Constraining Dark Matter - Dark Radiation Interactions With Lyman-α Data

Deanna C. Hooper

*Based on Archidiacono, **DCH**, Murgia, Bohr, Lesgourgues, Viel (1907.01496)*

IRN Terascale@Bruxelles

18th October 2019

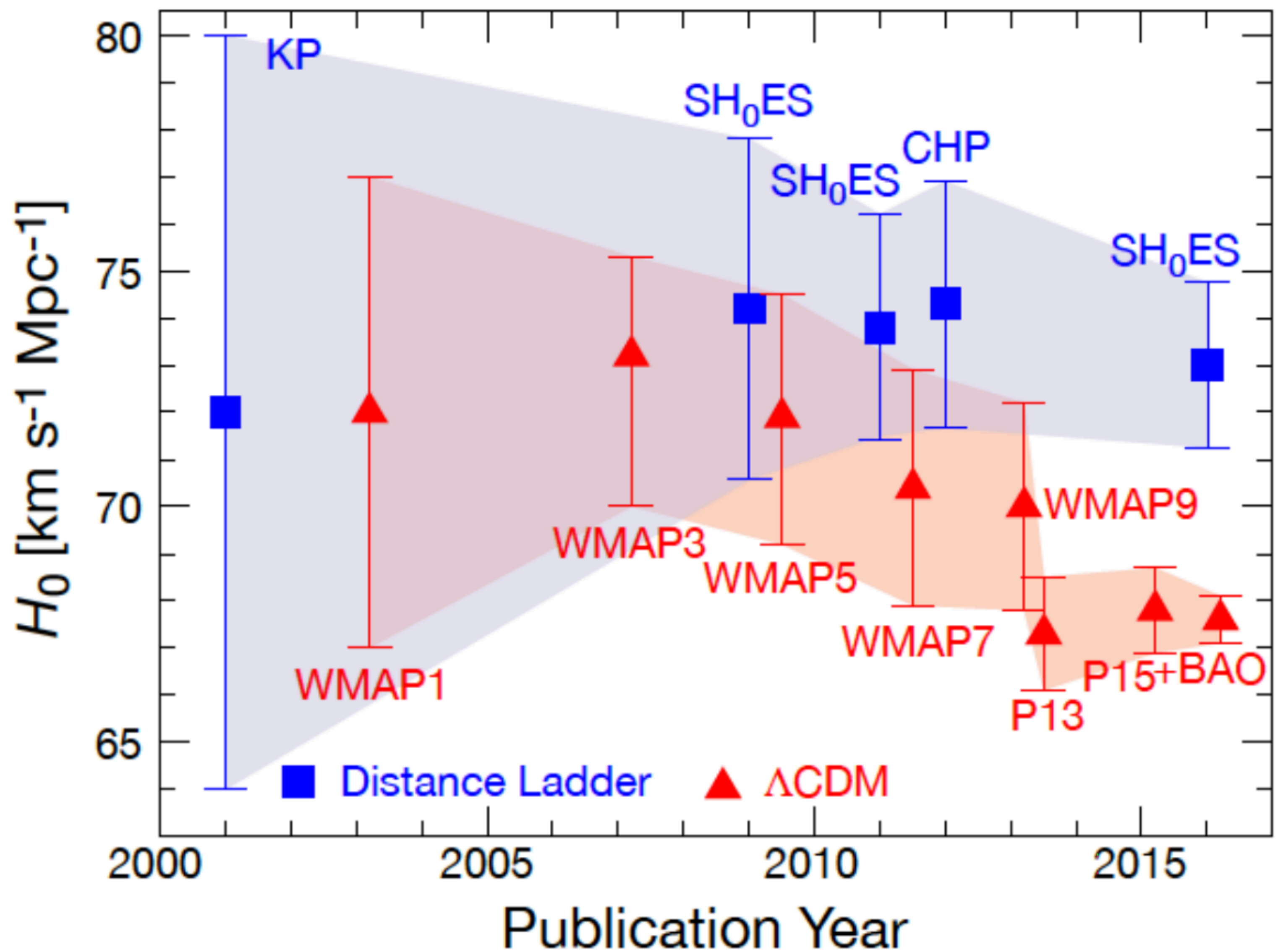
UNIVERSITÉ LIBRE DE BRUXELLES
fnrs FREEDOM TO RESEARCH

