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DYNAMICS OF MAGNETIZED YSO JETS: EXAMPLES OF RESULTS FROM THE JETSET NETWORK

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RESUMEN

Esta contribución resume los resultados sobre dinámica de jets de estrellas jóvenes obtenidos por la red JETSET, usando modelos teóricos MHD, simulaciones numéricas y experimentos de laboratorio. Los temas cubiertos incluyen vientos térmicos, eyecciones magnetosféricas, vientos de discos, inestabilidades magneto-rotacionales y de Kelvin-Helmholtz, inyección de turbulencia, formación de flujos moleculares y desarrollo y control de códigos MHD.

ABSTRACT

This contribution reviews recent results on the dynamics of YSO jets obtained by the JETSET network using theoretical MHD models, numerical simulations, and laboratory experiments. Topics include pressure-driven stellar winds, magnetospheric ejections, disk winds, MRI and KH instabilities, turbulence injection, molecular outflow formation, and MHD code development and testing.

Key Words: ISM: jets and outflows — stars: mass loss — stars: pre-main sequence

1. INTRODUCTION: THE JETSET NETWORK

JETSET (Jet Simulations, Experiments, and Theories) is a 4-year Marie Curie Research Training Network gathering 11 institutes in 7 european countries: England (Imperial College London), France (Laboratoire d'Astrophysique de Grenoble, Observatoire de Paris), Germany (Heidelberg University, Tautenburg Observatory), Greece (University of Athens), Ireland (Dublin Institute for Advanced Studies), Italy (Torino University, Arcetri and Rome Observatories), and Portugal (University of Porto). It also includes external associate experts such as H. Baty and T. Lery in Strasbourg, E. de Gouveia dal Pino in Brasil, A. Frank in the USA, and A. Raga in Mexico. Tom Ray (Dublin) is the network coordinator, and S. Cabrit has been acting as science coordinator.

JETSET provides high-level skills to young scientists through challenging research projects, training schools, and international collaborations. The scientific goal is to make key progress on the physics of jets from young stellar objects (YSOs) on all scales:

- **Small scale $<$ 10 AU: Jet launching**. What are the respective contributions of disk winds, stellar winds, and unsteady magnetospheric ejections in YSO jets?
- **Medium scale 10AU - 1pc: Jet propagation**. How is the jet stabilized, what is the origin of jet knots, and what do the associated shock diagnostics tell us?
- **Large scale 1000 AU - 10 pc: Interaction with the ambient cloud**. Are jets able to reproduce swept-up CO cavities in bipolar outflows, and to sustain turbulence in molecular clouds?

A characteristic of JETSET is its cross-disciplinary approach to these problems. Highlights of observational studies by JETSET members and their collaborators may be found in Tom Ray's contribution. Here we present a (non-exhaustive) outline of recent results obtained by JETSET through other approaches, namely theories of MHD jets, numerical simulations, and laboratory experiments.

2. THE MASS-FLUX CHALLENGE FOR STELLAR WINDS

The ratio of jet mass flux to disk accretion rate is a key constraint for jet launching mechanisms. Several JETSET studies have given more detailed estimates of this parameter. Simultaneous near-infrared

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spectroscopy in Brγ and [Fe II] of embedded protostars leads to a (one-sided) ratio $\simeq$ 1–10% in 3 sources (Antoniucci et al. 2008). Spatially resolved spectro-imaging of the microjets in RW Aur and in RY Tau give a one-sided ratio $\simeq$ 5–10% (Woitas et al. 2002; Agra-Amboage et al. 2009). The mean (one-sided) value of 1% obtained by Hartigan et al. (1995) on a large T Tauri microjet sample also reaches 10% when updated accretion rates from UV excess are adopted (Cabrit 2007). Therefore, the two-sided ejection/accretion ratio is confirmed to be high in YSO jets, at least 2% and possibly as high as 20%.

Ferreira et al. (2006) have argued that such a high ratio of $\dot{M}_{\rm jet}/\dot{M}_{\rm acc}$ poses a theoretical challenge to stellar winds: as T Tauri stars rotate at only 10% of break-up, magnetic acceleration is inefficient (at least initially) and most of the potential well must be overcome by pressure gradients. To reach a terminal jet speed of order the keplerian speed at the star, the net enthalpy deposition then needs to be $\simeq$ 3 times the jet mecanical luminosity $L_{\rm mech}$, ie. 3–30% of $L_{\rm acc}$. But the large radiative losses in a dense, hot wind would make the total heating rate prohibitive. Alternatively, driving by MHD wave pressure requires 5–10 times $L_{\rm mech}$ in the form of *coherent undamped Alfvén waves* (De Campli 1981), i.e. 5–100% of $L_{\rm acc}$, again quite challenging as dissipative waves would also be excited.

This mass-flux challenge to stellar winds, despite their presence in T Tauri stars (e.g. Kwan et al. 2007), suggests that additional flows launched from the disk and/or the star-disk interaction zone should be considered to explain YSO jets (Ferreira et al. 2006).

3. MHD SIMULATIONS OF STAR/DISC INTERACTION

Claudio Zanni (JETSET postdoc in Grenoble) recently conducted 2.5D numerical simulations of the interaction of a viscous and resistive accretion disk with a slowly rotating star harboring a kG dipolar field. Various values for the "turbulent" viscosity ν and resistivity η were investigated.

