DISCOVERY OF A 4σ DEVIATION FROM ΛCDM USING THE HUBBLE DIAGRAM OF QUASARS

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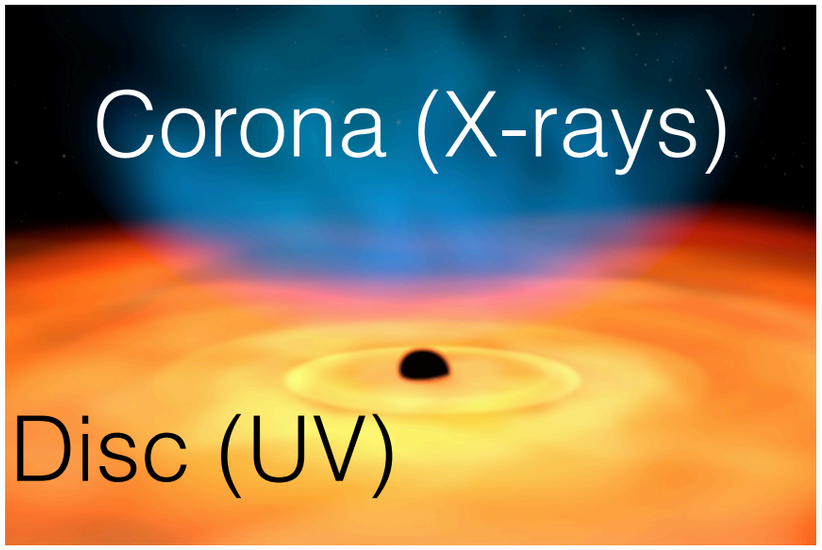
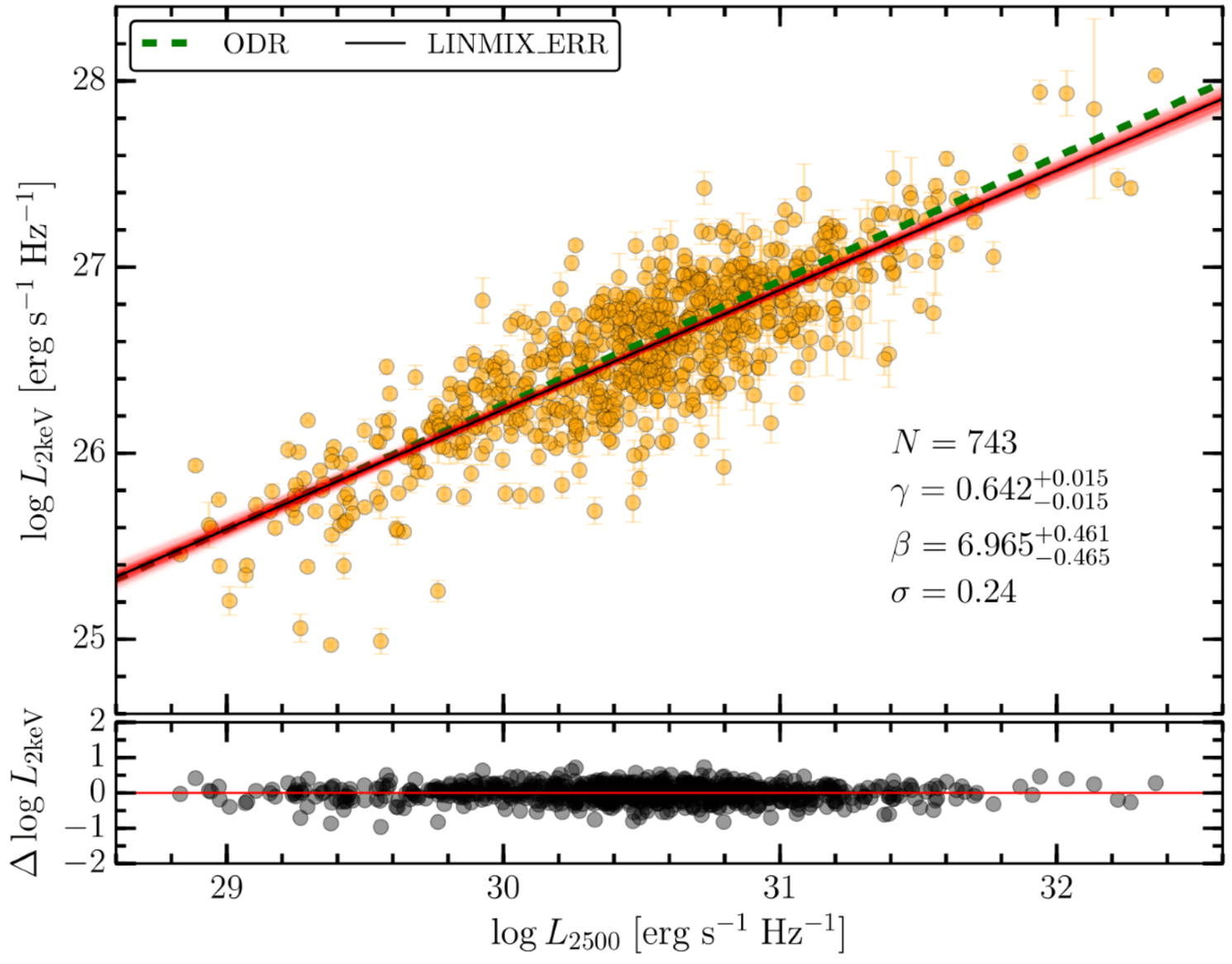
AGN13: *Beauty and the Beast*
Milano, 9-12 October 2018

The (tight) X-ray/UV non-linear relation



Log L_X~0.6 log L_{UV} + 7
σ=0.24 dex!

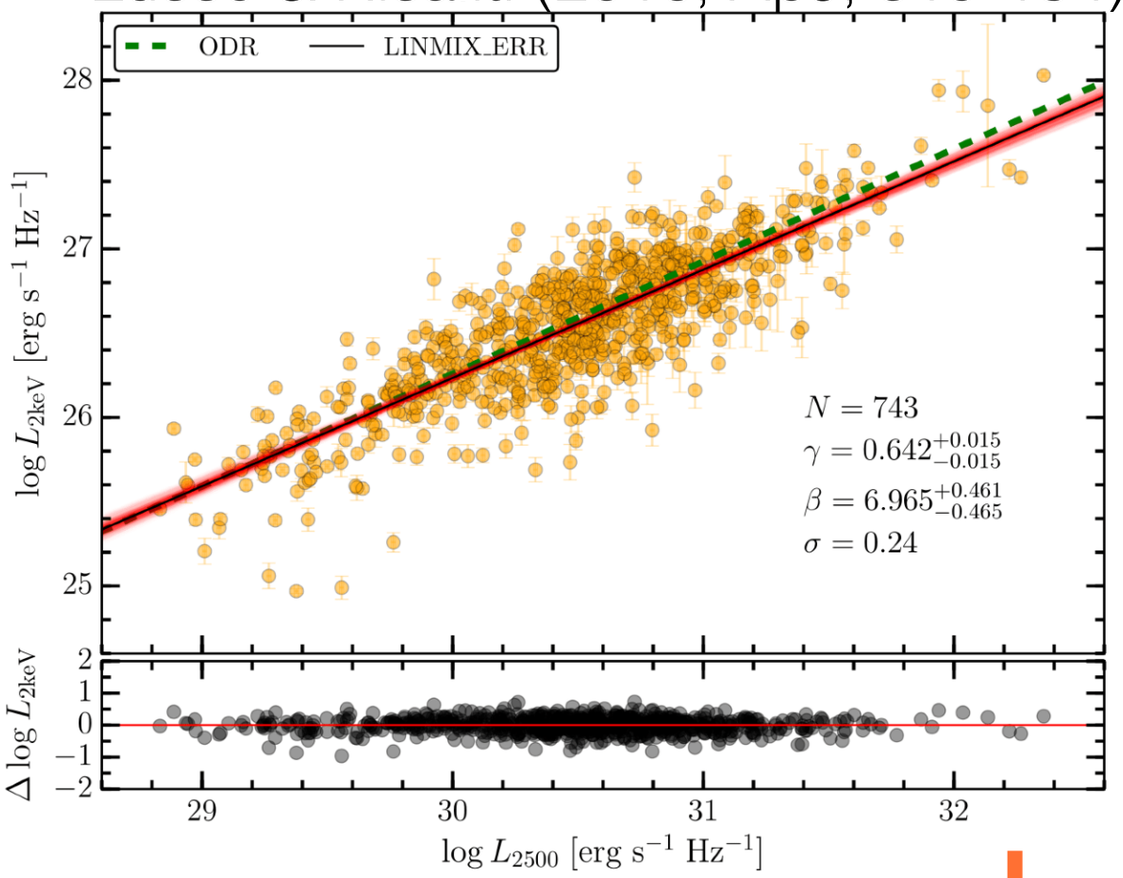
Lusso & Risaliti (2016, ApJ, 819-154)



