December, 2021

PIKIMO 11 @ University of Pittsburgh

Hidden Naturalness

In the Light of Precision Cosmological Data

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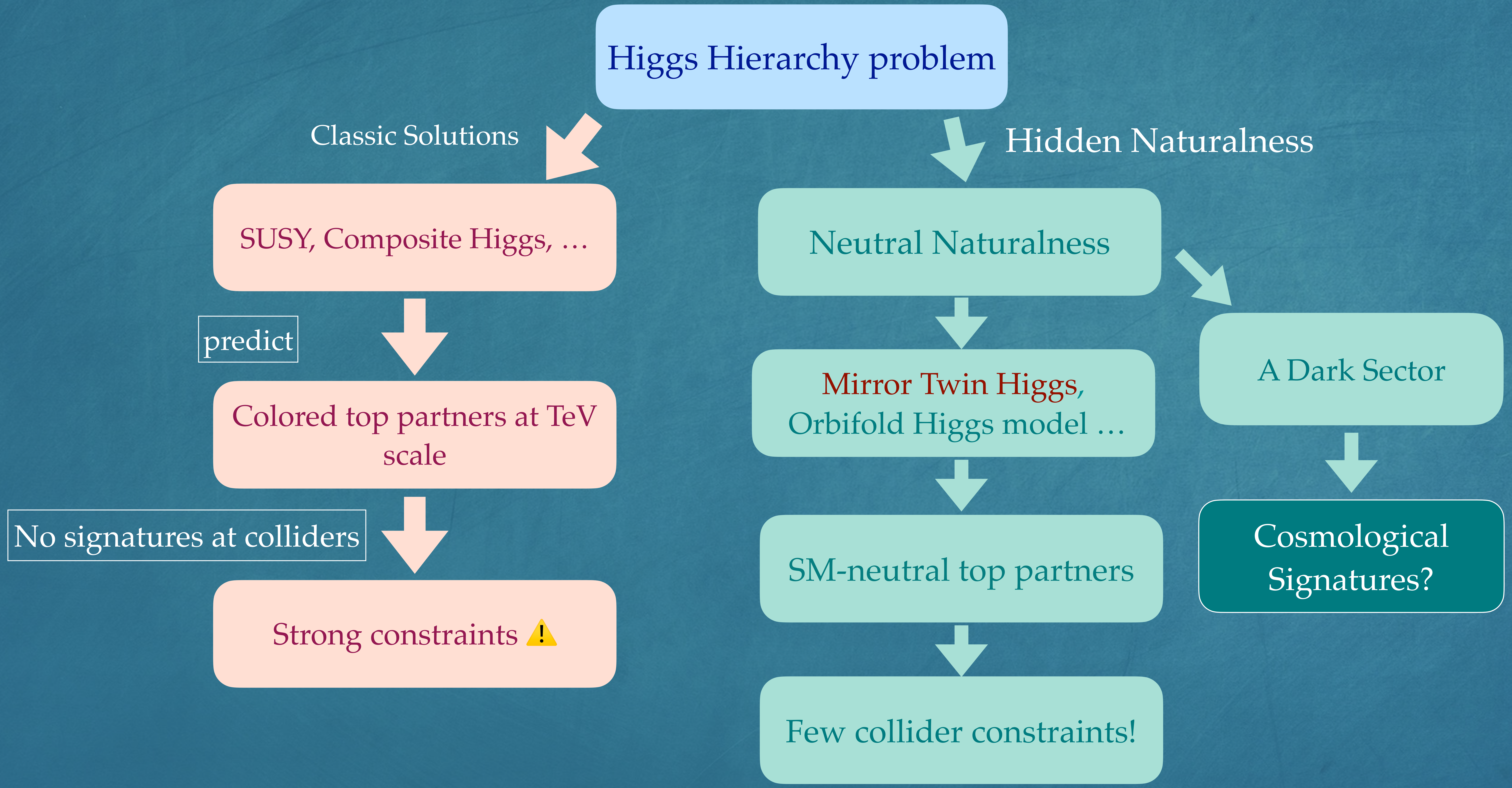
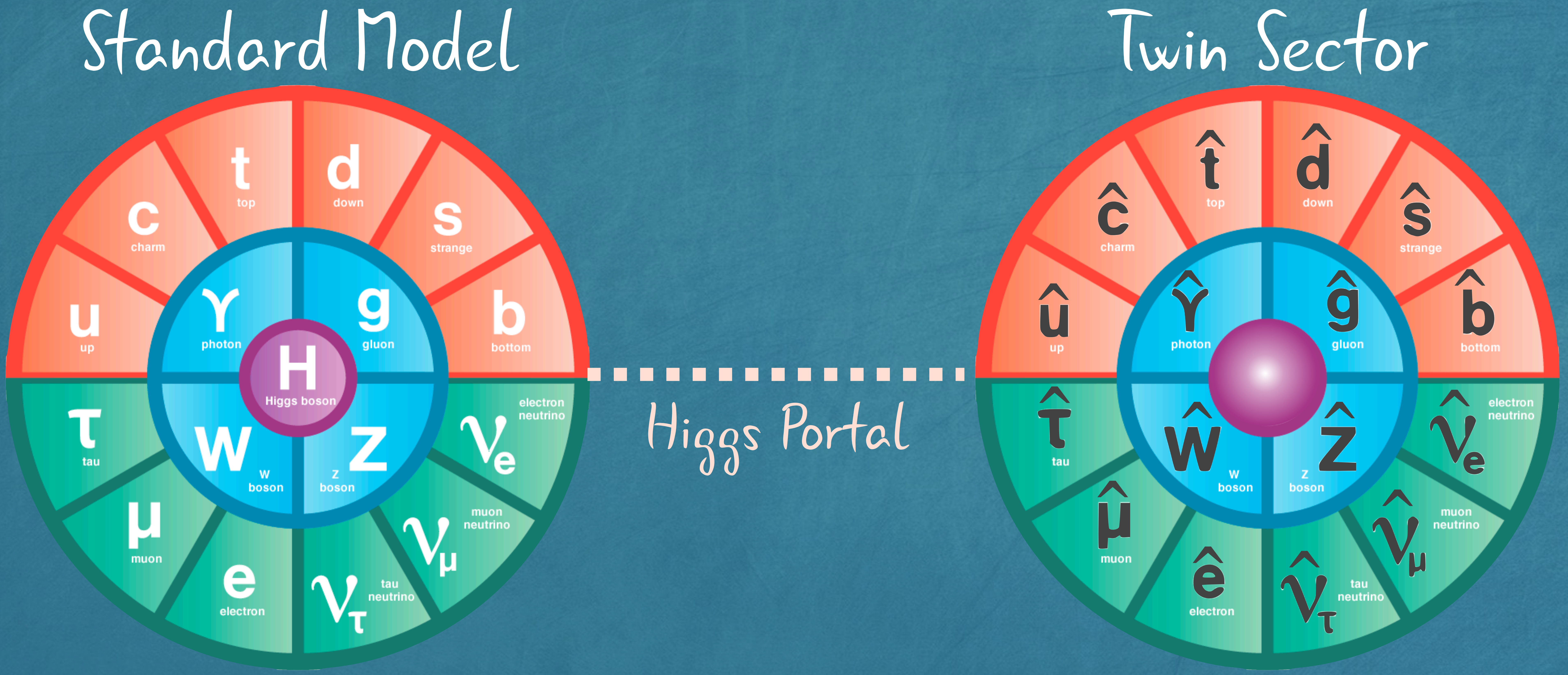
SB, J. Kim, C. Kolda, M. Low, Y. Tsai (2110.04317)

Motivation

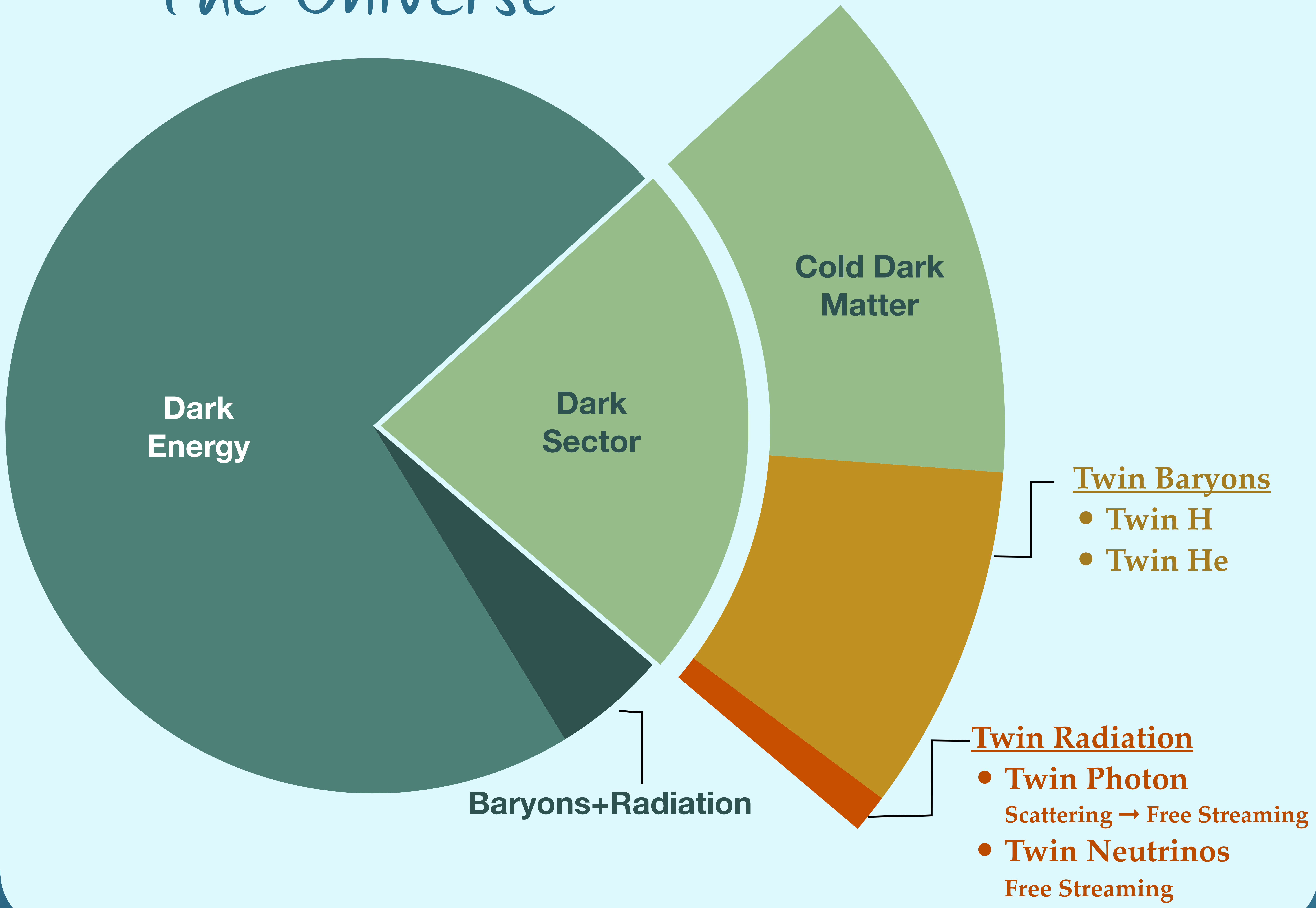

Higgs Hierarchy problem
Classic Solutions
Hidden Naturalness
SUSY, Composite Higgs, …
predict
Colored top partners at TeV scale
No signatures at colliders
Strong constraints ⚠️
Neutral Naturalness
Mirror Twin Higgs,
Orbifold Higgs model …
SM-neutral top partners
Few collider constraints!
A Dark Sector
Cosmological Signatures?

