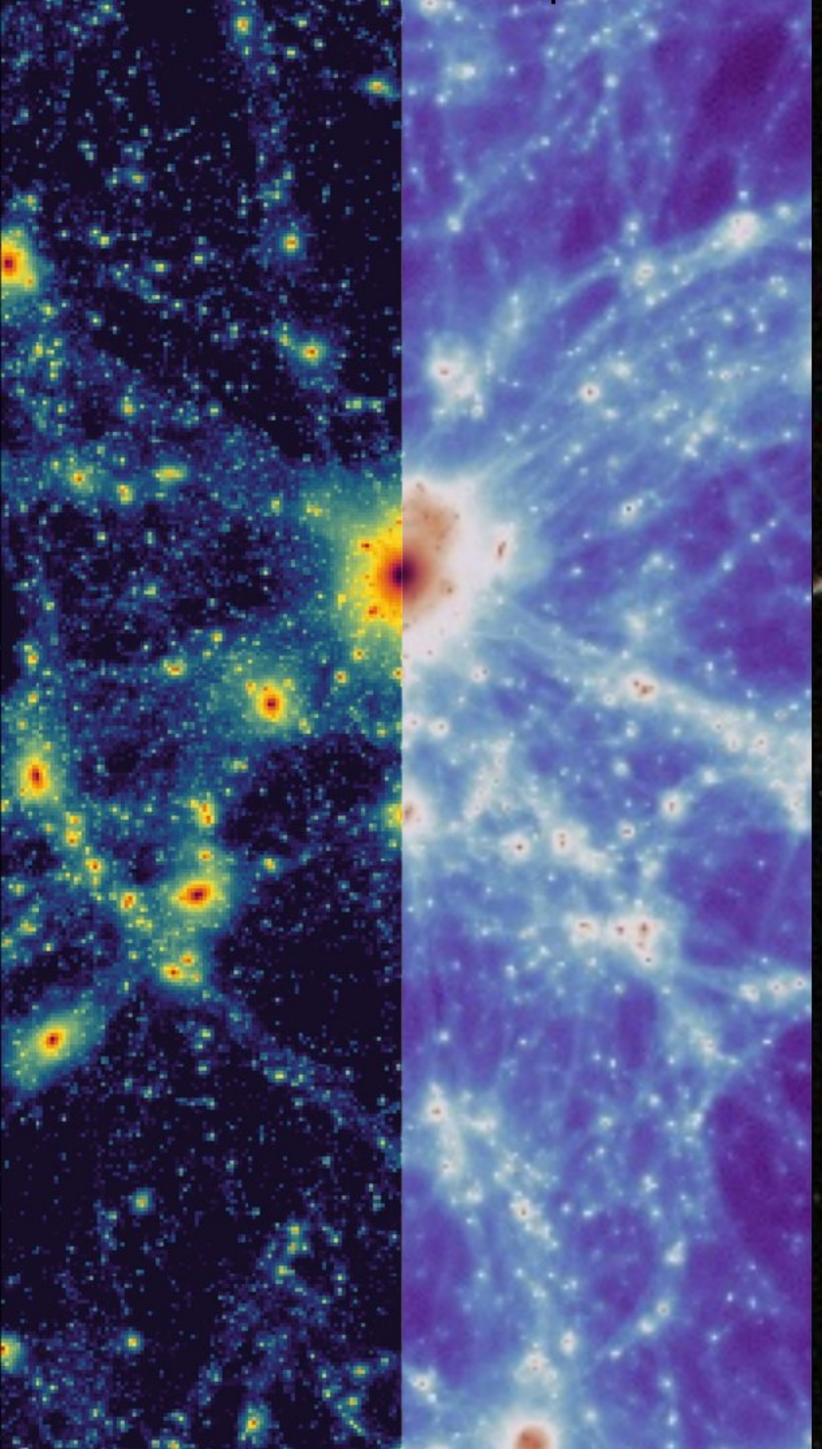


ASTROPHYSICAL TESTS OF DARK MATTER:

OBSERVATIONS & SIMULATIONS

Giulia Despali

University of Bologna



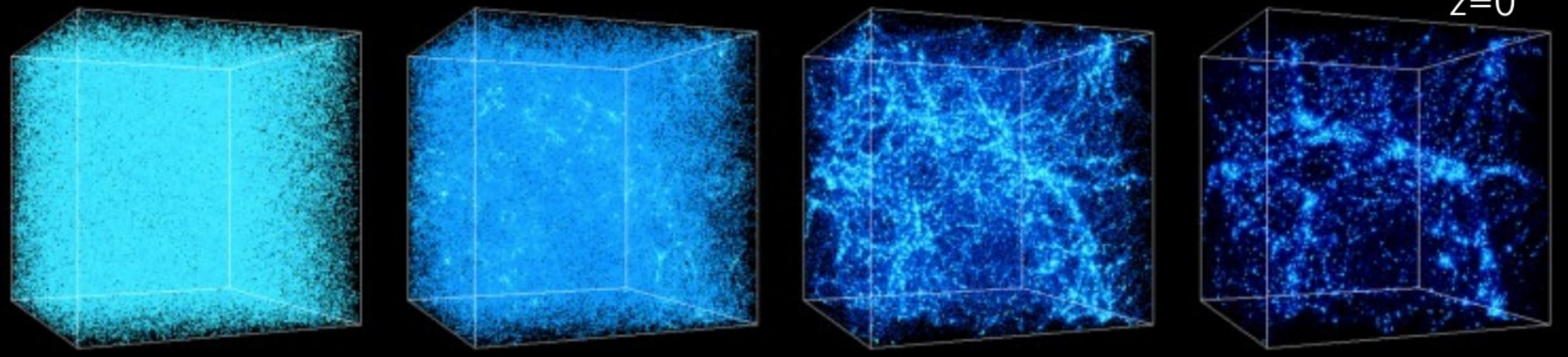
ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

ICSC
Centro Nazionale di Ricerca in HPC, Big Data and Quantum Computing

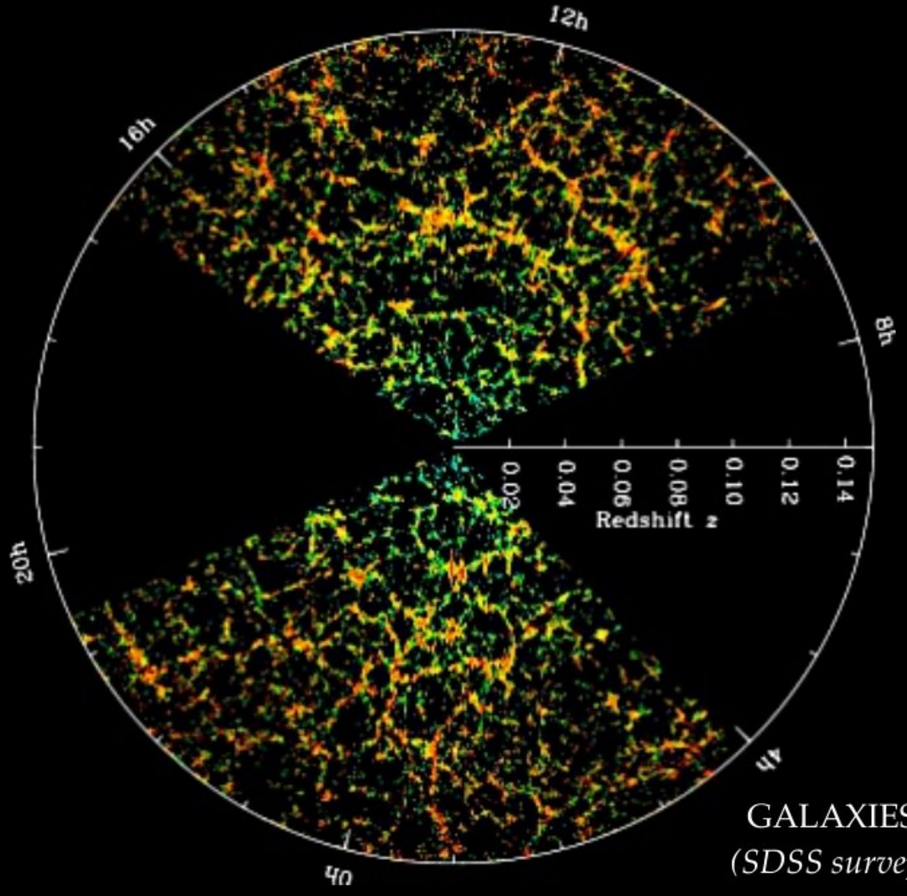
EuroHPC
Joint Undertaking

INTRODUCTION

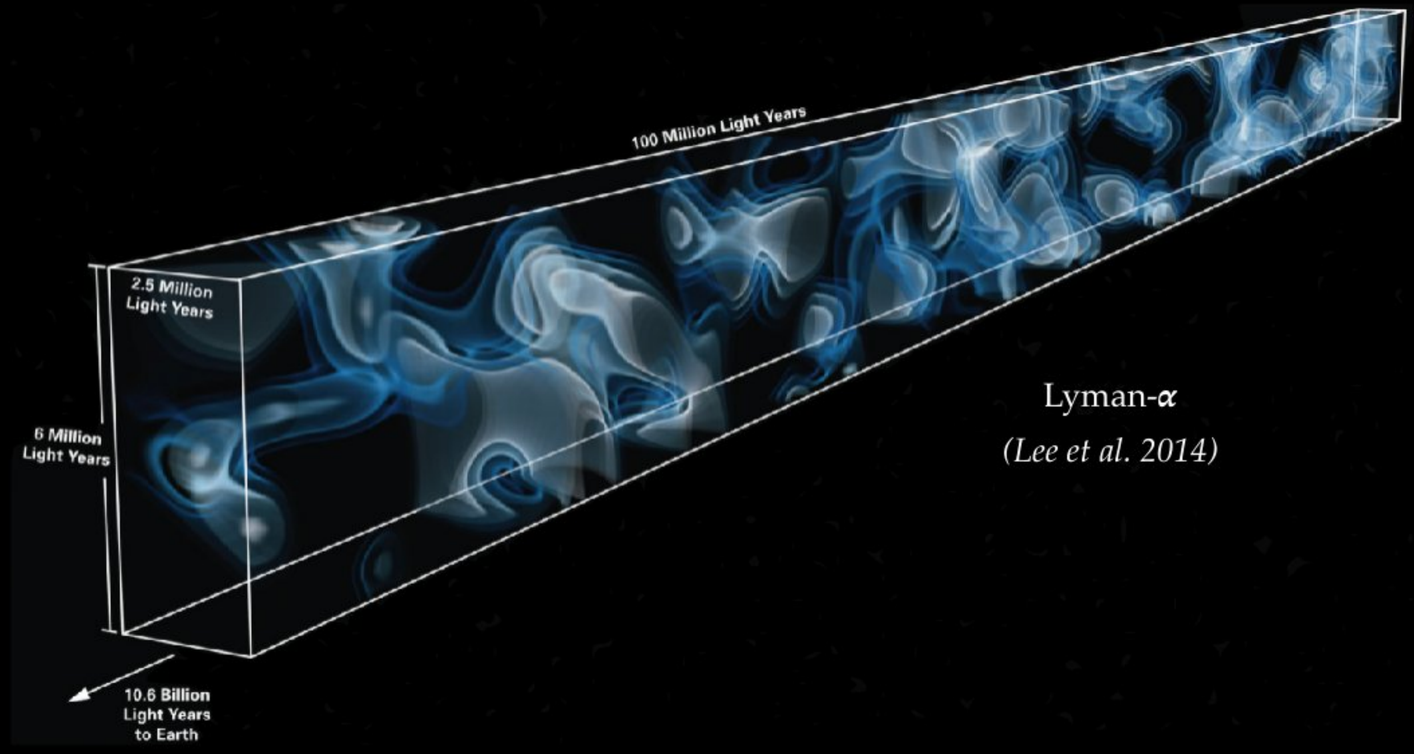
dark matter
shapes the formation
of structures in the universe



(A. Kravtsvov)



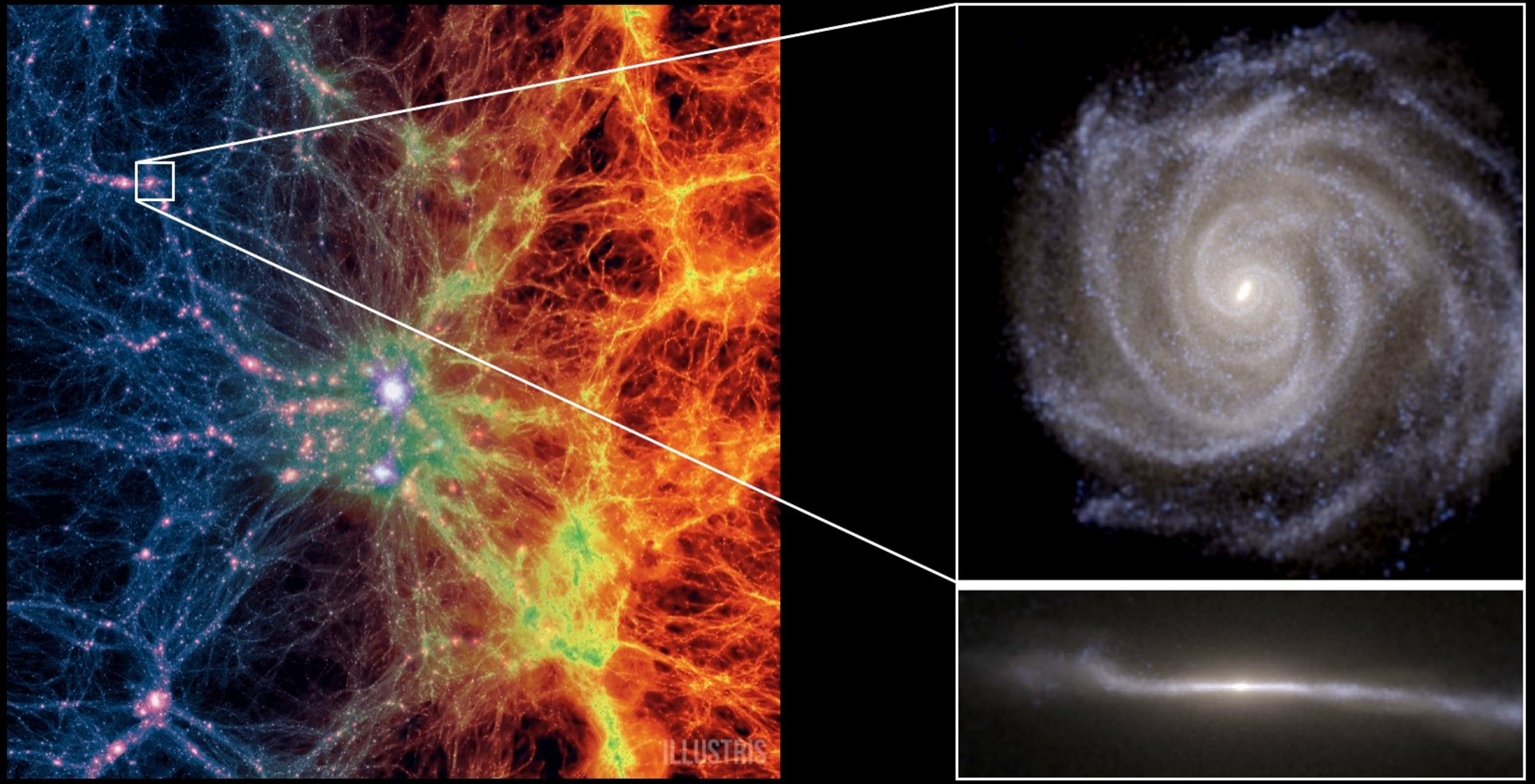
GALAXIES
(SDSS survey)



