Constraining the cosmological parameters with reverberation-measured quasars

Dr. Mary Loli Martínez-Aldama*

Prof. Bozena Czerny

Ms. Swayamtrupta Panda

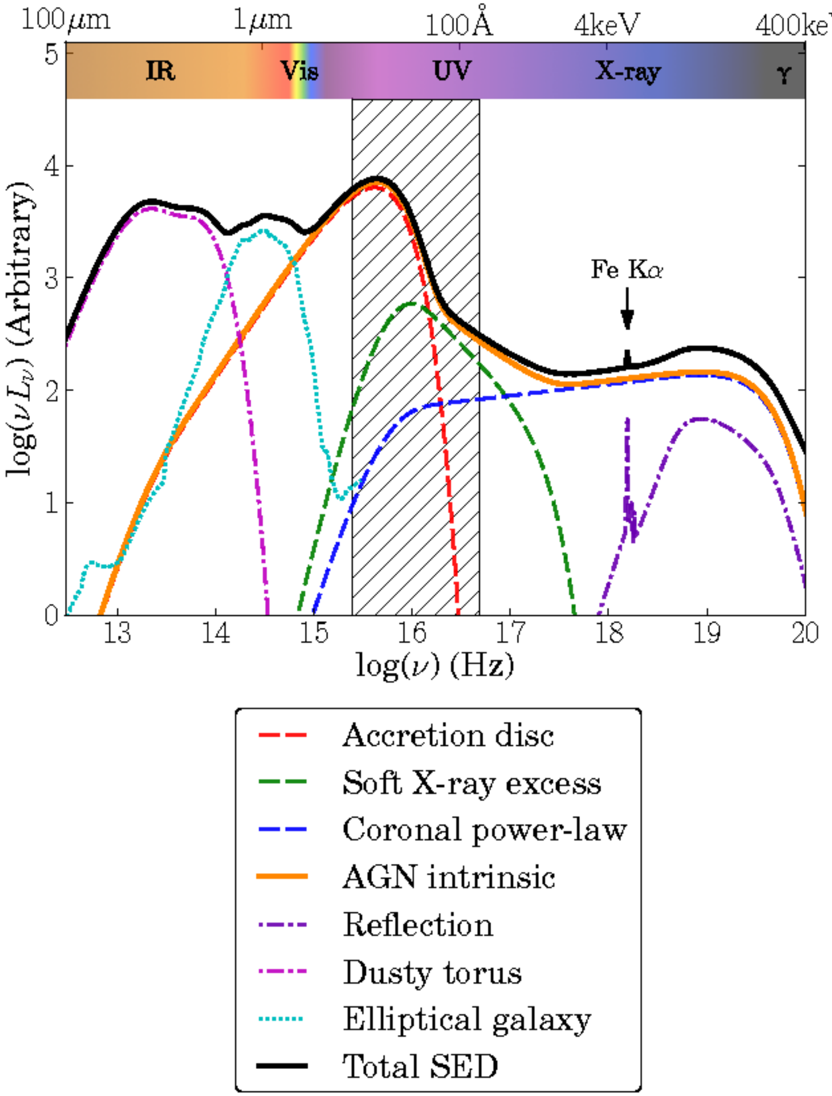
Dr. Michal Zajacek

Center for Theoretical Physics, PAN

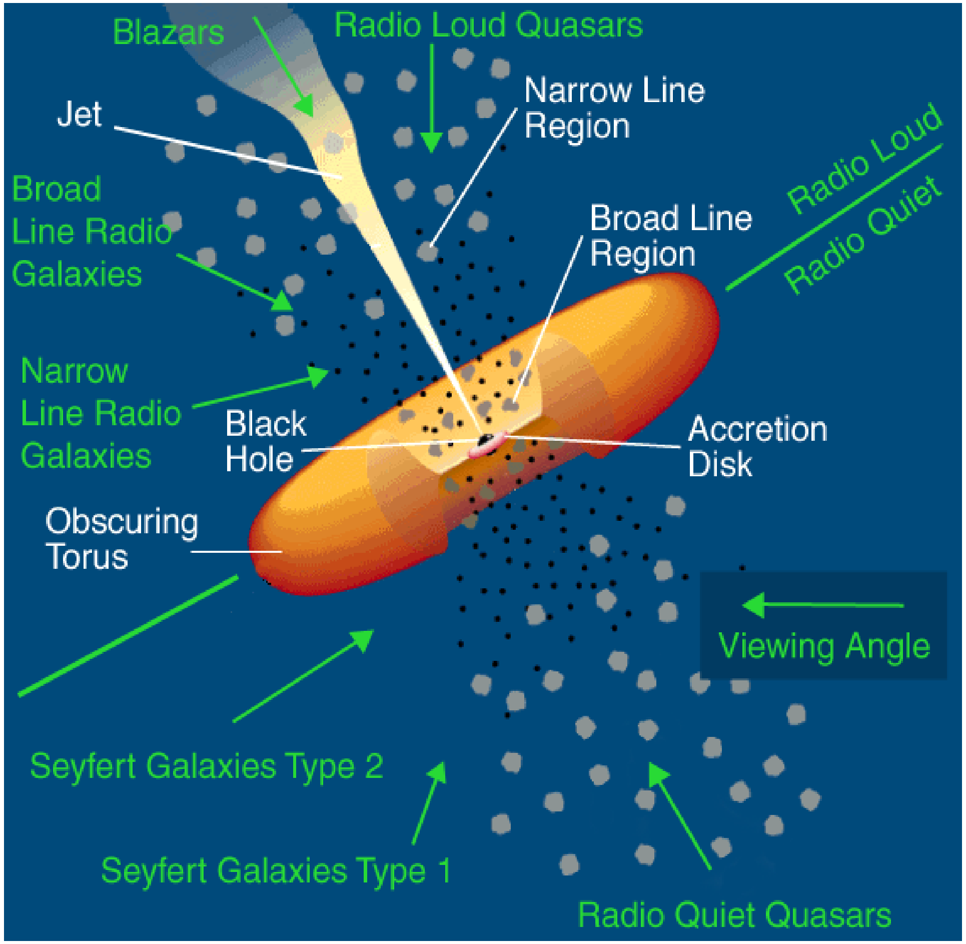
Particle Astrophysics in Poland 2019

*mmary@cft.edu.pl

Active Galactic Nuclei



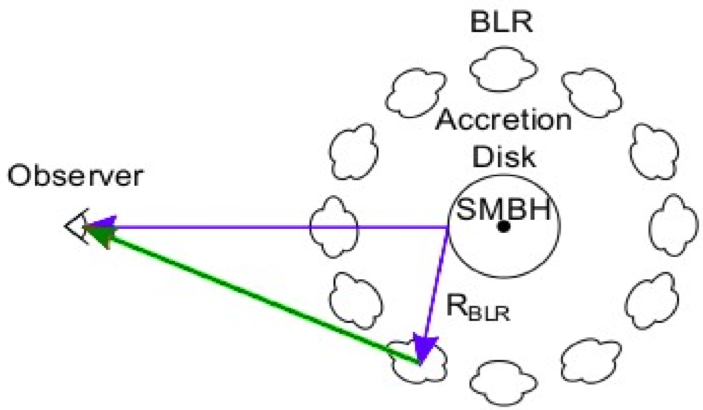
Collinston+ 17

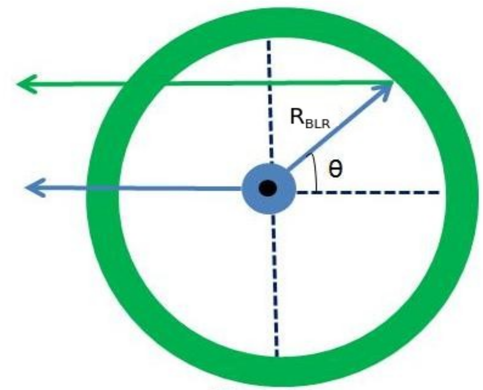


Urry & Padovani 95

