Measuring Quasars accretion discs sizes with the LSST

Dr. Francisco Pozo Nuñez
Heidelberg Institute for Theoretical Studies

Galactic Nuclei in the Cosmological Context

2024 June 3-6, Szczecin, Poland

Collaborators:

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- Swayamrupta Panda (LNA, Brazil)
- Eduardo Banados (MPIA, Germany)
- Jochen Heidt (LSW, Germany)

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Why measuring quasars ADs?

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- To estimate black hole masses (faster!)

$$\log\left(\frac{R_{\mathrm{BLR}}}{1\mathrm{lt-day}}\right) = (1.527 \pm 0.031) + 0.533^{+0.035}_{-0.033} \log\left(\frac{L_{5100\mathring{A}}}{10^{44}\mathrm{ergs}^{-1}]}\right)$$

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- To use quasars as standard candles

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

The redshift independent distance

$$v = cz = H_0 D_L$$

Hubble-Lemaitre law

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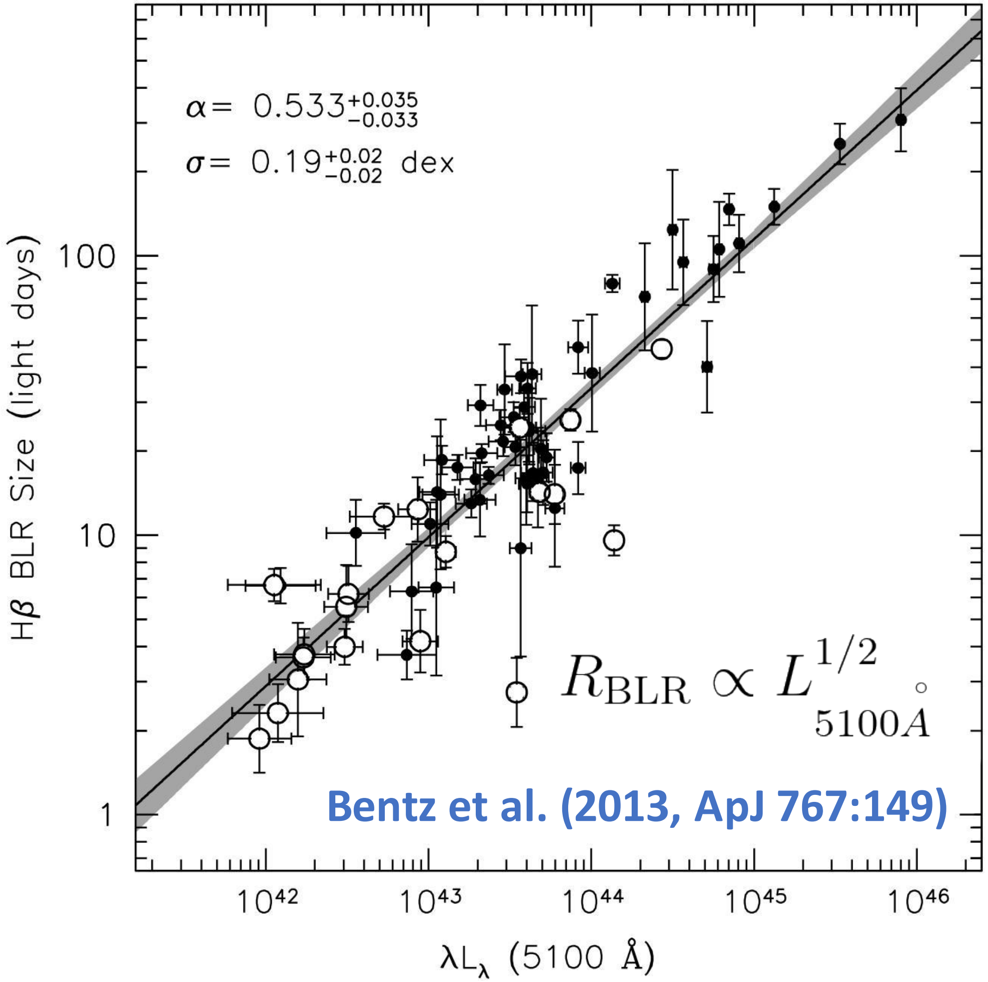
Peterson et al. (2004, ApJ 613:682)

$$M_{\rm BH} = f\frac{R\,\sigma_V^2}{G}$$



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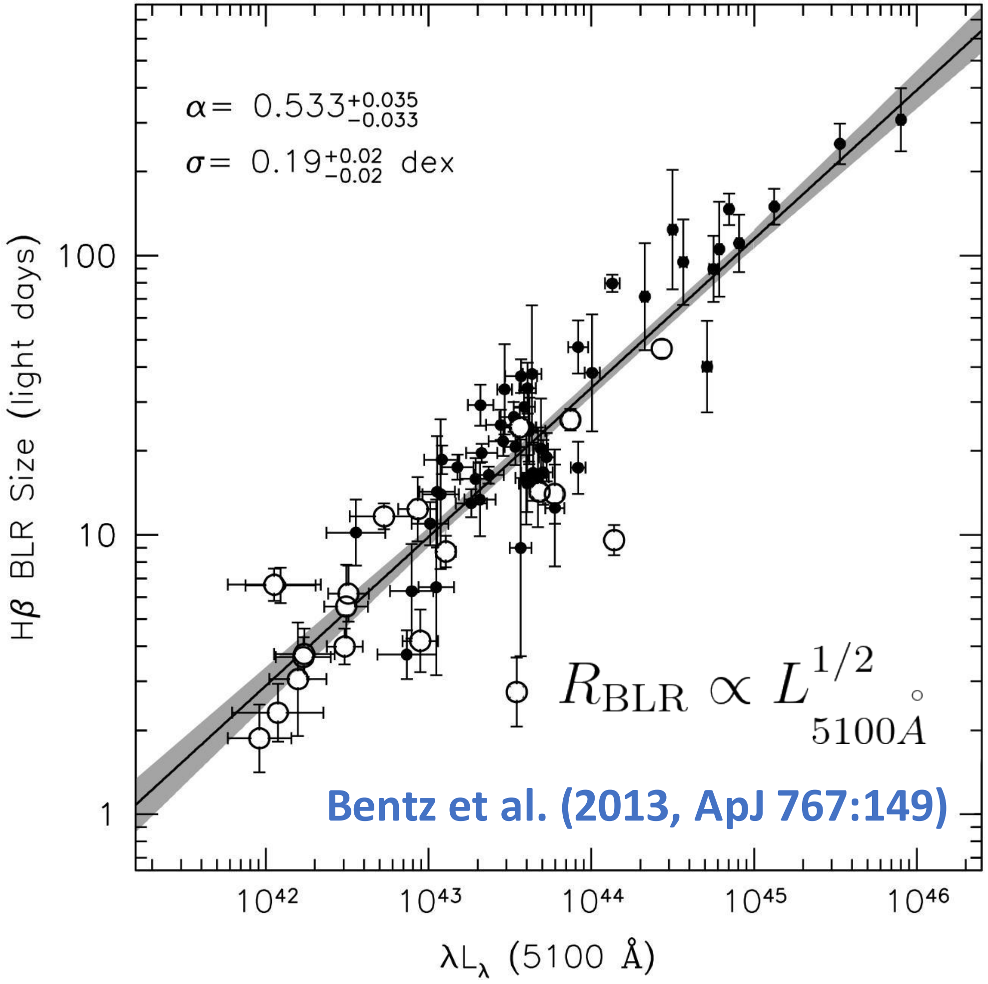

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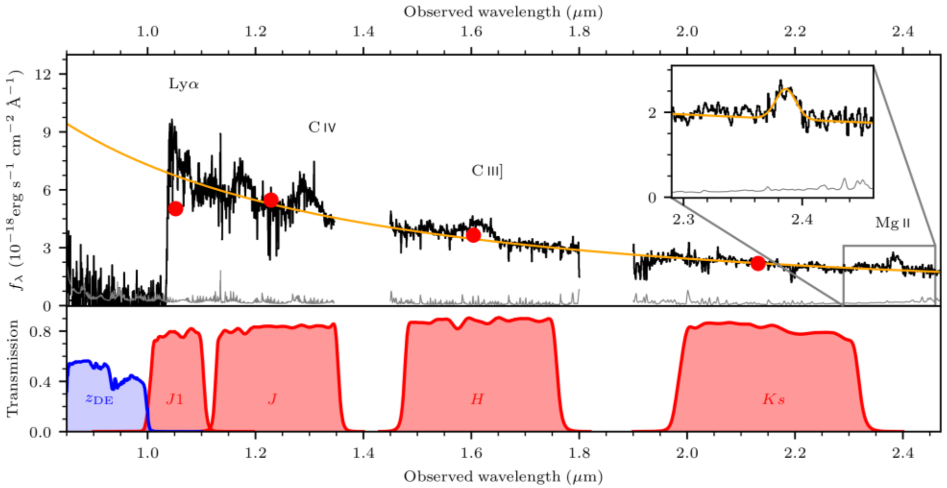
An 800-million-solar-mass black hole in a significantly neutral Universe at redshift 7.5



Bañados et al. (2017, Nature 553, 473-476)

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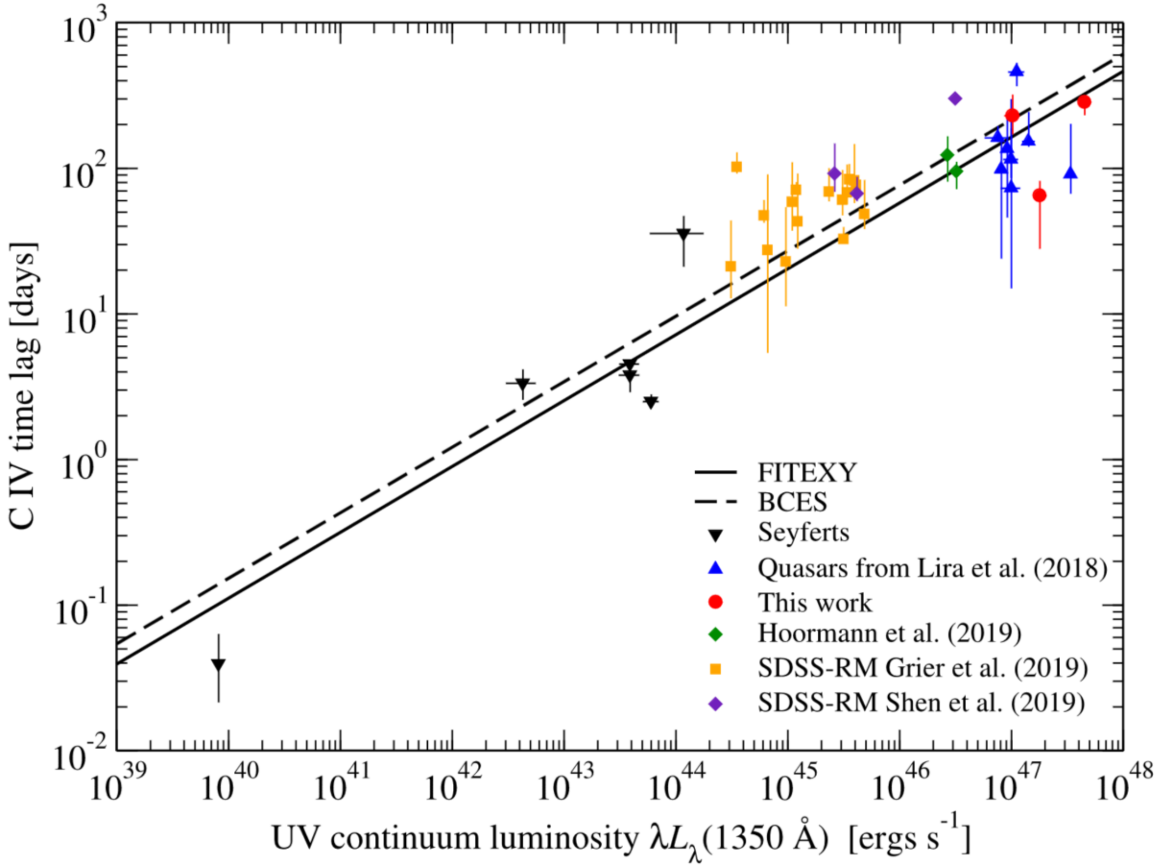

Kaspi et al. (2021, ApJ 915:129)

- 10 to 20 years monitoring (delays of 2 years z~ 2-3).

