SEARCHING FOR THE FUNDAMENTAL NATURE OF DARK MATTER IN THE COSMIC LARGE-SCALE STRUCTURE

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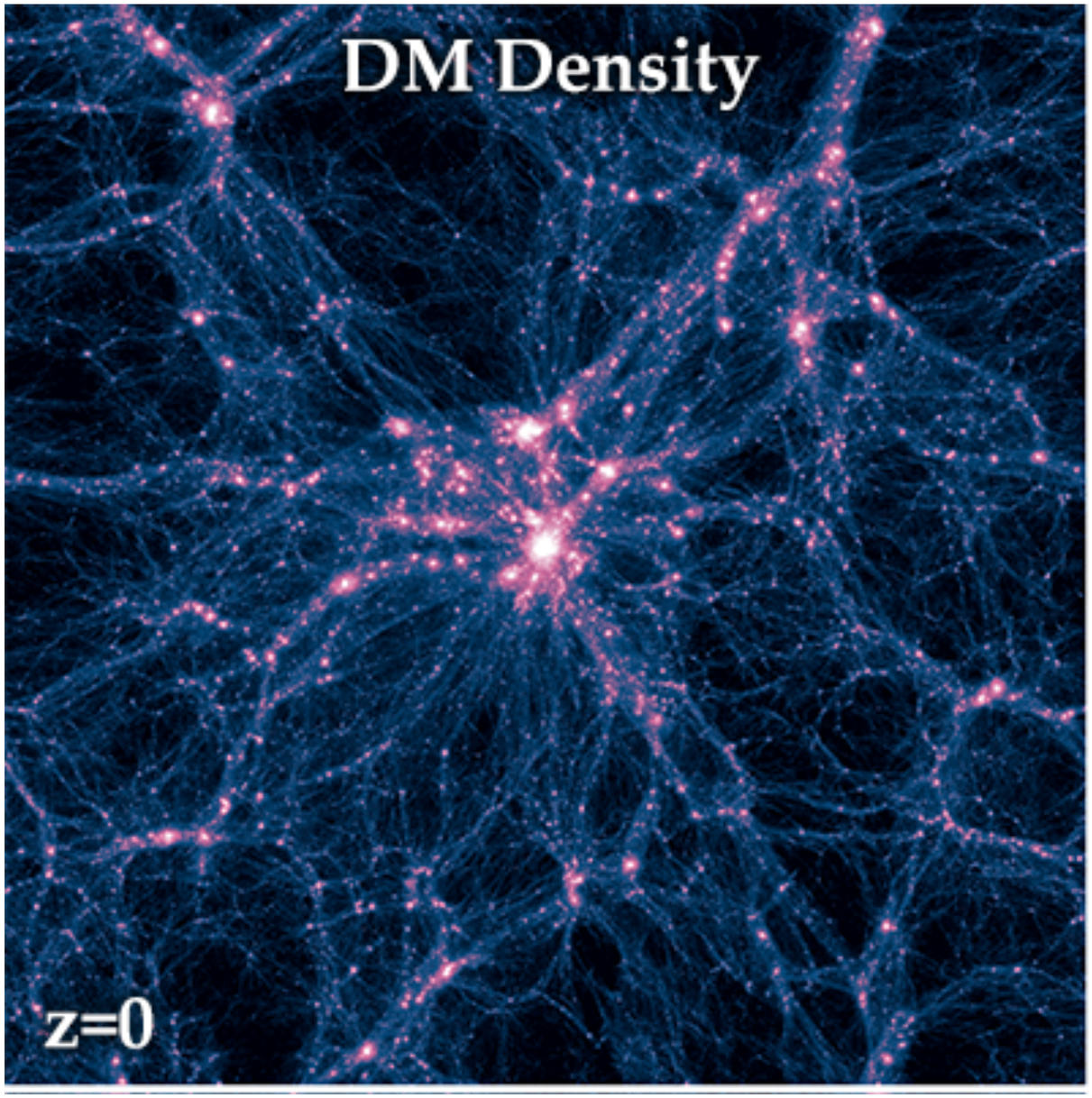
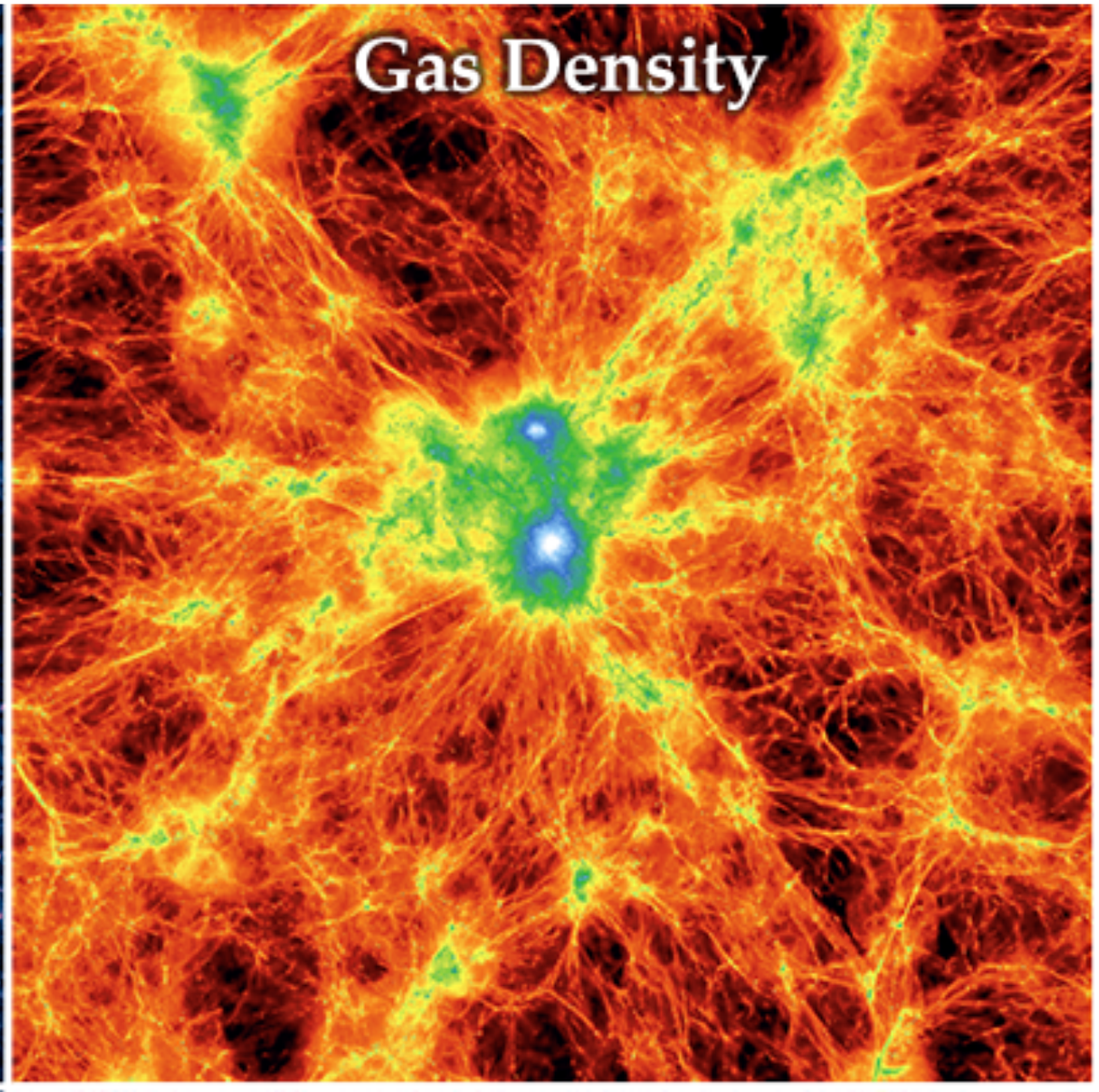
Find dark matter by only known interaction — gravity
— trace dark matter by galaxies & intergalactic gas





