

Quintessence with a sudden transitional feature and its late-time cosmological signals

with Kiyotomo Ichiki, Yuichiro Tada, and Shun Yoshioka, [arXiv:2602.14389](https://arxiv.org/abs/2602.14389) [astro-ph.CO]

Takahiro Terada (KMI, Nagoya U.), KEK-PH2026winter, Feb. 18, 2026

Supported by DAIKO FOUNDATION

Evidence of Dynamical Dark Energy

DESI+CMB+SNe showed an **evidence of dynamical dark energy** at $\sim 3\sigma$.

[Adame et al., DESI 2024 VI, 2404.03002] [Adame et al., DESI 2024 VII, 2411.12022] [Karim et al., DESI DR2 Results II, 2503.14738]

Eq.-of-state parameter: $w \equiv P/\rho$

ansatz: $w_0 w_a$ CDM model (CPL parametrization)

$$w(a) = w_0 + w_a(1 - a)$$

[Chevallier, Polarski, gr-qc/0009008]

[Linder, astro-ph/0208512]

without SNe: 3.1σ

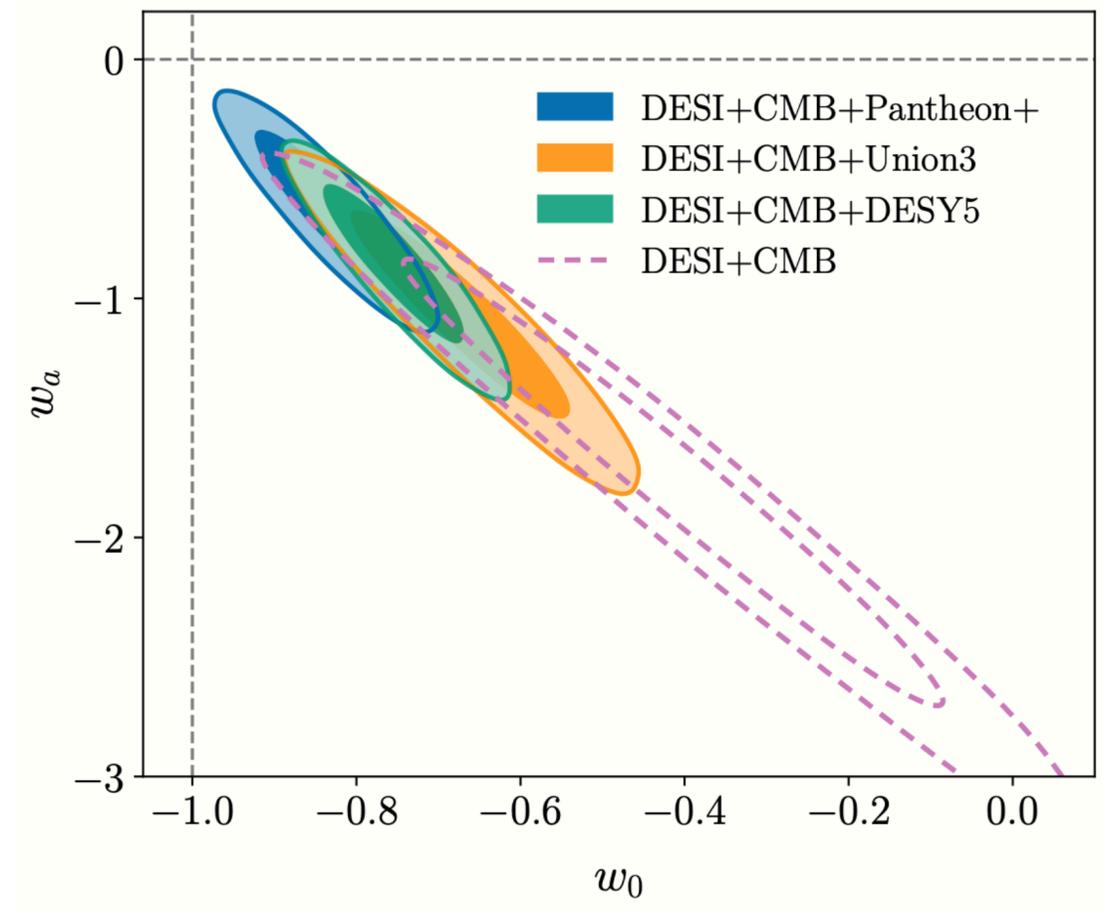
with Union3: 3.8σ

with Pantheon+: 2.8σ

with DES-Y5: 4.2σ

See [Popovic et al., 2511.07517]

for a reanalysis leading to 3.2σ .

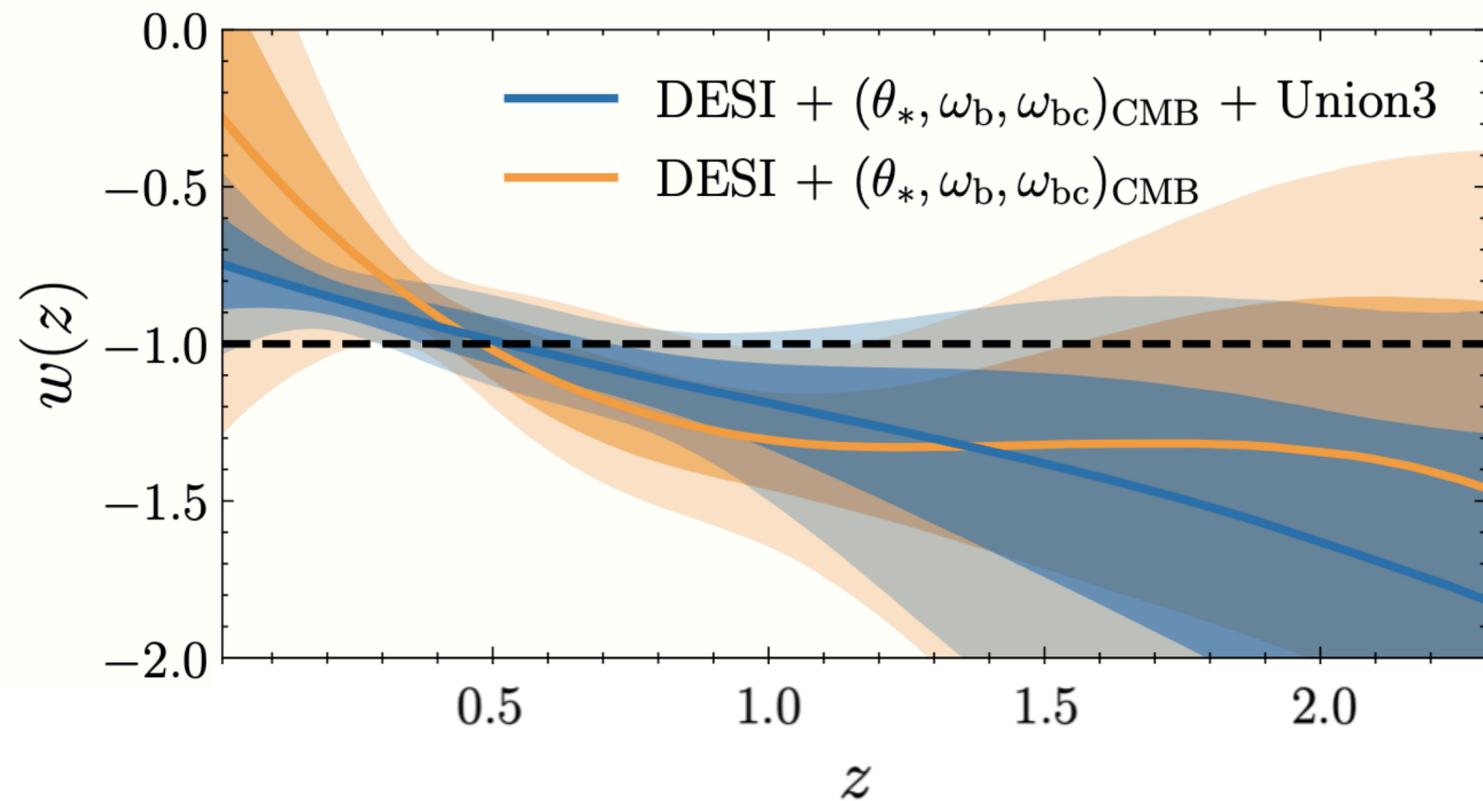


What is the **physical mechanism** of the dynamical dark energy?

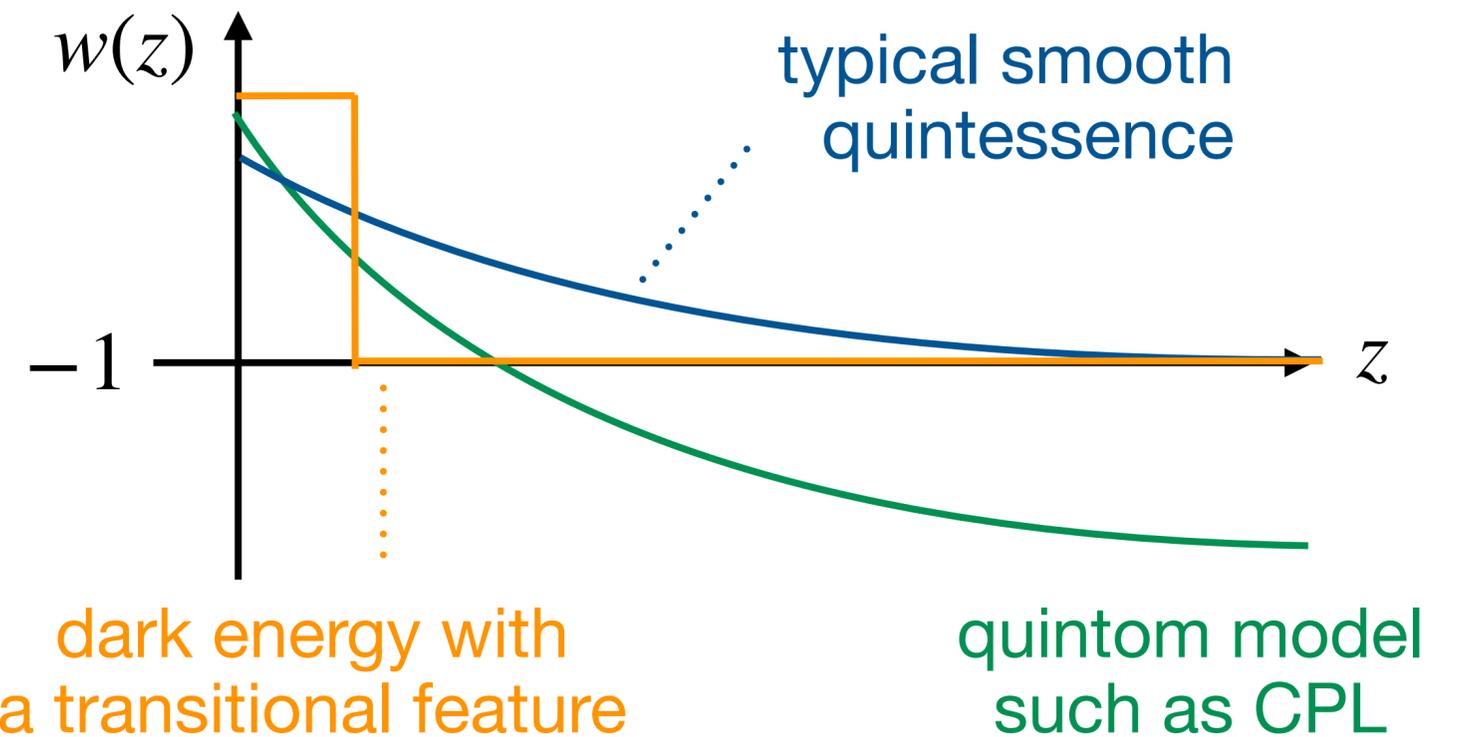
Phenomenological Possibilities

Observational constraints

modified version of
[Lodha et al., DESI DR2 dark energy, 2503.14743]



Phenomenological modeling



We consider **non-phantom** models in this talk.

Transitional VS Smooth Dark Energy

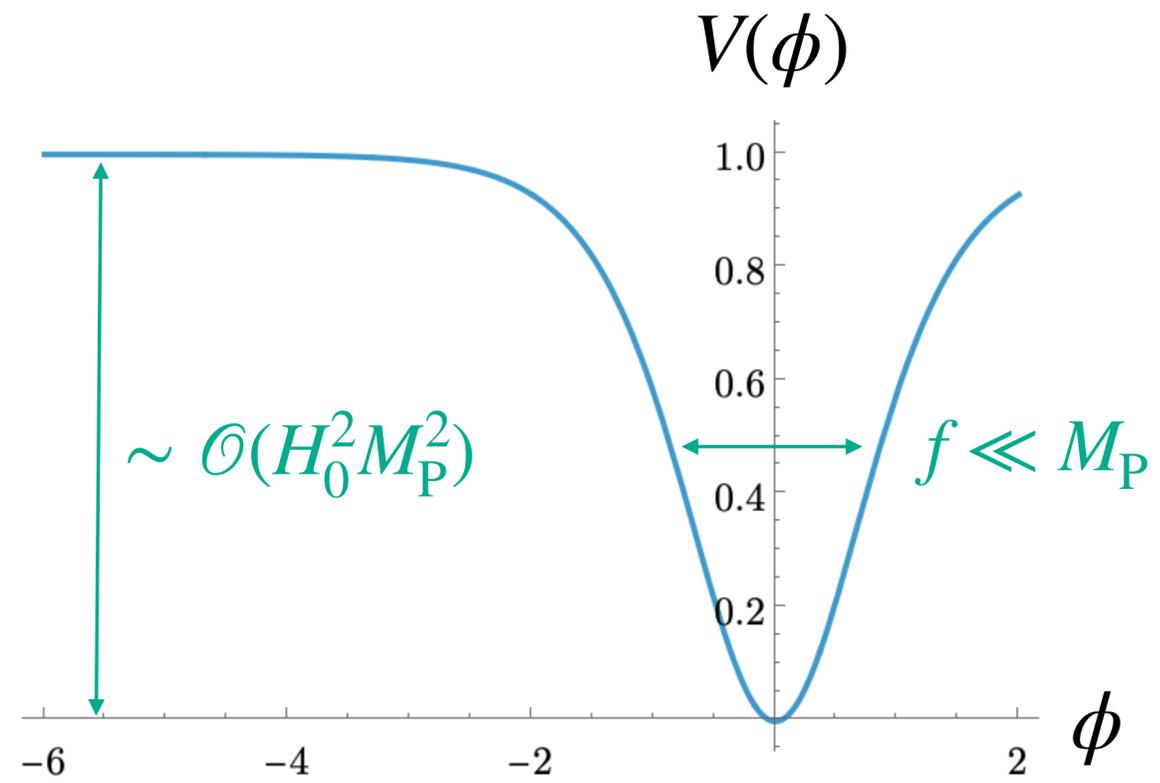
[Dutta, Scherrer, 0809.4441]
[Chiba, 0902.4037]