Lyman-α
(Lee et al. 2014)

INTRODUCTION

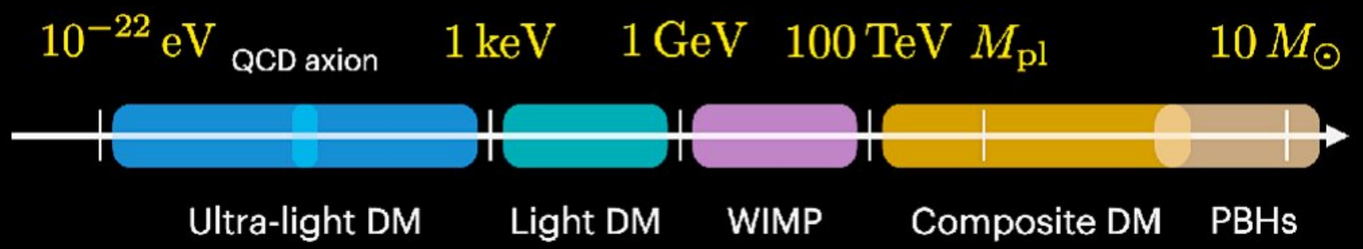
galaxies and clusters form at the centre of dark matter haloes and gas flows along the cosmic web filaments



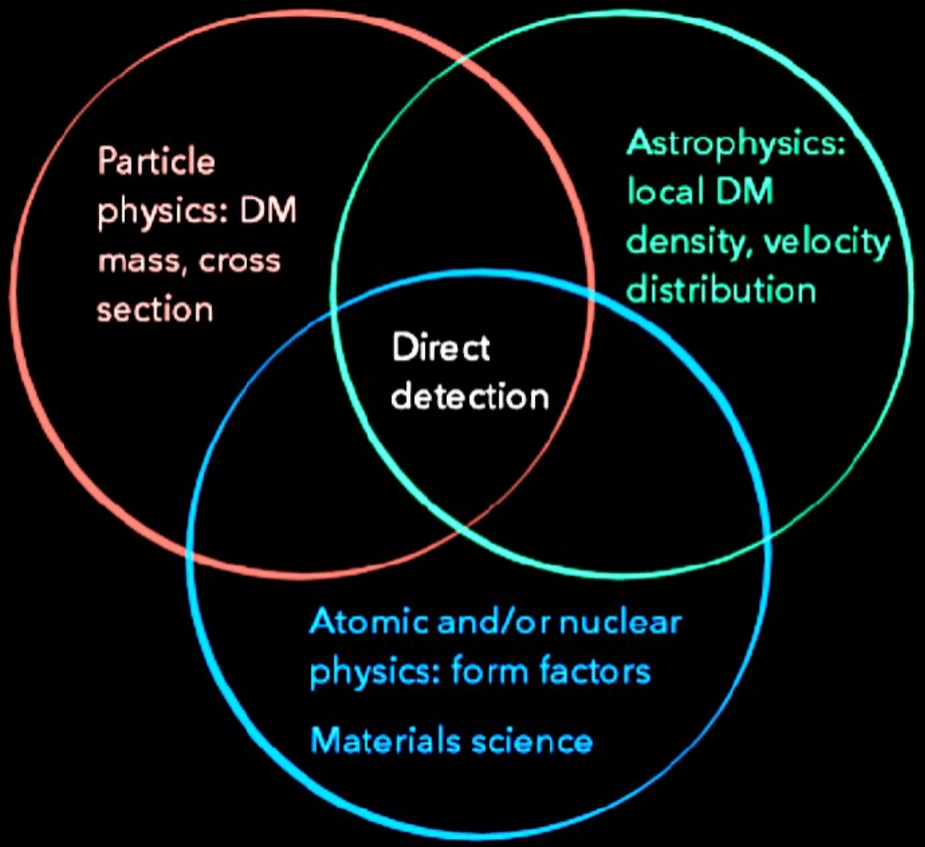
Cretit: D. Nelson/ Illustris simulation

Rose et al. 2023

INTRODUCTION

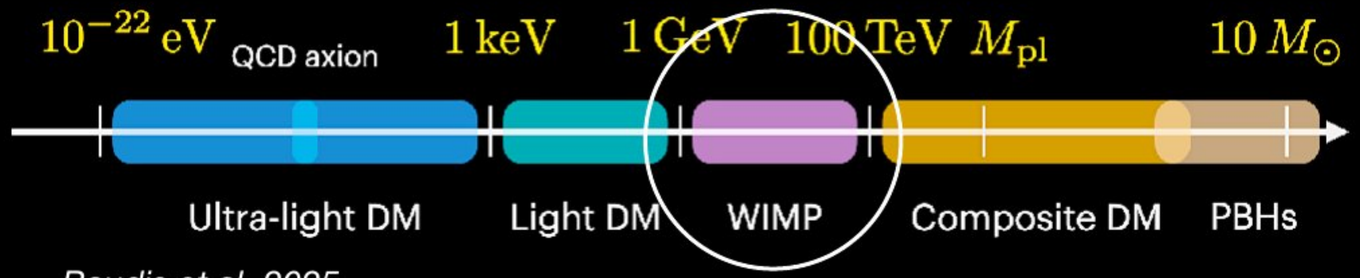


Baudis et al. 2025





INTRODUCTION

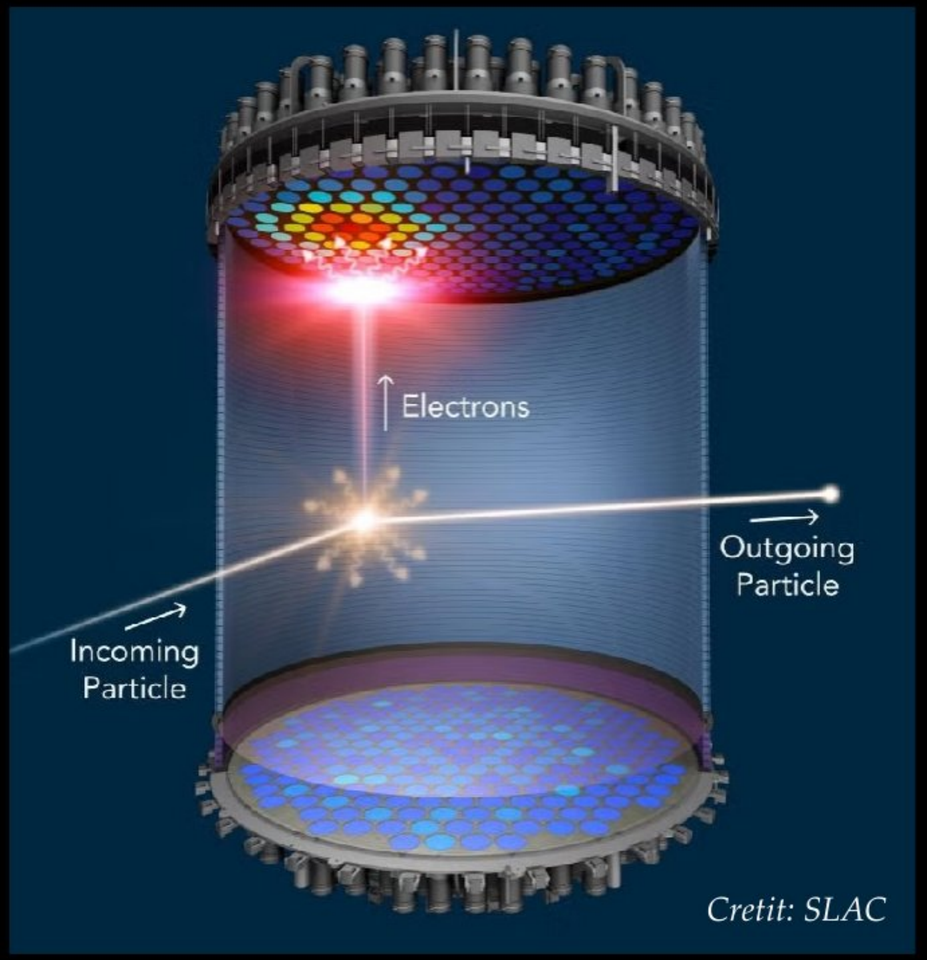


Baudis et al. 2025

Search for dark matter particle interactions in an extended nuclear recoil energy window with the LUX-ZEPLIN (LZ) experiment

D.S. Akerib,[1,2] A.K. Al Musalhi,[3] B.J. Almquist,[4] C.S. Amarasinghe,[5] A. Ames,[1,2] T. Anderson,[6] N. Angelides,[7] H.M. Araújo,[8,9] J.E. Armstrong,[10] M. Arthurs,[1,2] A. Baker,[11] S. Balashov,[9] J. Bang,[4] J.W. Bargemann,[5] E.E. Barillier,[7] D. Bauer,[8] A. Beauchene,[12] T.L. Benson,[13] A. Bhatti,[10] T.P. Biesiadzinski,[1,2] H.J. Birch,[7]

one nuclear recoil event
compatible with a ≥**200 GeV/c² WIMP particle**
at 2.6 σ



INTRODUCTION

Measures of dark matter at the galactic and sub-galactic scale



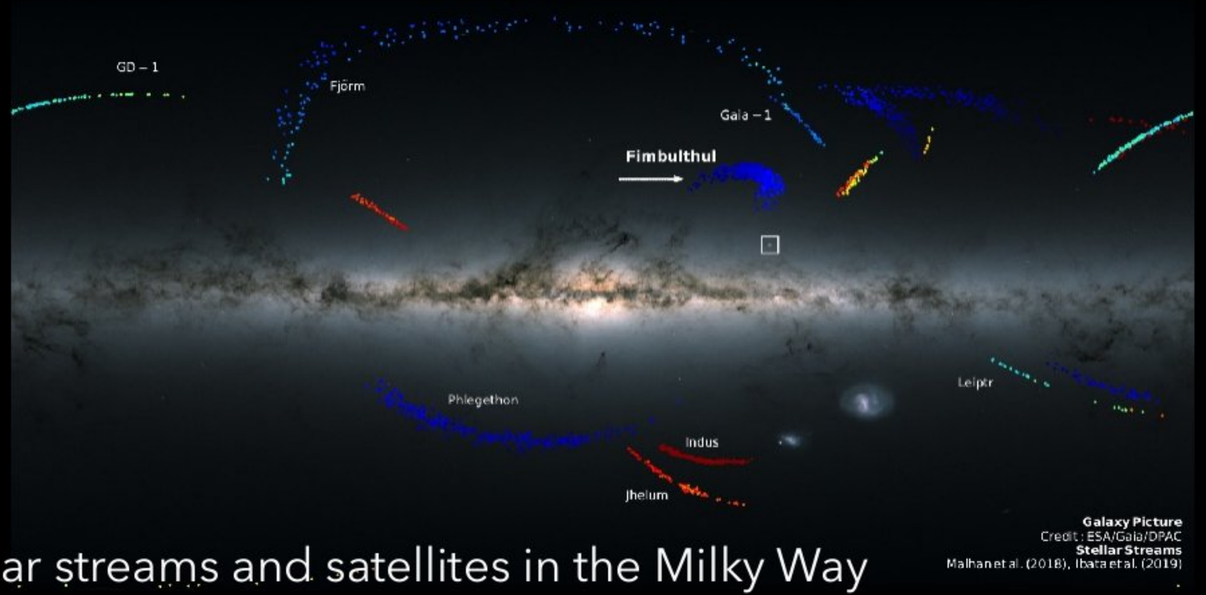
gravitational lensing
by clusters and galaxies





rotation curves and mass distribution in spiral galaxies and dwarfs





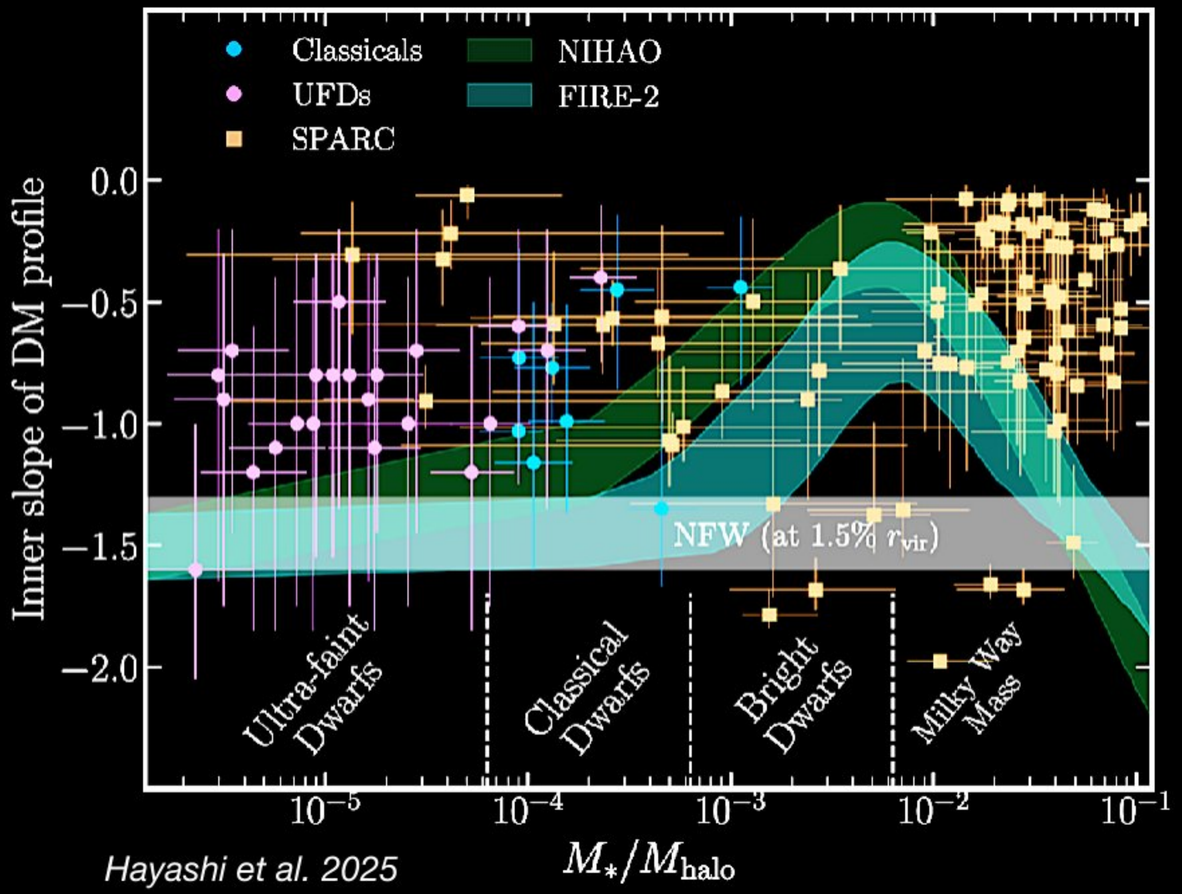
stellar streams and satellites in the Milky Way

