Hubble Hullabaloo and String Cosmology

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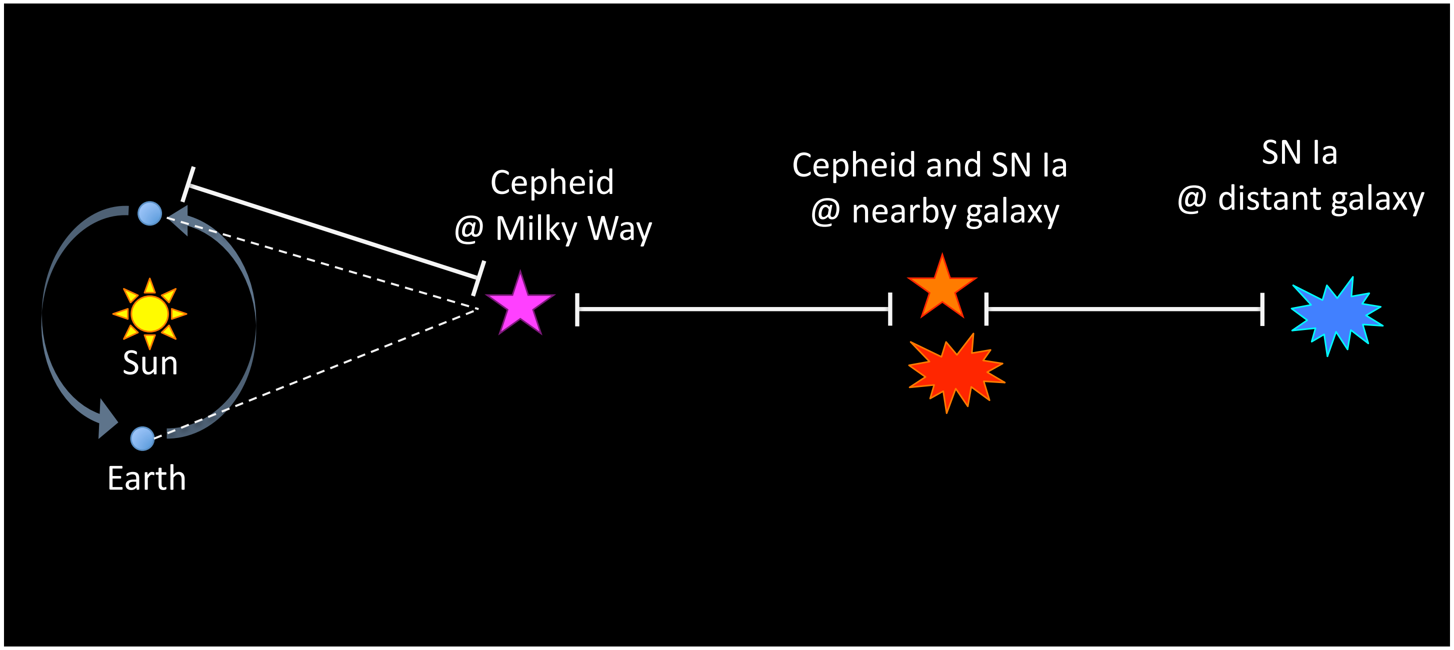
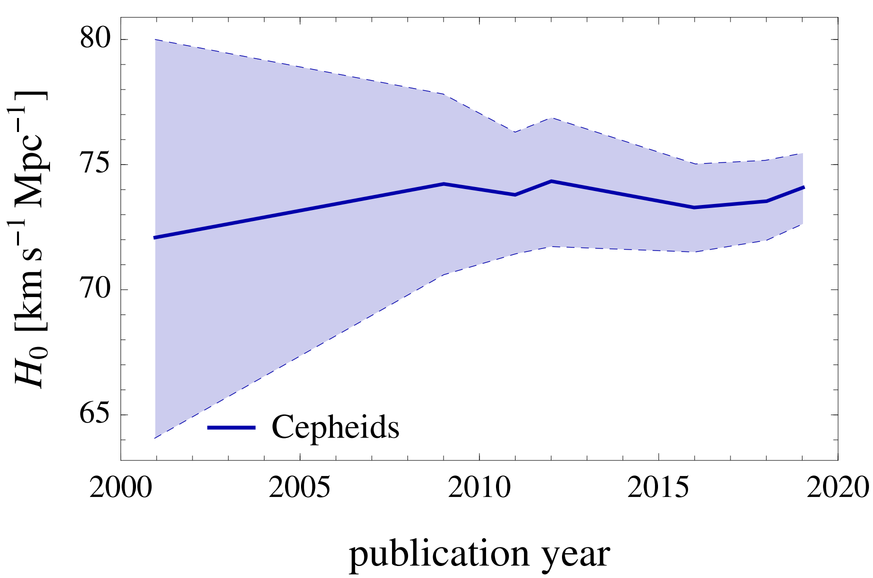
CUNY

