



**MAT $\Phi$**   
University of Belgrade  
Faculty of Mathematics

# Unusual broad line profiles of AGNs and sub-pc supermassive binary black holes

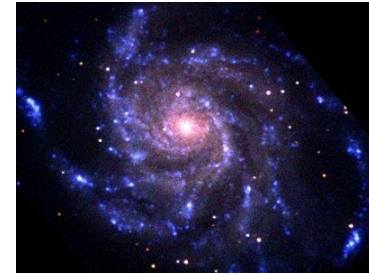
**Luka Č. Popović**

Astronomical Observatory, Belgrade

Department of Astronomy, Faculty of Mathematics, University of Belgrade

"Active galaxies at different scales and wavelengths"  
SAO RAS, October 14-17

# Coevolution of black holes and galaxies



Hierarchical  
growth

- Normal galaxy

Gas  
inflows

Galaxy formation  
and evolution

AGN  
feedback

Starburst and AGN starting phase

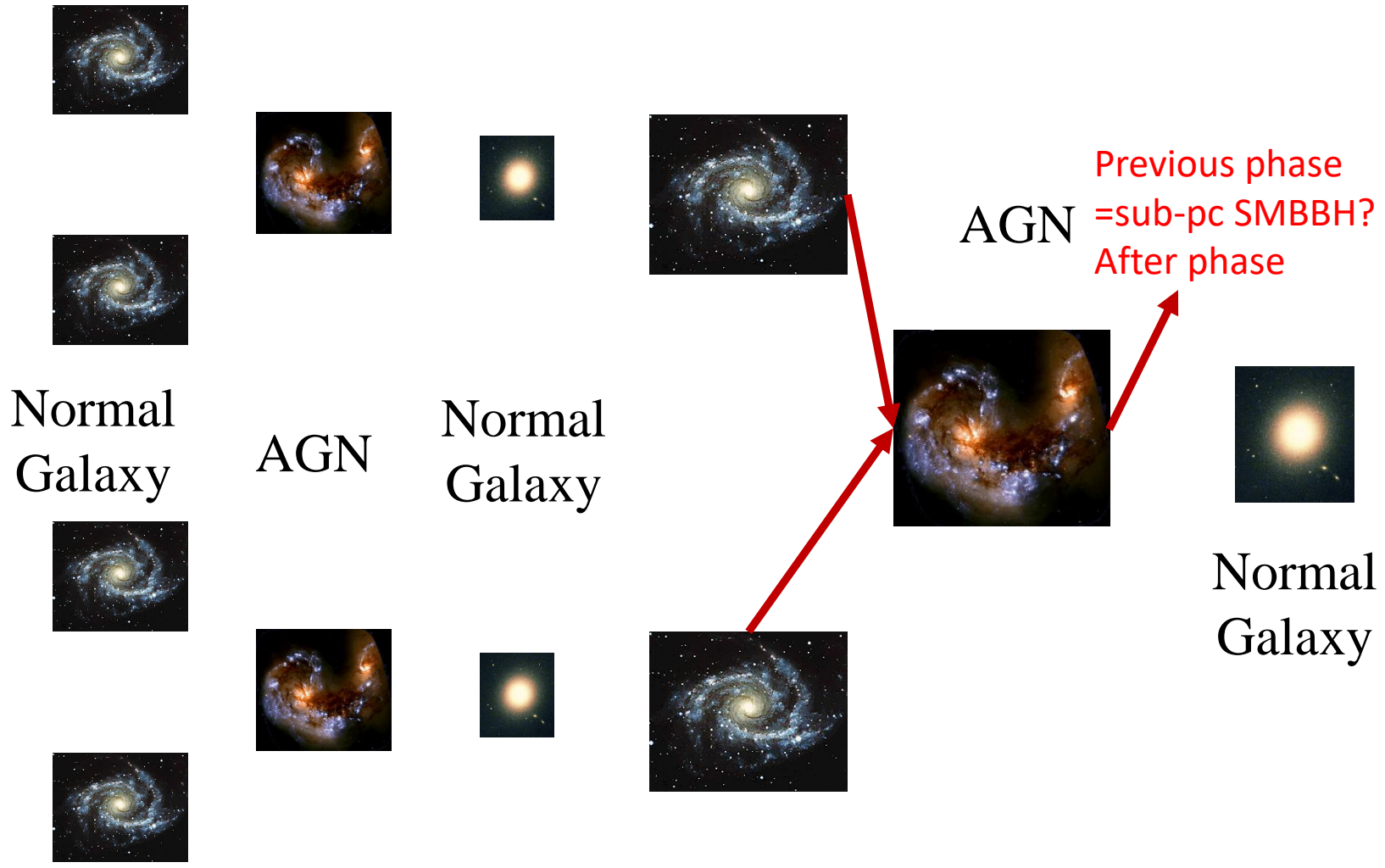
quasar



Growth of BH

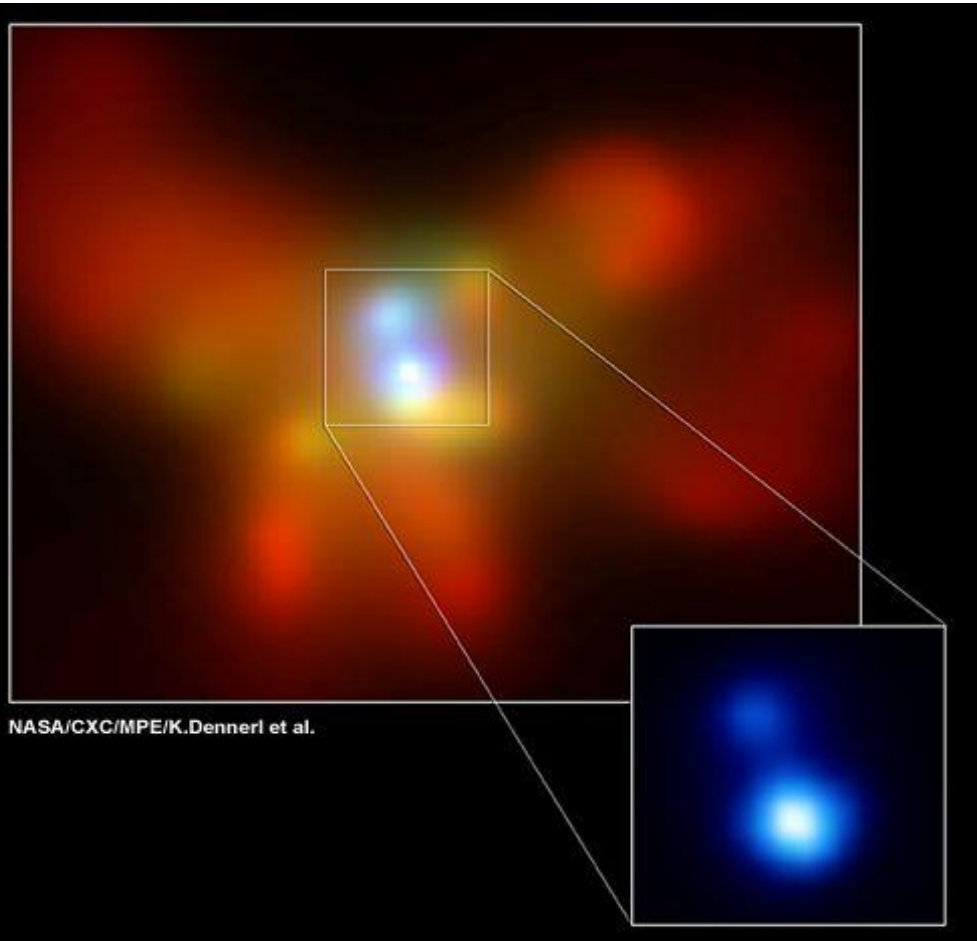


# Hierarchical Galaxy Formation - supermassive binary black holes (SMBBHs) in galaxies



# Supermassive binary black holes - SMBBHs

NGC 6240: X-ray  
emission (Komossa et  
al. 2003)



# sub-pc SMBBHs: Expected effects in emission (EM signal)

Two SMBBHs + surr. gas=> activity as in AGN

- Spectroscopy and variability

Line shapes (variability in the line shapes) and parameters, shift and width

Variability in the line and continuum

Effects in polarization

Unusual line profiles from the X-ray to the optical

# sub-pc SMBBHs: Expected effects in emission (EM signal)

Different geometry:

**In X-ray => emission of the accretion disc**

see Jovanović et al. 2020, Contrib. Astron. Obs. Skal. Pleso 50, 219, Jovanovic et al. 2024, accepted in ASR (<https://arxiv.org/pdf/2407.18871>)

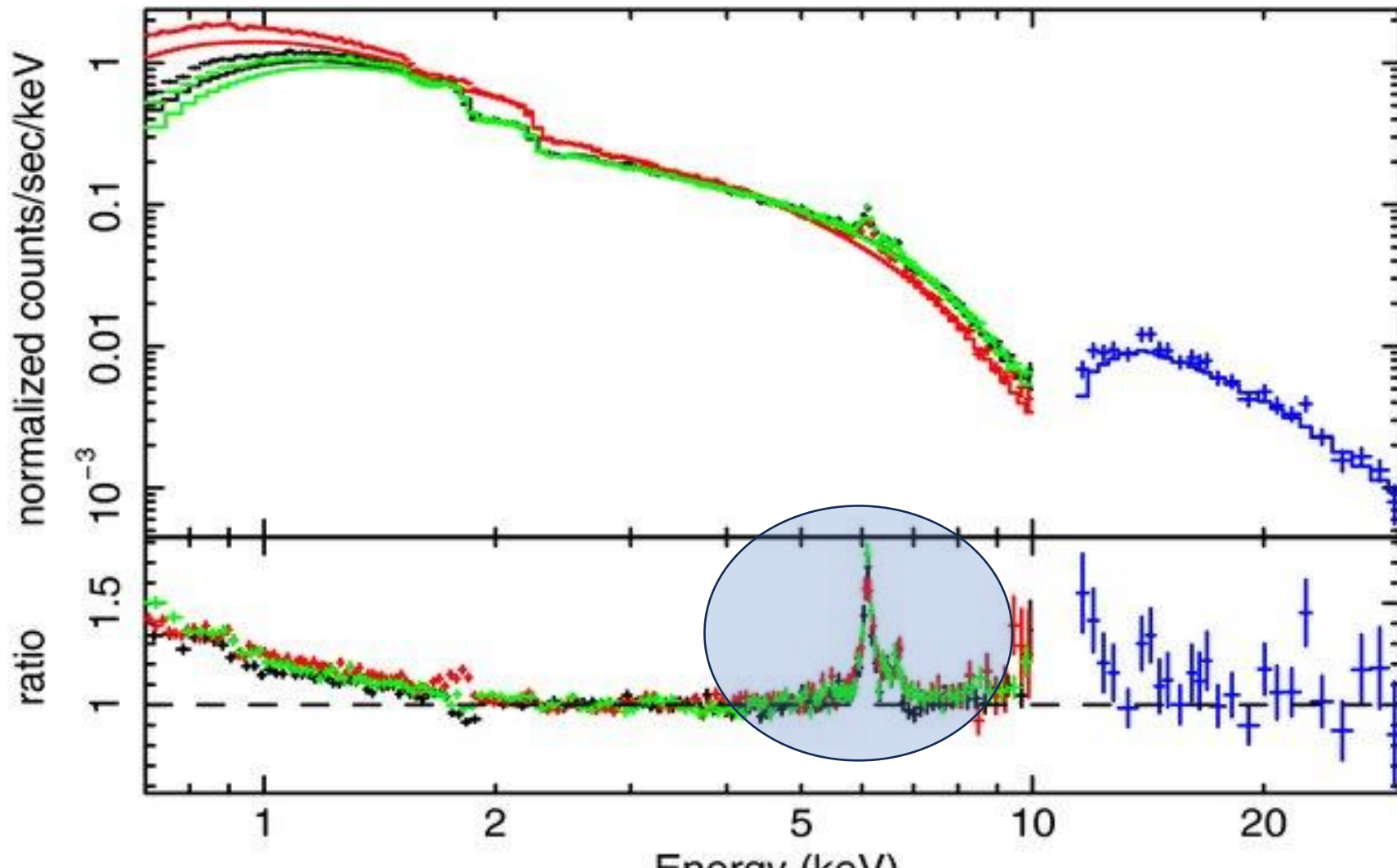
In UV optical lines => Broad Line Region (BLR)

