TENSION WITH THE ΛCDM MODEL *AT HIGH REDSHIFT* FROM A HUBBLE DIAGRAM OF QUASARS

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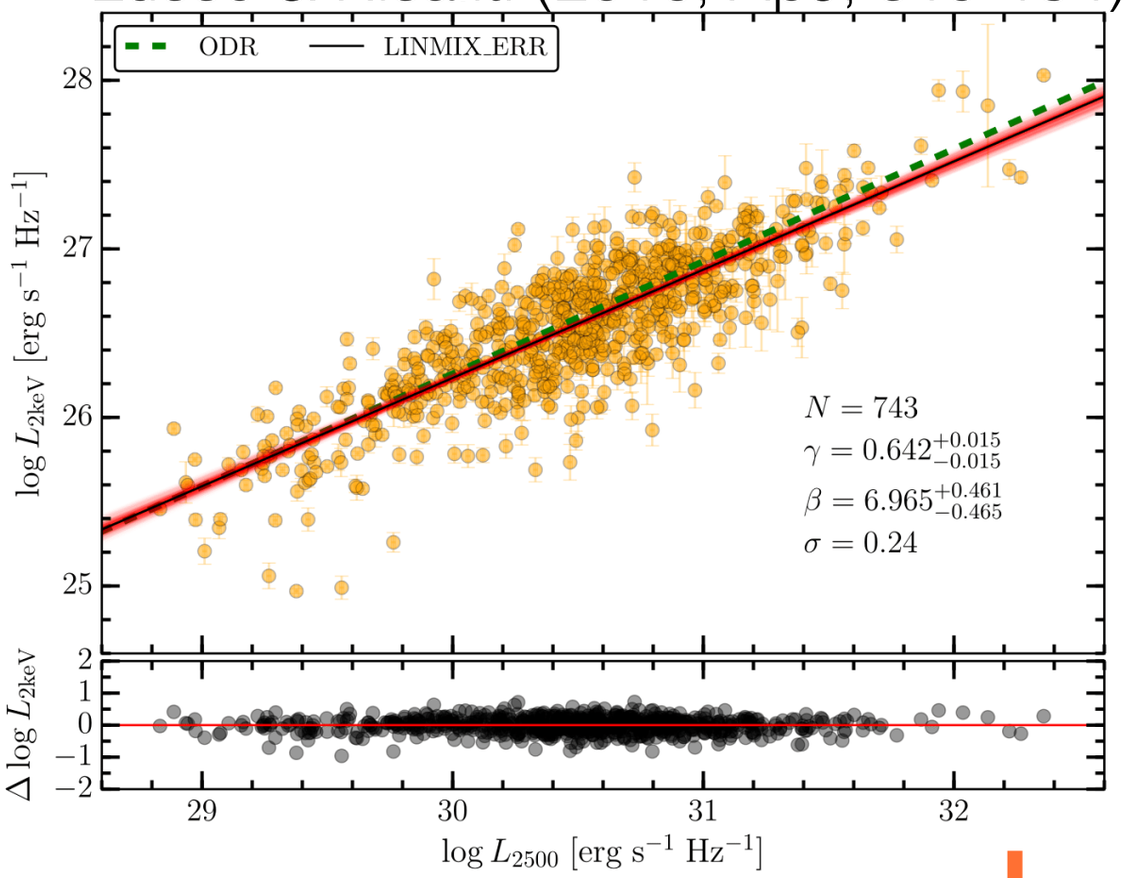
Maurizio Paolillo, Lorenzo Amati

Supermassive Black holes: evolution & environment
Corfu 19-22 June

Cosmology with quasars

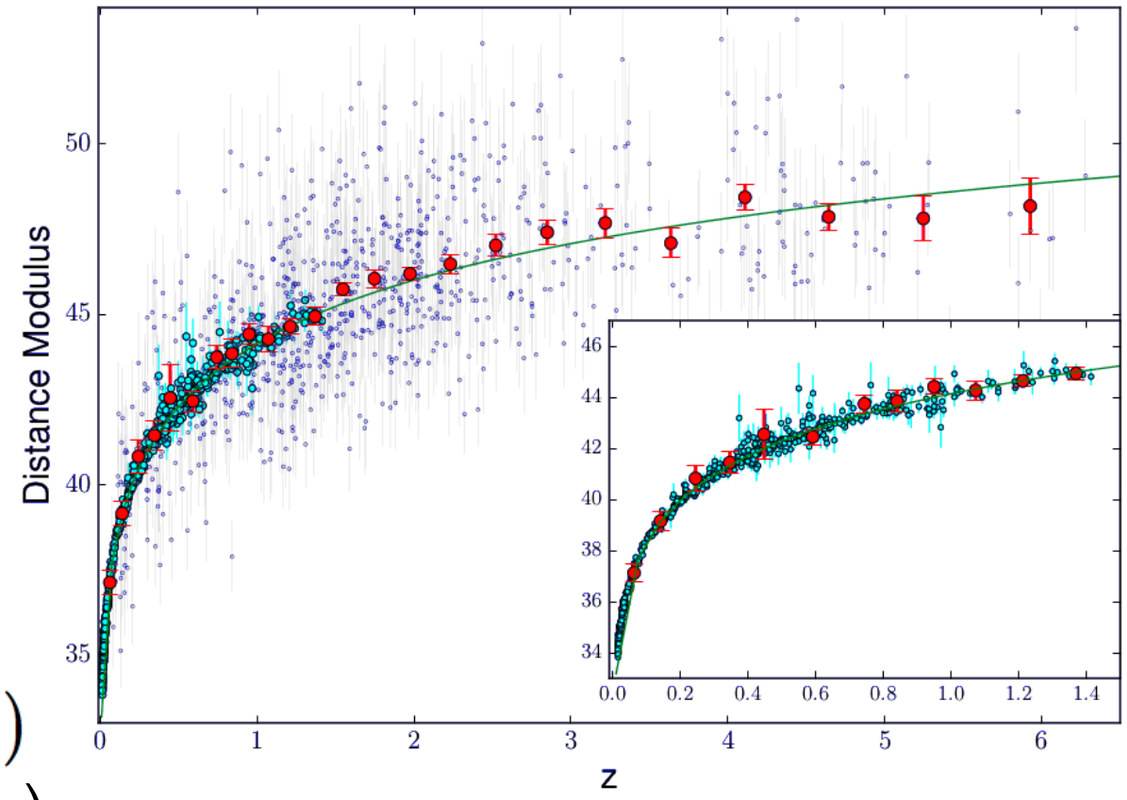
The distance modulus-*z* relation

Lusso & Risaliti (2016, ApJ, 819-154)



$$\log(L_{\mathrm{X}}) = \beta + \gamma \log(L_{\mathrm{UV}})$$

Risaliti & Lusso (2015, ApJ, 815-33)



Standardise the quasar emission

$$\log(F_{\mathrm{X}}) = \Phi(F_{\mathrm{UV}}, D_{\mathrm{L}})$$
$$= \beta' + \gamma \log(F_{\mathrm{UV}}) + 2(\gamma - 1)\log(D_{\mathrm{L}})$$

$D_L(z,\Omega_M, \Omega_\Lambda)$

The <u>L_X-L_{UV} non-linear relation</u> as a way to <u>measure quasar distances</u>

Cosmology with quasars

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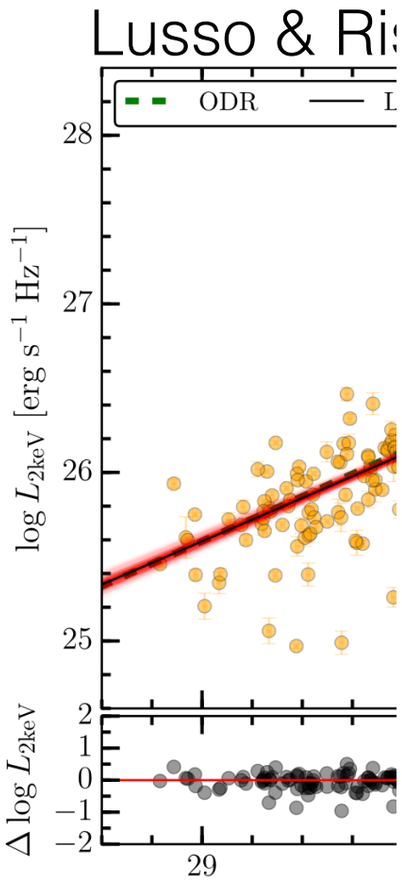
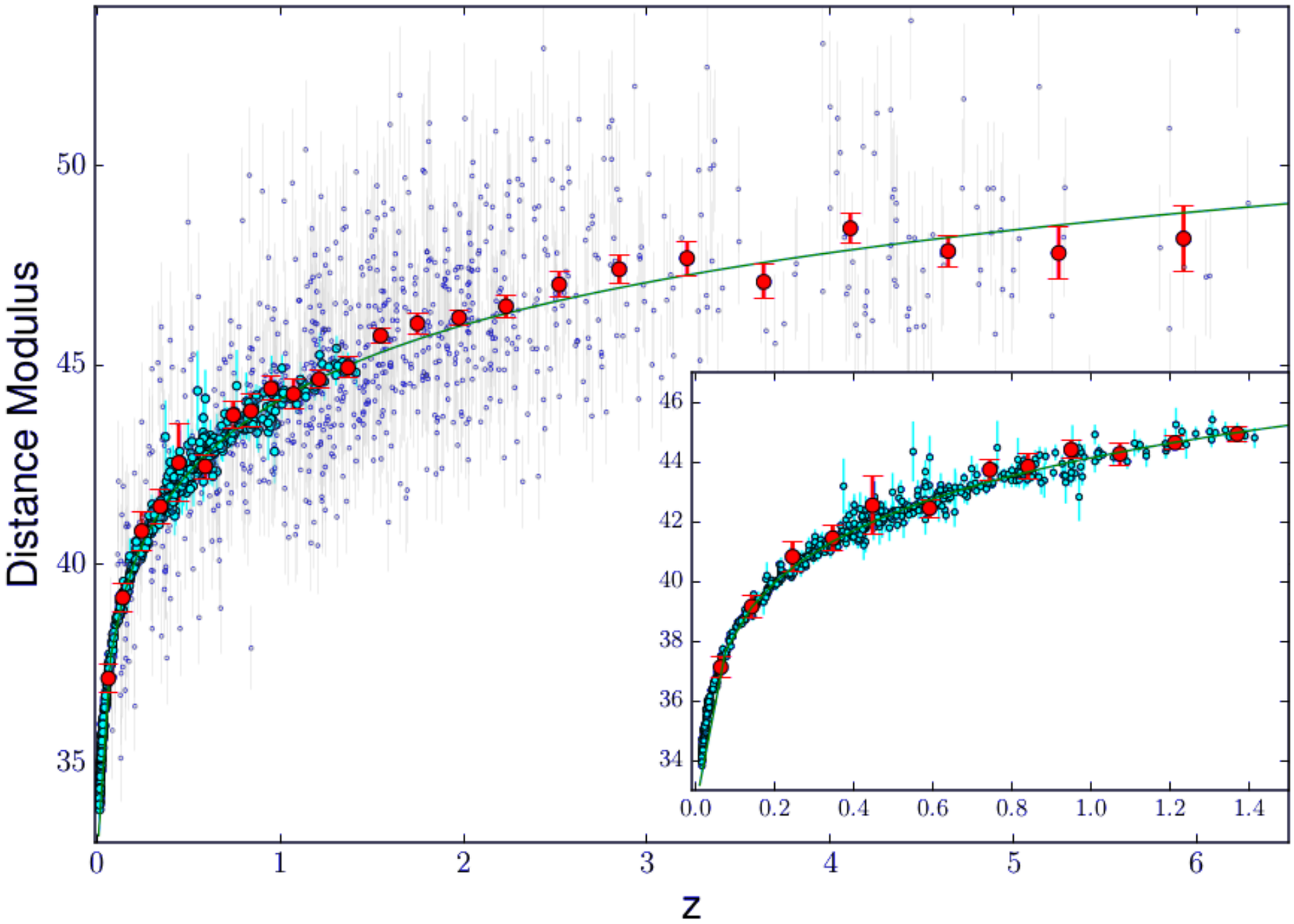
Risaliti & Lusso (2015, ApJ, 815-33)





