Model-independent constraints in the context of multi-messenger cosmology

CosmoVerse@Istanbul - June 25 - Istanbul

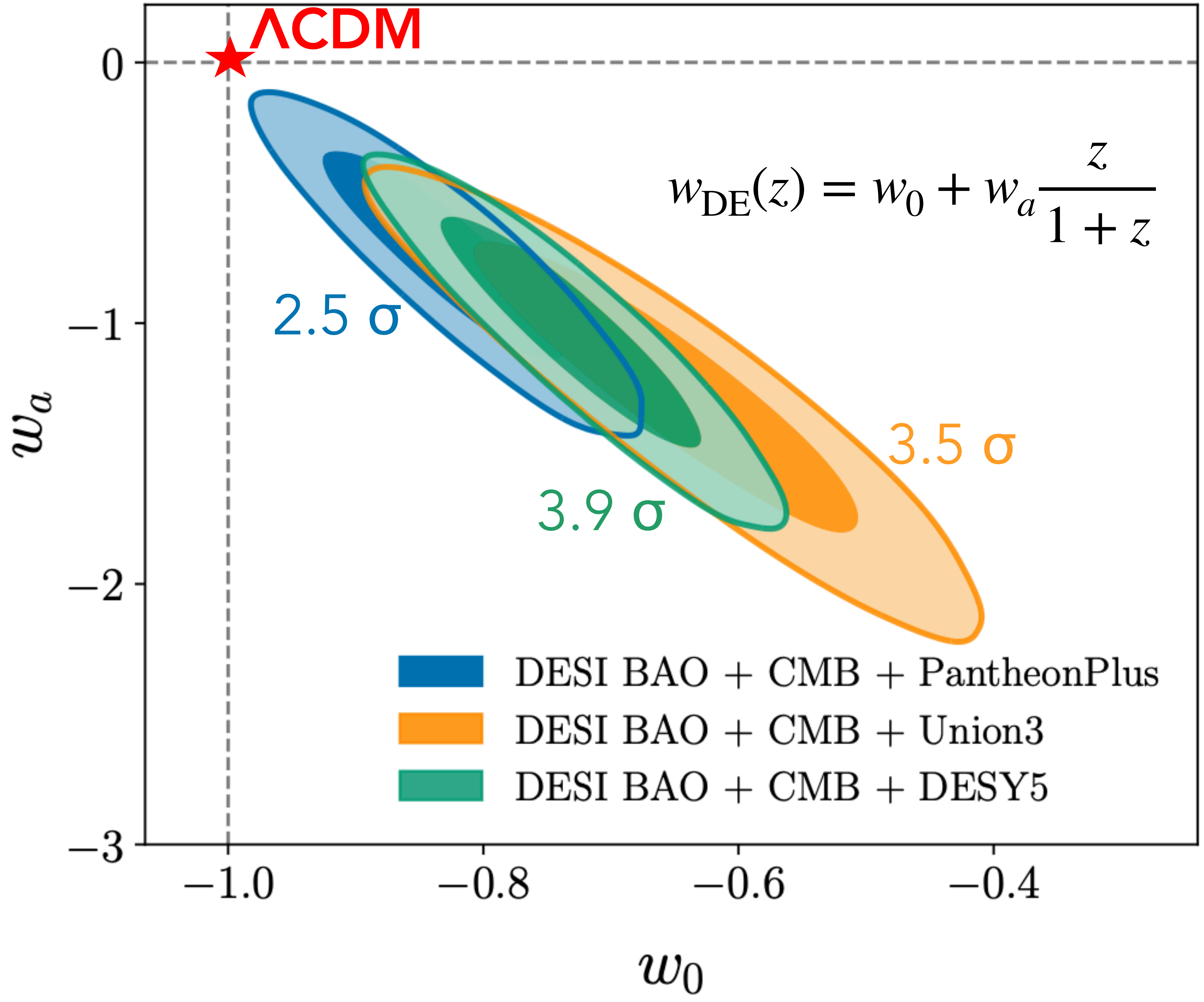
Andrea Cozzumbo

Riccardo Murgia   Gor Oganesyan   Marica Branchesi


JCAP05(2025)021
Andrea Cozzumbo
andrea.cozzumbo@gssi.it
in collaboration with
Ulyana Dupletsa
Rodrigo Calderón
Riccardo Murgia
Gor Oganesyan
Marica Branchesi

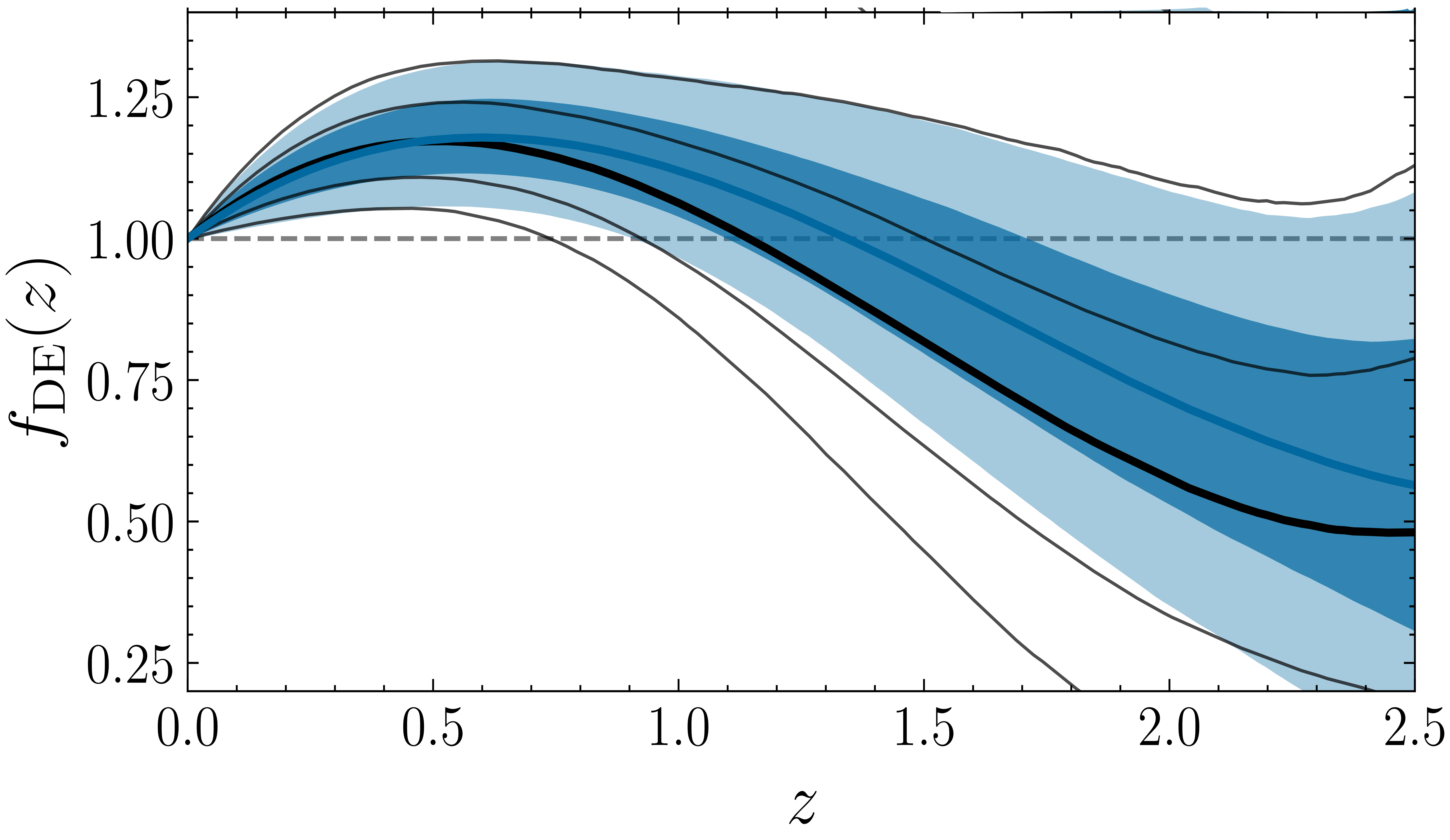
“Tantalizing suggestion” of dynamical DE

DESI collaboration, Adame+, 2024



“Tantalizing suggestion” of dynamical DE

DESI collaboration, Lodha+, 2025



$$H(z) = H_0 \sqrt{\Omega_{m,0}(1+z)^3 + \Omega_{\mathrm{DE},0} \exp\left[3\int_0^z \frac{1+w_{\mathrm{DE}}(z')}{1+z'}dz'\right]}$$

