BSM PANDEMIC

Double Feature

Hidden Naturalness

In the Light of Cosmological Datasets

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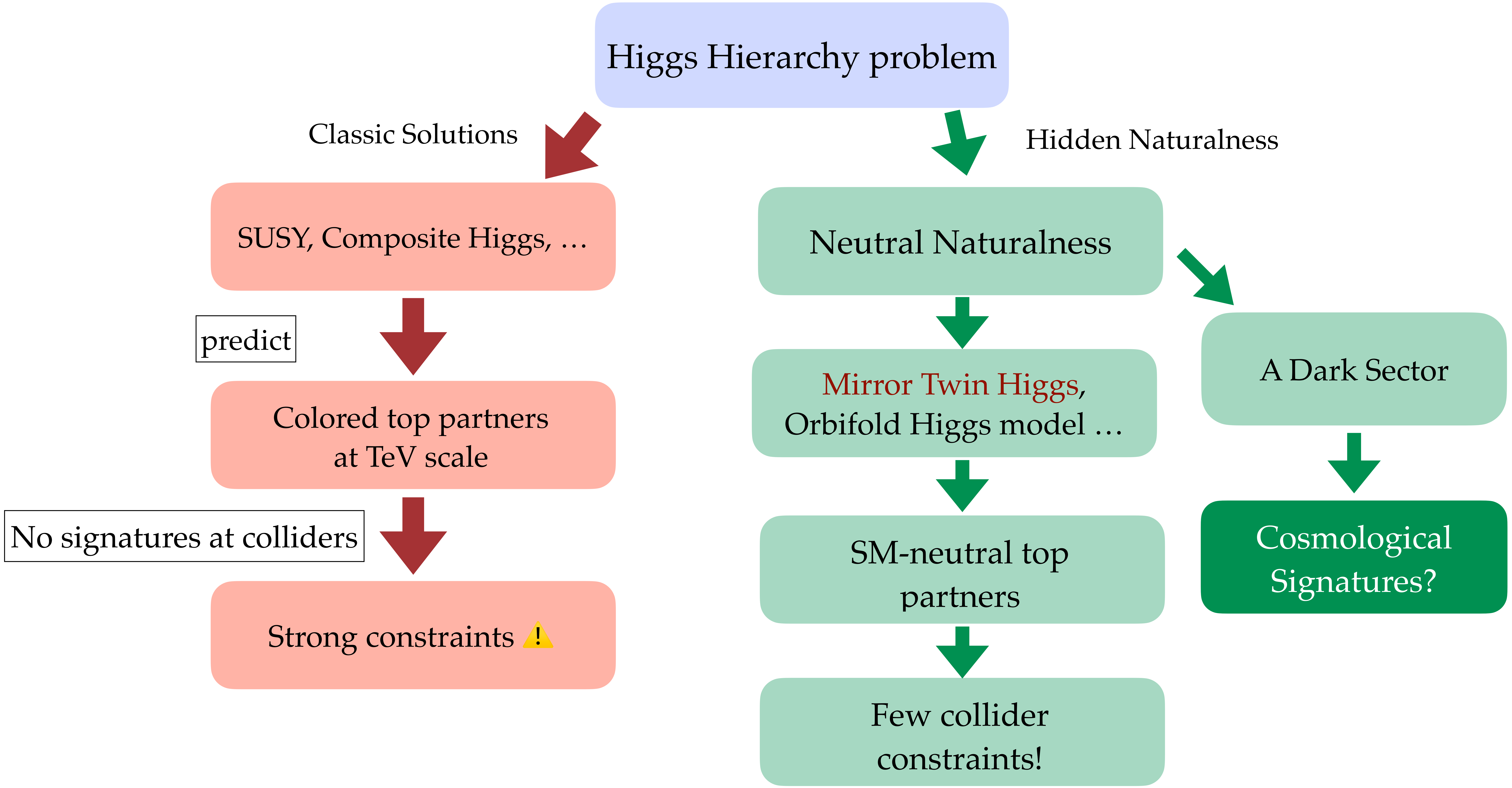
Motivation

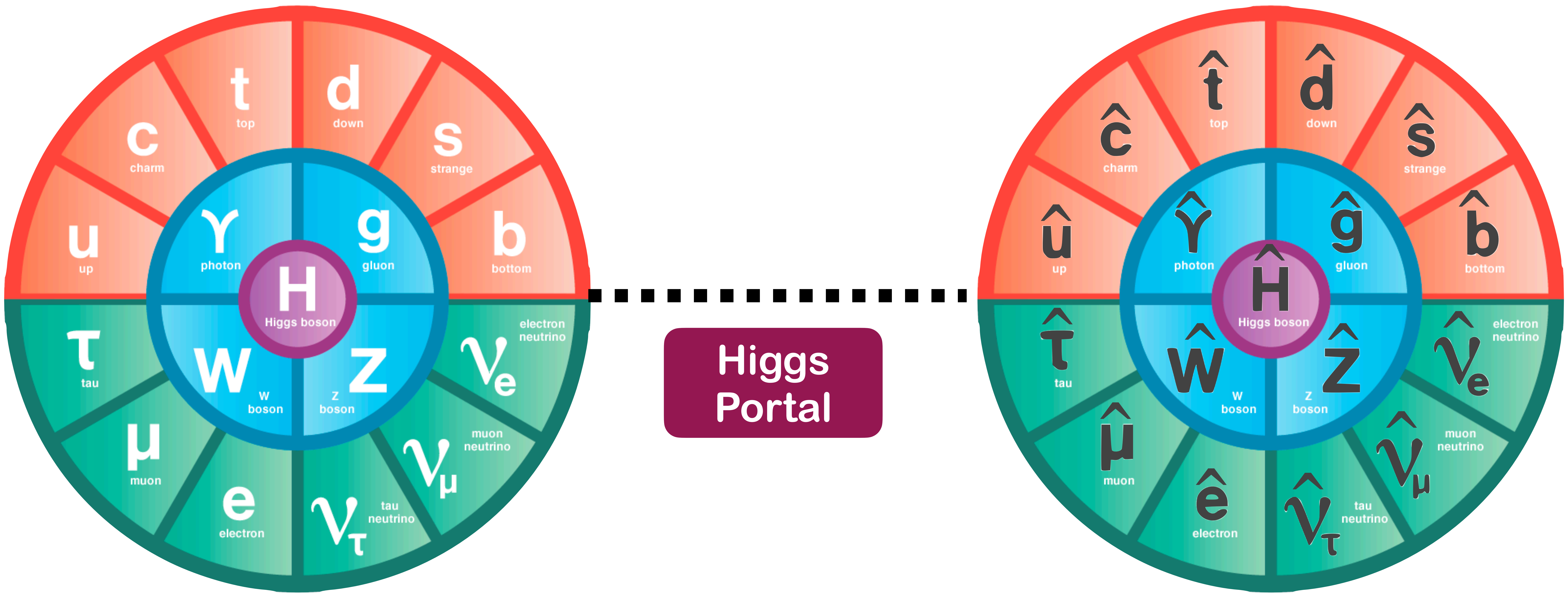


Higgs Hierarchy problem
Classic Solutions
Hidden Naturalness
SUSY, Composite Higgs, …
predict
Colored top partners at TeV scale
No signatures at colliders
Strong constraints ⚠️
Neutral Naturalness
Mirror Twin Higgs, Orbifold Higgs model …
SM-neutral top partners
Few collider constraints!
A Dark Sector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

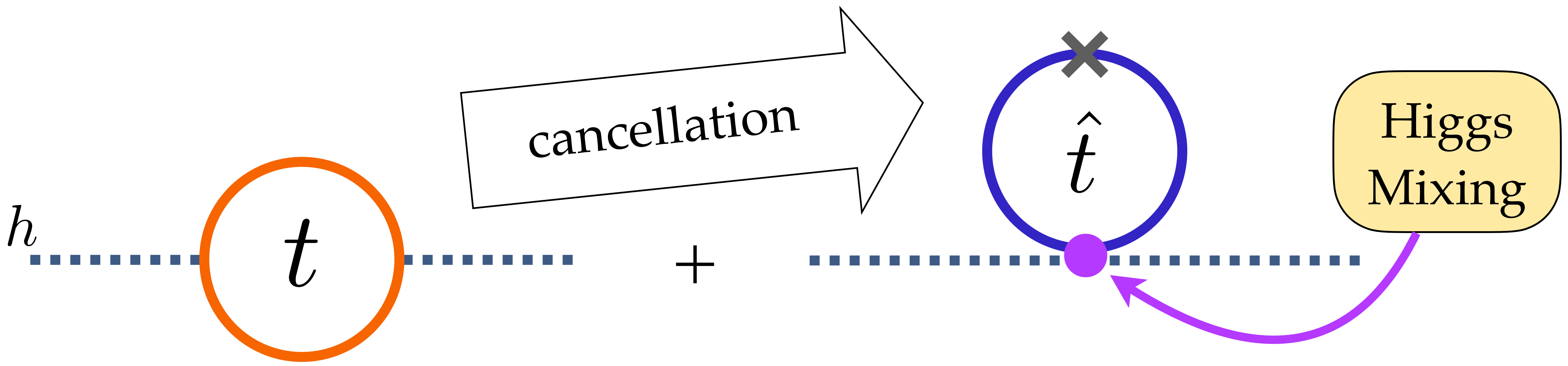
Mirror Twin Higgs model

Chacko, Goh, Harnik (2005)

Standard Model | **Mirror Sector**



Mirror Twin Higgs (MTH)



Solves the little Hierarchy problem

Up to 10 TeV

Mirror Twin Higgs model

- Vacuum expectation value of the mirror sector, $\hat{v}$.
- $\hat{v}$ dictates the mass spectrum of this sector.
- Electroweak tuning: $\dfrac{m_h^2}{\delta m_h^2} \sim \dfrac{2v^2}{(v+\hat{v})^2}$

$\hat{v}/v$	3	5	8
Tuning	20%	5%	2.5%

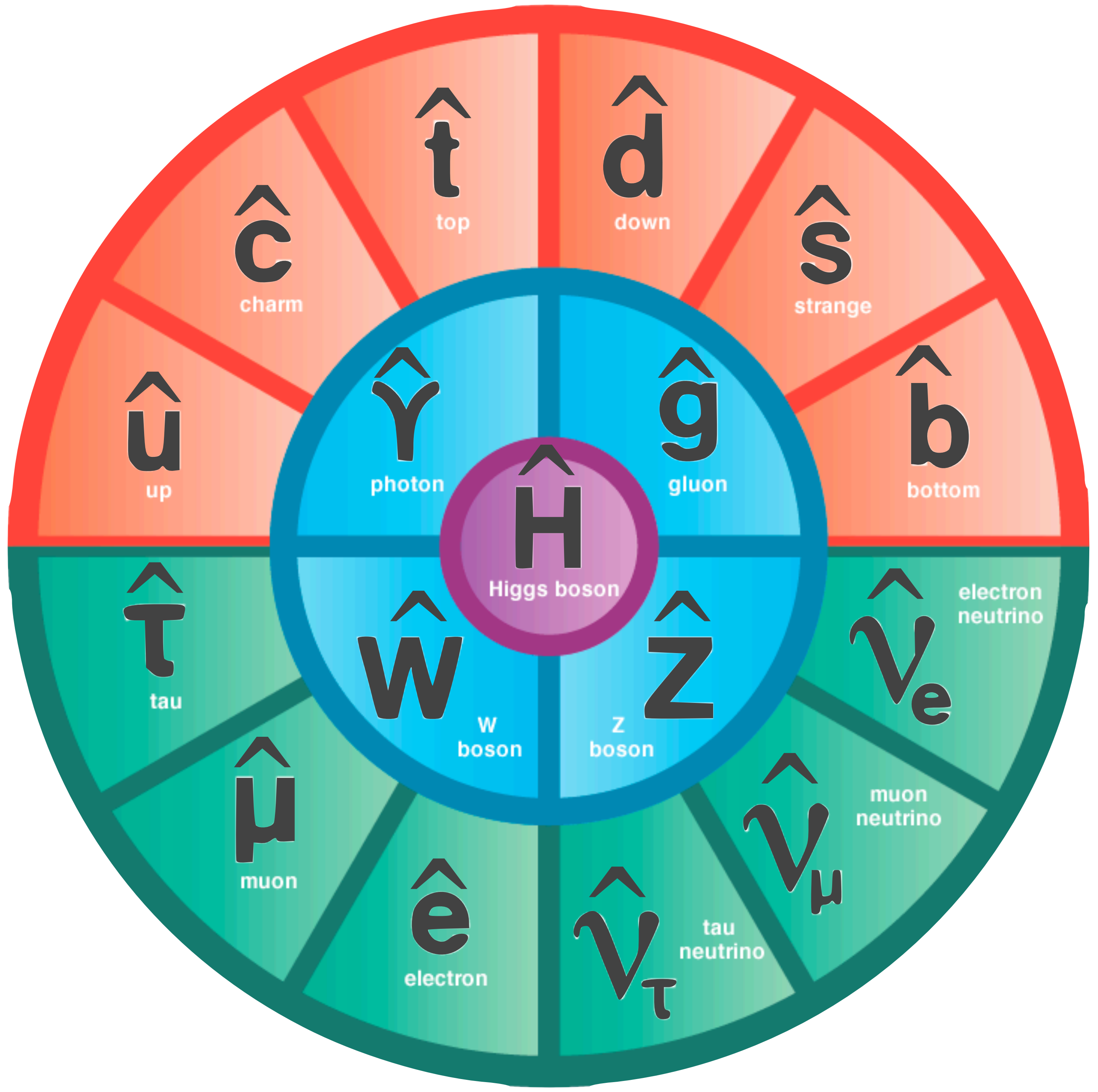
- Range of the vev we will be interested in,

