Building the high-redshift Hubble Diagram with Quasars

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Cosmoverse @ Lisbon

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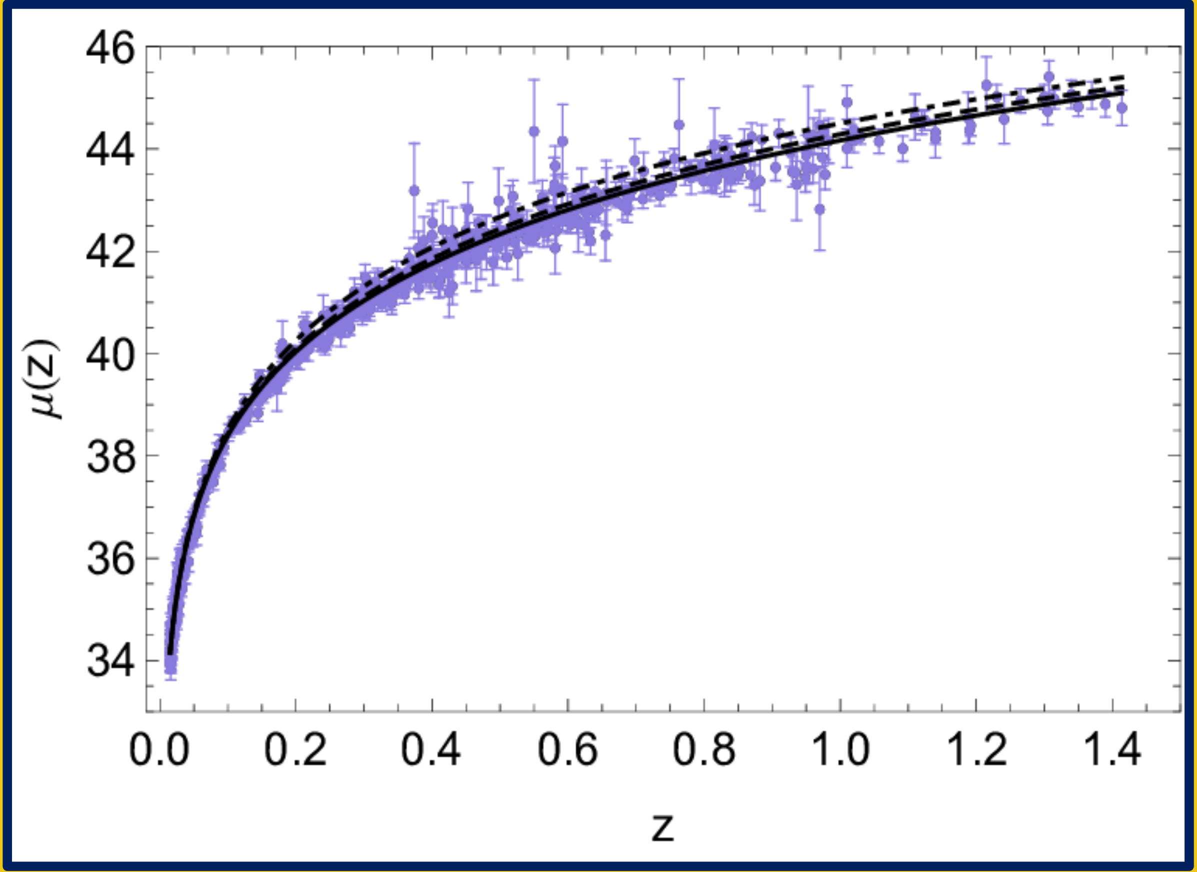
Giada Bargiacchi

Andrea Sacchi

Bartolomeo Trefoloni

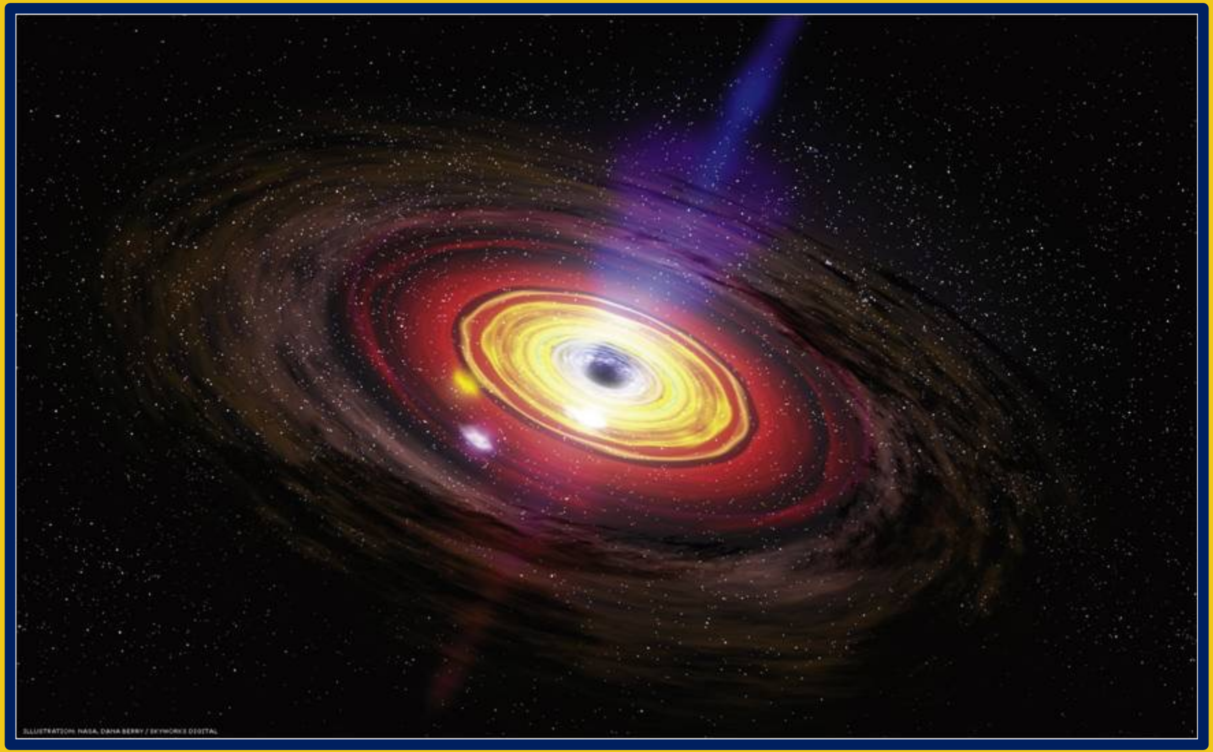
Hubble Diagram

Montiel+14 - SNIa



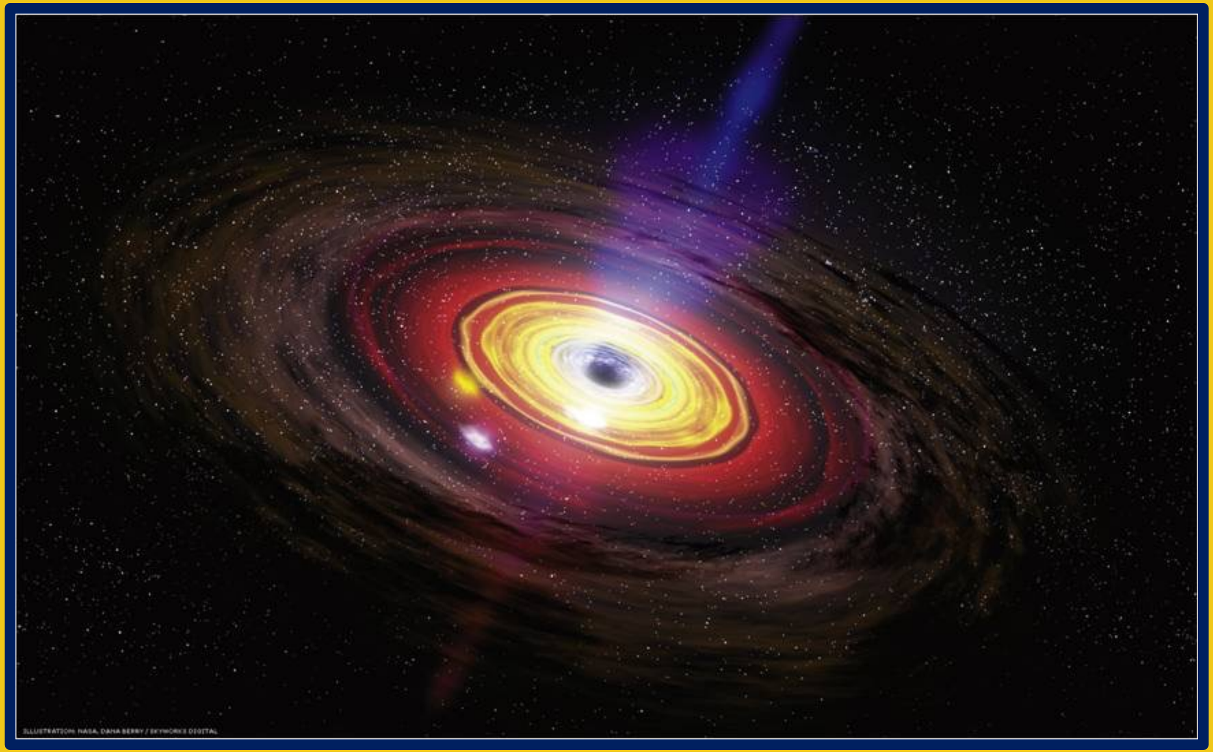
- Test cosmological models
- Constrain parameters given a model

Quasars as Standard Candles



- Numerous
- Observed at redshift z ~0-8 (Universe age < 1 Gyr)

