What can microlensing of strongly lensed quasars tell us about the quasars structure ?
The case study of QJ0158-4325

Eric Paic (EPFL)
PhD candidate
Collaborators : V. Bonvin, F. Courbin, M. Millon, J.H.Chan, G.Vernardos, D. Sluse

Time domain cosmology workshop
January 2021

Quasar structure and reverberation process

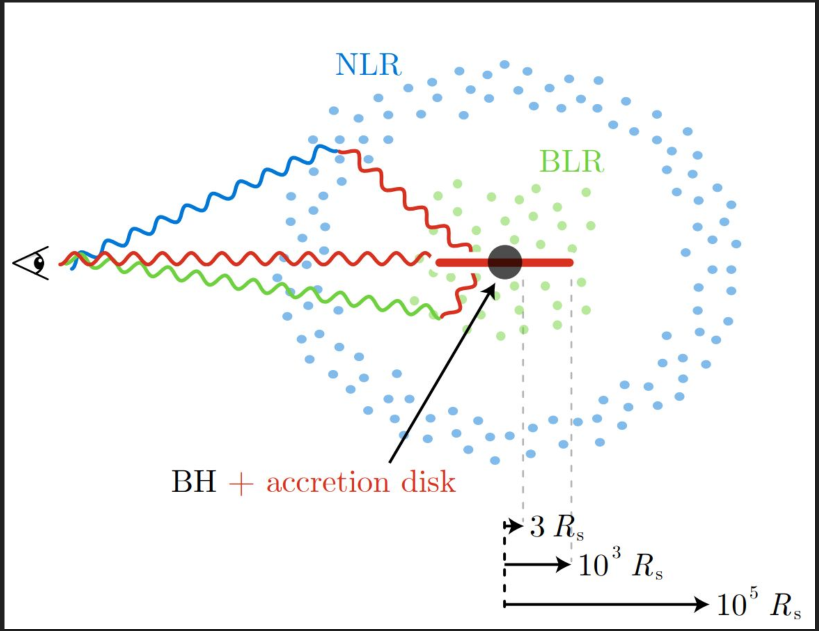
On top of the intrinsic variability of the quasar $I(t)$, a time lag between accretion disk emissions and BLR/NLR reverberations can add variability

(Sluse & Tewes 2014)

Check D. Sluse talk

BH: Black Hole NLR: Narrow Line Region

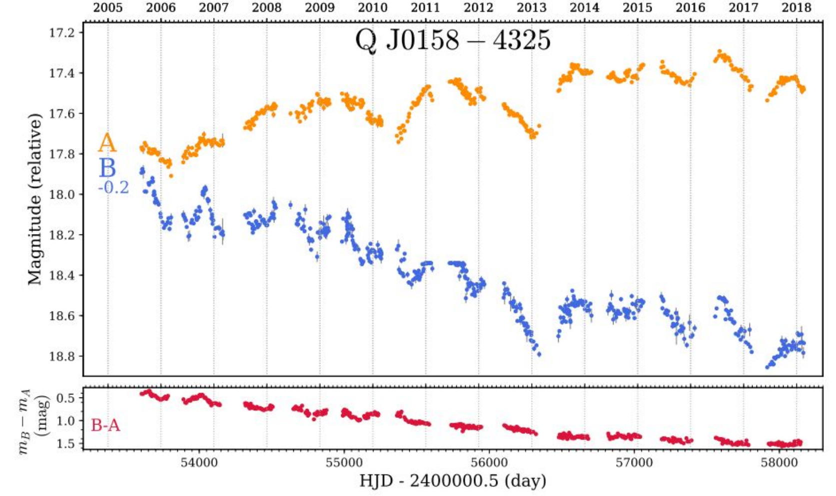
BLR: Broad Line region R_S: Schwarzschild radius