TABLE III. 68% CL posterior for each DE model

Parameters	TDE			DSCh		
	DES Y5	PantheonPlus	Union3	DES Y5	PantheonPlus	Union3
w_0	$-0.32^{+0.18}_{-0.61}$	$-0.54^{+0.21}_{-0.51}$	$-0.548^{+0.076}_{-0.40}$	> 0.00415	$-0.18^{+0.32}_{-0.71}$	$0.12^{+0.82}_{-0.34}$
a_t or K	$0.913^{+0.062}_{-0.0054}$	> 0.853	$0.861^{+0.10}_{-0.032}$	$14.8^{+5.5}_{-4.5}$	> 15.5	$12.0^{+3.1}_{-6.1}$
$\Omega_b h^2$	0.02255 ± 0.00013	0.02255 ± 0.00013	0.02256 ± 0.00013	0.02255 ± 0.00013	0.02254 ± 0.00013	0.02255 ± 0.00013
$\Omega_c h^2$	0.11760 ± 0.00066	0.11766 ± 0.00068	0.11752 ± 0.00068	0.11764 ± 0.00065	0.11767 ± 0.00064	0.11758 ± 0.00067
$100\theta_{MC}$	1.04122 ± 0.00028	1.04121 ± 0.00028	1.04123 ± 0.00028	1.04121 ± 0.00028	1.04122 ± 0.00028	1.04122 ± 0.00028
$\log(10^{10} A_s)$	$3.054^{+0.014}_{-0.016}$	$3.054^{+0.014}_{-0.015}$	3.054 ± 0.015	3.054 ± 0.015	3.053 ± 0.015	$3.054^{+0.014}_{-0.016}$
n_s	0.9709 ± 0.0033	0.9708 ± 0.0034	0.9711 ± 0.0034	0.9708 ± 0.0034	0.9707 ± 0.0034	0.9710 ± 0.0034
τ	$0.0611^{+0.0067}_{-0.0078}$	$0.0611^{+0.0066}_{-0.0078}$	$0.0615^{+0.0070}_{-0.0079}$	0.0611 ± 0.0074	$0.0610^{+0.0068}_{-0.0078}$	$0.0614^{+0.0067}_{-0.0079}$
$H_0 / (\text{km/s/Mpc})$	$65.97^{+0.88}_{-0.71}$	67.36 ± 0.74	65.8 ± 1.2	$65.89^{+0.59}_{-0.73}$	67.06 ± 0.66	$65.5^{+1.1}_{-1.3}$
$\Delta\chi^2$	-14.8	-3.66	-8.68	-15.4	-4.59	-7.26

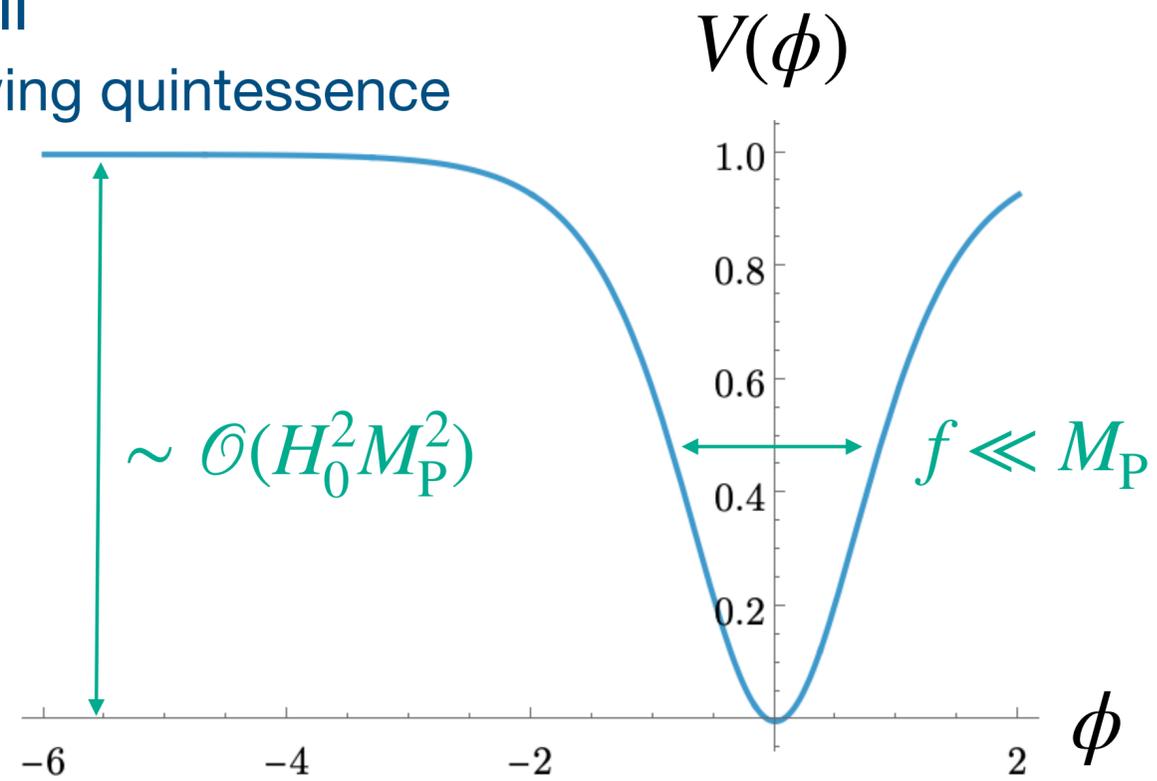
Their fitting qualities are comparable to each other.