Illustris simulation

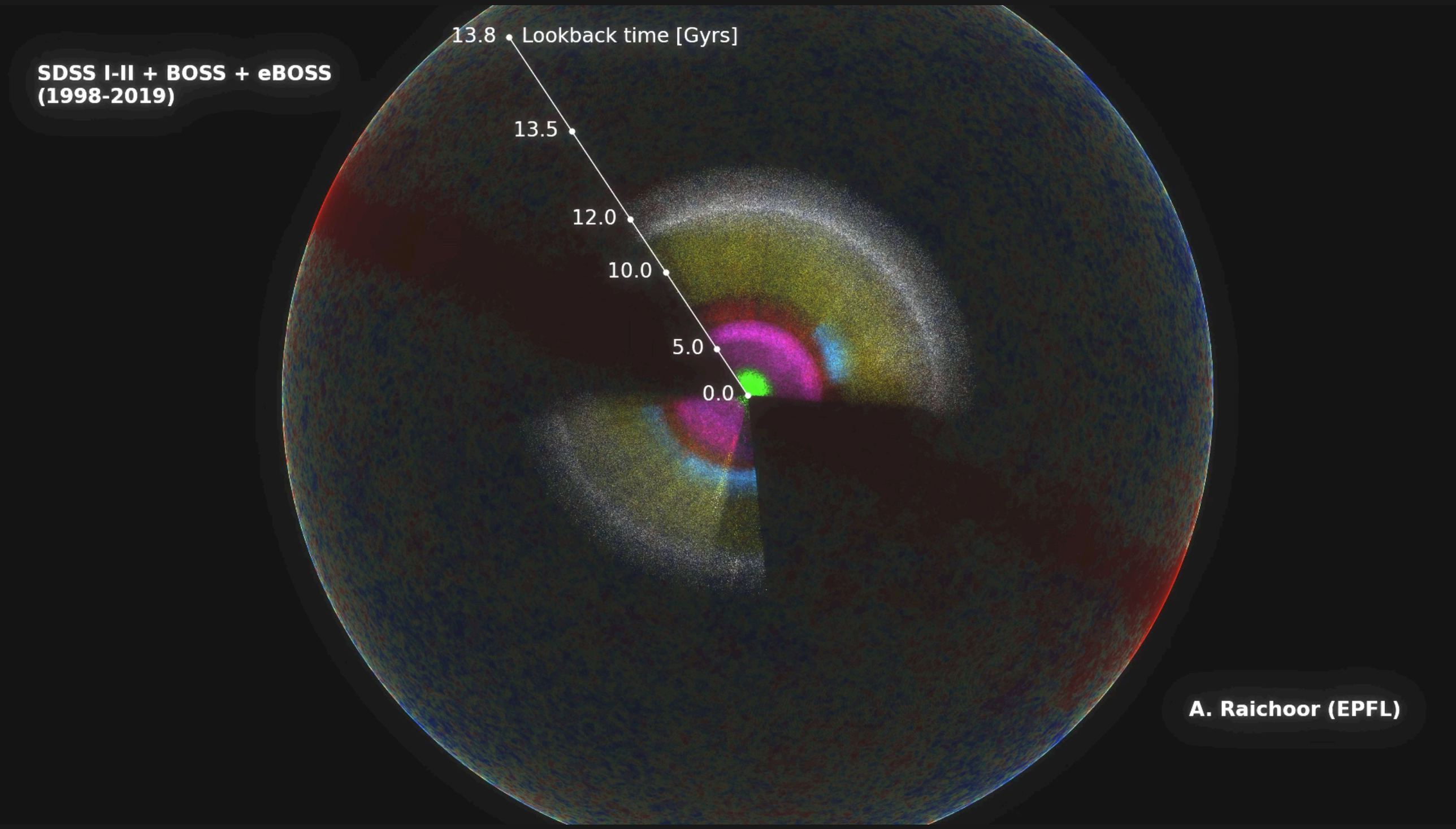
Early galaxy surveys ruled out hot dark matter

