Probing the geometry of Q2237+0305 with microlensing time-series

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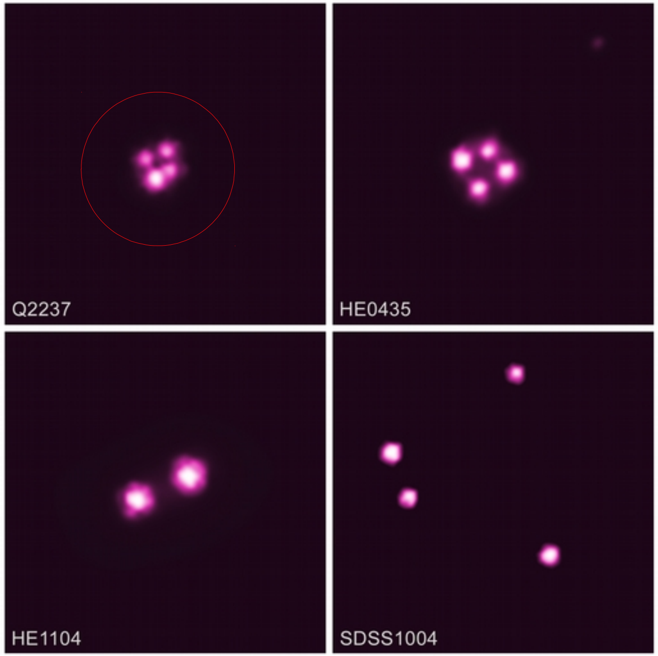
Q2237+0305 outline

- Observations of quad lense Q2237+0305
- Models using STOKES and SKIRT

- Micro-lensing simulation
- and caustic-crossing events

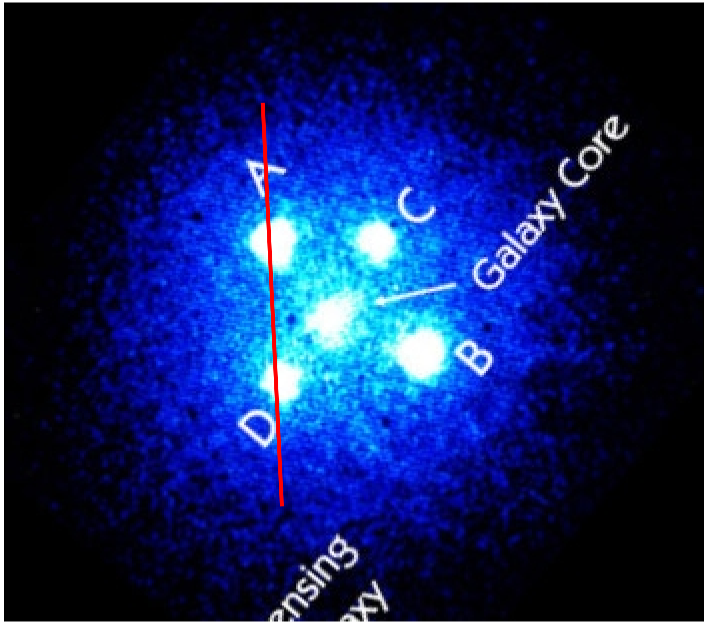
- Results



Importance of lensed quasars

- Detecting objects at large redshift due to magnification
- Constraining the innermost structure of AGNs (Jimenez-Vicente+2014; Hutsemekers+2017)
- Probing the accretion disk and its temperature profile (Cornachione & Morgan 2020)
- BLR kinematics and SMBH mass estimates (Popovic+2001,2020; Sluse+2012; Hutsemekers+2017,2019,2021,2023)
- Exploring the influence of gravitational micro- and macro-lensing on the polarization signature in AGNS
- Timescale investigations microlensed quasars Neira+2020

