Cosmological Signals of a Mirror Twin Higgs

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Introduction

The Twin Higgs framework is a promising approach to the naturalness problem of the Standard Model (SM).

- Mirror Twin Higgs — ZC, Goh & Harnik (2005)
- Fraternal Twin Higgs — Craig, Katz, Strassler & Sundrum (2015)

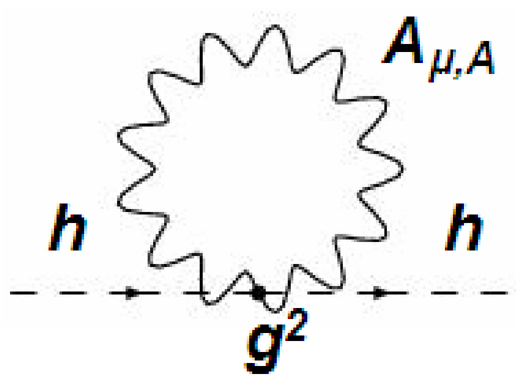
In Mirror Twin Higgs models, the SM is extended to include a complete mirror ("twin") copy of the SM, with its own particle content and gauge groups.

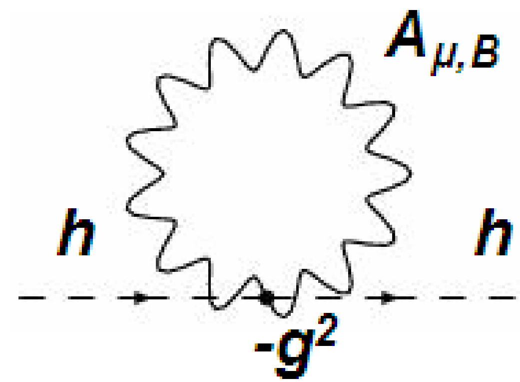
The SM and its twin counterpart are related by a discrete Z_2 "twin" symmetry.

$$\mathrm{SM}_A \xleftrightarrow{\;Z_2\;} \mathrm{SM}_B$$

The mirror particles are completely neutral under the SM strong, weak and electromagnetic forces. Only feel gravity.

In Mirror Twin Higgs models, the one loop quadratic divergences that contribute to the Higgs mass are cancelled by twin sector states that carry no charge under the SM gauge groups.





Discovery of these states at LHC is therefore difficult. May explain null results.

The SM and twin SM primarily interact through the Higgs portal.

$$|H_A|^2|H_B|^2$$

This interaction is needed for cancellation of quadratic divergences.

After electroweak symmetry breaking, SM Higgs and twin Higgs mix.

- Higgs couplings to SM states are suppressed by the mixing.
- Higgs now has (mixing suppressed) couplings to twin states.

A soft breaking of the Z_2 symmetry ensures that f, the VEV of the twin Higgs, is greater than v, the VEV of the SM Higgs.

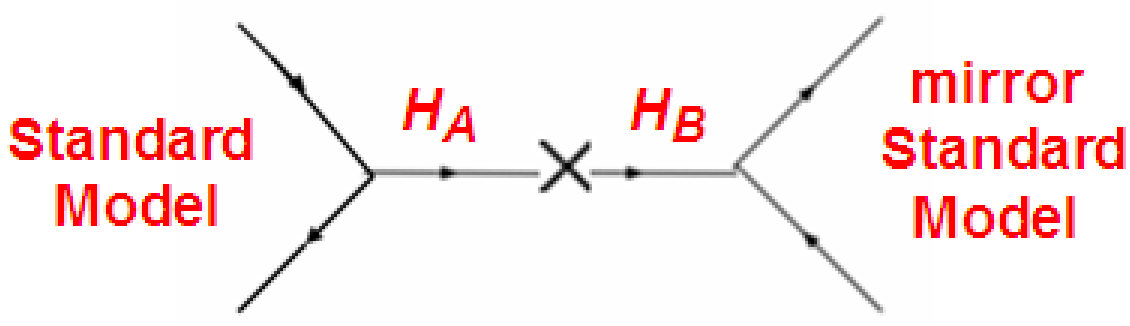
The mixing angle ~ v/f. Higgs measurements constrain $v/f \leq 1/3$.

