

Feedback-independent constraints on halo structure: concentrations challenge CDM

Sebastian Trujillo-Gomez

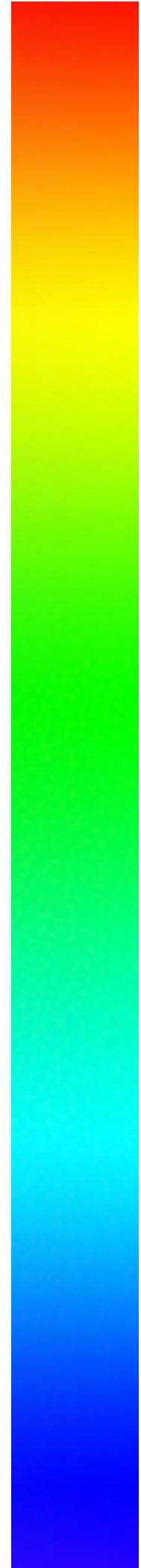
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Collaborators:

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Small-scale problems in Λ CDM

need for worrying about baryon physics



Λ CDM Tensions with Dwarf Galaxies

Sales+ 2022

No tension

Uncertain

Weak tension

Strong tension

Missing satellites

M_\star - M_{halo} relation

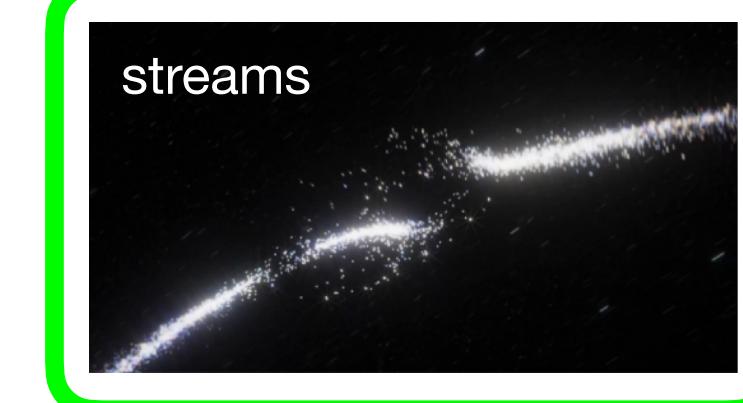
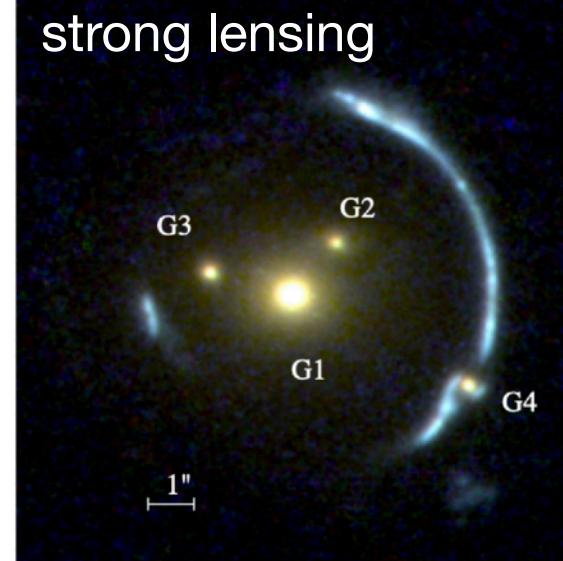
Too big to fail

Diversity of rotation curves

Core-cusp

Diversity of dwarf sizes

Satellite planes



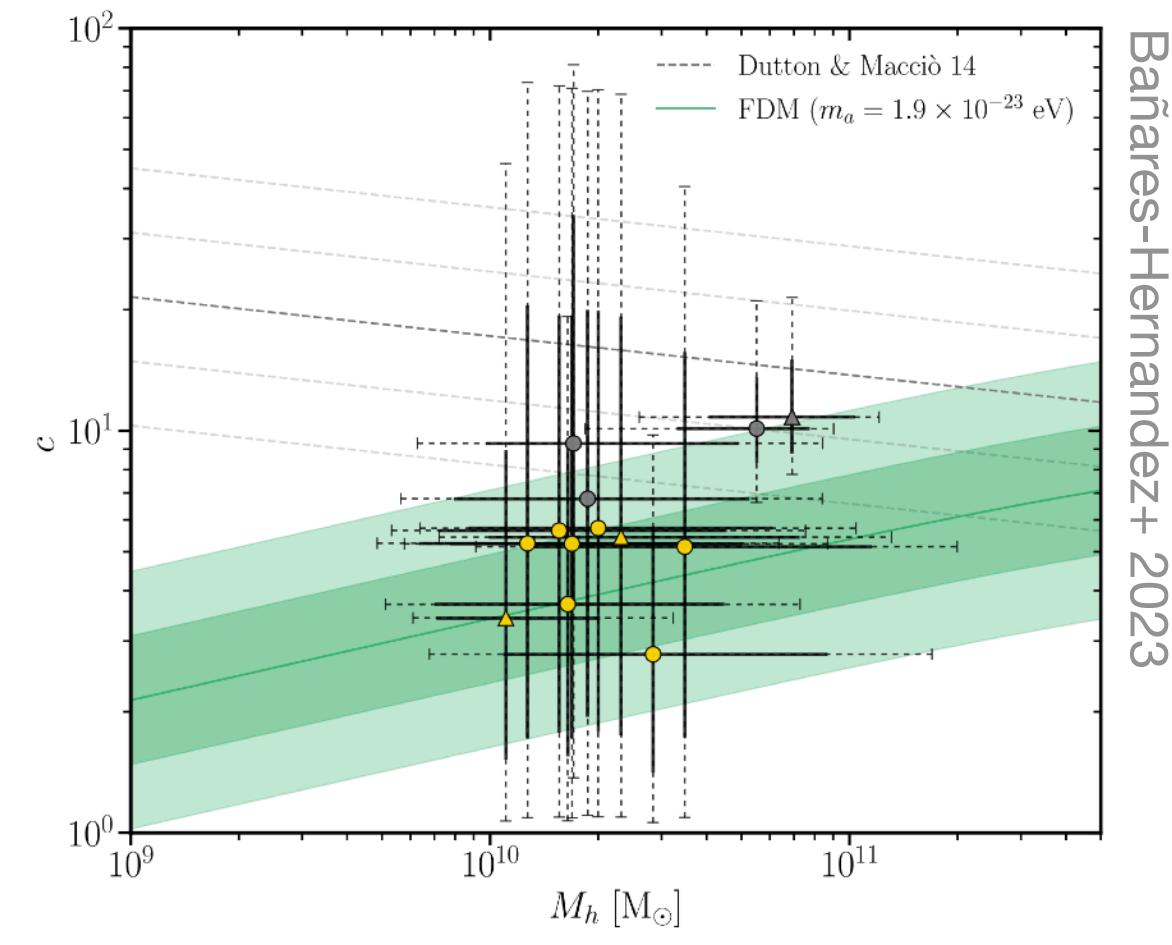
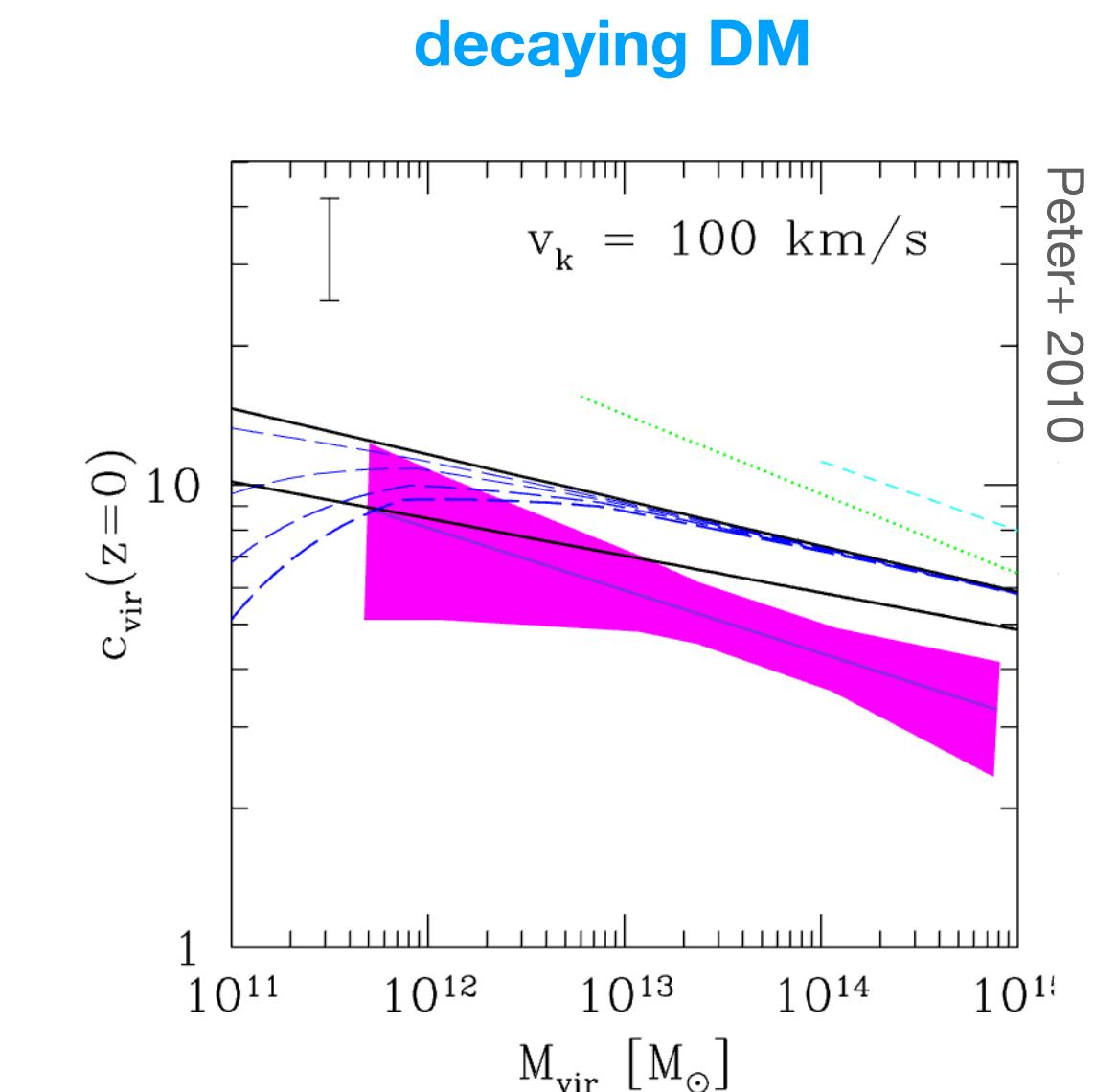
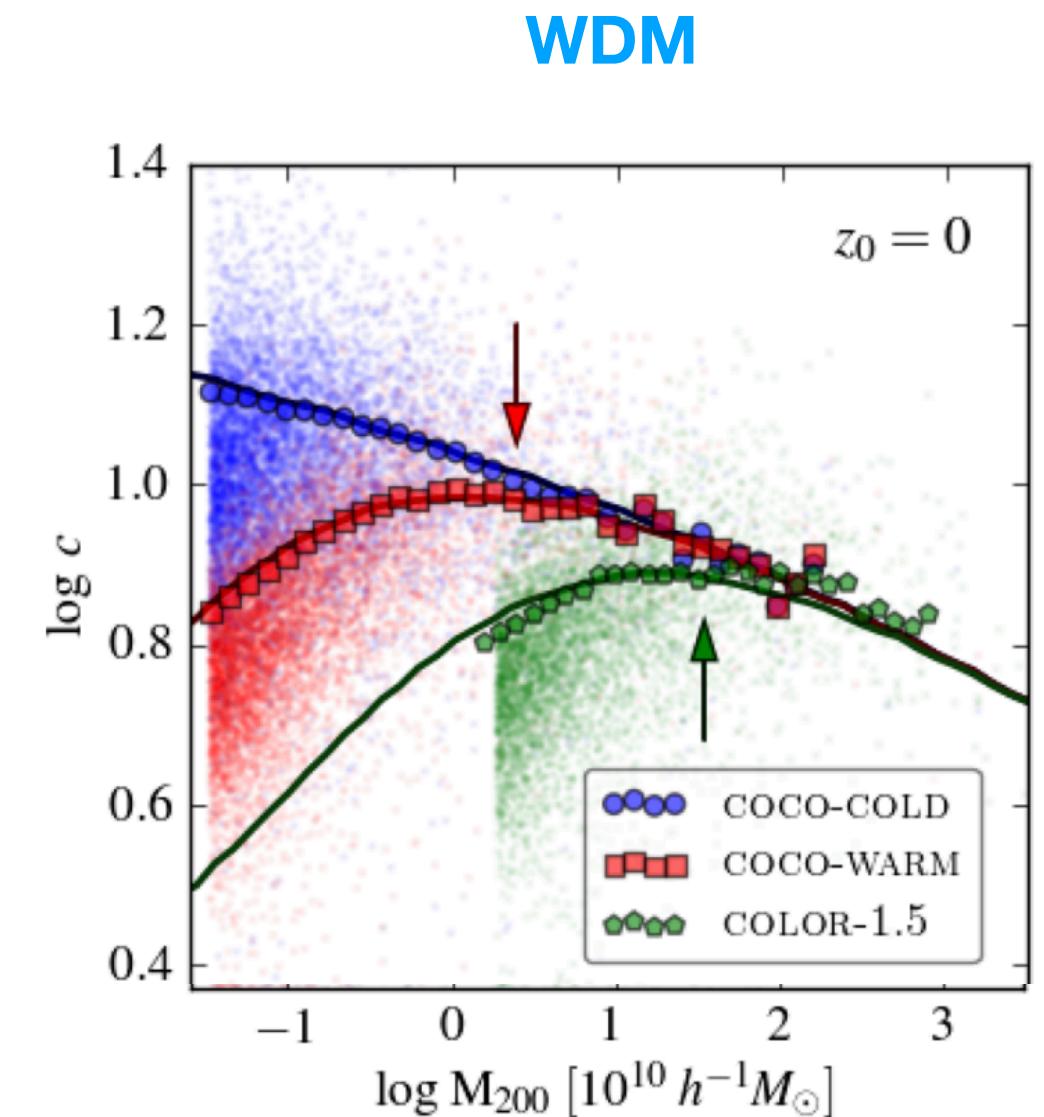
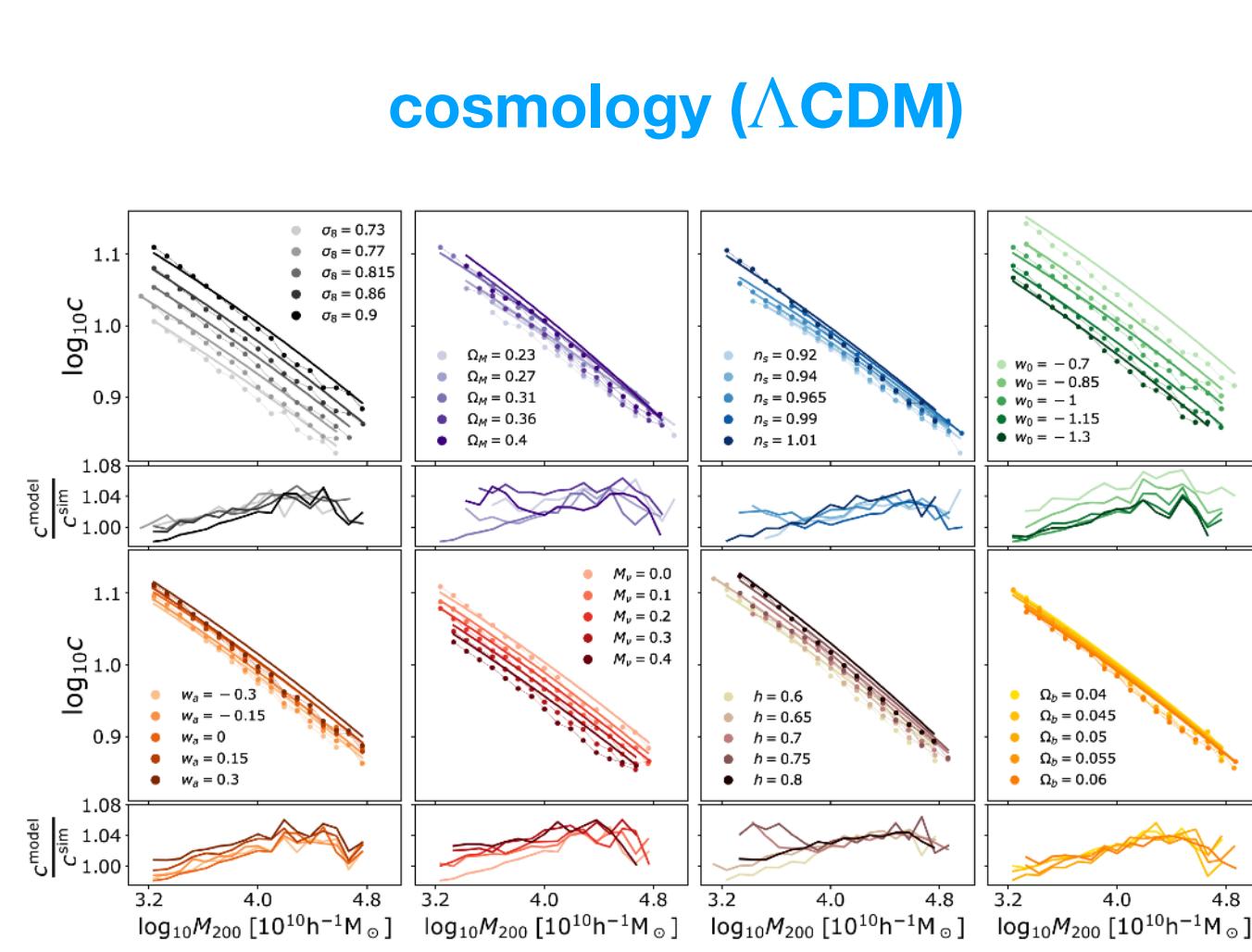
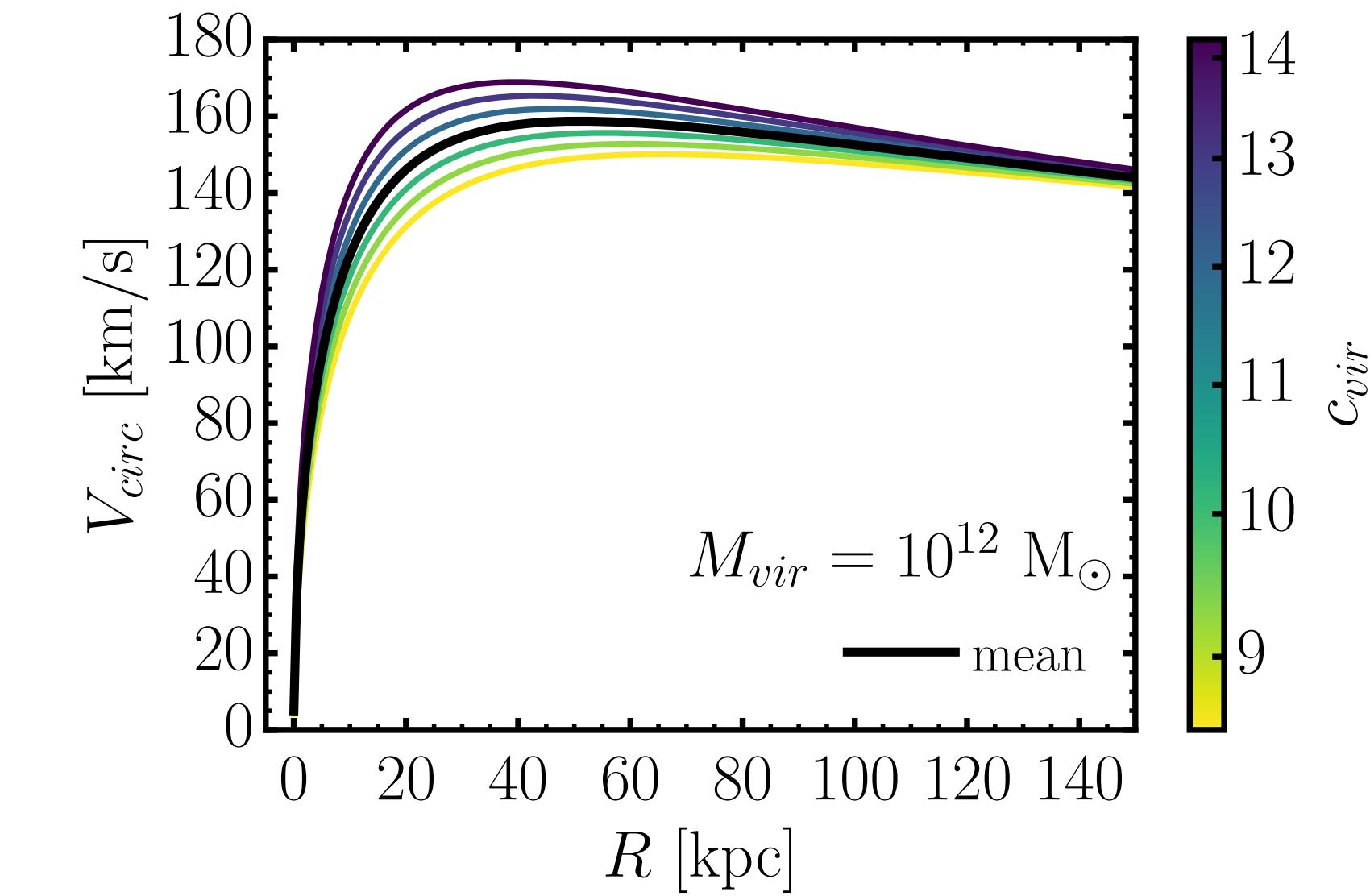
Identifying predictions that are robust to baryon physics crucial to discovery

