

THINKING EFFECTIVELY ABOUT THE DARK

UV PRIORS AND PREDICTIVE COSMOLOGY

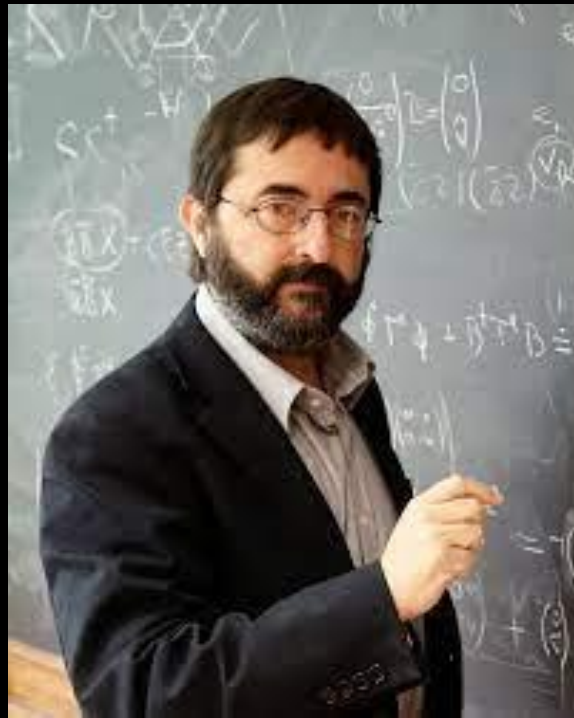
LBL SEMINAR
OCTOBER 20, 2026



CP BURGESS

IMAGE: CHATGPT

UV PEOPLE



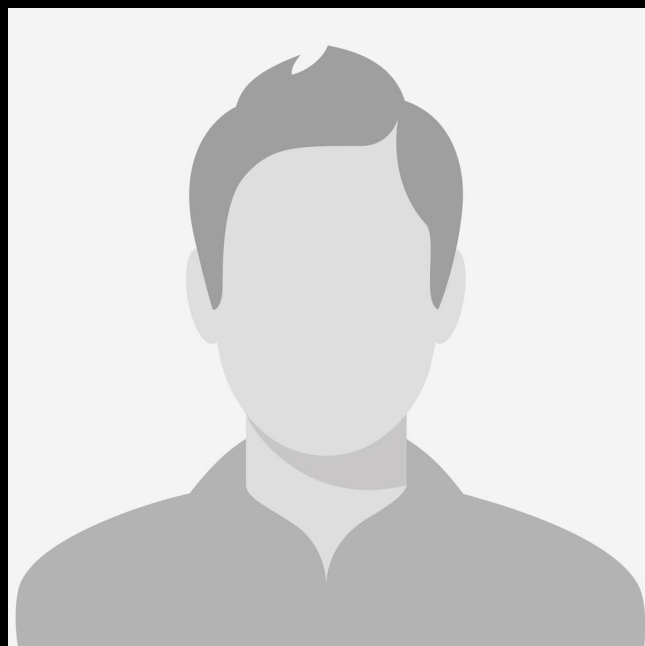
F. Quevedo



P. Brax



G. Villa



M. Ciupke



S. Krippendorf

M. Cicoli

IR PEOPLE



C. Van de Bruck



D. Dineen



E. Di Valentino



M. Mylova



A. Smith



A. Davis

OUTLINE

- ① UV STRATEGIES WHEN TESTING GRAVITY?
- ② MORE IS DIFFERENT
- ③ TWO SYMMETRIES & A MECHANISM
- ④ NATURAL RELAXATION
- ⑤ YOGA COSMOLOGY



UV STRATEGIES

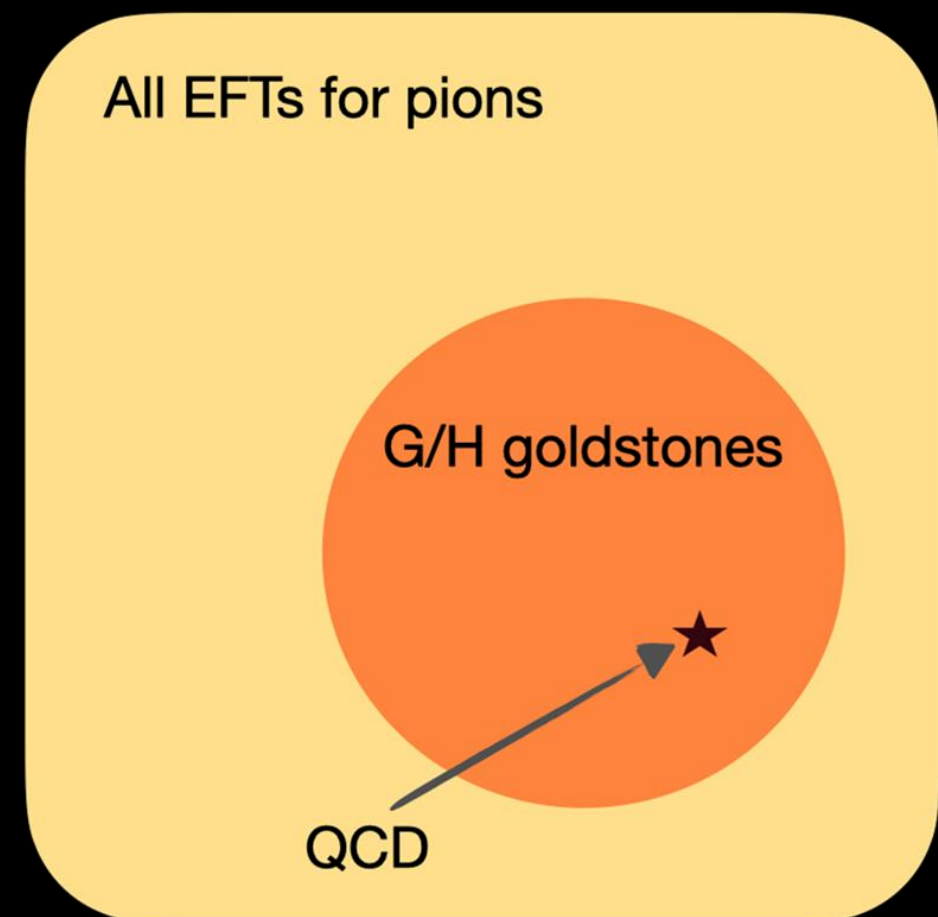
A G A I N S T T H E S W A M P L A N D

IMAGE: CHATGPT

ROBUST VS UV-SPECIFIC PREDICTIONS

UV information provides two very different types of low-energy predictions:

- **Very general symmetry arguments:** *eg soft pion theorems for QCD*



$$SU(2) \times SU(2) \rightarrow SU(2)$$

ROBUST VS UV-SPECIFIC PREDICTIONS

UV information provides two very different types of low-energy predictions:

- **Very general symmetry arguments:** *eg soft pion theorems for QCD*
- **Very UV-specific information:** *eg value of proton mass for QCD*

UV-specific predictions require detailed information and so are usually only made when UV theory is very well-understood and explored.

ROBUST VS UV-SPECIFIC PREDICTIONS

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Swampland assertions:

1. **There are sensible low-E theories with no UV completions**

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Swampland assertions:

1. **There are sensible low-E theories with no UV completions**
2. **Assertion 1 has useful implications for low-energy observables**
(eg can explain absence of de Sitter solutions)

Vafa 05

Swamplémentarity: *the surer we are a feature lies in the swampland the less informative it appears to be at low energies*

IMAGE: CHATGPT

HIGHLAND PROGRAM

- Use known UV physics (string theory) to identify robust UV symmetry predictions

Some things do seem common:

Garden-variety low-spin fields (spins 0, 1/2, 1, 3/2)

Possibly extra dimensions (possibly down to eV energies)

Often find accidental approximate symmetries and these can lead to light fields (axions, dilatons, and often many of them)

Supersymmetry present but broken

Scale invariances combined with SUSY can suppress potentials (and so help explain the small size of DE density).



MORE IS DIFFERENT

A G A I N S T H O R N D E S K I

IMAGE: CHATGPT

MORE IS DIFFERENT

EFFECTIVE FIELD THEORY

EFTs identify how low energies can depend on UV physics

eg effective description of gravity once particle of mass m is integrated out

$$\frac{\mathcal{L}}{\sqrt{-g}} = \boxed{m^4 + \frac{m^2}{2} R} + c_1 R^2 + c_2 R_{\mu\nu} R^{\mu\nu} + \frac{c_3}{m^2} R^3 + \dots$$

If multiple particles are integrated out then:

the *largest* mass wins in the numerator

$$\sum_m^M c_i m_i^2 \simeq M^2$$

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the *largest* mass wins in the numerator

$$\sum_m^M c_i m_i^2 \simeq M^2$$

the *smallest* mass wins in the denominator

$$\sum_m^M \frac{c_i}{m_i^2} \simeq \frac{1}{m^2}$$

MORE IS DIFFERENT

EFFECTIVE FIELD THEORY

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*A small scale **here** or a large scale **here** require explanation
(usually this is done using a selection rule)*

EFFECTIVE FIELD THEORY

- Low energies make this predictive. For example: using

$$\frac{\mathcal{L}}{\sqrt{-g}} = \frac{M_p^2}{2} R + c_1 R^2 + c_2 R_{\mu\nu} R^{\mu\nu} + \frac{c_3}{m^2} R^3 + \dots$$

e.g. compute correlator for E gravitons at L loops using V_n vertices involving f_n fields and d_n derivatives at low energies H :

$$\mathcal{B}_E(H) \simeq M_p \left(\frac{H^2}{M_p} \right)^{E-1} \left(\frac{H}{4\pi M_p} \right)^{2L} \prod_{d_n \geq 4} \left[\left(\frac{H}{M_p} \right)^2 \left(\frac{H}{m} \right)^{d_n-4} \right]^{V_n}$$

GR-QC/0311082

*Semiclassical (loop) expansion *is* the low-energy expansion!*

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GR-QC/0311082

Higher derivative interactions ($d_n > 2$) are more suppressed at low energies

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GR-QC/0311082

No penalty for $d_n = 2$ interactions (GR nonlinearities cannot be ignored)

MORE IS DIFFERENT

SCALAR TENSOR THEORIES

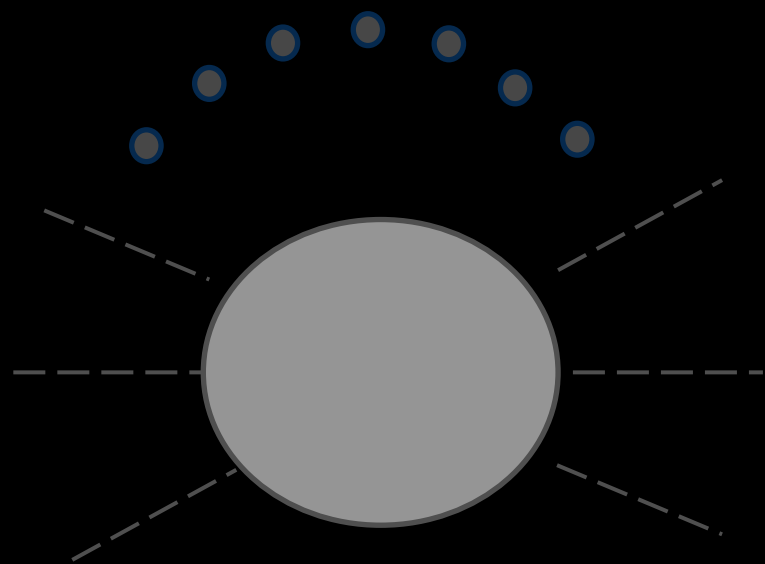
- Similar arguments go through for modifications to GR
(eg scalar tensor theories)

$$\mathcal{L}_W = -\sqrt{-g} \left[v^4 U(\phi) + \frac{1}{2} M_p^2 R + \frac{1}{2} M_p^2 \mathcal{G}_{ab}(\phi) \partial_\mu \phi^a \partial^\mu \phi^b + c_2 R^2 + \frac{c_3}{m^2} R^3 + \dots \right]$$

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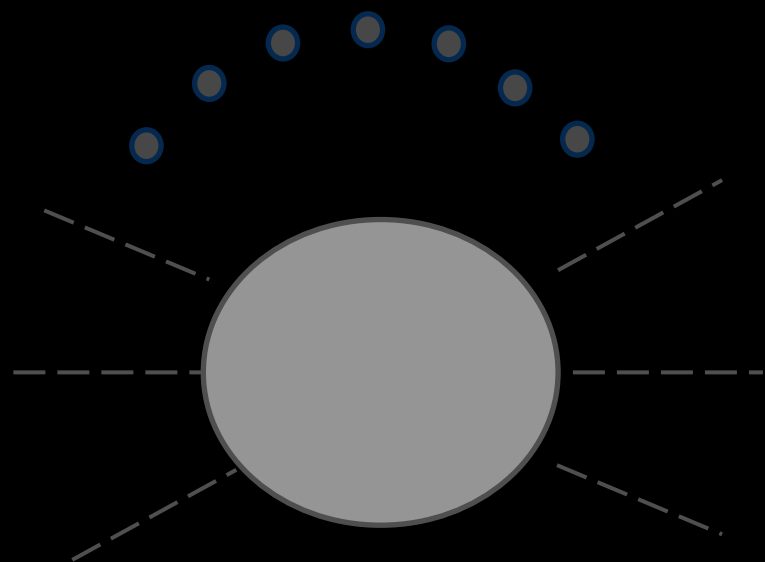


How do correlation functions with E external lines, L loops and V_n vertices involving d_n derivatives with low-energy scale H depend on the scales v, f, M_p, M ?

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MORE IS DIFFERENT

SCALAR TENSOR THEORIES

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$$\text{Each loop costs: } \left(\frac{H}{4\pi M_p} \right)^2 = \frac{GH^2}{2\pi}$$

The semiclassical approximation again *relies* on the derivative expansion

SCALAR TENSOR THEORIES

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Each higher-derivative interaction is again *additionally suppressed*

4- and higher-derivative interactions are ***always*** suppressed at low energies when the semiclassical approximation is under control

MORE IS DIFFERENT

SCALAR TENSOR THEORIES

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Each zero-derivative interaction **amplifies** by an *additional*: $\frac{v^4}{H^2 M_p^2}$

This generically undermines the derivative expansion
(and semiclassical control)

need not be a problem **if** $v^2 = HM_p$ or smaller

MORE IS DIFFERENT

SCALAR TENSOR THEORIES

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There is (again) *no penalty* for 2-derivative terms

UV LESSONS LEARNED

1. Should expect two-derivative scalar interactions to be the ones that compete with GR at energies relevant to observations

Most tests of scalar-tensor theories for simplicity specialize to a single scalar for which 2-derivative scalar interactions turn out to vanish

This is why higher-derivative interactions are so widely studied (eg Horndeski program) and why it has proven hard to get single-scalar models to compete with gravity at low energies in a controlled way

Could the two scalars needed to compete with GR also be the two things we know GR gets wrong? (DM and DE)

UV LESSONS LEARNED

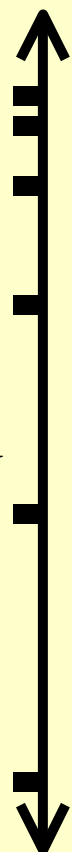
1. Should expect two-derivative scalar interactions to be the ones that compete with GR at energies relevant to observations
2. Should expect parameters to be technically natural (eg small m in numerators or large m in denominators) need explanation

$$M_p \sim 10^{18} \text{ GeV}$$



$$M \sim 10^{11} \text{ GeV}$$

$$M_w \sim 10^2 \text{ GeV}$$



A SMALL COUPLING IS **TECHNICALLY NATURAL** IF BOTH OF THE FOLLOWING ARE TRUE:

1. IT IS SMALL IN THE UV THEORY
2. IT STAYS SMALL AS SMALLER SCALES ARE INTEGRATED OUT

ALL KNOWN FUNDAMENTAL HIERARCHIES OF SCALE ARE TECHNICALLY NATURAL IN THIS WAY



TWO SYMMETRIES & A MECHANISM

APPROXIMATE SCALING

Seek more traditional EFT approach to suppression of scalar potential:
it is a reflection of robust approximate scaling ‘symmetries’?

2006.06694

$$g_{\mu\nu} \rightarrow \lambda g_{\mu\nu}$$

$$\Phi \rightarrow \lambda^s \Phi$$

$$\mathcal{L} \rightarrow \lambda^p \mathcal{L}$$

String theory has no parameters
so all perturbative expansions
are in powers of fields

$$\mathcal{L} = \sum_{mn} f_{mn} \Phi^m \Psi^n$$

$$\Phi \rightarrow \lambda^p \Phi \quad \Psi \rightarrow \lambda^q \Psi$$

$$\mathcal{L}_{mn} \rightarrow \lambda^{mp+nq} \mathcal{L}_{mn}$$

APPROXIMATE SCALING

Essentially every higher dimensional supergravity has such a symmetry

11D SUGRA admits single scaling corresponding to the α' expansion

$$\text{11D sugra: } \mathcal{L}_{11} \rightarrow \lambda^9 \mathcal{L}_{11}$$

$$g_{MN} \rightarrow \lambda^2 g_{MN}$$

$$A_{MNP} \rightarrow \lambda^3 A_{MNP}$$

+ fermion transfn

10D IIB SUGRA similarly admits two scalings, corresponding to the α' and g_s expansions

and so on for IIA, heterotic and other perturbative vacua...

$$\text{10D IIB sugra: } \mathcal{L}_B \rightarrow \lambda^{4u} \mathcal{L}_B$$

$$g_{MN} \rightarrow \lambda^u g_{MN} \quad B_{MN} \rightarrow \lambda^{2u-w} B_{MN}$$

$$C_{MN} \rightarrow \lambda^w C_{MN} \quad \tau \rightarrow \lambda^{2(w-u)} \tau$$

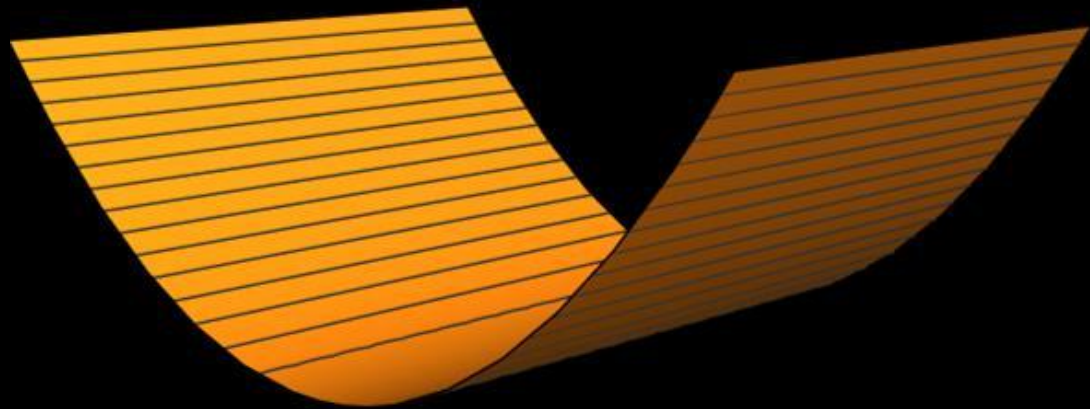
$$C_{MNPR} \rightarrow \lambda^{2u} C_{MNPR}$$

+ fermion transfn

APPROXIMATE SCALING

Scaling can suppress a scalar energy *even if spontaneously broken*

$$V(\lambda^p \Psi) = \lambda^w V(\Psi)$$



Must quantify effects due to explicit symmetry breaking

Peccei et al 87 Wetterich 88

Weinberg 89

$$\sum_i p_i \phi^i \left(\frac{\partial V}{\partial \phi^i} \right) = w V(\phi)$$

$$\text{if } \frac{\partial V}{\partial \phi^i} = 0 \quad \text{then}^* \quad V = 0$$

$$p_j \frac{\partial V}{\partial \phi^j} + \sum_i p_i \phi^i \frac{\partial^2 V}{\partial \phi^i \partial \phi^j} = w \frac{\partial V}{\partial \phi^j}$$

$$\text{if } \phi^i = 0 \quad \text{then}^* \quad \frac{\partial V}{\partial \phi^i} = 0$$

APPROXIMATE SCALING

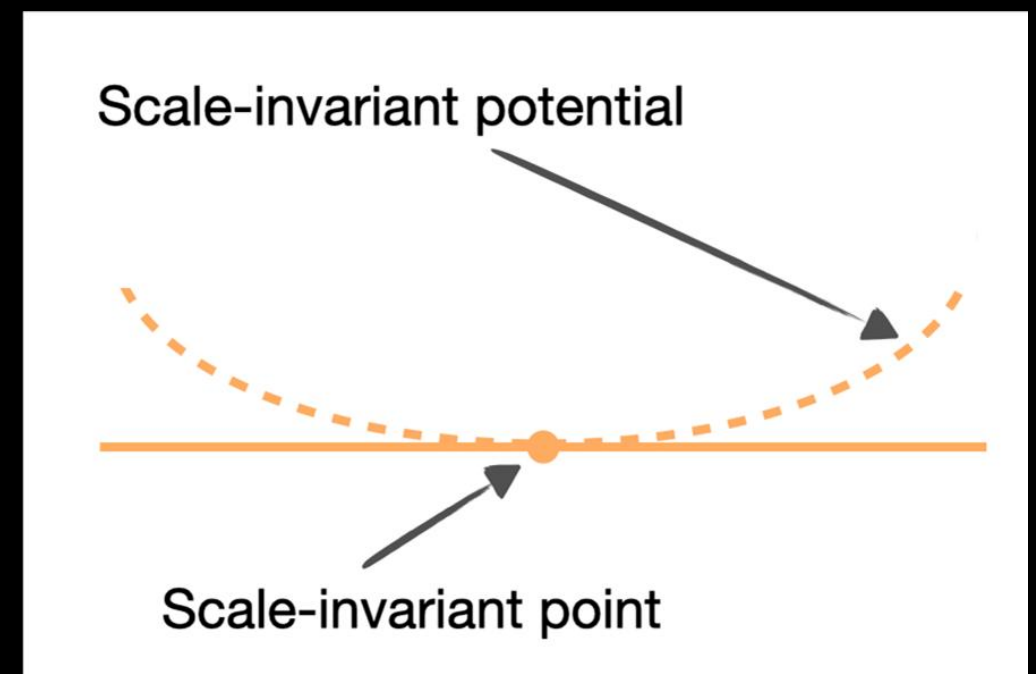
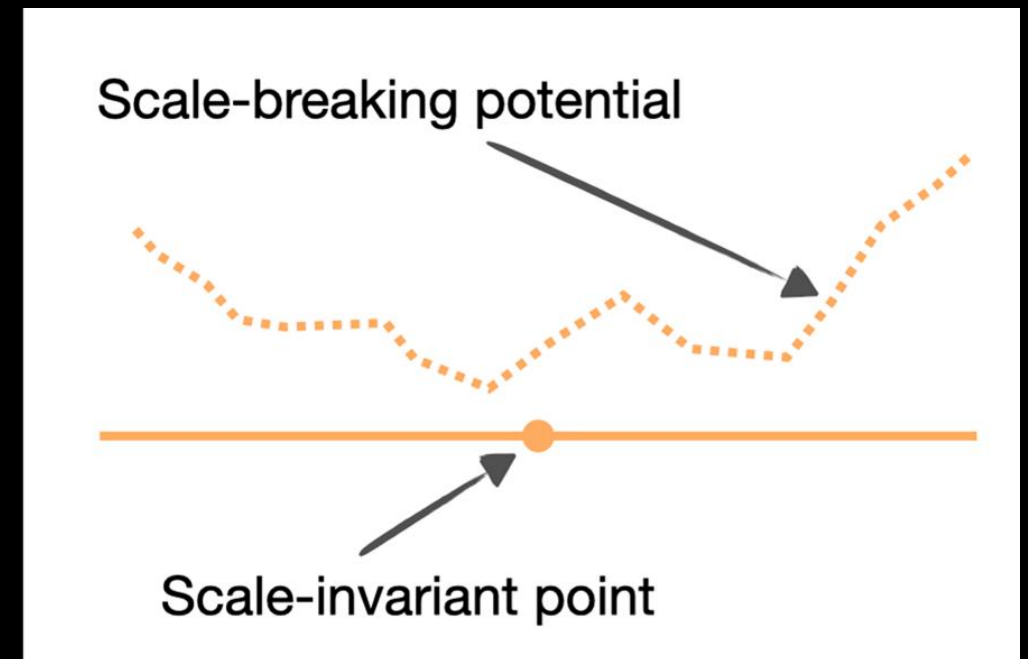
But there is a big BUT:

Not actually a symmetry

Even if it were a classical symmetry, it is usually anomalous

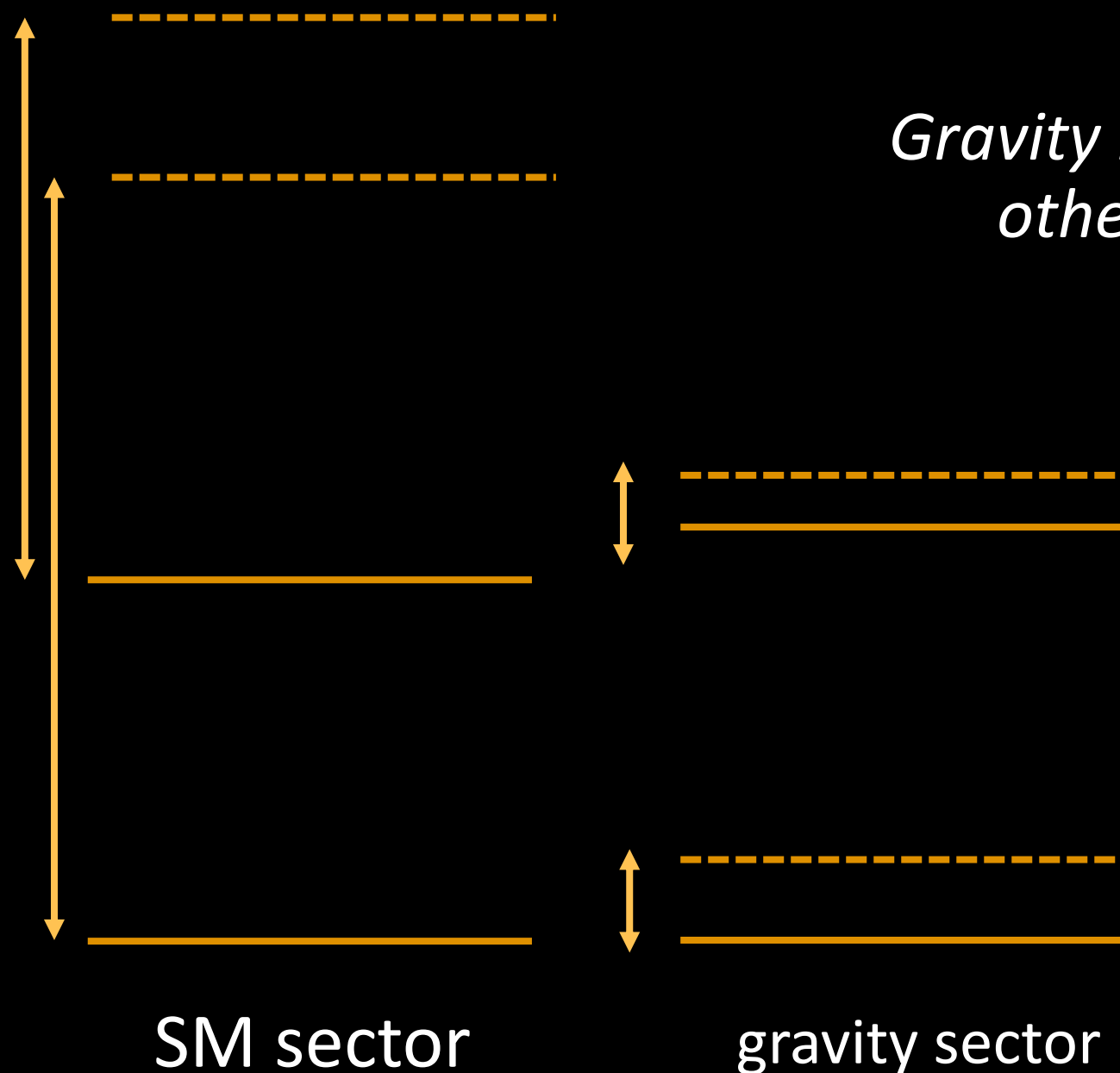
Weinberg No Go: Even if unbroken, scale inv cannot forbid lifting of flat direction

Restricting the lifting of flat directions is where supersymmetry might help



SUPERSYMMETRY? REALLY?