Reverberation mapping

Reverberation mapping measures the time delay (t) between the variability of the continuum source and the variability of the BLR.

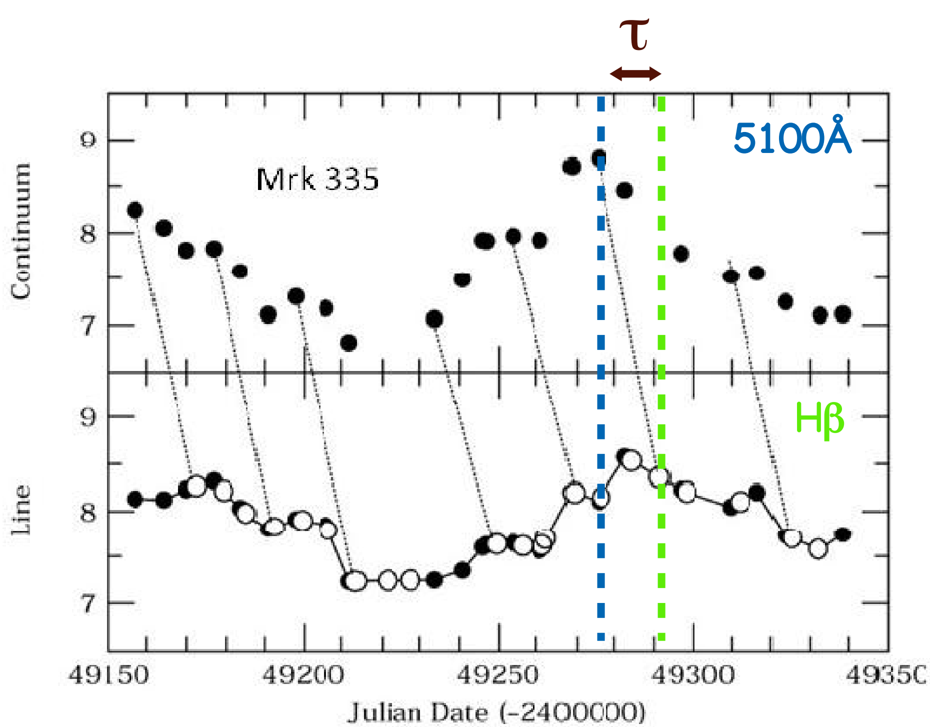




τ : Time delay

$R_{BLR} = c \cdot \tau$

Light curves

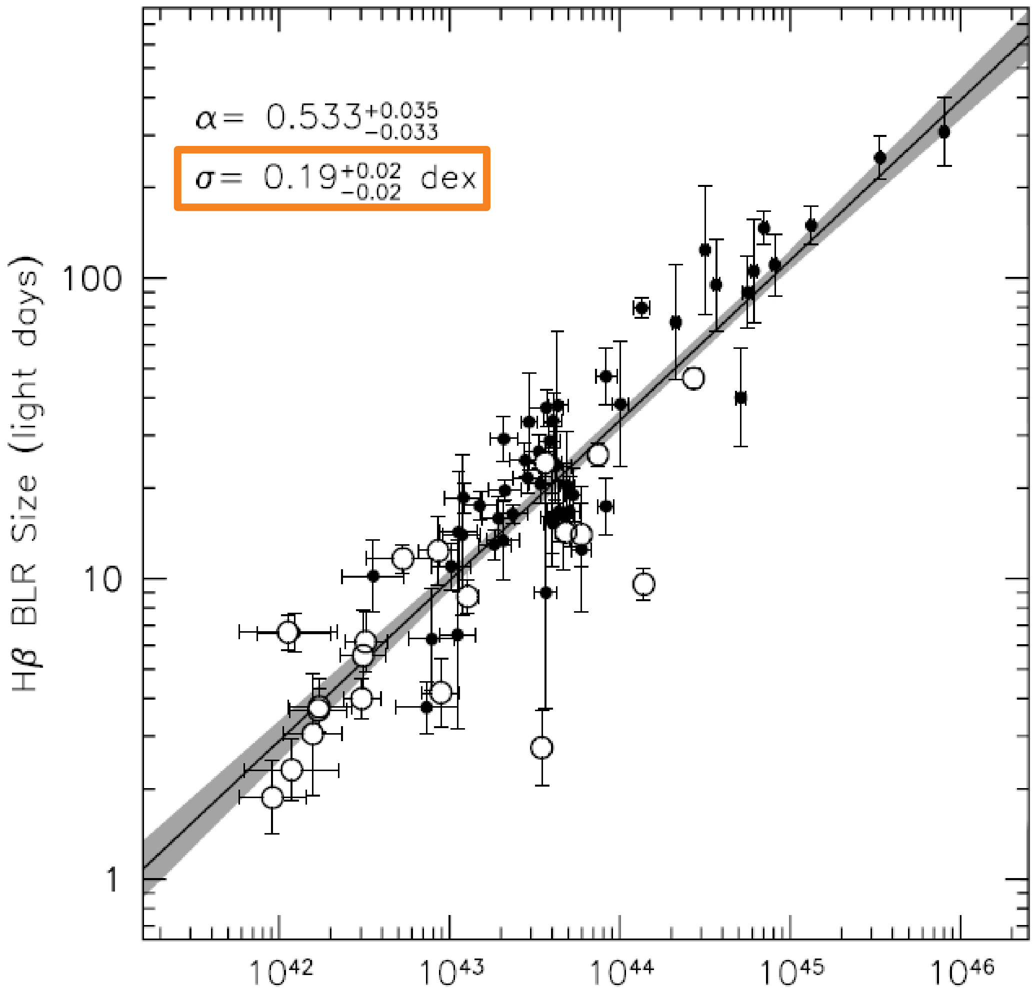


Peterson+ 01

Radius-Luminosity relation

$R_{BLR} = c \cdot \tau$

$$\log\left(\frac{R_{\rm BLR}}{1 \rm lt-day}\right) = (1.527 \pm 0.31) + 0.533^{+0.035}_{-0.033} \log\left(\frac{L_{5100}}{10^{44} L_\odot}\right)$$



