MAGNETIC ACCRETION MODEL FOR THE ACTIVITIES OF VERY YOUNG STARS

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ABSTRACT : A magnetodynamic model is proposed to interpret the observed inflow-outflow-X-ray emitting region complex in the atmospheres of T Tau stars.

Rapidly varying X-ray emissions (Feigelson and de Campli 1981) as well as the variation of the optical line emissions with widely separated components toward blue and red (eg., Mundt and Giampapa 1982) immediately suggest a highly dynamical character of what is occurring in the atmospheres of T Tau stars. For example, Hα line profile of RW Aur with distinct emission components, one with a blueshift of about 300 km/s and the other with a redshift of about 230 km/s separated by a minimum of near-zero intensity (Hartmann 1982), is difficult to explain, eg., by the rotation effect. Several models with stellar wind or mass accretion have been discussed (Kuhi 1964, Lynden-Bell and Pringle 1974, Ulrich 1976, Bertout 1979), but these models have encountered difficulties in explaining, eg., how in- and outflow can coexist without degenerating into turbulence, or the fact that the outflow is not of the coronal temperature as expected in the case of stellar winds from dwarf stars. Queer enough, further, some observations suggest that the X-ray emitting region is located below Hα emitting region.

We here present a dynamical model to resolve these difficulties. Since the magnetic moment of a new-born star formed from the nebulosity is expected to be parallel to the field of the nebulosity, a magnetically neutral ring is produced in the equatorial plane after the star formation (Uchida and Low 1981). The balance of the Lorentz force exerted by the stellar dipolar field and the gravity acting on the accreted mass gives the distance of the balancing point in the equatorial plane,

$$\frac{r}{r_*} \sim \left(\frac{B_p^2/8\pi\Delta r}{\rho \; GM/r_*^2} \right)^{1/4} \sim 6 ,$$

if we take $r_* \sim 7 \times 10^{10}$ cm, $M \sim 2 \times 10^{33}$ g, $B_p \sim 5 \times 10^2$ G, $\Delta r \sim 10^{10}$ cm, and the density of the suspended mass $\rho \sim 10^{-13}$ g/cm^3. The magnetic field of the nebulosity condensed to $\rho \sim 10^{-13}$ g/cm^3 can be of the same order as the stellar field there, and opposite in sign. The suspension

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of mass is equivalent to the storage of energy in the form of potential energy per unit mass, $\varepsilon \sim GM(r_*^{-1} - r^{-1}) \sim 2\cdot 10^{14}$ erg/g, and the flare energy of these stars may be explained if a release of the mass in a shell of thickness $d \sim 10^9$ cm at the innermost edge of the disk can take place. The release of the mass may be effected through the magnetic reconnection at the neutral ring when the increase of loaded mass distorts the field and compresses the neutral ring region and the critical condition for the magnetic reconnection may be violated (cf. Hayashi and Sato 1978). The reconnection transfers the mass to the stellar field, and the mass can fall almost freely to the stellar surface. The free fall time is $\tau_{ff} \sim (r^3/GM)^{1/4}$ s, and the terminal velocity $v_{ff} \sim (GM/r_*)^{1/2} \sim 3 \times 10^7$ cm/s. The temperature behind the shock produced in the crash amounts to $T_2 \sim (\mu m_H/3k)\, v_{ff}^2 \sim 3 \times 10^6$ K. These explain the infall velocity of the Hα-emitting gas and the production of X-ray emitting region closer to the stellar surface with a suitable time scale for the observed variation.

The problem of the ejection of the cool gas with high velocity requires some more elaboration. By using a tube with varying cross section and effective gravity simulating the critical flux tube in the equilibrium model by Uchida and Low (1981), Shibata and the present author have recently performed a gasdynamic simulation calculation by releasing a lump of mass from the location of the neutral ring. The cool gas falls along the tube with a terminal velocity of the order of 200 km/s, and the temperature of the region just above the stellar surface rises instantaneously to 10^7 K as the shock hits the surface, and drops to 3×10^6 K and maintained as the expansion of the heated gas takes place with the shock recoiled at the surface crashing into the tail of the infalling gas. The strength of the shock rapidly increases as it sweeps along the tail of the infalling gas, the gas is driven out with increasing velocity, and the expanded cool part of the driven gas attains a few hundred km/s after the shock has propagated. It is noted that the process of outflow takes place along the reconnected tube while the inflow takes place along the inner stellar flux tube when it comes into contact with the following flux tube of the nebular field. The reconnection separates the in- and outflows and thus both can occur without hindering each other.

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DISCUSSION

Basri: The model seems quite nice for the time when the magnetic field is largely determined by the configuration of the interstellar magnetic field as slipped in by interstellar accretion. But at that stage, if I recall correctly the star would not be visible to us anyway. It would, in fact, look like an infrared cocoon source. At the time when the star is visible and emitting X-rays the star will have started generating magnetic field and associated activity and probably stellar wind as well. Would that not have a large effect on the configuration you have calculated.

Uchida: I have not loocked into this possibility. Anyway in this stage of condensation a large fraction of the nebula's magnetic field escapes, probably at the molecular cloud stage. The magnetic field which I assumed is about 500-1000G. After settling it has a dipolar field and after that the nebular remnant with its magnetic field is accreted to the star causing this particular process. So this process may be applicable only to the very young stars which still 'remember' the nebular field.