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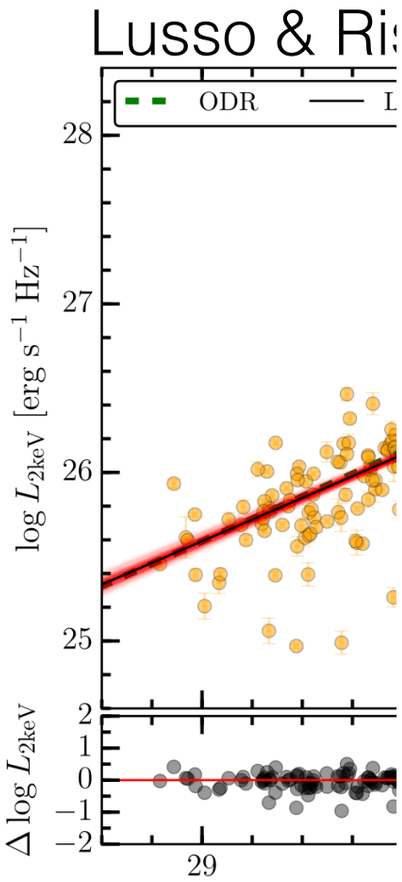

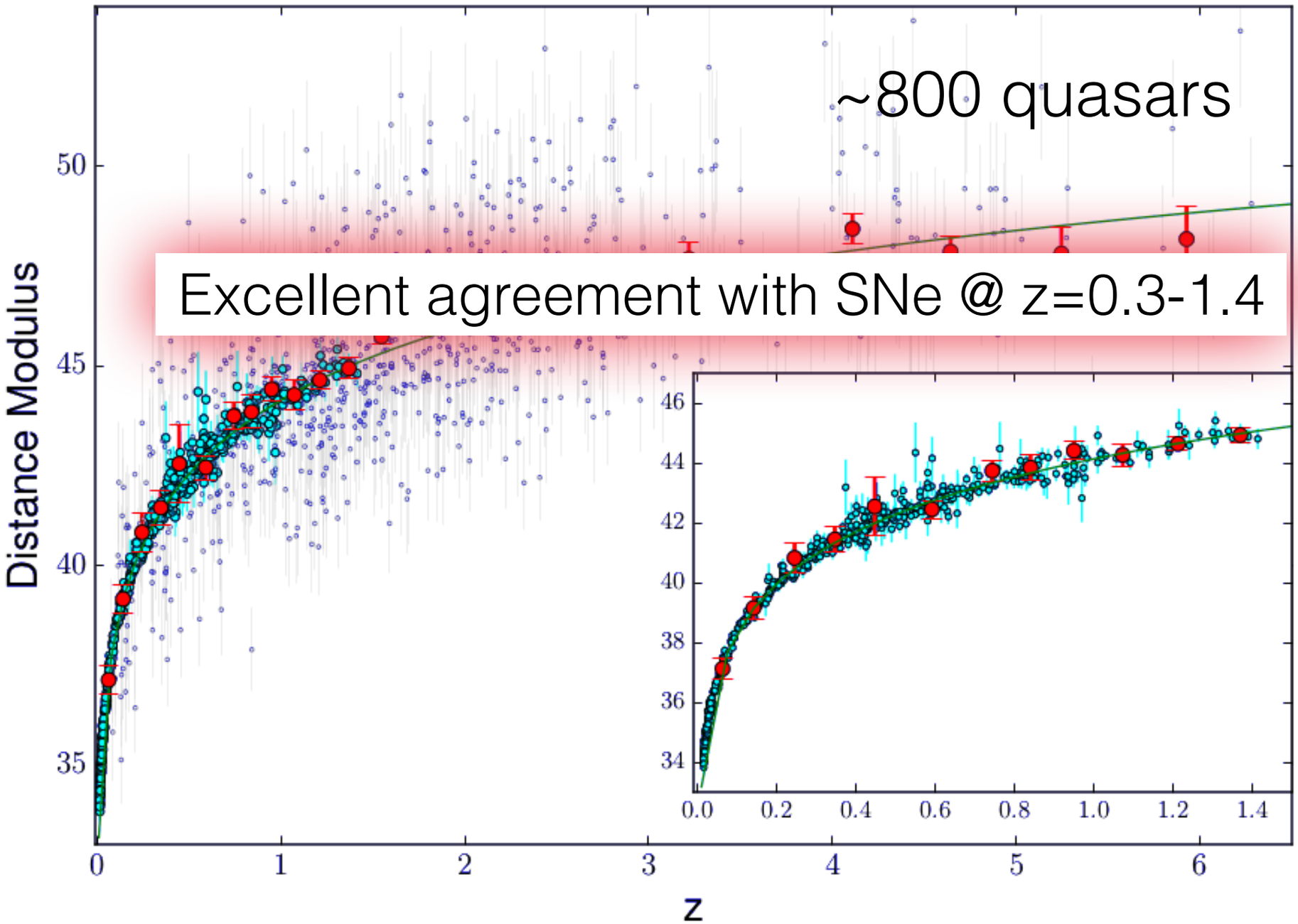

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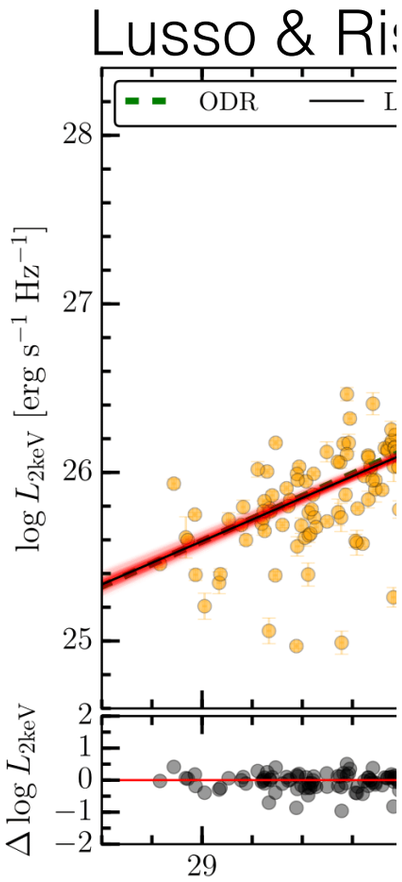

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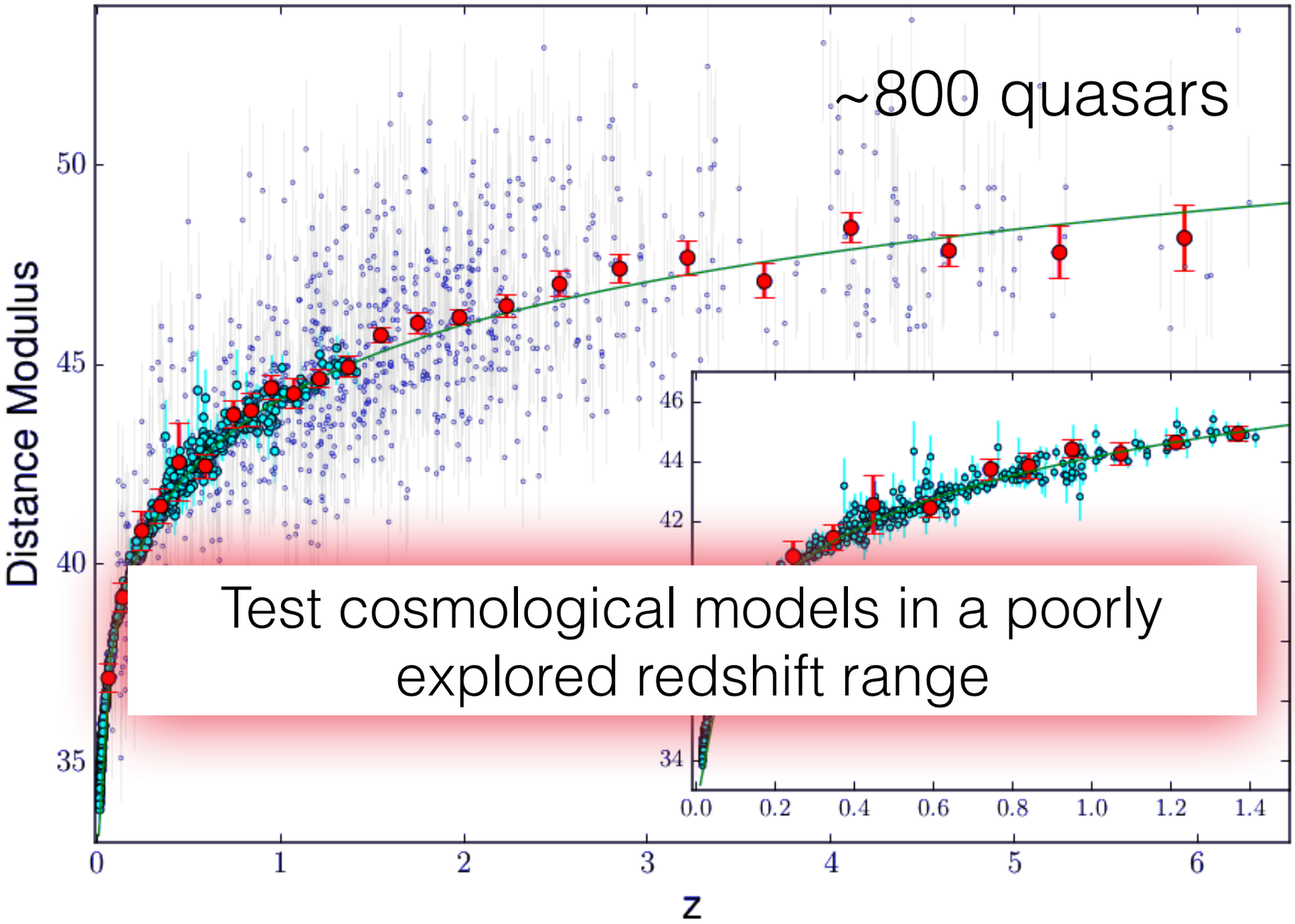