Our Basic Idea

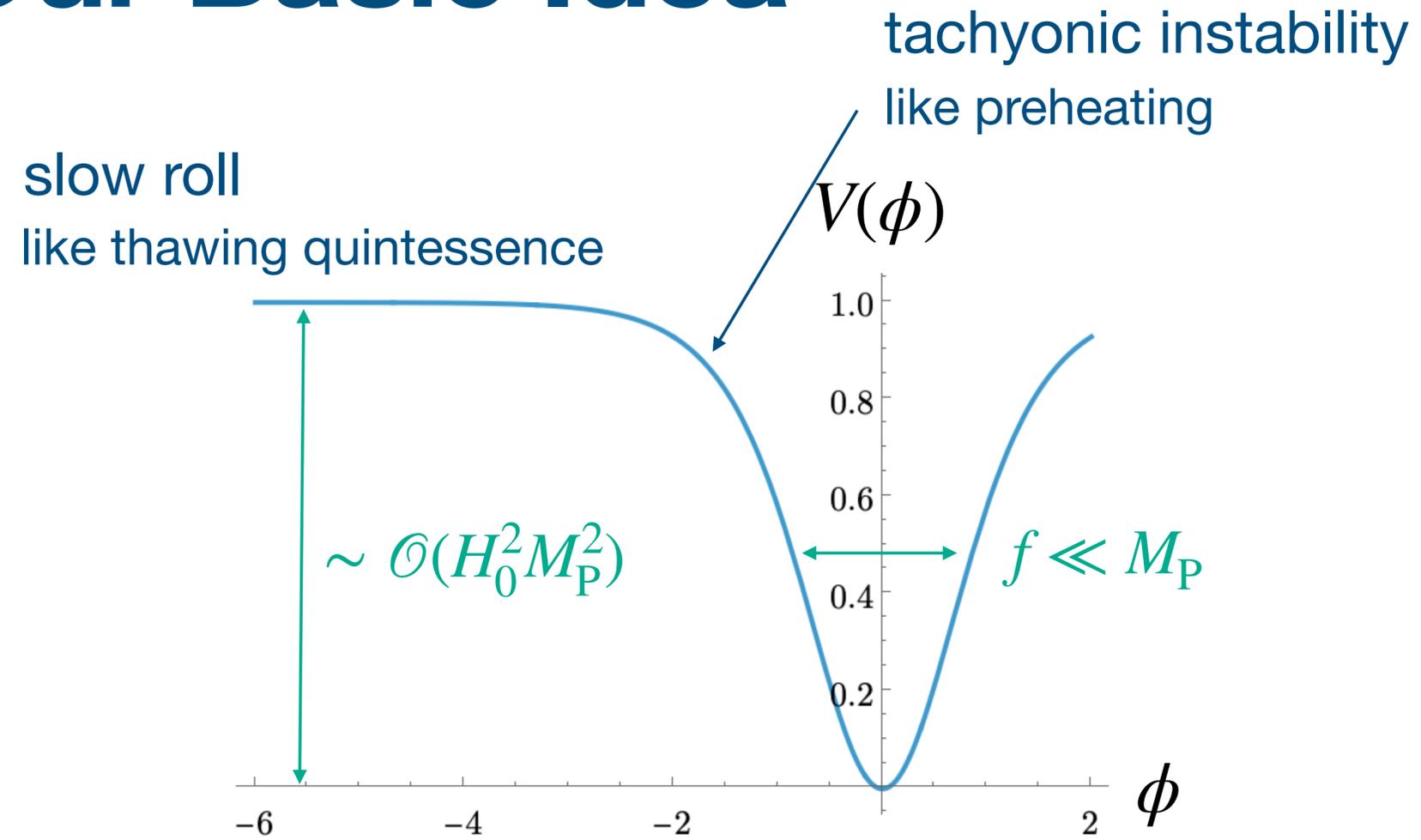


Our Basic Idea

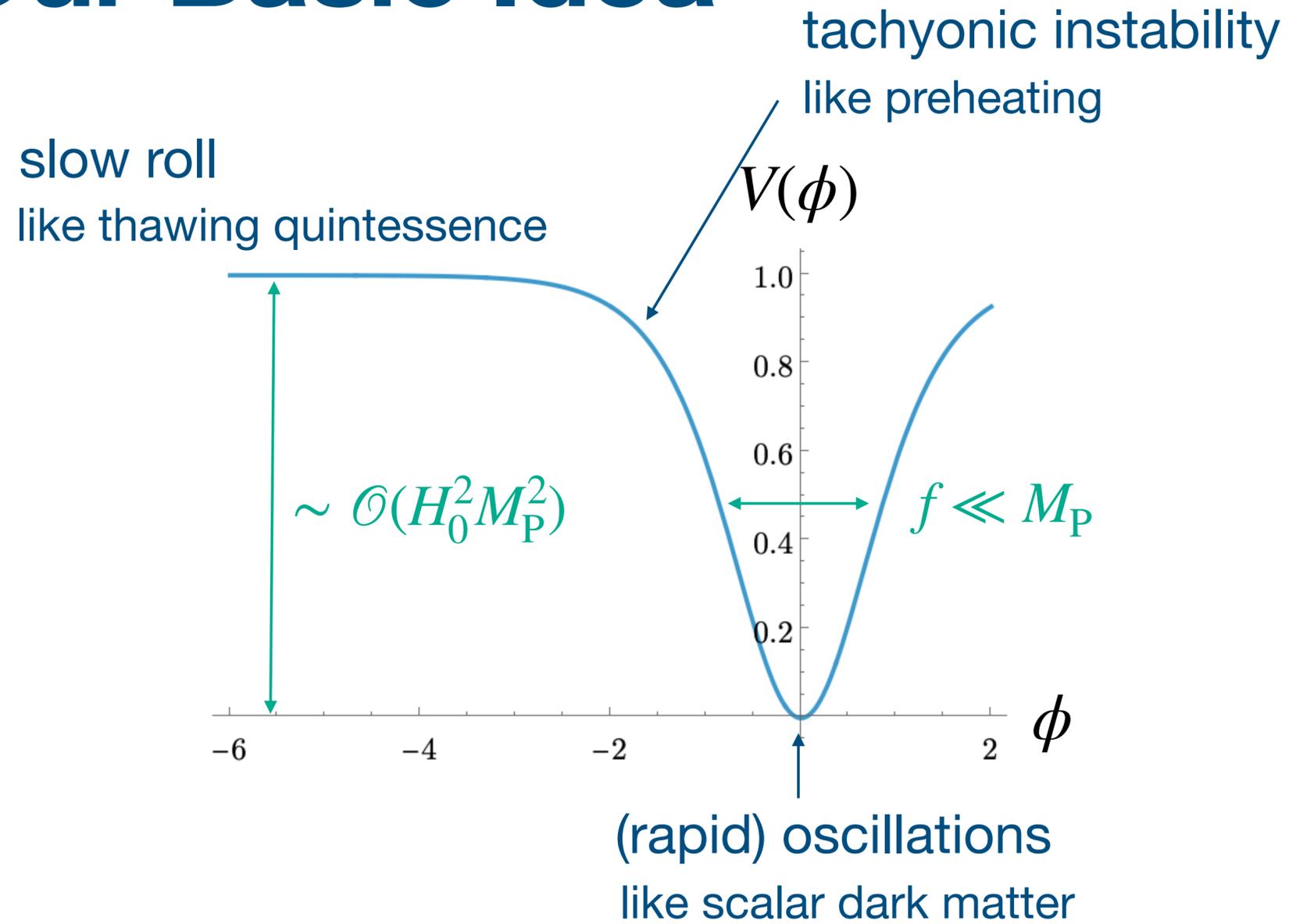
slow roll
like thawing quintessence



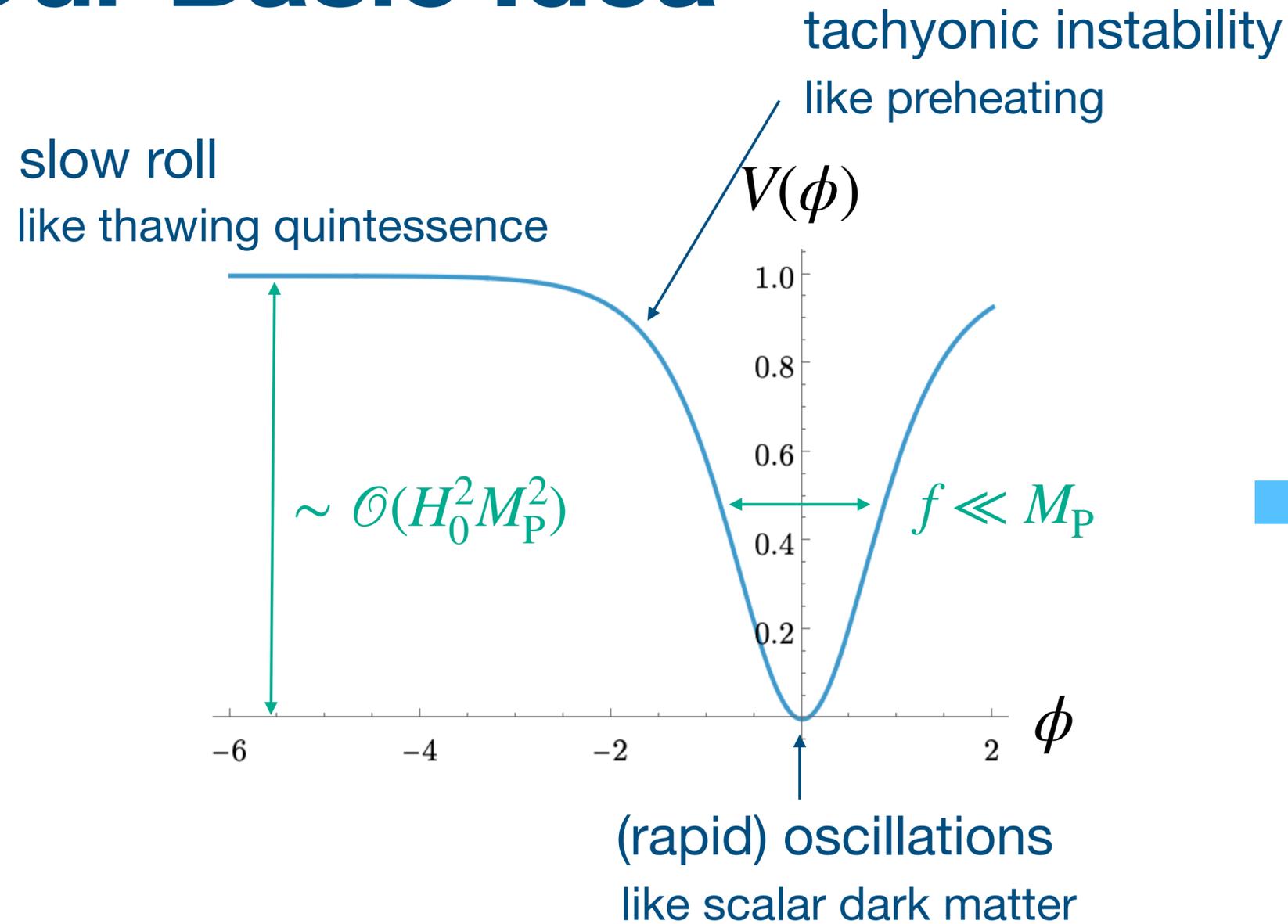
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Our Basic Idea



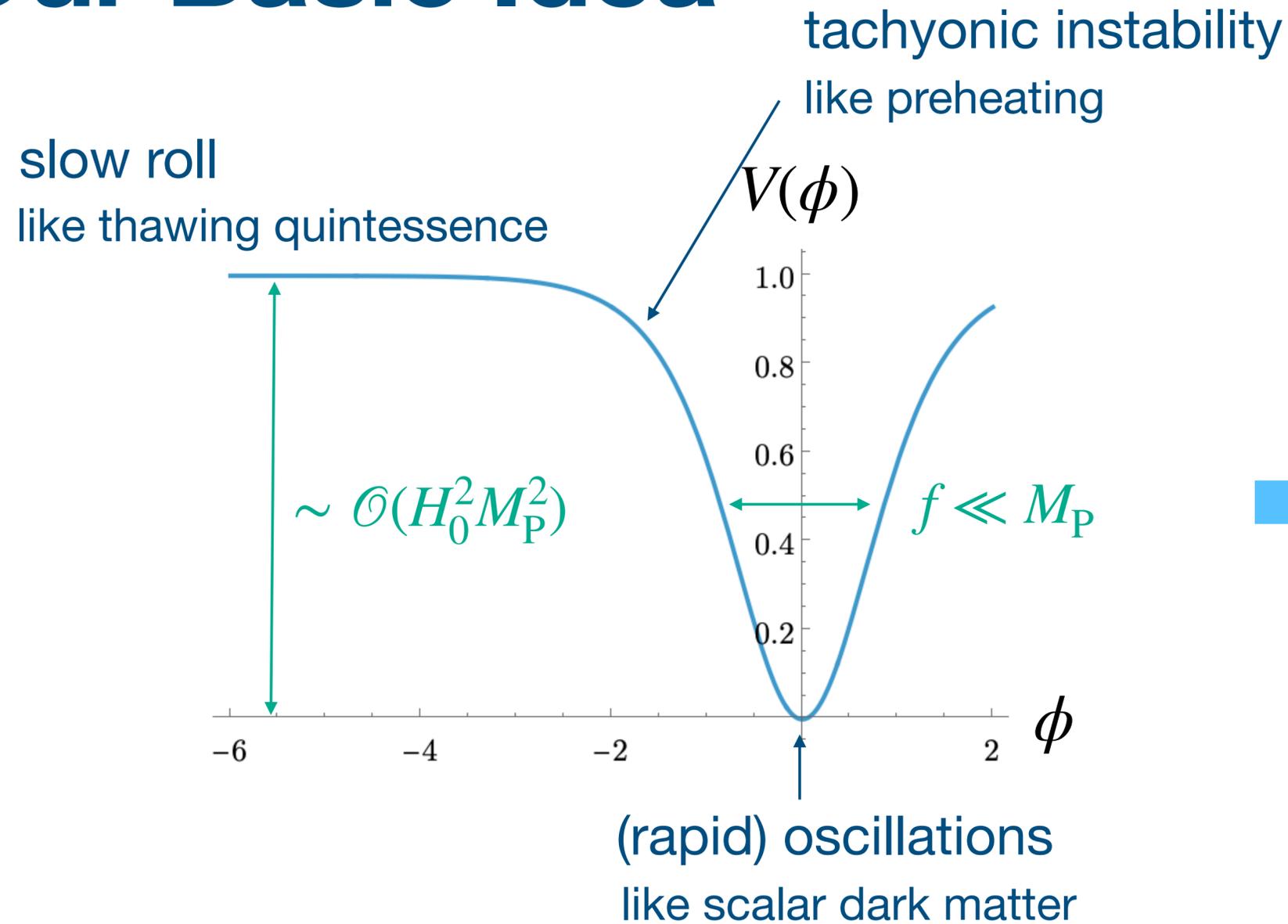
Our Basic Idea



Multiple Implications

- Transmutation of dark energy into dark matter
- Curvature perturbations
- Gravitational waves
- and perhaps more

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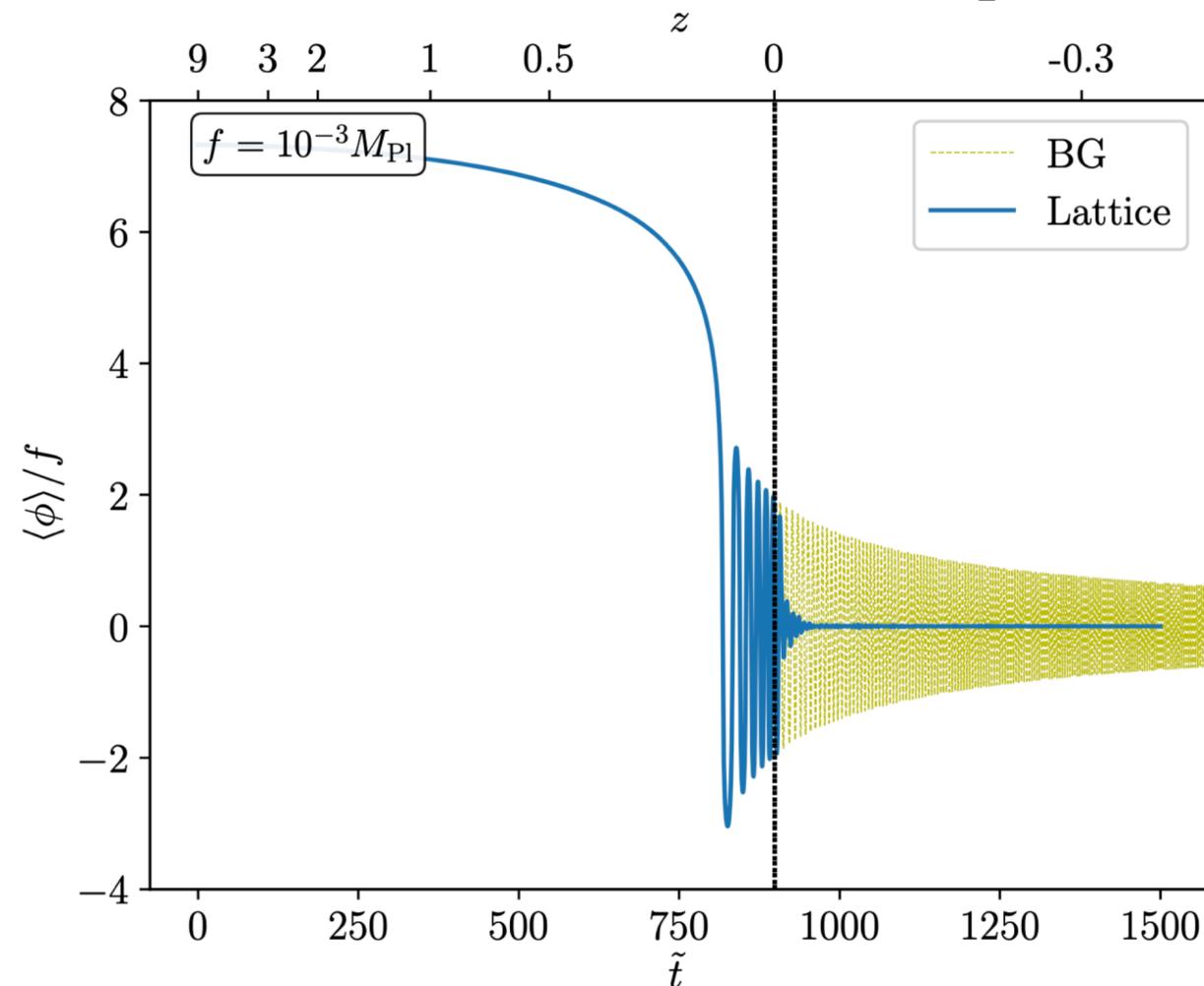
As a concrete example, we consider the following potential, $V(\phi) = V_0 \tanh^2(\phi/f)$, which appears in **approximately scale-invariant models**.

Approximate Realization of the Step Model

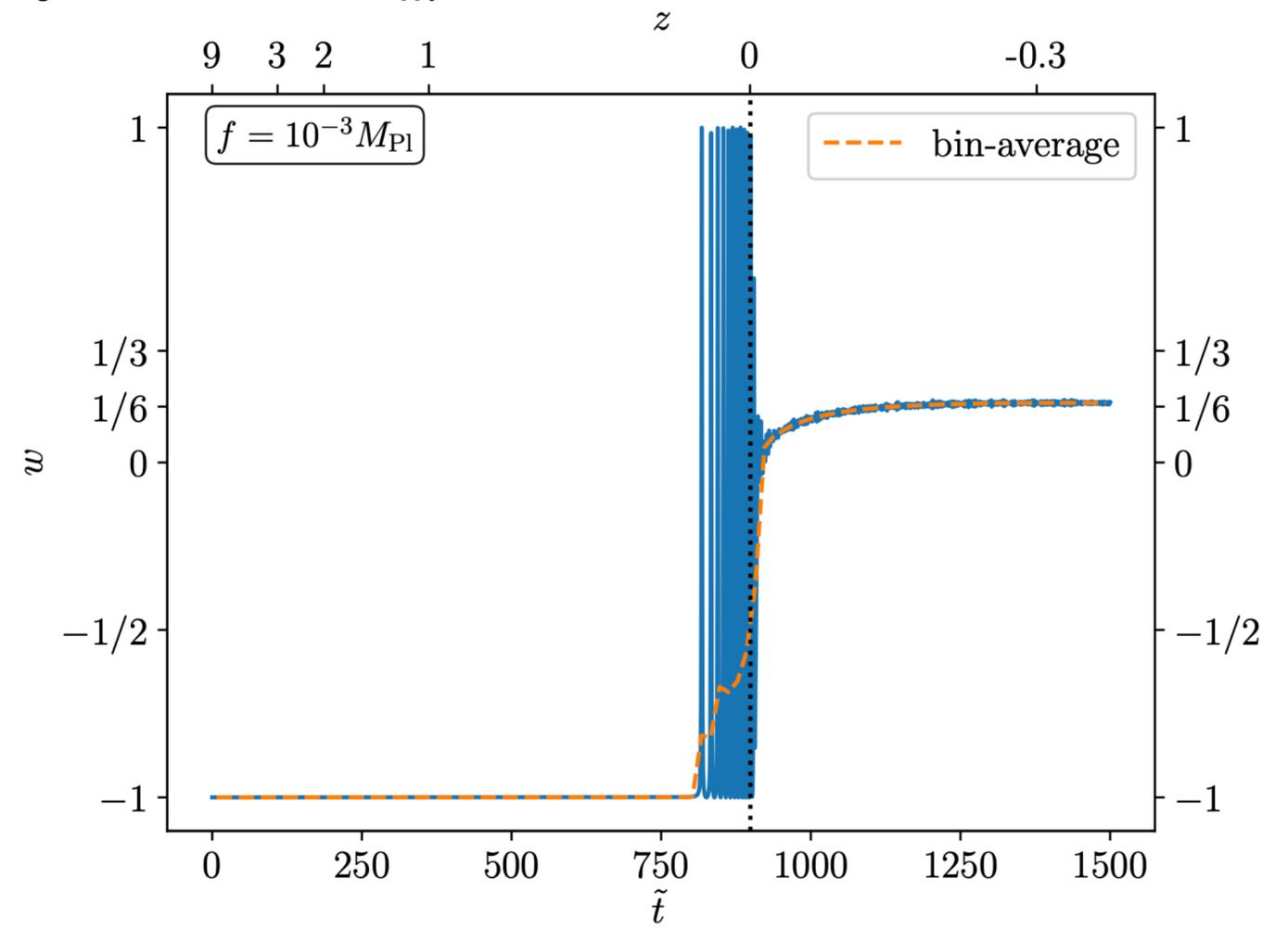
We use a classical lattice simulation program *CosmoLattice* to compute the nonlinear dynamics.

