Lorentz Invariance Violation using different cosmological backgrounds

Hassan Abdalla

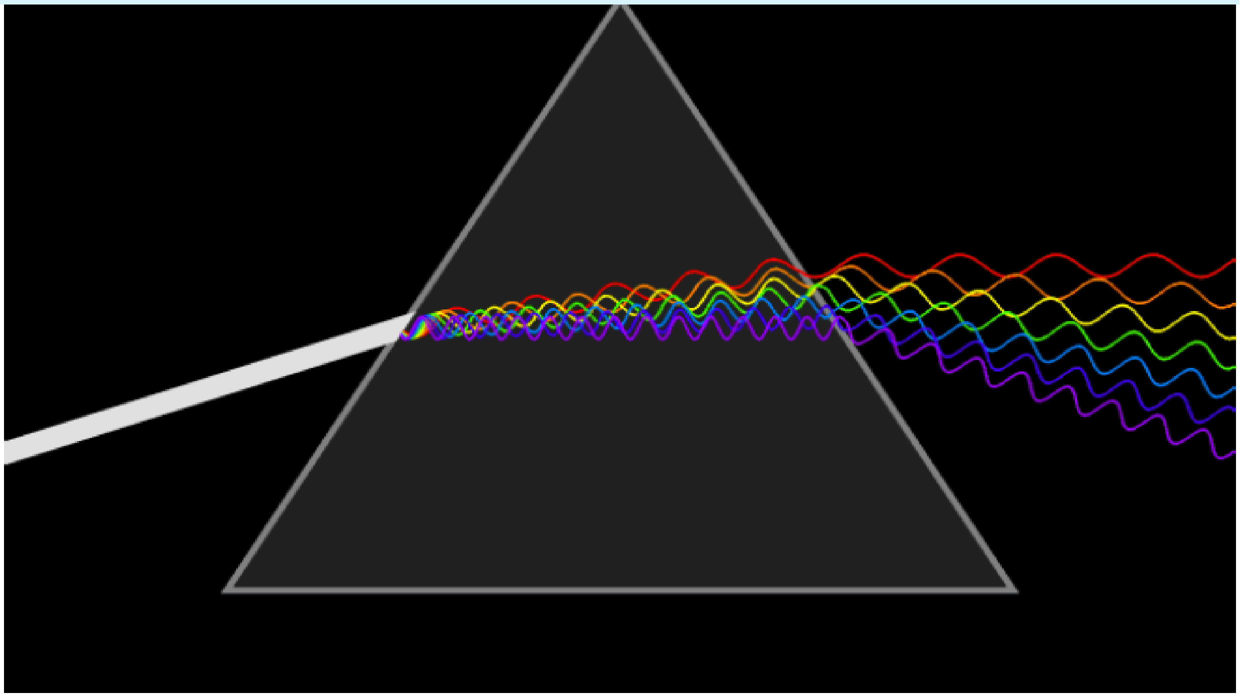
UNIVERSIDAD COMPLUTENSE MADRID

IPARCOS

Introduction:

The speed of light in a refractive medium depends on its wavelength.

Refractive index is the ratio of speed of light in vacuum to the speed of light in matter $n \equiv c / v_p$

