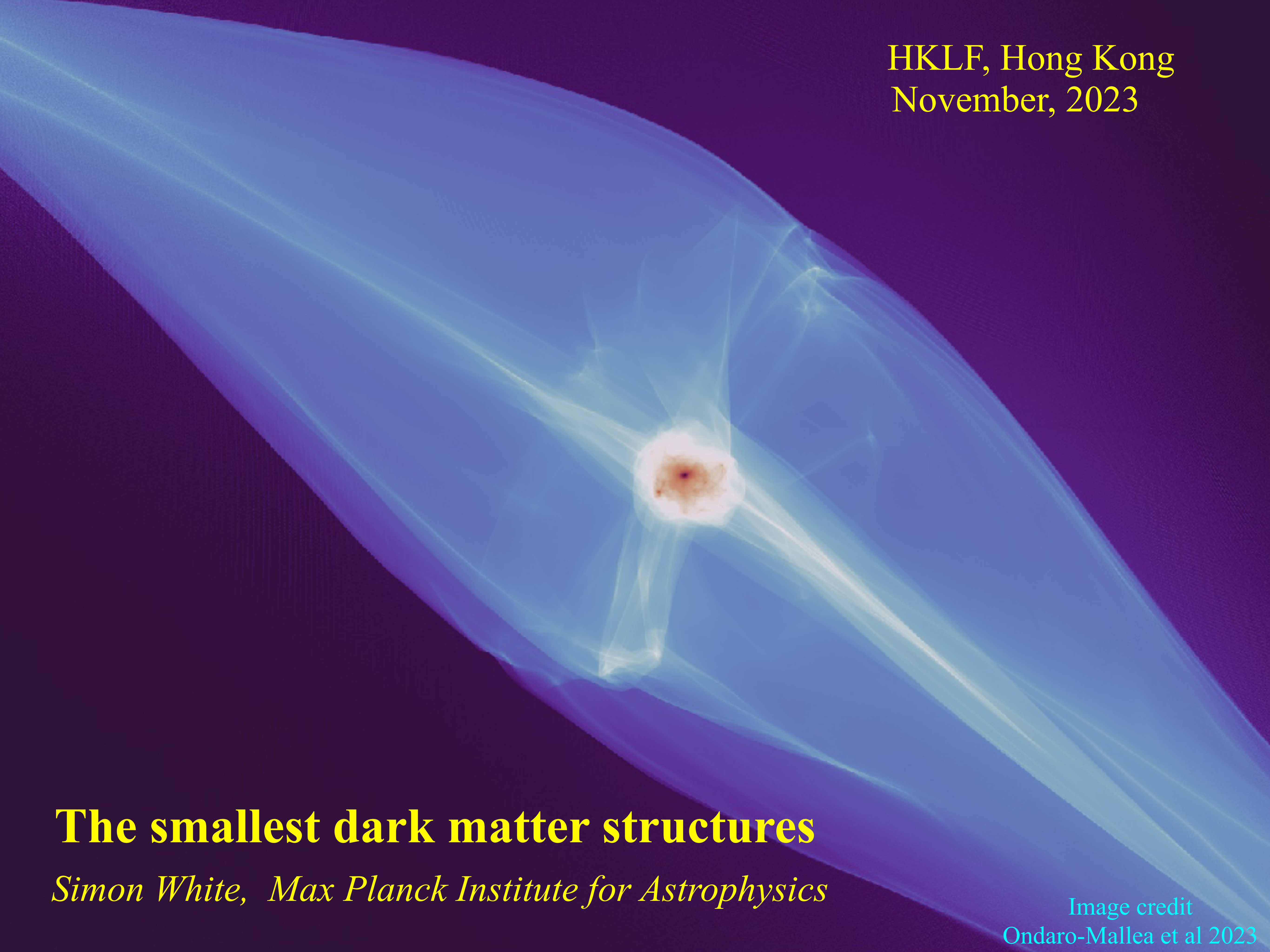