Cosmology with quasars

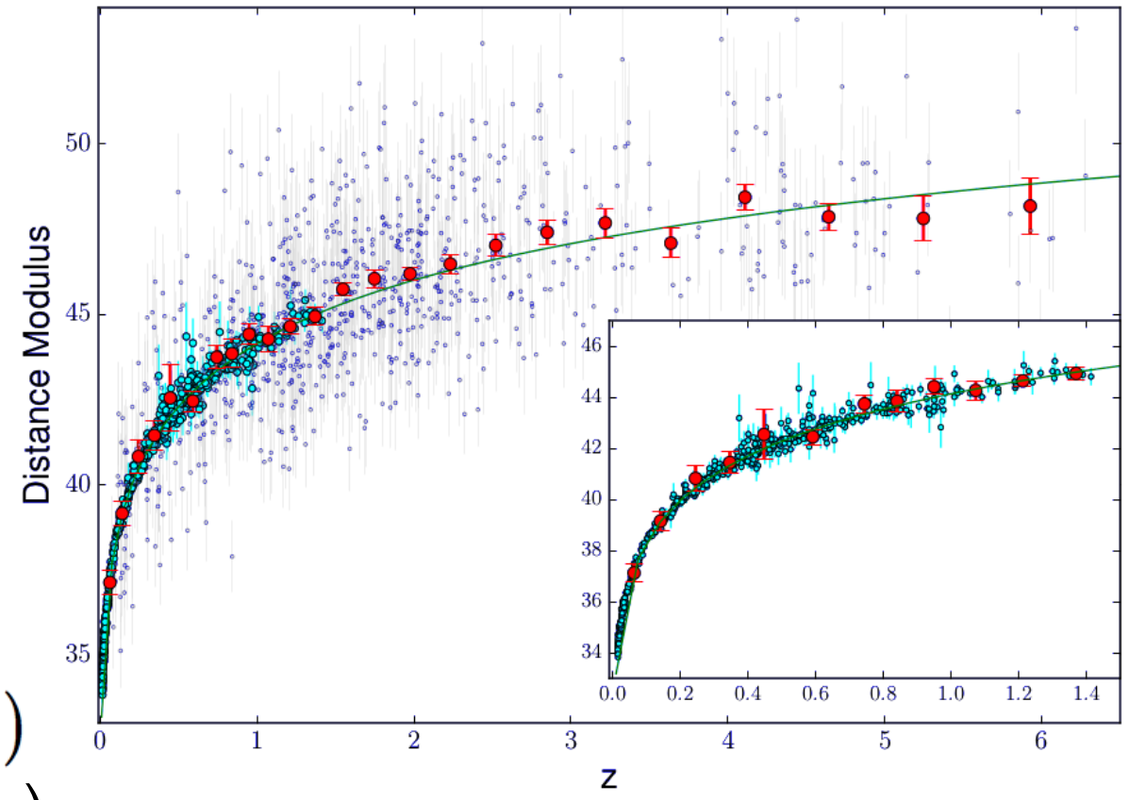
The distance modulus

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

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

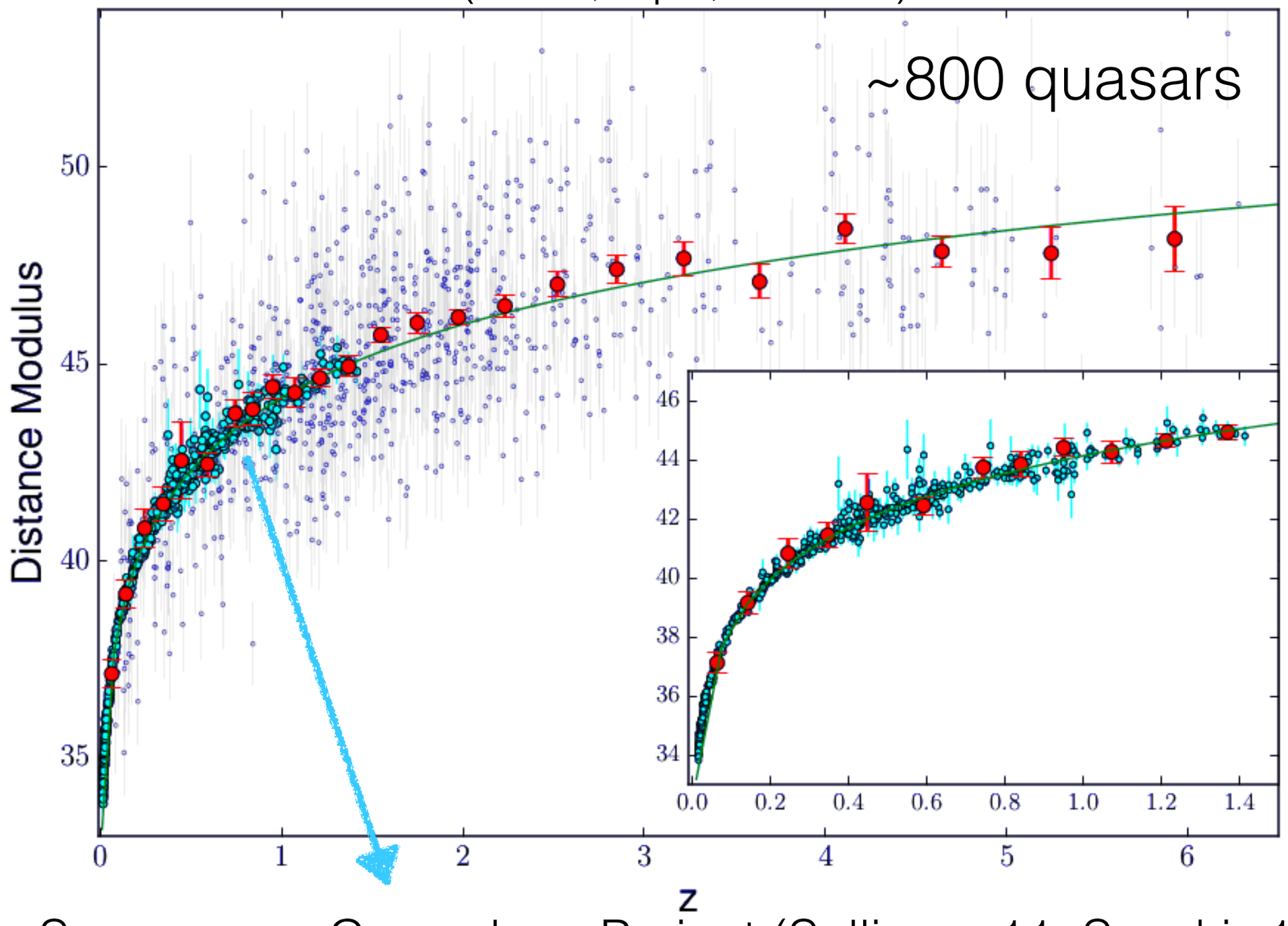
$D_L(z,\Omega_M, \Omega_\Lambda)$

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

Cosmology with quasars

The *Quasars Hubble Diagram*

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



Supernovae Cosmology Project (Sullivan+11, Suzuki+12)

Cosmology with quasars

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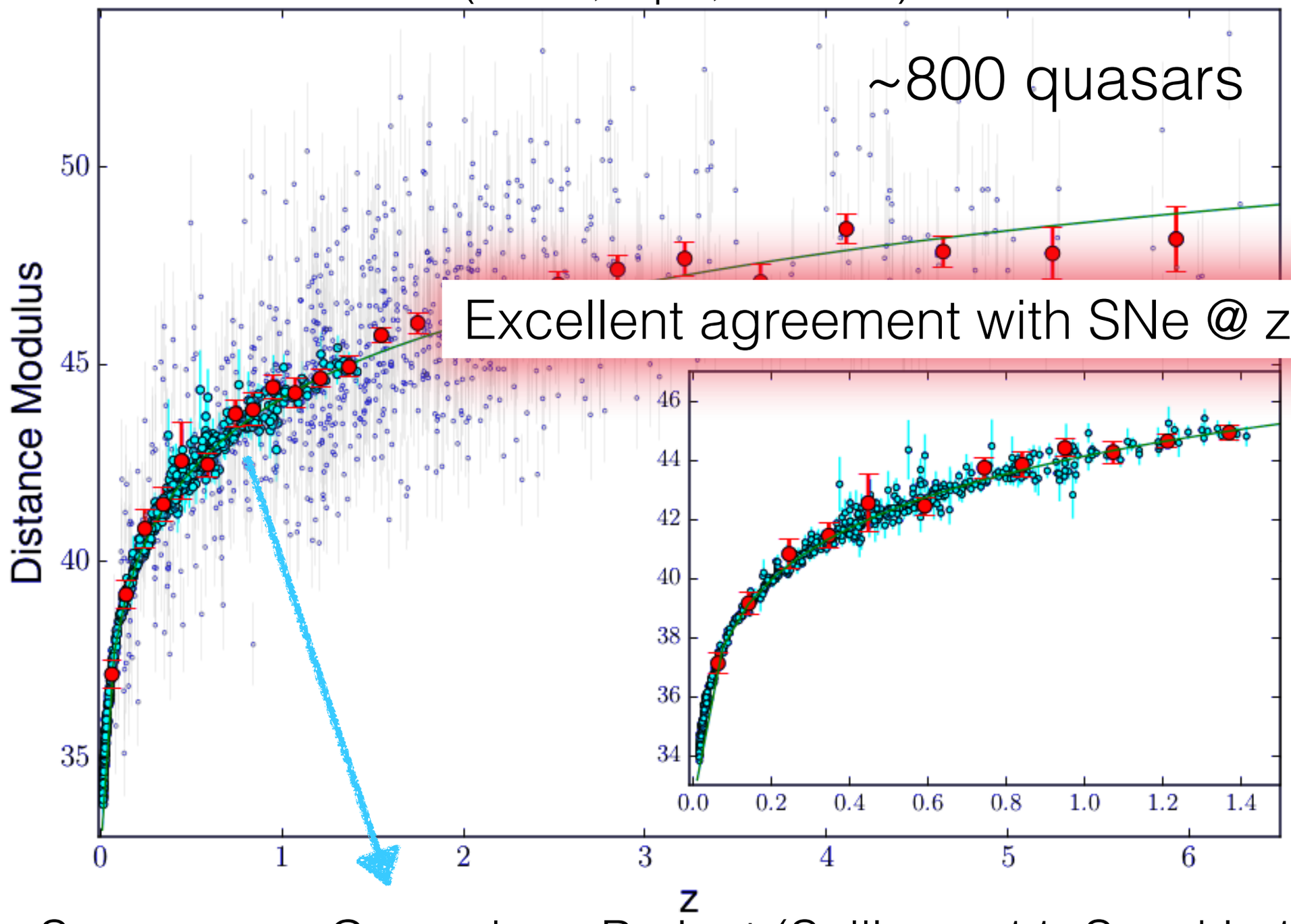

