Title: New Physics from the Lyman-Alpha Forest

Speakers: Vera Gluscevic

Collection/Series: Cosmic Ecosystems

Subject: Cosmology

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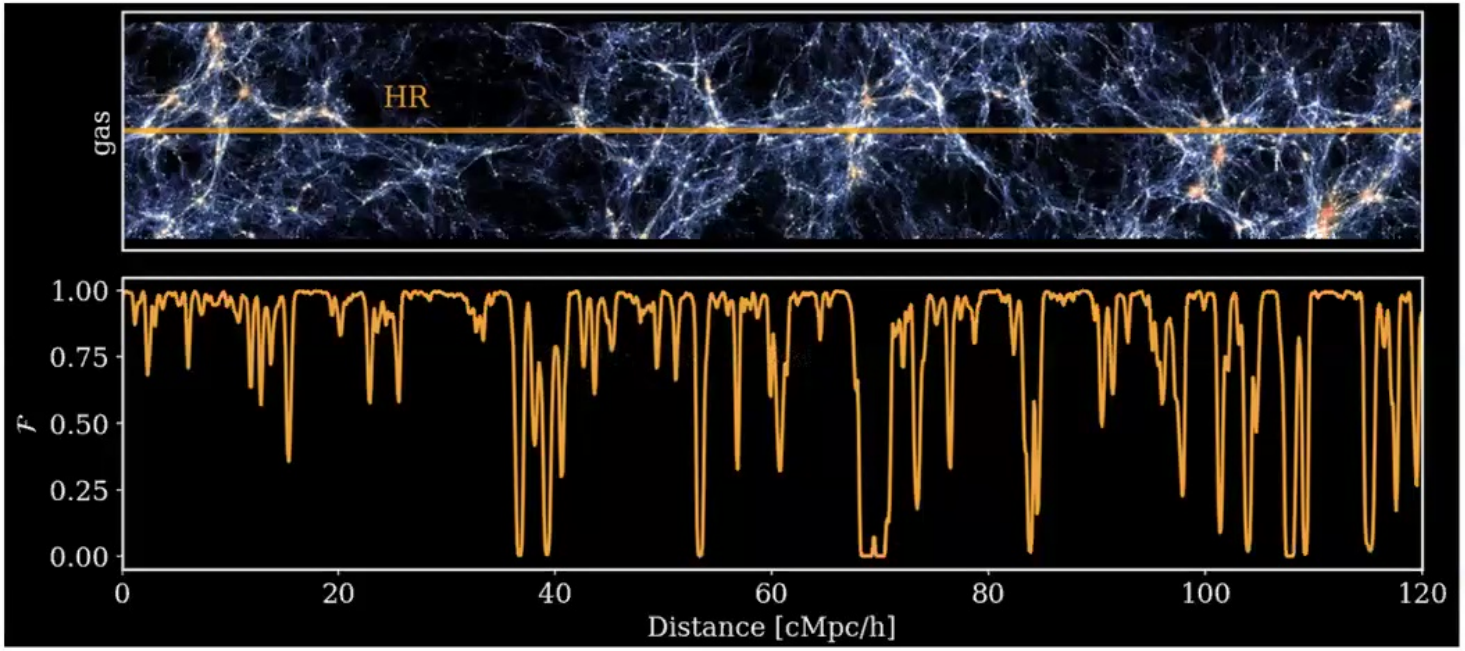
Abstract:

Lyman-alpha forest probes matter distribution on scales inaccessible to other observables, presenting a unique and under-explored testing ground for new physics. I will discuss recent advances in using forest observations to constrain particle interactions in the neutrino and dark matter sectors, and highlight promising opportunities for discovery in the coming decade.

