Lyman-α constraints on non-standard dark matter

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(they/them)

Based on 2206.08188 (and 2110.04024, 1907.01496)

IDM, Vienna

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Lyman-α data

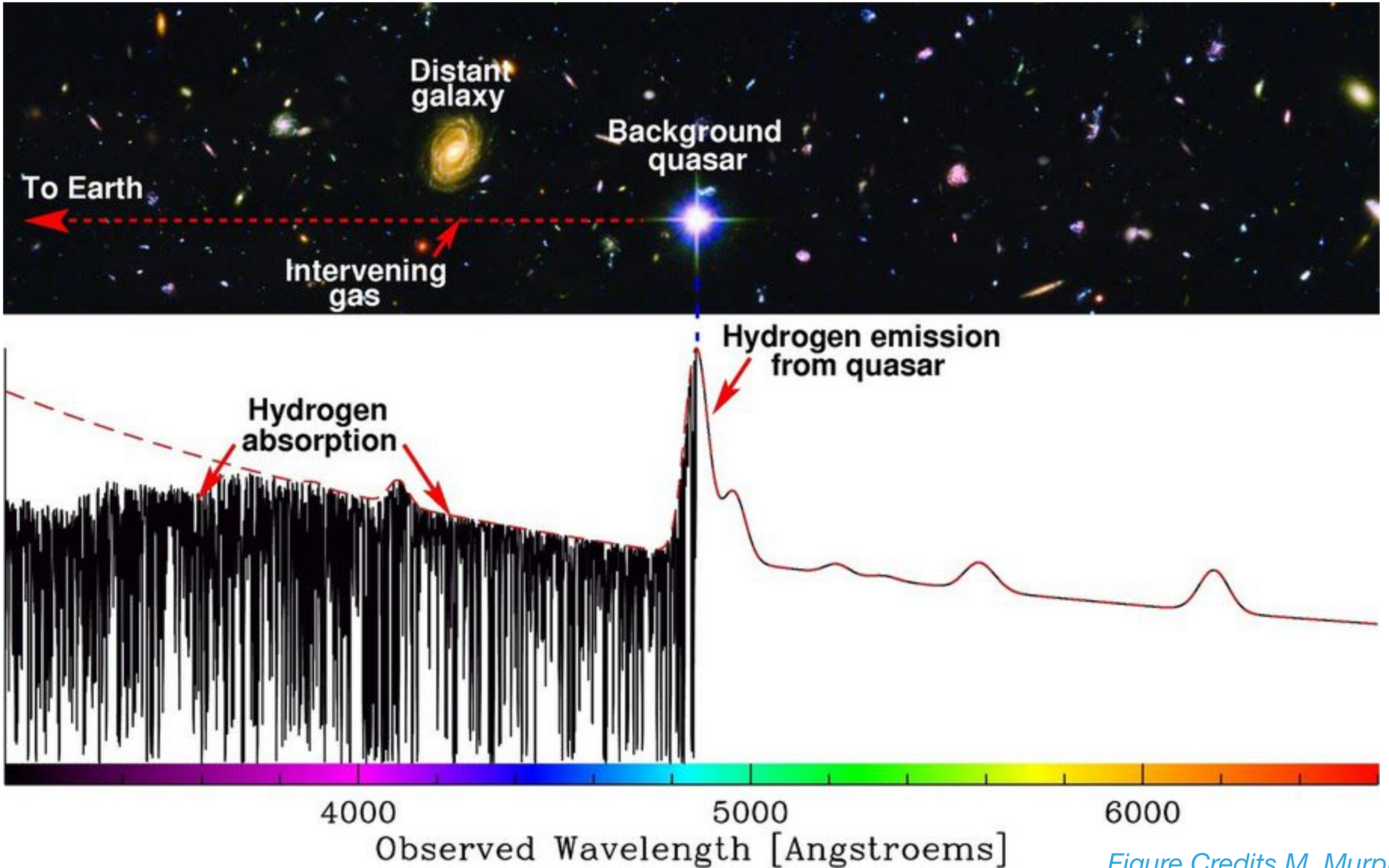
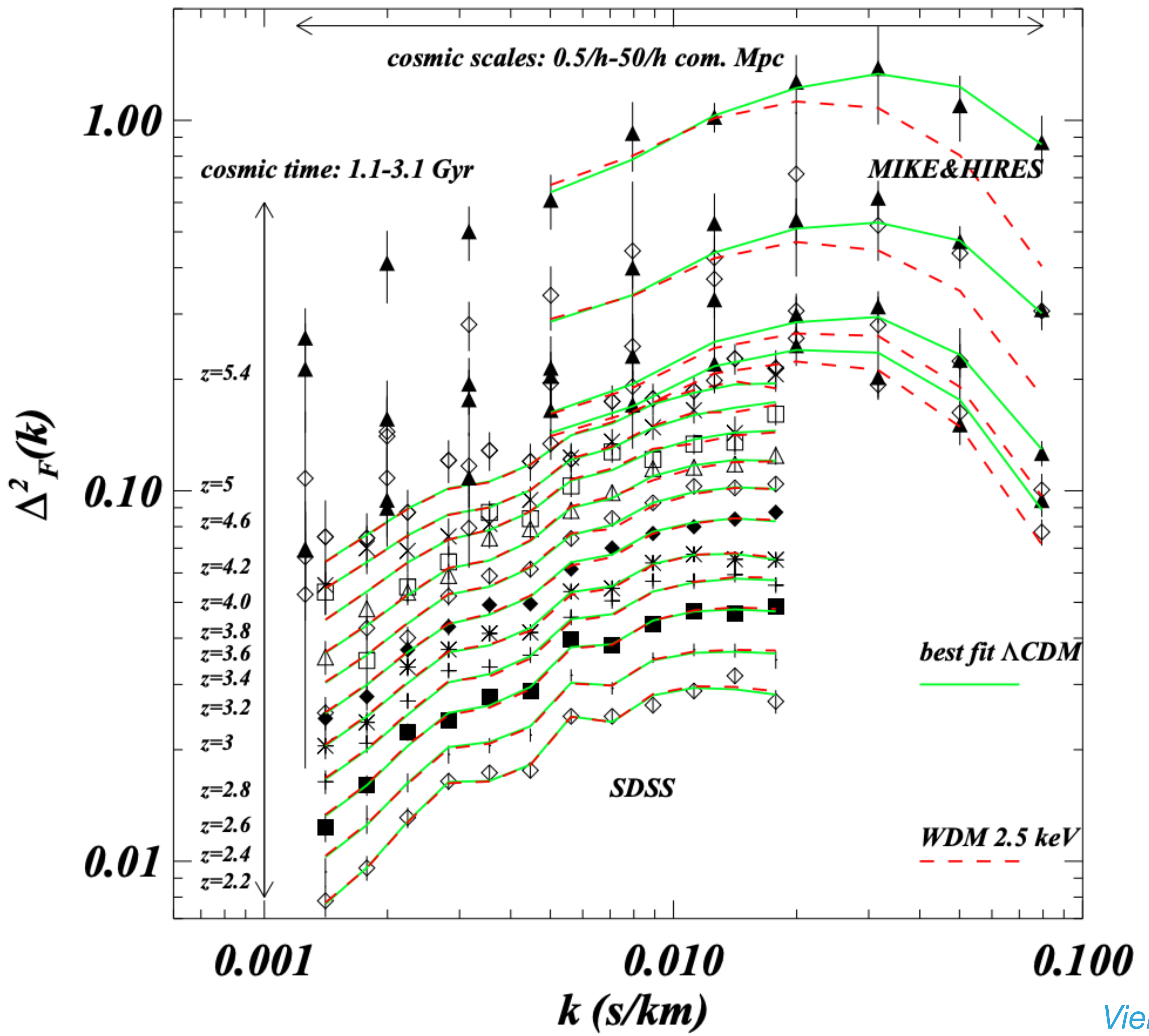