THE STORYLINE





$$H_0 = 100\ h\ \mathrm{km\,s^{-1}\,Mpc^{-1}}$$

HST Astrophys. J. 553 (2001) 47

Riess + Astrophys. J. 699 (2009) 539

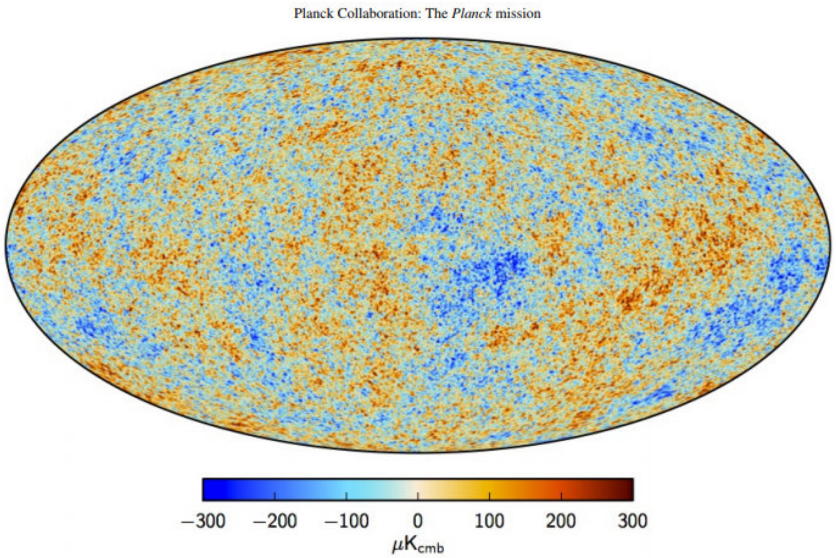
Riess + Astrophys. J. 730 (2011) 119

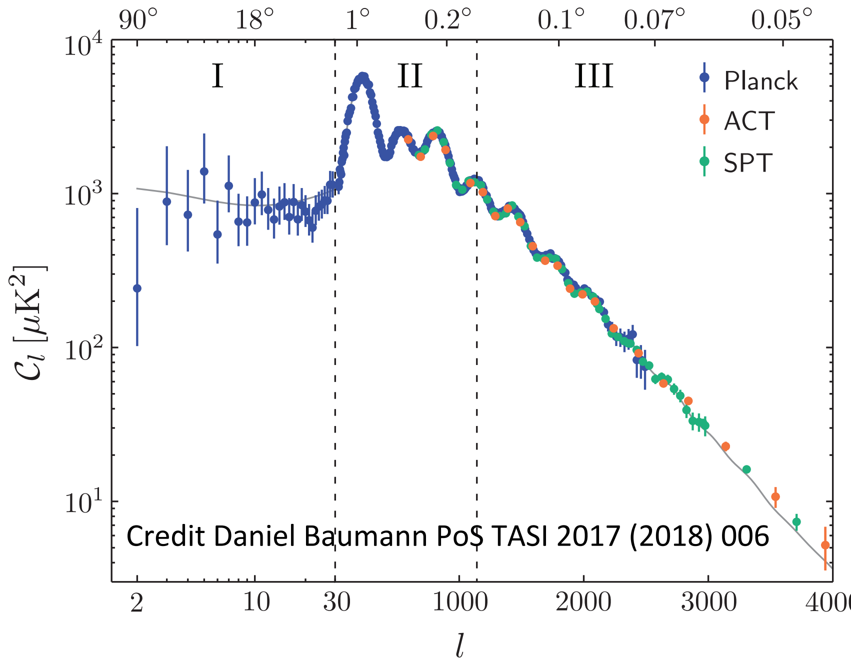
Freedman + Astrophys. J. 758 (2012) 24

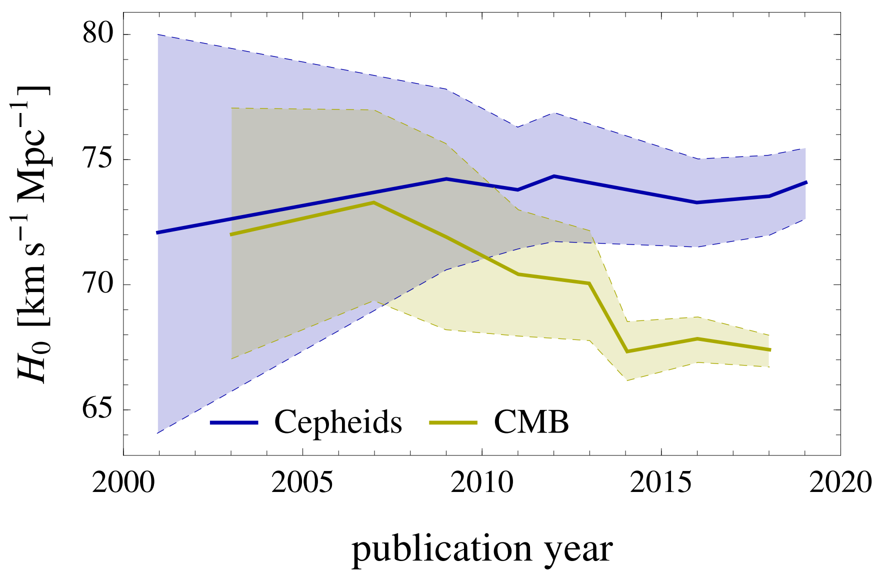
Riess + Astrophys. J. 826 (2016) 56

Riess + Astrophys. J. 861 (2018) 126

Riess + Astrophys. J. 876 (2019) 85







WMAP Astrophys. J. Suppl. 148 (2003) 175

WMAP Astrophys. J. Suppl. 170 (2007) 377

WMAP Astrophys. J. Suppl. 180 (2009) 330

WMAP Astrophys. J. Suppl. 192 (2011) 18

WMAP Astrophys. J. Suppl. 208 (2013) 19

Planck Astron. Astrophys. 571 (2014) A16

Planck Astron. Astrophys. 594 (2016) A13

