



INFLUENCE OF CLOSE SUPERMASSIVE BINARY BLACK HOLES ON SPECTRA OF ACTIVE GALACTIC NUCLEI: THE CASE LOWER MASSES BLACK HOLES

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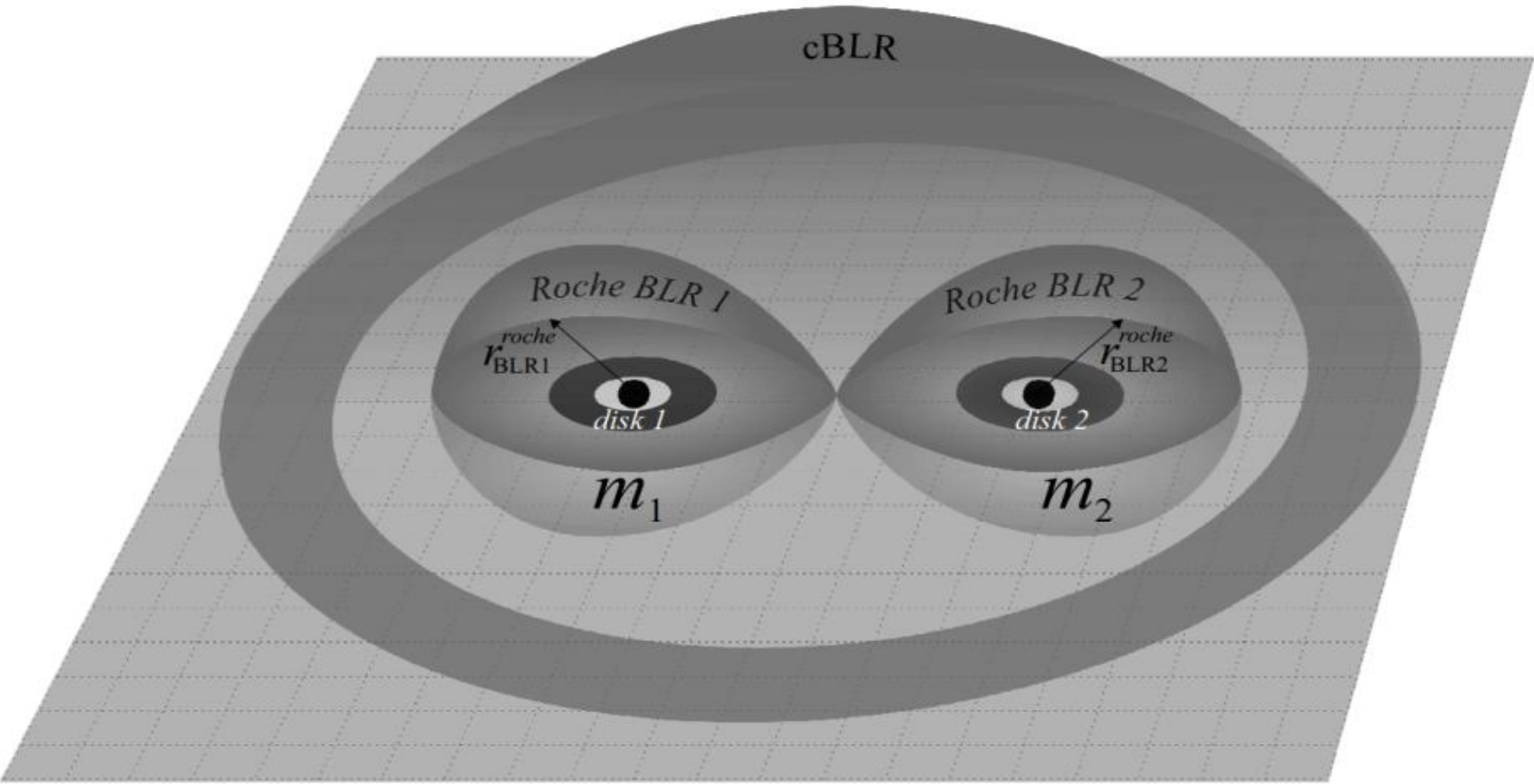
Abstract: We investigate the influence of sub-pc supermassive binary black holes (SMBBHs) on the variability in spectra of active galactic nuclei (AGNs), assuming that the masses of components are smaller than $10^6 M_{\odot}$. We used the PoSKI model (Popovic et al. 2021) to simulate a net of spectra taking SMBBH parameters, i.e., their different phases, masses and mass ratios. We explore changes in spectral parameters. We analyse the resulting broad line light curves and full width at half maximum (FWHM) variations during several orbits. Our analysis demonstrates that the simulated broad line profiles depend strongly on the mass ratio of the components. We found that the intensity light curves and FWHM variability could indicate the presence of SMBBHs with smaller masses than $10^6 M_{\odot}$. Finally, we conclude that the long-term AGN monitoring campaigns can be very prospective for detections of lower-mass SMBBHs in the centre of these objects.