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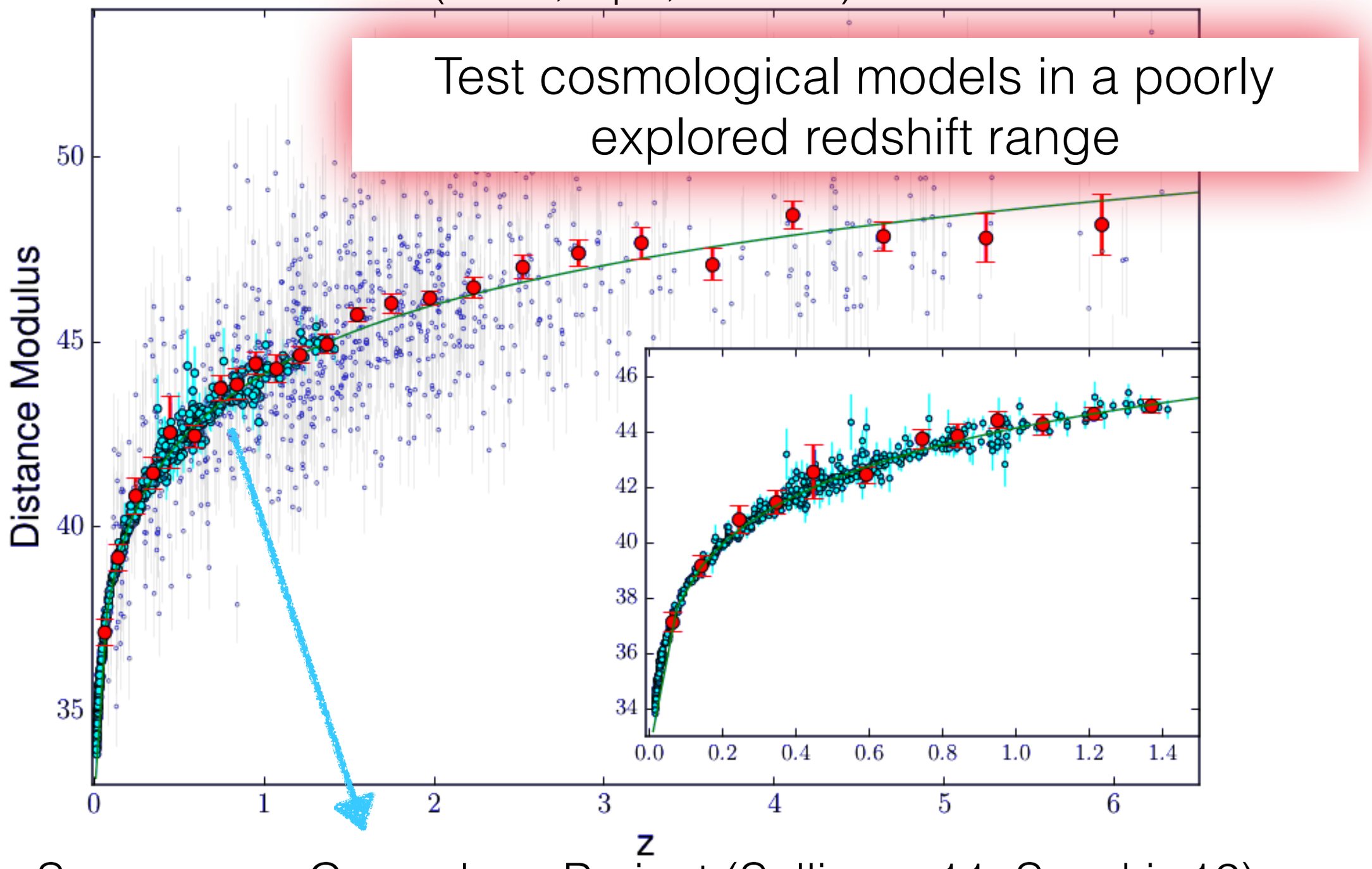


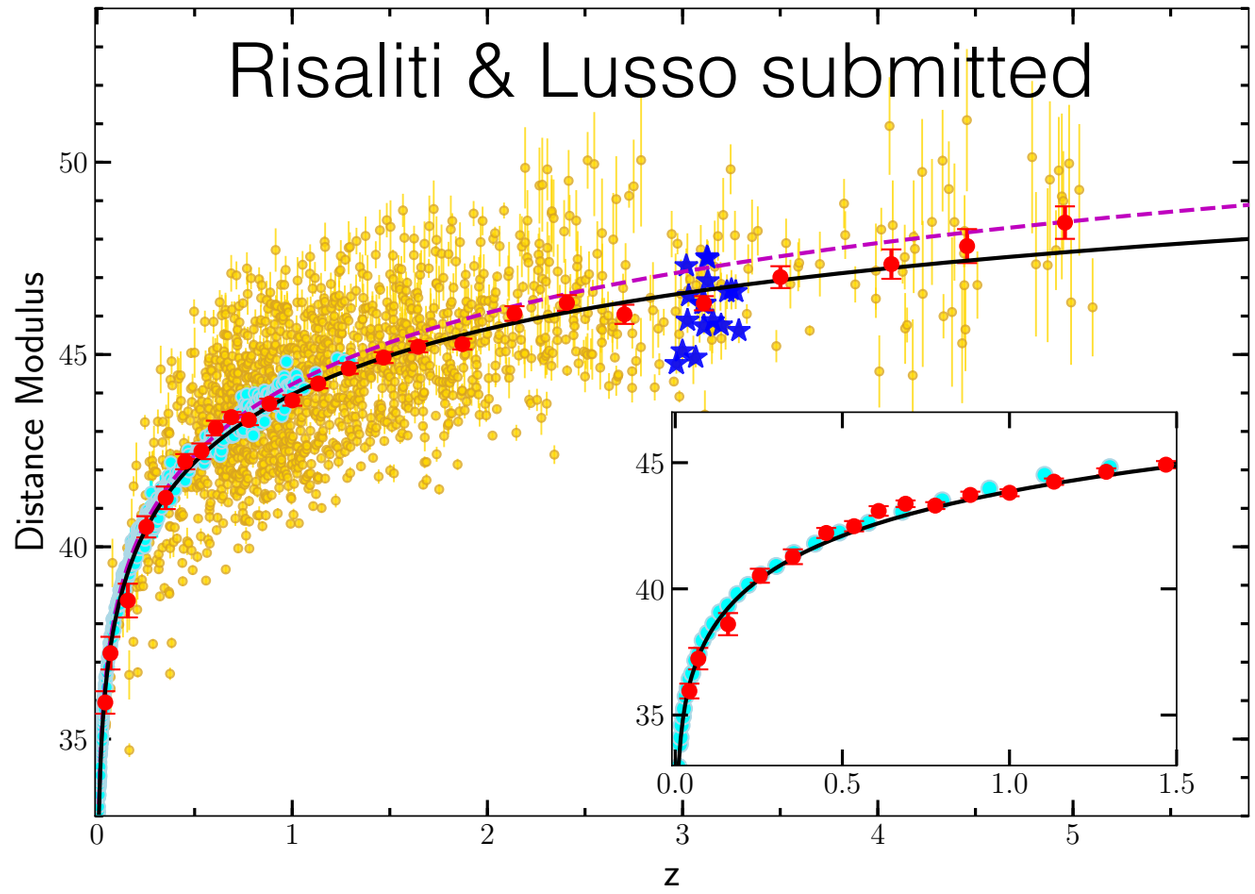
Test cosmological models in a poorly explored redshift range

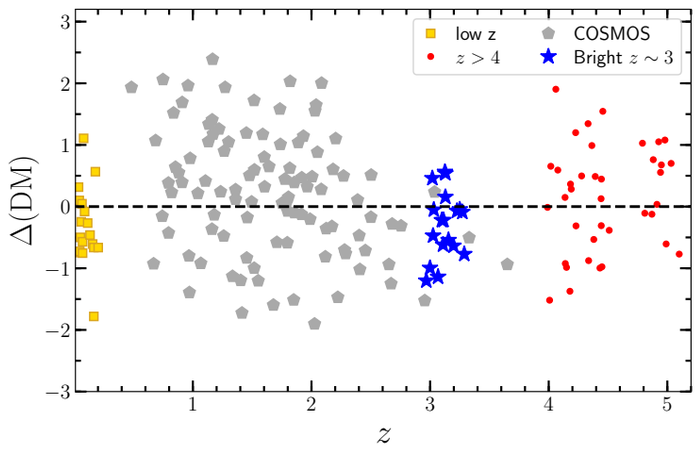
Supernovae Cosmology Project (Sullivan+11, Suzuki+12)