Hot dark matter simulation

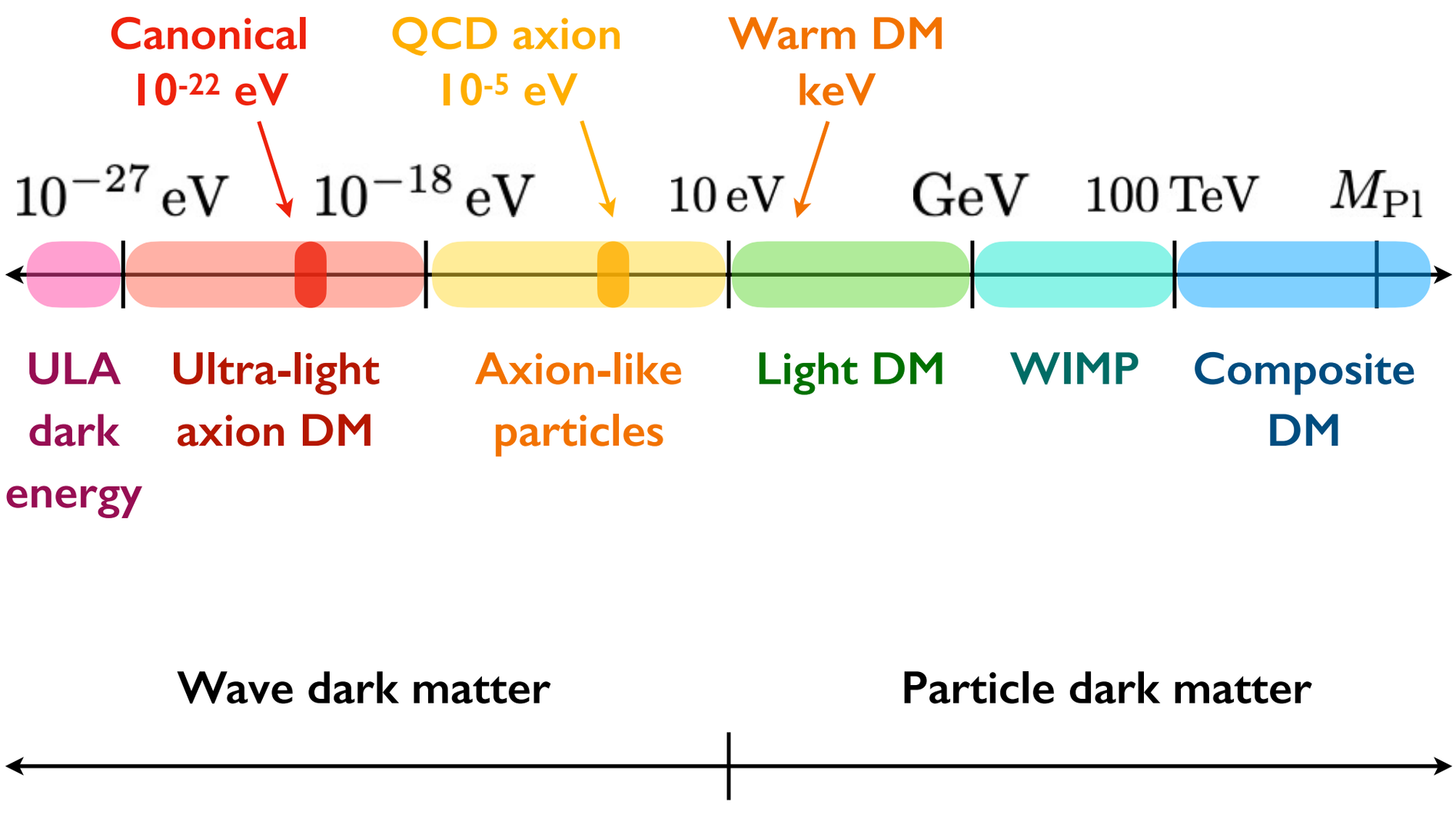
Cold dark matter simulation

White (1986)

Sloan Digital Sky Survey maps galaxies and intergalactic gas towards edge of observable Universe



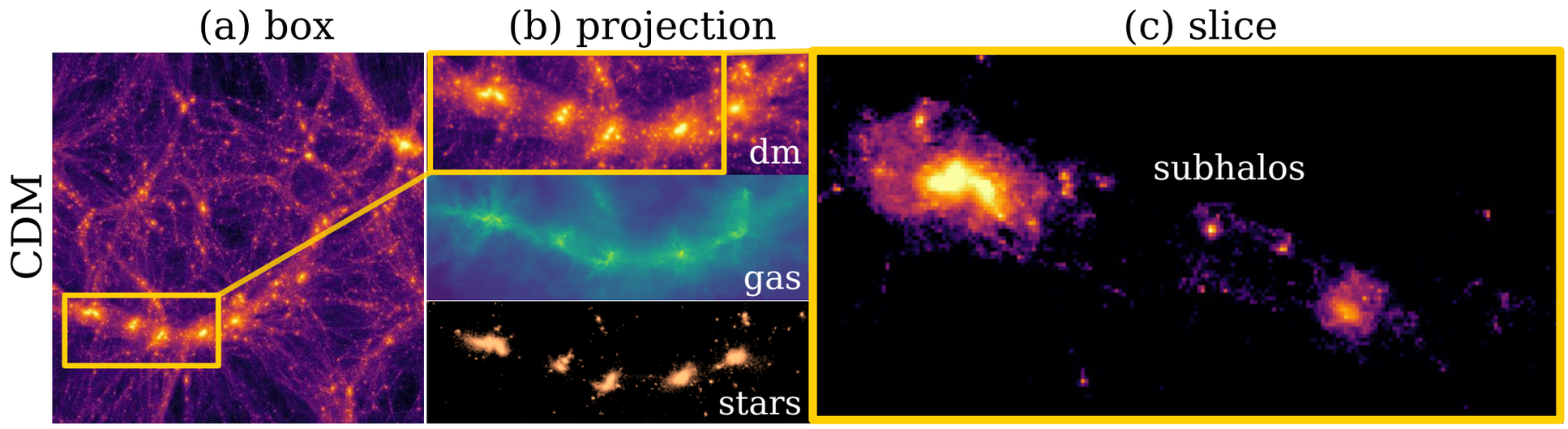
Beyond the WIMP: dark matter model space



