THREE-DIMENSIONAL SIMULATIONS OF ROTATIONALLY INDUCED LINE VARIABILTY FROM A CLASSICAL T TAURI STAR WITH A MISALIGNED MAGNETIC DIPOLE.

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We present three-dimensional (3-D) simulations of rotationally induced line variability arising from complex circumstellar environment of classical T Tauri stars (CTTS) using the results of the 3-D magneto-hydrodynamical simulations of Romanova et al. (2003); Romanova et al. (2004), who considered accretions onto a CTTS with a misaligned dipole magnetic axis with respect to rotational axis. The density, velocity and temperature structures of the MHD simulations are mapped on to the radiative transfer grid, and corresponding line source function and the observed profiles of neutral hydrogen lines (Hβ, Paβ and Brγ) are computed using the Sobolev escape probability method. We study the dependency of line variability on inclination angles (i), magnetic axis misalignment angles (Θ). The dependency on the adiabatic index of gas and the temperature structure of the flow are briefly discussed also. We find that the line equivalent widths of the red wing correlates with that in the blue wing; however, in some cases (e.g. with $\Theta = 15^\circ$ and $i = 80^\circ$) , they anti-correlates (even without a contribution from wind emission/absorption) because of the almost total eclipsing of rather narrow inflowing stream by a stellar surface. The results are compared with recent observations of AA Tau by Bouvier et al. (2007). We find the overall scale of the variability across Hβ agrees with the models with high inclination ($i \approx 75^\circ$) and larger misalignment angles ($\Theta > 60^\circ$); however, the models have a difficulty in producing a strong and persistent absorption near the line center which is seen in the observation. The disagreement may be caused by the lack of visibility of hot spots at certain rotational phases or by the lack of a wind component in our models. N.B. unlike the models of Kurosawa et al. (2006), the models presented here do not include wind/outflow components.

Figure 1 shows sample Paβ synthetic images and the corresponding profiles for three different misalignment angles: $\Theta = 15^\circ$, 60° and 90° at two different rotational phases (0 and 3/4). The inclination angle of the systems i is fixed at 60° for all cases. The stellar mass and the radius used here are $0.8\,\mathrm{M}_\odot$ and $1.8\,\mathrm{R}_\odot$ respectively. The mass-accretion rate and the rotational period of the systems are $\sim 2 \times 10^{-7}\,\mathrm{M}_\odot\,\mathrm{yr}^{-1}$ and 9.4 d respectively. The mass-weighted mean temperatures of the gas are $\sim 6500\,\mathrm{K}$, and the mean temperatures of the hot spots are $\sim 8000\,\mathrm{K}$ for all three cases in the figure.

Although the shape of the funnel flows looks different in each model, in all of them the accretion occurs in two stream hence causing two hot spots on the stellar surface. The width of the stream appears to be wider as Θ increases, and consequently the azimuthal extent of the hot spots becomes wider as well. The latitudinal position of the hot shots becomes lower as the misalignment angle increases. For $\Theta = 90^\circ$ case, the two wide and thin funnels are located almost on equatorial plane, and so are the hot spots. See Romanova et al. (2004) for larger and clearer depiction of the hot spot geometries and their physical properties.

We have also run models using the stellar parameters similar to those for AA Tau to examine the general characteristics of the line profile shapes and the amount of line variability as the star and the magnetosphere rotates with respect to an observer. Figure 2 shows Hβ and Paβ lines computed, with the magnetosphere with the misalignment angle $\Theta = 60^\circ$ (c.f. middle panels in Figure 1), at ten different rotational phases between 0 and 1. Note that the line strengths are not corrected for veiling which is relatively small (~ 0.25; Bouvier et al. 2007). Although Hβ and Paβ are different in their peak flux level, overall variability patterns for both lines are very similar to each other. Weak absorption-like features seen near the line centers are likely cased by the rotational motion of the double-arm accretion flows. In other word, they are double-peaked emission lines, but not likely cased by absorption near the line center. As one can see from the figure, the separation of the double peaks is largest around phase ~ 0.5 at which the rotational velocity of the two accretion funnel arms projected toward the observer is close to maximum. On contrary to this model, the observation by Bouvier et al. (2007) shows that depletion/absorption near the line center of Hβ is below the continuum at most of rotational phases.