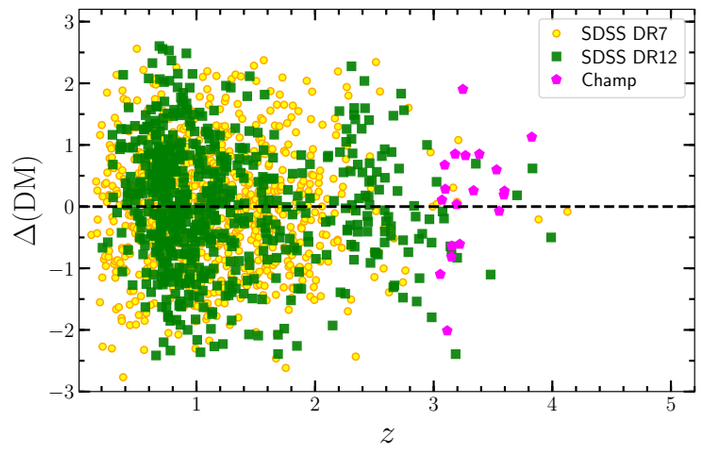
Cosmology with quasars

The new! Quasars Hubble Diagram

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

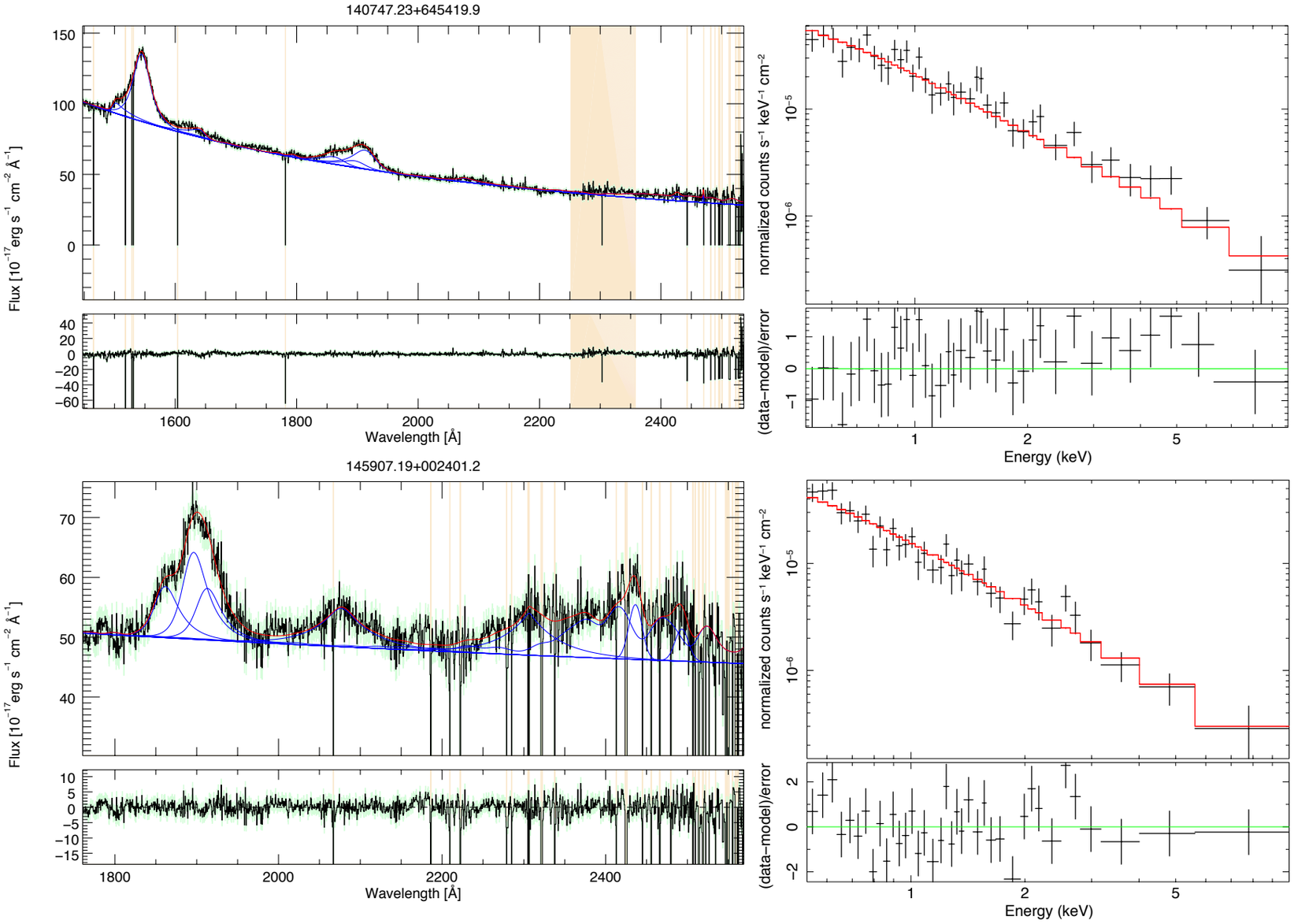






The XMM-Newton program on z~3 quasars

~1Ms AO-16 (co-I, PI: Risaliti): 30 non-jetted SDSS quasars @z=3-3.3 observed for 25-35 ks



Cosmology with quasars

The new! Quasars Hubble Diagram: sample

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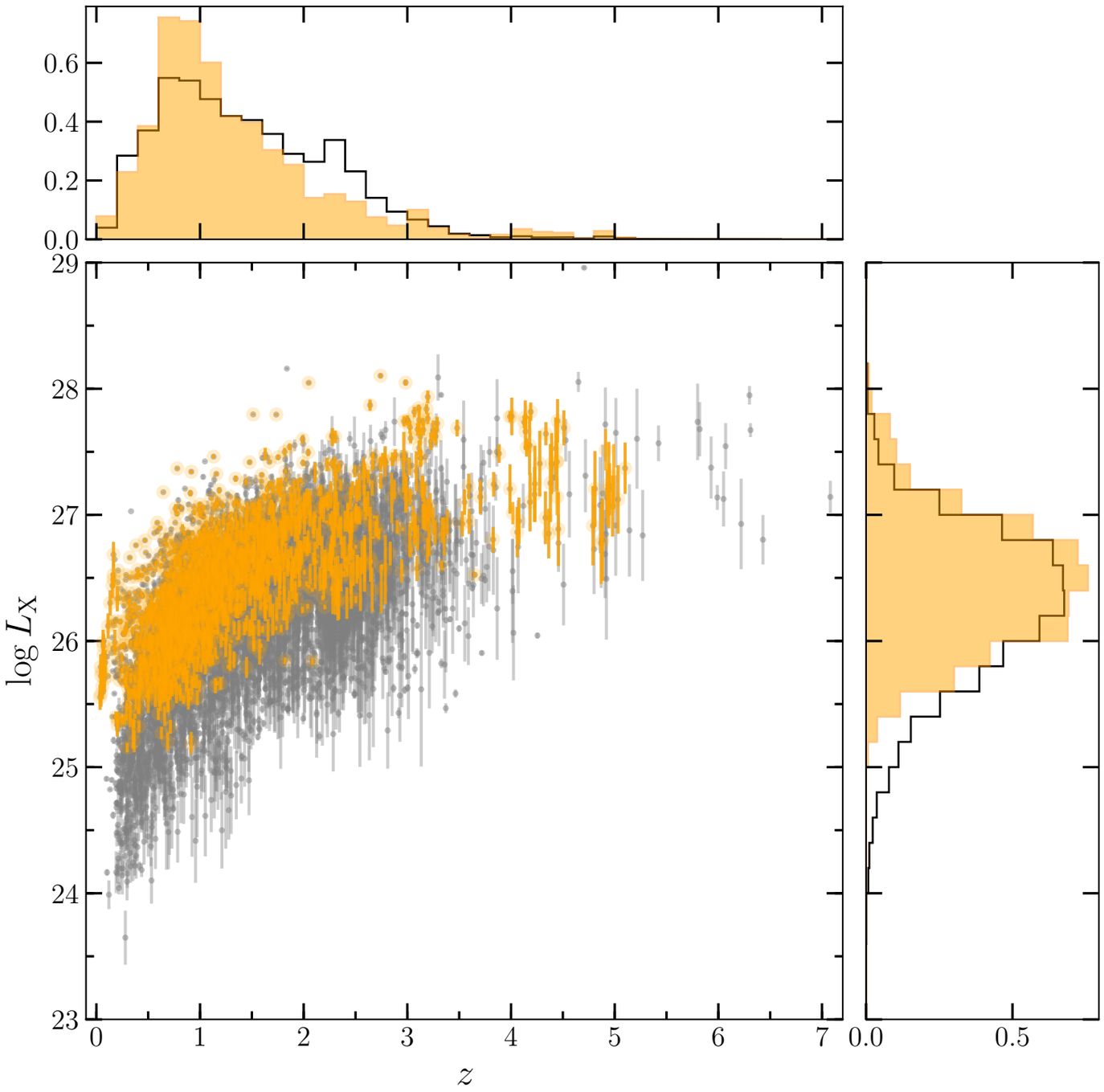
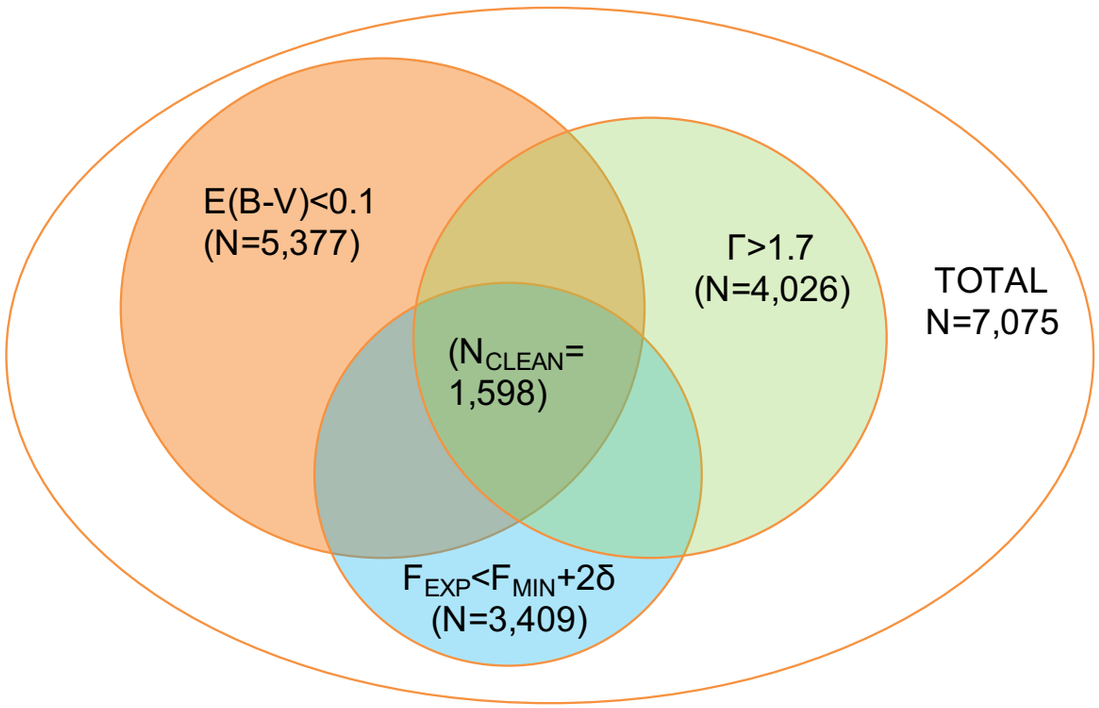
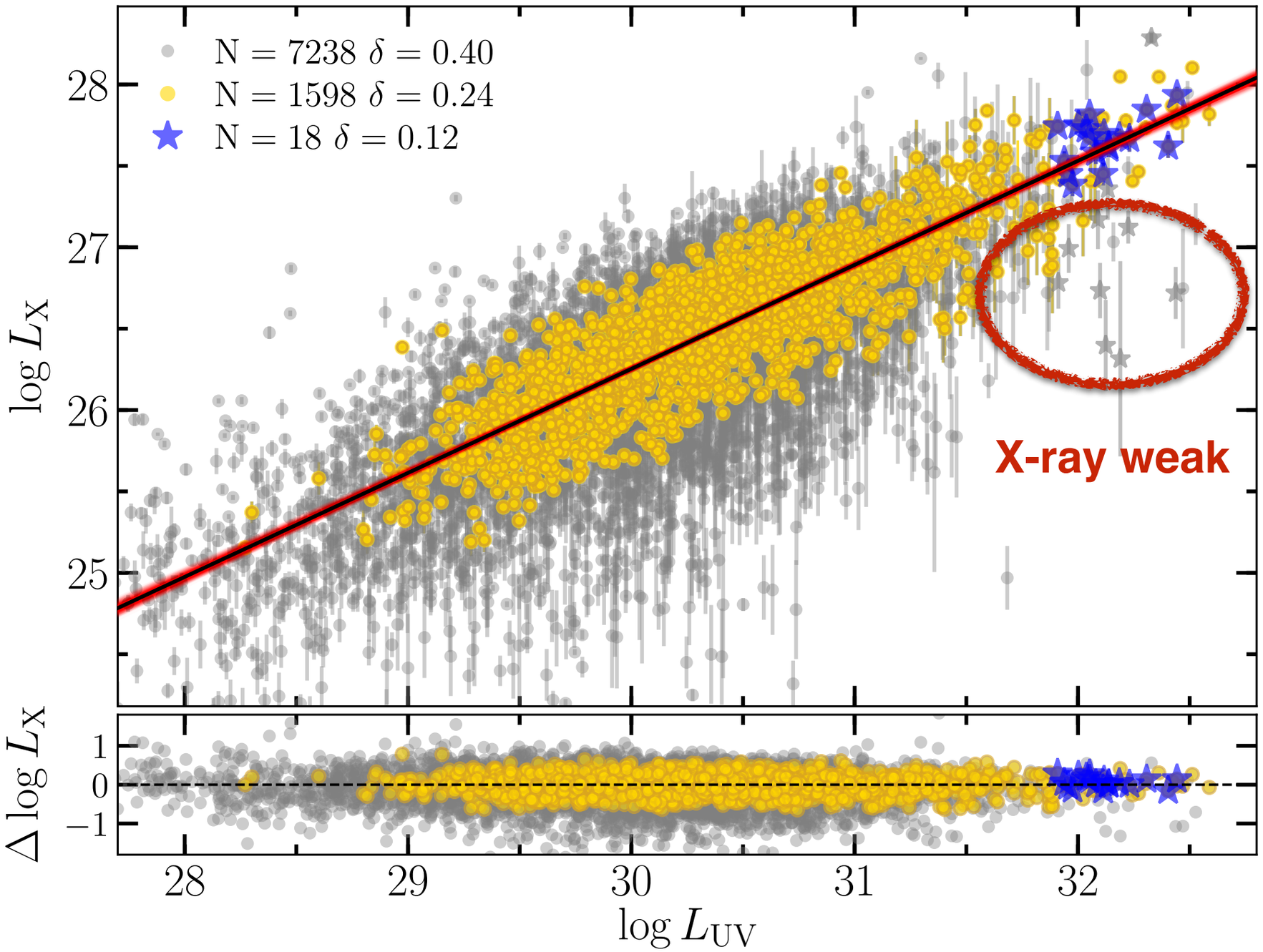




