TENSION WITH THE ΛCDM MODEL FROM A QUASAR HUBBLE DIAGRAM

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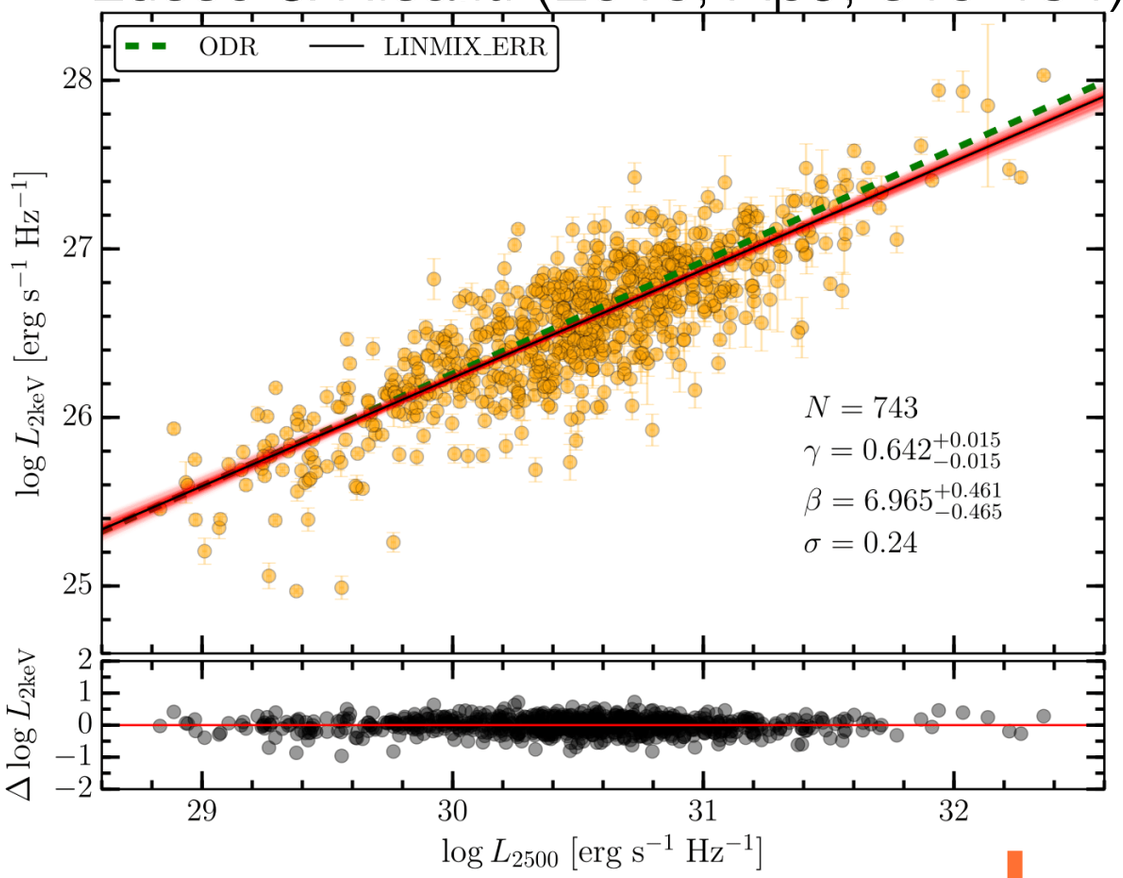
X-ray astronomy 2019:
Current Challenges &
new Frontiers in the Next Decade

Bologna — 8-13 September

Cosmology with quasars

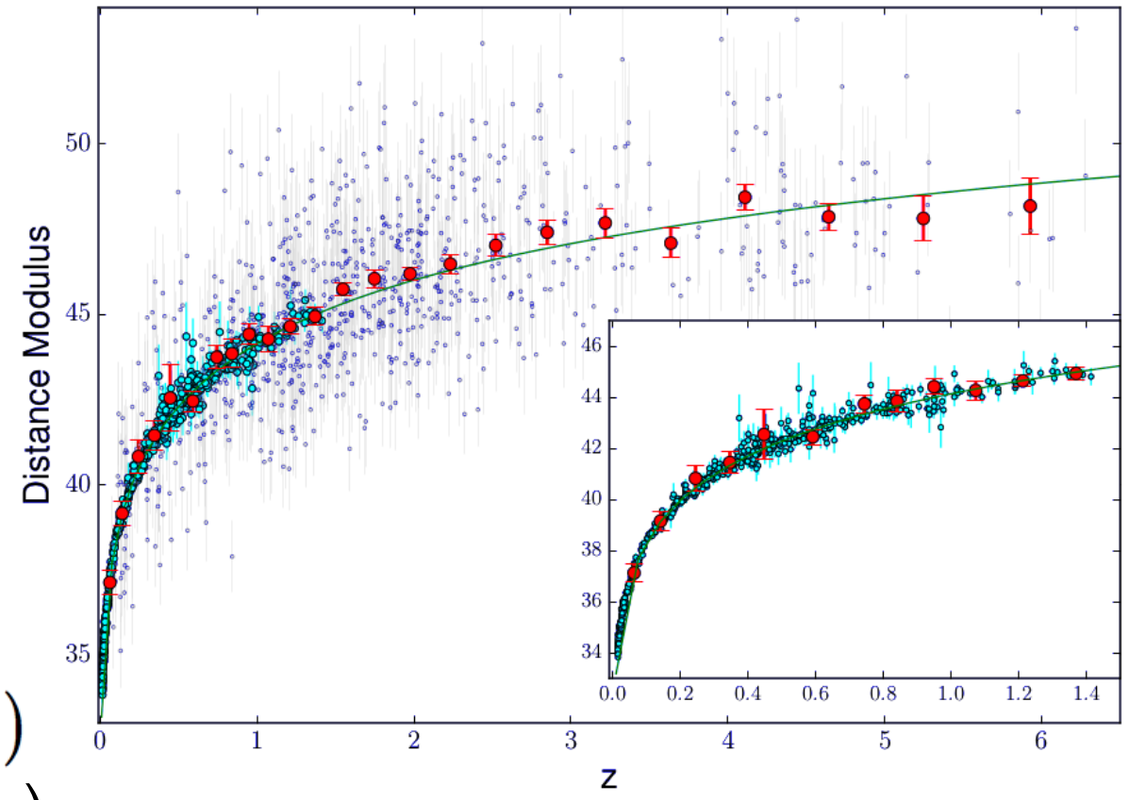
The distance modulus-*z* relation

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 L_X-L_{UV} non-linear relation as a way to measure quasar distances

Cosmology with quasars

T

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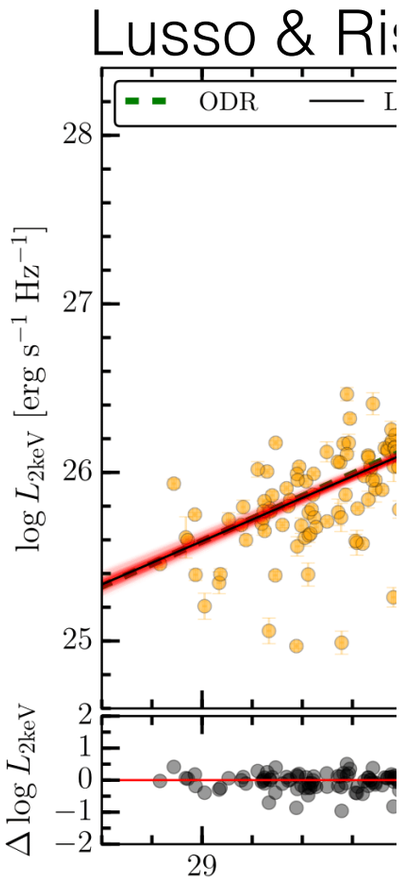

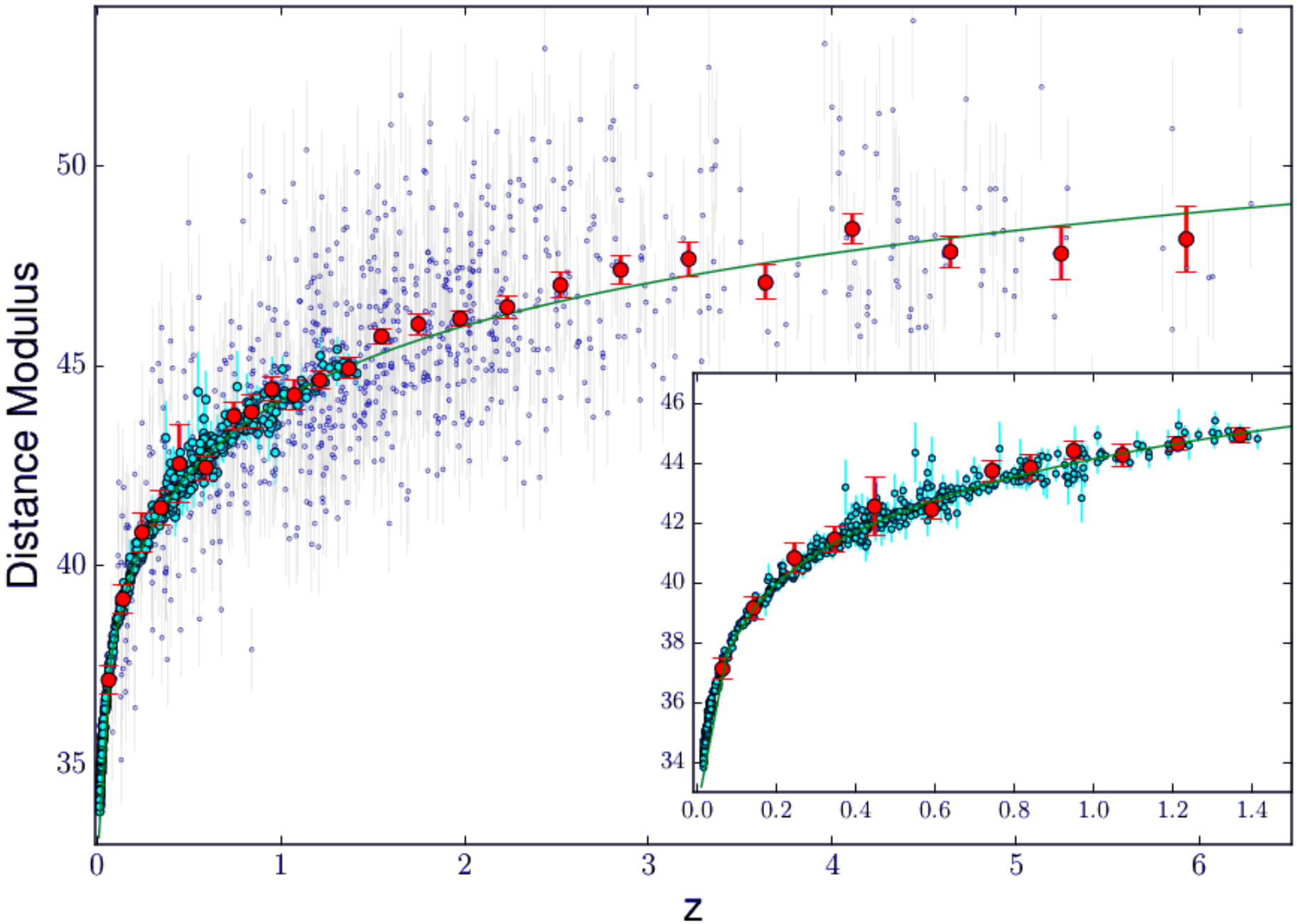

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$$= \beta'$$

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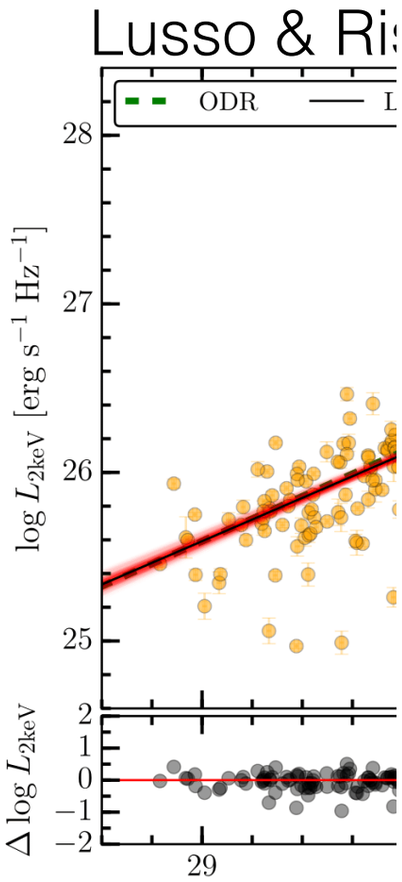

