Model-independent cosmology with Bright Sirens

XIV Einstein Telescope symposium

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Riccardo Murgia Gor Oganesyan Marica Branchesi

INFN LNGS

GSSI

Friedmann's equation

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

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

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

Friedmann's equation

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Friedmann's equation

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

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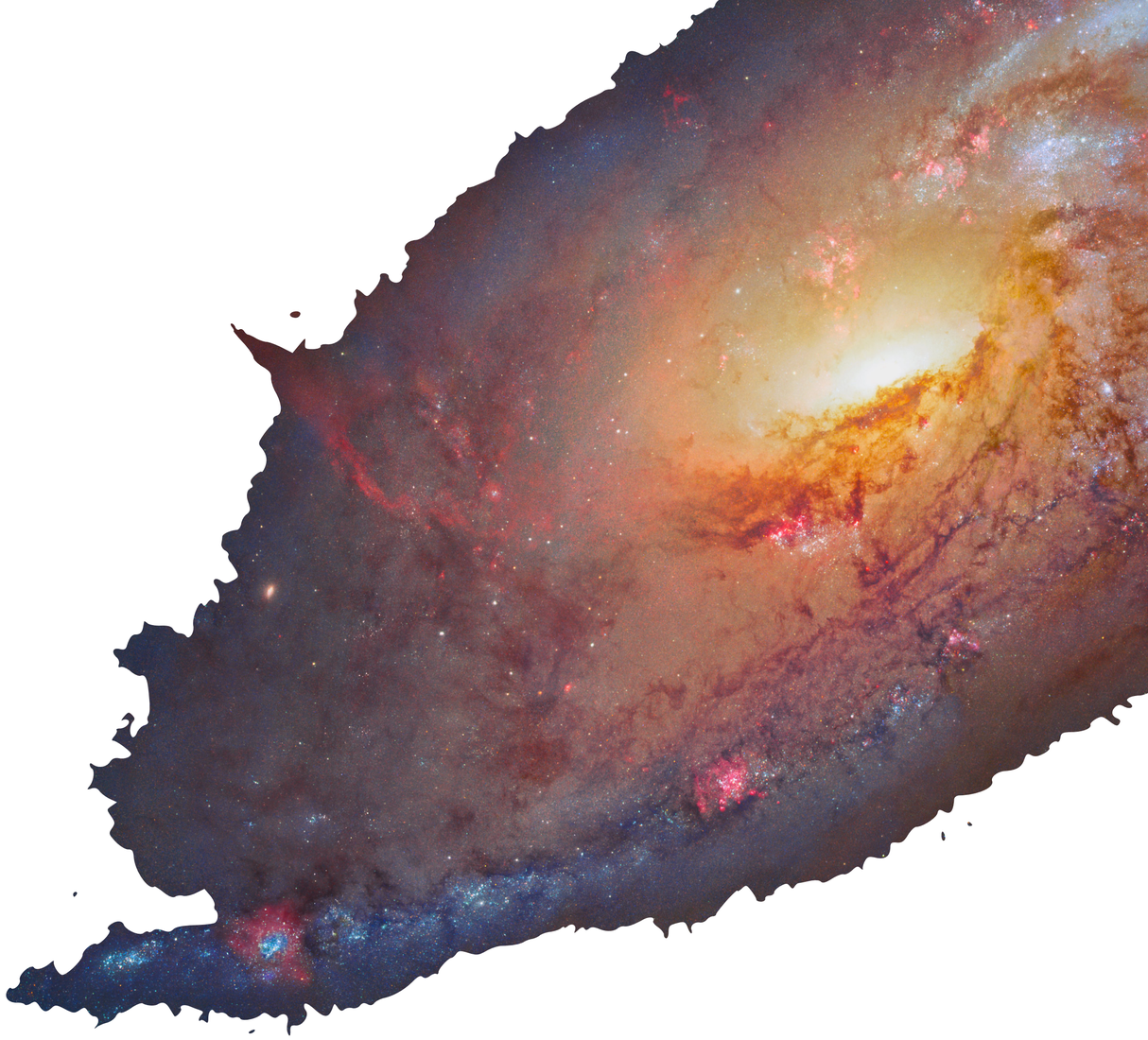
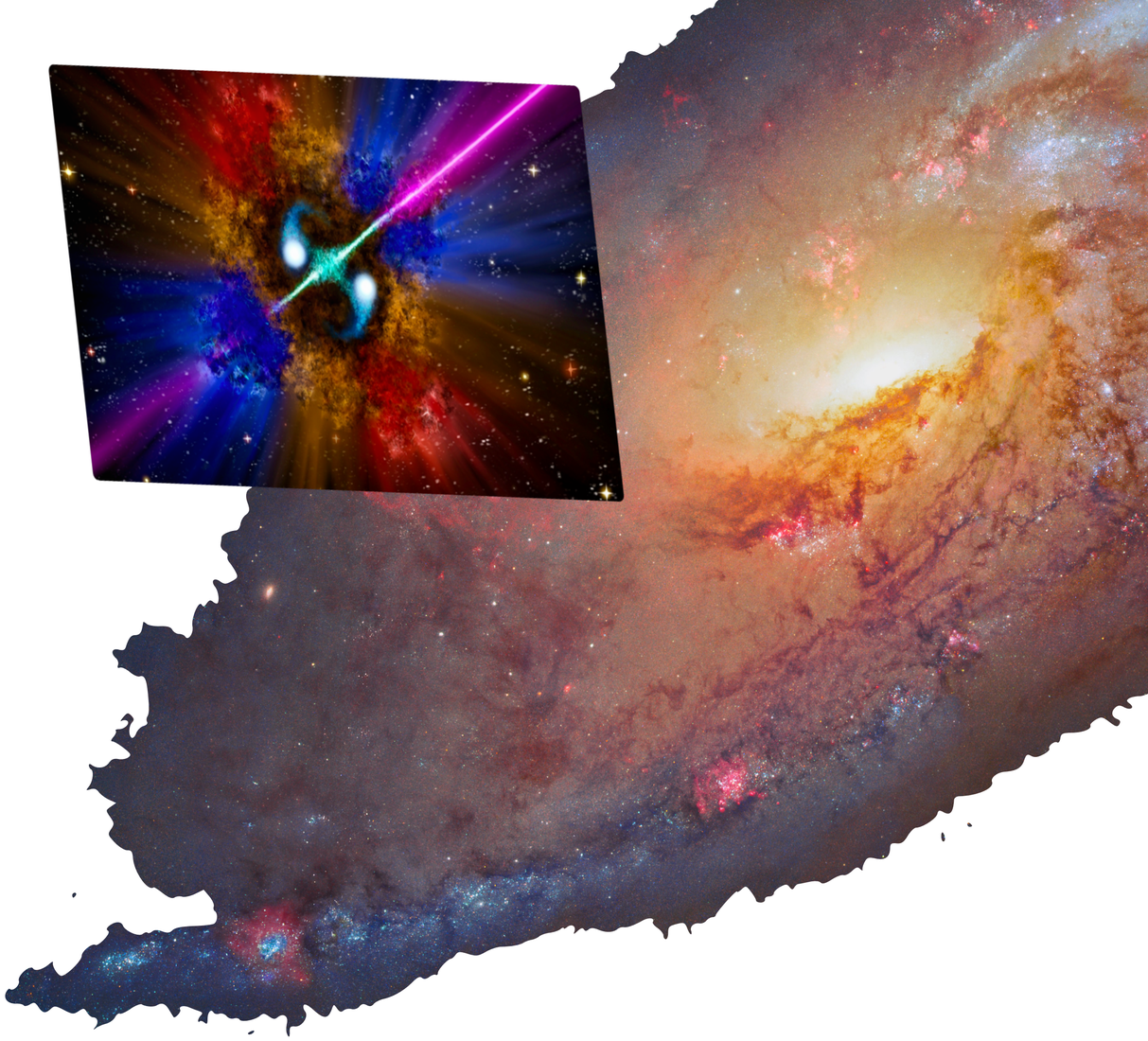
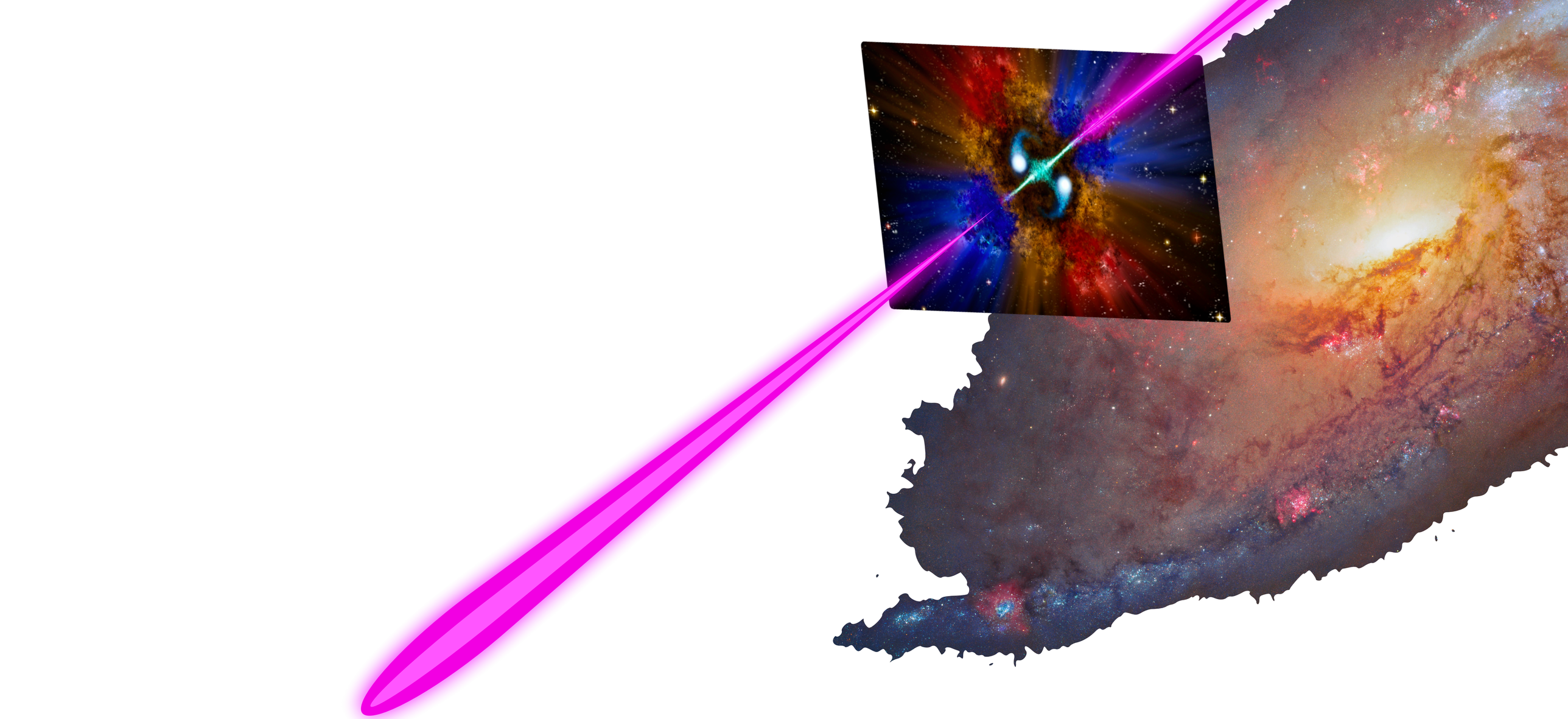
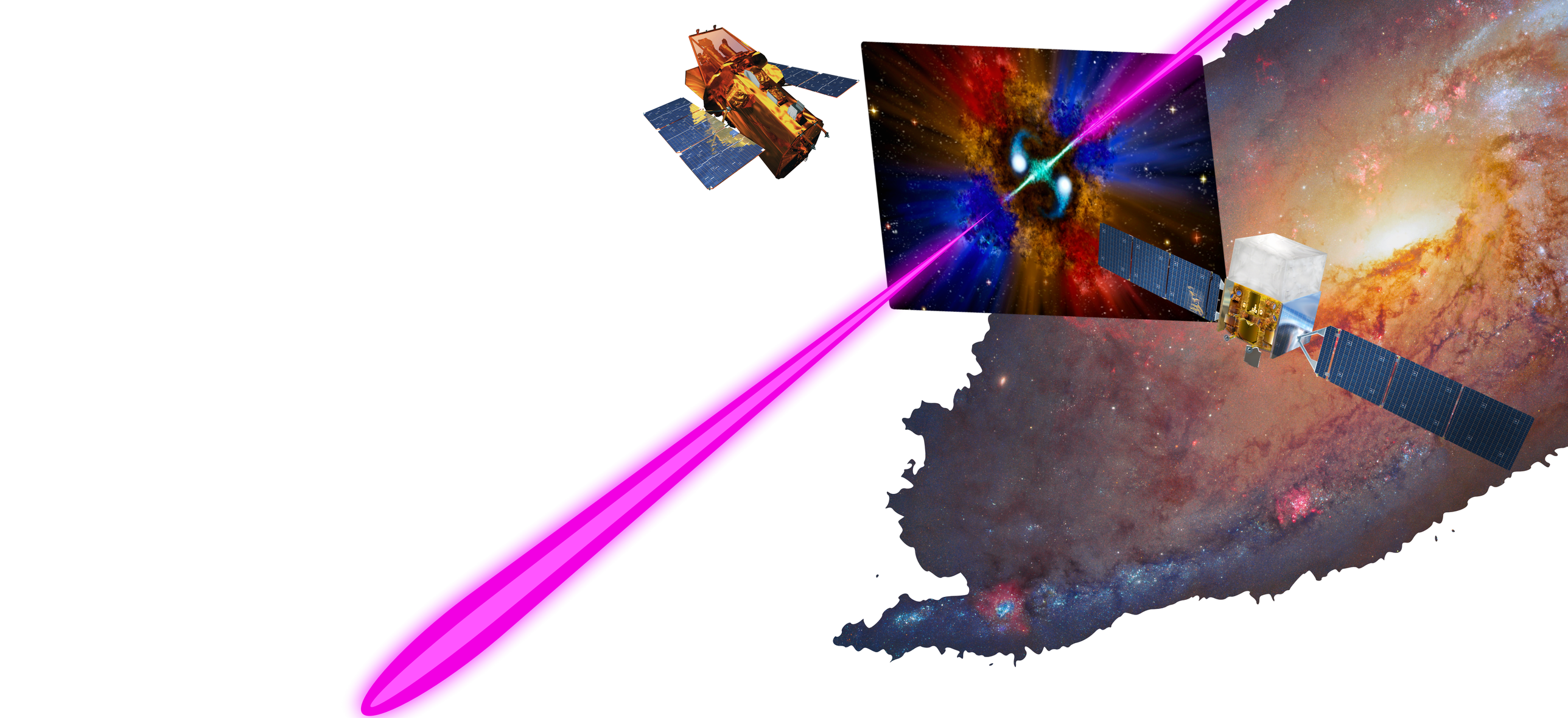
$$d_L(z) = c\,(1+z)\int_0^z \frac{dz'}{H(z')}$$