(star formation, stellar/AGN feedback, reionization, etc.)

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*



A golden era for cosmology with galaxies

Next-generation observatories data deluge:

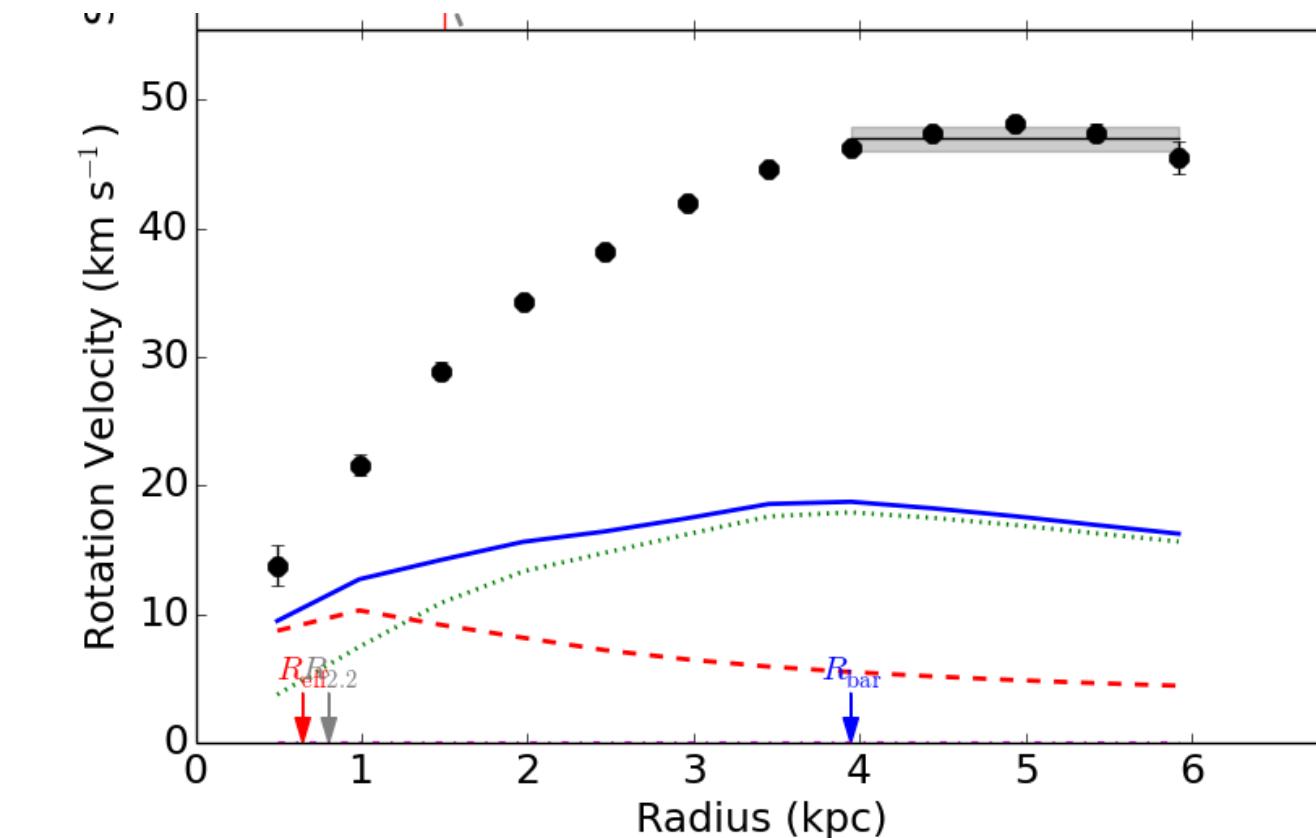
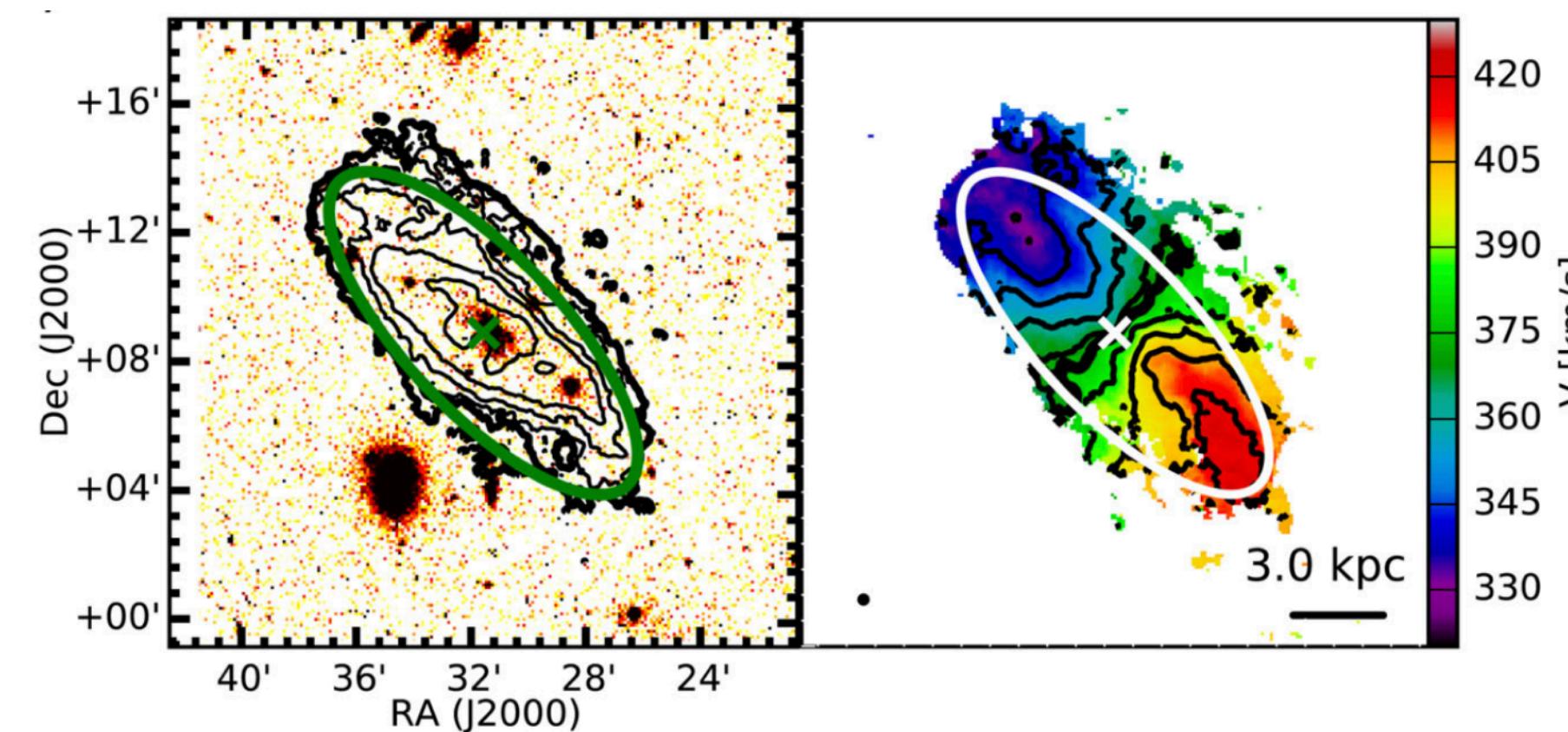
- Euclid: deep + wide field high-res imaging ($\sim 10^9$ galaxies)
- Roman: very deep + wide NIR imaging ($\sim 10^9$ galaxies)
- SKA: deep + wide high-res HI surveys ($> 5 \times 10^3$ rotation curves)



