

# **On the Hubble Tension and primordial magnetic fields**

**with Levon Pogosian, Andrey Saveliev, Robi Banerjee, Tom Abel, Silvia Galli, Lennart Balkenhol**

- A**      **A very quick summary of magnetic field observations**
- B**      **Evolution of primordial magnetic fields shortly before recombination**
- C**      **Primordial Magnetic Fields, the CMB, and the Hubble constant**
- D**      **General remarks about solving the Hubble tension with physics before recombination**

**Magnetic fields are observed almost anywhere throughout the local Universe**

in local galaxies with strength  $\sim 1\text{-}10$   $\mu\text{Gauss}$

in higher redshift galaxies with strength  $\sim 1\text{-}10$   $\mu\text{Gauss}$

in clusters of galaxies with strength  $\sim 1\text{-}10$   $\mu\text{Gauss}$

in the extra-galactic medium with high volume filling factor, lower limit  $10^{-9}$   $\mu\text{Gauss}$

**The question is not if, but how much, magnetic field survived from the early Universe**

## A present day correlation for primordial cosmic magnetic fields:

(pre gravitational collapse)

$$B_0 = 5 \times 10^{-12} \text{ Gauss} \left( \frac{L_c}{\text{kpc}} \right)$$

- Fields on smaller scales are dissipated
- this is the primordial field strength necessary to explain observed fields without dynamo

Imagine now magnetic fields on  $\sim \text{kpc}$  comoving scales before recombination

Photons are almost decoupled on these scales,  $\rightarrow$  enormous drop of speed of sound

Viscous MHD evolution with free-streaming photon drag:

$$\frac{d\mathbf{v}}{dt} + (\mathbf{v} \cdot \nabla) \cdot \mathbf{v} + c_s^2 \frac{\nabla \varrho}{\varrho} = -\alpha \mathbf{v} - \frac{1}{4\pi\varrho} \left( \frac{1}{2} \nabla B^2 - \mathbf{B} \cdot \nabla \mathbf{B} \right)$$

*the three important terms*

$$\frac{d\varrho}{dt} + \nabla(\varrho \mathbf{v}) = 0$$

*estimated baryon overdensities,  
back of the envelope*

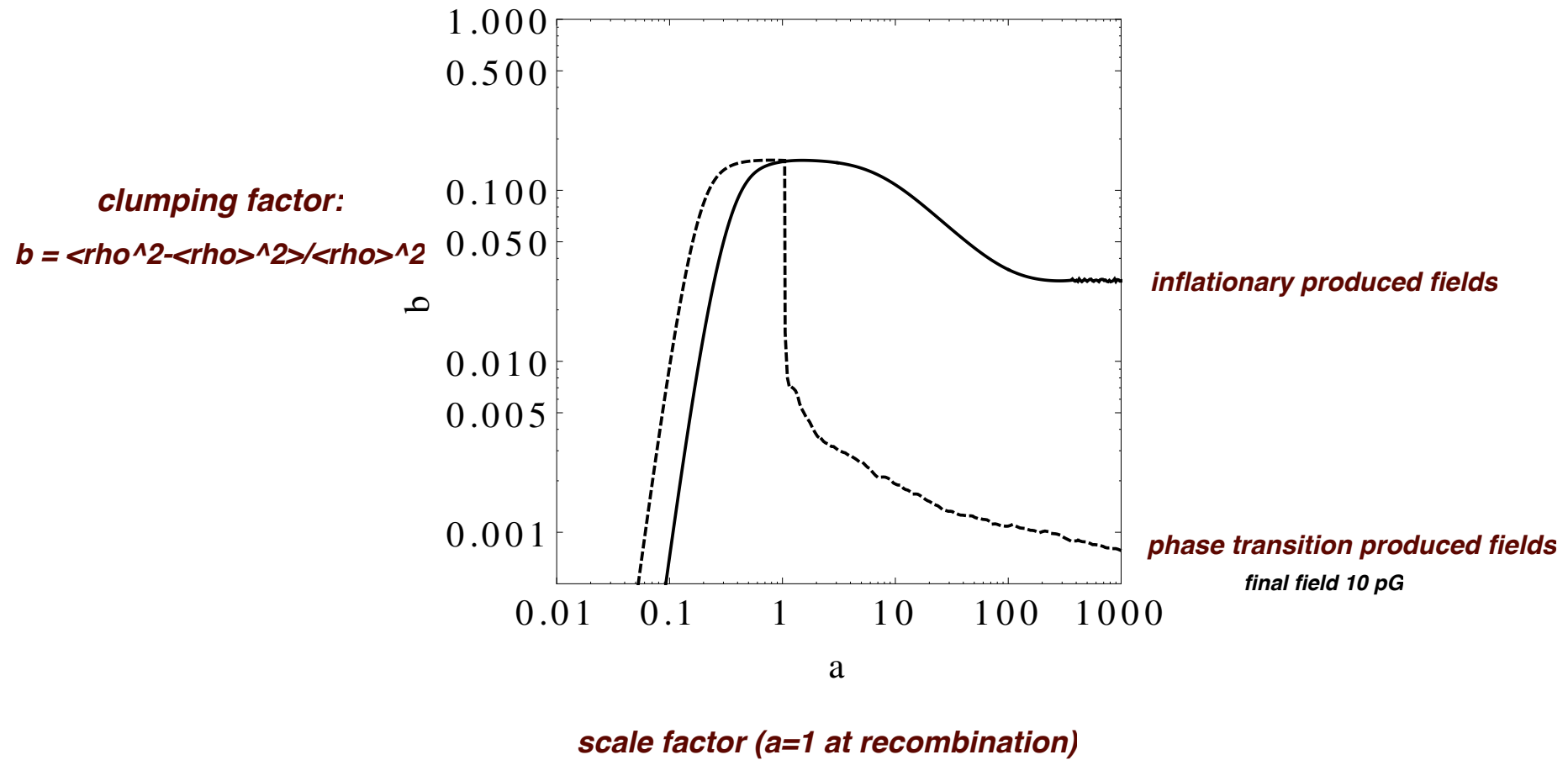
$$\frac{\delta \varrho}{\varrho} \simeq \min \left[ 1, \left( \frac{v_A^2}{c_s^2} \right) \right]$$

