Mirror Twin Higgs Cosmology

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12,31,2023

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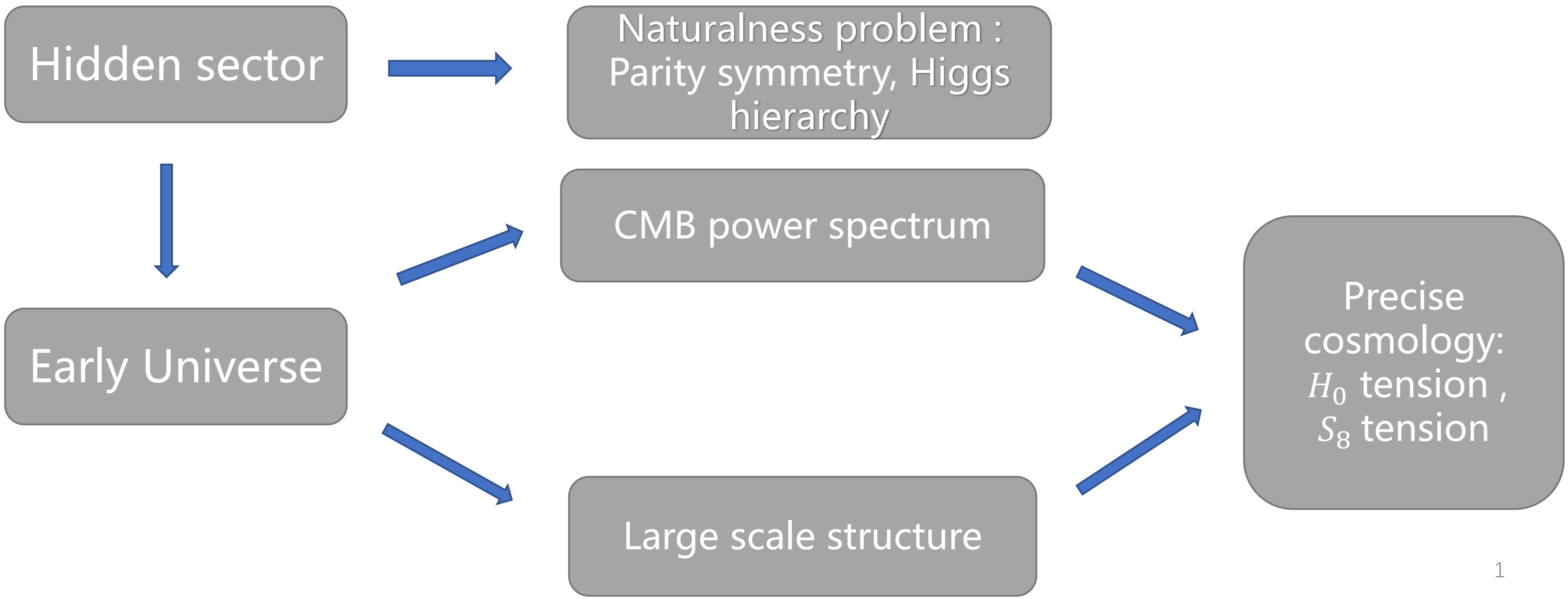
arXiv: 2304.06308

Story we will talk today :



Hidden sector

Dark matter evidences: cosmology, galaxy rotation curve, velocity dispersion and so on.

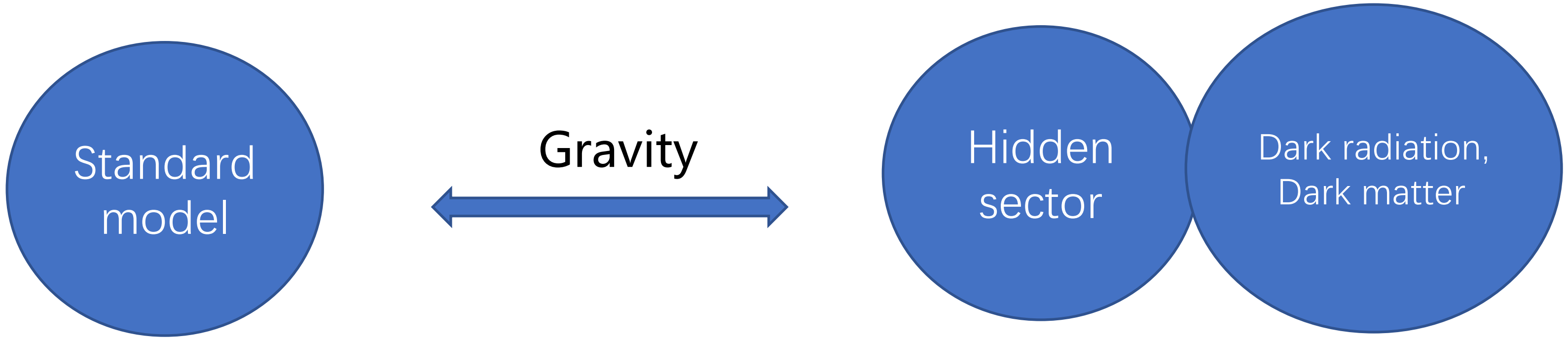
Standard model:
Lepton, quark, neutrino …
U(1),SU(2),SU(3)

How about hidden sector?
Hidden particles,
Hidden interaction?

Hidden sector

The interaction between two sectors is strongly constrained.
But how about the interaction within hidden sector?

One way to explore this interaction: cosmology



Mirror twin higgs

Parity symmetry: mirror sector will help to restore the symmetry

PHYSICAL REVIEW VOLUME 104, NUMBER 1 OCTOBER 1, 1956

Question of Parity Conservation in Weak Interactions*

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AND

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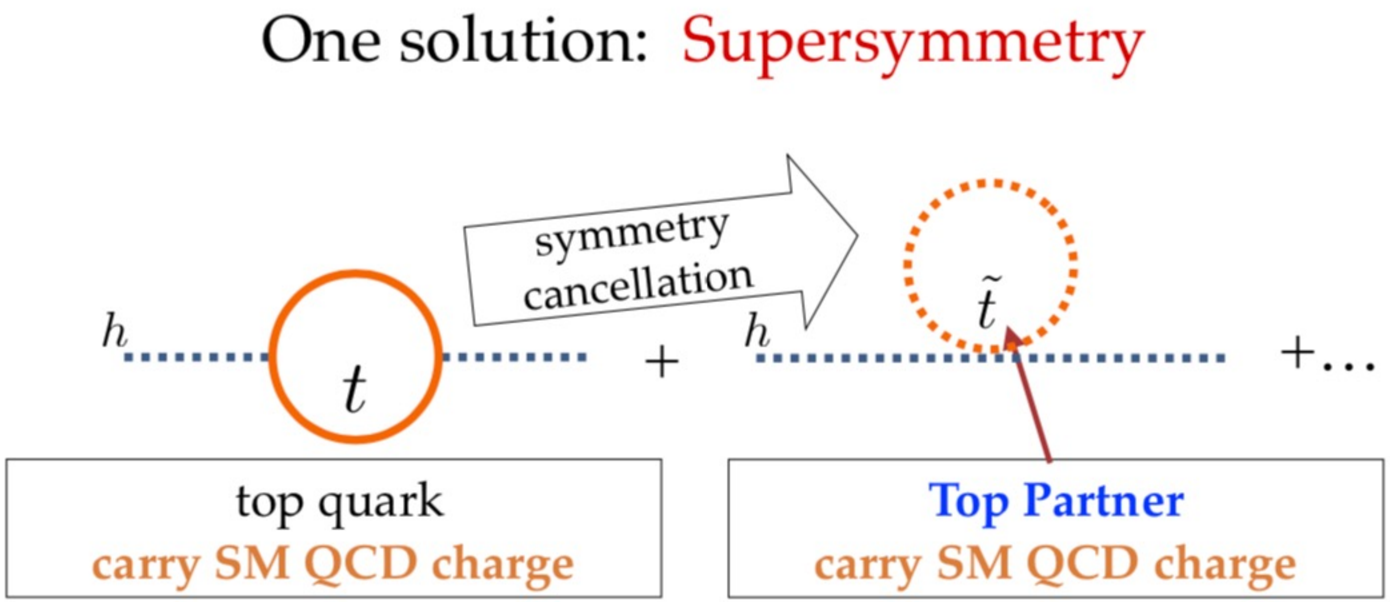
(Received June 22, 1956)

The question of parity conservation in β decays and in hyperon and meson decays is examined. Possible experiments are suggested which might test parity conservation in these interactions.

Mirror twin higgs

higgs hierarchy problem: why the weak force is 10^{24}times as strong as gravity ?

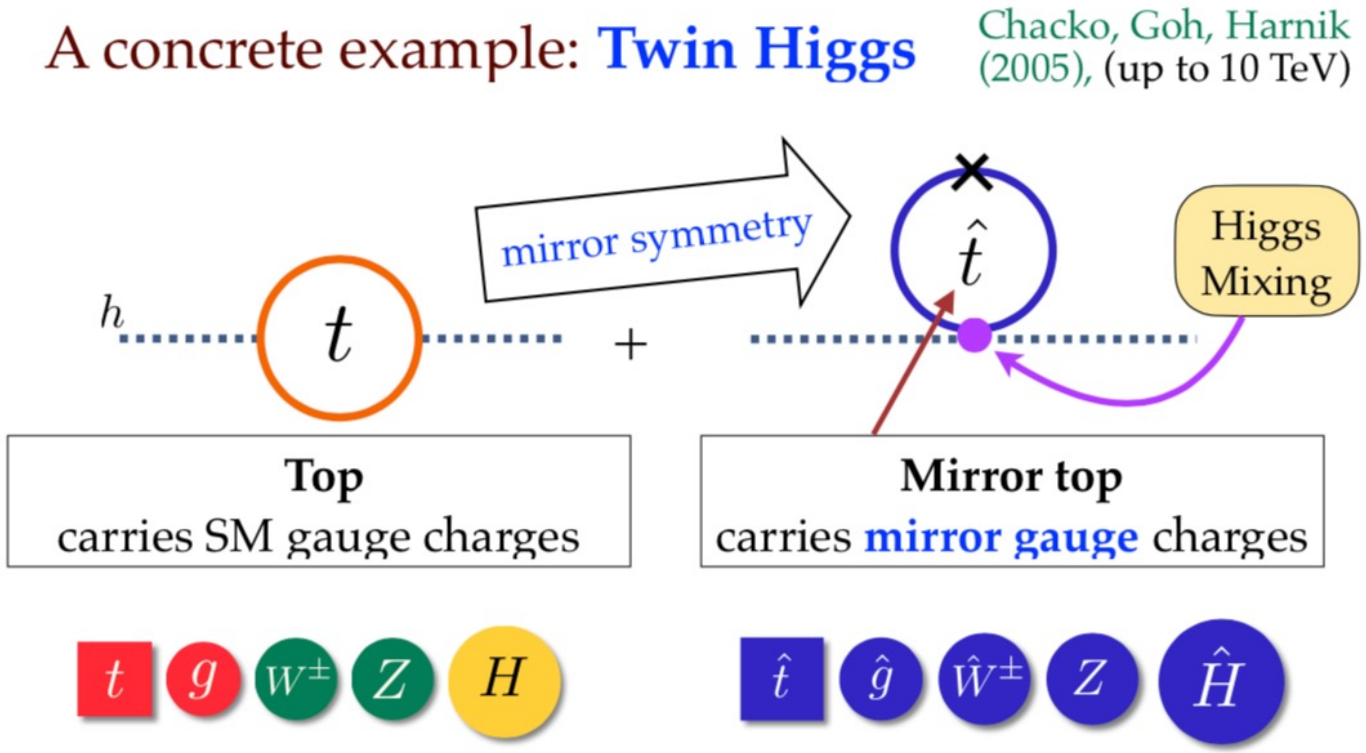
i.e. why higgs mass is so small compared to m_{pl} ?



