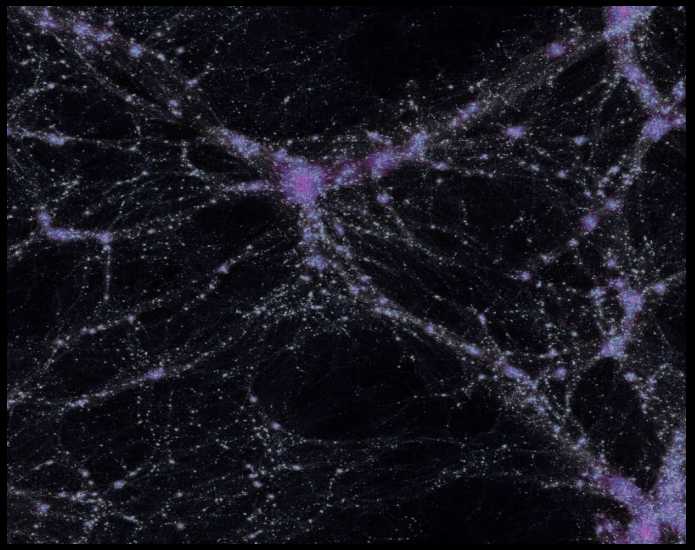
Is a model beyond CDM needed to describe structure formation?

CDM is an approximation.
Where does it break?

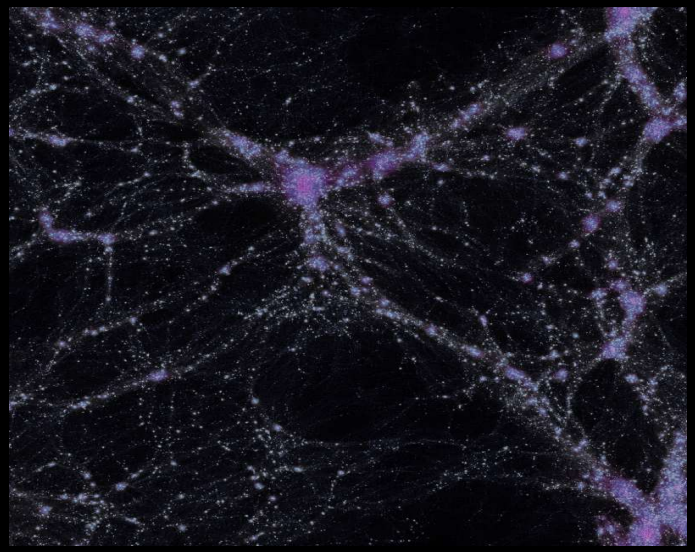
Does another model have a
simpler and better description?

Does the other model
have distinct signatures?

ΛCDM agrees well with the observed large-scale structure.



On these scales, CDM is the right description.



Dark sector particles can interact with each other (SIDM), like visible sector particles.

SIDM = CDM on large scales.

SIDM phenomenology

Spergel and Steinhardt, PRL 2000

With Sean Tulin and Hai-Bo Yu, PRL 2016

$\frac{\sigma}{m} = \text{few } \frac{cm^2}{g}$

(in galaxies)

But cross section must be much smaller at $v \sim 1000$ km/s.

Use:
Field galaxies → SIDM parameter space

Signatures:
Satellite galaxies and dark subhalos.

SIDM halo profile (where the stars are)

Depends on the outer halo profile (Vmax and Rmax)