***It doesn't take much field to get large baryon overdensities:***

$$c_s = 6.33 \frac{\text{km}}{\text{s}} \quad \text{isothermal speed of sound}$$

$$v_A = \frac{B}{\sqrt{4\pi\rho}} = 5.79 \frac{\text{km}}{\text{s}} \left( \frac{B}{0.04 \text{nG}} \right)$$

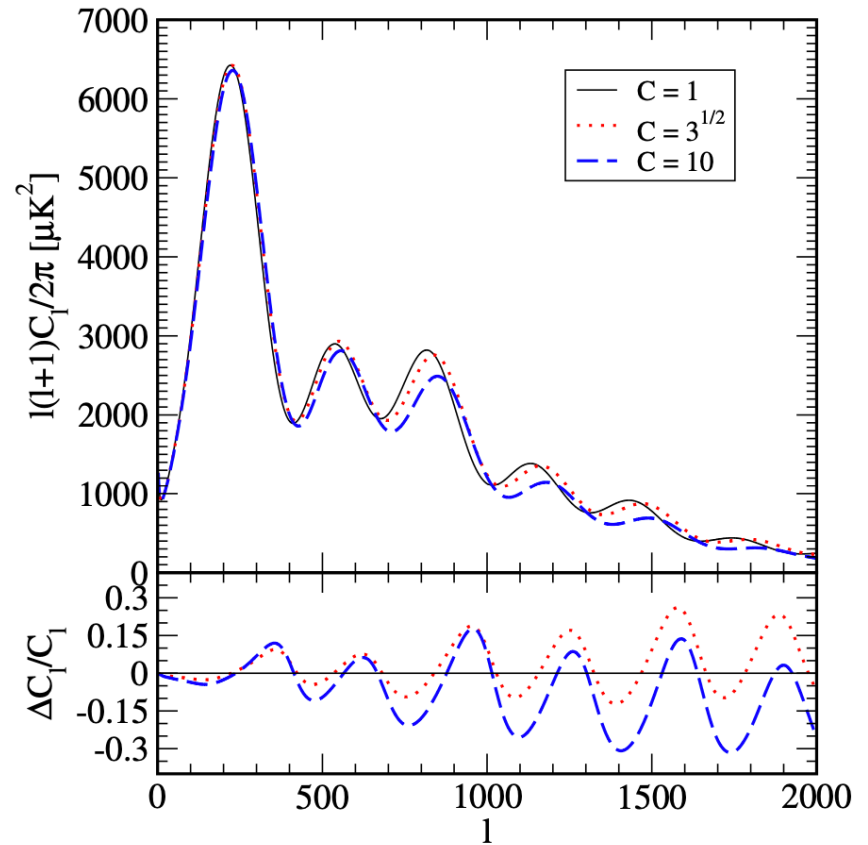
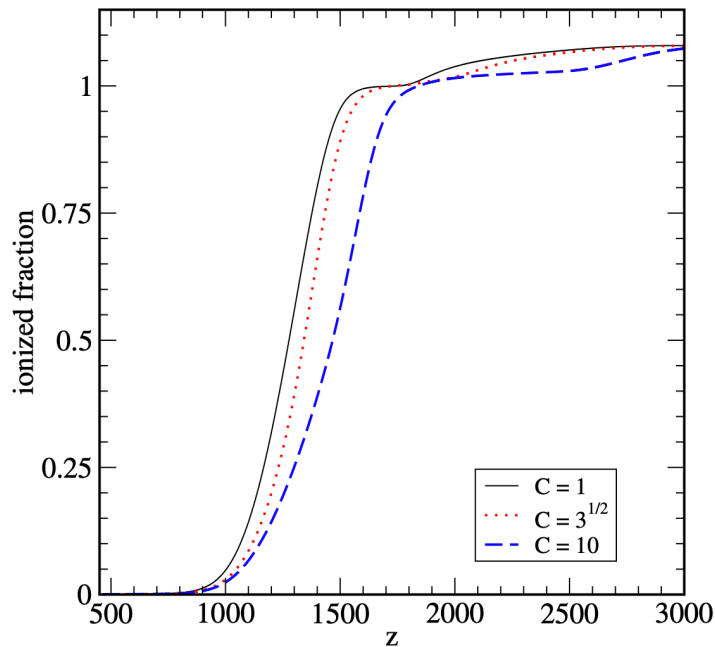
## ***Full MHD simulations:***