- Seasonal gaps, limited sampling, lcs based on modelling and interpolation.

Why measuring quasars ADs?

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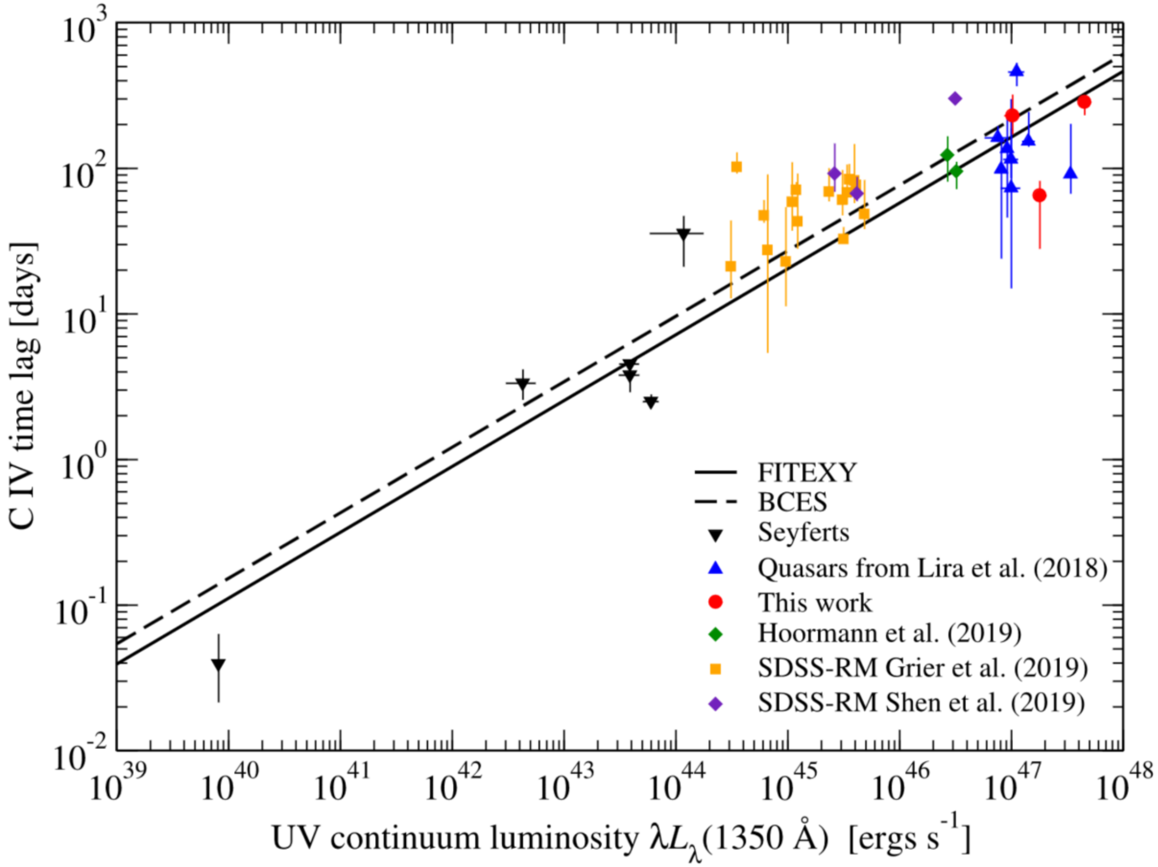
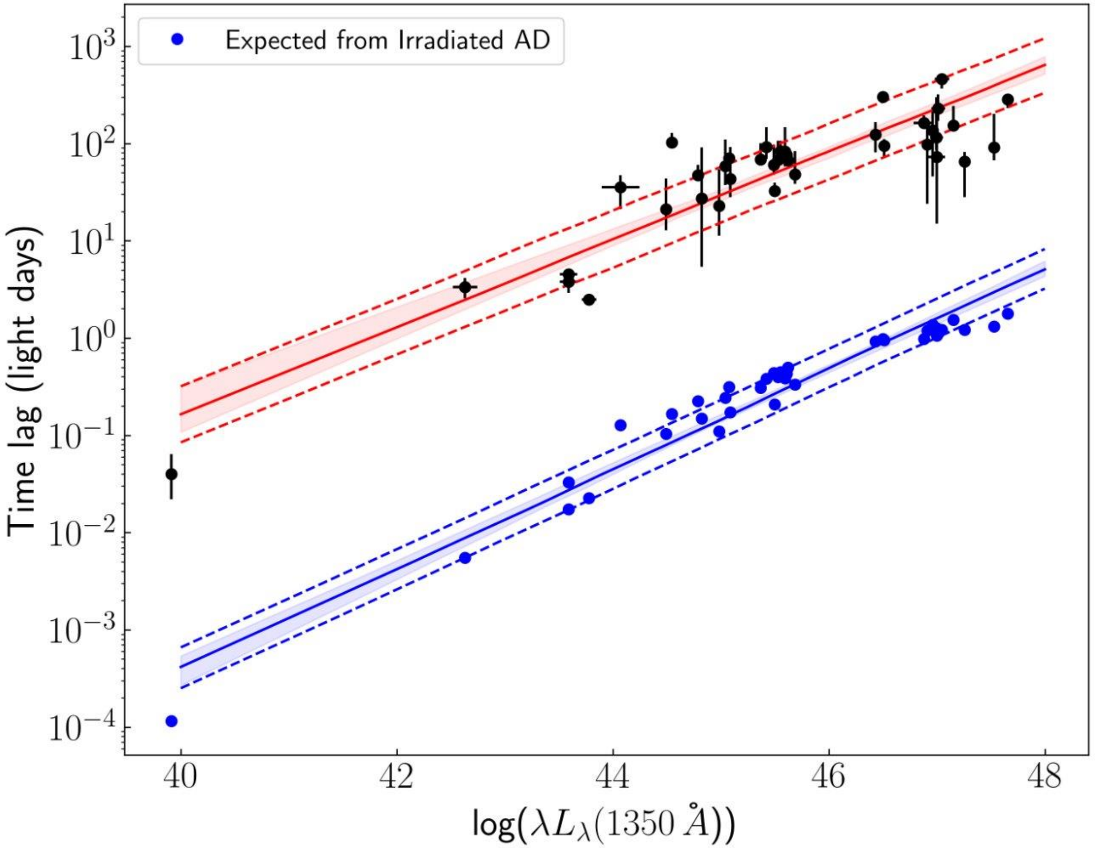
Panda, Pozo Nuñez et al. (2024, ApJ Letters)

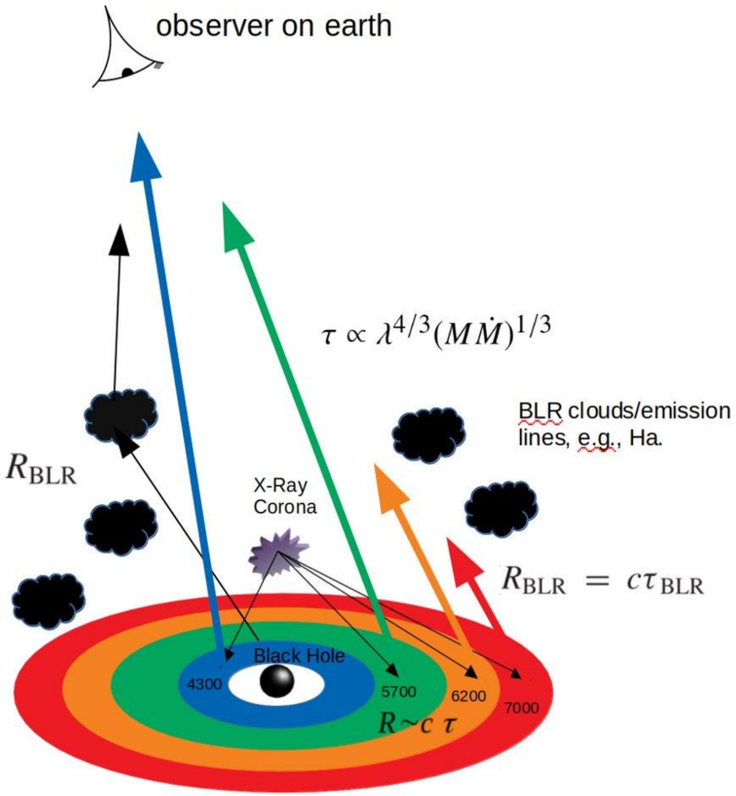




Kaspi et al. (2021, ApJ 915:129)

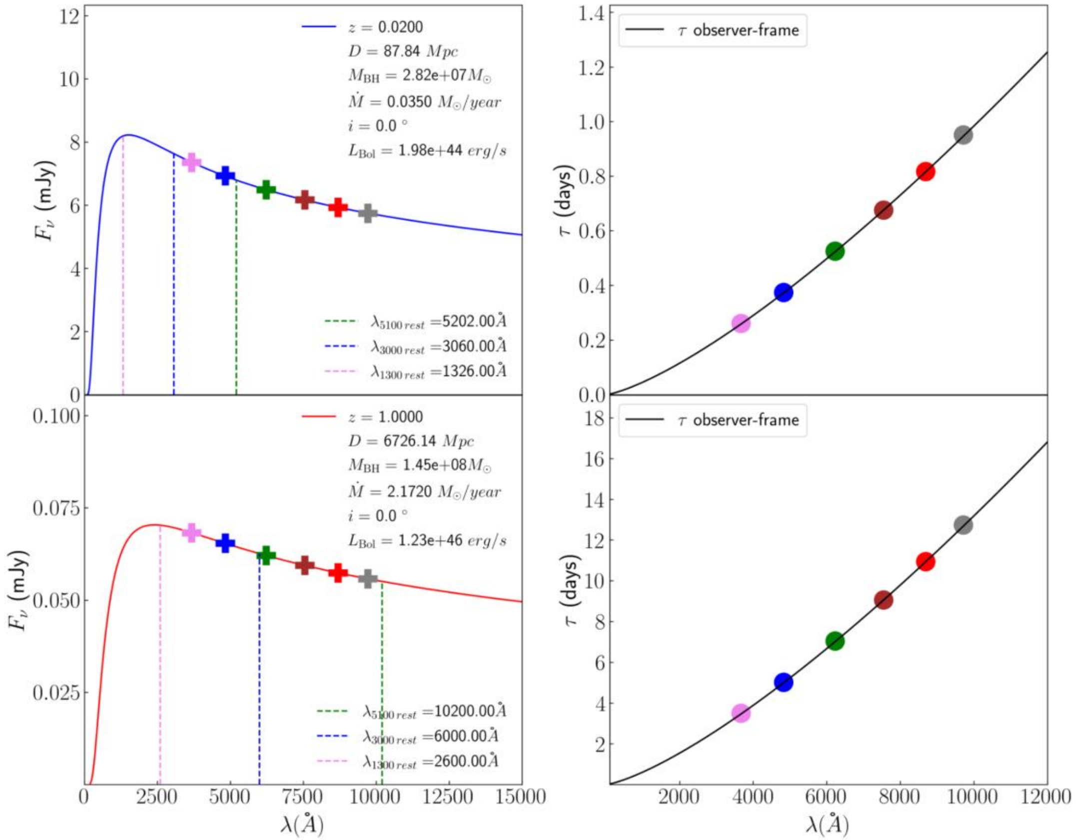
Why measuring quasars ADs?

