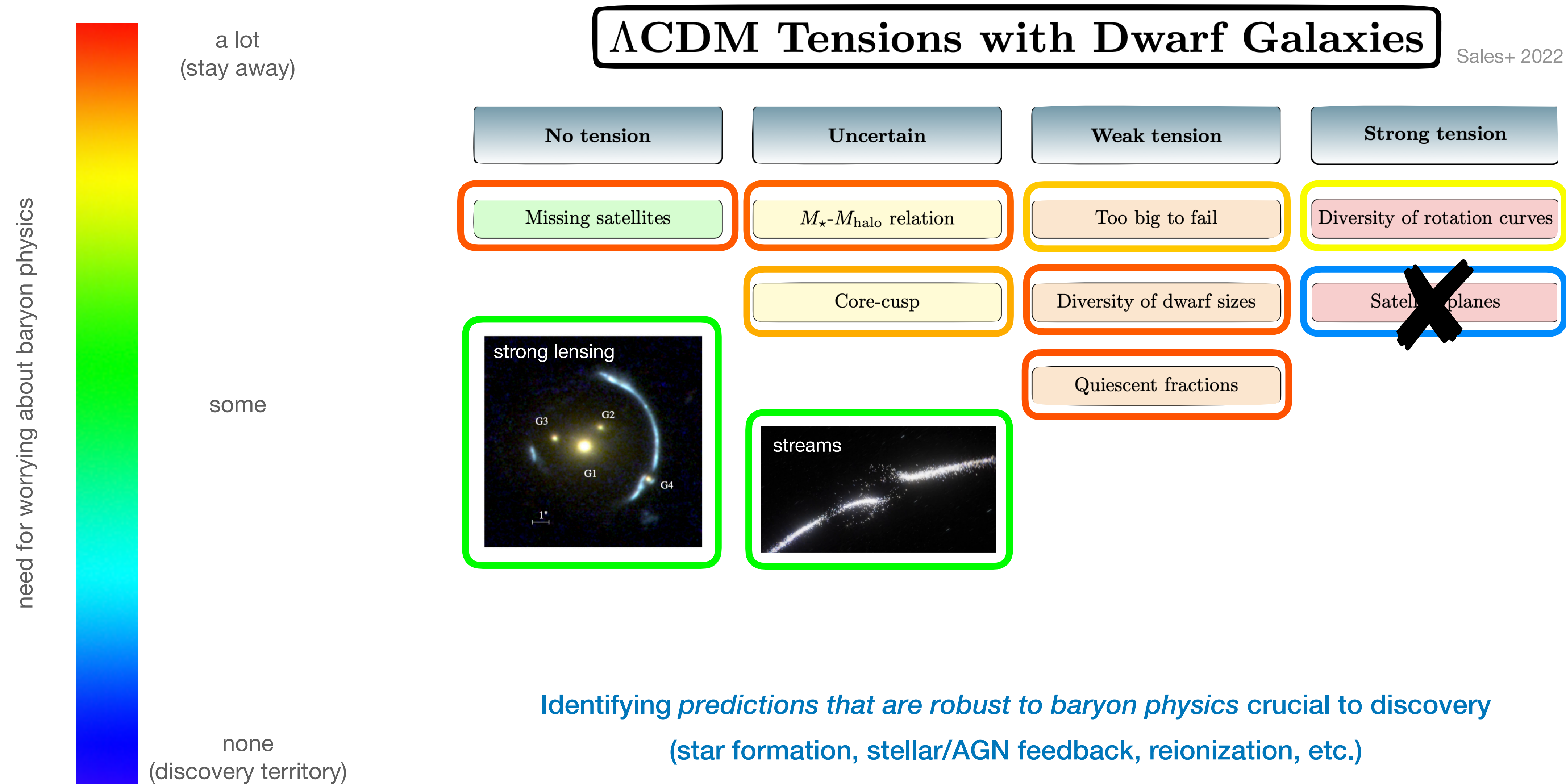


Feedback-independent constraints on halo structure: concentrations challenge CDM

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Heidelberg Institute for Theoretical Studies (HITS)
sebastian.trujillogomez@h-its.org

Collaborators:
Aurel Schneider, Nikos Gianniotis

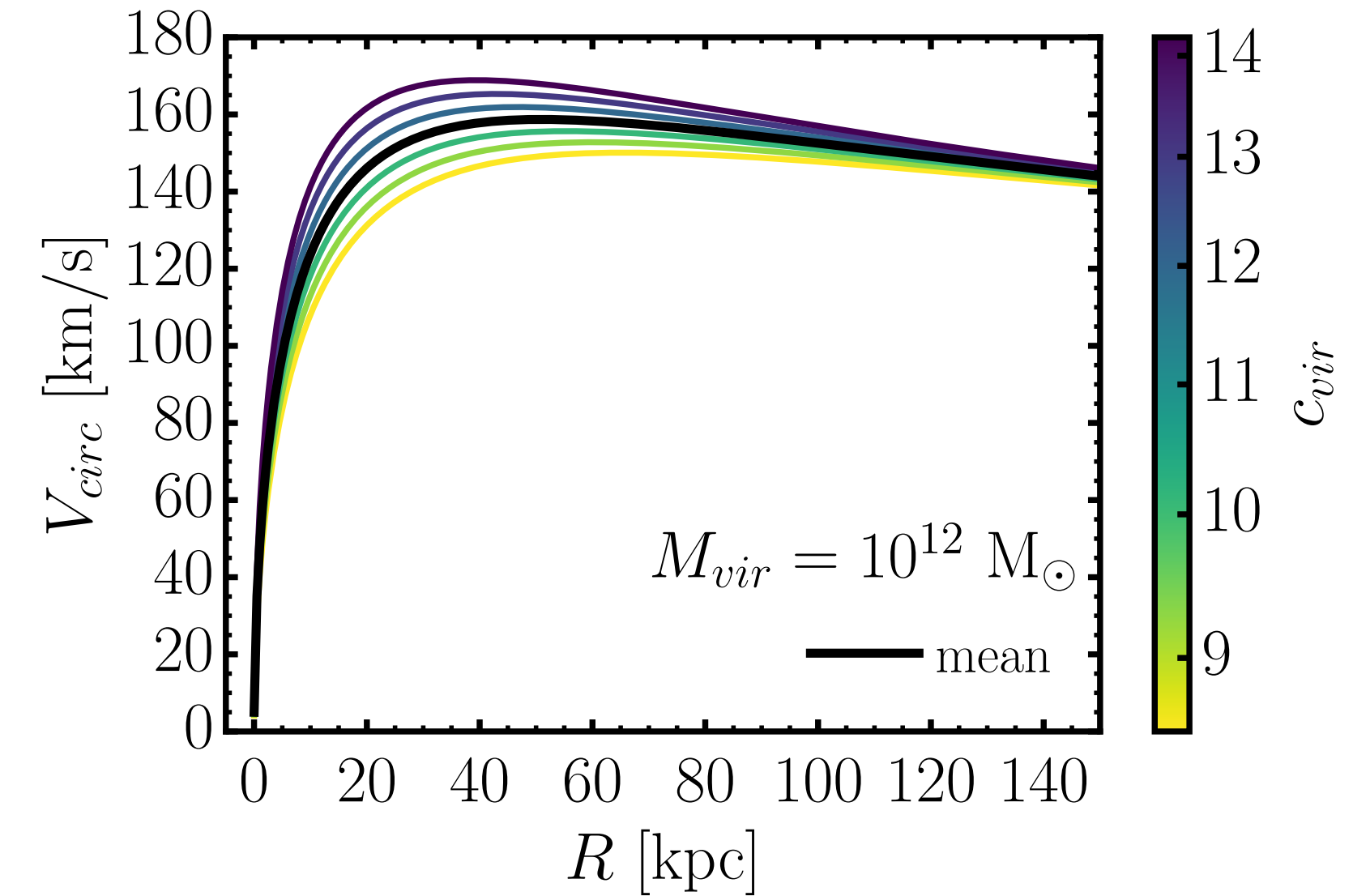
Small-scale problems in Λ CDM



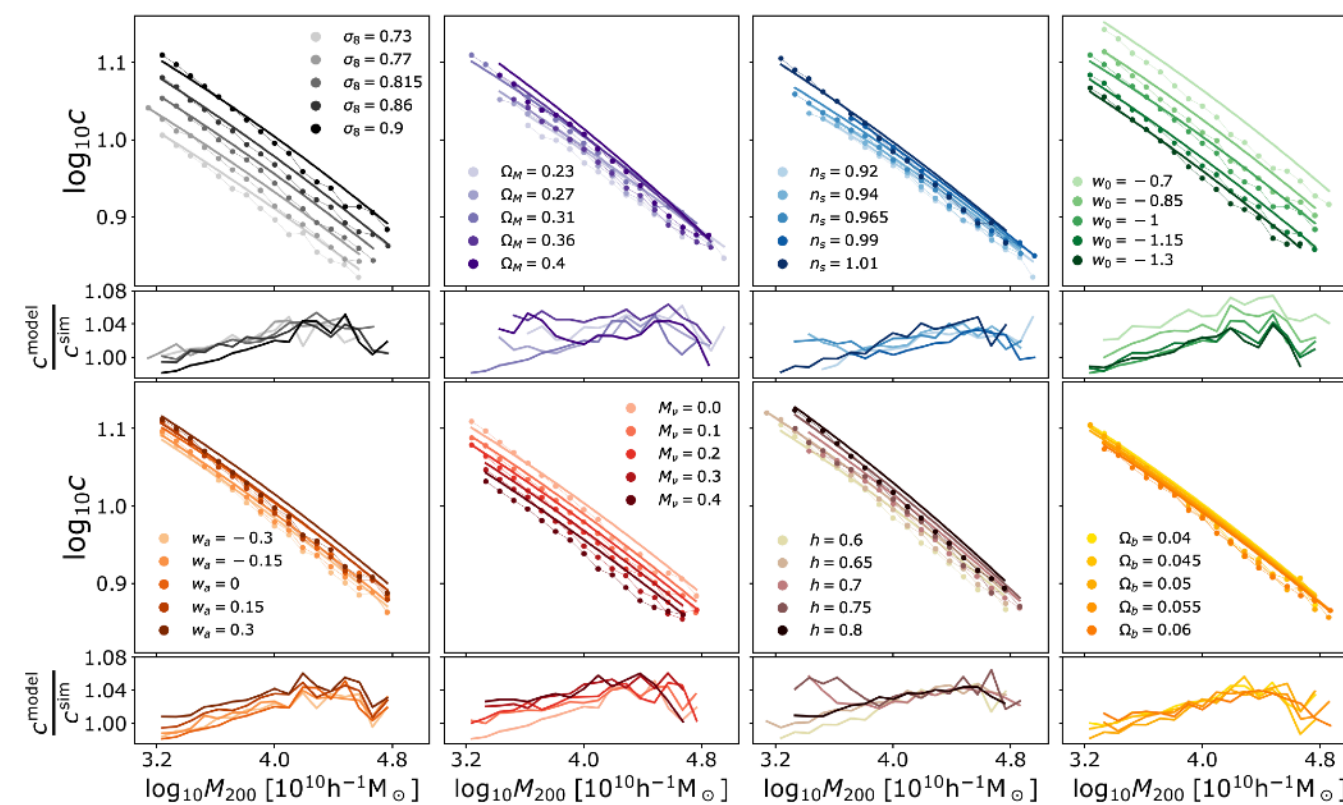
The experiment

Structure of cold DM halos

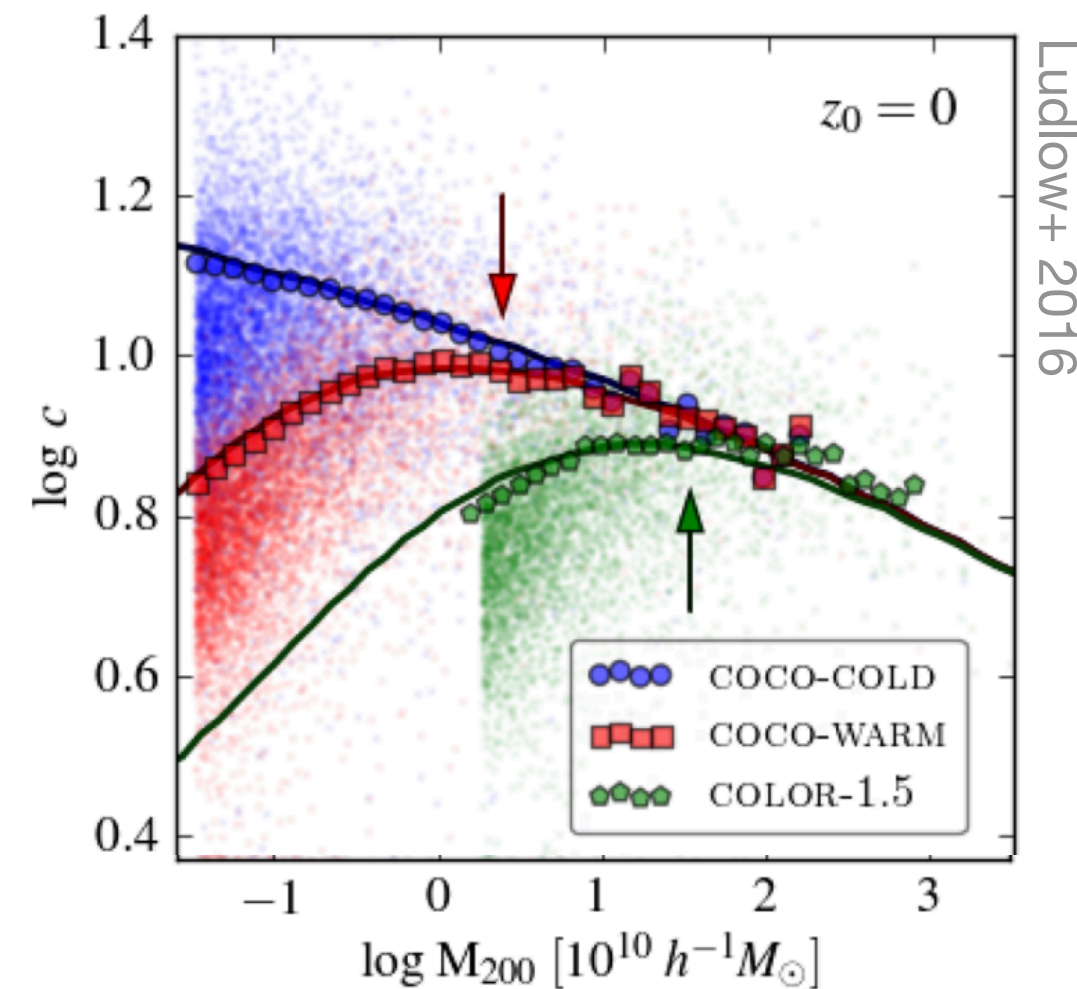
- 30 yr old prediction of CDM: self-similar density profiles (Navarro+ 1997)
- Halo concentration scales linearly with mass + 30% scatter from assembly history (e.g. Dutton & Macciò 2014)
- *Sensitive to cosmology and DM particle physics*



