Combining the Weyl potential and galaxy velocities: New measurements of E_G

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FACULTÉ DES SCIENCES

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How can we test modified gravity?
Possibility 1

Pick a modified gravity model → Data analysis with additional parameters → Obtain constraints for one model

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$\hat{J}$: A model-independent observable from weak lensing

Weyl potential in General Relativity:

$$\Psi_W = (\Phi + \Psi)/2 \quad \propto \quad D_1(z)\,\Omega_m(z)$$

Growth of matter perturbations

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Weyl potential in ~~General Relativity:~~ **any gravity theory:**

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$\Omega_m(z)$: Matter content in the Universe

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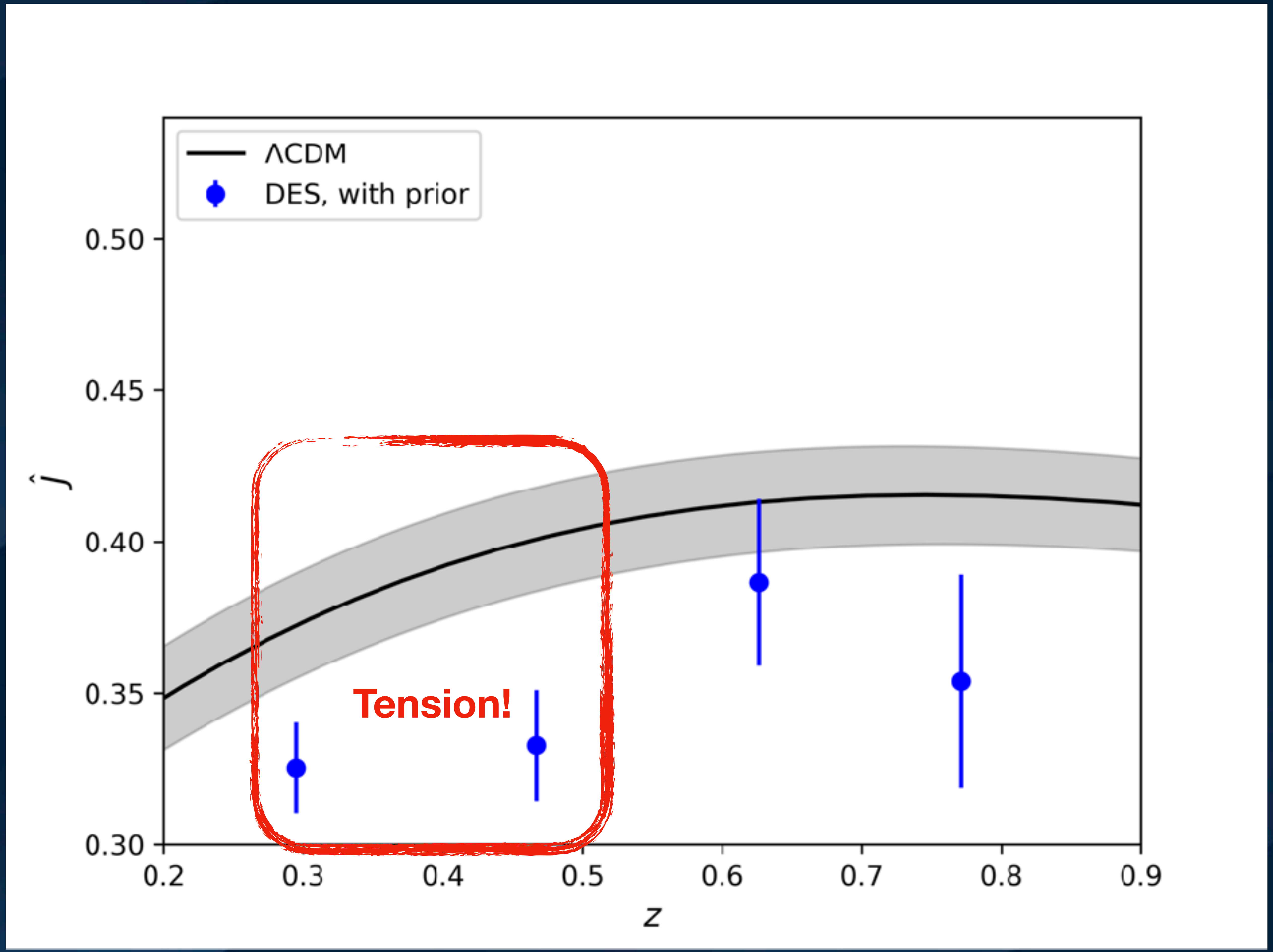
Matter content in the Universe

Combining galaxy-galaxy lensing and galaxy clustering → Measuring $\hat{J}(z) = \dfrac{J(z)\sigma_8(z)}{D_1(z)}$

Measurement of $\hat{J}(z)$ from Dark Energy Survey data



I. Tutusaus, C. Bonvin & NG, arXiv:2312.06434

More details: See Isaac's slides :)

Measurement in 4 bins of the MagLim sample, with 3σ Planck priors

Which model-independent observables can we use?

Weak gravitational lensing

↓

$\hat{J}(z)$

Redshift-space distortions

↓

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↘ E_G **statistic** ↙

The E_G statistic

Theoretically described in Zhang et al. (2007):

$$E_G(l) = \frac{a}{3H_0^2} \frac{C_{\kappa g}(l)}{C_{gv}(l)}$$

Galaxy-galaxy lensing

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In practise:

$$E_G(l) \propto \frac{C_{\kappa g}(l)}{(\, f/b \,) \cdot C_{gg}(l)}$$

Measured from RSD

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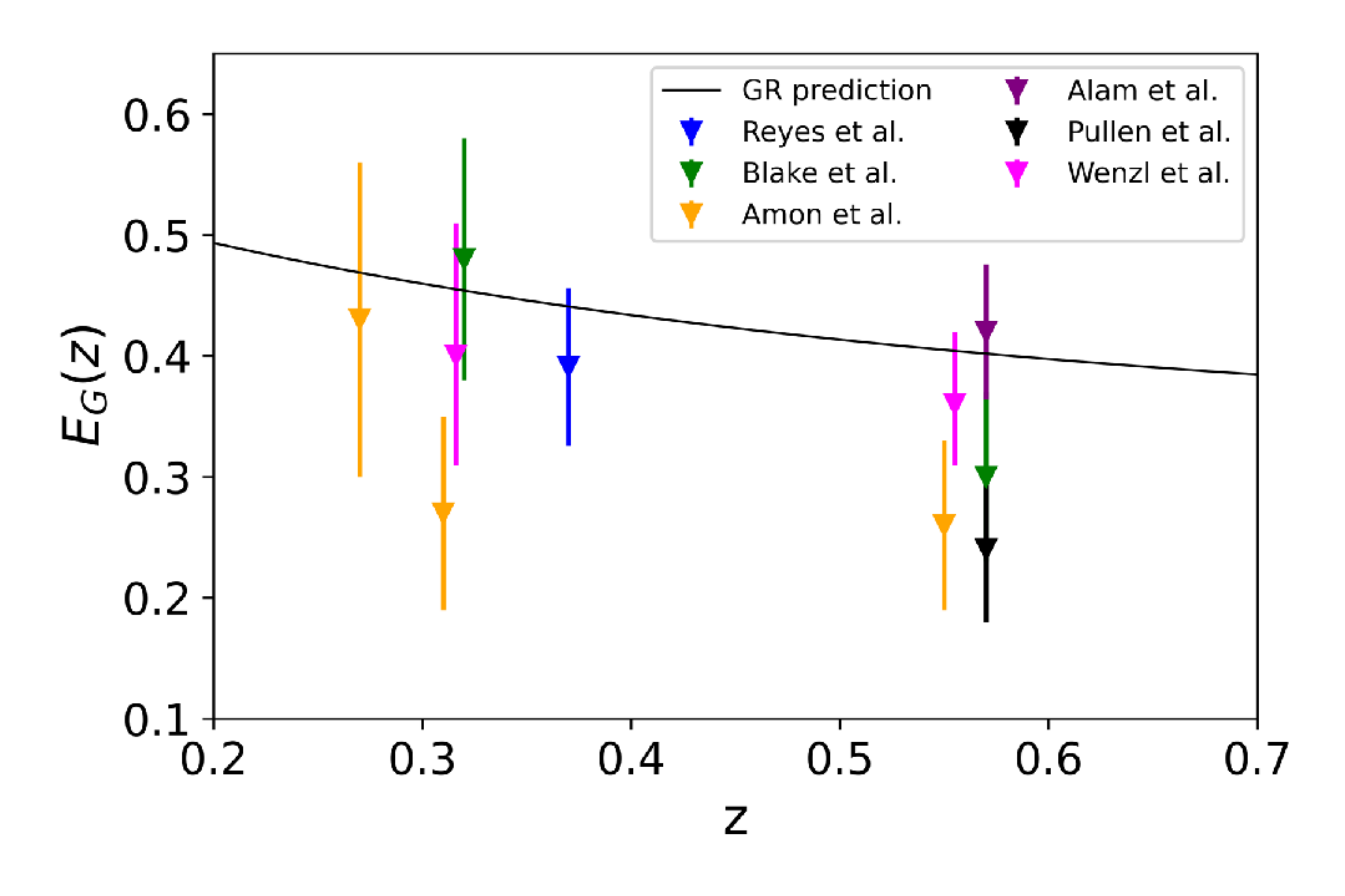
Why is it useful?