- The AD reverberates



Accretion disk temperature profile

$$T(R) = \left[\frac{3GM\dot{M}}{8\pi R^3 \sigma} + \frac{L_*(1-a)}{4\pi R^3 \sigma} H_* \cos\theta\right]^{1/4}$$



$$\tau_{jk} = \gamma \left[\lambda_k^{4/3} - \lambda_j^{4/3}\right] \left[\frac{3GM\dot{M}}{8\pi\sigma} + \frac{L_*(1-a)}{4\pi\sigma} H_* \cos\theta\right]^{1/3}$$

Pozo Nuñez et al. (2019) MNRAS 490, 3936

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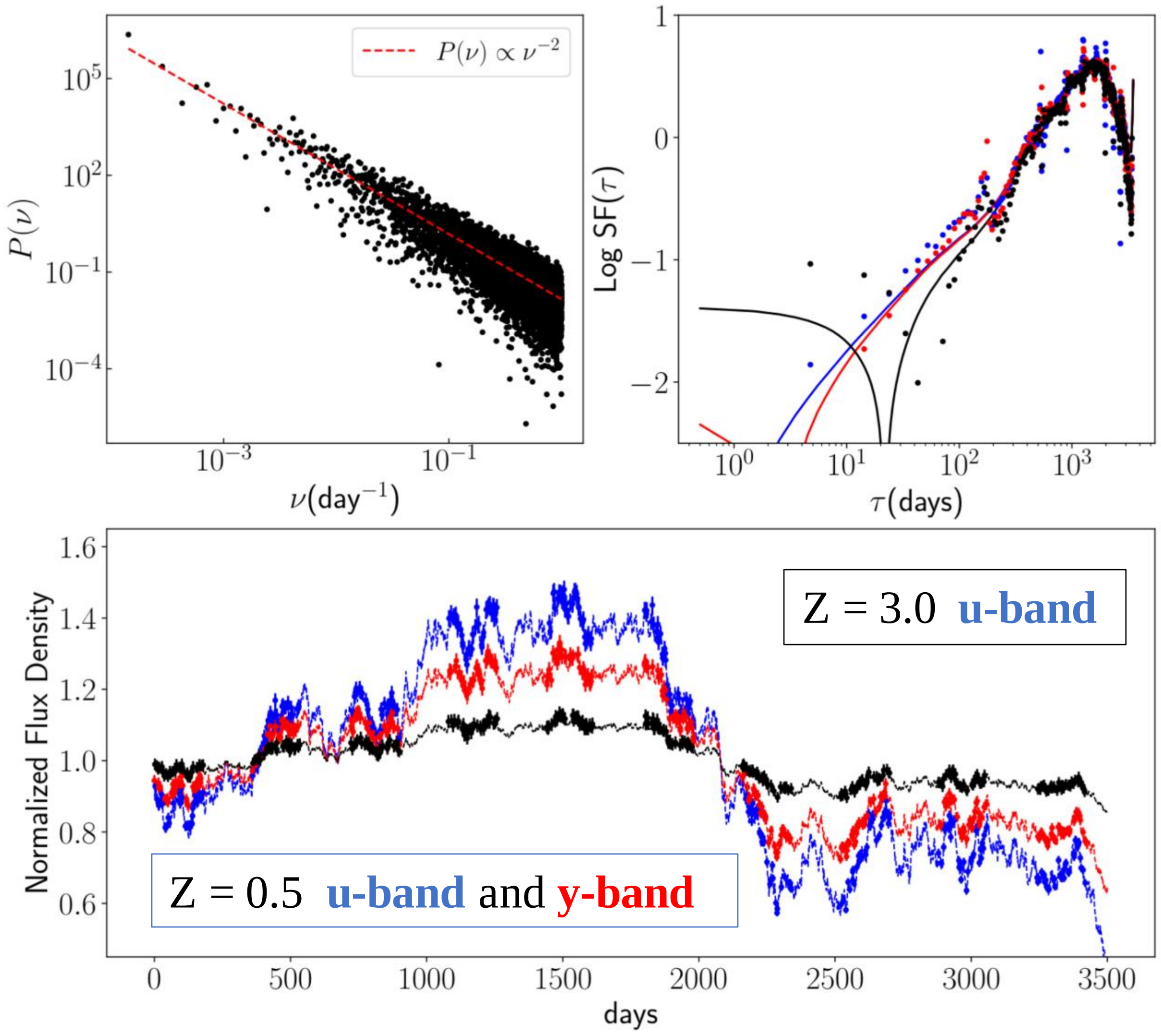


CAR(1) random walk

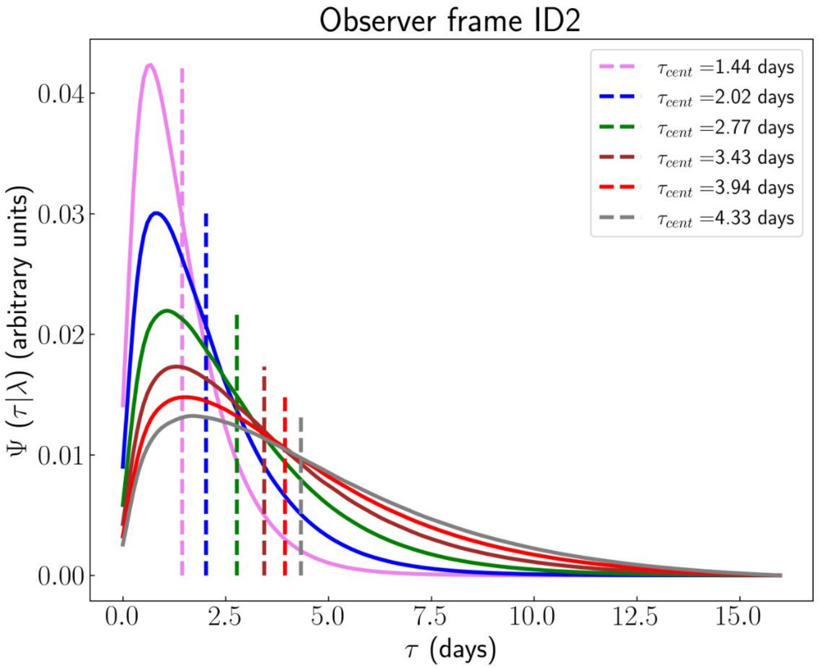
$$F_c(\lambda,t) = \int_0^\infty \Psi(\tau|\lambda) F_x(t-\tau)\mathrm{d}\tau$$

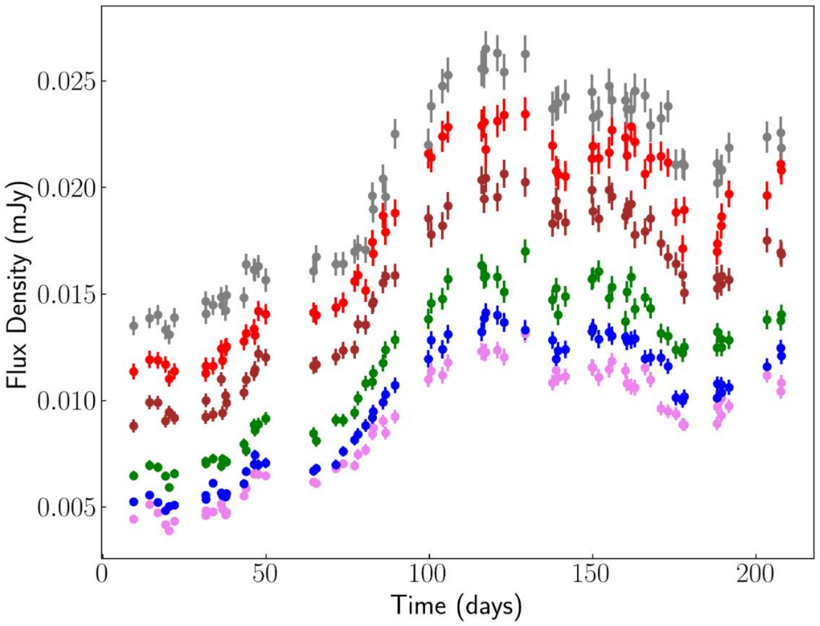
$$\tau(r,\phi,i) = \frac{1}{c}\left[\sqrt{r^2+h^2} + r\sin i\cos\phi + h\cos i\right]$$