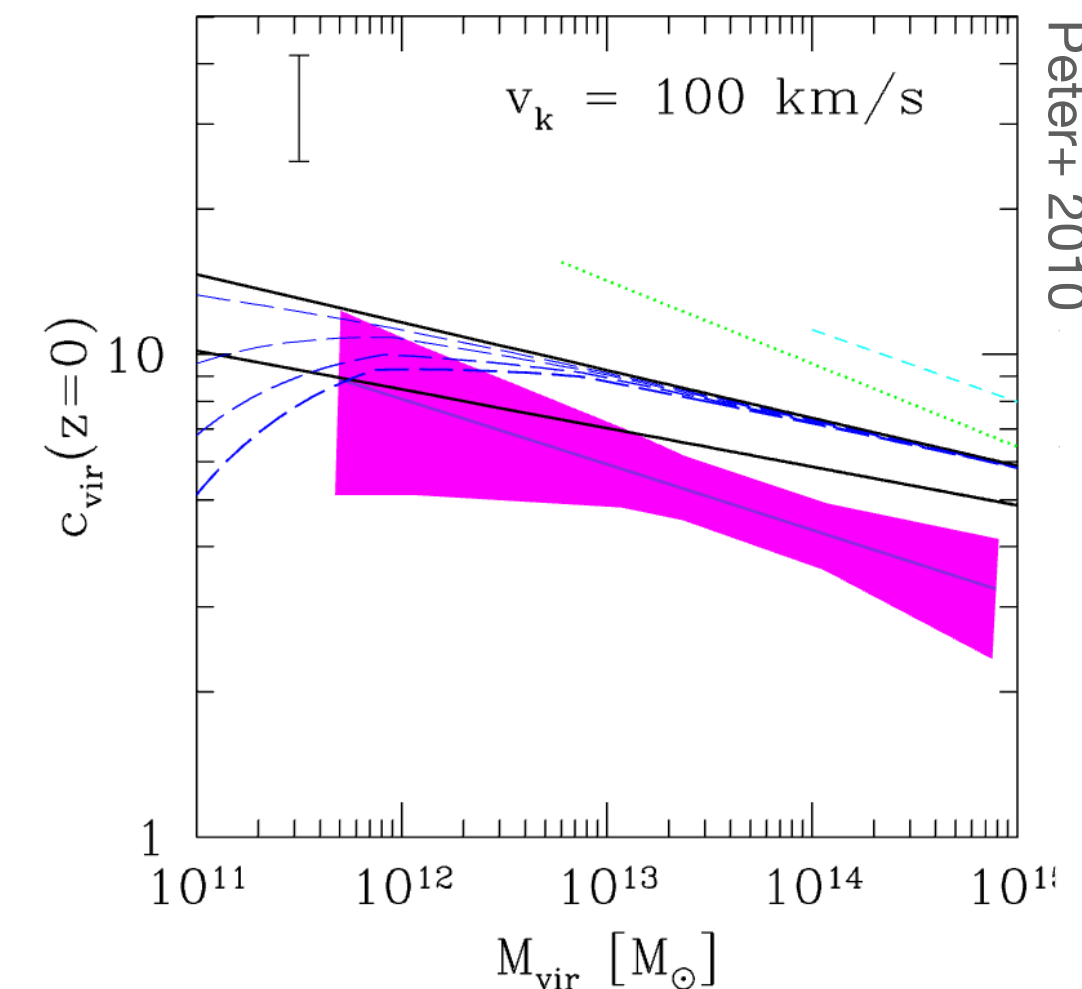
cosmology (Λ CDM)



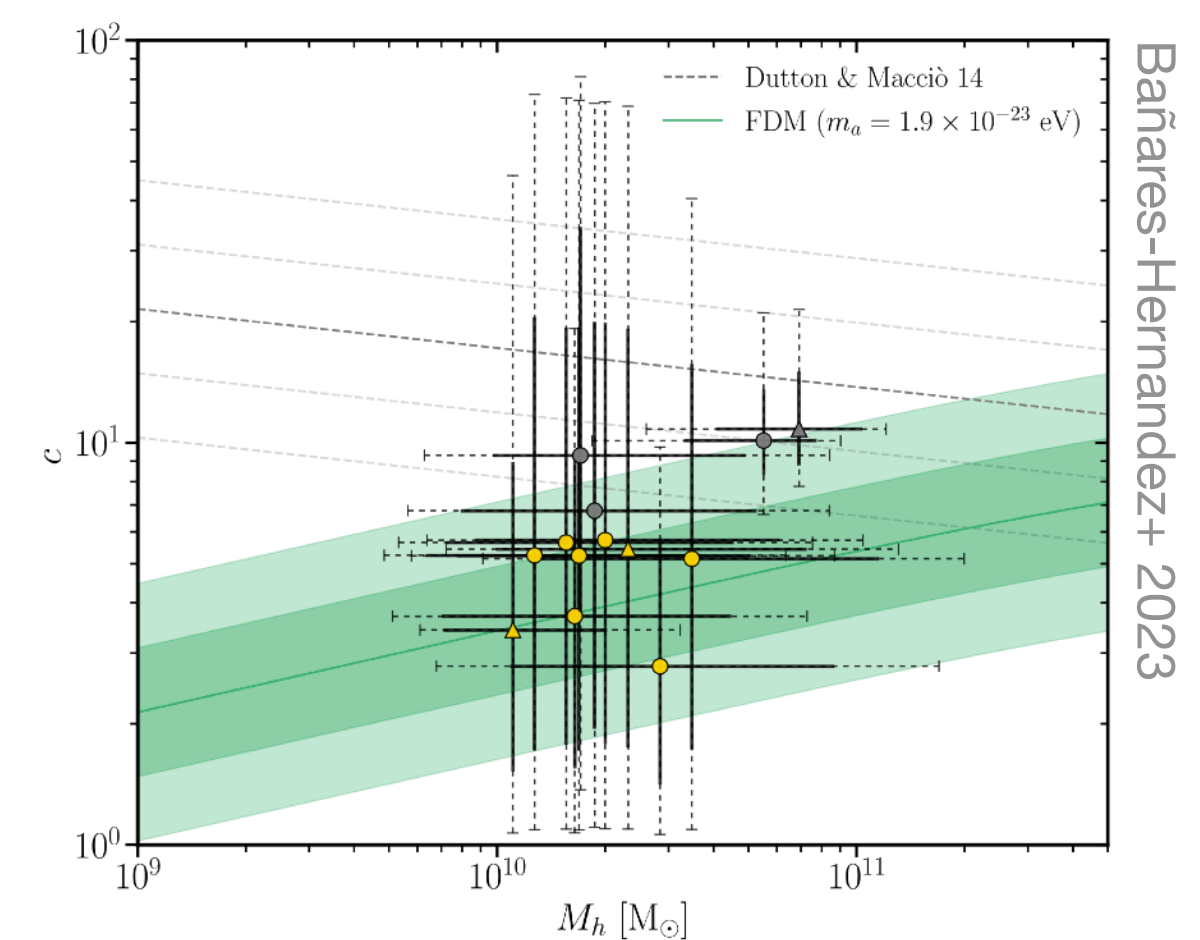
WDM



decaying DM



fuzzy (axion) DM



A golden era for cosmology with galaxies

Next-generation observatories data deluge:

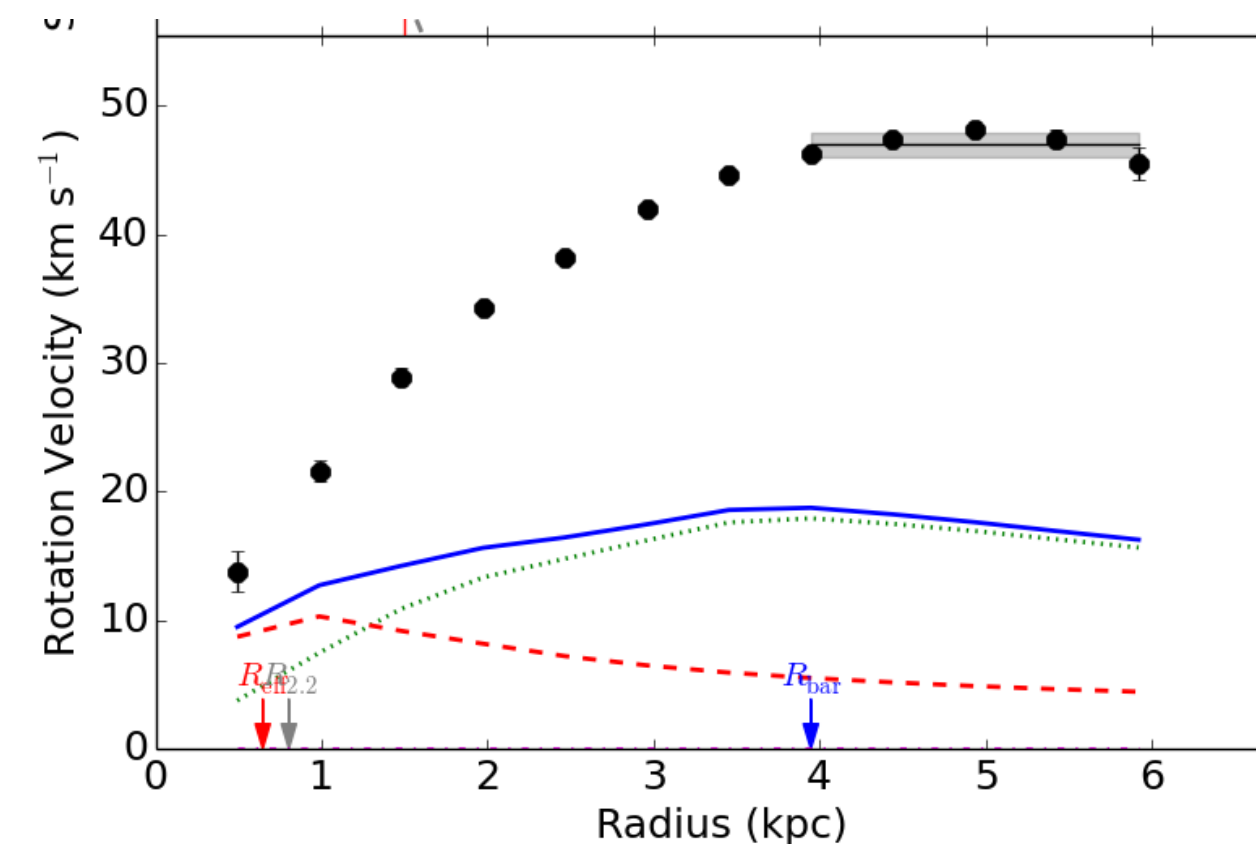
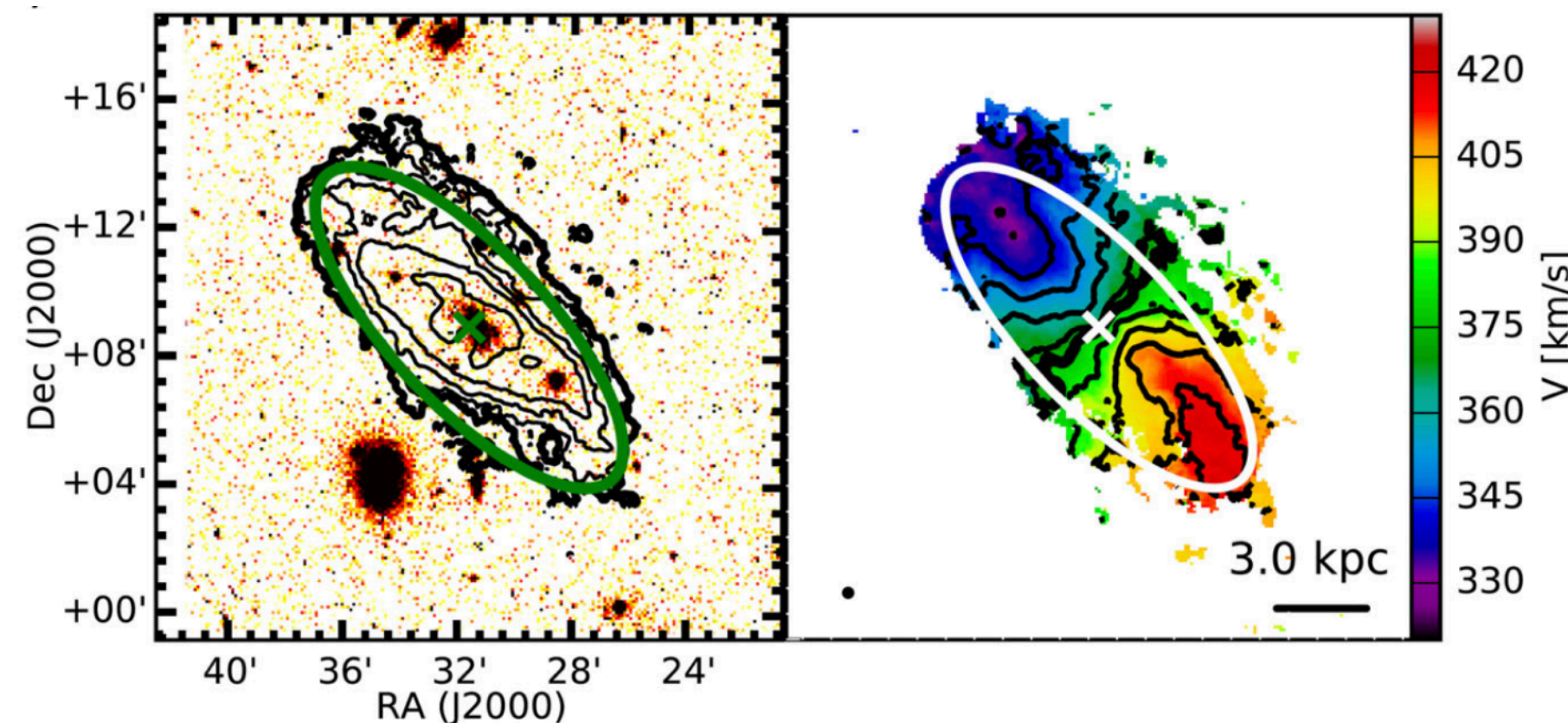
- Euclid: deep + wide field high-res imaging ($\sim 10^9$ galaxies)
- Roman: very deep + wide NIR imaging ($\sim 10^9$ galaxies)
- SKA: deep + wide high-res HI surveys ($> 5 \times 10^3$ rotation curves)

Wide-field high-res HI surveys + NIR maps:

mass models of thousands of *isolated* galaxies
(volume-limited)

Solve for the density directly from the cold gas kinematics

$$\nabla^2 \Phi = 4\pi G \rho$$



A golden era for cosmology with galaxies

Publications of the Astronomical Society of Australia (2022), 39, e059, 17 pages
doi:[10.1017/pasa.2022.43](https://doi.org/10.1017/pasa.2022.43)