Twin fermions are heavier than SM fermions by a factor of f/v.

Naturalness requires $v/f \geq 1/5$. (Twin top should not be too heavy.)

The Higgs portal interaction has implications for cosmology.

Interactions mediated by the Higgs keep the SM and twin sectors in thermal equilibrium until temperatures of order a few GeV.



Then the twin photon and twin neutrinos contribute significantly to the energy density in radiation at the time of BBN and CMB.

Leads to a contribution to effective number of neutrinos $\Delta N_{\rm eff} = 5.7$.

The 2σ bound from CMB on dark radiation is given by $\Delta N_{\rm eff} \lesssim 0.5$.

The simplest Mirror Twin Higgs model is excluded!

Two distinct approaches to this problem have been proposed.

- Introduce hard breaking of Z_2 to alter the decoupling temperature and the number of degrees of freedom in the twin sector at a given temperature.

  Farina; Barbieri, Hall & Harigaya; Csaki, Kuflik & Lombardo

- **Introduce new dynamics that preferentially heats up the SM sector** after the two sectors have decoupled. May not require further Z_2 breaking.

  ZC, Craig, Fox & Harnik; Craig, Koren & Trott

We will focus on the second approach, and assume no further breaking of Z_2.

Then the light degrees of freedom at CMB include the twin photon plus the 3 twin neutrinos. Treat $\Delta N_{\rm eff}$ as a free parameter.

If there is a baryon asymmetry in the mirror sector, the bath will also contain twin baryons and electrons. Treat the asymmetry as a non-zero free parameter.

What are the cosmological signals associated with this scenario?

- Twin photons and twin neutrinos constitute distinct forms of dark radiation that have different effects on the CMB, and can be distinguished.

    - The twin neutrinos free stream, suppressing inhomegeneities.
    - The twin photons scatter of dark baryons. Do not free stream till late.

Fraction of dark radiation that free streams is fixed by the model. A prediction!

- The twin baryons constitute an acoustic subcomponent of dark matter. Baryon acoustic oscillations in the twin sector lead to a characteristic suppression of large scale structure.

- The twin baryons in a galaxy might cool to form a double disc in some regions of parameter space.

CMB Signals of a Mirror Twin Higgs

How is CMB sensitive to dark radiation? Consider ΛCDM parameters.

