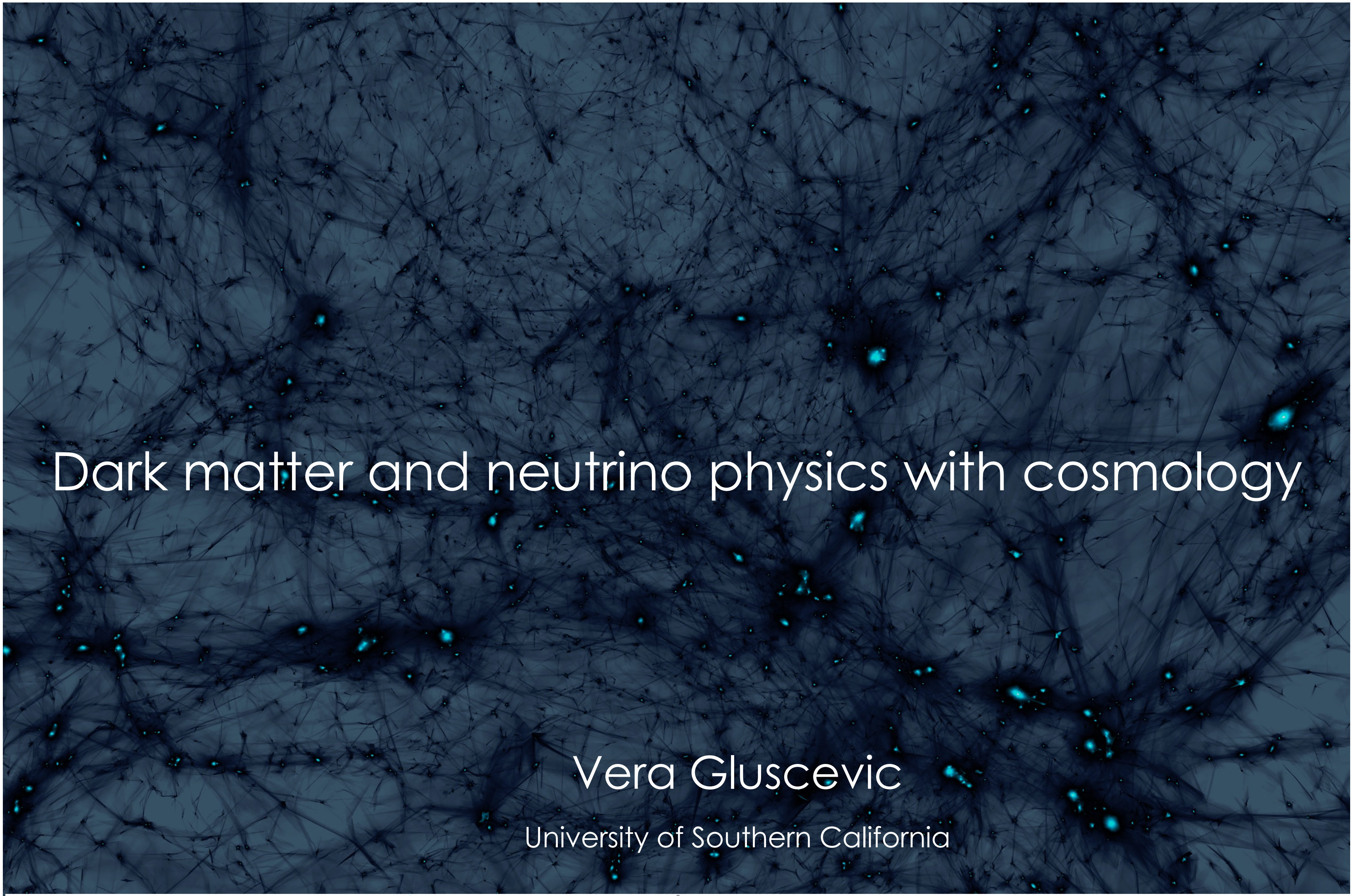
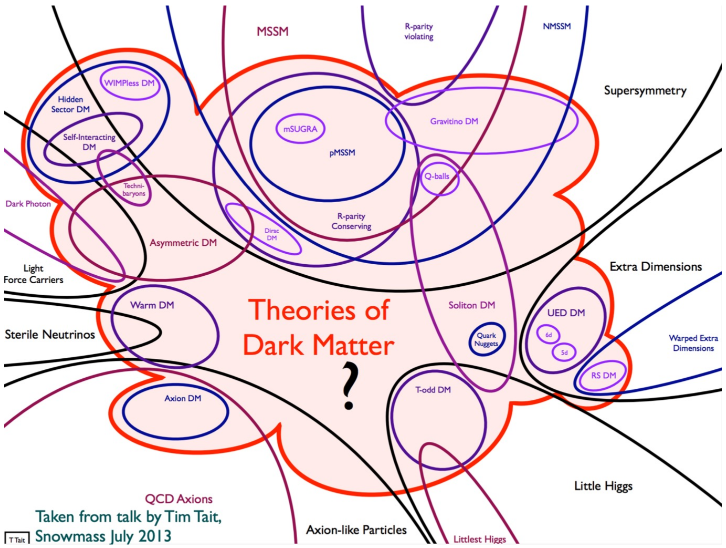


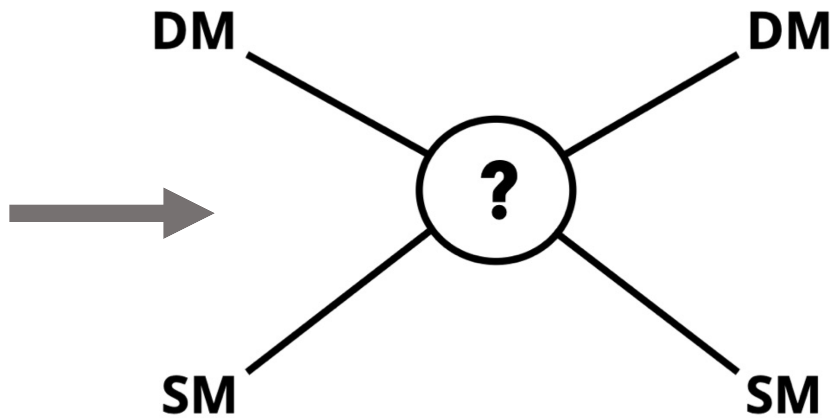
Dark matter and neutrino physics with cosmology

Vera Gluscevic

University of Southern California

mass, interactions, production = ?





Cosmological consequences?

How does microphysics matter?

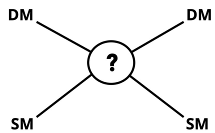
Warm DM can free stream out…

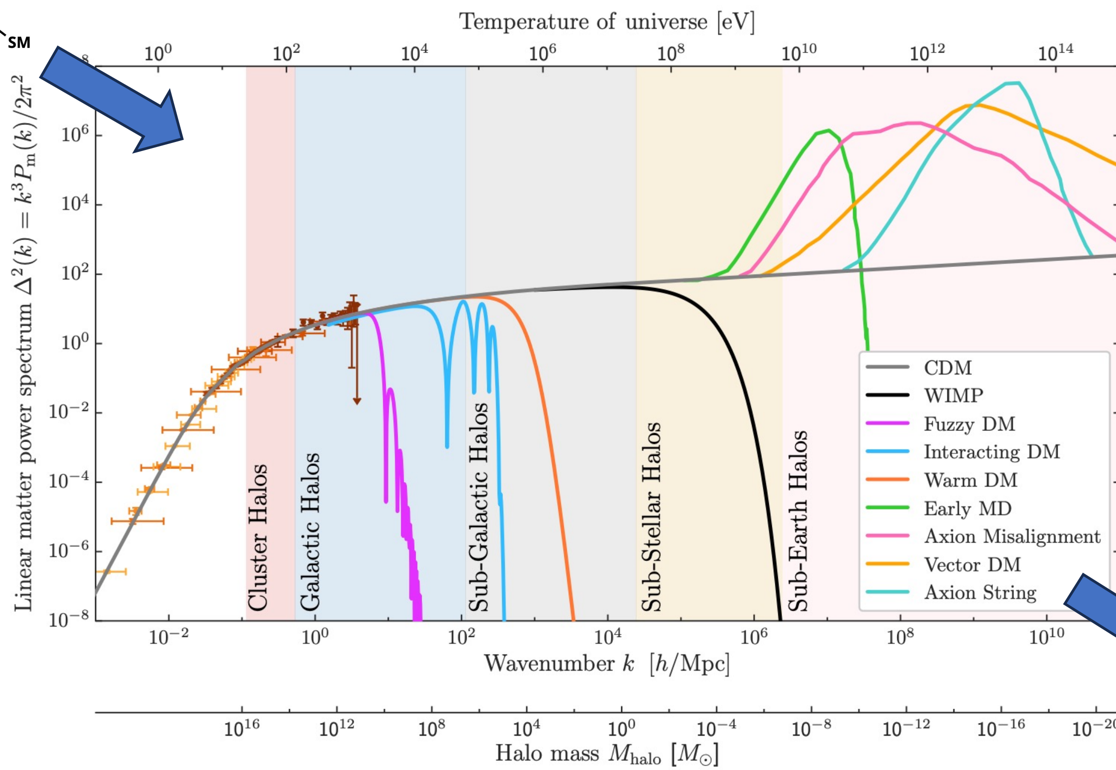
Interacting DM can overcool baryons…

Annihilating DM can alter the expansion history…

Fuzzy DM can have galactic-size de Broglie wavelength…

distribution of matter in the universe





Snowmass Cosmic Frontier
2023 Report

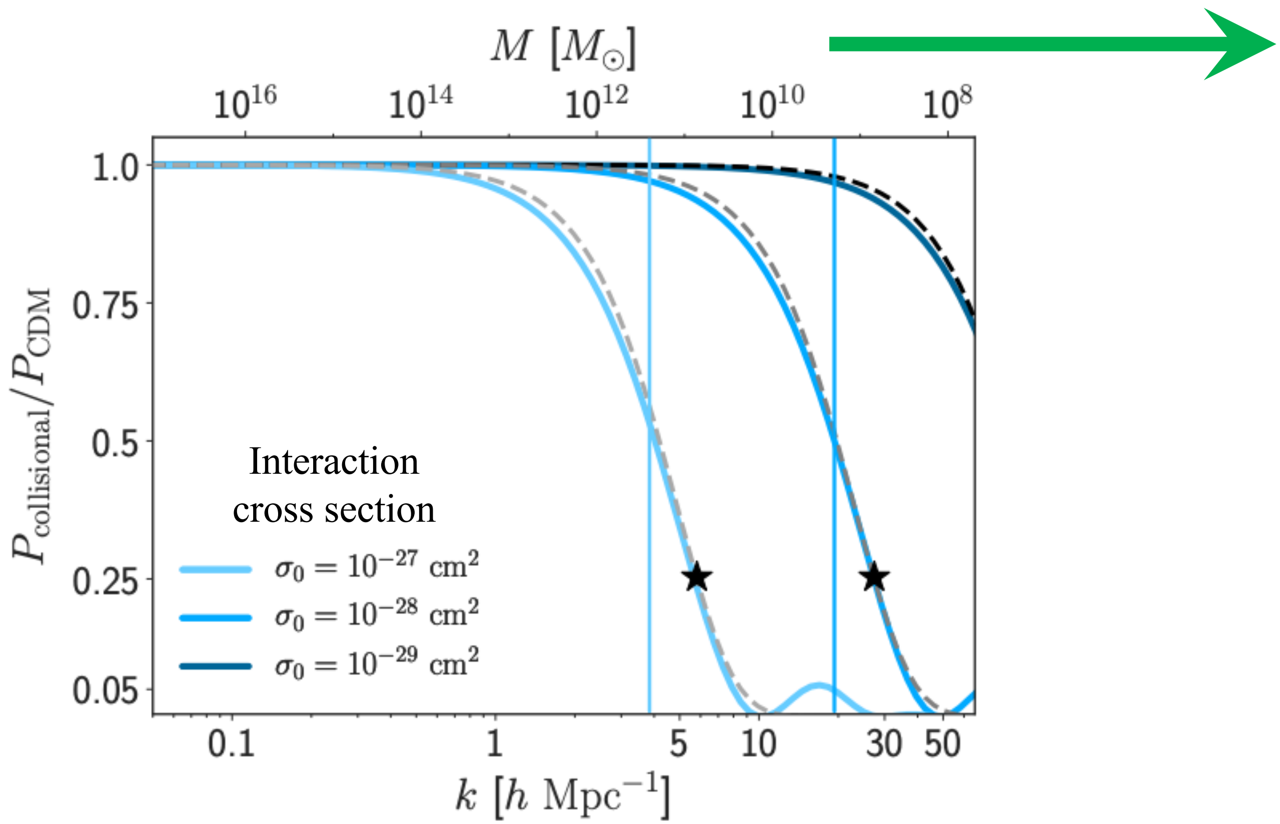
Observables:

- CMB primary/sec.
- Galaxy clustering
- Cosmic Shear
- Ly-alpha forest
- MW substructure
- Stellar streams
- Strong lensing

DM-proton (spin-independent) elastic scattering

Leads to an exchange of momentum and heat between DM and gas.