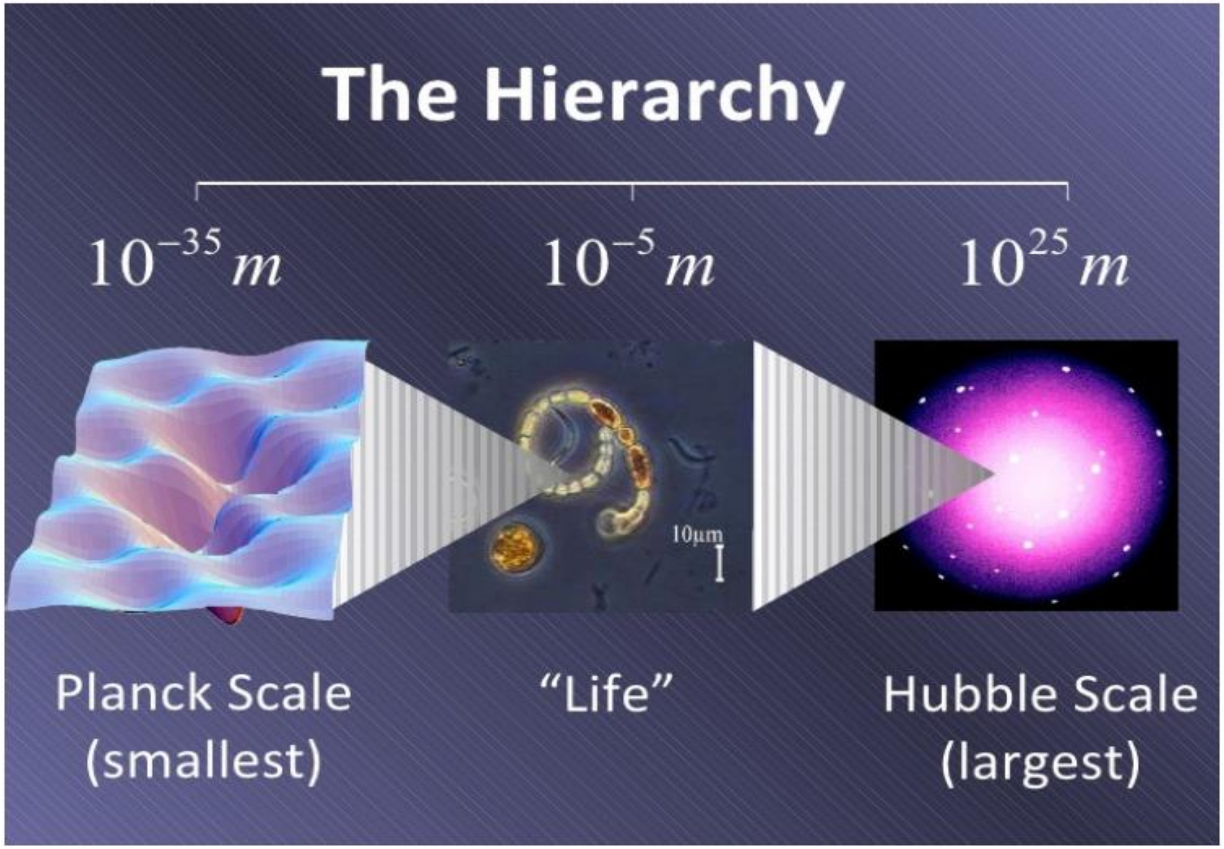


Credit: *Lucas V. Barbosa*

Lorentz-Invariance Violation:

At quantum gravity scale, VHE photons could be sensitive to the microscopic structure of space-time. Higher energy photons are expected to propagate more slowly than their lower-energy counterparts.

Image credits: Colin Gillespie, MGM; timeone.ca



Time-lag due to the LIV effect

- At Planck energy scale Lorentz symmetry will breakdown, the deviation from Lorentz symmetry can be described by modification of the dispersion relation as follows:

$$E^2 = p^2c^2 + m^2c^4 + S\,E^2\left(\frac{E}{E_{LIV}}\right)^n$$

where $S = -1$ for a subluminal case, $S = +1$ for a superluminal case, and n is the order of the leading correction.

The time-lag over energy difference can be written as:

$$\tau_n = \frac{\Delta t_n}{E_h^n - E_l^n} = S\,\frac{n+1}{2\,E_{LIV}}\int_0^z \frac{(1+z')^n}{H(z')}dz'$$

For details see e.g., Bolmont 2016

Constraints on LIV:

- Constraints on LIV from Mrk 501 during Flaring Time:

- **MAGIC (2005):**

  Lower limit on E_{LIV} (95% CL): 3 × 10^18 GeV

- **H.E.S.S. (2014):**

  Lower limit on E_{LIV} (95% CL): 3.6 × 10^17 GeV

- Combined study involving H.E.S.S., MAGIC, and VERITAS datasets is discussed in *Bolmont et al (2022)*

$$\tau_n = \frac{\Delta t_n}{E_h^n - E_l^n} = S\ \frac{n+1}{2\ E_{LIV}} \int_0^z \frac{(1+z')^n}{H(z')} dz'$$

↔ Cosmology (ΛCDM)

Hubble Parameter

$$H(z)_{\rm DE} = H_0\sqrt{\Omega_{\rm m}(1+z)^3 + \Omega_{\rm DE}f(z) + \Omega_{\rm rad}(1+z)^4}$$

For ΛCDM **model** → ***f(z) = 1***

$$f(z) = \exp\left[3\int_0^z \frac{(1+w(z'))}{(1+z')}dz'\right]$$

Cosmology:

Non-trivial equation of state $w \neq -1$

- There is a lot of work done on looking at the LIV signature using the ΛCDM framework

$$w = -1$$

- In this work we will consider non-trivial equation of the state

$$w \neq -1$$

Quadratic parametrisation of the DE equation of state w(z)