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

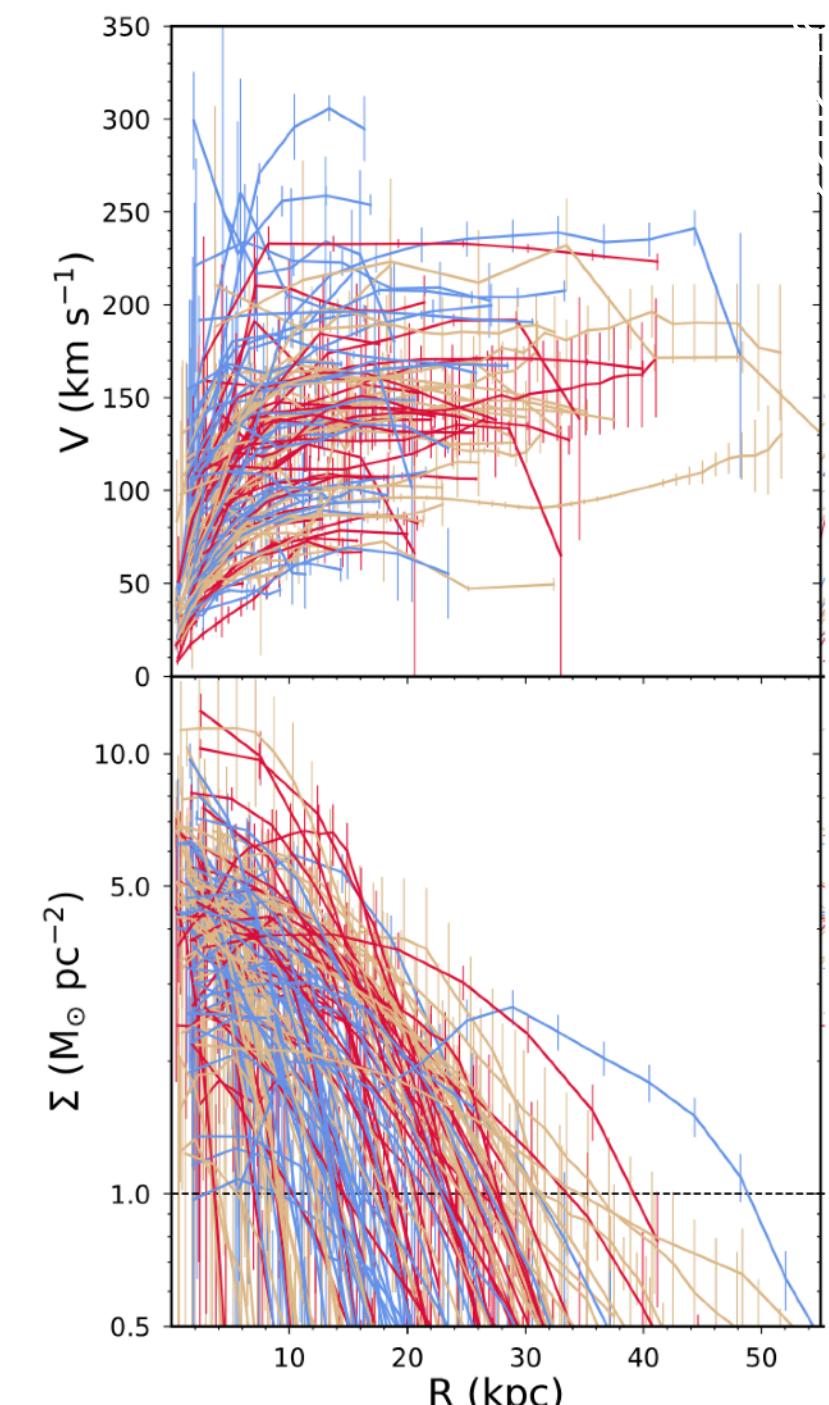
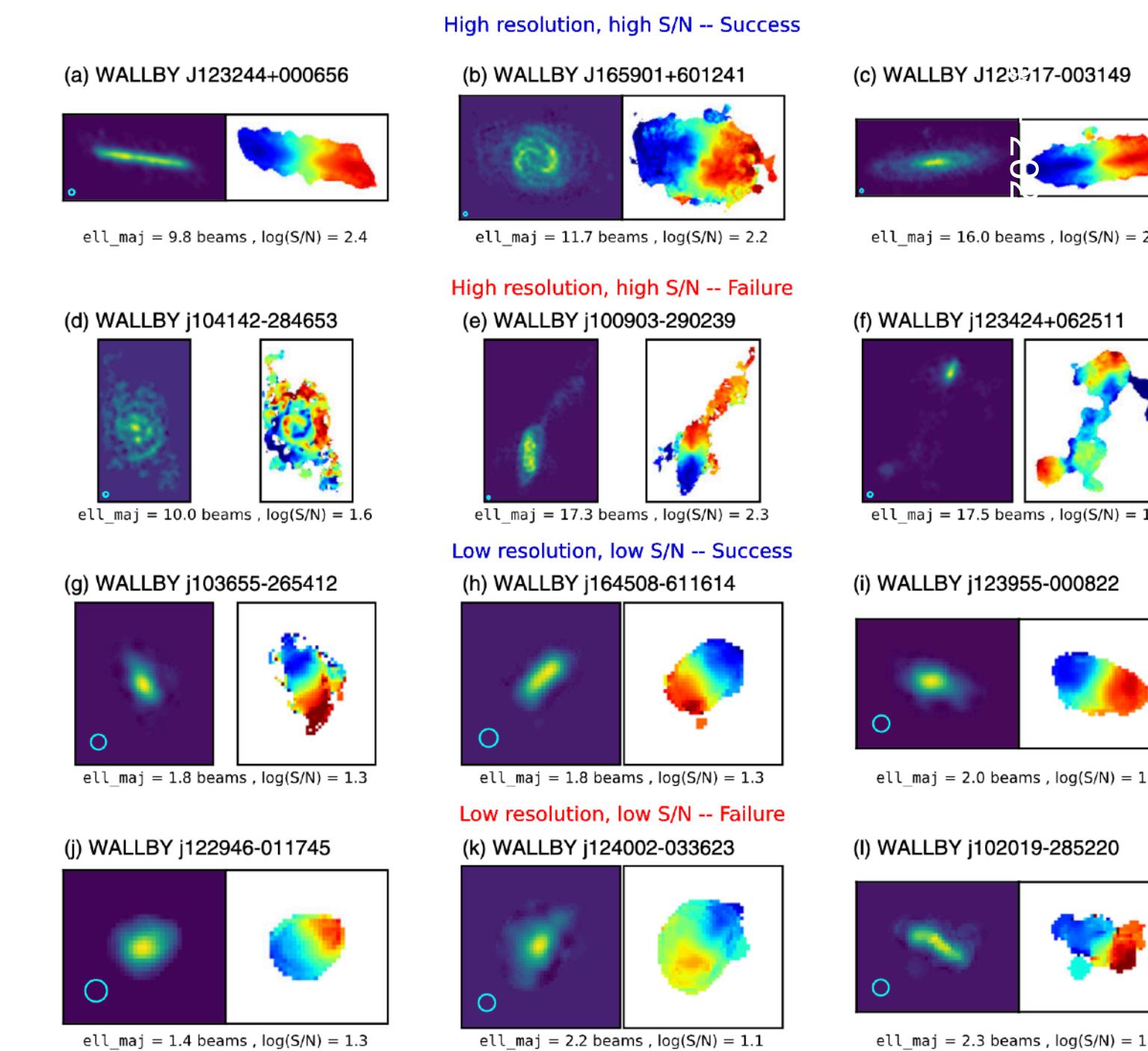


Research Article

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}

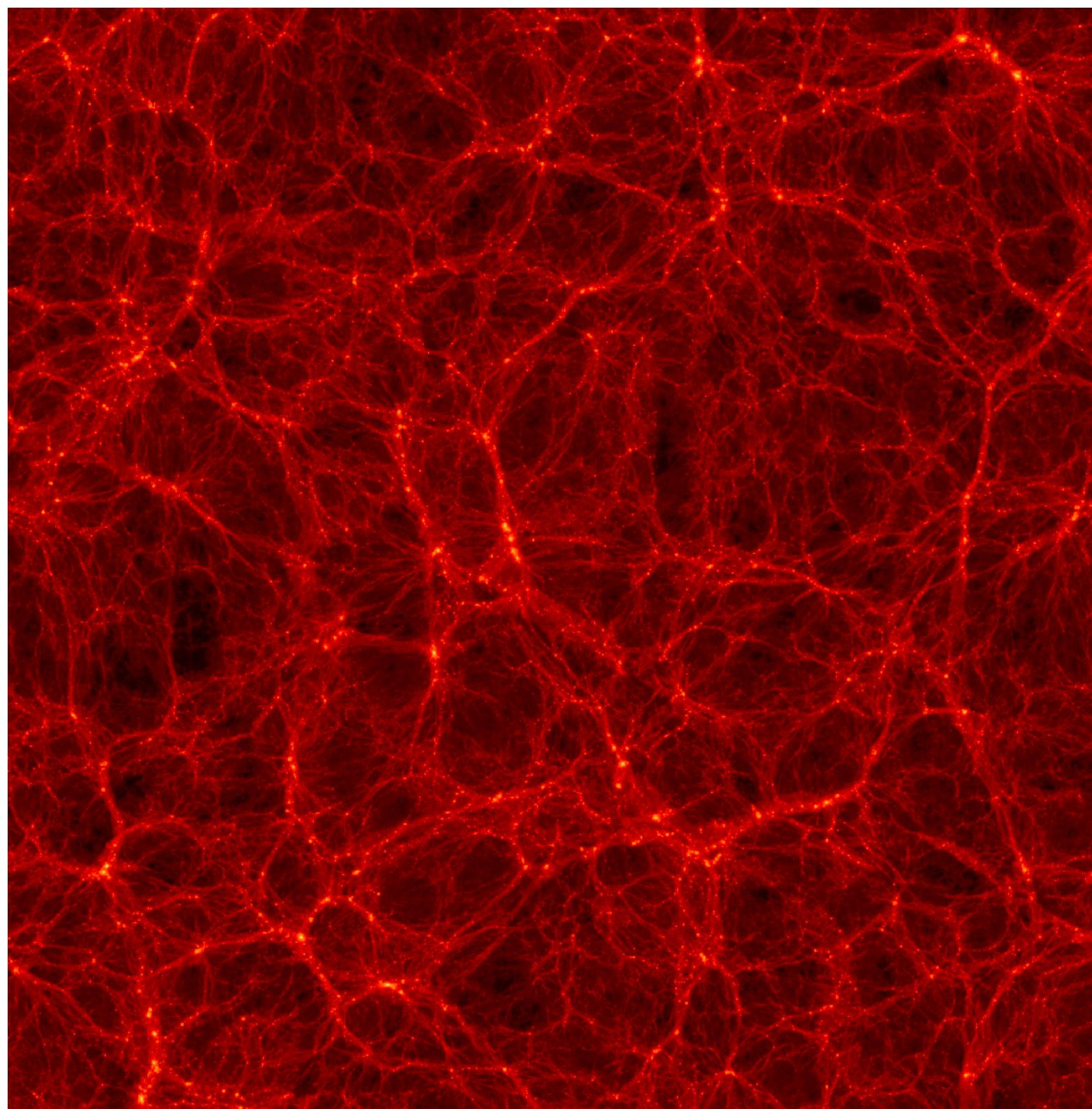
WALLABY Survey (Australian SKA Pathfinder)



Can we do this experiment with current data?

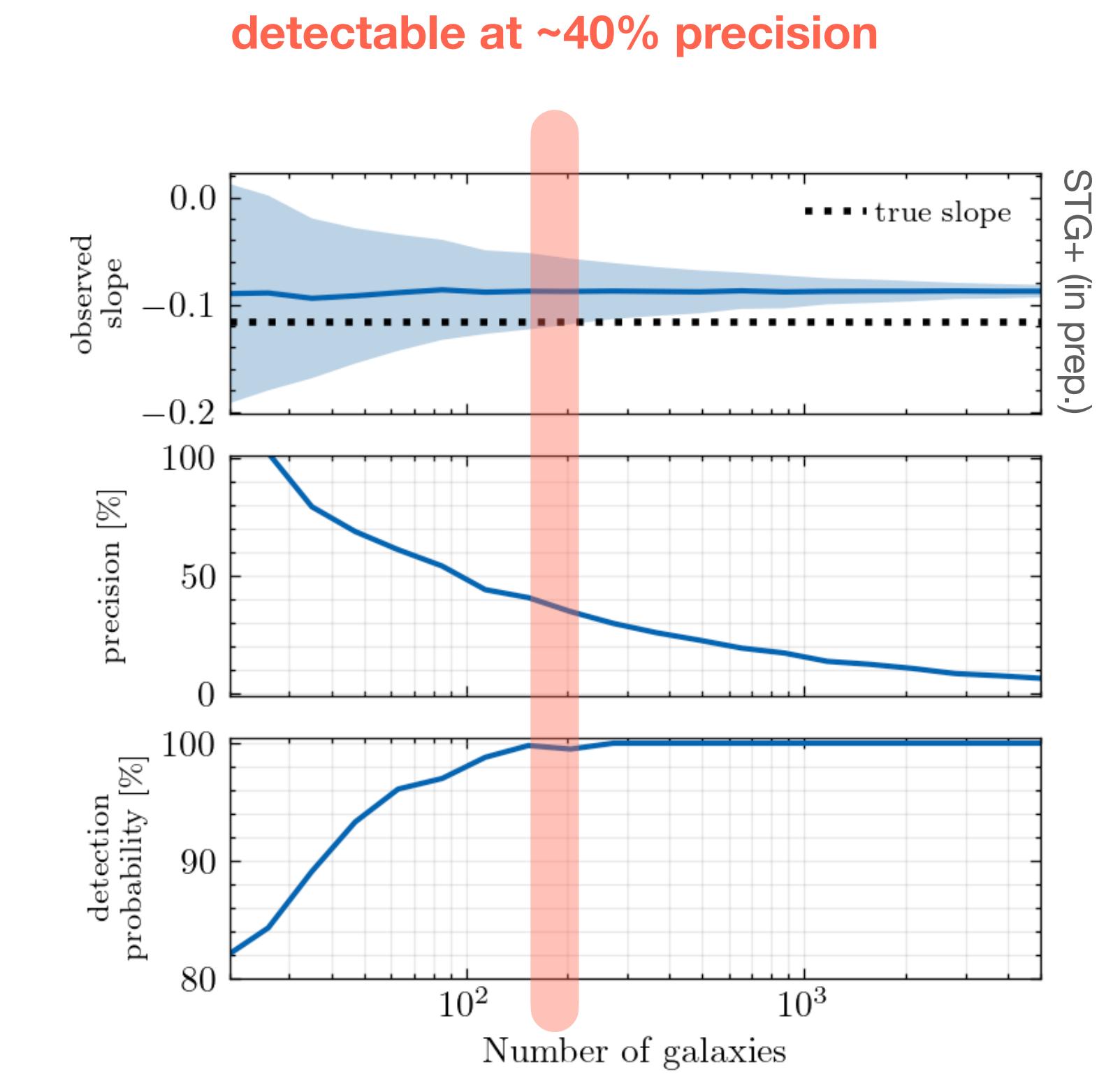
1. Pick your favorite cosmological simulation and make testable predictions

~0.5 million halos in observed mass range



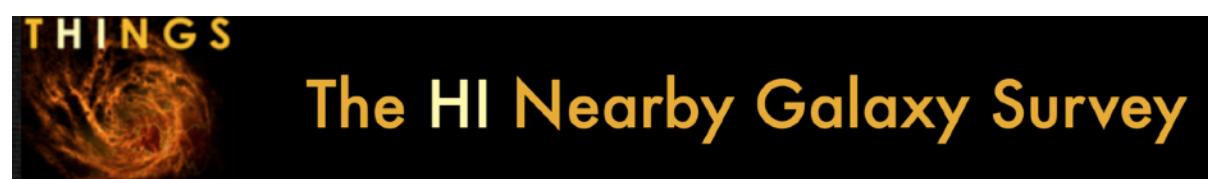
10^3 synthetic experiments:

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



The HI Nearby Galaxy Survey



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‡}

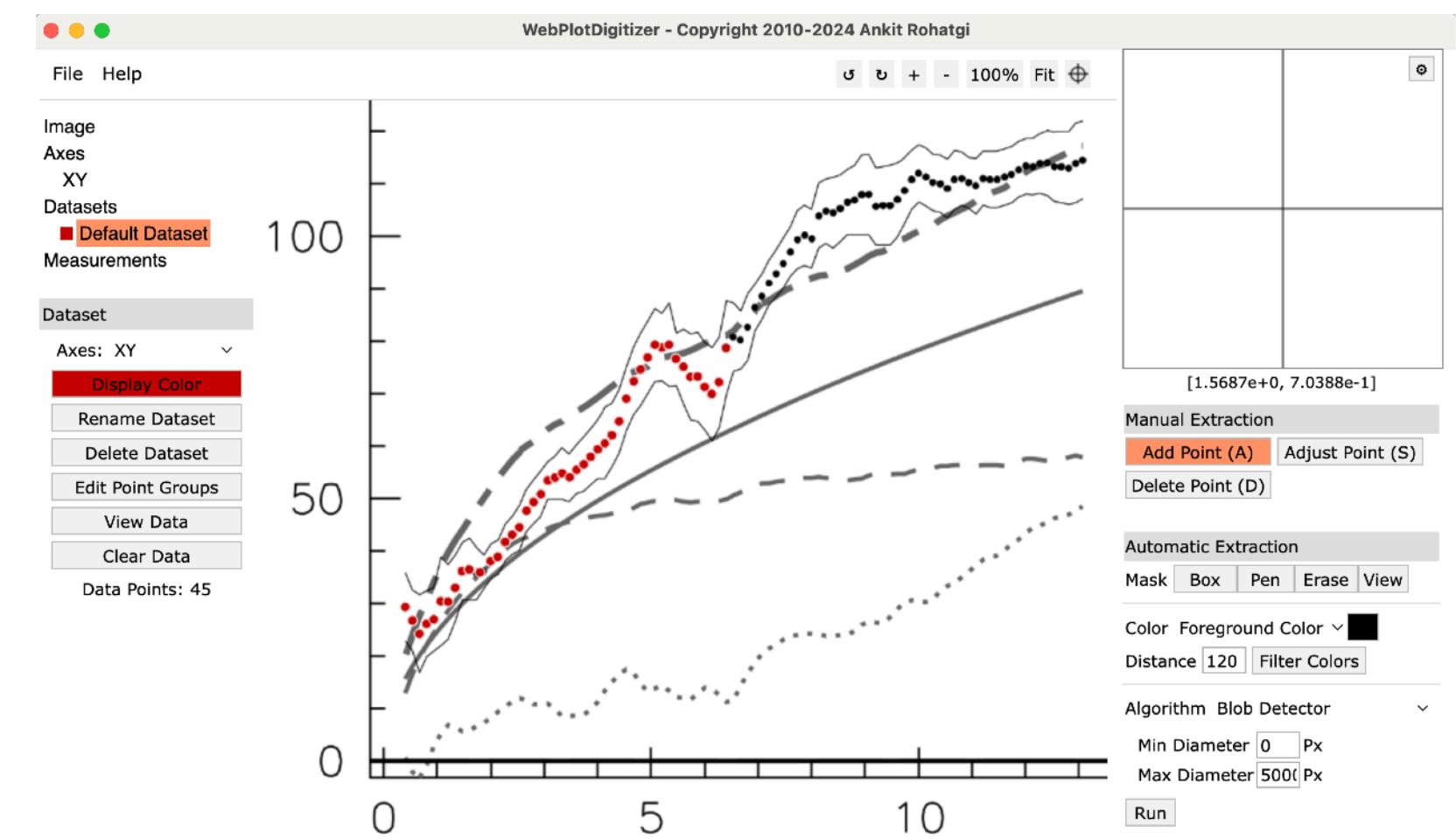


MNRAS **518**, 6340–6354 (2023)
Advance Access publication 2022 December 9
Dark matter halos and scaling relations of extremely massive spiral galaxies from extended HI rotation curves
Enrico M. Di Teodoro^{1,2,3*} Lorenzo Posti^{1,4} S. Michael Fall^{1,2} Patrick M. Ogle,² Thomas Jarrett^{1,5} Philip N. Appleton,⁶ Michelle E. Cluver^{1,7} Martha P. Haynes⁸ and Ute Lisenfeld^{9,10}



