Hunting for Dark Matter on Supercomputers

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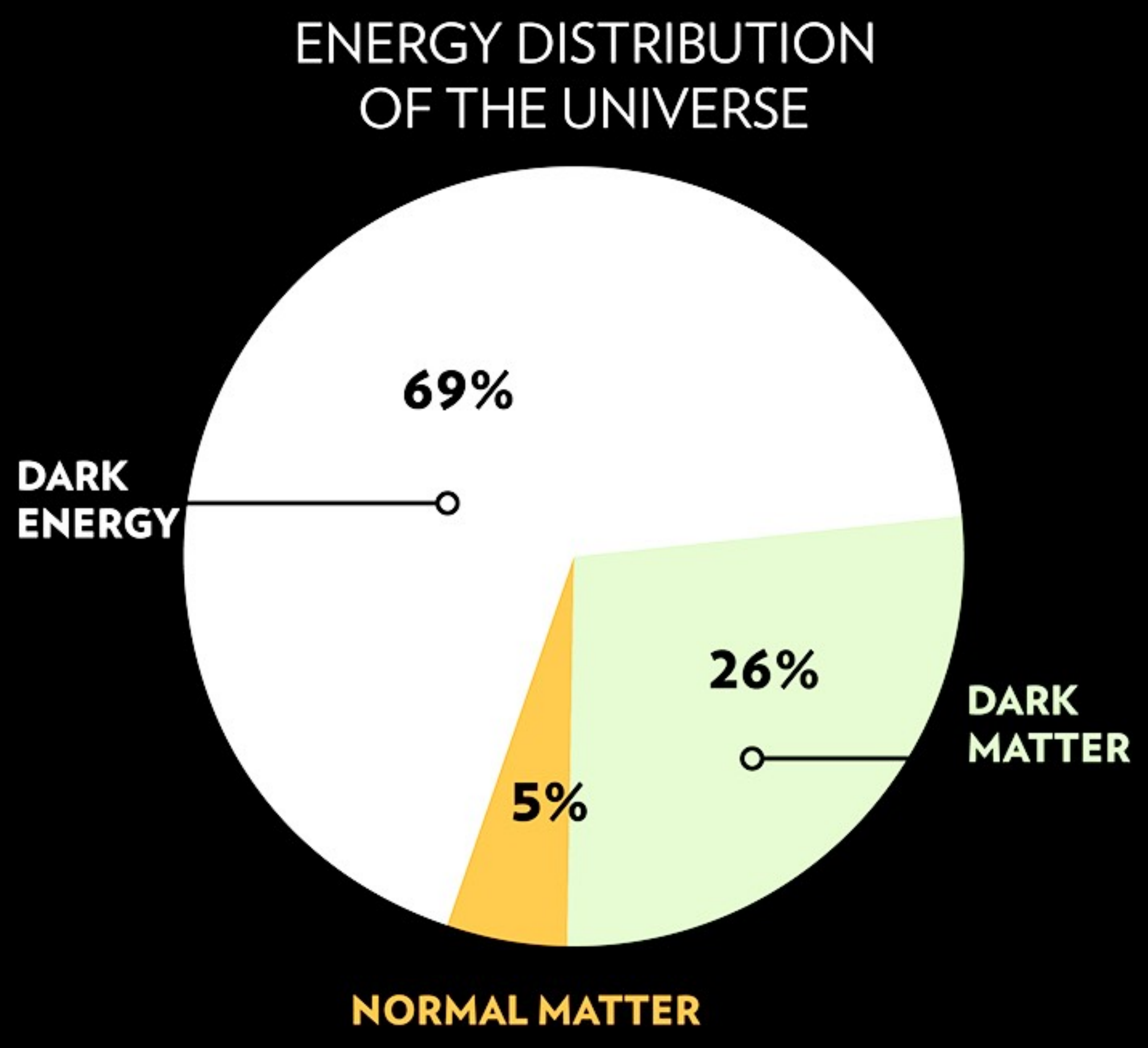
Self Introduction

- Second year graduate student at Caltech
- PhD candidate in Physics
- Advisor: Prof. Philip Hopkins

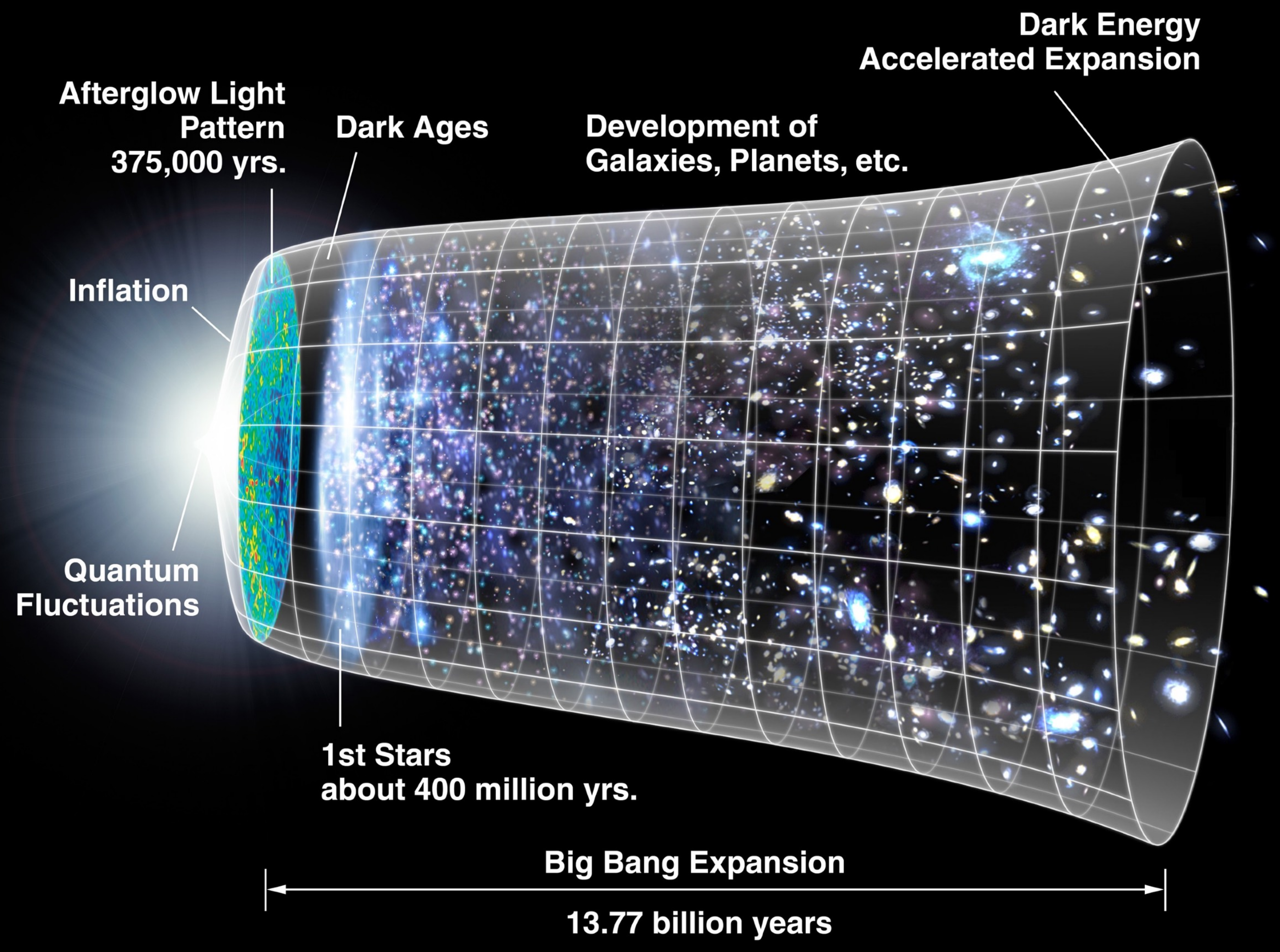
Research interests in general: Theoretical and computational cosmology

Current research focus:

- Cosmological hydrodynamical simulations of galaxies
- Explore the nature of dark matter in the context of galaxy formation & evolution



