FURTHER INDICATIONS AGAINST JET ROTATION IN YOUNG STELLAR OBJECTS

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ABSTRACT

I discuss recent observations of asymmetries in Doppler shifts across T Tauri jets, and argue that the observed asymmetric velocity shifts and gradients do not indicate jet rotation. These observations, therefore, cannot be used as a support of a magnetized disk wind. The interaction of the jets with a twisted-tilted (wrapped) accretion disk (or the variable velocity precessing model) accounts better for the observations.

Subject headings: accretion, accretion disks — ISM: jets and outflows — stars: pre–main-sequence

1. INTRODUCTION

Asymmetry in the line of sight velocity across some jets ejected by young stellar objects (YSOs) has been interpreted as caused by a large scale rotation of the material in each jet around the jet’s symmetry axis (e.g., Bacciotti et al. 2002; Coffey et al. 2004; Coffey et al. 2007; hereafter B2002, C2004 and C2007). Rotation around the jet axis is predicted by the magneto-centrifugal acceleration (MCA) model for jet launching (e.g., Anderson et al. 2003). In these models the magnetic fields that are anchored into the accretion disk-star system play a dominate role in accelerating the jet’s material from the accretion disk.

In an earlier paper (Soker 2005) I analyzed the results of B2002 and C2004 and argued that the observations do not support the earlier interpretation of jets rotating around their symmetry axes. Instead, I proposed that interaction of the jets with a twisted-tilted (wrapped) accretion disk can form the observed asymmetry in the jets’ line of sight velocity profiles. The jets interact with the ambient gas residing on the two sides of the disk, e.g., a weak disk outflow or corona. The proposed scenario is based on two plausible assumptions.

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1. There is an inclination between the jet and the outer parts of the disk, such that the jet is perpendicular to the inner part of the disk; i.e., there is a twisted-tilted (wrapped) disk.

2. The disk-jet interaction slows the jet down as the jet entrains mass from the disk, with larger deceleration of jet segments closer to the tilted disk.

I showed there that the proposed scenario can account for the basic properties of the observed velocity profiles, while offering the advantage of not needing to refer to any magnetic jet launching model, and there is no need to invoke jet rotation with a huge amount of angular momentum.

The claim that the observations of B2002 and C2004 do not support jet rotation was strengthened by the numerical simulations of Cerqueira et al. (2006). They assumed a precessing jet whose ejection velocity changes periodically with a period equals to the precession period. Practically, the dependance of the jet’s expansion velocity on direction around the symmetry axis leads to the same effect as the model of Soker (2005). Whereas in Soker (2005) the physical process behind this velocity profile is an interaction with the material in the jet’s surroundings, Cerqueira et al. (2006) give no justification for the periodic variation of the jet’s ejection speed. Therefore, as far as comparison with observation is considered, it is hard to distinguish between the model of jet interaction with its surrounding (Soker 2005), and the periodic jet’s speed of Cerqueira et al. (2006). I will list them together in the next section.

2. COMPARING OBSERVATIONS WITH MODELS

In this section I list some observations, and compare them with the two proposed explanations for the observed (B2002, C2004 and C2007) asymmetric velocity profiles in jets from YSO: The interaction of the jet with the ambient gas coming from the disk (Soker 2005; as mentioned above the model of Cerqueira et al. 2006 is basically the same), and with the MCA as was used by B2002, C2004 and C2007 (e.g., Anderson et al. 2003). These are summarized in Table I

The first four points were discussed in detail in the appendix of Soker (2005-on line material in A&A), and therefore I summarize them here briefly. The last four points are new.

1. **Stochastic velocity profiles.** Different lines show very different velocity profiles. These differences are larger than the claimed rotational velocity of the corresponding
jets. The interaction of the jet with its surrounding gas is expected to be somewhat stochastic, leading to different regions having different properties, like velocity and density, and hence different lines are prominent in different regions (Soker 2005).