$$w_{\mathrm{DE}}(z) = w_0 + w_a \frac{z}{1+z}$$

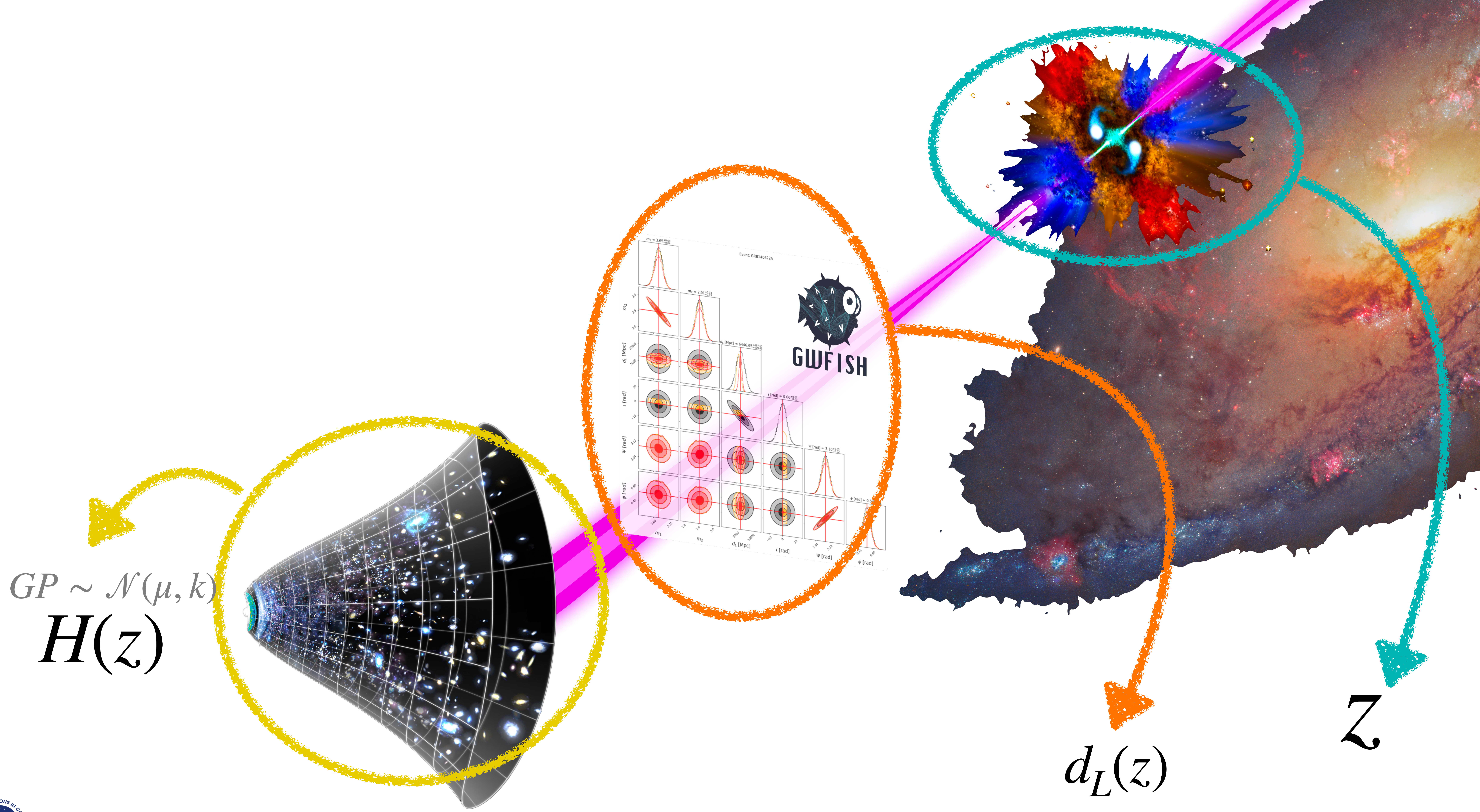
$$f_{\mathrm{DE}}(z) = (1+z)^{3(1+w_0+w_{\mathrm{a}})} \exp\left[\frac{-3w_{\mathrm{a}}z}{1+z}\right]$$

Why GWs

$$\tilde{h}_+(f) \propto \frac{\mathcal{M}^{5/6}}{2\,d_L} f^{-7/6}\, e^{i\phi(\mathcal{M},f)}\left(1 + \cos^2(\iota)\right) \qquad \tilde{h}_\times(f) \propto \frac{\mathcal{M}^{5/6}}{d_L} f^{-7/6}\, e^{i\phi(\mathcal{M},f)+i\,\pi/2}\cos(\iota)$$

