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Rapid Profile Variations in the Broad Hα Line of the Seyfert Galaxy Markarian 6: Possible Evidence for Turbulence in the Accretion Disk

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We report on implications for the geometrical and kinematic parameters of BLR gas on the basis of short timescale variability in the broad $H\alpha$ profile shape. Data on rapid variations have been obtained at the 2.6-m telescope of the BAO (Asatrian, Khachikian & Notni, 1999). To search for variations in the profile, difference spectra (second *minus* first epoch) were examined. We believe that the structure of the underlying stellar continuum and the atmospheric features do not affect significantly the $H\alpha$ difference profiles of Mark 6. Variations occurred simultaneously on the blue and red sides of $H\alpha$ on a time scale of $\simeq$ 50.7 minutes and take the form of three narrow, positive small bumps on each side in the difference spectrum. The positions of the bumps are -4400, -3100, -1700 and +1900, +4200 and +6600 $km\,s^{-1}$. These changes may indicate the response of circularly rotating emitting gas at three orbits to a light pulse from a central source. In this case the pairs of blue and red bumps observed at -4400 and +6600, -3100 and +4200, and -1700 and 1900 $km\,s^{-1}$ are formed in two opposite zones of gas close to the line of nodes. On the assumption that these orbits lie around a central massive object, orbital parameters (radii, velocities and inclination angles of orbital planes) of the clouds and the central mass can be found. The shift of each bump is defined by the combination of the relativistic Doppler effect due to the Keplerian orbital motion and the gravitational redshift. The six observed radial velocities are determined by six parameters: the orbital radii, R_1, R_2, R_3 (or velocities, V_1, V_2, V_3) and the inclination angles i_1, i_2, i_3 of the rotation planes. Thus, the expressions for the radial velocities form a system of six algebraic equations with six unknowns and can be solved. Using the difference of the orbital radii in absolute units ($R_3 - R_1 = \Delta t\, C$, where $\Delta t \simeq 50.7$ minutes and C is the speed of light) we can derive the central mass M. Analytical solution gives: $R_1 \simeq 200^{+80}_{-40}\, R_g$, $R_2 \simeq 410^{+500}_{-130}\, R_g$, $R_3 \simeq 2250^{+7750}_{-1350}\, R_g$, $V_1 \simeq 14800^{+1900}_{-2200}\, km\,s^{-1}$, $V_2 \simeq 10500^{+2100}_{-3400}\, km\,s^{-1}$, $V_3 \simeq 4500^{+2500}_{-2400}\, km\,s^{-1}$, $i_1 \simeq 22^\circ\,^{+5}_{-4}$, $i_2 \simeq 20^\circ\,^{+13}_{-4}$, $i_3 \simeq 24^\circ\,^{+38}_{-10}$ and $M \simeq 1.5^{+3.3}_{-1.2} \times 10^5\, M_\odot$. Error limits for the results are determined by the uncertainty of the input radial velocities, $300\, km\,s^{-1}$. However, the value of the mass obtained is smaller by two orders of magnitude than the estimate for the dynamical mass of the nucleus of Mark 6 ($M = 1 \times 10^7\, M_\odot$, Dibai 1984). Such a low mass is excluded, therefore.

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The discrepancy in the mass may be due to possible macroturbulence in the BLR. The sizes of macroturbulence cells are assumed to be greater than or equal to the sizes of the bump emission regions. The gas associated with each bump is assumed to take part in two motions: the common rotation with the local Keplerian velocity and the macroturbulent motion. These two motions are either added or subtracted for each bump emission region. If we assume the presence of such a macroturbulence, then the radial velocity V_r of a bump will be given by

$$1 + \frac{V_r}{C} = \frac{1 - (V \pm V_t \cos\varphi)\cos\theta/C}{\sqrt{1 - (V \pm V_t \cos\varphi)^2/C^2}} \left(1 + \frac{R_g}{2R}\right),$$

where V and V_t are the orbital and turbulent velocities of the cloud, φ is the azimuthal angle of V_t about V, $|\varphi| < 90°$, θ is the angle between the direction of orbital movement and the line-of-sight at the nodes of orbits, $i = |90 - \theta|$, $R_g = 2GM/C^2$ is the gravitational radius, $R = GM/V^2$, and G is the gravitational constant. Adopting the value $M = 1 \times 10^7\, M_\odot$ for the mass, we can solve for the remaining parameters trying various combinations of the velocities V and $V_t \cos\varphi$ at the two nodes. Only one out of 64 possibilities leads to real solutions. The overall solution is given in Table 1. The solution is independent of φ as long as the resulting V_t is less than the escape velocity of the turbulent cells, which we assume as the limiting allowable velocity. This is the case for $|\varphi| < 5°$. At greater $|\varphi|$, the ranges of solutions for R, i and V_t remain within the upper and lower limits given in Table 1. The maximum φ at which we have found a solution is 48°.

Table 1. Parameters of BLR Gas

R_1 (R_g)	R_2 (R_g)	R_3 (R_g)	i_1 (°)	i_2 (°)	i_3 (°)	$V_t \cos\varphi$ (km s^{-1})
269^{+21}_{-40}	297^{+13}_{-43}	300^{+21}_{-40}	19^{+2}_{-3}	25^{+2}_{-3}	9^{+1}_{-1}	4000^{+1400}_{-700}

Note that if we assume the same inclination angle for the three different orbital planes, we can form a system of equations with unknowns R_1, R_2, R_3 (or V_1, V_2, V_3), i, $V_t cos(\varphi)$, M, which do not contain any free parameters and include the mass. However, the numerical solution of this system gives an extremely low value for the mass ($\sim 10\, M_\odot$) and must be rejected, therefore. We are forced to interpret the different values of the inclination angles as resulting from inhomogeneities in the accretion zone. Further high sampling rate spectroscopic monitoring at higher quality is evidently required for a more reliable study of the structure and kinematics of the BLR. The parameters of the BLR gas found here for Mark 6 are very similar to those found for 3C 390.3 (see our other poster in this volume) and favor models of a relativistic accretion disk with supersonic turbulence in the BLR.

References

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