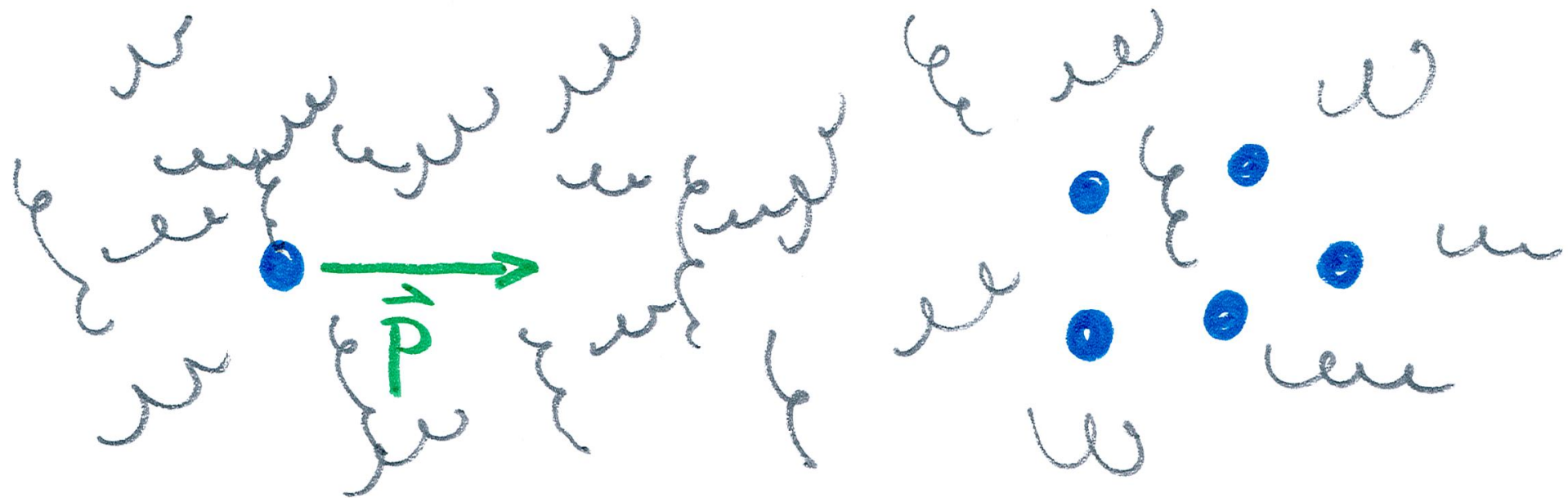


Natural Dark Matter/Dark Radiation Candidates



Manuel Buen Abad

(Boston)

1505.03542, 1507.04351, 170x.xxxxxx

Julien Lesgourgues

(Aachen)

Gustavo Marques-Tavares (Stanford)

Martin Schmaltz

(Boston)

Outline

1. Λ CDM, tension in data

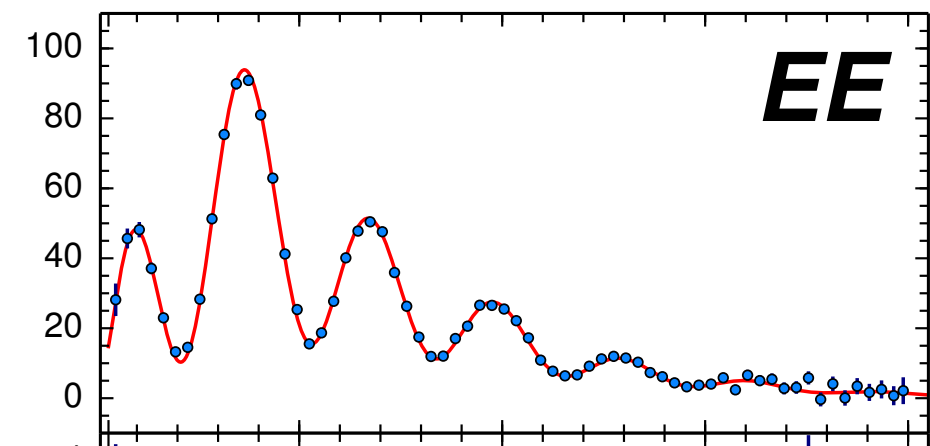
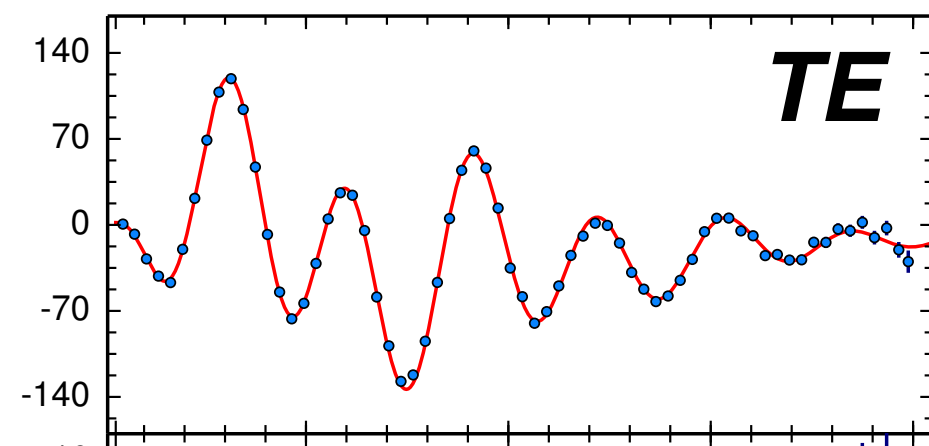
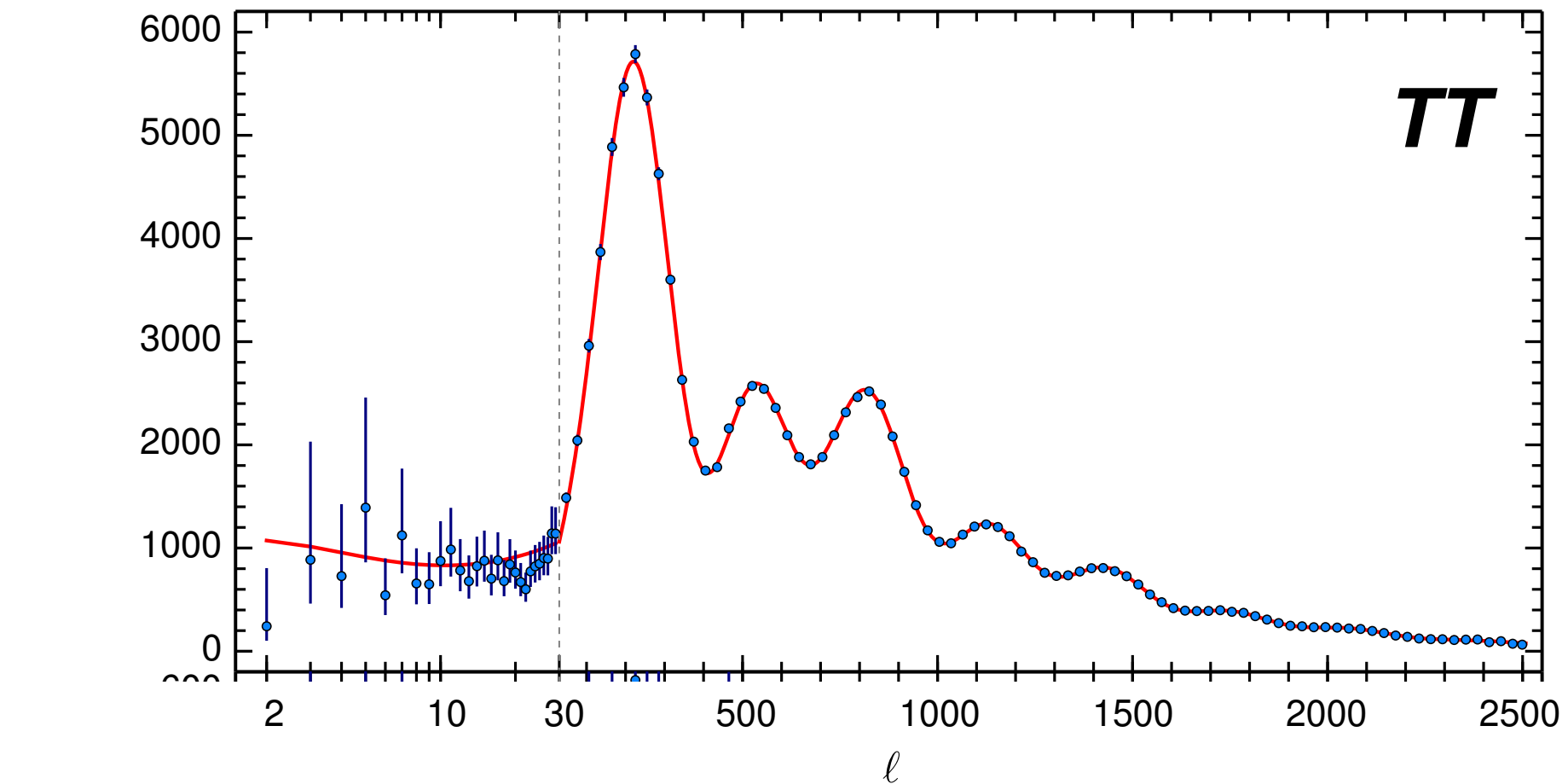
H_0 and σ_8