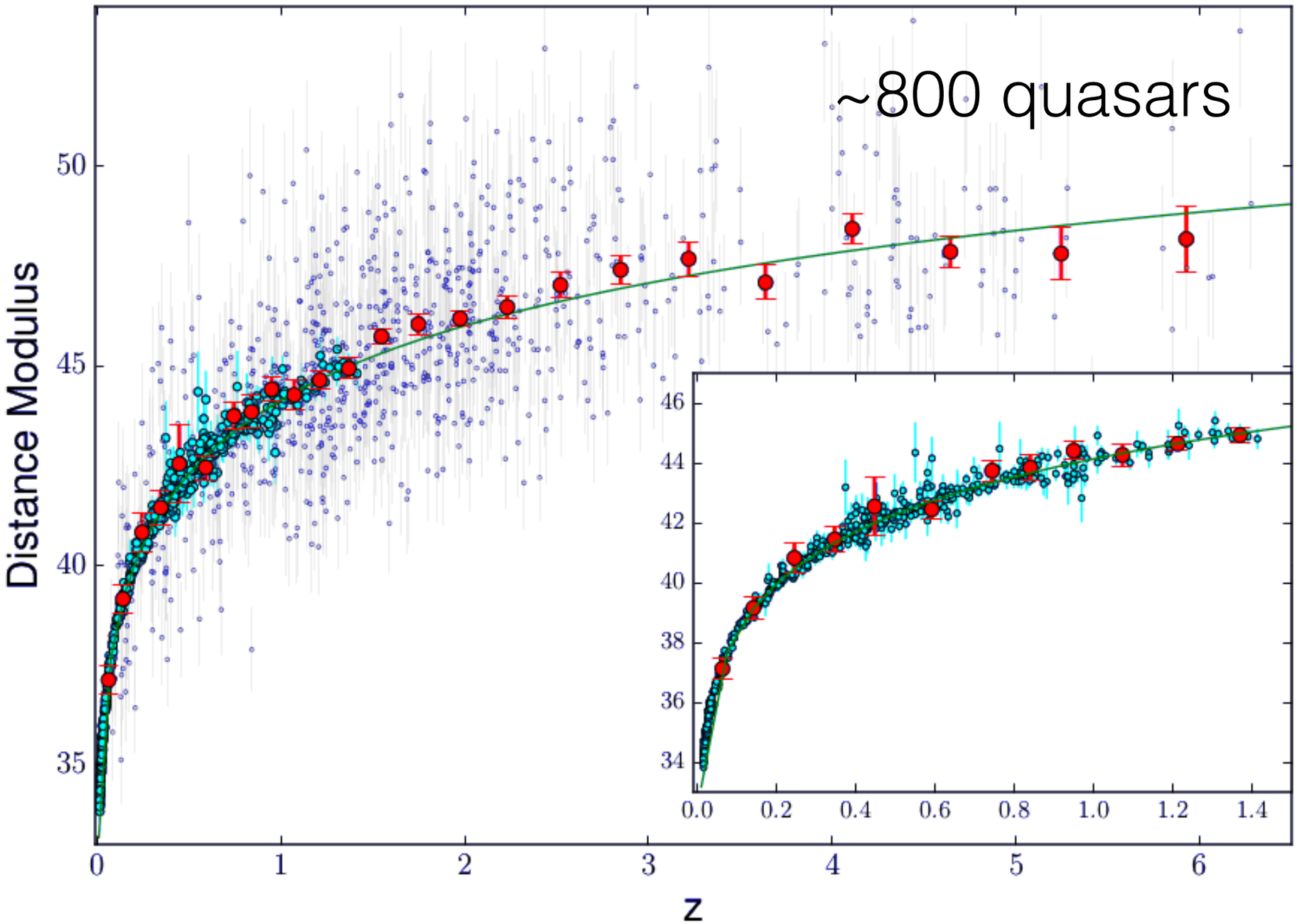

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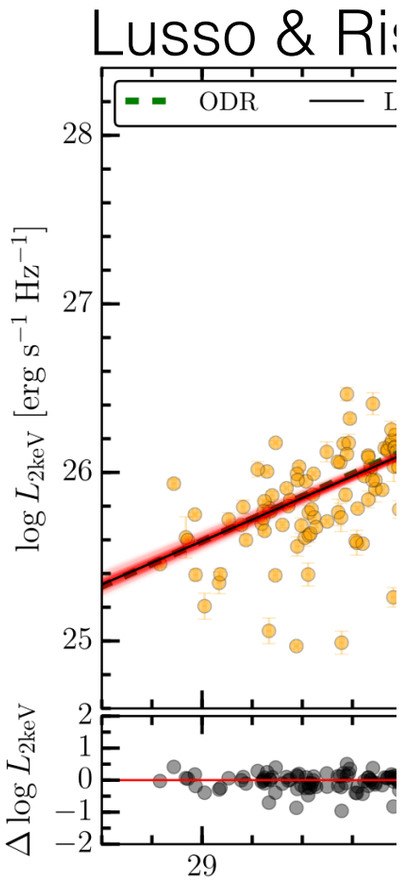

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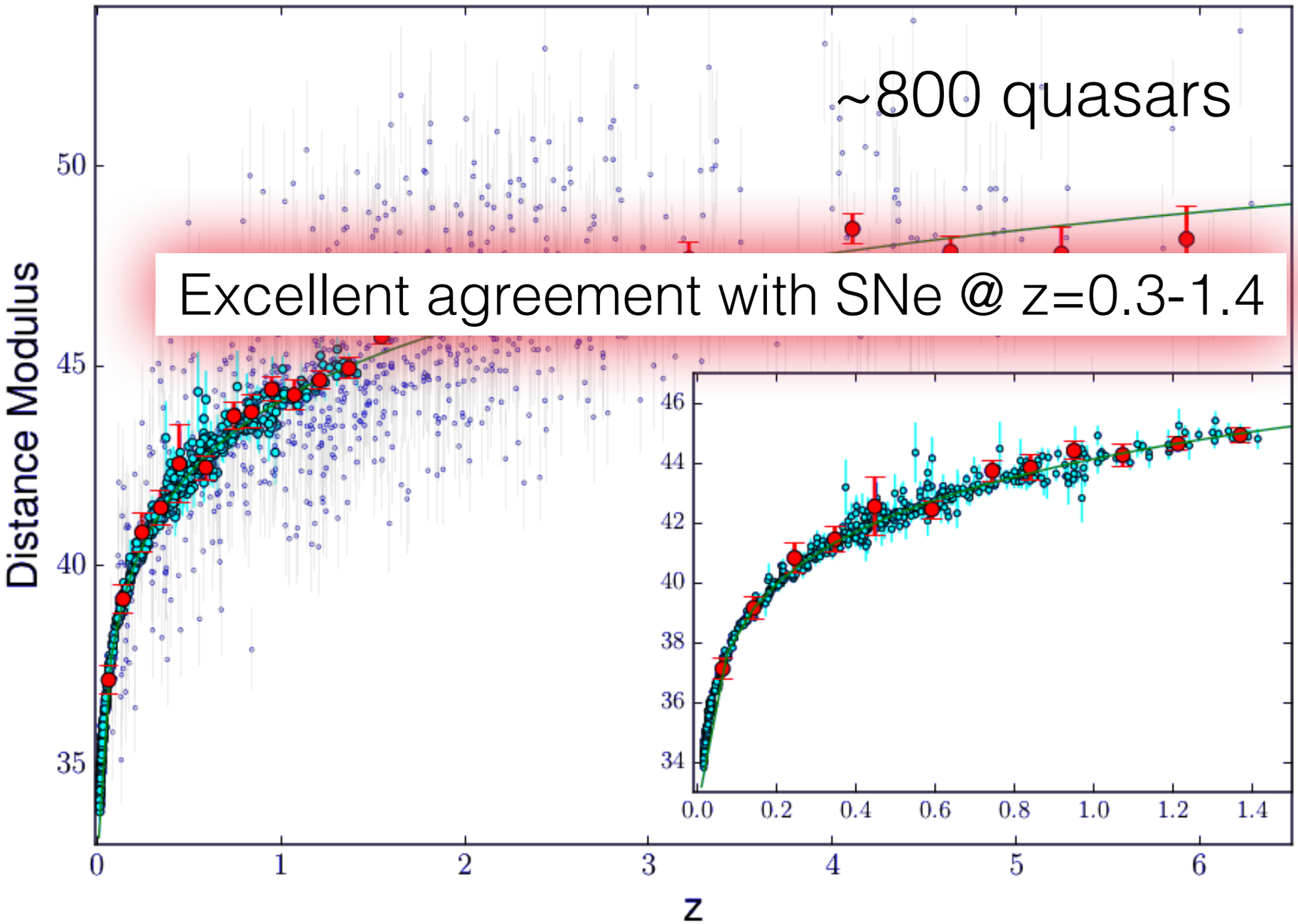

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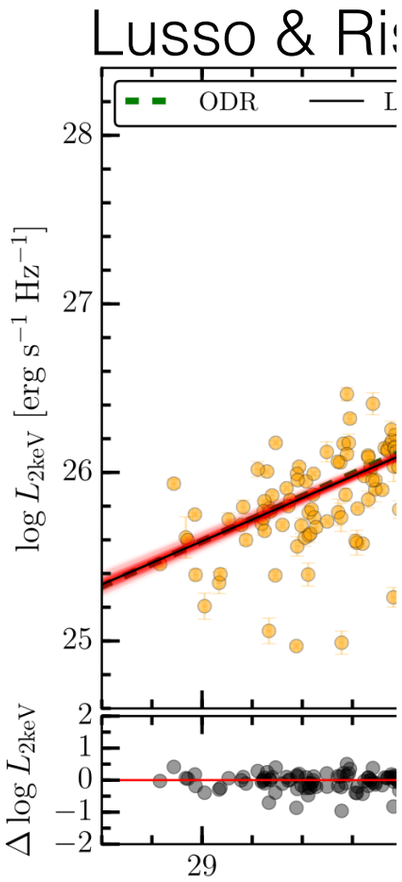

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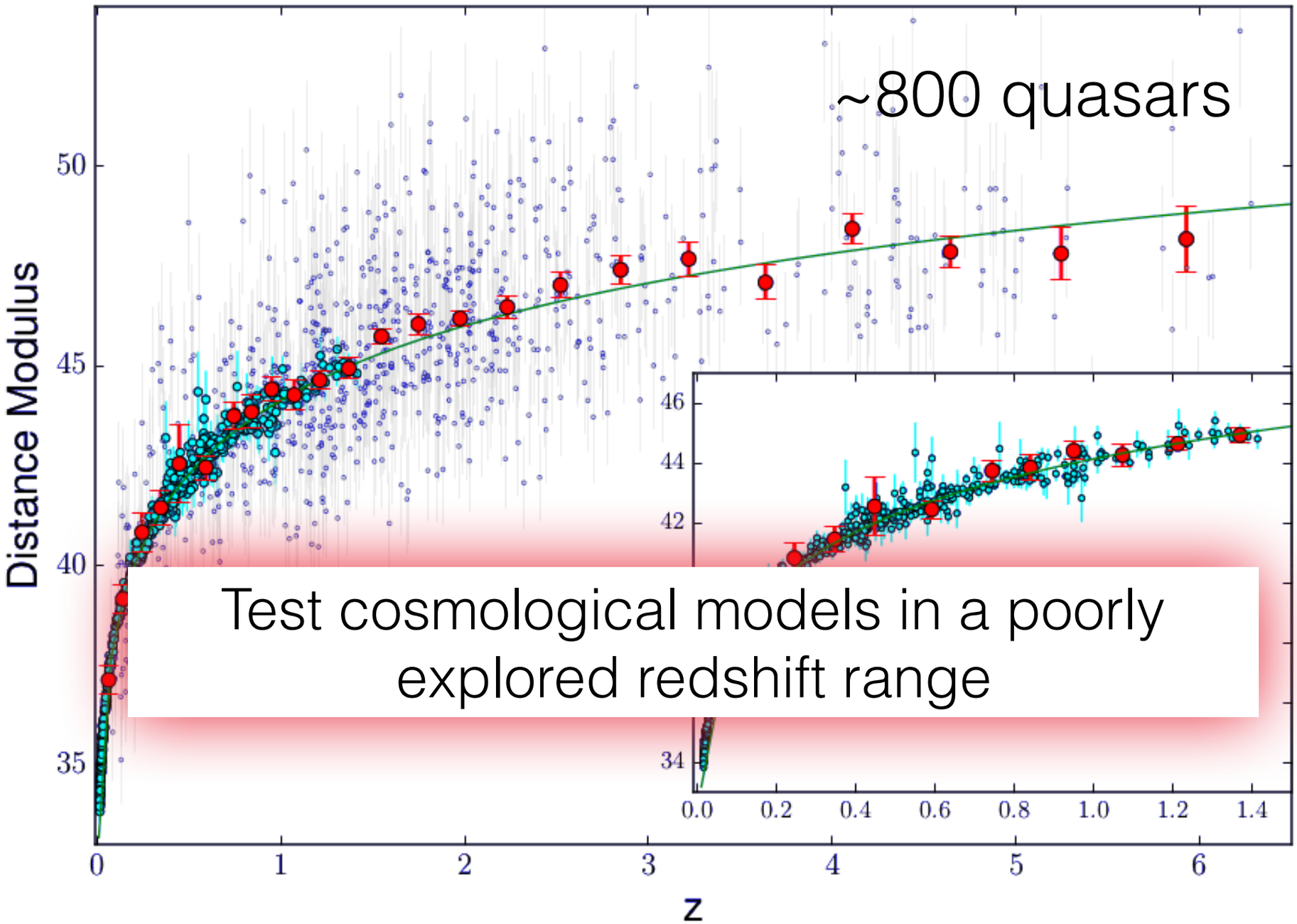


Test cosmological models in a poorly explored redshift range

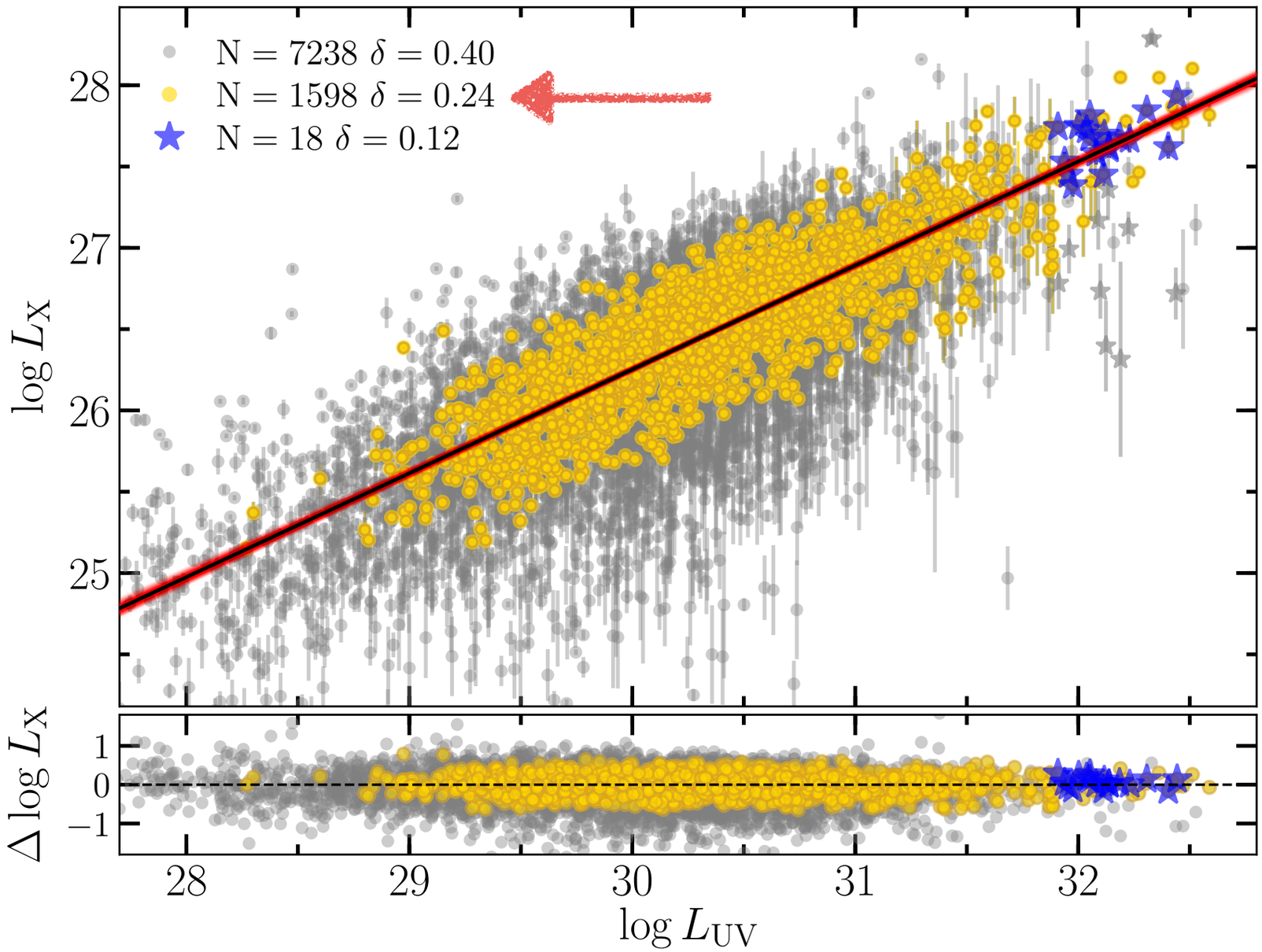
DL(z,x2M, x2A)