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

experimental bounds **fine tuning**

Burdman, Chacko, Harnik, Lima, Verhaaren (2014)

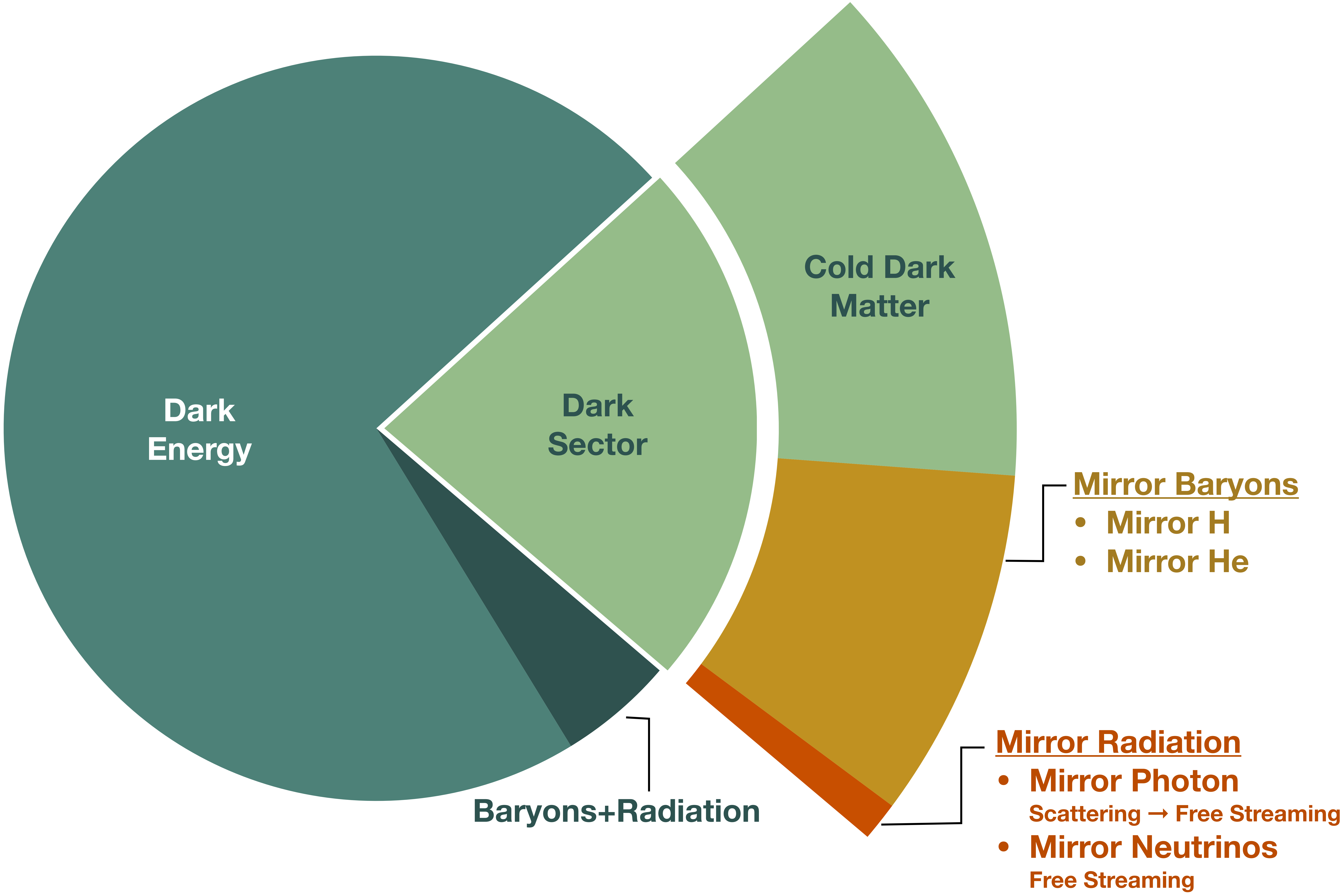
Mirror Sector



Mirror Twin Higgs (MTH)

- Mirror particles are heavier: Softly broken MTH model
- All the mirror couplings are identical to the SM couplings.
- Few collider signatures, what about cosmological signatures?

The Universe



Mirror Twin Higgs model

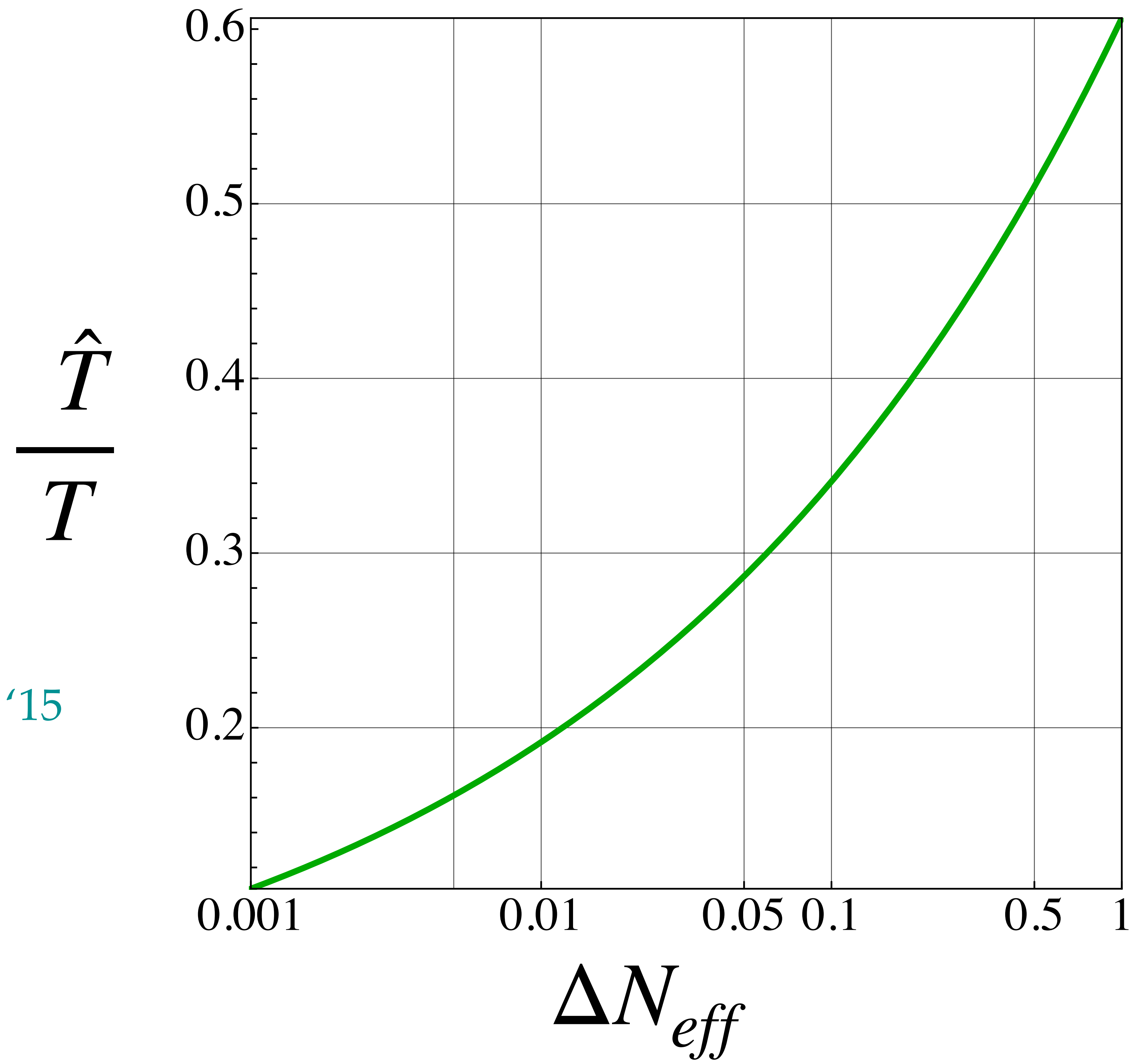
1. $\hat{v}$ Vacuum expectation value

2. $\hat{T}$ (or ΔN_{twin}) 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.

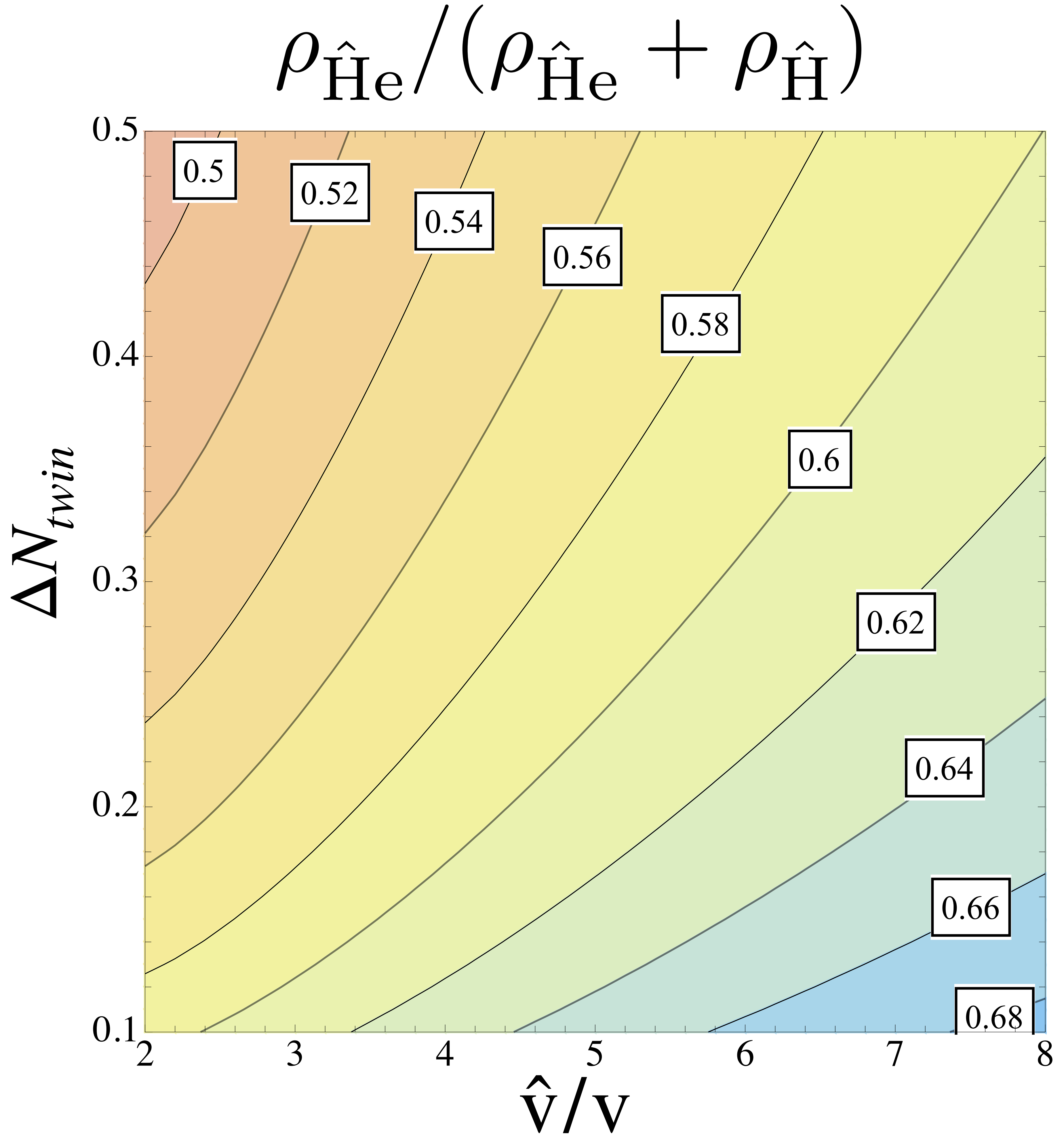
CLASS: Blasa, Lesgourgues, Tram (2011)

- Next, look at the early Universe processes of this model.