Overview

1. **Tensions in ΛCDM?**
    - H_0 measurements
    - Other tensions
2. **DM-DR interactions**
    - Formalism
    - Solving the tensions
3. **Using Lyman-α data**
    - What is Lyman-α
    - Parameterisation
    - Building a likelihood
4. **Results**
5. **Outlook**

Cosmological Tensions - H_0

- Expansion rate of the universe measured by CMB (early times) and supernovae (late times)
- Values do not agree! Currently there is a ~4.5σ tension
- CMB measurements assume ΛCDM. Supernovae assume a particular Cepheid calibration. Something has to be wrong…



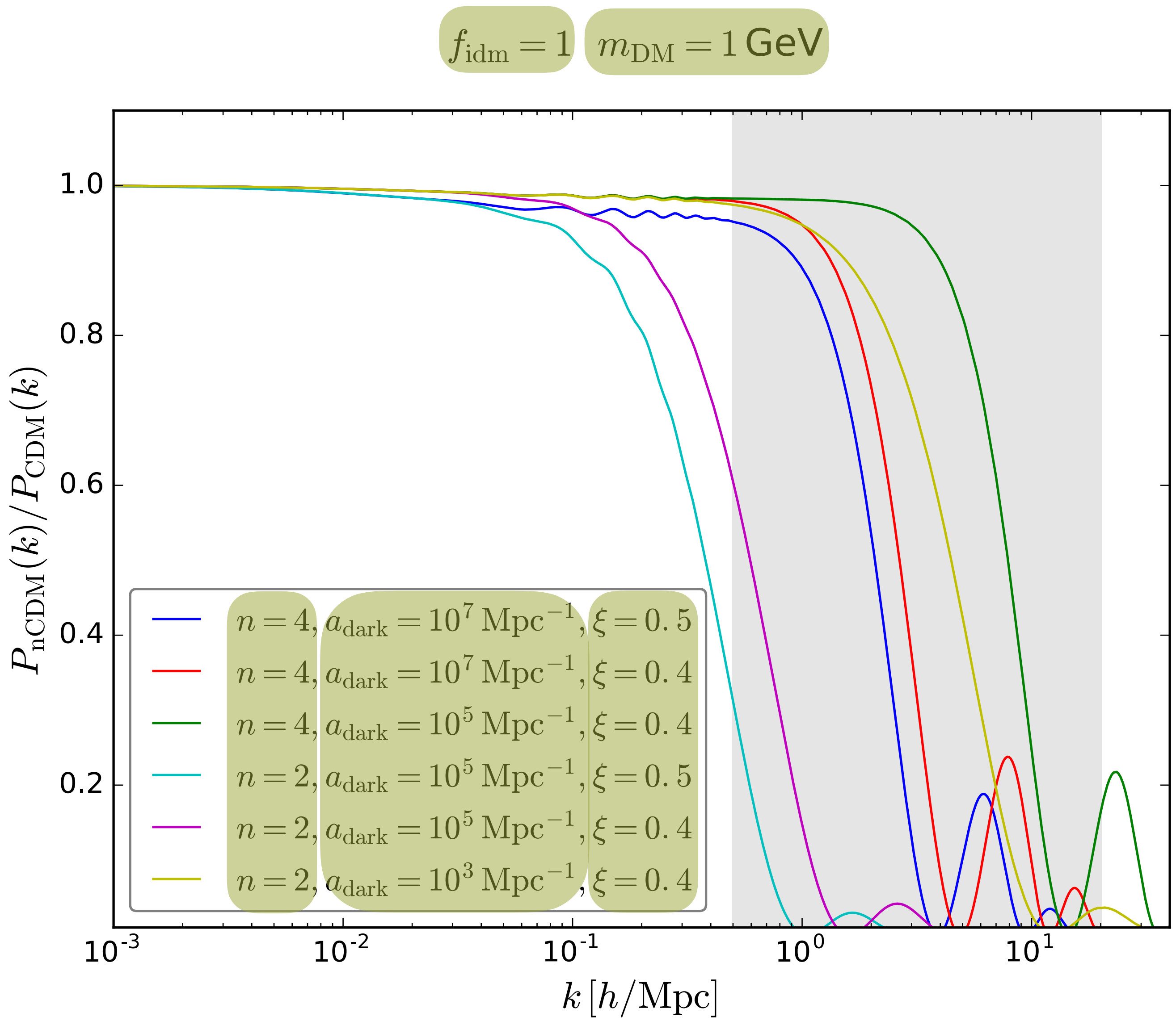
Freedman et al. 1706.02739

Other Cosmological Tensions

- σ_8 gives measurement of the amplitude of the power spectrum on the scale of 8 Mpc/h. Weak lensing and CMB values at ~2σ tension.
- A crisis on the smallest scales: mismatch between simulations and observations of structures in our local neighbourhood
  - Missing satellite problem: we observe fewer satellites than expected
  - Too-big-to-fail problem: most massive sub-halos have not ignited
  - Cusp-core problem: we see cored profiles, simulations prefer cusps
  - Diversity Problem: we see too many different galaxy profiles