235
extended rotation curves
+
baryonic mass models

data accessibility is far from ideal

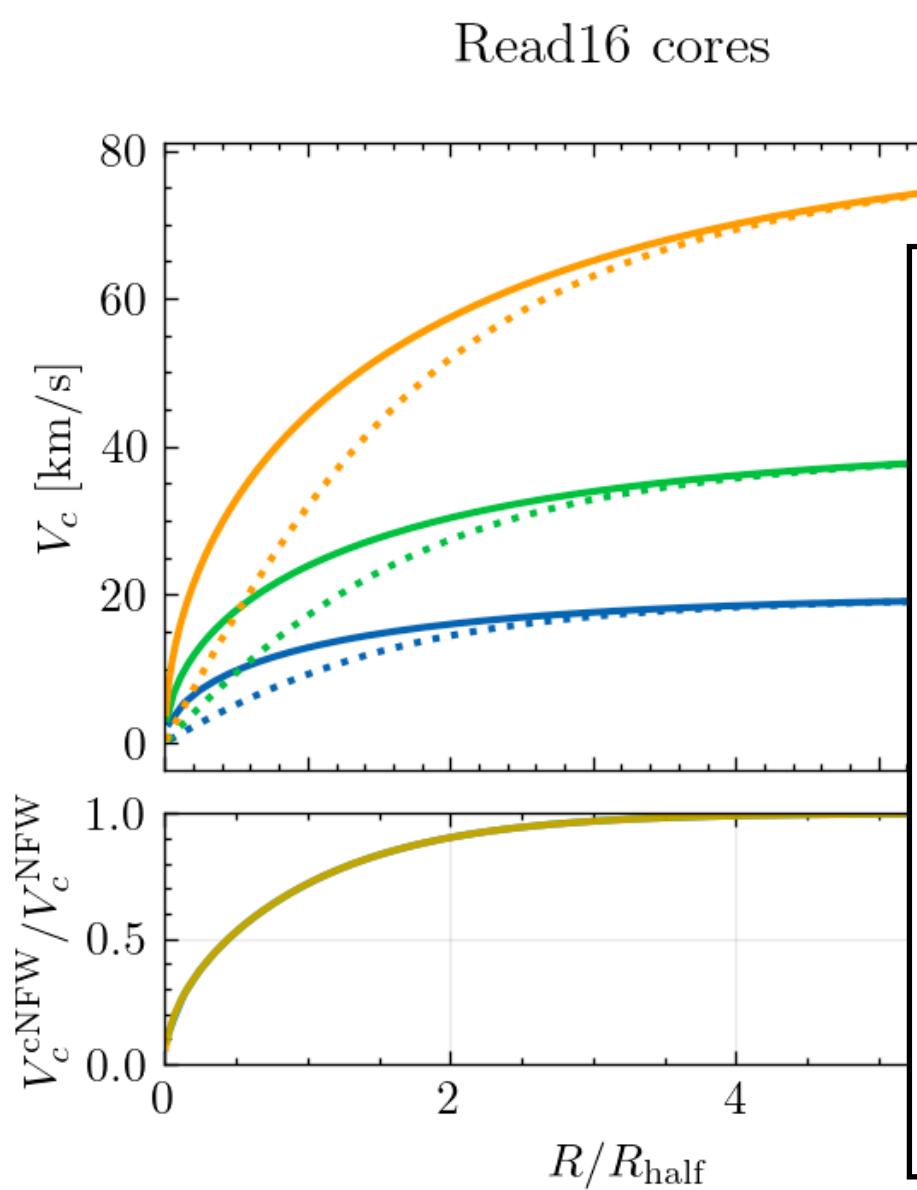


Webplotdigitizer

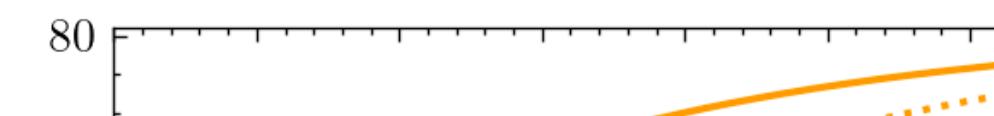
Can we do this experiment with current data?

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

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



DC14 cores



OBSERVATIONAL AND THEORETICAL CONSTRAINTS ON SINGULAR DARK MATTER HALOS

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

AND

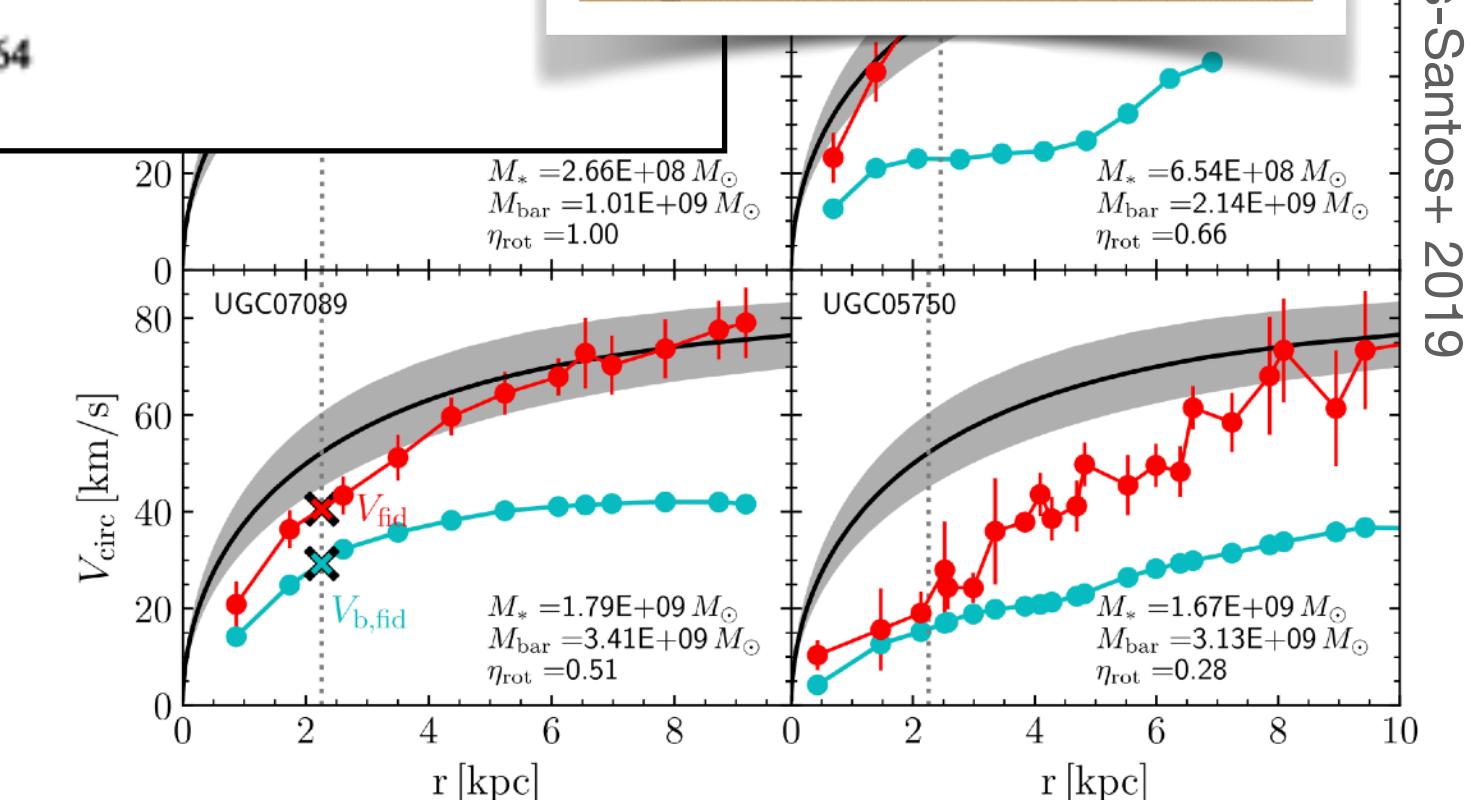
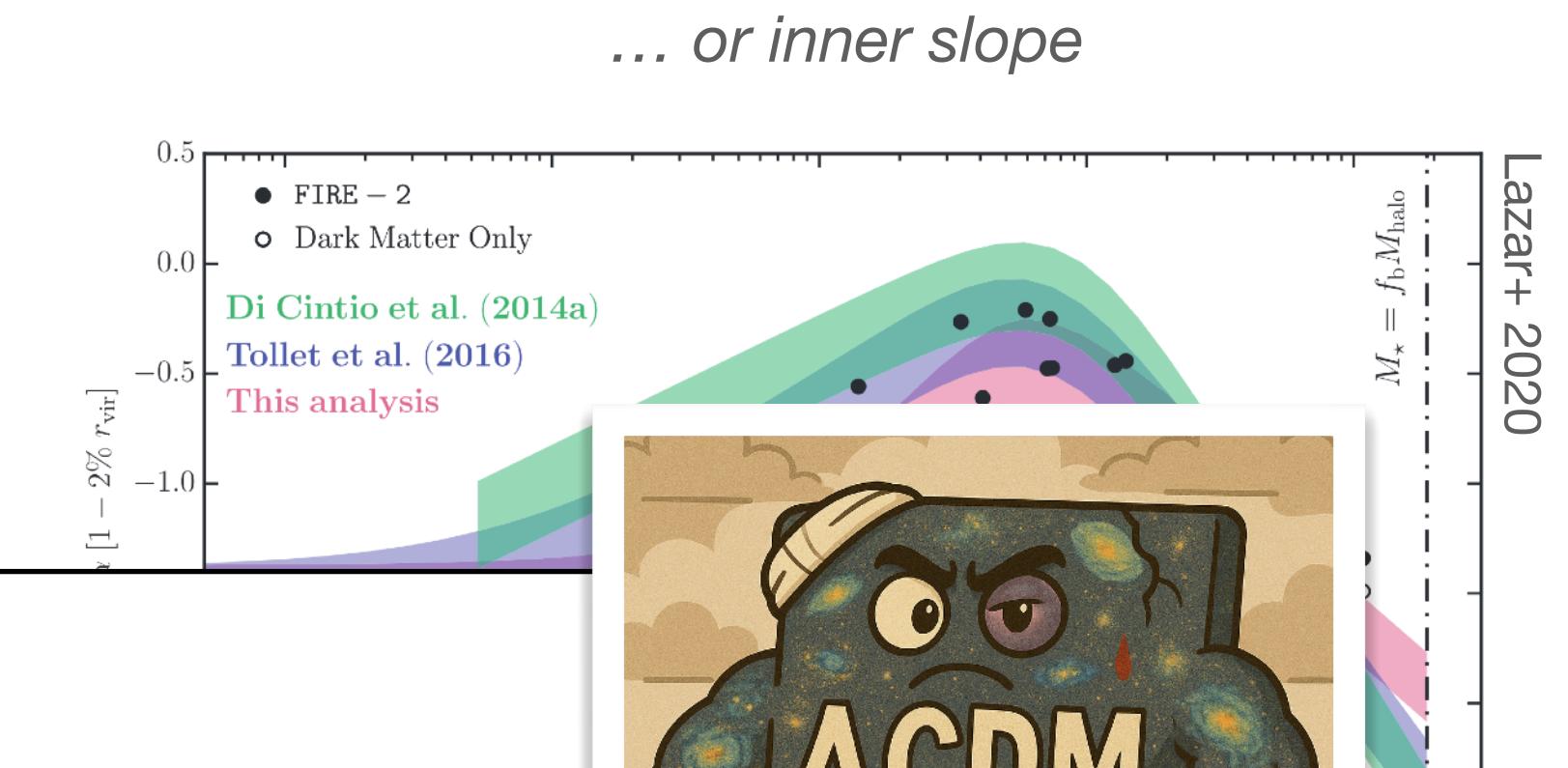
JOEL R. PRIMACK

Santa Cruz Institute for Particle Physics, University of California, Santa Cruz, CA 95064

