Reverberation-measured AGN as Cosmological Standard Candles

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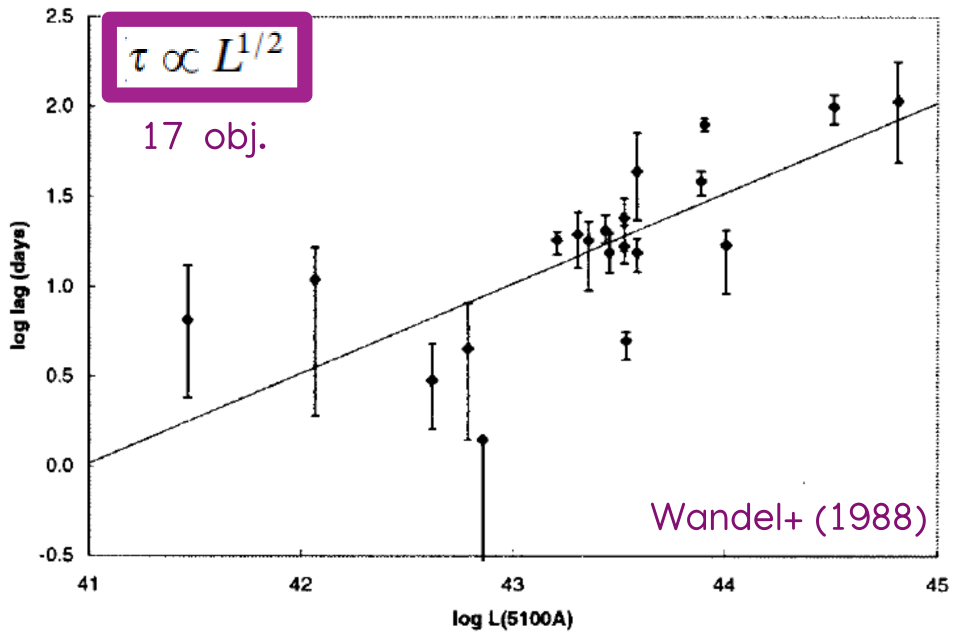
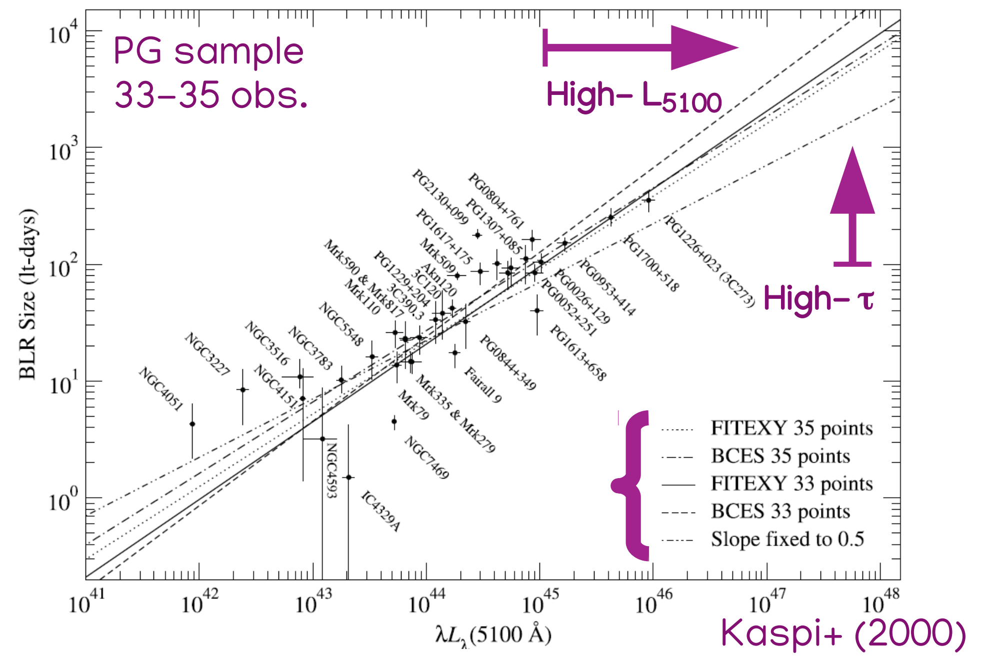
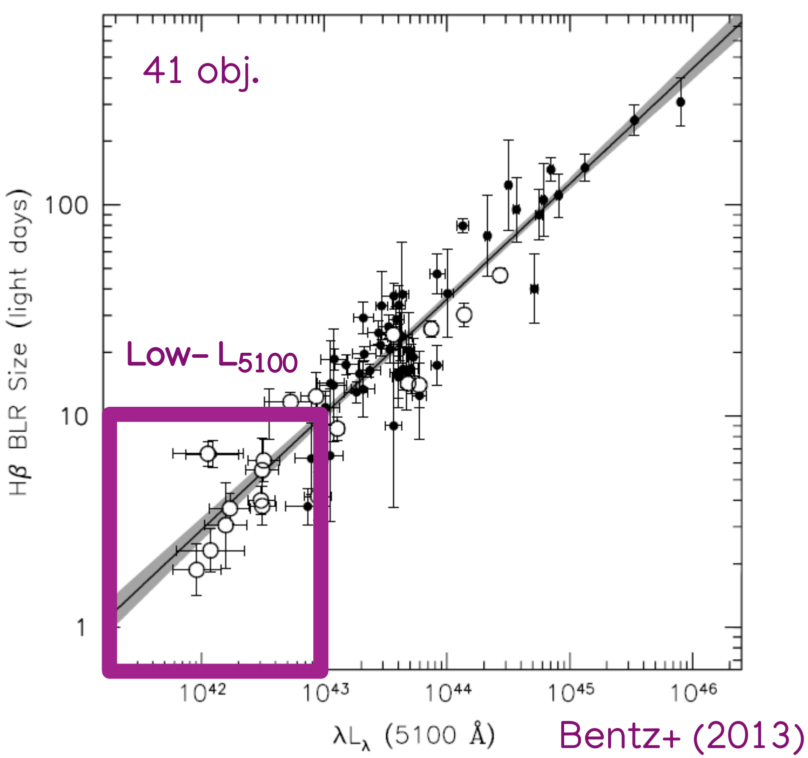
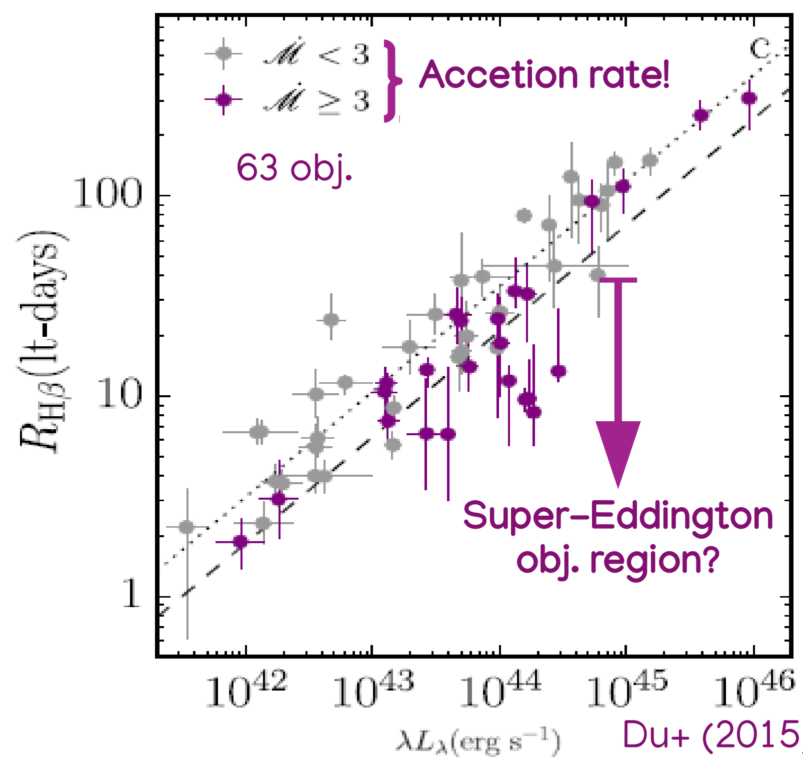
Mapping Central Regions of Active Galactic Nuclei