$$\rho_{\mathrm{SIDM}}(r) = \rho_0 \, e^{-\Phi(r)/kT}$$

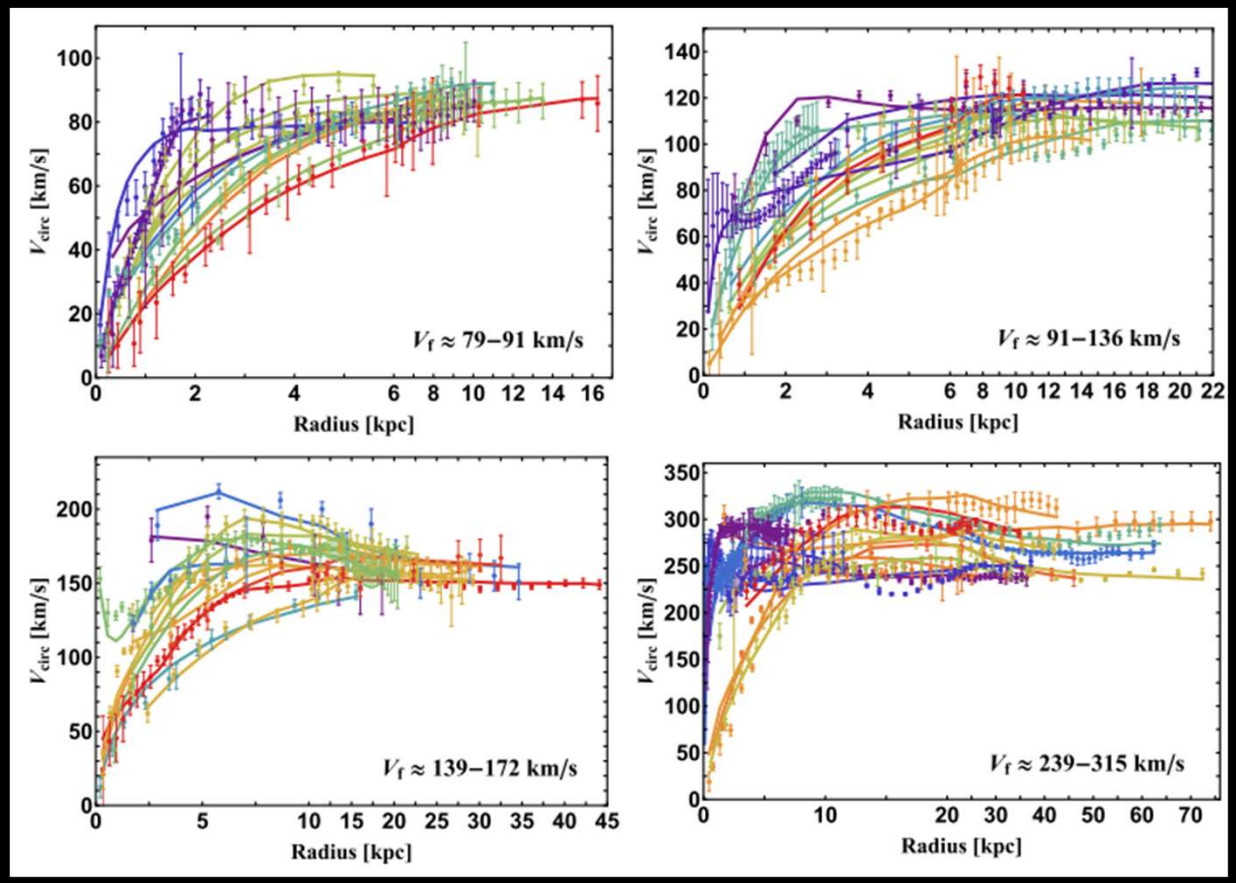
gravitational potential of dark matter and baryons

High-surface brightness galaxies are “cuspy”

Low surface brightness galaxies are “cored”