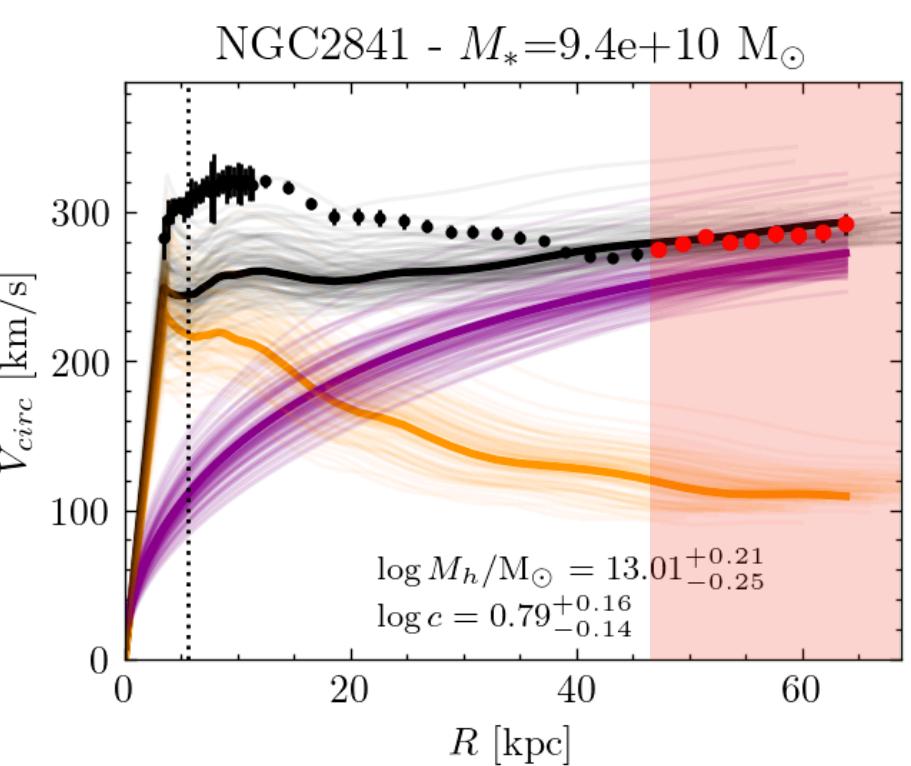
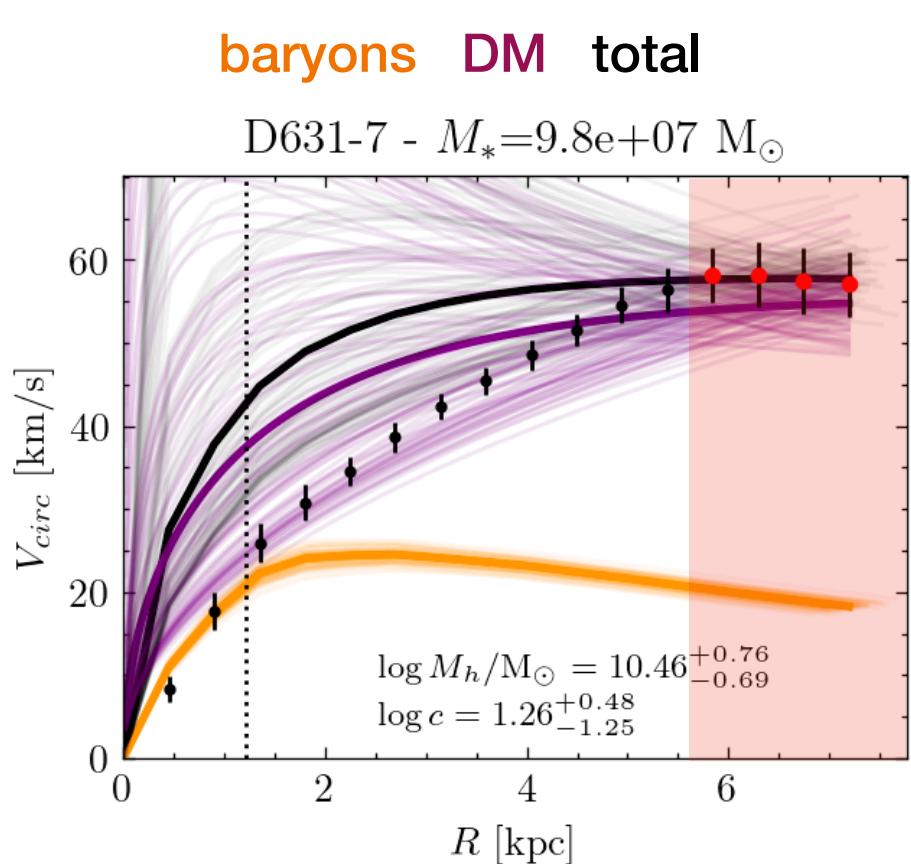
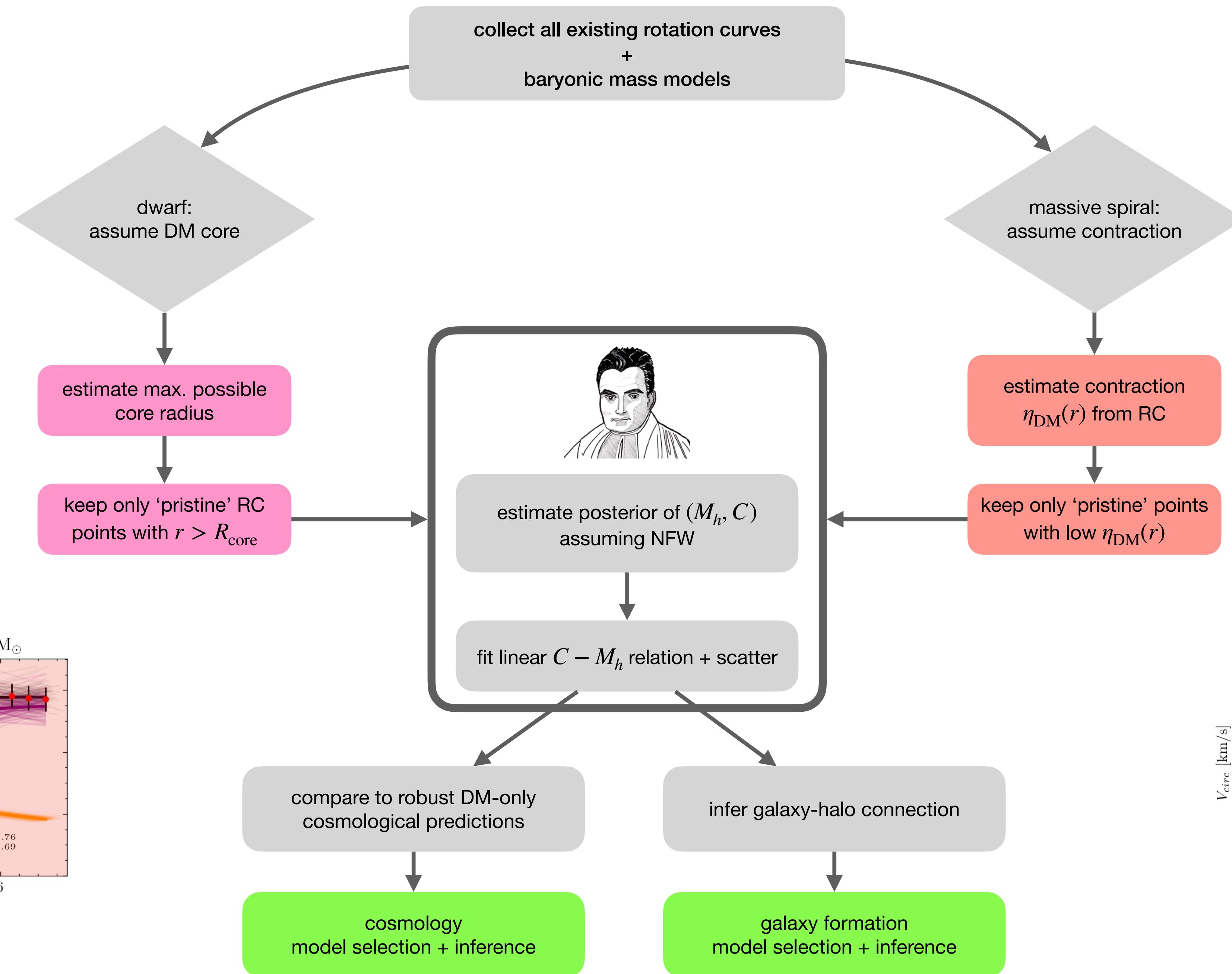
Received 1994 January 11; accepted 1994 March 4

cores from controlled experiments
with resolved feedback

cores from cosmological zooms

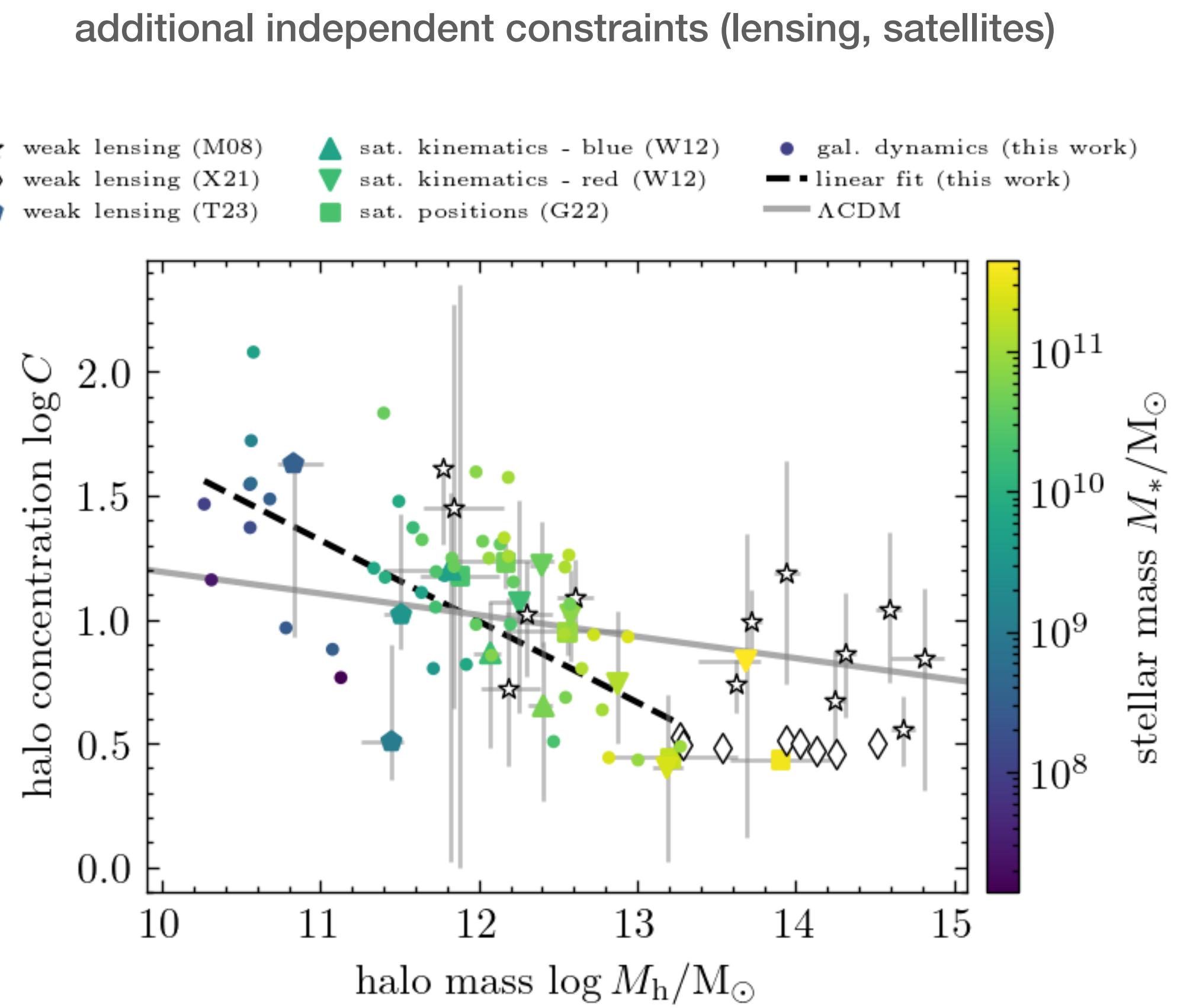
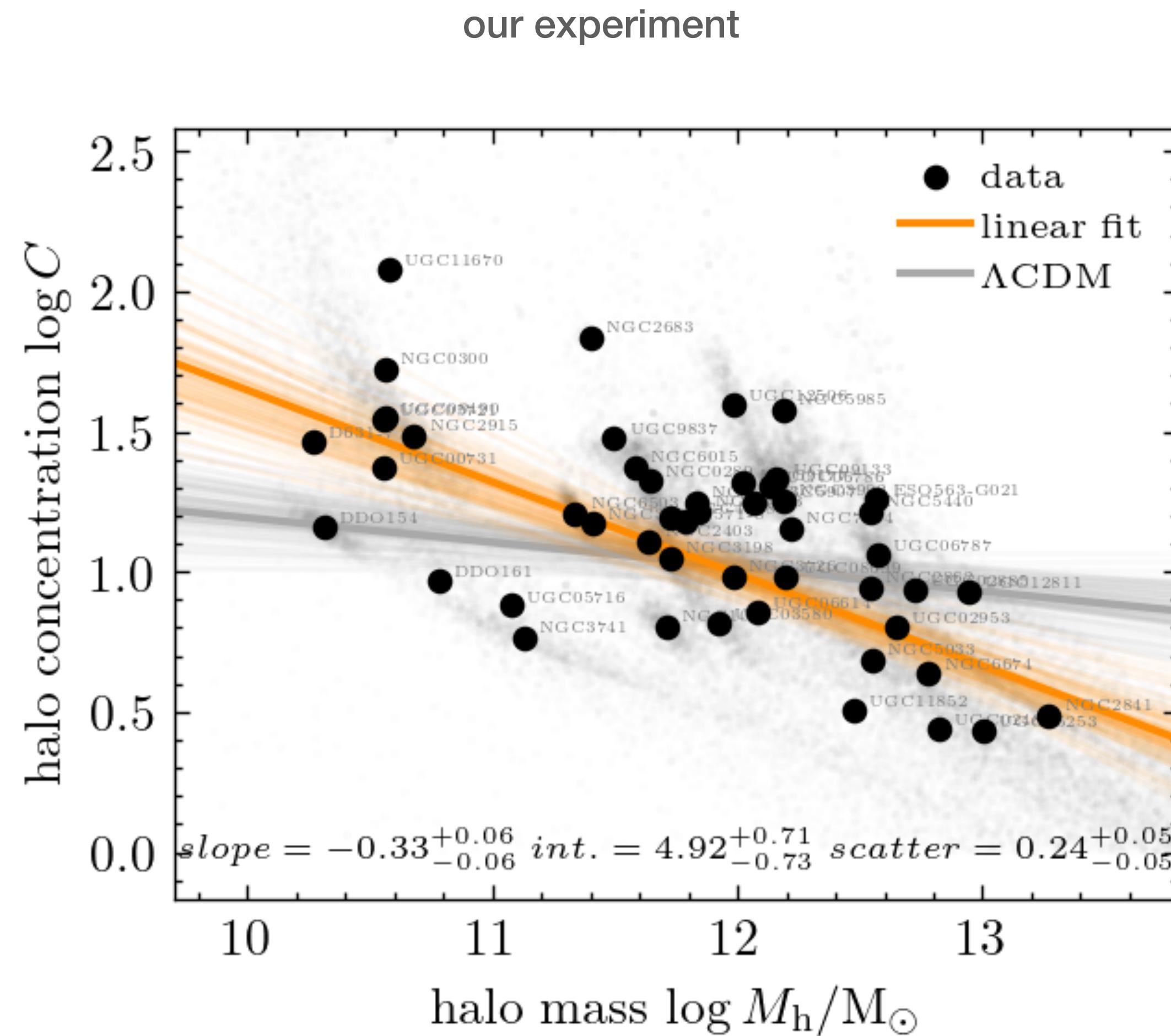


Santos-Santos + 2019



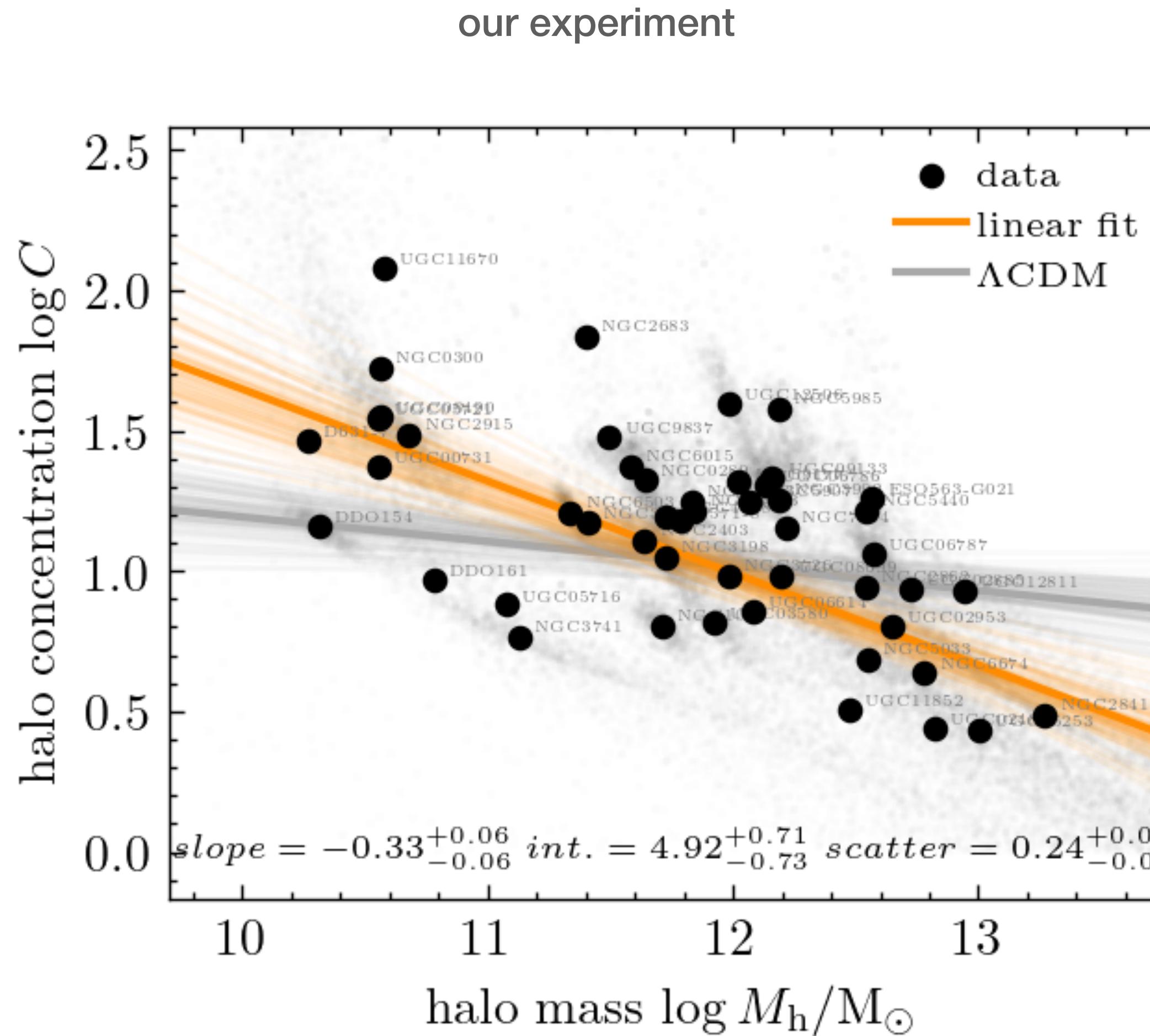
Can we do this experiment with current data?

