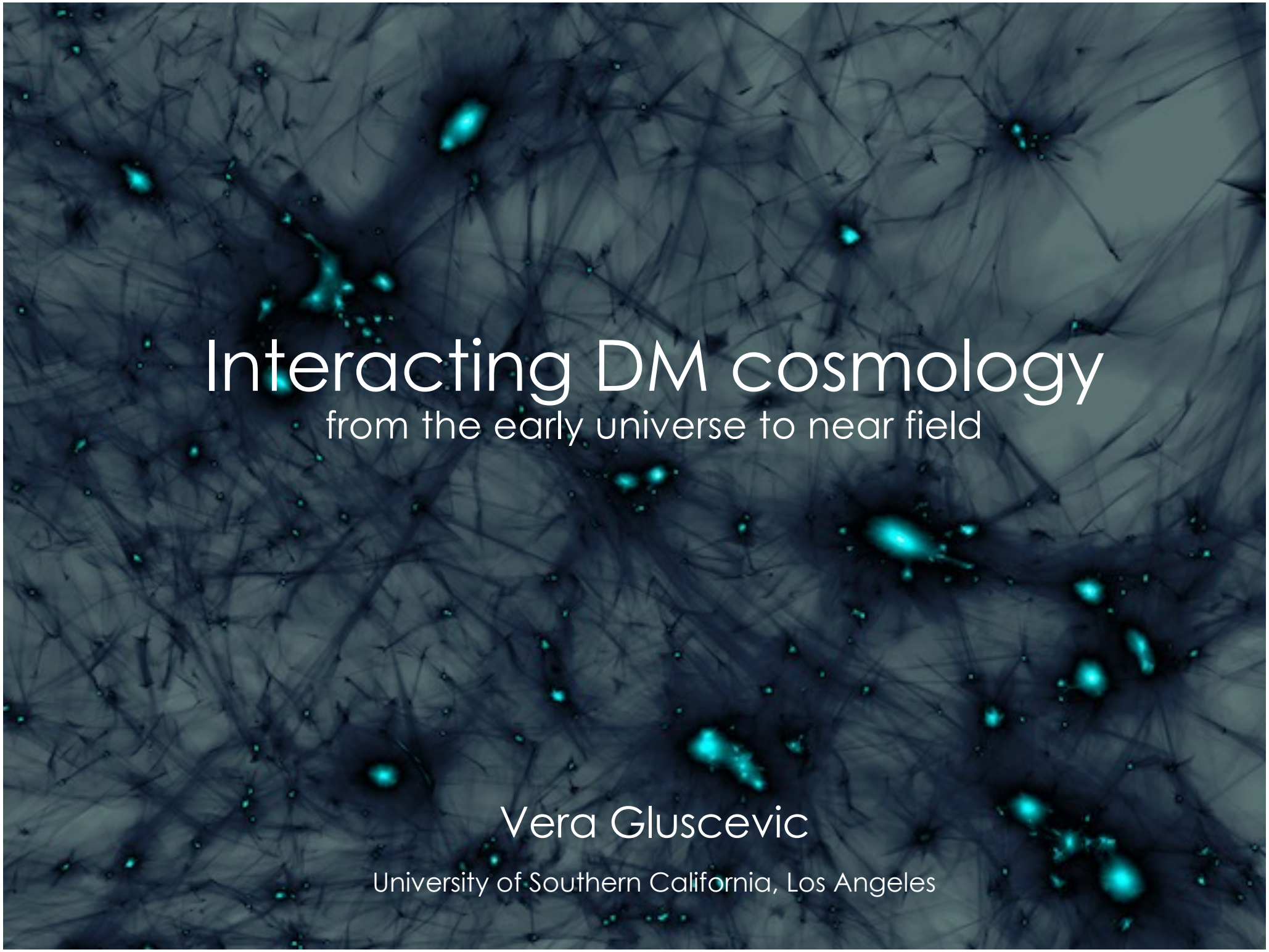
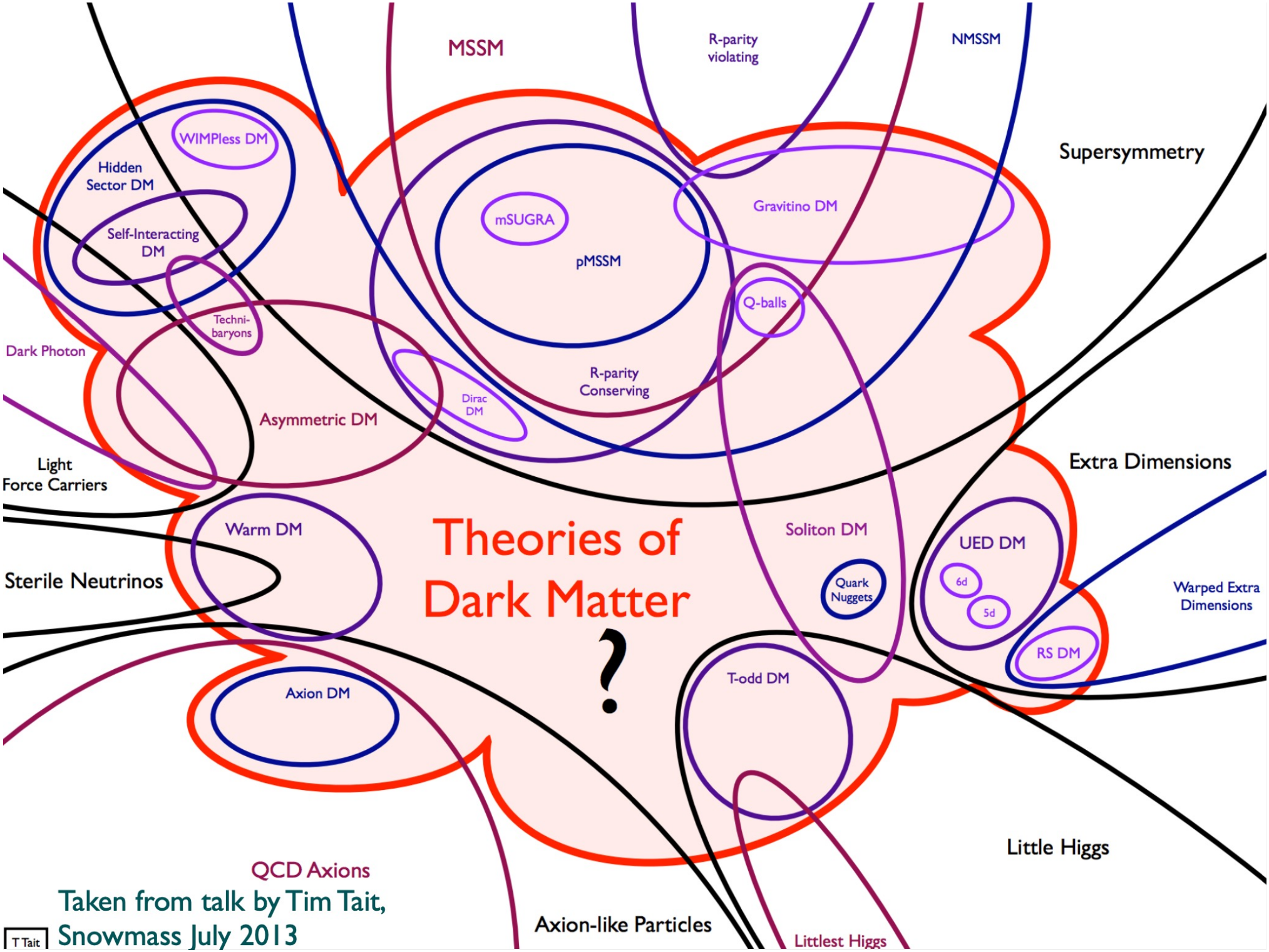


Interacting DM cosmology

from the early universe to near field

Vera Gluscevic

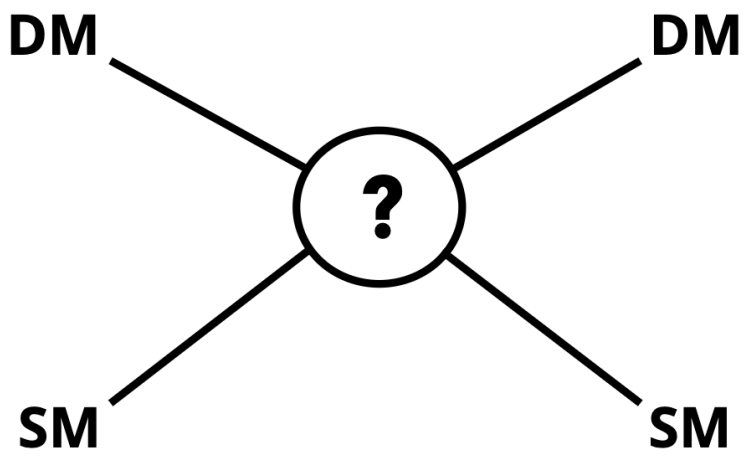
University of Southern California, Los Angeles



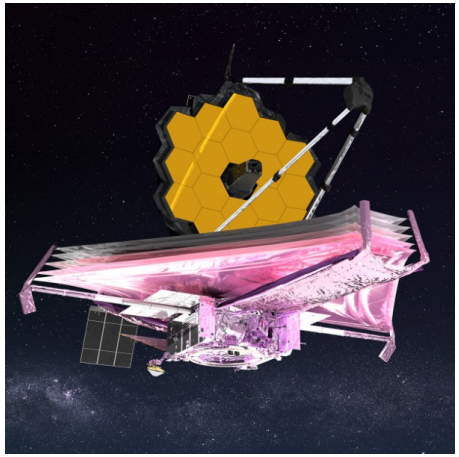
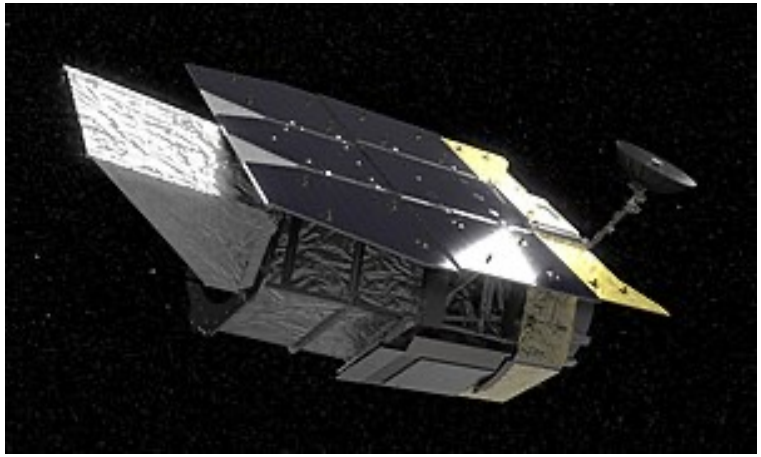
Taken from talk by Tim Tait, Snowmass July 2013

T Tait

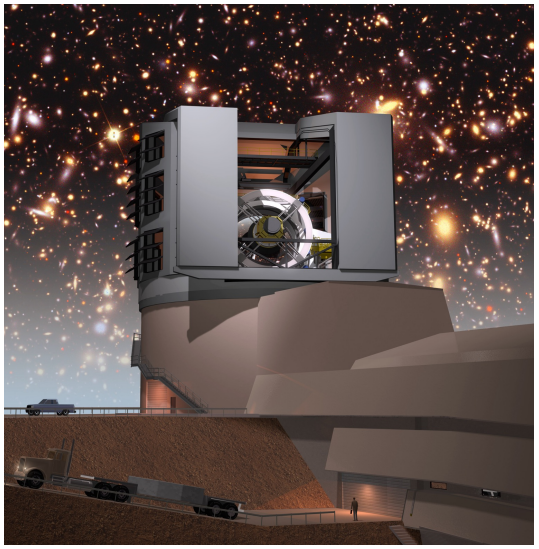
? mass, interactions, production ?