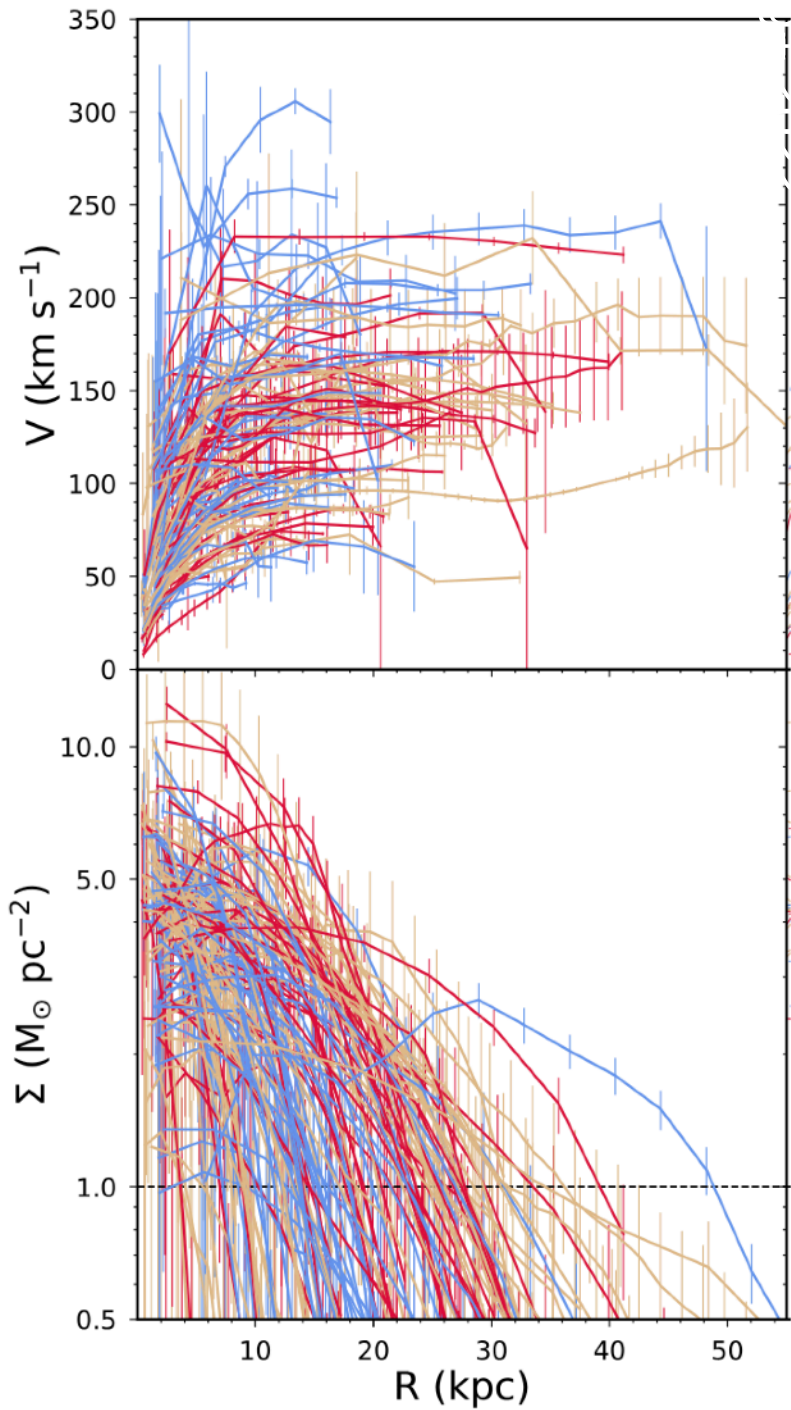
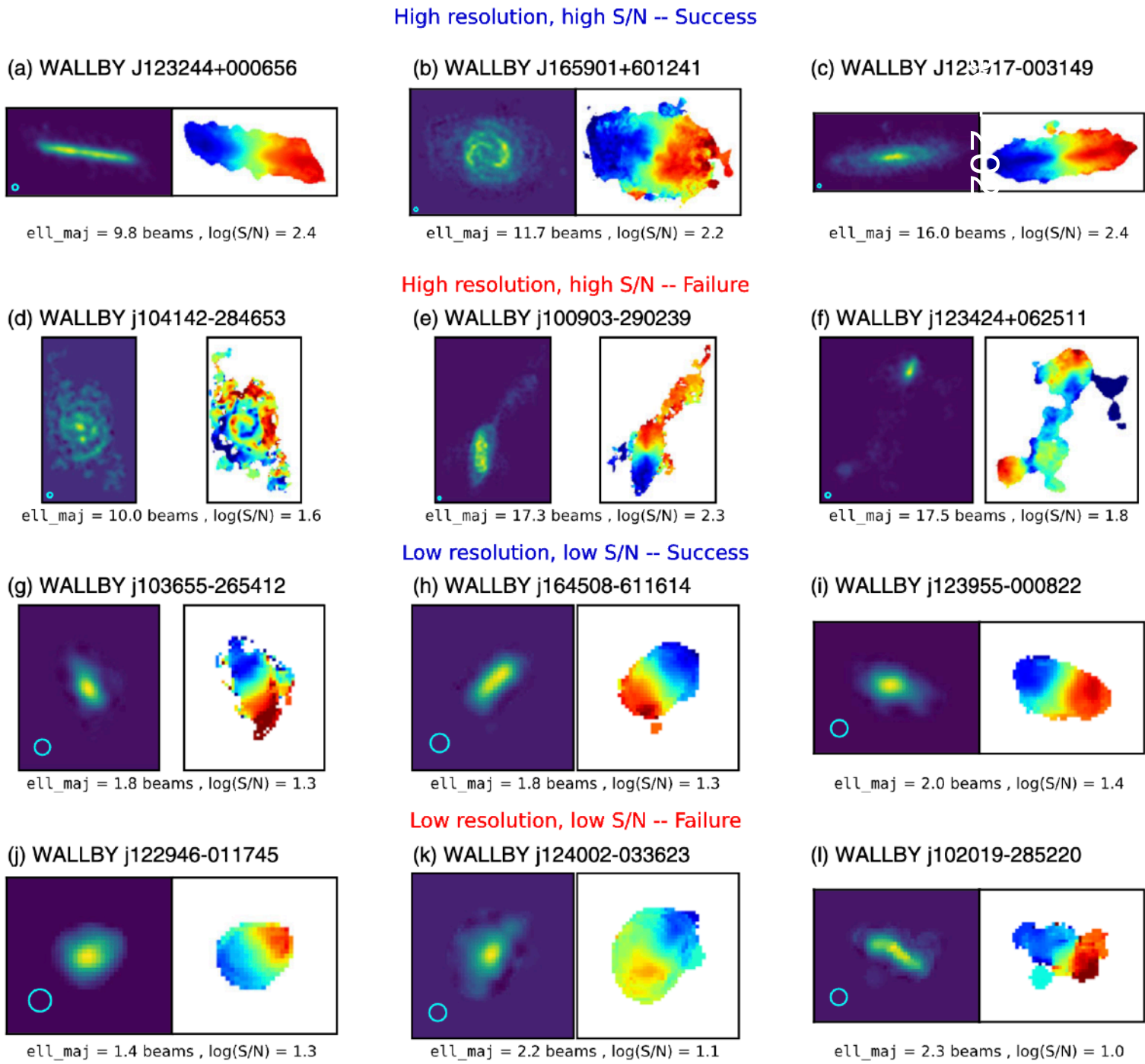


Research Article

WALLABY Pilot Survey: Public release of HI kinematic models for more than 100 galaxies from phase 1 of ASKAP pilot observations

N. Deg¹, K. Spekkens², T. Westmeier^{3,4}, T. N. Reynolds^{3,4}, P. Venkataraman⁵, S. Goliath⁶, A. X. Shen^{7,8}, R. Halloran¹, A. Bosma⁹, B. Catinella^{3,4}, W. J. G. de Blok^{10,11,12}, H. Dénes¹⁰, E. M. DiTeodoro^{13,14}, A. Elagali¹⁵, B.-Q. For^{3,4}, C. Howlett¹⁶, G. I. G. Józsa^{17,18}, P. Kamphuis¹⁹, D. Kleiner²⁰, B. Koribalski^{21,22}, K. Lee-Waddell^{3,7}, F. Lelli²³, X. Lin²⁴, C. Murugesan^{4,7}, S. Oh^{25,26}, J. Rhee^{3,4}, T. C. Scott²⁷, L. Staveley-Smith^{3,4}, J. M. van der Hulst¹², L. Verdes-Montenegro²⁸, J. Wang²⁹ and O. I. Wong^{3,4,7}

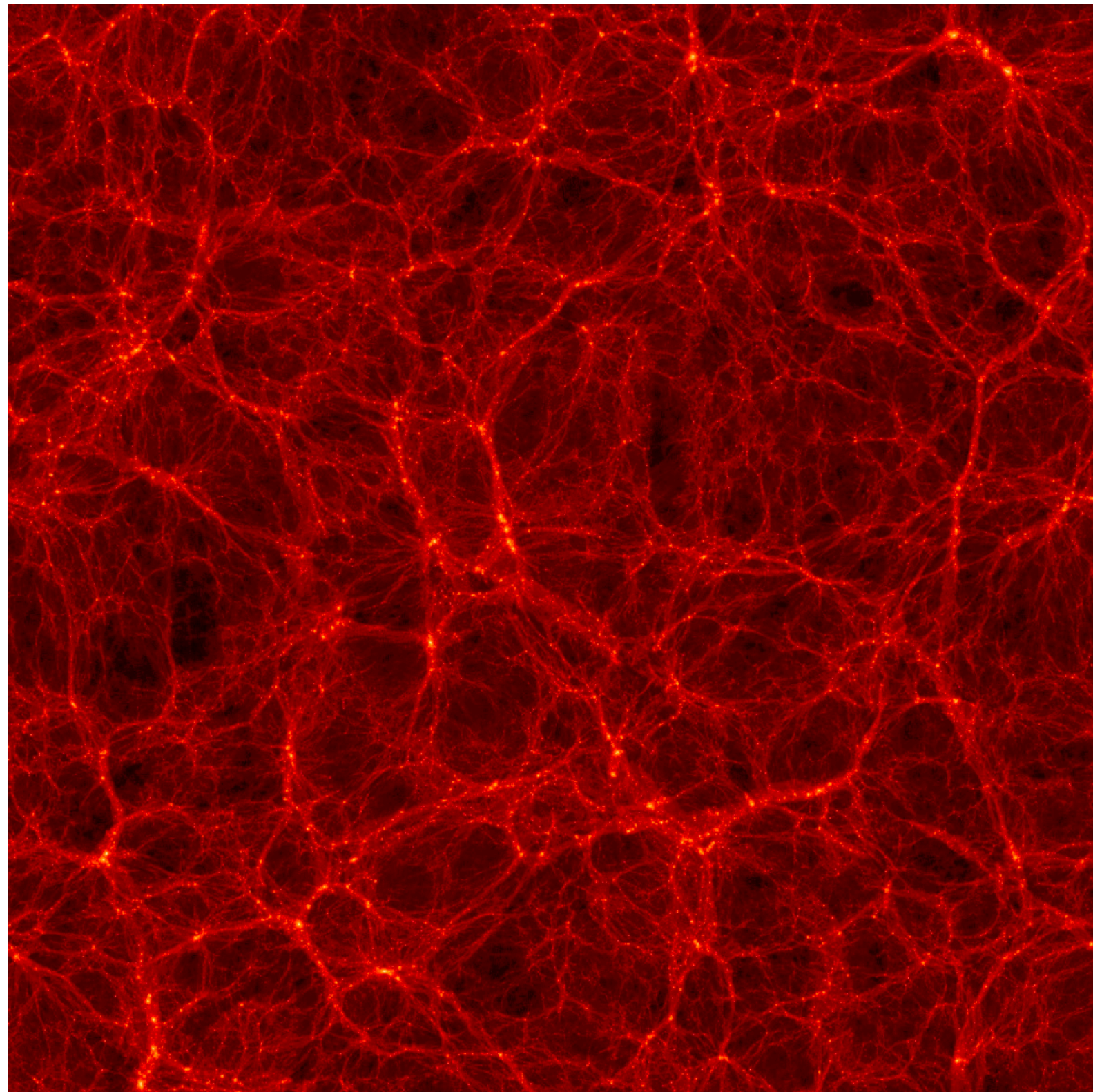
WALLABY Survey (Australian SKA Pathfinder)



Can we do this experiment with current data?

1. Pick your favorite cosmological simulation and make testable predictions

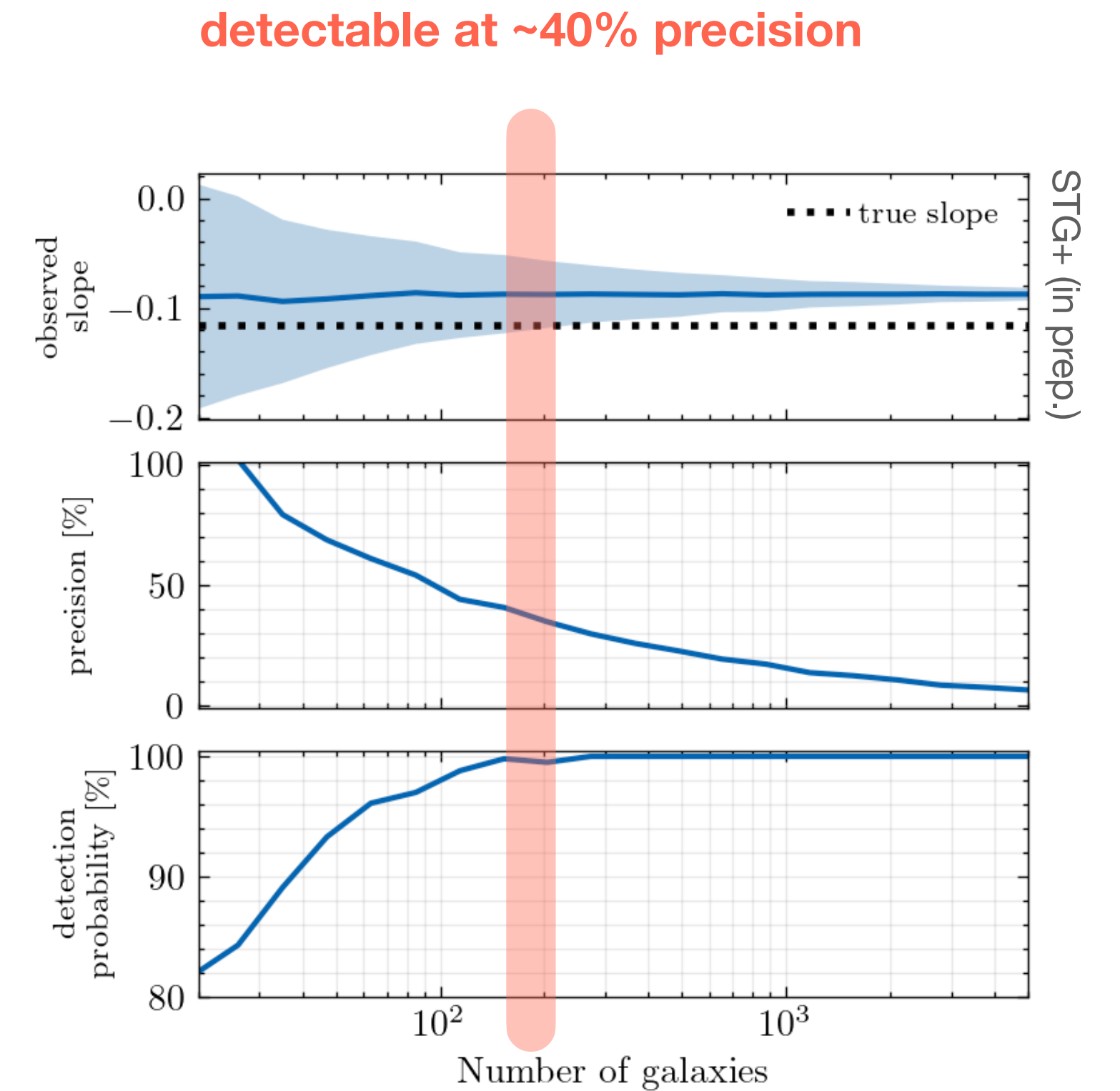
~0.5 million halos in observed mass range



Bolshoi (Klypin, STG, Primack 2010)

10^3 synthetic experiments:

1. randomly select N halos
3. inject noise according to uncertainties in (M_h, C)
5. fit $C - M_h$ slope



Can we do this experiment with current data?

