Relieving the Hubble Tension with primordial magnetic fields

with Levon Pogosian

A **Primer on magnetic field evolution in the early Universe**

I spare you details, mention only the main conclusions, but all statements are verified by full numerical MHD simulations

B **Primordial Magnetic Fields, the CMB, and the Hubble constant**

Generalities of the evolution of cosmic magnetic fields in the early Universe

After an epoch of magneto-genesis fields decay freely, no active source

magnetic field energy is not conserved, the quantity which is conserved during the evolution is magnetic helicity

for most part MHD evolution is incompressible due to the large speed of sound, however …

epochs where the viscosity is large and MHD is not turbulent but viscous

Only the smallest fraction of initial magnetic energy density at very high temperatures may survive to the present

for phase transition produced fields

Condition for magnetic energy dissipation:

$$t_{\text{eddy}} \approx \frac{L_p(T)}{v(L)} \approx \frac{1}{H(T)} \approx t_H$$

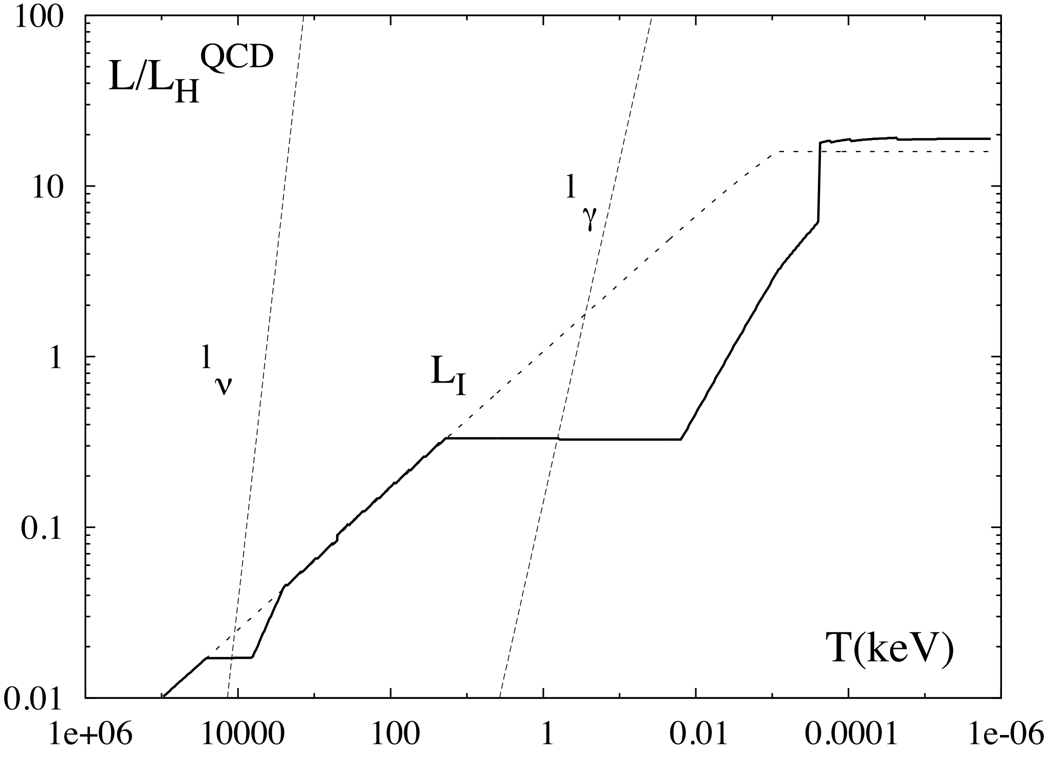
$v(L) \approx v_{\mathsf{A}}(L)\,;$ ***when turbulent***

in viscous MHD different

Banerjee and Jedamzik 2004, Campanelli 2007,2014

Evolution of the magnetic coherence lengths in the early Universe

coherence length growth equals dissipation of magnetic energy



coherence length

cosmic temperature

When the photon mean free path becomes large, magnetic field evolution stops temporarily

Banerjee and Jedamzik 2004

Magnetic fields survive Silk damping

Jedamzik, Katalinic, Olinto 1998, Subramanian and Barrow 1998

A Correlation for Primordial Cosmic Magnetic Fields

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

limit saturated when dynamically relaxed, i.e. $v_A(L)/L \approx H_0$

a particularity: after recombination magnetic fields do essentially not evolve further, until structure formation

Banerjee and Jedamzik 2004

Viscous MHD evolution with free-streaming photon drag:

$$\begin{aligned} \frac{d\mathbf{v}}{dt} + \left(\mathbf{v}\cdot\nabla\right)\cdot\mathbf{v} + c_s^2\frac{\nabla\varrho}{\varrho} &= -\alpha\mathbf{v} - \frac{1}{4\pi\varrho}\left(\frac{1}{2}\nabla\mathbf{B}^2 - \mathbf{B}\cdot\nabla\mathbf{B}\right) \\ \frac{d\varrho}{dt} + \nabla\left(\varrho\mathbf{v}\right) &= 0 \end{aligned}$$

the three important terms

back of the envelope estimate:

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

Jedamzik and Abel 2011

It doesn't take much field:

$$c_s = 6.33 \frac{\mathrm{km}}{\mathrm{s}}$$

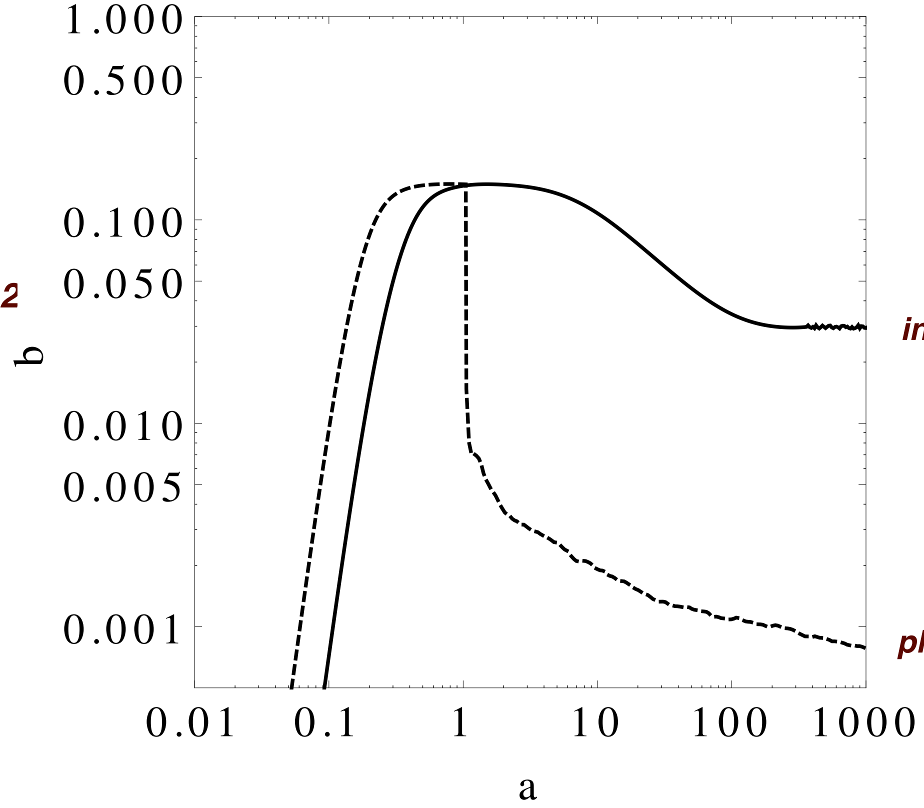
isothermal speed of sound

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

Full MHD simulations:

clumping factor:

b = <rho-<rho>^2>/<rho>^2



inflationary produced fields

phase transition produced fields

final field 10 pG

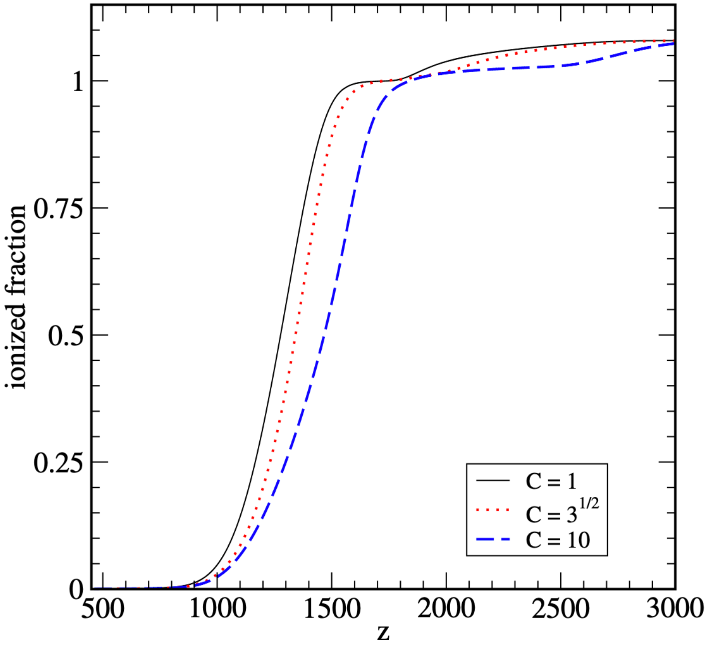
scale factor (a=1 at recombination)