Supersymmetric gravity sectors are generic in UV theories



Gravity multiplet typically split by less than others because gravity is weakest force

$$\Delta m^2 = m_B^2 - m_F^2 \sim gF$$

SCALING WITH SUPERSYMMETRY

Can supersymmetry combine
with scale invariance to
suppress lifting of flat
directions?

4D susy specified by functions
 $K(z, z^*)$, $W(z)$, $f_{ab}(z)$

Scale invariance implies rules
for how W , f_{ab} and $e^{-K/3}$ scale
as the fields z scale

$$\mathcal{L} = \int d^4\theta \, \bar{\Phi} \Phi e^{-K/3} \\ + \int d^2\theta \left[\Phi^3 W + f_{ab} \bar{\mathcal{F}}^a \mathcal{F}^b \right] + \text{c.c.}$$

$$\mathcal{L}_{\text{kin}} = -\sqrt{-g} \, K_{i\bar{j}} \partial_\mu z^i \partial^\mu \bar{z}^{\bar{j}} \\ V(z, \bar{z}) = e^K \left[K^{i\bar{j}} D_i W \overline{D_j W} - 3 |W|^2 \right] \\ D_i W = W_i + K_i W$$

SCALING WITH SUPERSYMMETRY

Special things happen if $e^{-K/3}$ is homogeneous degree 1:

Sufficient condition for flat direction along which susy breaks

No-Scale supergravity: scalar potential has a flat direction along which susy breaks

Cremmer et al 83
Barbieri et al 85

if $z^i \rightarrow \lambda z^i$ implies $e^{-K/3} \rightarrow \lambda e^{-K/3}$
then $K^{i\bar{j}} K_i K_{\bar{j}} = 3$
'no-scale' model

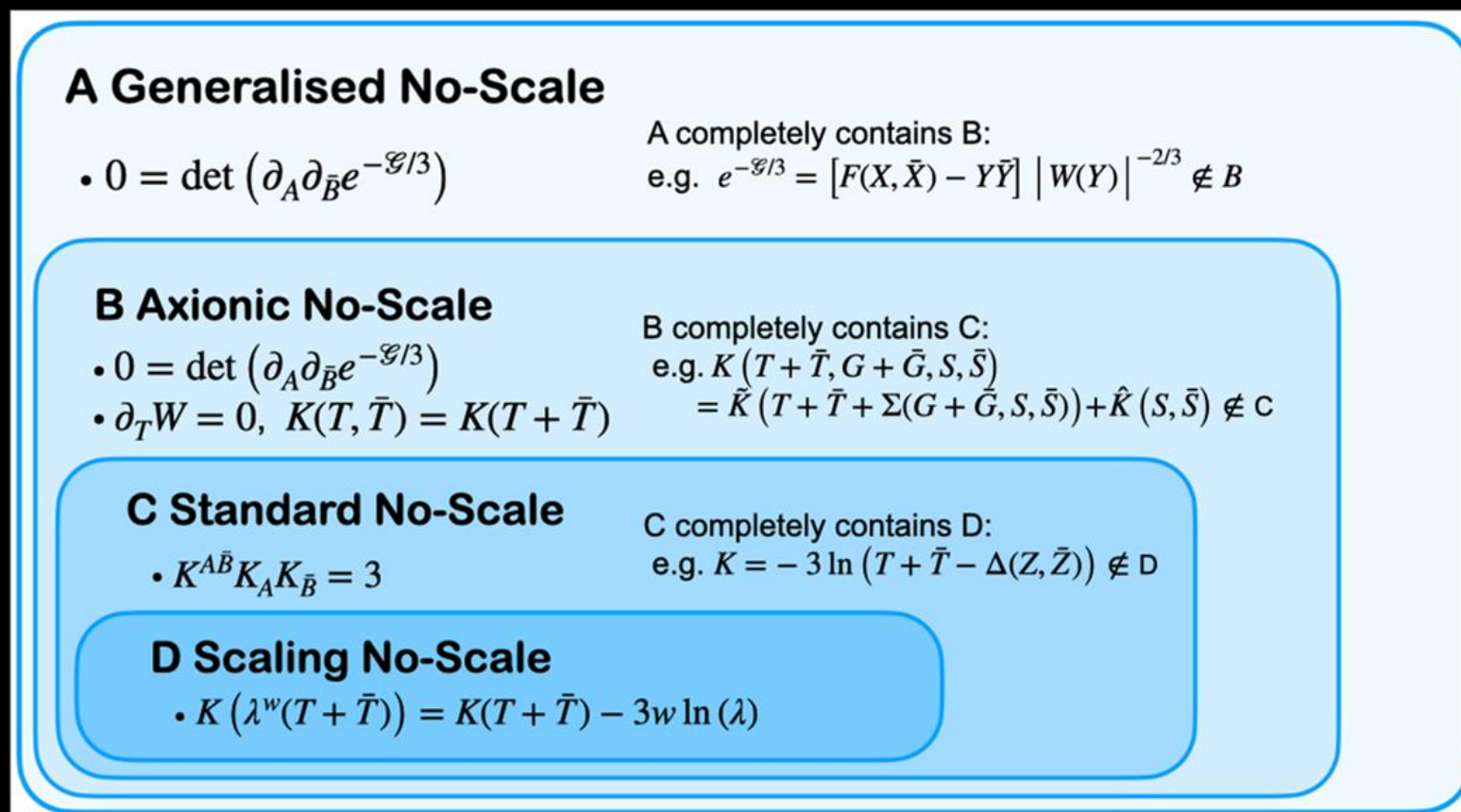
if $W_i = 0$ then
 $V = e^K [K^{i\bar{j}} K_i K_{\bar{j}} - 3] |W|^2 = 0$
 $D_i W = W_i + K_i W = K_i W \neq 0$

SCALING WITH SUPERSYMMETRY

Scale invariance is *sufficient* for no-scale supergravity, but is *not necessary*.

$$e^{-K/3} = T + T^* + f(z, z^*)$$

No-scale condition is sufficient for flat directions, but is also not necessary



SCALING WITH SUPERSYMMETRY

Interplay between scaling and supersymmetry provides a new mechanism for suppressing vacuum energies

Berg, Haack & Kors 05
Berg, Haack & Pajer 07
Cicoli, Conlon &
Quevedo 08

Suppose the lagrangian comes as a series in a large field τ :

$$e^{-K(\tau)/3} = A\tau + B + \frac{C}{\tau} + \dots$$

Scale invariant with a
flat potential

Not scale invariant
with a flat potential

Not scale invariant
with potential lifted

A black and white photograph showing the silhouettes of a man and a woman. The man is on the left, facing right, and the woman is on the right, facing left. They are in a close, intimate pose. The man is holding a small, lit candle in his right hand, which is near the woman's face. The background is a soft, out-of-focus grey. The text "NATURAL RELAXATION" is overlaid in white, sans-serif capital letters on the left side of the image.

NATURAL RELAXATION

IMAGE: THE BIG SLEEP

YOGA MODELS

The definition of the model

- One hierarchy to rule them all
- Axiodilaton couplings to matter
- Stabilization mechanisms and moduli

The need for relaxation

- The predicted Dark Energy potential
- Why relaxation doesn't ruin all scalars (like the Higgs) but can ruin some (like the QCD axion)



2111.07286
2212.14870

YOGA MODELS

Supersymmetry requires the large field τ to come with a scalar axion partner: axio-dilaton: $T = \tau + i a$

$$e^{-K/3} = T + \bar{T} + B(\psi, \bar{\psi}) + \frac{C}{T + \bar{T}} + \dots$$

Gives leading low-energy couplings of the form

$$\mathcal{L}_{\text{ad}} \sim M_p^2 \left[\mathcal{R} + \frac{(\partial\tau)^2 + (\partial a)^2}{\tau^2} \right] + V(\tau) + \mathcal{L}_m(\tilde{g}_{\mu\nu}, \psi)$$

$$\tilde{g}_{\mu\nu} = e^{-K/3} g_{\mu\nu} \simeq \frac{g_{\mu\nu}}{\tau}$$

ONE HIERARCHY TO RULE THEM ALL

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$$\tilde{g}_{\mu\nu} = e^{-K/3} g_{\mu\nu} \simeq \frac{g_{\mu\nu}}{\tau}$$

Scaling requires all particle masses to depend on τ because the Higgs vev depends on τ with $v \sim M_p/\tau^{1/2}$

$$m_{sm} \propto \frac{M_p}{\sqrt{\tau}} \qquad m_\nu \propto \frac{M_p}{\tau}$$

This works if
 $\tau_{\text{min}} \sim 10^{28}$

ONE HIERARCHY TO RULE THEM ALL

Is the size of the scalar potential also correctly set by τ ?

At face value 'no'.

$$V(\tau) \simeq M_p^4 \left[\frac{w_x^2}{\tau^2} + \frac{2Aw_x}{\tau^3} + \frac{B}{\tau^4} + \dots \right]$$

w_x, A, B functions of other fields and $\ln \tau$

$$\text{Recall } m_{sm} \propto \frac{M_p}{\sqrt{\tau}} \text{ so } V \sim \frac{M_p^4}{\tau^2} \sim \mathcal{O}(m_{sm}^4)$$

ONE HIERARCHY TO RULE THEM ALL

Is the size of the scalar potential also correctly set by τ ?

On closer inspection 'yes' (if relaxation is possible).

$$V(\tau) \simeq M_p^4 \left[\left(\frac{w_x}{\tau} + \frac{A}{\tau^2} \right)^2 + \frac{\tilde{B}}{\tau^4} + \dots \right]$$

Perfect-square structure allows other fields to relax to seek minimum. The value of the potential at the minimum is

$$V \sim \frac{M_p^4}{\tau^4} \sim \mathcal{O}(m_\nu^4) \quad \text{Recall} \quad m_\nu \propto \frac{M_p}{\tau} \sim \frac{m_{sm}^2}{M_p}$$

ONE HIERARCHY TO RULE THEM ALL

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On closer inspection 'yes' (if relaxation is possible).

More careful benchmark compares to the supersymmetry breaking scale for particle physics

$$V_{\min} \sim \frac{\epsilon^5}{\tau_{\min}} F^* F \quad F > (10 \text{ TeV})^2$$

$$\epsilon \sim 1/(\log \tau_{\min})$$

Out of the box: $V_{\min} = 10^{-91} M_p^4$ (not quite 10^{-120} , but wip...)

ONE HIERARCHY TO RULE THEM ALL

The potential relevant to cosmology becomes

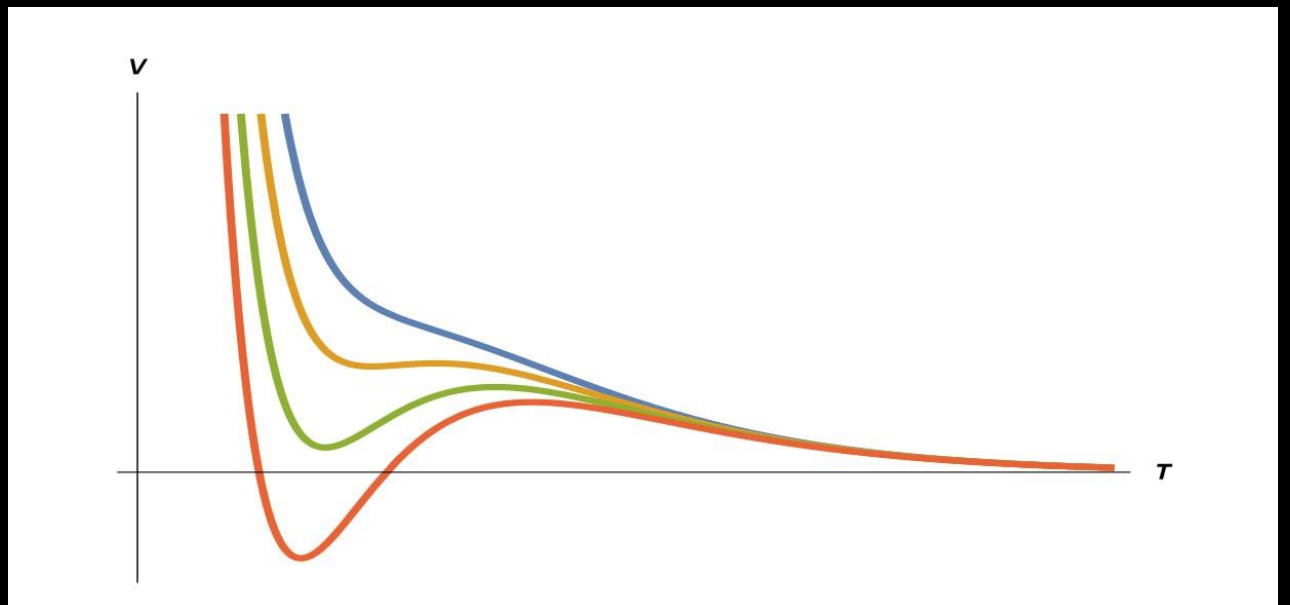
$$V(\tau) \simeq \frac{M_p^4}{\tau^4} U(\ln \tau)$$

This can have a minimum at large enough values using only input constants of order 50.

$$U(x) = a + bx + cx^2$$

$$\ln \tau_{\min} \sim b/c \sim 65$$

$$\text{gives } \tau_{\min} \sim 10^{28}$$



RICH DILATON DYNAMICS

$$\mathcal{L}_{\text{ad}} \sim M_p^2 \left[\mathcal{R} + \frac{(\partial\tau)^2 + (\partial a)^2}{\tau^2} \right] + V(\tau) + \mathcal{L}_m(\tilde{g}_{\mu\nu}, \psi)$$

$$\tilde{g}_{\mu\nu} = e^{-K/3} g_{\mu\nu} \simeq \frac{g_{\mu\nu}}{\tau}$$

Dilaton behaves like a Brans-Dicke scalar with Hubble scale mass, so constrained by Cassini probe to couple with at most sub percent of gravitational strength

Equivalence principle test less constraining at face value

Possible constraints on position- and time-dependence of particle masses (though mass ratios are field independent). 



YOGA COSMOLOGY

IMAGE: PHOTOWORKOUT.COM

YOGA MODEL IN A NUTSHELL

$$\mathcal{L} = \mathcal{L}_{\text{ad}}(g_{\mu\nu}, \chi, a) + \mathcal{L}_m(\tilde{g}_{\mu\nu}, a, \psi)$$

$$\mathcal{L}_{\text{ad}} = M_p^2 \left[\mathcal{R} + (\partial\chi)^2 + e^{-2\zeta\chi} (\partial a)^2 \right] + U(a, \chi) e^{-4\zeta\chi}$$

$$\tilde{g}_{\mu\nu} = e^{-2g\chi} g_{\mu\nu}$$

Dilaton couples to matter like a very light Brans-Dicke scalar:
(solar system tests require $g < 0.001$)

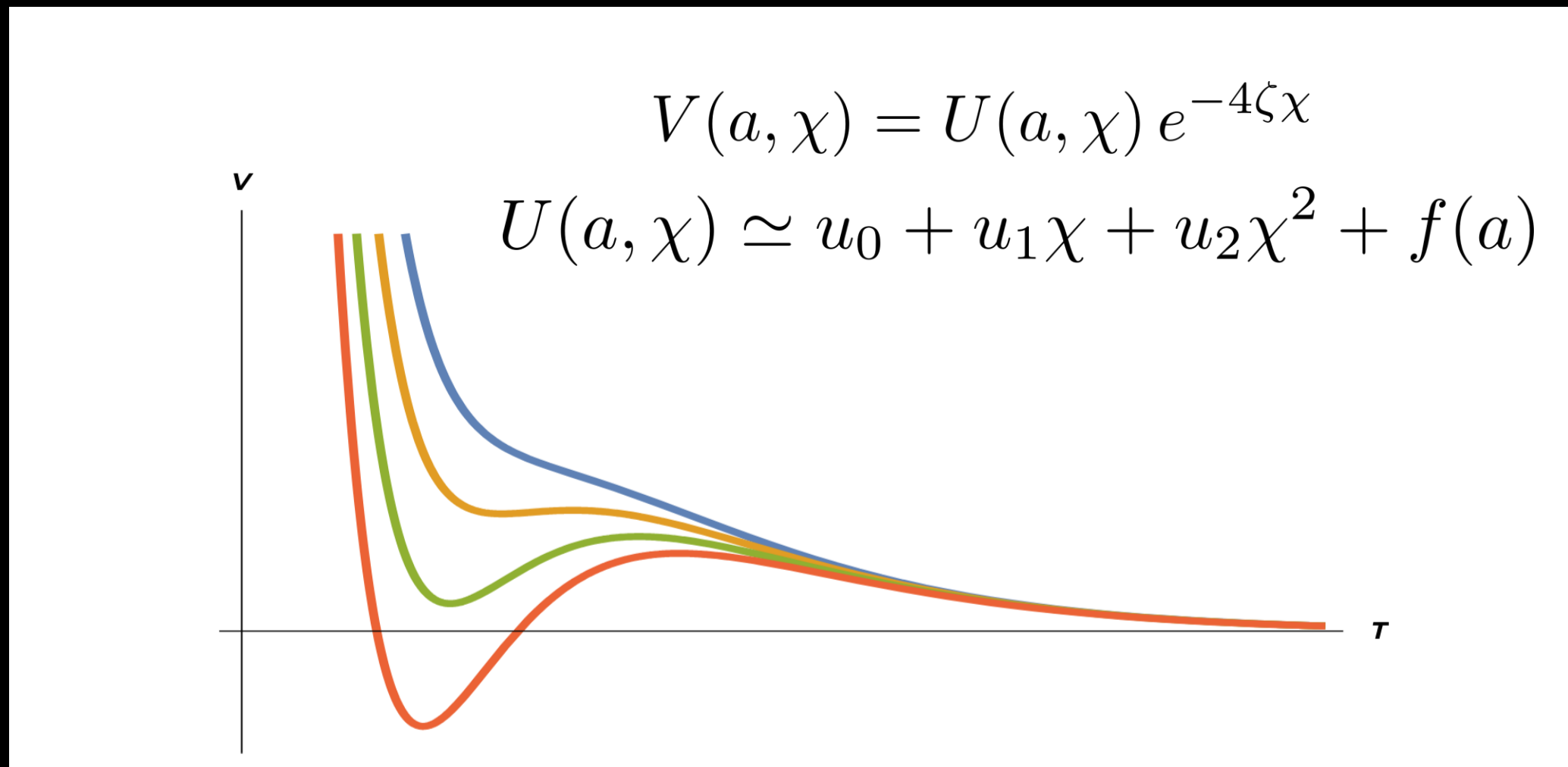
All ordinary particle masses acquire a universal dependence on the dilaton through the Higgs vev

$$m_{SM} \sim M_p e^{-g\chi} \quad m_\nu \sim M_p e^{-2g\chi} \quad (\text{successful if } g\chi \sim 32)$$

Axion also has a dilaton-dependent mass (though depends on ζ not g)

AXIODILATON AS DM + DE

Can easily arrange $g\chi = 32$ using only parameters in potential that are $O(10)$



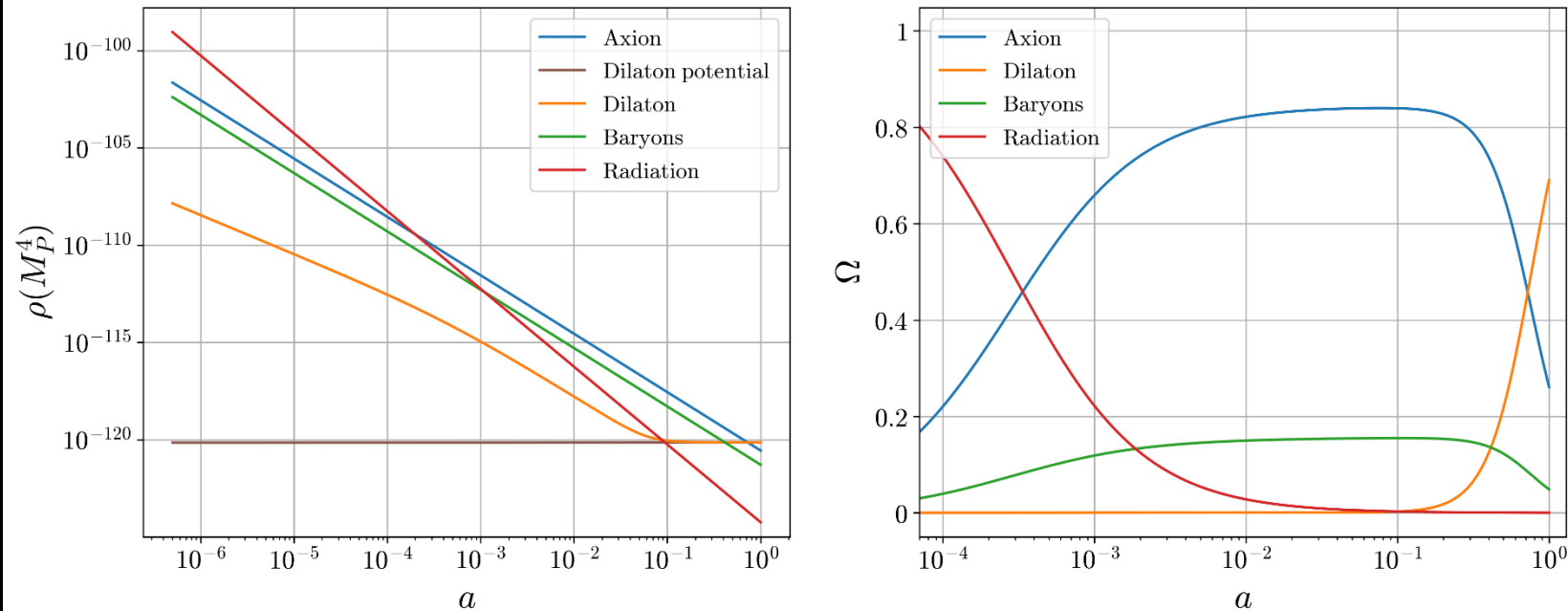
Choose $f(a)$ to cause axions to oscillate with DM type mass

Can this describe cosmological observations?

AXIODILATON AS DM + DE

Background cosmology can be reasonable

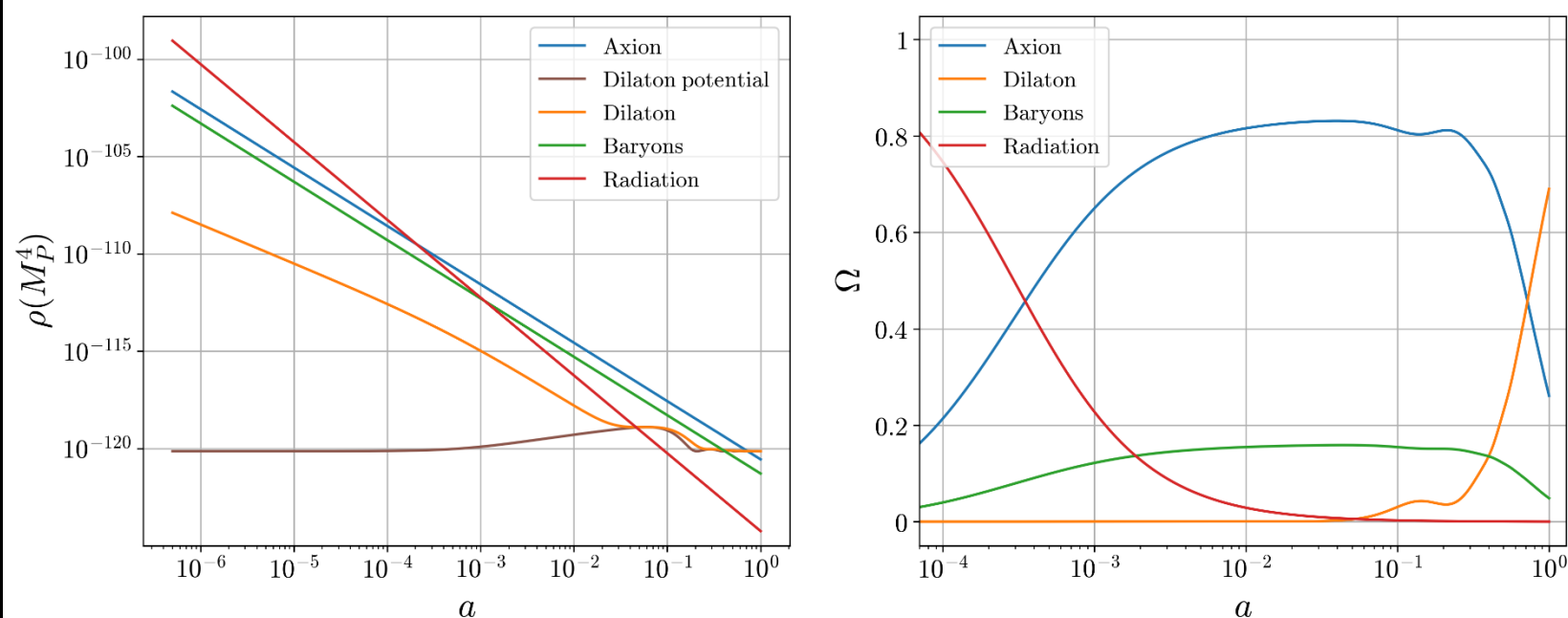
Exponential Potential



$$W = W_0 e^{-\zeta\chi/M_p}$$

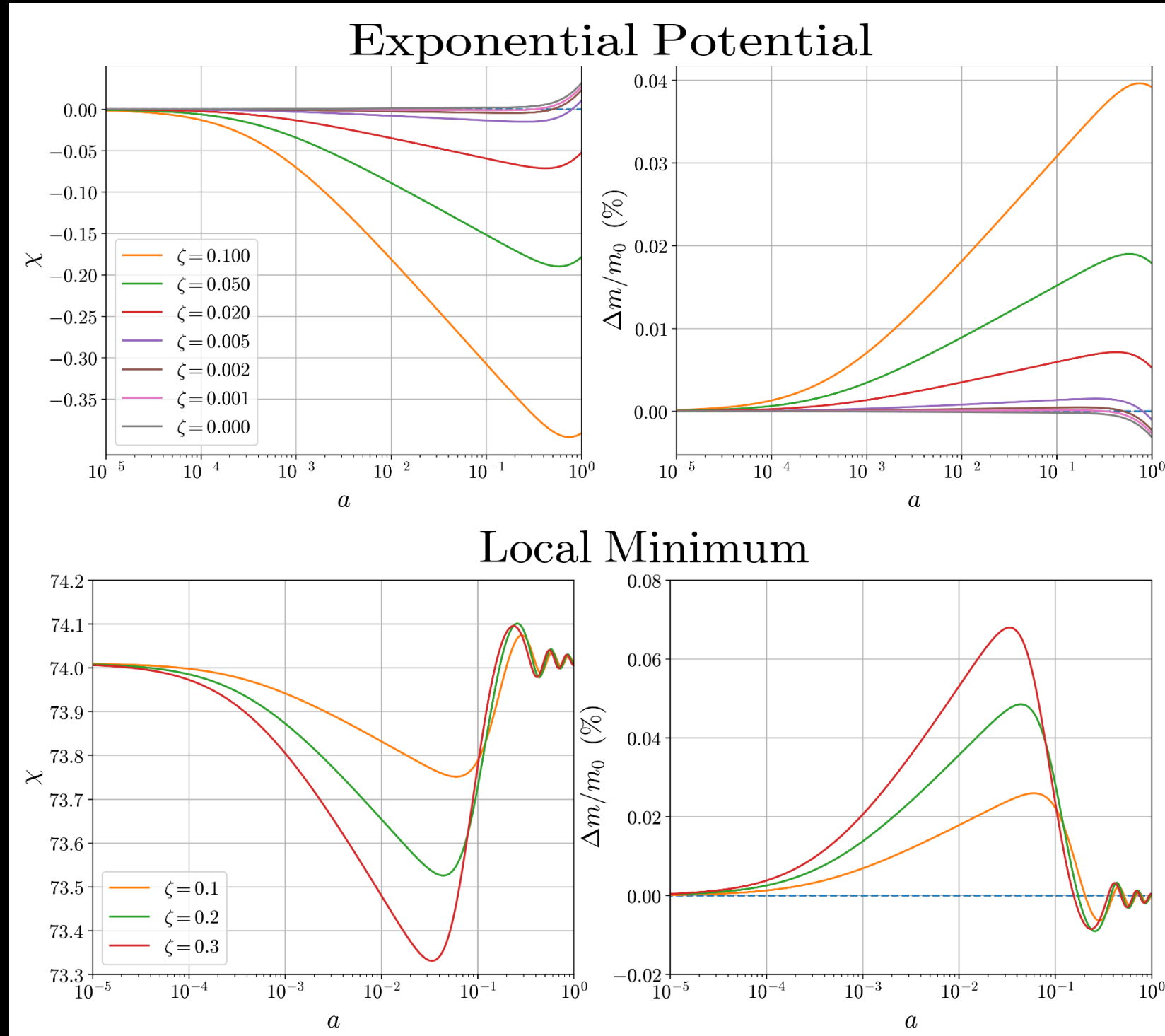
$$V(\chi) = U(\chi) e^{-4\zeta\chi/M_p}$$