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

Cosmology with quasars

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

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



- Radio quiet
- No BAL quasars
- No dust reddened objects
- No X-ray absorption
- Malmquist bias corrected

Risaliti & Lusso (2019, Nature Astro., 3-272)

Cosmology with quasars

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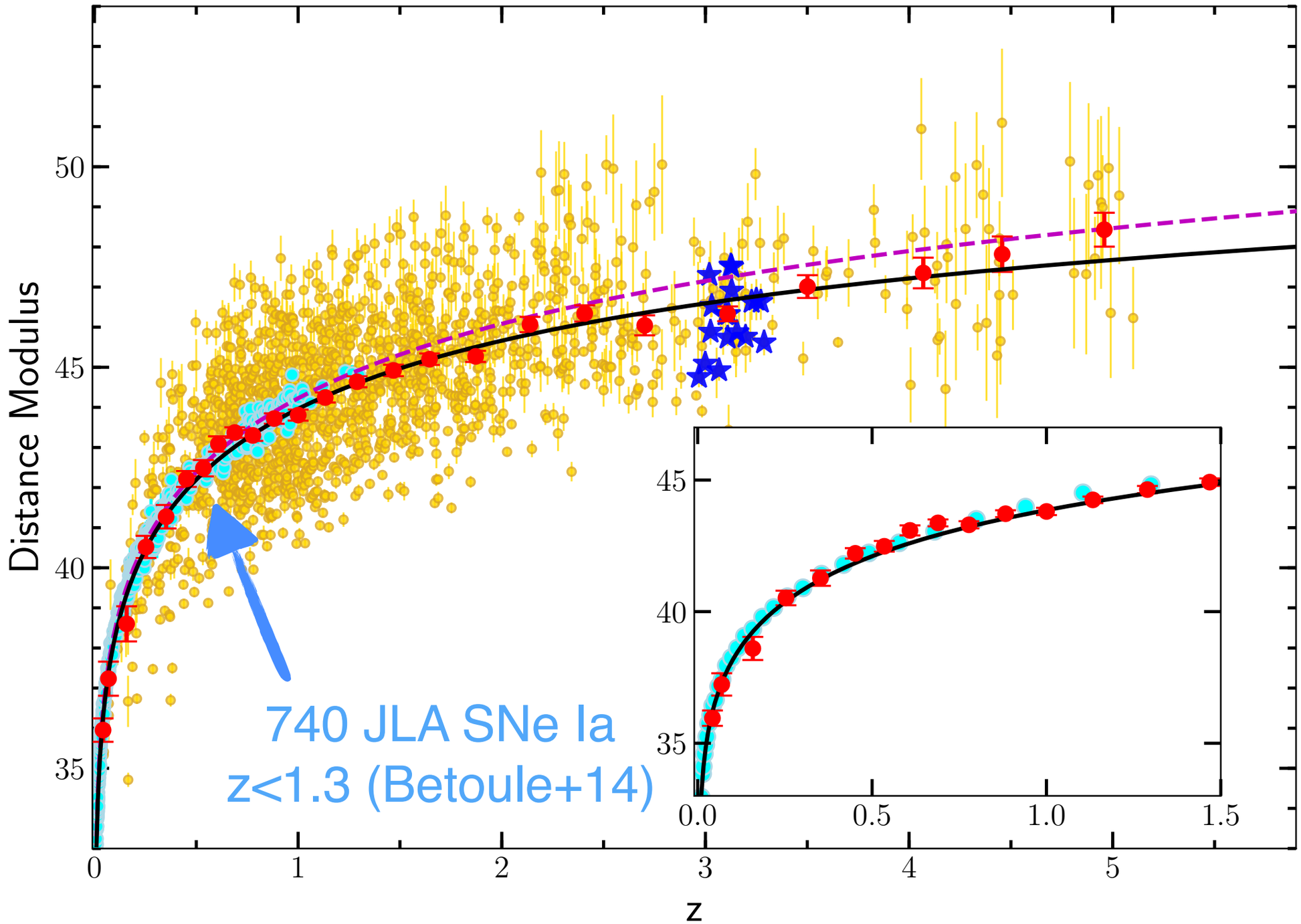

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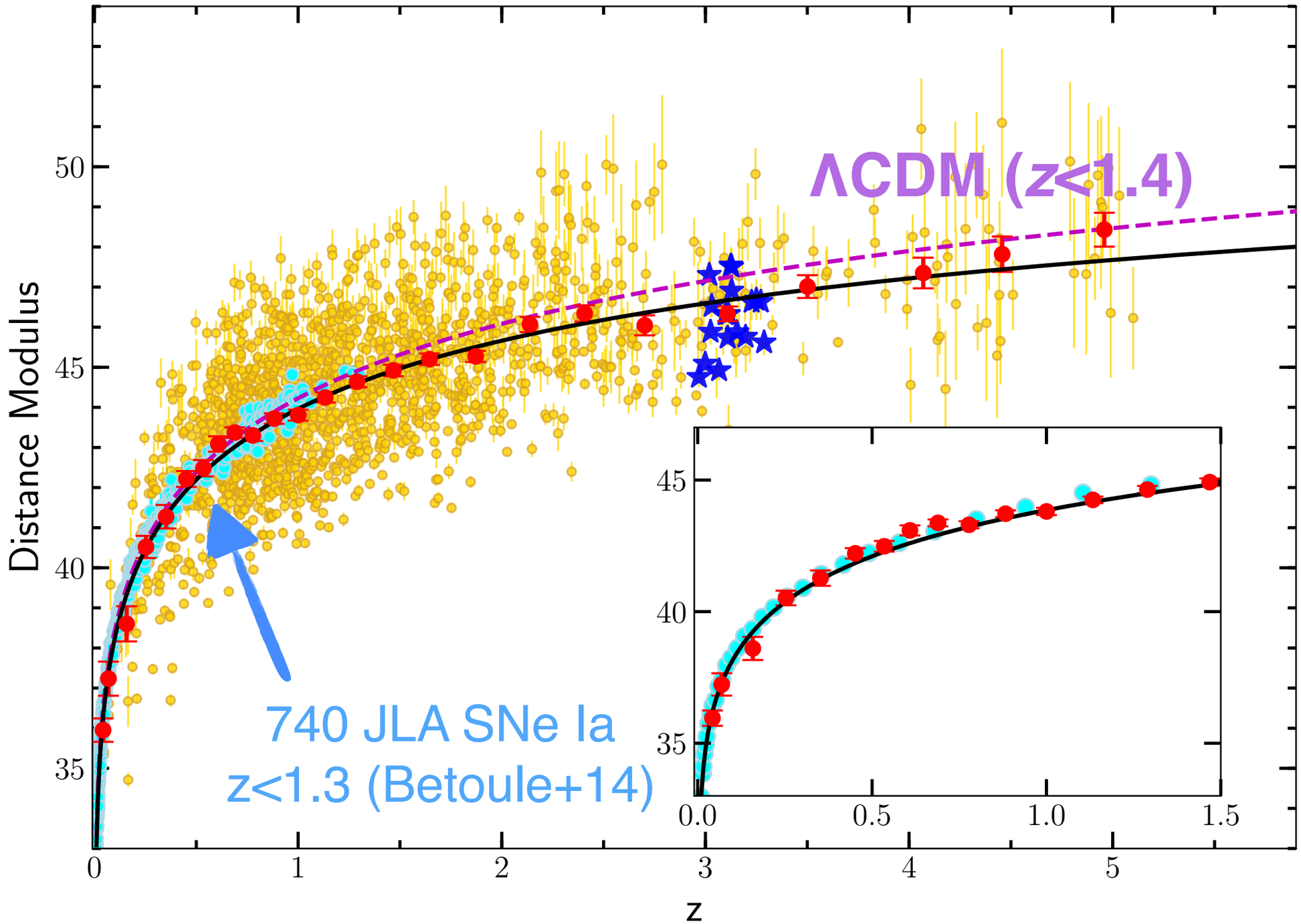

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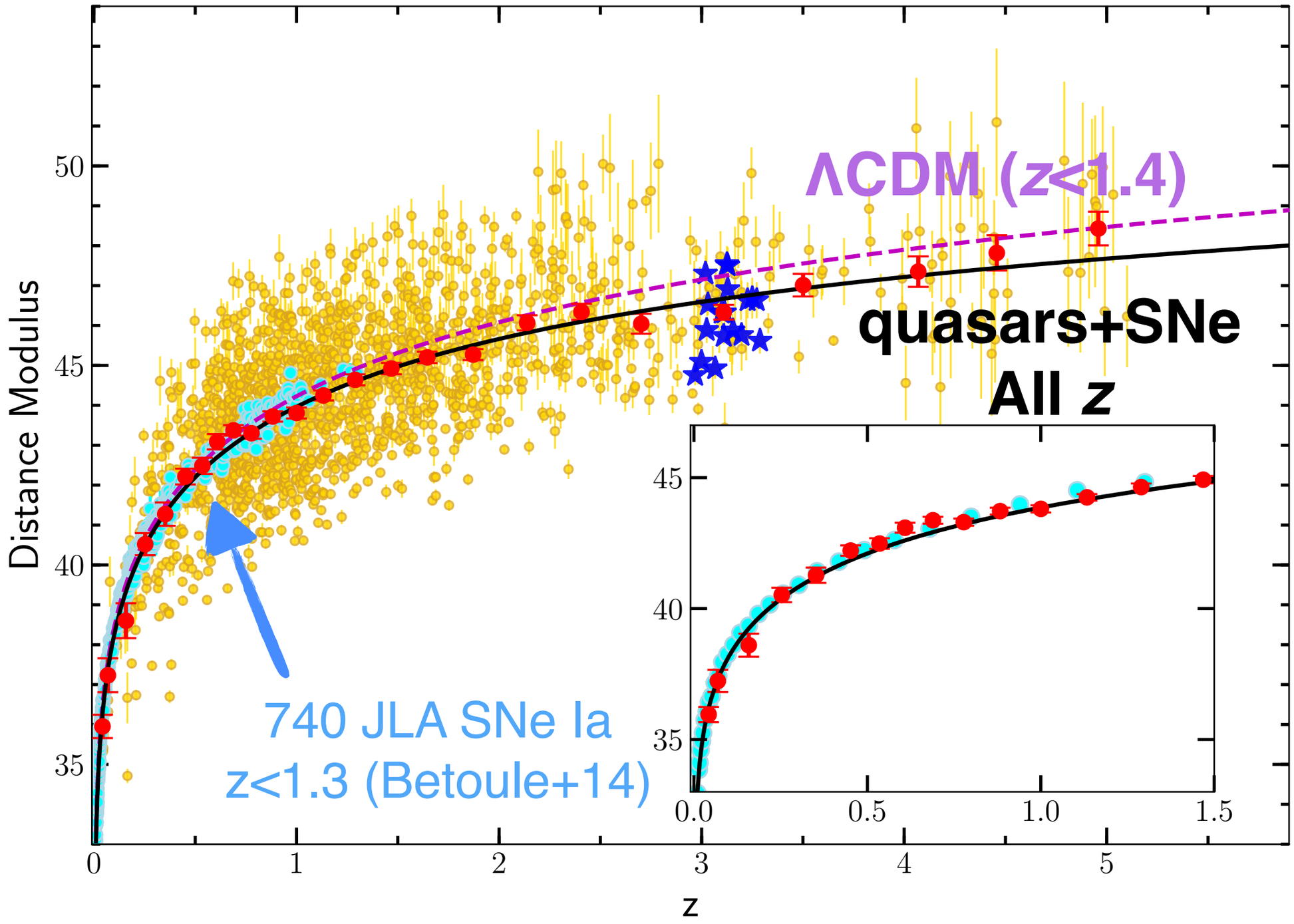

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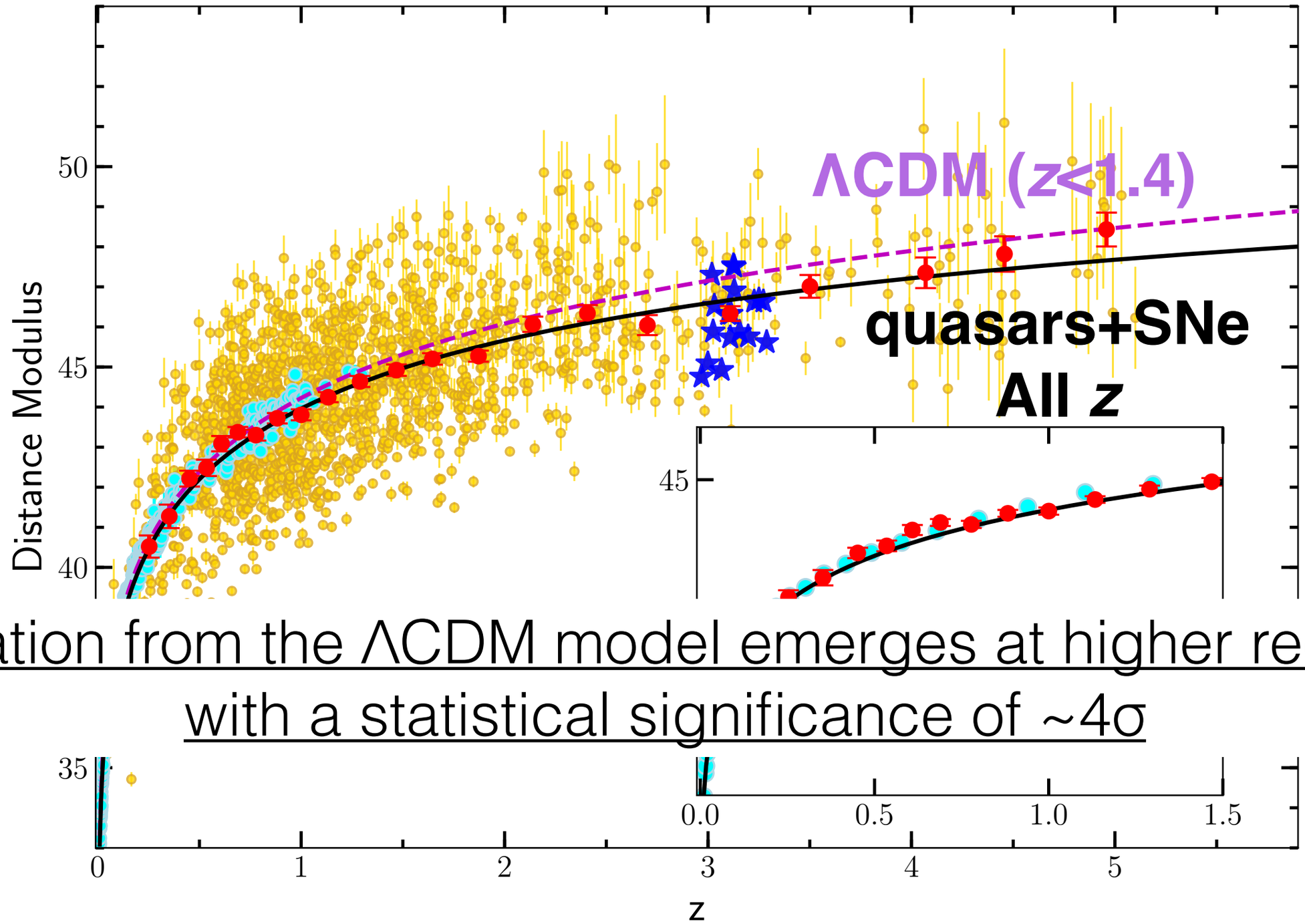

deviation from the ΛCDM model emerges at higher redshift, with a statistical significance of ~4σ

