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PERTURBATIONS IN THE ACCRETION DISK EMISSIVITY: THEORY VERSUS OBSERVATIONS

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Abstract. The double peaked lines can be observed in spectra of Active Galactic Nuclei (AGNs) indicating that an accretion disk is present in the center of these objects (around super-massive black hole). These lines show variability, not only in intensities, but also in shapes. This variability can be caused by bright spots in the accretion disk, which affect the disk emissivity. Here we study a bright spot model that can successfully explain double peak line shape variations in the case of 3C390.3 quasar.

1. INTRODUCTION

Broad, double-peaked emission lines provide dynamical evidence for presence of an accretion disk feeding a supermassive black hole in the center of AGN. Such line profiles are found in 20% of radio loud AGN at $z < 0.4$ (Eracleous & Halpern 1994, 2003) and 4% of the Sloan Digital Sky Survey (SDSS) quasars at $z < 0.33$ (Strateva et al. 2003). Variability of disk emission is observed in the line profiles (see e.g. Shapovalova et al. 2001, 2009, Gezari et al. 2007) on timescales from months to years. However, in some cases it shows certain irregularities which could not be explained by standard model of circular accretion disk. This variability has no correlation with changes in the continuum flux, so it likely traces changes in the accretion disk structure. Our goal was to test if the perturbations in the accretion disk emissivity could produce the observed variability of the Hβ line profiles in the case of quasar 3C 390.3.

2. MODEL OF PERTURBING REGION

We modeled the optical emission from outer parts of an accretion disk using numerical simulations based on ray-tracing method in Kerr metric (see e.g. Jovanović & Popović 2009a, and references therein). In order to introduce a bright spot–like perturbing region in the disk we adopt a modification of the power-law disk emissivity (Jovanović & Popović 2008, 2009a,b, Stalevski et al. 2008). Our model allows us to change amplitude, width and location of a bright spot. In that way we are able to simulate displacement of the bright spot along the disk, its widening and amplitude decrease with time (decay). As shown in Stalevski et al (2008), depending on the position of perturbing region, it has greater influence on particular part of line (such as e.g. its core if the spot is in the central part of the disk, or ”red” and ”blue” wings if the spot is located on receding and approaching part, respectively).

3. RESULTS

We applied the above bright spot model on 22 spectra of 3C 390.3 observed from November 1995 until June 1999 (see Fig. 8 in Shapovalova et al. 2001) with the 6 m and 1 m telescopes of the SAO RAS (Russia, 1995–2001) and with INAOE’s 2.1 m telescope of the “Guillermo Haro Observatory” (GHO) at Cananea, Sonora, Mexico (1998–1999) in monitoring regime in 1995-1999. Two large amplitude outbursts of the Hβ line were observed during this period (Shapovalova et al. 2001) and we studied them assuming stationary and moving perturbing regions.
The fitting of the observed Hβ line shapes of 3C 390.3 is performed separately in the case of moving and stationary perturbing regions. Several examples of comparisons between observed spectra and the obtained best fits are presented in Fig. 1. and the obtained best fit positions are shown in Fig. 2. As it can be seen from Fig. 2, the obtained positions of the moving perturbing regions are distributed in the form of two spiral arms on the approaching side of the disk, indicating that these perturbations originate in the inner regions of the disk and spiral away towards its outer parts. These perturbations can be most likely attributed to successive occurrences of two different bright spots, responsible for the two observed amplitude outbursts of the Hβ line. Using the time differences between two successive observed spectra we were able to estimate speeds of both moving bright spots. For an average velocity of the first bright spot we obtained the value of 7298 km/s and for the second one 6575 km/s. Widths of bright spots are increasing with time, indicating that they decay until they completely disappear.

4. DISCUSSION AND CONCLUSIONS

Several processes in the accretion disk may lead to perturbations in its emissivity, such as self gravity, disk-star collisions, baroclinic vorticity (Flohic & Eracleous 2008), tidal disruptions of stars by central black hole (Strubbe & Quataert 2009, and references therein) and fragmented spiral arms (Lewis et al. 2010, and references therein). Our results indicate that the most likely cause of perturbations in the case of quasar 3C 390.3 are fragments in the spiral arms of its accretion disk (Jovanović et al 2010). Also, our investigation shows that:

1. The model which includes perturbation (bright spot) in the accretion disk can successfully explain the observed variations of the Hβ line profile in the case of 3C 390.3.

2. Two outbursts observed by Shapovalova et al. (2001) could be explained by successive occurrences of two different bright spots on approaching side of the disk which are either moving, originating in the inner regions of the disk and spiralling outwards, or stationary. Both bright spots decay by time until they completely disappear.