Bentz+ 13

Obtaining the R_{BLR}, we can estimate the black hole mass:

$$M_{\rm BH} = f_{\rm BLR} \frac{R_{\rm BLR}\, v^2}{G}$$

G : Gravitational constant

R_{BLR} : size of the BLR

f_{BLR} : virial factor, ~1

Orientation effect

$$f^{c}_{\rm BLR} = \left(\frac{\rm FWHM_{obs}}{4550}\right)^{-1.17}$$

And the accretion parameters:

- Adimensionless accretion rate:

$$\dot{\mathscr{M}} = 20.1 \left(\frac{l_{44}}{\cos i}\right)^{3/2} m_7^{-2}$$

- Eddington ratio

$$L_{\rm bol}/L_{\rm Edd}.$$

L_{bol}=BC • L_{5100}, BC=10.33

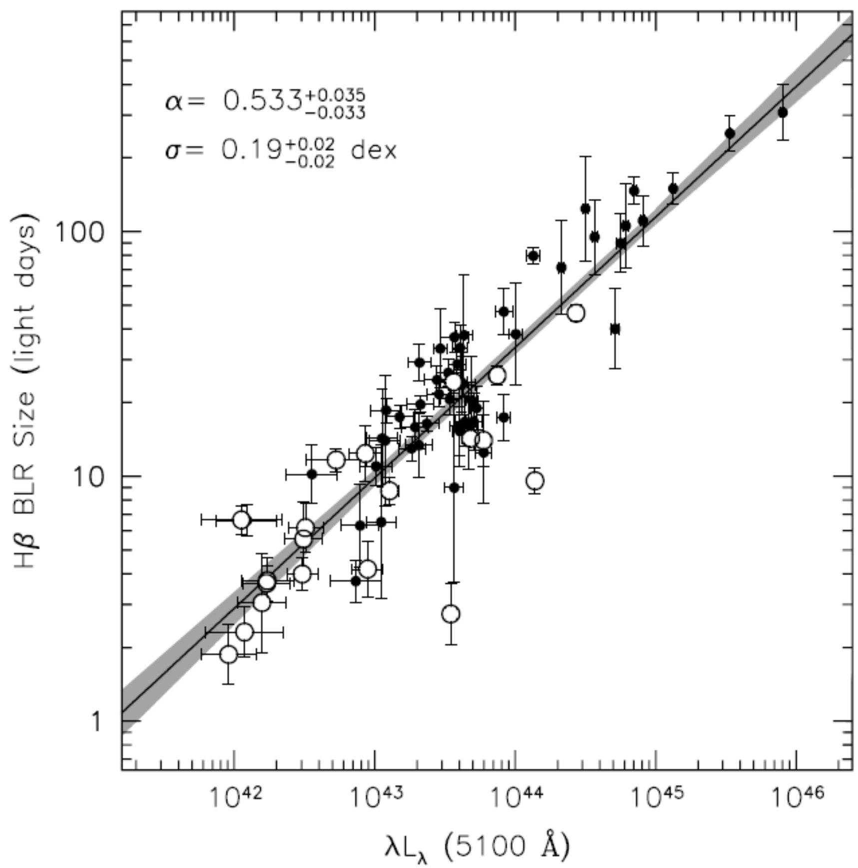
$$L_{\rm Edd} = 1.5 \times 10^{38} \left(\frac{M_{BH}}{M_\odot}\right)$$

Increasing the sample

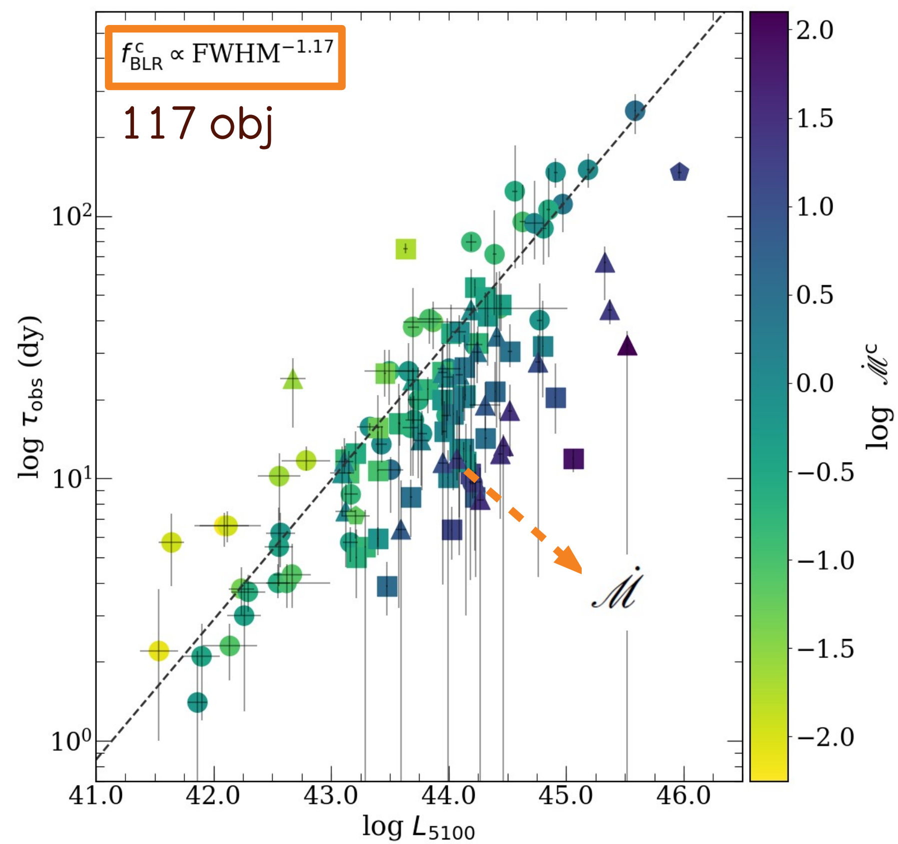
The inclusion of new sources (Du+ 15,16,18, Grier+17) increases the scattering in the RL relation, and the departures from it seems to be related with the accretion rate (Du+15,16,18).

