PHENO
2021

Hidden Naturalness

In the Light of Cosmological Datasets

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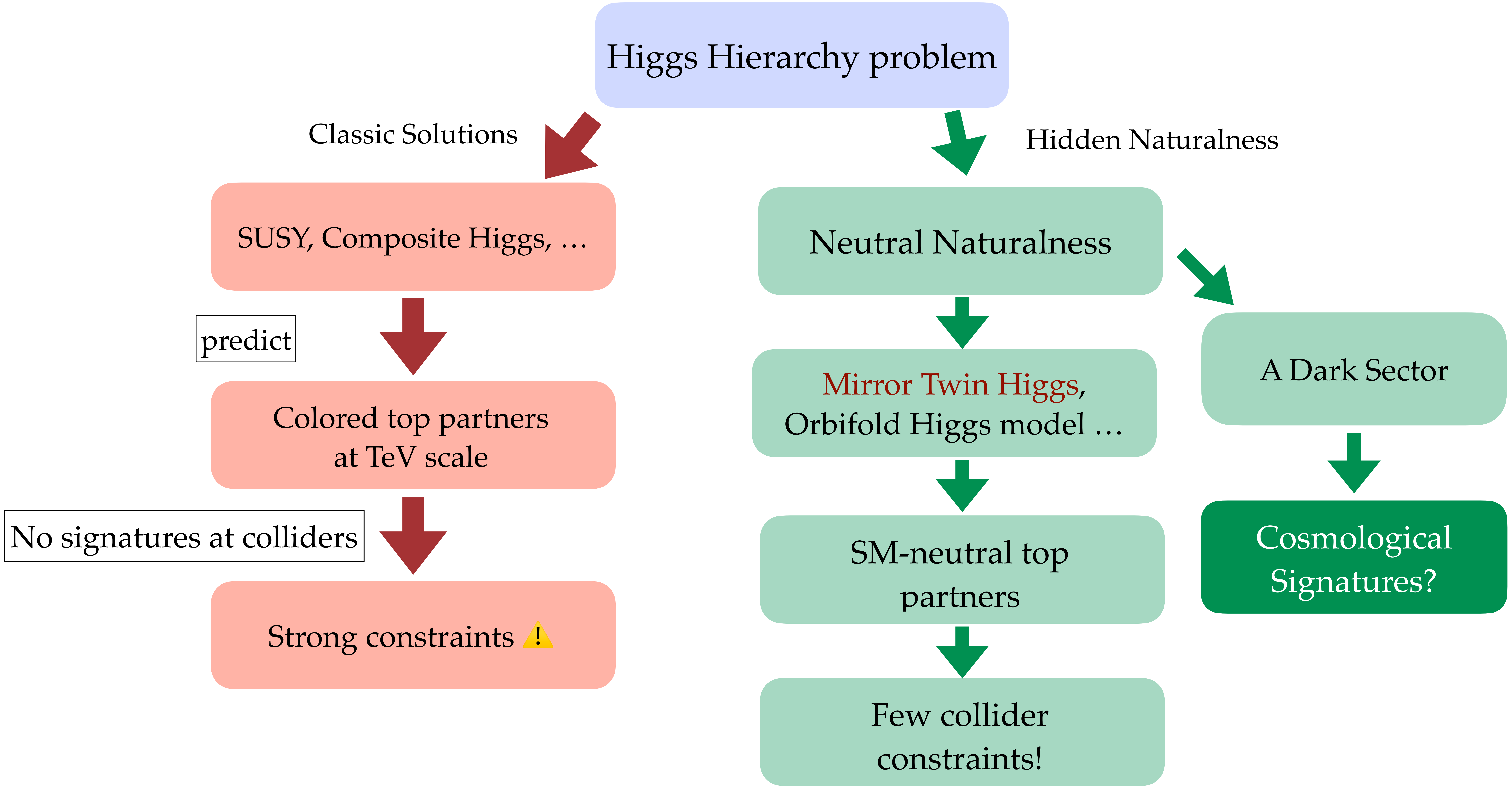
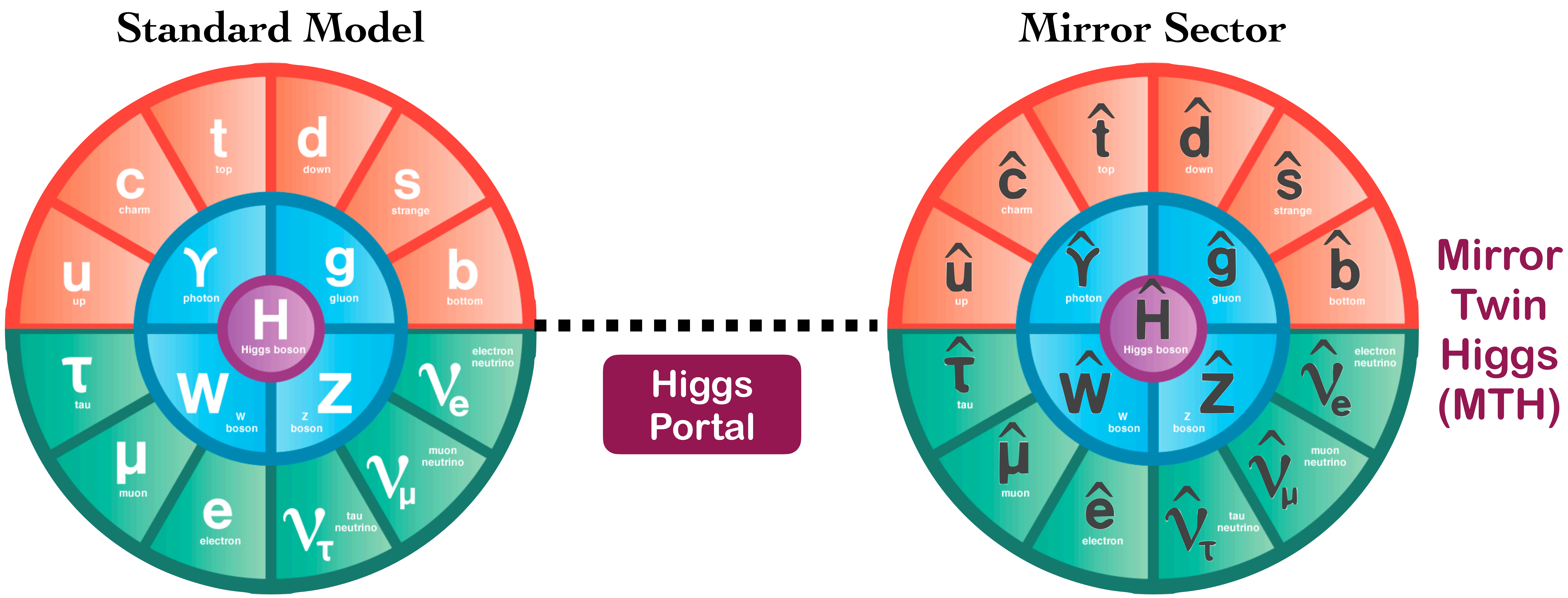
Motivation



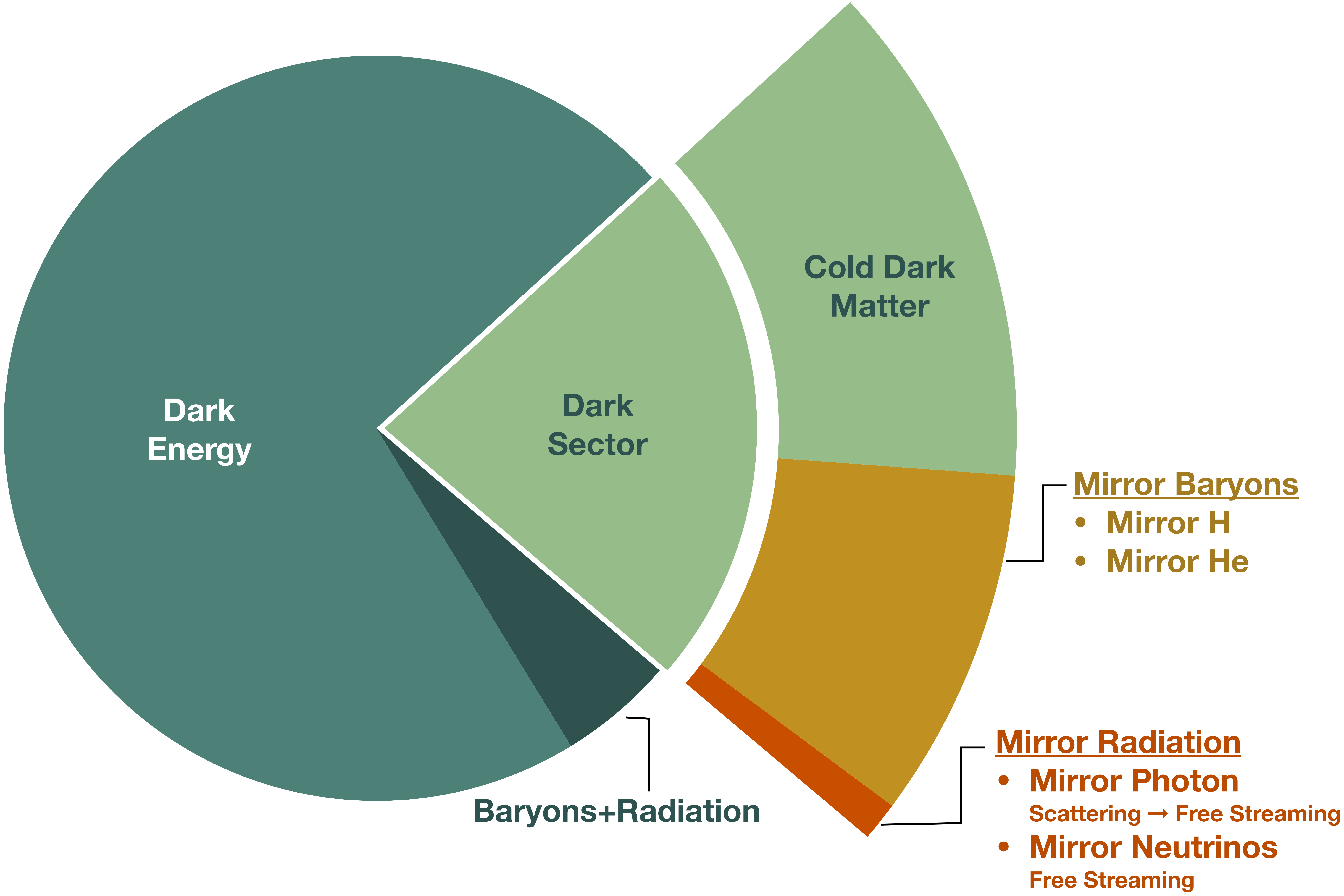
Higgs Hierarchy problem
Classic Solutions
Hidden Naturalness
SUSY, Composite Higgs, …
predict
Colored top partners
at TeV scale
No signatures at colliders
Strong constraints ⚠️
Neutral Naturalness
Mirror Twin Higgs,
Orbifold Higgs model …
SM-neutral top
partners
Few collider
constraints!
A Dark Sector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

Mirror Twin Higgs (MTH) model

Chacko, Goh, Harnik (2005)



The Universe



Mirror Twin Higgs model

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

$2 \lesssim (\hat{v}/v) \lesssim 8$

experimental bounds — fine tuning

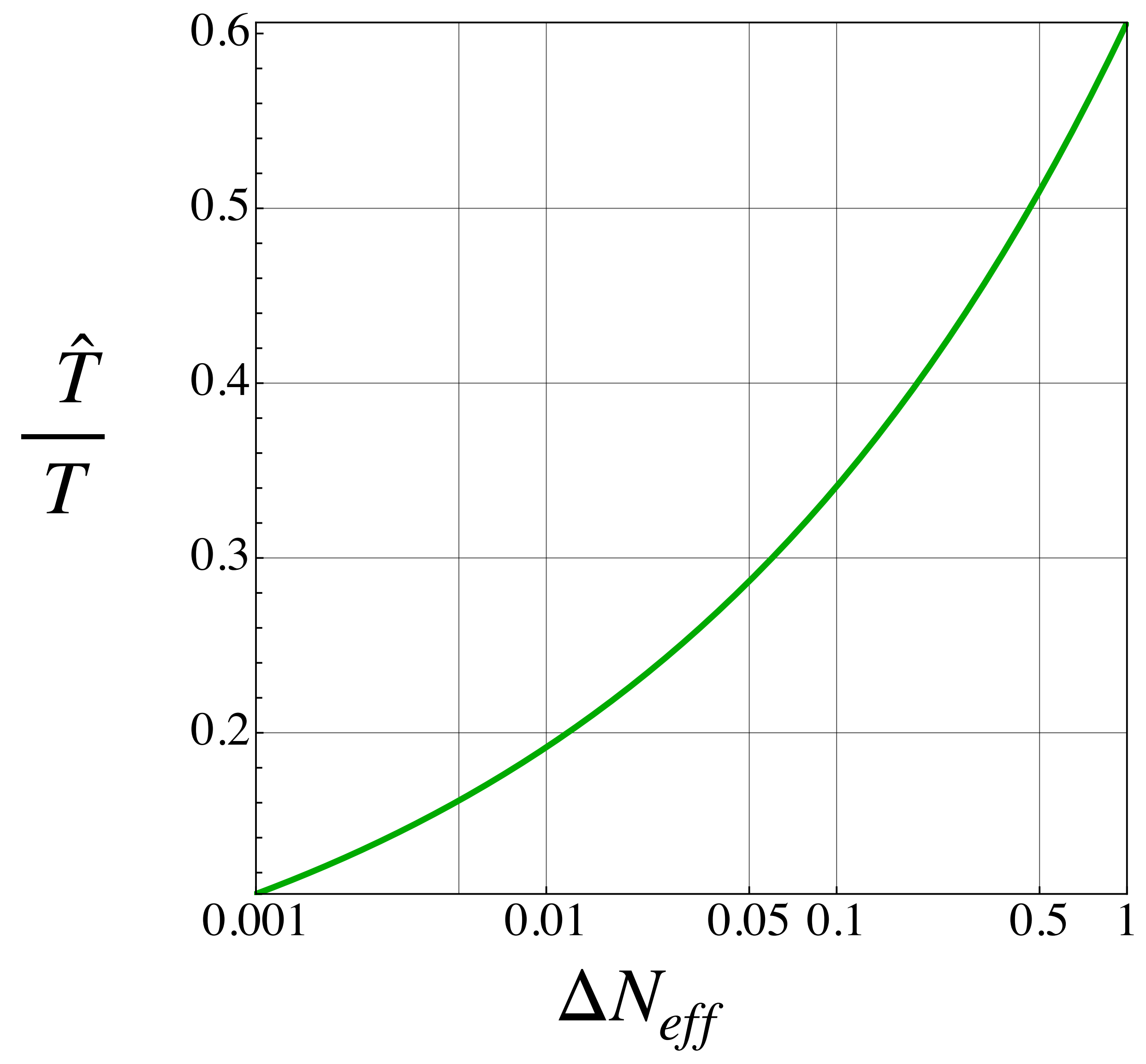
→ Mirror particles are heavier

Softly broken MTH model

2. $\hat{T}$ (or $\Delta\hat{N}$) Temperature of the mirror photons

ΔN_{eff} Constraints: $(\hat{T}/T) \lesssim 0.5$

Chacko, Craig, Fox, Harnik '16
Berezhiani, Dolgov, Mohapatra '96
Farina, Monteux, Shin '16
Craig, Koren, Trott '16
Garcia, Lasenby, March-Russell '15
Adshead, Cui, Shelton '16

