Dark matter and neutrino physics with cosmology

Vera Gluscevic

University of Southern California

Visualization by E. Nadler

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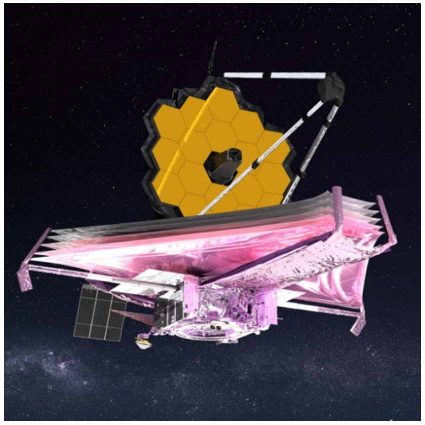
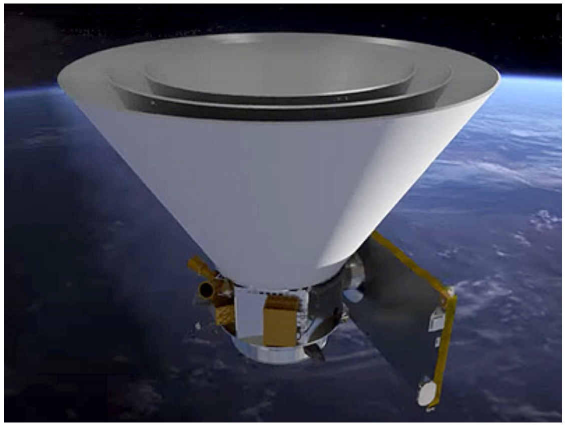
Data landscape



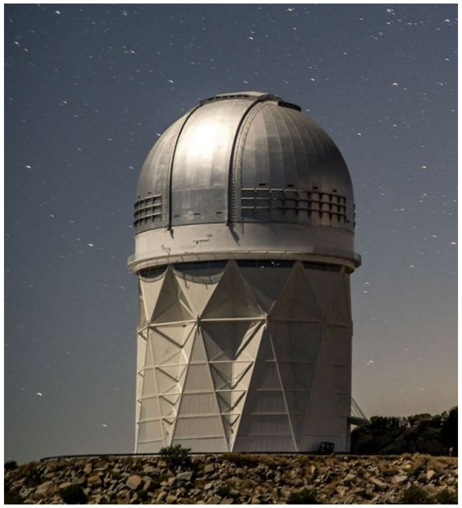
JWST



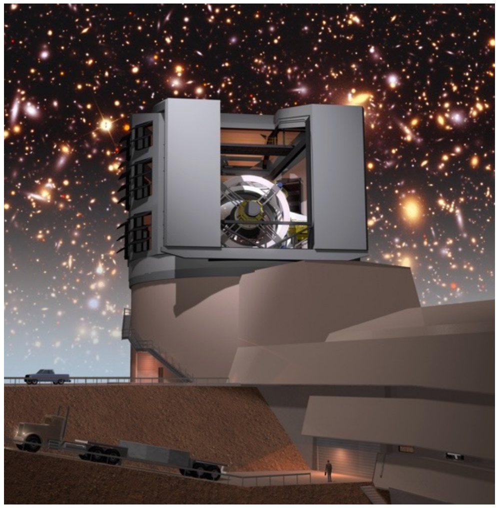
SPHEREx

Simons Observatory

DES

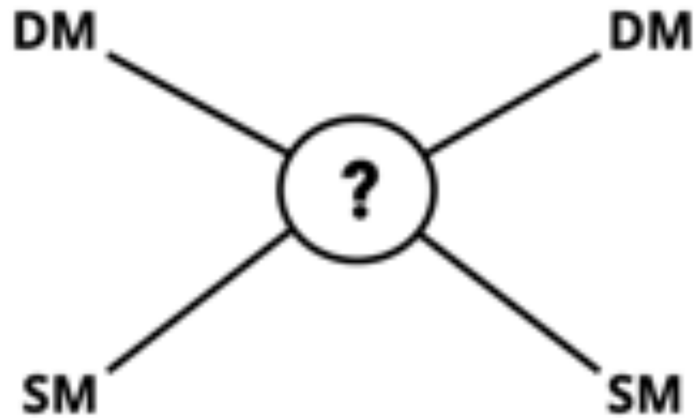


DESI



Vera C. Rubin Observatory

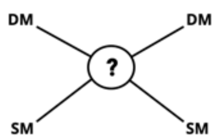
mass, interactions, production = ?

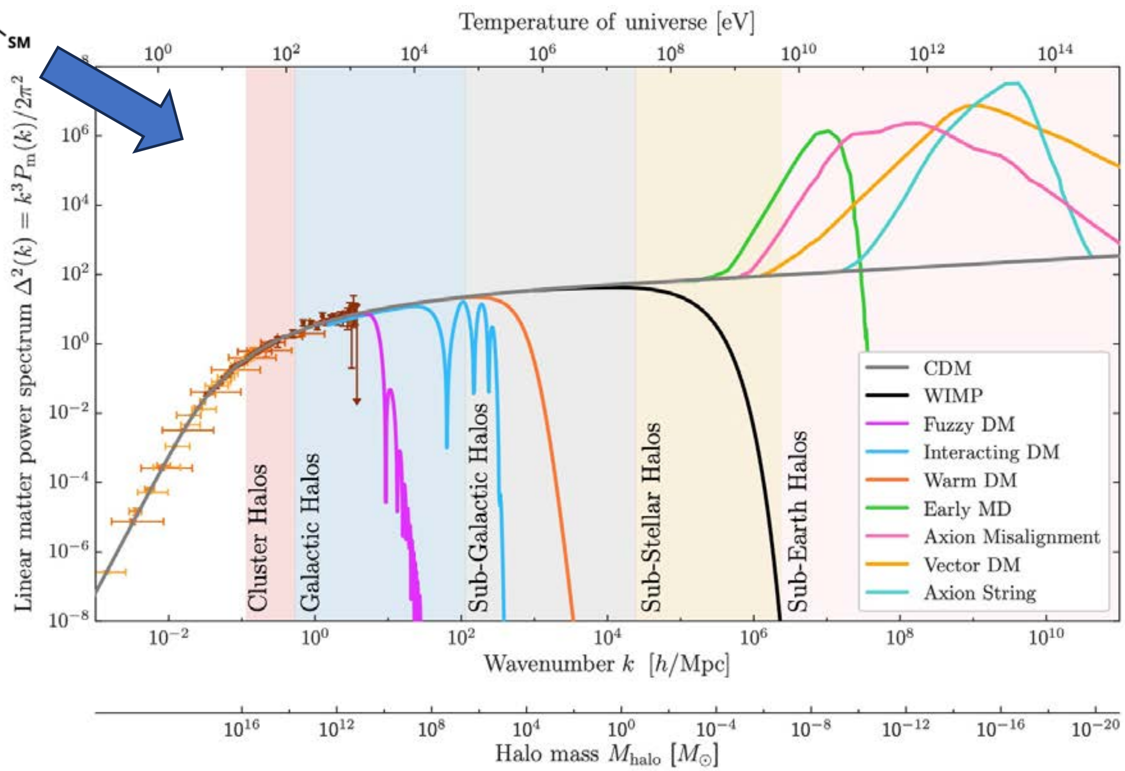


Cosmological consequences?

Matter distribution

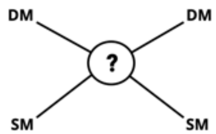
distribution of matter in the universe

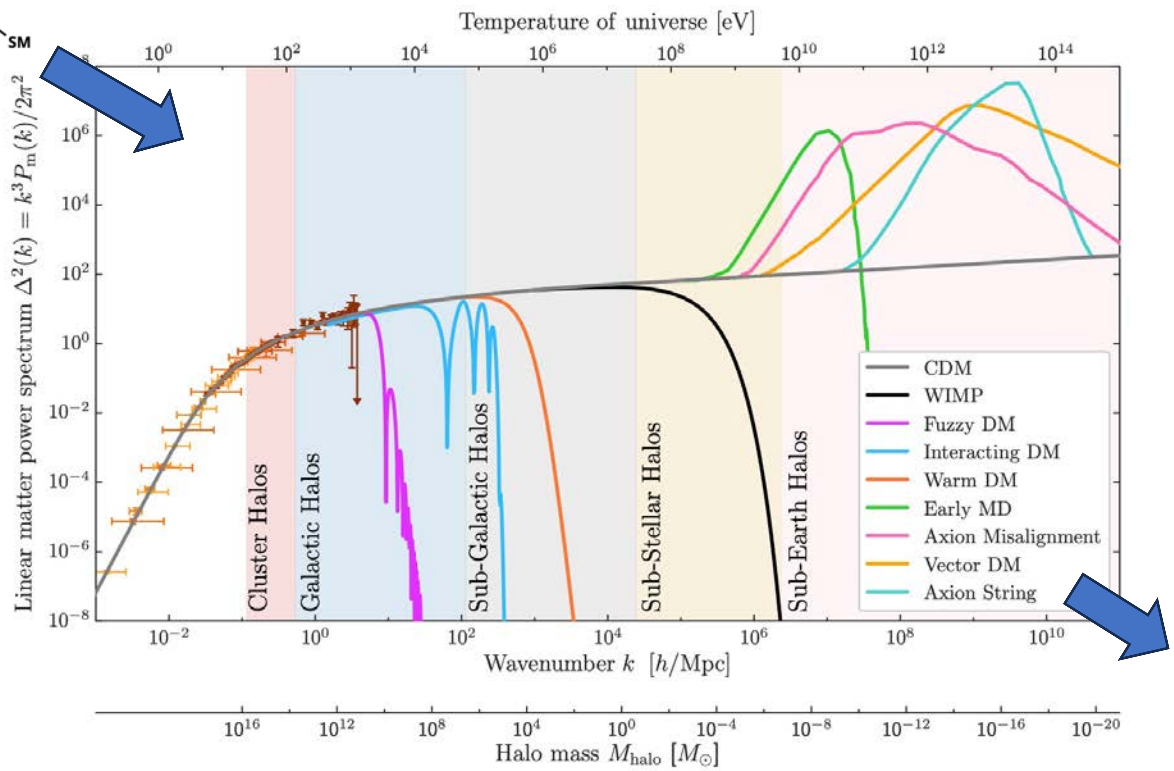




Snowmass Cosmic Frontier
2023 Report

distribution of matter in the universe



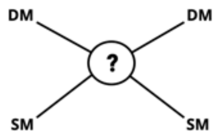


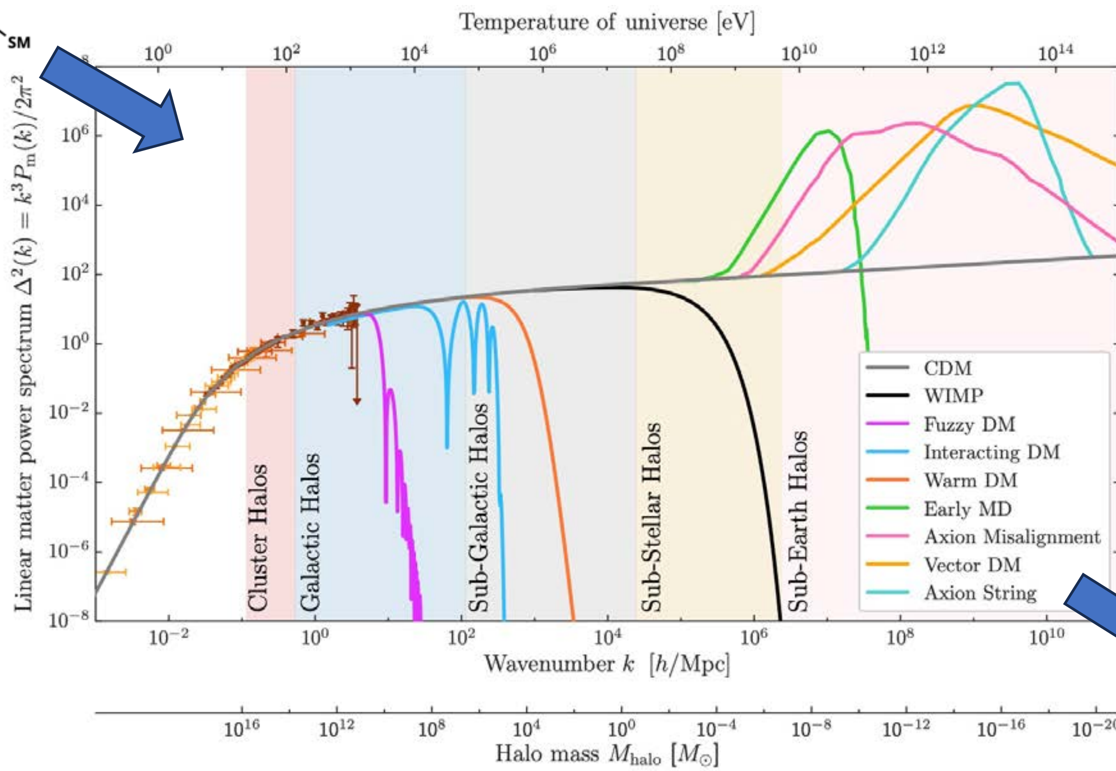
Snowmass Cosmic Frontier
2023 Report

Observables:

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

distribution of matter in the universe





Large Scale:
Linear

Snowmass Cosmic Frontier
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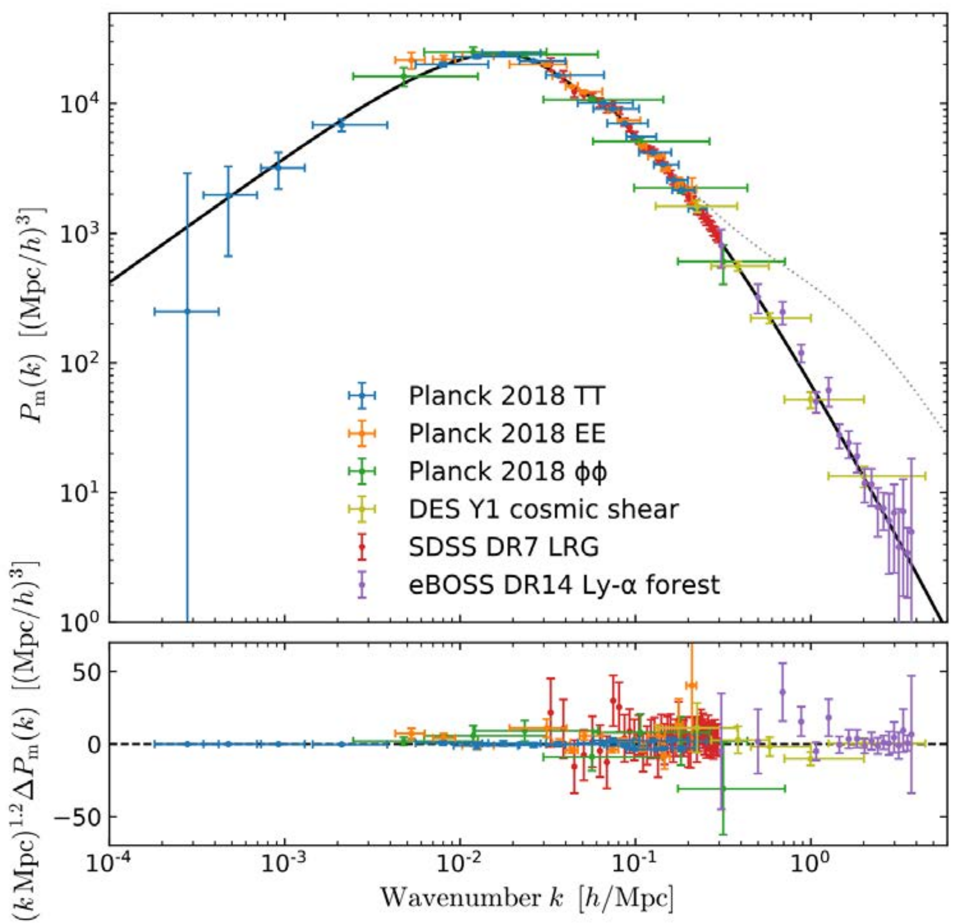

Chabanier+ 2019

Large Scale:
Linear

Observables:

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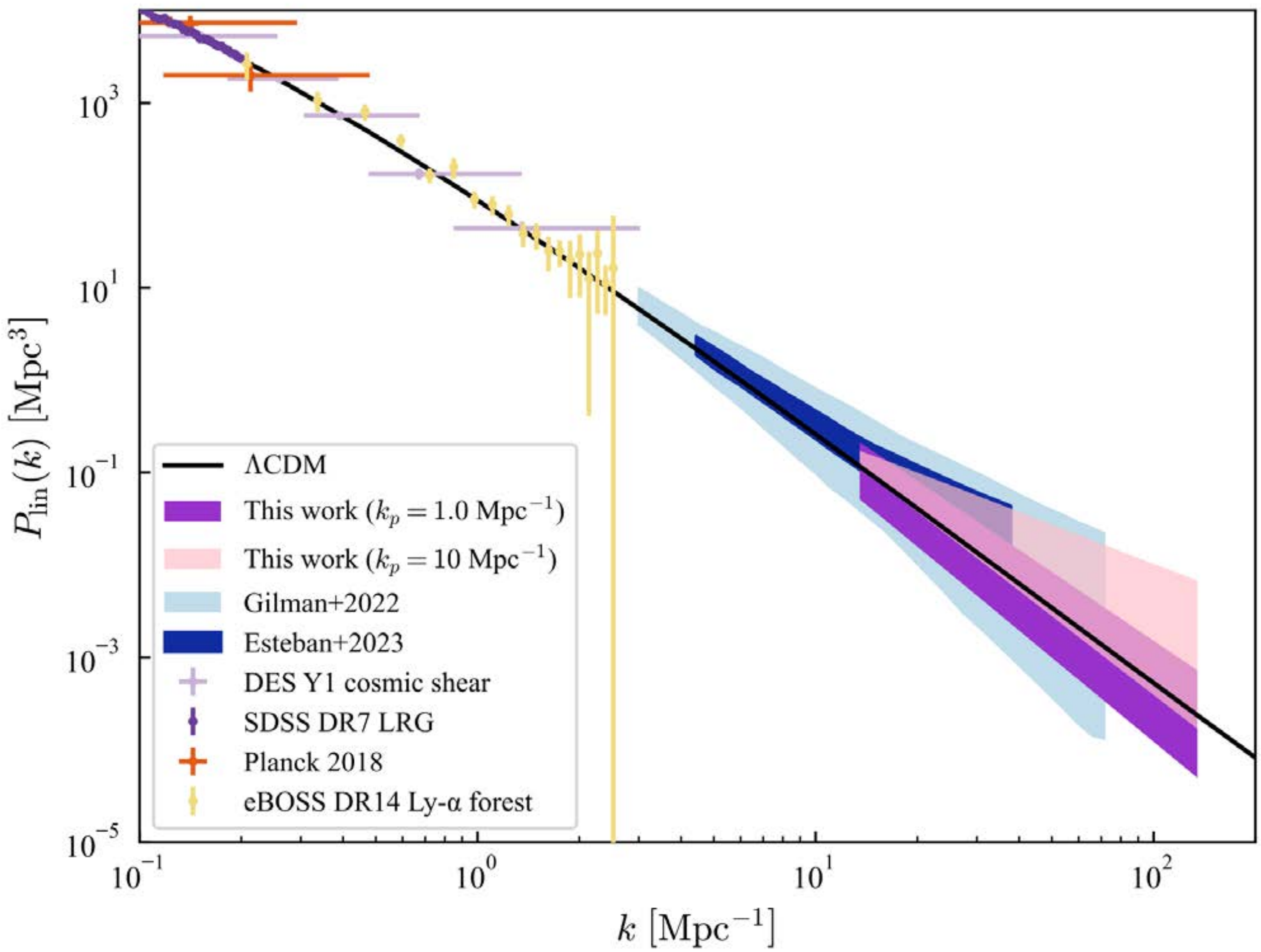
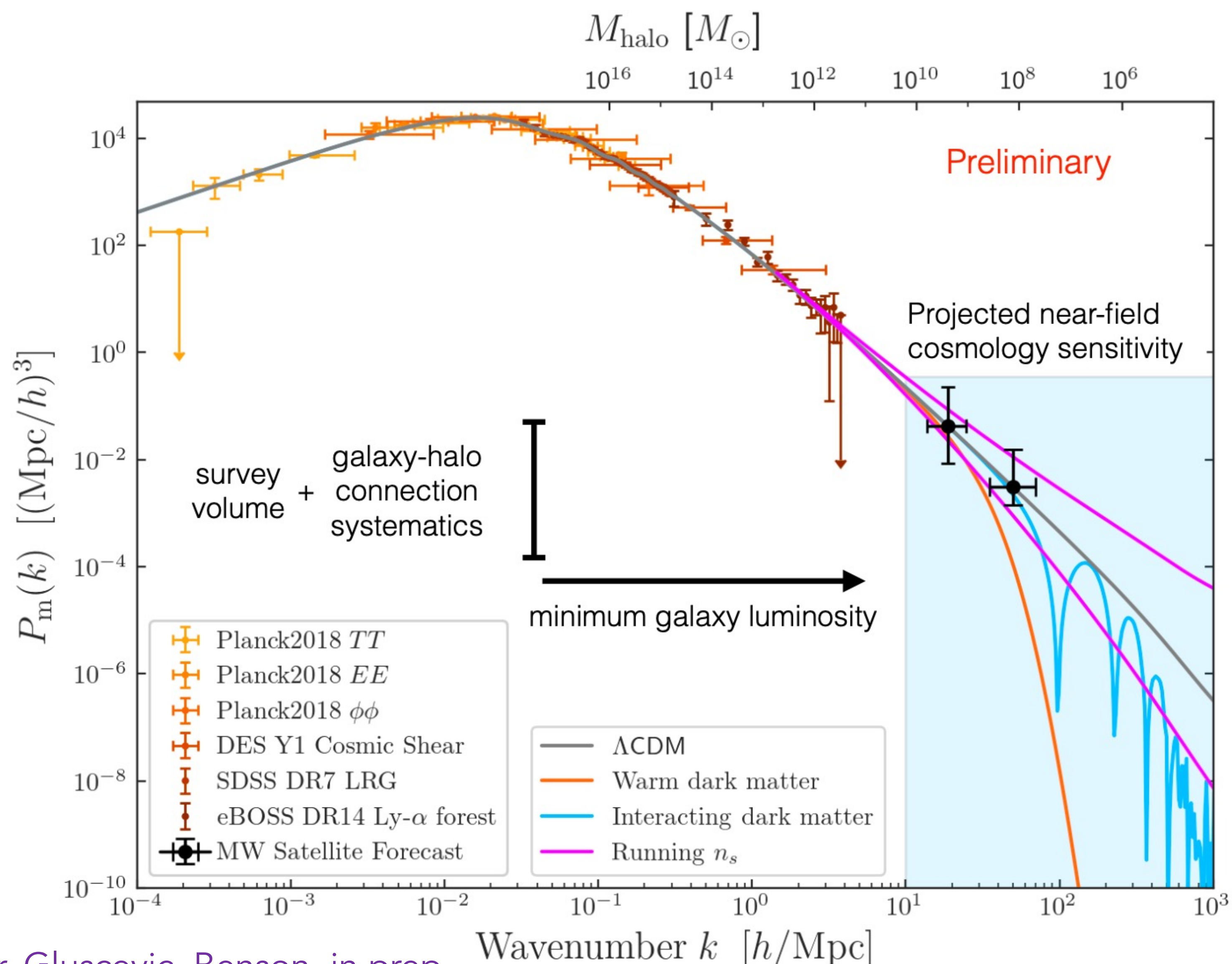
Example: Inflationary models with a tilt



Plot from Dekker and Kravtsov 2024

From central densities of dwarfs, velocity dispersions, strong lensing

Future with MW satellite population

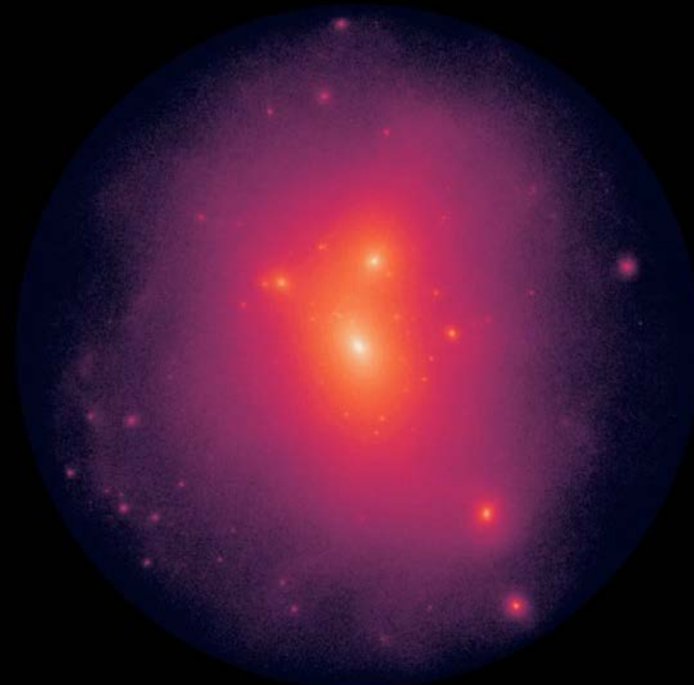


Nadler, Gluscevic, Benson, in prep.