OPEN PROBLEMS IN CDM



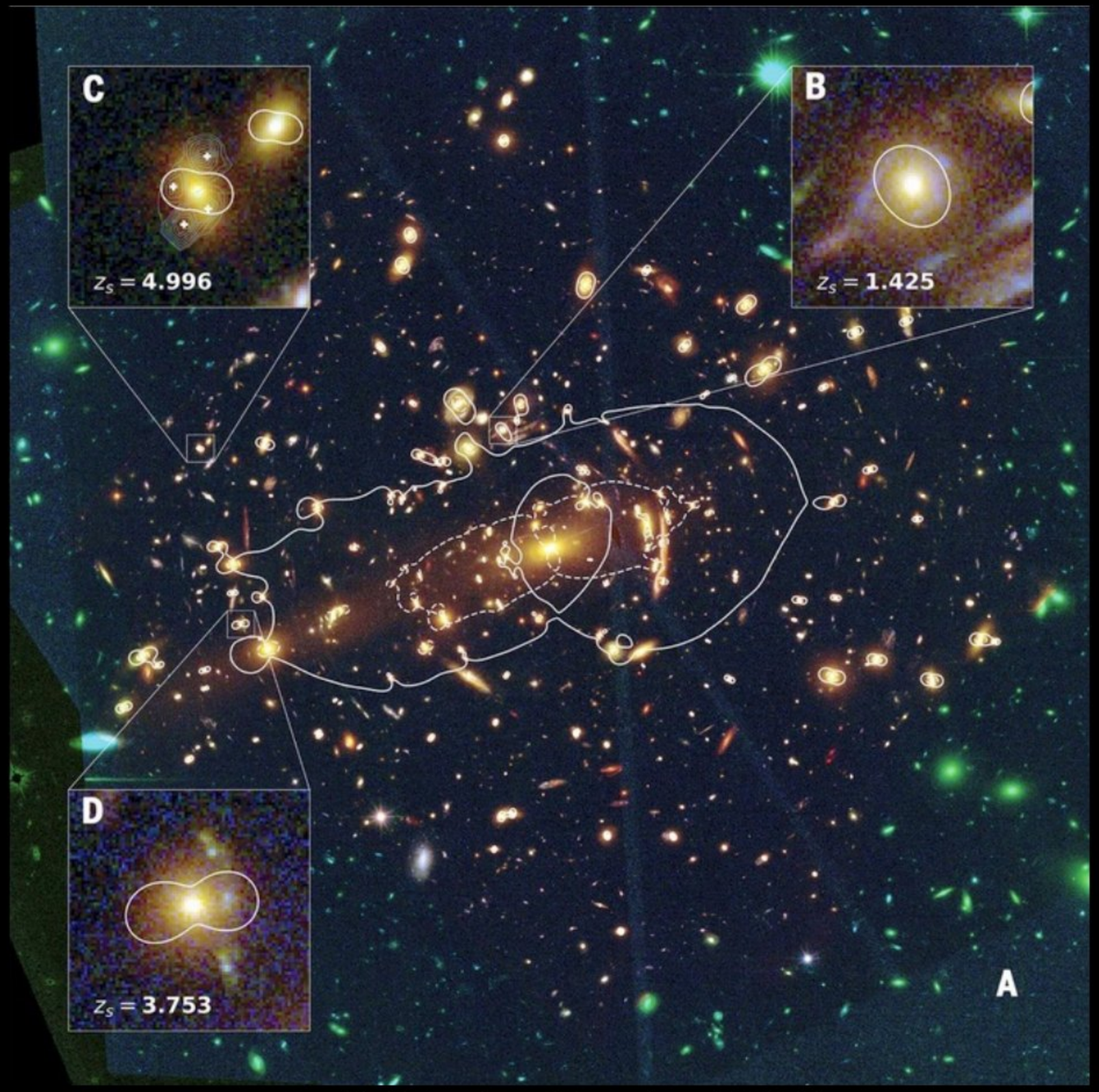


inner slopes diversity



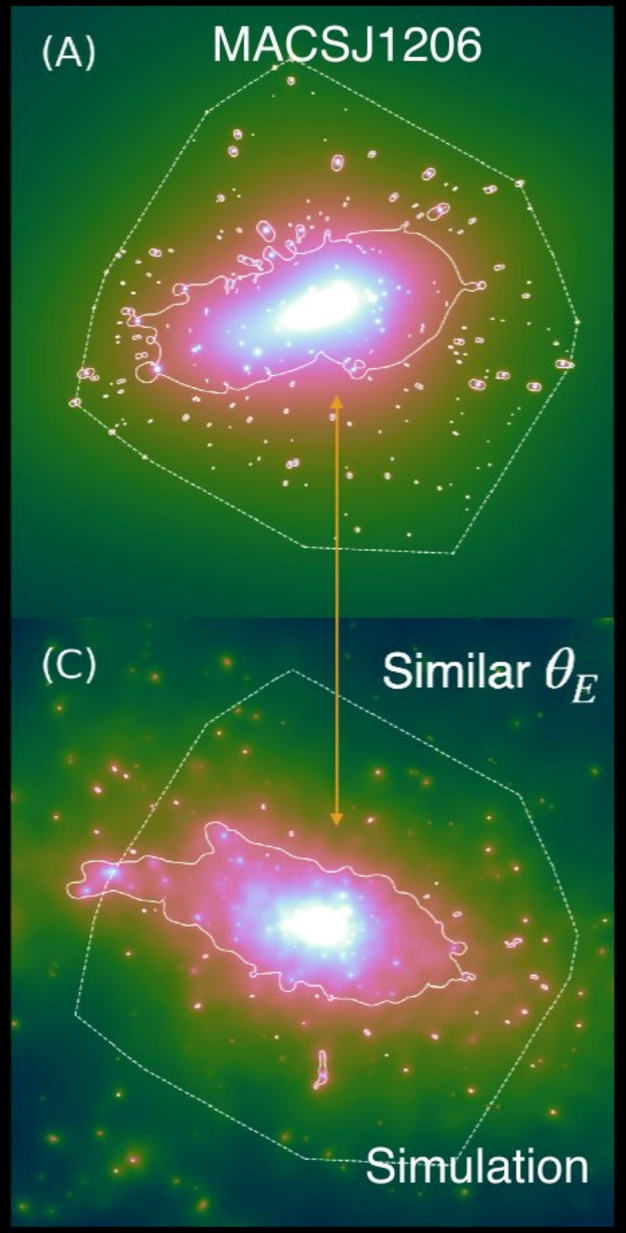
Hayashi et al. 2025

gravitational lensing by **galaxy clusters**



Credit: Massimo Meneghetti (2020)