Radius–Luminosity relation evolution

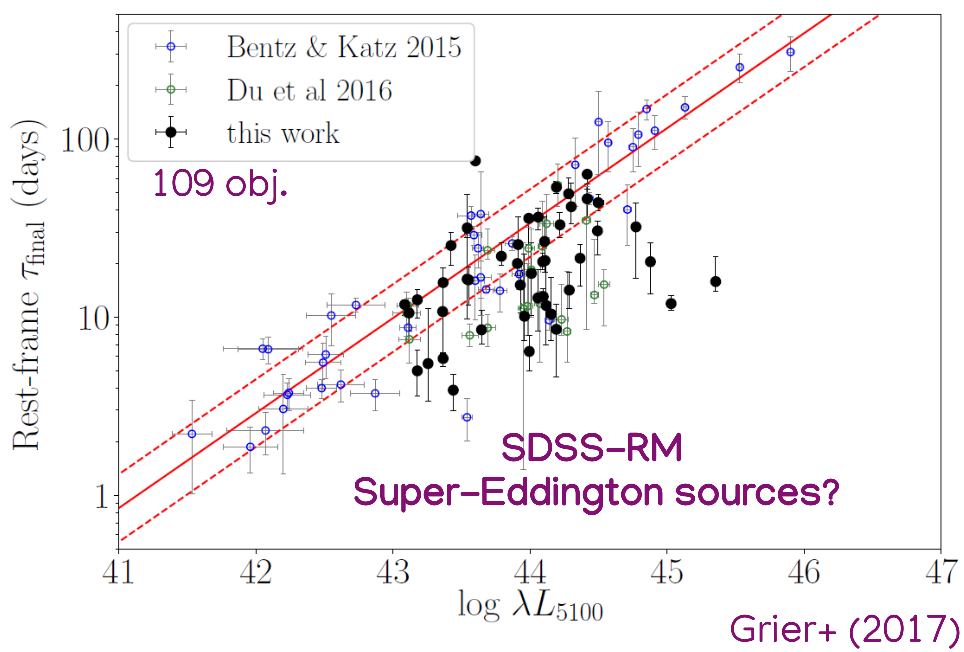


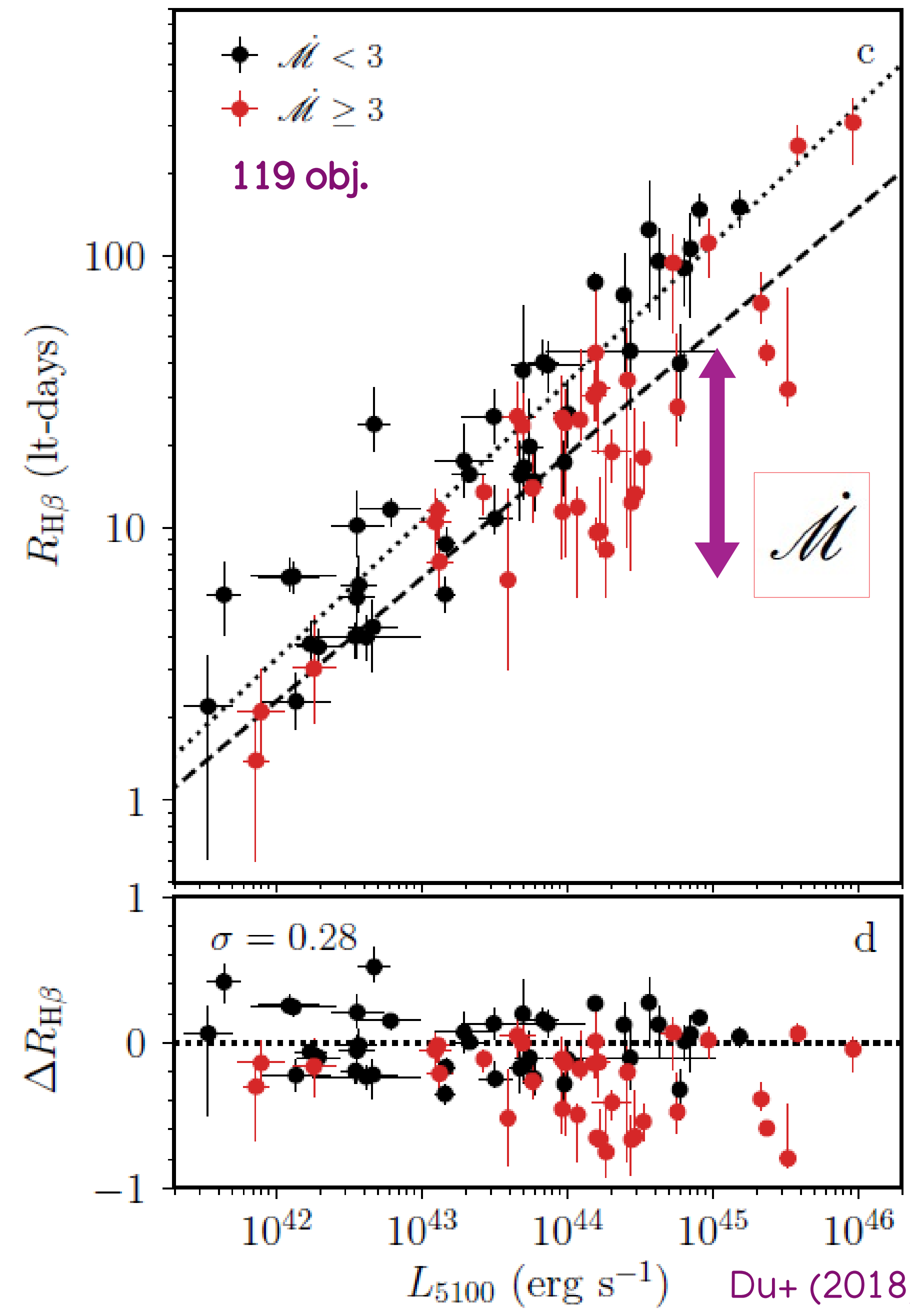






Radius–Luminosity relation evolution



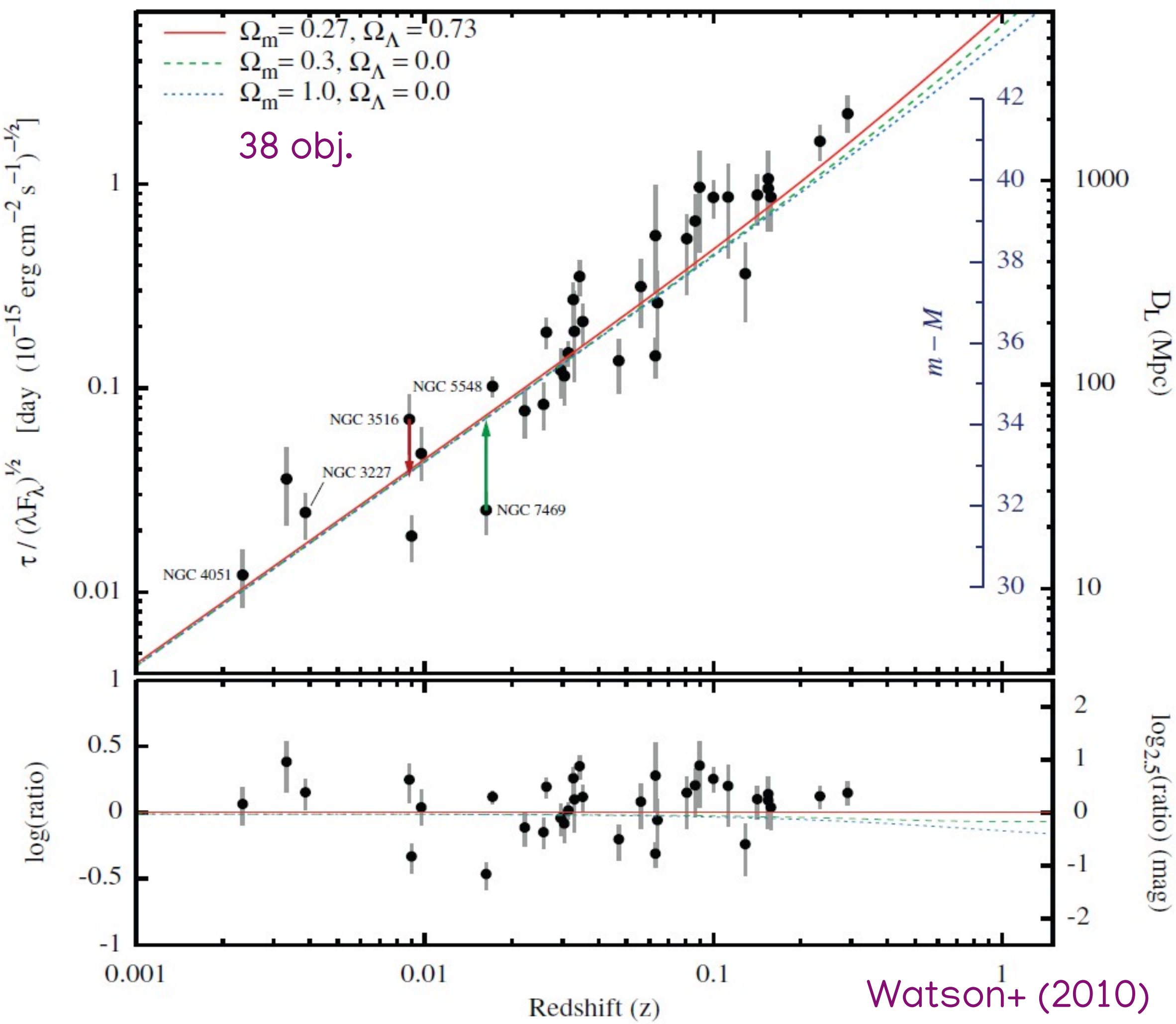


Why RL relation is important?: Cosmology

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

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

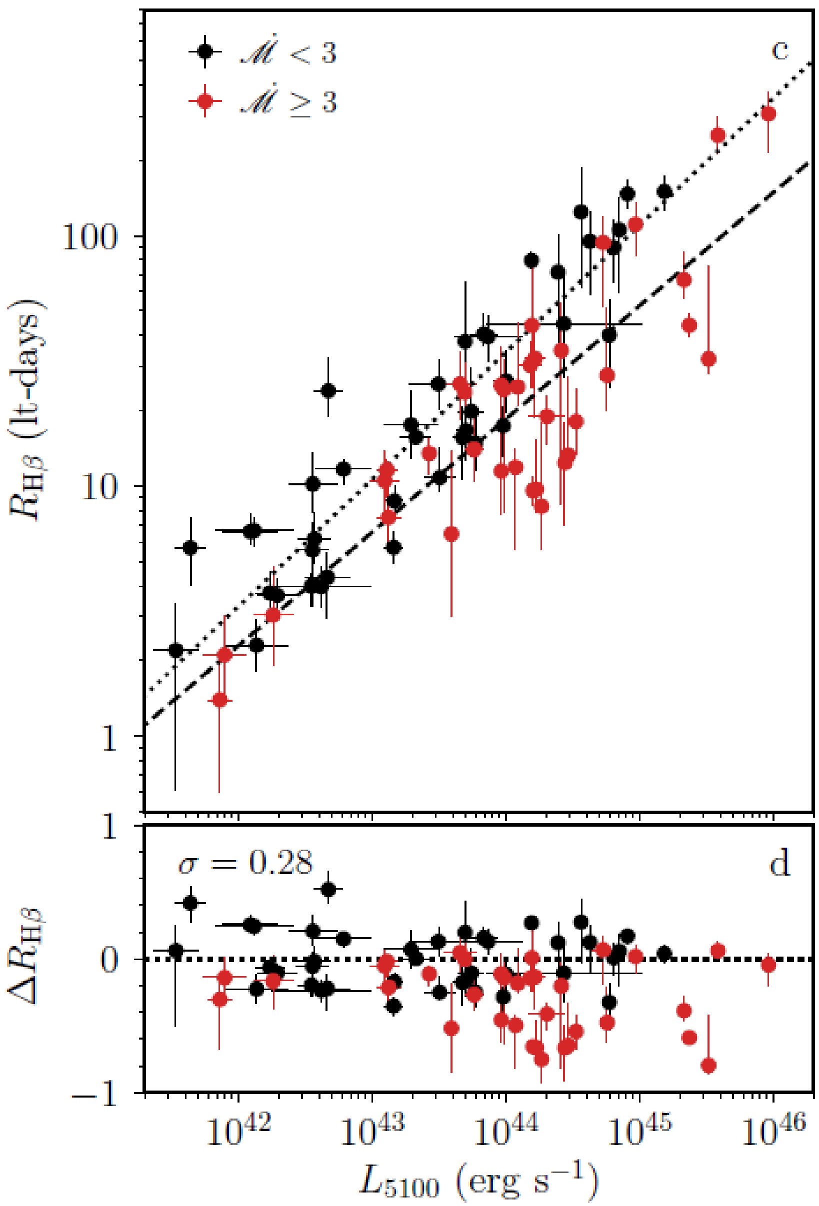
Luminosity distance → $D_L = \frac{c\,z}{H_0}$, H_0: Hubble constant



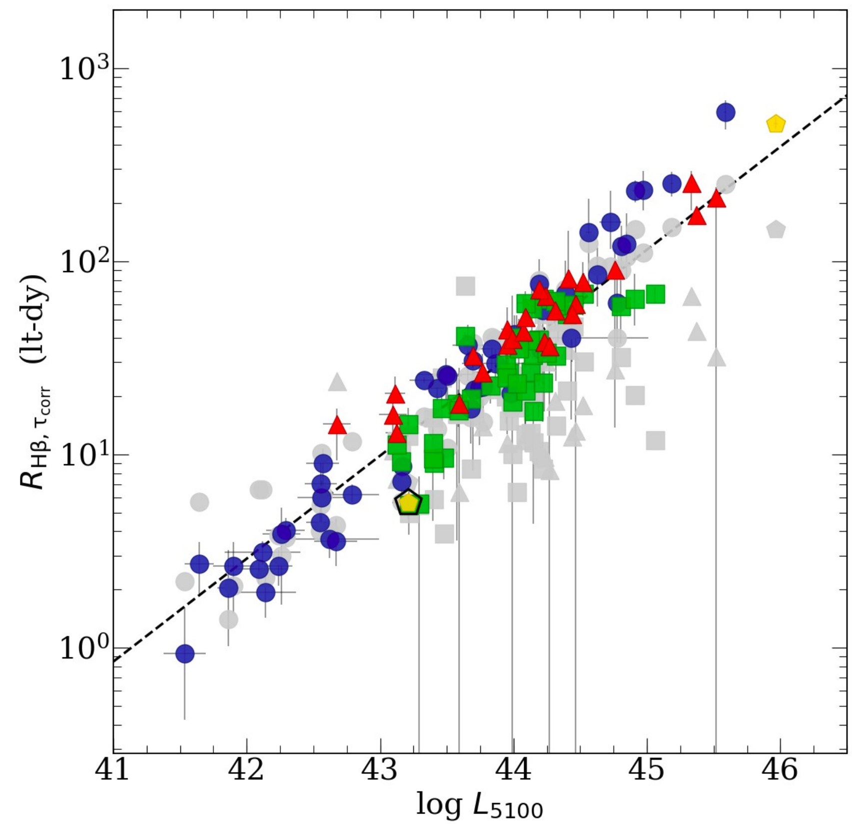
Watson+ (2010)

Are reverberation-mapped AGN like standard candles?

But...



Corrections



Martínez-Aldama+ (2019)

Du+ (2018)

Physical parameters estimation

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

- R_{BLR} = c • τ (!)
- f_{BLR}: **viral factor** (!)
