EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

BLACK HOLES IN A VIOLENT UNIVERSE
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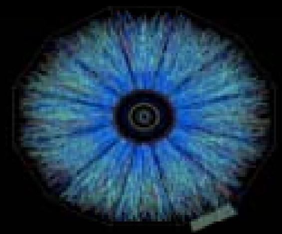

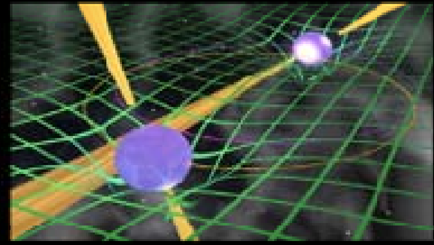

Line shapes and super-massive binary black holes

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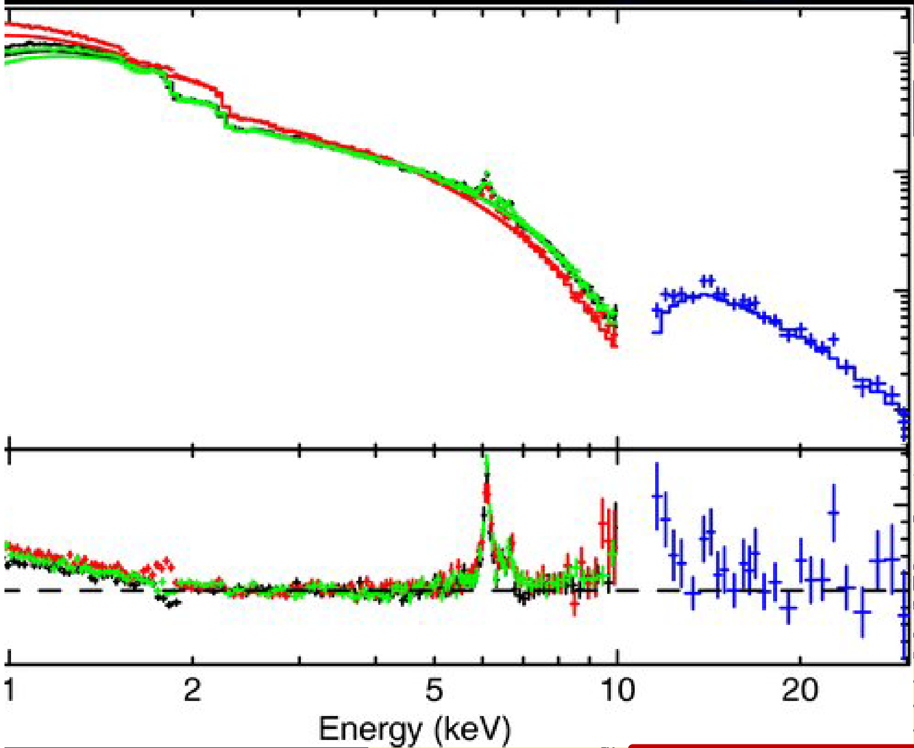
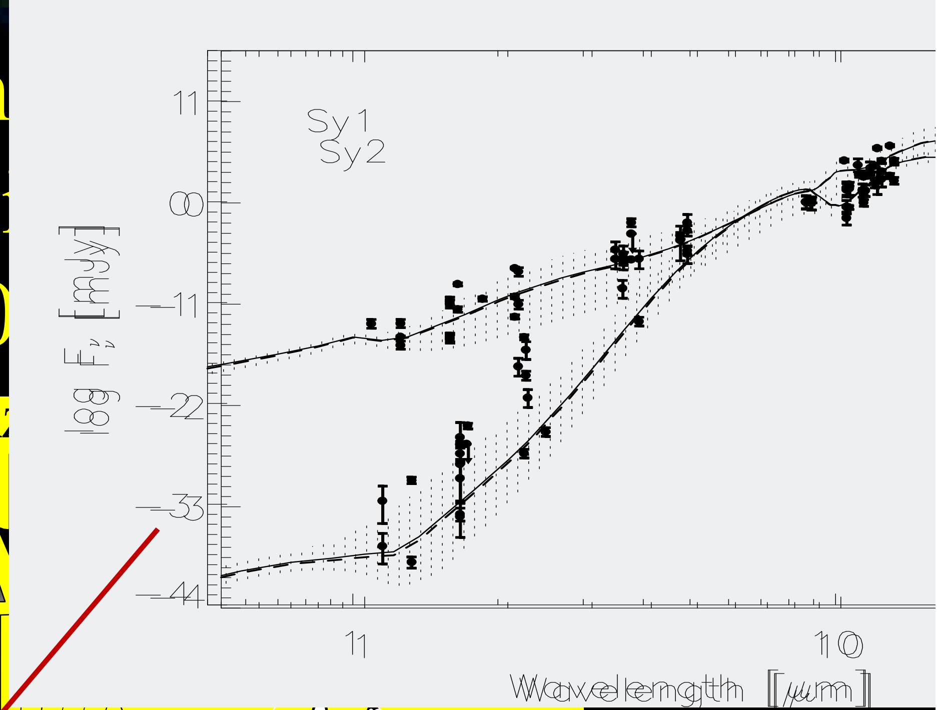
OMNIA IN NUMERO ET MENSURA · 1887 ·

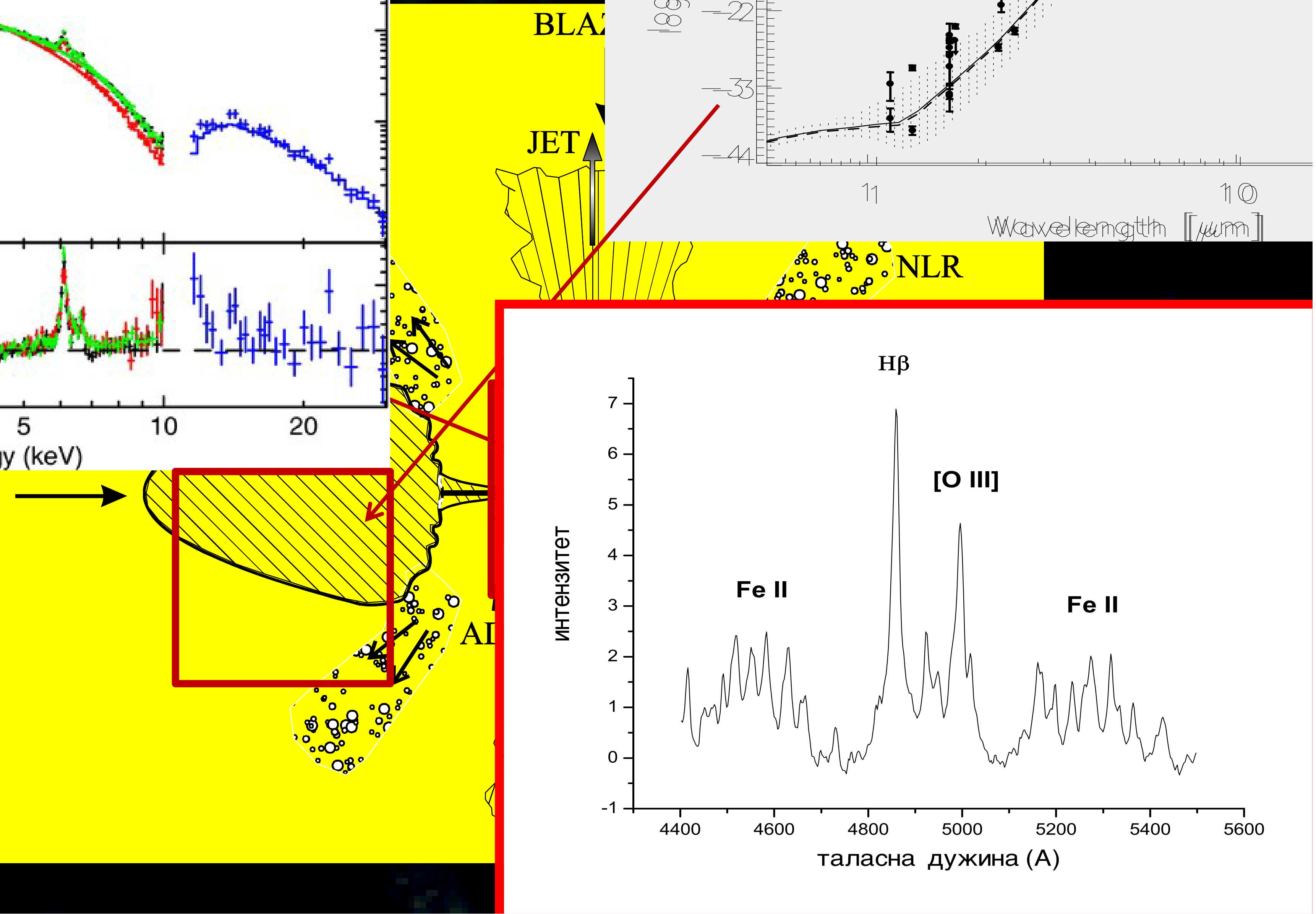
The line emitting regions in AGN

- Broad band spectra emitted from AGNs (from gamma to the radio emission)
- X-ray emission, as e.g. Fe K line
- UV/optical emission (Ly alpha, CIV, Balmer series)
- Narrow Line Emission region