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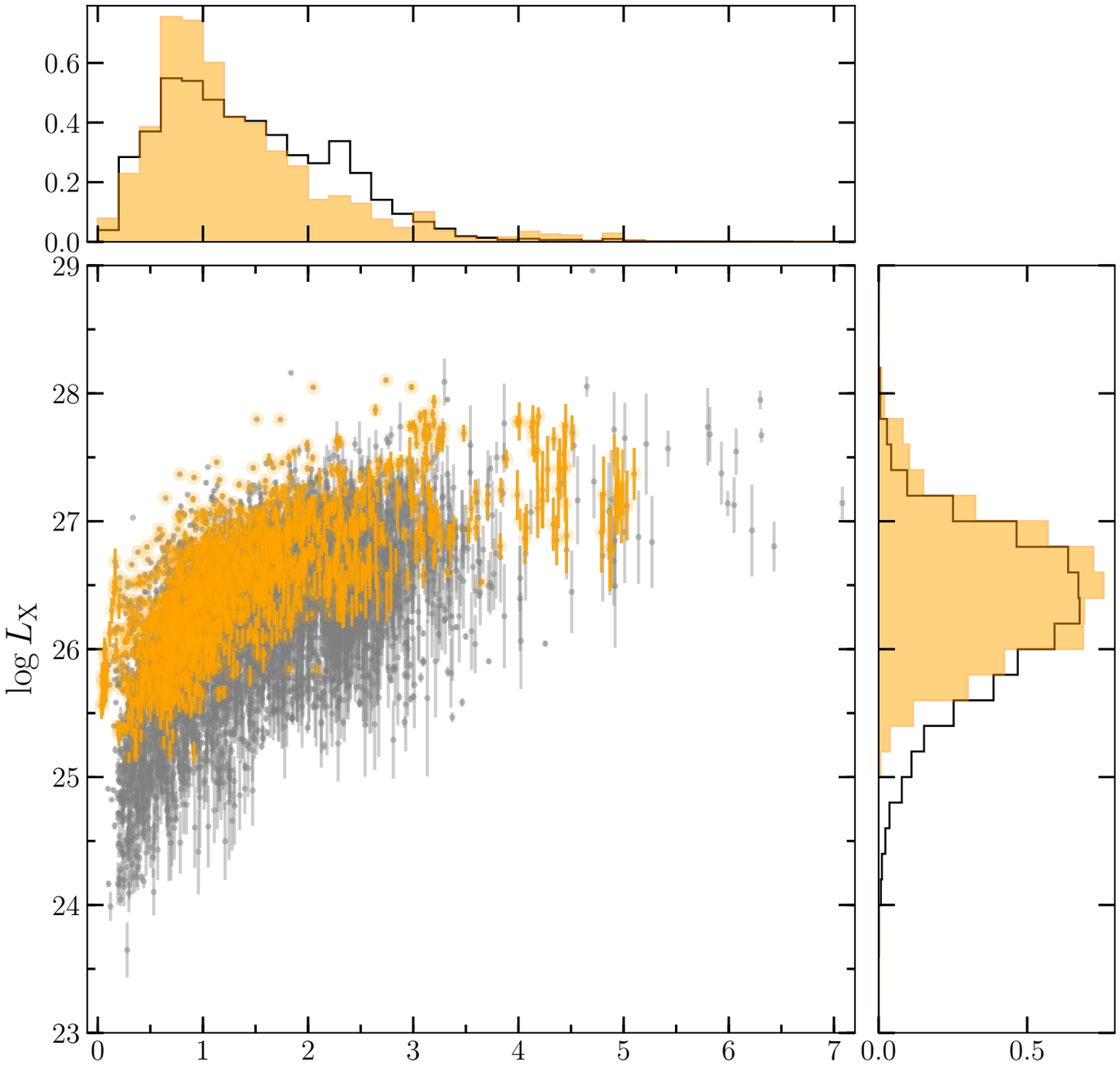
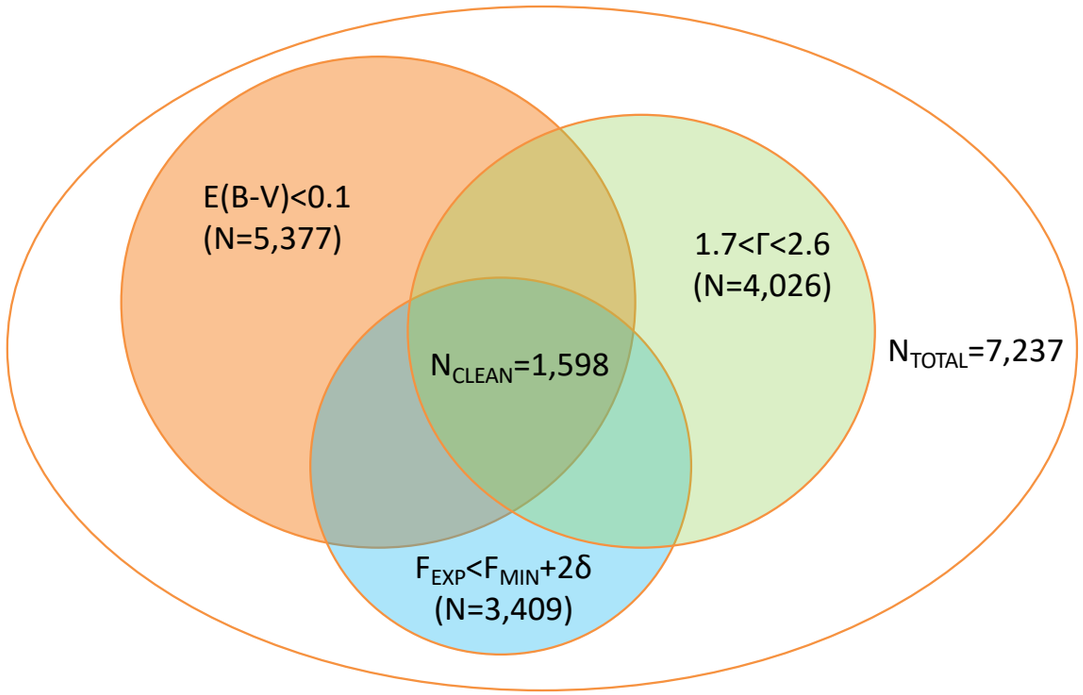
Cosmology with quasars

The new! Quasars Hubble Diagram: sample

~1600 quasars: SDSS+3XMM+XMM LP+archive/literature



Risaliti & Lusso (2019)