  - structure
  - kinematics
  - *inclination*

  f_{BLR}=1, 0.75, 4.47, 5.5, fwhm$^{\alpha}$, ...

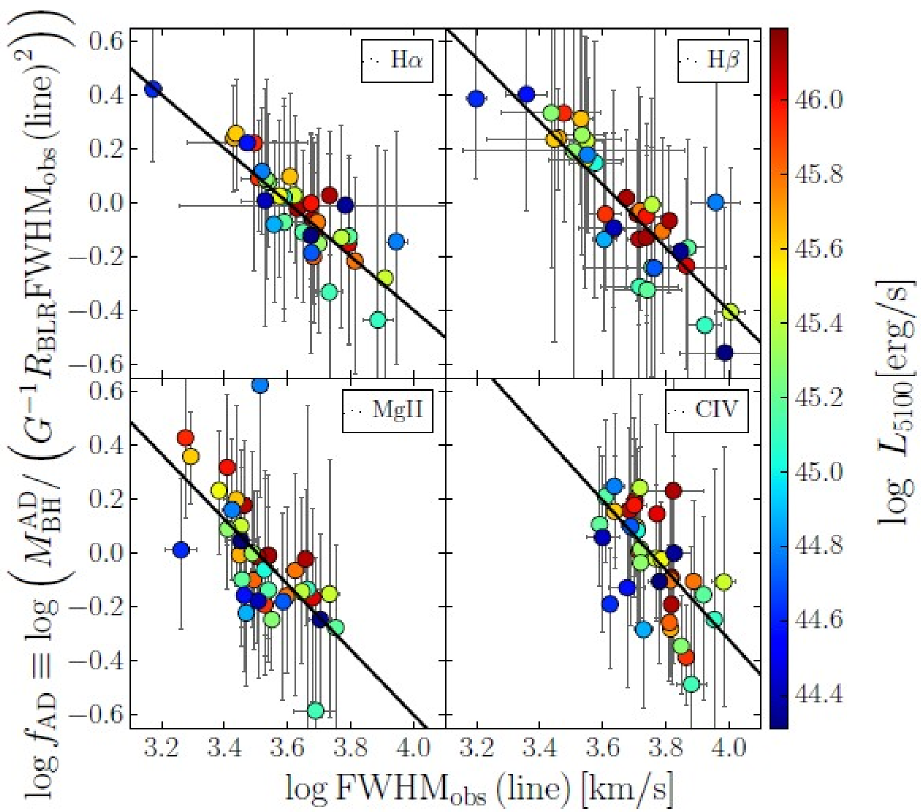
  (Netzer+90, Collin+06, Woo+15, Onken+04, ..., Mejía-Restrepo+18, Yu+19...)
- v^2: **virial velocity** (!)
  - FWHM: affected by inclination
  - σ_{line}: *less* affected by inclination

Do they represent all AGN population?

~1/3 reverberation-mapped sources are super-Eddington sources

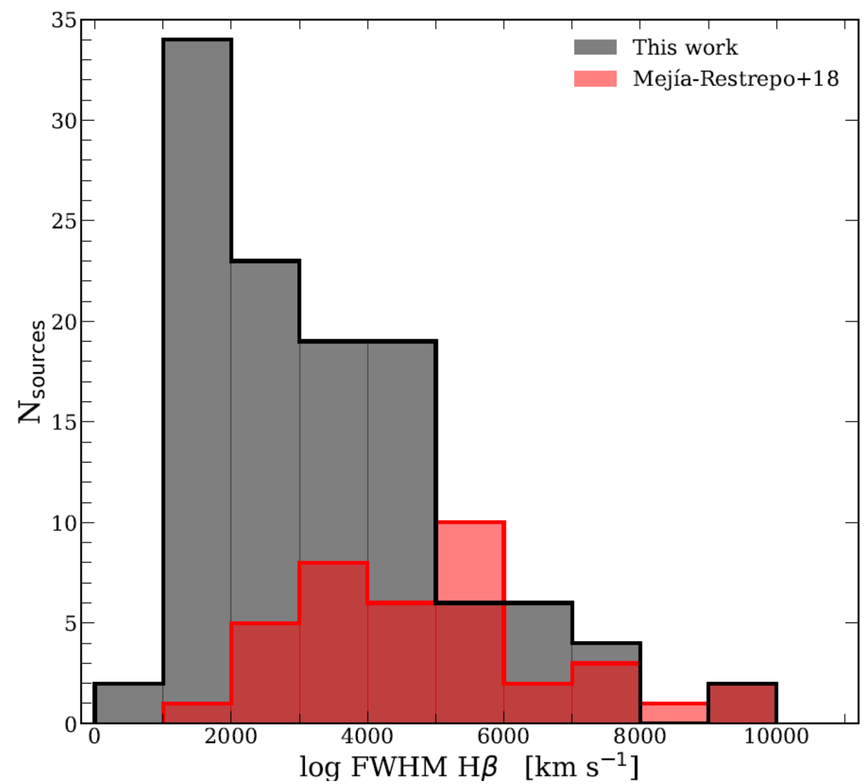
Viral factor anticorrelated with the FWHM

$$f^{c}_{\rm BLR} = \left(\frac{\rm FWHM}{\rm FWHM^{0}_{obs}}\right)^{\beta}$$



Mejía-Restrepo+18

Broad line	$\rm FWHM^{0}_{obs}$ [km s^{-1}]	β
Hα	4000±700	-1.00±0.10
Hβ	4550±1000	-1.17±0.11
Mg II λ2798	3200±800	-1.21±0.24
C IV λ1549	5650±3000	-1.29±0.35