Figure Credits M. Murphy

Lyman-α data

- Absorption lines produced by the inhomogeneous IGM along different line of sights to distant quasars
- Allows us to trace hydrogen clouds → smallest structures
- Provides a tracer of the matter power spectrum at high redshifts ($2 \lesssim z \lesssim 5$) and small scales ($0.5\,h/\mathrm{Mpc} \lesssim k \lesssim 20\,h/\mathrm{Mpc}$)
- Can constrain models that affect small scale structure formation
- IGM filament modelling requires nonlinear evolution: this needs hydrodynamical simulations → parameter scans are not feasible

Lyman-α data and ΛCDM



Viel et al. 1306.2314

How to use Lyman-α data

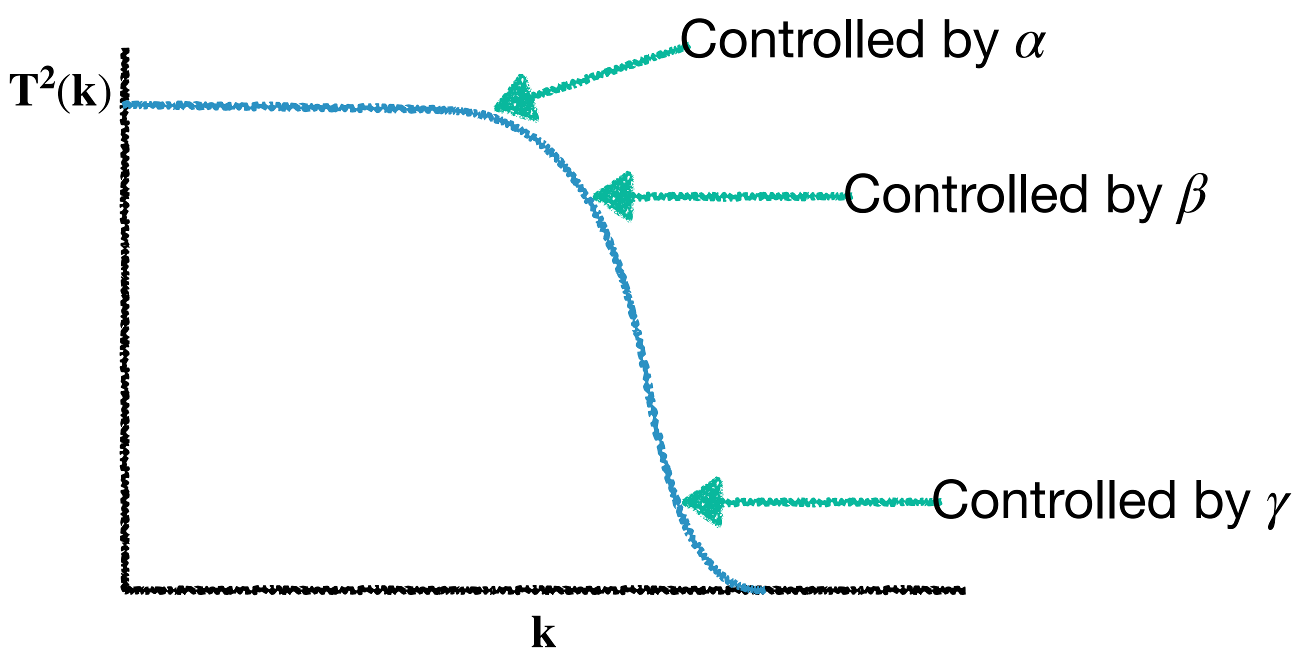
- Focus on the *shape* of the suppression in the matter power spectrum

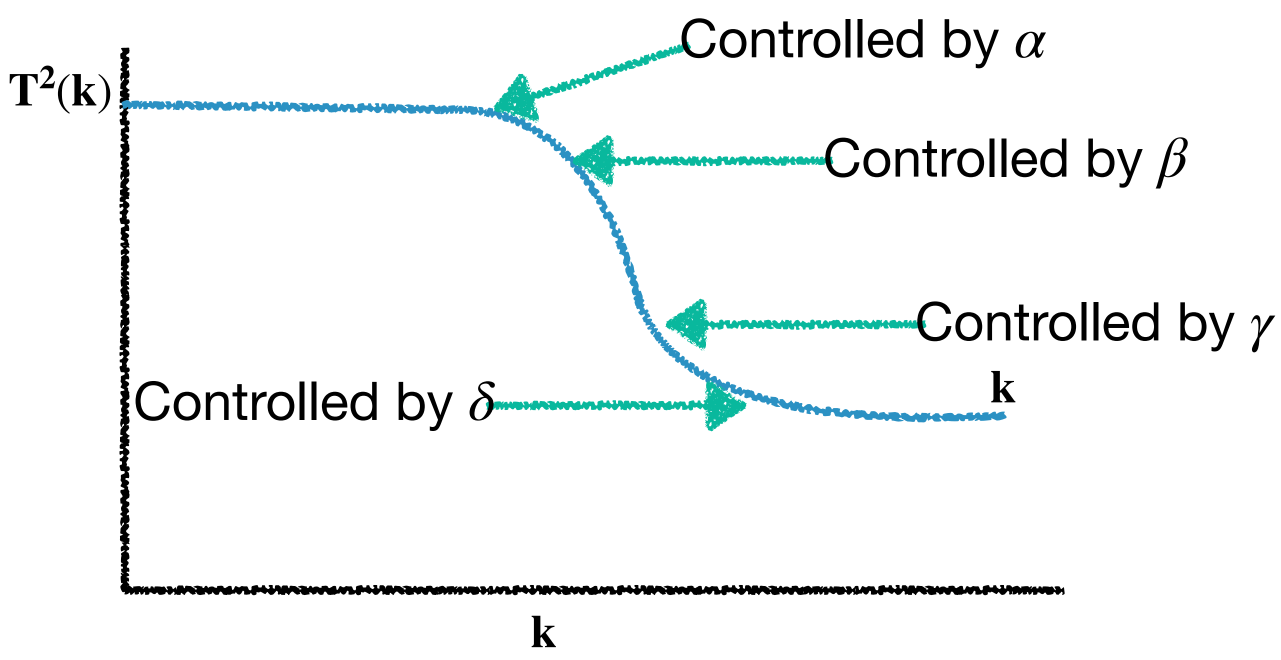
$$T(k) = \left[1 + (\alpha k)^{\beta}\right]^{\gamma}$$