[Figuera, Florio, Torrenti, Valkenburg, 2006.15122; 2102.01031]

$$f = 10^{-3} M_{\text{Pl}}, \quad N = 256, \quad h_0 = 0.66, \quad \Omega_m = 0.32$$

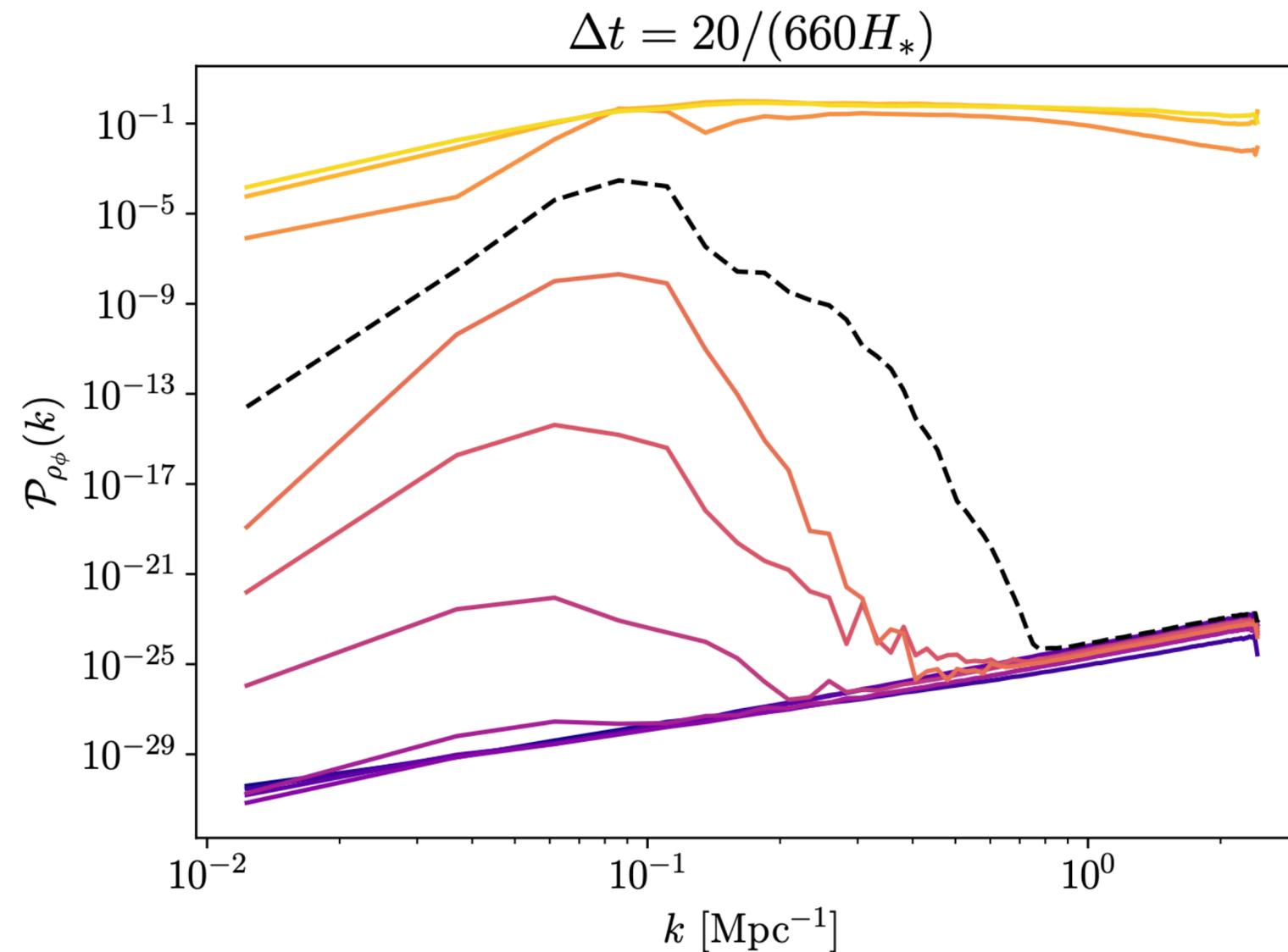
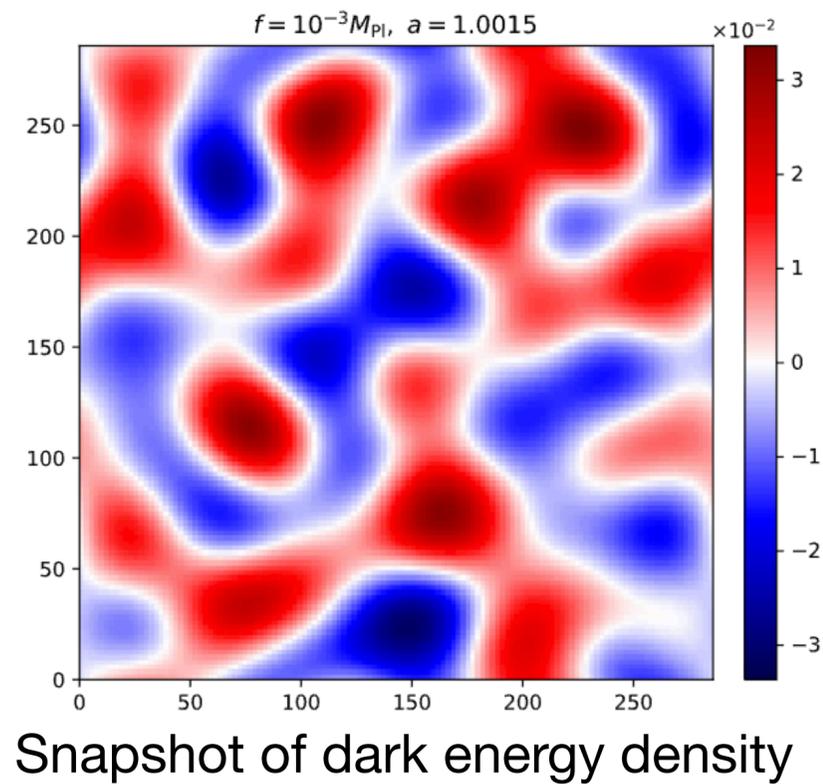


Time evolution of the spatial average of the dark energy field



Time evolution of the (time-averaged) equation-of-state (EoS) parameter

Dark Energy Density Perturbations



$$f = 10^{-3} M_{\text{P}}$$

peak wavenumber:

$$k_{\text{peak}} / a \approx 3.54 / T$$

half period:

$$T \approx \frac{\pi f}{\sqrt{2(V_0 - \rho)}}$$

[Tomberg, Veermäe, 2108.10767]

Dark Energy Perturbations Gravitationally Affect CMB

$$f = 10^{-3.25} M_P$$

Multipole moment of the transfer function of the temperature perturbations due to the **ISW effect**

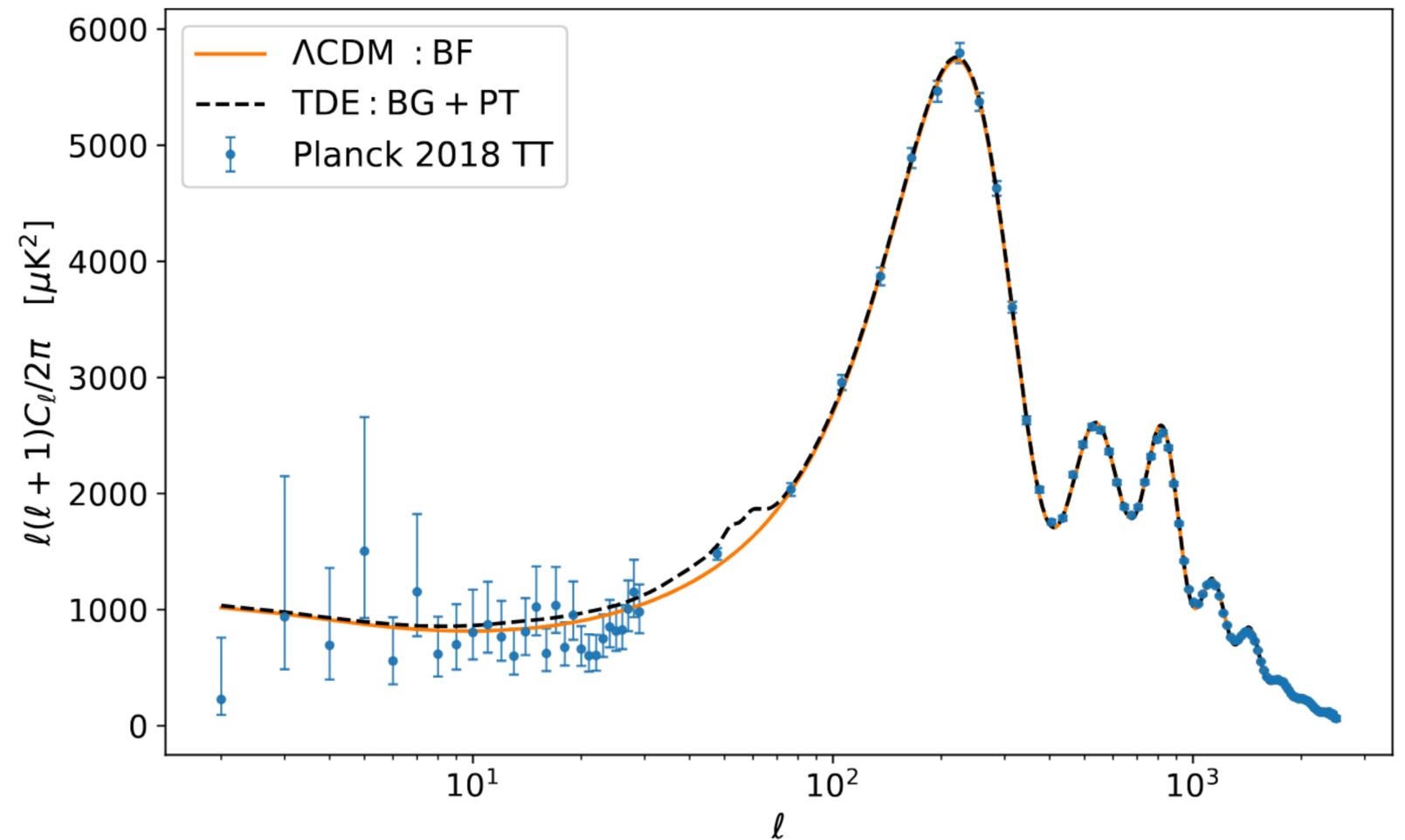
[Seljak, Zaldarriaga, astro-ph/9603033]

$$\Delta_{T,\ell}^{(S)}(k, \tau = \tau_0) \simeq \int_0^{\tau_0} d\tau (\dot{\Phi} + \dot{\Psi}) j_\ell(k(\tau_0 - \tau))$$

Combining it with the primordial power spectrum $P_\psi(k)$,

Multipole moment of the temperature perturbations is

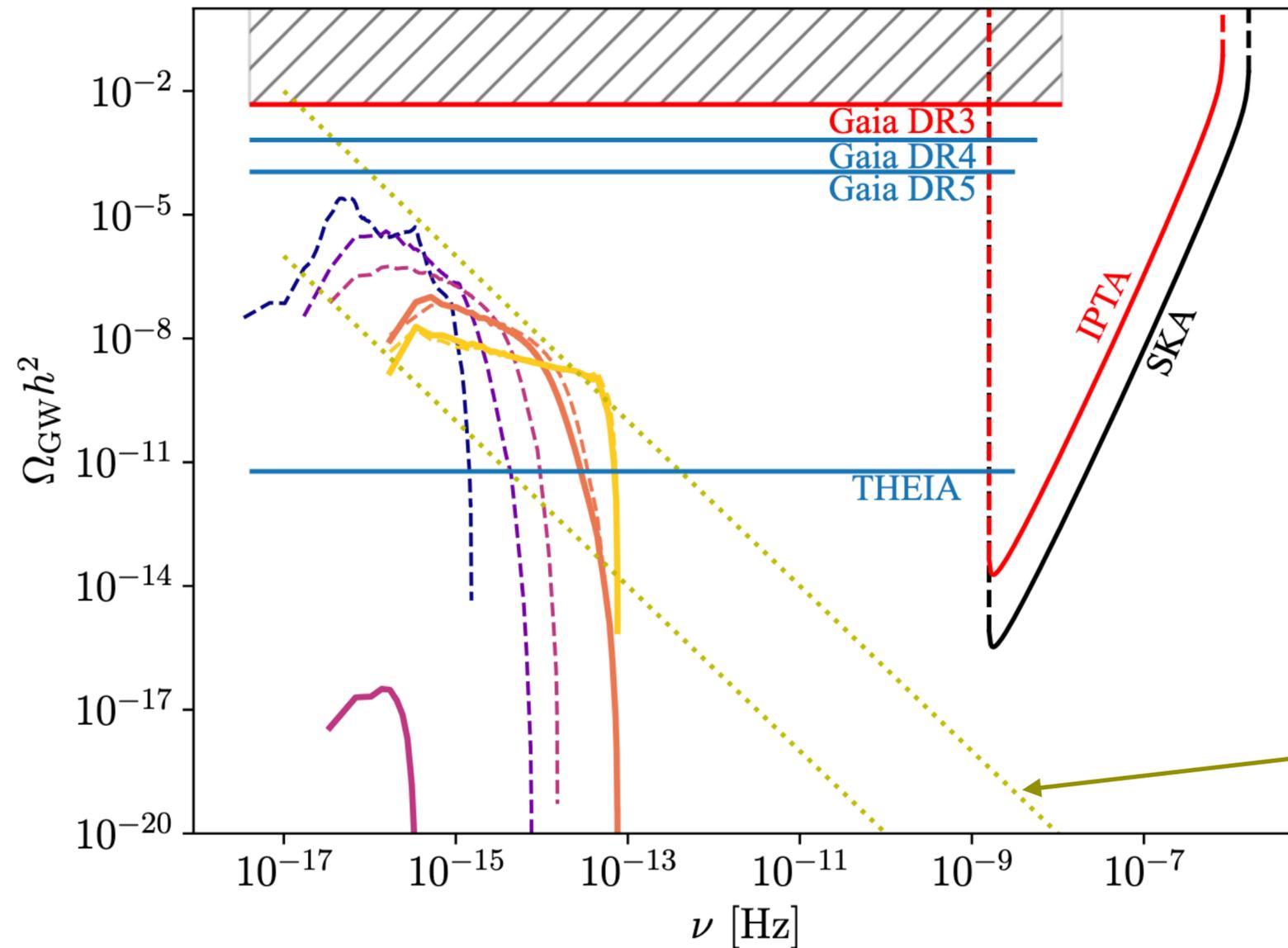
$$C_\ell^{(S)} = (4\pi)^2 \int dk k^2 P_\psi(k) |\Delta_{T,\ell}^{(S)}(k, \tau = \tau_0)|^2$$



Power spectrum of temperature perturbations

Observably large effects!