DES Mon. Not. Roy. Astron. Soc. 480 (2018) 3879

Planck arXiv:1807.06209

$$H_0 = 74.03 \pm 1.42 \text{ km s}^{-1} \text{ Mpc}^{-1}$$

$$H_0 = 67.4 \pm 0.5 \text{ km s}^{-1} \text{ Mpc}^{-1}$$

$$H_0 = 69.8 \pm 1.9 \text{ km s}^{-1} \text{ Mpc}^{-1}$$

$$H_0 = 73^{+1.7}_{-1.8} \text{ km s}^{-1} \text{ Mpc}^{-1}$$

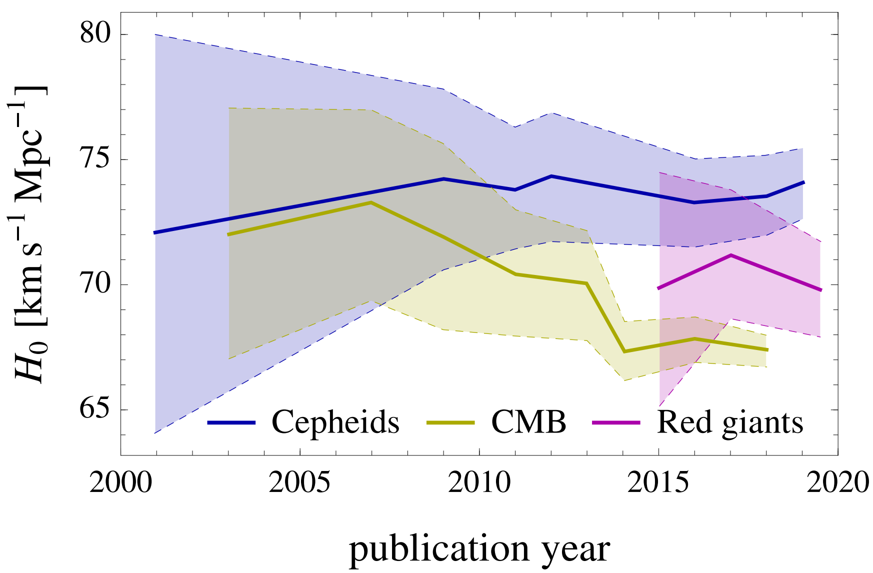
H0LiCOW arXiv:1907.04869

$$H_0 = 68^{+14}_{-7} \text{ km s}^{-1} \text{ Mpc}^{-1}$$

LIGO + Virgo arXiv:1908.06060

4.3σ discrepancy $\Rightarrow$ evidence for physics beyond ΛCDM

Verde, Treu, and Riess Nature Astron. 3 (2019) 891

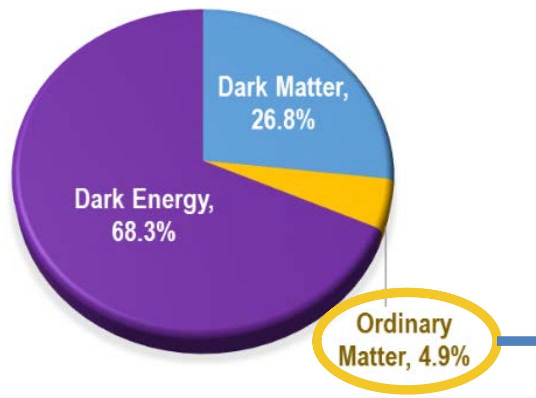


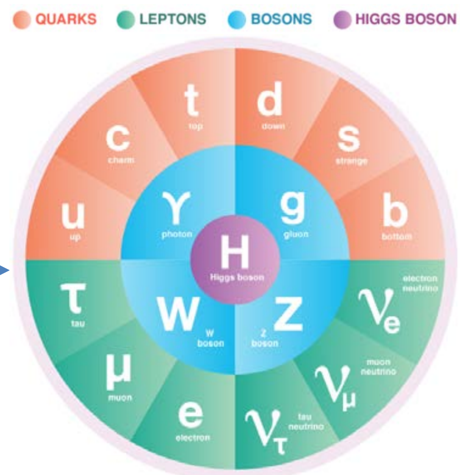
Jang and Lee Astrophys. J. 807 (2015) 133