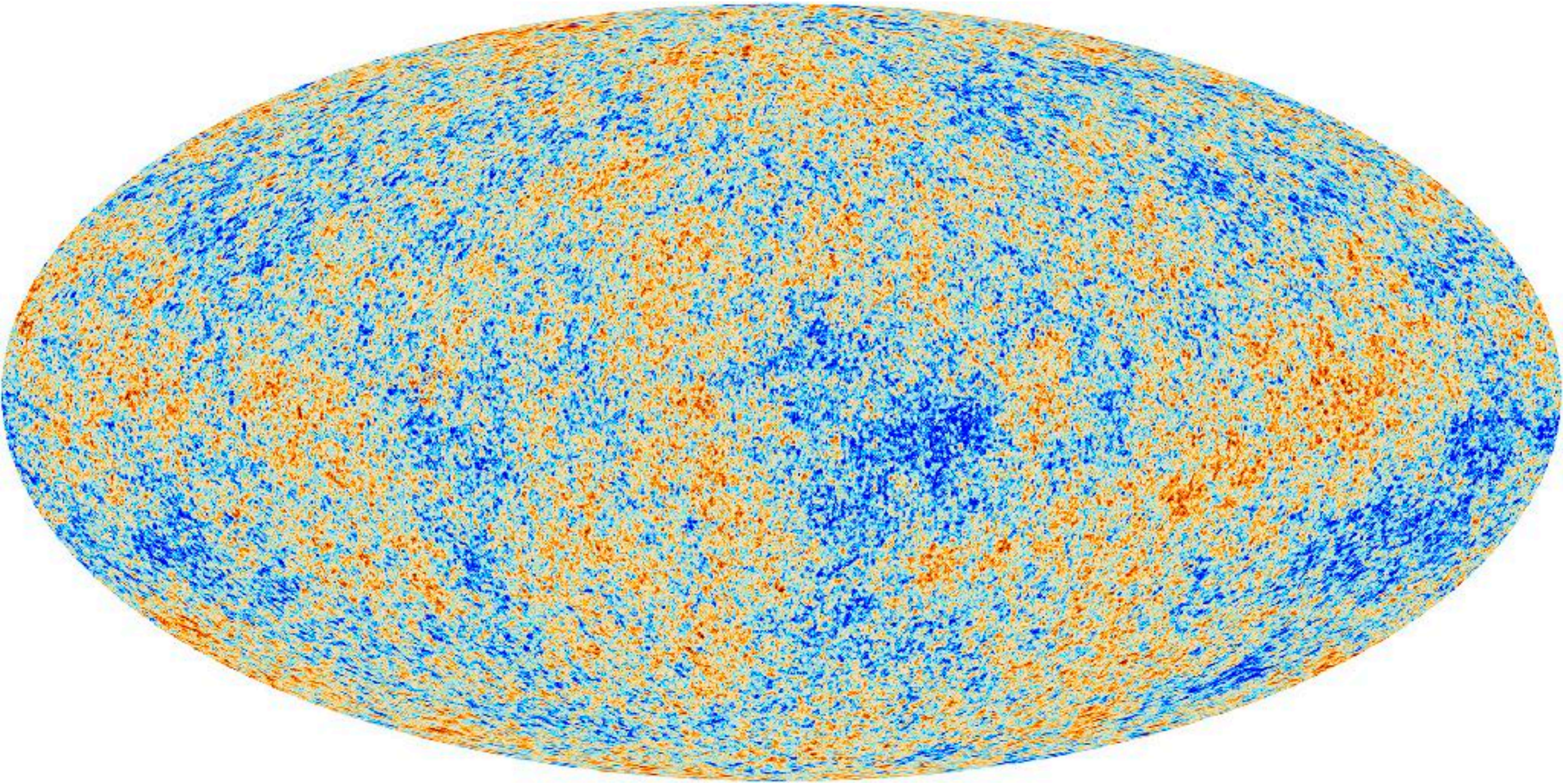