Quasars as Standard Candles

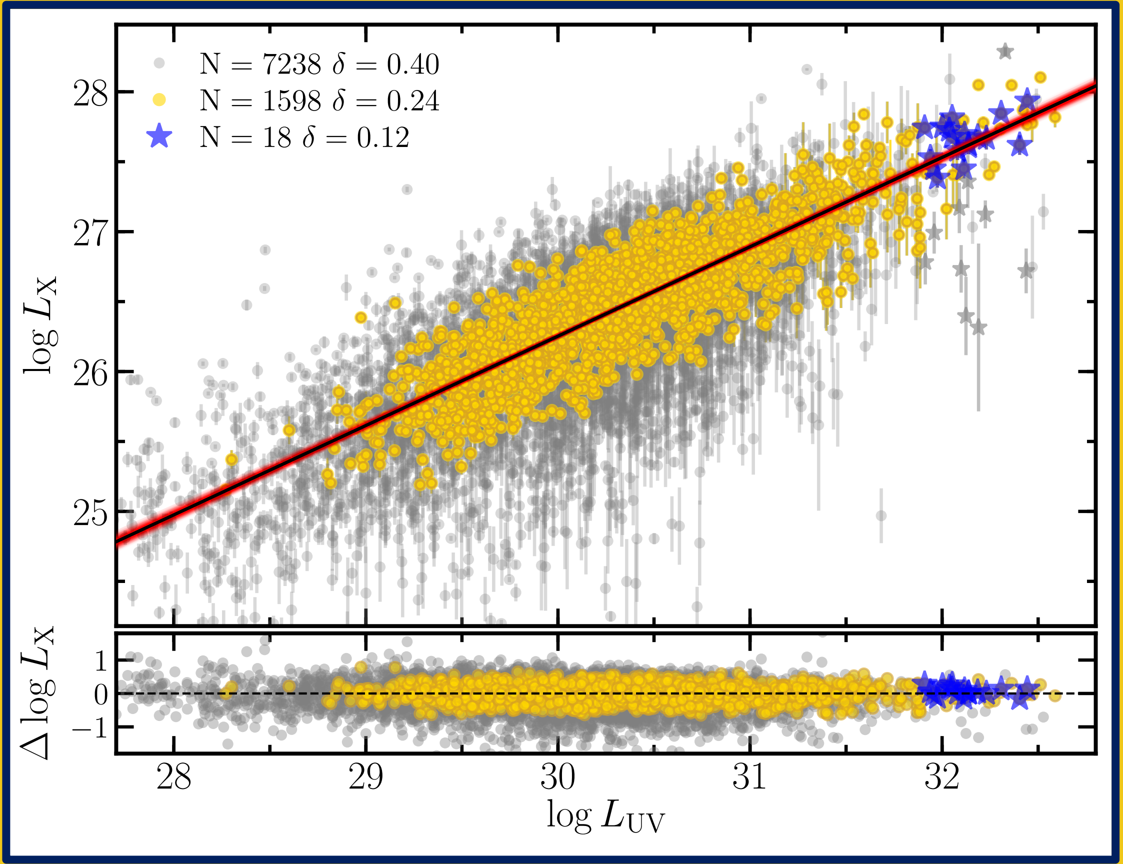


- Numerous
- Observed at redshift z ~0-8 (Universe age < 1 Gyr)

- Not standard! ($L_{bol} \sim 10^{11}$ - $10^{14} L_{\odot}$)

Quasars as Standard Candles

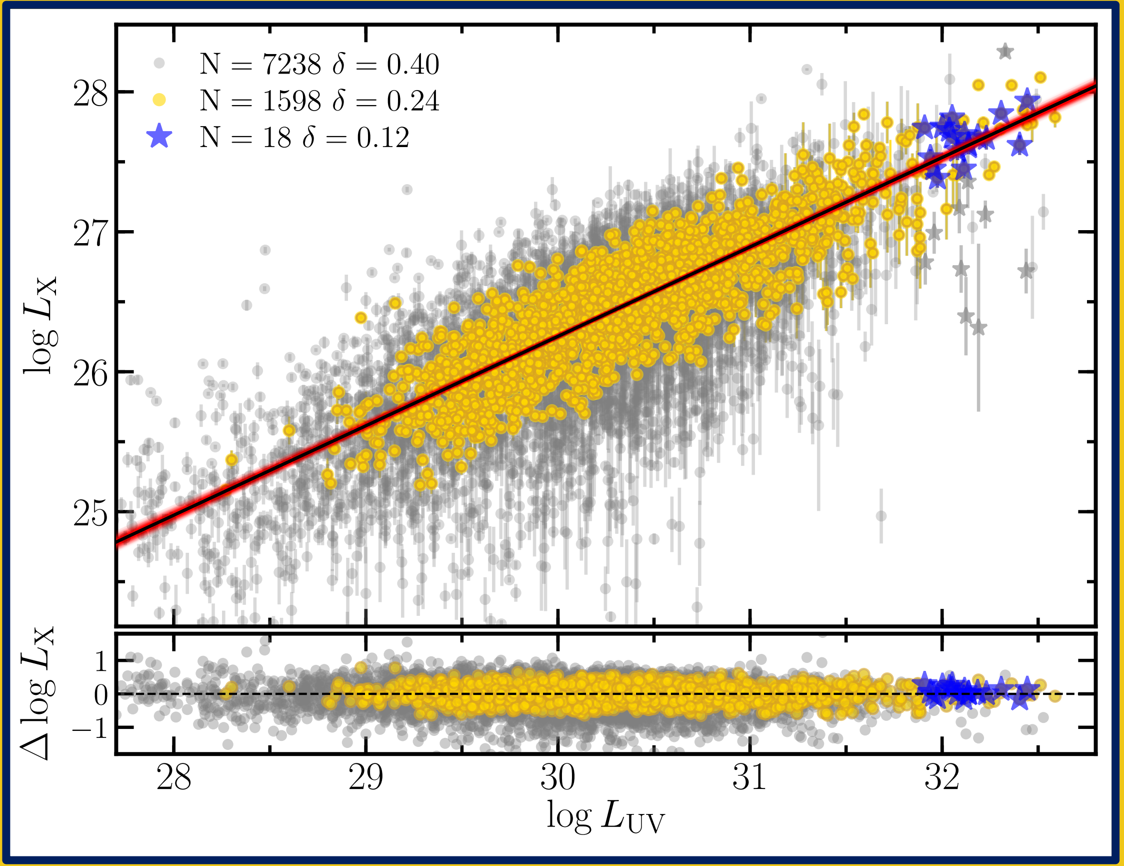
Risaliti&Lusso19



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

Quasars as Standard Candles

Risaliti&Lusso19



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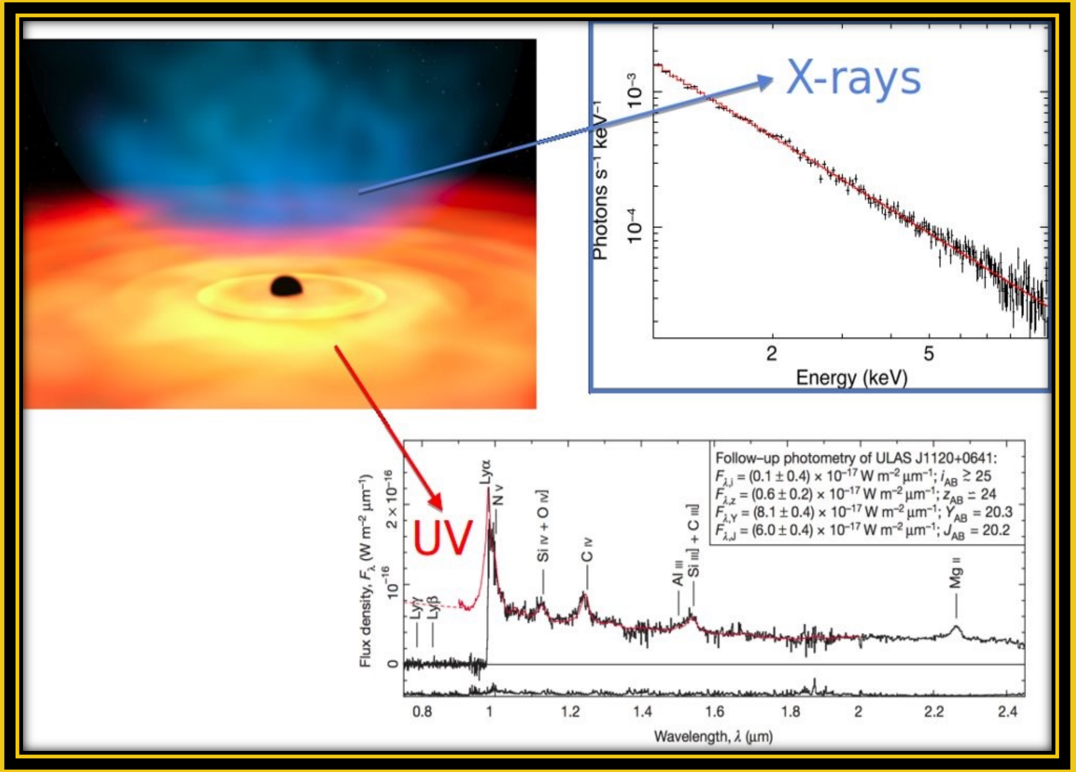
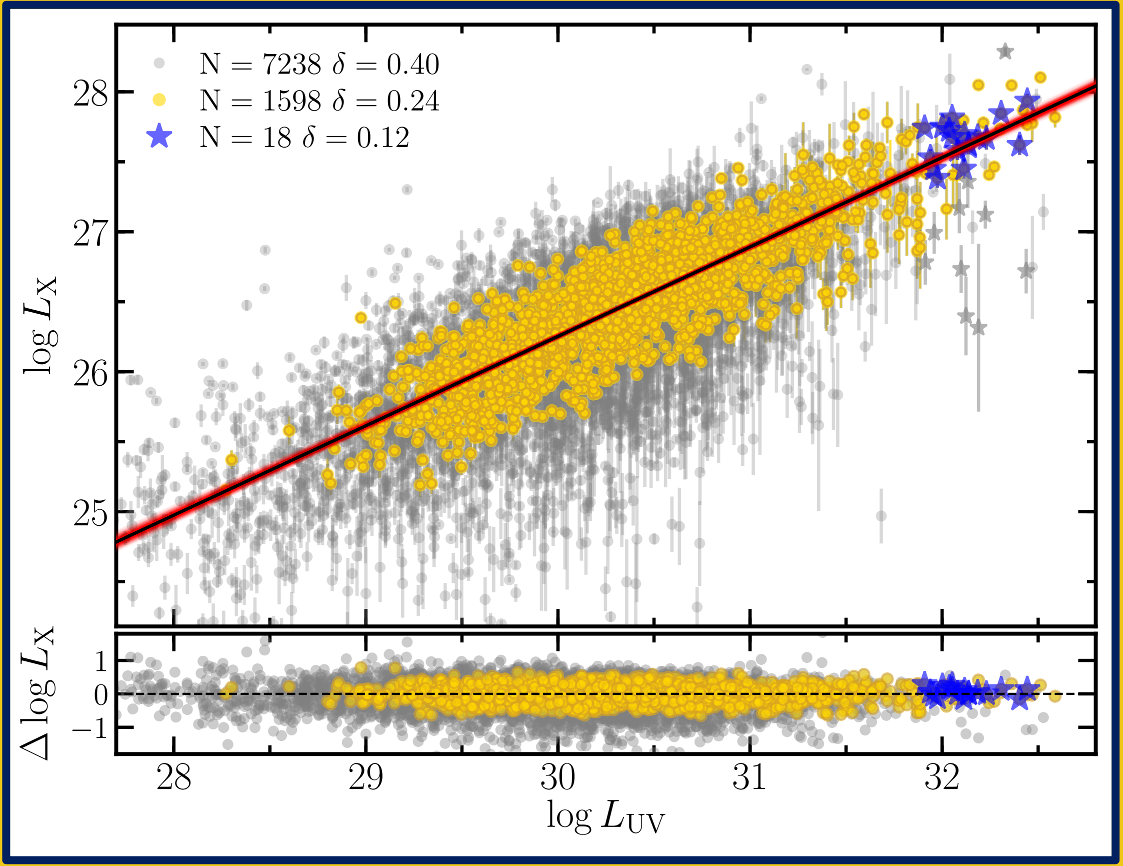