Chacko, Curtin, Geller, Tsai (2018)

Mirror BBN

Different vev ⇒ Different mass spectrum ⇒ Different abundances



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

SM: $\sim 25\%$ mass is in **He**

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

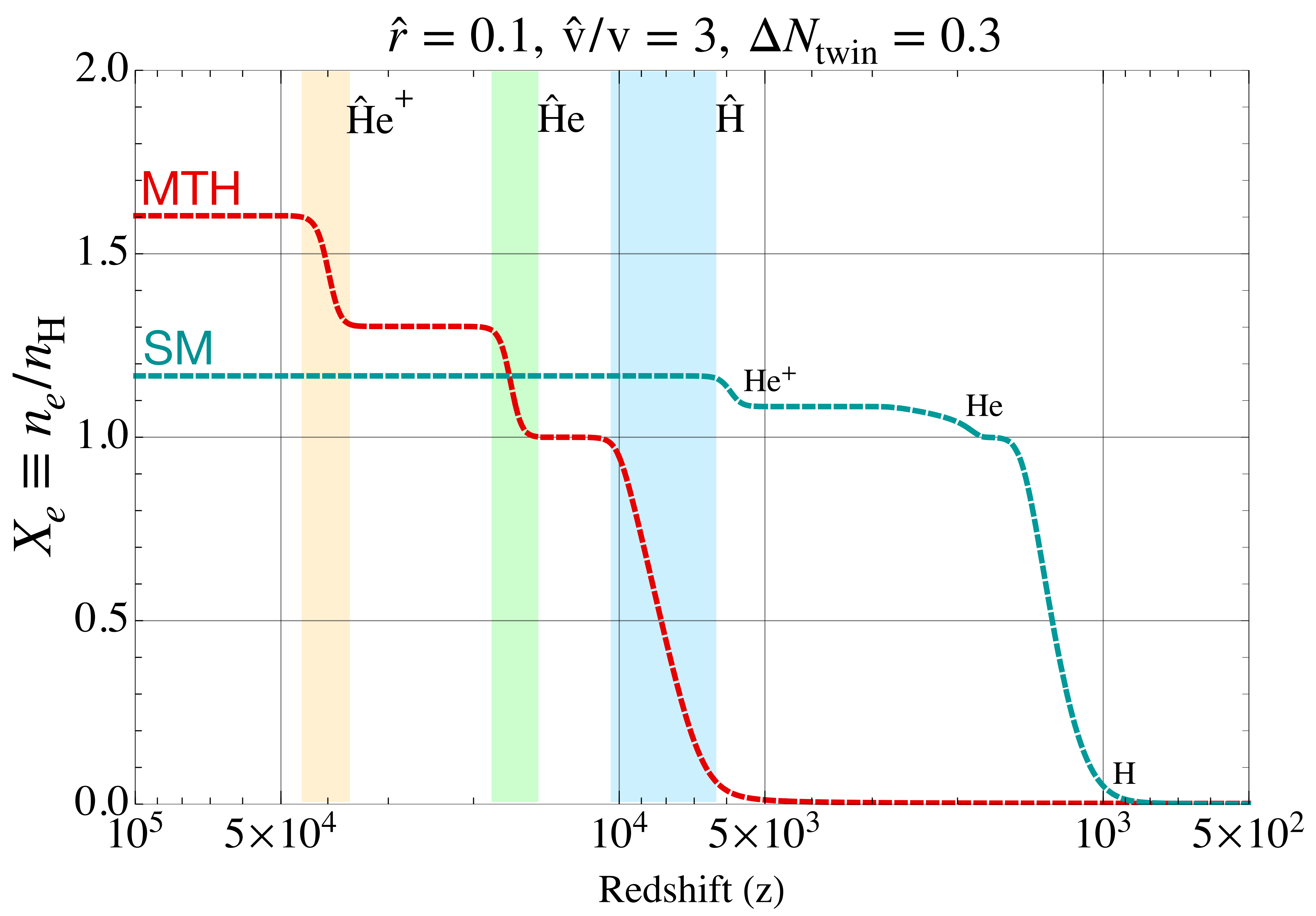
ΔN_{twin} ↑ ⇒ late BBN ⇒ Y_{He} ↓

$\hat{v}/v$ ↑ ⇒ early BBN ⇒ Y_{He} ↑

See also: Chacko, Curtin, Geller, Tsai (2018)

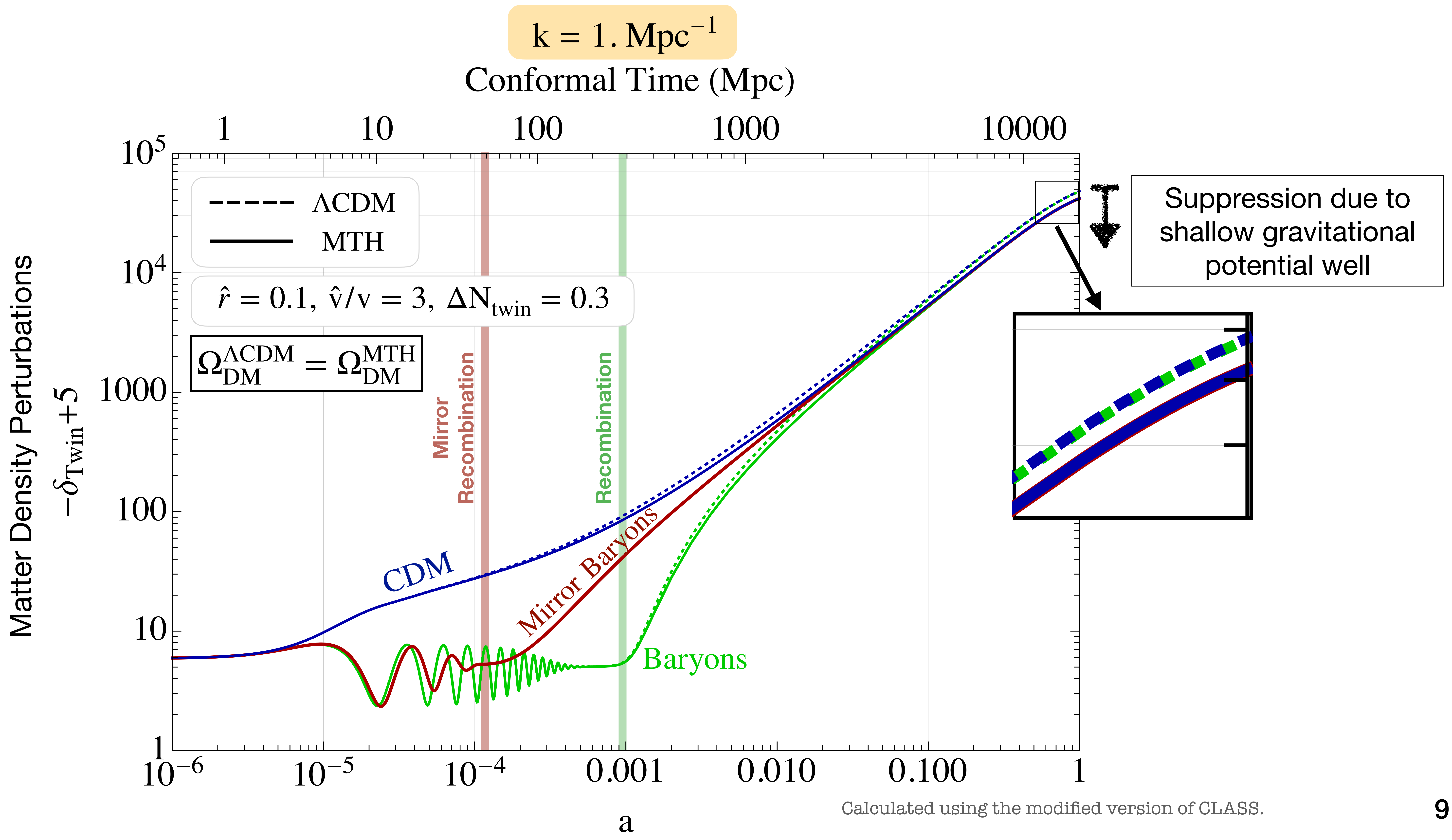
Mirror Recombination

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



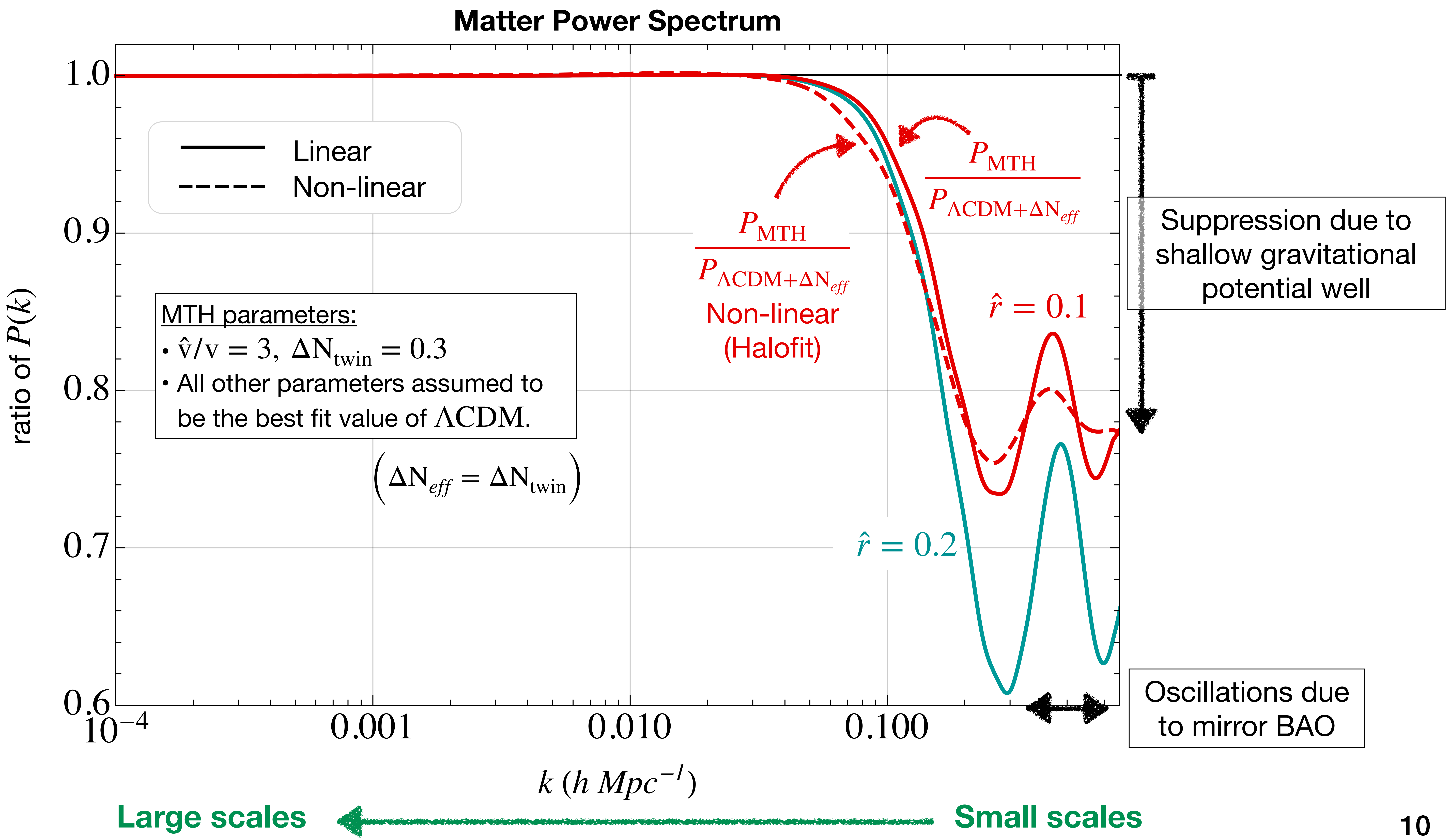
Calculated using the modified version of CLASS.