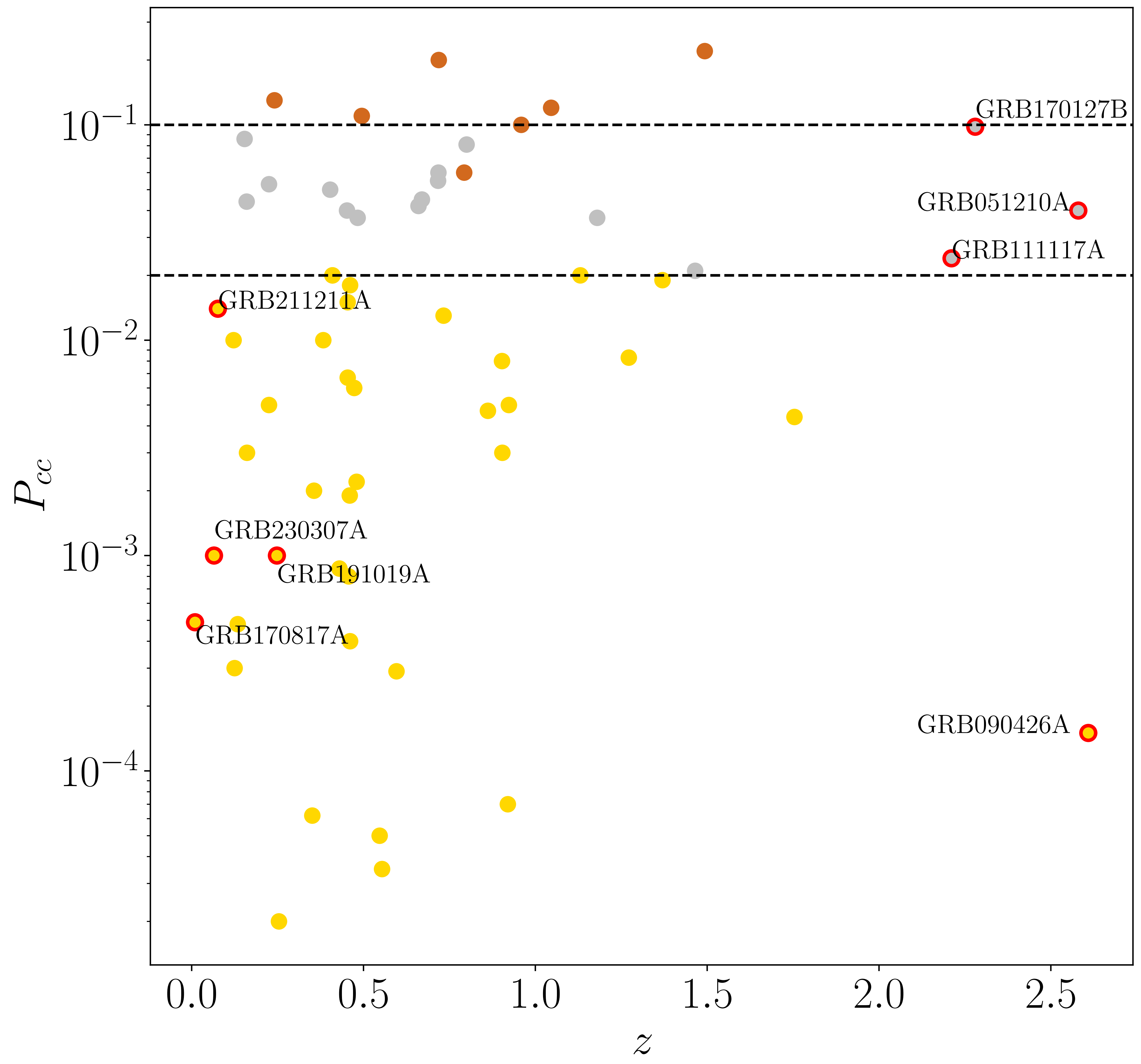
self-calibrated measure of distance

$$d_L(z) = c\,(1 + \overset{?}{z}) \int_0^z \frac{dz'}{H(z')}$$


GWFISH
$GP \sim \mathcal{N}(\mu, k)$
$H(z)$
$d_L(z)$
z

GRB data set

Cozzumbo+, 2024

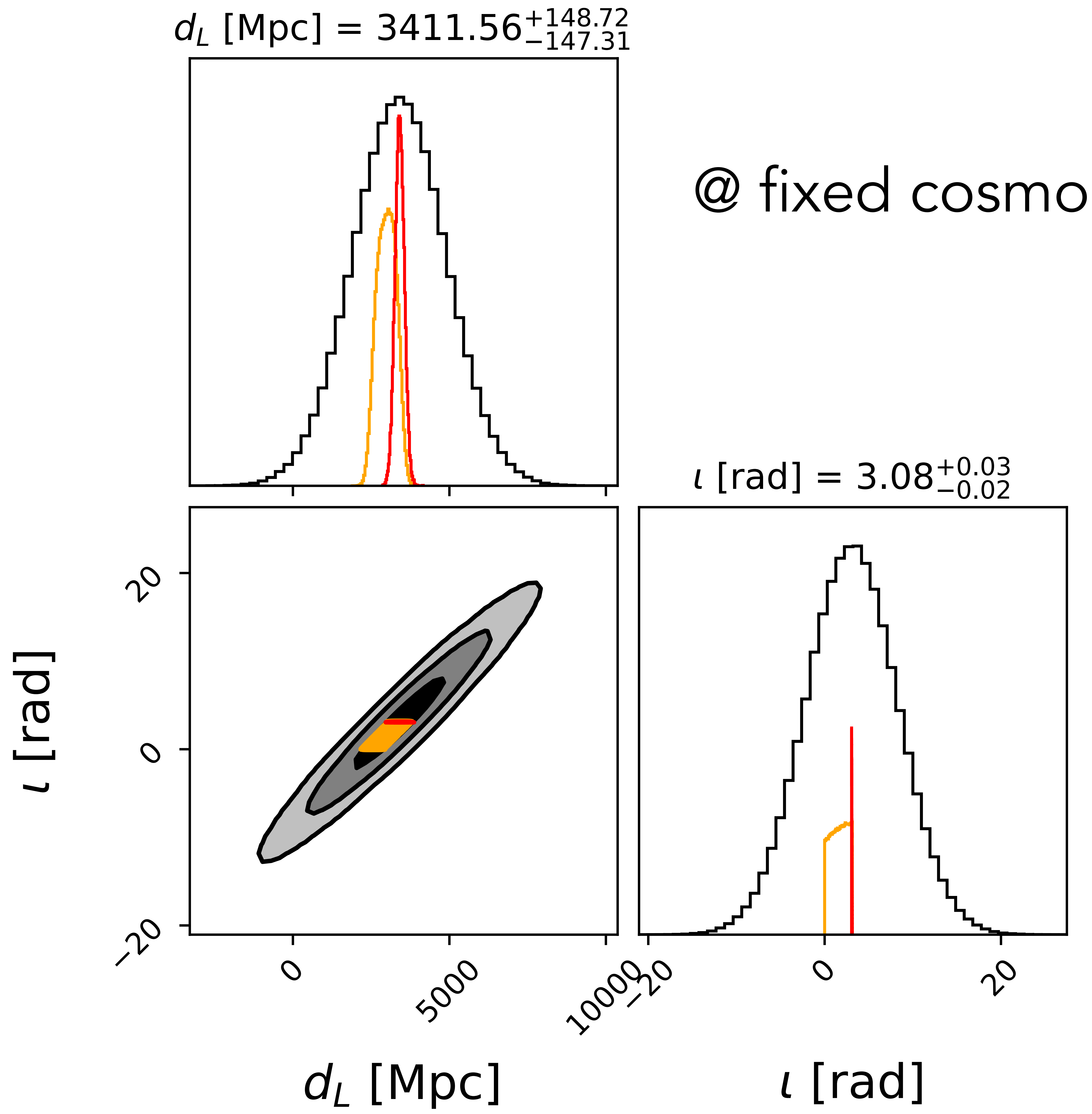


- Fermi-GBM & Swift-BAT/UVOT/XRT
- Merger-driven GRB events
- $\Delta z \leq 7\,\%$

If **Einstein Telescope** existed during the ***Swift*** and ***Fermi*** era, what new insights into cosmology would we have today?

GW posteriors

Dupletsa+, 2024



@ fixed cosmology

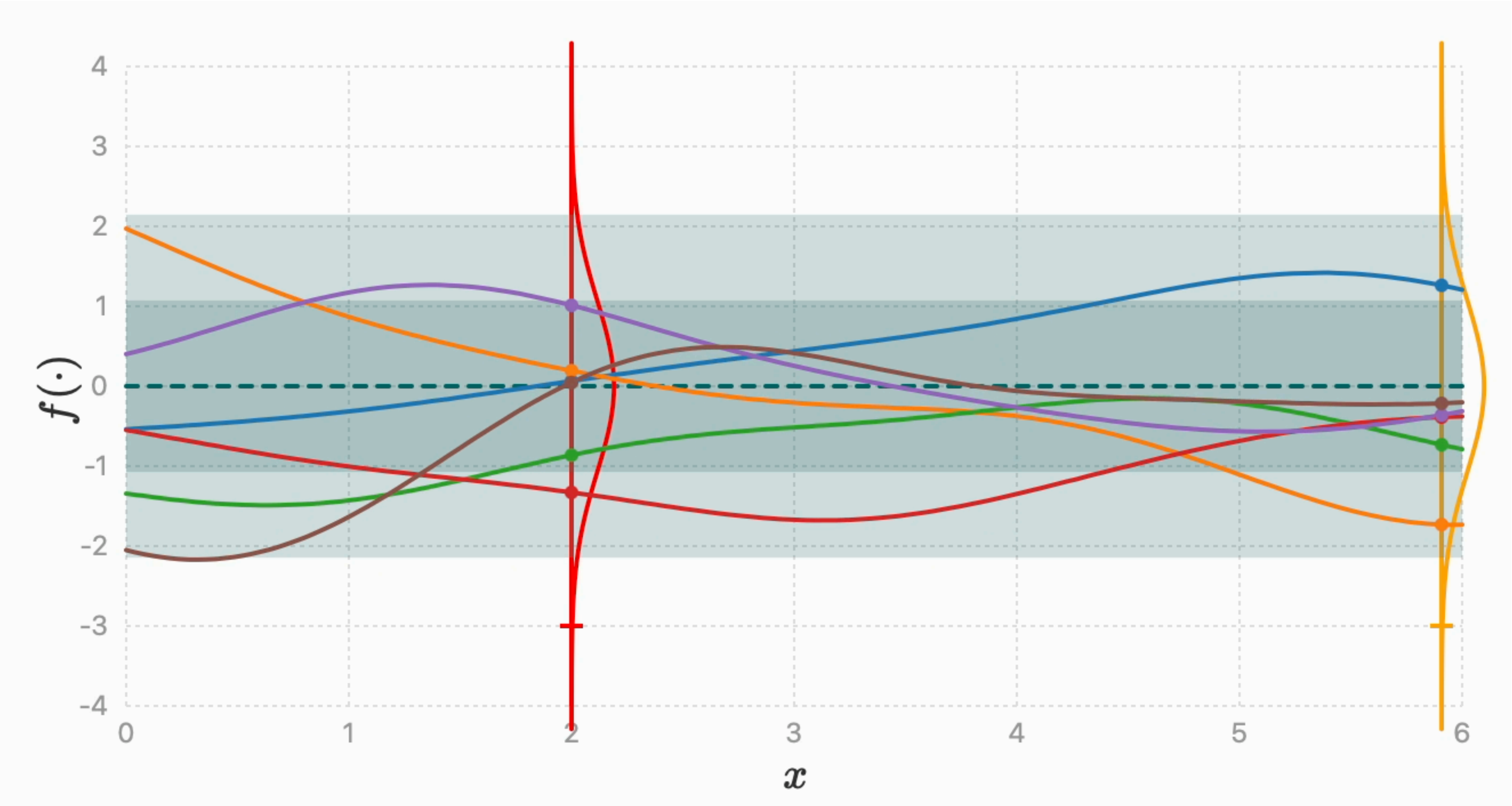
Non-parametric approach

GP → Gaussian Process

$$h^2(z) = \frac{H^2(z)}{H_0^2} = \Omega_{m,0}\,(1+z)^3 + (1-\Omega_{m,0})f_{\rm DE}(z)$$

$$f_{\rm DE}(z) \sim GP(\bar{f}_{\rm DE} = 1, k(\sigma_f, l_f))$$

$$k(\sigma_f, l_f) = \sigma_f^2\, e^{-\frac{(x-x')^2}{2\,l_f^2}}$$



Our strategy

- We generate mock joint GW-GRB data assuming 2 different cosmologies

ΛCDM *Planck18* DDE *Planck18, eBOSS, Pantheon+*

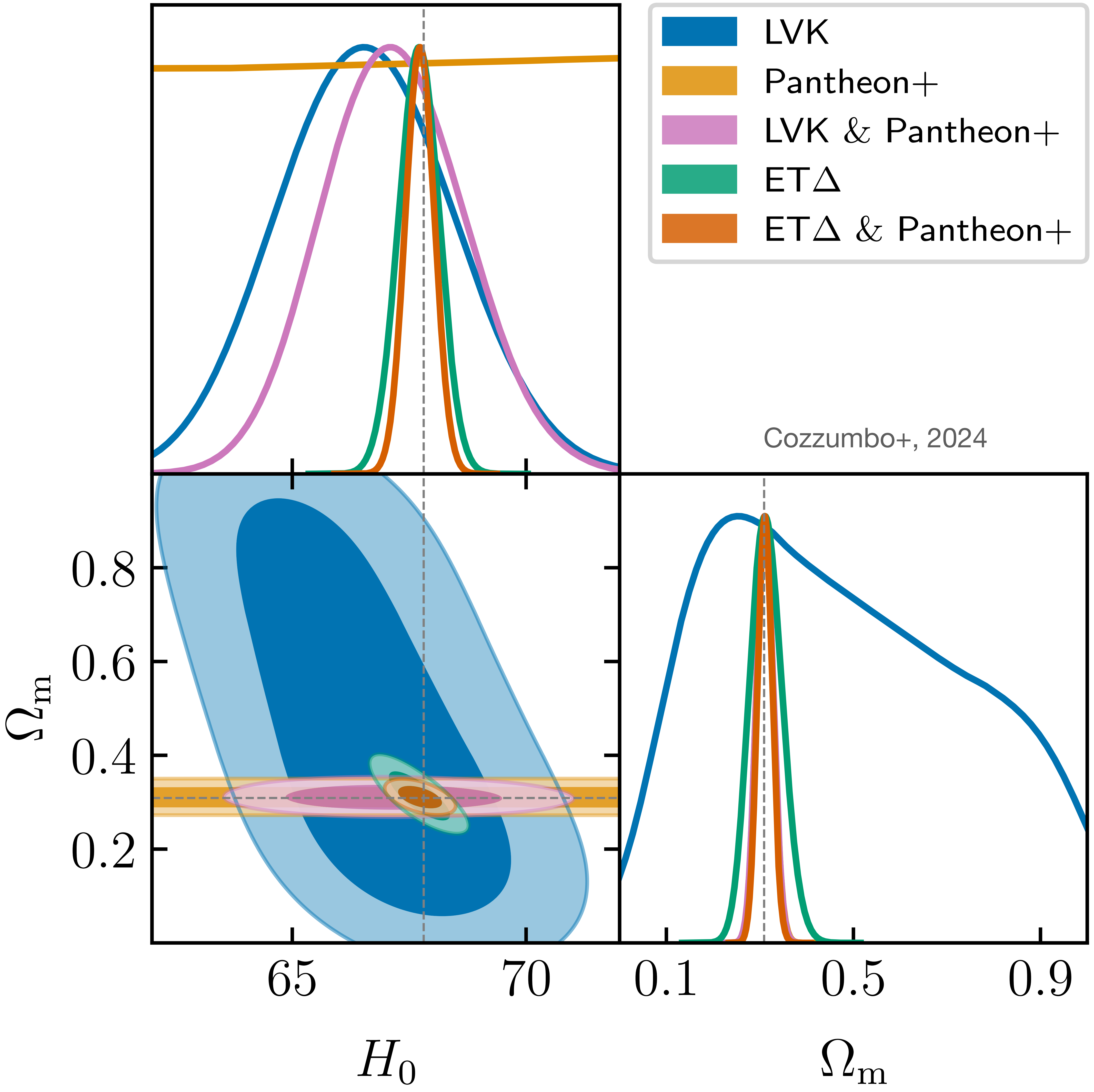
- We fit them with a parametric and a non-parametric approach with various observational configurations