Popović 2012, NewAR, 56, 74

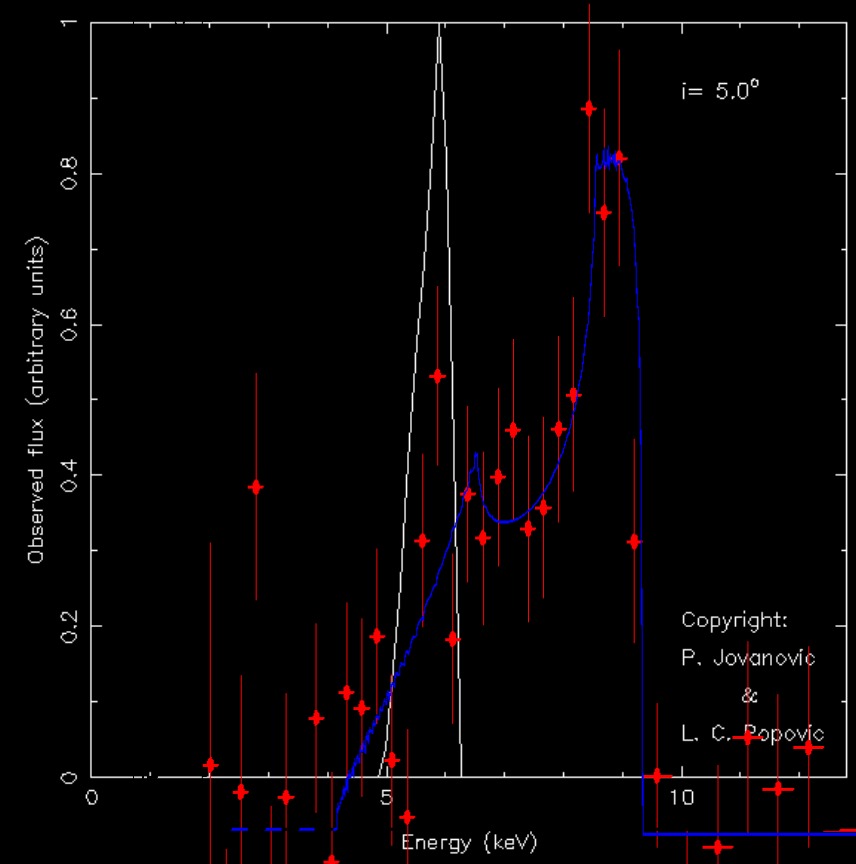
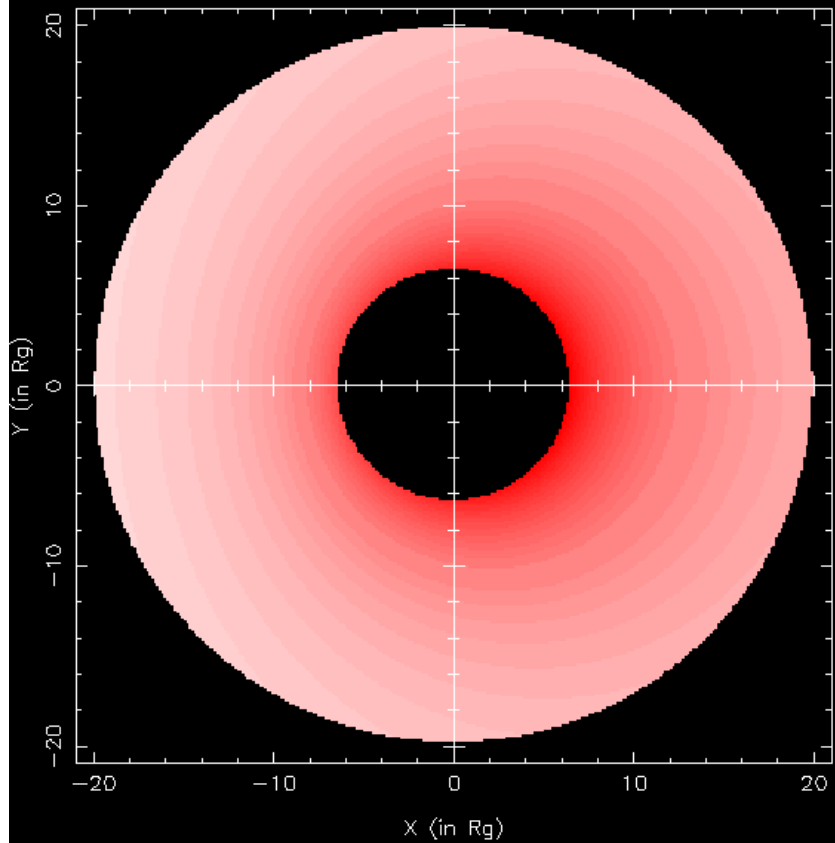
Popović et al. 2021, MNRAS, 505, 51

Deandra et al. 2024, in preparation

# Spectral lines – Fe $K\alpha$



Starting from x-ray, see Jovanović & Popović 2008,  
2009

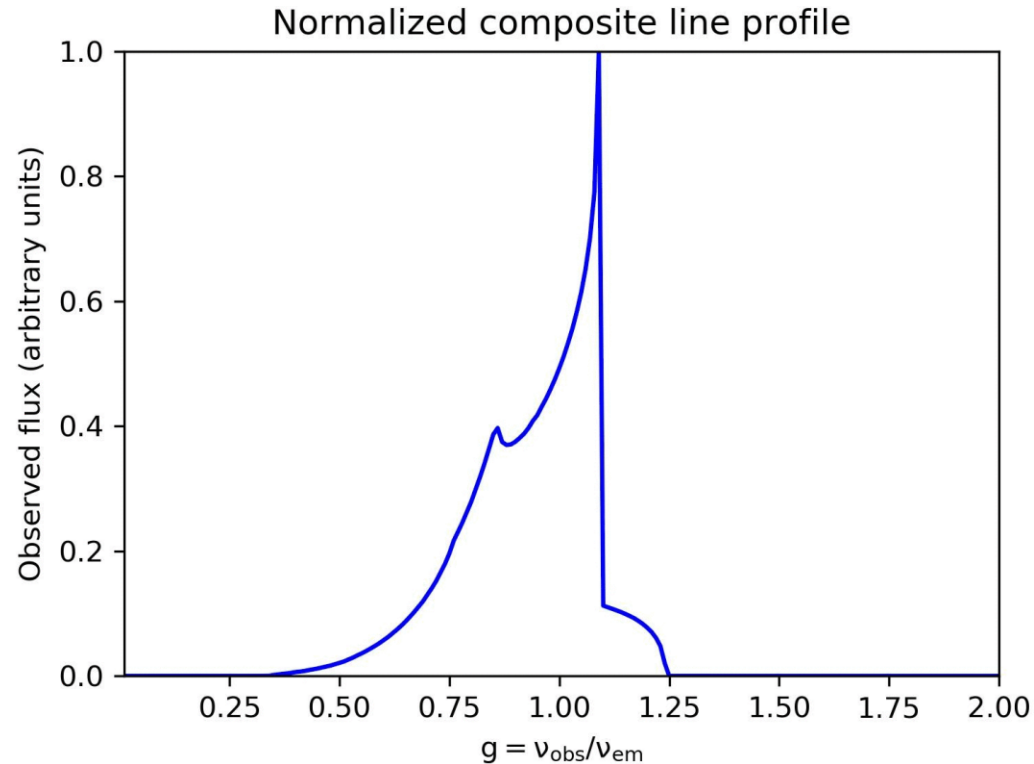
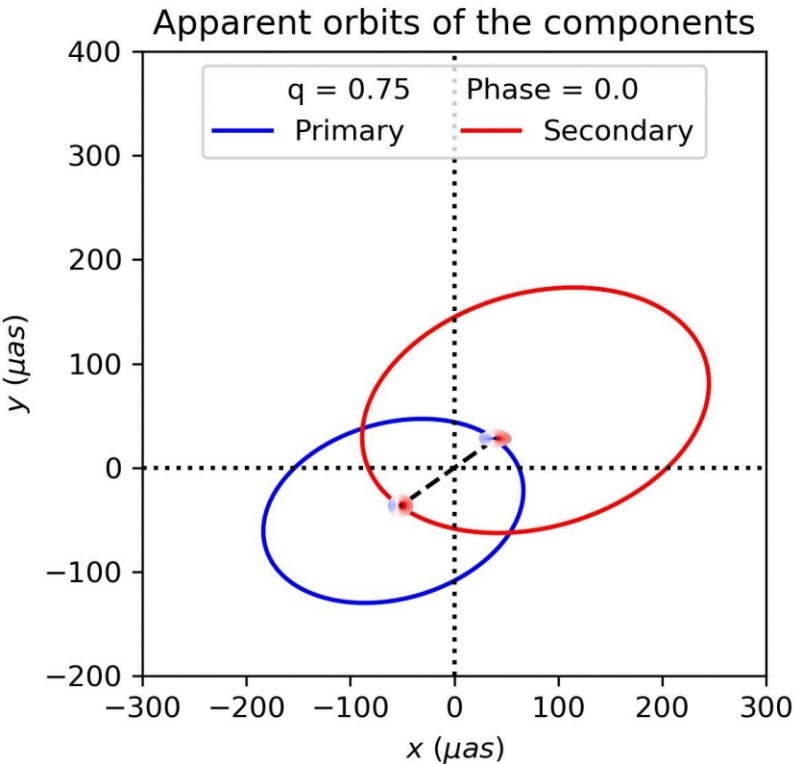


The X-ray accretion disk – Popović,  
Jovanović et al. 2003, A&A, 398, 975; 2006,

