A Hubble diagram for quasars

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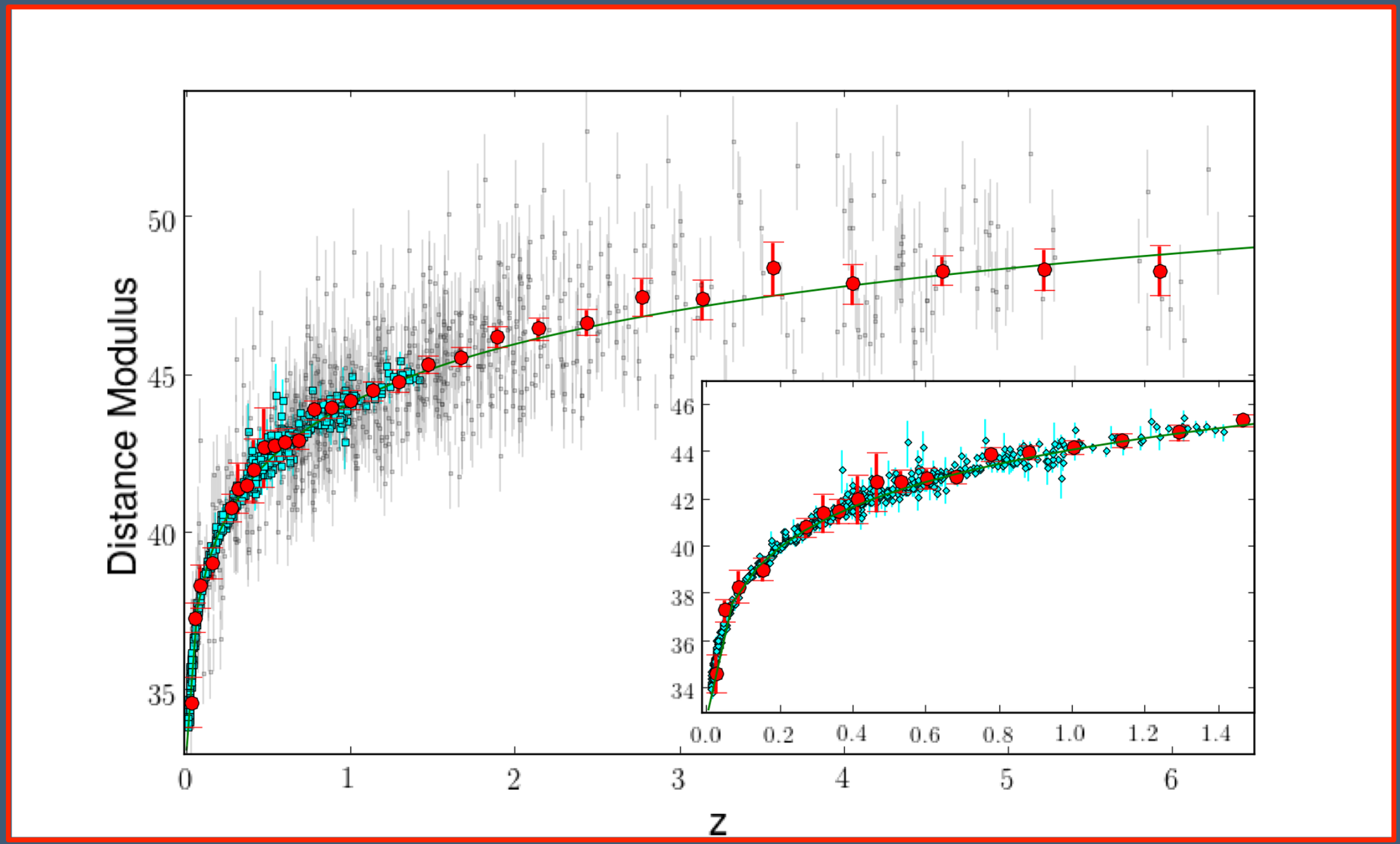


Athena Conference, 09/10/2015

Can we use quasars as standard candles?

Very luminous objects up to high redshift (z~7), but :

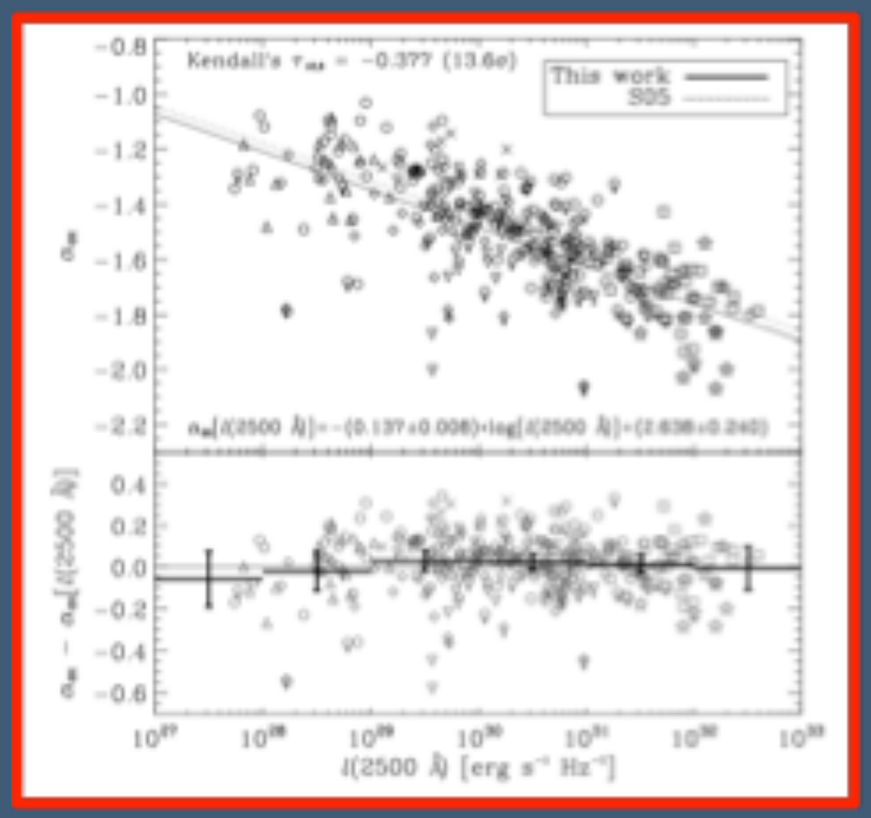
- no obvious spectral indicator of intrinsic luminosity
- highly variable in luminosity and SED