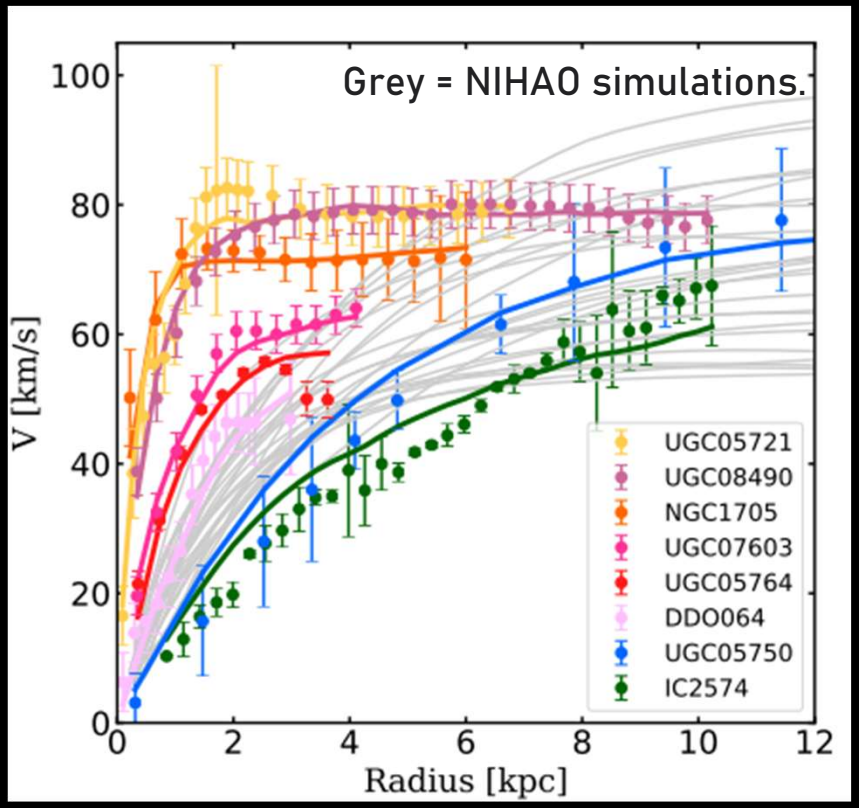
With Ryan Keeley, Tim Linden and Hai-Bo Yu, PRL 2014

SIDM captures the full diversity of rotation curves



With Tao Ren, Anna Kwa and Hai-Bo Yu, Phys. Rev. X (2019)

Current feedback models cannot be final word

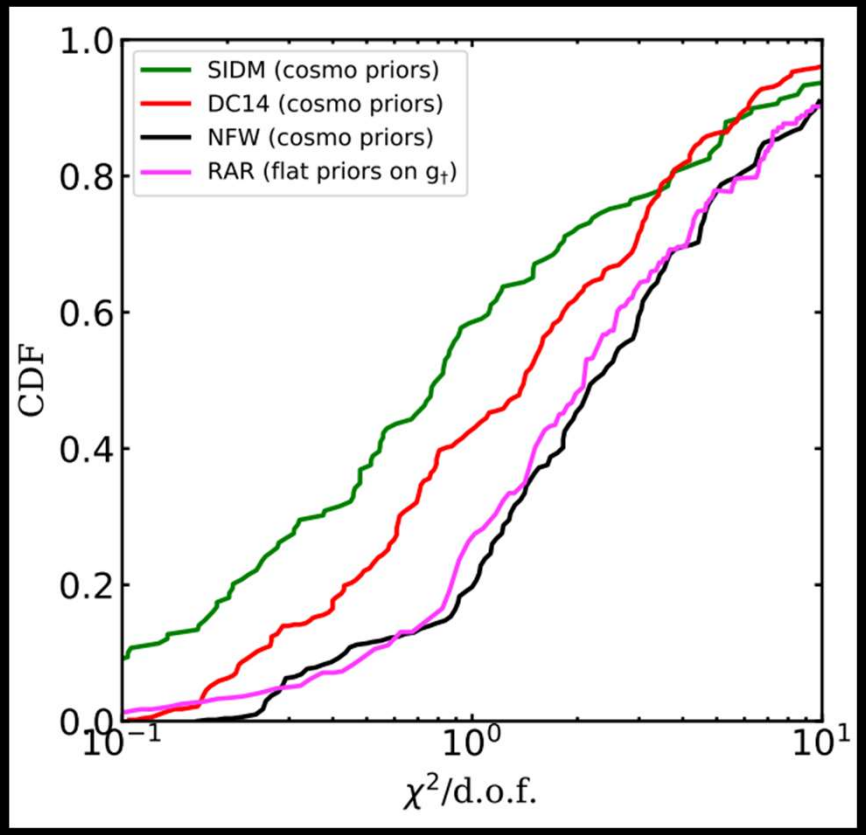


What you do to DM, you do to stars.

Strong feedback does not make high-surface brightness (compact) galaxies.