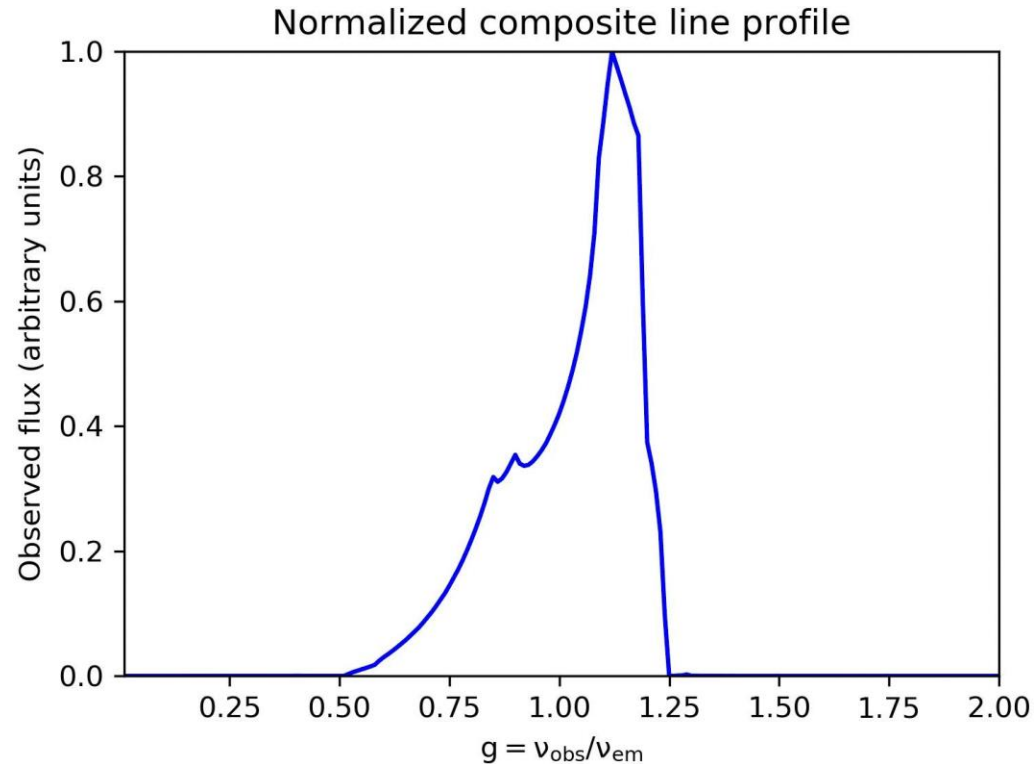
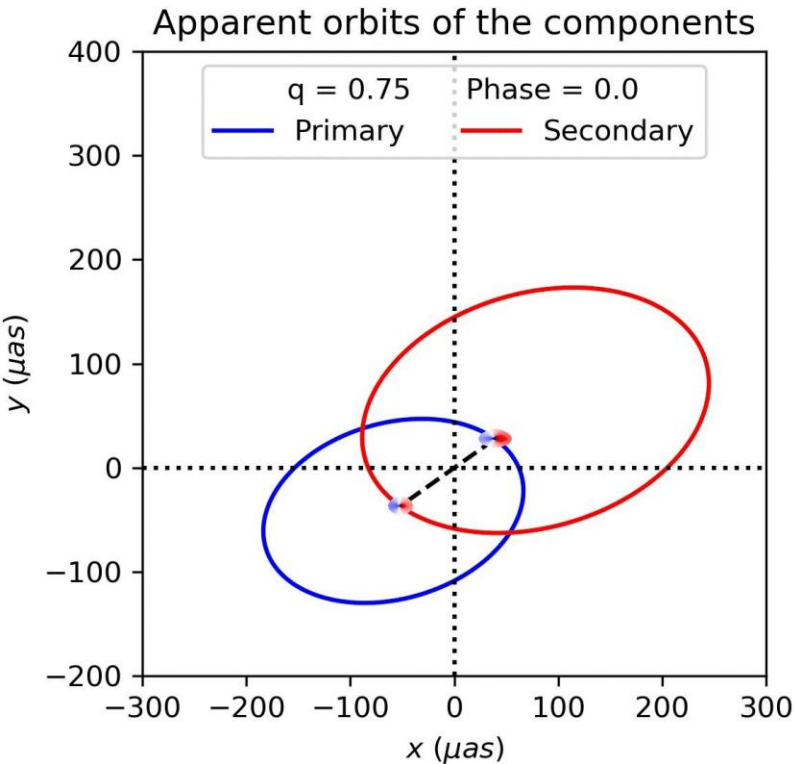
ApJ, 637, 620

Energy (keV)

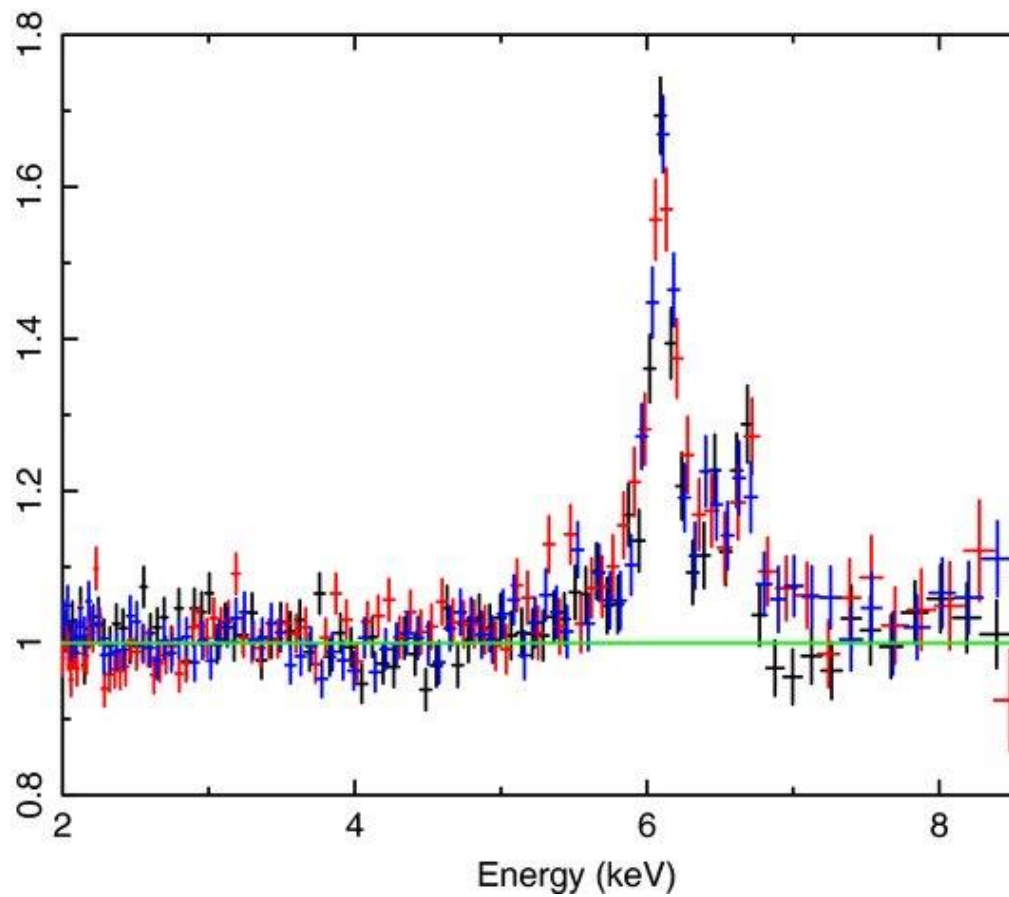
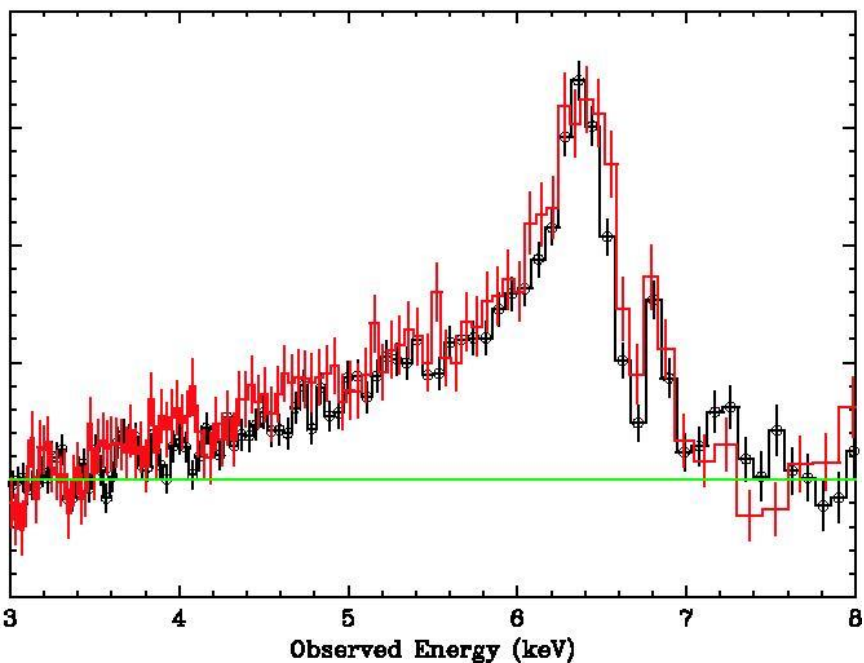
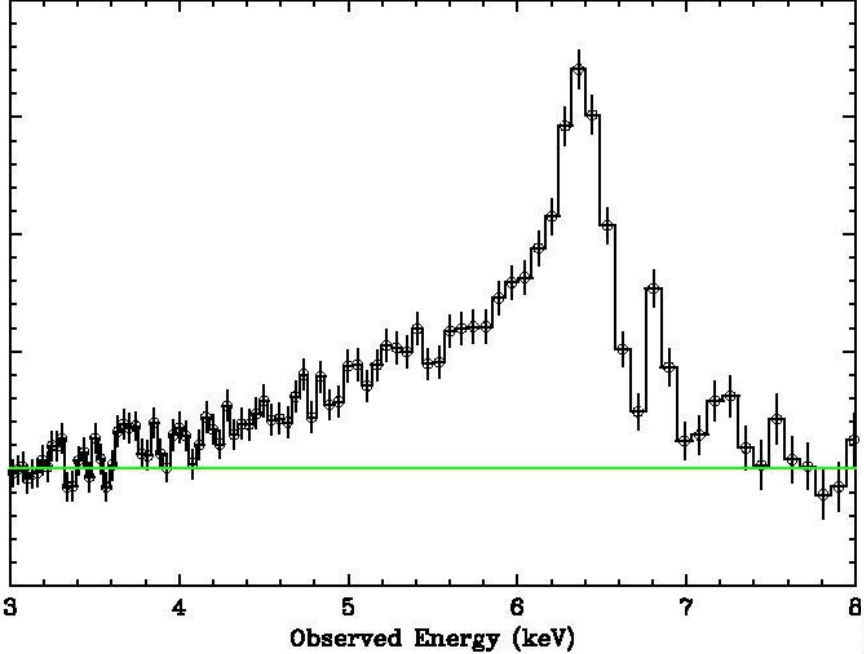
Changes in the Fe K $\alpha$  line profiles – different inclinations of discs, see Jovanovic et al. 2024, accepted in ASR  
(<https://arxiv.org/pdf/2407.18871>)



Changes in the Fe K line profiles –similar inclinations see Jovanovic et al. 2024, accepted in ASR (<https://arxiv.org/pdf/2407.18871>)



## Some indications and problems



# sub-pc SMBBHs: Expected effects in emission (EM signal)

Different geometry:

In X-ray => emission of the accretion disc

see Jovanović et al. 2020, Contrib. Astron. Obs. Skal. Pleso 50, 219, Jovanovic et al. 2024, accepted in ASR (<https://arxiv.org/pdf/2407.18871>)