DM-proton (spin-independent) elastic scattering

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

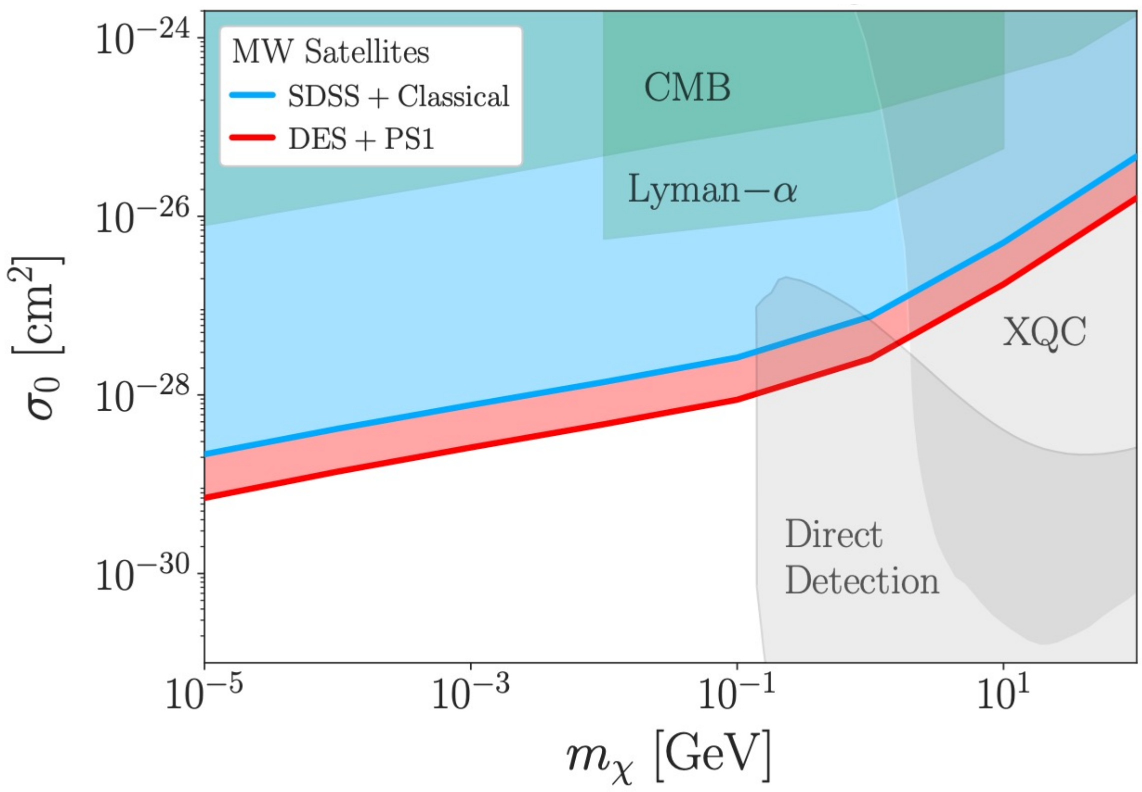
Cold DM



Interacting DM

Elastic scattering of DM with protons

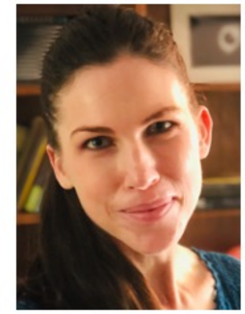
v-independent scattering



***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).

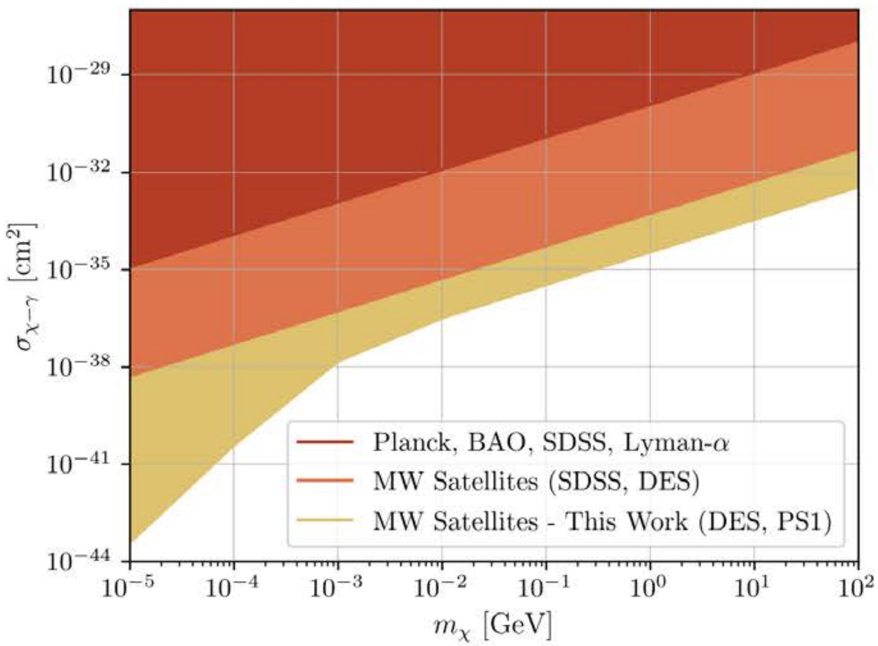
Nadler, Gluscevic + 2019 (2008.00022); DES collaboration, + 2020

Scattering of DM with radiation

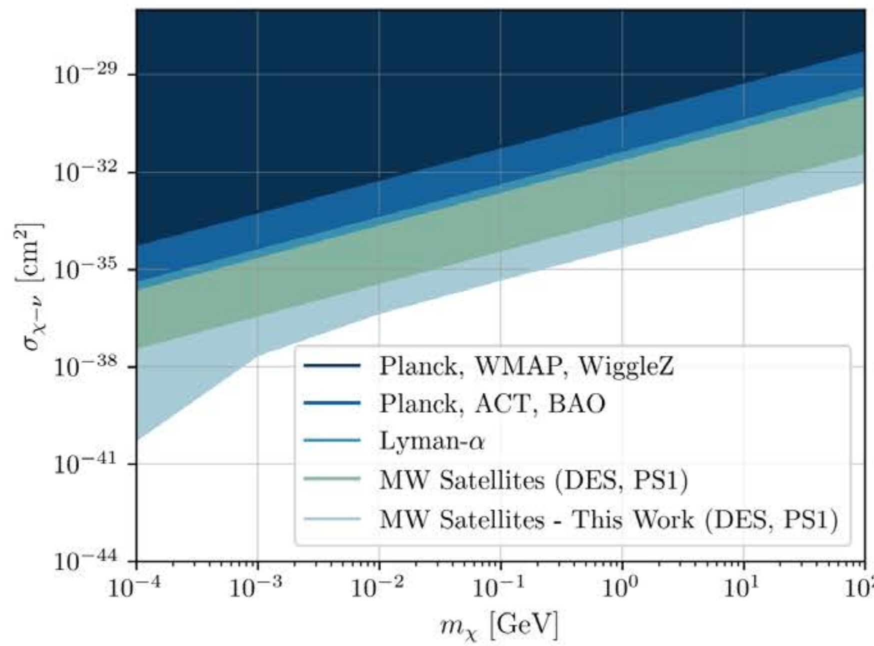


Wendy Crumrine

Photons



Neutrinos



Plot from Crumrine+ 2024 (2406.19458)
See also: Boehm and Schaeffer, 2005, +

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

There are assumptions…

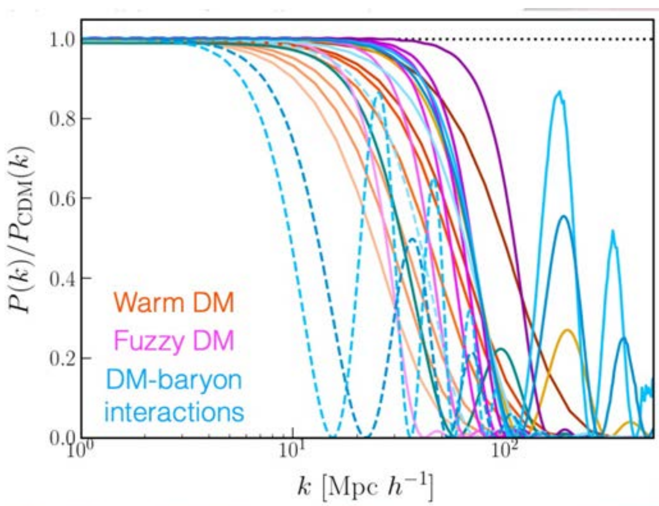
There are assumptions…

- 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, ++



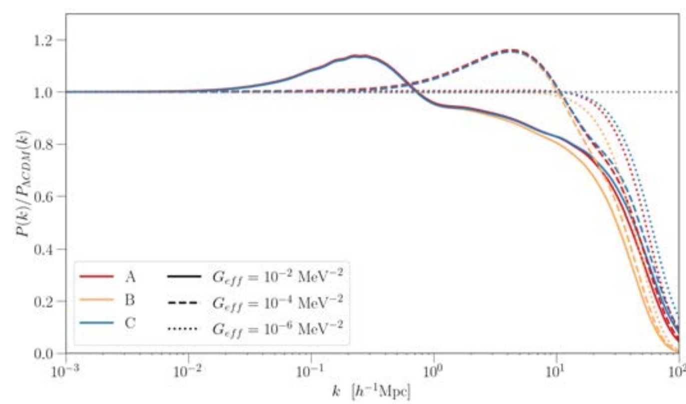
Plot by E. Nadler

Late-time effects:

SIDM/ETHOS, freeze-in, ++

Both:

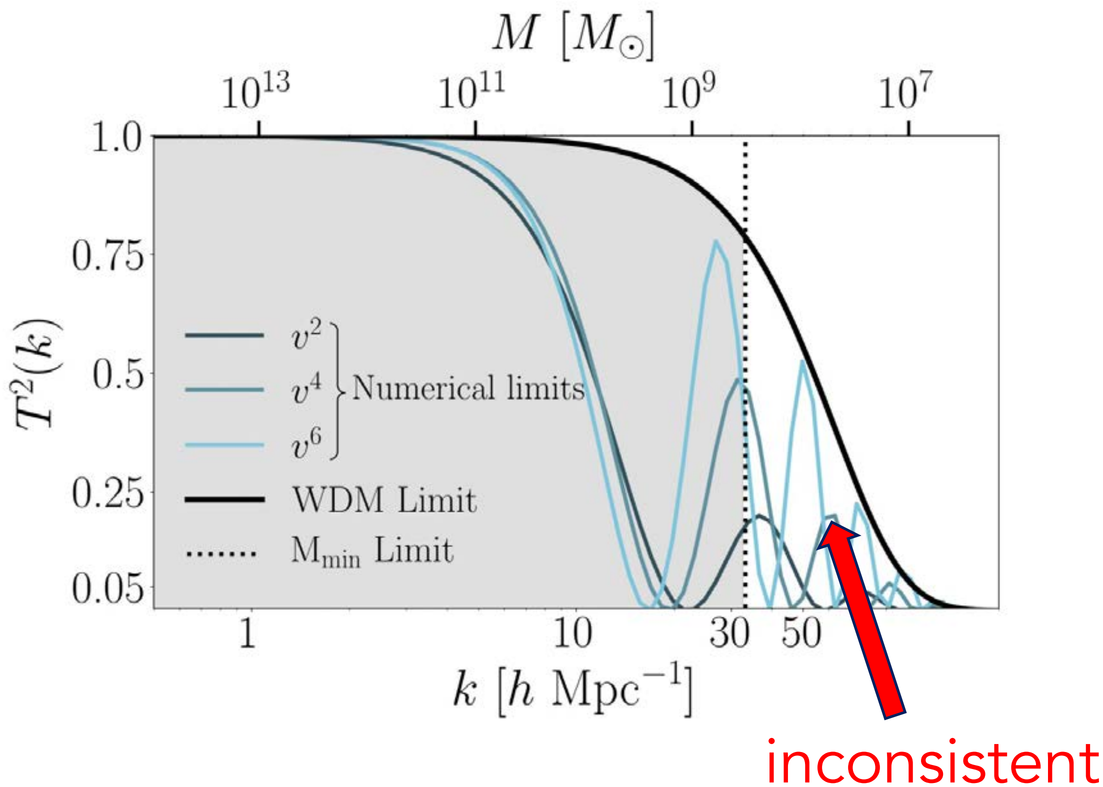
Sterile neutrino + neutrino self-interactions