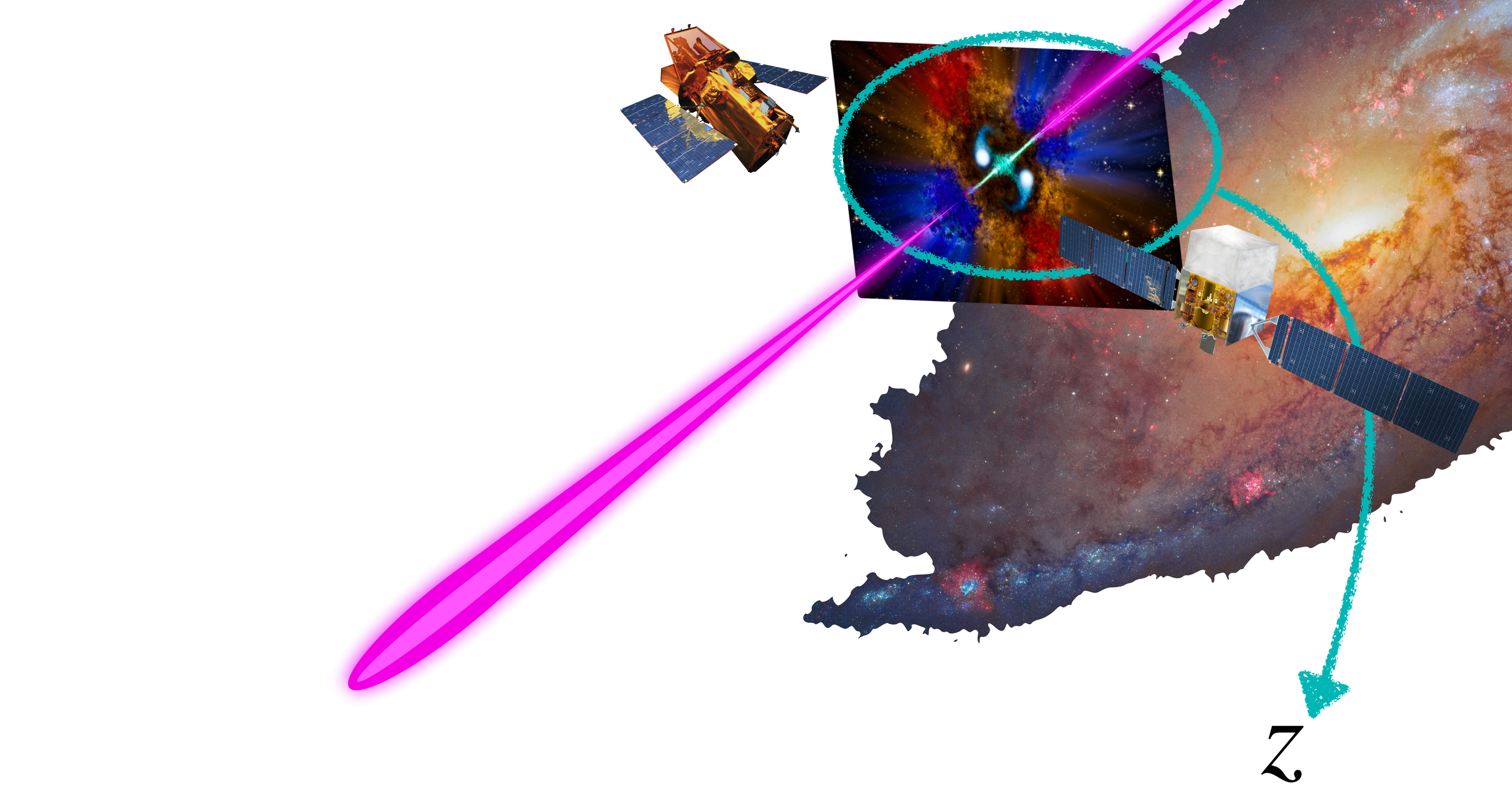
We want to trace the Hubble parameter $H(z)$

