Model-independent cosmology with Bright Sirens

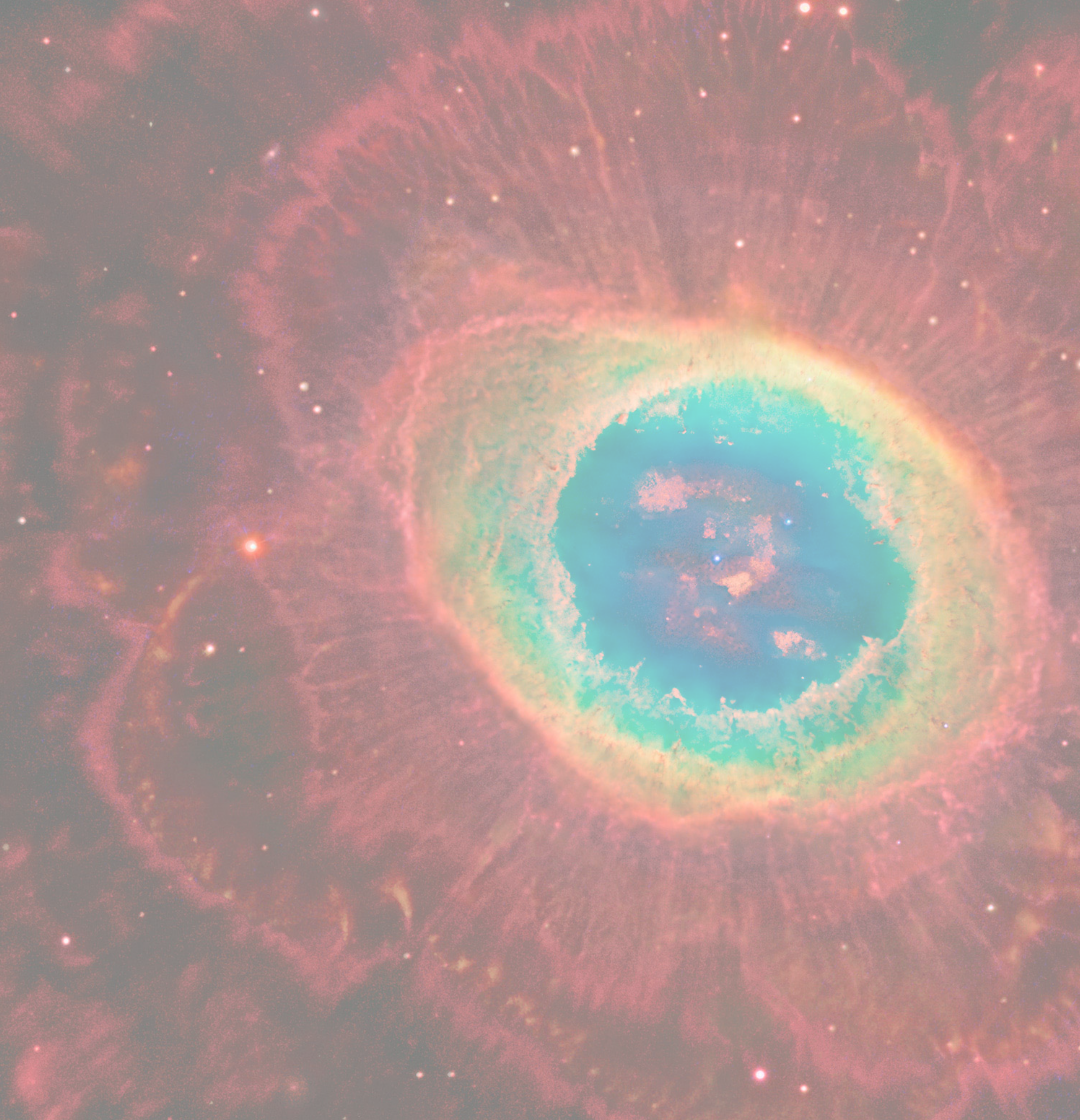
ModIC2024 - IFPU workshop - Trieste

Andrea Cozzumbo

Riccardo Murgia   Gor Oganesyan   Marica Branchesi

INFN LNGS

GSSI



Andrea Cozzumbo

in collaboration with

Ulyana Dupletsa   Rodrigo Calderón   Riccardo Murgia

Biswajit Banerjee   Gor Oganesyan   Marica Branchesi

Warm up

$$H(z) = H_0\sqrt{\Omega_{m,0}(1+z)^3 + \Omega_{r,0}(1+z)^4 + \Omega_{k,0}(1+z)^2 + \Omega_{\mathrm{DE},0}\,(1+z)^{3(1+w_{\mathrm{DE}}(z))}}$$

$$w_{\mathrm{DE}}(z) = \frac{P_{\mathrm{DE}}(z)}{\rho_{\mathrm{DE}}(z)}$$

$$f_{\mathrm{DE}}(z) = \frac{\Omega_{\mathrm{DE}}(z)}{\Omega_{\mathrm{DE},0}}$$

Warm up

$$H(z) = H_0\sqrt{\Omega_{m,0}(1+z)^3 + \Omega_{r,0}(1+z)^4 + \Omega_{k,0}(1+z)^2 + \Omega_{\mathrm{DE},0}\, f_{\mathrm{DE}}(z)}$$

$$w_{\mathrm{DE}}(z) = \frac{P_{\mathrm{DE}}(z)}{\rho_{\mathrm{DE}}(z)} \qquad f_{\mathrm{DE}}(z) = \frac{\Omega_{\mathrm{DE}}(z)}{\Omega_{\mathrm{DE},0}}$$

Warm up

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

$$w_{\mathrm{DE}}(z) = \frac{P_{\mathrm{DE}}(z)}{\rho_{\mathrm{DE}}(z)}$$

$$f_{\mathrm{DE}}(z) = \frac{\Omega_{\mathrm{DE}}(z)}{\Omega_{\mathrm{DE},0}}$$

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

We want to trace the Hubble parameter $H(z)$

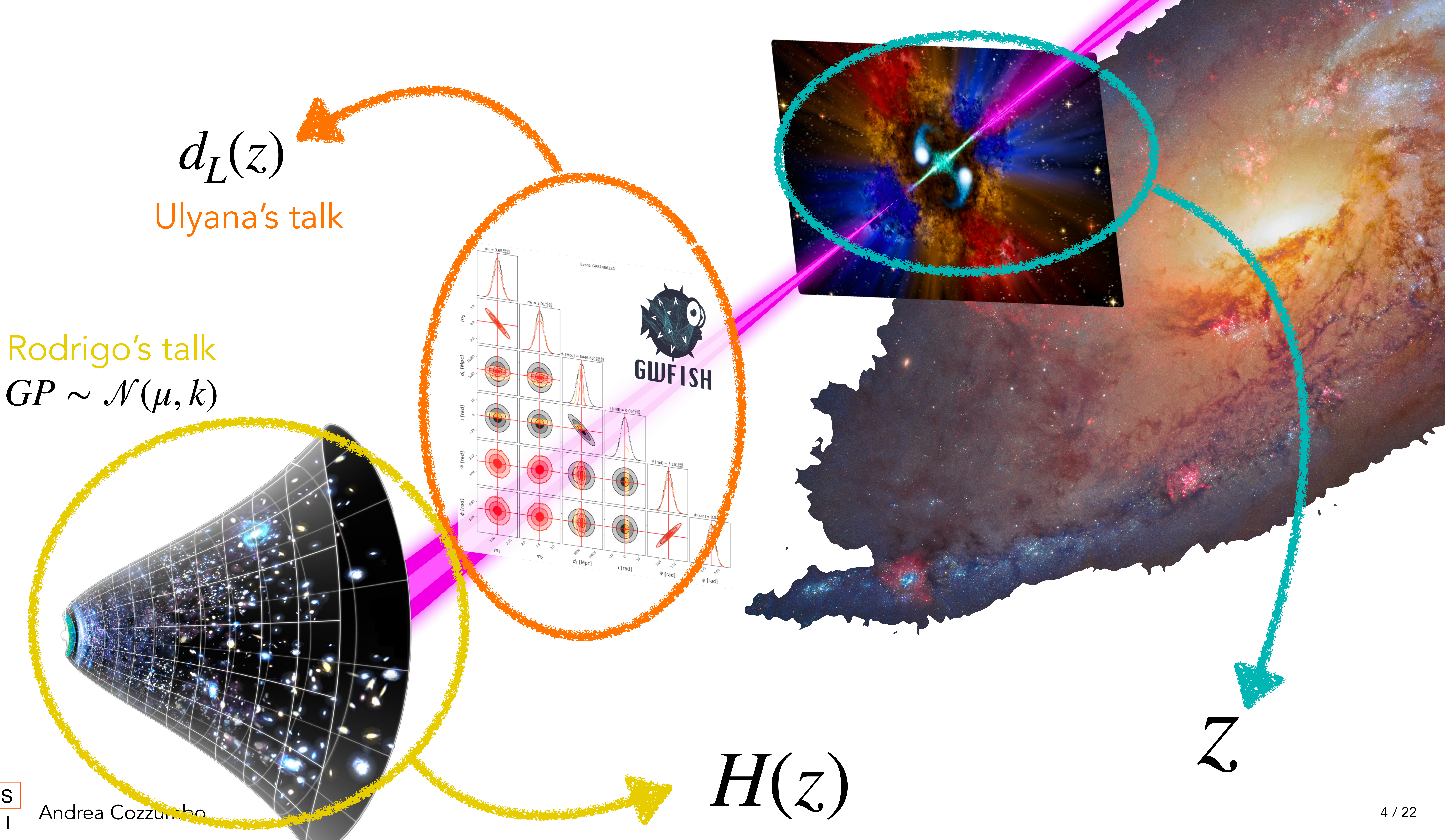
Why GWs

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

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

self calibrated measure of distance

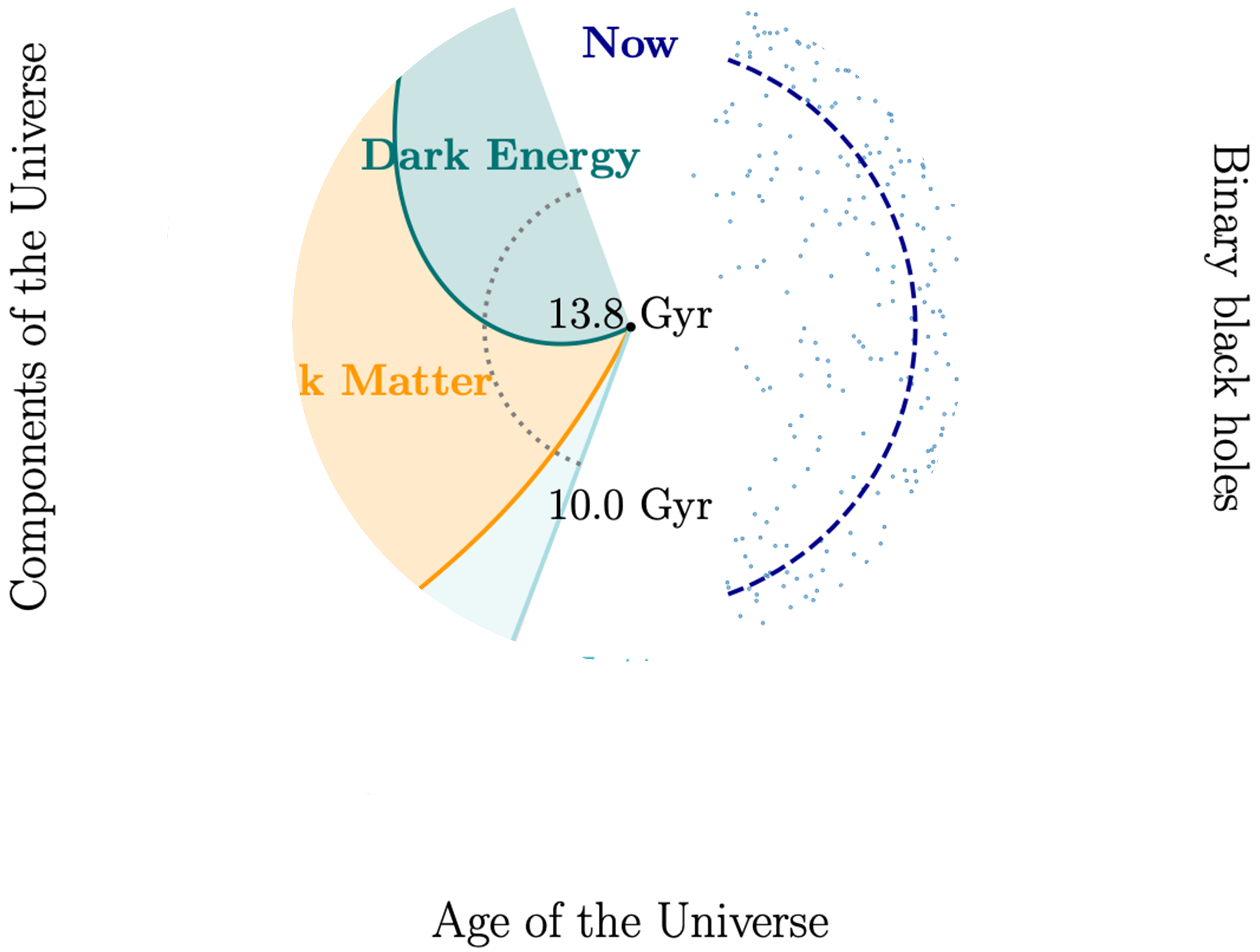
$$d_L(z) = c\,(1 + \overset{?}{z}) \int_0^z \frac{dz'}{H(z')}$$