* >20% are super-Eddington sources (NLS1) *

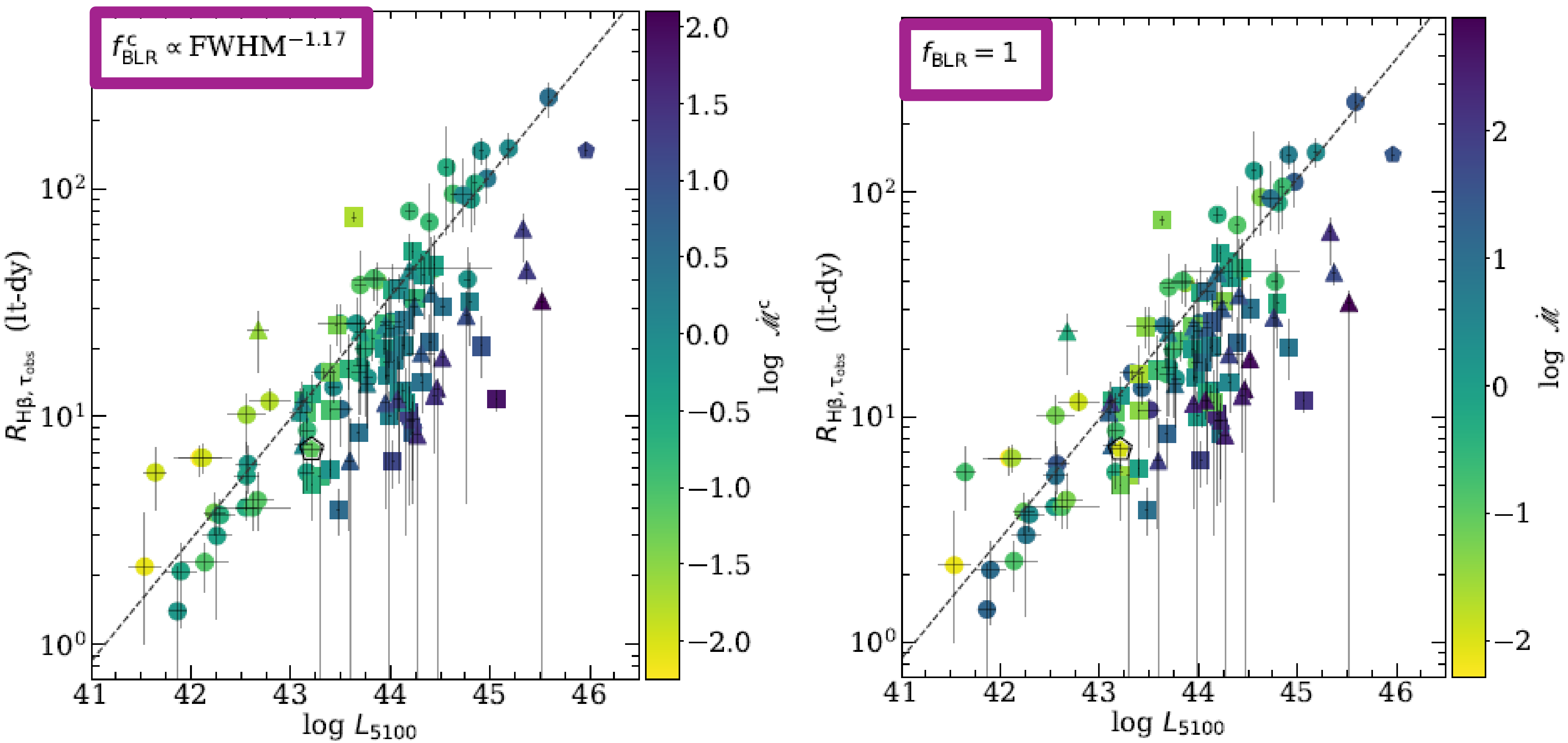
RL relation – accretion rate dependence

Dimensionless accretion rate

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

$\cos i = 0.75$ **(!)**

Sample: Du et al. 2014; Wang et al. 2014; Hu et al. 2015; Du et al. 2015 , 2016 , 2018, Bentz et al. 2009 , 2014; Barth et al. 2013; Pei et al. 2014; Bentz et al. 2016a b; Fausnaugh et al. 2017, Grier et al 2017

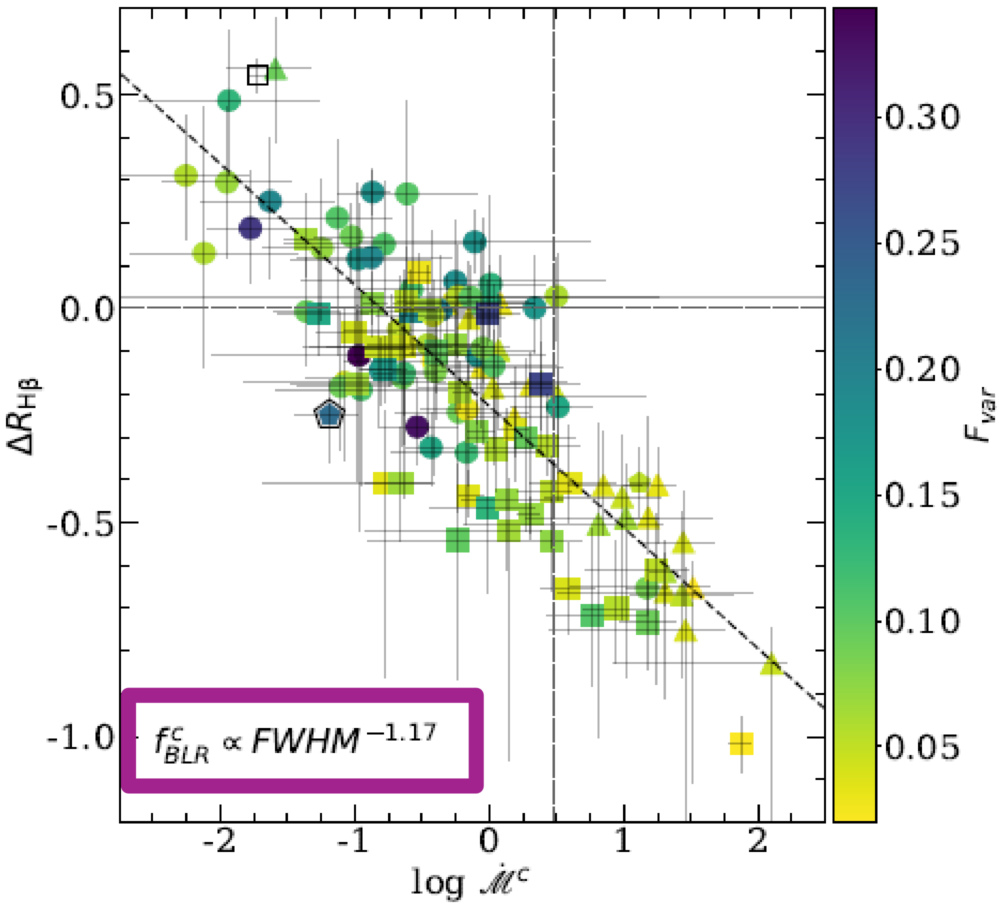


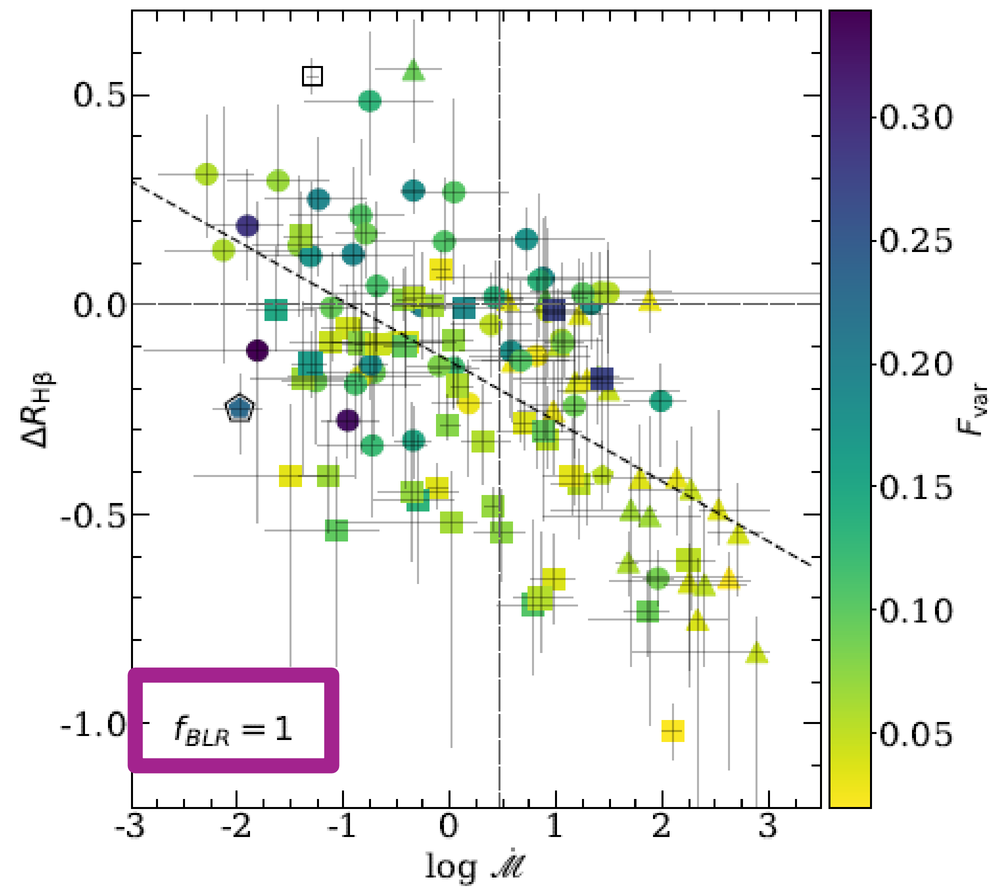
Martínez-Aldama+ (2019)

