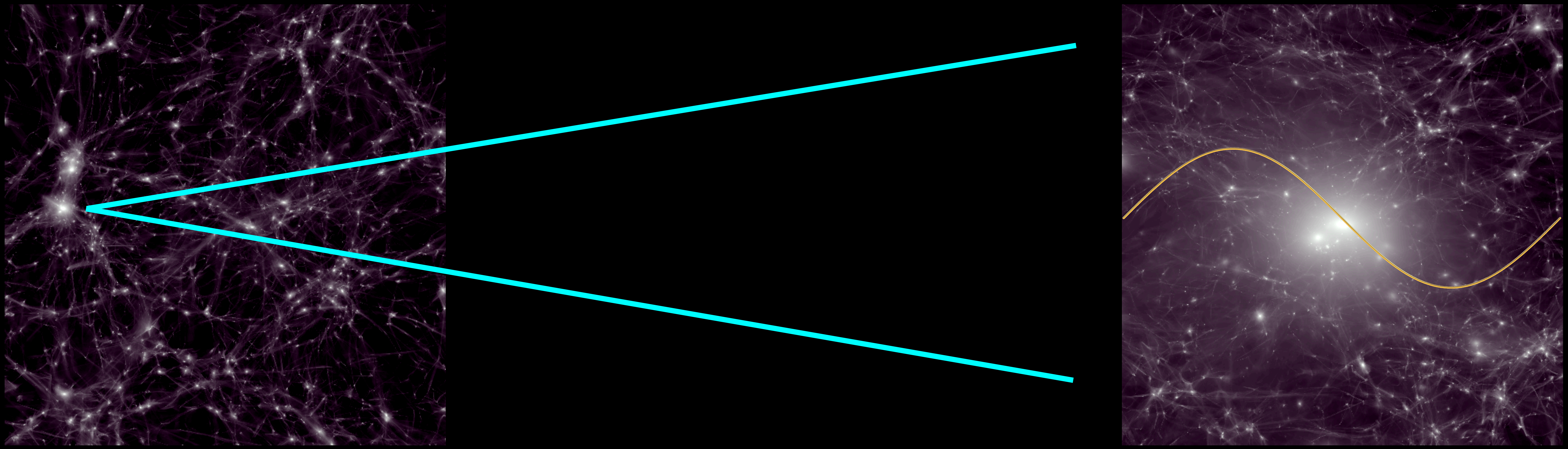
Near-field Cosmology and Ultra-light Axions