$d_L(z)$
Ulyana's talk
Rodrigo's talk
$GP \sim \mathcal{N}(\mu, k)$
GWFISH
$H(z)$
z

Why 3G

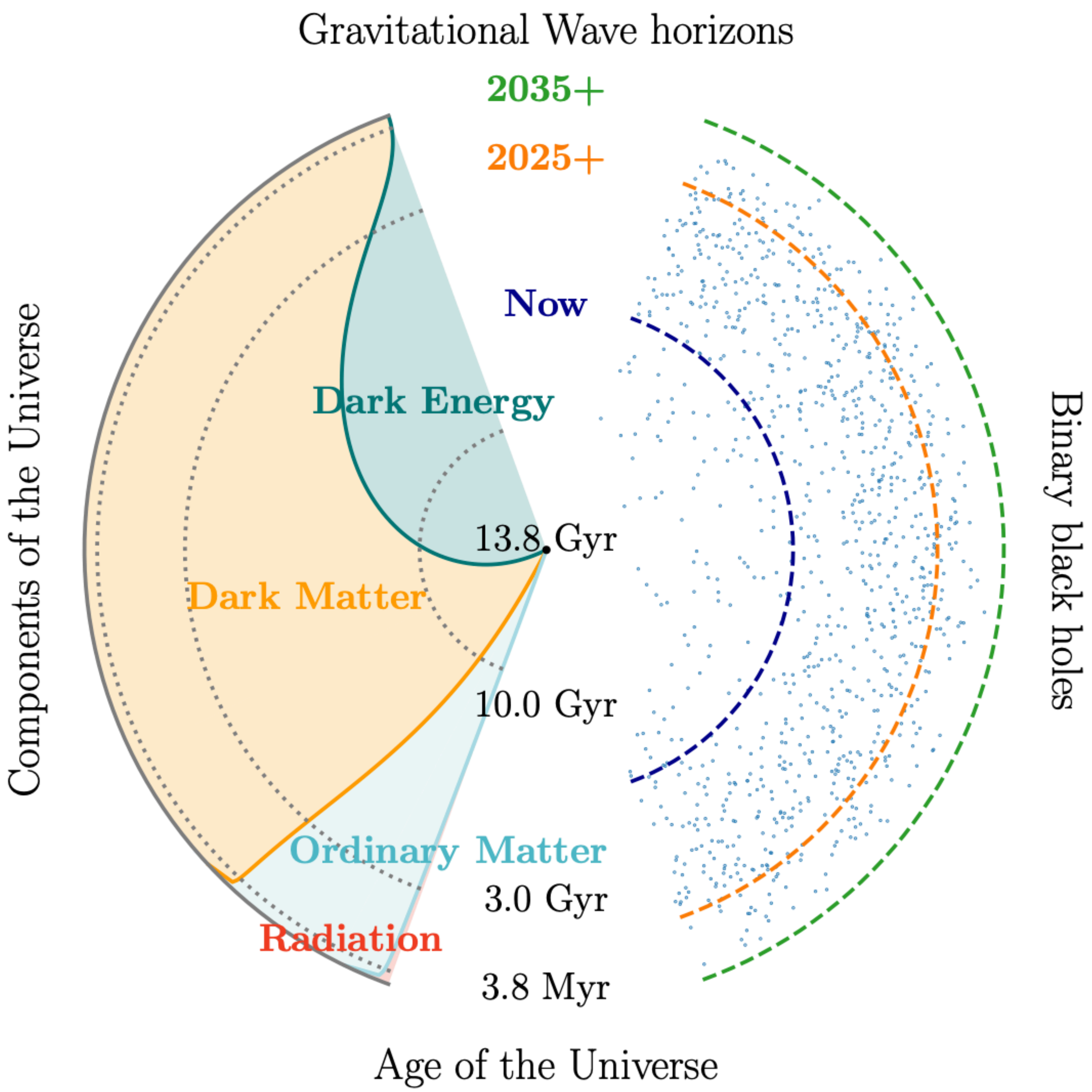
Gravitational Wave horizons

Chen+, 2024



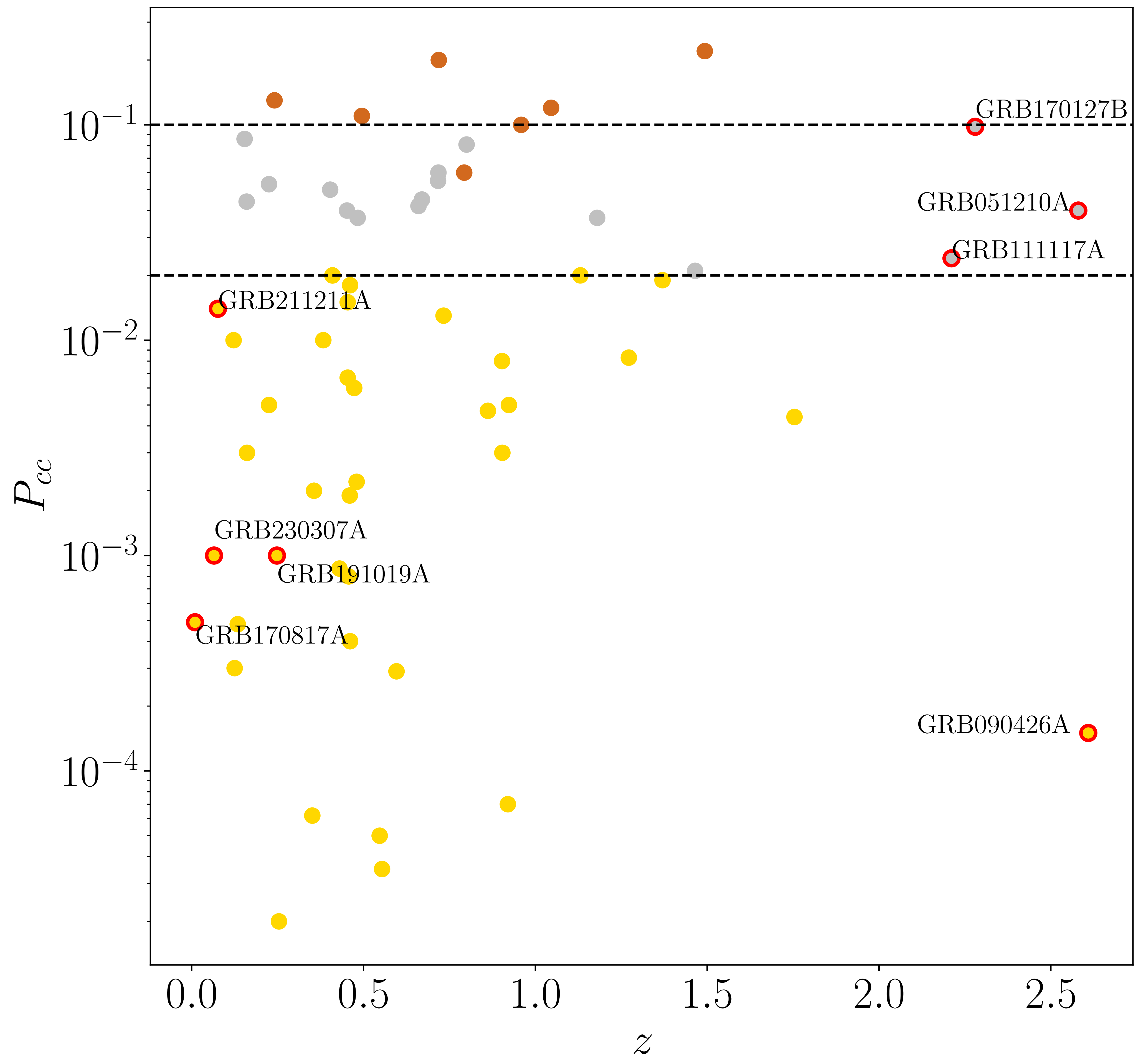
Why 3G

Chen+, 2024



GRB data set

Cozzumbo+, **in prep.**

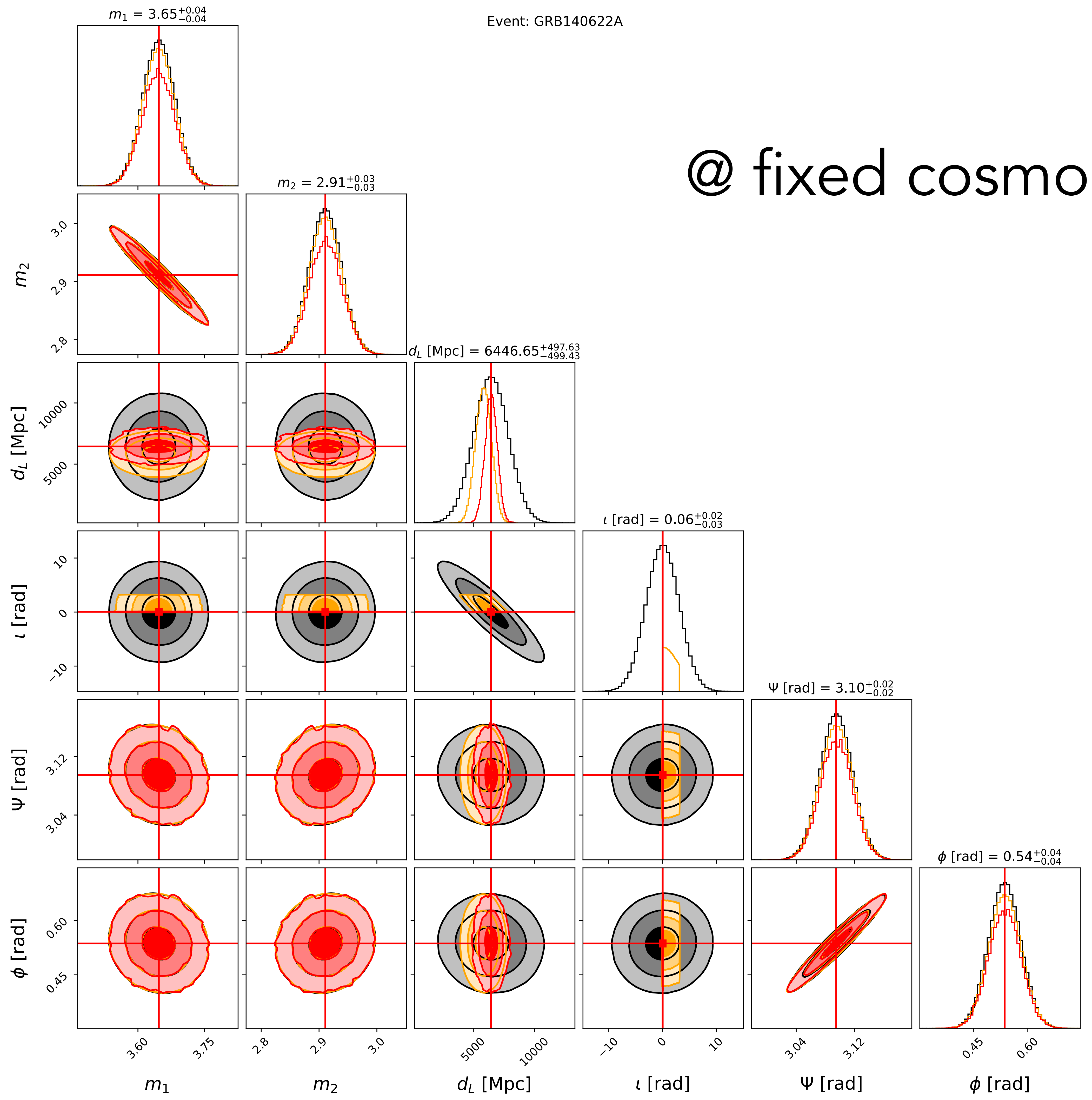


- Fermi-GBM & Swift-BAT/UVOT/XRT
- Merger-driven GRB events
- $\Delta z \leq 7\,\%$

