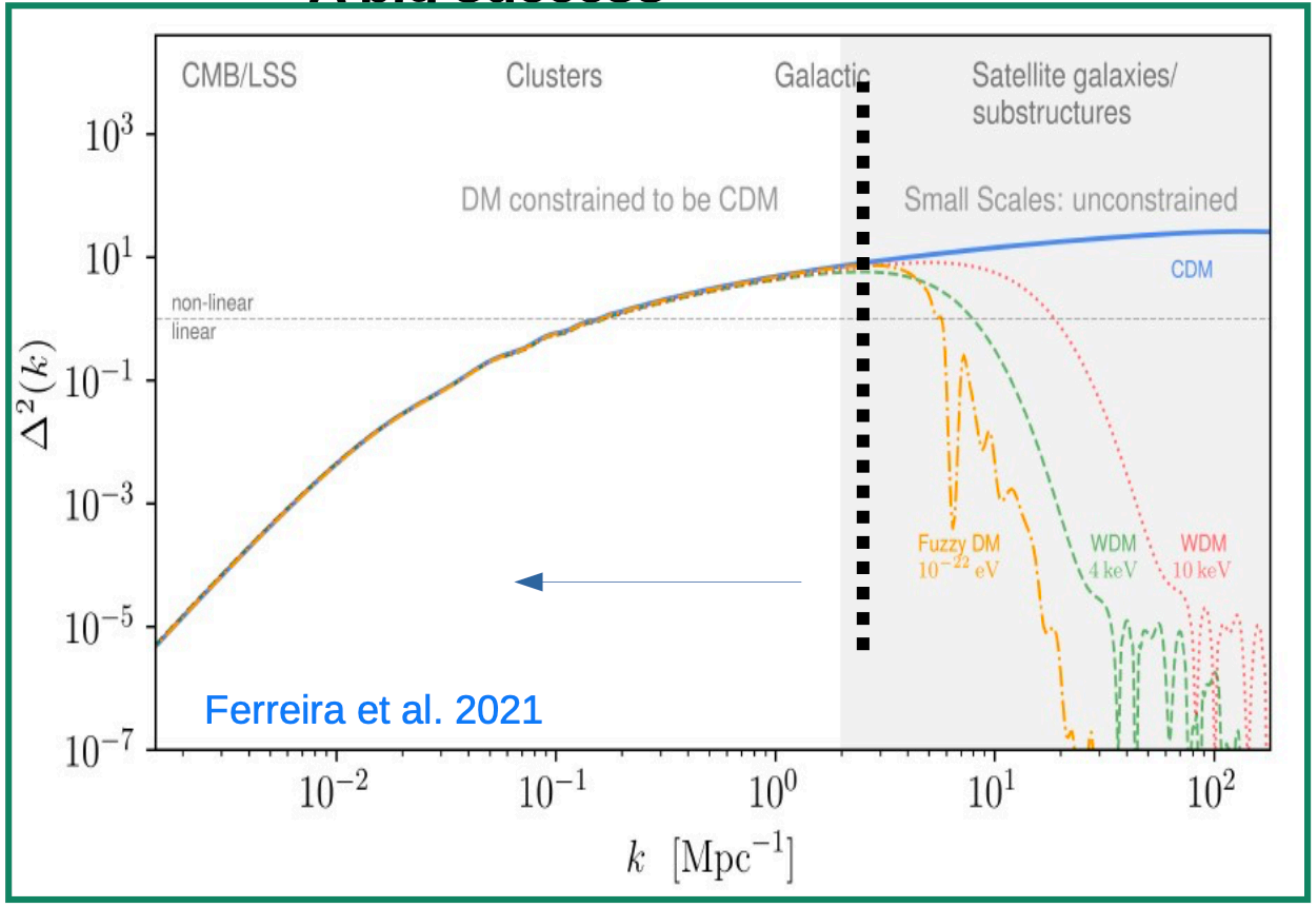
- ➡ Large scales: ΛCDM is a big success
- ➡ Small scales: retain information about possible deviations from ΛCDM

Large scale (>>1 Mpc):

A big success

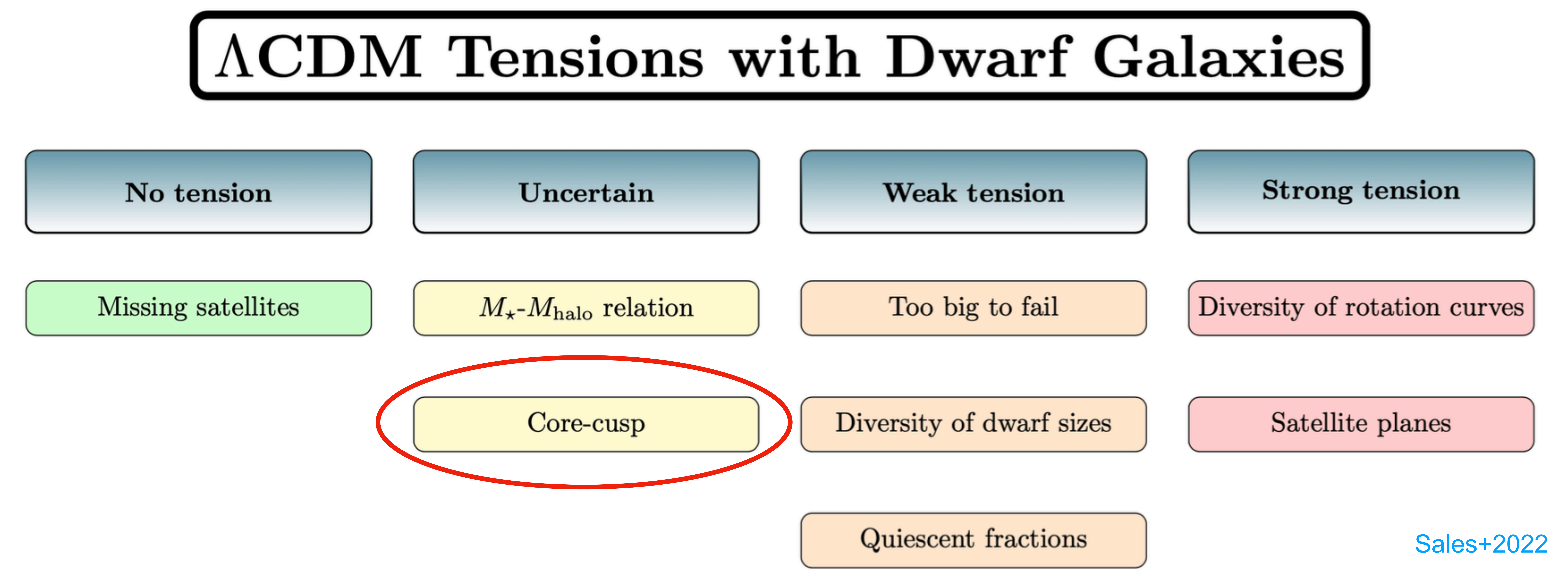
Small scale (<1 Mpc):

But baryons Can have an impact



Motivation:

➡On small scales: Small-scale problems of ΛCDM (e.g. Bullock+2017, Sales+2022)



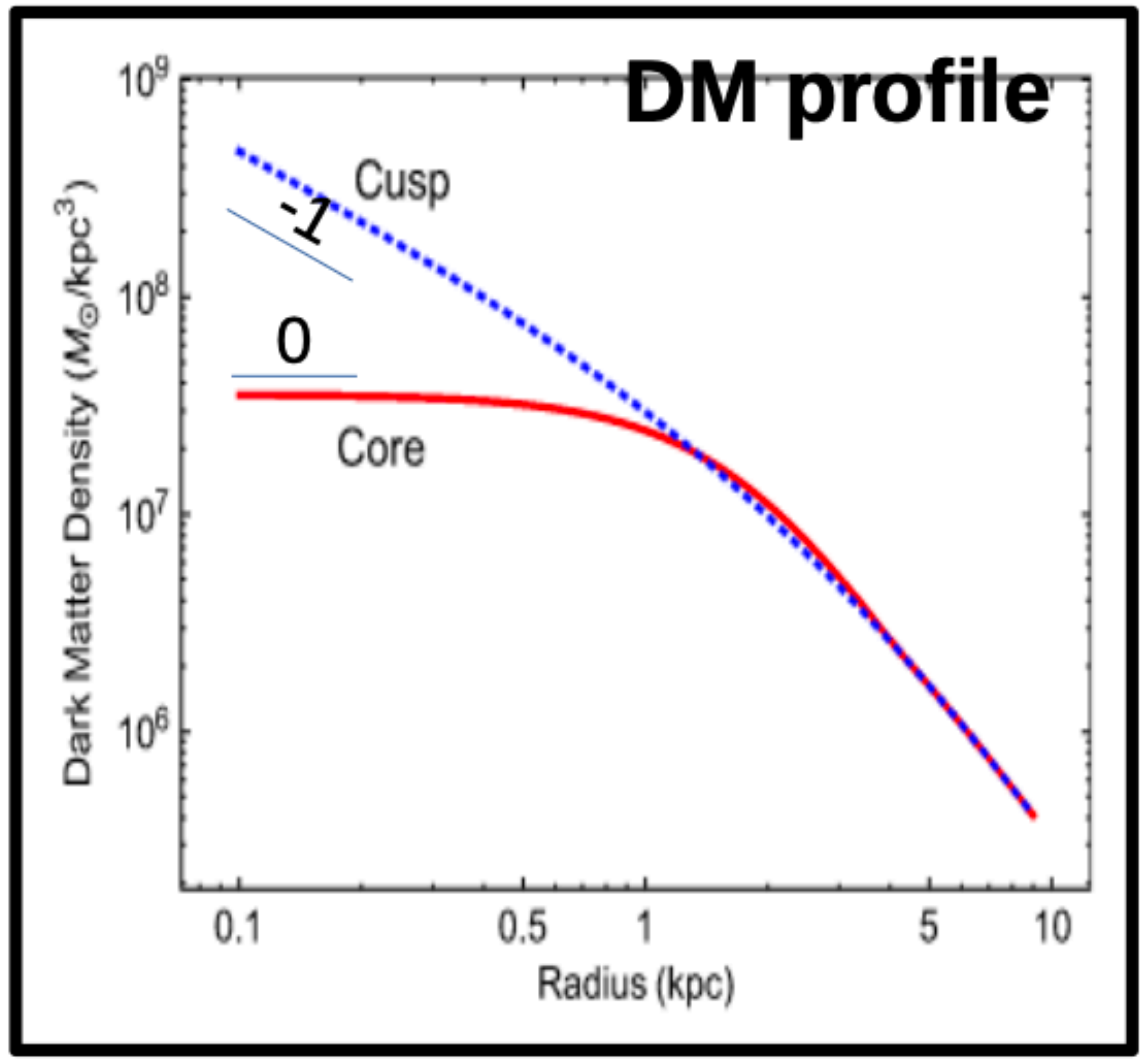
Sales+2022

Motivation:

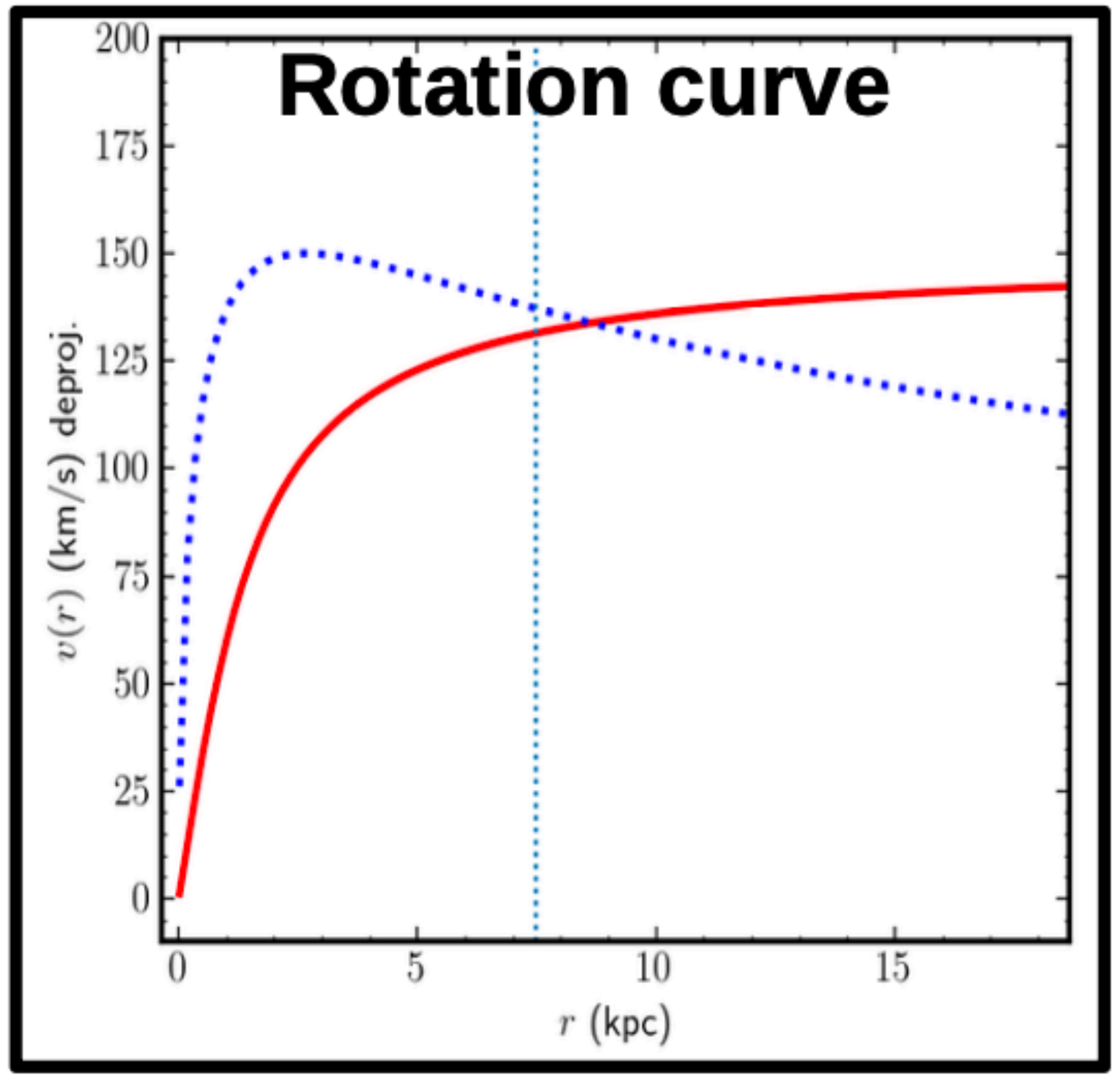
➡Core-cusp problem:

‣ N-body simulation predicts cuspy DM profiles (NFW, Navarro+1997)

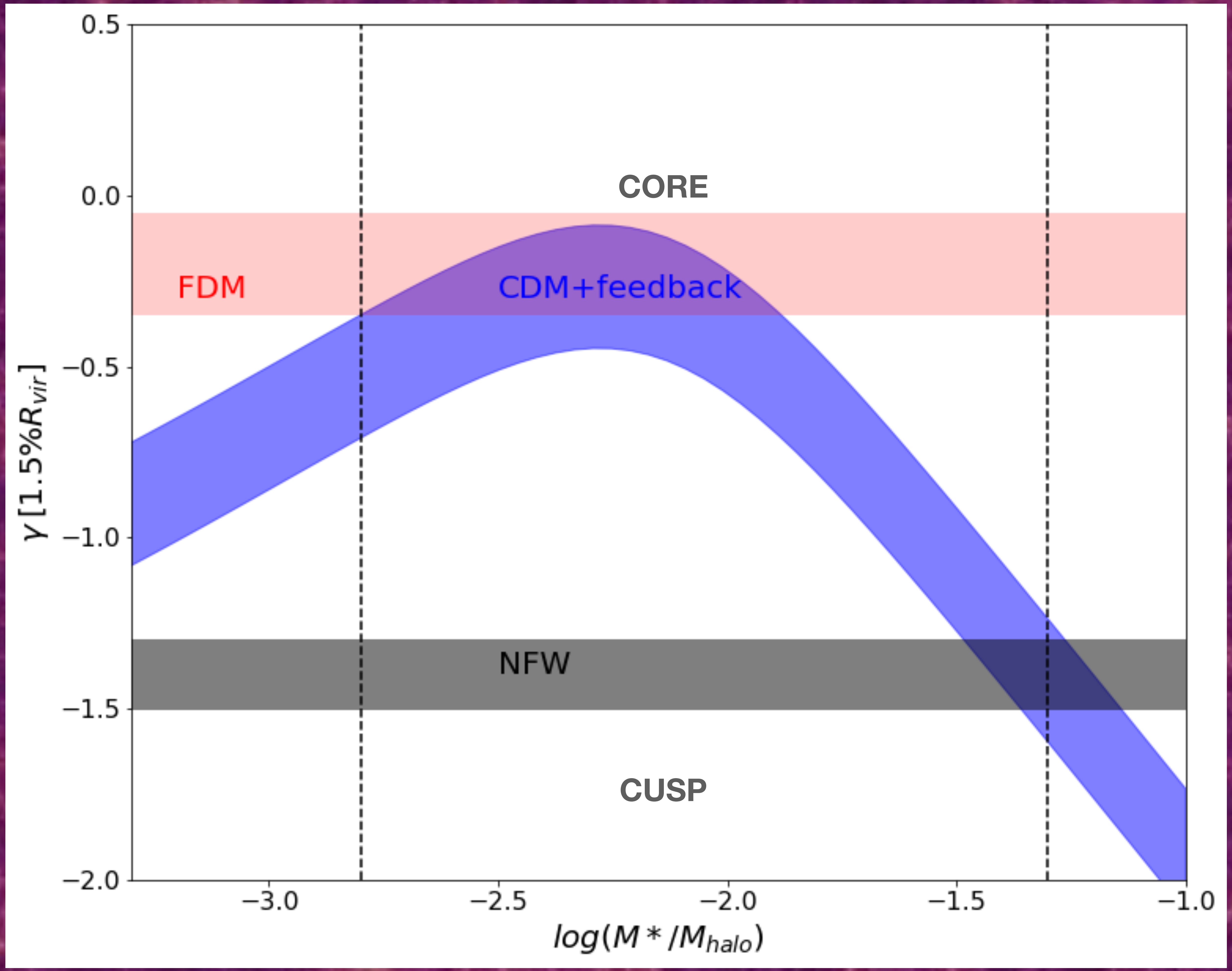
‣ observations of low-surface brightness galaxies (e.g. de Blok et al. 2001) find constant-density cores



$$v_c = \sqrt{\frac{GM}{r}}$$



Motivation: ➡Solutions to core-cusp problem

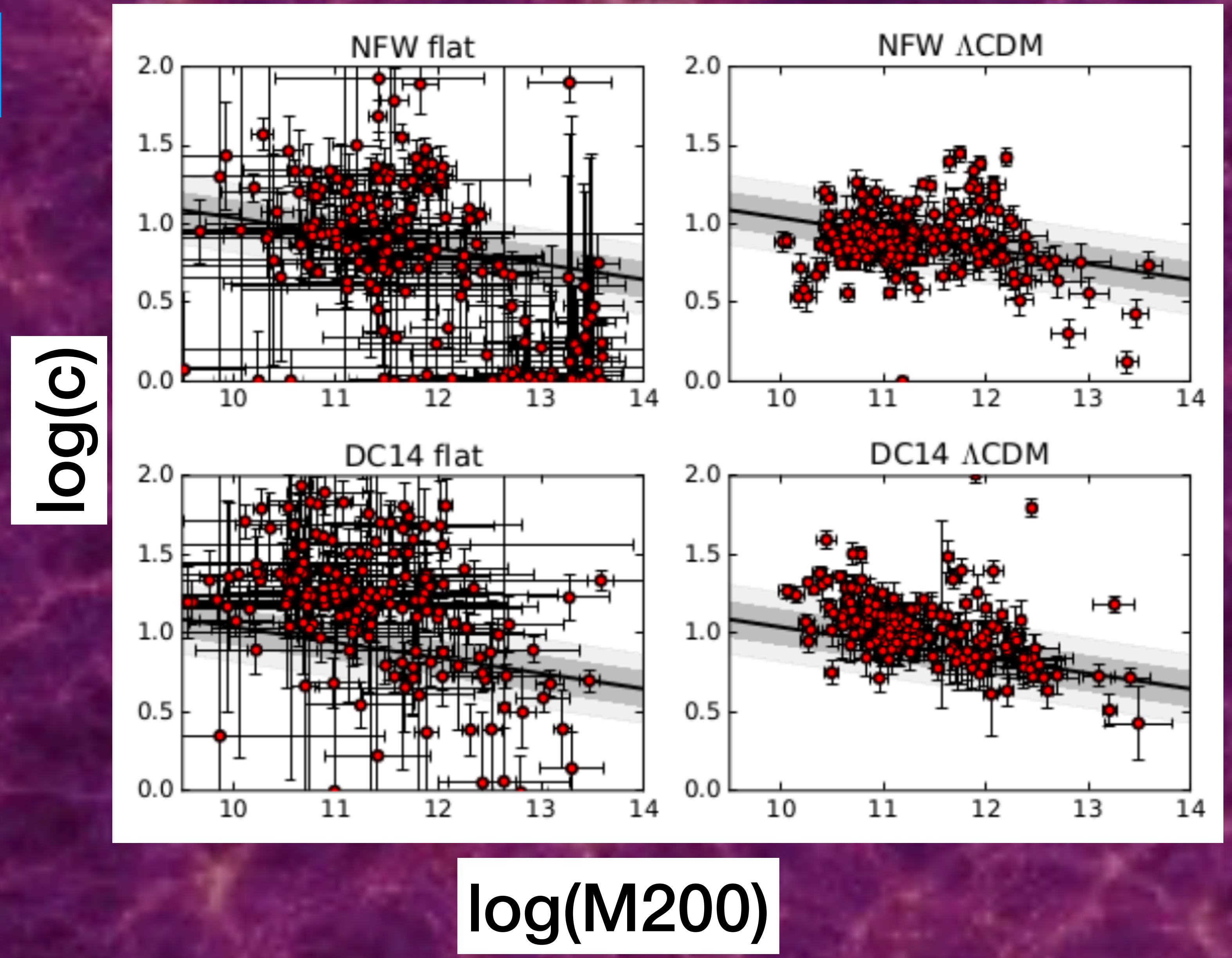


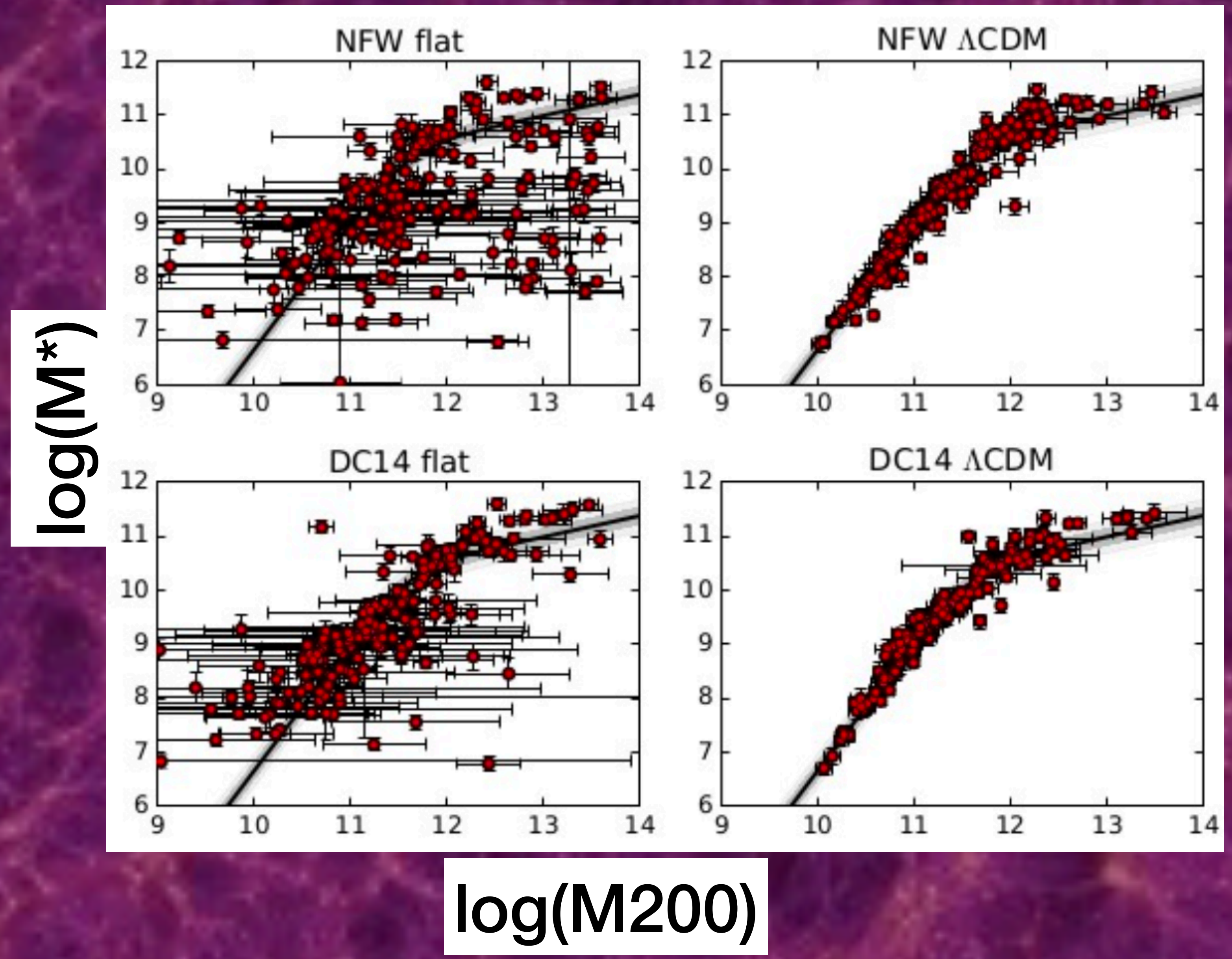
- in ΛCDM: baryonic processes (*stellar feedback*, central stellar bar, clumps infalling due to dynamical friction, AGN feedback)
- Rapid potential fluctuations (hard to observe)
- stellar feedback scenario: core formation most efficient for 9<log(M*/M☉)<10 (Di Cintio+ 14; Lazar et al. 2020; Tollet et al. 2016)
- alternative models of DM (self- interacting DM - Spergel +2000; axion-like fuzzy DM -Hu+2000)