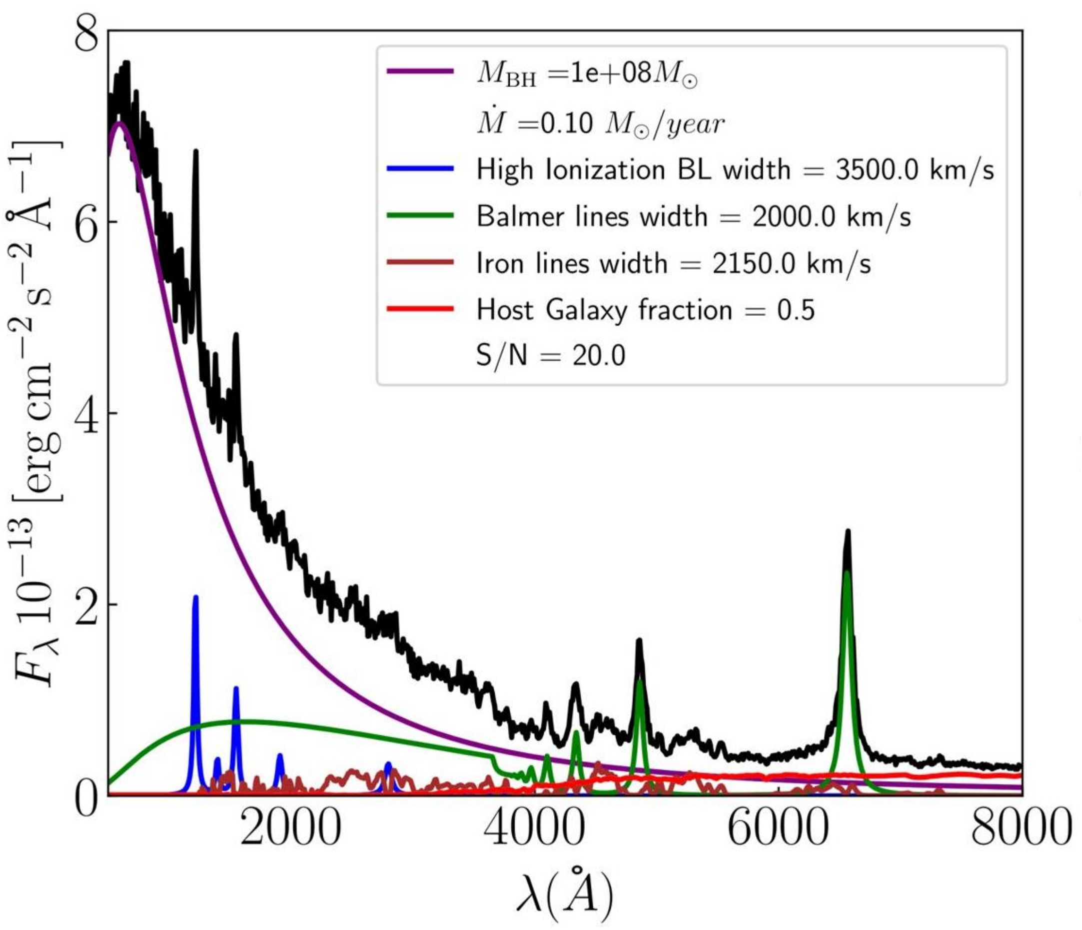
$$T(R) = \left[\frac{3GM\dot{M}}{8\pi R^3\sigma} + \frac{L_*(1-a)}{4\pi R^3\sigma} H_* \cos\theta\right]^{1/4}$$

$$\Psi(\tau|\lambda) = \int_{r_{\rm in}}^{r_{\rm out}} \frac{\partial B_\nu}{\partial T}\frac{\partial T}{\partial L_*}\delta\left(\tau - \tau(r,\phi,i)\right)\mathrm{d}\Omega$$

Pozo Nuñez et al. (2023) MNRAS 522, 2002



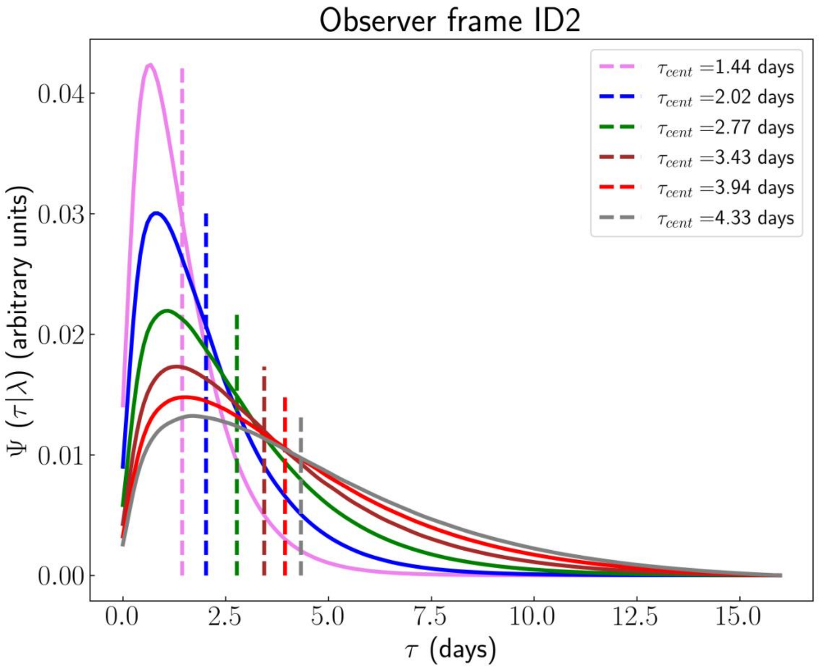


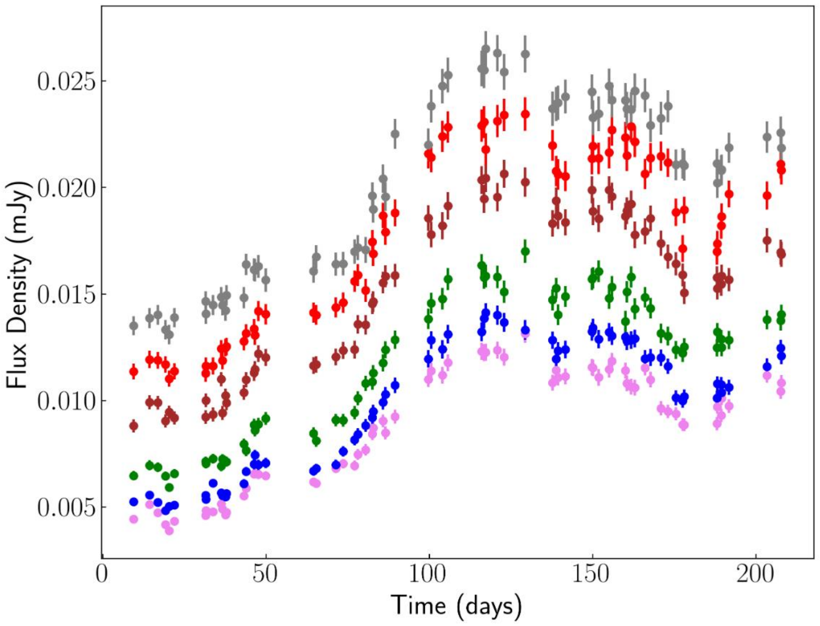


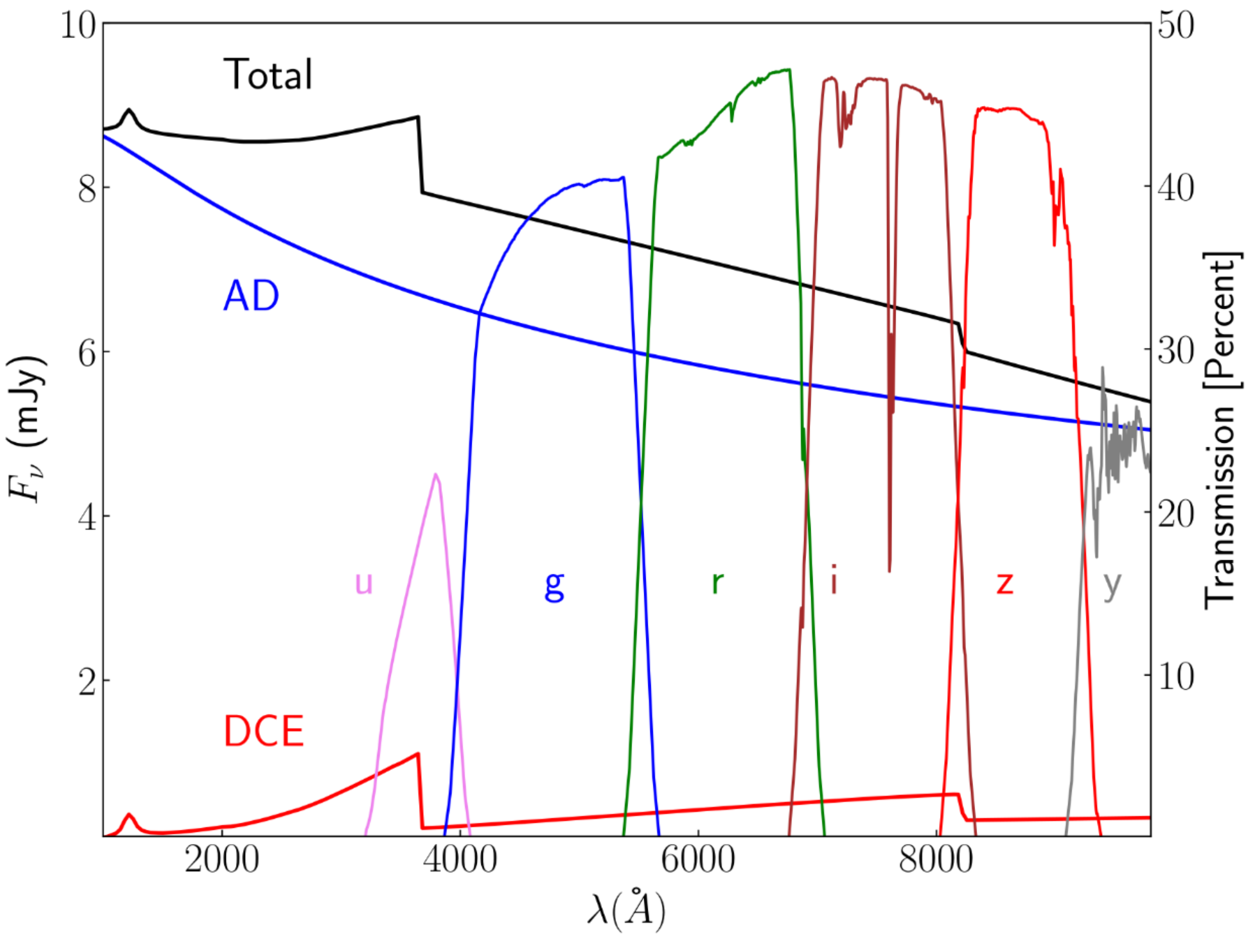
Simulated spectrum, transfer functions and light curves.

Various fraction of contribution from **BLR emission lines** and **diffuse continuum emission**