Archidiacono et al. 1907.01496

$$T(k) = (1-\delta)\left[1 + (\alpha k)^{\beta}\right]^{\gamma} + \delta$$

Hooper et al. 2206.08188





- Use grids of hydro sims for over 200 different benchmark $\alpha\beta\gamma$ or $\alpha\beta\gamma\delta$, with a corresponding χ^2 given by Lyman-α data (MIKE/HIRES)

- Interpolate in grid, obtain a χ^2 from Lyman-α data for specific model

Non-standard dark matter

- Current dark matter paradigm: cold, collisionless, non-baryonic matter that interacts gravitationally
- Non-cold dark matter: warm or mixed warm+cold, sterile neutrinos, …
- Interactions: neutrinos, baryons, dark radiation, photons, SIDM, …
- All of these models (NSDM) change DM clustering and induce a small-scale suppression of power

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$\alpha\beta\gamma\delta$ [1]

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$\alpha\beta\gamma$ [2] $\alpha\beta\gamma\delta$ [1] $\alpha\beta\gamma + \delta$ [1,3]

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[1] Hooper et al. 2206.08188 *[2] Hooper et al. 2110.04024* *[3] Archidiacono et al. 1907.01496*

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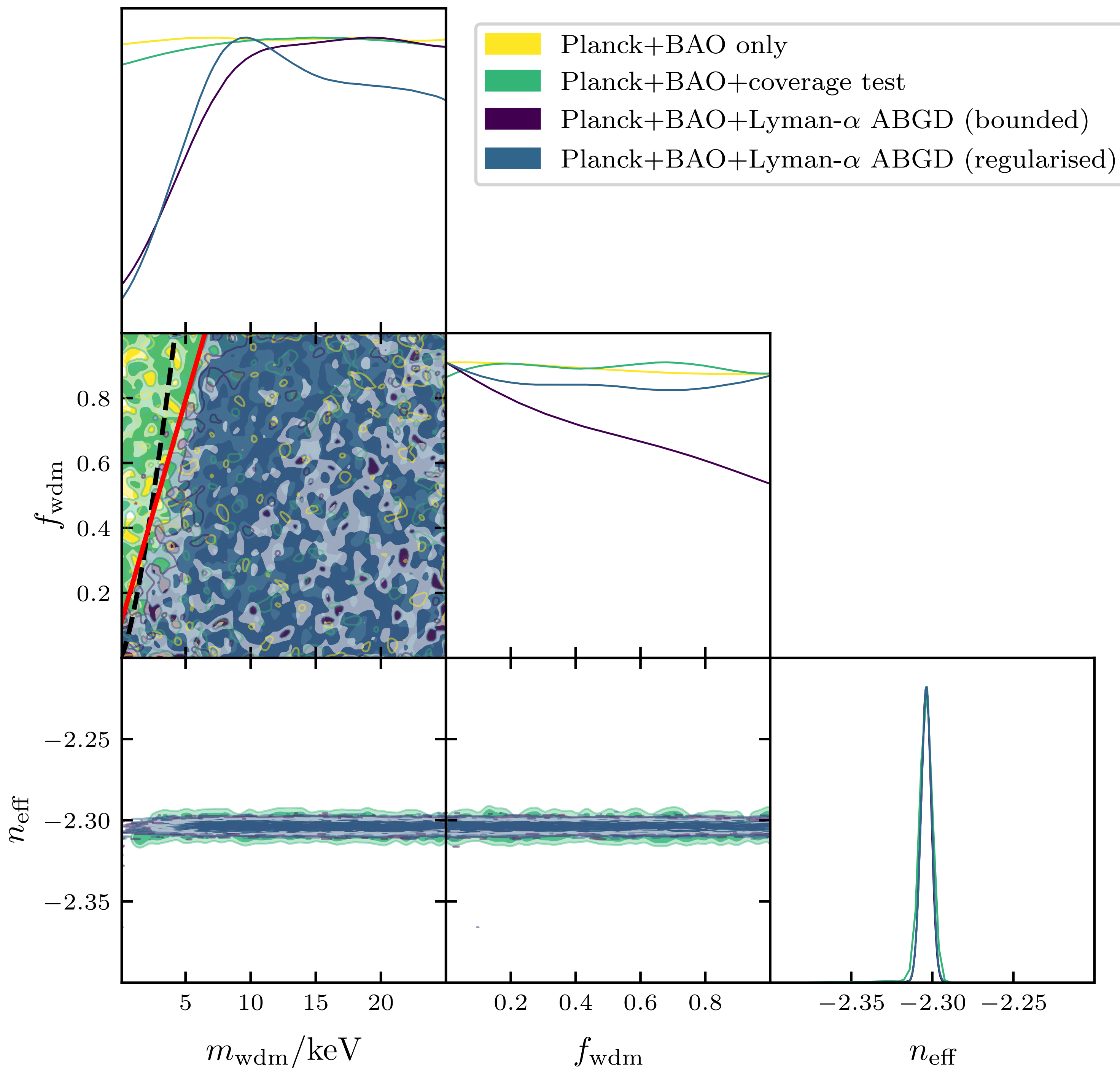
(Mixed) Warm dark matter



Bound $f_{\rm wdm}$ free:

