

Amplification and variability of the X-ray emission due to microlensing

Luka Č. Popović Astronomical Observatory, Belgrade

QSOs (AGN) emit radiation at a range of wavelengths from the radio to the X-ray (γ -ray)



A variability of the continuum and spectral lines (dimensions of emitting regions)



X-ray emitting region; e.g. the Fe K-alpha line (e.g. Nandra et al. 1997, Fabian et al. 2002, Ballantyne et al. 2003, etc.)



The X-ray accretion disk – Popović et al. 2003, A&A, 398, 975; Popović et al 2006, ApJ, 637, 620





The Fe Kalpha line variation (Popović et al. 2003) Schwar. vs. Kerr

-25,10	-20,10	-10,10	-5,10	0,10	5,10	10,10	20,10	-25,10	-20,10	-10,10	-5,10	0,10	5,10	10,10	20,10
1	A	A	M	M	A	A	$ \wedge $	1		A	M	M	M	M	~
-25,5	-20,5	-10,5	-5,5	0,5	5,5	10,5	20,5	-25,5	-20,5	-10,5	-5,5	0,5	5,5	10,5	20,5
1	A					\mathcal{A}	\mathcal{A}	1	A		Å	M		M	
-25,0	-20,0	-10,0	-5,0	0,0	5,0	10,0	20,0	-25,0	-20,0	-10,0	-5,0	0,0	5,0	10,0	20,0
$ \land $	A					\sim	\mathcal{A}	1				A	\square	\mathcal{A}	
-25,-5	-20,-5	-10,-5	-5,-5	0,-5	5,-5	10,-5	20,-5	-25,-5	-20,-5	-10,-5	-5,-5	0,-5	5,-5	10,-5	20,-5
1	A		M	A	\sim	\mathcal{A}	\mathcal{A}				A	M	M	\mathcal{A}	
-25,-10	-20,-10	-10,-10	-5,-10	0,-20	5,-10	10,-10	20,-10	-25,-10	-20,-10	-10,-10	-5,-10	0,-20	5,-10	10,-10	20,-10
	A	A	M	M	A	M	\mathcal{A}		1	Л	M	M	M	M	

Caustic crossing – Schwar. vs. Kerr



Modeling of different inclinations: Schwar. vs. Kerr



.

APPLICATION (Popović et al. 2006): MG J0414+0534

- z=2.64
- increase of the Fe Kα line equivalent width in the image B not followed by the Xray continuum (Chartas et al. 2002, ApJ, 568, 509)



QSO 2237+0305 (Einstein Cross)

- z=1.695
- measured amplification of the Fe Kα line in the component A but not in the continuum (Dai et al. 2003, ApJ, 589, 100)



H 1413+117

- z=2.55
- the continuum and the Fe Kα line are enhanced by different factors (Chartas et al. 2004, ApJ, 606, 78) – George, lecture on Tuesday



Amplification, special case (for QSO 2237+0305A): Mml=0.35 Ms, Mbh=1E9 Ms; a magnification map 334x669 Rg (Popović et al. 2006, ApJ, 637, 620)





1.0000

0.1000

0.0100

0.0010

0.0001

0.0000

0

2

z

з

4

The optical depth – probability that the high red-shifted quasars are lensed (Zakharov, Popović, Jovanović 2004, A&A, 420, 881; Jovanović 2006, PASP, 118, 656) The optical depth for microlensing by cosmologically distributed objects (for z>2) is higher then by objects (stars) in a foreground galaxy

 $\Omega_0 = 0.3$

F=0.15

0

k

Table 1. The calculated optical depth as a function of red-shift for different values of Ω_L and $\Omega_0 = 0.3$.

$z \setminus \Omega_L$	0.01	0.05	0.10
0.5	0.001100	0.005499	0.010998
1.0	0.004793	0.023967	0.047934
1.5	0.010310	0.051550	0.103100
2.0	0.016196	0.080980	0.161959
2.5	0.021667	0.108334	0.216669
3.0	0.026518	0.132590	0.265180
3.5	0.030770	0.153852	0.307703
4.0	0.034504	0.172521	0.345042
	0.000004	0.40040	0.000000

fable	1.	The	calcul ate	ed optica	l depth	$\mathbf{f}_{\mathbf{r}}$	З	gravitational
ensed	ьрі	ects ($\Omega_0 = 0.3,$	F = 0.13	5).			

Object.	z	TOL
MG J0414+0534	2.64	0.013652
QSO 2237+0305	1.695	0.00 66 35
BAL QSO H1413+117 AT	2.56	0.013049





Time scales of microlensing

(Jovanović 2006; Jovanović, Popović, Zakharov 2006, in preparation)

Object	z_s	z_l	T(years)
HS0818+1227	3.115	0.39	0.357
RXJ0911.4+0551	2.800	0.77	0.610
LBQS1009-0252	2.740	0.88	0.673
HE1104-1805	2.303	0.73	0.574
PG1115+080	1.720	0.31	0.282
HE2149-2745	2.033	0.50	0.422
Q2237+0305	1.695	0.04	0.041

- WORK IN PROGRESS
- FLUX ANOMALY (wavelength dependent amplification, see e.g. Popović & Chartas 2005, MNRAS, 357, 135)
- Optical, UV & X-ray flux ratio anomalies
- Differential extinction
- Microlensing by stars

Chandra (*X-ray*) and Magellan (*optical*) images of 1RX J1131–1231 –Blackburne 2006, ApJ, 640, 569

Chandra Image

Magellan Image





The case of SDSS J1004+4112 (Ota et al. 2006, astro-ph/061700; Lamer et al. 2006, astro-ph/0604378) – Chandra observations EW: A=1150; B=590; C=842; D=550 Flux anomaly, Fopt/Fx; A=1, B=0.58, C=0.33, D=0.35



SDSS J1004+4112A, kappa=0.39, gamma=0.64 (Schw. AD - Rout: X=100 Rg, UV=1000 Rg, Opt.=2000 Rg)





SDSS J1004+4112B, kappa=0.39, gamma=0.56





SDSS J1004+4112C; gamma=0.56, kappa= 0.31



SDSS J1004+4112D; gamma=0.55, kappa= 0.63





.

Conclusions:

- From simulation of X-ray emission microlensing:
- Small mass microlenses can affect X-ray emission (Fe Kα line)
- The optical depth for the X-ray emission microlensing for Z>2 is between 0.01 and 0.1 (0.1 corresponds if DM can form compact objects)
- The typical microlensing time is < 1 year (from 0.05 to 0.8 year in the considered cases)
- Microlensing contribution to the flux anomaly? => monitoring lensed and un-lensed QSOs in the X-ray (also in another wavelength) band.