The hope for supersymmetry cancelling is fading since the LHC bounds are too strong ......

Mirror twin higgs

Alternative method: cancelling partner through higgs mixing



Avoid collider constraints compared to supersymmetry

Mirror twin higgs

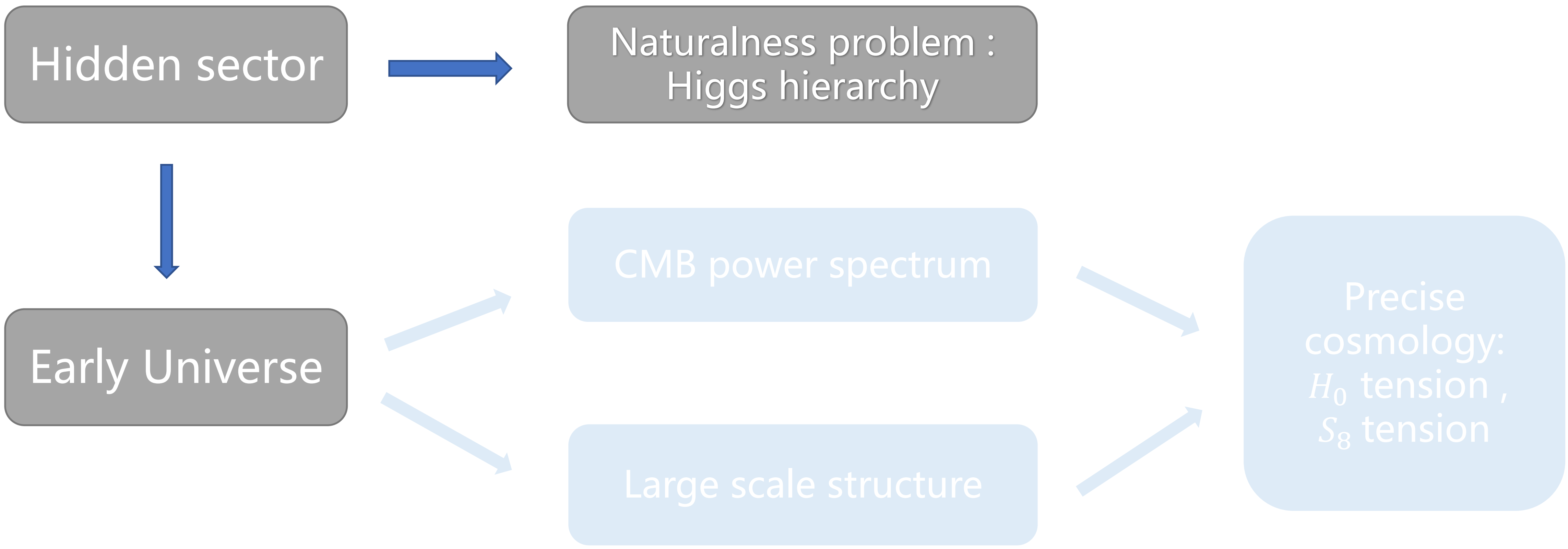
Just like supersymmetry, each particle in standard model has an exact counterpart in mirror sector

Standard model :
Lepton, quark,
neutrino ···
U(1),SUL(2),SU(3)

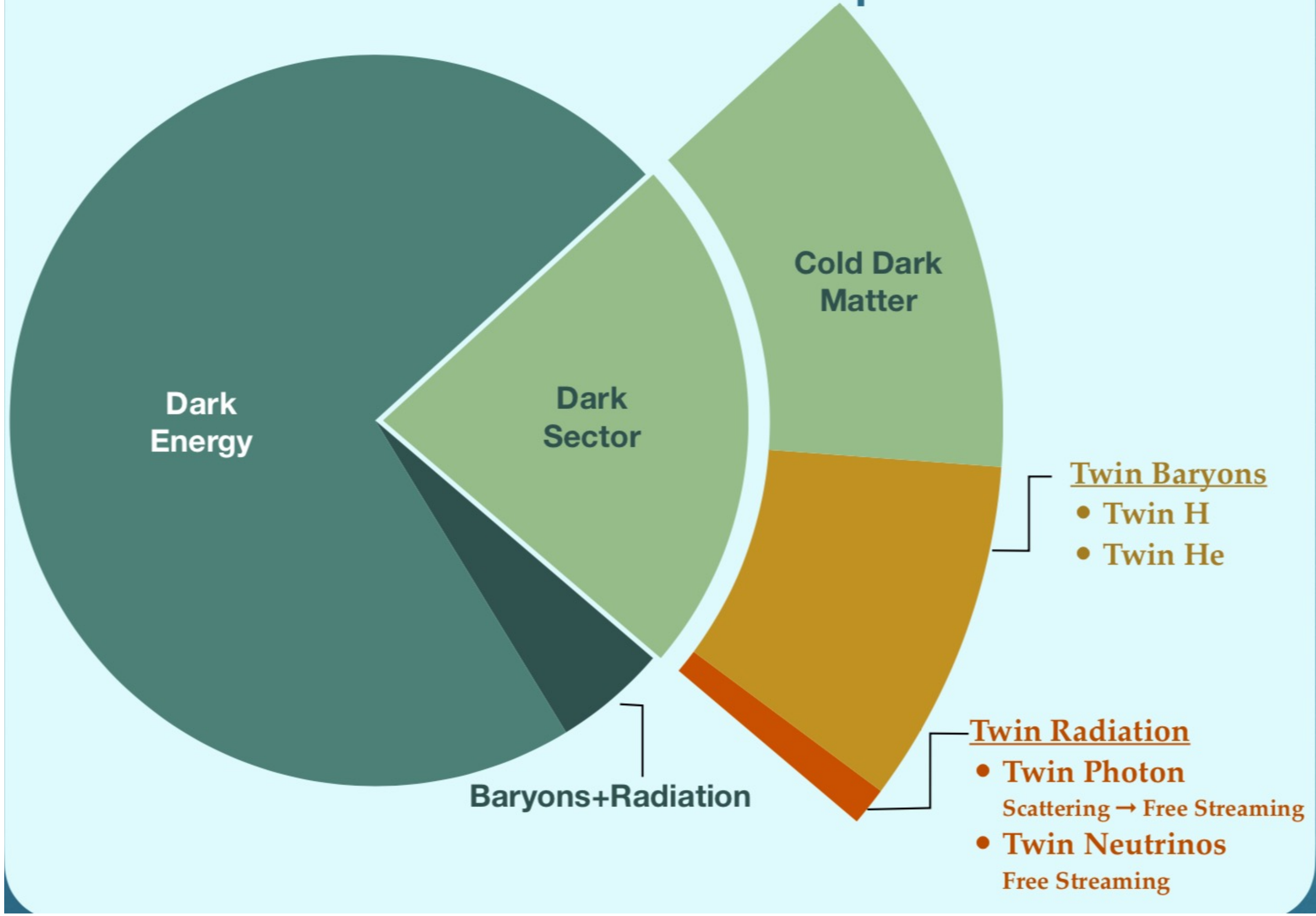
Gravity
↔
Higgs mixing

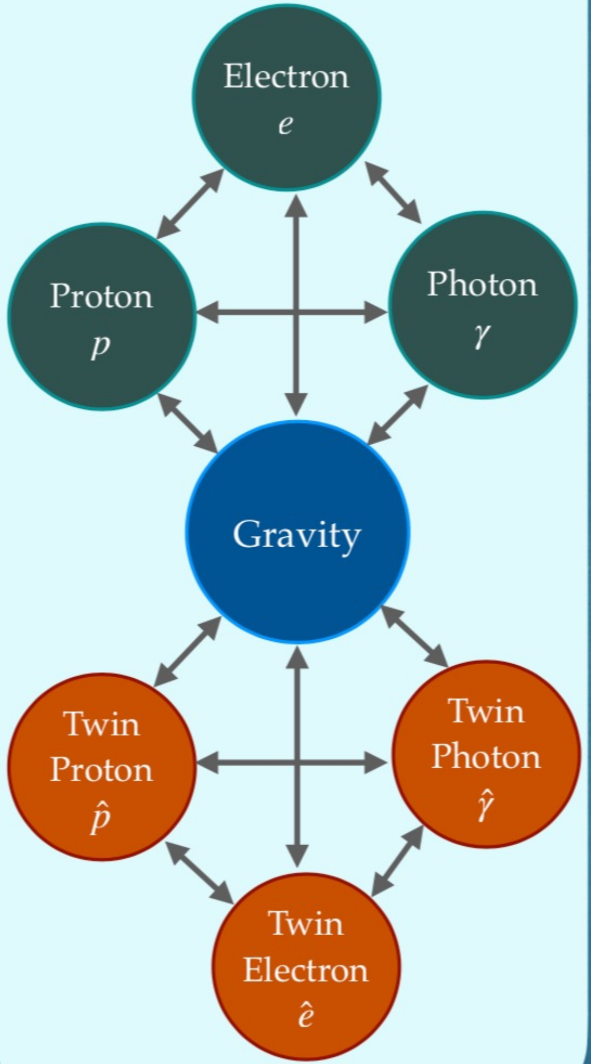
mirror sector:
Mirror lepton, mirror quark,
mirror neutrino ···
U(1),SUR(2),SU(3)