$$w(z) = w_0 + w_1 z + w_2 z^2$$

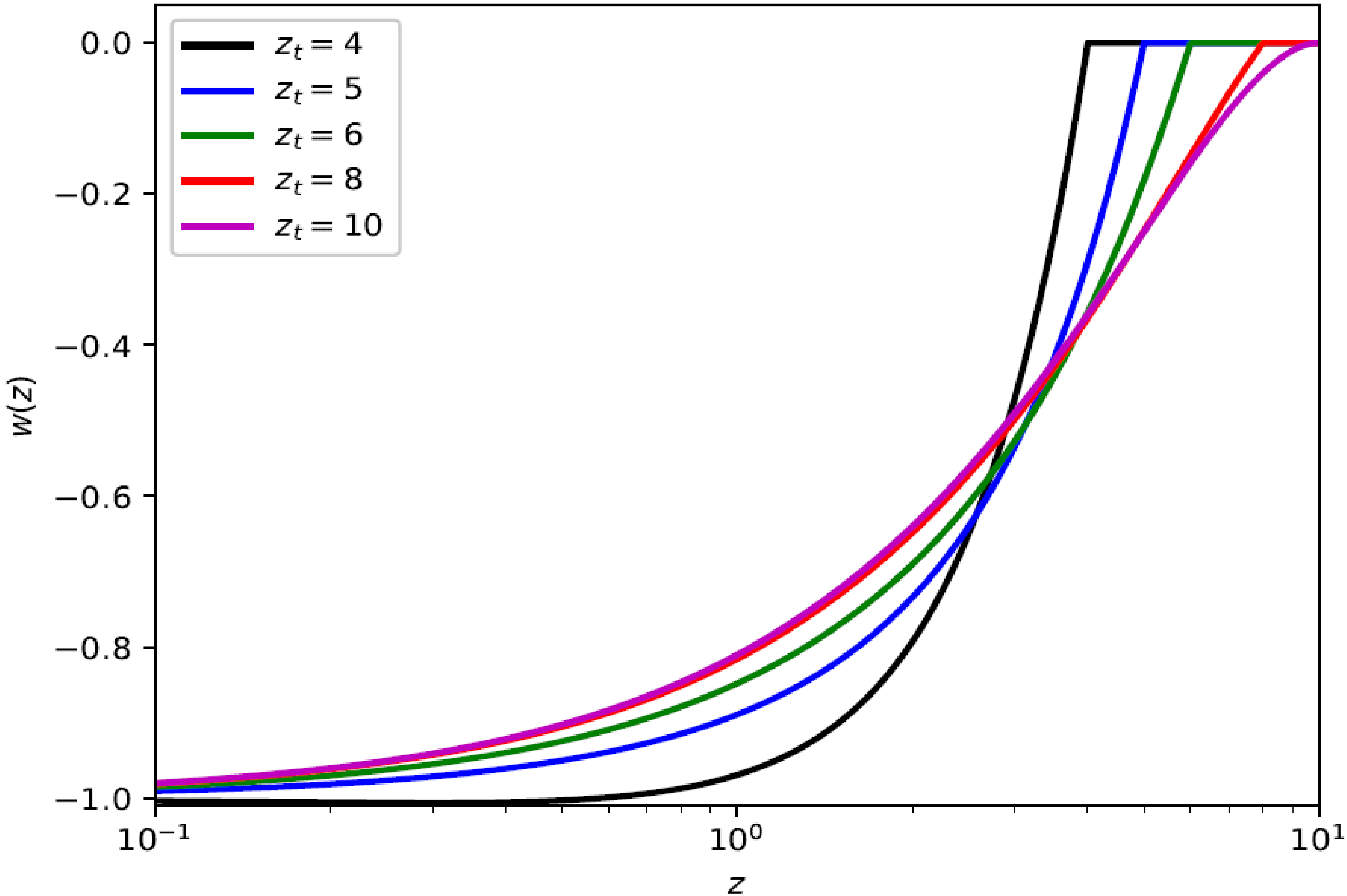
- The equation of state today $w(z=0) \equiv w_0 = -1$