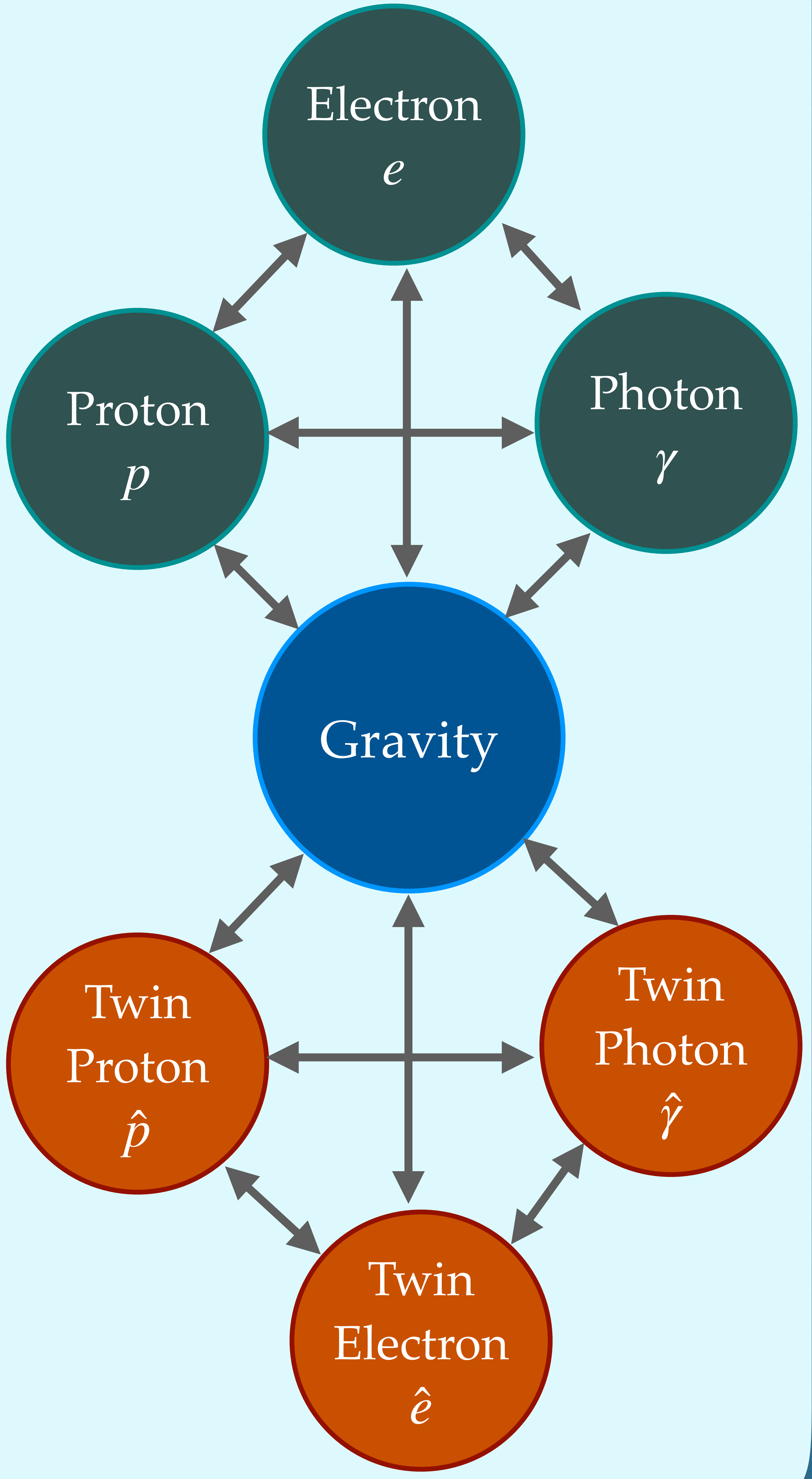
Mirror Twin Higgs (MTH) model

Chacko, Goh, Harnik (2005)



The Universe





Mirror Twin Higgs (MTH) model

1. $\hat{v}$ Vacuum expectation value

$3 \lesssim (\hat{v}/v) \lesssim 8$ Twin particles are heavier

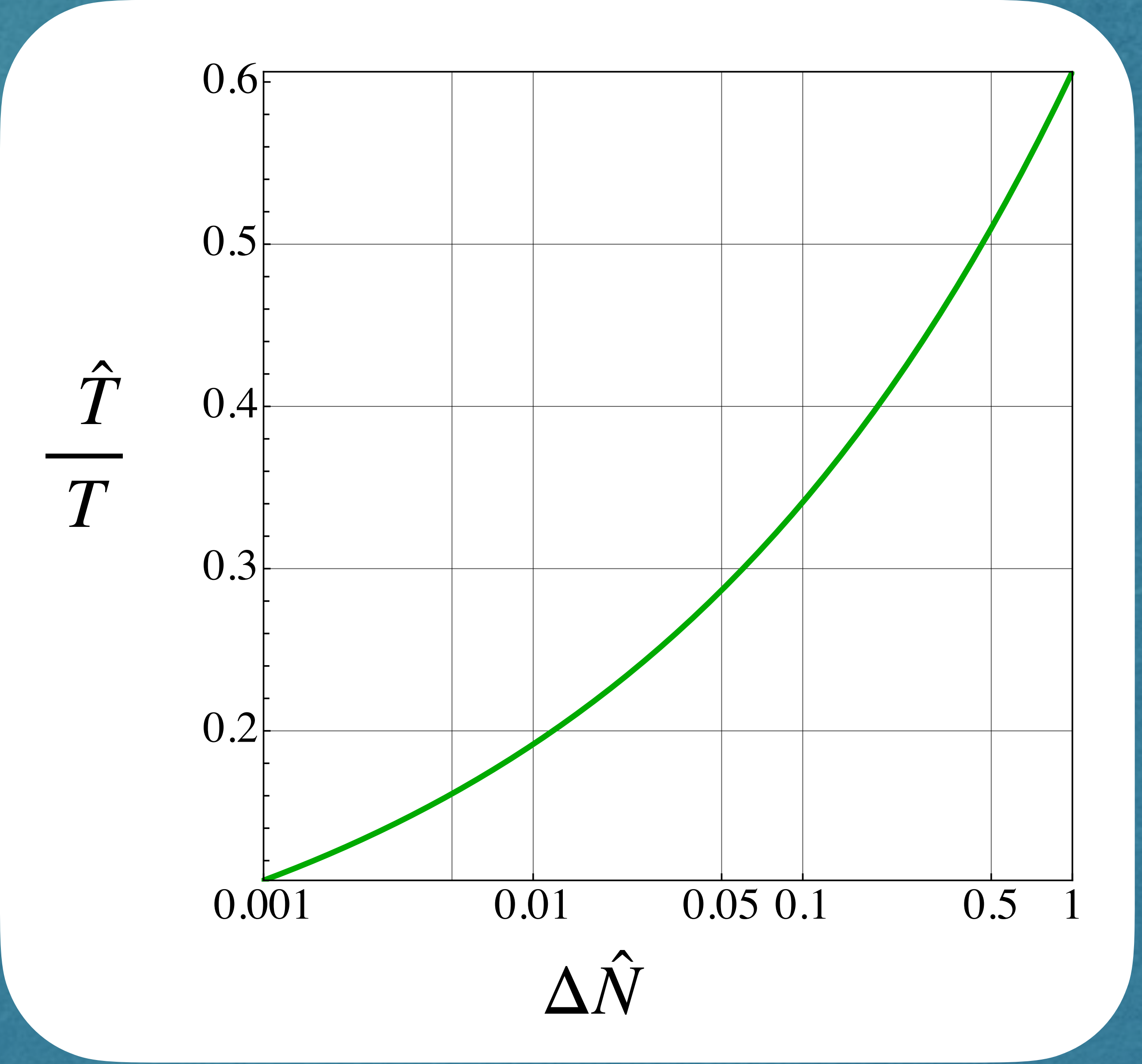
experimental bounds — fine tuning

2. $\Delta\hat{N}$ $(\equiv \Delta N_{\hat{\gamma}} + \Delta N_{\hat{\nu}})$ Contribution of twin radiation to ΔN_{eff}

For twin γ temp $(\hat{T})$ and twin ν temp $(T_{\hat{\nu}})$, $T_{\hat{\nu}} = (4/11)^{1/3}\,\hat{T}$

ΔN_{eff} Constraints: $(\hat{T}/T) \lesssim 0.5$ Twin sector is colder

For asymmetric reheating, see: Chacko, Craig, Fox, Harnik '16, Craig, Koren, Trott '16, Beauchesne and Kats '21



3. $\hat{r} = \Omega_{twin}/\Omega_{DM}$ Amount of twin baryons

- Incorporated the MTH model into CLASS.

SB, J. Kim, C. Kolda, M. Low, Y. Tsai (to appear)

CLASS: Blasa, Lesgourgues, Tram (2011)

Chronology of the MTH Universe

- Nuclei
- Decoupled

$T \gg$ MeV
Asymmetric Reheating

SM: $(p,\ n,\ e,\ \gamma,\ \nu)$
Twin: $(\hat{p},\ \hat{n},\ \hat{e},\ \hat{\gamma},\ \hat{\nu})$
$(\hat{T} < T)$

$T \sim$ few MeV

- Twin BBN: $\hat{p}, \hat{n}$ combine to form $\hat{\text{He}}$ nuclei
- $\hat{\nu}$ decouple and free stream
- $\hat{e}^-\hat{e}^+$ annihilate to $\hat{\gamma}$

Twin: $> 50\%$ mass is in **twin He**

SM: $(p,\ n,\ e,\ \gamma,\ \nu)$
Twin: $(\hat{p},\ \hat{\text{He}},\ \hat{e},\ \hat{\gamma},\ \hat{\nu})$

$T \sim 1$ MeV

- BBN: p, n combine to form He nuclei
- ν decouple and free stream
- e^-e^+ annihilate to γ

SM: $(p,\ \text{He},\ e,\ \gamma,\ \nu)$
Twin: $(\hat{p},\ \hat{\text{He}},\ \hat{e},\ \hat{\gamma},\ \hat{\nu})$

$T \sim$ few eV

- Twin recombination: $\hat{p}$ and $\hat{\text{He}}$ nuclei combine with $\hat{e}$ to form neutral atoms

SM: $(p,\ \text{He},\ e,\ \gamma,\ \nu)$
Twin: $(\hat{\text{H}},\ \hat{\text{He}},\ \hat{\gamma},\ \hat{\nu})$

$T \sim 0.3$ eV

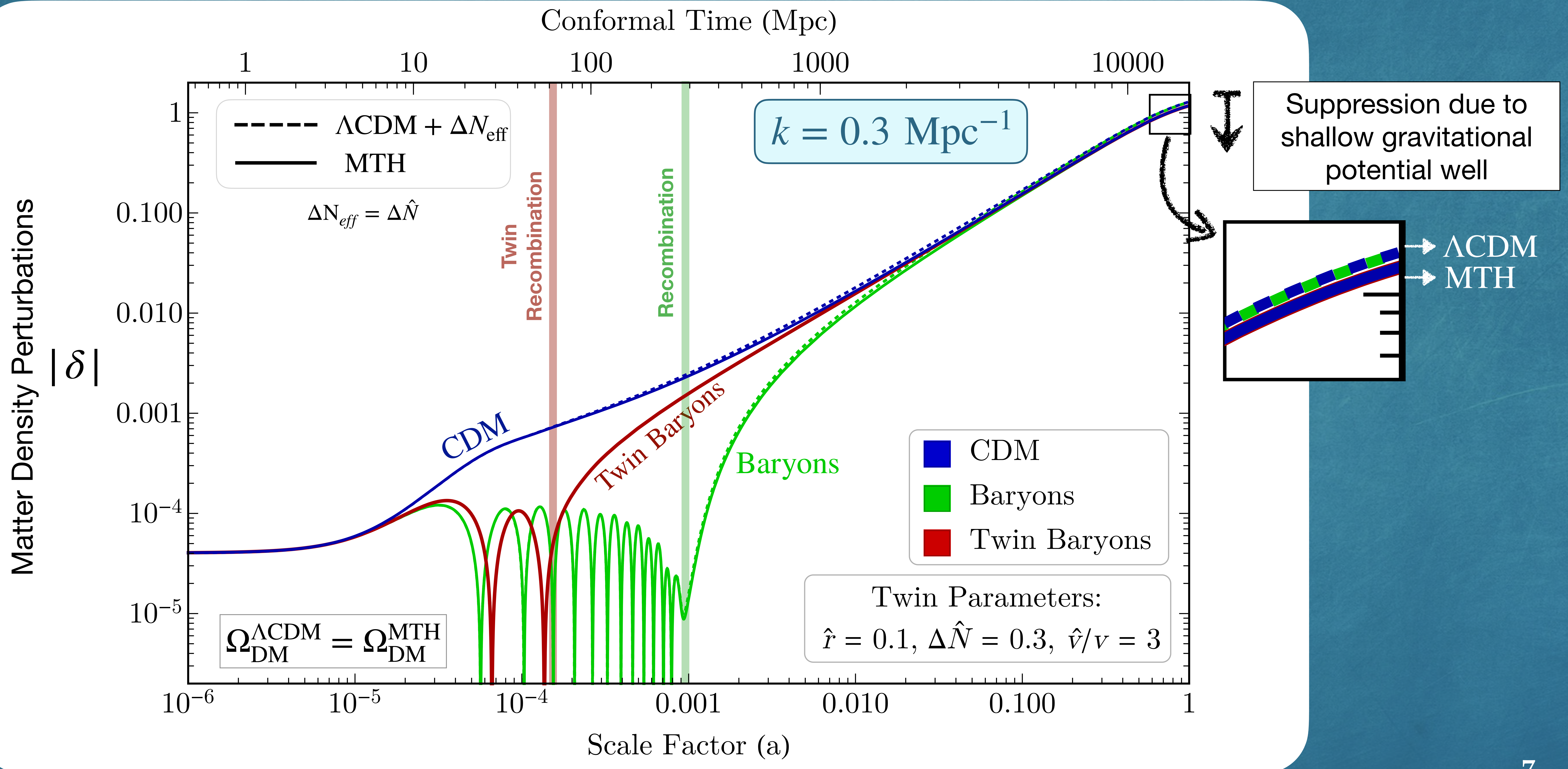
- Recombination: p and He nuclei combine with e^- to form neutral atoms

SM: $(\text{H},\ \text{He},\ \gamma,\ \nu)$
Twin: $(\hat{\text{H}},\ \hat{\text{He}},\ \hat{\gamma},\ \hat{\nu})$
structure formation

Today

Evolution of Matter perturbations

$\delta_i \equiv (\rho_i - \bar{\rho}_i)/\bar{\rho}_i$



Calculated using the modified version of CLASS.