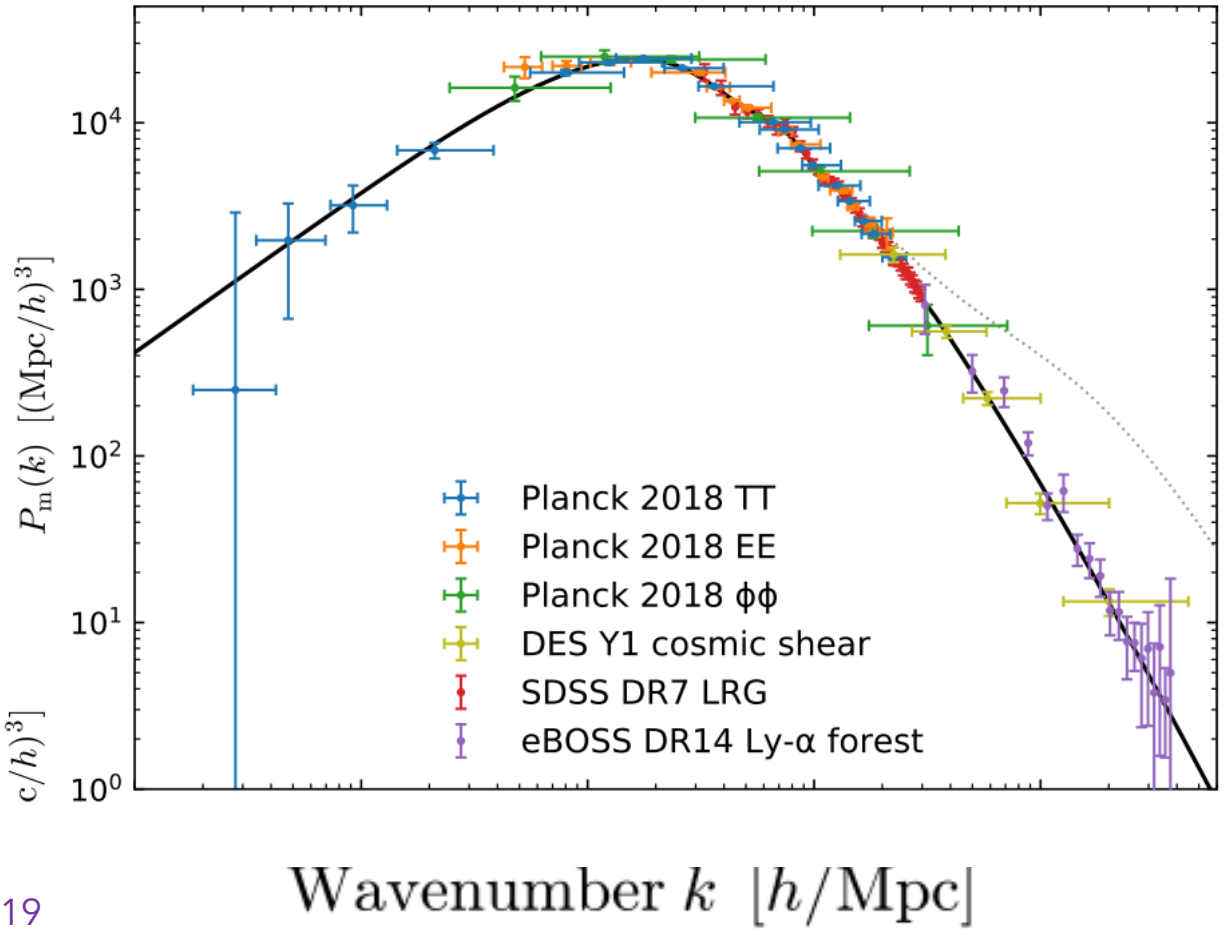
Data





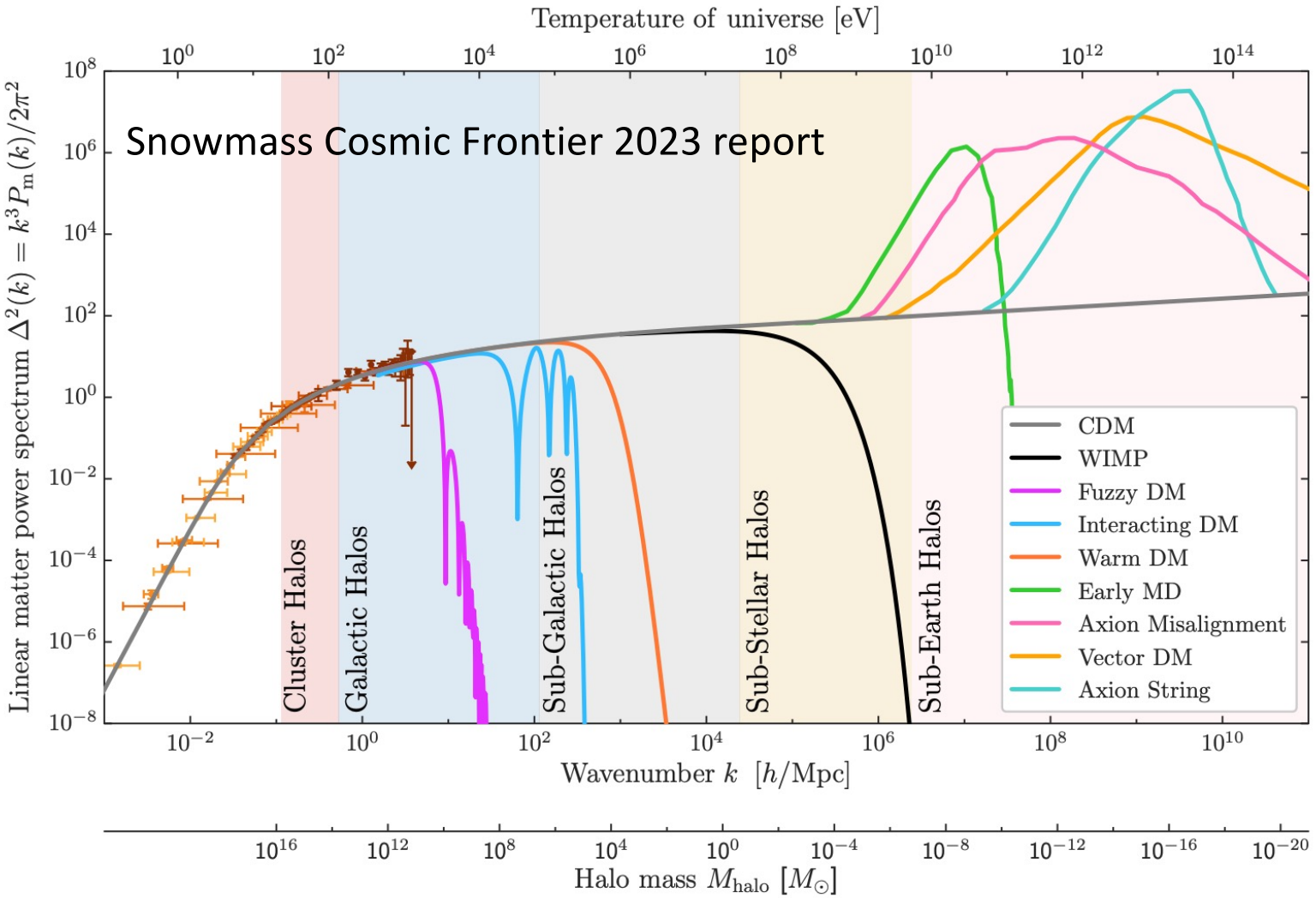
Distribution of matter: The Power Spectrum



Chabanier+ 2019

Lyman-alpha forest, dwarf galaxies, stellar streams, galaxy clustering, strong and weak lensing, intensity mapping, etc.

DM microphysics at the small-scale frontier



Lyman-alpha forest, dwarf galaxies, stellar streams, galaxy clustering, strong and weak lensing, intensity mapping, etc.

Outline

1. Bounds from linear theory

2. IDM in simulations

3. Insights from LSS

(Bonus: sterile neutrinos)

In collaboration with

Karime Maamari

Adam He

Wendy Crumrine

arxiv
2301.08299
2301.08260
2010.02936
2008.00022
1904.10000

Rui An

Ethan Nadler

Also: Mikhail Ivanov, Jordan Mirocha, Yue Zhang, Kim Boddy, Andrew Benson, Risa Wechsler, +DES and ACT Collaborations.

Outline

1. Bounds from linear theory
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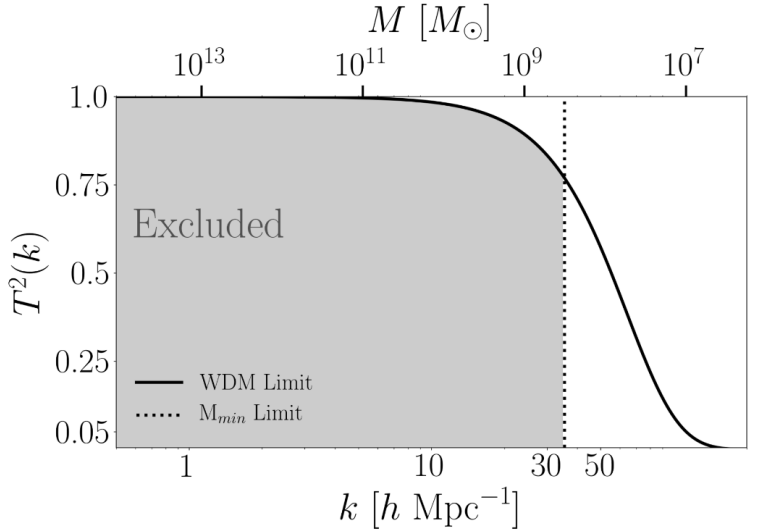
(Bonus: sterile neutrinos)

WDM bounds from satellites

Known MW satellites from DES + PanSTARRS + SDSS

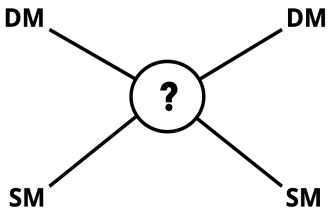
galaxy-halo connection model
(Nadler+ 2018)
+
mock observations

m_x > 6.5keV



Nadler, Gluscevic, Boddy, Wechsler (2019)
Nadler, DES+ (2020)

DM-baryon elastic scattering



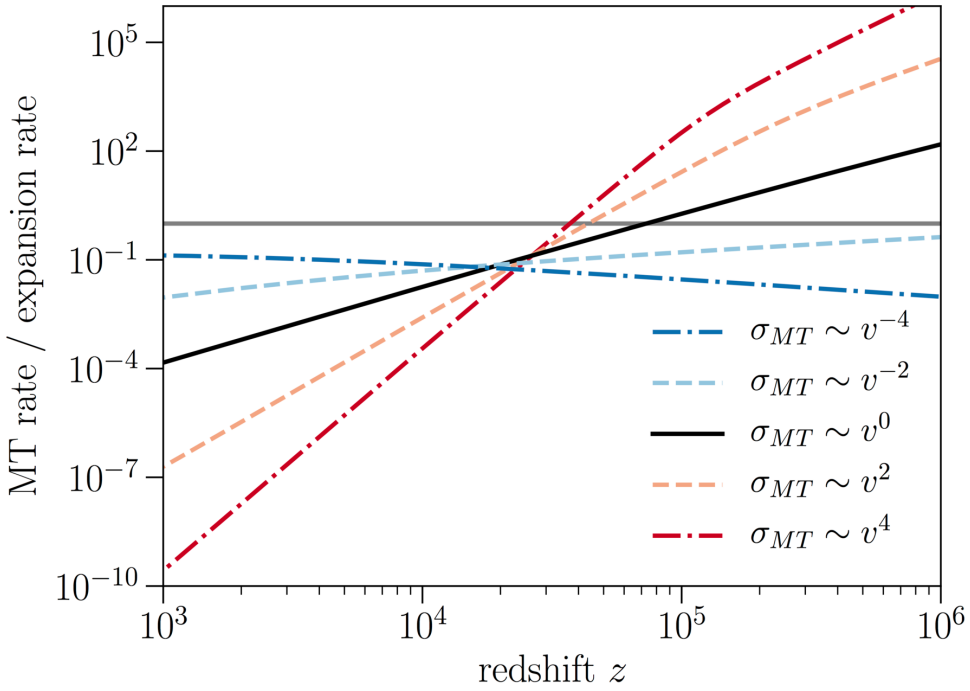
$$\sigma_{MT} = \sigma_0 v^n$$

momentum-transfer cross section

↓

momentum-transfer rate

$$R_\chi = a\rho_b \frac{\mathcal{N}_n \sigma_0}{m_\chi + m_b} \left(\frac{T_\chi}{m_\chi} + \frac{T_b}{m_b} \right)^{(n+1)/2}$$

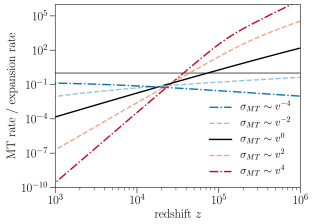


Boddy and VG 2018

Non-relativistic EFT operators describing contact interactions at low energy map to n>=0 cases, while n<0 arises due to interactions with very light mediators.