2. model: dark matter + dark radiation

Λ CDM cosmic concordance model

- + Standard Model (Baryons, γ , ν)
- + collisionless cold dark matter
- + cosmological constant
- + “big bang”

CMB - Planck 2015



Planck 2016

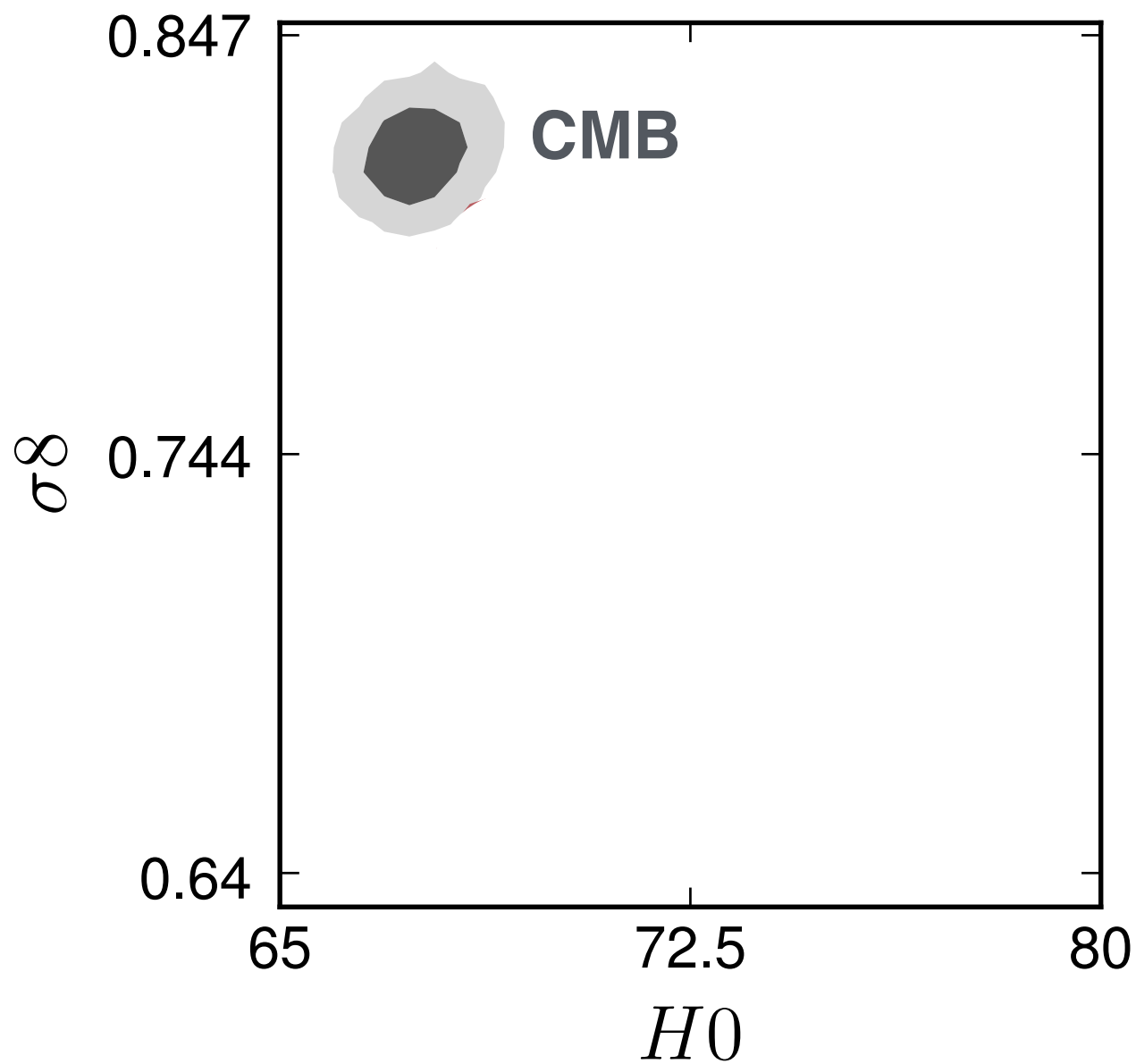
(TT,TE,EE,LowP)