Cosmological Data

Planck low ℓ TT, low ℓ EE, high ℓ TTTEEE, lensing — Planck Collaboration [1907.12875]

BAO BOSS DR12, 6dFGS at $z = 0.106$, MGS galaxy sample at $z = 0.15$ — [1106.3366] [1409.3242] [1607.03155]

H0 SH0ES $H_0 = 74.03 \pm 1.42\ \mathrm{km/s/Mpc}\ (68\,\%\ \mathrm{C.L.})$ — Riess et al. 2019 [1903.07603]

LSS KiDS+VIKING-450 ($k_{\max} = 0.3\, h\, \mathrm{Mpc}^{-1}$) — Hildebrandt et al. 2020 [1812.06076]

Planck SZ cluster counts $\sigma_8(\Omega_m/0.27)^{0.30} = 0.782 \pm 0.010\ (68\,\%\ \mathrm{C.L.})$ — Ade et al. 2014 [1303.5080]

Used MontePython along with the modified version of CLASS to perform MCMC scan of the three twin parameters, along with the six ΛCDM parameters.

MontePython 3: Brinckmann, Lesgourgues (2018)

Planck + BAO

low ℓ TT , low ℓ EE, high ℓ TTTEEE, lensing + BAO

MCMC Results

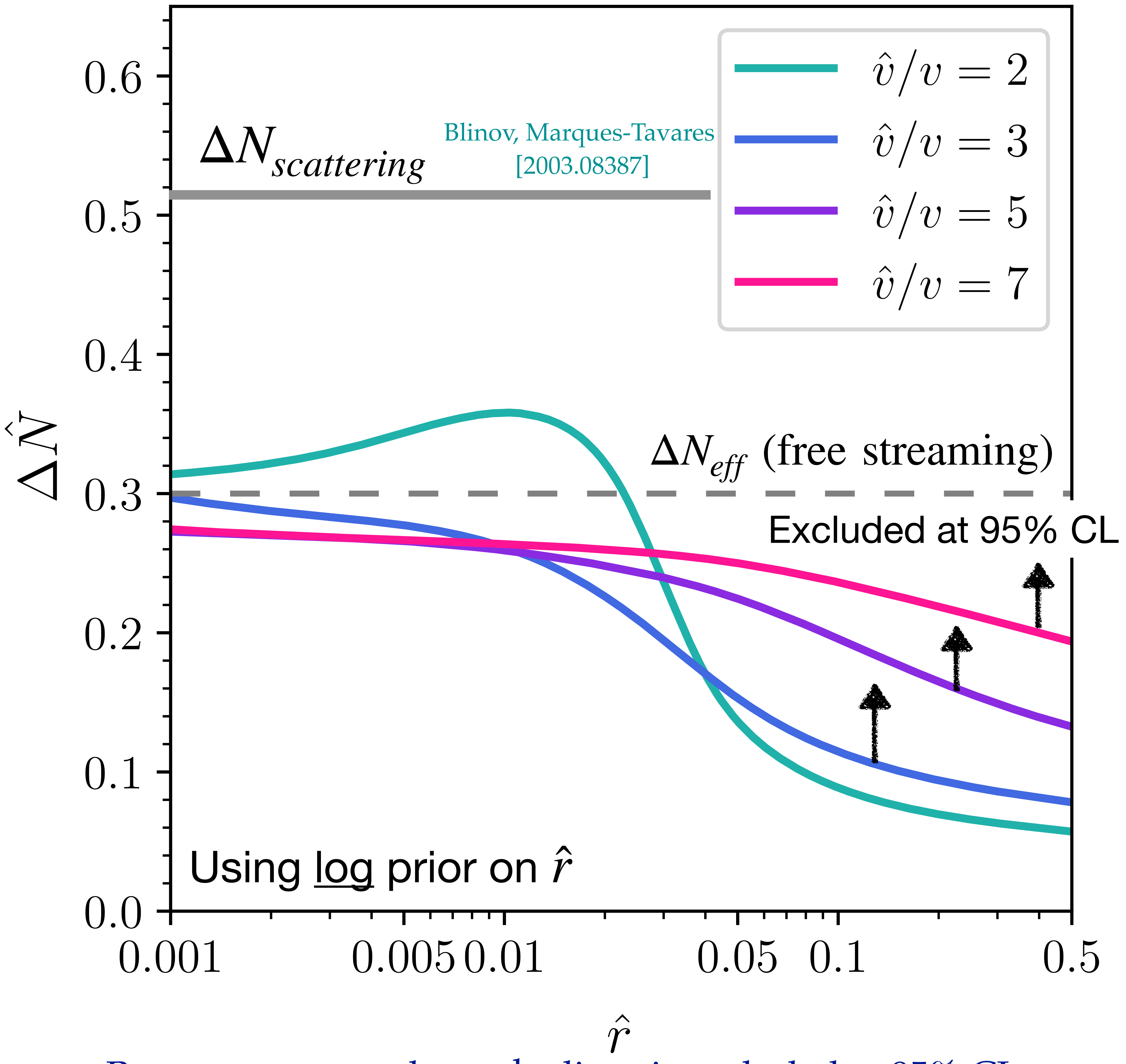
(Planck + BAO)

The MTH model does not improve the fit to the Planck data or there is no evidence of the MTH model in the Planck data !

Use this dataset to constrain the parameter of MTH model.

$\hat{r} \equiv \Omega_{twin}/\Omega_{DM}$

Constraints



Parameter space above the lines is excluded at 95% CL.

+ LSS + H_0

KiDS
&
VIKING
+
Planck SZ

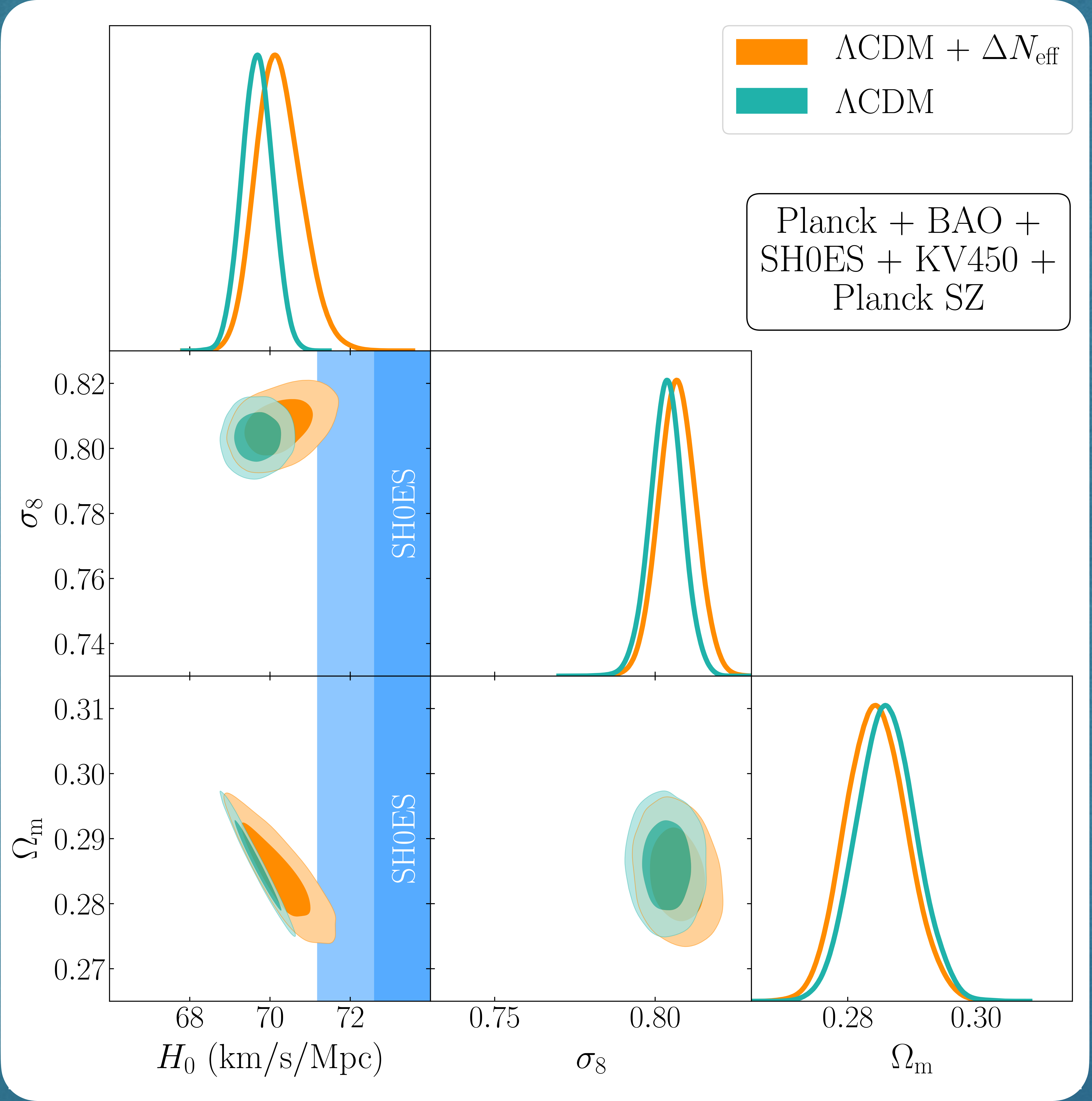
SH0ES

Range of MTH parameters: $0.001 \leq \hat{r} \leq 1$ | $2 \leq \hat{v}/v \leq 15$ | $0.001 \leq \Delta N_{twin} \leq 1$