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



Can we do this experiment with current data?

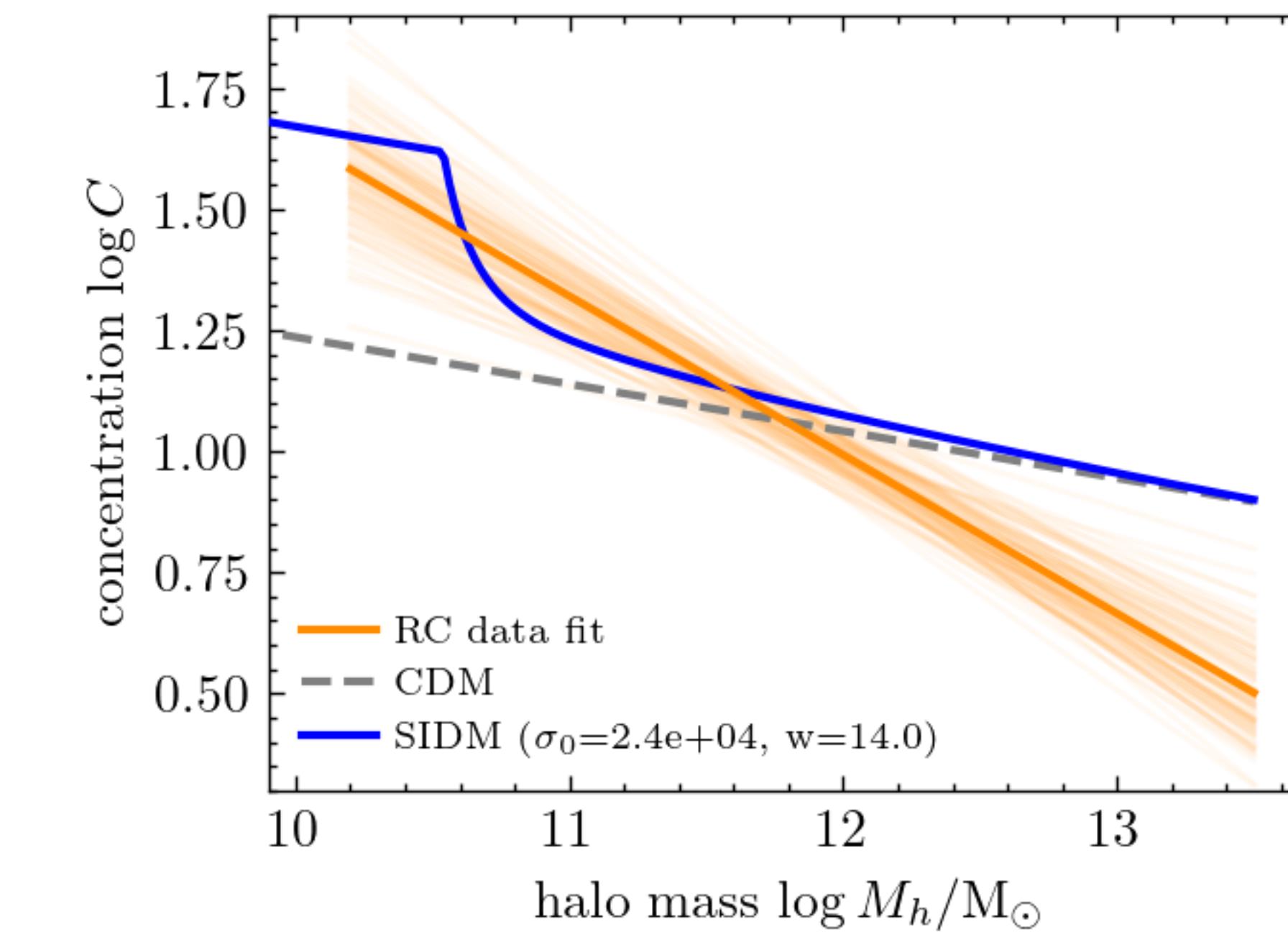
Robust statistical comparison of inferred $C - M_h$ to model predictions: test SIDM hypothesis



SIDM (Yang+ 2024 parametric model)

produces high concentrations in dwarfs
via core collapse

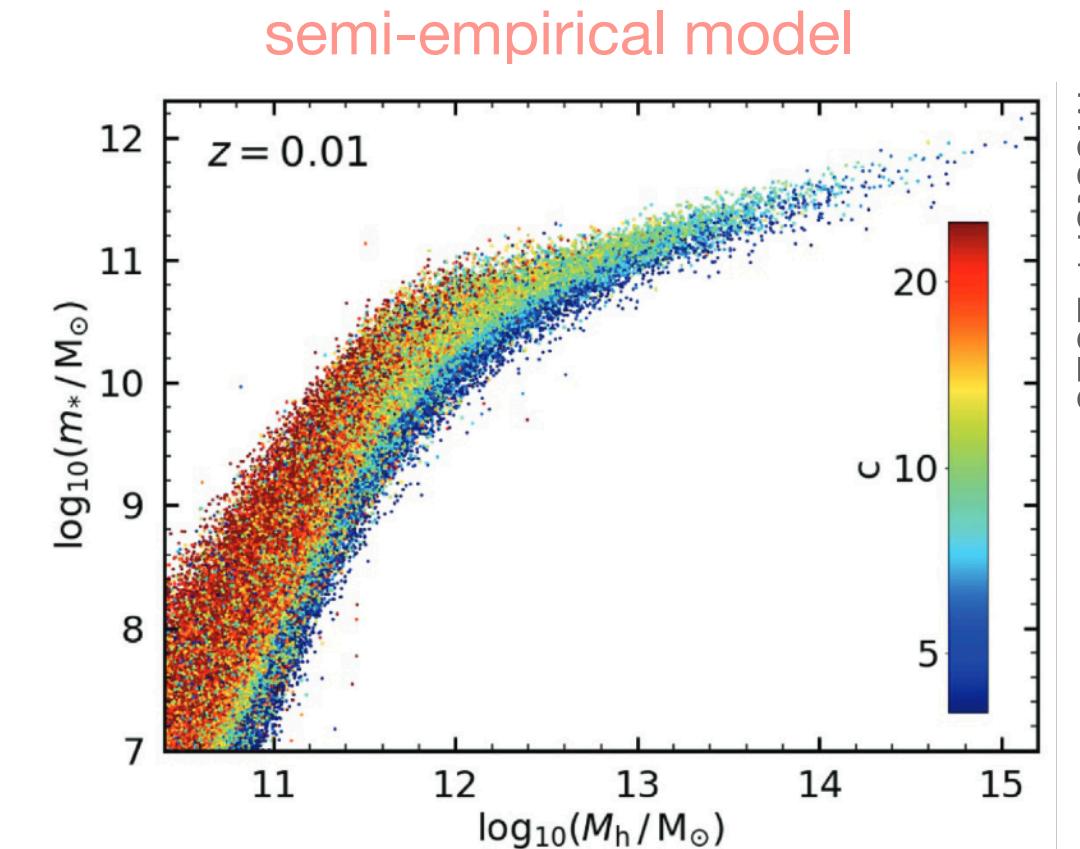
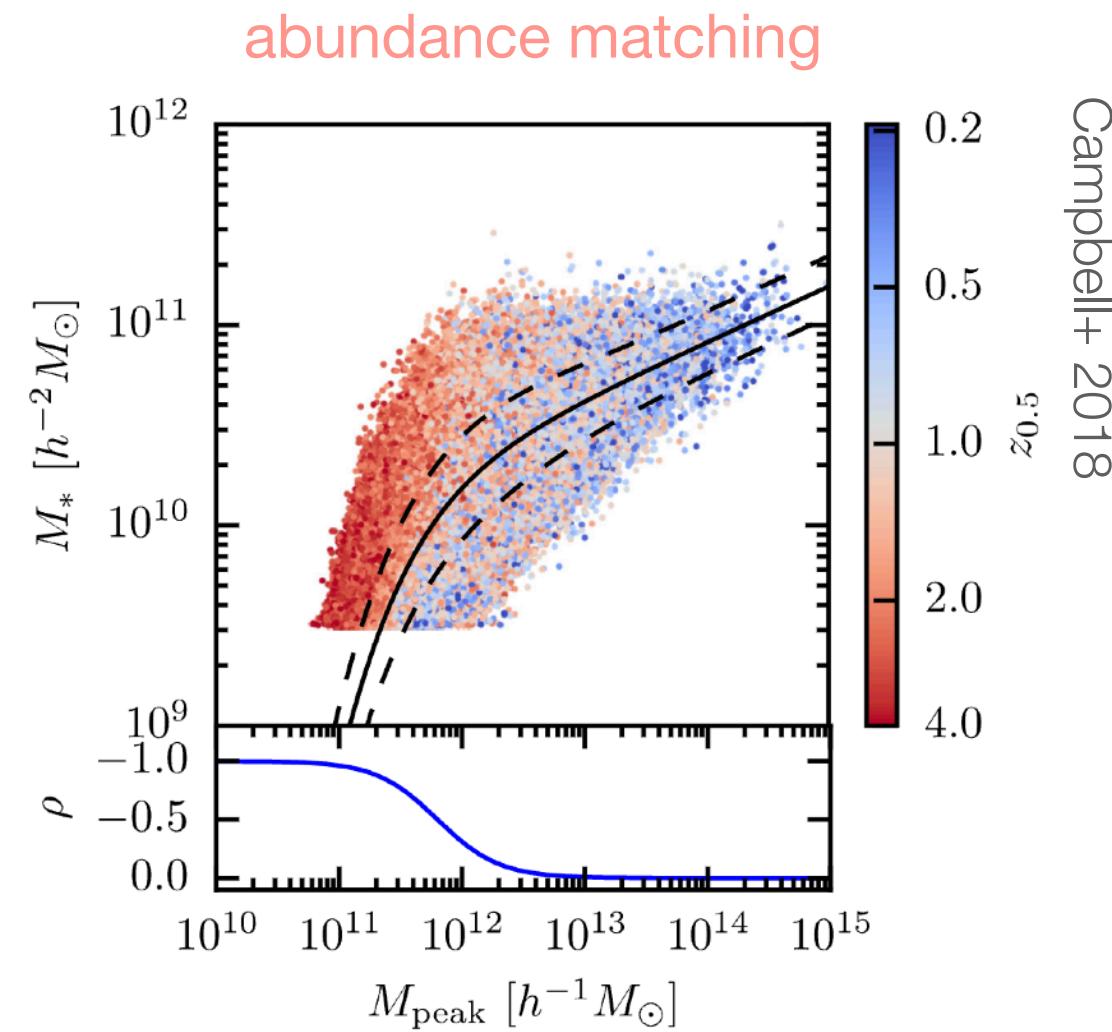
cannot reduce concentration in massive spirals



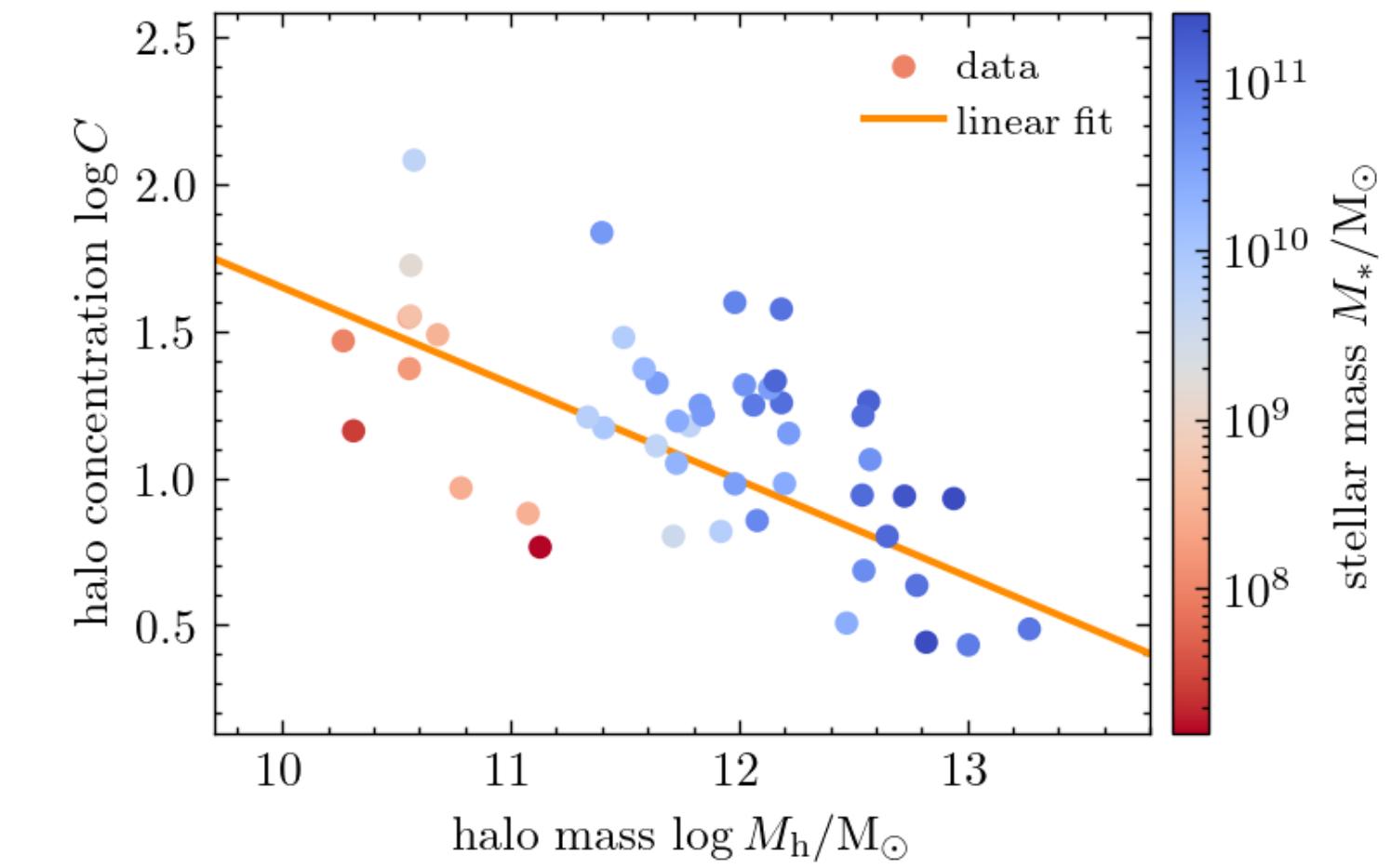
Can we do this experiment with current data?