Cosmology with quasars

The new! Quasars Hubble Diagram: L_X-L_{UV}

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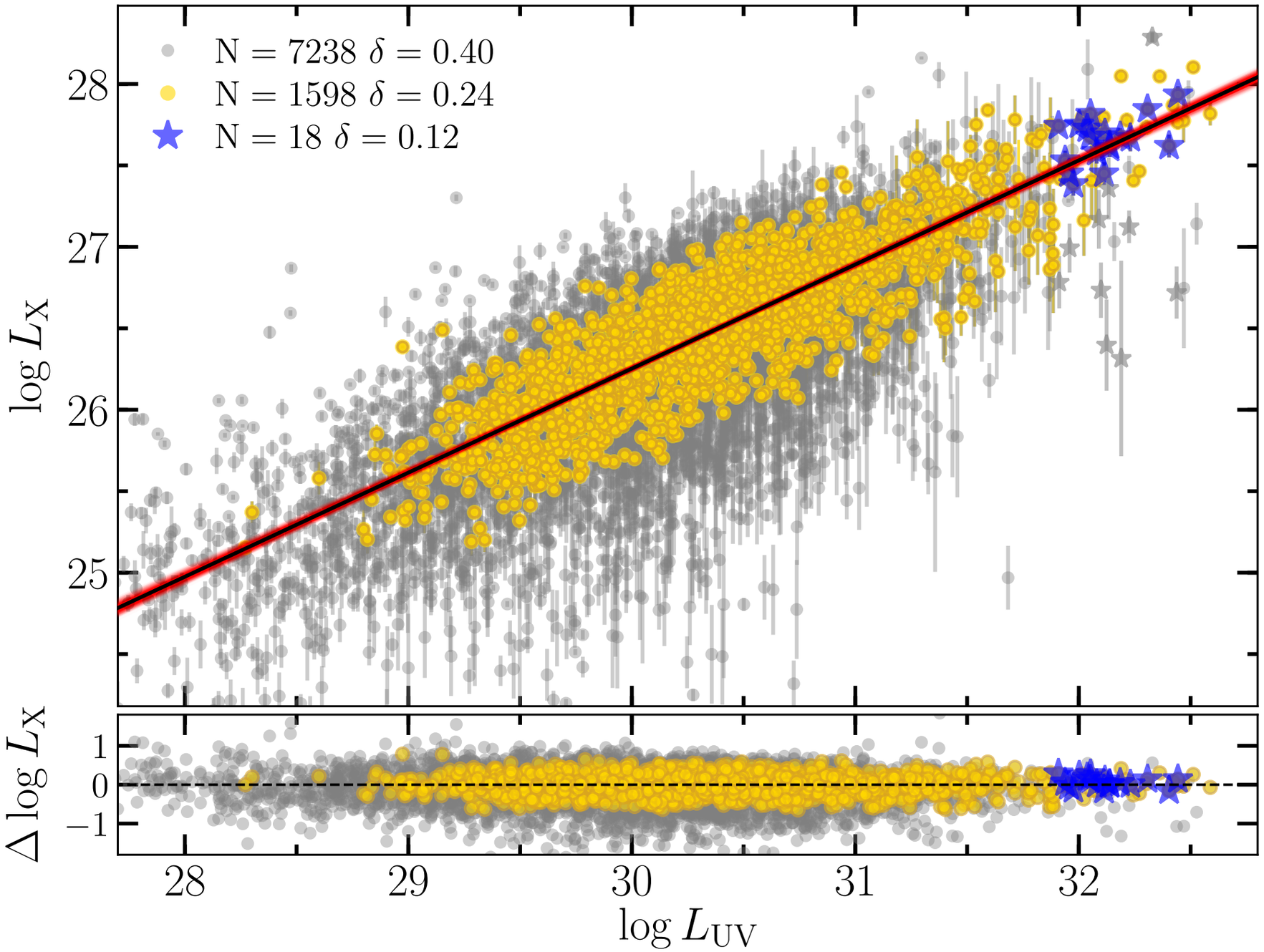
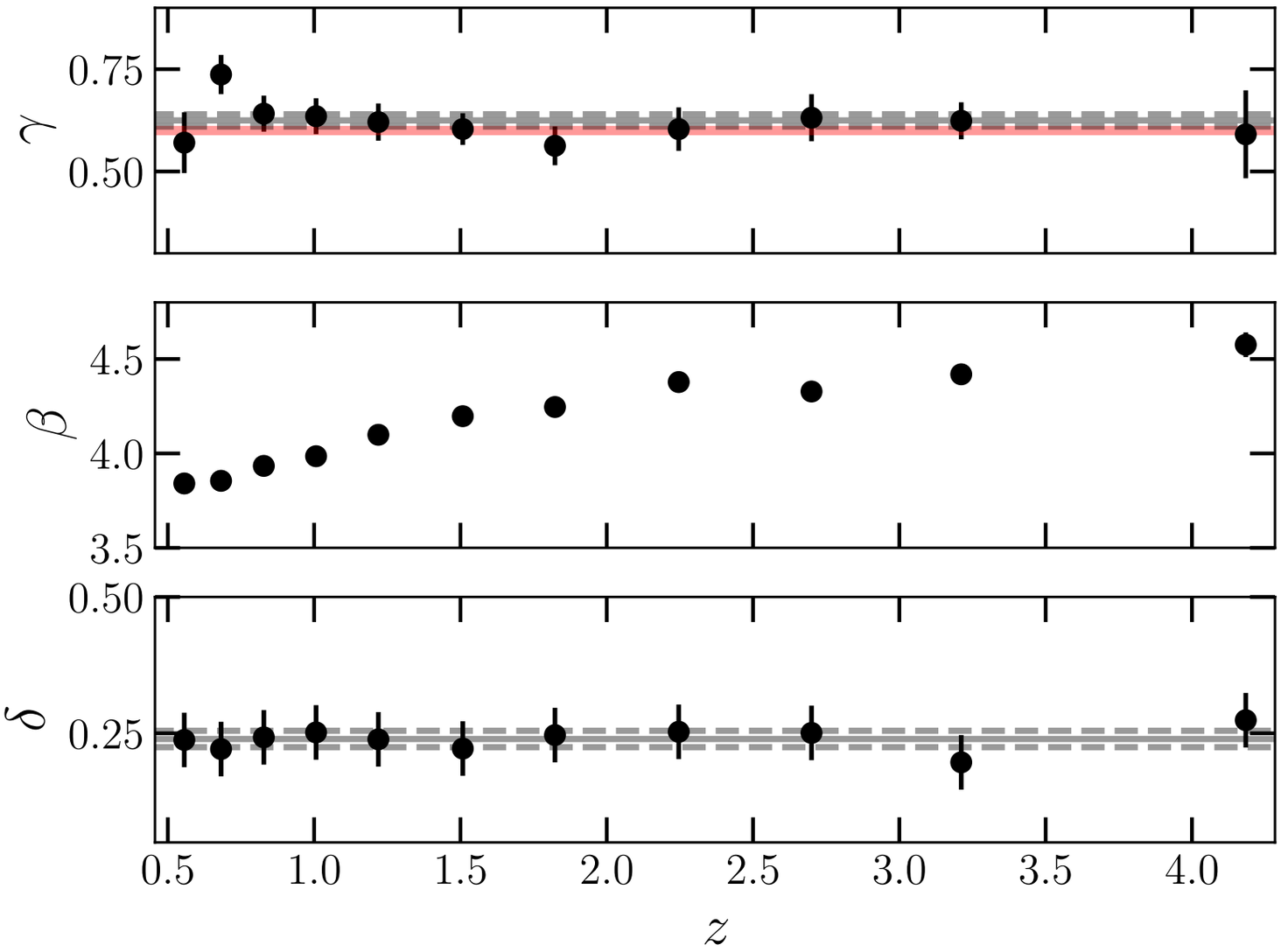


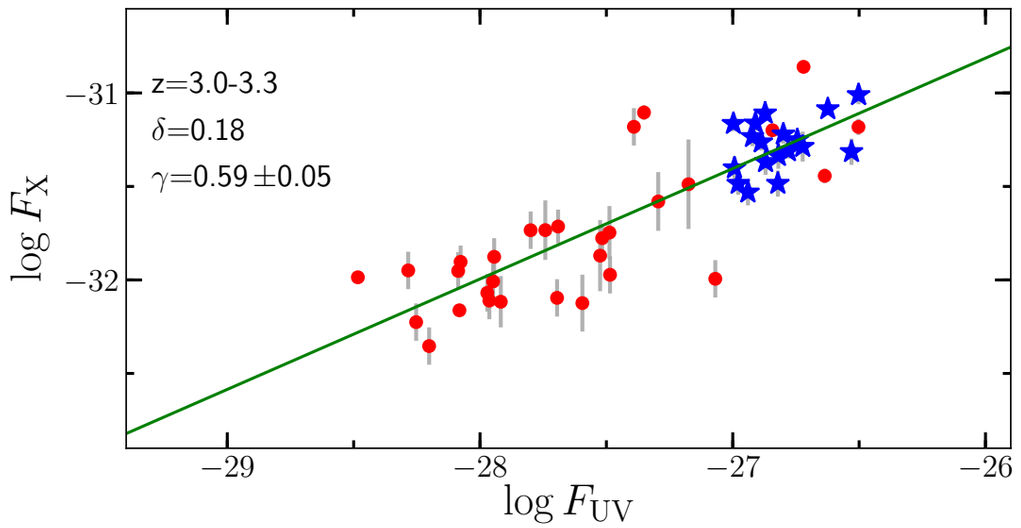
Risaliti & Lusso (2019)

Cosmology with quasars

The new! Quasars Hubble Diagram: redshift dependence



$$\log D_L = \frac{1}{2-2\gamma}(\gamma \log F_{UV} - \log F_X) + \beta.$$



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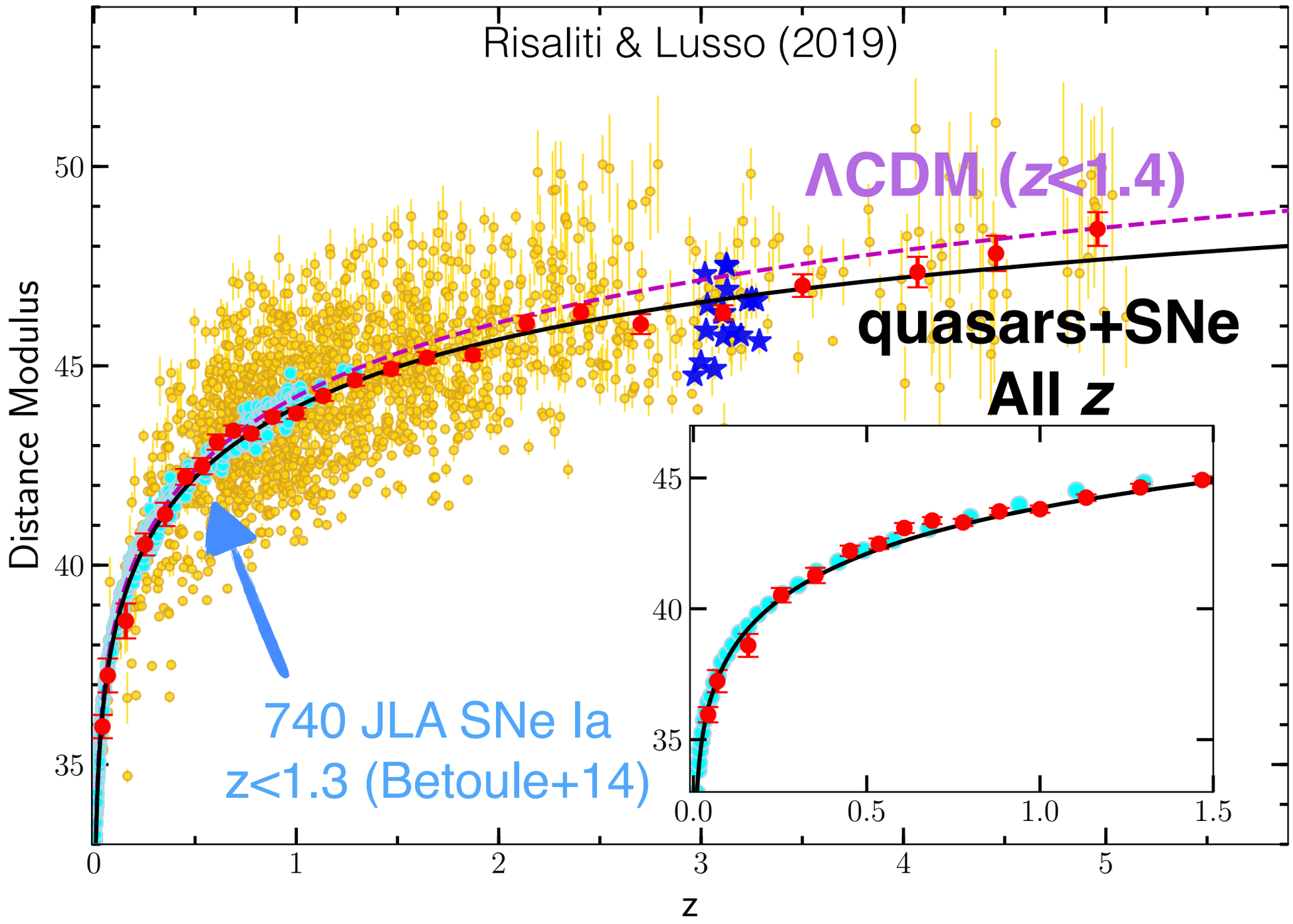