Using flat prior

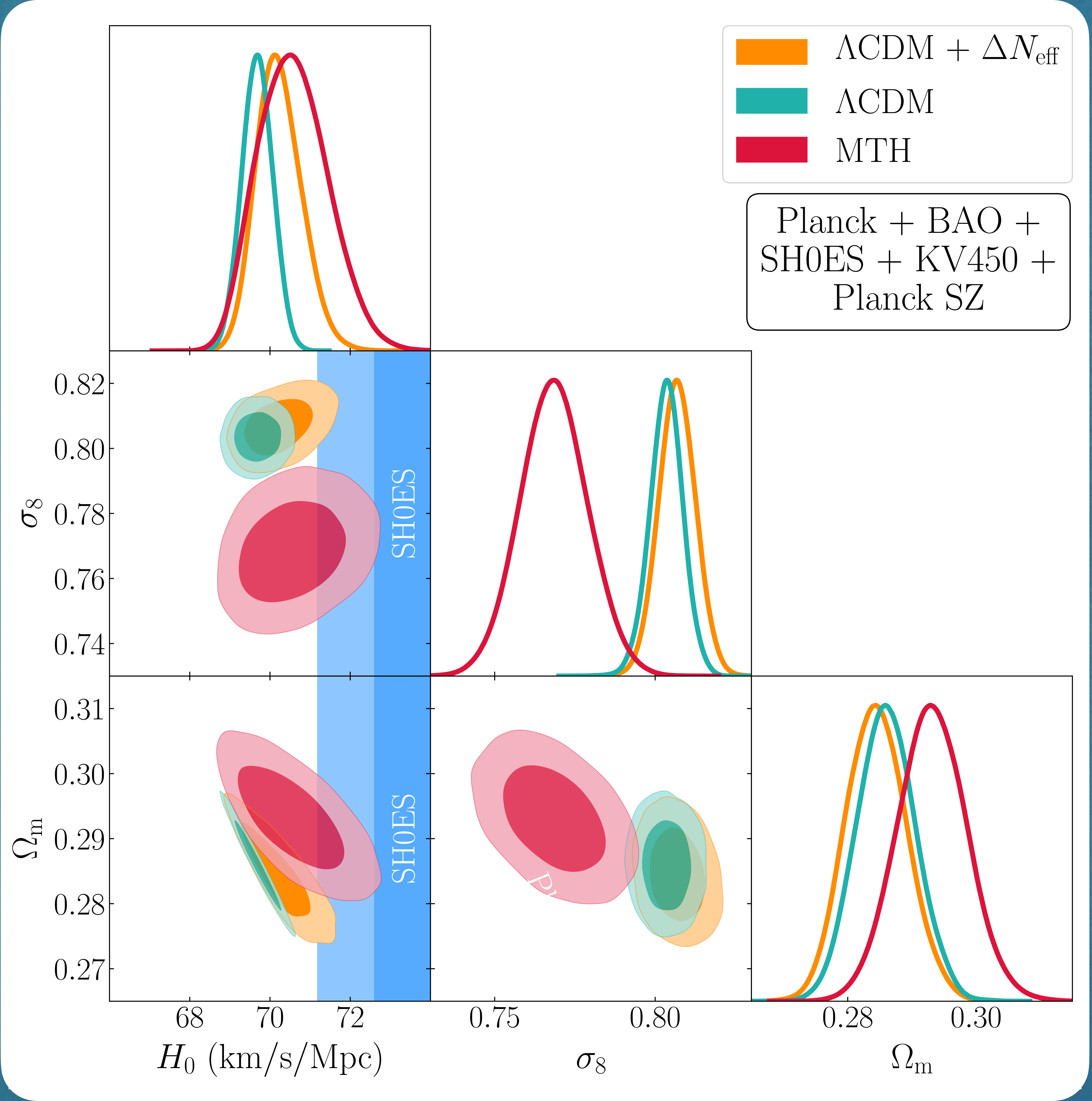
MCMC Results

- ΛCDM is in tension with both the SH0ES and Planck SZ measurement.
- ΛCDM + ΔN_{eff} model relaxes the tension with the SH0ES measurement, but worsens the SZ tension.



MCMC Results

- ΛCDM is in tension with both the SH0ES and Planck SZ measurement.
- ΛCDM + ΔN_{eff} model relaxes the tension with the SH0ES measurement, but worsens the SZ tension.
- The MTH model helps in relaxing both the SH0ES and SZ tensions!



MCMC Results

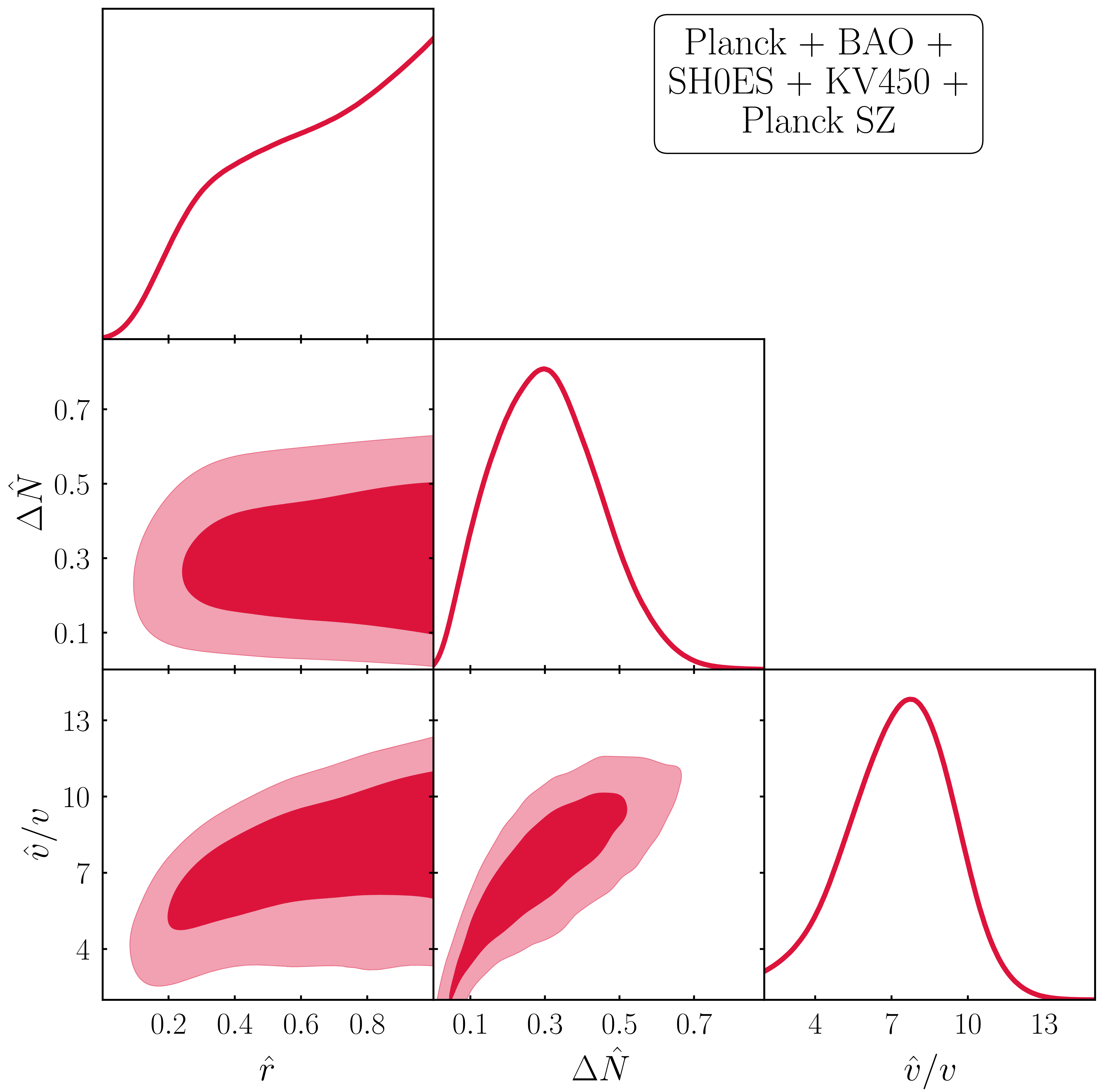
There is a statistical preference for >20% of the DM to be made up of twin particles.

	95% C.L. range	Bestfit
$\hat{r}$	{0.21,1}	0.24
$\Delta\hat{N}$	{3.02,11.05}	0.28
$\hat{v}/v$	{0.05,0.57}	5.8

Preferred twin recombination redshift:

$$1 \times 10^4 \lesssim z_{\text{rec, twin}} \lesssim 2.5 \times 10^4$$

$$(2 \text{ eV} \lesssim T_\gamma \lesssim 6 \text{ eV})$$



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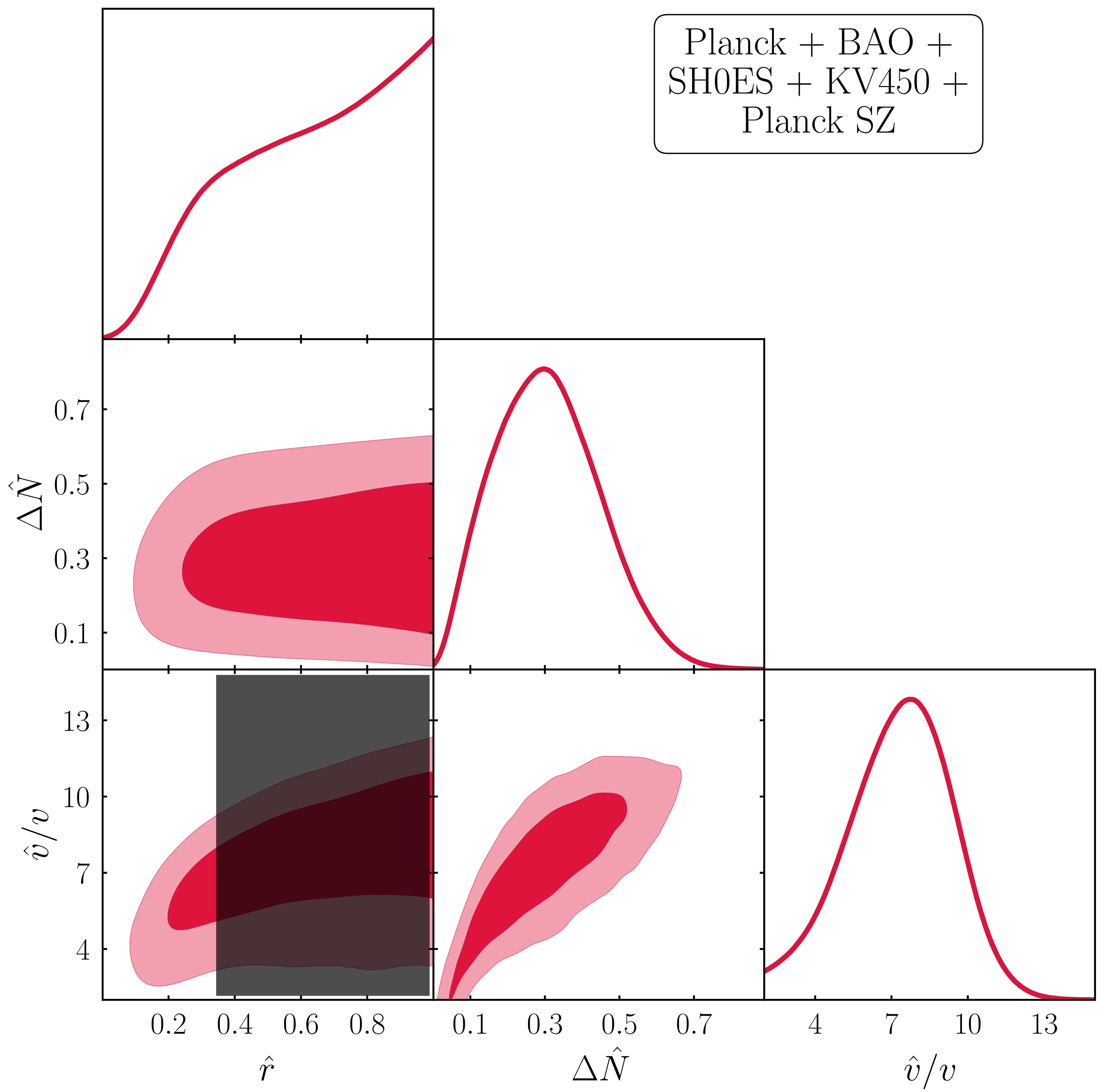


$\hat{r} \equiv \Omega_{twin}/\Omega_{DM}$

MCMC Statistics

Experiment	Minimum χ^2		$\Delta\chi^2$ MTH – ΛCDM
	ΛCDM	MTH	
Planck high ℓ TTTEEE + Planck low ℓ TT + Planck low ℓ EE	2779.12	2781.35	2.23
BAO	8.27	7.16	-1.11
Planck lensing	13.31	10.39	-17.56
KV450	268.36	268.21	
Planck SZ	14.65	0.16	σ_8
SH0ES	10.60	5.85	-4.75
Total	3094.31	3073.12	**-21.19**

Planck

BAO

LSS

H_0

Bestfit	
$\hat{r}$	0.24
$\Delta\hat{N}$	0.28
$\hat{v}/v$	5.8

The MTH model improves the total χ^2 by 21 units, *i.e.* $\sim 4\sigma$!!

Future Cosmological Probes

Question:

If the MTH model is the correct description of the universe, how precisely can we measure the twin parameters with future experiments and surveys?