- Galaxy bias b cancels out.
- Measurements of E_G can be compared to their ΛCDM prediction, $E_G = \Omega_{m,0}/f(z)$.

The E_G statistic: Past measurements



Some literature values show mild tensions (up to 2.6σ) with GR.

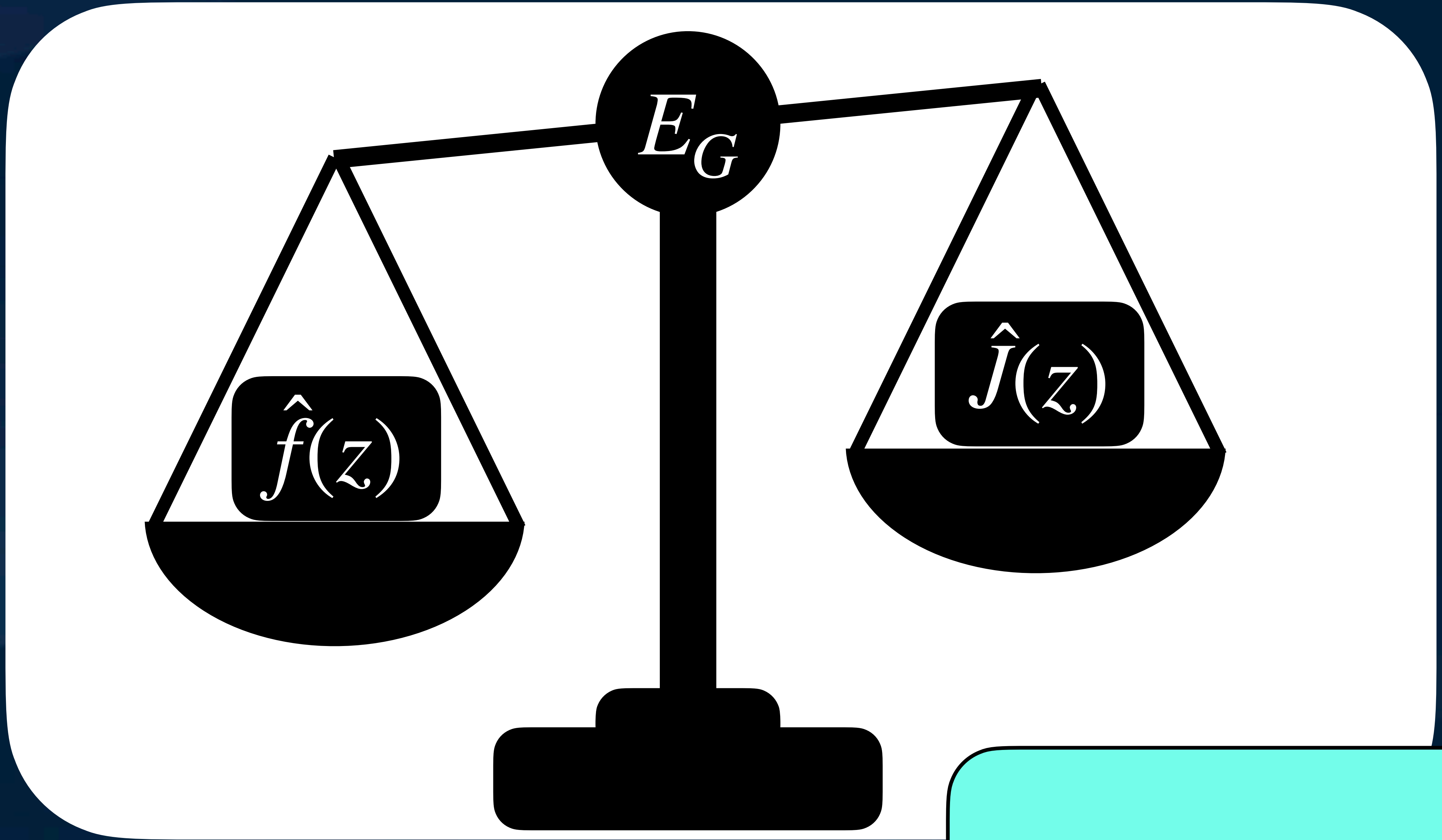
A limitation:

All these measurements need one common spectroscopic data set to cancel out galaxy bias.

The E_G statistic: A new method

E_G can be written as the ratio of model-independent observables:

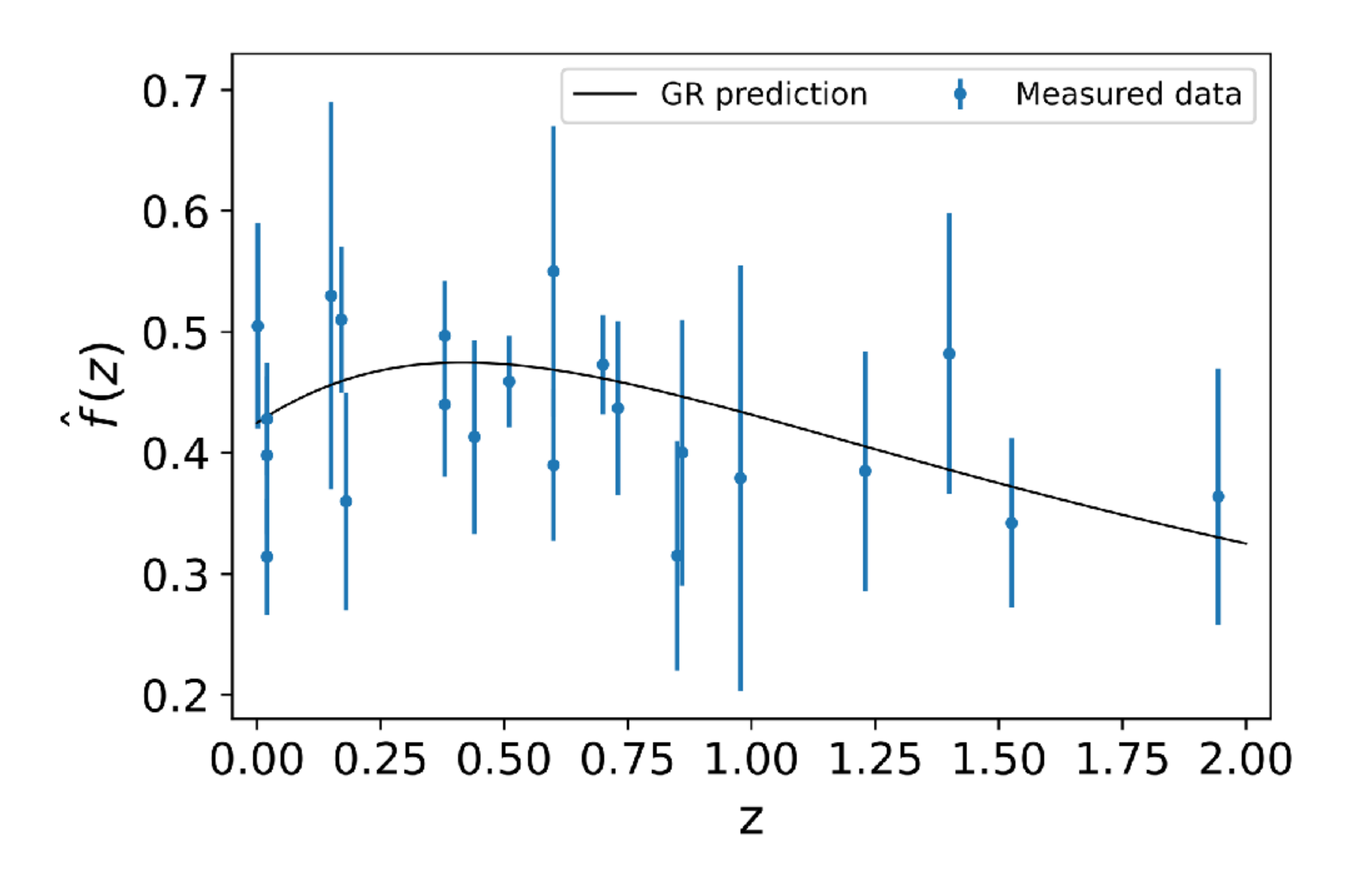
$$E_G(z) = \left(\frac{H(z)}{H_0}\right)^2 \frac{1}{1+z} \frac{\hat{J}(z)}{\hat{f}(z)}$$



- $\hat{J}(z)$ and $\hat{f}(z)$ can come from different data sets.
- $\hat{J}(z)$ and $\hat{f}(z)$ need to be obtained at the same z.
- $\hat{J}(z)$ is currently available at only 4 redshifts.

NG, C. Bonvin and I. Tutusaus, arXiv:2403.13709

$\hat{f}(z)$ data



Data:

- 22 measurements of $\hat{f}$ between $z = 0.001$ and $z = 1.944$.
- Based on the Gold-2017 compilation (Nesseris et al. 2017), with updated data from SDSS-IV.

→ **Robust and independent data set!**

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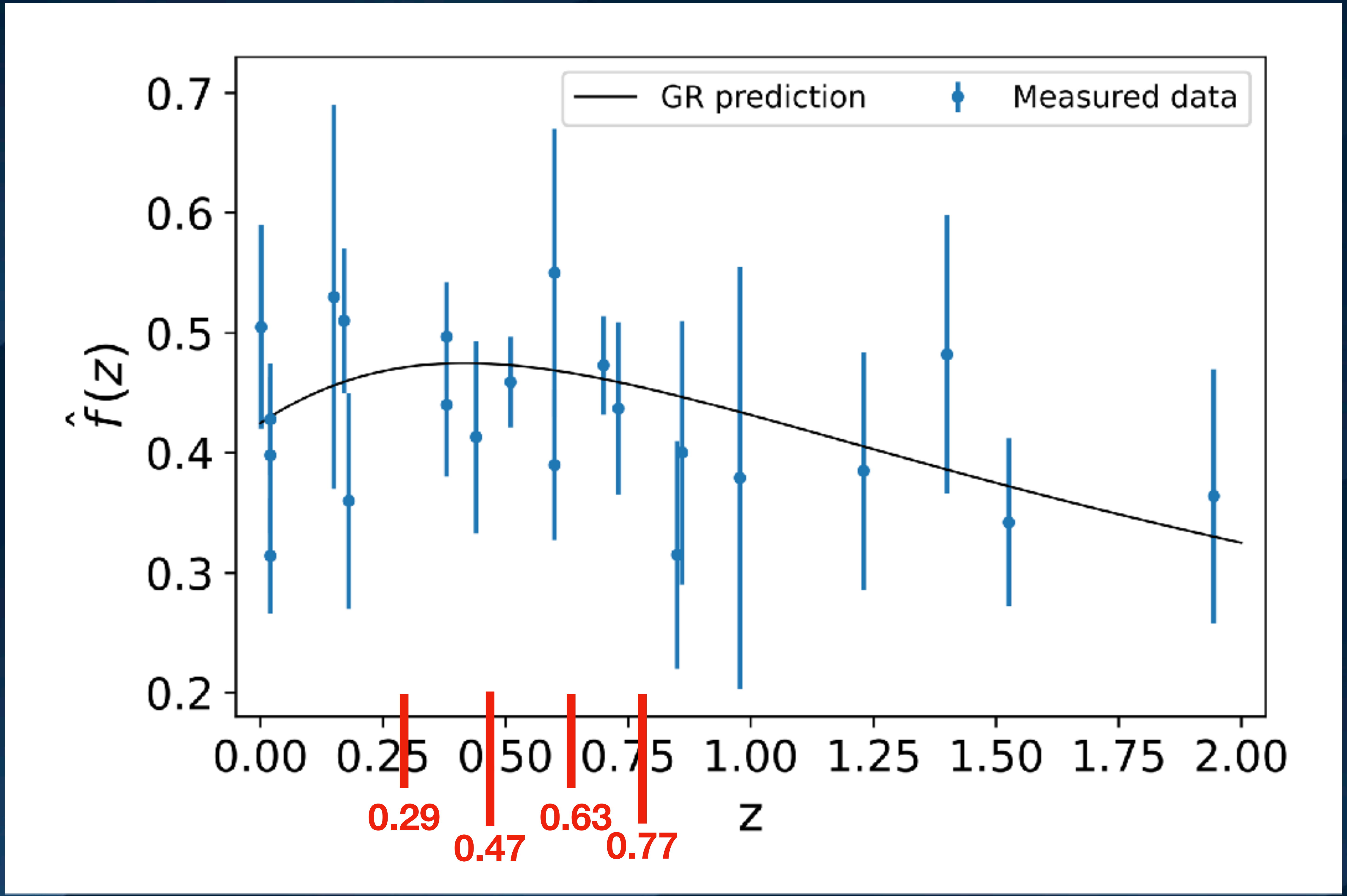