Departure of 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+ (2015)

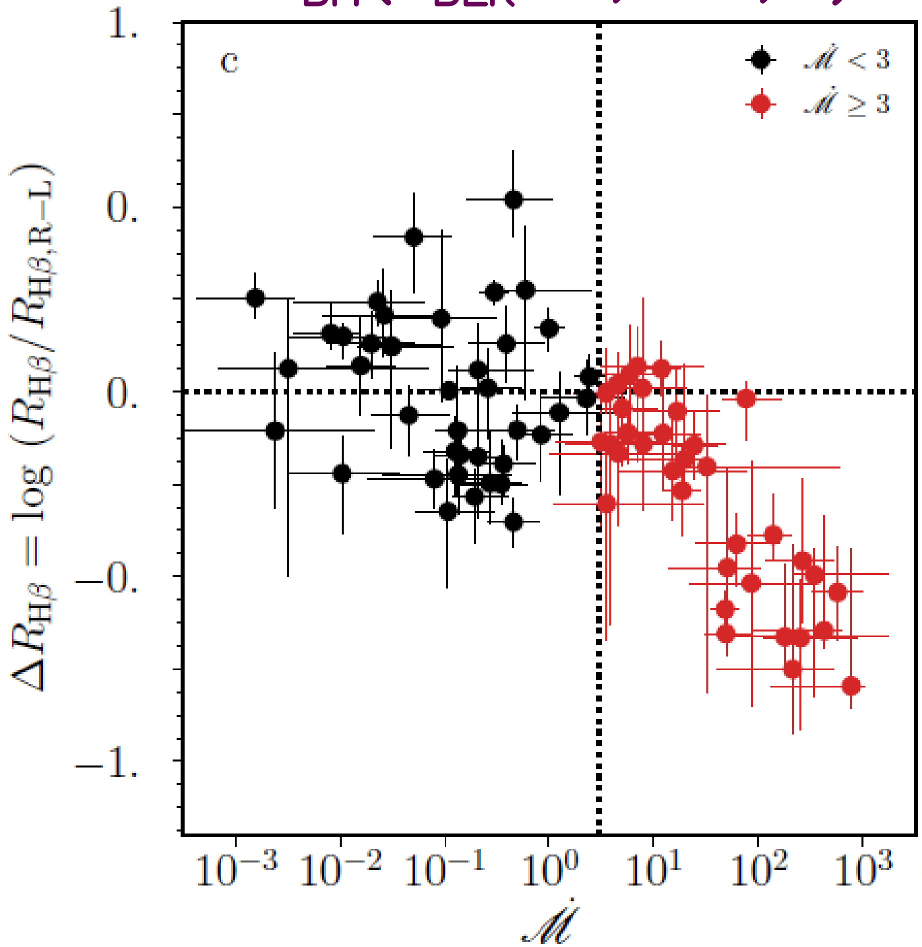




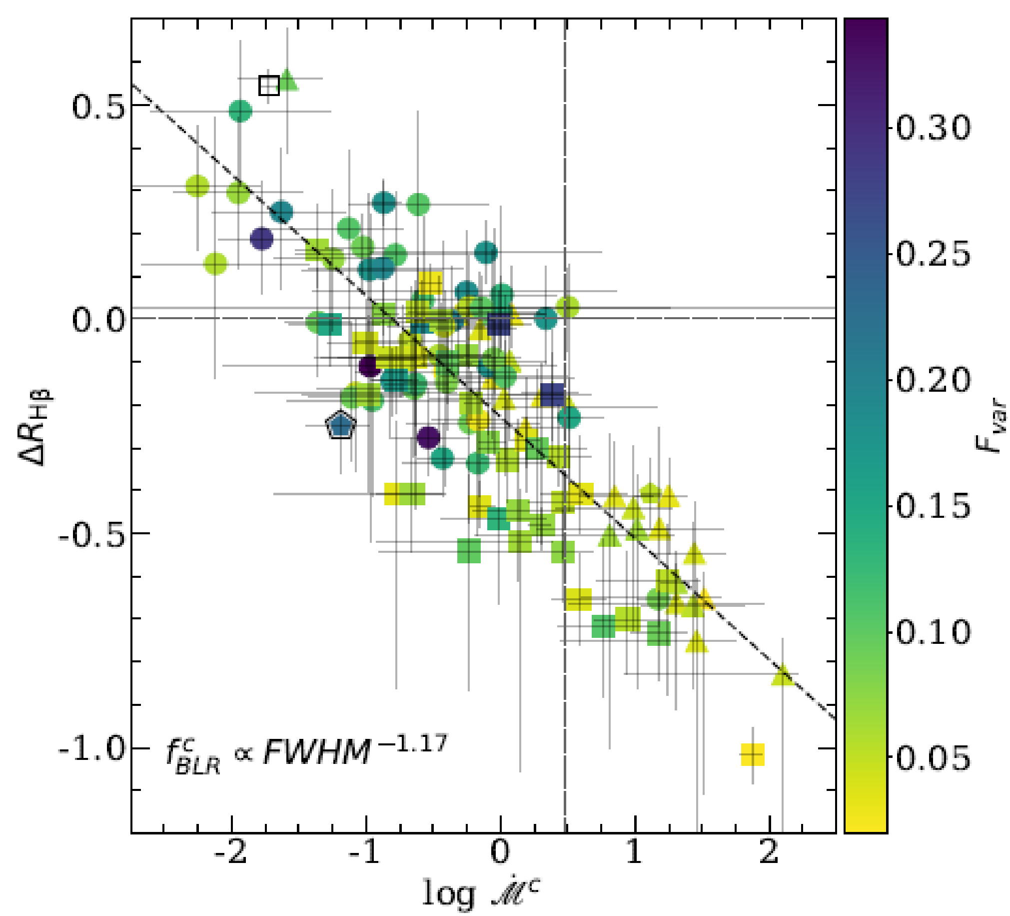
Martínez–Aldama+ (2019)

Departure of the RL relation

M_{BH} (f_{BLR} = 1, 4.47, ...)



M_{BH} ($f_{BLR} \propto FWHM^{-1.17}$)



Du+ (2018)