ρ_m ρ_b ρ_Λ

A_s n_s

τ_r

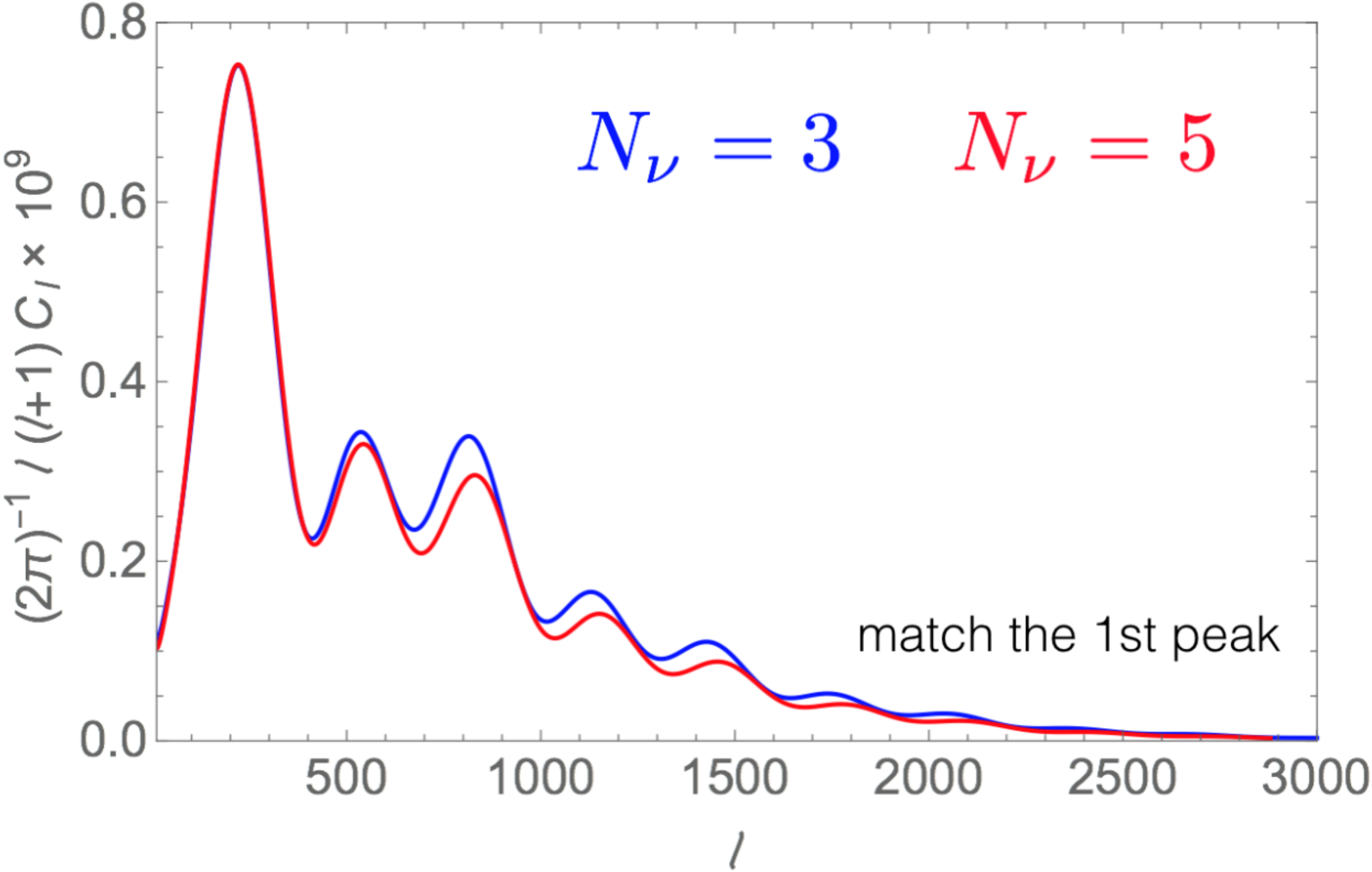
The amplitude of a CMB mode is very sensitive to the fraction of energy density in matter when it crosses the horizon.

In the presence of dark radiation, the ΛCDM fit will increase ρ_m to keep the time of matter-radiation equality fixed.

But then Hubble expansion is larger! Time to last scattering reduced.

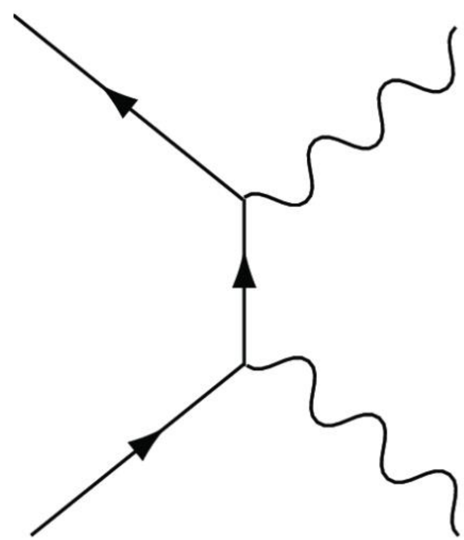
The fit will also increase ρ_Λ to keep the angular size of the last scattering surface fixed.

The primary CMB sensitivity to dark radiation is because the amount of time for diffusion damping during the era of acoustic oscillations is affected.