See: Fan+, 2010; Fitzpatrick+, 2012; Gresham and Zurek 2014; Anand+, 2013; VG, Boddy 2018

Collisional damping



Momentum transfer Rx = Hubble rate

σ_0, m_χ

↓

z_{crit}

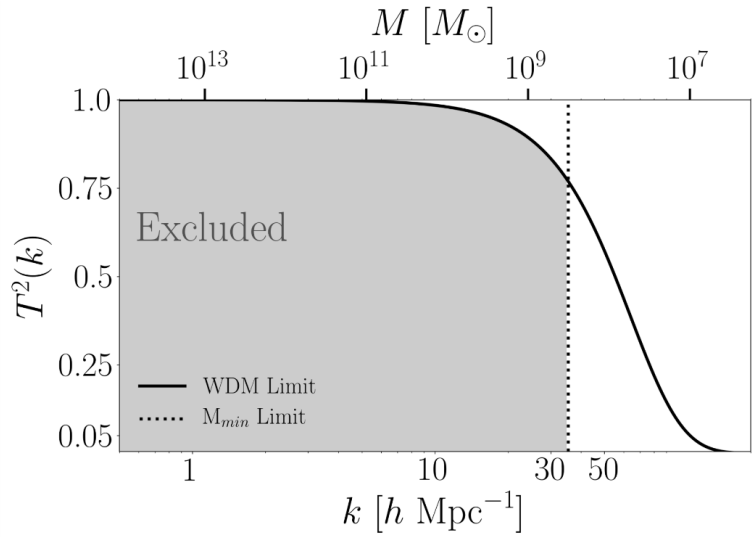
↓

↓

$k_{crit}(\sigma_0, m_\chi)$

↓

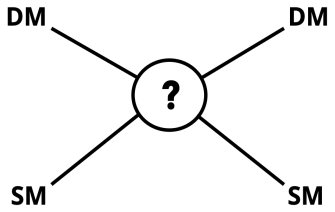
$M_{crit}(\sigma_0, m_\chi)$



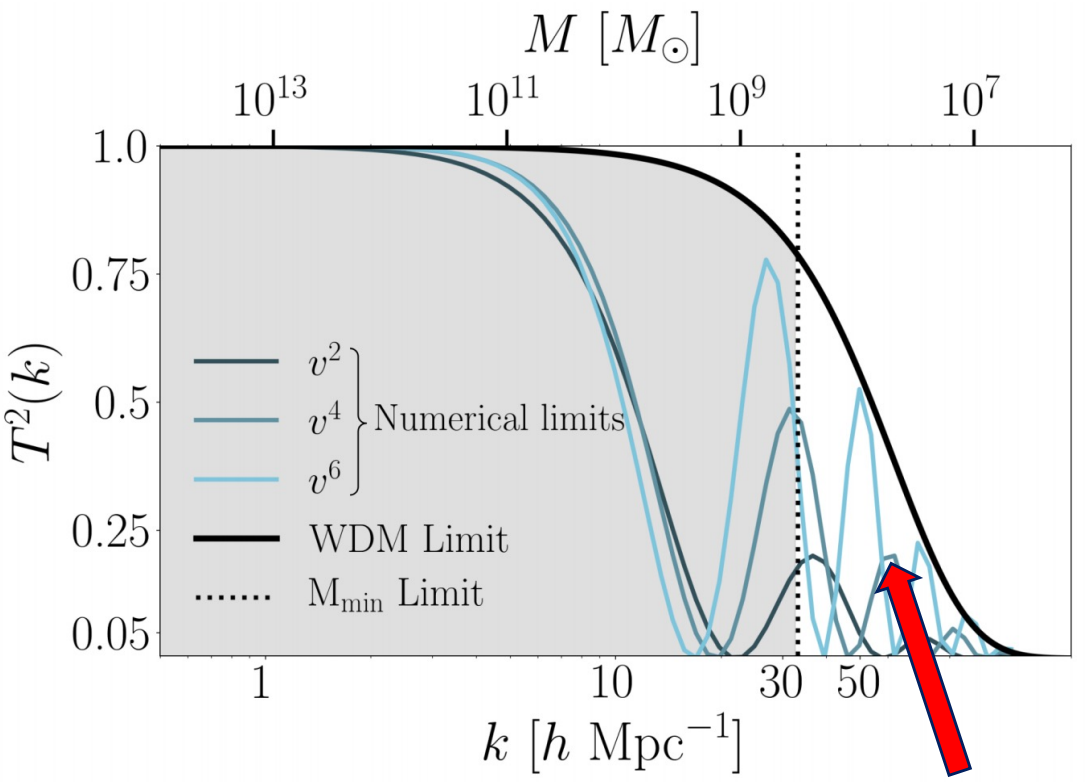
SDSS + DES + PanSTARRS: $M_{min} \sim 3.2 \times 10^8 M_{\rm sun}$

Nadler, Gluscevic, Boddy, Wechsler (2019)
DES+ (2020)

DM-baryon elastic scattering



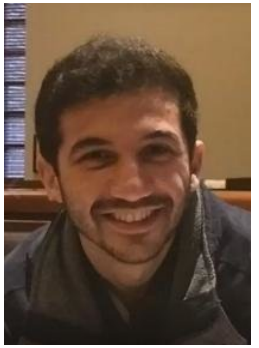
$$\sigma_{MT} = \sigma_0 v^n$$



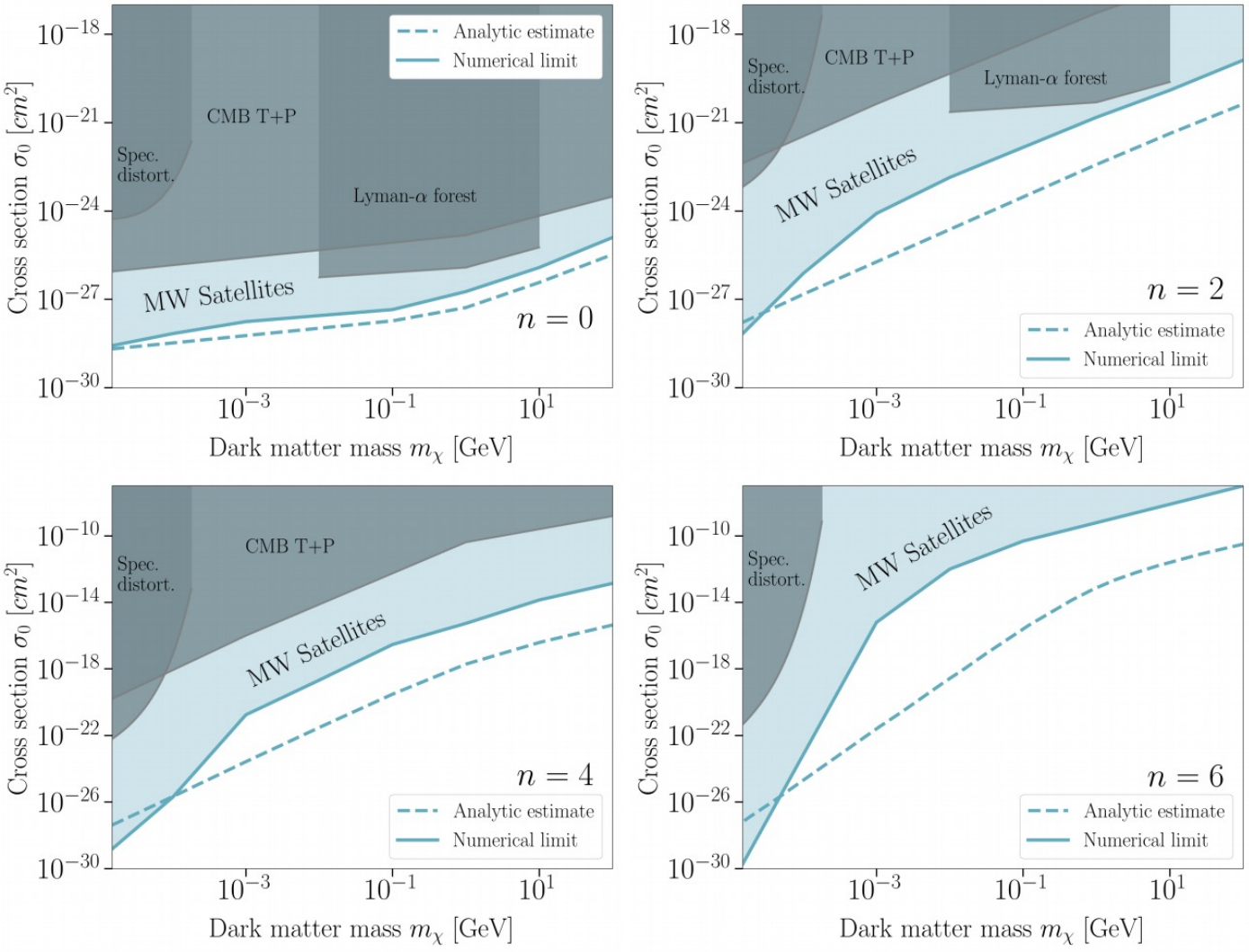
inconsistent

Maamari, Gluscevic, Nadler+ (2021), arXiv:2010.02936

DM-proton scattering bounds



Karime Maamari
(USC)



=>

3-5 OOM improvement.

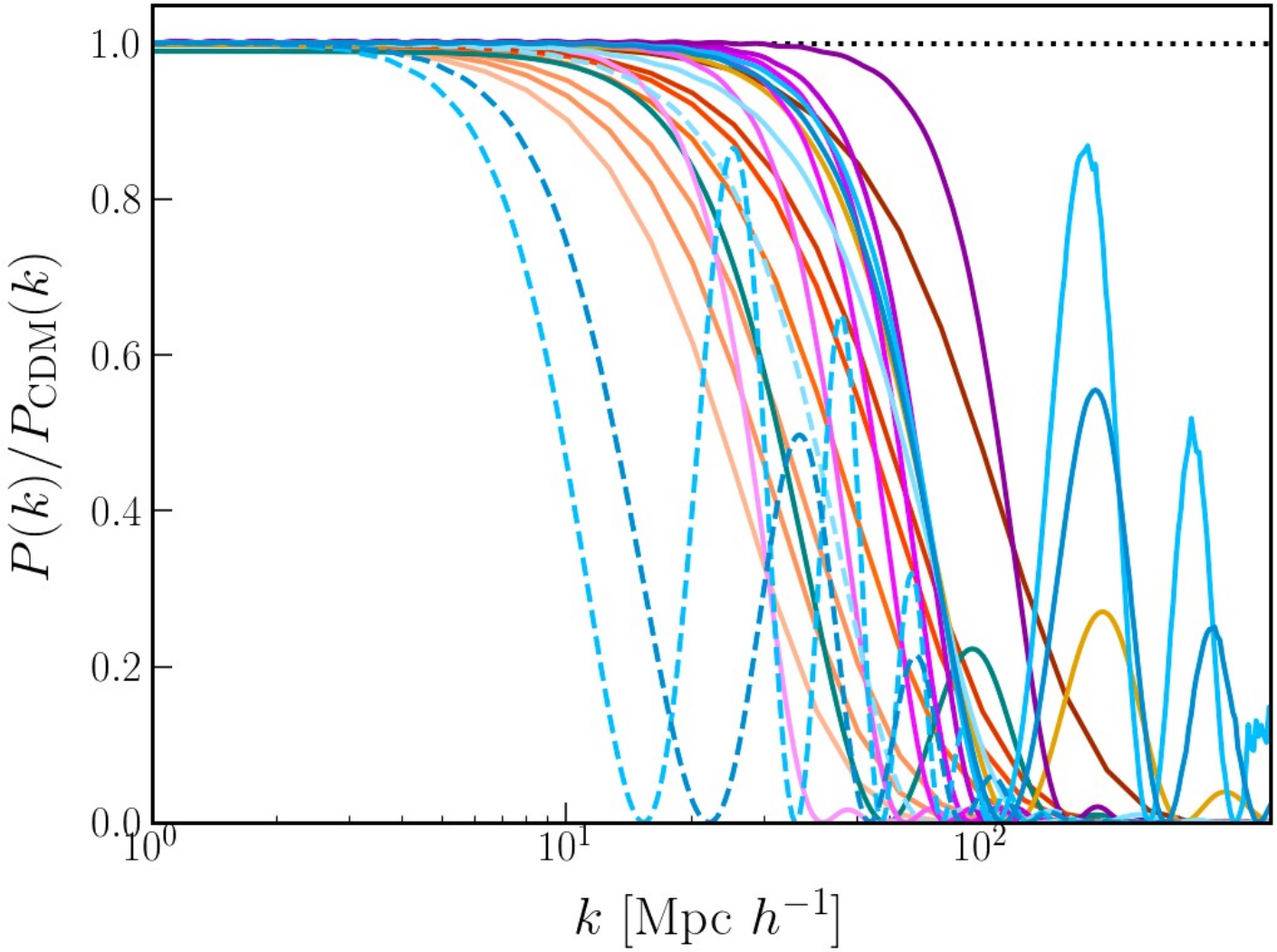
Maamari, Gluscevic,+ (2021), arXiv:2010.02936