- We compare the performances

Parametric approach

Injected

ΛCDM *Planck18*



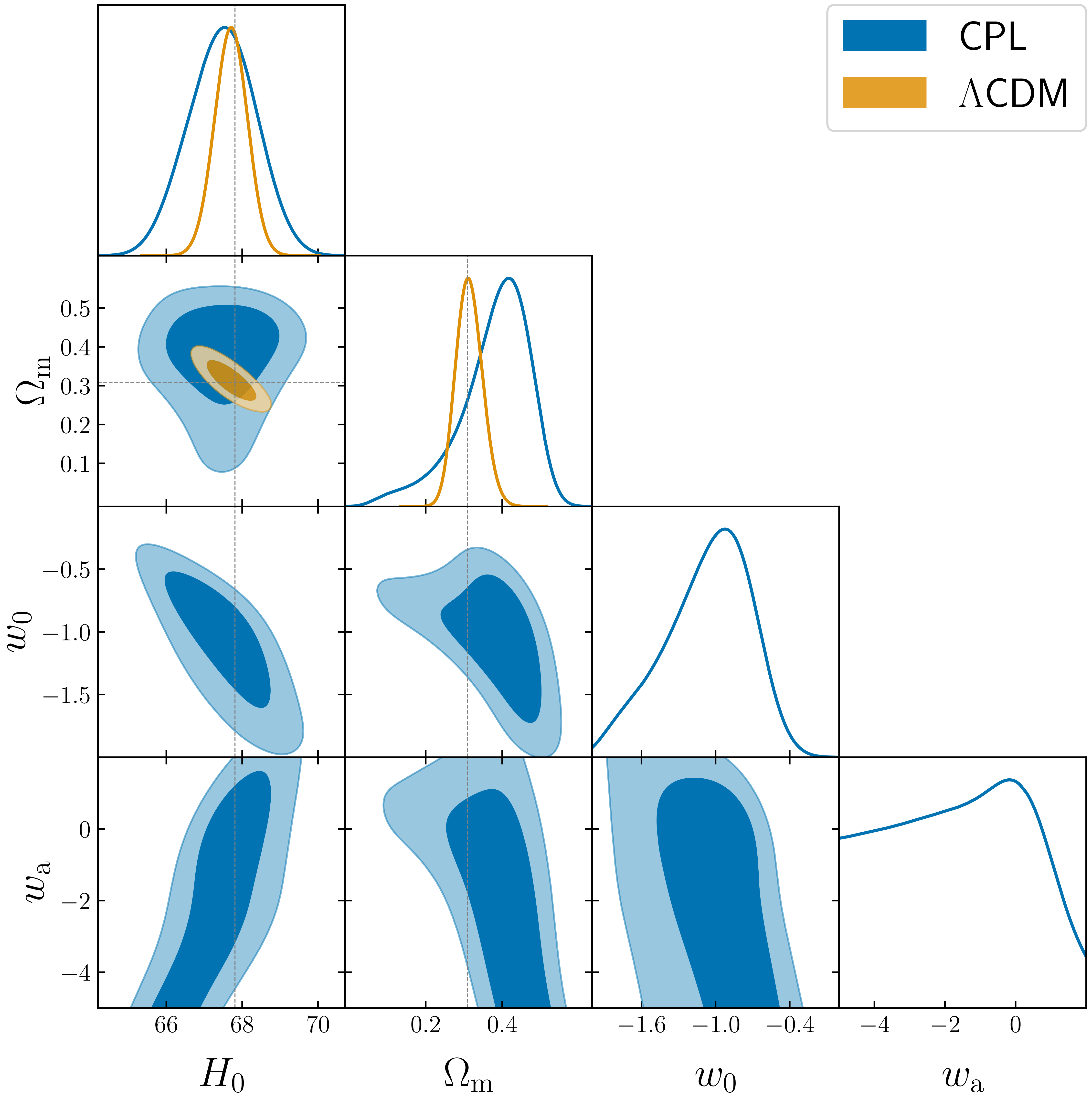
Fit

ΛCDM

Injected

ΛCDM *Planck18*

Parametric approach



Fit

CPL

$$h^2(z) = \frac{H^2(z)}{H_0^2} = \Omega_{m,0}\,(1+z)^3 + (1-\Omega_{m,0}) f_{\rm DE}(z)$$

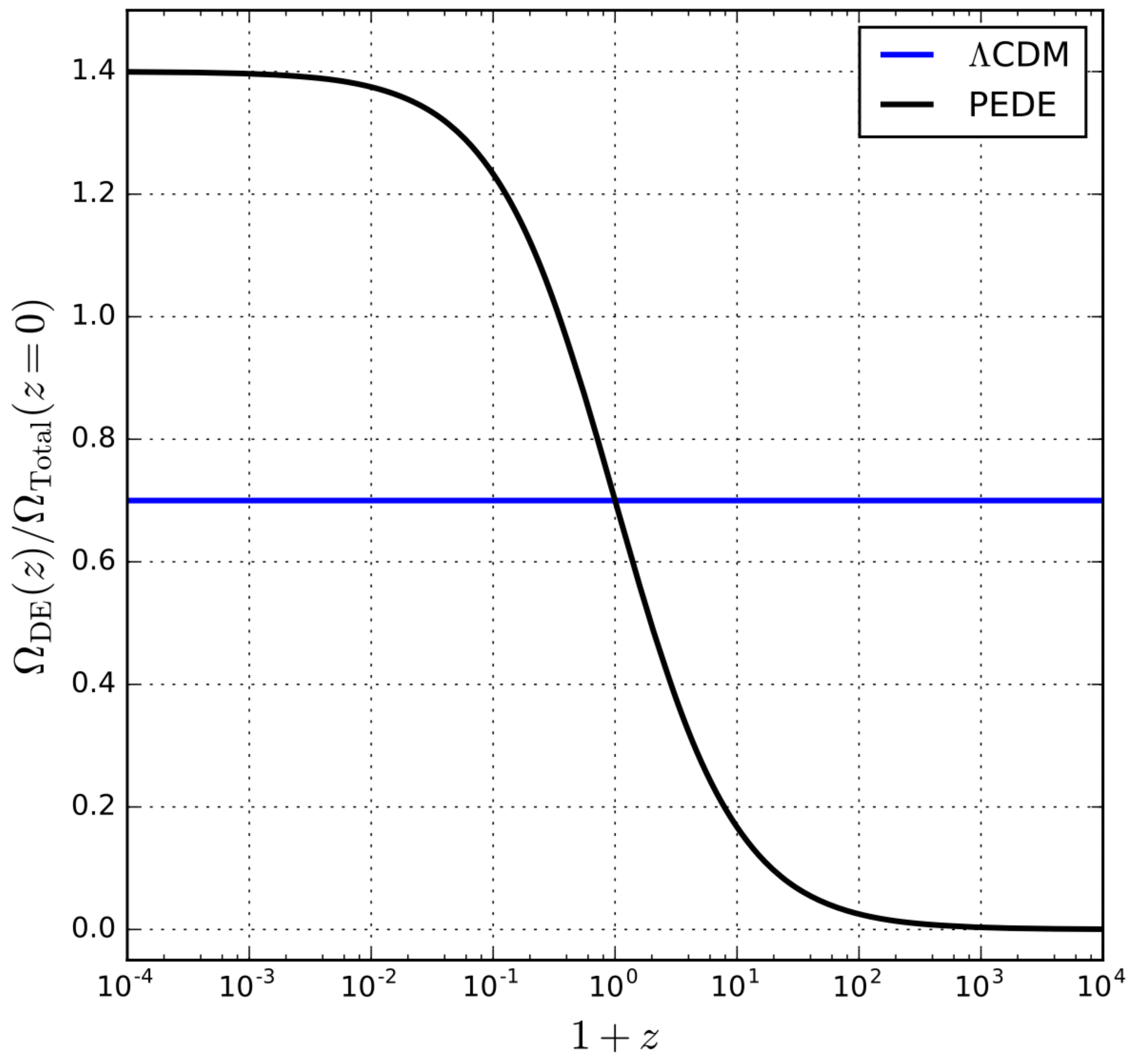
$$w(z)^{\rm CPL} = w_0 + w_a \frac{z}{1+z}$$

