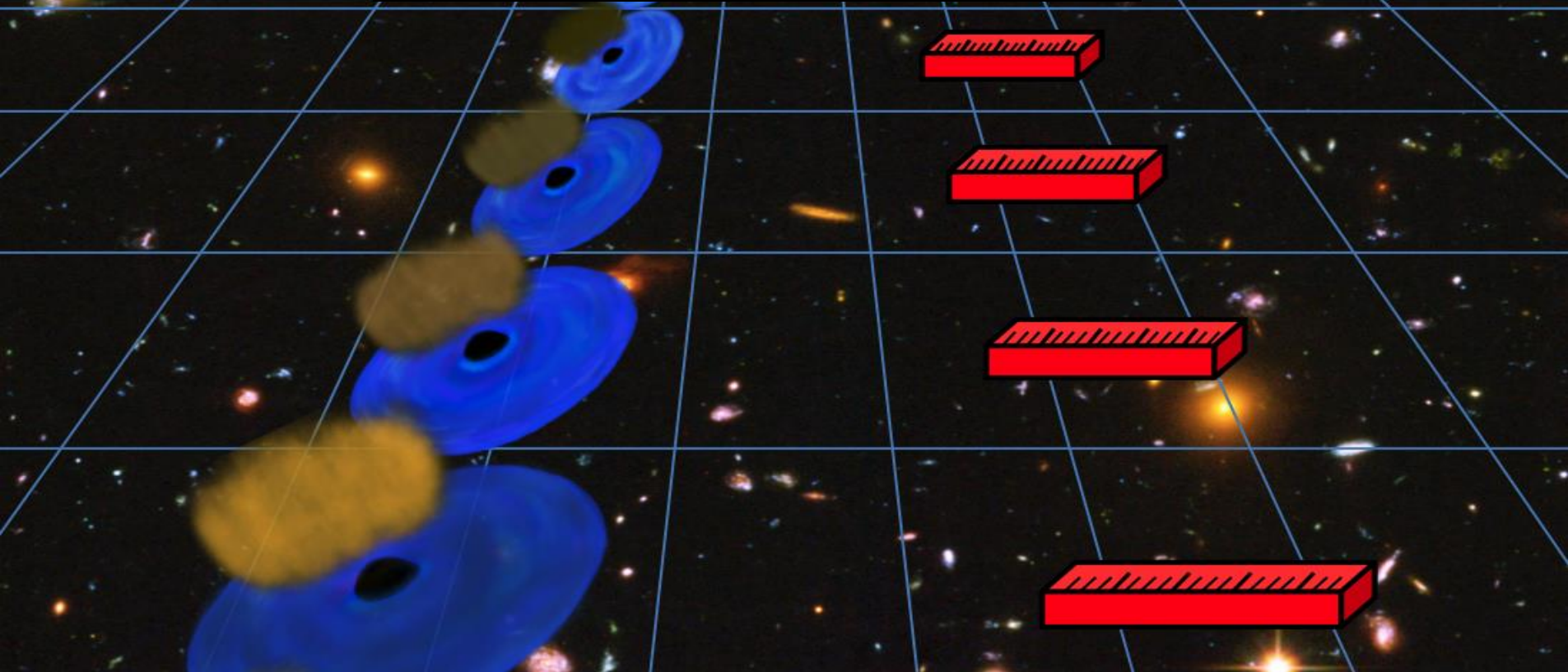


Evidence of evolving dark energy from a Hubble Diagram of Quasars

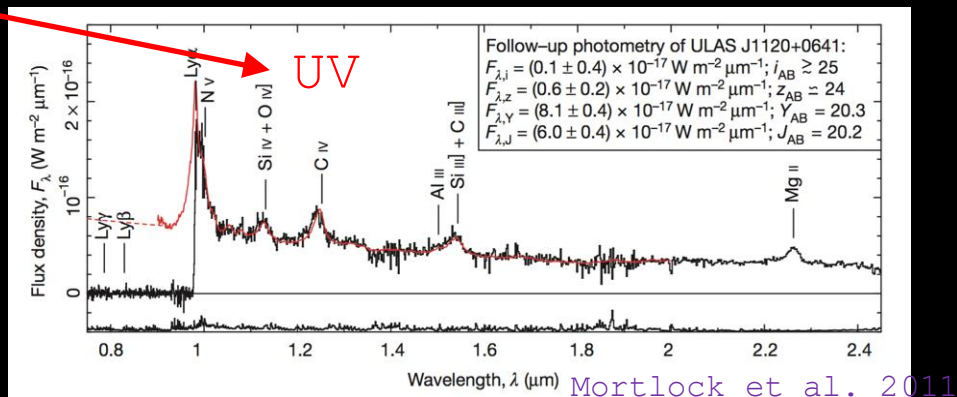
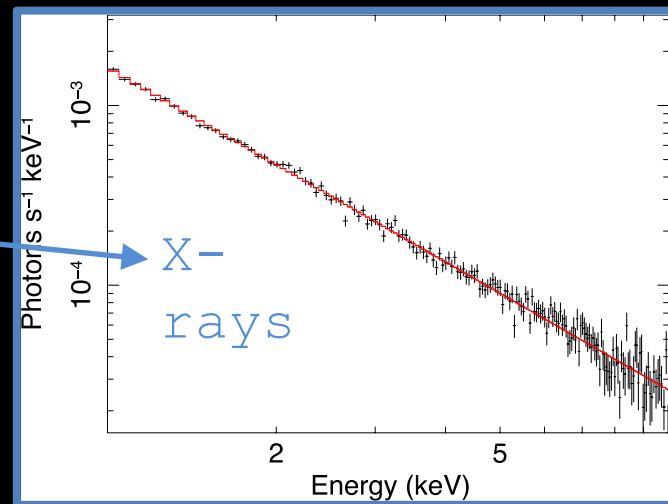
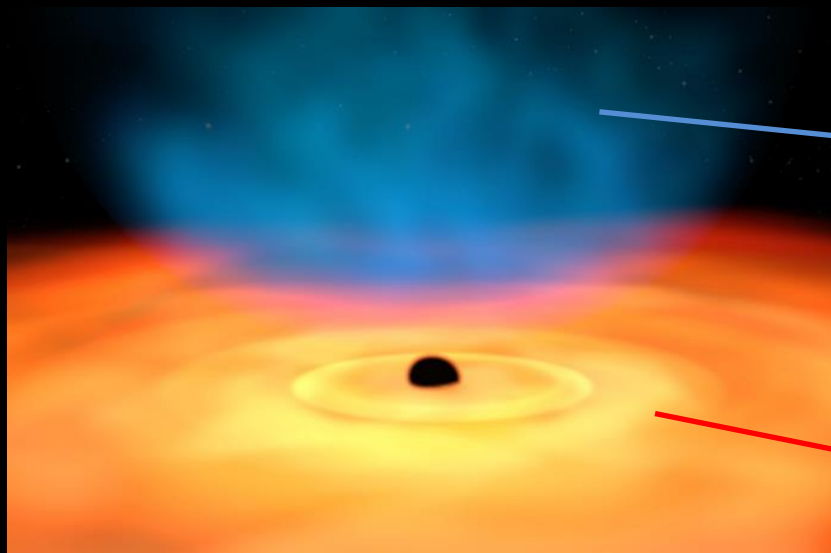
