The Broad Line Region of Mrk 668 & NGC 4151: An Outflow Model

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Overview:

One of the interesting spectral features of active galactic nuclei (AGN) are broad emission lines (BEL) originating in the broad-line region (BLR). According to the complex lines shapes of the BEL, the BLR structure is supposed to be very complex. Until now, many different models have been proposed to explain the kinematics and geometry of the BLR (e.g. biconical ejection (Zheng et al. 1990), disk wind (Murrey & Chiang 1995), two-component model (Popović et al. 2004), etc.) and so far there is no unique model. Moreover in the case of some AGN (e.g. Mrk 668, 3c390.3) a single model has failed to explain line profiles from different epochs. In order to provide a better model framework, we introduce the possibility of acceleration of the outflowing material. We study here two well known AGN: Mrk 668, which is a broad-line radio galaxy with peculiar BEL profiles (Marziani et al. 1993, Gezari et al. 2007) and NGC 4151, the brightest Seyfert 1.5 galaxy which BEL profiles are highly variable. We show that in the case of Mrk 668 and NGC 4151, the complex BEL can be explained with this model for some epochs. Moreover, the characteristics of the BLR outflow obtained from broad line fitting are in a good agreement with theoretical prediction of radio-jet formation (Marscher 2005, Lobanov 2007).

The Outflow Model:

In the model we assume to have an accelerating outflow in an emission region between inner radius R_i to outer radius R_o. We take that the outflow is starting very close to the massive black hole (several tens of gravitation radii) and that is accelerating as a function of the distance from the black hole from R_i, with small starting velocity V_0: $V(r) = V_0(R_i/r)^{p_1}$. Assuming that acceleration stops at radius R_a, we can expect that for $r > R_a$ the velocity of the outflow is decreasing in the same way,but with another power law index p_2. Additionally, we take that the brightness of the outflowing material is strong and flat up to a radius R_e, after which it is decreasing as $\varepsilon(r) = \varepsilon_0(R_e/r)^{p_3}$. Since the outflow is assumed to start very close to the black hole, we take into account the gravitational redshift. Additionally, we consider a random velocity component, assuming that it is changing across the emission region. One should expect that this velocity is increasing while the outflow is accelerating, but after some point we expect that it begins to decrease. This can be a very complex radial function, but here we assume that the maximum of the random velocity coincide with radius R_e after which the emission $\varepsilon(r)$ is decreasing (Popović et al. in prep).

Line Profile:

$$I(\lambda) = \frac{1}{R_0 - R_i}\int_{R_i}^{R_0} \varepsilon(r)\cdot \exp\left(-\left(\frac{\lambda-\lambda_0-\Delta\lambda_r(r)-\Delta\lambda_g(r)}{w(r)}\right)^2\right)dr$$