Cosmology with quasars

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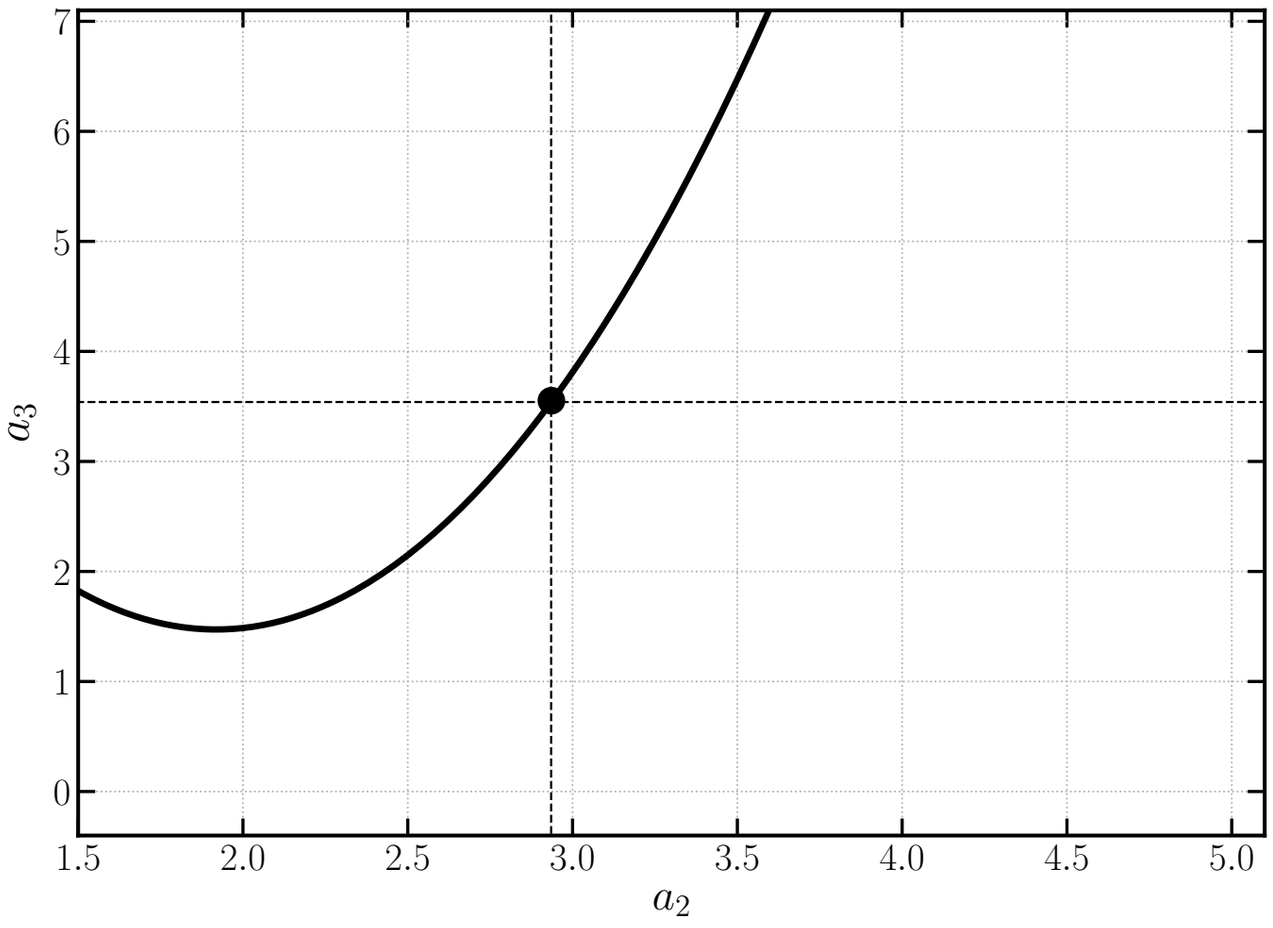
Risaliti & Lusso (2019, Nature Astro., 3-272)



Cosmographic approach

$$D_L = \frac{c}{H_0} \ln(10) \times \sum_{i=1}^{3} a_i \log^i(1+z)$$

Cosmology with quasars

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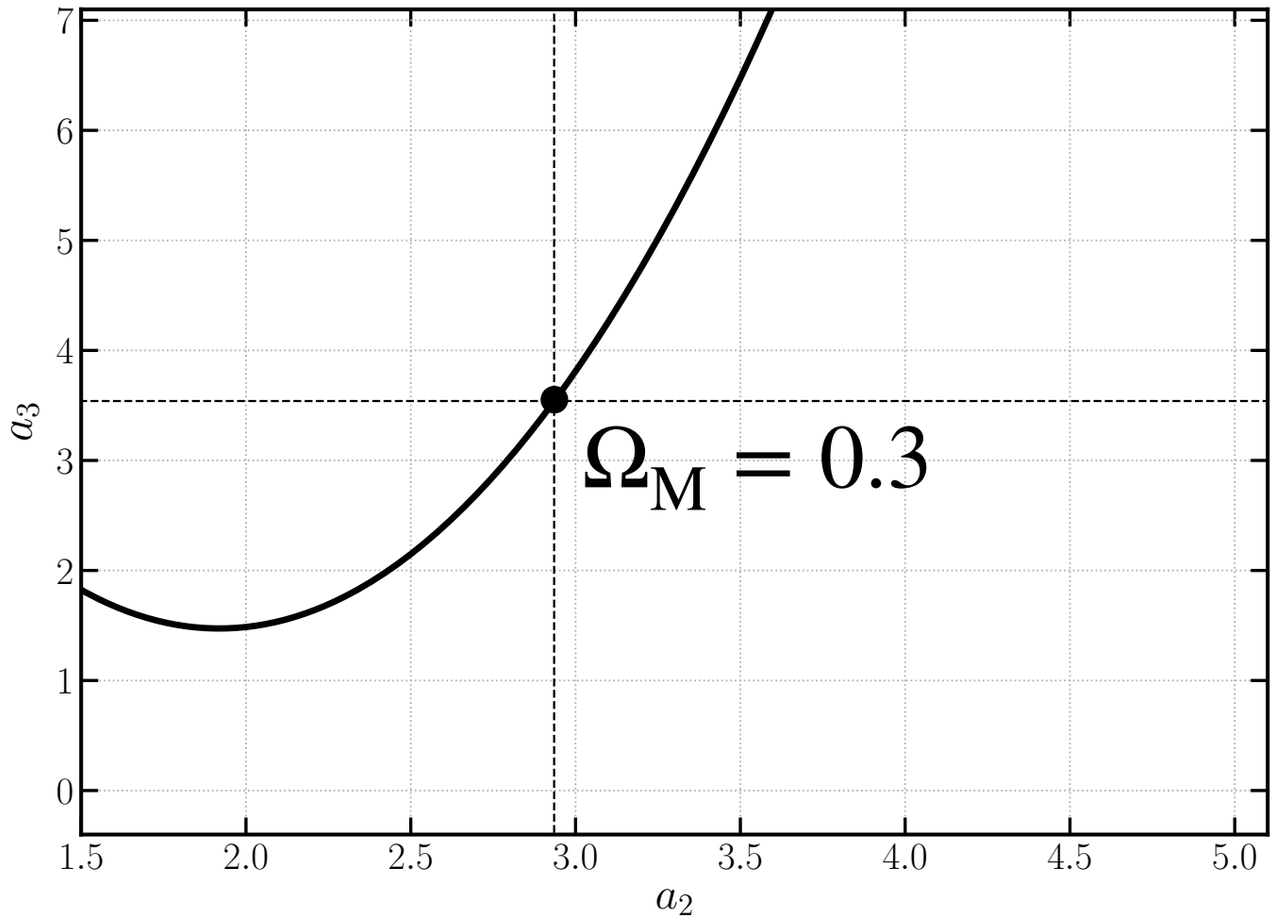

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—— Flat ΛCDM

$$a_1 = 1$$

$$a_2 = \frac{3}{2} - \frac{3}{4}\Omega_{\rm M}$$

$$a_3 = \frac{9}{8}\Omega_{\rm M}^2 - 2\Omega_{\rm M} + \frac{7}{6}$$

Cosmology with quasars

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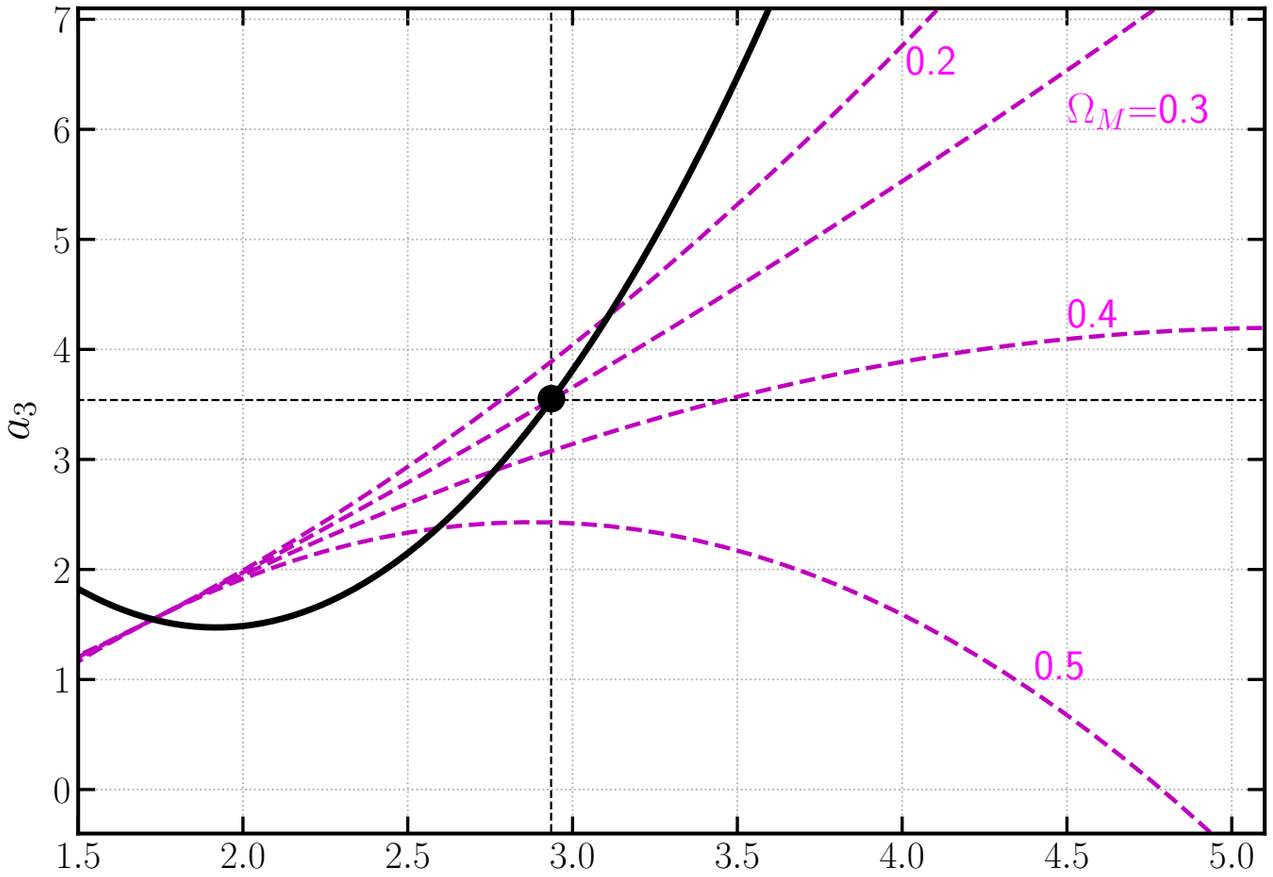