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

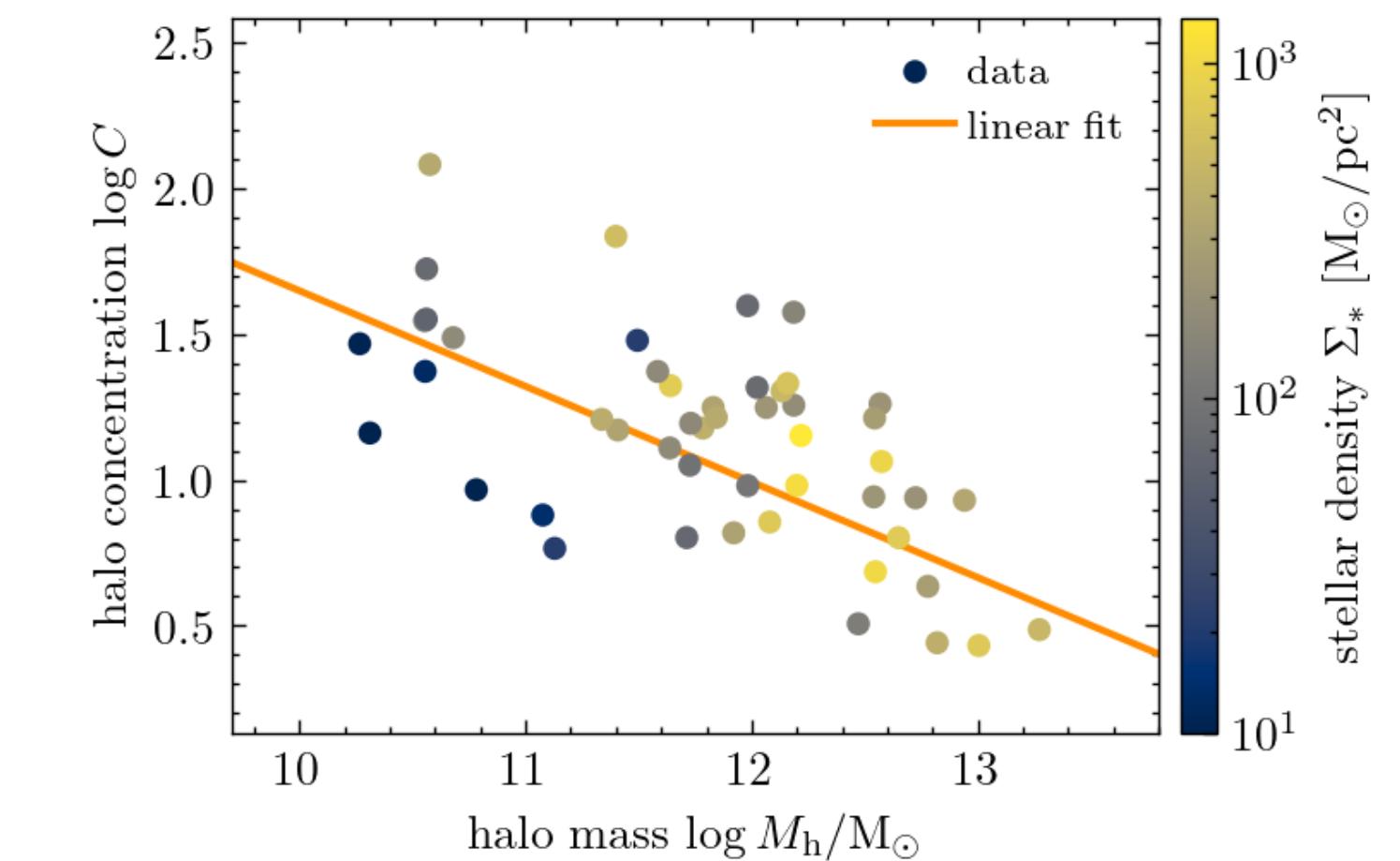
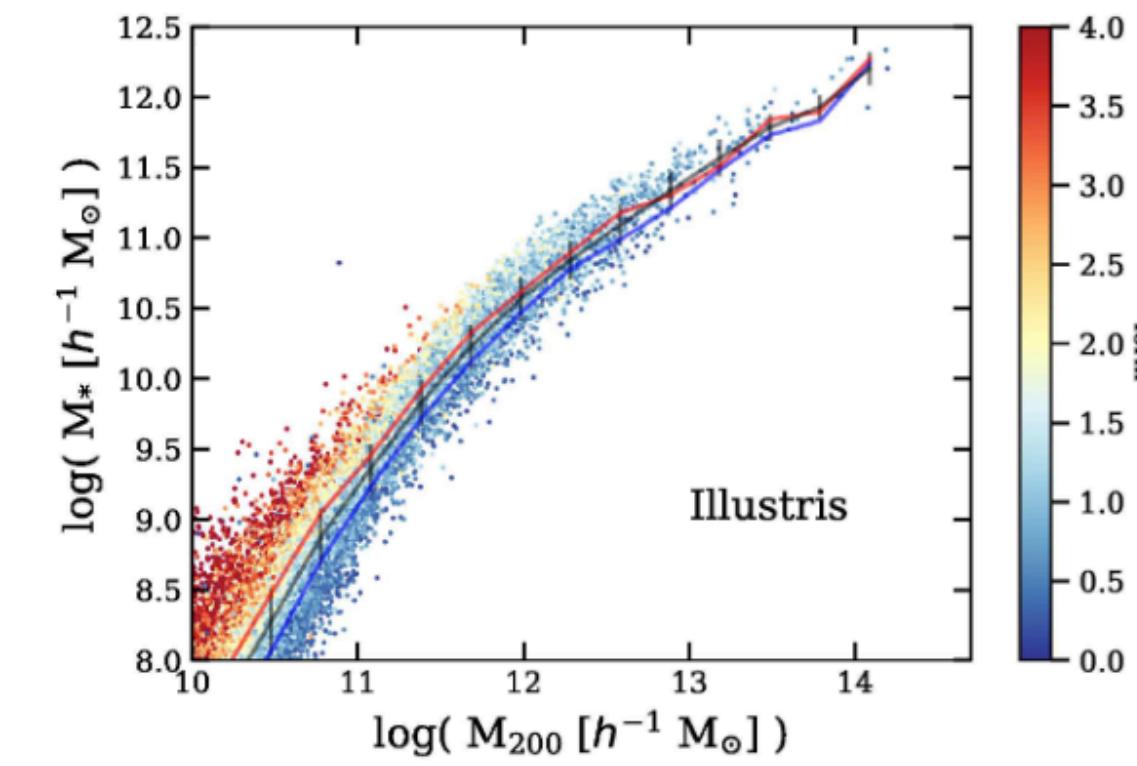
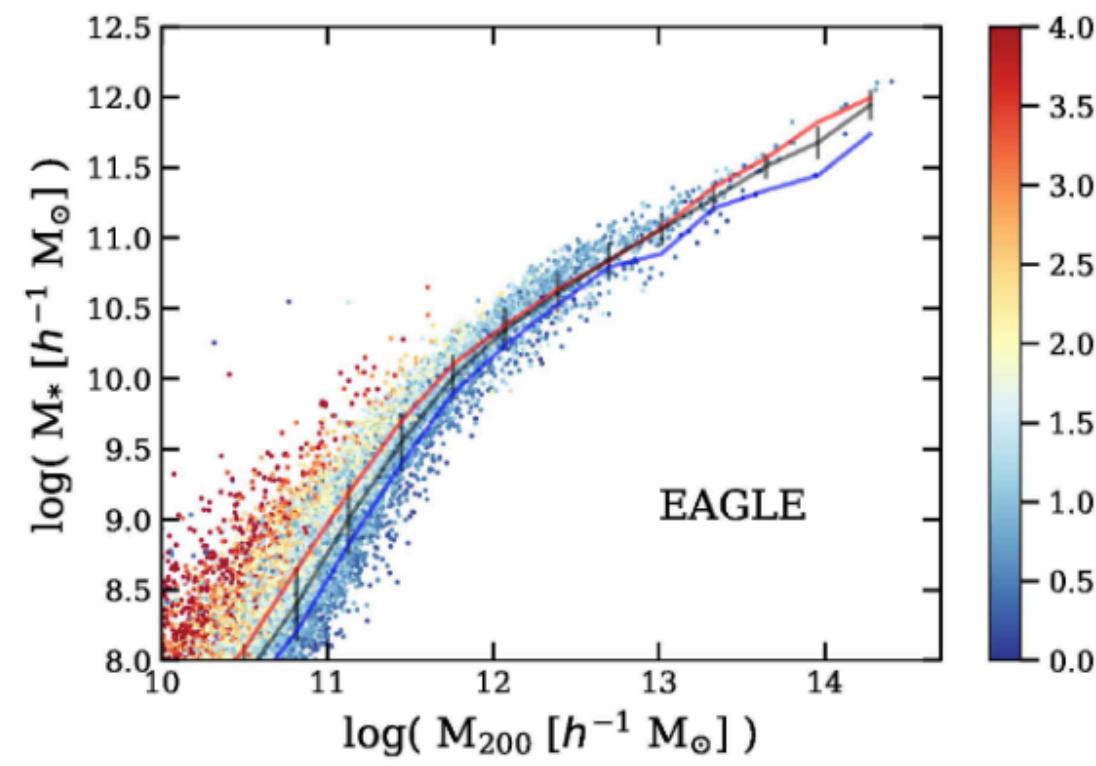
robust prediction of all models



our experiment

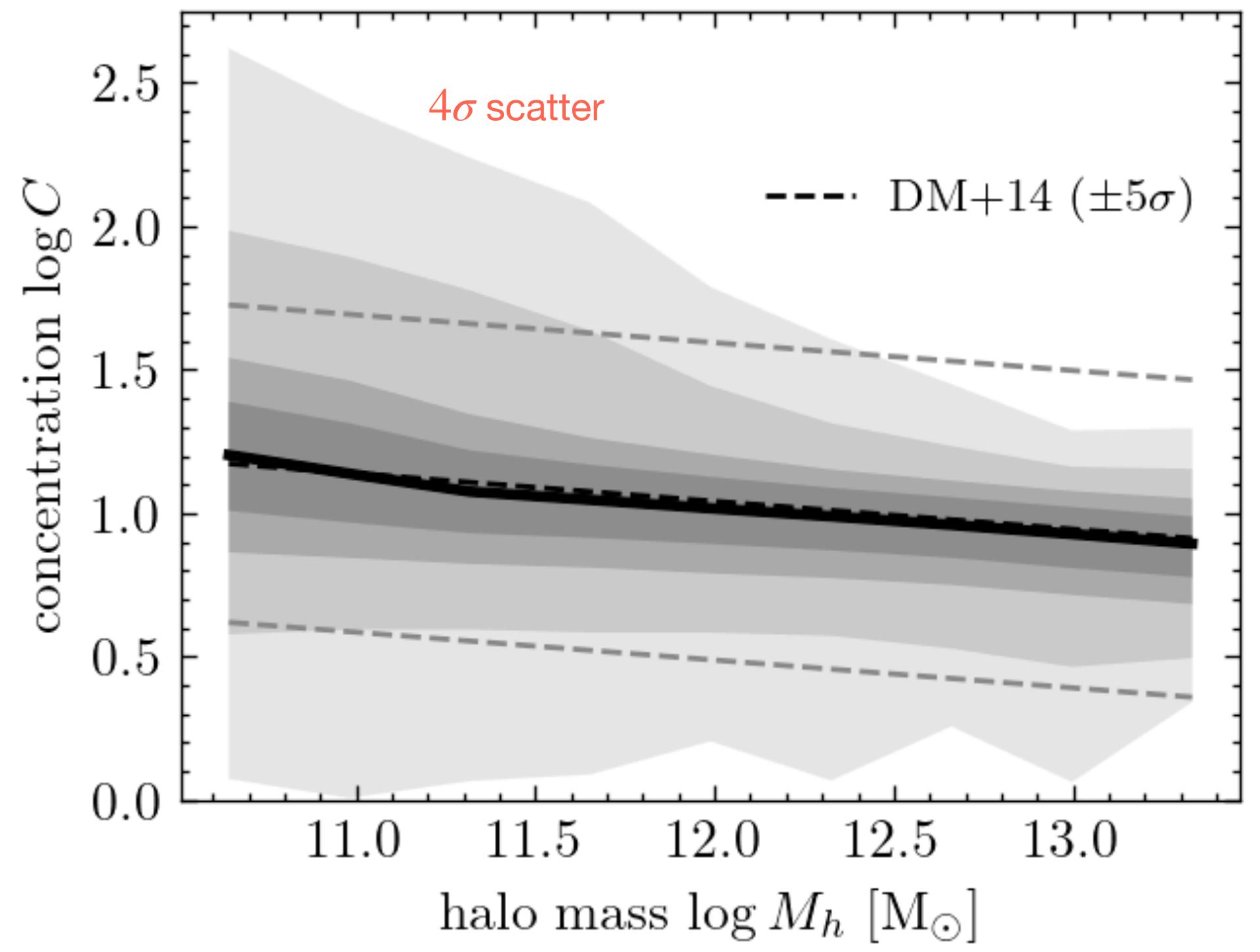
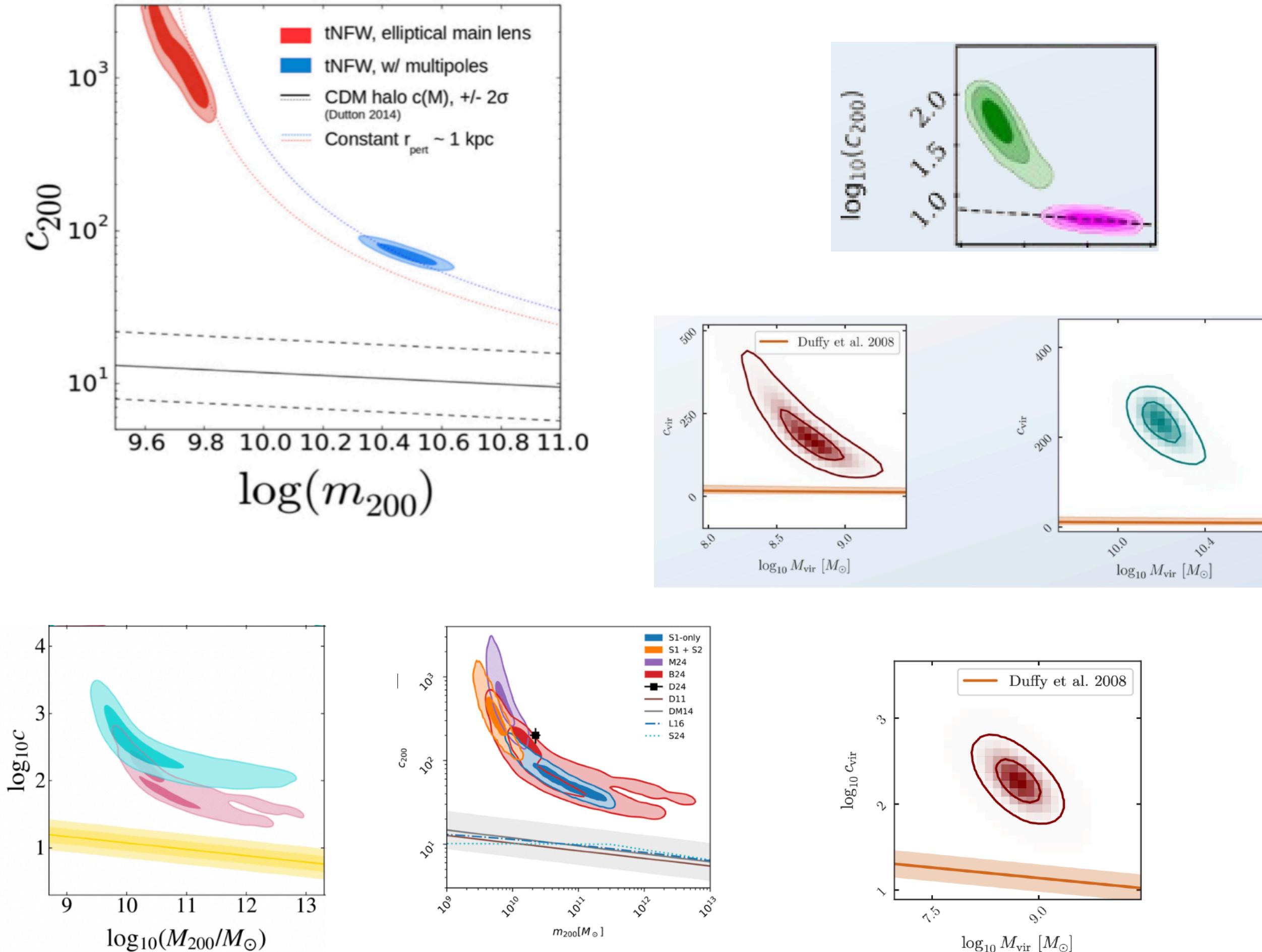
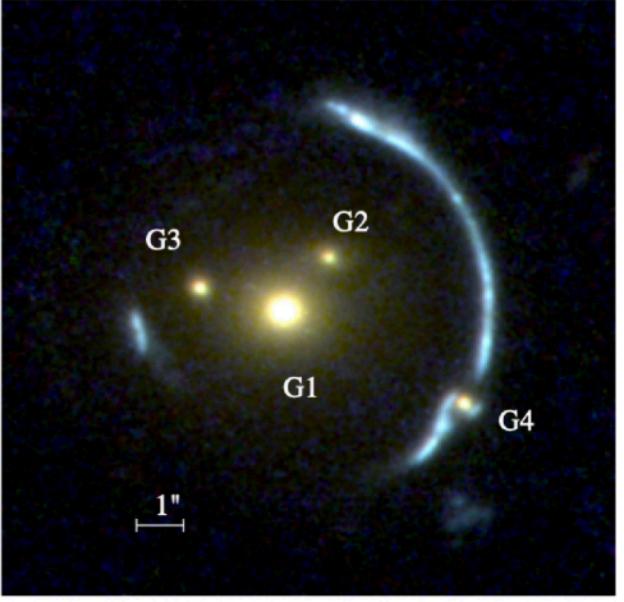