Cosmology with quasars

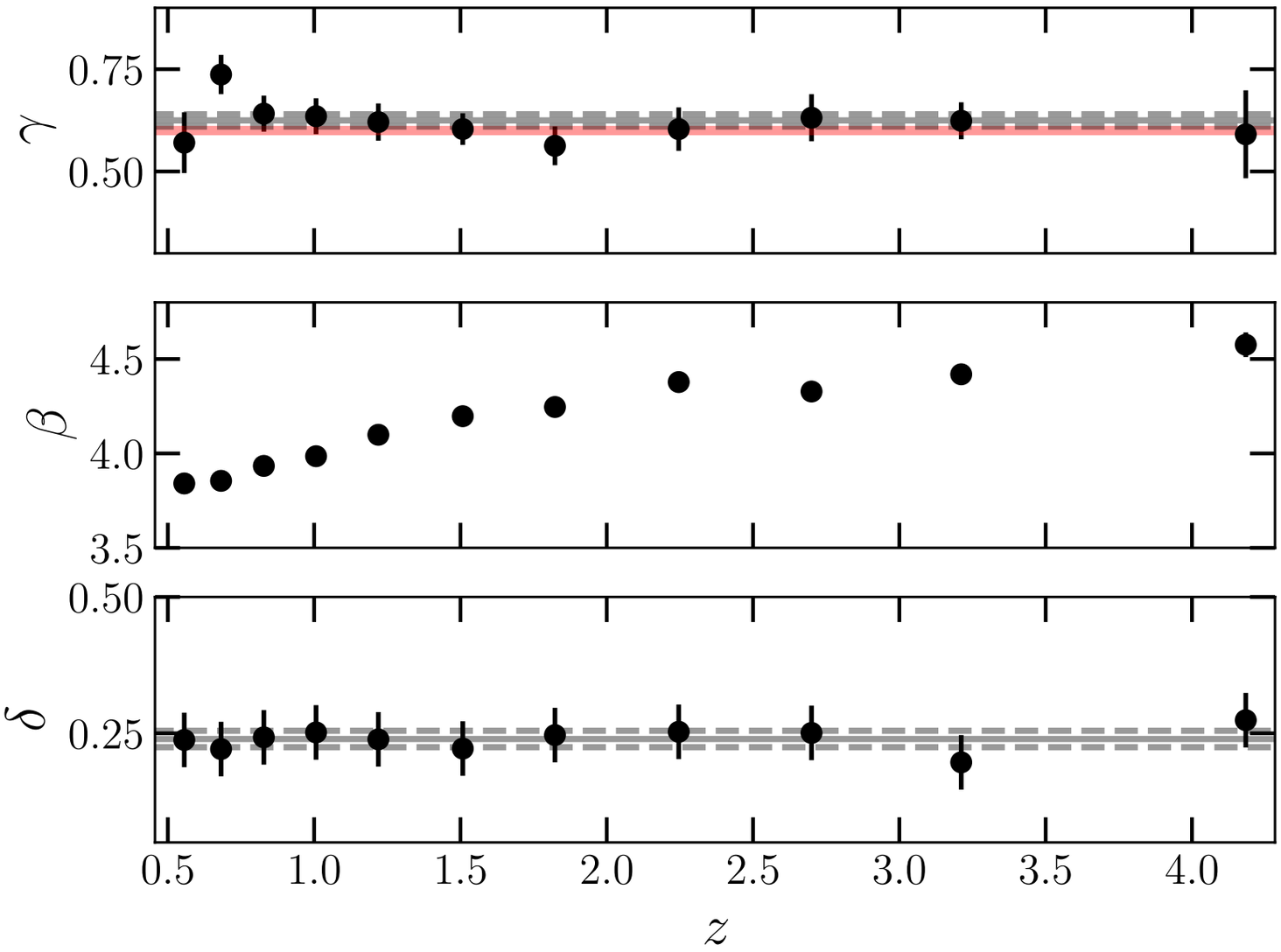
The new! Quasars Hubble Diagram: L_X-L_{UV}