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

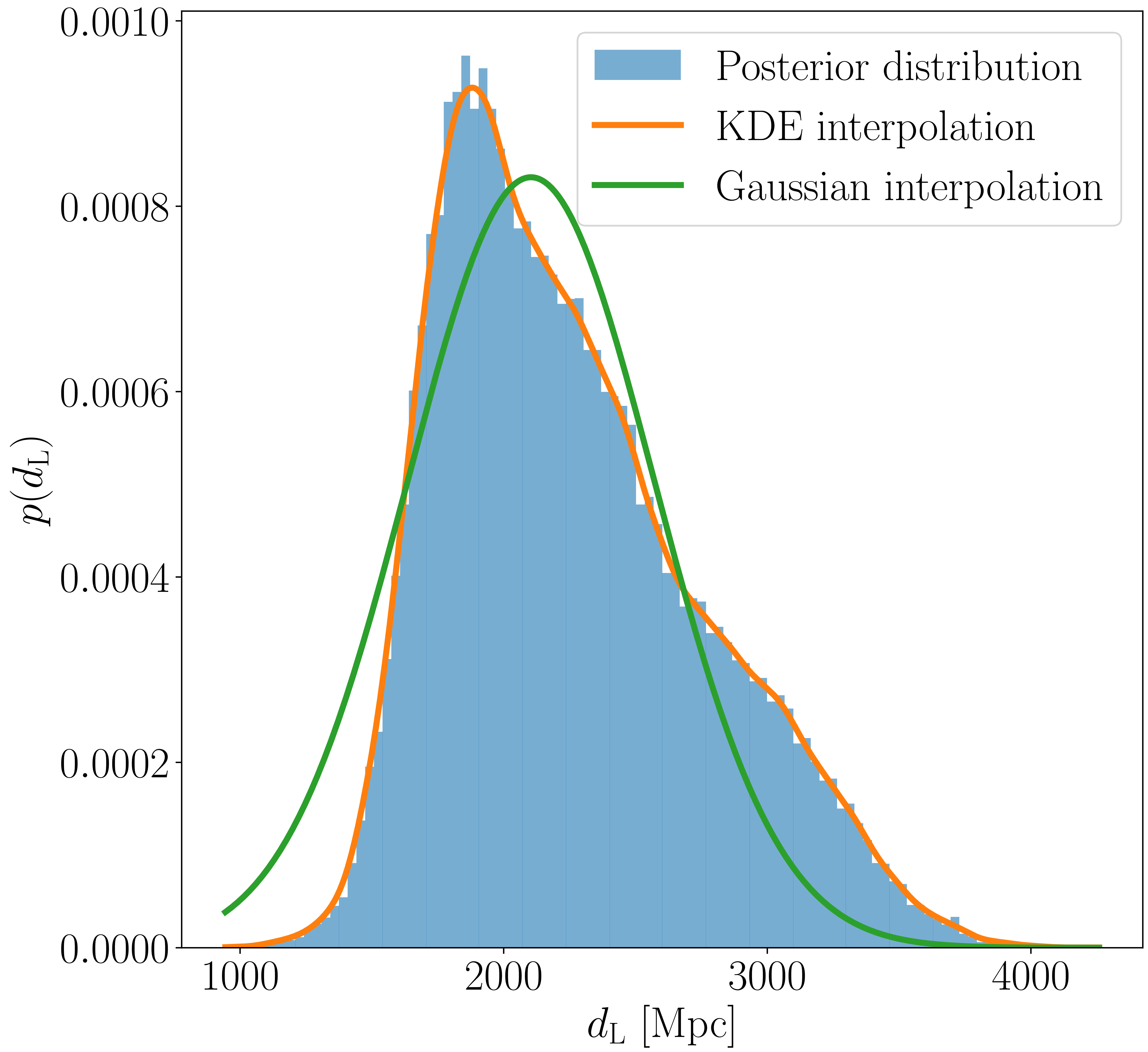
GW posteriors

Dupletsa+, 2024

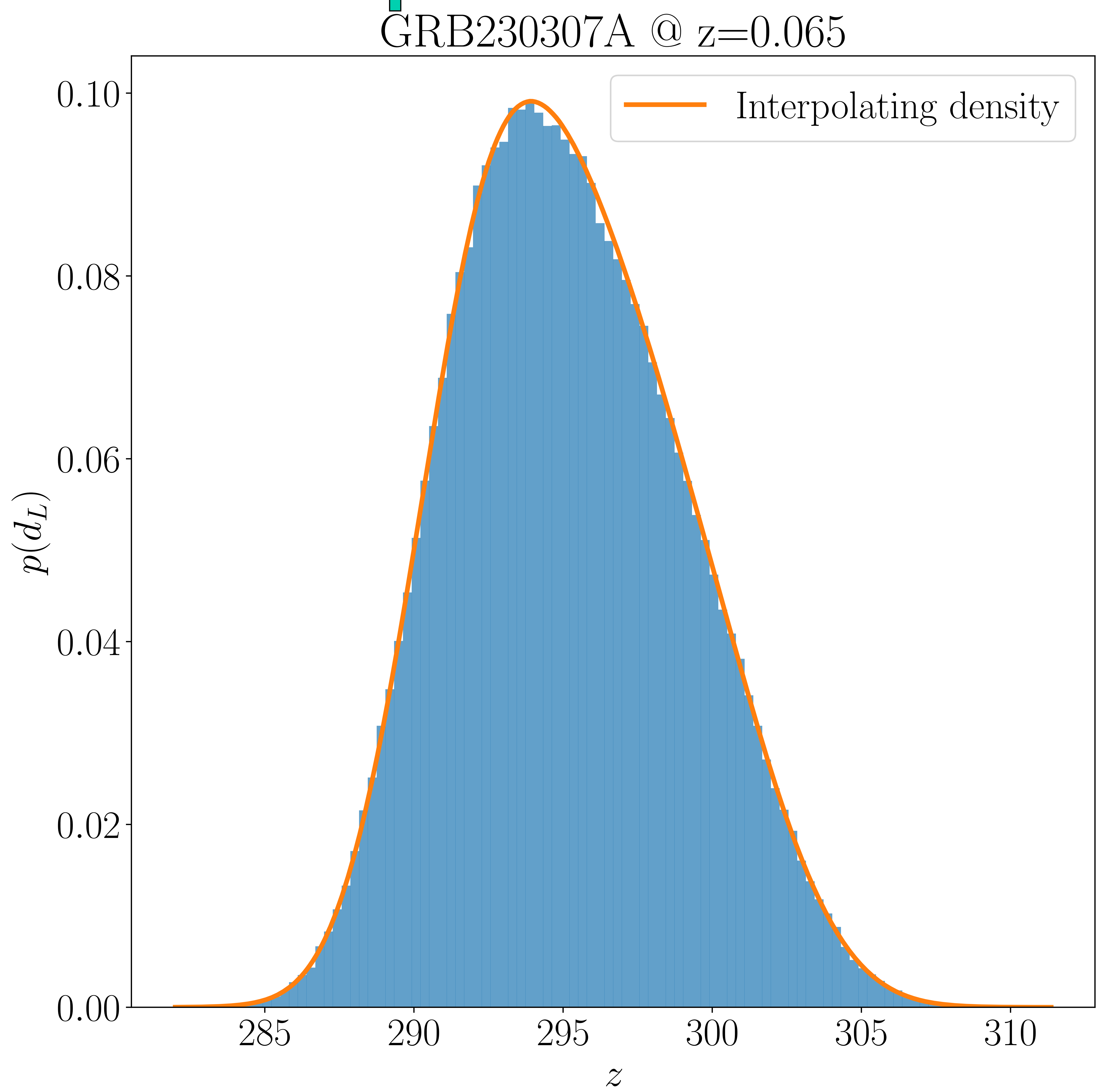


@ fixed cosmology

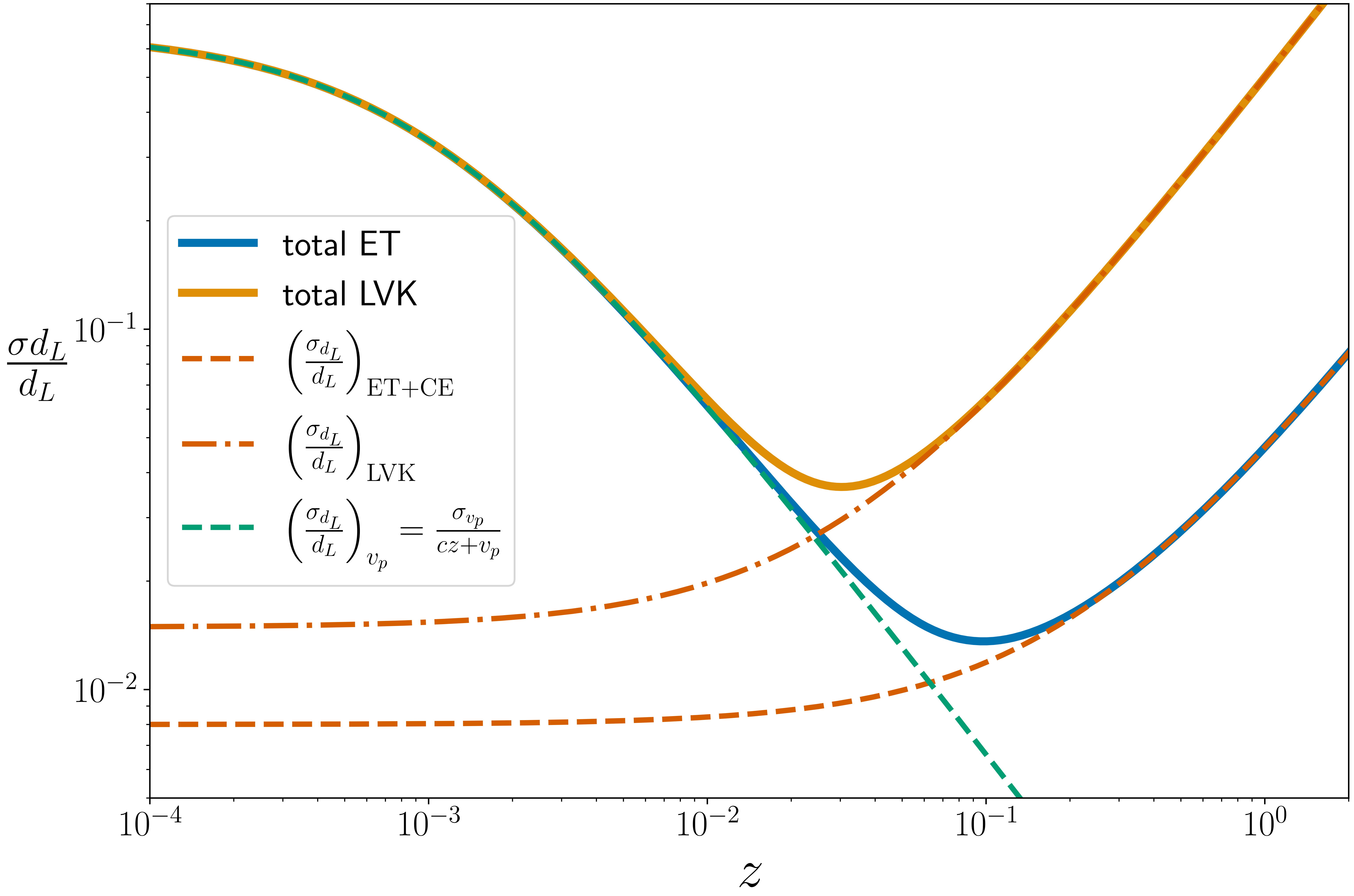
GW posteriors



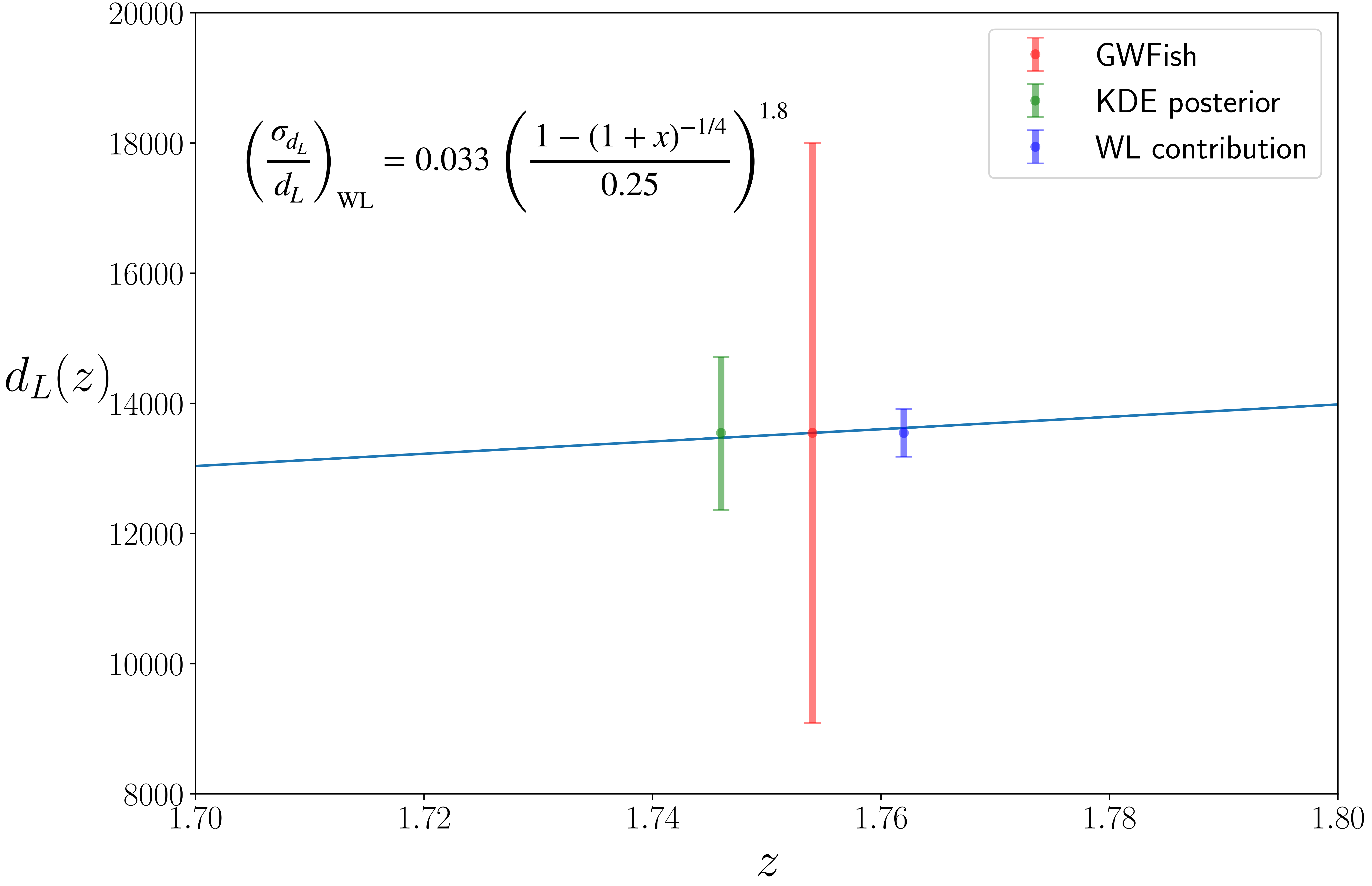
GW posteriors



Systematics



Systematics



Cosmological MCMC

$$\log \mathscr{L}(\theta) \propto \sum_{i}^{\mathrm{N_{events}}} - \frac{\left(d_L^{\mathrm{th}}(\theta) - d_L^{\mathrm{obs},i}\right)^2}{2\sigma^2_{d_L,i}}$$