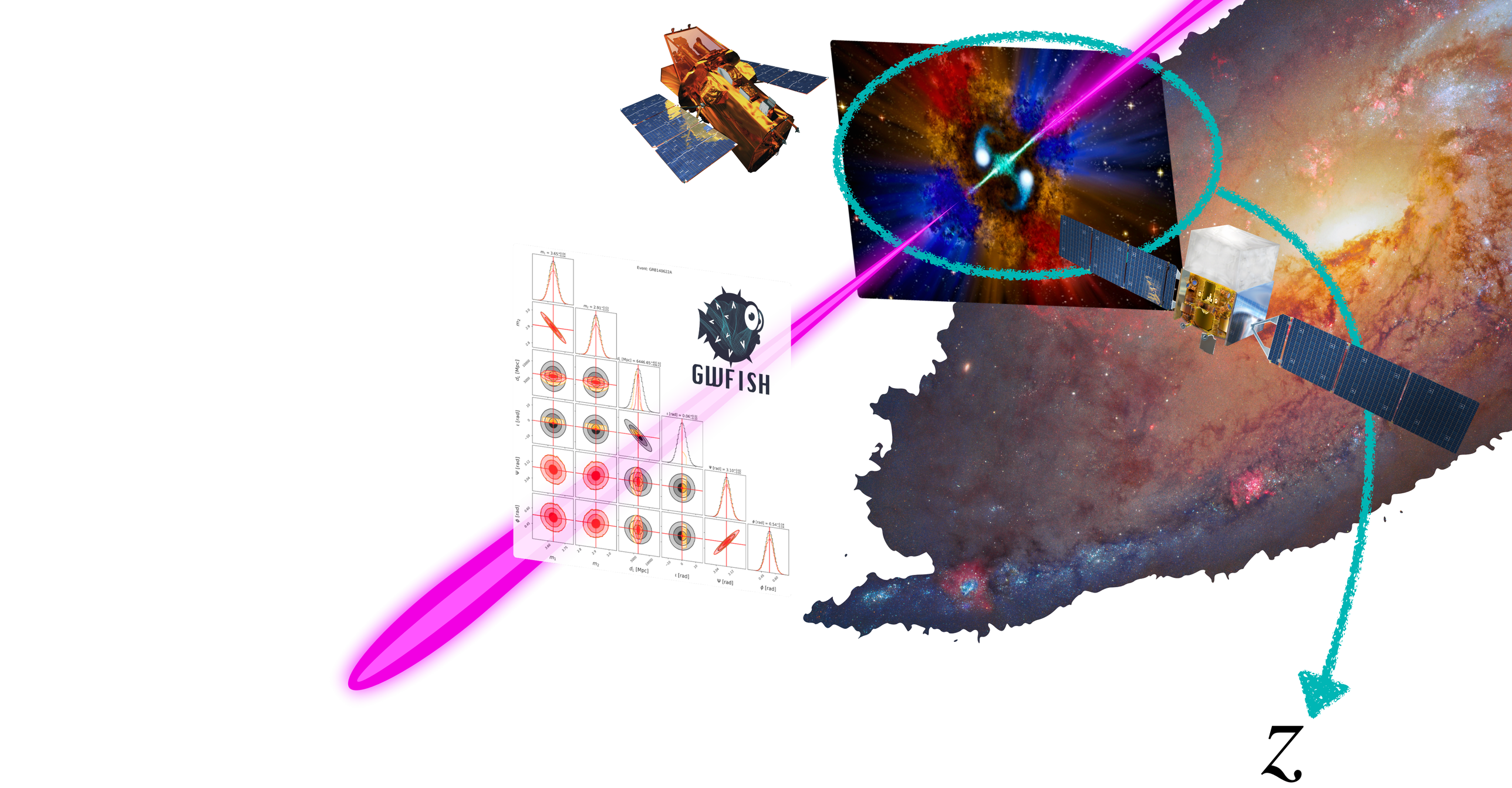


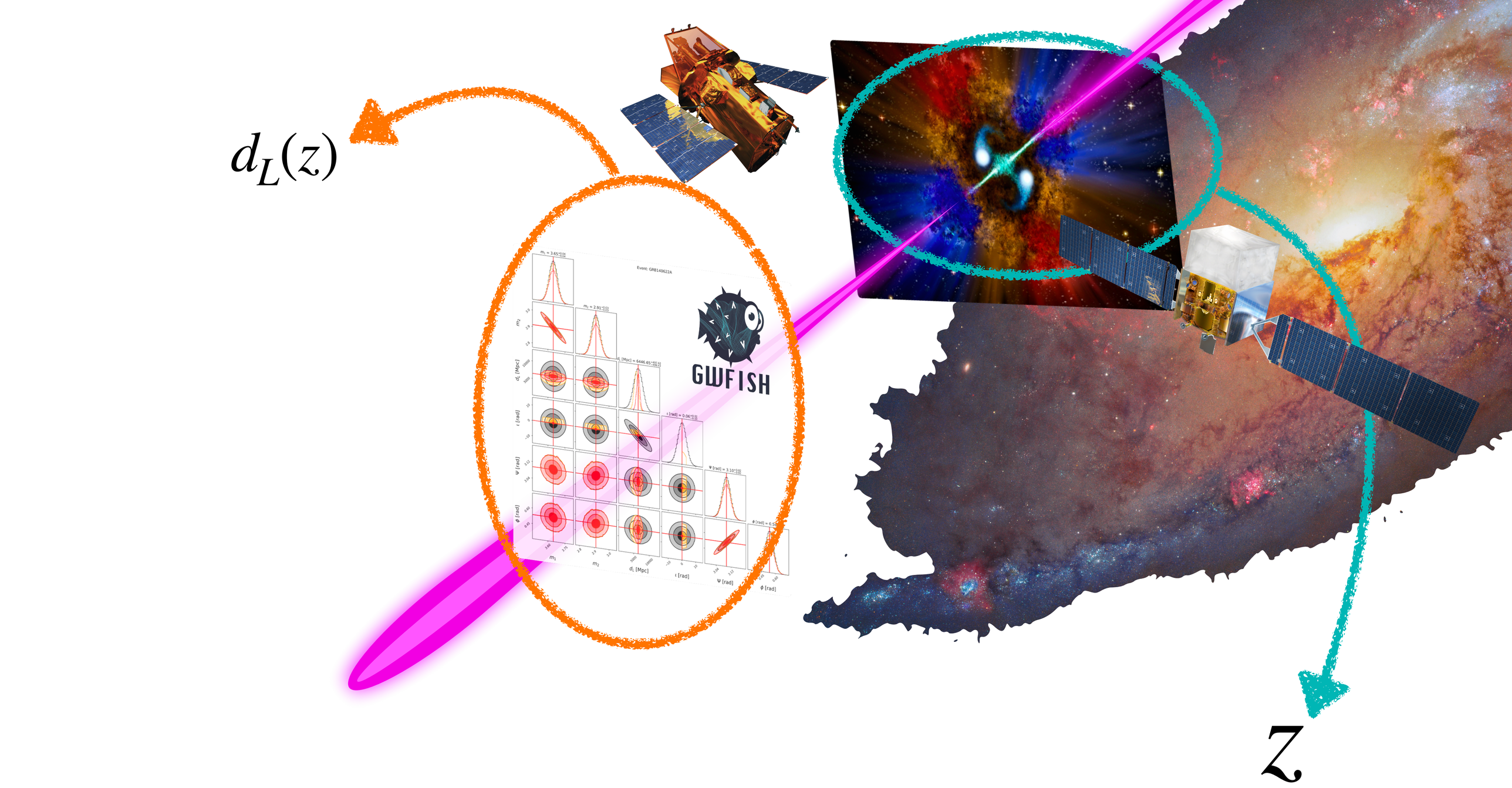


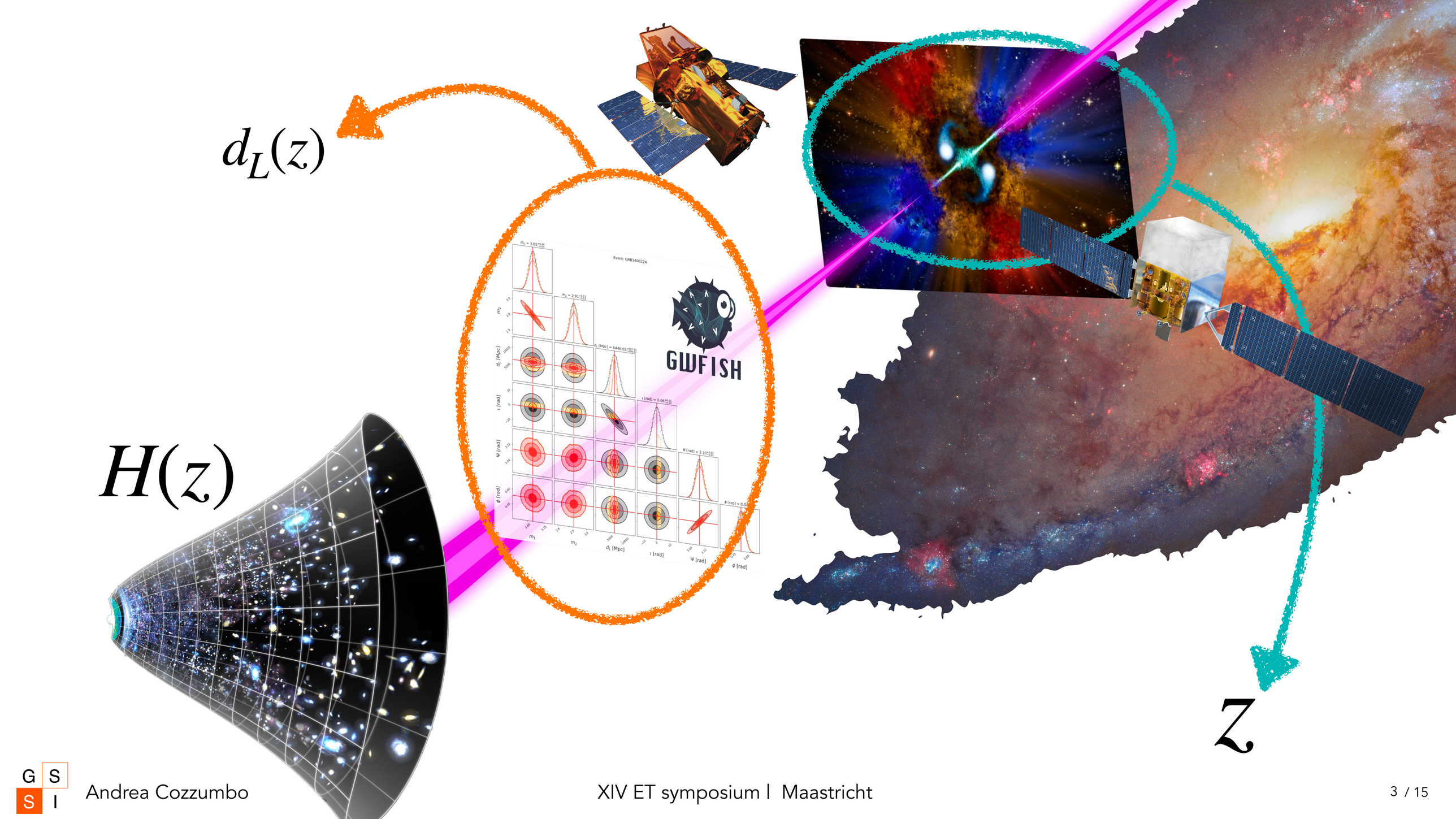




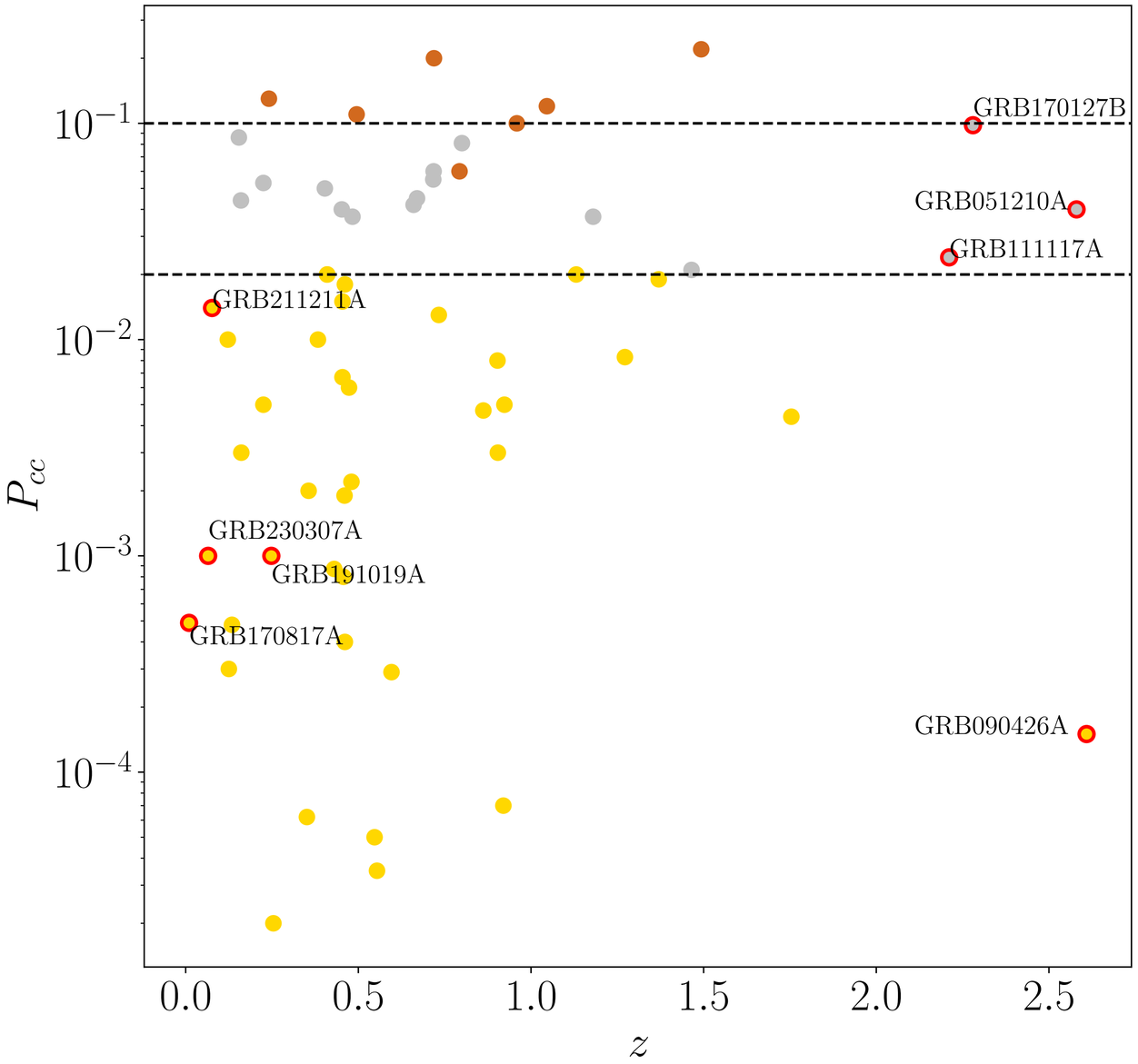

z


Event: GRB140622A
GWFISH
z


$d_L(z)$
GWFISH
z


$d_L(z)$
$H(z)$
GWFISH
Event: GRB140622A
z

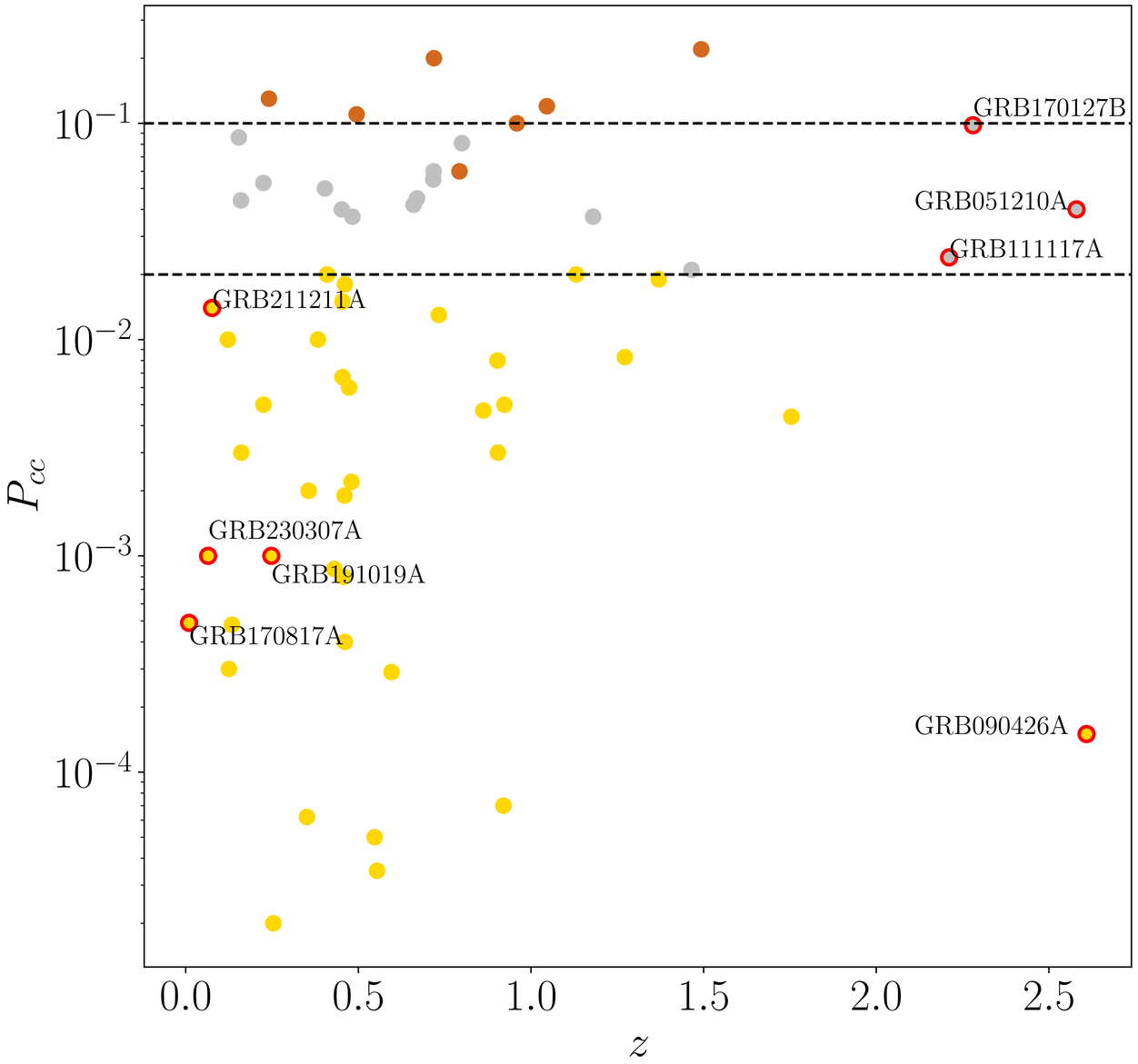
GRB data set



Fong+, 2022

Cozzumbo+, **in prep.**

GRB data set

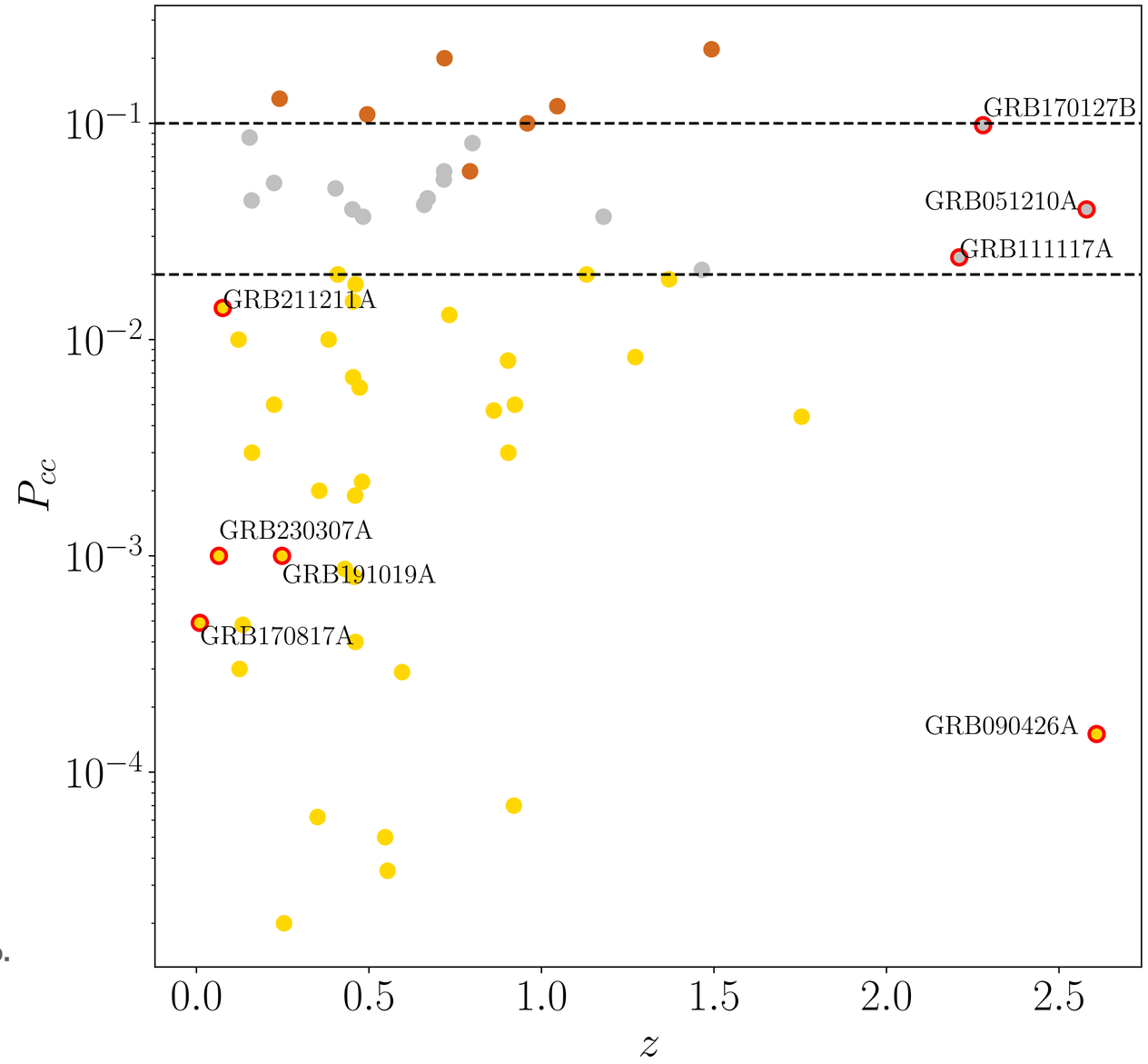


- Merger-driven GRB events

Fong+, 2022

Cozzumbo+, **in prep.**

GRB data set



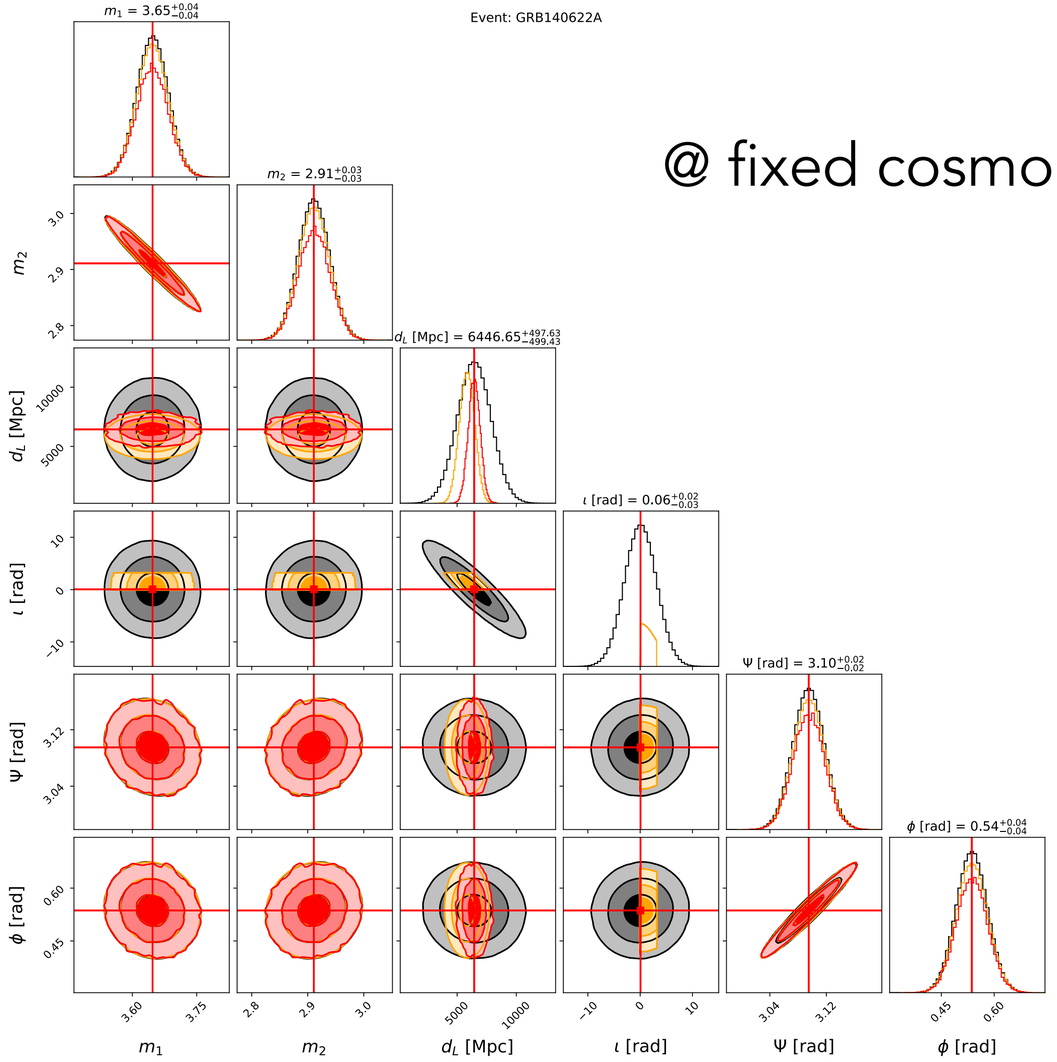
- Merger-driven GRB events
- $\Delta z \leq 7\,\%$