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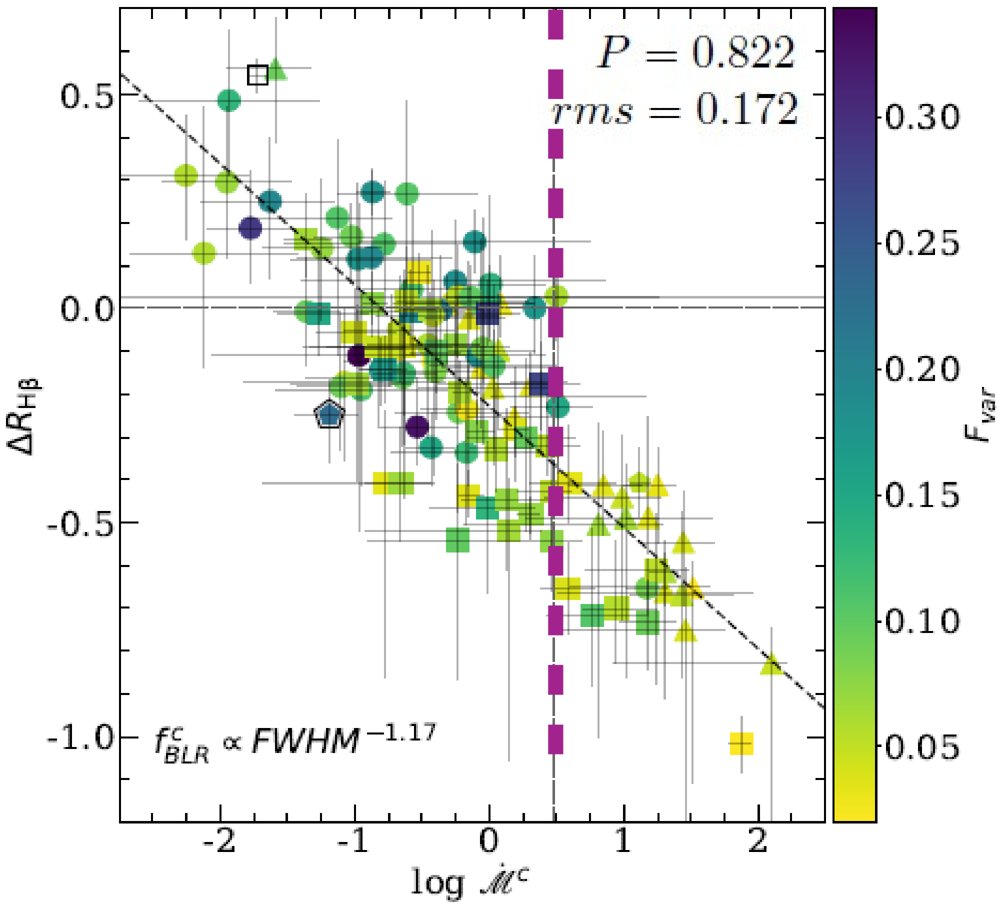
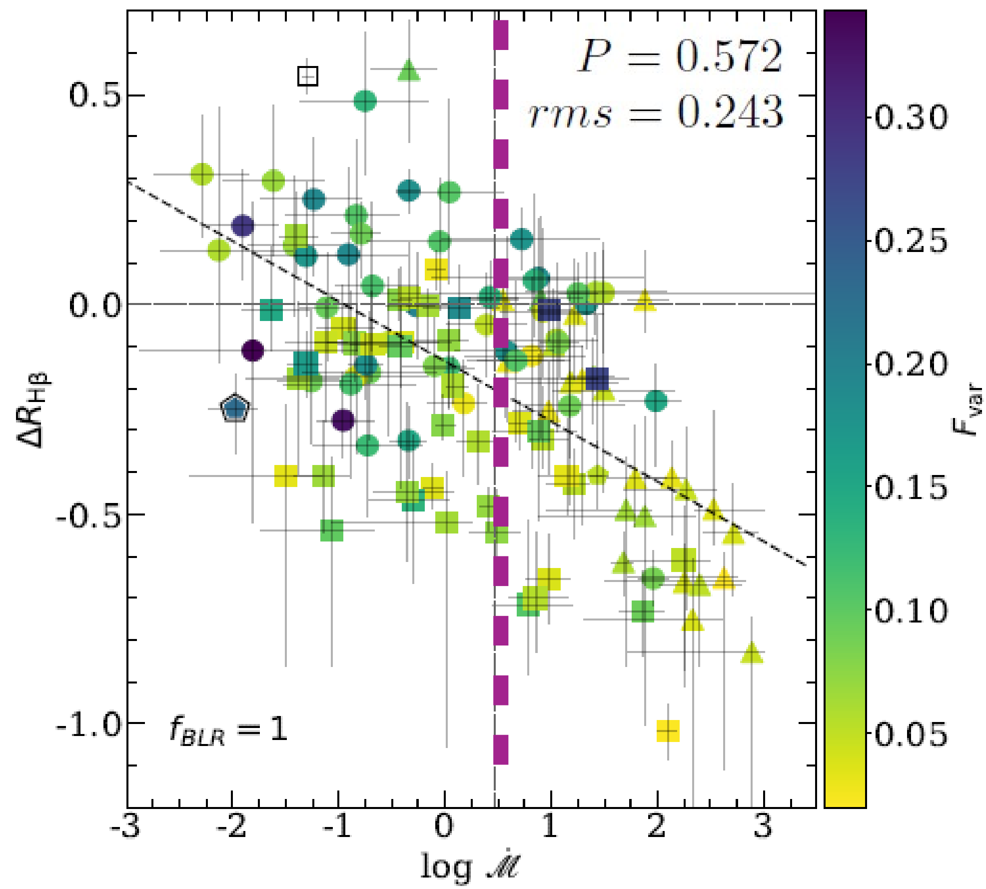
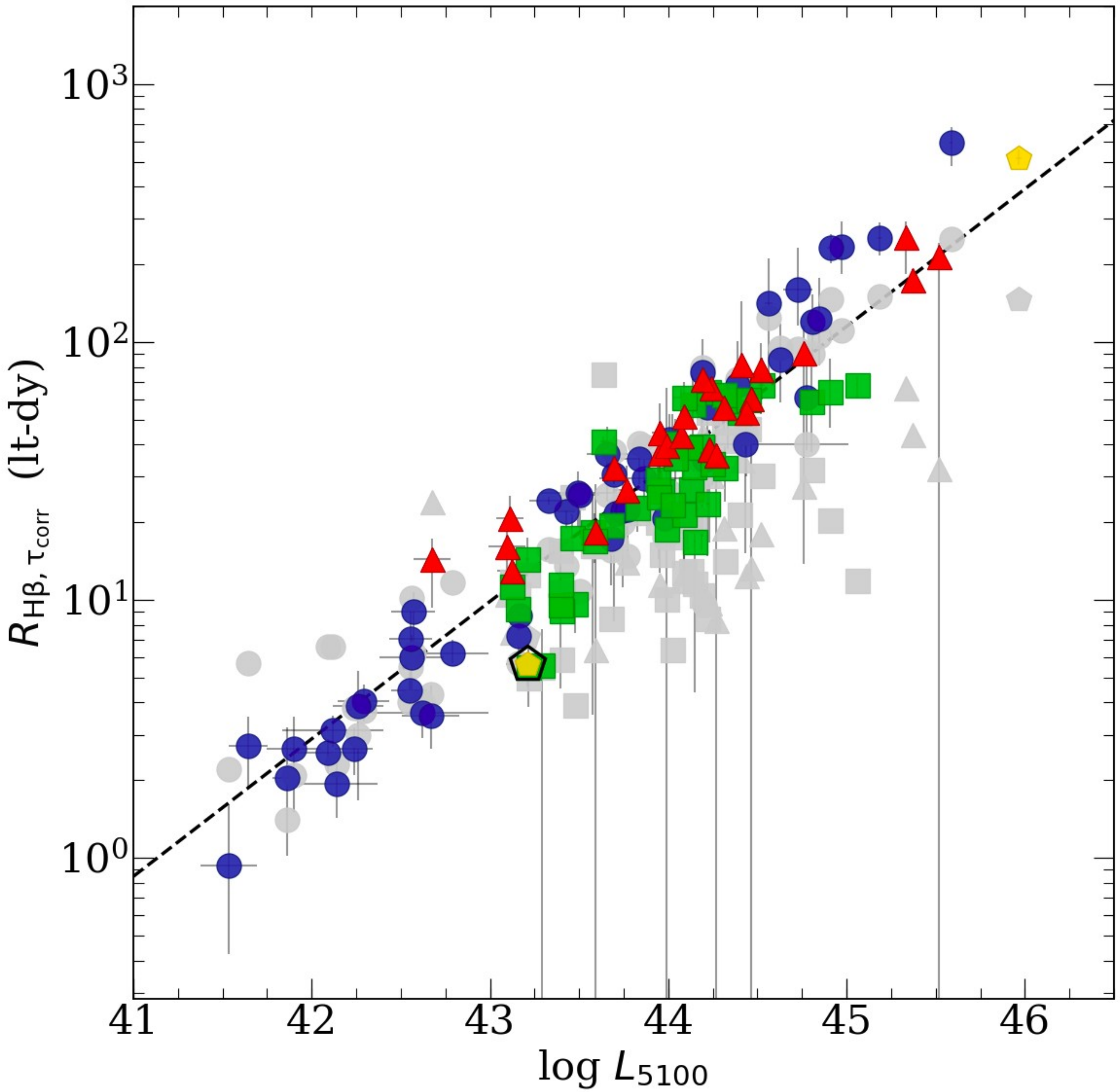




$$\Delta R_{\mathrm{H}\beta,\dot{\mathscr{M}}^{\mathrm{c}}} = (-0.283 \pm 0.017)\log\dot{\mathscr{M}}^{\mathrm{c}} + (-0.228 \pm 0.016)$$

$$\Delta R_{\mathrm{H}\beta,\dot{\mathscr{M}}} = (-0.143 \pm 0.018)\log\dot{\mathscr{M}} + (-0.136 \pm 0.023)$$