$$f_{\rm DE}(z) = (1+z)^{3(1+w_0+w_a)} \exp\left[\frac{-3w_a z}{1+z}\right]$$

Cozzumbo+, 2024

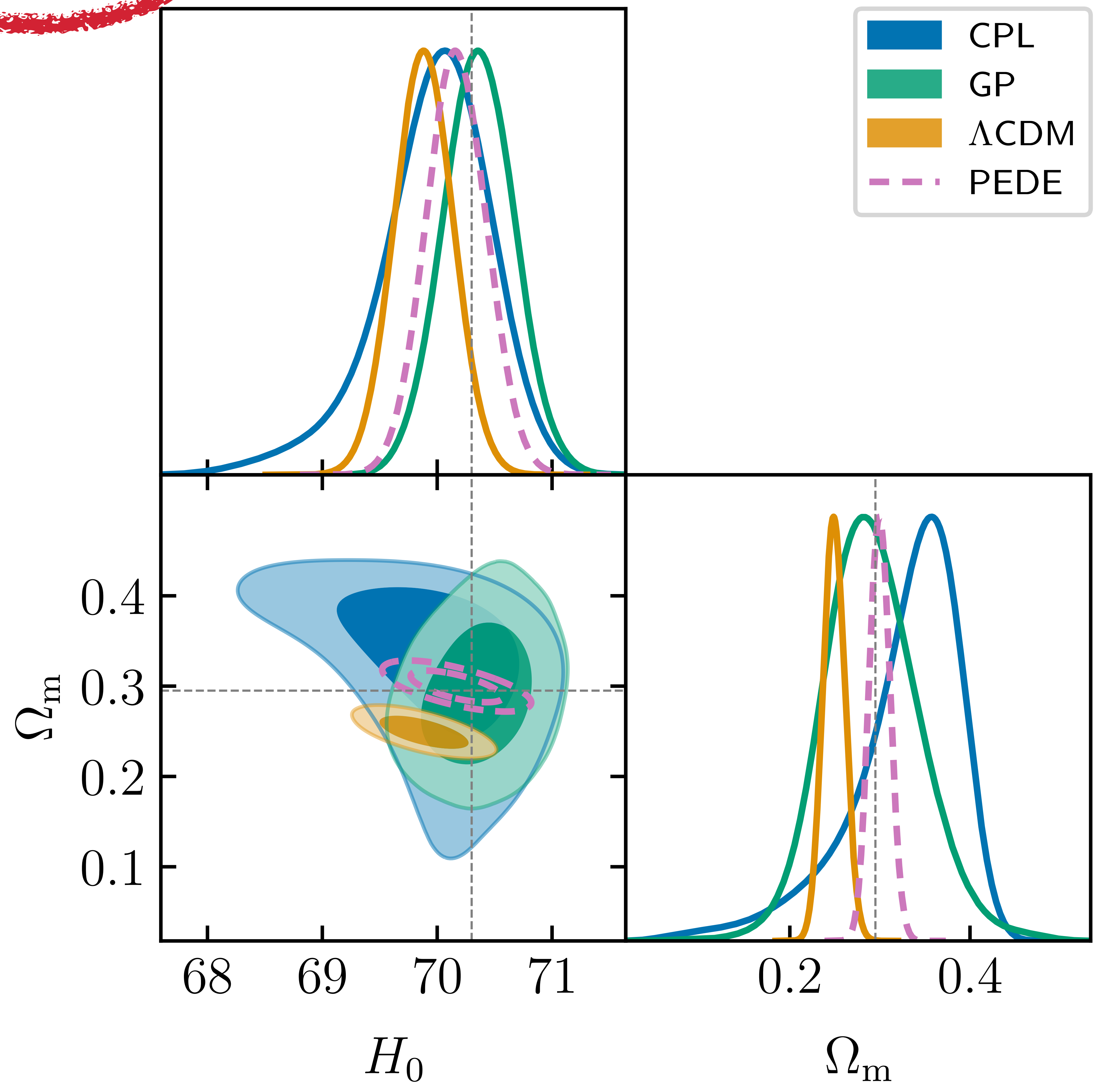
Non-parametric approach

Phenomenologically Emergent Dark Energy



Li and Shafieloo, 2019

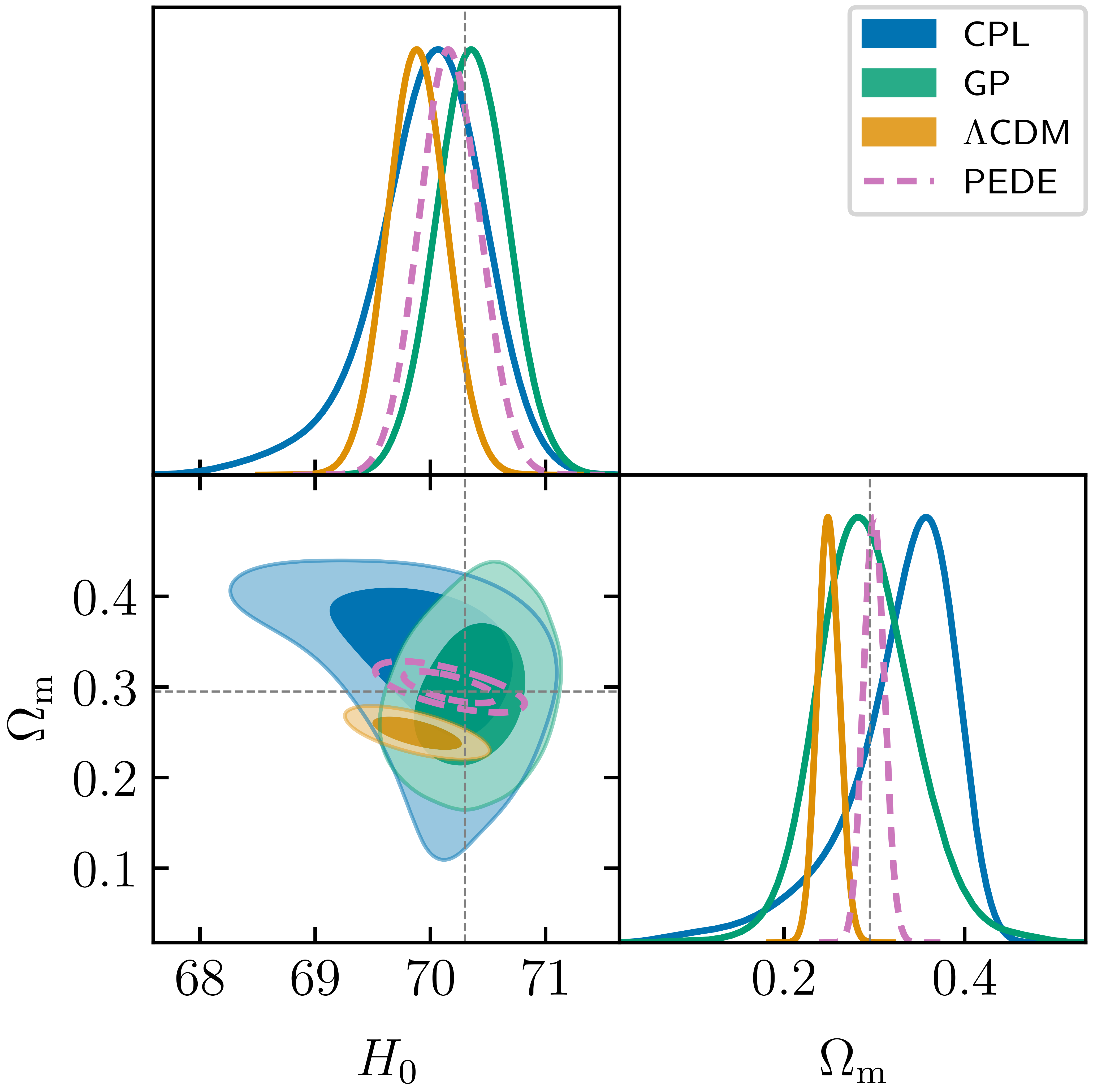
PEDE Universe | Pantheon+ & ET Δ + CE



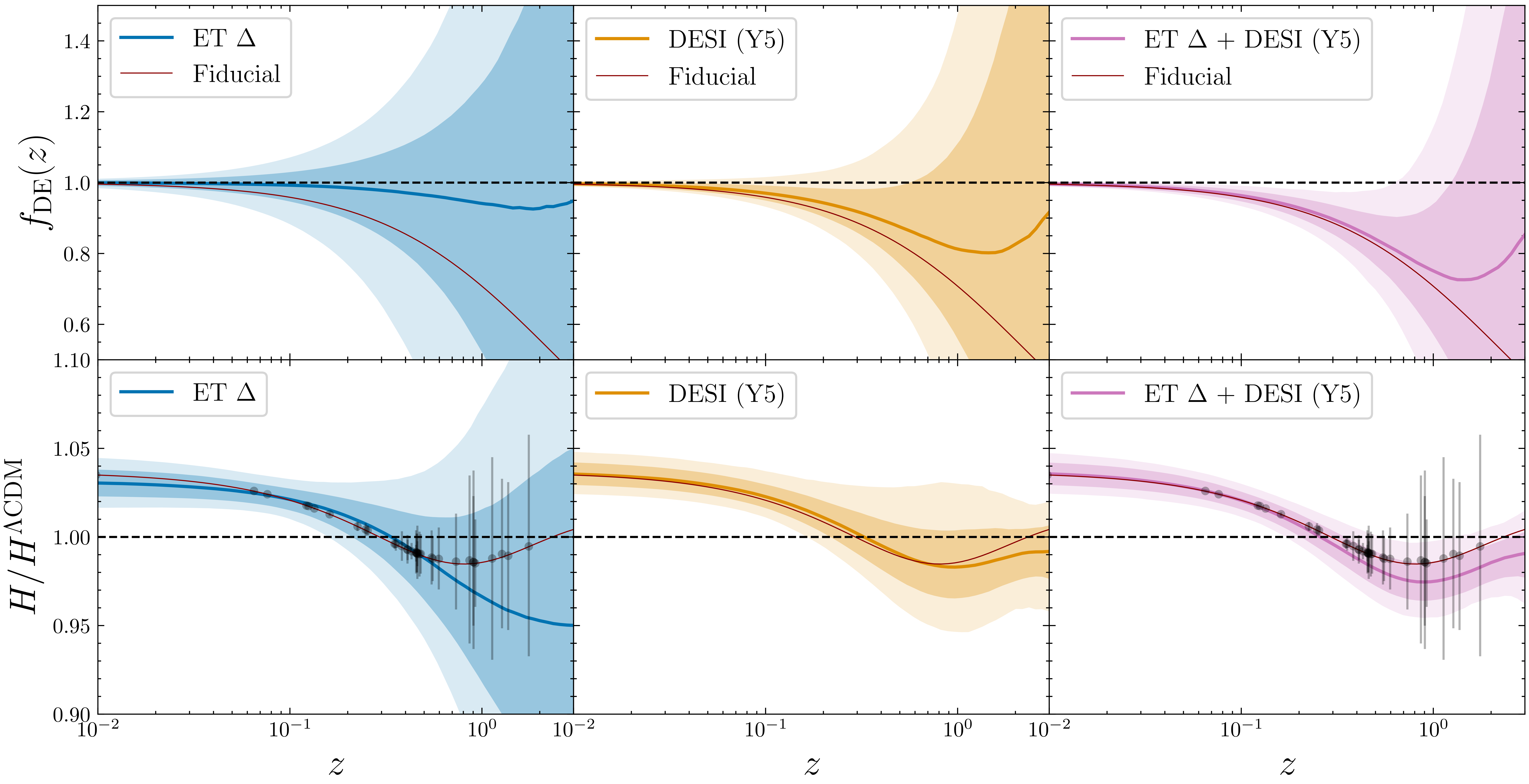
Cozzumbo+, 2024

Non-parametric approach

PEDE Universe | Pantheon+ & ET Δ + CE



Non-parametric approach



Two birds with one method

DDE

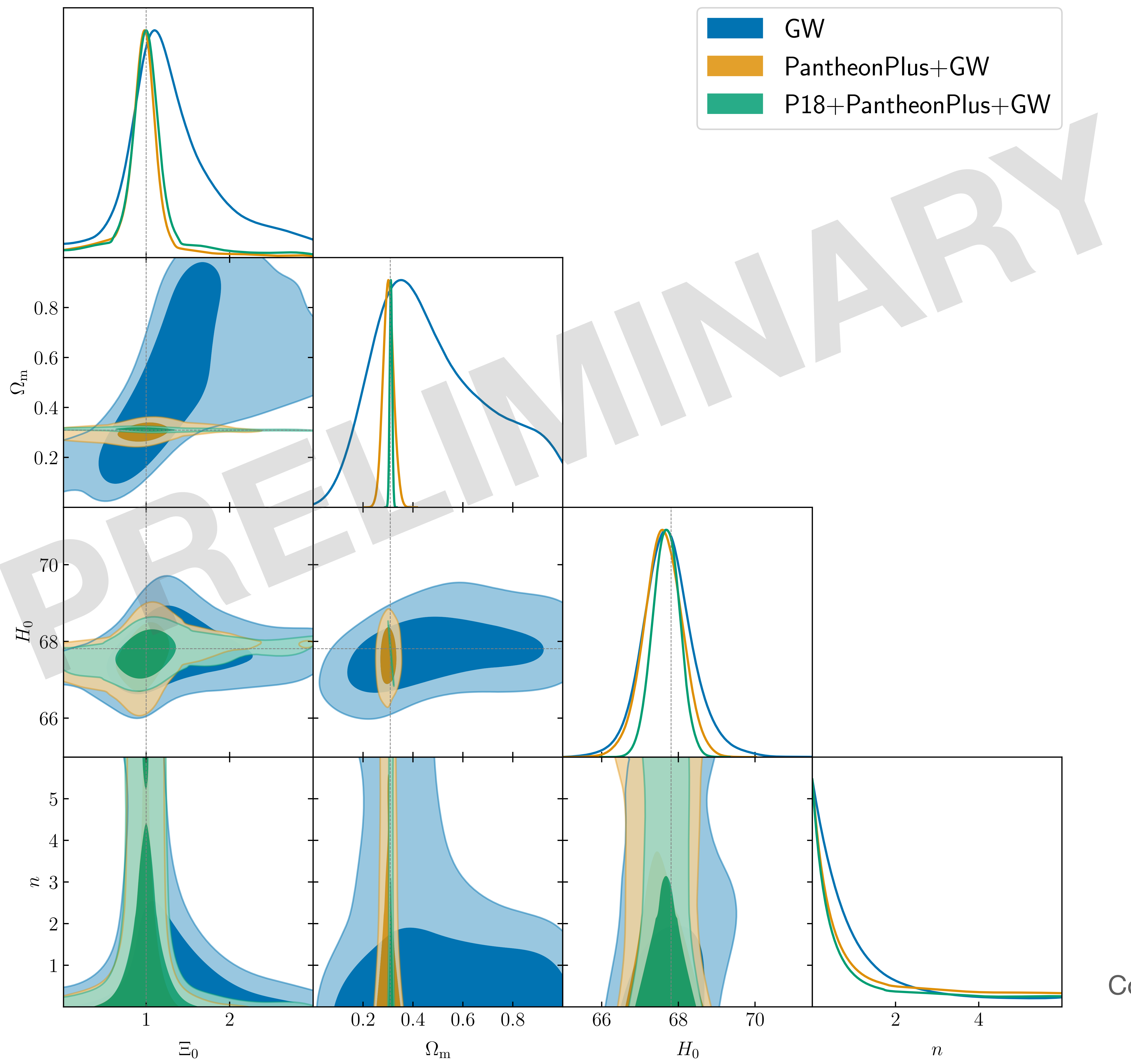