Ethan Nadler

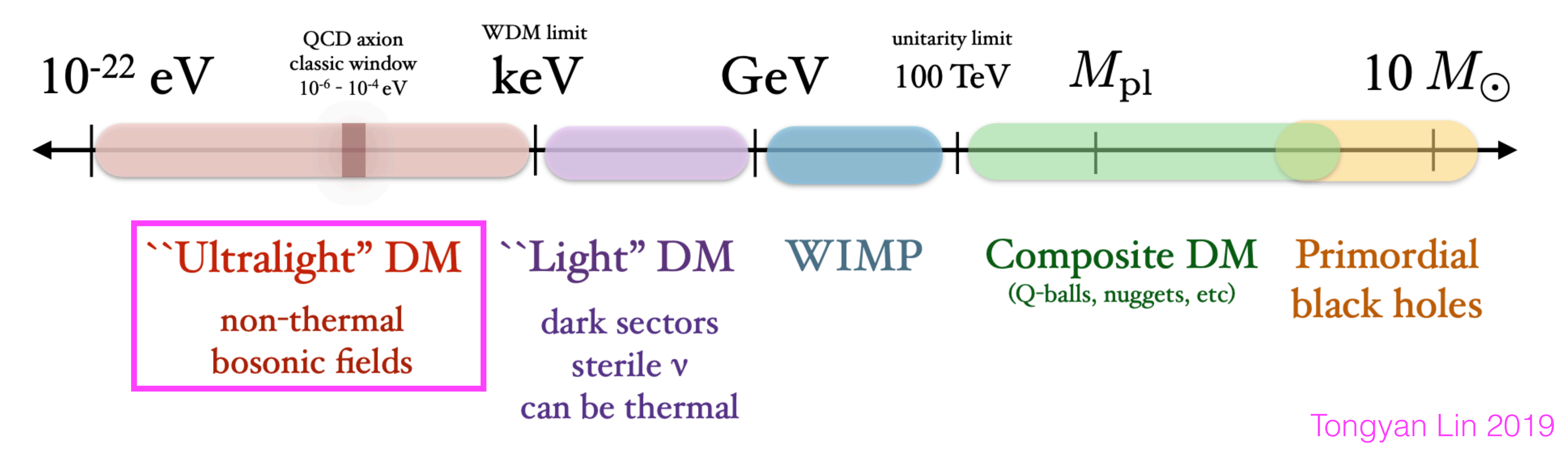
Snowmass CF02

10/20/2021

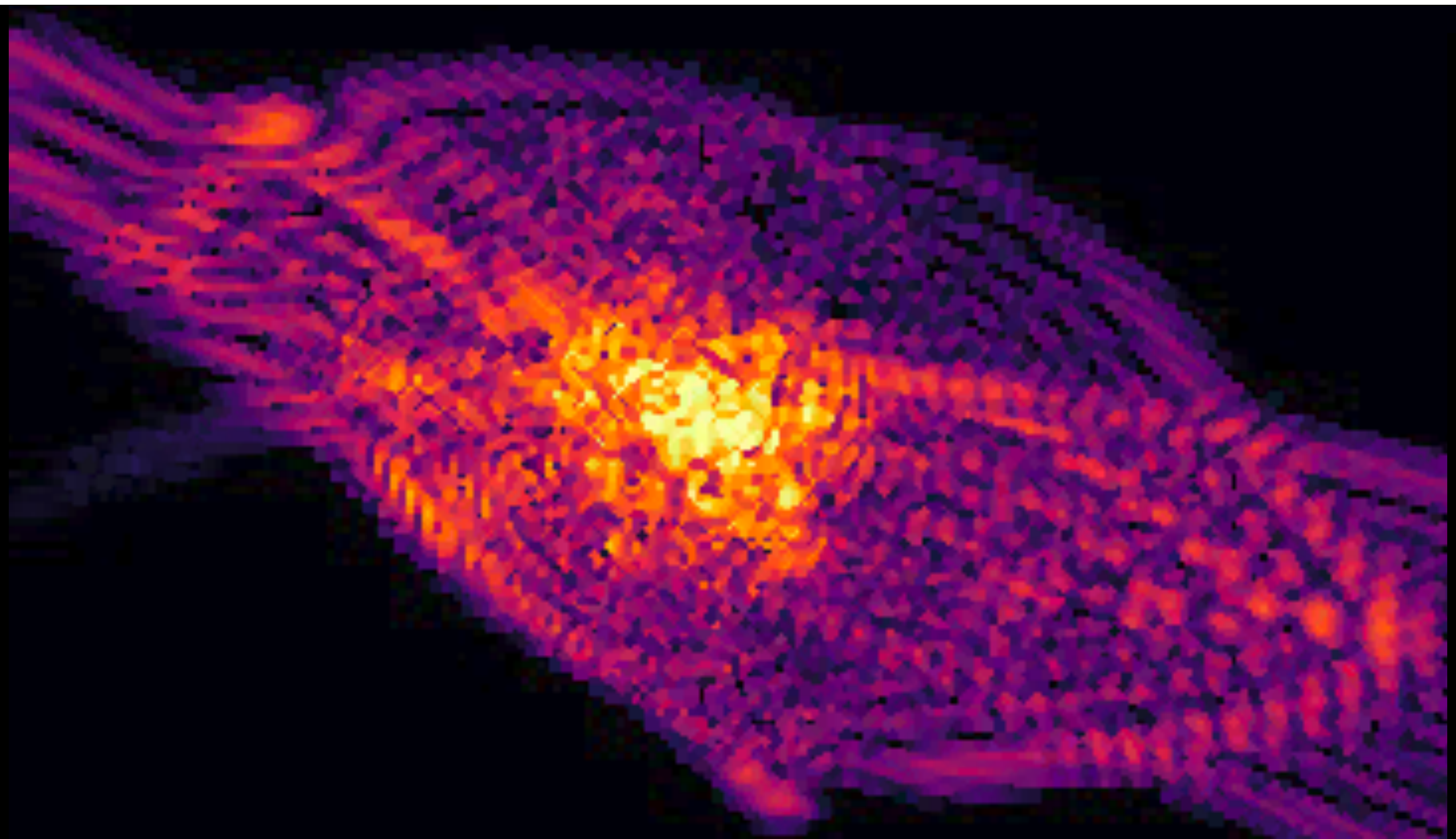
USC University of Southern California

Carnegie Science

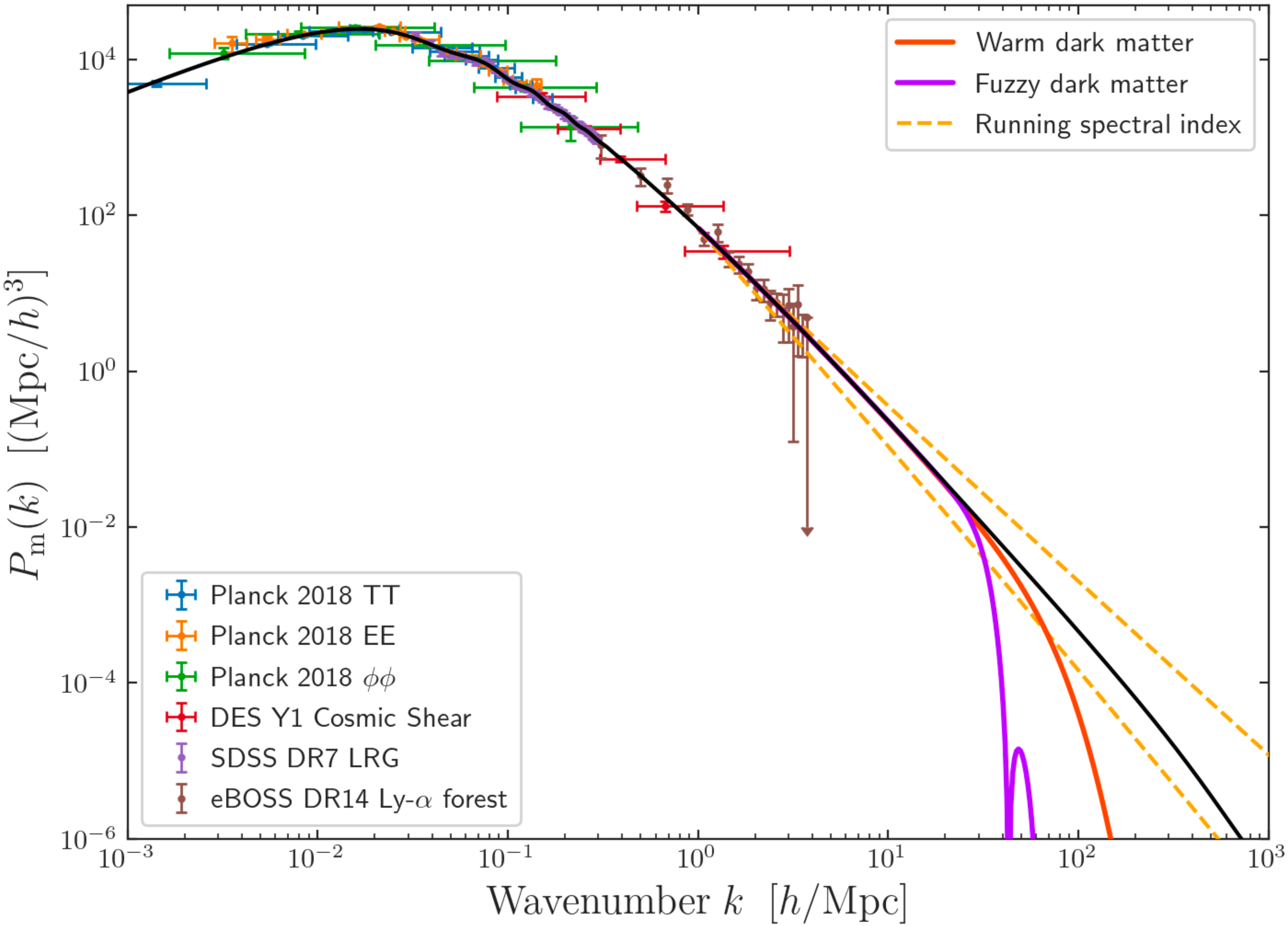
Structure Formation and Ultra-light Axions