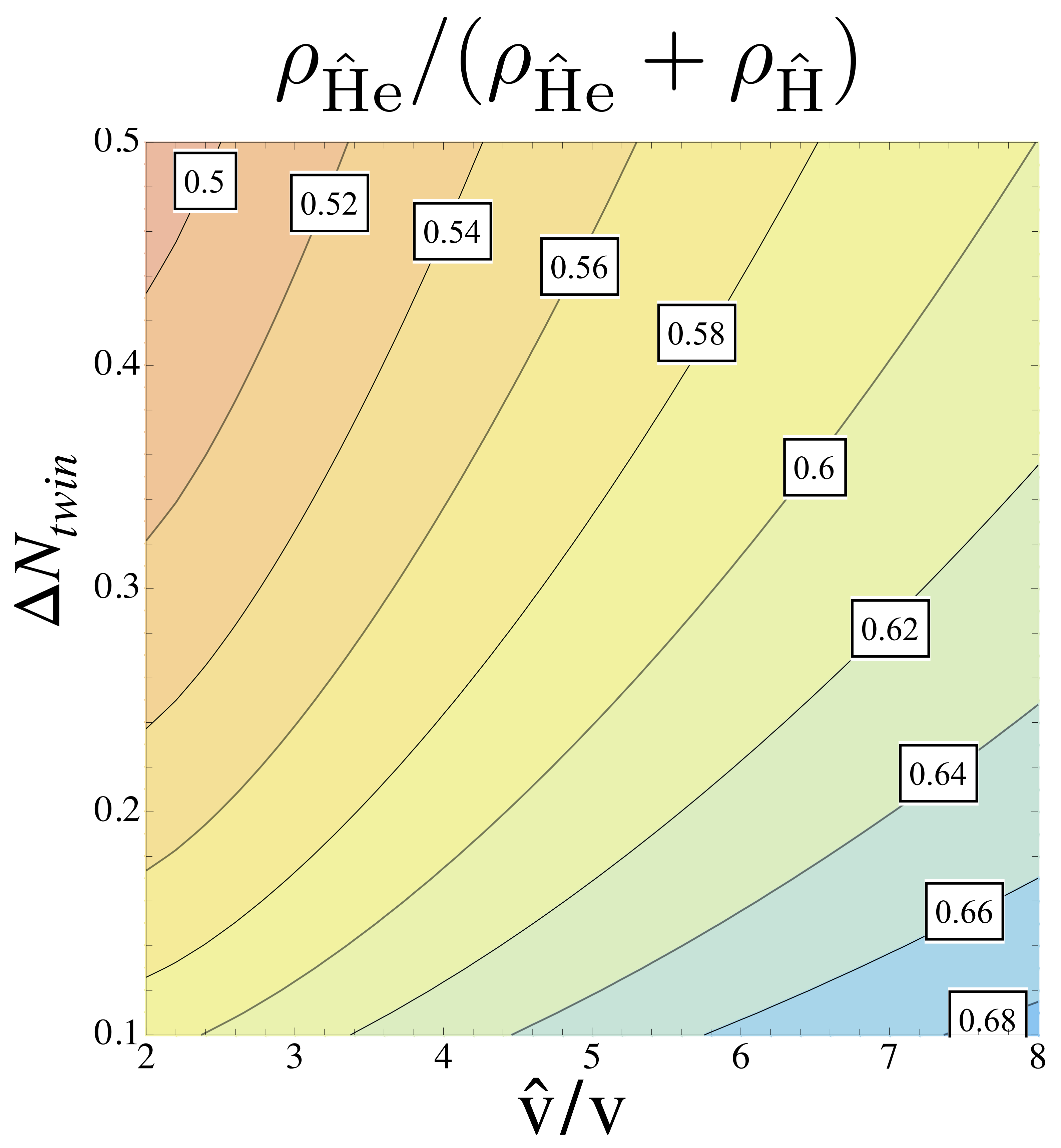


3. $\hat{r} = \Omega_{MTH}/\Omega_{DM}$ Amount of mirror baryons today

- Incorporated MTH model into CLASS with 3 additional input parameters.

CLASS: Blasa, Lesgourgues, Tram (2011)

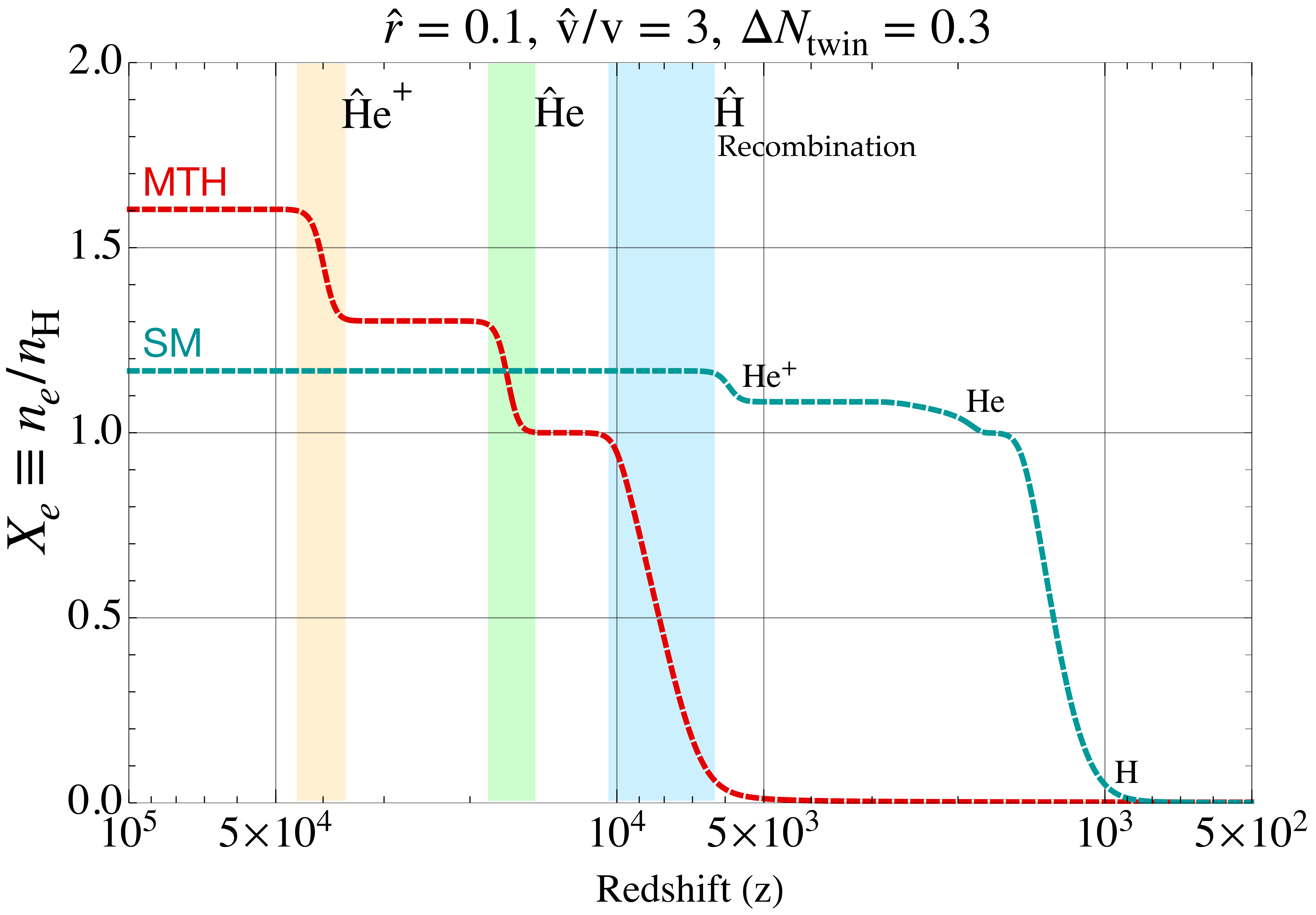
Mirror BBN



Mirror: $>50\%$ mass is in **mirror He**

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

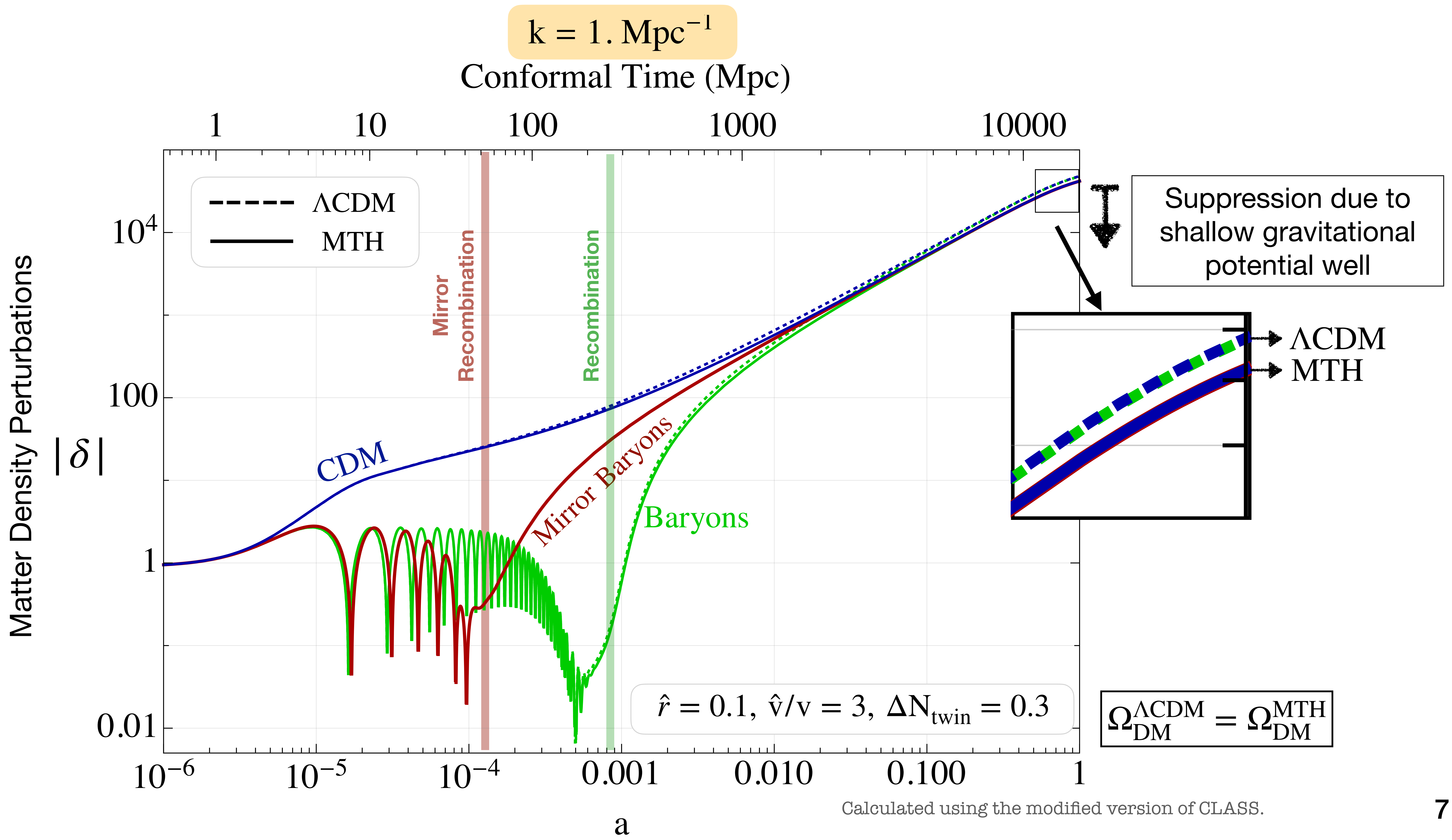
Mirror Recombination



Calculated using the modified version of CLASS.

Chacko, Curtin, Geller, Tsai (2018, see also 2021 for galaxy structure)

Evolution of Matter perturbations



Calculated using the modified version of CLASS.

Cosmological Data

- Planck 2018: Planck low ℓ TT , Planck low ℓ EE, Planck high ℓ TTTEEE, lensing
- BAO: BOSS BAO-only DR12, $D_V/r_{\rm drag}$ by 6dFGS at $z = 0.106$, MGS galaxy sample at $z = 0.15$
- LSS:
  -KiDS+VIKING-450 ($k_{\rm max} = 0.3\, h\, {\rm Mpc}^{-1}$), Planck 2018 lensing
  - Planck SZ cluster counts $\sigma_8(\Omega_m/0.27)^{0.30} = 0.782 \pm 0.010$ $(68\,\%\ {\rm C.L.})$
- SH0ES: $H_0 = 74.03 \pm 1.42$ km/s/Mpc $(68\,\%\ {\rm C.L.})$
- Used MontePython along with the modified version of CLASS to perform MCMC scan of the three mirror parameters, along with the six ΛCDM parameters.

MontePython 3: Brinckmann, Lesgourgues (2018)

Planck 2018

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

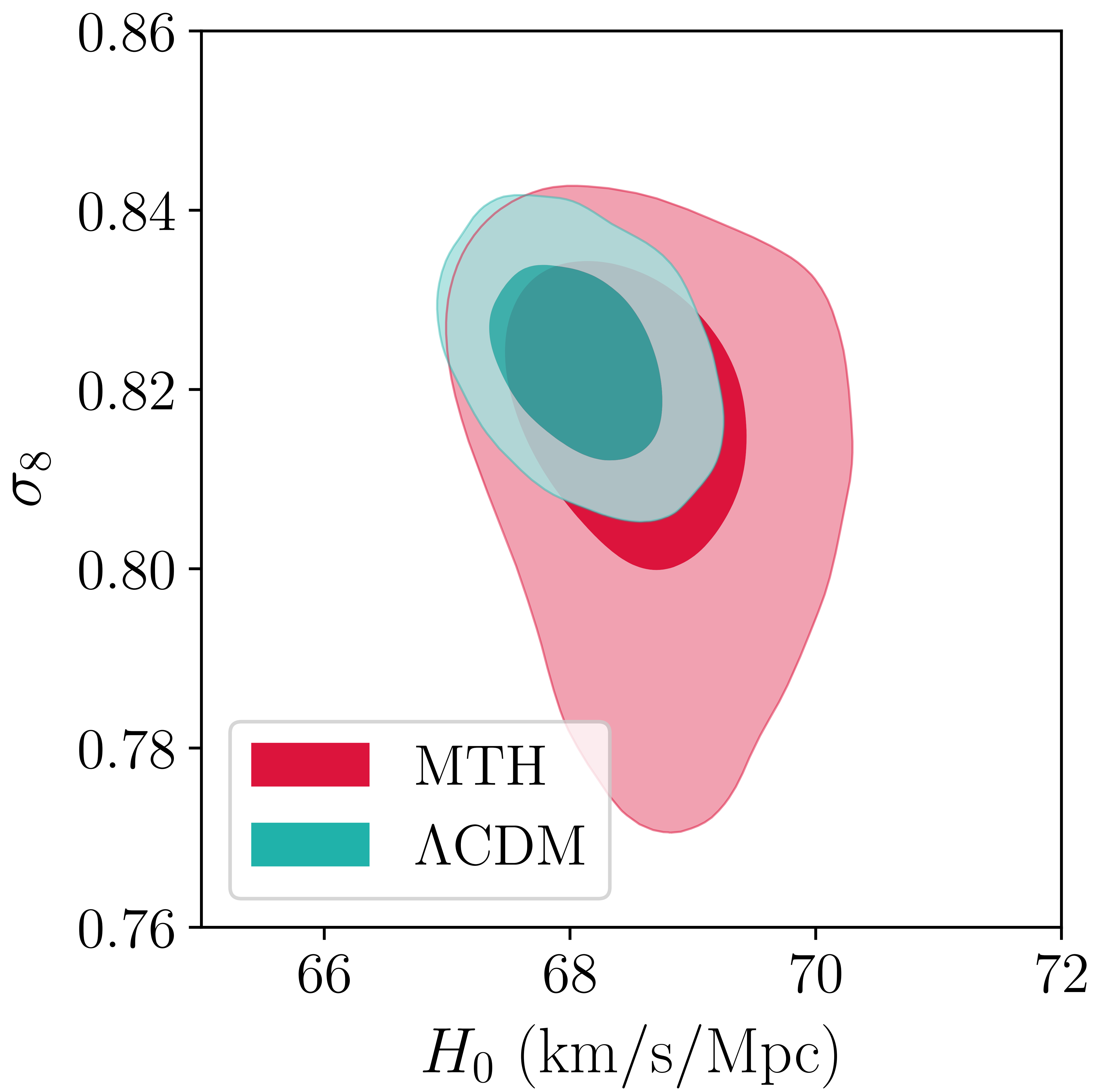
MCMC results

Planck 18 TT, TE, EE, Lensing

Model	Minimum χ^2
ΛCDM	2773
MTH	2775

The MTH model does not improve the fit to the Planck data for the range of parameter used in our analysis!