Cosmological MCMC

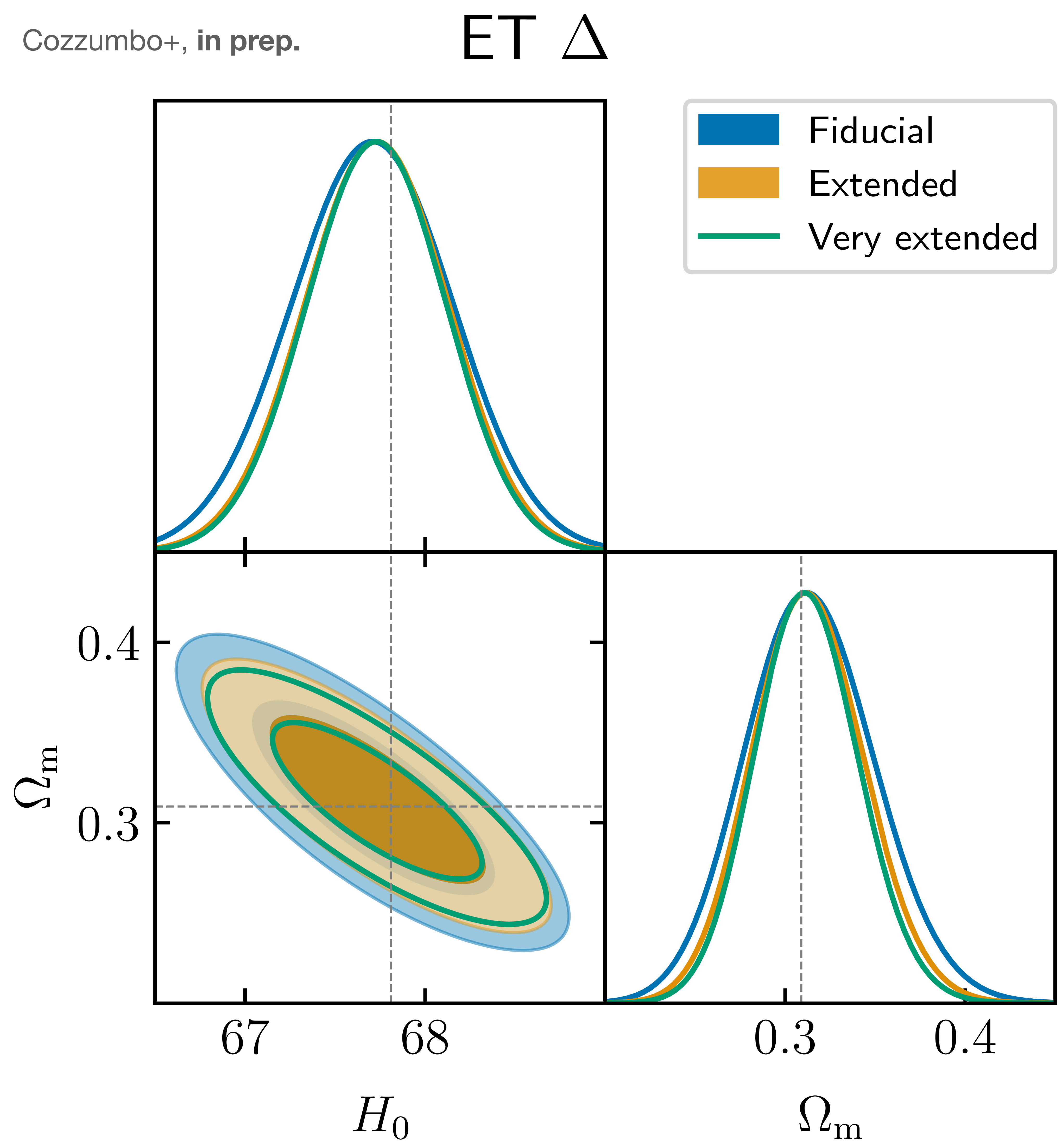
$$\log \mathscr{L}(\theta) \propto \sum_{i}^{\mathrm{N_{events}}} \mathscr{K}^{i}\left(d_L^{\mathrm{th}}\right)$$

COBAYA

MontePython CLASS

Parametric approach

Cozzumbo+, **in prep.**



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

$$w(z)^{\Lambda CDM} = w^{\Lambda CDM} = -1$$

$$f_{DE}(z) = (1+z)^{3\left(1+w^{\Lambda CDM}\right)} = 1$$

Parametric approach

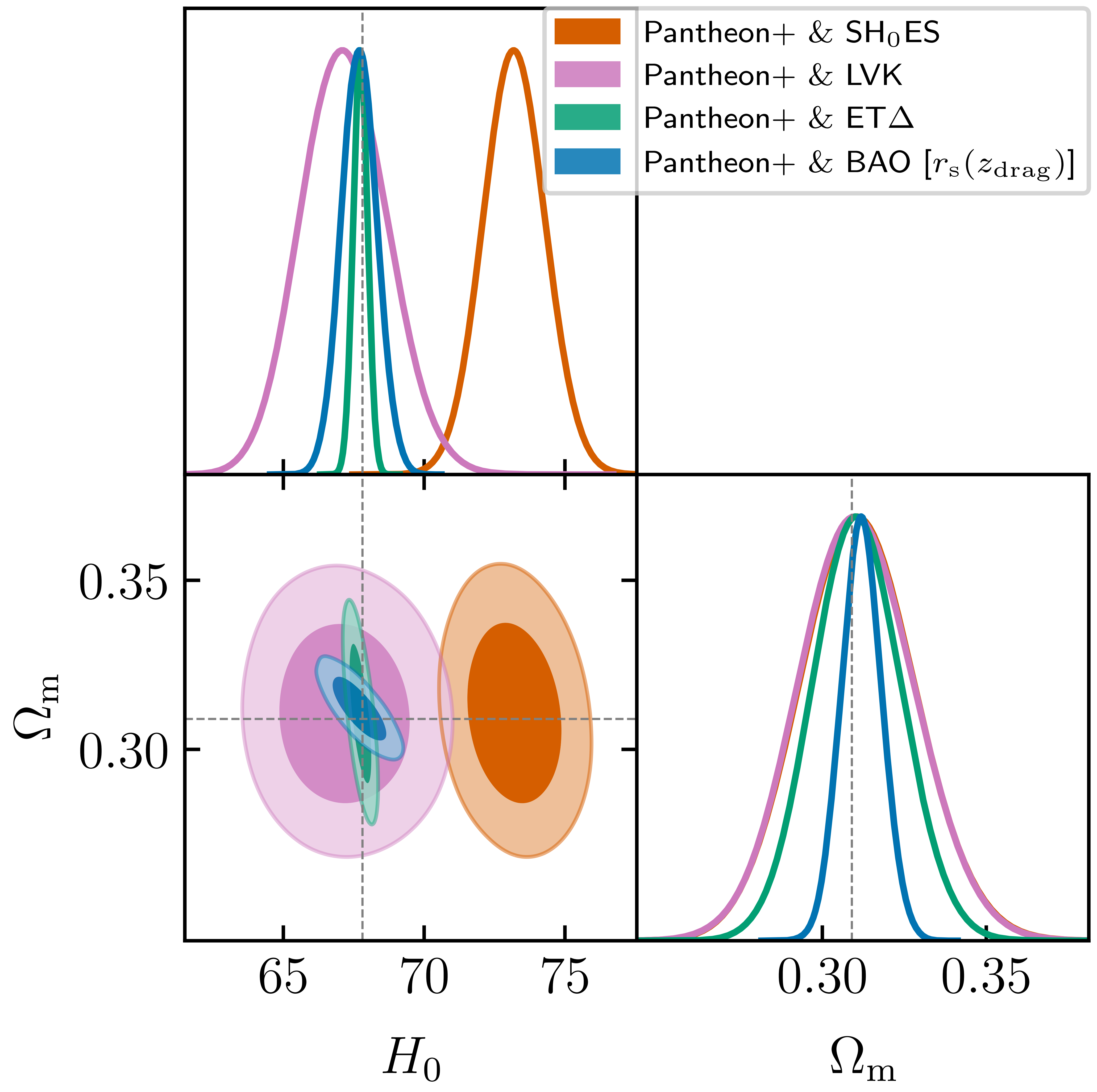


Figure of Merit (FoM)