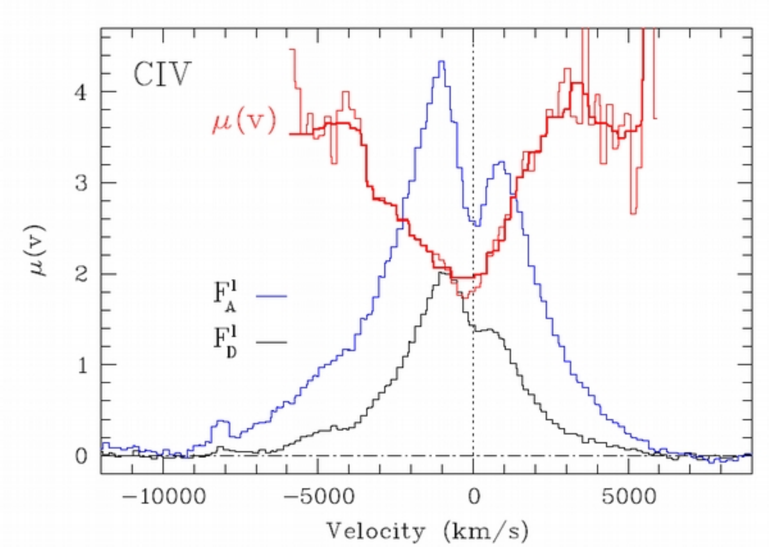
Q2237+0305



- A four image lensed system
- Source redshift Zs = 1.695
- Lense redshift Zl = 0.00394
- 1.6” separation between the components
- Huchra lense (Huchra et al. 1985)
- Asymmetry of the blue wing of the C IV in the component A (Hutsemekers & Sluse 2021)
- Time delay between components <1 day

Q2237+0305 - observations

- ESO-VLT FORS1 (8.2m)
- Multi-object observing mode (MOS)
- Spectrophotometric monitoring
- from october 2004-december 2007
- Reduction Eigenbrod et al. (2008);
- Sluse et al. (2011);



Q2237+0305 - indices

- Four observable quantities (Braibant+2017;Hutsemekers+2019)

$$\lambda L_{\lambda}(1450\,\text{Å})$$

$$\mu^{cont}$$

- Continuum – (1 variable)
- BLR (3 variables)

$$\mu^{BLR} = \frac{1}{M}\frac{\int_{v_-}^{v_+} F_A^l(v)dv}{\int_{v_-}^{v_+} F_D^l(v)dv},$$

$$WCI = \frac{\int_{v_-}^{v_+} \mu(v)/\mu(v=0)dv}{\int_{v_-}^{v_+} dv},$$

- WCI – wing/core deformation
- RBI – red/blue asymmetry

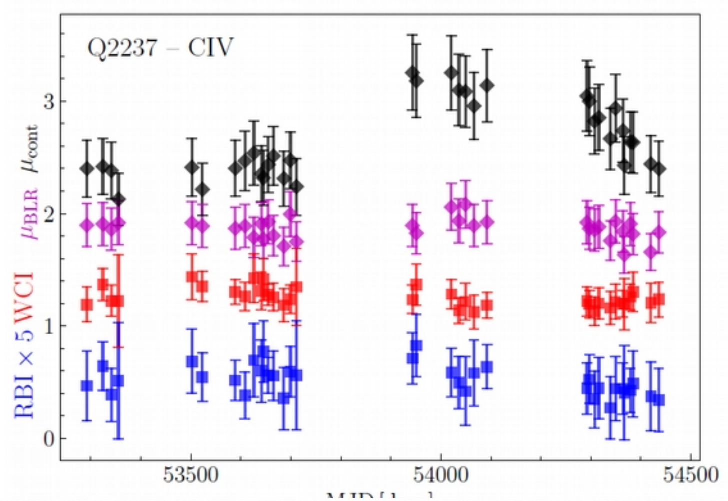
$$RBI = \frac{\int_0^{v_+} \log\mu(v)dv}{\int_0^{v_+} dv} - \frac{\int_{v_-}^{0} \log\mu(v)dv}{\int_{v_-}^{0} dv},$$