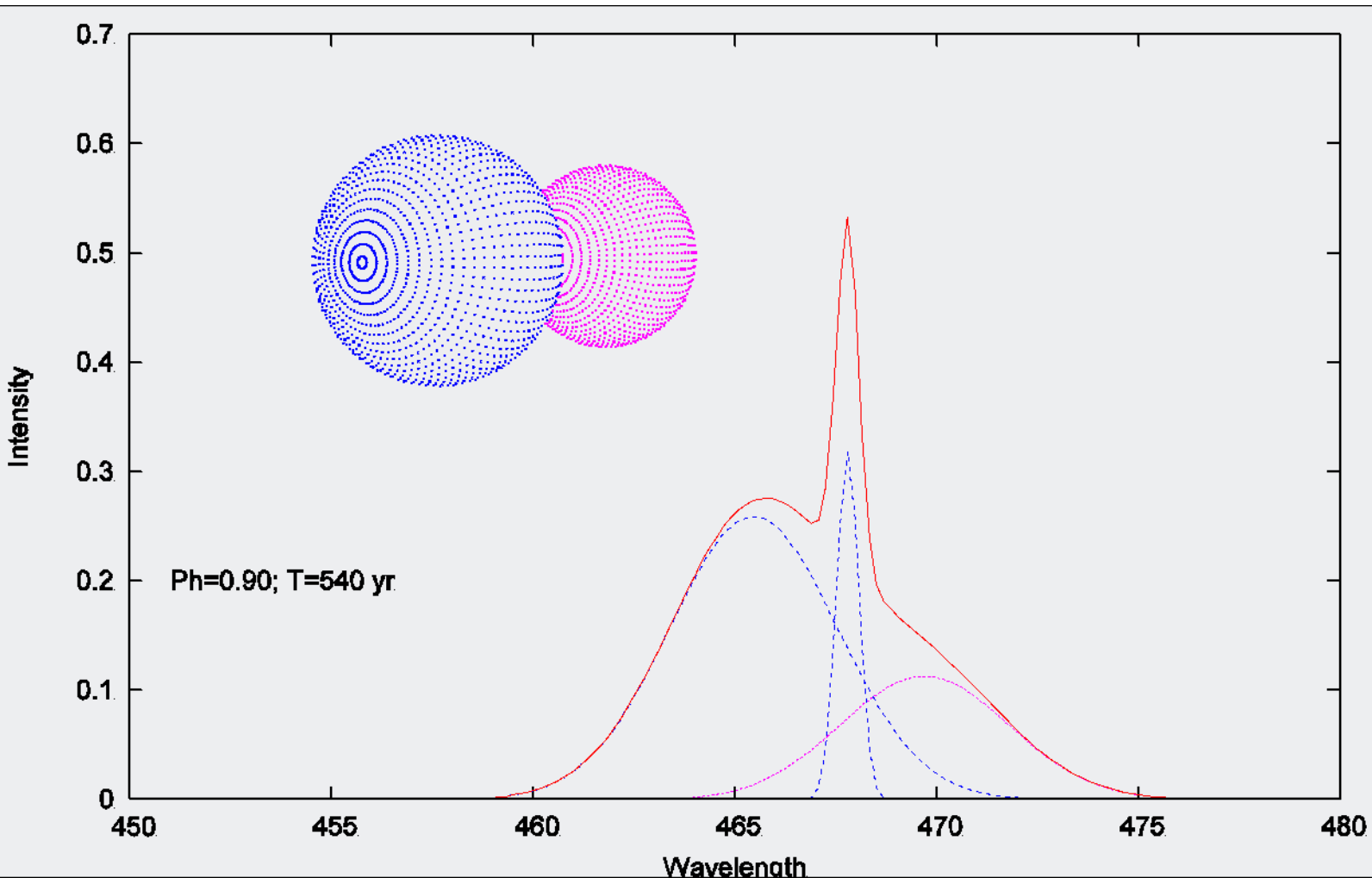
**In UV optical lines => Broad Line Region (BLR)**

Popović 2012, NewAR, 56, 74

Popović et al. 2021, MNRAS, 505, 51

Deandra et al. 2024, in preparation

sub-pc SMBBHs => Some unusual profiles, see  
Popović 2012, NewAR, 56, 74

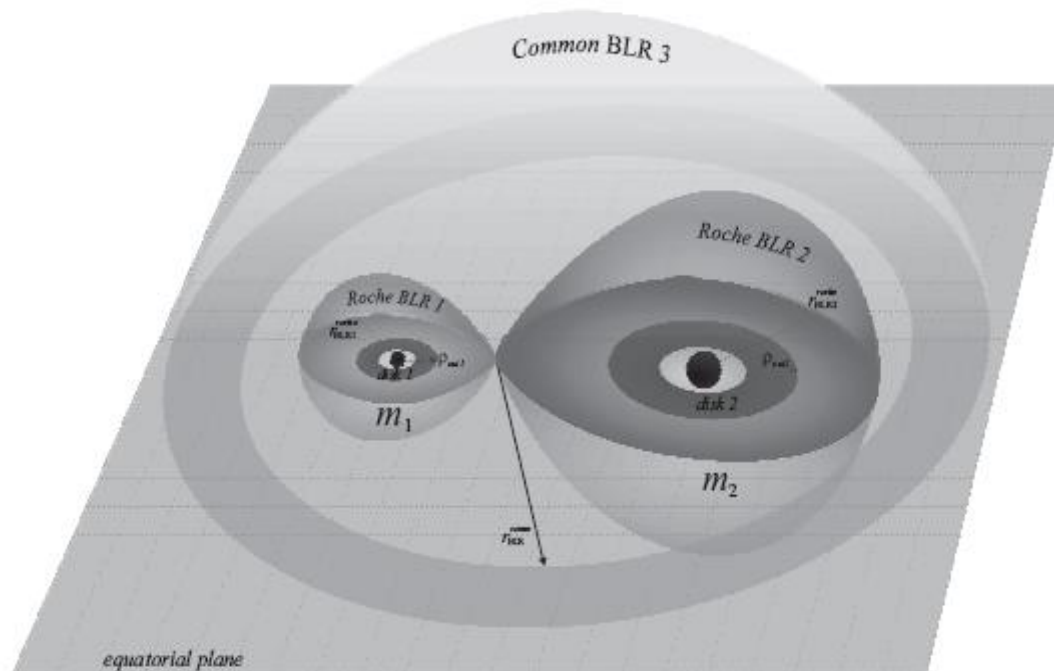


# Variability in broad line profiles – unusual BLF

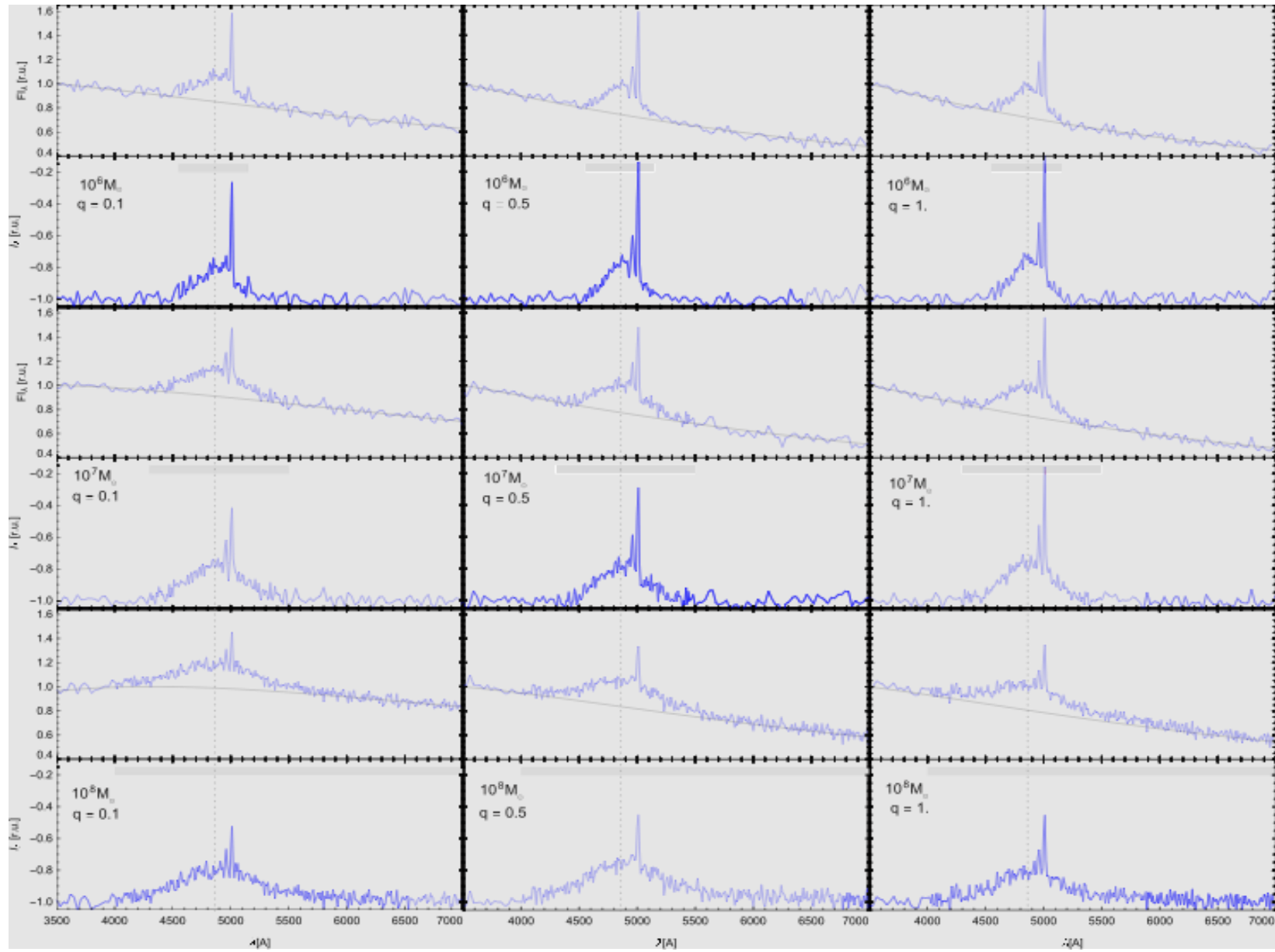
Popović, Simić, Kovačević, Ilić 2021, MNRAS, 505, 51

## PoSKI model

Semi-empirical model based on the correlation between different AGN spectral parameters:  $\text{FWHM} = f(M_{\text{BH}})$   
 $\text{RBLR} \sim L_{5100} = f(M_{\text{BH}})$  and three BLRs