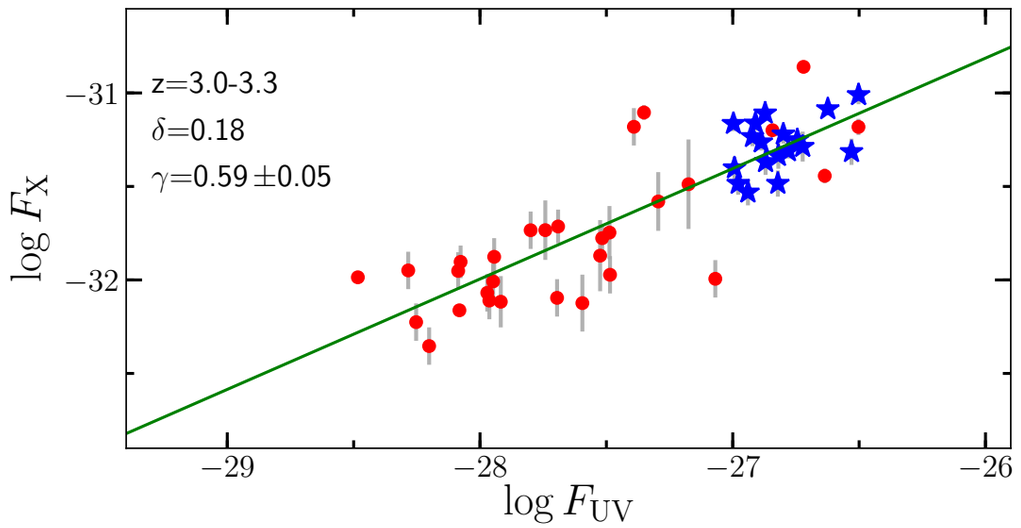
Risaliti & Lusso submitted

Cosmology with quasars

The new! Quasars Hubble Diagram: redshift dependence

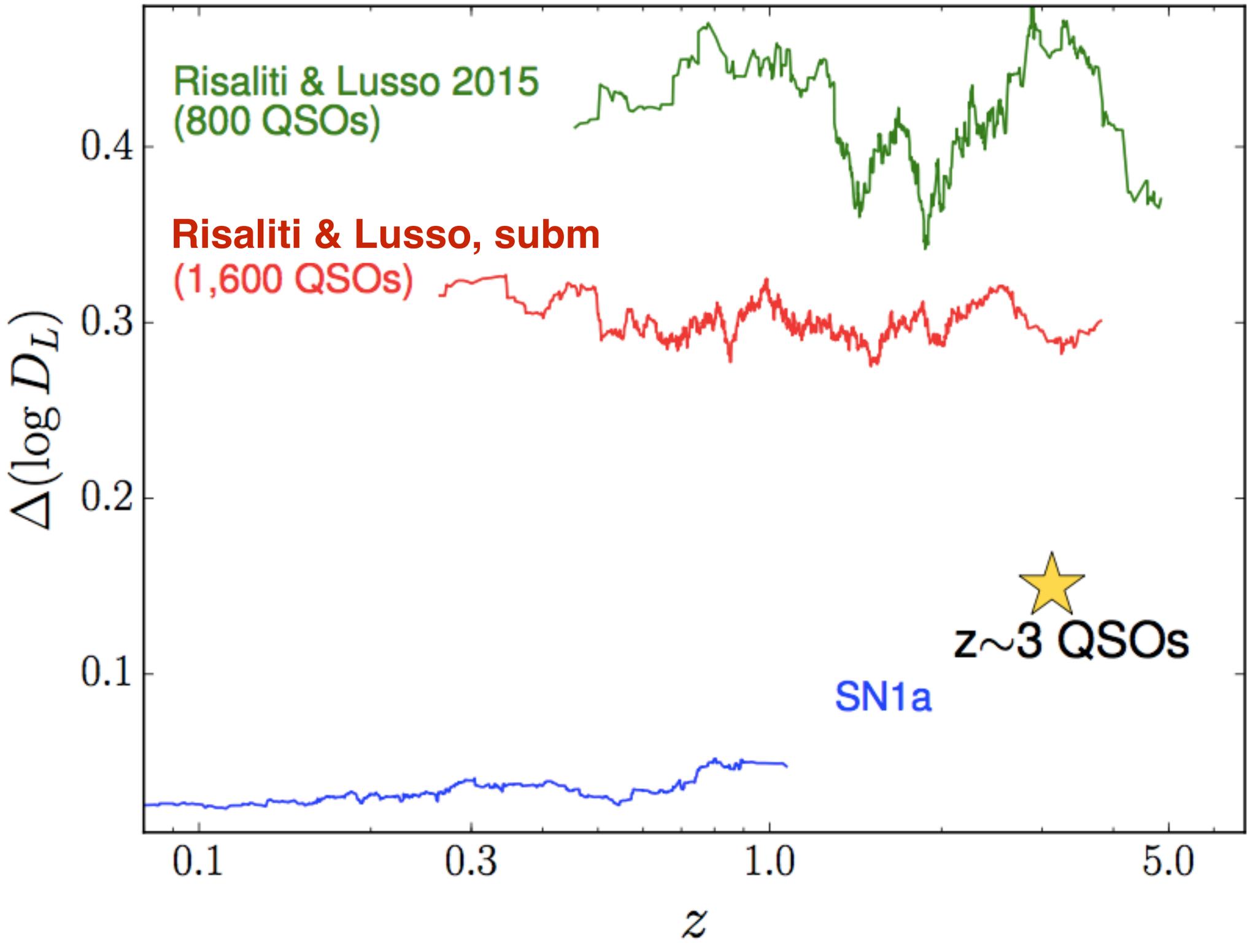


$$\log D_L = \frac{1}{2-2\gamma}(\gamma \log F_{UV} - \log F_X) + \beta.$$



Risaliti & Lusso submitted

Dispersion in the Hubble diagram



Cosmology with quasars

The new! Quasars Hubble Diagram

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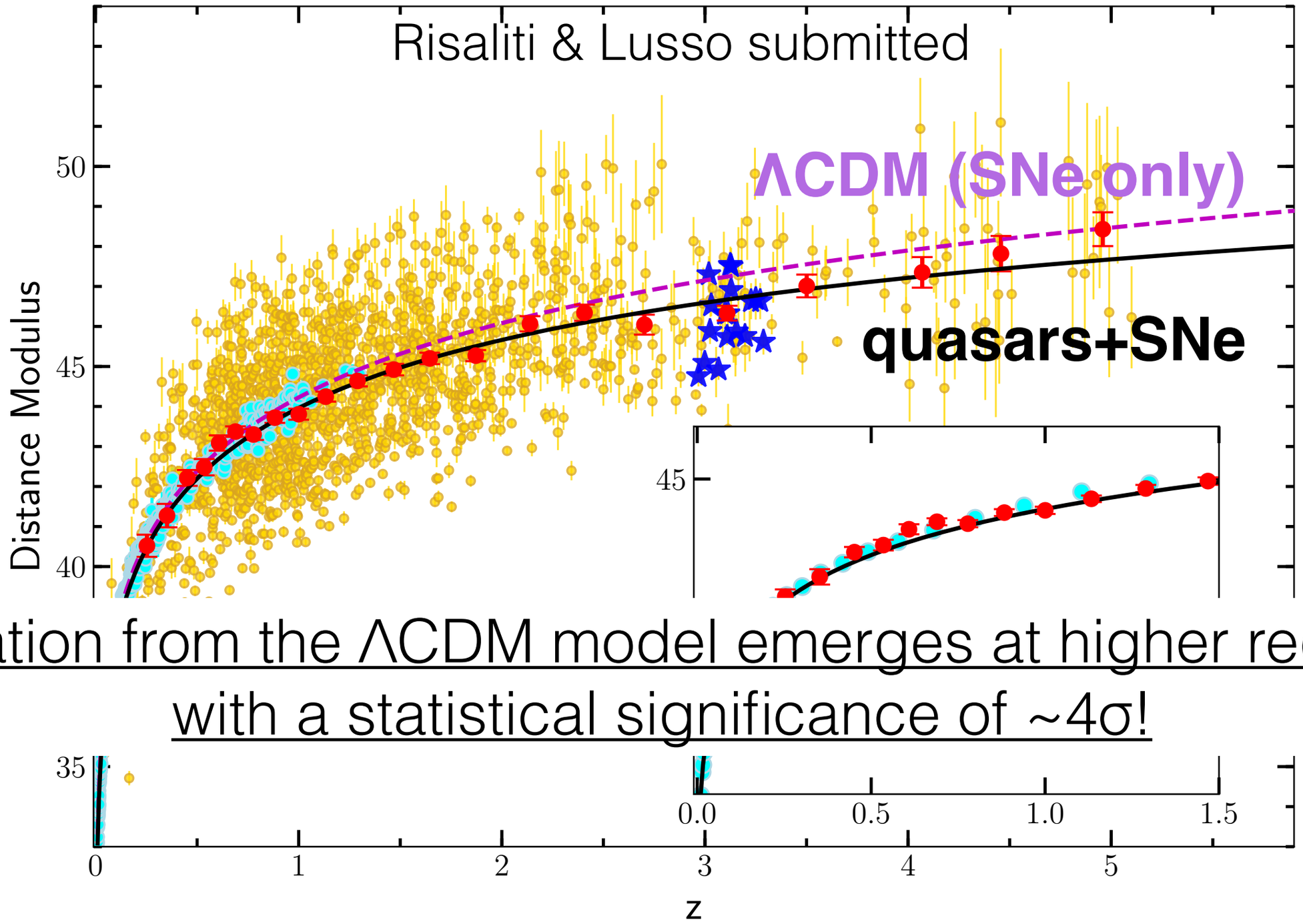
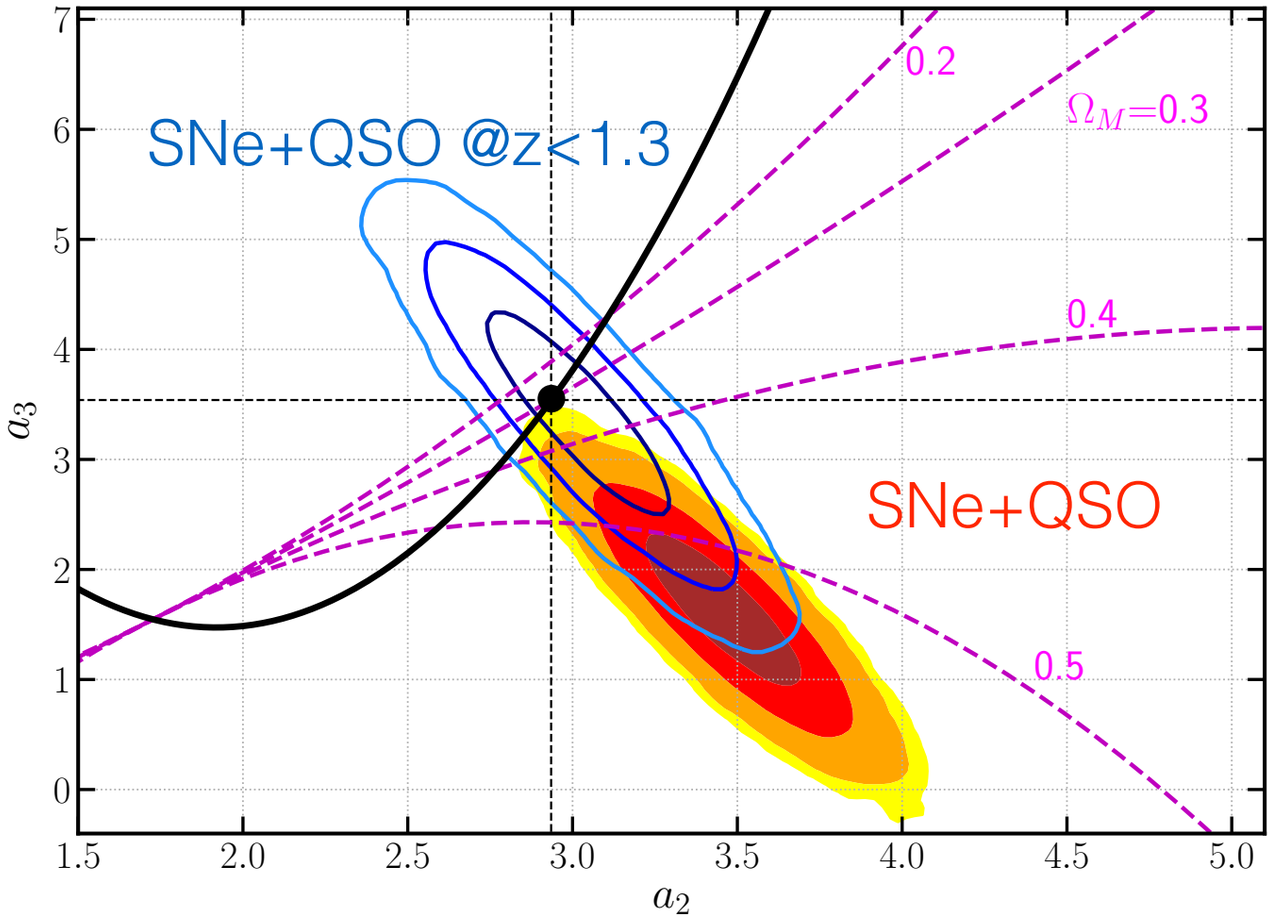


deviation from the ΛCDM model emerges at higher redshift, with a statistical significance of ~4σ!