Detection Problems of (S)BBHs

- The problem is that we do not observe pc and sub-pc scale SMBs.
- Direct imaging of binary AGNs on pc scales can only be carried out in the local universe, and only in the radio band when both BHs are radio sources.
- We should find some effects showing that SMB systems affect of its nearby environment.
- Spectroscopic studies may provide an alternative method for revealing binary AGNs.
- However, it is interesting that of those AGNs, which have been detected as SMB candidates by spectroscopic methods, are *controversial because of other explanations for the same phenomenon* or because of some inconsistency with other observational evidence.
- *Nevertheless, the emission lines of AGNs, at least, could indicate the possibility of SMB existence.*
- Gaskell (1983) suggested that some complex broad line profiles may be caused by SMBs in AGNs.
- The broad emission spectral lines emitted from AGNs are our main probe of the geometry and physics of the BLR close to the SMBH.

Model and Method of Simulation SMBBHs

- A sub-pc SMBBH system that is surrounded by gas produces an activity that is similar to the one observed in an AGN. This has an advantage that we could detect the activity produced by an SMBBH system, but also it has a disadvantage that it is hard to separate an SMBBH activity from the single AGN activity (see for a review Popović, 2012).
- *To confirm an SMBBH presence one should follow the spectral variability of the system.* It is expected that SMBBHs have similar variability, but with some particular characteristics caused by dynamical effects of a binary system, e.g., *periodicity*, that can be used to distinguish them from other mechanisms which produce spectral variability.
- In Popovic et al. (2021), the phenomenological model-*PoSKI model* of an SMBBH system was elaborated, introducing complex structure of the continuum and line-emitting regions, and *exploring the time-domain perspective necessary in the analysis of the long-term monitoring results.*
- The model considers two AGNs at a sub-pc mutual distance in which both SMBHs have their own accretion disc and BLR, and consequently, that activity can be detected from both SMBBHs. In addition, it is introduced that SMBBH system is surrounded by a common circum-binary BLR.



Source: Popovic et al., 2021

- *The total line profile of a proposed binary system contains three broad components.* The first coming from the BLR1 - defined by the Roche lobe of the primary component, the second from the BLR2 - defined by the Roche lobe of secondary, and finally, the third component is emitted by the cBLR - the circum-binary BLR surrounding both SMBBHs. Both SMBBHs heat the gas in cBLR, i.e., gas kinematics is due to the net effect of both masses and luminosities

- This configuration has important effects on the line profiles emitted from BLRs, since the BLR1 and BLR2 are following the dynamics of their SMBBHs (orbital motion). Therefore they have radial velocities, while the cBLR is assumed to be a stationary region. It is difficult to estimate the exact contribution in the total emission of those moving BLRs since it would require comprehensive magneto-hydrodynamic modeling. Thus were three cases assumed– the dynamical BLRs contribution is 70%, 50%, and 30%, while the rest of the emission is coming from the stationary cBLR.

Results

- Unlike previous research where SMBBHs masses order of magnitude hundreds of millions or billion solar masses ($10^8 M_{\odot}$, $10^9 M_{\odot}$) were considered, *here we consider BBHs lower masses, order of magnitude million solar masses ($10^6 M_{\odot}$).* These lower-masses BHs are present in nuclei of AGs lower-masses in which variability in spectrum and spectral lines were observed .
- We applied *PoSKI model* presented in Popovic et. al. (2021), only in contrast to the data given in this paper we consider lower-masses BHs. We simulate the H_{β} spectral band for different mass ratios of components of SMBBH system at eccentric orbits, where masses of the components are order of magnitude million solar masses ($10^6 M_{\odot}$). *We considered the effects of different mass ratios of the system (q=1, 0.3, 0.1) at H_{β} line profiles, line light curves, variability of line width at half maximum (FWHM) and correlations between line parameters.*

Parameters of the Simulated Model

- In our case one set of parameters includes:

- mass of the primary BH (order of magnitude $10^6 M_{\odot}$) and
- different mass ratios (q=1, 0.3, 0.1)

e=0.3 (eccentricity in all simulations)

i=45° (orbital inclination angle in all simulations)

- Our simulations show that clear separated BLRs can influence the line profiles. Therefore we present results of simulation for SMBBHs at distance of 0.02 pc (sub-parsec) in which three BLRs are present.