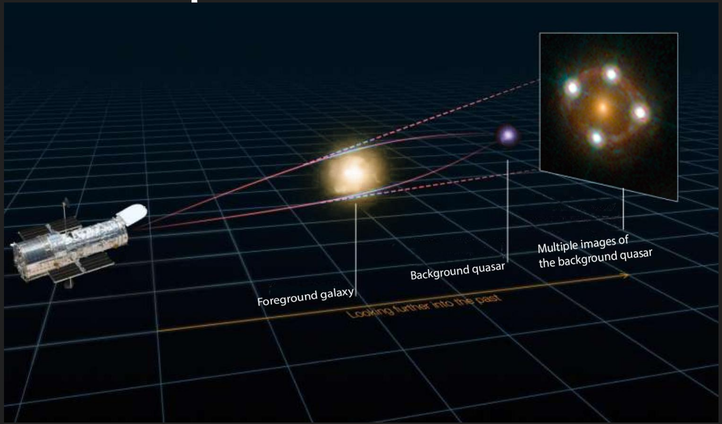
Credits: A. Galan

Microlensing of strongly lensed quasars

Microlensing by stars in the foreground galaxy adds extrinsic variability to the strongly lensed images $m_{\mathrm{A}}(t)$ and $m_{\mathrm{B}}(t)$



Millon et al. (2020)



Credits: TDCOSMO collaboration

$$S_{\mathrm{A}}(t) = I(t) + m_{\mathrm{A}}(t)$$

$$S_{\mathrm{B}}(t) = I(t - \Delta t_{\mathrm{AB}}) + m_{\mathrm{B}}(t)$$

For QJ0158: $\Delta t_{\mathrm{AB}} = 22.7 \pm 3.6$ days

$$S_{\mathrm{A}}(t) - S_{\mathrm{B}}(t + \Delta t_{\mathrm{AB}}) = m_{\mathrm{A}}(t) - m_{\mathrm{B}}(t)$$

Accretion disk measurement methods

Light curve fitting method : Use simulated microlensing light curves to find the scale radius R_0

For QJ0158 yields $log\,(R_0/cm) = 15.6 \pm 0.3$

Morgan et al.(2012)

Luminosity method : Thin disk theory gives $R_0 \propto M_{\rm BH}^{2/3} L^{1/3}$

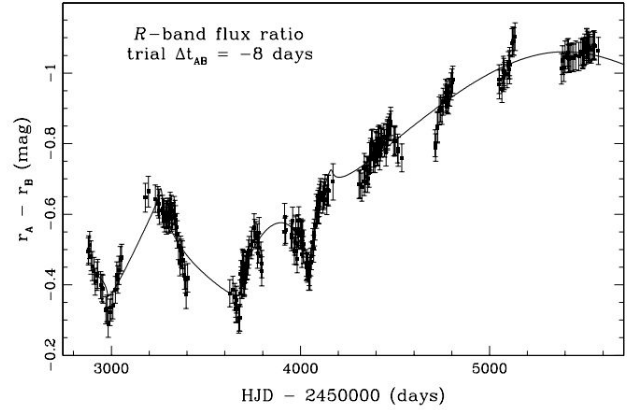
Shakura & Sunyaev (1973)

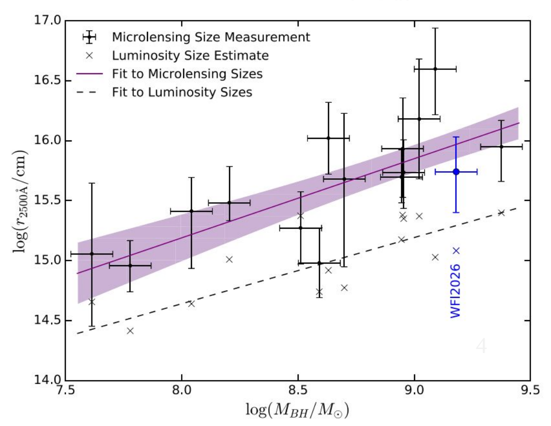
For QJ0158 yields $log\,(R_0/cm) = 15.07$. Hereafter $R_{\rm ref}$

Mosquera & Kochanek (2011)

Overall, a scale factor of 3 to 4 is observed between the microlensing and luminosity measurements

The non-fitting of the high frequency features (shorter than 750 days) in the light curve may lead to an overestimation of the scale radius





Cornachione et al. (2019)