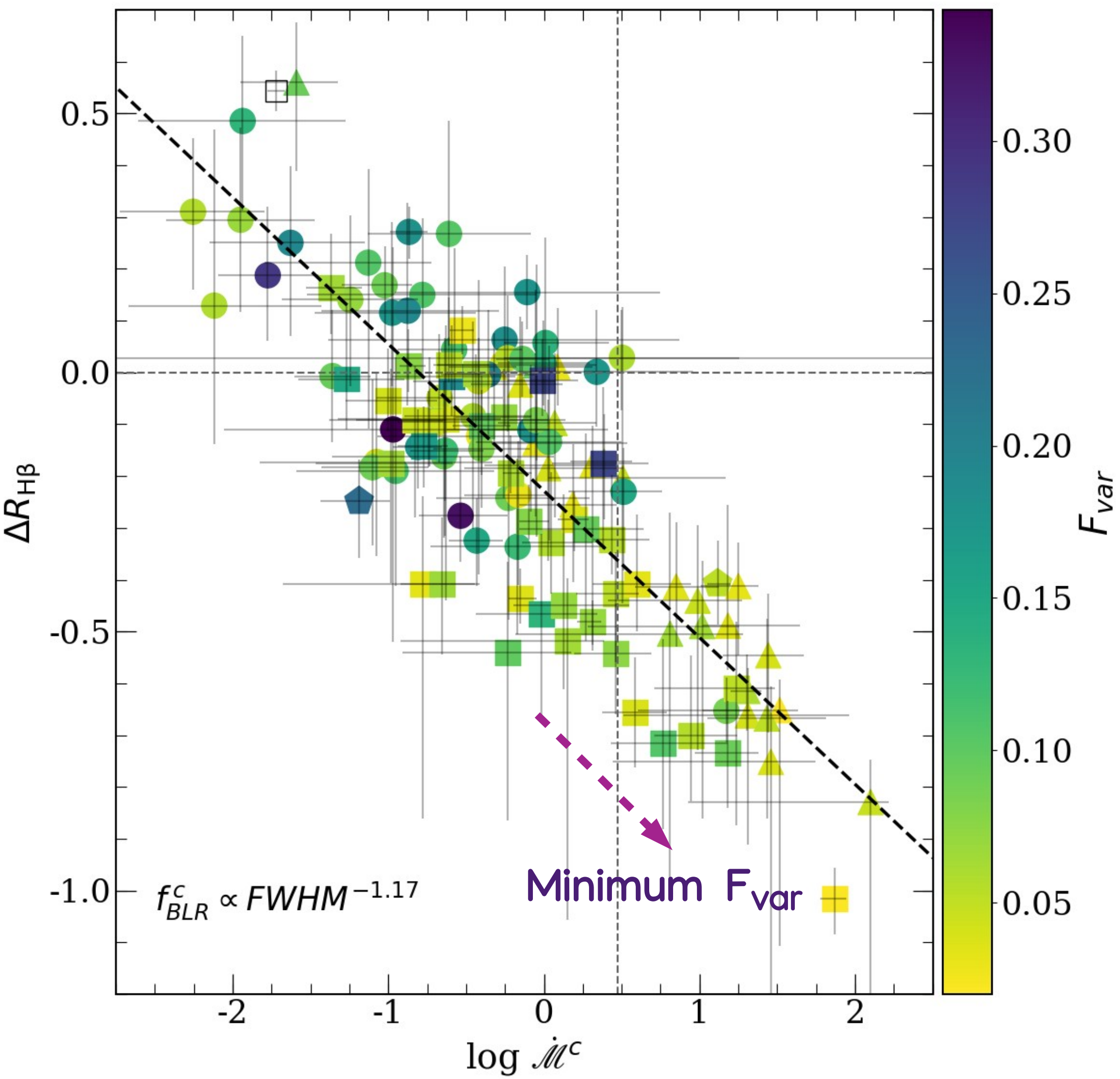
Corrected RL relation



→ Cosmology

$$D_L = \frac{c\ z}{H_0}$$

Variability



***rms* of the intrinsic variability**

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

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

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

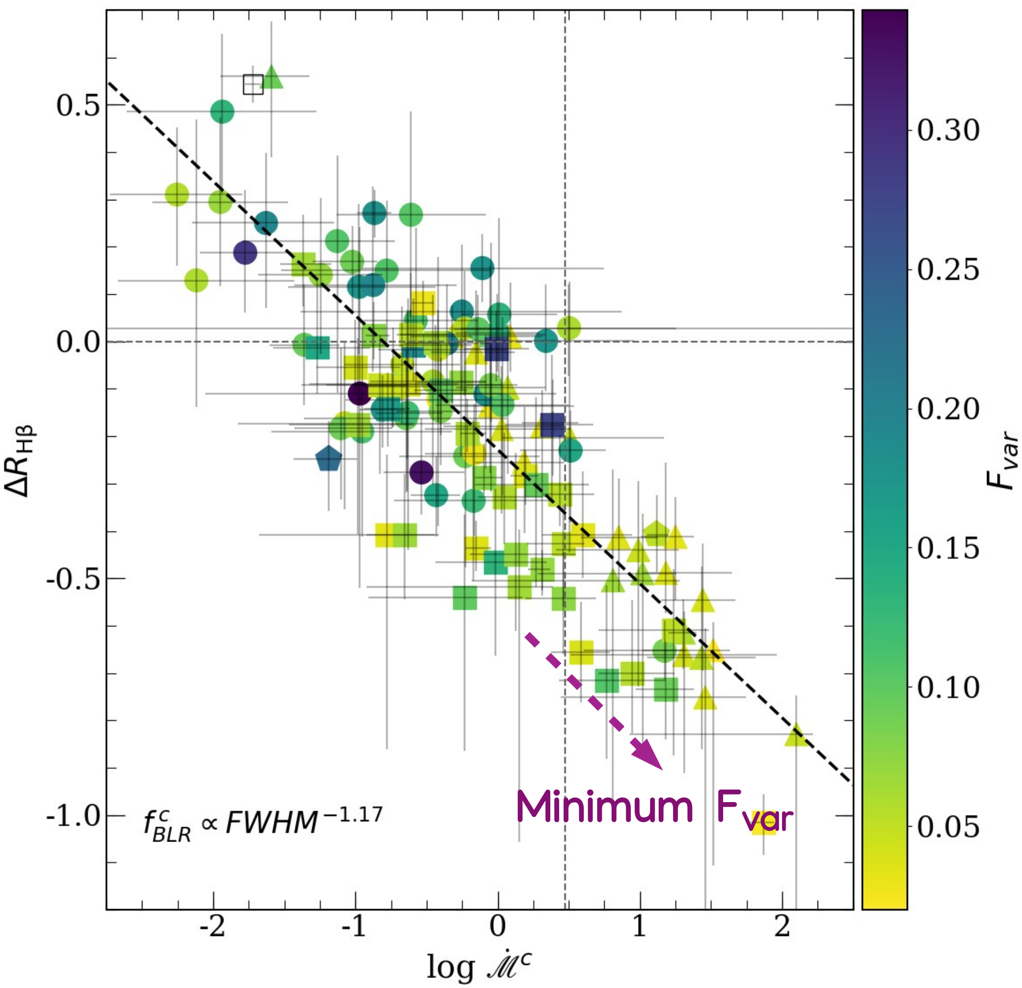
$$\langle f \rangle = \frac{1}{N} \sum_{i=1}^{N} f_i$$

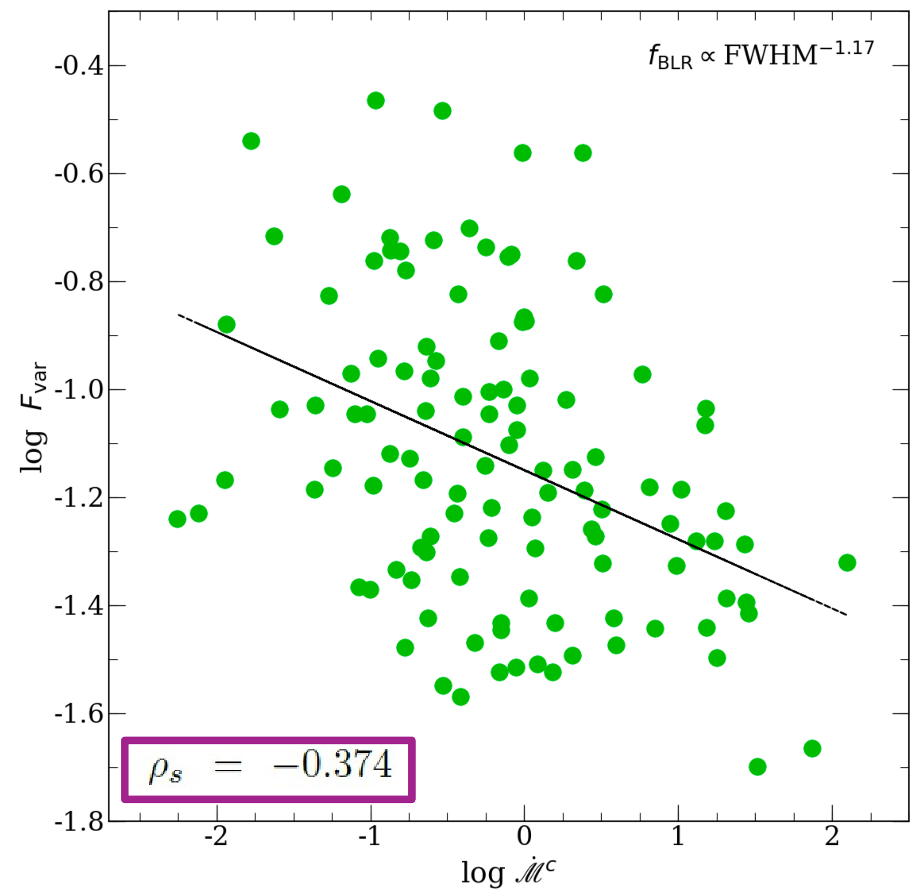
(Rodríguez-Pascual+ 97)

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

Variability

Wilhite+ (2008), MacLeod+ (2010), Simm+(2016), Rakshit & Stalin (2017), Sánchez-Sáez+ (2018), Li+ (2018).