0.8
0.6
0.4
0.2
0.0
$(2\pi)^{-1}\, l\,(l+1)\, C_l \times 10^9$
$N_\nu = 3$
$N_\nu = 5$
match the 1st peak
500
1000
1500
2000
2500
3000
l

At a subdominant level, the CMB signals of dark radiation also depends on whether it free streams (like neutrinos), or scatters with a short mean free path (like a fluid).

While the twin neutrinos free stream, the twin photons are prevented from free streaming by Compton scattering off twin electrons.



At later times, after recombination happens in the twin sector, the twin photons also free stream. Since the twin electron is heavier, this happens during the CMB epoch, when the SM temperature is of order an eV.

The size of these subleading effects depends on the free streaming fraction, f_ν.

This is defined as the total energy in free streaming radiation expressed as a fraction of the total energy in radiation.

$$f_\nu \equiv \frac{\rho_{\text{all free rad}}}{\rho_{\text{all rad}}} = \frac{3\rho_{1\nu} + \rho_{\text{DR}}^{\text{free}}}{3\rho_{1\nu} + \rho_\gamma + \rho_{\text{DR}}^{\text{free}} + \rho_{\text{DR}}^{\text{scatt}}}$$

In the limit that ΔN_{eff} is small, free streaming dark radiation and scattering dark radiation contribute to f_ν with opposite sign!

$$f_\nu - f_\nu\big|_{\text{SM}} = \frac{0.41}{3}\left(0.59\Delta N_{\text{eff}}^{\text{free}} - 0.41\Delta N_{\text{eff}}^{\text{scatt}}\right)$$

Their effects on the CMB are different!

The amplitudes of the CMB modes depend on f_ν.

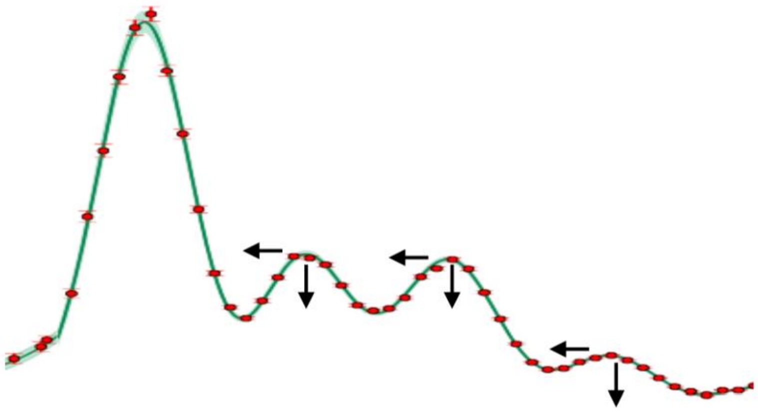
$$\frac{\delta C_\ell}{C_\ell} = -\frac{8}{15} f_\nu$$

Peebles
Hu & Sugiyama

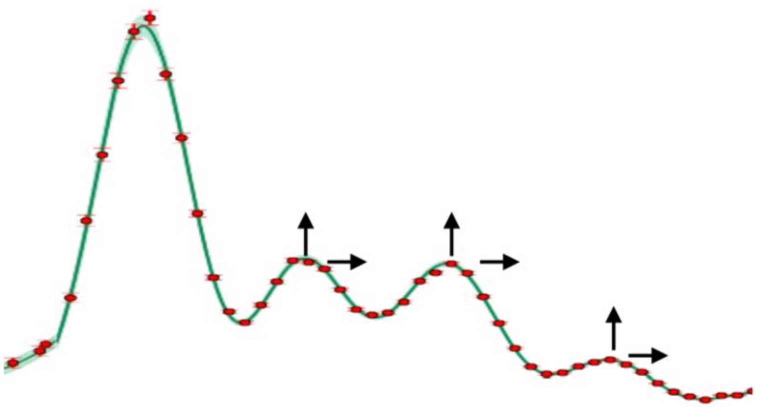
The locations of the CMB peaks also depend on f_ν. For higher l,

$$\delta\ell \simeq -57\, f_\nu\, \frac{\ell_A}{300}$$

Bashinsky & Seljak



Free Streaming DR



Scattering DR

The sign of the effect is different in the two cases! Distinguishable!