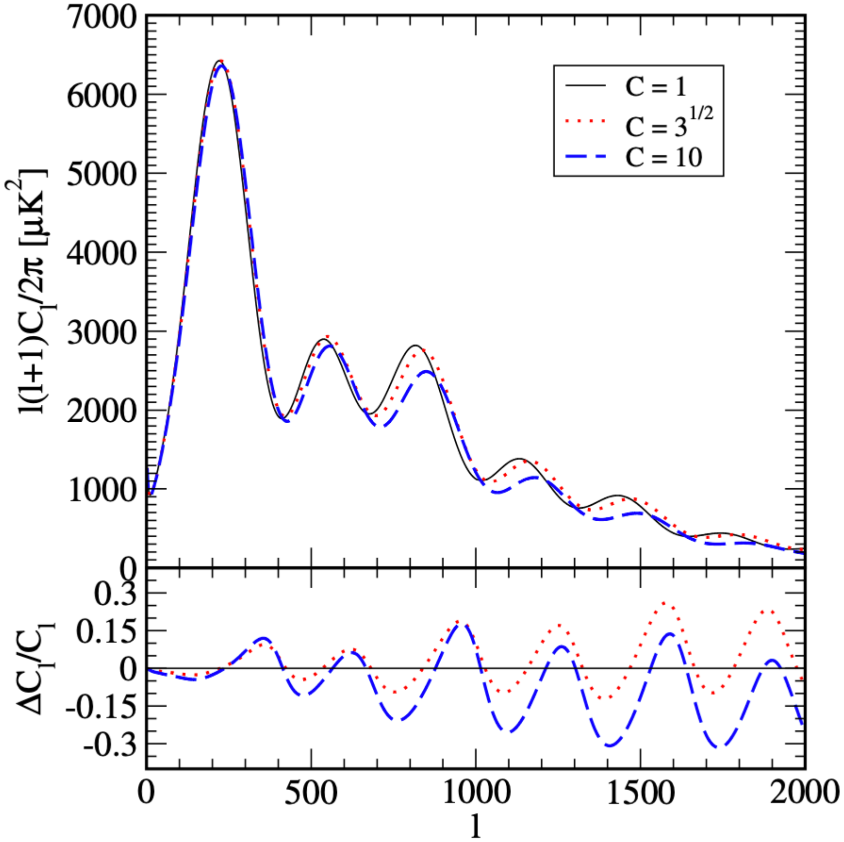
Jedamzik and Saveliev 2018

Inhomogeneities enhance the recombination rate

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

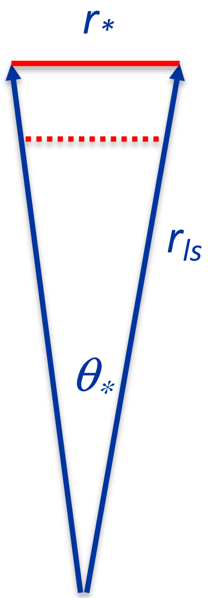
$$\langle n_e^2\rangle \;>\; \langle n_e\rangle^2$$

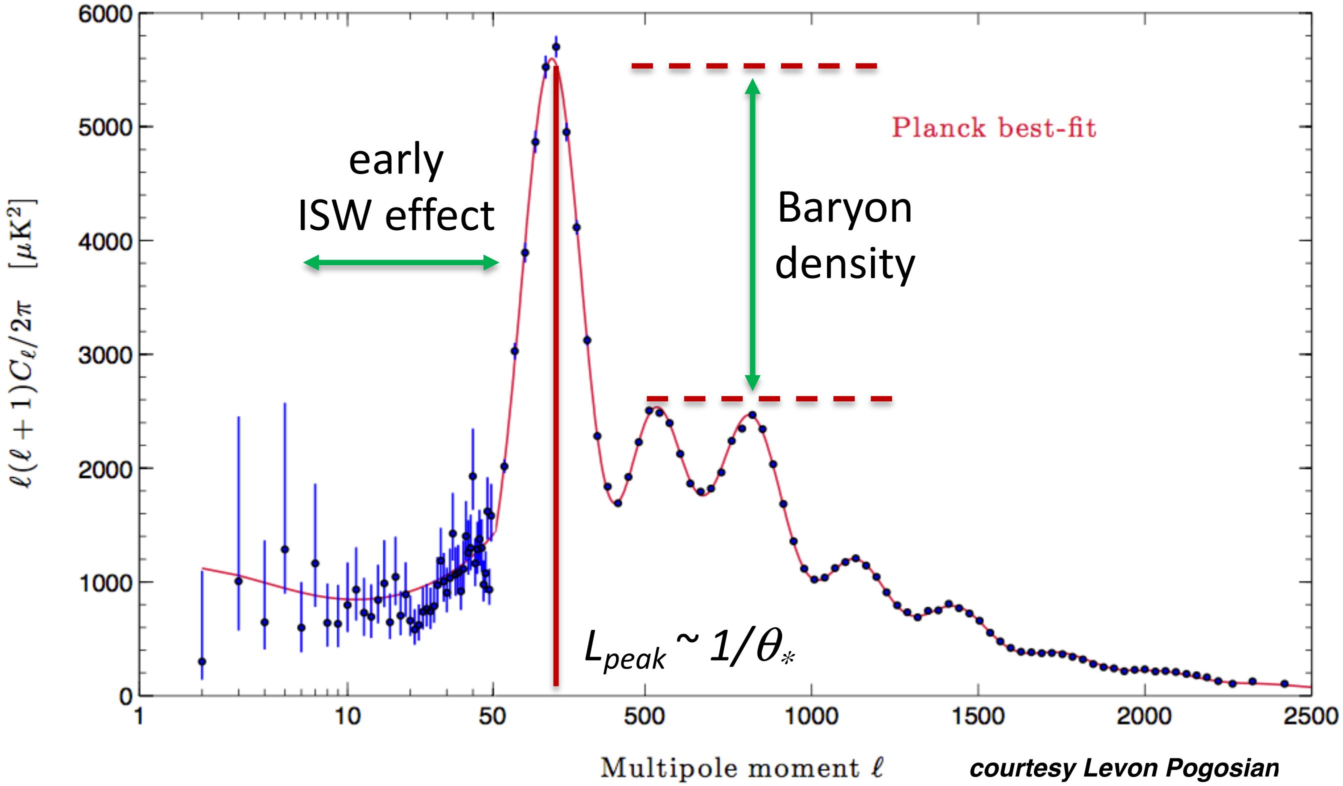




Jedamzik and Abel, arXiv:1108.2517, JCAP (2013)

How does CMB constrain H0?