Fong+, 2022

Cozzumbo+, **in prep.**

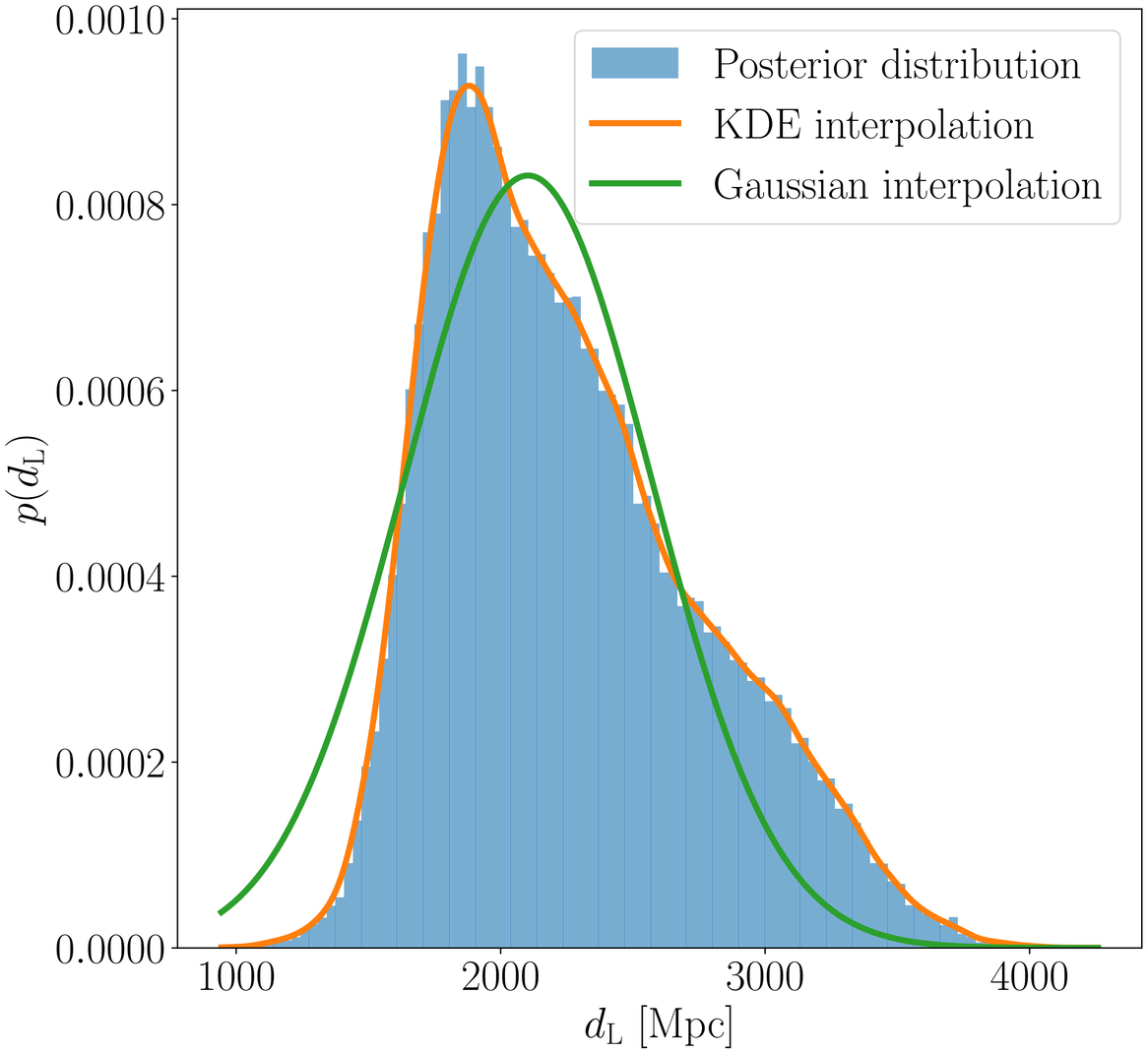
GW posteriors

Dupletsa+, 2024



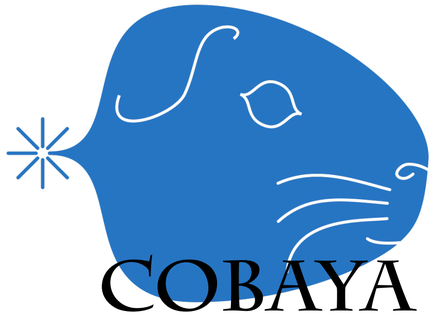
@ fixed cosmology

GW posteriors



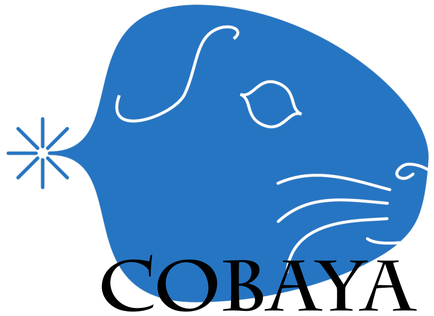
Cosmological MCMC

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



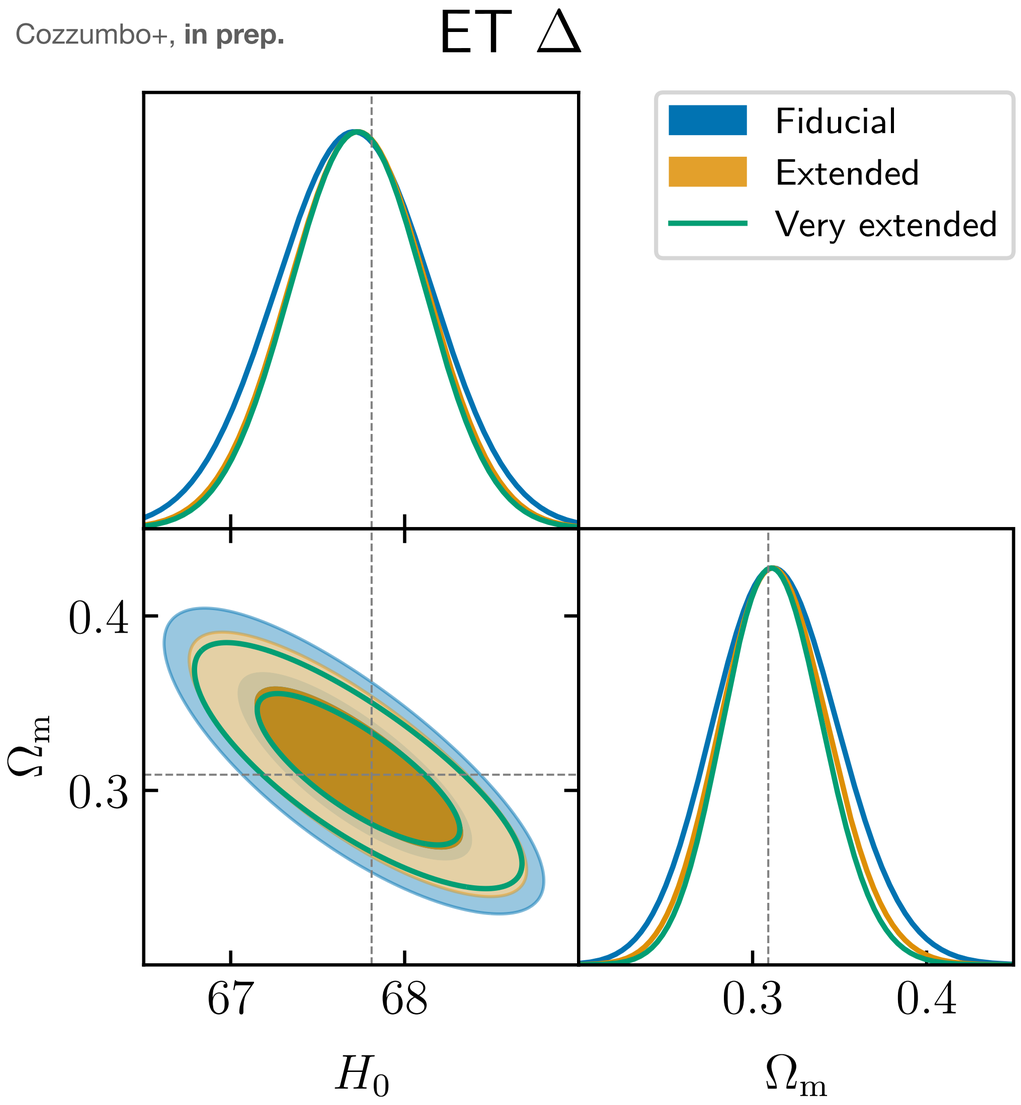
Cosmological MCMC

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



Parametric approach

Cozzumbo+, **in prep.**

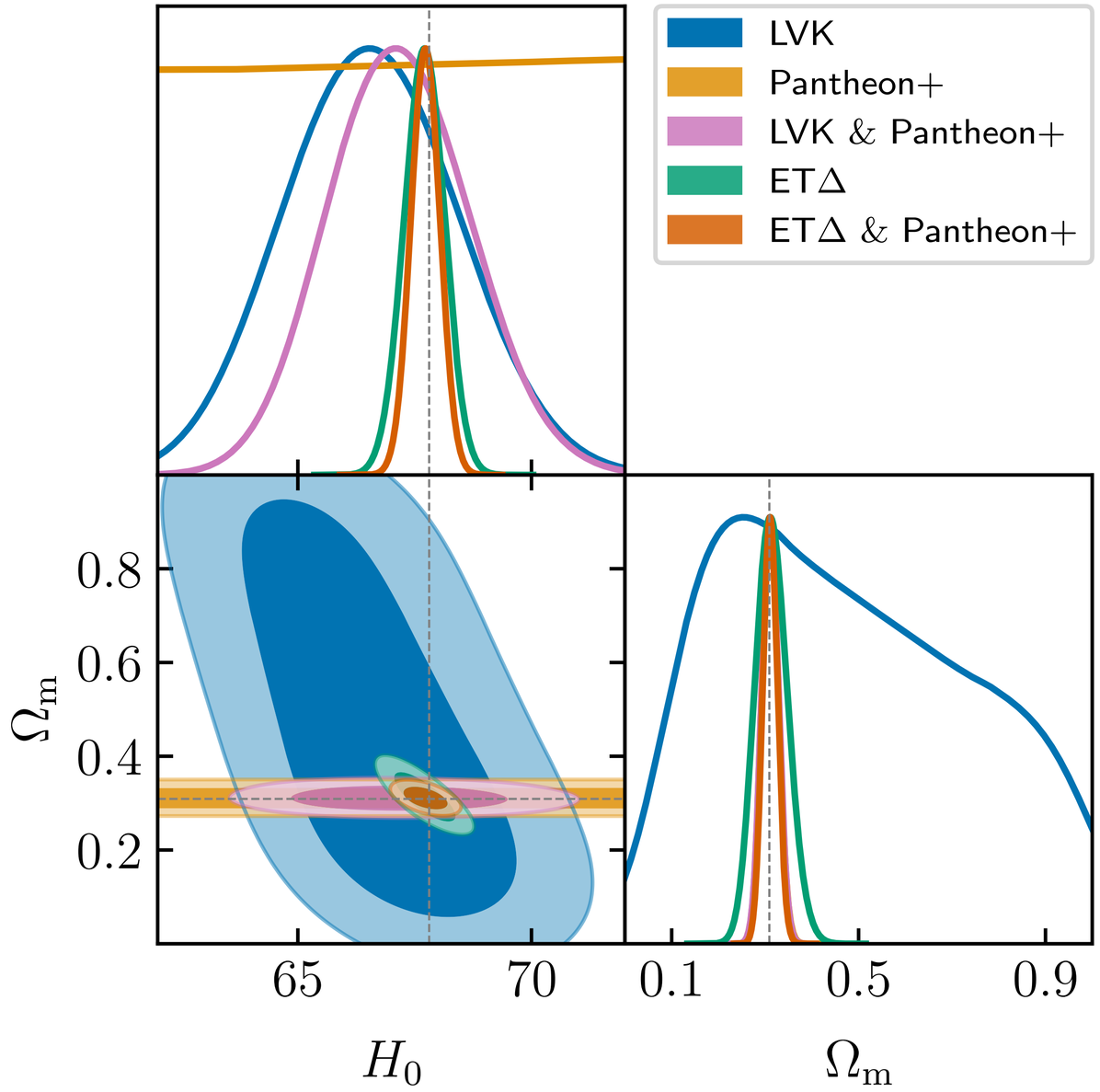


$$h^2(z) = \frac{H^2(z)}{H_0^2} = \Omega_{m,0}\,(1+z)^3 + (1-\Omega_{m,0}) f_{\rm DE}(z)$$