Outline

1. Bounds from linear theory
2. IDM in simulations
3. Insights from LSS

(Bonus: sterile neutrinos)

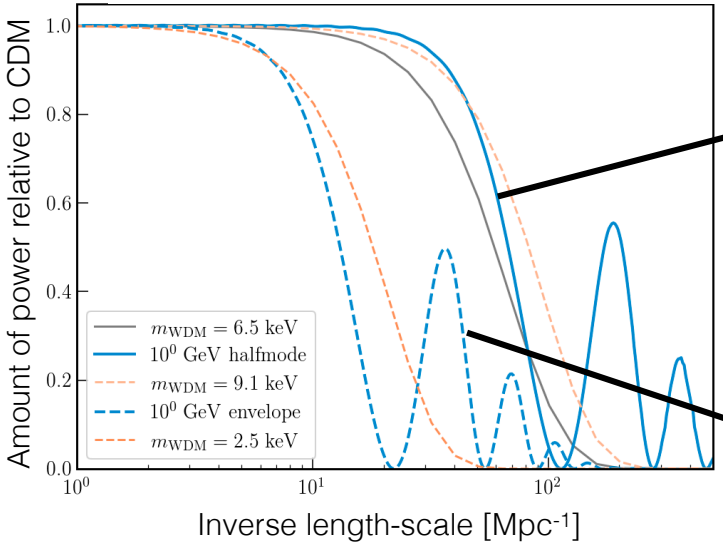
IDM transfer + N-body simulations + galaxy-halo model

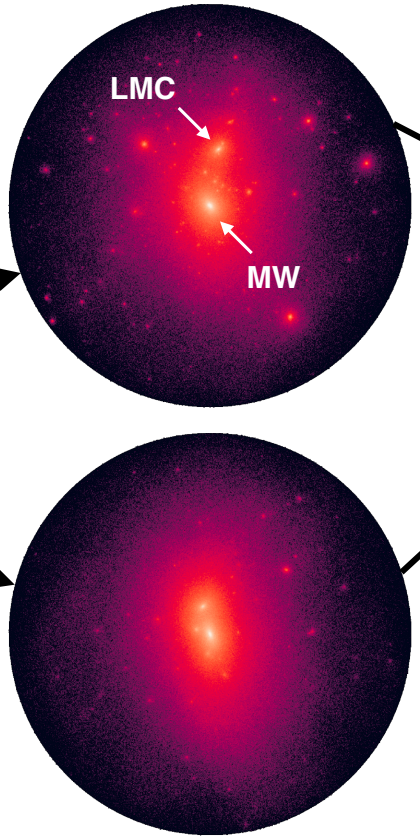


Plot by E. Nadler

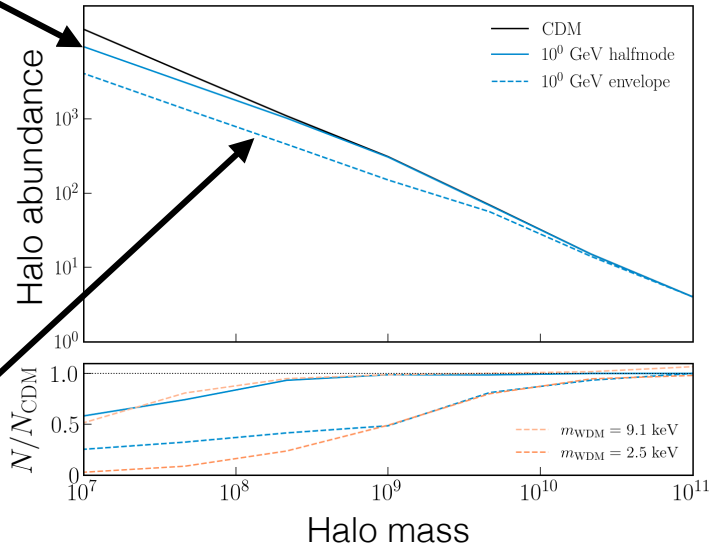
IDM ICs + DMO sims + galaxy-halo model

Initial conditions from linear theory





Halo and subhalo populations



72 cosmological simulations of Milky Way-like systems in various dark matter models: warm, ultra-light, interacting

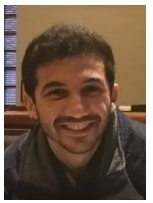
Ethan Nadler

Rui An

Andrew Benson

Expect improvement with current data: 2-3 OOM in bounds.

Hydrodynamical simulations with DM-baryon scattering



Karime Maamari

Ethan Nadler

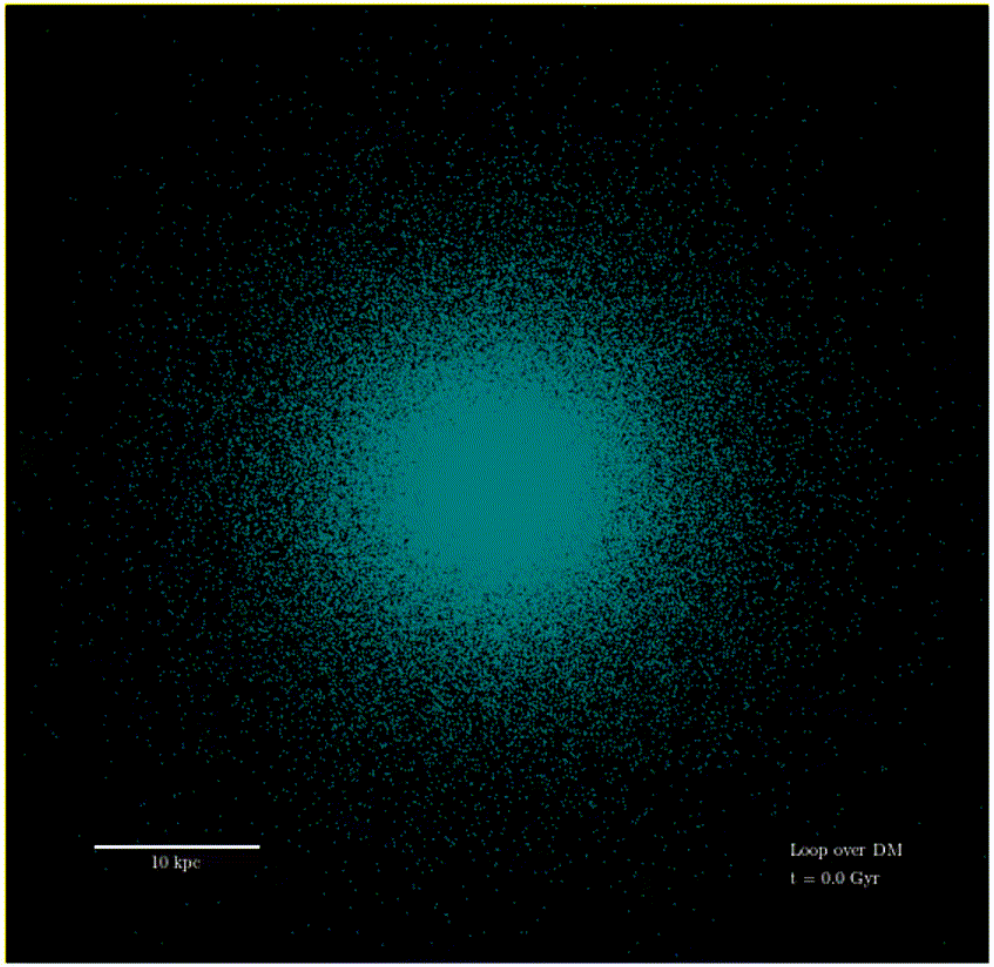
- ✓ Based on **Monte Carlo scattering algorithm**

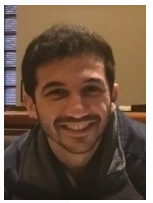
  [extension of SIDM case, Rocha+ 2013]

  - Assume isotropic scattering through contact interaction
  - Choose adaptive softening (evaluated locally, based on density)
  - Choose timestep such that interaction rate is small.
  - Compute interaction probability based on particle kernel overlap
  - If P > 0, do rejection sampling to decide whether scattering occurs
  - If scattering, choose random angle and exchange momenta self-consistently
- ✓ Modification of **gizmo** to include 2 fluids with rare interactions, but also model gas cooling, star formation, stellar feedback, and Agora ICs
- ✓ **Tests so far:** momentum transfer and interaction rate are consistent with analytic expectations in test systems, energy and momentum are conserved.

Hydrodynamical simulations with DM-baryon scattering

PRELIMINARY





Karime Maamari

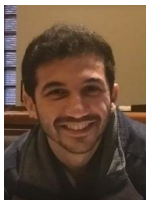
Ethan Nadler

Maamari, Nadler, Gluscevic, in prep.

