Imprints of the AGN structure on time delay light curves in LSST era

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Strong Lensing in a nutshell

MACRO-images

C A B

D

Observer

MACRO-lens = Lensing galaxy

3 arcsec

AGN + host

C A B D
Microlensing in Strongly lensed AGNs

Observer

MACRO-lens = Lensing galaxy

MACRO-images

micro-images

5 µarcsec

3 arcsec

micro-lenses = stars in the lensing galaxy

Lensing galaxy

AGN + host
Which regions of AGN are microlensed?

Today: \( \sim 10 \text{ mas} \sim 80 \text{ pc} \) resolution (\( z=3; \text{AO} \))
\( \sim 1-0.1 \text{ pc} \) (VLTI, low \( z \))

Future: 0.1 mas \( \sim 0.8 \text{ pc} \) resolution (\( z = 3 \))

Microlensing: 0.04 pc resolution (up to \( z=4 \))

\[ \eta_0 = \sqrt{\frac{4G<M>}{c^2}} \frac{D_{os}D_{ls}}{D_{ol}} \sim 2.03 \times 10^{16} \sqrt{\frac{<M>}{0.3 M_\odot}} \text{ cm} \]

Einstein Radius

$4000\text{ days}$

$\sigma_0(1126 \, \text{Å}) = 1 \text{ l-d}$

$\nu = 4/3$

$T_{\text{eff}} \propto r^{-1/\nu}$

Courtesy: T. Anguita
Disc size

\[ T_{\text{eff}} \propto r^{-1/\nu} \]

\[ \sigma_0(1126 \text{ Å}) = 0.1 \text{ l-d} \]

\[ \nu = 4/3 \]

Courtesy: T. Anguita
Example on real data: Einstein Cross

Observed micro-lensed induced chromatic variations of the continuum

Results of the simulation

Accretion disk model:

\[ \frac{R}{R_{\text{ref}}} = \left( \frac{\lambda}{\lambda_{\text{ref}}} \right)^{\eta} \]

- \( \eta = 1.3 \) (Shakura & Sunayev, 1973)
- \( \eta = 1.15 \) (Agol & Krolik, 2000)
- \( \eta = 1.75 \) (Gaskell 2008)

The time-domain to probe AGN structure

Current status

• Analysis of tens of microlensed AGN (not all with the same data quality as Einstein cross) indicate that the size of the accretion disc is larger than the standard (Shakura Sunyaev) AD size by a factor 3 to 10 (e.g. Morgan+ 2010, Blackburne+ 2011).

• “AD – reverberation mapping” of a few nearby Seyfert galaxies (Shappee+ 2014; Fausnaugh+ 2015) have confirmed this result.

• Evidence in one system for extended continuum emission (likely light scattered in the vicinity of the BH; at least 30% of AD continuum) in a BAL AGN (Sluse+ 2015)
Strongly lensed AGNs in LSST era

About **2000 (8000)** lensed QSOs down to $i_{AB} = 24$ (24.9) mag

One order of magnitude more systems than currently known!

Strongly lensed AGNs in LSST era

COSMOGRAIL lightcurve as a pilot for LSST

COSMOGRAIL = Cosmological Monitoring of Gravitational lenses (PI: F. Courbin, EPFL)
Strongly lensed AGNs in LSST era
Microlensing in Strongly lensed AGNs
Microlensing in Strongly lensed AGNs

Difference lightcurve = microlensing signal

Example of Fast microlensing
Test other AD models: Inhomogeneous disc

ML: difference with standard disc

Dexter & Agol 2011
Other imprints of AGN structure?

Imprint of the BLR in ML lcves (see Sluse and Tewes 2014 A&A, 571, A10)

Imprints of “extended continuum” (i.e. scattered light; Sluse+ 2015 A&A 582, A109)
Test other AD models: Relativistic BH

Microlensing: Caustic crossing

Abolmasov & Shakura 2012b
Conclusions

1. More than 2000 lensed AGNs to be monitored in LSST era (down to $i_{AB} = 24$ mag)

2. Those lightcurves provide unique insights on the structure of accretion discs in distant AGNs:
   – Disc size and temperature profile (PL Energy profile)
   – Test more advanced accretion disc models: towards a new paradigm of AD ...
   – Possibly measure AD spin
   – Probe scattered continuum emission
Supplementary slides
Disc temperature profile

Courtesy: T. Anguita
Disc temperature profile

\[ T_{\text{eff}} \propto r^{-1/\nu} \]

\[ \sigma_0(1126 \text{ Å}) = 1 \text{ l-d} \]

\[ \nu = 0.9 \]

Courtesy: T. Anguita
Disc temperature profile

\[ T_{\text{eff}} \propto r^{-1/\nu} \]

\[ \sigma_0(1126 \text{ Å}) = 1 \text{ l-d} \]

\[ \nu = 1.75 \]

Courtesy: T. Anguita
Strongly lensed AGNs: Cosmological probes

\[ \Delta t \]
Strongly lensed AGNs: cosmological probes

Long and high cadence lightcurves are keys to derive time-delays with a few percent accuracy.
Time delays for cosmology

Error budget on $\Delta t$
Fixes the maximum uncertainty on $H_0$

Тhе Large Universe, low $H_0$, Large time delays

Maximum accuracy on $\Delta t$?
TDC1 – Time delay challenge 1

Small Universe, high $H_0$, Small time delays