MOD1 | ΛCDM fit

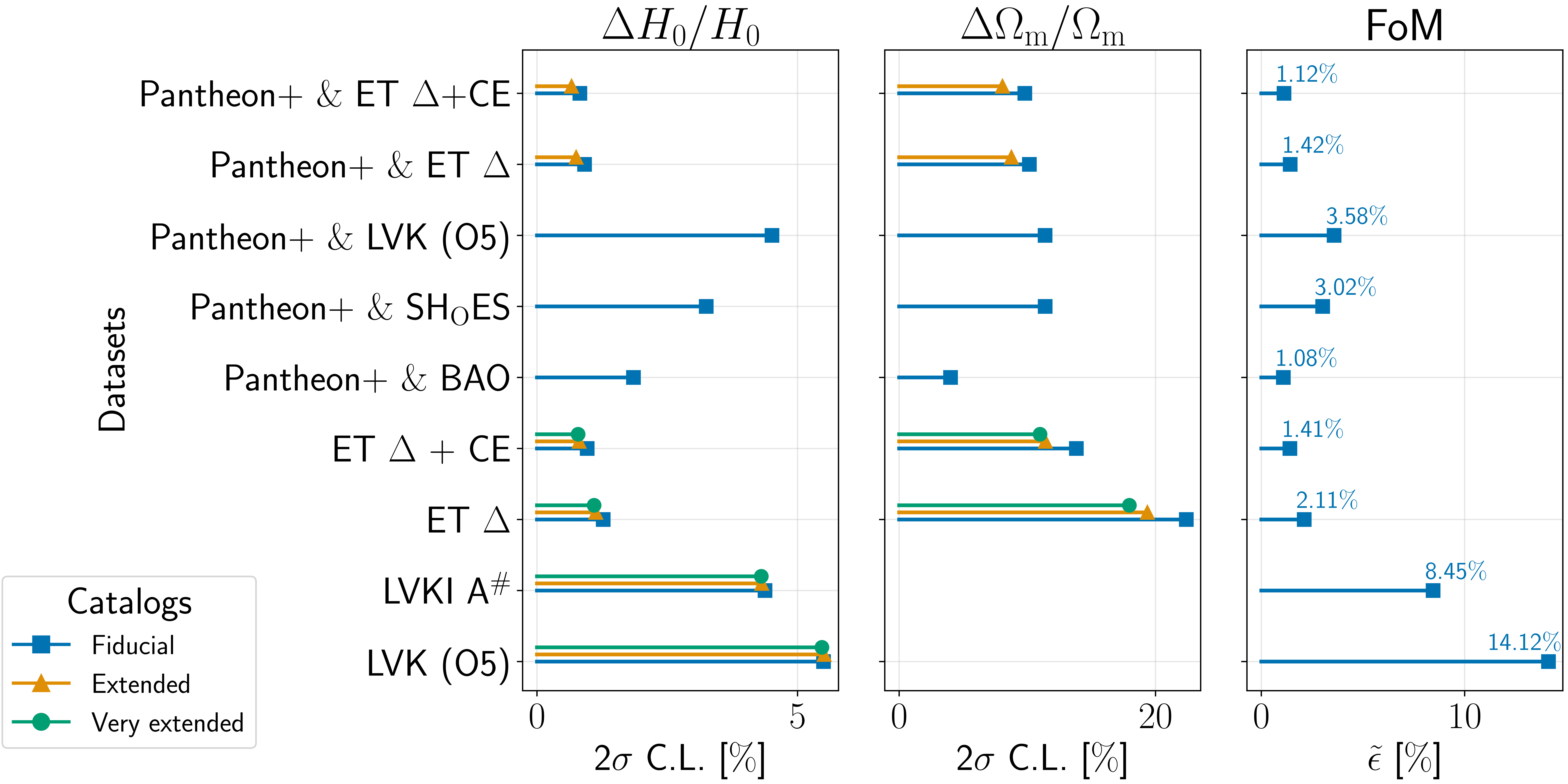


Figure of Merit (FoM)

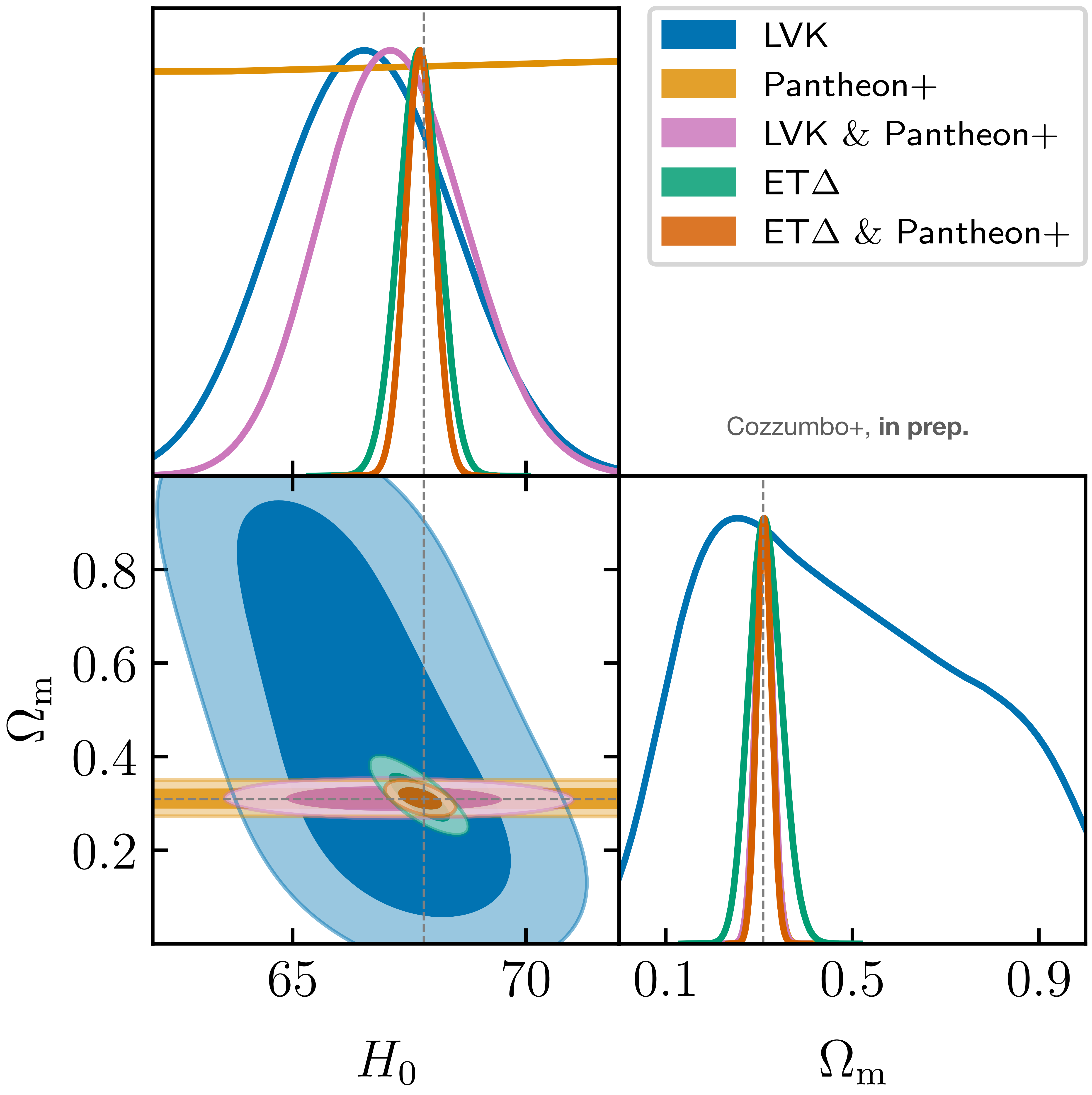
Hirata & Eisenstein, 2009

$$\mathrm{FoM}_X = \left[\det \mathscr{C}_X(\theta_c)\right]^{-1/2}$$

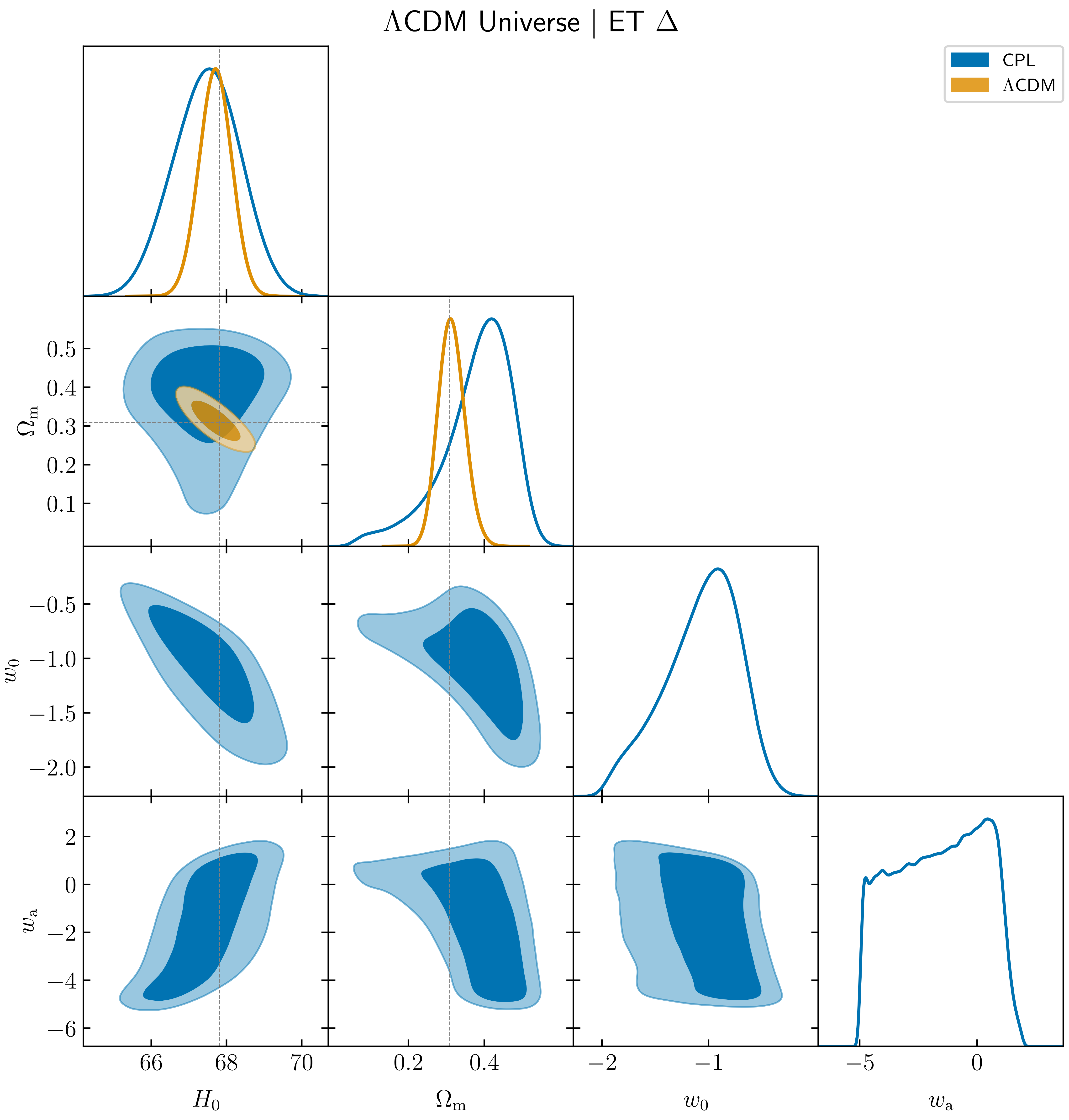
$$\mathrm{FoM}_X^{\mathrm{ref}} = \left[\det \begin{pmatrix} \sigma_{H_0}^2 & 0 \\ 0 & \sigma_{\Omega_\mathrm{m}}^2 \end{pmatrix}\right]^{-1/2} \overset{\frac{\sigma_{\theta_c}}{\bar{\theta}_c}}{=} \left[\det \begin{pmatrix} \epsilon_X^2\, \bar{H}_0^2 & 0 \\ 0 & \epsilon_X^2\, \bar{\Omega}_\mathrm{m}^2 \end{pmatrix}\right]^{-1/2} = \frac{1}{\epsilon_X^2 \bar{H}_0\, \bar{\Omega}_\mathrm{m}}$$

$$\tilde{\epsilon}_X = \sqrt{\frac{1}{\mathrm{FoM}_X \bar{H}_0\, \bar{\Omega}_\mathrm{m}}}$$