Several experiments:

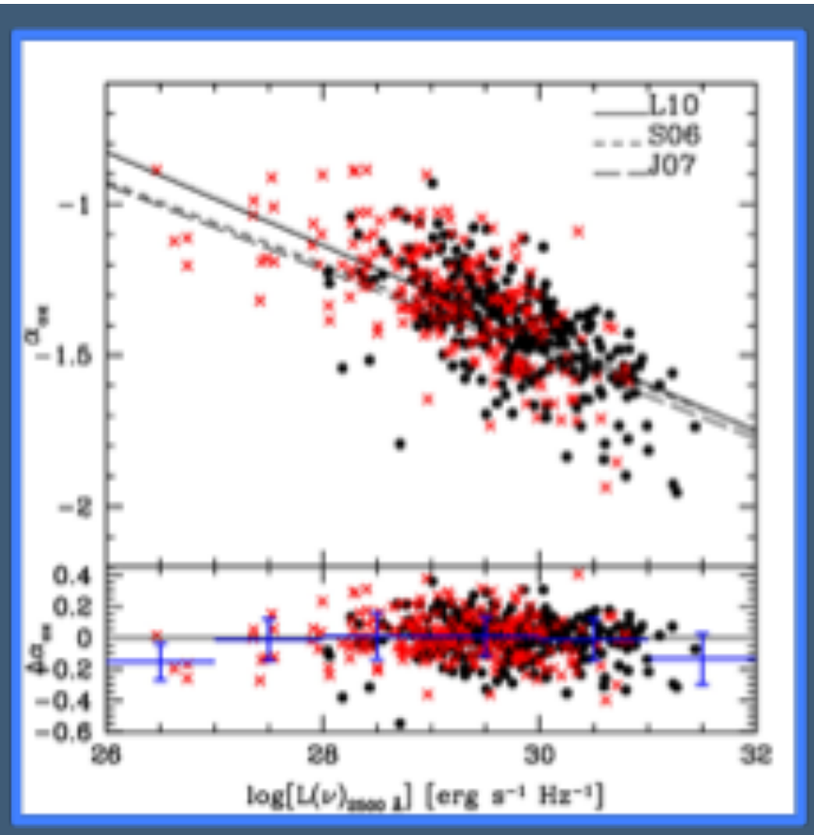
- Quasar light curves (De-Chang Dai, et al 2012, Phys. Rev. Lett.)
- Baldwin effect (anti-correlation between the EW of em. lines and continuum luminosity, very high dispersion)
- Radio-luminosity relation (Watson et al. 2011, Kilerci Eser et al. 2015)
- X-ray variability – luminosity relation (La Franca et al. 2014)
- **Luminosity dependence of the UV/X-ray flux ratio**

Starting point: the non-linear relation between X-ray and UV emission in QSO

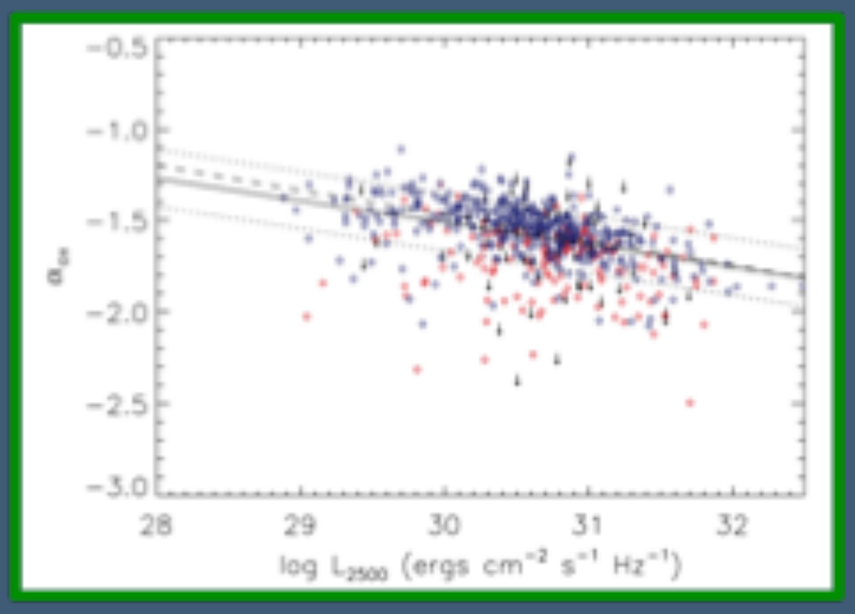
$$\alpha_{\rm ox} = \frac{\log\left(L_{2\ \rm keV}/L_{2500}\right)}{\log\left(\nu_{2\ \rm keV}/\nu_{2500}\right)}$$