Quasars as Standard Candles

Risaliti&Lusso19



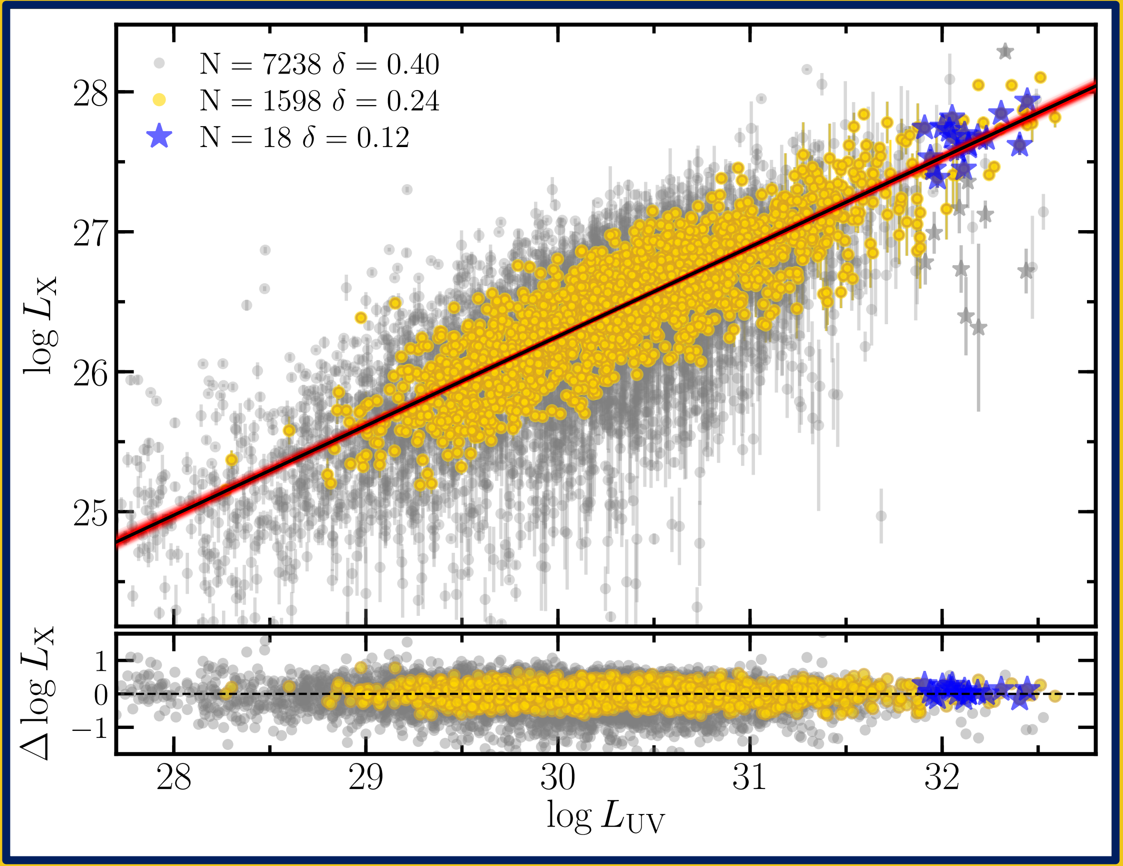
$$\log(L_X) = \gamma \log(L_{UV}) + \beta$$

$$F_X = \frac{L_X}{4\pi DL^2} \qquad F_{UV} = \frac{L_{UV}}{4\pi DL^2}$$

$$\log(D_L) = \frac{1}{2-2\gamma}\left(\log(f_X) - \gamma(f_{UV})\right) + \beta'$$

Quasars as Standard Candles

Risaliti&Lusso19



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

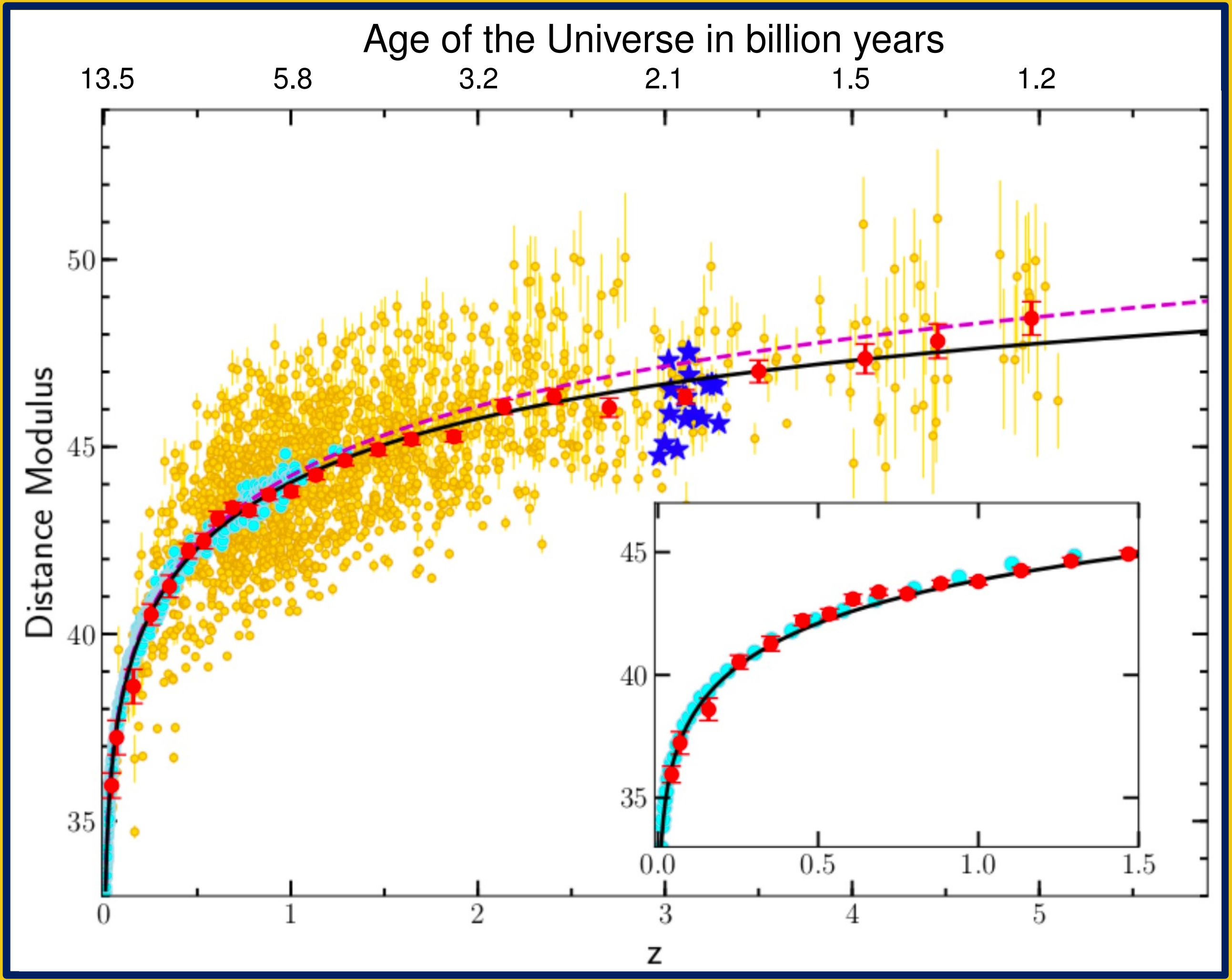
Remove objects affected from:

- dust reddening
- gas absorption
- Eddington bias

0.40 dex ➡ 0.24 dex

Hubble Diagram

- Extension to earlier epochs
- 4σ tension with flat-ΛCDM

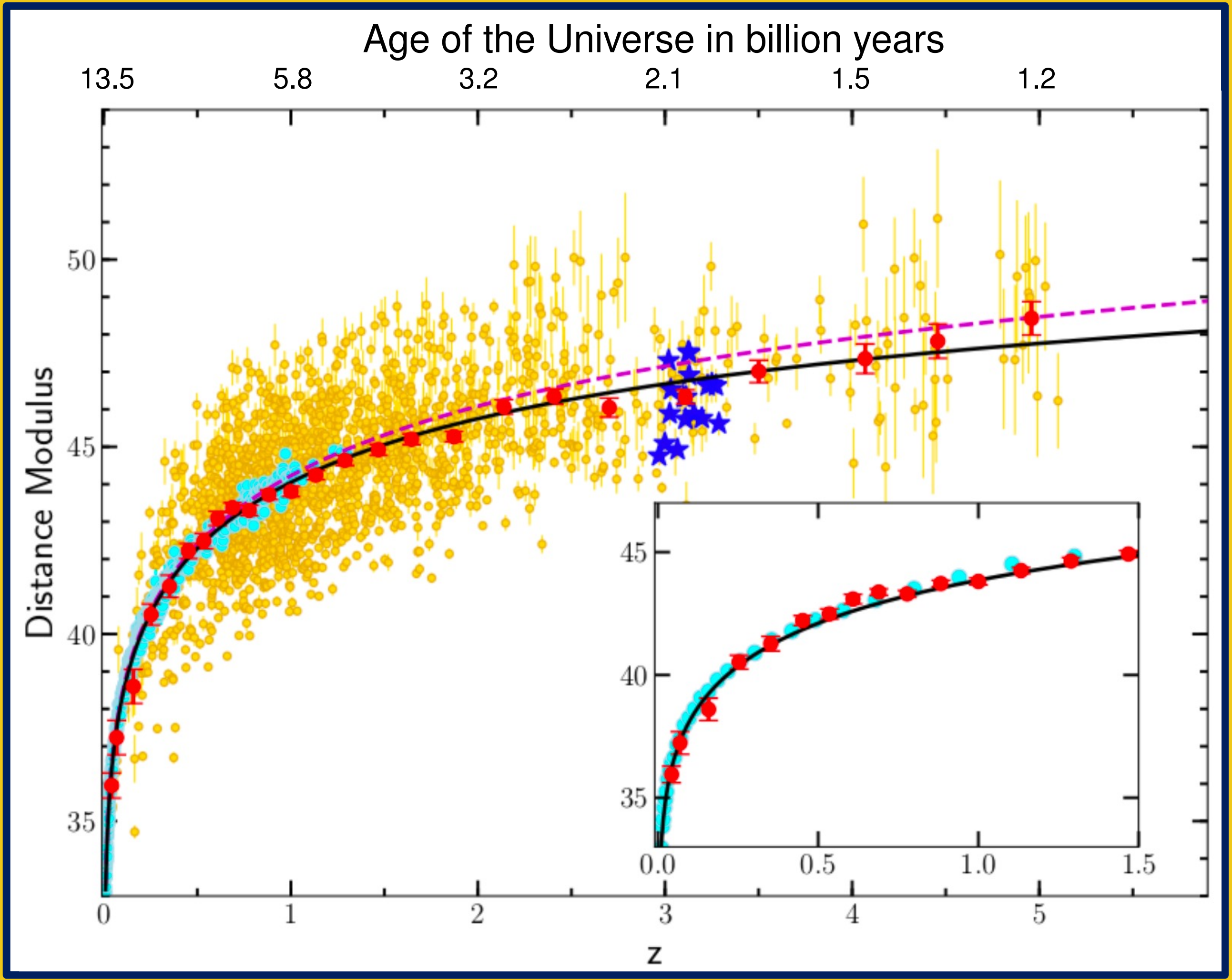


Risaliti&Lusso19

Validation

- ➢ Does the relation evolve with the redshift?
- ➢ Could residual reddening explain the tension?
- ➢ Are the quasars we are using *average* objects?