- At redshift zt , the dark energy starts to evolve like matter w(zt) = 0

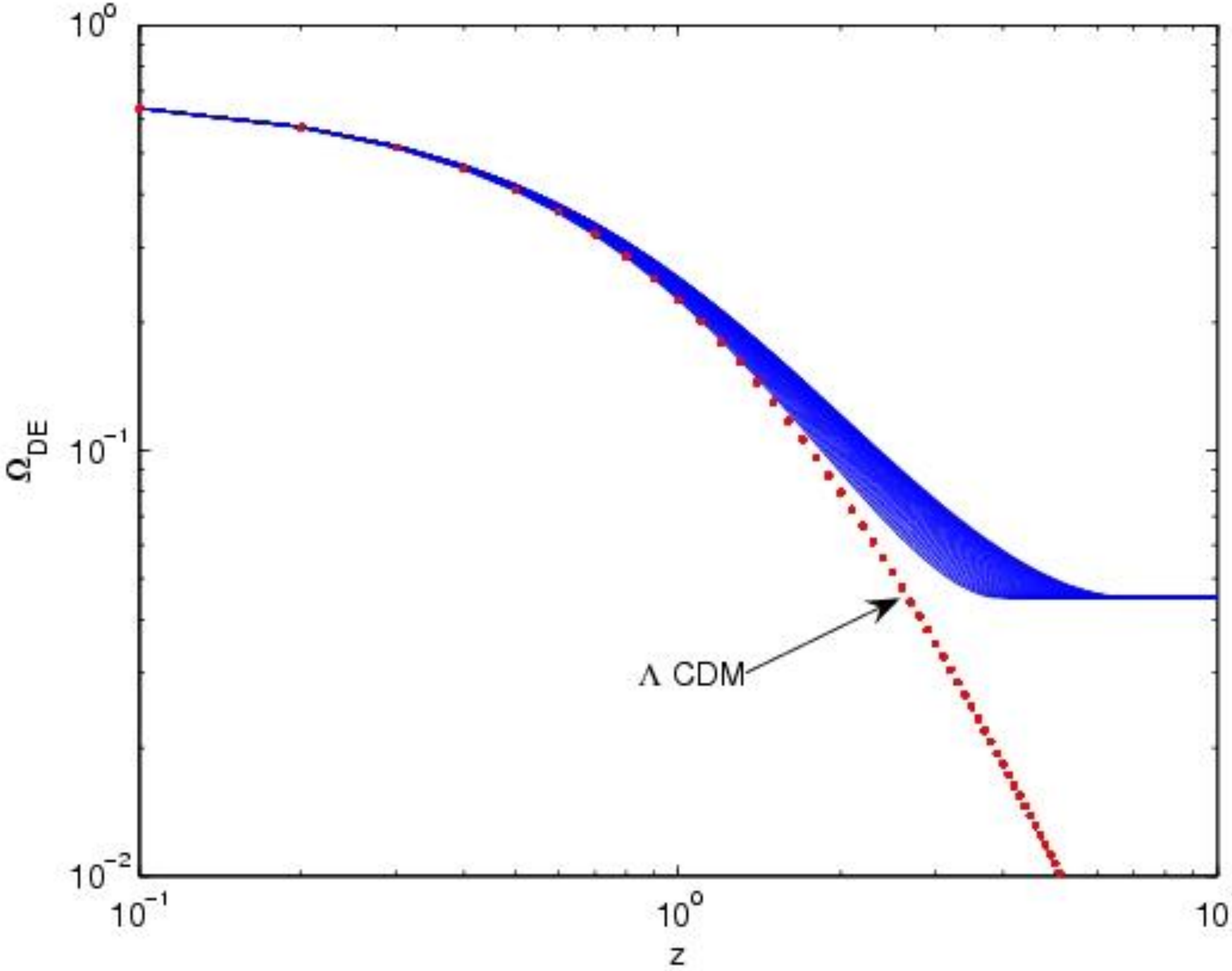
$$f(z) = \exp\left[3\int_0^z \frac{w_1 z' + (\frac{1}{z_t^2} - \frac{w_1}{z_t})z'^2}{(1+z')}\right]$$

Bassett et al (2008)