Plot by R. An

A way out: exclude only models where suppression is severe.
Example: Effective interactions of DM with protons

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



Warm DM mass >6.5 keV

Maamari, Gluscevic,+ (2021) 2010.02936

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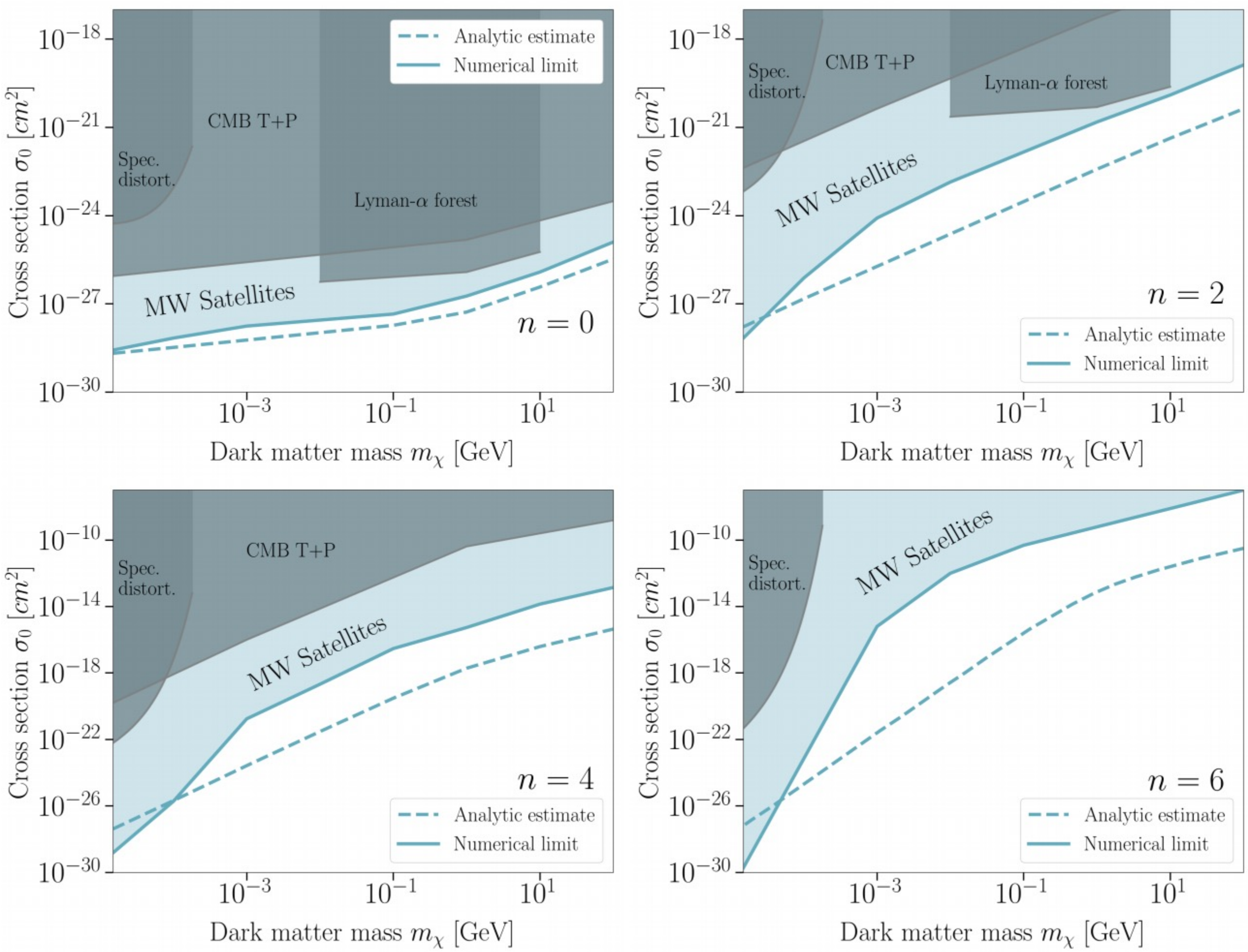

=> **3-5 OOM improvement.**

Karime Maamari

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

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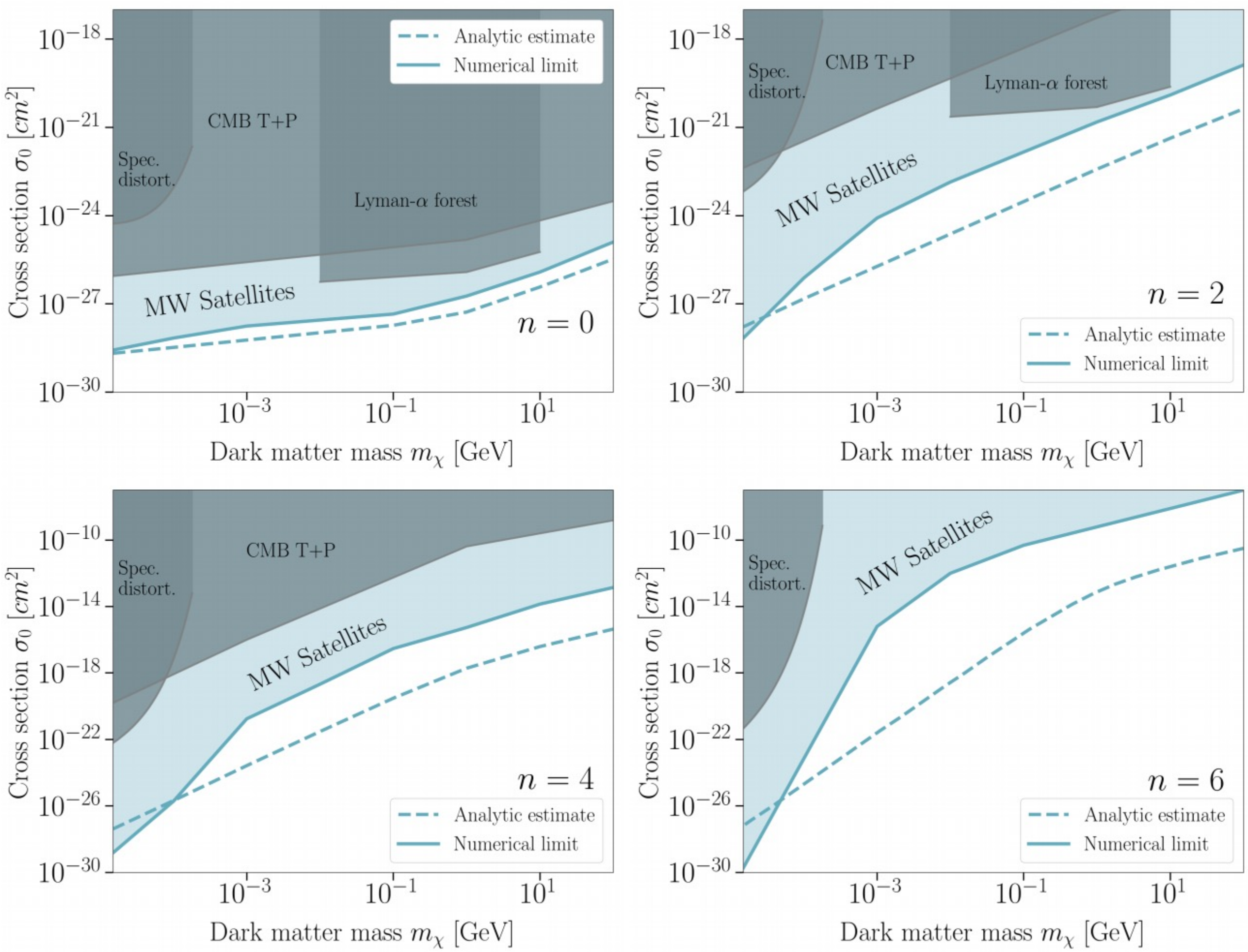


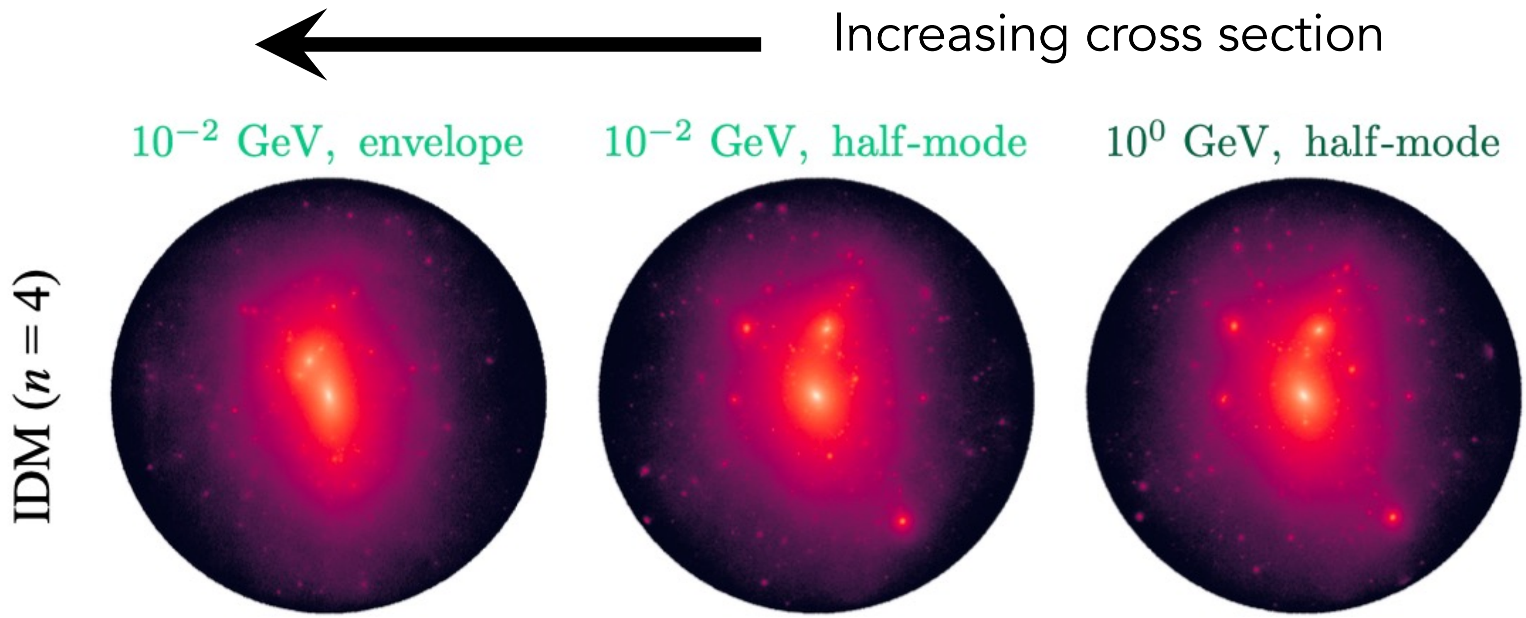
Caveat: cannot discover a signal this way.