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

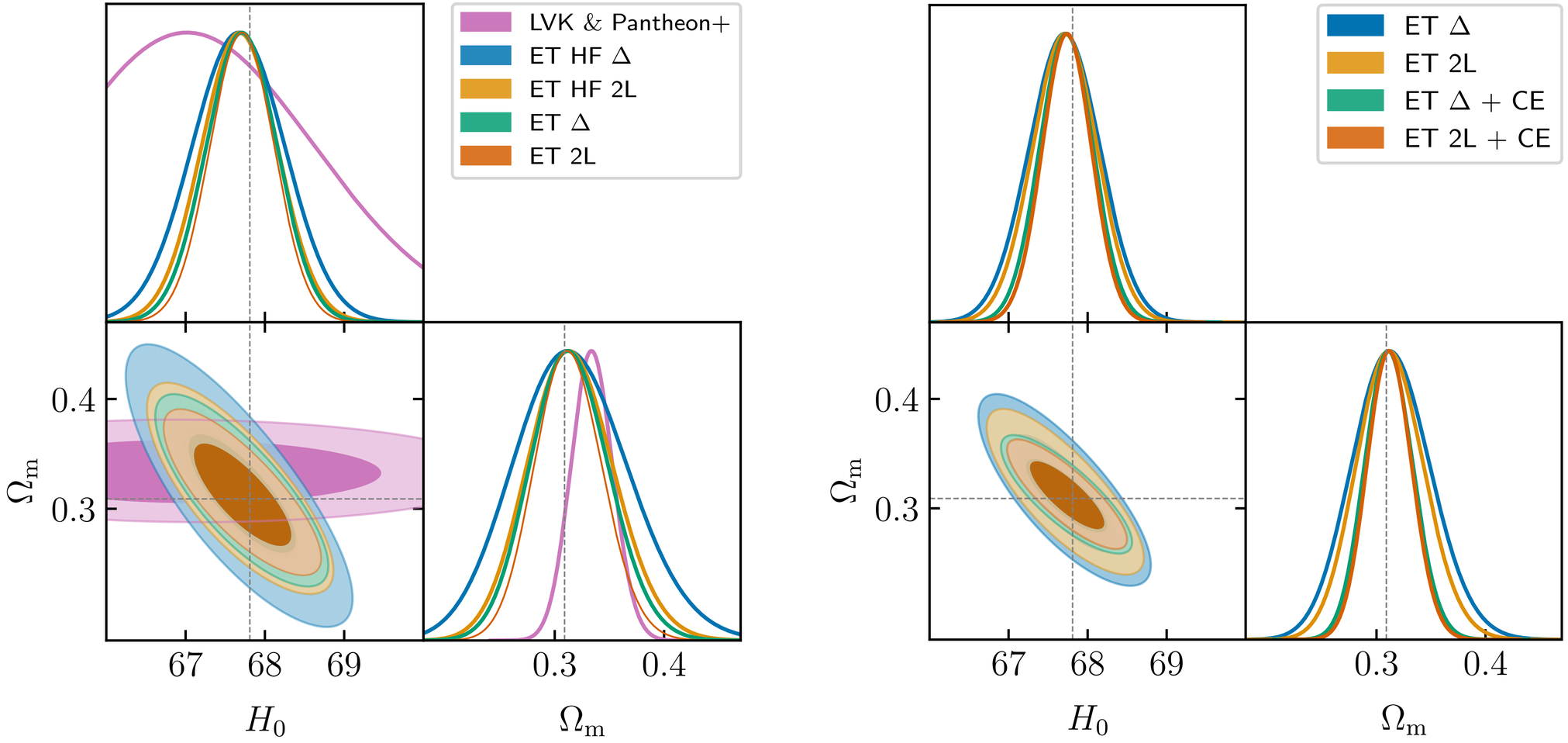
$$f_{\rm DE}(z) = (1+z)^{3\left(1+w^{\Lambda{\rm CDM}}\right)} = 1$$

Parametric approach

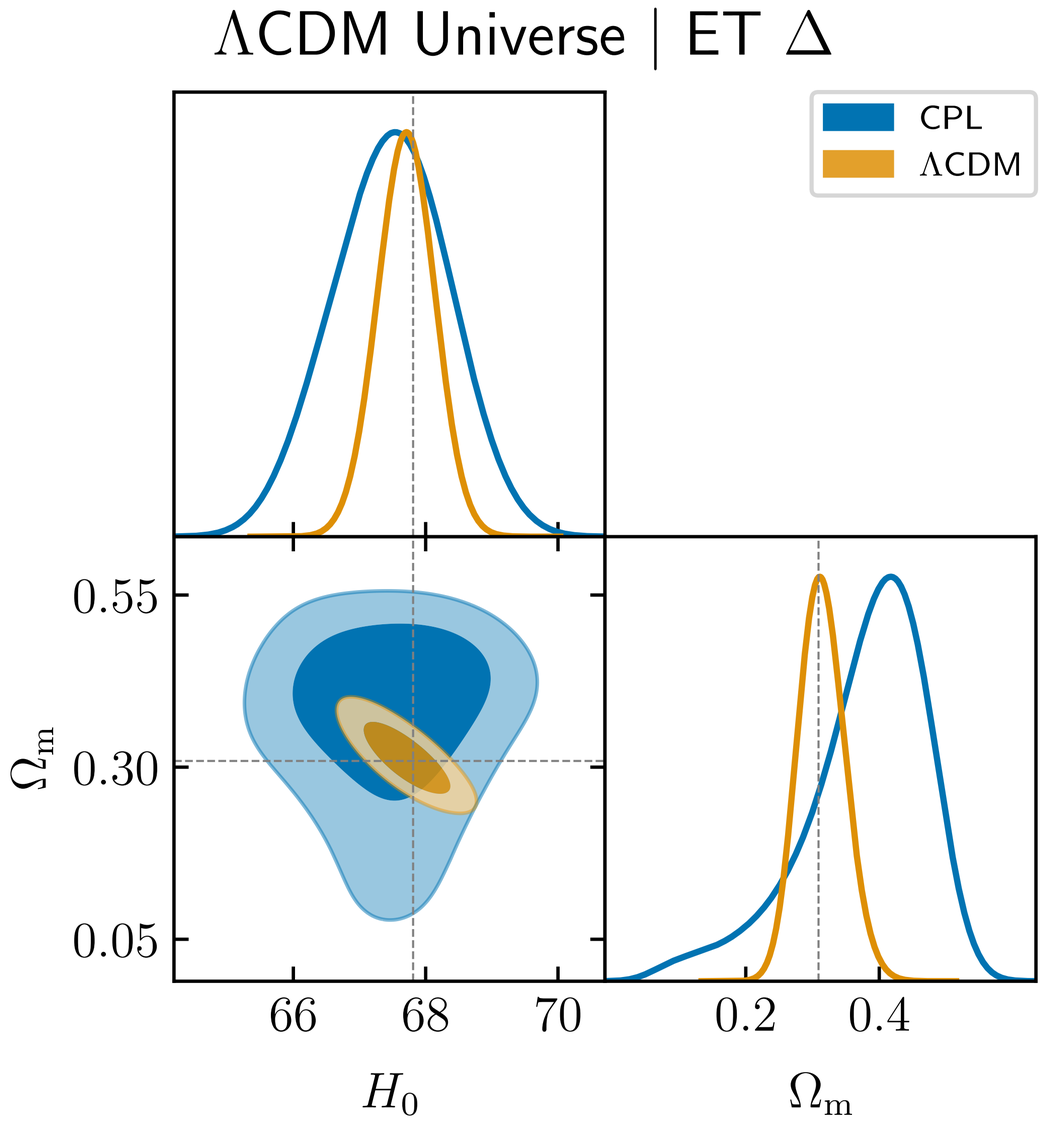


Parametric approach

@ fixed catalog



Parametric approach

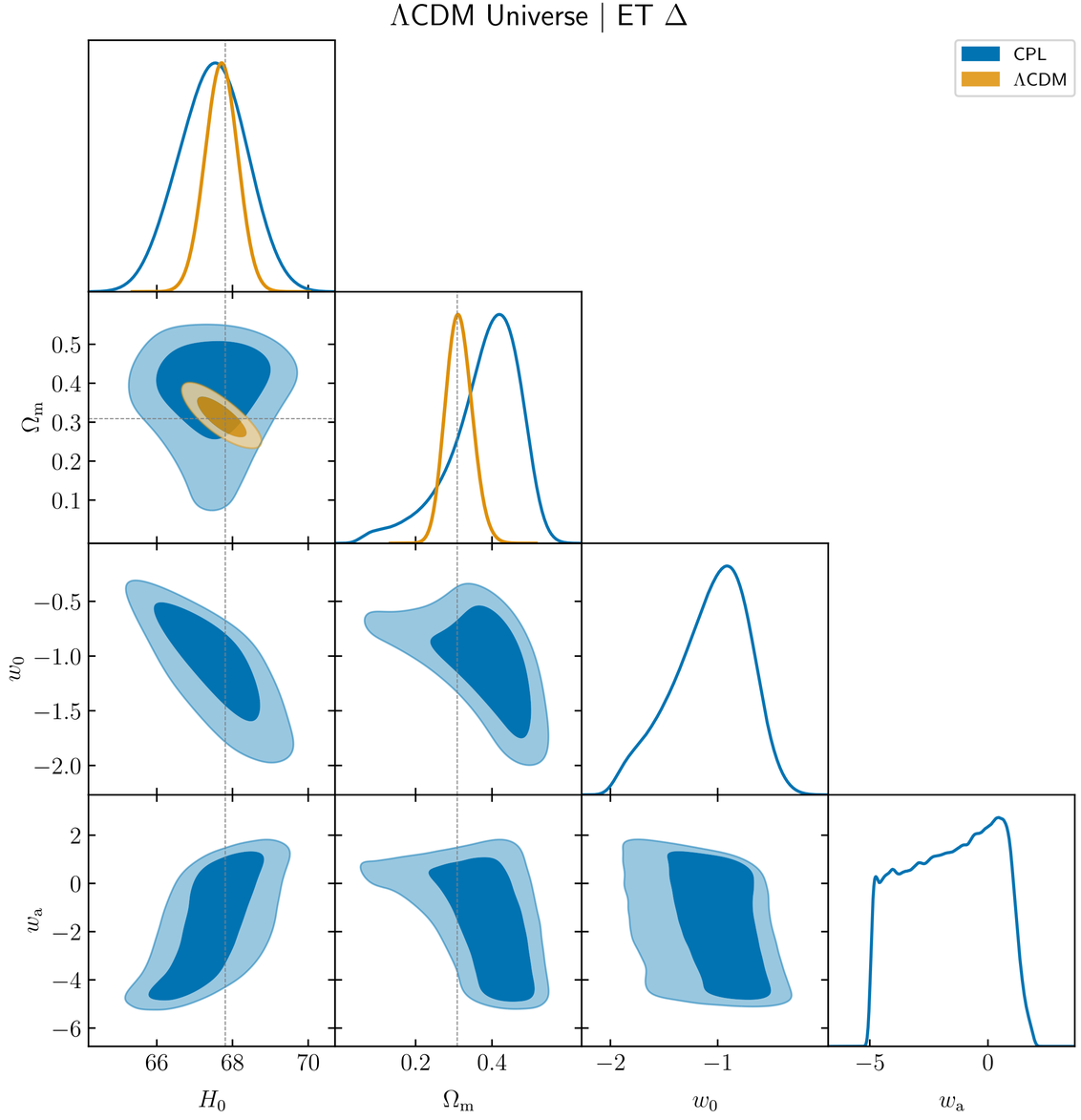


$$h^2(z) = \frac{H^2(z)}{H_0^2} = \Omega_{m,0}(1+z)^3 + (1-\Omega_{m,0}) f_{\rm DE}(z)$$

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

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

Parametric approach



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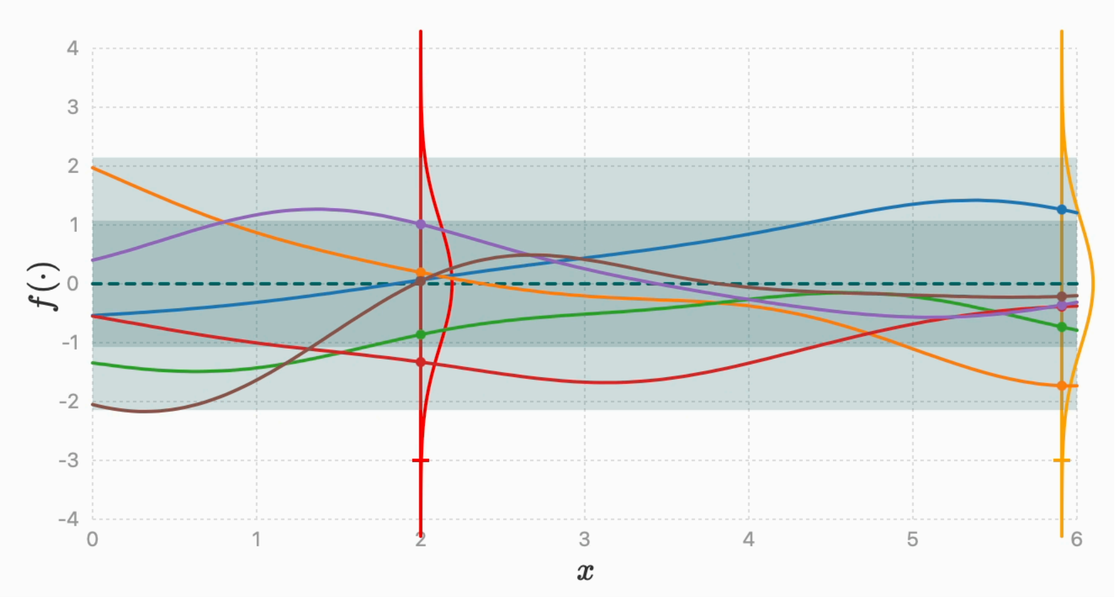
Non-parametric approach