Weaker interaction / smaller scale



Nadler, Gluscevic, Boddy, Wechsler 2019 (2008.00022);
See also: Dvorkin+ 2013, Boehm+ 2009, ++

No missing satellites anymore.

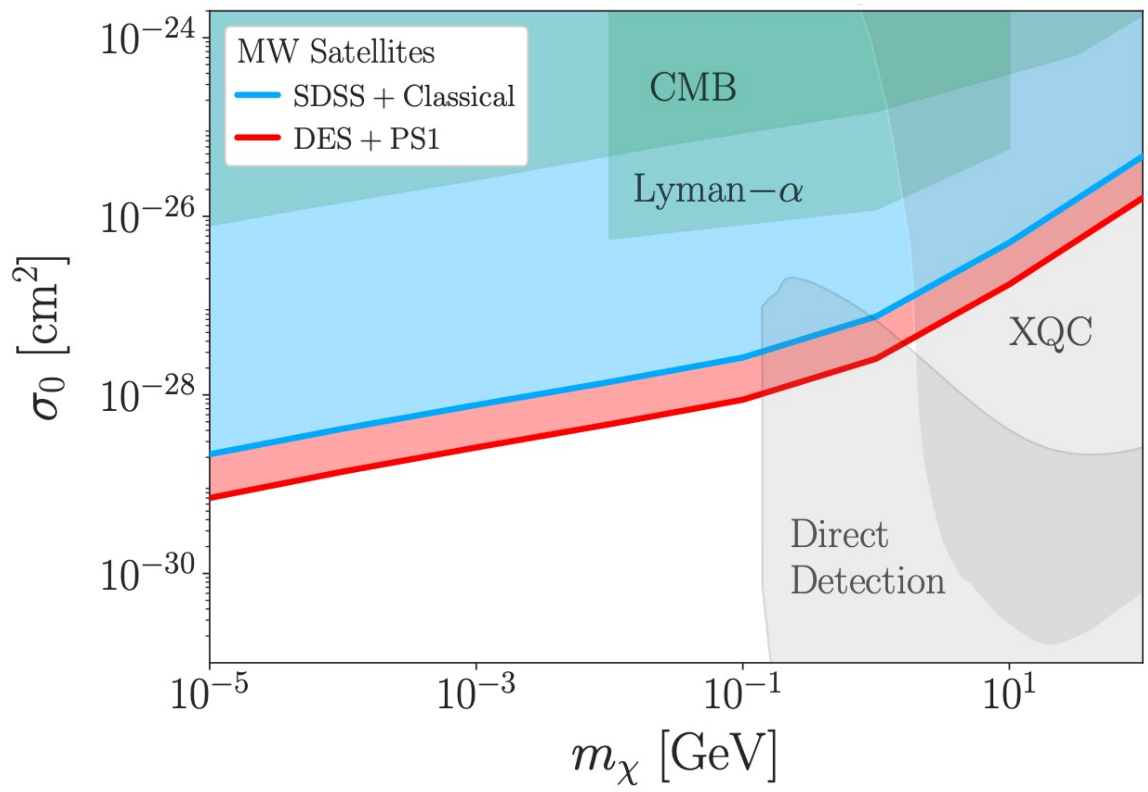
~60 Milky Way satellite galaxies detected in surveys (SDSS, DES, PanSTARRs) down to halo masses of ~few 10^8 solar masses

Cold dark matter

New dark matter physics

Elastic scattering of DM with protons

v-independent scattering



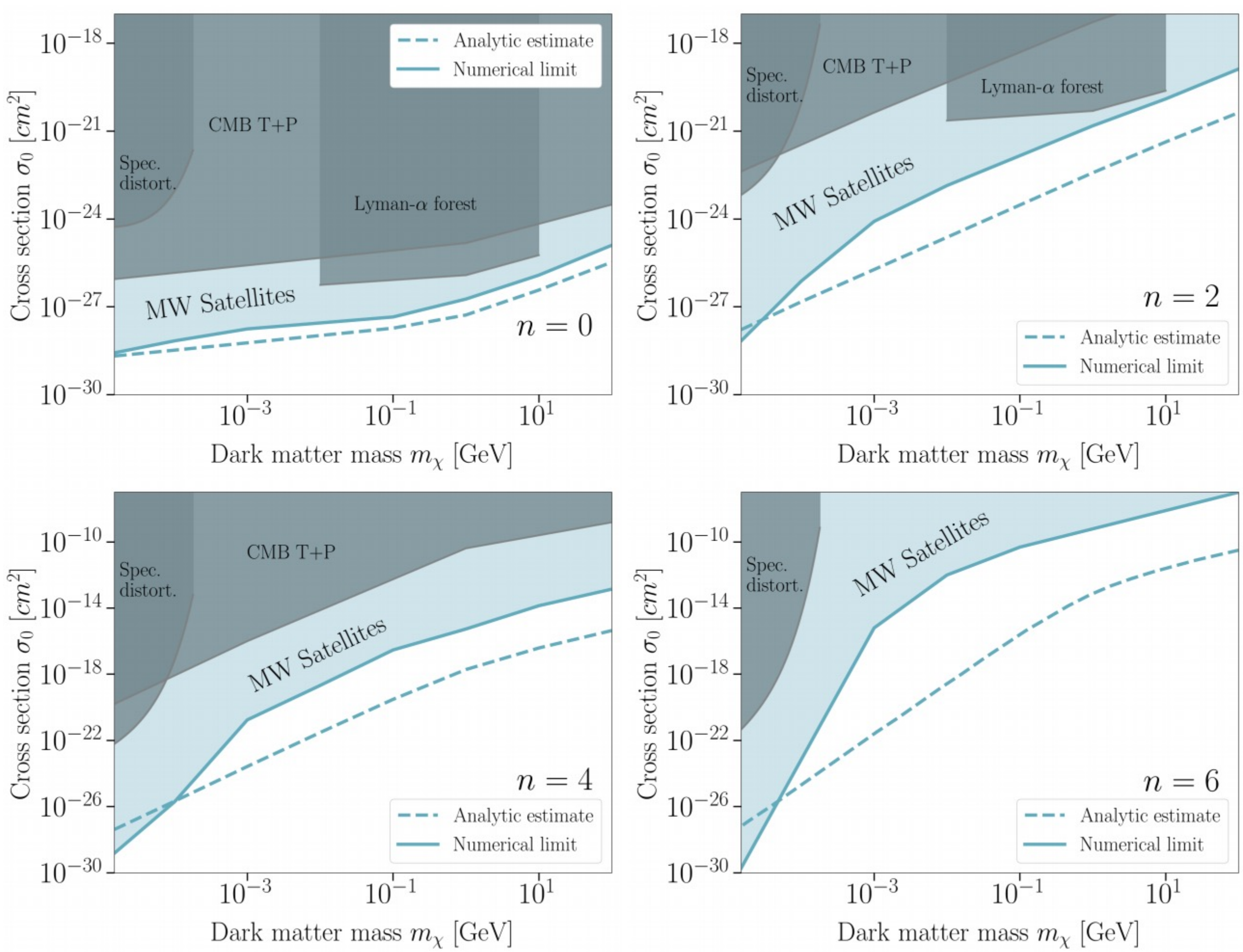
Sub-GeV masses, high cross sections

***Including:** completeness correction, uncertainties related to the galaxy-halo connection (incl. disruption of subhalos by the Milky Way disk) and mock observations (luminosity, size, and radial distribution).

Nadler, Gluscevic + 2019 (2008.00022); DES collaboration, + 2020

Effective interactions of DM with protons

Karime Maamari

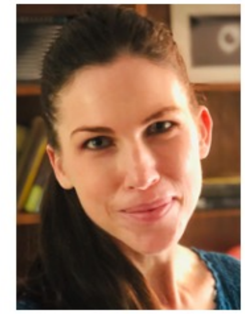


$$\sigma_{MT} = \sigma_0 v^n$$

=> **3-5 OOM improvement.**

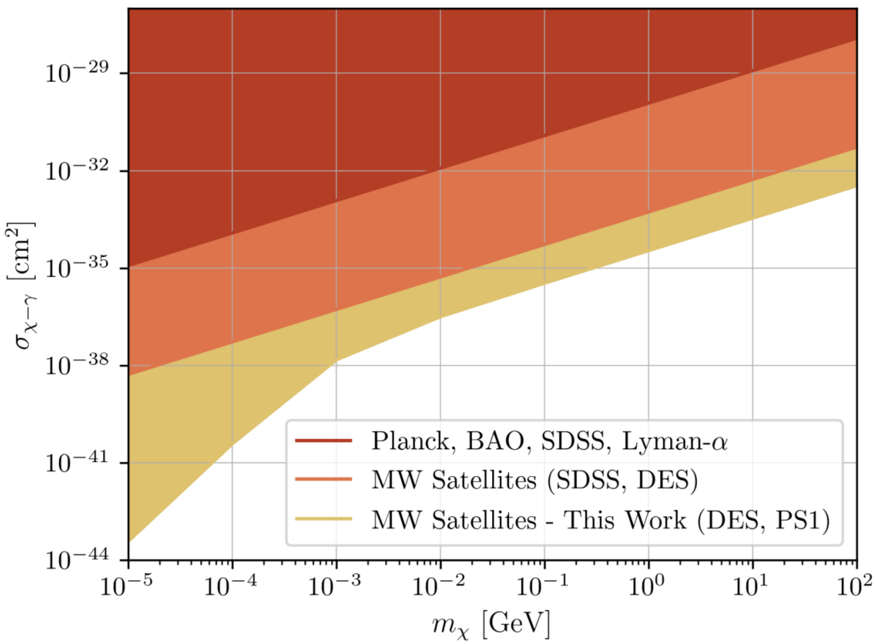
Maamari, VG,+ (2021), arXiv:2010.02936

Scattering of DM with radiation

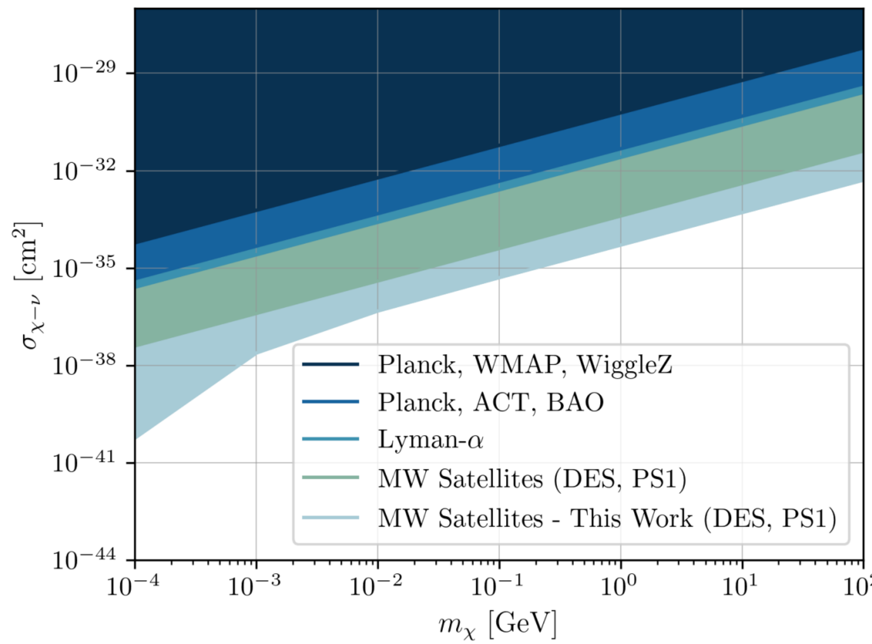


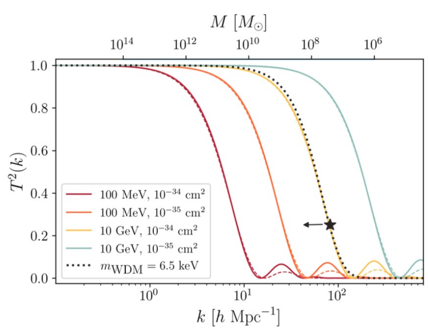
Wendy Crumrine

Photons



Neutrinos





Crumrine+ 2024
(2406.19458)

$$\Gamma_{\chi\text{-}i} = \frac{4\rho_i}{3\rho_\chi} a\sigma_{\chi\text{-}i} n_\chi c = \frac{4}{3}\rho_i \frac{\sigma_{\chi\text{-}i}}{m_\chi} ac,$$

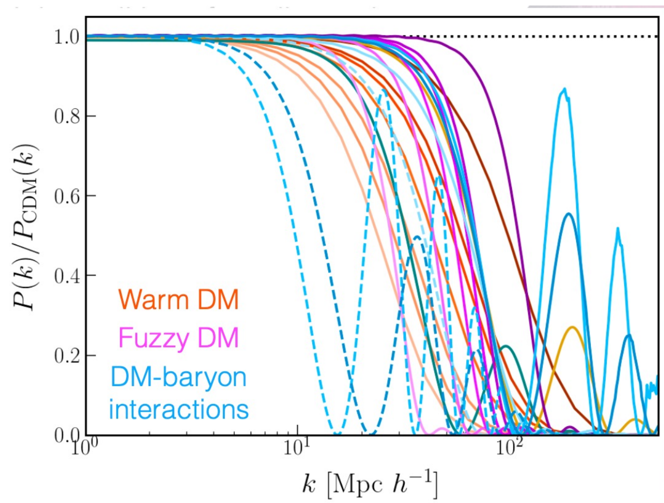
There are assumptions…

- Initial conditions are identical to WDM
- No effects at late times (during growth).