Dark Energy Particles Induce Gravitational Waves



Dimensional analysis
for the peak position

$$h(\nu_{\text{peak}}) \sim \frac{\rho_{\text{DE}}}{\nu_{\text{peak}}^2 M_{\text{P}}^2} \sim \frac{H_0^2}{\nu_{\text{peak}}^2}$$

$$\Omega_{\text{GW}}(\nu_{\text{peak}}) \sim \frac{\nu_{\text{peak}}^2 h(\nu_{\text{peak}})^2}{H_0^2}$$

$$\sim \frac{H_0^2}{\nu_{\text{peak}}^2}$$

Quasar astrometry can constrain the scenario in the future!

Other Observational Implications

- Gravitational effects of DE oscillations. (PTA constraints on ultralight scalar)
- Gravitational effects of DE inhomogeneity. (oscillons)
- GW-induced curl mode in weak gravitational lensing. (CMB & LSS)
- Violation of the consistency relations for correlation functions. (LSS)
- Effects on black holes. (superradiance; modified BBH merger signals)
- Cosmic birefringence and astrophysical constraints in extended models.
- Any implications for cosmological tensions?

Summary

Summary

$\sim 3\sigma$ evidence of dynamical dark energy has been observed.

Models with *a sharp transitional feature* at $z \sim 0.1$ can also fit the observational data.

Preheating-like dynamics (tachyonic resonance) occur.

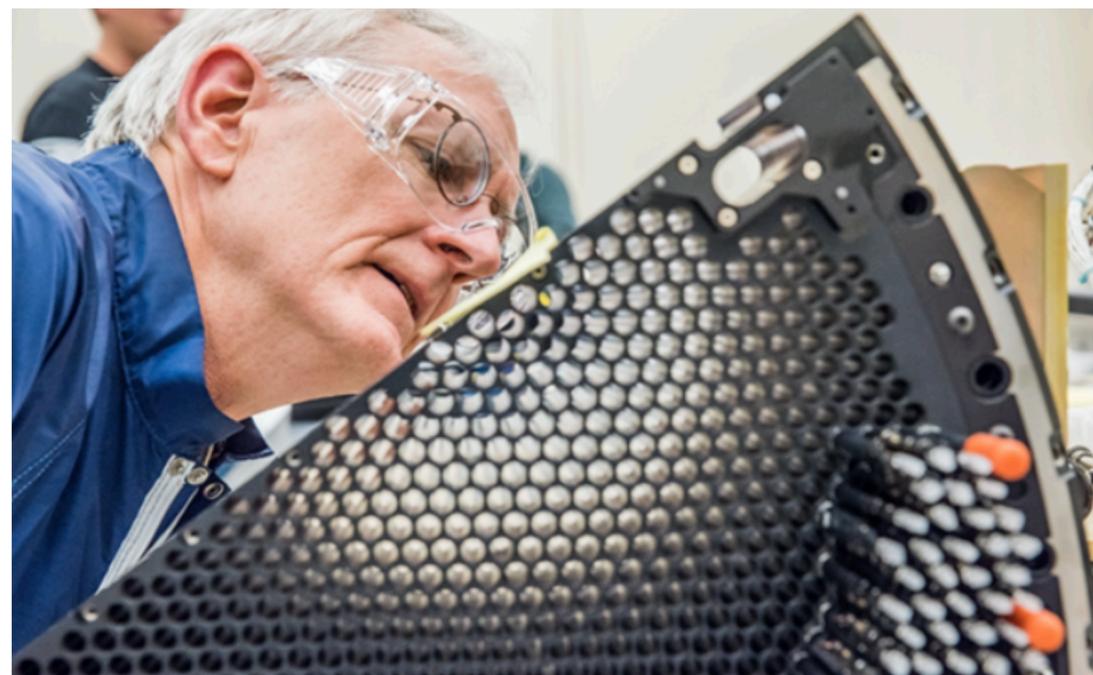
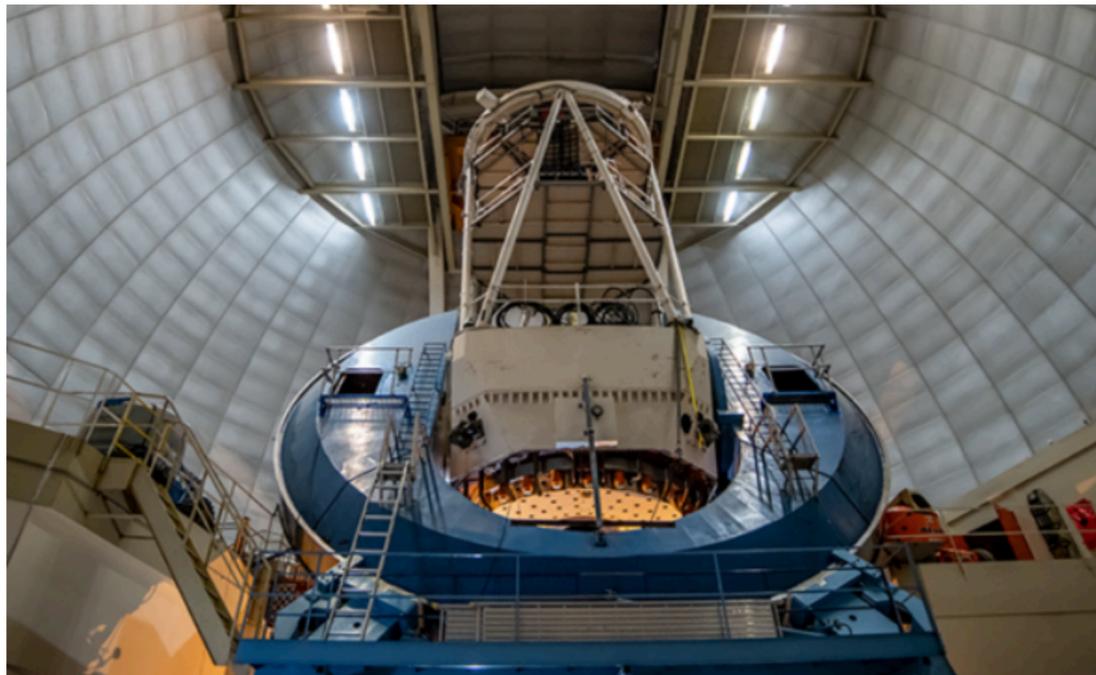
- Dark energy field **behaves like** (an additional component of) **dark matter**.
- Dark energy perturbations are explosively produced at very late time.
 - They gravitationally **affect the CMB**.
 - They produce the **stochastic GW background**.
- More cosmological signals to be explored.

Appendix

Dark Energy Spectroscopic Instrument



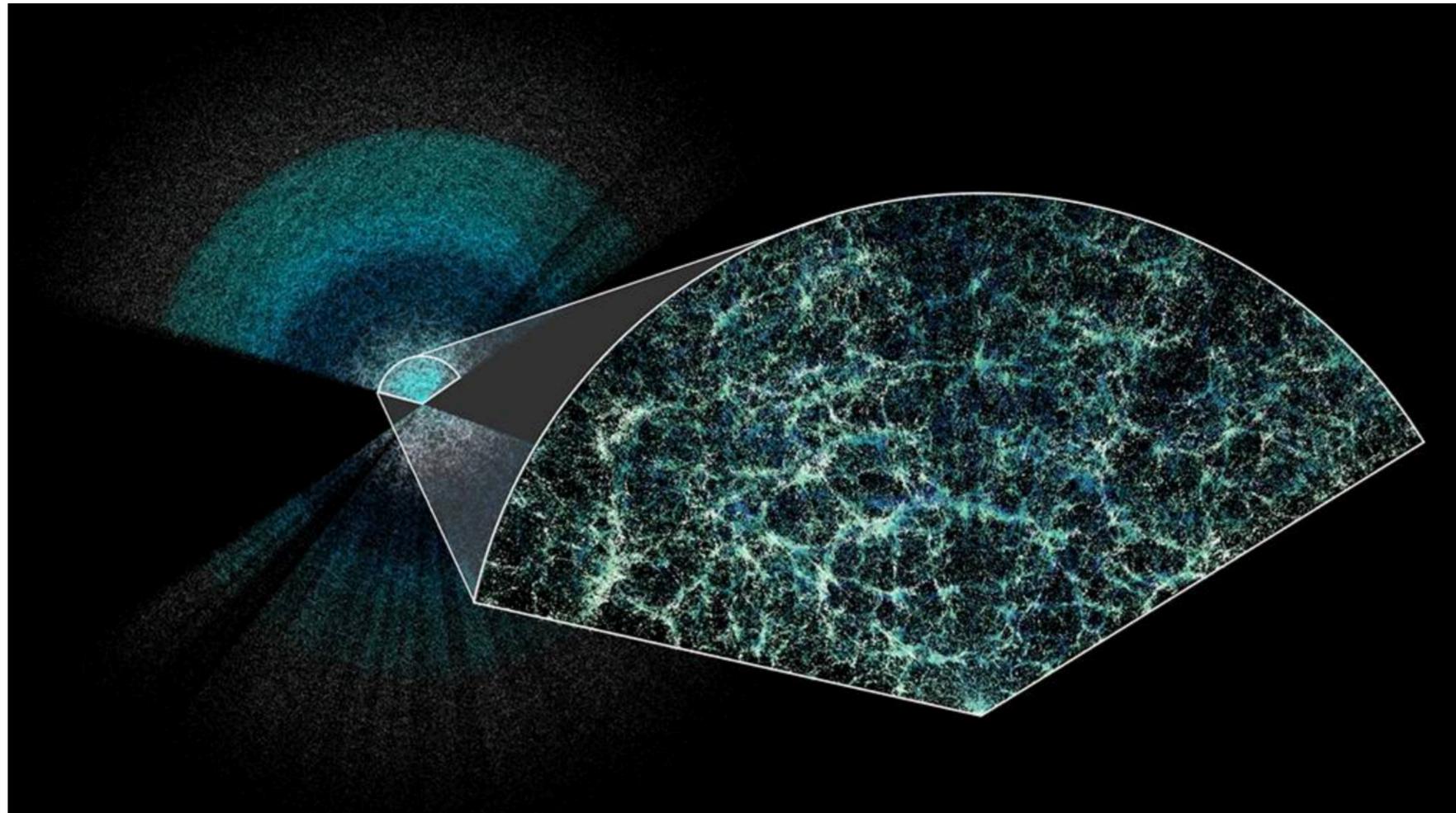
- 4m-aperture telescope in Arizona
- First cosmic observation at Stage 4
- 8 yr observations since 2021 (extended)
- Spectroscopy of 50+ million galaxies & quasars
- 5000 independent robotic optical fibers



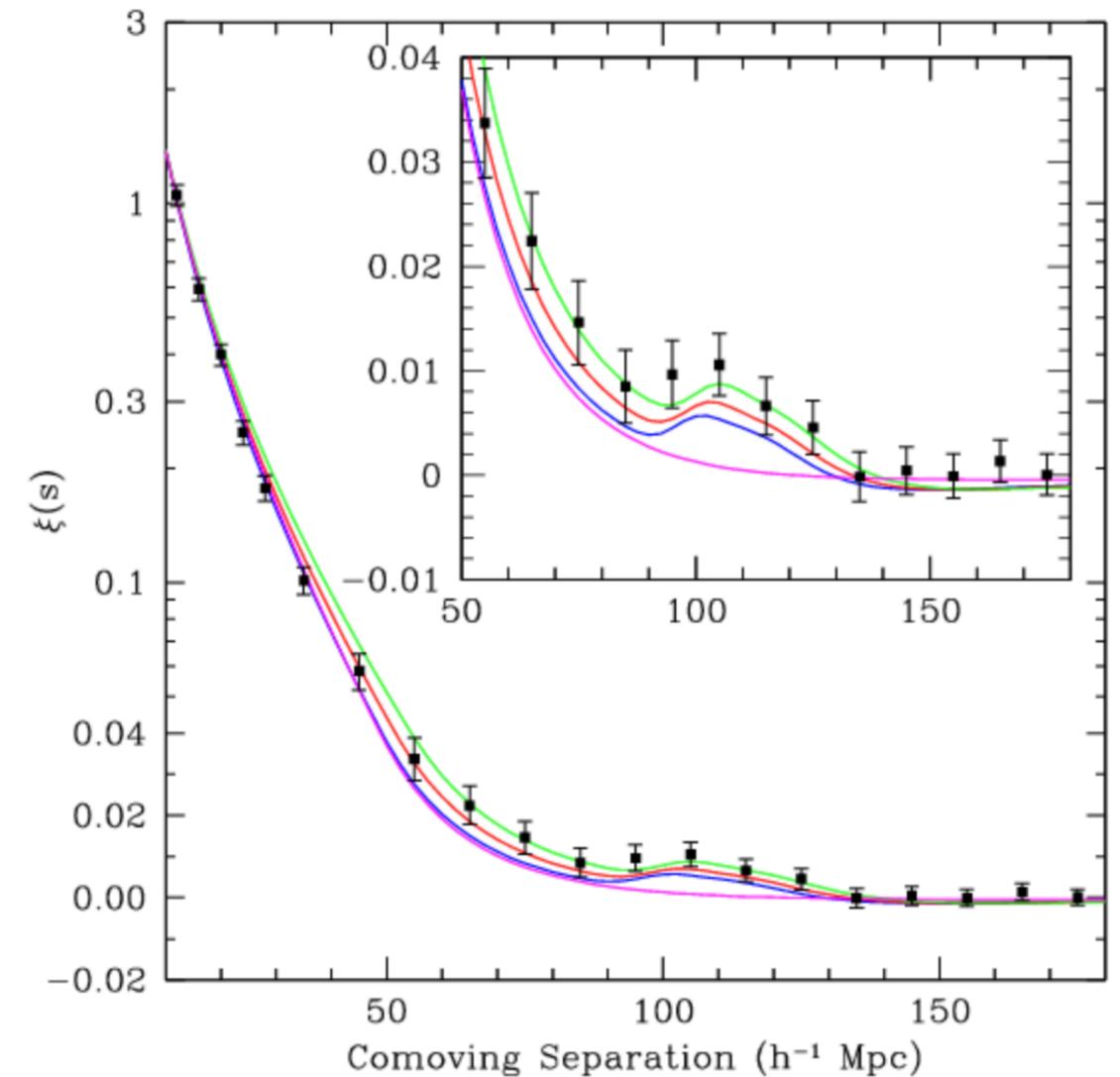
[Images from the web site of DESI]

Baryon Acoustic Oscillations (BAO)

Typical scale of perturbations in the mixed photon-baryon fluid → Typical scale between galaxies



[Courtesy: Claire Lamman/DESI collaboration/custom colormap package by cmastro]