2. Compile all available galaxy mass models from the past ~50 years



MNRAS **466**, 4159–4192 (2017)
Advance Access publication 2016 December 17

LITTLE THINGS in 3D: robust determination of the circular velocity of dwarf irregular galaxies

G. Iorio,^{1,2★} F. Fraternali,^{1,3} C. Nipoti,¹ E. Di Teodoro,⁴ J. I. Read⁵ and G. Battaglia^{6,7}

Mon. Not. R. Astron. Soc. **340**, 12–28 (2003)

A high-resolution rotation curve of NGC 6822: a test-case for cold dark matter

D. T. F. Weldrake,¹ W. J. G. de Blok^{2★†} and F. Walter^{3‡}

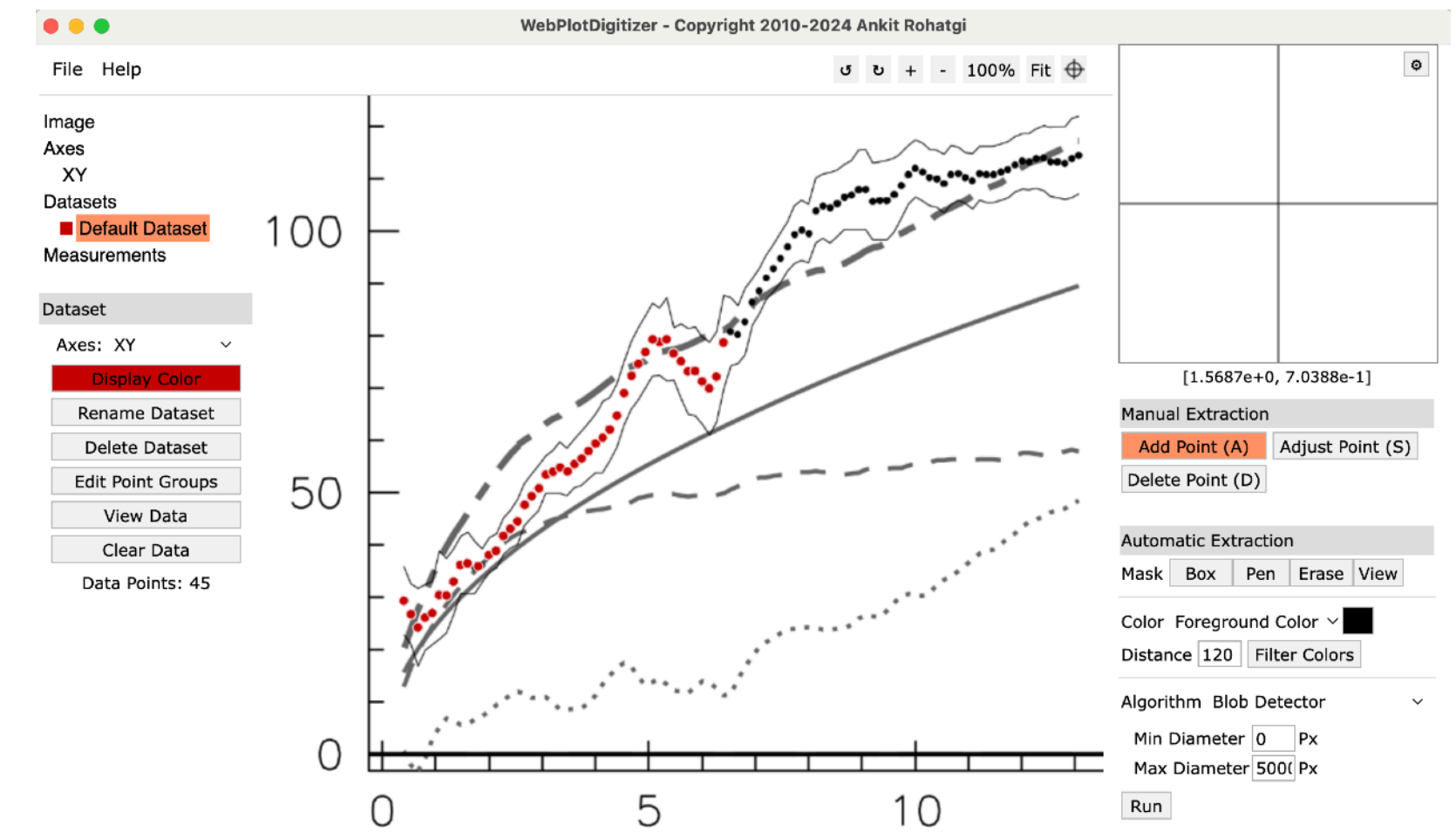
MNRAS **518**, 6340–6354 (2023)
Advance Access publication 2022 December 9

Dark matter halos and scaling relations of extremely massive spiral galaxies from extended H I rotation curves

Enrico M. Di Teodoro^{1,2,3*}, Lorenzo Posti⁴, S. Michael Fall², Patrick M. Ogle², Thomas Jarrett⁵, Philip N. Appleton⁶, Michelle E. Cluver⁷, Martha P. Haynes⁸ and Ute Lisenfeld^{9,10}

235
extended rotation curves
+
baryonic mass models

data accessibility is far from ideal



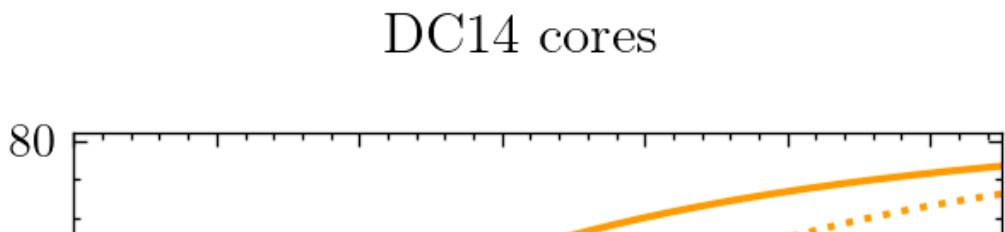
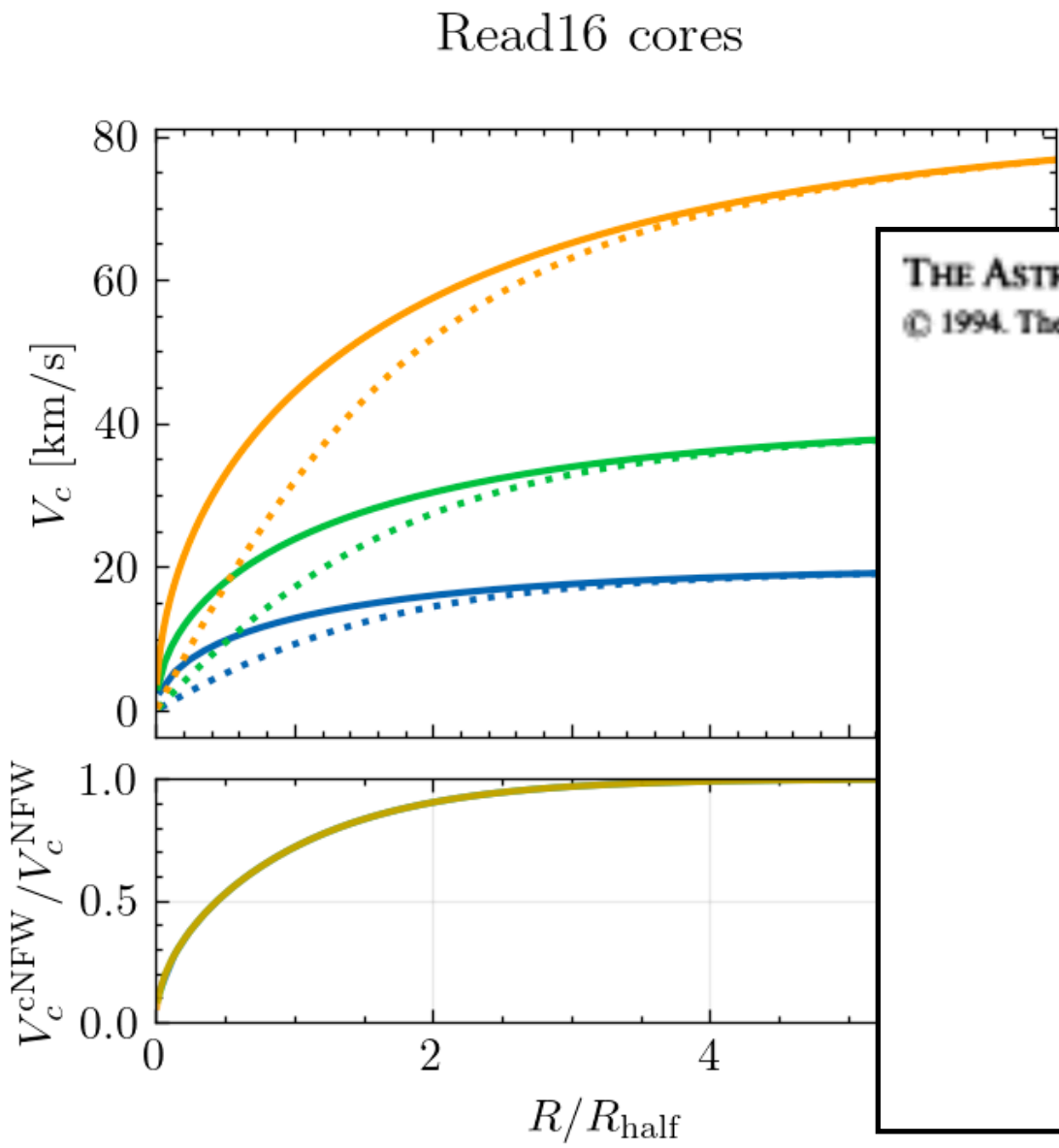
Webplotdigitizer

Can we do this experiment with current data?

3. Model effects of baryons on DM: need to solve galaxy formation first 🥲

... or inner slope

Most simulations with dense ISM produce cores, but *no agreement on extent*



THE ASTROPHYSICAL JOURNAL, 427:L1–L4, 1994 May 20
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OBSERVATIONAL AND THEORETICAL CONSTRAINTS ON SINGULAR DARK MATTER HALOS

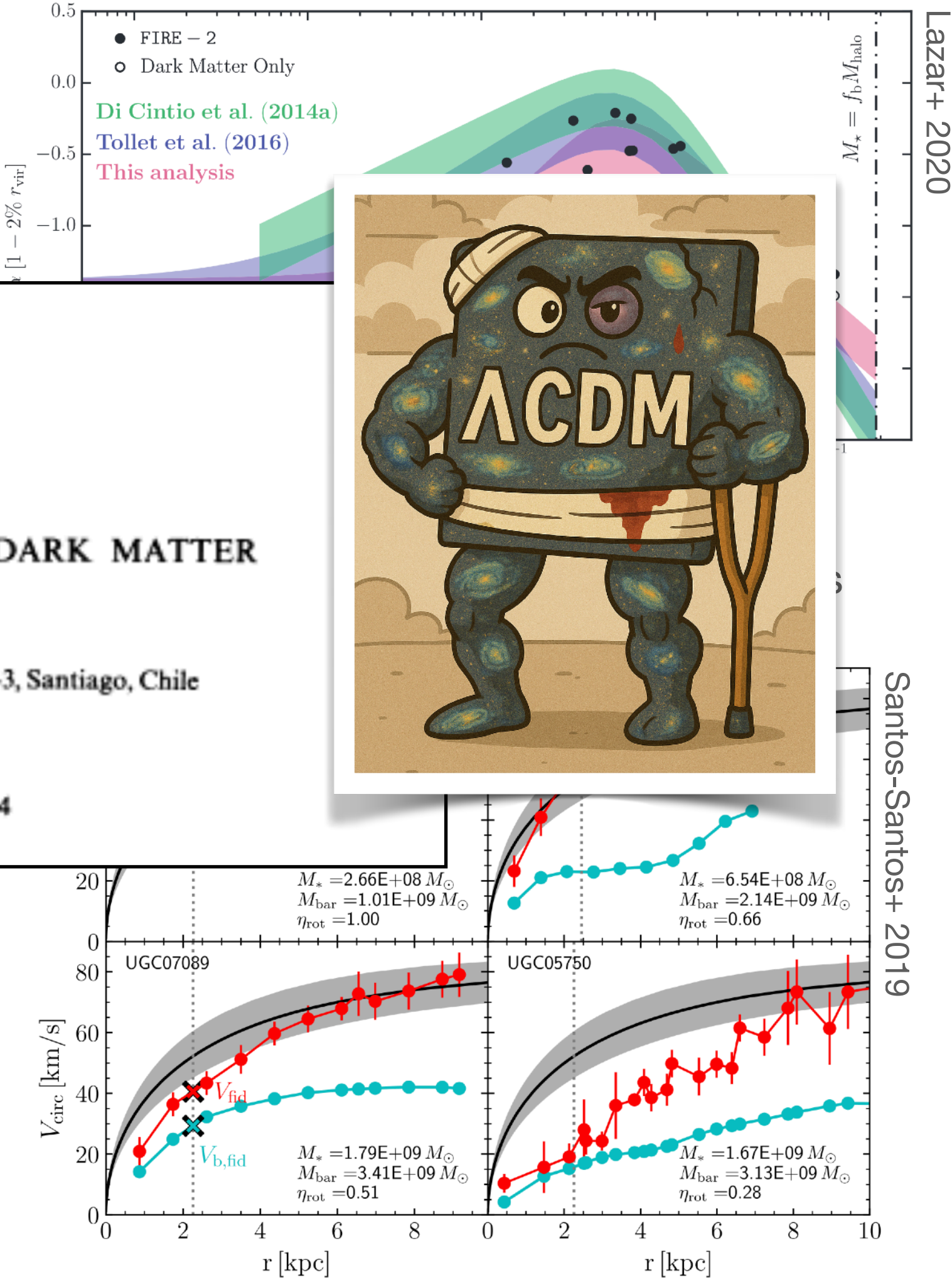
RICARDO A. FLORES¹
Departamento de Física, Facultad de Ciencias Físicas y Matemáticas, Universidad de Chile, Casilla 487-3, Santiago, Chile