Explore mirror sector with cosmology



The Universe with MTH particles





MTH cosmology

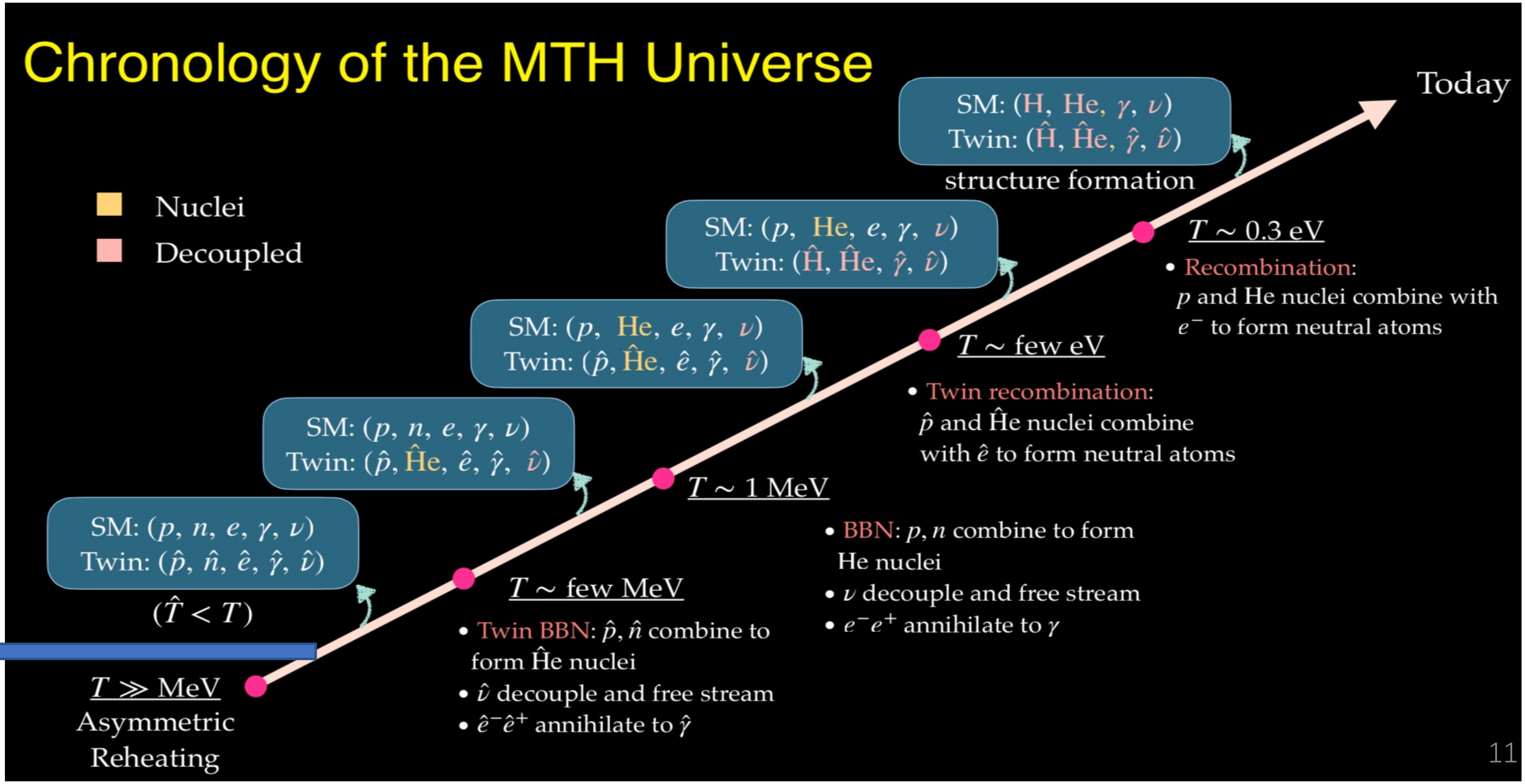
3 extra parameters:

- $\hat{r} = \frac{\Omega_{mb}}{\Omega_{cdm}}$: Amount of twin baryons compared to the DM density
- ΔN_{eff} : Twin radiation energy , effective neutrino numbers
- $\hat{v}/v$: Ratio of the twin and SM electroweak symmetry breaking

ΔN_{eff} depend on the temperature of twin recombination and ΔN_{eff} , $\hat{v}/v$ determines the time of the twin recombination.

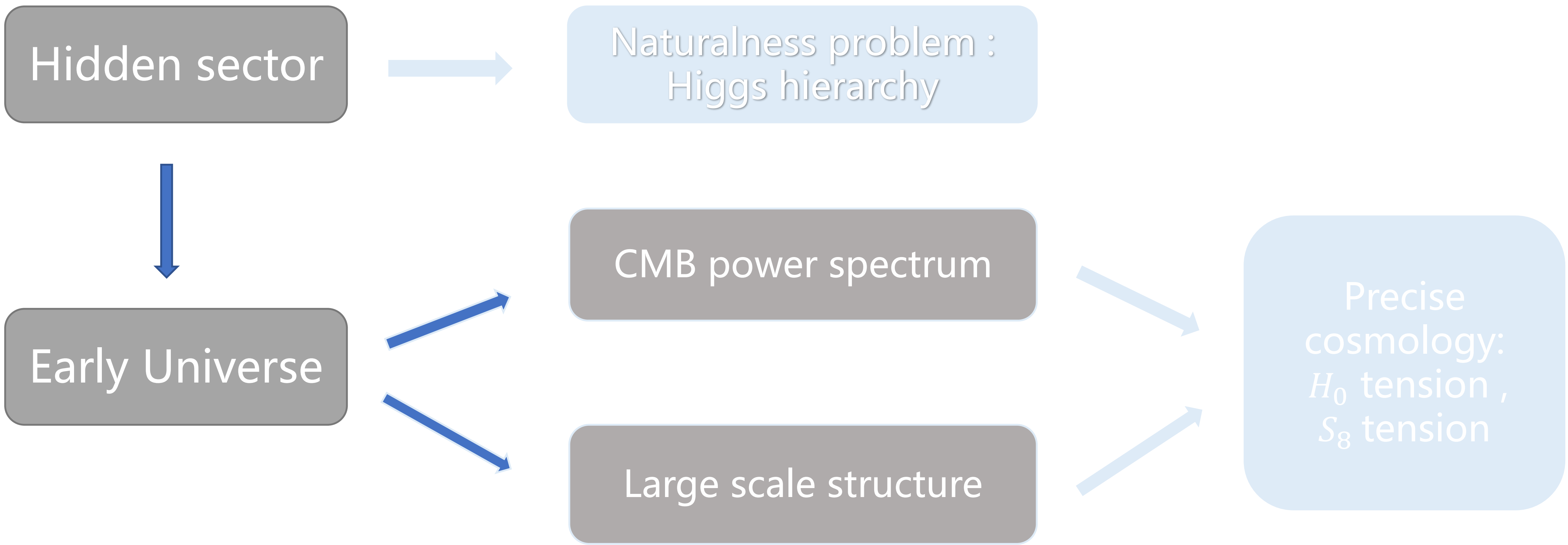
MTH cosmology

One possible method to explain the different temperature between two sectors : asymmetric post-inflationary reheating .



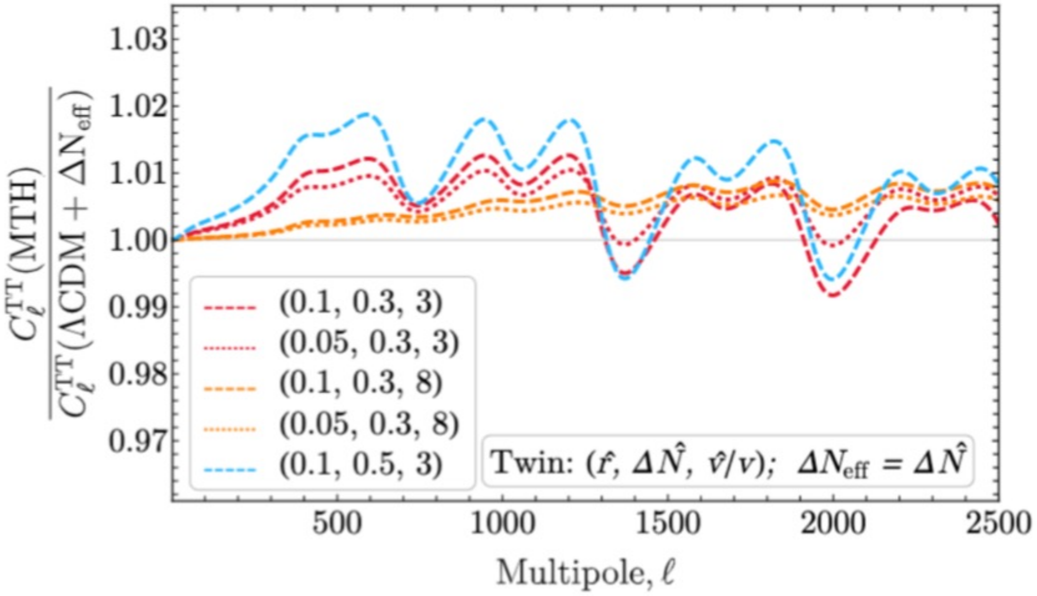
Twin QCD phase transition ~ few 100 MeV

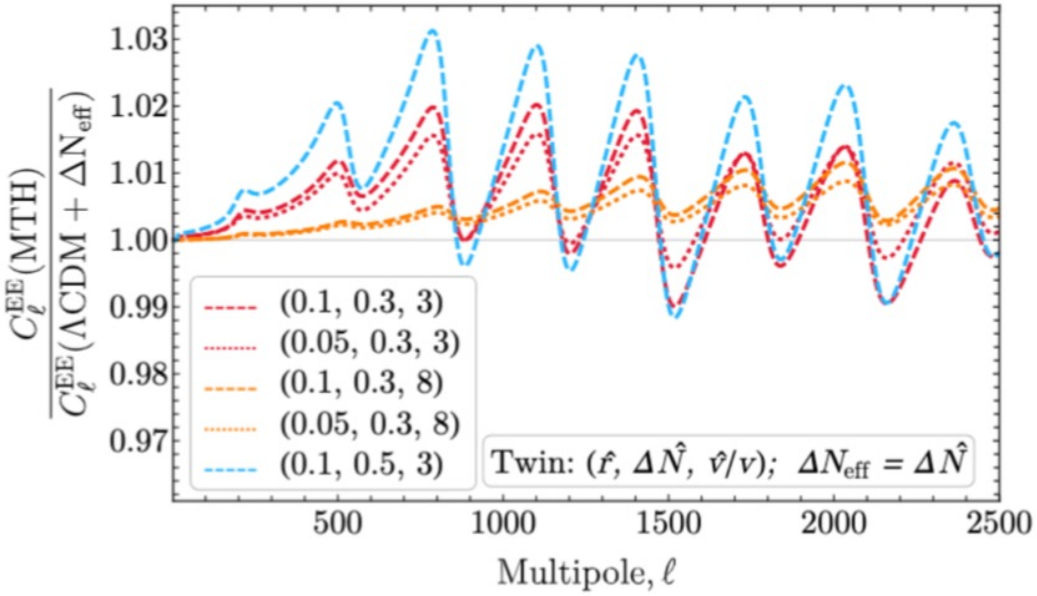
Cosmology signals



CMB power spectrum

Twin BAOs suppress the gravity perturbation and generate different phase.