Jang and Lee Astrophys. J. 836 (2017) 74

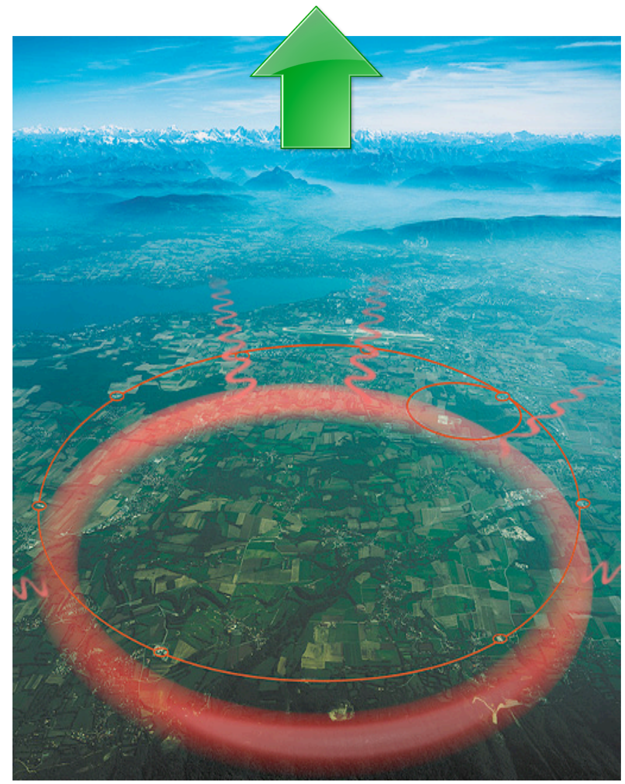
Freedman + arXiv:1907.05922

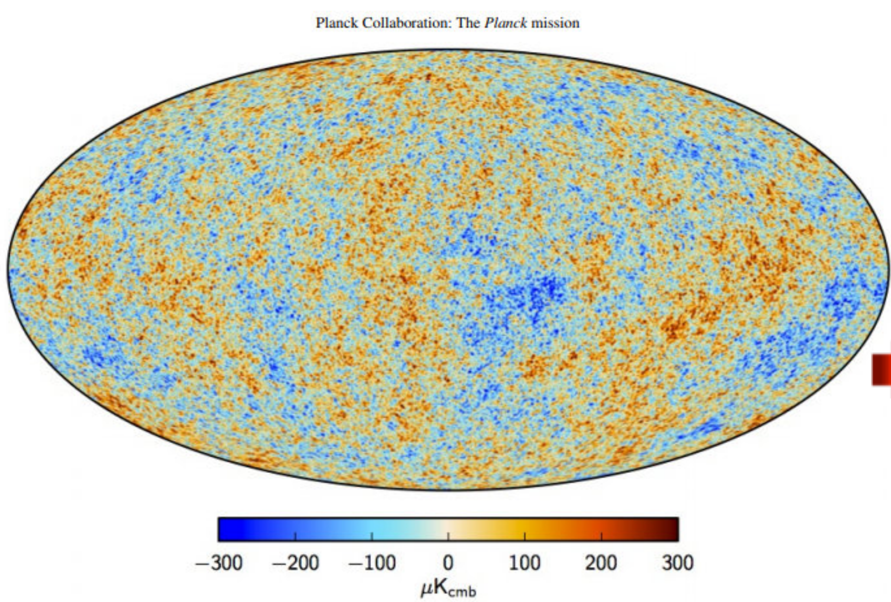
The Standard Model of Particle Physics





Heavy particles



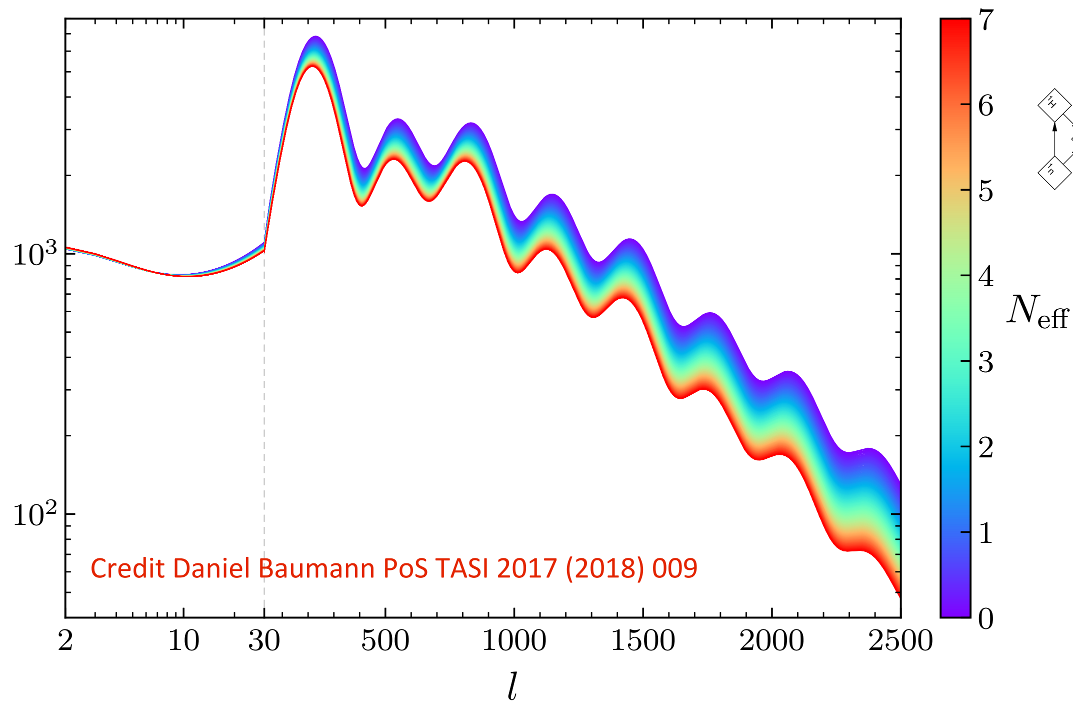


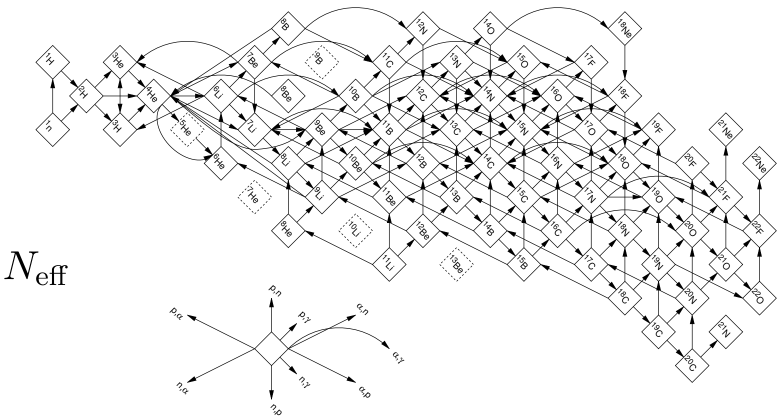
Light relics

THE HUNT FOR LIGHT RELICS

$$\Delta N_{\rm eff} \equiv N_{\rm eff} - N_{\rm eff}^{\rm SM} = g \left(\frac{10.75}{g_*(T_{\rm dec})}\right)^{4/3} \times \begin{cases} 4/7 & \text{boson} \\ 1/2 & \text{fermion} \end{cases}$$