With Tao Ren and Hai-Bo Yu (to be posted)

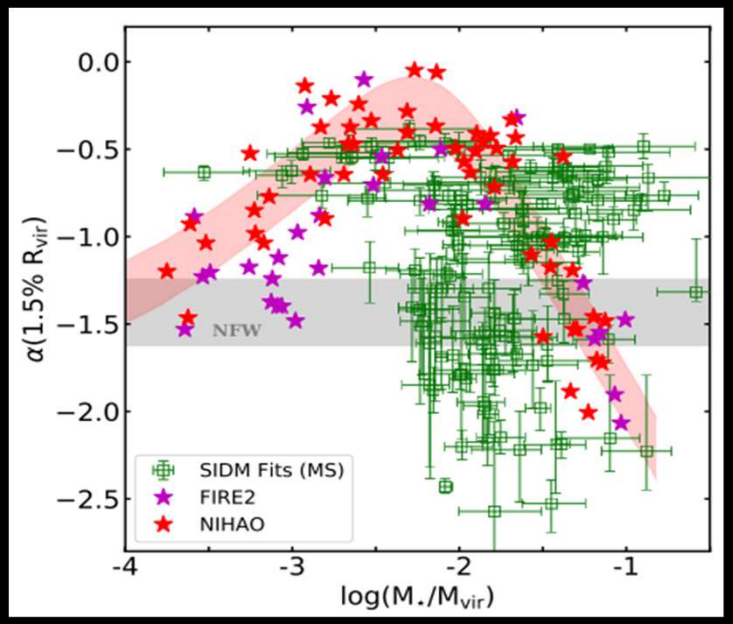
Comparing SIDM and CDM fits (NIHAO, FIRE-2)



With Tao Ren and Hai-Bo Yu (to be posted)

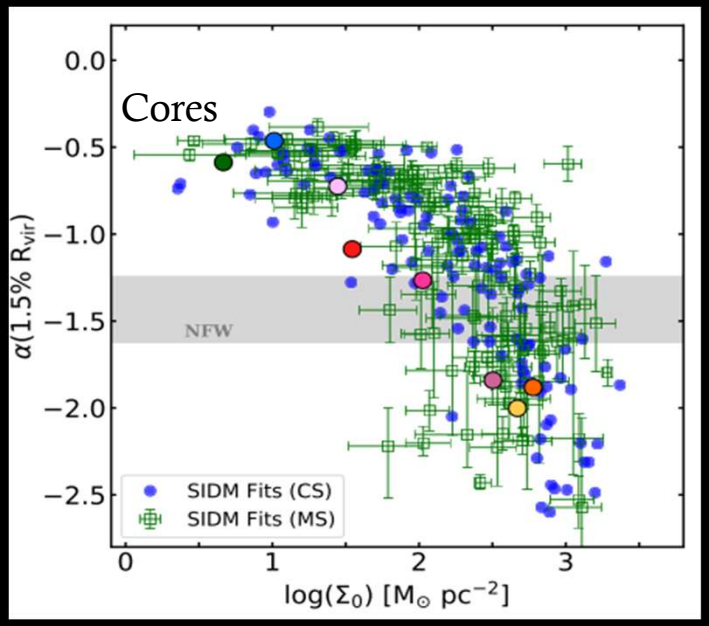
Why does SIDM get the rotation curves right?