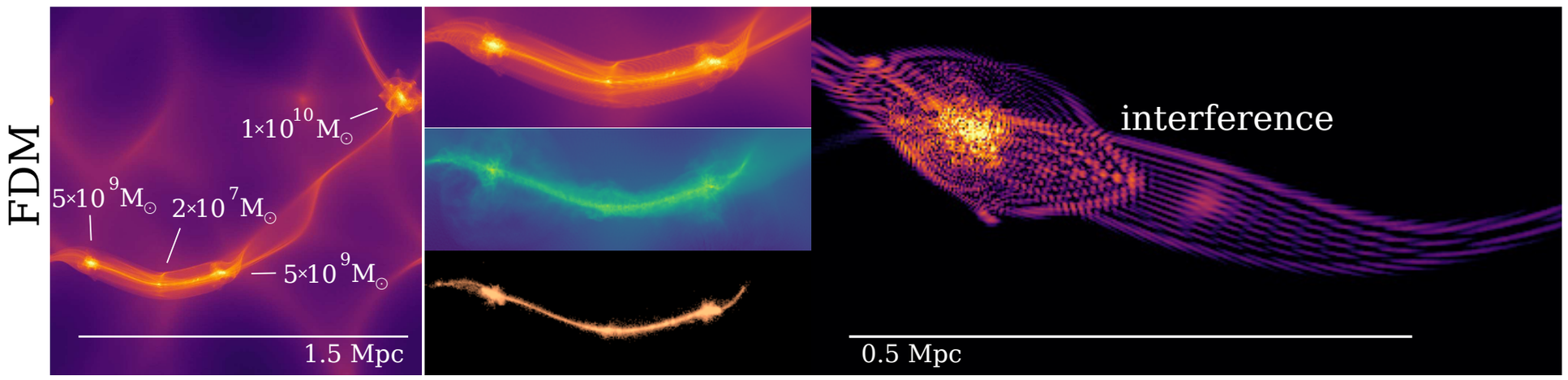
Canonical ULA DM: Rogers & Peiris (2021, PRL); *Light particle DM*: Rogers et al. (2022, PRL)

Wave vs particle dark matter

Cold (massive particle) DM

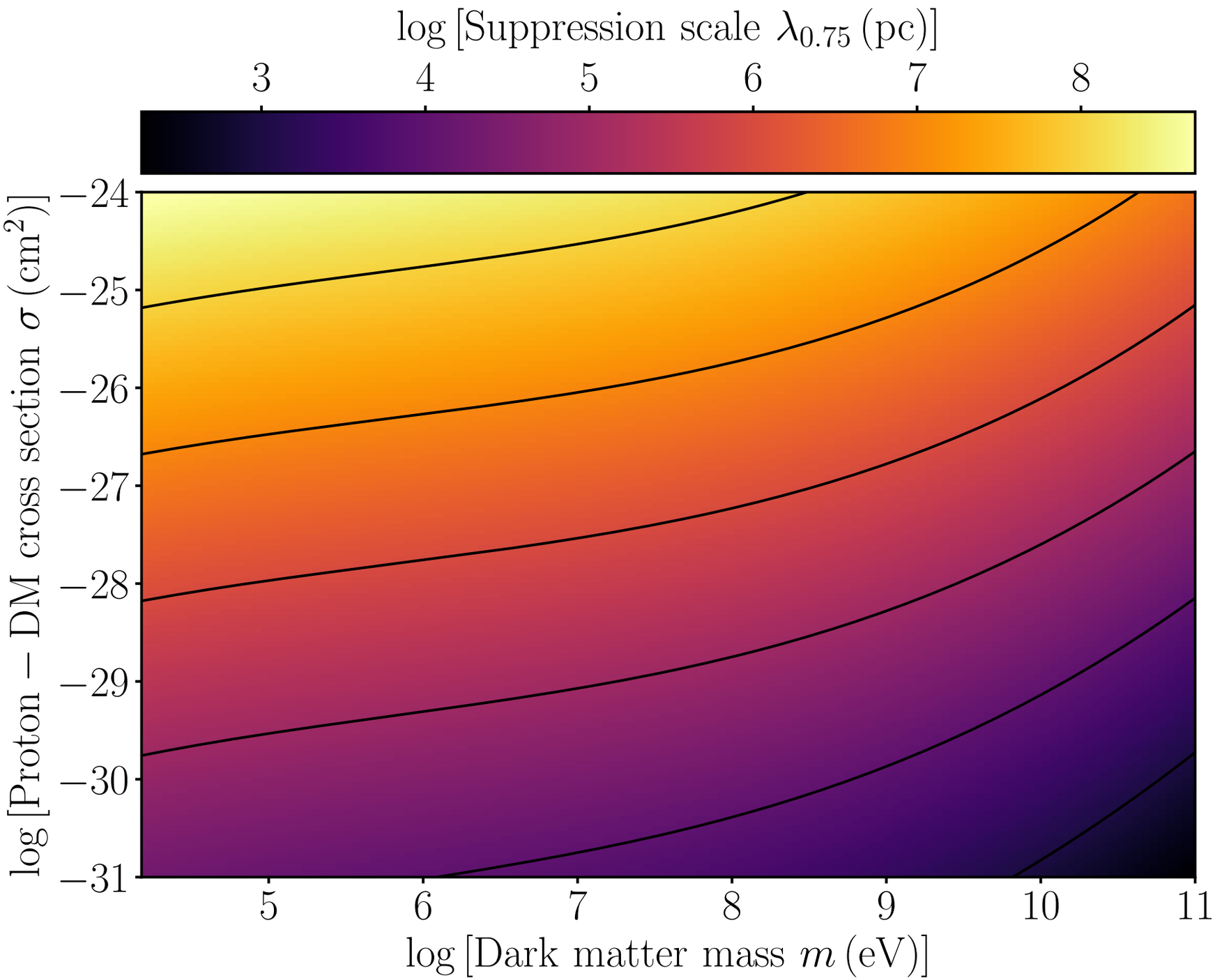


Fuzzy (wave) DM ($m < 10^{-18}$ eV)



Mocz et al. (2019)

Light (sub-GeV) particle DM collisionally dampens growth of small-scale structure