Resulting line profiles are asymmetric, shifted and vary during the orbital period.

Variability of Broad Line

We study the broad H_{β} emission variability and construct their corresponding light curves. The spectrum in H_{β} wavelength range is plotted in pictures for different mass ratios (q=1, 0.3, 0.1) and order of magnitude of component masses $10^6 M_{\odot}$. *This model accounts for three BLR*, two BLRs from primary and secondary component, from corresponding Roche lobes (BLR1 & BLR2) and one component from cBLR. *Pictures show the case where 30% of line luminosity comes from Roche lobes and 70% from cBLR.*

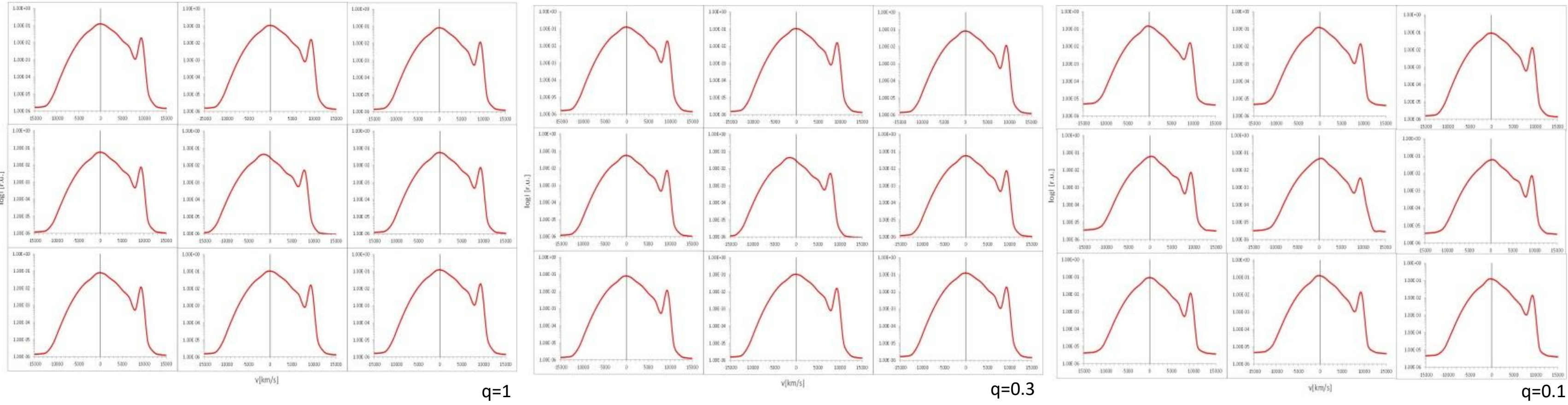
Correlation Tables Based on Pearson Correlation Coefficients (r)

q=0.1	Asymmetry at 50% max	Asymmetry at 10% max	Line shift
FWHM	-0.80	-0.79	(small)

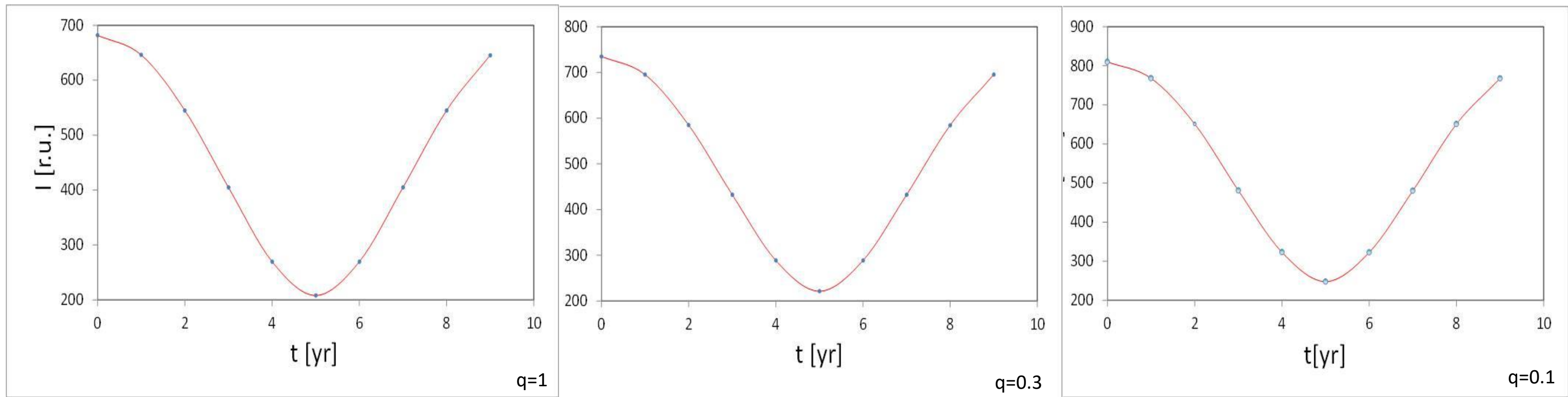
q=0.3	Asymmetry at 50% max	Asymmetry at 10% max	Line shift
FWHM	-0.19	-0.11	-0.24