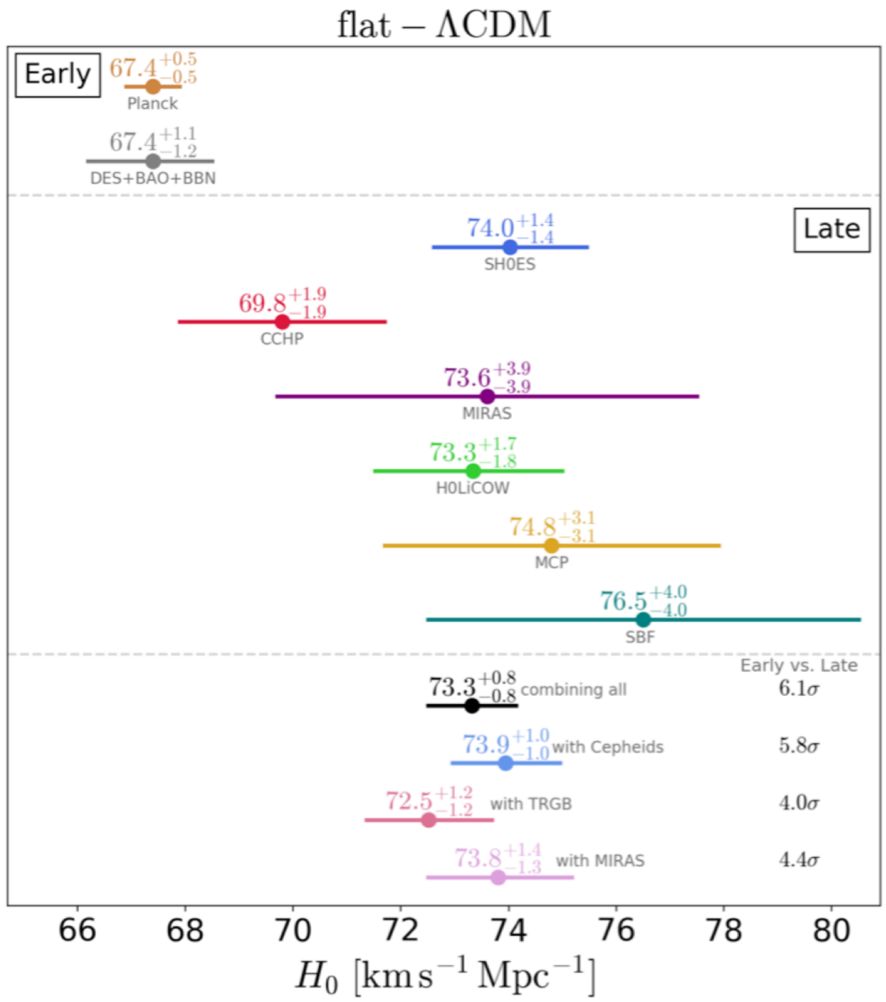
courtesy Levon Pogosian

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 ~ h^-0.2

observed angle of CMB peak: smaller sound horizon -> larger Hubble constant

The Hubble tension

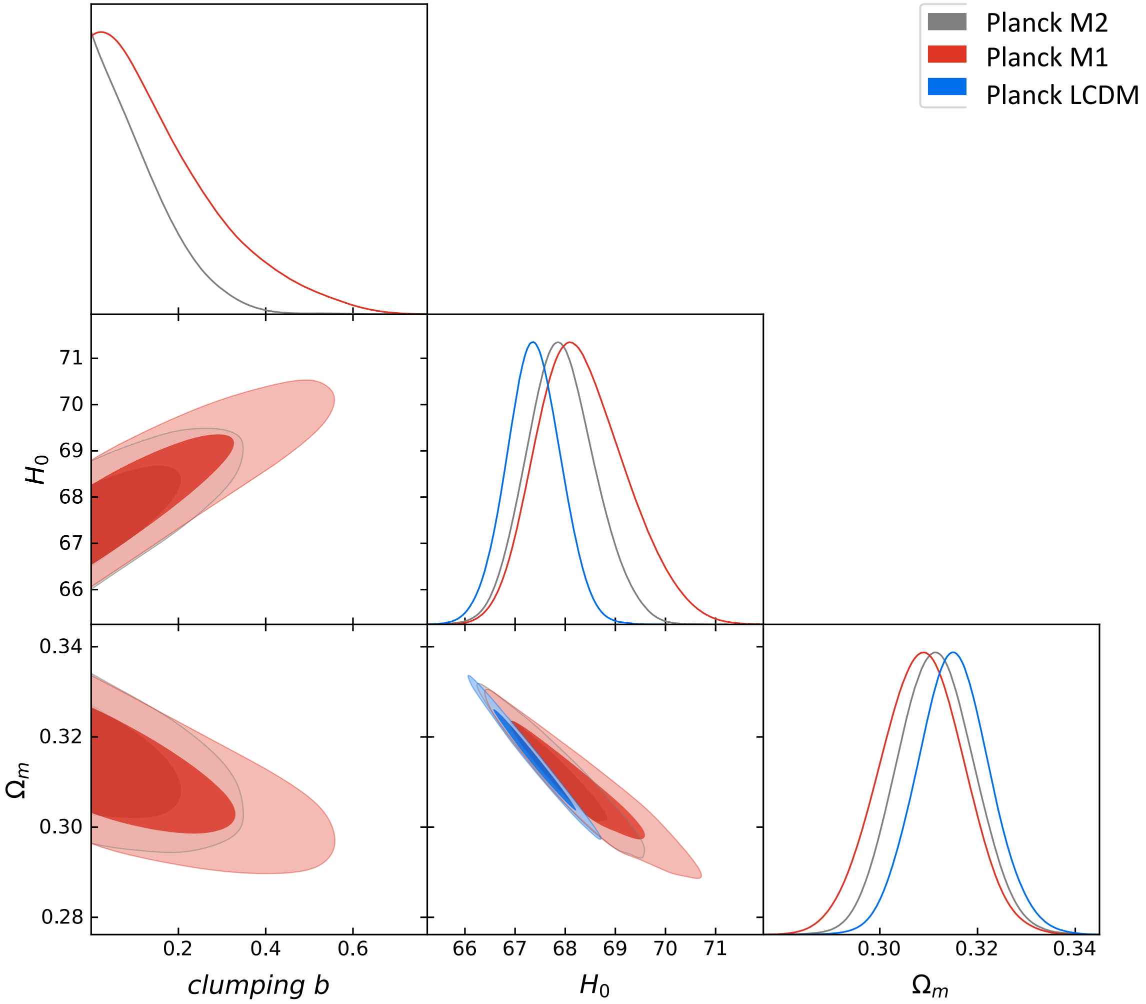


Tensions between the Early and the Late Universe

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

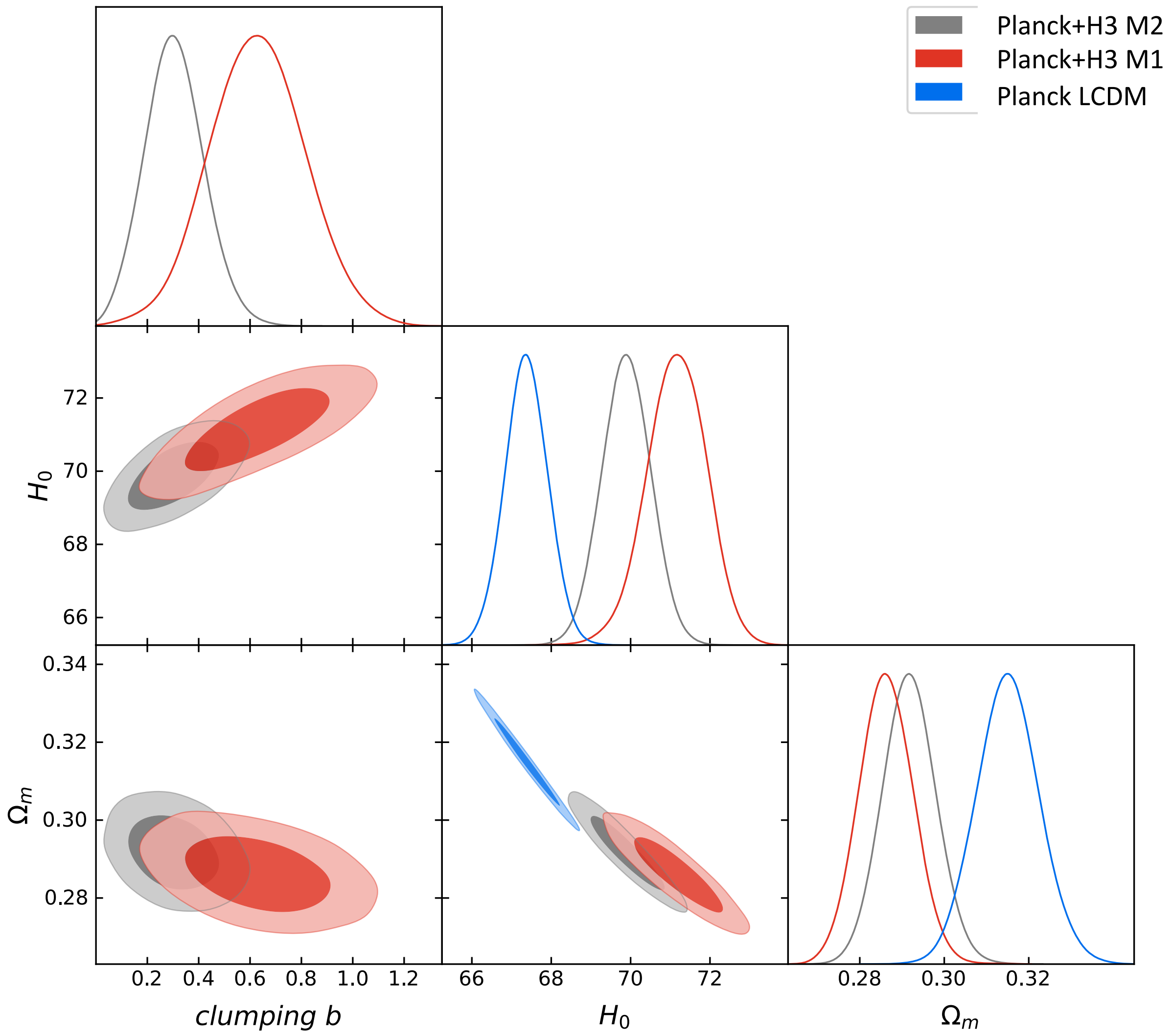
The tension is between the measurements that require calculating r_* and r_{drag} and those that do not

Fitting to Planck only



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

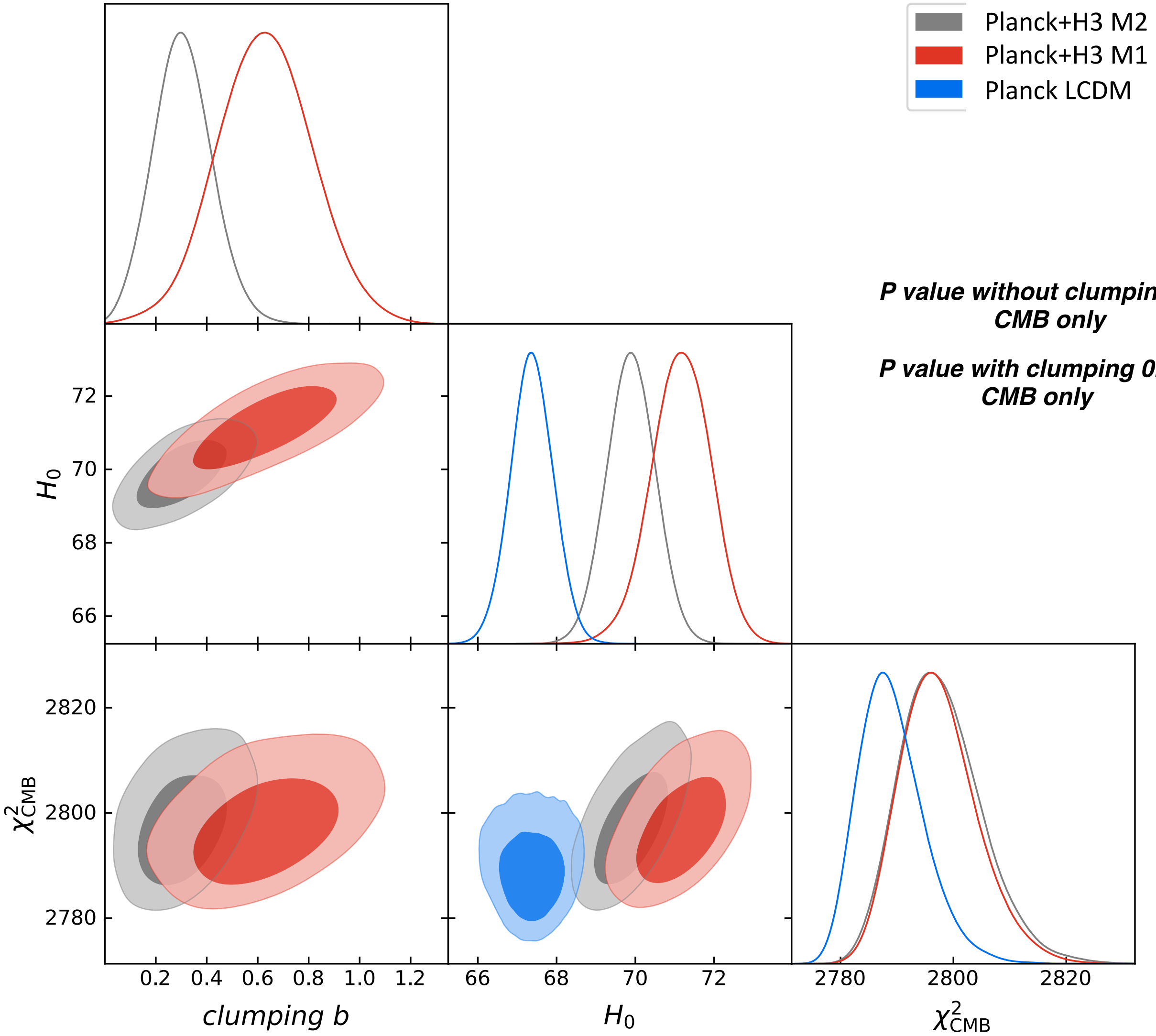
Fitting to Planck + H3



a clear detection of clumping!

at almost 4 sigma for M1

Does the fit to CMB get worse?