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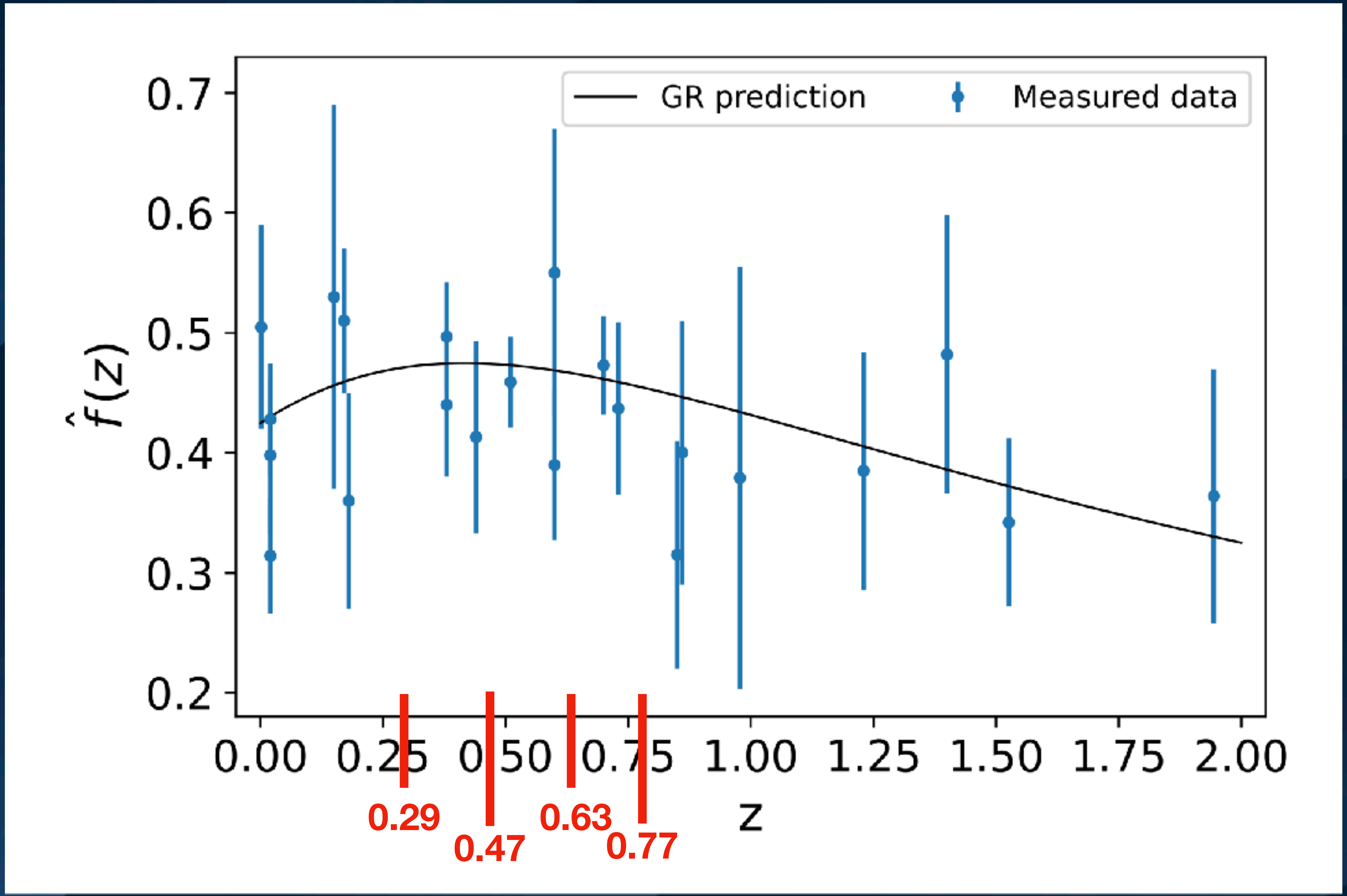
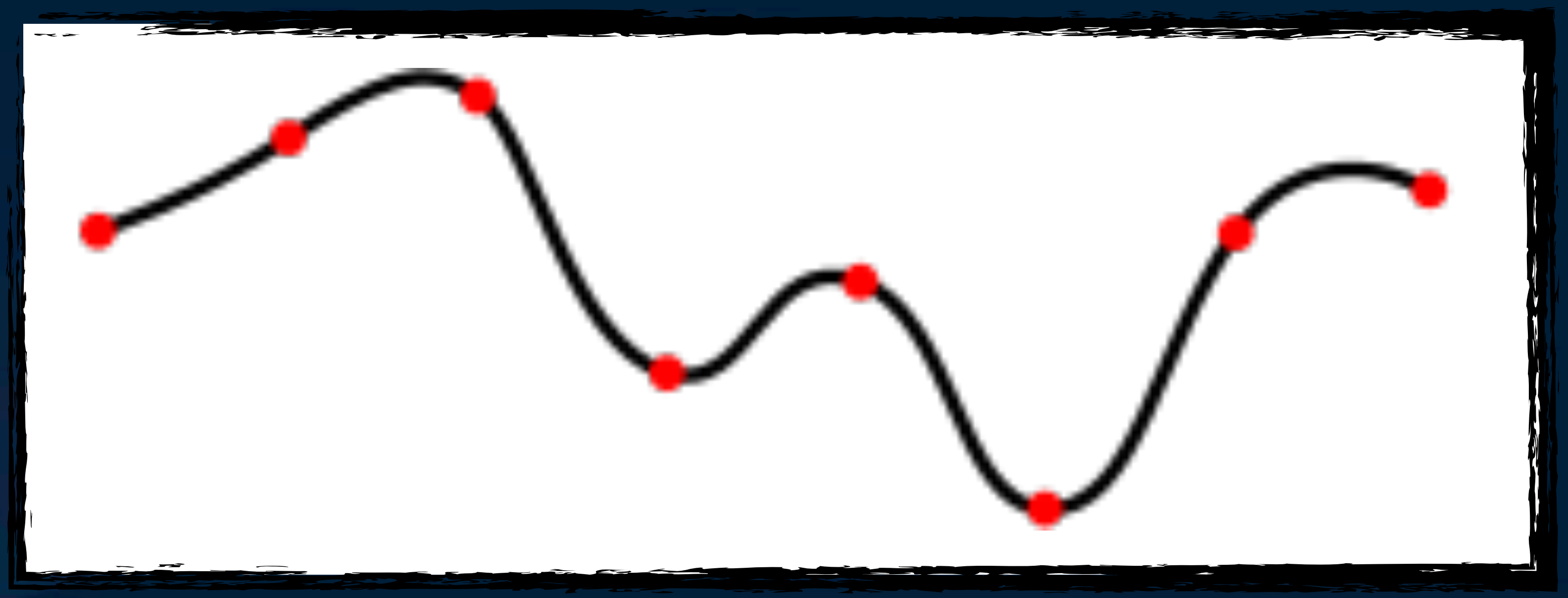


Interpolation Method:

- Cubic spline interpolation



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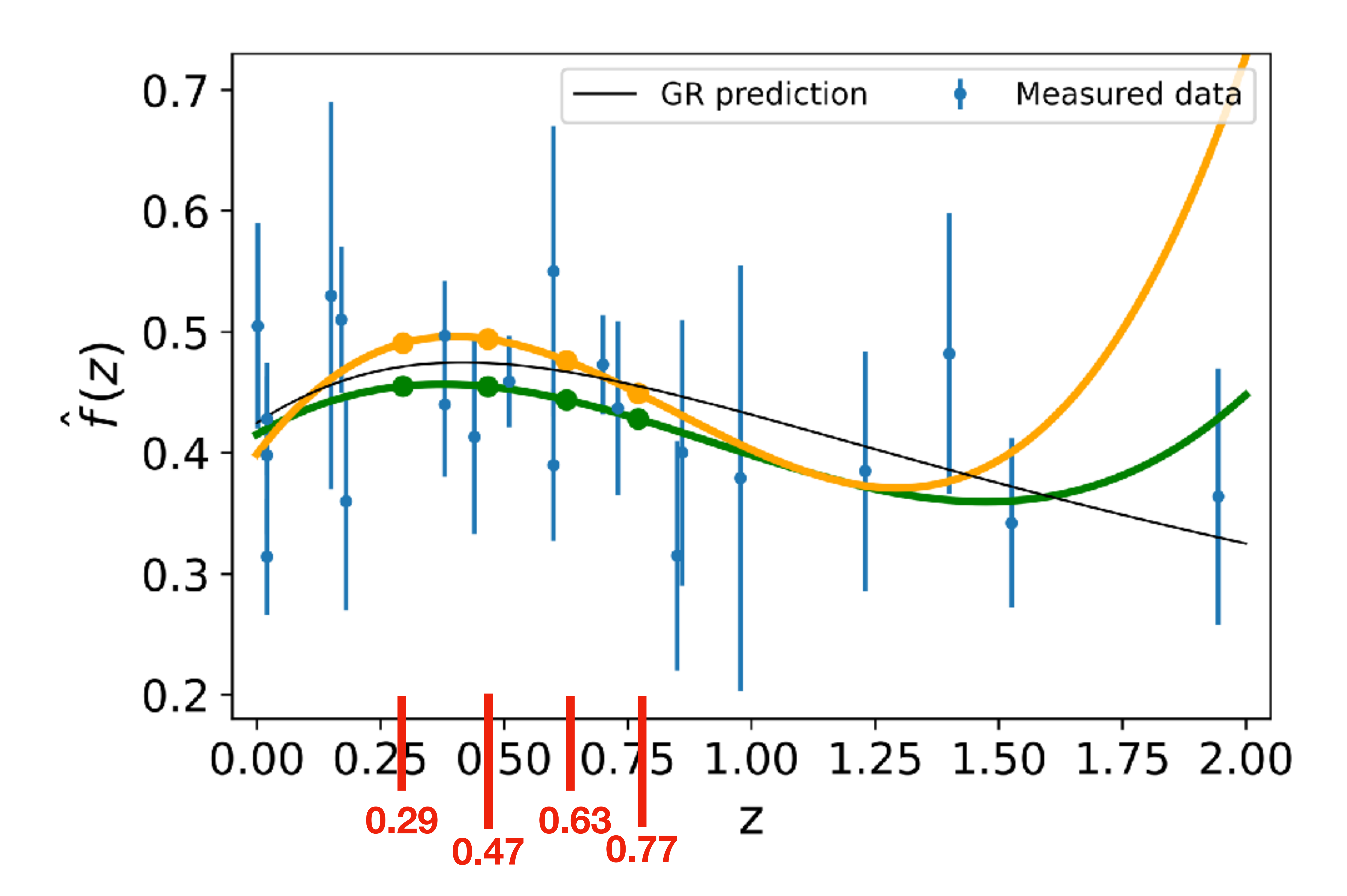