HKLF, Hong Kong
November, 2023

The smallest dark matter structures

Simon White, Max Planck Institute for Astrophysics

Image credit
Ondaro-Mallea et al 2023



The Planck image of the Cosmic Microwave Background

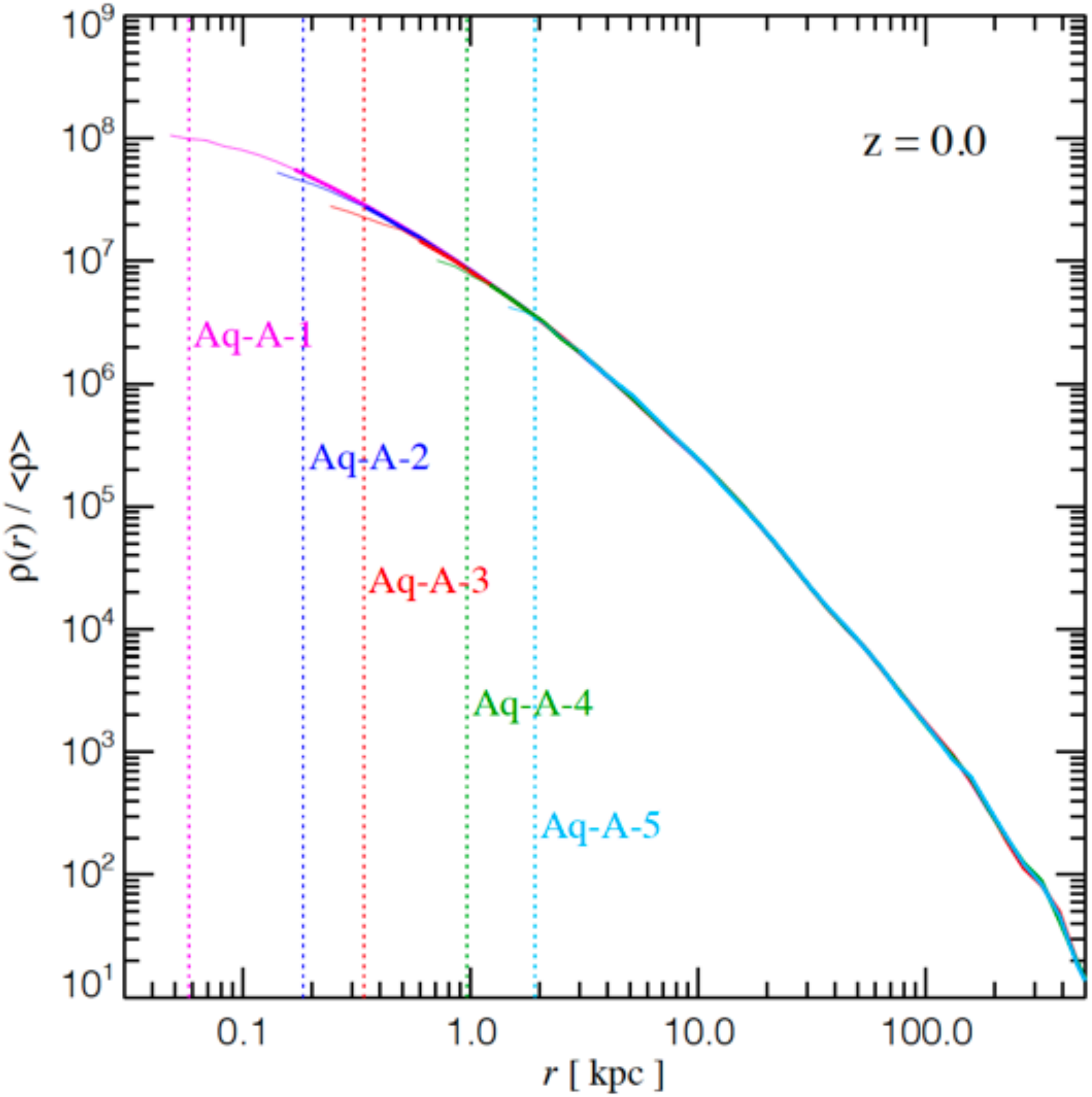
The Universe at an age of 400,000 years — hot and almost uniform

The initial conditions for the formation of *all* cosmic structure

[redacted]