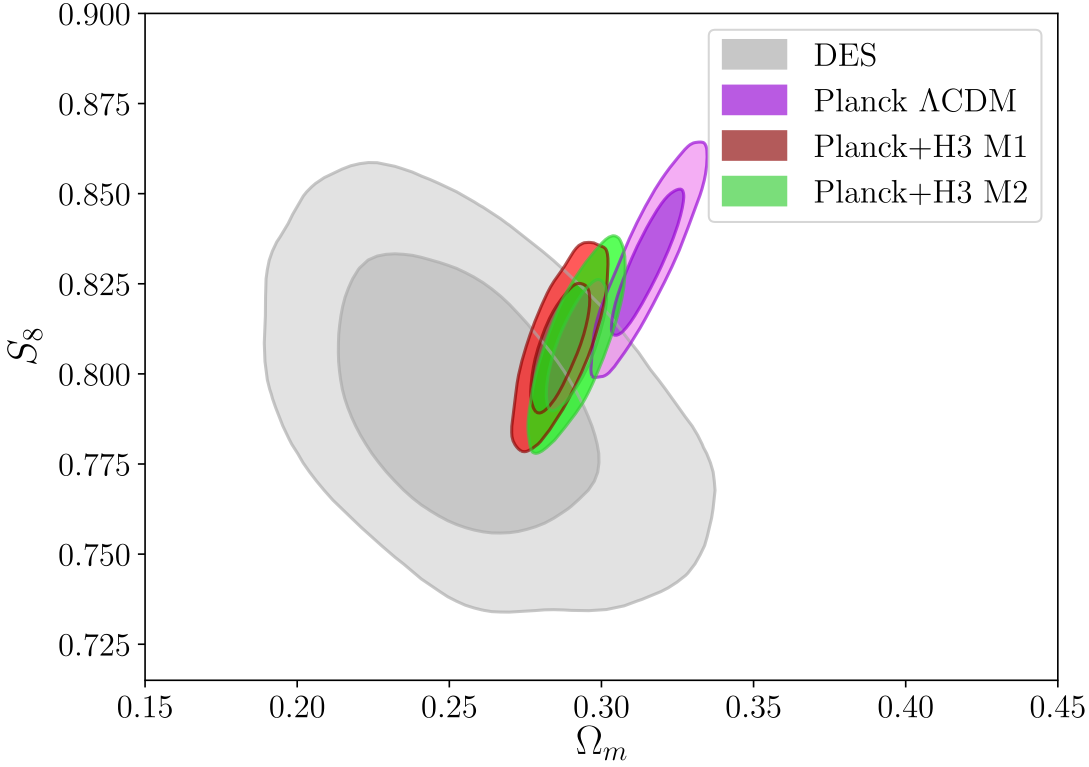


P value without clumping 0.2, CMB only

P value with clumping 0.17, CMB only

The LCDM model and the clumping models give comparable fits

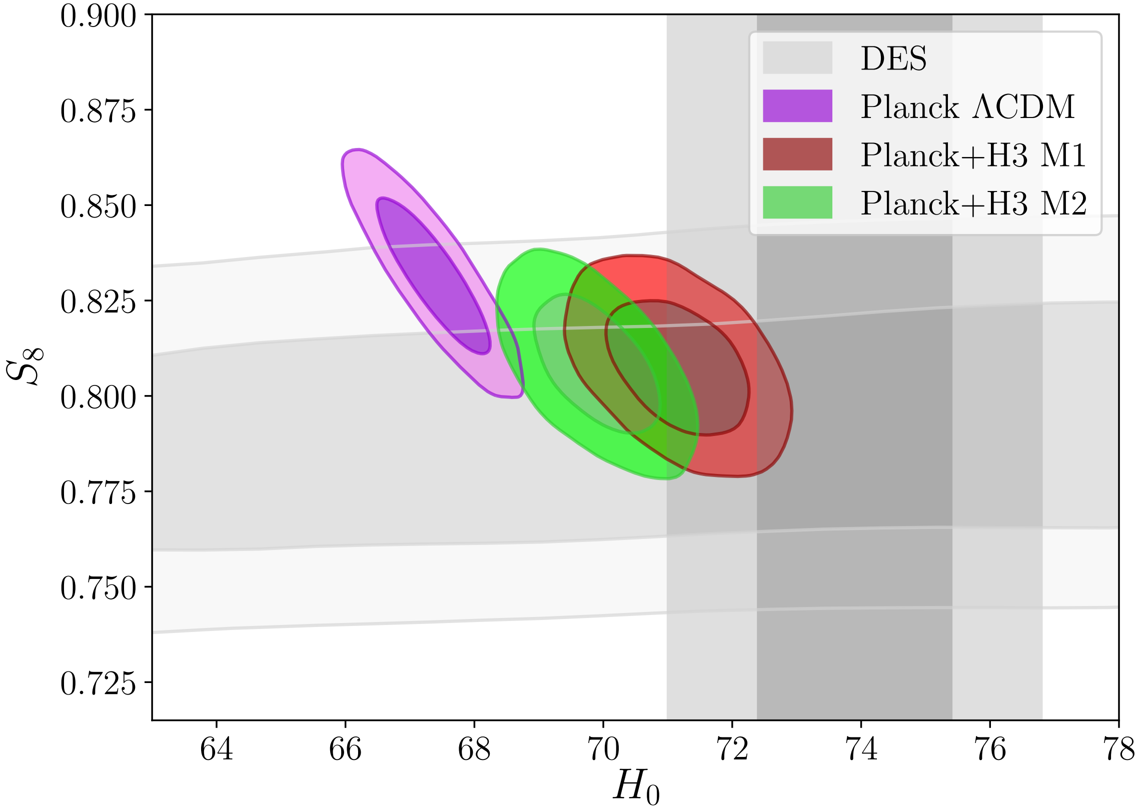
Relieving the S_8-Ω_m tension



As a byproduct, clumping models also relieve the S_8-Ω_m tension

K. Jedamzik and L. Pogosian, arXiv:2004.09487

Relieving both tension in one plot



K. Jedamzik and L. Pogosian, arXiv:2004.09487

Alternative sources of small-scale baryon clumping:

Enhanced small-scale adiabatic fluctuations do not survive Silk-damping

Extra baryon isocurvature fluctuations violate BBN constraints

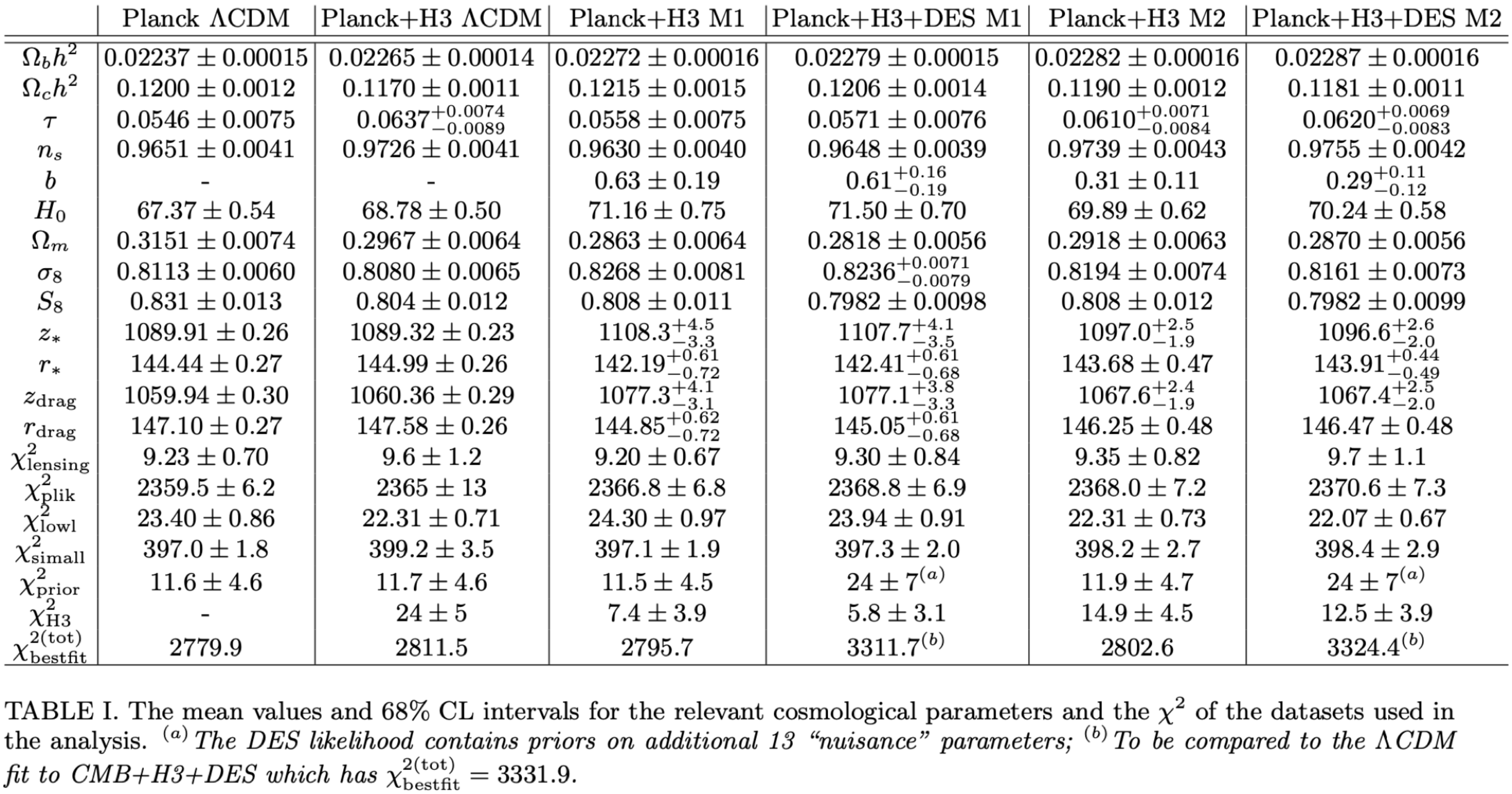
B-balls or quark nuggets evaporating before recombination also violate BBN constraints