Future Experiments:

Euclid and CMB-S4

Future Precision (95% C.L.):

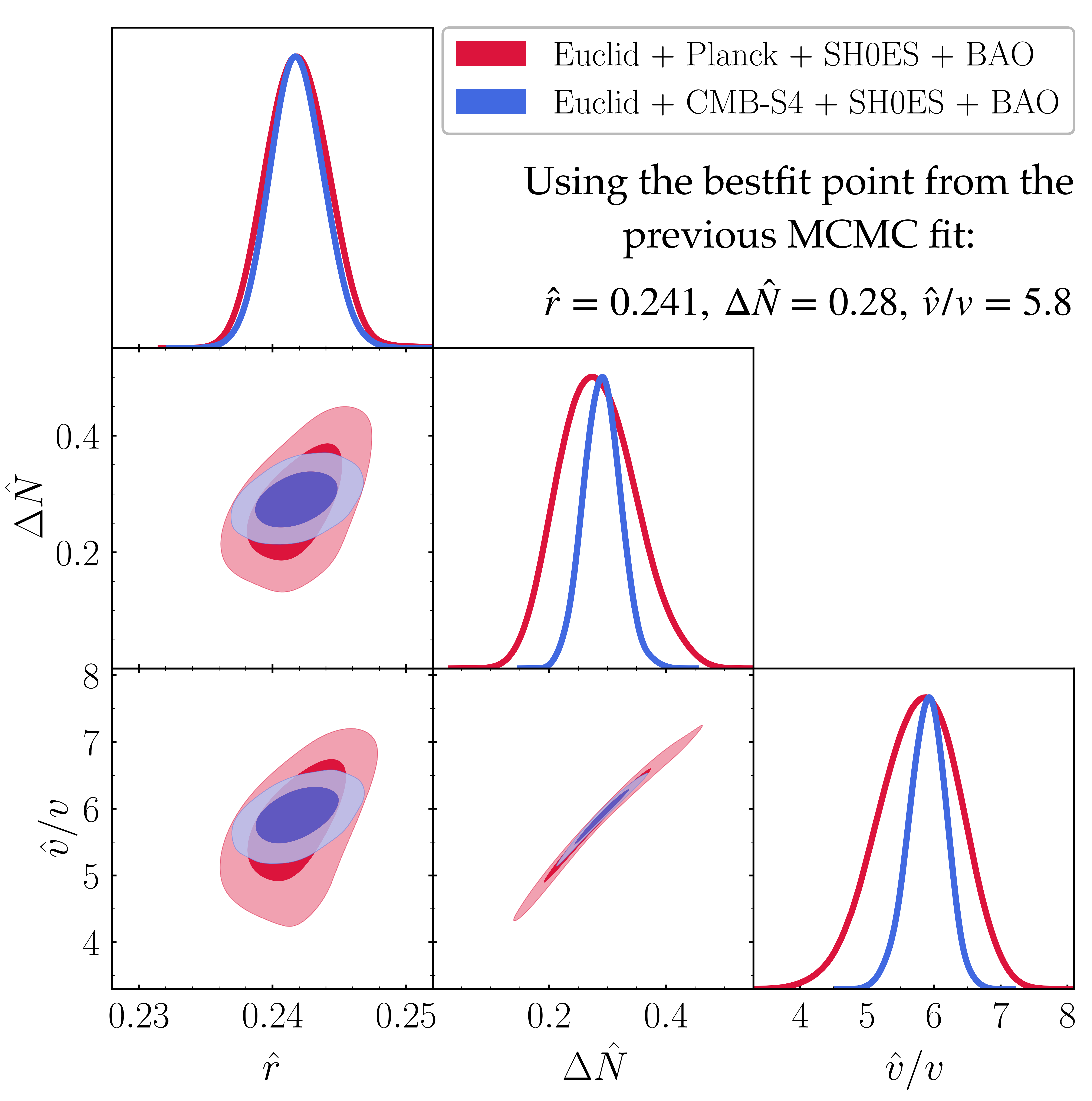
$\hat{r} \sim 1\,\%$ level

$\hat{v}/v \sim 10\,\%$ level

$\Delta\hat{N} \sim 0.13$

$\Delta z_{\rm rec,\,twin} \sim 2\times10^3$

Current datasets: $1\times10^4 \lesssim z_{\rm rec,\,twin} \lesssim 2.5\times10^4$



Summary

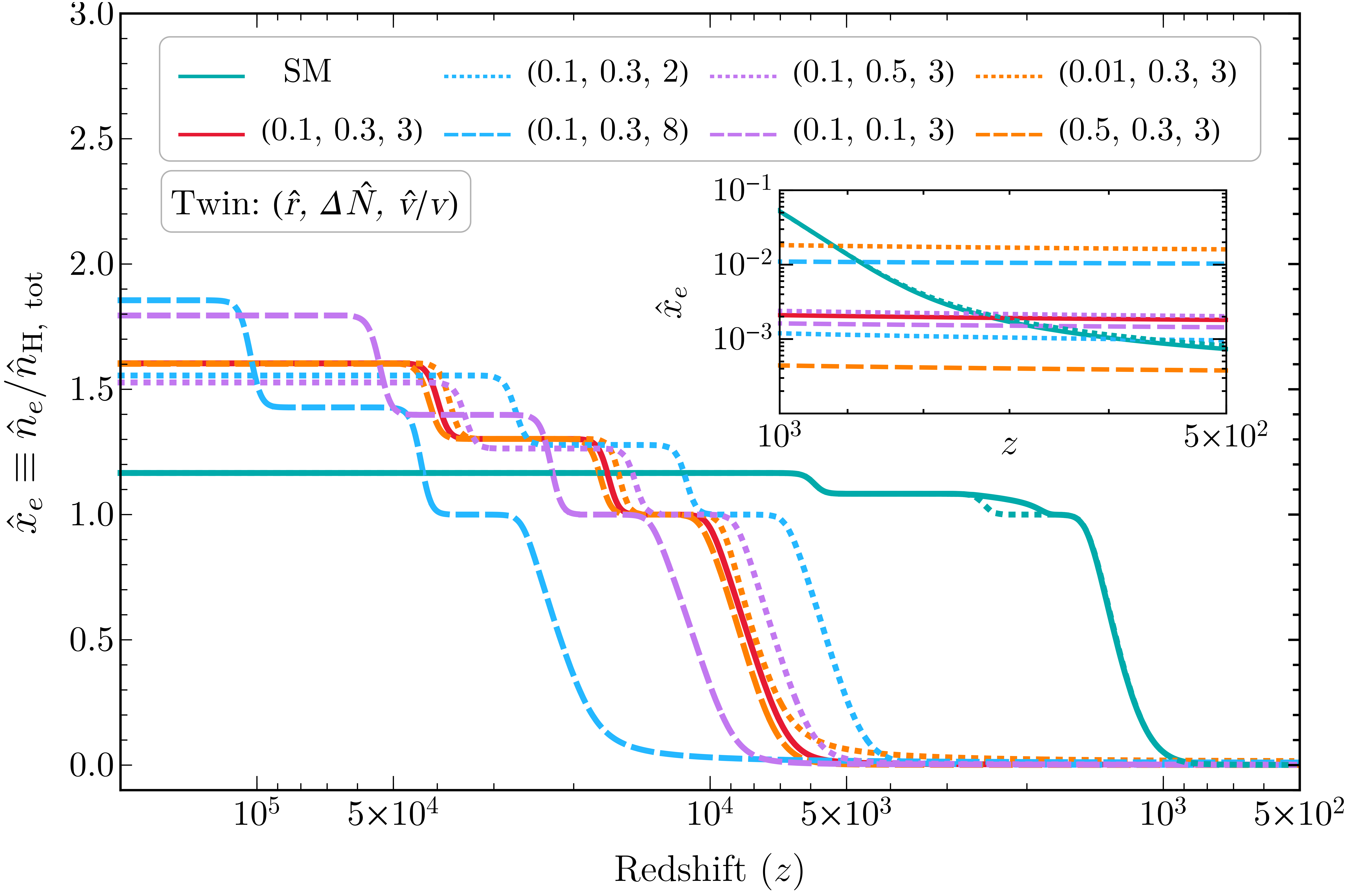
- The MTH model is motivated by hidden naturalness arguments, but leads to a rich dark sector,

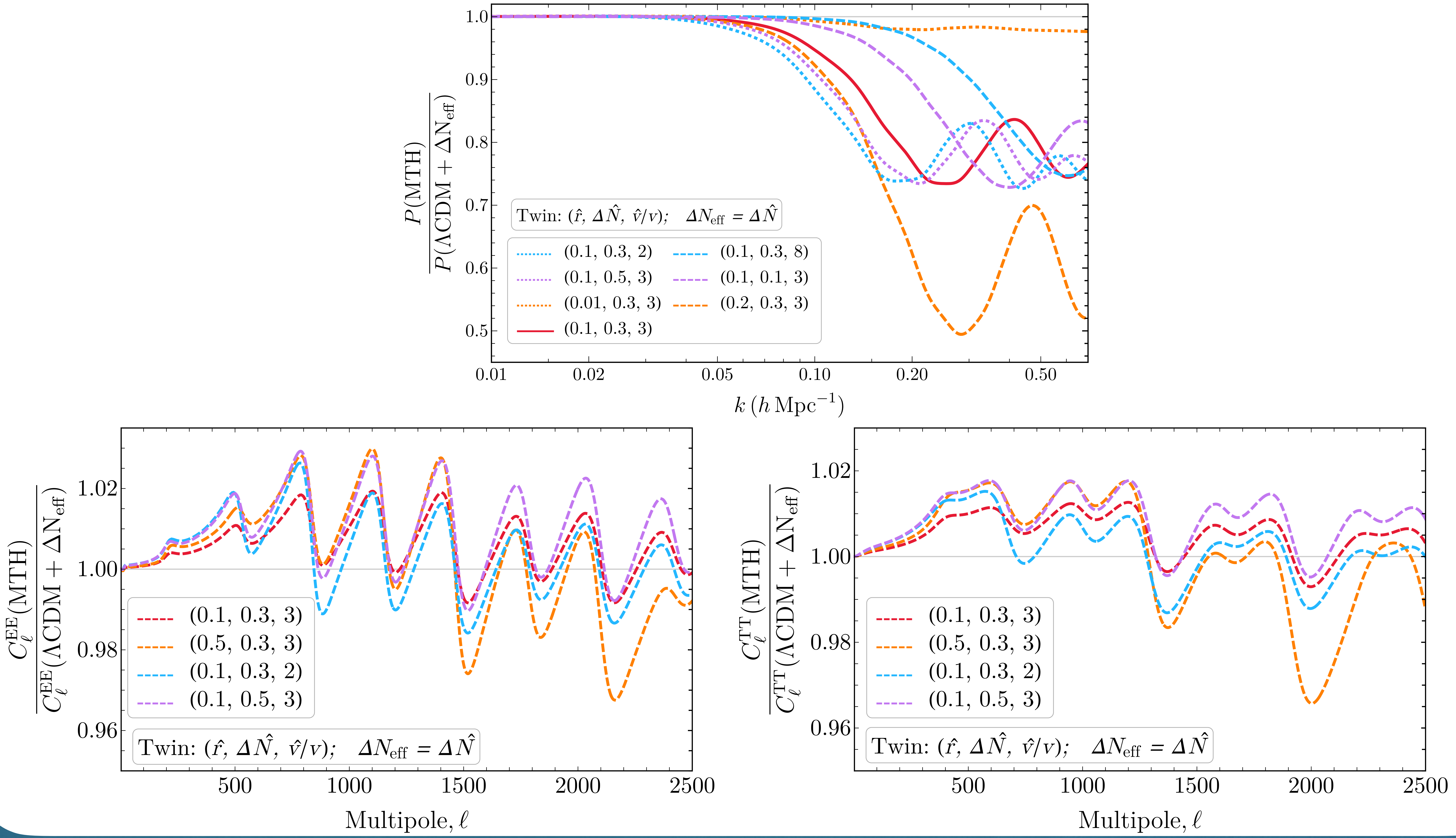
IDM = twin baryons | DR = twin photons | Free-streaming = twin neutrinos

- Taken alone, the Planck data strongly constrains the twin sector, preferring it be heavy, cold or sparse.
- On including the late Universe measurements of LSS and H_0, the combined data prefers a dark sector with >20% twin baryons.
- In this case, the MTH model can ameliorate both the σ_8 and H_0 tensions!
- The future cosmological can measure the twin parameters very precisely.
- Similar analysis can be carried out for other models within the hidden naturalness framework.