- Invariant to macro-amplification

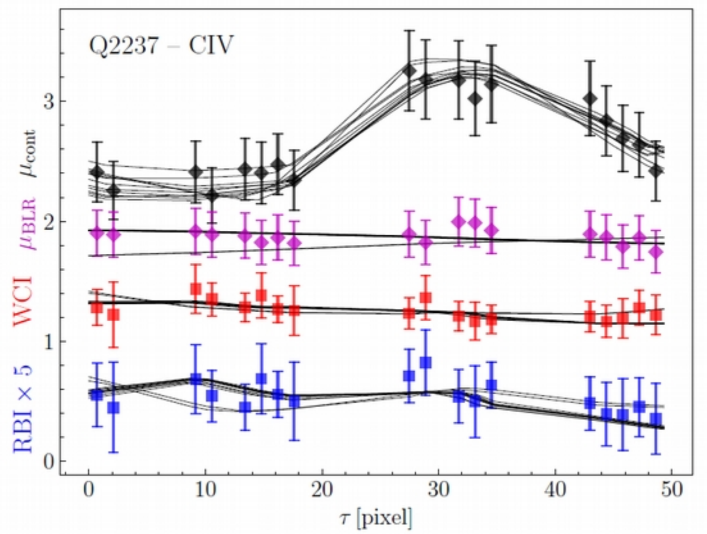
$$\mu(v) = \frac{F_A^l(v)}{M \times F_D^l(v)},$$

Q2237+0305 - indices

Original



Binned



$$\mu^{cont}$$

$$\mu^{BLR} = \frac{1}{M}\frac{\int_{v_-}^{v_+} F_A^l(v)dv}{\int_{v_-}^{v_+} F_D^l(v)dv},$$

$$WCI = \frac{\int_{v_-}^{v_+} \mu(v)/\mu(v=0)dv}{\int_{v_-}^{v_+} dv},$$

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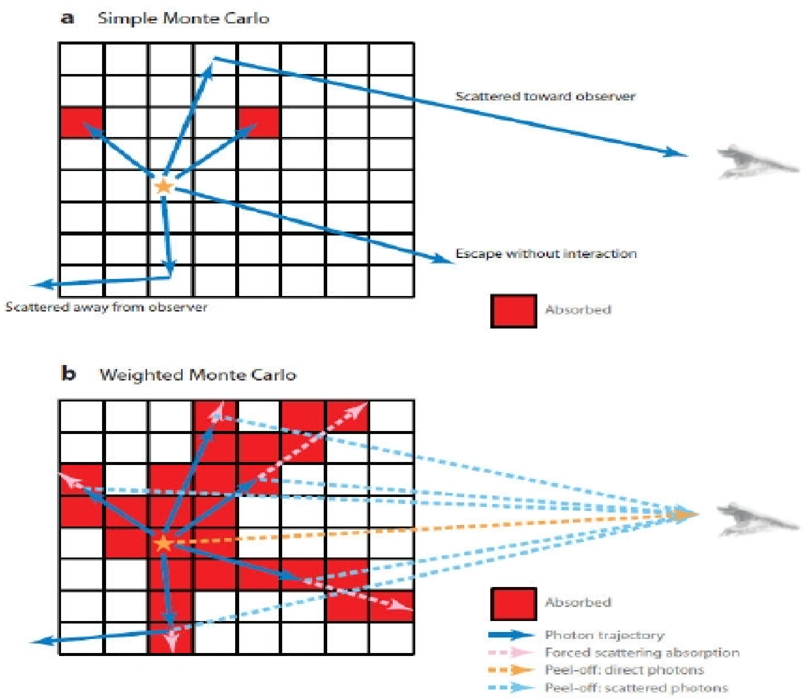
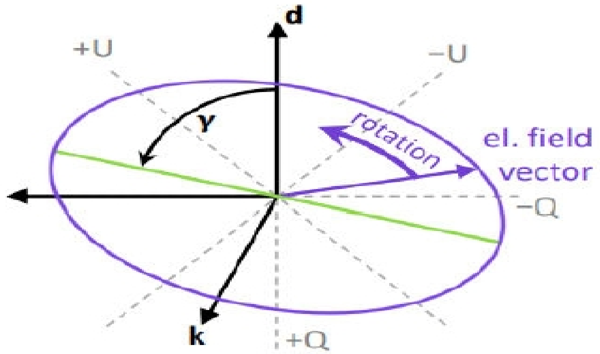
$$\mu(v) = \frac{F_A^l(v)}{M \times F_D^l(v)},$$