The history of our Universe

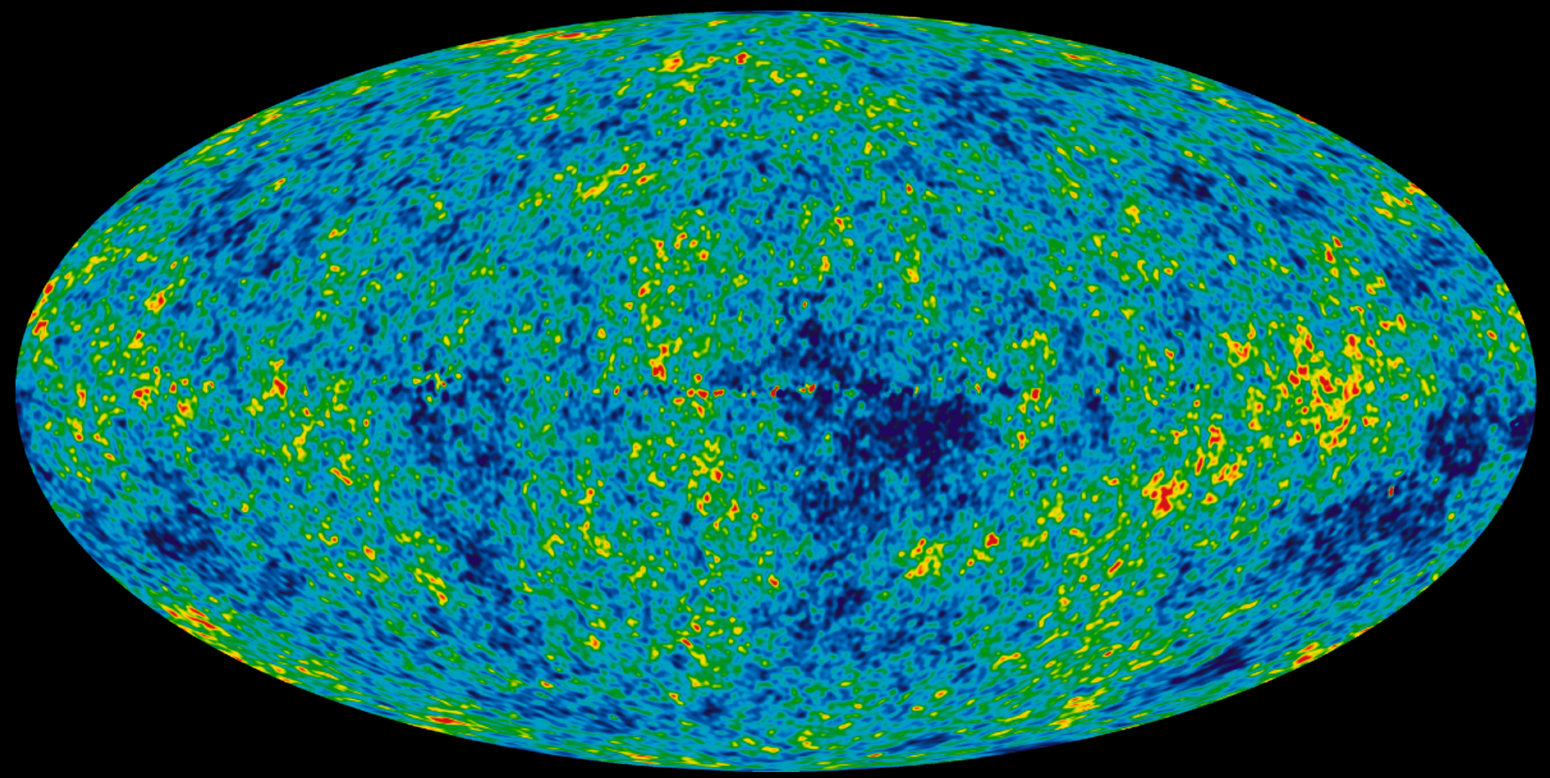


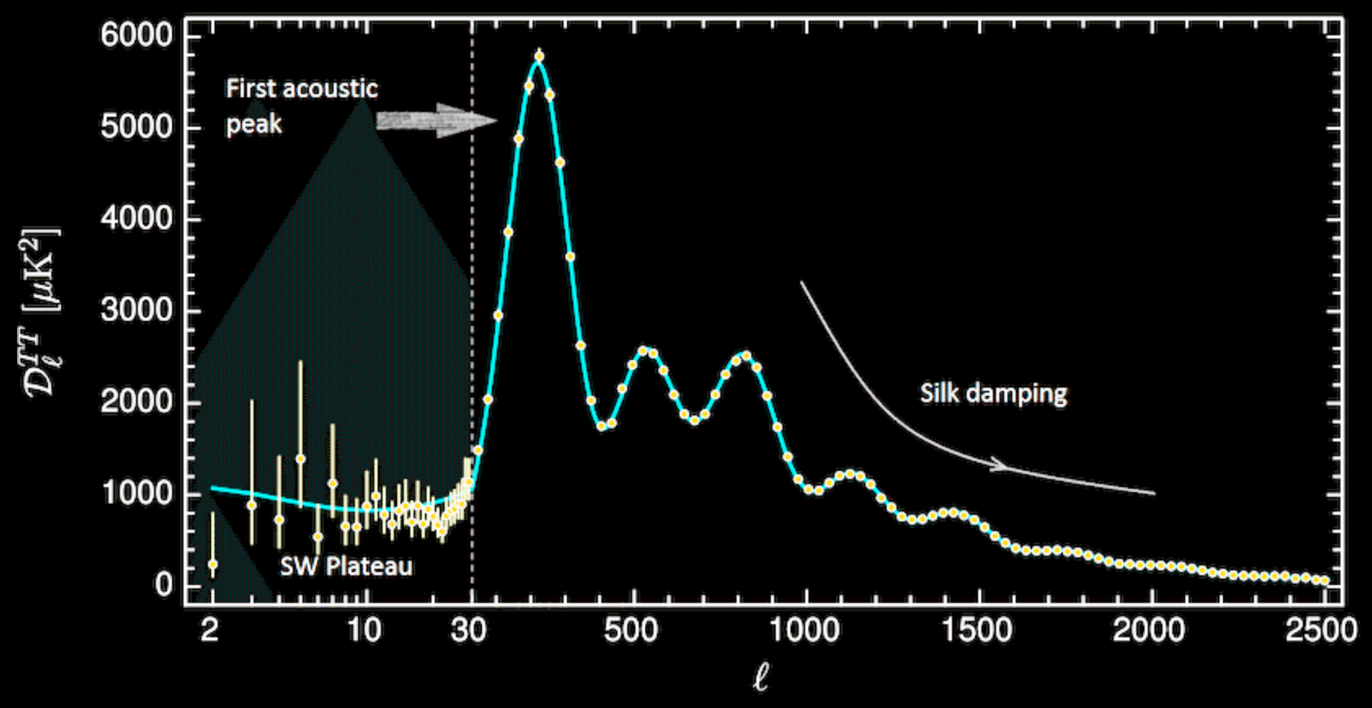
ESA 2015

- normal matter only accounts for about 5% of the energy density
- about 26% of the energy density are contributed by the so-called "dark matter"