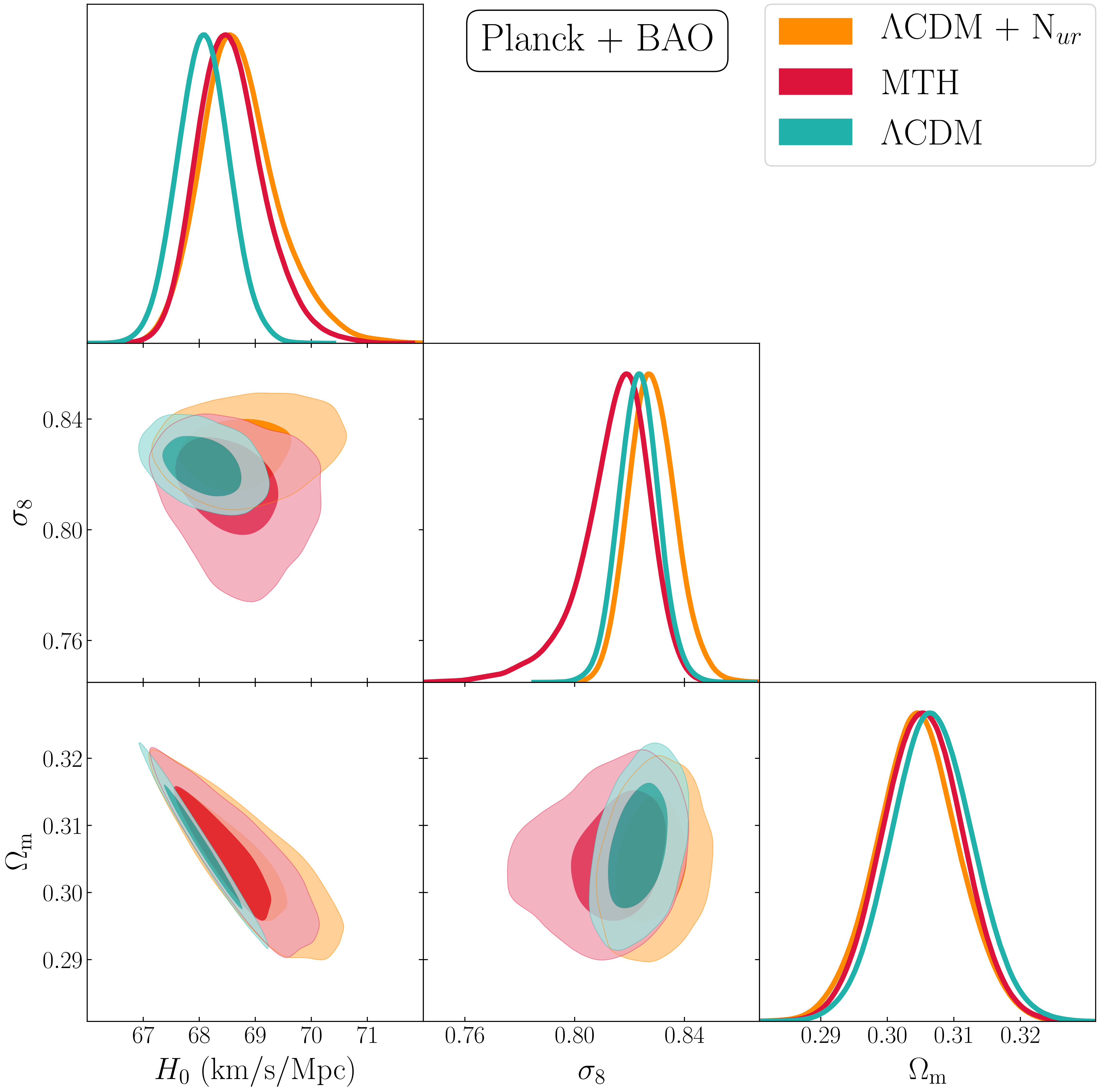
Thanks!

Back Up

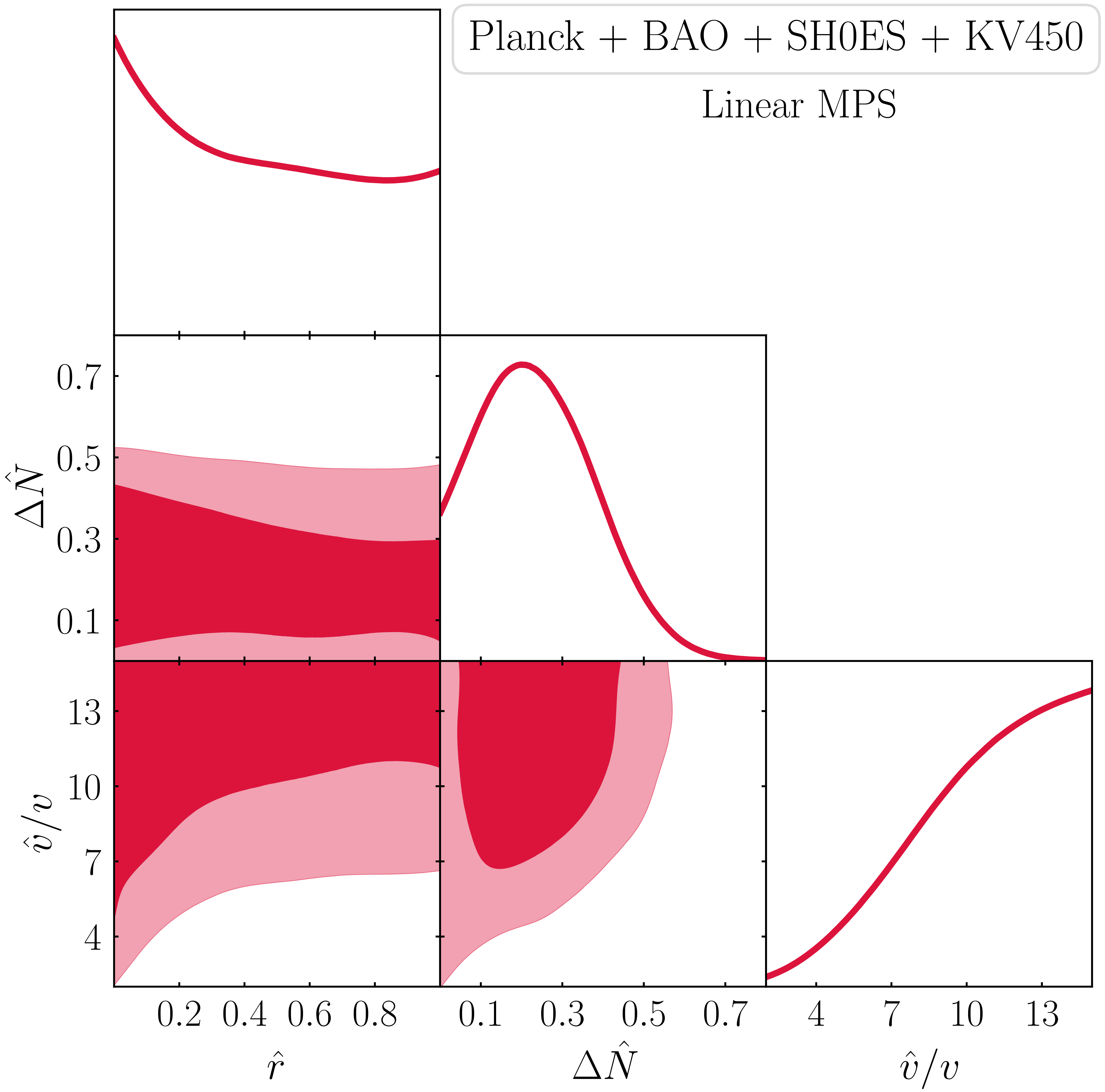

SM
(0.1, 0.3, 3)
(0.1, 0.3, 2)
(0.1, 0.3, 8)
(0.1, 0.5, 3)
(0.1, 0.1, 3)
(0.01, 0.3, 3)
(0.5, 0.3, 3)
Twin: ($\hat{r}$, $\Delta\hat{N}$, $\hat{v}/v$)
$\hat{x}_e \equiv \hat{n}_e/\hat{n}_{\mathrm{H,\ tot}}$
Redshift (z)
$\hat{x}_e$
z



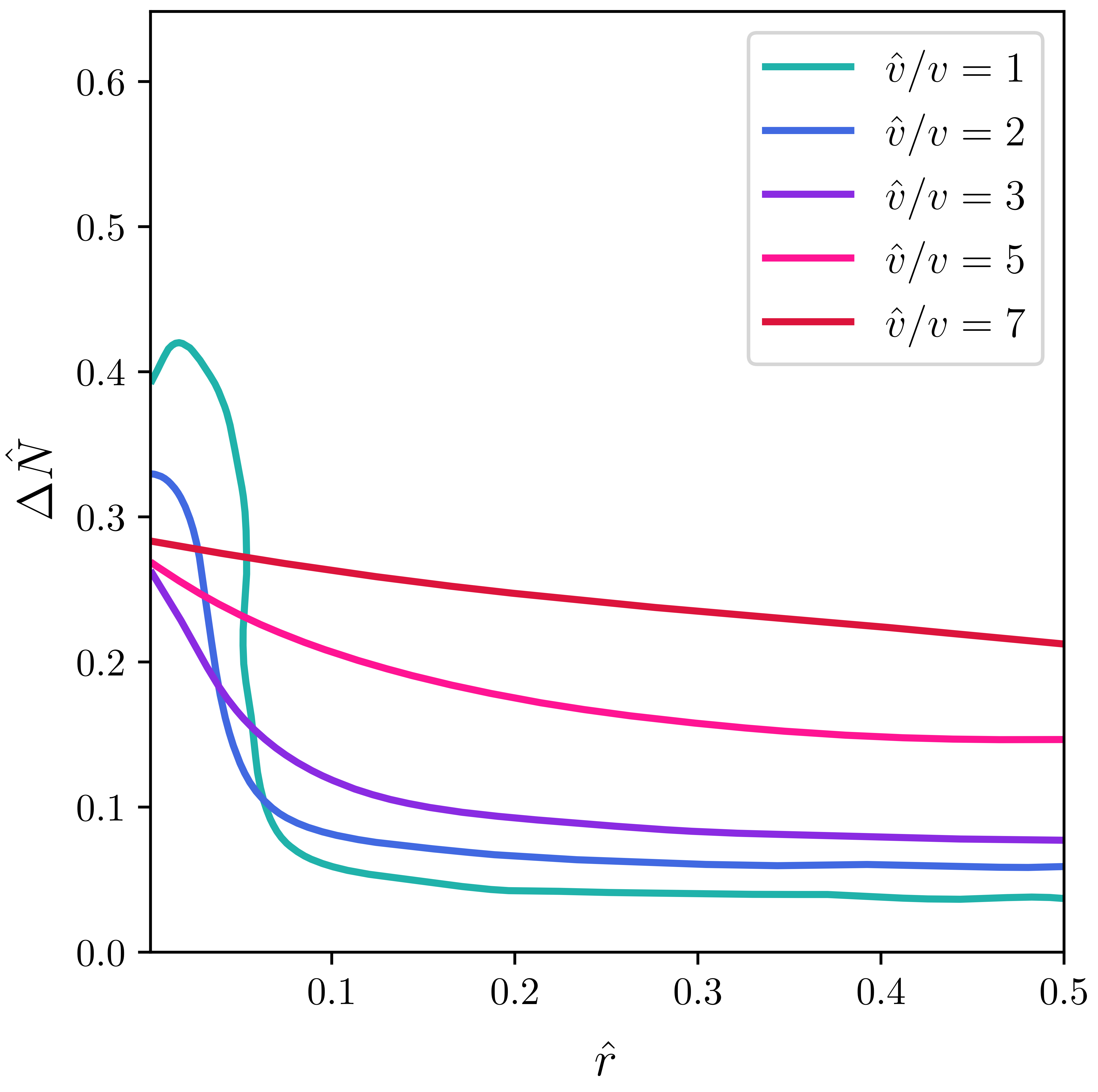
$\frac{P(\mathrm{MTH})}{P(\Lambda\mathrm{CDM}+\Delta\mathrm{N_{eff}})}$
$k\,(h\,\mathrm{Mpc}^{-1})$
Twin: $(\hat{r},\ \Delta\hat{N},\ \hat{v}/v)$; $\Delta N_{\rm eff} = \Delta\hat{N}$
(0.1, 0.3, 2)
(0.1, 0.3, 8)
(0.1, 0.5, 3)
(0.1, 0.1, 3)
(0.01, 0.3, 3)
(0.2, 0.3, 3)
(0.1, 0.3, 3)
$\frac{C_\ell^{\rm EE}(\mathrm{MTH})}{C_\ell^{\rm EE}(\Lambda\mathrm{CDM}+\Delta\mathrm{N_{eff}})}$
(0.1, 0.3, 3)
(0.5, 0.3, 3)
(0.1, 0.3, 2)
(0.1, 0.5, 3)
Twin: $(\hat{r},\ \Delta\hat{N},\ \hat{v}/v)$; $\Delta N_{\rm eff} = \Delta\hat{N}$
Multipole, ℓ
$\frac{C_\ell^{\rm TT}(\mathrm{MTH})}{C_\ell^{\rm TT}(\Lambda\mathrm{CDM}+\Delta\mathrm{N_{eff}})}$
(0.1, 0.3, 3)
(0.5, 0.3, 3)
(0.1, 0.3, 2)
(0.1, 0.5, 3)
Twin: $(\hat{r},\ \Delta\hat{N},\ \hat{v}/v)$; $\Delta N_{\rm eff} = \Delta\hat{N}$
Multipole, ℓ