AND

JOEL R. PRIMACK
Santa Cruz Institute for Particle Physics, University of California, Santa Cruz, CA 95064
Received 1994 January 11; accepted 1994 March 4

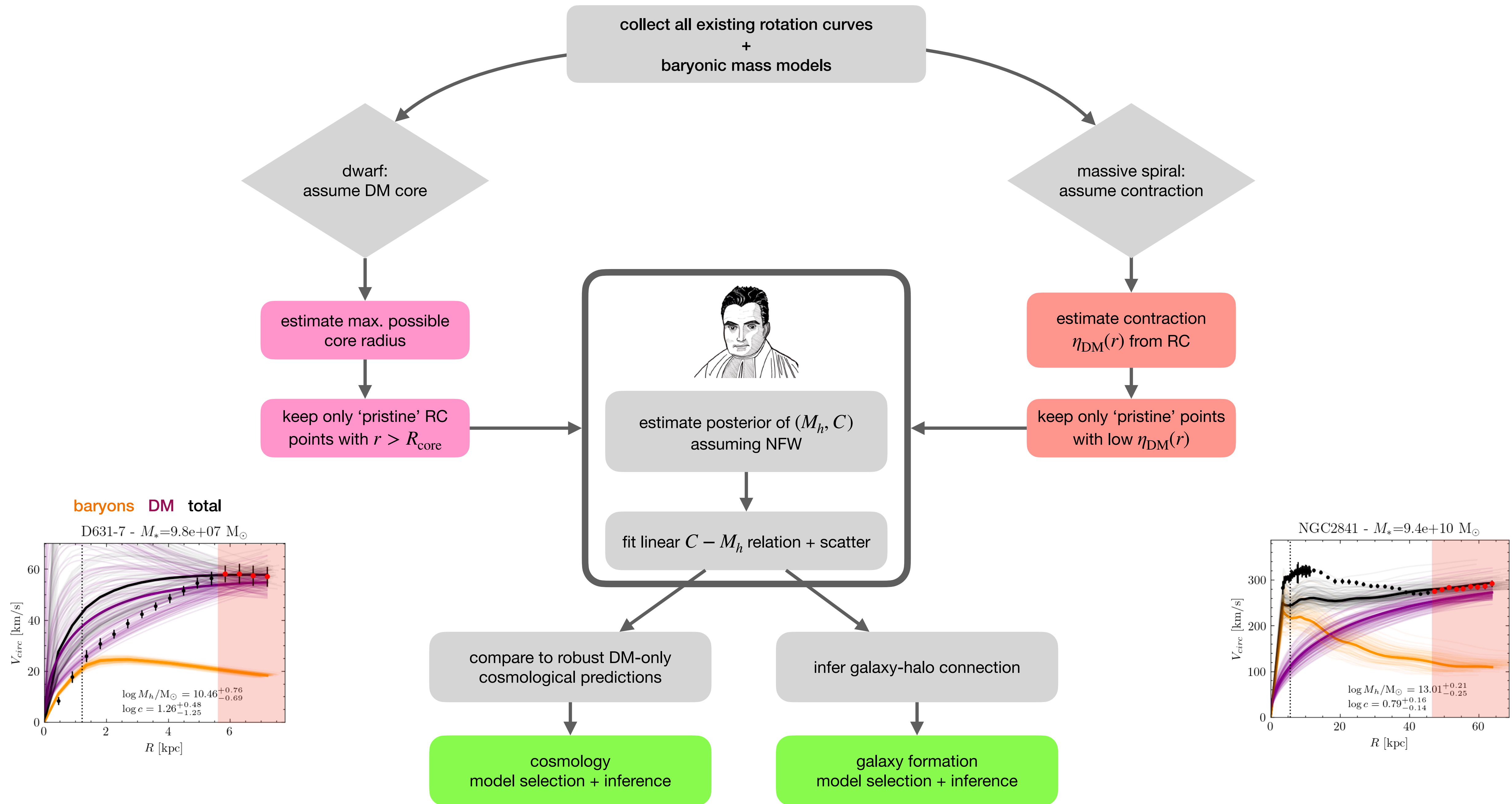
cores from controlled experiments with resolved feedback

cores from cosmological zooms



Santos-Santos+ 2019

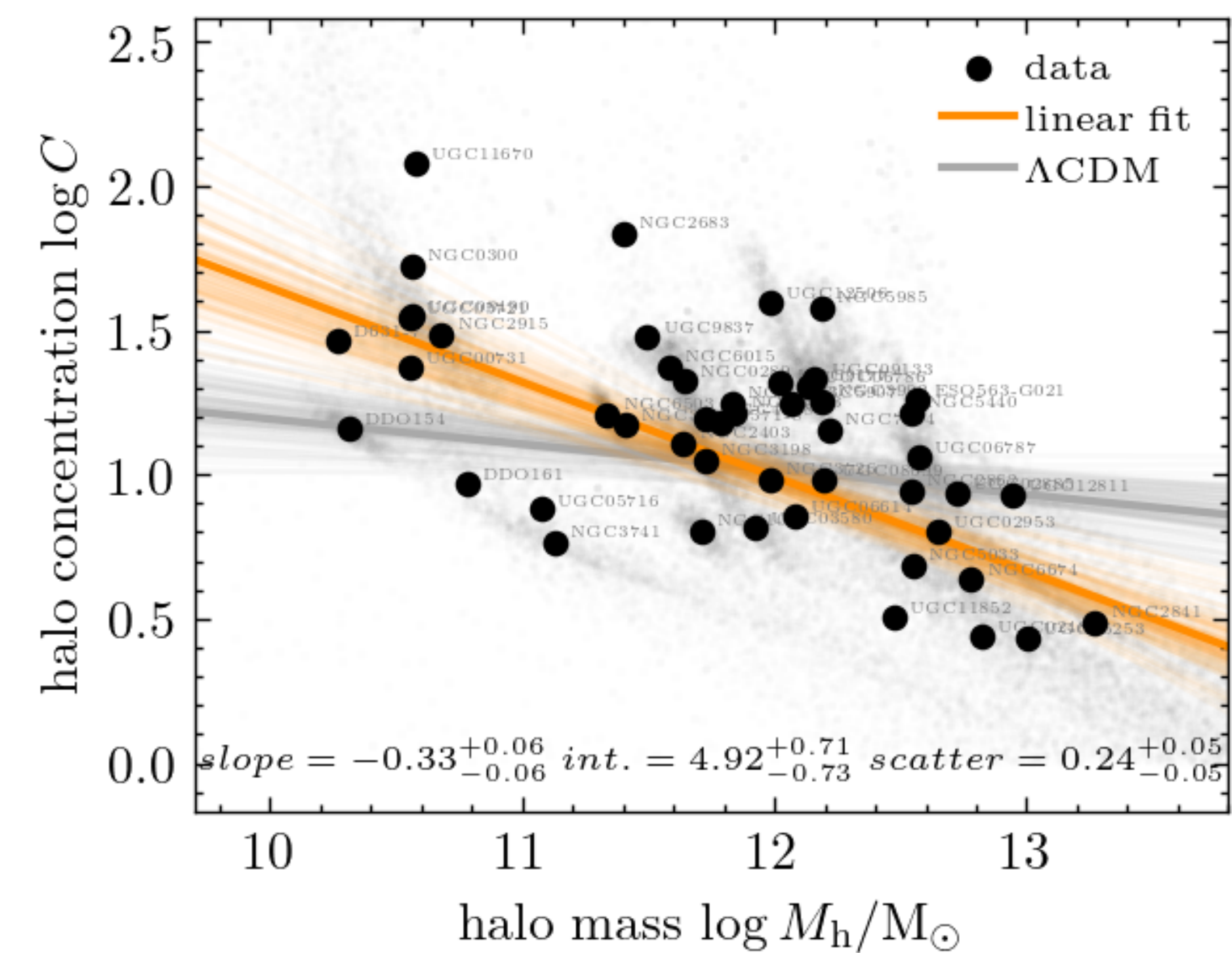
Lazar+ 2020



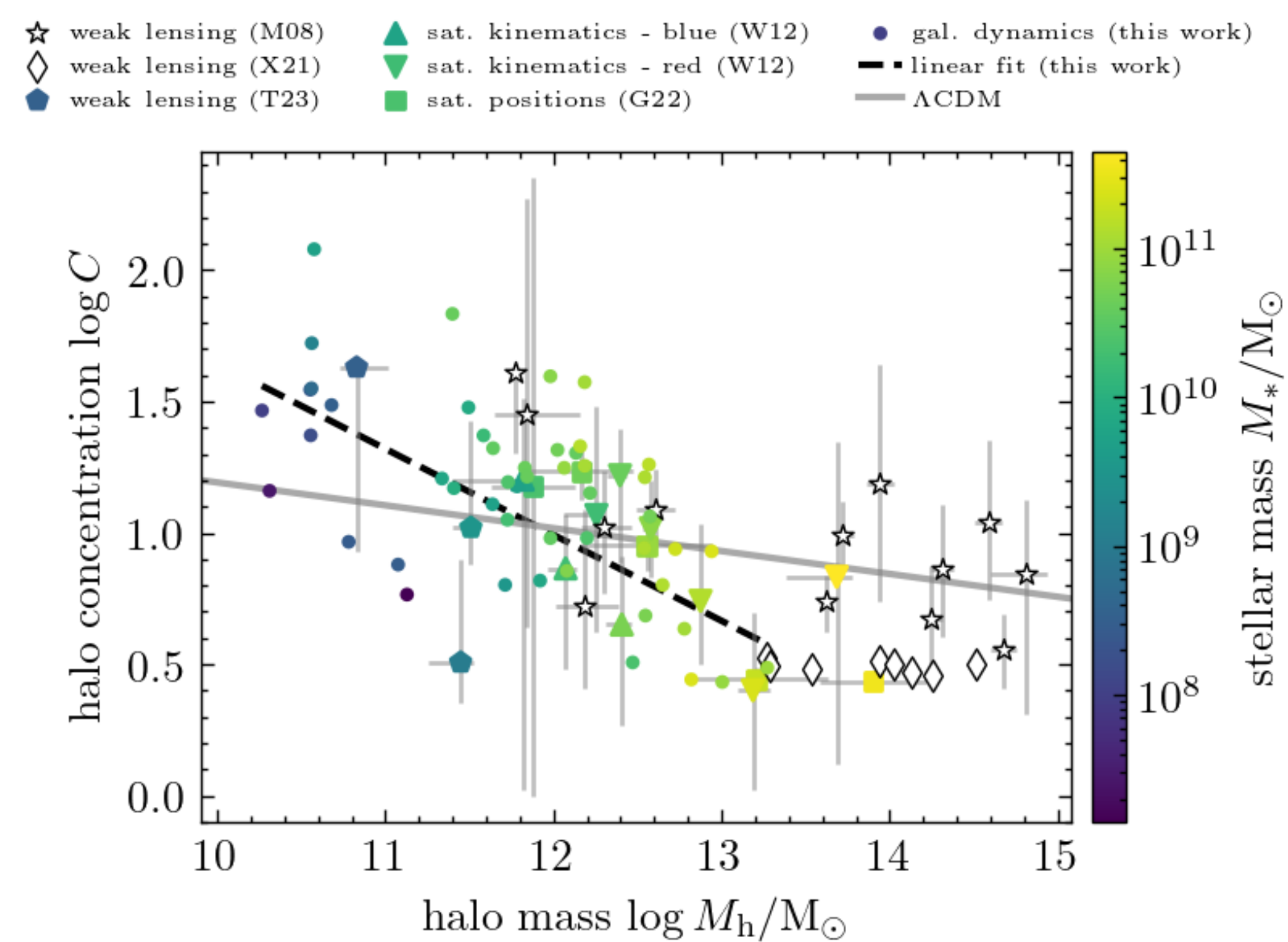
Can we do this experiment with current data?

Robust statistical comparison of inferred $C - M_h$ to model predictions: reject CDM hypothesis?