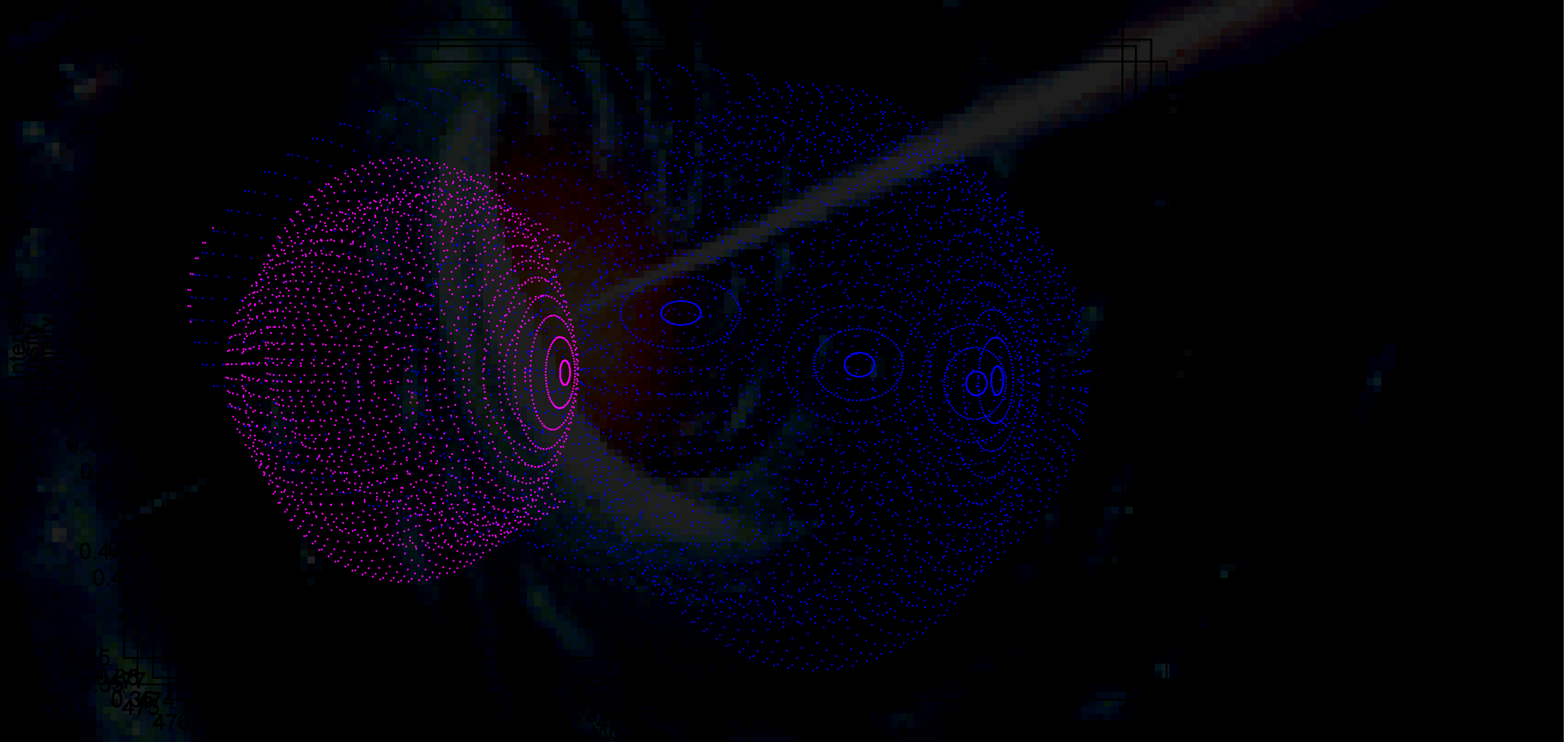
Model (scheme from Jovan… book Black Holes: Properti… …ures, 20…







A binary system



Binary black holes

- Orbits, period and distance
- Gravitational potential – motion of emitting clouds
- Possible interactions
- Etc.

Gravitational potential of close binaries (Paczynski, B. 1971, *ARA&A 9, 183)*

$$\Phi = \frac{R}{r_1} + \frac{R \cdot q}{r_2} + \frac{1+q}{2}\left[\left(\frac{x}{R} - \frac{q}{1+q}\right)^2 + \left(\frac{y}{R}\right)^2\right] - \frac{q^2}{2(1+q)}$$

Mass ratio and distances between BBHs

$$\Phi = \frac{R}{r_1} + \frac{R \cdot q}{r_2} + \frac{1+\cancel{q}}{2}\left[\left(\frac{x}{R} - \cancel{\frac{q}{1+q}}\right)^2 + \left(\frac{y}{R}\right)^2\right] - \cancel{\frac{q^2}{2(1+q)}}$$

- If q<<1, small black hole orbiting the larger one, can smaller BH have emitting regions
- Gravitational potential – motions of clouds similar as in the case of an ordinary AGN (it depends on distances from smaller BH)
- Perturbation in the spectra is expected

q~1

$$\Phi = \frac{R}{r_1} + \frac{R \cdot q}{r_2} + \frac{1+q}{2}\left[\left(\frac{x}{R} - \frac{q}{1+q}\right)^2 + \left(\frac{y}{R}\right)^2\right] - \frac{q^2}{2(1+q)}$$

- If q~1, masses and distances play very important role
- Distance in comparison with sizes of line emitting regions, and two parameters, period of orbiting and radial velocities of the components are important

Estimations these parameters using circular orbits (Yu & Lu 2001, A&A 377, 17)

$$P^{\mathrm{orb}} = 210\left(\frac{R}{0.1\mathrm{pc}}\right)^{3/2}\left(\frac{2\times10^{8}M_{\mathrm{sun}}}{m_1+m_2}\right)^{1/2}\mathrm{yr}$$

$$\left|v_i\right| = 1.5\times10^{3}\left(\frac{0.1\mathrm{pc}}{\mathrm{R}}\right)^{1/2}\left(\frac{m_1+m_2}{2\times10^{8}M_{\mathrm{sun}}}\right)^{1/2}\left[\frac{2m_1m_2}{m_i(m_1+m_2)}\right]\sin\theta_{\mathrm{orb}}$$

- Only not semi-touched systems
- Sizes of regions: Fe K ~ 10^{-5} – 10^{-4}
- BLR ~ 10^{-4} – 10^{-5}
- NLR ~ several pc to several kpc

Characteristic distances (taken as two order of magnitude larger than ELR)

Table 1: Estimated P and $V_{\rm rad}^{\rm max}$ for binary black holes with the same masses of 10^8 $M_\odot$ for characteristic distances.

Distances	corresponding line	FWHM in km s^{-1}	P in yr	$V_{\rm rad}^{\rm max}$ in km s^{-1}
$10^{-3} - 10^{-2}$ pc	Fe Kα	$\sim 10^4 - 10^5$	$\sim 2 \cdot 10^{-4} - 7 \cdot 10^{-3}$	$1.5 \cdot 10^4 - 5 \cdot 10^3$
$10^{-2} - 1$ pc	Broad UV/optica lines	$\sim 10^3 - 10^4$	$\sim 7 \cdot 10^{-3} - 7 \cdot 10^2$	$\sim 5 \cdot 10^3 - 5 \cdot 10^2$
$10^2 - 10^4$ pc	Narrow lines	$\sim \cdot 10^2 - 10^3$	$\sim \cdot 10^6 - 10^9$	$\sim 50 - 0.5$

FWHM and Vmax

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Quasi-periodical oscillations in spectra