$$N_{\rm eff}^{\rm SM} = 3.046$$



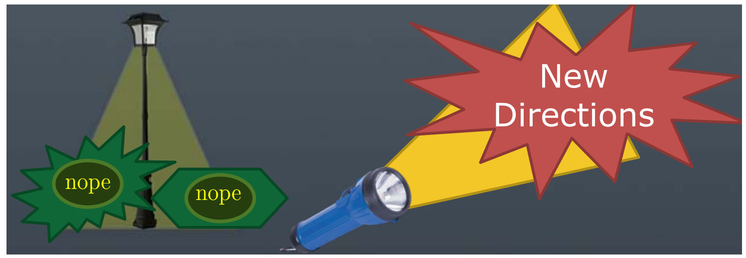


BBN

LIMITS @ TWO DETERMINATIONS OF HELIUM ABUNDANCE

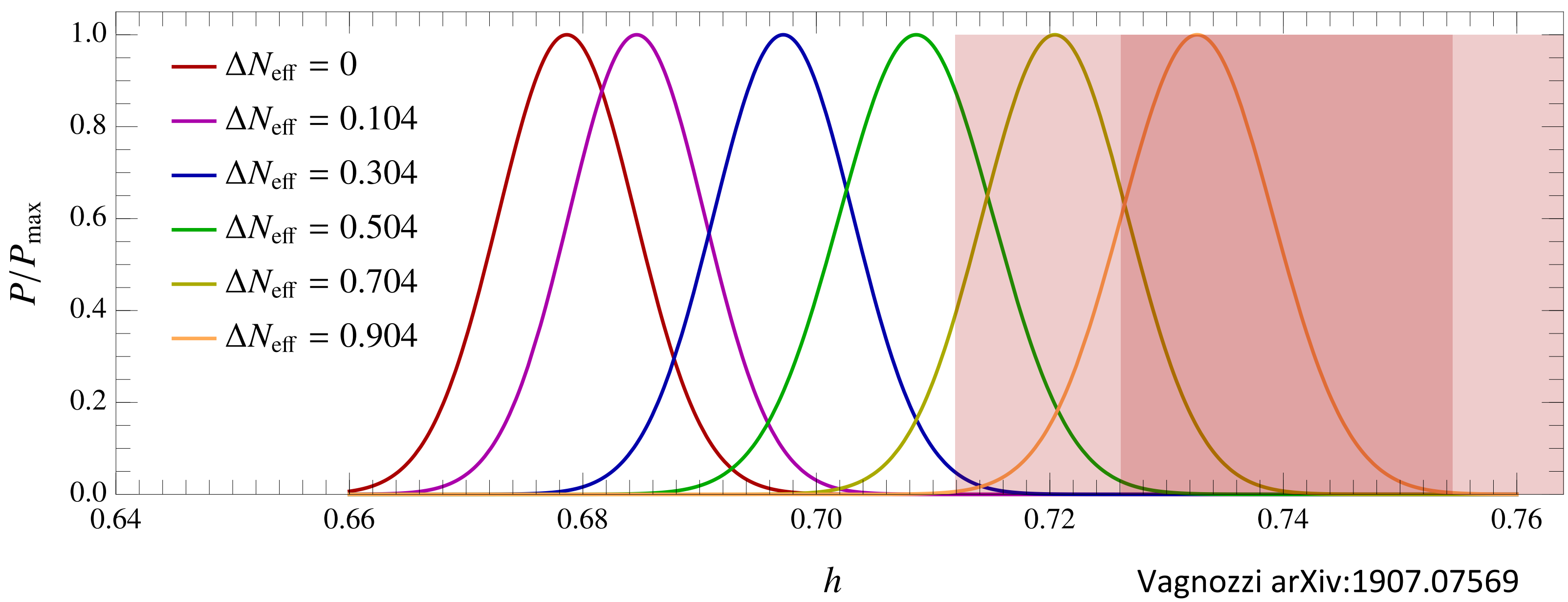
$\Delta N_{\rm eff} < 0.214 \ @\, 95\%\text{CL}$ $\Delta N_{\rm eff} < 0.544 \ @\, 95\%\text{CL}$

Planck arXiv:1807.06209



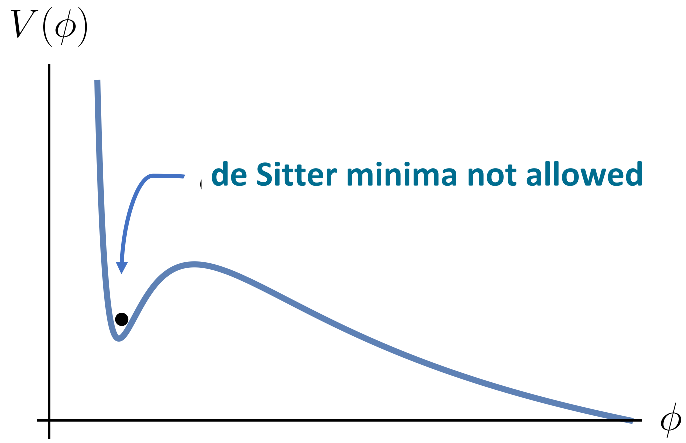
Severe constraints on beyond SM physics models