- ➢ What is the *intrinsic* dispersion of the relation?
- ➢ How much can we lower the observed dispersion?



Risaliti&Lusso19

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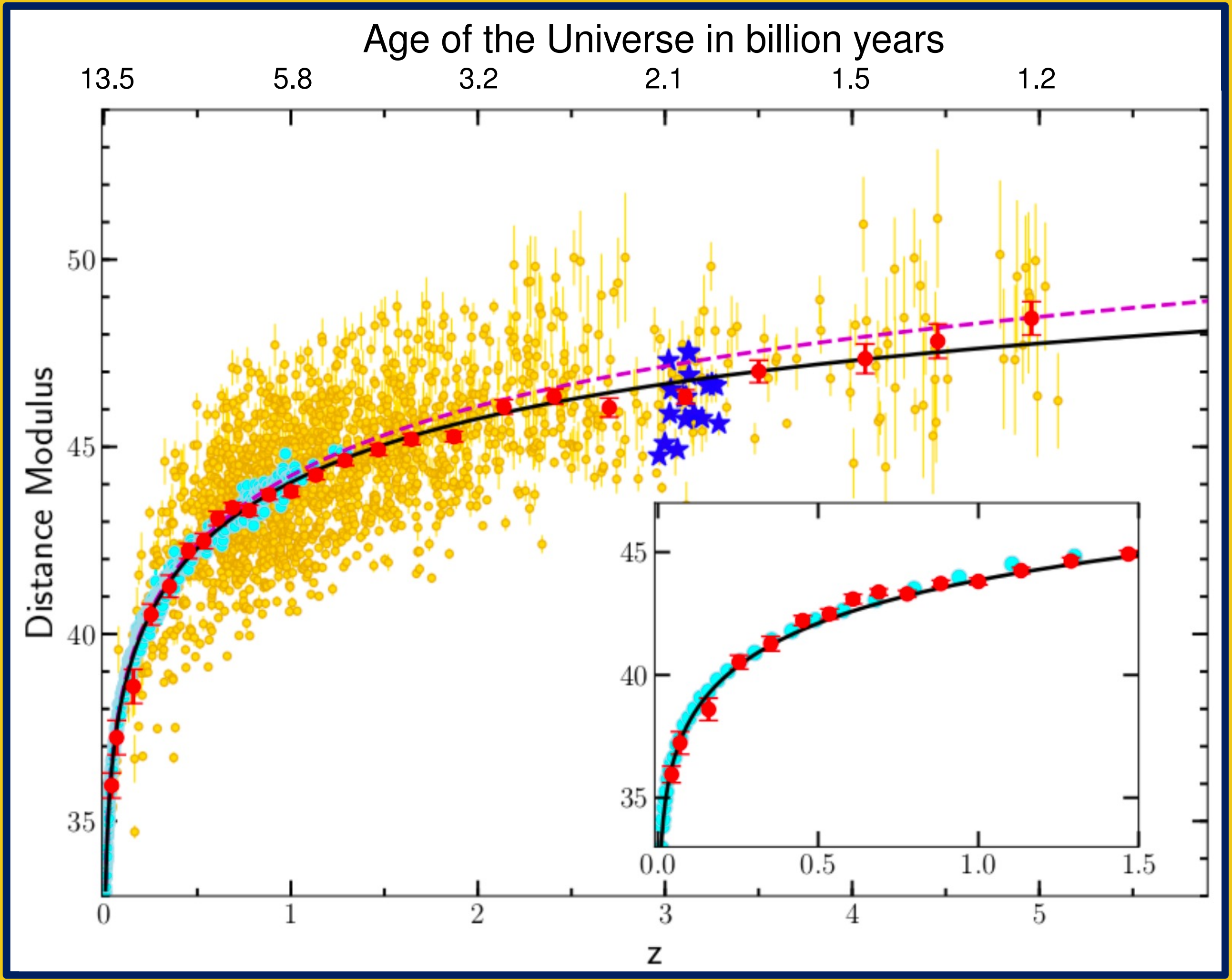
cosmology independent analysis