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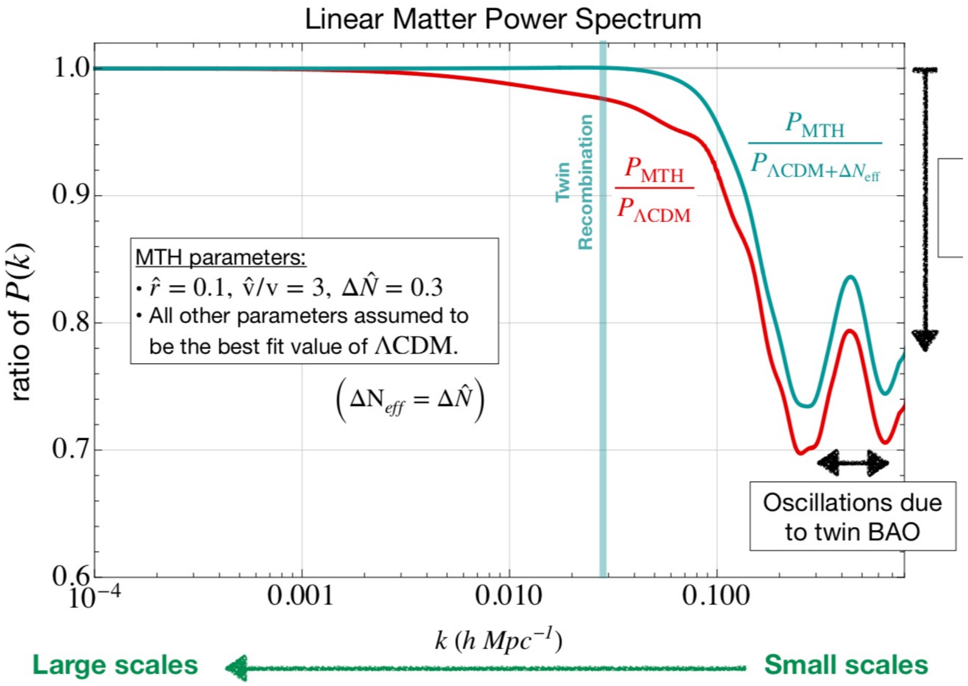
Large scale structure

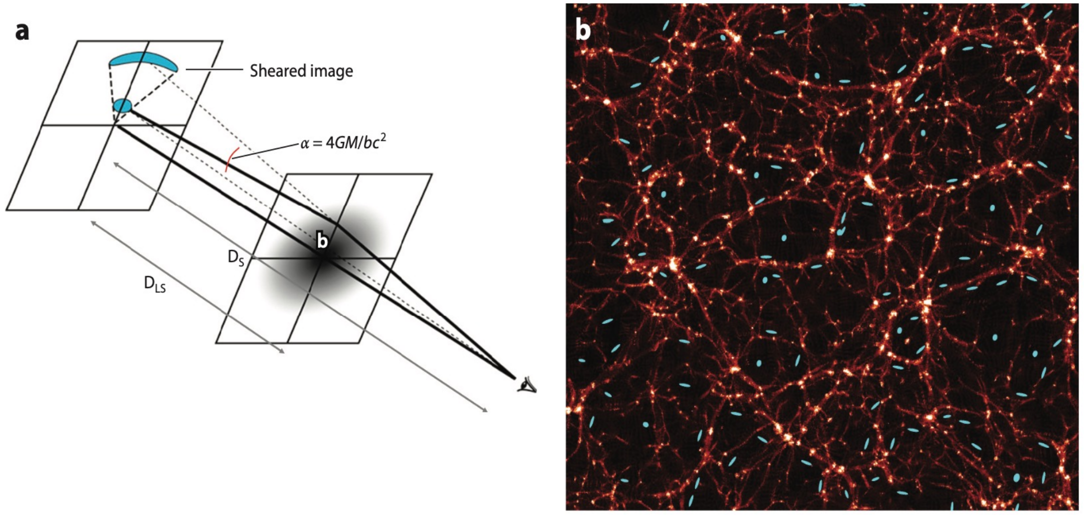
Compared to ΛCDM: Oscillations and suppression due to twin BAO, additional radiation for delay of a_{eq} and ISW effects.



The diversity between MTH cosmology and ΛCDM is mainly at models that enter horizon before twin recombination , i.e. nonlinear scale for the parameter range of the interest. (k > 0.1 h/Mpc)

How to test this scale?

To probe the matter power spectrum P(k) at k > 0.1 h/Mpc (and k < 10 h/Mpc to avoid the baryonic effects): weak lensing survey



- Correspond to three set of correlation, respectively:
- position-position within foreground lens galaxies;
- position- shape of foreground lens galaxies with background source;
- shape-shape of background source due to LSS.

Cosmic gravitational lensing!

Cosmic shear

Two components for a galaxy : $\gamma = \gamma_1 + i\gamma_2$. $\xi_+ \equiv \langle \gamma\gamma^* \rangle$ $\xi_- \equiv \langle \gamma\gamma \rangle$

$$\xi_\pm^{ij}(\theta) = \langle \hat{\epsilon}_t \hat{\epsilon}_t \pm \hat{\epsilon}_\times \hat{\epsilon}_\times \rangle (\theta)$$

(i) Insensitive to galaxy bias, trace the matter directly;

(ii) Sensitive to detect the growth of structure and redshift evolution, constrain cosmological parameters S_8;

(iii) Well describe the geometry of the universe through the lensing kernel.

Nonlinear correction

Nonlinear gravity effects on the scale k > 1h/Mpc , when perturbation theory fails.

ΛCDM : HMcode and Halofit (analytic method based on the simulation)

How about MTH cosmology? If we use the HMcode and Halofit to do the nonlinear correct, how much errors we will get?

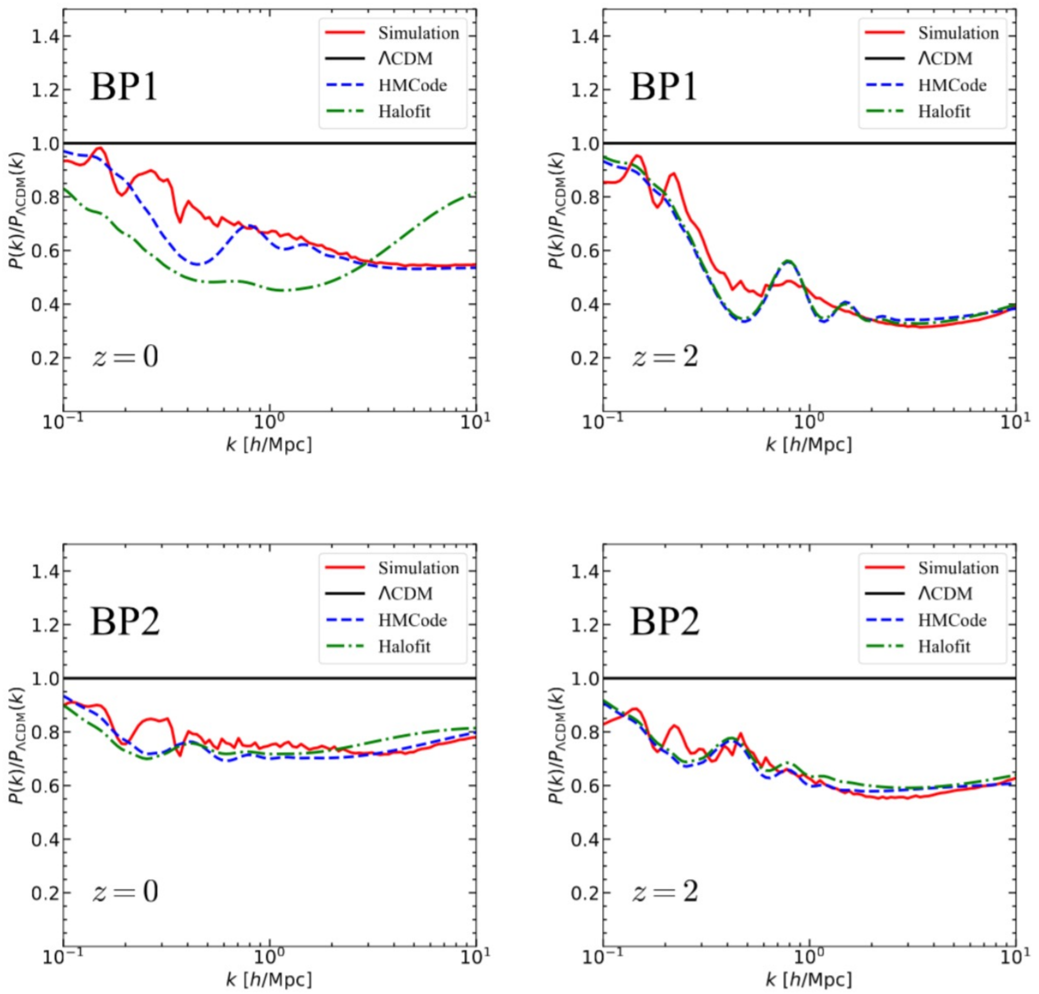
simulation

Gravity-only simulation with P-Gadget3

$N_0 = 512^3$ particles in a periodic box of volume $(200Mpc/h)^3$, The mass of a simulation particle is $4.733 \times 10^9 M_\odot/h$