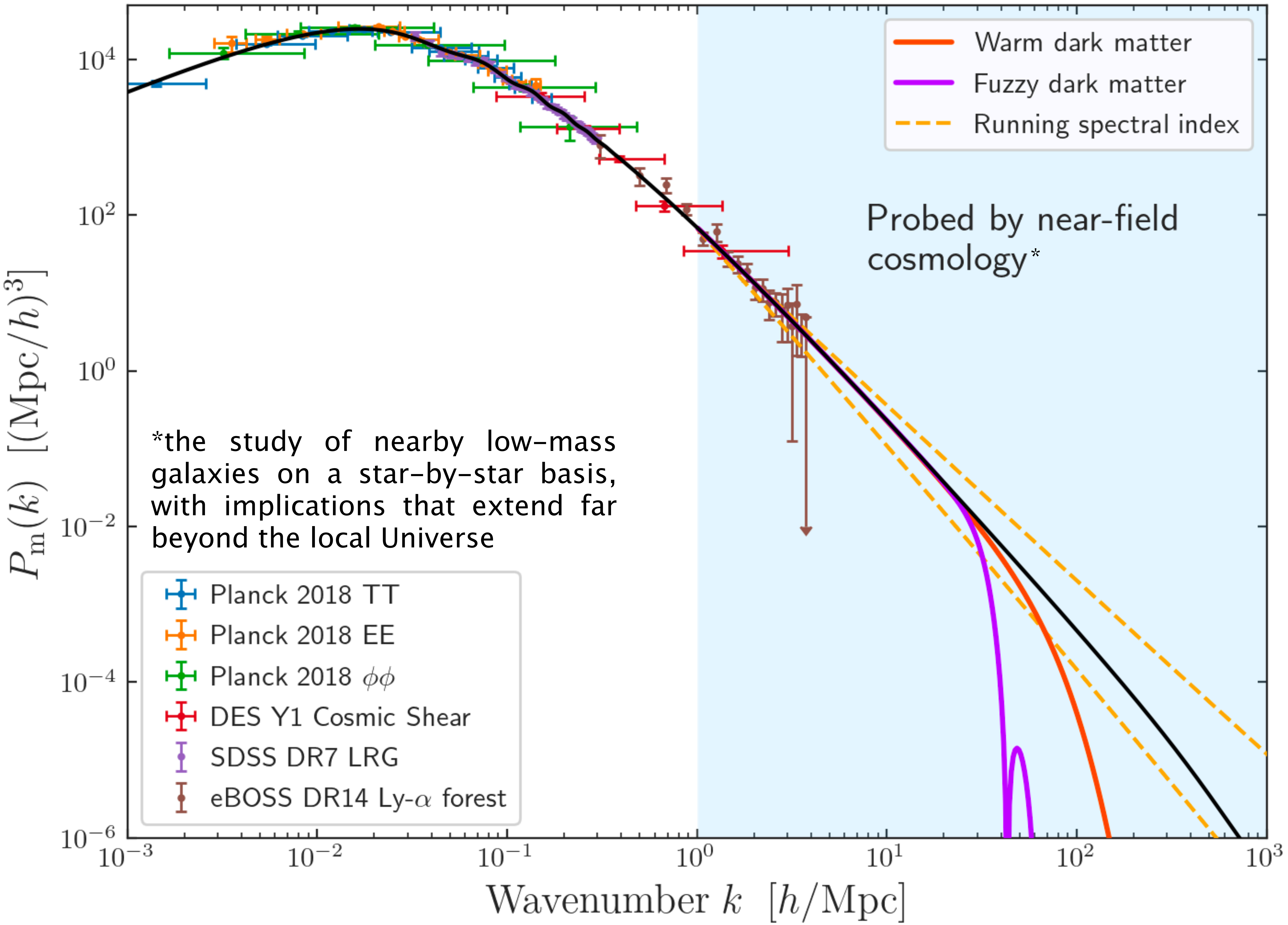
Tongyan Lin 2019



Mocz et al. 2019



Warm dark matter
Fuzzy dark matter
Running spectral index
Planck 2018 TT
Planck 2018 EE
Planck 2018 $\phi\phi$
DES Y1 Cosmic Shear
SDSS DR7 LRG
eBOSS DR14 Ly-α forest
$P_{\rm m}(k)$ $[({\rm Mpc}/h)^3]$
Wavenumber k $[h/{\rm Mpc}]$
10^{4}
10^{2}
10^{0}
10^{-2}
10^{-4}
10^{-6}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}



Warm dark matter
Fuzzy dark matter
Running spectral index
Probed by near-field cosmology*
*the study of nearby low-mass galaxies on a star-by-star basis, with implications that extend far beyond the local Universe
Planck 2018 TT
Planck 2018 EE
Planck 2018 $\phi\phi$
DES Y1 Cosmic Shear
SDSS DR7 LRG
eBOSS DR14 Ly-α forest
$P_m(k)$ $[(\mathrm{Mpc}/h)^3]$
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10^4
10^2
10^0
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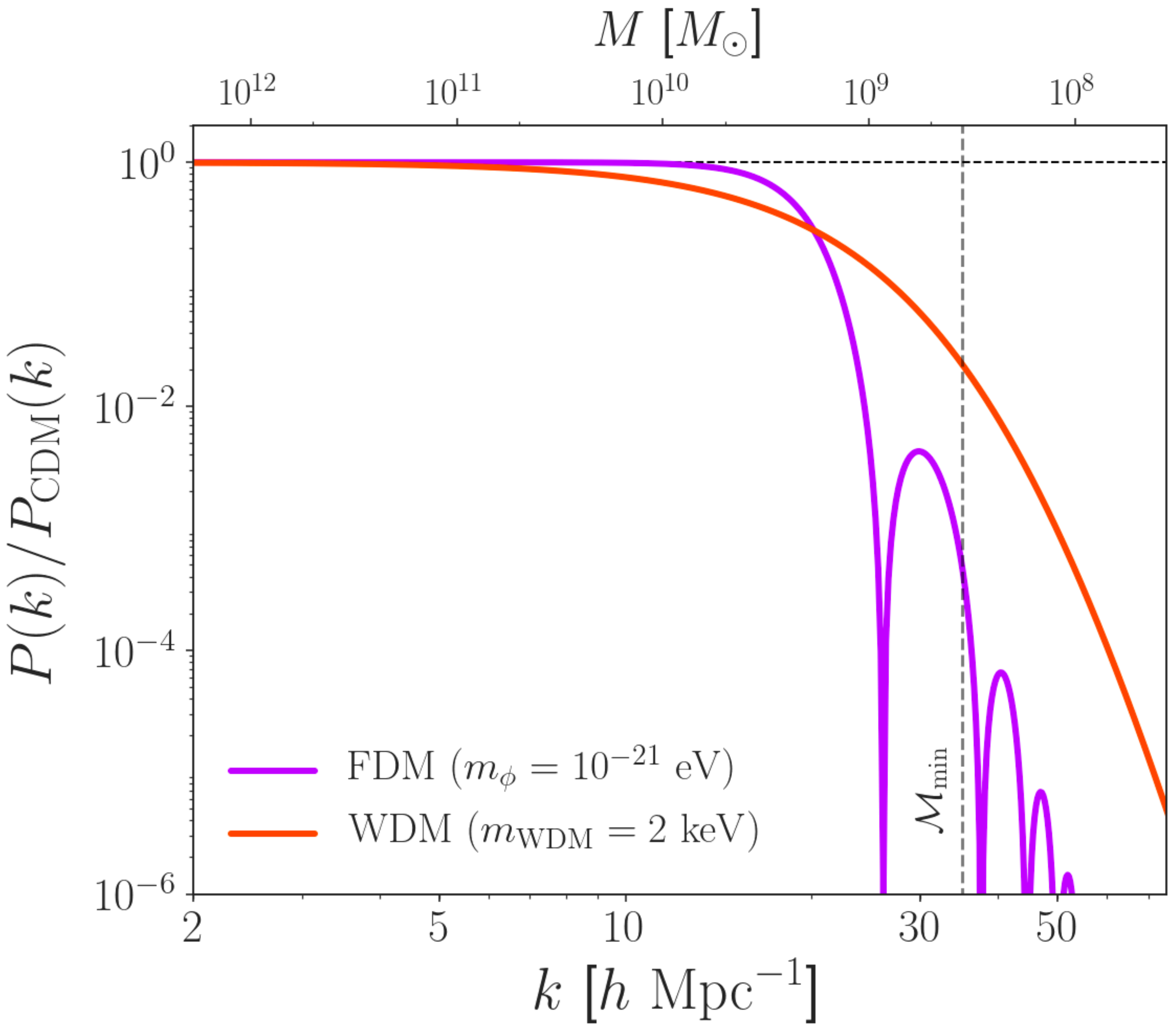
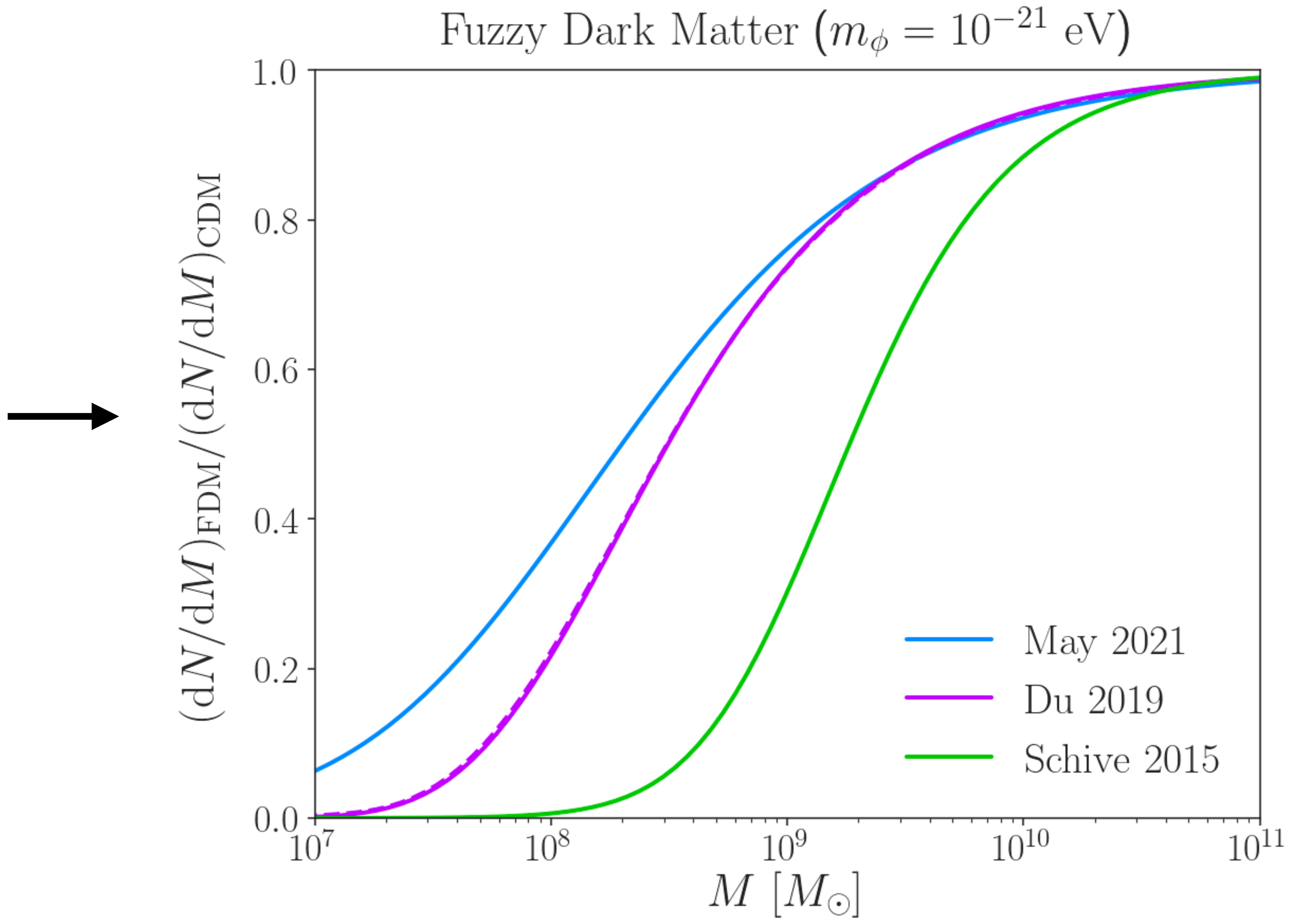
10^{-4}
10^{-6}
10^{-3}
10^{-2}
10^{-1}
10^0
10^1
10^2
10^3

