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Doppler Tomography in 2D and 3D of the X-ray Binary Cyg X-1 for June 2007

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Abstract. The 2D and 3D Doppler tomograms of X-ray binary system Cyg X-1 (V1357 Cyg) were reconstructed from spectral data for the line HeII 4686Å obtained with 2-m telescope of the Peak Terskol Observatory (Russia) and 2.1-m telescope of the Mexican National Observatory in June, 2007. Information about gas motions outside the orbital plane, using all of the three velocity components V_x, V_y, V_z, was obtained for the first time. The tomographic reconstruction was carried out for the system inclination angle of 45°. The equal resolution ($50 \times 50 \times 50$ km/s) is realized in this case, in the orbital plane (V_x, V_y) and also in the perpendicular direction V_z. The checkout tomograms were realized also for the inclination angle of 40° because of the angle uncertainty. Two versions of the result showed no qualitative discrepancy. Details of the structures revealed by the 3D Doppler tomogram were analyzed.

Keywords. Accretion, accretion disks – binaries: x-ray – binaries: imaging – stars: individual (Cyg X-1) – techniques: image processing

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The realization of the 3D Doppler tomography became possible due to the development of the Radioastronomical Approach for reconstruction in the case of few projections (Agafonov & Sharova 2005a; Agafonov & Sharova 2005b). A direct comparison was made between the observed spectra and those computed from the constructed 3D Doppler tomograms. Chi-square statistics show the good quality of the reconstruction. The number of Mexican observation profiles (83) was larger than the 51 spectra from Terskol, so we used mainly the results of the 3D Mexican Doppler tomogram, and the Terskol results were used only as a test. However, there was good similarity in the discovered features.

Two-Dimensional standard Doppler tomograms for 2007 June are similar to the earlier reconstructed tomograms for 1997, 2003 and 2004 (Karitskaya *et al.*, 2005; Karitskaya *et al.*, 2007). They show: A) the emission component of the HeII 4686Å line is generated mainly in the outer parts of the accretion structure closest to the donor star (O-supergiant) and from the optically thick accretion disk; B) the absorption component is the feature of the O-supergiant atmosphere.

Three-Dimensional tomograms are reconstructed in 3D velocity space (V_x, V_y, V_z). Their structure shows that the formation of He II 4686Å line profiles is also connected both with the area of accretion structure (see Fig. 1 and 2) and with the donor-star (supergiant). However, some additional features have been discovered.

A. The first predominant feature is the emission component located around the central slice. This area consists of individual feature components with different V_z. But all these V_z values lie within the limits of −200 to +160 km/s. Here we can see a combination of three main emission feature components: 1) the emission of the outer part of the accretion

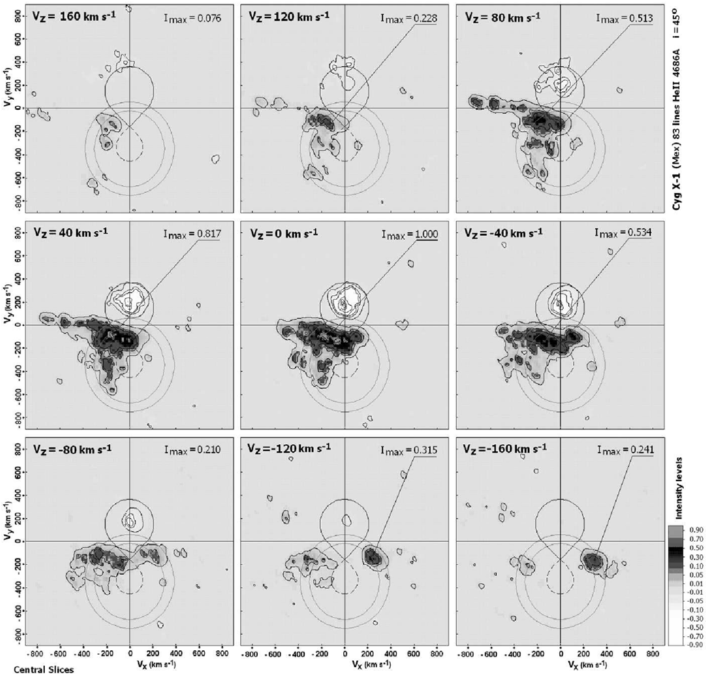

Figure 1. Nine central slices of the Cyg X-1 3D Doppler tomogram in the (V_x, V_y) plane for different V_z. The outlines of the Roche lobe of the donor star and the pattern of the outer parts of the accretion disk are plotted on the slices. We used the mass ratio of $q = M_x/M_O = 1/3$ and two versions of the disk size.

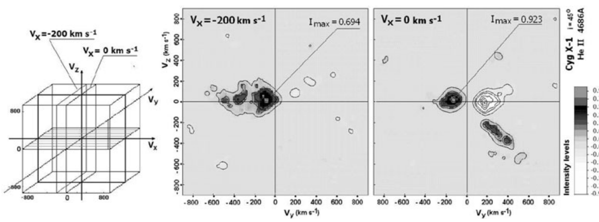

Figure 2. Cross-sections of of the Cyg X-1 3D Doppler tomogram in the (V_y, V_z) plane for two different V_x. The cube shows the geometry of the arrangement of the slices in 3D velocity space.

structure near the donor-star; 2) the elongated feature of the stream emerges from the L1 point; 3) the emission produced by the stream - accretion structure interaction.

B. The other predominant feature is visible in absorption and is associated with the supergiant. It is a compact structure. The maximum of absorption corresponds to the central slice (V_x, V_y) of the tomogram with $V_z = 0$ km/s. There is also an interesting emission feature identified with a structure related with the supergiant (in the co-rotation coordinate system). It has a $V_z \sim -200$ to -400 km/s and an intensity $I \sim 20 - 30\%$ of the maximum 3D tomogram intensity (see Fig. 2). That is probably a stream from the donor-star visible in emission flowing almost perpendicularly to the orbital plane.

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