Halos converge to NFW outside $r_{\rm Power}(t_f)$

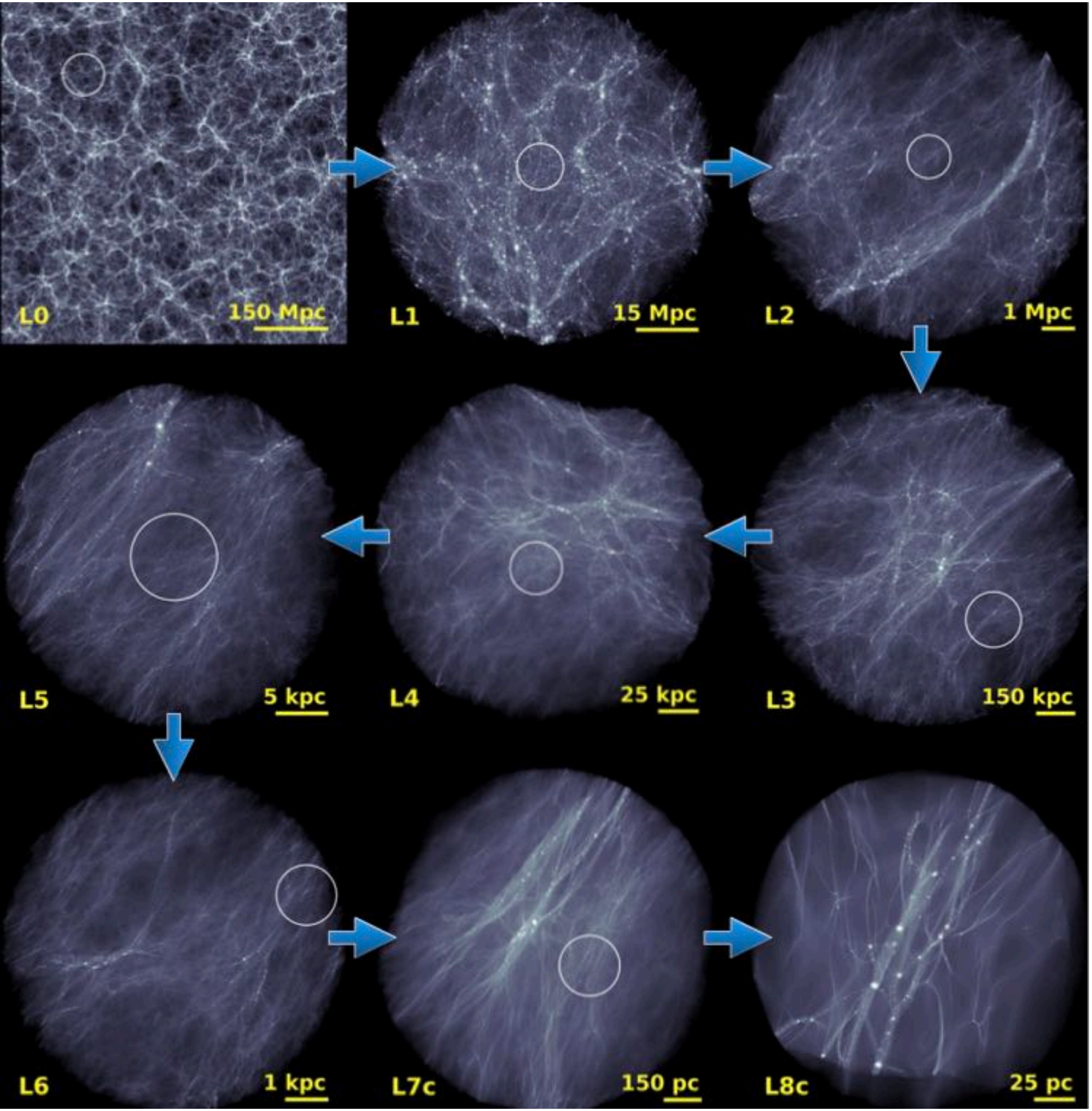
Springel et al 2008



The NFW shape is a good fit over

6 orders of magnitude in density