Guido Risaliti

University of Florence & INAF – Arcetri Observatory, ITALY

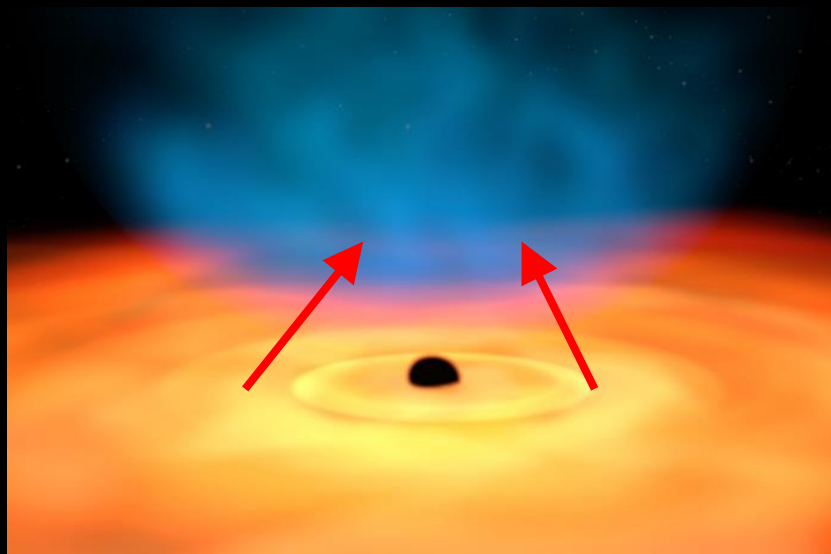
Elisabeta Lusso, G. Bargiacchi, S. Bisogni, E. Nardini, A. Sacchi, M. Signorini, B. Trefoloni