“Cosmic Concordance”

$\Omega_b h^2$	0.02225 $\pm$ 0.00016
$\Omega_c h^2$	0.1198 $\pm$ 0.0015
$100\theta_{\text{MC}}$	1.04077 $\pm$ 0.00032
τ	0.079 $\pm$ 0.017
$\ln(10^{10} A_s)$	3.094 $\pm$ 0.034
n_s	0.9645 $\pm$ 0.0049
H_0	67.27 $\pm$ 0.66
Ω_m	0.3156 $\pm$ 0.0091
σ_8	0.831 $\pm$ 0.013

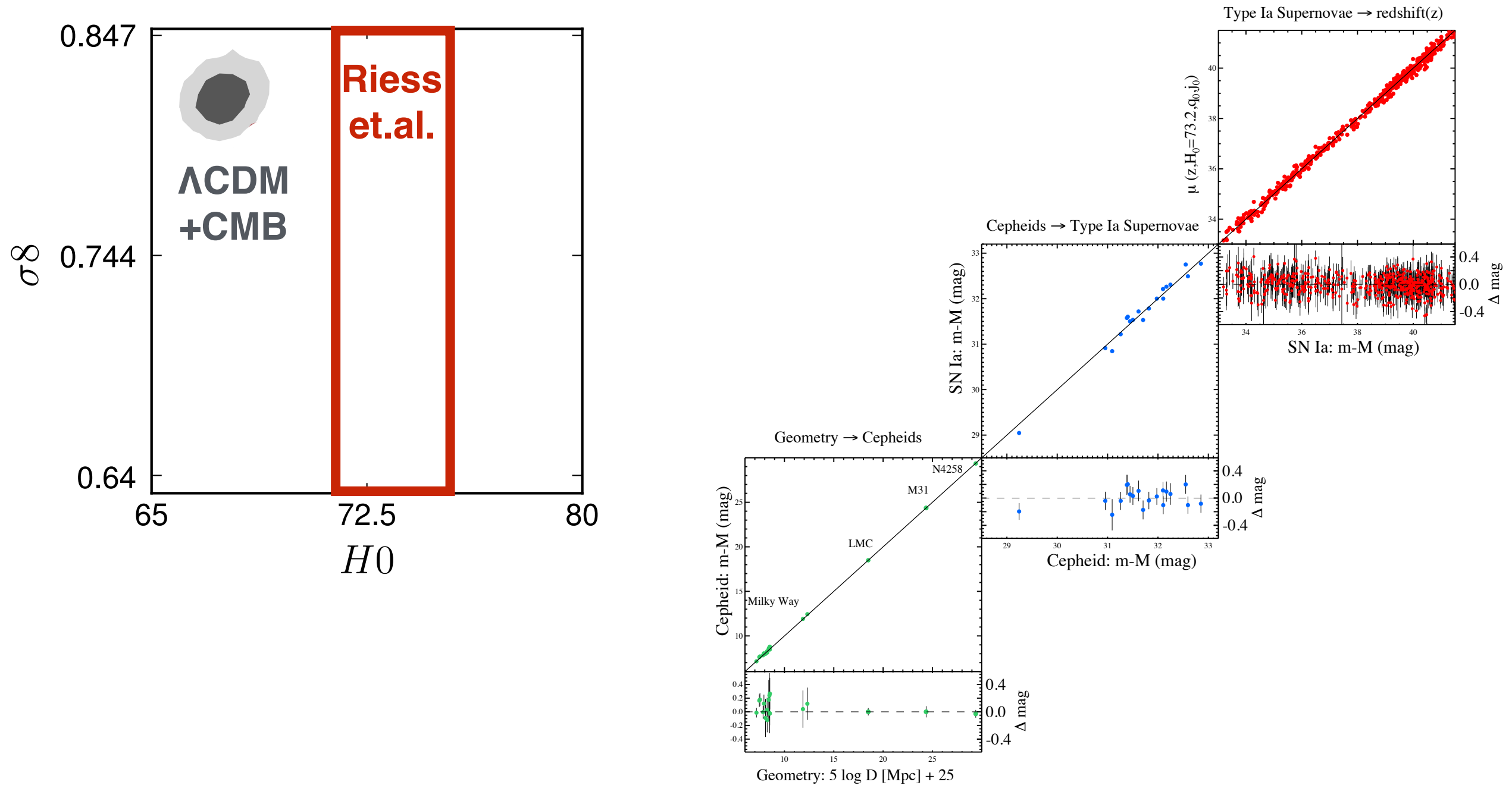
Λ CDM

Poulin, Serpico, Lesgourgues
astro-ph/1606.02073

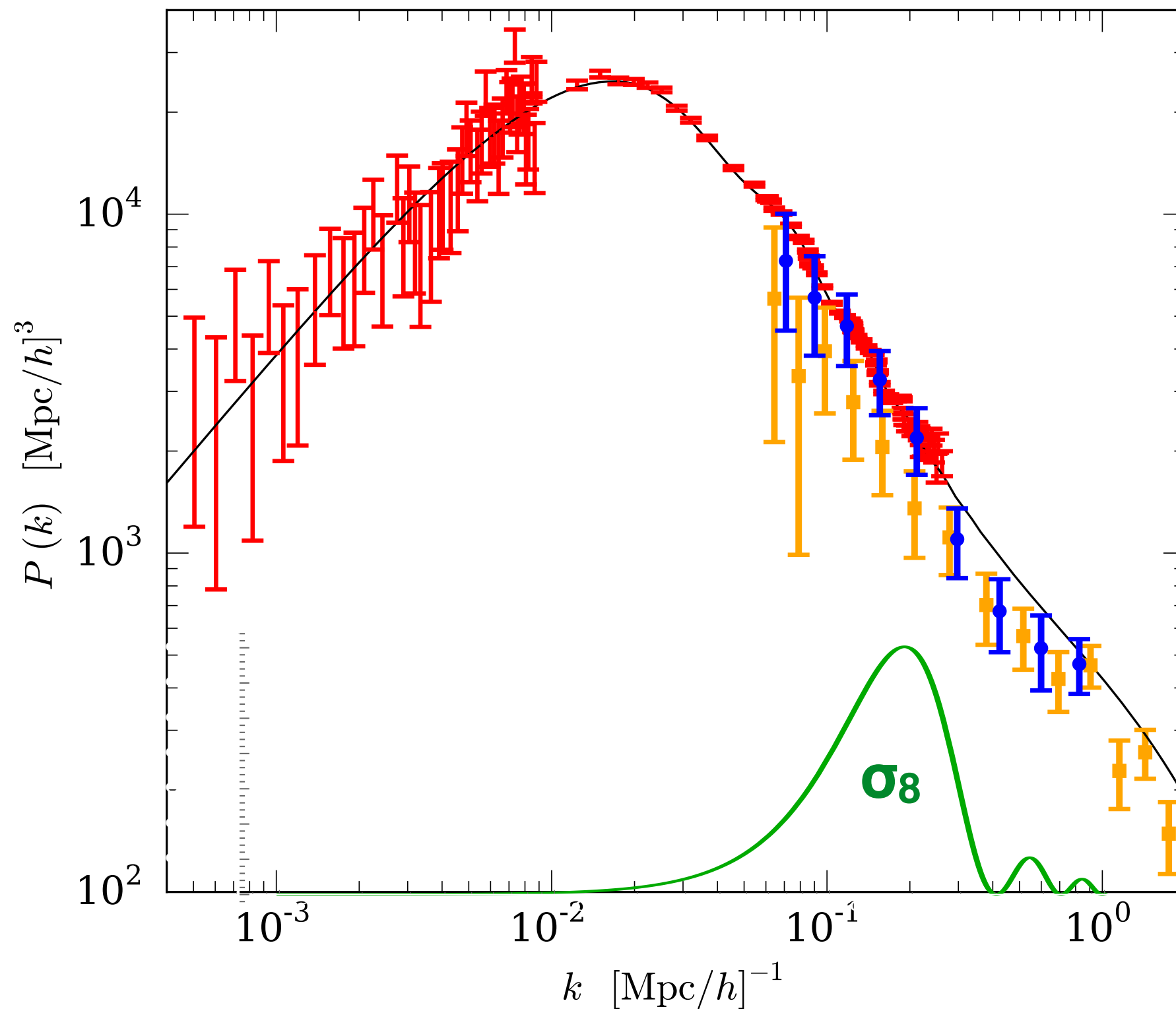


Adam Riess et.al. (2016)