Dark matter are actually not that "hidden" from us

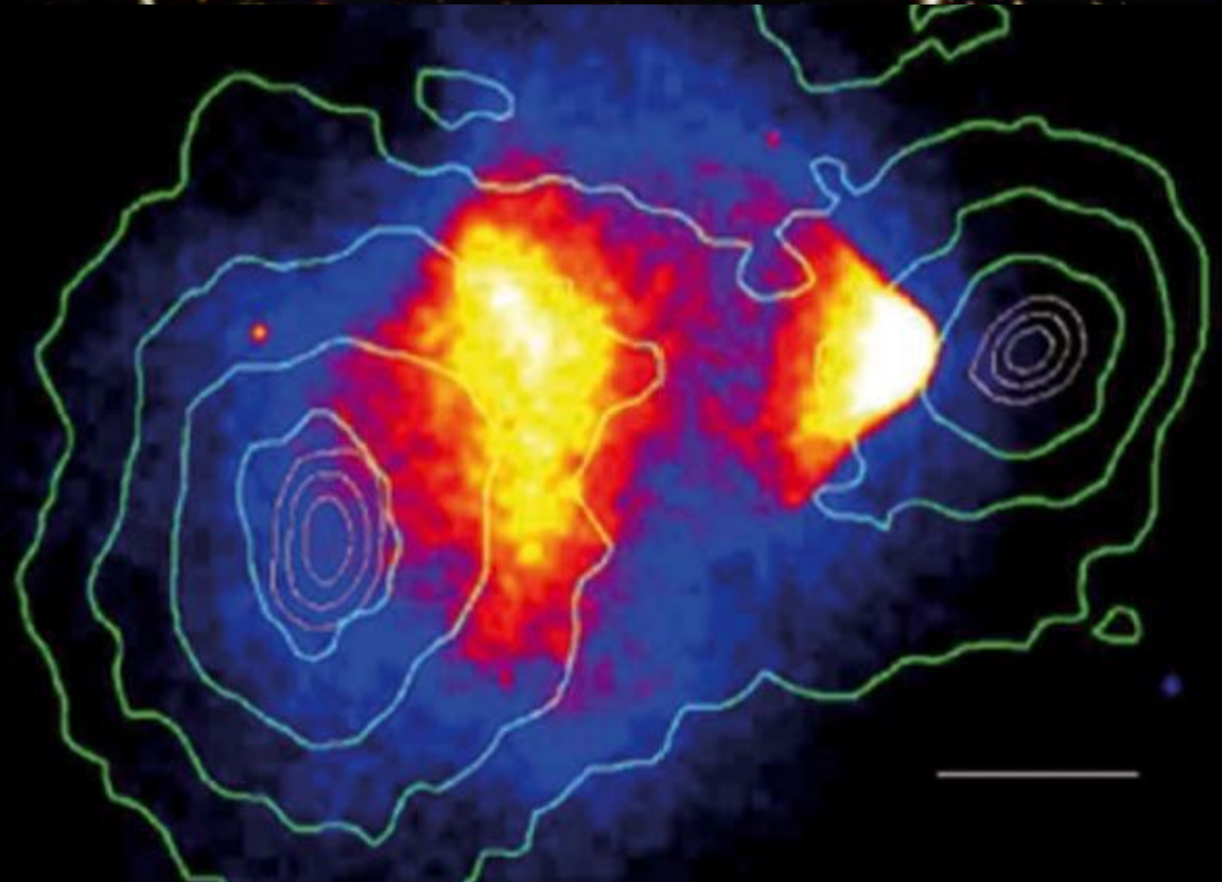
- The Cosmic Microwave Background (afterglow light of the BigBang)





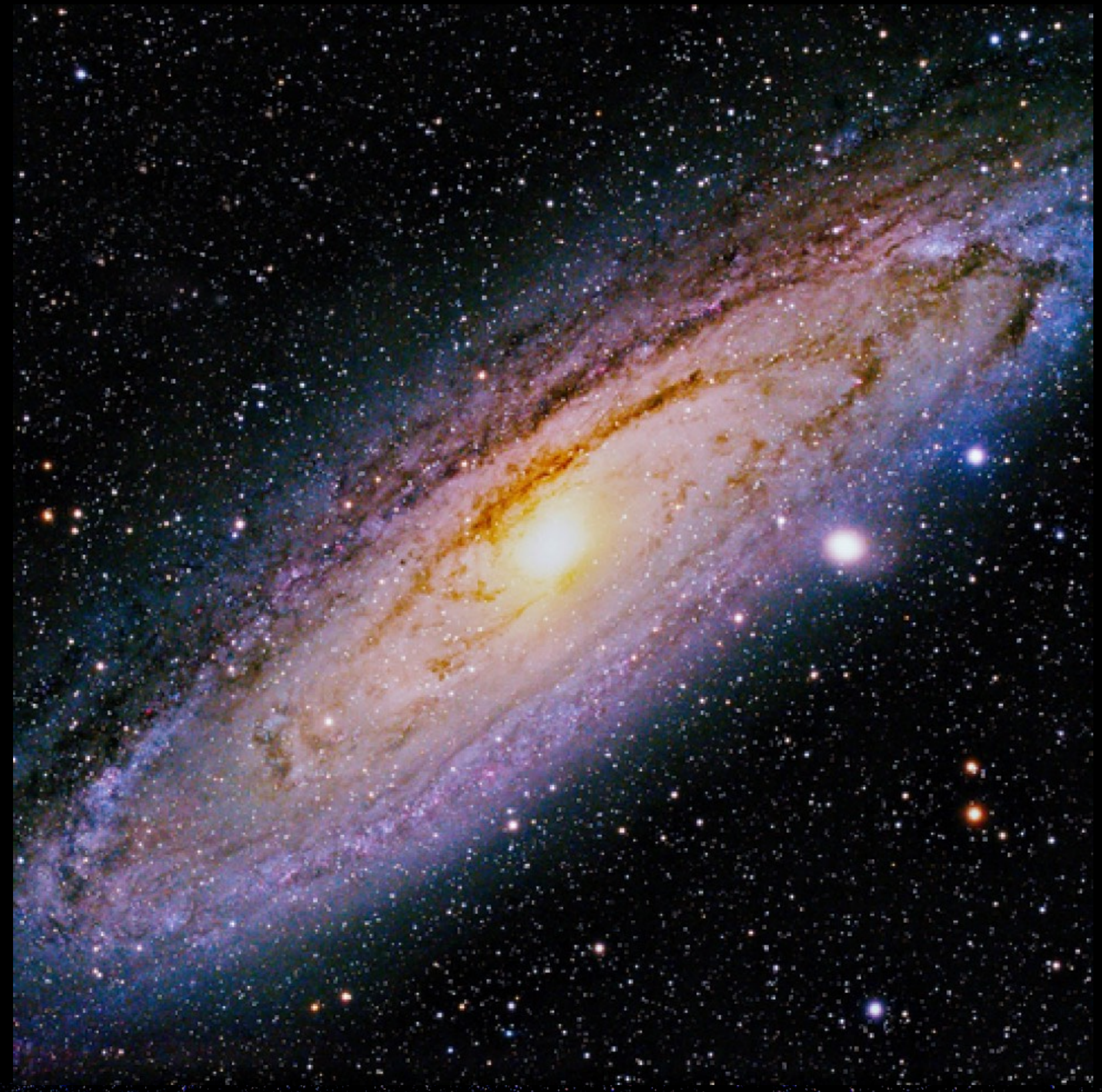
Wiggles in the angular power spectrum of the CMB

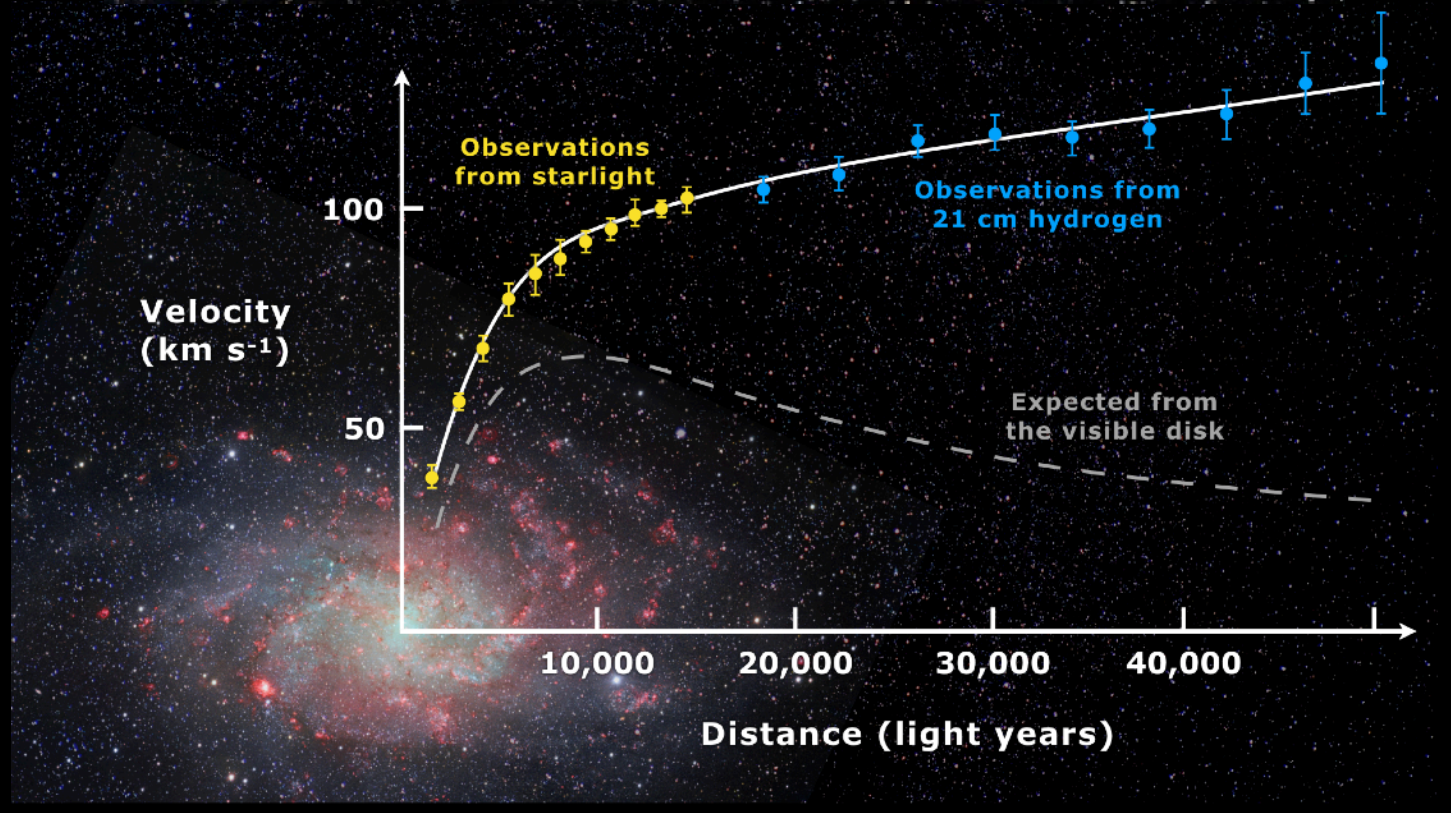
- Gravitational lensing of merging galaxy clusters