Fundamental physics from the Lyman-alpha forest

Vera Gluscevic University of Southern California

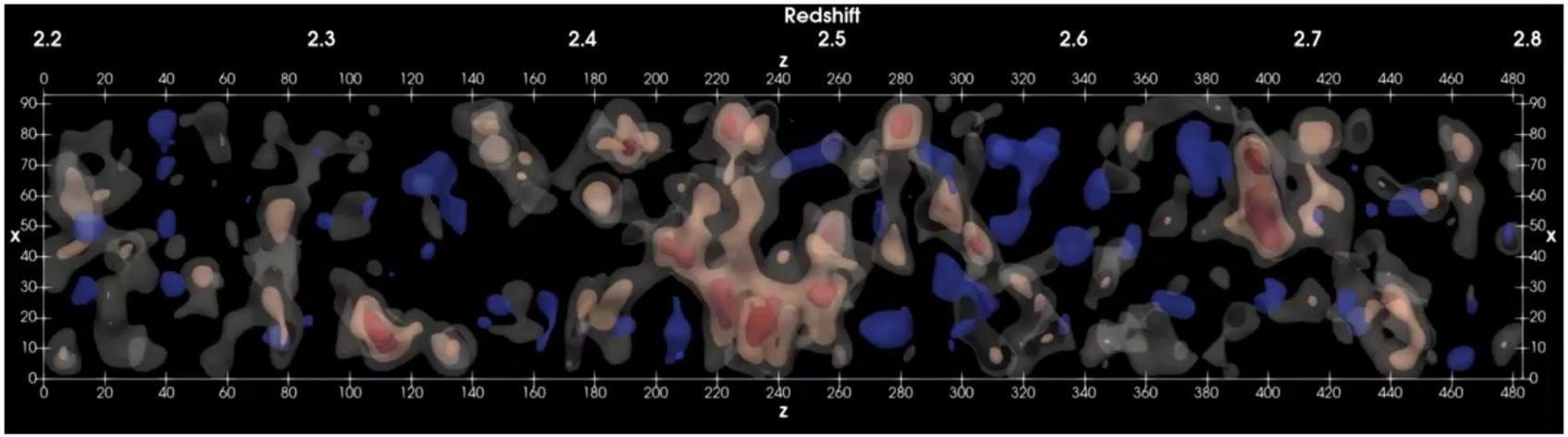
Lyman-alpha forest from quasars



Plot by S. Bird

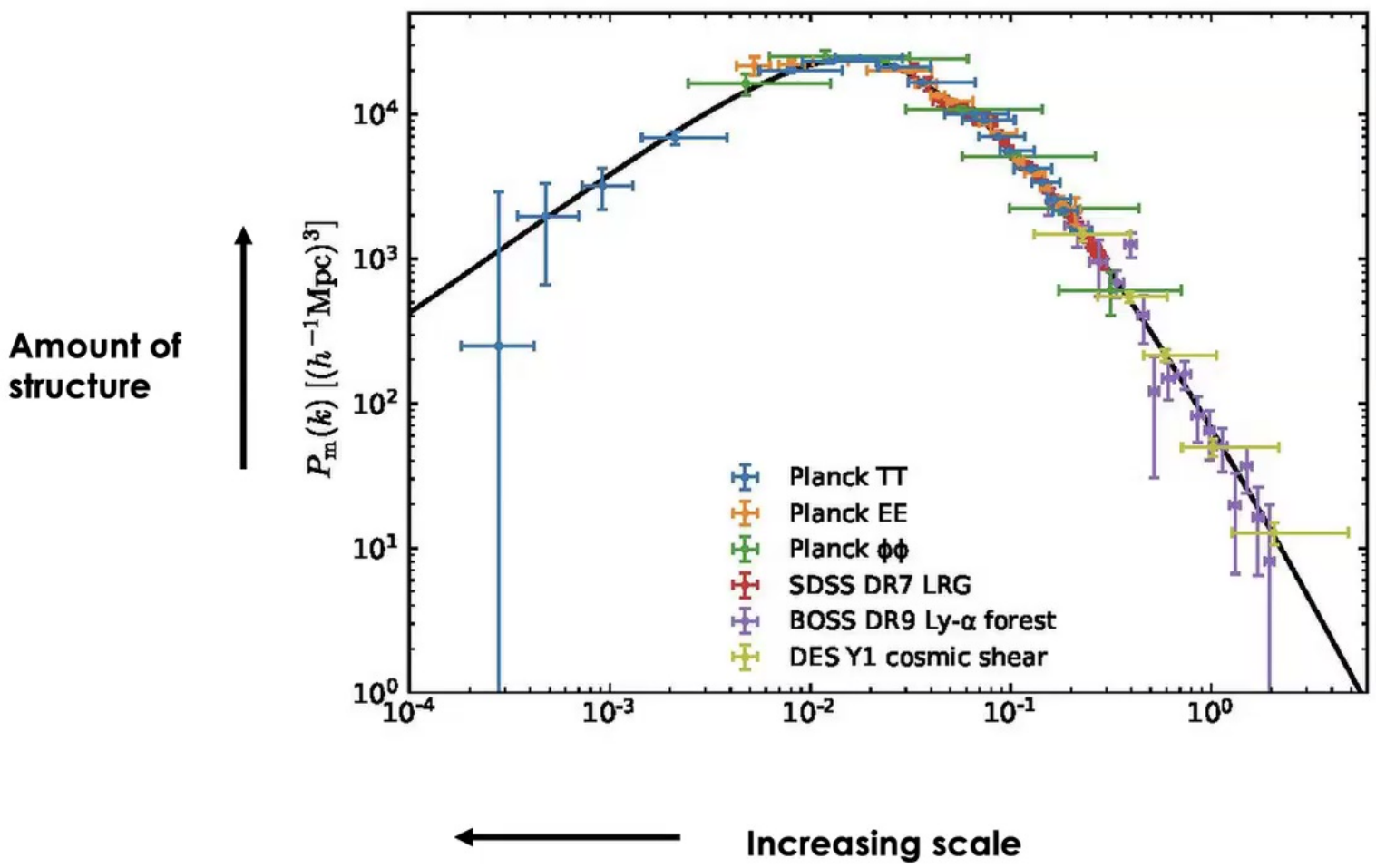
See also Ivanov 2024, Bird+ 2024, Palanque-Delabrouille+ 2020, Rogers+ 2023, Goldstein+ 2023, etc.