[Eisenstein et al. (SDSS), astro-ph/0501171]

Cosmic History from BAO

$$D_M(z) = \frac{c}{H_0 \sqrt{\Omega_K}} \sinh \left[\sqrt{\Omega_K} \int_0^\infty \frac{dz'}{H(z')/H_0} \right] = \frac{r_d}{\Delta\theta}$$

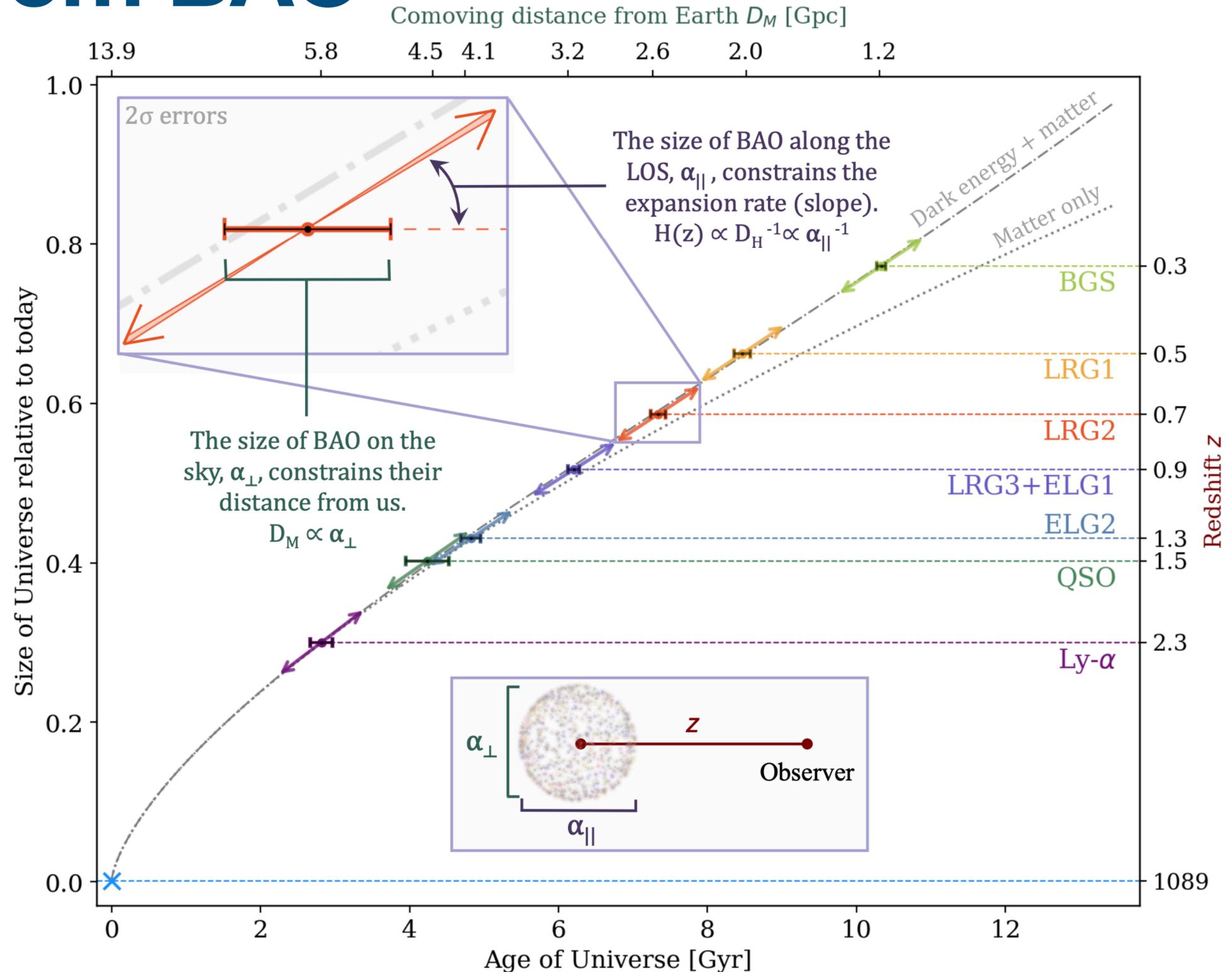
$$D_H(z) = \frac{c}{H(z)} = \frac{r_d}{\Delta z} \quad r_d = \int_{z_d}^\infty \frac{c_s(z)}{H(z)} dz \approx 147 \text{ Mpc}$$

$$D_V(z) = (z D_M(z)^2 D_H(z))^{1/3}$$

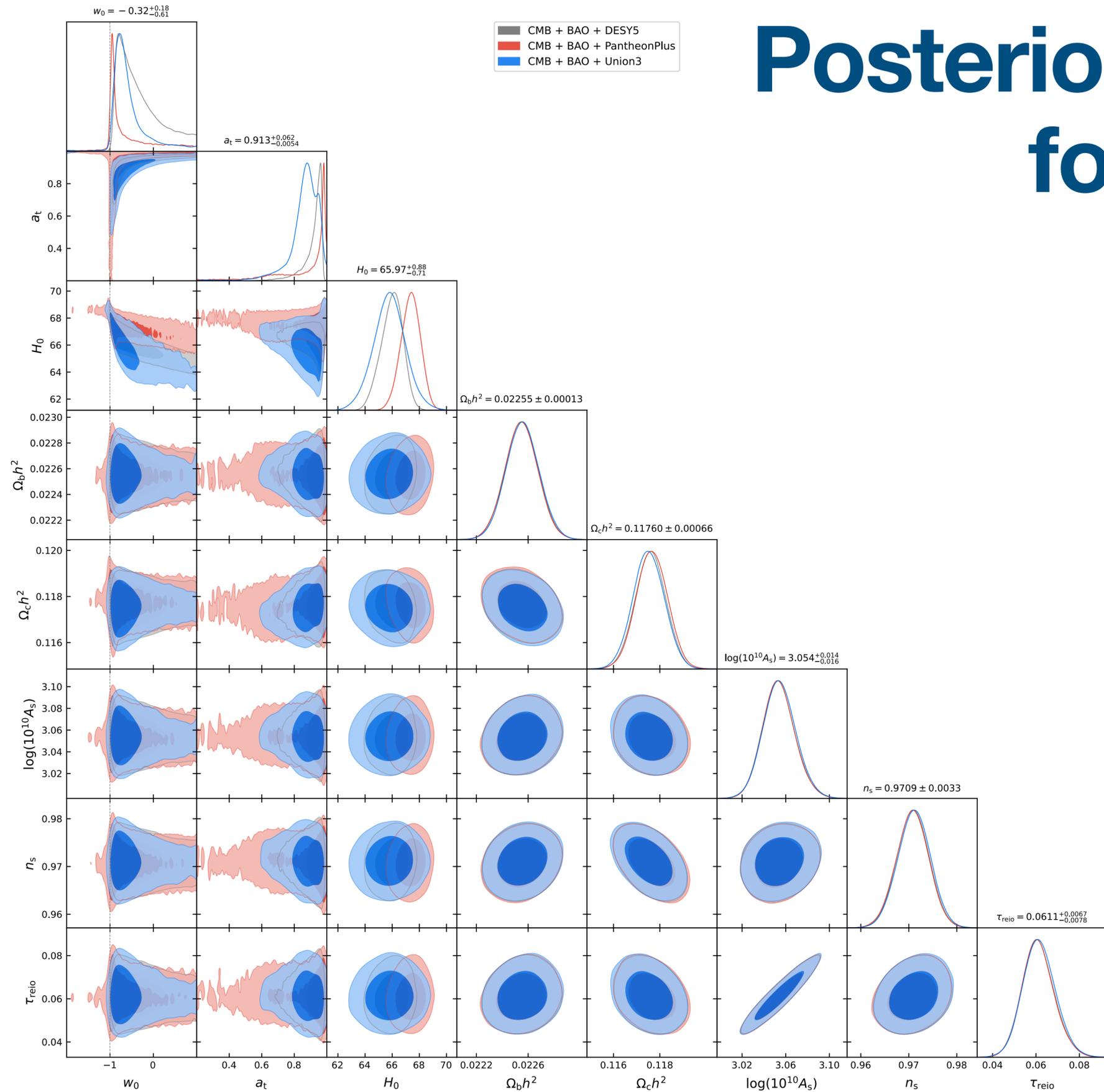
$$F_{AP} = \frac{D_M}{D_H}$$

[Adame et al., DESI 2024 VI, 2404.03002]

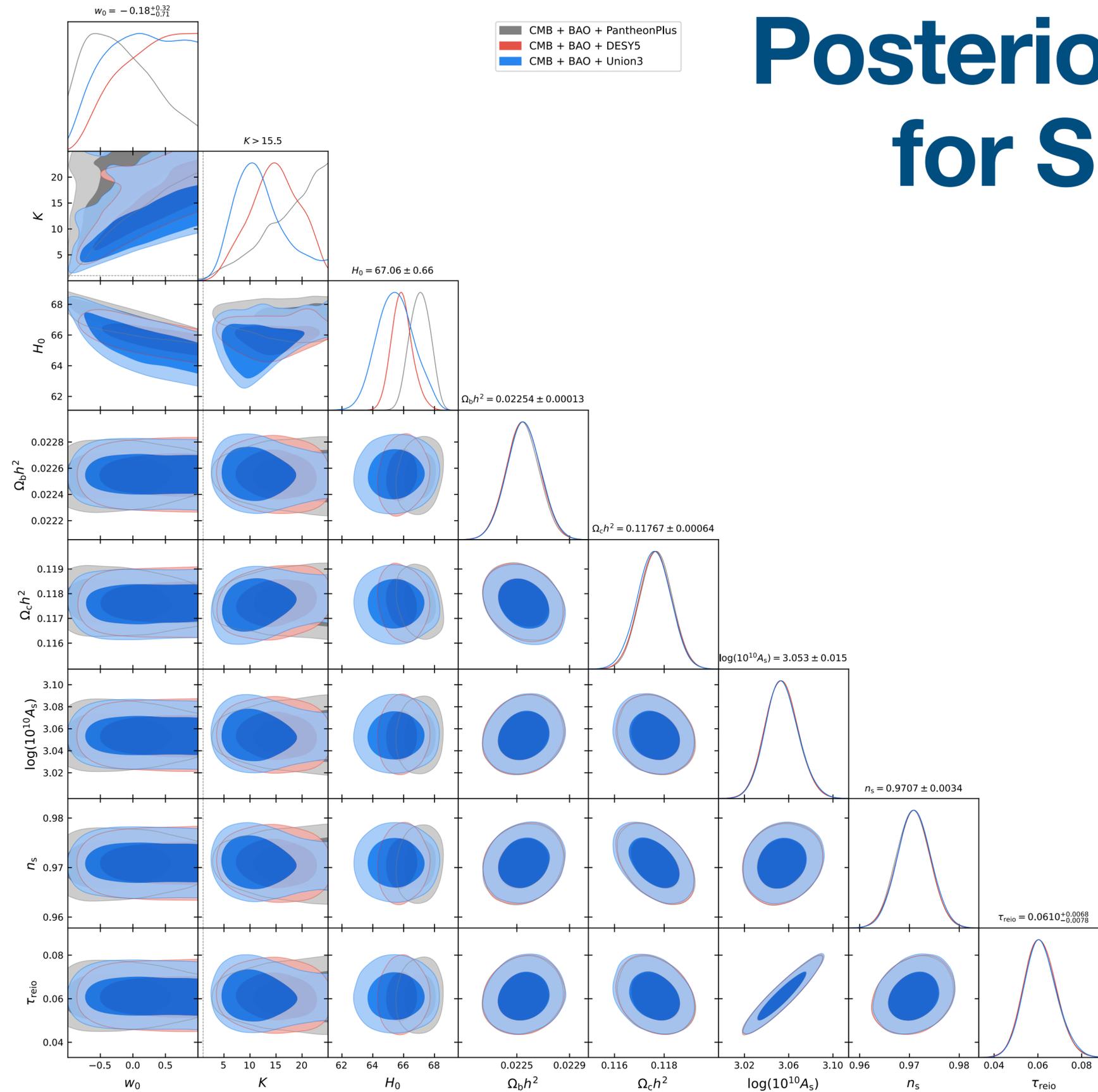
[Karim et al., DESI DR2 Results II, 2503.14738]



Posterior Distribution for Step Model

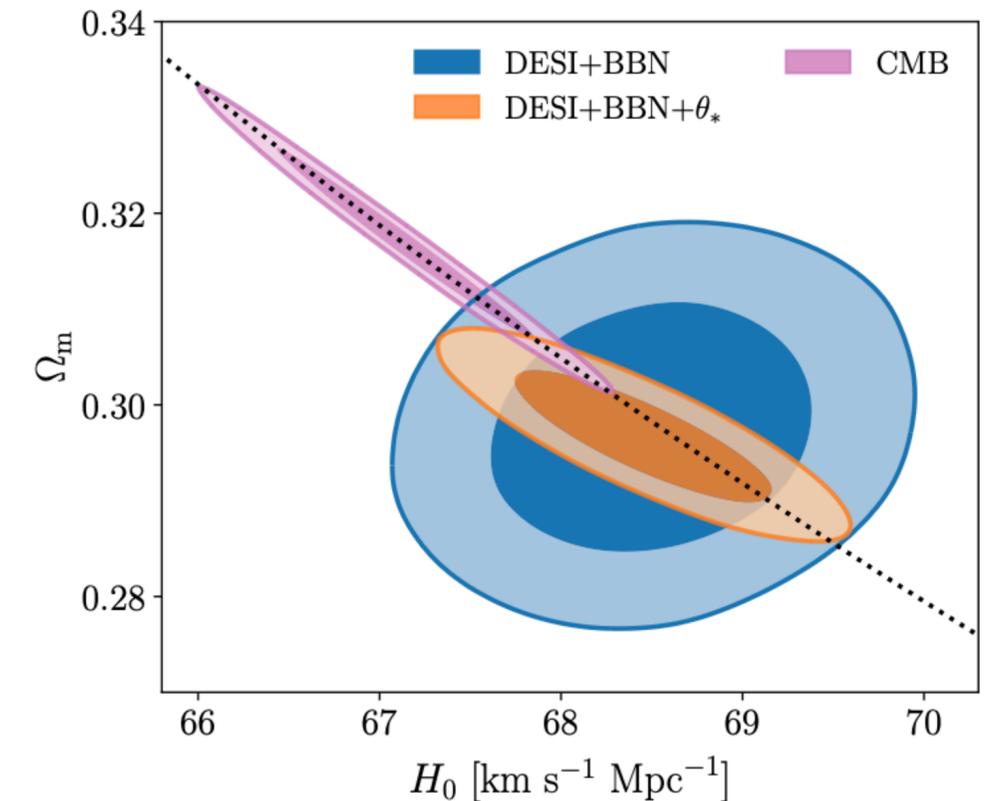


Posterior Distribution for Smooth Model



DESI Results History

- **DR1 BAO:** reported **evidence of dynamical dark energy** [Adame et al., DESI 2024 VI, 2404.03002]
- **DR1 full-shape:** similar results [Adame et al., DESI 2024 VII, 2411.12022]
- **DR2 BAO:** similar tendency with smaller uncertainties; **larger tension with CMB.** [Karim et al., DESI DR2 Results II, 2503.14738]
 - Still dominated by statistical uncertainties.
 - An outlier at $z \approx 0.5$ in DR1 BAO is now closer to Λ CDM.