Evolution of Matter perturbations



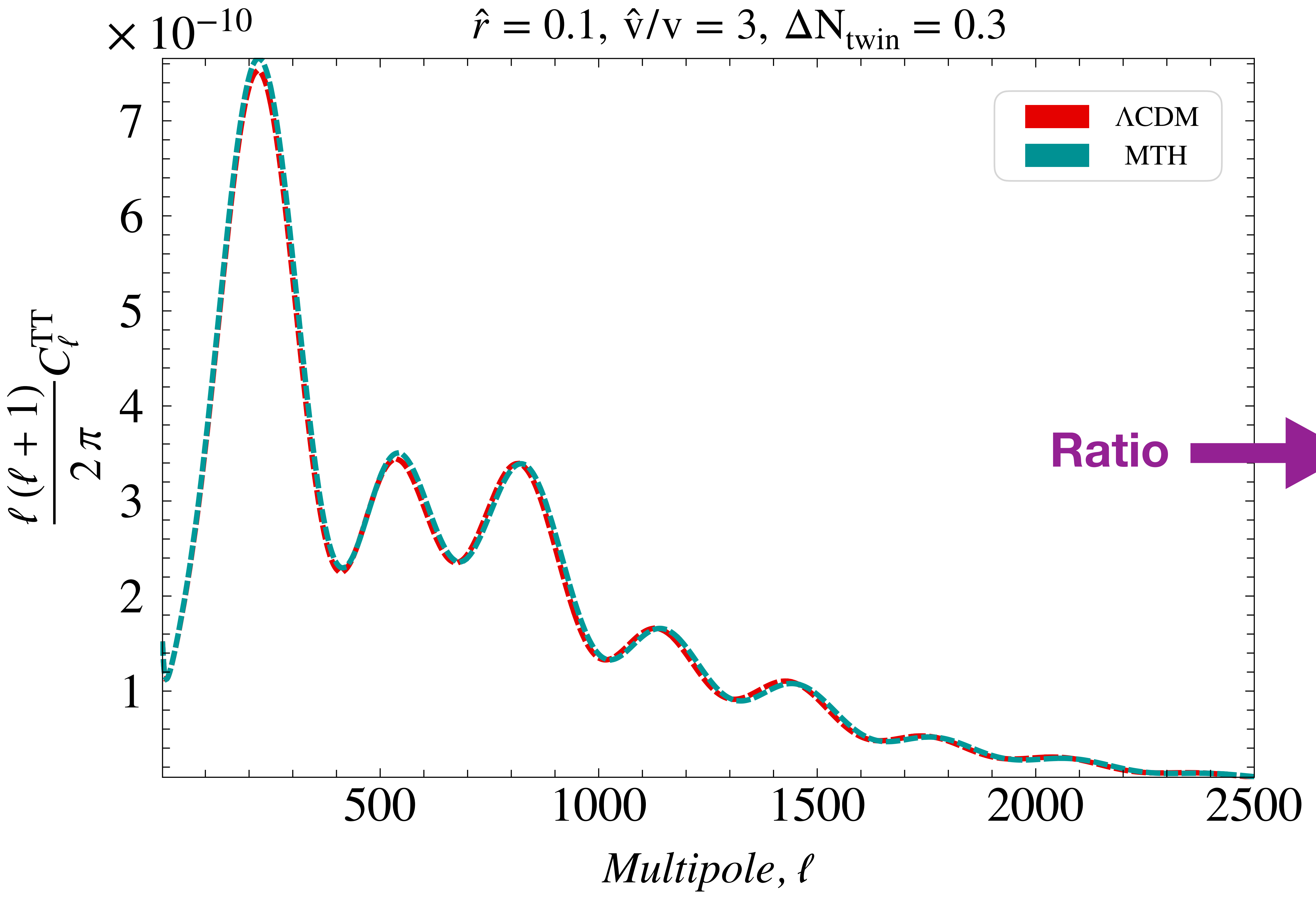
Calculated using the modified version of CLASS.

Large Scale Structures

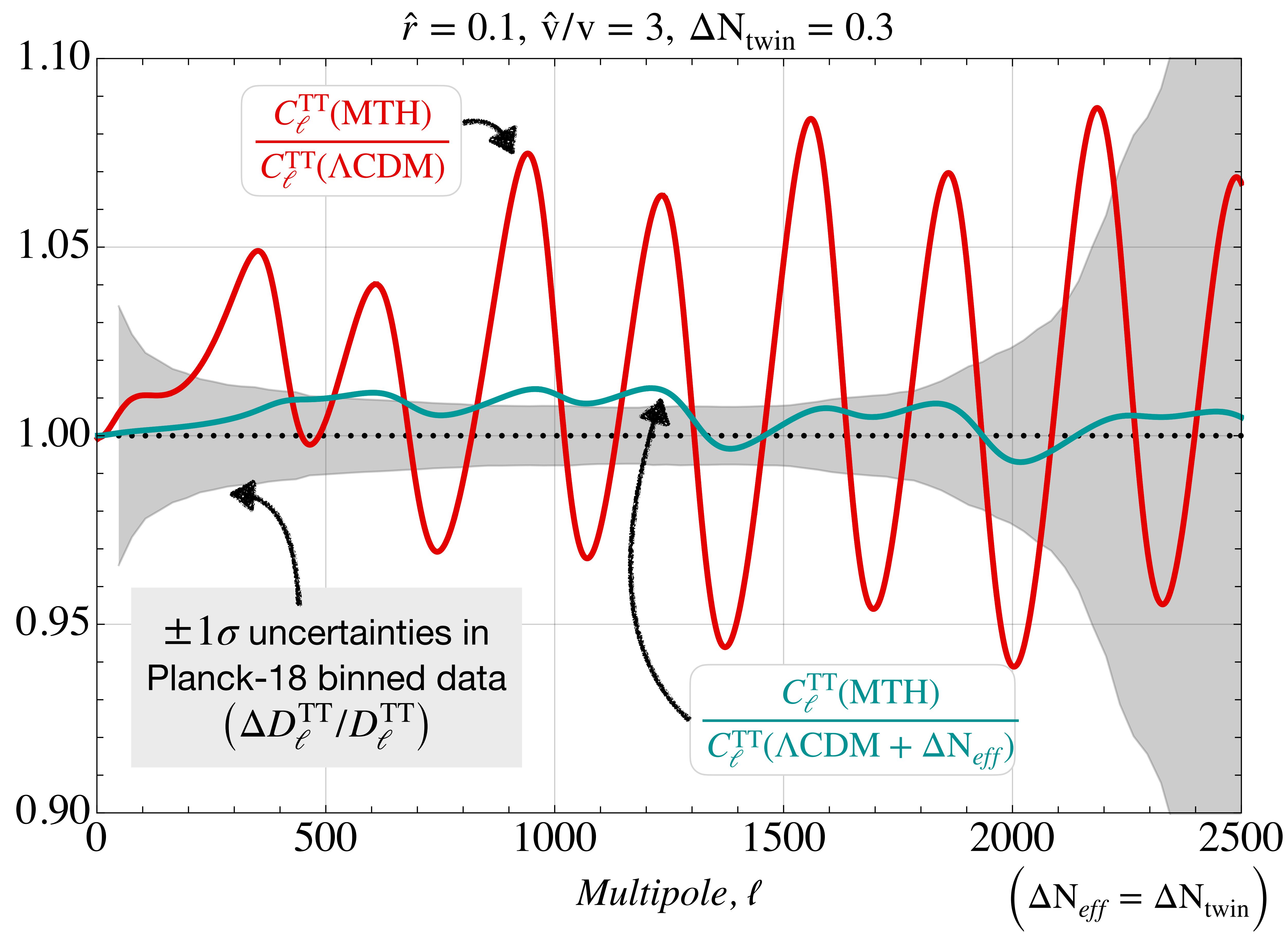


CMB Power Spectrum

Mirror BAO ⟷ **Gravitational Potential** ⟷ **CMB**



Ratio →



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:
  - (Planck 2018 lensing), CFHTLens* weak lensing survey, halo power spectrum from SDSS-DR7. (To be included in the future: KiDS)
  - Planck SZ cluster counts $\sigma_8(\Omega_m/0.27)^{0.30} = 0.782 \pm 0.010$ (68 % C . L.)
- SH0ES: $H_0 = 74.03 \pm 1.42$ (68 % 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)

Range of MTH parameters: $0.001 \leq \hat{r} \leq 0.3$ | $2 \leq \hat{v}/v \leq 8$ | $0.01 \leq \Delta N_{\rm twin} \leq 1$