DM slope at 1.5% of Rvir



Stellar mass

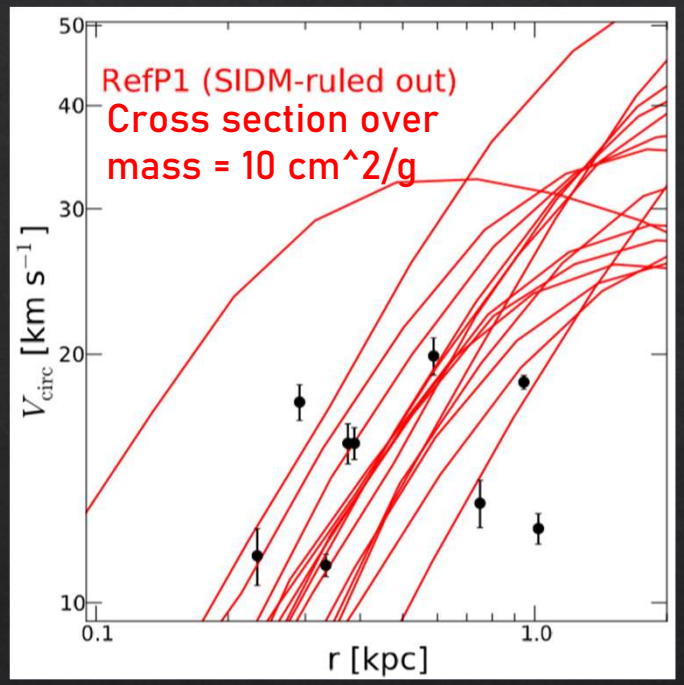
CDM: slope correlated with stellar-to-halo mass



Stellar surface density

SIDM: slope correlated with stellar surface density

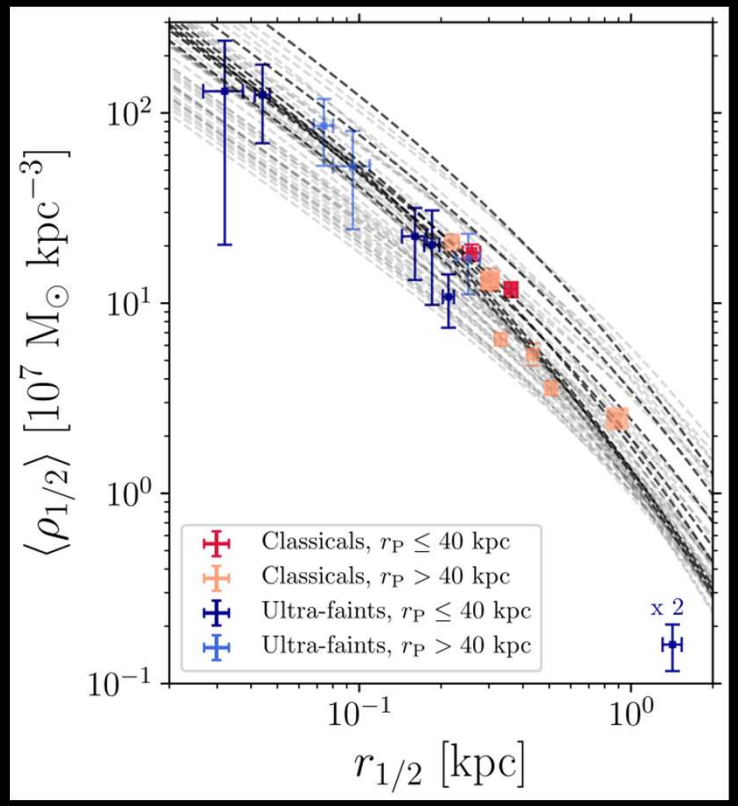
With Tao Ren and Hai-Bo Yu (to be posted)



Vogelsberger, Zavala, Loeb MNRAS (2012)