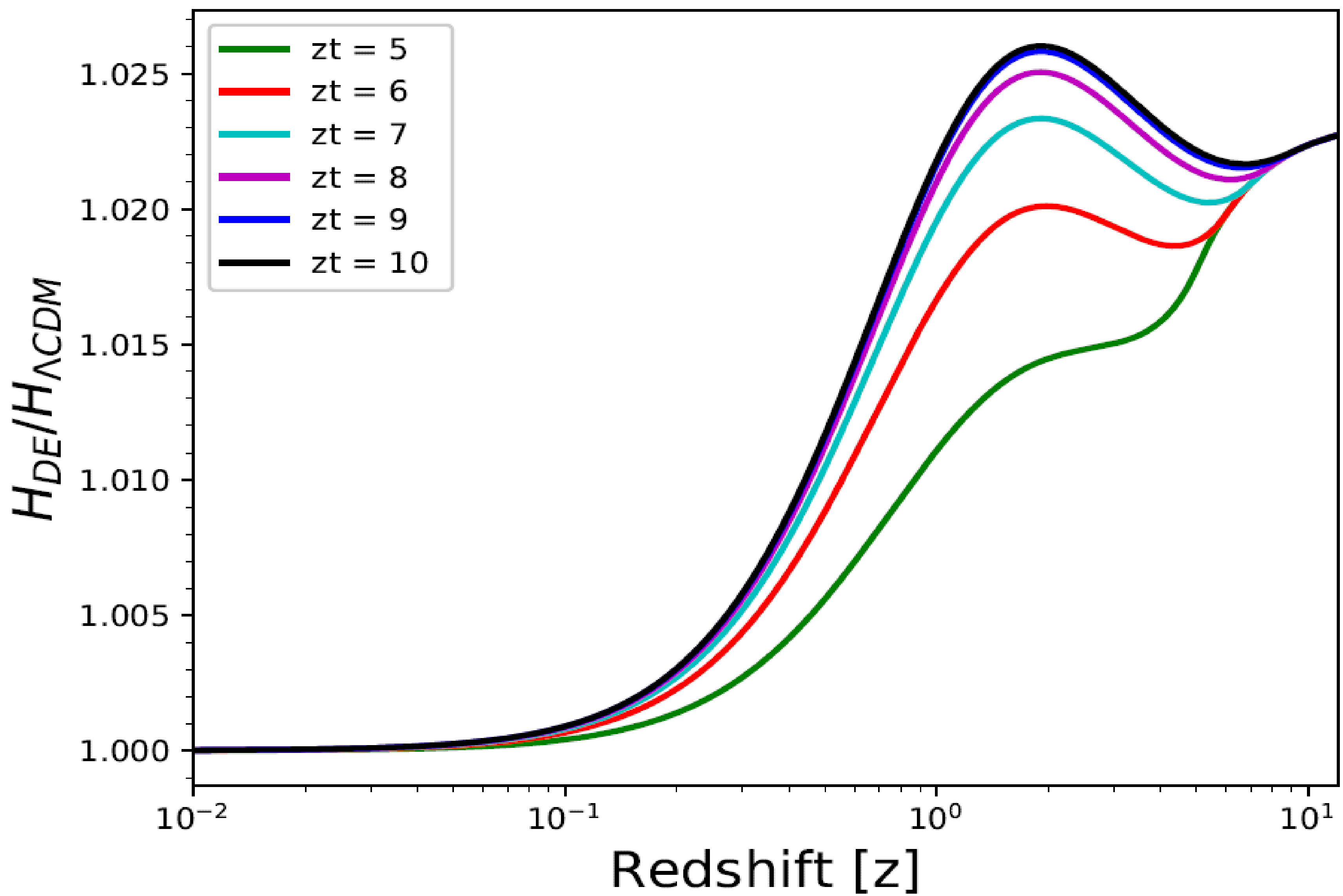
$$w(z) = w_0 + w_1 z + w_2 z^2$$



$$\Omega_{DE}(z) = \frac{\Omega_{DE,0}F(z)}{\Omega_{r,0}(1+z)^4 + \Omega_{m,0}(1+z)^3 + \Omega_{DE,0}F(z)}$$



Hubble parameter



+

Other w(z) forms