Steffen et al. 2006
333 quasars
X-ray: mostly ROSAT
UV: mixed bag

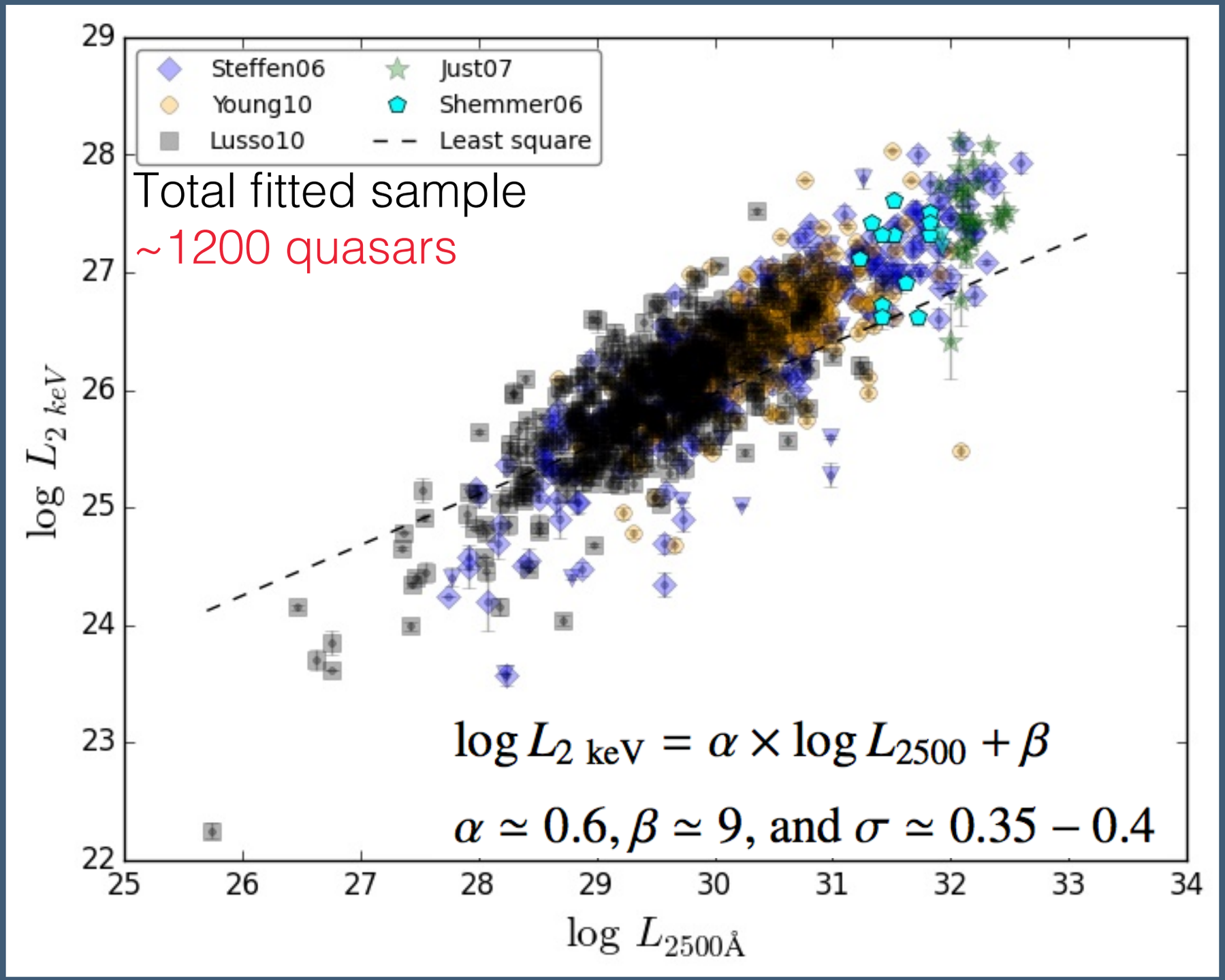


Lusso et al. 2010
545 quasars
COSMOS+XMM-Newton



Young et al. 2010
327 quasars
X-ray: XMM-Newton
UV: SDSS-DR5

The non-linear relation between X-ray and UV emission in QSO: merging literature samples



See also: Tananbaum+79; Zamorani+81; Vignali+03; Strateva+05; Steffen+06; Just+07; Young+10

The non-linear relation between X-ray and UV emission in QSO: method

$$\log L_{2\ \mathrm{keV}} = \alpha \times \log L_{2500} + \beta$$

$$\alpha \simeq 0.6, \beta \simeq 9, \text{ and } \sigma \simeq 0.35 - 0.4$$

Possible use for cosmological measurements:

$$\log F_X = \alpha\ \log F_{UV} + (2 - 2\alpha) \log \mathrm{D_L} + \beta'$$

$$D_L = \frac{(1+z)}{\sqrt{\Omega_k}} \sinh\left[\sqrt{\Omega_k} \int_0^z \frac{dz}{H_0 \sqrt{\Omega_M (1+z)^3 + \Omega_\Lambda + \Omega_k (1+z)^2}}\right]$$