Satellite galaxies

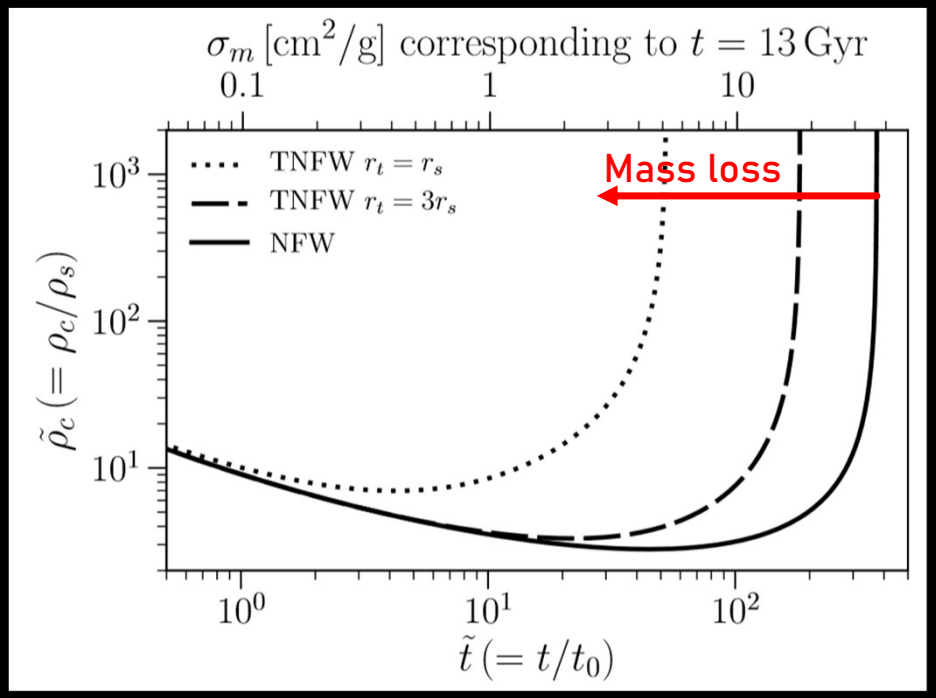
Diversity of satellite galaxies



SIDM provides a potential explanation of the diversity.

With Mauro Valli and Hai-Bo Yu (2019)

Accelerated evolution of SIDM subhalos



Core density

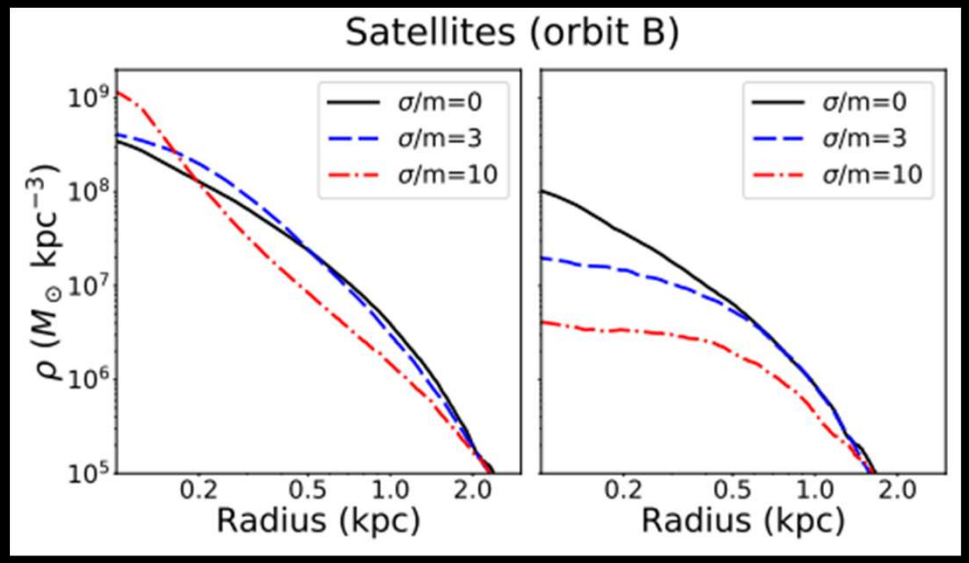
Age/(interaction time)

Core collapse is unique and generic to SIDM and it provides a smoking gun for discovering dark matter self-interactions.

With Nishikawa and Boddy (2019)