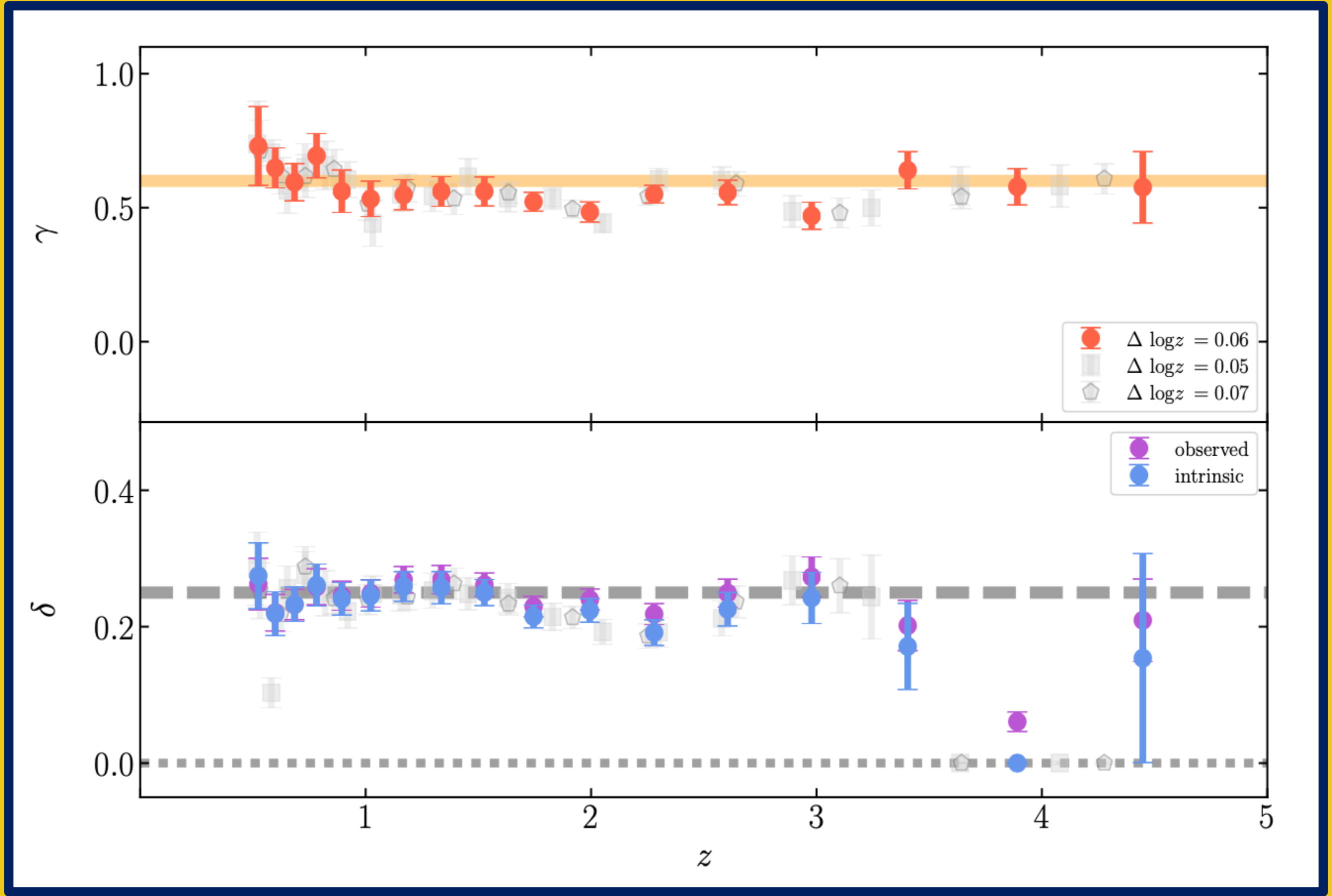
Risaliti&Lusso19

Validation

- **Does the relation evolve with the redshift?**

test in small redshift bins

$$\log(f_X) = \gamma \log(f_{UV}) + \beta$$



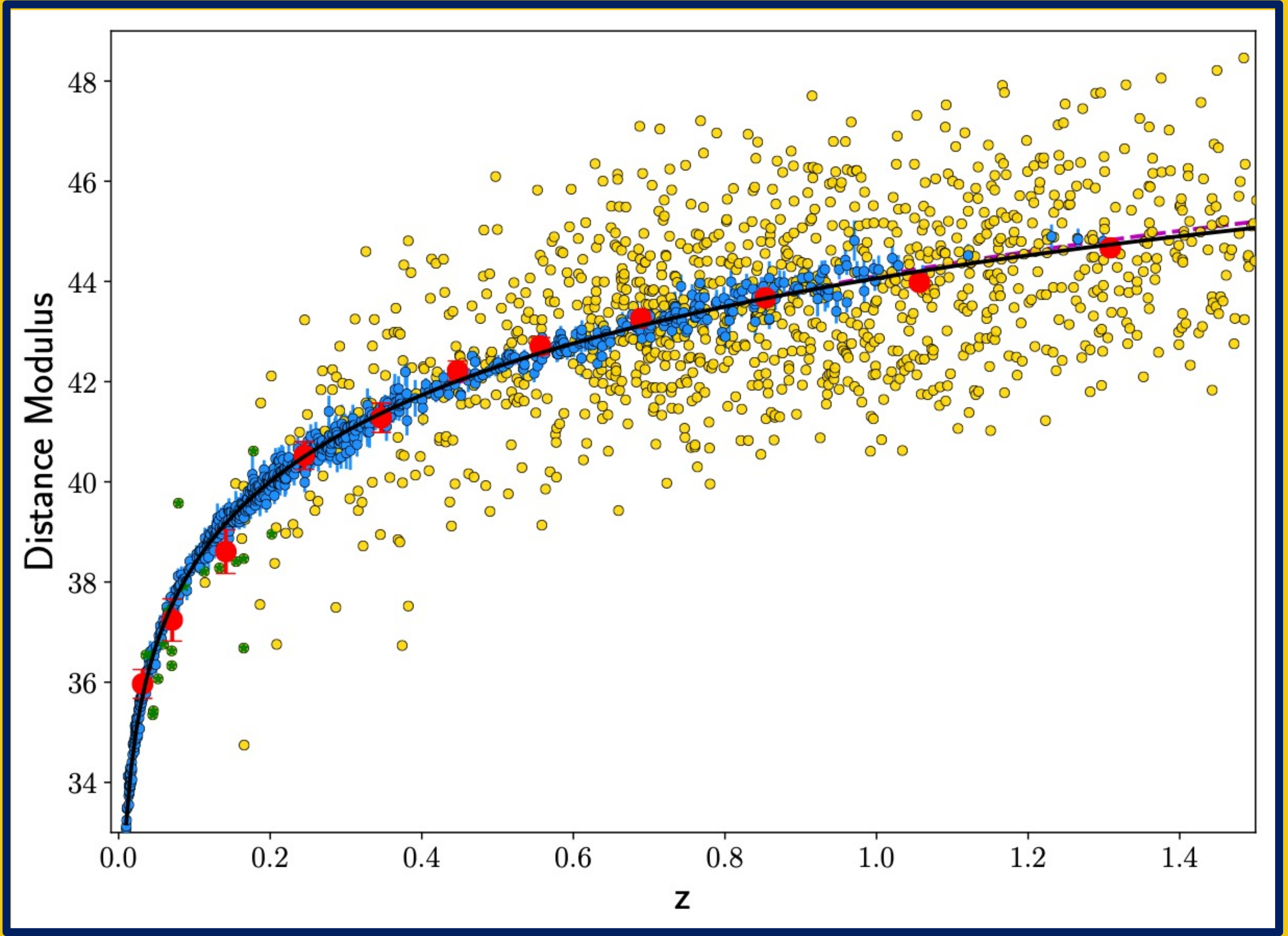
Bisogni+21

Validation

- **Does the relation evolve with the redshift?**

test in small redshift bins

calibration with SNIa in common redshift range

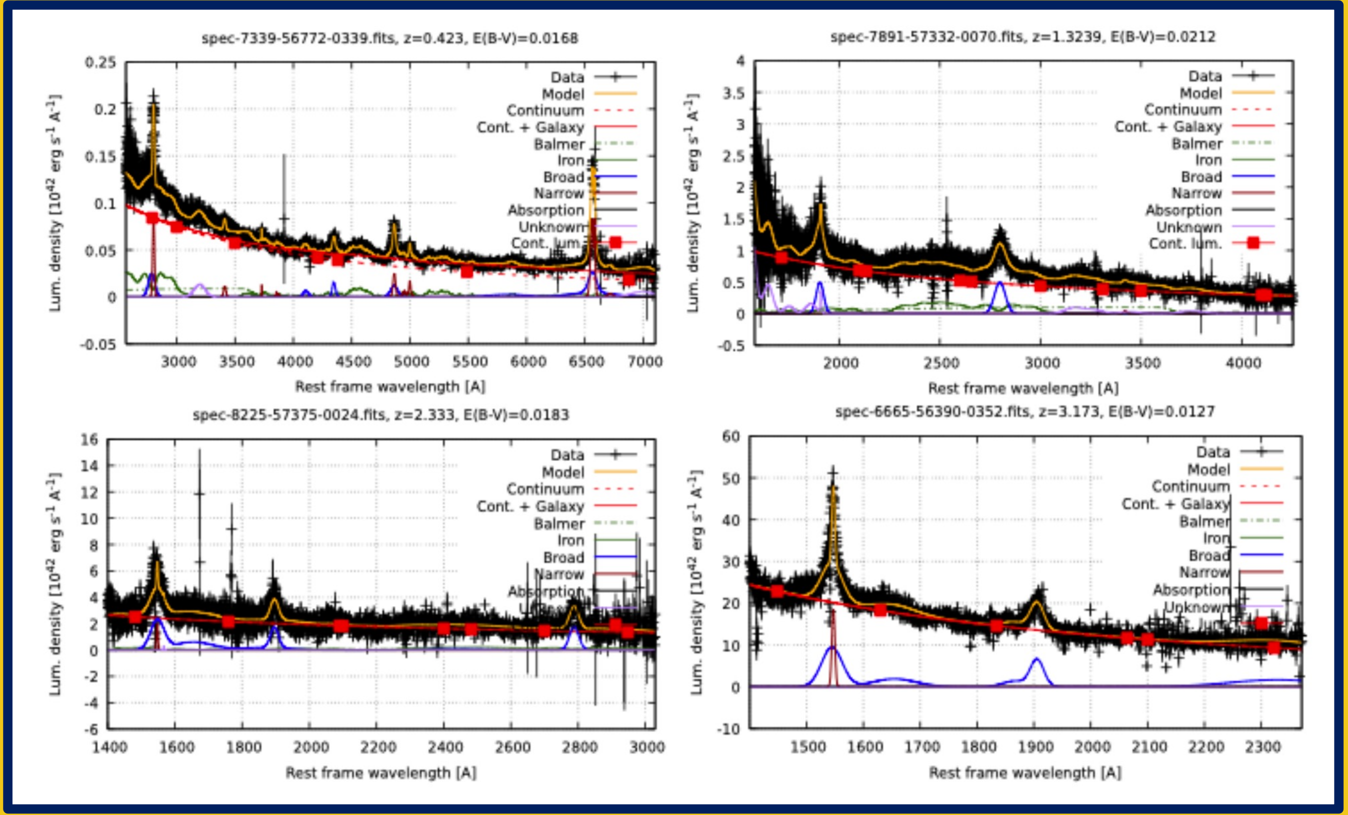


Risaliti&Lusso19

Validation

- ➢ **Could residual reddening explain the tension?**

Complete UV spectral analysis (SDSS-DR16 - 4XMM-DR10)



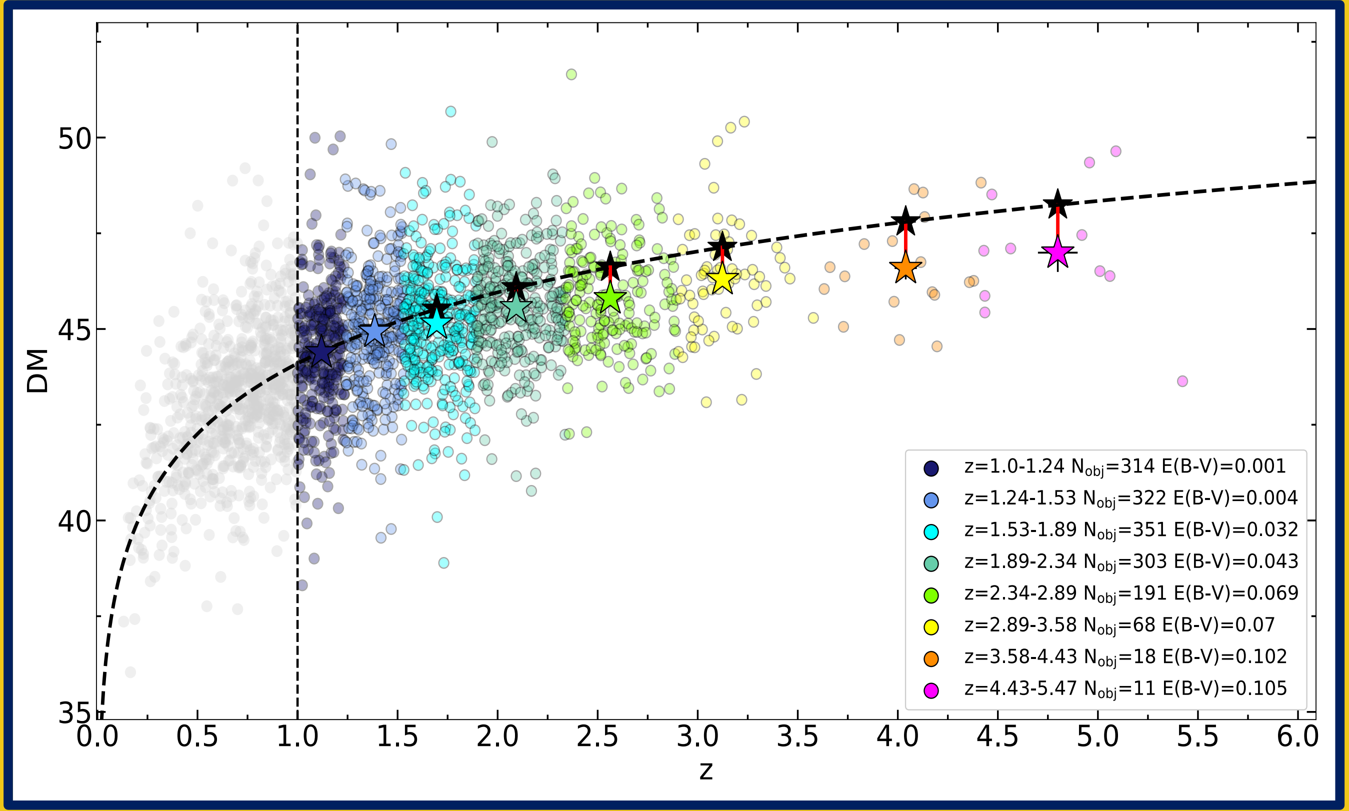
Signorini+23a (submitted)

Validation

➢ **Could residual reddening explain the tension?**

Complete UV spectral analysis (SDSS-DR16 - 4XMM-DR10)

We calculate the reddening in terms of E(B-V) that would be needed for that



Trefoloni+23 (in prep)