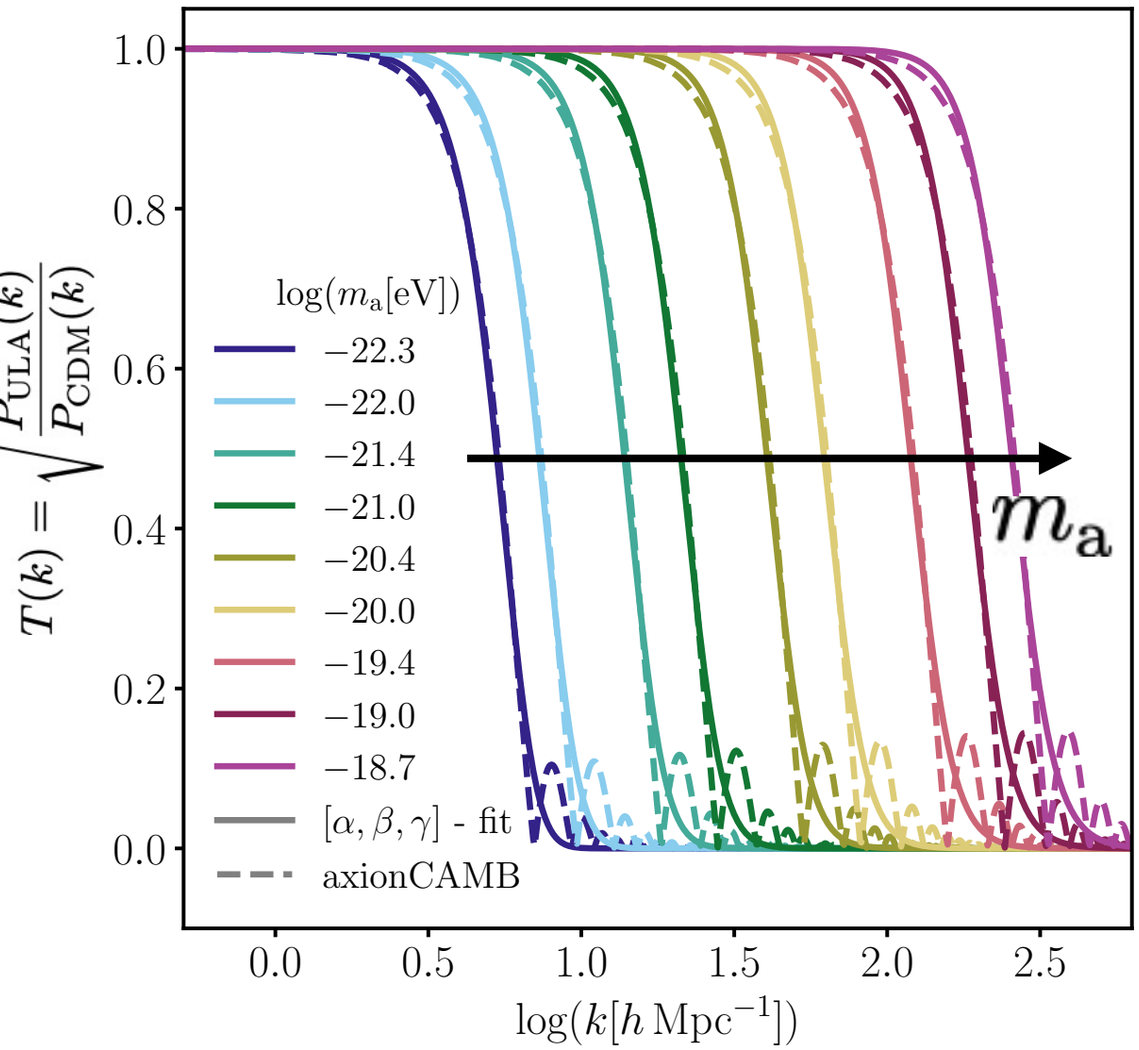


Chen et al. (2002); Dvorkin et al. (2014); Rogers et al. (2022, Phys. Rev. Lett.)

Access smaller cosmic scales
to test "canonical" 10^{-22} - 10^{-21} eV ULA dark matter

$$k_{\frac{1}{2}} \propto m_{\rm a}^{\frac{4}{9}}$$

Hu et al. (2000)



- Ly-alpha forest traces linear, high-redshift ($z \sim 5$), small-scale density perturbations