Structure Formation for Ultra-light Axions





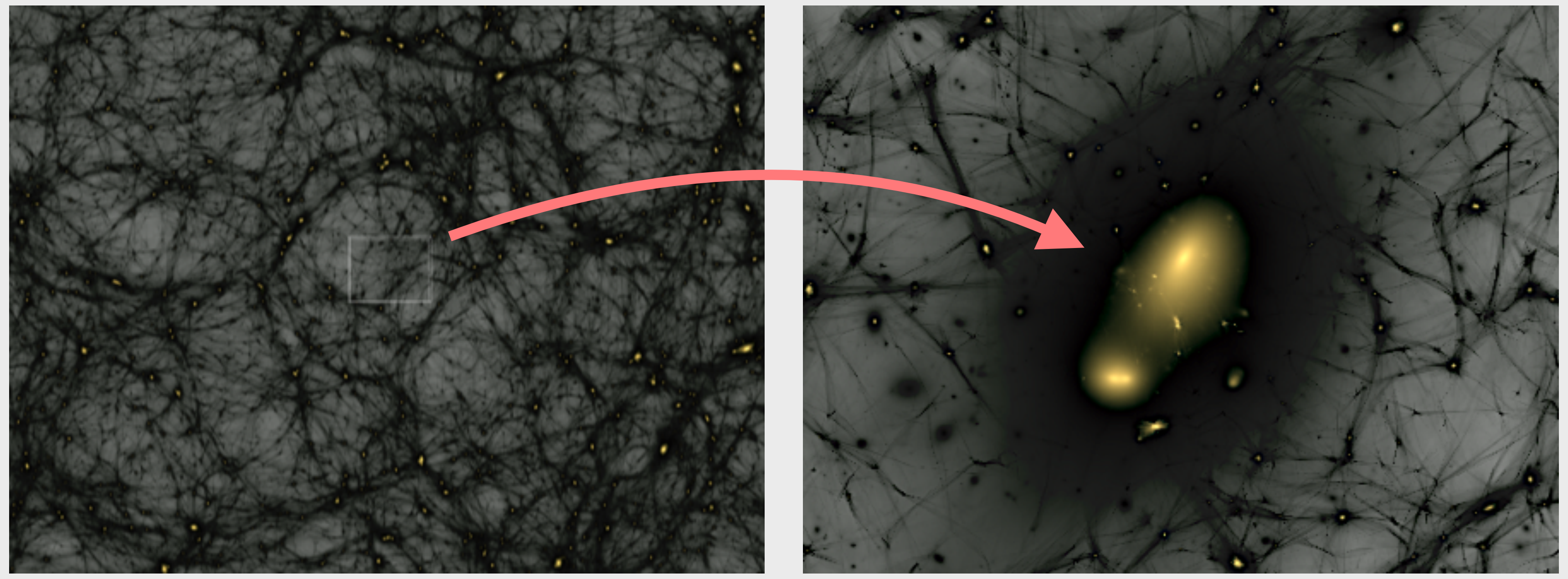
Ultra-light dark matter models can **severely suppress** low-mass halo abundances relative to CDM.