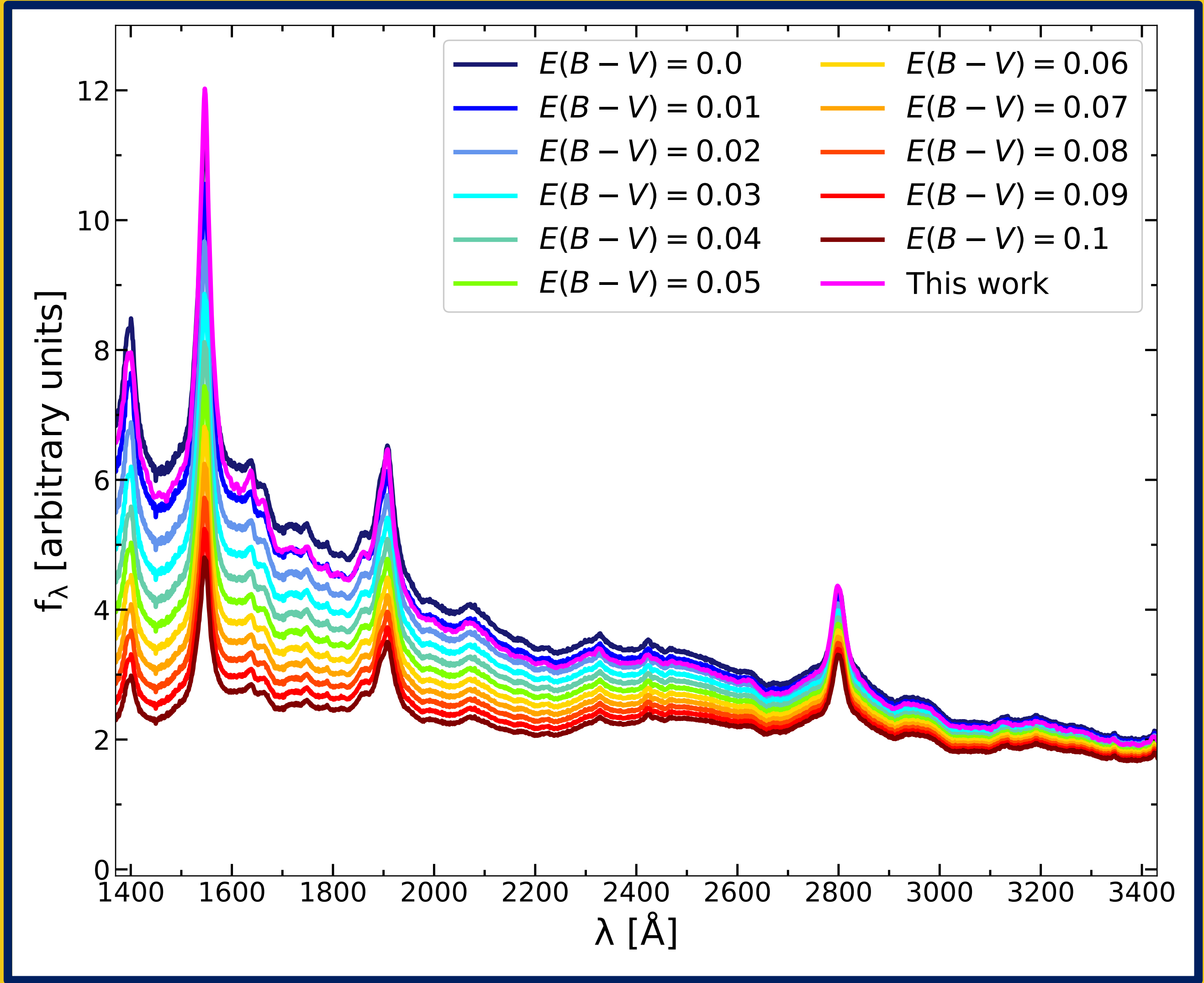
Validation

- **Could residual reddening explain the tension?**

Complete UV spectral analysis (SDSS-DR16 - 4XMM-DR10)

We calculate the reddening in terms of E(B-V) that would be needed for that

But our spectra are not compatible with such high reddening!



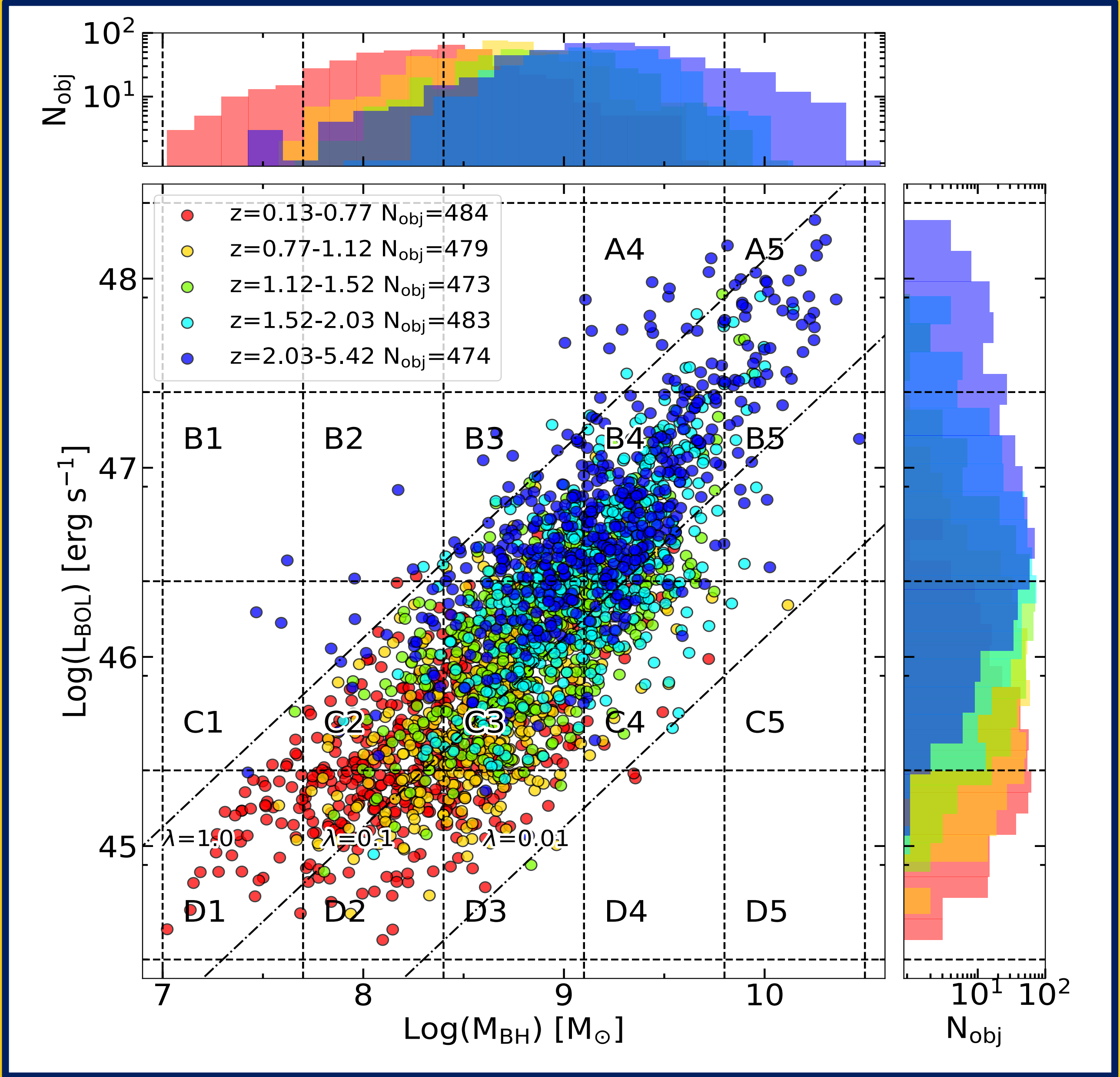
Trefoloni+23 (in prep)

Validation

- ➢ **Are the quasars we are using *average* objects?**

Complete UV spectral analysis (SDSS-DR16 - 4XMM-DR10)

We stack spectra in Luminosity, redshift, and BH mass bins



Trefoloni+23 (in prep)

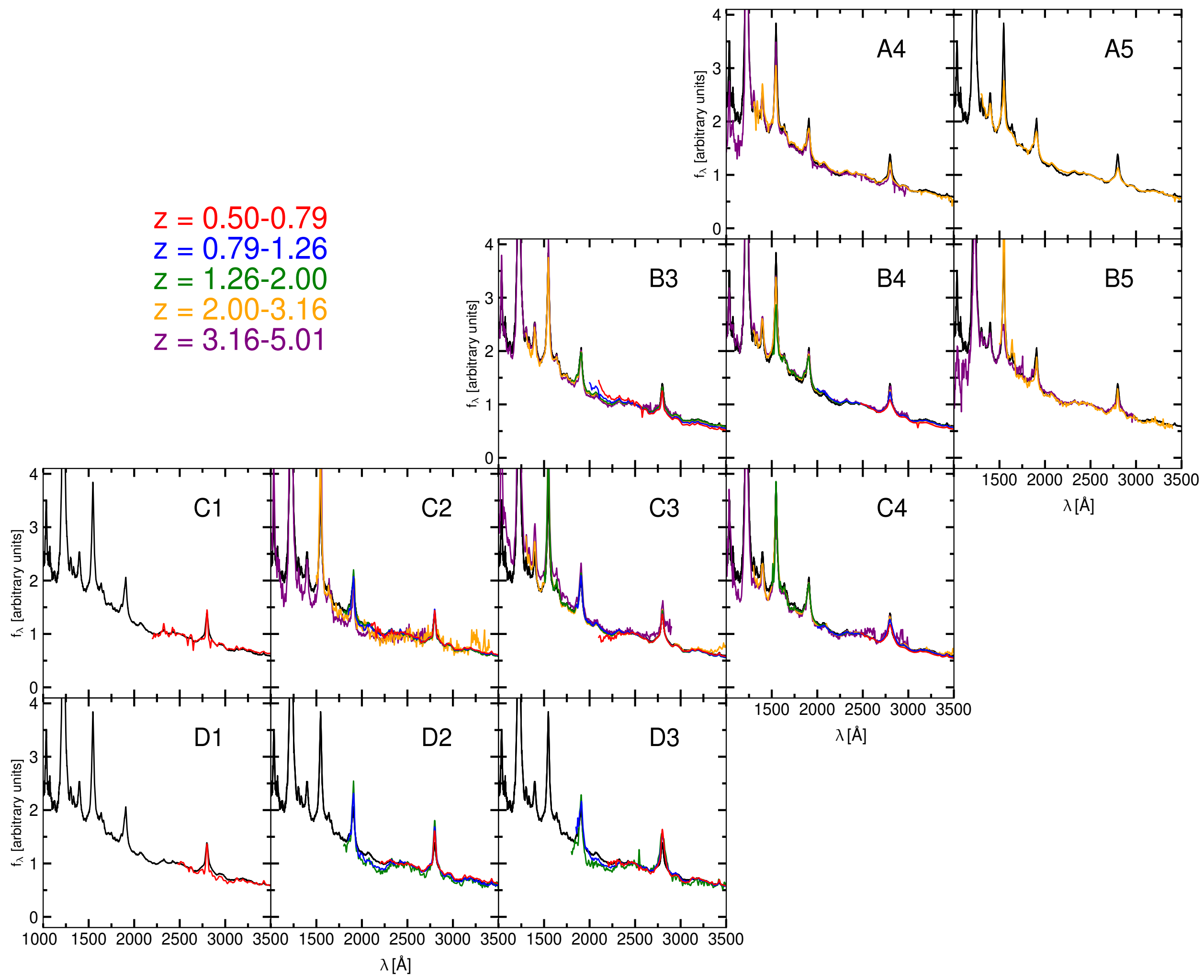
Validation

- ➢ **Are the quasars we are using *average* objects?**

Complete UV spectral analysis (SDSS-DR16 - 4XMM-DR10)