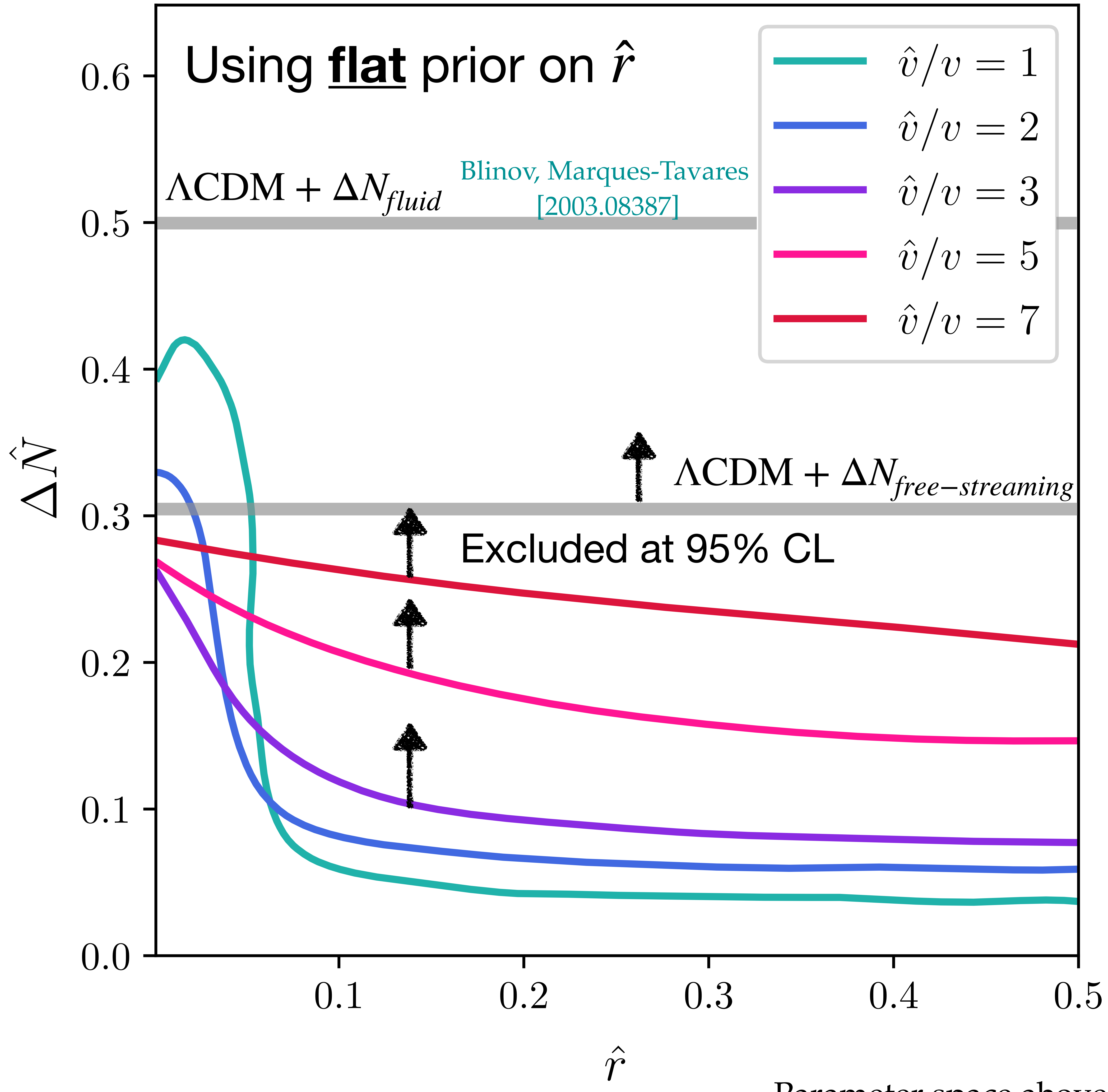
Use this dataset to constrain the parameter of MTH model.

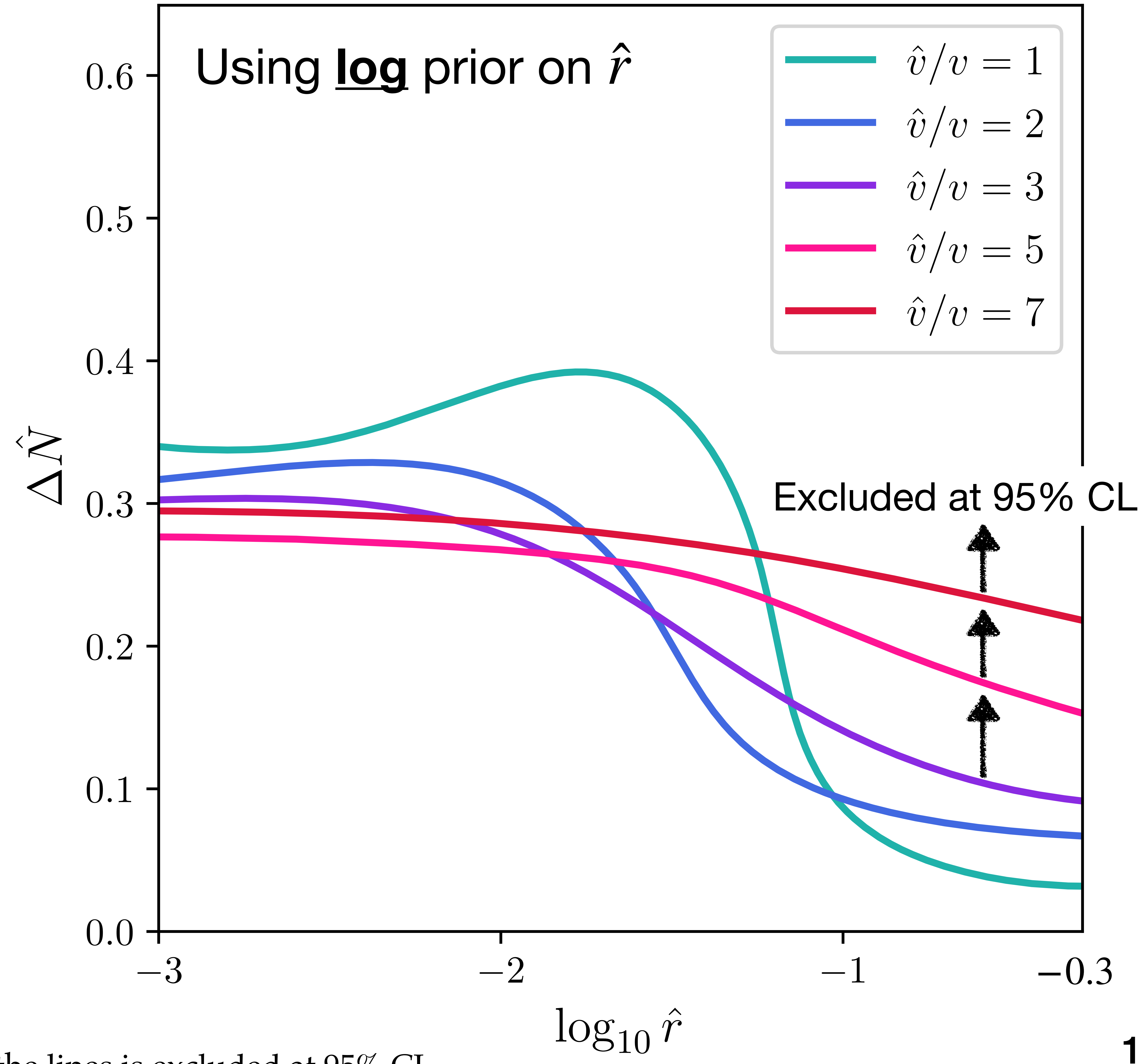


Constraints Fixed $\hat{v}/v$

Planck 18 TT, TE, EE, lensing, BAO

$\hat{r} = \Omega_{MTH}/\Omega_{DM}$





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

+ LSS

KiDS
&
VIKING
+
Planck SZ

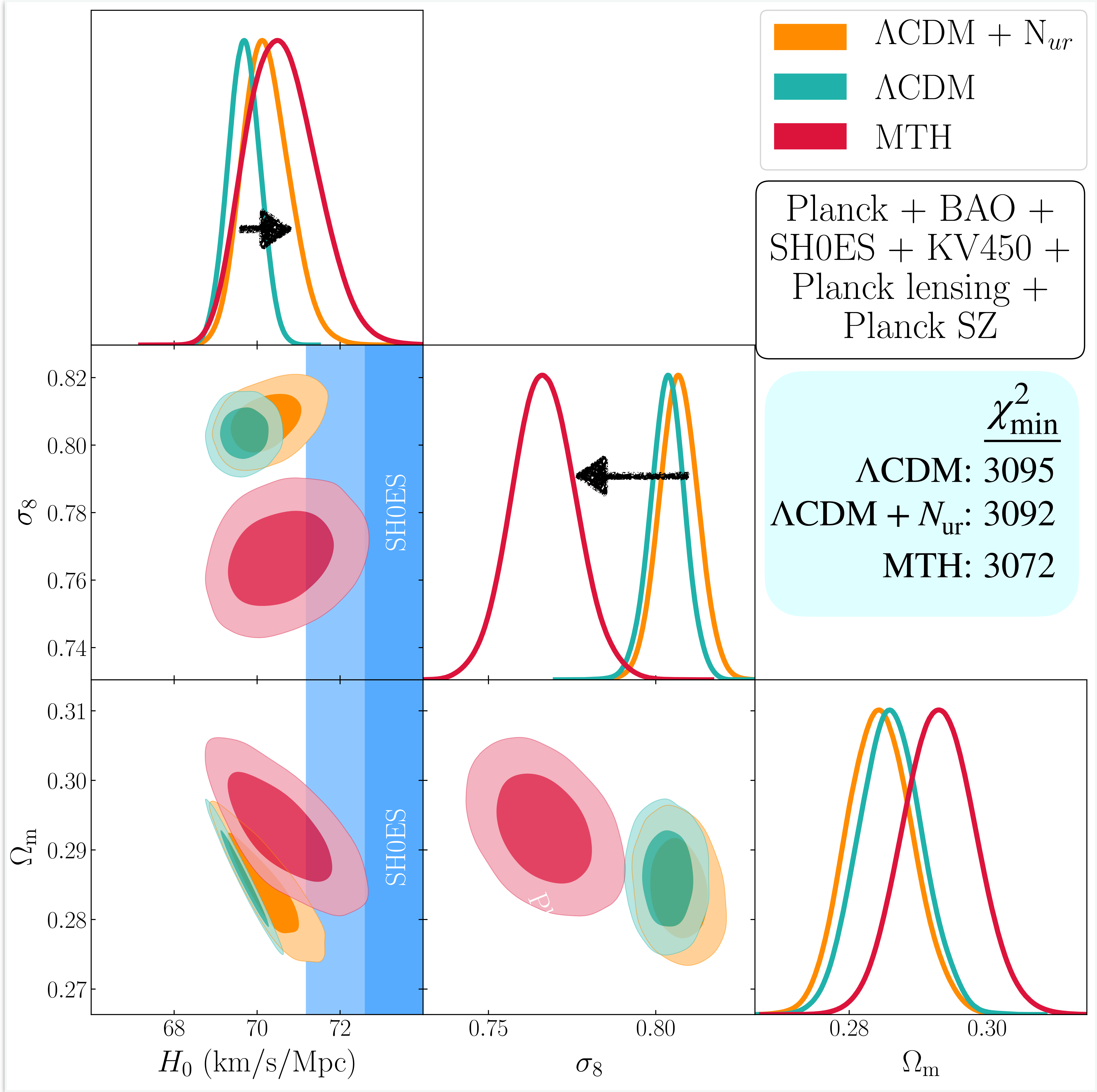
+ H_0

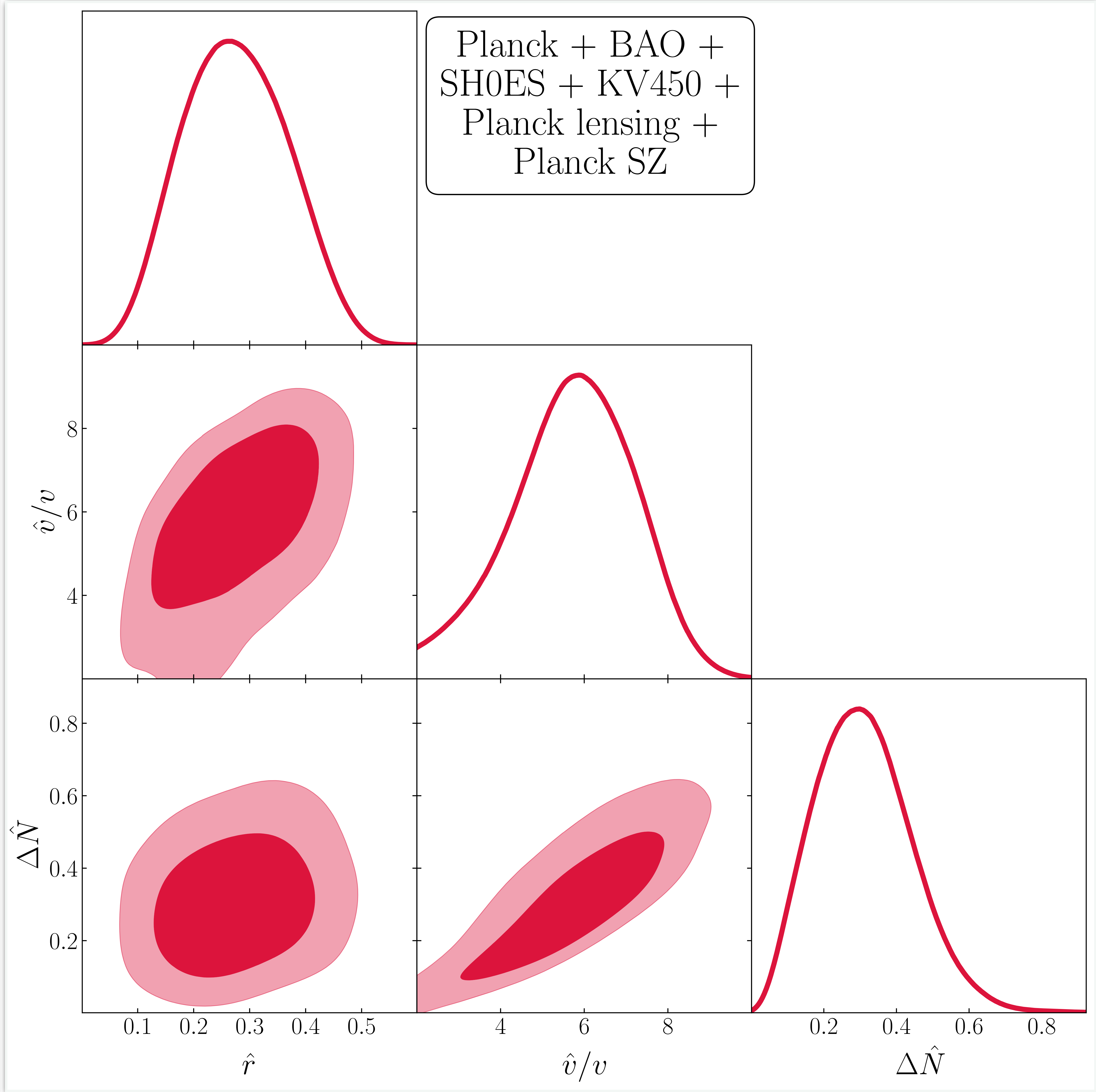
SH0ES

Range of MTH parameters: $0.001 \leq \hat{r} \leq 0.75$ $2 \leq \hat{v}/v \leq 10$ $0.001 \leq \Delta N_{\rm twin} \leq 1$

Using **flat** prior

MCMC results





$\hat{r} = \Omega_{MTH}/\Omega_{DM}$

MCMC results

Experiment	Minimum χ^2 ΛCDM	Minimum χ^2 MTH	$\Delta\chi^2$ MTH − ΛCDM	
Planck high ℓ TTTEEE	2363.6	2361.8	-1.7 ✔	Planck
Planck low ℓ TT	21.9	22.1		
Planck low ℓ EE	396.0	395.9		
BAO	8.5	7.2	-1.3 ✔	BAO
Planck lensing	12.0	10.4	-17.4 ✔	LSS
KV450	268.3	267.2		
Planck SZ	15.0	0.3	σ_8	
SH0ES	10.0	7.5	-2.5 ✔	H_0
Total	3095.3	3072.3	**-23.0**	

Parameter	Mean Value MTH	Mean Value ΛCDM
$\hat{r}$	$0.2755^{+0.095}_{-0.1}$	-
$\hat{v}/v$	$5.725^{+1.7}_{-1.3}$	-
ΔN_{twin}	$0.3082^{+0.11}_{-0.16}$	-
σ_8	$0.7669^{+0.0092}_{-0.01}$	$0.8041^{+0.0056}_{-0.0049}$
H_0	$70.62^{+0.75}_{-0.98}$	$69.55^{+0.36}_{-0.38}$

The MTH model improves χ^2 for all the categories.