Chevalier–Polarski–Linder (CPL) and PADE parameterization

CPL →

$$w_{\rm DE}(z) = w_0 + w_1 z/(1+z)$$

PADE1 →

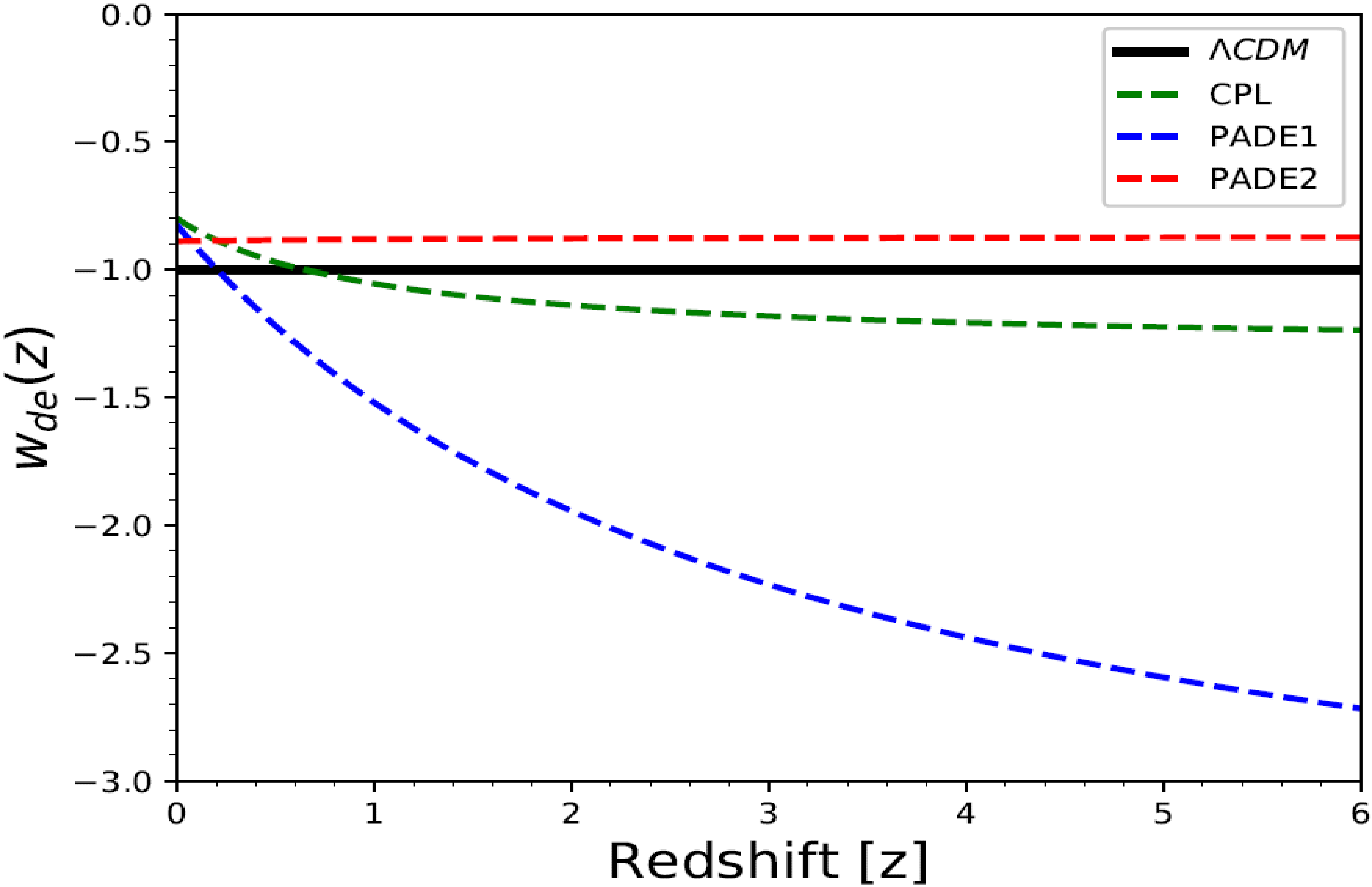
$$w^{I}_{\rm DE}(z) = \frac{w_0 + (w_0 + w_1)z}{1 + (1 + w_2)z},$$