our experiment



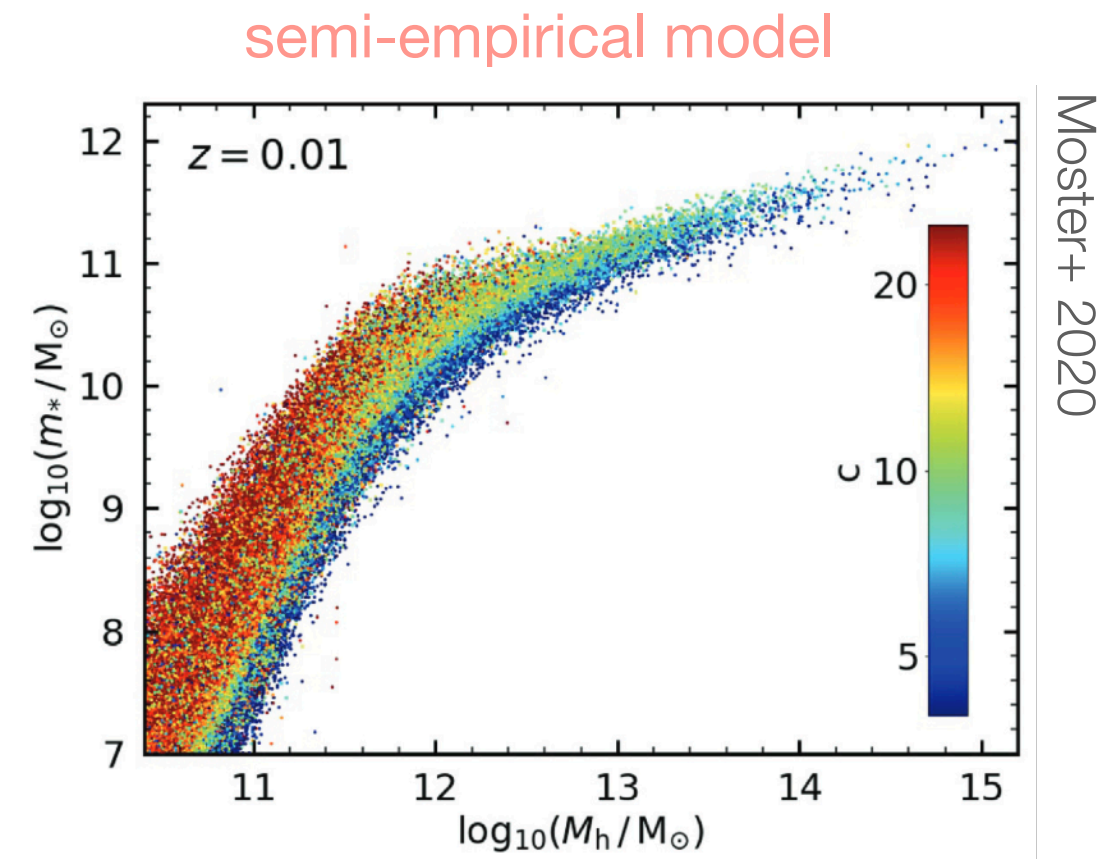
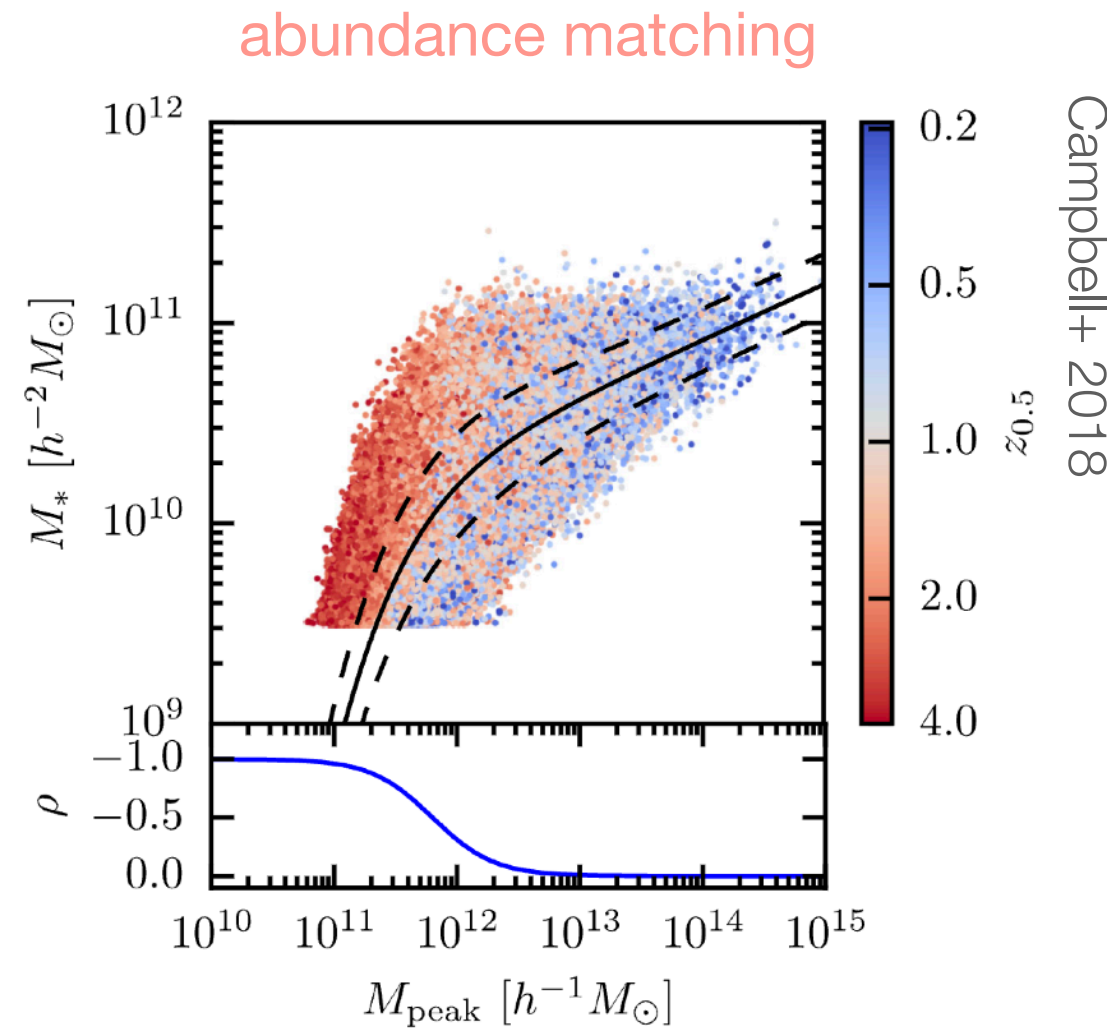
additional independent constraints (lensing, satellites)



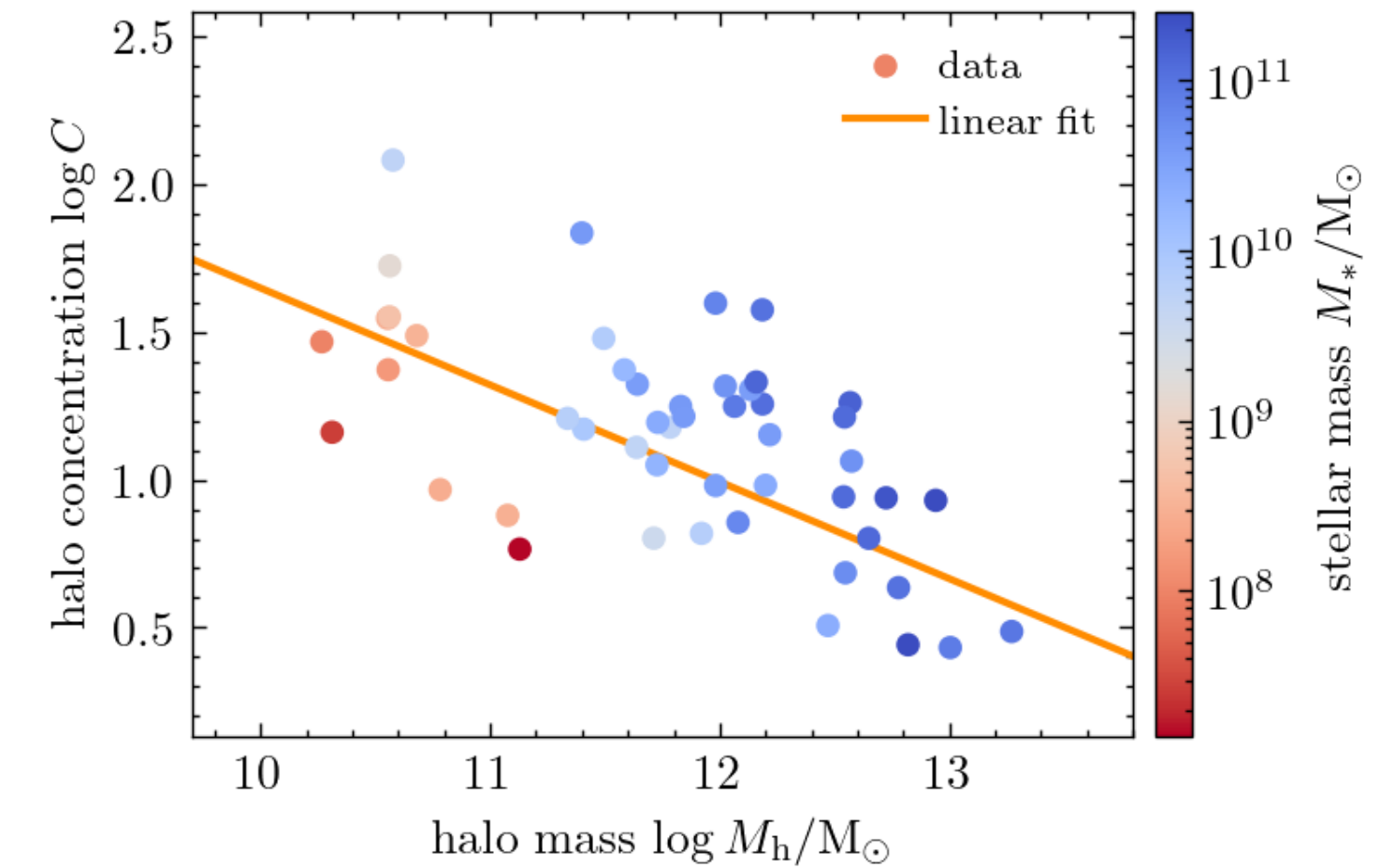
Can we do this experiment with current data?

Galaxy formation physics: infer the *galaxy - halo structure* connection

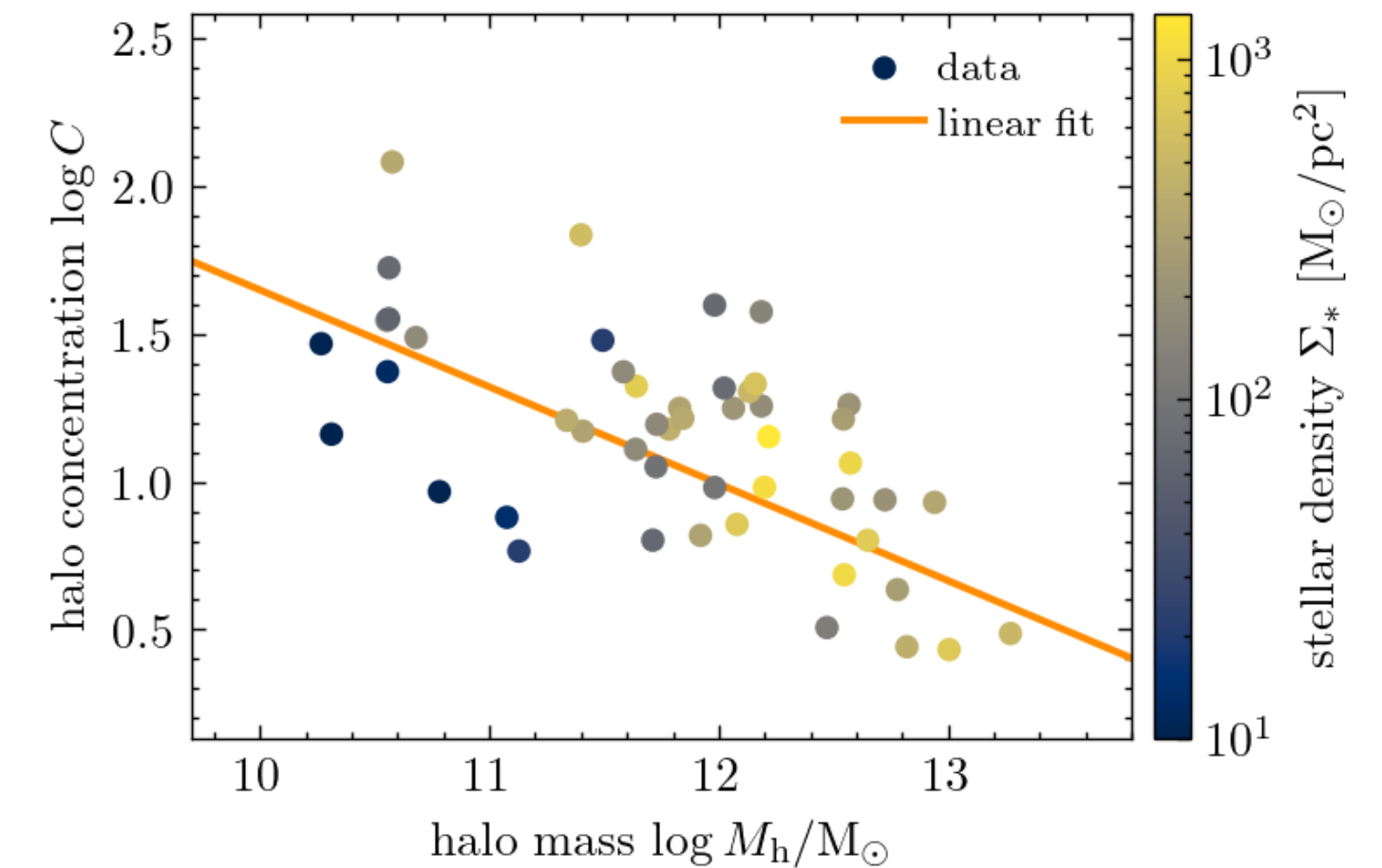
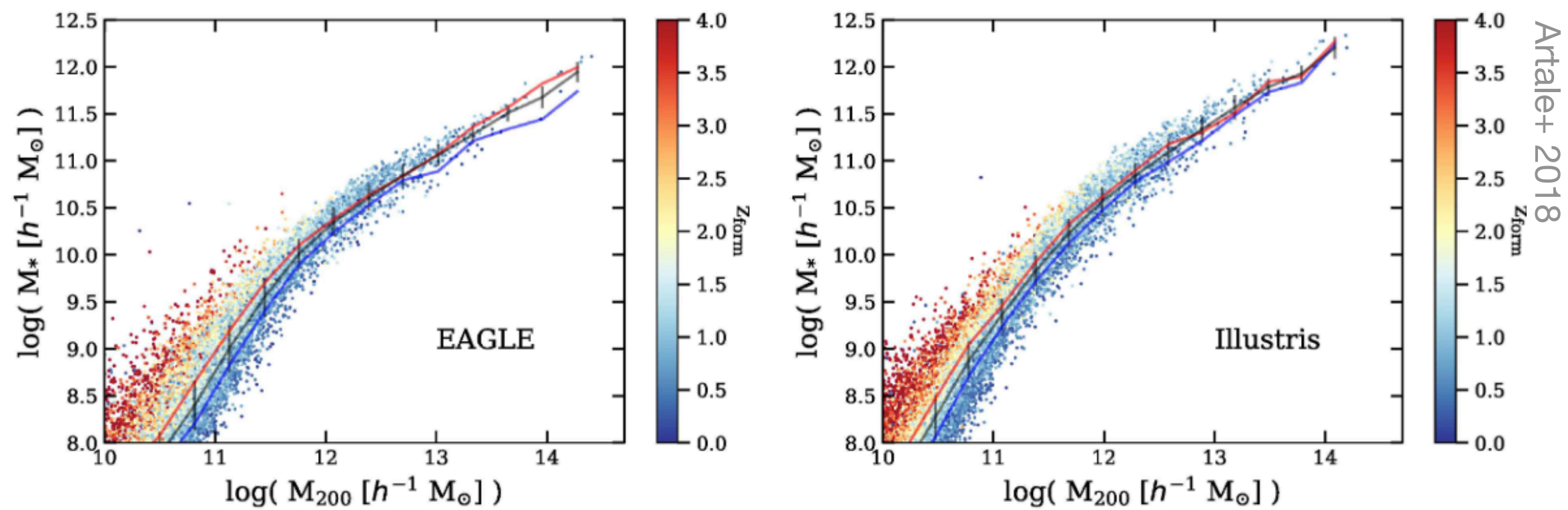
robust prediction of all models