For general IDM-DR model, see: Buen-Abad. Schmaltz, Lesgourgues, Brinckmann ’17

Summary

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

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

- Taken alone, the Planck data strongly constrains the mirror 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 ~25% mirror baryons.
  - In this case, the MTH model can ameliorate both the σ_8 and H_0 tensions!

- In the future,
  - Pursue improvements to the non-linear evolution of the mirror sector.
  - Generalize this analysis to a broad range of hidden naturalness scenarios.

Thanks!

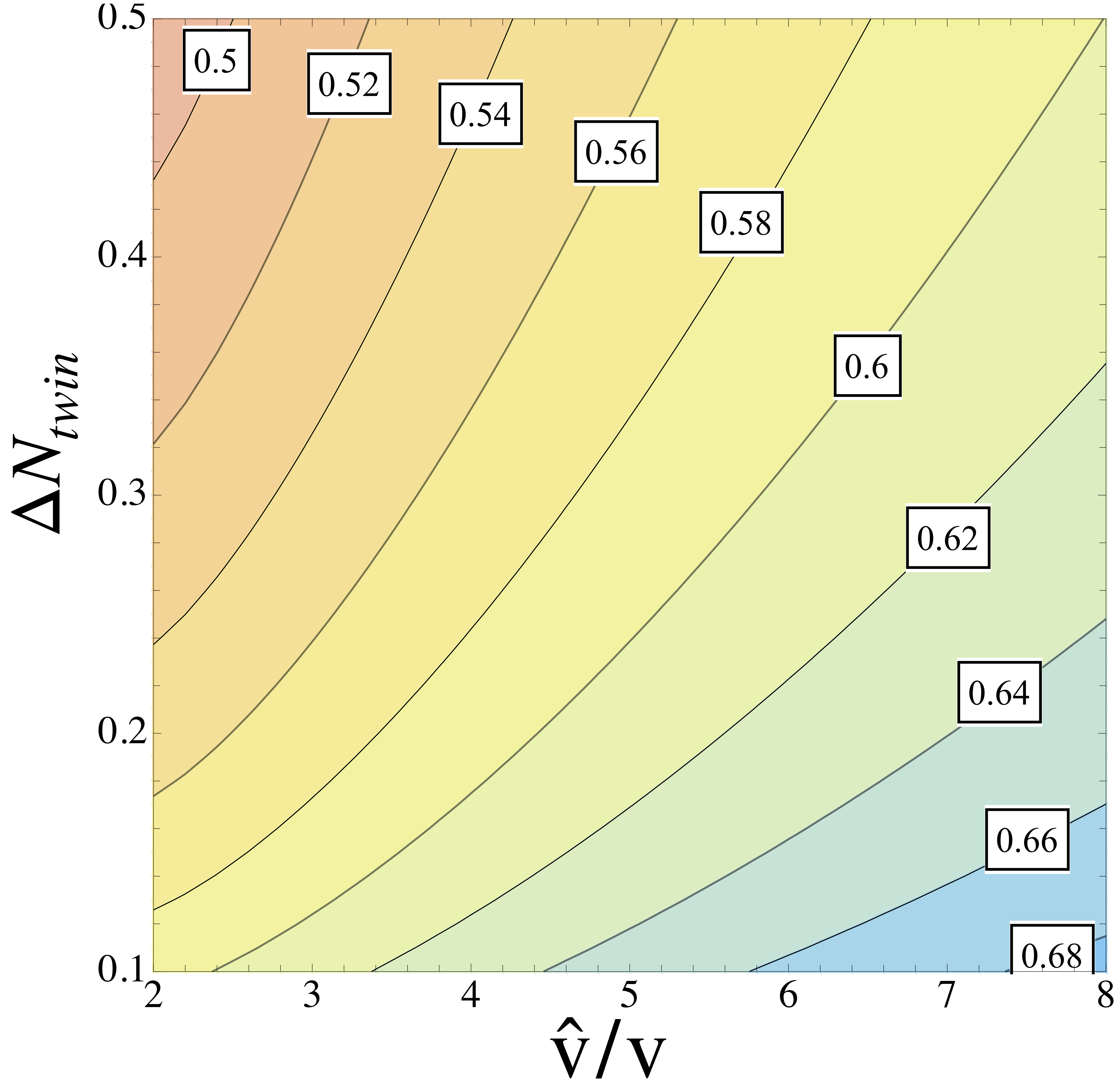
Backup

Mirror BBN

Chacko, Curtin, Geller, Tsai (2018)

Different vev ⇒ Different mass spectrum ⇒ Different abundances

$\rho_{\hat{\mathrm{He}}}/(\rho_{\hat{\mathrm{He}}} + \rho_{\hat{\mathrm{H}}})$



Mirror: $>$ 50% mass is in **mirror He**

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

$T_{FO} \sim 2 - 50$ MeV

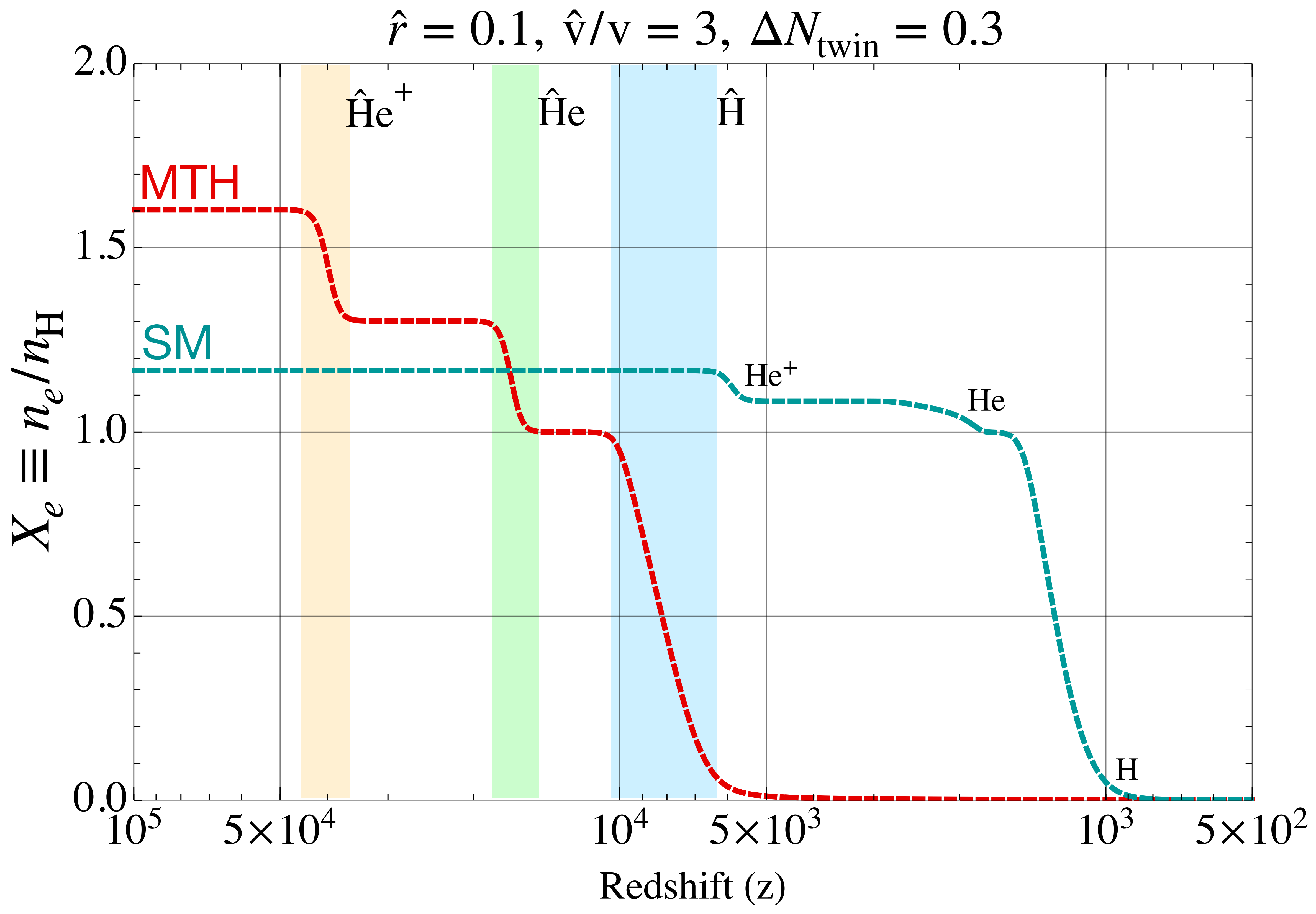
ΔN_{twin} ↑ ⇒ late BBN ⇒ Y_{He} ↓

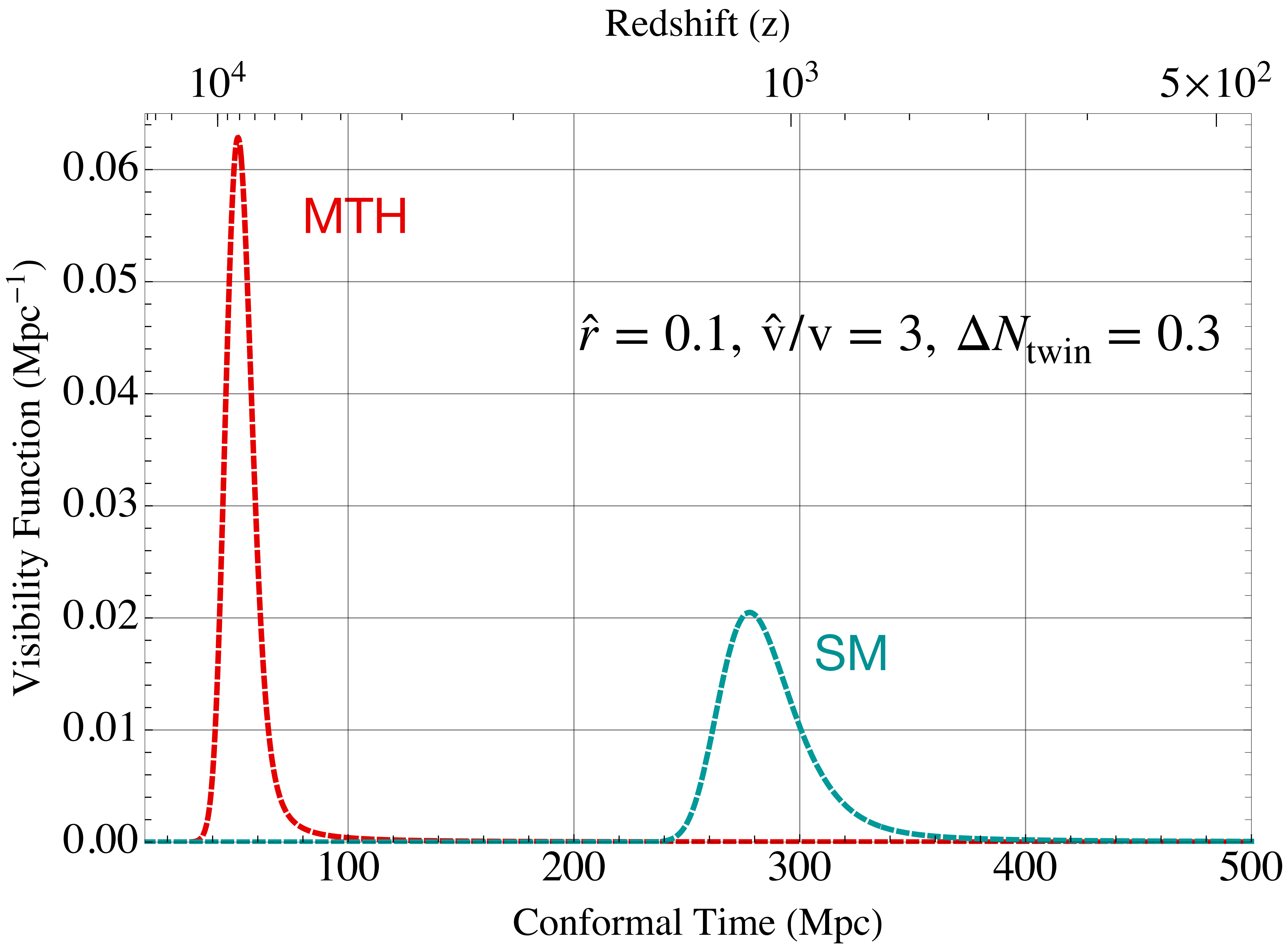
$\hat{v}/v$ ↑ ⇒ early BBN ⇒ Y_{He} ↑

Mirror Recombination

Chacko, Curtin, Geller, Tsai (2018)

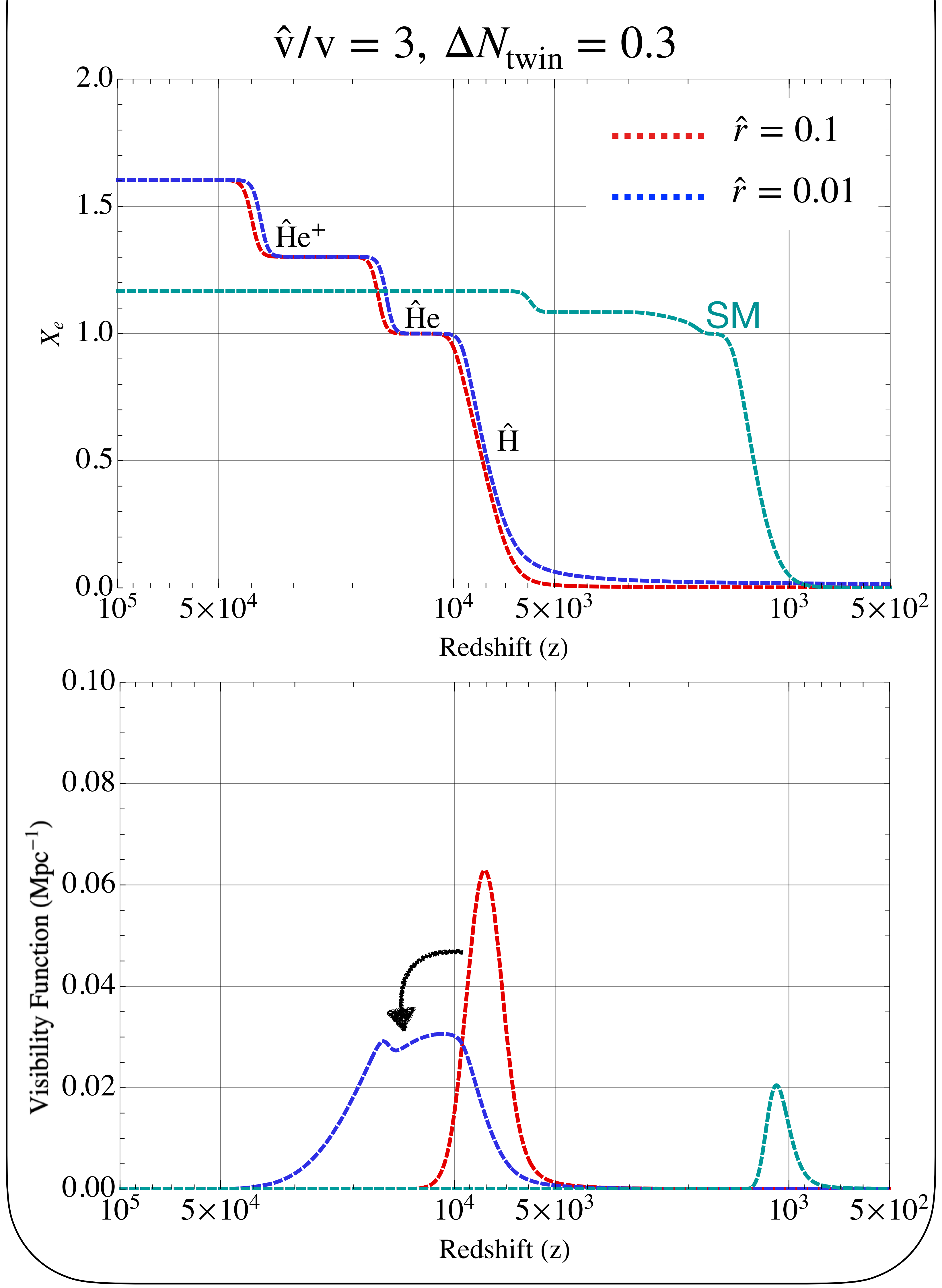
$\hat{\mathrm{He}}^{2+} + \hat{e}^- \rightarrow \hat{\mathrm{He}}^+ + \hat{\gamma}$	$\hat{\mathrm{He}}^+ + \hat{e}^- \rightarrow \hat{\mathrm{He}} + \hat{\gamma}$	$\hat{p} + \hat{e}^- \rightarrow \hat{\mathrm{H}} + \hat{\gamma}$
Approximation using Saha Equation	Approximation using Saha Equation	Peebles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