Parametric approach



Parametric approach



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

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

$$f_{DE}(z) = (1+z)^{3(1+w(z))}$$

Cozzumbo+, **in prep.**

Non-parametric approach

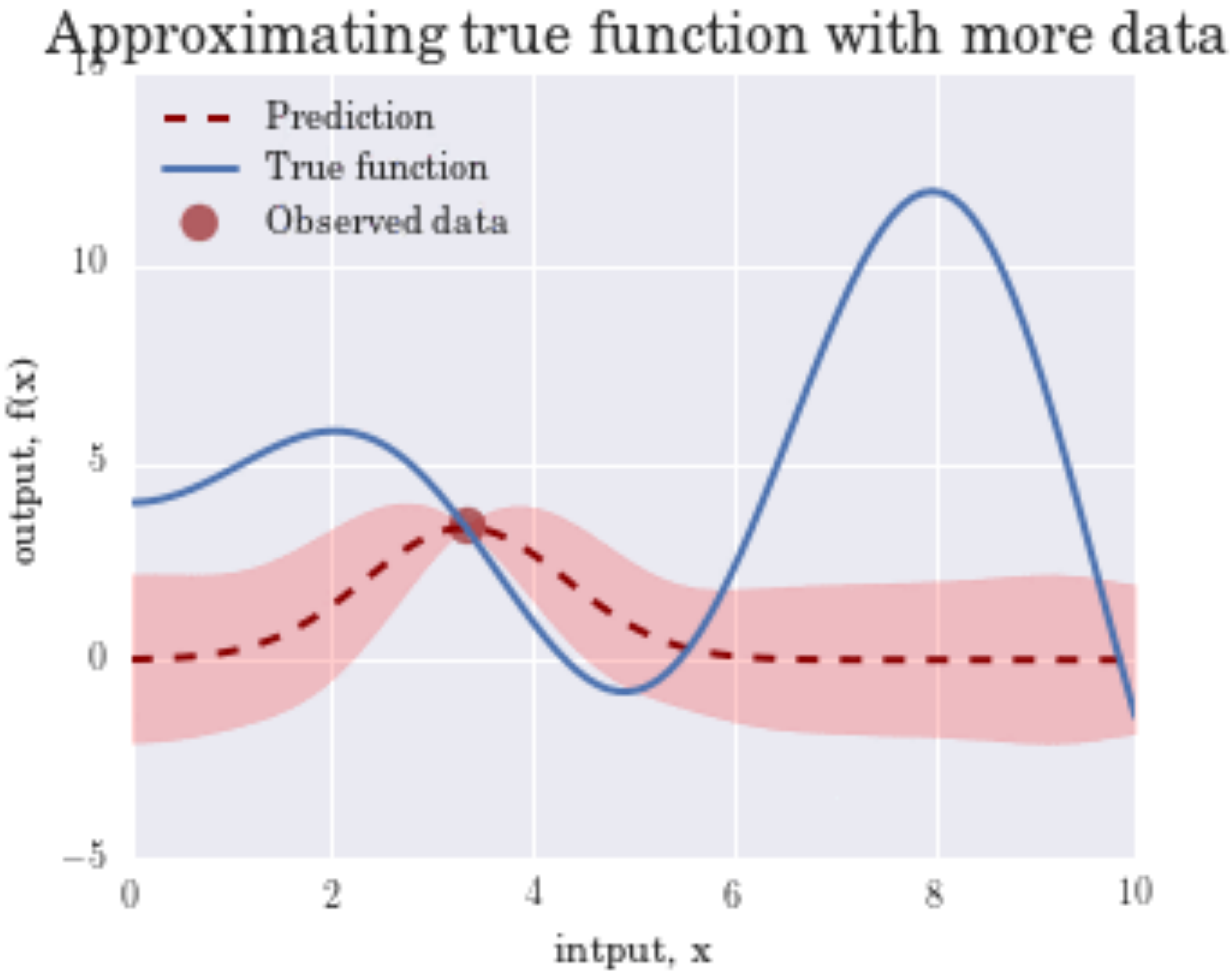
GP → Gaussian Process

$$GP \sim \mathcal{N}(\mu, k)$$

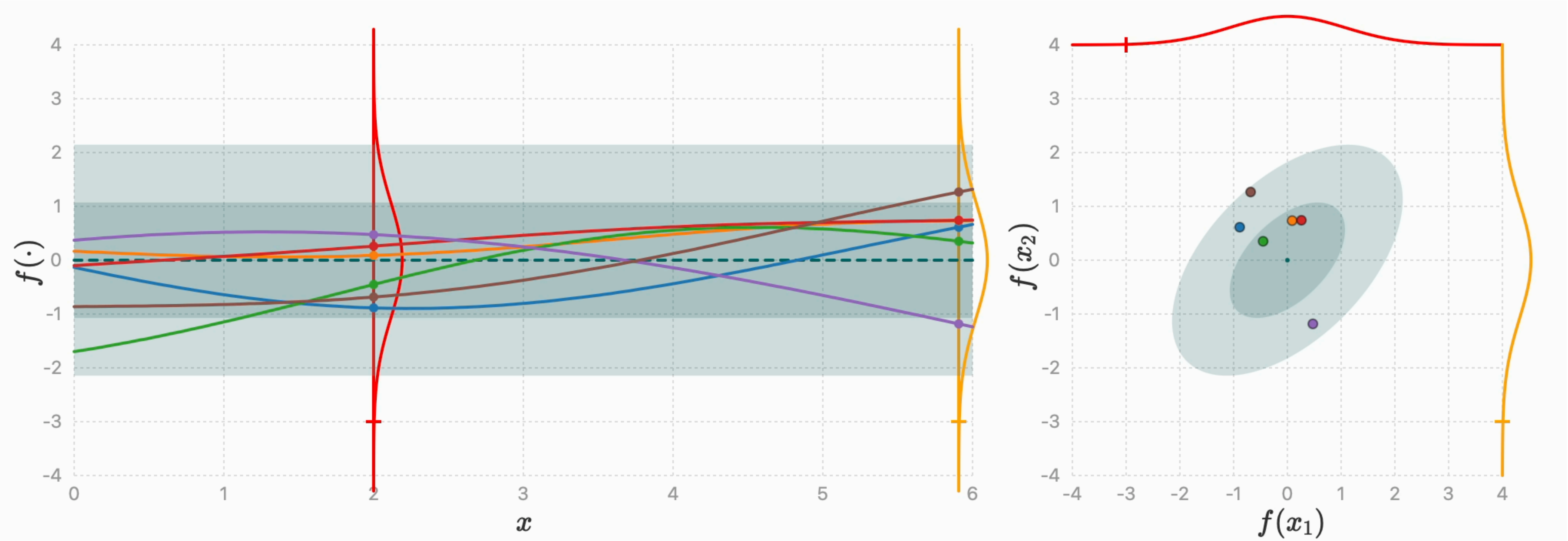
$$h^2(z) = \frac{H^2(z)}{H_0^2} = \Omega_{m,0}(1+z)^3 + (1-\Omega_{m,0})f_{\mathrm{DE}}(z)$$