Cosmology with quasars

The new! Quasars Hubble Diagram

Risaliti & Lusso submitted



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*)

Intersections magenta lines and black curve are the points with *w*=1 (left) and *w*=-1 (right), values of *w* decrease from left to right

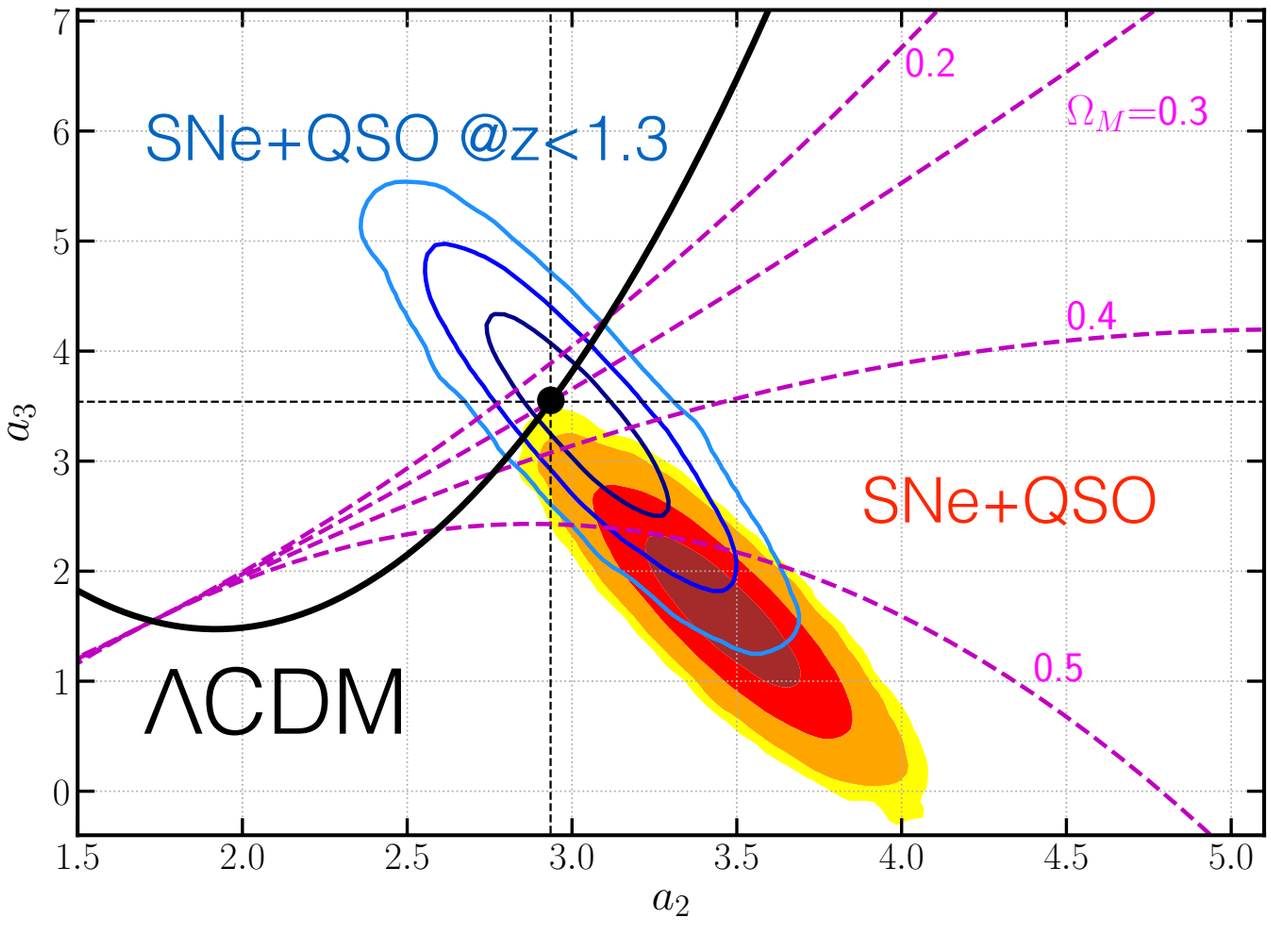
data suggest: **dark energy density increasing with time**.

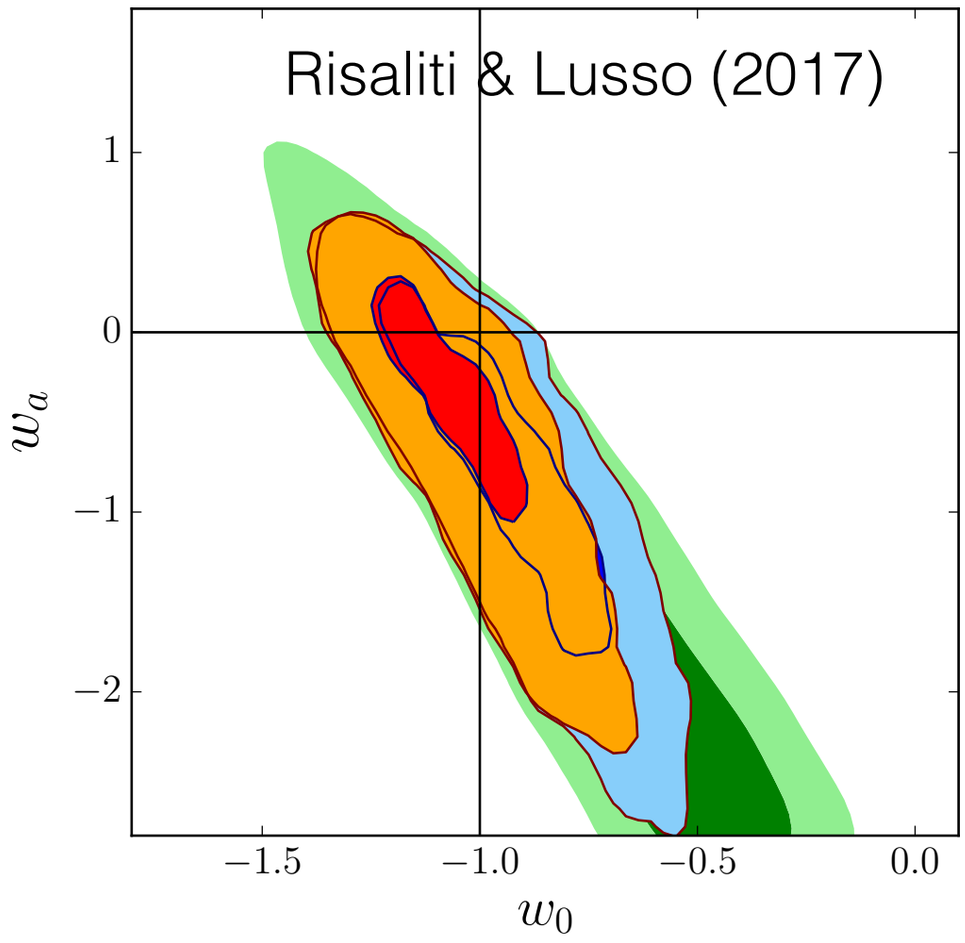
Within the *w*CDM model: Ω_M>0.3 and *w*<-1.3

Cosmology with quasars

The new! Quasars Hubble Diagram

w_0-w_a plane where $w(z)=w_0+w_a{*}z/(1+z)$, w=-1 no evolution data suggest: **dark energy density increasing with time**. Within the wCDM model: $\Omega_M>0.3$ and $w<-1.3$