$m_{\rm WDM} \gtrsim 7.2{\rm keV}\left(f_{\rm WDM} - 0.1\right)$

Bound $f_{\rm wdm} = 1$, WDM:

$m_{\rm WDM} \gtrsim 5.9{\rm keV}$

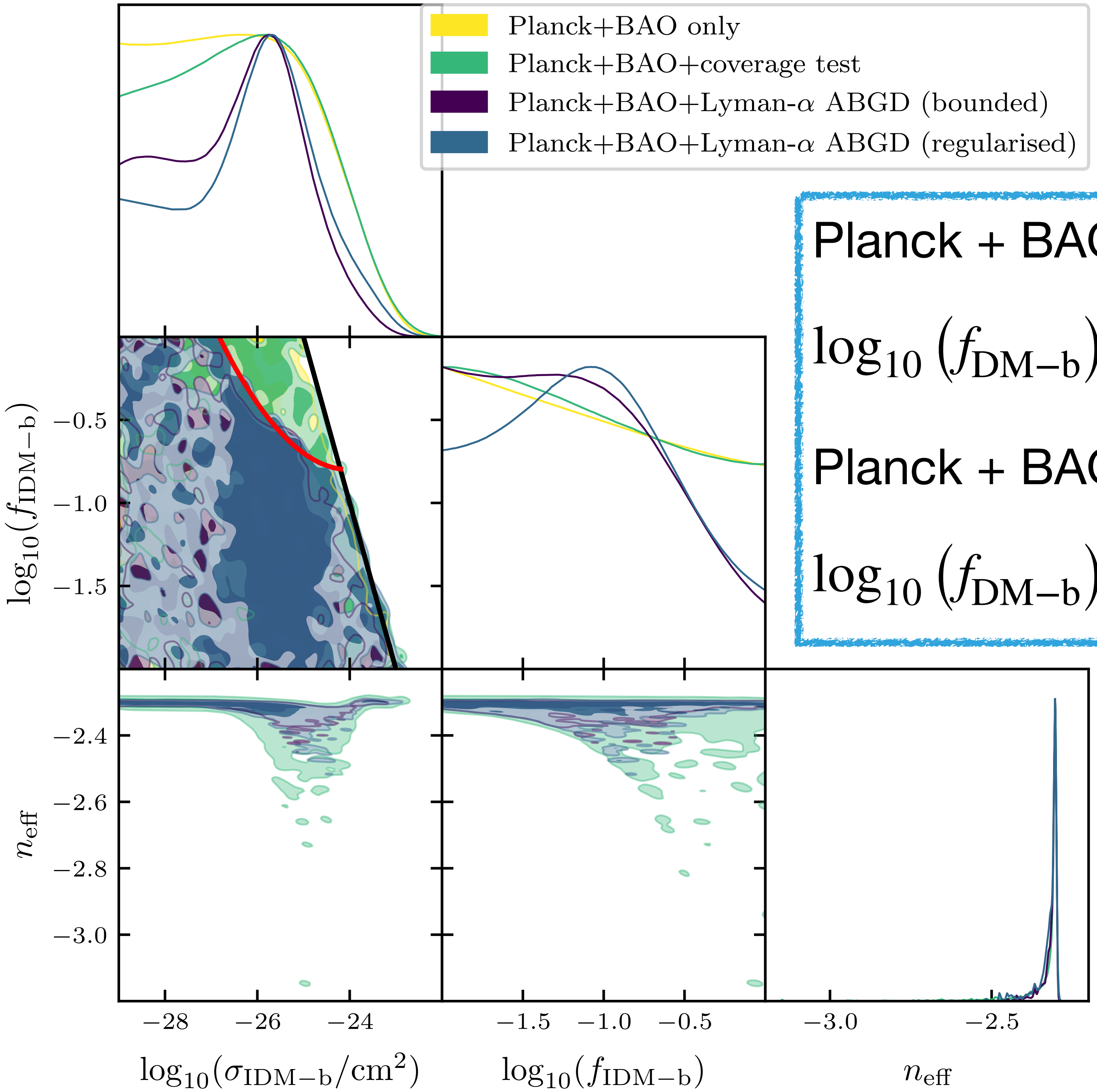
Bound $f_{\rm wdm} = 1$, using $1/m_{\rm wdm}$ prior

$m_{\rm WDM} \gtrsim 3.0{\rm keV}$

$\alpha\beta\gamma\delta$ likelihood reproduces previous results when using same priors

Hooper et al. 2206.08188

DM - baryon interactions



Planck + BAO:

$$\log_{10}\left(f_{\rm DM-b}\right) < -25 - \log_{10}\left(\sigma_{\rm DM-b}/{\rm cm}^2\right)$$

Planck + BAO + Lyman-α:

$$\log_{10}\left(f_{\rm DM-b}\right) < -0.8 + 0.1\left(\log_{10}\left(\sigma_{\rm DM-b}{\rm cm}^2\right) + 24\right)^2$$

When $f_{\rm IDM-b} = 1$, $\alpha\beta\gamma\delta$ likelihood can reproduce previous results