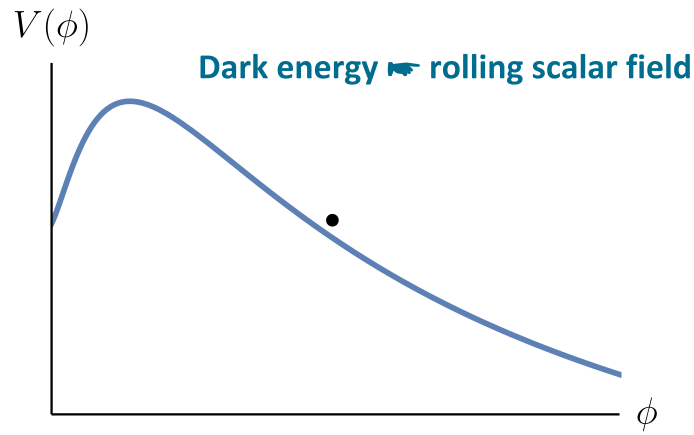
LAA-Perez Bergliaffa Phys.Rev. D 100 (2019) 123525



Vagnozzi arXiv:1907.07569

ECHOES OF VIBRATING STRINGS?

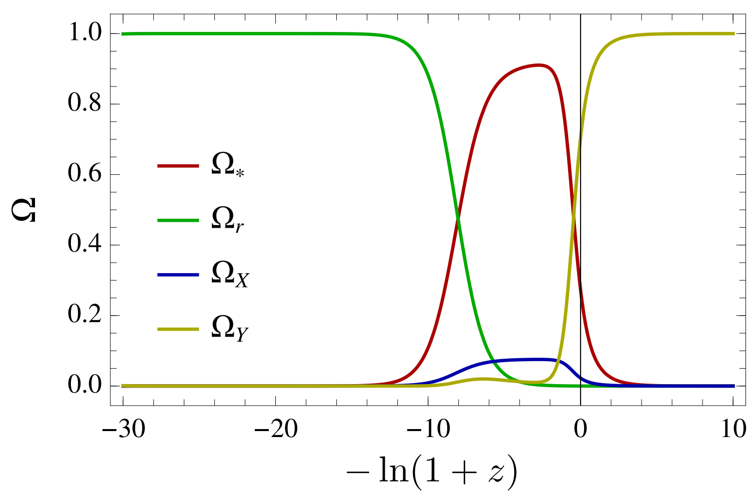


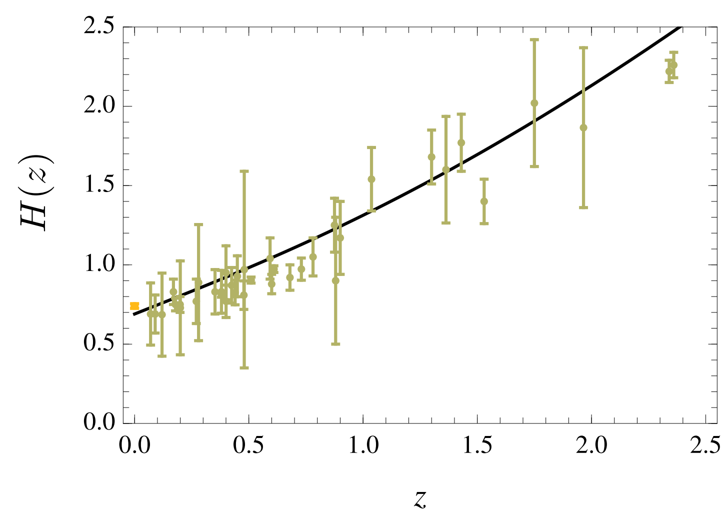


$m_{\rm DM} \propto \exp\{-\tilde{c}\,\phi\}$ ☛ $\tilde{c} \sim \mathcal{O}(1)$ **in Planck units**