Local Minimum



AXIODILATON AS DM + DE

Dilaton evolves in tracker solutions: always excursion at radiation-matter equality *implying masses at recombination differ from those at BBN and now.*



Evolution of dilaton and particle masses for various ζ

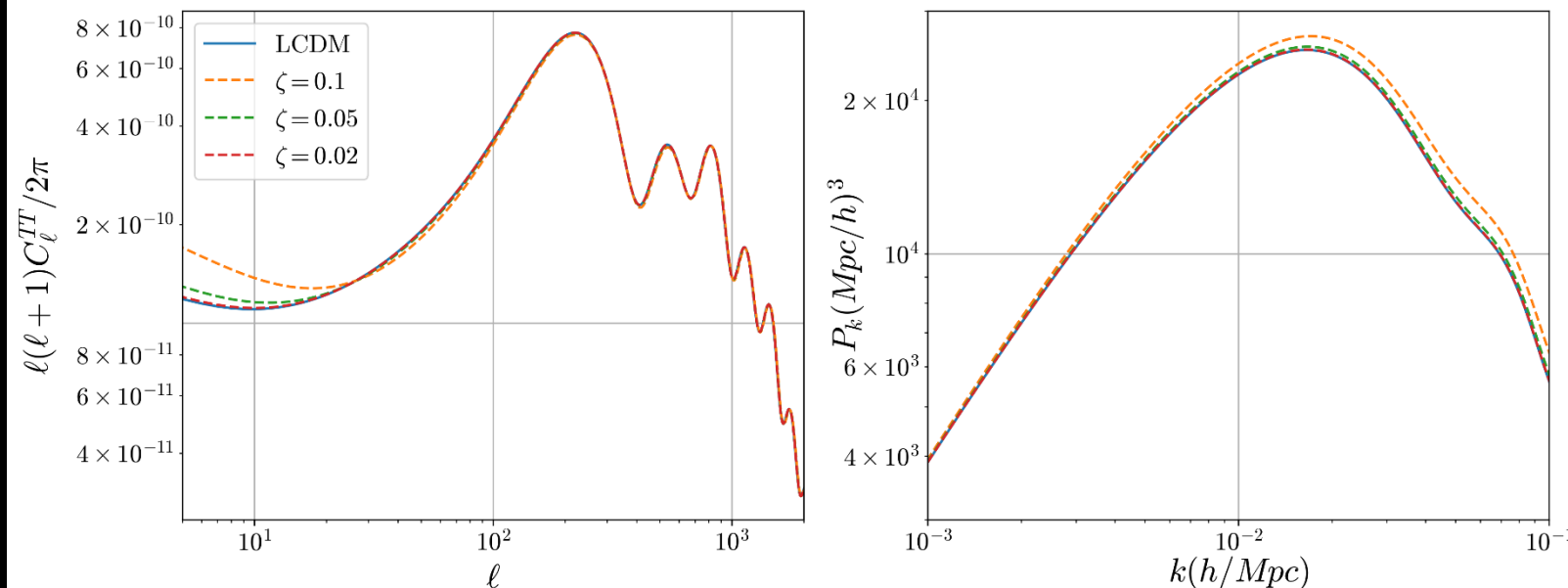
$$W = W_0 e^{-\zeta \chi / M_p}$$

$$V(\chi) = U(\chi) e^{-4\zeta \chi / M_p}$$

AXIODILATON AS DM + DE

Fluctuations in CMB and Power spectrum can be reasonable

Exponential Potential

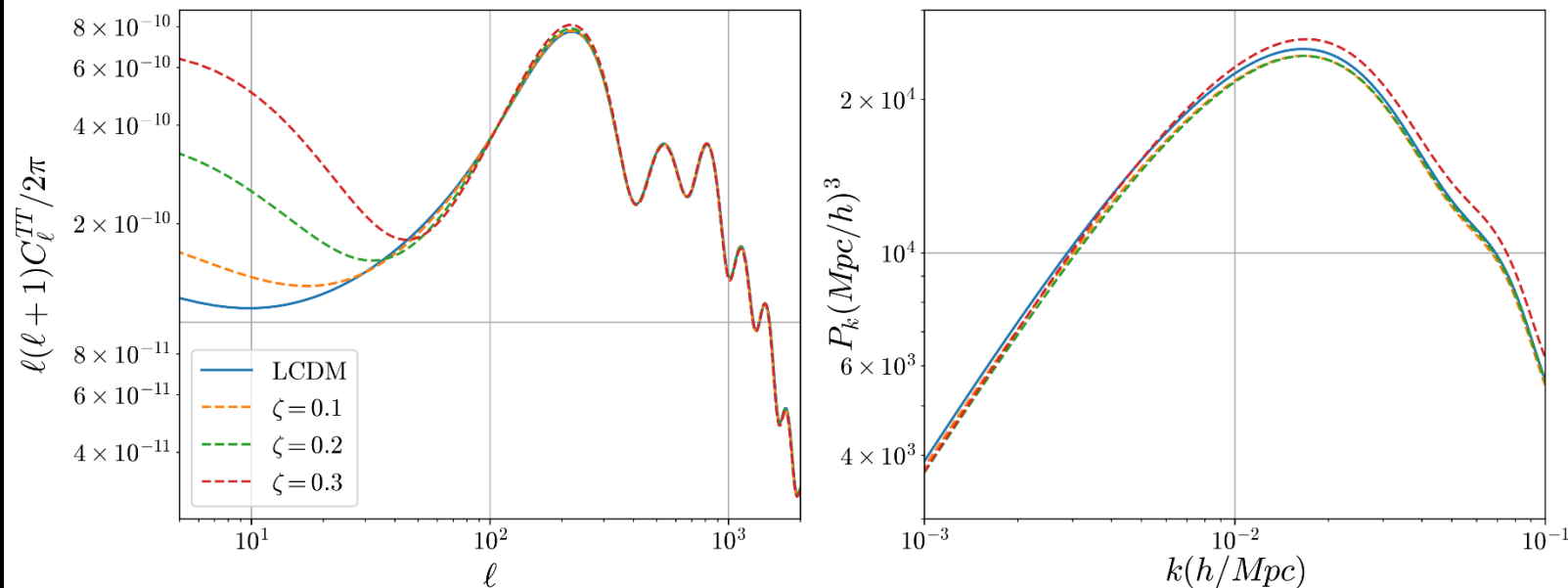


CMB and Power Spectrum for various choices for ζ

$$W = W_0 e^{-\zeta\chi/M_p}$$

$$V(\chi) = U(\chi) e^{-4\zeta\chi/M_p}$$

Local Minimum



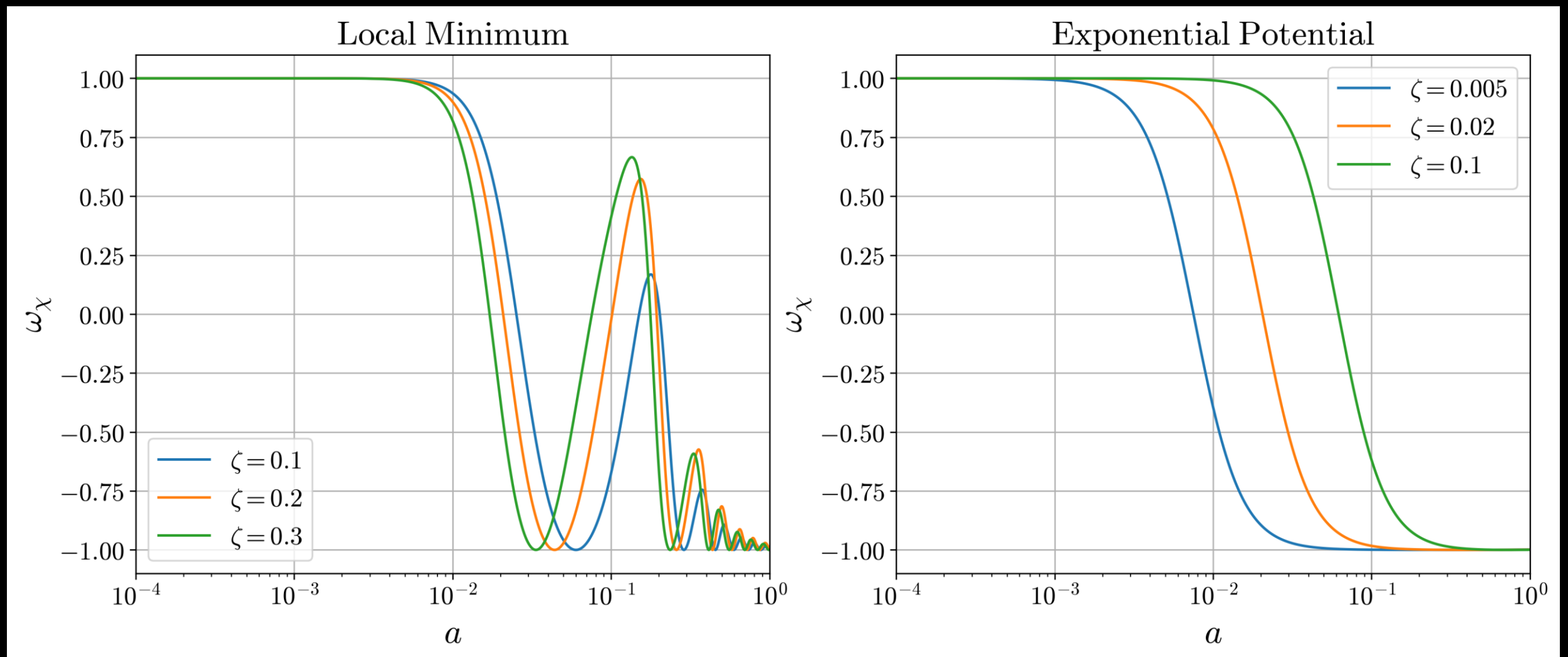
AXIODILATON AS DM + DE

Evolution can fake $w < -1$ because DM density does *not* evolve like $1/a^3$

Evolution of actual DE equation
of state parameter with z

$$W = W_0 e^{-\zeta\chi/M_p}$$

$$V(\chi) = U(\chi) e^{-4\zeta\chi/M_p}$$

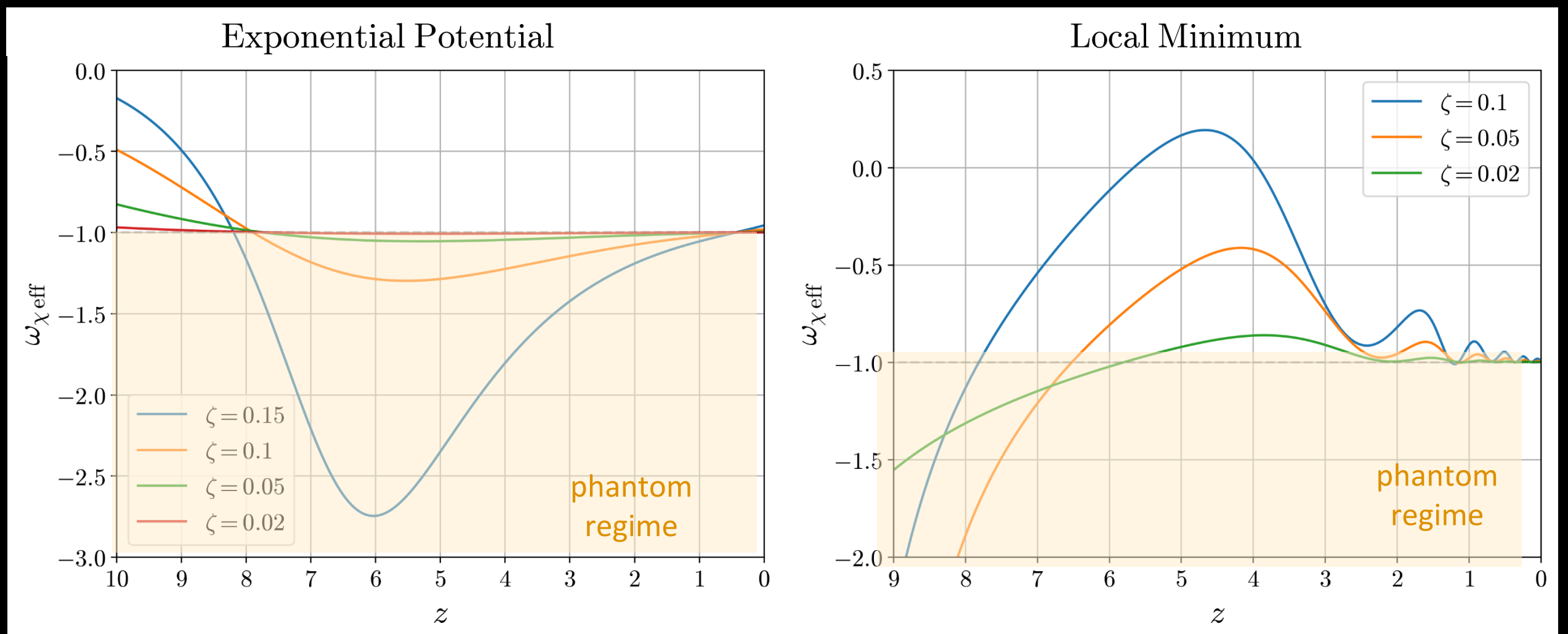


AXIODILATON AS DM + DE

The effective equation of state inferred by eg DESI
assumes vanilla DM:

$$\hat{\rho}_{\text{dm}} \propto a^{-3}$$

$$\omega_{\chi \text{ eff}} = \frac{\omega_{\chi}}{1 + (\rho_{\text{ax}} - \hat{\rho}_{\text{dm}}) / \rho_{\chi}}$$



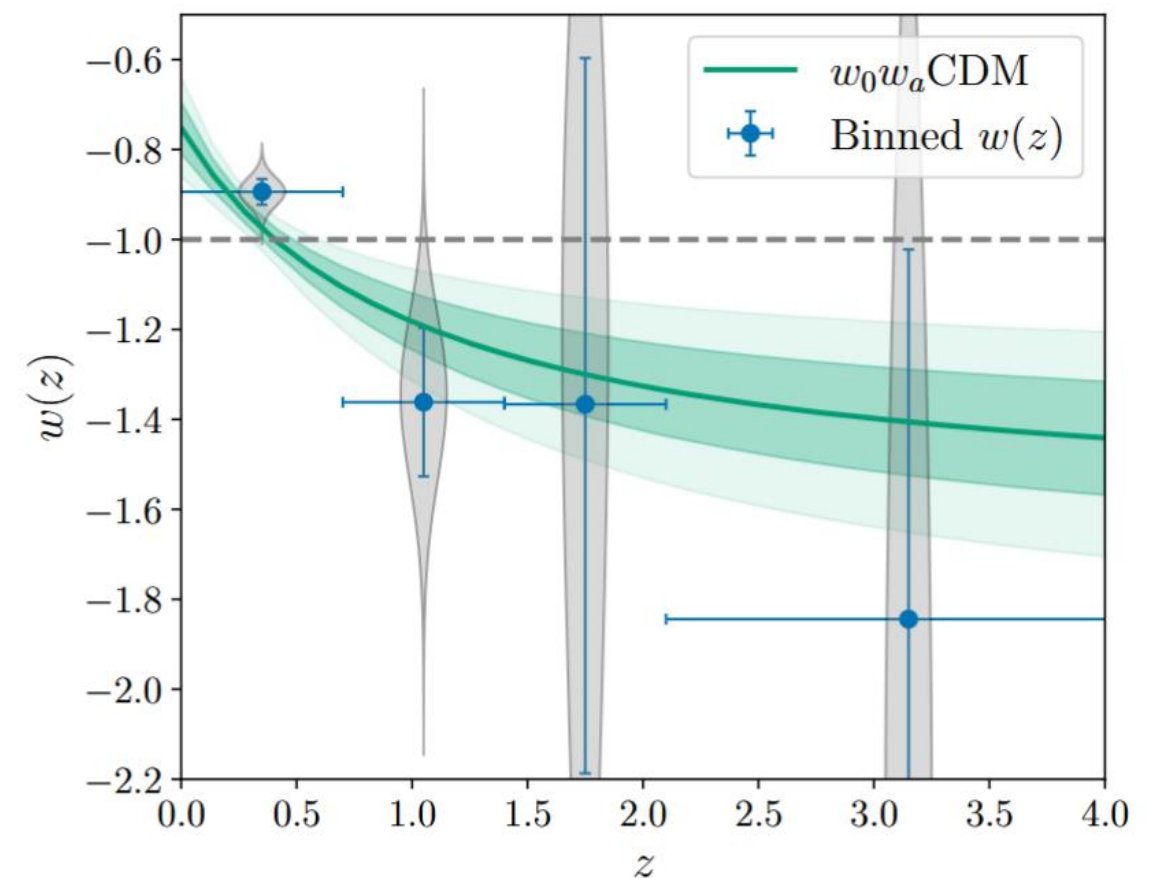
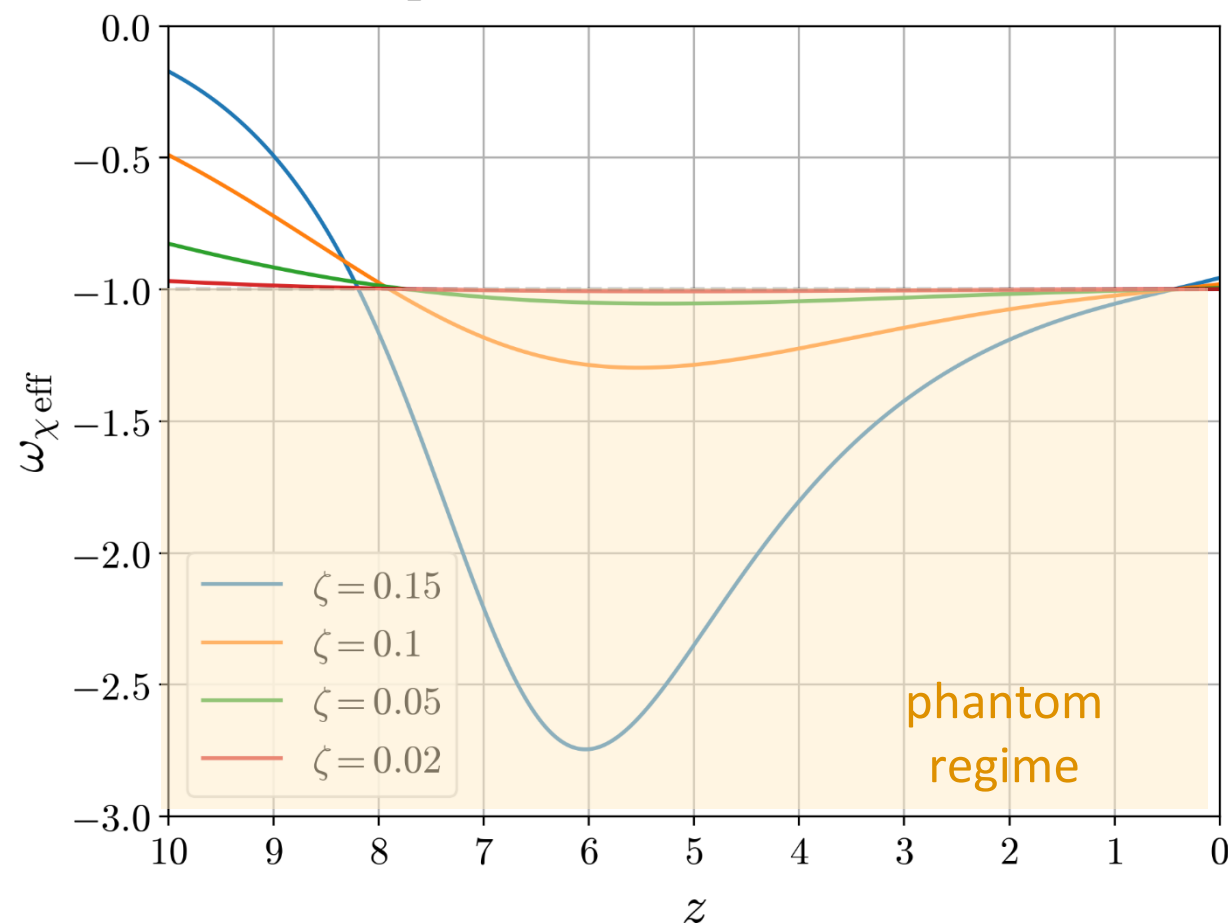
AXIODILATON AS DM + DE

The effective equation of state inferred by eg DESI
assumes vanilla DM:

$$\hat{\rho}_{\text{dm}} \propto a^{-3}$$

$$\omega_{\chi}^{\text{eff}} = \frac{\omega_{\chi}}{1 + (\rho_{\text{ax}} - \hat{\rho}_{\text{dm}}) / \rho_{\chi}}$$

Exponential Potential



AXIODILATON AS DM + DE

But best-fit value of Hubble scale rises relative to Λ CDM due to mass evolution, bringing the SH0ES range to within 3σ , and so permitting combining datasets

Model	Dataset	H_0	g	ζ	χ_i	$R - 1$	$\Delta\chi^2$
Yoga-VI	CMB-B DESI PP	$69.17^{+0.66}_{-0.76}$ (69.13)	-0.001 ± 0.095 (-0.052)	0.003 ± 0.050 (-0.003)	74.010 ± 0.150 (73.844)	0.102	-7.2
	CMB-B DESI	69.42 ± 0.72 (69.58)	-0.011 ± 0.097 (0.102)	-0.002 ± 0.049 (-0.039)	$73.98^{+0.18}_{-0.15}$ (74.142)	0.195	-6.3
EXP	CMB-B DESI PP	69.17 ± 0.67 (69.99)	0.002 ± 0.093 (0.104)	-0.001 ± 0.044 (-0.022)	—	0.338	-7.3
	CMB-B DESI	69.37 ± 0.72 (69.12)	0.000 ± 0.093 (-0.023)	-0.003 ± 0.045 (-0.038)	—	0.885	-6.1
	CMB-B	$67.50^{+0.68}_{-1.2}$ (67.78)	-0.005 ± 0.074 (0.041)	0.002 ± 0.047 (-0.002)	—	0.029	—
w0-wa + me	CMB-B DESI PP	68.32 ± 0.83 (67.95)	—	—	—	0.098	-12.1
	CMB-B DESI	$64.2^{+1.9}_{-2.6}$ (63.78)	—	—	—	0.041	-10.5
w0-wa	CMB-B DESI PP	67.65 ± 0.59 (67.52)	—	—	—	0.010	-9.6
Λ CDM	CMB-B DESI PP	68.04 ± 0.26 (68.25)	—	—	—	0.007	0.0
	CMB-B DESI	68.13 ± 0.26 (68.23)	—	—	—	0.006	0.0

TABLE V: Posterior means with quoted 1σ marginal uncertainties and best-fit values in parentheses for all models fit to the CMB-B dataset combinations including SPT-3G. Columns list the inferred Hubble constant, the dilaton coupling g , the axion CDM kinetic coupling ζ , the initial dilaton value χ_i when present, and the change in best-fit $\Delta\chi^2$ relative to the corresponding Λ CDM run.

AXIODILATON AS DM + DE

Model resolves (to smaller than 3 sigma) the Hubble tension in the CMB-B DESI and PP datasets including a SH0ES prior on H_0

Comparable to the combined $w_0w_a + m_e$ model (though is a real theory and so predicts correlations between properties at recombination and later epochs)

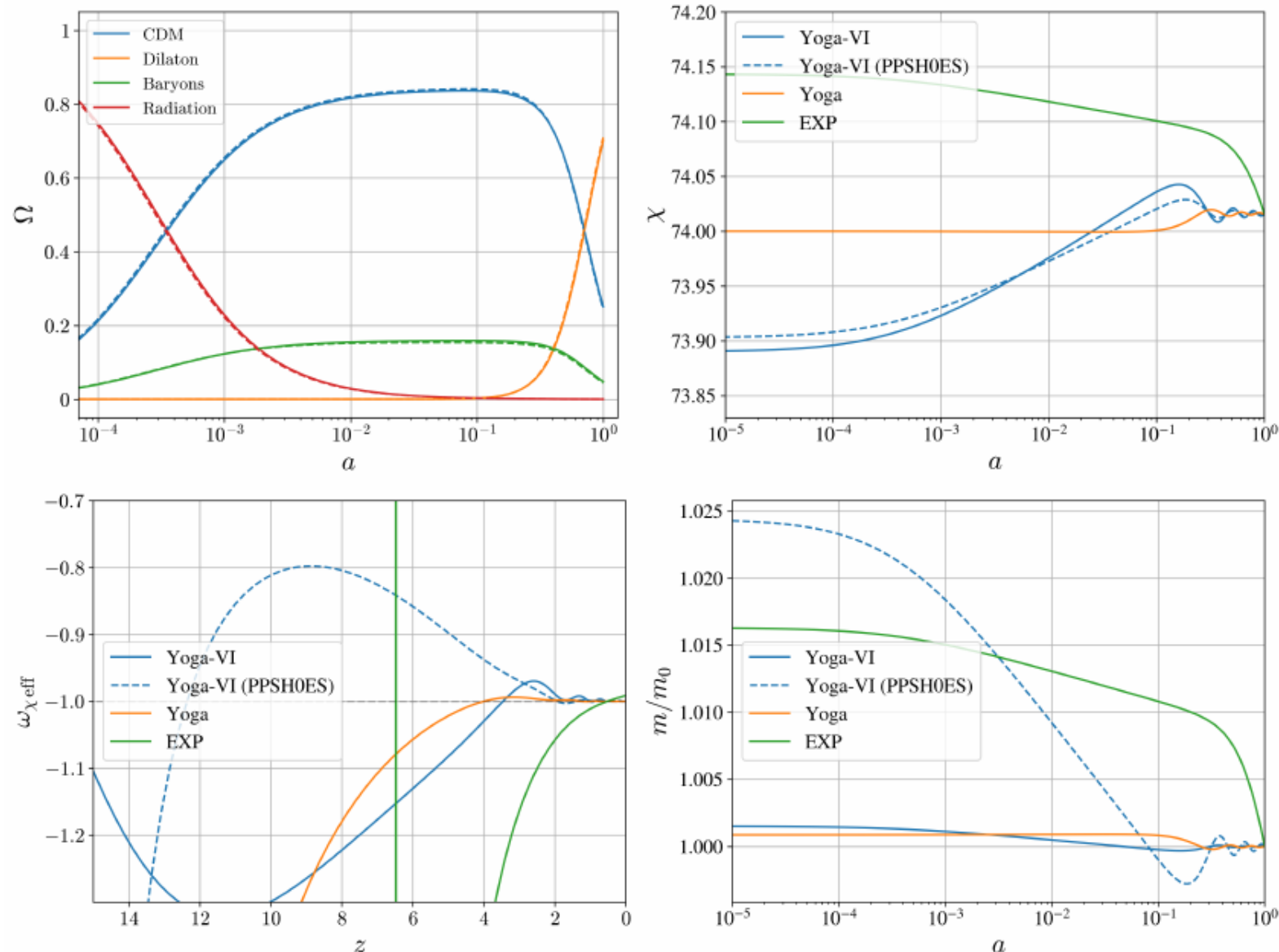
Model	Dataset	H_0	g	ζ	χ_i	$R - 1$	$\Delta\chi^2$
Yoga VI	CMB-A DESI PPSH0ES	70.85 ± 0.58 (71.11)	$0.03^{+0.17}_{-0.20}$ (-0.214)	-0.012 ± 0.060 (0.082)	$74.03^{+0.20}_{-0.23}$ (73.903)	10.313	-19.7
EXP	CMB-A DESI PPSH0ES	70.79 ± 0.59 (71.03)	0.000 ± 0.160 (0.161)	-0.003 ± 0.062 (-0.058)	–	68.516	-18.9
w0-wa + me	CMB-A DESI PPSH0ES	70.51 ± 0.73 (70.37)	–	–	–	0.005	-19.4
Λ CDM+me	CMB-A DESI PPSH0ES	70.97 ± 0.57 (71.34)	–	–	–	0.006	-19.2
Λ CDM	CMB-A DESI PPSH0ES	68.72 ± 0.28 (68.77)	–	–	–	0.006	0.0

TABLE VI: Posterior means ($\pm 1\sigma$) with best-fit values in parentheses, and $\Delta\chi^2$ relative to the Λ CDM run with the same dataset (CMB-A DESI PPSH0ES).