Power spectrum method - Flow chart

Light curve fitting method

Generate magnification maps

$\langle M \rangle$: Mean stellar mass

⇨

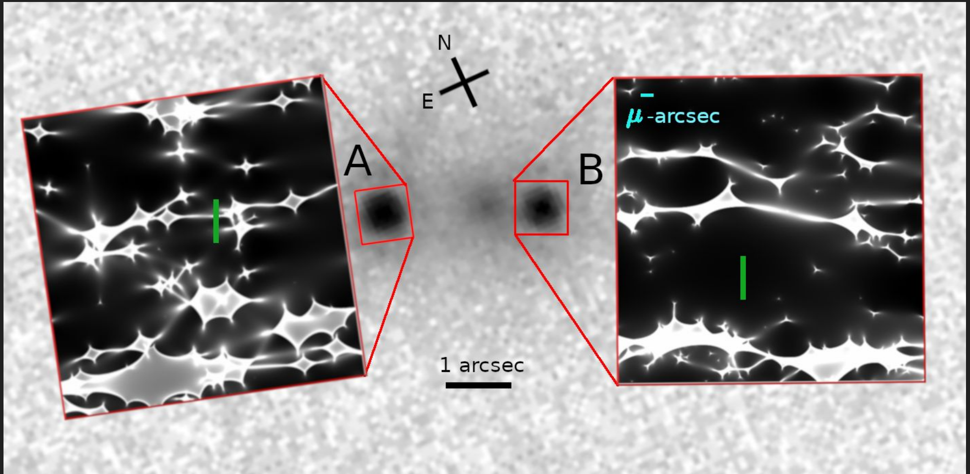
Convolve them with source light profile

R_0 : Accretion disk scale radius

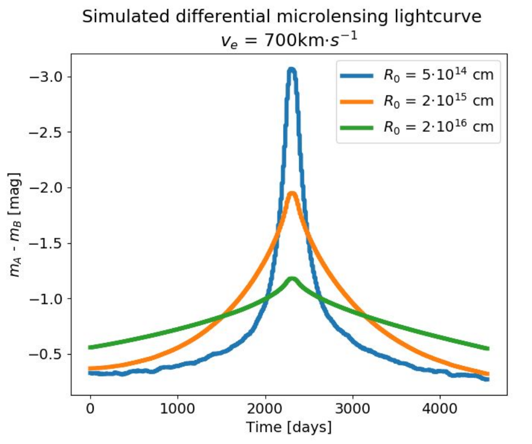
⇨

Draw trajectories in the maps

v_e : Effective velocity



⇨



Power spectrum method - Flow chart

Light curve fitting method

Generate magnification maps

$\langle M \rangle$: Mean stellar mass

⇨

Convolve them with source light profile

R_0 : Accretion disk scale radius

⇨

Draw trajectories in the maps

v_e : Effective velocity

Additional steps for our method

⇨

Add reverberation process and generate 100’000 light curves

f_{BLR} : Fraction of reverberated flux

R_{BLR} : BLR radius

⇨

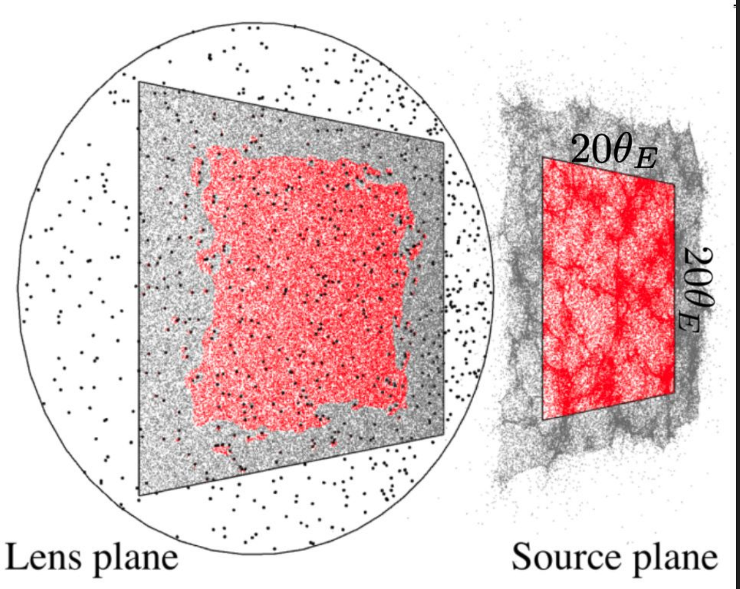
Compute their power spectra to give equal weight to every time scale of variation