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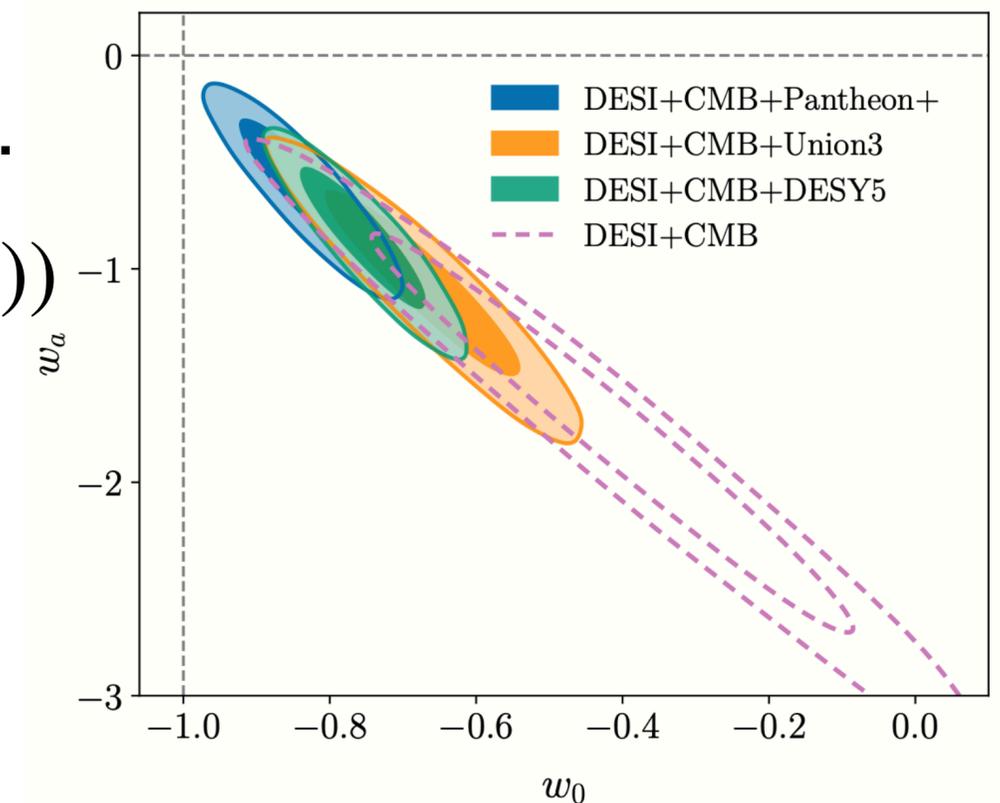
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Analyses with $w_0 w_a$ CDM model ($w(a) = w_0 + w_a(1 - a)$)

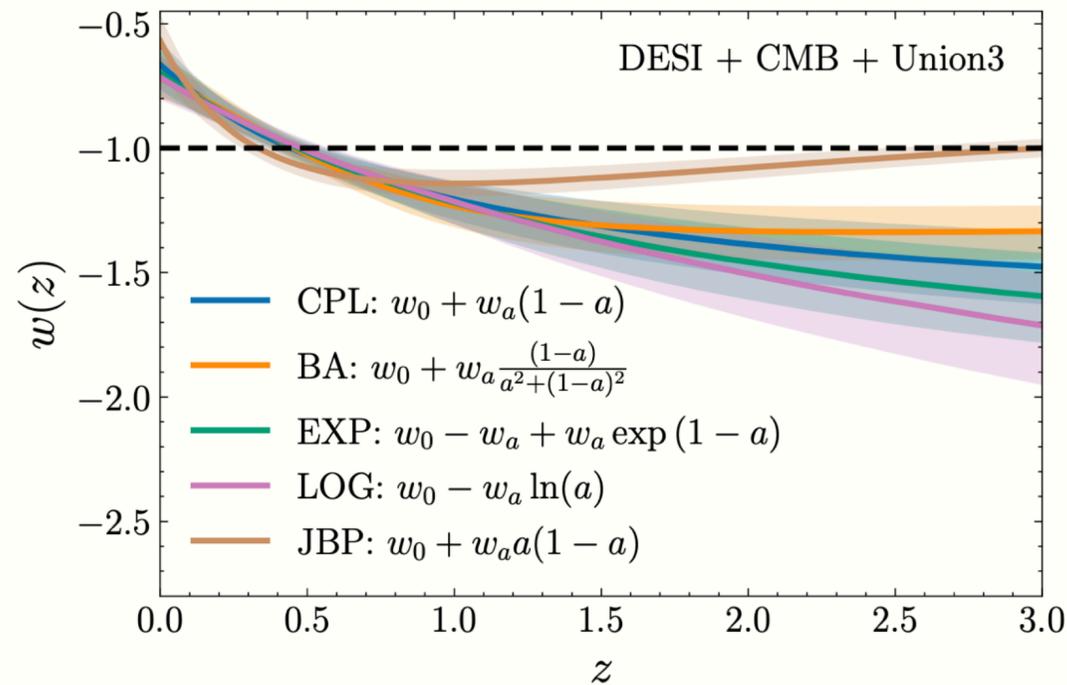
- **DESI+CMB (w/o SNe) gives 3.1σ .**
- With SNe,
2.8 σ (Pantheon+), 3.8 σ (Union3), 4.2 σ (DES-Y5).
- DESI+SNe fitting **automatically fits CMB** as well.



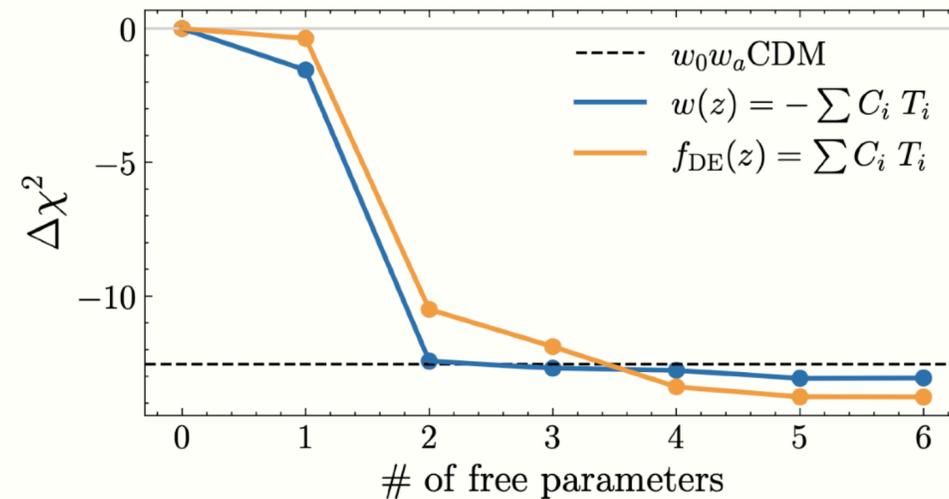
Dynamical Dark Energy

[Lodha et al., DESI DR2 dark energy, 2503.14743]

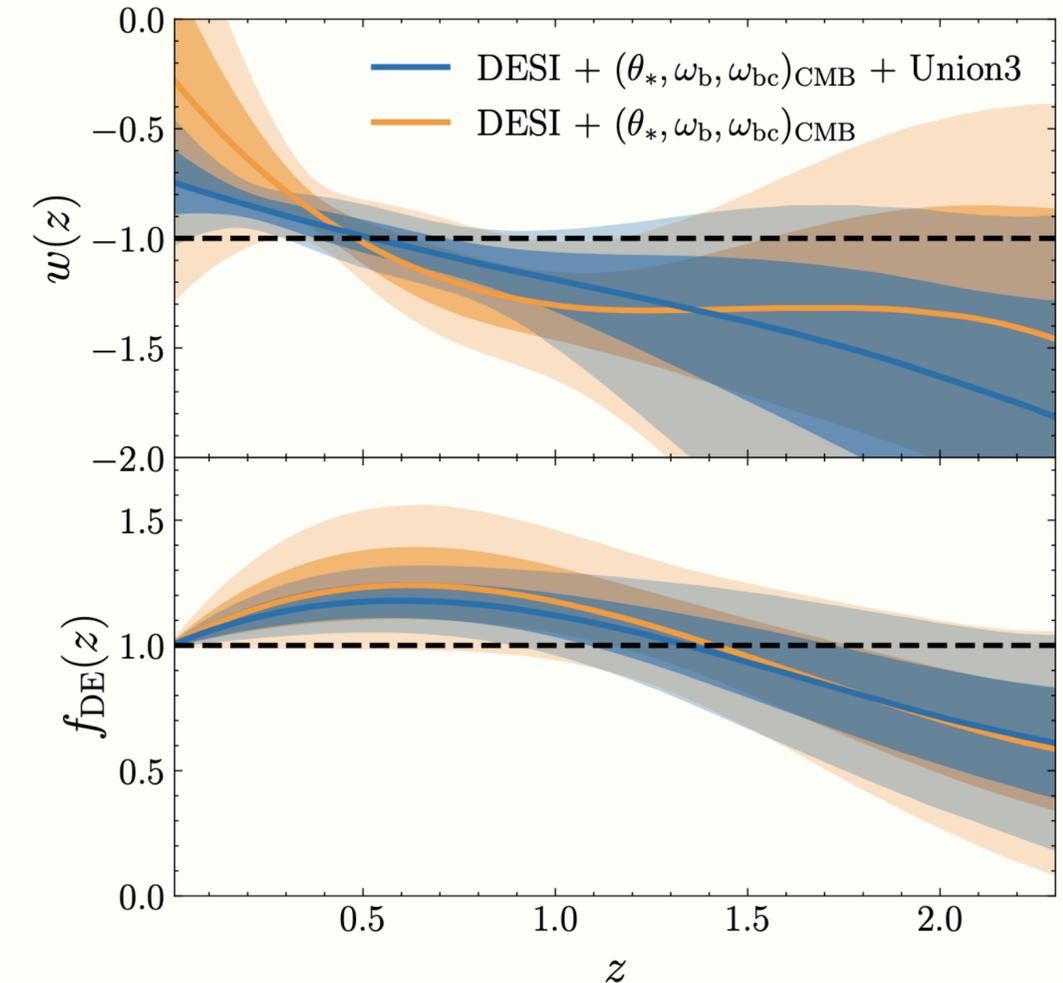
Equation of State $P = w\rho \rightarrow \rho \propto a^{-3(1+w)}$



Not only CPL ($w_0 w_a$ CDM) but various 2-parameter models favor the phantom ($w < -1$) regime.
Large uncertainty at high-z.



Fits are not significantly improved with more than 2 parameters.



Fit by cubic Chebyshev polynomials.
Large uncertainty at high-z.

Phantom or Not?

$$w = \frac{\langle \frac{1}{2} \dot{\phi}^2 - \frac{1}{6} (\nabla \phi)^2 - V \rangle}{\langle \frac{1}{2} \dot{\phi}^2 + \frac{1}{2} (\nabla \phi)^2 + V \rangle} \geq -1$$

The standard scalar field (classically) satisfies the **Null Energy Condition (NEC)**.

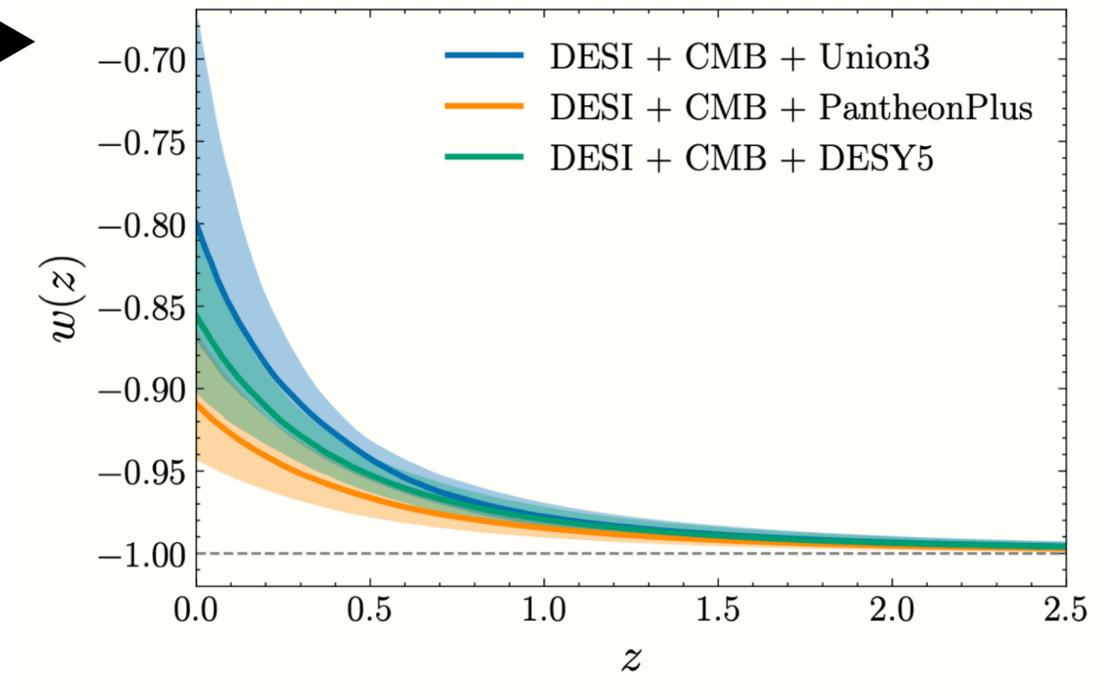
A natural explanation is given by the **thawing quintessence**.