Tomographic mapping



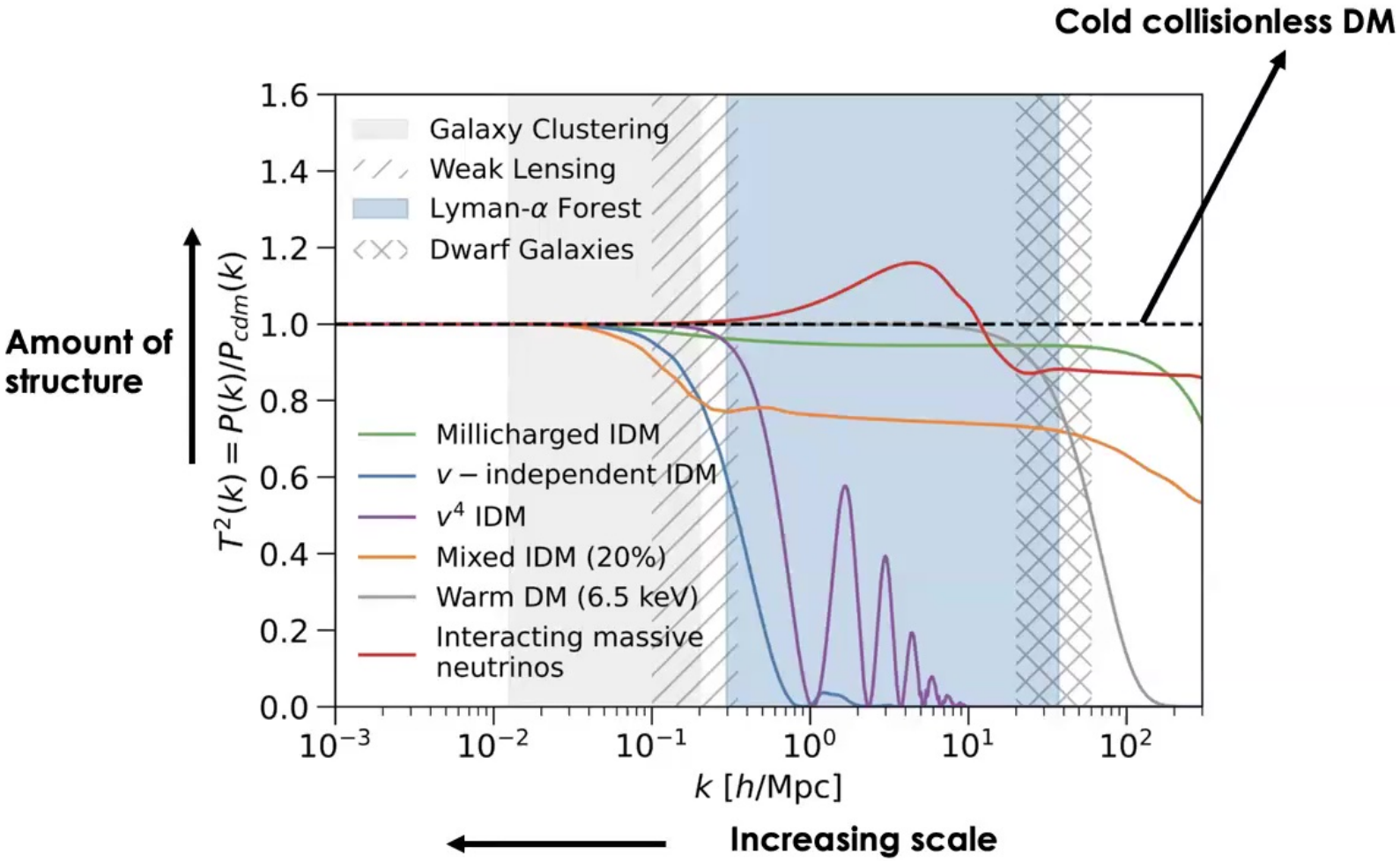
A contiguous map of gas in the intergalactic medium, reconstructed from the LATIS survey (Newman+ 2025)

Tracing the matter power spectrum



Chabanier+ 2019

Matter distribution = testing ground for new physics



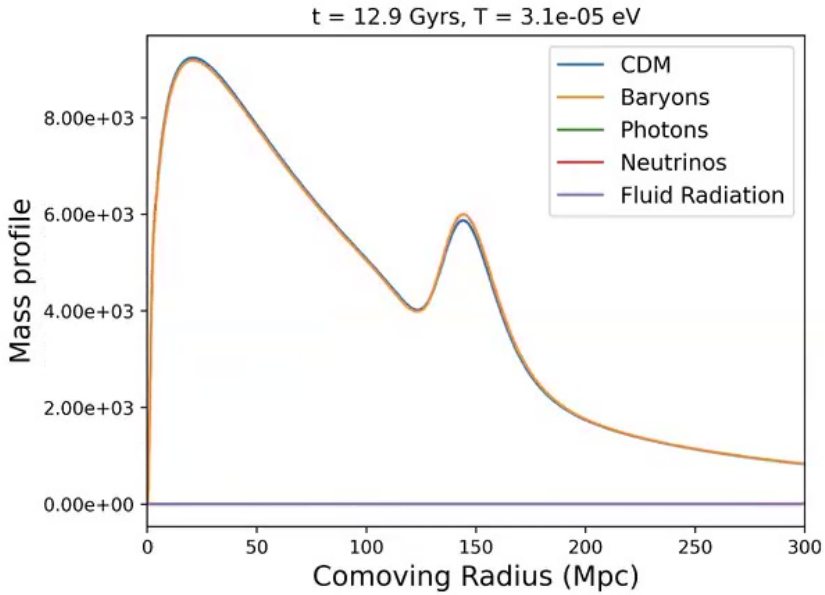
Plot by A. He

What is there to learn?