w=-1

w>-1 Ω_M=0.3 *w*<-1

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

$w(z)=w_0+w_{a^*}z/(1+z)$

Cosmology with quasars

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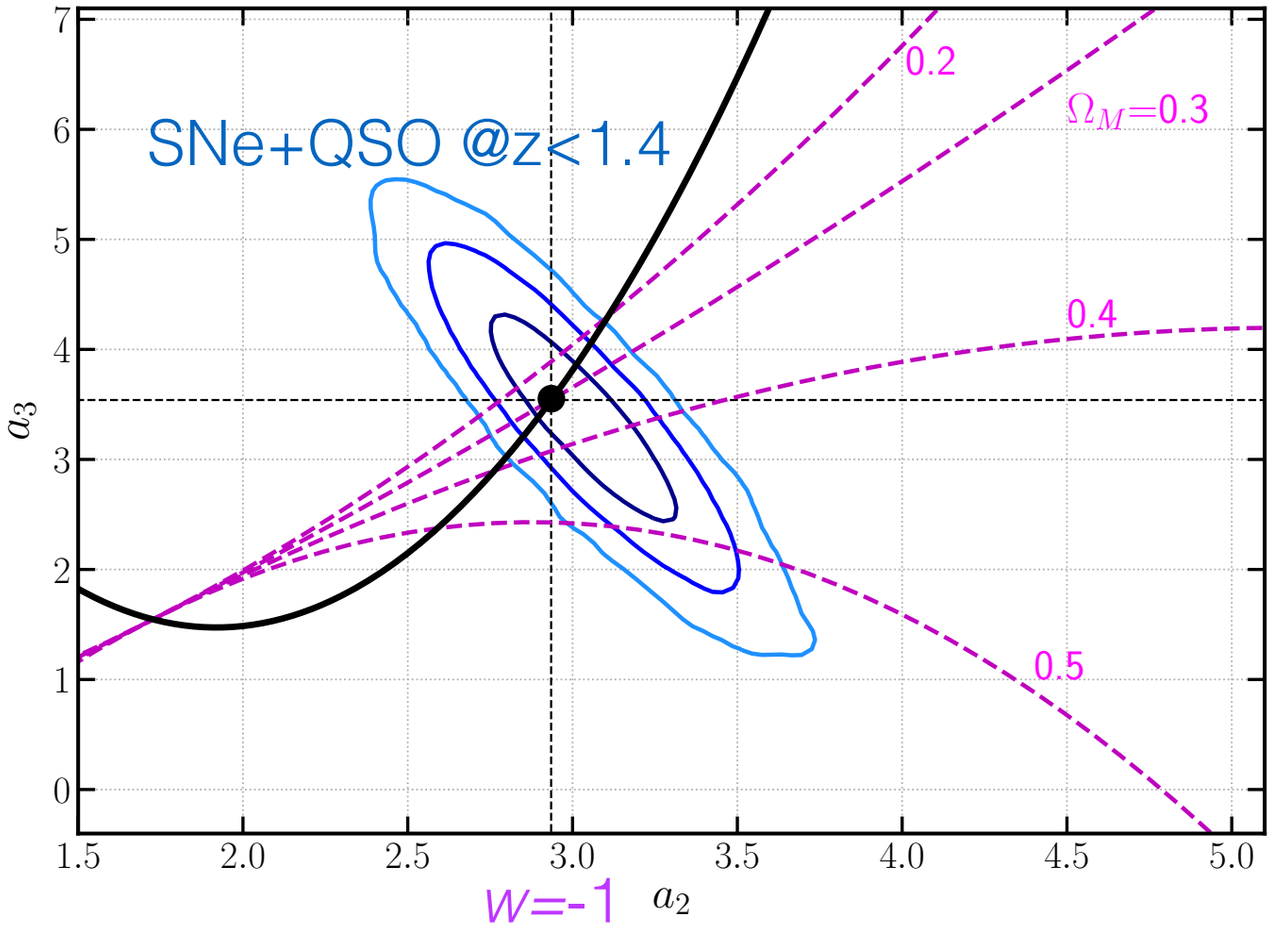

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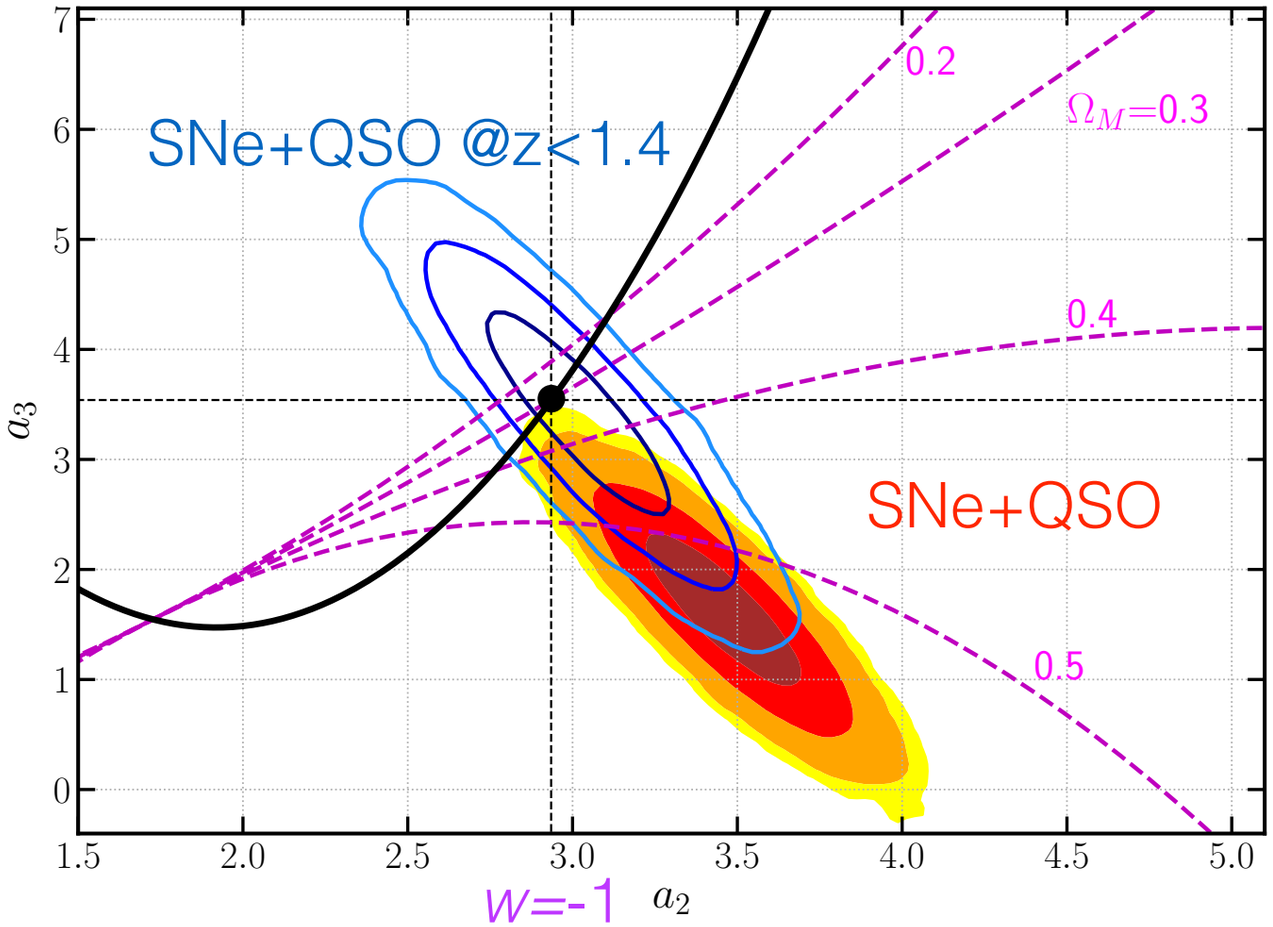

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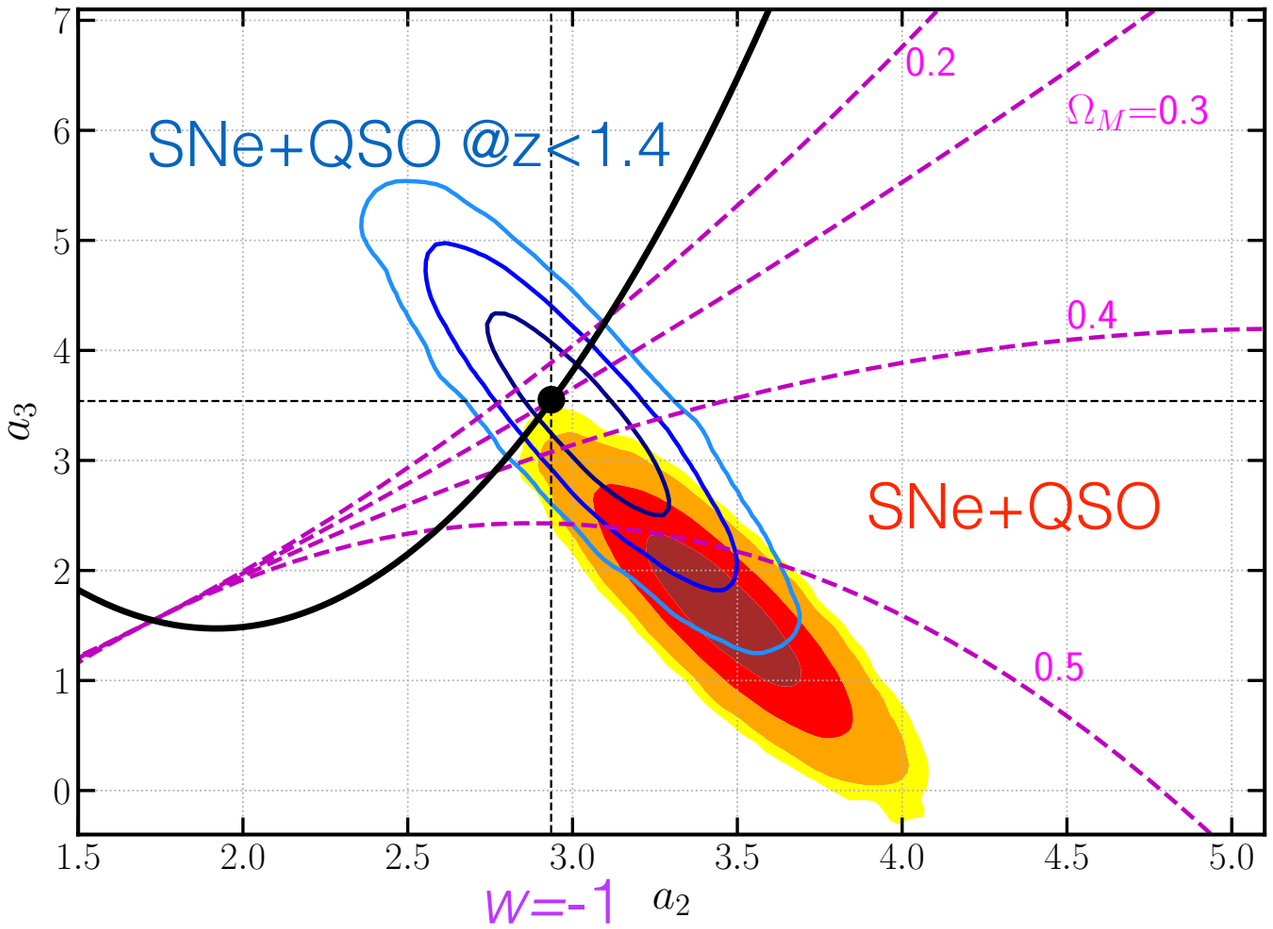

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data suggest: **dark energy density increasing with time**.

Within the *w*CDM model: Ω_M>0.3 and *w*<-1.3

Cosmology with quasars: What's next

Test source of systematics & physical properties

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

2. Different model-independent techniques

3. Detailed analysis of both X-ray and UV spectroscopy **Poster #443: Nardini**

4. Test relation at z>5 **Poster #453: Salvestrini**

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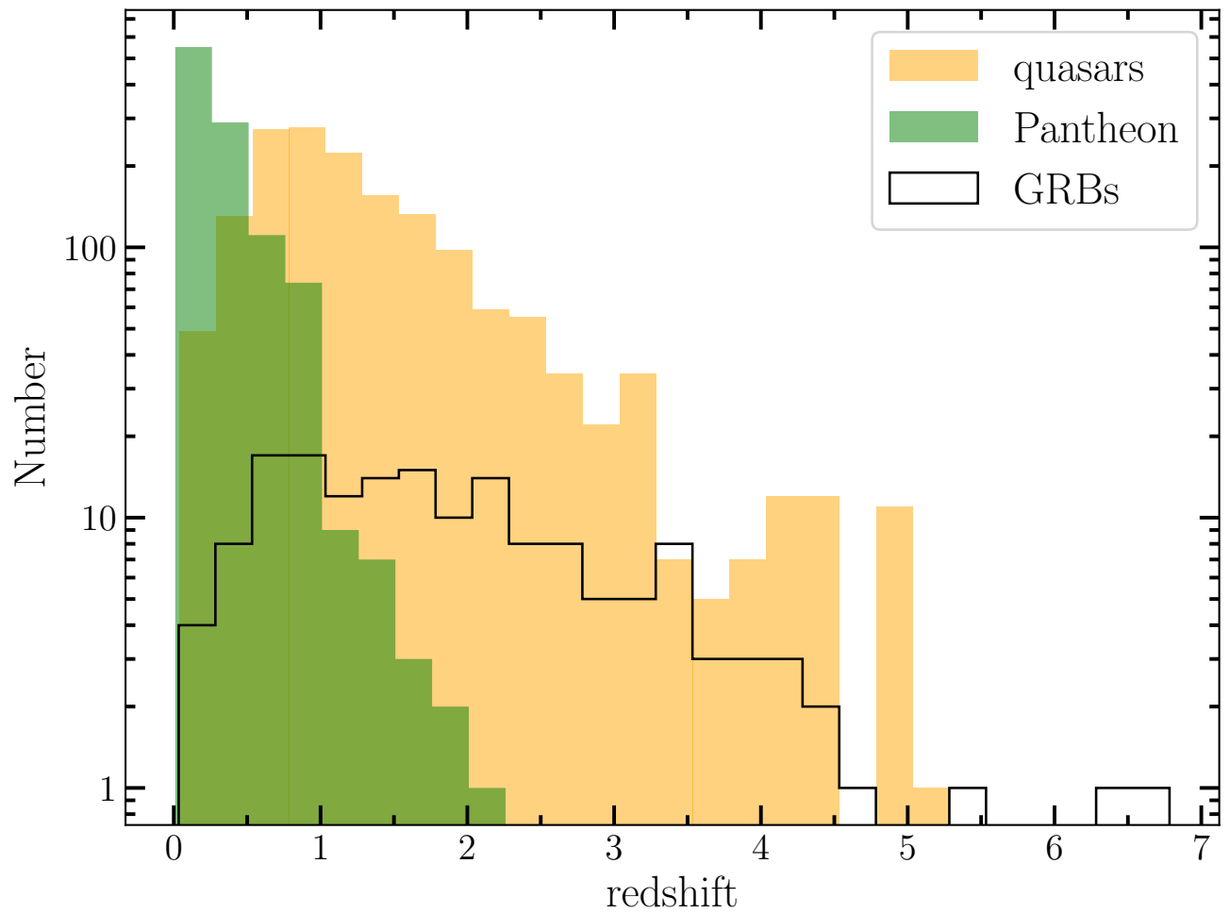
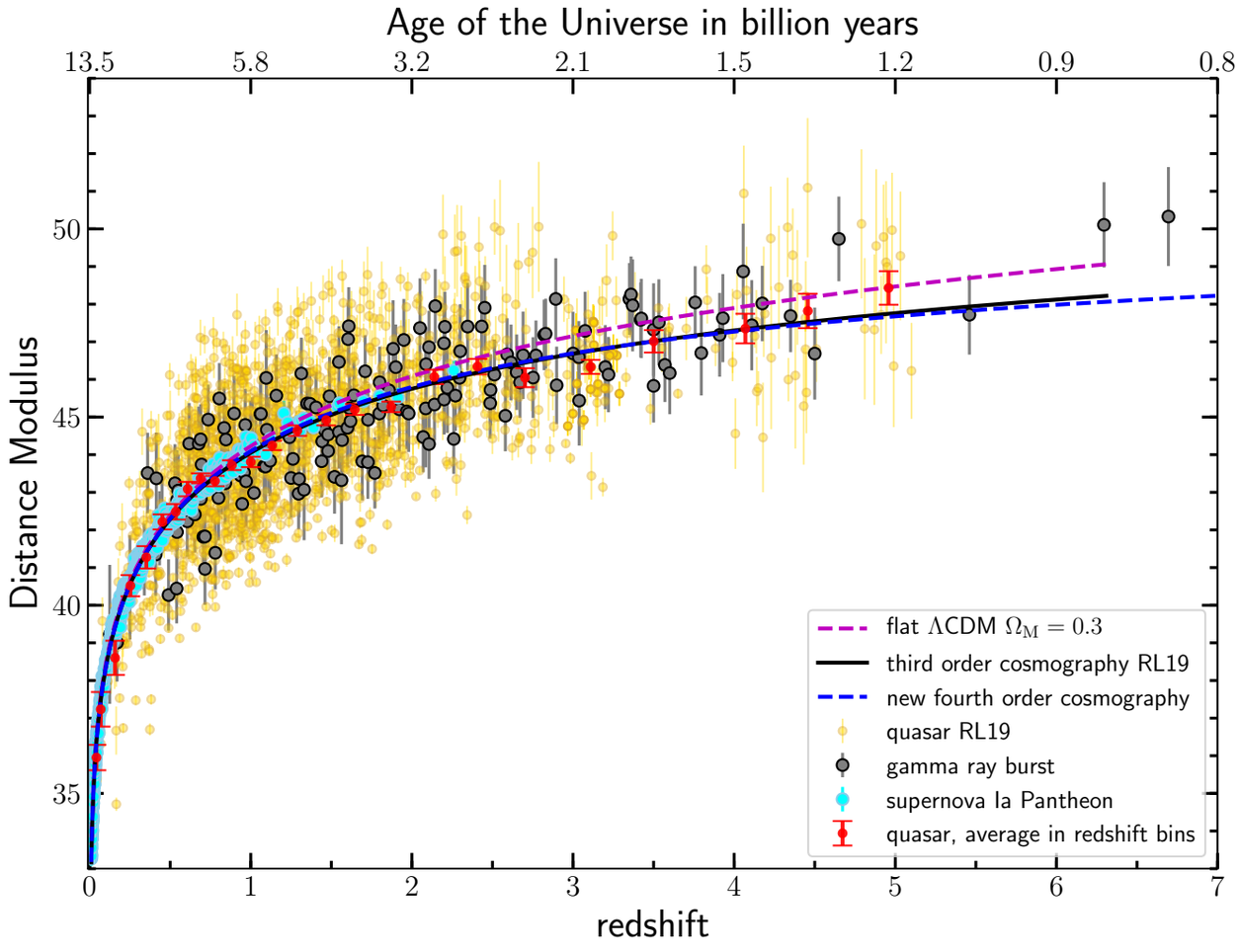
The Quasars + SNe + GRBs Hubble Diagram