State-of-the-art: Dark matter halo properties of local star-forming galaxies

➡ SPARC sample (Lelli+2016, Li + 2019)

- 7 halo profiles
- Navarro-Frenk-White always bad
- Investigate halo scaling relations

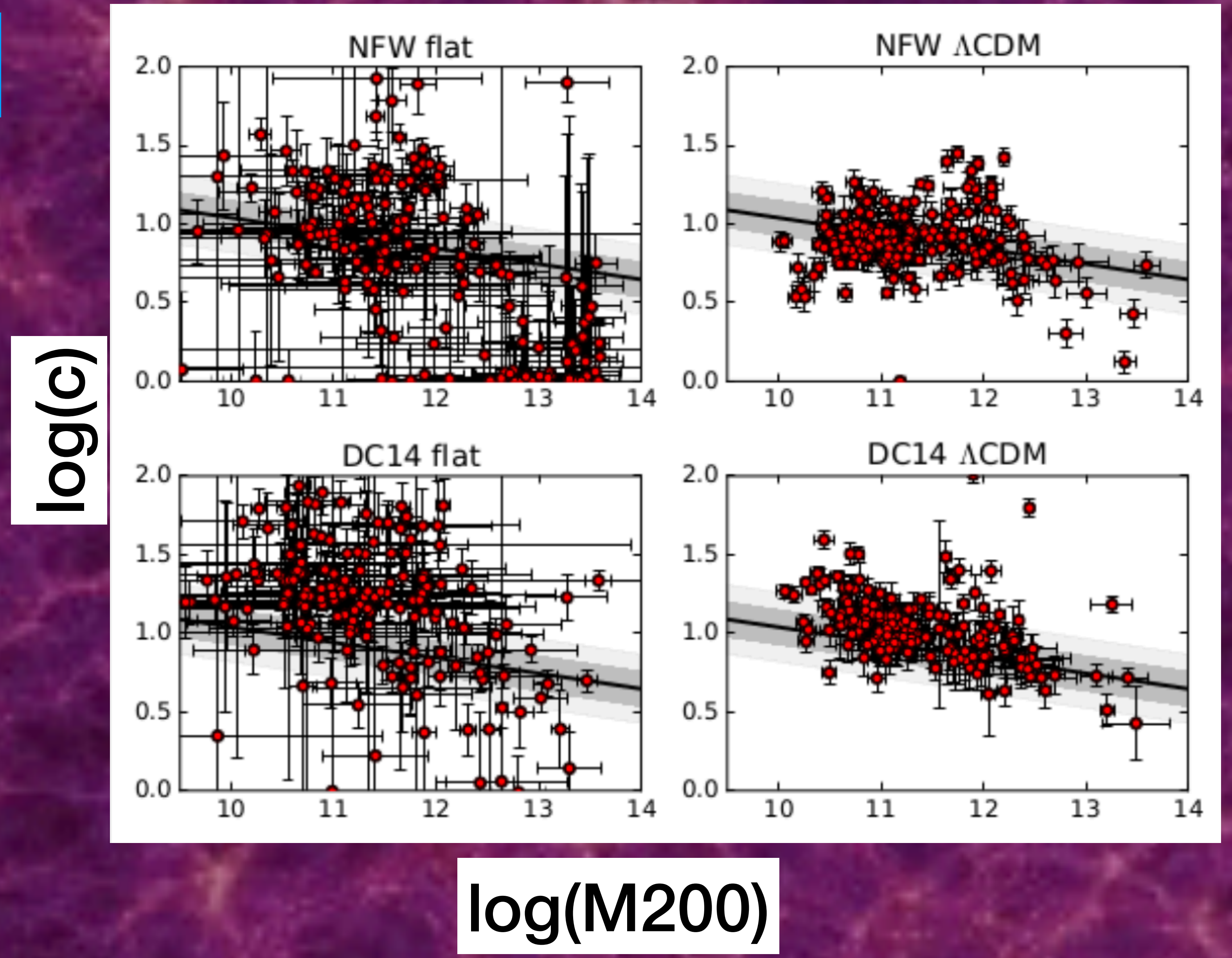


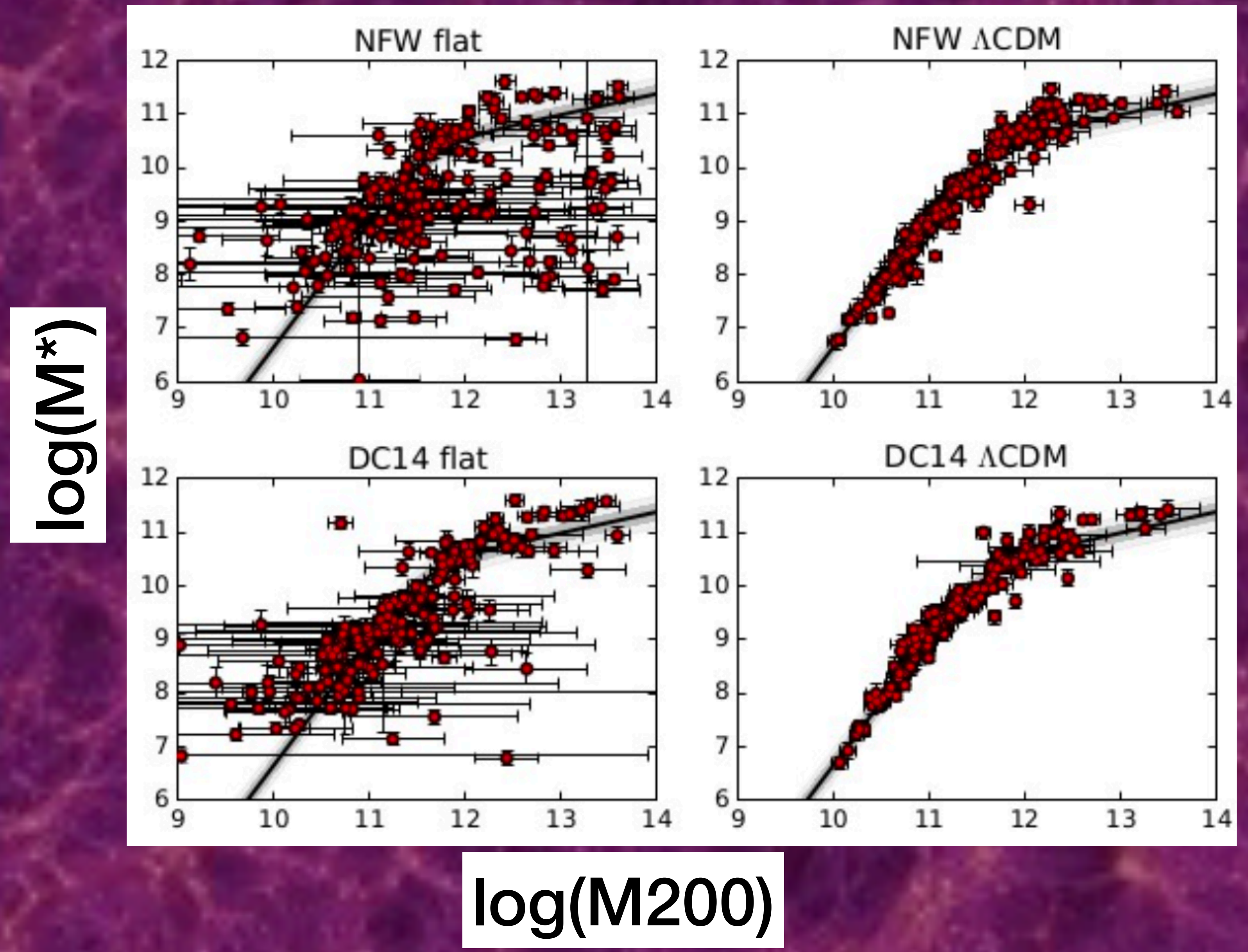


State-of-the-art: Dark matter halo properties of local star-forming galaxies

➡ SPARC sample (Lelli+2016, Li + 2019)

- 7 halo profiles
- Navarro-Frenk-White always bad
- Investigate halo scaling relations

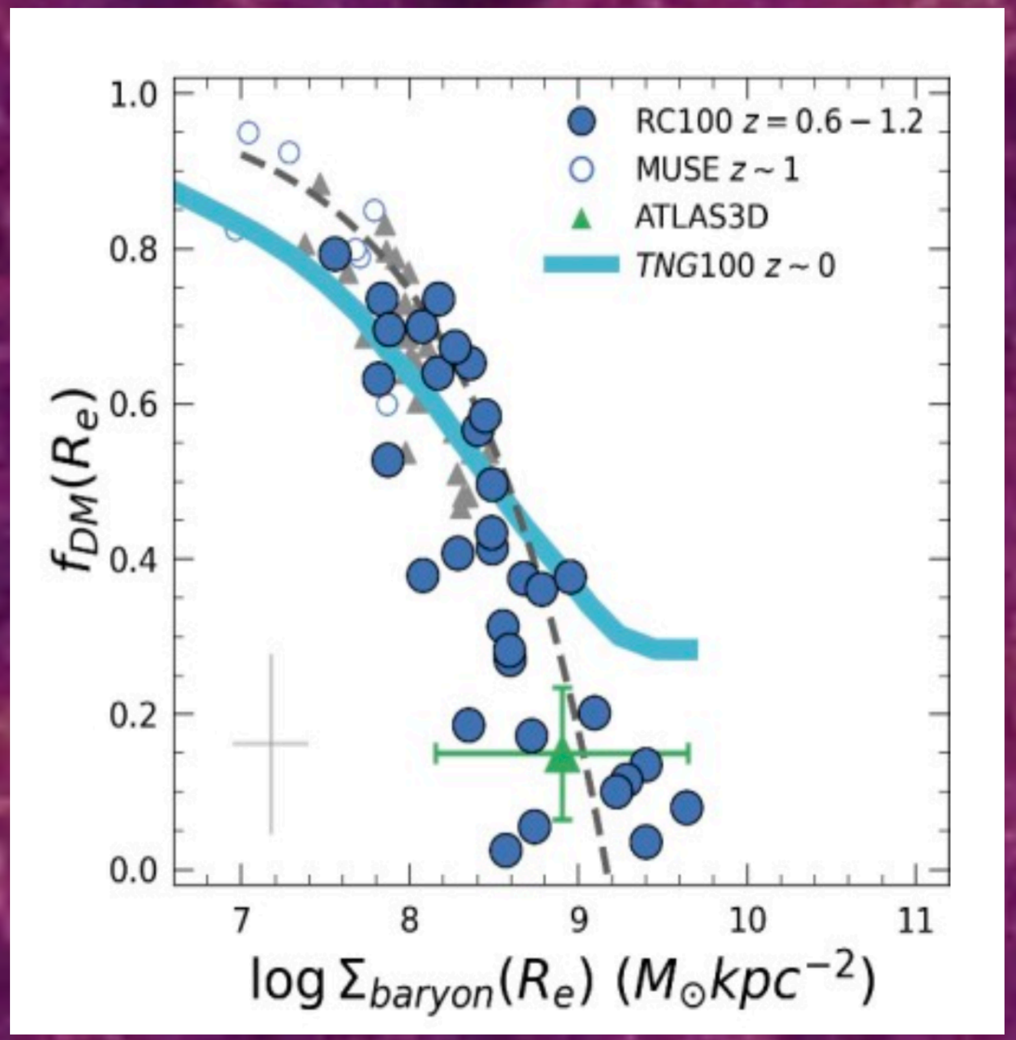




State-of-the-art: Dark matter halo properties of intermediate-z star-forming galaxies