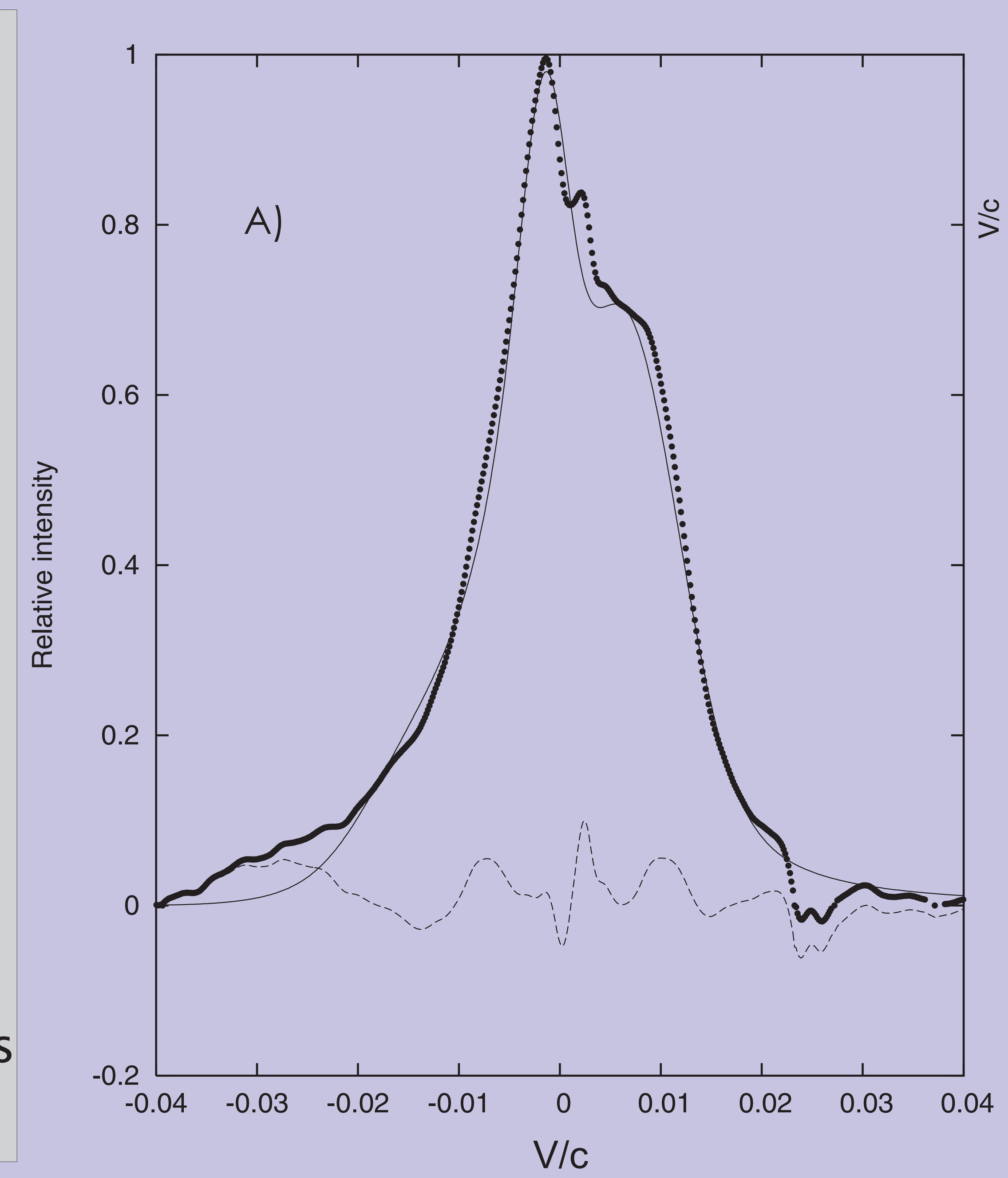
Radial velocity: $$Vr = \frac{\Delta\lambda(r)}{\lambda_0}c$$

Gravitational redshift: $$Vg = \frac{\Delta\lambda_g(r)}{\lambda_0}\cdot c = \left(-1+\sqrt{1-\frac{2}{r}}\right)\cdot c$$

Random velocity: $$w(r) = \frac{V_{ran}(r)}{c}\lambda_0$$

Model vs. Observations:

We applied the proposed model to the BEL of NGC 4151 and Mrk 668. The data for NGC 4151 were obtained by Shapovalova et al. (2008), while Mrk 668 data were provided by M. Eracleous. From Figure 1 & 2 we can see that the model can describe well the observed emission line profiles. The predicted outflow acceleration (up to distances of ~ 500 R_g) is in good agreement with theoretical model of radio-jet formation, where it is assumed that the acceleration of radio-jet is in the same range of R_g (Marscher 2005, Lobanov 2007). From this it seems that an accelerating outflow could be a possible explanation of the BLR geometry.