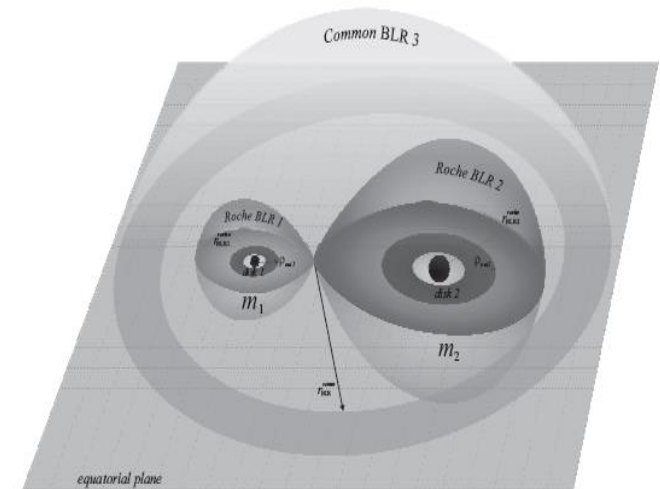
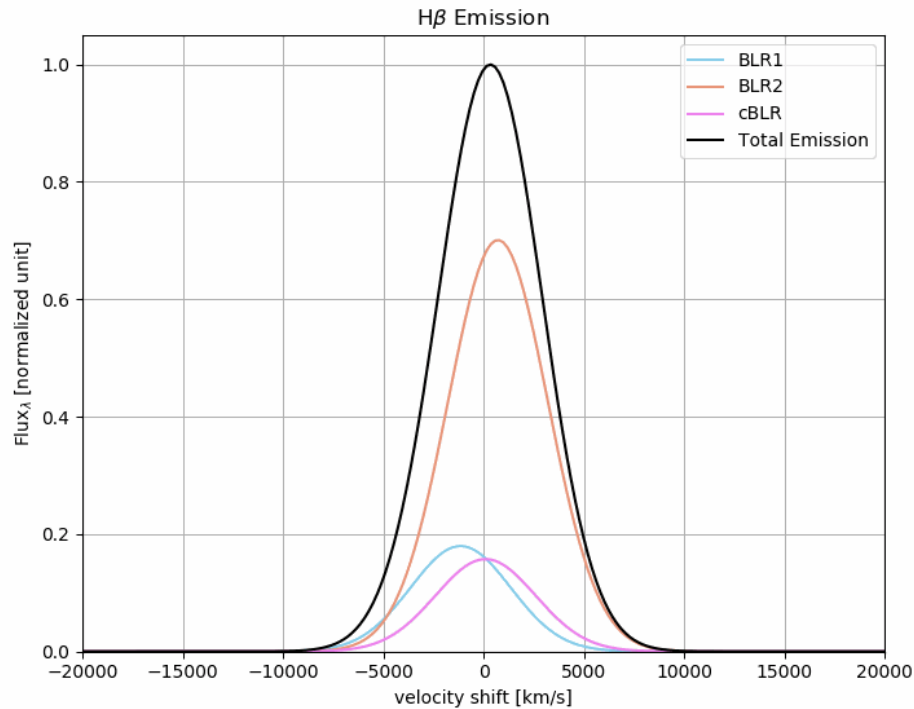


# Simulation of the broad line profiles

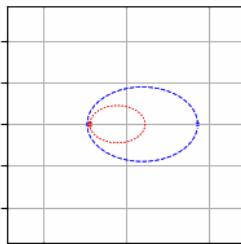


# PoSKI Model – line profile variability

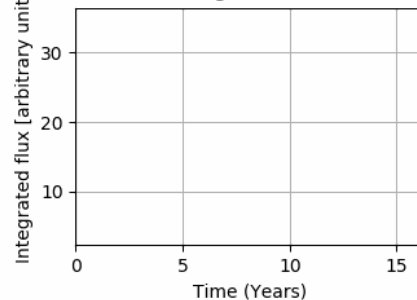
Deandra et al. 2024, in preparation



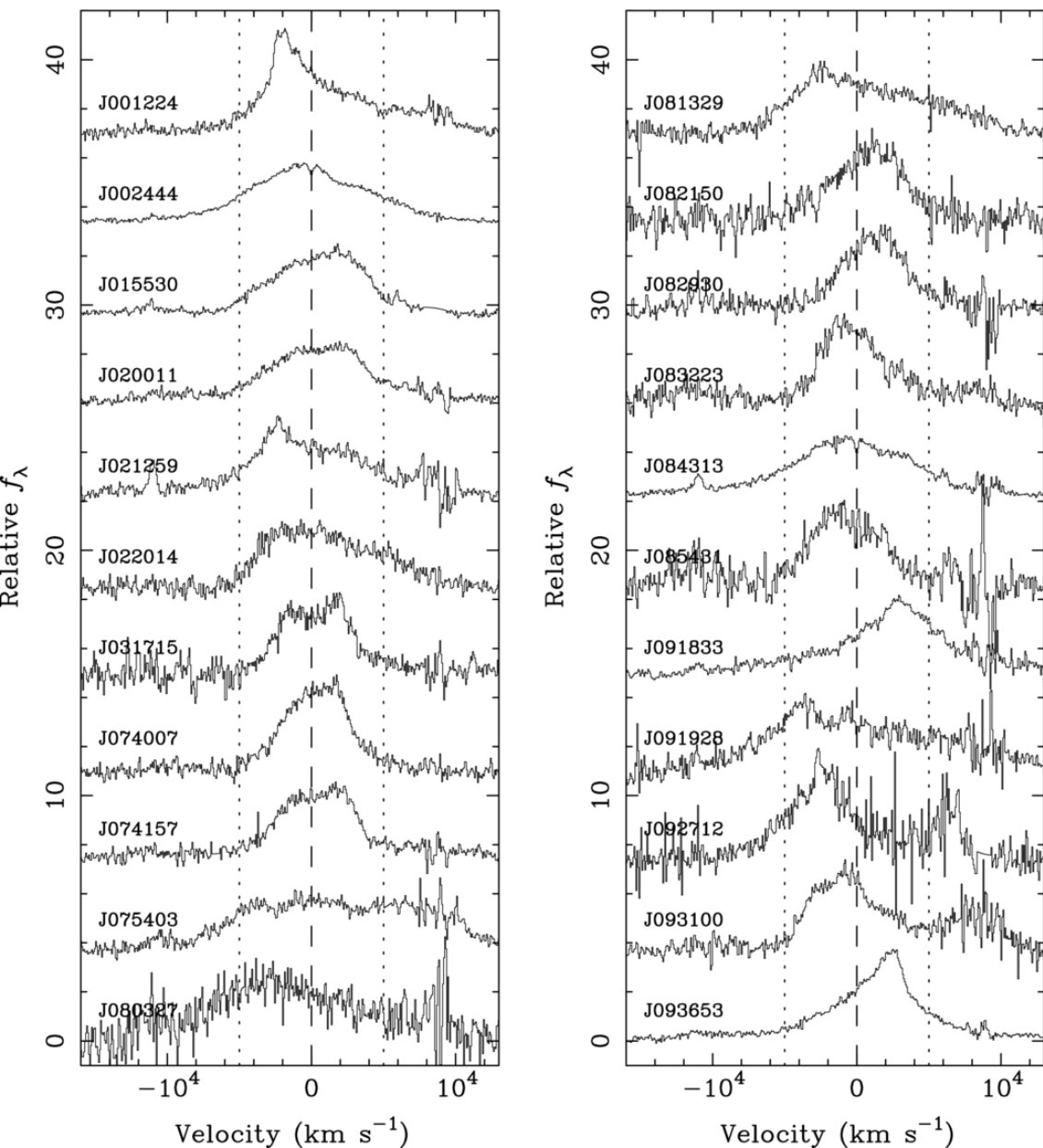
SMBH Configuration



Integrated Flux

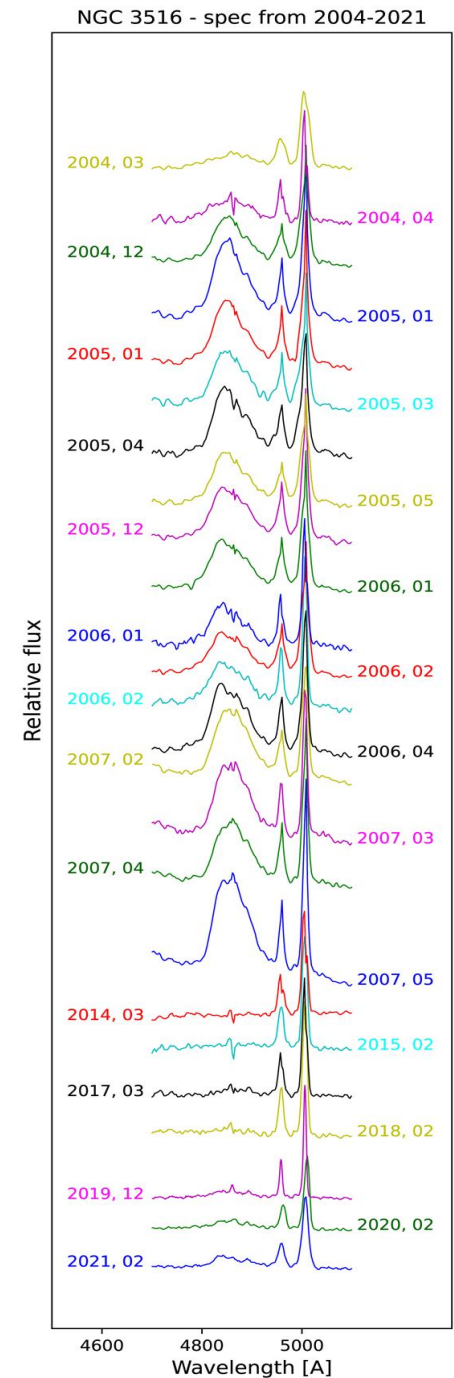
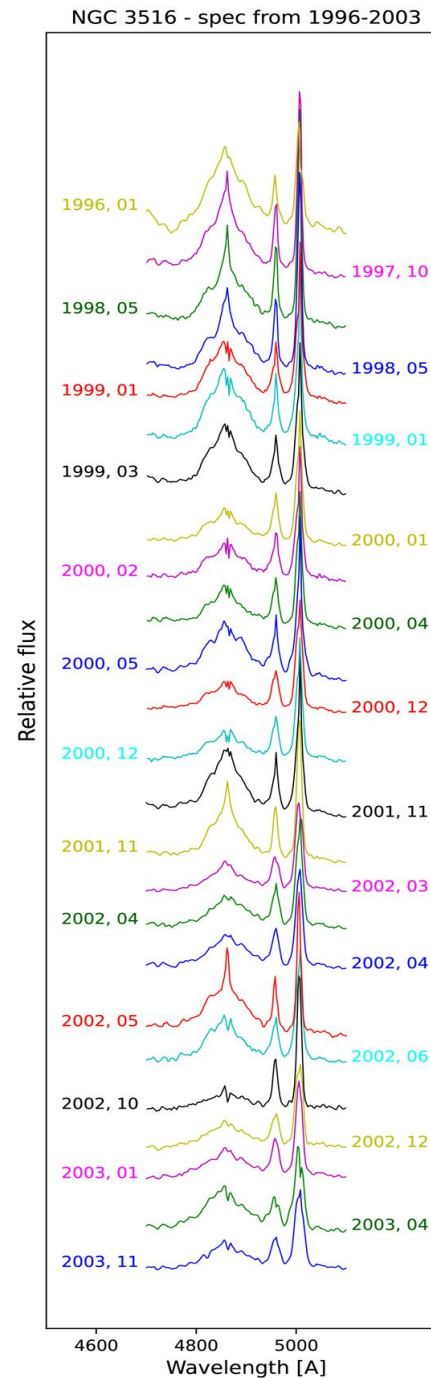


# Observations - complex line profile in the optical and UV spectra of AGNs (Eracleous et al. 2012)



Long term variability  
– learn about the  
physics; changing  
look AGNs (Dragana  
this morning)

Popovic et al. 2023,  
A&A, 575, 178  
(continue the work of  
Shapovalova et al.  
2019)