The Milky Way Satellite Population

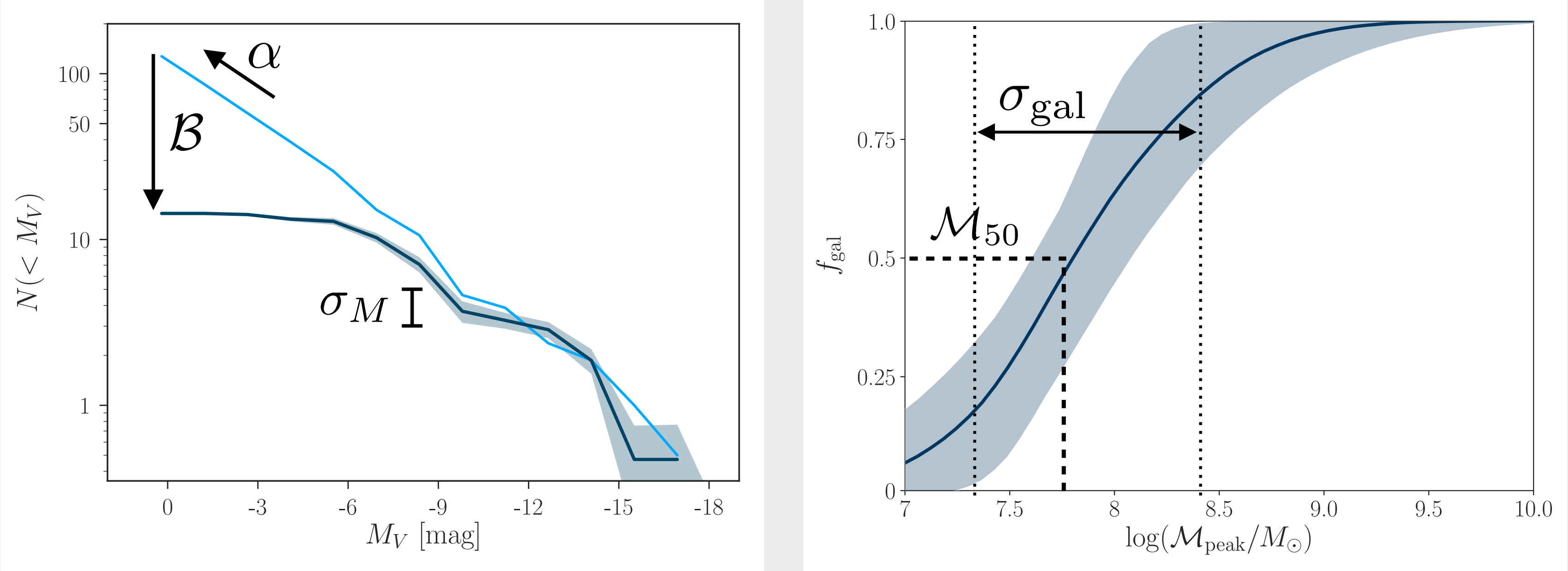
Drlica-Wagner & Bechtol et al. 2020

Markov Chain Monte Carlo

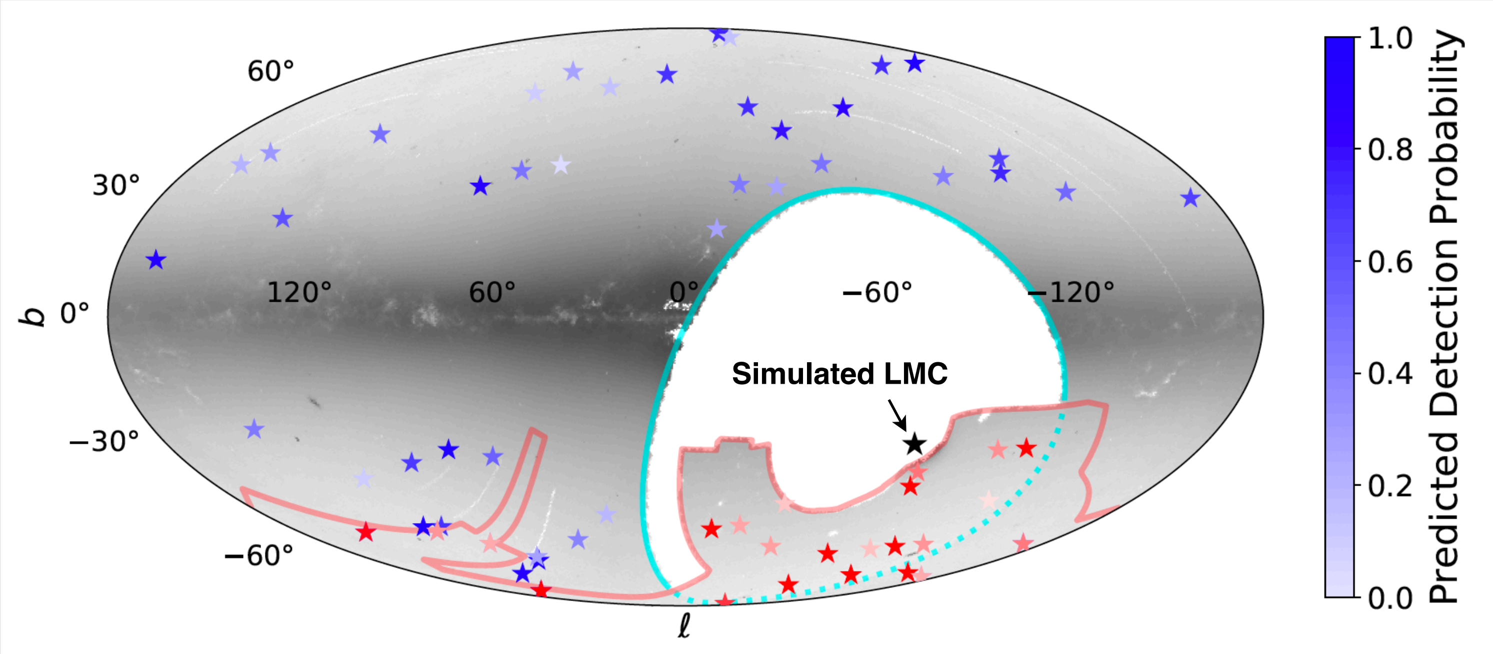
1. Resimulate Milky Way-like halos from large cosmological volume.



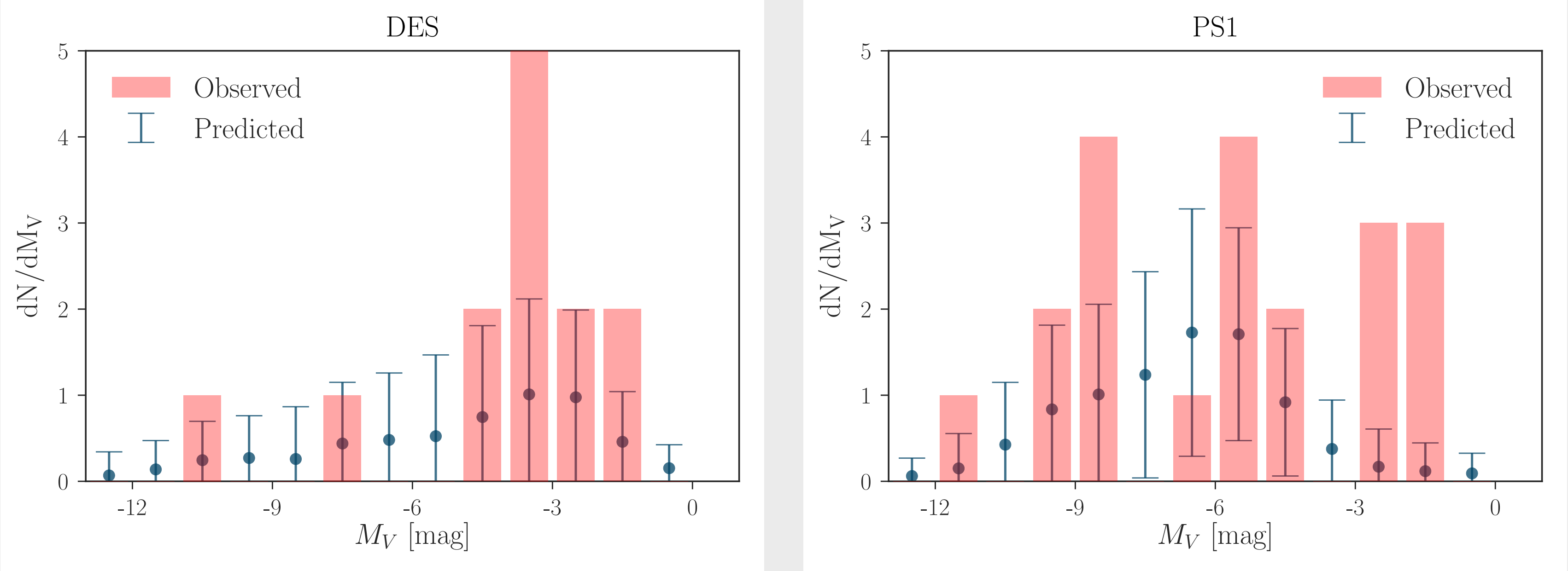
2. Paint satellite galaxies onto subhalos using galaxy—halo model.