Hydrodynamical simulations with DM-baryon scattering

Prediction:

$r_{dm} / r_b \sim m_b / m_{dm}$

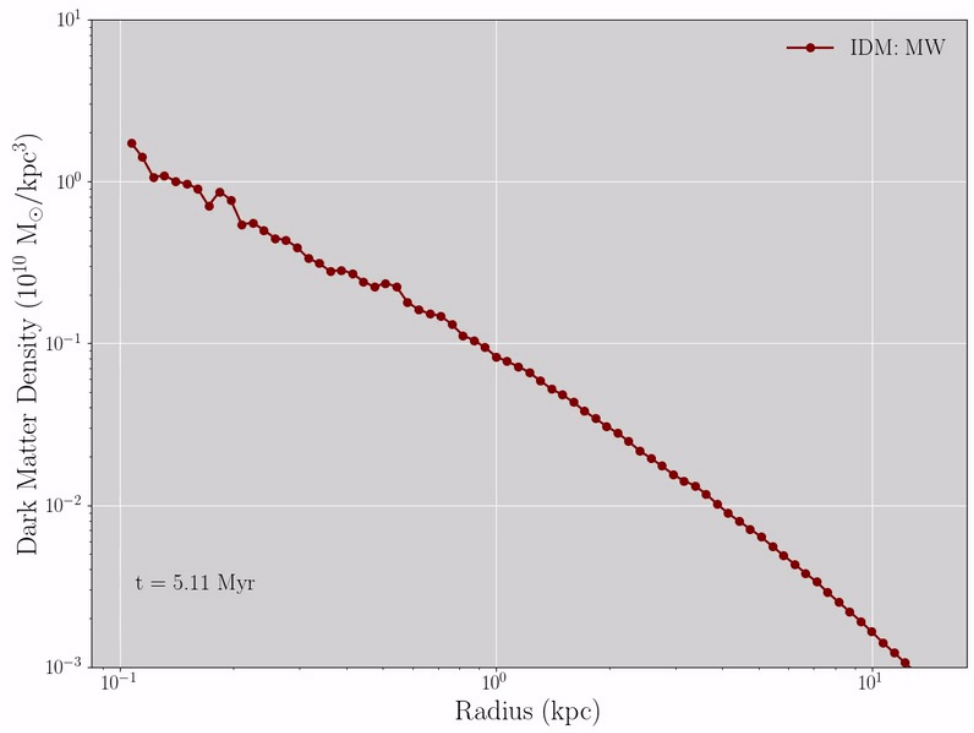


Karime Maamari

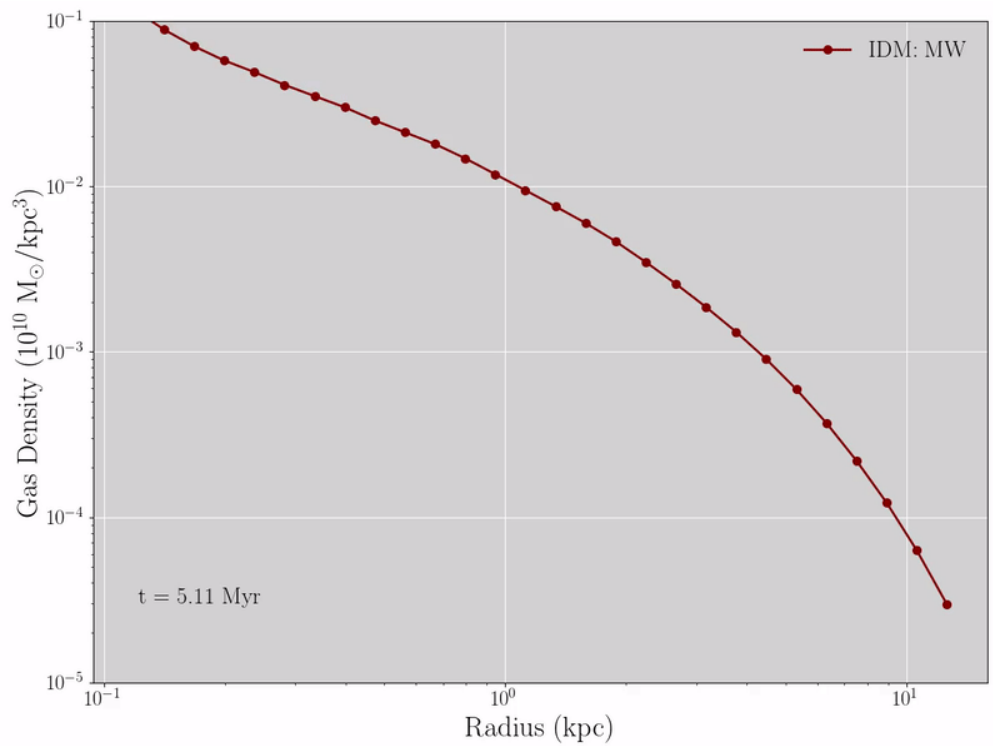
Ethan Nadler

PRELIMINARY

Dark matter

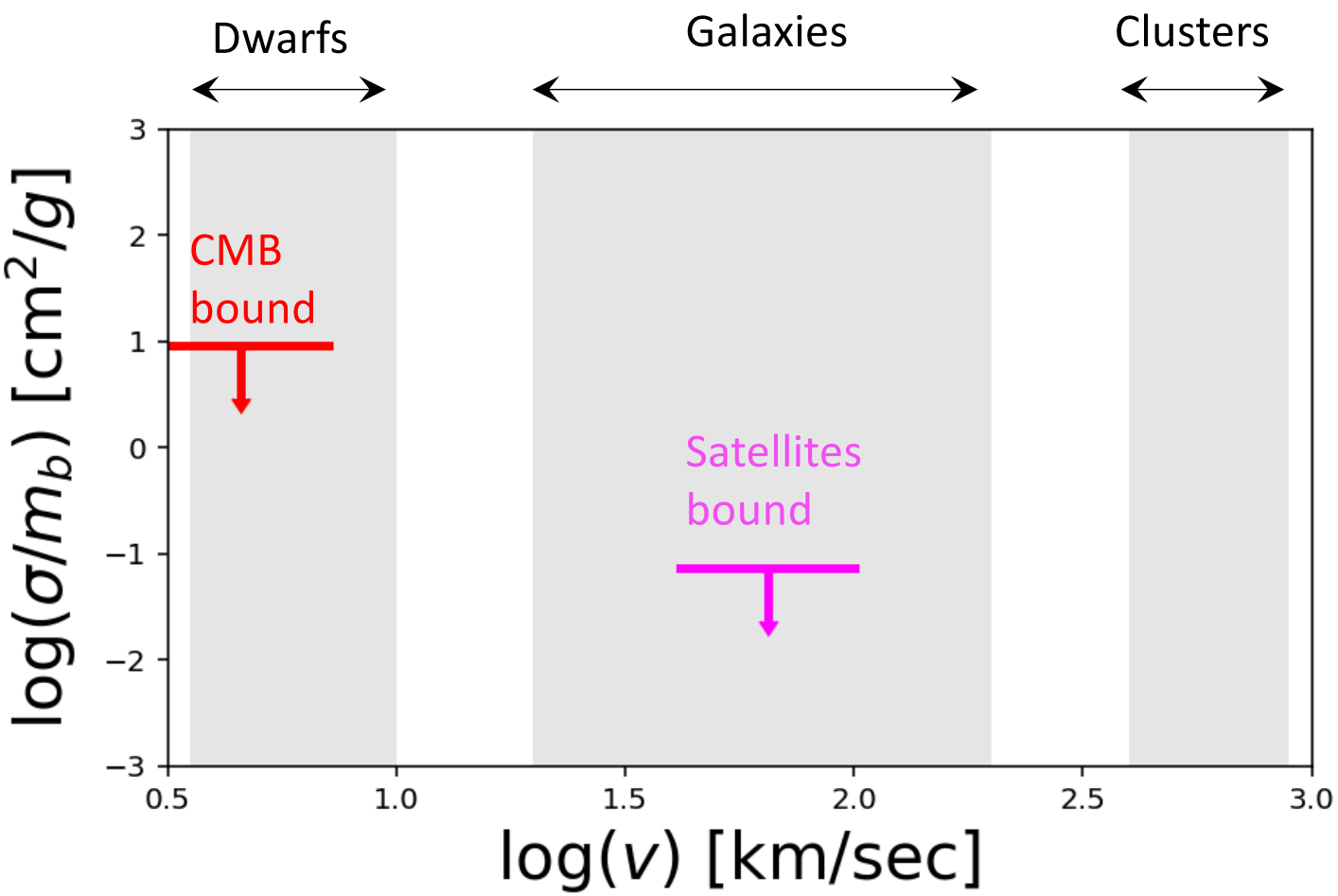


Gas



Maamari, Nadler, Gluscevic, in prep.

Probing interactions across (energy) scales



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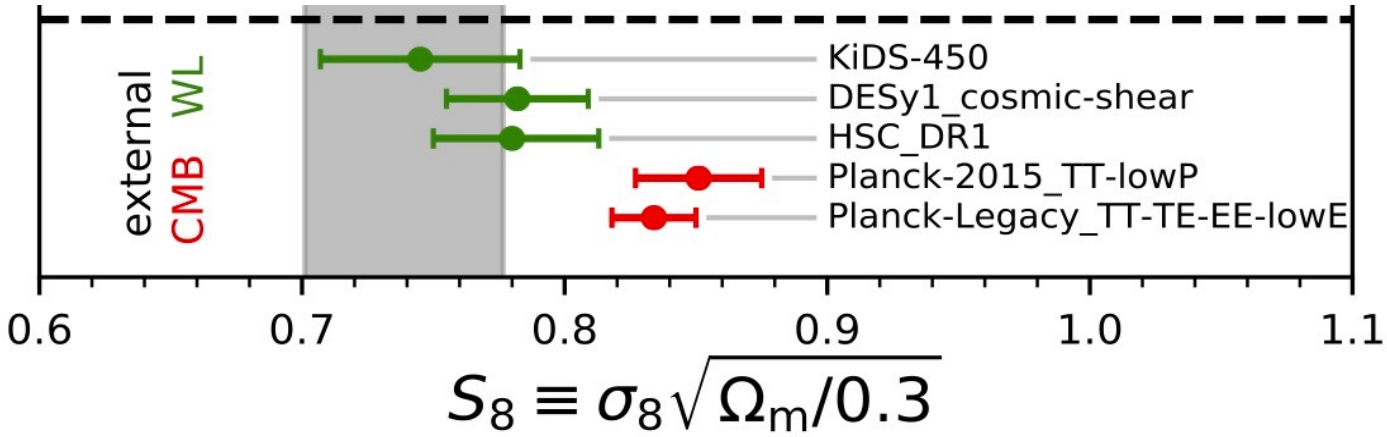
(Bonus: sterile neutrinos)

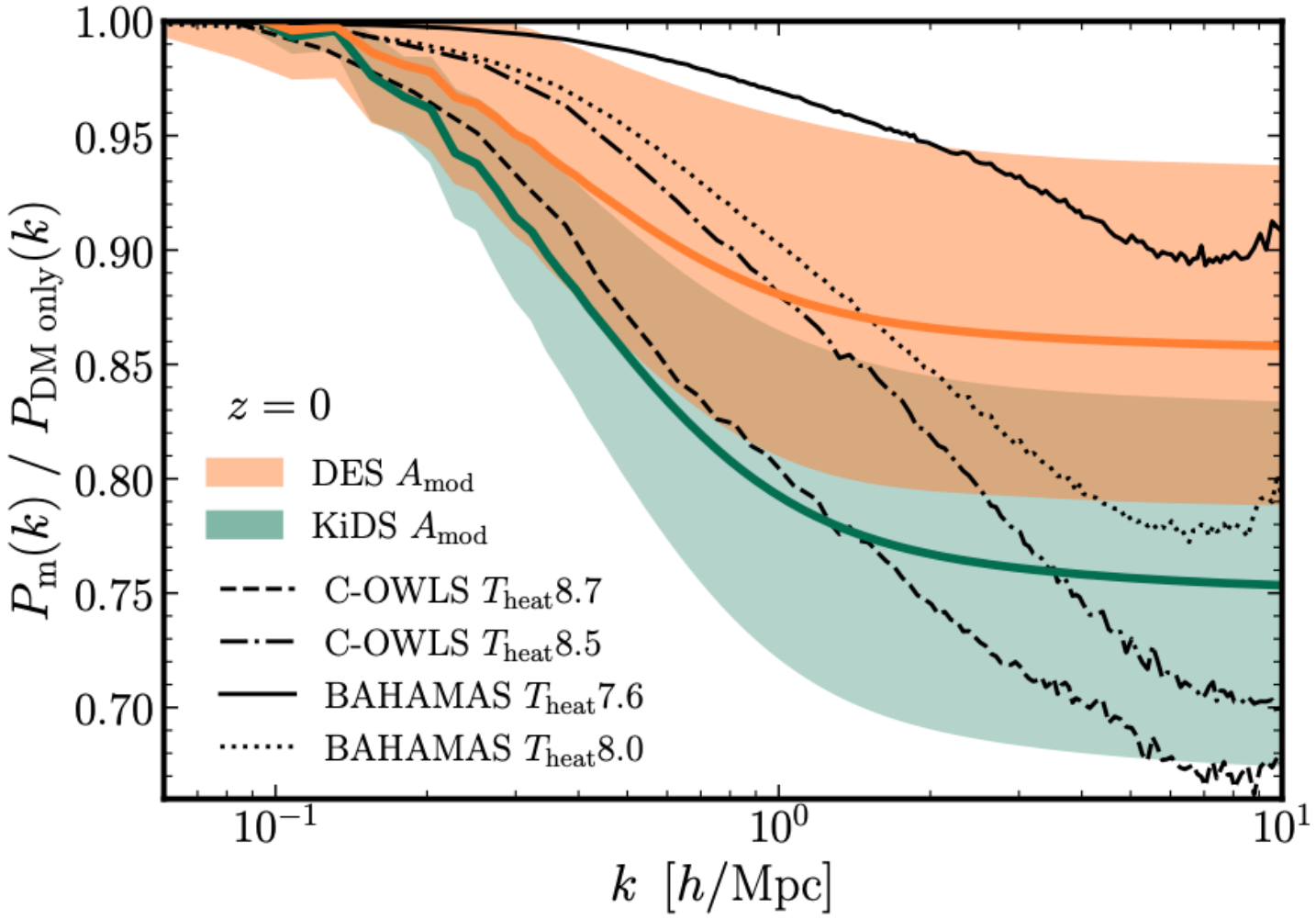
S8 tension

Less matter clustering is measured by weak lensing surveys, than anticipated by CMB + LCDM.



https://arxiv.org/pdf/2203.06142.pdf; Plot by KiDS collab.