$$H_0 = 73.24 \pm 1.74 \text{ km/s/Mpc}$$

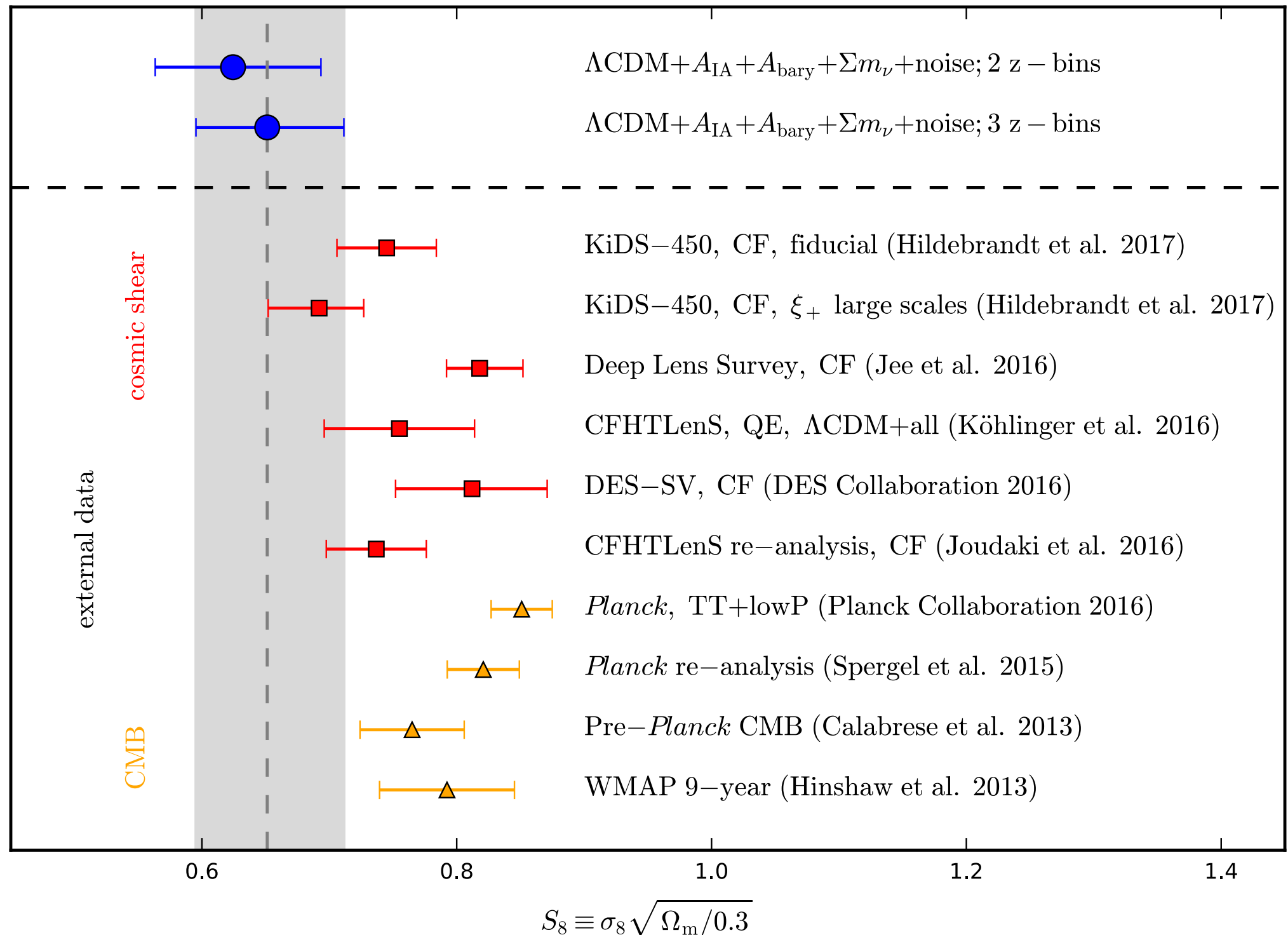


$\sigma_8 \sim$ Matter power spectrum

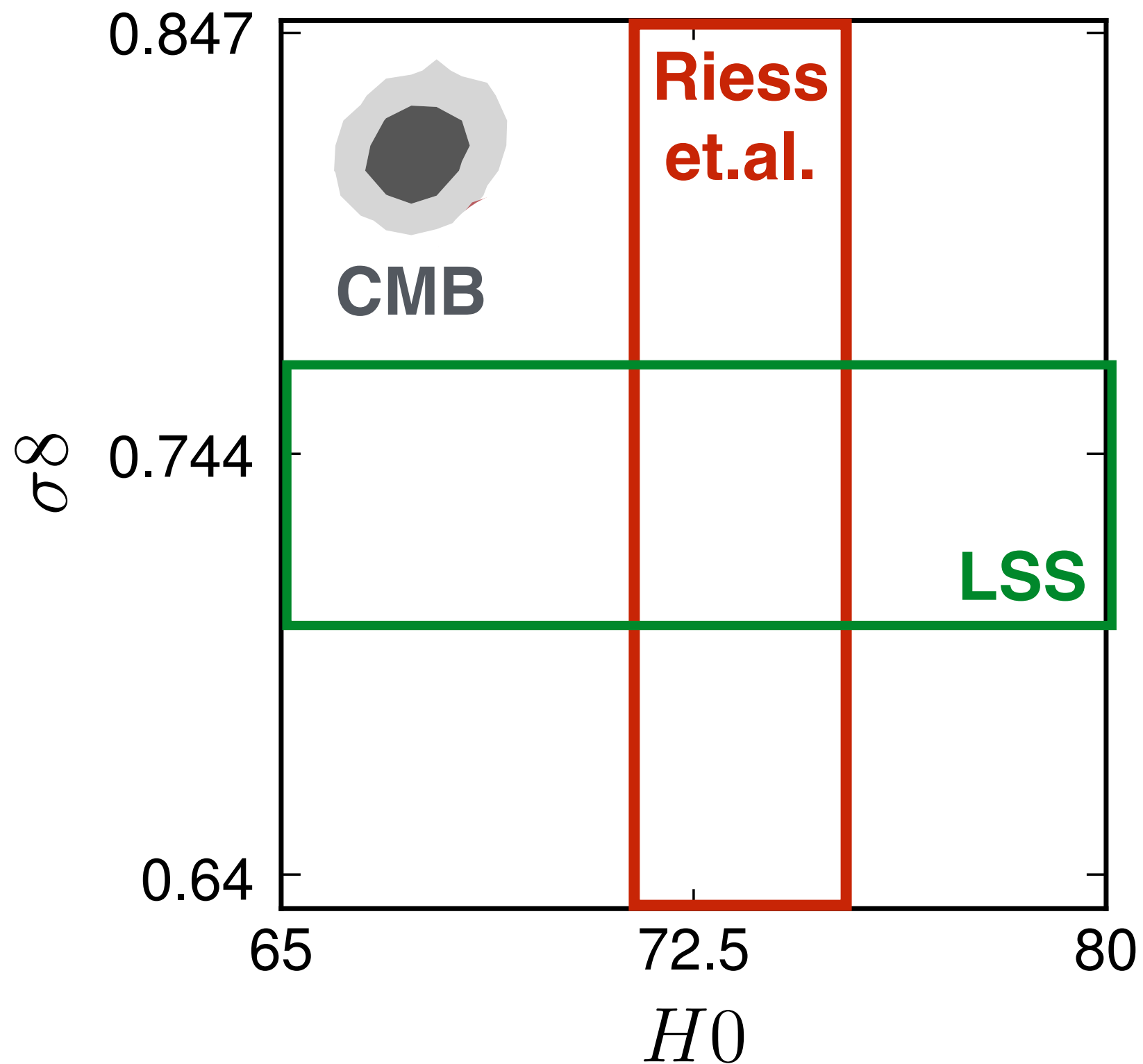


KiDS-450: *weak lensing* power spectrum

1706.02892v1 [astro-ph.CO] 9 Jun 2017



Cosmic Discordance in Λ CDM



Outline

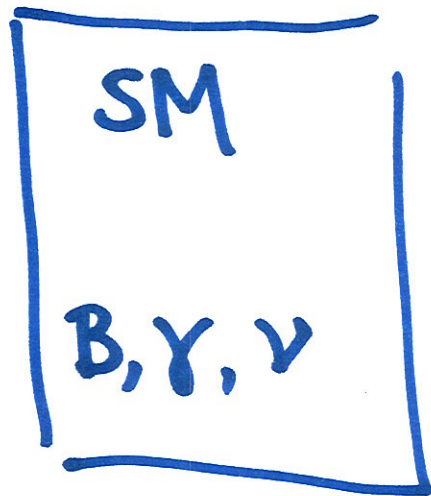
1. data

H_0 and σ_8

2. model

DM+DR

DM + DR model



T_γ

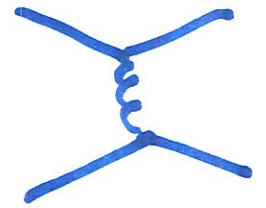


$T_{DR} \lesssim T_\gamma$

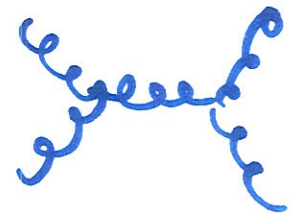
$M_{DM} \gg T_{DR}$ "cold"

example : non-Abelian dark sector

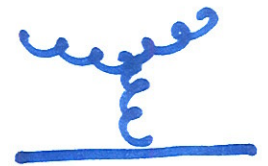
DM massive "dark quarks"