Displacement between X-ray emission from hot gas and matter distribution measured by lensing

- Rotation curves of nearby disk galaxies





Galaxies are rotating faster than expected from the amount of visible matter

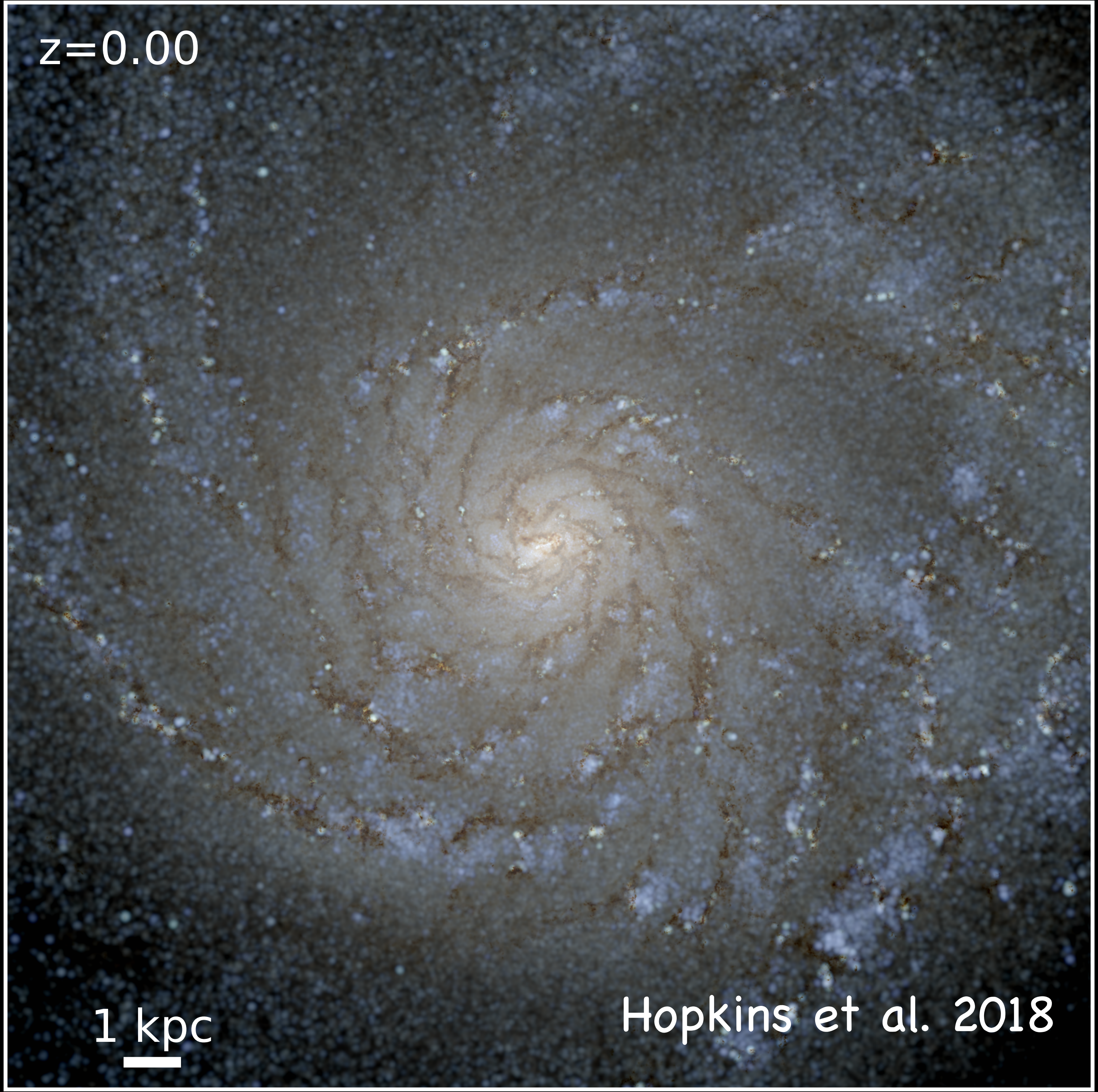
The state-of-art numeric simulations of galaxies