The Mirror Twin Higgs predicts the ratio

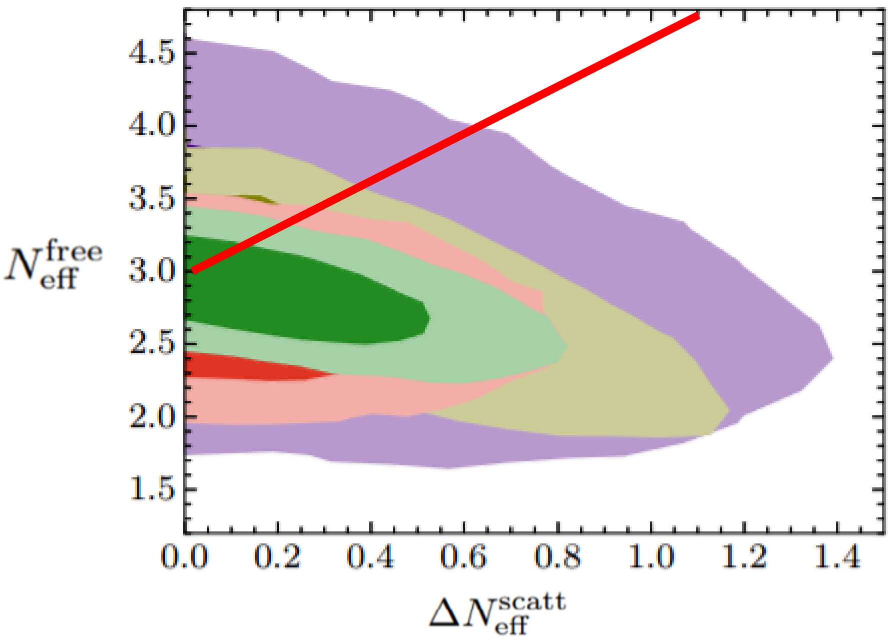
$$\frac{\Delta N_{\rm eff}^{\rm scatt}}{\Delta N_{\rm eff}^{\rm free}} = \frac{3}{4.4}$$

How well can current and future CMB experiments distinguish this?

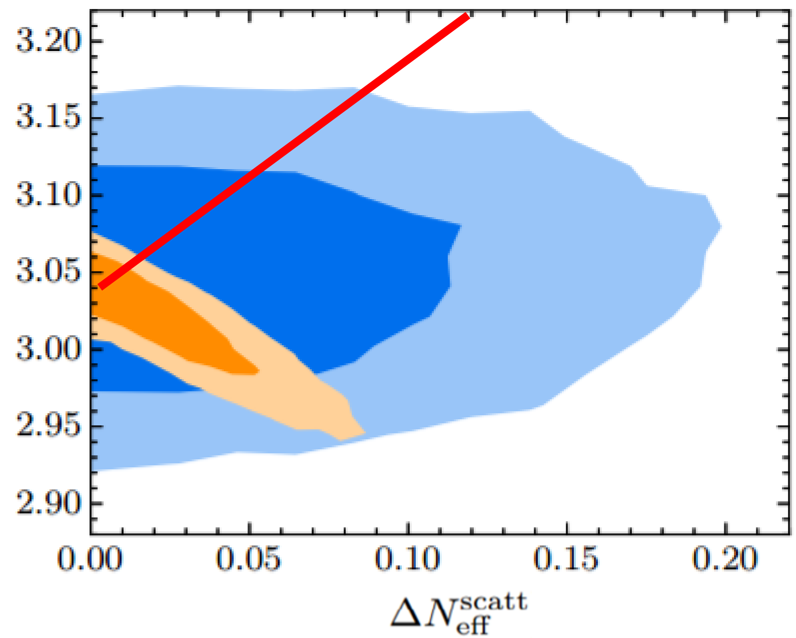
The current 2σ bounds on $\Delta N_{\rm eff}^{\rm free}$ and $\Delta N_{\rm eff}^{\rm scatt}$ stand at 0.5 and 0.6 respectively. The sensitivity is expected to improve by an order of magnitude in CMB-S4.