The inner emission regions in quasars



The inner emission regions in quasars



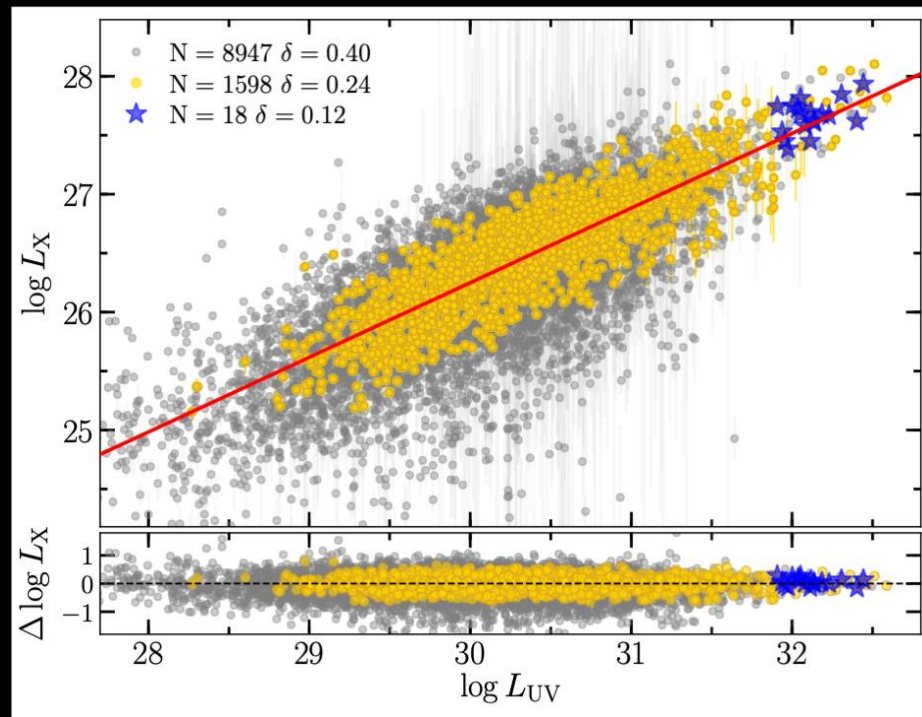
$$\log(L_X) = 0.6 \log(L_{UV}) + 8.5$$



$L_v(2 \text{ keV})$



$L_v(2500 \text{ Å})$

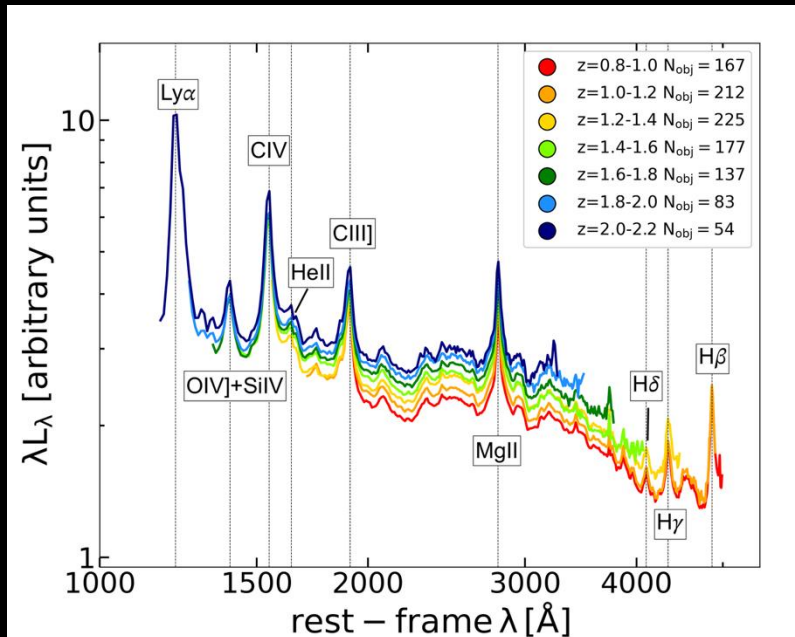
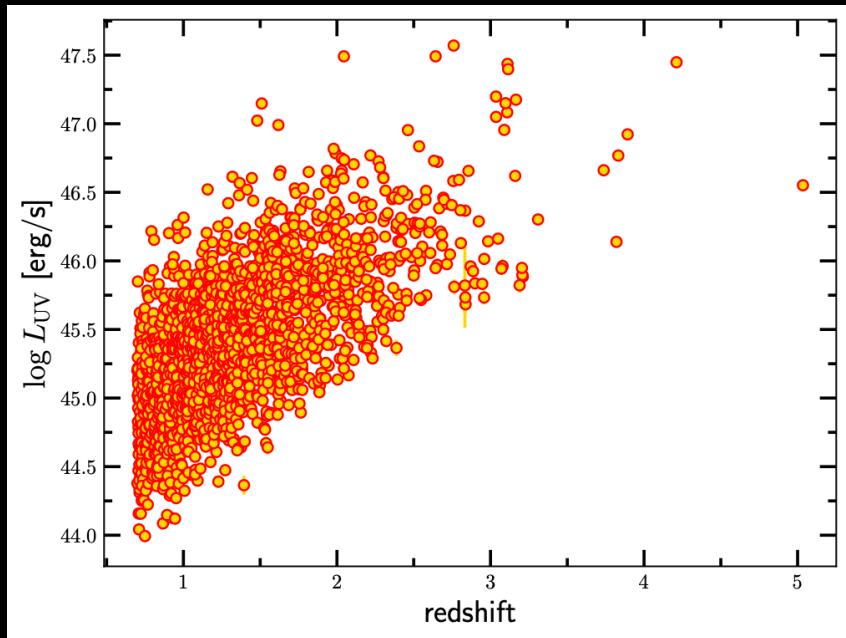