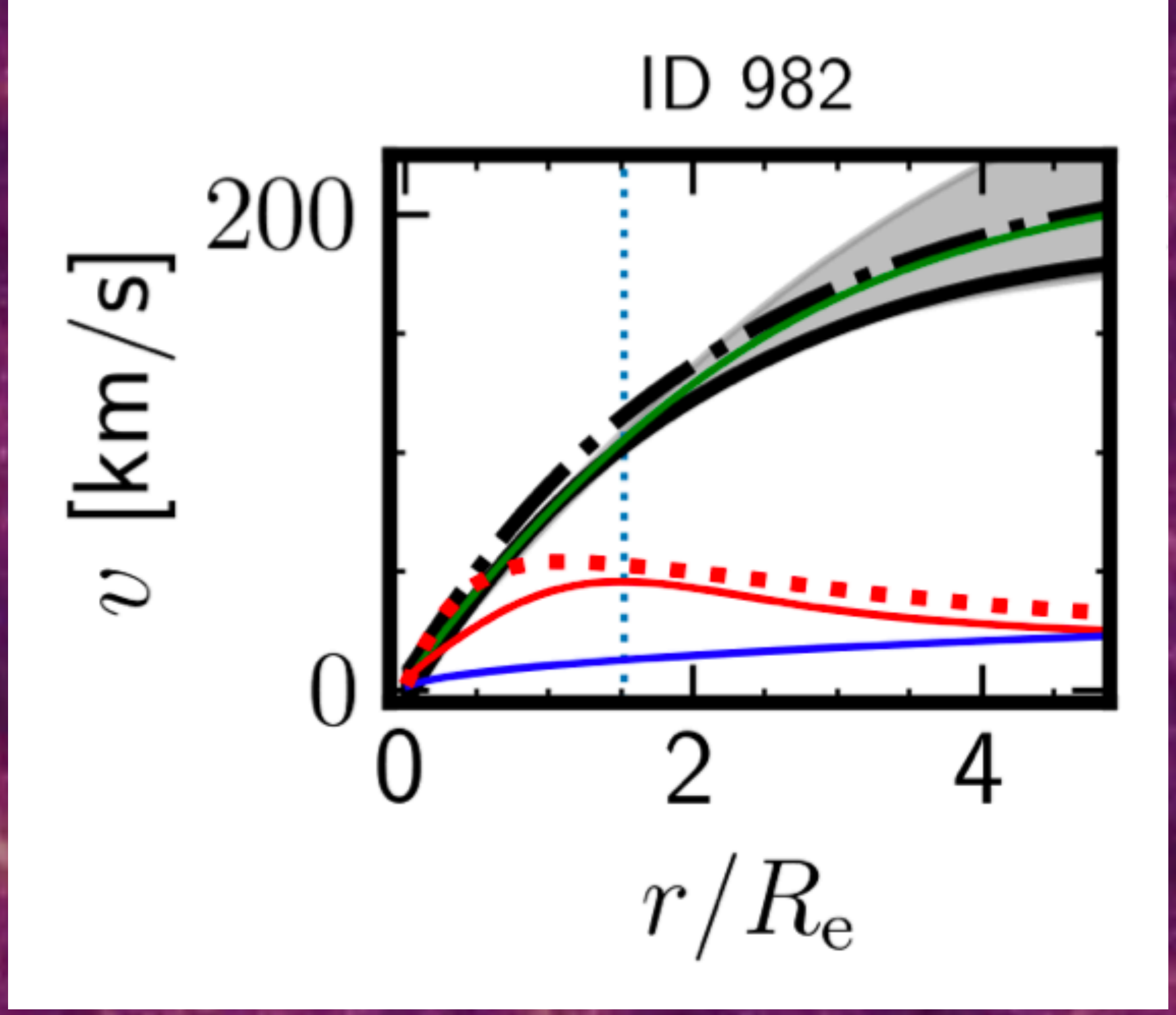
➡ Genzel+ 2017,2020, Nestor Shachar+2023, Puglisi+2023

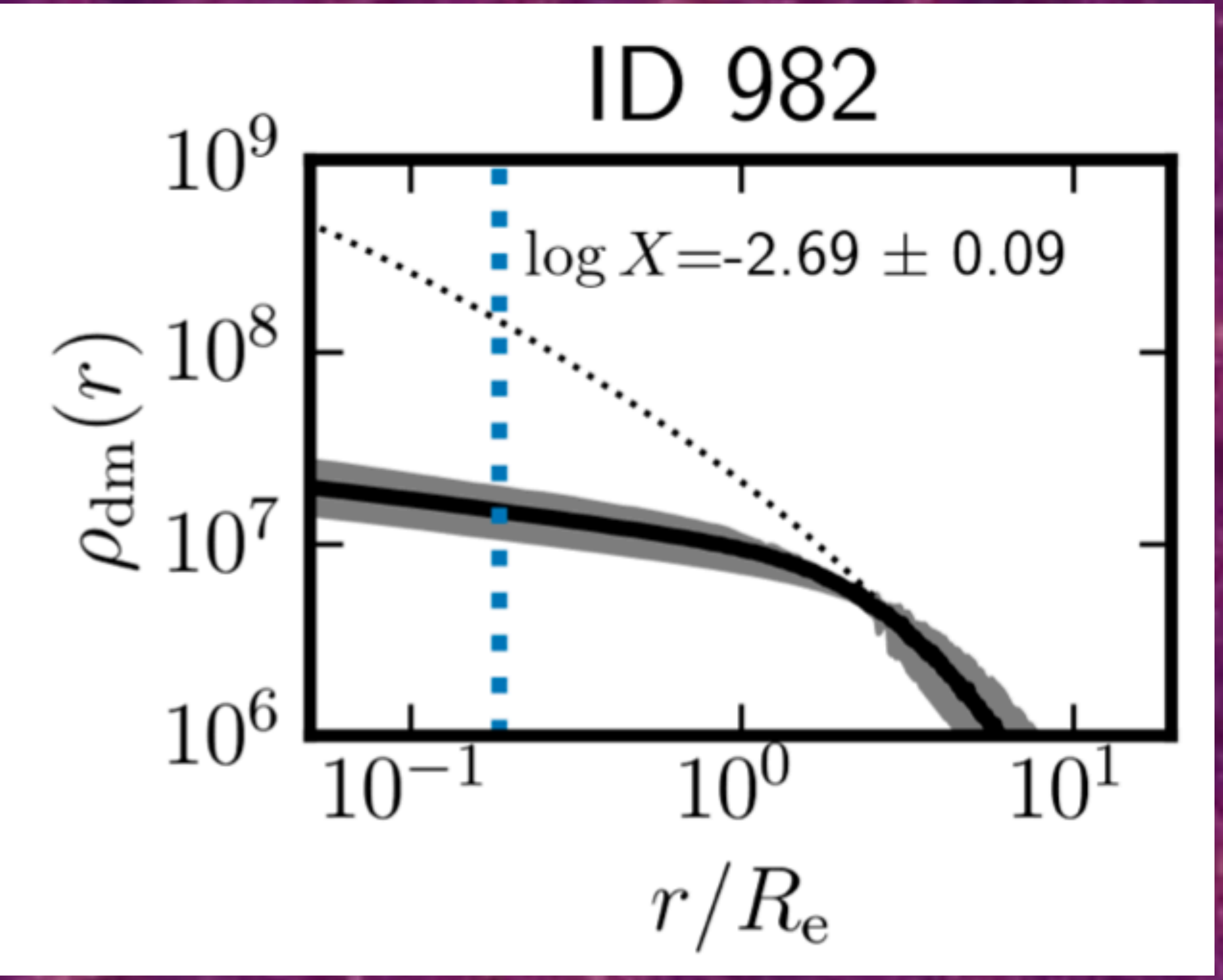
- mainly probe high-M end
- use NFW
- Investigate DM fractions



This project: **Dark matter halo properties of intermediate-z star-forming galaxies**

➡ We use the rotation curves of a large sample of galaxies with 0.2<z<1.5 and 7<log(M*/M☉)<11 to study the properties of their dark matter halos using a 3D forward modelling approach with 6 different DM halo profiles

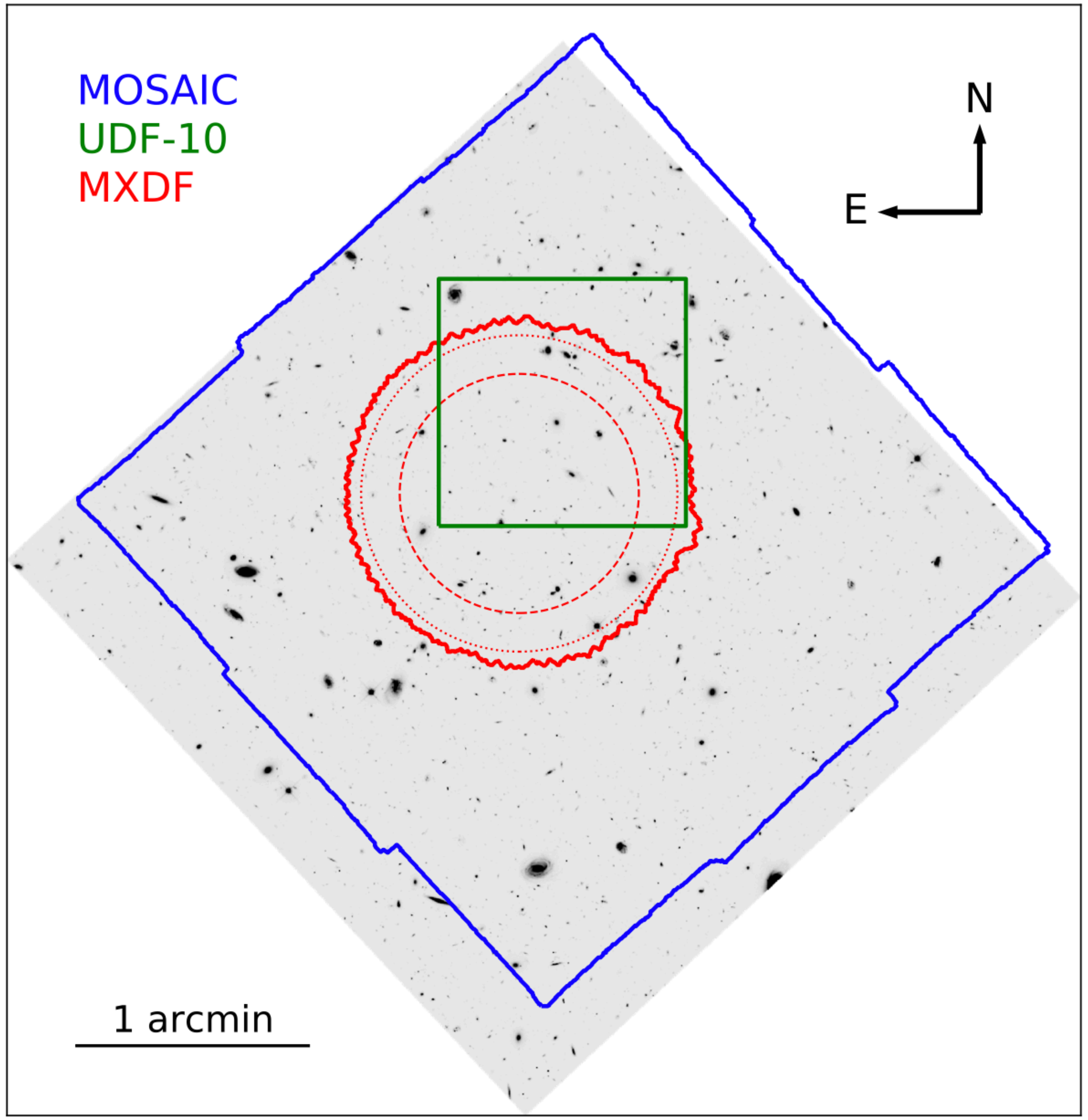


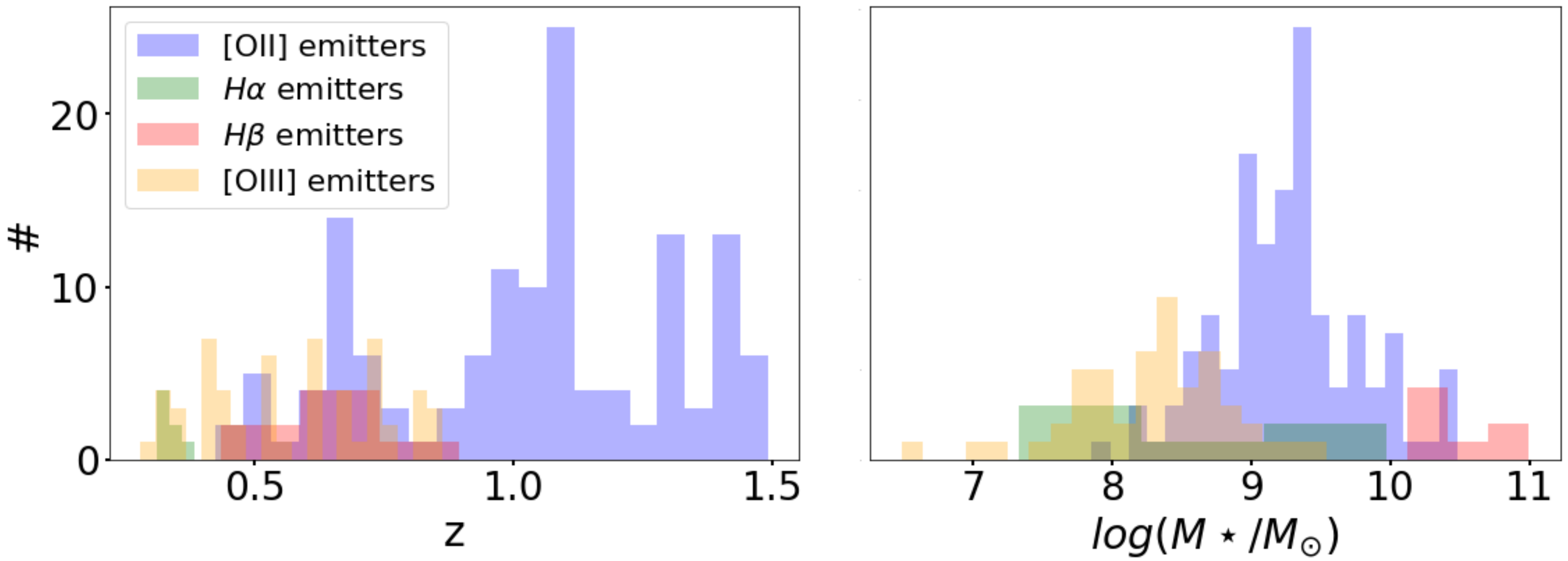


Bouche et al. 2022

Data

The MUSE Hubble Ultra Deep Field survey (Bacon+2023)