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

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

Karime Maamari

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

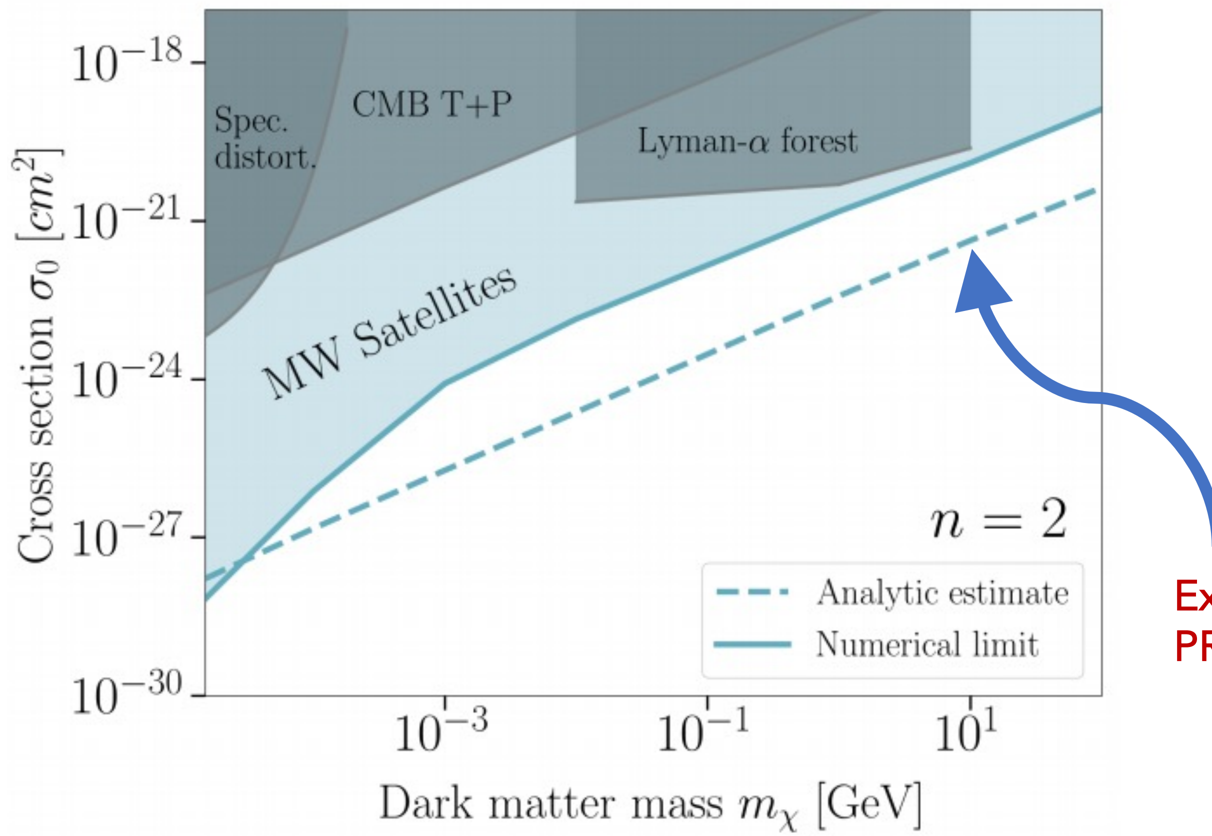


Projected dark matter density maps

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

Nadler, An, Gluscevic, Benson, Du in prep.

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



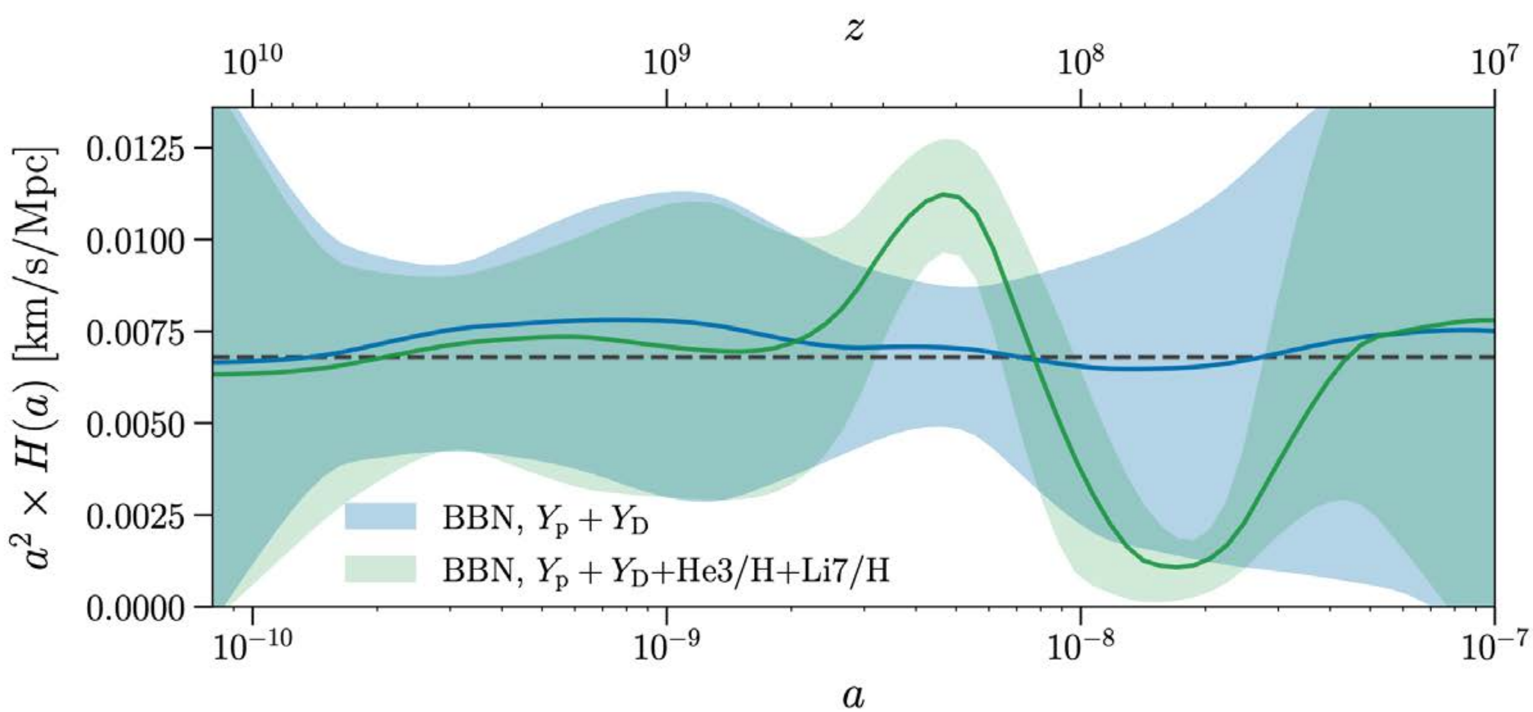
Expected new bound:
PRELIMINARY

Nadler, An, Gluscevic, Benson, Du in prep.

Expansion & thermal history

Expansion history: in-situ probes

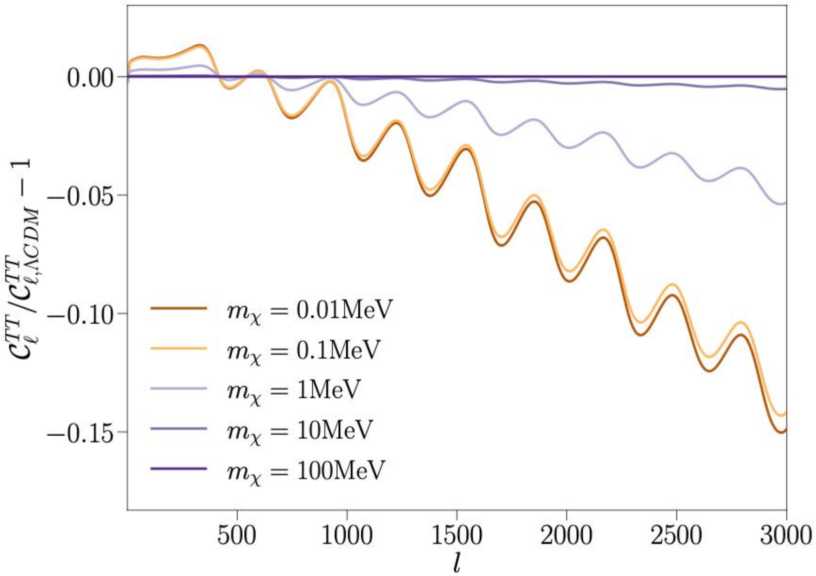
Rui An



Plot from An and Gluscevic 2023 (2310.17195)
See also: Sobotka, Erickcek, Smith 2023; An+ 2022; Boehm+ 2012; Steigman+ 2013, etc.

Thermal relic DM

Rui An



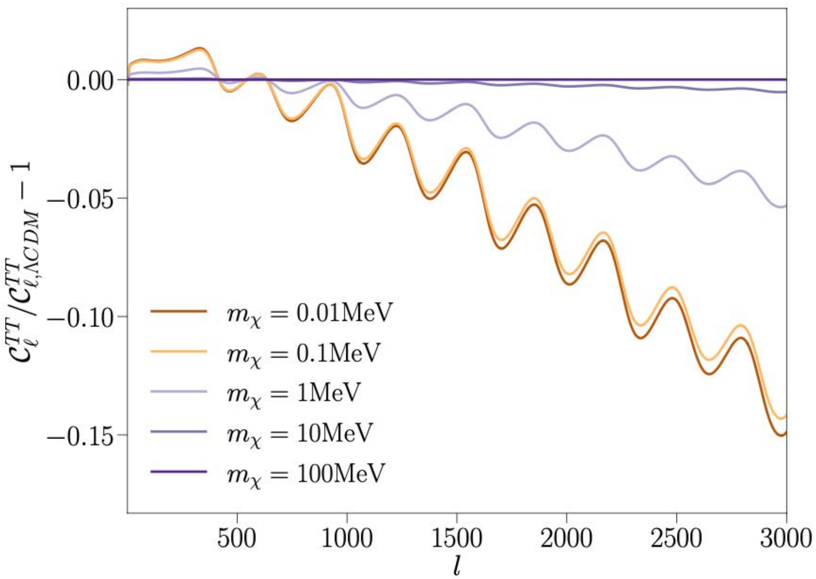
If DM annihilates during BBN:

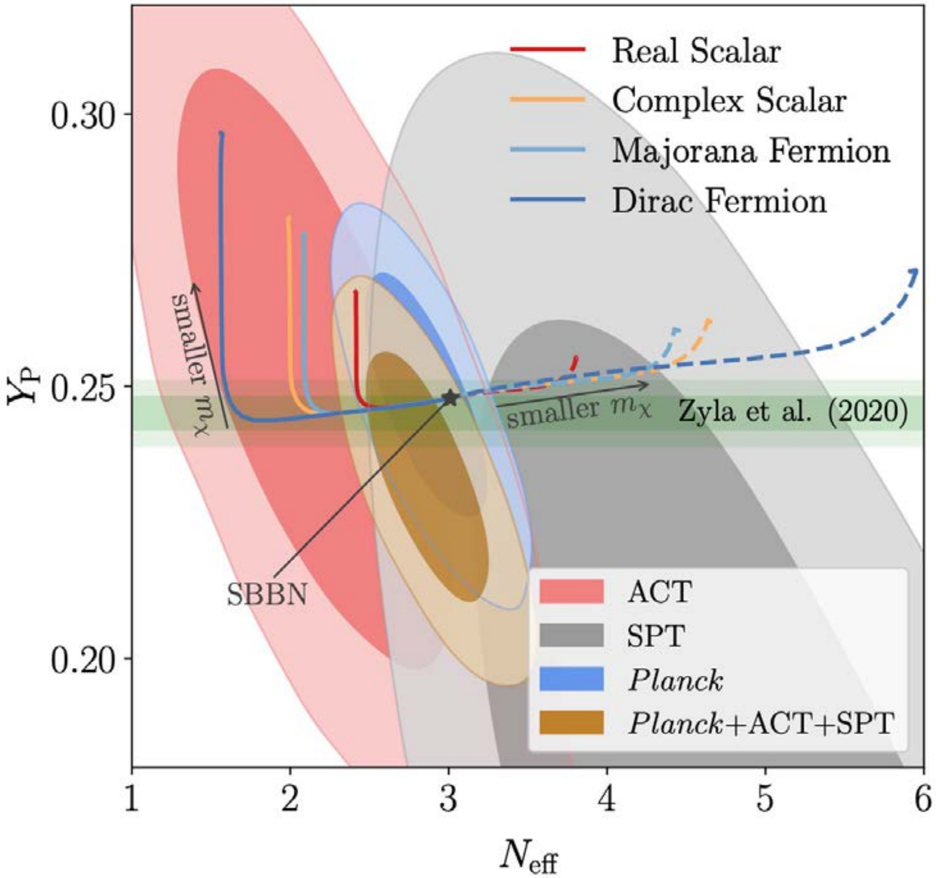
- Yp increases, leading to suppression of the CMB anisotropy.
- Neff changes (increase, if annihilating to neutrinos).