Risaliti & Lusso 2019
Lusso et al. 2020

A NEW XMM-SDSS AGN SAMPLE FOR COSMOLOGY

SDSS DR16 - 4XMM-DR14

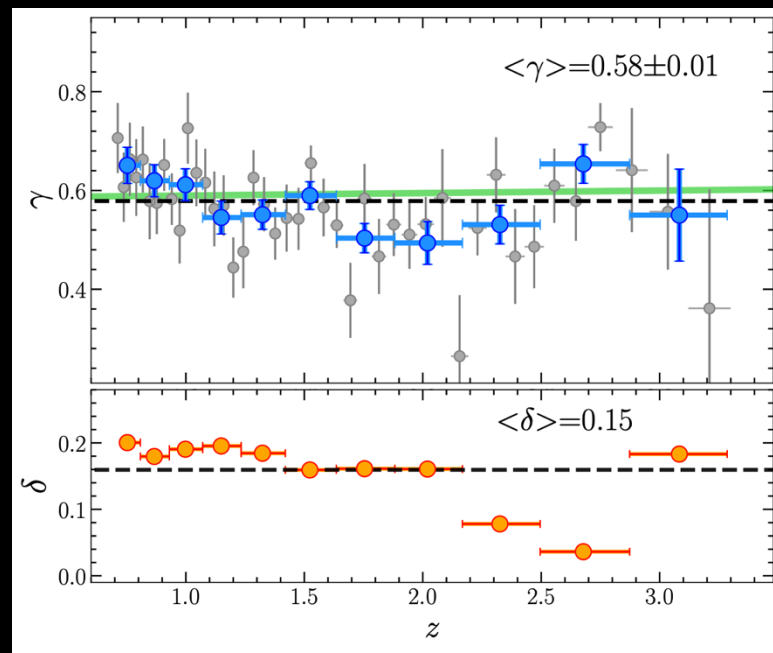
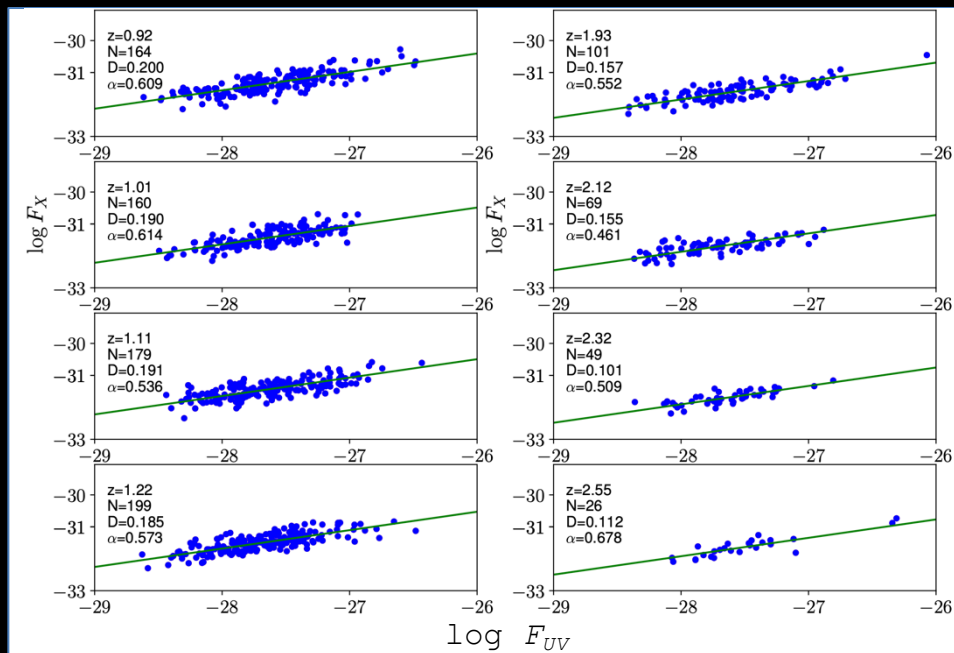
1972 quasars $0.7 \lesssim z \lesssim 3.5$ highly homogeneous
e.g. no BAL, no red AGN (UV), no gas obscured AGN (X-ray), no radio
bright, corrected for the Eddington bias