Baumann, Green, Meyers & Wallisch
Brust, Cui & Sigurdson

Planck 2015

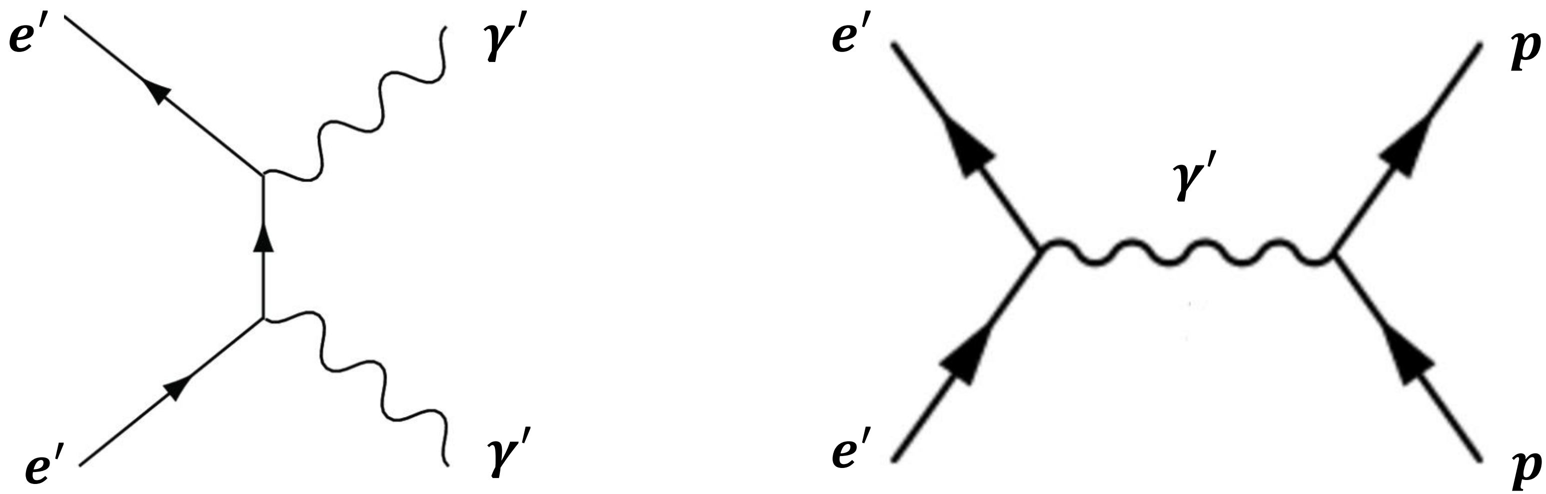


CMB-S4



Signals in Large Scale Structure

The interactions of twin baryons with twin photons at early times suppresses the growth of density perturbations in the twin sector.