Q2237+0305 - simulations

- 3D Monte Carlo radiative transfer using STOKES and SKIRT





$$\mathbf{S} = \begin{pmatrix} I \\ Q \\ U \\ V \end{pmatrix} \qquad \mathbf{S}' = \mathbf{M}\,\mathbf{S}$$

$$P_{\rm L} = \frac{\sqrt{Q^2+U^2}}{I} \leq 1,$$

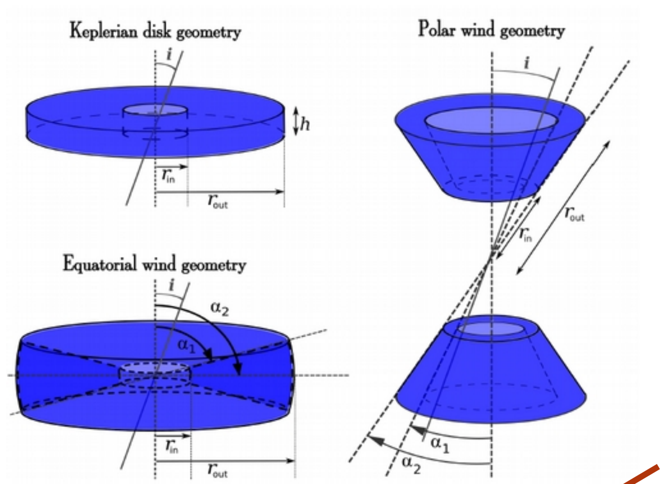
$$\mathbf{M}(\theta) = \begin{pmatrix} S_{11} & S_{12} & 0 & 0 \\ S_{12} & S_{11} & 0 & 0 \\ 0 & 0 & S_{33} & S_{34} \\ 0 & 0 & -S_{34} & S_{33} \end{pmatrix}.$$

$$\gamma = \frac{1}{2}\arctan\left(\frac{U}{Q}\right).$$

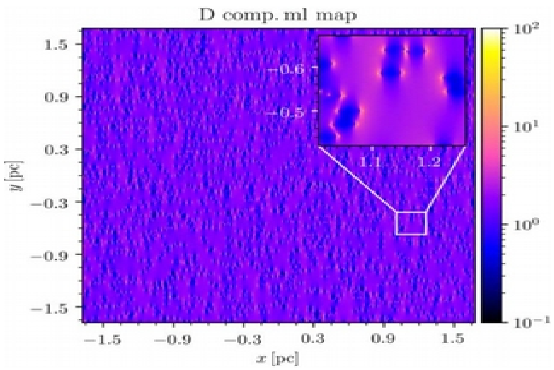
Q2237+0305 - microlensing map

- Flat universe; $H_0 = 68\,\mathrm{km\,s^{-1}\,Mpc^{-1}},\ \Omega_m = 0.31,\ \Omega_\Lambda = 0.69$
- Cosmological distances;
$$D_{\mathrm{ol}} = 166\,\mathrm{Mpc}\ \text{(observer-lens)}$$
$$D_{\mathrm{os}} = 1793\,\mathrm{Mpc}\ \text{(observer- source)}$$
$$D_{\mathrm{ls}} = 1729\,\mathrm{Mpc}\ \text{(lens-source)}$$
- Einstein radius ~40light days
- Transfersal velocity;
$$v_\perp(\text{source plane}) = \frac{D_{\mathrm{os}}}{D_{\mathrm{ol}}}\frac{1+z_s}{1+z_l}v_\perp(\text{lens plane})$$
$$v_\perp = [300, 400, 500, 600]\,\mathrm{km\,s^{-1}}$$
- Code MICROLENS (Wambsganss 1999)