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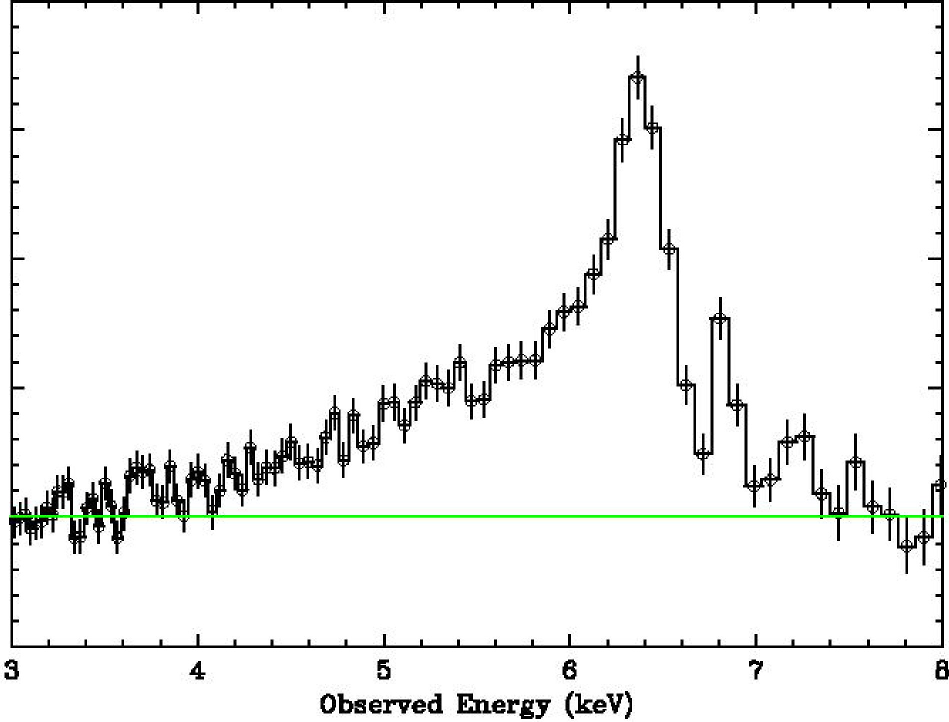
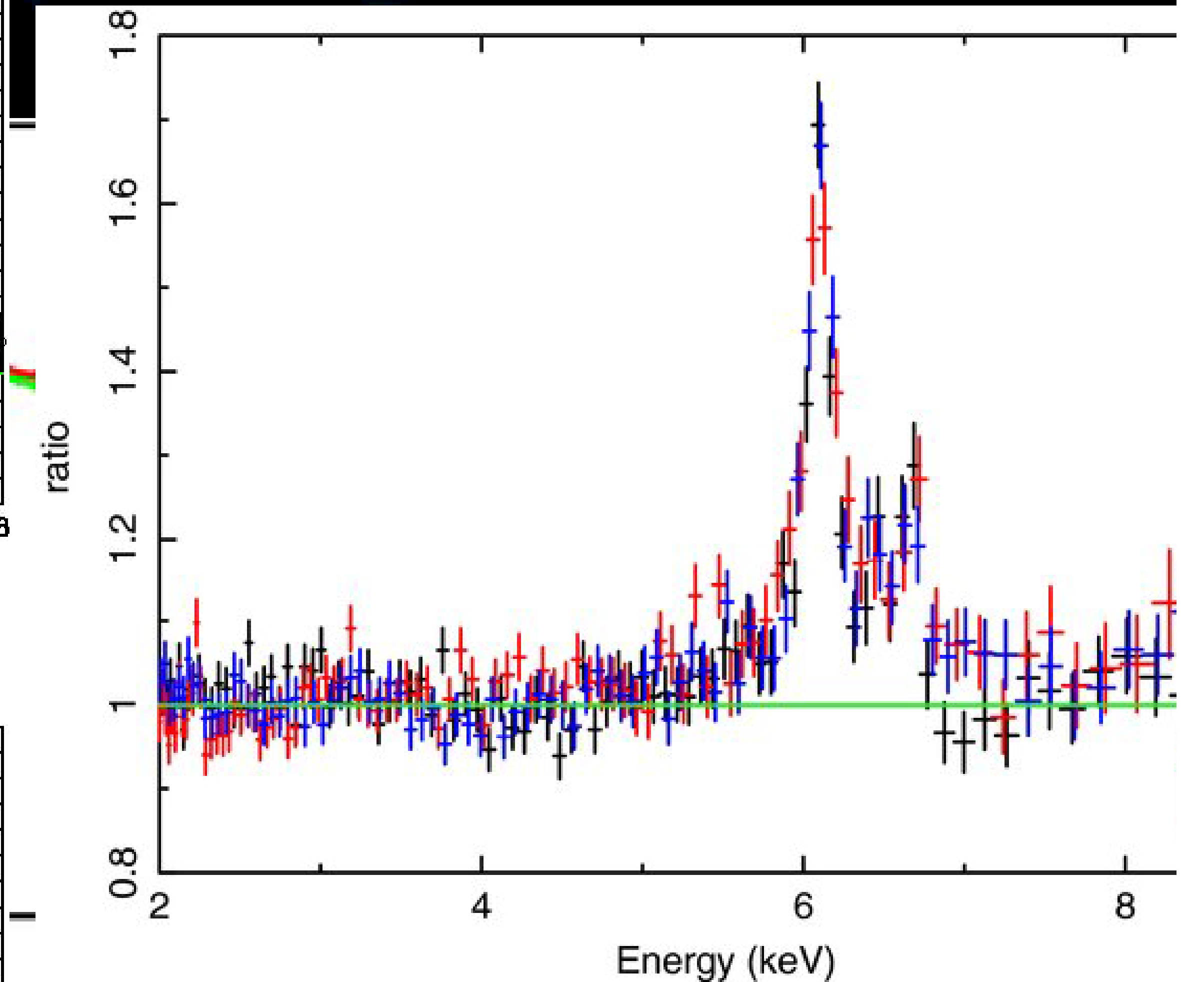
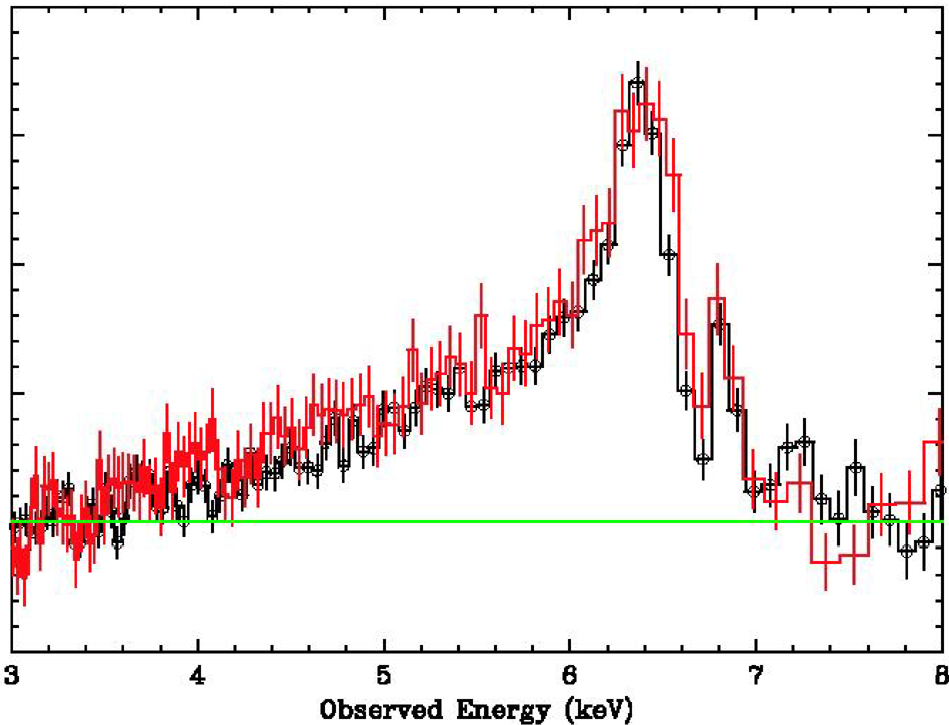
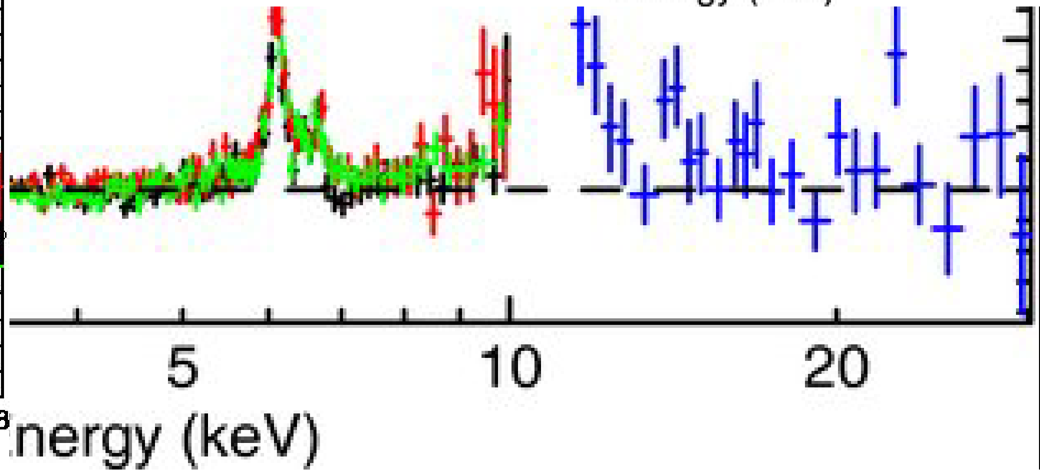
Expected effects

- Line shapes (variability in the line shapes)
- Shift of line
- Width of line (very broad lines?)
- Quasi-periodical oscillations (in Fe K and broad lines)


3
4
5
6
7
8
Observed Energy (keV)


ratio
1.8
1.6
1.4
1.2
1
0.8
2
4
6
8
Energy (keV)

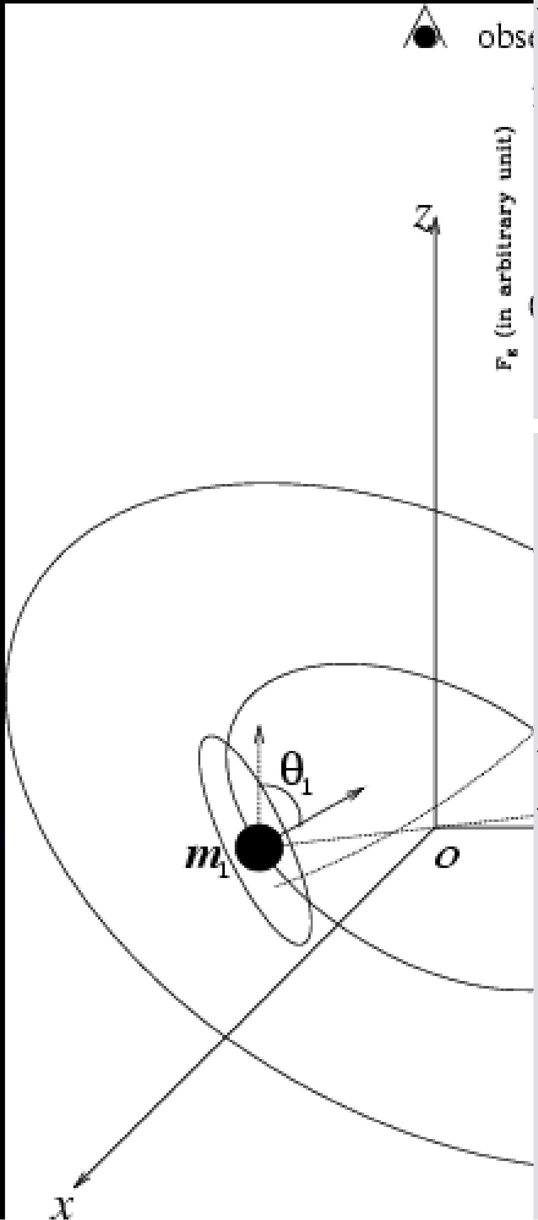

3
4
5
6
7
8
Observed Energy (keV)