- Dark matter particle mass
- Dark matter spin statistic
- Neutrino mass sum
- Relativistic species
- New forces

Case study:
The neutrino sector

- ✓ 3 species (cosmological detection)
- ✓ Light, but not massless
- ✓ Behave like matter now
- ✓ Free streaming since minutes after the Big Bang



Plot by Murali Saravanan (UW)

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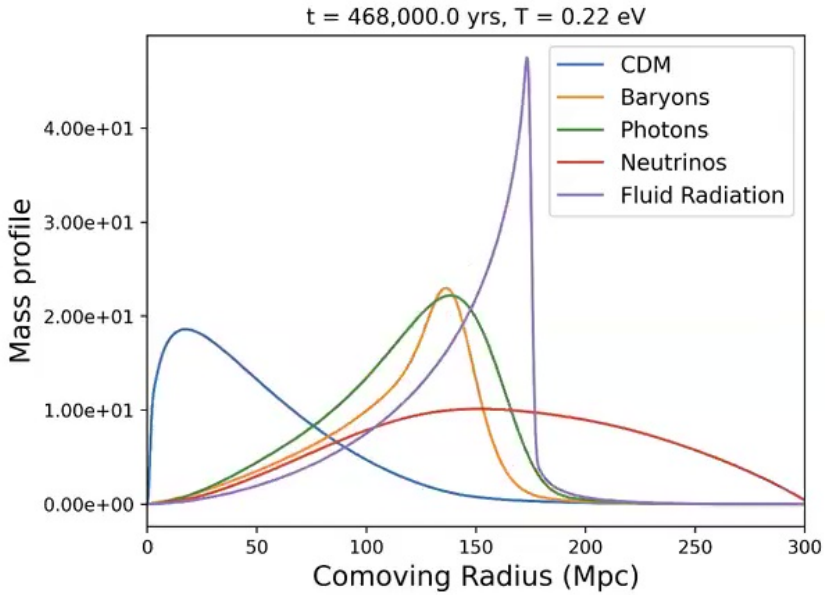


Plot by Murali Saravanan (UW)

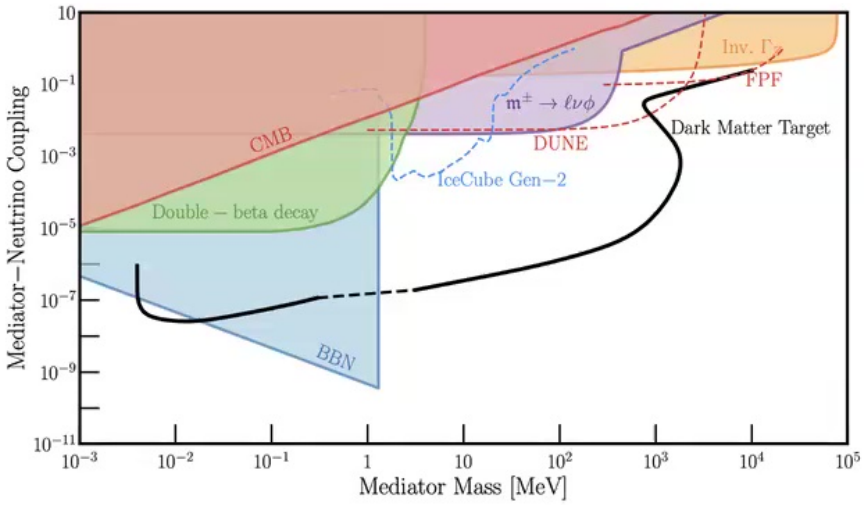
Neutrino self interactions

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

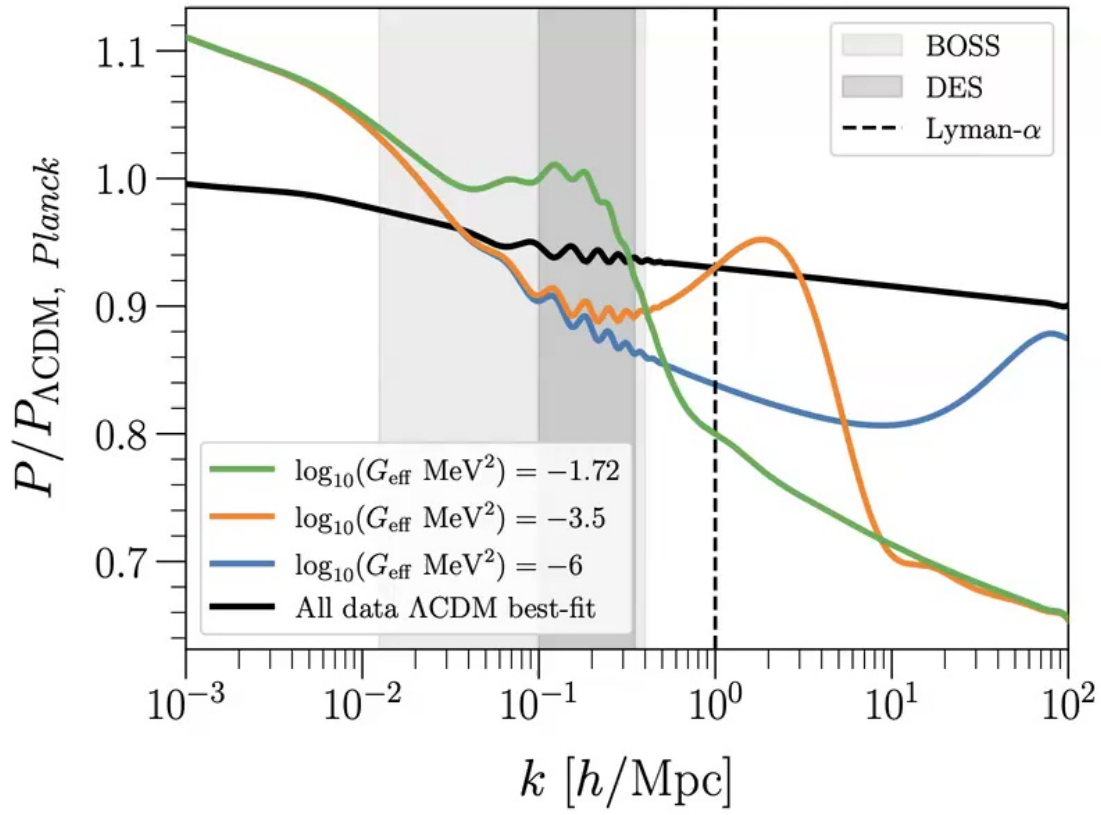
Blinov+ 2022

See also: Bassett & Hlozek 2009
Eisenstein et al. 2007
See also: Brinckmann+ 2020, Loverde+ 202
Berryman+ 2022; Kreisch+ 2020, etc