⇨

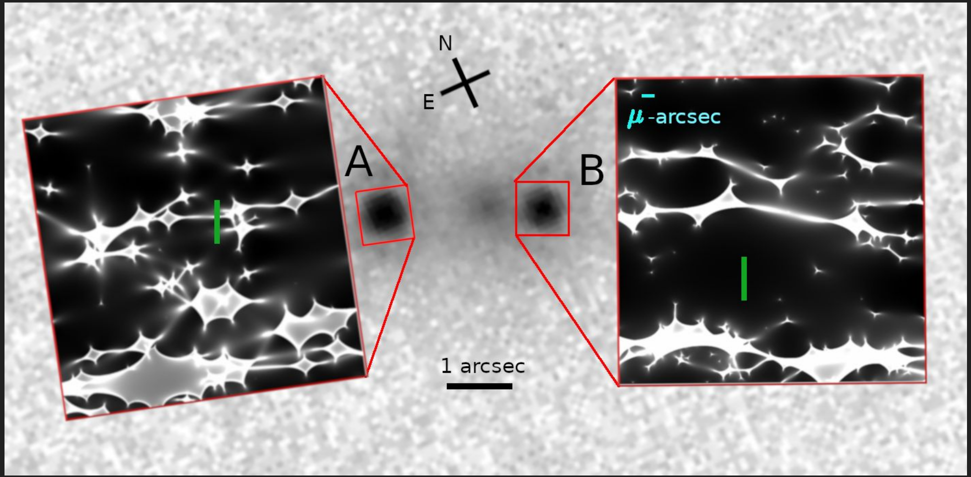
Compute the posterior probability of a given set of parameter

$\zeta : (\langle M \rangle, v_e, R_0, f_{\mathrm{BLR}}, R_{\mathrm{BLR}})$

Light curve fitting - Magnification maps



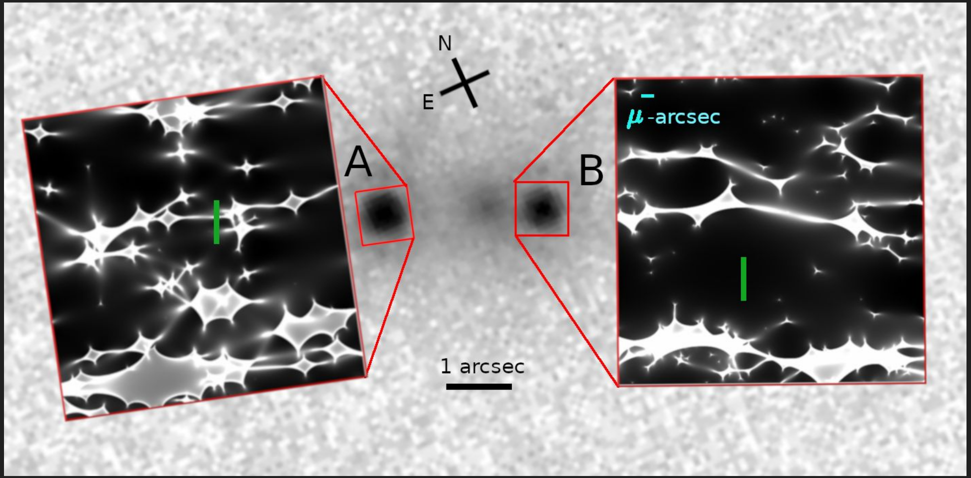
Vernardos & Fluke (2014)