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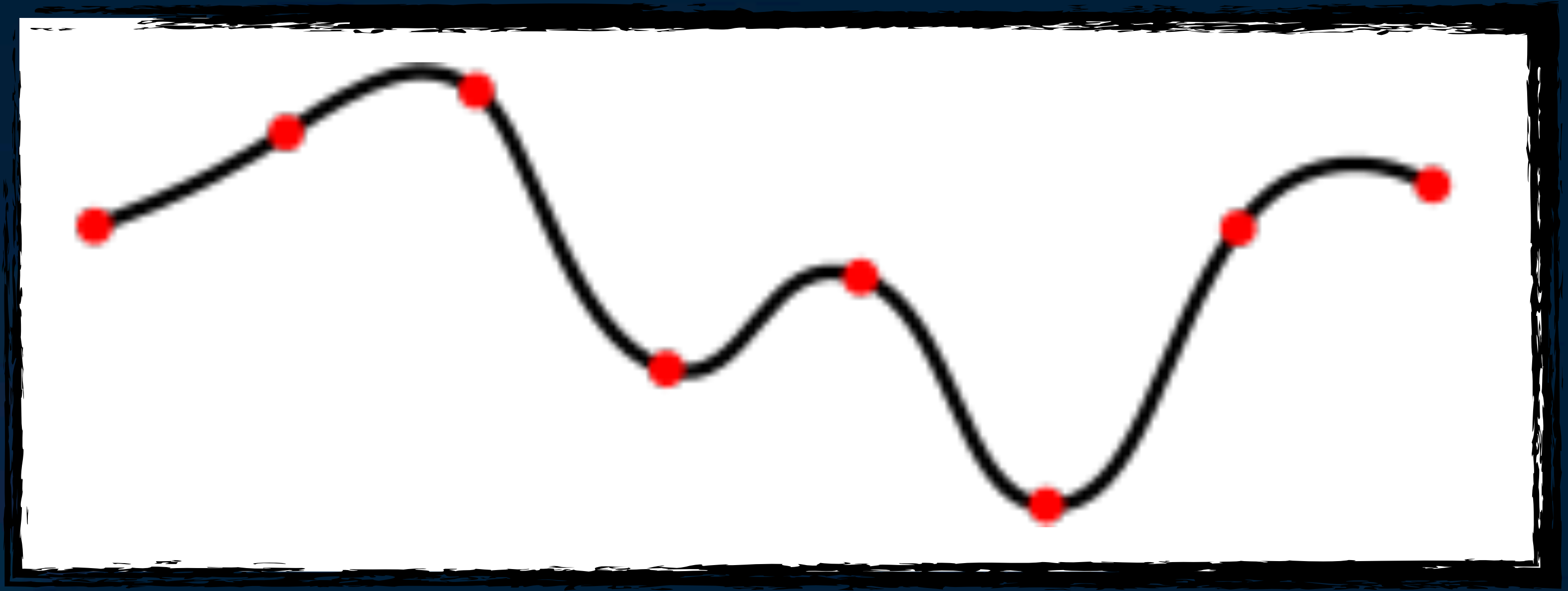
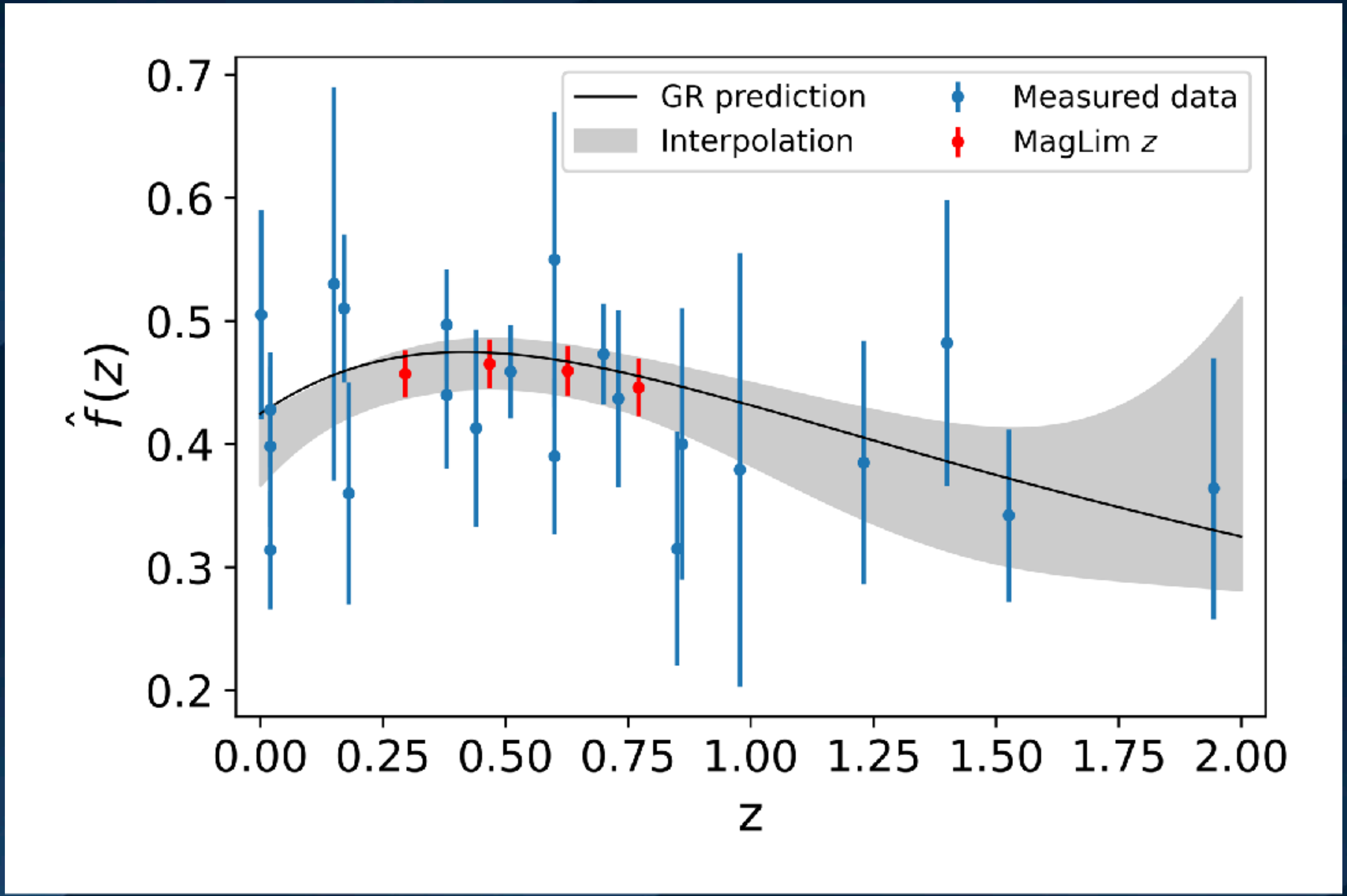


- We set the nodes to the 4 values $z = 0.29, 0.47, 0.63, 0.77$.
- The associated values $\hat{f}_1, \hat{f}_2, \hat{f}_3, \hat{f}_4$ are free parameters.