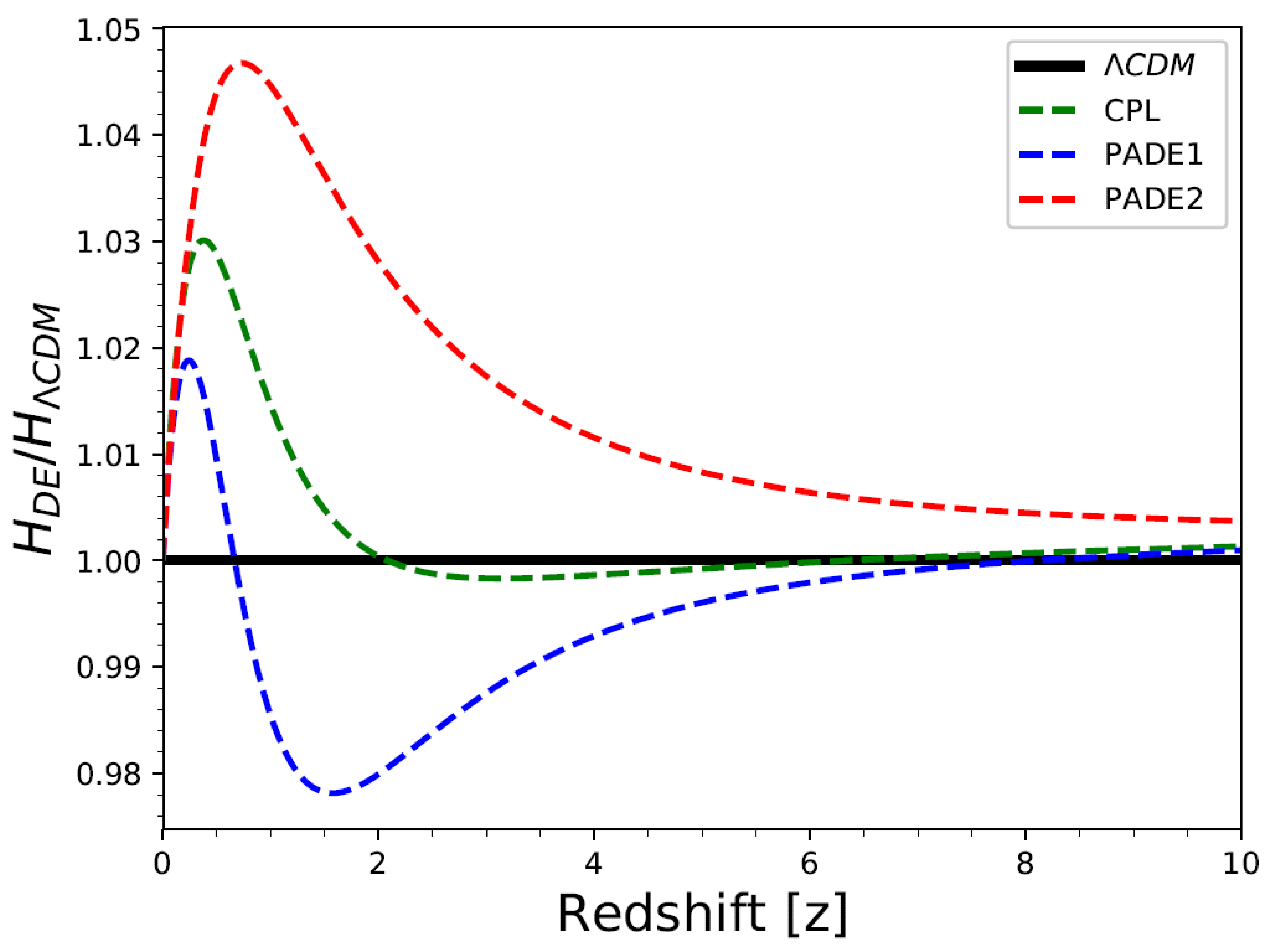
PADE2 →

$$w^{II}_{\rm DE}(z) = \frac{w_0 + w_1 \ln a}{1 + w_2 \ln a}$$

$$a = 1/(1+z)$$

Chevalier–Polarski–Linder (CPL) and PADE parameterization

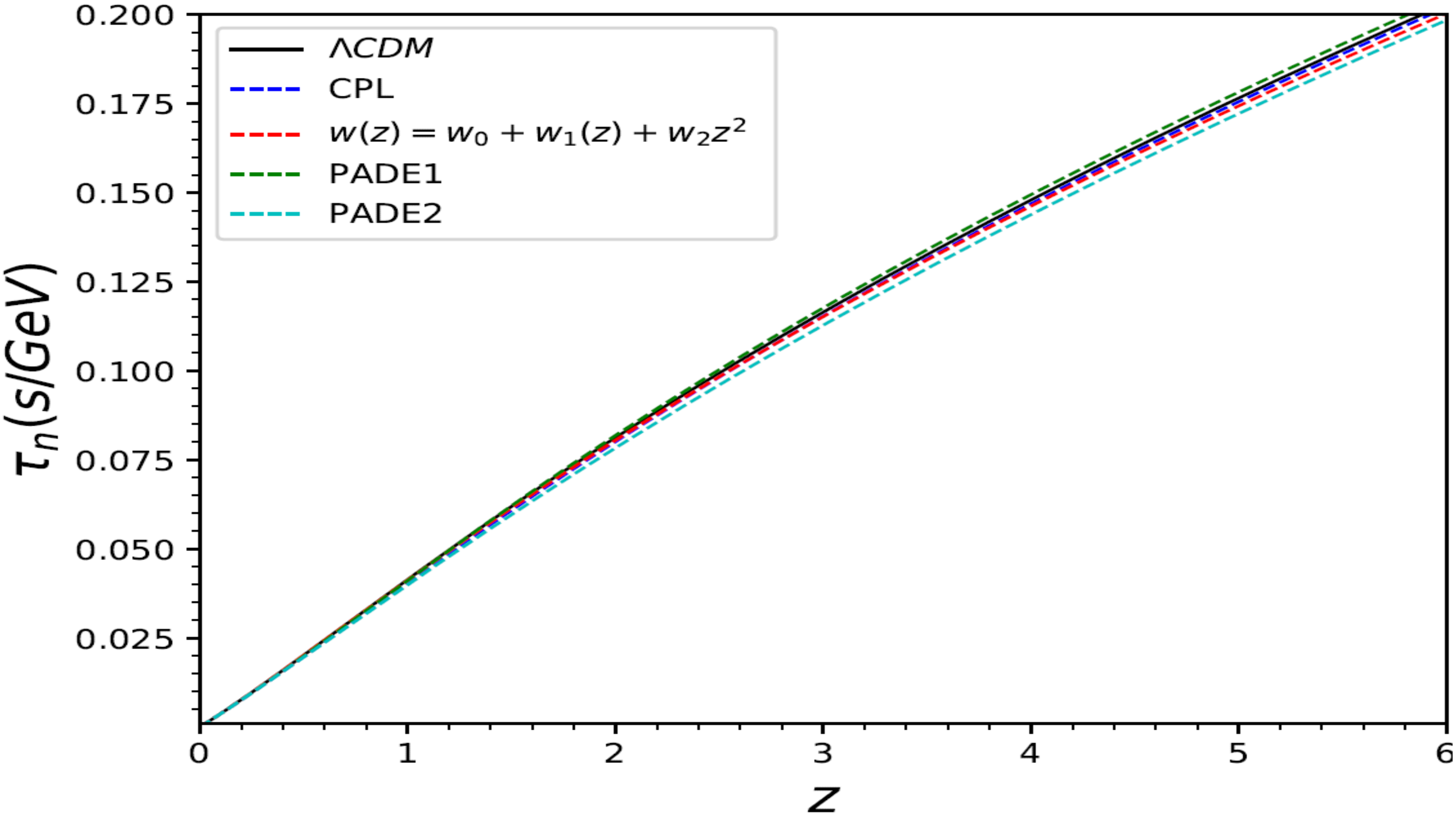




1.05
1.04
1.03
1.02
1.01
1.00
0.99
0.98
$H_{DE}/H_{\Lambda CDM}$
0
2
4
6
8
10
Redshift [z]
ΛCDM
CPL
PADE1
PADE2