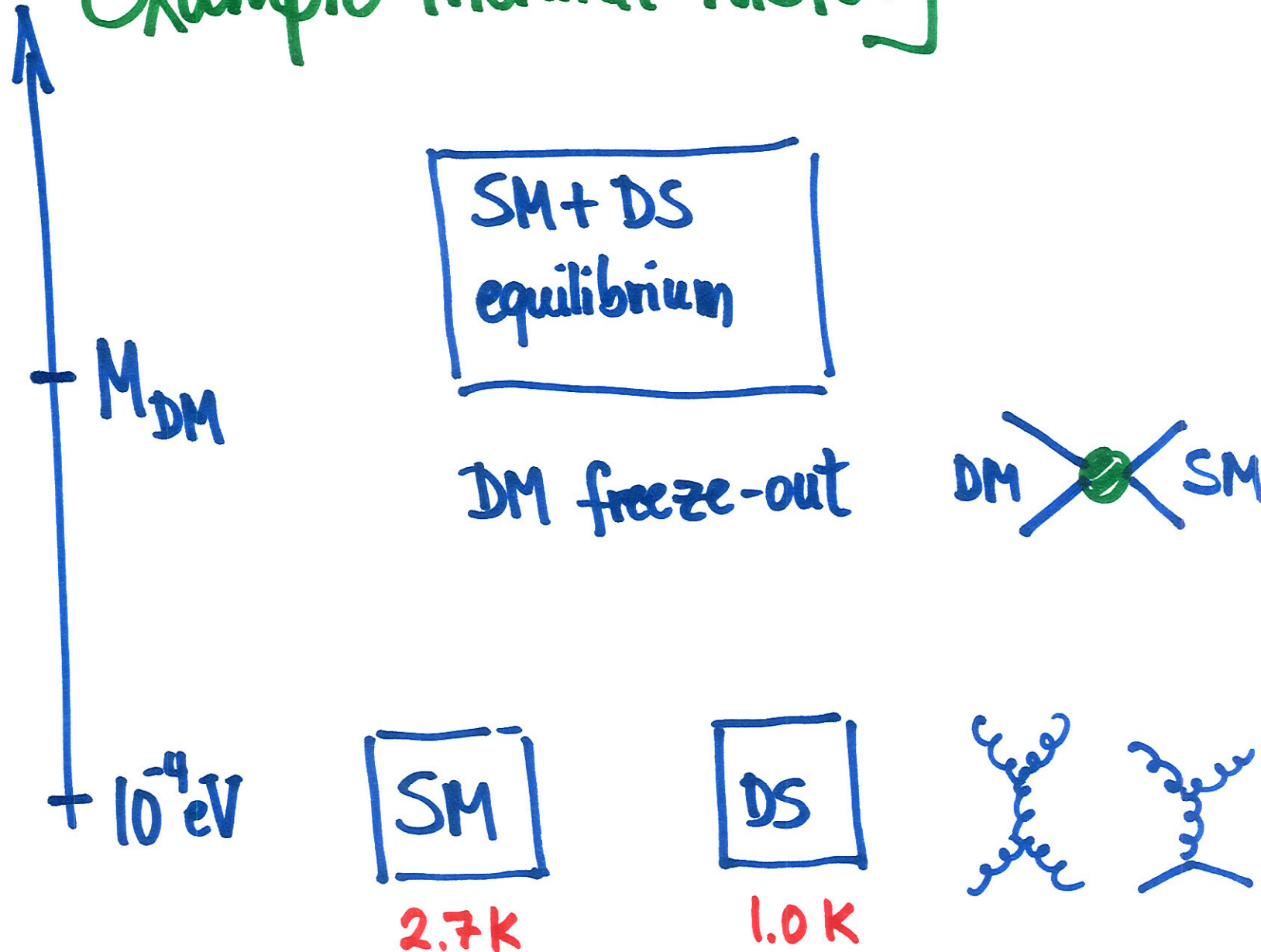
DR massless "dark gluons"