➡ 140 galaxies for disk-halo decomposition

Methodology

3D disk-halo decomposition with Galpak3D (Bouche et al. 2015, 2022)

- Galpak3D compares 3D parametric models directly to the 3D data, taking into account the LSF and PSF

$$v_c(r)^2 = v_{DM}(r)^2 + v_\star(r)^2 + v_{gas}(r)^2$$

+ correction for pressure support

- Dark matter halo parametrised with 6 different density profiles:

(1) generalised profile of DC14 (Di Cintio+2014)

(2) NFW (Navarro, Frenk, White 1997)

(3) Dekel (Freundlich+ 2020)

(4) Burkert (Burkert 1995)

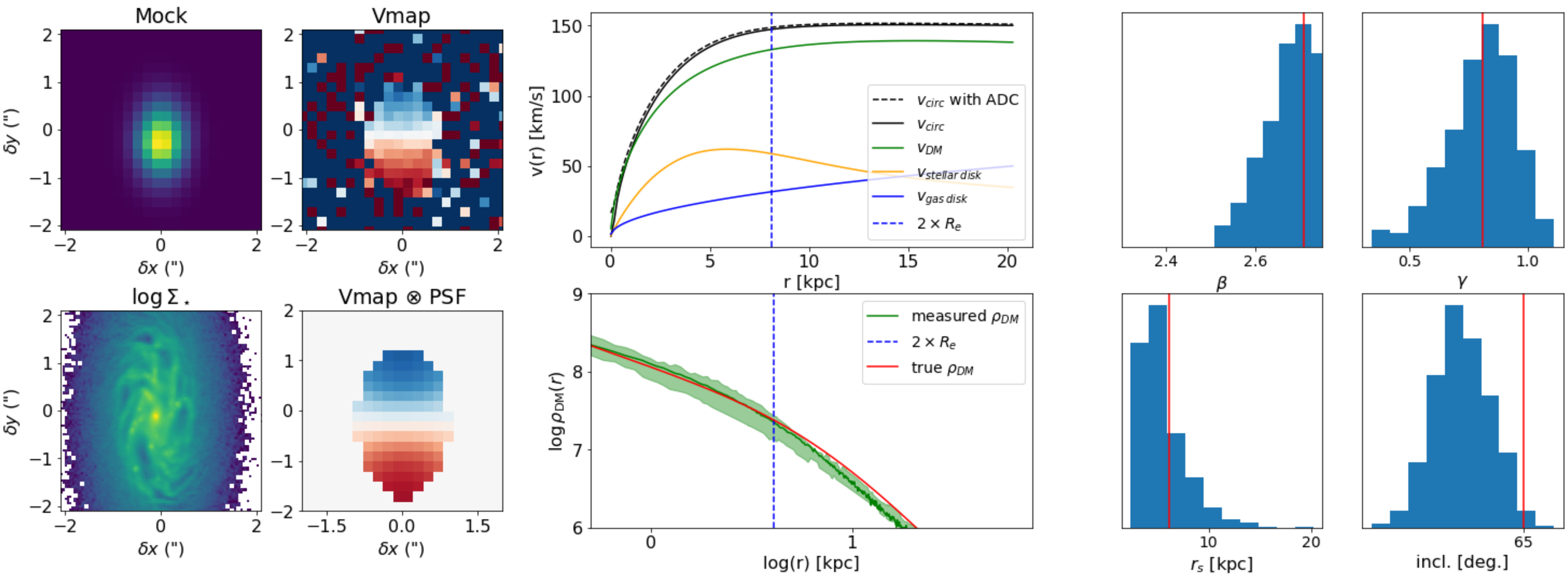
(5) coreNFW (Read+ 2016)

(6) Einasto (Navarro + 2004)

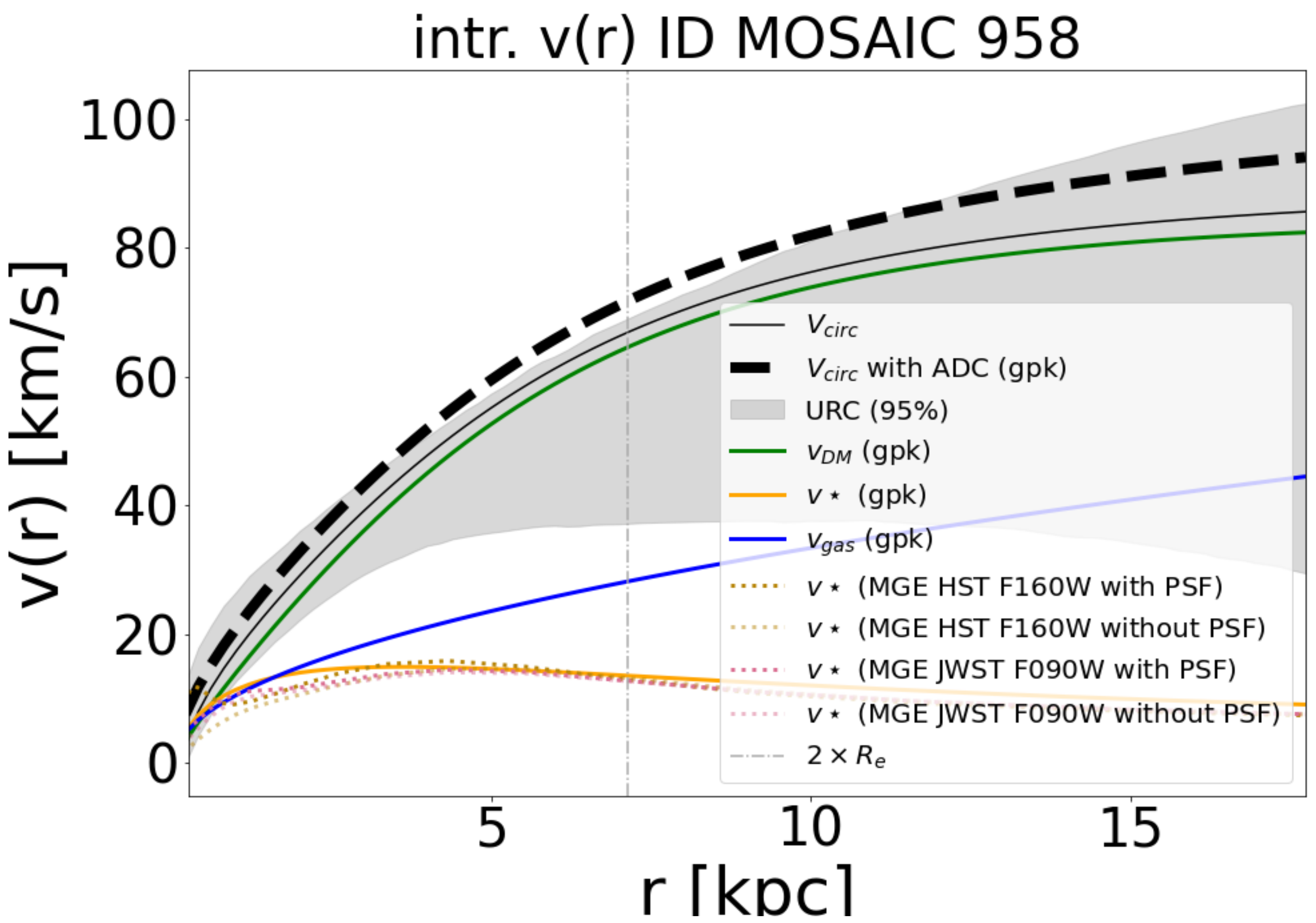
- 13 - 19 parameters in our models
- Only use priors on inclination and M* (except for DC14 where no priors on M* are used)
- We optimise the parameters simultaneously with GALPAK3D using an MCMC fitting routine (pyMultiNest, Buchner+2014)

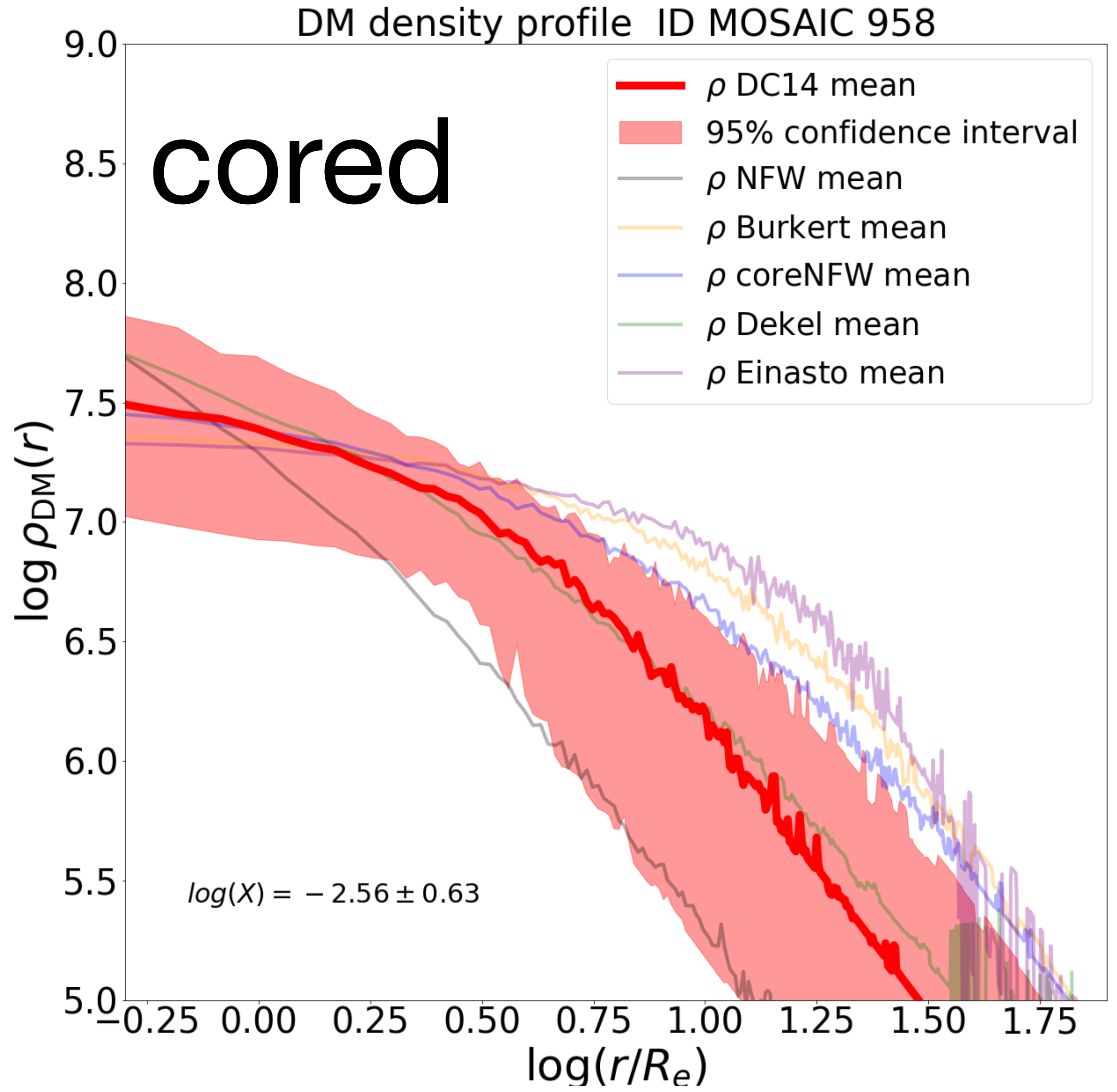
Validation of methodology with simulations