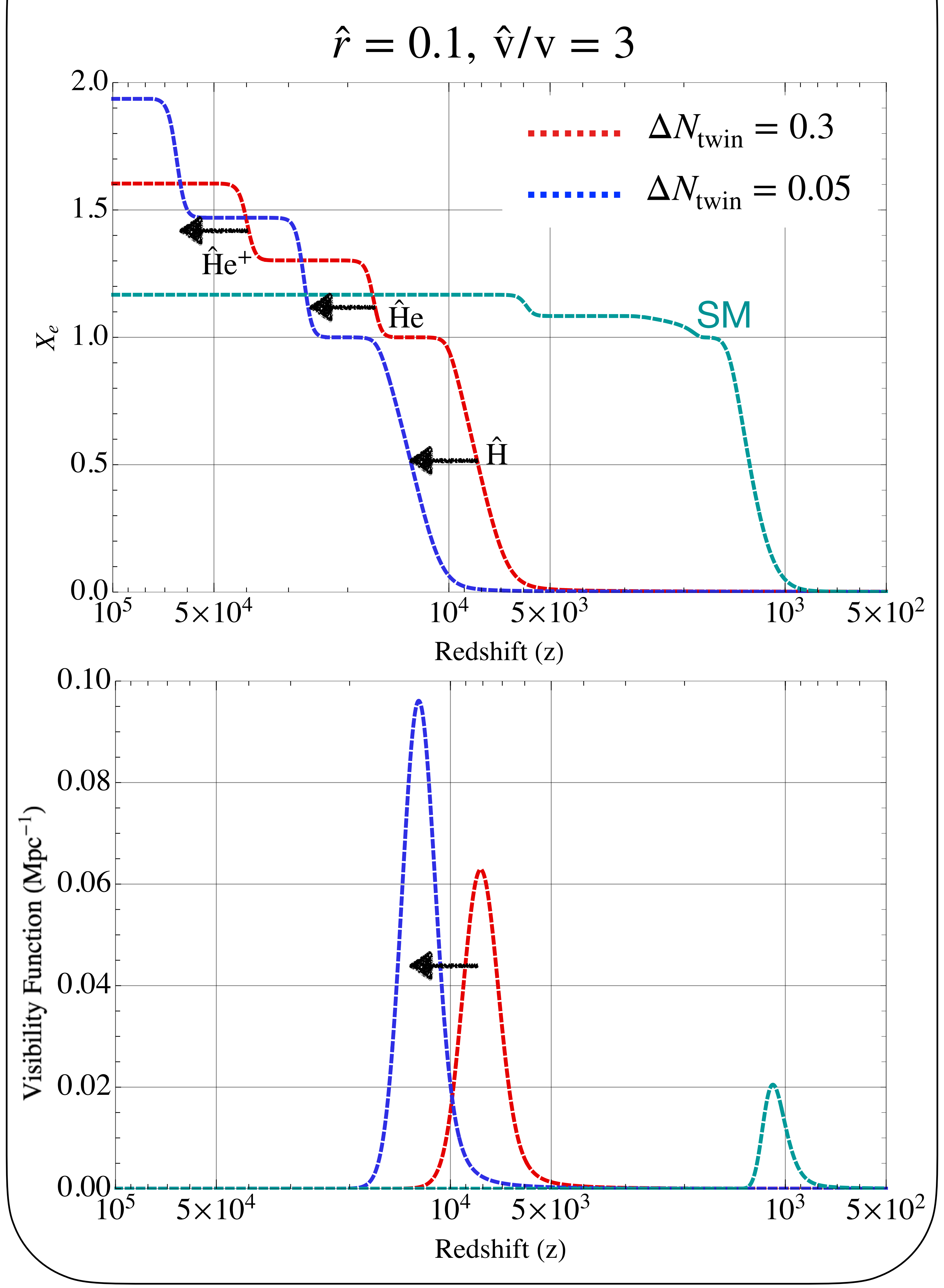
Calculated using the modified version of CLASS.

$\hat{r}$: 0.1 → 0.01



Sparse mirror sector ⇒ Many dark photons last interacted with $\hat{He}$

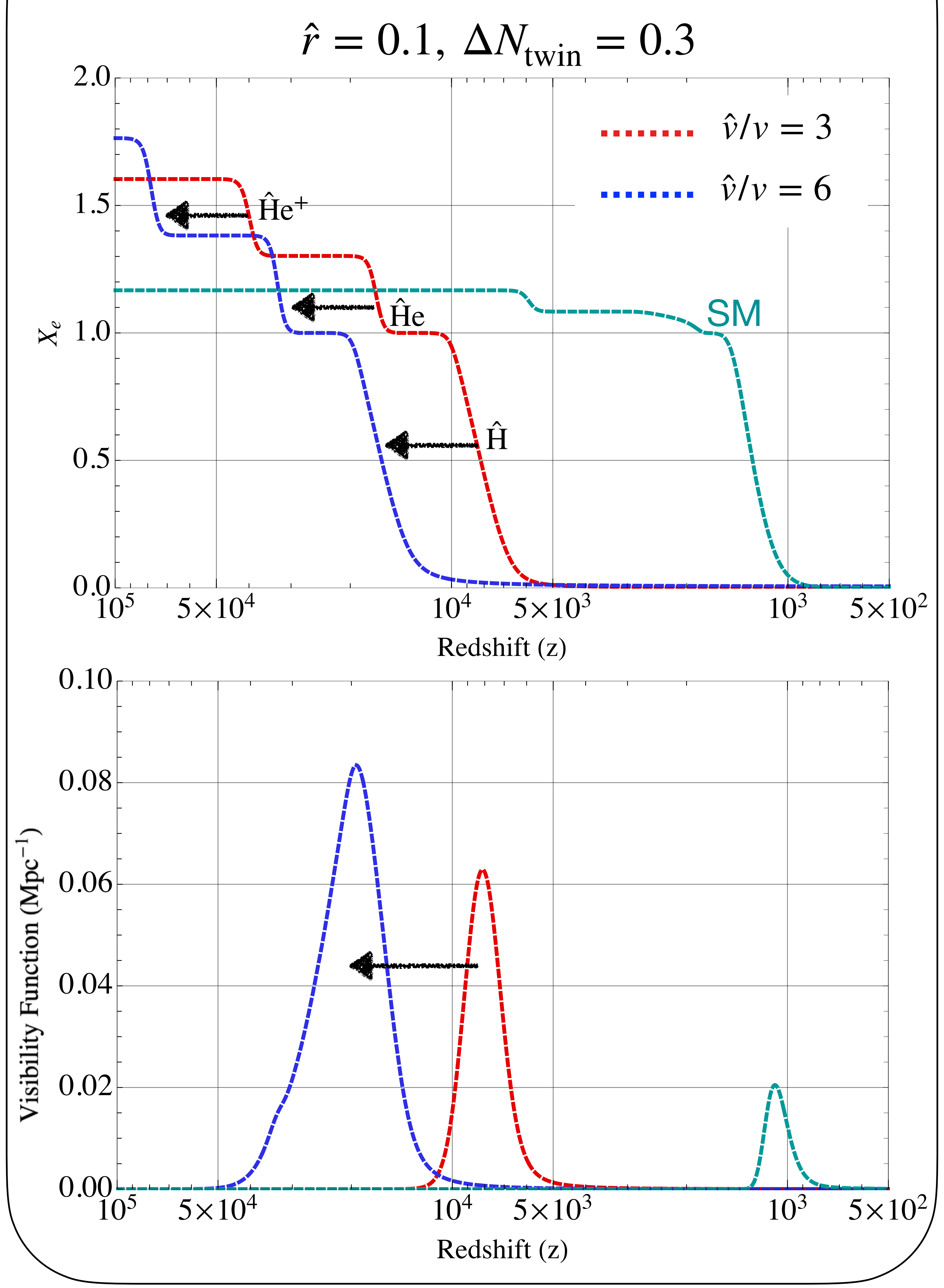
ΔN_{twin} : 0.3 → 0.05



Colder mirror sector ⇒ Early recombination

Hotter mirror sector ⇒ Late recombination

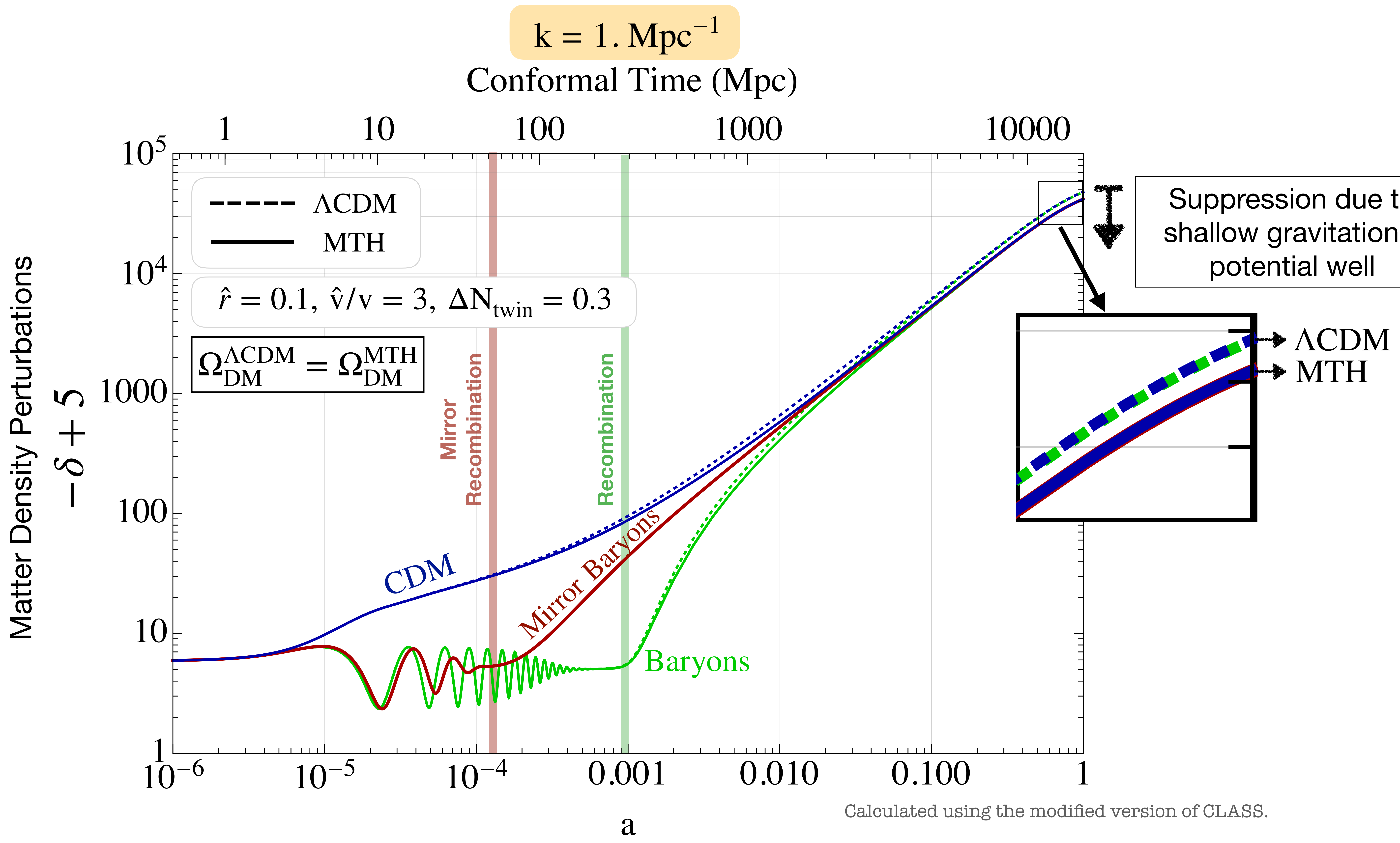
$\hat{v}/v$: 3 → 6



Heavier mirror sector ⇒ Early recombination

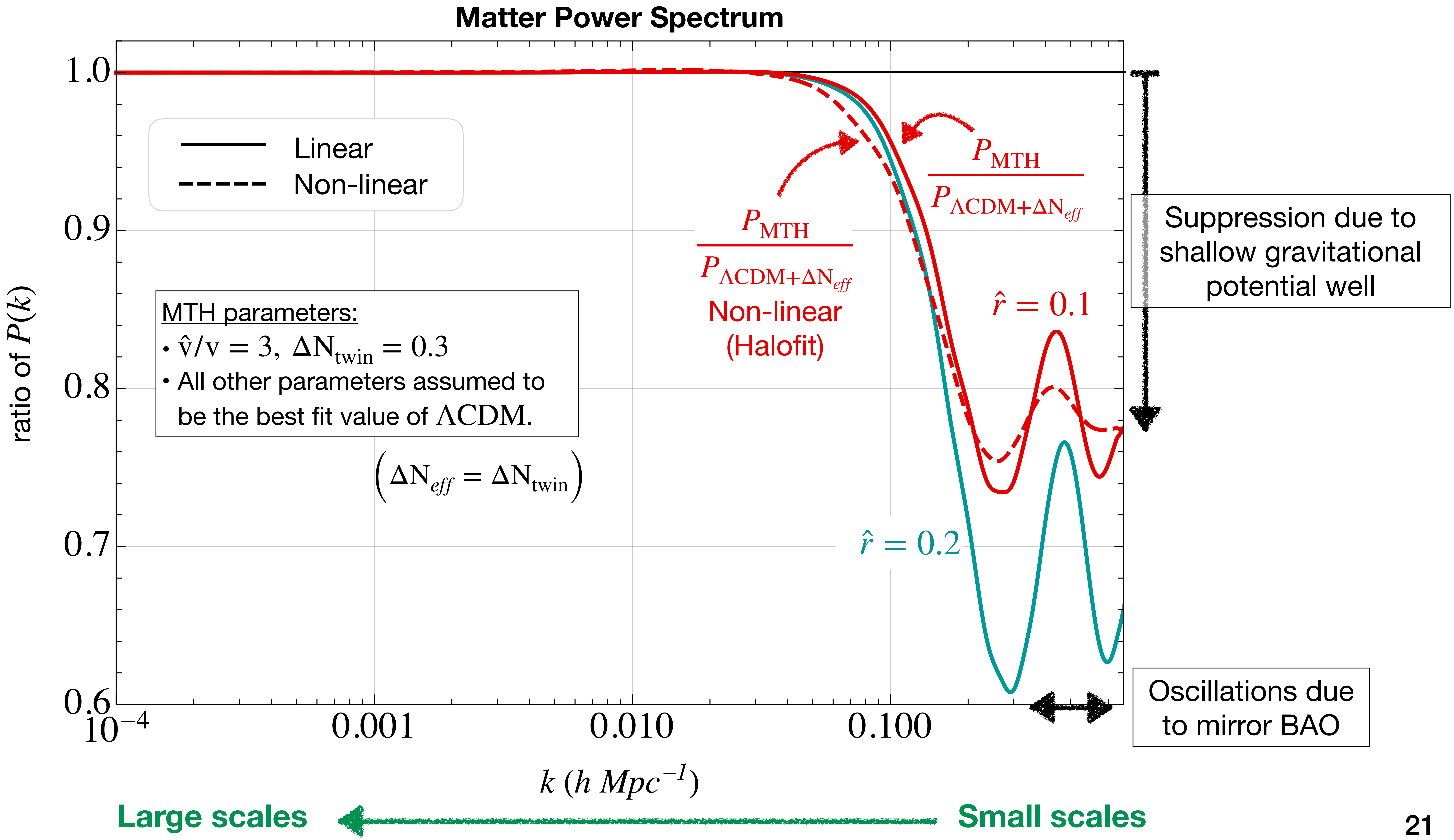
Lighter mirror sector ⇒ Late recombination