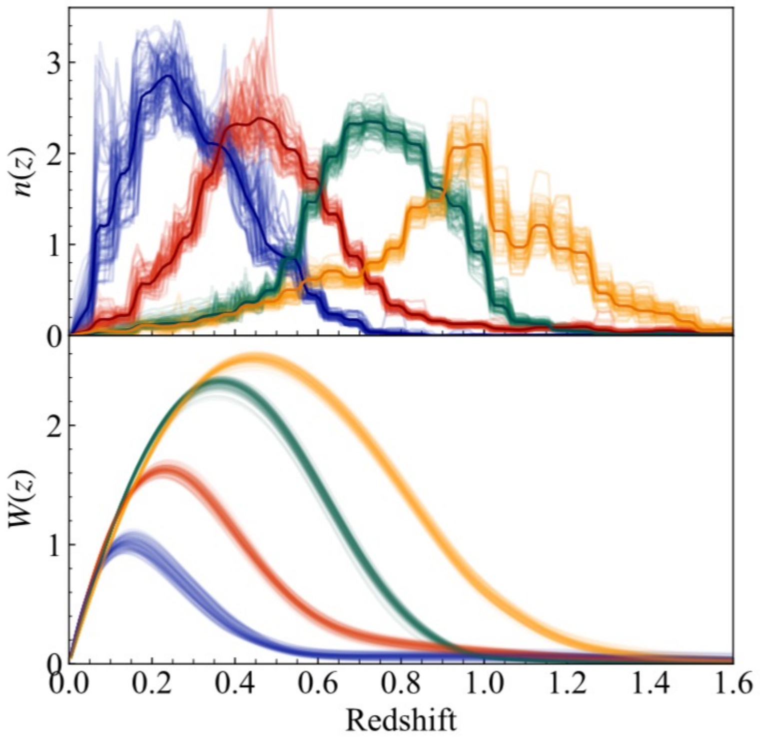
$$\mathbf{BP1}: \{\Omega_m = 0.2936,\ \Omega_\Lambda = 0.7064,\ h = 0.7084,\ n_s = 0.9727,\ \sigma_8 = 0.7599\},$$

$$\mathbf{BP2}: \{\Omega_m = 0.3254,\ \Omega_\Lambda = 0.6746,\ h = 0.6756,\ n_s = 0.9727,\ \sigma_8 = 0.7648\}.$$

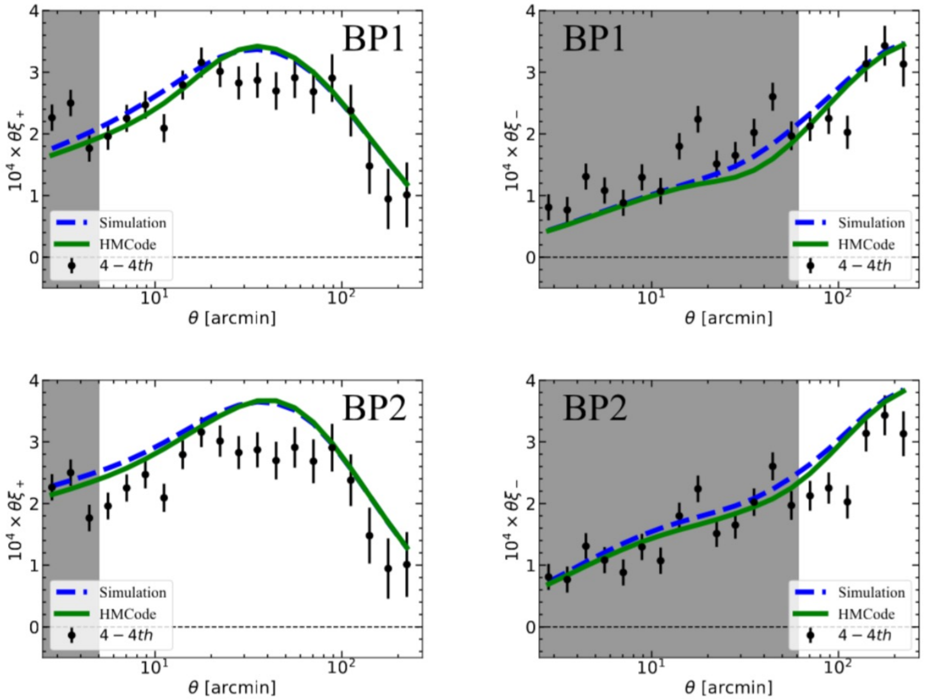


Cosmic shear

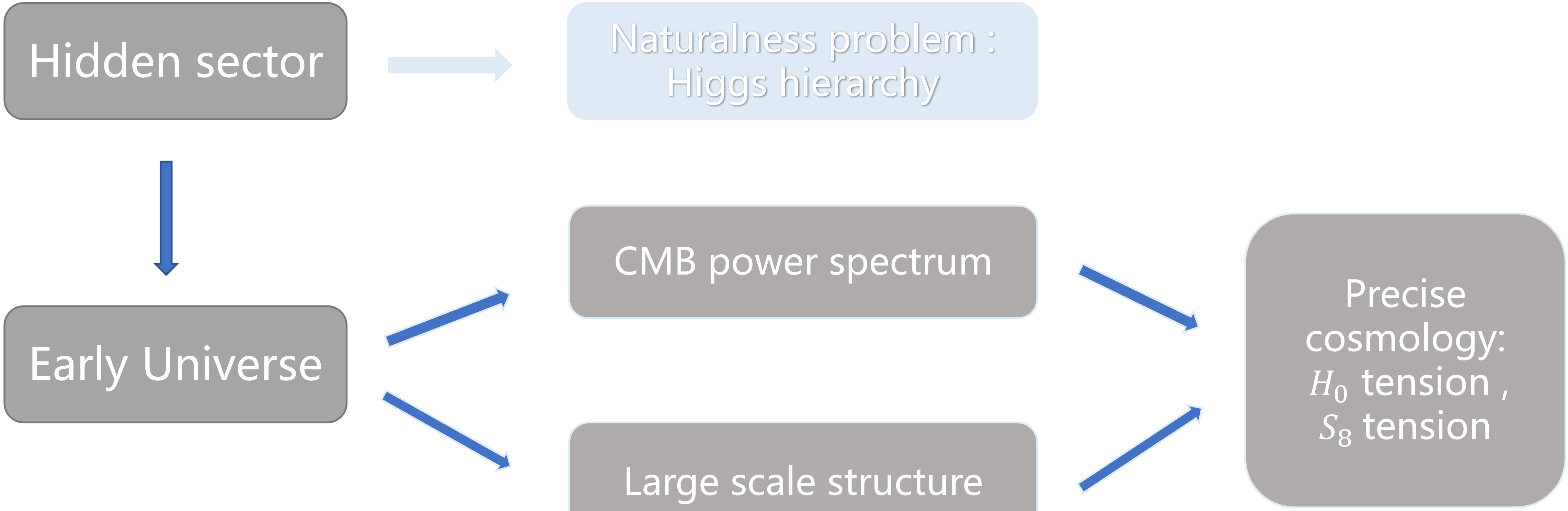
4 redshift bins :



Deviation mainly on small scale, and the $\Delta\chi^2/\mathrm{d.o.f} \sim 0.1$
$\hat{r} \sim 0.25 \rightarrow 0.21$ for BP1 and $0.1 \rightarrow 0.065$ for BP2
We use HMcode for nonlinear correction in our MCMC scan