Mild preference for non-zero interactions

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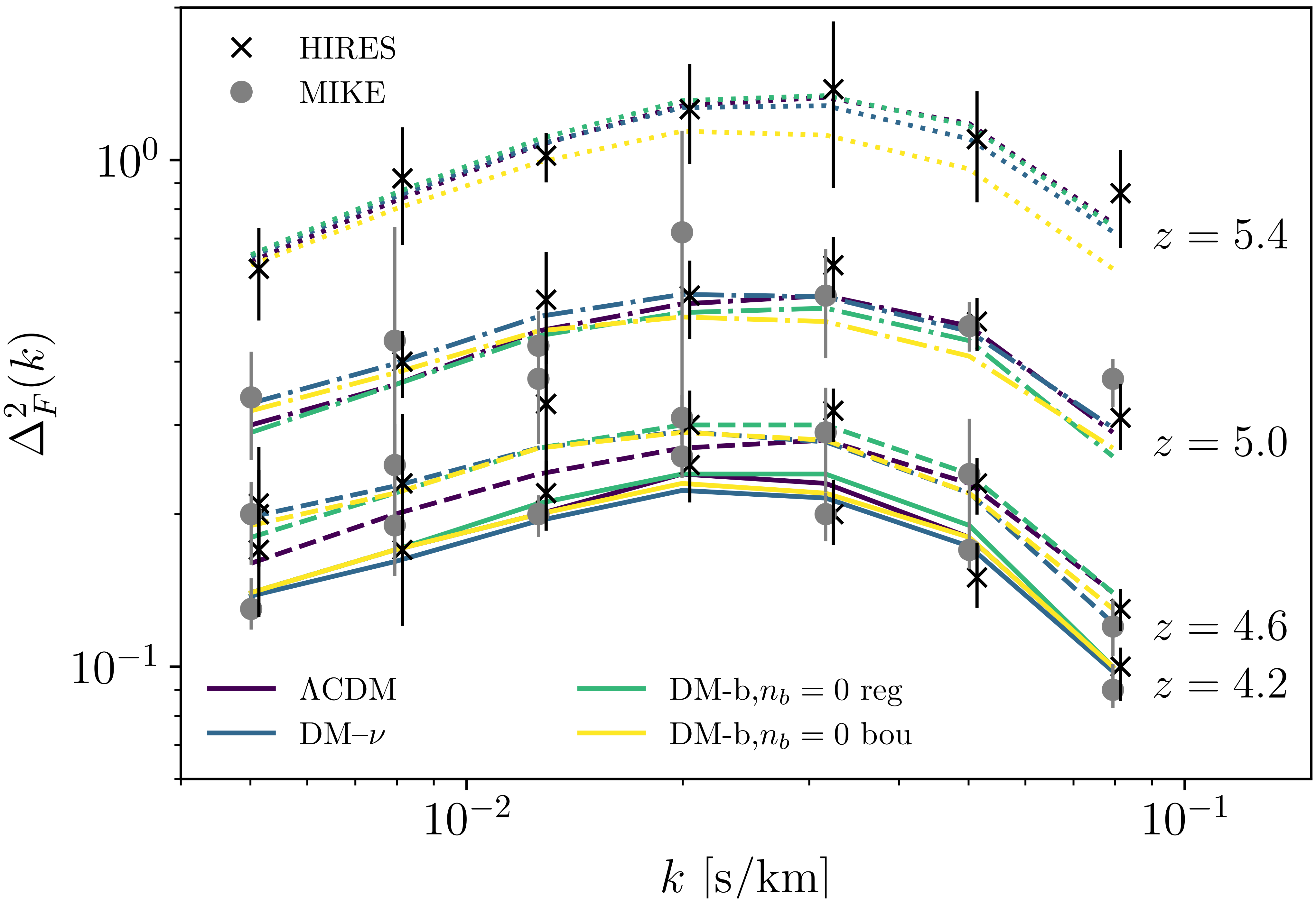
DM - baryon interactions



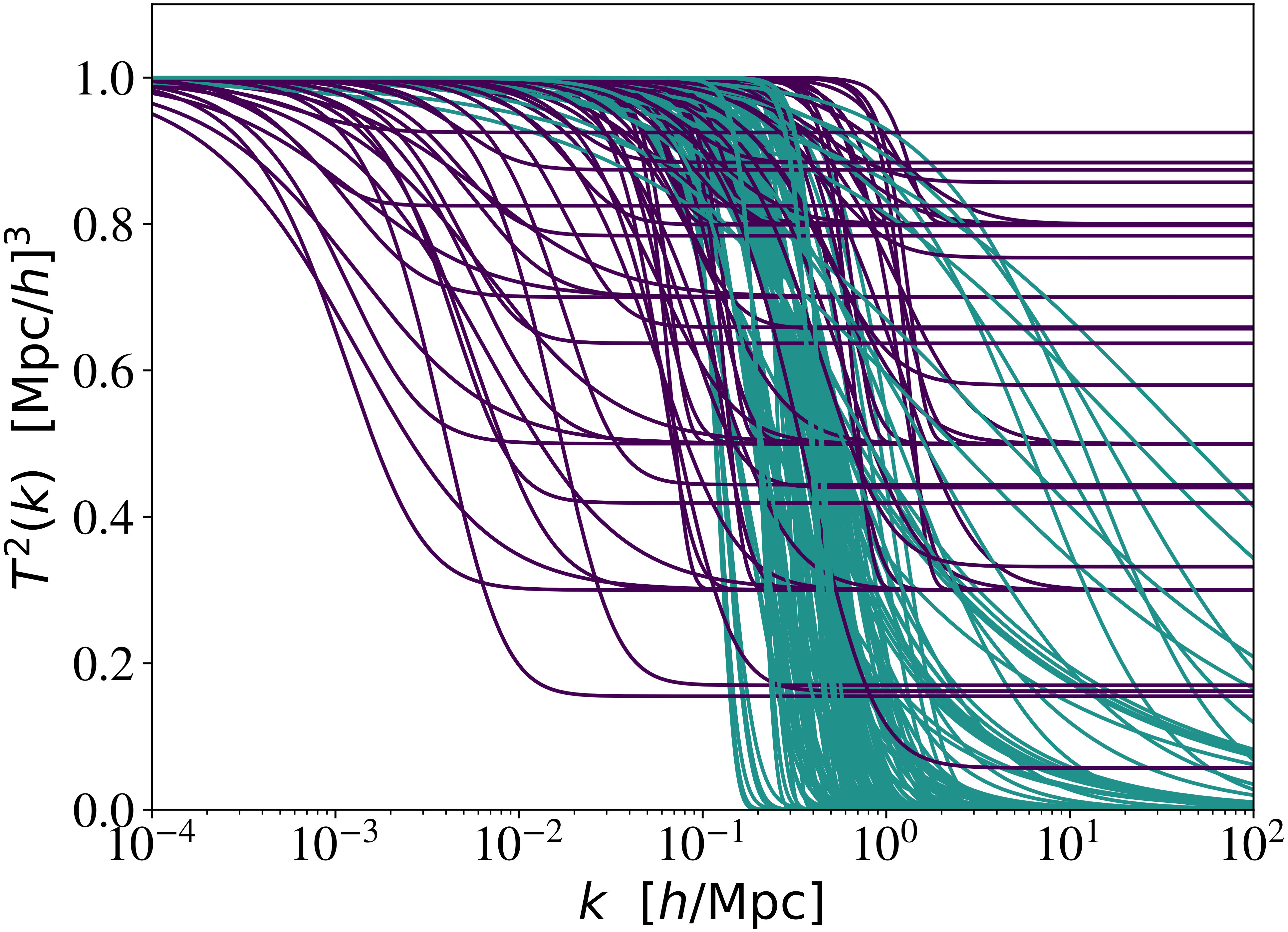
Hooper et al. 2206.08188

Summary

- New Lyman-α likelihoods to constrain many non-standard dark matter models, including mixed models
- WDM bounds provide a cross-check, updated bounds on mixed models
- We previously found that Lyman-α data prefer non-zero interactions between DM and neutrinos (using $\alpha\beta\gamma$)
- Newer, more accurate $\alpha\beta\gamma\delta$ likelihood finds similar mild preference for interactions between DM and baryons
- Lyman-α data seem to prefer a non-ΛCDM flux: this data has great potential for discovery