Evolution of Matter perturbations



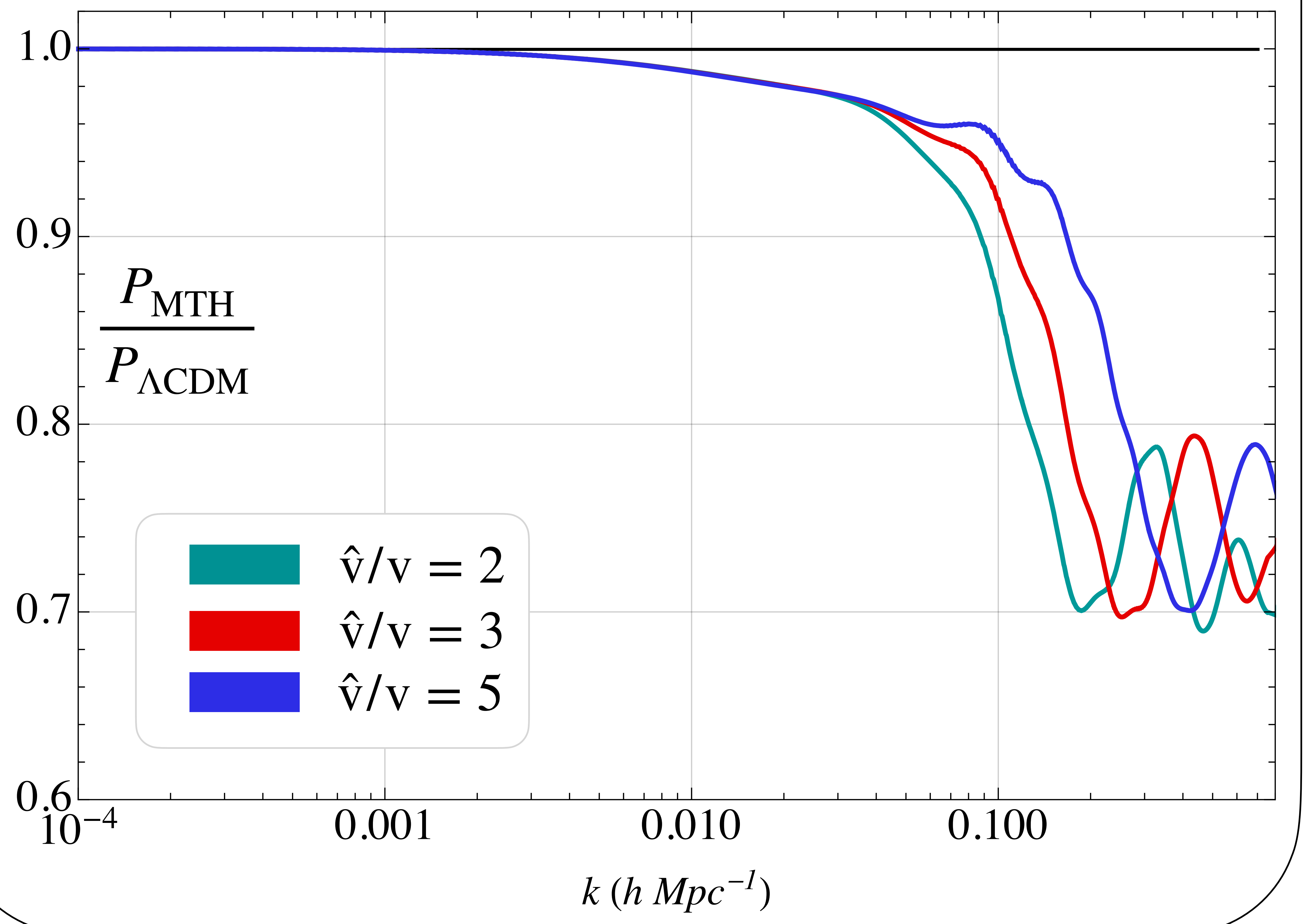
Calculated using the modified version of CLASS.