→ Minimize χ^2 between interpolated values and data points.

Spline interpolation of $\hat{f}(z)$ data

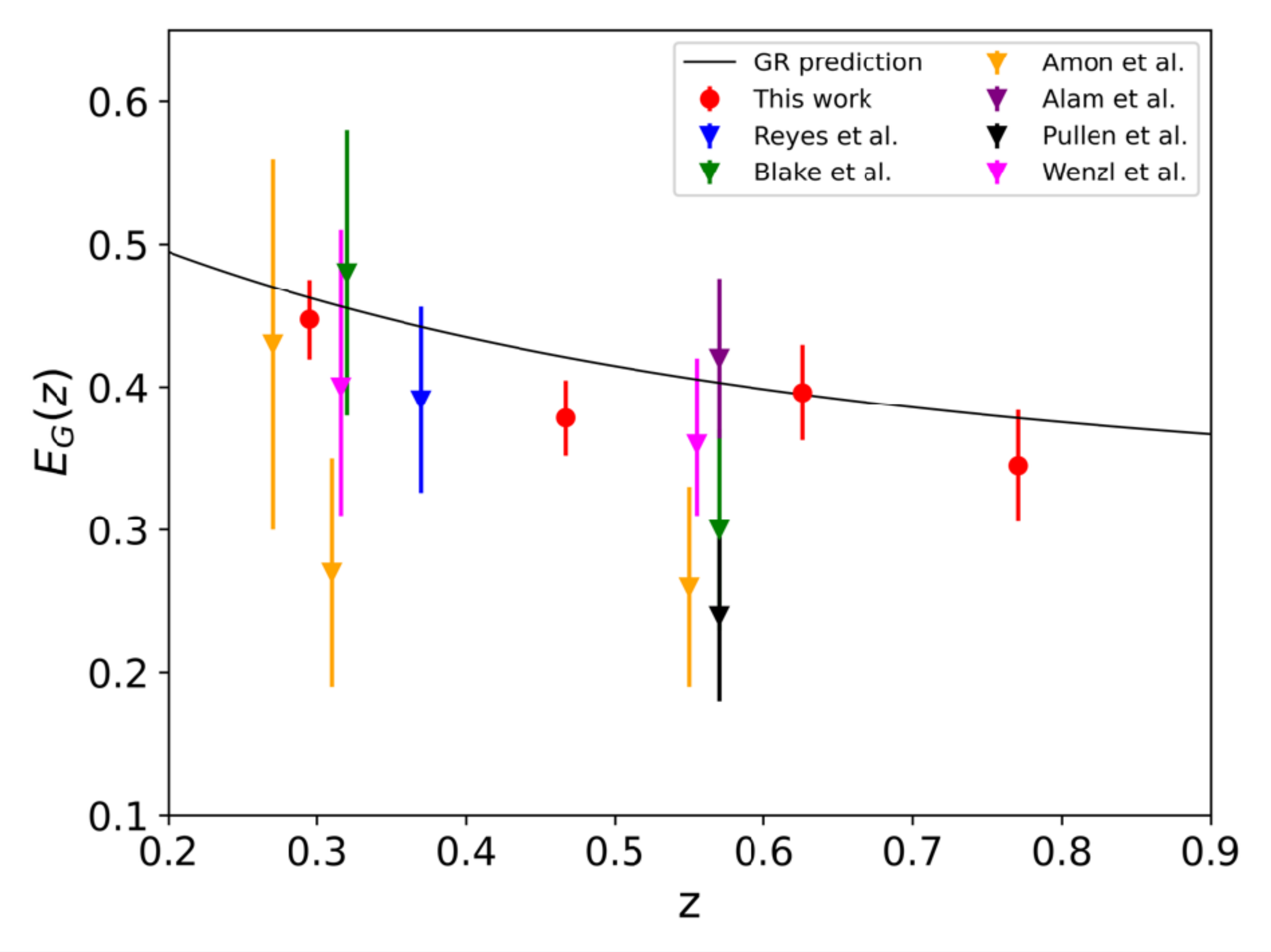


Result:

We obtain measurements of $\hat{f}(z)$ at the 4 MagLim effective redshifts, with 4–5% precision.

NG, C. Bonvin and I. Tutusaus, arXiv:2403.13709

New E_G measurement



Result:

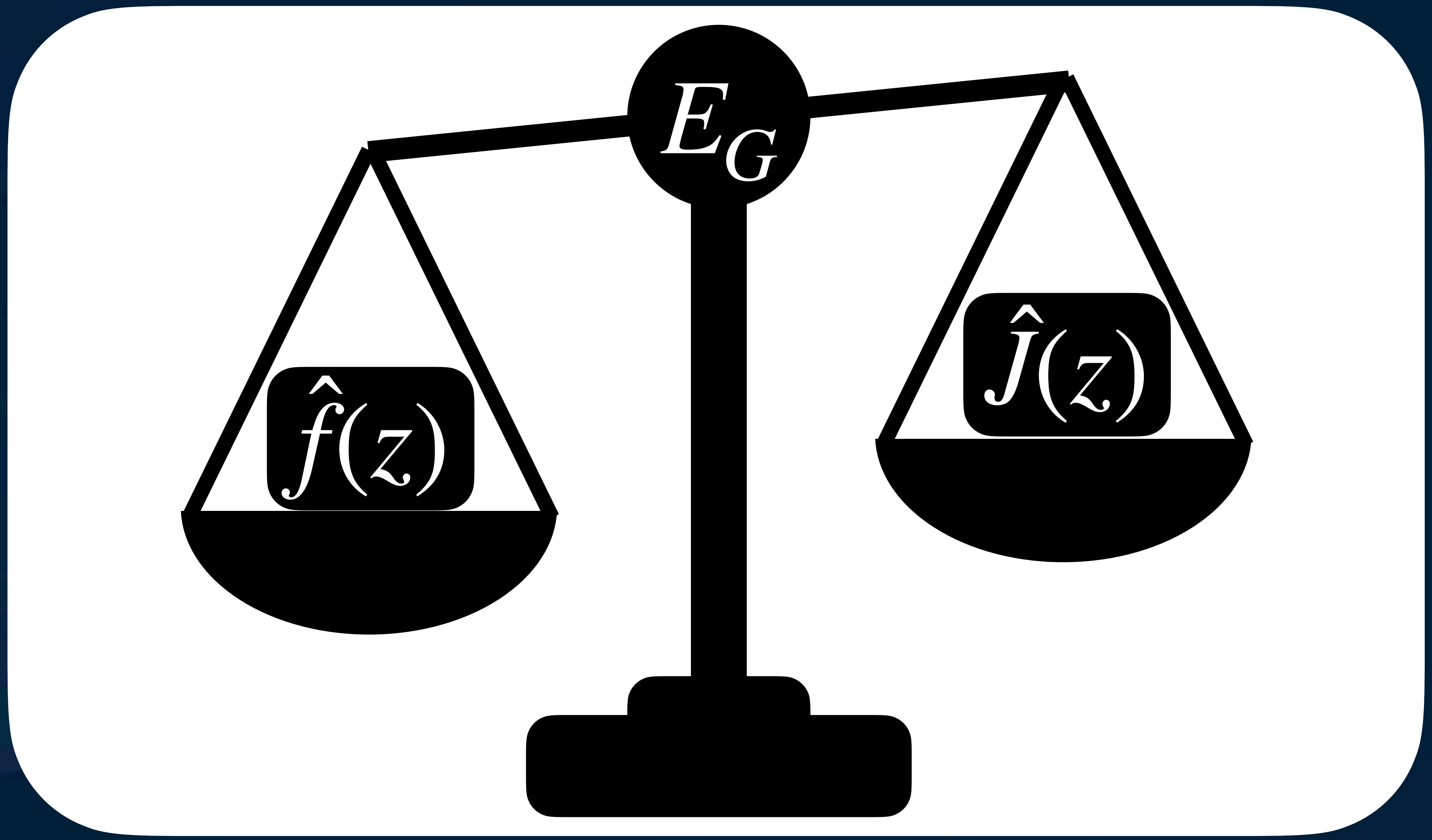
- We can measure E_G with 6—11% precision (compared to 13 – 30% for previous measurements.)
- Agreement with GR (1.6σ deviation in the second bin)