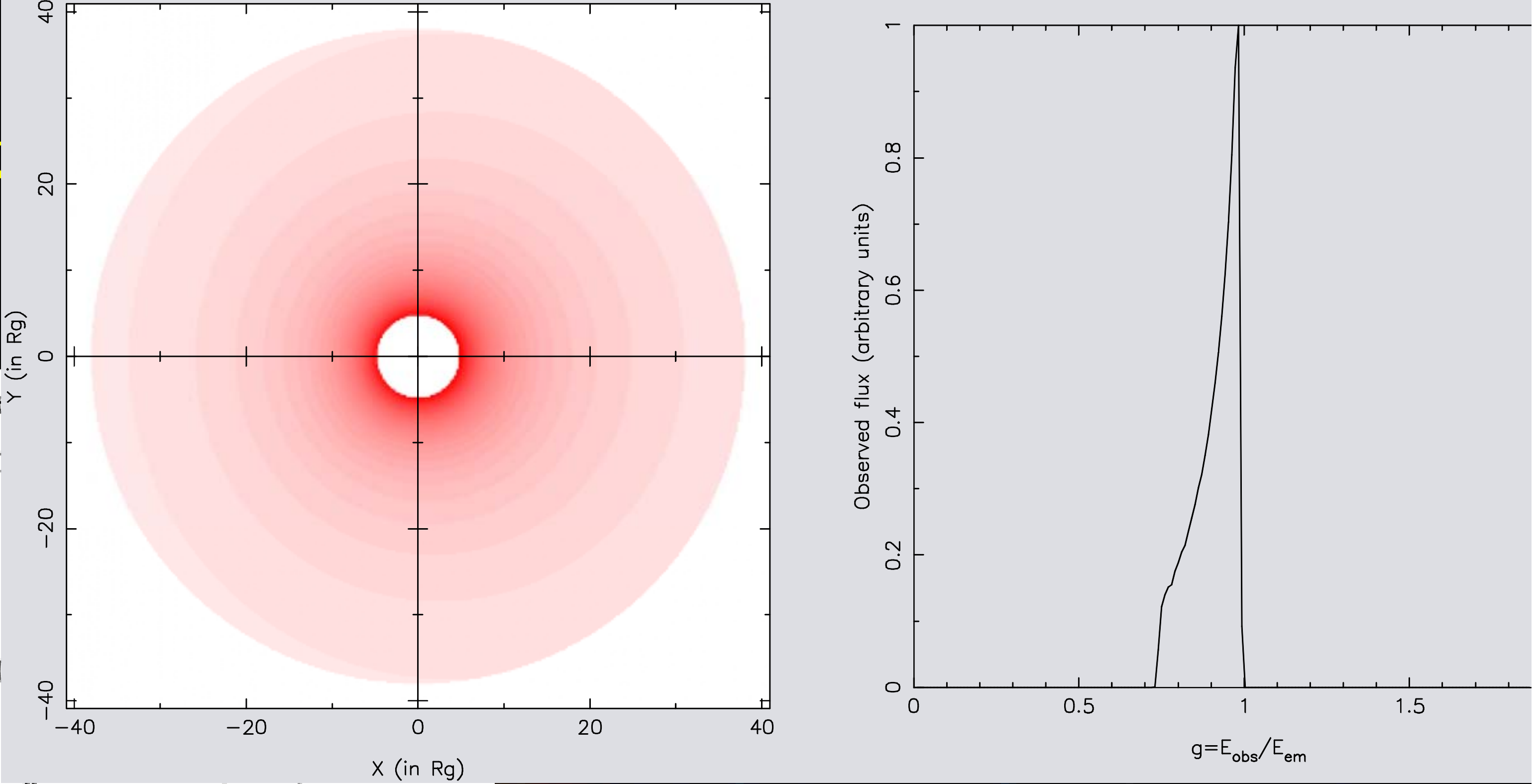

5
10
20

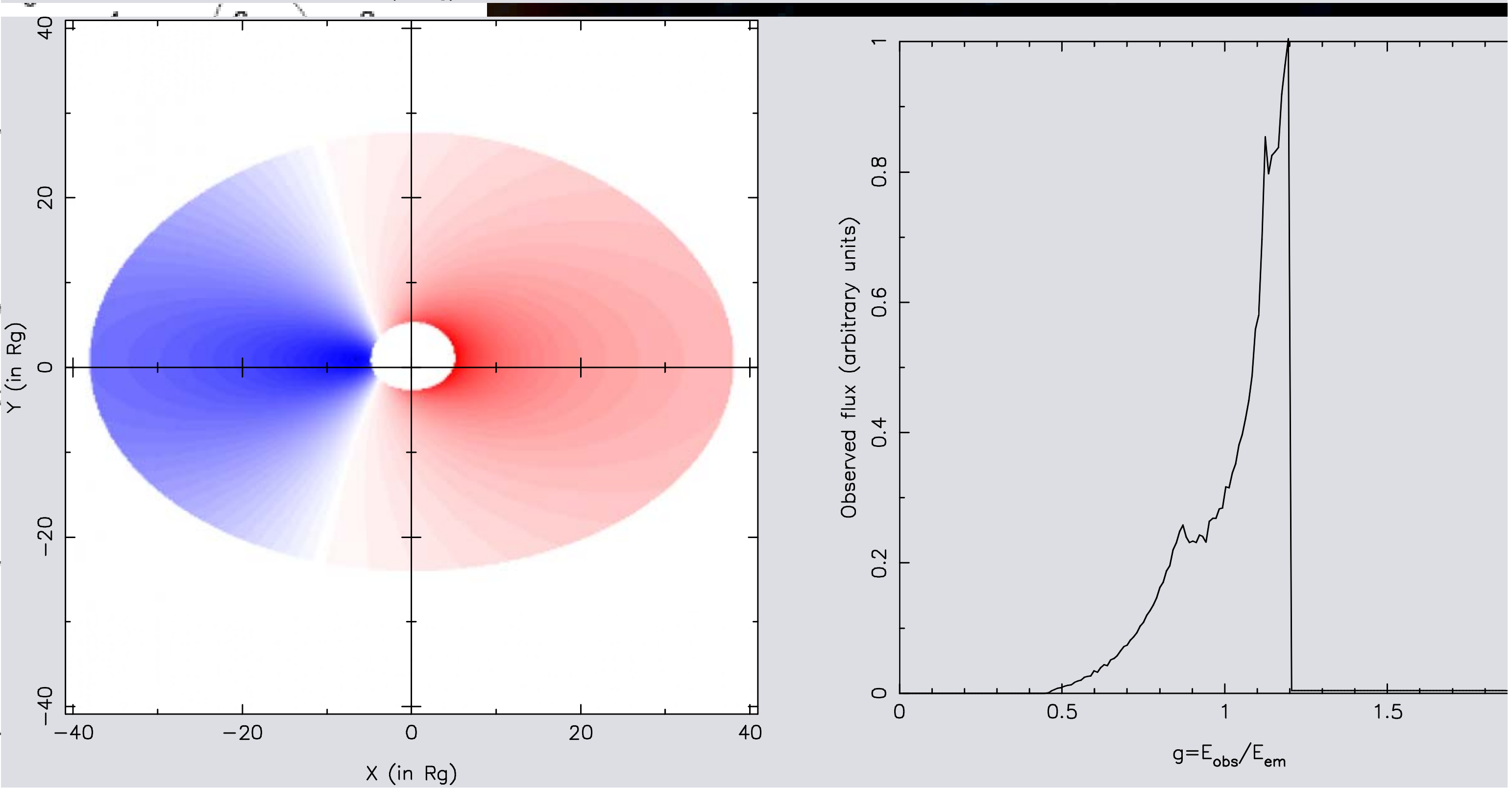
Why is the Fe K alpha important?

- Fe K alpha – can be originated very close to the black hole (first rms)
- => physics of the plasma close to black hole (in a strong gravitational fields)
- => Accretion disk geometry
- => spin of the black hole
- A high number of papers
- BBHs detection using by Fe K?