3. Apply observational selection functions based on imaging data.



4. Calculate likelihood of observed satellites given galaxy—halo connection parameters.



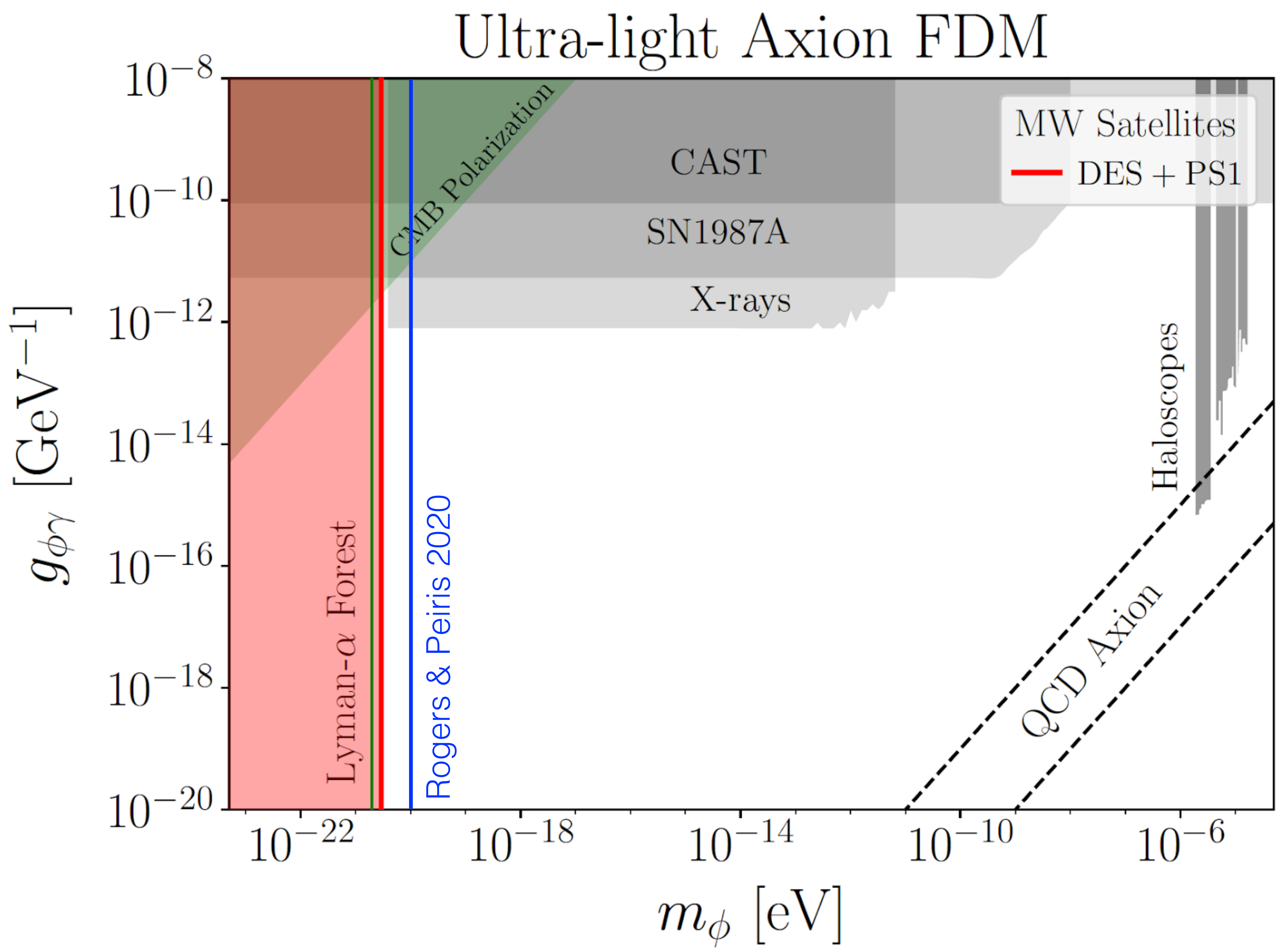
EN & Wechsler et al. 2020

Ultra-light Axion Constraints

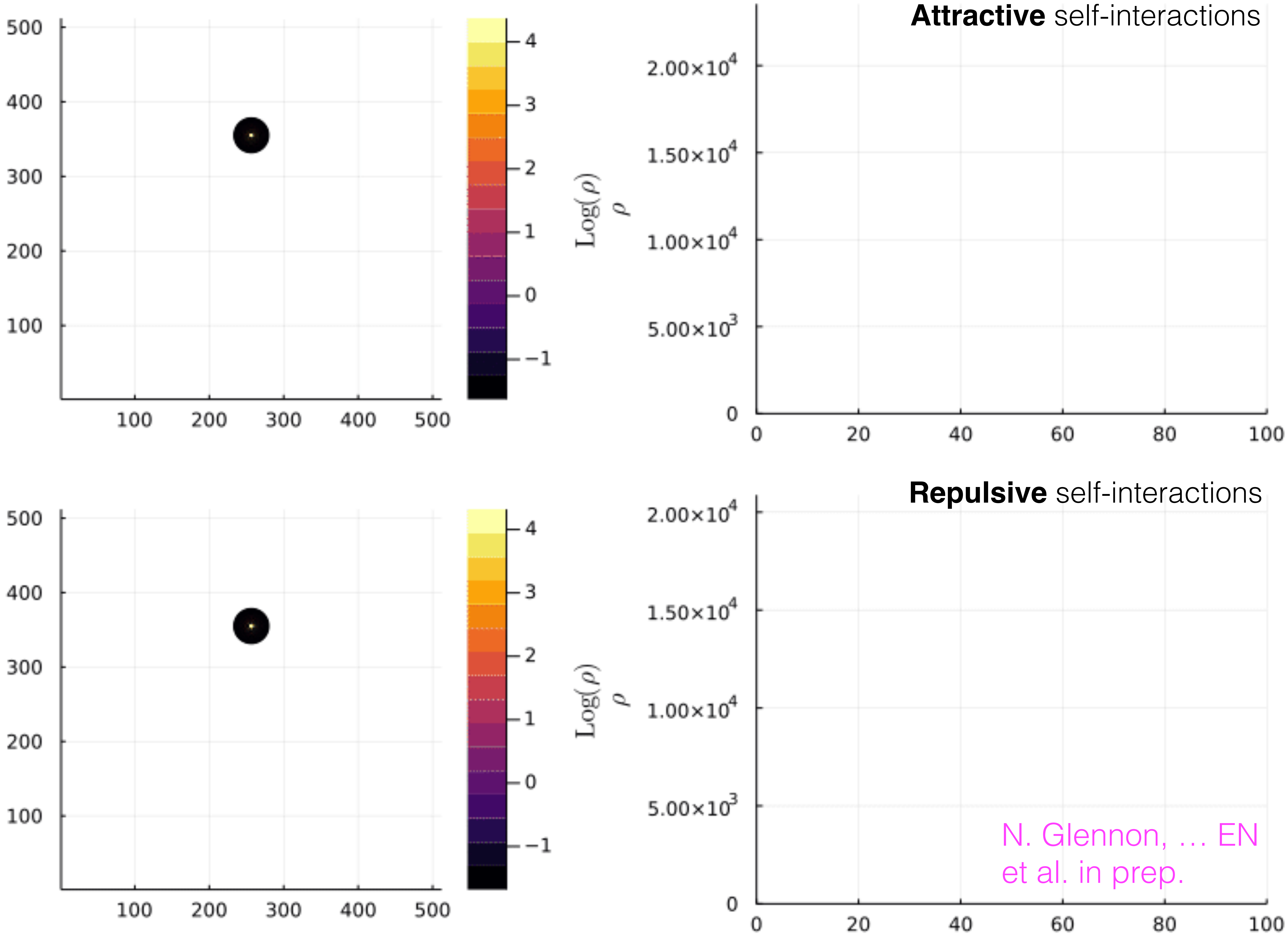
- Dark matter masses below **10^{-21} eV** are in tension with MW satellite abundances

- ULA models that create kpc-scale cores in dwarf galaxies are strongly disfavored

- Future facilities including the Vera C. Rubin Observatory will significantly improve near-field sensitivity to ultra-light DM