117 objects
SDSS-RM
SEAMBH
Bentz collection

- $0.02 < z < 0.89$
- $41.5 < \log L_{5100} < 45.9$
- $0.005 < \dot{\mathscr{M}}^{c} < 778.79$



Bentz+ 13

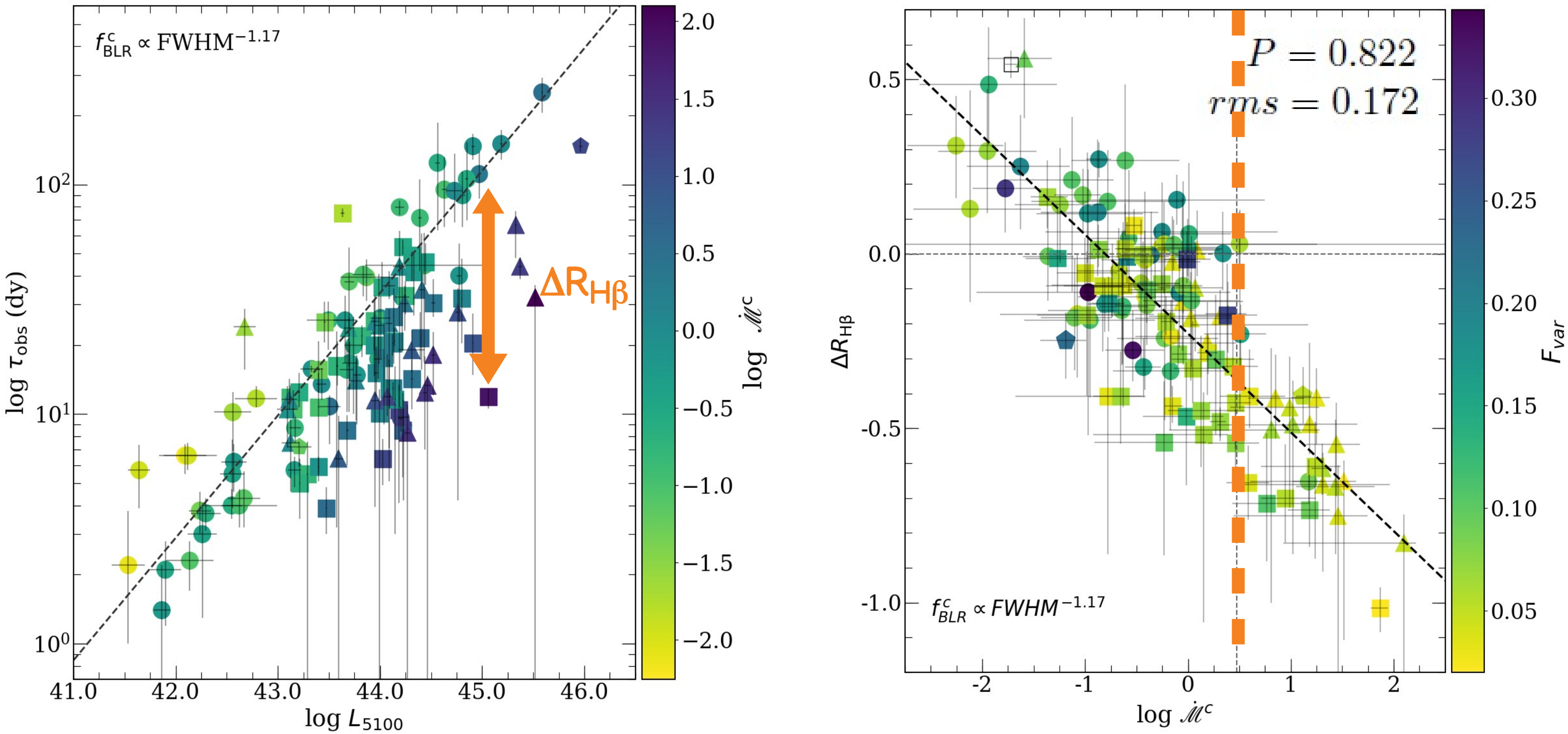


Martínez-Aldama+19 submitted

Departures from the RL relation

$$\Delta R_{\mathrm{H}\beta} = \log\left(\frac{R_{\mathrm{H}\beta}}{R_{\mathrm{H}\beta\,\mathrm{R-L}}}\right) = \log\left(\frac{\tau_{\mathrm{obs}}}{\tau_{\mathrm{H}\beta\,\mathrm{R-L}}}\right)$$