NG, C. Bonvin and I. Tutusaus, arXiv:2403.13709

Outlook on Future Work

The E_G statistic:

- has been used in the past to provide a robust, model-independent test of gravity.
- **But some modifications of gravity could be hidden!**



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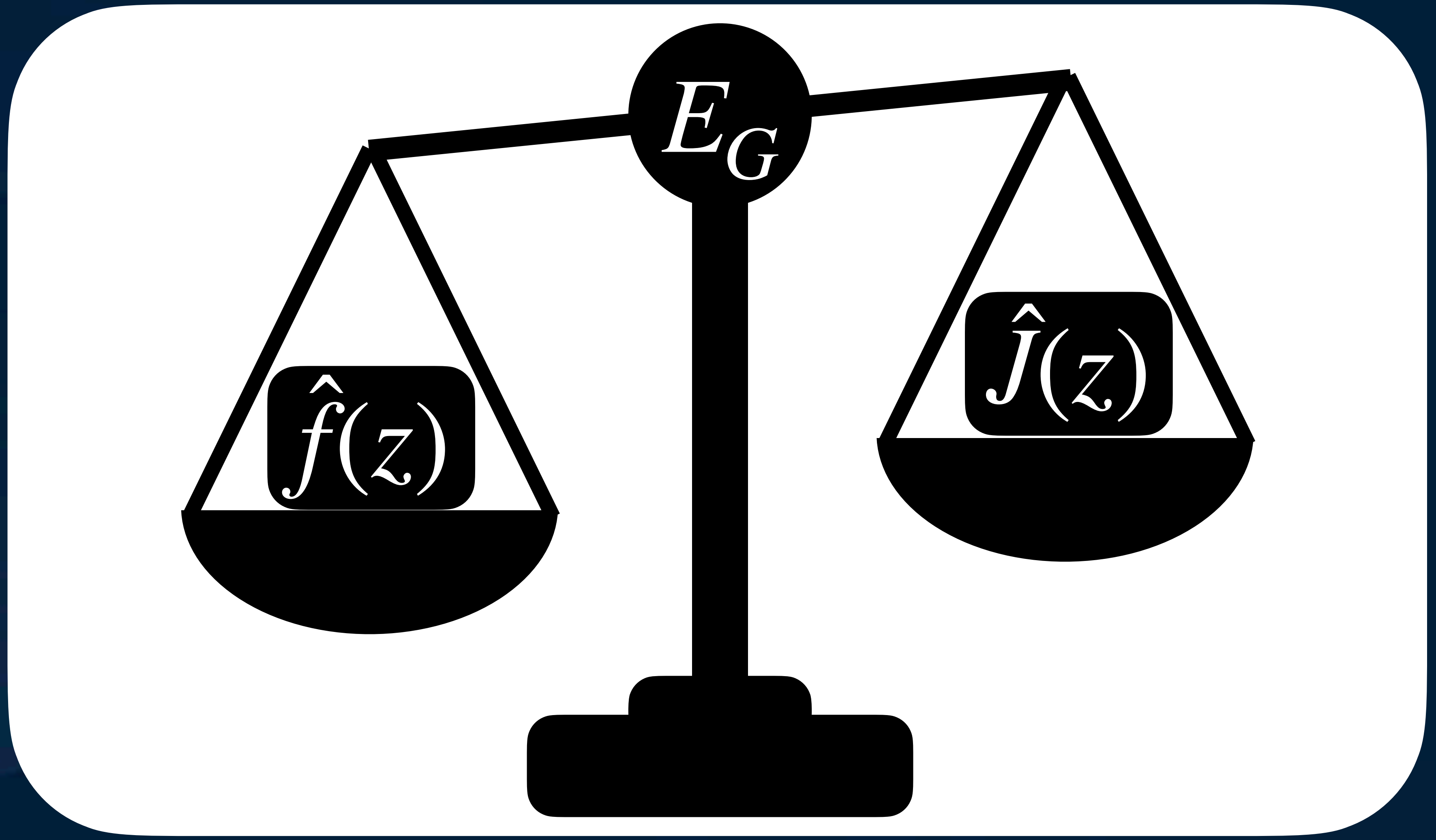

Future work:

Alternative ways of combining $\hat{f}$ and $\hat{J}$, e.g. for a test of Euler's equation.

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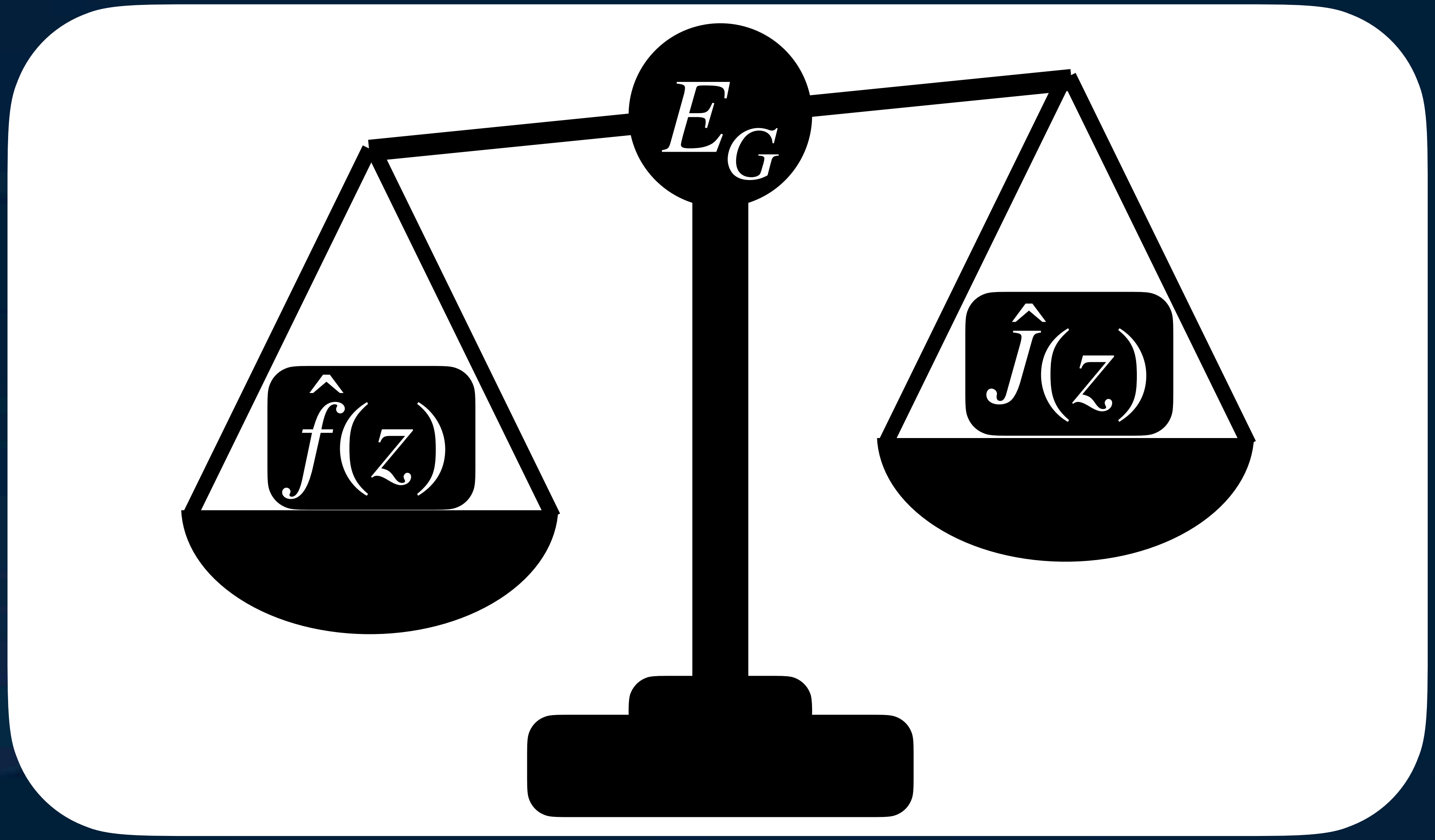