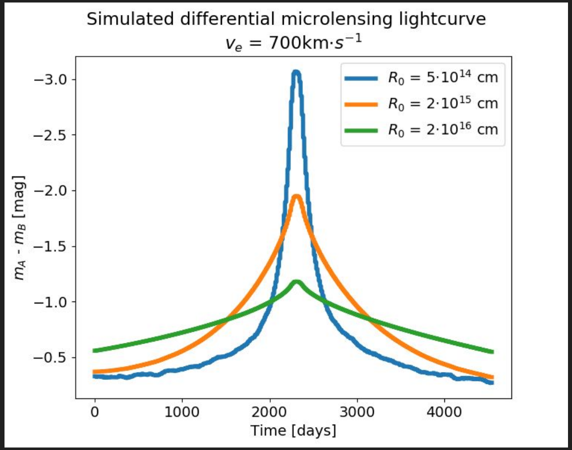


Paic et al. (in prep)

- A population of stars with a mean mass $\langle M \rangle$ is drawn in the lens plane following Salpeter's IMF
- This population is projected onto the source plane using the direct inverse ray shooting method
- The relative motion of the observer, the lens, the stars within and the source translates into a trajectory of the source in the magnification map with a velocity v_e

Light curve fitting - Microlensing light curves





The magnification maps are convolved with the source light profile for a given scale radius of the accretion disk R_0

Add of the reverberation process

Generation of light curves with reverberated flux

$$F_\alpha(t) = M_\alpha \mu_\alpha(t) F_{acc}(t) + M_\alpha F_{\mathrm{reverb}}(t)$$

Sluse & Tewes (2014)

$$F_\alpha(t) = M_\alpha \mu_\alpha(t) F_{acc}(t) + M_\alpha f_{\mathrm{BLR}}(F_{\mathrm{acc}}(t) * \Psi(t, R_{\mathrm{BLR}}))$$

$\mu_\alpha(t)$: **micro** – magnification of image α

M_α : **macro** – magnification of image α

f_{BLR} : Fraction of reverberated flux

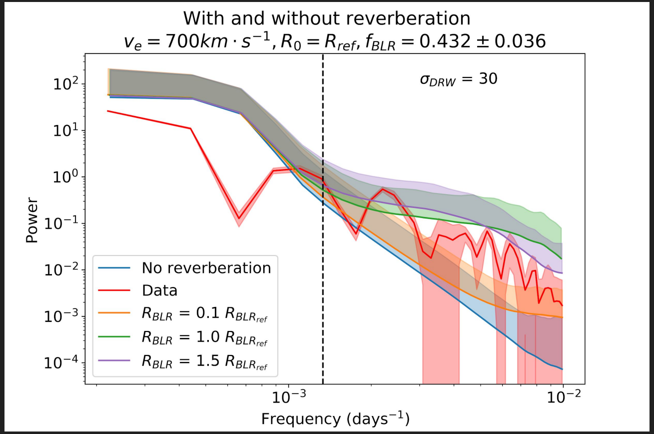
$\Psi(t, R_{\mathrm{BLR}})$: Transfer function related to the radius of the BLR

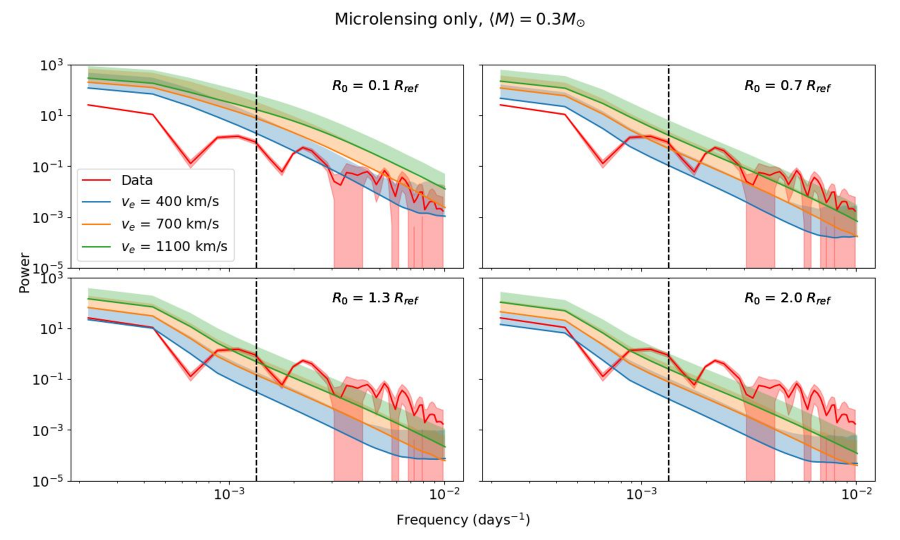
$F_{\mathrm{acc}}(t)$: Flux of the accretion disk modeled as a Damped Random Walk