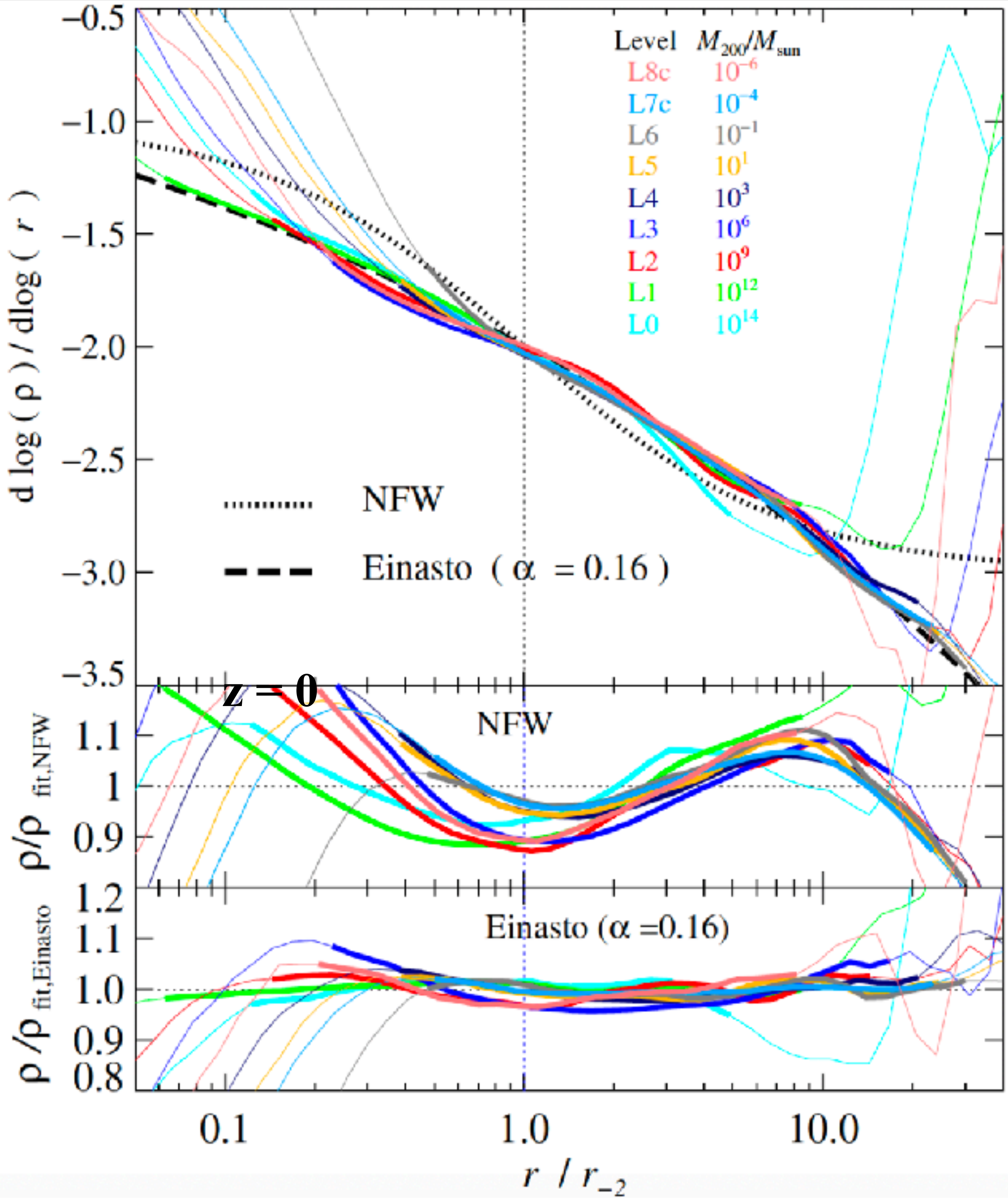
$$\rho_{\rm NFW}(r) \approx r_{-2}^3 \rho_{-2} / r(r + r_{-2})^2$$



The VVV simulation suite zooms into a low-density region of a z=0 ΛCDM universe by a factor 4.10^6