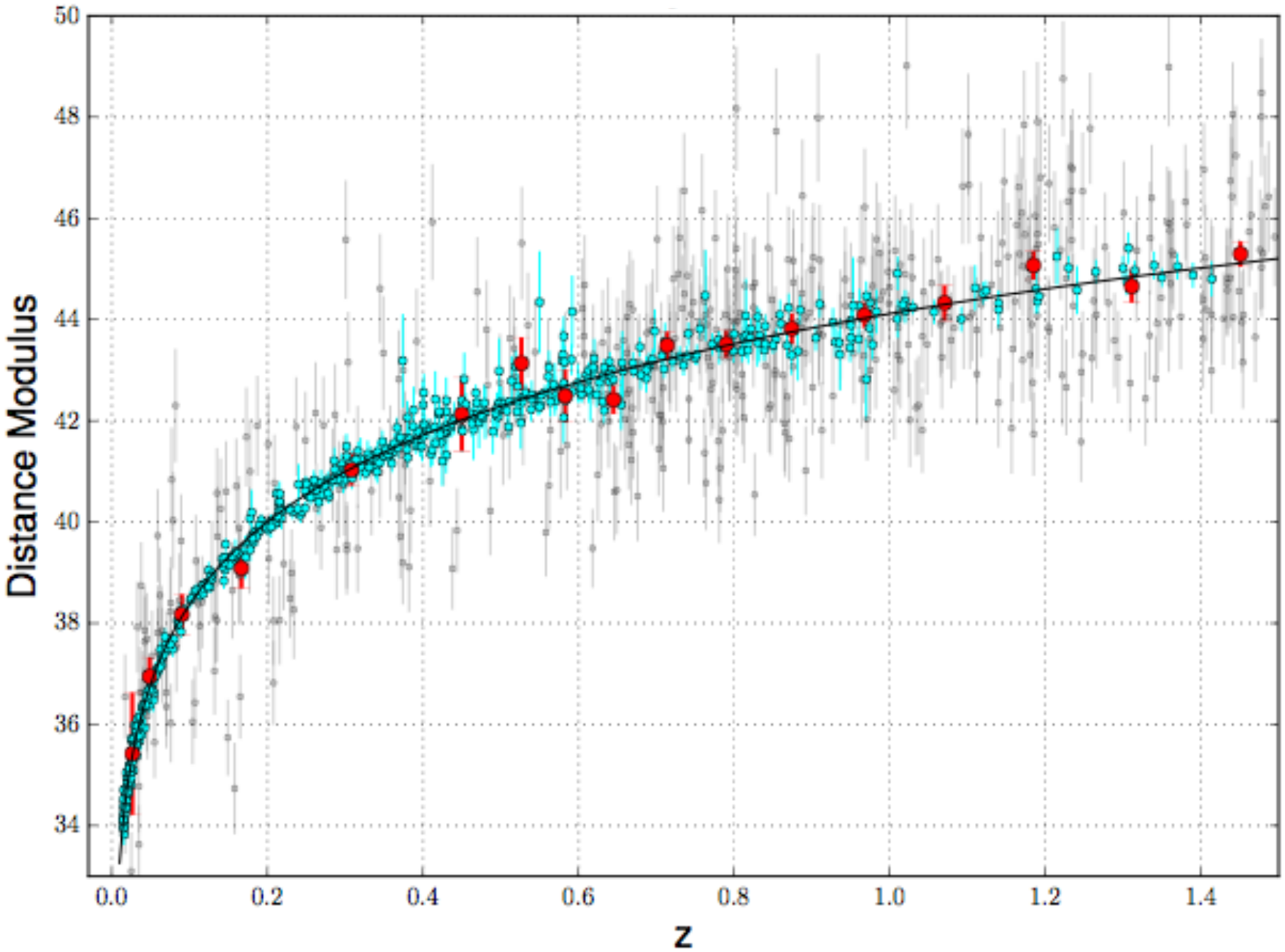
$\Omega_k = 1 - \Omega_M + \Omega_\Lambda$

Free parameters:

Ω_M, Ω_Λ, β, α, δ (intrinsic dispersion)