OPEN PROBLEMS IN CDM



cluster satellites are mode lensing efficient than predicted by CDM simulations

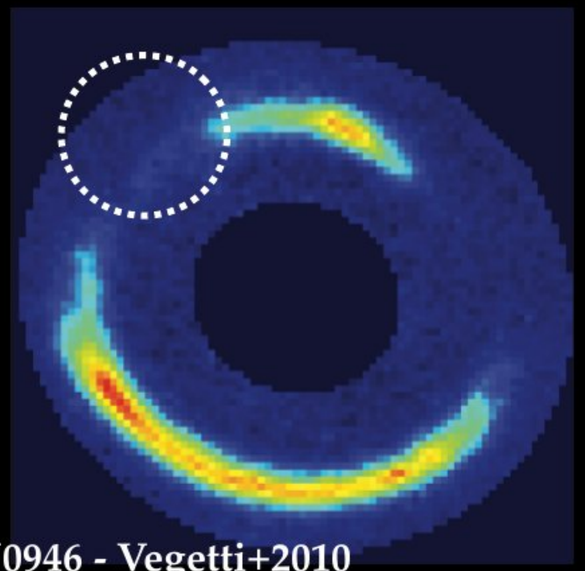
↓

denser/more compact
&
different mass distribution

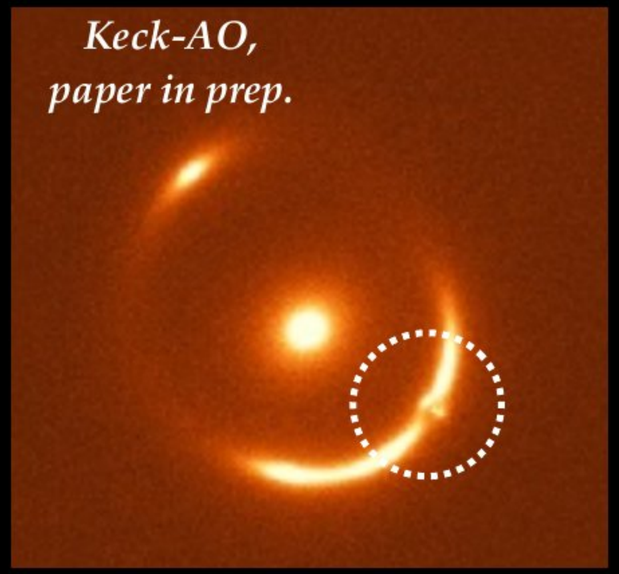
gravitational lensing by **galaxies**

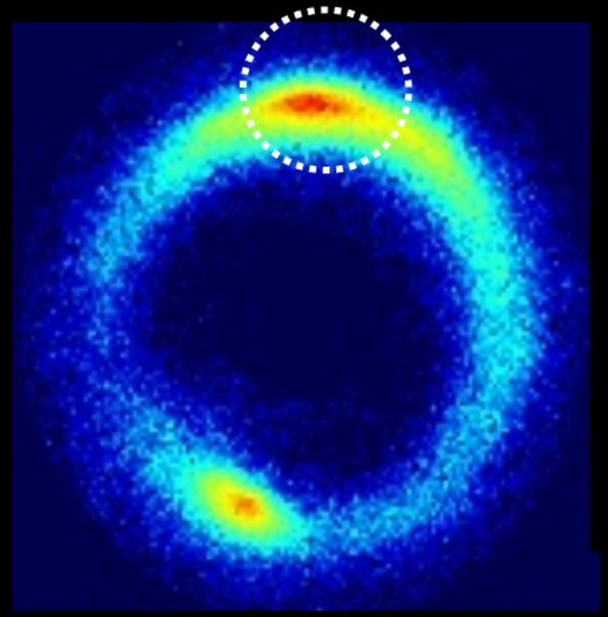
OPEN PROBLEMS IN CDM



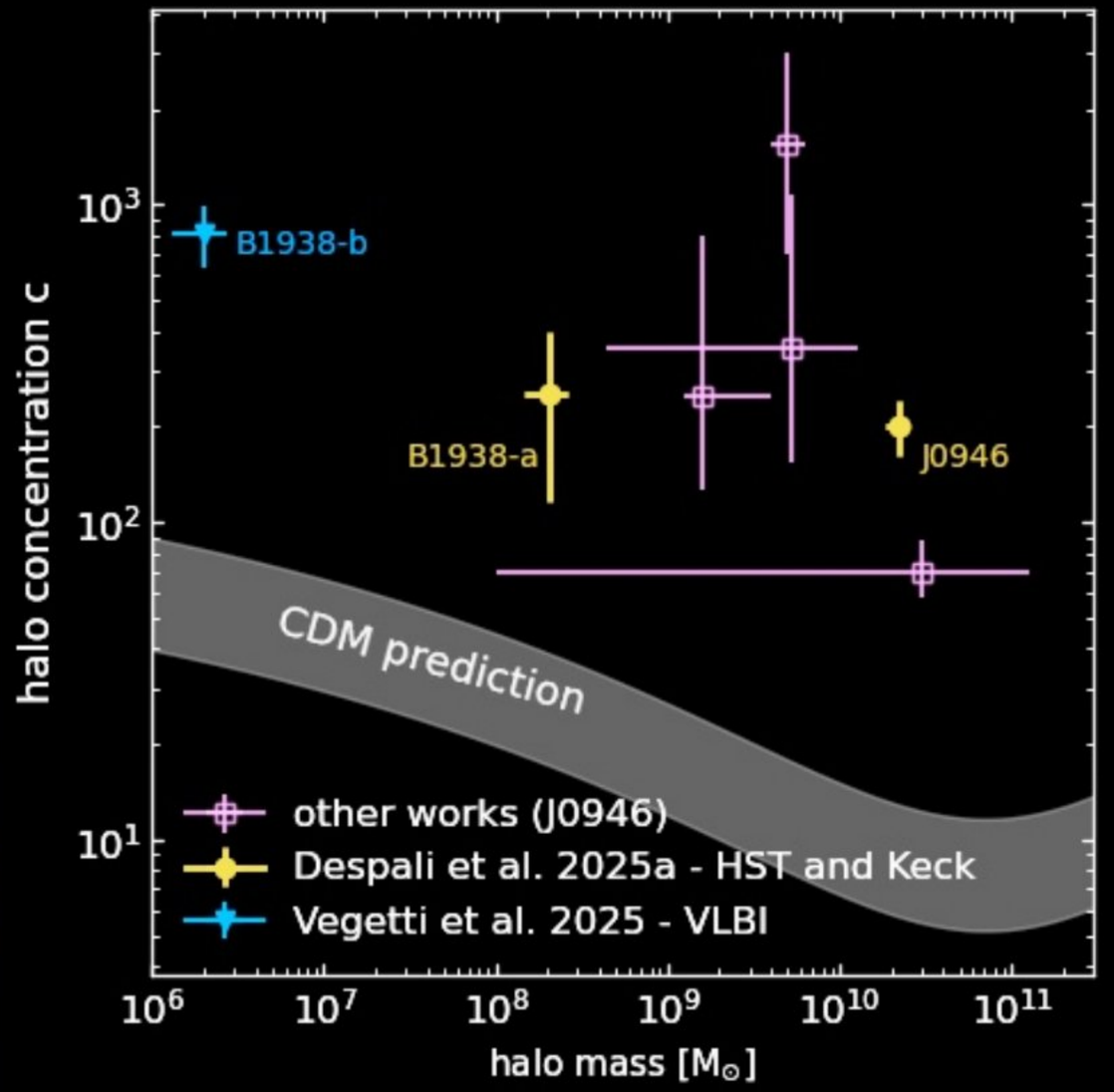


J0946 - Vegetti+2010





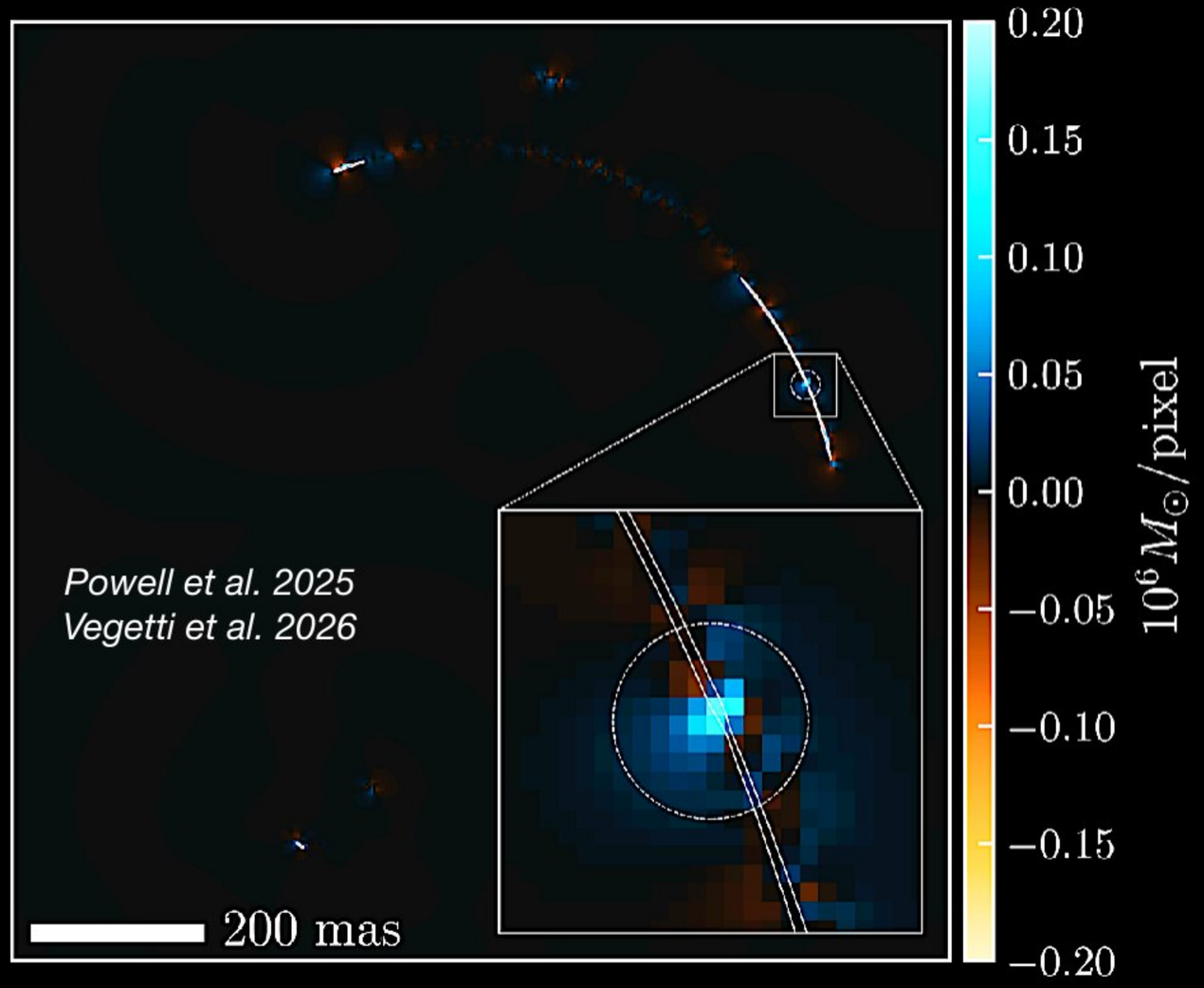
B1938 - Vegetti+2012



Vegetti et al. 2026 / Despali et al. 2025 / Tajalli et al. 2025

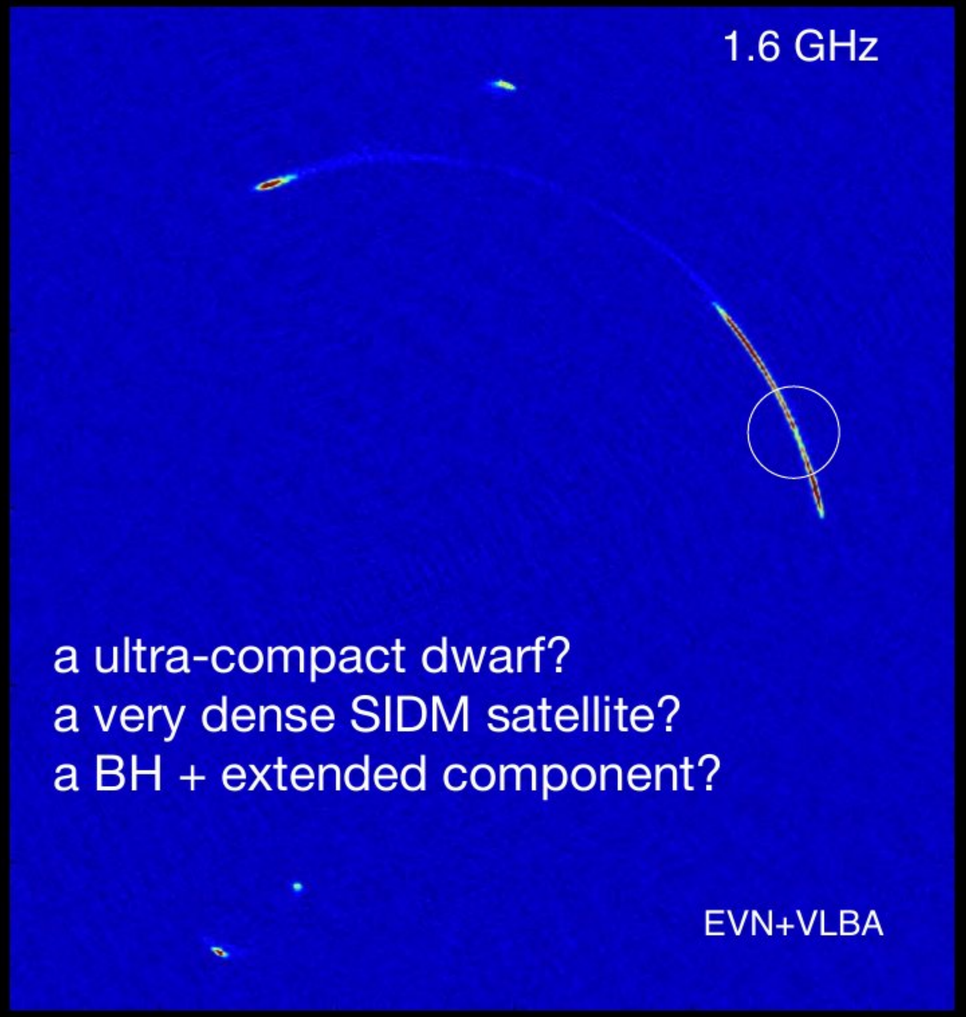
gravitational lensing by galaxies: **smallest detection so far**





The break in the arc is consistent with a very low-mass perturber $M_{\rm t} \sim 2 \times 10^6 M_\odot$ with a size of ~ 139 pc

gravitational lensing by galaxies: **smallest detection so far**



Tested 23 different density profile models:

PL, SER, PJ, NFW, KG and PM

The detection is robust against different assumptions on its profile with an evidence of log-evidence

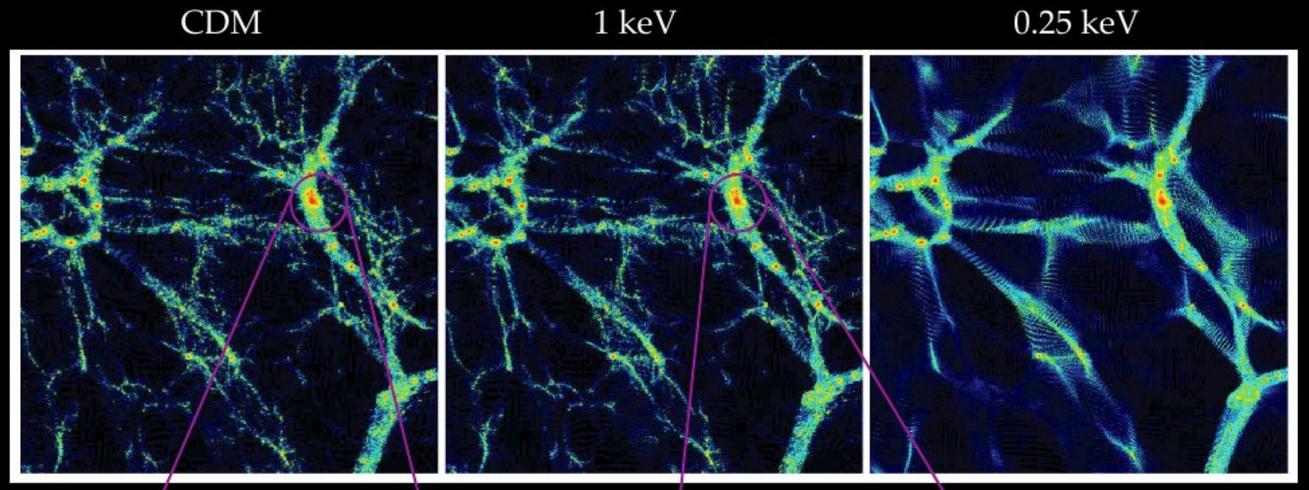
$259 \leq \Delta \log E \leq 351$

~23-26 σ

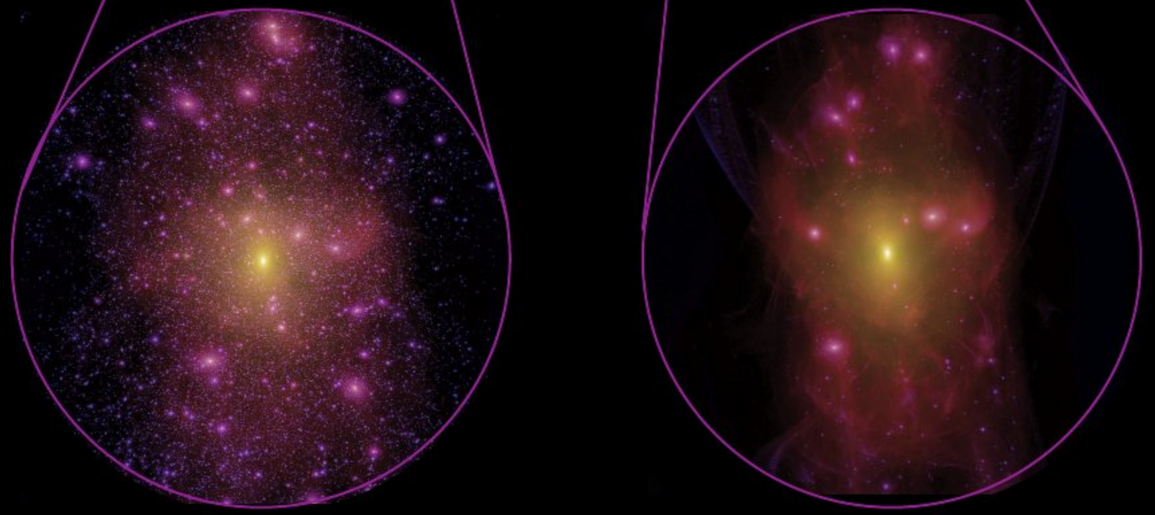


The break in the arc is consistent with a very low-mass perturber $M_t \sim 2 \times 10^6 M_\odot$ with a size of ~ 139 pc