Goodness of fit comparison using CMB-B DESI PP datasets including a SH0ES prior on H_0

AXIODILATON AS DM + DE

Unlike in models where this is done by hand can predict why variation happens (recombination is not long after radiation-matter equality) and why this need not cause problems for BBN



*Evolution of key
model parameters
with redshift*

COSMOLOGY UPSHOT

Yoga cosmology seems to help with several cosmological tensions (Hubble tension, $w < -1$ in evolving DE, early structure formation) *despite not being designed to do so*

Predicts masses should undergo transient evolution after radiation-matter equality

Brans-Dicke coupling puzzle:

The couplings favoured by cosmology are at face value ruled out in the solar system

Potential way out: if the Sun's dilaton coupling is not simply the naïve sum of the couplings of its atoms



LESSONS LEARNED

UV LESSONS FOR LOW ENERGIES

EFTS ARE THE TOOLS FOR OUR TIMES

We have a very successful theory that fails in a few specific ways at low energies

HIGH ROAD TO UV INFERENCES CAN BE PREDICTIVE

Power counting, technical naturalness issues are both robust *and* constraining



IMAGE: THE MATRIX

RICH, ACCESSIBLE DARK SECTOR

UV constraints hint at a rich Dark Sector

Supersymmetry, multiple scalars, possible extra dimensions,...

Many phenomenological implications despite being gravitationally coupled.



Possibly entering the era where UV constraints are driving understanding of cosmological puzzles.



FIN

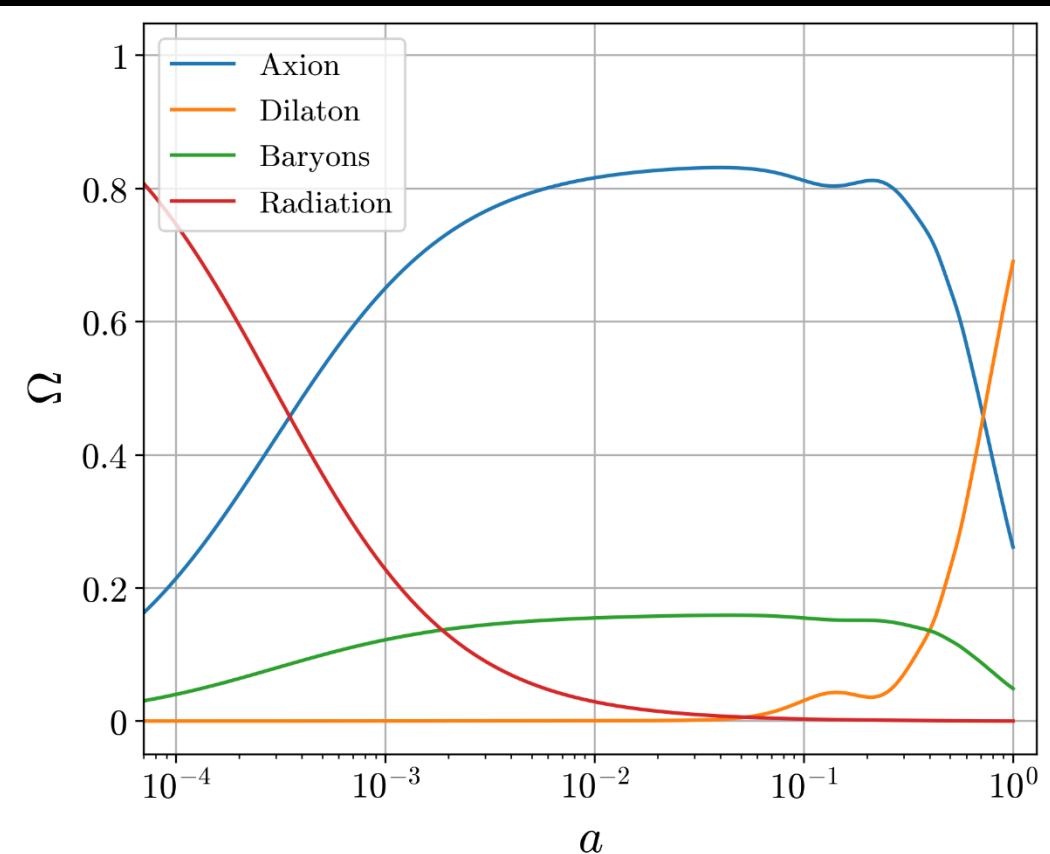
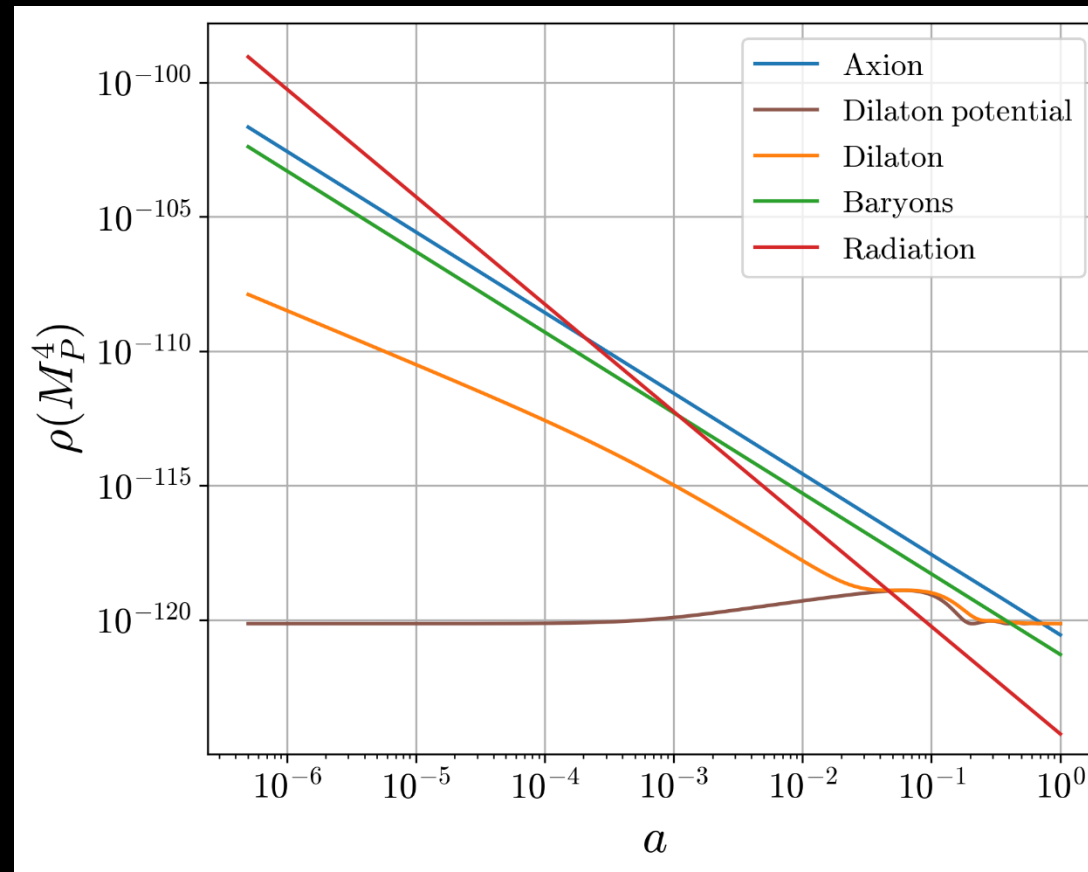


EXTRA FIGURES

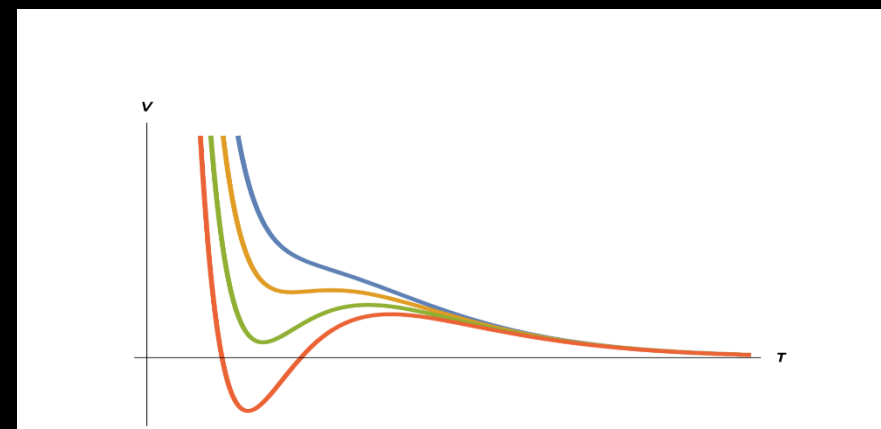
IMAGE: CHATGPT

EVOLUTION

Sensible cosmology can arise wherein the axion is DM and dilaton is DE



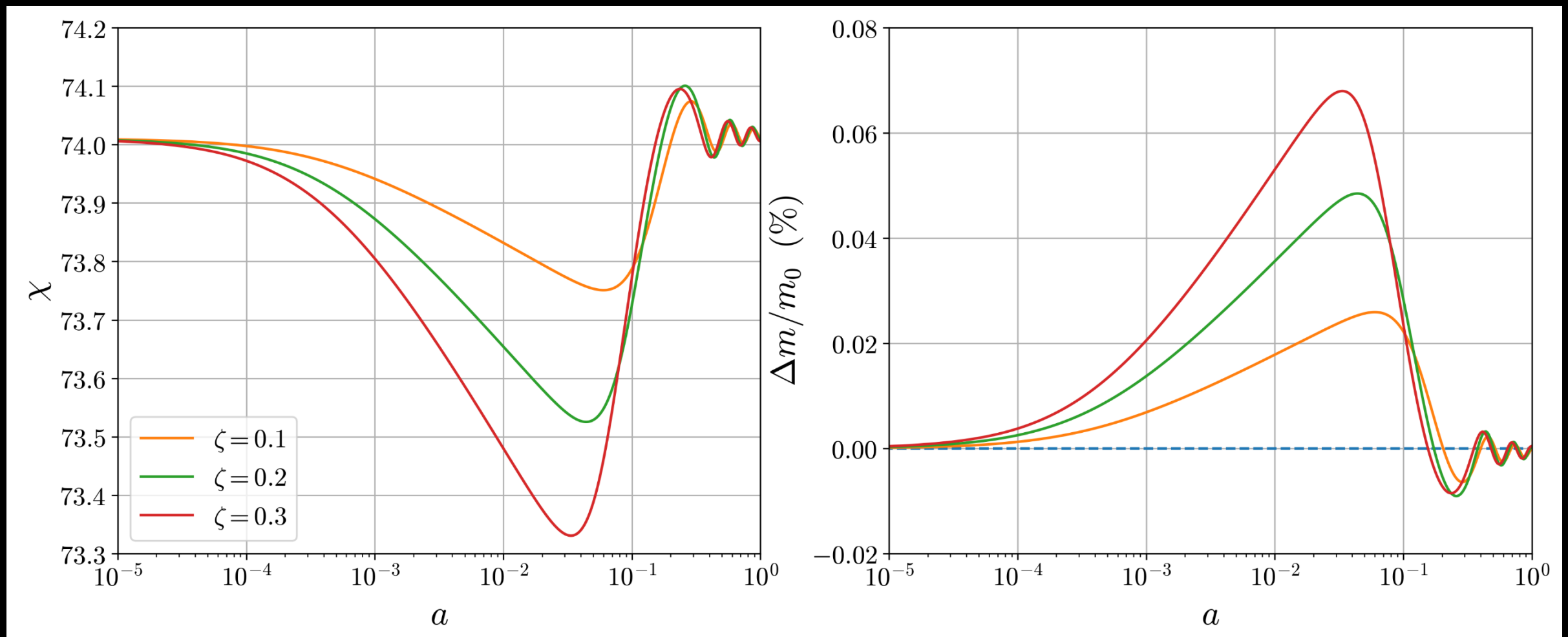
Dilaton potential shape:
(axion potential trigonometric)



EVOLUTION

CC problem requires dilaton to couple to ordinary matter, making all particle masses field dependent in a universal way

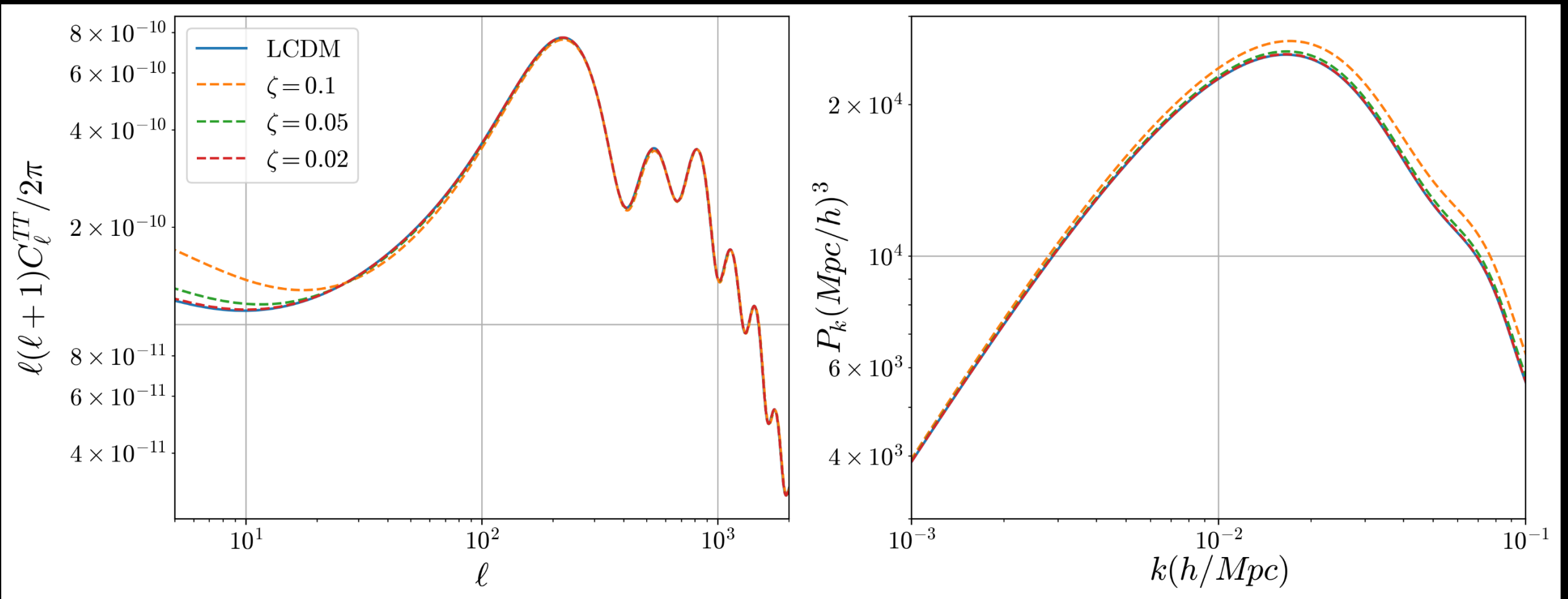
Becomes very generic for dilaton to undergo transient evolution following matter-radiation equality, causing particle masses to differ at recombination



EVOLUTION

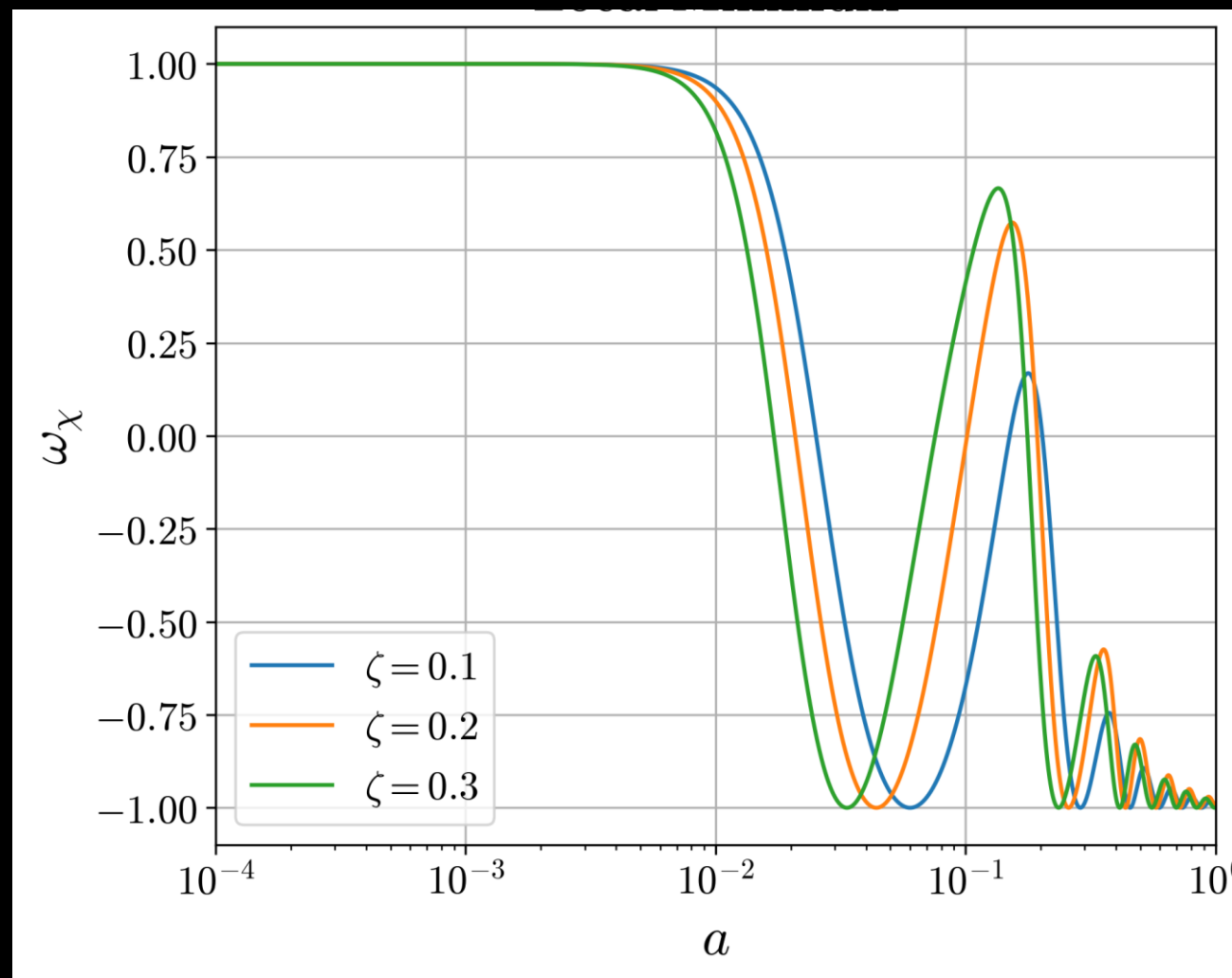
CMB and power spectrum look OK for small enough couplings. Dominant effect is ISW due to nonstandard evolution in time of DM densities

Couplings of order 10% seem likely to be visible

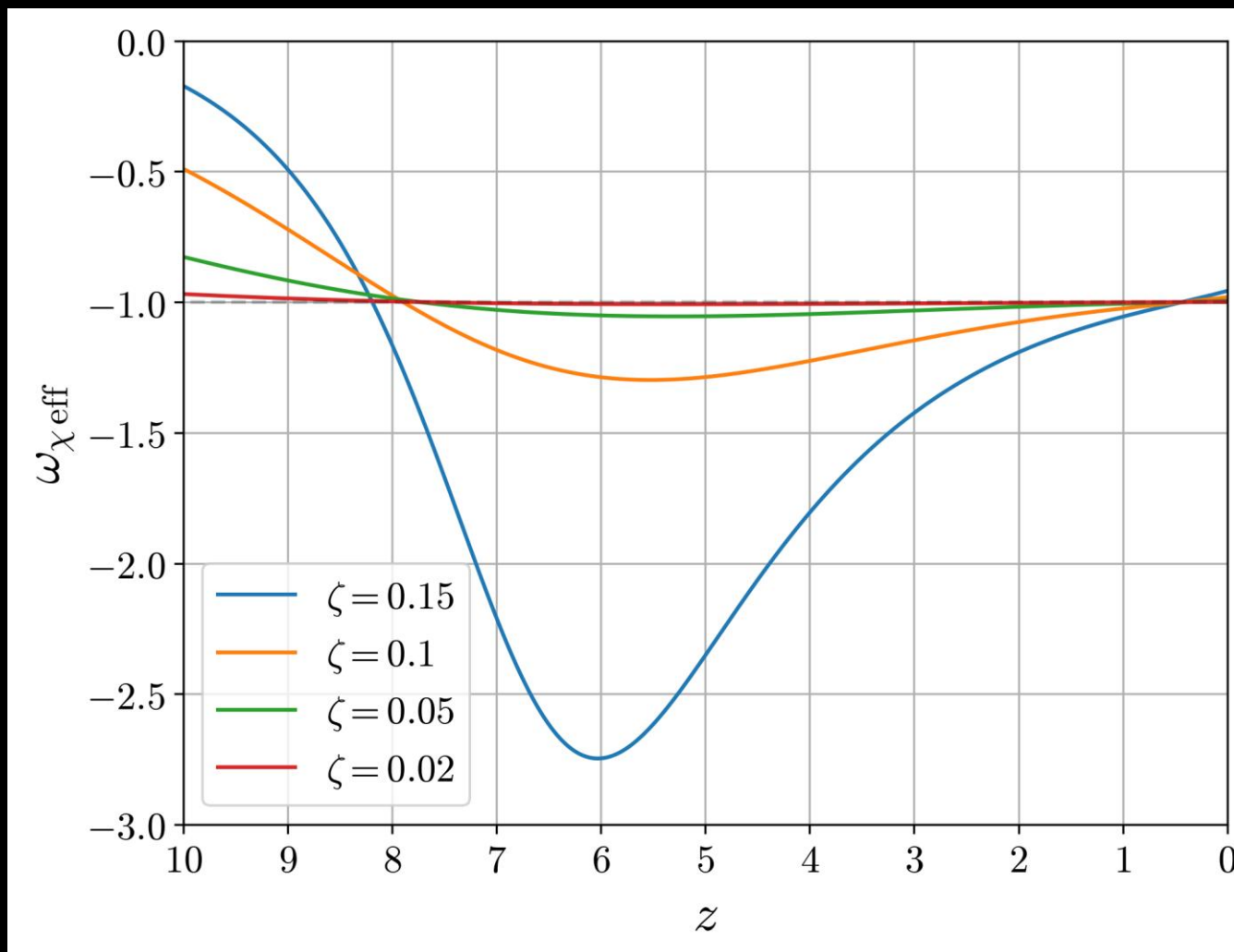


EVOLUTION

Nonstandard DM mass evolution makes the theory ‘fake’ a DE equation of state parameter $w < -1$ if analyzed as DESI does.



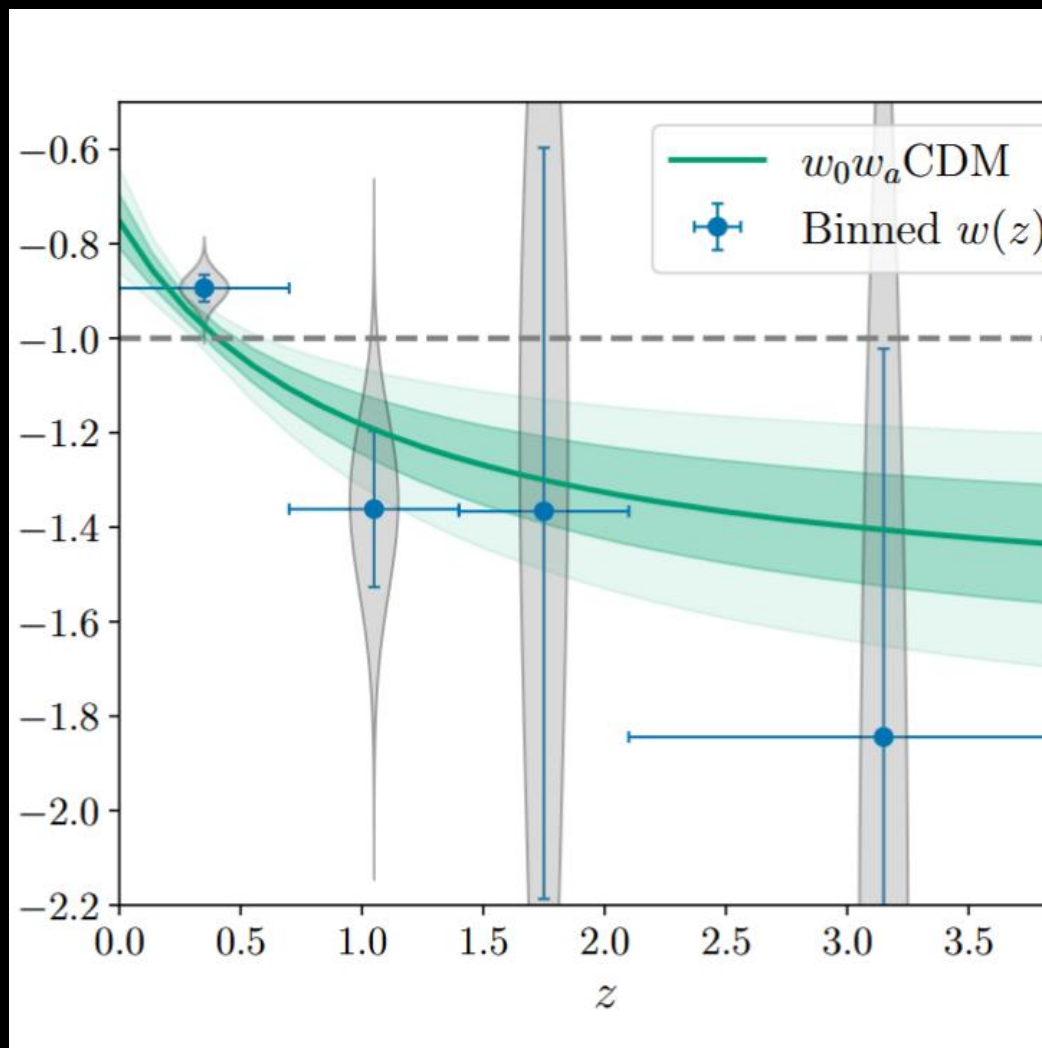
Actual eq. of state parameter w



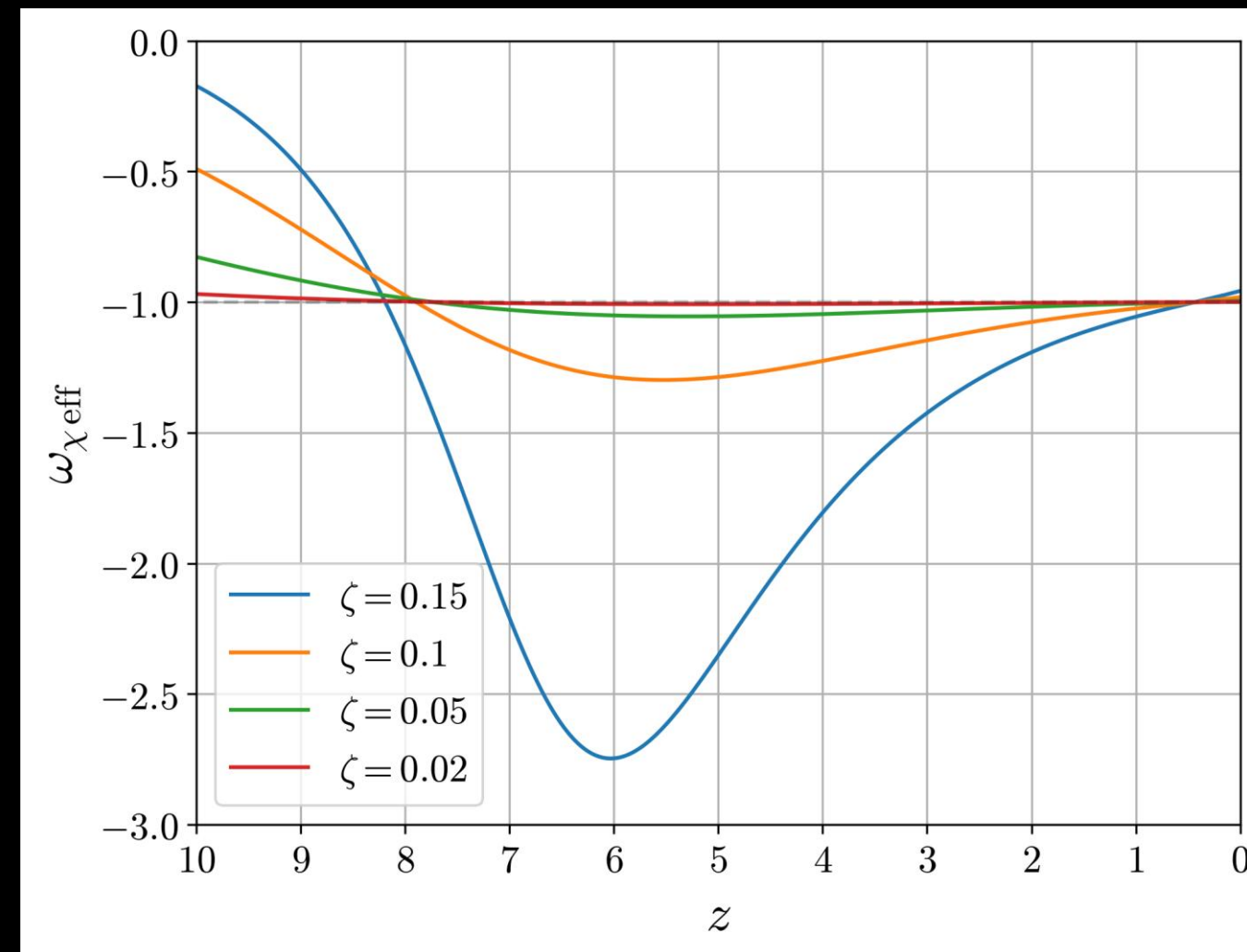
Apparent eq. of state parameter w_{eff}

EVOLUTION

Nonstandard DM mass evolution makes the theory ‘fake’ a DE equation of state parameter $w < -1$ if analyzed as DESI does.