$$H(z) = H_0\sqrt{\Omega_{m,0}(1+z)^3 + \Omega_{\mathrm{DE},0}\,A(z)}$$

MG

$$\frac{d_L^{\mathrm{GW}}(z)}{d_L^{\mathrm{EM}}(z)} = \Xi_0 + \frac{1-\Xi_0}{(1+z)^n} = B(z)$$

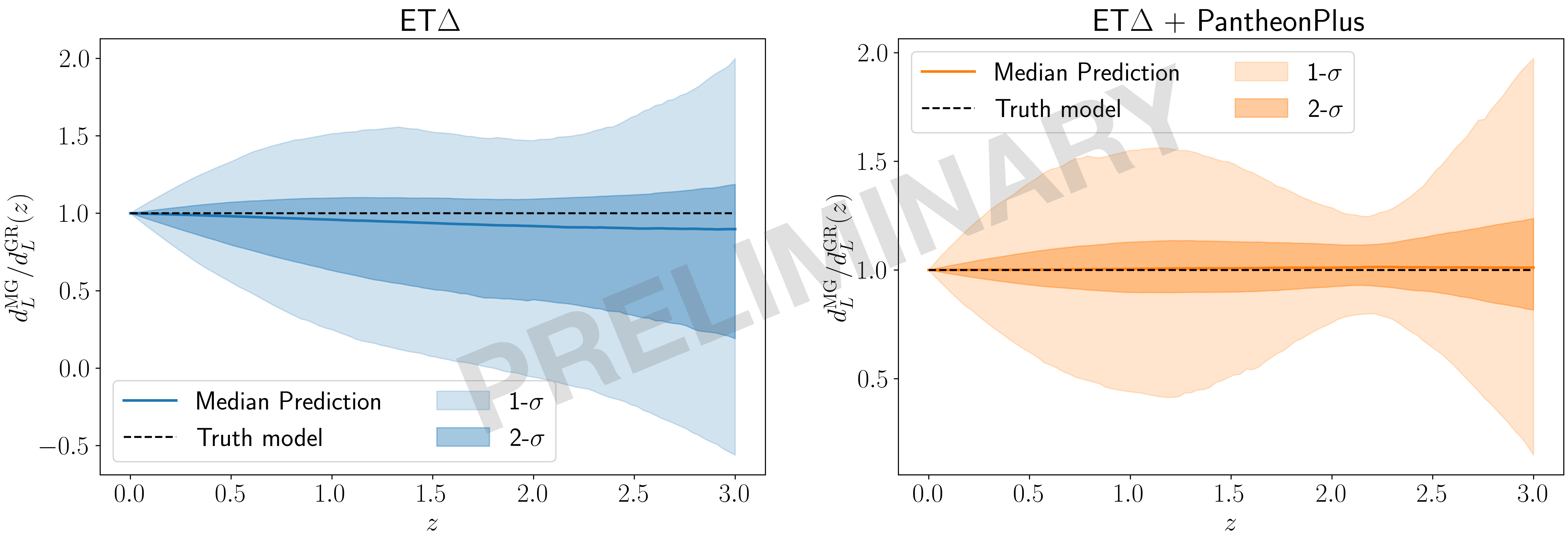
Modified gravity

ΛCDM Universe | ETΔ | 38 ev



Cozzumbo+, **in prep.**

Modified gravity



Cozzumbo+, **in prep.**

Conclusions

- We compare different catalogs of GRBs and configuration of 3G GW detectors to understand the **future prospects of cosmological constraints with Bright Sirens**