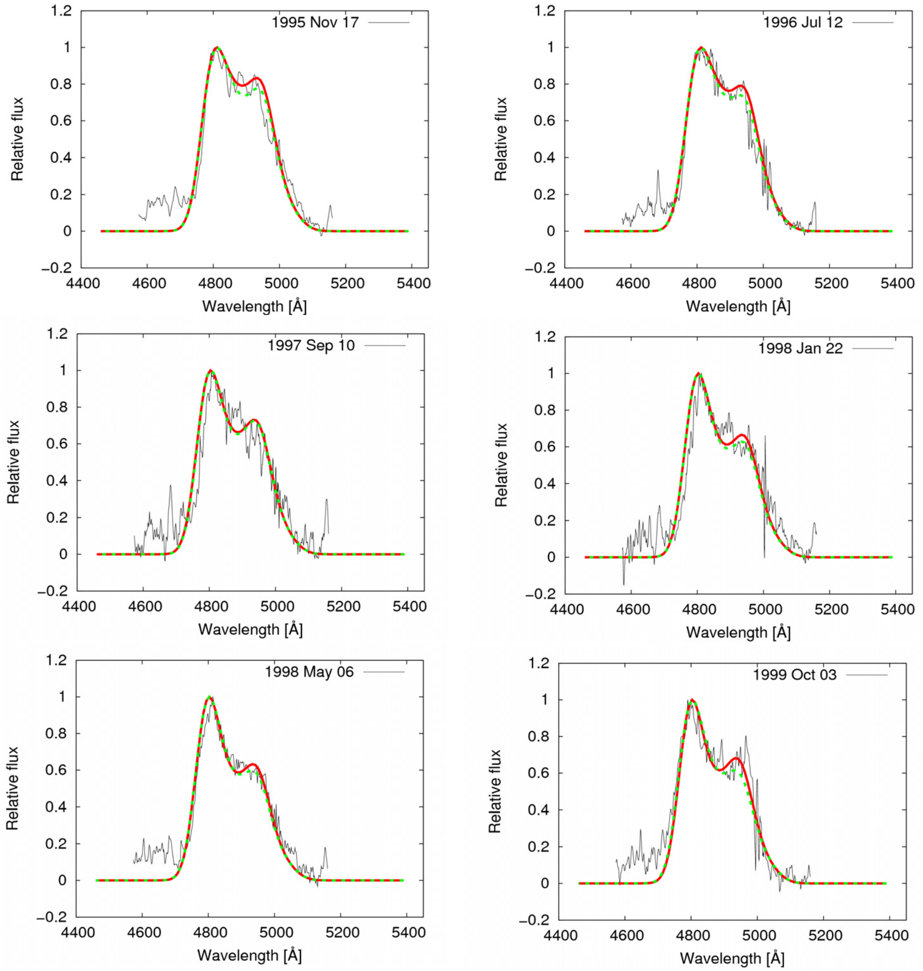

Figure 1: Comparison between observed spectra (black solid line) and the obtained best fits assuming the moving (red solid line) and stationary (green dashed line) perturbing regions. Obtained parameters of the disk are: inclination $i = 20^{o}$, inner and outer radii R_{in} = 100 and R_{out} = 1300 R_g, broken power law emissivity with index $q = -1$ for $R_{in} < r < R_{br}$ and $q = -3$ for $R_{br} < r < R_{out}$, radius at which slope of emissivity changes R_{br} = 500 R_g, emissivity of perturbing region $\varepsilon_p = 1$, local turbulent broadening σ = 2000 km/s.

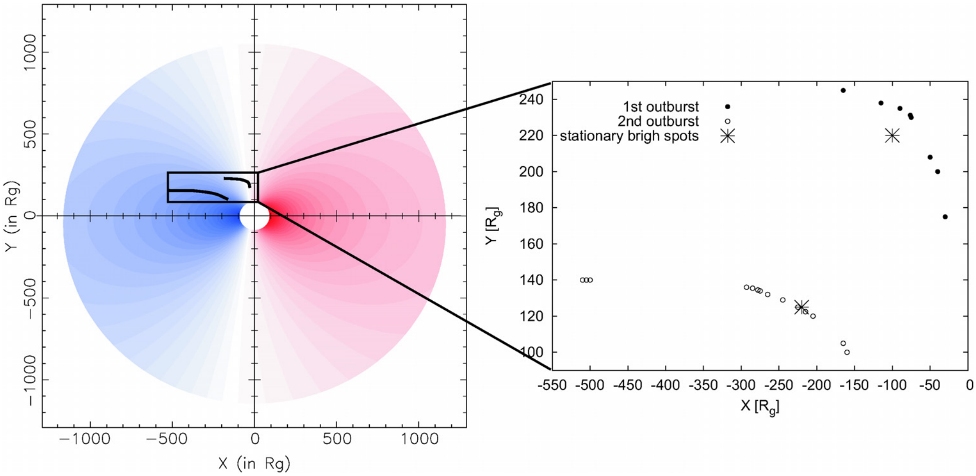

Figure 2: Positions of moving perturbing region along the accretion disk corresponding to two observed amplitude outbursts: October 1994 – July 1997 outburst (full circles) and July 1997 – June 1999 outburst (open circles). In both cases, the moving perturbation originates in the inner regions of the disk and spirals away towards its outer parts. Stationary bright spots are positioned at $x = -100$ R$_g$, $y = 220$ R$_g$ during the first outburst and at $x = -220$ R$_g$, $y = 125$ R$_g$ during the second outburst.

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