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Rapid Variations in the Broad Hβ Profile of the Radio Galaxy 3C 390.3: 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 $H\beta$ profile.

Data on rapid variations have been obtained at the 6-m telescope of the SAO (Asatrian, Khachikian & Notni, 1999). To search for variations in the profile shape, difference spectra (first *minus* second epoch) were examined. We believe that the structure of the underlying stellar continuum and the atmospheric features do not affect the $H\beta$ difference profiles of 3C 390.3 significantly.

Variations occurred simultaneously on the blue and red sides of $H\beta$ on a timescale of $\sim$ 1.452 hours and take the form of three narrow, positive and negative small bumps drifting across the line profile in the difference spectrum. The positions of the bumps are -2300, +4700 (negative) and -3700 $km\,s^{-1}$ (positive).

These changes may indicate the response of circularly rotating emitting gas at two orbits to a light pulse from a central source. In this case the two bumps observed at -2300 and 4700 $km\,s^{-1}$ are formed in two opposite zones at the outer orbit close to the line of nodes. On the assumption that the inner and the outer orbits lie in the same plane around a central massive object, orbital parameters (radius, velocity and the inclination angle of the orbital plane) of the clouds and the central mass can be calculated. The shift of a bump is defined by the combination of the relativistic Doppler effect due to the Keplerian orbital motion and the gravitational redshift. The three observed radial velocities are determined by three parameters: the inner and outer orbital radii, R_{in}, R_{out}, (or velocities, V_{in}, V_{out}) and the inclination angle i of the rotation plane. Thus, the expressions for the radial velocities form a system of three nonlinear algebraic equations with three unknowns and can be solved numerically. Using the difference of the orbital radii in absolute units ($R_{out} - R_{in} = \Delta t\, C$, where $\Delta t \simeq 1.452$ hours and C is the speed of light) we can derive the central mass M. The results are: $R_{in} \simeq 63^{+18}_{-14}\, R_g$, $R_{out} \simeq 247^{+3}_{-4}\, R_g$,

$V_{in} \simeq 26600^{+3300}_{-3100}\, km\,s^{-1}$, $V_{out} \simeq 13500^{+110}_{-90}\, km\,s^{-1}$,

$i \simeq 15.01^\circ\, ^{+0.07}_{-0.04}$ and $M \simeq 2.9^{+0.3}_{-0.2} \times 10^6\, M_\odot$.

However, the value of the mass obtained is smaller by two orders of magnitude than estimates for the dynamical mass of the nucleus of 3C 390.3 obtained in different ways (Wandel et al, 1999). Such a low mass is excluded, therefore.

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 defined 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 a value $M = 3.91^{+1.2}_{-1.5} \times 10^8 \, M_\odot$ (Wandel et al. 1999) for the mass, we can solve for the remaining parameters trying possible combinations of the directions of the velocities V and $V_t \, cos\varphi$ at the two nodes. Only one out of 8 possibilities leads to real solutions. Error limits for the results are determined by the uncertainty of the input radial velocities, $300 \, km \, s^{-1}$.

The overall solution is given in Table 1. At these high masses, it is nearly independent of the mass, and the inner and outer radii are barely different in R_g units. The mean radius of orbits is $R_{orb} \simeq 526^{+253}_{-136} \, R_g$ or 24^{+22}_{-13} light-days. 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 $|\varphi| < 48°$. Outside of this limit, the ranges of solutions for R_{orb}, i and V_t become successively smaller. R_{orb} and i remain within the upper and lower limits given in Table 1, and the upper limit of V_t increases to $4450 \, km \, s^{-1}$. The maximum φ at which we have found a solution is 66°.

Table 1. Parameters of BLR gas

R_{in} in (R_g)	R_{out} in (R_g)	i in (°)	$V_t \, cos\varphi$ in (km s^{-1})
526^{+253}_{-136}	525^{+253}_{-137}	$21.8^{+4.2}_{-2.6}$	2050^{+800}_{-700}

The results are consistent with the predictions for an accretion disk model for 3C 390.3 proposed by Eracleous & Halpern (1994). In addition, our estimates of R_{orb} and i are in agreement with the size of the maximum emission region (to order of magnitude) and its inclination derived from Hβ profile fitting (Shapovalova et al. 2001) and with the BLR size measured by the reverberation-rms method (Wandel et al. 1999). Thus, our results support the presence of a relativistic accretion disc with supersonic turbulence in the nucleus of 3C 390.3.

References

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