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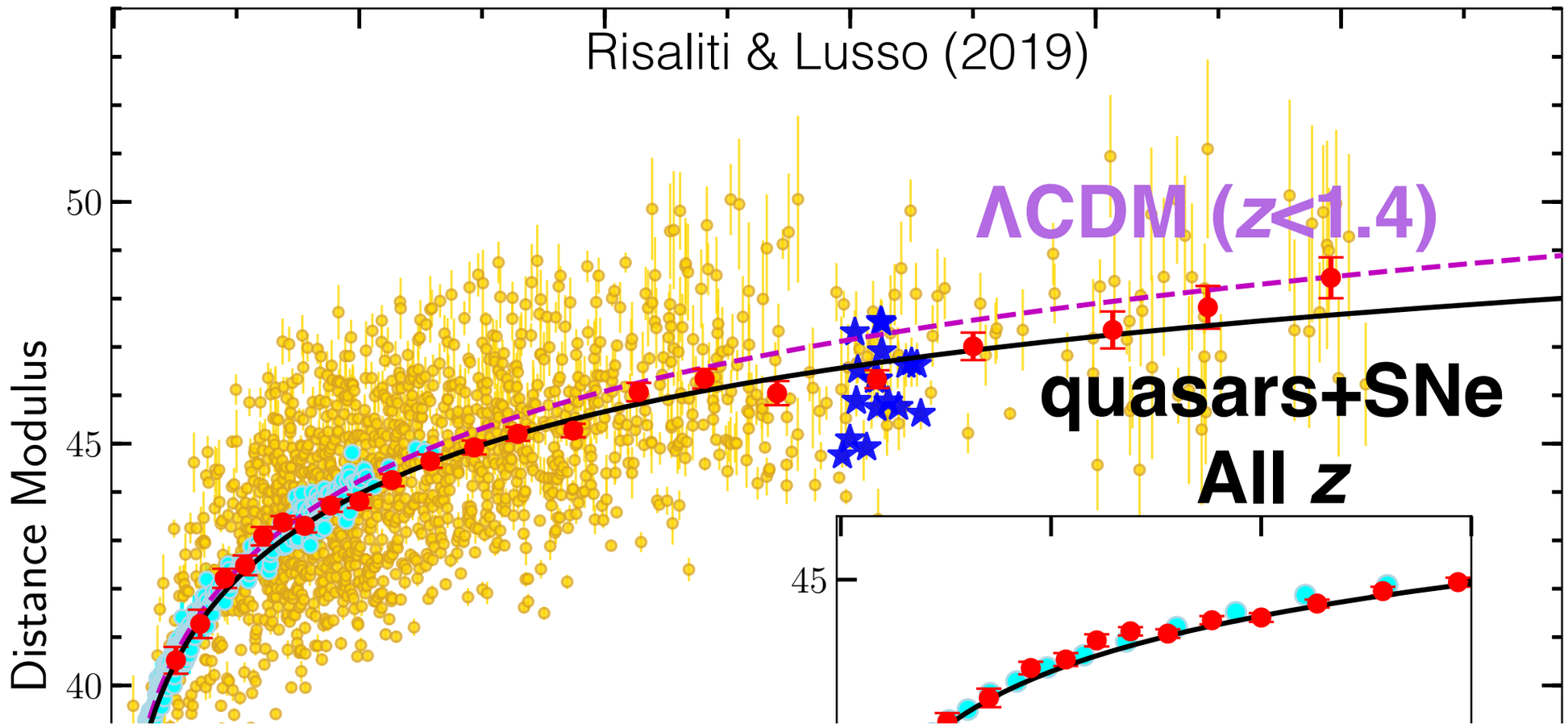
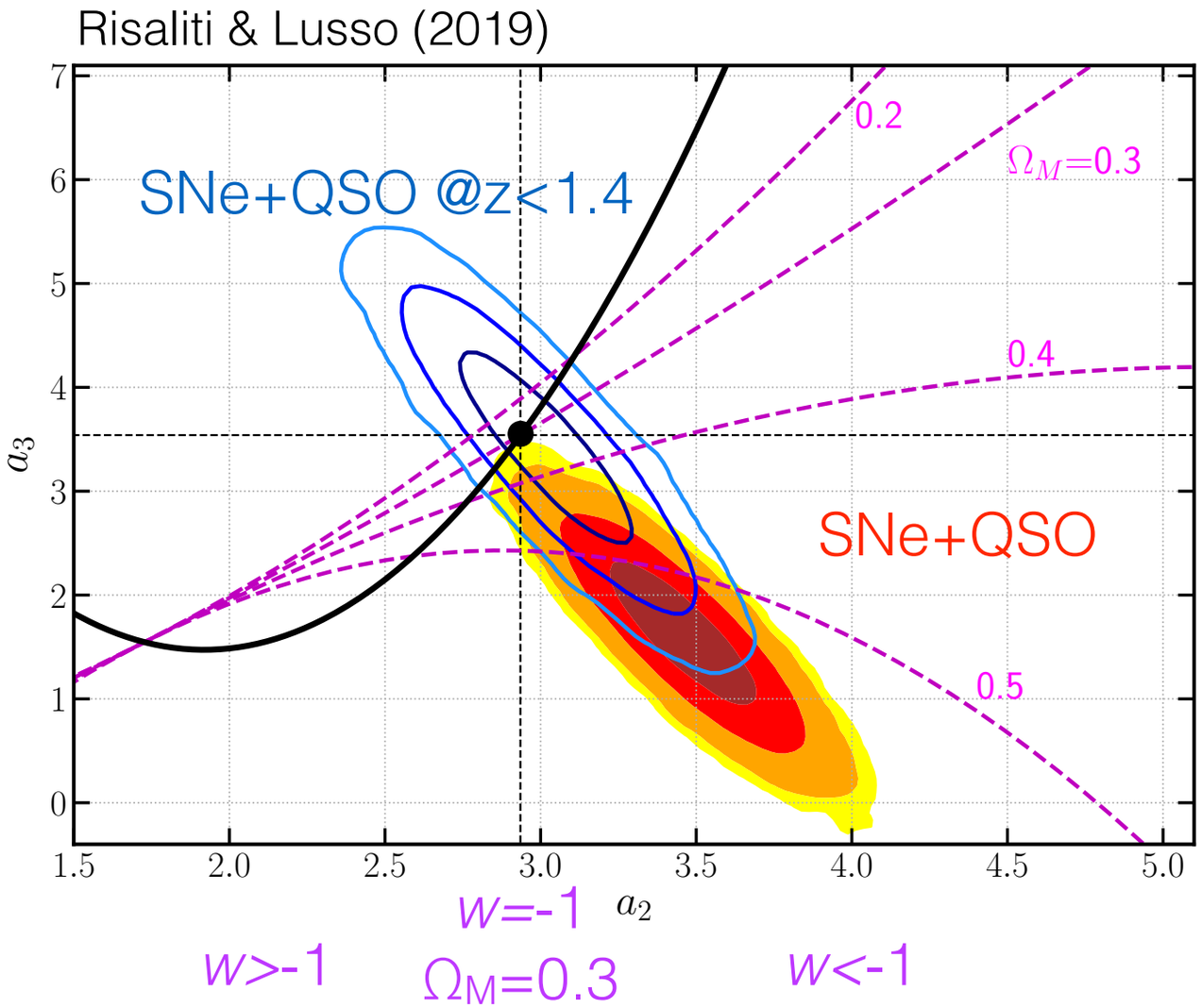


deviation from the ΛCDM model emerges at higher redshift, with a statistical significance of ~4σ

Cosmology with quasars

The new! Quasars Hubble Diagram



Cosmographic approach

P[log(1+*z*)]: $D_L = k\Sigma_i a_i [\log(1+z)]^i$

$k = \ln(10)c/H_0$

$a_2(\Omega_M)$, $a_3(\Omega_M)$

—— Flat ΛCDM

- - - - - Flat *w*CDM (free *w*)

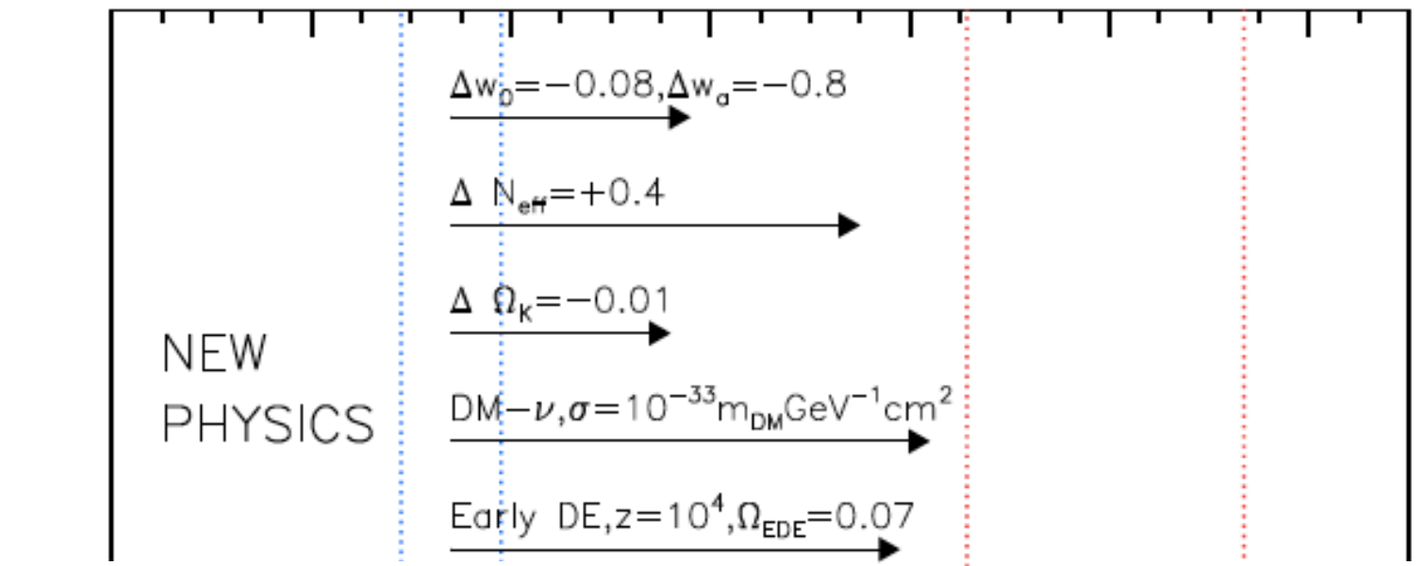
$w(z) = w_0 + w_a \cdot z/(1+z)$

data suggest: **dark energy density increasing with time**.