Thank you for your attention

Grid of simulations



$\delta = 0$

Archidiacono et al. 1907.01496

$\delta \neq 0$

Hooper et al. 2206.08188

DM - baryon cross-checks

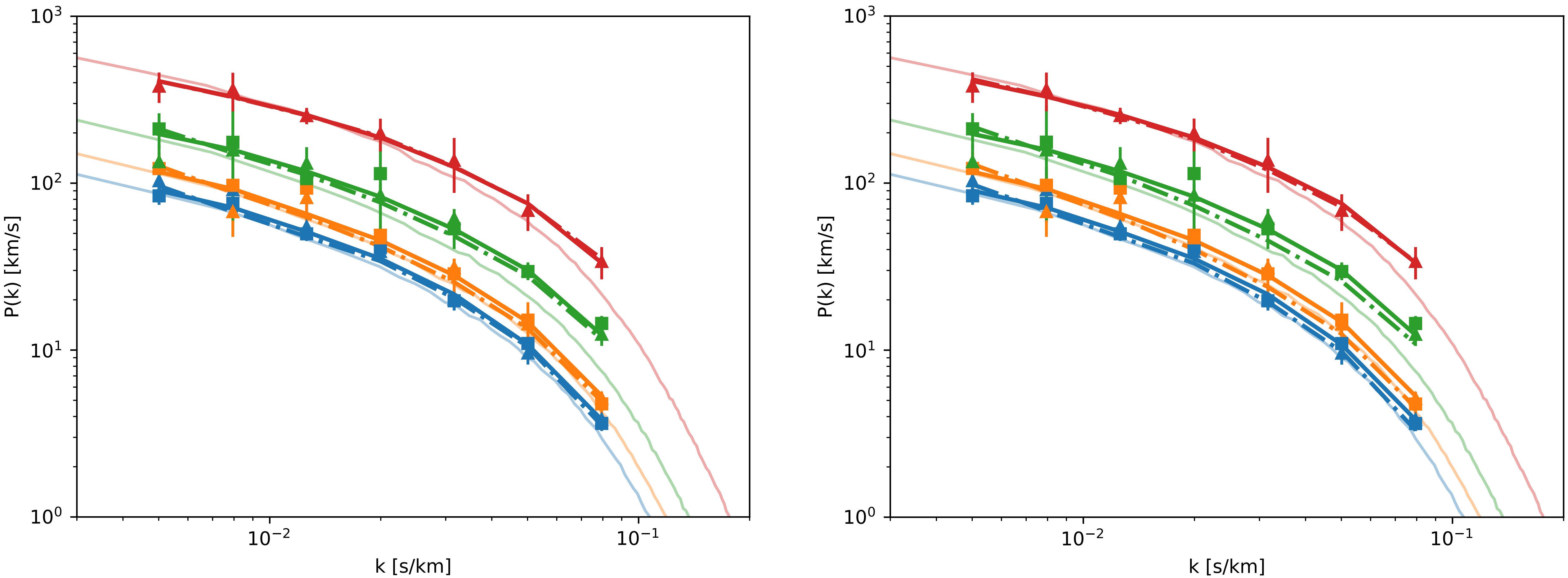
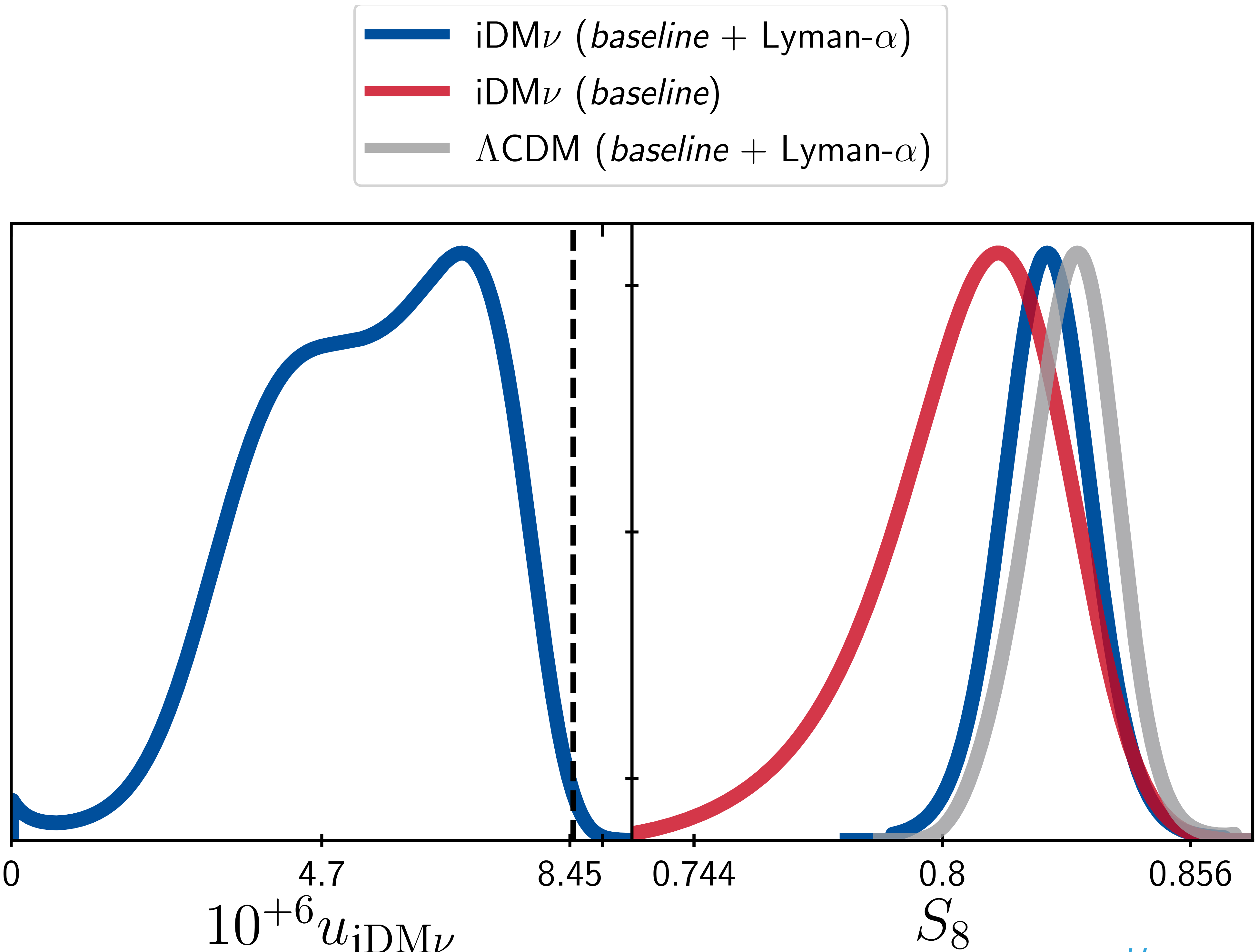