Using **flat** priors

*using mid-conservative cuts

Planck 2018

Planck low ℓ TT , Planck low ℓ EE, Planck high ℓ TTTEEE

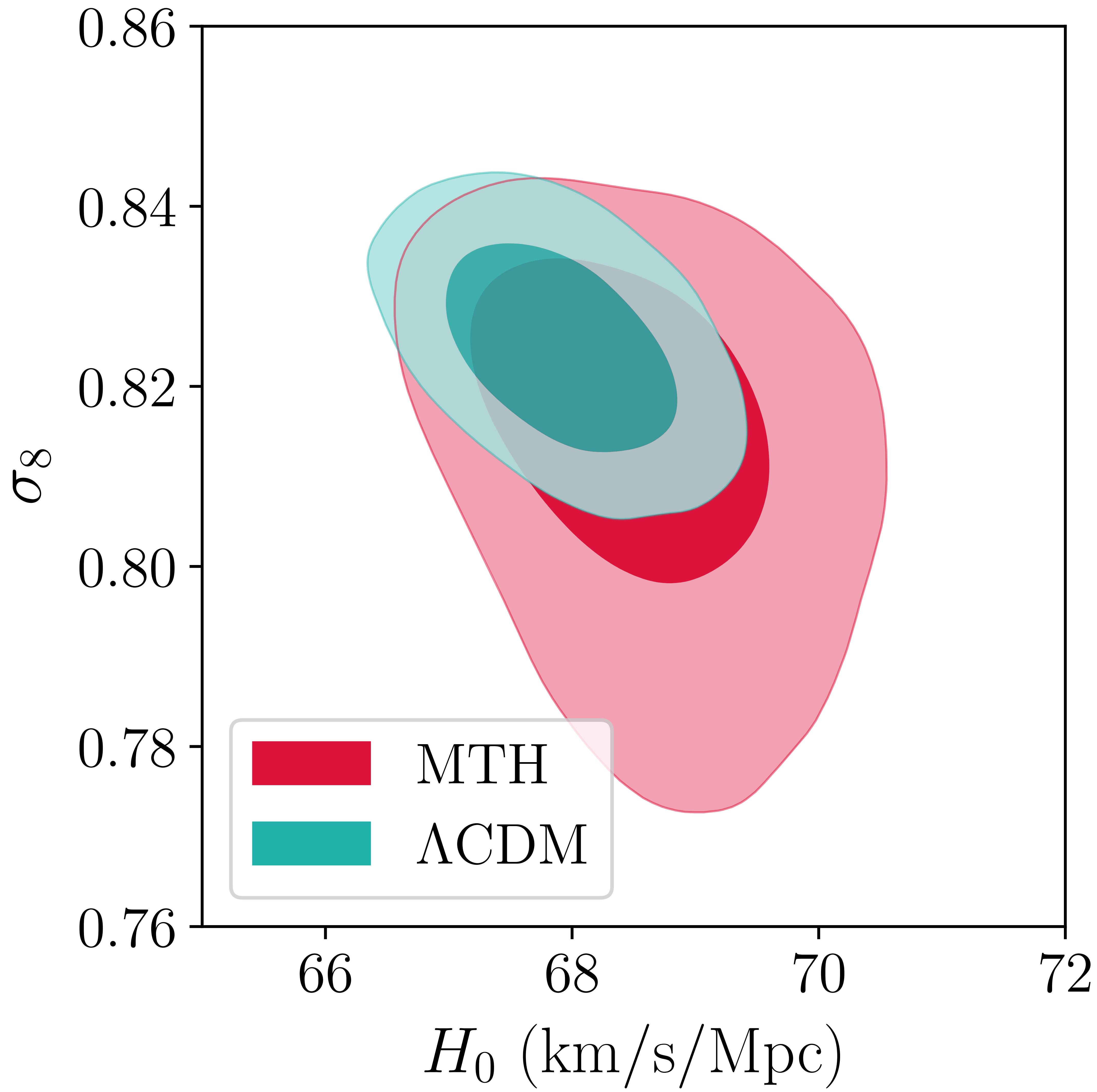
MCMC results

Planck 18 TT, TE, EE

Model	Minimum χ^2
ΛCDM	2769
MTH	2771

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

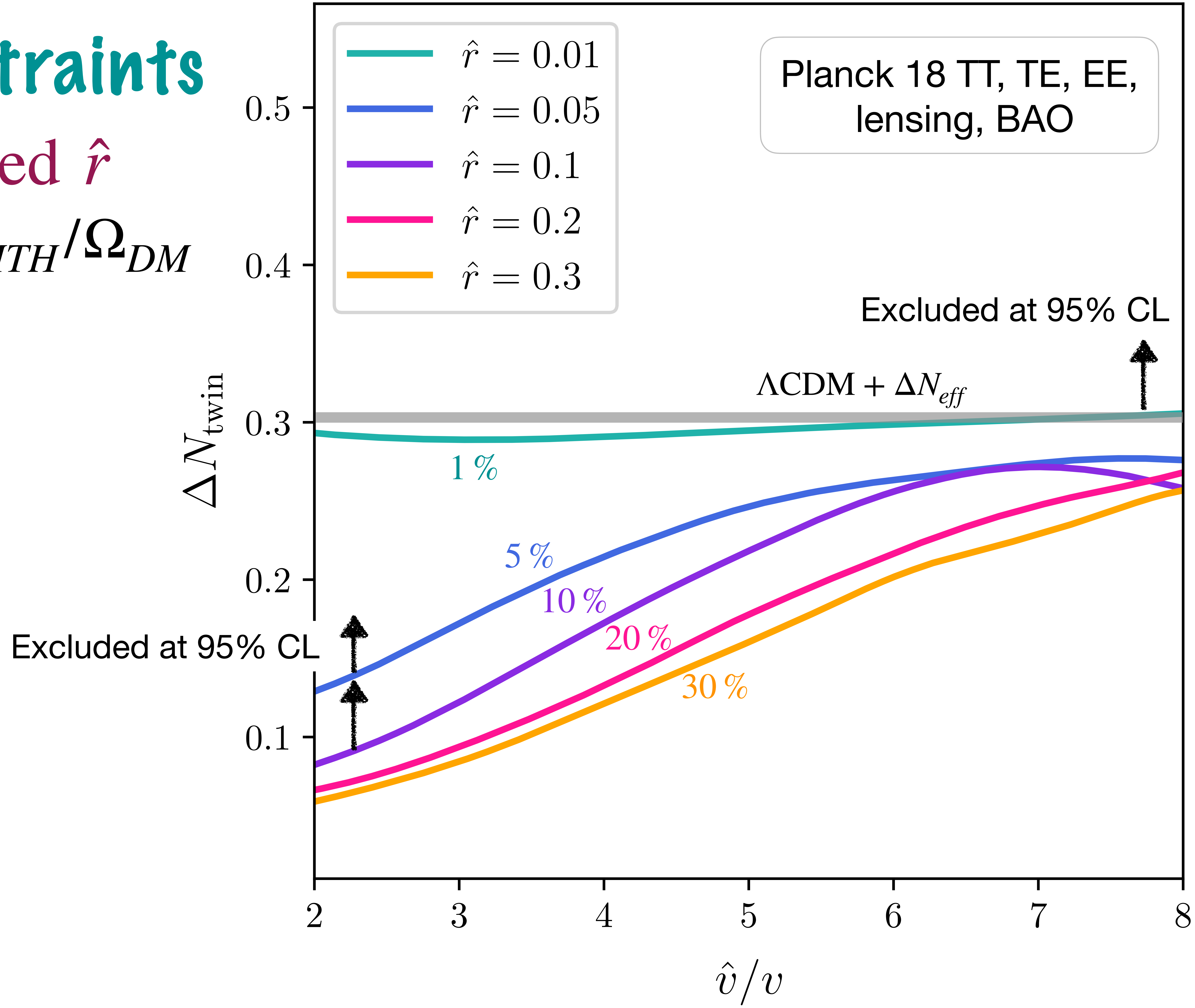
Use this dataset to constrain the parameter of MTH model.



Constraints

Fixed $\hat{r}$

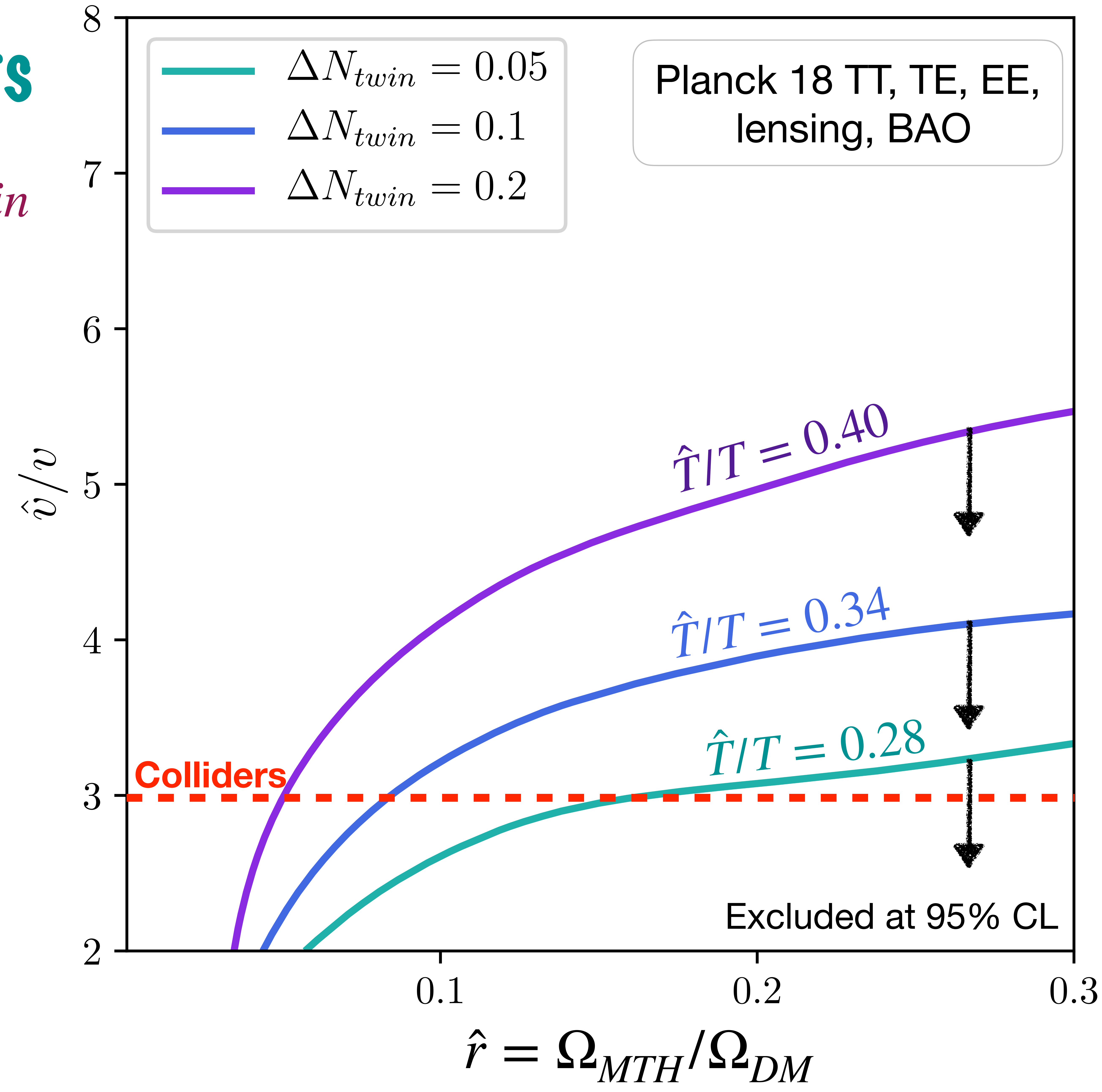
$\hat{r} = \Omega_{MTH}/\Omega_{DM}$



The CMB temperature and polarization power spectra can impose stronger constraints on ΔN_{twin} than ΛCDM + ΔN_{eff}.