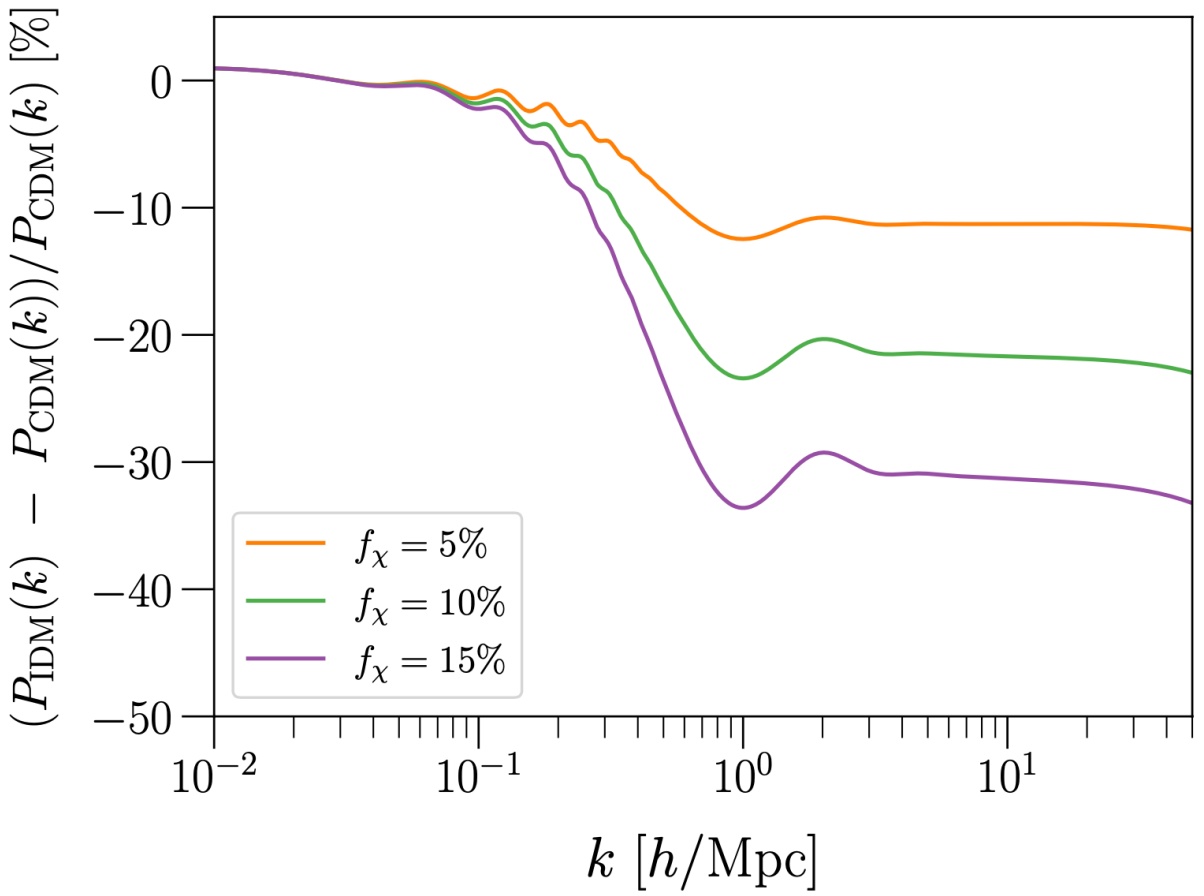
S8 tension = k-dependent suppression?



Amon and Efstathiou (2022), Preston+ (2023)

S8 tension: IDM?

Adam He

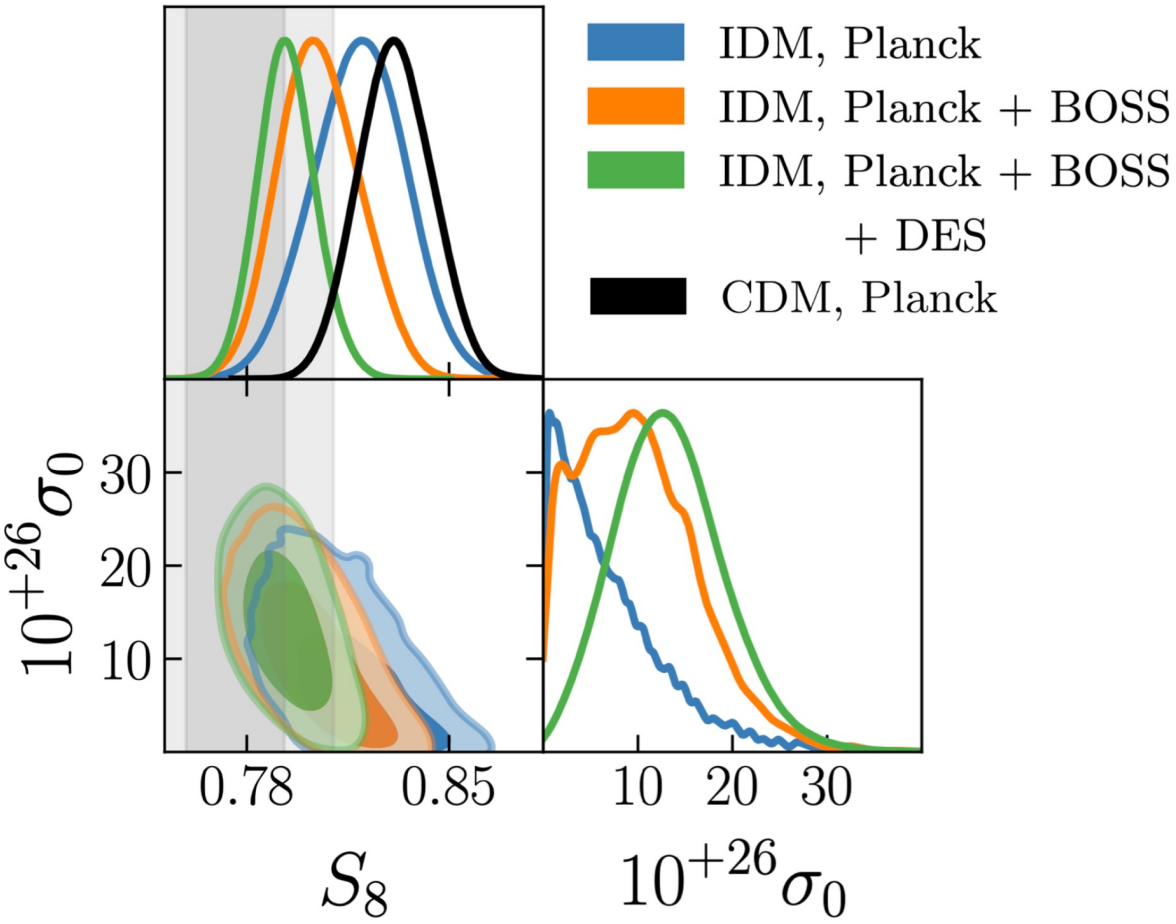


$$\sigma_{MT} = \sigma_0 v^n$$

He, Ivanov, An, Gluscevic (2023)

Does IDM alleviate S8 tension?

Adam He

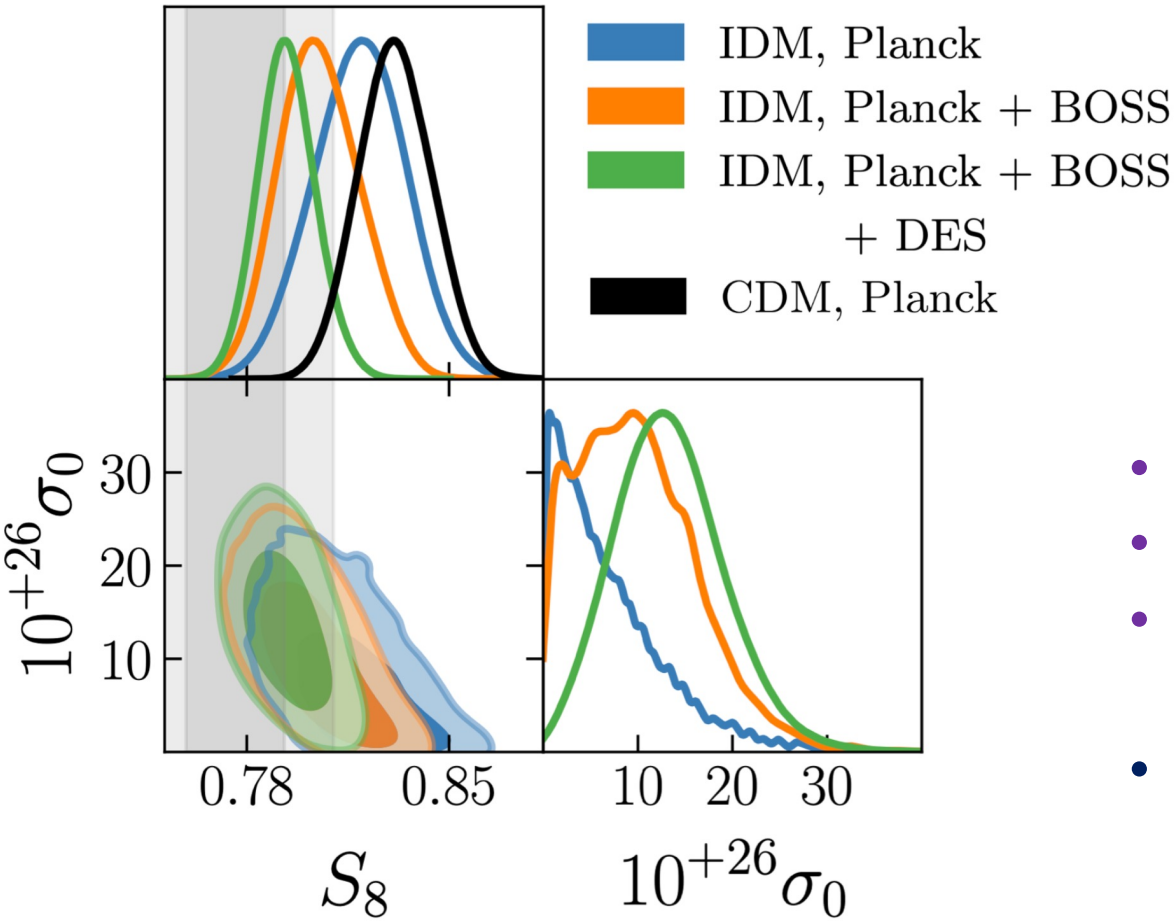


Model	ΛCDM, *Planck* + BOSS + DES	IDM, *Planck* + BOSS + DES
σ_0 $[10^{-26}$ cm$^2]$	–	$13.23\ (5.163)^{+5.2}_{-6.5}$
S_8	$0.813\ (0.813) \pm 0.009$	$0.794\ (0.804)^{+0.009}_{-0.01}$
$\Delta\chi^2_{\rm min}$	–	-6.7

He, Ivanov, An, Gluscevic (2023)

Does IDM alleviate S8 tension?