A NEW XMM-SDSS AGN SAMPLE FOR COSMOLOGY

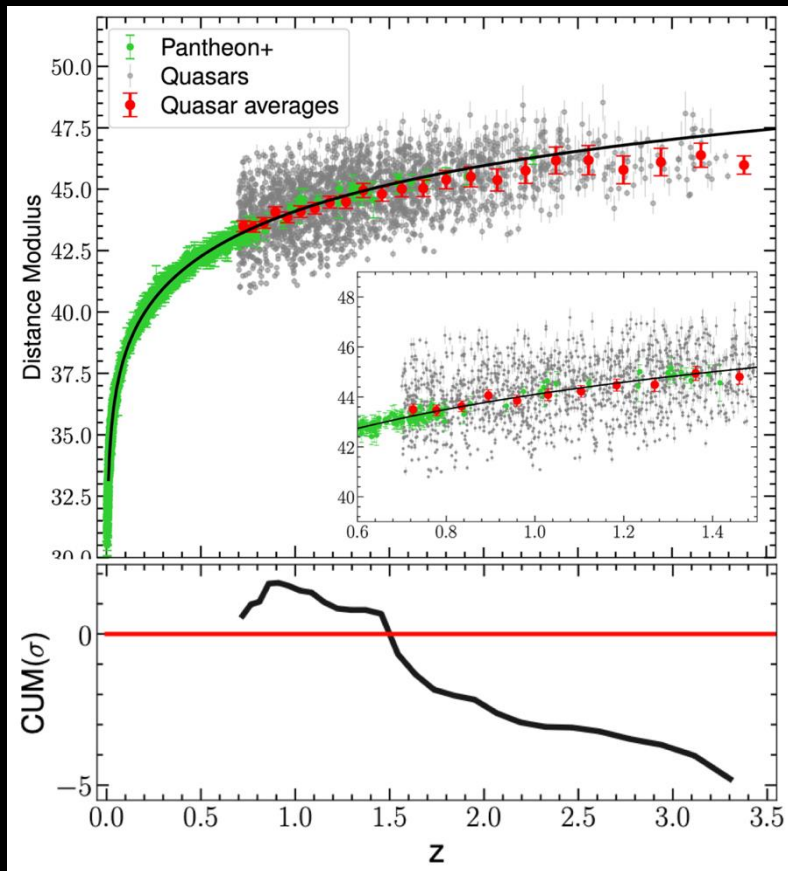
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A NEW XMM-SDSS AGN SAMPLE FOR COSMOLOGY

Hubble Diagram with $\sim 2,000$ quasars

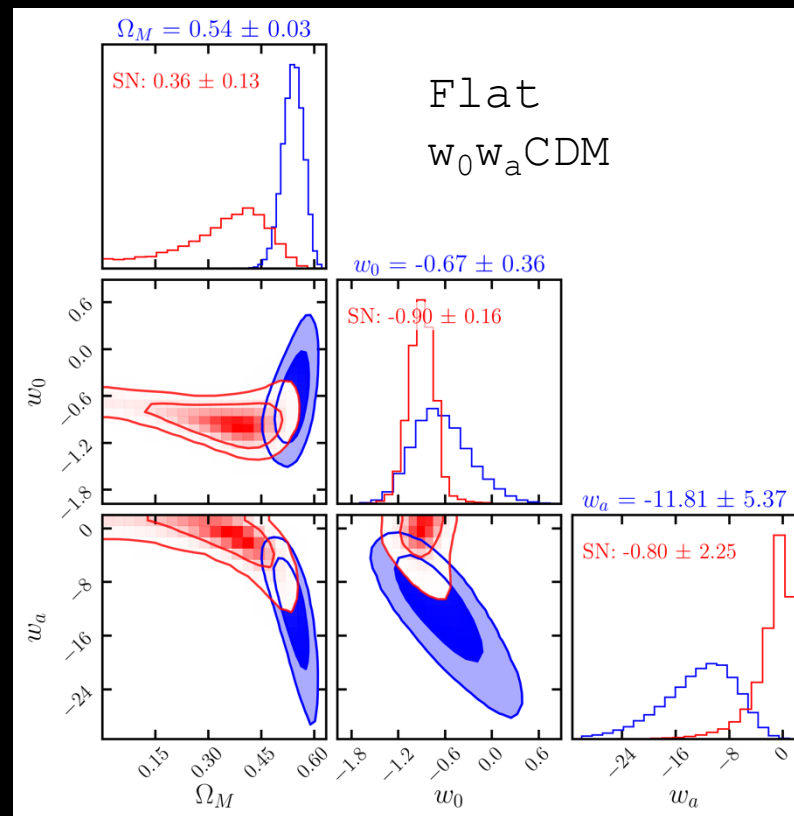
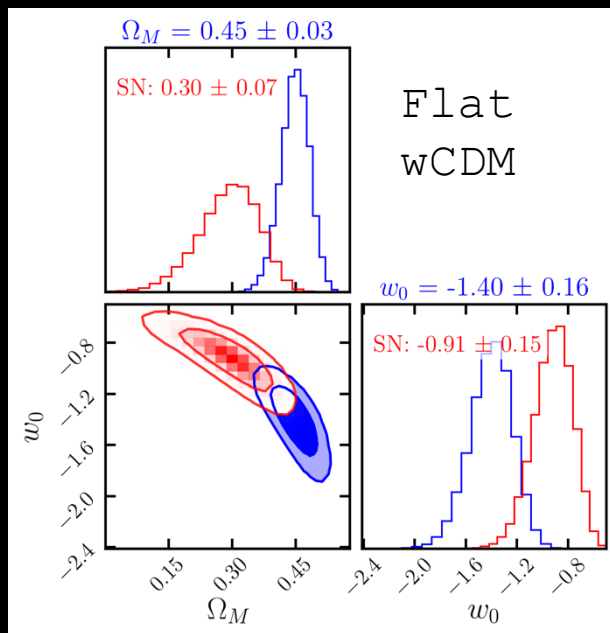