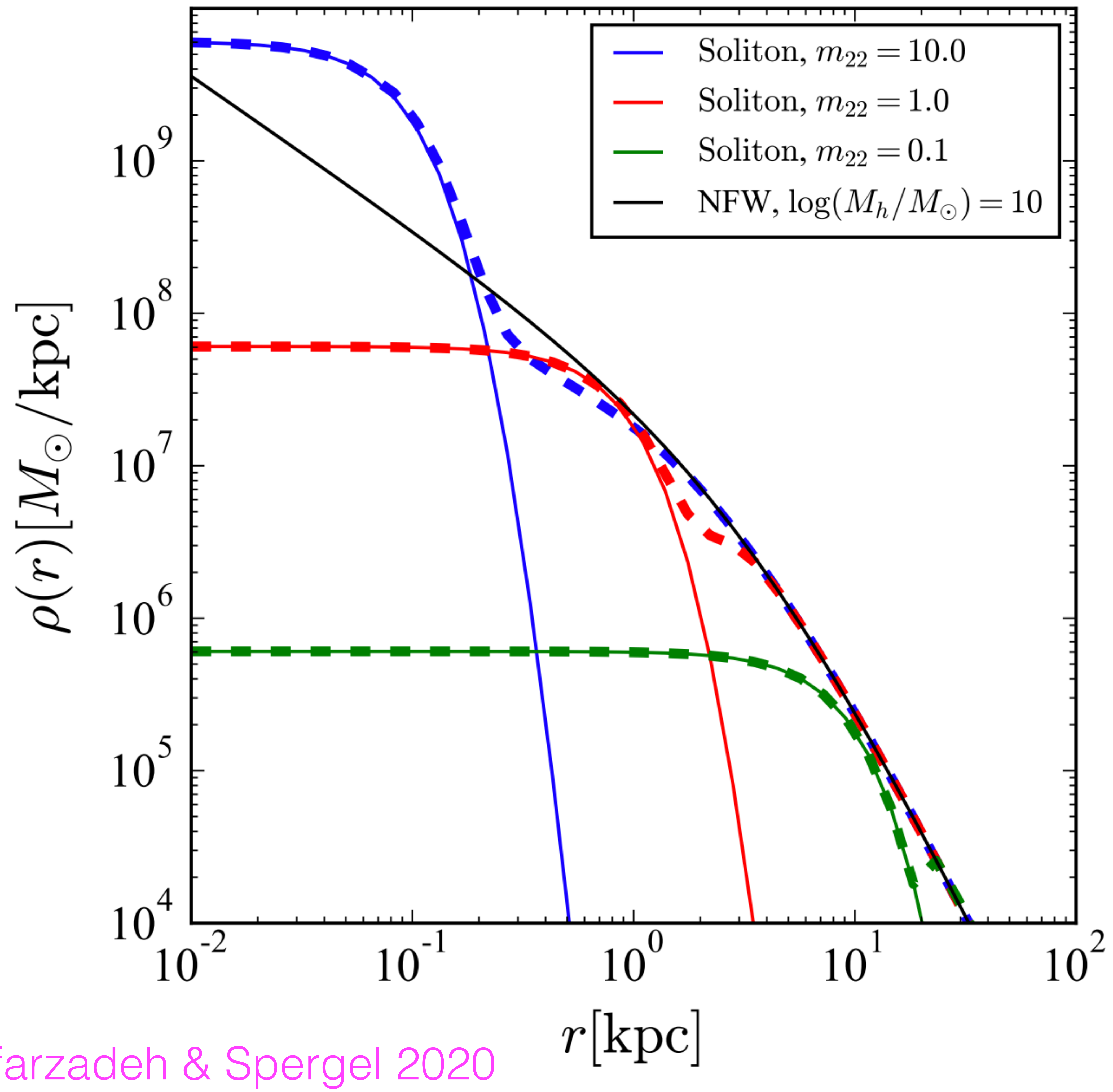
EN & Drlica-Wagner et al. 2020



Current predictions for soliton evolution within host halos **do not include** axion self-interactions.

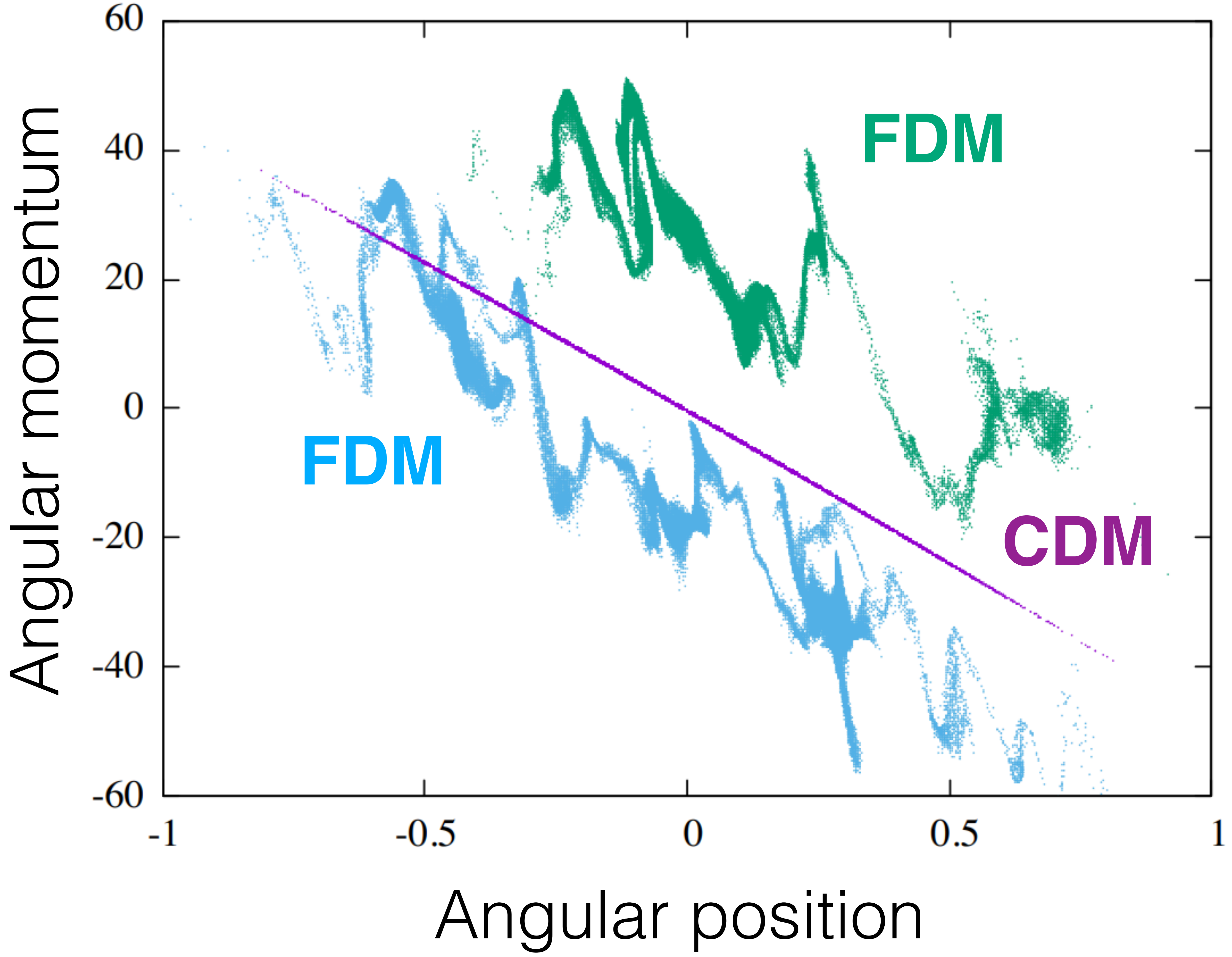
Other Near-field and Low-Redshift Probes