Adam He



- **Pre-tension physics**
- **Consistent across data**
- **Does not mess up H0**

- **Soon falsifiable with small scale data??**

Model	ΛCDM, *Planck* + BOSS + DES	IDM, *Planck* + BOSS + DES
σ_0 $[10^{-26}$ cm$^2]$	–	$13.23\ (5.163)^{+5.2}_{-6.5}$
S_8	$0.813\ (0.813) \pm 0.009$	$0.794\ (0.804)^{+0.009}_{-0.01}$
$\Delta\chi^2_{\rm min}$	–	-6.7

He, Ivanov, An, Gluscevic;
ApJL 2023

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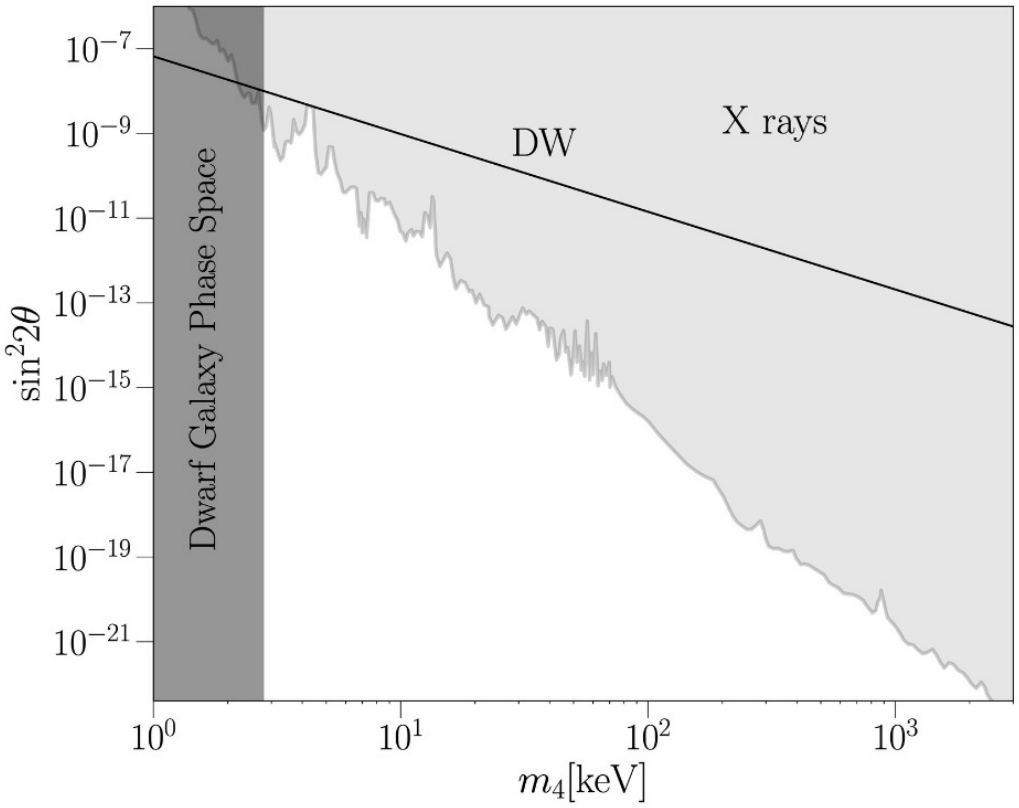
(Bonus: sterile neutrinos)

Sterile neutrinos by Dodelson & Widrow

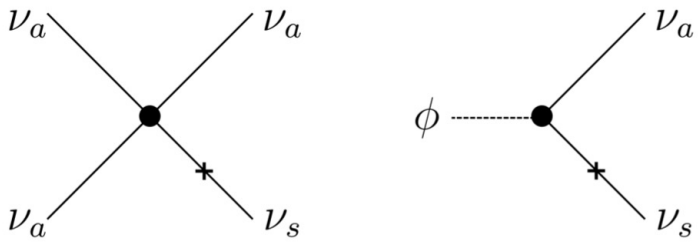
$$\nu_4 = \cos\theta\,\nu_s + \sin\theta\,\nu_a$$

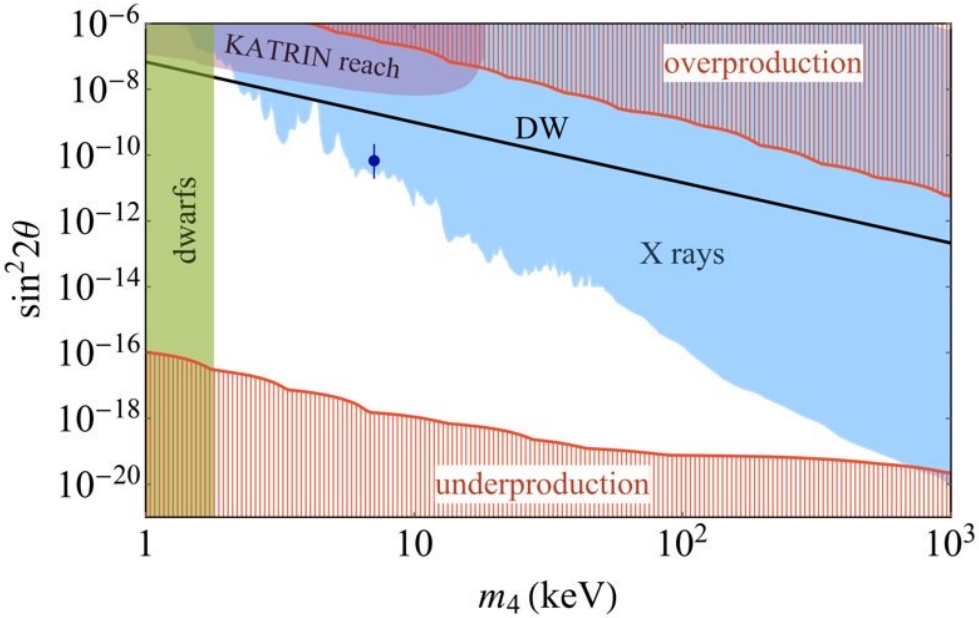


Problem: sterile nus decay and produce observable X-rays.

Sterile neutrinos + **neutrino self-interactions**

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

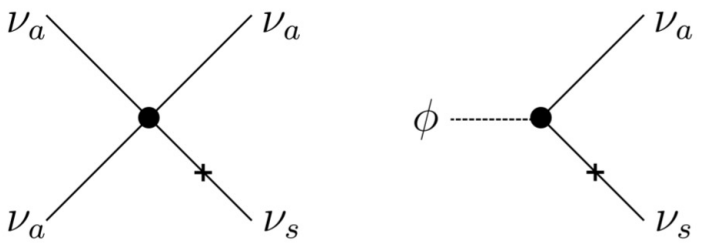




de Gouvea + (2019), etc.

Sterile neutrinos + **neutrino self-interactions**

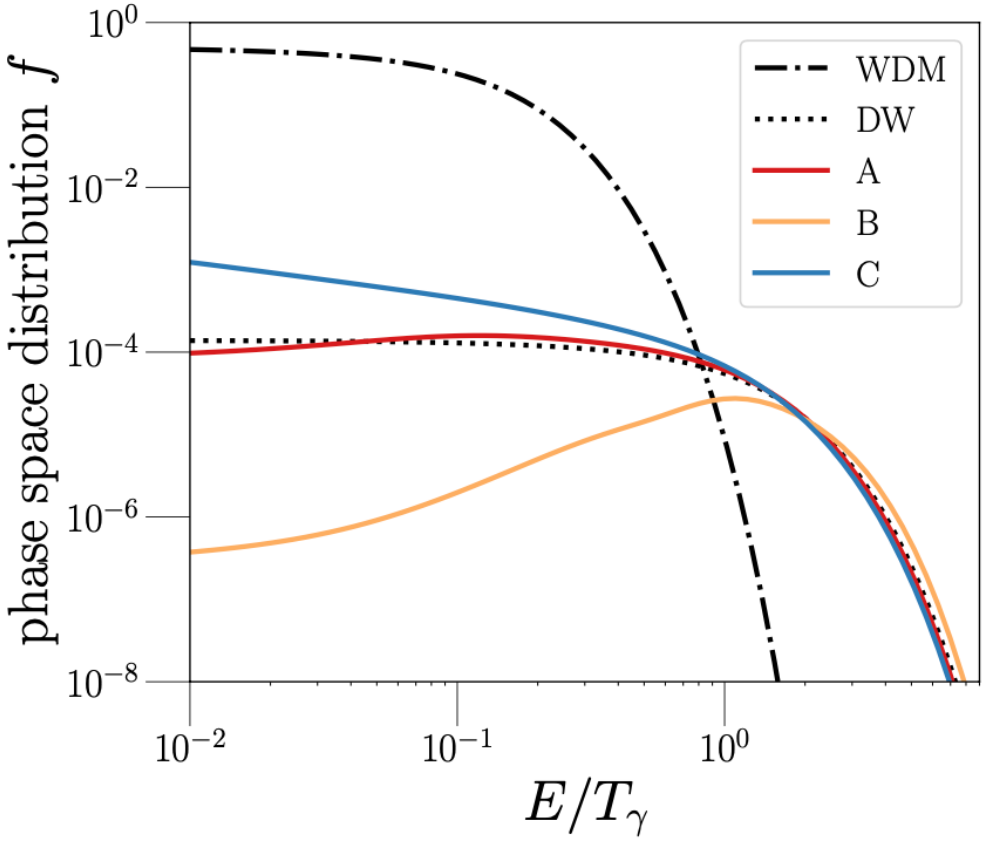
Rui An



Case A (heavy ϕ)

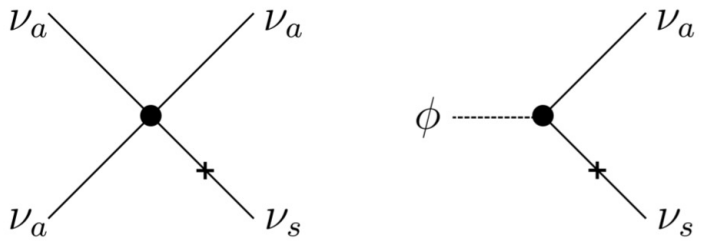
Case B (light ϕ)

Case C (light ϕ)