We stack spectra in Luminosity, redshift, and BH mass bins

The spectra fully overlap with the Vanden Berk (2001) spectrum, with no L-z-M trends



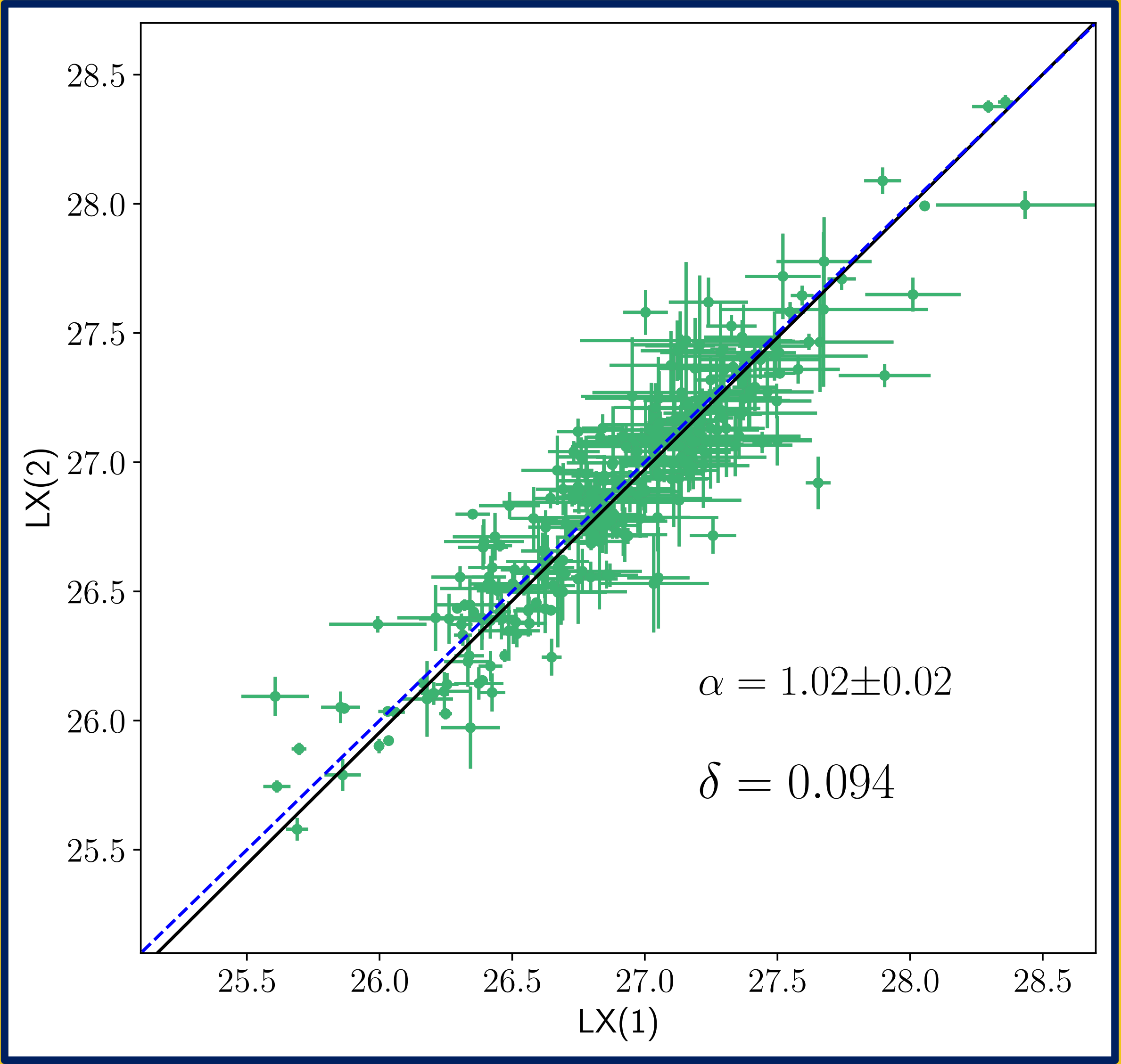
Trefoloni+23 (in prep)

Validation

➢ **What is the intrinsic dispersion of the relation?**

We know two residual contributions:

- Variability: 0.09 dex



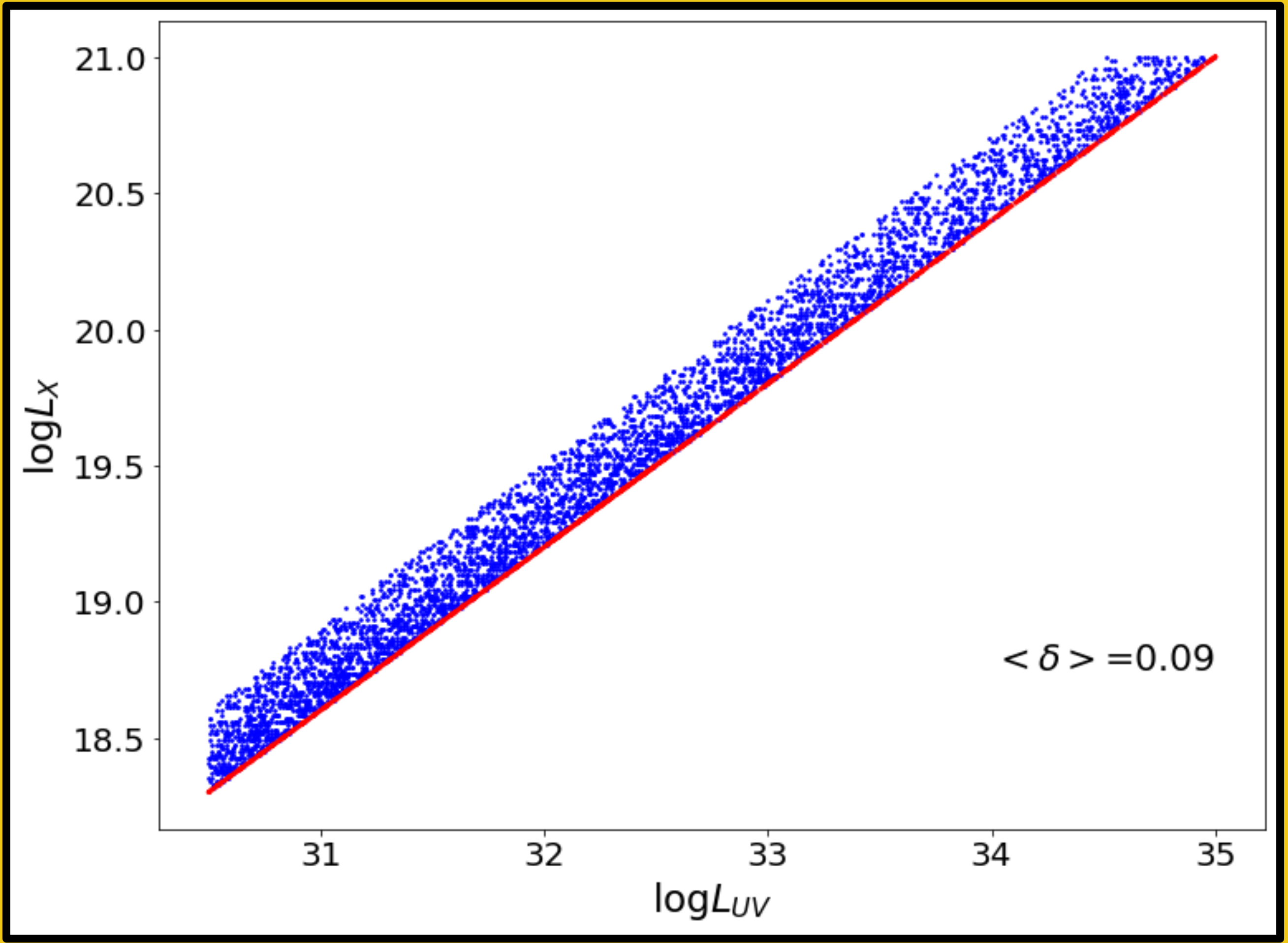
Signorini+23b (in prep)

Validation

➢ **What is the intrinsic dispersion of the relation?**

We know two residual contributions:

- Variability: 0.09 dex
- Inclination: 0.09 dex



Signorini+23b (in prep)