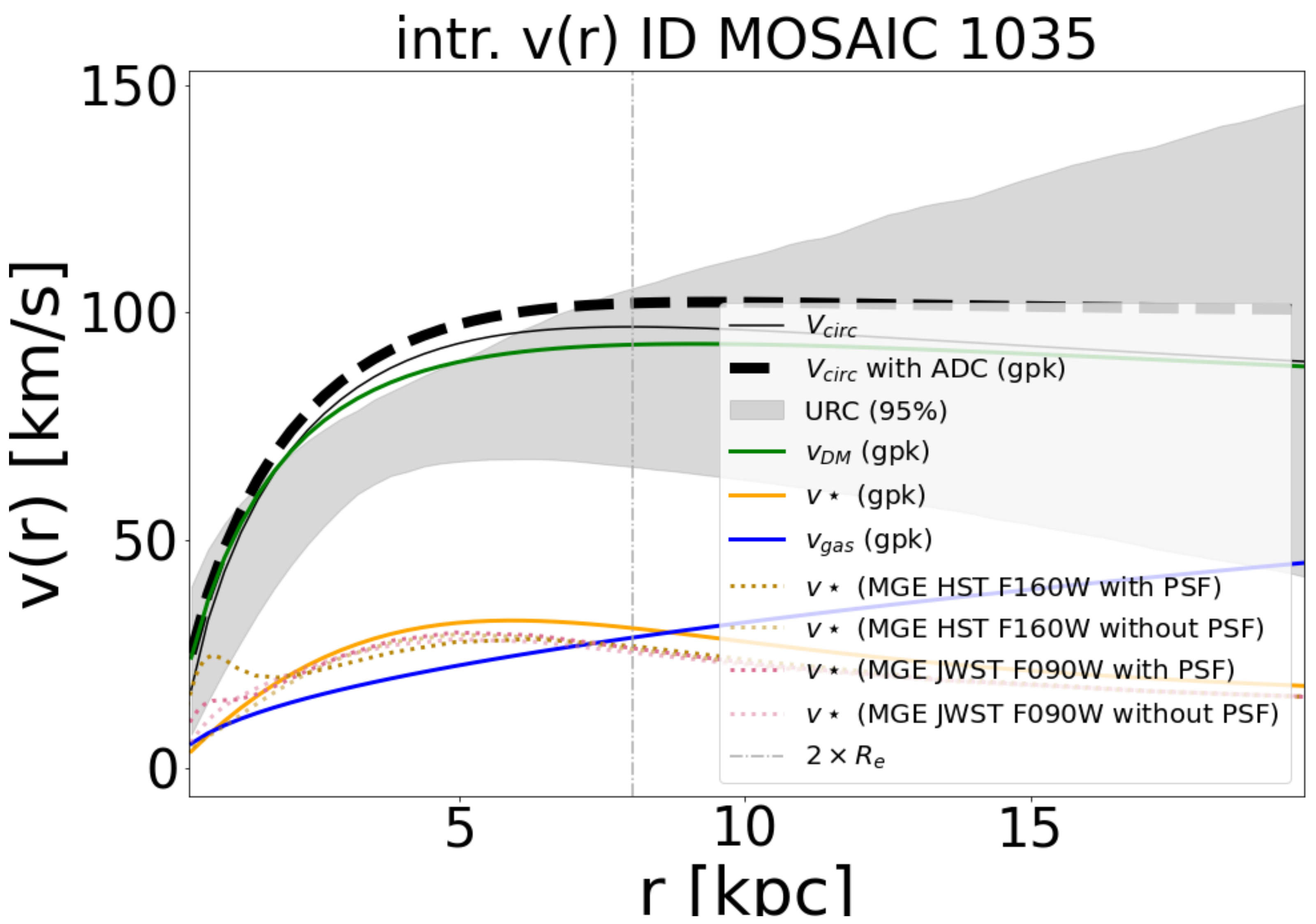
➡Apply 3D disk-halo decomposition on mock data cubes