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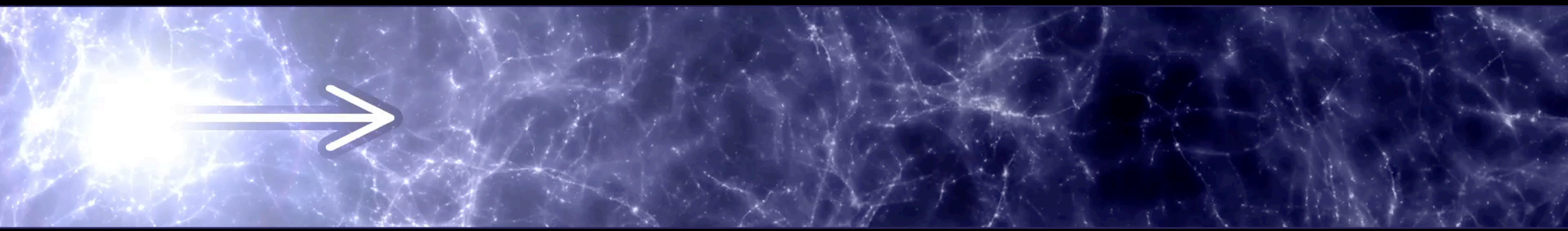
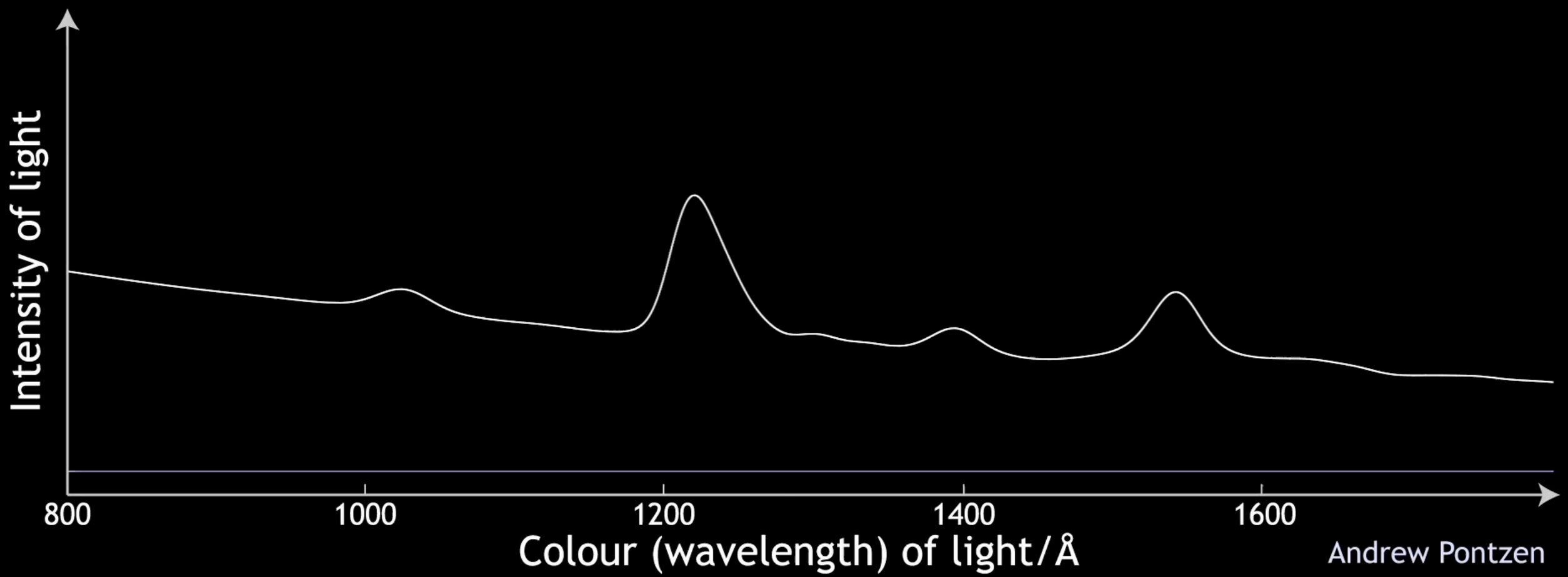
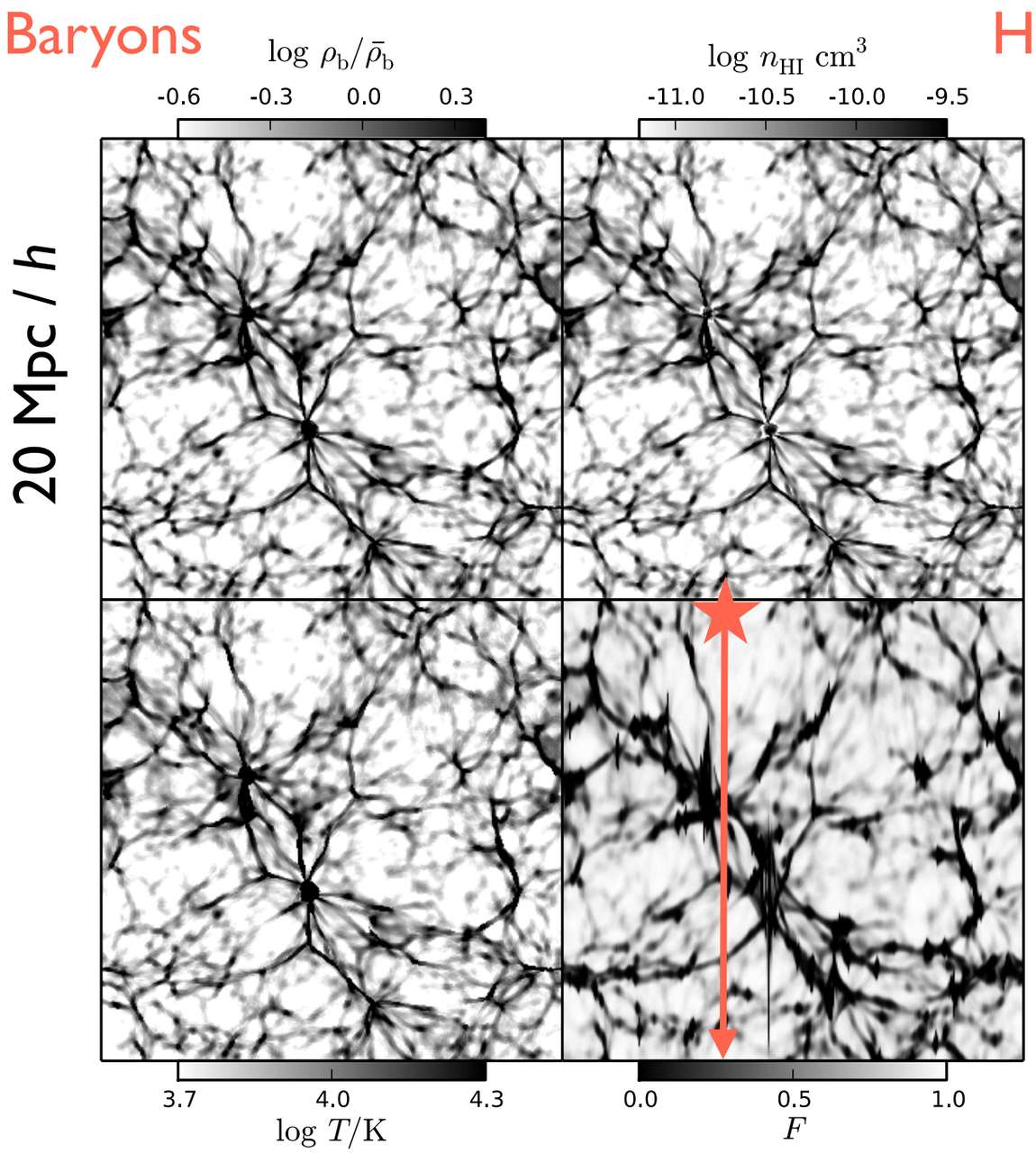
Rogers & Peiris (2021ab, Phys. Rev. Lett., Phys. Rev. D)

Lyman-alpha forest absorption traces dark matter — robustly account for range of astrophysical states