Sterile neutrinos + **neutrino self-interactions**

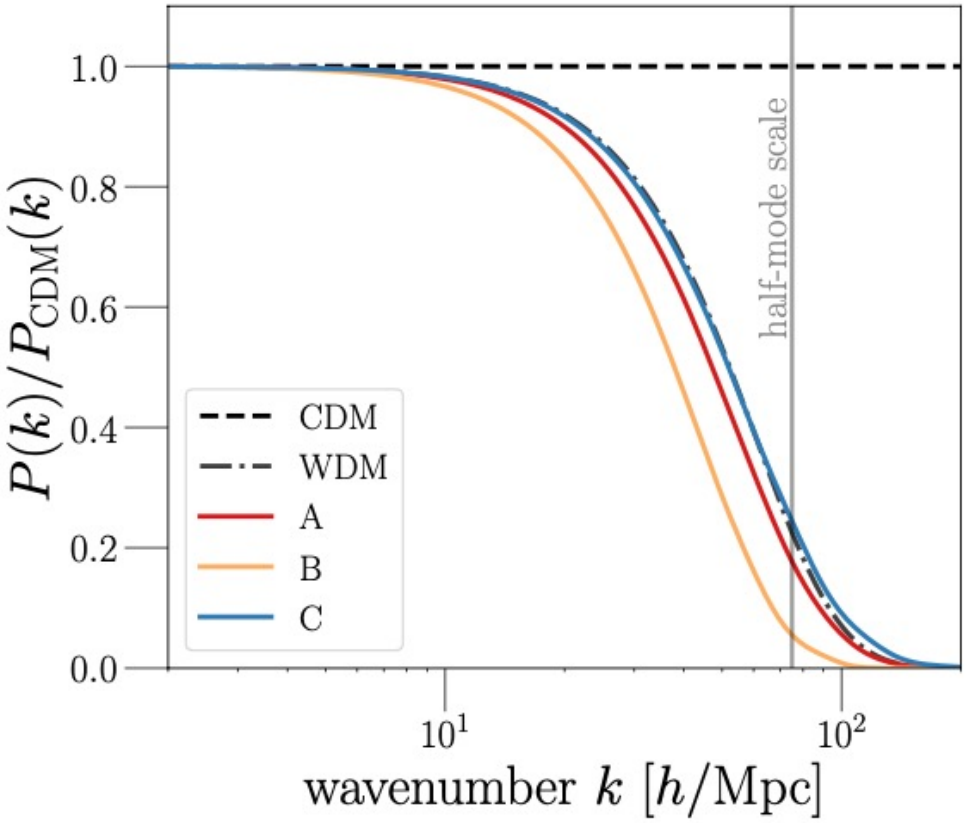
Rui An



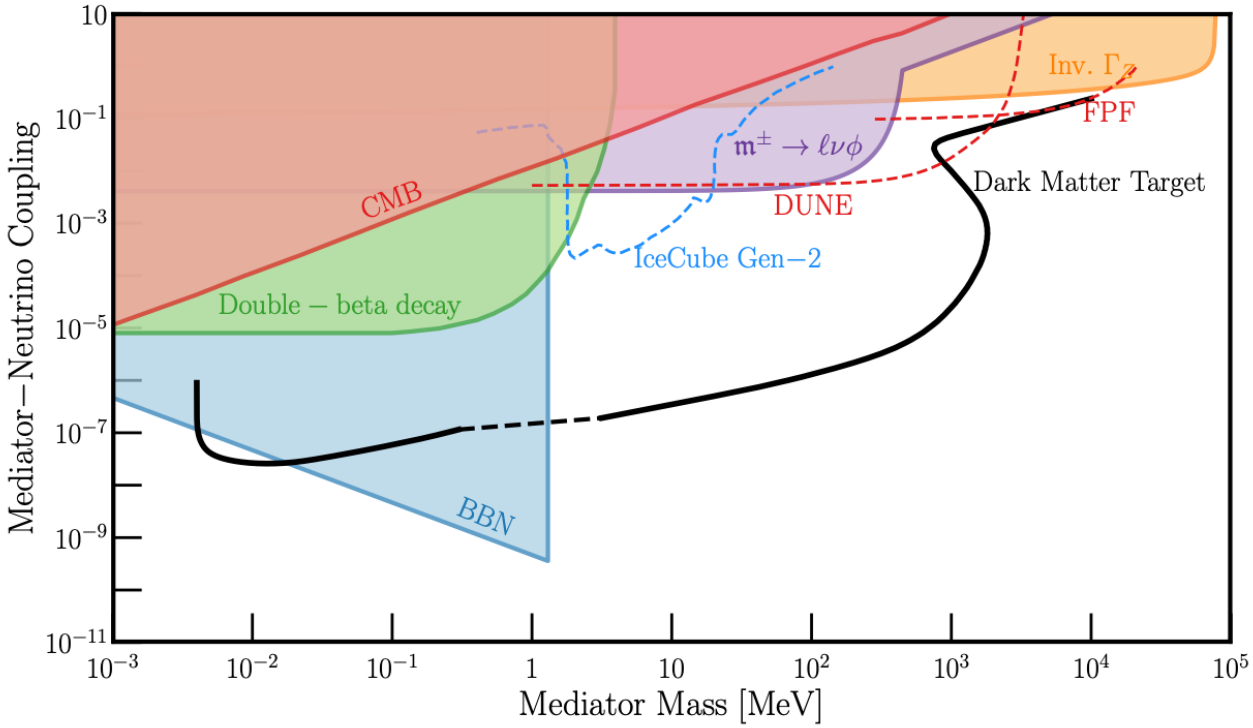
Case A (heavy ϕ)

Case B (light ϕ)

Case C (light ϕ)



Lab bounds on neutrino self-interactions

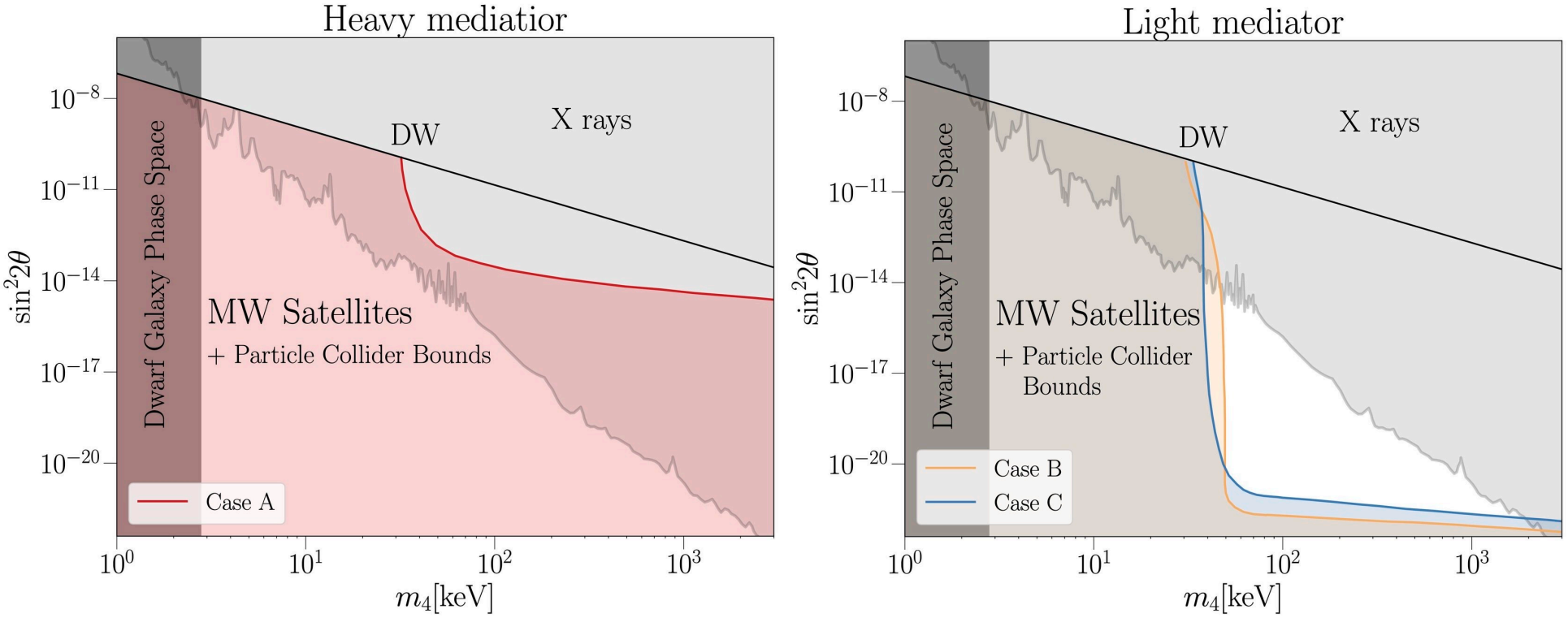


https://arxiv.org/pdf/2203.01955.pdf

New bounds on sterile neutrinos (with neutrino self-interactions)

Rui An

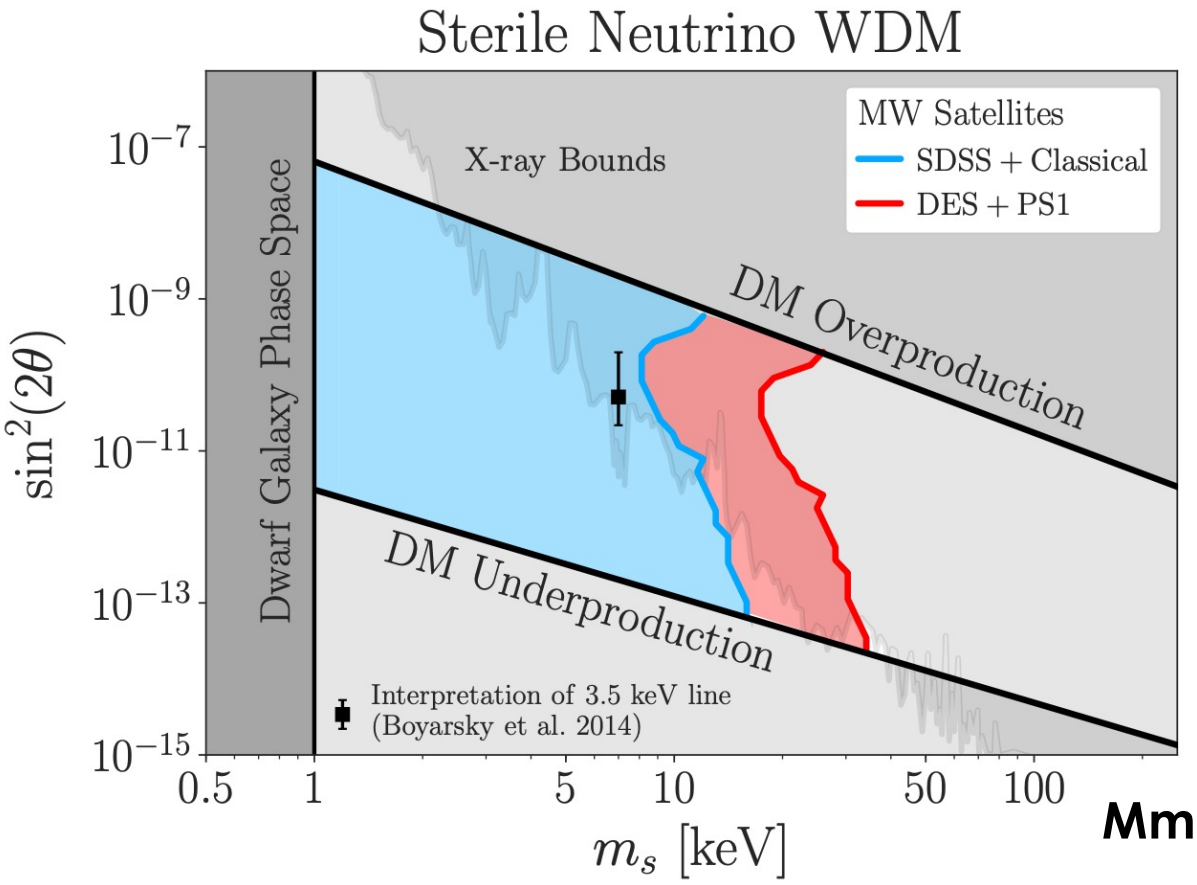
Mediators > 1GeV are ruled out.



An, Gluscevic, Nadler, Zhang (2023)

Shi-Fuller mechanism is also ruled out (for 100% DM)

Ethan Nadler
(USC/Carnegie)

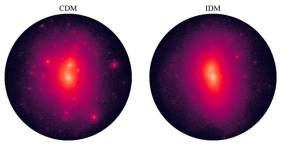


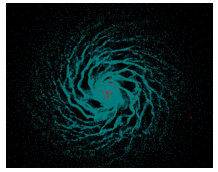
Mmin < 10^8 Msun

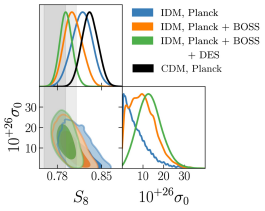
Nadler, DES+ (2020)
2008.00022

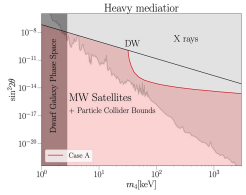
***Including:** realistic modeling of galaxy-halo connection (incl. disruption of subhalos by the Milky Way disk) and mock observations of the satellite abundance (luminosity, size, and radial distribution).

Key Points









- Small scale structure and **MW satellite population bounds** already drive the IDM frontier.
- Improvement of <u>up to 3 OOM</u> with current data expected, when correct ICs are taken into account for **velocity-dependent DM-baryon scattering.**
- **Late-time DM-proton interactions**, now in hydrodynamical simulations, can modify internal properties of halos in new ways (differentiation?).
- DM-baryon scattering **alleviates S8 tension** at larger scales, through scale-dependent power suppression. Testable soon on small scales?
- **Bonus: Sterile neutrino** DM is heavily constrained by small scale structure, regardless of the initial phase space density.