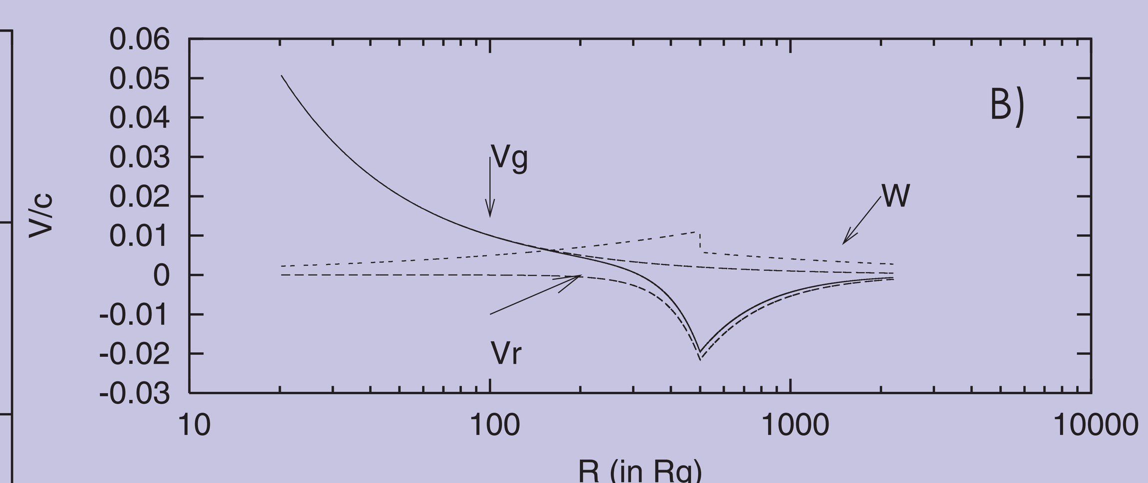
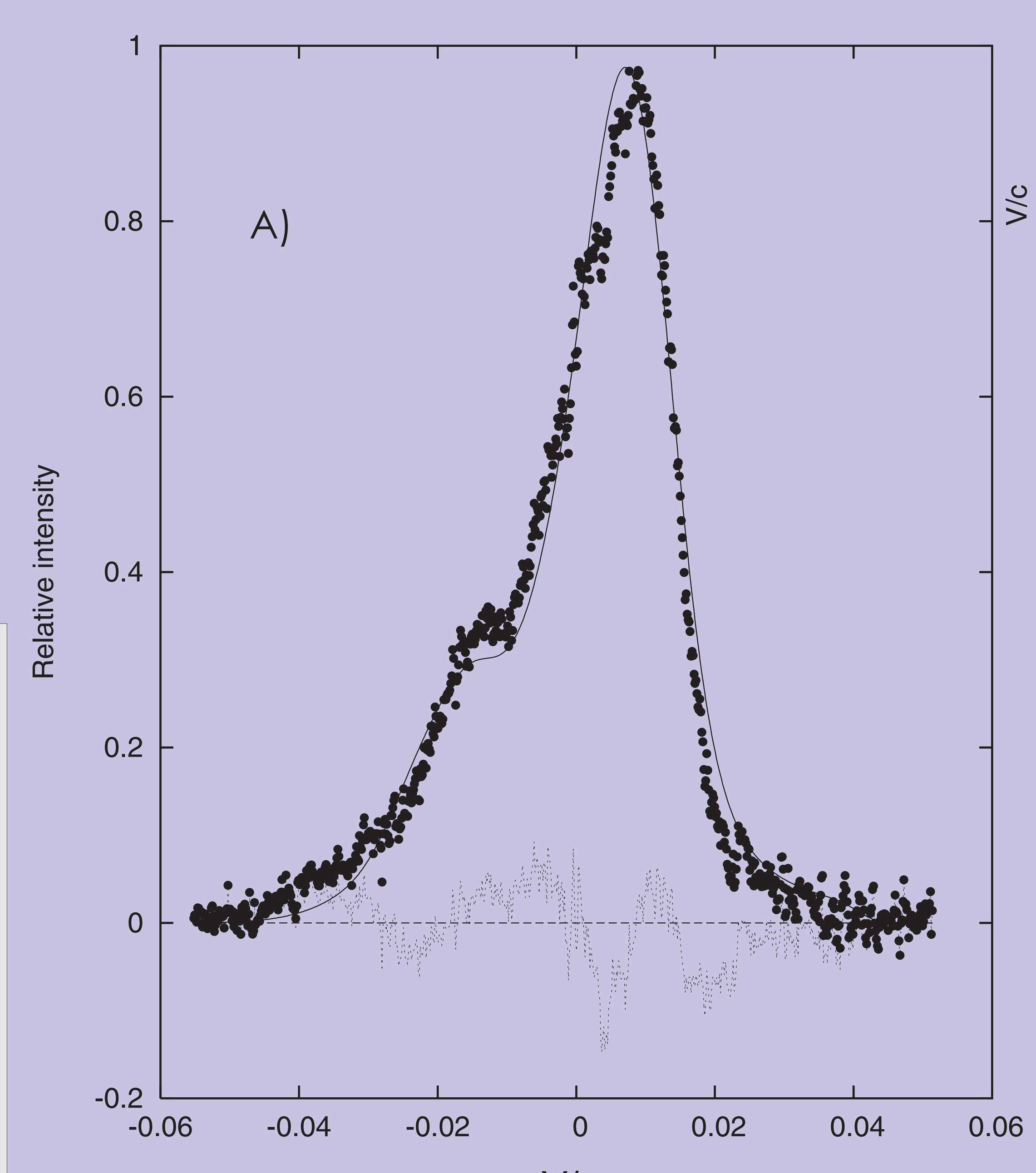