Smooth time evolution from smooth scalar potential ►

DE classes	DESI+CMB: +PantheonPlus	+Union3	+DESY5
	$\Delta\text{DIC} (\Delta\chi^2)$		
Thaw. (Cal.)	+0.4 (-1.6)	-0.6 (-2.5)	-5.8 (-7.1)
Thaw. (Alg.)	-1.0 (-2.9)	-4.6 (-6.9)	-10.1 (-13.2)
Emergent	+2.1 (-0.05)	+1.8 (-0.1)	+0.2 (-1.5)
Mirage	-9.1 (-10.5)	-13.8 (-16.2)	-18.7 (-20.7)
$w_0 w_a$	-6.8 (-10.7)	-13.5 (-17.4)	-17.2 (-21.0)

better than ΛCDM , but worse than $w_0 w_a\text{CDM}$

* A more negative value is better.



Marginalized constraints in the case of the axion-like potential

$$V = m_a^2 f_a^2 [1 + \cos(\phi/f_a)]$$

Dark Energy with Transitional Feature

step model (our main focus)

$$w(a) = \begin{cases} -1 & (a < a_t) \\ w_0 & (a \geq a_t) \end{cases}$$



broken-linear model

$$w(a) = \begin{cases} -1 & (a < a_t) \\ -1 + (w_0 + 1) \frac{a - a_t}{1 - a_t} & (a \geq a_t) \end{cases}$$



[Gialamas, Hütsi, Kannike, et al., 2406.07533]

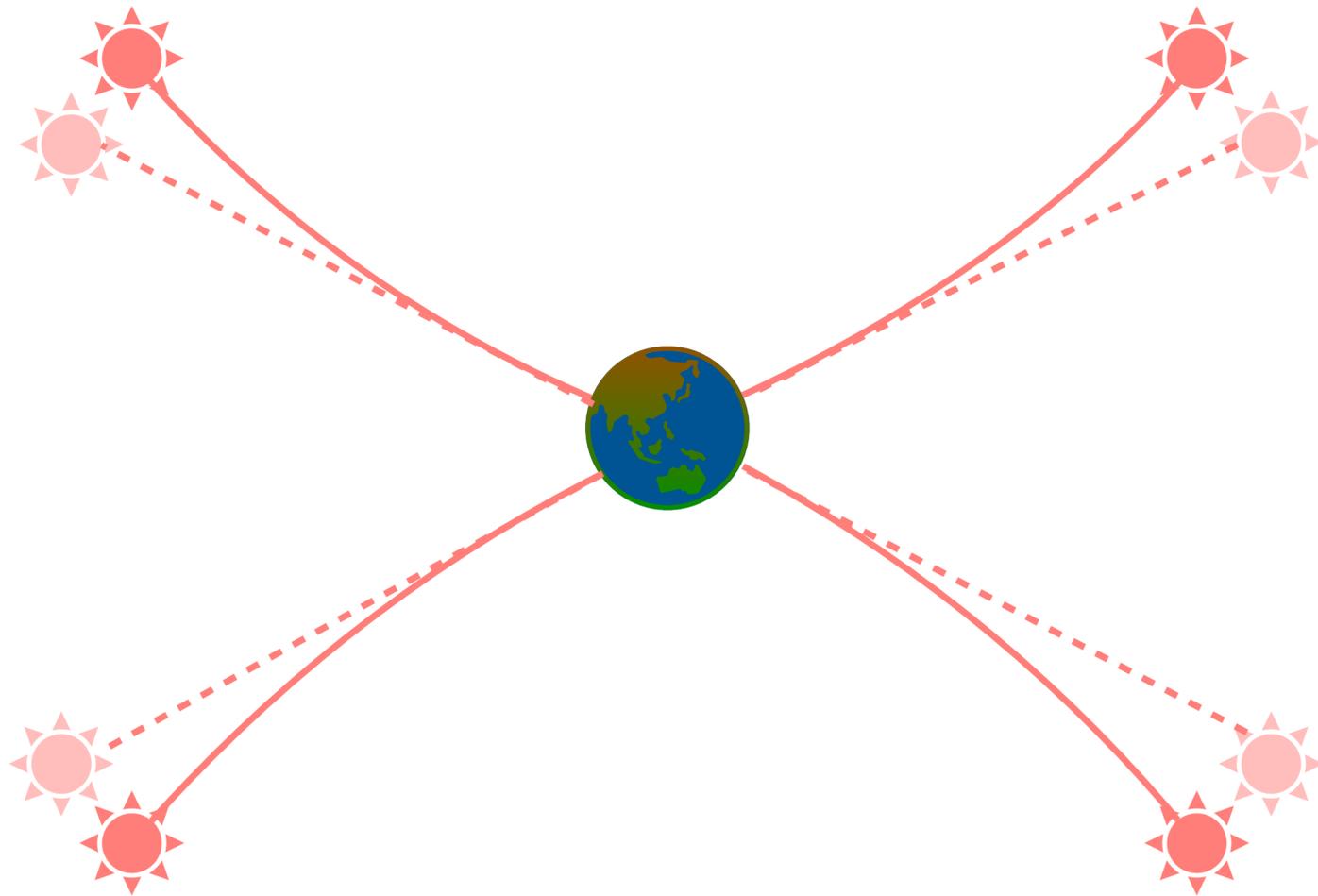
[Keeley, Joudaki, Kaplinghat, Kirkby, 1905.10198]

[Keeley, Abazajian, Kaplinghat, Shafieloo, 2502.12667]

cf. [Notari, Redi, Tesi, 2406.08459]

Quasar Astrometry

quasar (so bright and visible at a distance)



$$\Delta\theta \sim h$$

$$\frac{d\Delta\theta}{dt} \sim hf$$

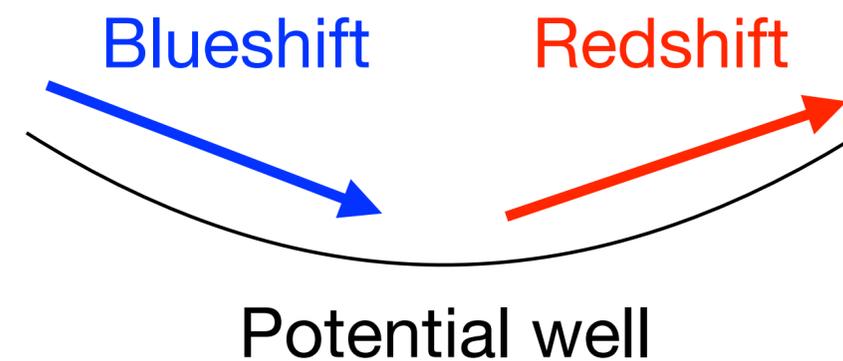
Expand it by spherical harmonics.
Extract the quadrupole component.
(Similar to the principles of PTA)

Search for the global-sky correlation due to GWs; each quasar has peculiar motion.

Integrated Sachs-Wolfe (ISW) Effect

Energy of the CMB photon changes as it passes through gravitational potential.

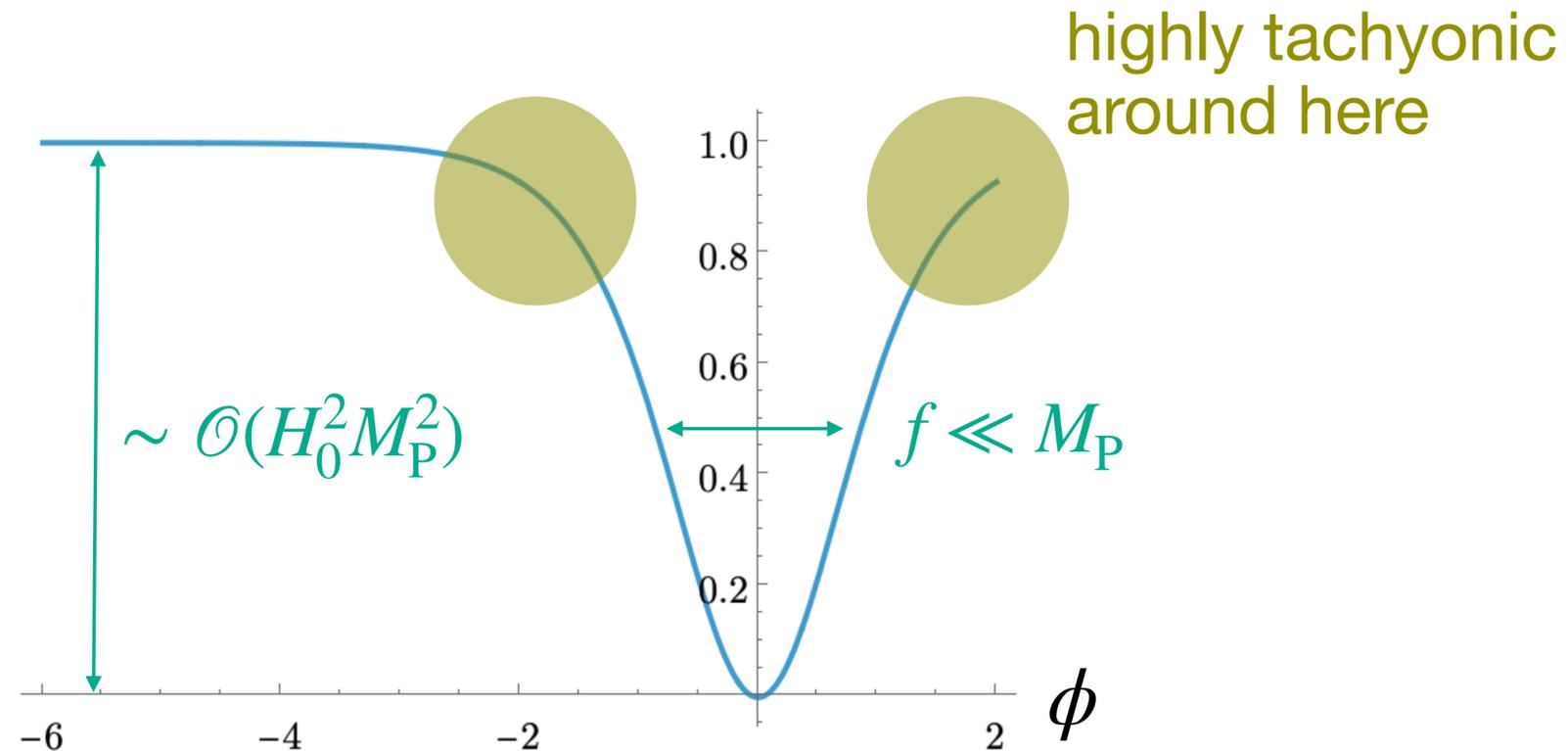
For static potential, there is no effect.



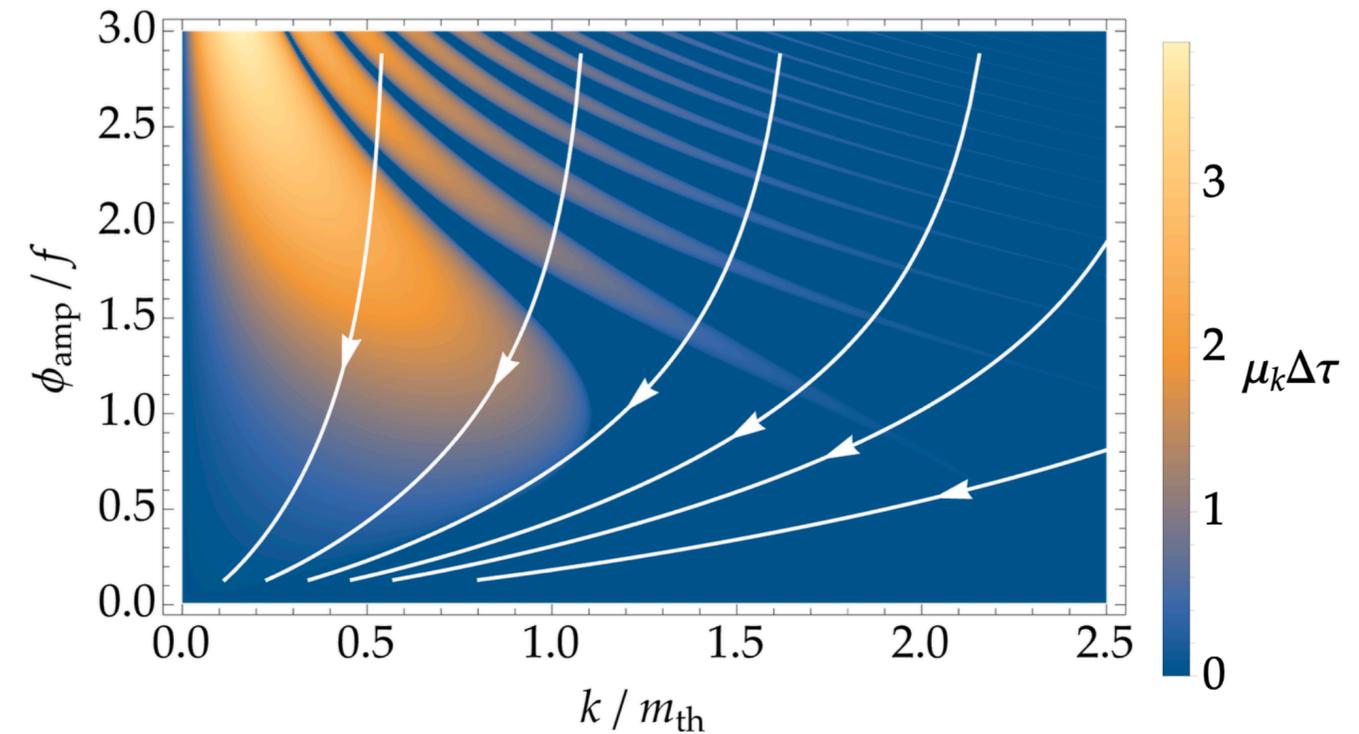
With time evolution, the effect remains.

$$\frac{\Delta T}{T} \sim \int d\tau (\dot{\Phi} + \dot{\Psi})$$

Tachyonic Resonance



Repeated tachyonic instability leads to a resonance structure.



Floquet chart

UV Cutoff Scale

$V(\phi) = V_0 \tanh^2(\phi/f) \longrightarrow$ higher dimensional ops. of the form $\exp(-2m\bar{\phi}/f)(\delta\phi/f)^n$

The strongest bounds come from $m = 1$ and $n \rightarrow \infty$.

Neglecting $\mathcal{O}(1)$ numerical coefficients, the **tree-level perturbative unitarity bound** is $\Lambda \sim f$.

The typical energy scale (for sufficiently small f), $H_0 M_{\text{Pl}}/f$, should not exceed the cutoff scale Λ .

\rightarrow We obtain an absolute lower bound, $f \gtrsim f_{\text{min}} := \sqrt{H_0 M_{\text{Pl}}} \approx 10^{-3} \text{ eV} \approx 10^{-30} M_{\text{Pl}}$.