Constraints

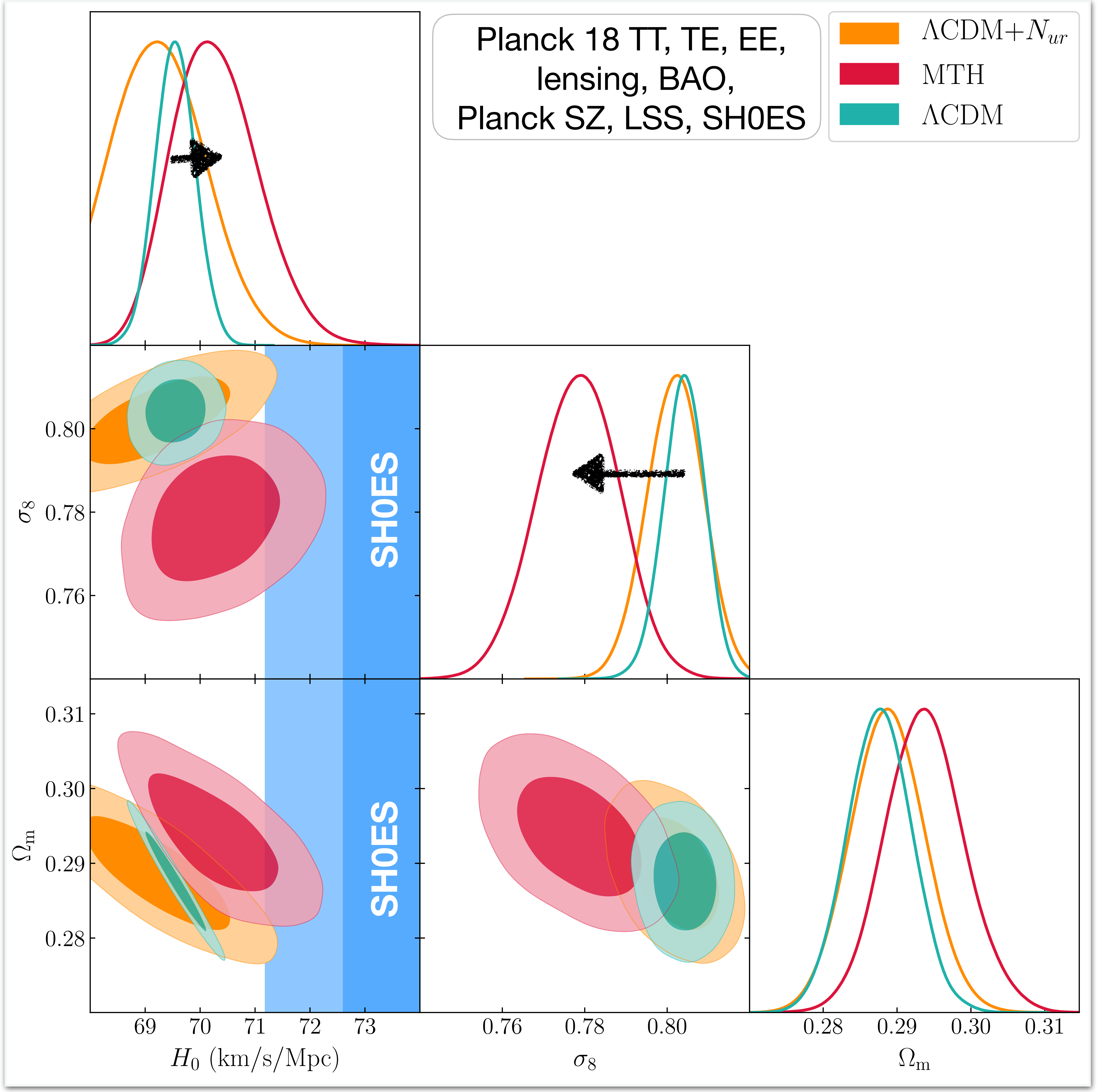
Fixed ΔN_{twin}

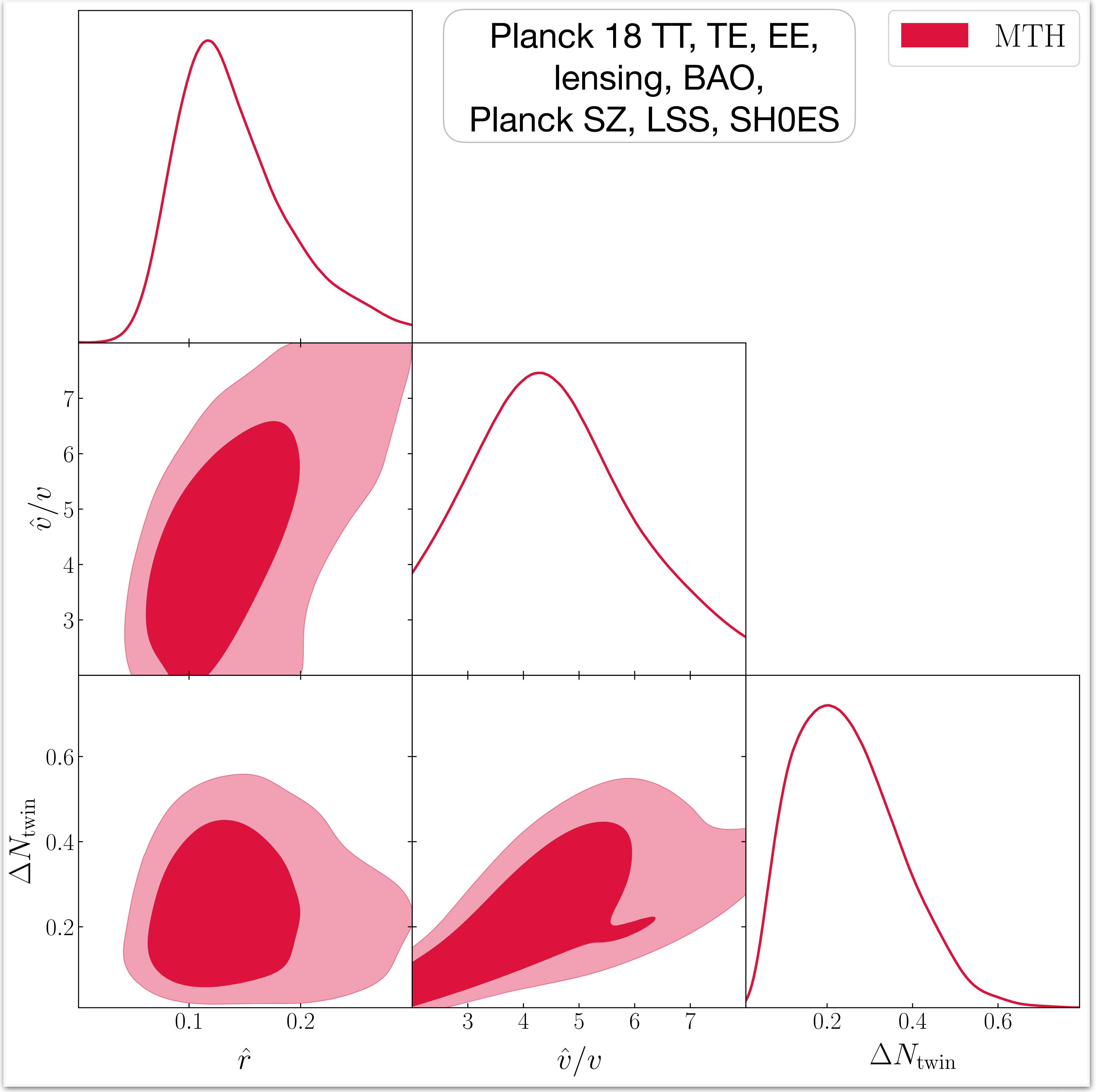


The CMB temperature and polarization power spectra can impose stronger constraints on $\hat{v}$ than colliders.

+ LSS + H_0 (SH0ES)

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	2362.1	2359.9	-0.5 ✓	Planck
Planck low ℓ TT	21.6	21.8		
Planck low ℓ EE	395.7	397.2		
BAO	9.5	6.8	-2.7 ✓	BAO
Planck lensing	12.7	9.5	-12.8 ✓	LSS
SDSS	45.6	47.1		
CFHTLens	97.9	99.3		
Planck SZ	14.2	1.7	σ_8	
SH0ES	9.6	8.7	-0.9 ✓	H_0
Total	2969.0	2952.0	**-16.9**	

Parameter	Mean Value MTH	Mean Value ΛCDM
$\hat{r}$	$0.1416^{+0.031}_{-0.065}$	-
$\hat{v}/v$	$4.555^{+1.1}_{-1.8}$	-
ΔN_{twin}	$0.2469^{+0.089}_{-0.16}$	-
σ_8	$0.7726^{+0.011}_{-0.01}$	$0.8041^{+0.0056}_{-0.0049}$
H_0	$70.29^{+0.7}_{-0.89}$	$69.55^{+0.36}_{-0.38}$

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

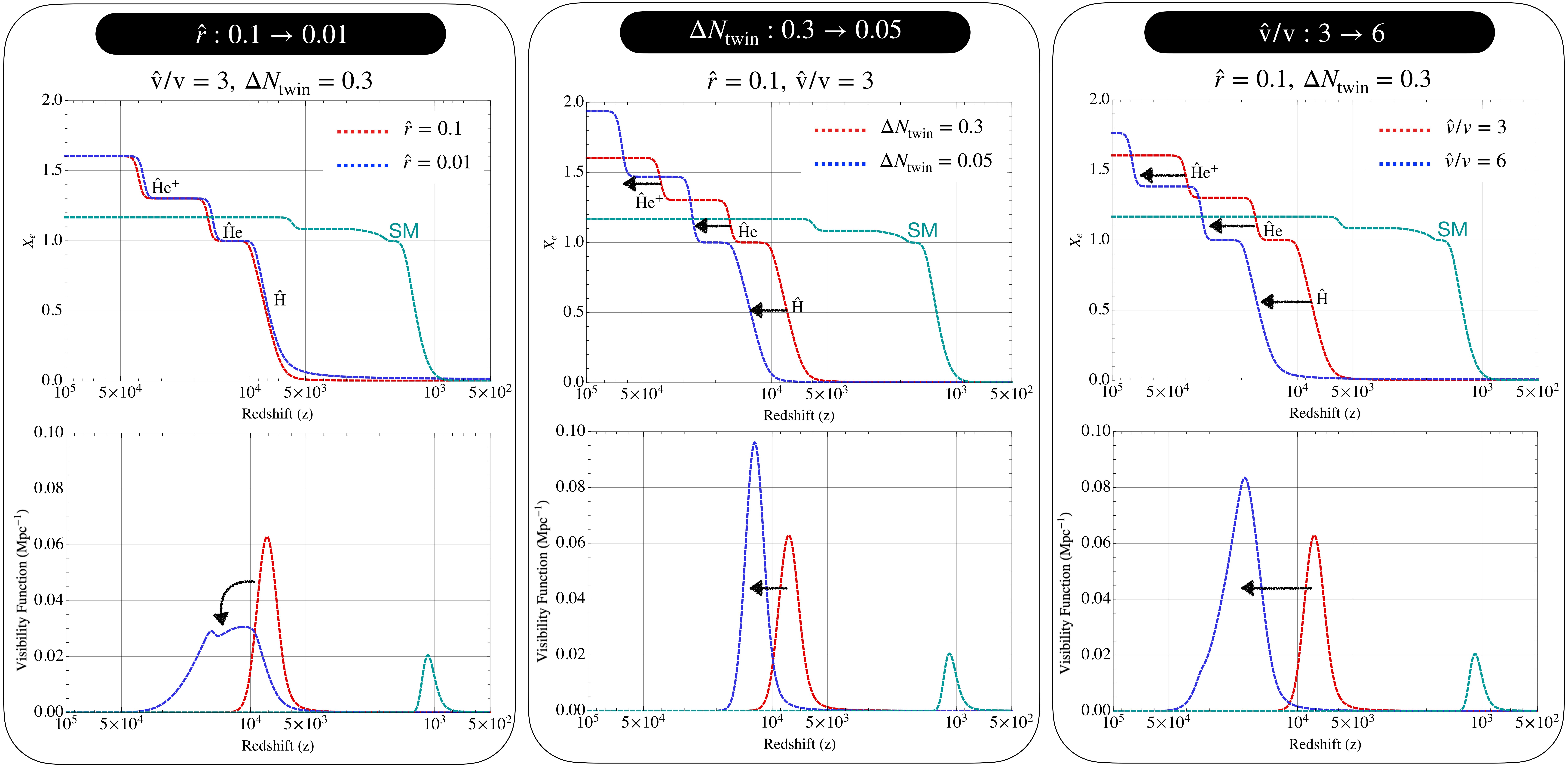
- Taken alone, the Planck data strongly constrains the mirror sector, preferring it be heavy, cold or sparse.

- On including the late Universe measurements of LSS and H_0, the combined data prefers a dark sector with 5-20% 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