DESI eq of state parameter



Apparent eq. of state parameter w_{eff}

FIT TO CMB DATA

Fits to CMB datasets similar quality to Λ CDM fits, though best-fit H_0 is higher because evolving electron mass pushes back last-scattering surface

Model	Dataset	H_0	$\mathbf{g}$	ζ	χ_i	$R - 1$	$\Delta\chi^2$
Yoga-VI	CMB-A DESI PP	$69.20^{+0.64}_{-0.81}$ (68.65)	-0.010 ± 0.100 (-0.012)	$0.003^{+0.059}_{-0.053}$ (-0.041)	74.000 ± 0.130 (73.890)	0.095	-1.9
	CMB-A DESI	$69.38^{+0.68}_{-0.83}$ (69.61)	0.000 ± 0.100 (0.147)	-0.001 ± 0.052 (-0.060)	74.010 ± 0.140 (74.086)	0.039	-3.5
(no- m_e)	CMB-A DESI PP	68.50 ± 0.35 (68.51)	0.005 ± 0.083 (-0.009)	0.001 ± 0.054 (-0.050)	$74.02^{+0.19}_{-0.16}$ (73.876)	0.017	-2.1
Yoga	CMB-A DESI PP	68.42 ± 0.35 (68.33)	-0.038 ± 0.086 (-0.055)	$0.020^{+0.077}_{-0.094}$ (0.032)	–	0.010	-0.7
	CMB-A DESI	68.53 ± 0.36 (68.54)	-0.041 ± 0.088 (-0.078)	$0.023^{+0.076}_{-0.097}$ (0.050)	–	0.025	-1.8
EXP	CMB-A DESI PP	$69.10^{+0.64}_{-0.76}$ (68.81)	-0.003 ± 0.099 (0.127)	0.005 ± 0.049 (-0.058)	–	0.082	-2.7
	CMB-A DESI	$69.34^{+0.70}_{-0.78}$ (69.81)	$0.004^{+0.12}_{-0.098}$ (0.122)	0.001 ± 0.049 (-0.044)	–	0.061	-4.0
	CMB-A	$68.01^{+0.78}_{-1.7}$ (67.43)	0.000 ± 0.088 (-0.013)	0.001 ± 0.051 (0.036)	–	0.074	-1.1
w0-wa + me	CMB-A DESI PP	68.26 ± 0.87 (68.29)	–	–	–	0.008	-8.2
	CMB-A DESI	$63.9^{+1.9}_{-2.7}$ (64.78)	–	–	–	0.006	-8.6
w0-wa	CMB-A DESI PP	67.64 ± 0.60 (67.71)	–	–	–	0.012	-6.9
Λ CDM+me	CMB-A DESI PP	69.62 ± 0.69 (69.91)	–	–	–	0.007	-2.6
	CMB-A DESI	69.85 ± 0.69 (70.12)	–	–	–	0.006	-4.2
Λ CDM	CMB-A DESI PP	68.30 ± 0.28 (68.03)	–	–	–	0.021	0.0
	CMB-A DESI	68.39 ± 0.29 (68.53)	–	–	–	0.009	0.0
	CMB-A	67.30 ± 0.54 (67.27)	–	–	–	0.007	0.0

TABLE IV: Posterior means with 1σ confidence intervals, best-fit values in parentheses, and $\Delta\chi^2$ relative to the corresponding Λ CDM run for each dataset combination. The table summarises how the different axio-dilaton (Yoga and EXP), w_0 - w_a , and varying- m_e models shift H_0 , the scalar couplings ($\mathbf{g}, \zeta$), and overall goodness-of-fit relative to Λ CDM across the CMB-A, CMB-A DESI, and CMB-A DESI PP datasets.

FIT TO CMB DATA

Higher H_0 reduces Hubble tension to 2.8σ and so makes it consistent to apply a SH0ES prior. With this fit is better than for Λ CDM.

Model	Dataset	H_0	g	ζ	χ_i	$R - 1$	$\Delta\chi^2$
Yoga-VI	CMB-B DESI PP	$69.17^{+0.66}_{-0.76}$ (69.13)	-0.001 ± 0.095 (-0.052)	0.003 ± 0.050 (-0.003)	74.010 ± 0.150 (73.844)	0.102	-7.2
	CMB-B DESI	69.42 ± 0.72 (69.58)	-0.011 ± 0.097 (0.102)	-0.002 ± 0.049 (-0.039)	$73.98^{+0.18}_{-0.15}$ (74.142)	0.195	-6.3
EXP	CMB-B DESI PP	69.17 ± 0.67 (69.99)	0.002 ± 0.093 (0.104)	-0.001 ± 0.044 (-0.022)	—	0.338	-7.3
	CMB-B DESI	69.37 ± 0.72 (69.12)	0.000 ± 0.093 (-0.023)	-0.003 ± 0.045 (-0.038)	—	0.885	-6.1
	CMB-B	$67.50^{+0.68}_{-1.2}$ (67.78)	-0.005 ± 0.074 (0.041)	0.002 ± 0.047 (-0.002)	—	0.029	—
w0-wa + me	CMB-B DESI PP	68.32 ± 0.83 (67.95)	—	—	—	0.098	-12.1
	CMB-B DESI	$64.2^{+1.9}_{-2.6}$ (63.78)	—	—	—	0.041	-10.5
w0-wa	CMB-B DESI PP	67.65 ± 0.59 (67.52)	—	—	—	0.010	-9.6
Λ CDM	CMB-B DESI PP	68.04 ± 0.26 (68.25)	—	—	—	0.007	0.0
	CMB-B DESI	68.13 ± 0.26 (68.23)	—	—	—	0.006	0.0

TABLE V: Posterior means with quoted 1σ marginal uncertainties and best-fit values in parentheses for all models fit to the CMB-B dataset combinations including SPT-3G. Columns list the inferred Hubble constant, the dilaton coupling g , the axion CDM kinetic coupling ζ , the initial dilaton value χ_i when present, and the change in best-fit $\Delta\chi^2$ relative to the corresponding Λ CDM run.

FIT TO CMB DATA

Best fit prefers nonzero dilaton matter coupling g because this sets the size of mass change at recombination.

Coupling preferred by cosmology is larger than solar system constraints, which require $g < 0.001$.

Is the Sun Screened?

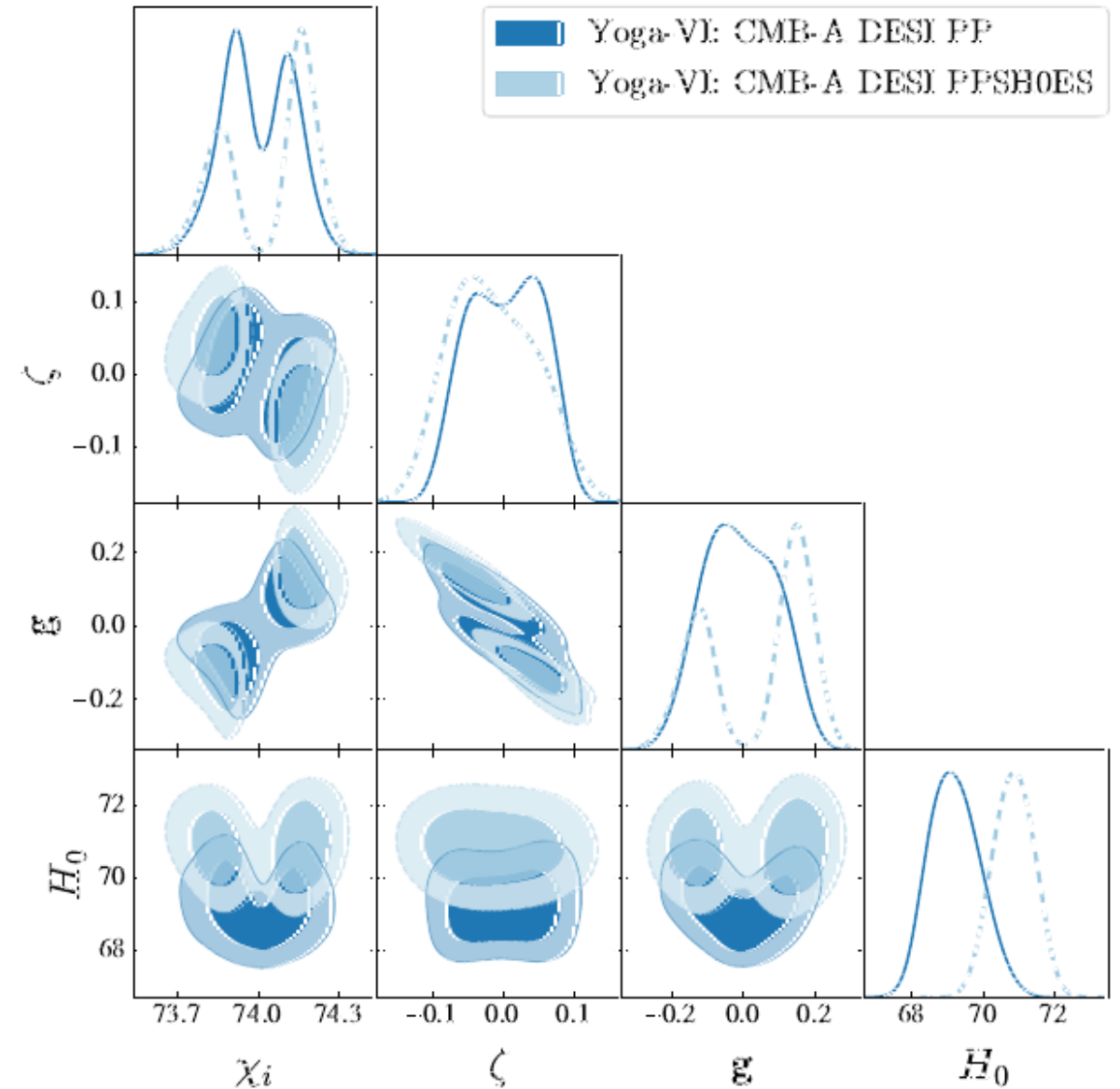


FIG. 5: Triangle plot showing constraints on the minimal Yoga-VI model with and without the SH0ES prior calibration with CMB-A DESI PP datasets. Imposing the SH0ES prior amplifies the existing correlations among g , ζ and H_0 , with much larger couplings and initial dilaton displacements being preferred.

21 CM SIGNAL

Best-fit CMB couplings predict 21 cm signals differ from Λ CDM

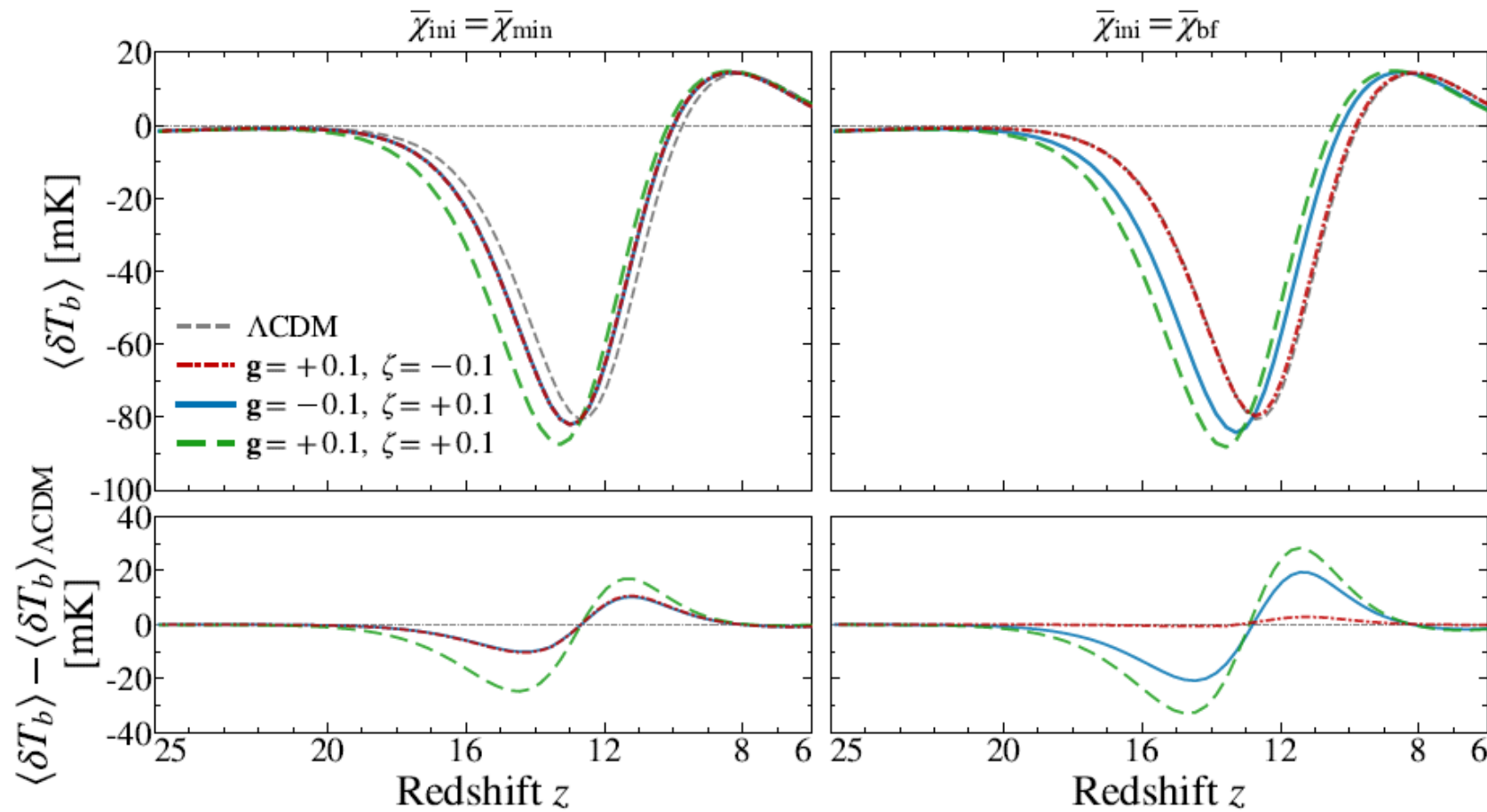


Figure 1: Volume-averaged differential 21 cm brightness temperature $\langle \delta T_b \rangle$ (upper panels) as computed for Yoga and ΛCDM models as a function of redshift for $\bar{\chi} = \bar{\chi}_{\text{min}} = 74.010$ chosen initially at the potential's minimum (left) or at the value $\bar{\chi} = \bar{\chi}_{\text{bf}} = 74.213$ that provides the best fit to CMB data (right). Lower panels provide the residuals between the Yoga and ΛCDM calculations. Colors and line styles denote the three (g, ζ) and ΛCDM choices indicated in the legends.

21 CM SIGNAL

Dominant source of changes to 21 cm signal is due to earlier structure formation (as opposed to changes to $H(z)$ or masses)

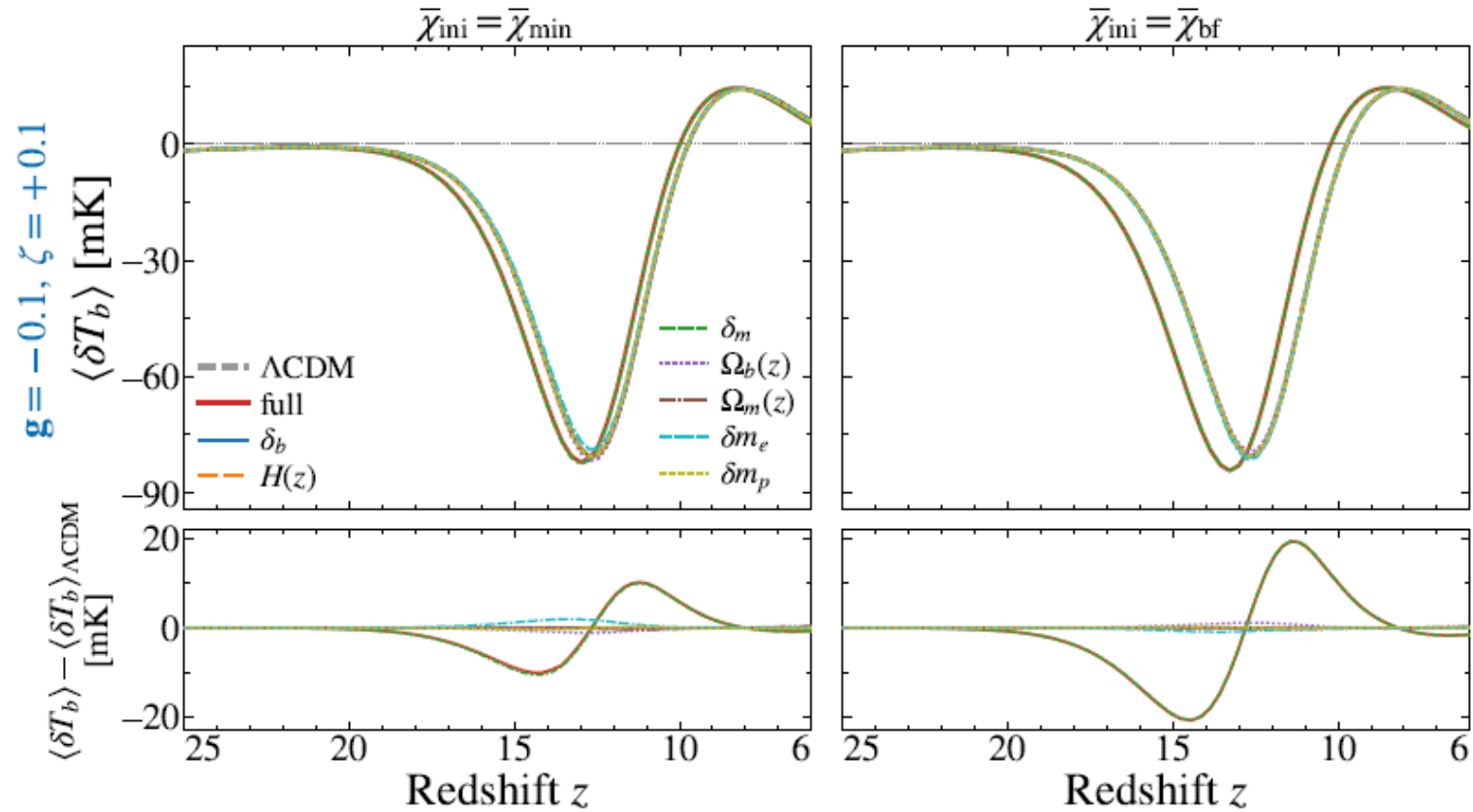
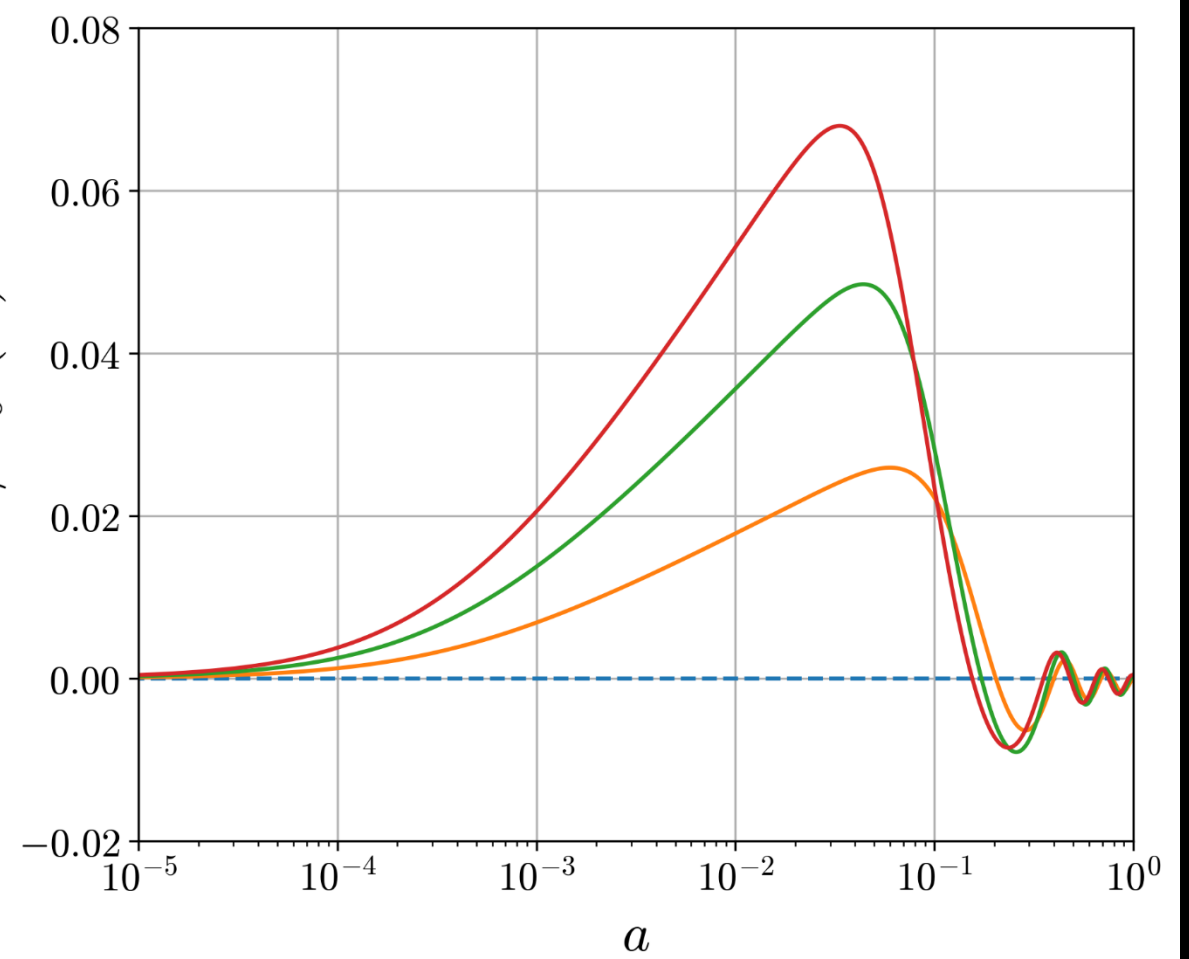
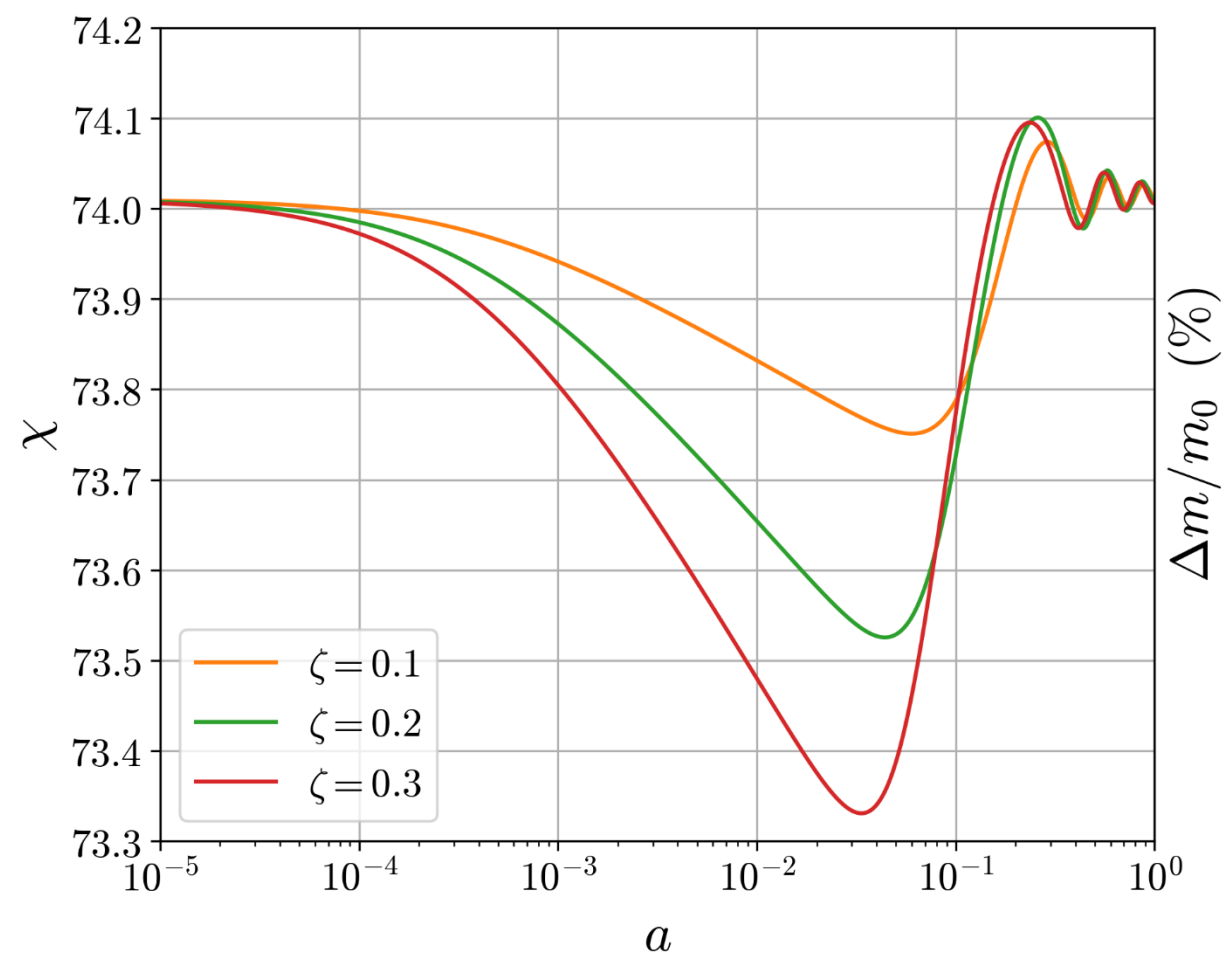
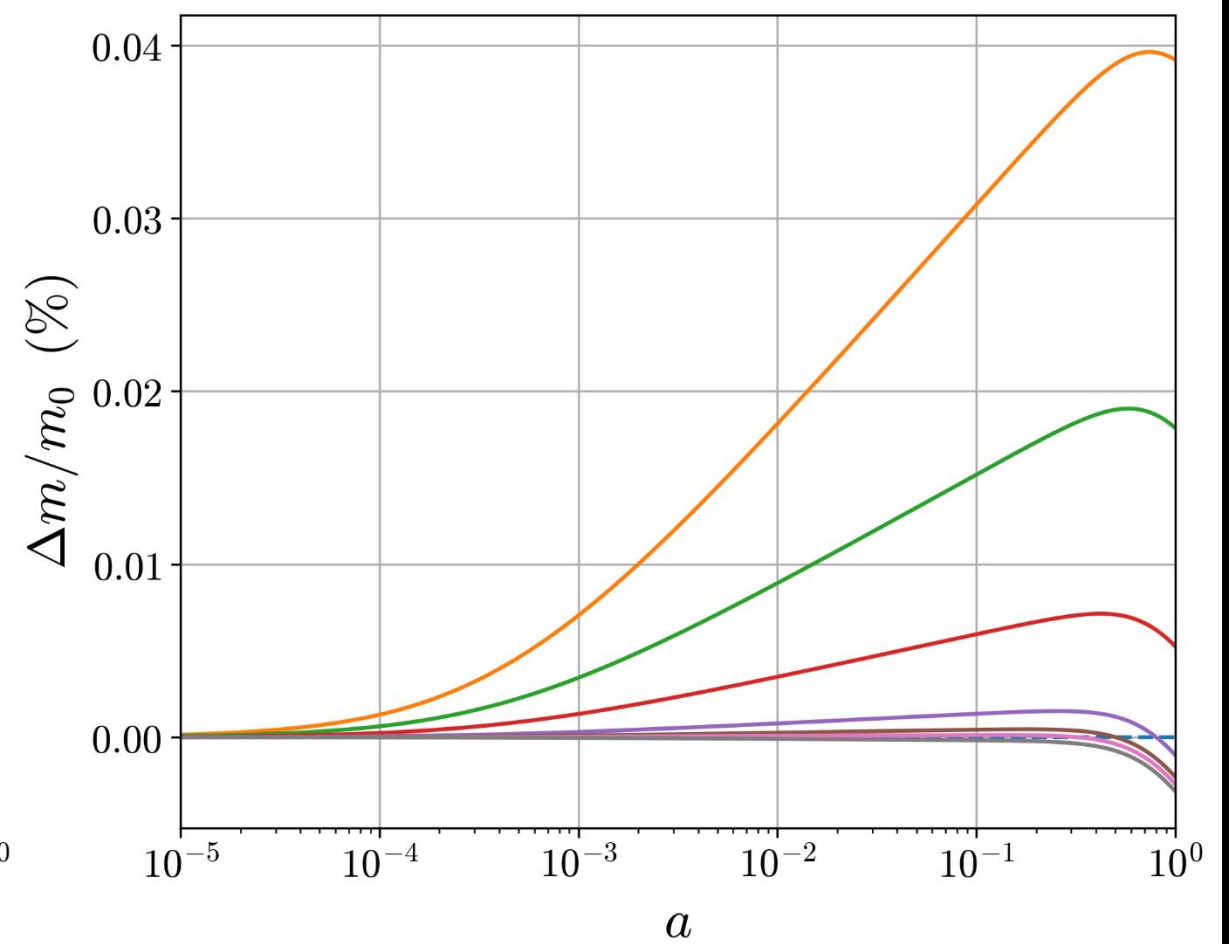
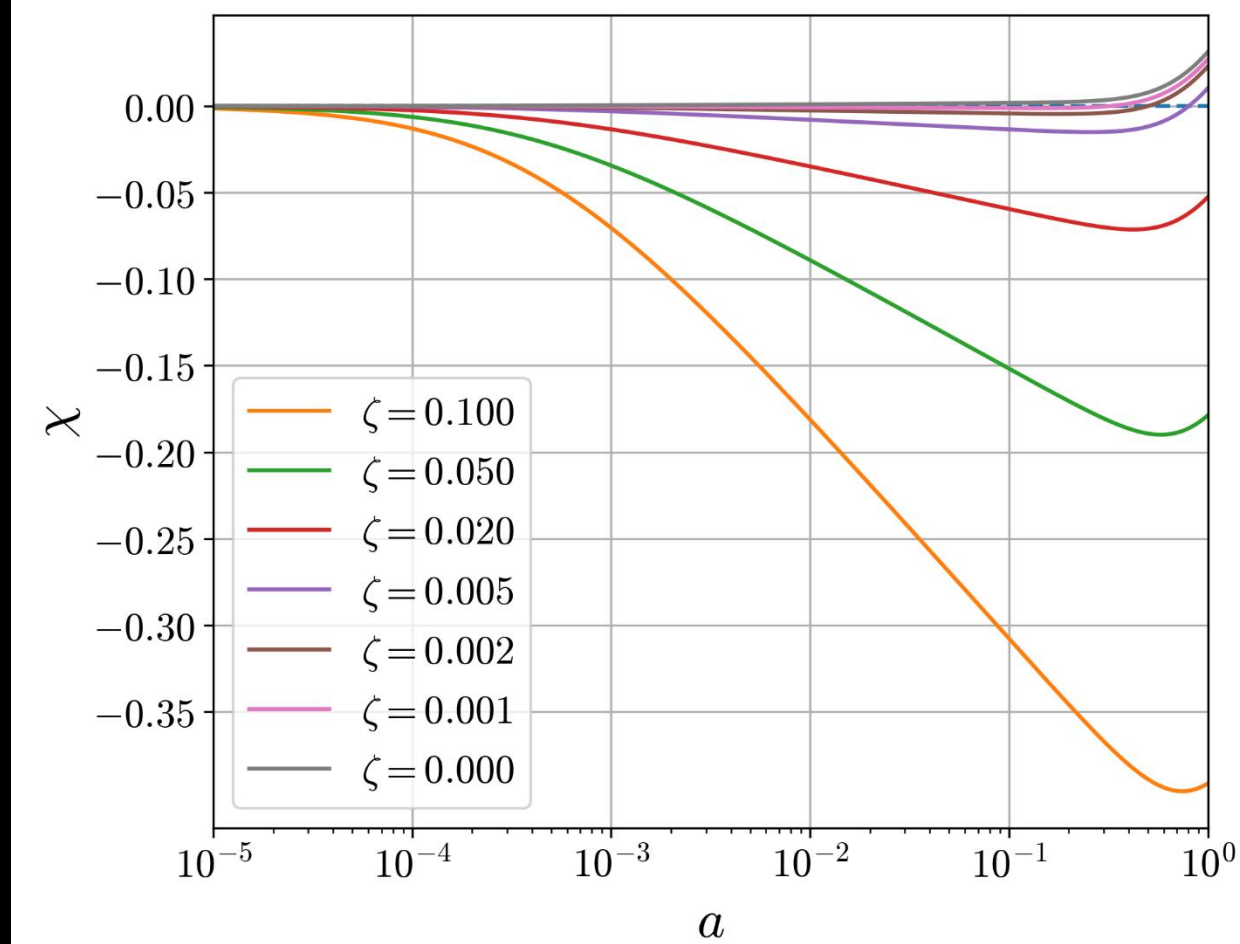