Baryon inhomogeneities produced by cosmic strings may not reach high volume filling factors

Implications:

A clumping factor of b~0.5 corresponds to post-recombination field strength of ~0.02-0.1 nGauss. If such primordial fields indeed were present, magnetic fields in galaxies, clusters of galaxies, and the extragalactic medium would be entirely primordial !!!!!!! Such fields would likely originate from the electroweak phase transition or less likely from an inflationary scenario. These scenarios may be tested by future CMB missions.

The effect on other parameters



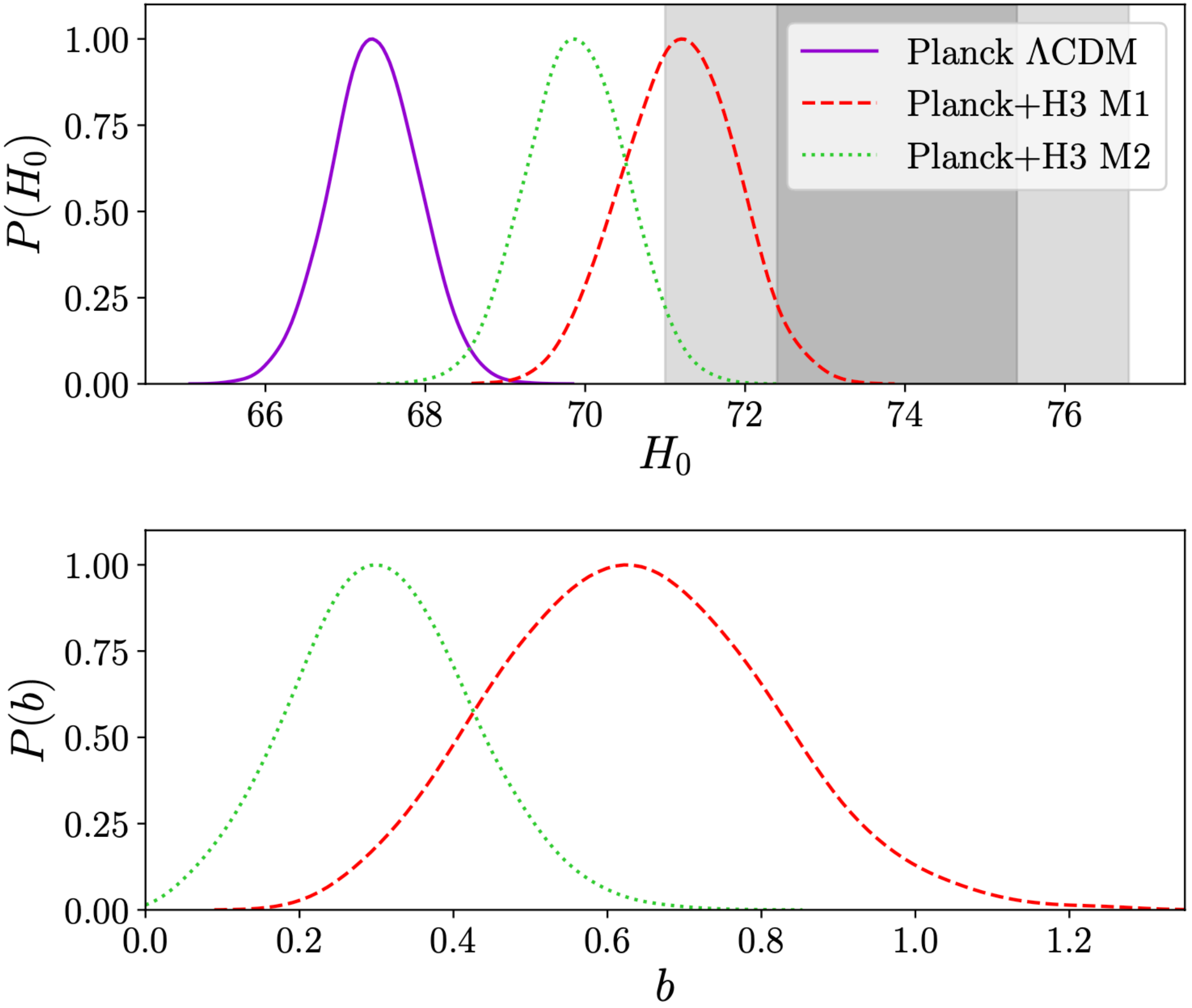
	Planck ΛCDM	Planck+H3 ΛCDM	Planck+H3 M1	Planck+H3+DES M1	Planck+H3 M2	Planck+H3+DES M2
$\Omega_b h^2$	0.02237 ± 0.00015	0.02265 ± 0.00014	0.02272 ± 0.00016	0.02279 ± 0.00015	0.02282 ± 0.00016	0.02287 ± 0.00016
$\Omega_c h^2$	0.1200 ± 0.0012	0.1170 ± 0.0011	0.1215 ± 0.0015	0.1206 ± 0.0014	0.1190 ± 0.0012	0.1181 ± 0.0011
τ	0.0546 ± 0.0075	$0.0637^{+0.0074}_{-0.0089}$	0.0558 ± 0.0075	0.0571 ± 0.0076	$0.0610^{+0.0071}_{-0.0084}$	$0.0620^{+0.0069}_{-0.0083}$
n_s	0.9651 ± 0.0041	0.9726 ± 0.0041	0.9630 ± 0.0040	0.9648 ± 0.0039	0.9739 ± 0.0043	0.9755 ± 0.0042
b	-	-	0.63 ± 0.19	$0.61^{+0.16}_{-0.19}$	0.31 ± 0.11	$0.29^{+0.11}_{-0.12}$
H_0	67.37 ± 0.54	68.78 ± 0.50	71.16 ± 0.75	71.50 ± 0.70	69.89 ± 0.62	70.24 ± 0.58
Ω_m	0.3151 ± 0.0074	0.2967 ± 0.0064	0.2863 ± 0.0064	0.2818 ± 0.0056	0.2918 ± 0.0063	0.2870 ± 0.0056
σ_8	0.8113 ± 0.0060	0.8080 ± 0.0065	0.8268 ± 0.0081	$0.8236^{+0.0071}_{-0.0079}$	0.8194 ± 0.0074	0.8161 ± 0.0073
S_8	0.831 ± 0.013	0.804 ± 0.012	0.808 ± 0.011	0.7982 ± 0.0098	0.808 ± 0.012	0.7982 ± 0.0099
z_*	1089.91 ± 0.26	1089.32 ± 0.23	$1108.3^{+4.5}_{-3.3}$	$1107.7^{+4.1}_{-3.5}$	$1097.0^{+2.5}_{-1.9}$	$1096.6^{+2.6}_{-2.0}$
r_*	144.44 ± 0.27	144.99 ± 0.26	$142.19^{+0.61}_{-0.72}$	$142.41^{+0.61}_{-0.68}$	143.68 ± 0.47	$143.91^{+0.44}_{-0.49}$
$z_{\rm drag}$	1059.94 ± 0.30	1060.36 ± 0.29	$1077.3^{+4.1}_{-3.1}$	$1077.1^{+3.8}_{-3.3}$	$1067.6^{+2.4}_{-1.9}$	$1067.4^{+2.5}_{-2.0}$
$r_{\rm drag}$	147.10 ± 0.27	147.58 ± 0.26	$144.85^{+0.62}_{-0.72}$	$145.05^{+0.61}_{-0.68}$	146.25 ± 0.48	146.47 ± 0.48
$\chi^2_{\rm lensing}$	9.23 ± 0.70	9.6 ± 1.2	9.20 ± 0.67	9.30 ± 0.84	9.35 ± 0.82	9.7 ± 1.1
$\chi^2_{\rm plik}$	2359.5 ± 6.2	2365 ± 13	2366.8 ± 6.8	2368.8 ± 6.9	2368.0 ± 7.2	2370.6 ± 7.3
$\chi^2_{\rm lowl}$	23.40 ± 0.86	22.31 ± 0.71	24.30 ± 0.97	23.94 ± 0.91	22.31 ± 0.73	22.07 ± 0.67
$\chi^2_{\rm simall}$	397.0 ± 1.8	399.2 ± 3.5	397.1 ± 1.9	397.3 ± 2.0	398.2 ± 2.7	398.4 ± 2.9
$\chi^2_{\rm prior}$	11.6 ± 4.6	11.7 ± 4.6	11.5 ± 4.5	$24 \pm 7^{(a)}$	11.9 ± 4.7	$24 \pm 7^{(a)}$
$\chi^2_{\rm H3}$	-	24 ± 5	7.4 ± 3.9	5.8 ± 3.1	14.9 ± 4.5	12.5 ± 3.9
$\chi^{2({\rm tot})}_{\rm bestfit}$	2779.9	2811.5	2795.7	$3311.7^{(b)}$	2802.6	$3324.4^{(b)}$

TABLE I. The mean values and 68% CL intervals for the relevant cosmological parameters and the χ^2 of the datasets used in the analysis. $^{(a)}$ *The DES likelihood contains priors on additional 13 "nuisance" parameters;* $^{(b)}$ *To be compared to the ΛCDM fit to CMB+H3+DES which has* $\chi^{2({\rm tot})}_{\rm bestfit} = 3331.9$.