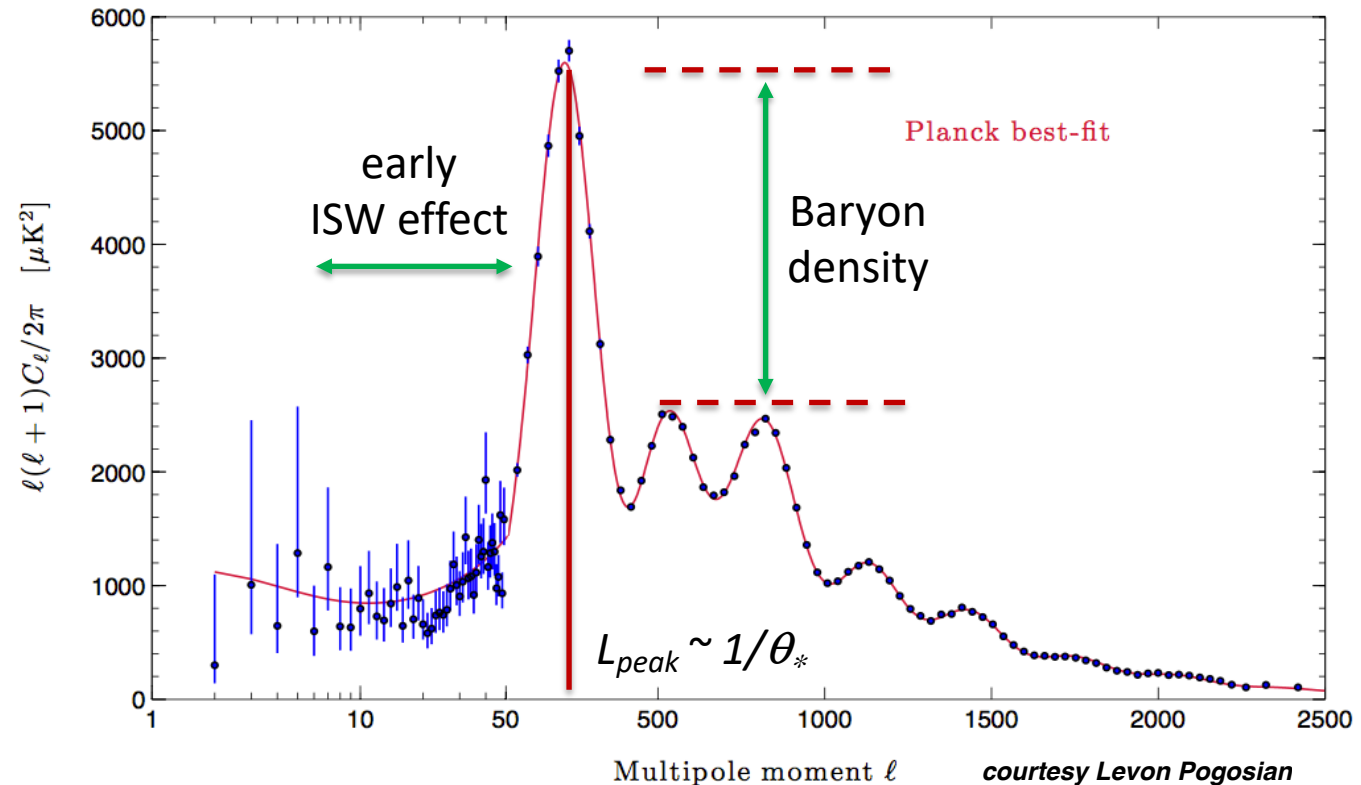
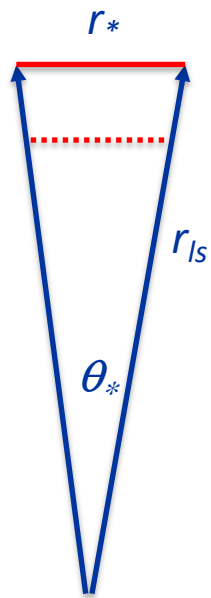
# Inhomogeneities enhance the recombination rate

$$\frac{dn_e}{dt} + 3Hn_e = -C \left( \alpha_e n_e^2 + \beta_e n_{H^0} e^{-h\nu_\alpha/T} \right)$$

$$\langle n_e^2 \rangle > \langle n_e \rangle^2$$



# How does CMB constrain $H_0$ ?



*physical baryon density, radiation density, and CDM density, well determined from CMB, for given  $z^*$  sound horizon fixed*

*distance to large scattering surface dependant on Hubble constant, i.e.  $r_{ls} \sim h^{-0.2}$*

*observed angle of CMB peak: smaller sound horizon  $\rightarrow$  larger Hubble constant*

CMBR Doppler peak at angle:

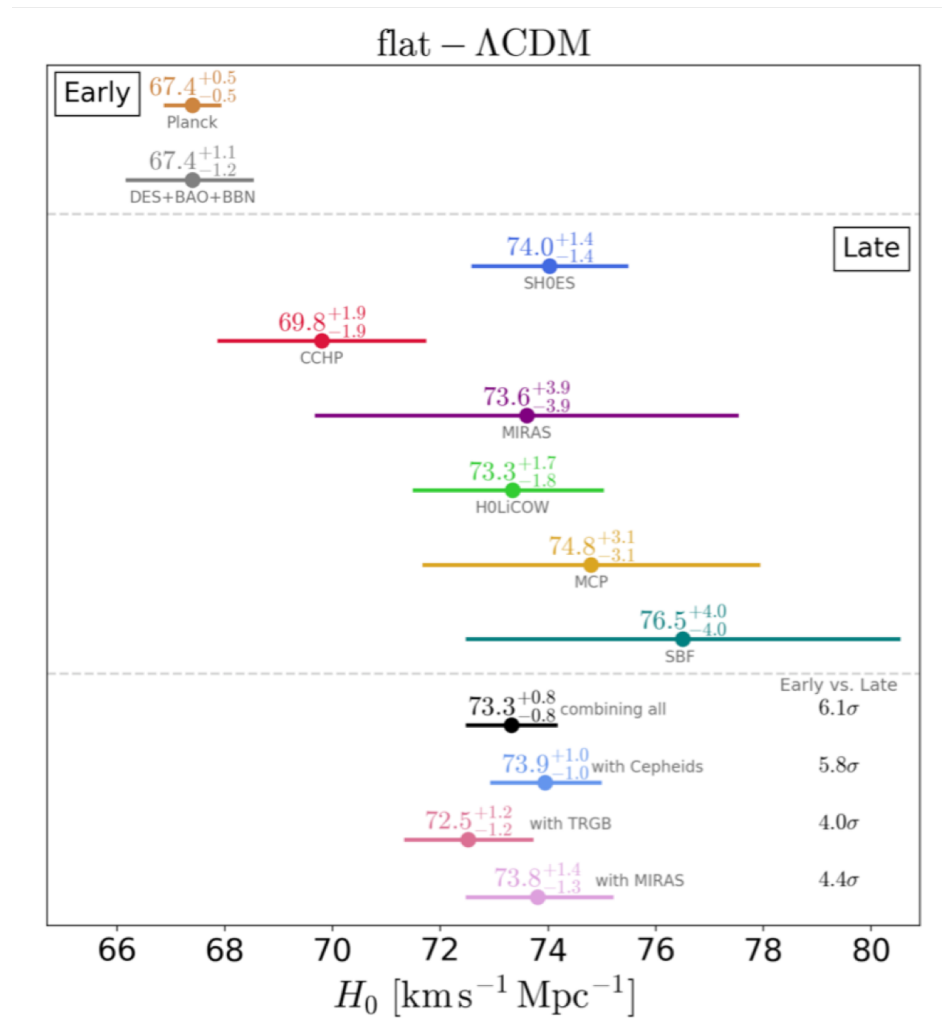
$$\theta_{\star} = \frac{r_{\star}}{D_A(z_{\star})} = \frac{\int_{z_{\star}}^{\infty} c_s(z) dz / H(z)}{\int_0^{z_{\star}} c dz / H(z)}$$

$$H(z) = 100 \text{ km/s/Mpc} \sqrt{\Omega_r h^2 (1+z)^4 + \Omega_m h^2 (1+z)^3 + \Omega_{\Lambda} h^2}$$

- $\Omega_{\gamma} h^2$  well known from current CMBR temperature
- $\Omega_{\nu} h^2$  well known from standard model of particle physics and cosmology
- $\Omega_b h^2$  well known from CMBR and BBN
- $z_{\star}$  well known from atomic physics
- $\Omega_m h^2$  well known in any particular model from CMBR
- criticality condition:  $\Omega_{\Lambda} + \Omega_m + \Omega_r = 1$

**=> Measure Doppler peak angle, assume LCDM, predict the Hubble constant**

# The Hubble tension



*Tensions between the  
Early and the Late  
Universe*

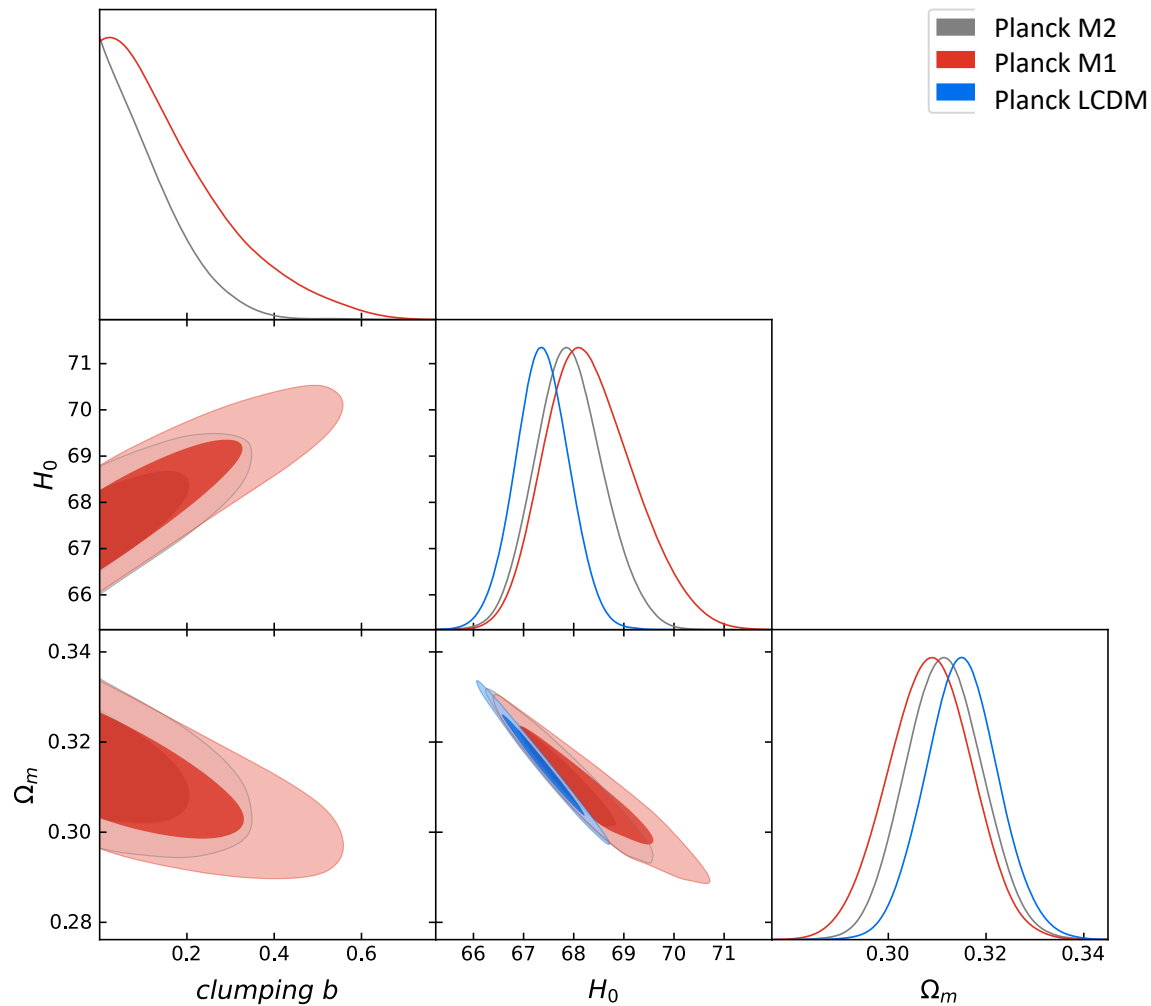
L. Verde, T. Treu, A. Riess,  
arXiv:1907.10625