Pozo Nuñez et al. (2023) MNRAS 522, 2002







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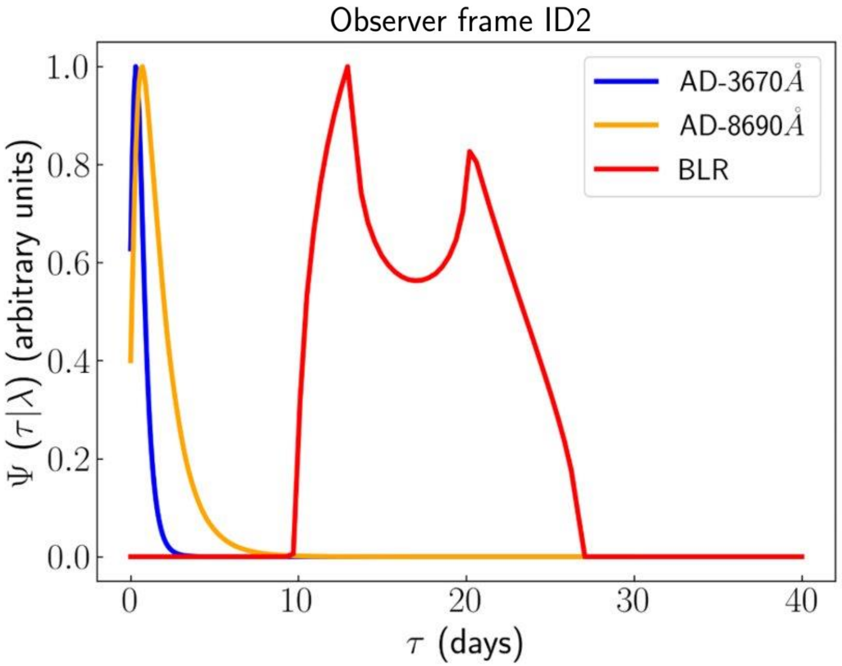
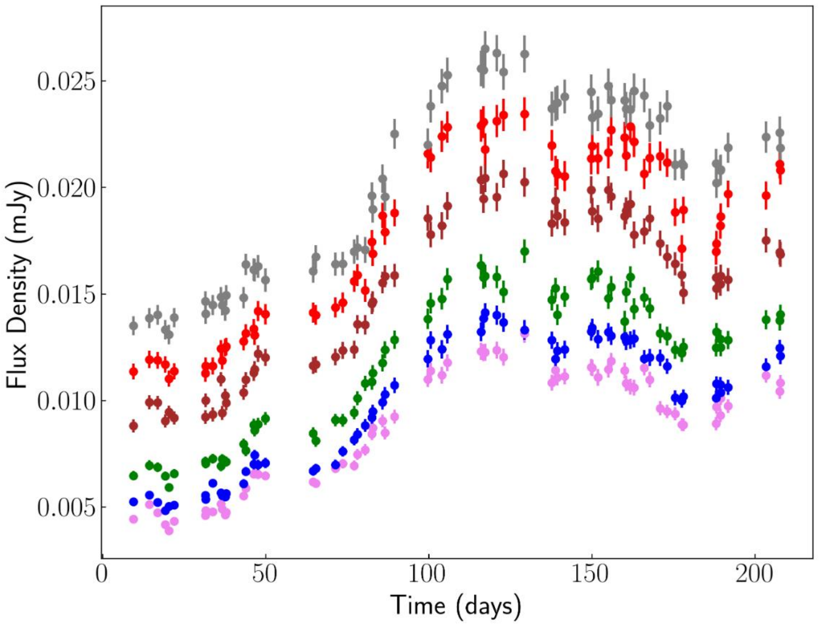
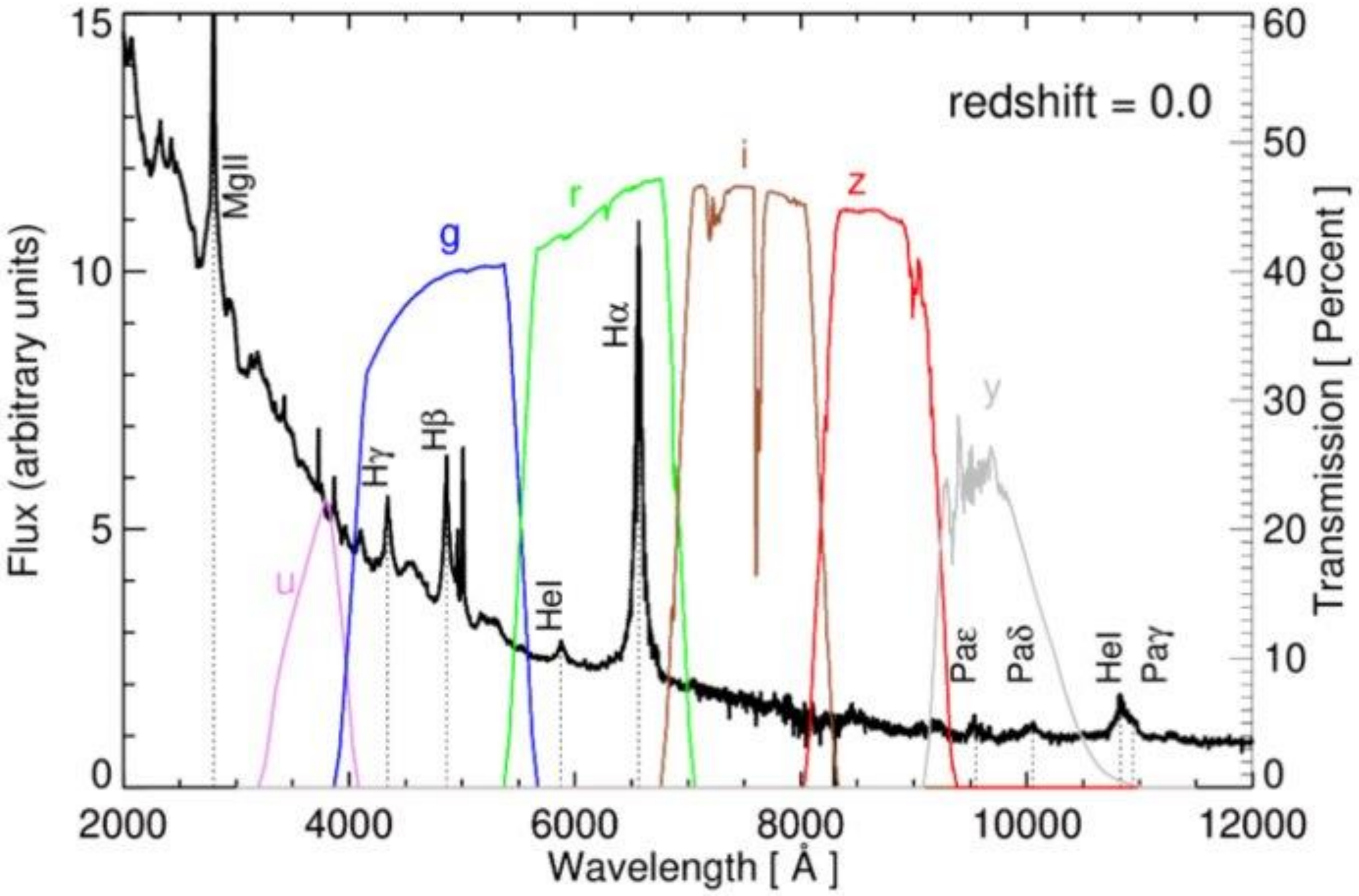






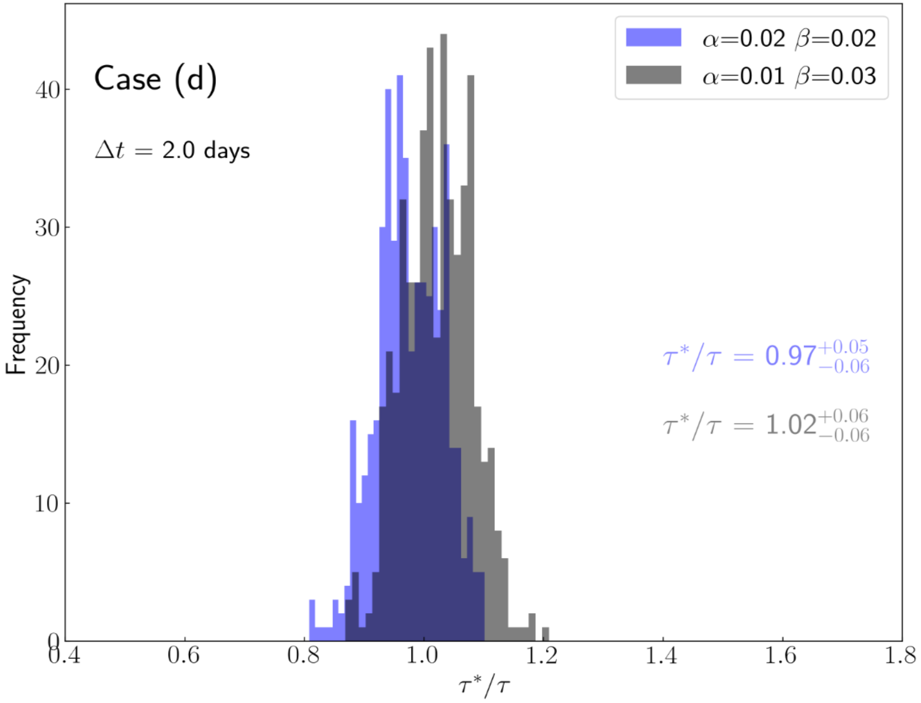
$$f_{\lambda_1}(\alpha, t) = \alpha F_L(t) + (1 - \alpha) F_c(t)$$

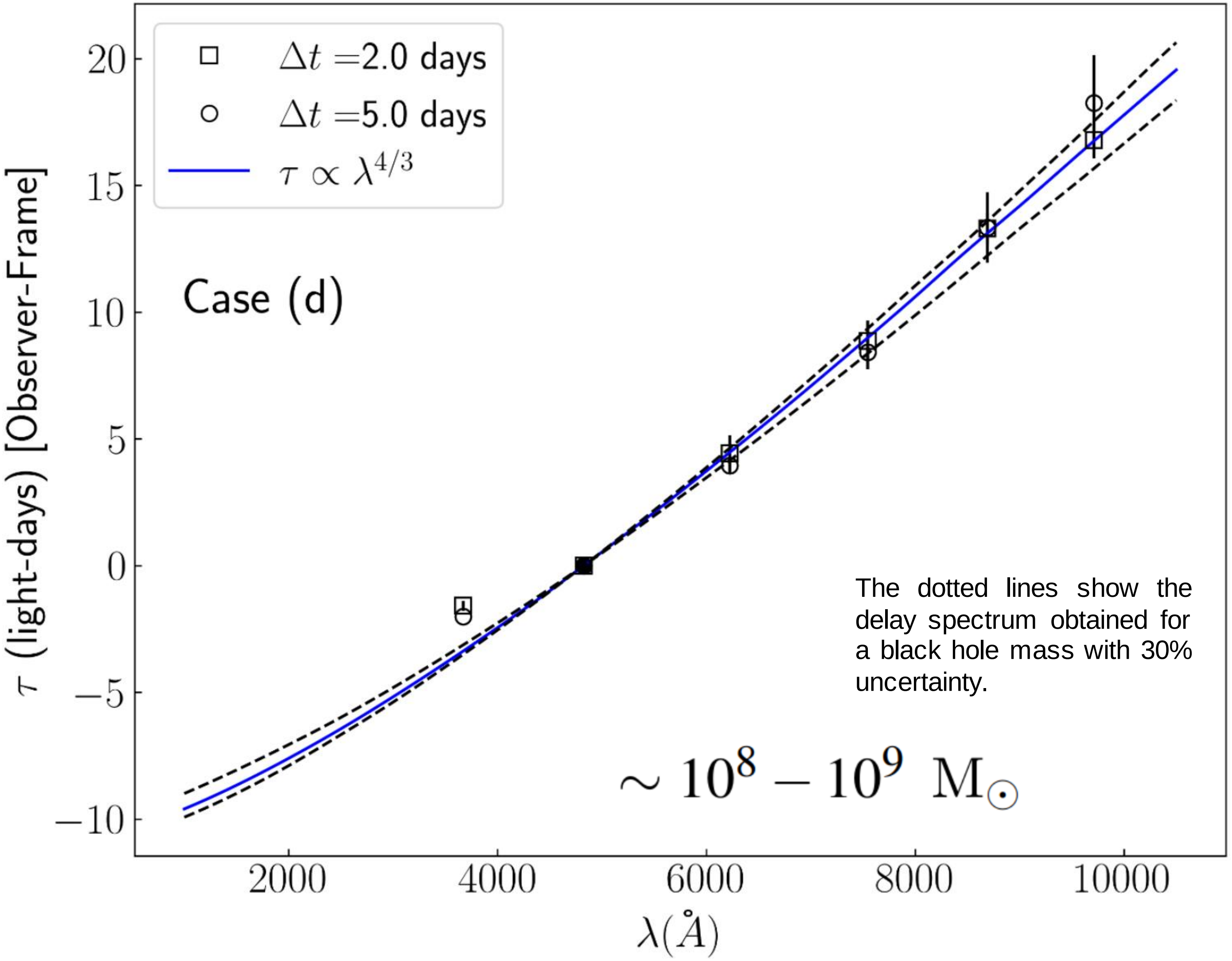
$$f_{\lambda_2}(\beta, t) = \beta F_L(t) + (1 - \beta) F_c(t)$$