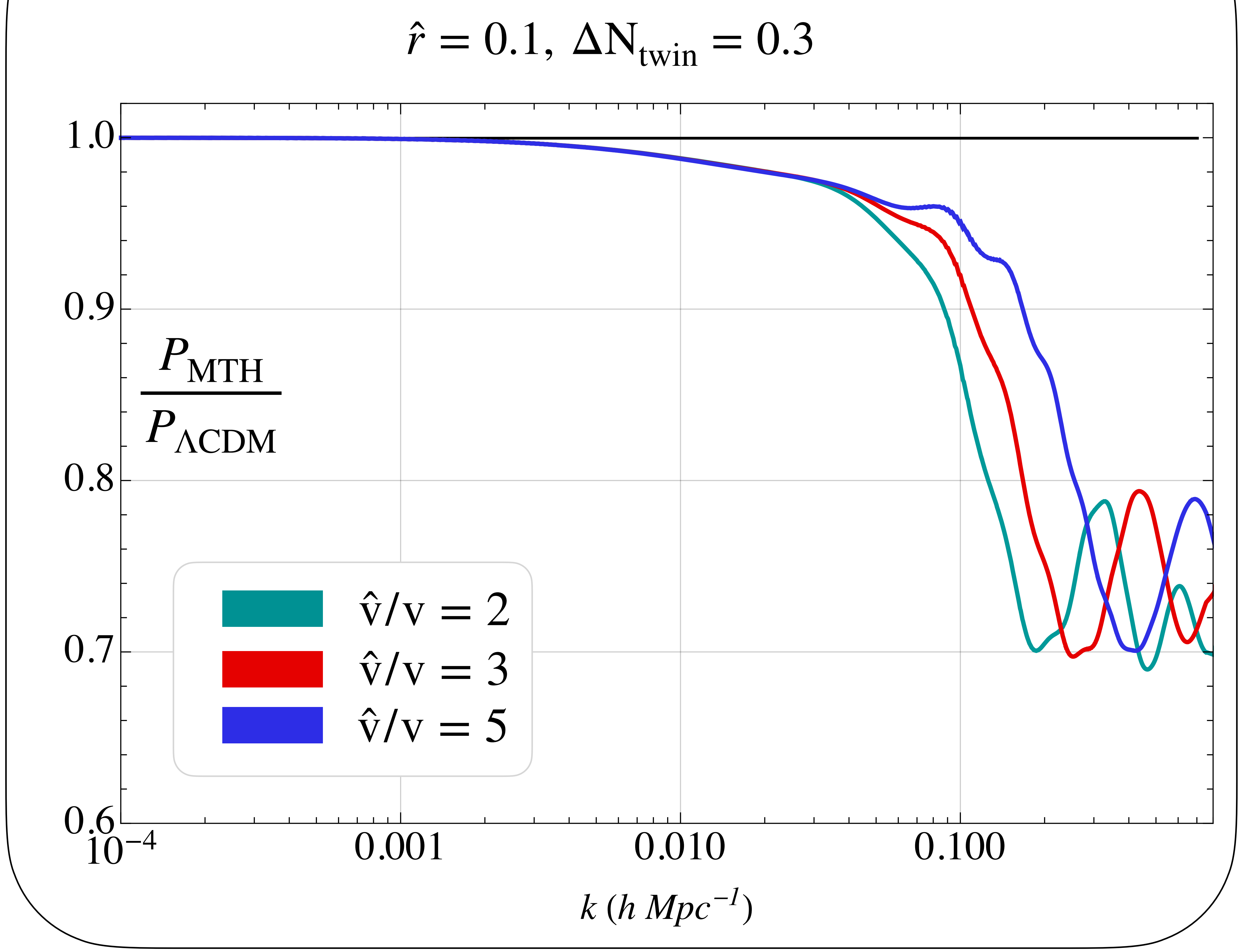


Sparse mirror sector ⇒ Many dark photons last interacted with $\hat{He}$

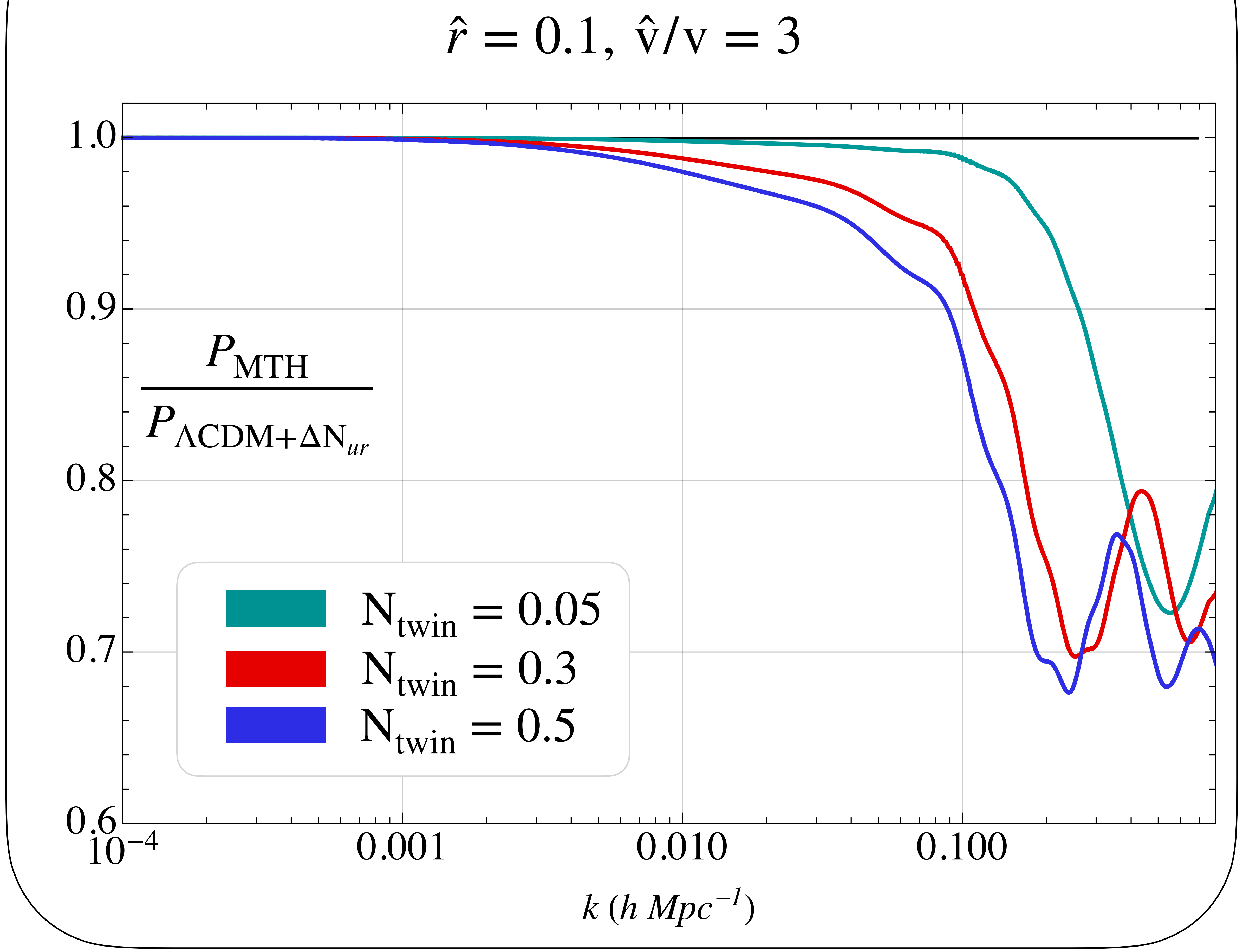
Colder mirror sector ⇒ Early recombination
Hotter mirror sector ⇒ Late recombination

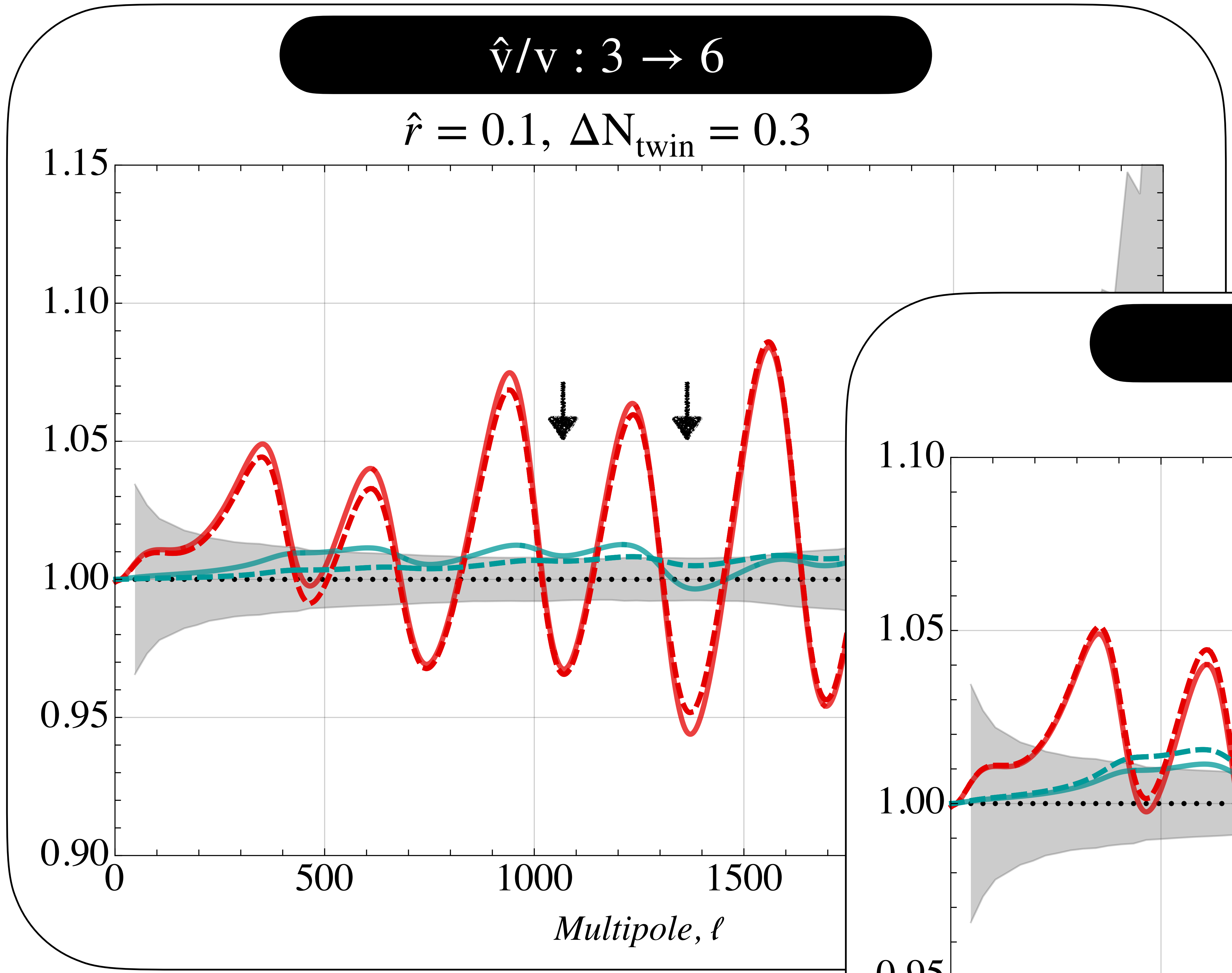
Heavier mirror sector ⇒ Early recombination
Lighter mirror sector ⇒ Late recombination