q=1	Asymmetry at 50% max	Asymmetry at 10% max	Line shift
FWHM	0.49	-0.71	-

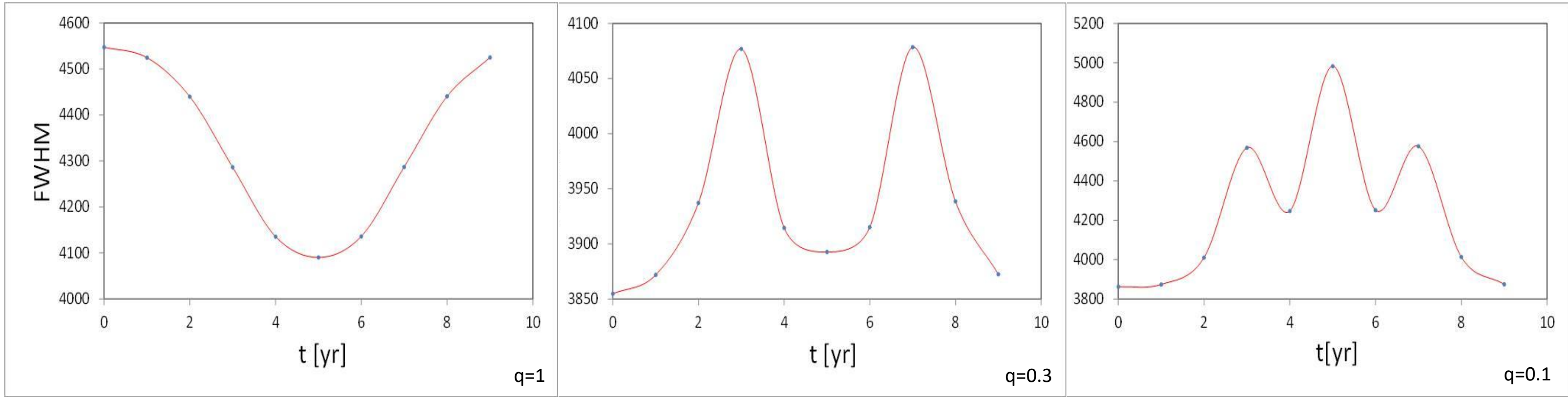
Broad H_{β} Line Profiles



Line Intensity Light Curves



Variability of the Broad H_{β} Line at FWHM



Conclusion

- The broad H_{β} line profiles of SMBBH with masses of order $10^6 M_{\odot}$ at sub-parsec distances strongly depend on the mass ratio of the components of the SMB system and vary during the orbital motion. The H_{β} line profiles are asymmetric and shifted.
- Intensity variability of the broad H_{β} line as well as variability of width of H_{β} line at the FWHM is periodic which is a good indicator of presence of binary systems. We could say that long-term monitoring perspective of candidates for binary black holes lower masses could give valid information of nature of these objects.
- We found correlations between the line parameters, with correlation coefficients that depend on the mass ratio. These coefficients could be one of indicators of a binary system presence.
- The line flux should have periodical variability that indicates the presence of SMBBH. Here we demonstrate the influence of white and red noise added to the modeled SED, and show that both periodicity in the light curve, as well as some effects in the broad line profiles caused by the dynamics of the binary system, may be affected by the noises in the spectra. Therefore, the high quality spectral observations of the SMBBH candidates should be performed in order to confirm or rule out the binary hypothesis.