Agrawal-Obied-Steinhard-Vaffa Phys. Lett. B 784 (2018) 271

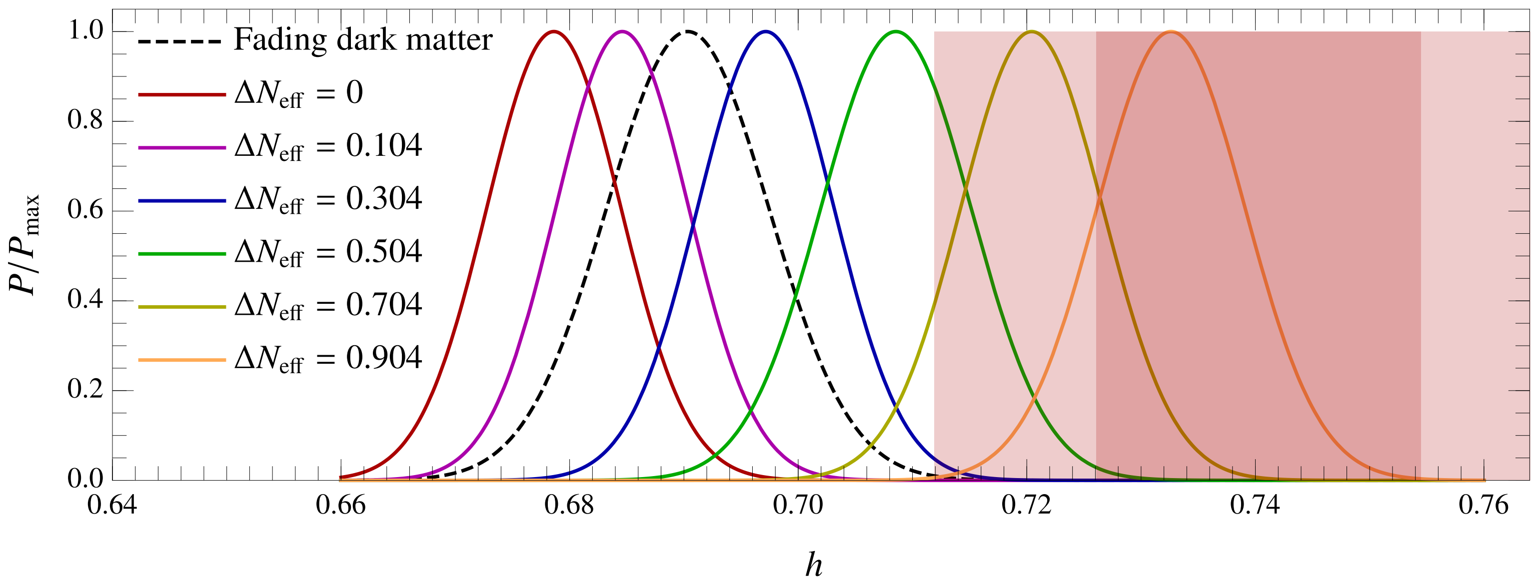
Agrawal-Obied-Vaffa arXiv:1906.08261

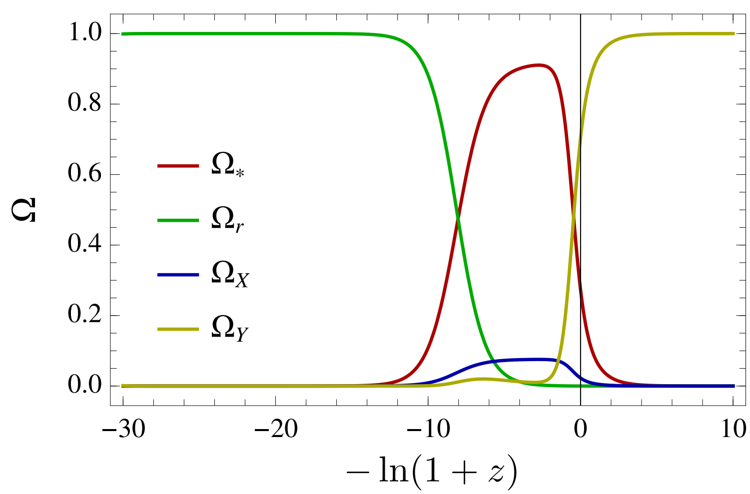


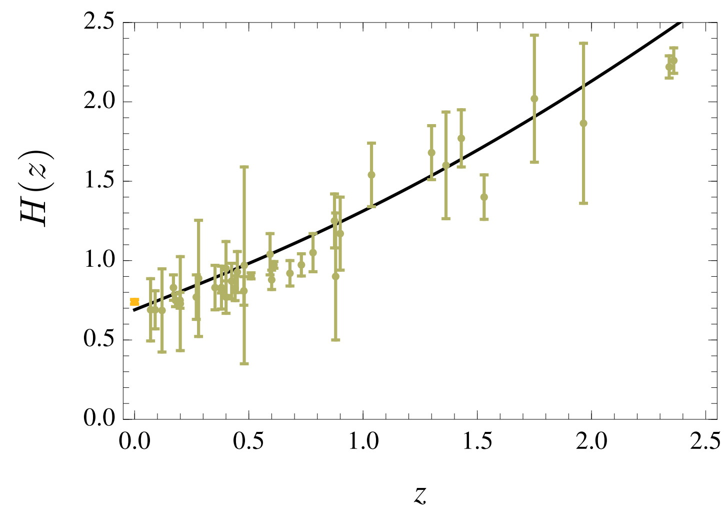


LAA-Antoniadis-Lüst-Soriano-Taylor Phys. Rev. D 101 (2020) 083532

ECHOES OF VIBRATING STRINGS?