Figure 9: Model with $\sigma_{\rm DM-b} = 6.2 \cdot 10^{-26}$ and $f_{\rm DM-b} = 0.23$. The colors are [$z = 4.2$–blue, $z = 4.6$–orange, $z = 5.0$–green, $z = 5.4$–red]. The faint lines in the background are the additional simulation spectra themselves, which are then corrected using the astro/kriging grid in solid lines. The dashed lines are instead the predictions from the simulation grid. The triangle correspond to HIRES data, while the squares correspond to MIKE data. **Left:** Bounded method. **Right:** Regularised method.

Hooper et al. 2206.08188

DM - neutrino interactions



Hooper et al. 2110.04024

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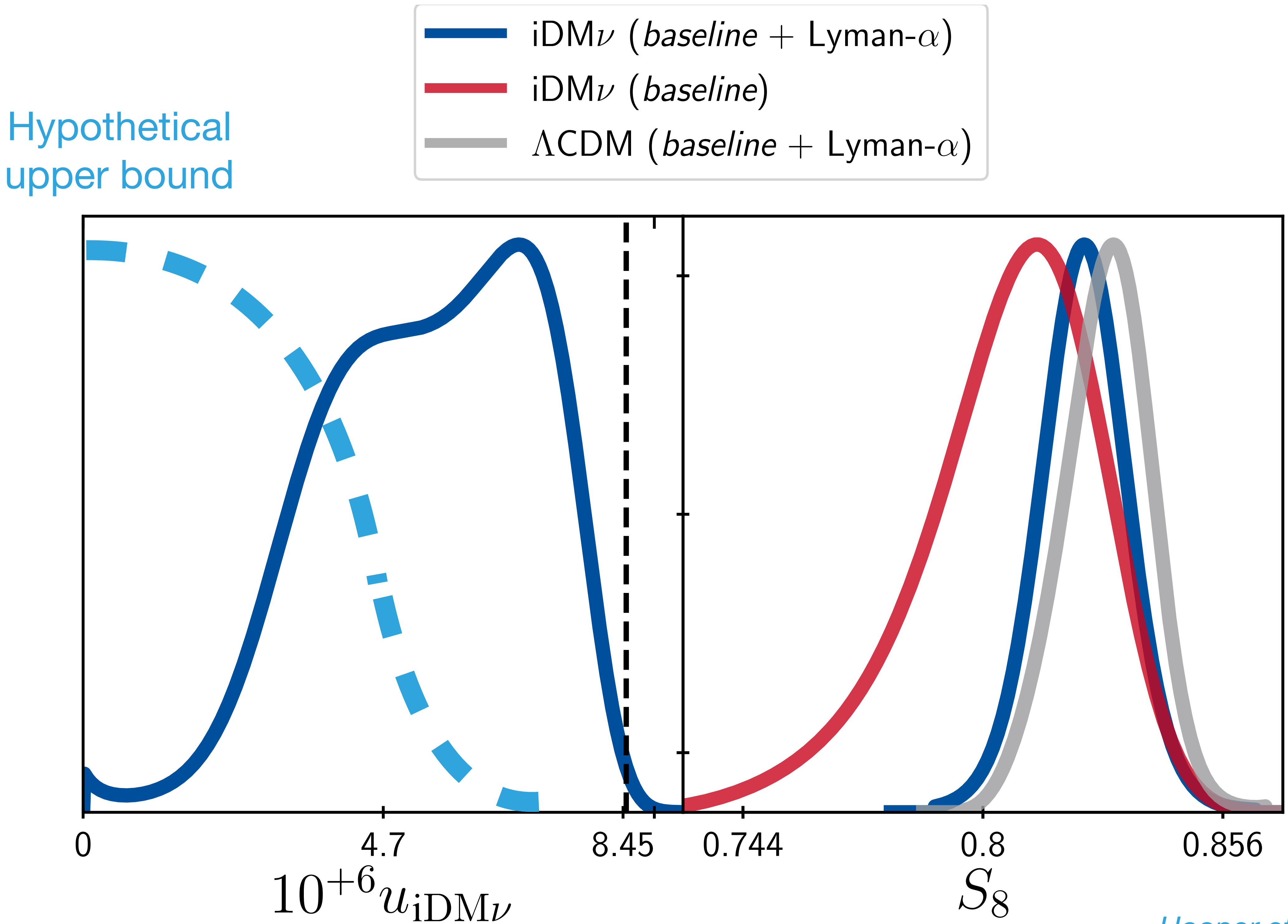