Collider bounds



Neutrino self interactions

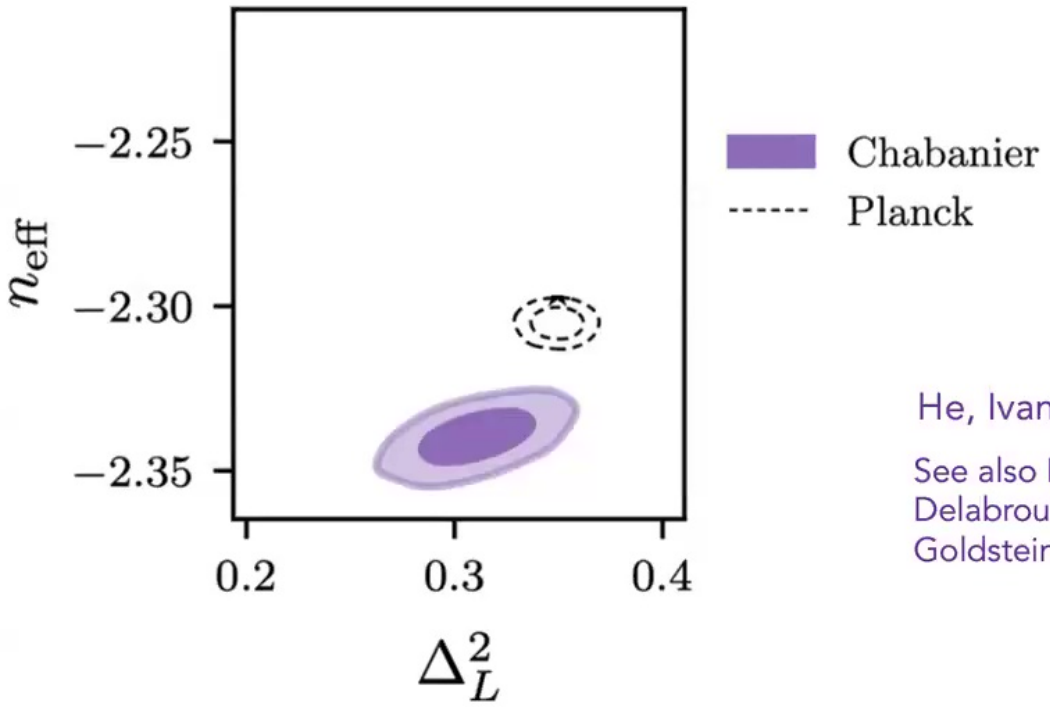


Plot by Adam He (2503.15592, 2309.03956)

Reduced Lyman-alpha likelihood, prior to 2025

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

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



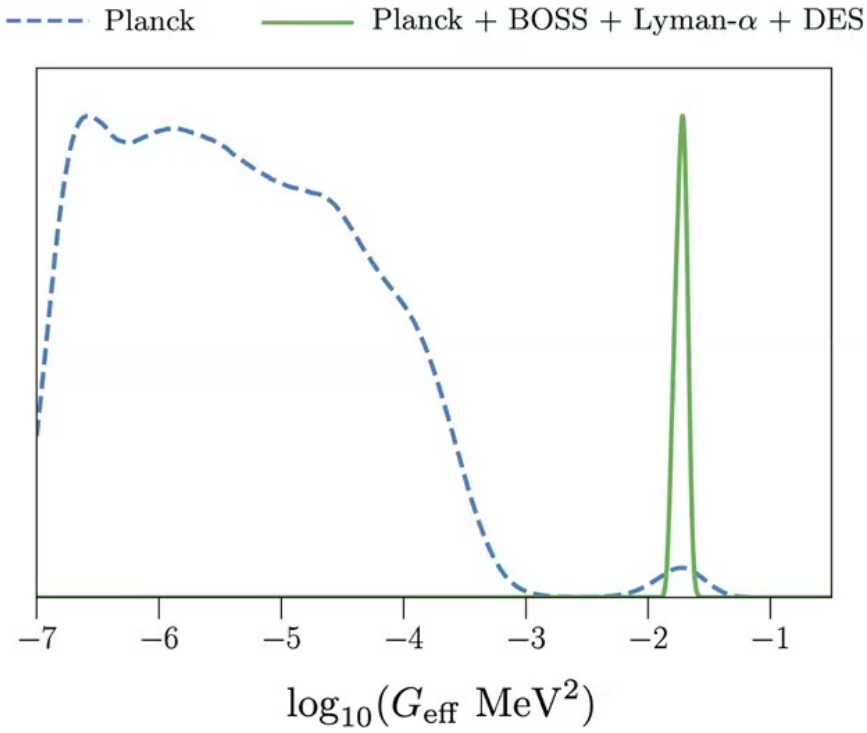
He, Ivanov, Bird, VG (2503.15592)

See also Ivanov 2024, Bird+ 2024, Palanque-Delabrouille+ 2020, Rogers+ 2023, Goldstein+ 2023, etc.

Original compressed eBOSS Lya likelihood was in tension with Planck.