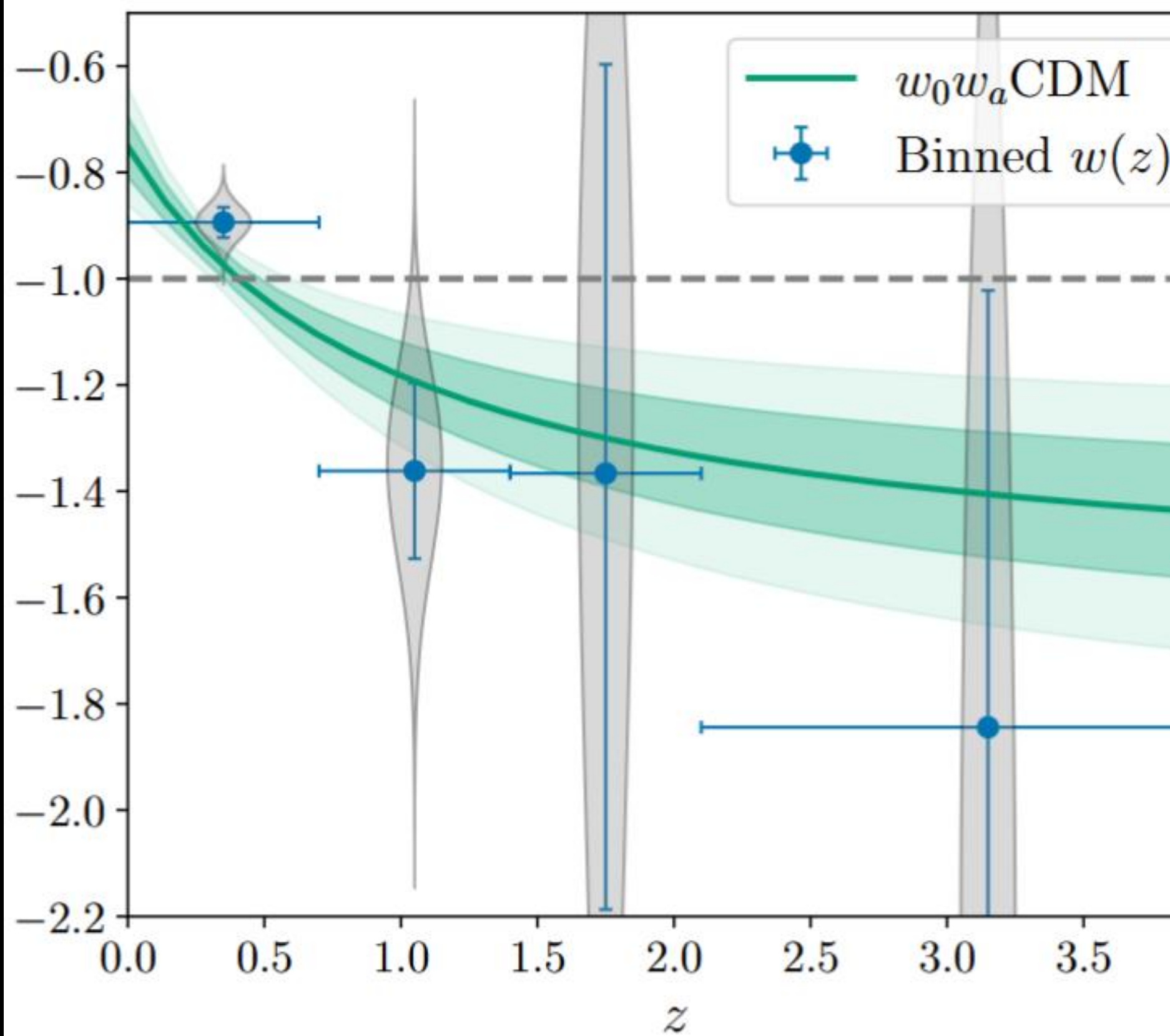
Figure 3: Volume-averaged differential 21 cm brightness temperature $\langle \delta T_b \rangle$ for $(g, \zeta) = (-0.1, +0.1)$ when the axio-dilaton modifications enter the 21 cm calculation one at a time, for $\bar{\chi}_{\text{ini}} = \bar{\chi}_{\text{min}} = 74.010$ chosen at the potential's minimum (left) or at the value $\bar{\chi}_{\text{ini}} = \bar{\chi}_{\text{bf}} = 74.213$ that provides the best fit to CMB data (right). Current cosmological data prefer coupling combinations of opposite sign [35], of which this is one. Colors and line styles denote the varied quantity indicated in the legend, with $\delta m_e(z)$ and $\delta m_p(z)$ given by Eq. (2.8). The gray dashed curves denote ΛCDM and the red full curves include all modifications together, with the δ_m curve following the red curve most closely.

Identify

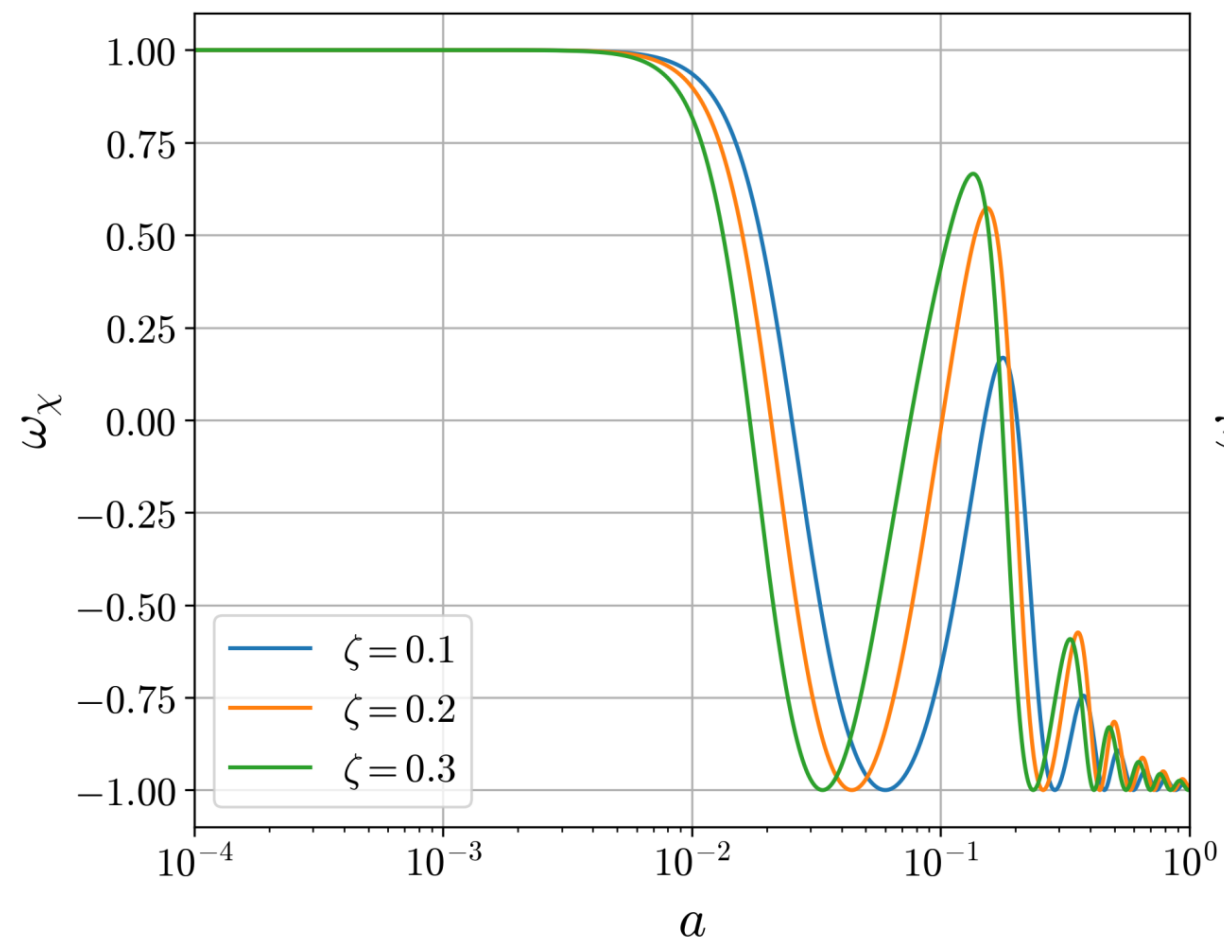


"Rugby Ball"

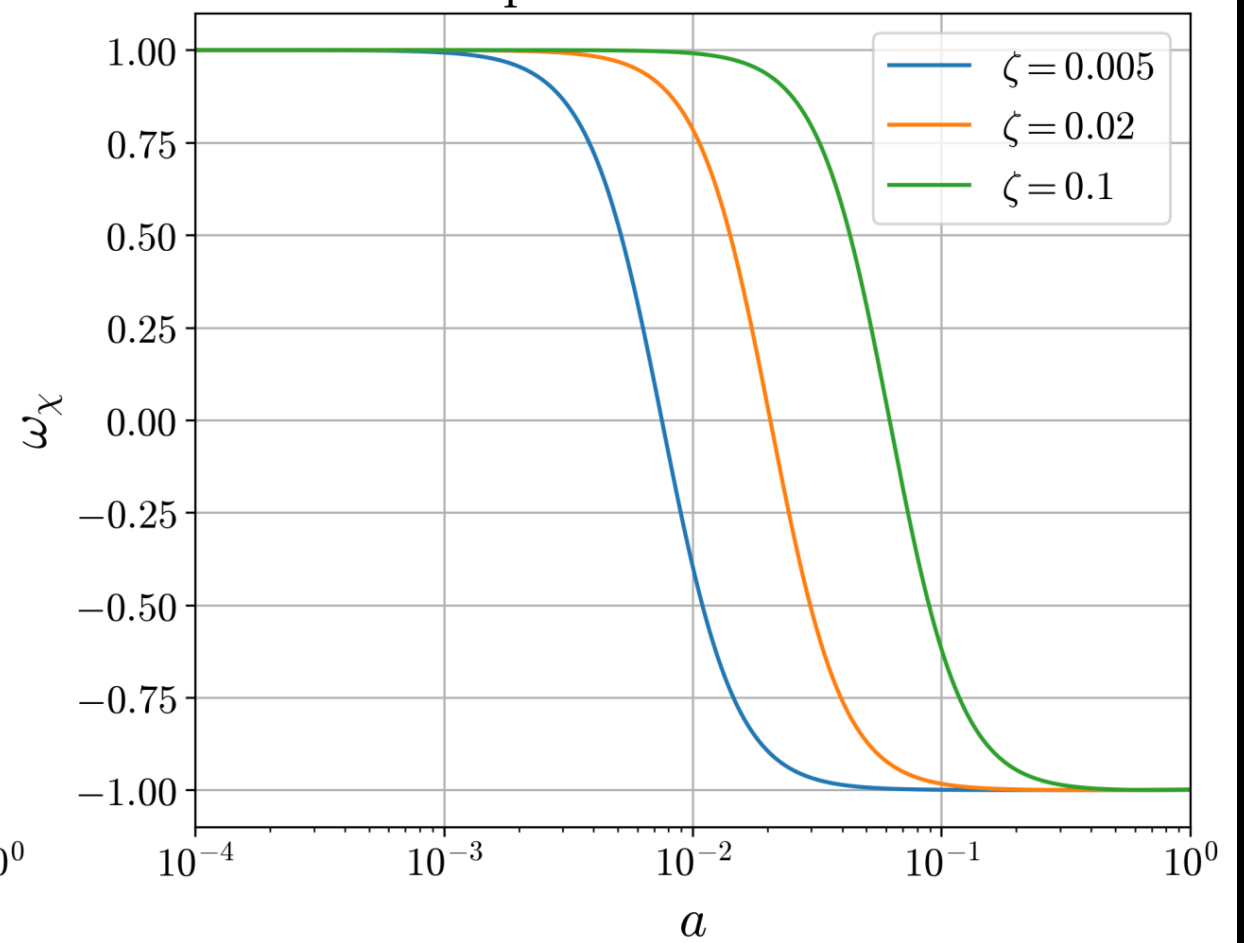


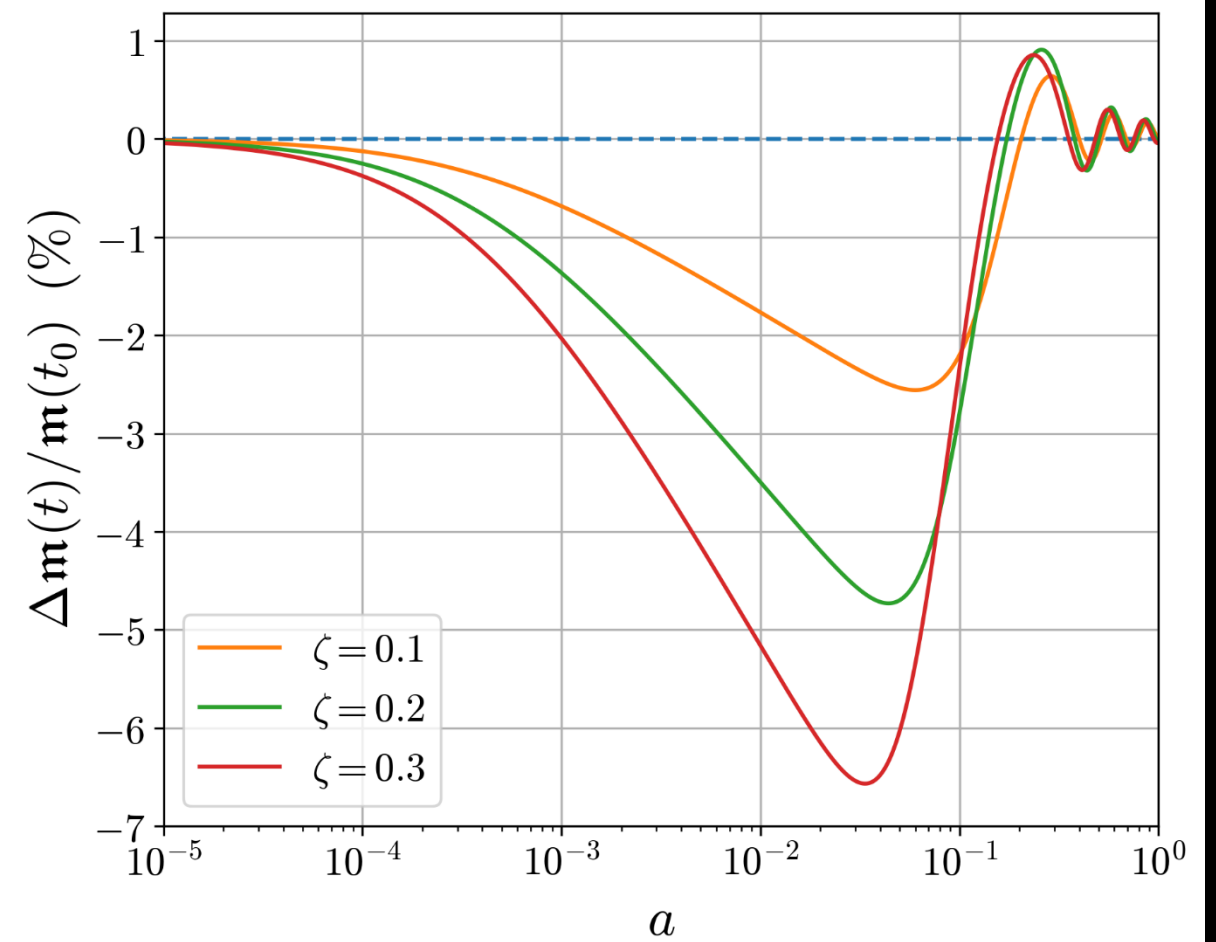
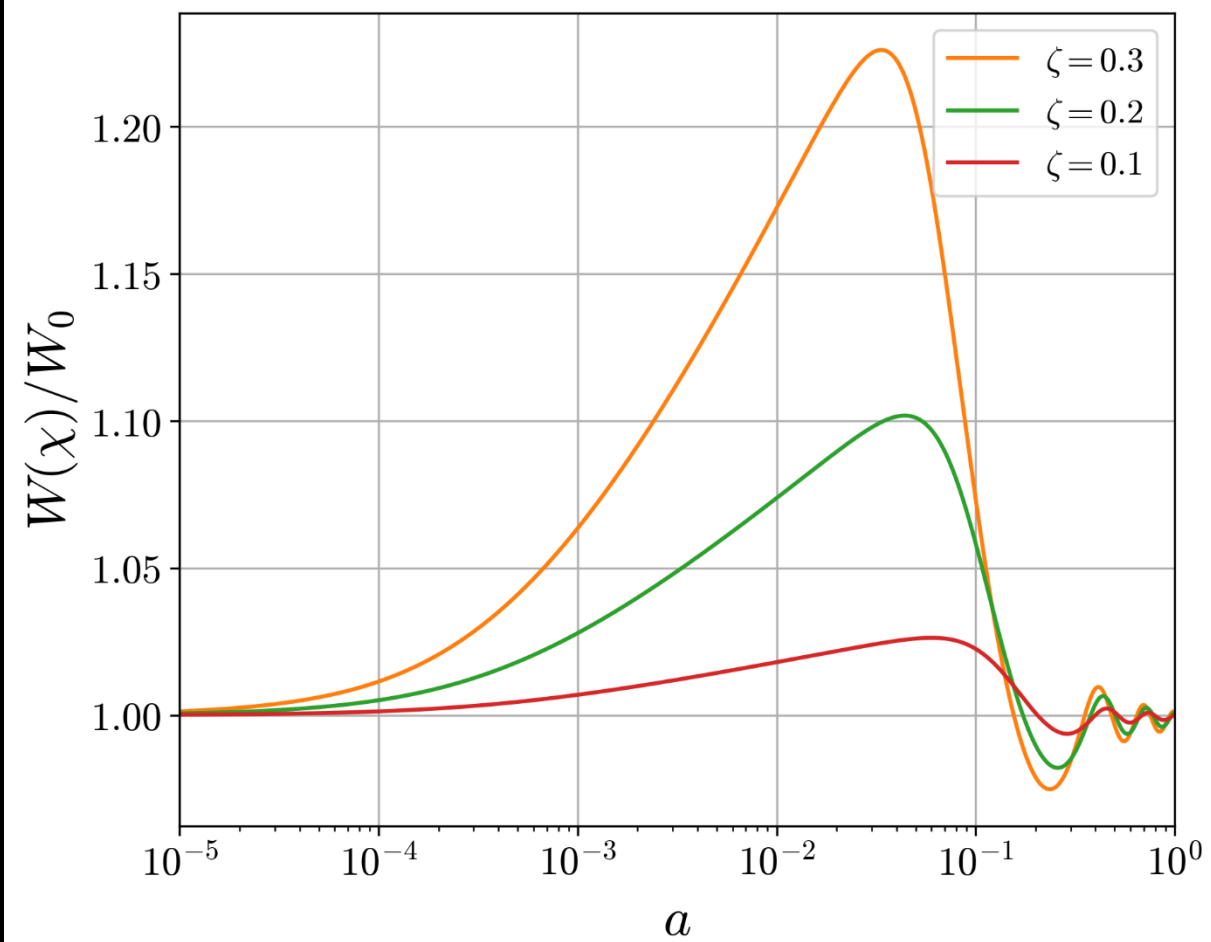
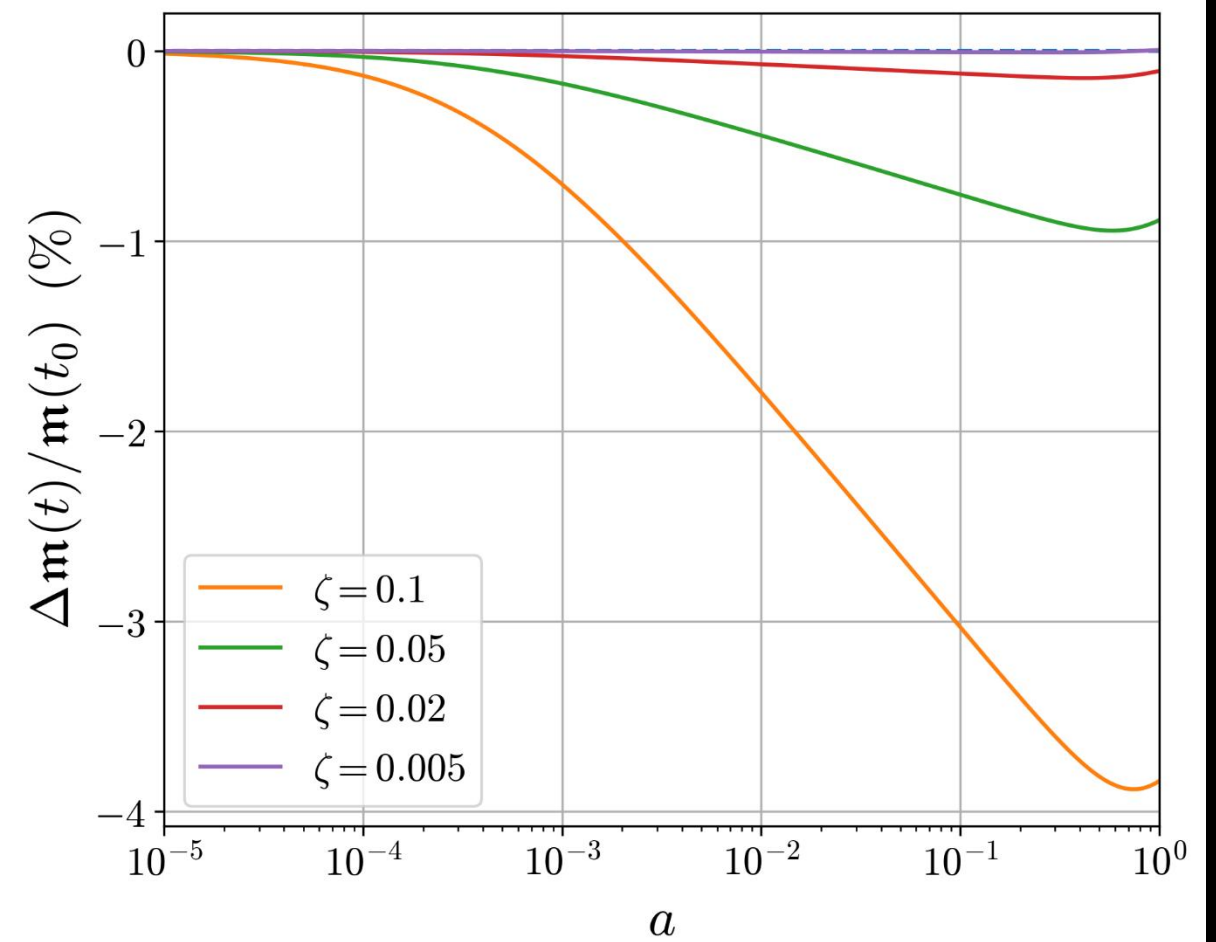
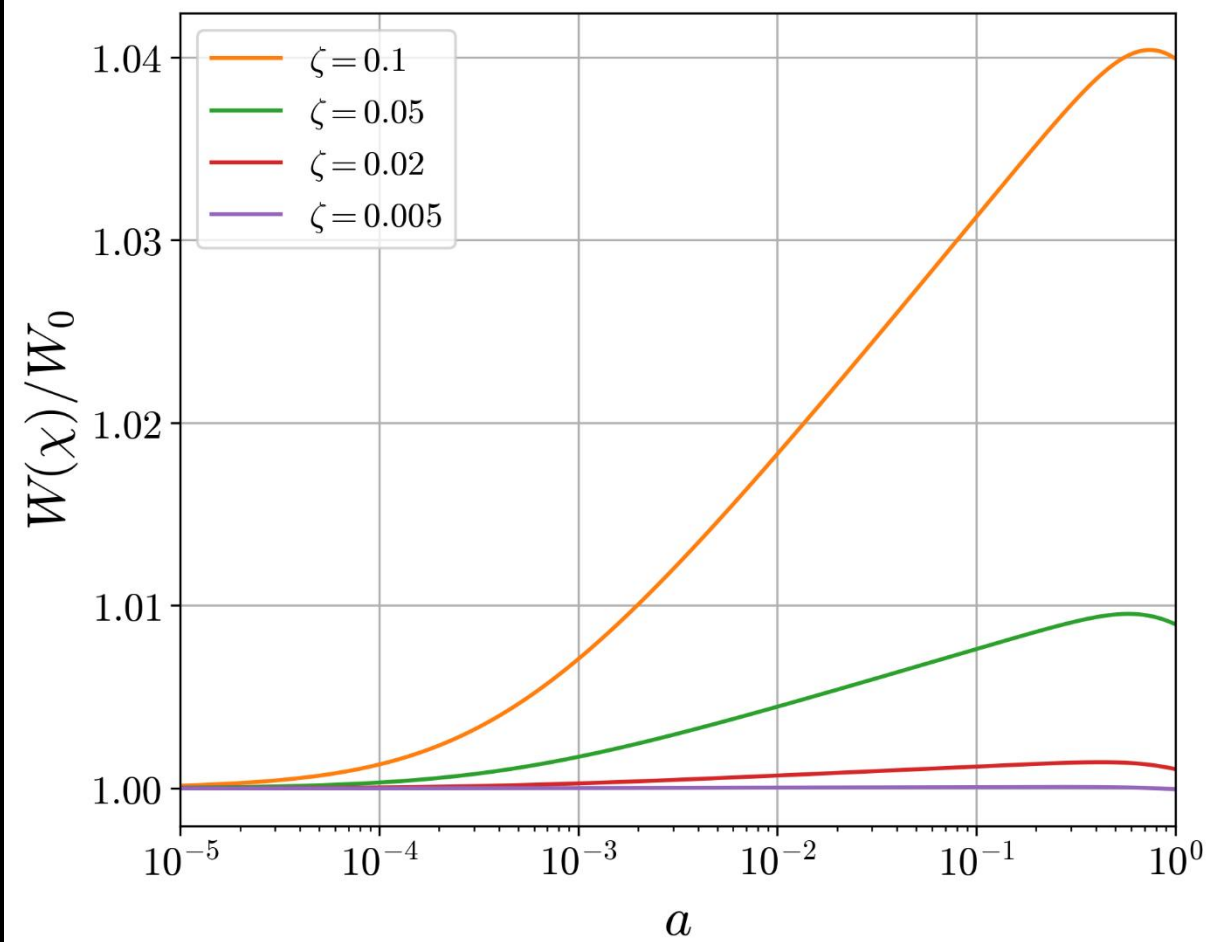