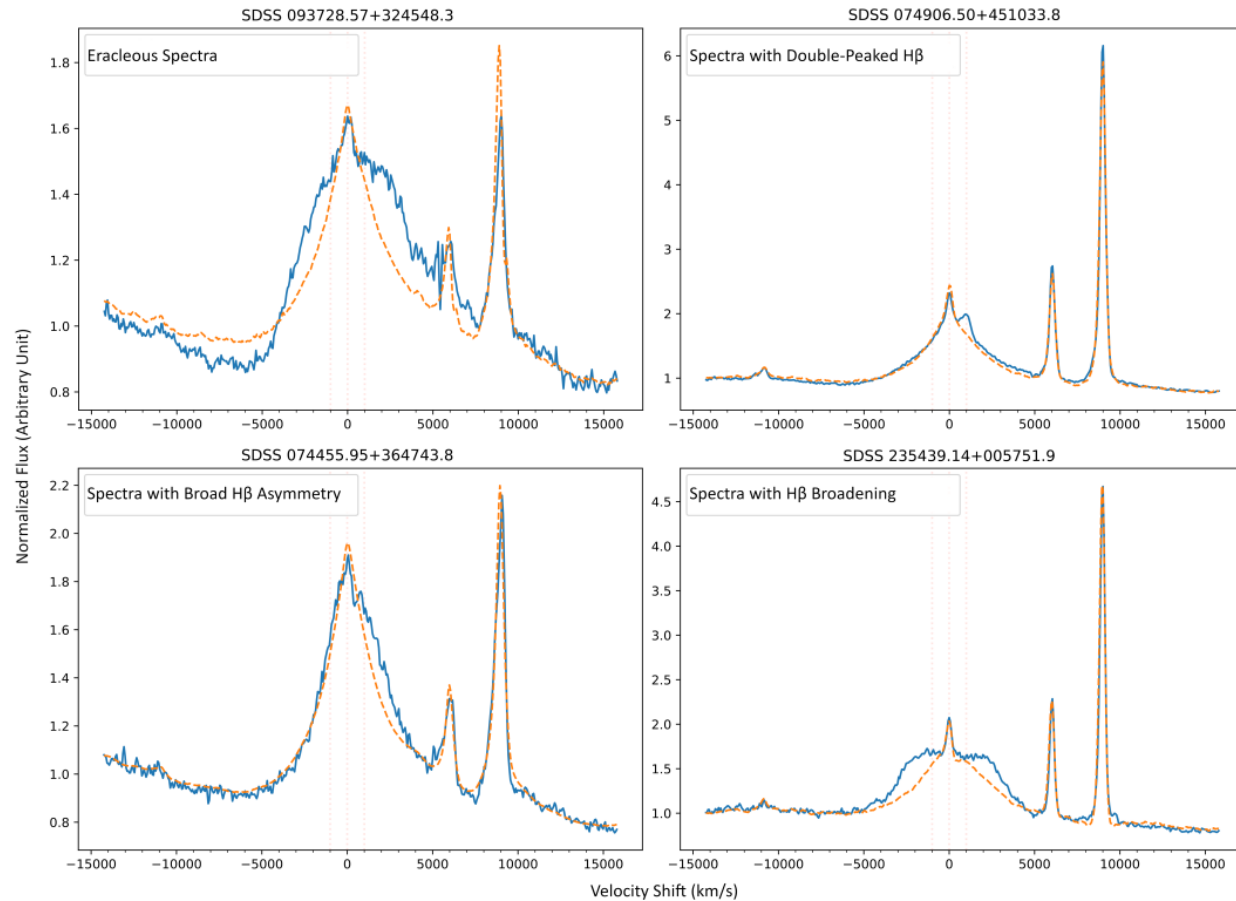
# Deandra et al. 2024, in preparation

Updating the SMBBH candidates catalogue with the spectra data of SDSS DR16 and widening the search to  $z < 0.8$ ; Similar as in Eracleous et al. 2012

76466 objects with  $z < 0.8$  were chosen instead.

All spectra are preprocessed using FANTASY package (Ilić et al., 2023, ApJS, 267, 19)

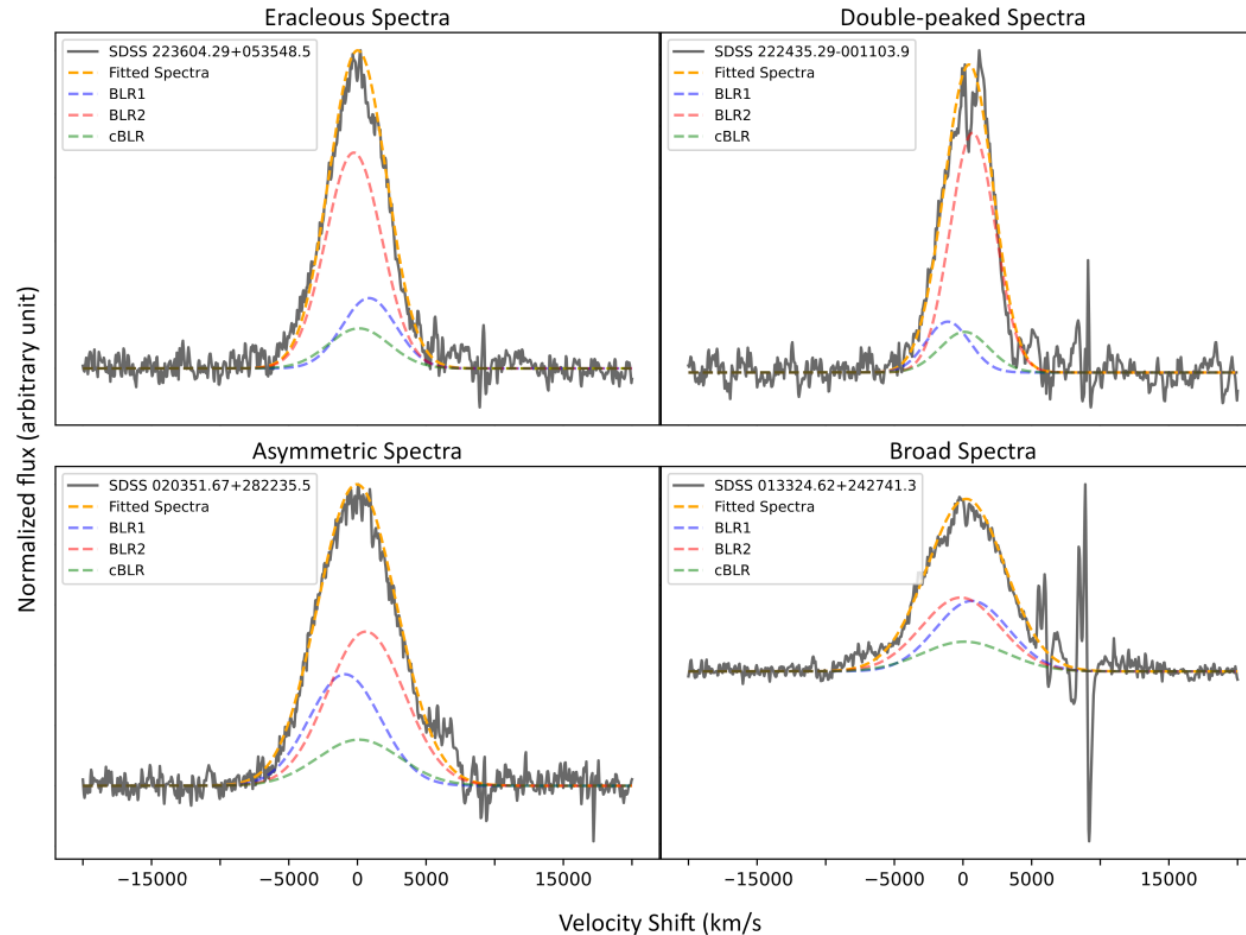
Extracted 294 objects with unusual line profiles (double-peaked, asymmetry, very broad) – candidates for sub-pc SMBBHs



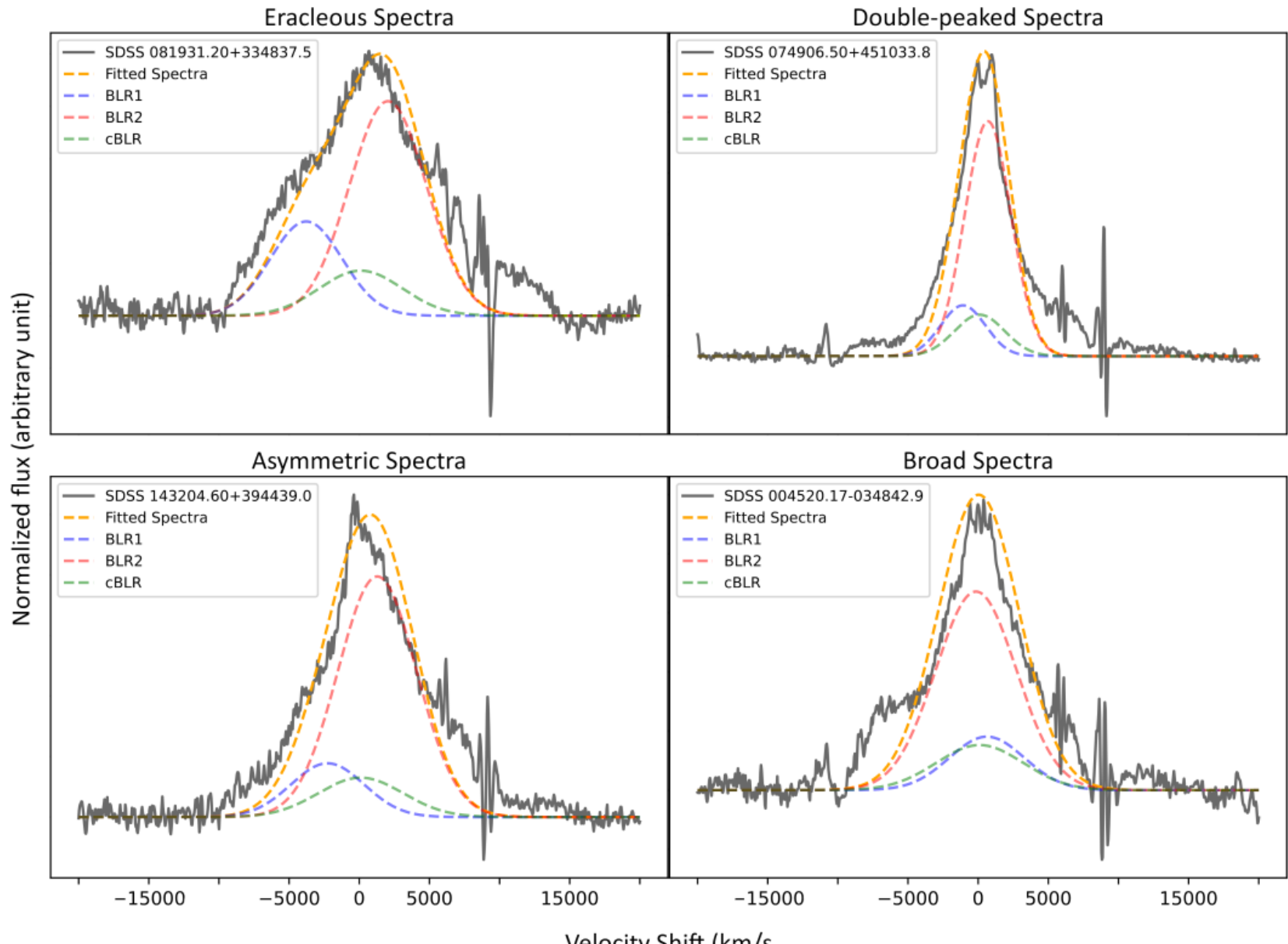
# Deandra et al. 2024, in preparation

.Further verifying the SMBBH candidates by obtaining an estimate of mass, mass ratio, and component separation using PoSKI model (Popović et al., 2021) by line profile comparison in optical wavelength, focusing on H $\beta$  broad line.