The tension is between the measurements that require calculating  $r_*$  and  $r_{drag}$  and those that do not

Can baryon clumping before recombination  
due to primordial magnetic fields help the  
tension ?

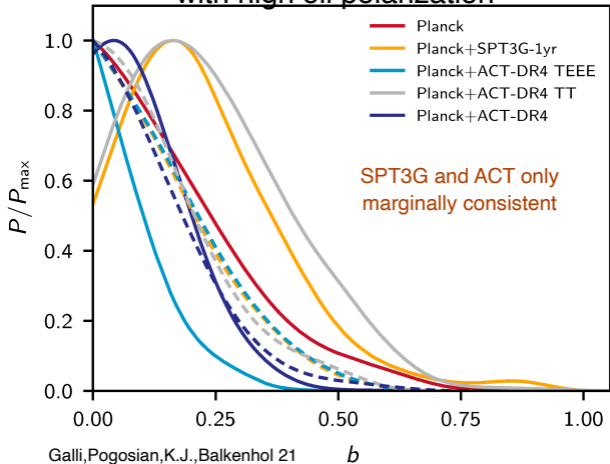
three zone toy model M1 and M2, missing evolution and velocity gradients

# LCDM + clumping: Fitting Planck only

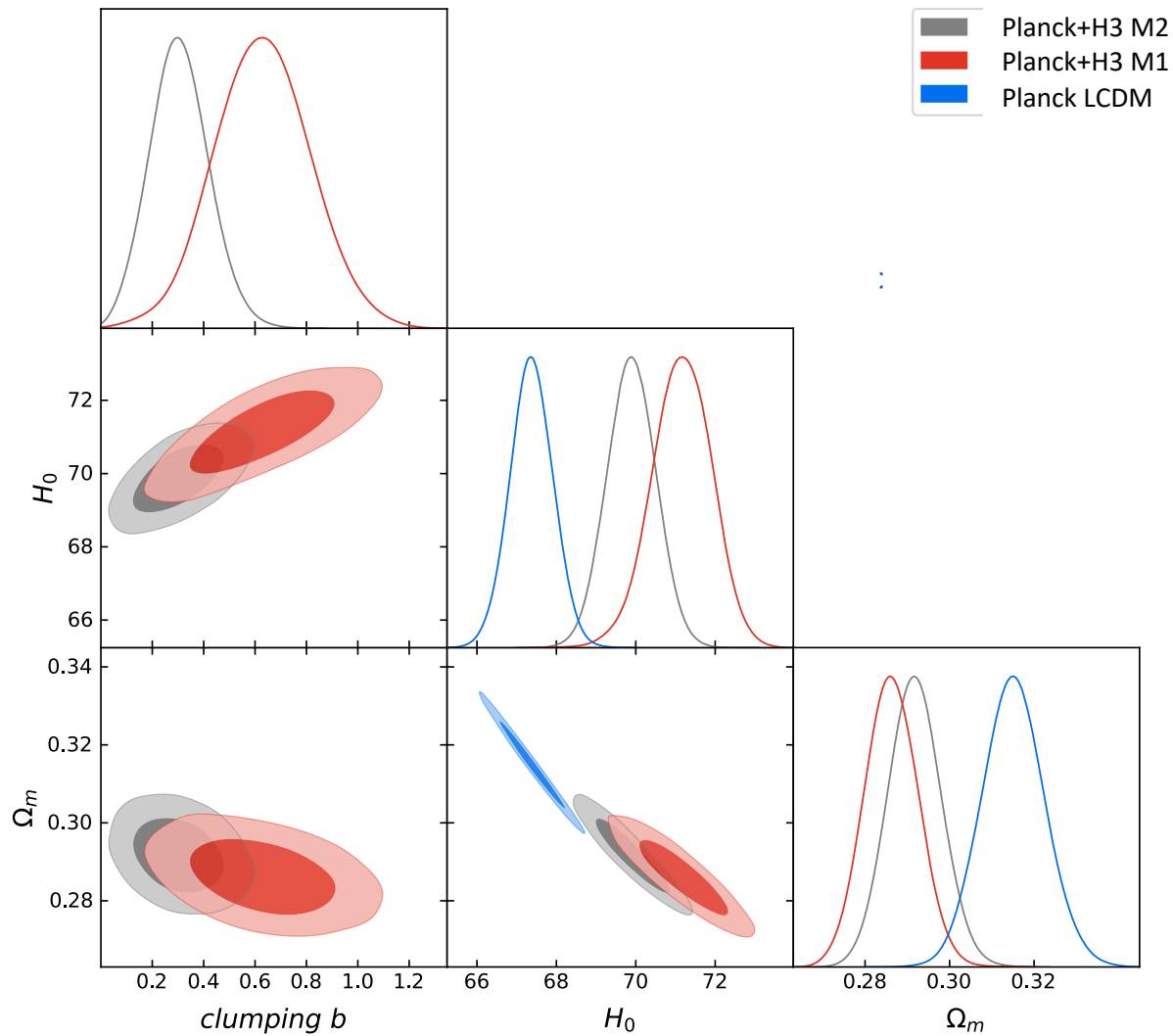


- Strong degeneracy between the clumping parameter  $b$  and  $H_0$
- No preference for a non-zero value of  $b$