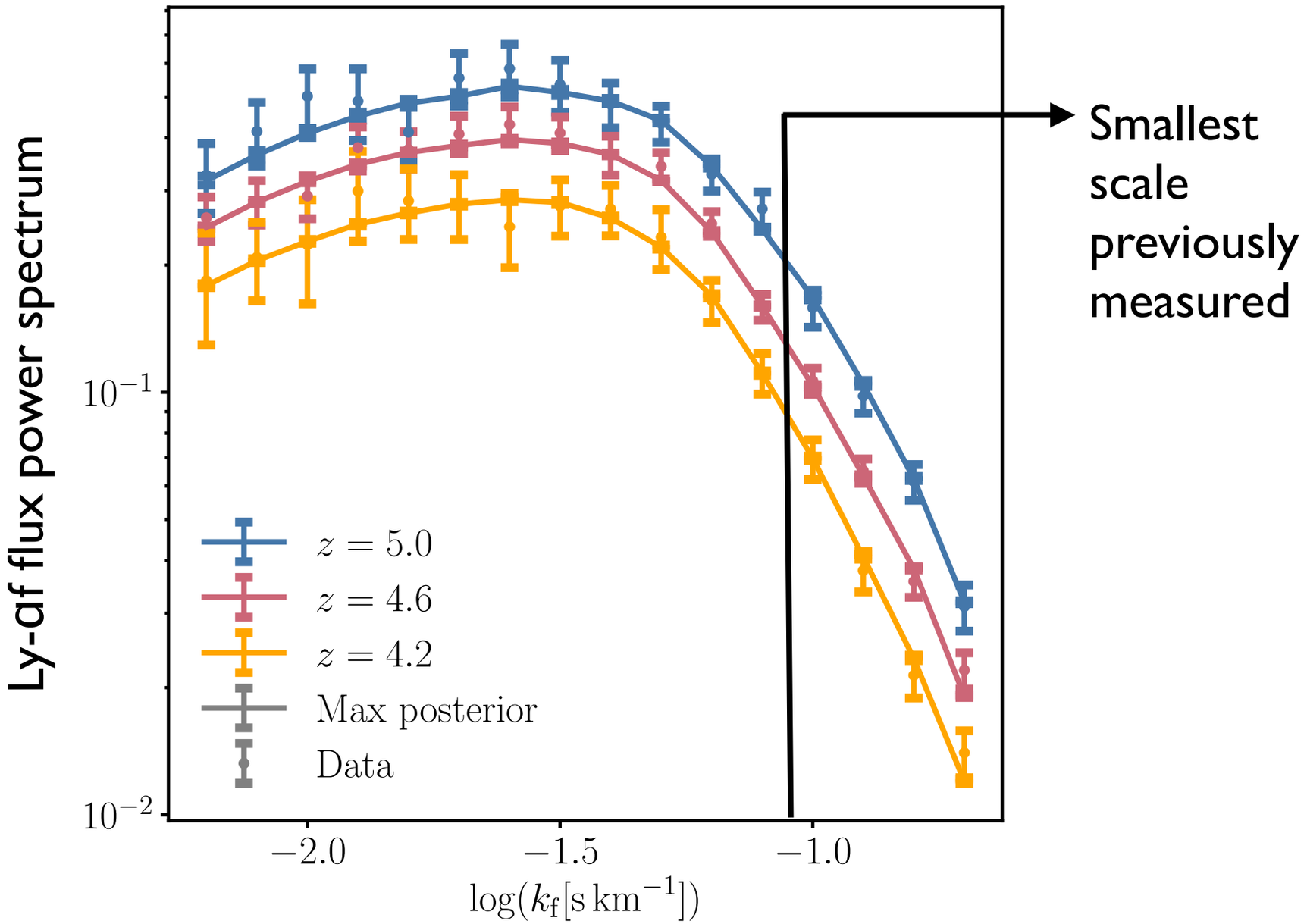
Lyman-alpha forest absorption traces dark matter — robustly account for range of astrophysical states



- Ly-alpha forest traces DM & intergalactic medium astrophysics
- ~ 3000 CPU-hours per simulation in 12-D parameter space
- ⇒ need ML-accelerated "emulator"

Lukić et al. (2015); Rogers et al. (2019); Rogers & Peiris (2021)

Dark matter bounds driven by new small-scale data



Data: Boera et al. (2019)

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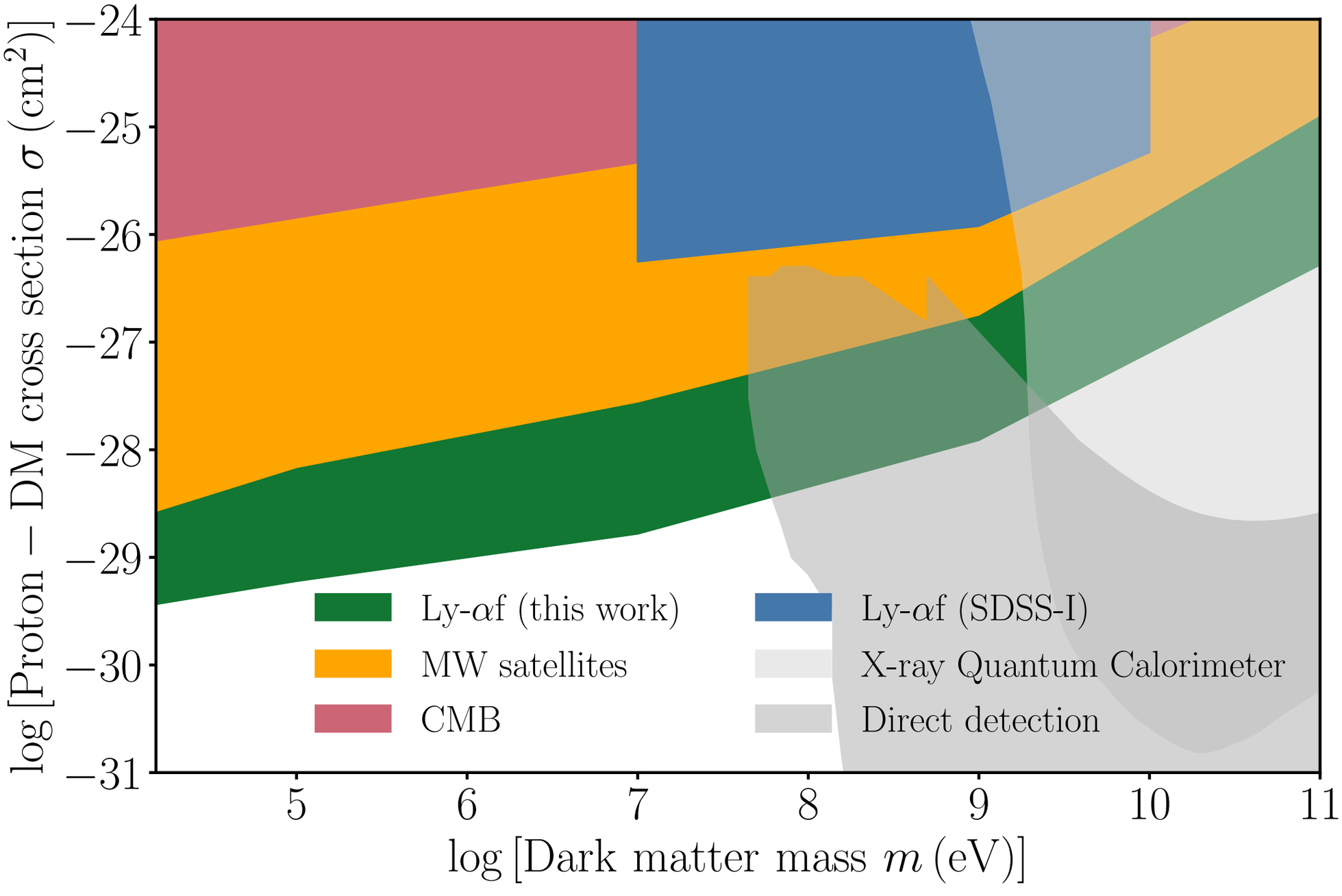
Rogers & Peiris (2021, PRL); Rogers et al. (2022, PRL)