1598 quasars (Risaliti & Lusso 2019)

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

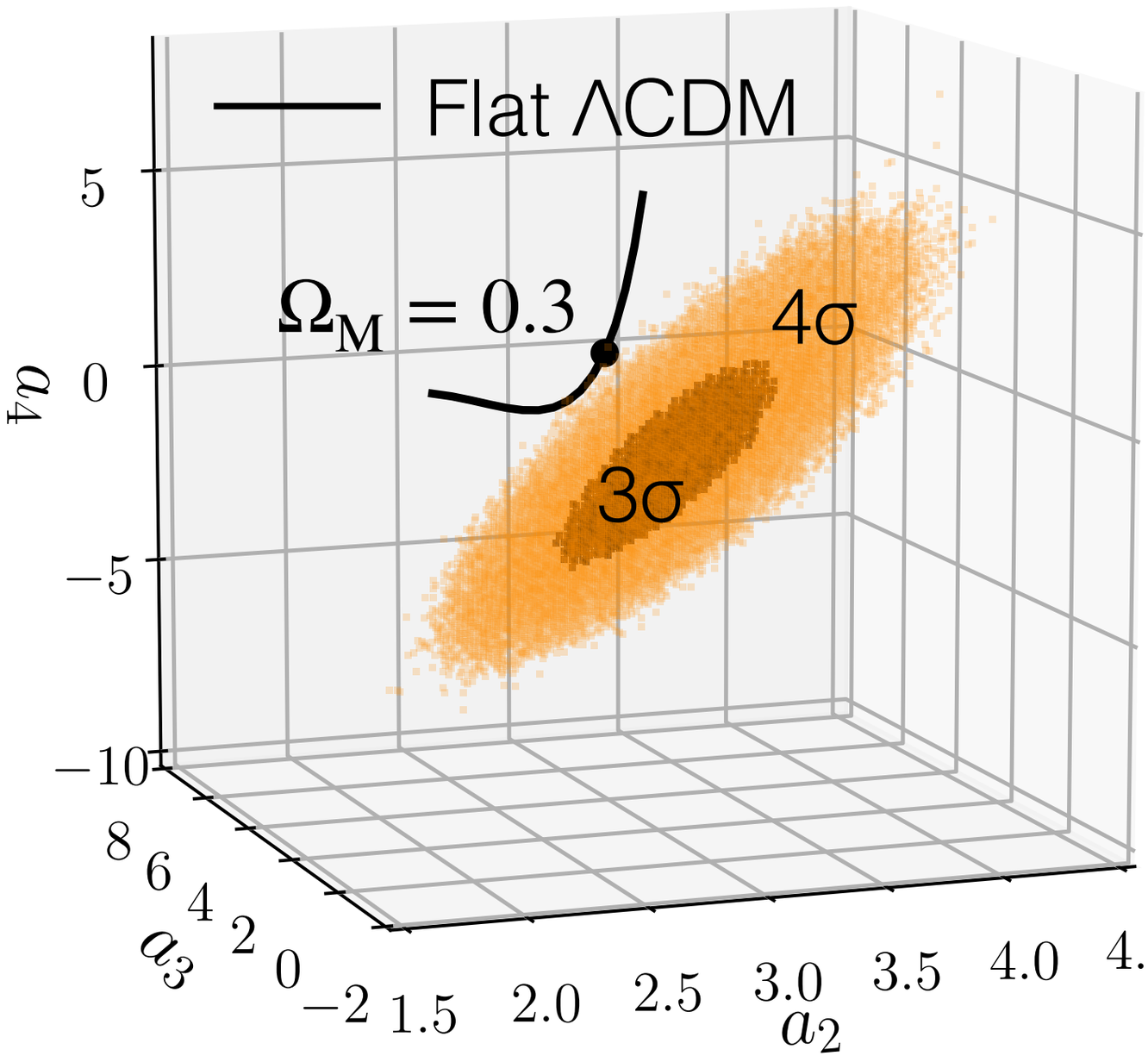
160 GRBs (Demianski et al. 2017)

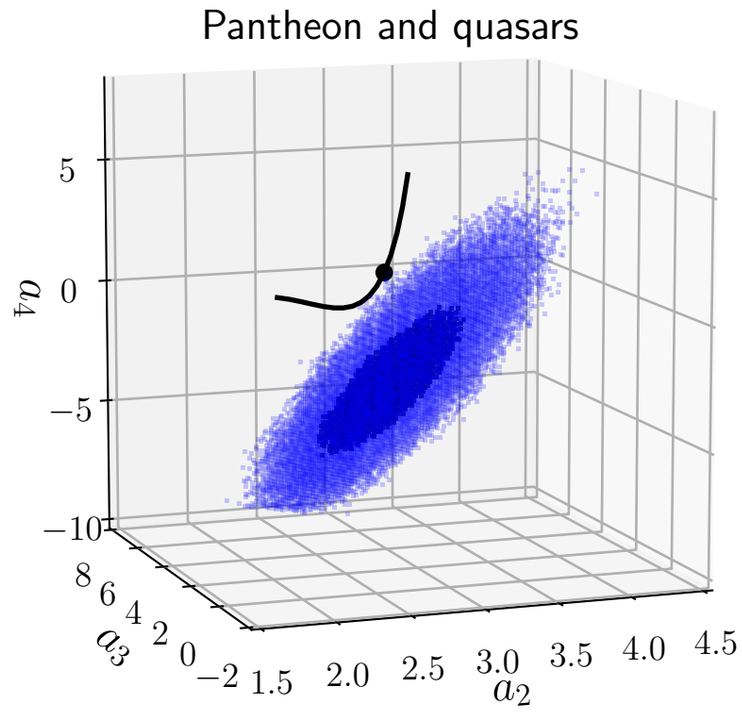


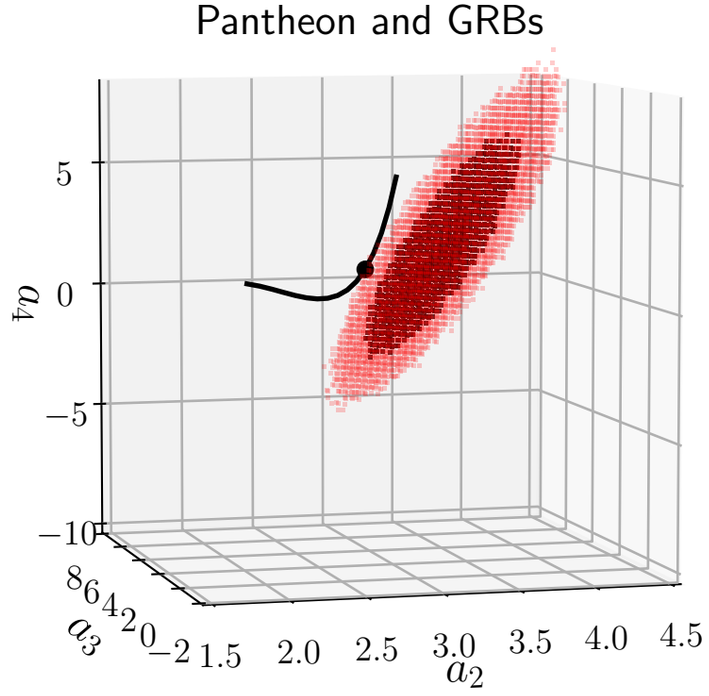


Lusso, Piedipalumbo, Risaliti, et al. A&A 628-4

The Quasars + SNe + GRBs Hubble Diagram







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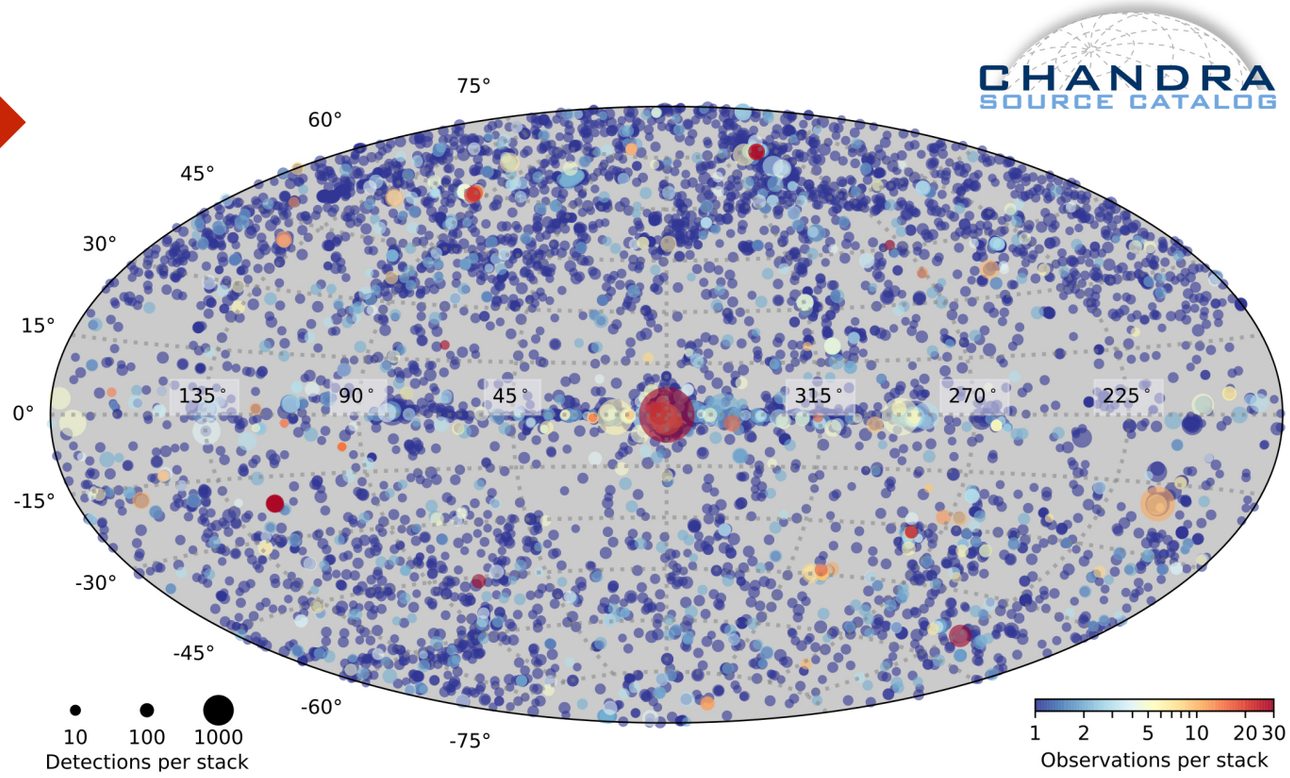
Present: the treasure in the archives