with high  $ell$  polarization

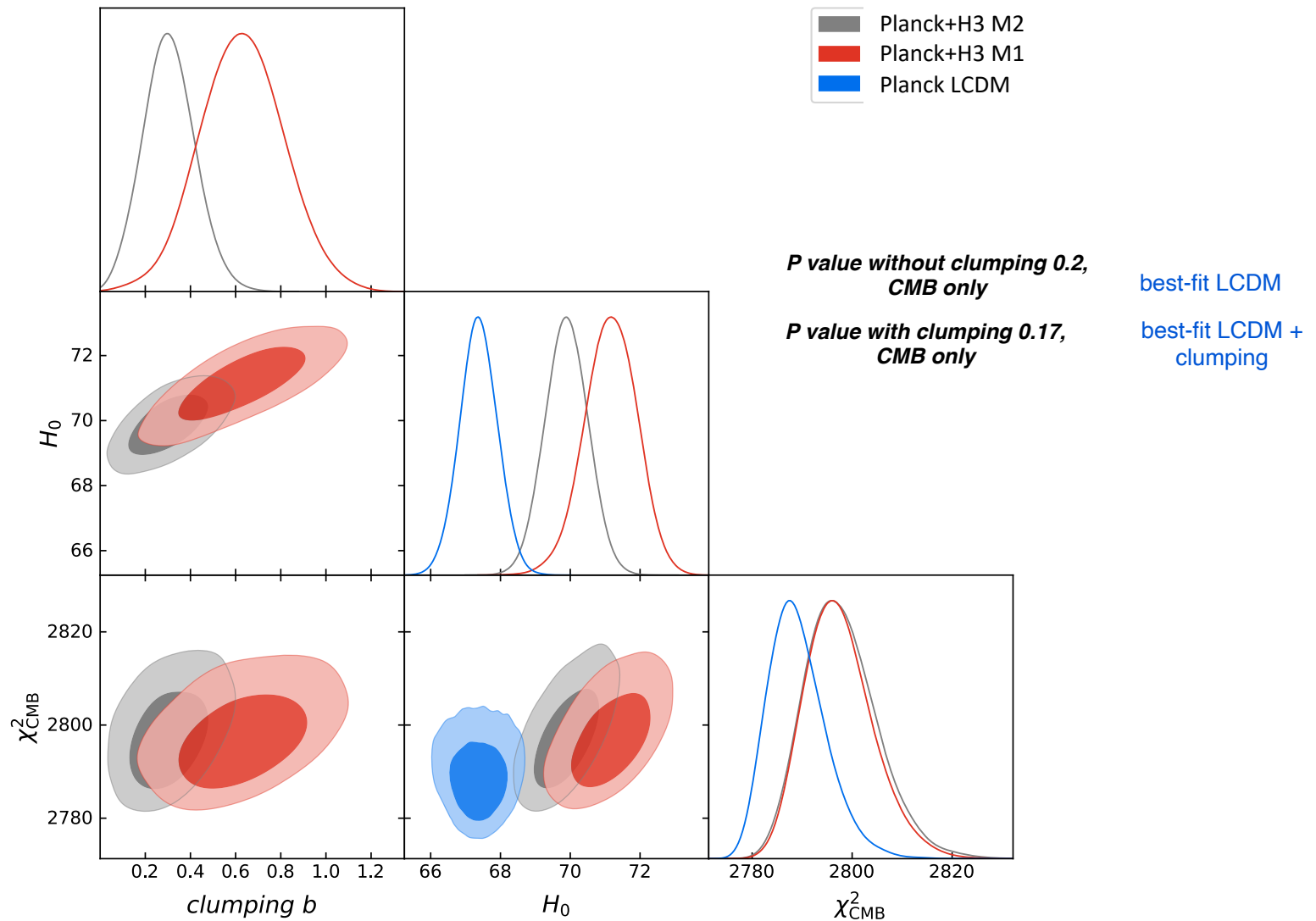


# ΛCDM + clumping: Fitting Planck and 3 Hubble determinations



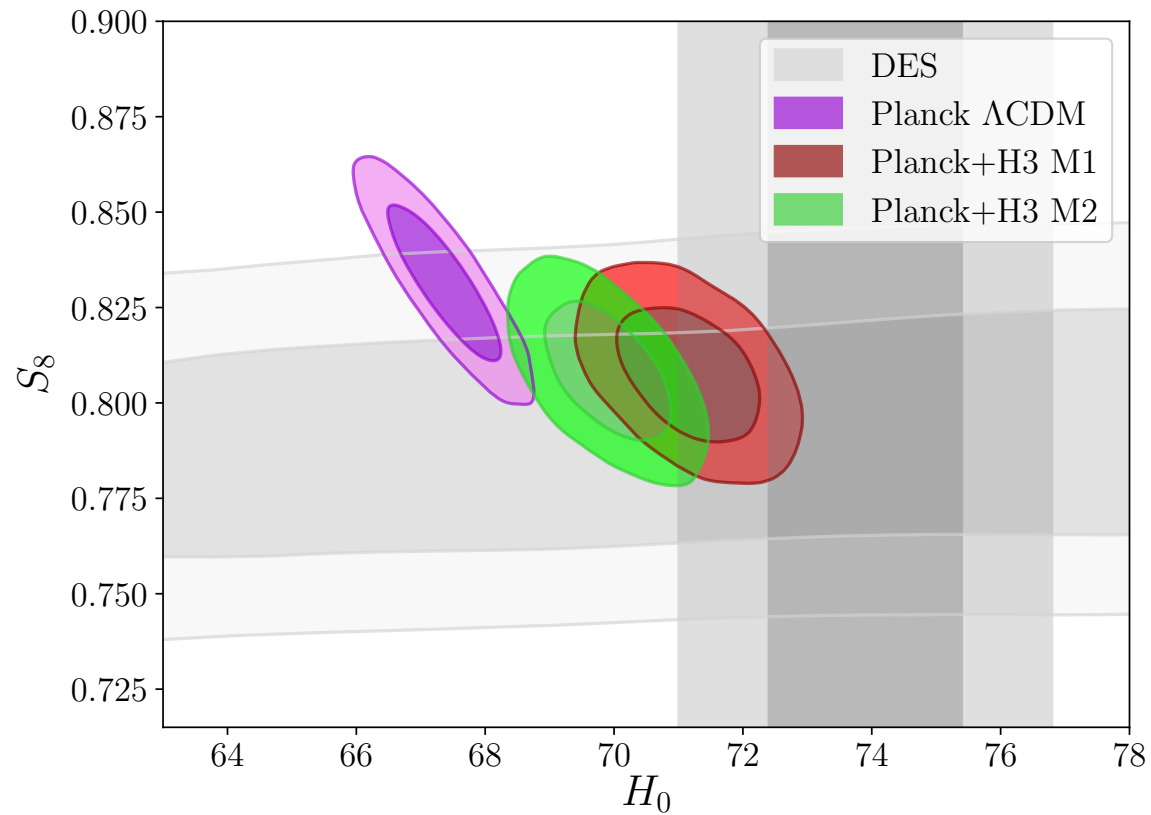
when late time Hubble data is used clumping is preferred, M1 at 4 sigma

# Does the fit to CMB get worse?



The LCDM model and the clumping models give comparable fits

## Relieving the Hubble (and sigma8) tension in one plot



## Implications:

Primordial magnetic fields induce clumping before recombination which may relieve the Hubble tension

Clear predictions for this essentially one-parameter family of non-exotic amendment of LCDM can be made

More detailed theoretical calculations on their impact on the CMB have to be performed

Interestingly, the approximately required field strength to relieve the Hubble tension would explain cosmic magnetic fields in the current Universe

The PMF scenario is testable by future CMB and gamma ray observations

However, PMFs can not be a full resolution of the Hubble tension, may only reach values of  $H$  around 70

# Why is it difficult to solve the Hubble tension ?

with Levon Pogosian and Gong-Bo Zhao

CMBR Doppler peak at angle:

$$\theta_{\star} = \frac{r_{\star}}{D_A(z_{\star})} = \frac{\int_{z_{\star}}^{\infty} c_s(z) dz / H(z)}{\int_0^{z_{\star}} c dz / H(z)}$$

Planck LCDM  $\rightarrow H_0 = 67.36 \pm 0.54 \text{ km/s/Mpc}$

local measurements, i.e. SH0ES  $\rightarrow H_0 = 73.5 \pm 1.4 \text{ km/s/Mpc}$