Bounds on neutrino self interactions

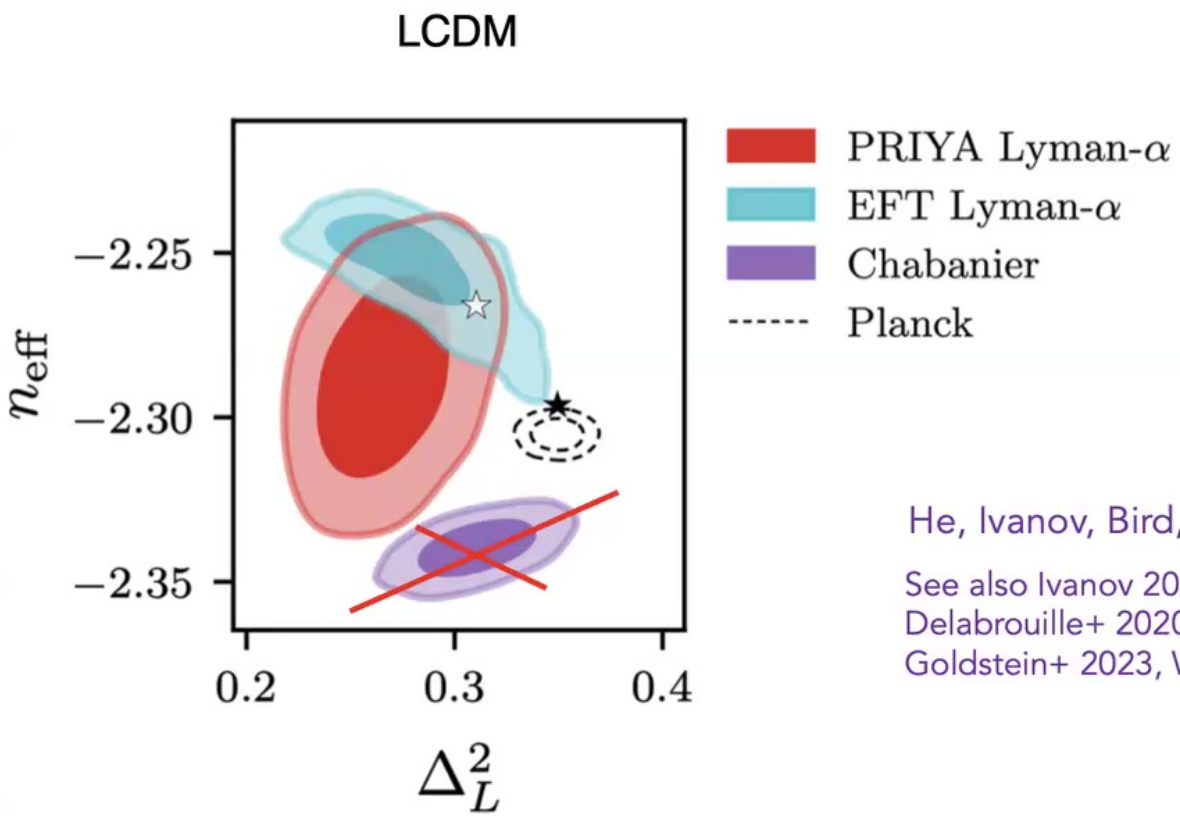
Adam He



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

He, An, Ivanov, VG (2023)

Reduced Lyman-alpha likelihood, a fresh look



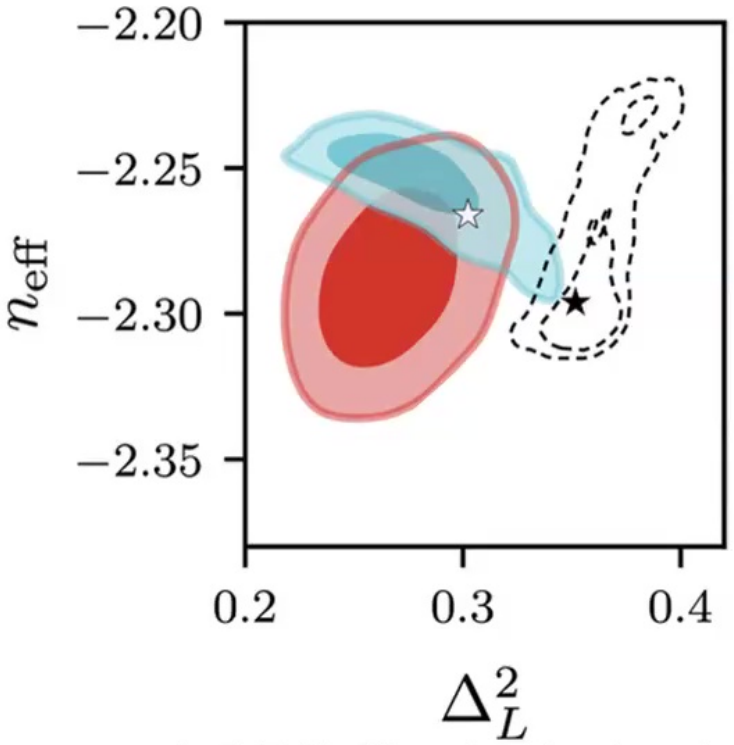
He, Ivanov, Bird, VG (2503.15592)

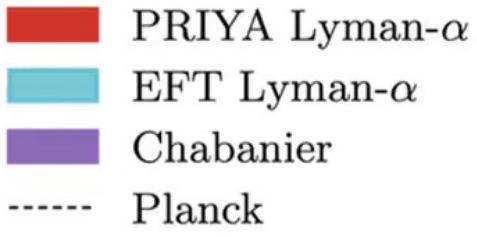
See also Ivanov 2024, Bird+ 2024, Palanque-Delabrouille+ 2020, Rogers+ 2023, Goldstein+ 2023, Walther+ 2024.