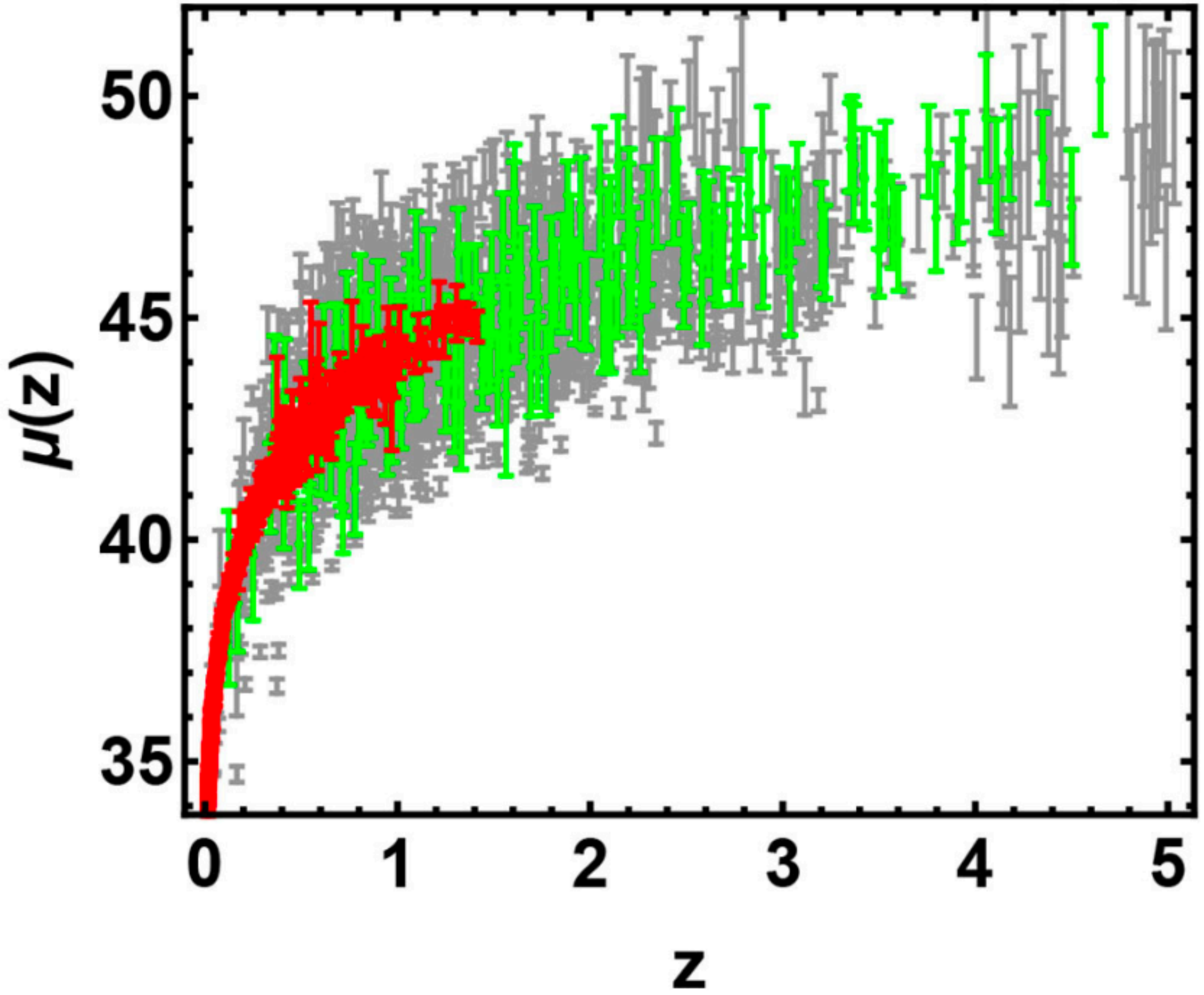
- We compare parametric and non-parametric approaches, underlining the **biases incurring when choosing the wrong fitting model**.
  The non-parametric reconstruction is a factor **~1.5 better** than the parametric one.

- We show the potential of a model-independent reconstruction for **Einstein Telescope and next generation cosmological probes**.
  With less than **40 GRBs** we will be able to achieve unprecendent precision on H_0 and Ω_m and accurately reconstruct the **DE density evolution** and the **nature of gravity**.

Backup

Standard candles

Demianski+ 2020

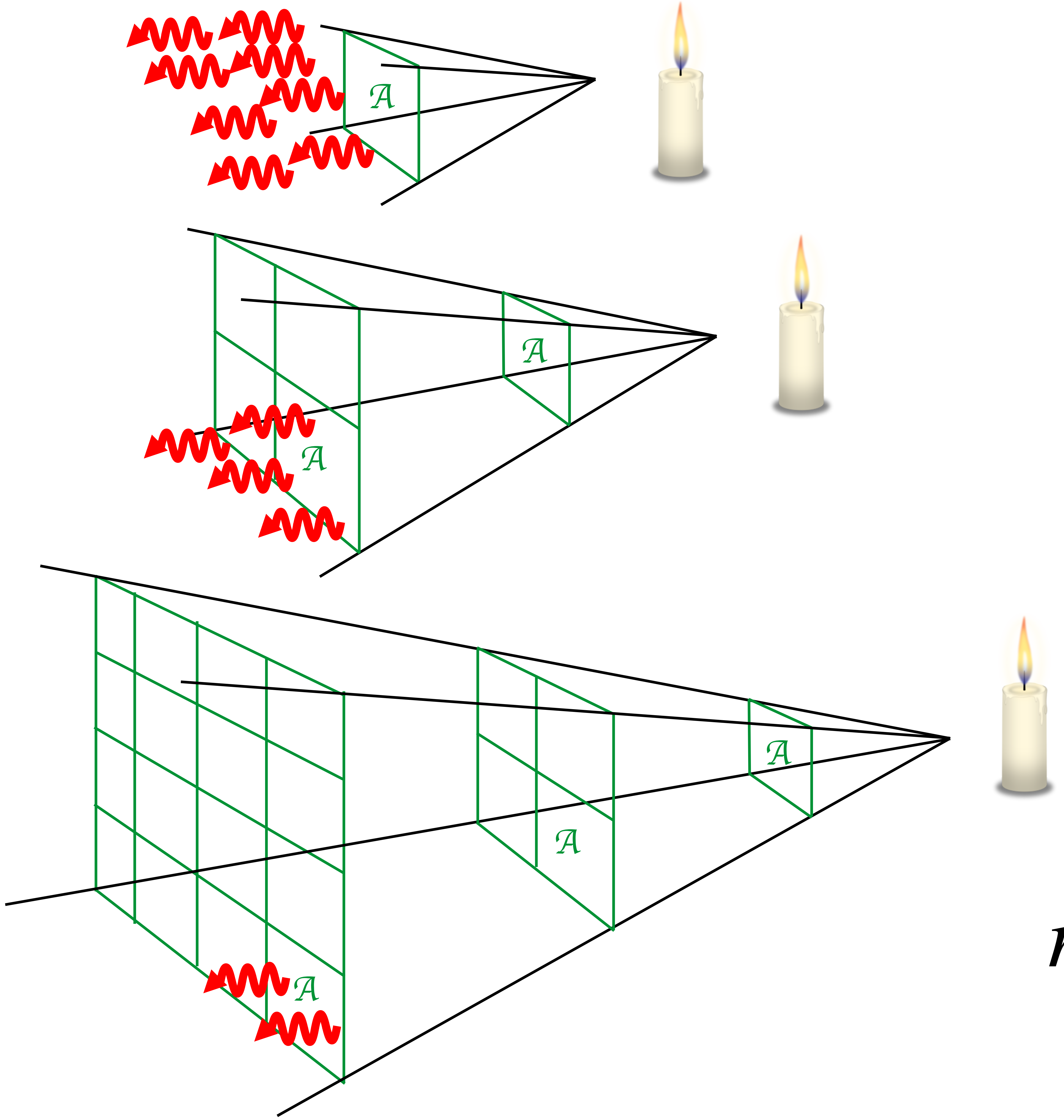


SNIa (Cepheids)

GRBs (SNIa)

QSOs (F_X - F_{UV})

Standard candles



$$d_L^2 = \frac{L}{4\pi F}$$

Related to absolute magnitude (M)

Measured

$$m - M = \mu = 5\log_{10}\left(\frac{d_L}{1\mathrm{Mpc}}\right) + 25$$

Modified gravity theories

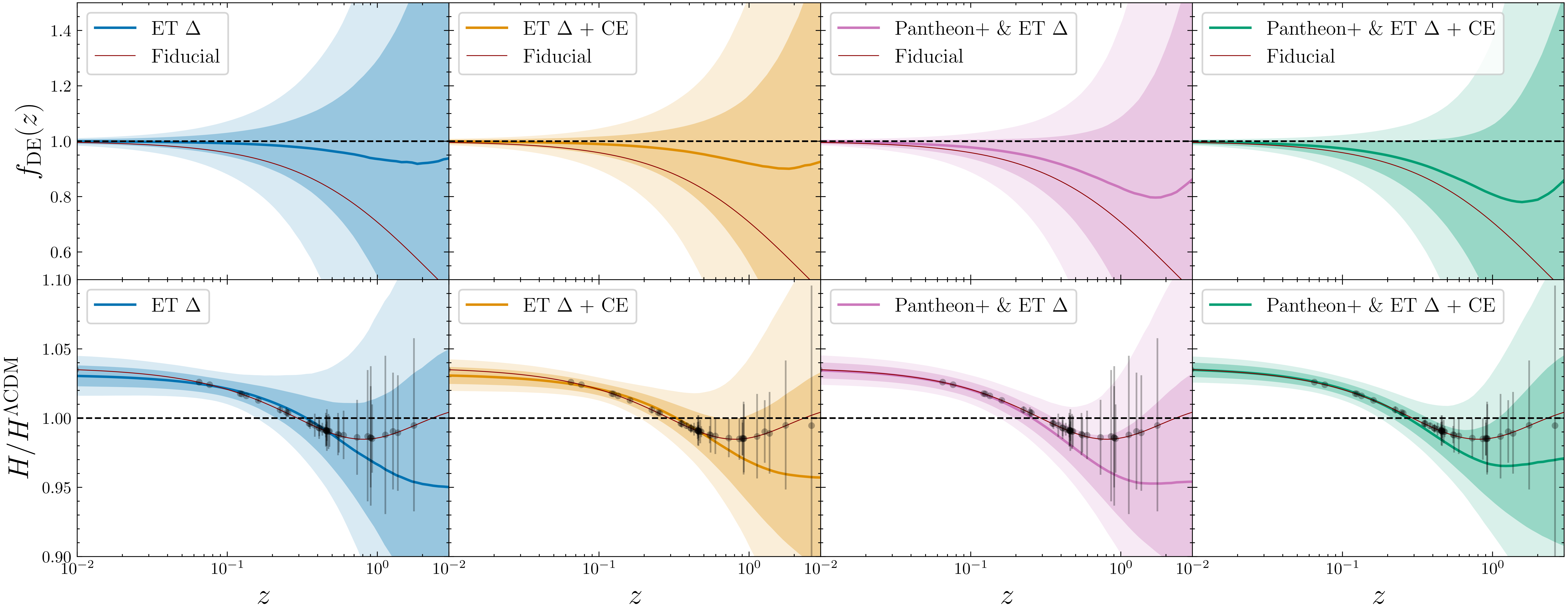
$$\tilde{h}''_A + 2\mathscr{H}\left[1-\delta(\eta)\right]\tilde{h}'_A + k^2\tilde{h}_A = 0$$

$$\frac{\tilde{a}'}{\tilde{a}} = \mathscr{H}\left[1-\delta(\eta)\right]$$

$$\tilde{h}_A \propto \frac{\tilde{a}(z)}{\tilde{a}(0)}\frac{a(0)}{a(z)}\frac{1}{d_L(z)} = \frac{\tilde{a}(z)}{a(z)}\frac{1}{d_L(z)} = \frac{1}{d_L^{\mathrm{GW}}(z)}$$