Precise Cosmology

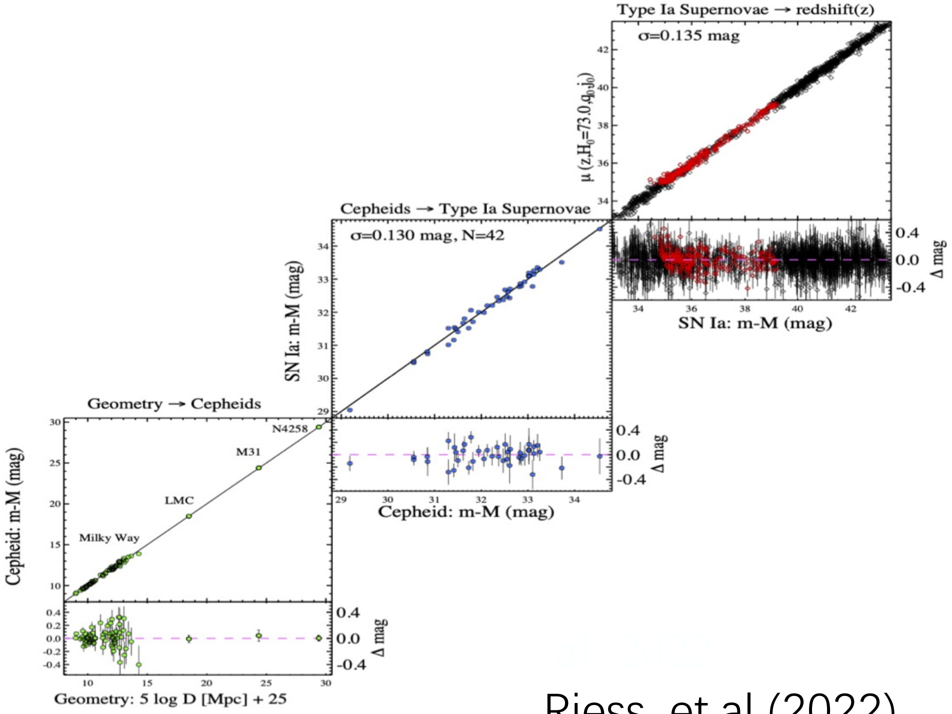


Precise cosmology beyond ΛCDM

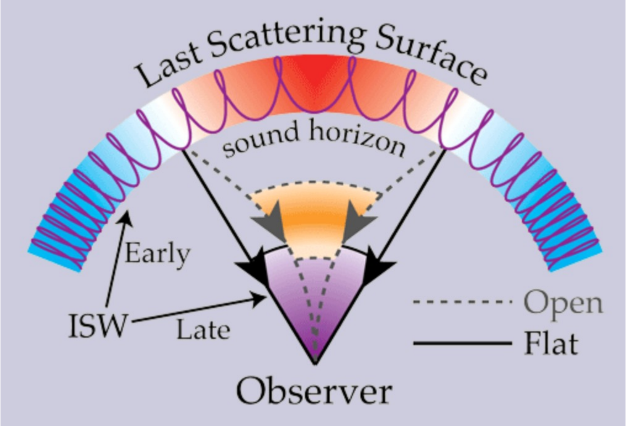
H_0 measurement: *~ 4.8 σ tension*

Direct : $H_0 = 73.04 \pm 1.04\ \mathrm{km\ s^{-1}\ Mpc^{-1}}$

Indirect : $H_0 = 67.4 \pm 0.5\ \mathrm{km\ s^{-1}\ Mpc^{-1}}$



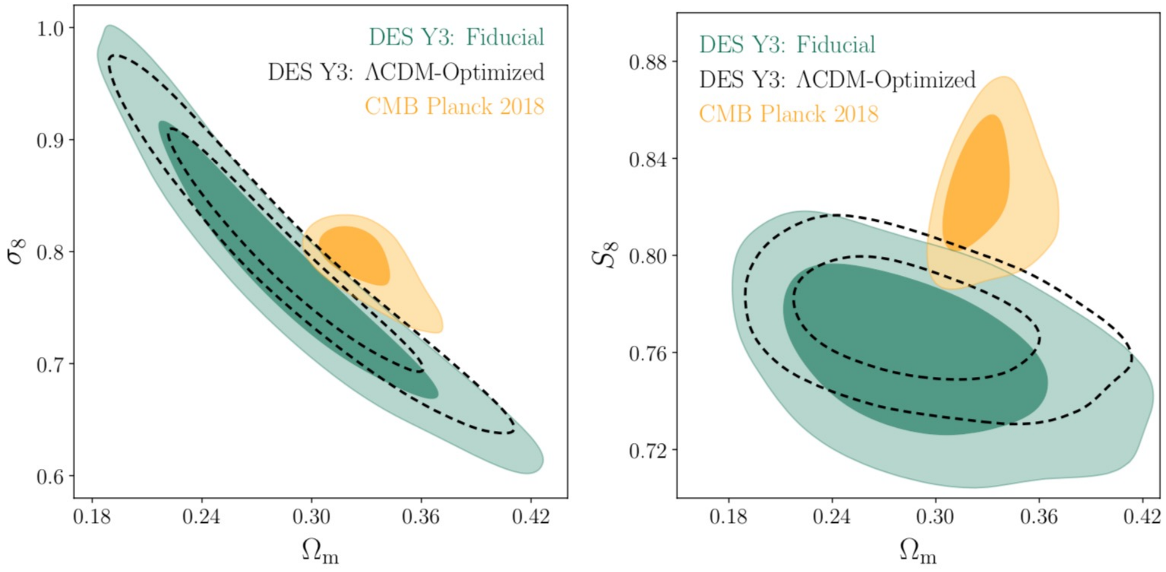
Riess .et.al (2022)



$$\theta_s = \frac{r_s(z^\star)}{D_A(z^\star)},$$

S_8 *tension*

Amplitude of the matter perturbation within 8Mpc size of the structure



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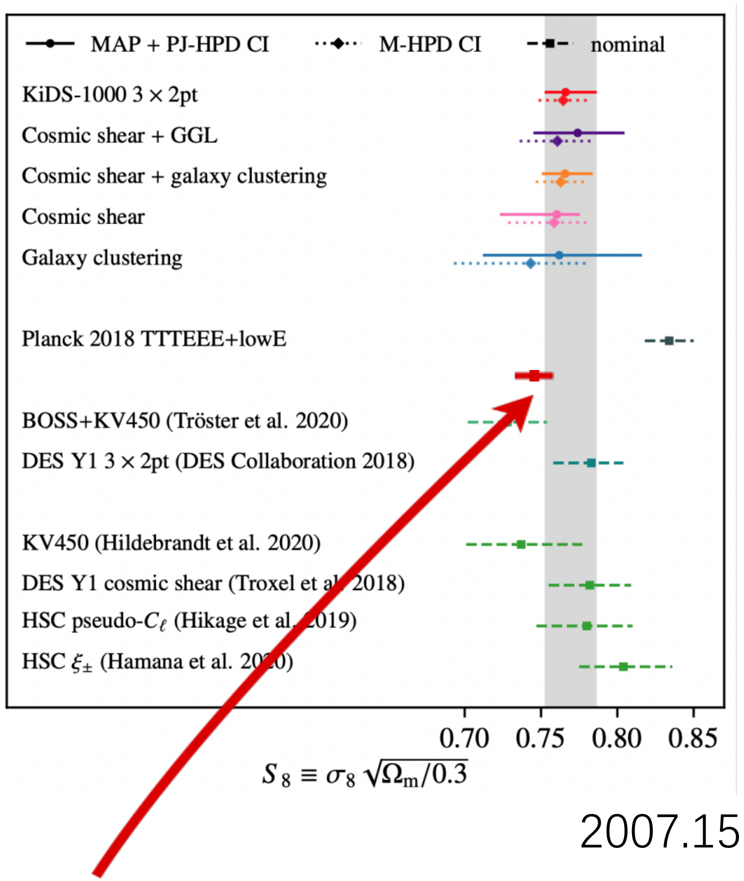


2007.15632

$$\text{Planck 2013 SZ}: S_8^{SZ} \equiv \sigma_8 \left(\Omega_m/0.27\right)^{0.3} = 0.782 \pm 0.010$$

The tension is about 2-3 σ . The significance may grow if the systematic uncertainty gets improved in the future

Models that solve the H_0 tension usually worse the S_8 tension

Additional fluid or free-streaming radiation (2003.28382):

	ΛCDM	$N_{\rm eff}$	$N_{\rm eff}=3.046,\ N_{\rm fld}$	$N_{\rm tot},\ f_{\rm fs}$
$100\theta_s$	$1.042^{+0.00029}_{-0.00028}$	$1.0414^{+0.00043}_{-0.00049}$	$1.0423^{+0.0003}_{-0.00032}$	$1.0427^{+0.00074}_{-0.00088}$
$100\Omega_b h^2$	$2.249^{+0.013}_{-0.015}$	$2.265^{+0.017}_{-0.016}$	$2.275^{+0.016}_{-0.018}$	$2.275^{+0.018}_{-0.017}$
$\Omega_c h^2$	$0.11861^{+0.00093}_{-0.00092}$	$0.1229^{+0.0026}_{-0.0026}$	$0.1248^{+0.0026}_{-0.0029}$	$0.1244^{+0.0029}_{-0.0029}$
$\ln 10^{10} A_s$	$3.049^{+0.014}_{-0.015}$	$3.058^{+0.015}_{-0.016}$	$3.043^{+0.014}_{-0.016}$	$3.036^{+0.021}_{-0.019}$
n_s	$0.9681^{+0.0035}_{-0.004}$	$0.9761^{+0.0061}_{-0.0057}$	$0.9704^{+0.004}_{-0.0038}$	$0.9669^{+0.0082}_{-0.0075}$
τ	$0.0576^{+0.007}_{-0.0078}$	$0.0575^{+0.007}_{-0.0076}$	$0.0574^{+0.0066}_{-0.0082}$	$0.0575^{+0.007}_{-0.0074}$
$N_{\rm tot}$	3.046	$3.3^{+0.15}_{-0.15}$	$3.38^{+0.13}_{-0.15}$	$3.35^{+0.16}_{-0.15}$
$f_{\rm fs}$	1	1	$0.901^{+0.039}_{-0.036}$	$0.87^{+0.08}_{-0.06}$
H_0 [km/s/Mpc]	$68.55^{+0.46}_{-0.41}$	$70.0^{+0.93}_{-0.9}$	$70.64^{+0.93}_{-1.0}$	$70.5^{+1.0}_{-1.0}$
$r_s^{\rm drag}$ [Mpc]	$147.34^{+0.22}_{-0.23}$	$144.8^{+1.4}_{-1.5}$	$143.9^{+1.5}_{-1.3}$	$144.1^{+1.5}_{-1.6}$
σ_8	$0.8216^{+0.0061}_{-0.0062}$	$0.8335^{+0.0089}_{-0.0093}$	$0.8299^{+0.0068}_{-0.0078}$	$0.826^{+0.011}_{-0.01}$
$\chi^2_{\rm tot}$	2797.46	2795.16	2793.65	2793.44

early dark energy (1811.04083):

1.04149 Parameter	ΛCDM	$n=2$	$n=3$	$n=\infty$
$100\ \theta_s$	$1.04198\ (1.04213) \pm 0.0003$	$1.04175\ (1.0414)^{+0.00046}_{-0.00064}$	$1.04138\ (1.0414) \pm 0.0004$	$1.04159\ (1.04149) \pm 0.00035$
$100\ \omega_b$	$2.238\ (2.239) \pm 0.014$	$2.244\ (2.228)^{+0.019}_{-0.022}$	$2.255\ (0.258) \pm 0.022$	$2.257\ (2.277) \pm 0.024$
$\omega_{\rm cdm}$	$0.1179\ (0.1177) \pm 0.0012$	$0.1248\ (0.1281)^{+0.003}_{-0.0041}$	$0.1272\ (0.1299){\pm}0.0045$	$0.1248\ (0.1249) \pm 0.0041$
$10^9 A_s$	$2.176\ (2.14) \pm 0.051$	$2.185\ (2.230) \pm 0.056$	$2.176\ (2.177) \pm 0.054$	$2.151\ (2.177) \pm 0.051$
n_s	$0.9686\ (0.9687) \pm 0.0044$	$0.9768\ (0.9828)^{+0.0065}_{-0.0072}$	$0.9812\ (0.9880) \pm 0.0080$	$0.9764\ (0.9795) \pm 0.0073$
$\tau_{\rm reio}$	$0.075\ (0.068) \pm 0.013$	$0.075\ (0.083) \pm 0.013$	$0.068\ (0.068) \pm 0.013$	$0.062\ (0.066) \pm 0.014$
$\mathrm{Log}_{10}(a_c)$	–	$-4.136\ (-3.728)^{+0.57}_{-0.013}$	$-3.737\ (-3.696)^{+0.110}_{-0.094}$	$-3.449\ (-3.509)^{+0.047}_{-0.11}$
$f_{\rm EDE}(a_c)$	–	$0.028\ (0.044)^{+0.011}_{-0.016}$	$0.050\ (0.058)^{+0.024}_{-0.019}$	$0.054\ (0.057)^{+0.031}_{-0.027}$
$r_s(z_{\rm rec})$	$145.05\ (145.1) \pm 0.26$	$141.4\ (139.8)^{+2}_{-1.5}$	$140.3\ (138.9)^{+1.9}_{-2.3}$	$141.6\ (141.3)^{+1.8}_{-2.1}$
S_8	$0.824\ (0.814) \pm 0.012$	$0.826\ (0.836) \pm 0.014$	$0.838\ (0.842) \pm 0.015$	$0.836\ (0.839) \pm 0.015$
H_0	$68.18\ (68.33) \pm 0.54$	$70.3\ (71.1) \pm 1.2$	$70.6\ (71.6) \pm 1.3$	$69.9\ (70) \pm 1.1$