Chandra Source Catalogue CSC 2.0

Poster #408: Civano



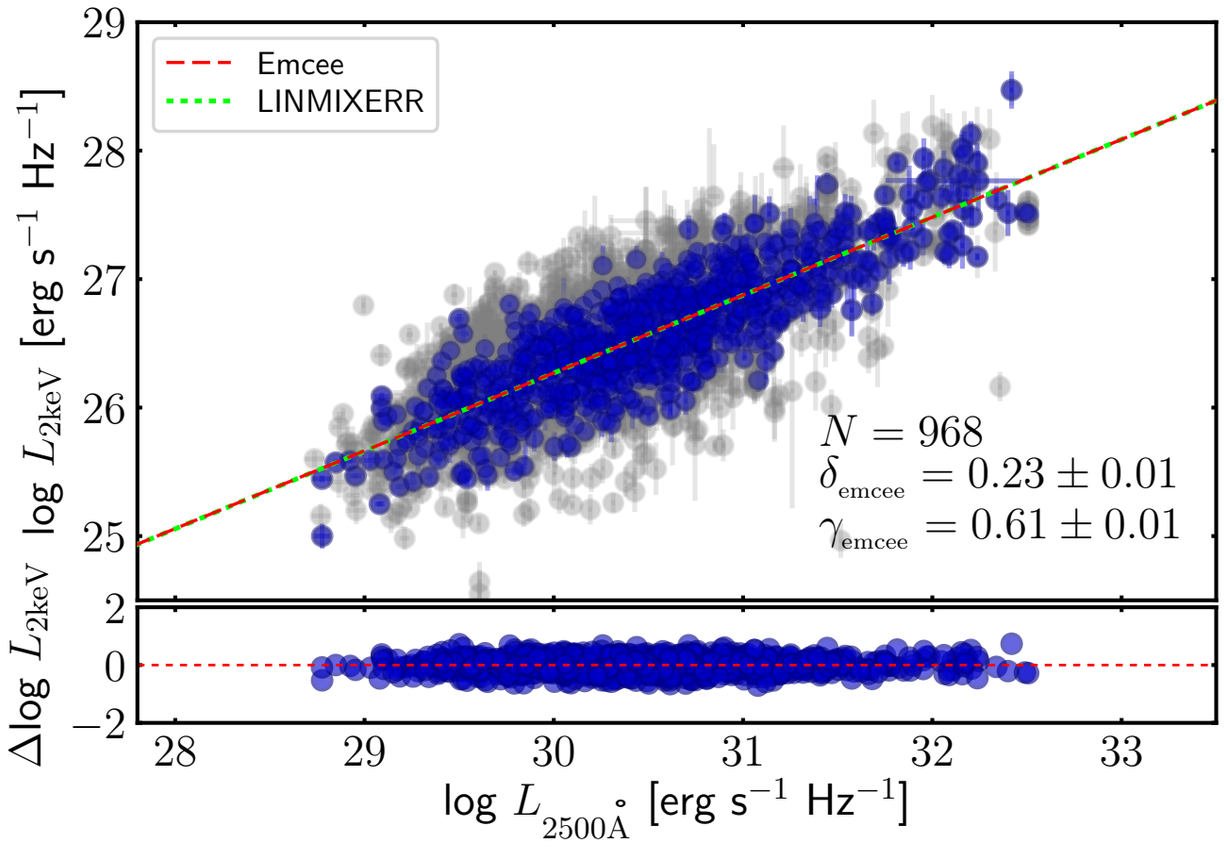
Area covered ~600 deg²

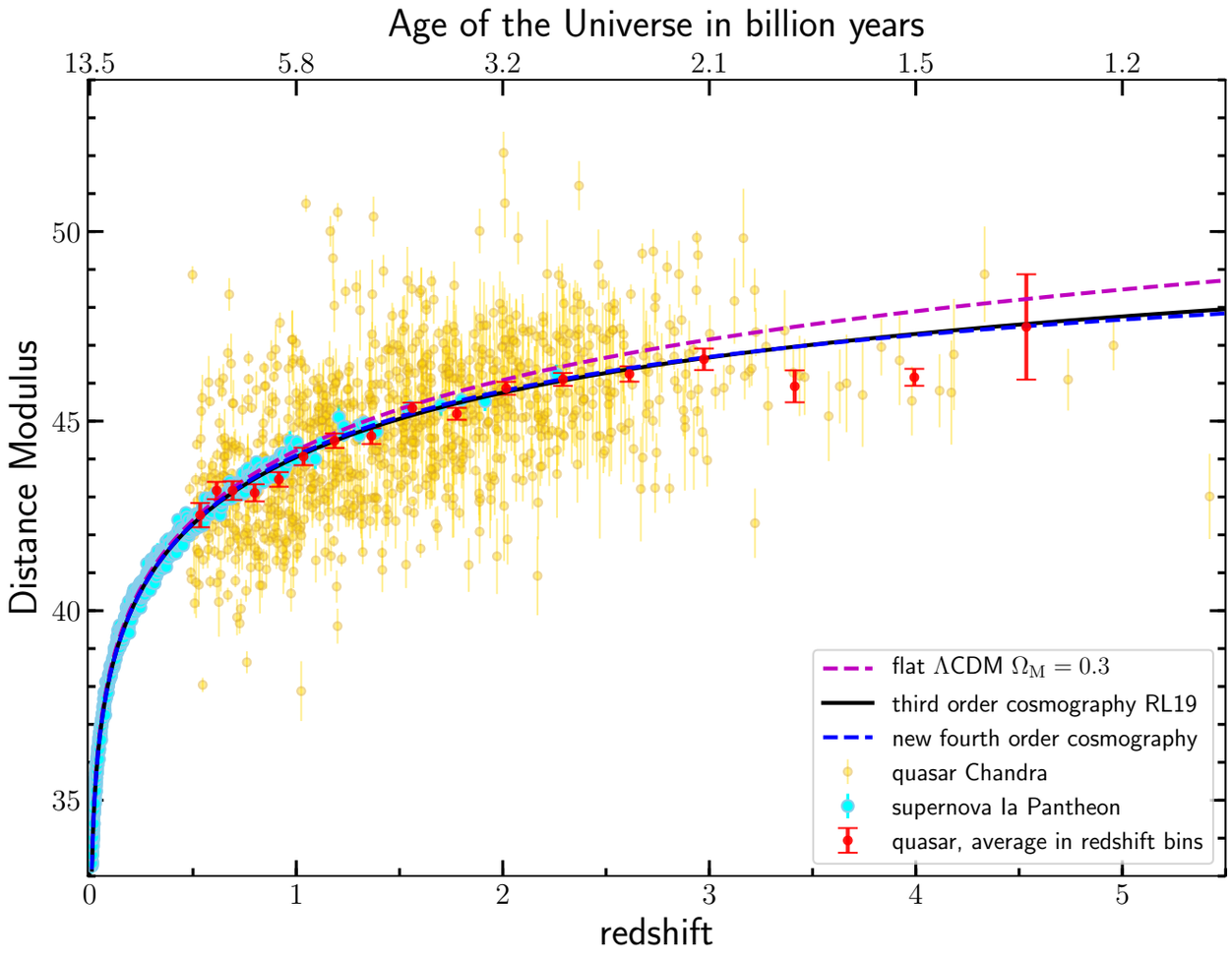
- 10,382 *Chandra* imaging observations released publicly 1999–2014
- overlapping detections are combined (~5 net counts for exposures < 15 ks)
- 315,875 sources, created from 374,349 detections

Evans, I. N., et al.in prep

The CSC2.0+SDSS DR14 quasar sample

Poster #404: Bisogni

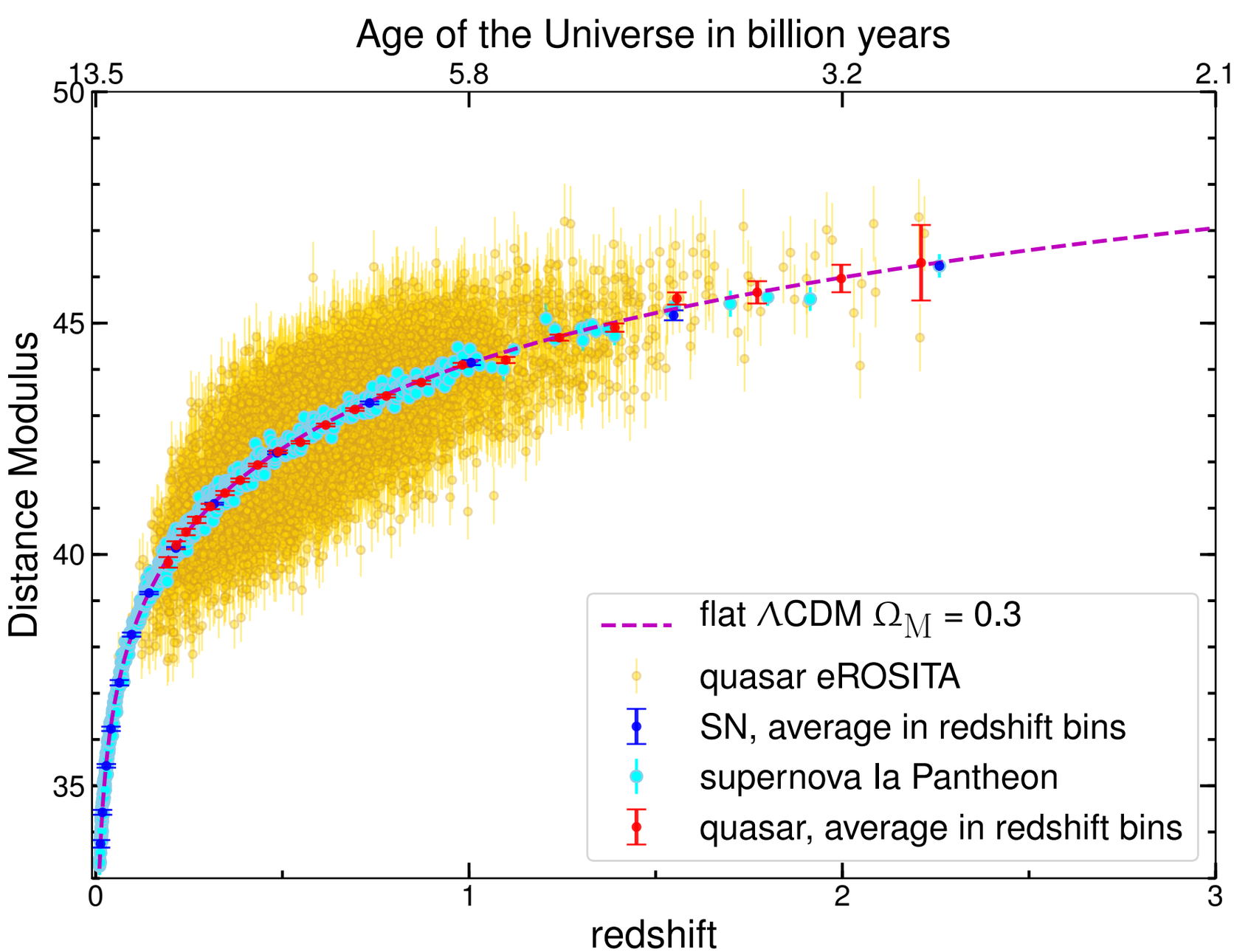


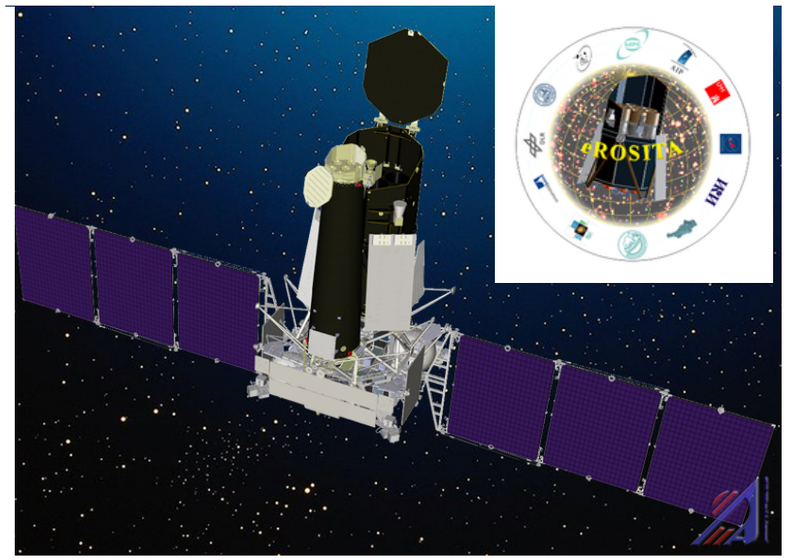


Bisogni et al. in prep.

Future (a reality!): eROSITA

Flagship instrument of the Russian *Spektrum-Roentgen-Gamma* (SRG) mission (Predehl et al. 2012; Merloni et al. 2012)





Talk today: Merloni

~9000 quasars
SDSS DR14 coverage
X-ray depth 0.5-2 keV
>4x10^{-14} erg s^{-1} cm^{-2}

$$\Omega_M = 0.31 \pm 0.04$$

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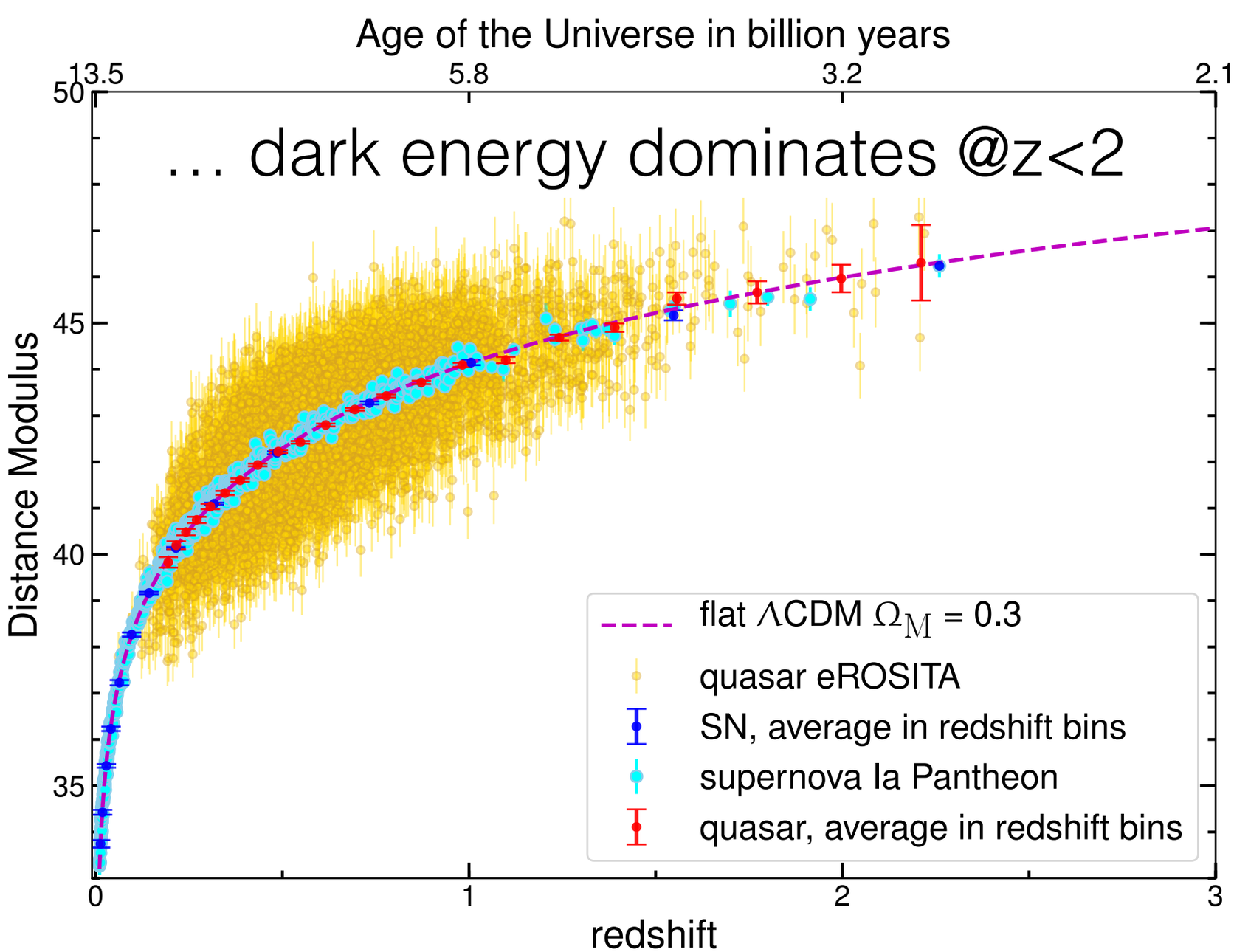