---

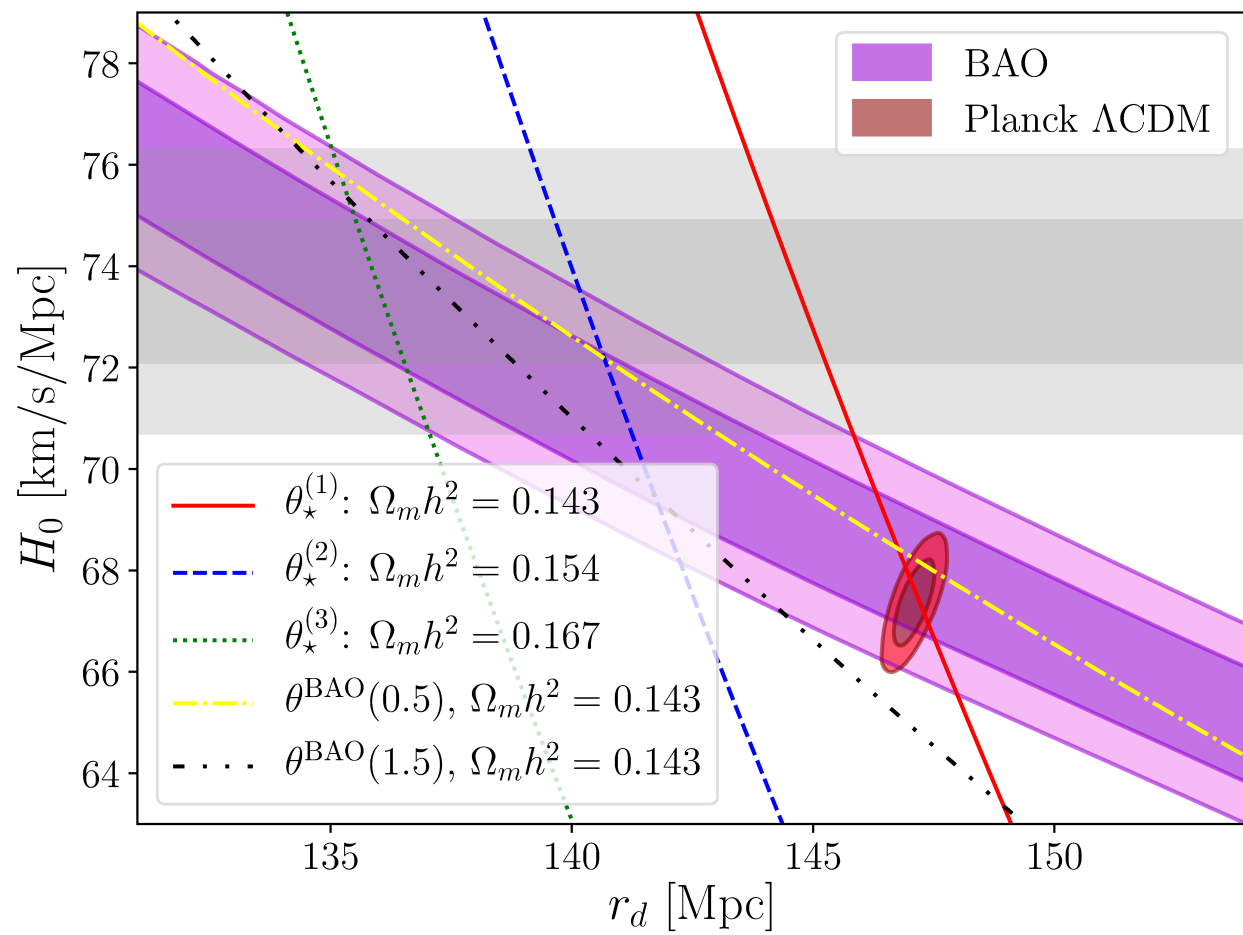
---

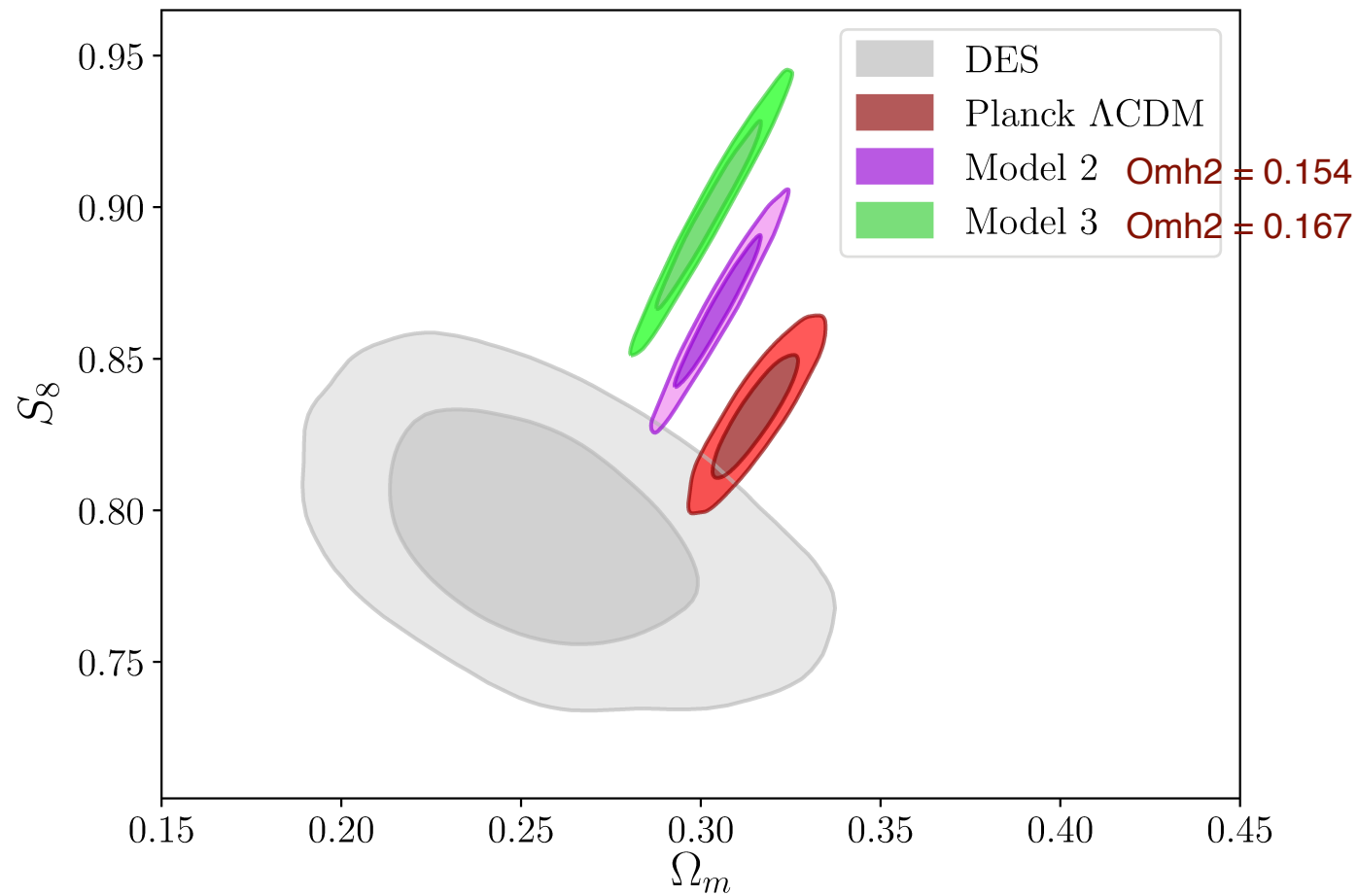
treat  $r_*$  as a free parameter

$$r_* = \theta_* \int_0^{z_*} \frac{2998 \text{ Mpc } dz}{\omega_m^{1/2} \sqrt{(1+z)^3 + h^2/\omega_m - 1}}$$

$$\omega_m = \Omega_m h^2$$

very similar relationship from baryon acoustic oscillations !





-> when only changing the sound horizon impossible to reconcile CMB peak positions, SH0ES, BAO, and DES