Validation

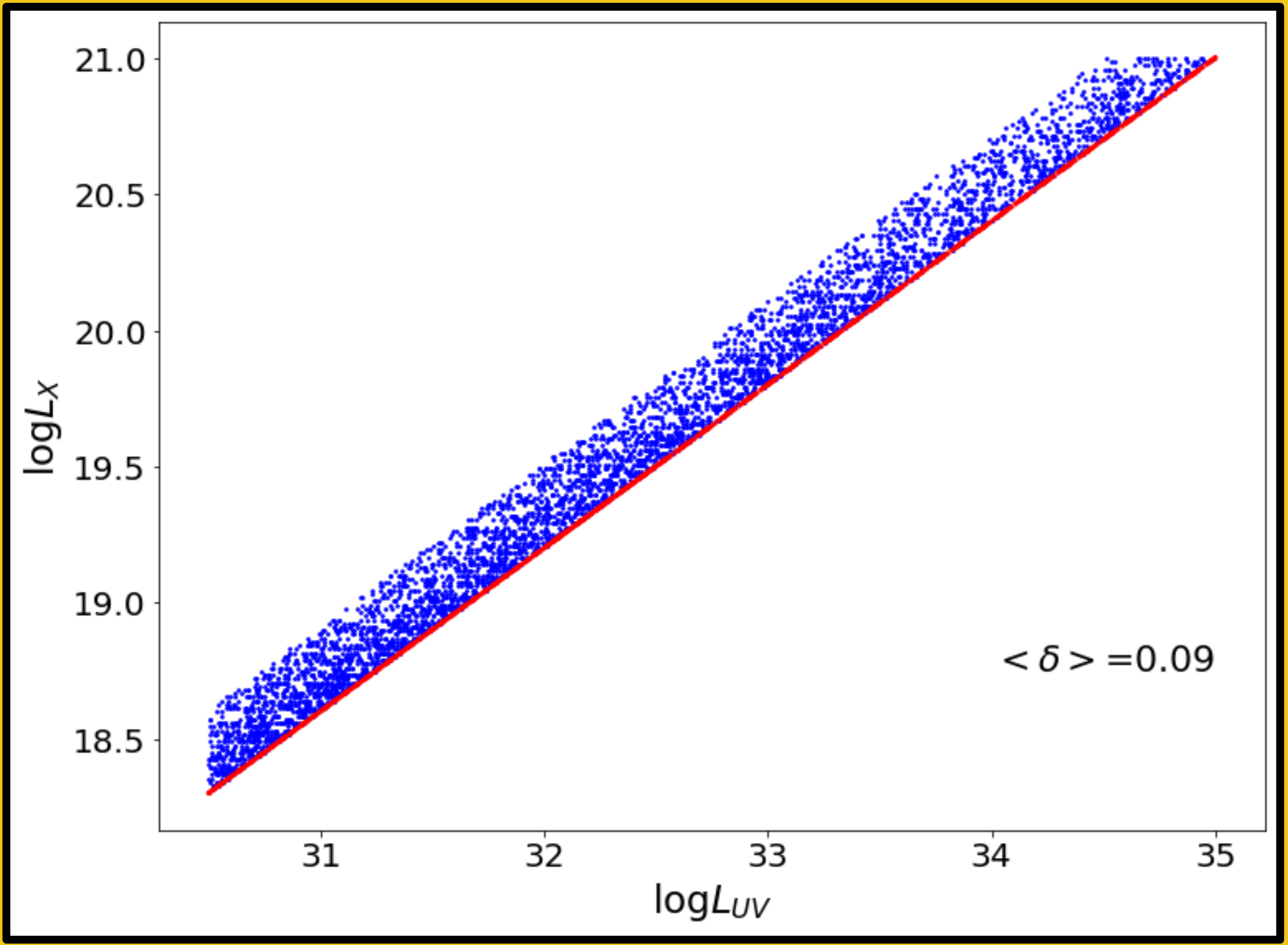
➢ **What is the intrinsic dispersion of the relation?**

We know two residual contributions:

- Variability: 0.09 dex
- Inclination: 0.09 dex

0.13 dex

The intrinsic dispersion must be very small!



Signorini+23b (in prep)

Validation

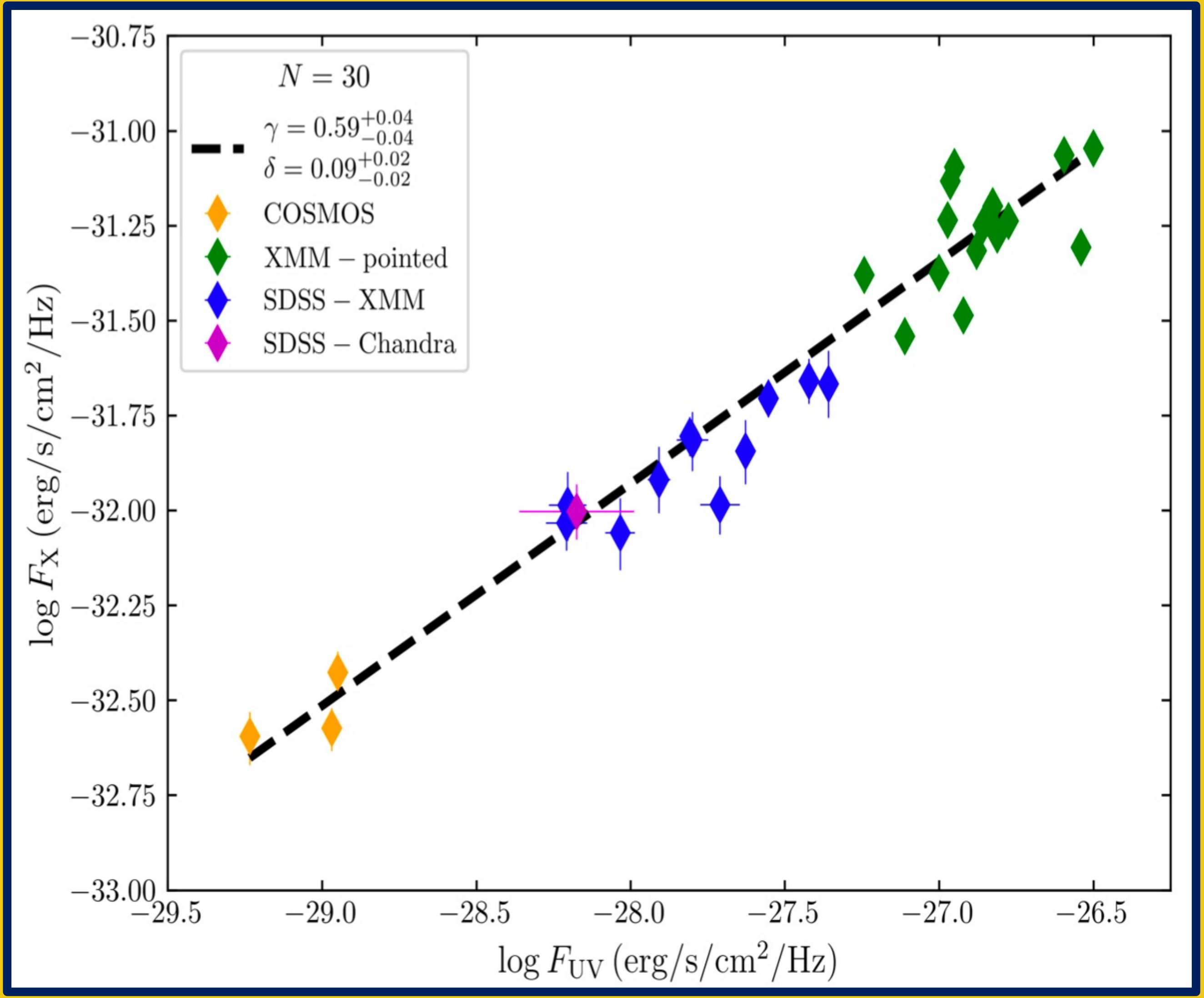
➢ **How much can we lower the observed dispersion?**

"Golden sample":
30 objects at 3.0 < z < 3.3, high L

Full X-ray and UV spectroscopic analysis + subsample with pointed X-ray observations

0.09 dex

The intrinsic dispersion must be very small!



Sacchi+22

Validation

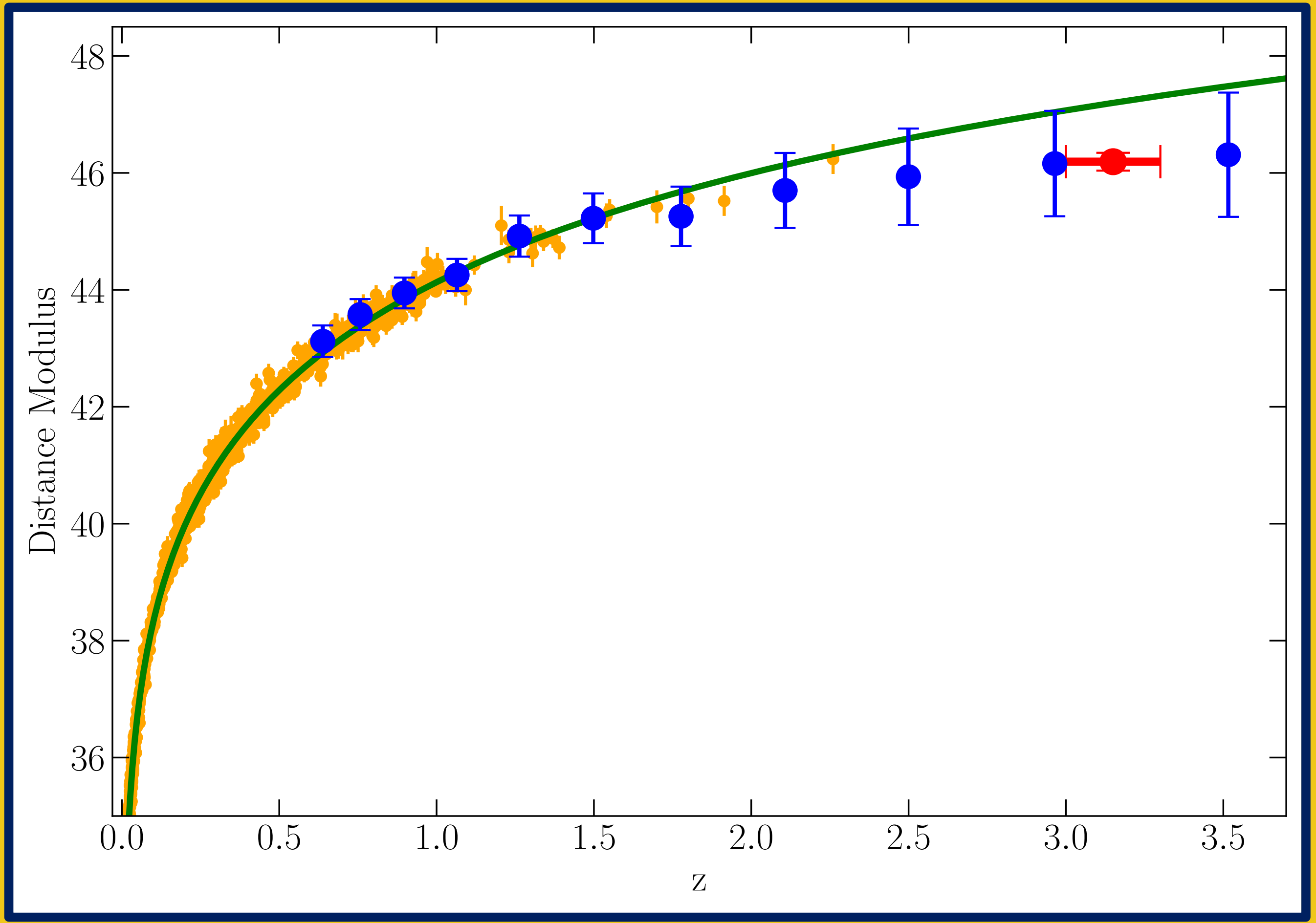
- **How much can we lower the observed dispersion?**

"Golden sample":
30 objects at 3.0 < z < 3.3, high L

Full X-ray and UV spectroscopic analysis + subsample with pointed X-ray observations

A 4σ tension with flat-ΛCDM is confirmed!

Sacchi+22



Quasars as standard candles validation

- There is no redshift evolution of the relation
- Our sample is made of average objects, as we find out with spectral analysis
- Residual reddening cannot explain the tension with the LCDM model
- With very high-quality data, we can lower the dispersion to <0.10 dex, and the presence of a strong tension with LCDM is confirmed
- The intrinsic dispersion must be very low – the physical relation behind this method is very tight

Thank you!