An+ 2022 (2202.03515)

Thermal relic DM

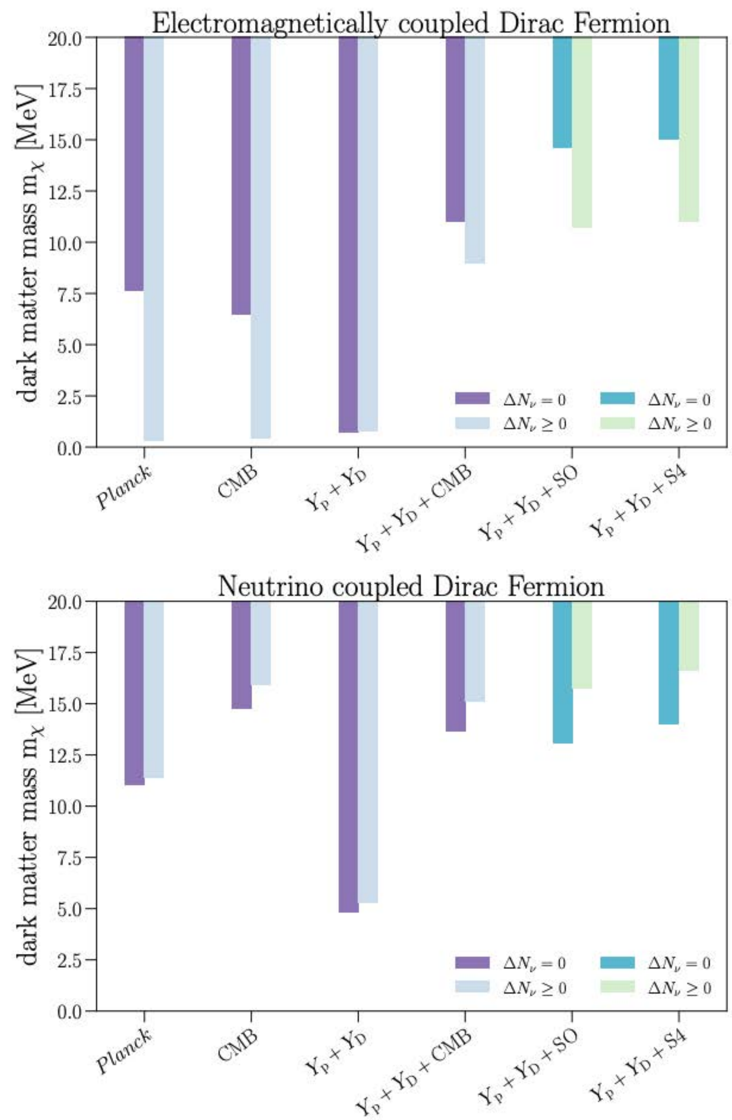
Rui An





An+ 2022 (2202.03515)

Thermal-relic
mass bounds
from CMB +
primordial
abundances:
> 7 MeV



Rui An

An+ 2022 (2202.03515)

What about a non-thermal relic?

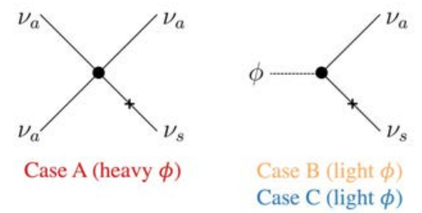
Dodelson-Widrow's sterile neutrino

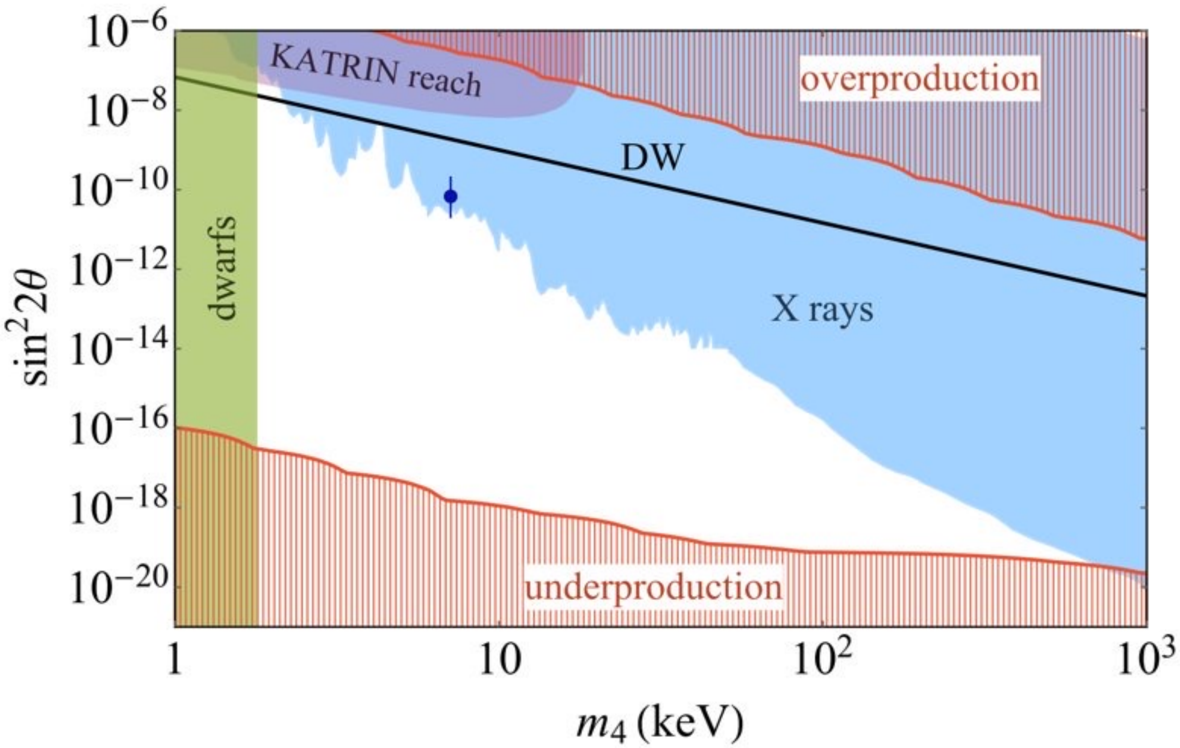
DM = Fourth, heavy (~keV) neutrino that doesn't talk to the SM, but mixes with active neutrinos.

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

But DW is excluded, so add neutrino self-interactions…

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

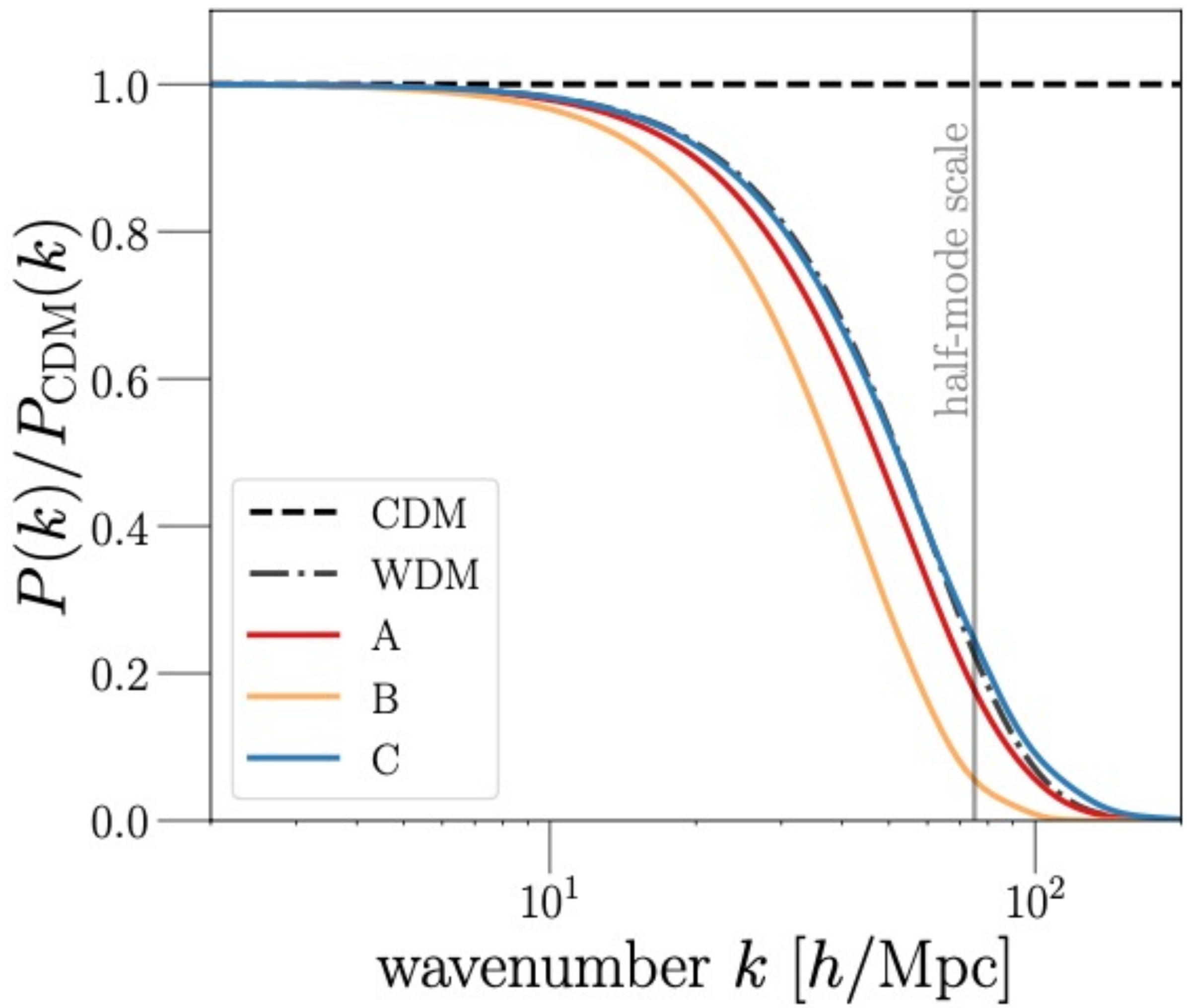


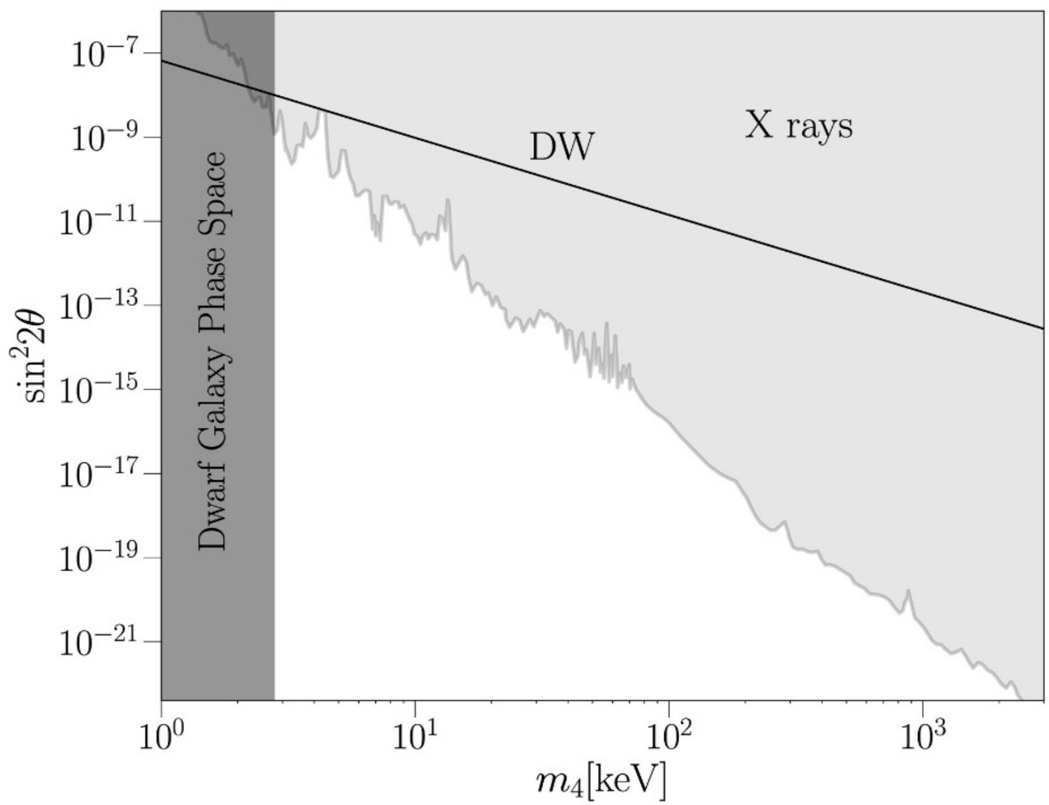


de Gouvea + (2019), etc.
See also Ruderman+ 2020

=> non-thermal PSD.