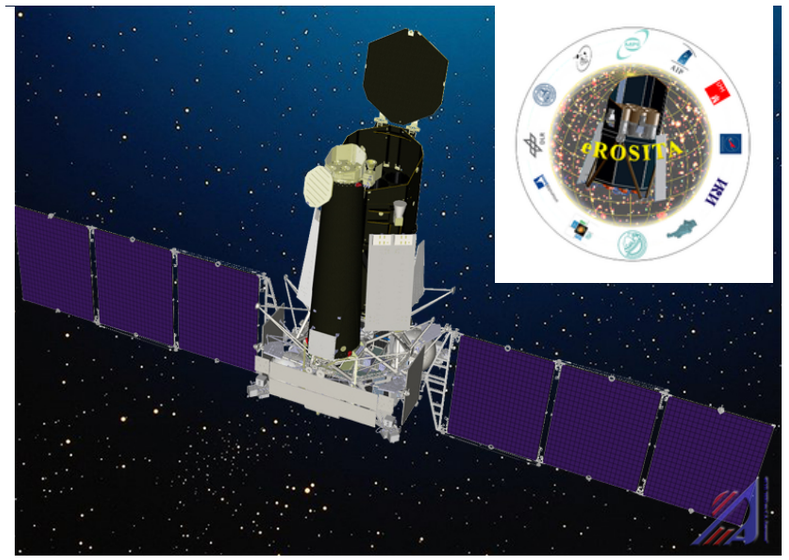

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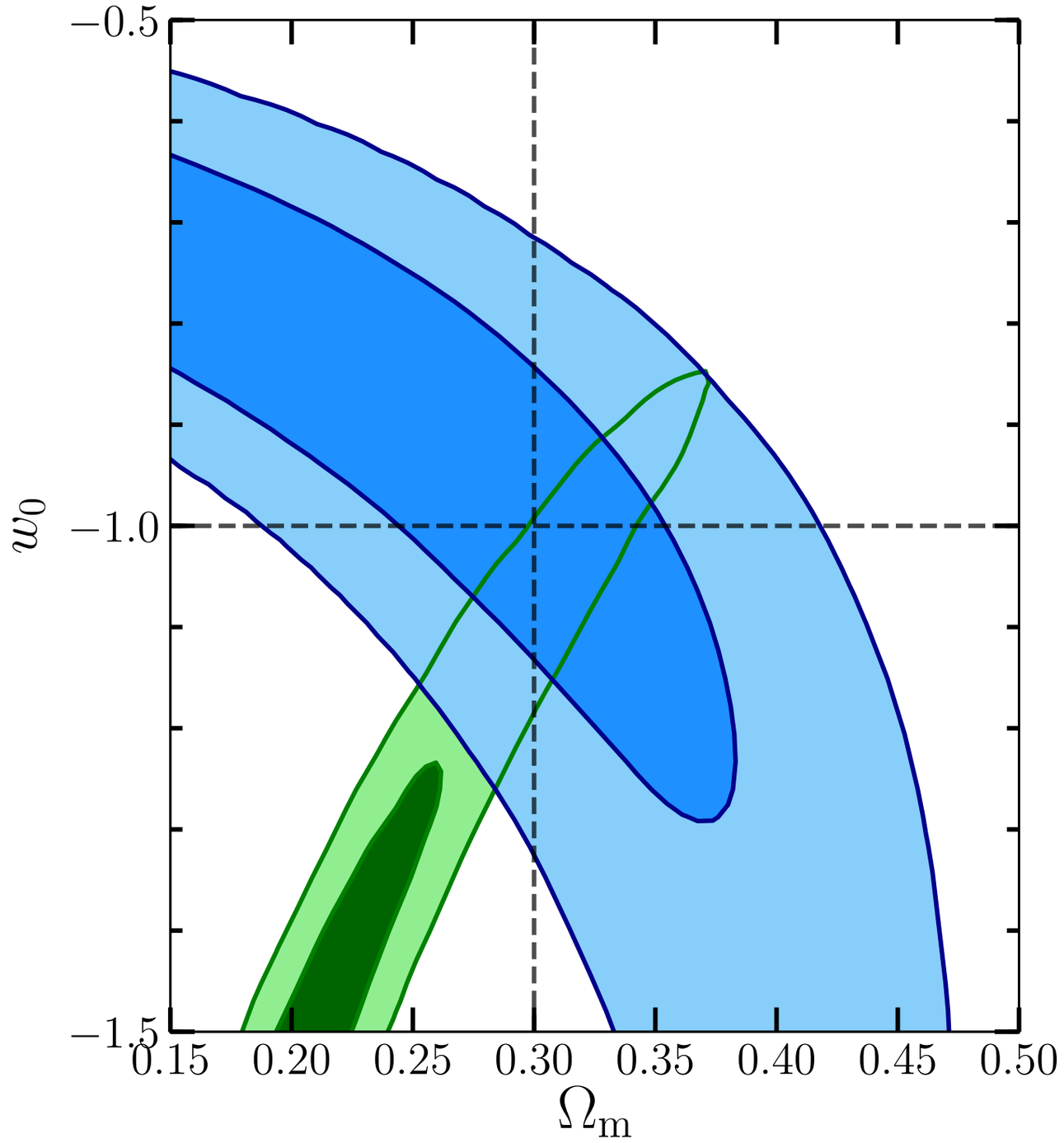


$$\Omega_M = 0.25^{+0.13}_{-0.16}$$

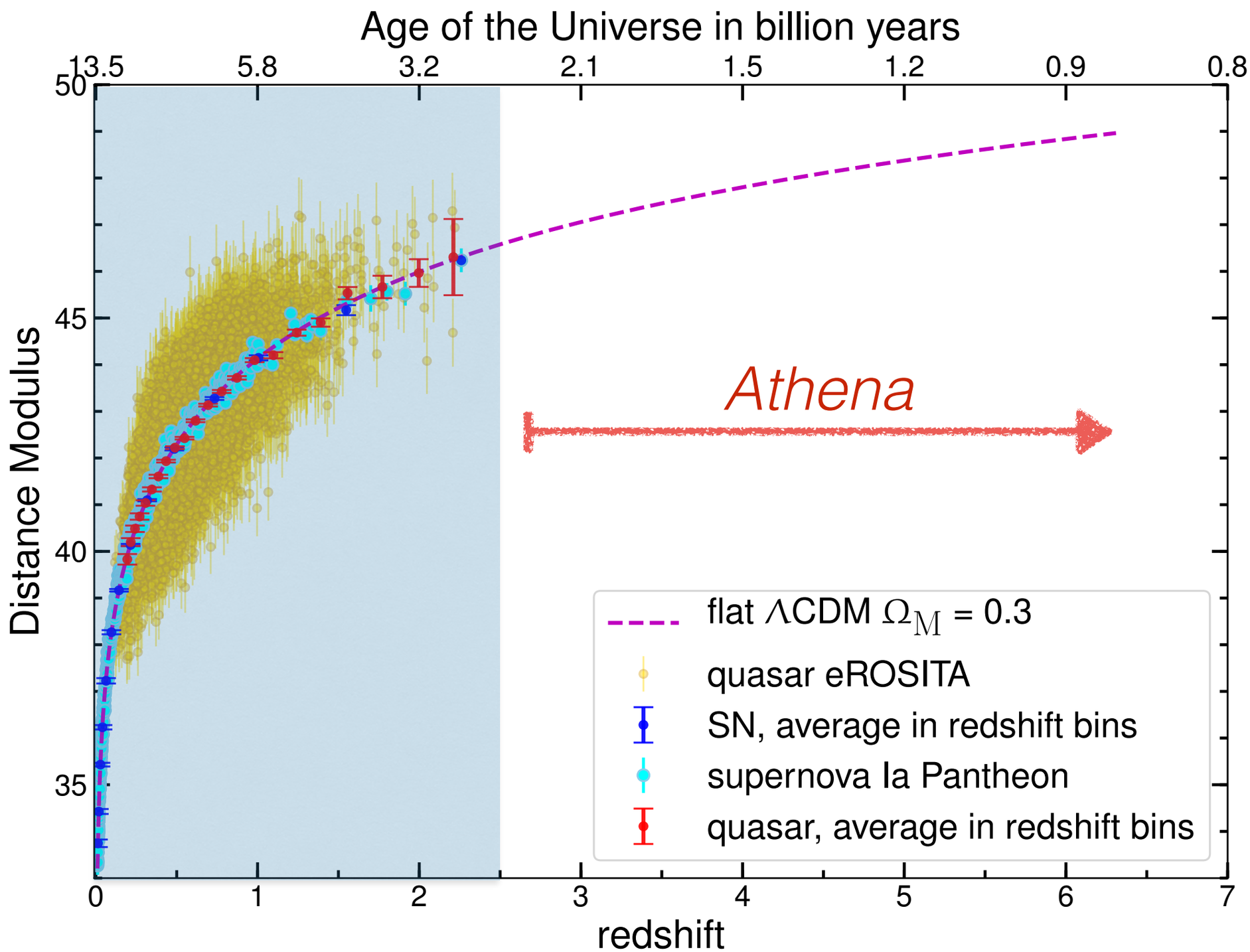
$$w_0 = -0.9^{+0.2}_{-0.4}$$

~9000 quasars
SDSS DR14 coverage
X-ray depth 0.5-2 keV>
4×10^{-14} erg s^{-1} cm^{-2}

$$\left(w_0 = -1.57^{+0.5}_{-0.4}\right)$$

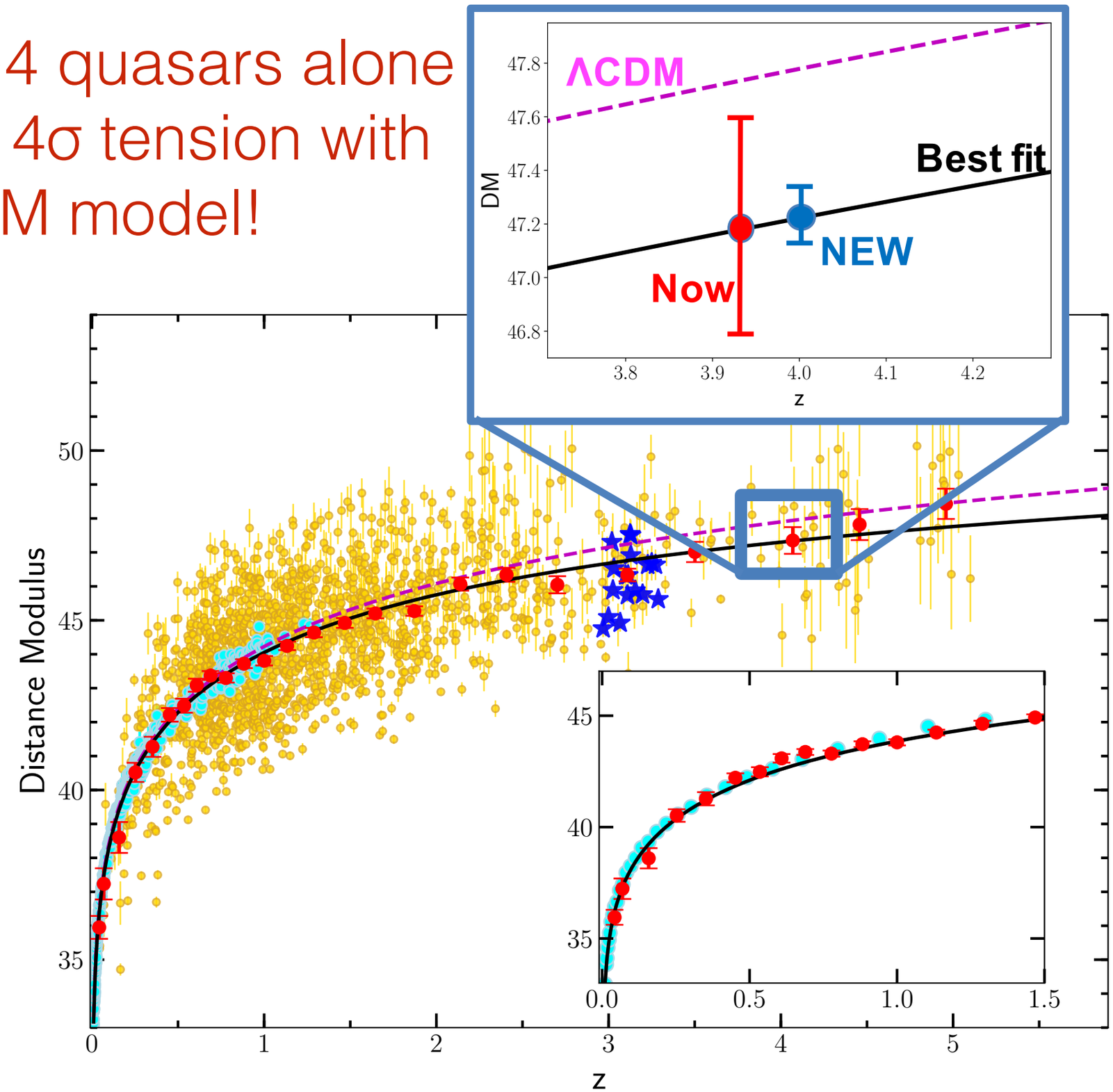
CMB+lensing (Planck+18)

Future (a reality!): eROSITA+*Athena*



Sampling the Hubble diagram at high-*z*
Forthcoming XMM-*Newton AO19: z~4 LP proposal*

The new z~4 quasars alone will have a 4σ tension with ΛCDM model!



To conclude

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. A&A letters).

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. A&A letters).

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.