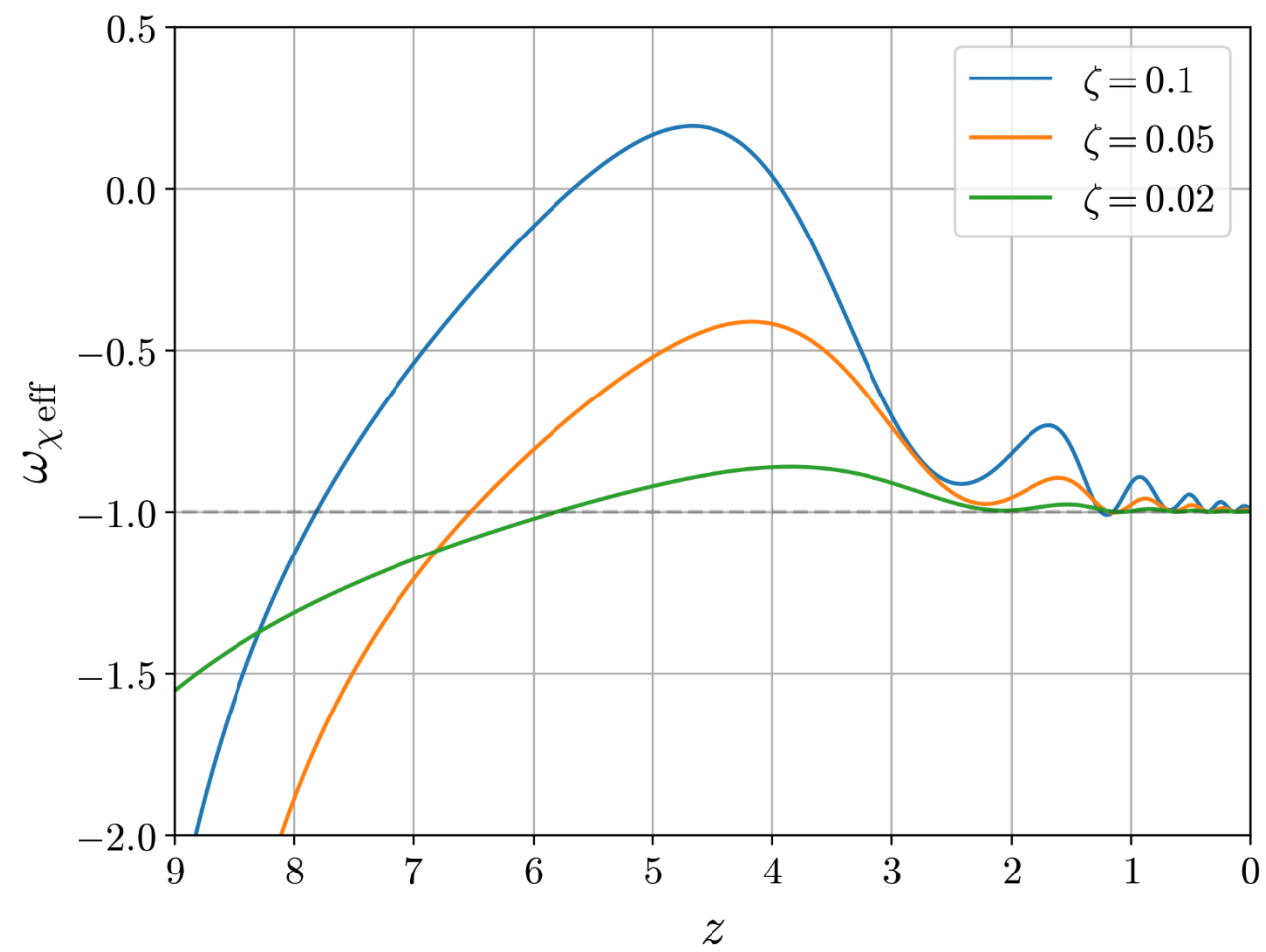
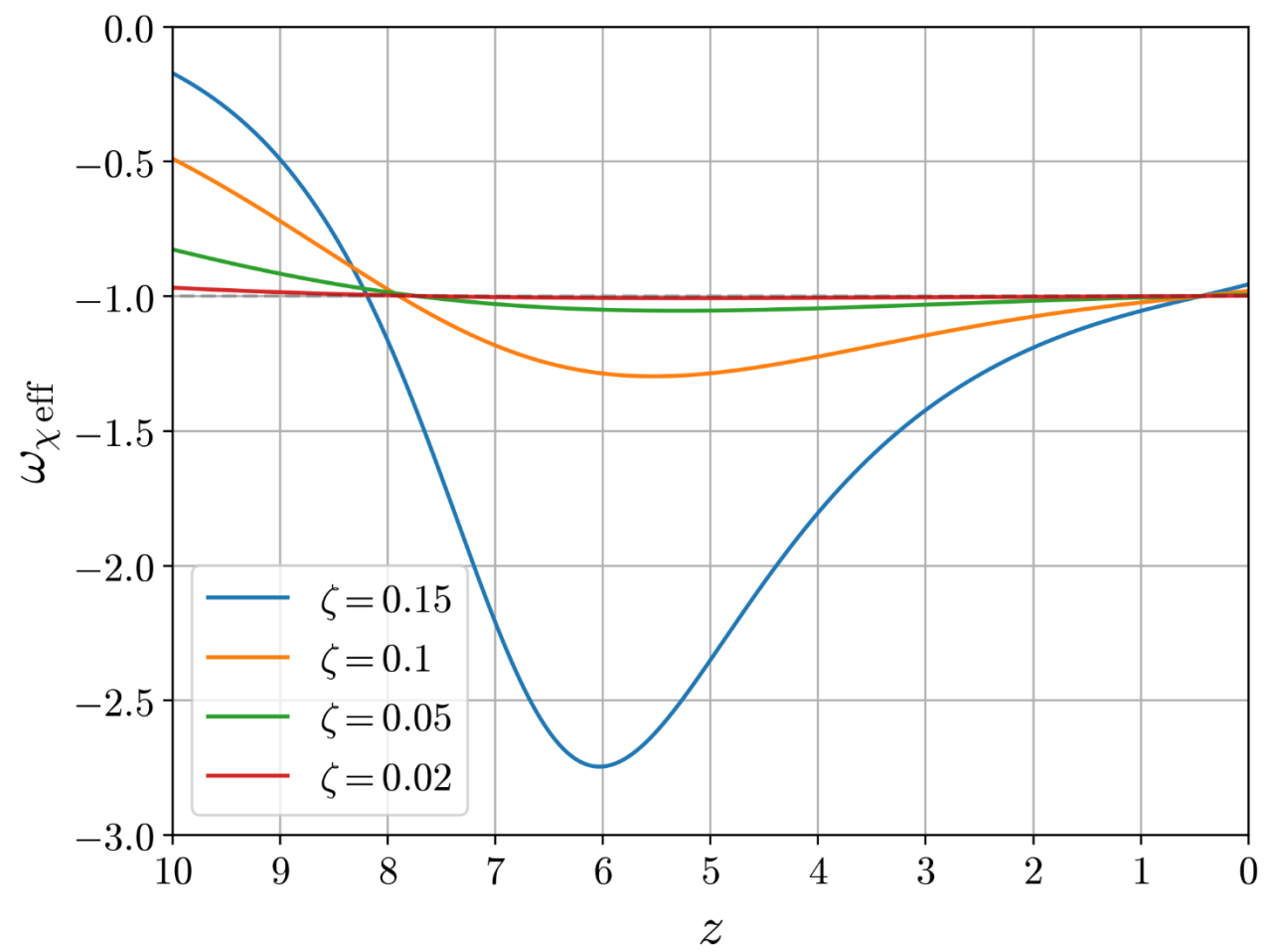
Local Minimum



Exponential Potential







Parameter	Yoga-VI (CMB-A DESI PP)	EXP (CMB-A DESI PP)	Yoga-VI (CMB-B DESI PP)	EXP (CMB-B DESI PP)
H_0	$69.20^{+0.65}_{-0.80}$ (68.653)	69.170 ± 0.670 (69.991)	$69.17^{+0.66}_{-0.75}$ (69.134)	$69.10^{+0.64}_{-0.76}$ (68.814)
$\Omega_b h^2$	0.023 ± 0.000 (0.022)	0.022 ± 0.000 (0.022)	0.022 ± 0.000 (0.022)	0.023 ± 0.000 (0.022)
$\Omega_c h^2$	$0.1201^{+0.0019}_{-0.0023}$ (0.118)	0.120 ± 0.002 (0.123)	0.121 ± 0.002 (0.121)	0.120 ± 0.002 (0.120)
n_s	0.970 ± 0.004 (0.970)	0.969 ± 0.003 (0.968)	0.969 ± 0.003 (0.970)	0.970 ± 0.003 (0.971)
A_s	3.051 ± 0.013 (3.049)	3.045 ± 0.008 (3.049)	3.046 ± 0.009 (3.054)	3.049 ± 0.013 (3.050)
τ	0.057 ± 0.007 (0.059)	0.053 ± 0.004 (0.050)	0.053 ± 0.004 (0.056)	0.057 ± 0.007 (0.055)
$\mathbf{g}$	-0.010 ± 0.100 (-0.012)	0.002 ± 0.093 (0.104)	-0.001 ± 0.095 (-0.052)	$0.00^{+0.11}_{-0.10}$ (0.127)
ζ	0.003 ± 0.052 (-0.041)	-0.001 ± 0.044 (-0.022)	$0.003^{+0.056}_{-0.051}$ (-0.003)	0.005 ± 0.049 (-0.058)
χ_i	74.000 ± 0.130 (73.890)	–	74.010 ± 0.150 (73.844)	–

TABLE VII: Posterior means ($\pm 1\sigma$) with best-fit values in parentheses for the Yoga-VI and EXP models using the CMB-A DESI PP datasets.

Model	Parameters	Priors
Λ CDM	$\Omega_B h^2$	[0.005, 0.1]
	$\Omega_c h^2$	[0.001, 0.99]
	τ_{reio}	[0.01, 0.8]
	A_s	$[5 \times 10^{-10}, 5 \times 10^{-9}]$
	n_s	[0.8, 1.2]
	θ_s	[0.5, 10]
$+m_e$	m_e	[0.9, 1.1]
Minimal Yoga	ζ	[-0.2, 0.2]
Exponential Yoga	$\mathbf{g}$	[-0.3, 0.3]
Minimal Yoga + VI	χ_i	[73.5, 75]

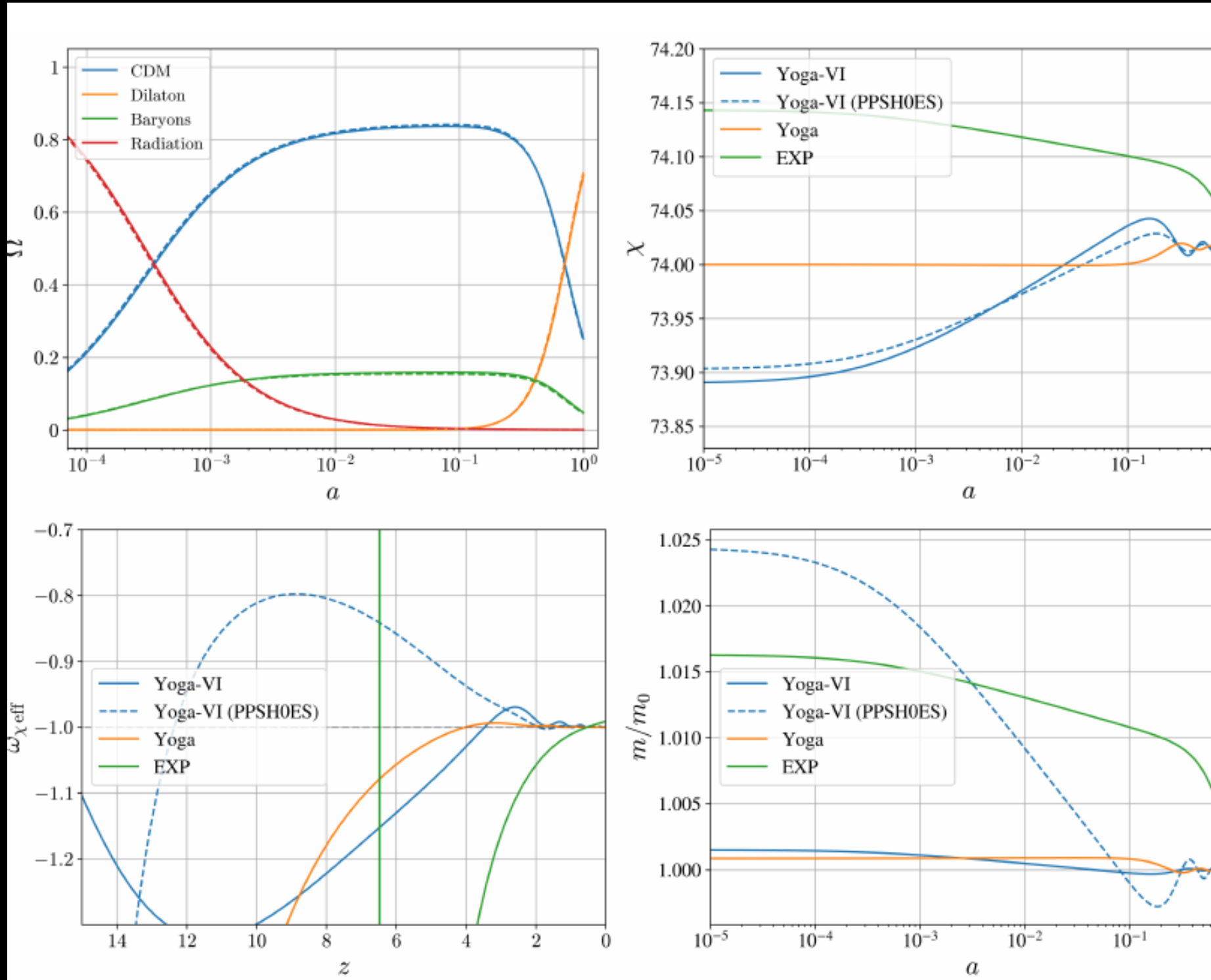


FIG. 3: Best-fit background evolution in different model variants using CMB-A DESI and PP datasets (calibrated with the SH0ES prior where stated). **Top left:** Fractional energy densities $\Omega_i(a)$ for the Yoga-VI model in solid blue, with the SH0ES prior in dashed. **Top right:** Dilaton field evolution $\chi(a)$. **Bottom left:** Effective equation of state $\omega_{\chi}^{\text{eff}}(z)$ showing deviations from -1 and damped late-time oscillations in the Yoga cases. **Bottom right:** Relative electron and other standard model particle's mass variation m/m_0 ; the PPSHOES fit exhibits the largest excursions before relaxing at late times.

Model	Dataset	H_0	$\mathbf{g}$	ζ	χ_i	$R - 1$	$\Delta\chi^2$
Yoga-VI	CMB-A DESI PP	$69.20^{+0.64}_{-0.81}$ (68.65)	-0.010 ± 0.100 (-0.012)	$0.003^{+0.059}_{-0.053}$ (-0.041)	74.000 ± 0.130 (73.890)	0.095	-1.9
	CMB-A DESI	$69.38^{+0.68}_{-0.83}$ (69.61)	0.000 ± 0.100 (0.147)	-0.001 ± 0.052 (-0.060)	74.010 ± 0.140 (74.086)	0.039	-3.5
(no- m_e)	CMB-A DESI PP	68.50 ± 0.35 (68.51)	0.005 ± 0.083 (-0.009)	0.001 ± 0.054 (-0.050)	$74.02^{+0.19}_{-0.16}$ (73.876)	0.017	-2.1
Yoga	CMB-A DESI PP	68.42 ± 0.35 (68.33)	-0.038 ± 0.086 (-0.055)	$0.020^{+0.077}_{-0.094}$ (0.032)	—	0.010	-0.7
	CMB-A DESI	68.53 ± 0.36 (68.54)	-0.041 ± 0.088 (-0.078)	$0.023^{+0.076}_{-0.097}$ (0.050)	—	0.025	-1.8
EXP	CMB-A DESI PP	$69.10^{+0.64}_{-0.76}$ (68.81)	-0.003 ± 0.099 (0.127)	0.005 ± 0.049 (-0.058)	—	0.082	-2.7
	CMB-A DESI	$69.34^{+0.70}_{-0.78}$ (69.81)	$0.004^{+0.12}_{-0.098}$ (0.122)	0.001 ± 0.049 (-0.044)	—	0.061	-4.0
	CMB-A	$68.01^{+0.78}_{-1.7}$ (67.43)	0.000 ± 0.088 (-0.013)	0.001 ± 0.051 (0.036)	—	0.074	-1.1
w0-wa + me	CMB-A DESI PP	68.26 ± 0.87 (68.29)	—	—	—	0.008	-8.2
	CMB-A DESI	$63.9^{+1.9}_{-2.7}$ (64.78)	—	—	—	0.006	-8.6
w0-wa	CMB-A DESI PP	67.64 ± 0.60 (67.71)	—	—	—	0.012	-6.9
Λ CDM+me	CMB-A DESI PP	69.62 ± 0.69 (69.91)	—	—	—	0.007	-2.6
	CMB-A DESI	69.85 ± 0.69 (70.12)	—	—	—	0.006	-4.2
Λ CDM	CMB-A DESI PP	68.30 ± 0.28 (68.03)	—	—	—	0.021	0.0
	CMB-A DESI	68.39 ± 0.29 (68.53)	—	—	—	0.009	0.0
	CMB-A	67.30 ± 0.54 (67.27)	—	—	—	0.007	0.0

TABLE III: Posterior means with 1σ confidence intervals, best-fit values in parentheses, and $\Delta\chi^2$ relative to the corresponding Λ CDM run for each dataset combination. The table summarises how the different axio-dilaton (Yoga and EXP), w_0 - w_a , and varying- m_e models shift H_0 , the scalar couplings ($\mathbf{g}, \zeta$), and overall goodness-of-fit relative to Λ CDM across the CMB-A, CMB-A DESI, and CMB-A DESI PP datasets.

Model	Dataset	H_0	$\mathbf{g}$	ζ	χ_i	$R - 1$	$\Delta\chi^2$
Yoga-VI	CMB-A DESI PP	$69.20^{+0.64}_{-0.81}$ (68.65)	-0.010 ± 0.100 (-0.012)	$0.003^{+0.059}_{-0.053}$ (-0.041)	74.000 ± 0.130 (73.890)	0.095	-1.9
	CMB-A DESI	$69.38^{+0.68}_{-0.83}$ (69.61)	0.000 ± 0.100 (0.147)	-0.001 ± 0.052 (-0.060)	74.010 ± 0.140 (74.086)	0.039	-3.5
(no- m_e)	CMB-A DESI PP	68.50 ± 0.35 (68.51)	0.005 ± 0.083 (-0.009)	0.001 ± 0.054 (-0.050)	$74.02^{+0.19}_{-0.16}$ (73.876)	0.017	-2.1
Yoga	CMB-A DESI PP	68.42 ± 0.35 (68.33)	-0.038 ± 0.086 (-0.055)	$0.020^{+0.077}_{-0.094}$ (0.032)	—	0.010	-0.7
	CMB-A DESI	68.53 ± 0.36 (68.54)	-0.041 ± 0.088 (-0.078)	$0.023^{+0.076}_{-0.097}$ (0.050)	—	0.025	-1.8
EXP	CMB-A DESI PP	$69.10^{+0.64}_{-0.76}$ (68.81)	-0.003 ± 0.099 (0.127)	0.005 ± 0.049 (-0.058)	—	0.082	-2.7
	CMB-A DESI	$69.34^{+0.70}_{-0.78}$ (69.81)	$0.004^{+0.12}_{-0.098}$ (0.122)	0.001 ± 0.049 (-0.044)	—	0.061	-4.0
	CMB-A	$68.01^{+0.78}_{-1.7}$ (67.43)	0.000 ± 0.088 (-0.013)	0.001 ± 0.051 (0.036)	—	0.074	-1.1
w0-wa + me	CMB-A DESI PP	68.26 ± 0.87 (68.29)	—	—	—	0.008	-8.2
	CMB-A DESI	$63.9^{+1.9}_{-2.7}$ (64.78)	—	—	—	0.006	-8.6
w0-wa	CMB-A DESI PP	67.64 ± 0.60 (67.71)	—	—	—	0.012	-6.9
Λ CDM+me	CMB-A DESI PP	69.62 ± 0.69 (69.91)	—	—	—	0.007	-2.6
	CMB-A DESI	69.85 ± 0.69 (70.12)	—	—	—	0.006	-4.2
Λ CDM	CMB-A DESI PP	68.30 ± 0.28 (68.03)	—	—	—	0.021	0.0
	CMB-A DESI	68.39 ± 0.29 (68.53)	—	—	—	0.009	0.0
	CMB-A	67.30 ± 0.54 (67.27)	—	—	—	0.007	0.0

TABLE IV: Posterior means with 1σ confidence intervals, best-fit values in parentheses, and $\Delta\chi^2$ relative to the corresponding Λ CDM run for each dataset combination. The table summarises how the different axio-dilaton (Yoga and EXP), w_0 - w_a , and varying- m_e models shift H_0 , the scalar couplings ($\mathbf{g}, \zeta$), and overall goodness-of-fit relative to Λ CDM across the CMB-A, CMB-A DESI, and CMB-A DESI PP datasets.

Model	Dataset	H_0	$\mathbf{g}$	ζ	χ_i	$R - 1$	$\Delta\chi^2$
Yoga-VI	CMB-B DESI PP	$69.17^{+0.66}_{-0.76}$ (69.13)	-0.001 ± 0.095 (-0.052)	0.003 ± 0.050 (-0.003)	74.010 ± 0.150 (73.844)	0.102	-7.2
	CMB-B DESI	69.42 ± 0.72 (69.58)	-0.011 ± 0.097 (0.102)	-0.002 ± 0.049 (-0.039)	$73.98^{+0.18}_{-0.15}$ (74.142)	0.195	-6.3
EXP	CMB-B DESI PP	69.17 ± 0.67 (69.99)	0.002 ± 0.093 (0.104)	-0.001 ± 0.044 (-0.022)	–	0.338	-7.3
	CMB-B DESI	69.37 ± 0.72 (69.12)	0.000 ± 0.093 (-0.023)	-0.003 ± 0.045 (-0.038)	–	0.885	-6.1
	CMB-B	$67.50^{+0.68}_{-1.2}$ (67.78)	-0.005 ± 0.074 (0.041)	0.002 ± 0.047 (-0.002)	–	0.029	–
w0-wa + me	CMB-B DESI PP	68.32 ± 0.83 (67.95)	–	–	–	0.098	-12.1
	CMB-B DESI	$64.2^{+1.9}_{-2.6}$ (63.78)	–	–	–	0.041	-10.5
w0-wa	CMB-B DESI PP	67.65 ± 0.59 (67.52)	–	–	–	0.010	-9.6
Λ CDM	CMB-B DESI PP	68.04 ± 0.26 (68.25)	–	–	–	0.007	0.0
	CMB-B DESI	68.13 ± 0.26 (68.23)	–	–	–	0.006	0.0

TABLE V: Posterior means with quoted 1σ marginal uncertainties and best-fit values in parentheses for all models fit to the CMB-B dataset combinations including SPT-3G. Columns list the inferred Hubble constant, the dilaton coupling $\mathbf{g}$, the axion CDM kinetic coupling ζ , the initial dilaton value χ_i when present, and the change in best-fit $\Delta\chi^2$ relative to the corresponding Λ CDM run.