Strongest upper limit on light dark matter cross section



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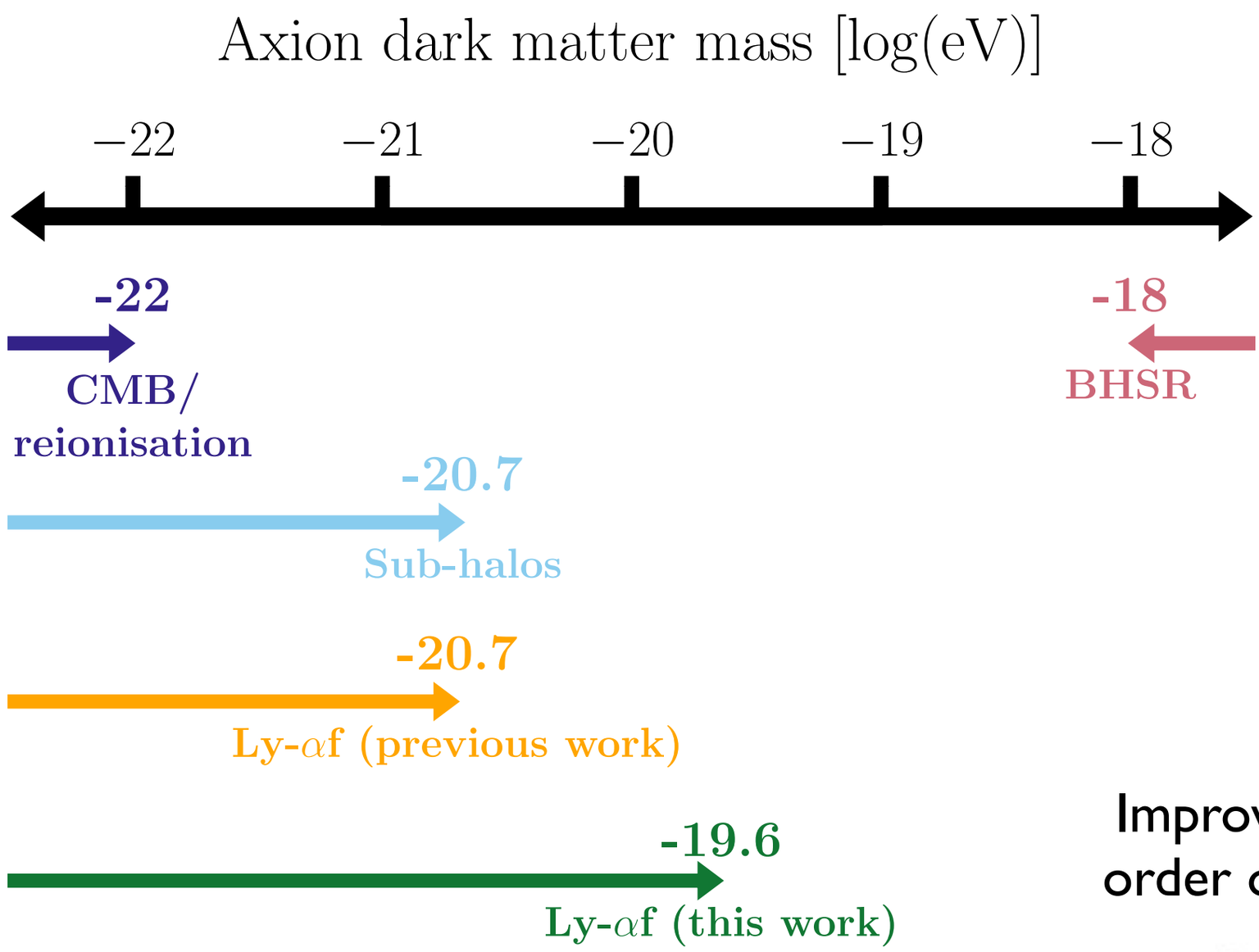
Rogers, Dvorkin, Peiris (Phys. Rev. Lett., 128, 17, 171301, 2022)

"Canonical" 10^{-22} - 10^{-21} eV ULA DM is ruled out



Improve bound by order of magnitude

$$m_{\rm a} > 2 \times 10^{-20}\,{\rm eV}$$

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Rogers & Peiris (Phys. Rev. Lett., 126, 7, 071302, 2021)

Summary

- Detect DM in large-scale structure by **only known property — gravity**

- Strongest upper limit on **light DM** — proton cross section

- Strongest lower limit on DM mass — **rule out canonical 10^{-22} eV mass**