2. **Angular momentum.** If the radial velocity gradient is attributed to the jet’s rotation, then the specific angular momentum of the gas at the edge of the jets is extremely high. This implies (see Soker 2005) that if C2004 interpretation of the jets in RW Aur is correct, then according to the jet-disk models they use, the disk must lose *all* of its angular momentum already at \( r_d = 0.4 \) AU. This is a much larger radius than that of the accreting central star, which implies that the disk is truncated at a very large radius, where escape speed is much below the jet’s speed.

3. **Energy.** In the analysis of Anderson et al. (2003; see also 2005), the poloidal speeds along jets’ stream lines of the YSO DG Tauri are < 3 times what would be the escape velocity at the footpoints of the stream lines. The velocities found by C2004 are much higher than the theoretical expectation. In the YSO LkH\(\alpha\) 321, for example, the jet speed is \( \sim 4 - 4.5 \) times the escape velocity. In one streamline in DG Tau this ratio as given by C2007 is \( \sim 5 \). The required efficiency of energy transfer from accreted to ejected mass seems to be higher than that expected in MCA models. Higher velocities are obtained in the numerical simulations of Garcia et al. (2001) which include the thermal state of the jet, but the fraction of ejected mass (out of the accreted mass) is \( 1 - 2\% \), much below the value of \( \sim 10\% \) in RW Tau (Woitas et al. 2005).

4. **Model versus observations.** C2004 use the jet launching model as presented by Anderson et al. (2003), who use it for the YSO DG Tau. However, in that model the toroidal velocity decreases with distance from the jet’s axis, while in the observations, both of DG Tau (Anderson et al. 2003) and the three YSOs studied by C2004, the toroidal velocity increases with distance from the jet’s axis. Pesenti et al. (2004) present a more detailed MHD model based on jet rotation to account for the observation of DG Tau (B2002). Pesenti et al. (2004) find a good fit between their model and the velocity map of DG Tau. However, the model of Pesenti et al. (2004) for DG Tau has two significant differences from that of TW Aur (Woitas et al. 2005). First, their derive typical toroidal velocity for stream lines with footpoints of \( \sim 1 \) AU is much lower than that in TW Aur. The second difference involved the theoretical model used by Pesenti et al. (2004). Pesenti et al. (2004) find that only the warm jet model fit the observations. In this model the jet is thermally-driven (Casse & Ferreira 2002). Both these differences, that the jets have low specific angular momentum, and are thermally driven, are along the main theme of the present paper, although significant differences exist between the warm MHD model used by Pesenti et al. (2004) and the
model proposed by Soker & Regev (2003). Because a more sophisticated and detailed MHD models for jet rotation might overcome these problems, I put ‘=’ for the MCA model in Table [I].

5. **Faint low velocity component.** In the position-velocity maps of CW Tau in [OI] $\lambda6300$ and of DG TAu and TH 28 in the Mg II line, there is a faint component of velocity close to zero, or even with a velocity opposite to that of the jet (C2007). Such a component is expected from the backflowing material formed from the jet-ambient medium interaction, e.g., Stone & Norman (1993, figs. 13 and 16) and (1994, fig 8). This component has no particular explanation in the MCA model.

6. **Counter disk rotation.** Cabrit et al. (2006) found the rotation of the disk in RW Aur to be in opposite direction to the jet rotation argued for by Woitas et al. (2005). This is in contradiction with the MCA model.

7. **No velocity gradient in HH 30.** The jet of HH 30 is in the plane of the sky (inclinacion of 1°). At that inclination the jet rotation should have its larger amplitude. But there is no indication for jet rotation in HH 30 (C2007), or in the CO outflow associated with it (Pety et al. 2006). In the jet interaction model at that inclination the velocity gradient should be zero. TH 28 is also close to the plane of the sky (inclinacion of 10°), and show very low velocity asymmetries (C2007).

8. **Asymmetry between two opposite jets.** In TH 28 the two jets were observed by C2007. the velocity profiles of the two jets are dissimilar. In the jet-ambient medium interaction this is accounted for by a different surrounding medium on the two sides. If the velocity profiles were due to jets’ rotation, the two jets should have shown similar velocity profiles. This observation pose a problem to the periodic jet’s speed model of Cerqueira et al. (2006) as well.