Does not apply to every DM scenario

Different ICs:

Models with DAOs, fuzzy DM, ++



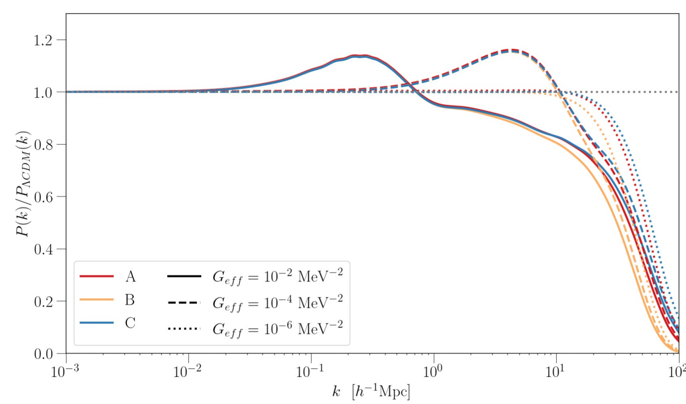
Plot by E. Nadler

Late-time effects:

SIDM/ETHOS, freeze-in, ++

Both:

Sterile neutrino + neutrino self-interactions



Plot by R. An

The bottleneck:

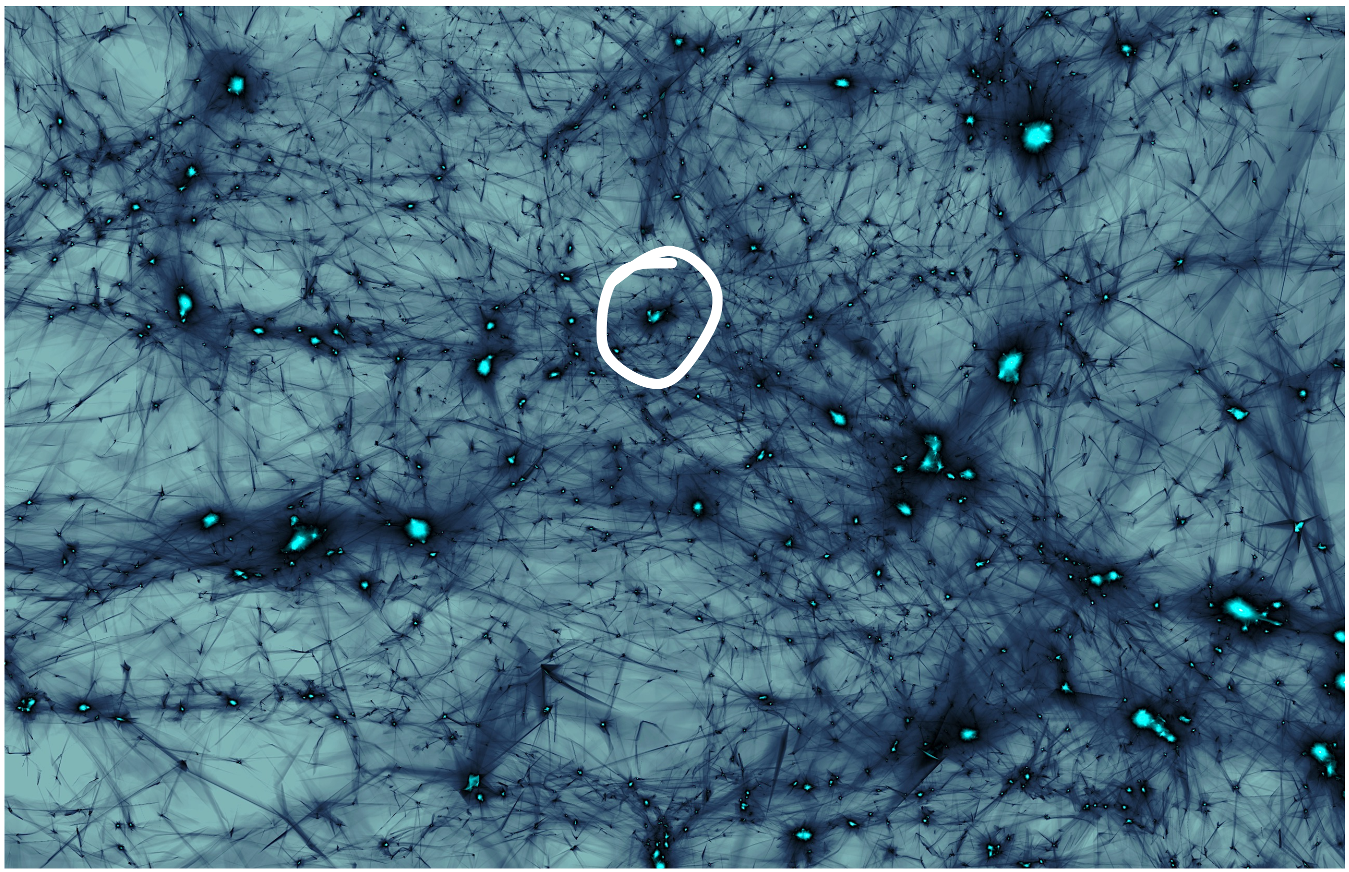
Forward-modeling small-scale universe in novel DM scenarios.

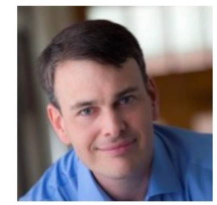
COZMIC: Cosmological Zoom-in Simulations with Initial Conditions Beyond CDM

Ethan Nadler
(USC/Carnegie)

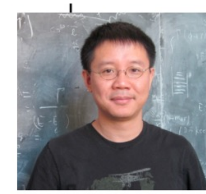
Rui An
(USC)

Daneng Yang
(UCR)





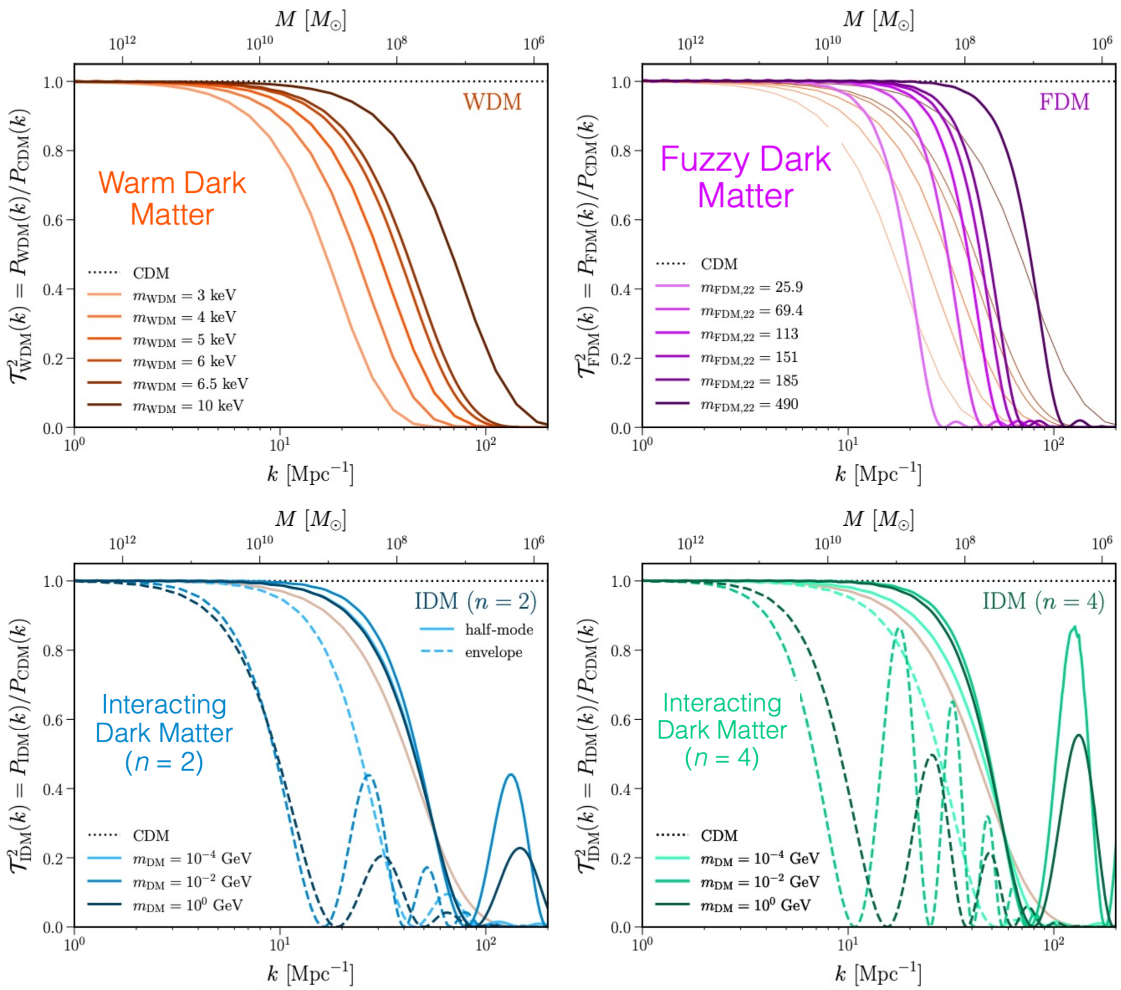
Andrew Benson
(Carnegie)



Haibo Yu
(UCR)