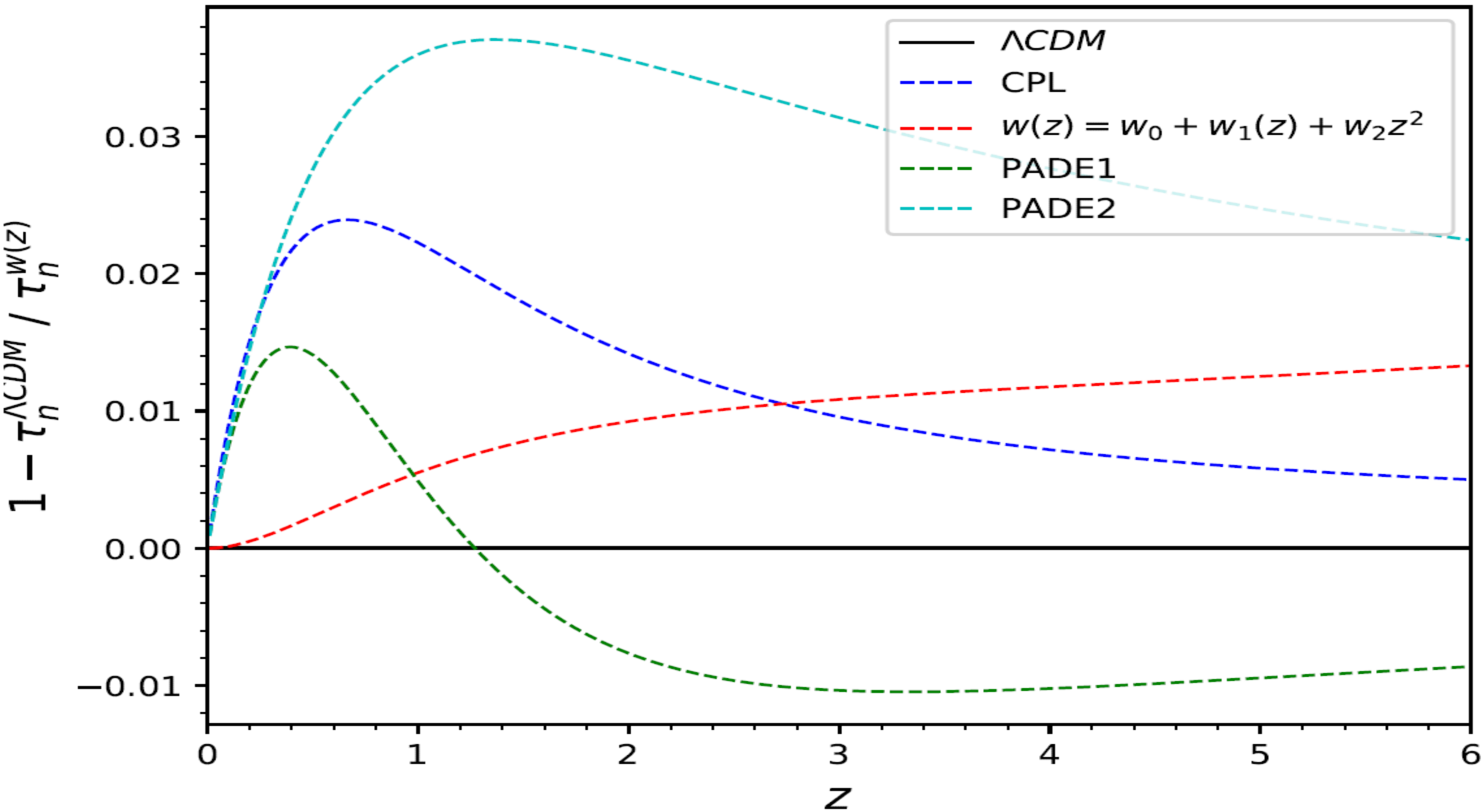
Time-lag due to the LIV effect using different equation of states w(z):

$$\tau_n = \frac{\Delta t_n}{E_h^n - E_l^n} = S\ \frac{n+1}{2\ E_{LIV}} \int_0^z \frac{(1+z')^n}{H(z')} dz'$$



In collaboration with: G. Cotter, M. Backes, E. Kasai & M. Böttcher

Time-lag due to the LIV effect using different equation of states w(z):



In collaboration with: G. Cotter, M. Backes, E. Kasai & M. Böttcher

Summary and Conclusions:

- The relative deficit/surplus for **the time-lag due to the LIV effect** using **different forms for equations of state w(z)** compared to **ΛCDM model** is **very small (<4%)**

- **Gamma rays** might be used for **probing fundamental physics and cosmology**

- **The forthcoming Cherenkov Telescope Array (CTA) will present exceptional prospects for investigating the LIV effect. Also, may enable us to test this hypothesis.**

Thank you!