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Cosmology with quasars

The new! Quasars Hubble Diagram

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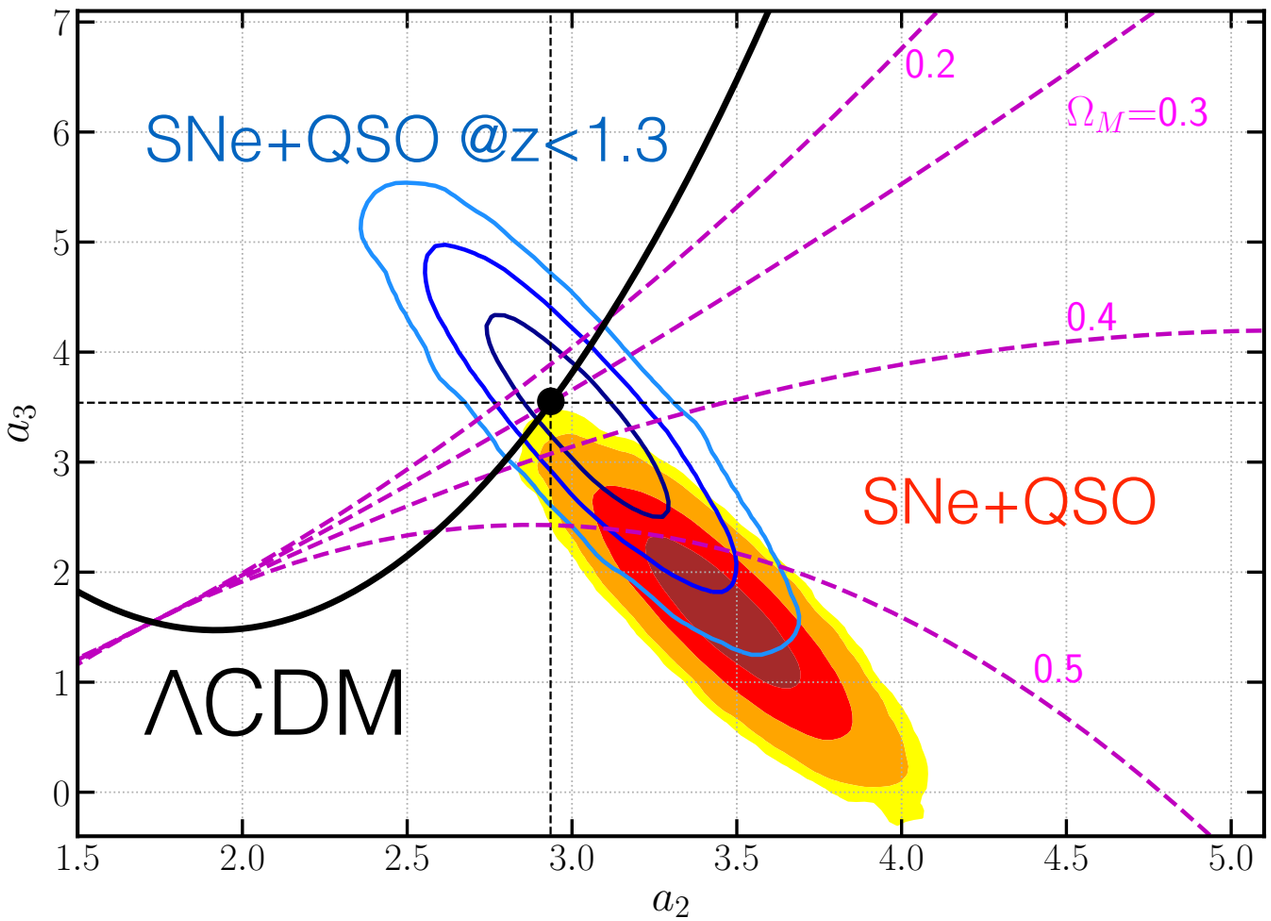
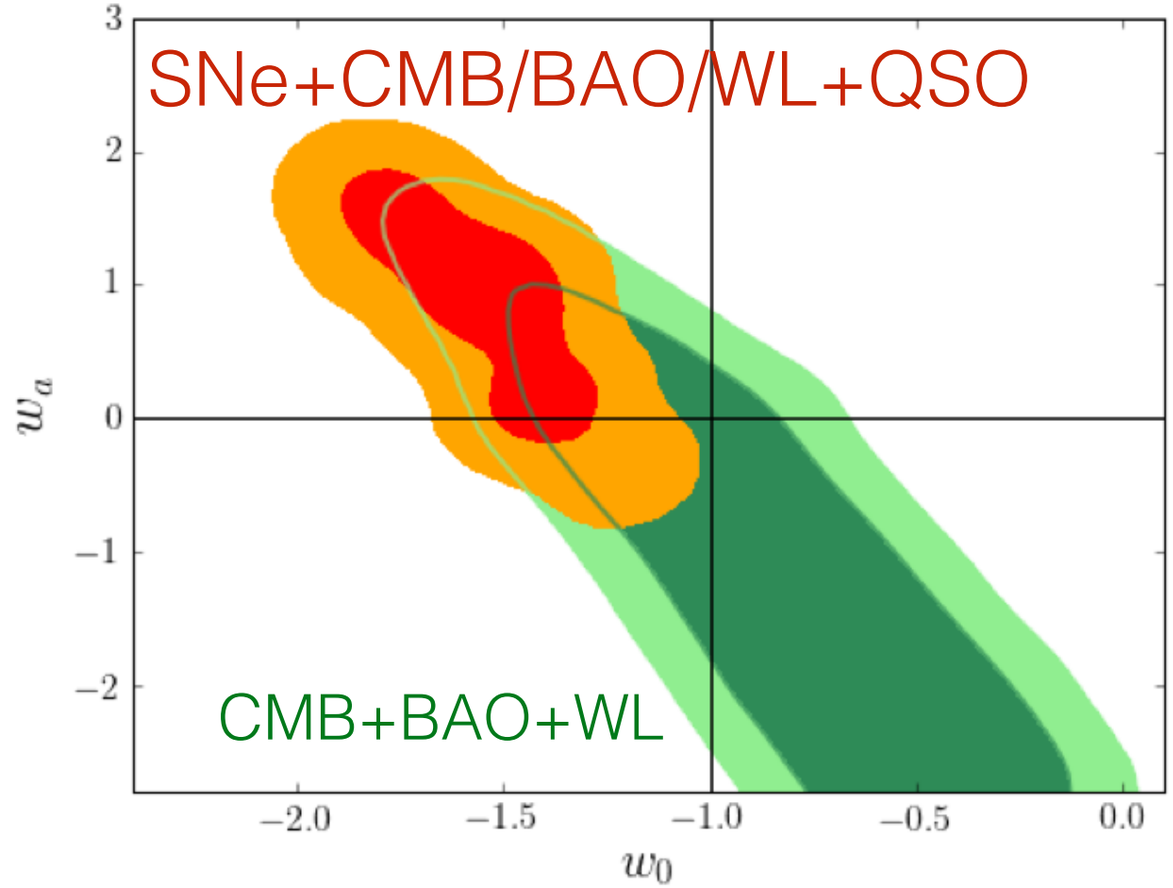
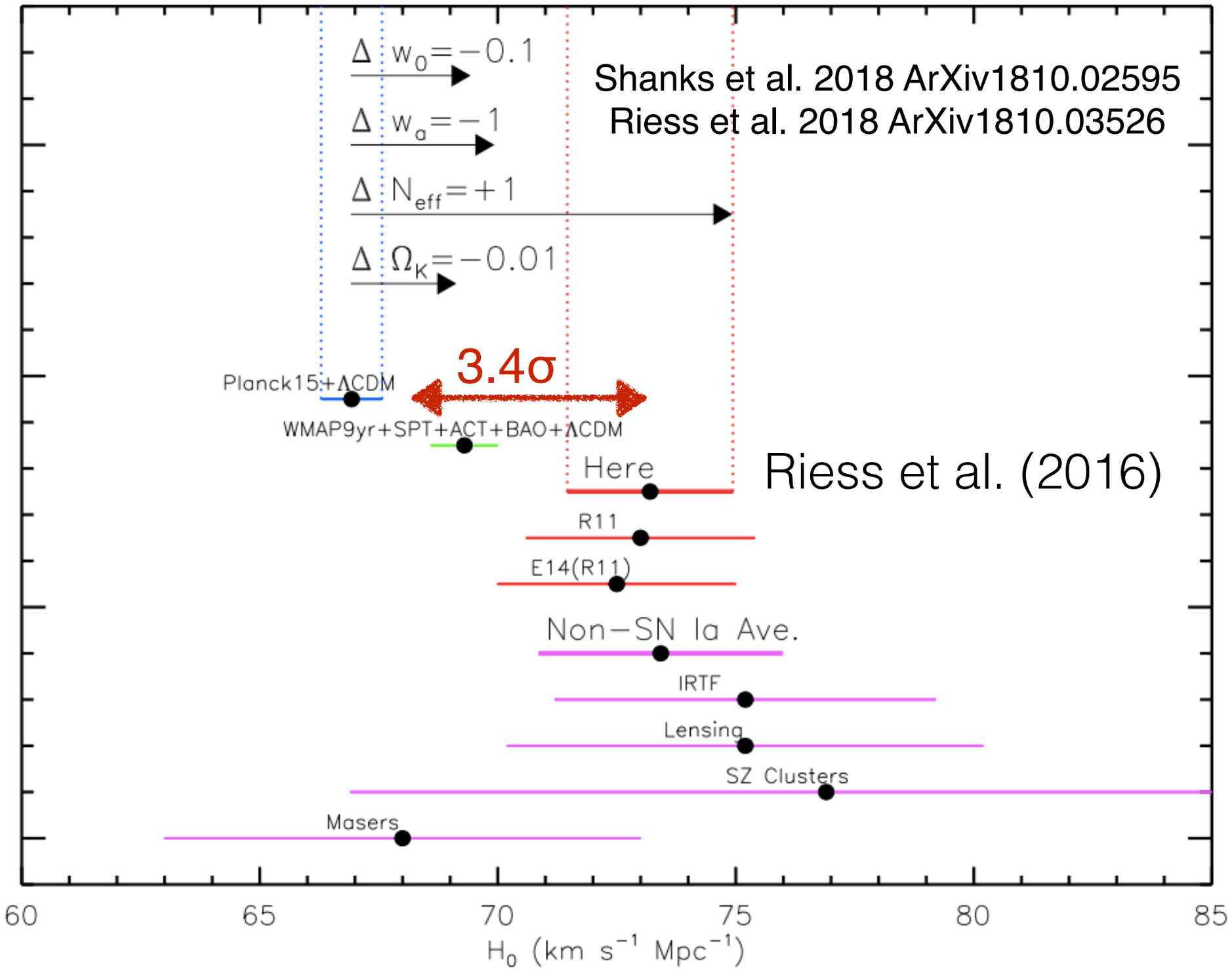




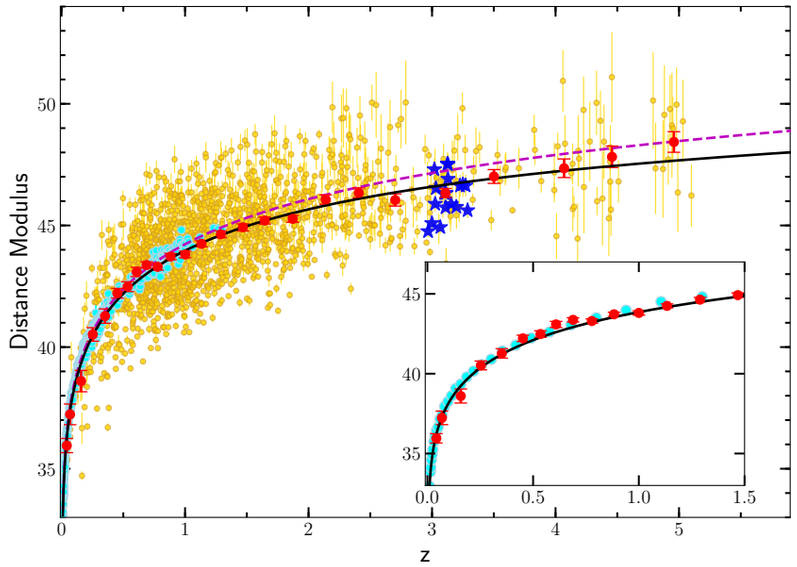
Risaliti & Lusso submitted

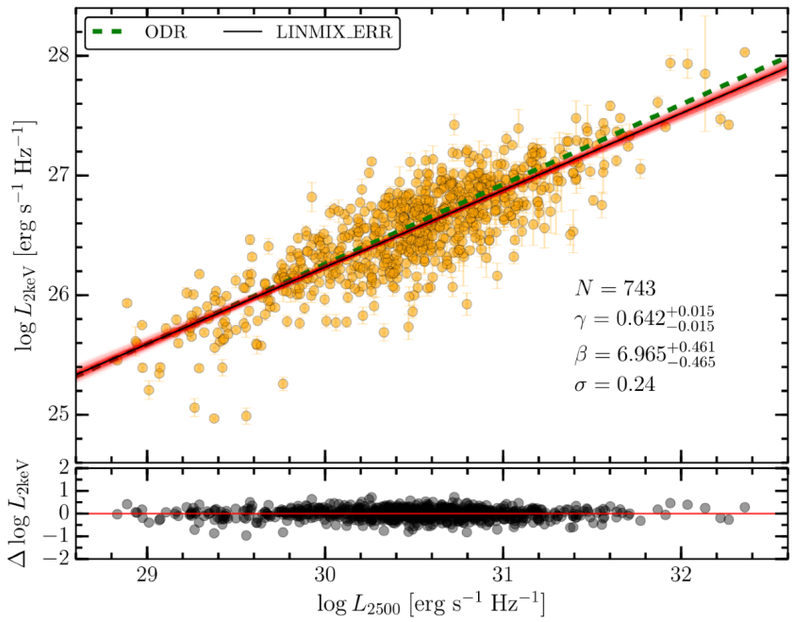
Do we need an extension to the ΛCDM? Yes, we do!



To summarise

New branch of Observational Cosmology using
Quasars are standard candles
Measure the Dark Matter & Energy content in the Cosmos
Deviation from the ΛCDM model at high redshift, with a statistical significance of ~4σ





Lusso & Risaliti (2016, ApJ, 819-154)
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Risaliti & Lusso (2017, AN, 201713351)
Lusso & Risaliti (2017, A&A, 602, 79)