hydro simulations



Using single objects to test CDM

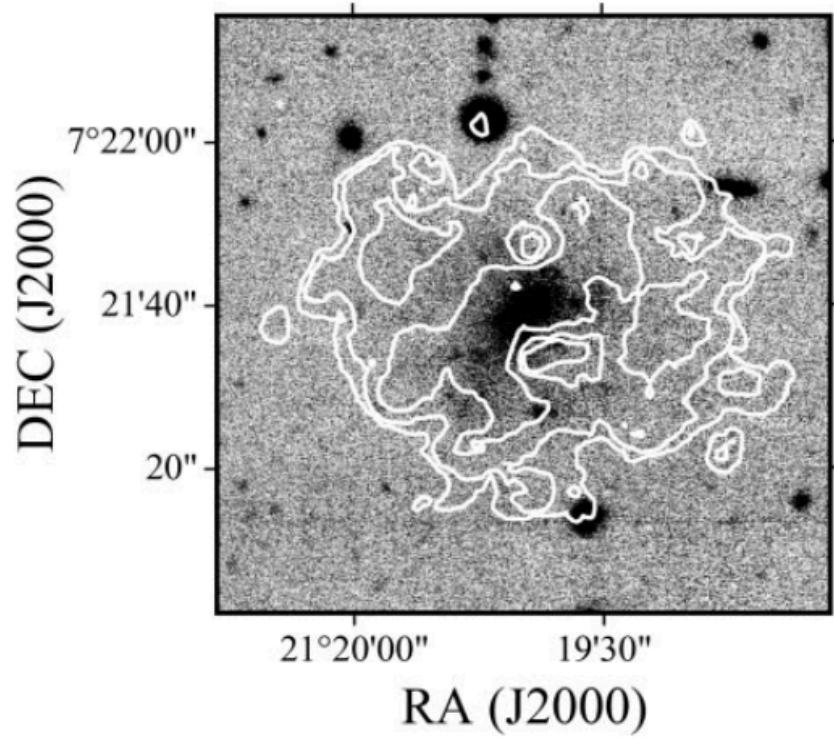
Do dense dark strong lensing perturbers break CDM?



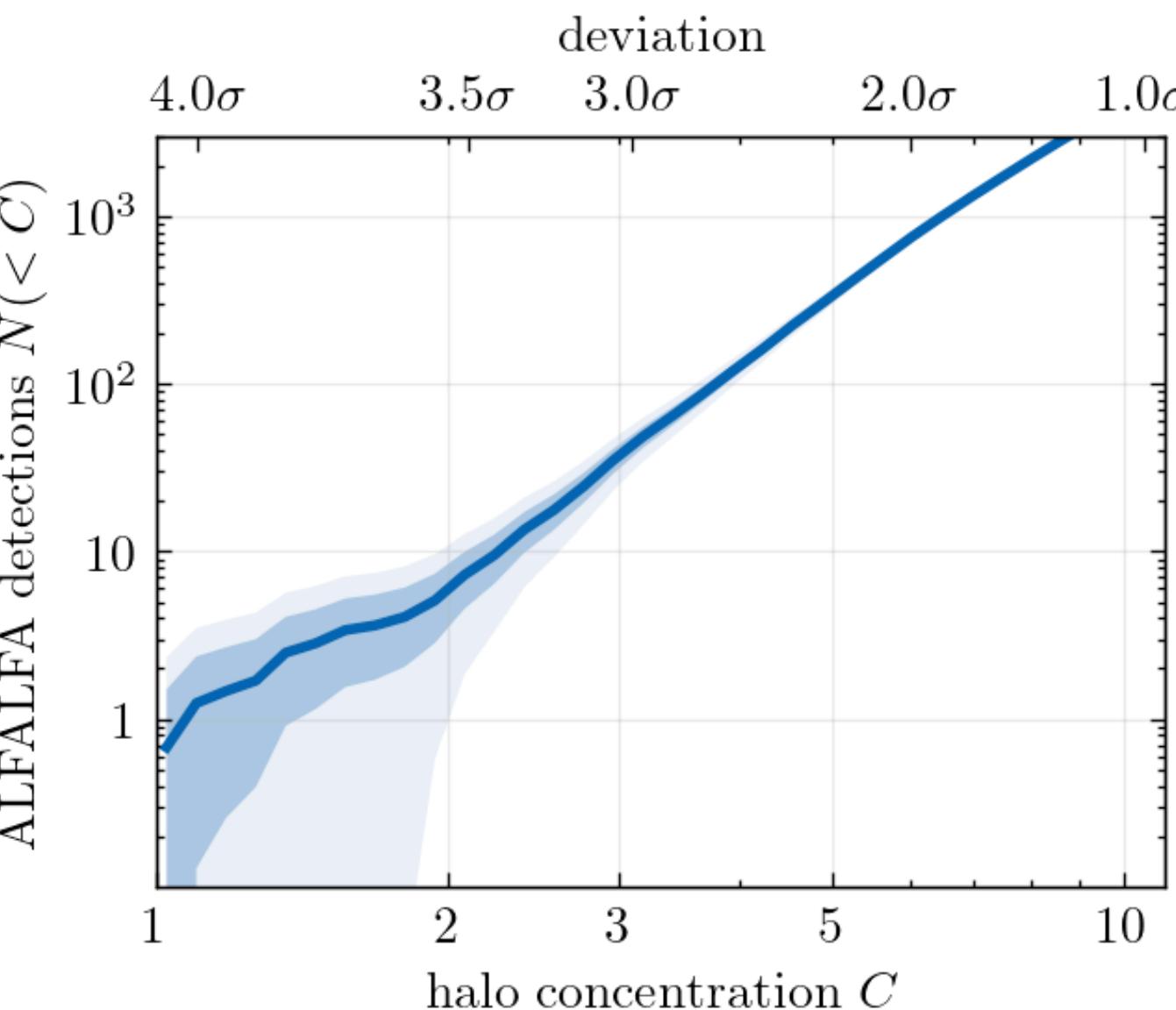
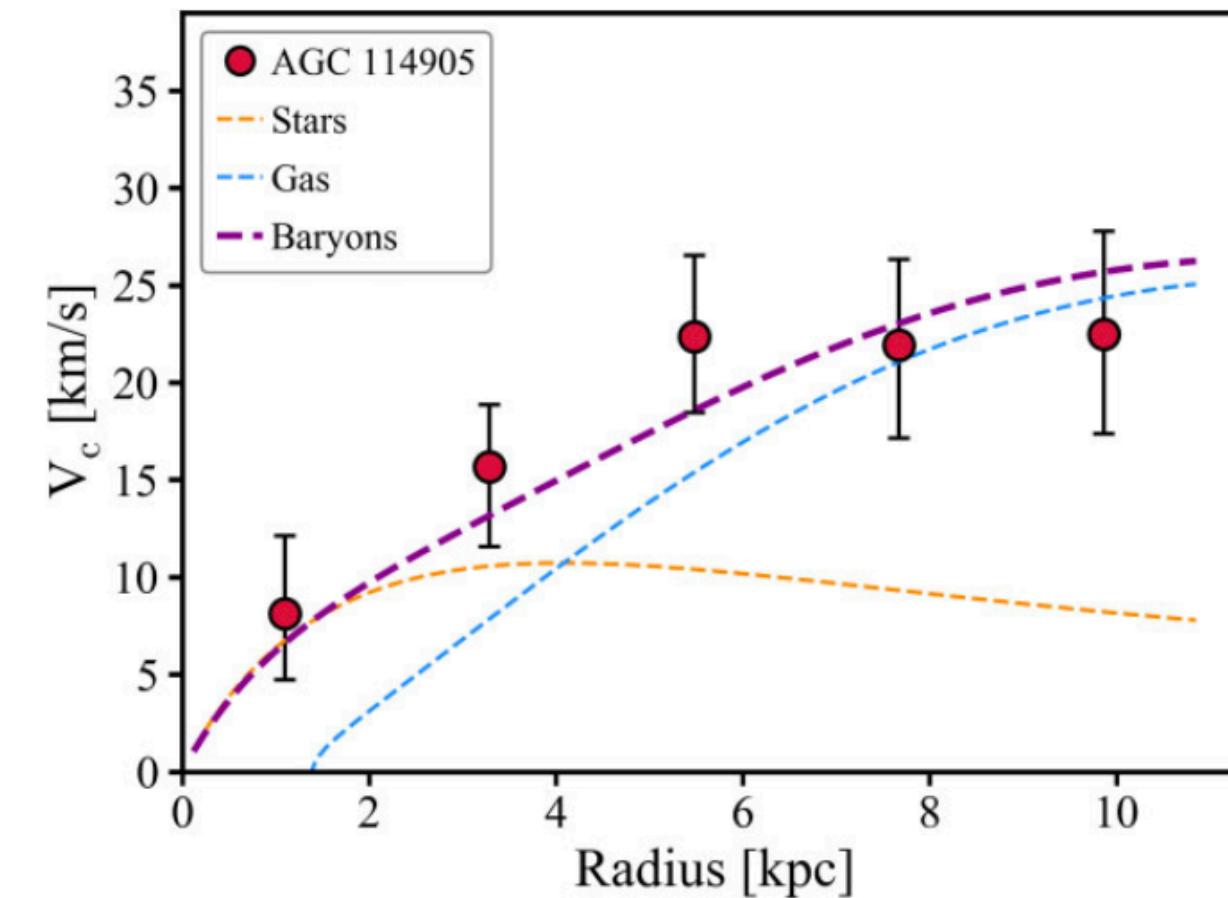
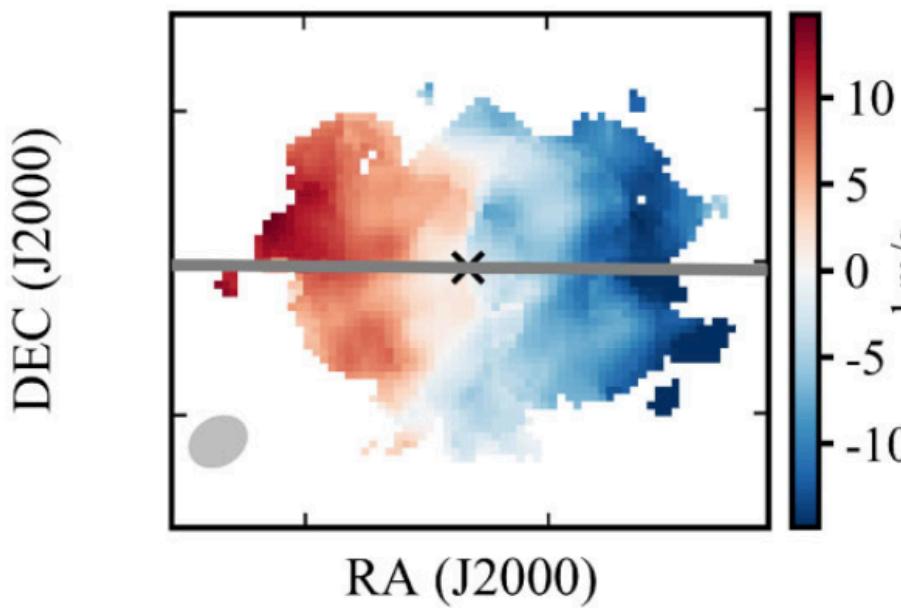
Mass-concentration distribution in *Bolshoi* simulation

Using single objects to test CDM

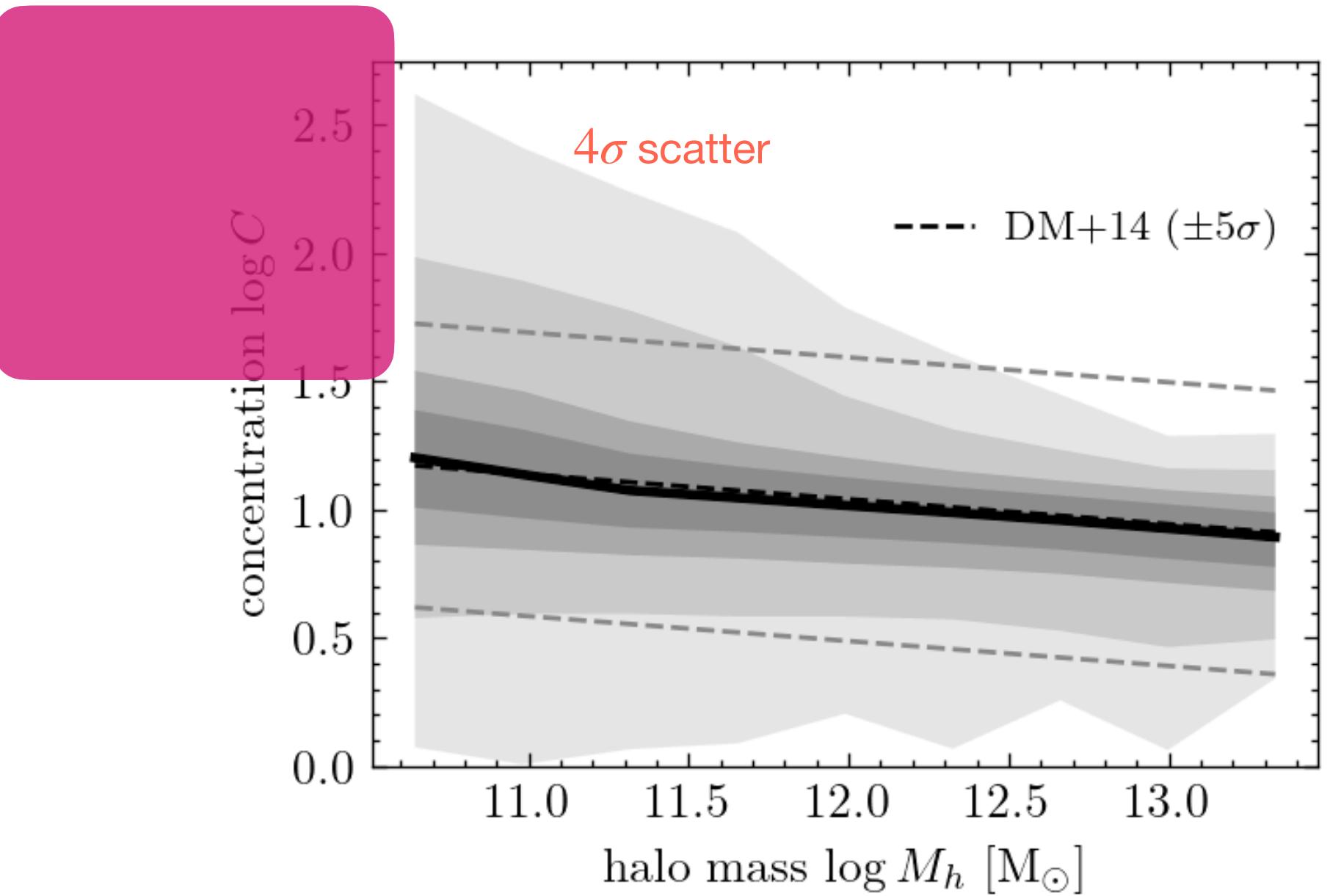
Do DM-deficient galaxies break CDM?



the *extreme low-density tail*
of the diversity problem



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