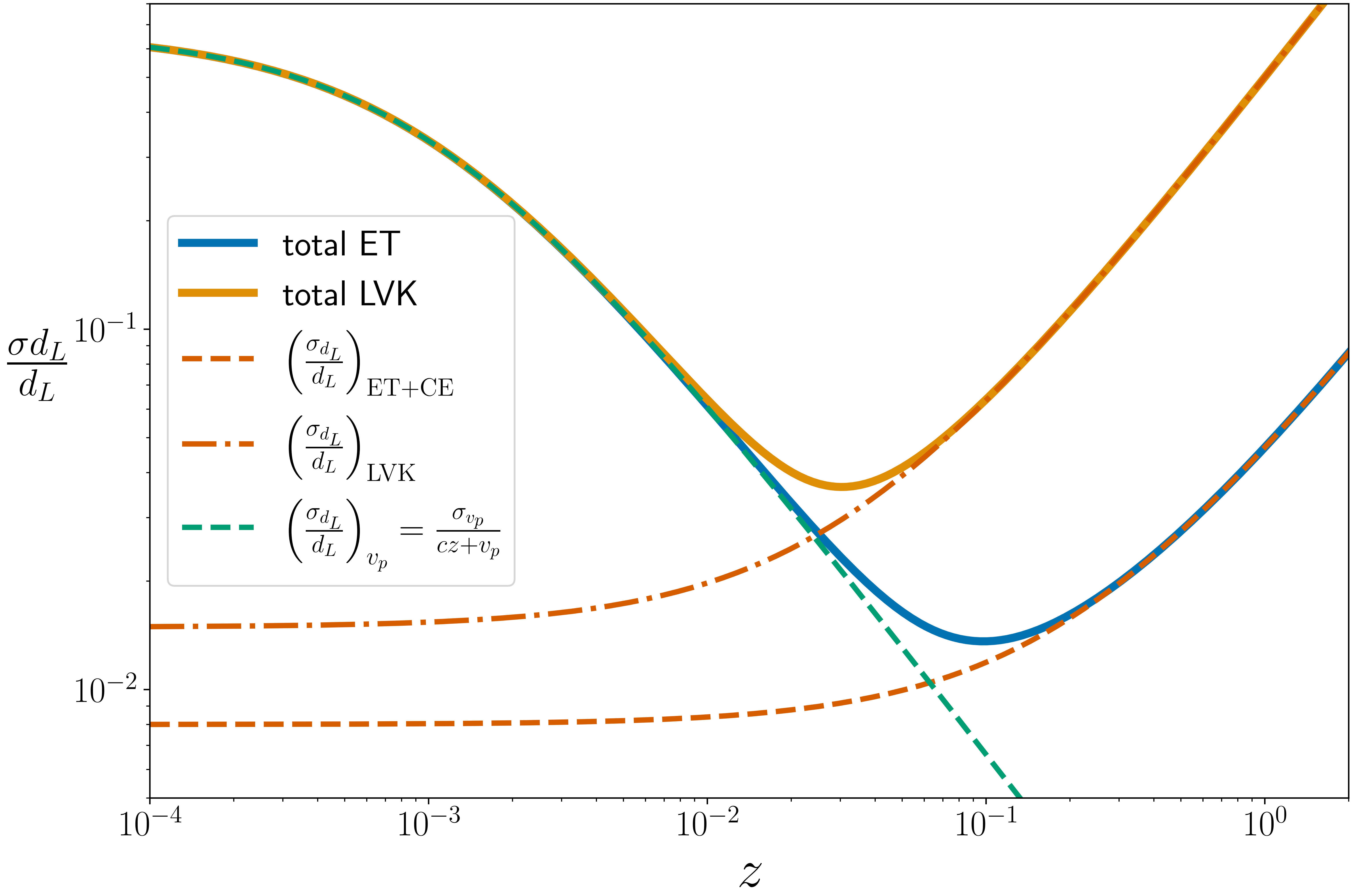
$$\frac{d_L^{\mathrm{GW}}(z)}{d_L^{\mathrm{EM}}(z)} = \Xi_0 + \frac{1-\Xi_0}{(1+z)^n}$$

Non-parametric approach

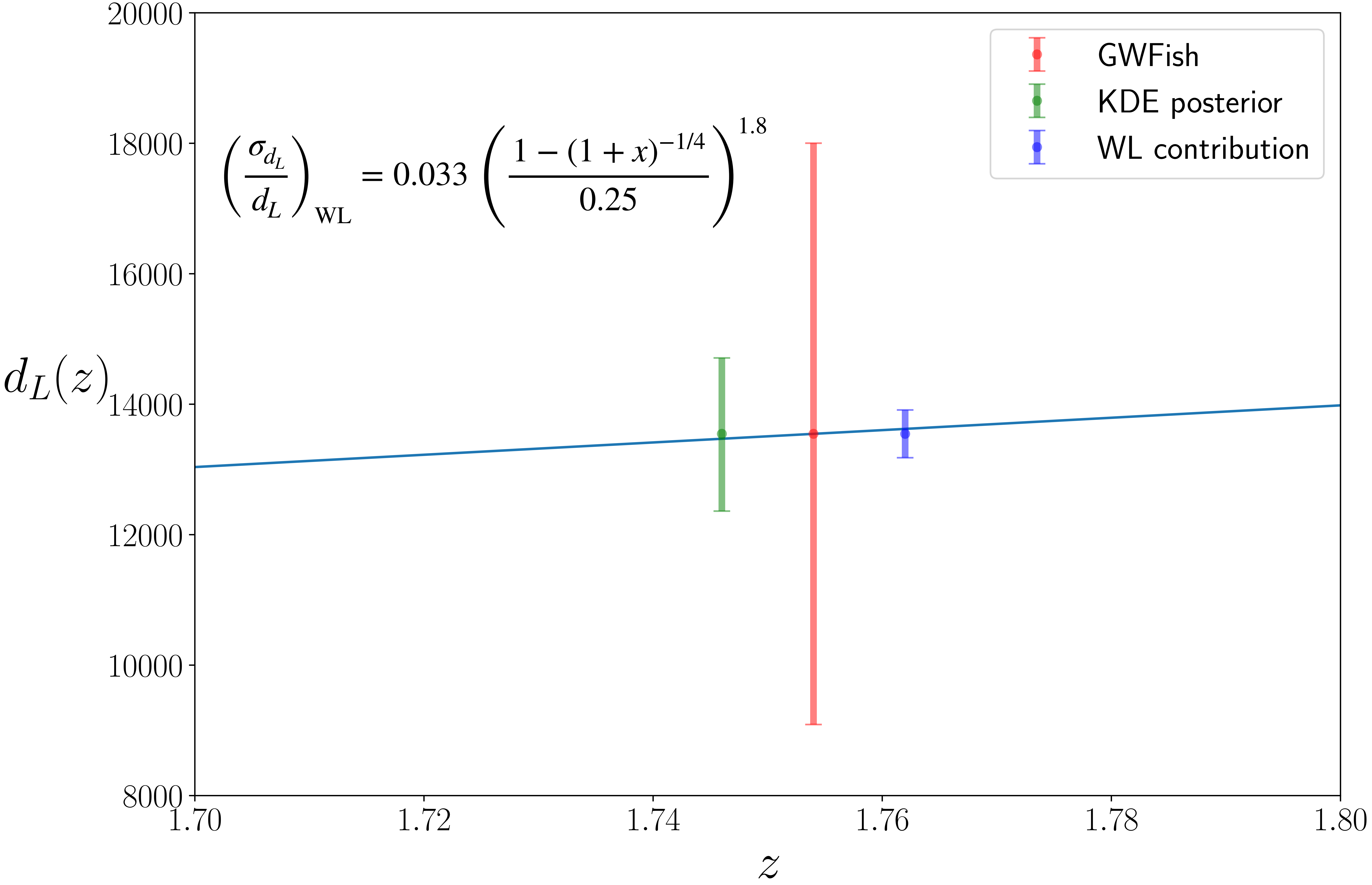


Cozzumbo+, 2024

Systematics



Systematics



PEDE

$$f_{\mathrm{DE}}(z) = 1 - \tanh\left(\log_{10}(1+z)\right)$$

$$w(z)^{\mathrm{PEDE}} = \frac{1}{3}\frac{d\ln f_{\mathrm{DE}}(z)}{dz} - 1 = -\frac{1}{3\ln 10}\left(1 + \tanh\left(\log_{10}(1+z)\right)\right)$$