Pozo Nuñez et al. (2023) MNRAS 522, 2002

Quasars at redshift 1.5 < z < 2.0

- **Accuracy of 5 and 15% for light curves with time sampling of 2 and 5 days, respectively.**

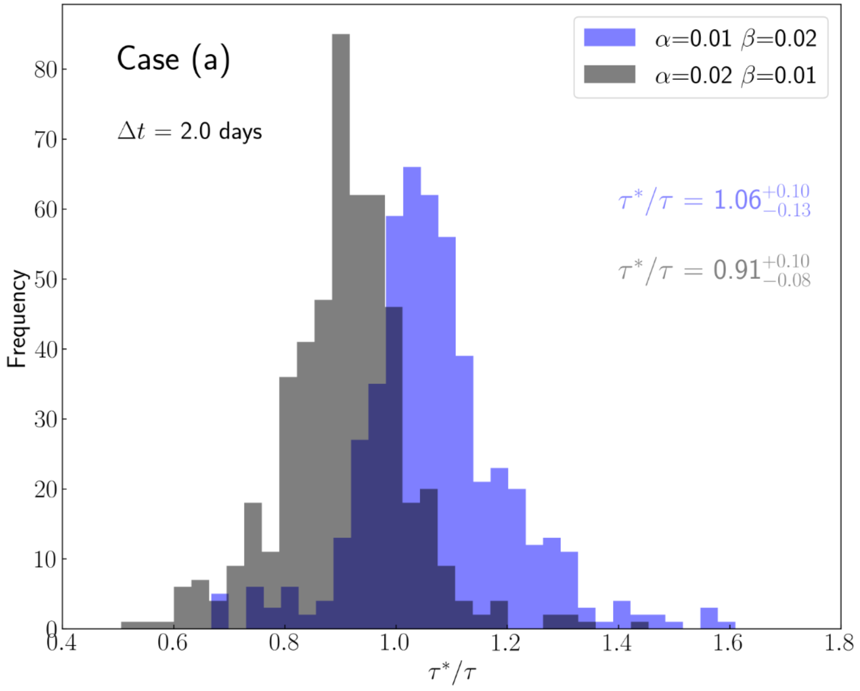


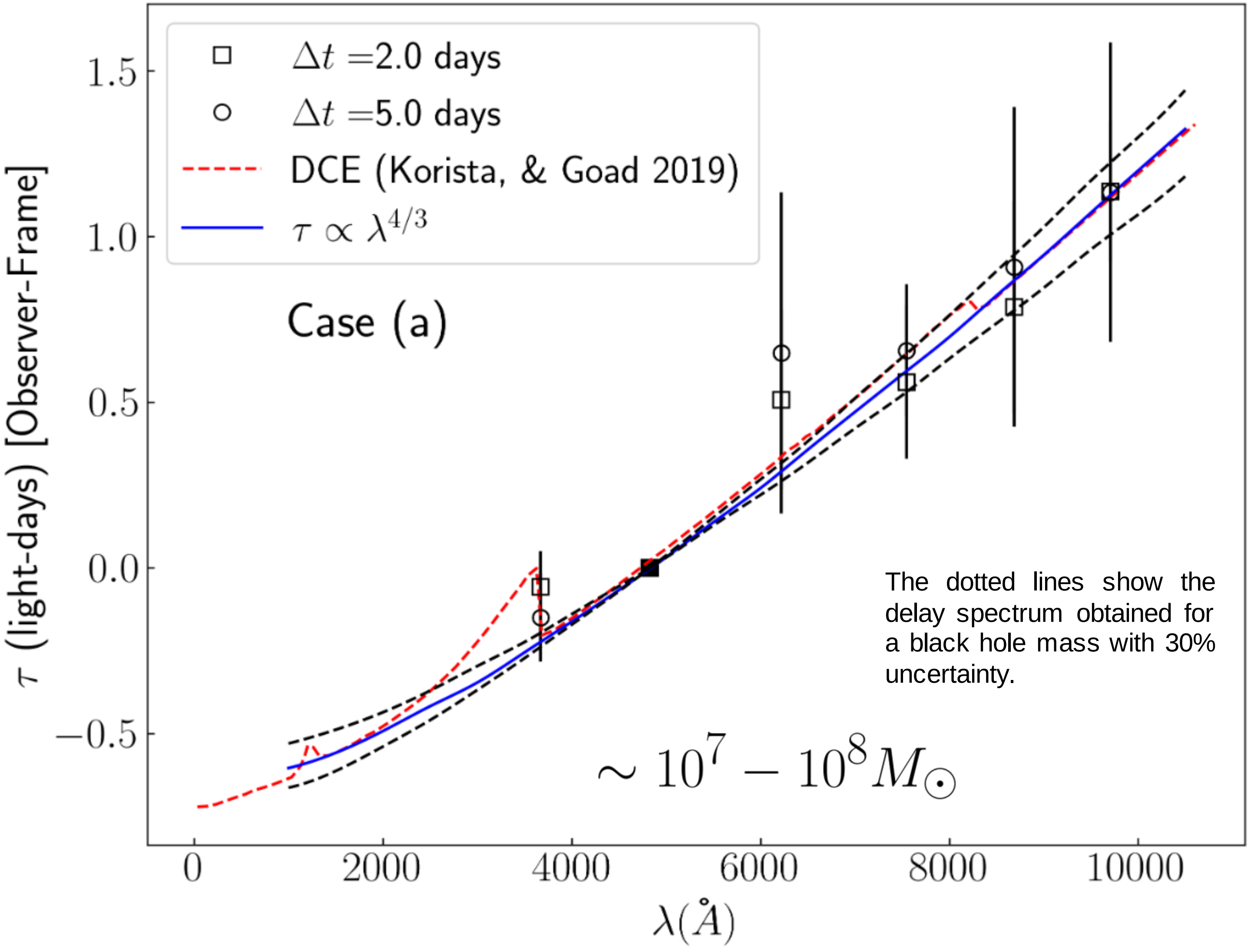


Pozo Nuñez et al. (2023) MNRAS 522, 2002

Quasars at redshift 0.01 < z < 0.5

- **Accuracy of 25% and 50% for light curves with time sampling of 2 and 5 days, respectively.**





The dotted lines show the delay spectrum obtained for a black hole mass with 30% uncertainty.

Pozo Nuñez et al. (2023, MNRAS 522, 2002)

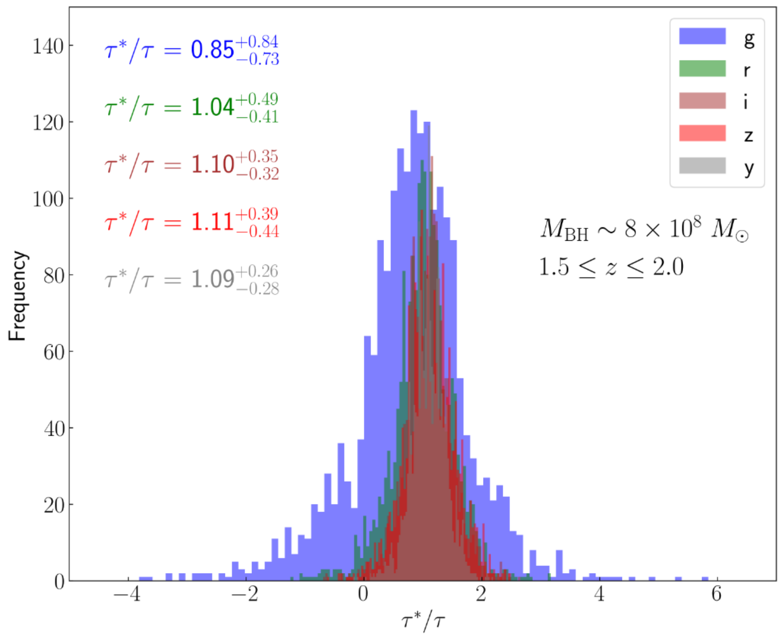
- A minimum signal-to-noise ratio (S/N) of **100** with a BLR emission line contribution of less than **10%** in the filters can lead to recovery of the time delays with **5** and **10%** accuracy for a time sampling of **2** and **5** days, respectively, and for quasars at **1.5 < z < 2.0**.
- An accuracy of **10 to 20%** can be achieved for quasars at **z < 1.5** only if the contribution of the BLR emission lines is less than **5%**.
- Increasing the S/N does not improve the results significantly. **Increased time sampling and reduced BLR emission line contamination is the solution to improve time delay accuracy.**

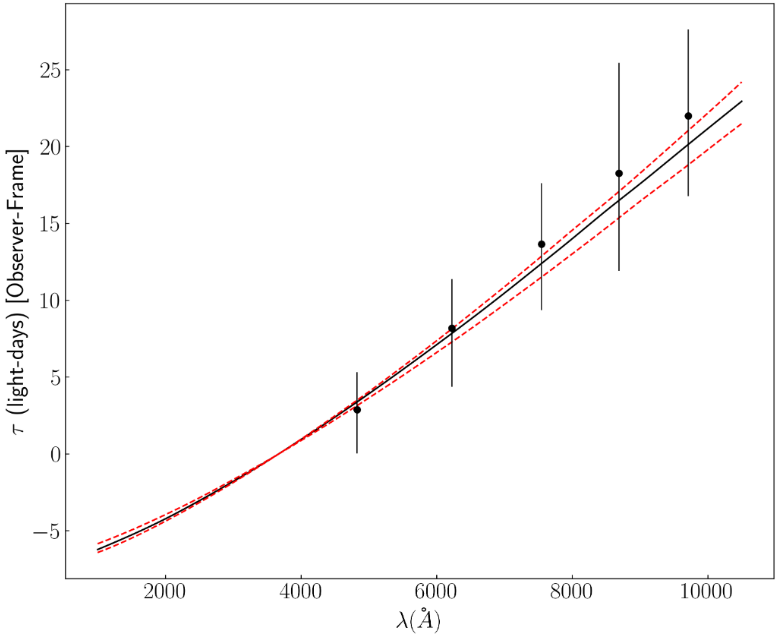
More realistic LSST cadences:

ELAIS-S1

Czerny et al. (2023, A&A 675A)

The best-case recovery is for *i*, *z*, and *y* bands, with uncertainties around **30%**. For *g* and *r* bands, uncertainties are approximately 90% and 40%, respectively.