Results- Comparing simulations with data

Mean and upper 1-σ envelope of 100’000 simulated power spectra along with data power spectrum

<ins>Frequencies above</ins> $1/750\ \text{days}^{-1}$ are hard to fit

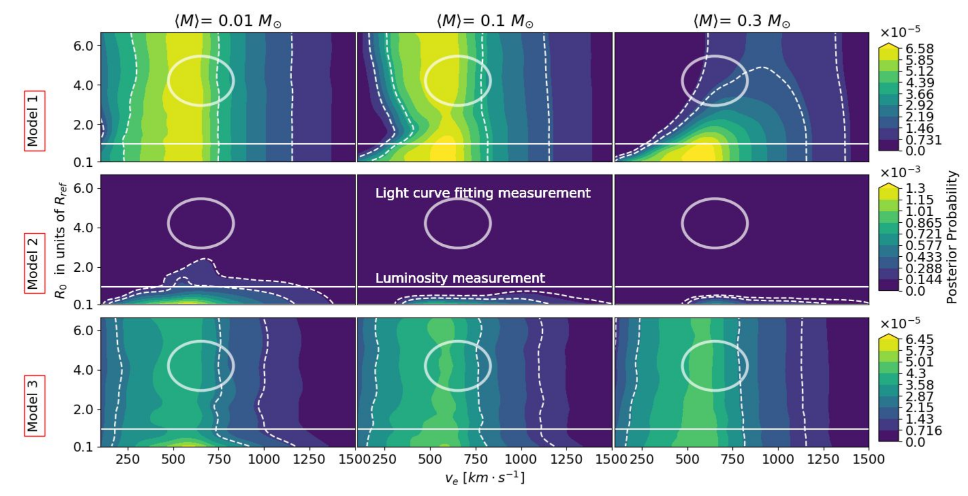


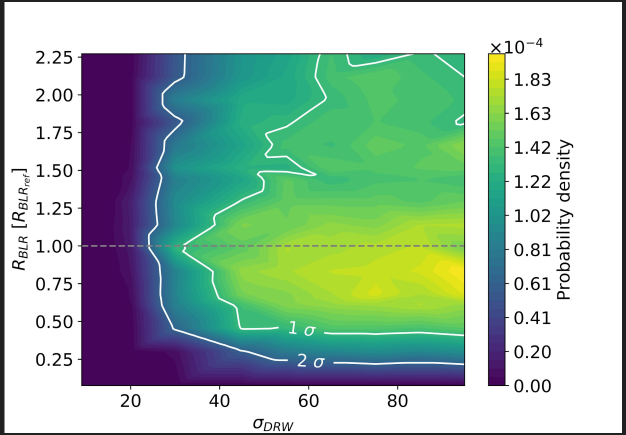


Reverberation process adds power in the high frequency as a function of R_{BLR}

Paic et al. (in prep)

Results - Measurement of the scale and BLR radius





Paic et al. (in prep)

Microlensing is <u>not the cause</u> of the high frequency signal.

We are able to <u>measure the radius of the BLR</u> in agreement with measurement of Mosquera & Kochanek (2011)

<u>Model 1</u>: $f_{\rm BLR} = 0$, only low frequencies (up to $1/750 \text{ days}^{-1}$)

<u>Model 2</u>: $f_{\rm BLR} = 0$, low and high frequencies

<u>Model 3</u>: $f_{\rm BLR} = 0.432 \pm 0.036$, low and high frequencies

Conclusion

In this talk a new method to measure the accretion disk radius using the power spectrum of the microlensing light curve was presented.

- This method takes into both low and high frequency variations
- Our results show that microlensing is not the cause of the high frequency signal.
- We show that the short events are due to reverberation inside the source.
- We are able to measure the radius of the BLR and are compatible with the measurement of Mosquera & Kochanek (2011).

Thank you for your attention !

Questions on the dedicated slack channel or to eric.paic@epfl.ch