High conc

Low conc

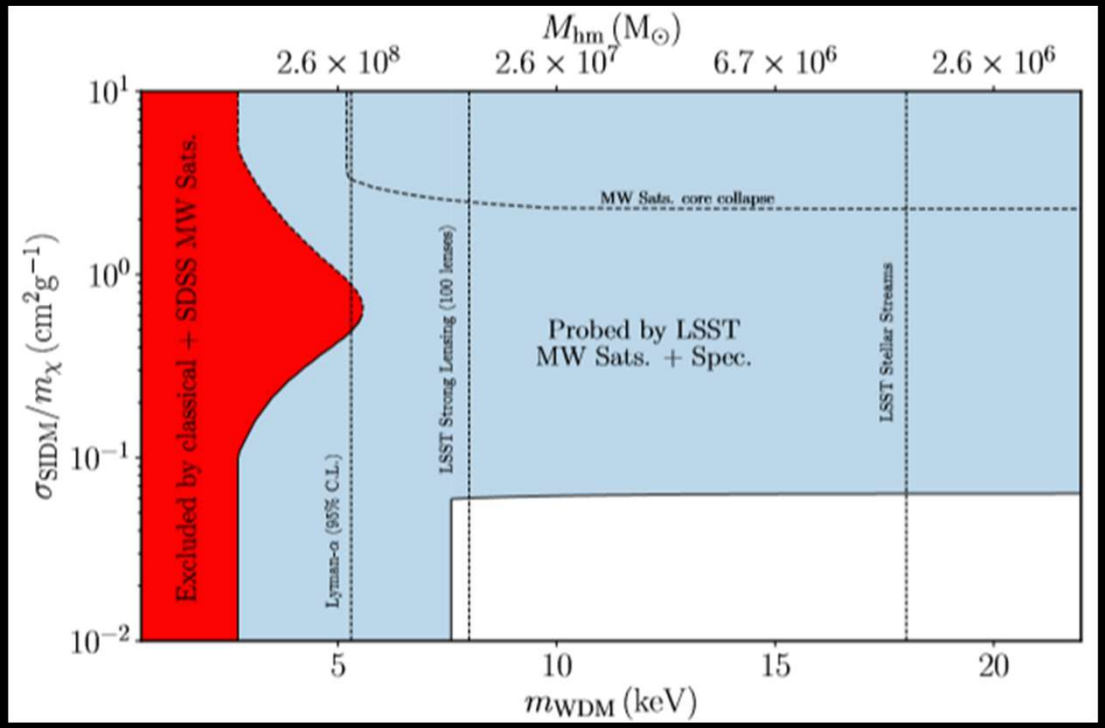


Small pericenter distance

SIDM subhalos that survive close passages will mostly be dense

With Felix Kahlhoefer, Tracy Slatyer and Chih-Liang Wu (2019)

Ultrafaint satellites of the Milky provide an exciting future test of dark matter self-interactions

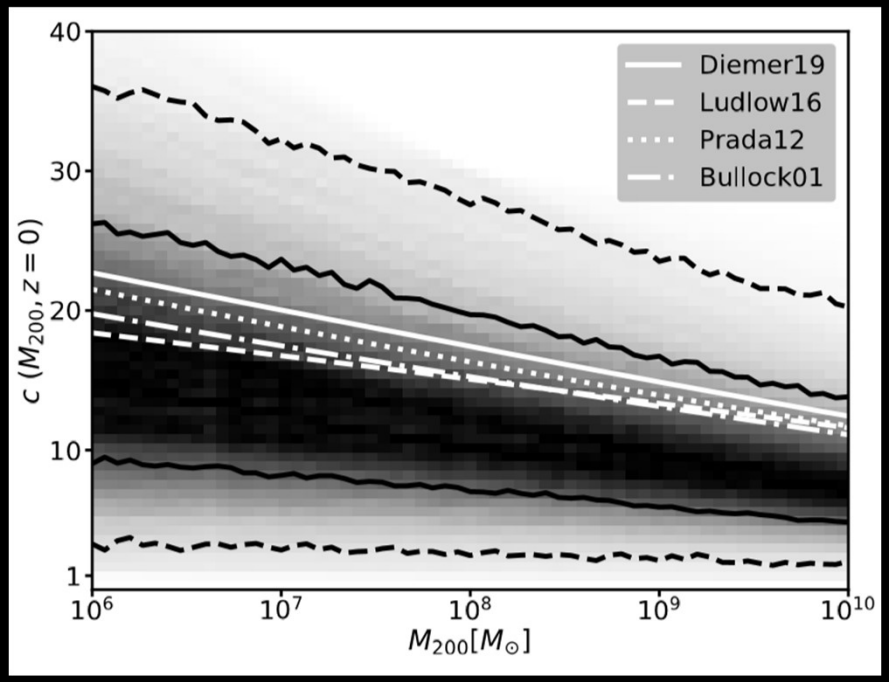


Keith Bechtol et al, LSST dark matter working group (2019)