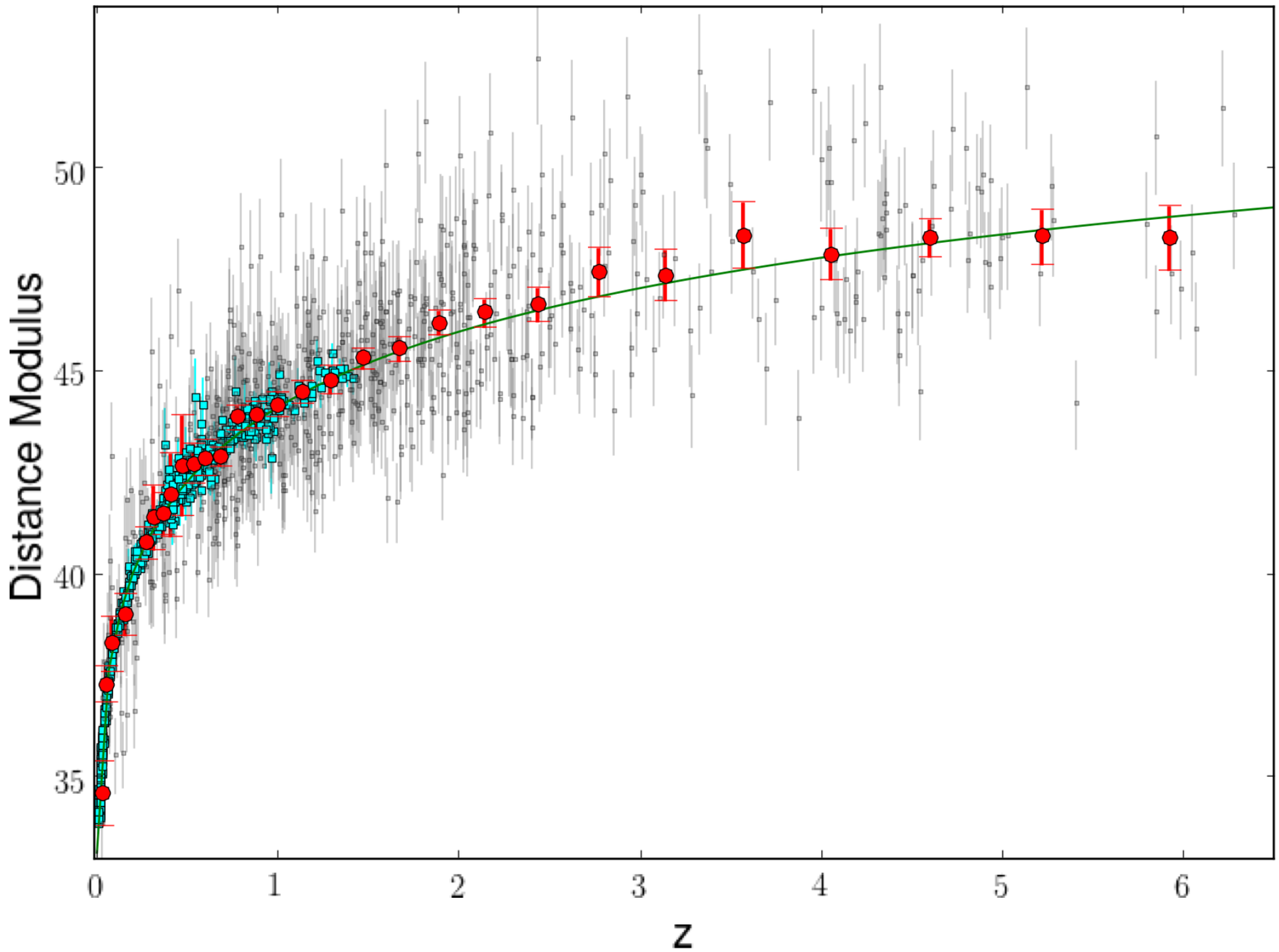
Risaliti & Lusso 2015, arXiv 1505.7118

Quasar “Hubble Diagram”



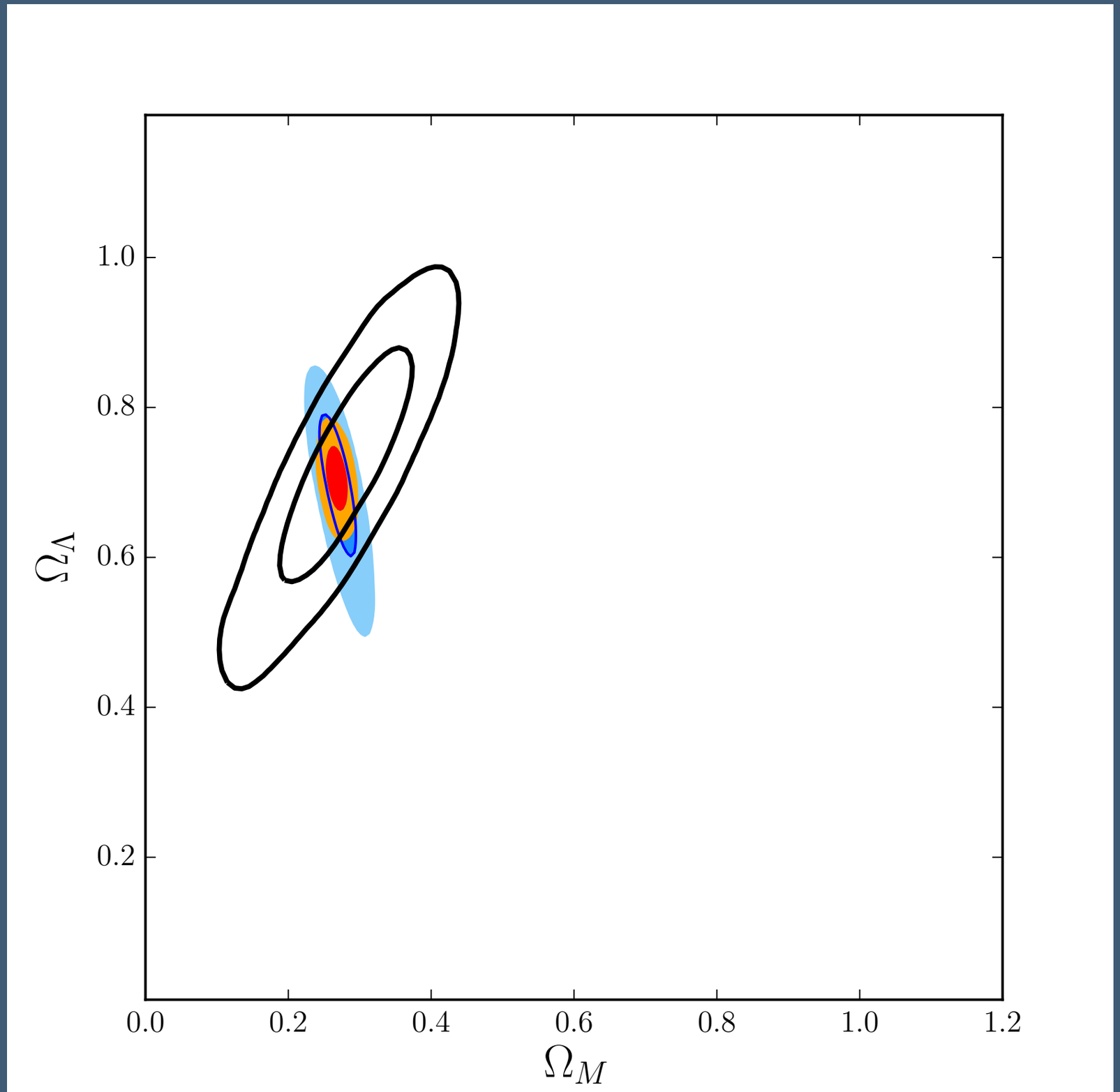
Supernovae Cosmology Project (Sullivan+11, Suzuki+12)