Minor changes in the values and uncertainties of other cosmological parameters
Adding the DES Y1 data pushes the detection of clumping beyond 4σ

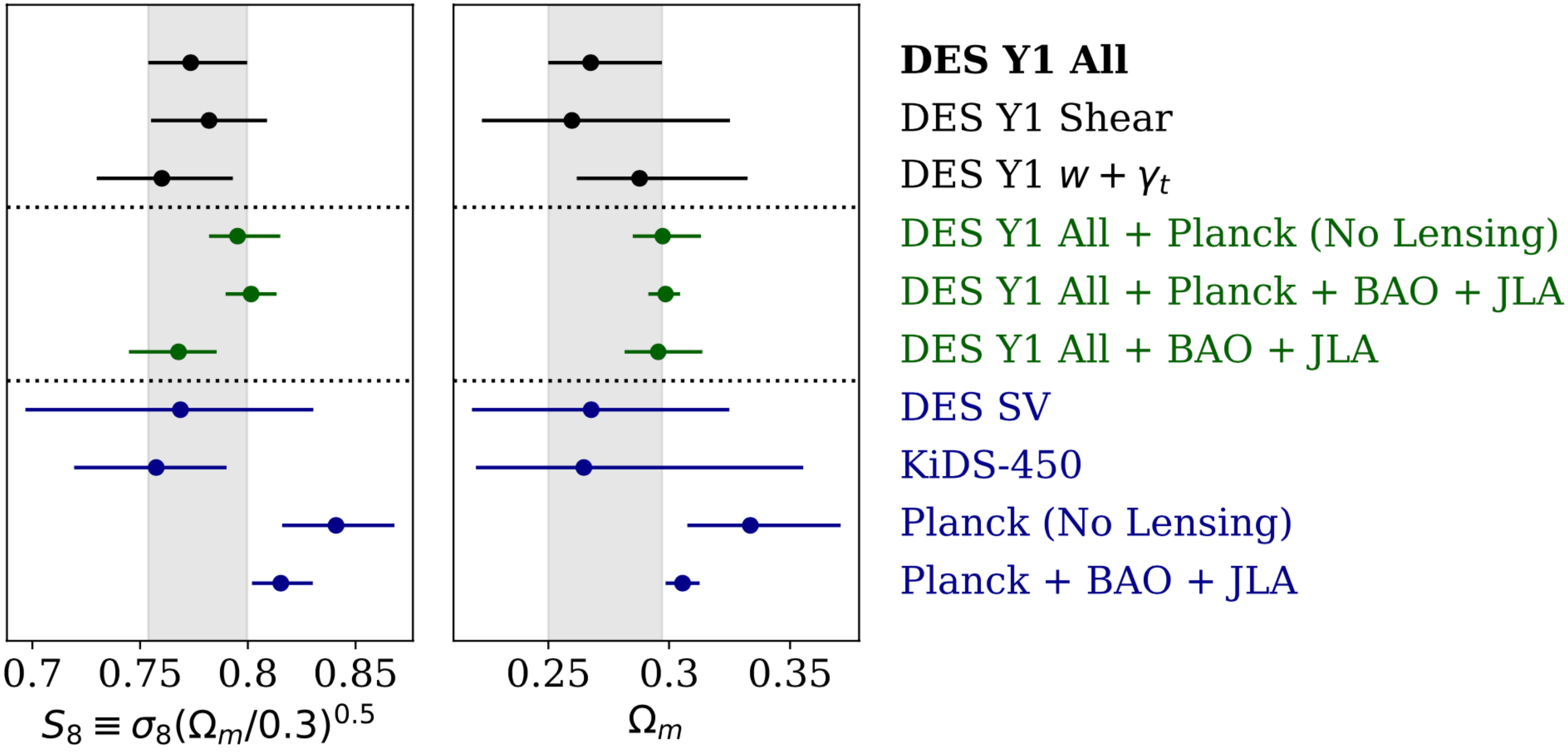
K. Jedamzik and L. Pogosian, arXiv:2004.09487

Relieving the Hubble tension



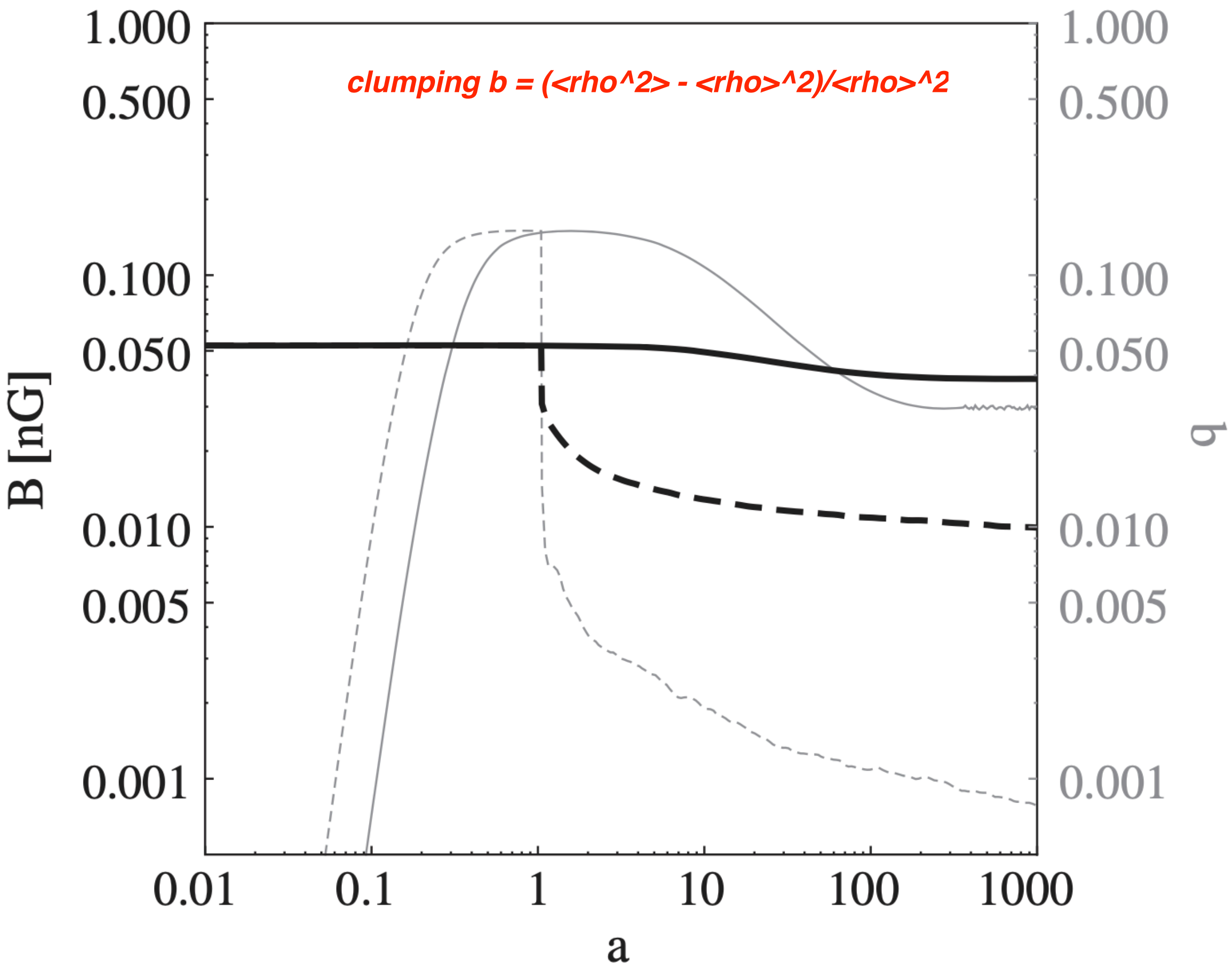
K. Jedamzik and L. Pogosian, arXiv:2004.09487

The S_8-Ω_m tension



DES Y1 Results: Cosmological Constraints from Galaxy Clustering and Weak Lensing, arXiv:1708.01530

Magnetic field evolution through recombination



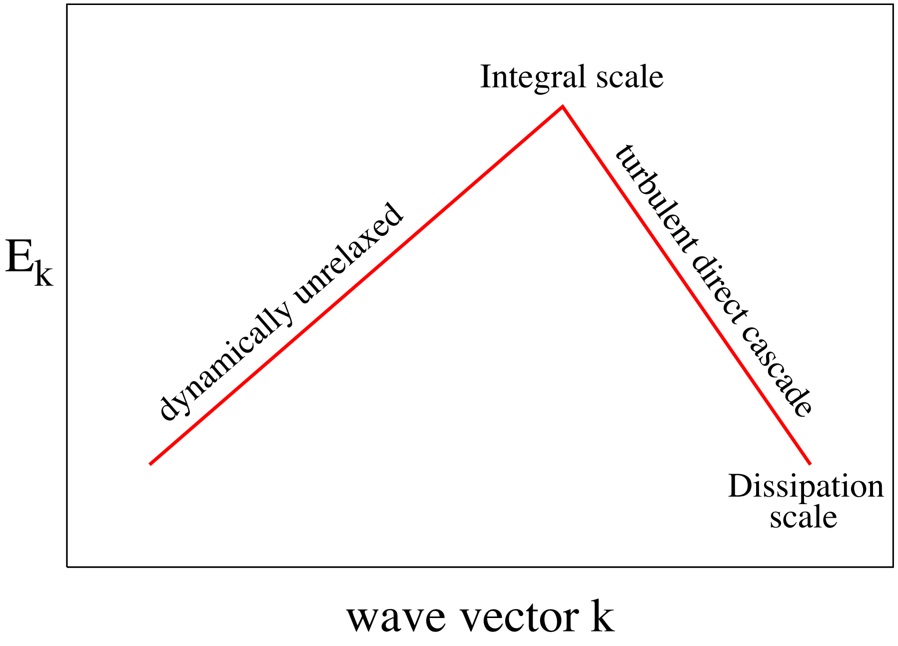
Jedamzik and Saveliev, arXiv:1804.06115, PRL (2019)