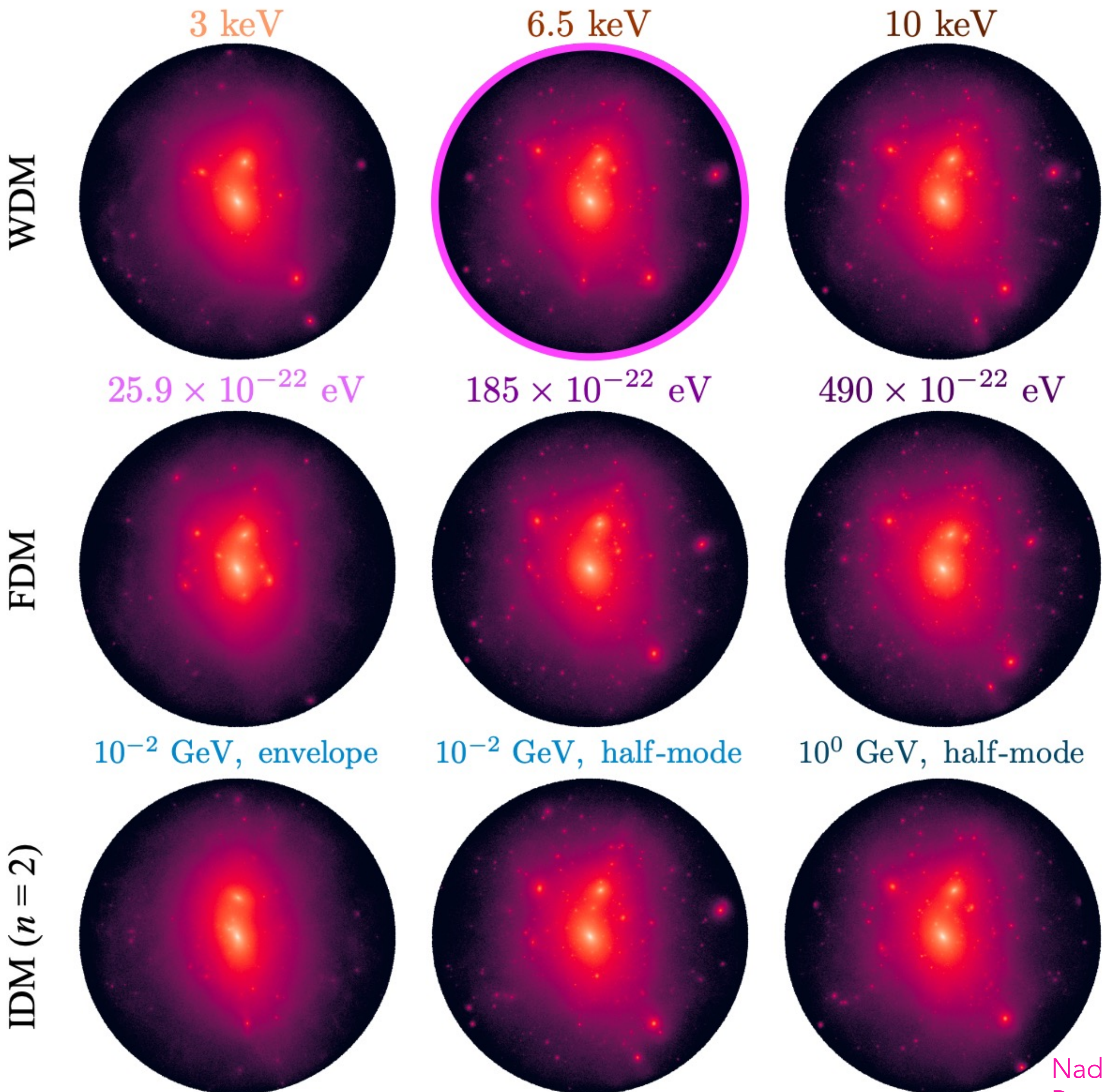
COZMIC I: Cosmological Zoom-in Simulations with Initial Conditions Beyond CDM

~100 new cosmological dark matter–only zoom-ins with ICs appropriate for IDM, FDM, and WDM.



Nadler, An, Gluscevic, Benson, Du (2410.03635).

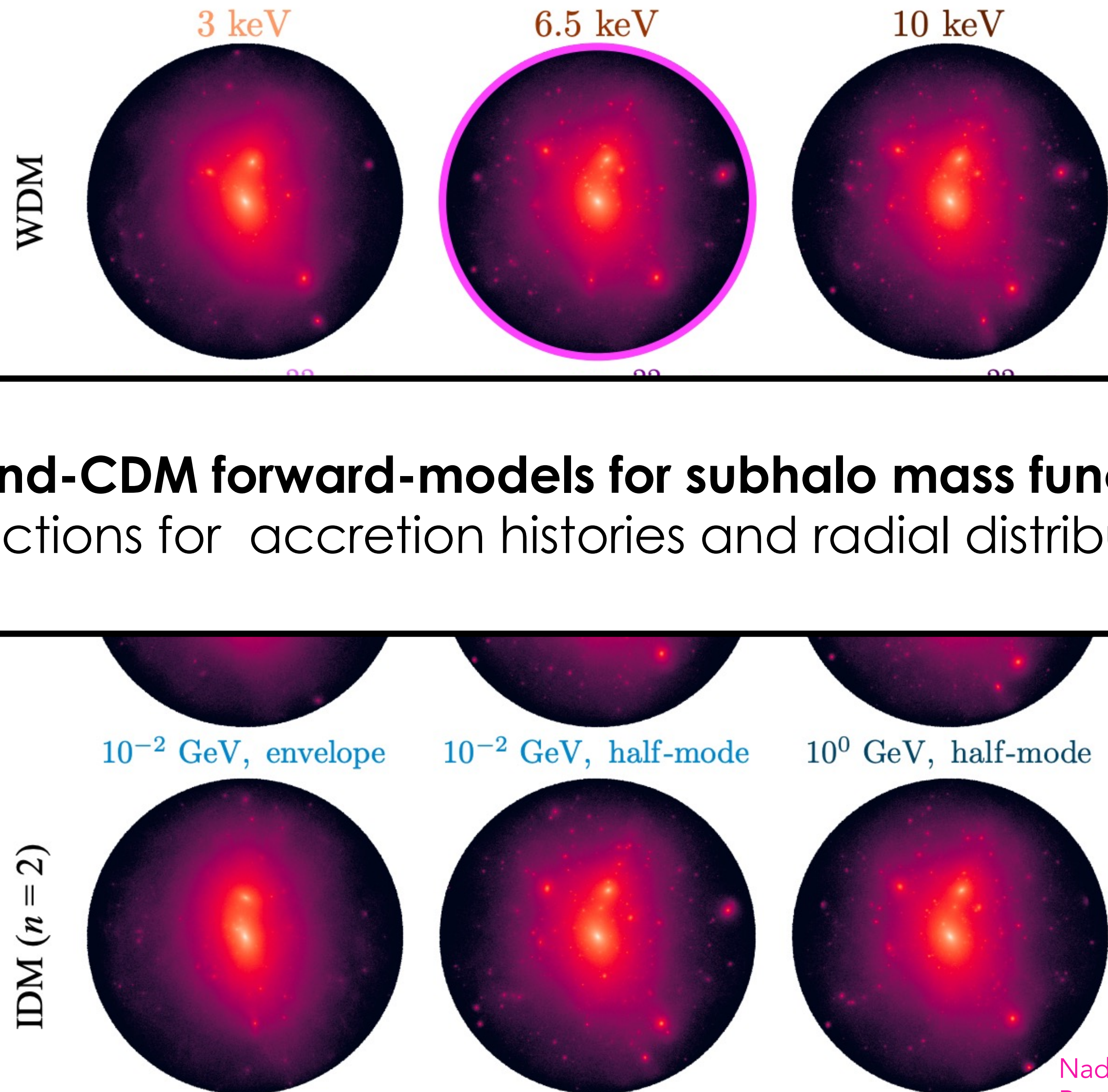
COZMIC I



$\sigma_{MT} = \sigma_0 v^n$

Nadler, An, Gluscevic, Benson, Du (2410.03635).

COZMIC I



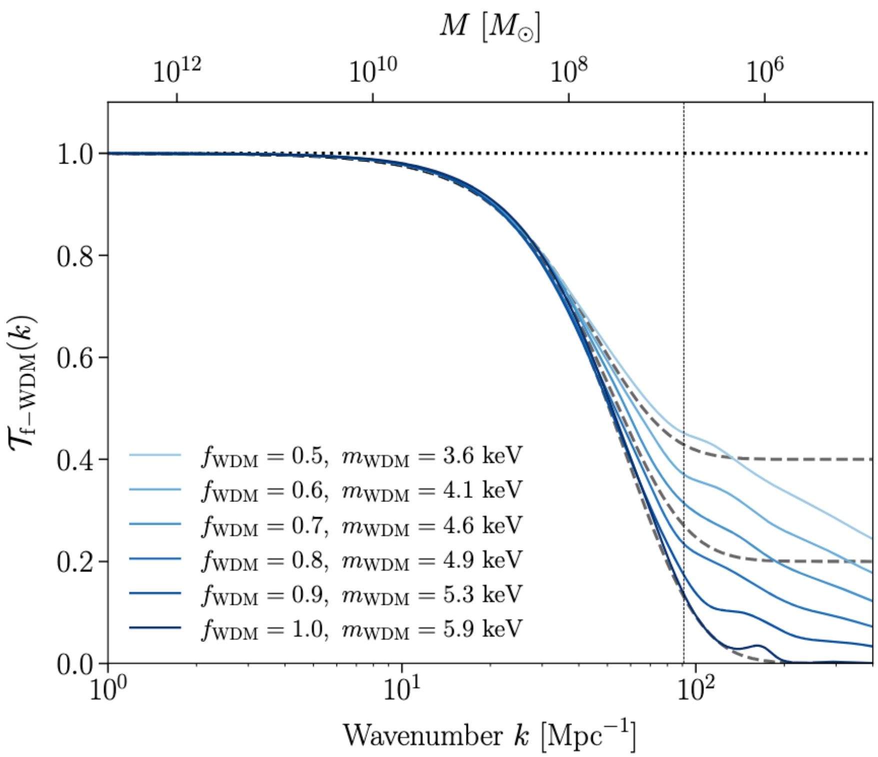
Beyond-CDM forward-models for subhalo mass functions, predictions for accretion histories and radial distributions.

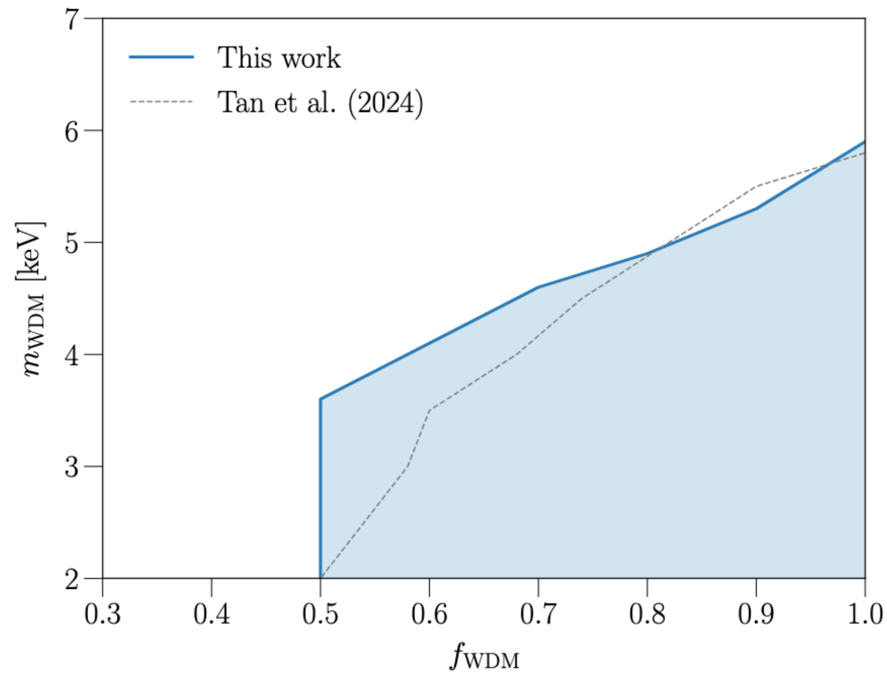
$\sigma_{MT} = \sigma_0 v^n$

Nadler, An, Gluscevic, Benson, Du (2410.03635).

COZMIC II: Fractional dark matter

PRELIMINARY

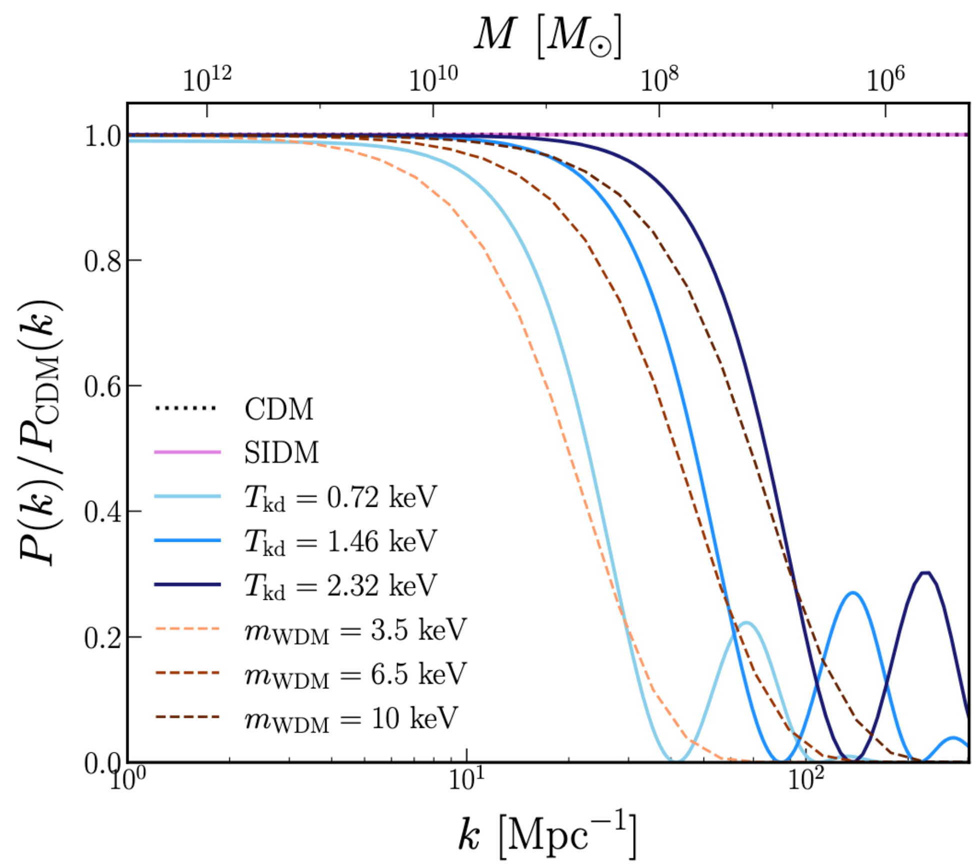




An, Nadler, Gluscevic, + (in prep).