DM-DR

*Archidiacono, **DCH**, Murgia, Bohr, Lesgourgues, Viel 1907.01496*

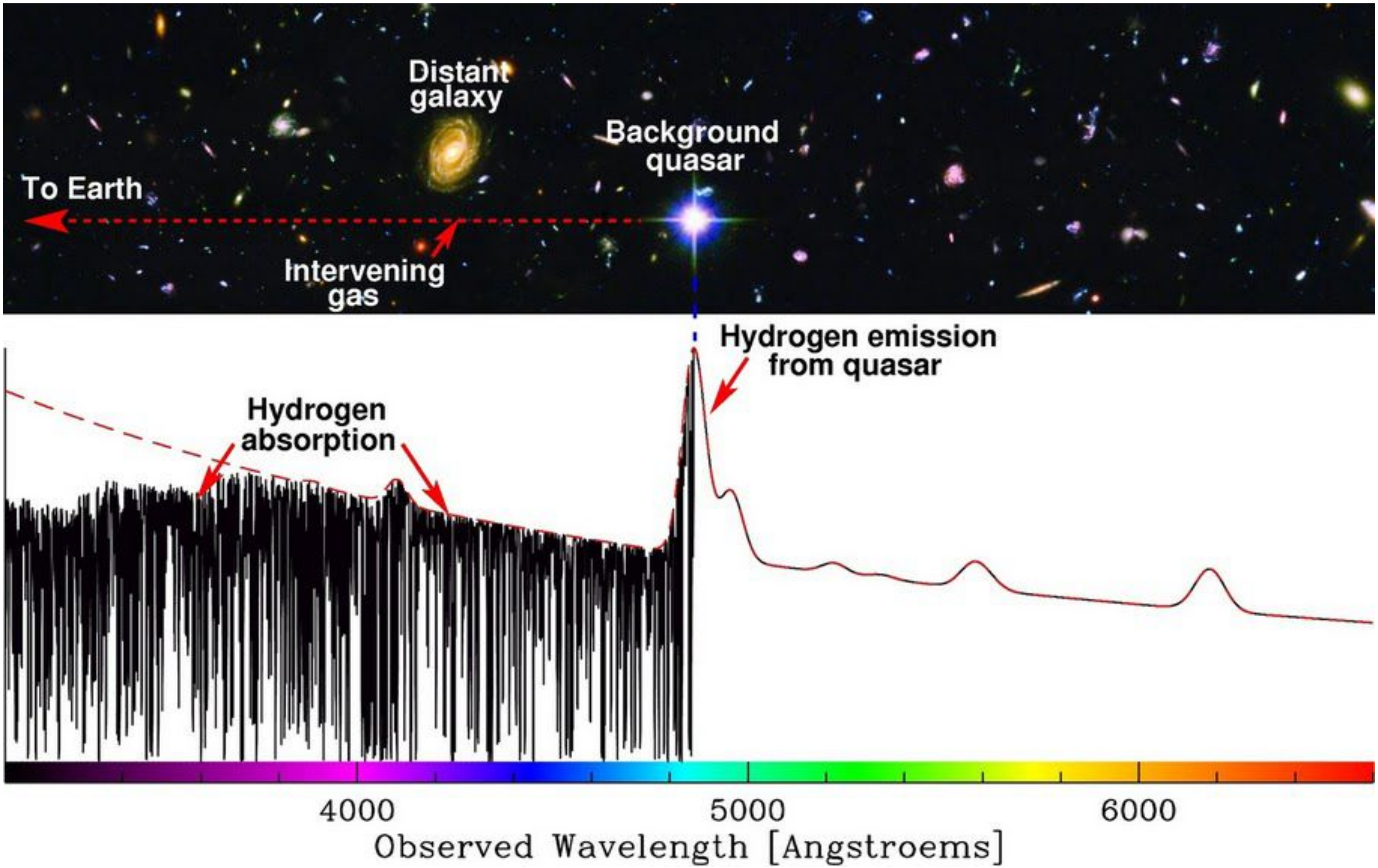


- Dark Matter - Dark Radiation interactions induce a suppression of the matter power spectrum on small scales
- For general interactions, we use ETHOS formalism (Cyr-Racine et al. 1512.05344)
- We consider only the process $\chi\tilde{\gamma} \leftrightarrow \chi\tilde{\gamma}$, with no DM or DR self-interactions
- Relevant parameters: amplitude of scattering rate $a_{\rm dark}$, amount of dark radiation $\xi = T_{\rm dr}/T_\gamma$, temperature dependence of scattering rate n, dark matter mass $m_{\rm DM}$, and fraction of interacting dark matter $f_{\rm idm}$

Solving the tensions

- Case of $n = 0$ may solve H_0 and σ_8 tensions (e.g. Buen-Abad et al. 1505.03542)
- DR acts like extra N_{eff} $\rightarrow$ H_0 increases to maintain z_{eq}
- Collisional damping with DR suppresses DM growth, leading to a small scale matter power suppression $\rightarrow$ lower σ_8
- The combination of relativistic particles and the DM-DR coupled fluid allows us to avoid constraints that kill other solutions to these tensions (extra Silk damping, added lensing, …)
- Case of $n = 4$ can explain missing satellites (Archidiacono et al. 1706.06870)
- Later kinetic decoupling results in the matter power spectrum being suppressed on small scales $\rightarrow$ number of satellites is reduced

Lyman-α Data



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 $(\,0.5\,h/\mathrm{Mpc} \lesssim k \lesssim 20\,h/\mathrm{Mpc}\,)$