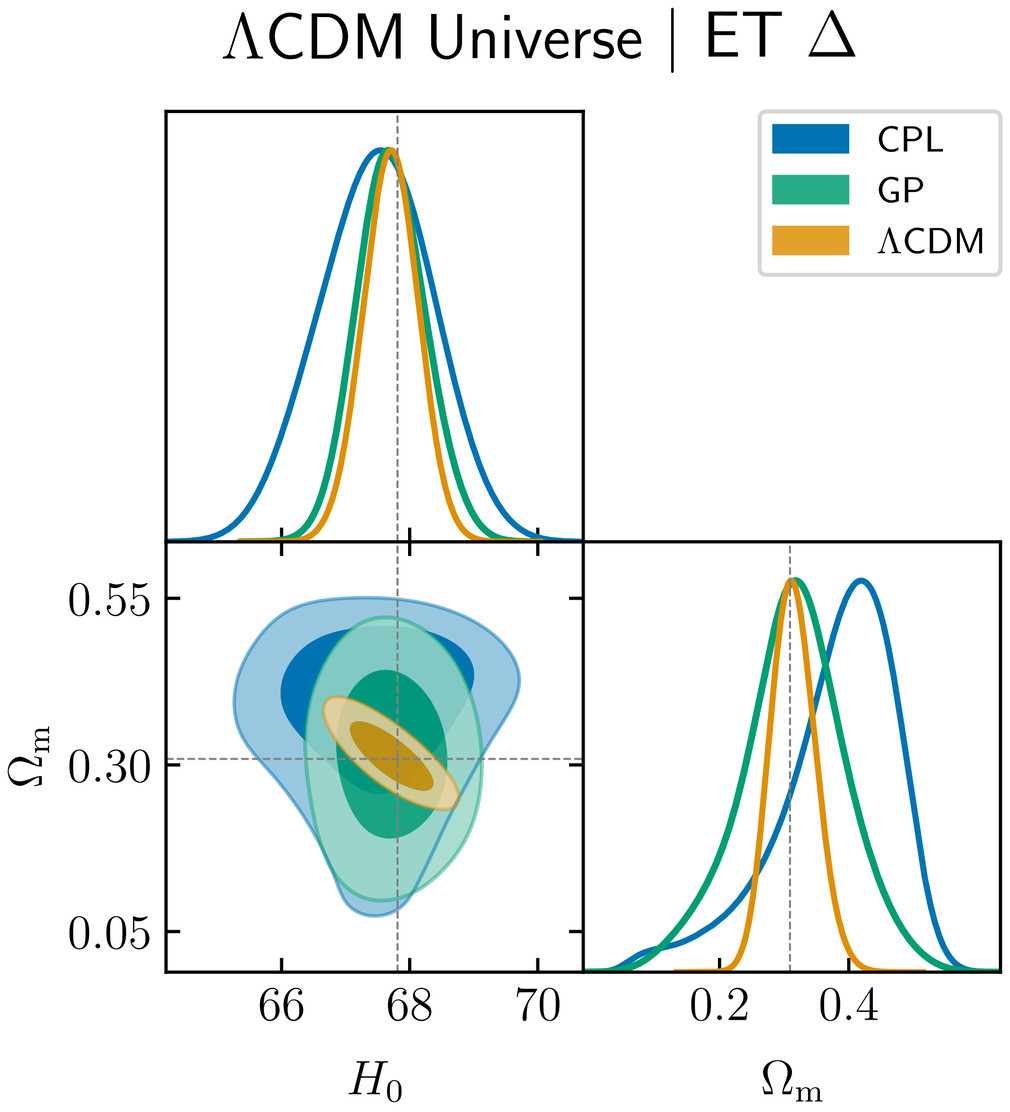
GP → Gaussian Process

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

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

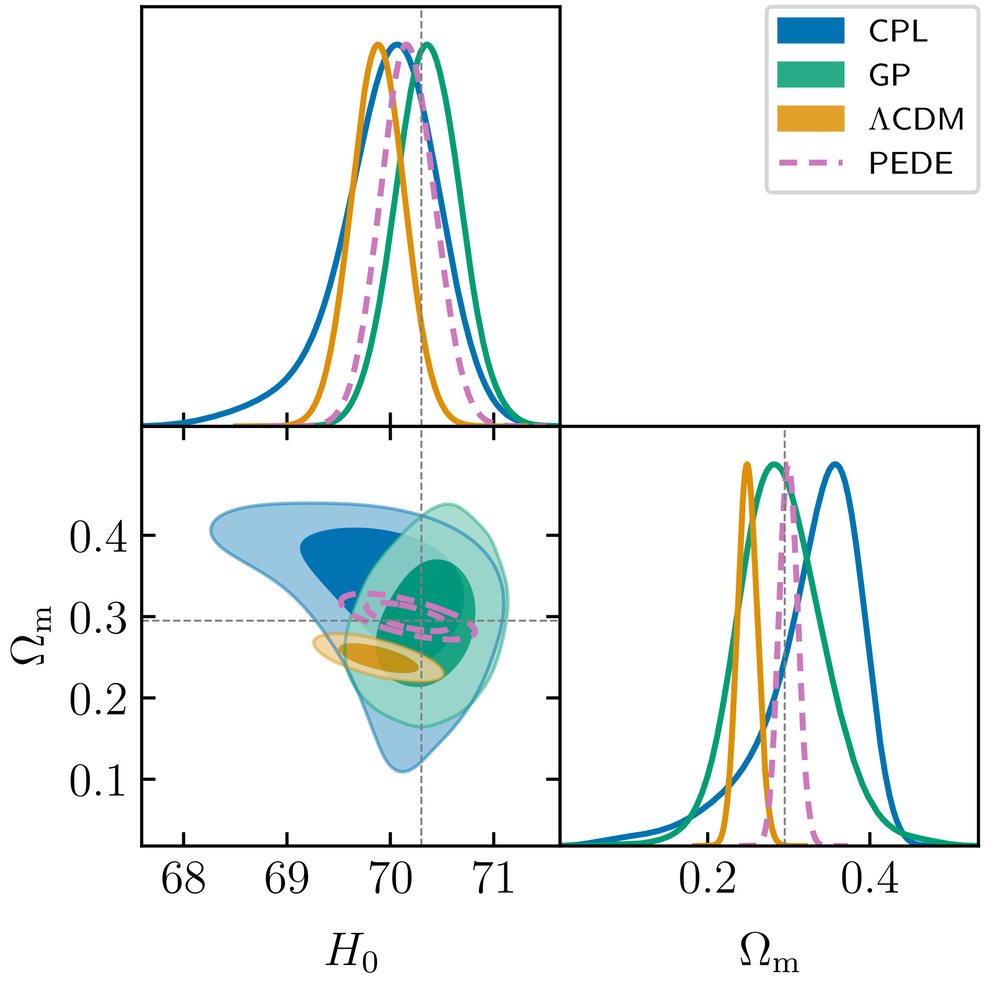


Non-parametric approach



Non-parametric approach

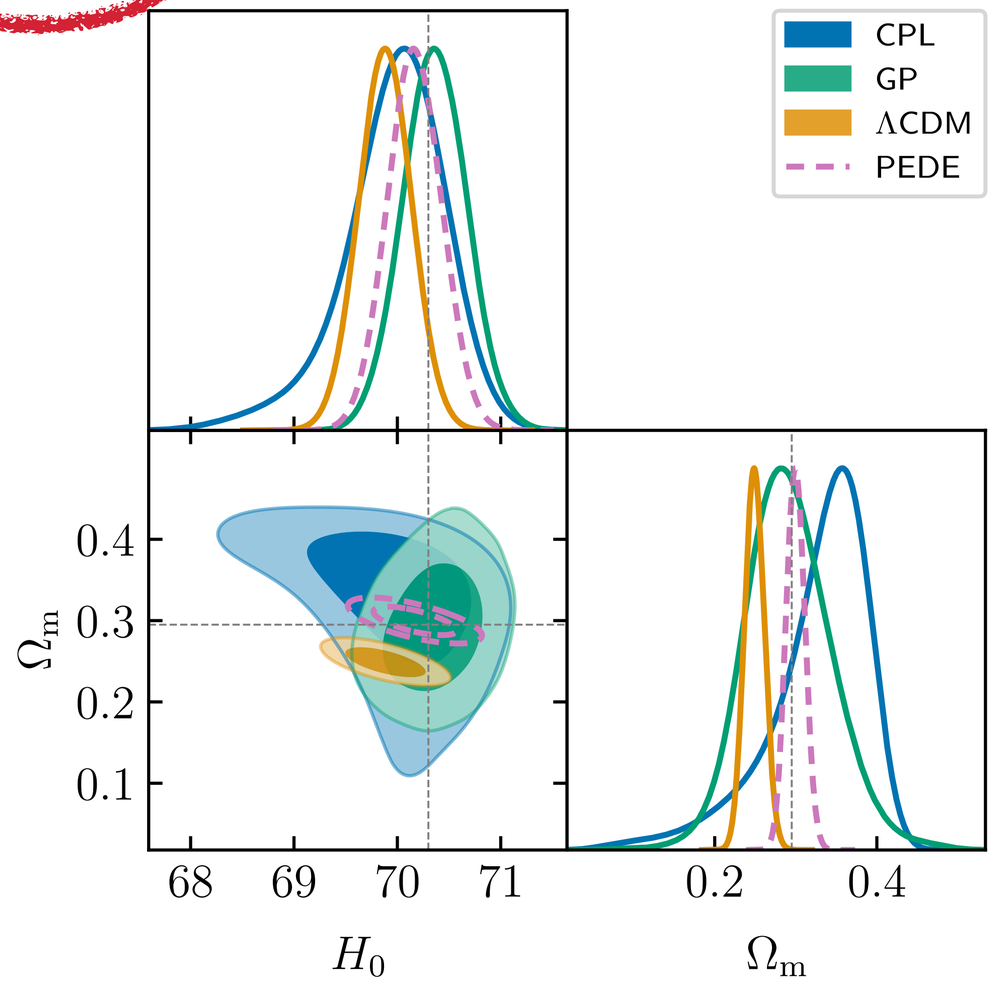
PEDE Universe | Pantheon+ & ET Δ + CE



Cozzumbo+, **in prep.**

Non-parametric approach

Phenomenologically Emergent Dark Energy



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Non-parametric approach

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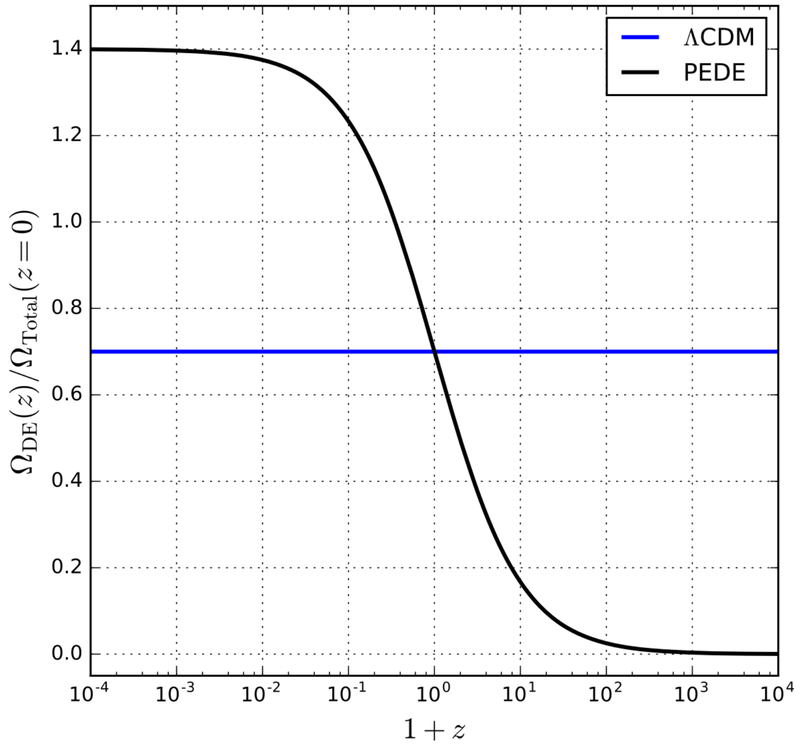
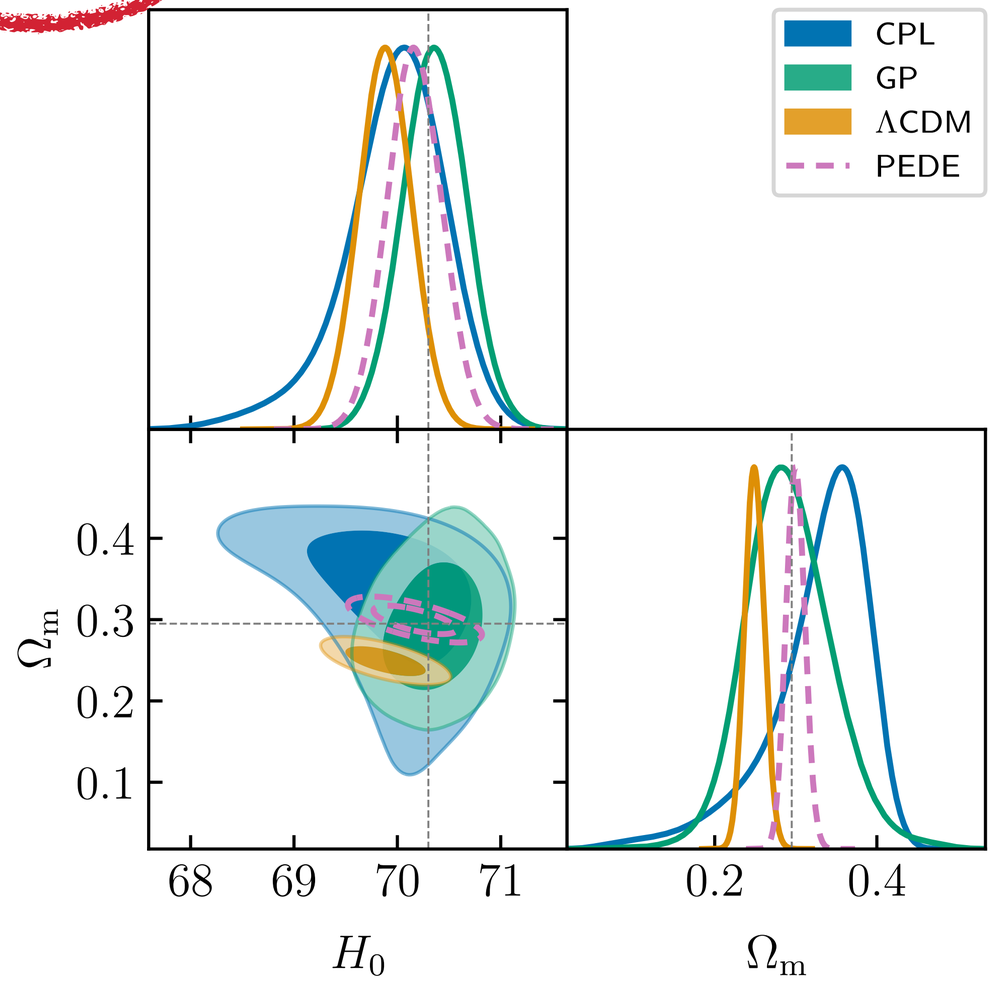