COZMIC III: Warm SIDM

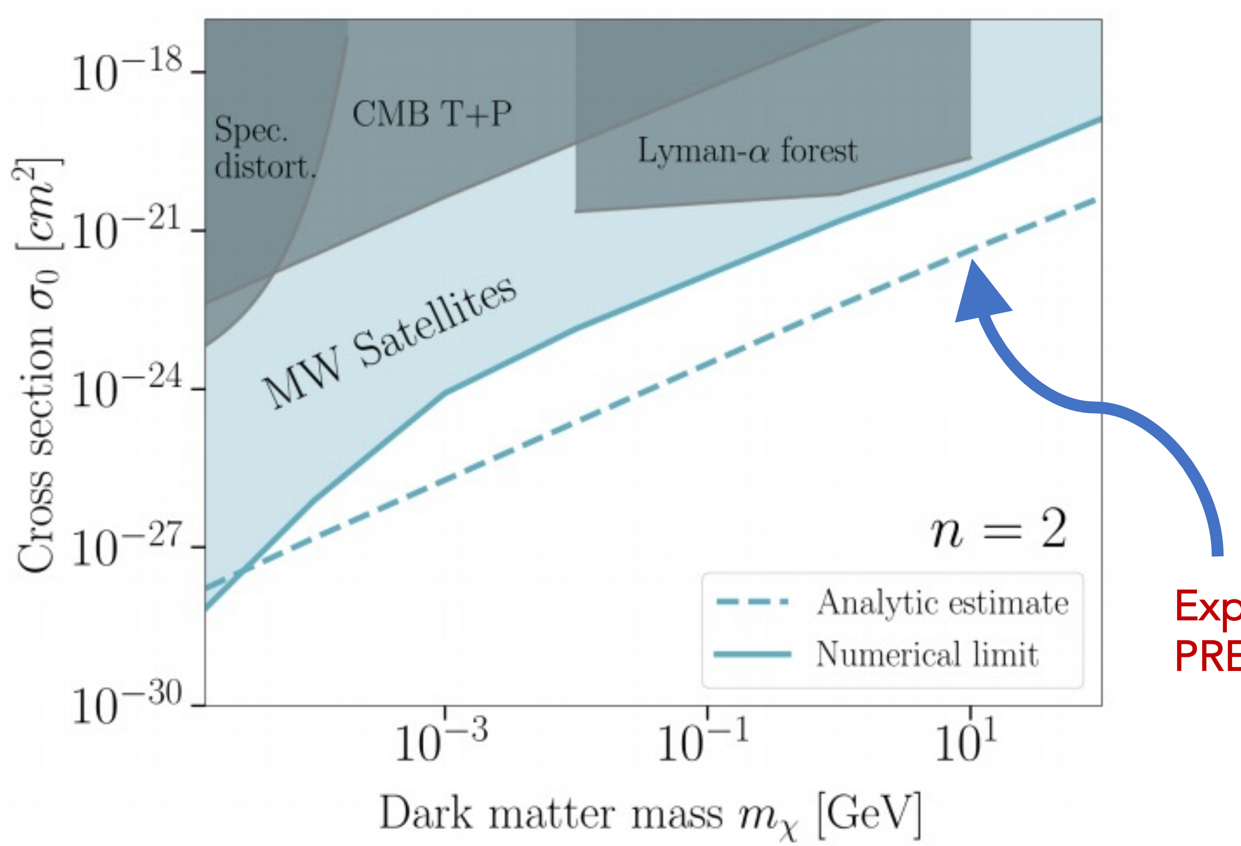
PRELIMINARY



$$\mathcal{L}_{\text{int}} = -ig_\chi \bar{\chi}\gamma^\mu \chi \phi_\mu + m_\chi \bar{\chi}\chi + \frac{1}{2} m_\phi^2 \phi^\mu \phi_\mu - ig_f \bar{f}\gamma^\mu f \phi_\mu$$

Nadler, An, Gluscevic, + (in prep).

COZMIC: enabling new bounds

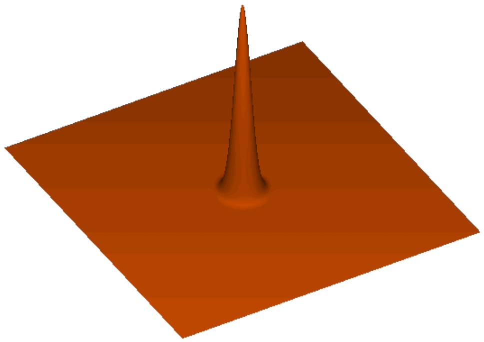


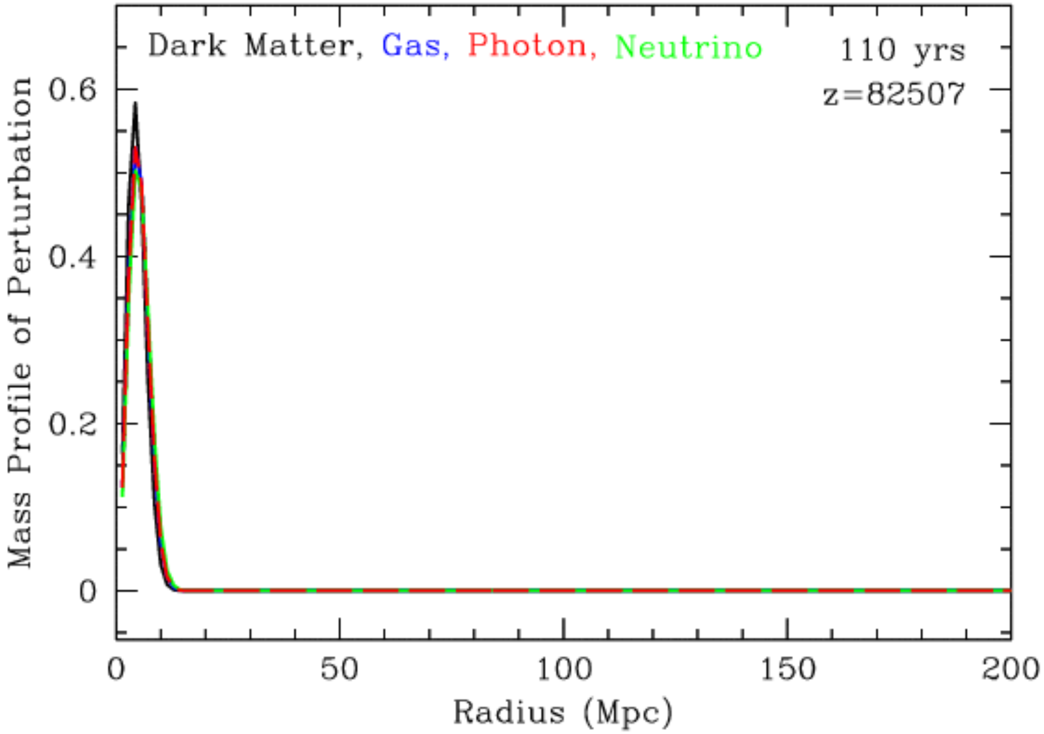
Expected new bound:
PRELIMINARY

Interacting neutrinos?

Standard neutrino cosmology

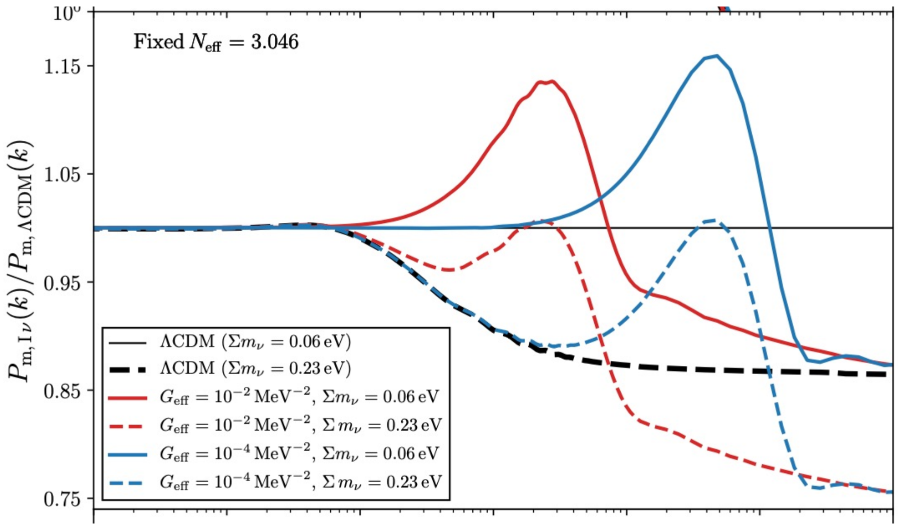
- ✓ Decoupled at ~1 MeV
- ✓ Free-streaming radiation
- ✓ Clustering after z~ x00

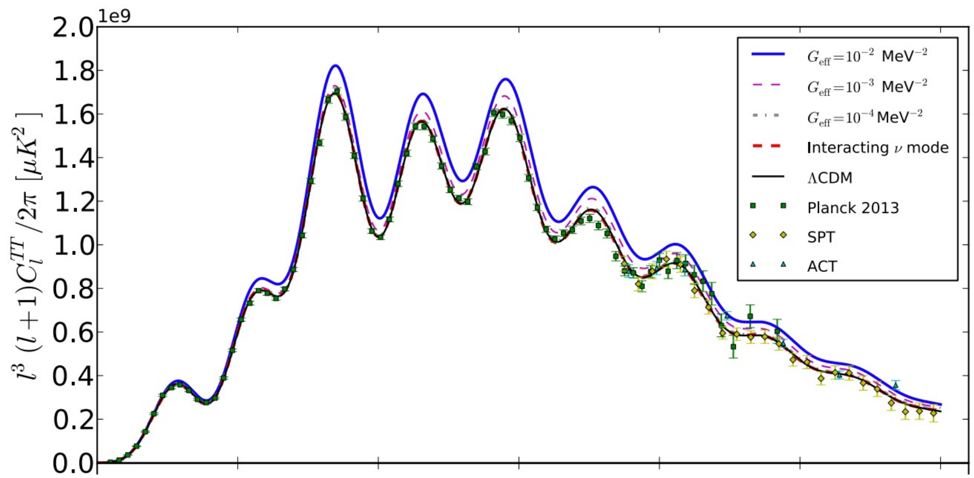




Bassett & Hlozek 2009
Eisenstein et al. 2007

Interacting neutrino cosmology





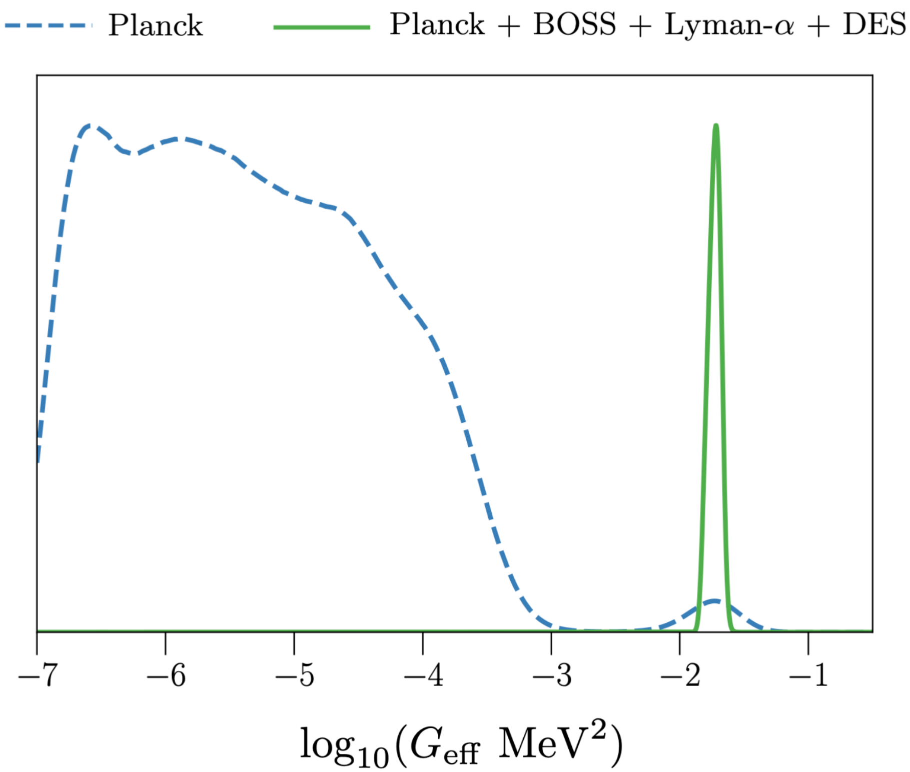
neutrino self-interaction rate

$$\Gamma_\nu \propto G_{\rm eff}^2 T_\nu^5$$

$$\mathcal{L}_{\rm int} = g_{ij}\bar{\nu}_i \nu_j \varphi$$

Cyr-Racine+Sigurdson 2013; Lancaster+ 2018; Park+ 2019; Kreisch+ 2019, etc.