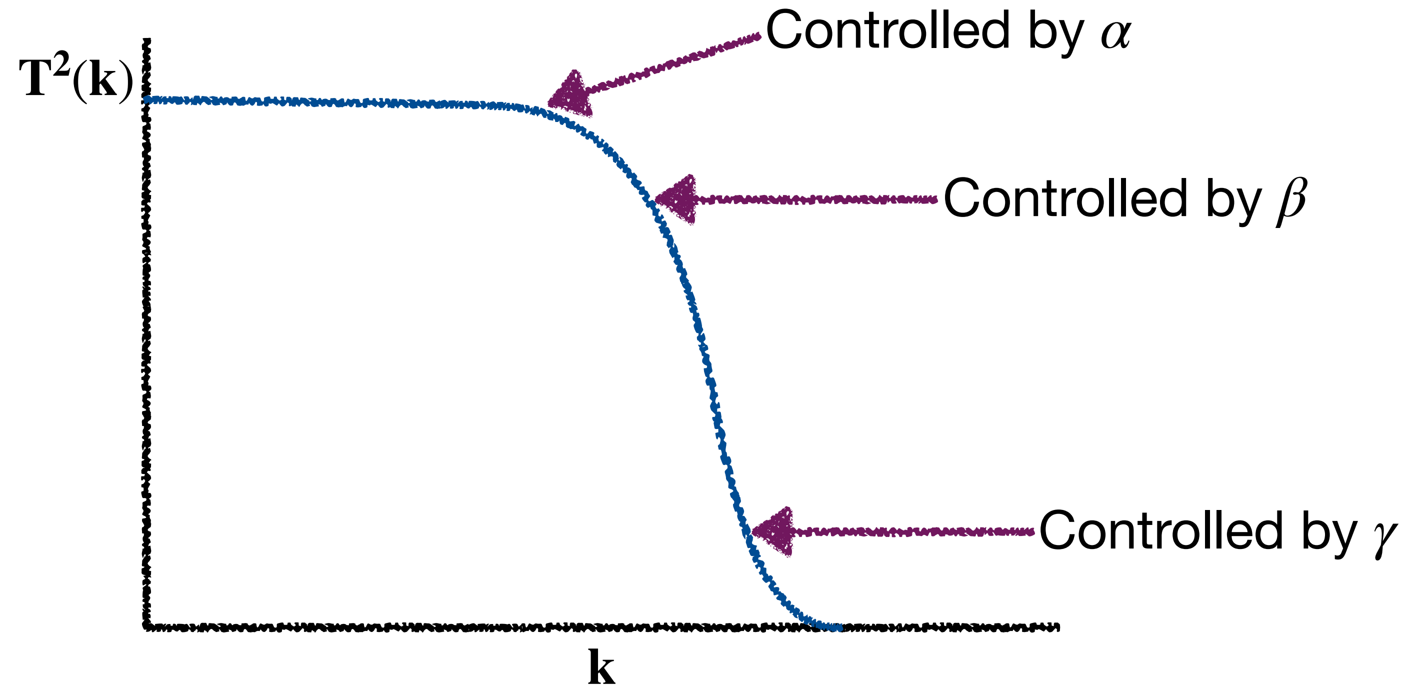
- IGM filament modelling requires nonlinear evolution: this needs N-body hydrodynamical simulations

- Every new set of cosmological parameters would require a new simulation, making MCMC analyses prohibitive

Lyman-α Likelihood

- Alternative: focus on the *shape* of the suppression caused by nCDM models

$$T^2(k) = \frac{P(k)_{\rm nCDM}}{P(k)_{\rm CDM}} = \left[1 + (\alpha k)^\beta\right]^{2\gamma}$$