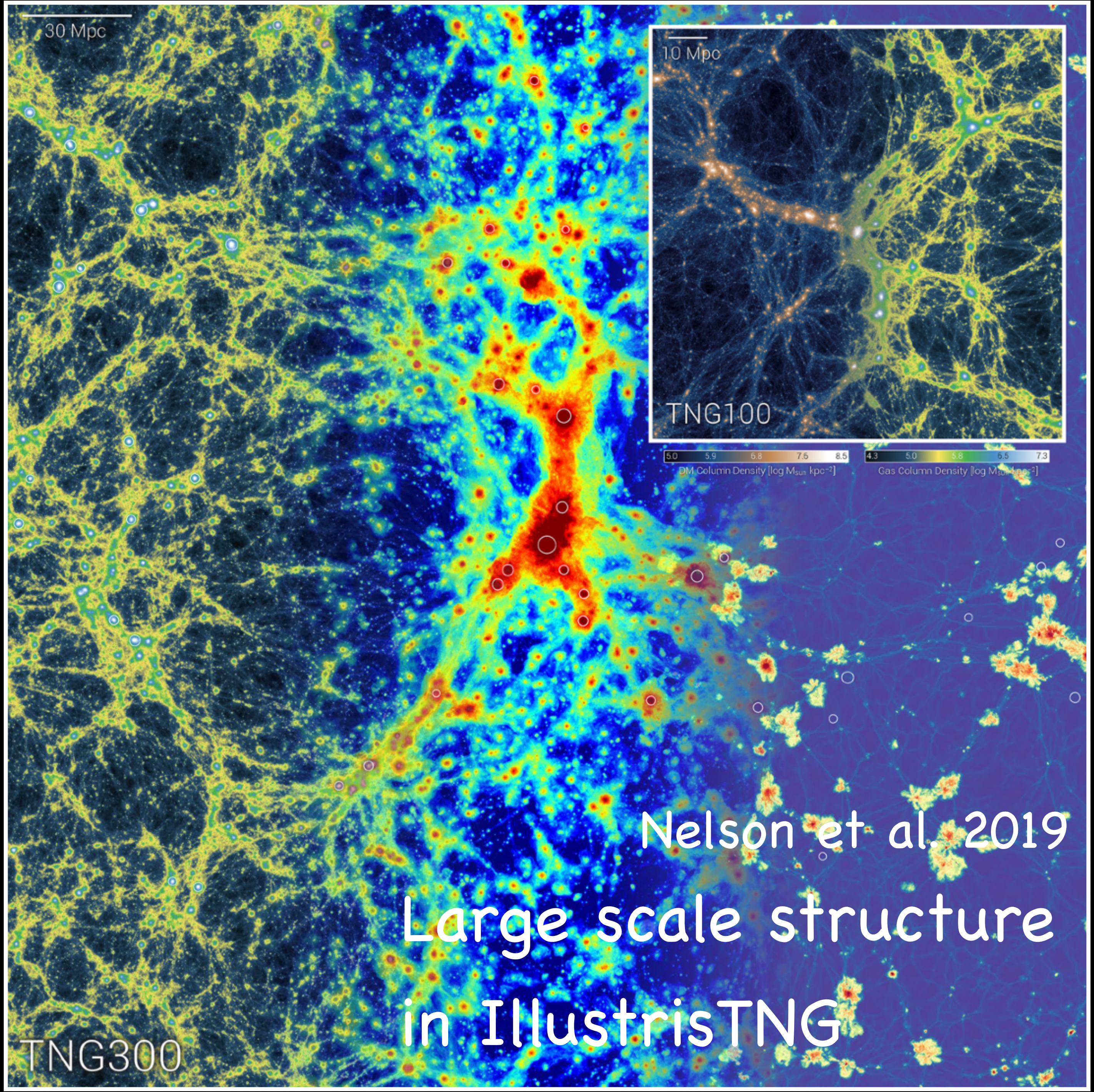
Solving gravity of N-bodies

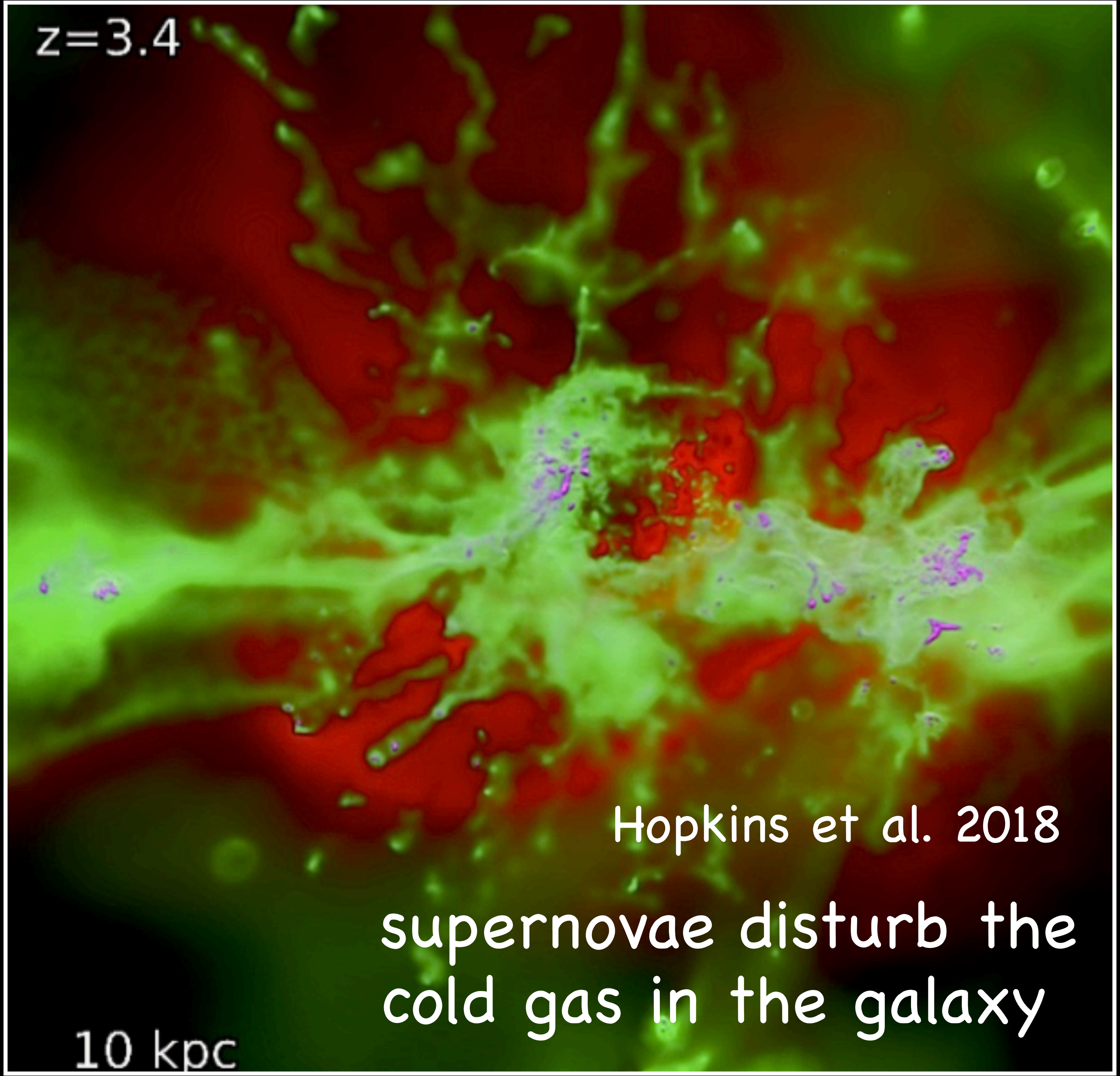
Solving hydrodynamics on a moving mesh/with meshless finite volumes

Self-consistently includes:

- the initial density fluctuation seeded in the BigBang
- cooling/heating/star formation in self-gravitating gas
- the evolution of stellar populations and their feedback to the interstellar medium
- magnetic fields/ cosmic rays/ growth & feedback of supermassive black holes







Simulations of dwarf galaxies in the Local Universe

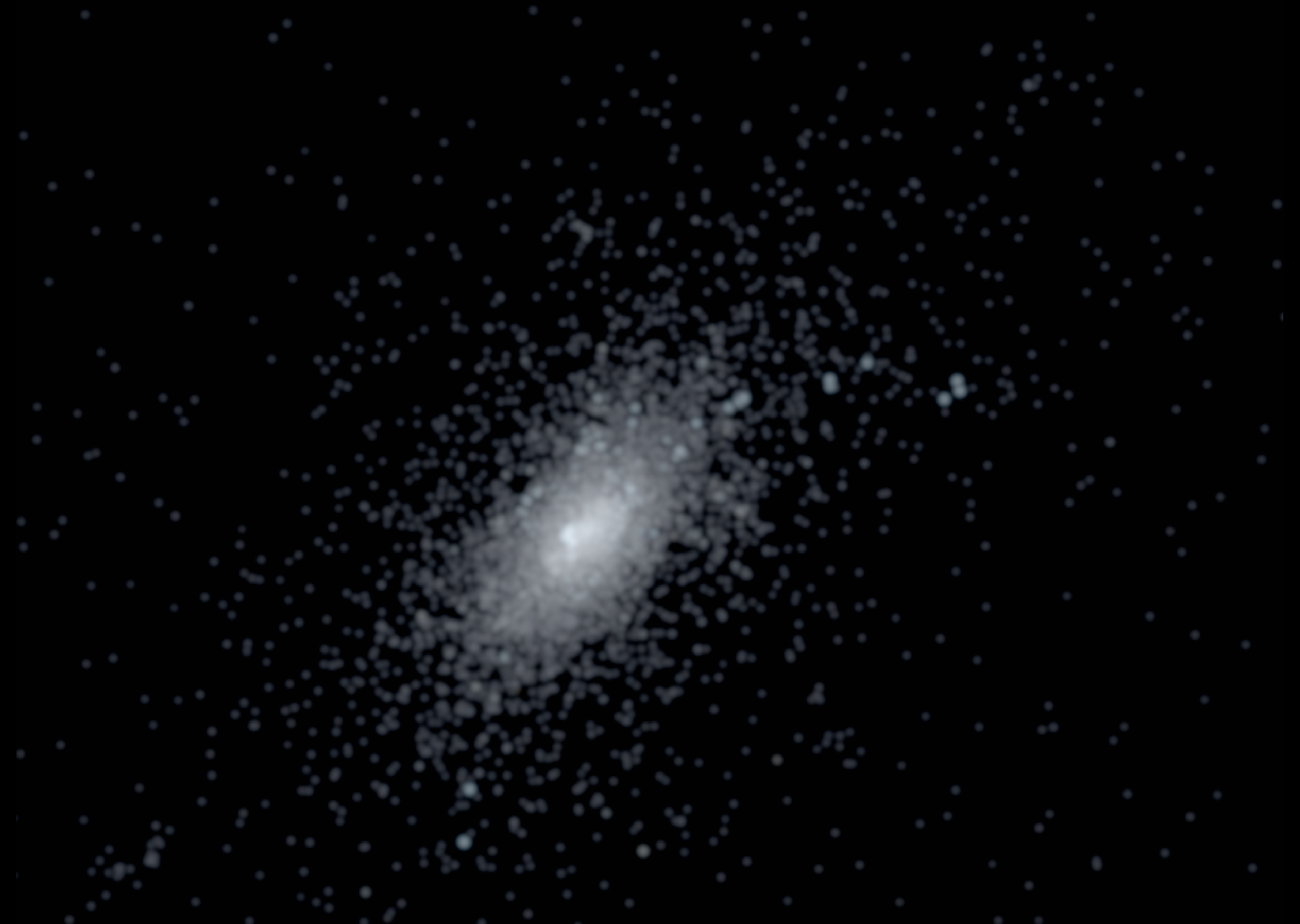
target: dissipative self-interacting dark matter (dSIDM)