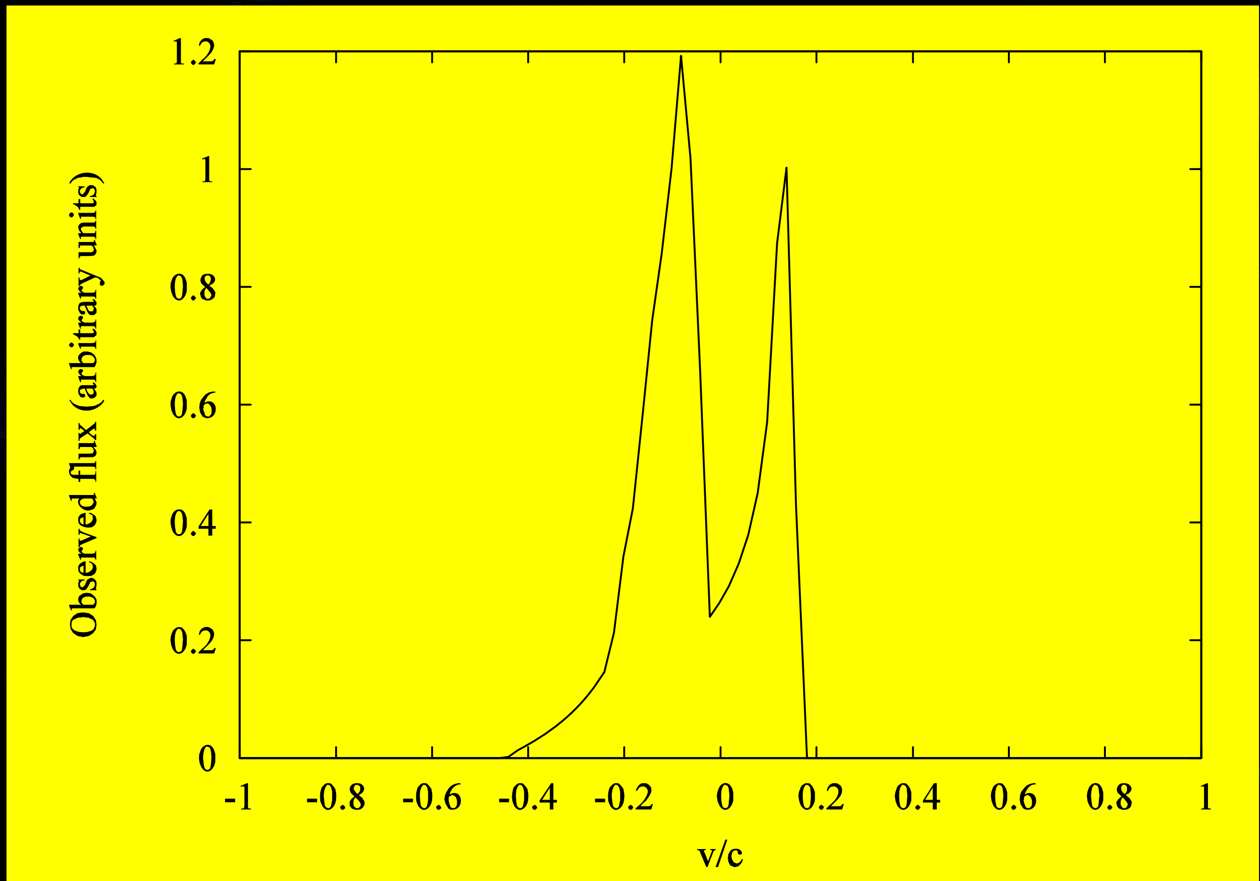
Binary black



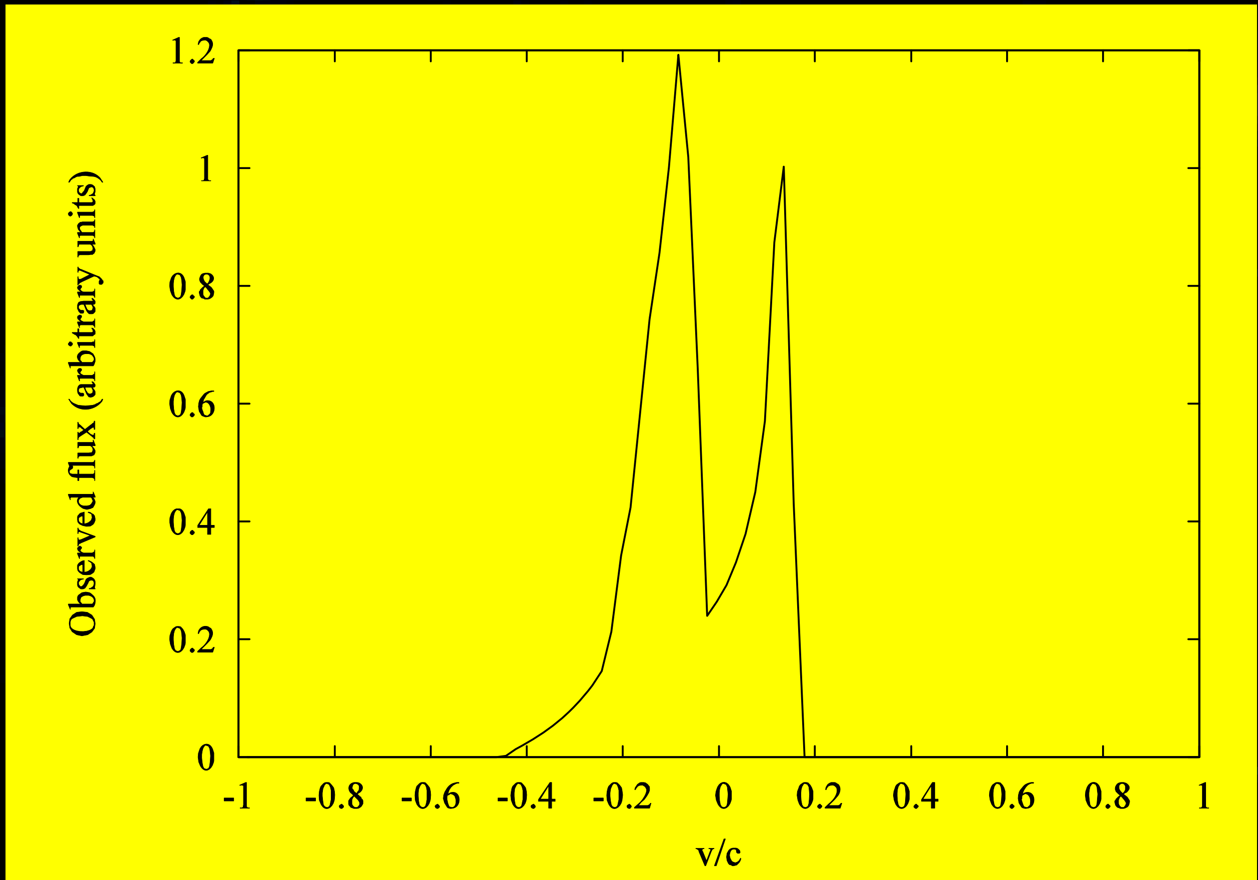




Vrad=0 km/s

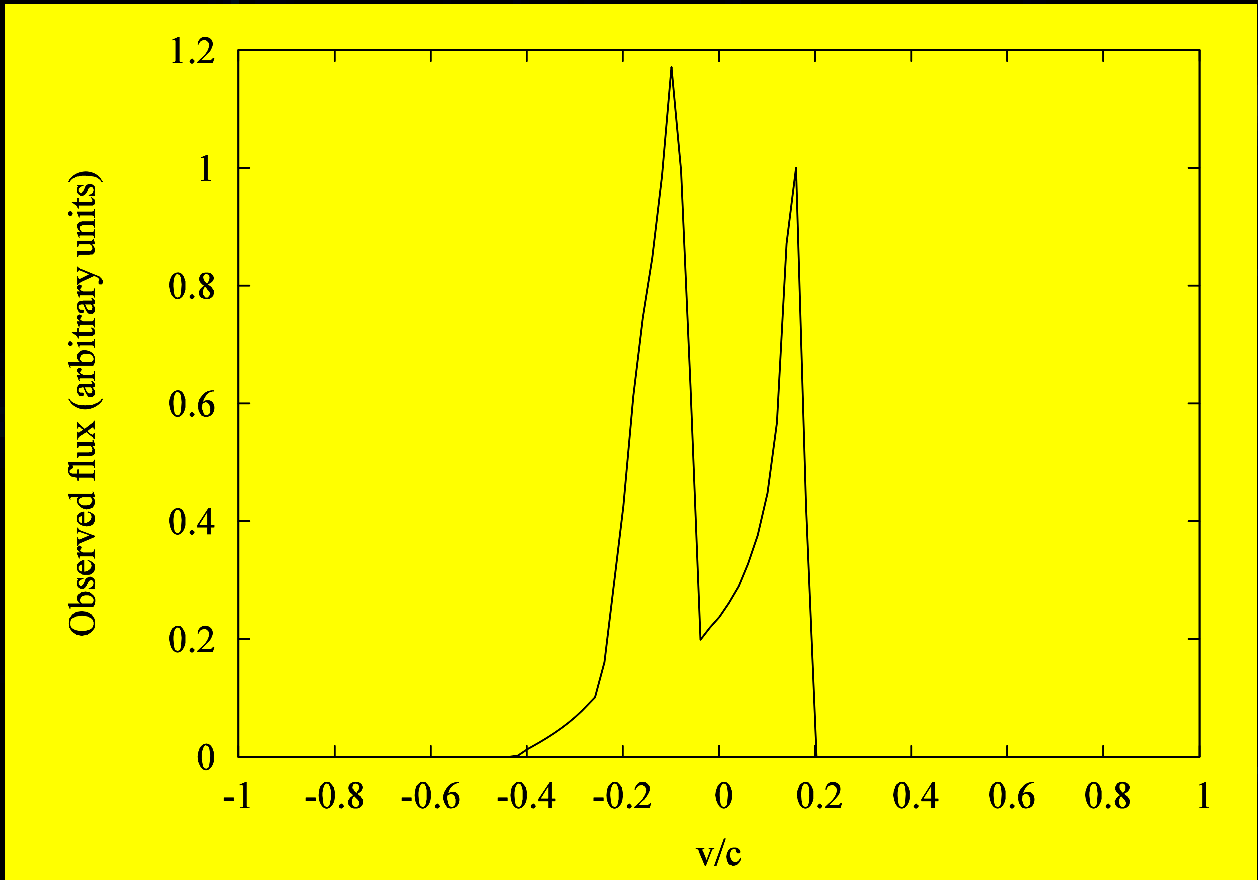

1.2
1
0.8
0.6
0.4
0.2
0
Observed flux (arbitrary units)
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
v/c

Vrad=500 km/s



Observed flux (arbitrary units)
1.2
1
0.8
0.6
0.4
0.2
0
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
v/c

Vrad=5000 km/s



Some indications

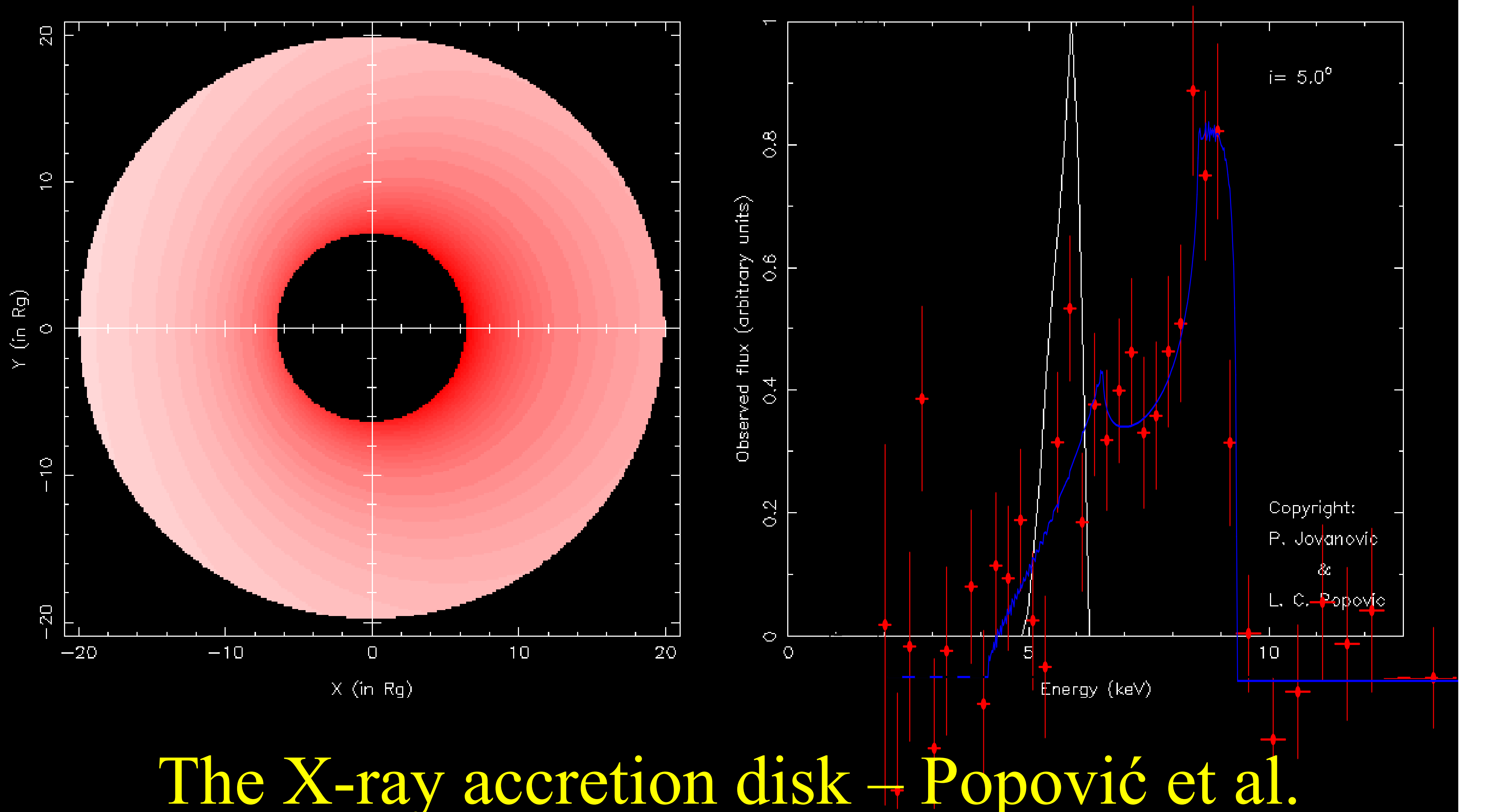
- as e.g. NGC 4151 and NGC 3516, it was found that two disks with different inclinations better fit the Fe K line profile (see e.g.Wang et al., 1999;   Pariev. Et al. 2001)

What can we expect?