Dwarf galaxy density profiles



Safarzadeh & Spergel 2020

Stellar stream perturbations

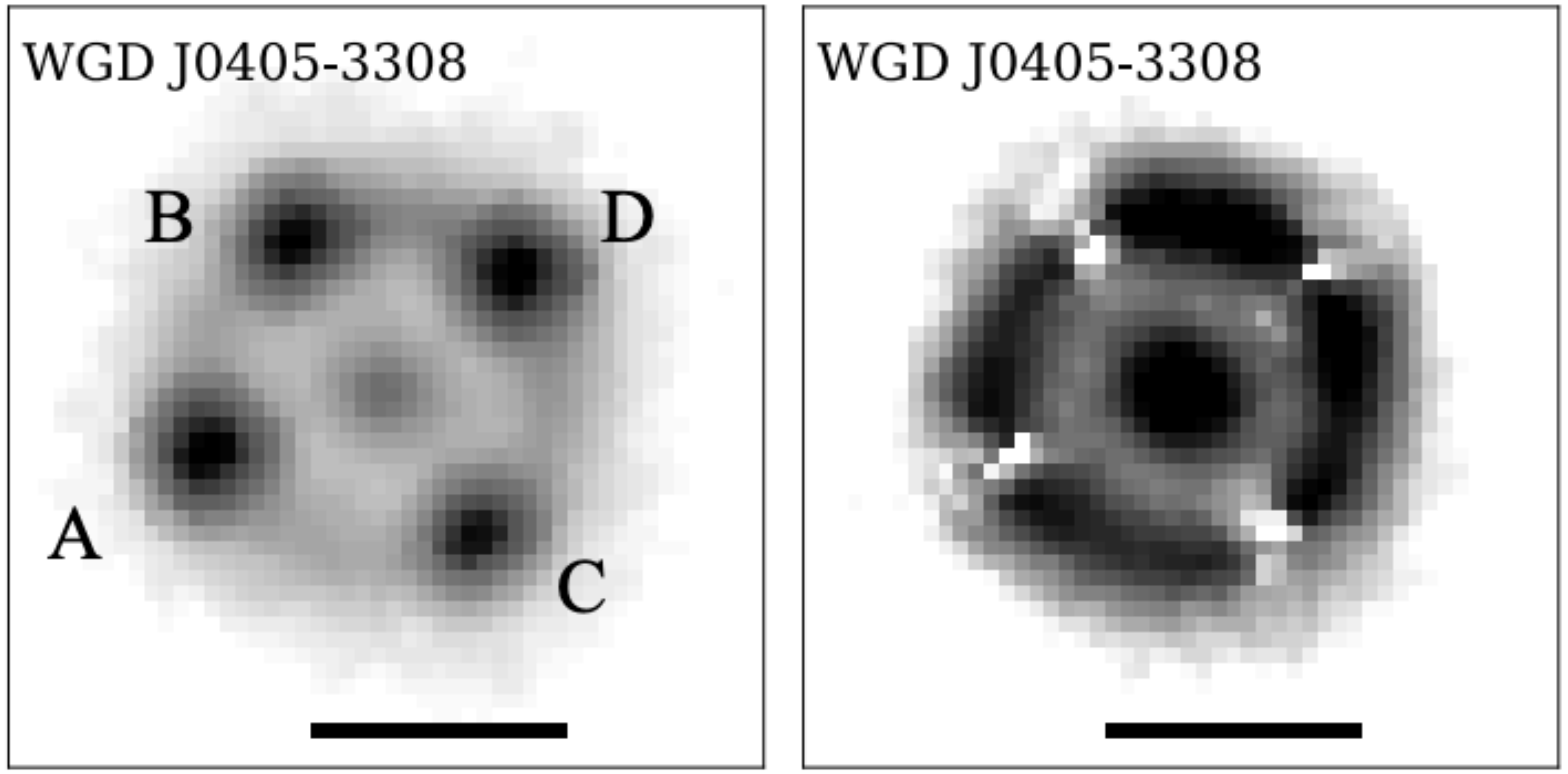


Dalal et al. 2021

Other Near-field and Low-Redshift Probes

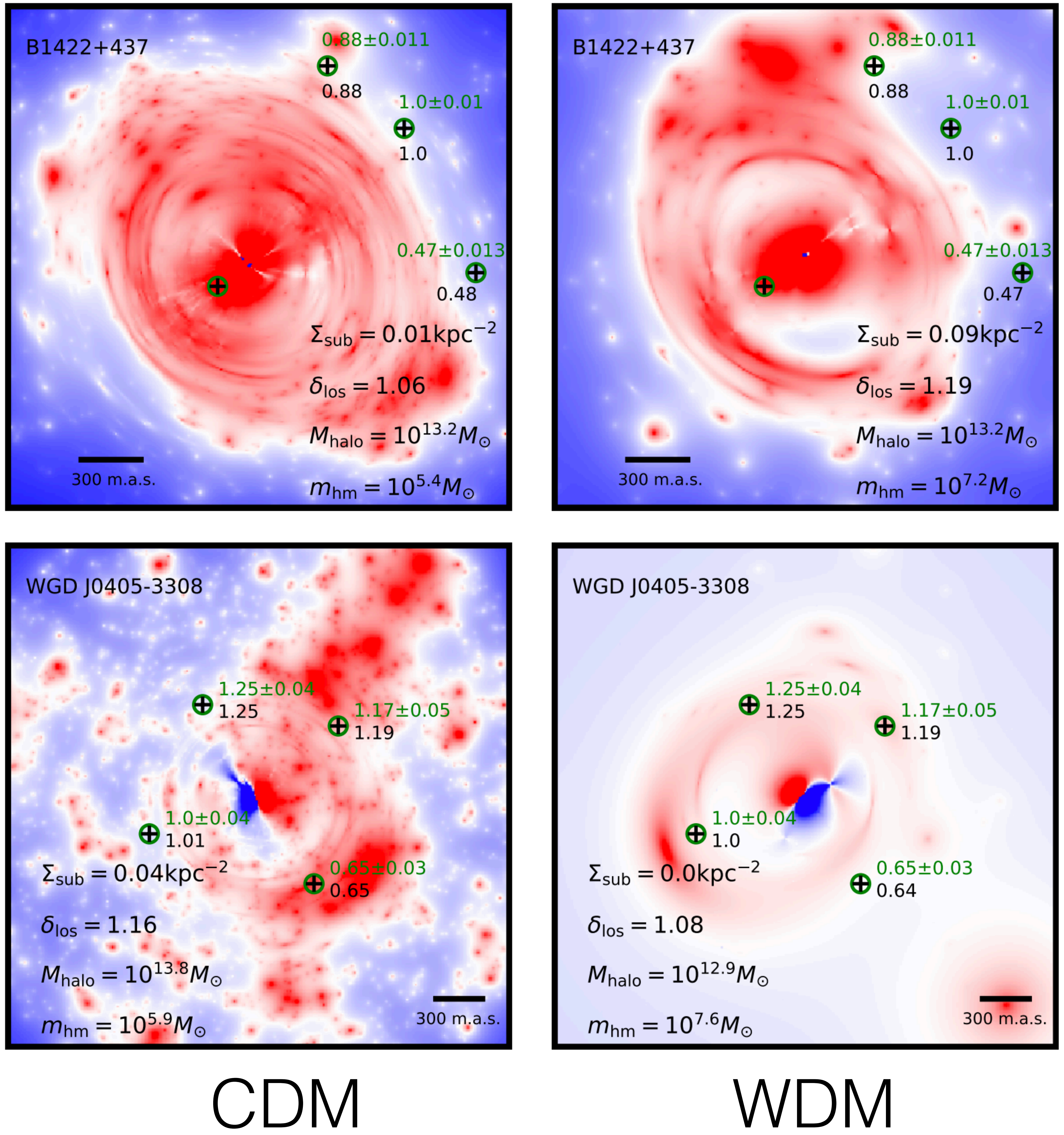
- **Strong lensing** probes the abundance and density profiles of low-mass halos within the lens and along the line of sight

- Recent flux ratio analyses use ~10 strong lenses: this number will increase soon!



Nierenberg et al. 2019

Gilman et al. 2020



CF03. Dark Matter: Cosmic Probes

- Covers uniquely astrophysical probes of dark matter, including via its impact on the structure and dynamics of galaxies, and through its interactions with astrophysical objects

- "If the dark matter or its direct products hit detectors on/around Earth, it's CF01/CF02; otherwise, it's CF03."

White papers of interest

- Dark matter physics from halo measurements: Google doc, Slack channel

- Dark Matter Facilities: Google doc, Slack channel

- Numerical simulations and systematics: Google doc, Slack channel

Outlook

- Near-field cosmological observables, including dwarf galaxy abundances and dynamics, are **sensitive probes** of ultra-light dark matter

- Constraints on ultra-light axions will **continue to improve** with future facilities including the Vera C. Rubin Observatory

- Dark matter masses below **10^{-21} eV** are in significant tension with the data; more detailed simulations including axion self-interactions are needed

- Other near-field and low-redshift probes including **stellar streams** and **strong lensing** provide complementary sensitivity to ULAs