Large Scale Structures



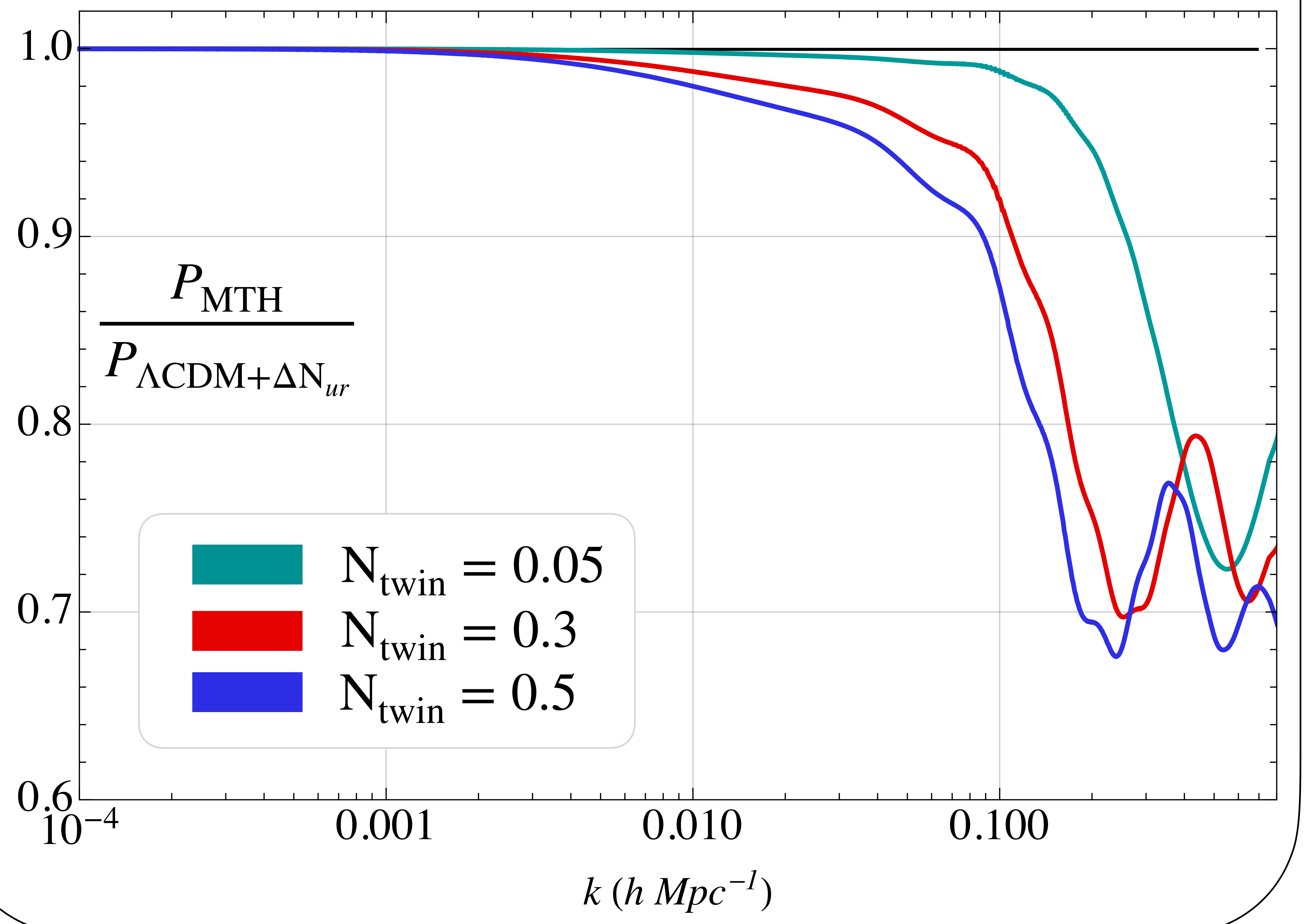
Variation of Linear MPS with $\hat{v}$

$\hat{r} = 0.1,\ \Delta N_{twin} = 0.3$



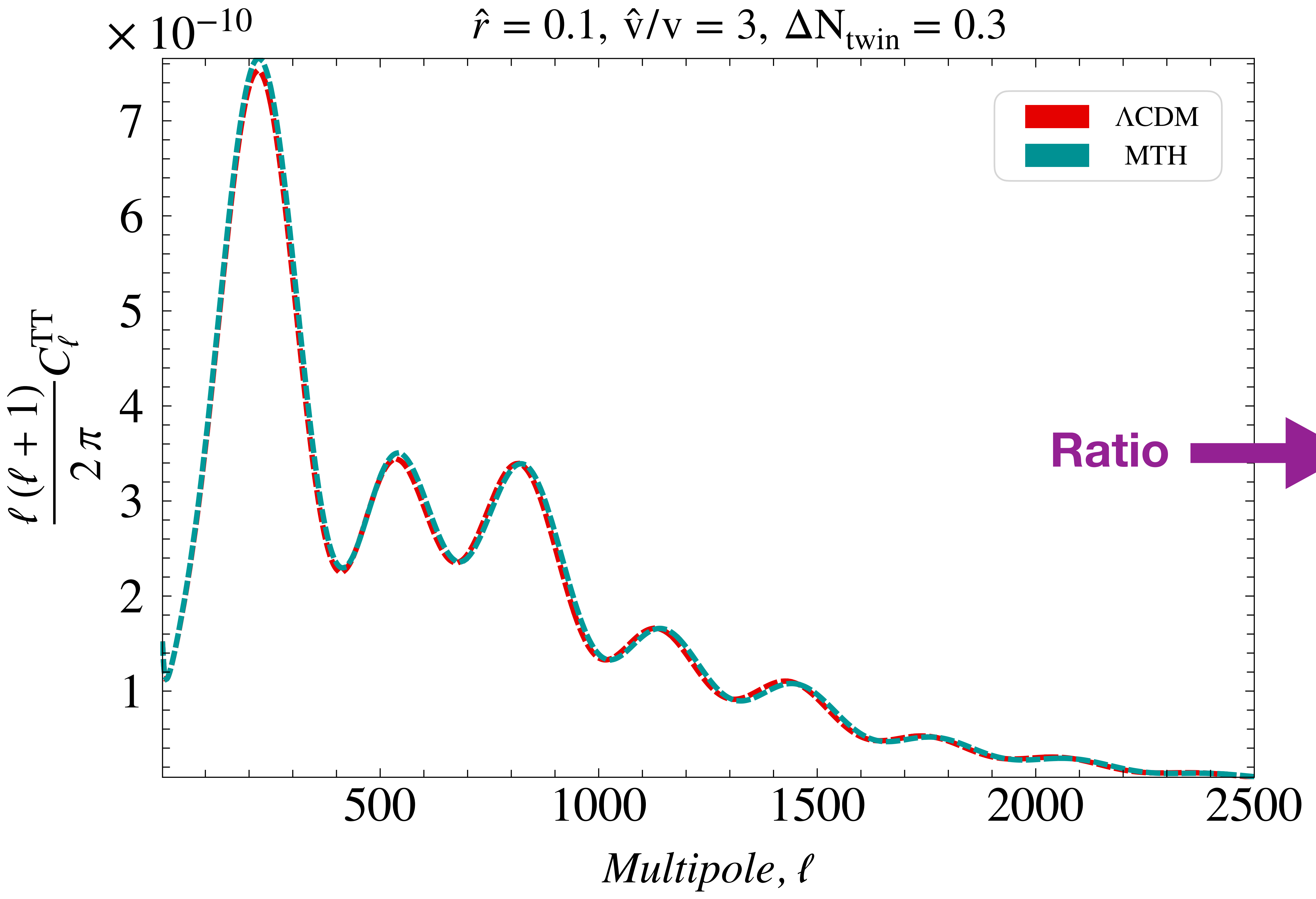
Variation of Linear MPS with ΔN_{twin}

$\hat{r} = 0.1,\ \hat{v}/v = 3$

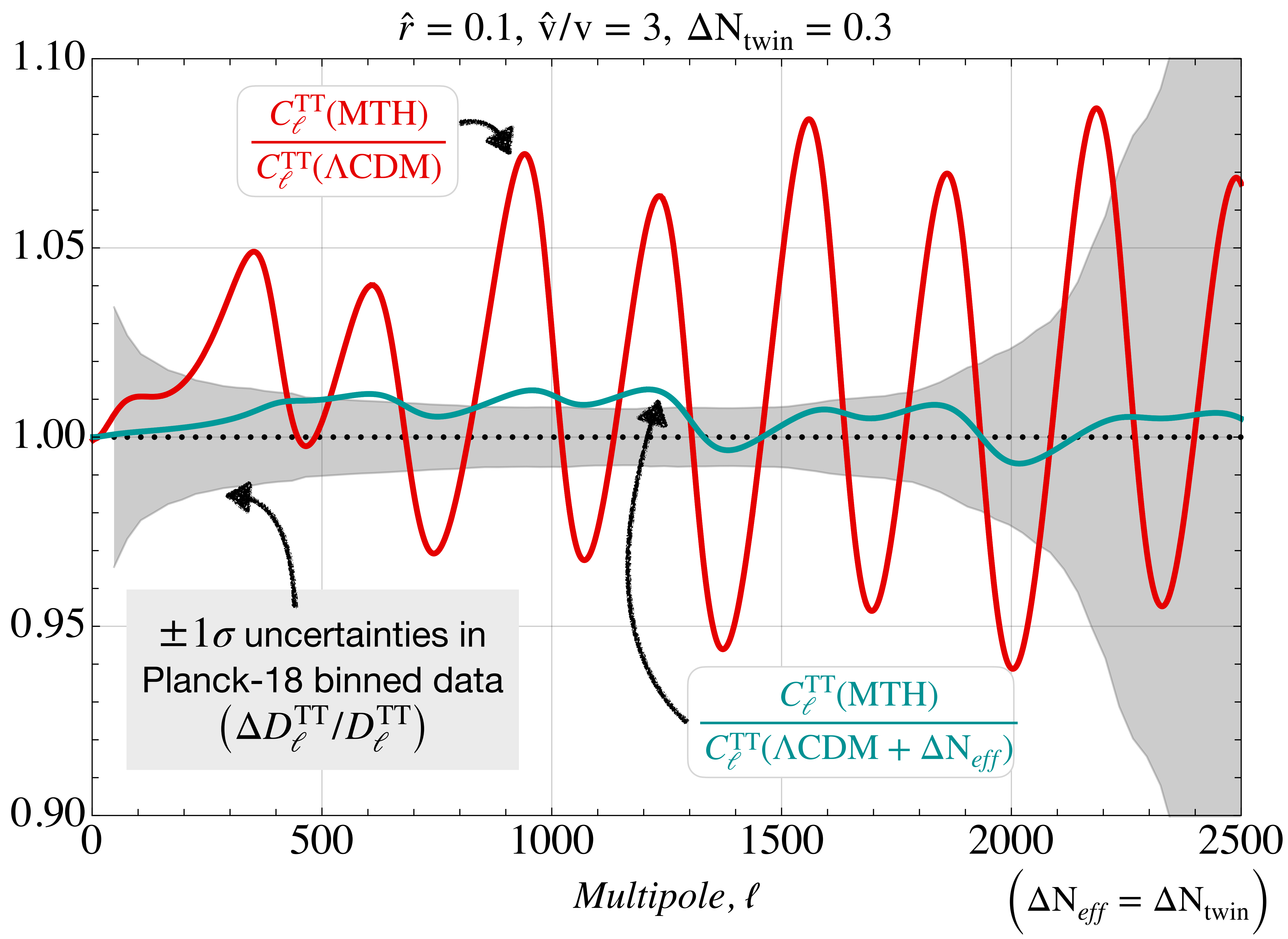


CMB Power Spectrum

Mirror BAO ⟷ Gravitational Potential ⟷ CMB



Ratio



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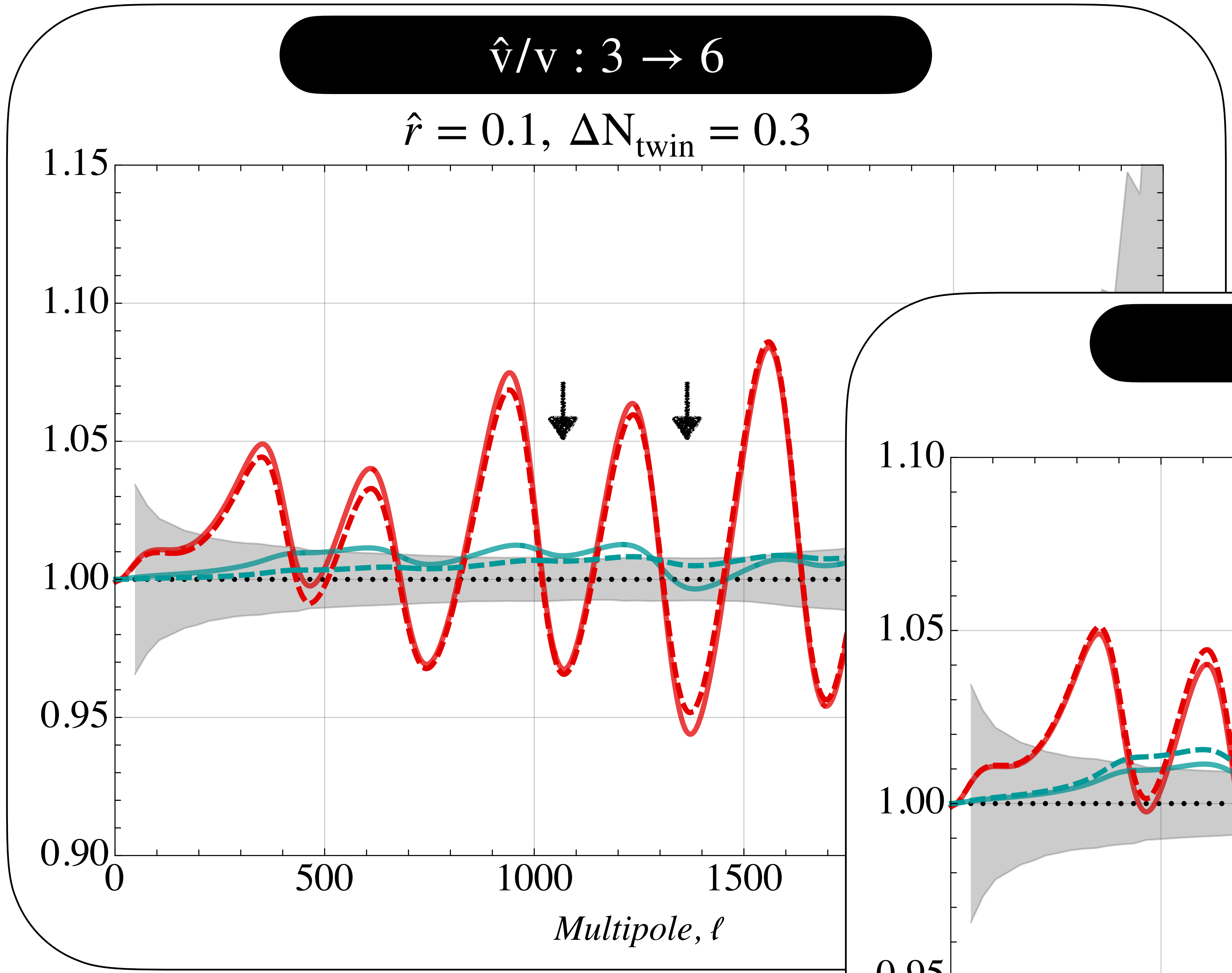
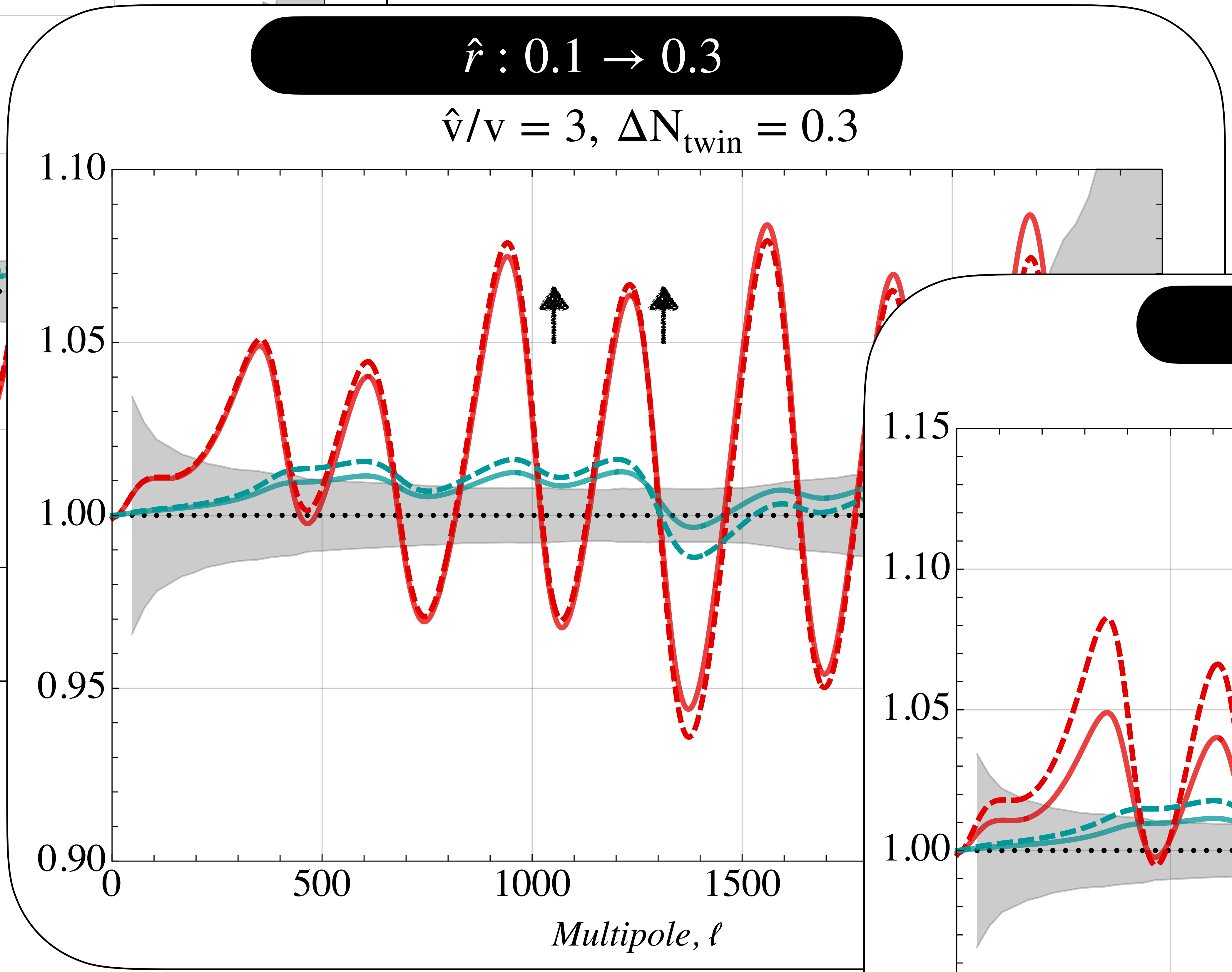
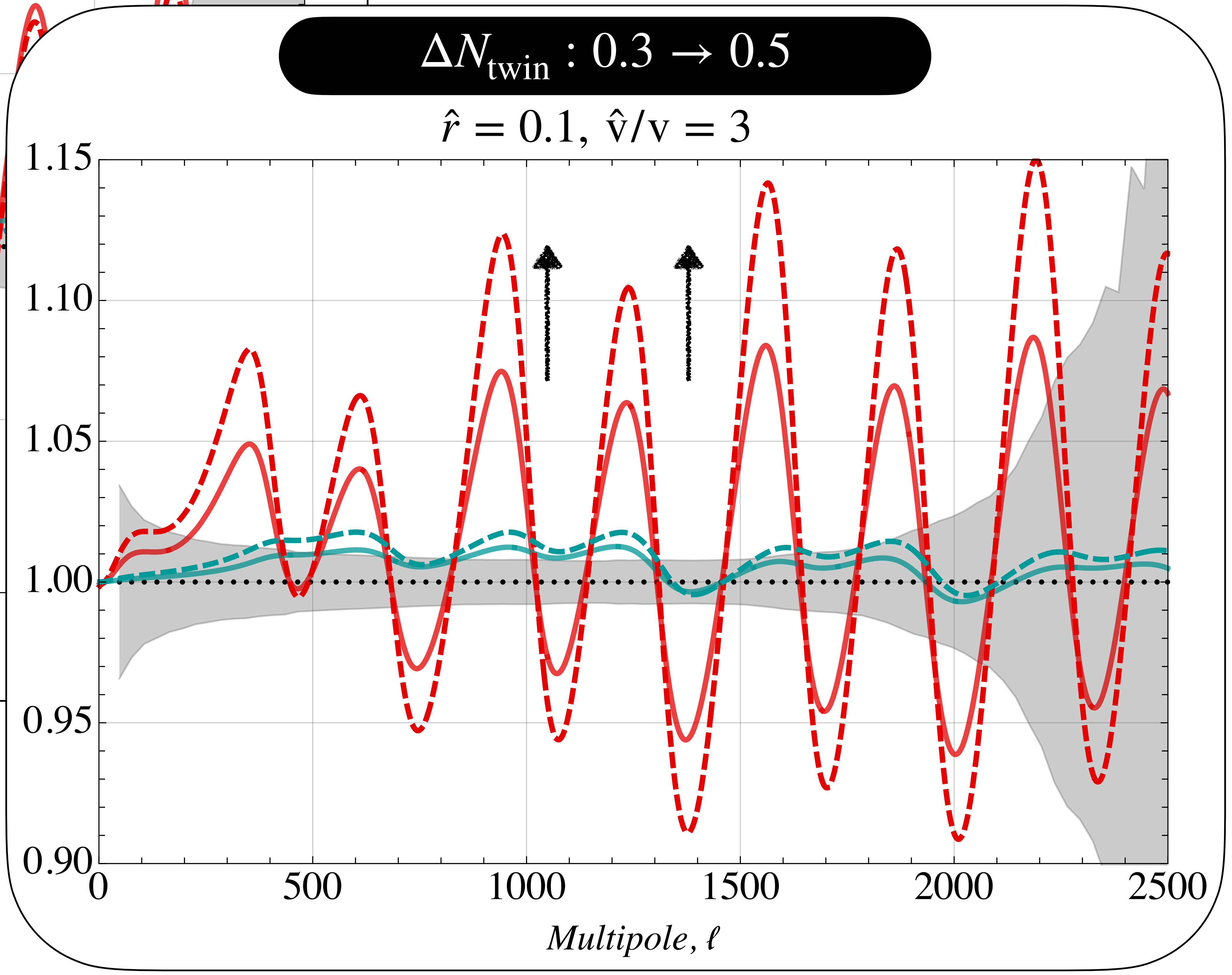


Heavier twin baryons flatten the oscillations, and lead to smaller deviations.



More twin baryons lead to stronger oscillations and larger deviations.

More twin radiation lead to stronger oscillations and larger deviations.



$\frac{C_\ell^{TT}(\mathrm{MTH})}{C_\ell^{TT}(\Lambda\mathrm{CDM})}$

$\frac{C_\ell^{TT}(\mathrm{MTH})}{C_\ell^{TT}(\Lambda\mathrm{CDM} + \Delta N_{eff})}$

$\hat{r} = 0.1,\ \hat{v}/v = 3,\ \Delta N_{twin} = 0.3$

Modified

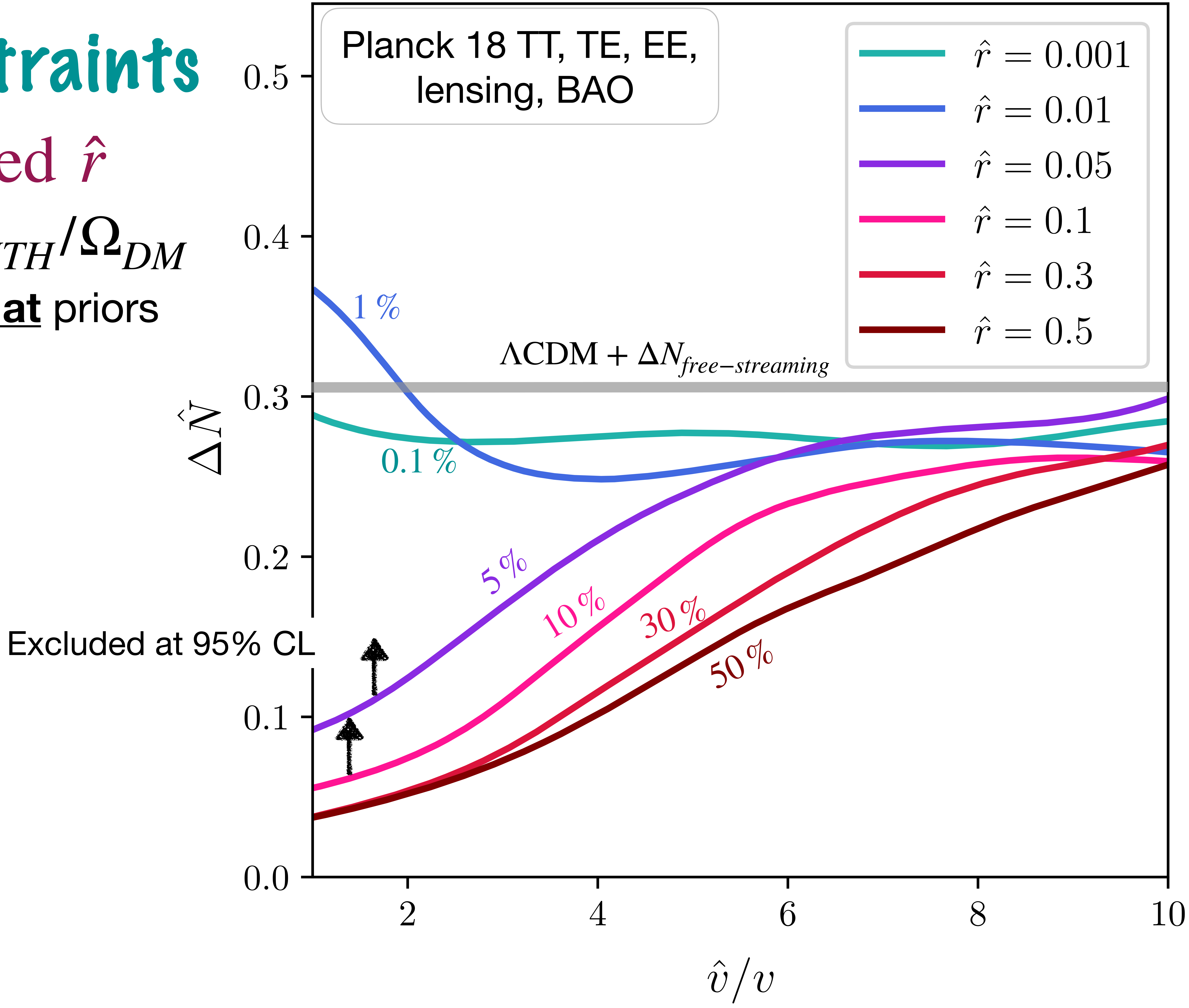
$\left(\Delta N_{eff} = \Delta N_{twin}\right)$