Quasar "Hubble Diagram"



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

Cosmological parameters: data



Open, **QSOs only**:

$$\Omega_M = 0.26^{+0.11}_{-0.07}$$

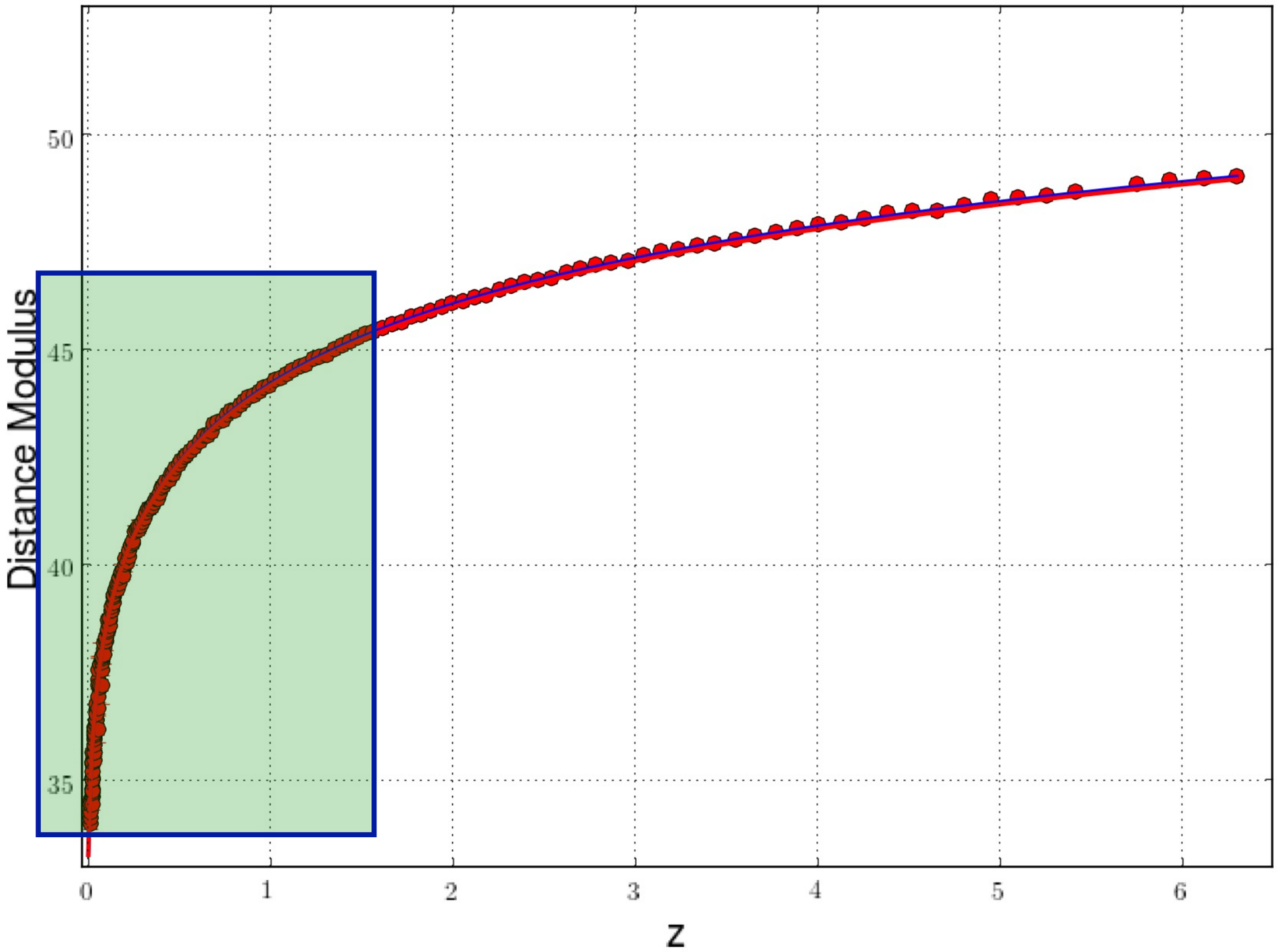
$$\Omega_\Lambda = 0.88^{+0.18}_{-0.34}$$

Open, **QSOs + Sne**:

$$\Omega_M = 0.26^{+0.04}_{-0.04}$$

$$\Omega_\Lambda = 0.71^{+0.10}_{-0.08}$$

Simulated 500,000 quasars sample + Athena



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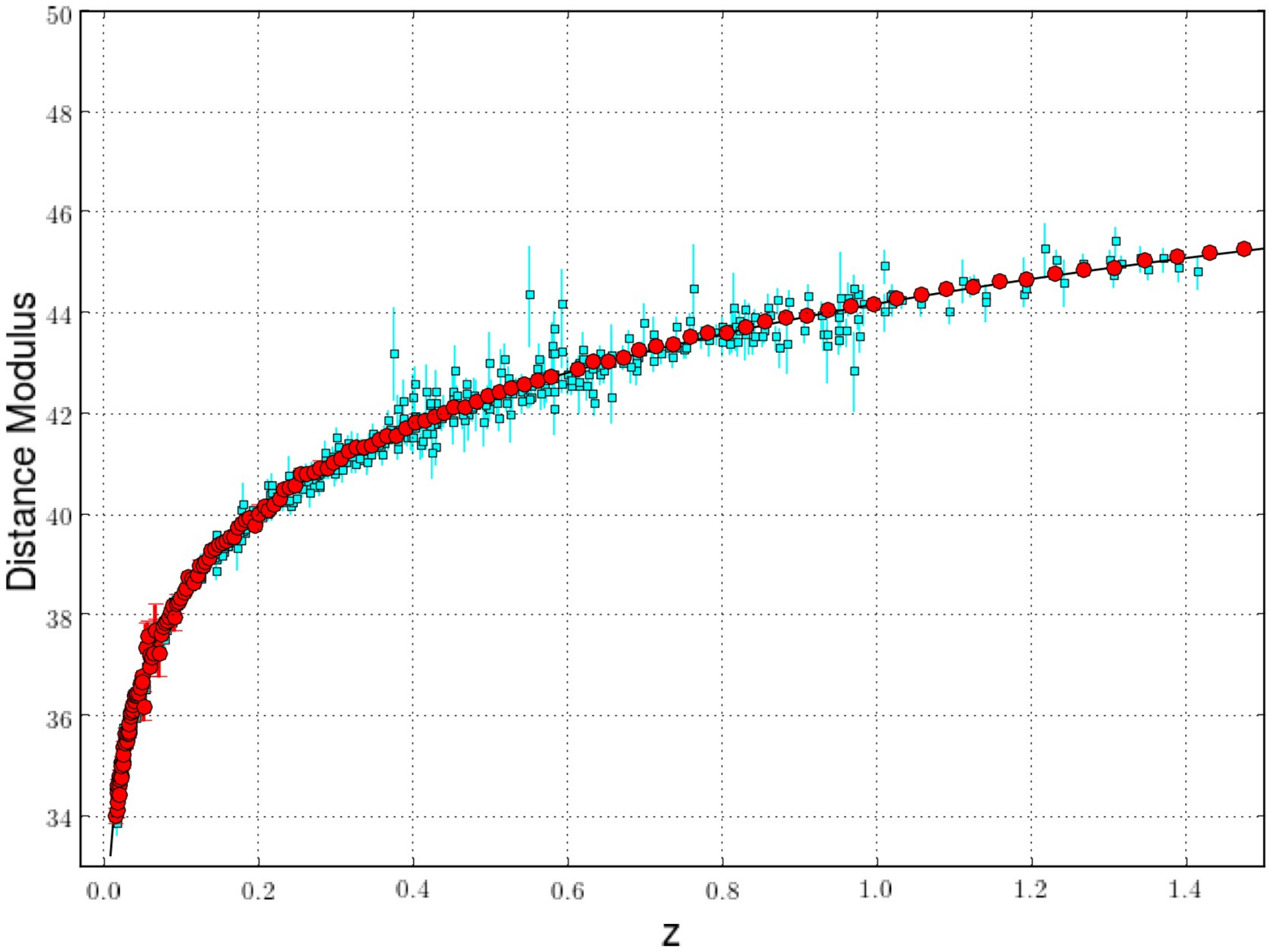

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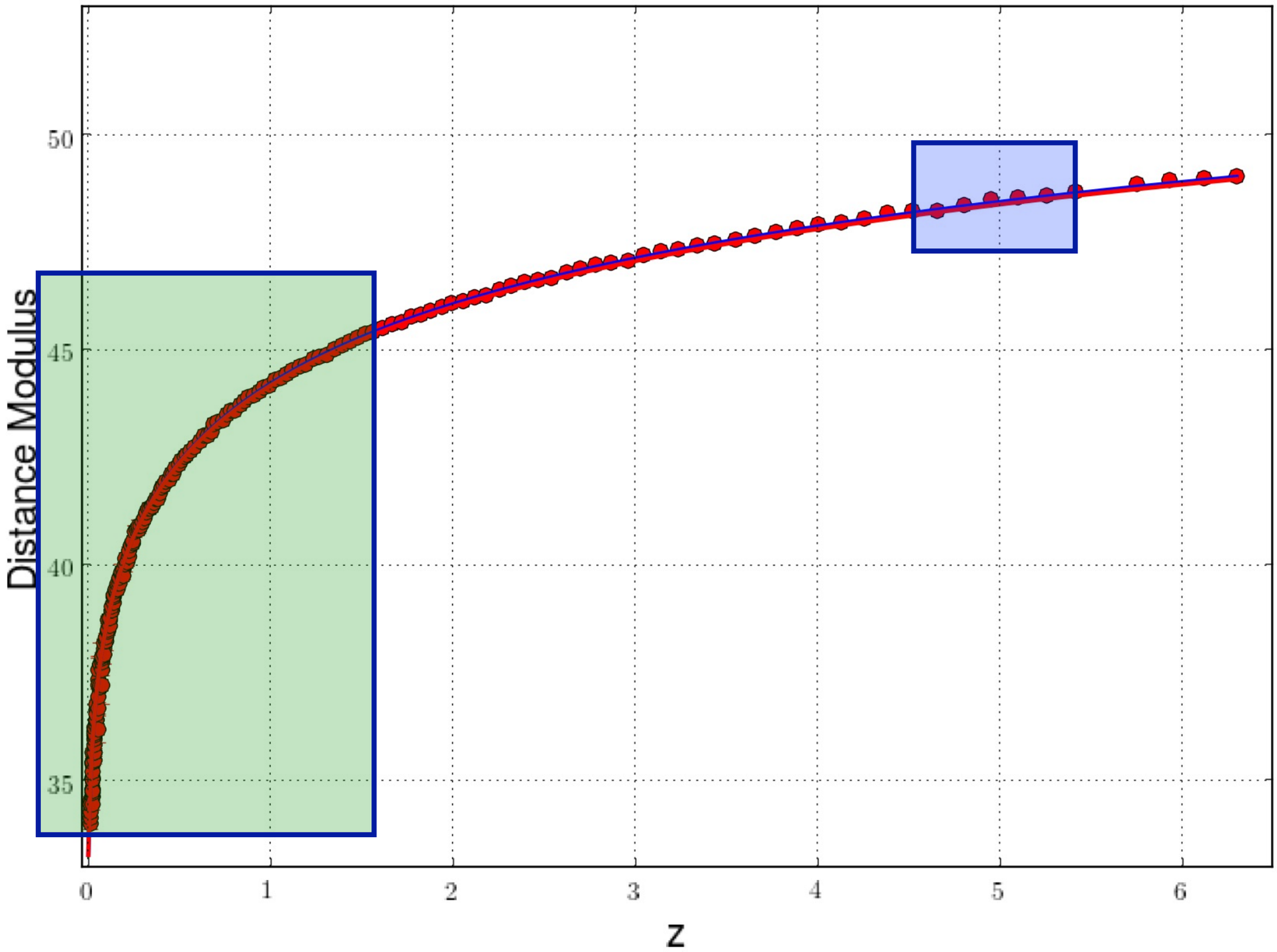