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

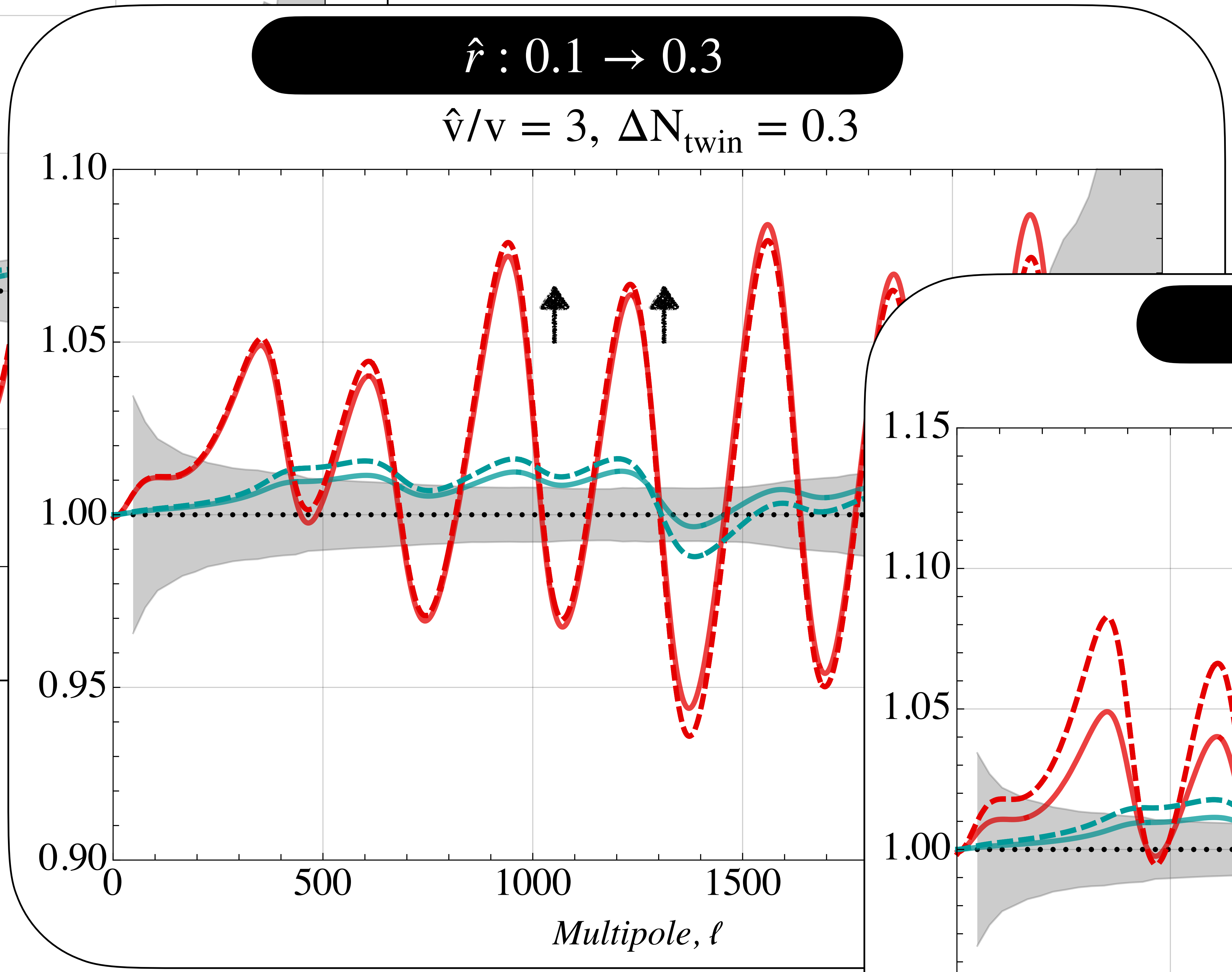


Variation of Linear MPS with ΔN_{twin}



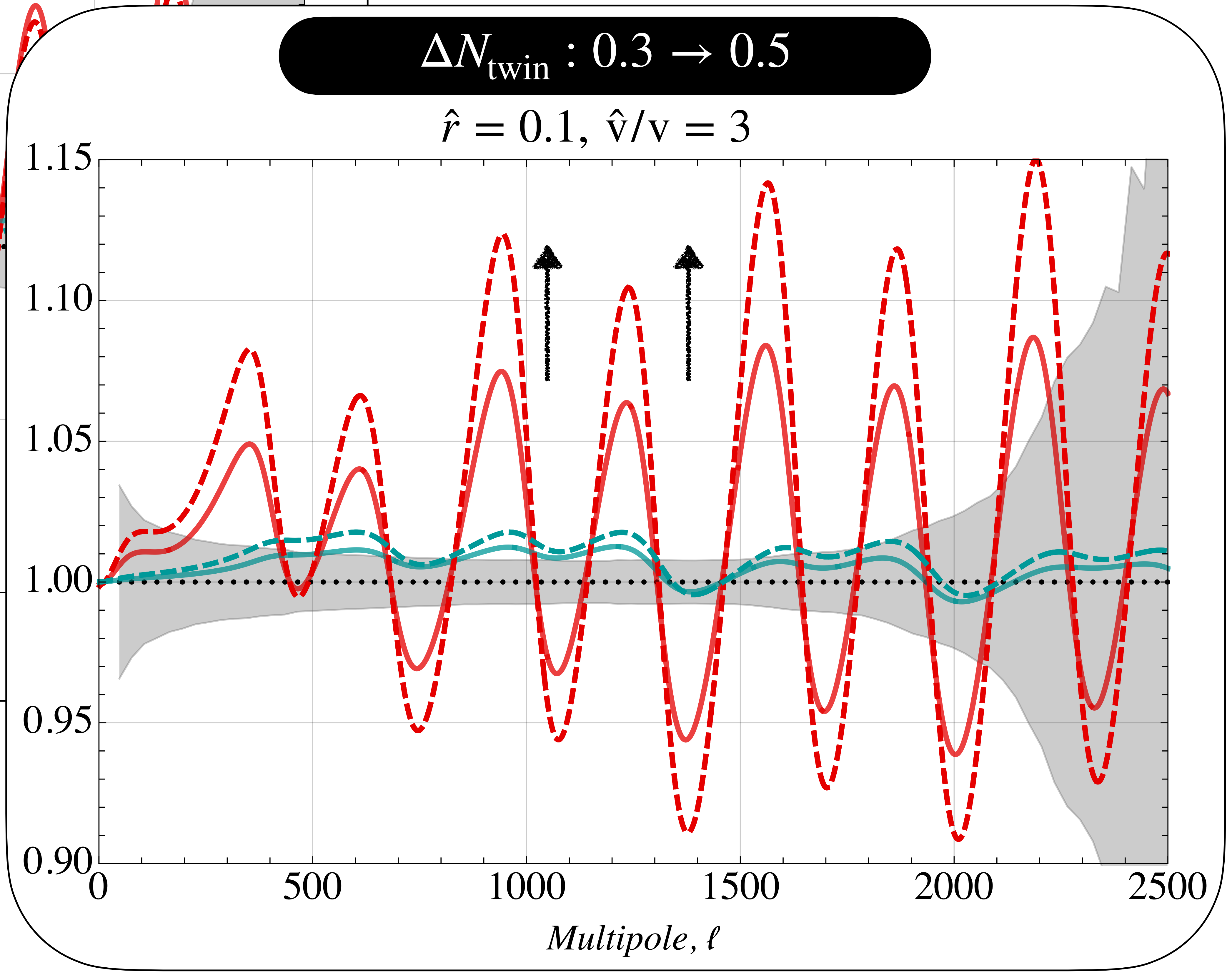


Heavier twin baryons flatten the oscillations, and lead to smaller deviations.



More twin baryons lead to stronger oscillations and larger deviations.

More twin radiation lead to stronger oscillations and larger deviations.



$\dfrac{C_\ell^{TT}(\text{MTH})}{C_\ell^{TT}(\Lambda\text{CDM})}$

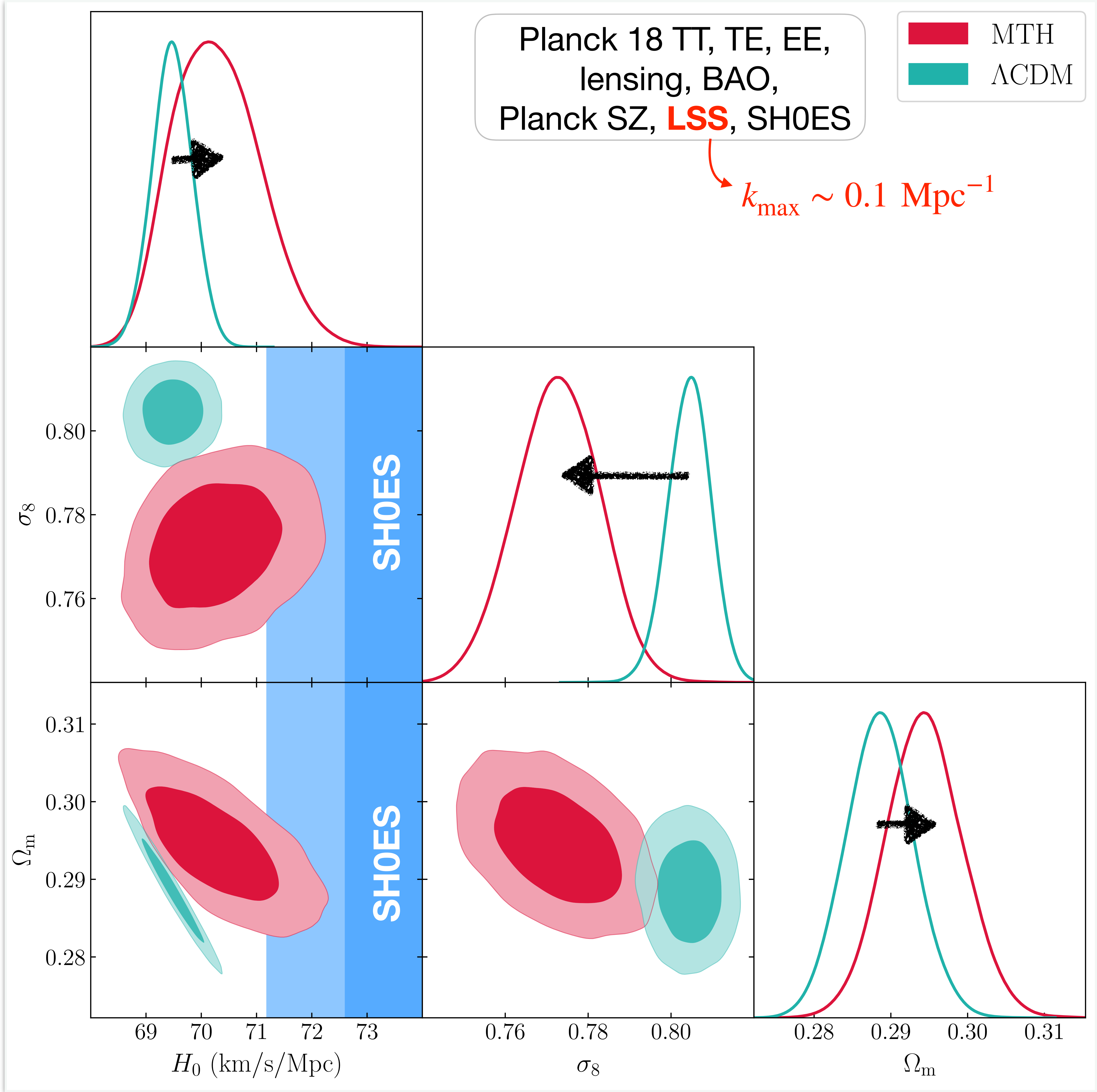
$\dfrac{C_\ell^{TT}(\text{MTH})}{C_\ell^{TT}(\Lambda\text{CDM} + \Delta N_{eff})}$

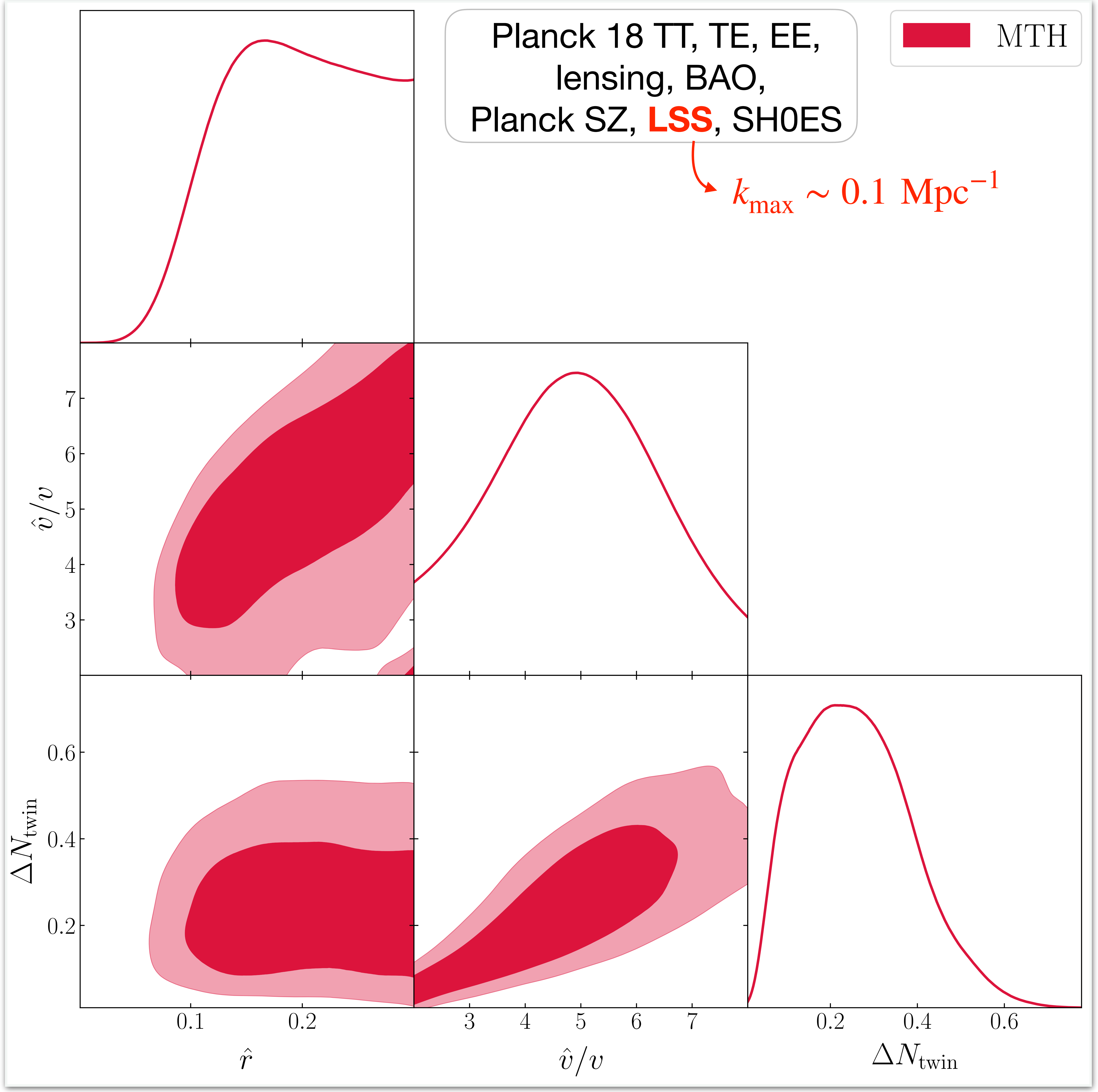
—— $\hat{r} = 0.1,\ \hat{v}/v = 3,\ \Delta N_{twin} = 0.3$

- - - - Modified

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

MCMC results





MCMC results

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SDSS	45.8	50.9	-7.2 ✓	LSS
CFHTLens	27.2	27.1		
Planck SZ	13.6	1.4		
SH0ES	10.5	9.0	-1.5 ✓	H_0
Total	2898.6	2881.7	**-16.9**	

Parameter	Value
$\hat{r}$	0.20
$\hat{v}/v$	5.21
ΔN_{twin}	0.26
σ_8	$0.7726^{+0.011}_{-0.01}$
H_0	$70.28^{+0.68}_{-0.93}$

The MTH model improves χ^2 for all the data sets!