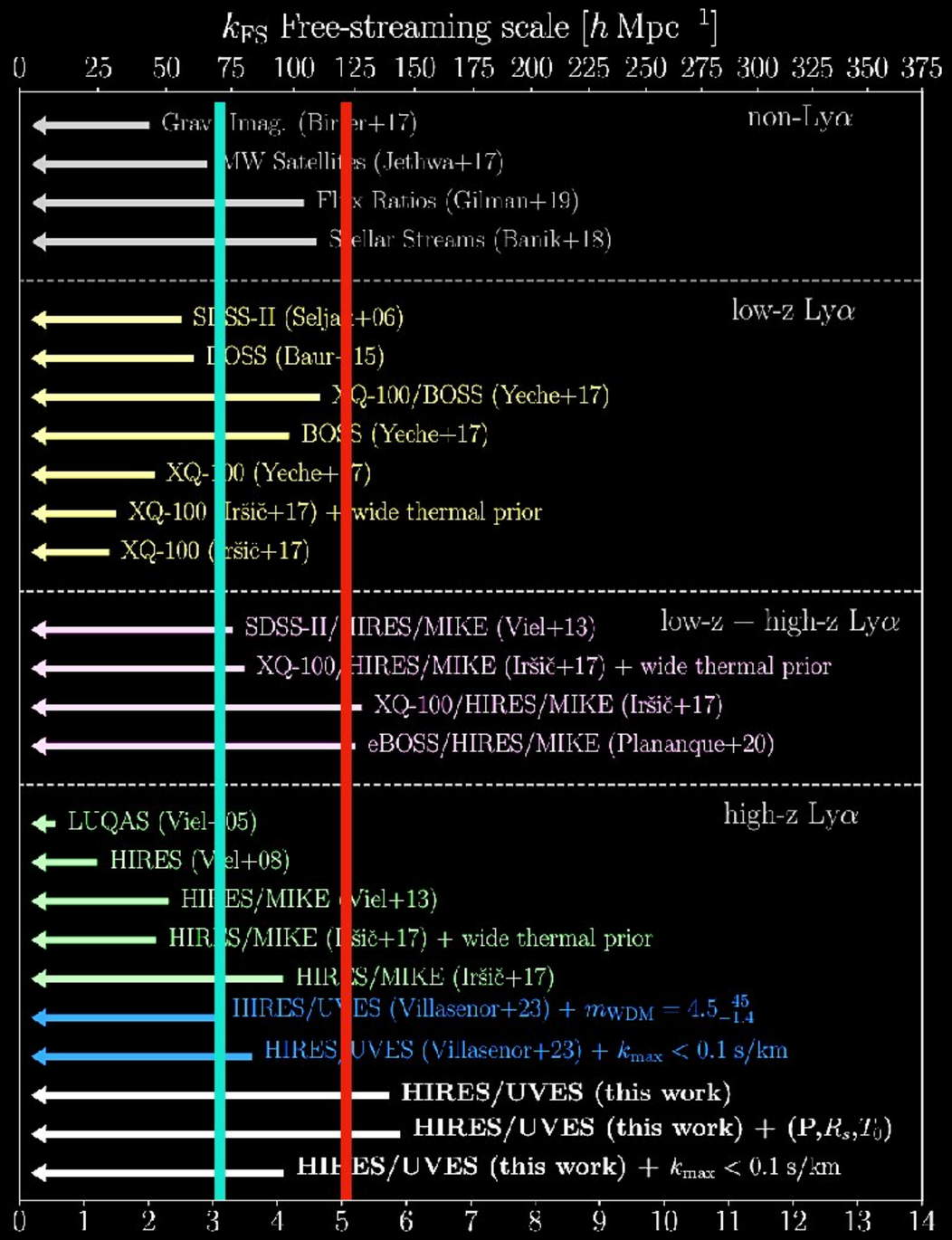
WARM DARK MATTER



(Schneider et al. 2012)

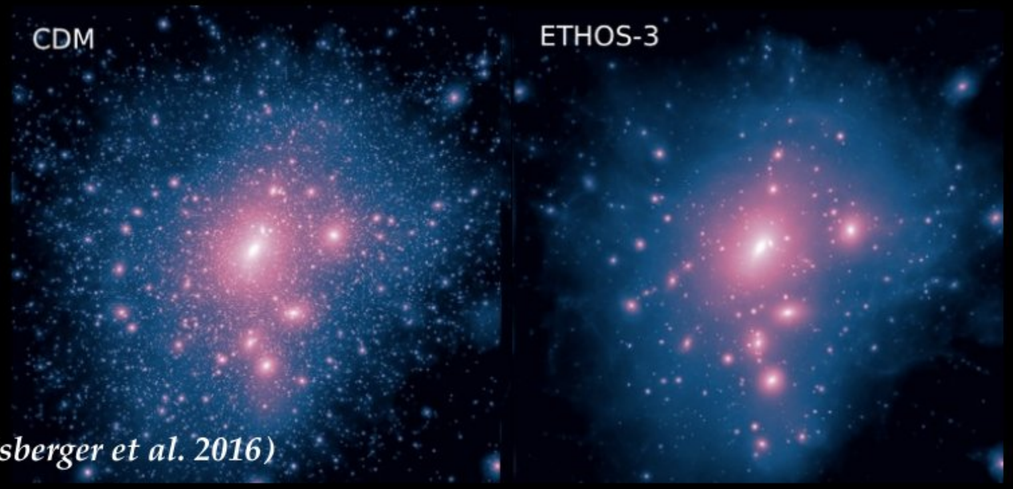


(Lovell et al. 2012)

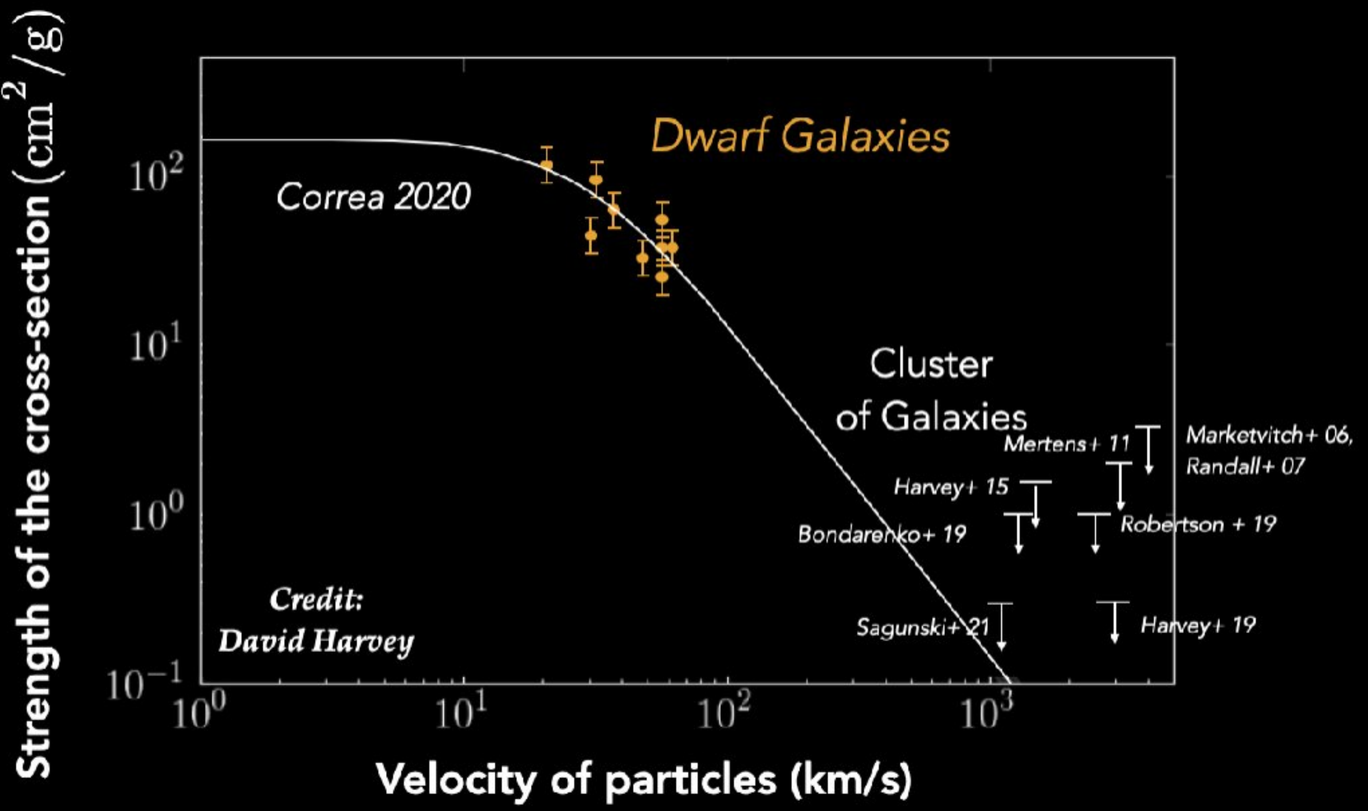


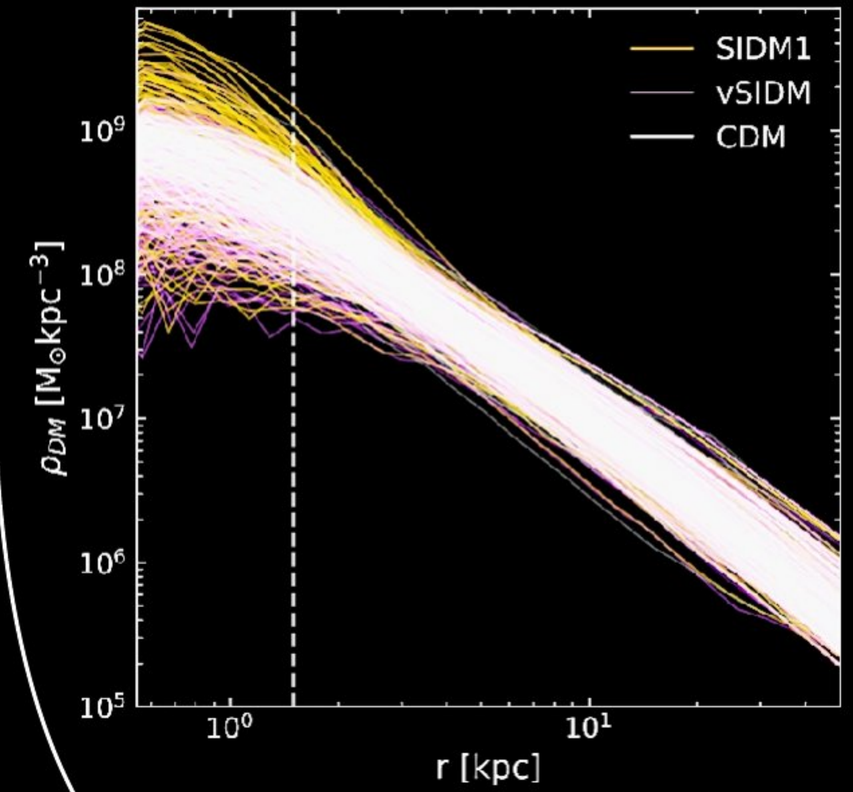
(Iršič et al. 2024)

SELF-INTERACTING DARK MATTER



(Vogelsberger et al. 2016)



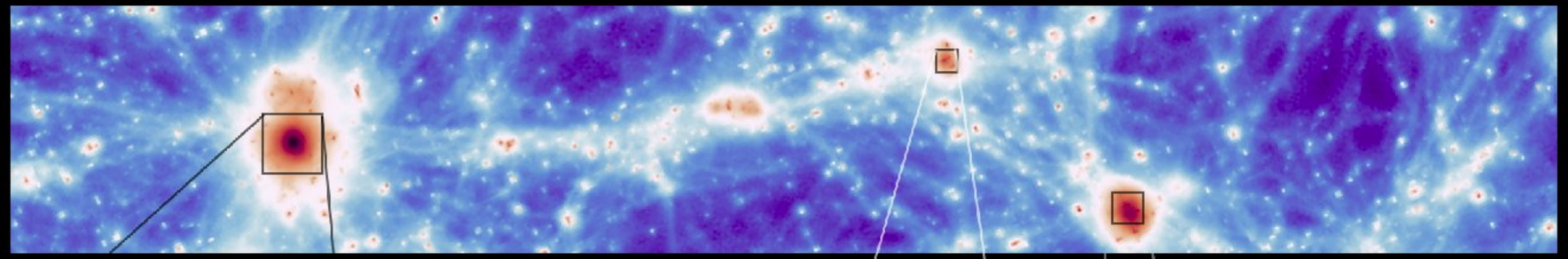


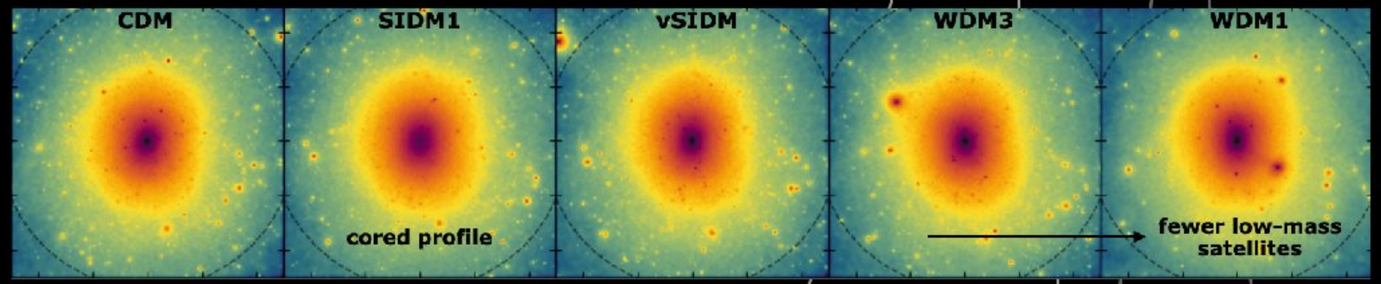
(Despali et al. 2026)

larger variety of profiles!