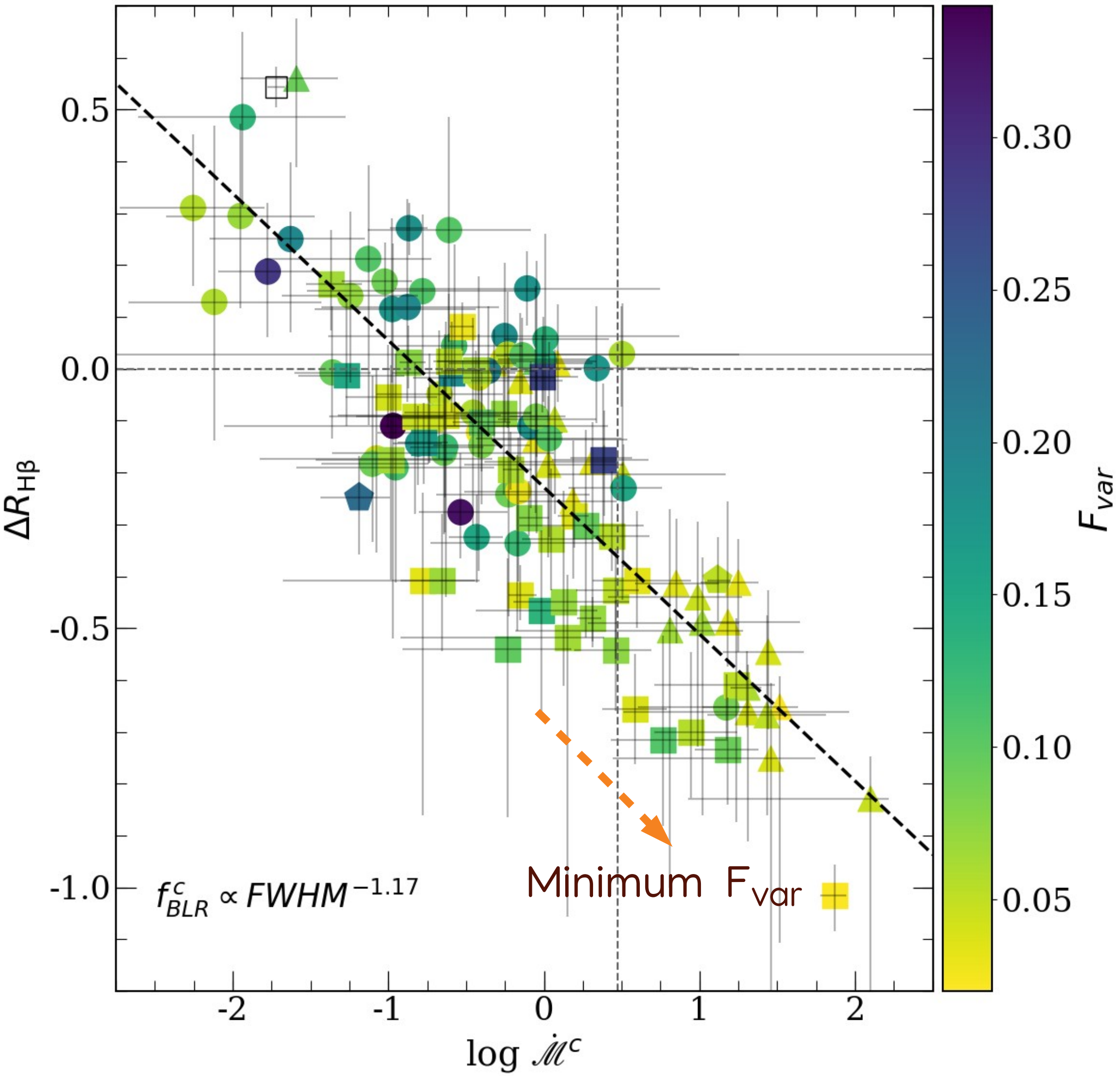
(Du+ 15,16,18)



$$\Delta R_{\mathrm{H}\beta,\dot{\mathscr{M}}^c} = (-0.283 \pm 0.017)\log\dot{\mathscr{M}}^c + (-0.228 \pm 0.016)$$

Variability

From the light curves is possible to estimate the parameter F_{var}, which measures the *rms* of the intrinsic variability relative to the mean flux.



$$F_{\rm var} = \frac{(\sigma^2 - \Delta^2)^{1/2}}{\langle f \rangle}$$

$$\sigma^2 = \frac{1}{1-N} \sum_{i=1}^{N} (f_i - \langle f \rangle)^2$$

$$\Delta^2 = \frac{1}{N} \sum_{i=1}^{N} \Delta_i^2$$

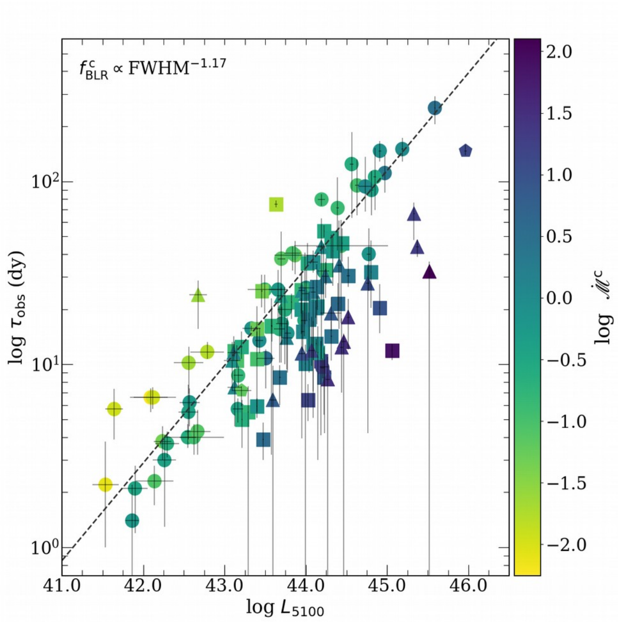
$$\langle f \rangle = \frac{1}{N} \sum_{i=1}^{N} f_i$$

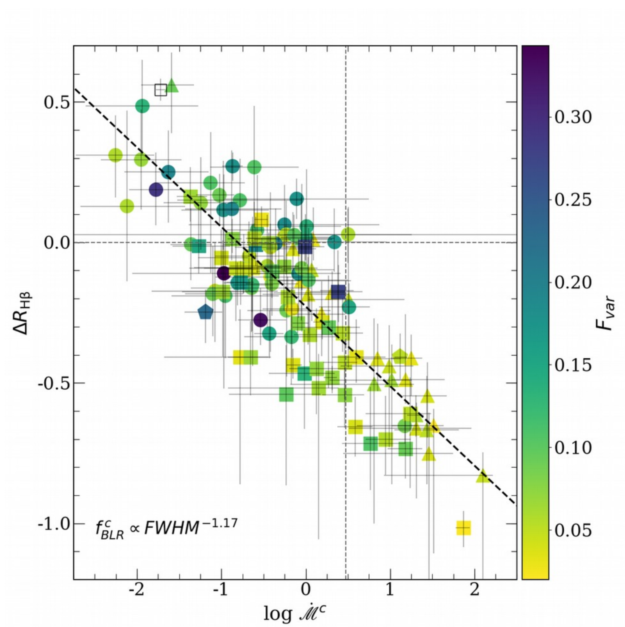
(Rodríguez-Pascual+ 97)