our experiment

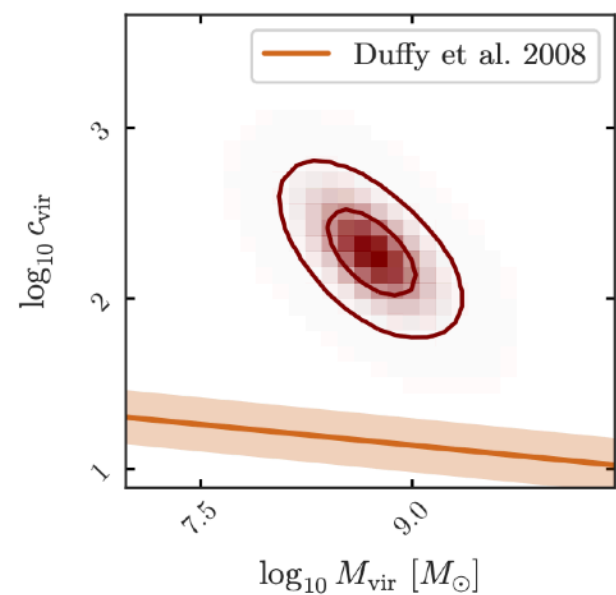
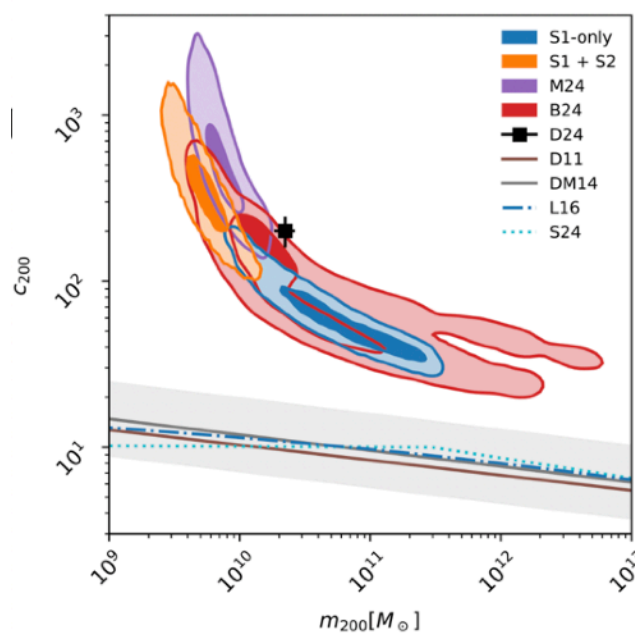
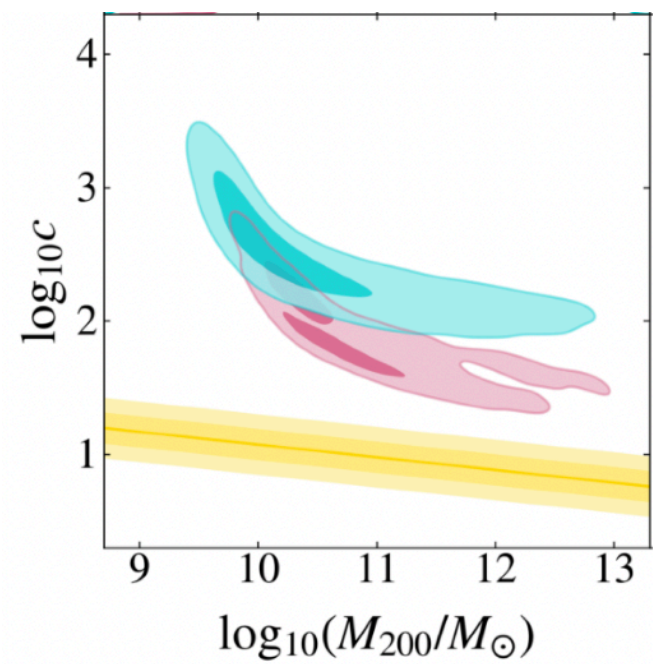
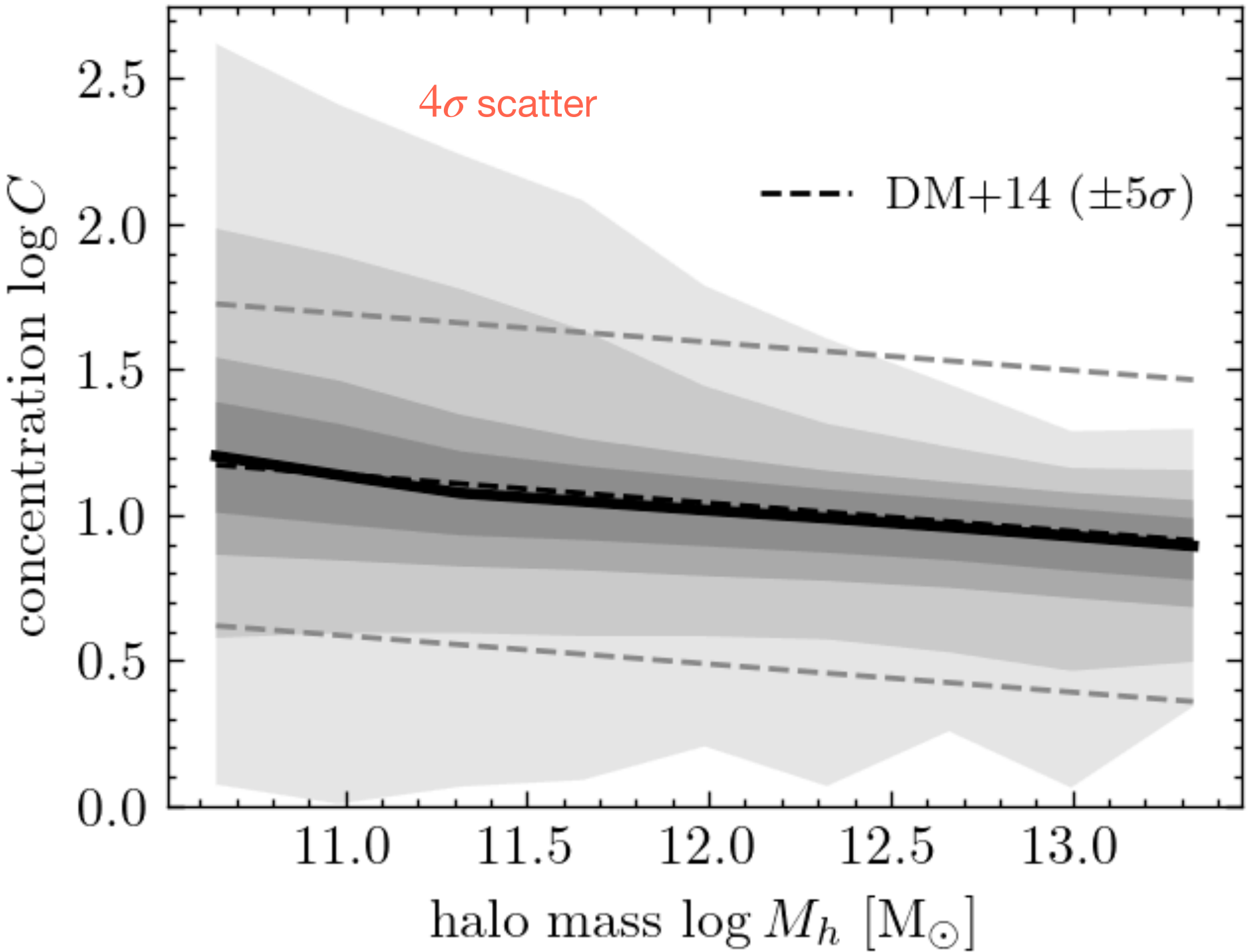
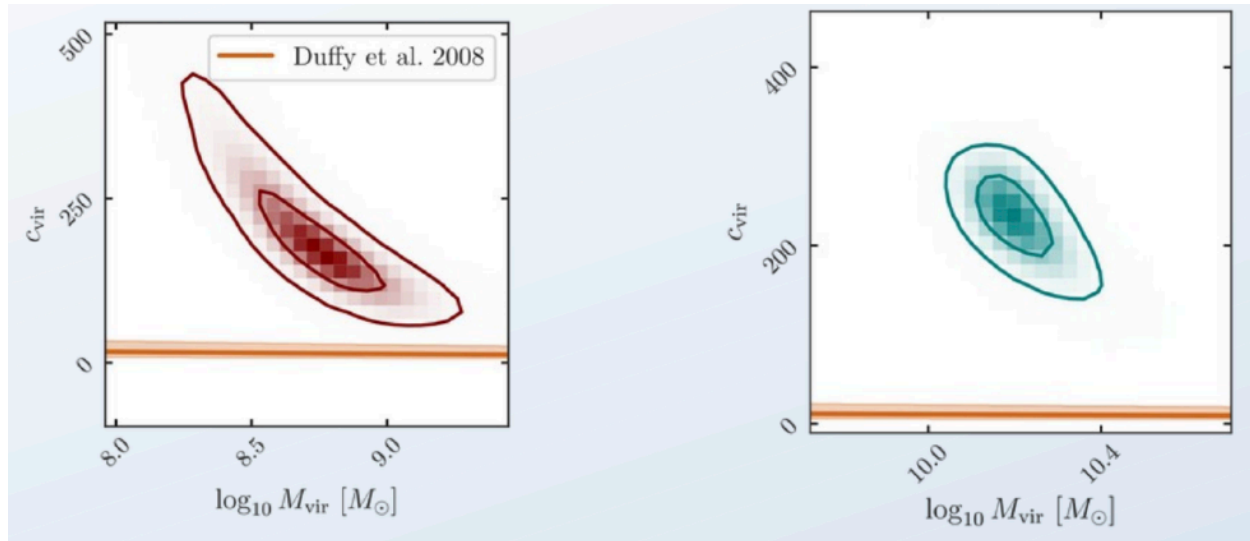
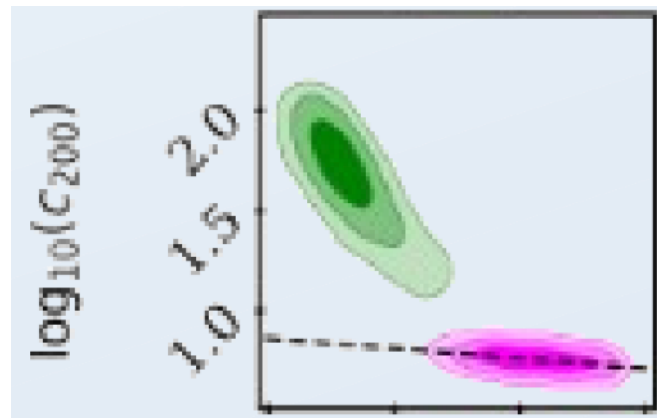
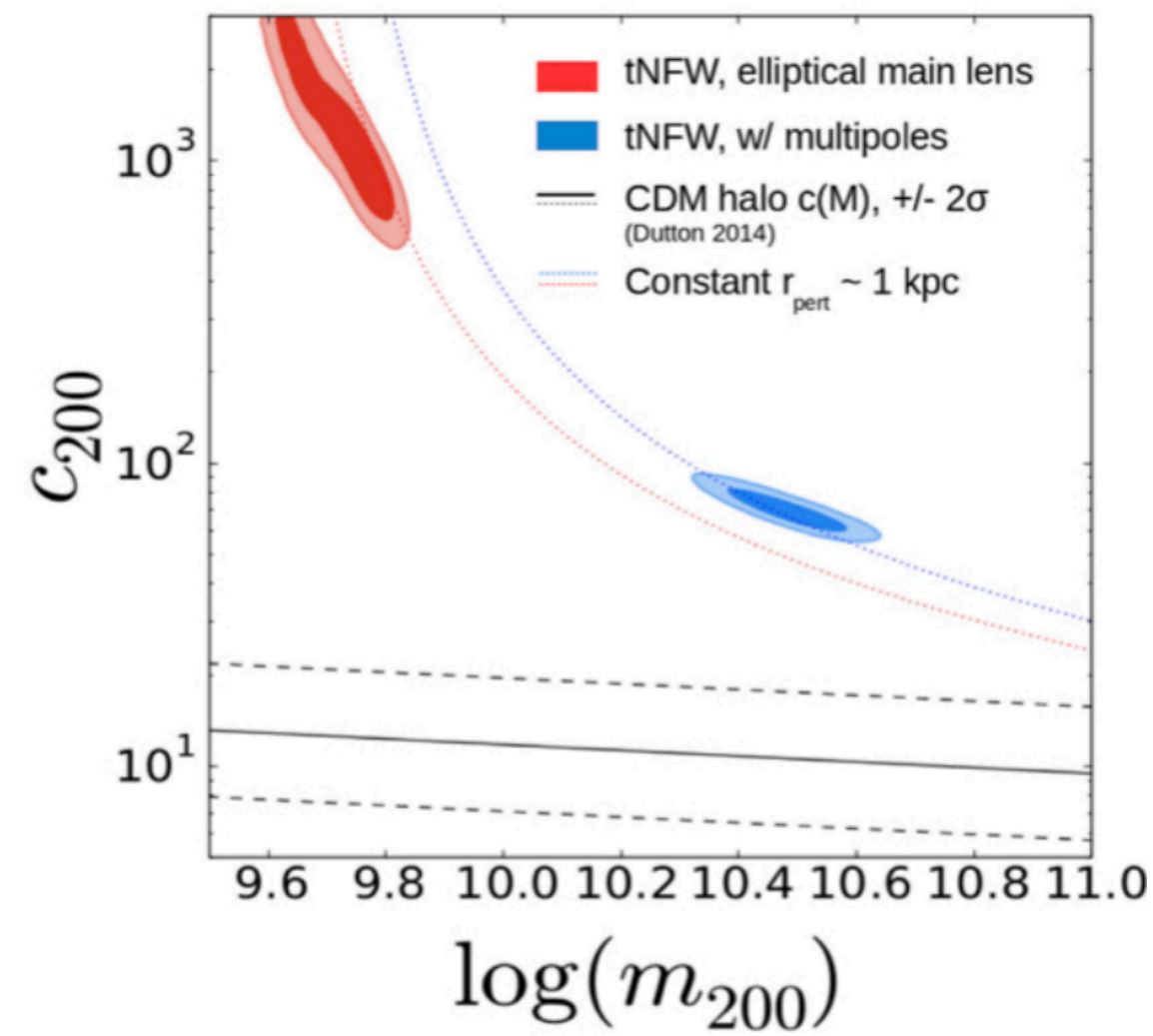
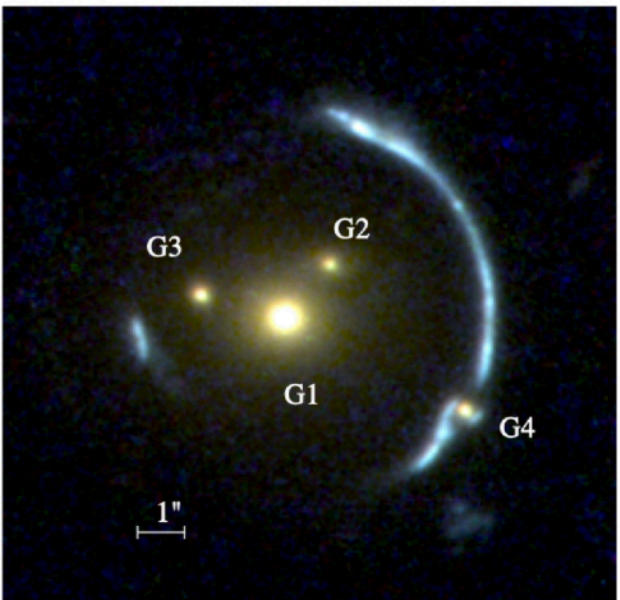