Dwarf galaxies: small, dark matter dominated galaxies

- Null hypothesis: Cold dark matter (dark matter is "slow moving" and has no interactions other than gravity, "boring")

- What we want to test: Dissipative self-interacting dark matter (dark matter has new types of interactions beyond the standard model physics)

dwarf in the real Universe



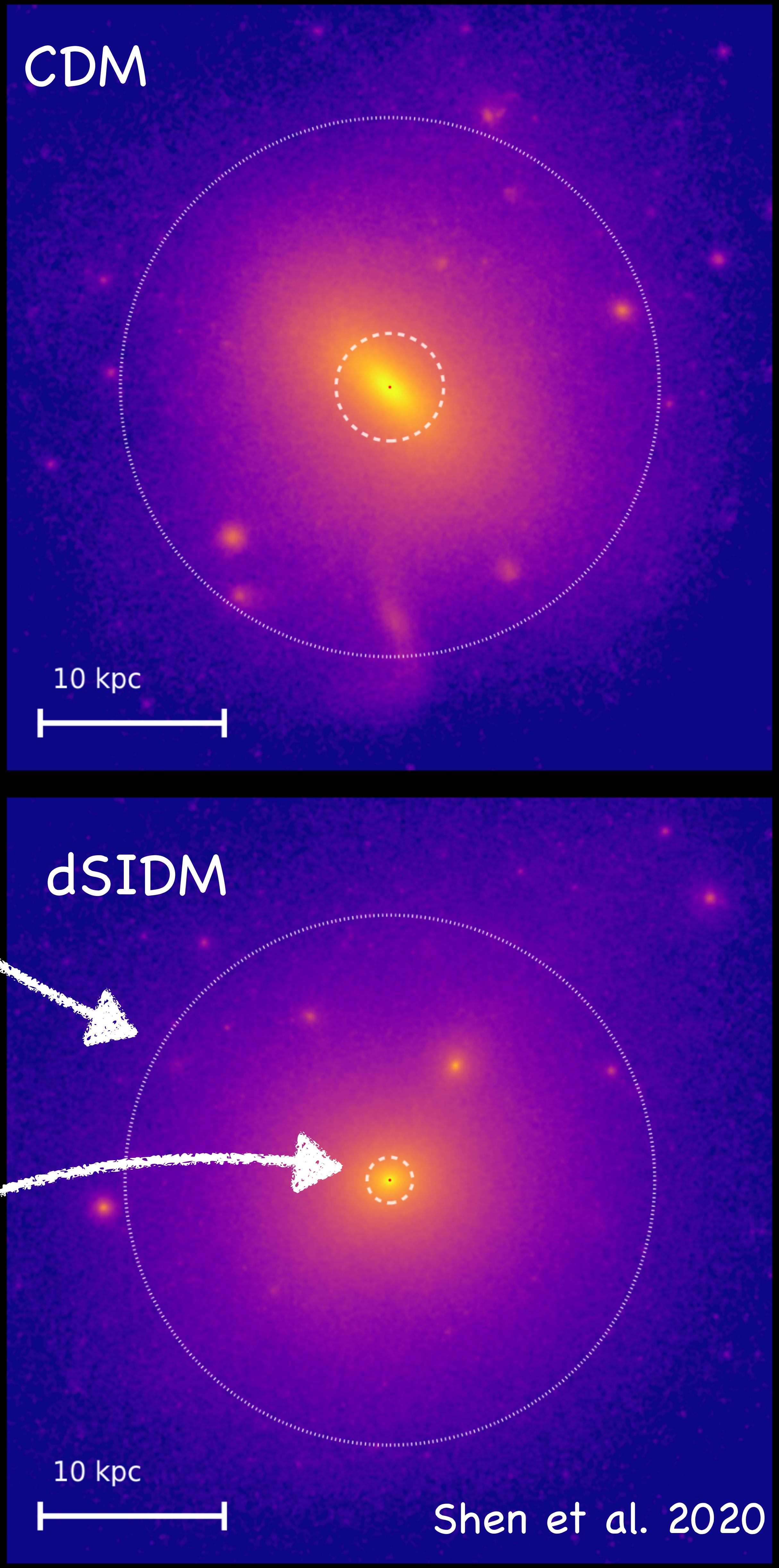
dwarf in simulation

Radial contraction of haloes in dissipative self-interacting dark matter (dSIDM)

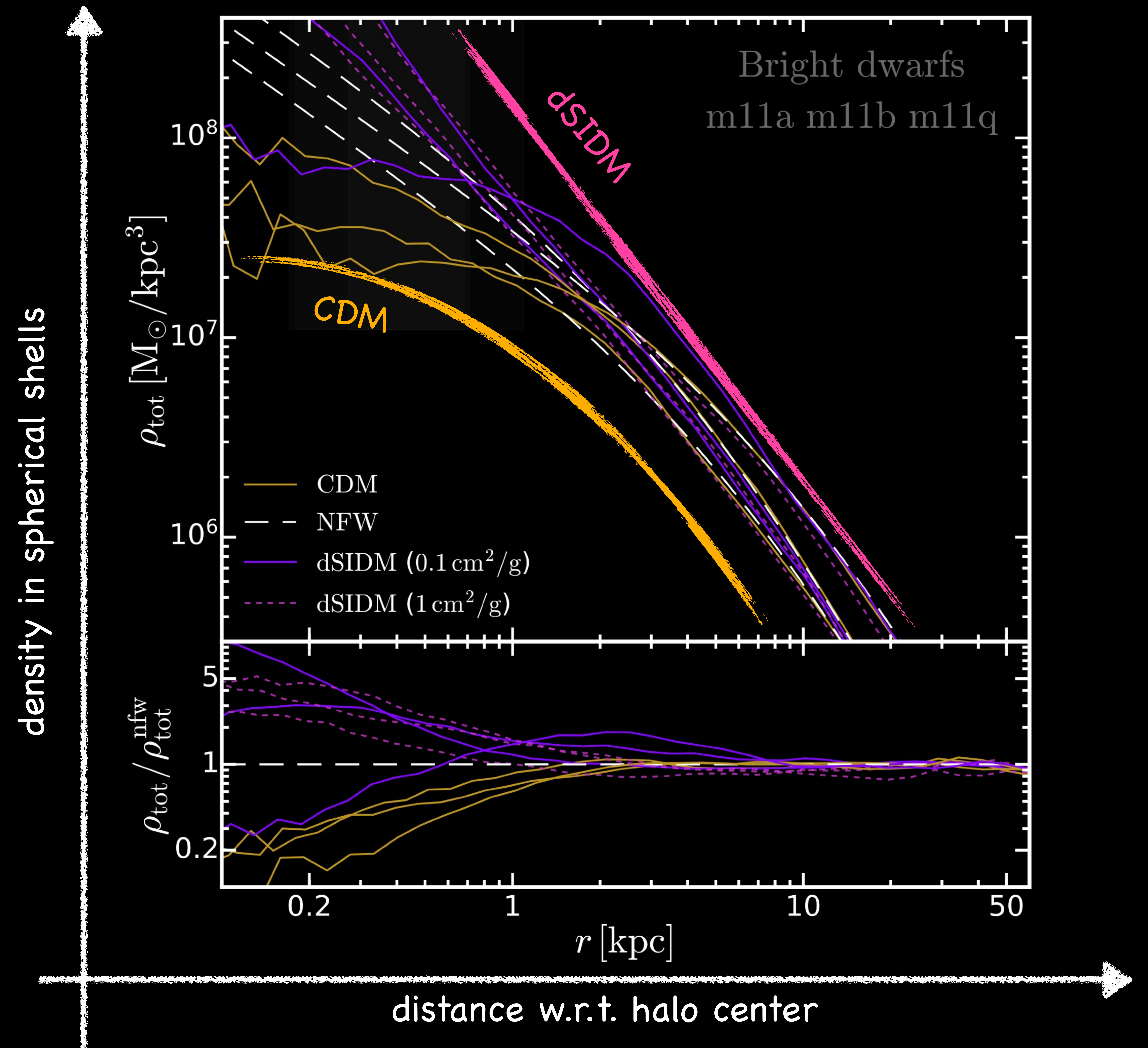
(A dark matter "halo" is the host of a galaxy)