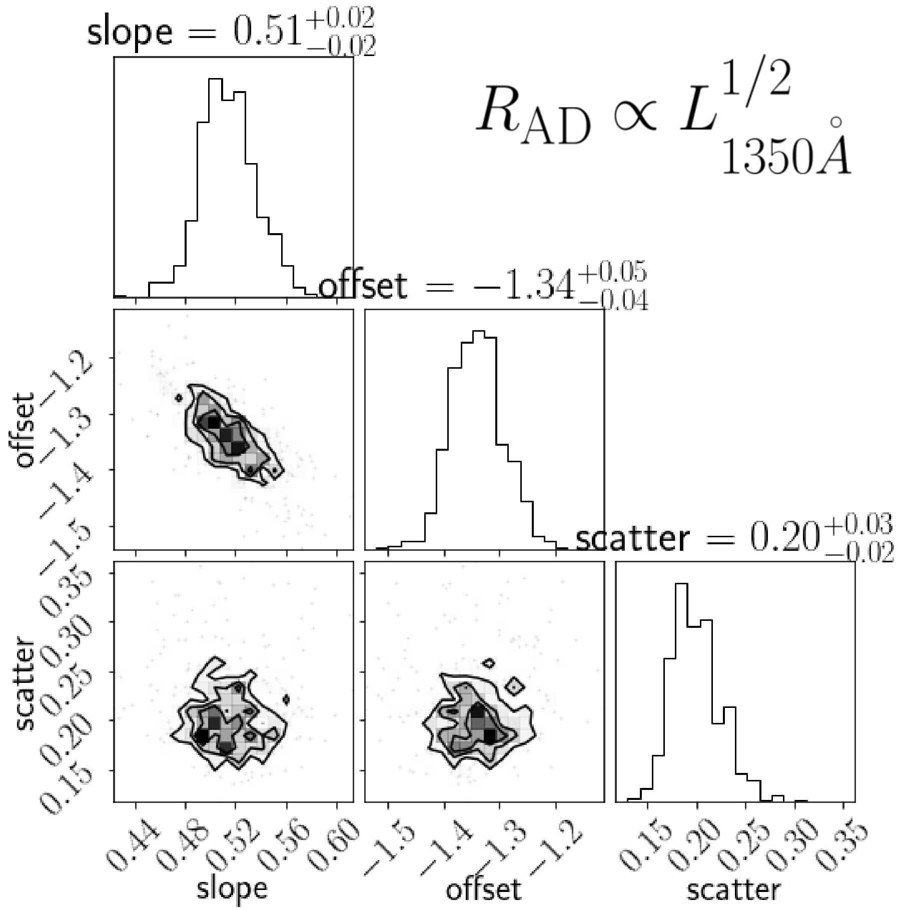


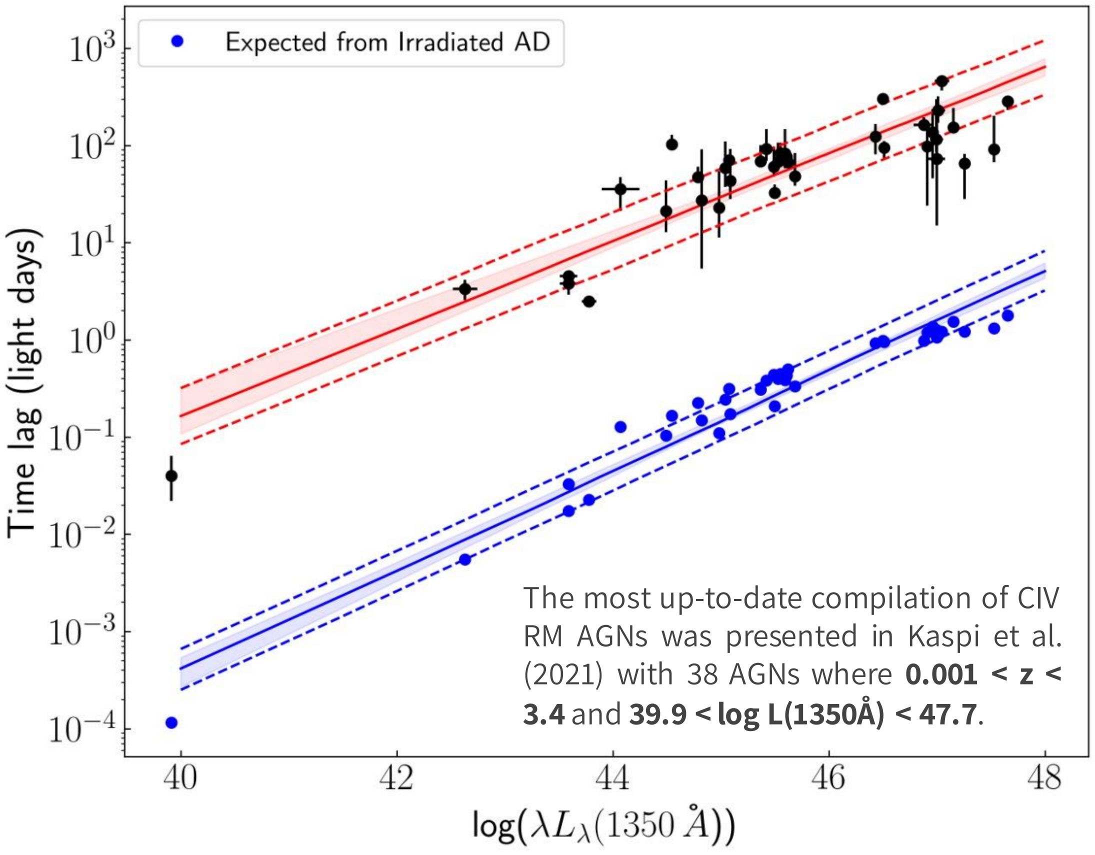


Pozo Nuñez, Czerny et al. (2024, Res. Notes AAS 8 47)

High redshift quasars BHMs

- To estimate black hole masses.

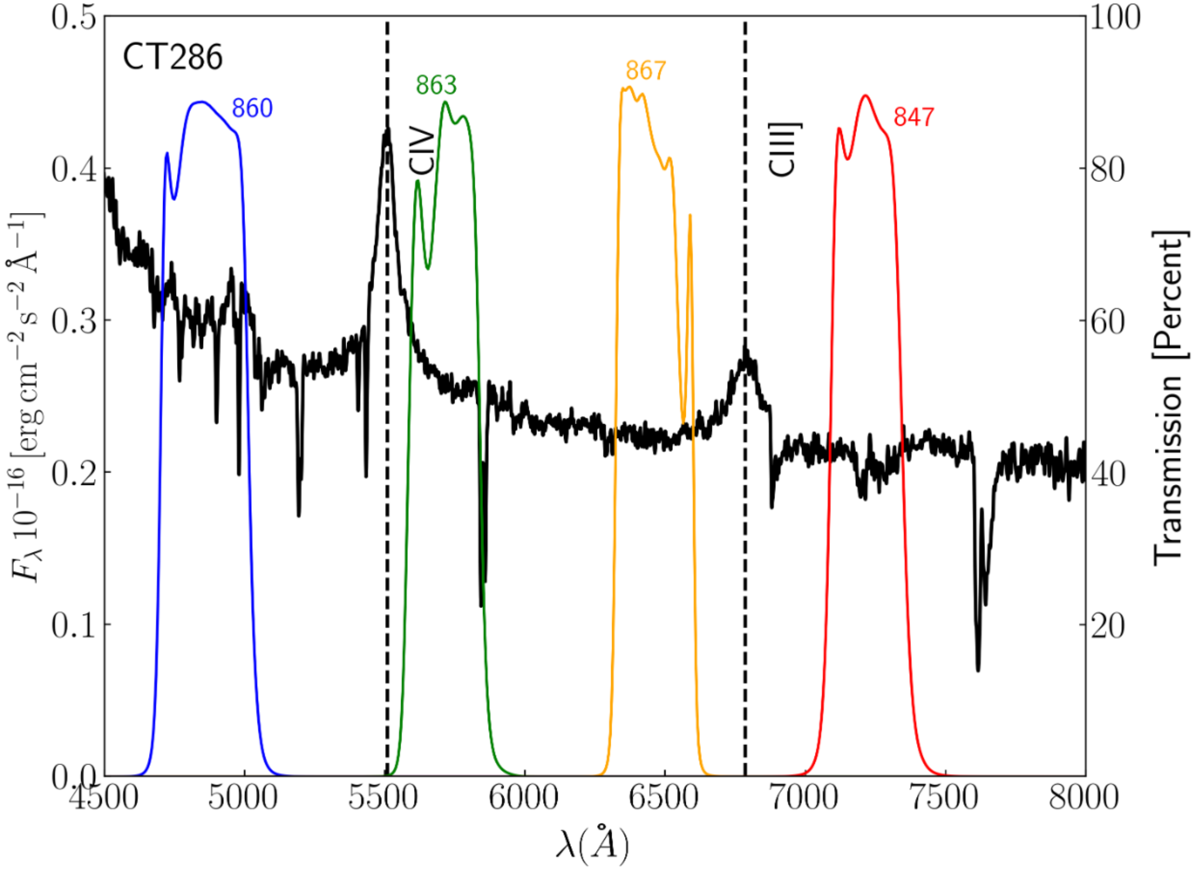


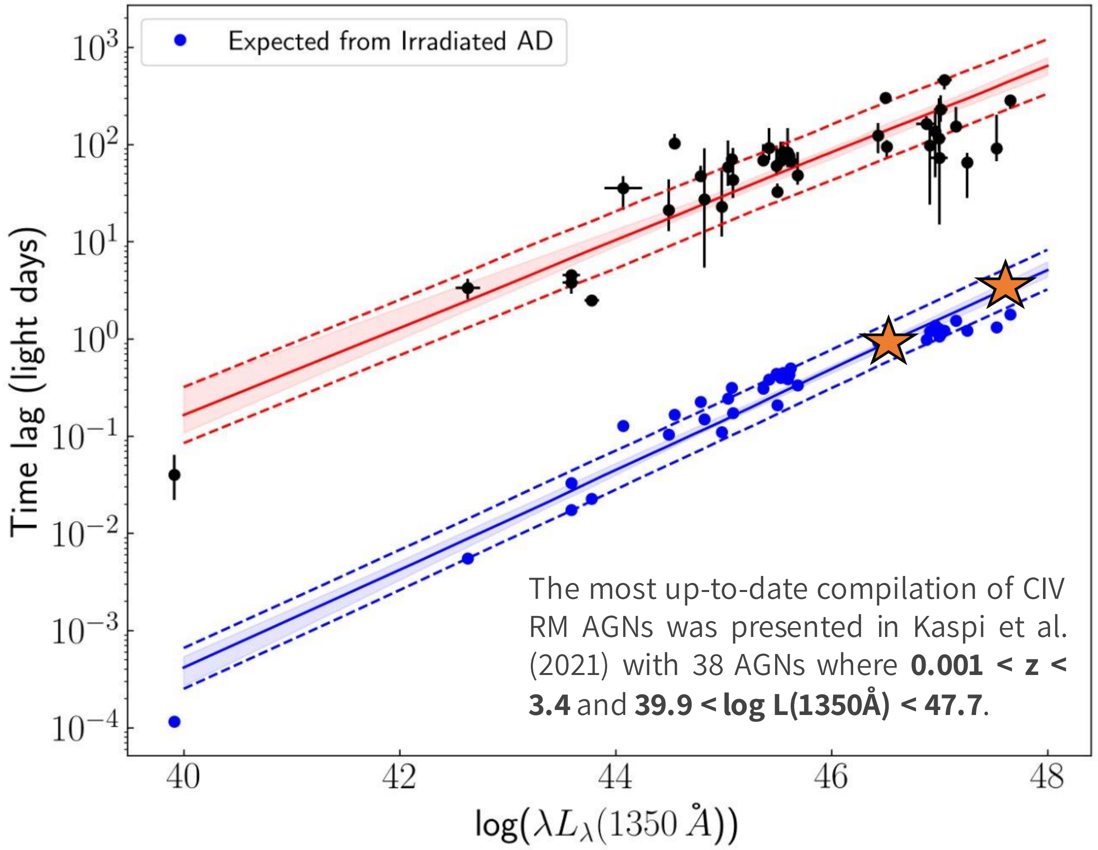


Panda, Pozo Nuñez et al. (2024, ApJ Letters)