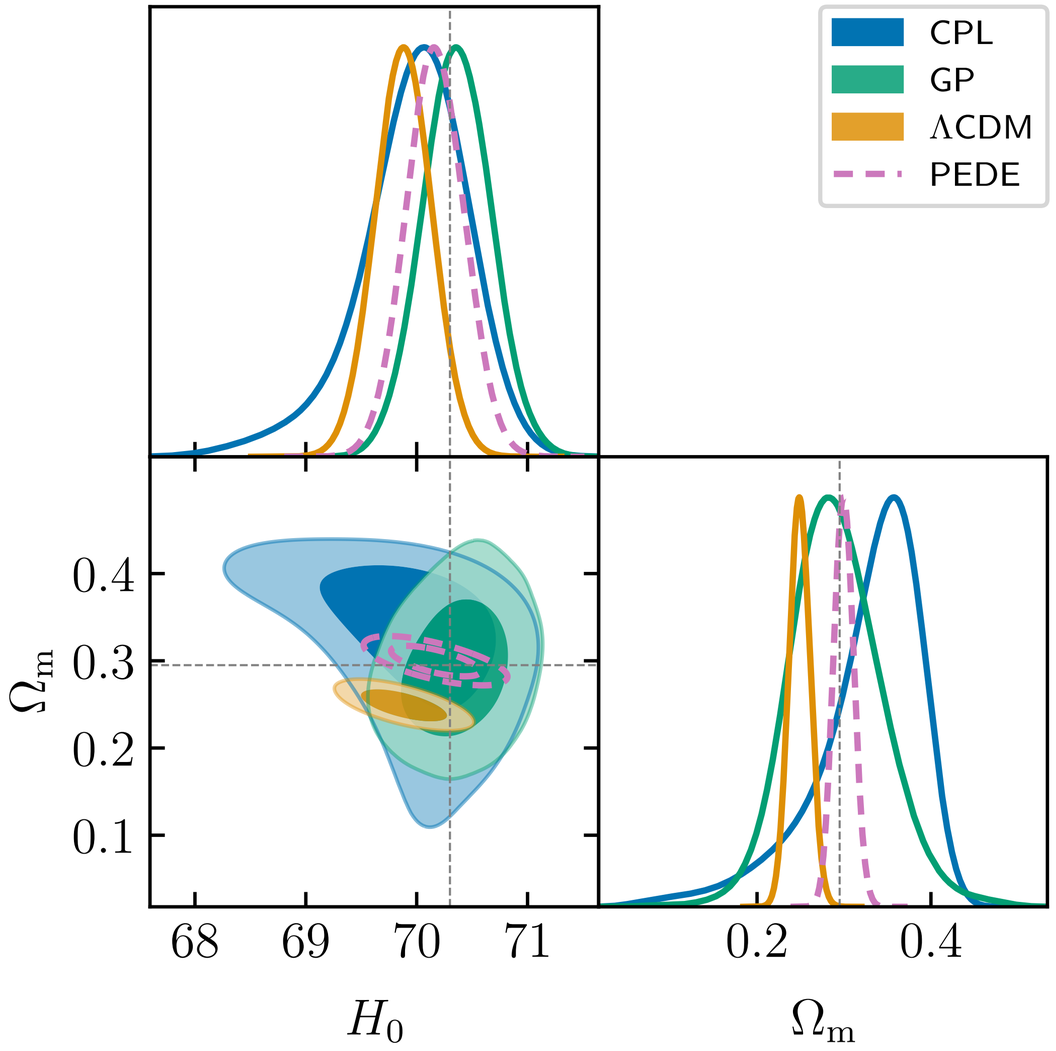
Li and Shafieloo, 2019



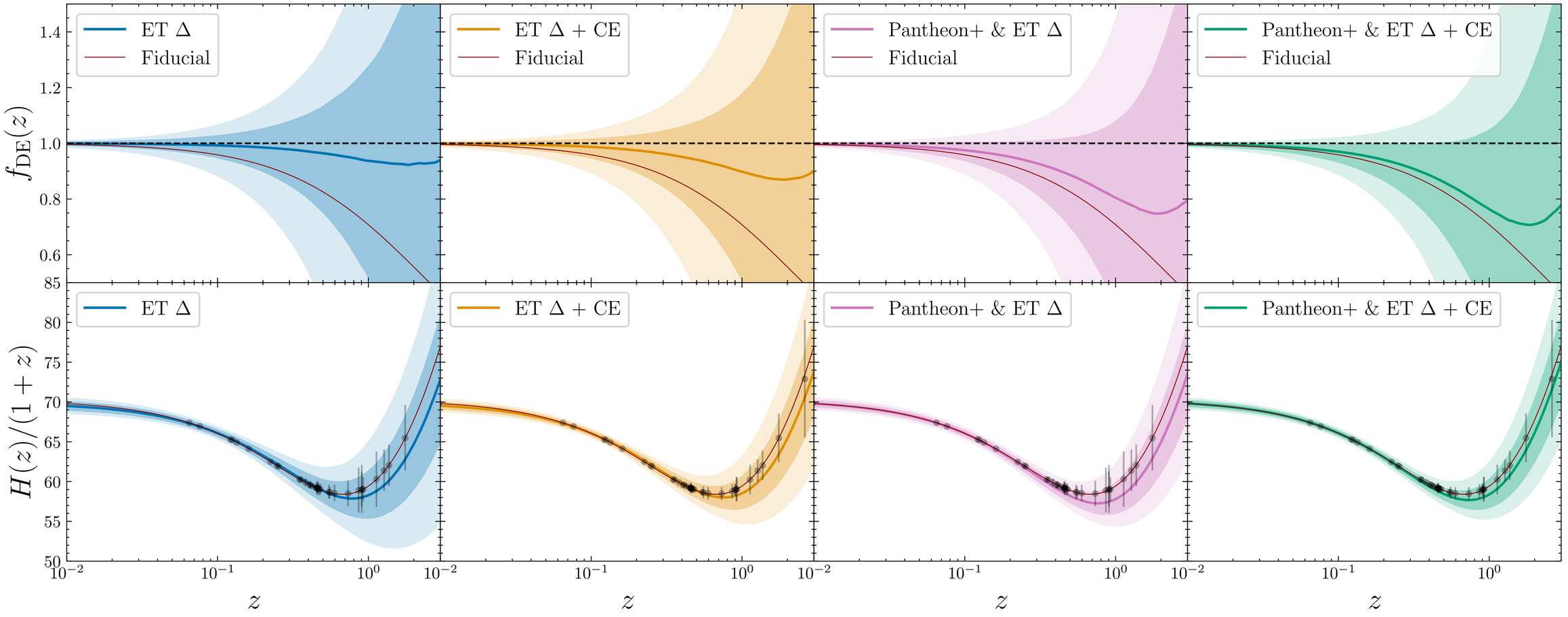
Cozzumbo+, **in prep.**

Non-parametric approach

PEDE Universe | Pantheon+ & ET Δ + CE

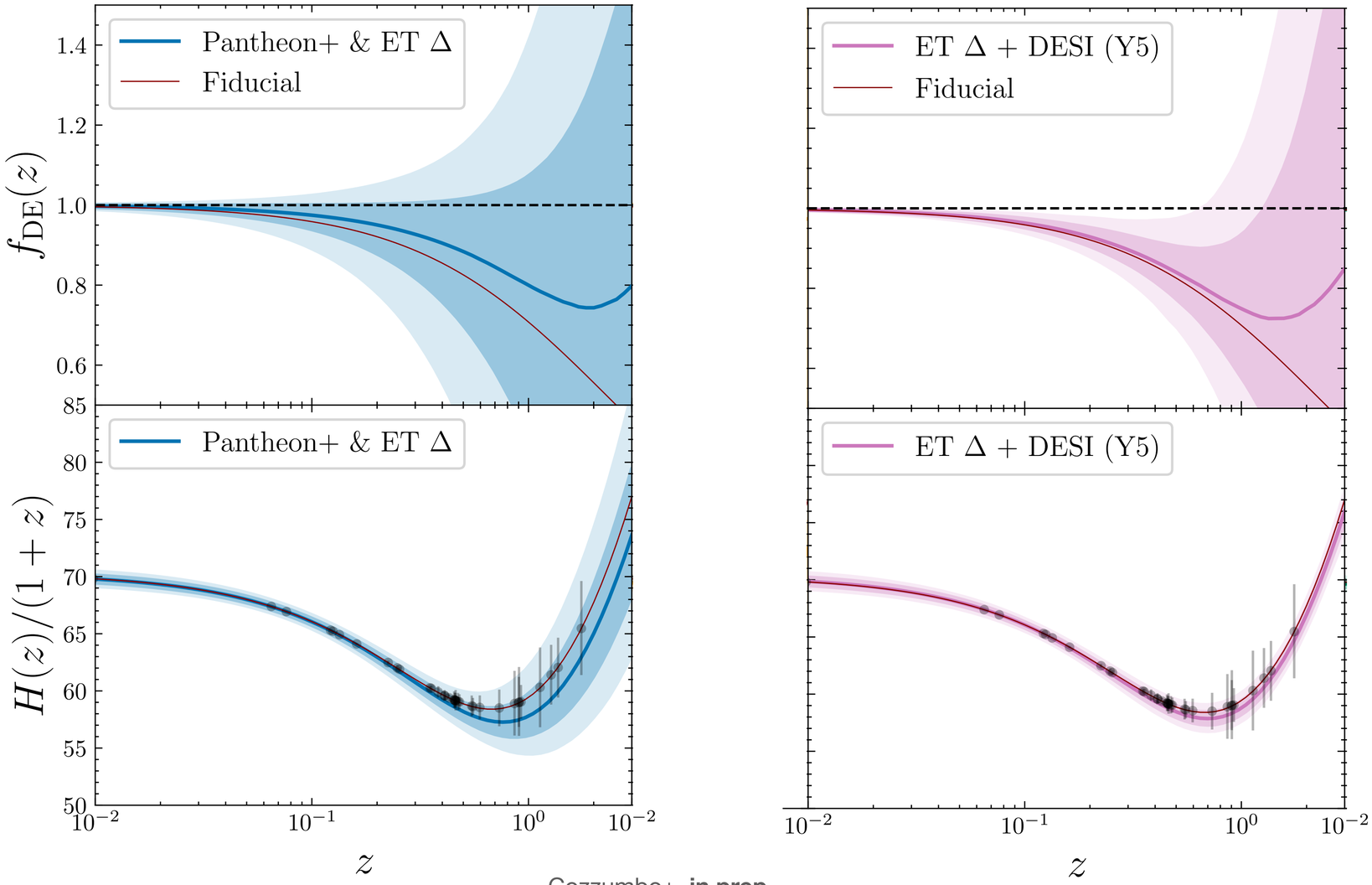


Non-parametric approach



Cozzumbo+, **in prep.**

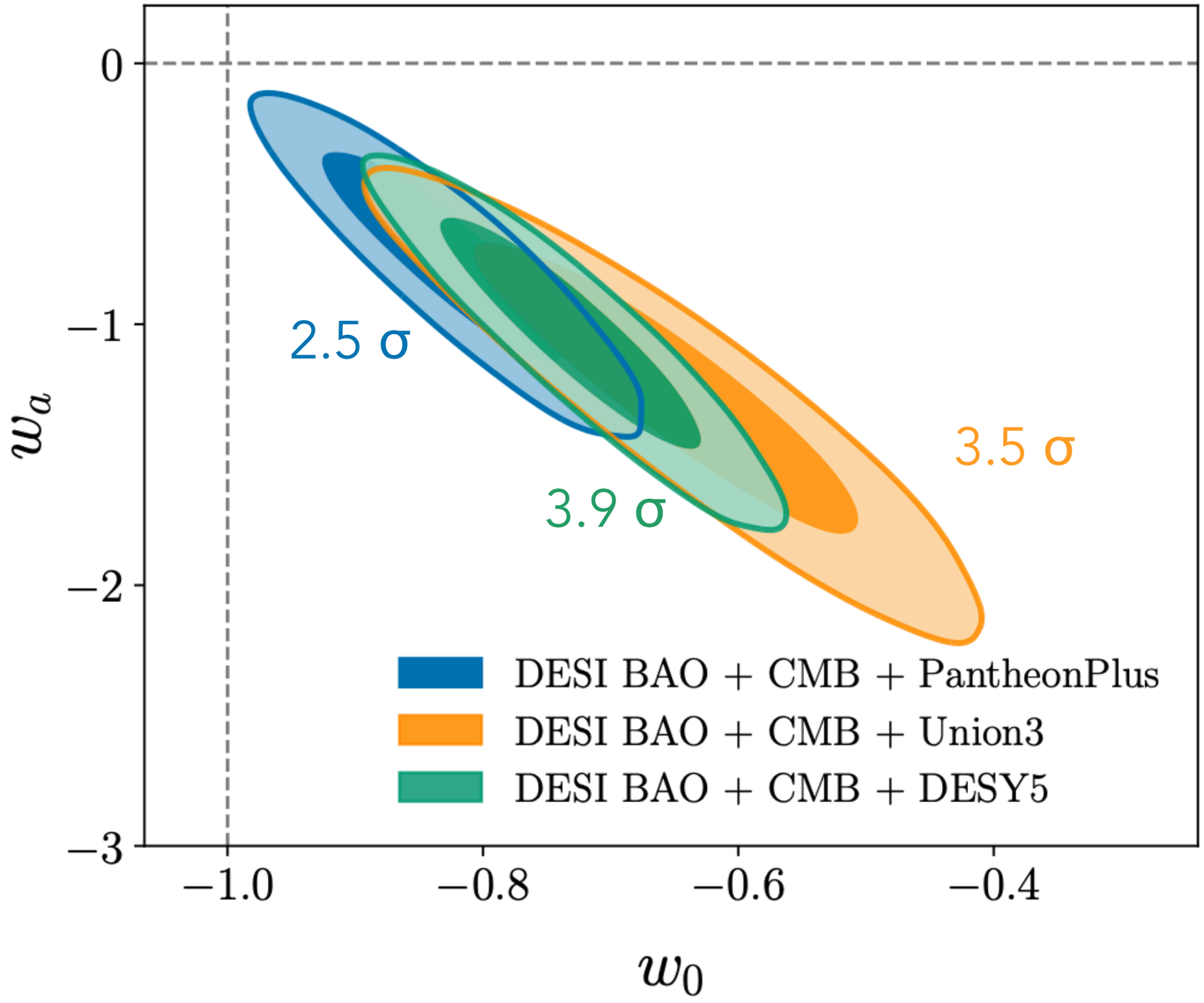
Non-parametric approach



Cozzumbo+, **in prep.**

Model-independent cosmology

DESI collaboration, Adame+, 2024



Conclusions

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

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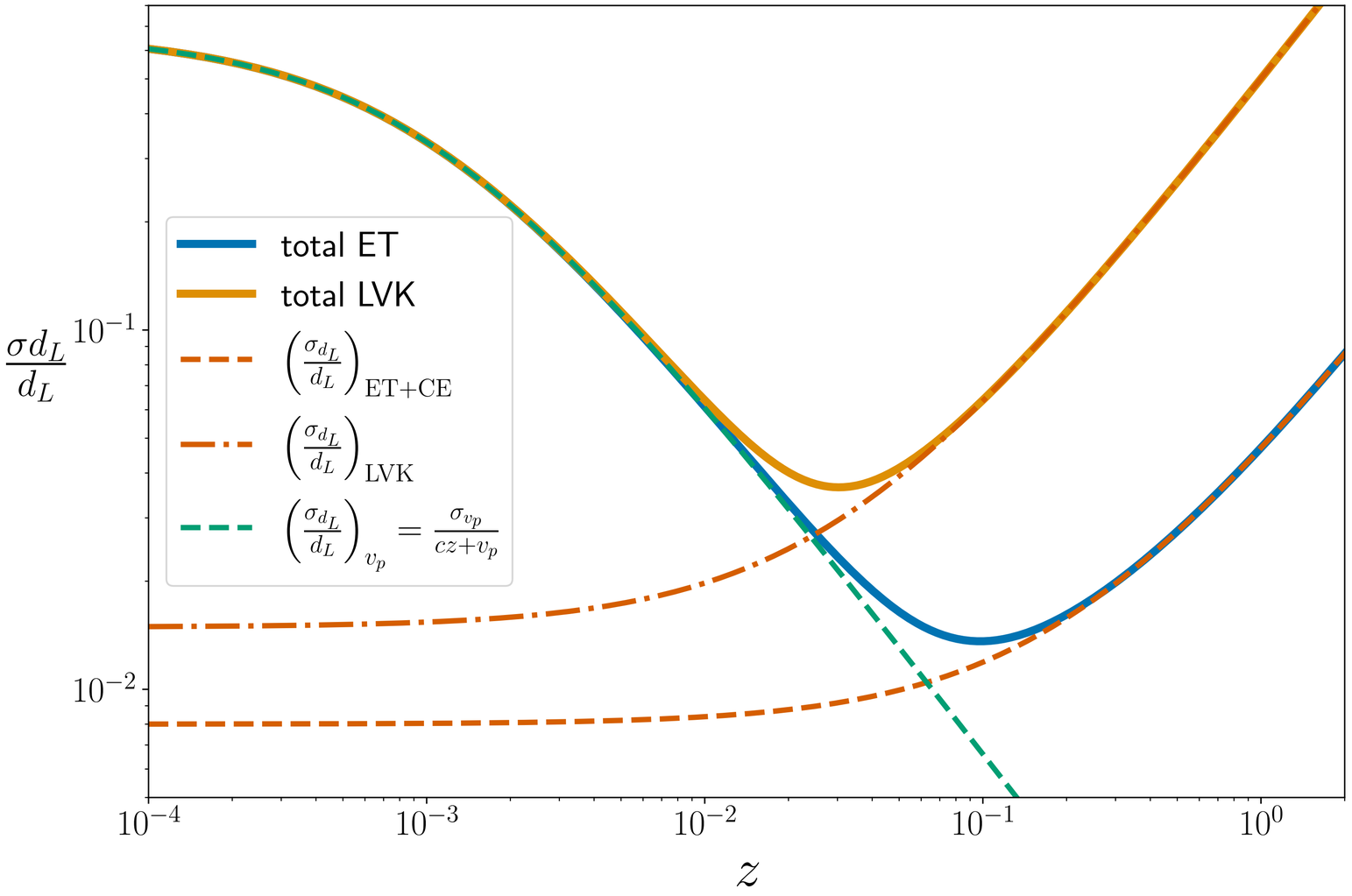
Conclusions

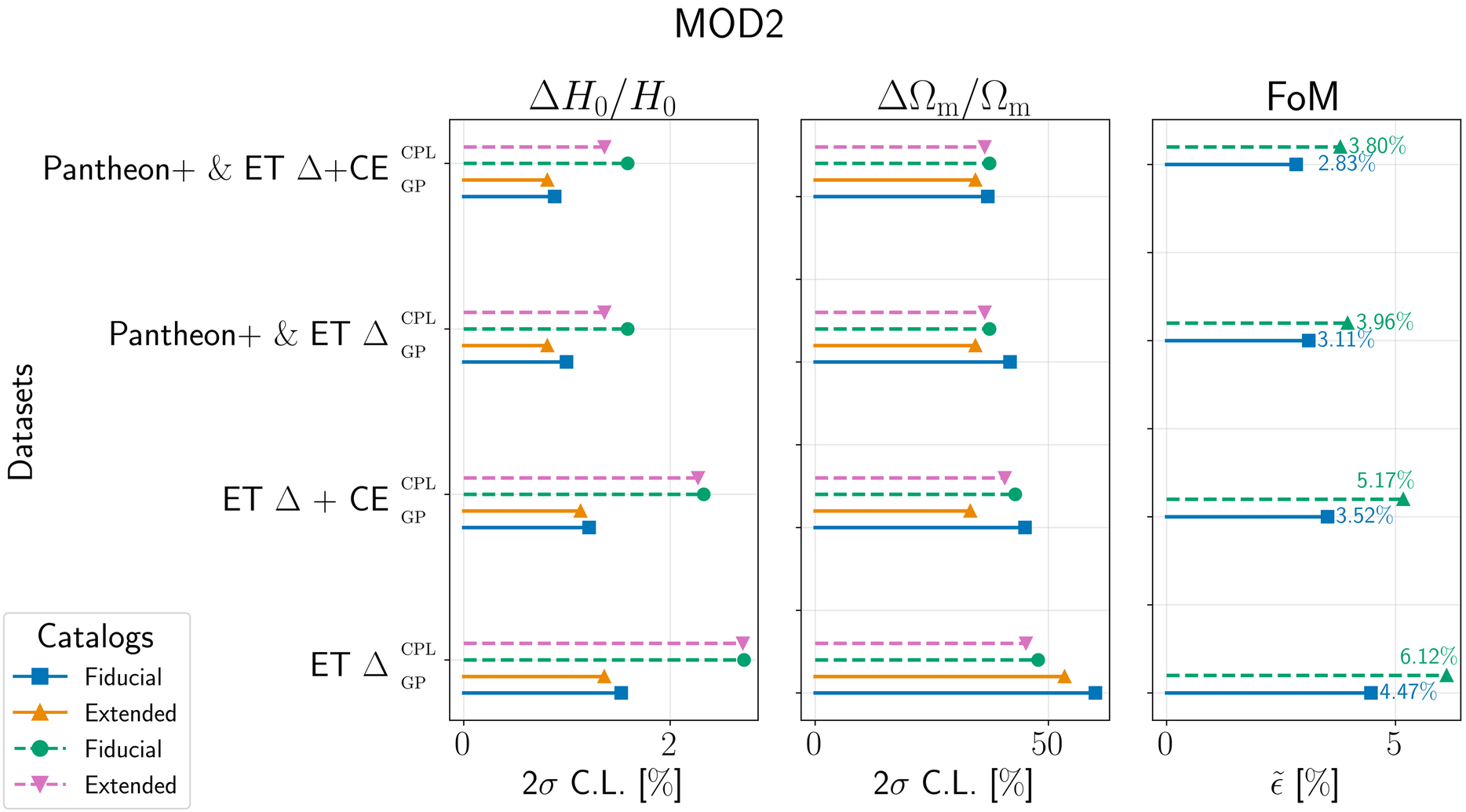
- We compare different catalogs of GRBs and configuration of 3G GW detectors to understand the **future prospects of cosmological constraints with Bright Sirens**
- We compare parametric and non-parametric approaches, underlining the **biases incurring when choosing the wrong fitting model**