Resolves dark matter halos over a mass range of 10^{20}

Wang J et al 2020

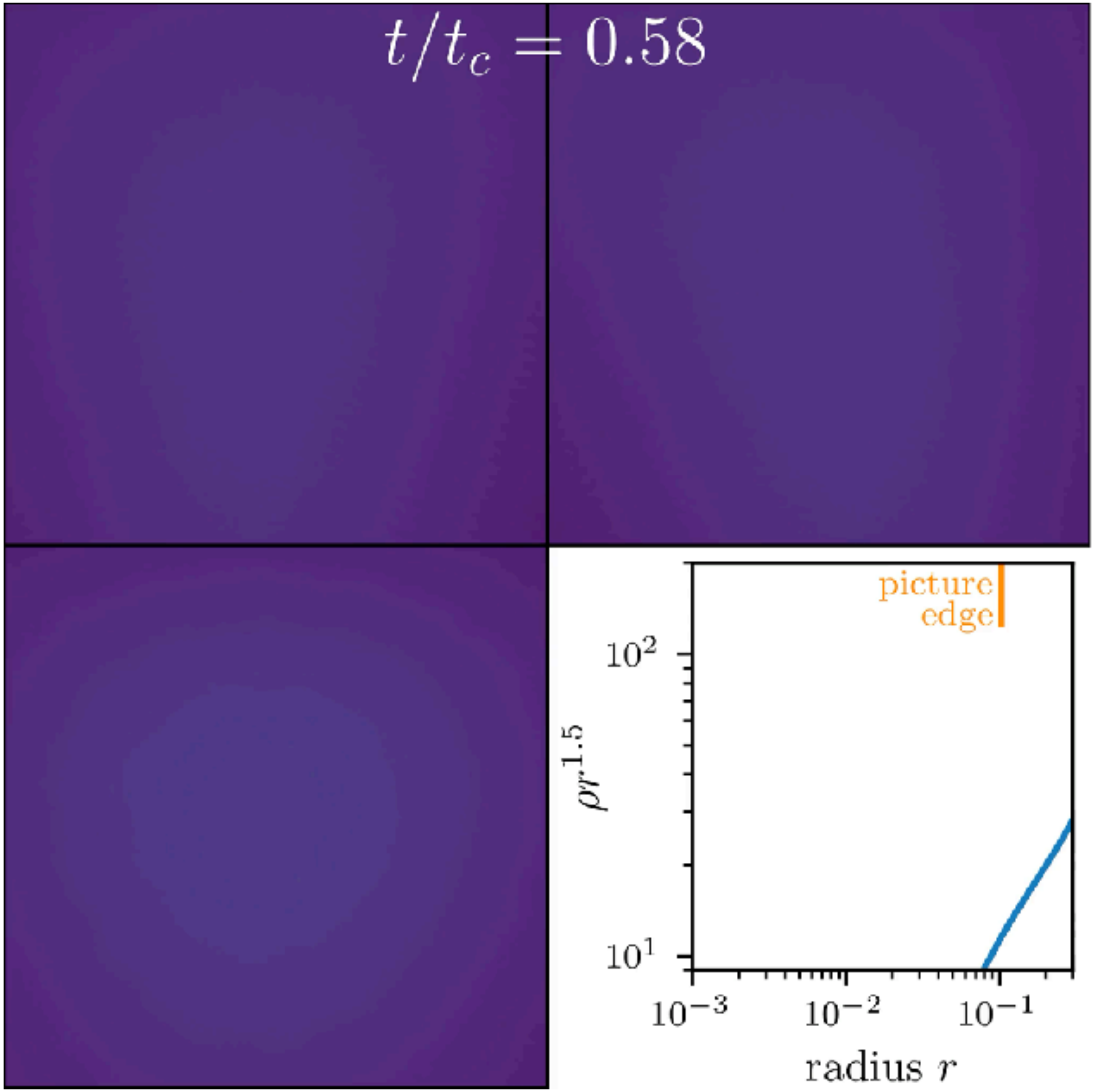


Density profile shapes

Over 19 orders of magnitude in halo mass and 4 orders of magnitude in density, the mean density profiles of halos are fit by NFW to within 20% and by Einasto (with α = 0.16) to within 7%