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

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



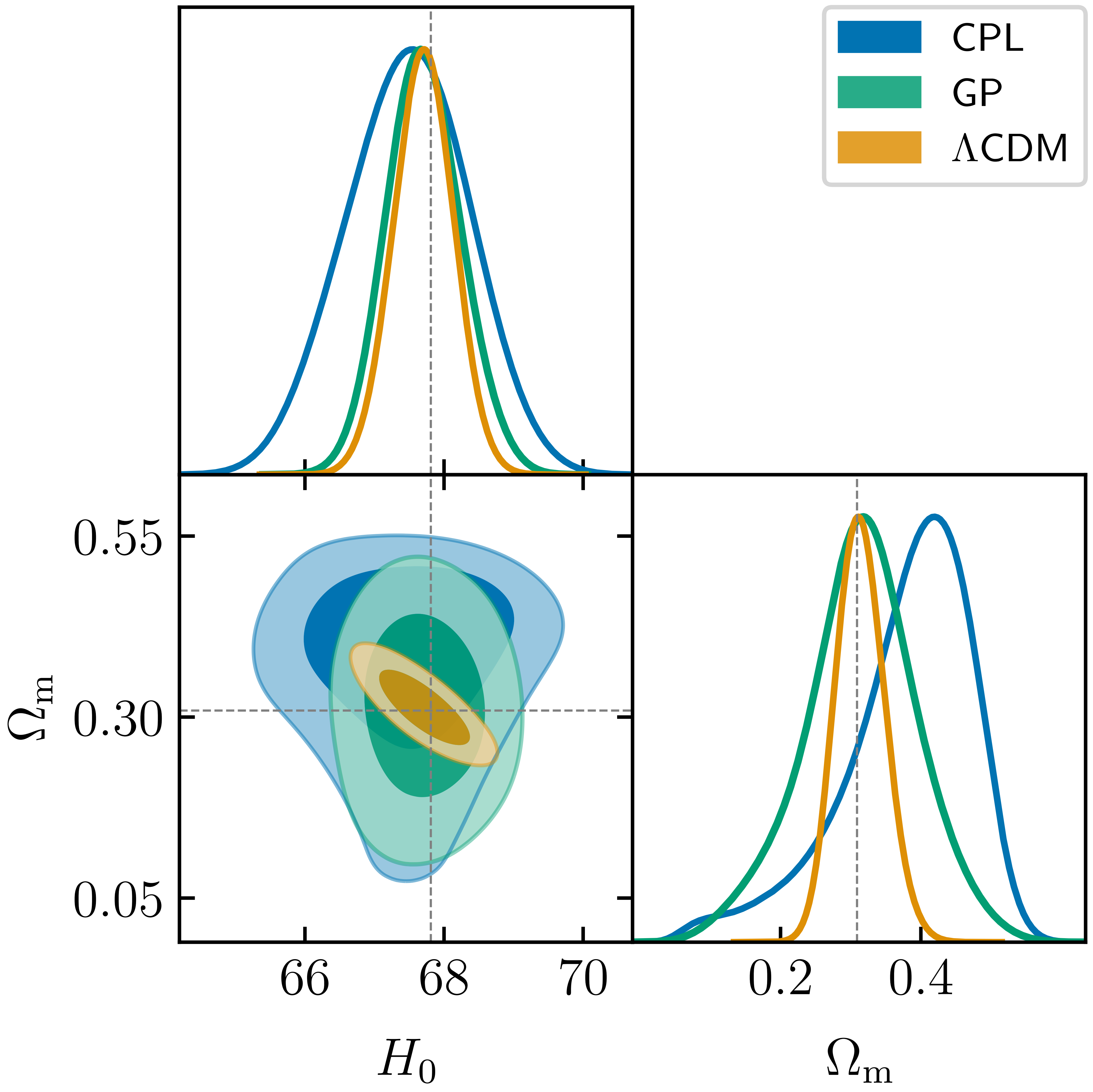
Non-parametric approach



Untrained GP ⟶ Forward modeling

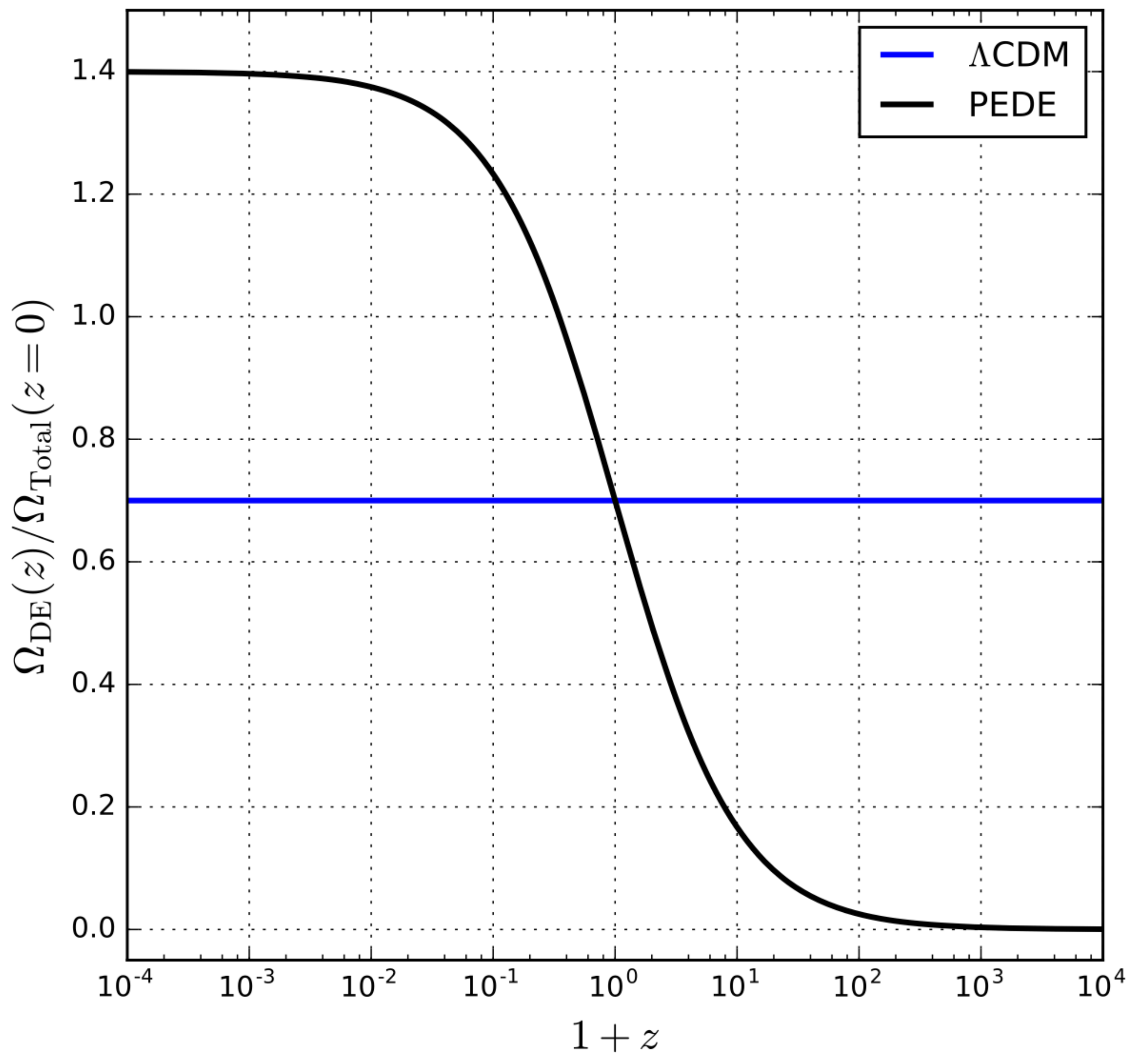
Non-parametric approach

ΛCDM Universe | ET Δ



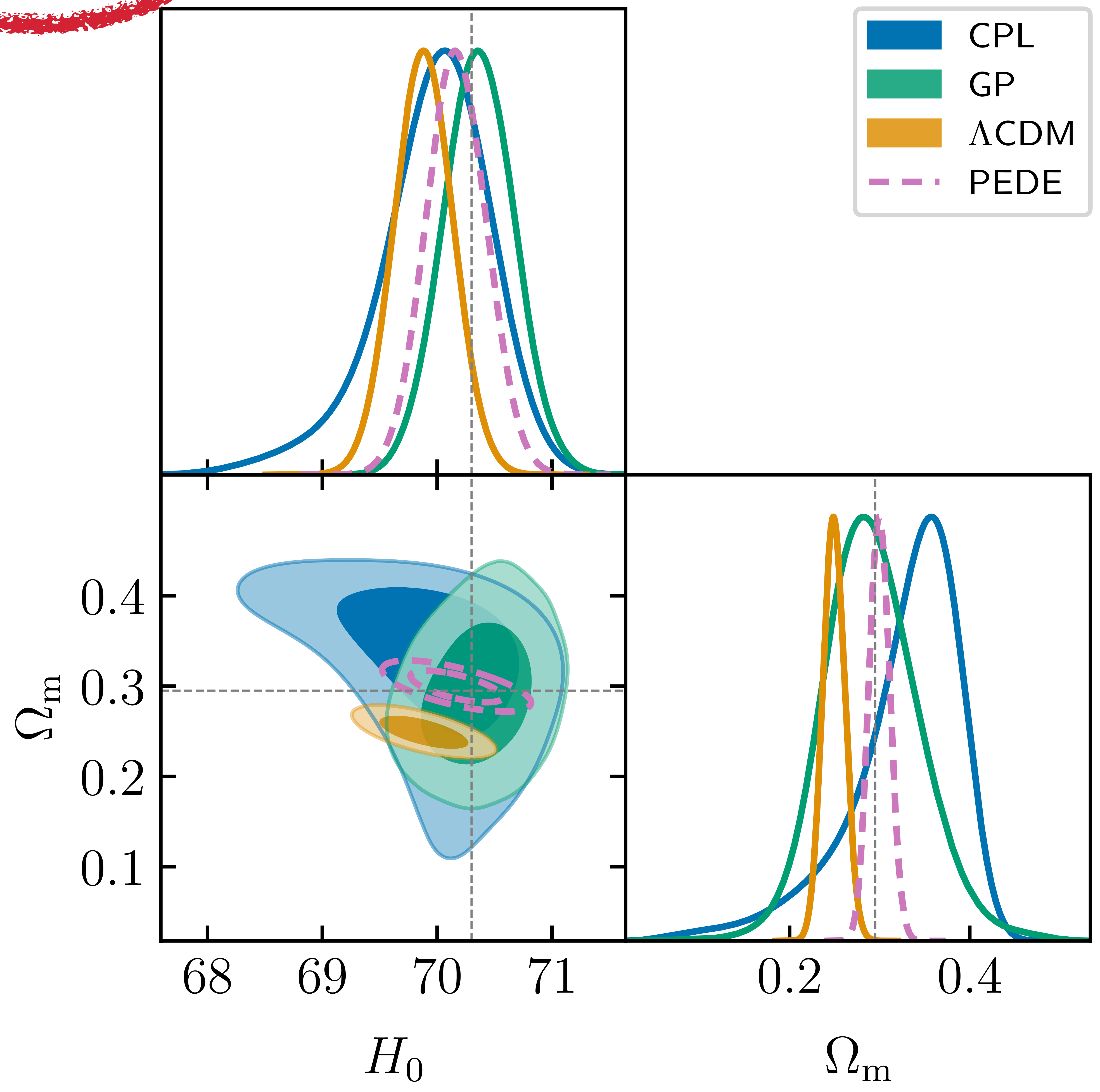
Non-parametric approach

Phenomenologically Emergent Dark Energy



Li and Shafieloo, 2019

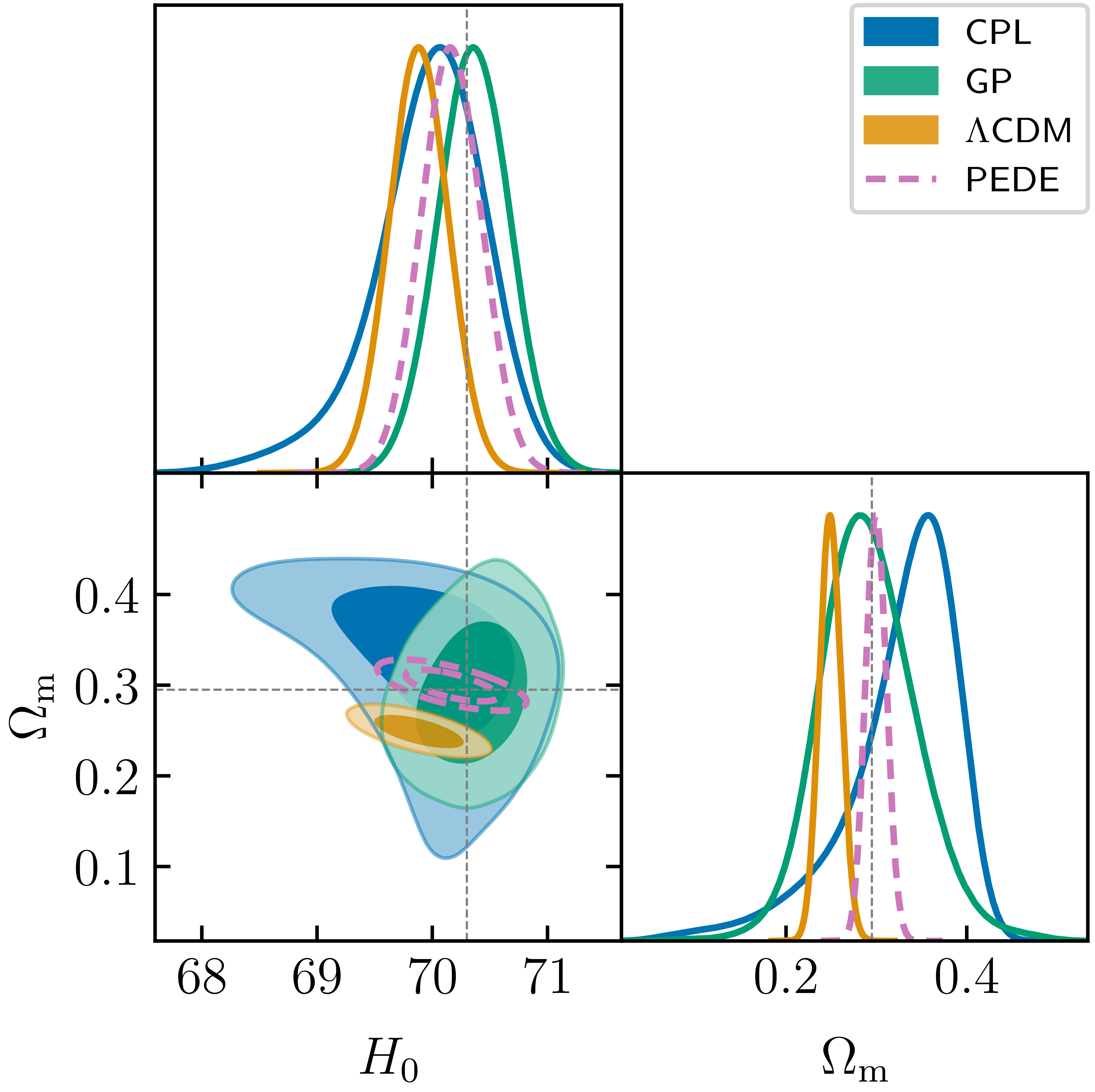
PEDE Universe | Pantheon+ & ET Δ + CE



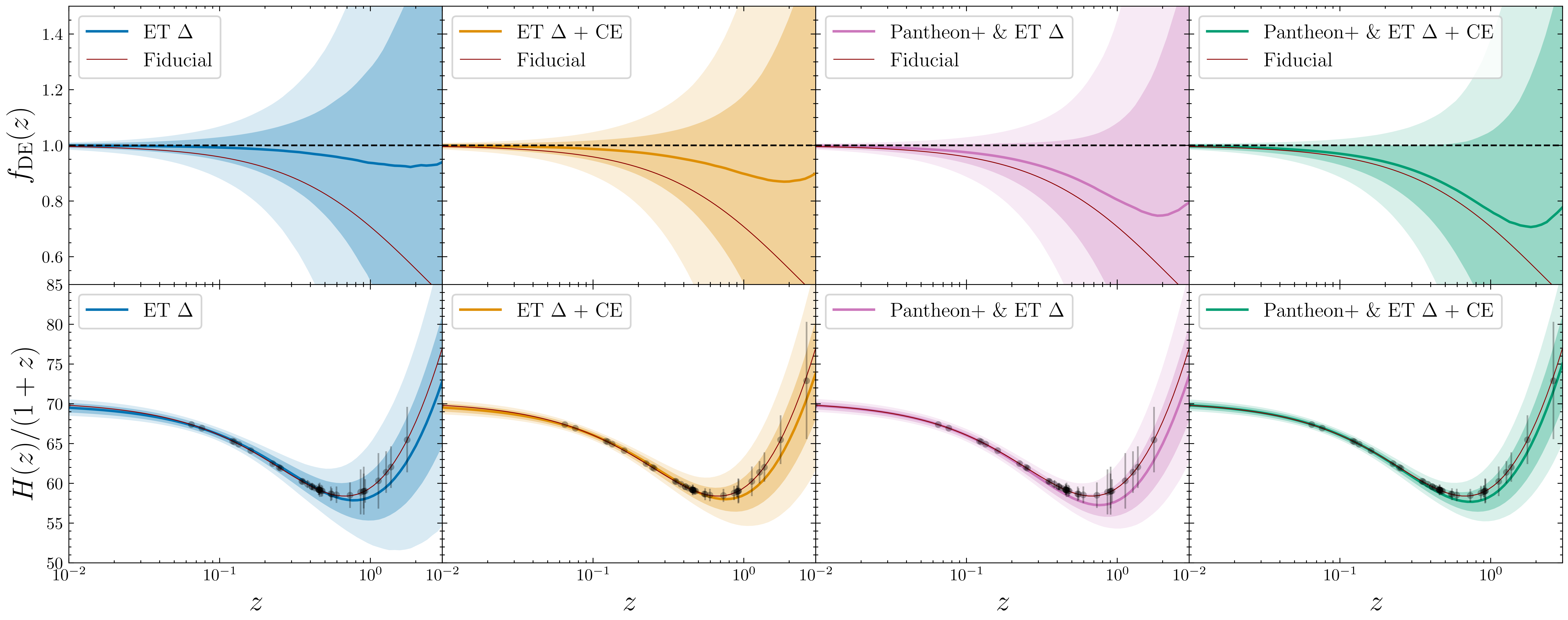
Cozzumbo+, **in prep.**

Non-parametric approach

PEDE Universe | Pantheon+ & ET Δ + CE

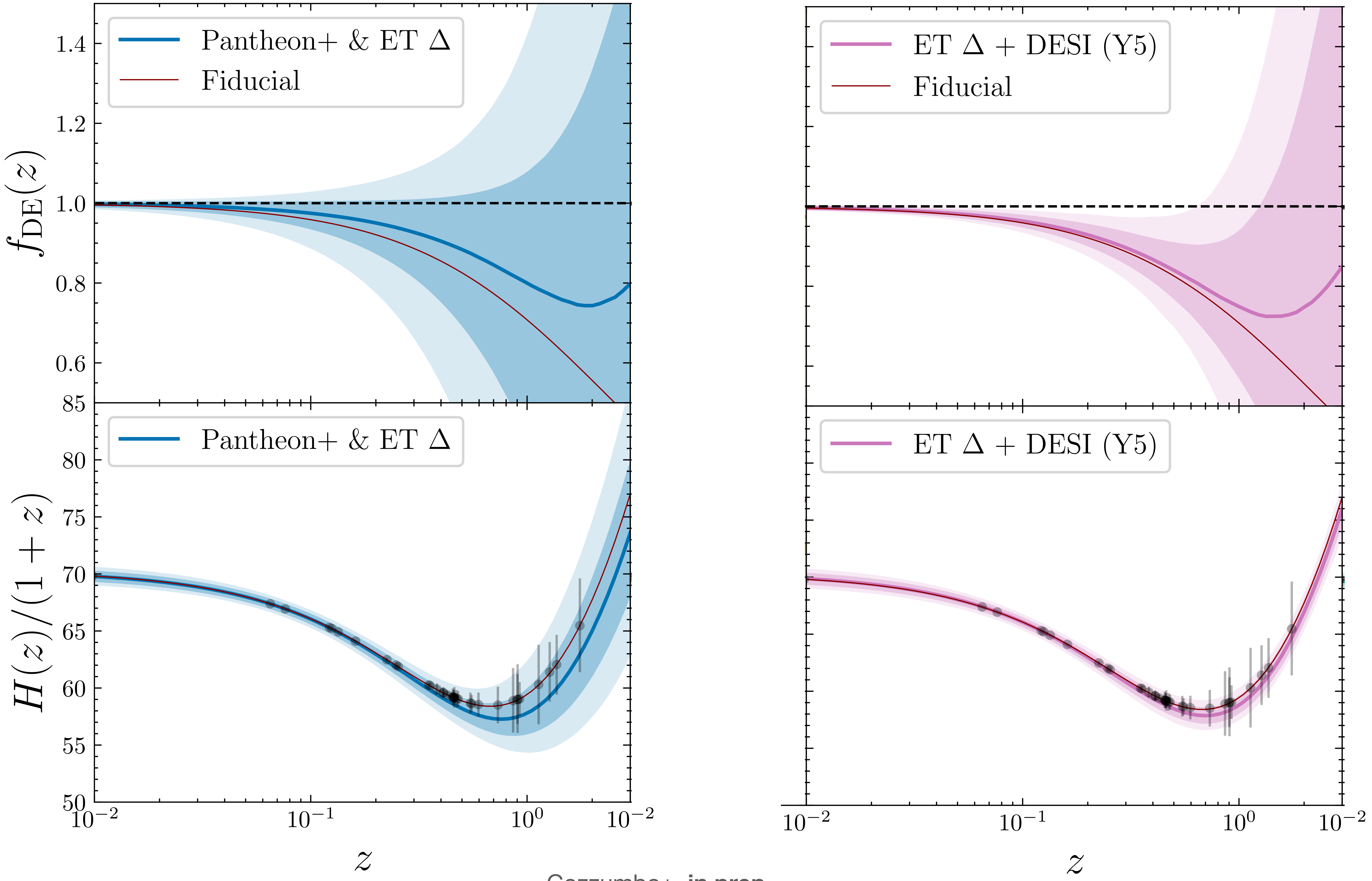