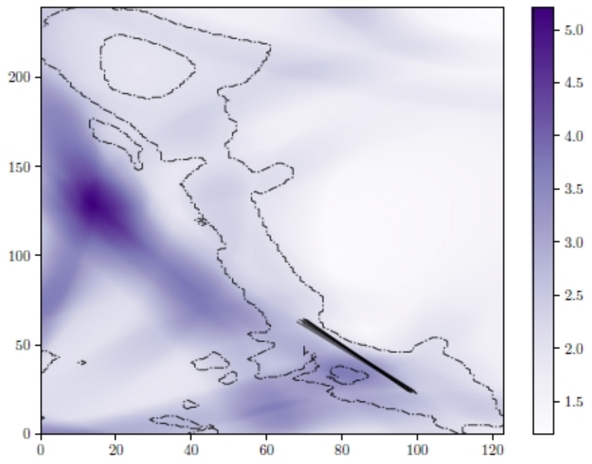
Q2237+0305 - simulations

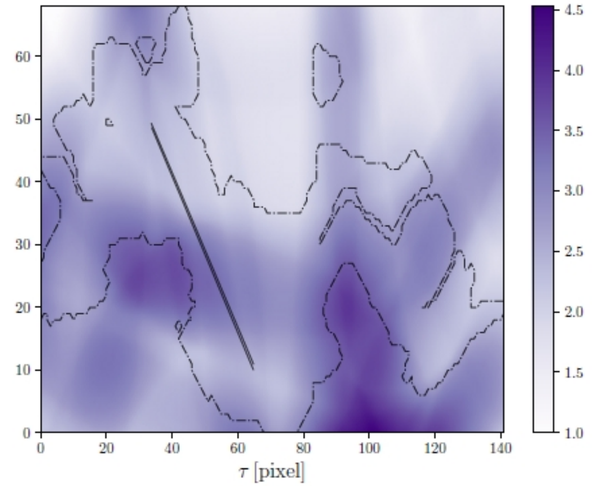


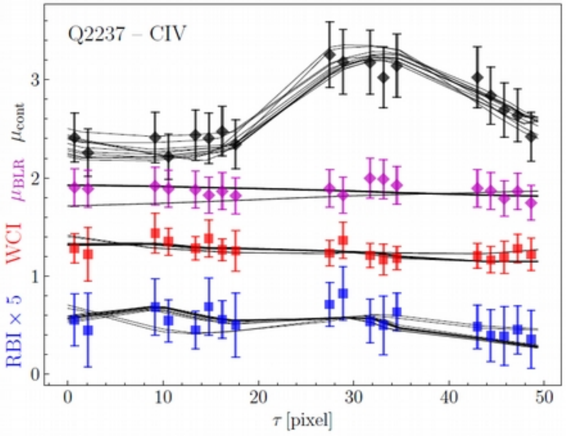
convolution



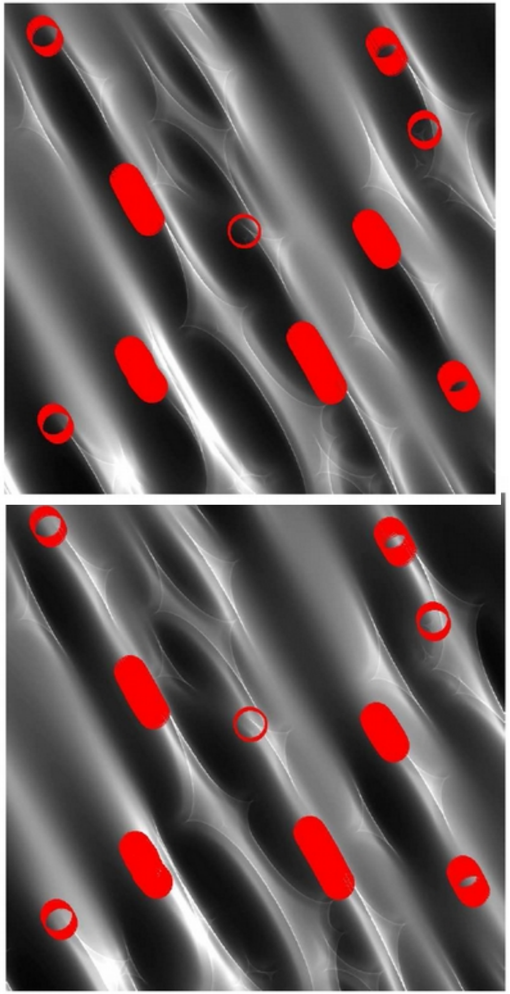
track finding



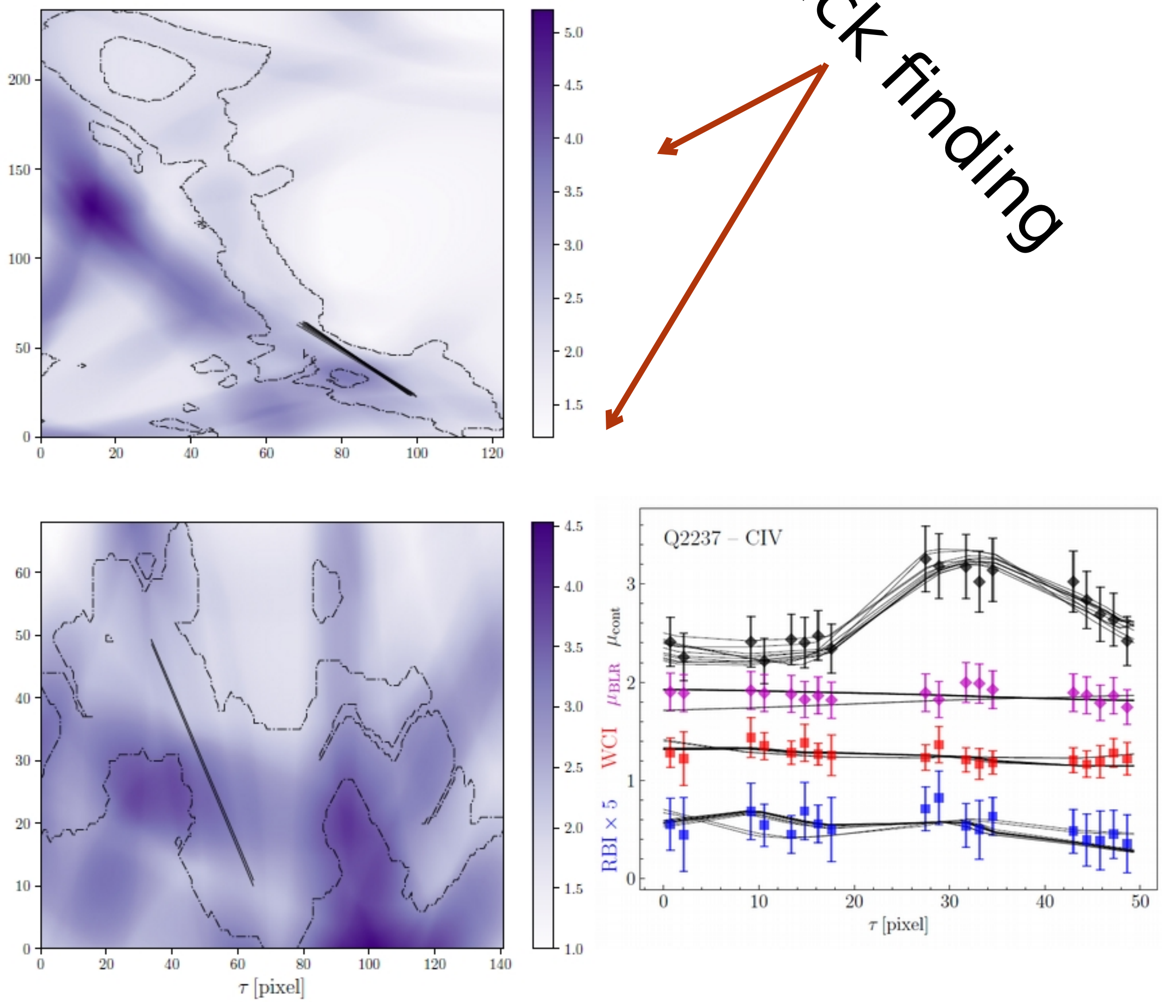