Figure 1: NGC 4151: (A) Modeled line profile (solid line) in comparison with the observed Hα line (dots). (B) Velocity field. The fitting results are: R_i=20 R_g; R_o=2200 R_g; R_a=500 R_g; R_e=260 R_g; W_0/λ=0.0083; V_0=0.012 km/s; p_1= - 4.1; p_2= 2.0; p_3= 0.5



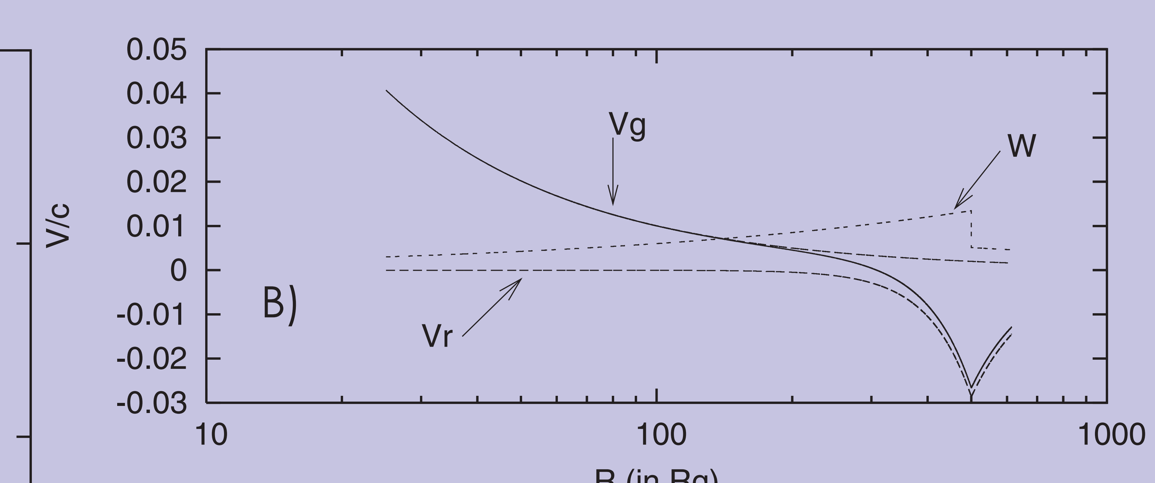


Figure 2: Mrk 668: (A) Modeled line profile (solid line) in comparison with the observed Hα line (dots). (B) Velocity field. The fitting results are: R_i=25 R_g; R_o=615 R_g; R_a=500 R_g; R_e=190 R_g; W_0/λ=0.0083; V_0=0.012 km/s p_1= - 4.5; p_2= 3.3; p_3= 0.5

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