* EFT likelihood with priors from **Sherwood** simulation
* compressed likelihood from an emulator of **PRIYA** simulation

Reduced Lyman-alpha likelihood, a fresh look

With neutrino self-scattering





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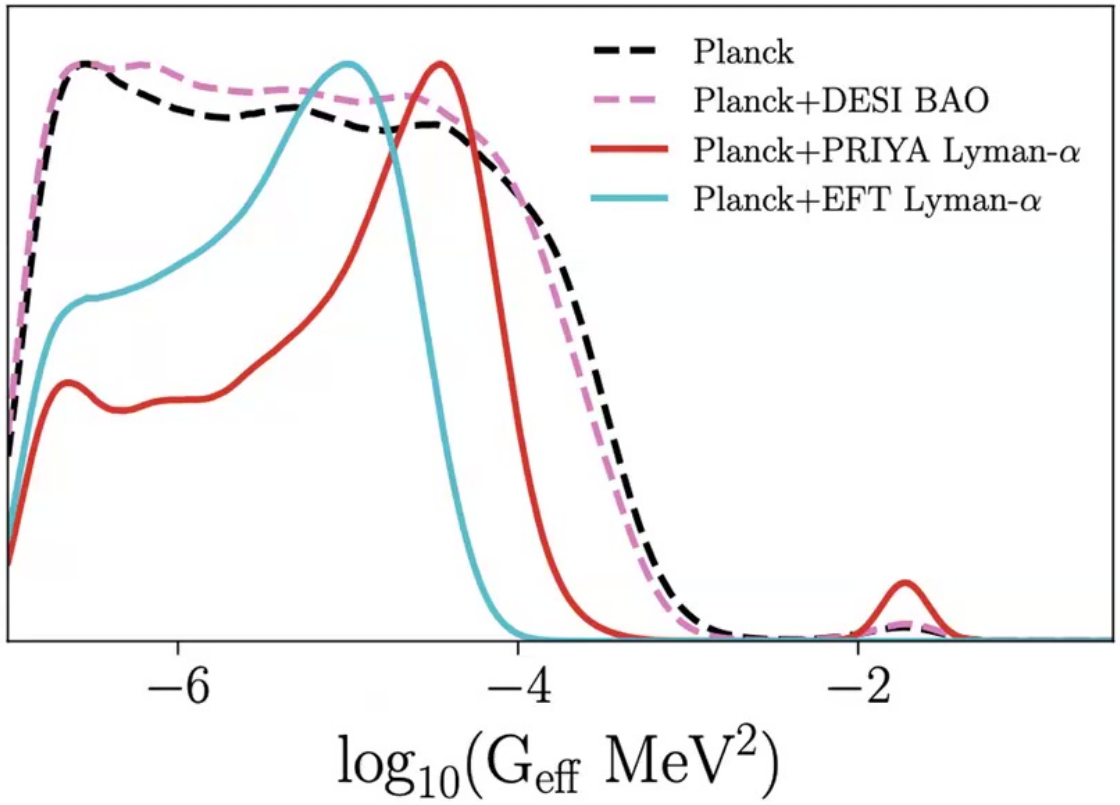
Fresh bounds on neutrino self interactions

Adam He

He, Ivanov, Bird, VG (2503.15592)



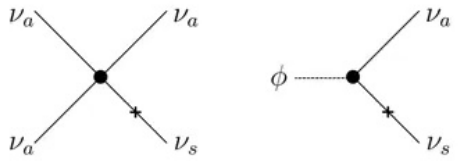
Addendum: producing sterile neutrino DM

Dark matter may be a fourth, heavy (~keV) neutrino that doesn't talk to the SM, but mixes with active neutrinos.

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

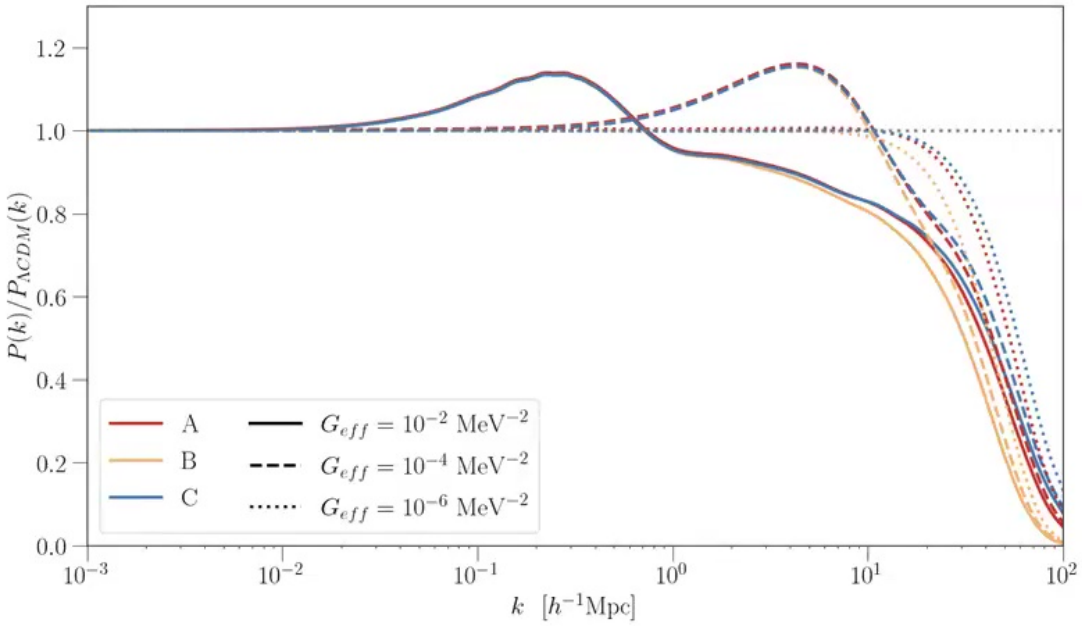
Need neutrino self-interactions to produce the observed abundance of dark matter.