Dark subhalos

On average subhalos are less dense in SIDM than CDM

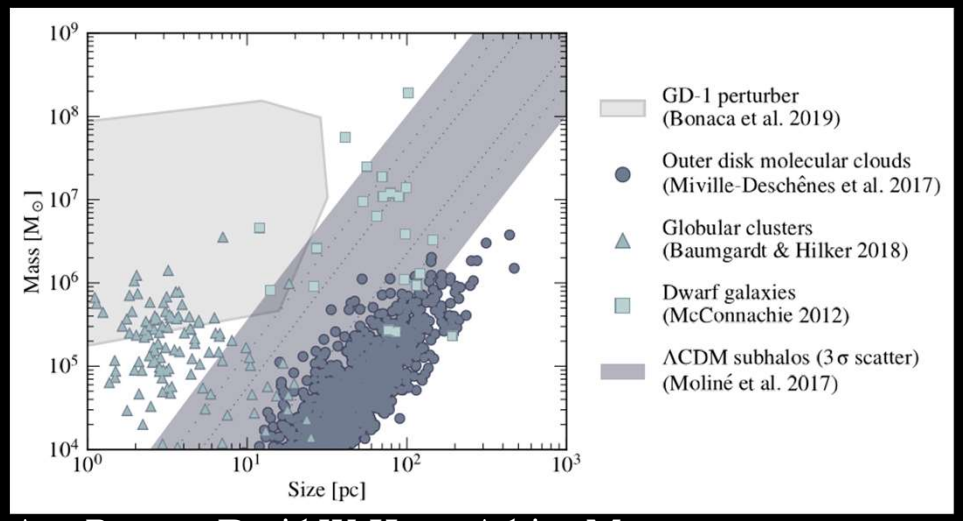
Vogelsberger, Zavala, Loeb (2012)
Dooley, Peter et al (2016)



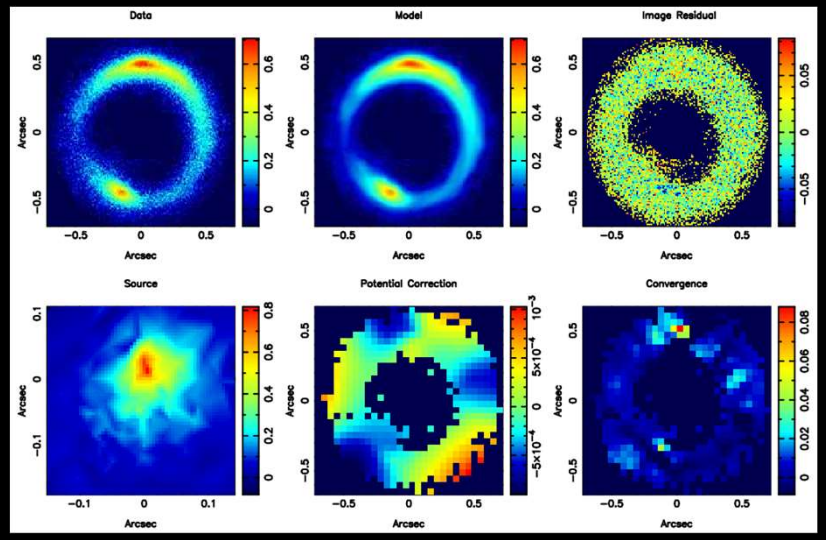
Gilman, Du et al (2019)

SIDM more consistent with data. Will this method be incisive enough?

Dark subhalos



Ana Bonaca, David W. Hogg, Adrian M. Price-Whelan, Charlie Conroy, ApJ 2018



S. Vegetti, L. V. E. Koopmans, A. Bolton, T. Treu, R. Gavazzi, MNRAS 2009

Neither detection is consistent with CDM predictions – they are too compact and too dense. Is this a signature of SIDM (core collapse)?

Is a model beyond SIDM needed to describe structure formation?