Sterile neutrino is still warm

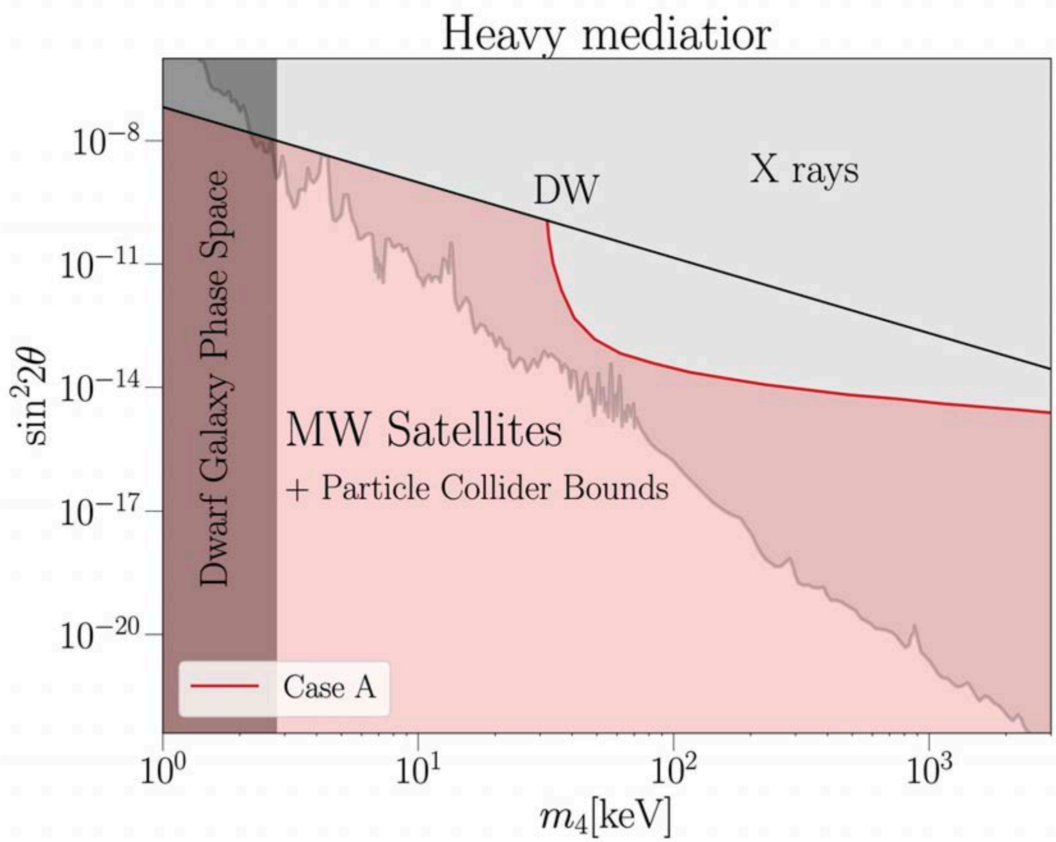




An, Gluscevic, Nadler, Zhang (2023)

Near-field cosmology + lab bounds:

Mediators > 1GeV are ruled out.

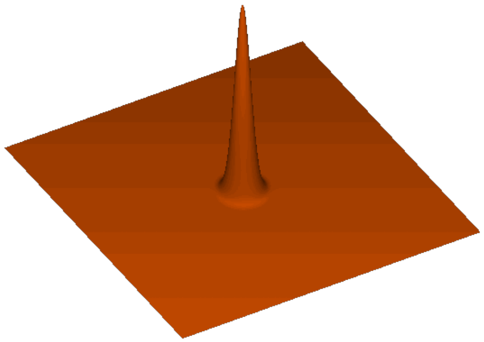


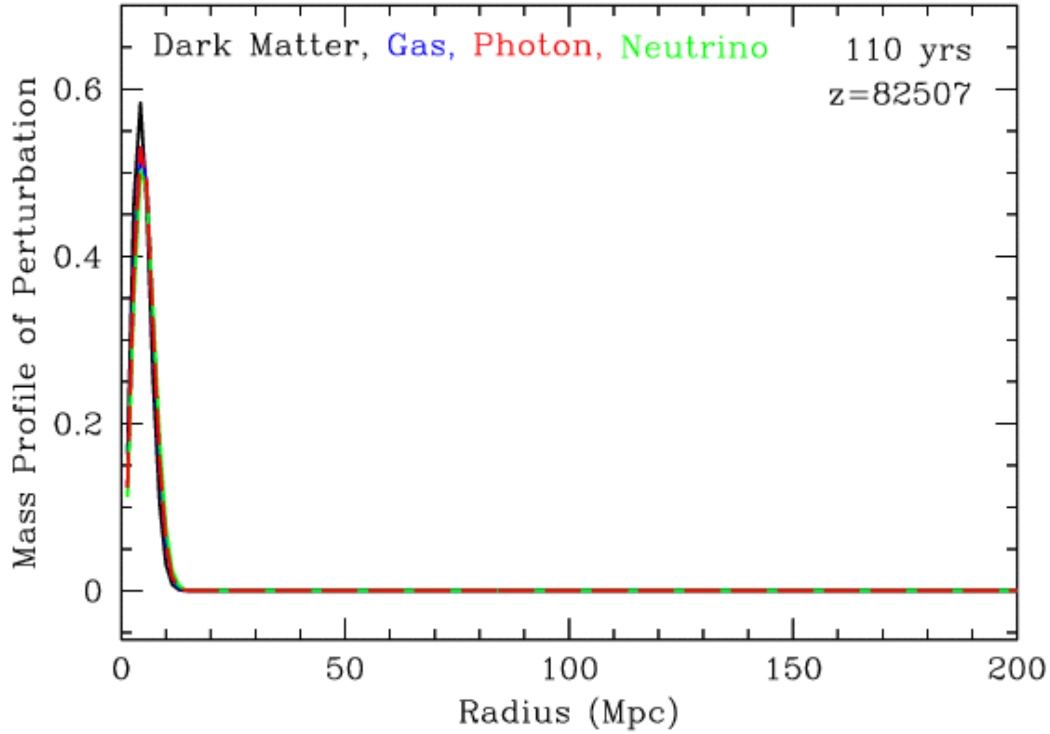
An, Gluscevic, Nadler, Zhang (2023)

Interacting neutrinos?

Standard neutrino cosmology

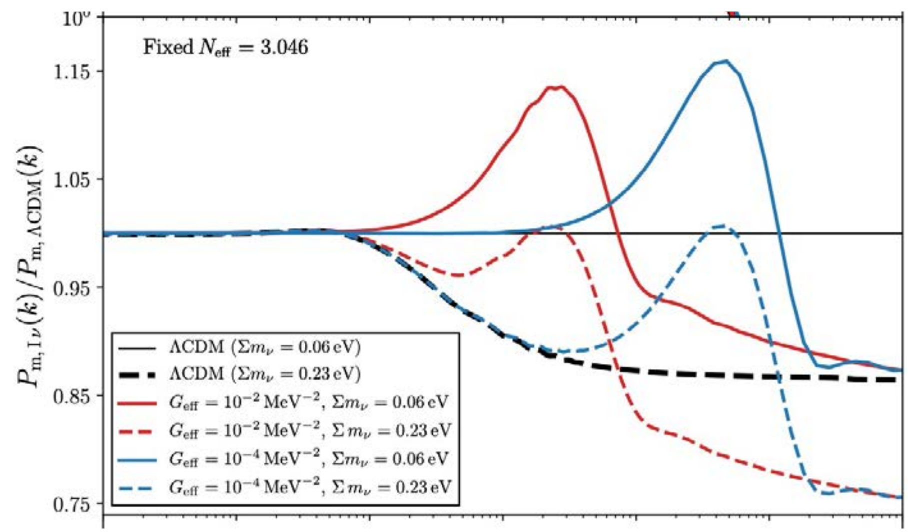
- ✓ Decoupled at ~1 MeV
- ✓ Free-streaming radiation
- ✓ Clustering after z~ x00

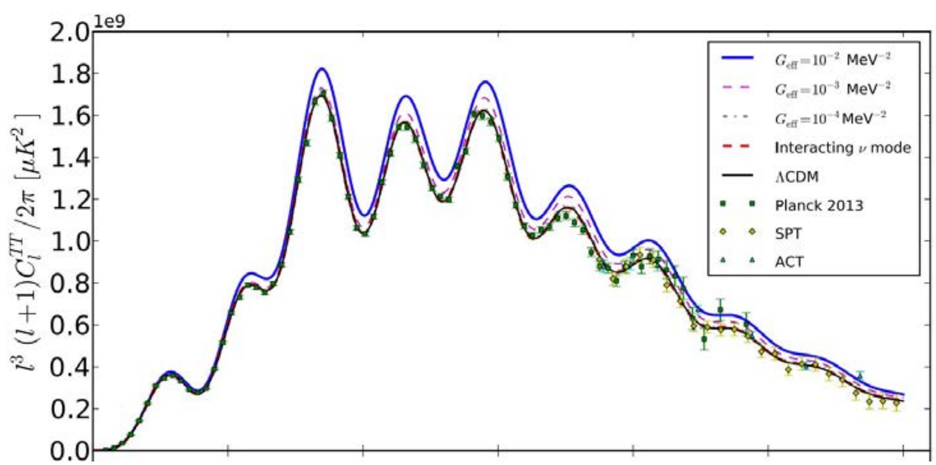




Bassett & Hlozek 2009
Eisenstein et al. 2007

Interacting neutrino cosmology





neutrino self-interaction rate

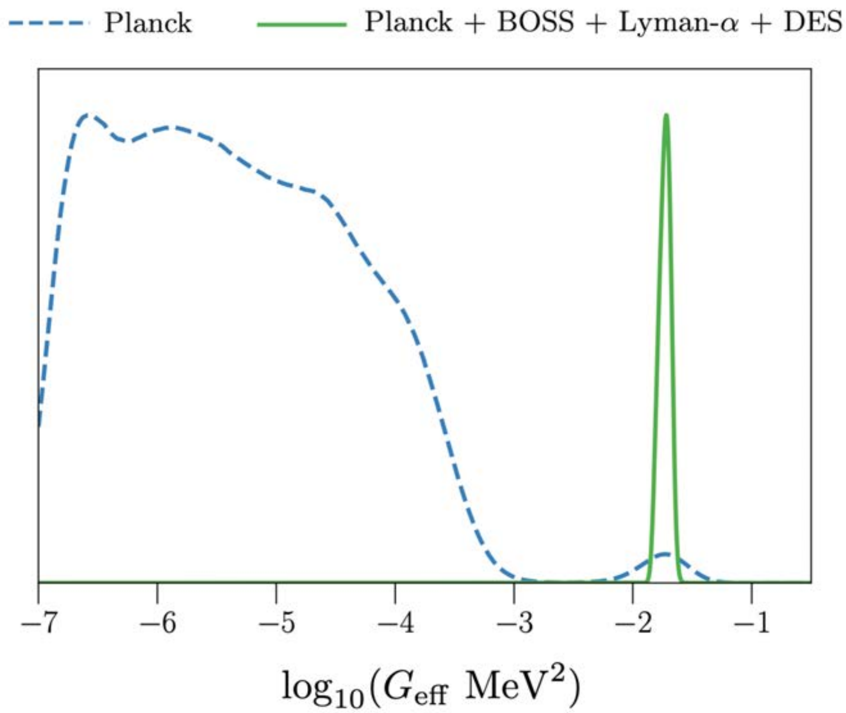
$$\Gamma_\nu \propto G_{\rm eff}^2 T_\nu^5$$

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

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

Interacting neutrinos and LSS

Adam He



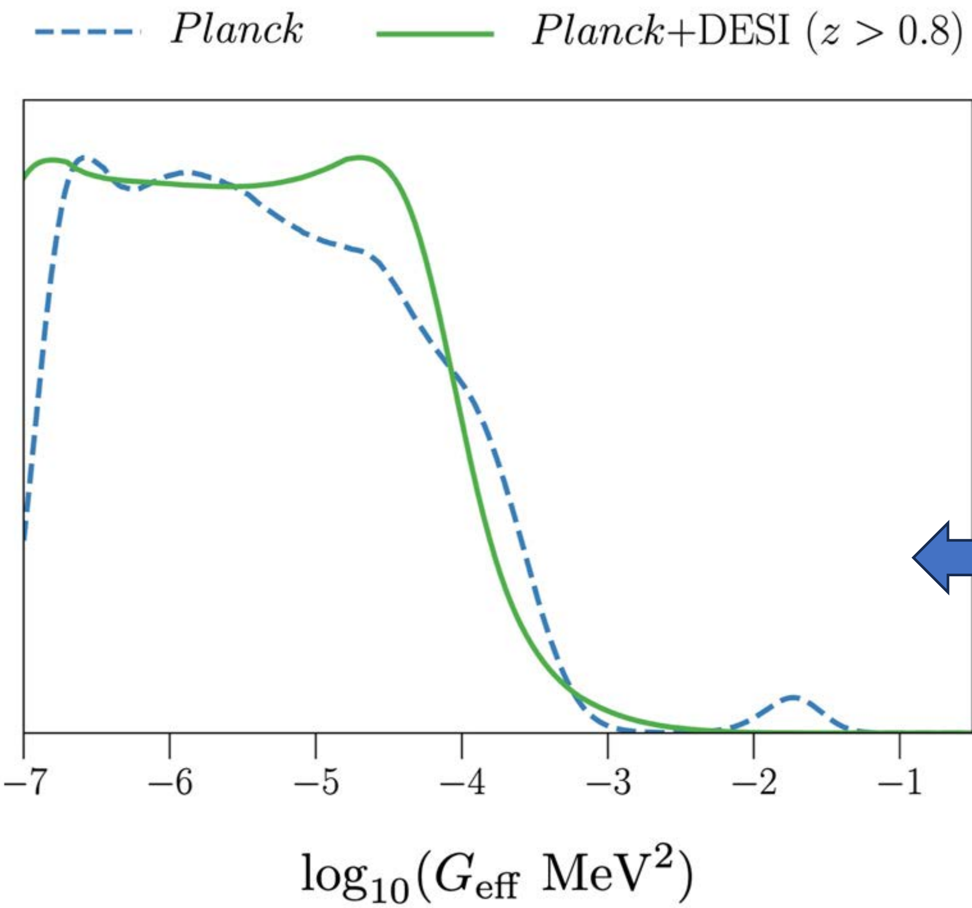
He, An, Ivanov, Gluscevic (2023)
See also Kreisch+ 2020;
Also Ivanov 2024, Bird+ 2024.