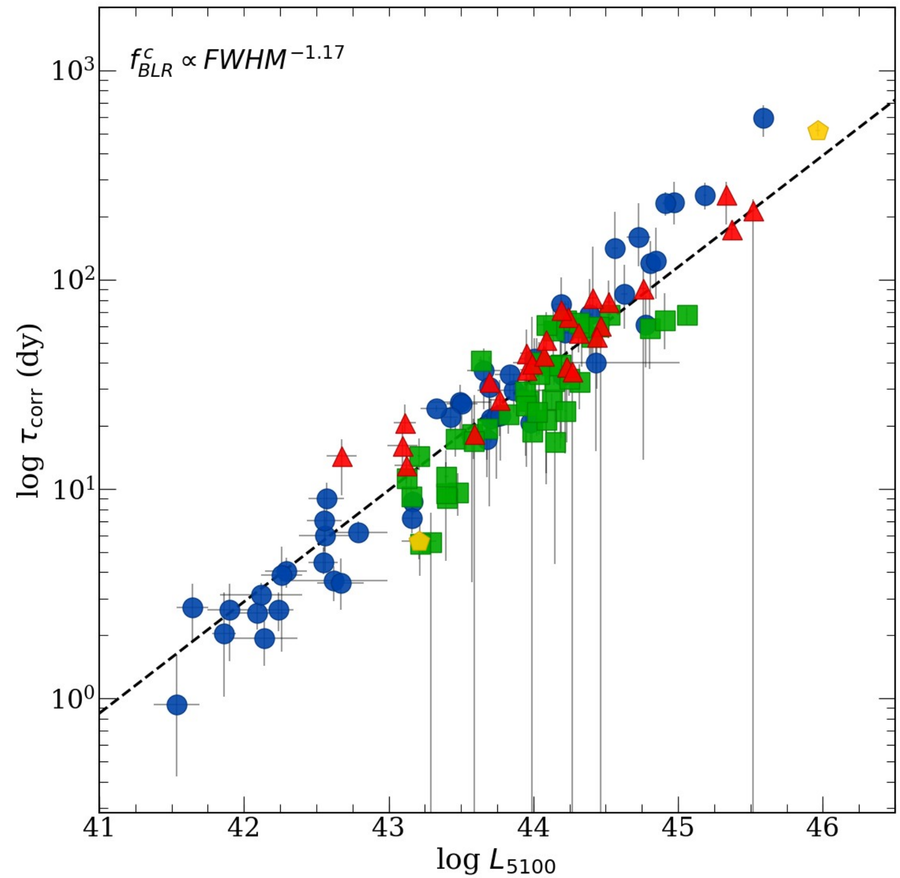
F_{var} seems to be anti-correlated with the dimensionless accretion rate, $\dot{\mathscr{M}}^c$.

Times delay corrected by the accretion rate effect

$$\tau_{\rm corr}(\dot{\mathscr{M}}^{c}) = 10^{-\Delta R_{\rm H\beta}(\dot{\mathscr{M}}^{c})} \cdot \tau_{\rm obs}$$







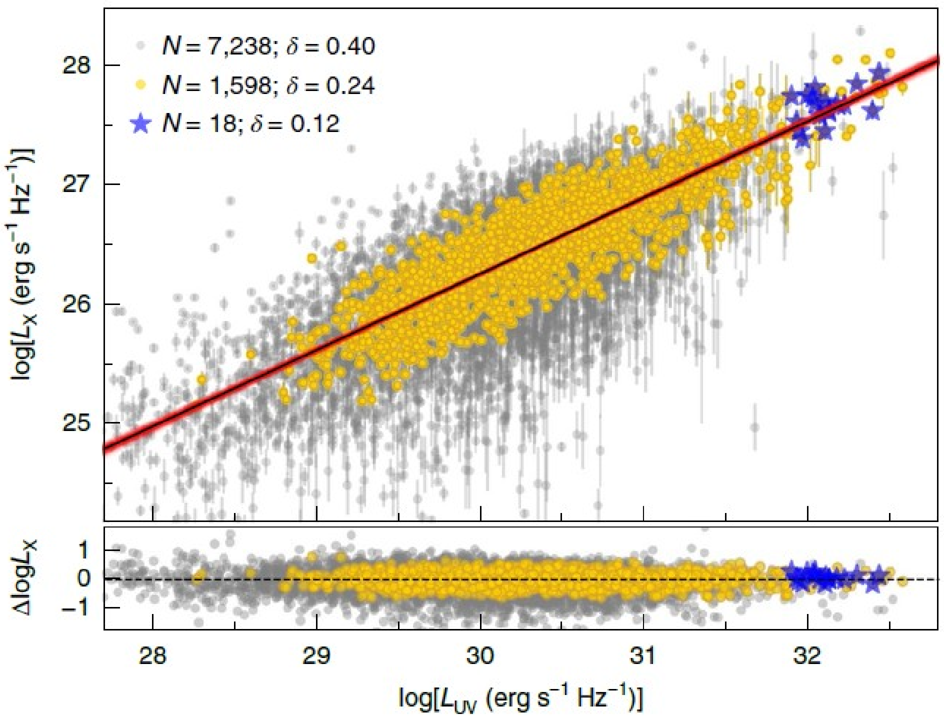
Recovering the expected values, we are in a strong position to used the information provided by the RL with cosmological purposes.

QSO & Cosmology

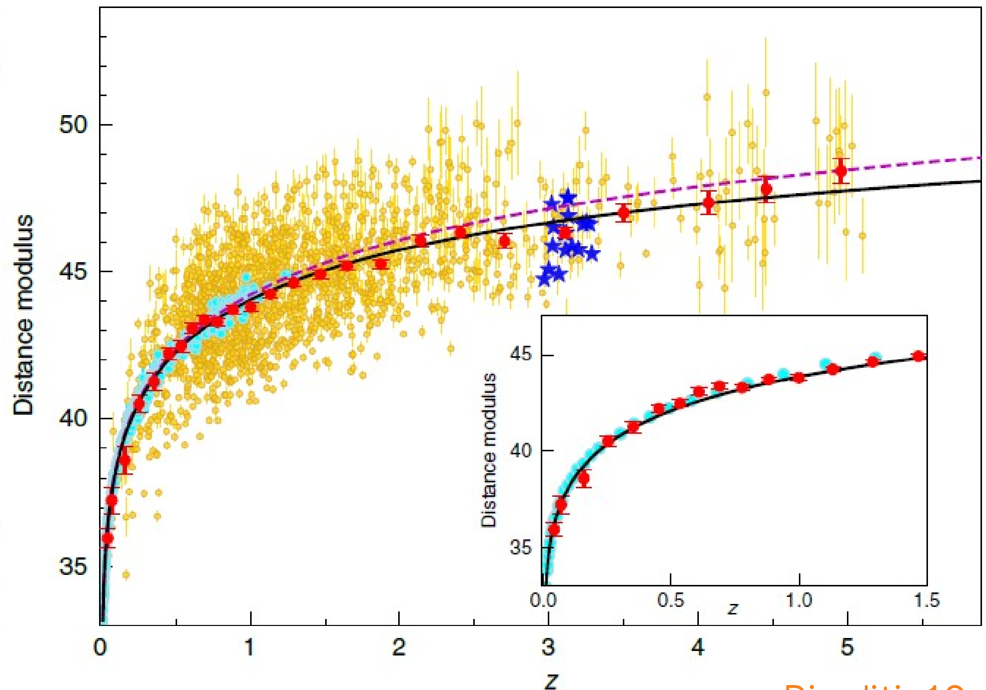
- SN1A has been observed in a low redshift range, z~1.4
- QSO are amog the brightest objects observed in a large redshift range (z~7, Mortlock+, 11).