From 294 objects 57 can be described with high confidence as good candidates for sub-pc SMBBHs, but only 13 object with high confidence



# Low confidence

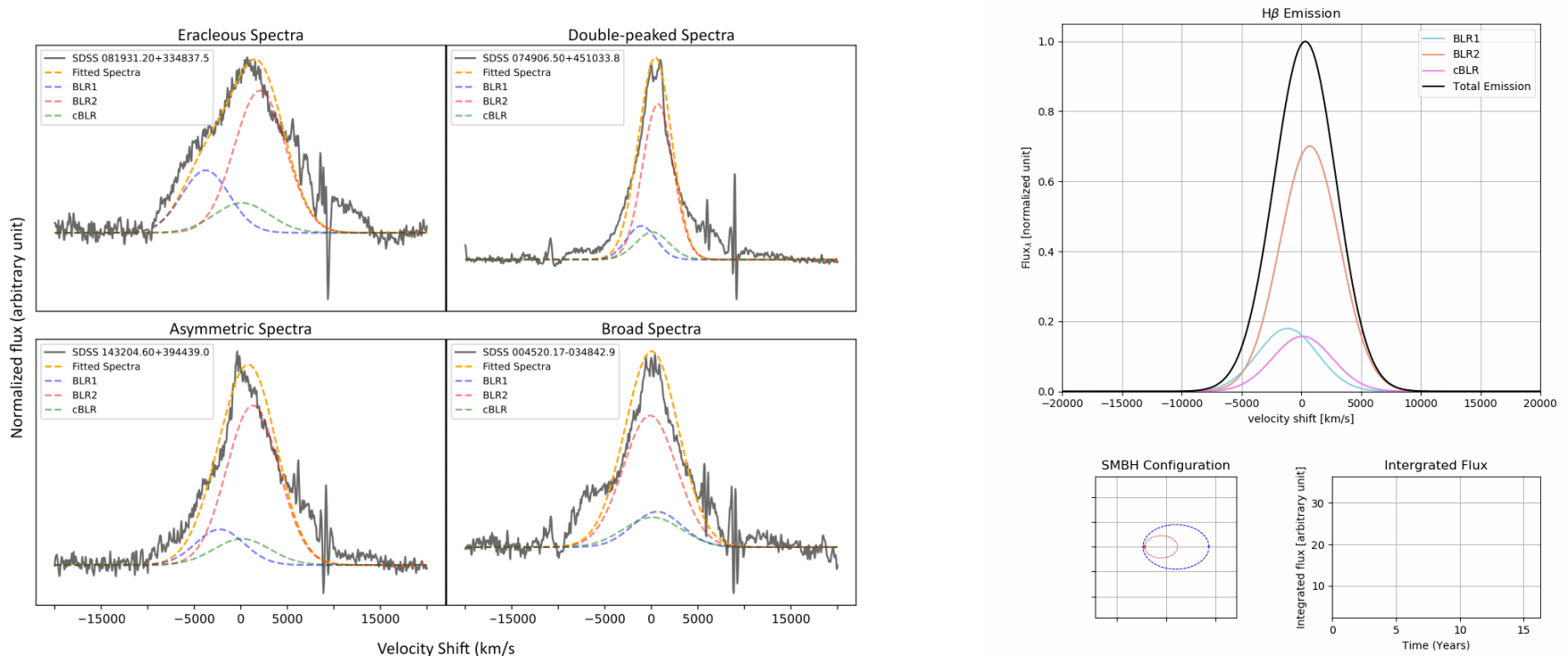


# 13 objects with very high confidence

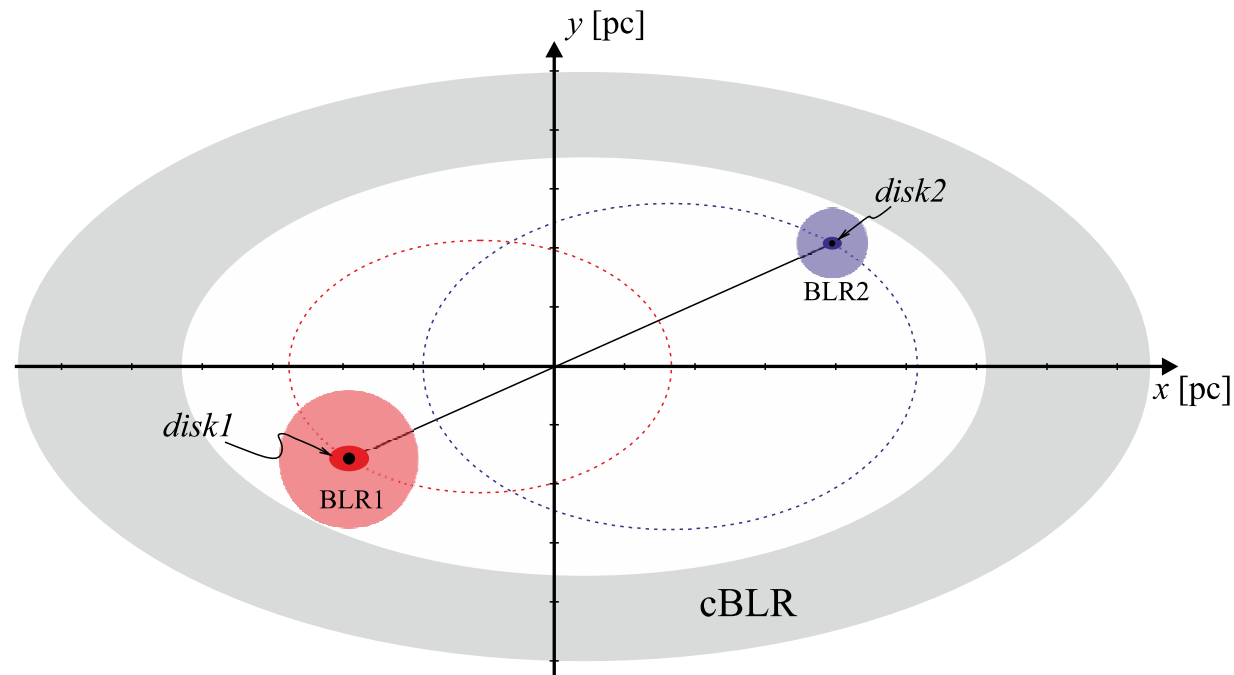
<b>SDSS</b>	<b><math>\log M_{\odot}</math></b>	<b>q</b>	<b><math>R</math> (pc)</b>	<b>Position (Year)</b>
223604.29+053548.5	7	1:2	0.005	3.862
125337.71+212618.1	7	1:2	0.01	9.075
224113.54-012108.8	9	1:2	0.1	18.601
123516.14+462309.3	7	1:2	0.001	0.388
222435.29-001103.9	6	1:2	0.001	0.084
224113.54-012108.8	9	1:2	0.1	33.481
125157.90+061341.6	6	1:2	0.001	0.588
020351.67+282235.5	9	1:2	0.1	38.796
170553.87+455113.3	6	1:1	0.1	0.000
222435.29-001103.9	6	1:2	0.001	0.084
075730.38+152453.0	8	1:2	0.1	104.197
013324.62+242741.3	9	1:2	0.01	0.504
135529.06+352332.1	7	1:2	0.005	3.565

# For future work

- Check the objects with very high confidence, we can propose the line variability – proposal for new observations



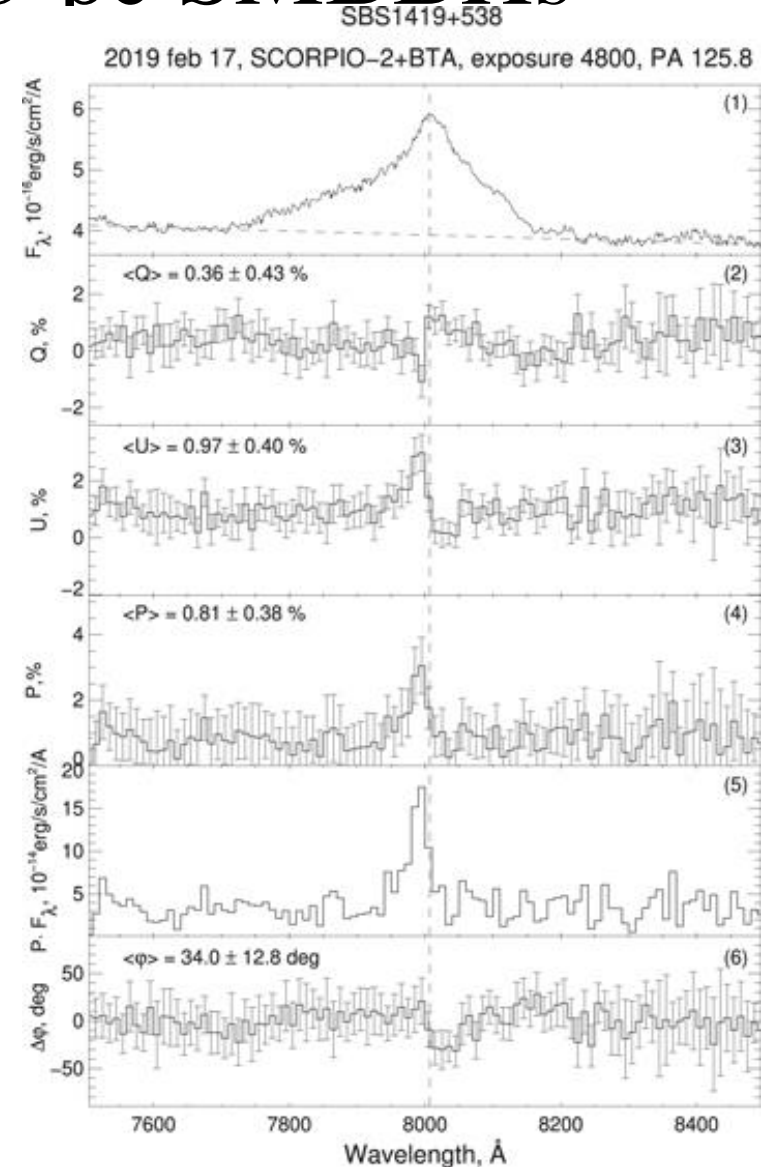
# For future work: Optical vs. X-ray emission in SMBBHs