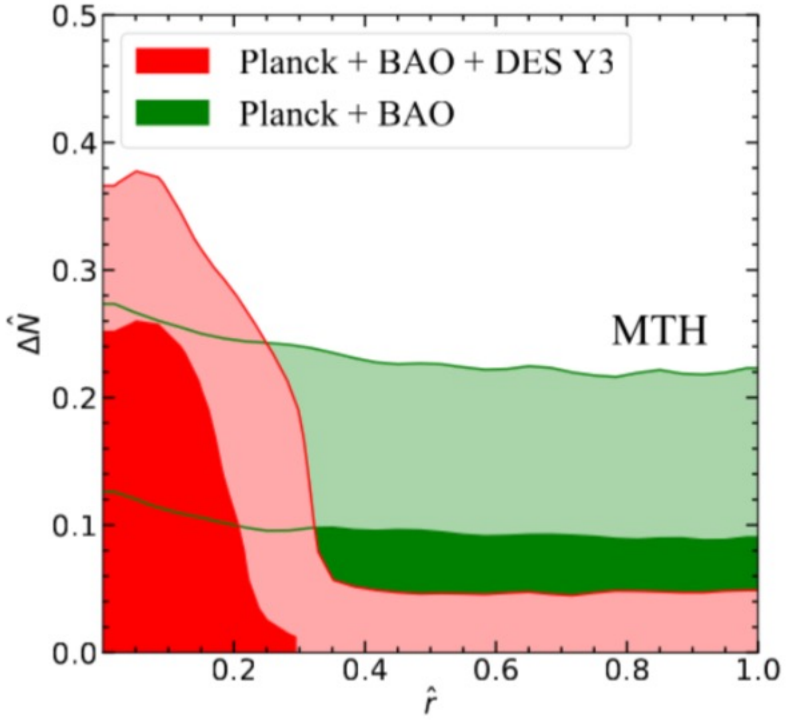
MTH relax both tension

Dark radiation(twin photon and twin neutrinos) as additional radiation components to relax H_0 tension.

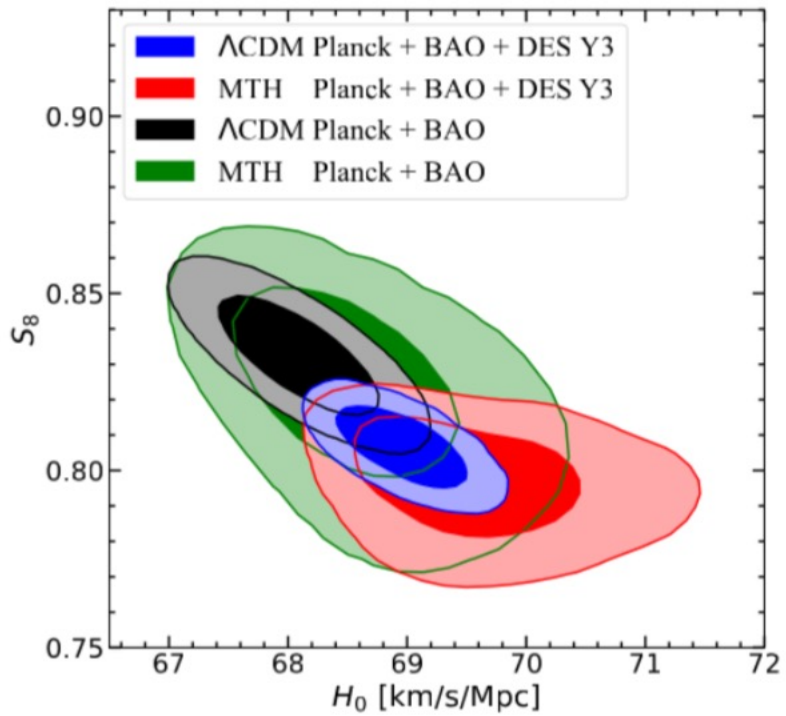
While twin BAOs suppress the mass perturbation at small scale, thus relax the S_8 tension.