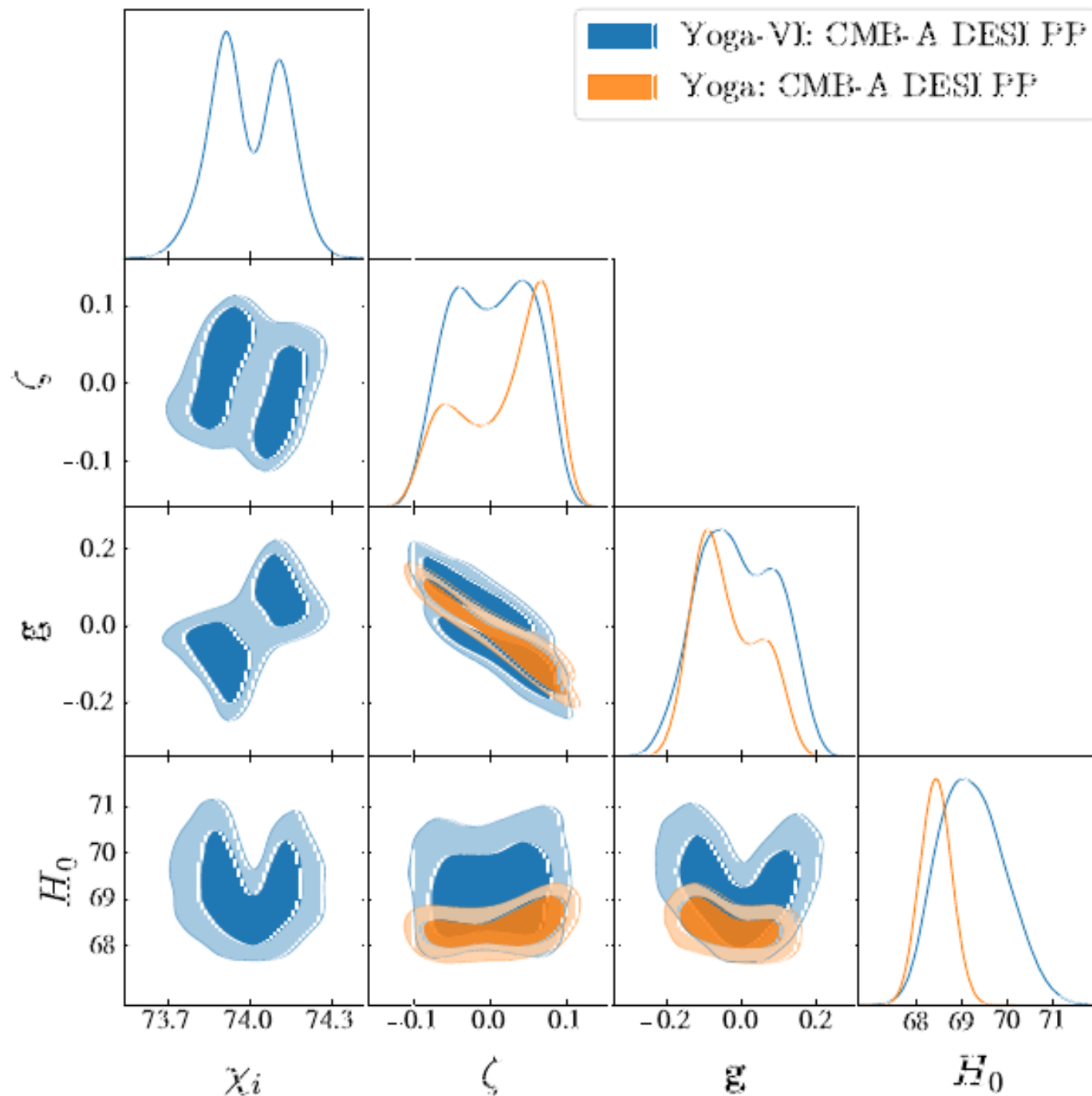


FIG. 1: Triangle plot comparing the minimal Yoga model with fixed initial field values and varying initial conditions (VI). Both analyses use the same CMB-A DESI PP dataset combination. The two setups exhibit the same correlation directions among g and ζ , but differ in the correlation to H_0 , with large g only correlating with large H_0 in the VI case.

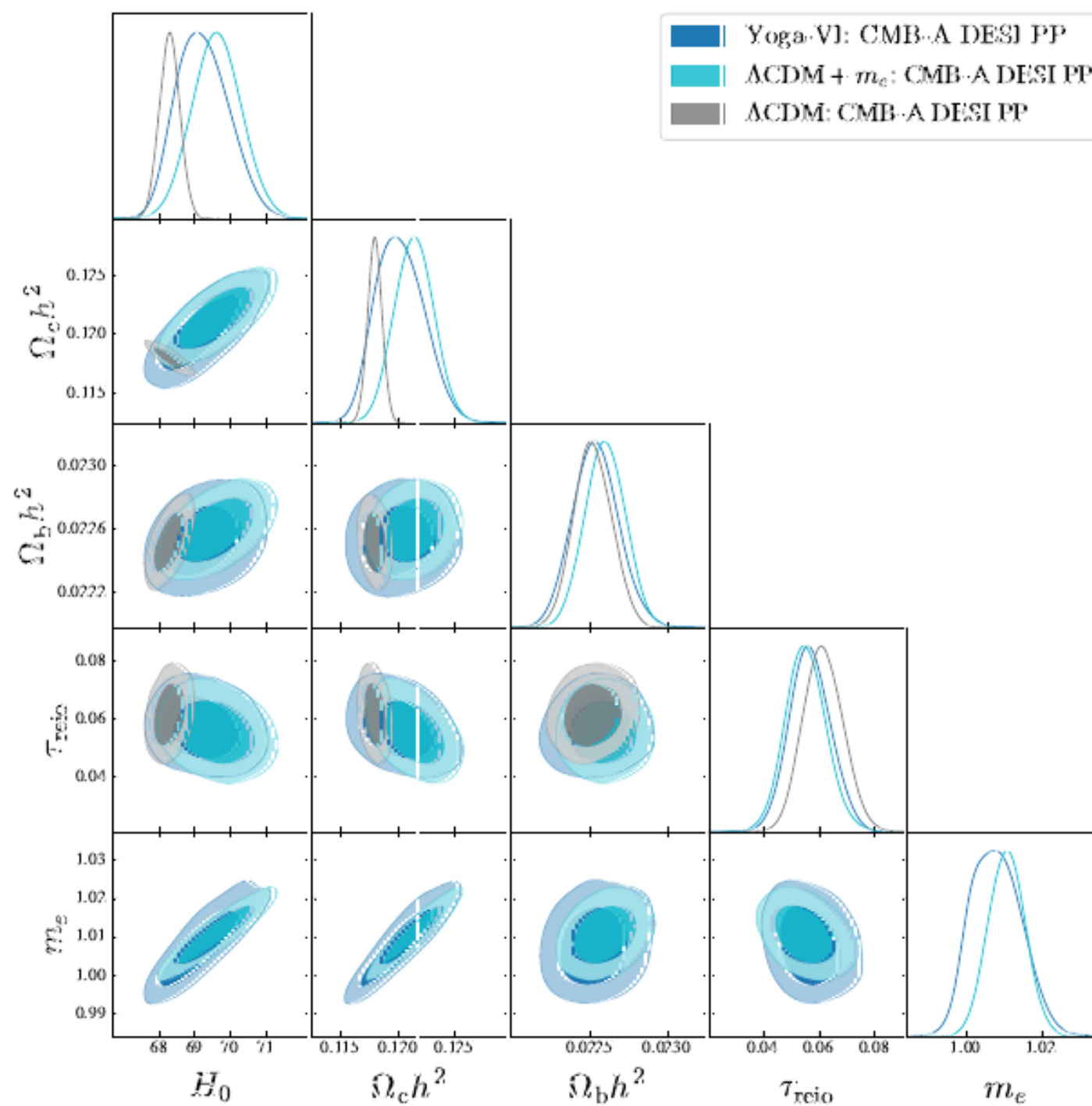


FIG. 2: Triangle plot comparing standard cosmological parameters of Λ CDM and Λ CDM+ m_e with the minimal Yoga model. All cases use the same CMB-A DESI PP dataset combination.

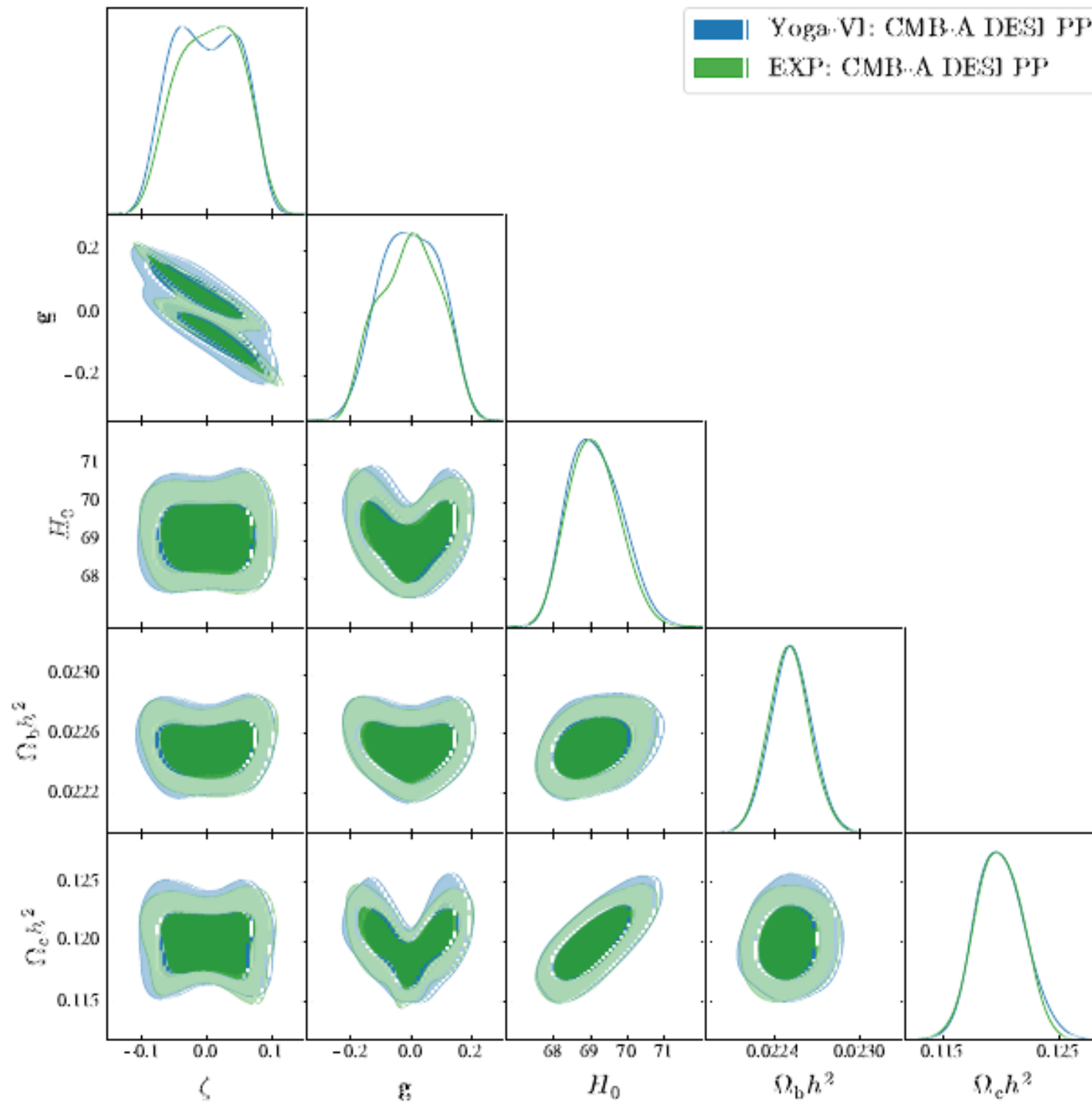
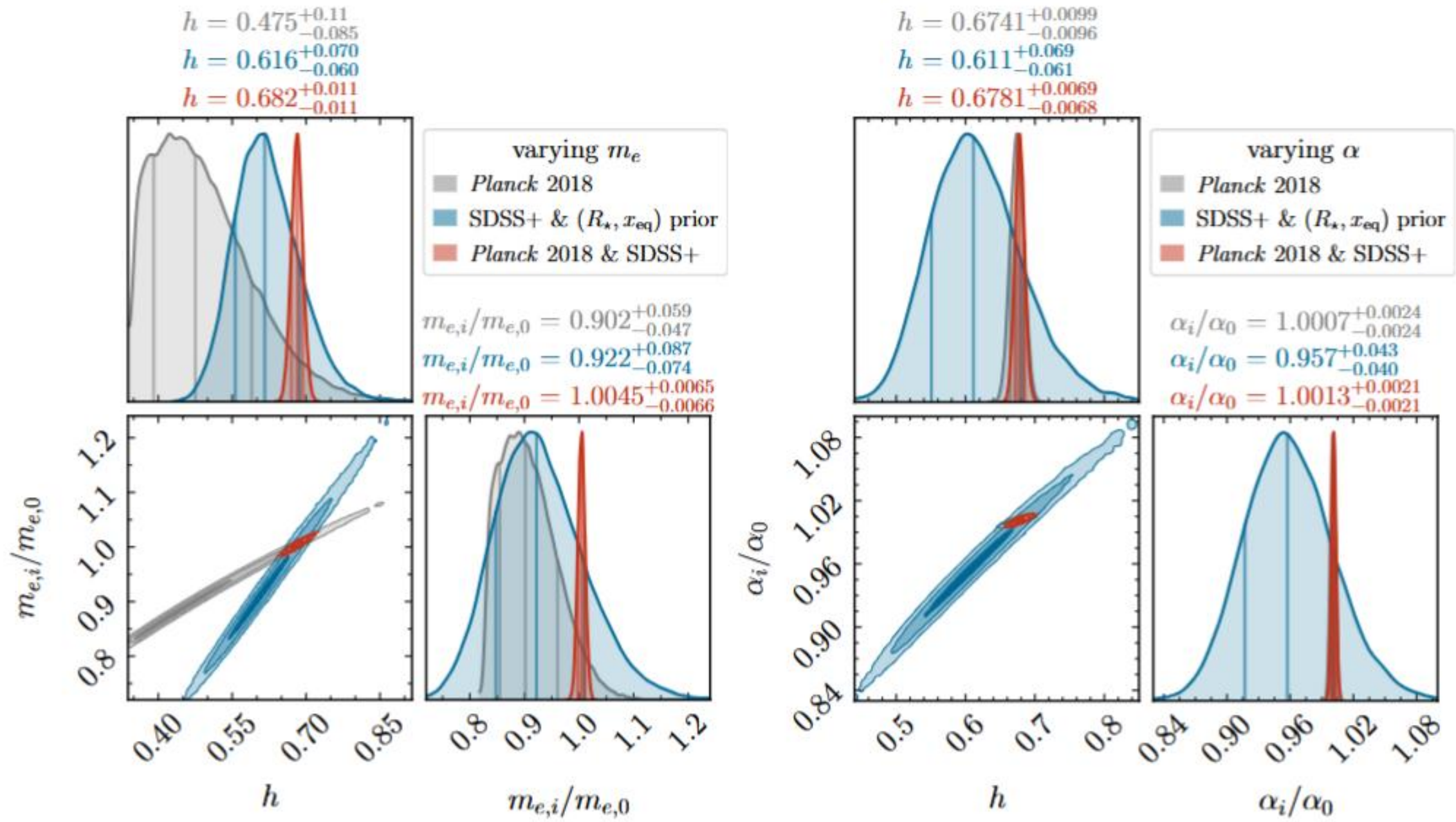


FIG. 4: Comparison of the main common parameter constraints on the Exponential and Yoga style axio-dilaton models



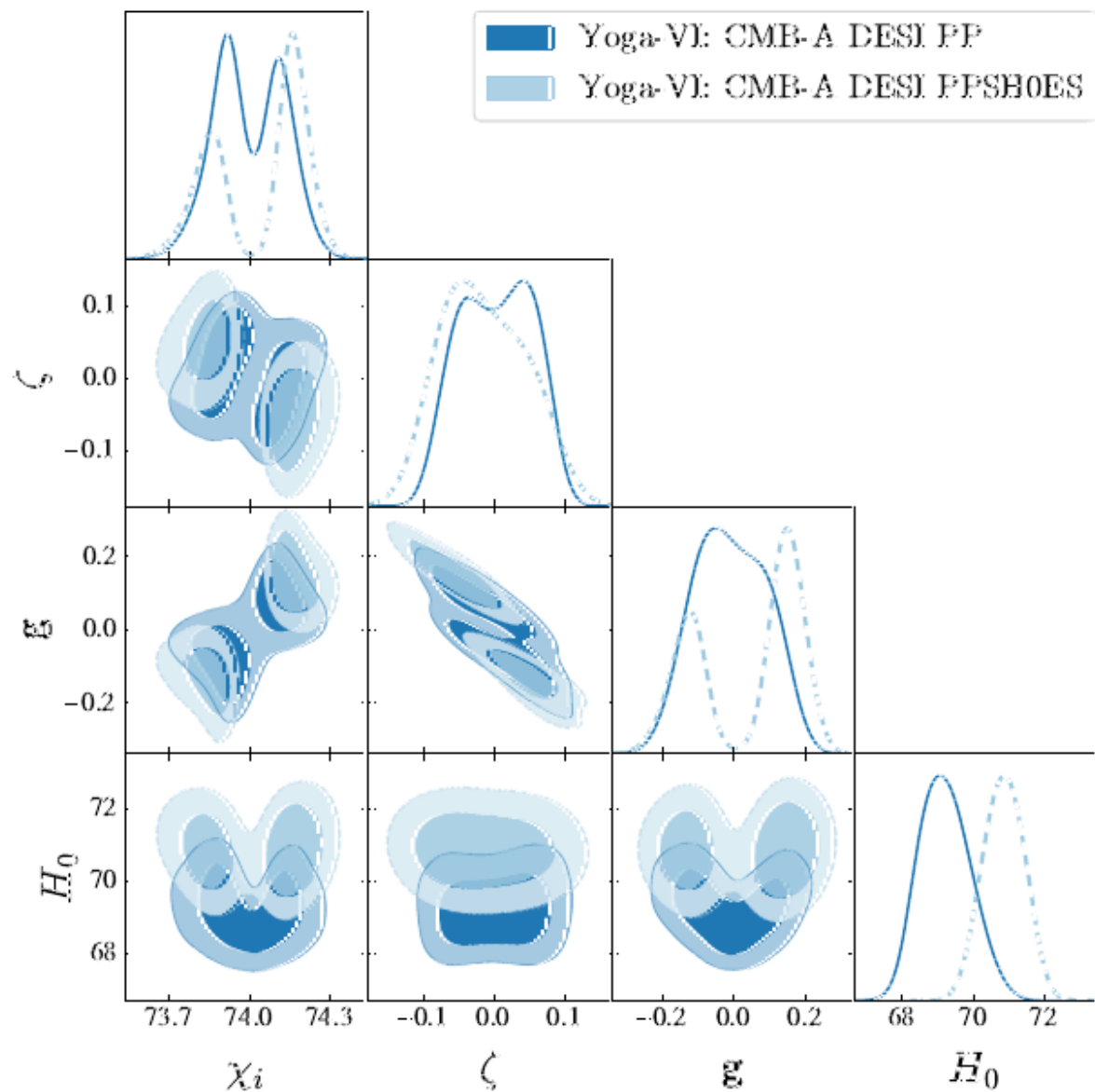


FIG. 5: Triangle plot showing constraints on the minimal Yoga-VI model with and without the SH0ES prior calibration with CMB-A DESI PP datasets. Imposing the SH0ES prior amplifies the existing correlations among g , ζ and H_0 , with much larger couplings and initial dilaton displacements being preferred.

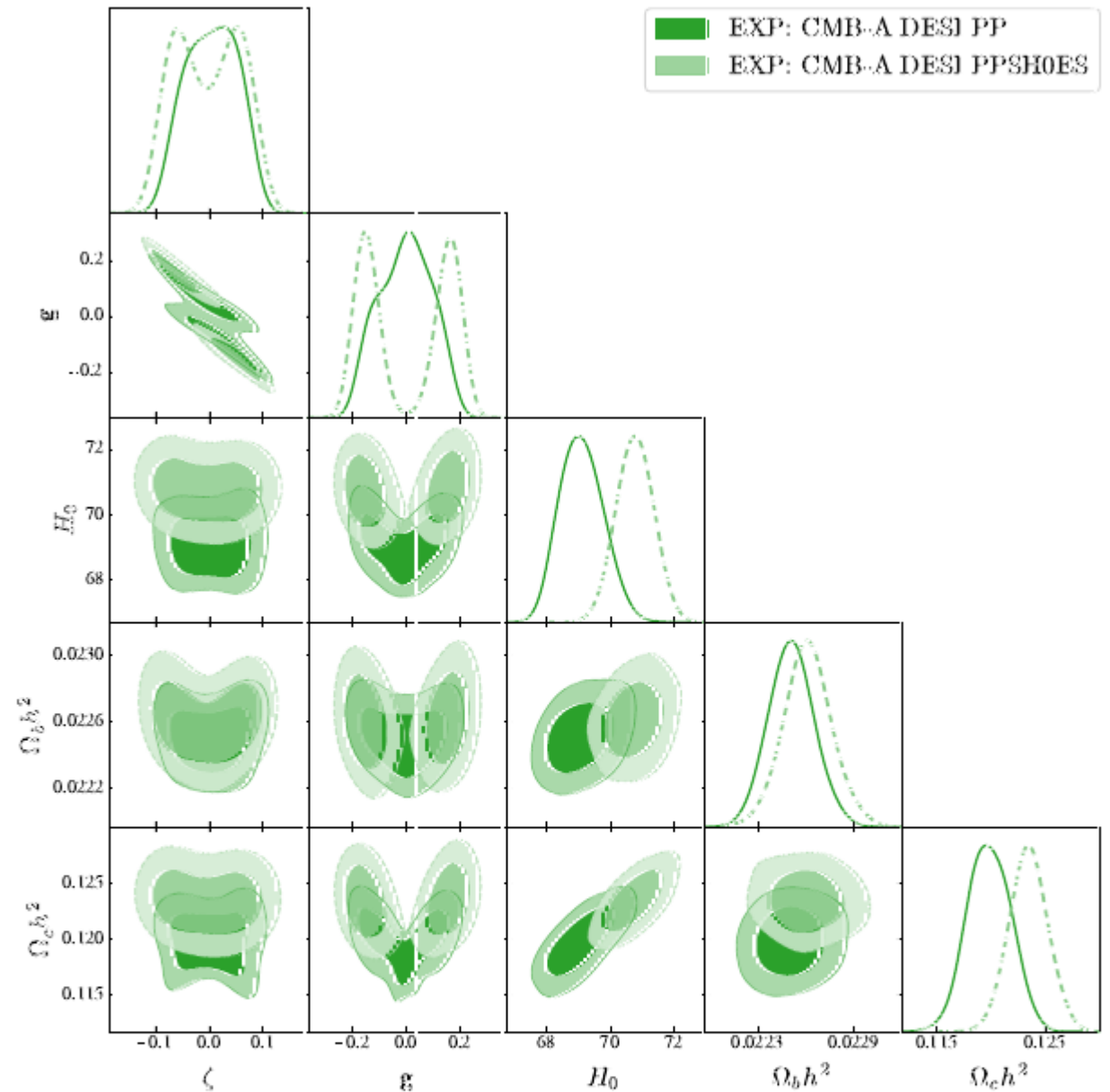


FIG. 6: Triangle plot showing constraints on the minimal Exponential model with and without the SH0ES prior calibration with CMB-A DESI PP datasets.

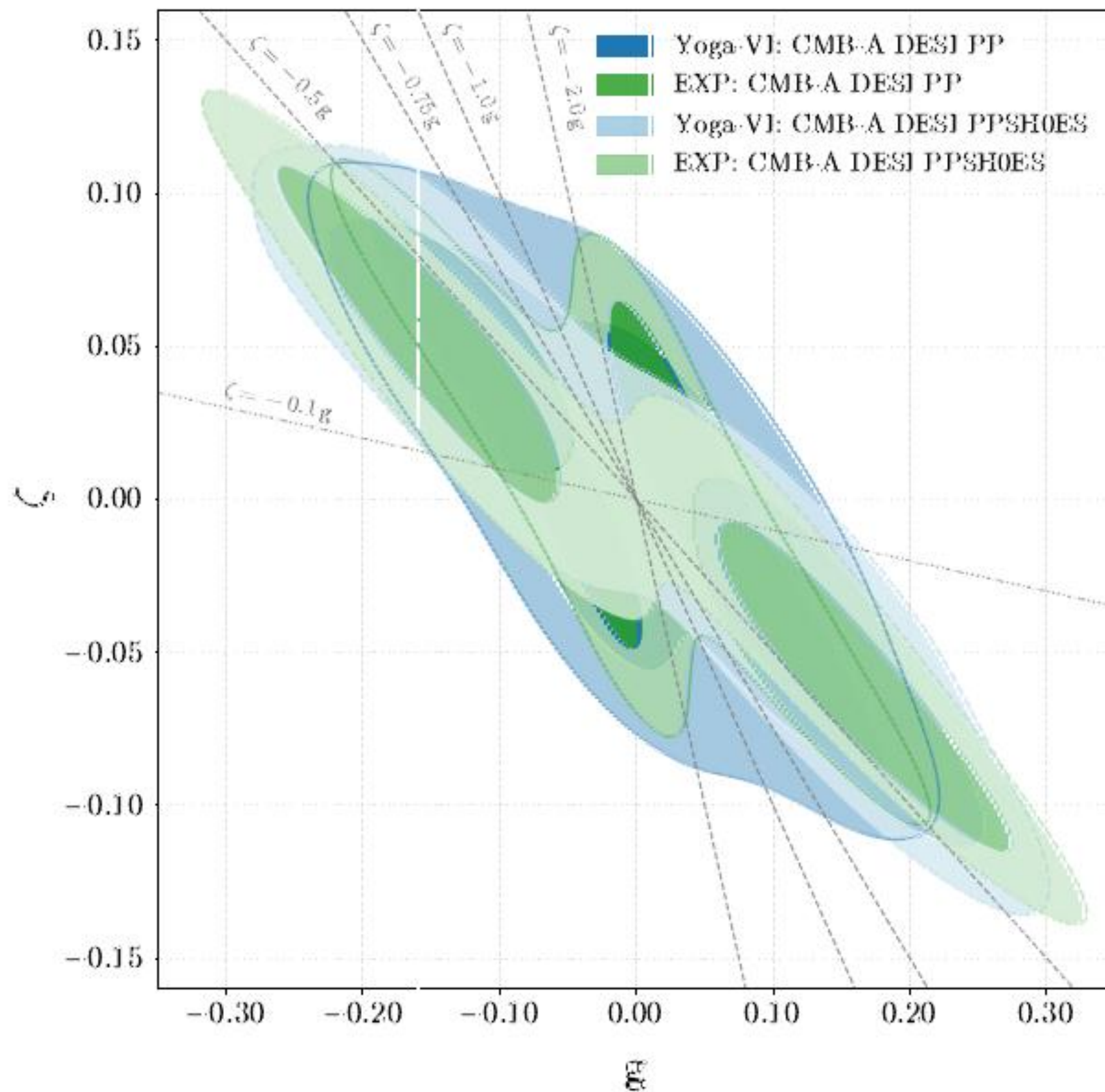


FIG. 7: Posteriors in the $\zeta - g$ plane for the relevant models with and without SH0ES priors.