Hooper et al. 2110.04024

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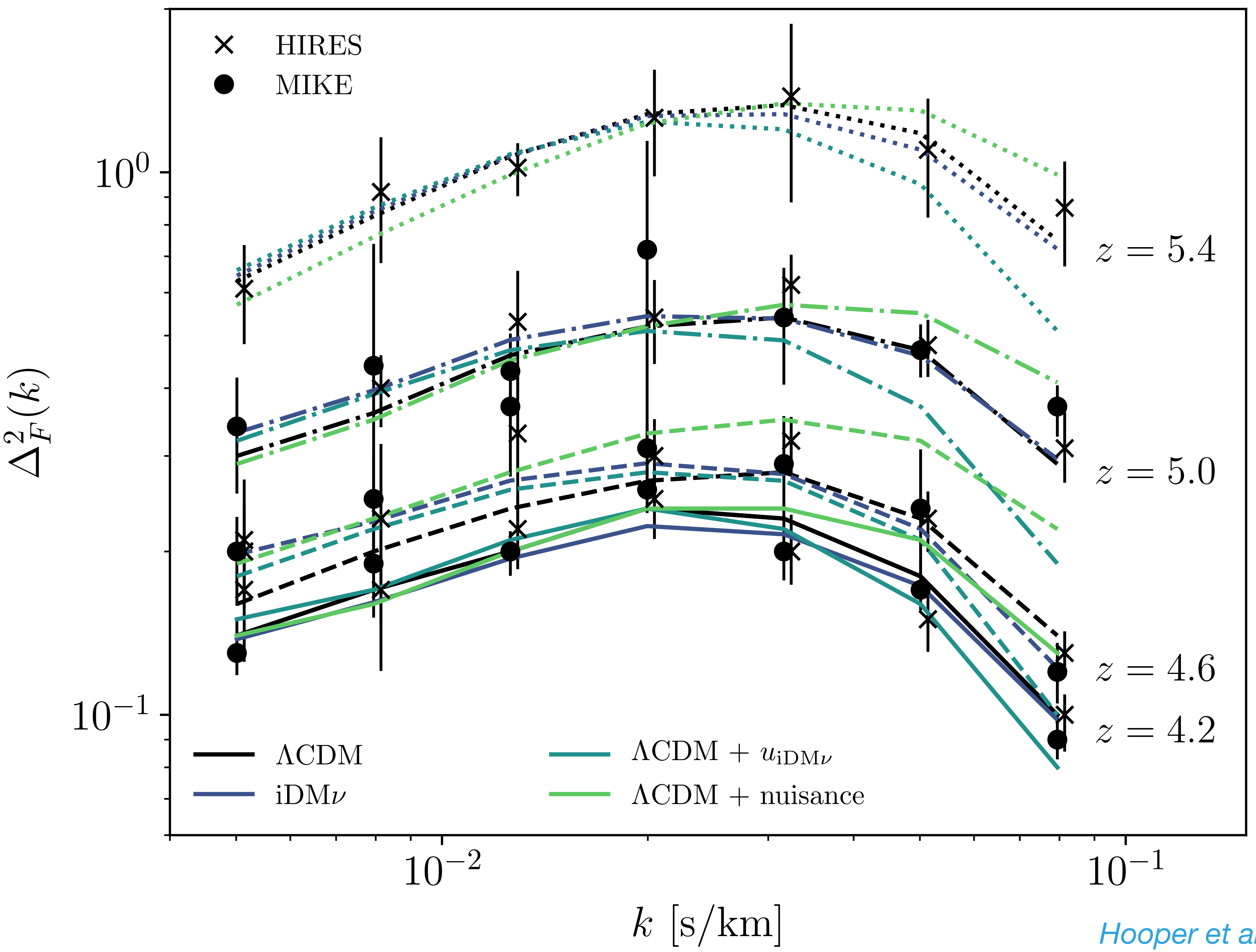

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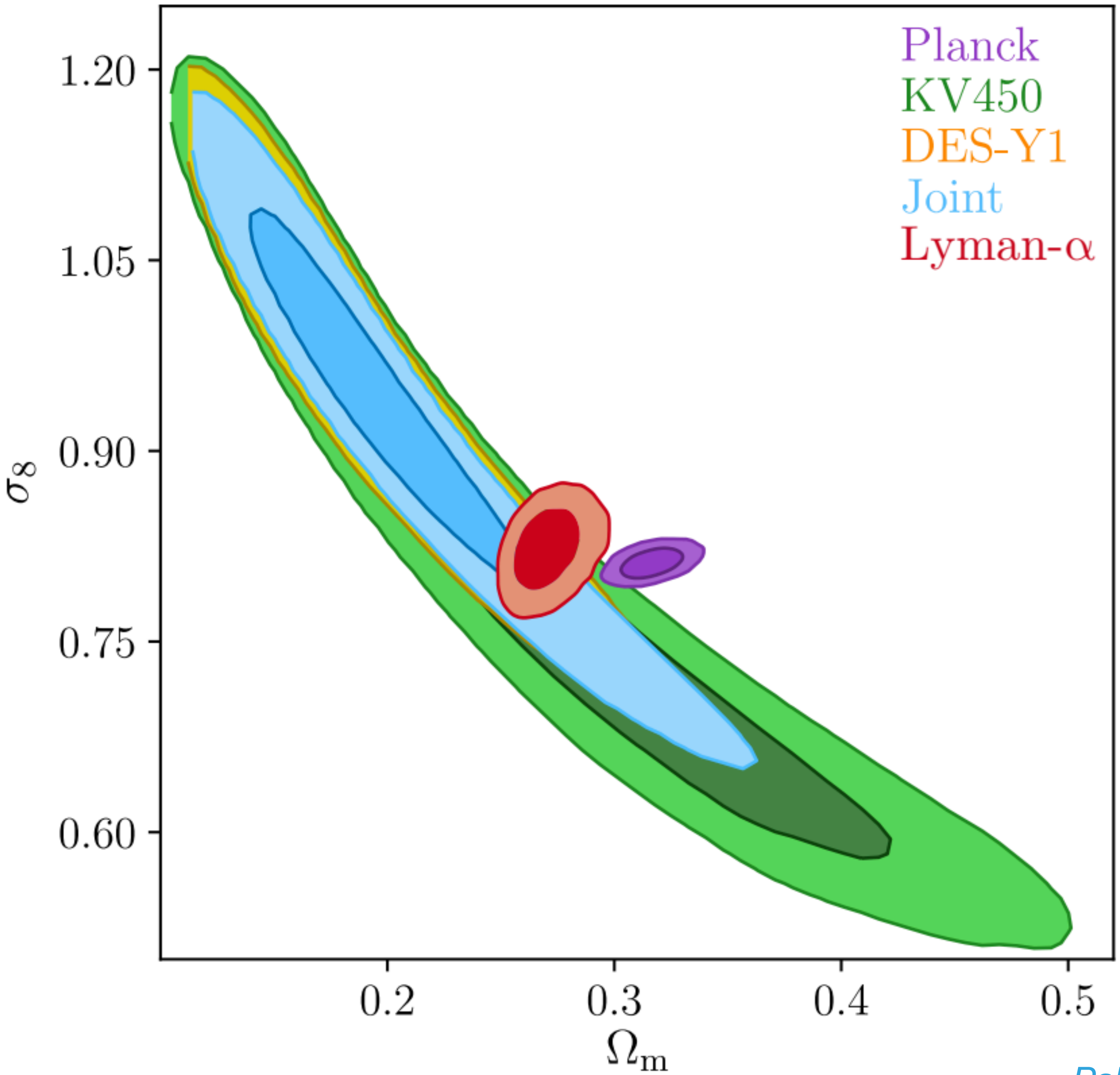

Combined parameter:

$$S_8 = \sigma_8\sqrt{\Omega_m/0.3}$$

Palanque-Delabrouille et al. 1911.09073