"natural" interactions often modeled as a Yukawa potential

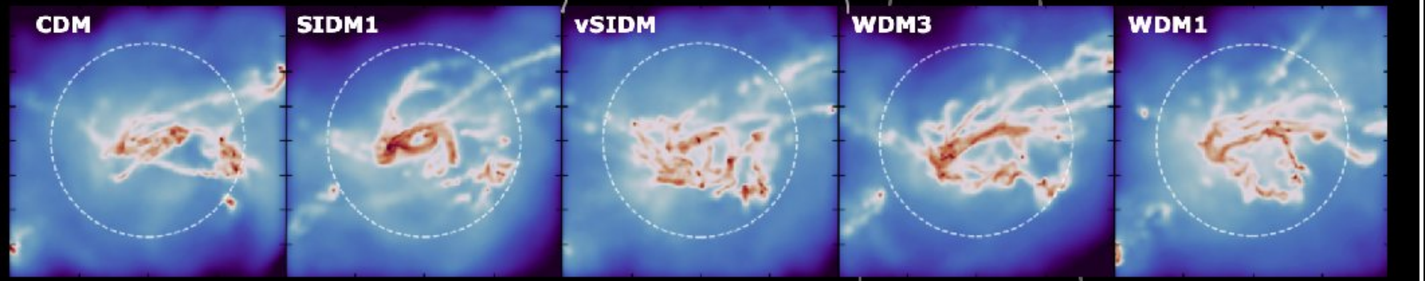
AIDA-TNG SIMULATIONS

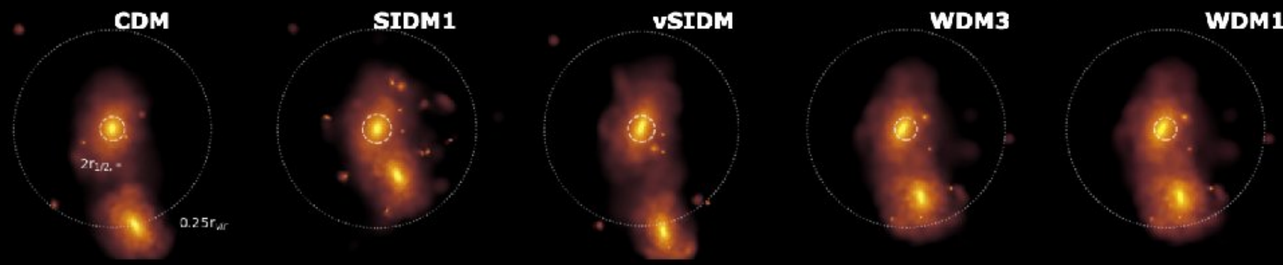




dark matter

gas





stars

LAURO MOSCARDINI
DYLAN NELSON
ANNALISA PILLEPICH
MARK VOGELSBERGER
VOLKER SPRINGEL

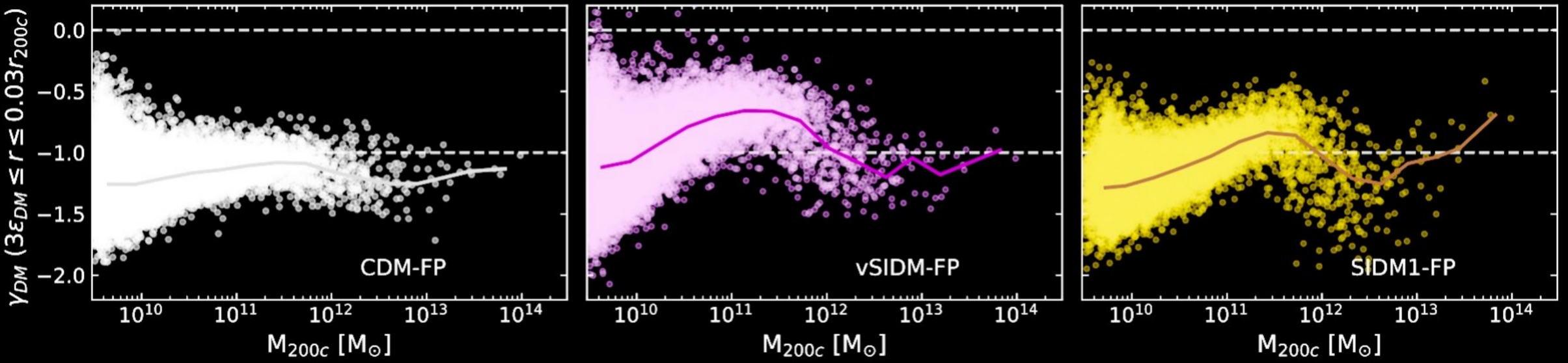
(Despali et al. 2025)

- most global properties of galaxies are statistically preserved:

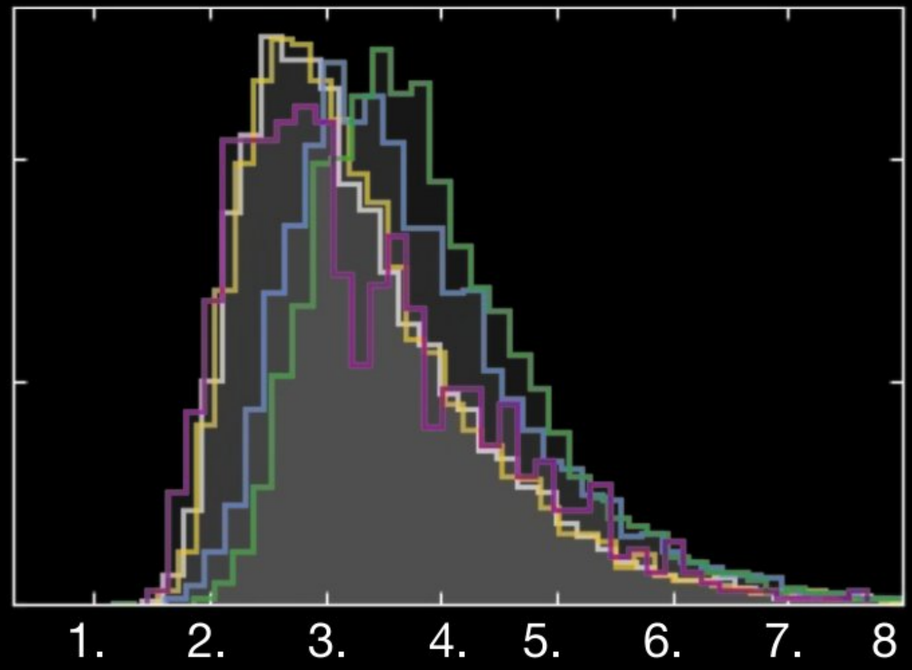
  stellar mass functions
  gas fractions
  BH masses vs M*
  etc

- differences arise in the **structure** of haloes and galaxies

HALO/GALAXY PROPERTIES

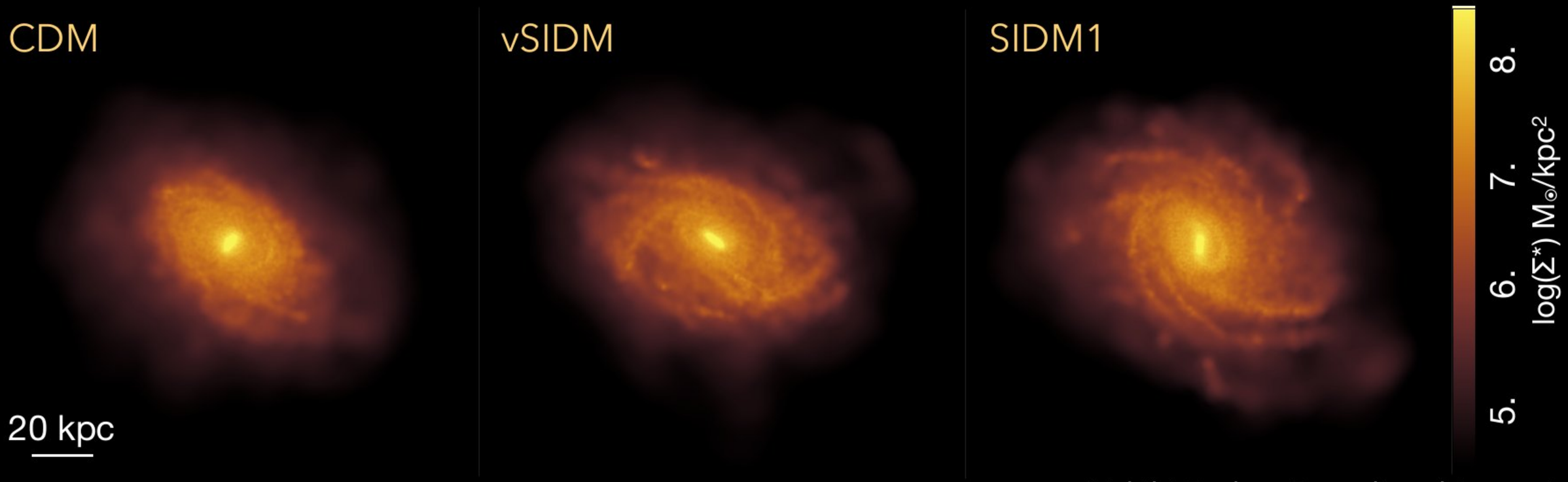


stellar helf-mass radius [kpc]



galaxies are ~15-20%
more extended in SIDM models

GALAXY MORPHOLOGY



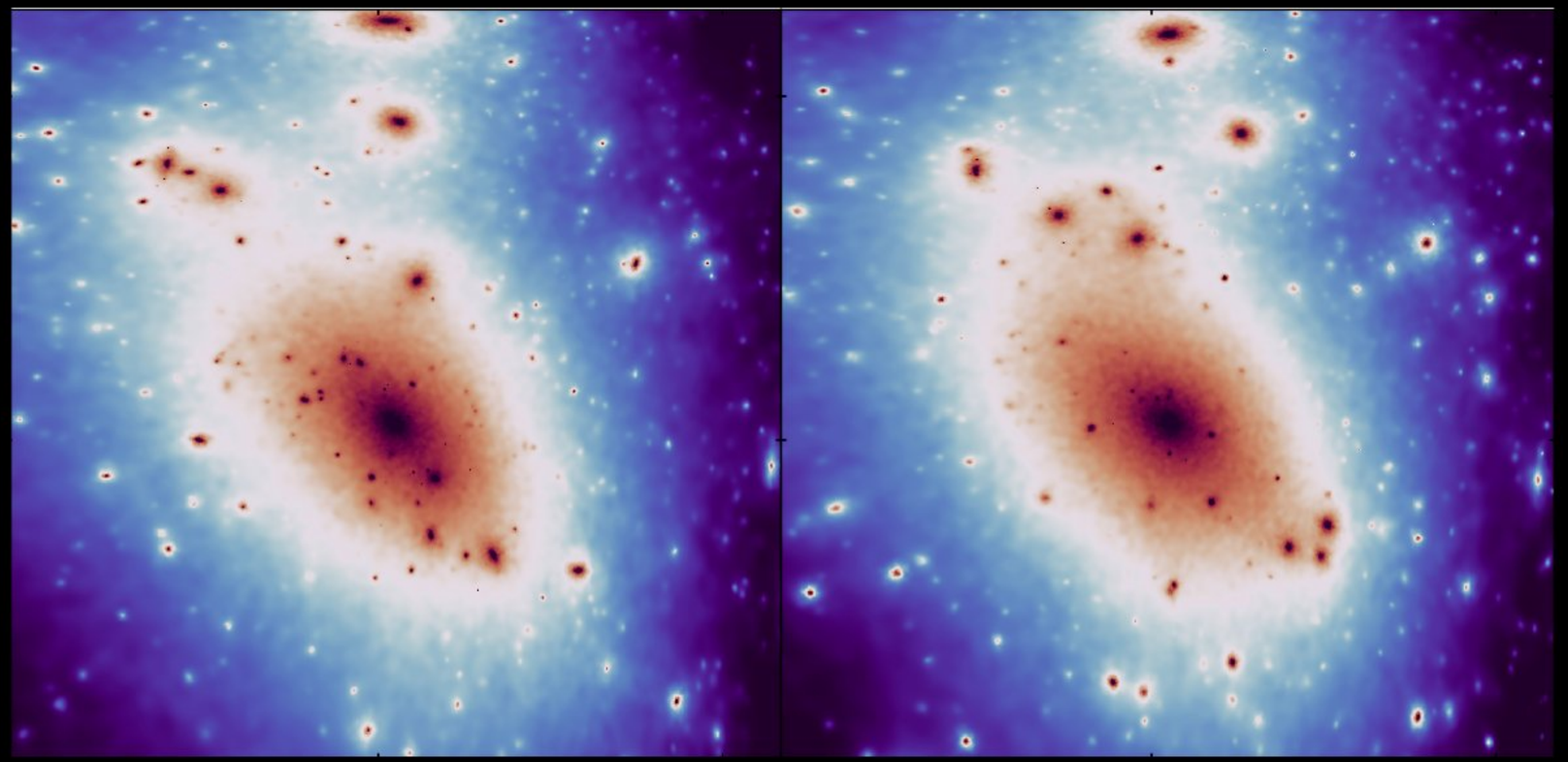
(Habibi, Roshan, Despali et al. in prep)

- galactic bars are longer
- their rotation velocity is slower
- dynamical friction is enhanced because of a more efficient exchange of angular momentum

SIMULATED LENSES

CDM

velocity-dependent SIDM



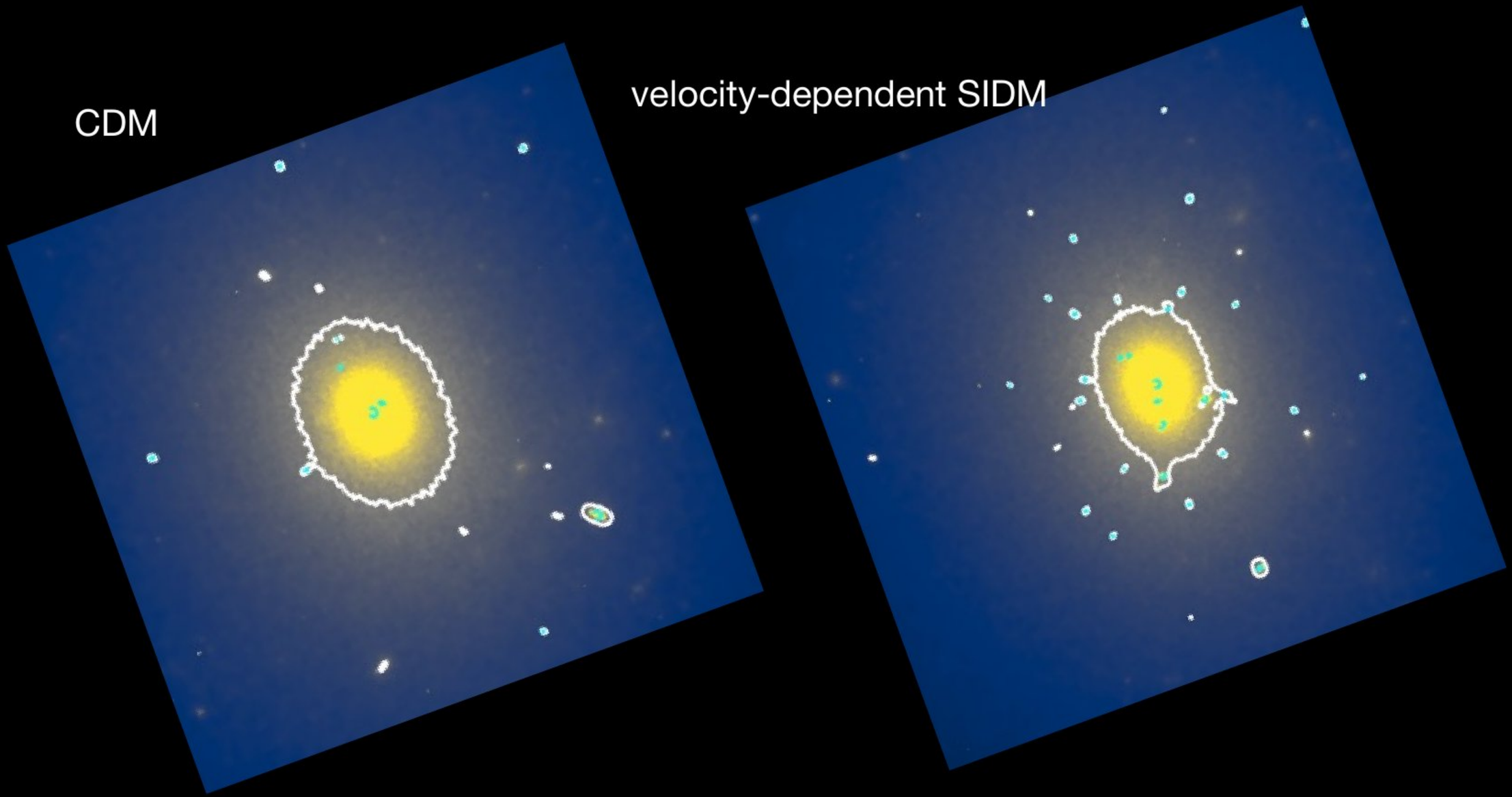
(AIDA team in prep)