Perfect match with Pantheon+ SNe and with the flat Λ CDM model in the overlapping redshift range ($0.7 < z < 1.5$)

Strong deviation at $z > 1.5$

A NEW XMM-SDSS AGN SAMPLE FOR COSMOLOGY

Hubble Diagram with $\sim 2,000$ quasars



Deviation from the **flat Λ CDM** model at **high redshift**
Prevalence for **evolving dark energy over time**
(e.g. Risaliti & Lusso 2019, Lusso et al. 2020)

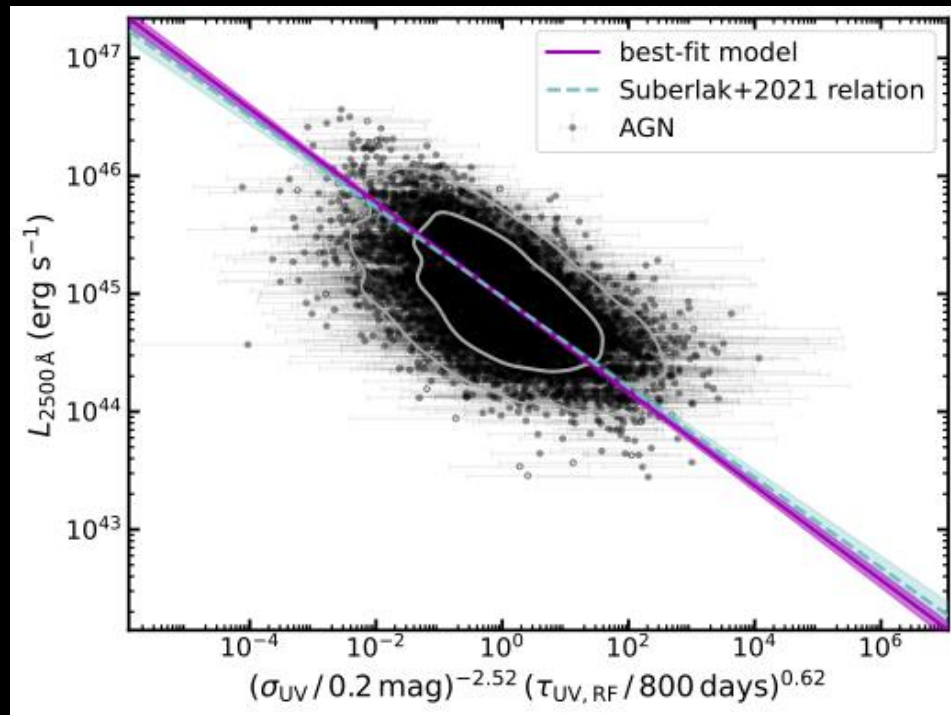
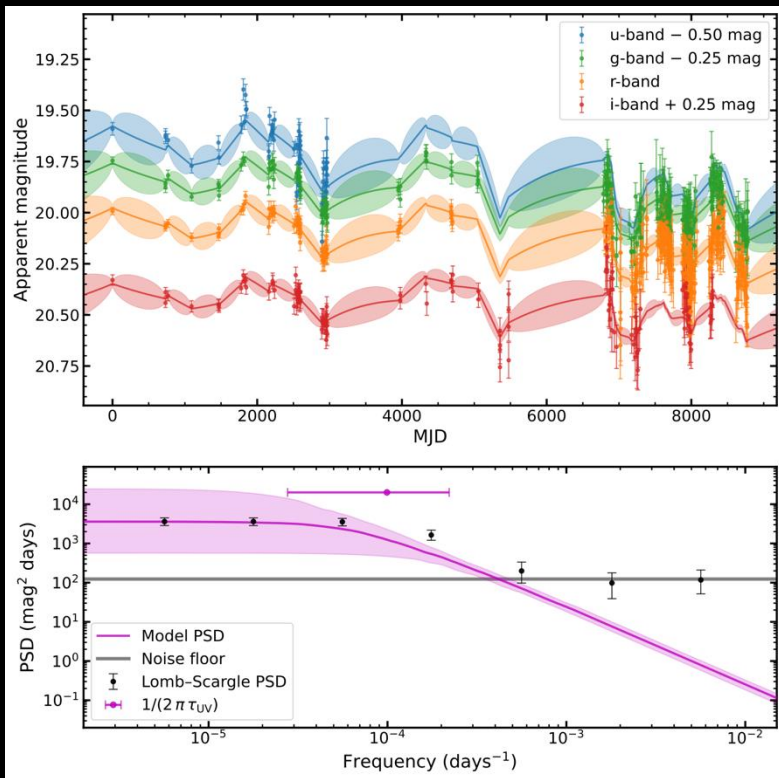
We did all the boring, but required, analysis to test possible
biases and systematics
(e.g. Lusso et al. 2025)

Do we really have to wait for high- z SNe Ia for an
independent confirmation of our results?