MHD Cascades in Fourier Space

$$E_B = \frac{\varrho}{2}\frac{1}{V}\int \mathrm{d}^3x\, \mathbf{v_A}^2 = \int \mathrm{d}^3k \langle |v_{A,k}|^2 \rangle \equiv \int \mathrm{d}\ln\, k\, E_k\,, \tag{1}$$

quasi-stationary state (Kolmogoroff, Iroshnikov-Kraichnan)

$$\frac{\mathrm{d}E_k}{\mathrm{d}t} \approx \frac{E_k}{\tau_k} \approx \mathrm{const}(k)\ , \tag{2}$$

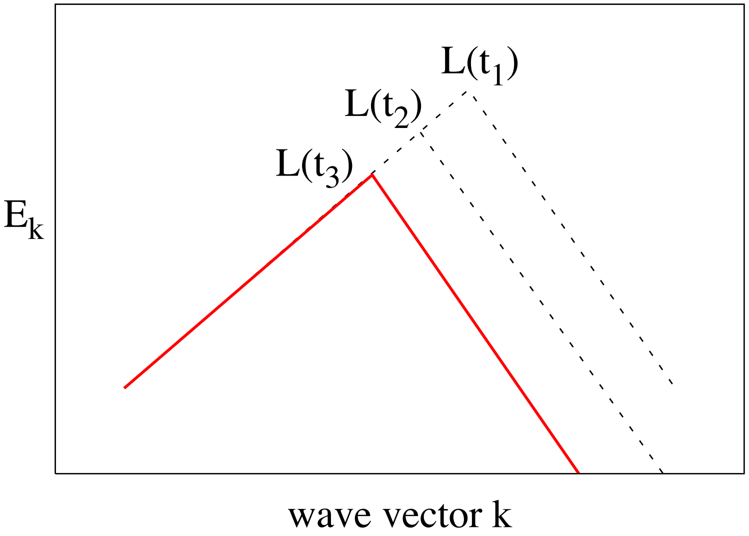


Decay of magnetic energy in MHD

Assume initial small-k spectrum:

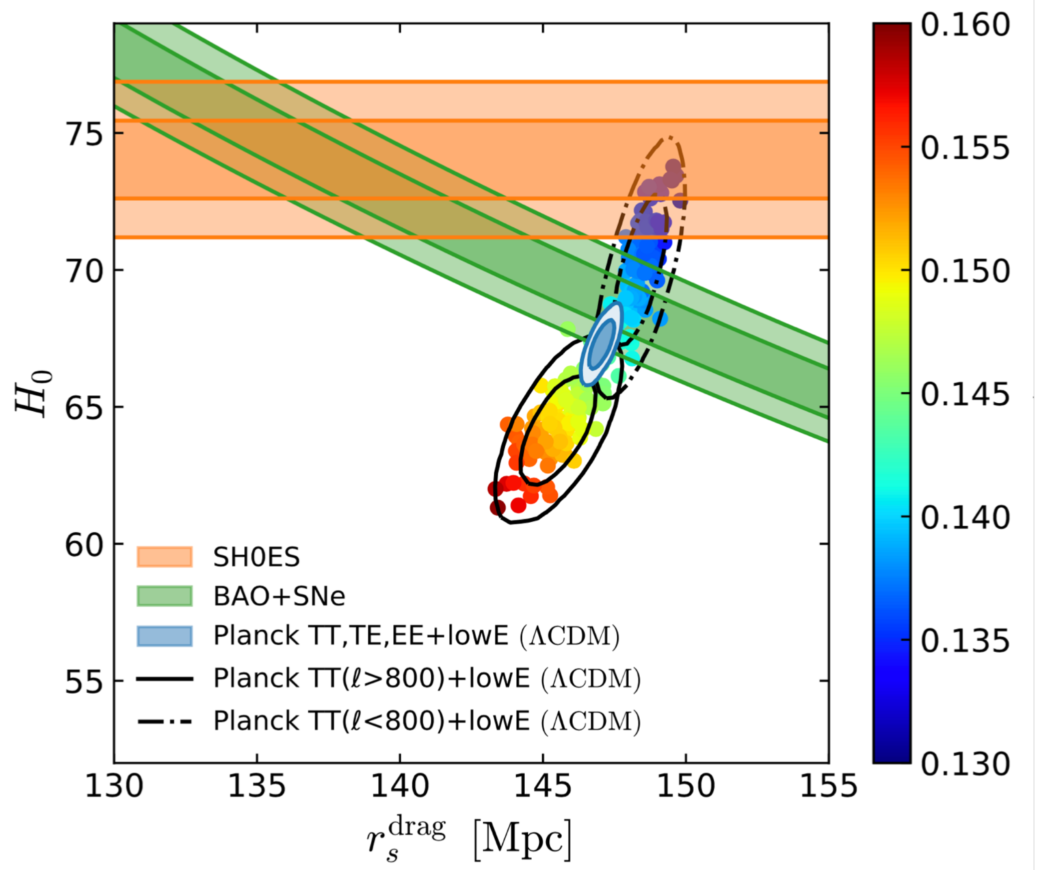
$$E_l(t_0) = E_0 \left(\frac{l}{L_0}\right)^{-n} \quad \text{for } l > L_0$$

Processing on Integral Scale by development of fluid eddies and cascade of energy to dissipation scale

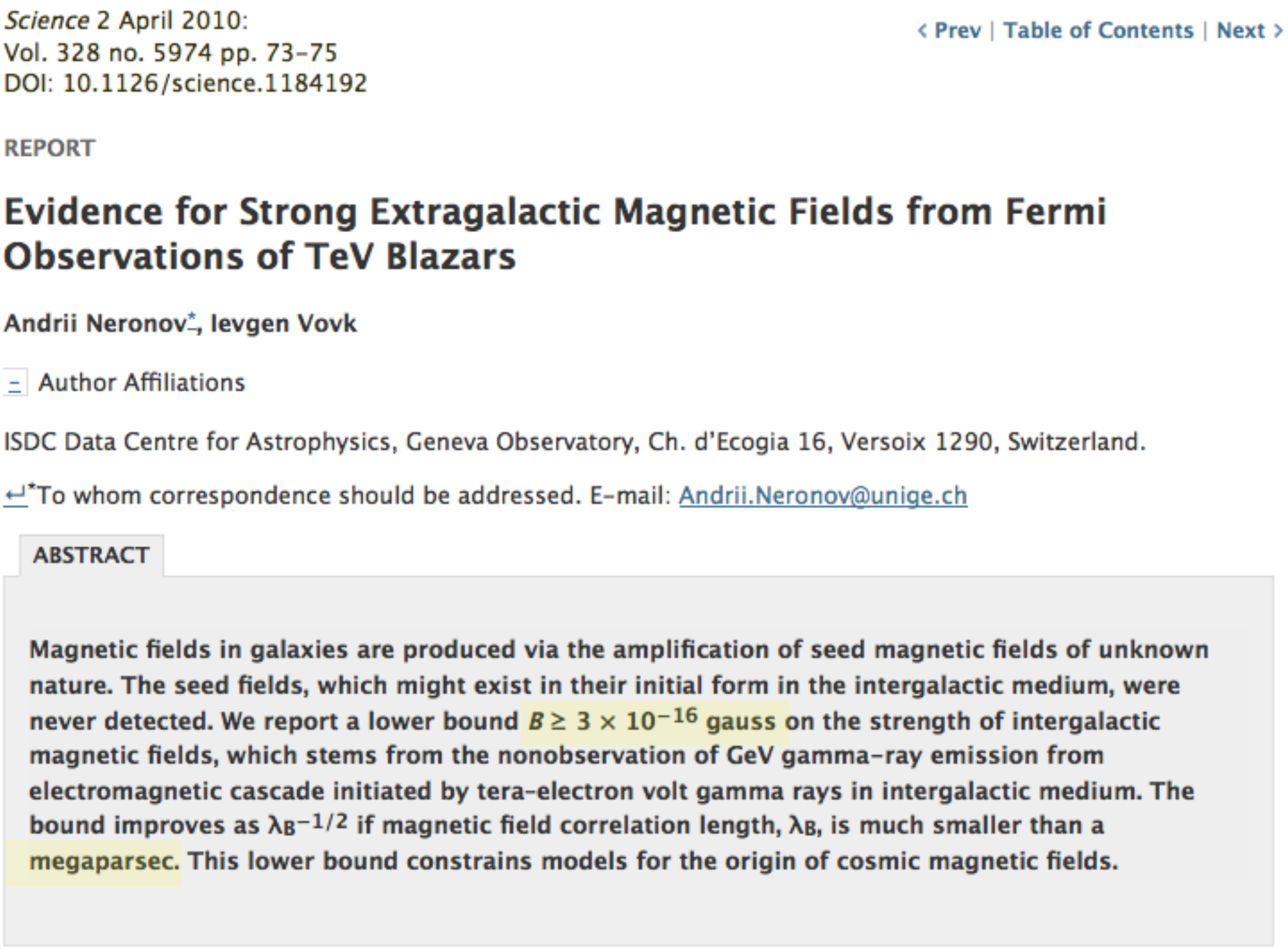


relaxation time: $\tau_L = t \sim L/v_L \sim L/\sqrt{E_L}$

Baryon Acoustic Oscillations



The Hubble Hunter's Guide, L. Knox and M. Millea, arXiv:1908.03663



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REPORT

Evidence for Strong Extragalactic Magnetic Fields from Fermi Observations of TeV Blazars