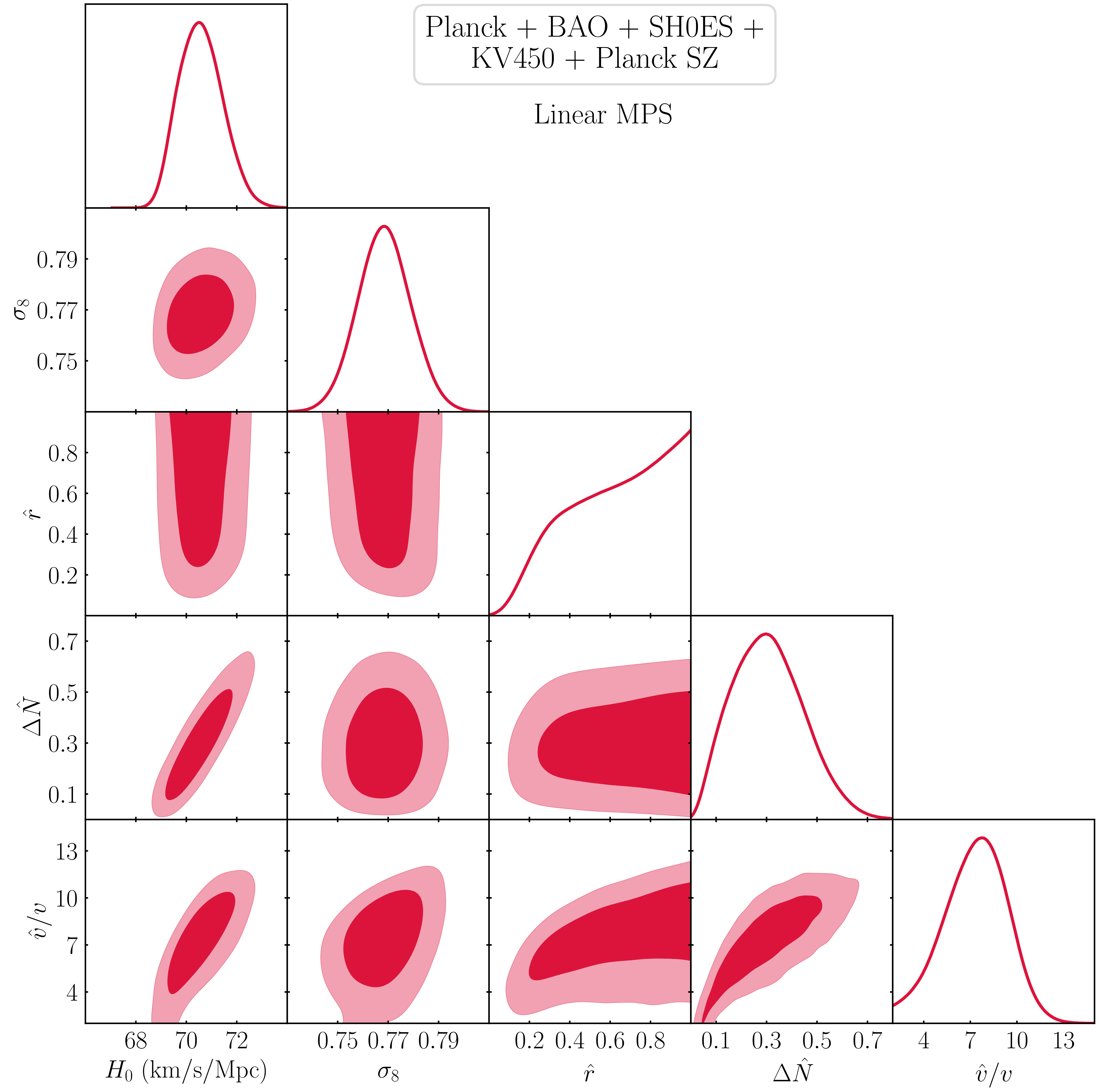


Planck + BAO
ΛCDM + N_{ur}
MTH
ΛCDM
σ_8
0.84
0.80
0.76
Ω_m
0.32
0.31
0.30
0.29
67 68 69 70 71
H_0 (km/s/Mpc)
0.76 0.80 0.84
σ_8
0.29 0.30 0.31 0.32
Ω_m



Planck + BAO + SH0ES + KV450
Linear MPS
$\Delta\hat{N}$
0.7
0.5
0.3
0.1
$\hat{v}/v$
13
10
7
4
0.2 0.4 0.6 0.8
$\hat{r}$
0.1 0.3 0.5 0.7
$\Delta\hat{N}$
4 7 10 13
$\hat{v}/v$

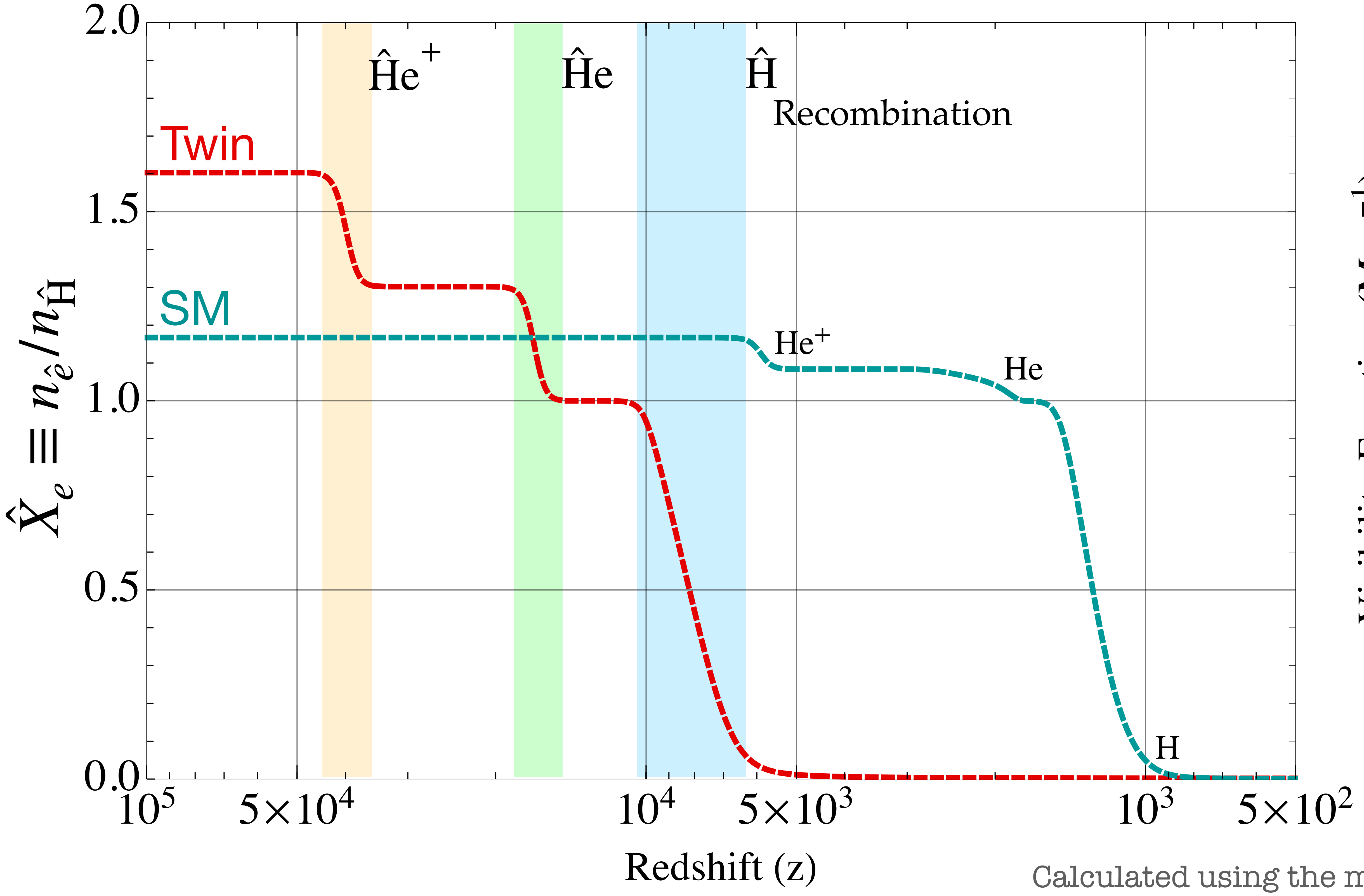

$\hat{v}/v = 1$
$\hat{v}/v = 2$
$\hat{v}/v = 3$
$\hat{v}/v = 5$
$\hat{v}/v = 7$
$\Delta\hat{N}$
$\hat{r}$

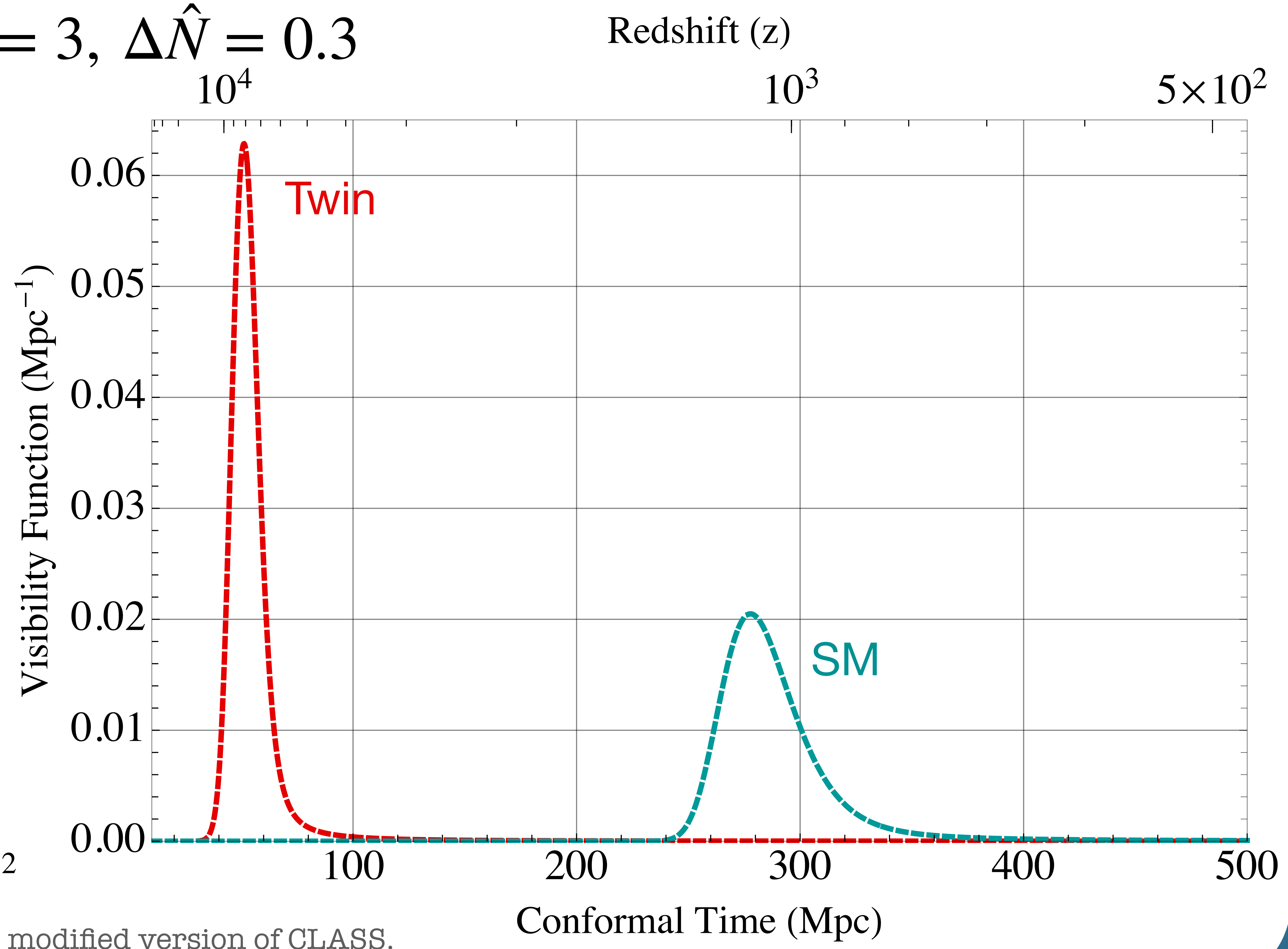

Planck + BAO + SH0ES + KV450 + Planck SZ
Linear MPS
σ_8
$\hat{r}$
$\Delta\hat{N}$
$\hat{v}/v$
H_0 (km/s/Mpc)