References

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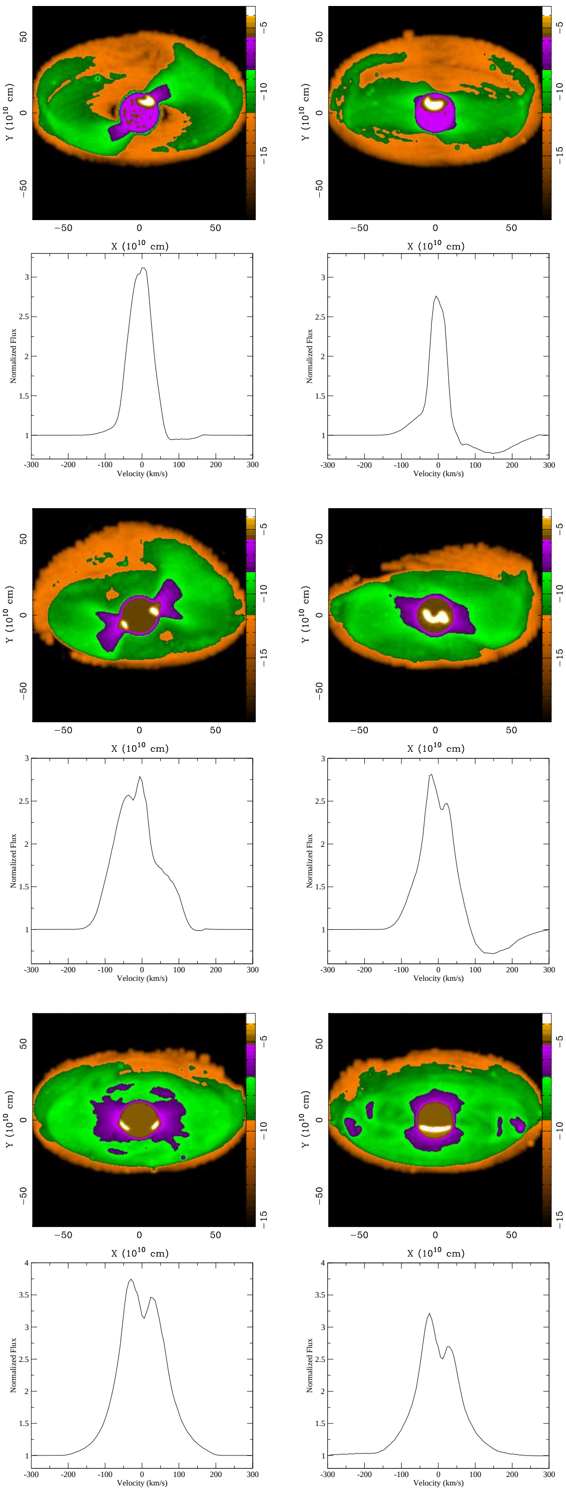

Figure 1: Paβ model intensity maps and the corresponding profiles computed at rotational phases $t = 0.0$ (left panels) and 0.75 (right panels) and for different dipole mis-alignment angles $\Theta = 15^{\circ}$, 60°, and 90° (from top to bottom). The inclination angle (of rotational axis with respect to an observer) is $i = 60^{\circ}$ for all the models shown here. The intensity is shown in logarithmic scale with an airbitray units.

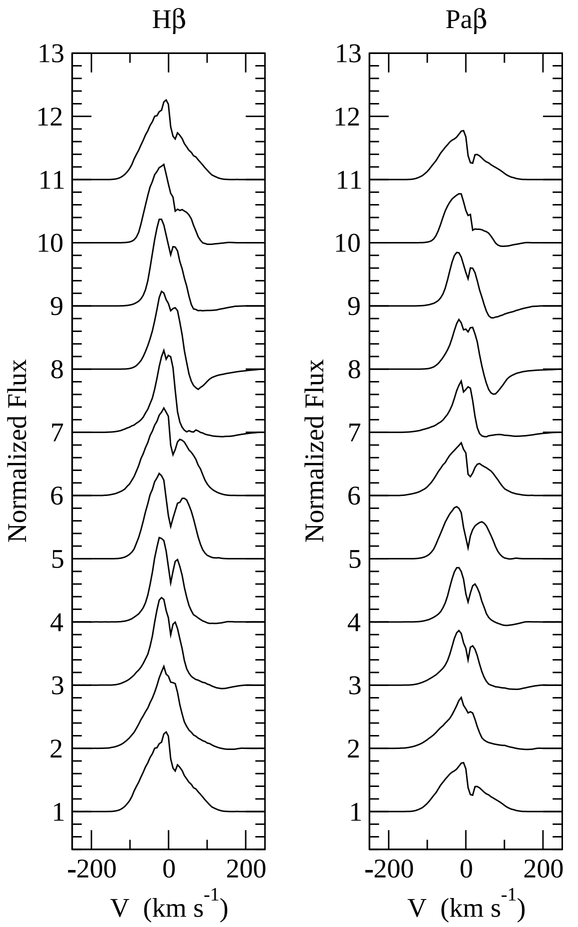

Figure 2: Comparision of variability in Hβ and Paβ for AA Tau models. The time-series spectra of Hβ (left) and Paβ (right) are shown as a function of rotational phase. The bottom and top spectra correspond to phase $= 0$ and 1.0 respectively, and each profile is separated by the rotational phase of $\sim$0.1. For clarity, the spectra are shifted upward by 1.0 as the rotational phase increases. The inclination angle $i = 75^{\circ}$ and the dipole mis-alignment angle $\Theta = 60^{\circ}$ are used.