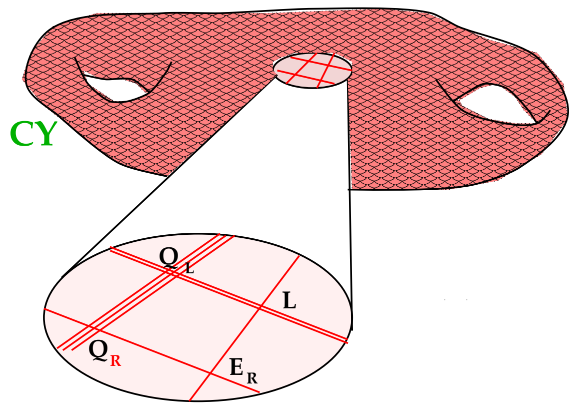


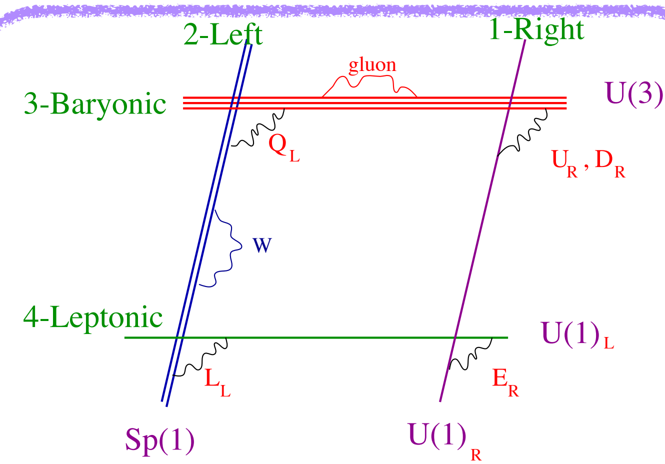




LAA-Antoniadis-Lüst-Soriano-Taylor Phys. Rev. D 101 (2020) 083532

THE DRAMATIS PERSONAE





lex	Fields	Sector	$SU(3)_C \times SU(2)_L$	$U(1)_B$	$U(1)_L$	$U(1)_{I_R}$	$U(1)_Y$	g'	g''
1	U_R	$3 \to 1^*$	$(3,1)$	$\frac{1}{3}$	0	$\frac{1}{2}$	$\frac{2}{3}$	0.368	-0.028
2	D_R	$3 \to 1$	$(3,1)$	$\frac{1}{3}$	0	$-\frac{1}{2}$	$-\frac{1}{3}$	0.368	-0.209
3	L_L	$4 \to 2$	$(1,2)$	0	1	0	$-\frac{1}{2}$	0.143	0.143
4	E_R	$4 \to 1$	$(1,1)$	0	1	$-\frac{1}{2}$	-1	0.142	0.262
5	Q_L	$3 \to 2$	$(3,2)$	$\frac{1}{3}$	0	0	$\frac{1}{6}$	0.368	-0.119
6	N_R	$4 \to 1^*$	$(1,1)$	0	1	$\frac{1}{2}$	0	0.143	0.443
-	H	$2 \to 1$	$(1,2)$	0	0	$\frac{1}{2}$	$\frac{1}{2}$	2.5×10^{-4}	0.090

Cremades-Ibañez-Marchesamo JHEP 0307 (2003) 038

LAA-Antoniadis-Lüst-Goldberg-Huang-Taylor Phys. Rev. D 85 (2012) 086003

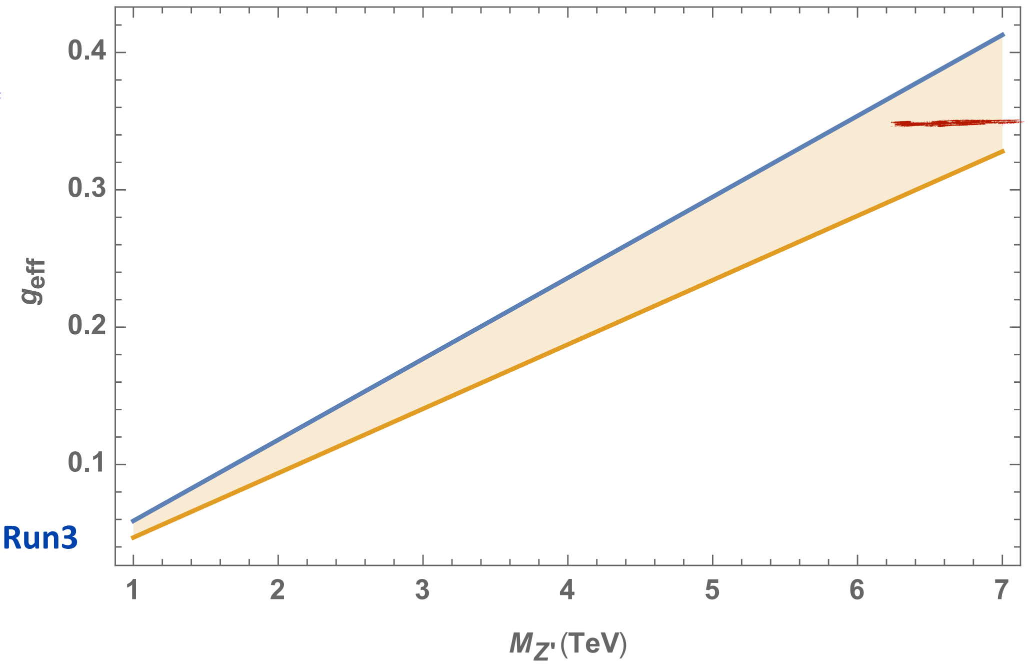
THE BEST OF ALL MODELS: U(1) FOR EVERYONE

ν_R decouples from plasma when its mean free path becomes greater than Hubble radius at that time

$$\Gamma(T_{\rm dec}) = H(T_{\rm dec})$$

ν_R interaction rate **Hubble expansion rate**

$$\frac{g_{\rm eff}}{M_{Z'}} = \left(\frac{3}{\Delta N_{\rm eff}}\right)^{3/32} \left(\frac{17.41}{M_{\rm Pl}\, T^3_{\rm dec}}\right)^{1/4}$$



Model is fully predictive
and can be confronted with future data from LHC Run3

LAA-Goldberg Phys. Rev. Lett. 108 (2012) 081805

LAA-Antoniadis-Lüst-Goldberg-Huang-Taylor-Vlcek Phys. Rev. D 86 (2012) 066004

LAA-Goldberg-Steigman Phys. Lett. B 718 (2013) 1162

Take Home Message

- Solving the Hubble (ΛCDM) tension is very much an ongoing enterprise.
- The resolution of this conundrum will likely require a coordinated effort from the side of theory, interpretation, data analysis, and observation: CMBPol is expected to reach a 2σ precision of $\Delta N_{\rm eff} = 0.09$ and CMB-S4 is expected to reach a 2σ precision of $\Delta N_{\rm eff} = 0.06$.
- If the past is any guidepost to the future we can expect surprising results connecting string theory to data.


That's all Folks!