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

PRELIMINARY:
Rederived eBOSS likelihood (based on EFTofLSS and on new Lya simulations) shows better consistency with LCDM – the preference will go down/away.

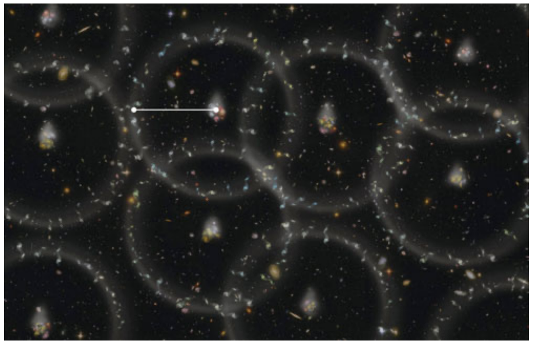
Interacting neutrinos with DESI

PRELIMINARY



Adam He

Acoustic horizon scale measurement by DESI consistent with LCDM.



He, An, Gluscevic, in prep.

The future

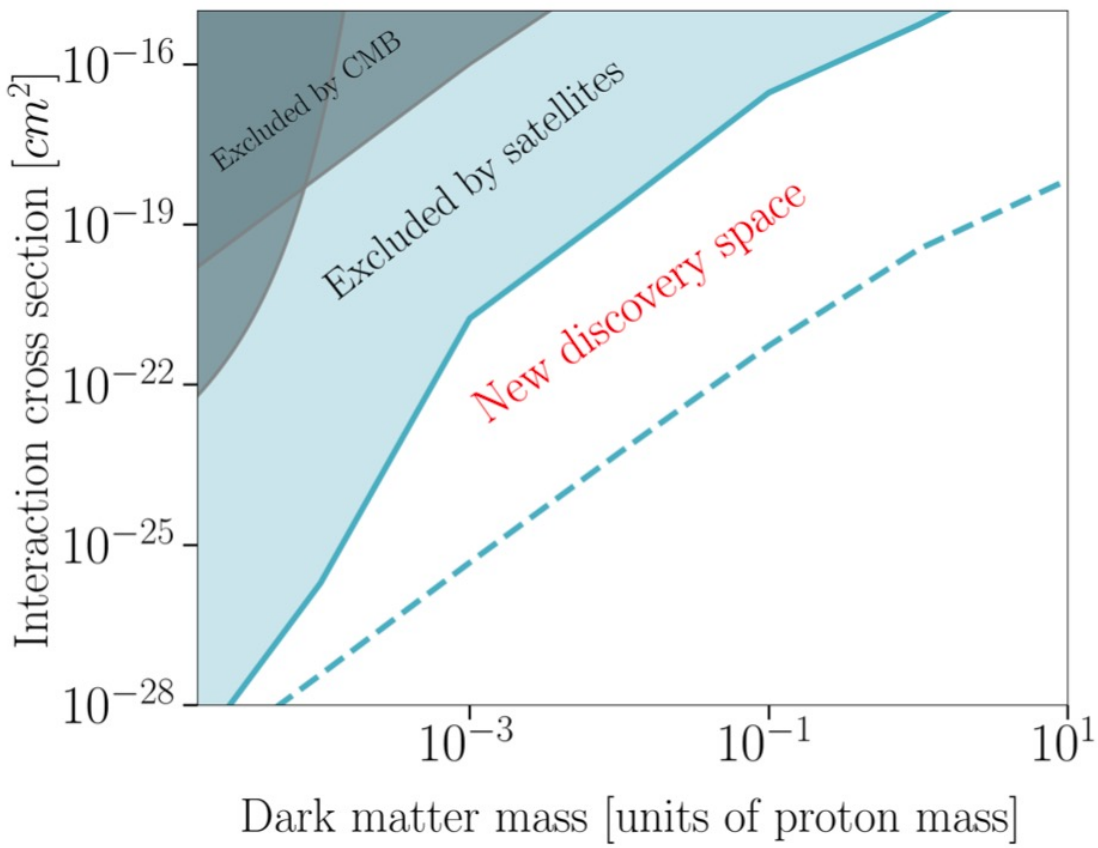
Key challenges in cosmological searches for new physics

Forward-modeling of structure in beyond-CDM cosmologies.

Understanding sample variance + stat. analyses of small-scale data.

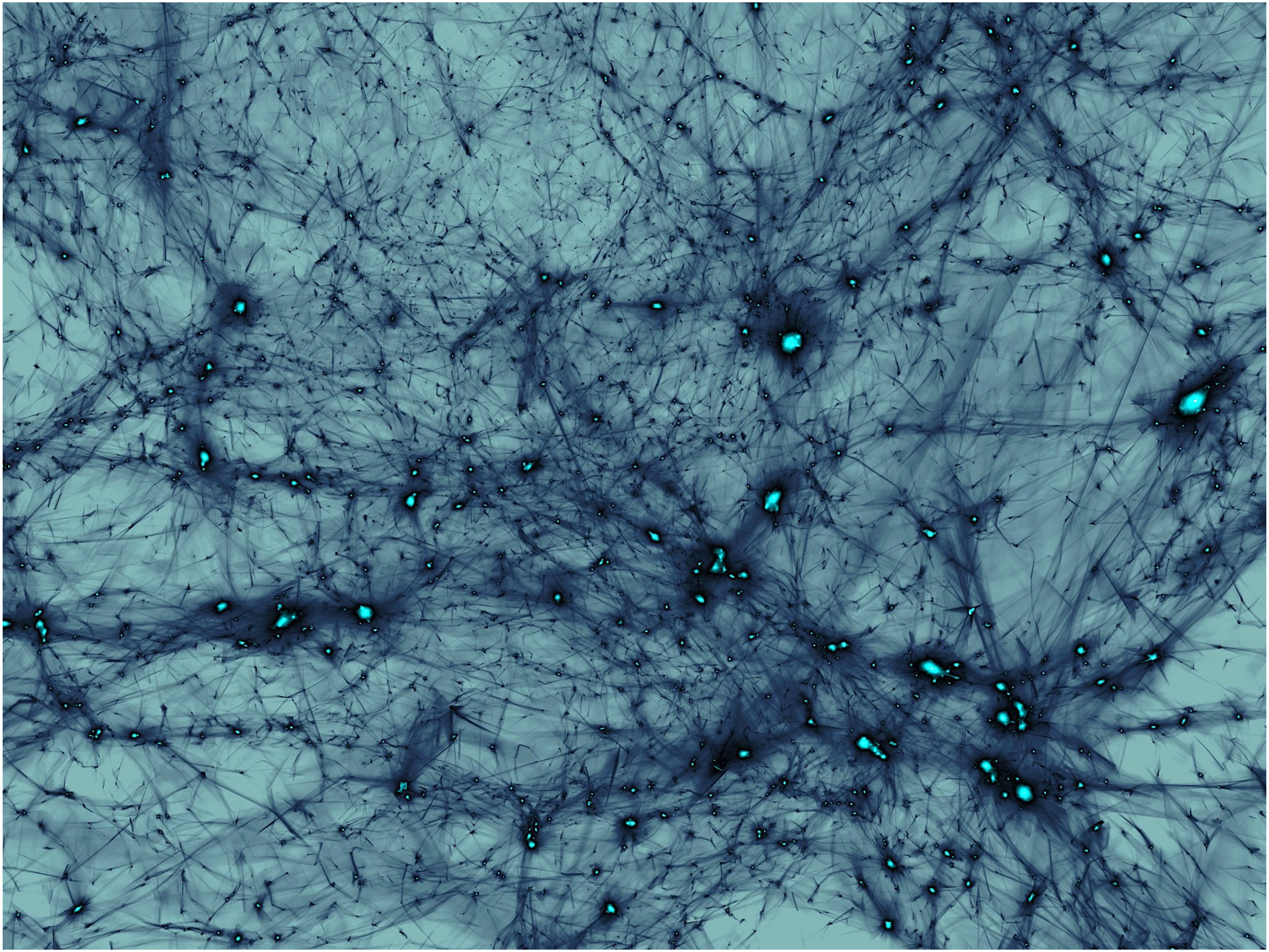
Understanding data congruence in beyond-CDM cosmologies.

Huge discovery space is becoming available this decade

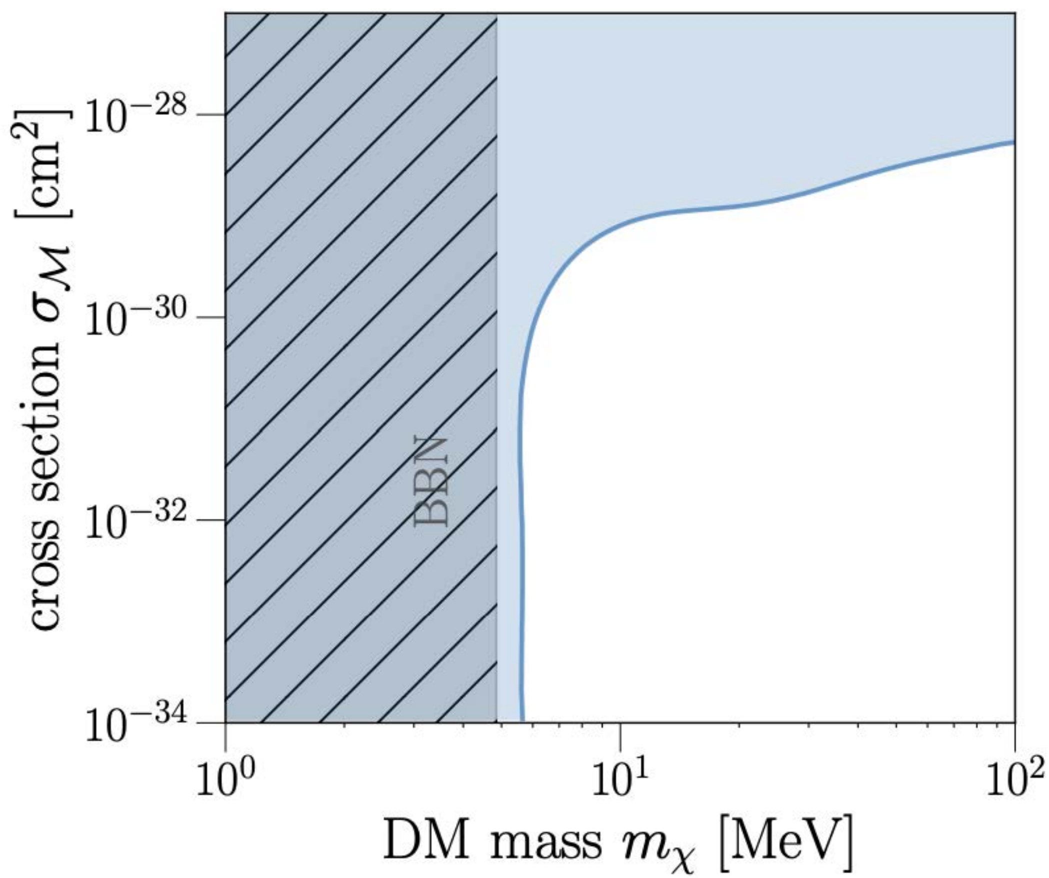


In Conclusion

- We don’t know what we’re looking for?
- Fair, but we’ve only just started.



Combining bounds: for which model?



An, Gluscevic, Boddy, 2024, 2402.14223