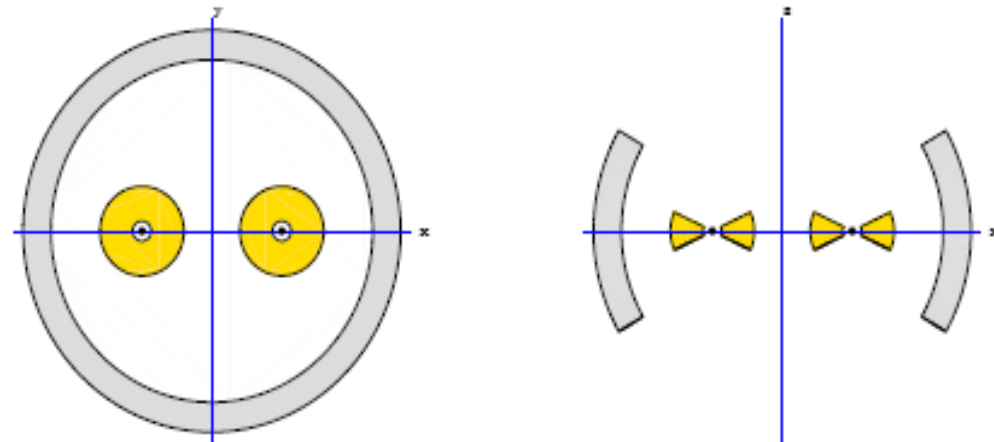
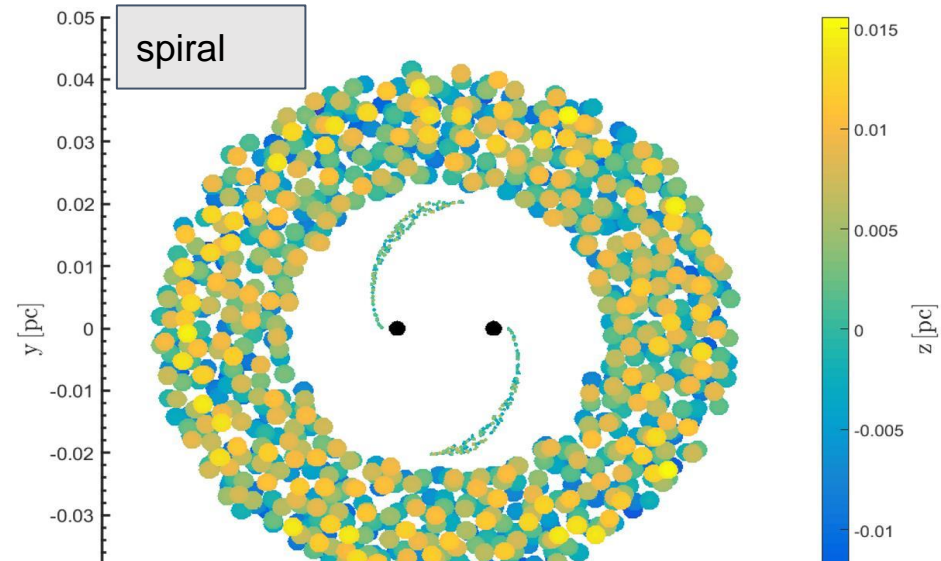
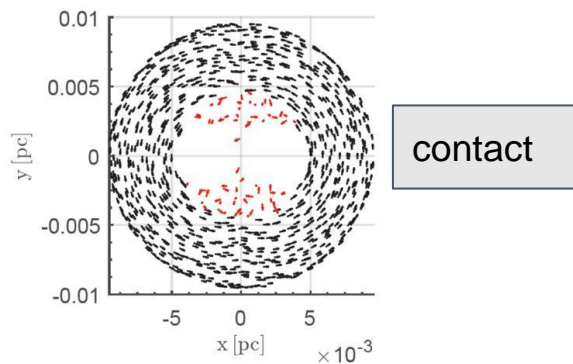
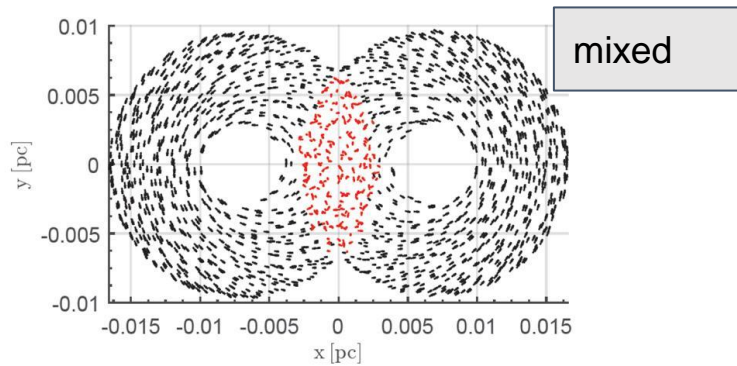
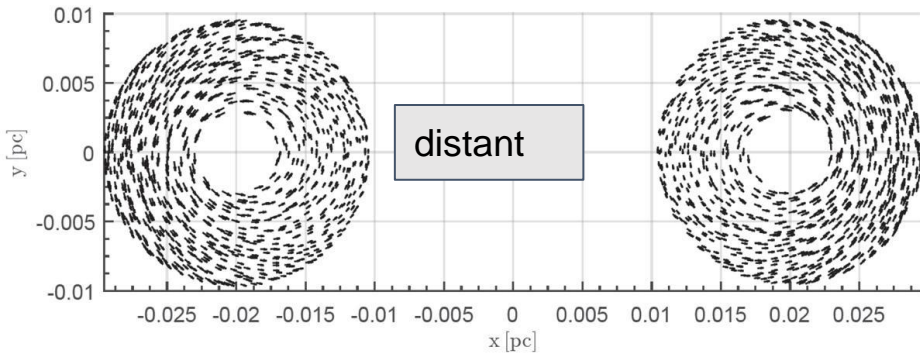
# For future work: Polarized light in the line profiles and sub-pc SMBBHs

AGN show polarization in the broad line profiles

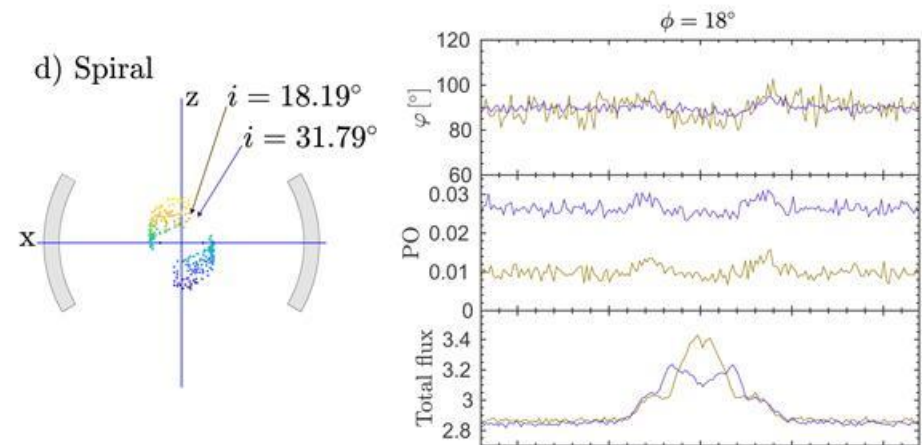
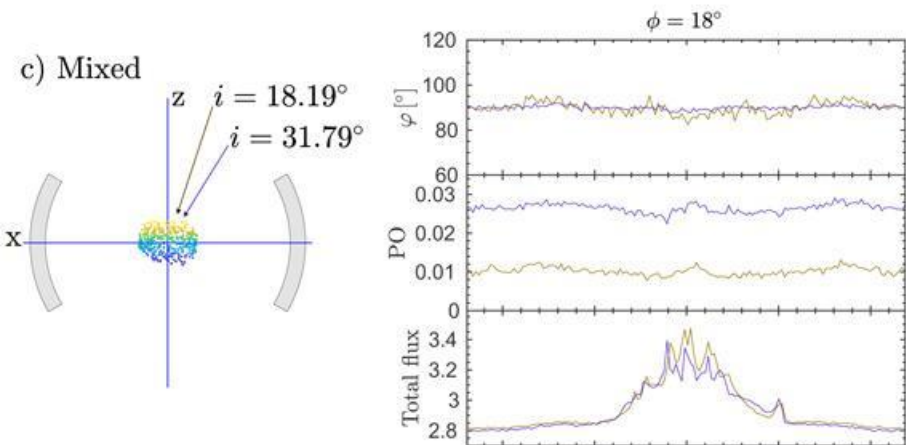
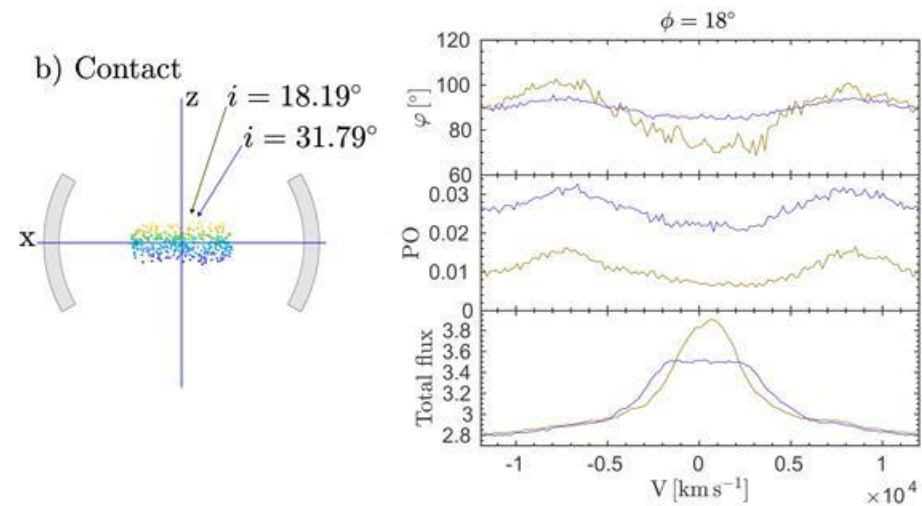
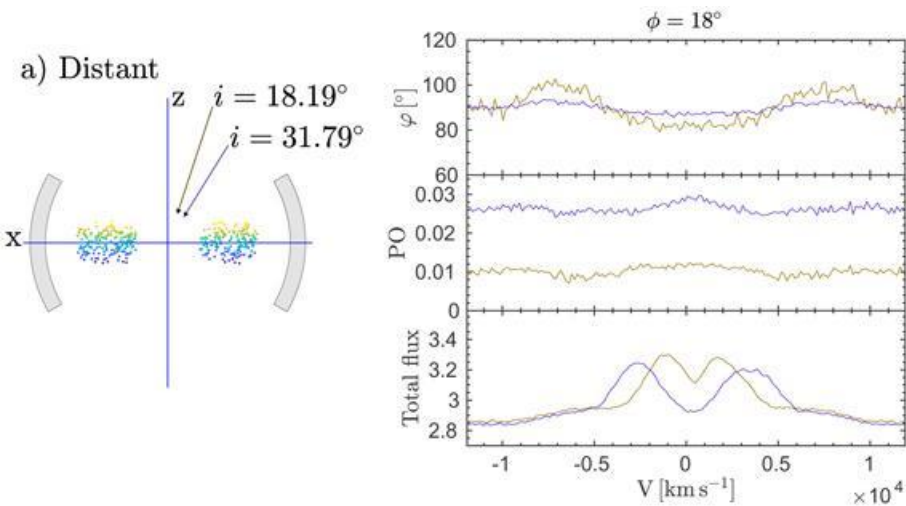
(e.g. H $\alpha$ : Afanasiev & Popović 2015, ApJL, 800, 35 and Mg II, Savić, Popović, Shablovinskaya 2022, ApJL, 921, 21)



# SMBBHs – polarization in broad lines, see Savić, Marin & Popović 2019, A&A,623, 56



# Savić et al. 2019



Thank you for your attention!