Sources	Parameters	Basic equation	Reference	Virial
extremely accreting quasars (xA)	Hard X-ray slope, velocity dispersion	$\mathcal{D}_\bullet = \frac{1}{\sqrt{4\pi}}\left[\frac{l_0\,(1+a\ln\dot{m}_{15})\,f_{\rm BLR}R_0}{G\kappa_{\rm B}}\right]^{1/2(1-\alpha)}\frac{V_{\rm FWHM}^{1/(1-\alpha)}}{F_{5100}^{1/2}}.$	Wang et al.2013	V
extremely accreting quasars (xA)	virial velocity dispersion: FWHM(Hβ) Eddington ratio = const	$L \propto \mathrm{FWHM(H\beta)}^4$	Marziani & Sulentic 2014	V
general quasar populations	X-ray variability, velocity dispersion	$\log\frac{L}{\mathrm{erg\,s^{-1}}} + 4\log\frac{\mathrm{FWHM}}{10^3\,\mathrm{km\,s^{-1}}} = \alpha\log\sigma^2_{\rm rms} + \beta,$	La Franca et al. 2014	V
mainly quasars at z<1	Reverberation mapping time delay τ	$\tau/\sqrt{F} \propto d_L$	Watson et al 2011, 2013; Czerny et al.	
general quasar populations	non linear relation between soft X and UV	$\log(F_X) = \Phi(F_{UV}, D_L) = \beta' + \gamma\log(F_{UV}) + 2(\gamma-1)\log(D_L),$	Risalti & Lusso 2016	

QSO & Cosmology: The case of the L_X–L_{UV} relation



Hubble diagram



Risaliti+19

- Individual measurements
- QSO average in redshift bins
- SN1A – JLA survey
- ΛCDM with z<1.4
- $D_L = \ln(10)c/H_0(x + a_2x^2 + a_3x^3)$

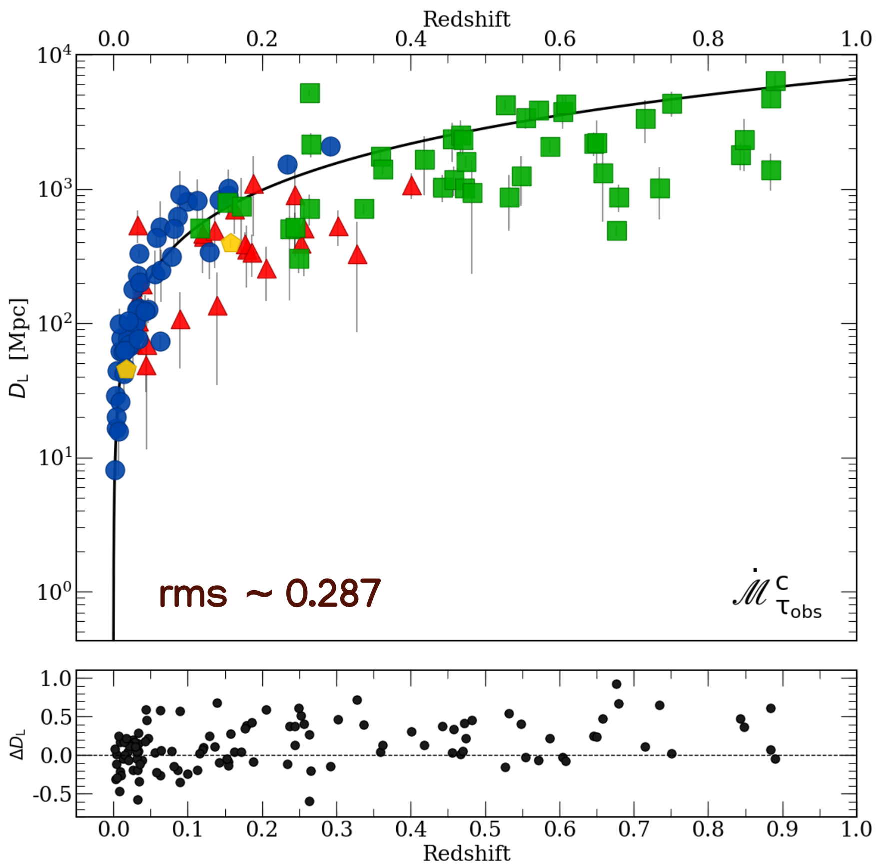
  $x = \log(1+z)$

QSO & cosmology: reverberated-measured QSO

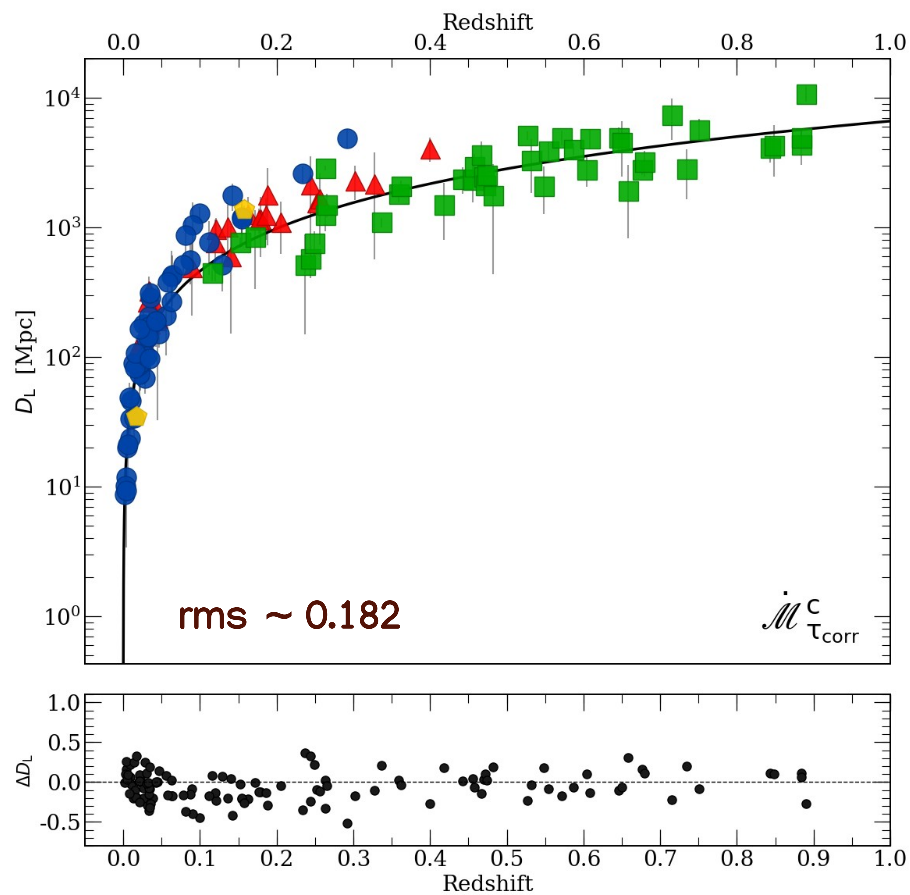
Considering the time delays corrected and the flux of Hβ, we can determine the luminosity at 5100A and after the luminosity distance (D_L).