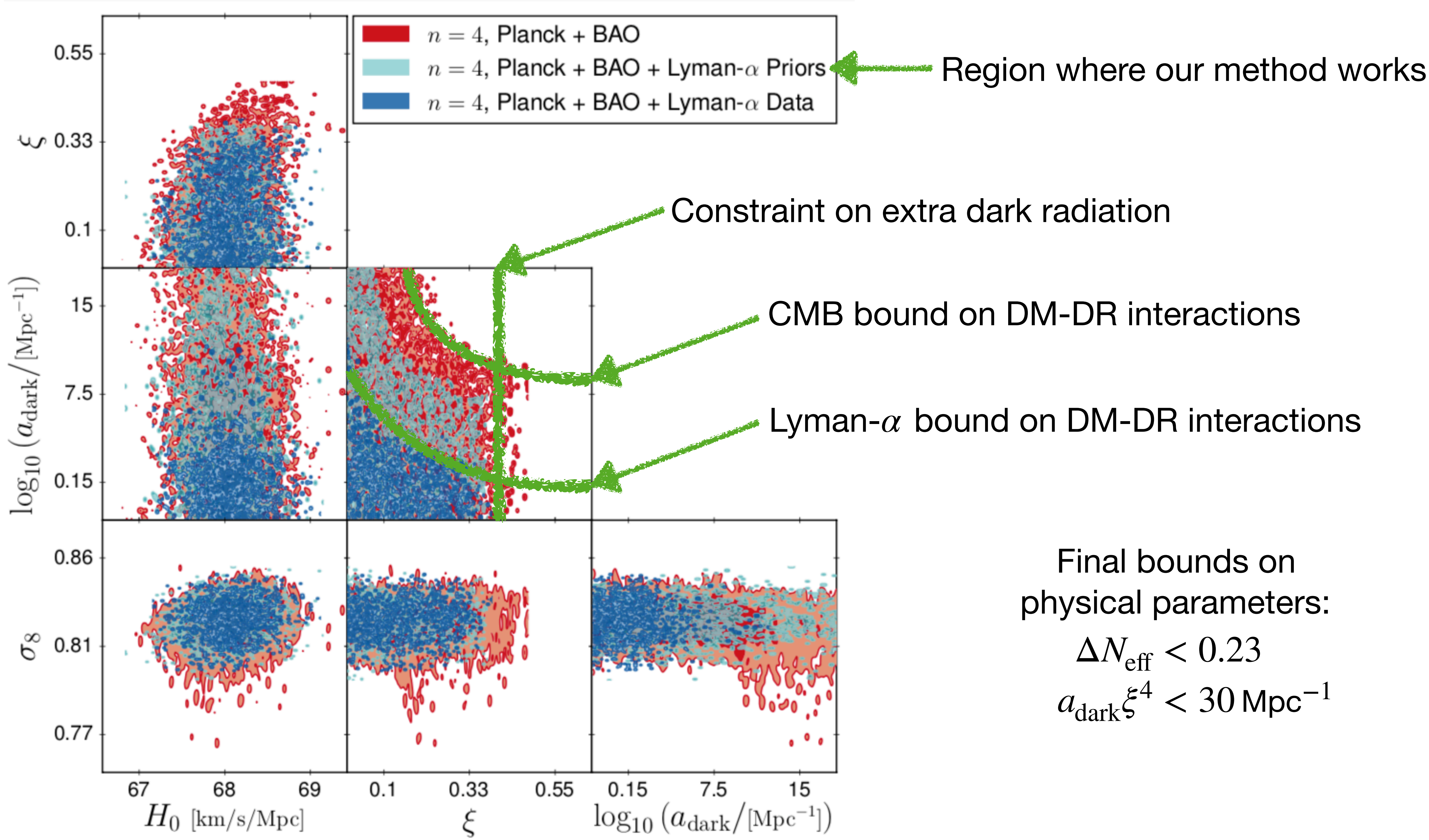


- We have built a grid of hydro sims for over 100 different benchmark $\alpha\beta\gamma$, with a corresponding χ^2 given by Lyman-α data

- We interpolate in our grid to obtain a χ^2 from Lyman-α data for any nCDM model that can be described by $\alpha\beta\gamma$