Constraints

Fixed $\hat{r}$

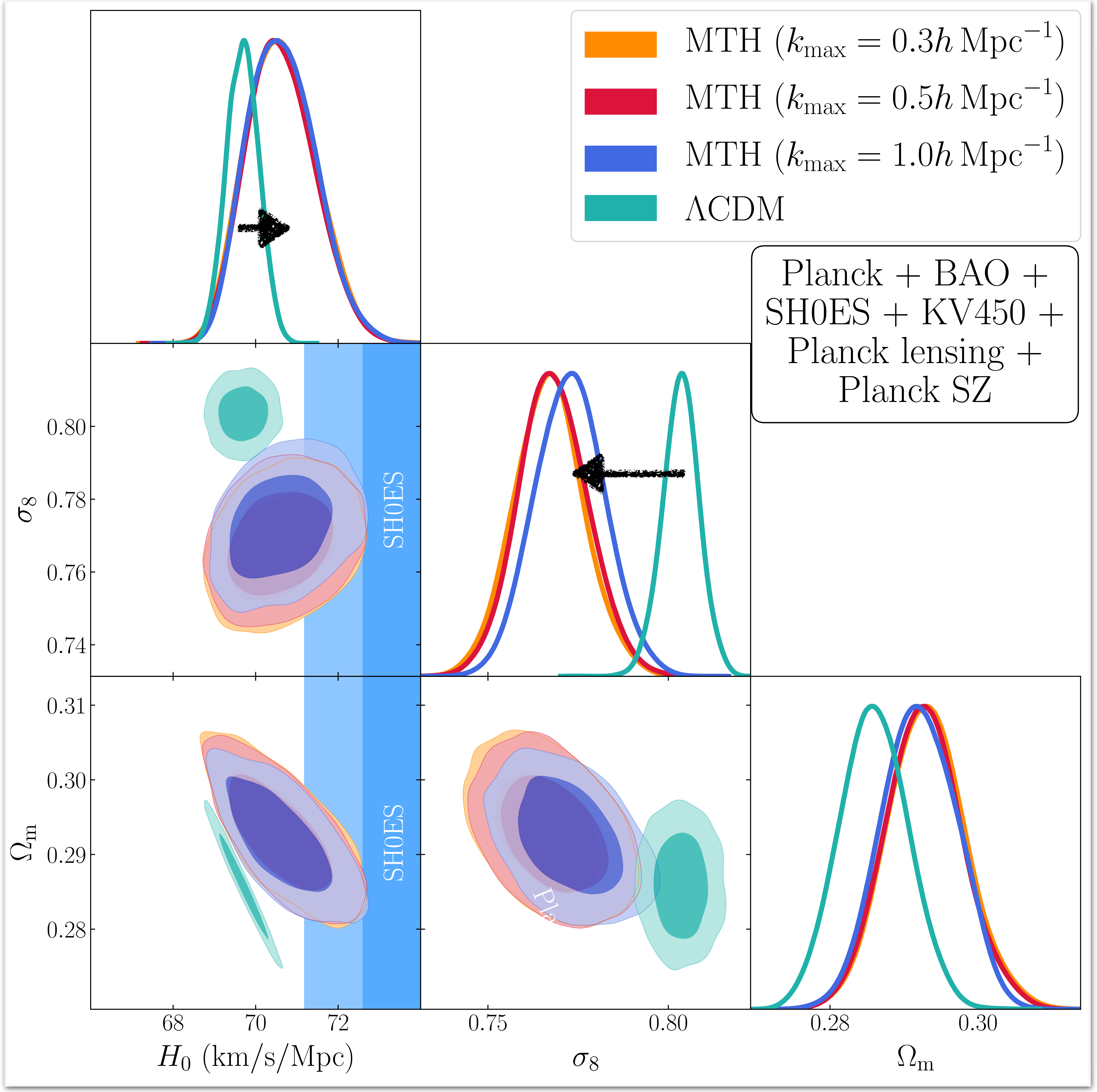
$\hat{r} = \Omega_{MTH}/\Omega_{DM}$

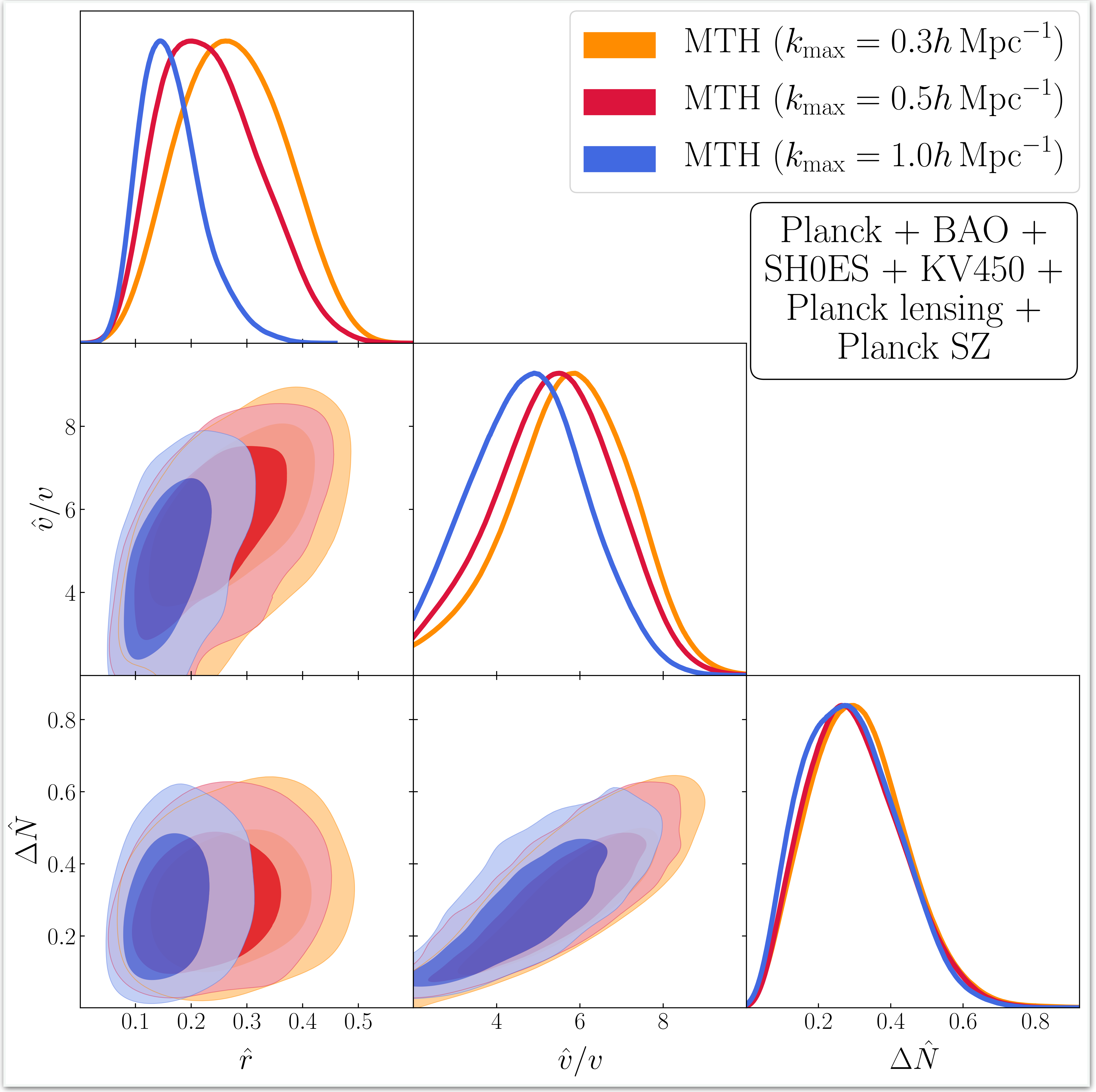
Using **flat** priors



The CMB temperature and polarization power spectra generally impose stronger constraints on $\Delta\hat{N}$ than ΛCDM + ΔN_{eff}.

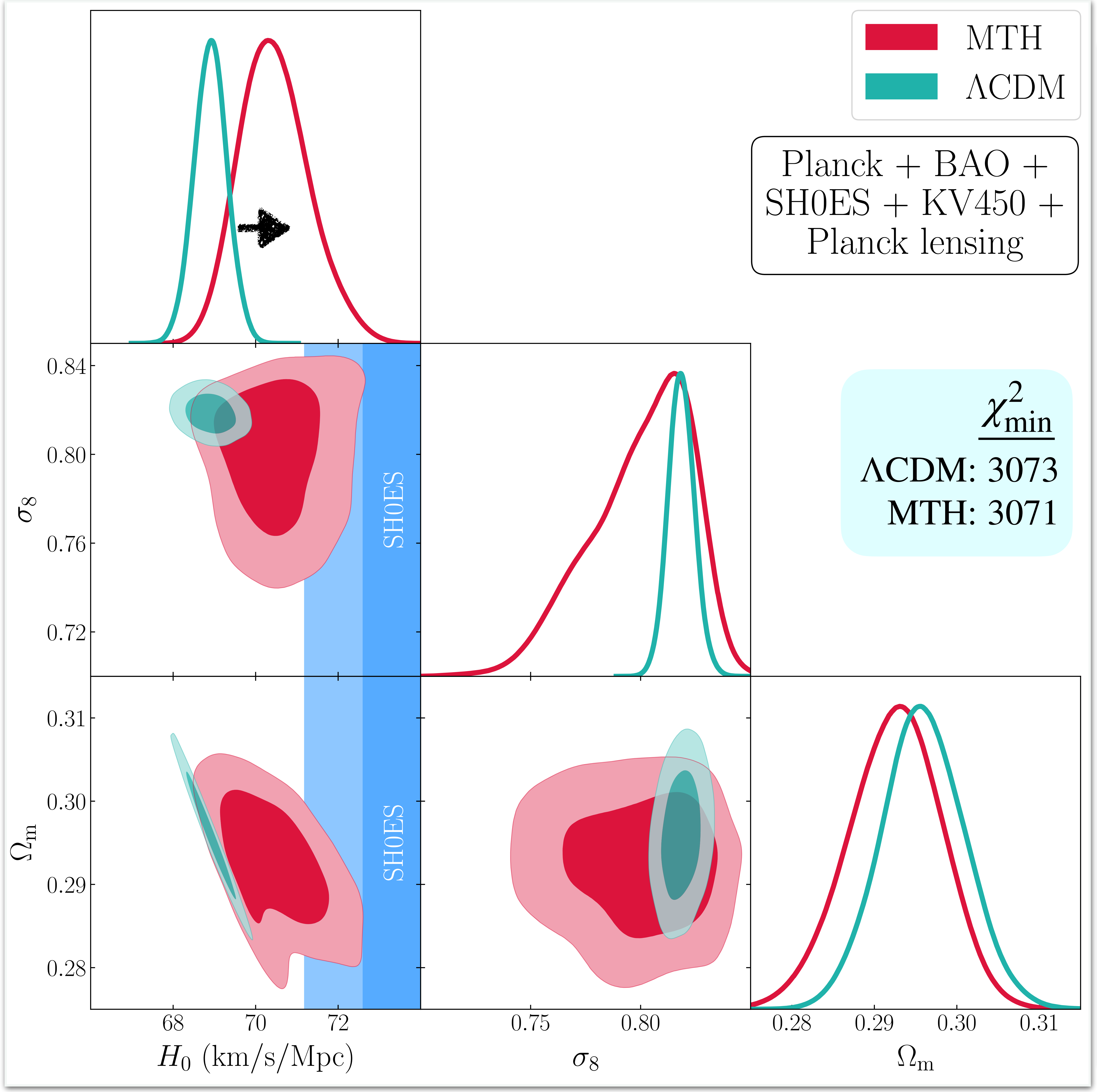
MCMC results

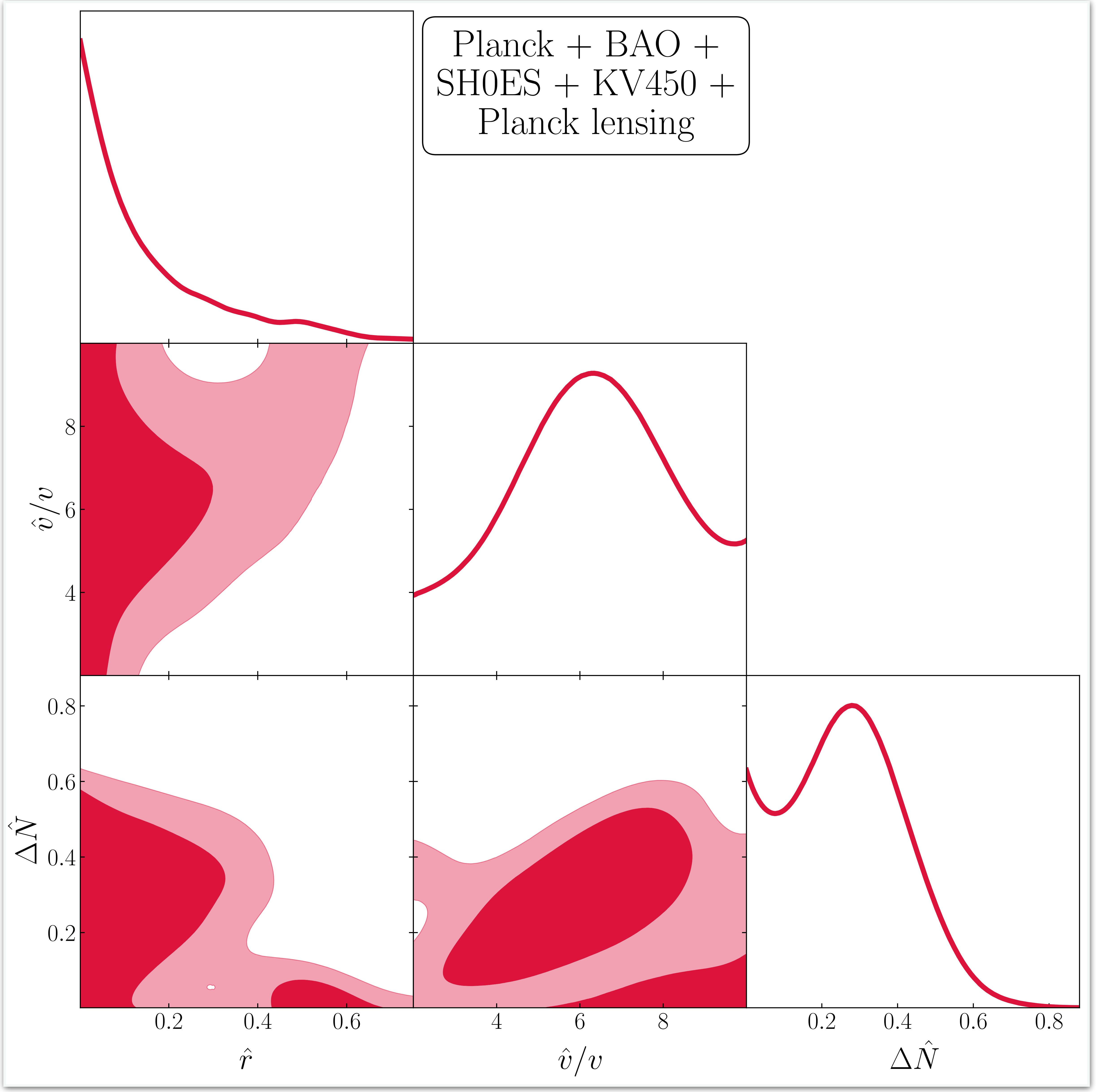




$\hat{r} = \Omega_{MTH}/\Omega_{DM}$

MCMC results





$\hat{r} = \Omega_{MTH}/\Omega_{DM}$