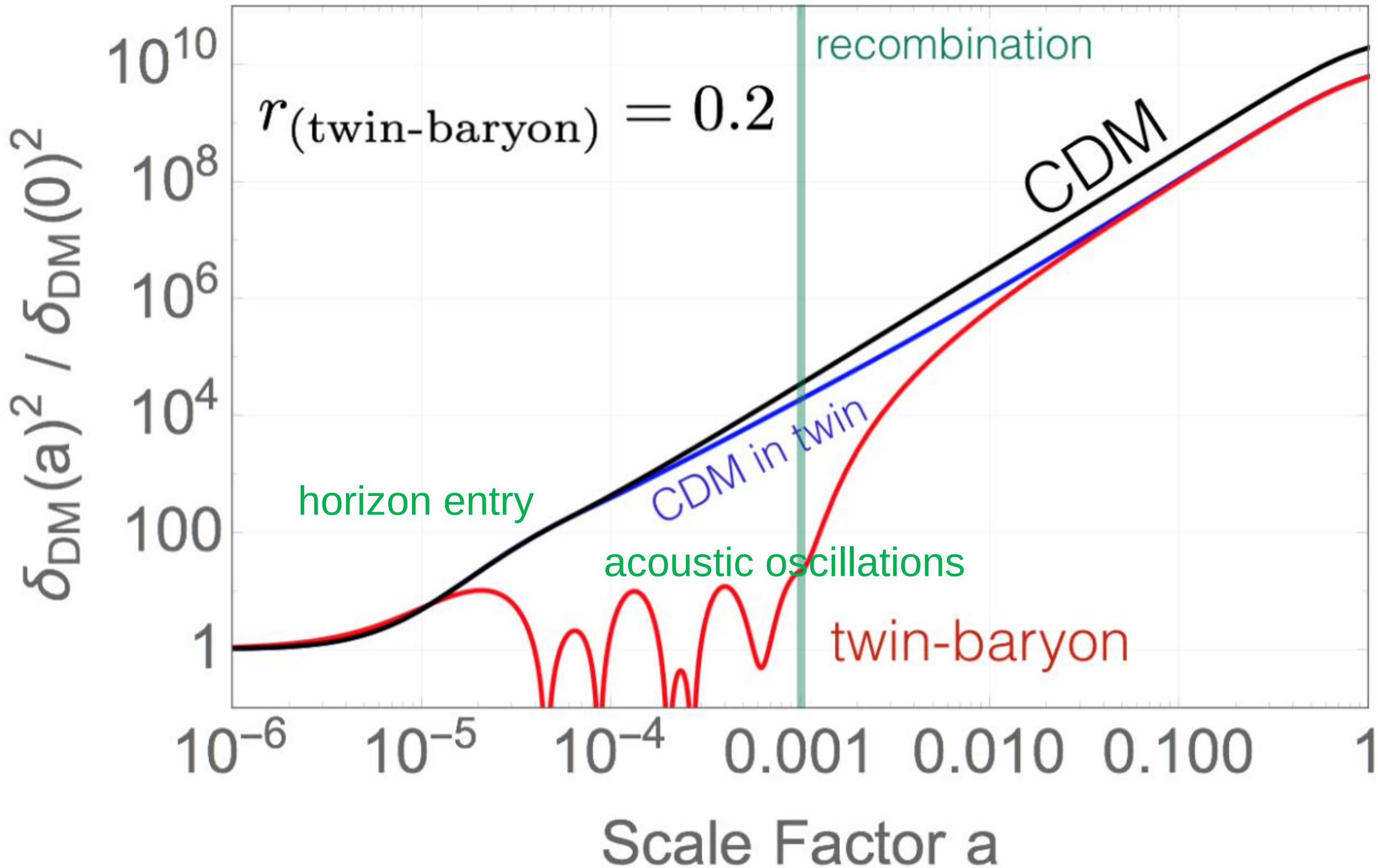


The size of these effects is determined by Γ, the rate of momentum transfer between twin photons and twin baryons,

$$\Gamma \equiv \frac{1}{\langle p^2 \rangle} \frac{\mathrm{d}\langle \delta p^2 \rangle}{\mathrm{d}t}$$

Since $\Gamma > H$ at early times, these effects are large and suppress the growth of structure in the twin sector till recombination occurs (at around an eV).