ANOTHER METHOD TO DERIVE QUASAR DISTANCES!

Dutra et al. 2025 arXiv: 2512.07931

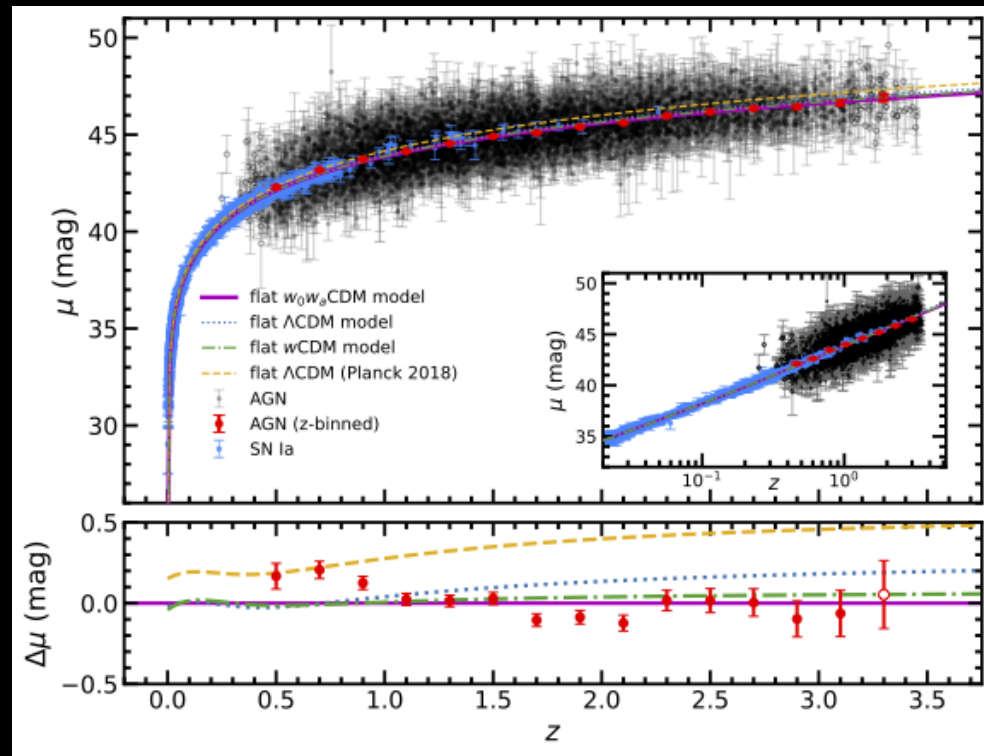
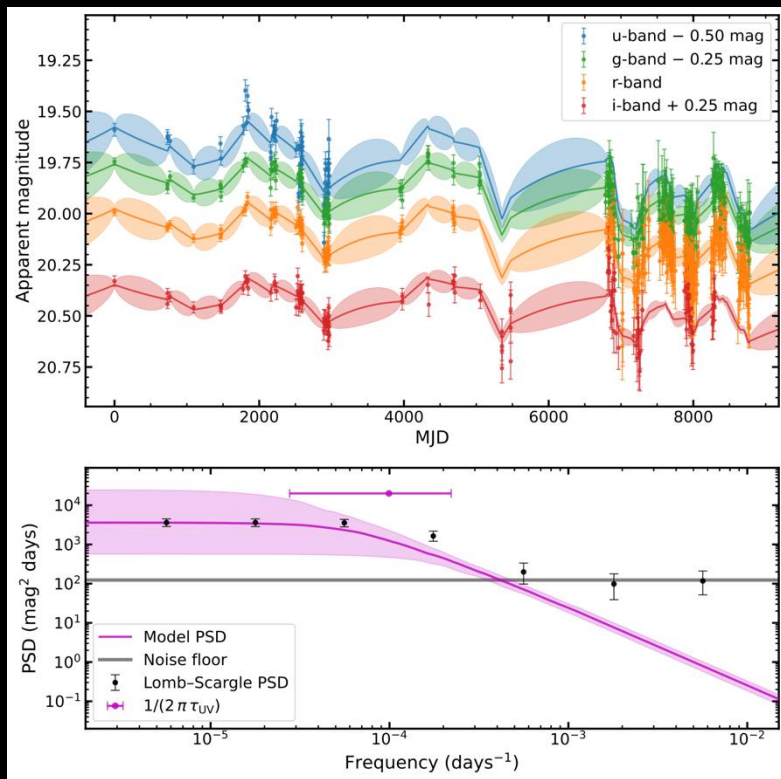
~20-year, multi-band optical light curves for ~7000 AGN $0.4 < z < 3.2$