Interacting neutrinos and LSS (using EFT of LSS)



Adam He

He, An, Ivanov, Gluscevic (2023)
See also Kreisch+ 2020;
Also Ivanov 2024, Bird+ 2024.

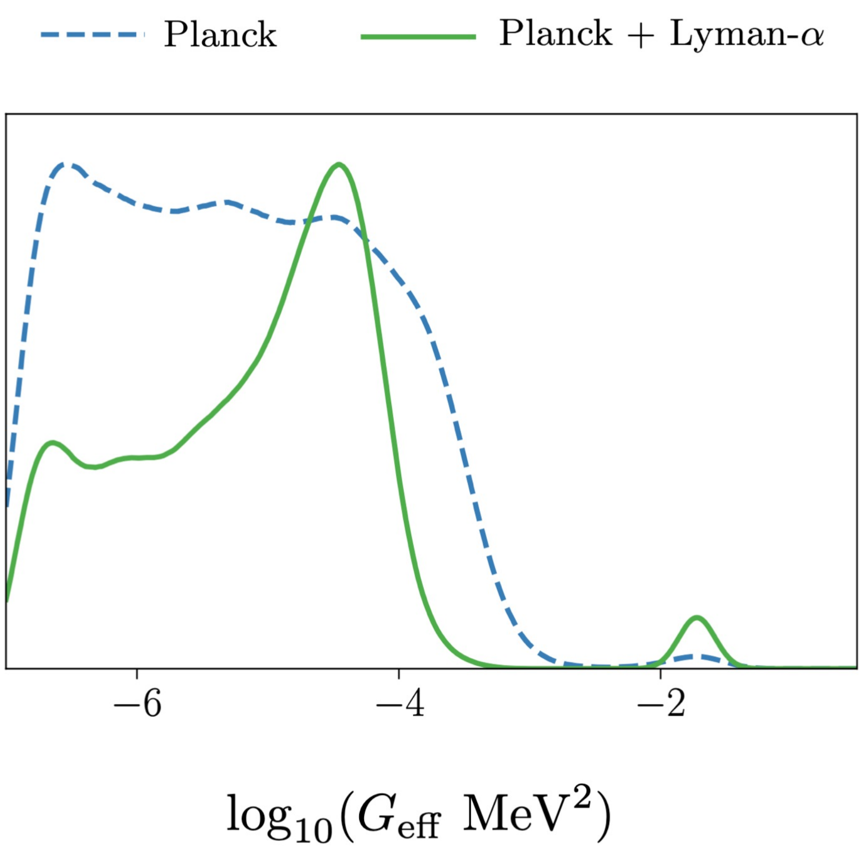
Data set	$\Delta\chi^2$ wrt ΛCDM+$\sum m_\nu$
Planck low–ℓ TT	-0.13
Planck low–ℓ EE	$+0.99$
Planck high–ℓ	$+0.15$
Planck lensing	-0.14
BOSS	-1.12
Lyman–α	-22.18
DES	-1.87
Total	-24.3

NOTE 1: cosmology probes free streaming, rather than the specifics of the coupling.

NOTE 2: assumed flavor-universal interaction.

UPDATE: Interacting neutrinos and LSS

Adam He

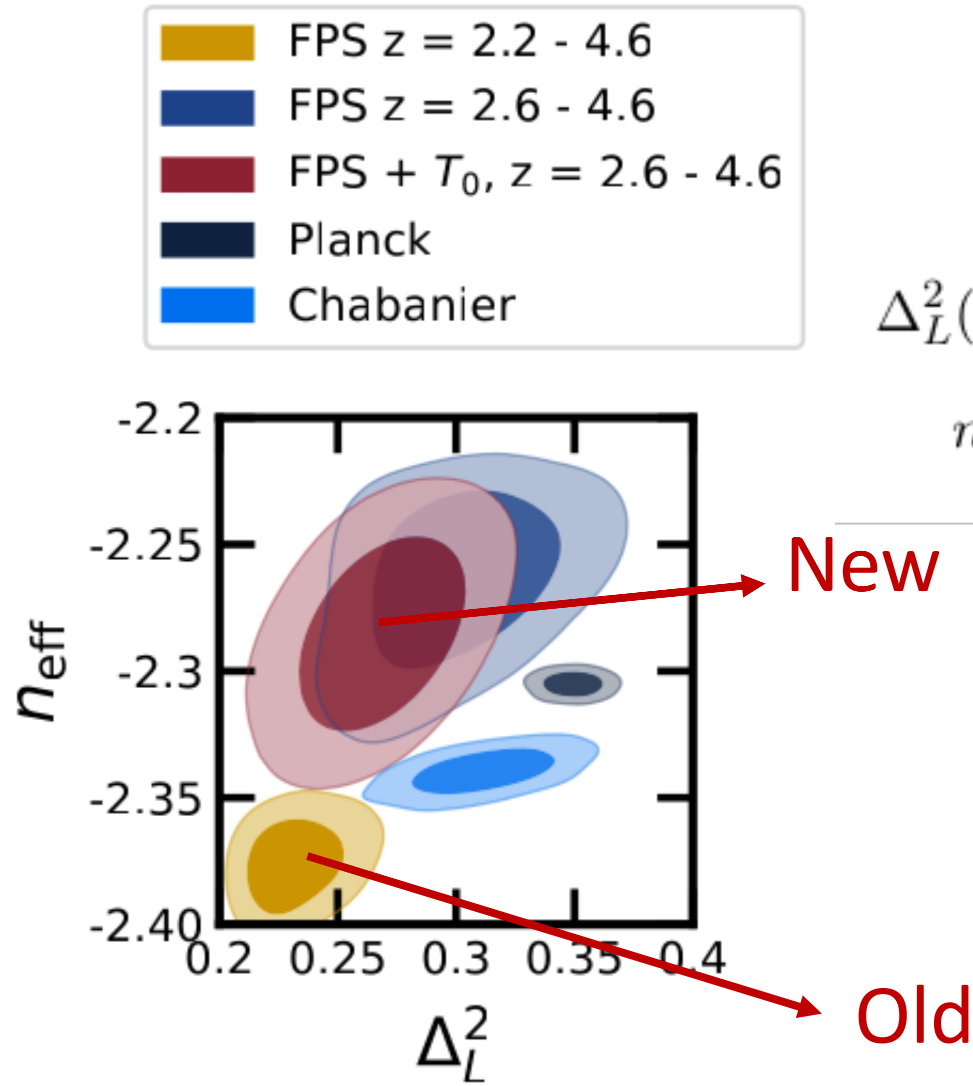


He, Bird, Gluscevic (in prep).

PRELIMINARY

Rederived eBOSS likelihood (based on new Lya simulations) does not prefer a delay in free streaming.

Re-analysis of the reduced Lyman-alpha likelihood (updated sims + conservative data cuts)

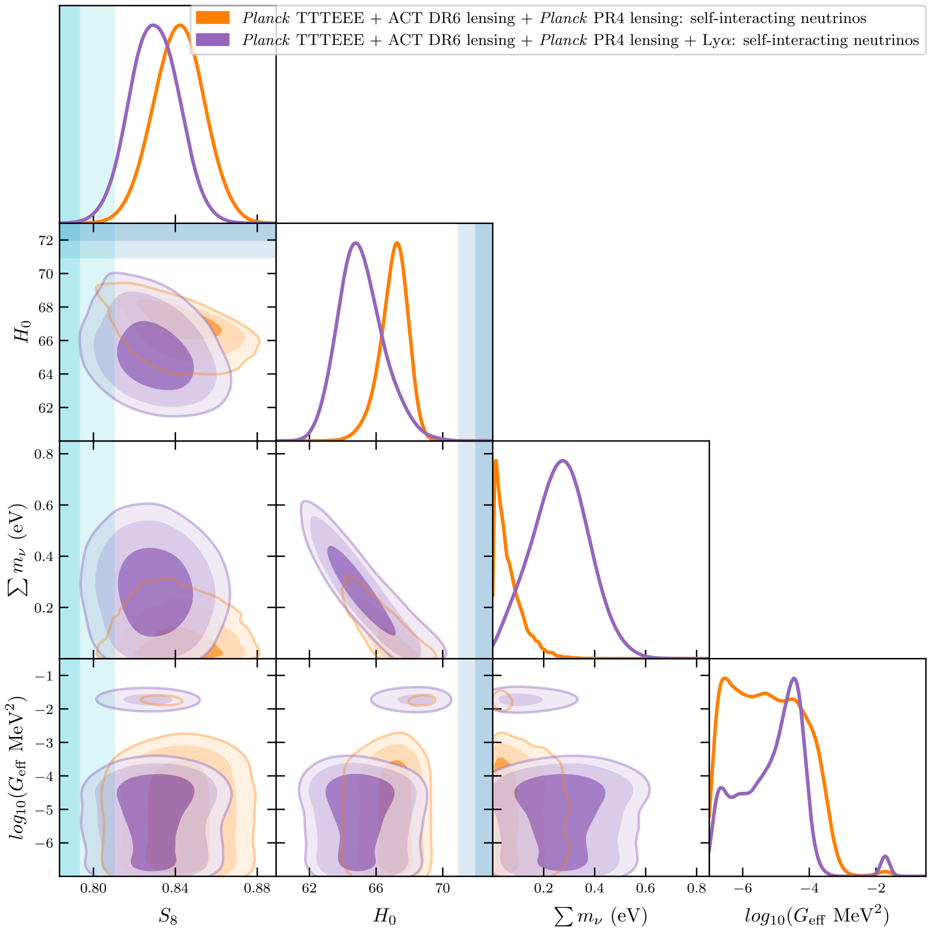


$$\Delta_L^2(k_*, z_*) = k_*^3 P_L(k_*, z_*)/(2\pi^2)$$

$$n_{\rm eff}(k_*, z_*) = \frac{d \ln P_L}{d \ln k}(k_*, z_*) \,.$$

Slide by Simeon Bird

UPDATE: Interacting neutrinos and LSS



Adam He

He, Bird, Gluscevic (in prep).