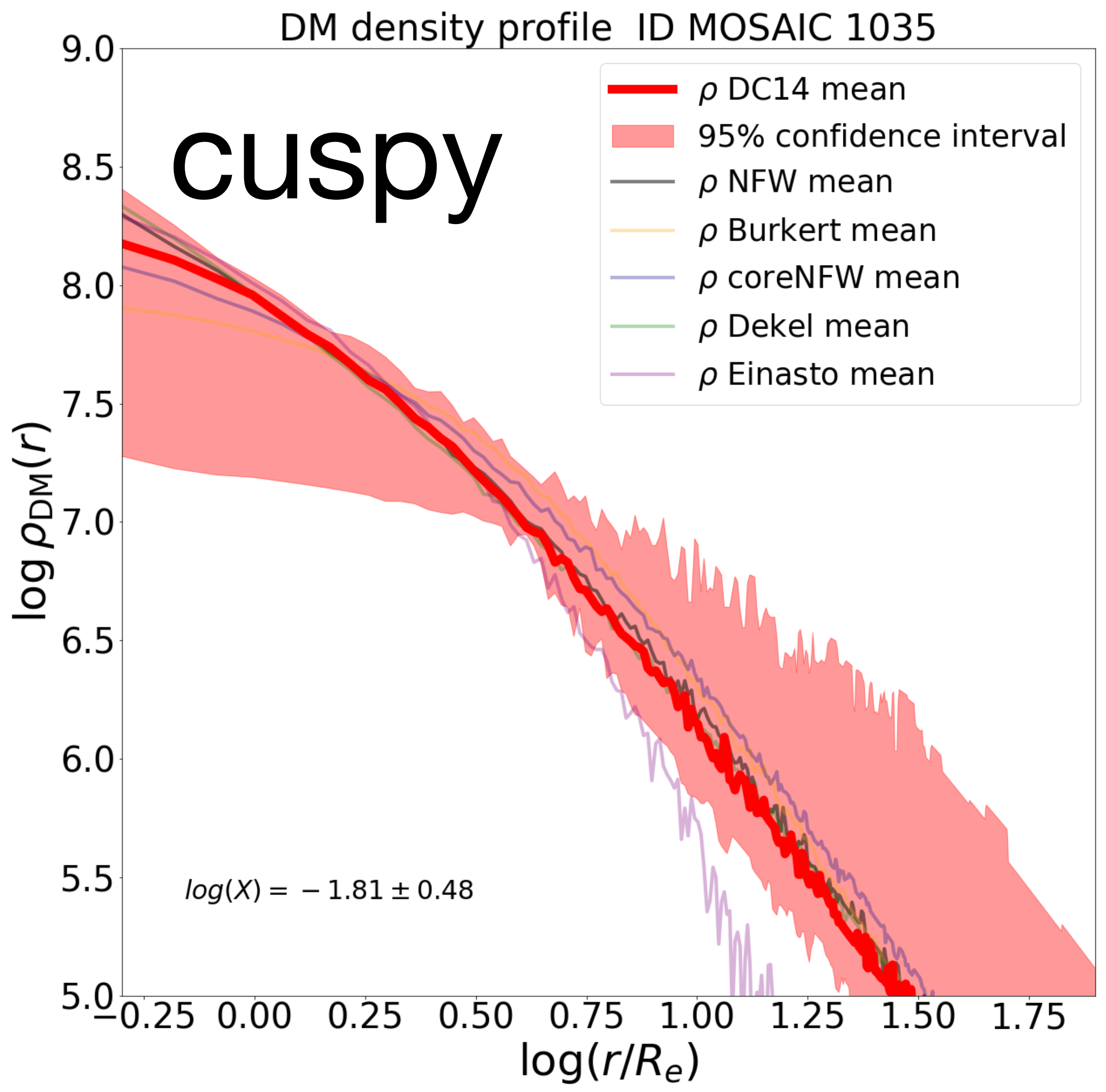


Results ‣ Examples of rotation curves & dark matter density profiles







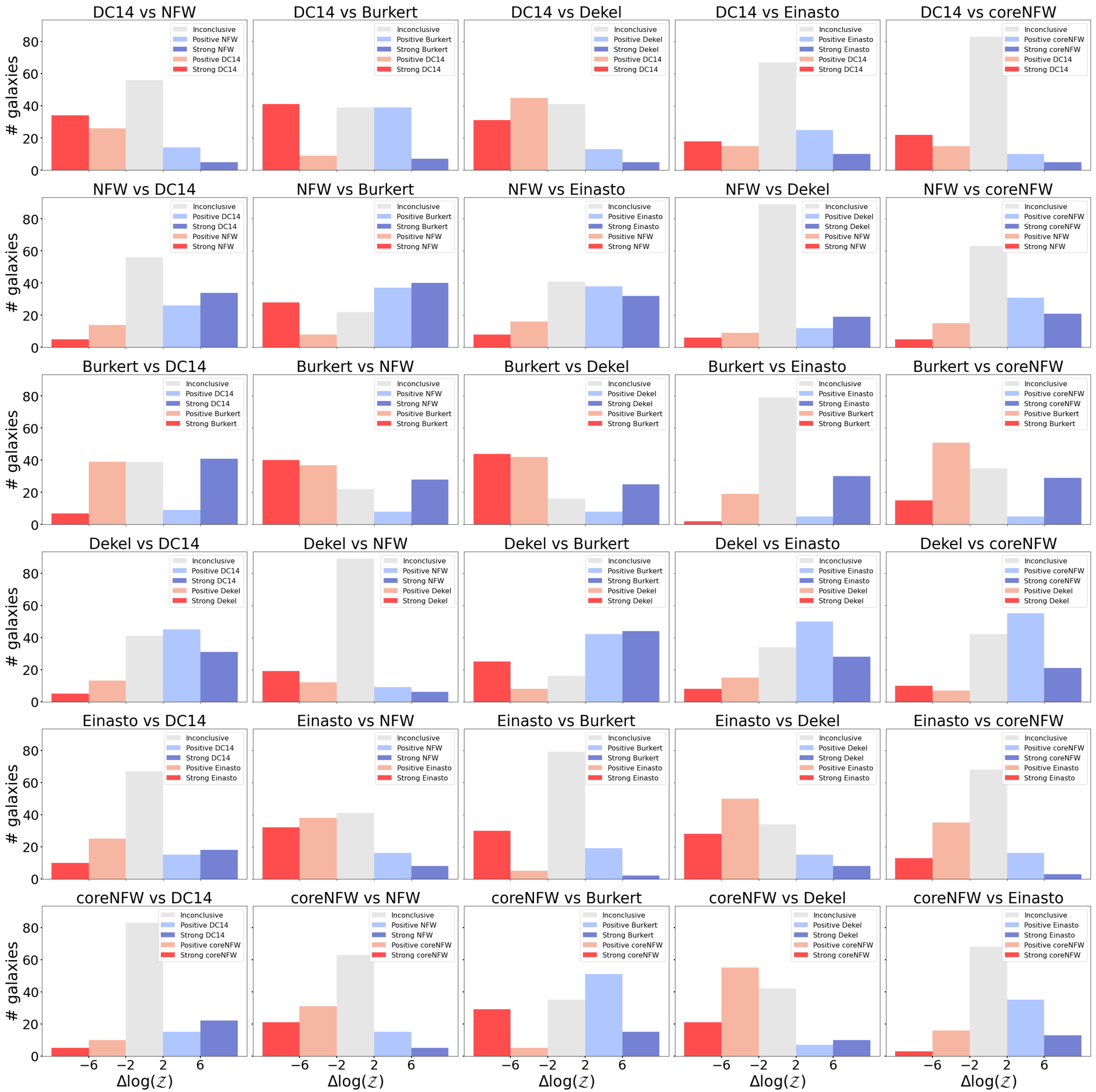


➡ **diversity of RCs similar to local universe**

Results

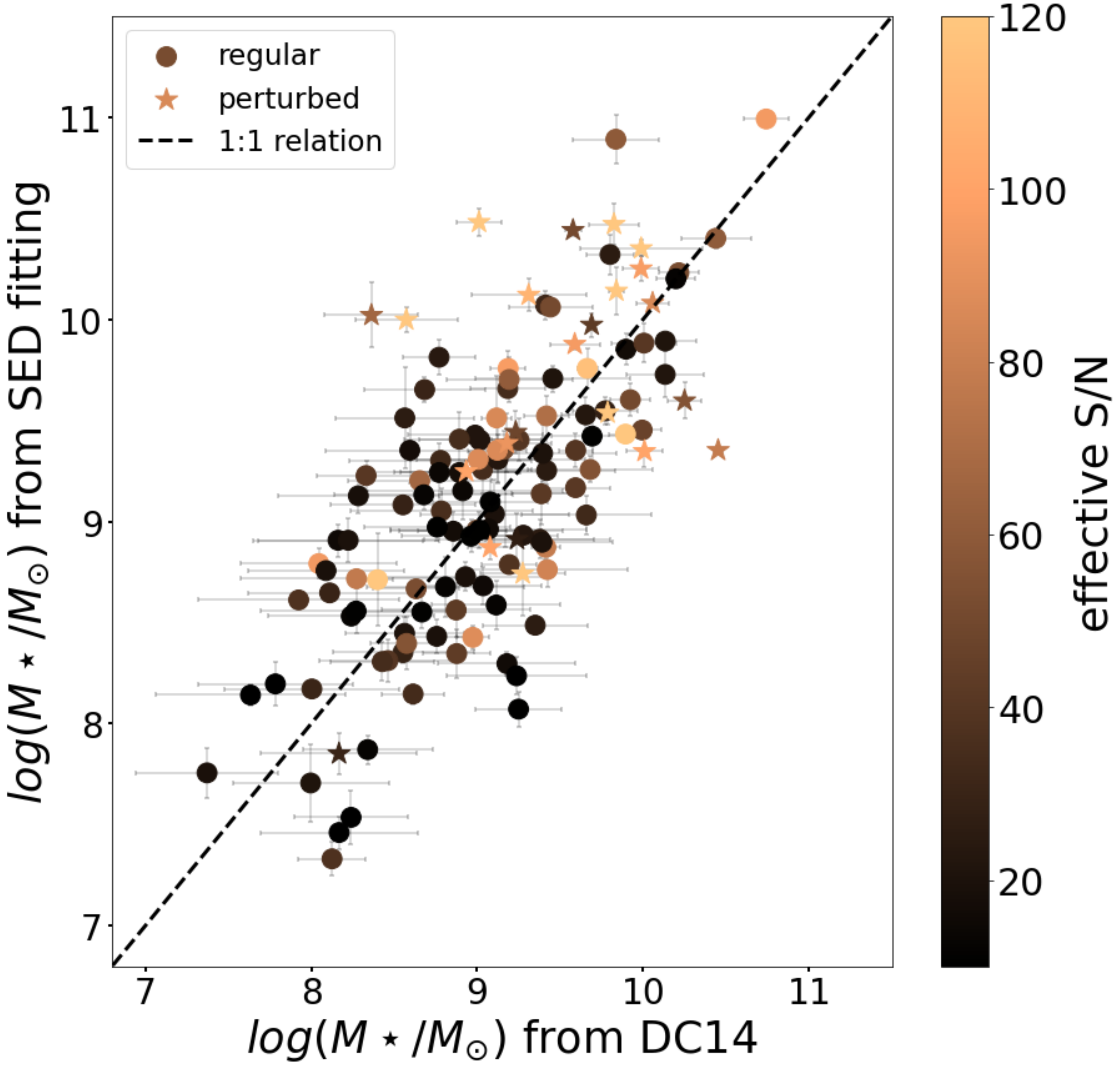
- Bayesian Model Comparison

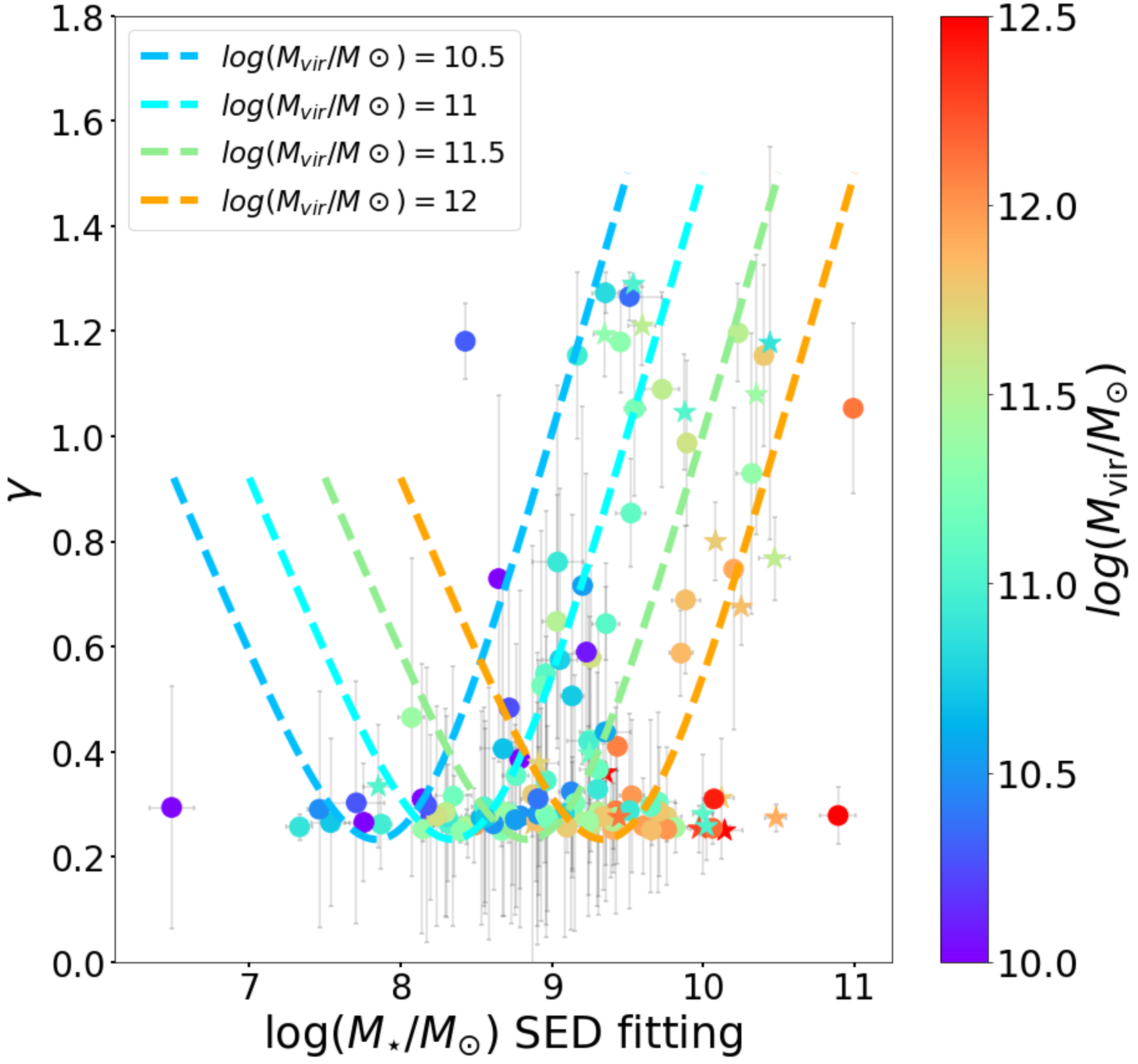
➡compared to NFW, Burkert, Dekel, Einasto and coreNFW, *DC14* performs as well or better in 85%, 66%, 86%, 74%, 88% of the sample, respectively



Results

- Consistency checks of DC14



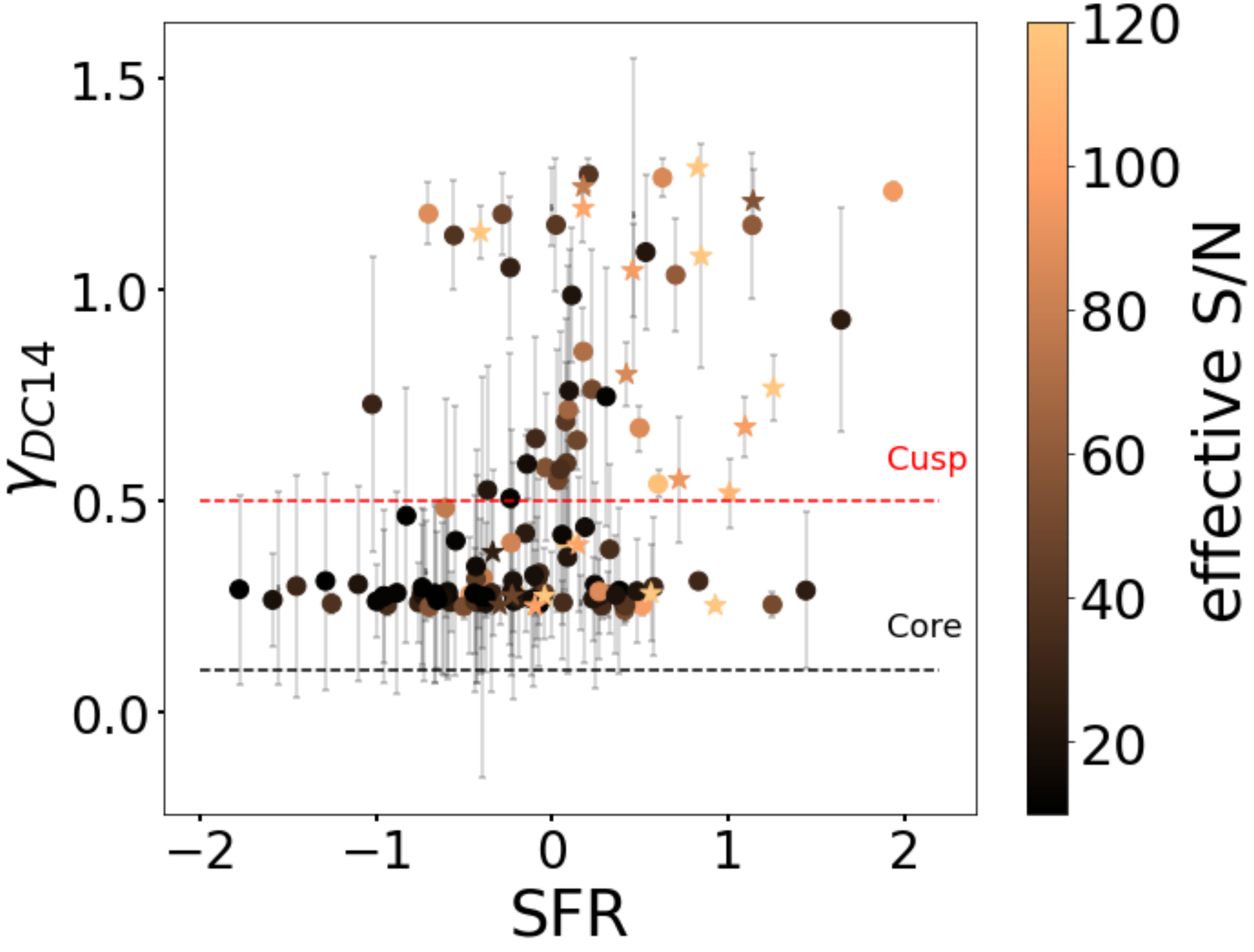


➡ Kinematic-based M* agree to SED M*

➡ Measured γ in accordance with DC14 expectations

Results

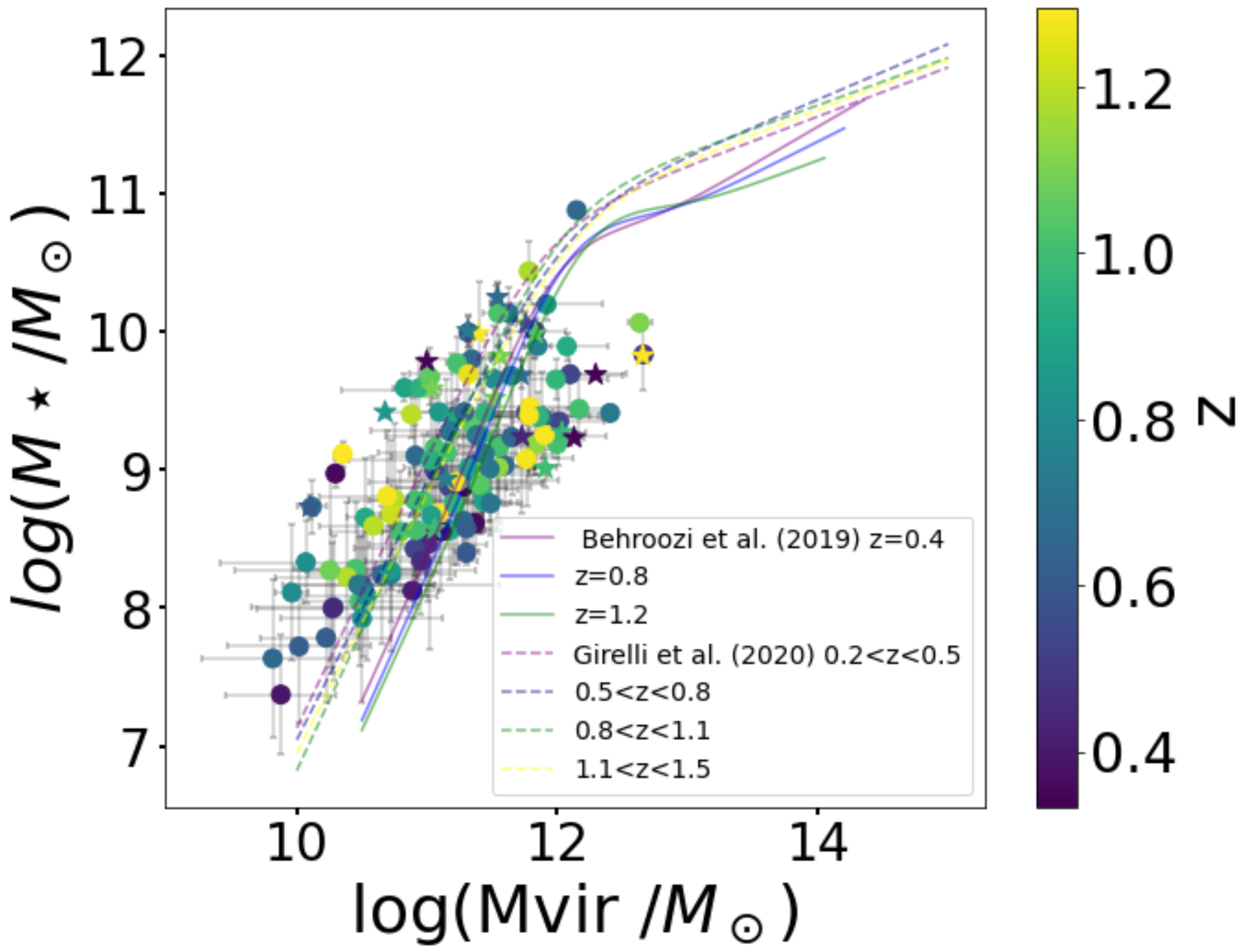
- Core/cusp formation:



➡ 66% of the sample has cored density profiles
➡no correlation with star formation rates

Results

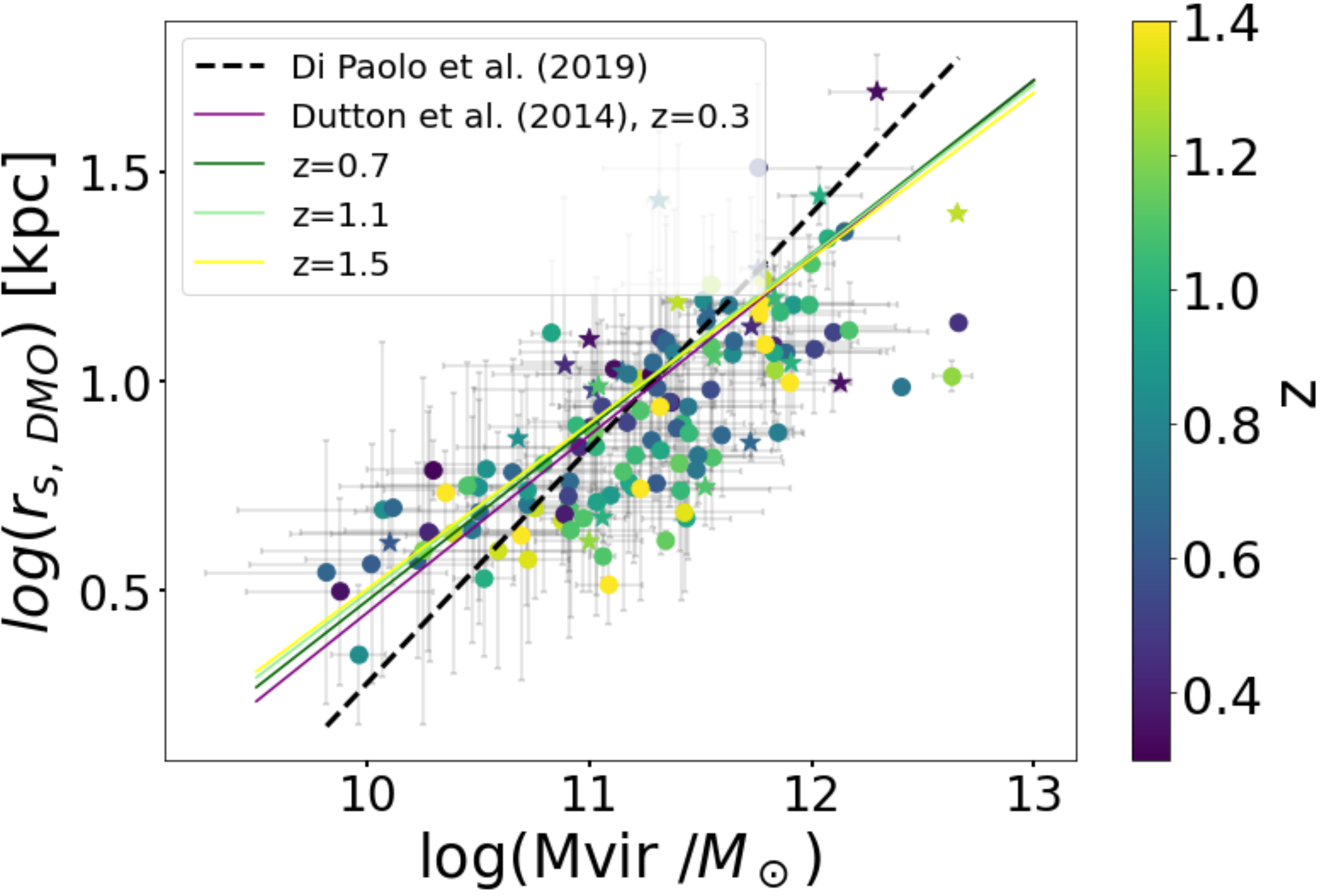
- Stellar Mass - Halo Mass relation:



➡Stellar mass-halo mass relation in agreement with the predictions from Behroozi+2019 and Girelli+2020

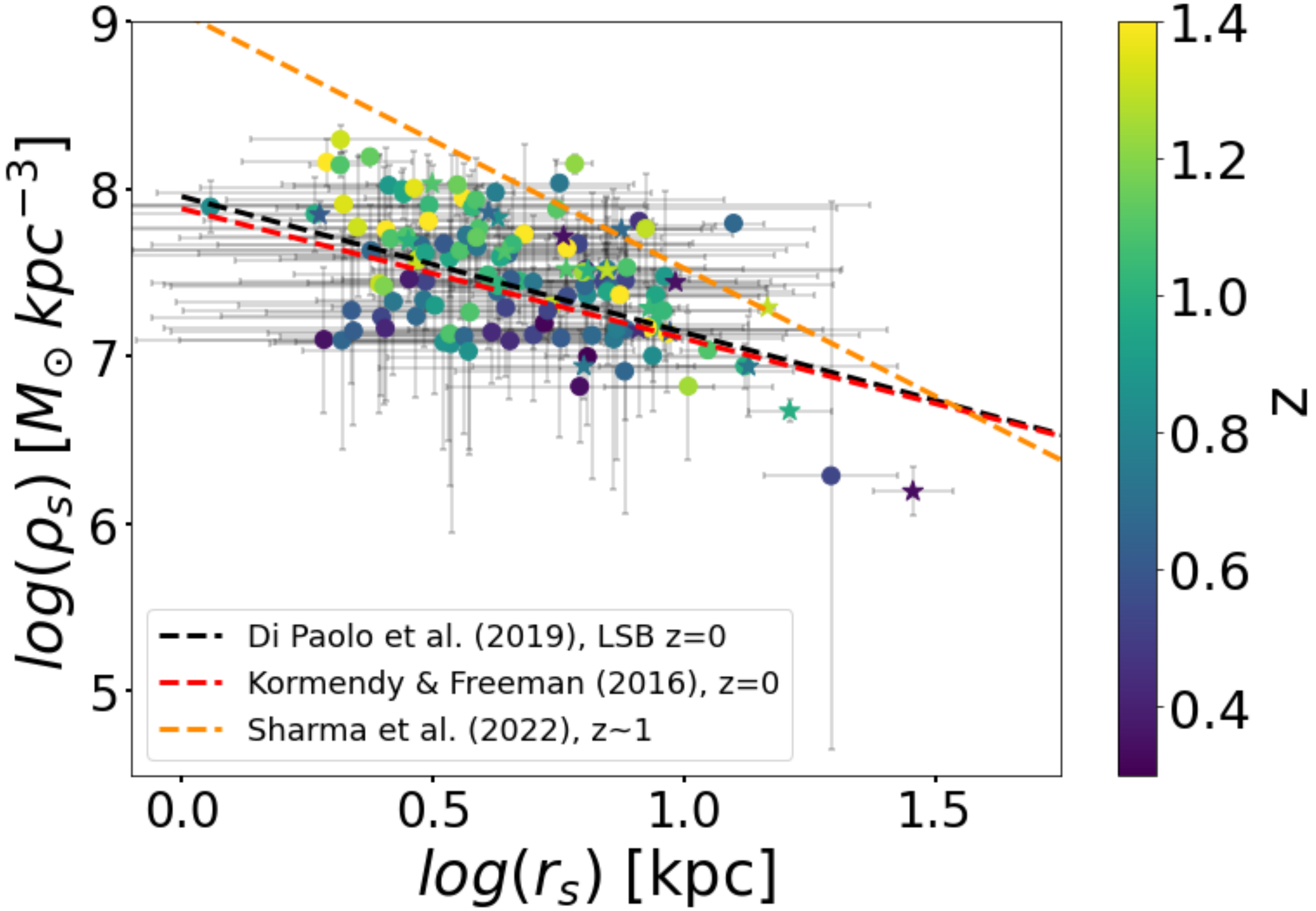
Results

- Halo scale radius - Halo Mass relation



➡ in agreement with observations & simulations

- Halo scale radius-density relation



$\rho \propto R^{-3(3+n)/(5+n)}$ $n \sim -2$ (Djorgovski 1992)

➡anticorrelation results from the expected scaling relation of dark matter predicted by hierarchical clustering

Results

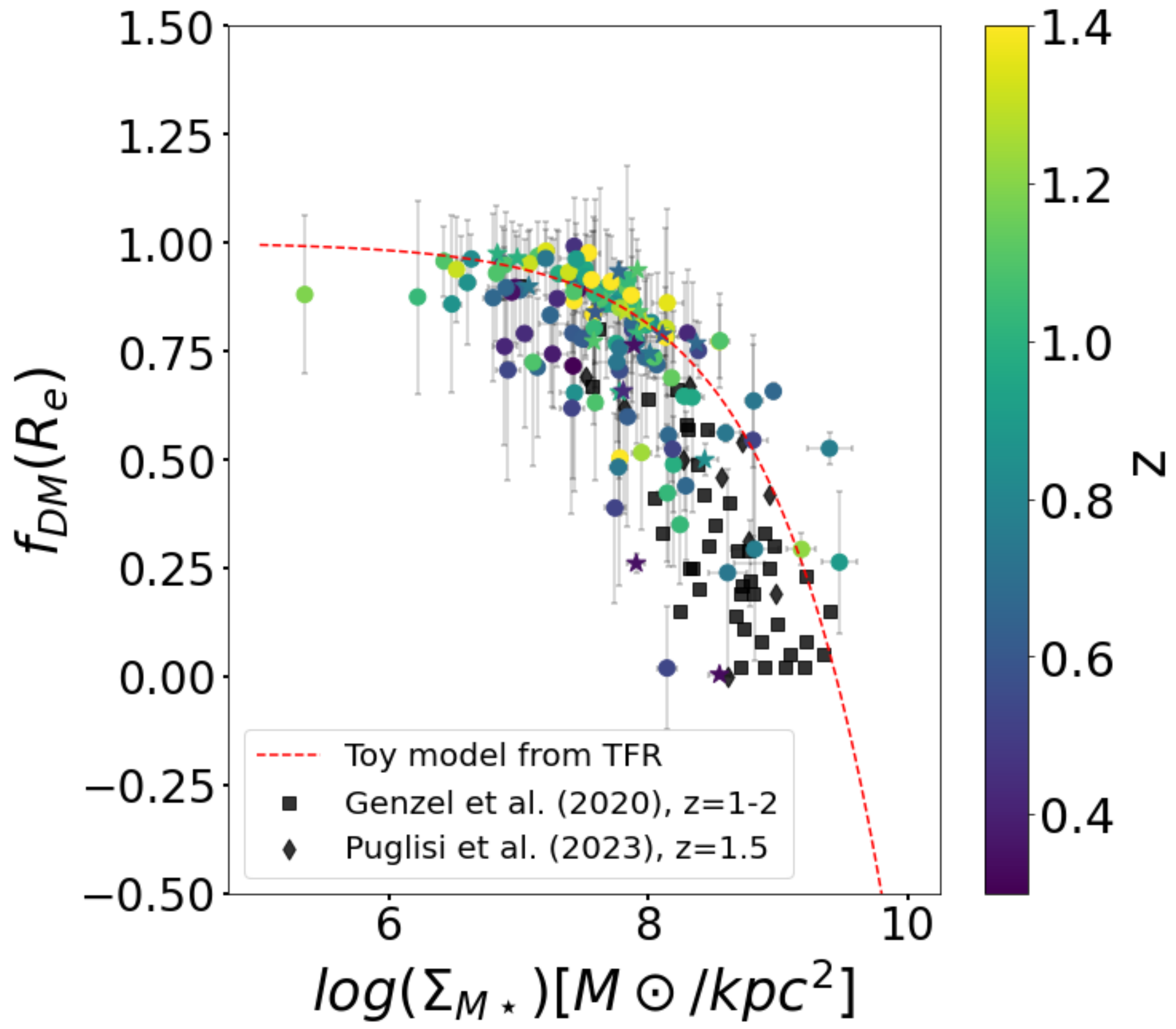
- halo scale radius - stellar mass relation
- core density - stellar mass relation
- DM surface density - stellar mass relation

➡Tentative evidence: Dark matter cores of z~0.85 SFGs are slightly smaller (~ 0.16 dex) and denser (~0.3 dex) than their local counterparts

Results

- Dark matter fractions

➡89% of the sample has dark matter fractions larger than 50% within Re



Conclusions

➡the generalised halo profile of Di Cintio+14 fits the data best

➡66% of the SFGs at z~0.85 have cored density profiles, with $\gamma<0.5$

➡no correlation between core/cusp formation and star formation rate

➡cores of z~0.85 SFGs are slightly smaller and denser than than at z=0

➡89% of the sample has dark matter fractions larger than 50%

Future prospects

➡Perform disk-halo decomposition on intermediate-z galaxies using alternative models of DM (self-interacting - Spergel +2000; axion-like fuzzy DM -Hu+2000) as well as modified gravity models such as Cotton Gravity (Harada +2022)