~$5 \times 10^{14}\ M_{\odot}$

SIMULATED LENSES

CDM

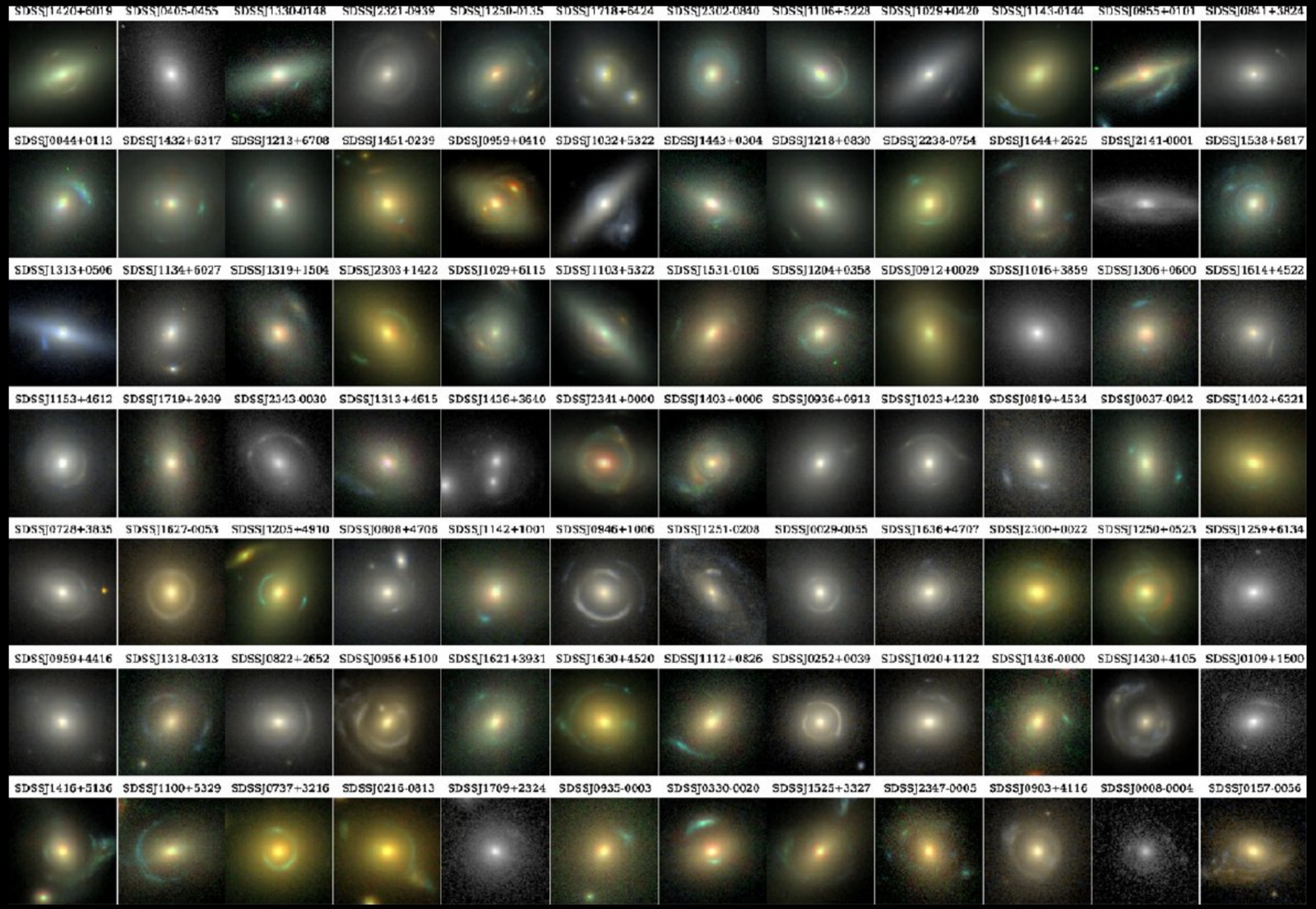
velocity-dependent SIDM



(AIDA team in prep)

GRAVITATIONAL LENSES

SLACS LENSES

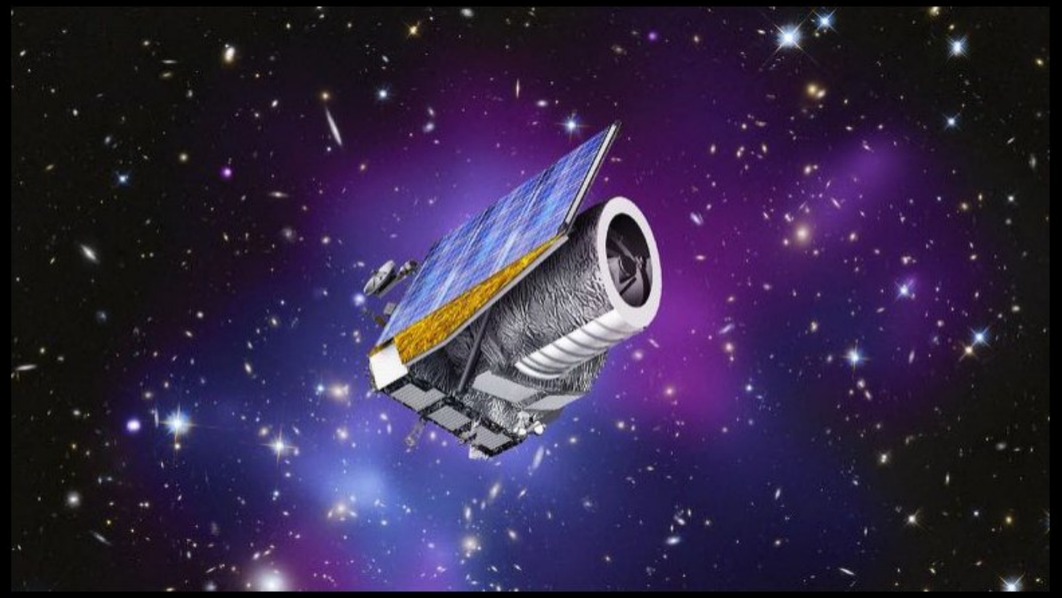


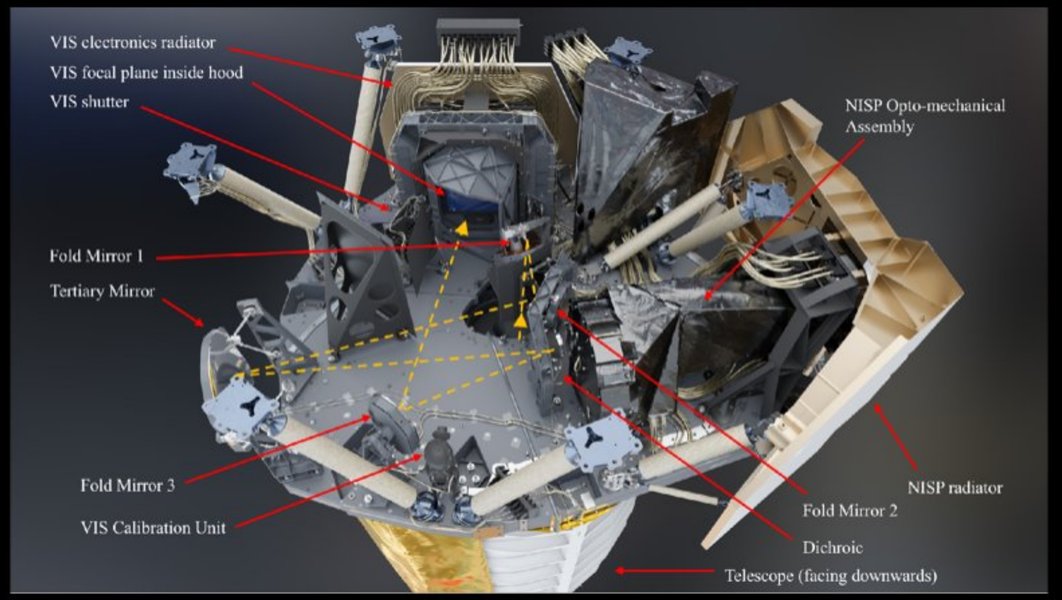
only 11/100 lenses
had good quality
for substructure lenses

(Auger et al. 2009)

THE EUCLID MISSION

- 1.2m space telescope, 0.56 sq. deg. FOV
- Launched in July 2023
- Observing the universe at optical and NIR wavelengths from L2 (imaging VIS+NISP; slitless spectroscopy NISP)
- 0.1" pixel scale in the VIS band (not far from HST). PSF is ~0.16".
- Nominal 6 yrs mission lifetime
- ~13000 sq. deg. (EWS); 53 sq. deg. (3 EDFs)
- 1,5 billion galaxies