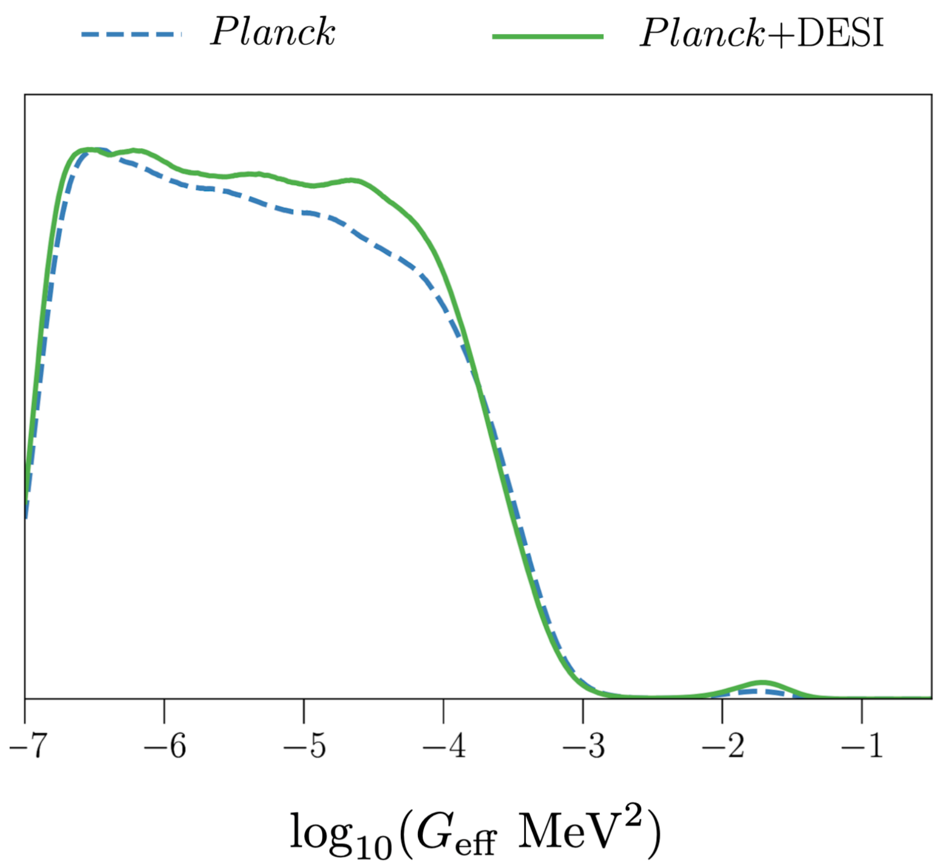
PRELIMINARY

No help for Hubble tension…

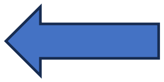
Interacting neutrinos with DESI

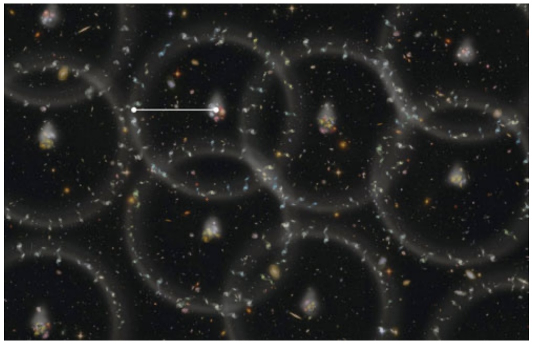
Adam He

PRELIMINARY



No evidence for a free-streaming delay in DESI BAO measurements of the acoustic horizon scale either.





He, Gluscevic, in prep.

Neutrinos meet dark matter

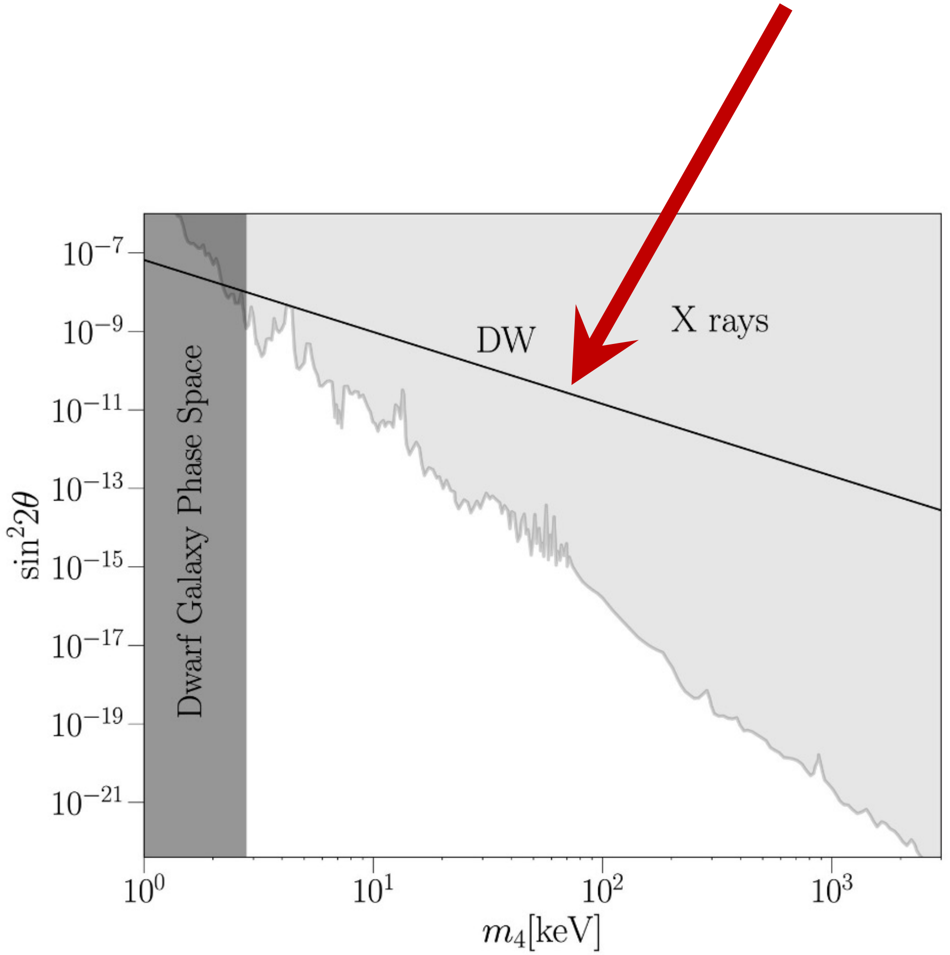
Dodelson & Widrow

DM = Fourth, heavy (~keV) neutrino that doesn't talk to the SM, but mixes with active neutrinos.

$$\nu_4 = \cos\theta\, \nu_s + \sin\theta\, \nu_a$$

$$n \leftrightarrow p + e^- + \nu_e$$
$$p + e^- \leftrightarrow \nu_e + \mathrm{n}$$
$$p + \nu_e \leftrightarrow e^+ + n$$

Dodelson-Widrow mechanism

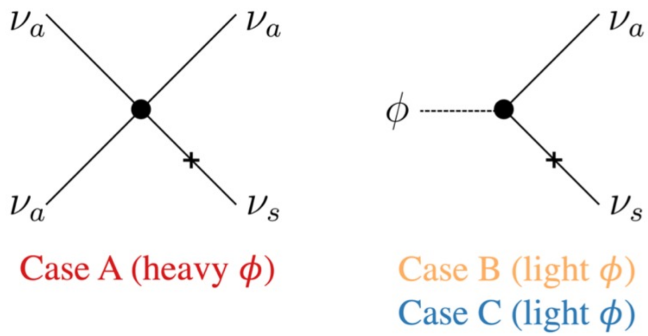


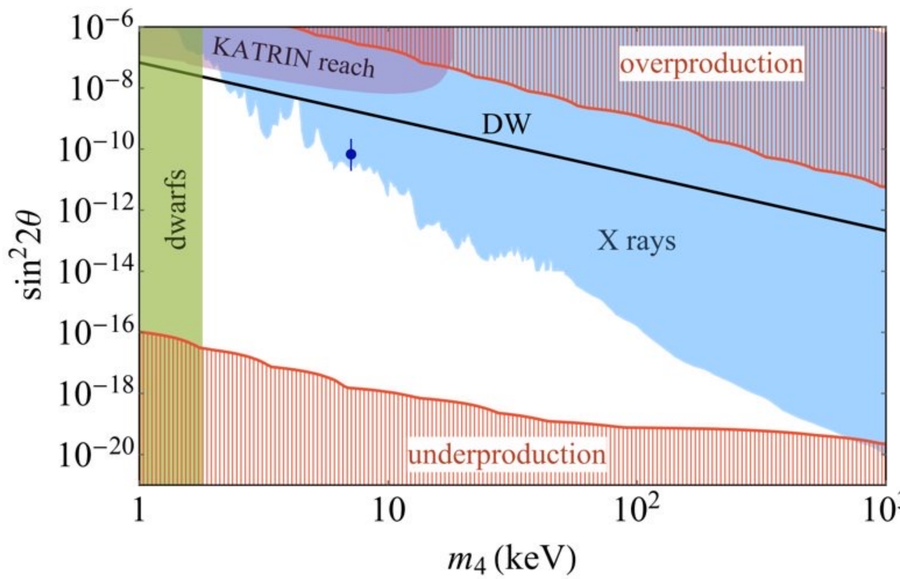
Dessert, Rodd, Safdi (2020)

…ruled out, due to decay and X-ray production.

Sterile neutrinos + **neutrino self-interactions**

$$\mathcal{L} \supset \frac{\lambda_\phi}{2}\nu_a\nu_a\phi + \text{h.c.}$$



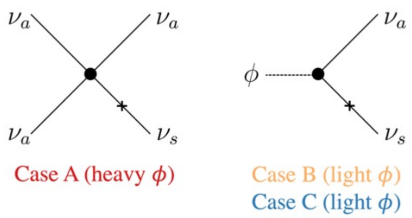


4 free params: m_4, m_ϕ, θ, λ_ϕ

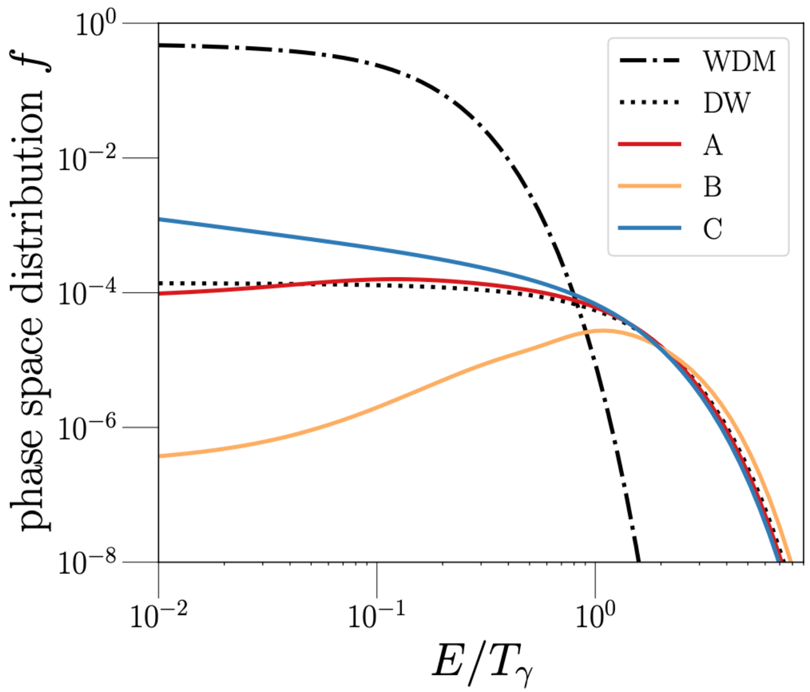
de Gouvea + (2019), etc.

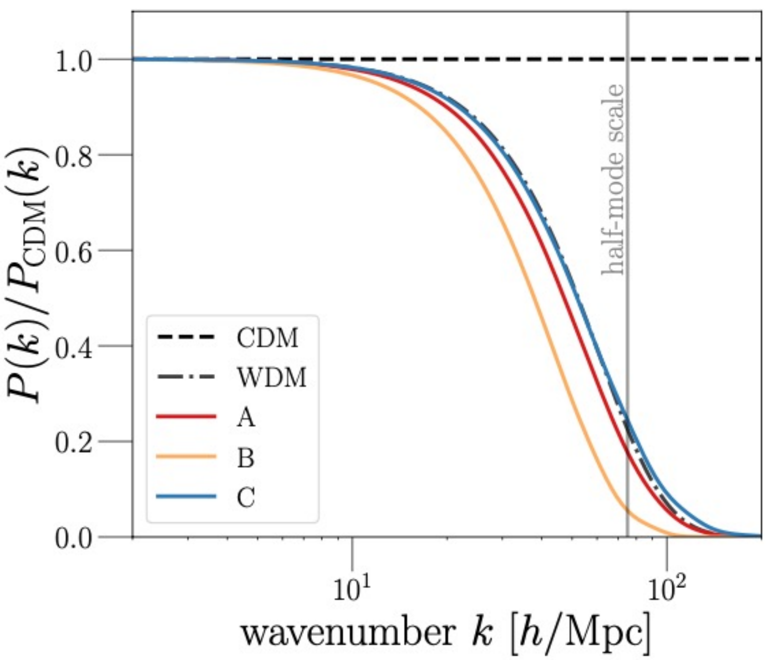
Power suppression from sterile neutrino free streaming:

Rui An

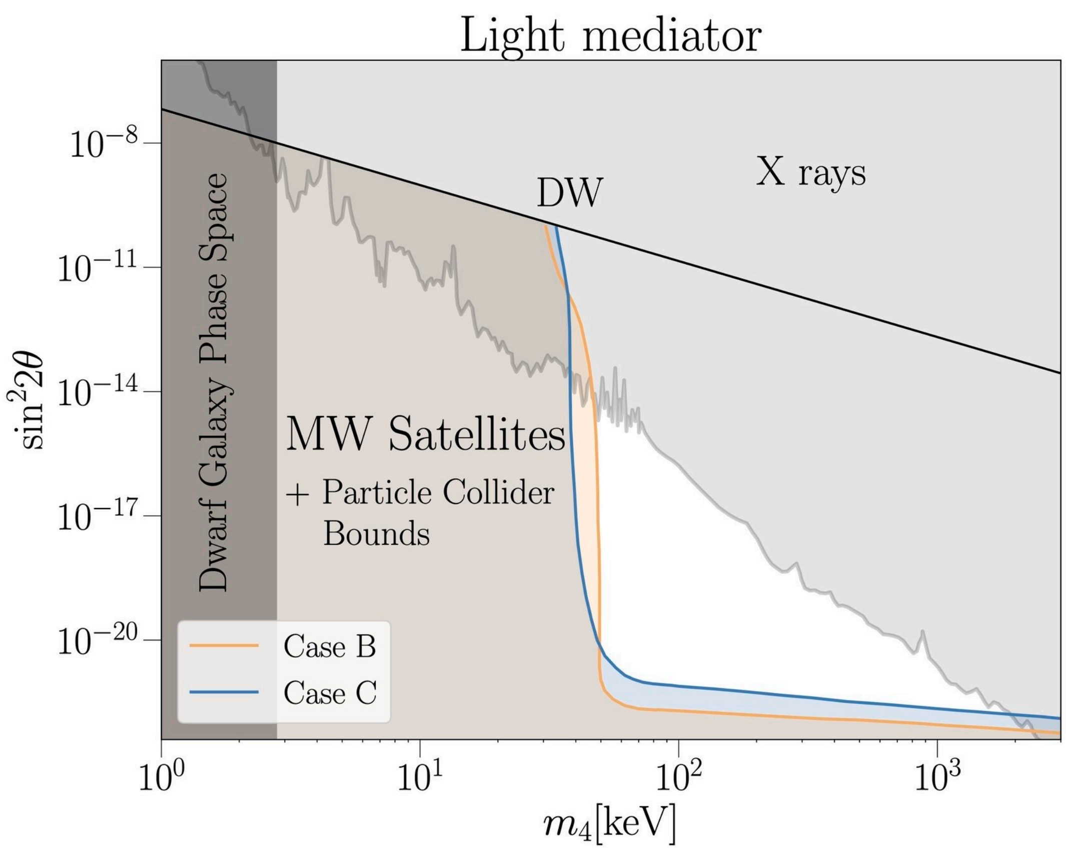


=> a cosmology were DM free streams out of grav. potentials.





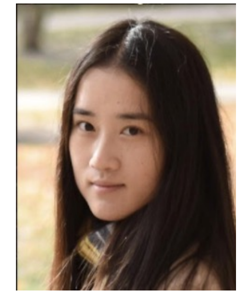
Combined bounds on sterile neutrino dark matter



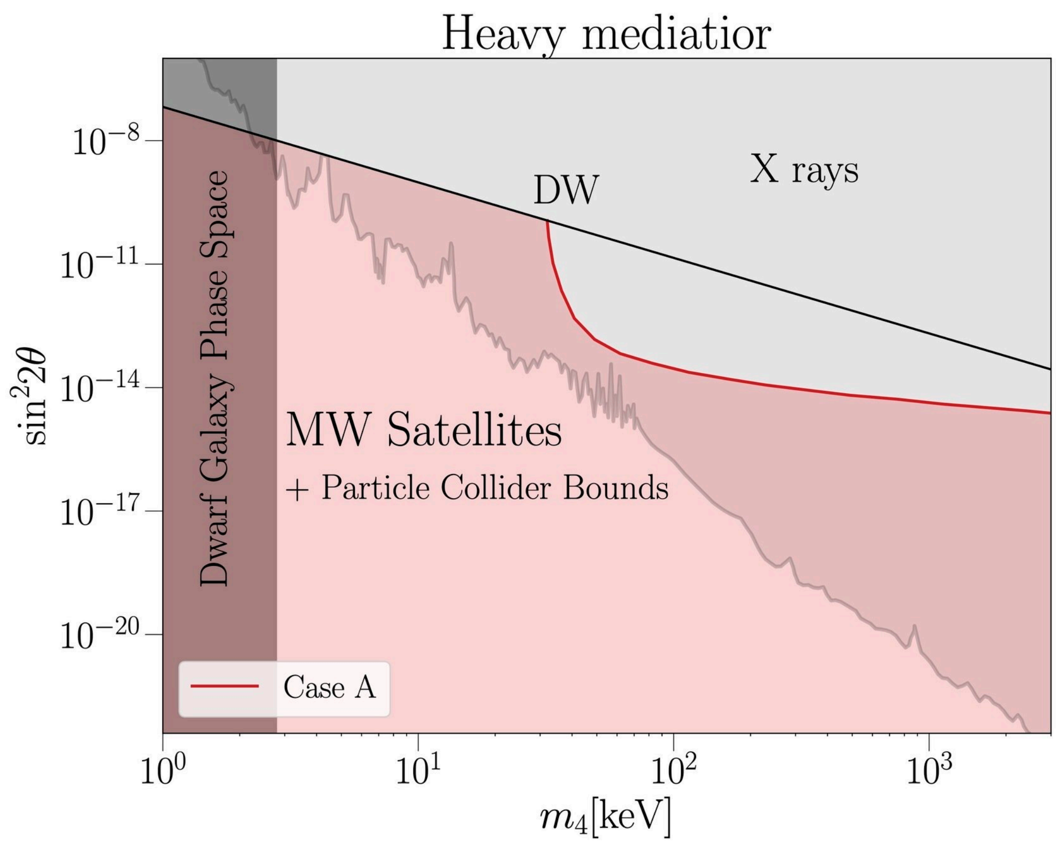
Rui An

An, Gluscevic, Nadler, Zhang (2023)

Mediators > 1GeV are ruled out.



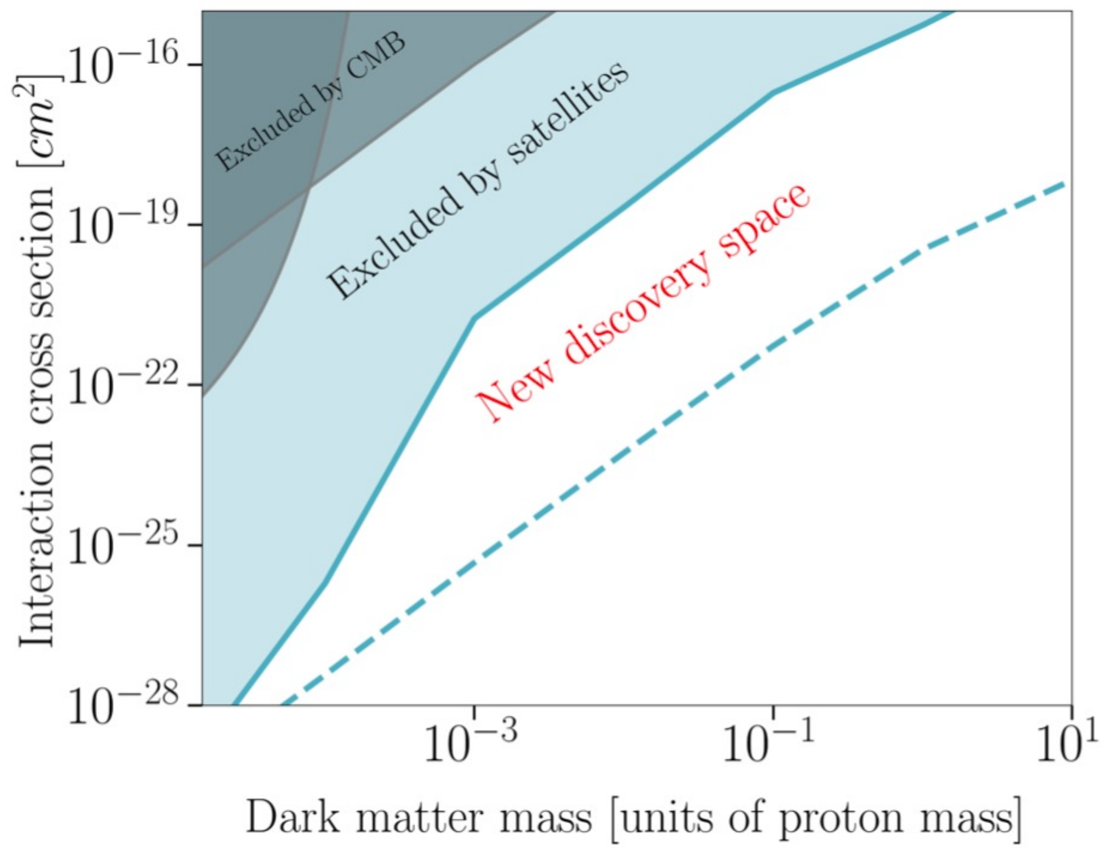
Rui An



An, Gluscevic, Nadler, Zhang (2023)

The future

Huge discovery space is becoming available this decade



Summary

- Cosmology (near and far field) probes complementary parameter space to lab experiments, in both DM and neutrino physics.

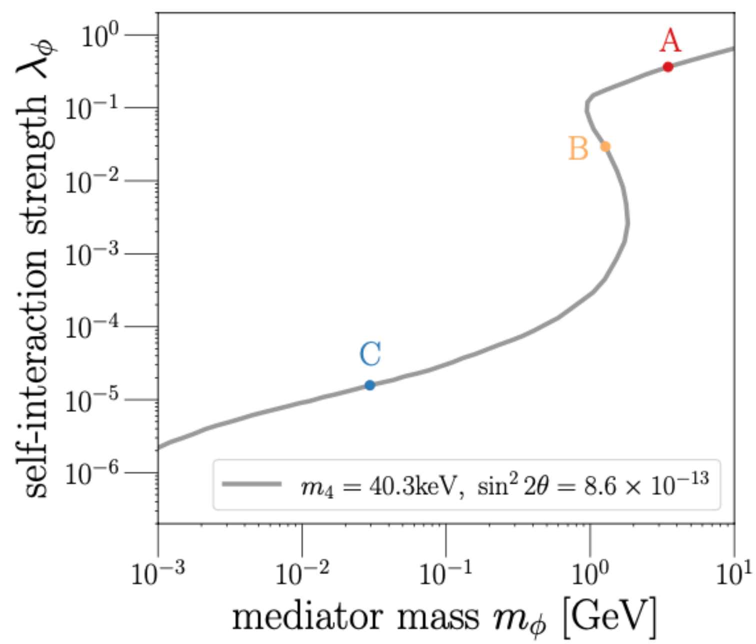
- Matter distribution on subgalactic scales is a promising new-physics testbed, given the landscape of data in the coming decade.

- Current key limitation is forward-modeling. **COZMIC** zoom-ins are a step forward.

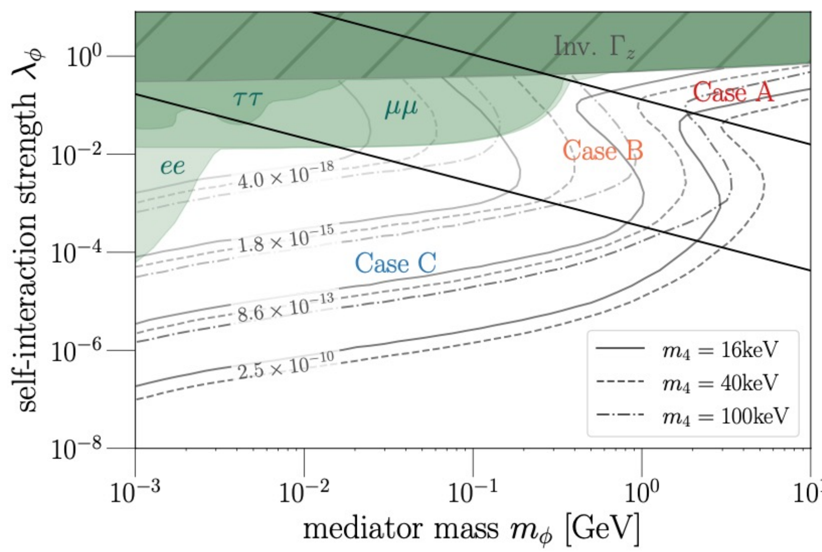
- Neutrino self-interaction "strong mode" is disfavored by re-derived Lyman-alpha likelihood, and by DESI.

- Joint information from the near-field measurements + lab tests of neutrino physics put pressure on a broad range sterile neutrino production mechanisms.

Sterile neutrino production and bounds



Combinations of neutrino self-interaction strength λ_ϕ and mediator mass m_ϕ that produce sterile-neutrino DM at the correct relic abundance, for a DM mass of m_4 = 40.3 keV and vacuum mixing angle of $\sin^2 2\theta = 8.6 \times 10^{-13}$.



light green shaded regions show experimental flavor-dependent constraints (Berryman et al. 2018; Berryman et al. 2022; Esteban et al. 2021).