- Complex Fe K line profiles & rapid variation (a couple of hours, see Yu & Lu)
- Example of three AGNs (pointed out by De Paolis et al. 2003, A&A 410, 741)

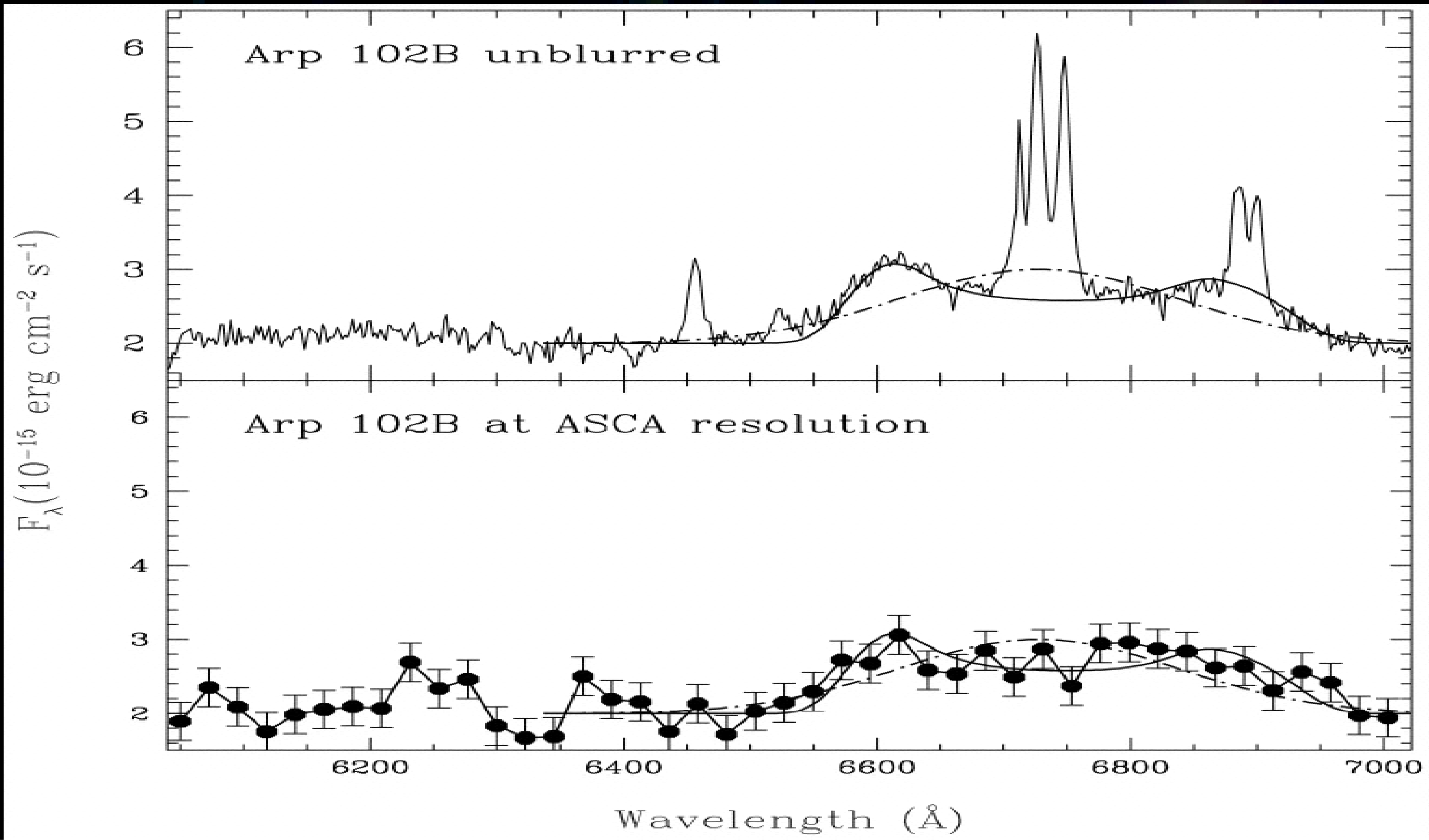
Mrk 501, Mrk 421 and Mrk 766

Jovanovic & Popovic 2008, 2009



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

Problem to use the Fe K line: Low resolution in the X-ray (Sulentic et al. 1998, ApJ)

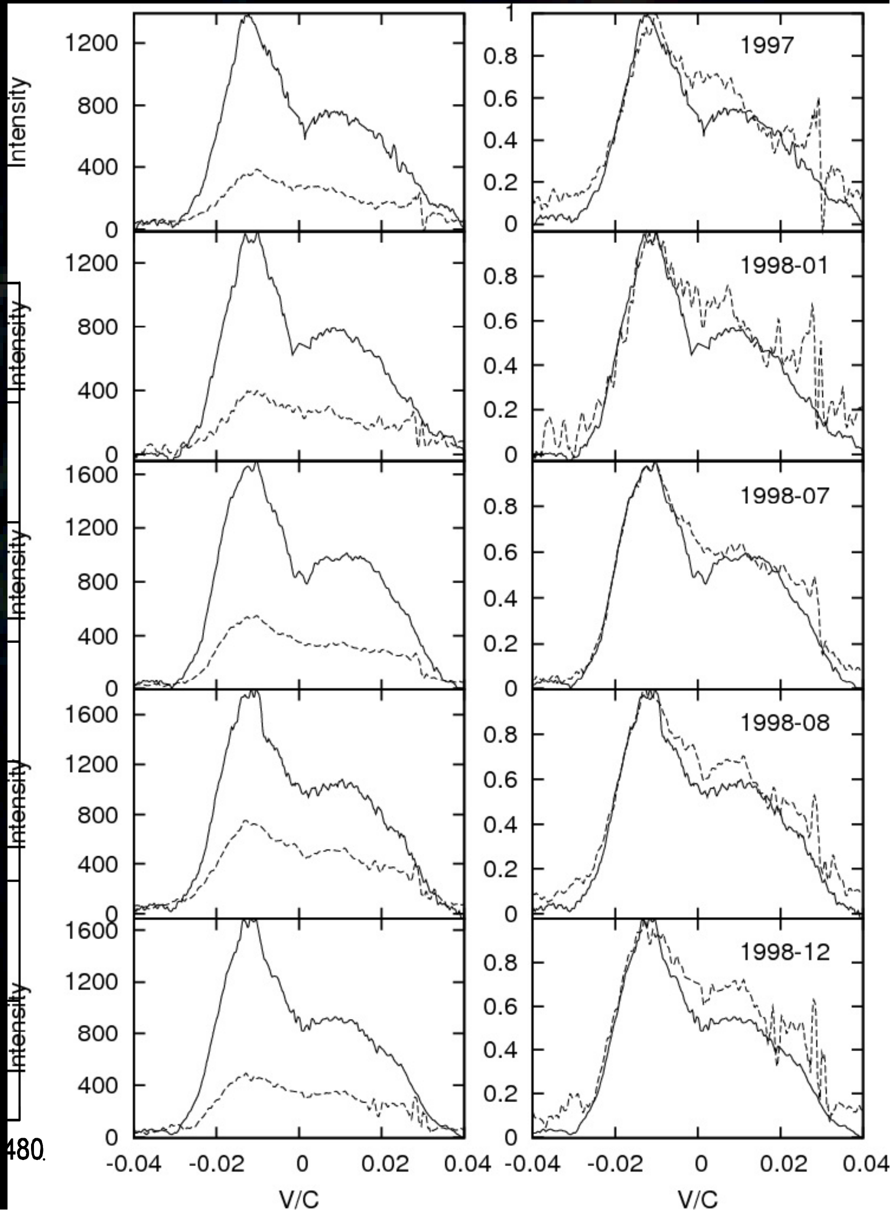


The Broad Line Emission Region

- Gaskell 1983

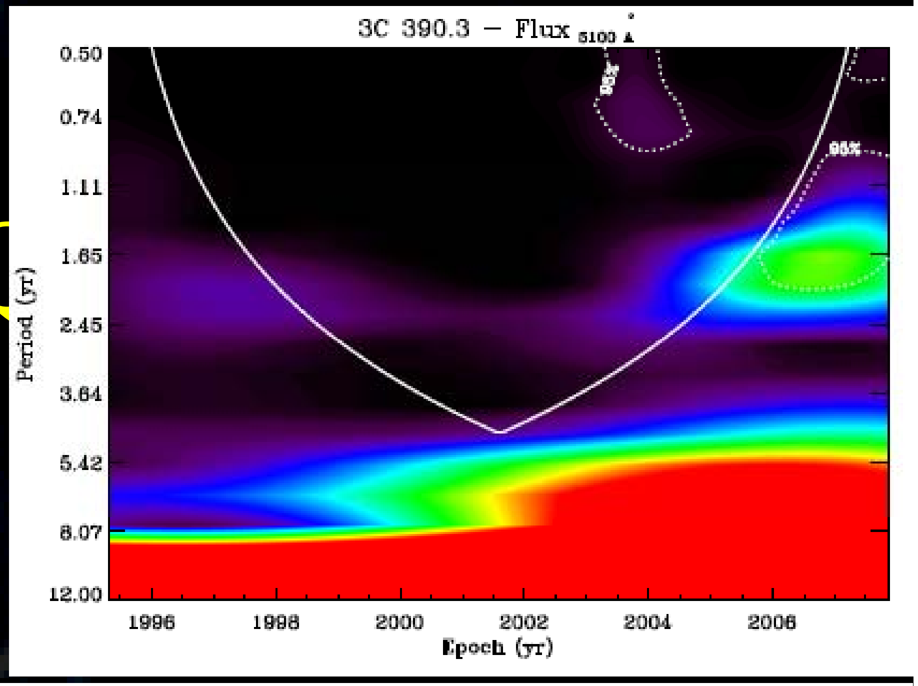
Double peaked lines

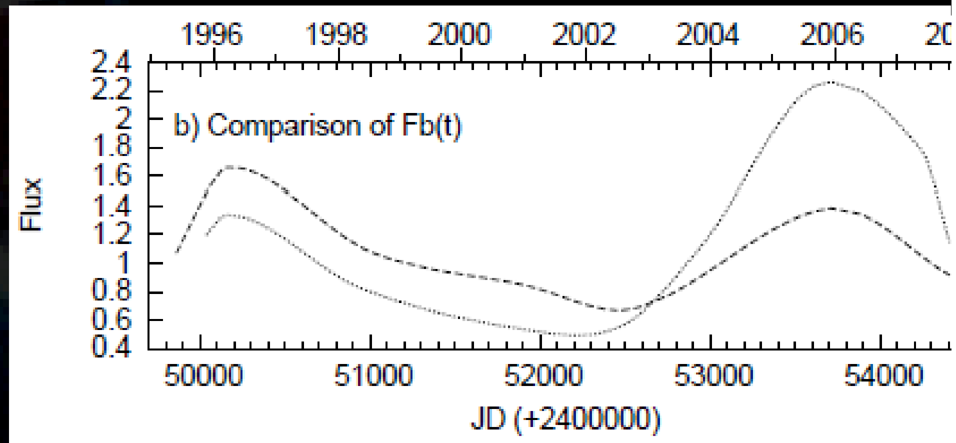
- E.g. 3c390.3; Very broad
- Radio loud AGN
- Variability in line intensities and line shapes (Shapovalova, Popovic et al. 2010, Popovic et al. 2011)