$$g_D \sim 10^{-4} \Rightarrow \Lambda_{\text{QCD}} \ll T_{\text{DR}}$$



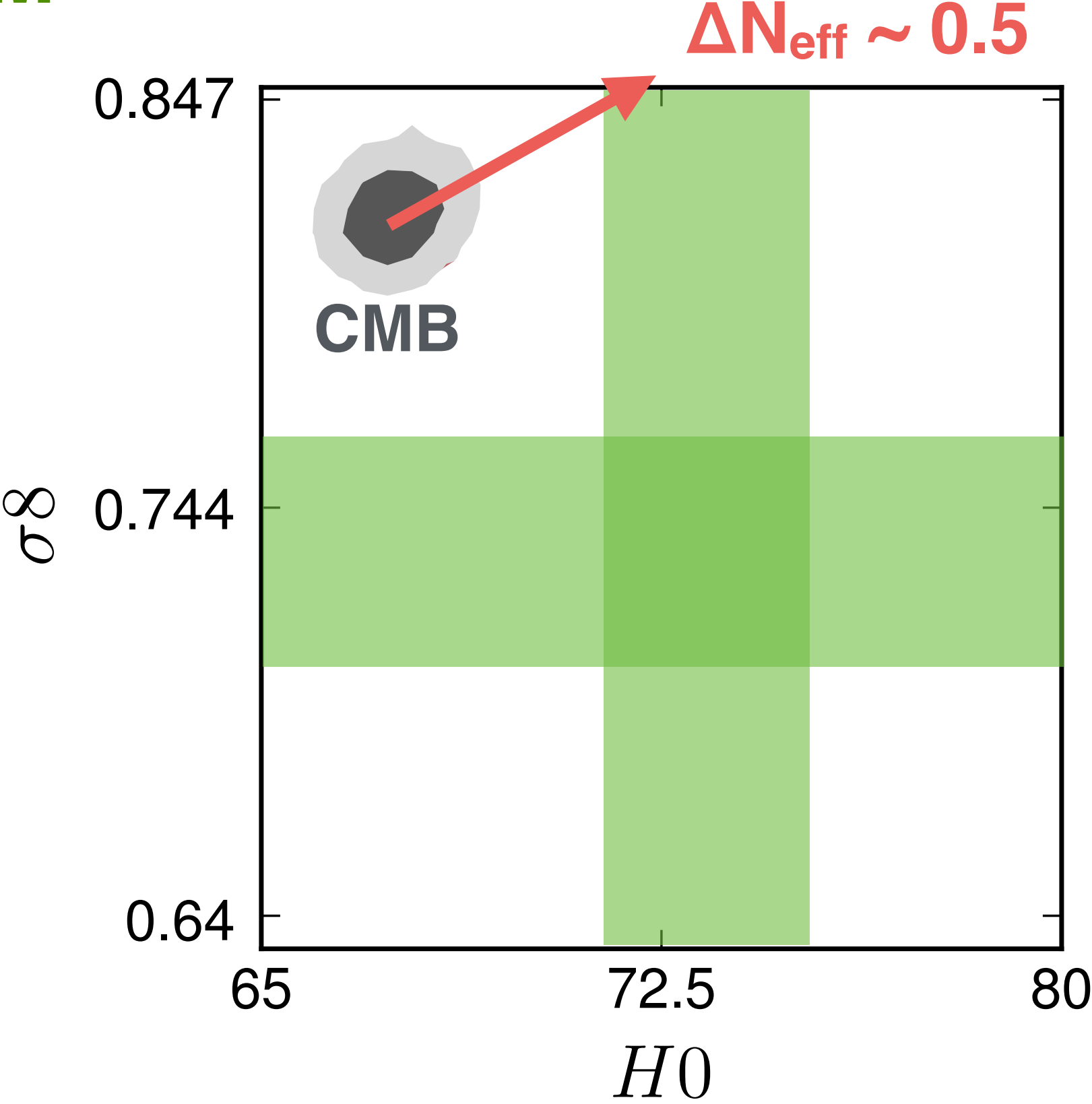
example thermal history



What are important new effects ?

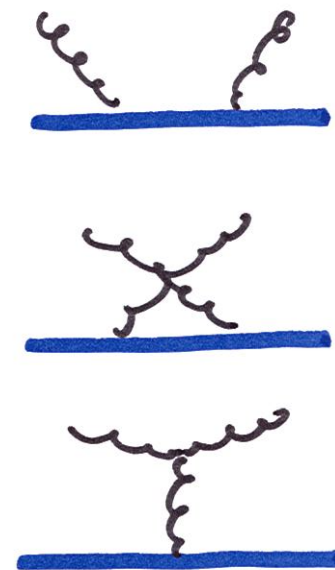
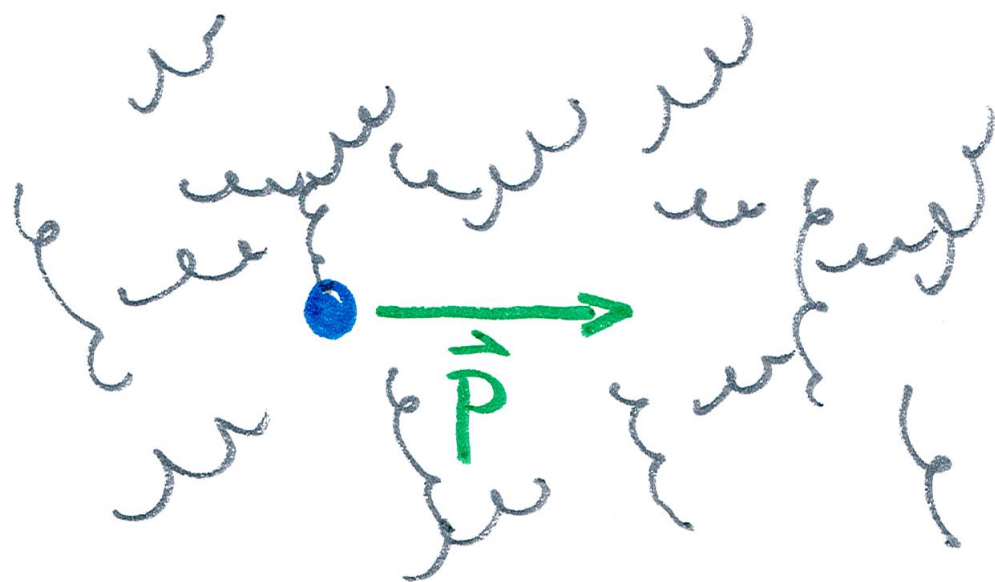
- energy density in dark radiation $\Rightarrow \Delta N_{\text{eff}}$
- DM-DR coupling $\Rightarrow$ large scale structure