hydro simulations



Using single objects to test CDM

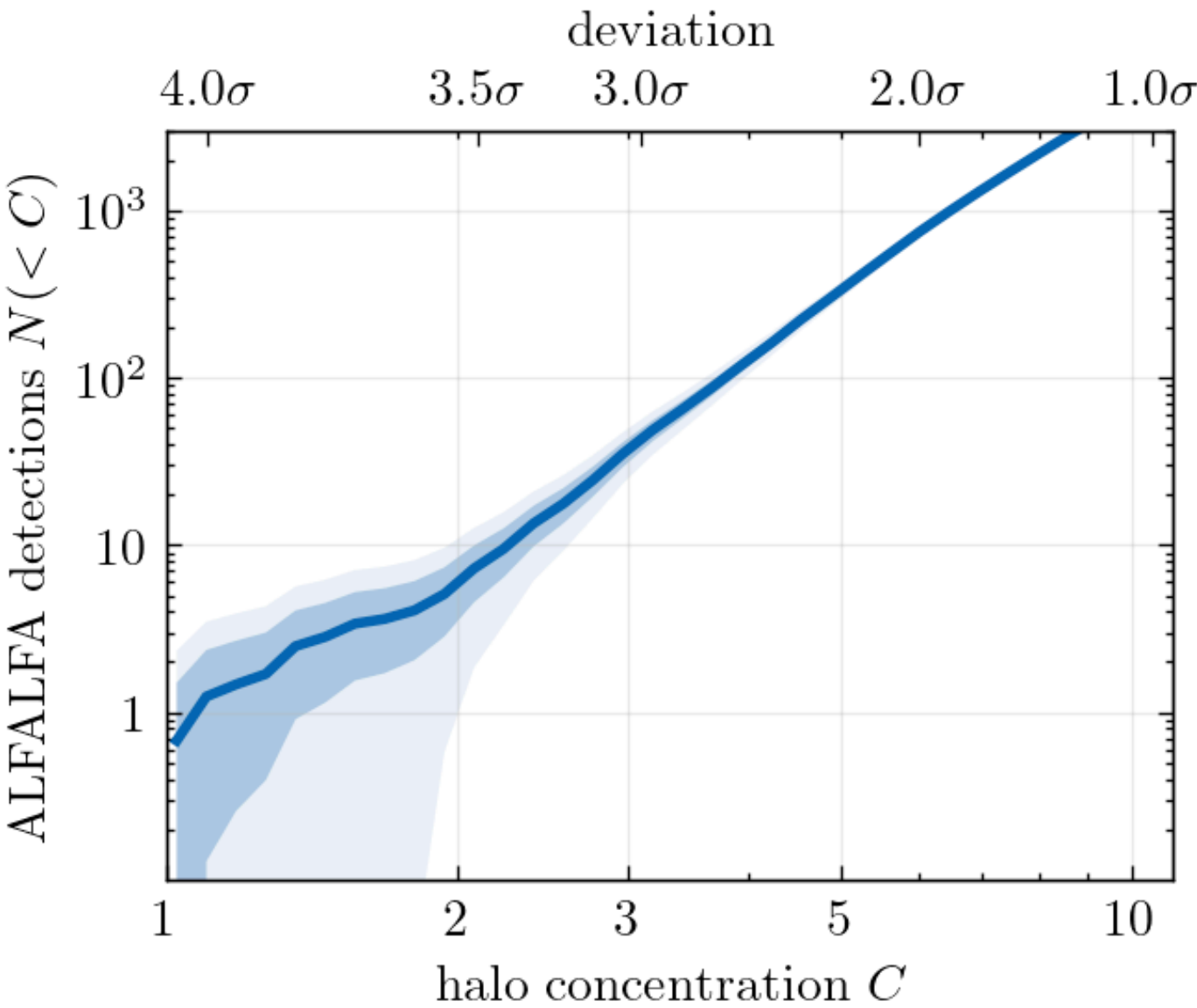
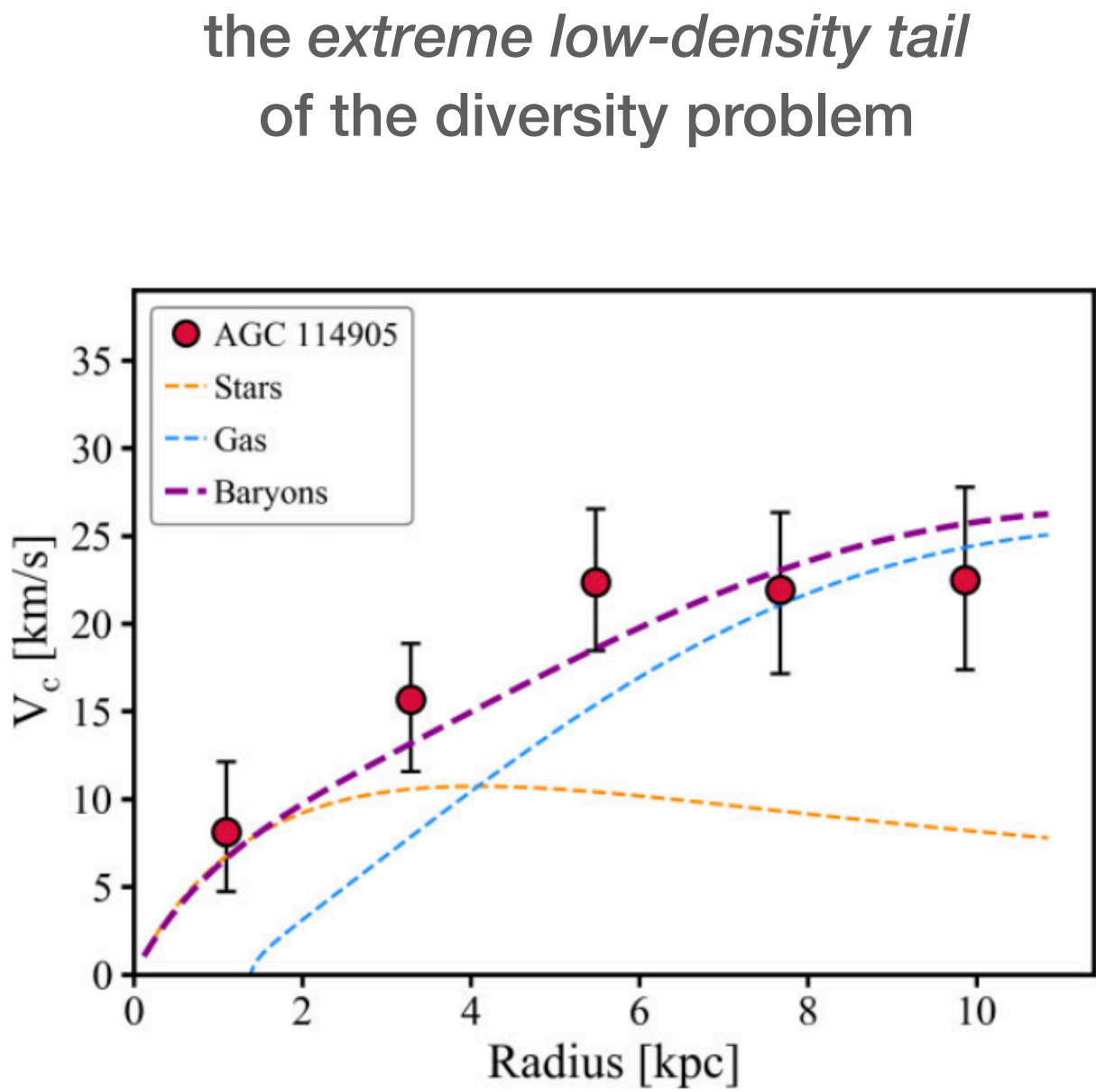
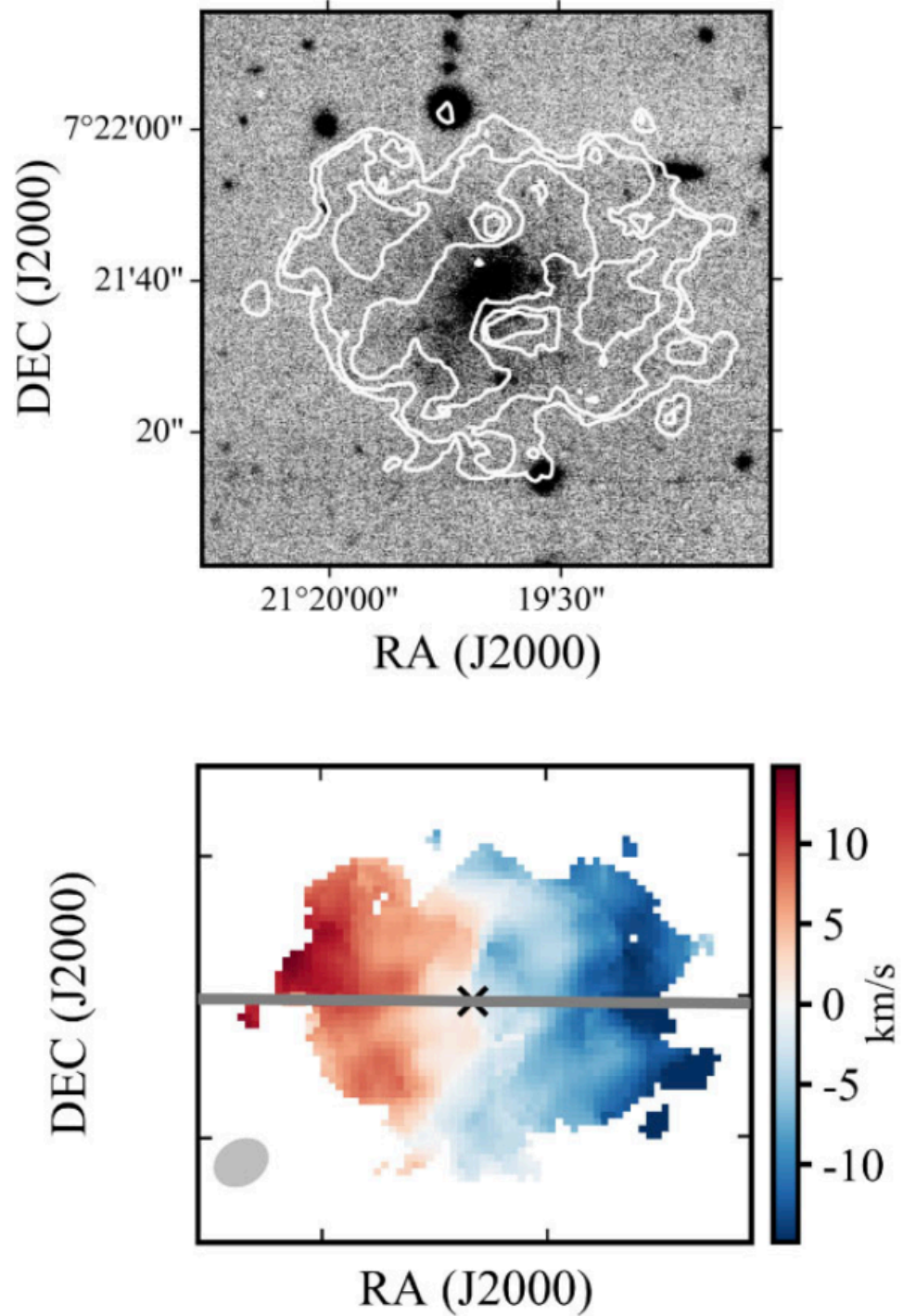
Do dense dark strong lensing perturbers break CDM? 🤯



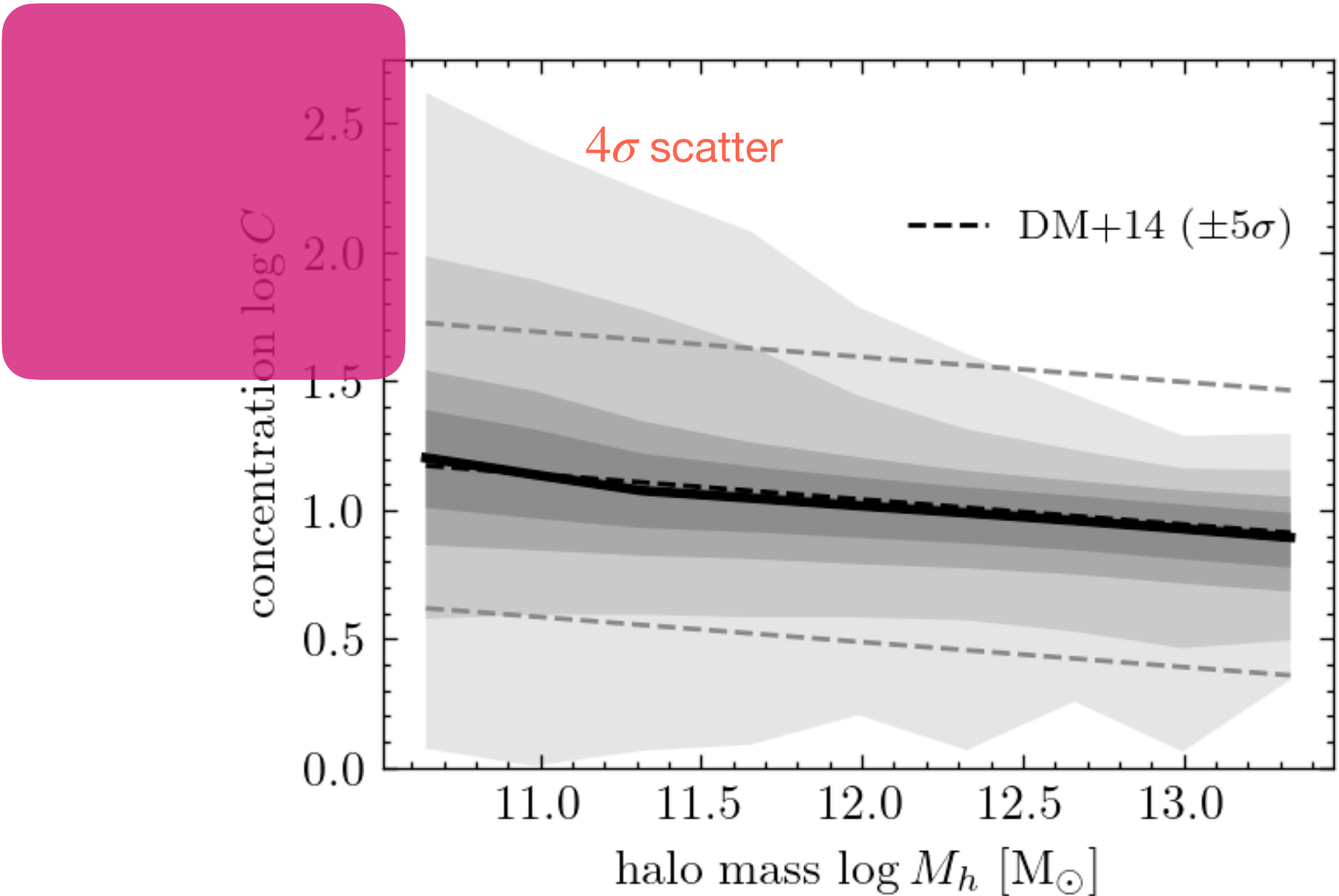
Mass-concentration distribution in *Bolshoi* simulation

Using single objects to test CDM

Do *DM-deficient galaxies* break CDM? 🤯



CDM:
expect <10-30 objects
in survey volume



Conclusions

- Need more *clean tests of CDM that avoid baryon physics*
- Next-gen *kinematics surveys* of $> 10^3$ galaxies ideal for testing DM models
- Feedback-independent constraints from current data:
 1. halo concentration correlates with mass, *but slope* $> 3\sigma$ *steeper than CDM*
 2. SIDM fits high concentration dwarfs but not low concentration massive spirals
 3. signs of strong connection between galaxies and halo structure