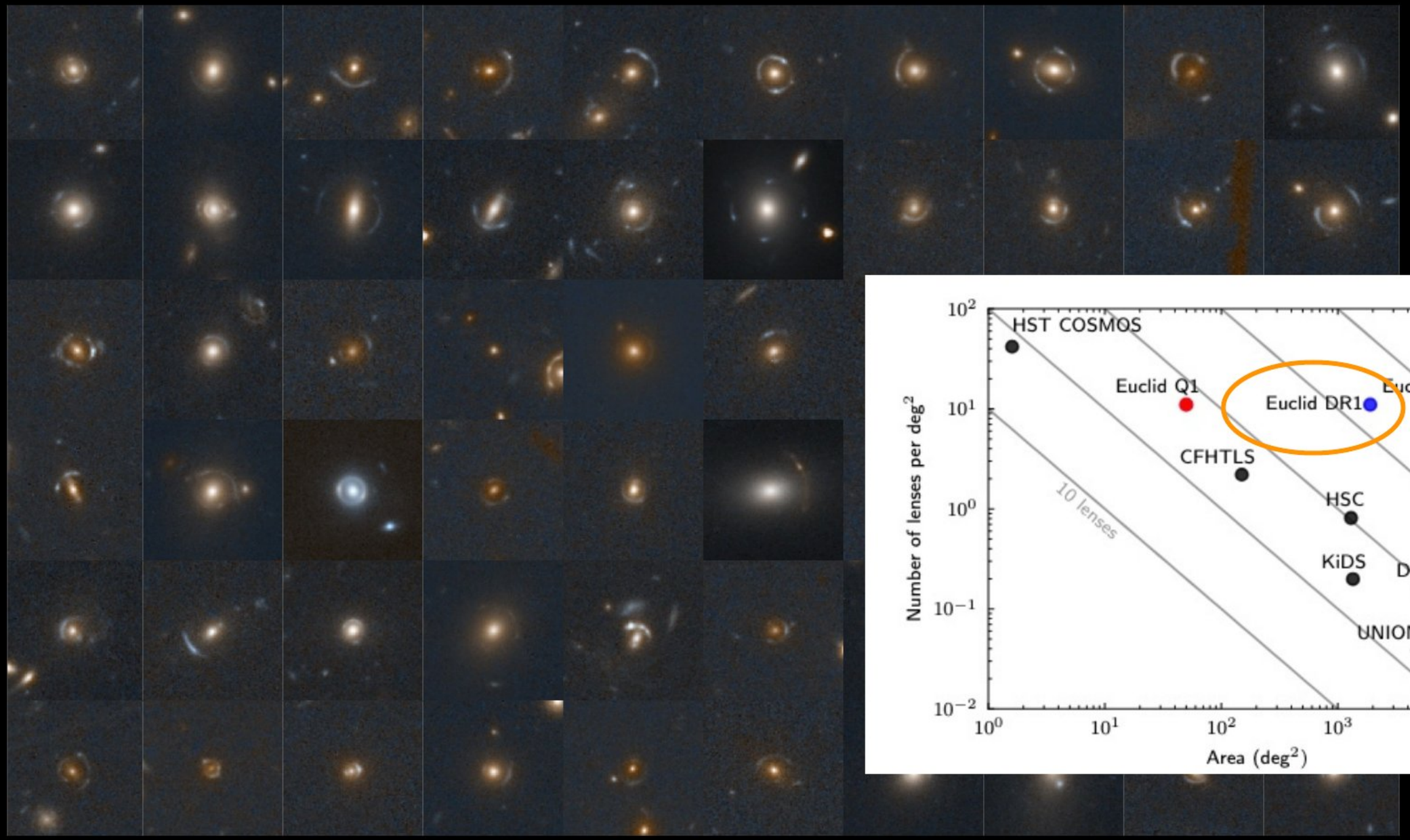




GALAXY LENSES IN EUCLID Q1

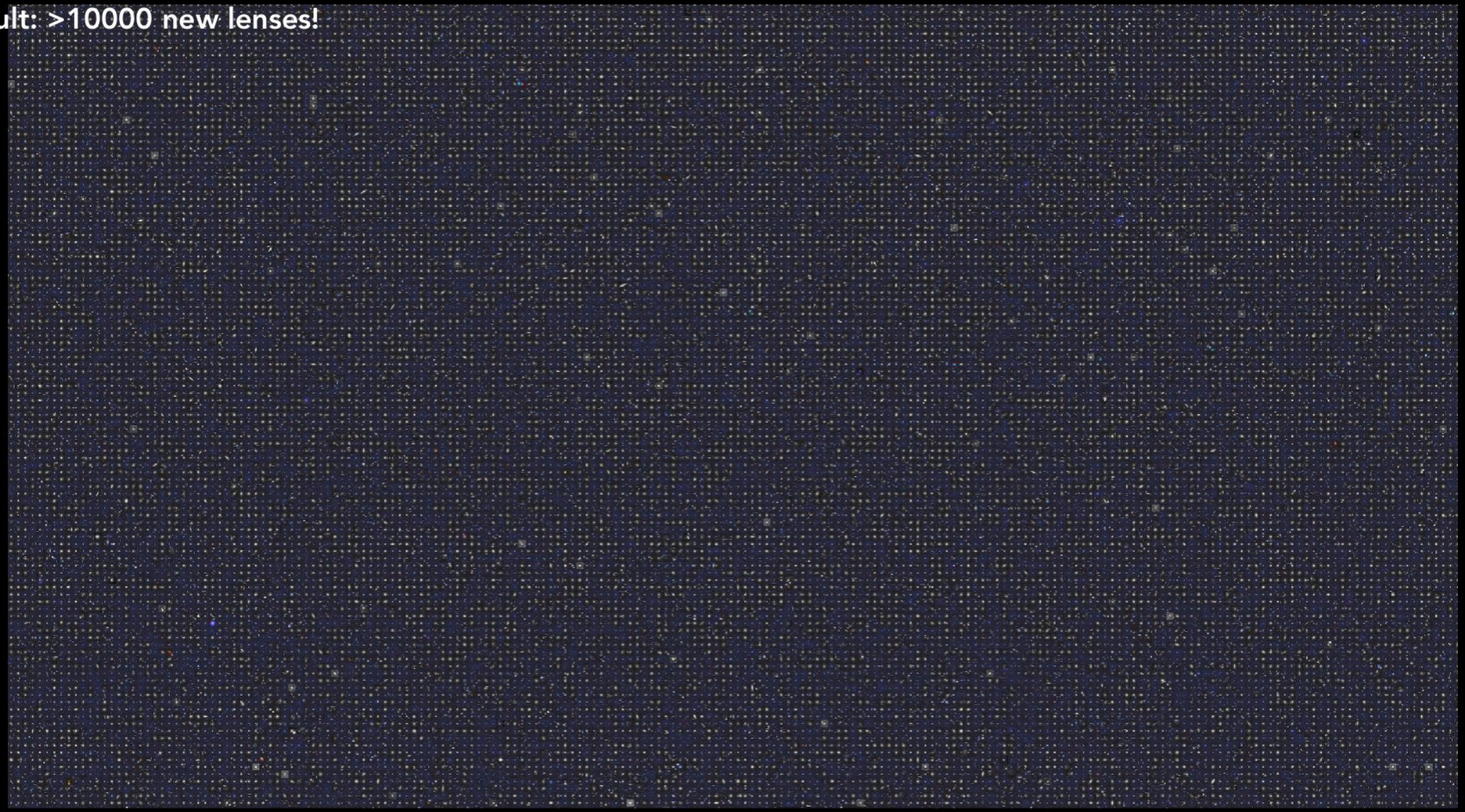
A: Welmsley et al.
"System overview and lens catalogue"

Result: ~500 new lenses



GALAXY LENSES IN EUCLID DR1

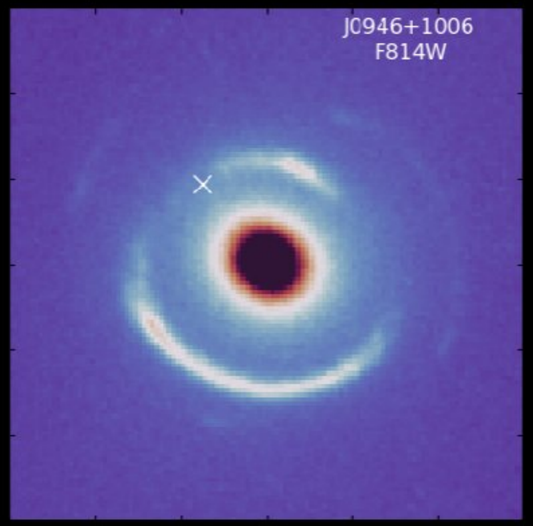
Result: >10000 new lenses!



DARK MATTER WITH EUCLID

now:

<10 detections + candidates



Euclid: assuming CDM

O'Riordan et al. 2023

1 in 70

lenses yield a detection

1 in 3

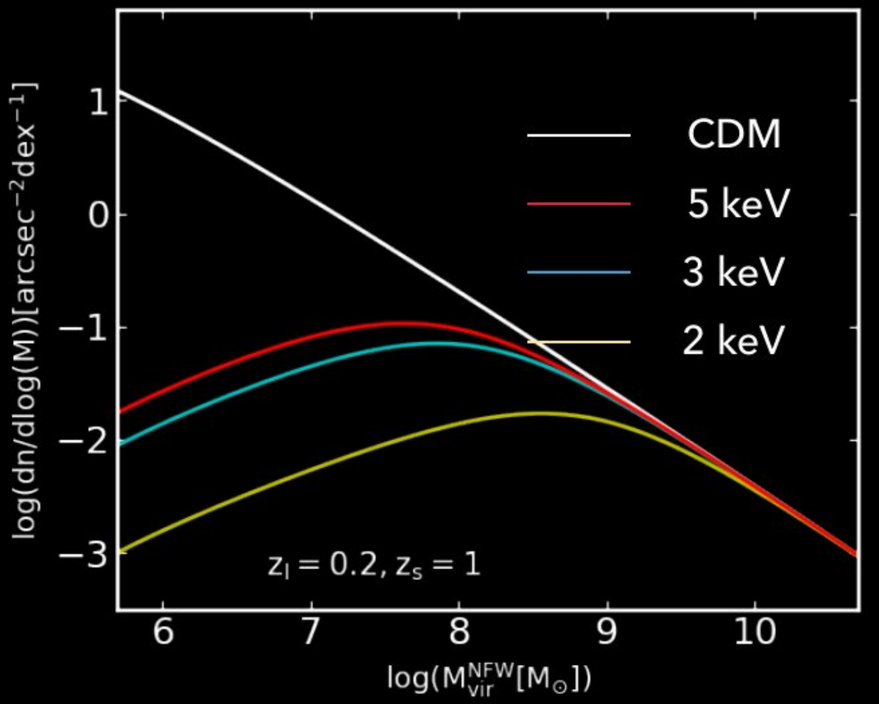
in the most sensitive lenses

$10^{8.8}\ M_{\odot}$

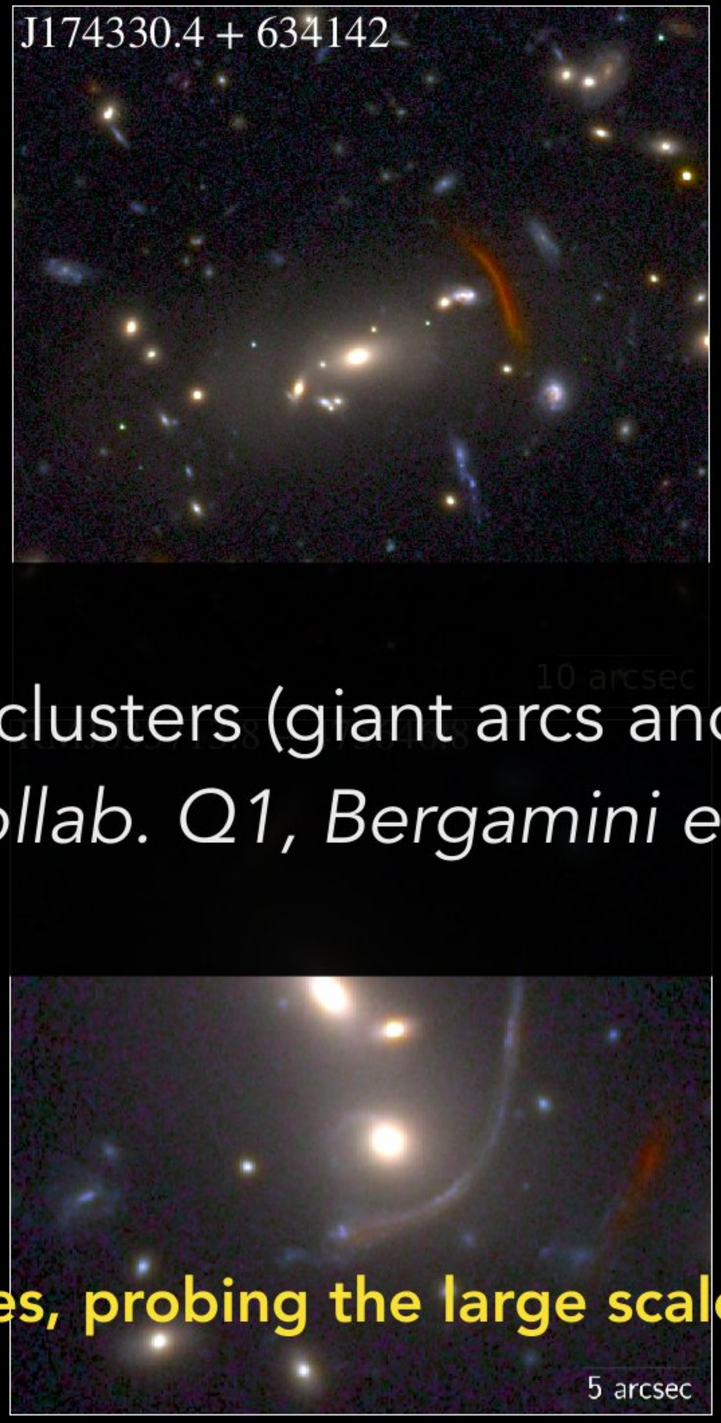
sensitivity limit in $M_{\rm max}$ and CDM

2500

new detections





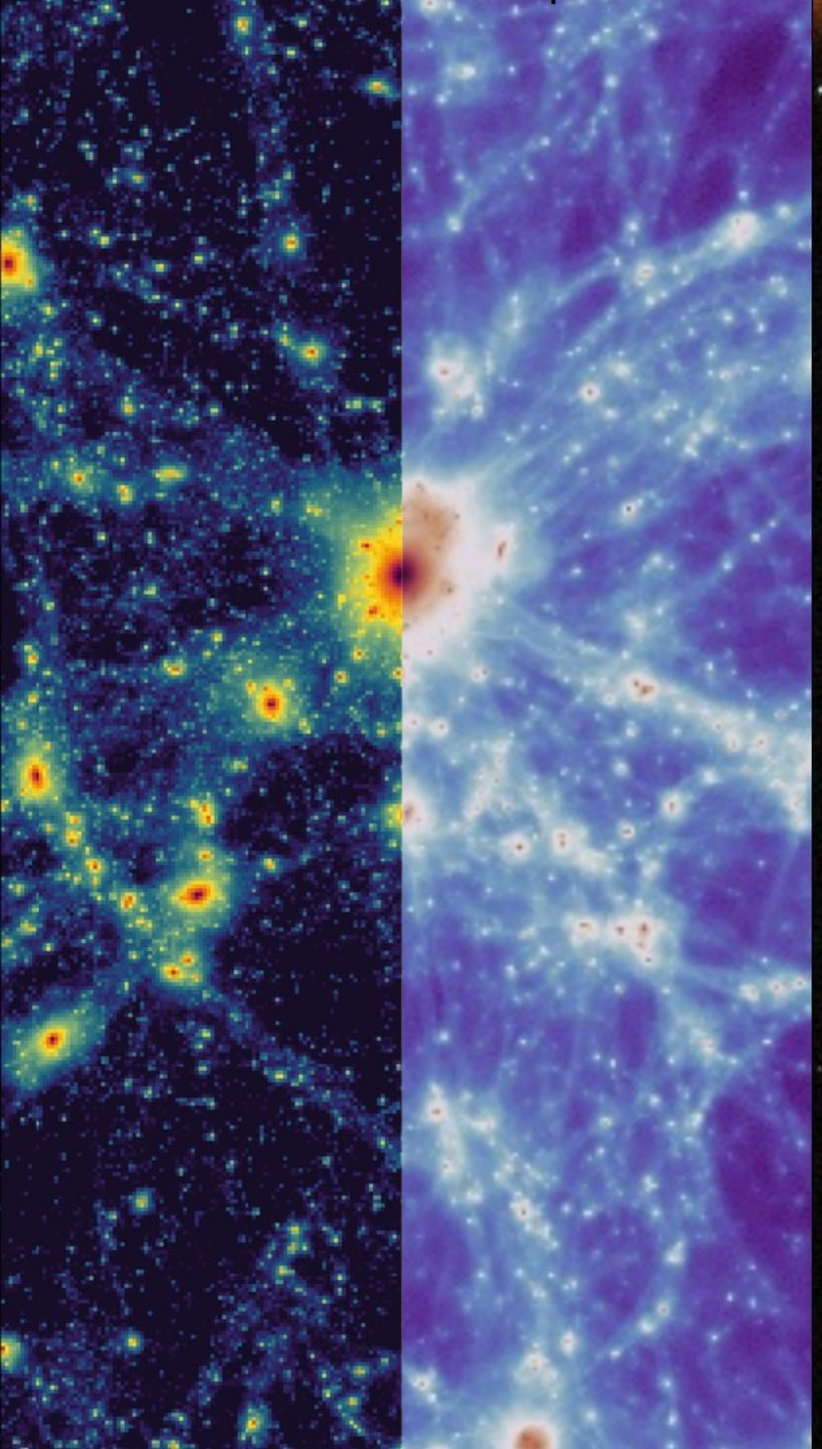




83 strong lensing clusters (giant arcs and multiple images)

Euclid Collab. Q1, Bergamini et al. 2025

Giant arcs and multiple images, probing the large scale grav. potential of SL clusters



SUMMARY

dark matter studies are still alive and well

Search for dark matter particle interactions in an extended nuclear recoil energy window with the LUX-ZEPLIN (LZ) experiment

D.S. Akerib,[1,2] A.K. Al Musalhi,[3] B.J. Almquist,[4] C.S. Amarasinghe,[5] A. Ames,[1,2] T. Anderson,[6] N. Angelides,[7] H.M. Araújo,[8,9] J.E. Armstrong,[10] M. Arthurs,[1,2] A. Baker,[11] S. Balashov,[9] J. Bang,[1] J.W. Bargemann,[5] E.E. Barillier,[7] D. Bauer,[8] A. Beauchene,[12] T.L. Benson,[13] A. Bhatti,[10] T.P. Biesiadzinski,[1,2] H.J. Birch,[7]

new simulations and observational surveys will
very soon tell us more about the nature of dark matter

THANK YOU!