Q2237+0305 - simulations



region finding



track finding

Q2237+0305 - results

- BLR effective size

$i = 35 \pm 3°$

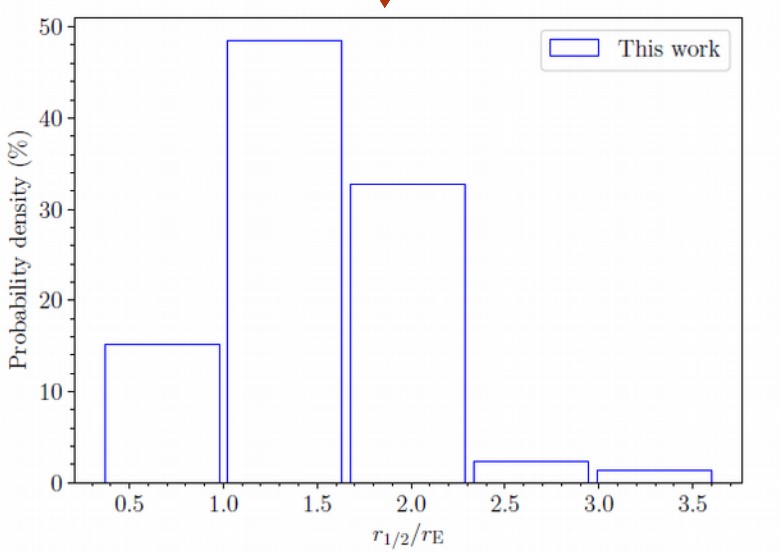
$$R(\mathrm{CIV}) = 55 \pm 30\,\mathrm{ld}$$

$$f = (4\sin^2 i)^{-1} = 0.44 \pm 0.07$$

$$\mathcal{M}_{\mathrm{BH}} = f\frac{R_{\mathrm{BLR}}V^2}{G} = 7 \pm 2 \times 10^7\,\mathcal{M}_{\odot}$$

- Good agreement with previous
- reports

C IV time-series				
	KD	PW	EW	ALL
22°	34	0	0	34
34°	21	9	1	31
44°	23	3	1	27
62°	7	1	0	8
All i	85	13	2	