$$\log\left(\frac{R_{BLR}}{1\mathrm{lt-day}}\right) = (1.527 \pm 0.31) + 0.533^{+0.035}_{-0.033} \log\left(\frac{L_{5100}}{10^{44} L_\odot}\right)$$

$$D_L = \left(\frac{L_{5100}}{4\pi F_{5100}}\right)^{1/2}$$



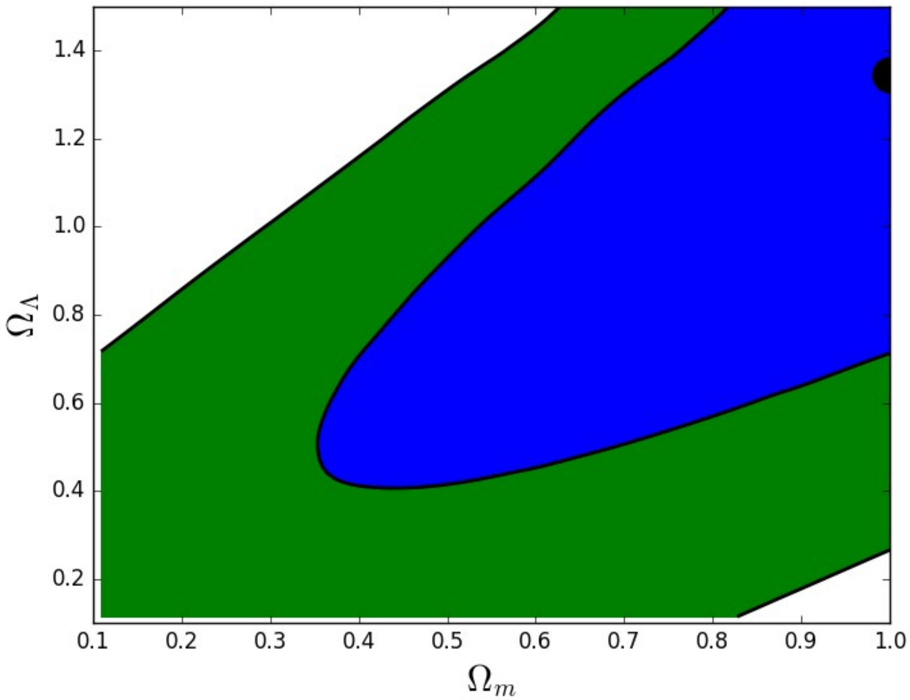
Before $\dot{\mathscr{M}}^c$ correction



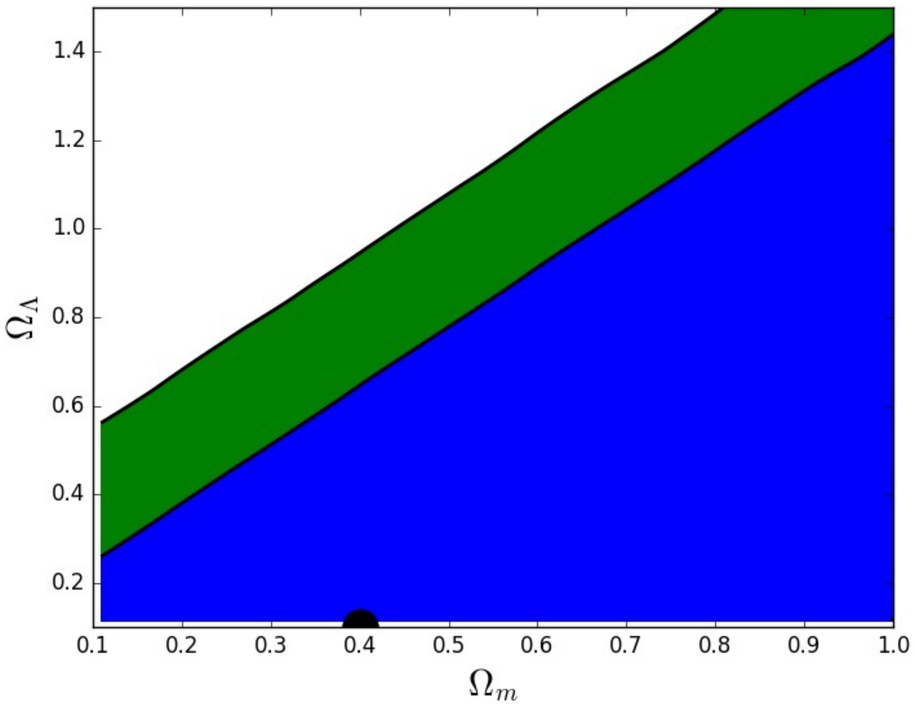
After $\dot{\mathscr{M}}^c$ correction

Cosmological parameters

We are able to estimate the cosmological parameters Ω_m and Ω_Δ, which are consistent with the standard values **(2σ confidence levels).** However, errors are so large and new samples are needed, e.g. SDSS-RM and Oz-DES survey (King+ 15).



117 objects



Object with z>0.4
~30 objects

Summary

- Time delay is affected by the accretion parameters and a correction is needed in order to recover the classical RL relation.

- Variability is anti-correlated with the accretion parameters.

- These results support the idea that *accretion rate is the main driver* in the physical properties of QSO.

- RM results can be used in the future to constrain cosmological models, however it is necessary:

    - A better understanding of the physics of AGN
    - Analyze the light curves with the same method
    - Enlarge the sample; new RM-SDSS date will be published soon
    - Apply a multivariable or Bayesian analysis in the statistical analysis.