DM-DR New Constraints

*Archidiacono, **DCH**, Murgia, Bohr, Lesgourgues, Viel 1907.01496*



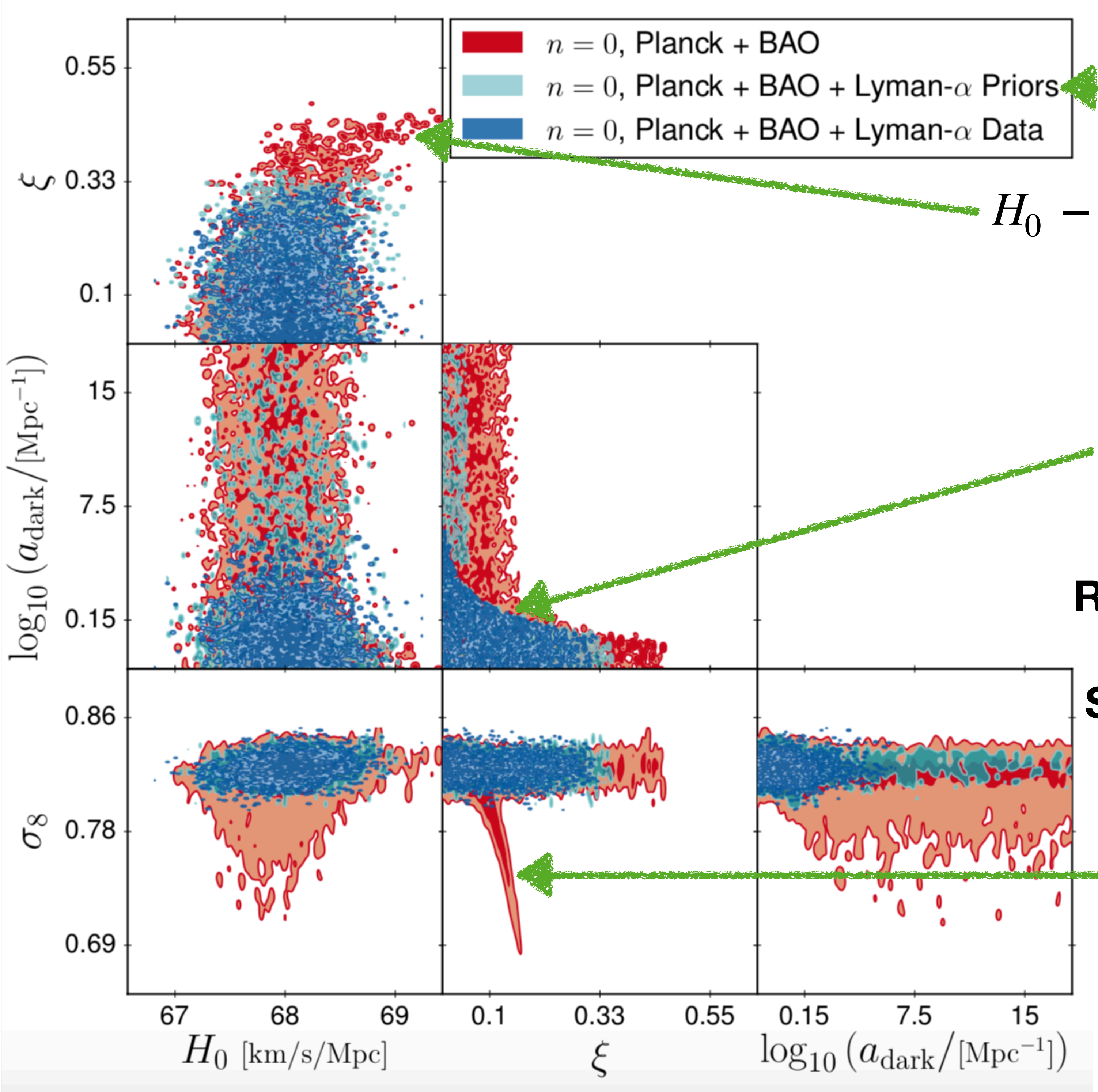
Final bounds on physical parameters:

$$\Delta N_{\rm eff} < 0.23$$

$$a_{\rm dark}\xi^4 < 30\,{\rm Mpc}^{-1}$$

DM-DR New Constraints

*Archidiacono, **DCH**, Murgia, Bohr, Lesgourgues, Viel 1907.01496*



Region where our method works

$H_0 - \xi$ degeneracy: more dark radiation leads to higher H_0 values

Problem: our method and our Lyman-α constraints overlap: method can not be fully trusted in this regime

Reason: suppression too step-like for $\alpha\beta\gamma$

Solution: expand our grid of simulations!

$\sigma_8 - \xi$ degeneracy: with the right amount of dark radiation, we can get lower σ_8 values

Summary

- There are some unresolved tensions in ΛCDM. Dark Matter - Dark Radiation interactions can alleviate these tensions
- The resulting suppression on the matter power spectrum makes Lyman-α data crucial to constrain these models
- Novel parameterisation allows us to interpolate in pre-computed grid of hydrodynamical simulations, allowing for MCMC analysis
- We obtained state-of-the-art constraints on interaction strength and amount of DR from Lyman-α data
- Our method is being extended to cover many more models and interactions

Thank you for your attention