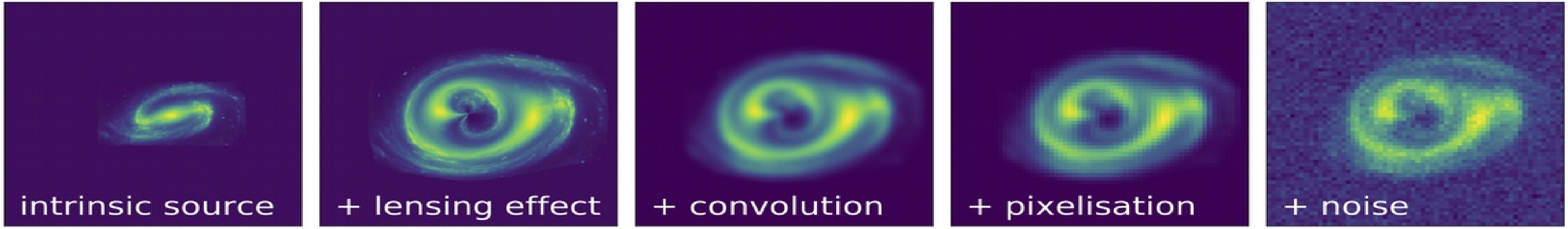


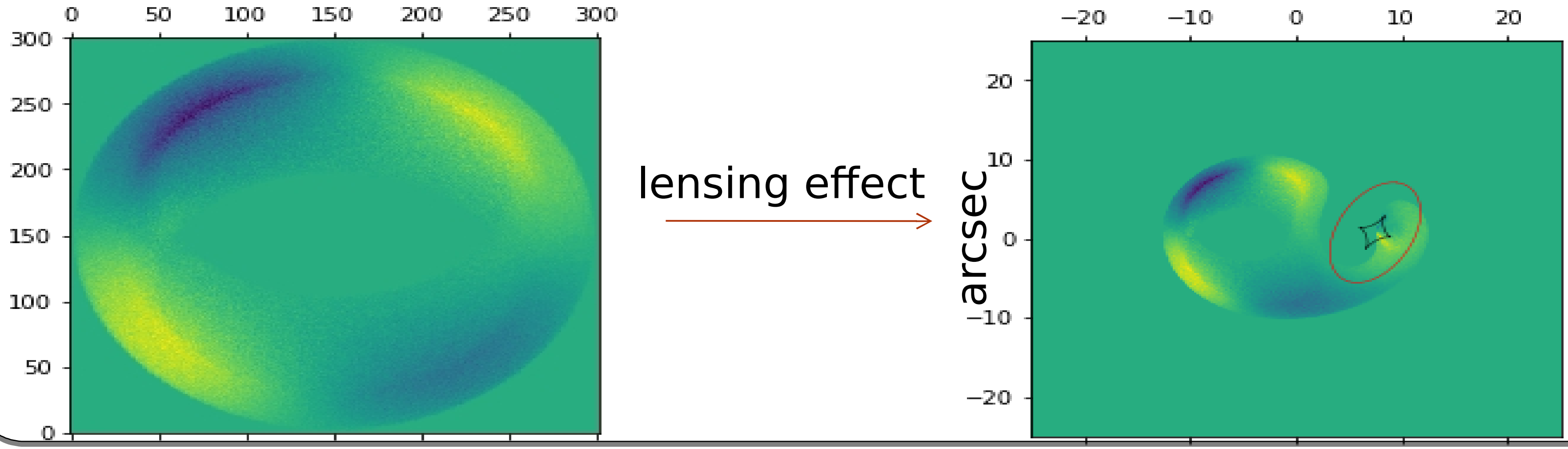
Future prospects

- New observations in different modes (spectroscopy and polarimetry)
- A large grid of models using 3D radiative transfer code SKIRT for modeling multiwavelength imaging (possible polarimetry)
- Computation of different microlensing maps (source-lens dependant)
- Influence of macrolensing on polarized and unpolarized radiation using lenstronomy (various lens parameters)

Future prospects

- Lenstronomy – gravitational lensing software package
  Birrer+2015,18,21 https://github.com/sibirrer/lenstronomy
- Open source, multi-purpose models and simulations





Conclusions

- Microlensing estimated BLR parameters are in a good agreement with previous findings

- A complete caustic crossing events with time-series

- Application to other observed systems.

- Savic+2023 (in prep)