Wang J et al 2020

Prompt cusp formation in a ΛCDM density peak

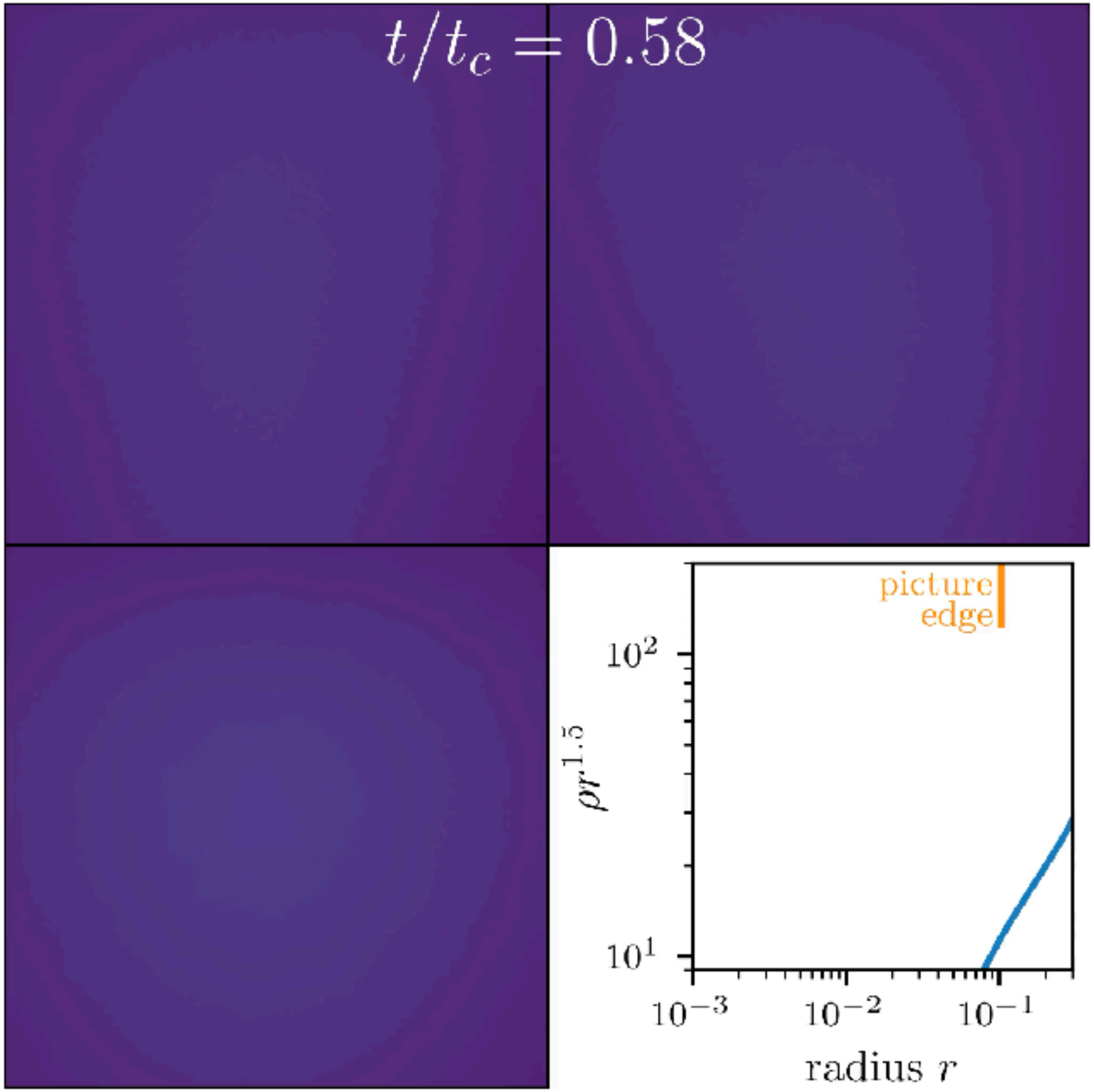


$t_c \longrightarrow z = 87$

$M_{pk} \sim 10^{-6} M_{\rm sun}$

Delos & White 2023

Prompt cusp formation in a ΛCDM density peak



$t_c \longrightarrow z = 87$

$M_{pk} \sim 10^{-6} M_{\rm sun}$

Prompt cusp formation differs qualitatively from “normal” halo formation

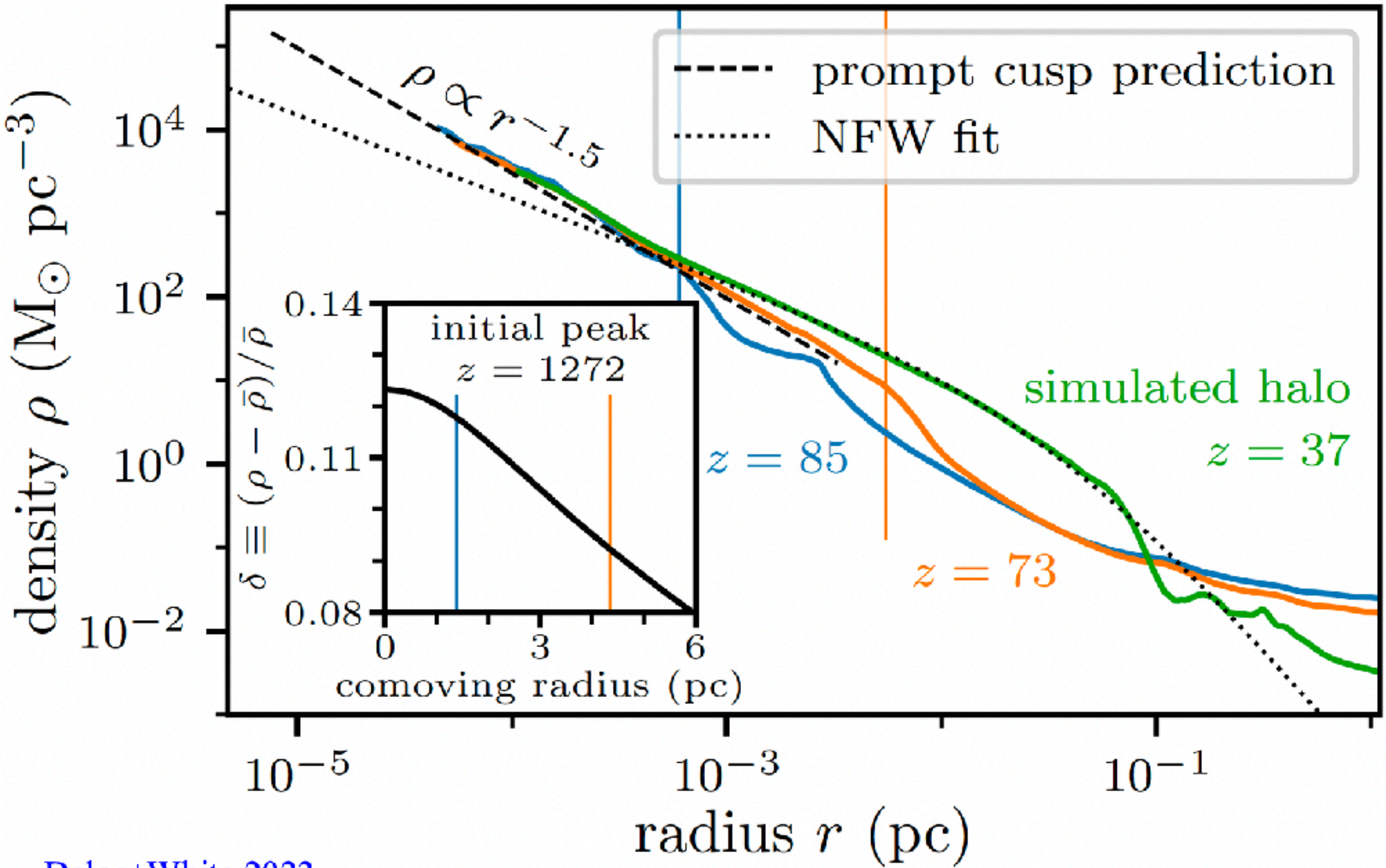
Violent relaxation is important

No close link of profile to cusp growth history

A “universal” profile *different* from NFW

Delos & White 2023

Prompt cusp and subsequent halo growth for a peak with $z_{coll} = 87$



Delos+White 2023

Prompt cusps

- ….form almost instantaneously as each peak in the initial density field collapses
- Their density is a power-law of radius $\rho(r) \approx Ar^{-1.5}$ for $r_{\rm core} < r < r_{\rm out}$ where A and $r_{\rm out}$ depend on the properties of the peak
- Their central density, $\rho_{\rm core} = Ar_{\rm core}^{-1.5}$ depends on the *nature* of the dark matter
- More massive dark matter objects build up *gradually* by merging and accretion and have "universal" density profiles $\rho_{\rm NFW}(r) \approx r_{-2}^3 \rho_{-2} / r(r + r_{-2})^2$
- Prompt cusps are so dense relative to later halos that most should survive to today
- For a standard Cold Dark Matter WIMP, they should have ~Earth mass, should be 10 times the size of the Solar System, should be $\sim 10^5$ as abundant in our Galaxy as planets, and should dominate any γ-rays from dark matter annihilation