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



Addendum: producing sterile neutrino DM

Priyank Parashari



Addendum: producing sterile neutrino DM

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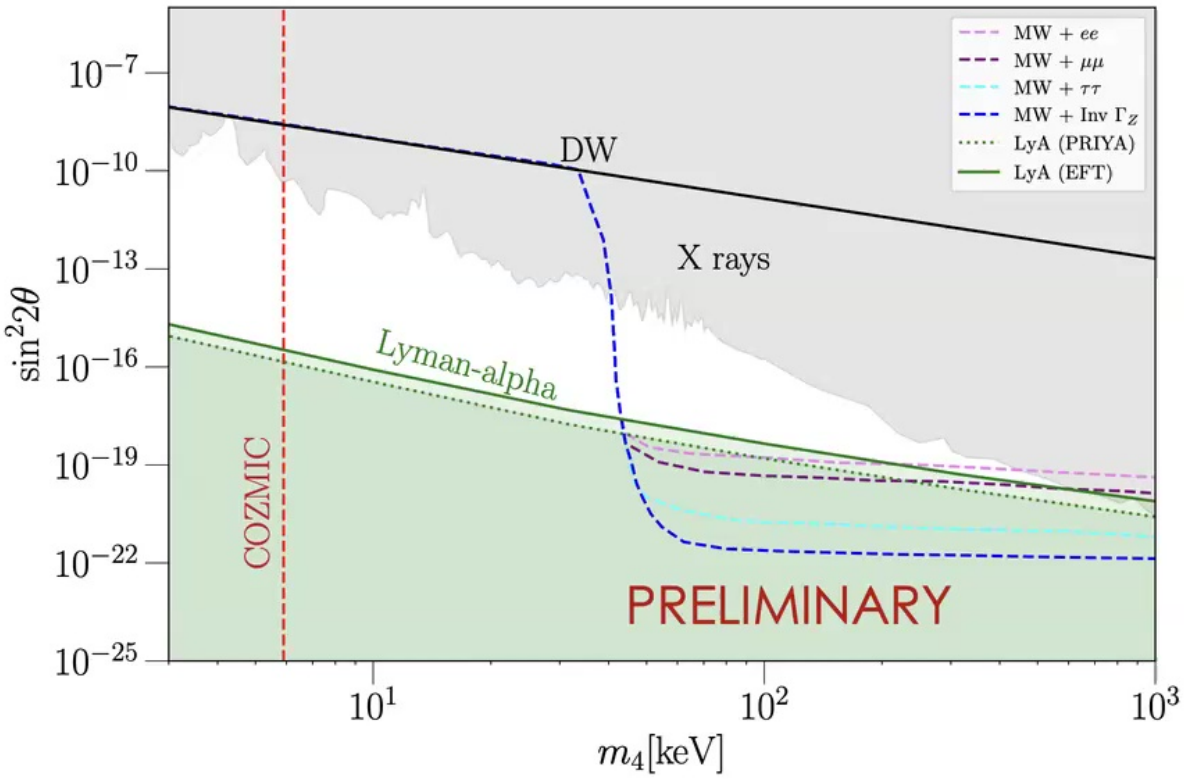
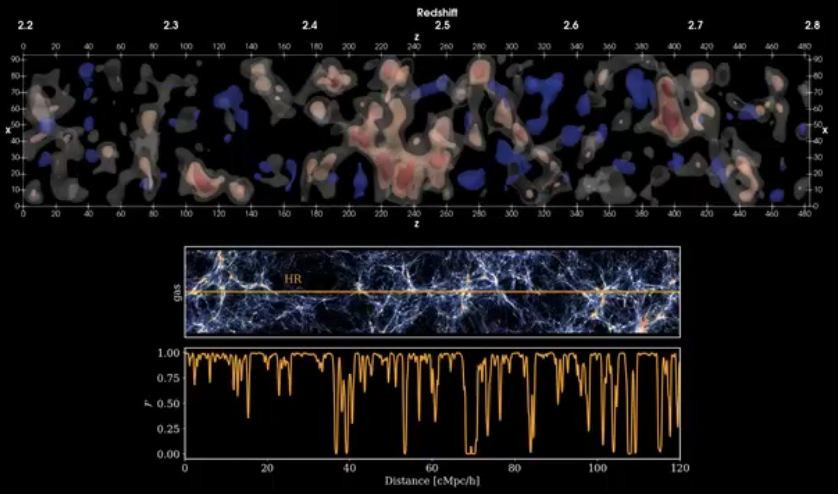


The lessons

- ✓ Need to better understand the gas to do cosmology/fundamental physics with the forest observations.
- ✓ Necessitates modeling and observations beyond cosmological surveys.

LARC

Lyman-alpha forest Research Collaboration (USC x Carnegie x UCR)



Goals:

- Forest simulations in **dark matter and neutrino cosmologies**
- Observation-driven calibration of astrophysics
- Cosmology with tomographic maps
- Probabilistic analyses across scales