Twin Recombination $(T \sim \text{few eV})$

$\hat{\mathrm{He}}^{2+} + \hat{e}^- \to \hat{\mathrm{He}}^+ + \hat{\gamma}$	$\hat{\mathrm{He}}^{+} + \hat{e}^- \to \hat{\mathrm{He}} + \hat{\gamma}$	$\hat{p} + \hat{e}^- \to \hat{\mathrm{H}} + \hat{\gamma}$
Approximation using Saha Equation	Approximation using Saha Equation	Peebles Equation

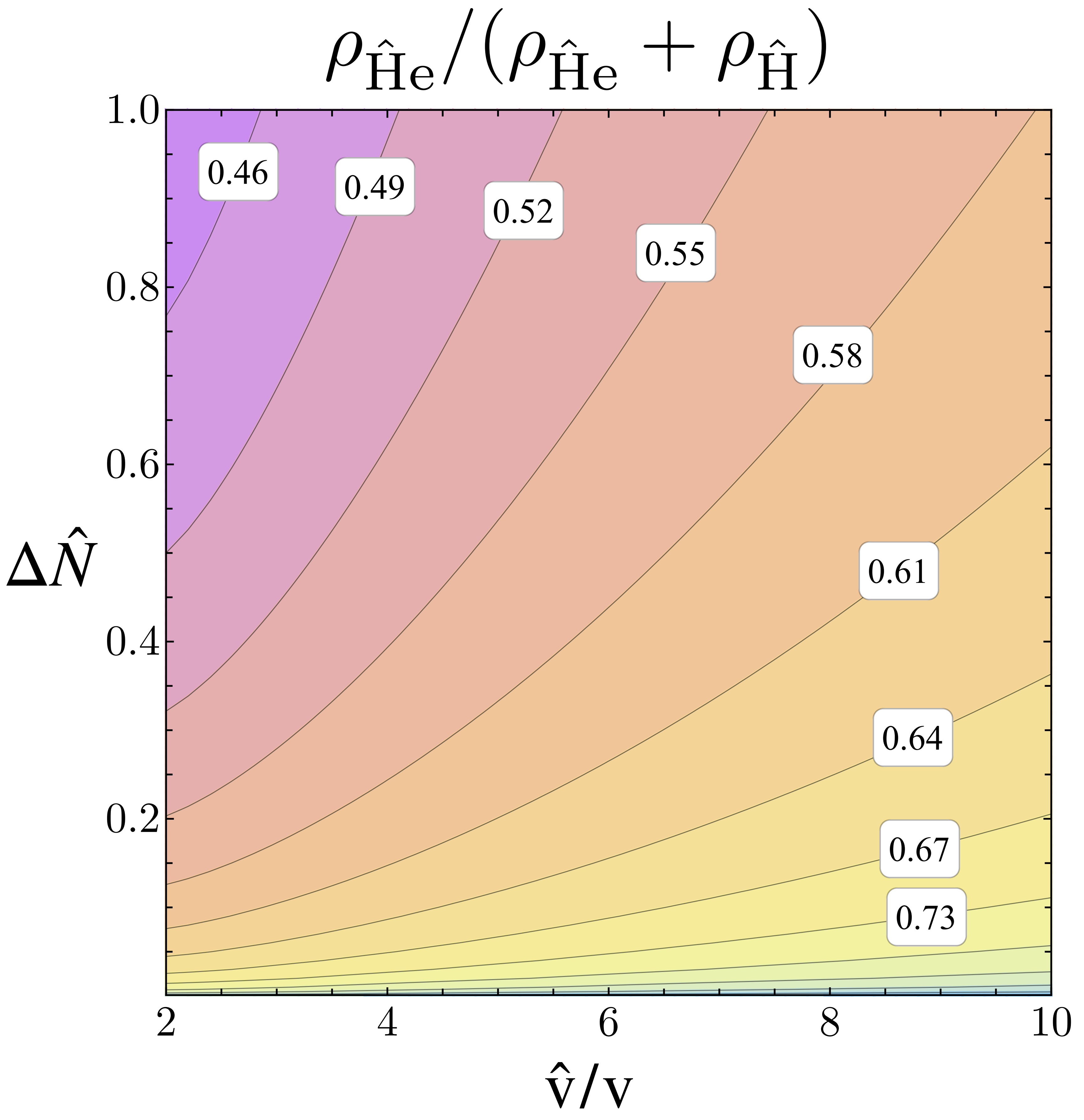
$$\hat{r} = 0.1,\ \hat{\mathrm{v}}/\mathrm{v} = 3,\ \Delta\hat{N} = 0.3$$





Calculated using the modified version of CLASS.

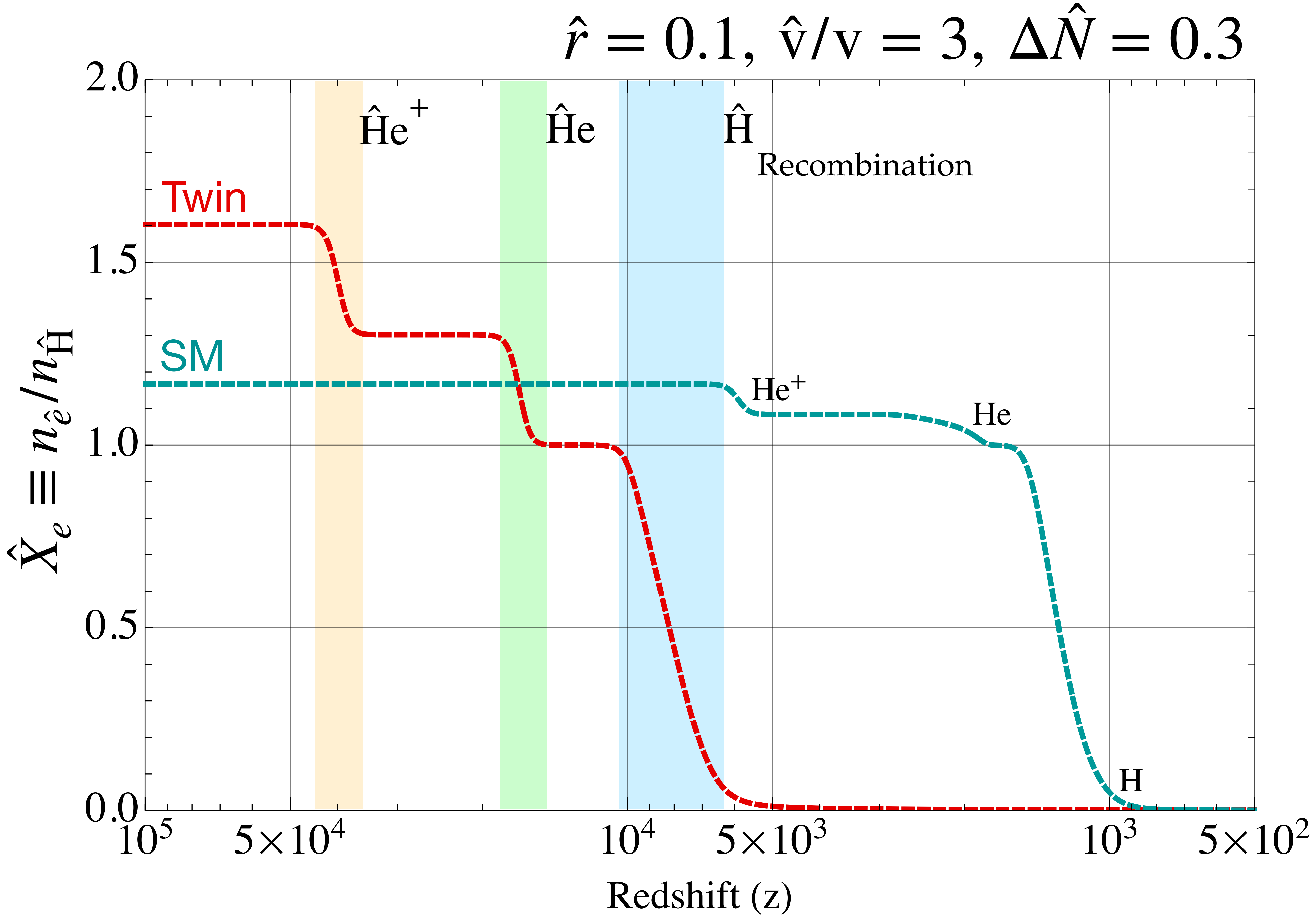
Twin BBN ($T \sim$ few MeV)



SM: ~ 25% mass is in **He**

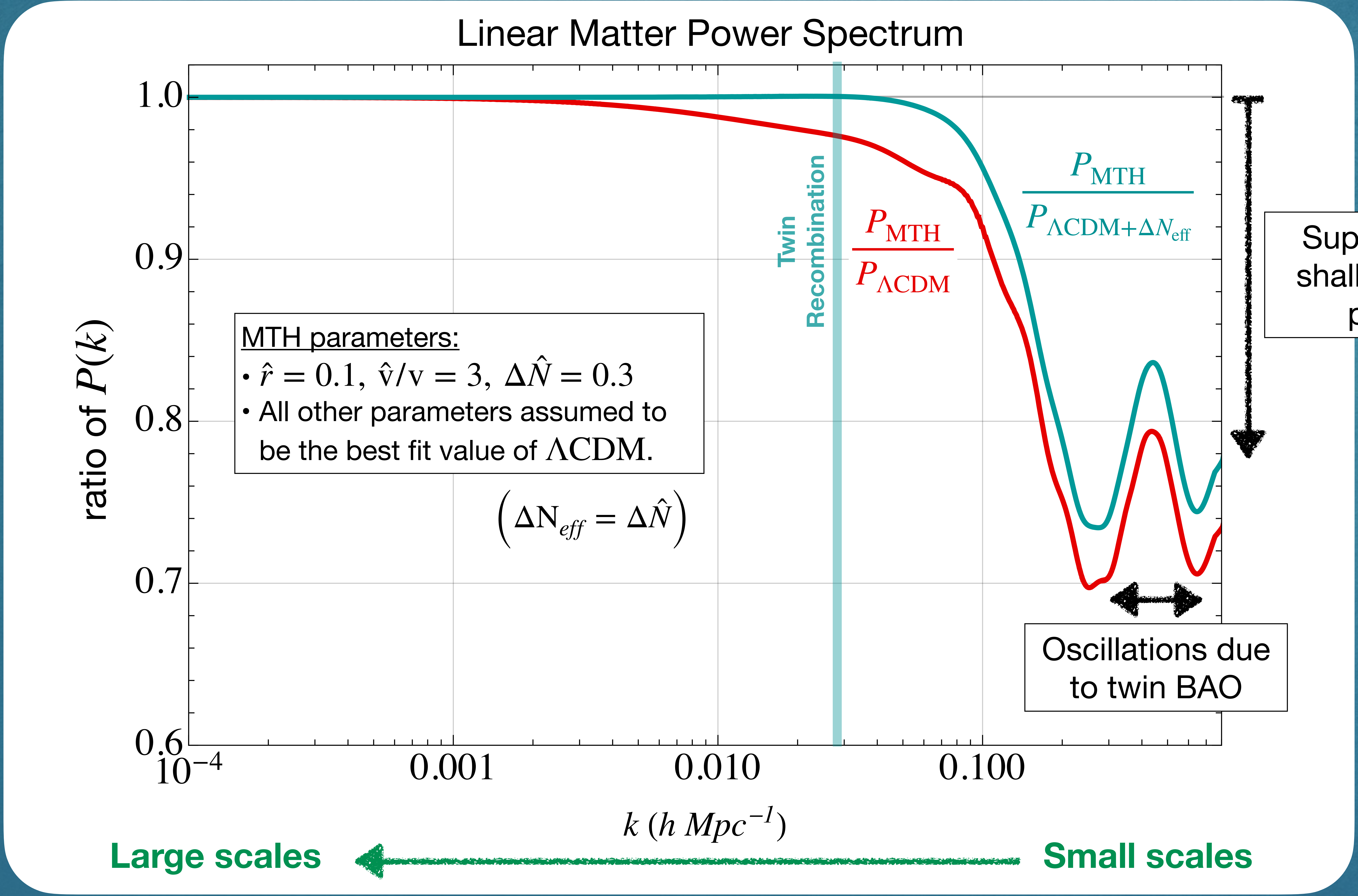
Twin: > 50% mass is in **twin He**

Twin Recombination ($T \sim$ few eV)



ADD TEXT

Large Scale Structures



Cosmic Microwave Background