Non-parametric approach



Cozzumbo+, **in prep.**

Non-parametric approach



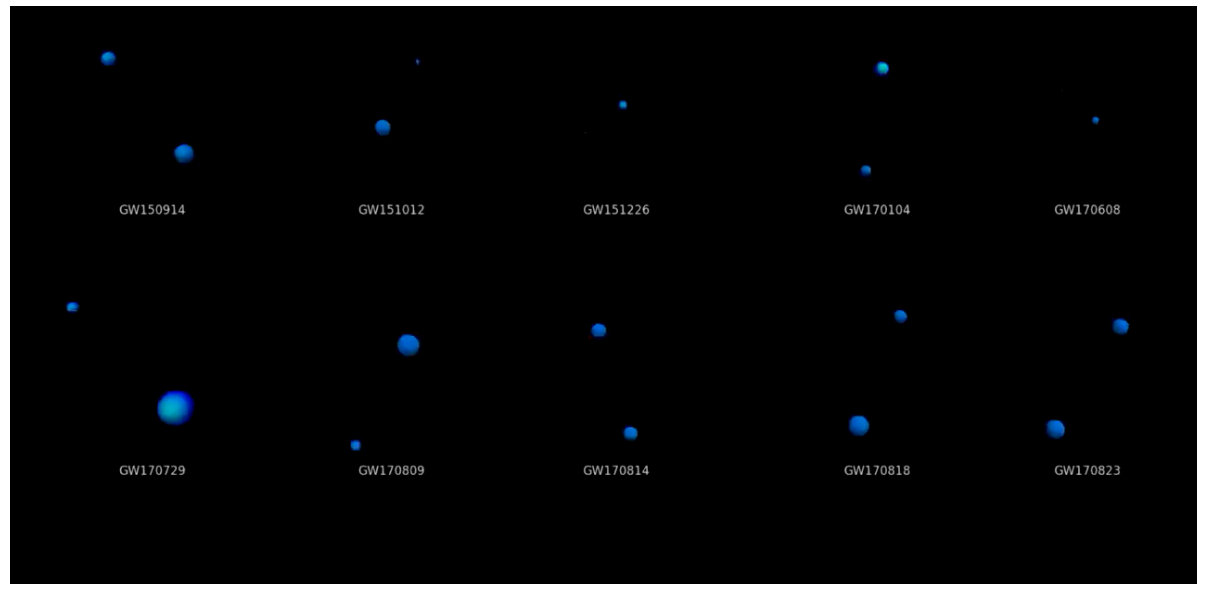
Cozzumbo+, **in prep.**

Conclusions/Proposal

- 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**
- We show the potential of a model-independent reconstruction for **Einstein Telescope and next generation cosmological probes**

Conclusions/Proposal

Multi-probes

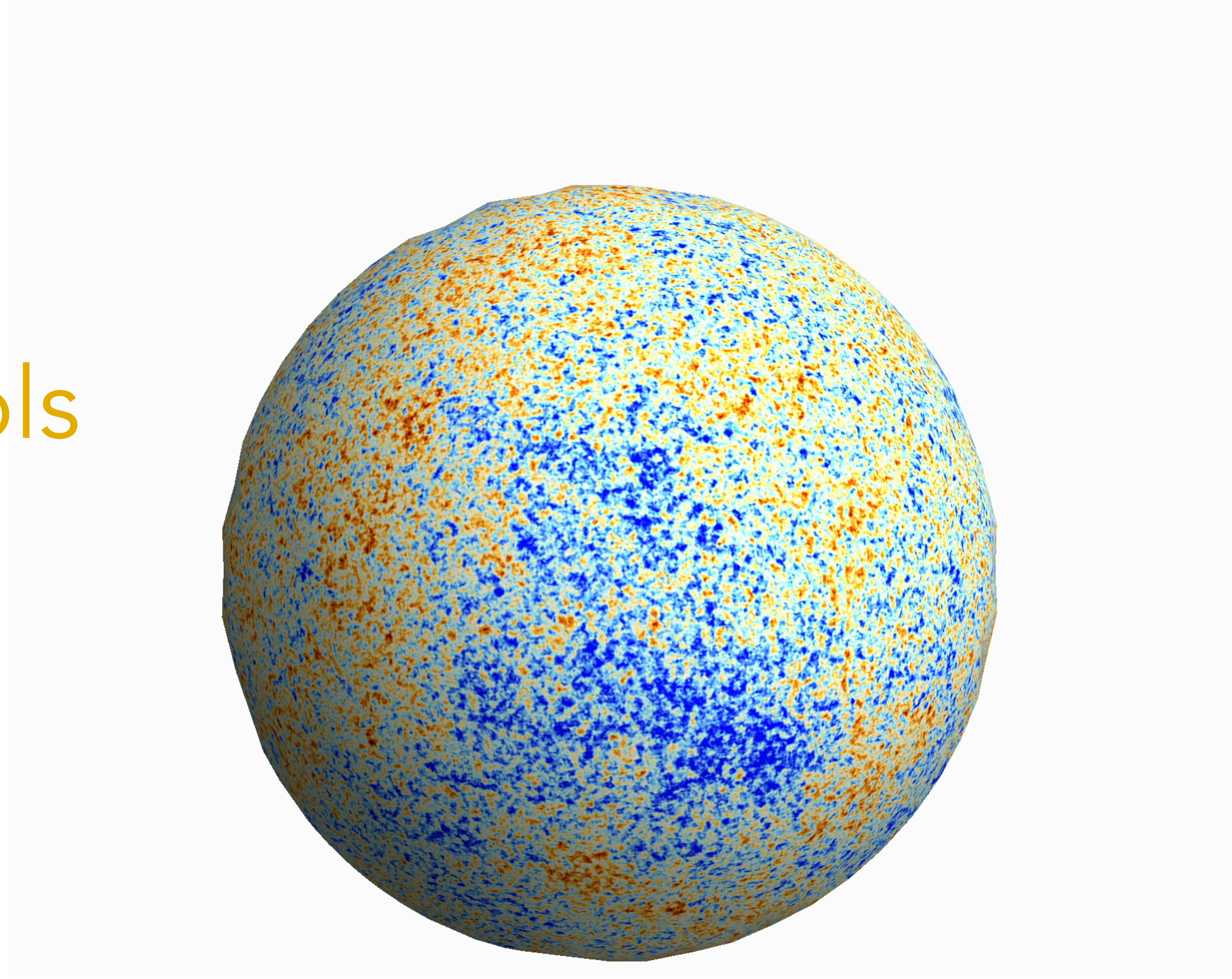


Cosmological tracers
@ late time

Validation

Model-independent tools

Reconstruction



Physics @ early time

Conclusions/Proposal

- We can use **different $H(z)$ tracers**, giving us a z estimate
- We can get constraints with a **modified gravity theory**
- **????**