Within the *w*CDM model: $\Omega_M > 0.3$ and $w < -1.3$

The schism between the early & late Universe

Do we need an extension to the ΛCDM? Maybe yes…

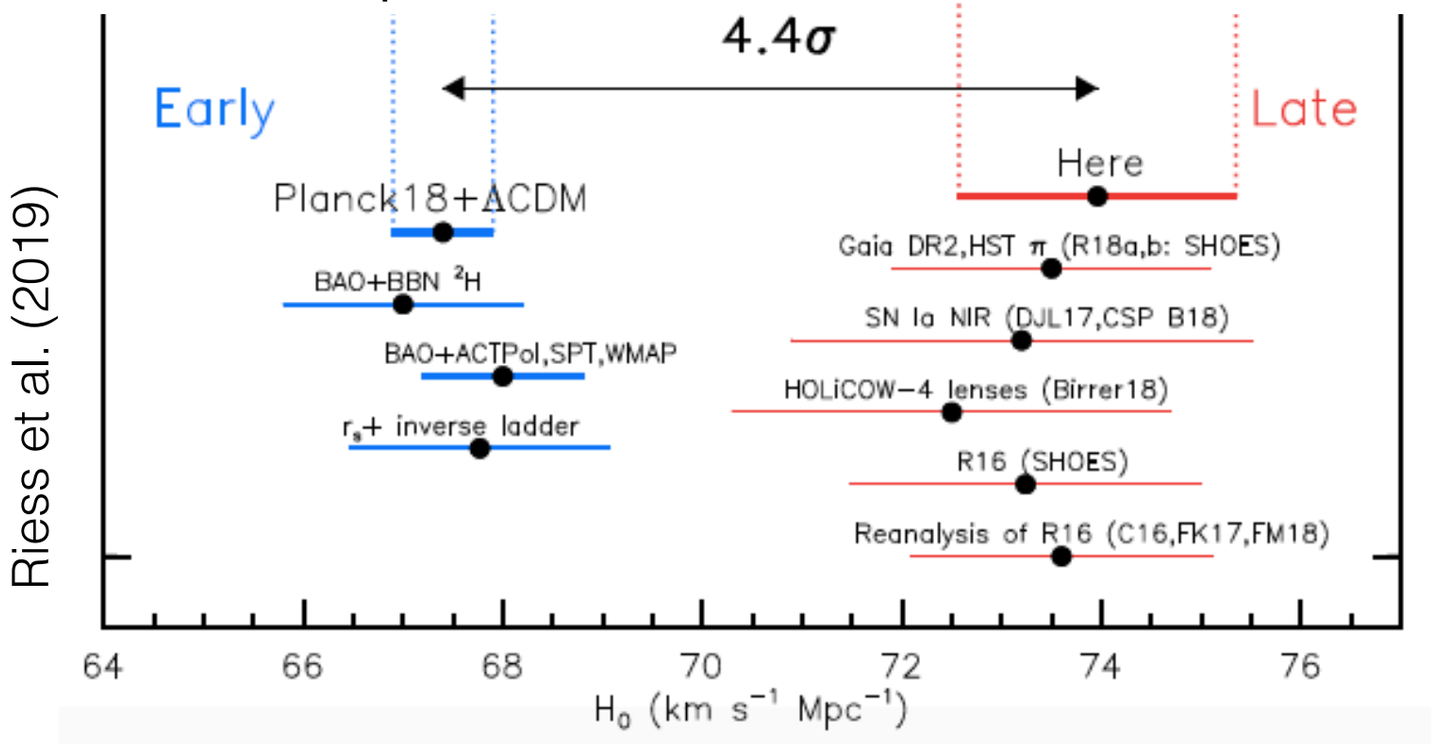


Planck et al. (2018)

H_0=67.06±0.62 km s^{-1} Mpc^{-1}

Riess et al. (2019)

H_0=74.03±1.42 km s^{-1} Mpc^{-1}



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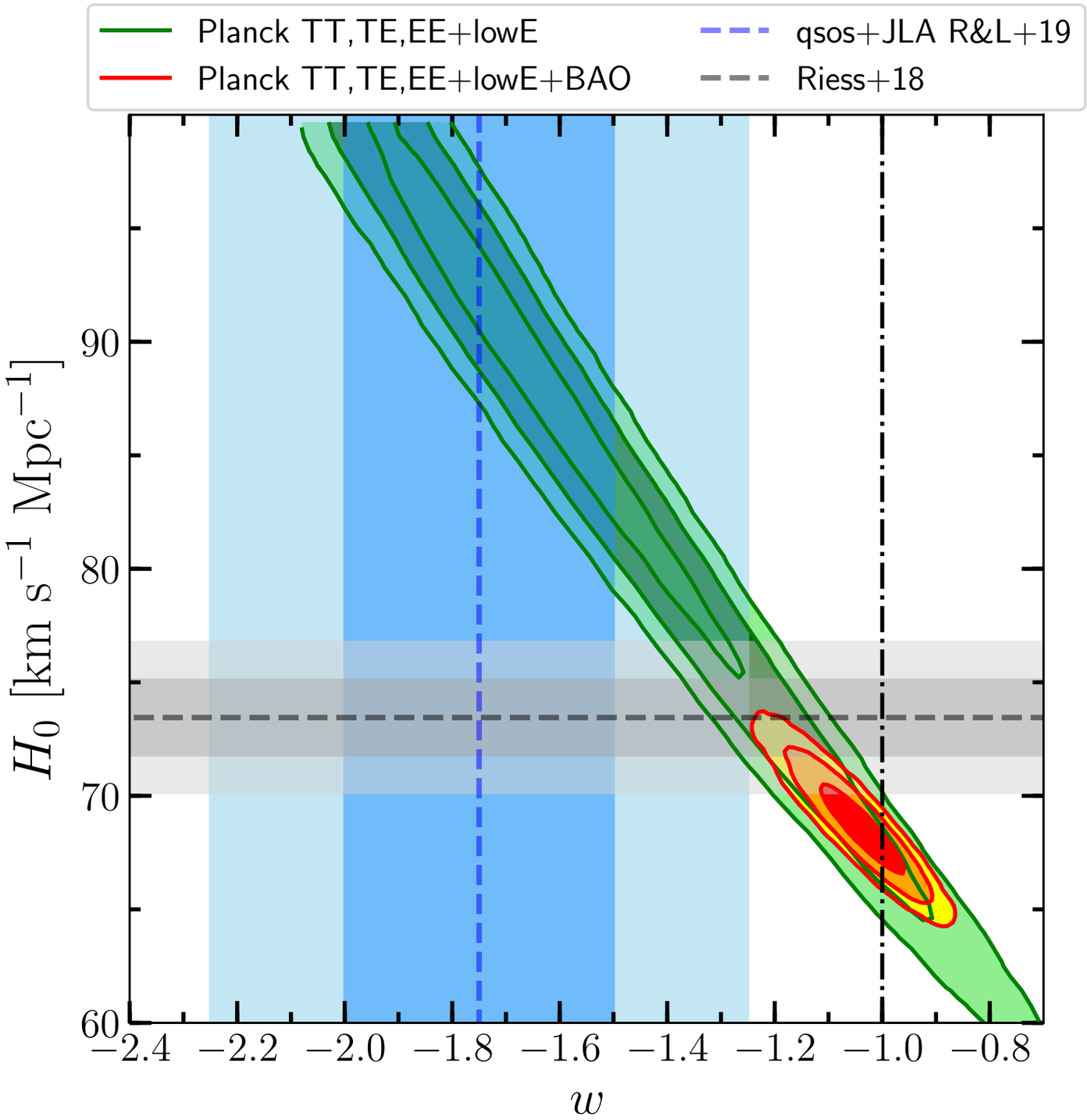


Cosmology with quasars

Test source of systematics

1. Independent samples over a wide redshift range key to test observed tensions and systematics

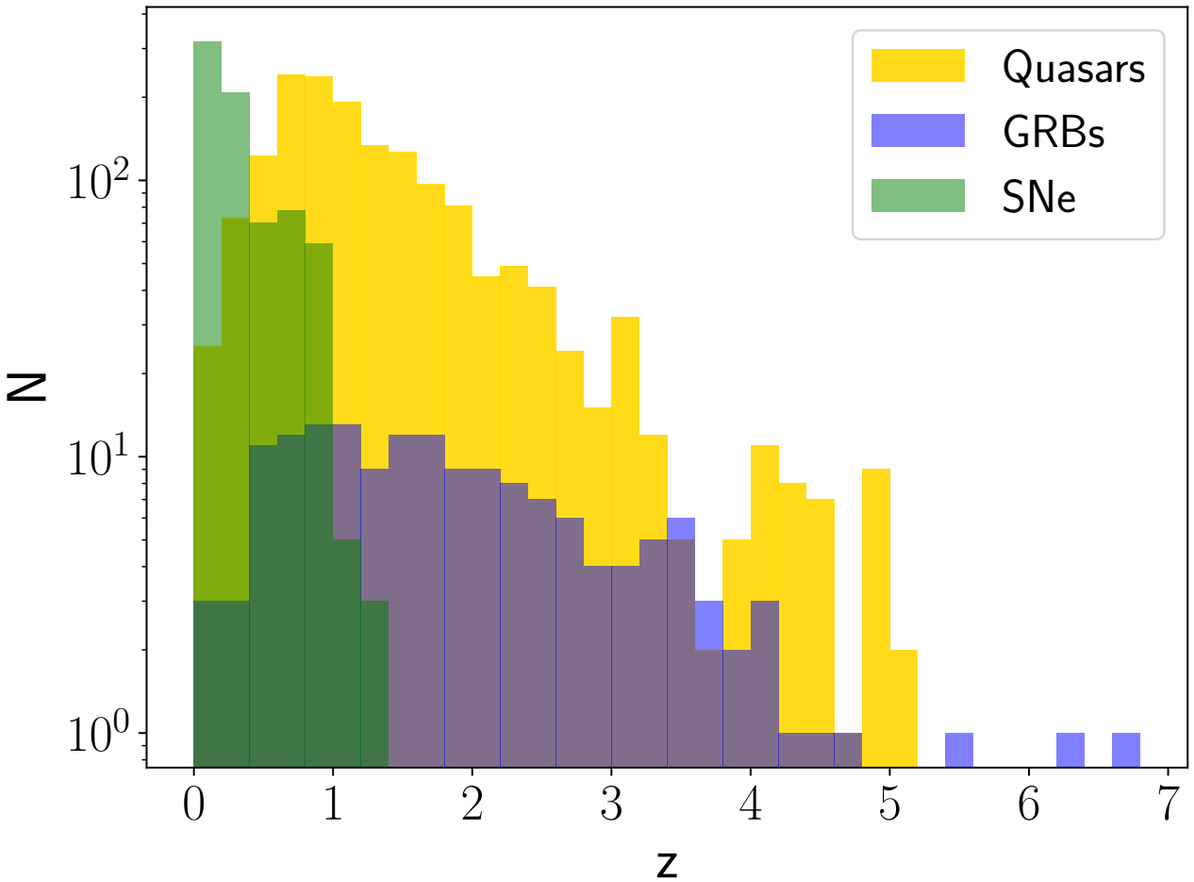
2. Different model-independent techniques