Λ CDM



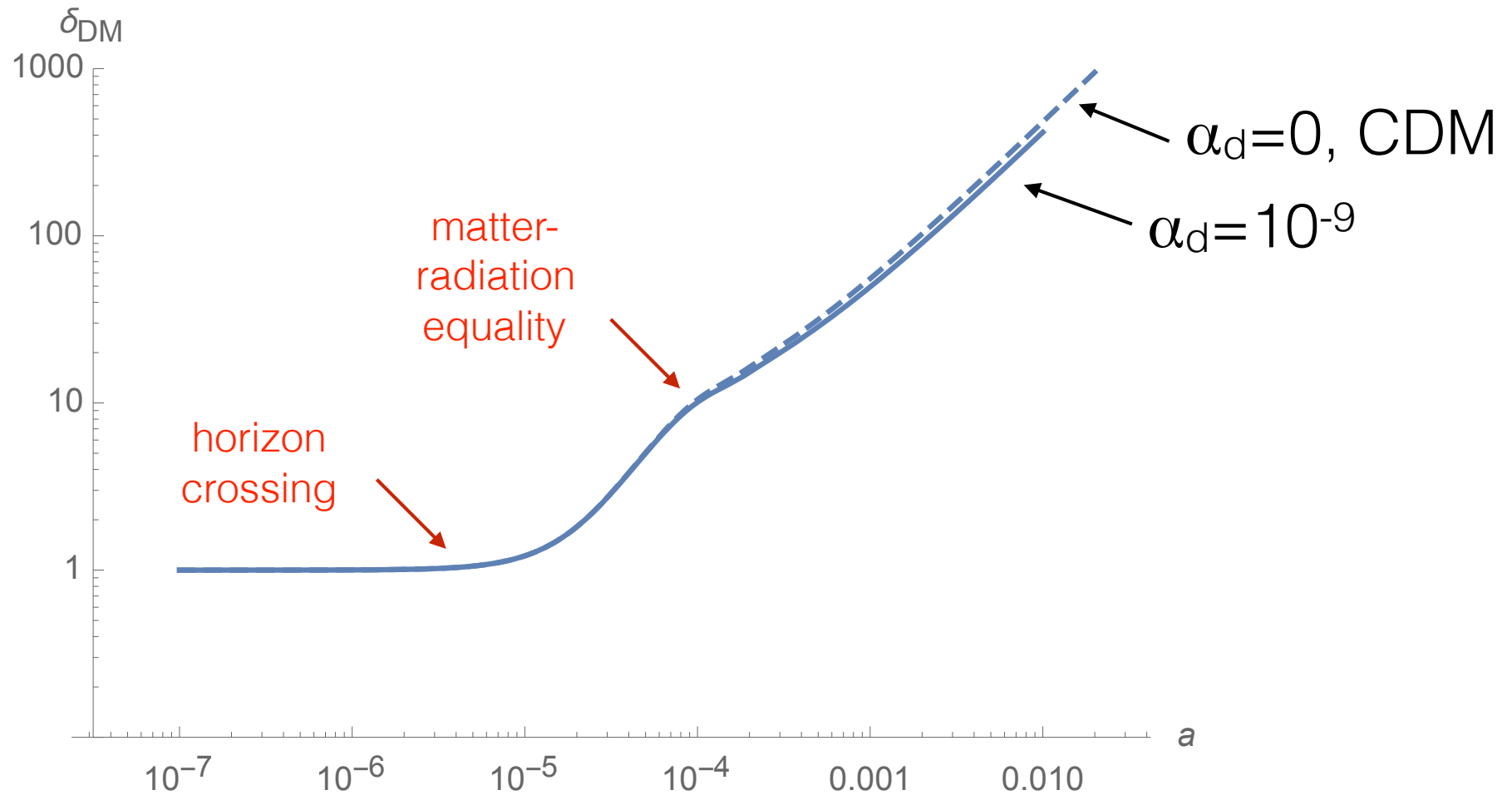
momentum transfer rate

$$\Gamma_p \equiv \frac{\dot{p}}{p} \sim \alpha_d^2 \log \frac{1}{\alpha_d} \frac{T_g^2}{M_\chi} \quad \text{"drag"}$$

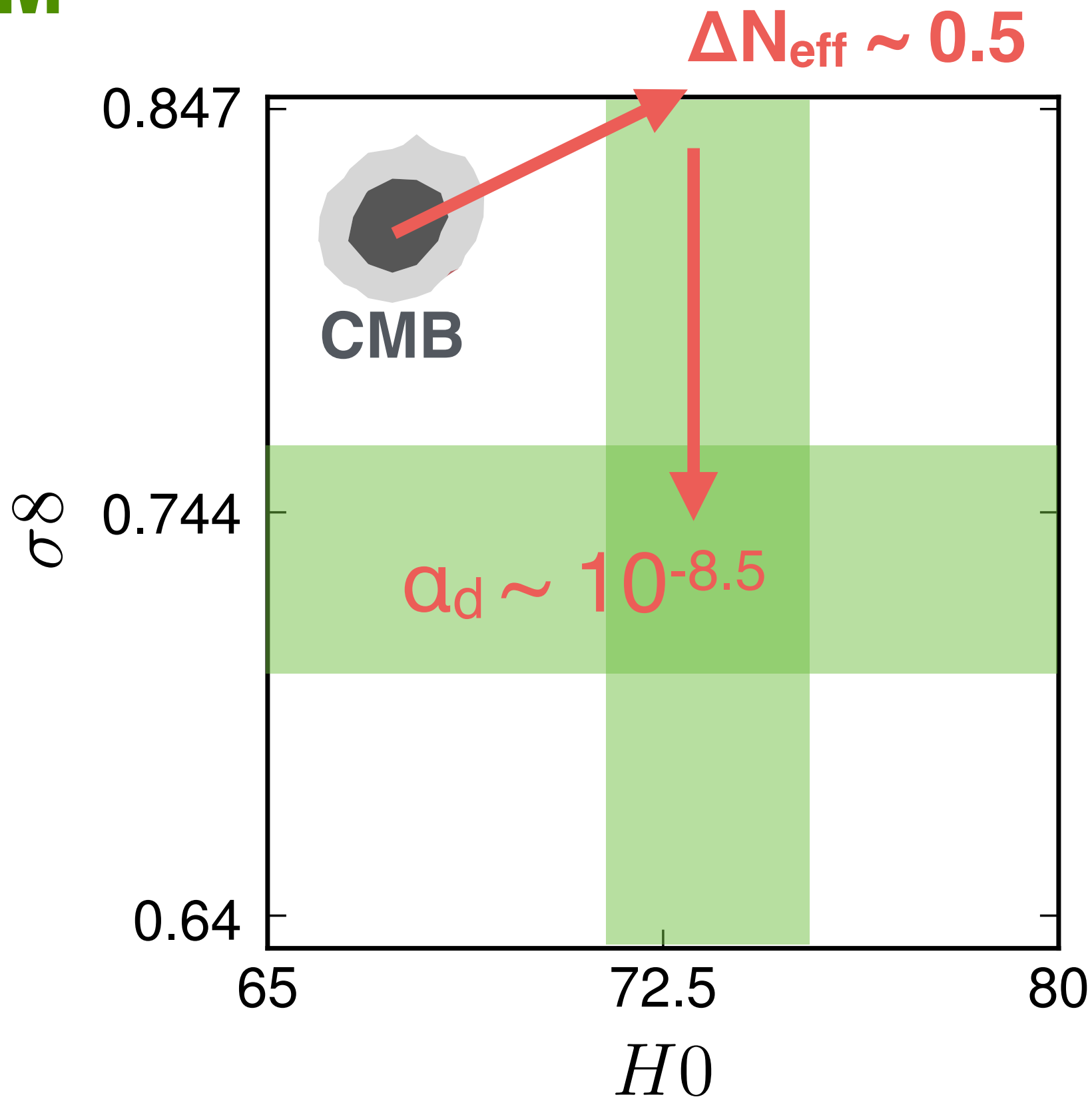


growth of perturbations

$$k=0.2 \text{ Mpc}^{-1}$$



Λ CDM



Conclusion: How well do we do? (preliminary)

$$\Delta\chi^2 = -12.7 \quad \text{with 2 new parameters}$$

$$\text{Fisher - test: } p=0.002 \quad (>3\sigma)$$

- dark radiation fixes H_0

-  $\sim \frac{T^2}{M}$ fixes σ_8