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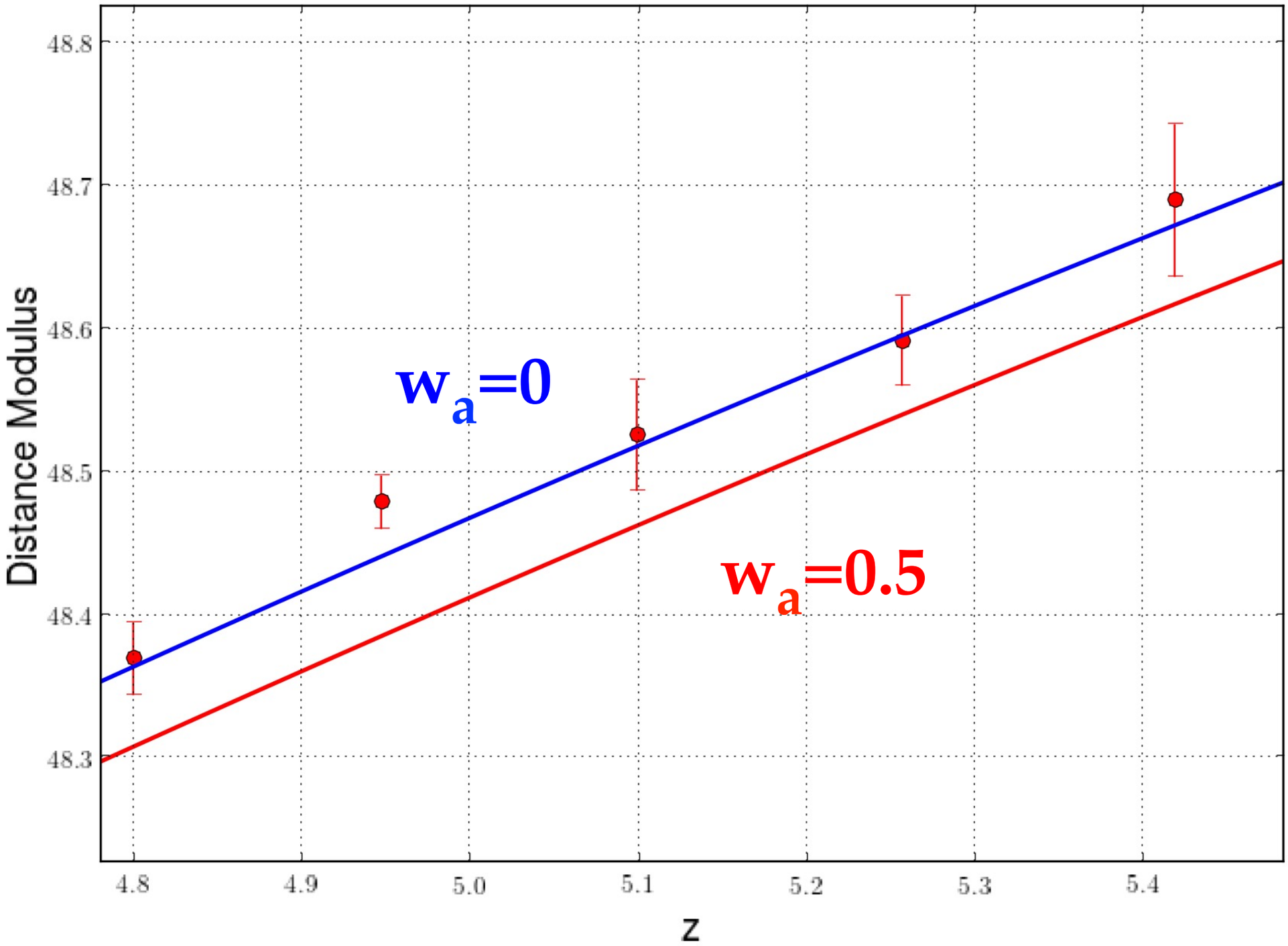

Conclusions

- The standard cosmological model has been tested in a previously unexplored redshift range ($1.4 \leq z \leq 6.3$)

- **Quasars** can be used as **"standard candles"**

- Athena can probe the cosmological model at high redshift with unprecedented precision, and put strong constraints on the equation of state of dark energy

Risaliti & Lusso 2015, arXiv 1505.7118)