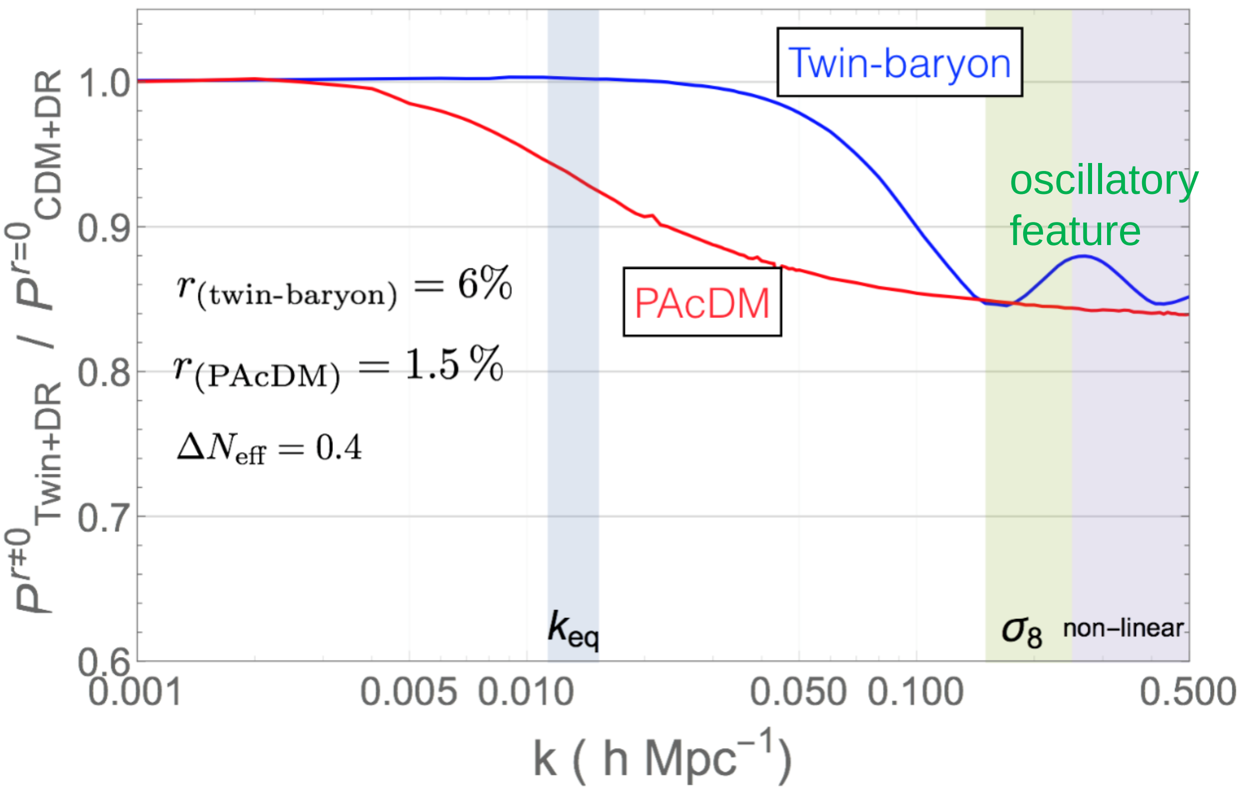
Consider a mode that enters the horizon well before recombination. Acoustic oscillations in the twin sector suppress growth of structure relative to ΛCDM.



Modes which enter after twin recombination are relatively unaffected.

However, for modes that entered before recombination, the growth of density perturbations is different from ΛCDM even after recombination.

This is because the density fluctuations in twin baryons are suppressed and contribute less to the gravitational potential that sources this growth.



Can potentially resolve the "$\boldsymbol{\sigma_8}$ problem".

Weak lensing, CMB lensing and eventually 21 cm line measurements will test this.

Conclusions

The Mirror Twin Higgs framework leads to characteristic cosmological signals.

Twin photons and twin neutrinos constitute distinct forms of dark radiation that have different effects on the CMB, and can be distinguished. While the twin neutrinos free stream, the twin photons scatter off dark baryons.

Fraction of dark radiation that free streams is a prediction of the Mirror Twin Higgs framework that can potentially be tested in future CMB experiments.

The twin baryons constitute an acoustic subcomponent of dark matter. Baryon acoustic oscillations in the twin sector leave a characteristic imprint on large scale structure that can be probed in future experiments.

These two effects together can help address two large scale anomalies, the H_0 problem and σ_8 problem.

The twin baryons in a galaxy might cool to form a double disc in some regions of parameter space.