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Investigate the improvement expected from future survey data (DESI, LSST, Euclid)

Conclusion & Outlook

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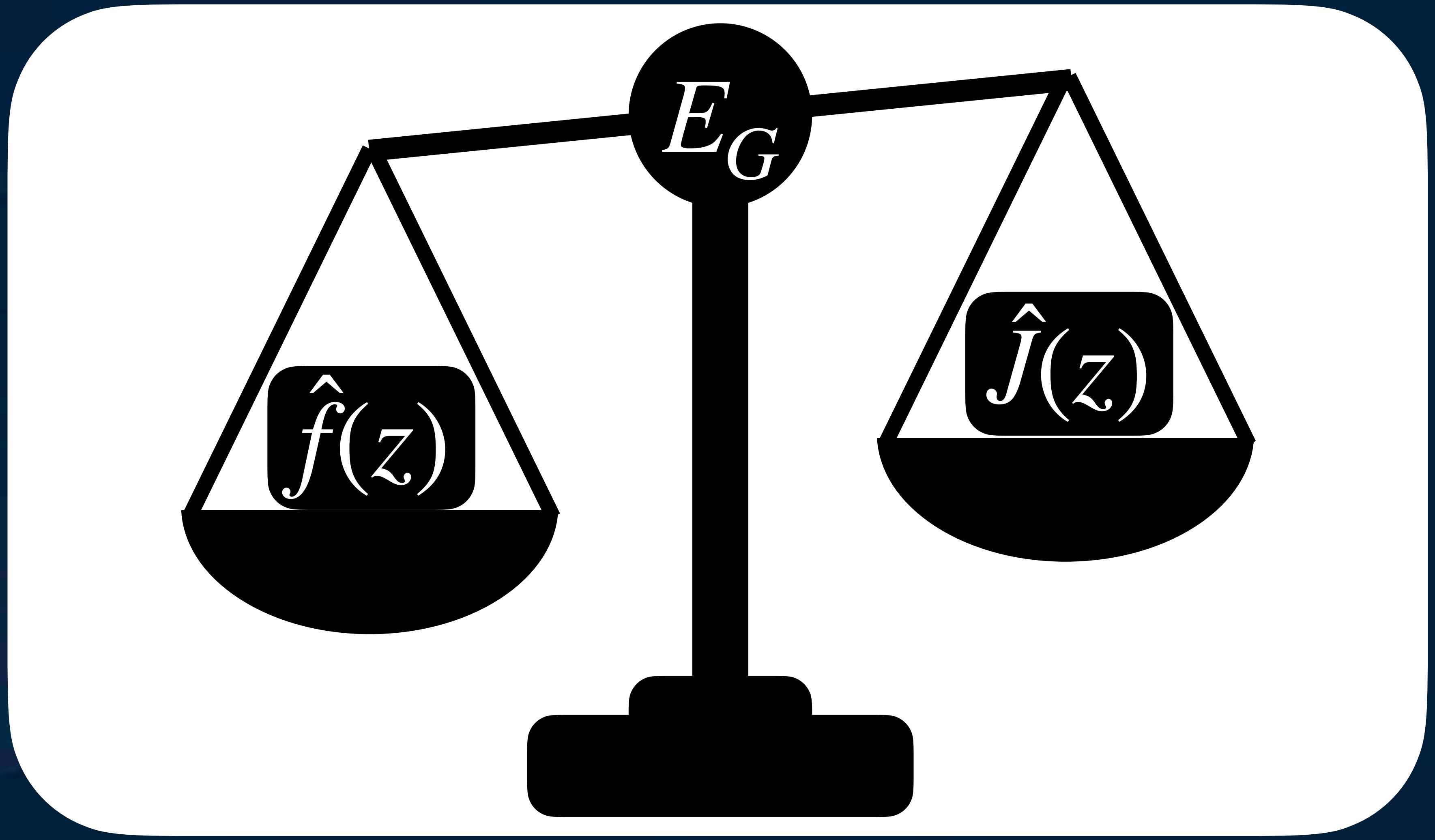

Upcoming work:

Alternative ways of combining $\hat{f}$ and $\hat{J}$, e.g. for a test of Euler's equation.

Investigate the improvement expected from upcoming survey data (DESI, LSST, Euclid)

Investigate alternative interpolation methods, in particular Gaussian processes.

Backup

Table I. List of $\hat{f}(z)$ measurements used in this work.

Dataset	z	$\hat{f}(z)$	Ref.
2MTF	0.001	0.505 ± 0.085	[5]
6dFGS+SNIa	0.02	0.4280 ± 0.0465	[6]
IRAS+SNIa	0.02	0.398 ± 0.065	[7, 8]
2MASS	0.02	0.314 ± 0.048	[7, 9]
2dFGRS	0.17	0.510 ± 0.060	[20]
GAMA	0.18	0.360 ± 0.090	[21]
GAMA	0.38	0.440 ± 0.060	[21]
SDSS-IV (MGS)	0.15	0.53 ± 0.16	[22]
SDSS-IV (BOSS Galaxy)	0.38	0.497 ± 0.045	[22]
SDSS-IV (BOSS Galaxy)	0.51	0.459 ± 0.038	[22]
SDSS-IV (eBOSS LRG)	0.70	0.473 ± 0.041	[22]
SDSS-IV (eBOSS ELG)	0.85	0.315 ± 0.095	[22]
WiggleZ	0.44	0.413 ± 0.080	[23]
WiggleZ	0.60	0.390 ± 0.063	[23]
WiggleZ	0.73	0.437 ± 0.072	[23]
Vipers PDR-2	0.60	0.550 ± 0.120	[24]
Vipers PDR-2	0.86	0.400 ± 0.110	[24]
FastSound	1.40	0.482 ± 0.116	[25]
SDSS-IV (eBOSS Quasar)	0.978	0.379 ± 0.176	[26]
SDSS-IV (eBOSS Quasar)	1.230	0.385 ± 0.099	[26]
SDSS-IV (eBOSS Quasar)	1.526	0.342 ± 0.070	[26]
SDSS-IV (eBOSS Quasar)	1.944	0.364 ± 0.106	[26]

$\hat{f}(z)$ data