Cosmology data we used in MCMC scans: Planck , BAO, SH0ES, DES Y3

Planck+BAO+DES Y3

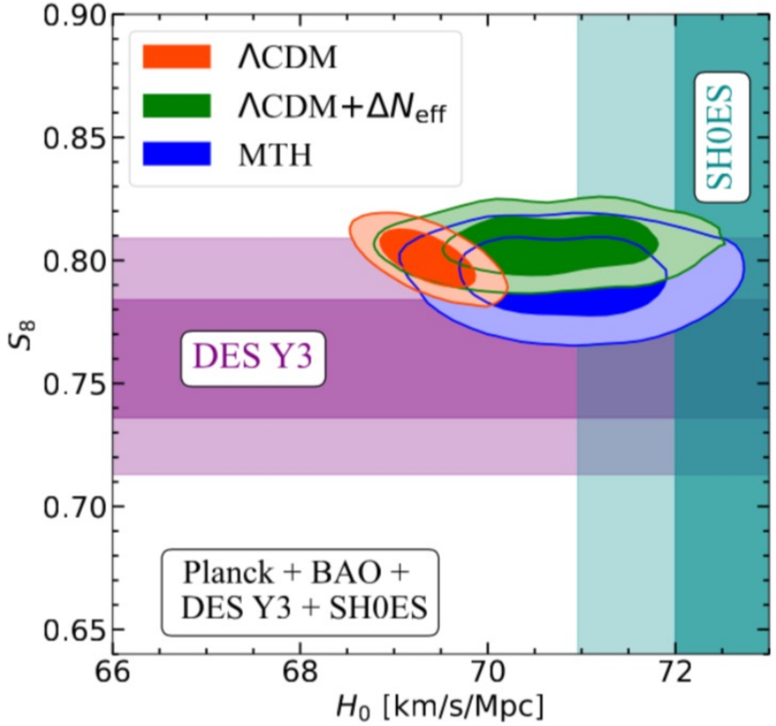


An up limits for fraction of MTH DM



More flexible for MTH cosmology

Planck+BAO+DES Y3+SH0ES

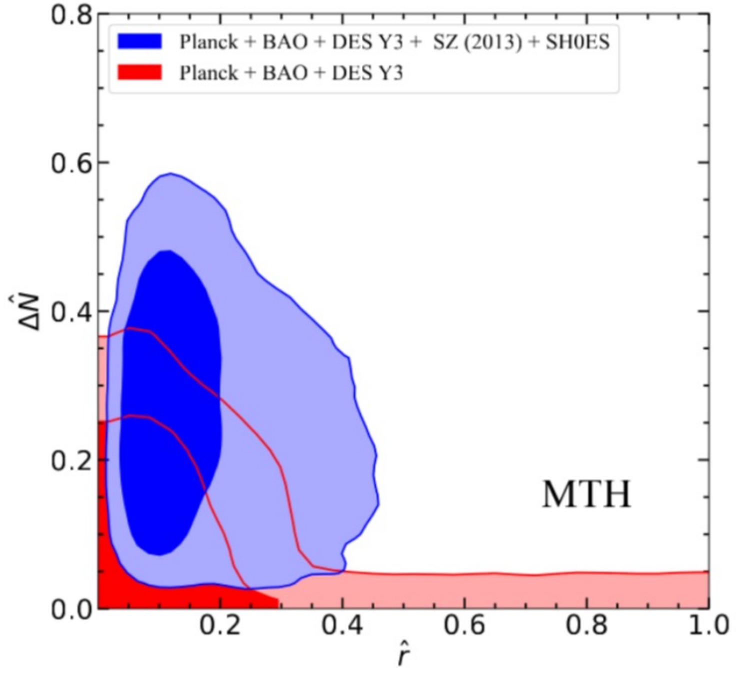


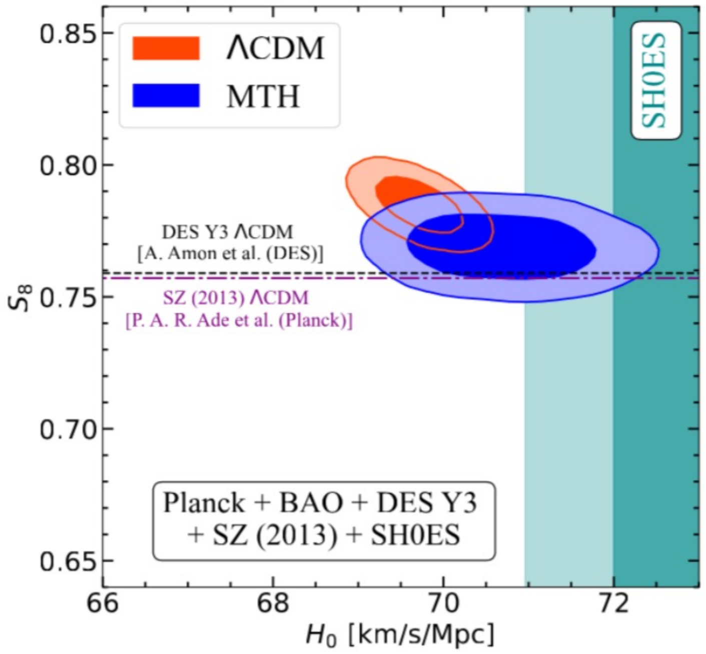
	ΛCDM		ΛCDM + $\Delta N_{\rm eff}$		MTH	
Parameters	best-fit	mean $\pm\sigma$	best-fit	mean $\pm\sigma$	best-fit	mean $\pm\sigma$
$100\Omega_b h^2$	2.270	$2.268^{+0.0099}_{-0.0148}$	2.275	$2.282^{+0.0115}_{-0.0175}$	2.273	$2.283^{+0.012}_{-0.017}$
$\Omega_{dm} h^2$	0.1166	$0.1167^{+0.0009}_{-0.0005}$	0.1204	$0.1211^{+0.017}_{-0.0026}$	0.1210	$0.1224^{+0.0021}_{-0.0028}$
$100\theta_s$	1.042	$1.042^{+0.0002}_{-0.0003}$	1.042	$1.042^{+0.00046}_{-0.00032}$	1.042	$1.042^{+0.00042}_{-0.00035}$
$\ln(10^{10} A_s)$	3.048	$3.044^{+0.012}_{-0.016}$	3.052	$3.05^{+0.012}_{-0.016}$	3.054	$3.051^{+0.013}_{-0.016}$
n_s	0.9735	$0.9736^{+0.0028}_{-0.0041}$	0.9803	$0.9811^{+0.0038}_{-0.0062}$	0.9740	$0.9795^{+0.0036}_{-0.0054}$
$\tau_{\rm reio}$	0.0595	$0.0572^{+0.0060}_{-0.0082}$	0.05784	$0.0555^{+0.0067}_{-0.0074}$	0.05866	$0.05566^{+0.0068}_{-0.0074}$
$\hat{r}$	–	–	–	–	0.1144	$0.1128^{+0.091}_{-0.076}$
$\hat{v}/v$	–	–	–	–	9.62	$8.98^{+3.76}_{-4.04}$
$\Delta\hat{N}$	–	–	0.2071	$0.2588^{+0.093}_{-0.1545}$	0.1979	$0.3098^{+0.0950}_{-0.1520}$
Ω_m	0.2908	$0.2901^{+0.0039}_{-0.0040}$	0.288	$0.2873^{+0.0041}_{-0.0041}$	0.2915	$0.2895^{+0.0046}_{-0.005}$
H_0	69.51	$69.48^{+0.21}_{-0.43}$	70.5	$70.65^{+0.775}_{-0.732}$	70.22	$71.04^{+0.52}_{-0.92}$
S_8	0.8159	$0.8145^{+0.0052}_{-0.0055}$	0.8086	$0.8062^{+0.0078}_{-0.0078}$	0.8034	$0.794^{+0.0117}_{-0.0099}$
$-2\ln\mathcal{L}$	3046.49		3042.76		3042.21	
Planck + BAO	2794.87		2794.27		2792.9	
DES Y3	240.09		242.52		241.81	
SH0ES	11.53		5.966		7.355	

Compared to $\Lambda CDM + \Delta N_{eff}$,
The fitting results are similar while
MTH is able to get a lower S_8.

Future test (Planck SZ(2013))

If future observation provides a much more precise observation and the uncertainty of S_8 is comparable to Planck SZ (2013), MTH model could also give a good fit.

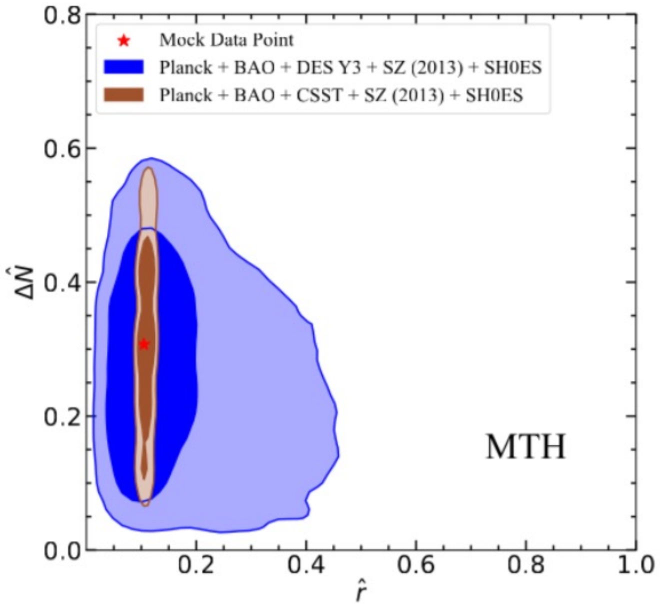


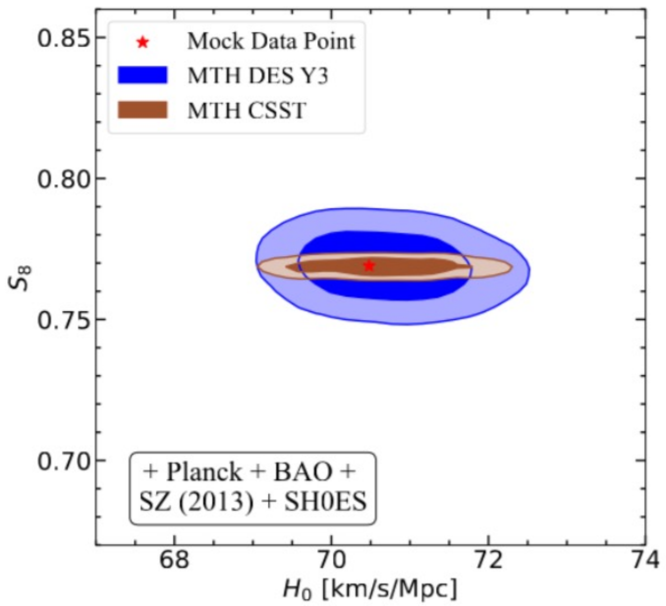


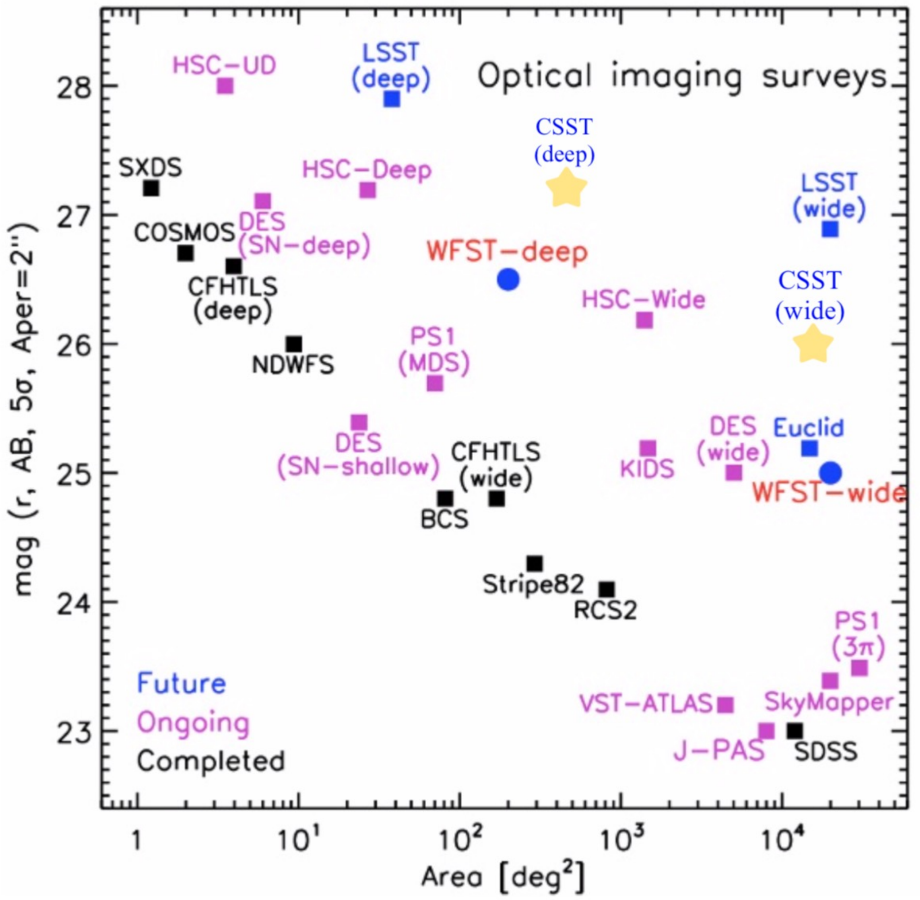
	ΛCDM		MTH	
Param	best-fit	mean $\pm\sigma$	best-fit	mean $\pm\sigma$
$100\Omega_b h^2$	2.272	$2.273^{+0.011}_{-0.015}$	2.286	$2.285^{+0.012}_{-0.018}$
$\Omega_{dm} h^2$	0.1164	$0.1159^{+0.00089}_{-0.00052}$	0.1205	$0.1226^{+0.0020}_{-0.0028}$
$100\theta_s$	1.042	$1.042^{+0.00025}_{-0.00031}$	1.042	$1.042^{+0.00040}_{-0.00034}$
$\ln(10^{10}A_s)$	3.03	$3.026^{+0.011}_{-0.016}$	3.034	$3.046^{+0.013}_{-0.016}$
n_s	0.9749	$0.9744^{+0.0029}_{-0.0041}$	0.9747	$0.9772^{+0.0034}_{-0.0051}$
τ_{reio}	0.05286	$0.05^{+0.0059}_{-0.0082}$	0.05058	$0.05419^{+0.0068}_{-0.0076}$
$\hat{r}$	–	–	0.06745	$0.1537^{+0.087}_{-0.074}$
$\hat{v}/v$	–	–	2.725	$5.968^{+2.329}_{-2.513}$
$\Delta\hat{N}$	–	–	0.1676	$0.3002^{+0.0898}_{-0.1449}$
Ω_m	0.2867	$0.2856^{+0.0040}_{-0.0039}$	0.2908	$0.29^{+0.0051}_{-0.0050}$
H_0	69.65	$69.72^{+0.33}_{-0.34}$	70.23	$70.71^{+0.70}_{-0.72}$
S_8	0.7896	$0.7847^{+0.0065}_{-0.0065}$	0.7631	$0.769^{+0.0082}_{-0.0082}$
$-2\ln\mathcal{L}$	3063.72		3048.68	
Planck + BAO	2798.51		2801.012	
DES Y3	238.2		239.3	
SZ (2013)	16.39		1.068	
SHOES	10.625		7.3	

Future test (CSST)

CSST is much more powerful compared to DES.







Summary

MTH model is motivated by the naturalness problem while leads to a rich dark sector.

Dark radiation and self-interacting dark matter, Additional radiation components ΔN_{eff} and Dark BAOs.

The combined data provide an up limit for the fraction of MTH DM : $\hat{r}$ < 0.4, unless the temperature of twin photons is low enough.

MTH model could alleviate both the H_0 and S_8 tensions.

Cosmology is a powerful tool for exploring particle physics.