High redshift quasars BHM

- **MPIA 2.2m selected filters**





High redshift quasars BHM

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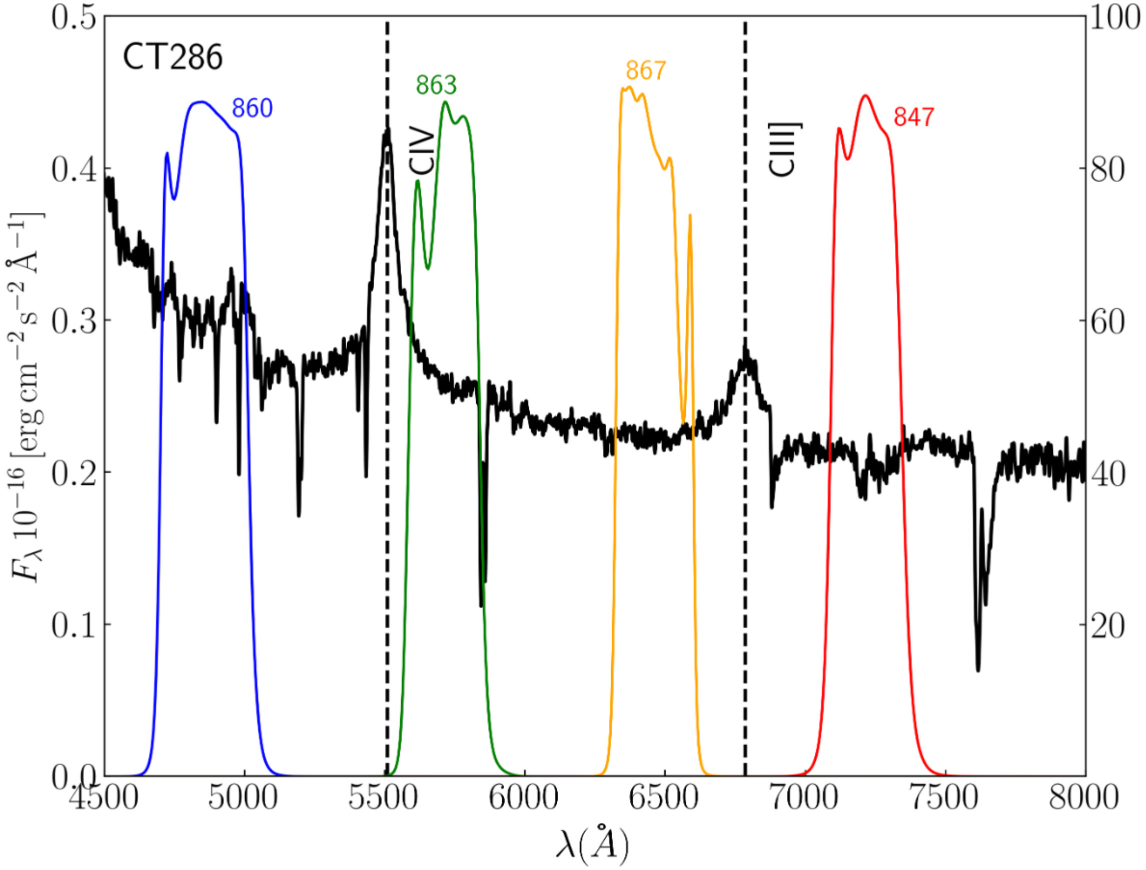
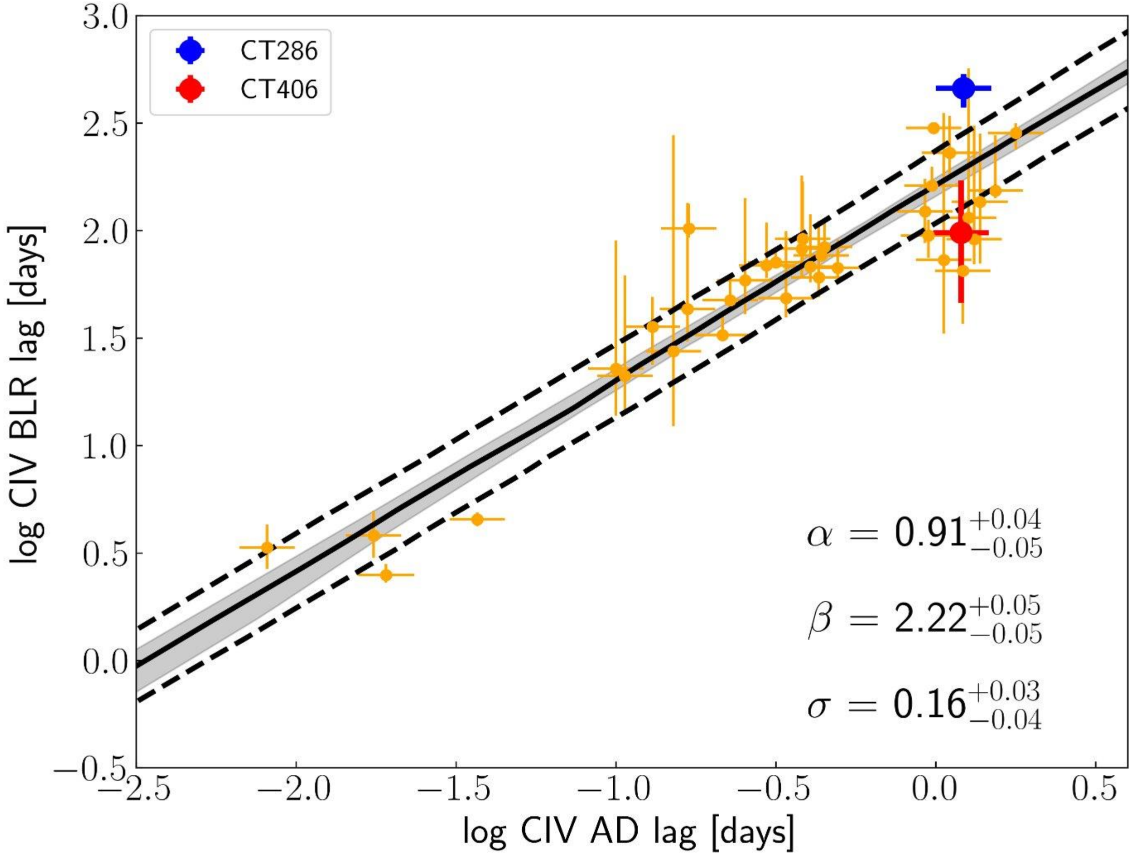
CIV-emitting R_{BLR} is 165.96 times (2.22 dex) larger than the R_{CER}





Panda, Pozo Nuñez et al. (2024, ApJ Letters)

High redshift quasars BHM

CIV-emitting R_{BLR} is **165.96** times (2.22 dex) larger than the R_{CER}

For example, for a quasar with an AD size of

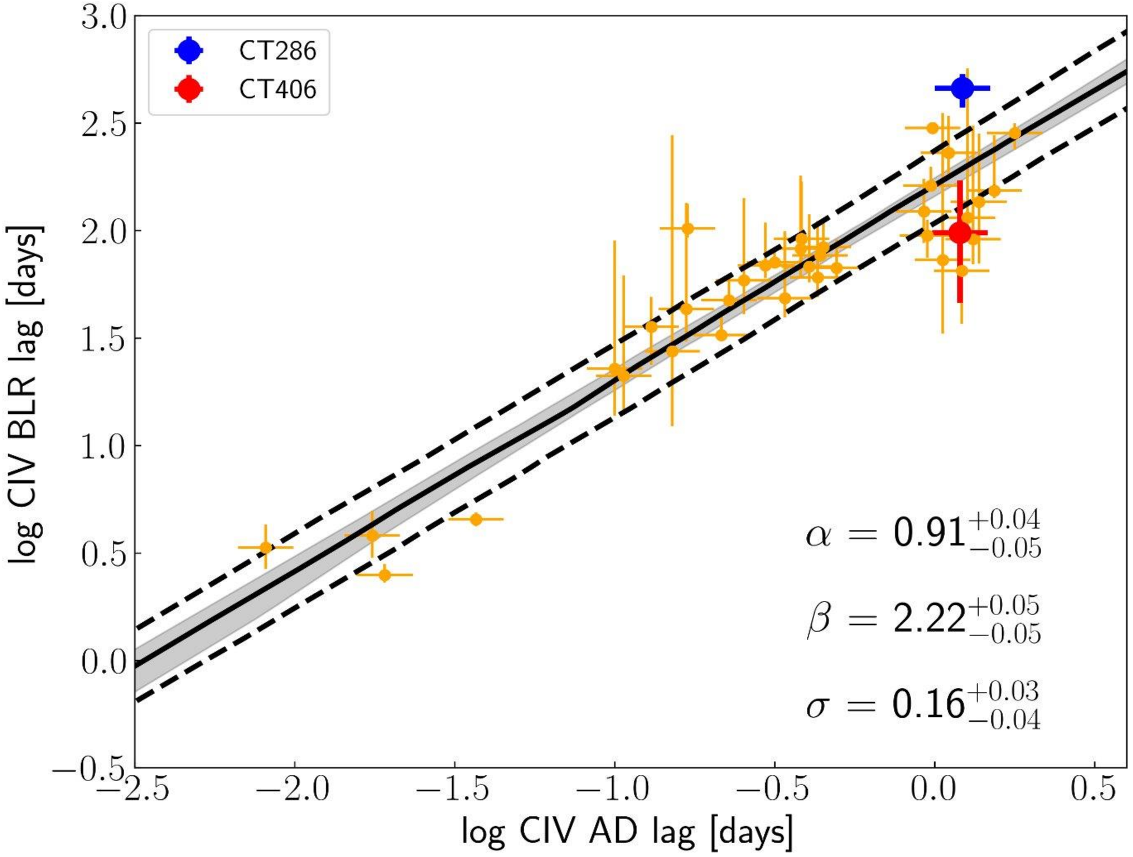
$$R_{\rm AD} = 1\,\text{lt-day}$$

we can predict a BLR size of

$$R_{\rm BLR} = 165.9^{+36.2}_{-35.4}\,\text{lt-day}$$

with an uncertainty of about 22%, considering the uncertainties of the parameters α, β and the intrinsic scatter σ.

Taking into account the ~5% uncertainty in the FWHM measurements for the sources reported in Kaspi et al. (2021) (see their Table 6) and combining it with the 22% uncertainty in the RBLR scaling from our predictions, we calculate an overall uncertainty of **~23%** in the BHM estimates.



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Thank you