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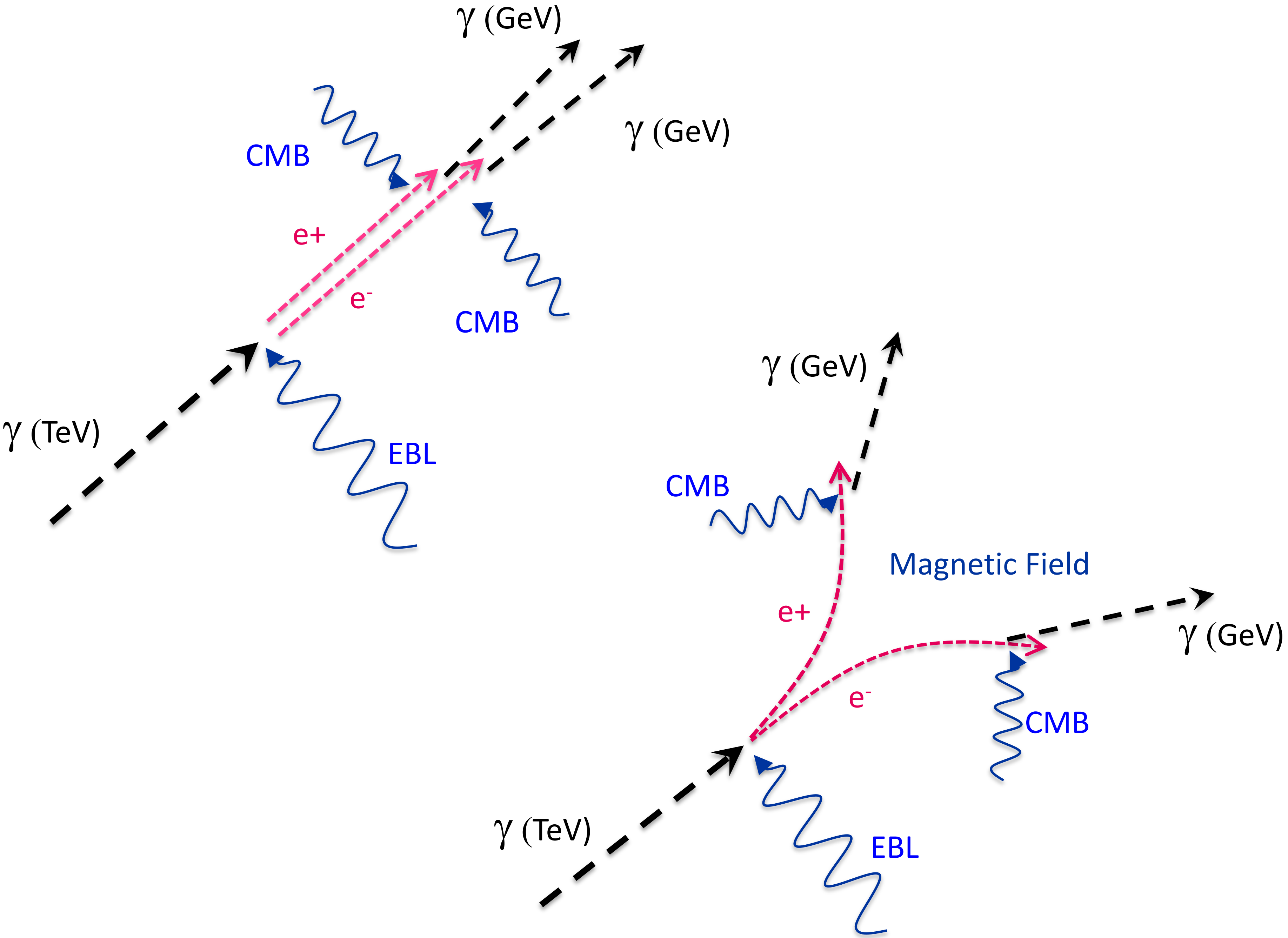
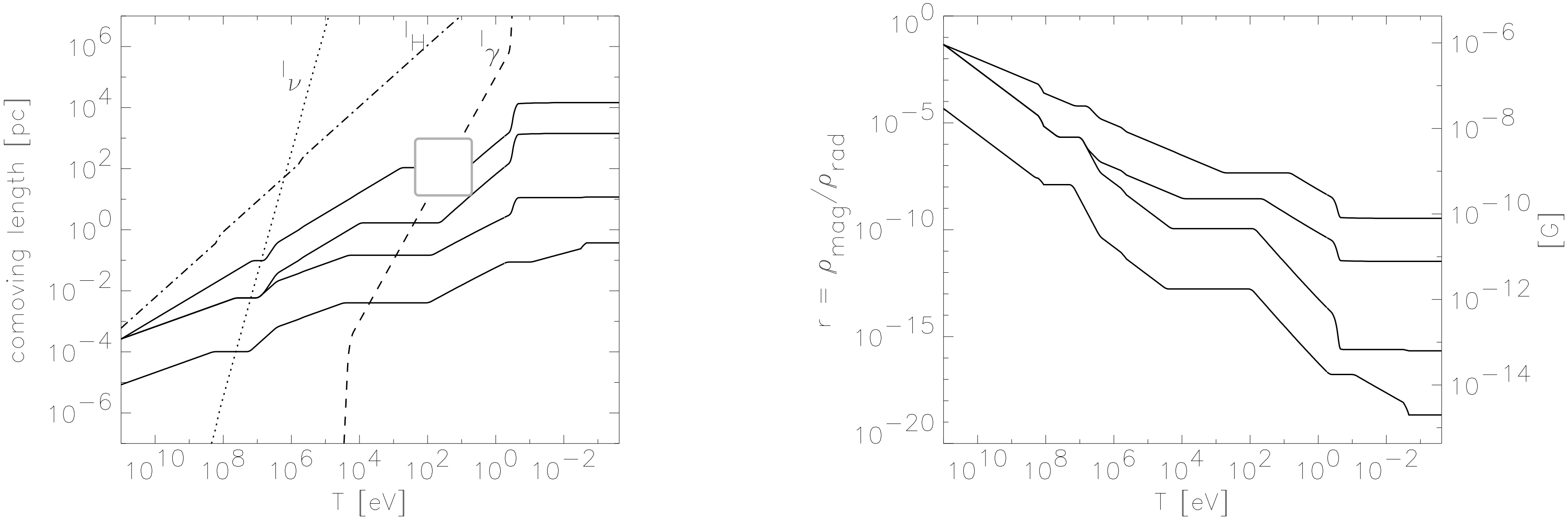
ABSTRACT

Magnetic fields in galaxies are produced via the amplification of seed magnetic fields of unknown nature. The seed fields, which might exist in their initial form in the intergalactic medium, were never detected. We report a lower bound $B \geq 3 \times 10^{-16}$ gauss on the strength of intergalactic magnetic fields, which stems from the nonobservation of GeV gamma-ray emission from electromagnetic cascade initiated by tera-electron volt gamma rays in intergalactic medium. The bound improves as $\lambda_B^{-1/2}$ if magnetic field correlation length, λ_B, is much smaller than a megaparsec. This lower bound constrains models for the origin of cosmic magnetic fields.


γ (GeV)
γ (GeV)
CMB
e+
e-
CMB
γ (TeV)
EBL
γ (GeV)
CMB
Magnetic Field
e+
γ (GeV)
e-
CMB
γ (TeV)
EBL

Evolution: The Global Picture



from top to bottom: (a) $h_{\mathrm{g}} = 1$, $r_{\mathrm{g}} = 0.01$, (b) $h_{\mathrm{g}} = 10^{-3}$, $n = 3$, $r_{\mathrm{g}} = 0.01$, (c) $h_{\mathrm{g}} = 0$, $n = 3$, $r_{\mathrm{g}} = 0.01$, (d) $h_{\mathrm{g}} = 0$, $n = 3$, $r_{\mathrm{g}} = 10^{-5}$

Banerjee and Jedamzik 2004

Cosmic Magnetic Fields

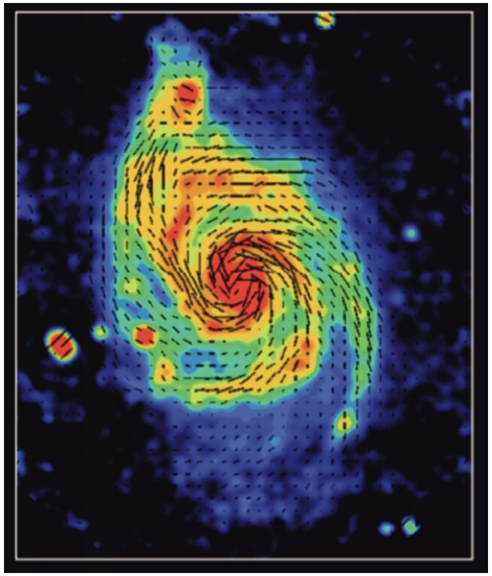


Image courtesy of NRAO/AUI

- Origin of 1-10 μG fields in galaxies and clusters
  - mostly astrophysical? (dynamo, SN, …)
  - mostly primordial? (need 0.01-0.1 nG)
  - some combination of the two?
- Evidence of magnetic fields in voids?
  - missing GeV γ-ray halos around TeV blazars
- Generated in the early universe – not “if”, but “how much”
  - phase transitions
  - inflationary mechanisms
  - a window into the early universe
- A distinct signature in CMB could prove their primordial origin