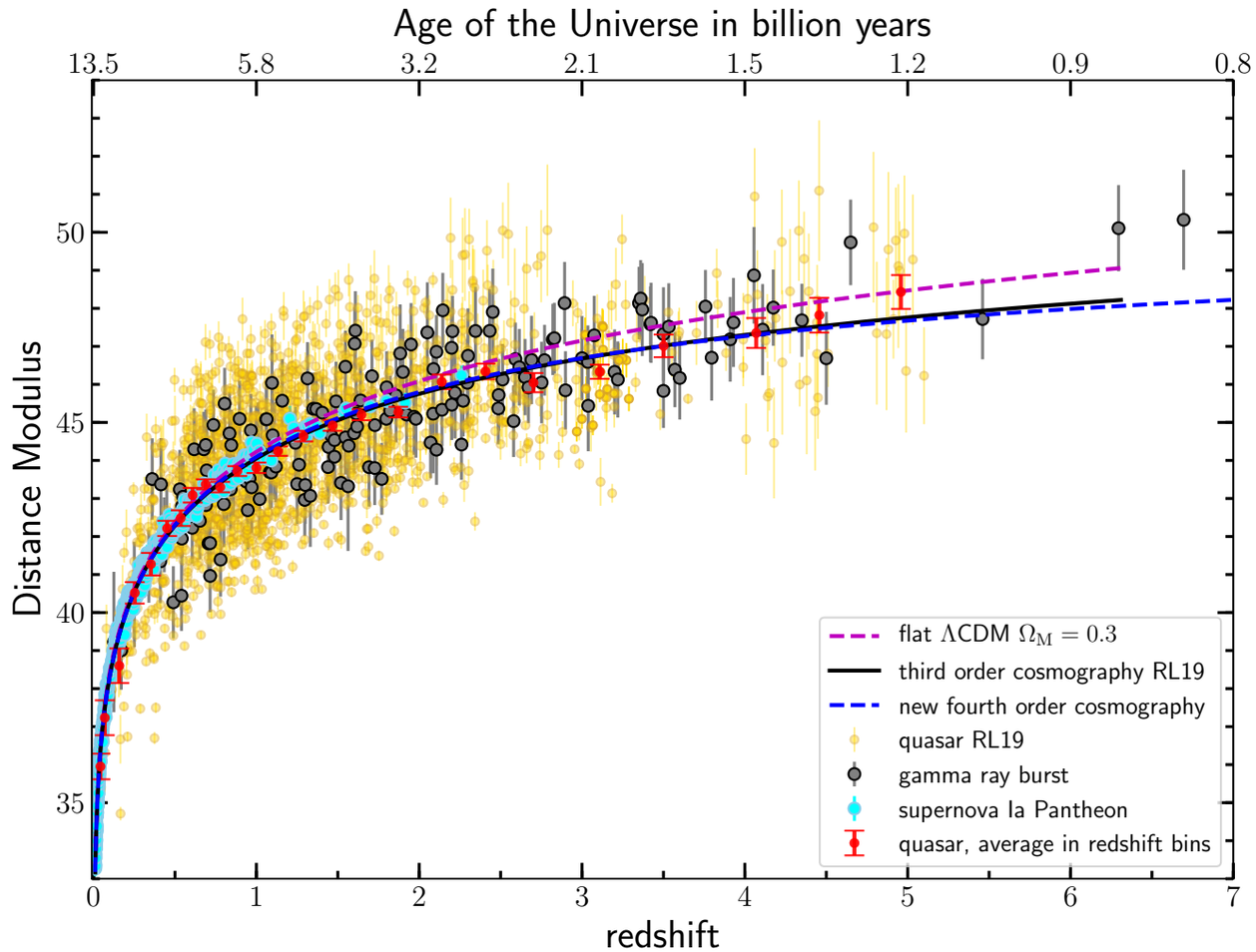
The Quasars + SNe + GRBs Hubble Diagram

1598 quasars (Risaliti & Lusso 2019)

1048 Type Ia supernovae - *Pantheon* survey (Scolnic et al. 2018)

160 GRBs (Demianski et al. 2017)





Lusso, Piedipalumbo, Risaliti, et al. A&A to be submitted

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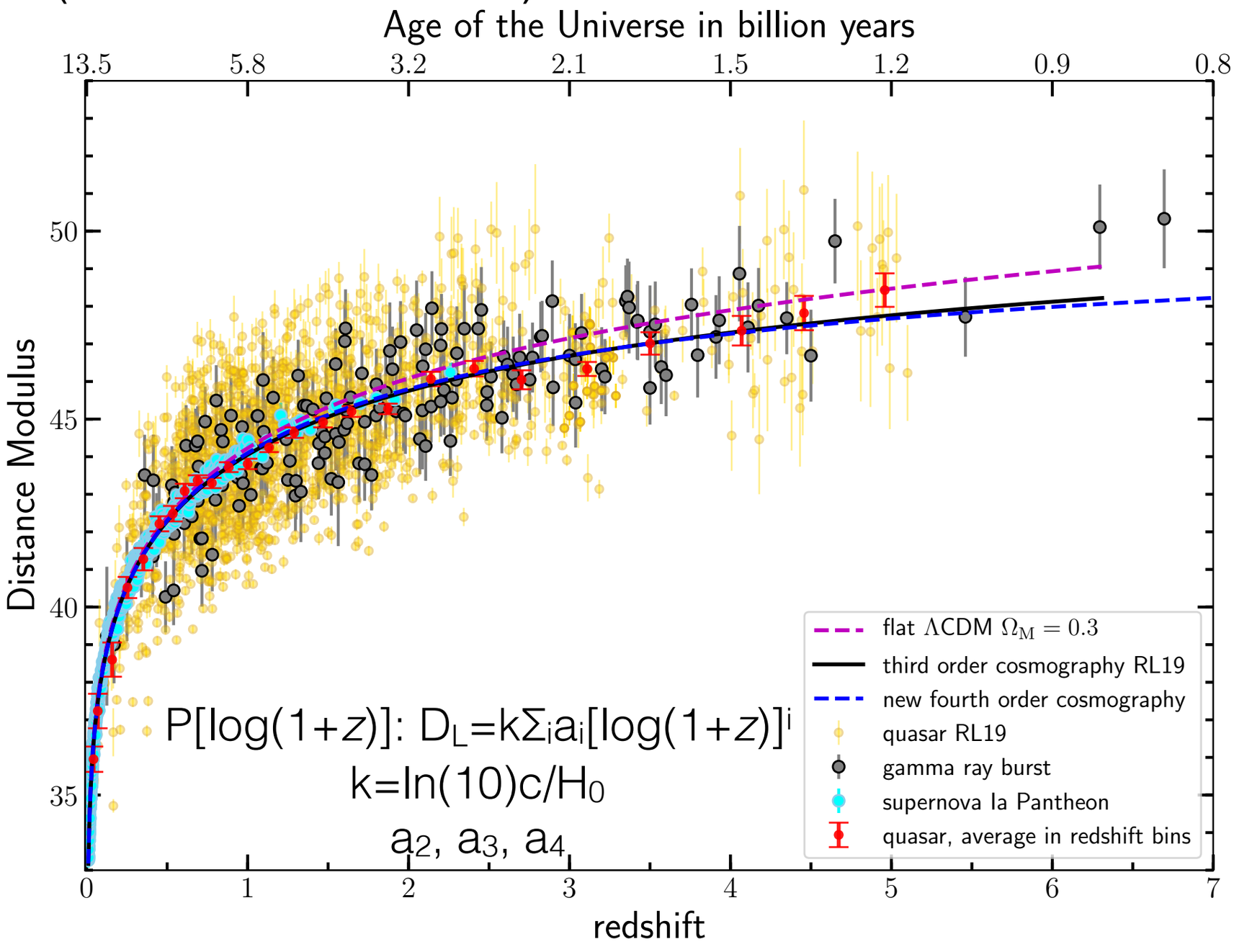

