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Observational and numerical tests of jet models in young stars

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Abstract. Jets are found in a wide range of accreting young stars, from brown dwarfs to massive protostars, but their launch region(s) and their role in angular momentum extraction are still debated. Many observational constraints exist on jet properties, including jet widths, kinematics along and across the jet, possible rotation signatures, ejection/accretion ratio, depletion and molecular counterparts. This contribution compares popular models, in particular disk winds, with these constraints and with MHD numerical simulations, highlighting a few open issues.

Keywords. accretion disks, MHD, stars: pre–main-sequence, ISM: jets and outflows

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1. Stellar winds

He I profiles indicate accretion-powered inner "stellar" winds in $\geqslant 60\%$ of TTS (Kwan *et al.* 2007). However, launching from the stellar surface meets three caveats in explaining observed jets: (i) energetic difficulty to eject $>1\%$ of the accretion rate (Cranmer 2009, Ferreira *et al.* 2006), (ii) lack of dust, whereas iron and calcium depletion is measured in several jets (Podio *et al.* 2006, Dionatos *et al.* 2009), (iii) insufficient collimation (Bogovalov & Tsinganos 2001, Fendt 2009, Cabrit 2007); Other ejection sites thus seem required. More details may be found in the proceedings of IAU Symp. 243 and of the Conference *Protostellar jets in Context* (eds. T. Ray & K. Tsinganos).

2. Steady MHD winds from the disk surface

This mechanism is so far the only one where the difficult mass-loading problem from the accretion disk has been rigorously solved, and validated by numerical simulations (e.g. Casse & Ferreira 2000, Zanni *et al.* 2007, Salmeron *et al.* 2007). Synthetic predictions calculated for steady solutions compare well with high resolution observations such as: apparent jet widths (Garcia *et al.* 2001, Ray *et al.* 2007, Stute *et al.* 2009), maximum poloidal speeds and drop in velocity away from the jet axis (Cabrit 2007), and atomic jet rotation signatures (Pesenti *et al.* 2004). The latter require "warm" disk winds with a moderate magnetic lever arm $\lambda \leqslant 13$, launched out to a maximum radius of 0.1–3 AU, yielding an ejection to accretion ratio $\simeq$ 4%–13% in the observed range (Ferreira *et al.* 2006). However, T Tauri jet rotation signatures are still tentative due to possible contamination by shock asymmetries (e.g. Soker 2005). Disk winds could also naturally explain the presence of dust and molecules in/around jets (Panoglou *et al.* 2009)†. A caveat noted by Shu *et al.* (2008) is that a powerful disk wind induces transonic accretion; but since it occurs only out to a few AUs (limited by X-ray ionization of the disk surface), the disk lifetime is unaffected. The surface density in the inner "jet emitting" region is

† Note that the small launch radii < 0.1 AU inferred in molecular class 0 jets with SMA (Lee *et al.* 2008) are very uncertain since jet widths are unresolved, and rotation signatures are strongly suppressed in this case (Pesenti *et al.* 2004). ALMA will be crucial to settle this issue.

lowered, with possible impact on planet migration and disk photoevaporation, but the SED changes only moderately for typical accretion rates (Combet & Ferreira 2008). Infrared line profiles might offer a stronger test of disk wind extent in young stars.

3. The X-wind scenario

A scenario put forward by F. Shu and collaborators assumes that excess angular momentum from infalling matter is extracted by the funnel flow and transferred across corotation to power a steady centrifugal disk wind. A nice aspect is that for a terminal jet speed of 150 km s^{-1}, the required ejection/accretion ratio is 30%, close to observed. Adequate apparent jet collimation and excitation conditions can also be achieved (Shang *et al.* 2002). However, two key elements of the scenario are still unsolved: the angular momentum transfer across the X-region locked in corotation, since there is no shear to induce transport (and high magnetization could quench MRI turbulence); and how to load such a large mass-flux. MHD numerical simulations of star-disk interaction are so far unable to reproduce the X-wind conditions. The funnel flow spins *up* the star, rather than spin it down, and the conical wind from the inner disk edge is thus too slow (typically 50 km/s) compared to observed jets (Romanova *et al.* 2009). Stellar magnetic towers or sporadic reconnexion winds from the magnetosphere appear more promising to brake down the star (Ferreira *et al.* 2000, Zanni 2009, Romanova *et al.* 2009).

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