- We show the potential of a model-independent reconstruction for **Einstein Telescope and next generation cosmological probes**


Thank you
for the attention!

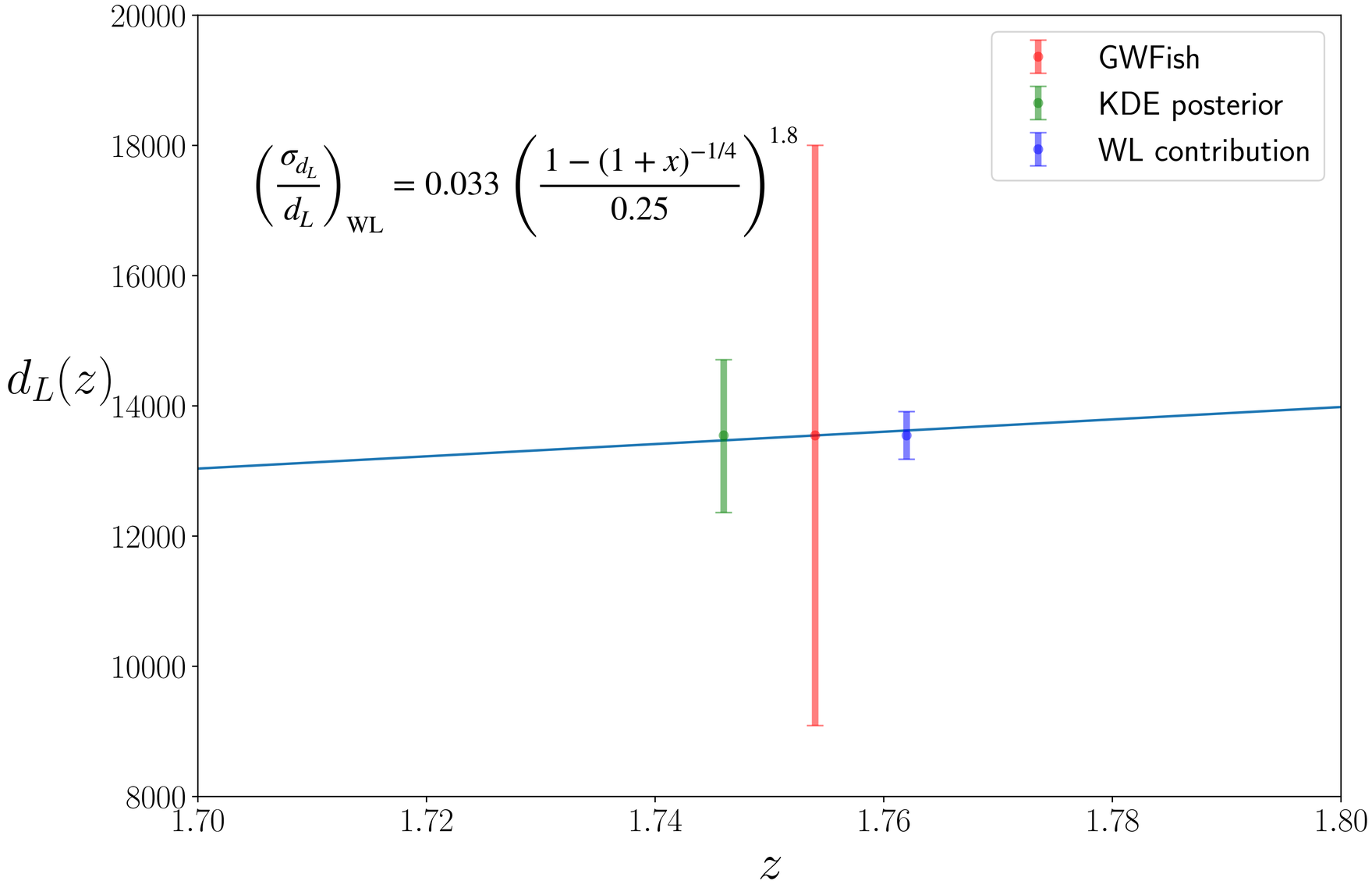
Back-up


total ET
total LVK
$\left(\frac{\sigma_{d_L}}{d_L}\right)_{\rm ET+CE}$
$\left(\frac{\sigma_{d_L}}{d_L}\right)_{\rm LVK}$
$\left(\frac{\sigma_{d_L}}{d_L}\right)_{v_p} = \frac{\sigma_{v_p}}{cz+v_p}$
$\frac{\sigma d_L}{d_L}$
10^{-1}
10^{-2}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
z

Back-up


MOD2
$\Delta H_0/H_0$
$\Delta\Omega_{\rm m}/\Omega_{\rm m}$
FoM
Datasets
Pantheon+ & ET Δ+CE
Pantheon+ & ET Δ
ET Δ + CE
ET Δ
CPL
GP
3.80%
2.83%
3.96%
3.11%
5.17%
3.52%
6.12%
4.47%
0
2
50
5
2σ C.L. [%]
2σ C.L. [%]
$\tilde{\epsilon}$ [%]
Catalogs
Fiducial
Extended
Fiducial
Extended

Back-up


$\left(\frac{\sigma_{d_L}}{d_L}\right)_{\rm WL} = 0.033 \left(\frac{1-(1+x)^{-1/4}}{0.25}\right)^{1.8}$
GWFish
KDE posterior
WL contribution
$d_L(z)$
20000
18000
16000
14000
12000
10000
8000
1.70
1.72
1.74
1.76
1.78
1.80
z