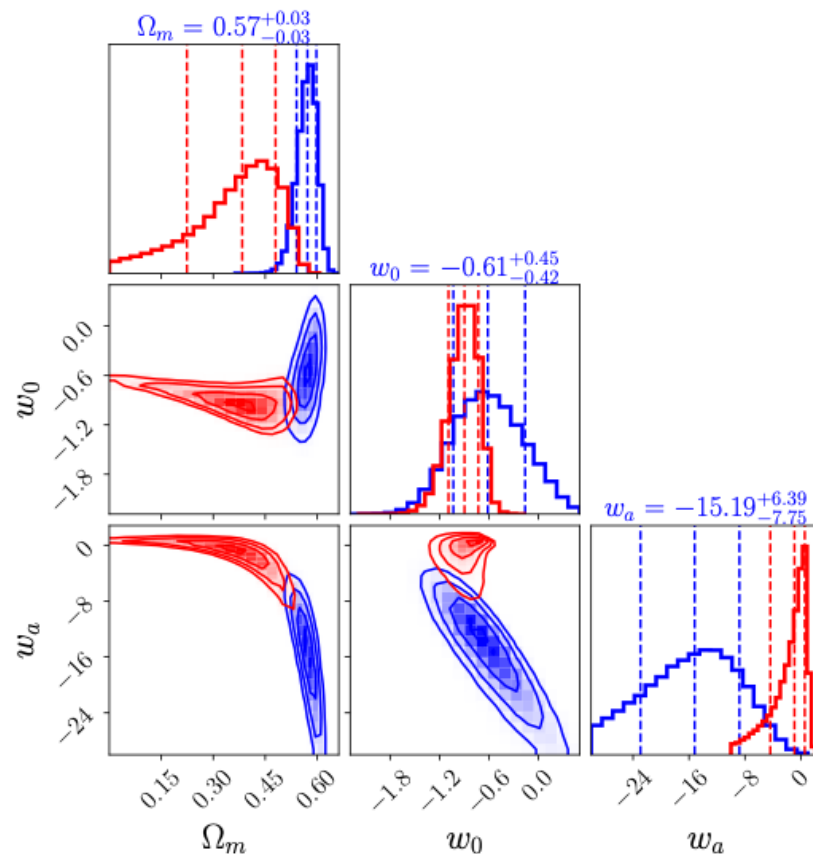
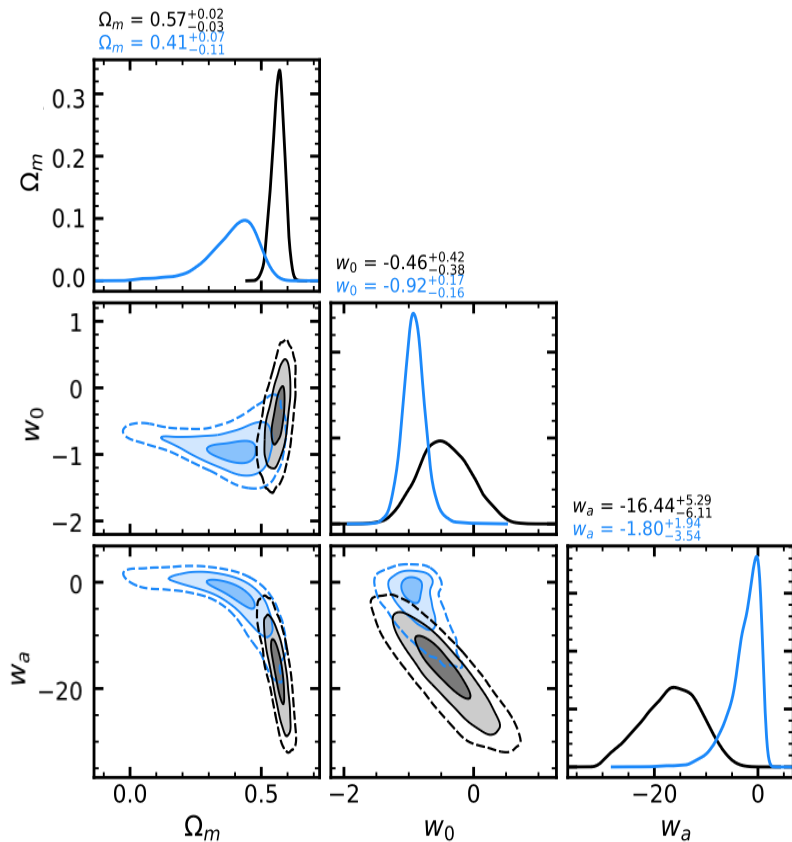
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~20-year, multi-band optical light curves for ~7000 AGN $0.4 < z < 3.2$



ANOTHER METHOD TO DERIVE QUASAR DISTANCES!



ANOTHER METHOD TO DERIVE QUASAR DISTANCES!

$$\Omega_m = 0.57^{+0.02}_{-0.03}$$

For the **first time**, independent AGN probes find evidences for **evolving dark energy** (and are in agreement 😊!)