Virial radius (overall size of a halo)

"Core" radius



Mass density profiles: density measured in spherical shells w.r.t. halo center

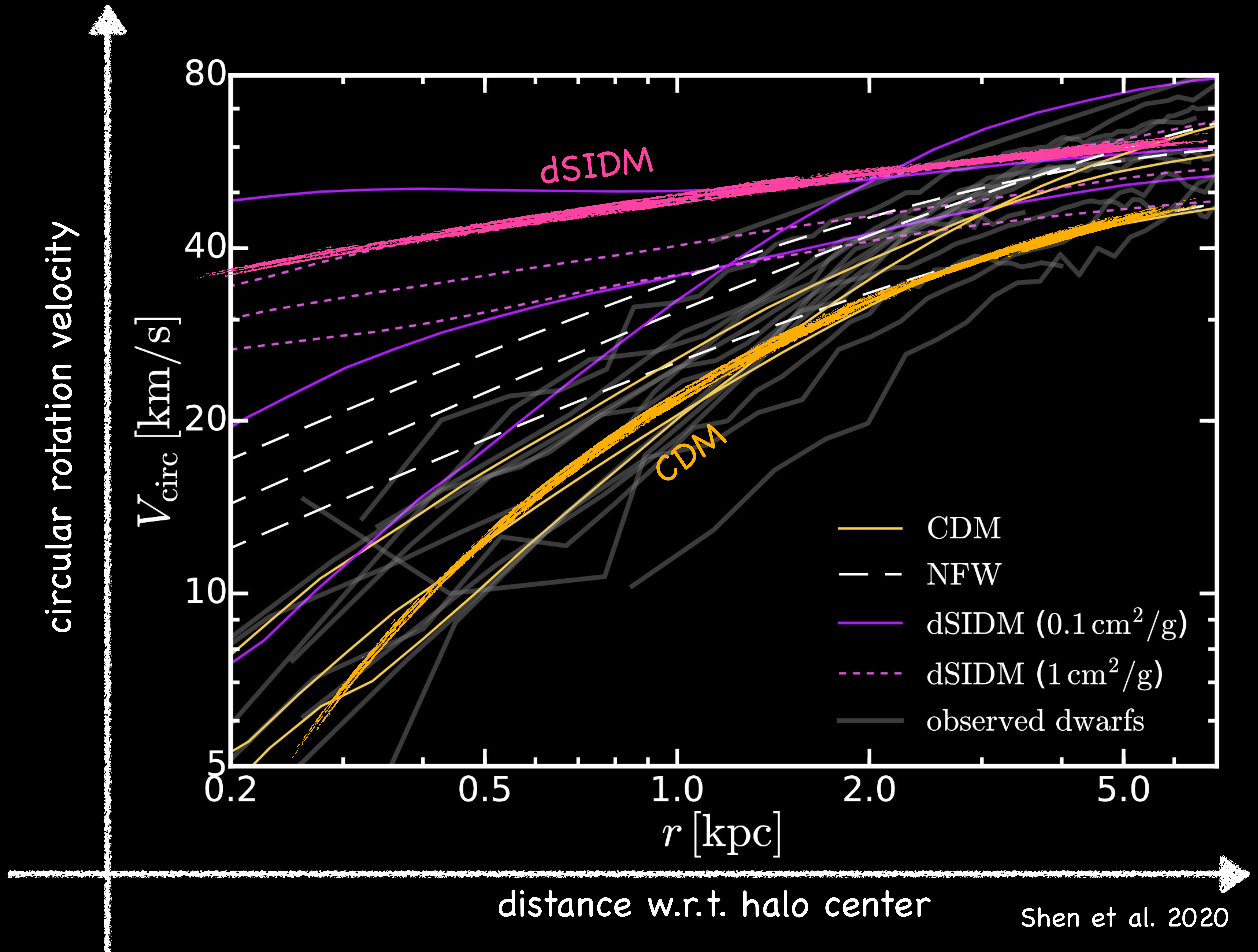


Observations:

- Kinematics of individual stars of the Local Group dwarfs
- 21cm emission of neutral hydrogen in dwarfs

Confronted with observations, **we put the first constraint on the interaction cross section of dSIDM.**

Rotation curves: the expected velocity of stars/gas if they are on circular orbits at a distance from galaxy center