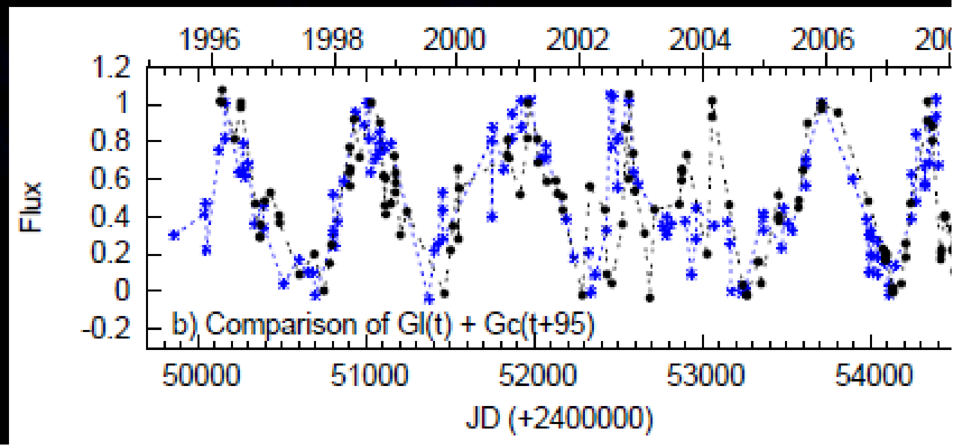


3c390.3 - Q

- quasi-periodic oscillations (QPOs)
  - Morlet wavelet transformation
  - analysis of the minima and maxima of Hβ and continuum
- QPOs with periods:
  ~ 10 years (Veilleux & Zheng 1991)
  ~ 2-4 years
- shock waves near the SMBH spreading in the outer part of the disc OR contribution of either ejection or jets to QPOs
- Shapovalova et al. 2010



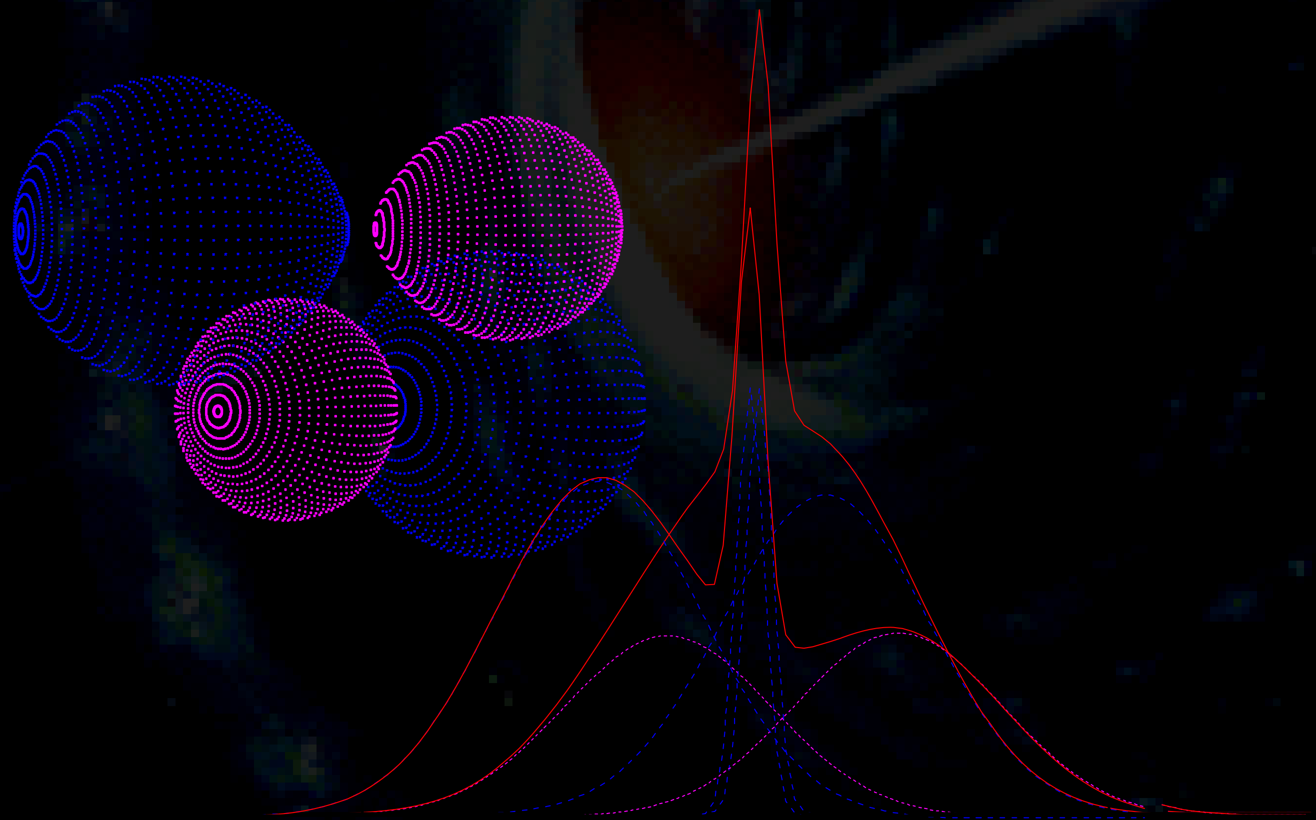




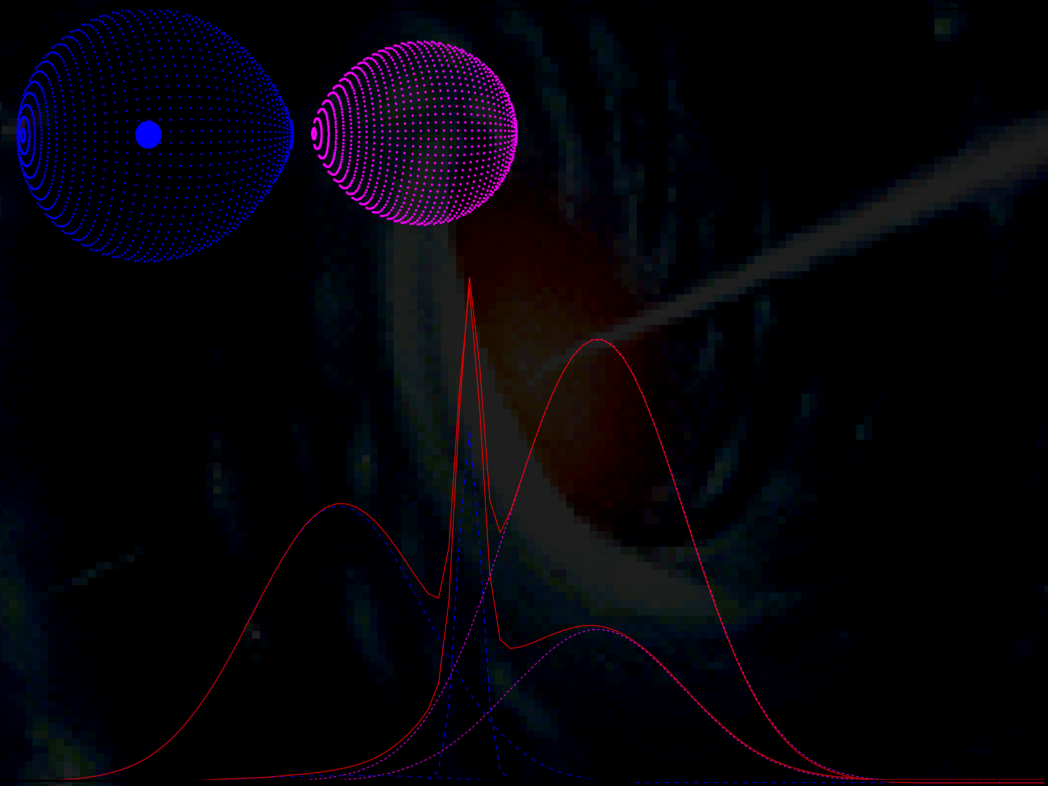
Disk emission in the optical broad lines – geometry of the BLR – e.g. 3C390.3

- Eracleous & Halpern 1994, 2003, ApJ
- Shapovalova, et al. 2010, A&A
- Popovic, et al. 2011, A&A

The Binary Broad Line Region (model Popovic et al. 2000, SerAJ)