### 3. SUMMARY

This short paper has one point (Soker 2005; Cerqueira et al. 2006): The observed asymmetric velocity shift on the two sides of some YSO jets cannot serve as confirmation for the magneto-centrifugal acceleration (MCA) model for jet formation. In this paper I went further, and argue that the observed velocity gradients and asymmetries are actually in contradiction with the MCA model.

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Table 1: Observations and theory

| Observed property                          | Jet-disk interaction  | Magneto-centrifugal acceleration |
|--------------------------------------------|-----------------------|----------------------------------|
| (1) Different lines show very different velocity profiles. | (+)\textsuperscript{a} Interaction with disk forms different regions with different properties. | (=) Possible to explain under a particular jet structure only. |
| (2) If the velocity profile is rotation, then jet’s angular momentum is large. | (+) The velocity gradients do not indicate rotation. | (−) The disk loses most of its angular momentum at large radius. |
| (3) Observed jets’ outflow speed. | (+) Jet are launched from the inner radius of the disk, where escape velocity is high enough. | (−) Too high for the MCA model. |
| (4) Rotation interpretations do not fit well the model used. | (+) In the thermal-launching model only a minor rotation is expected. | (=) The model used to explain observations is not in accord with the observations. |
| (5) A separate low velocity component. | (+) Emission from the cocoon or from the interacting surroundings. | (−) No explanation. |
| (6) Disk and jet rotations in RW Aur are opposite. | (+) The observations are not of jet’s rotation. | (−) In contradiction. |
| (7) No rotation signature in HH 30, although the jet is in the plane of the sky. | (+) No velocity gradient is expected. | (−) Rotation signature should be at maximum. |
| (8) The two opposite jets of TH 28 show different velocity profiles. | (+) The ambient medium is different in the two sides. | (−) Not expected if velocity gradients are due to rotation. |

\textsuperscript{a}(+) Expected by the model; (−) Cannot (very difficult to) be explained by the model; (=) Possible to explain by the model
REFERENCES

Anderson, J. M., Li, Z.-Y., Krasnopolsky, R., & Blandford, R. D. 2003, ApJ, 590, L107
Anderson, J. M., Li, Z.-Y., Krasnopolsky, R., & Blandford, R. D. 2005, ApJ, 630, 945
Bacciotti, F., Ray, T. P., Mundt, R., Eisloeffel, J., & Solf, Jo. ApJ, 576, 222 (B2002)
Cabrit, S., Pety, J., Pesenti, N., & Dougados, C. 2006, A&A, 452, 897
Casse, F., & Ferreira, J. 2000, A&A, 361, 1178
Cerqueira, A. H., Velazquez, P. F., Raga, A. C., Vasconcelos, M. J., & de Colle, F. 2006, A&A, 448, 231
Coffey, D., Bacciotti, F., Woitas, J., Ray, T. P., & Eisloeffel, J. 2004, ApJ, 604, 758 (C2004)
Coffey, D., Bacciotti, F., Ray, T. P., Ray, T. P., Eisloeffel, J., & Woitas, J., (astro-ph/0703271) (C2007)
Garcia, P. J. V., Ferreira, J., Cabrit, S., & Binette, L. 2001, A&A, 377, 589
Pesenti, N., Dougados, C., Cabrit, S., Ferreira, J., Casse, F., Garcia, P., & O'Brien, D. 2004, A&A, 416, L9
Pety, J., Gueth, F., Guilloteau, S., & Dutrey, A. 2006, A&A, 458, 841
Soker, N. 2005, A&A, 435, 125
Soker, N., & Regev, O. 2003, A&A, 406, 603
Stone, J. M., & Norman, M. L. 1993, ApJ, 413, 210
Stone, J. M., & Norman, M. L. 1994, ApJ, 420, 237
Woitas, J., Bacciotti, F., Ray, T. P., Marconi, A., Coffey, D., & Eisloffel, J. 2005, A&A, 432, 149

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