OzDES – LSST

Variability can be used as a tool to determine other physical parameters

Hubble diagram

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

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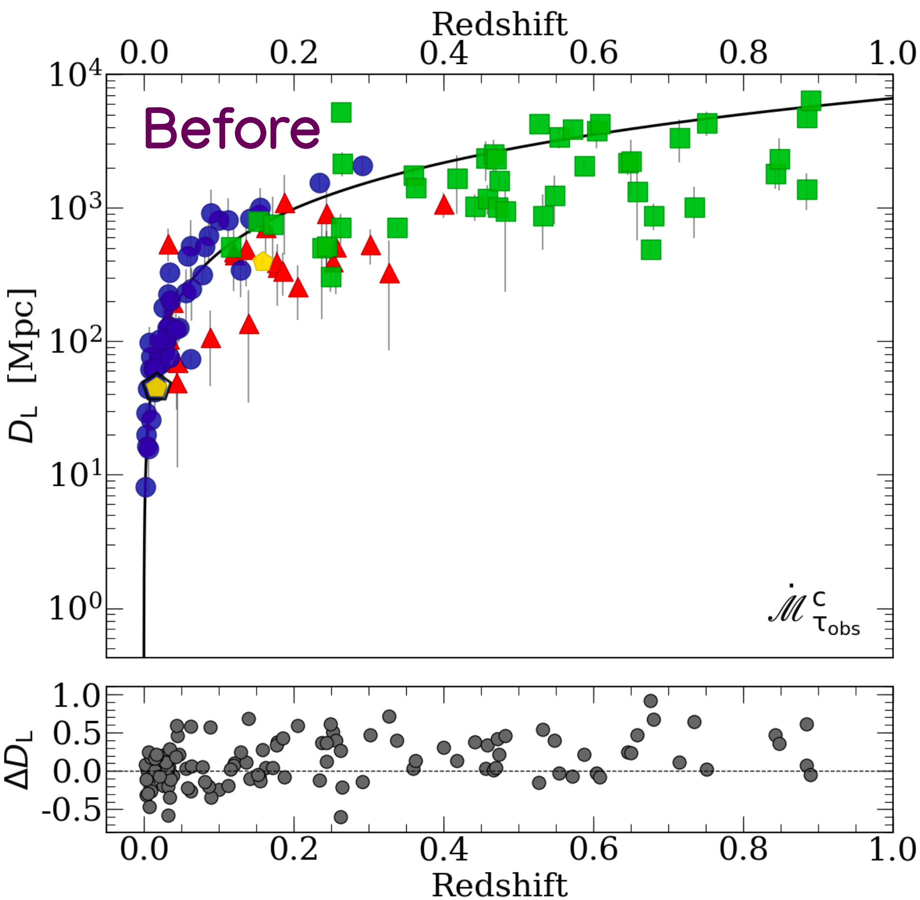

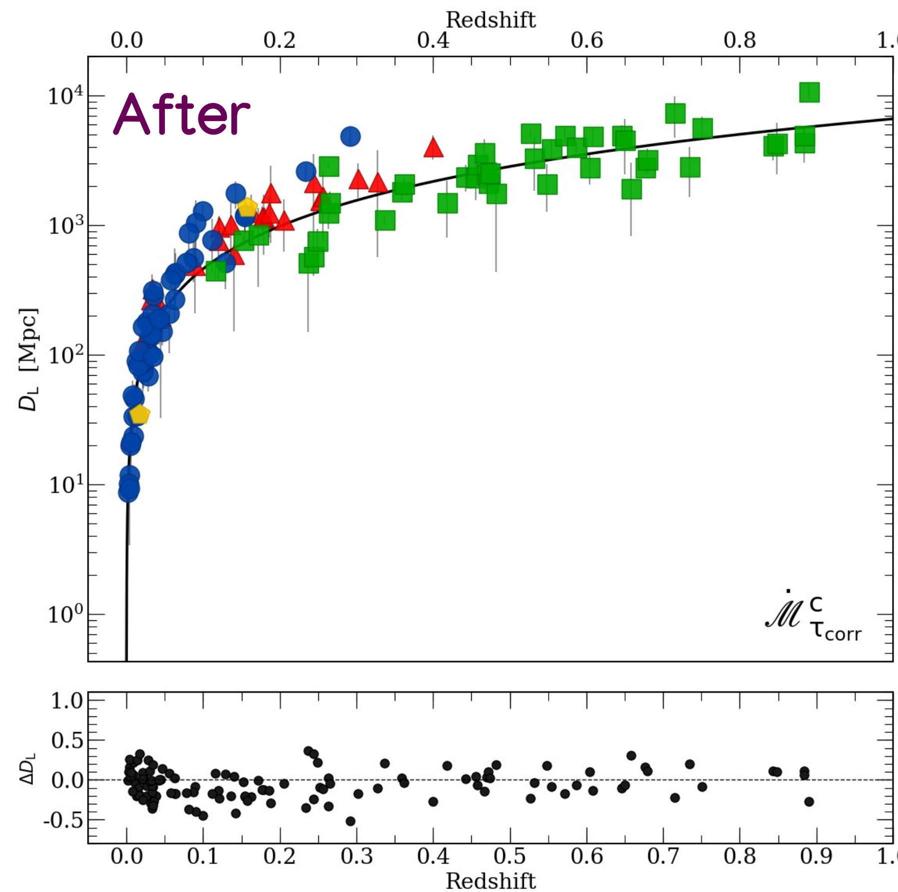

Martínez-Aldama+ 2019

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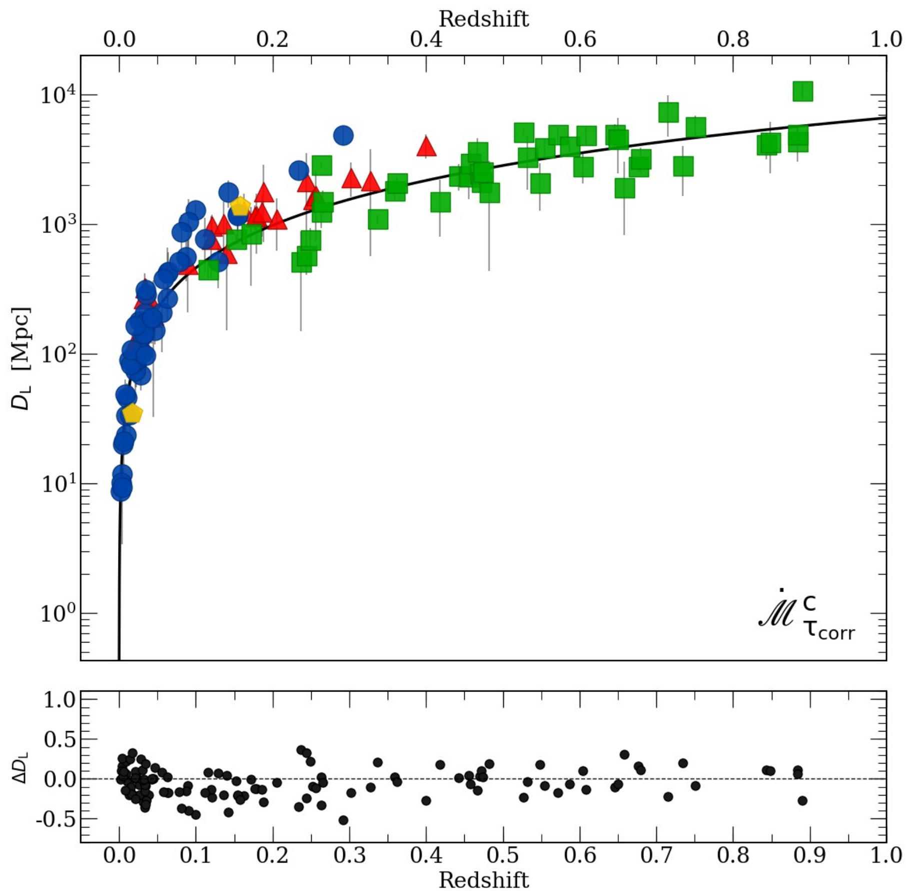

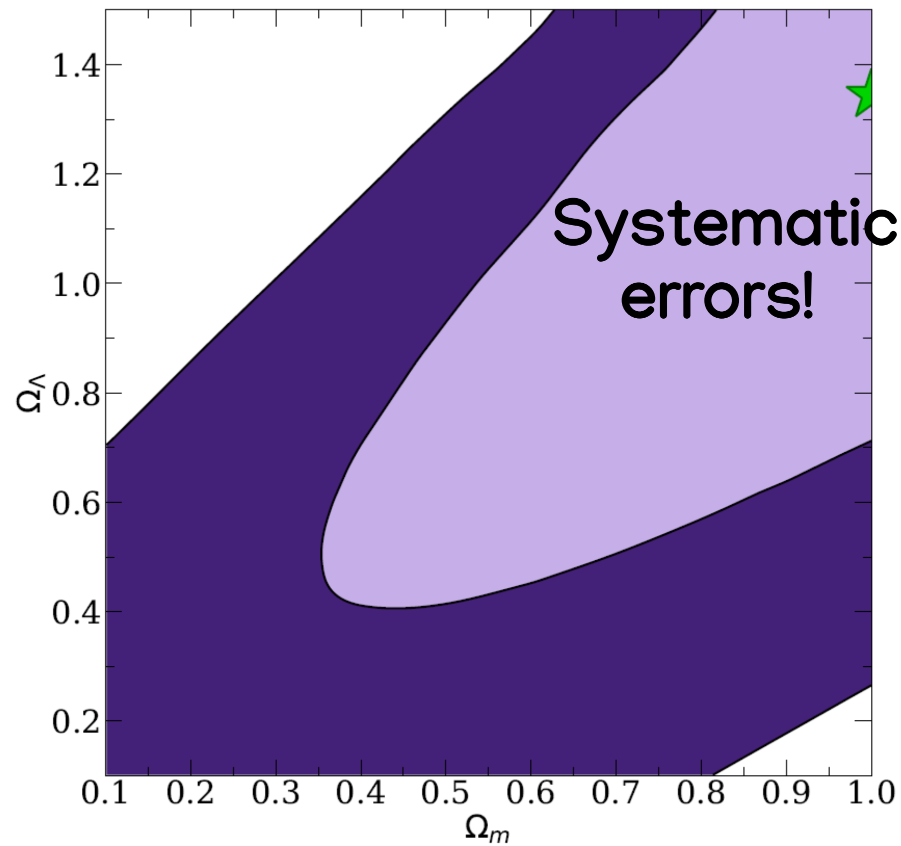

Martínez-Aldama+ 2019

Conclusions

RM low-z

- QSO & Reverberation mapping
  - *Systematic errors* !
    - AGN physics:
      - Virial factor -> Inclination angle effect
    - Systematic analysis of light curves
    - *Correction by the accretion rate effect*
    - Enlarge the sample
      - SDSS-RM: MgII, z~2.5
      - SEAMBH (Wang, Du, Hu, ...): Hβ, z<0.1
    - High redshift ranges (cosmology)

↓

OzDES – LSST