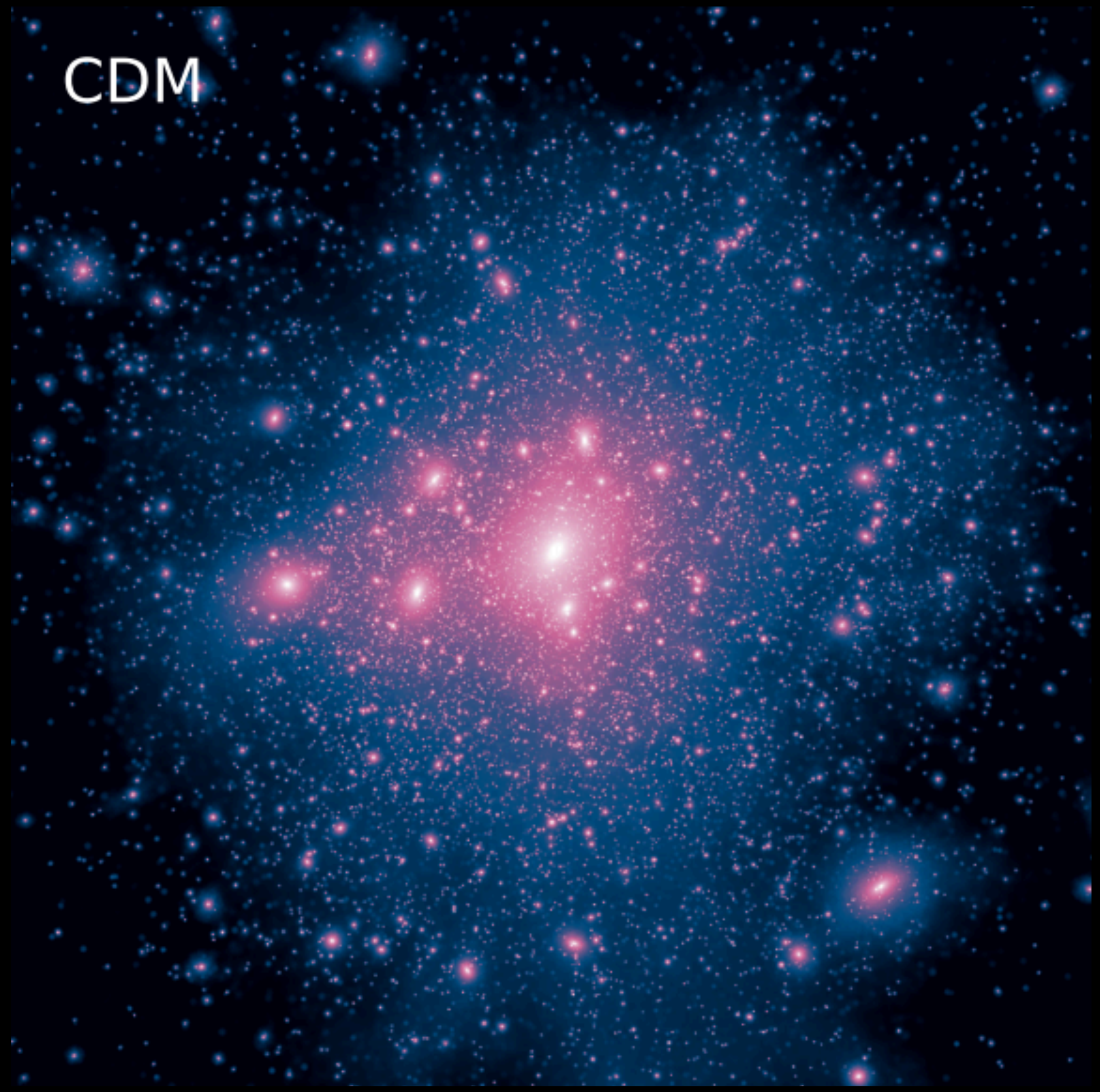
Shen et al. 2020

Simulations of galaxies in the early Universe

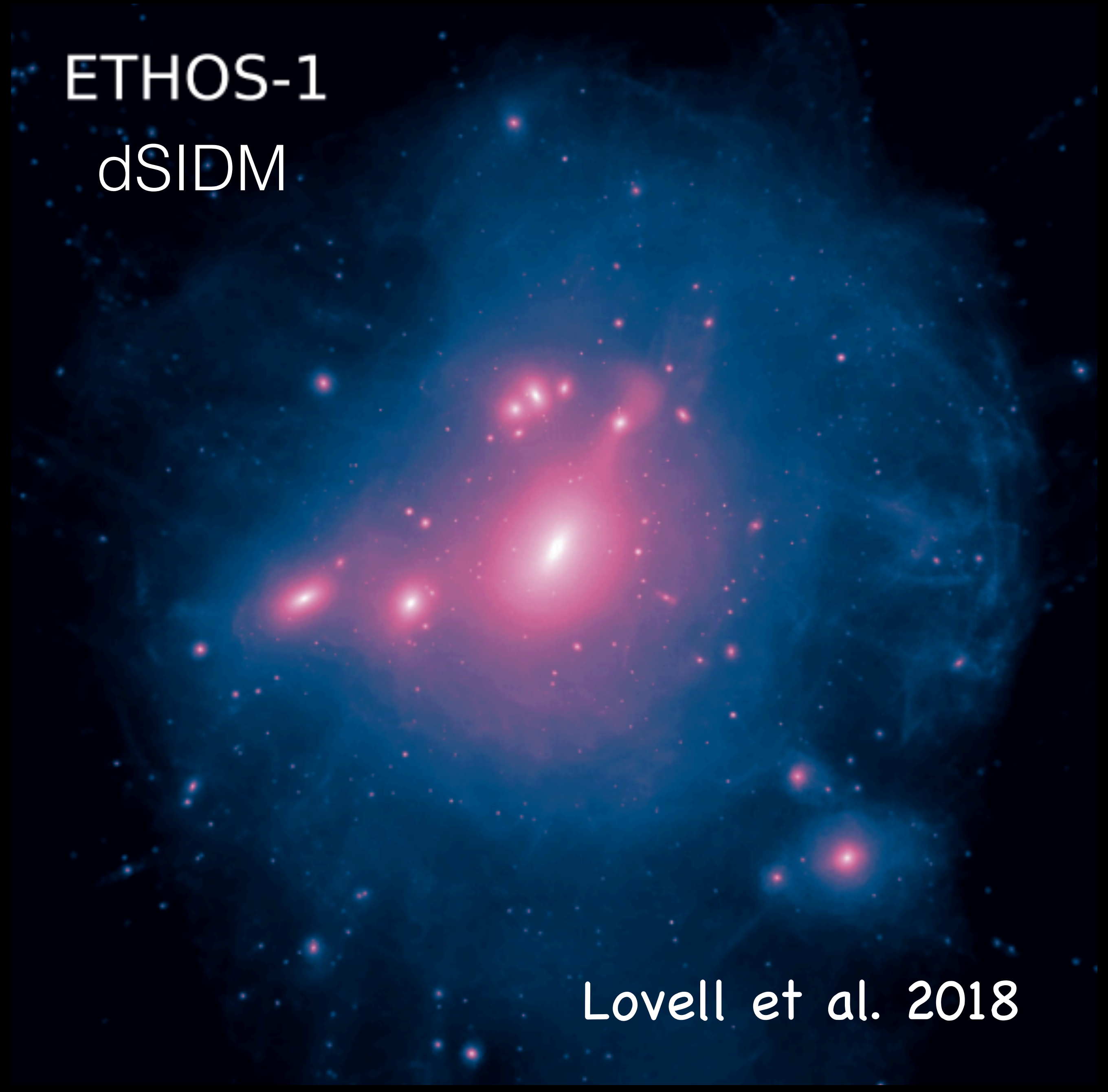
target: warm dark matter (WDM)/ dSIDM/ fuzzy dark matter (FDM)

Many dark matter models generate suppression on the power of fluctuation at small scales, e.g.

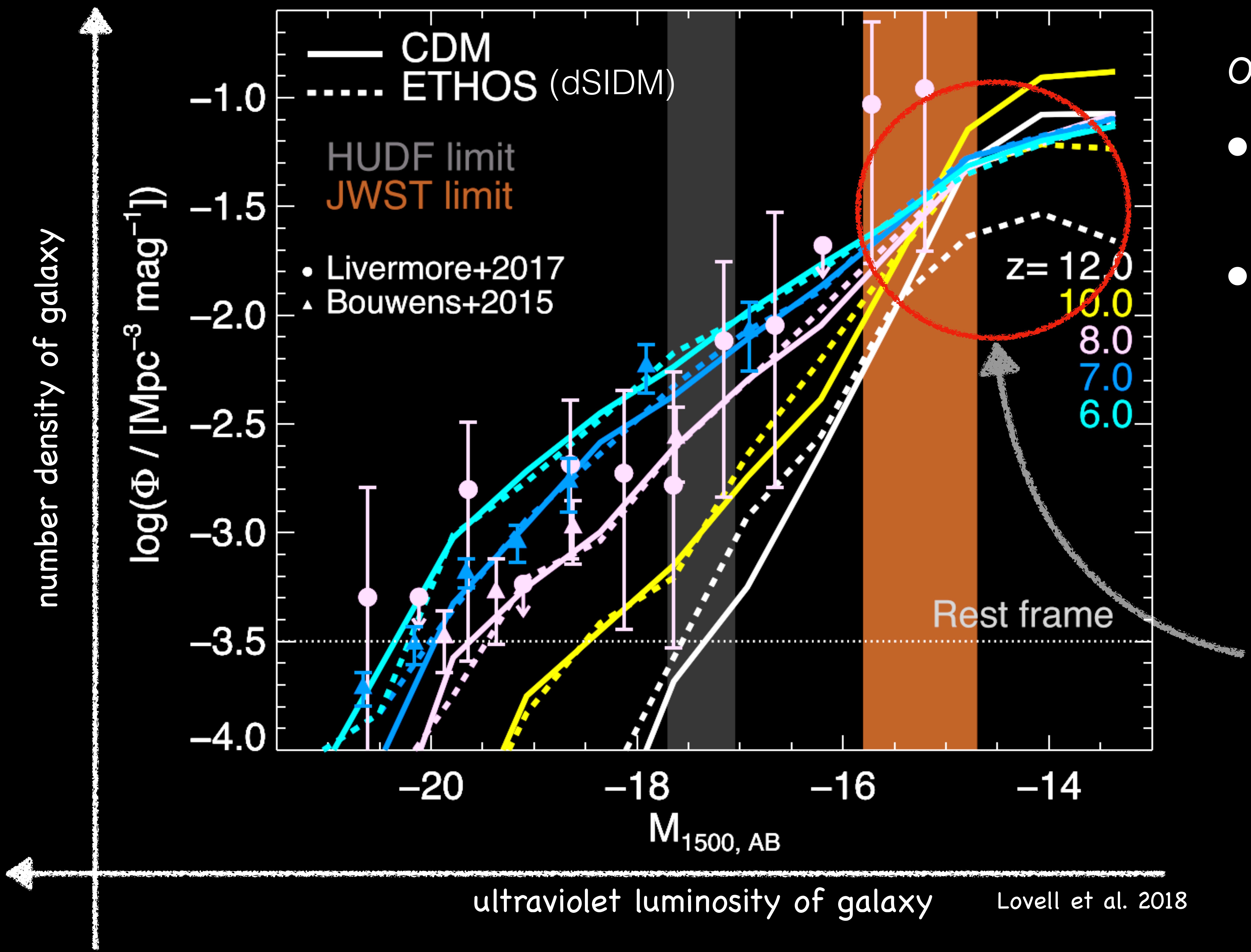
- WDM: relativistic motion of dark matter at early epochs
- dSIDM: imperfect coupling of dark matter with the mediator of interactions
- FDM: effective quantum pressure of ultralight particles



Decreased abundance of small haloes/ galaxies formed in the early Universe



Luminosity functions: abundance of galaxies versus luminosity of galaxies



Lovell et al. 2018

Observations:

- Hubble ultra deep field survey (HUDF)
- future observations with the James Webb Space Telescope (JWST)

We show that JWST can detect the cut-off at the faint-end of the luminosity function.

Thanks for your attention!