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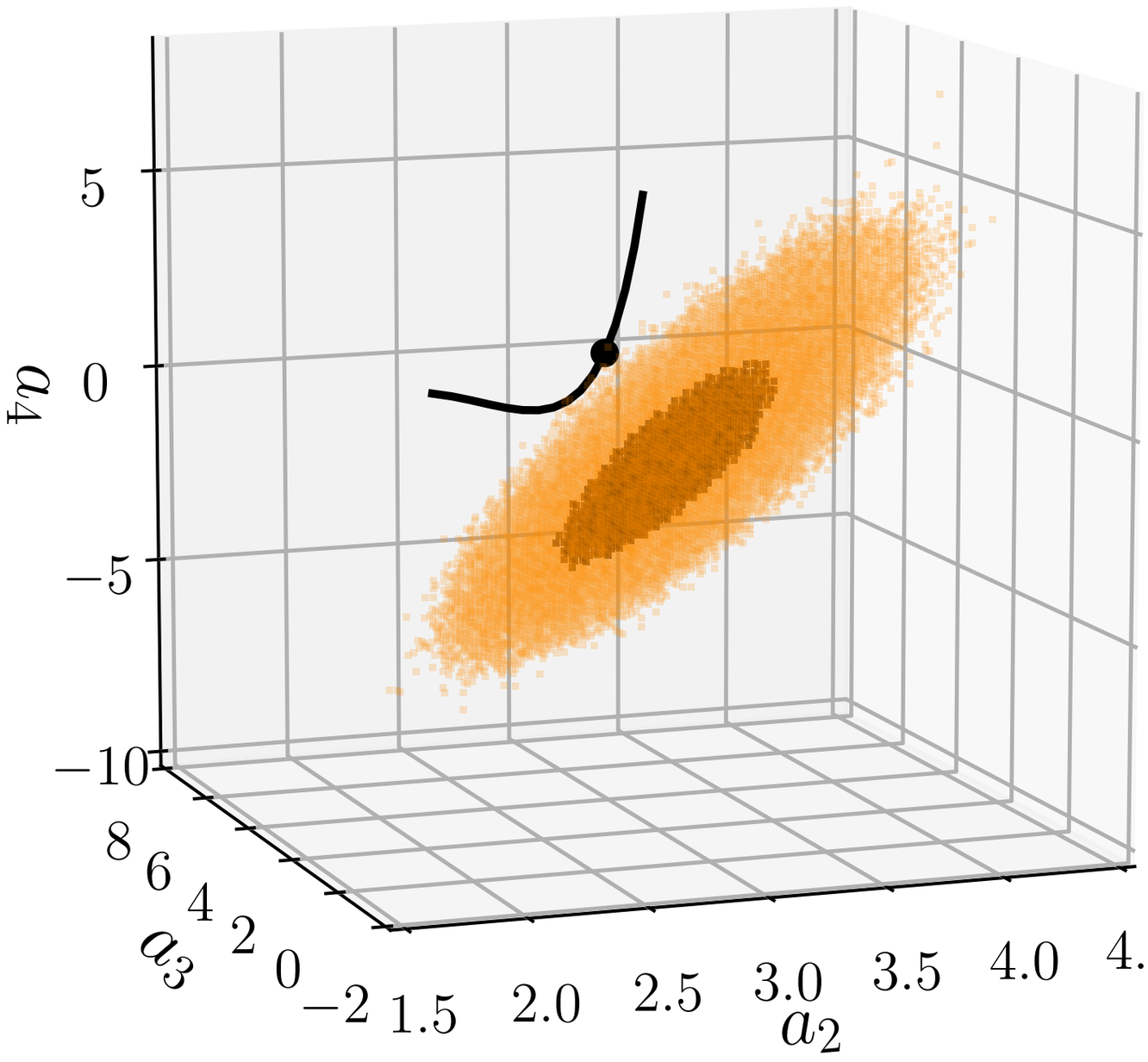

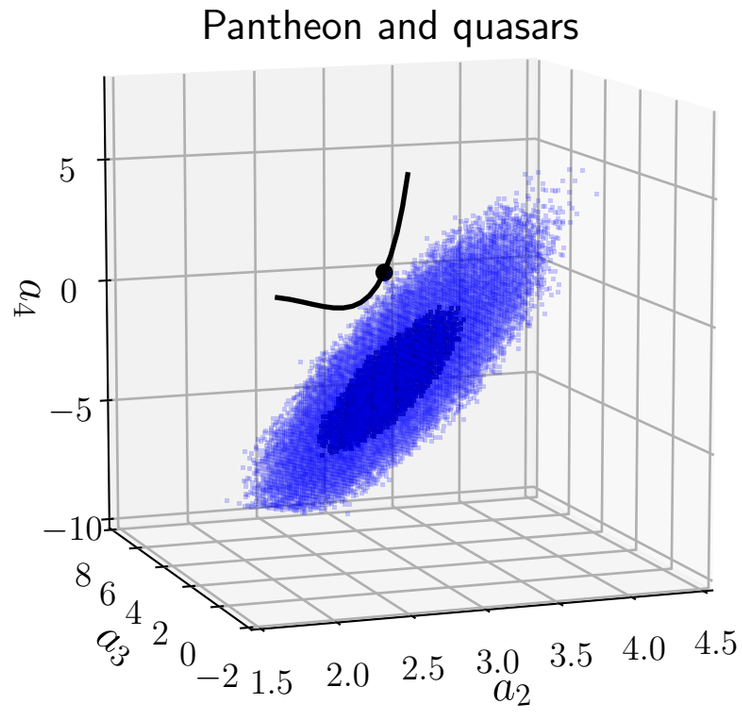

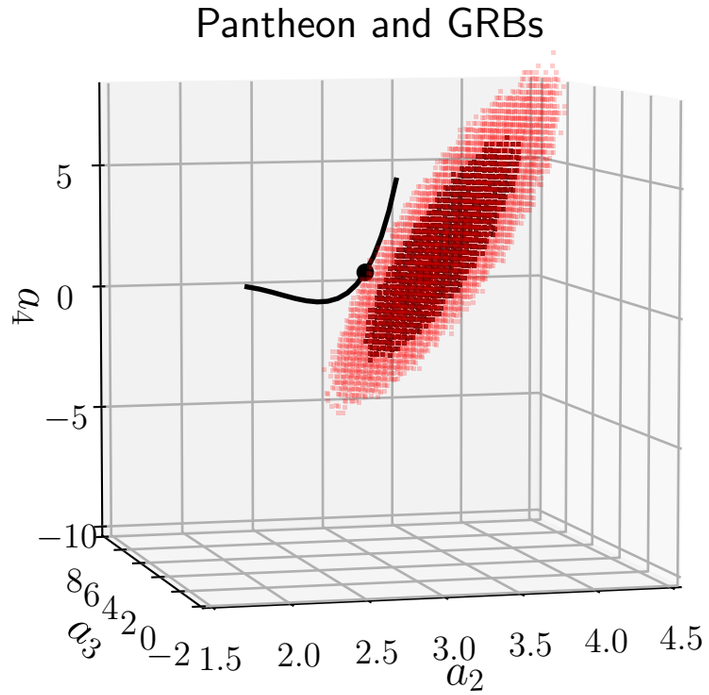

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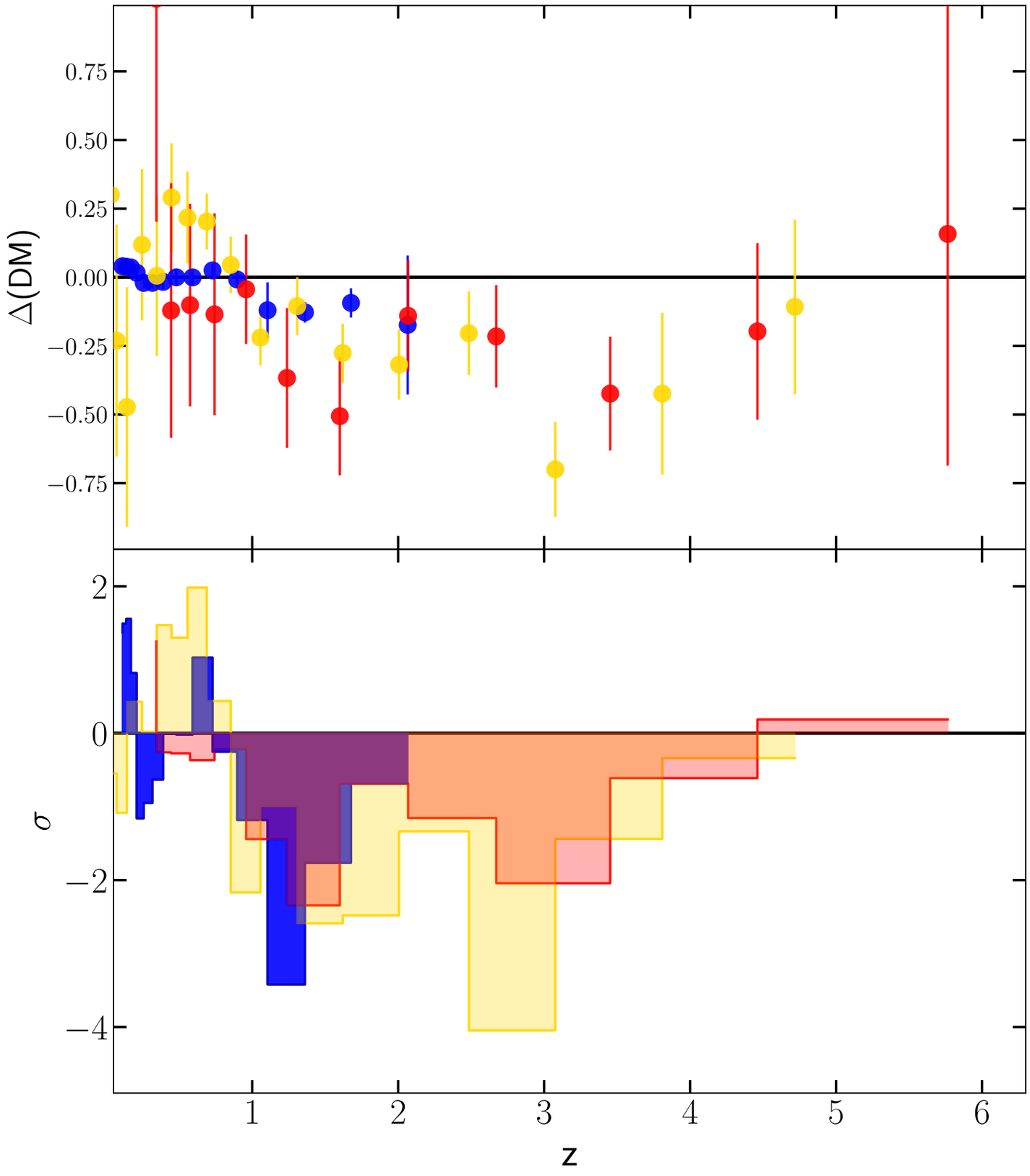

Flat ΛCDM
Ω_M=0.3

To summarise

1. Risaliti & Lusso+19: 4σ tension with the flat ΛCDM model through a model-independent parametrization of a Hubble Diagram of SNe Ia (JLA) and quasars.

2. Confirm the tension with the flat ΛCDM model from a high redshift Hubble Diagram of SNe Ia (Pantheon), quasars and gamma-ray bursts with a statistical significance of >4σ (Lusso et al. to be subm).

3. We also confirm that this tension becomes statistically significant (above 3σ) only at high redshifts (z>1) for SNe Ia and quasars taken independently and ~2σ for GRBs alone (Lusso et al. to be subm).

The completely independent high-redshift Hubble diagrams are fully consistent with each other, strongly suggesting that the deviation from the standard model is not due to unknown systematic effects but to new physics.