BBHs: one or two BLRs



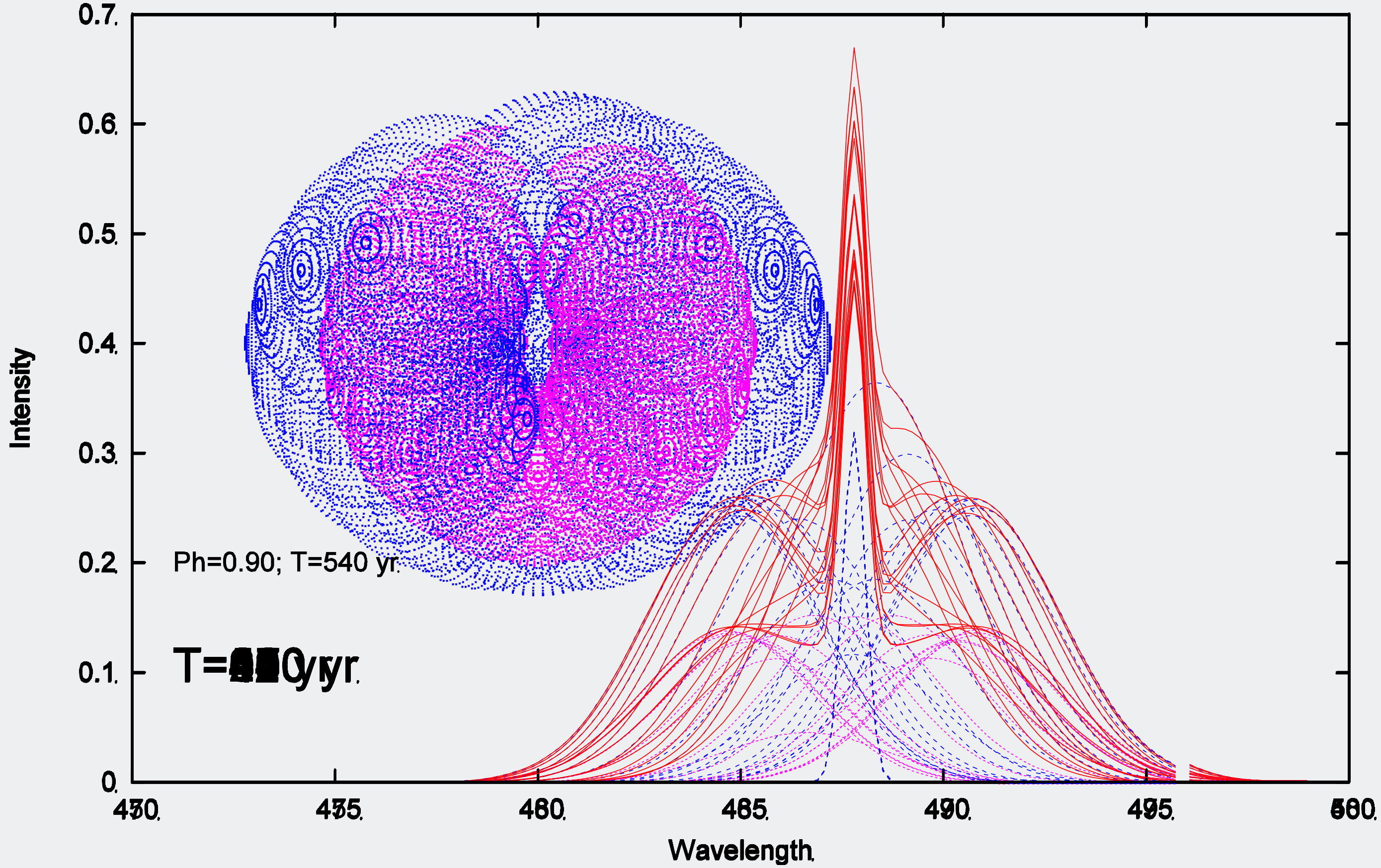
See Boroson & Lauer 2009, Gaskell 2010

Broad line profiles

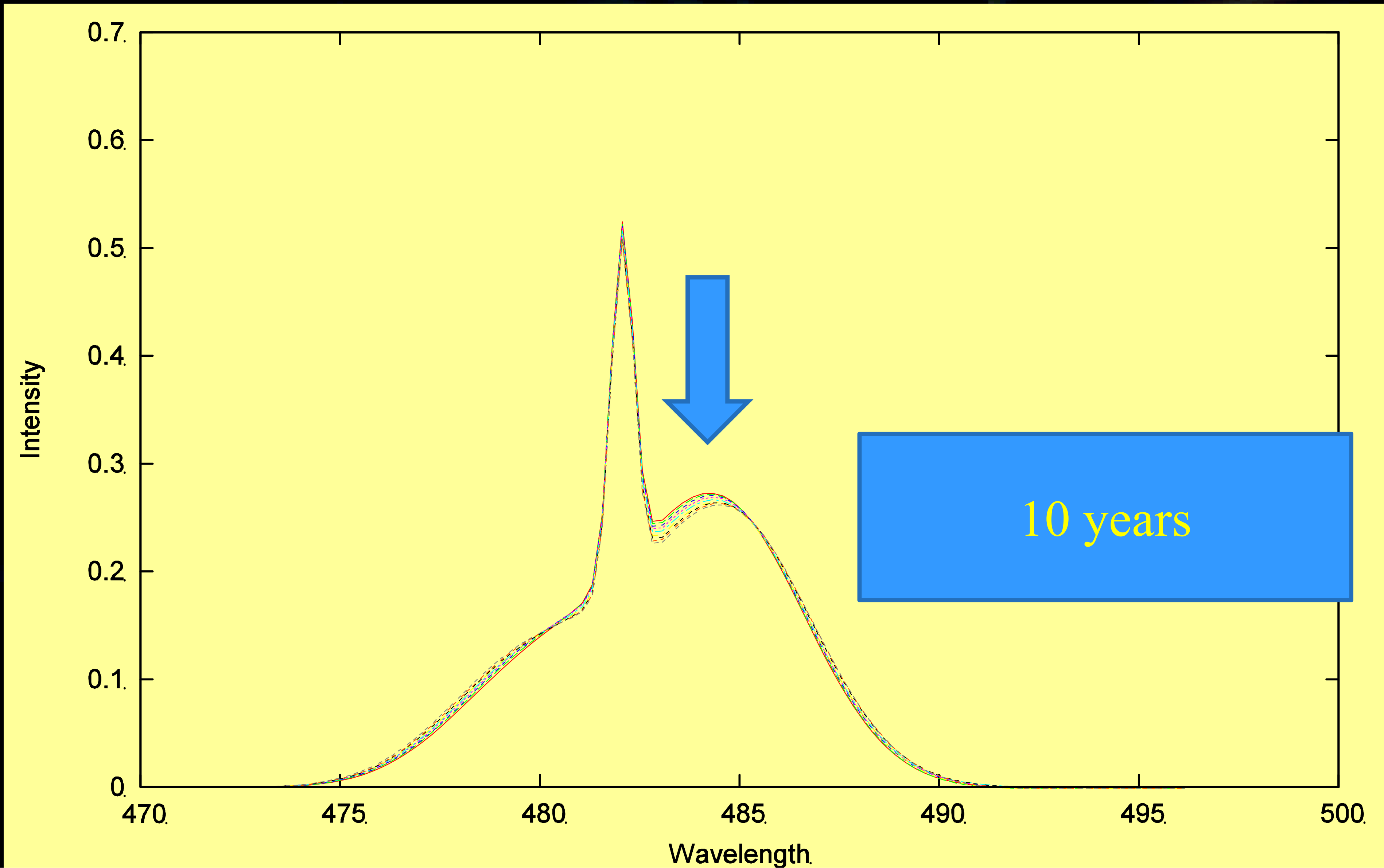
- Popovic et al. 2000
- Shen & Loeb, 2010

- Line profiles can be very different (not only double – peaked)

Some interesting profiles

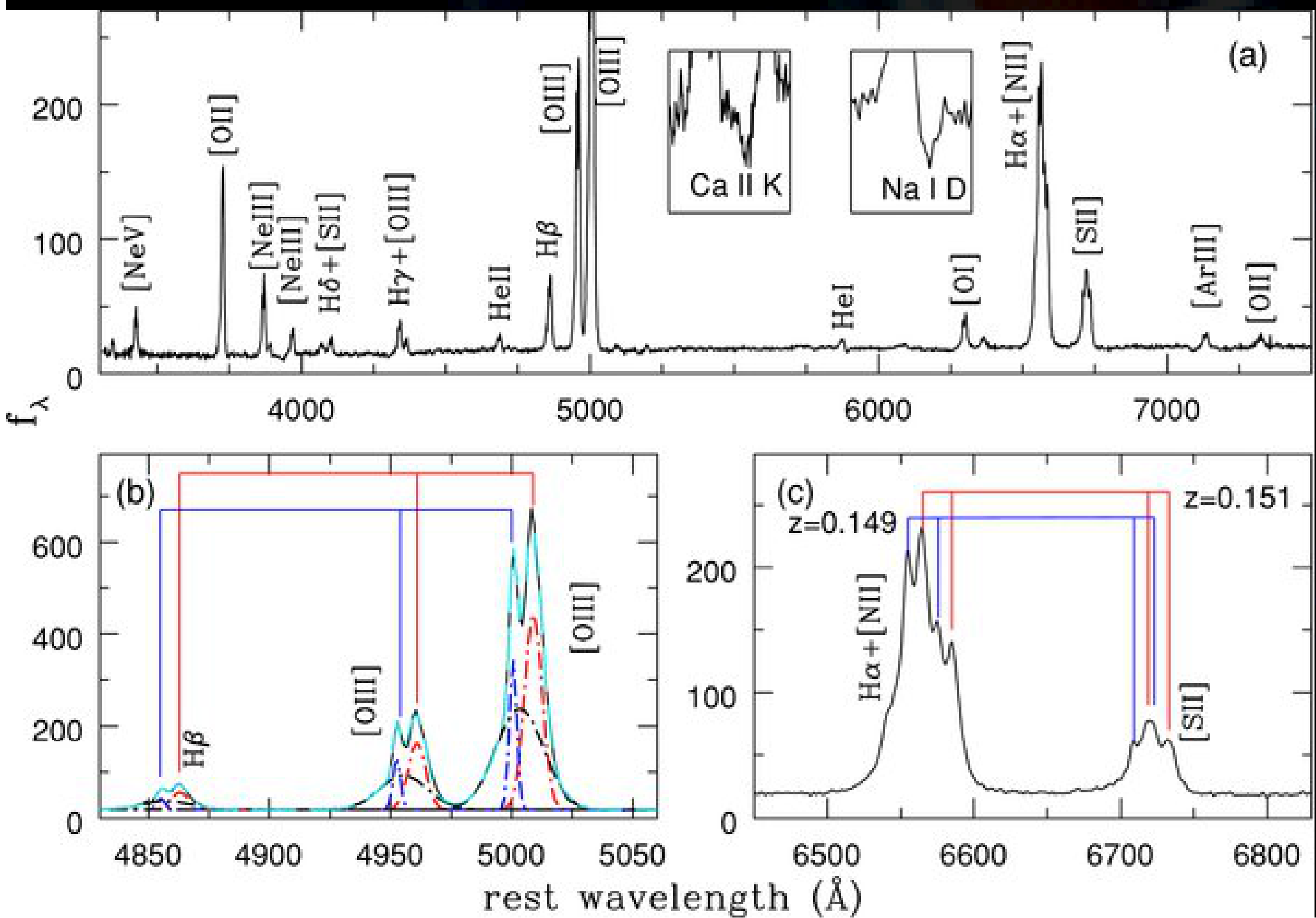


Variability due to the binary BLR



Narrow lines – double peaked (Xu & Komosa 2009)

- SDSS J131642.90+175332.5



- Vrad~600 km/s
- Taking the same masses, R~2.5 pc?
- Very compact object

A number of papers about DPNLRs

- Xu & Komossa, 2009; Wang et al., 2009; Smith et al., 2010; Liu et al., 2010a,b; Chornock et al., 2010

- There are some cases that may be BBH,
- but mostly of the DPNLRs are caused by complex NLR geometry

Emission lines and Super-massive BBHs

- Variability (caused by interaction, unlikely by motion of the components)
- Quasi-periodical oscillations

- Very hard to detect BBHs using only emission lines
- Double-peaked narrow lines are probably from complex kinematics …

Popovic & Gaskell (N...)

- Aims:
- To give an critical overview abo... emission l... BBH...
- ...e, broad ...arrow LER
- ...st of ...n candidates
- Any suggestion is welcome

Thank you for your attention