Figure 1 presents results after 92 rotation periods in the case of a low resistivity, where the disk is well coupled to the magnetic field and the shearing effect of differential rotation between star and disk is more evident. The ratio of $\nu/\eta = 10 \simeq r/h$, as advocated by Shu et al. (2007). When closed stellar field lines anchored beyond corotation inflate and open up, mass from the corona is sporadically ejected along the current sheet through reconnection (as described early-on by Goodson & Winglee 1999). The present simulations do not show a disruption of accretion columns during outflow. More details may be found in C. Zanni's contribution. See also de Gouveia dal Pino et al. (2009) for a discussion of the importance of reconnection.

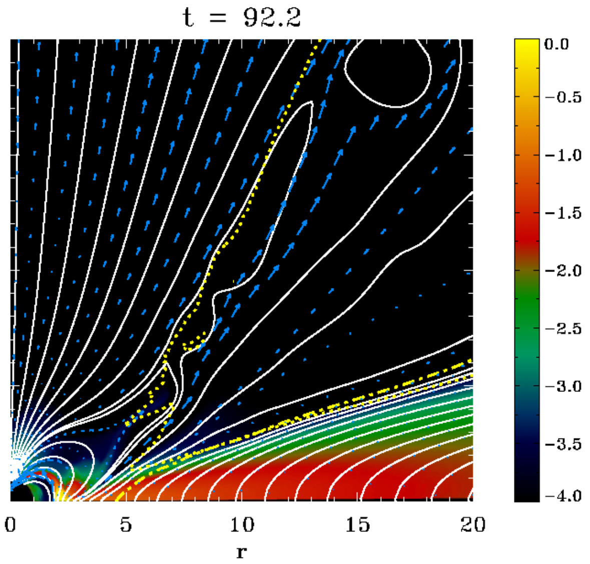

Fig. 1. Density (colour scale) and magnetic field lines (white curves) after 92.2 stellar rotation periods for a simulation with $\nu/\eta = 10$, $\alpha_v \equiv \nu/C_s h = 1$, $B_\star = 800$ G, $\Omega_\star$ = 10% of Kepler. Plasmoid ejection due to inflation and opening of the magnetosphere is clearly visible (cf. Zanni 2009).

These magnetospheric ejections are conceptually distinct from the X-wind proposed by Shu and collaborators, where launching occurs from the disk surface along already opened field lines through the classical *steady-state* magneto-centrifugal mechanism. Here, the launching occurs in a highly unsteady fashion on a field line still connecting the star and disk, and matter flows out along the current sheet (the "dead zone" in the Shu et al. nomenclature).

Since magnetospheric ejections occur at a 45° angle, asymptotic collimation into a jet would require a strong confining magnetic field in the outer disk, as predicted, e. g., by the collapse and advection models of Krasnopolsky & Königl (2002) and Galli et al. (2009).

4. JET LAUNCHING FROM RESISTIVE ACCRETION DISKS

4.1. *2D analytical results*

The steady mass loading from a resistive accretion disk into an ideal MHD jet has been rigorously solved in 2D self-similar geometry, taking into account all force terms entering the disk dynamics (Ferreira 1997; Casse & Ferreira 2000a). The azimuthal, radial, and vertical acceleration along a streamline are calculated self-consistently, automatically including the departure from keplerian rotation and the vertical compression caused by the disk magnetization (cf. Lizano et al. 2009).

In some conditions, an efficient magnetic spin-up torque develops at the disk surface and leads to wind launching and (assisted by the Lorentz force) acceleration into a steady super-alfvénic jet. These conditions still hold in the absence of self-similarity (Ferreira & Casse, in prep). The main results, and differences with the treatment of Shu et al. (2007, 2008), are recalled below:

- All 3 components of $\vec{B}$ are comparable at the disk surface, with B_z typically reaching half of equipartition in the disk midplane, i.e. $\mu \equiv B_z^2/(4\pi P_0) \simeq 0.5$. The resulting scaling with disk radius is (Garcia et al. 2001)

$$B_{\rm equ}(R) \simeq 0.3 R_{\rm 1AU}^{-5/4} \dot{M}_{\rm acc,-7}^{1/2} M_{\star,\odot}^{1/4}\ {\rm G}\,, \qquad (1)$$

where $\dot{M}_{\rm acc}$ is normalized to $10^{-7} M_\odot {\rm yr}^{-1}$, R to 1 AU, and $M_\star$ to 1 $M_\odot$. Shu et al. (2007) propose the same B_z scaling for their self-similar advection model, but for an extra factor $(f/DA)^{0.5}$ amounting to 2–4 in their protostar/FUOr models and 50 in their T Tauri disk model (however, they set $B_\phi = 0$).

- The magnetic braking torque must dominate over the viscous torque, i.e. the ratio of turbulent viscosity to magnetic resistivity, ν/η, must remain $\ll r/h$. Otherwise, accretion power is dissipated viscously and little mass is ejected magnetically (Casse & Ferreira 2000a). Shu et al. (2007) argue that $\nu/\eta \simeq r/h$ in MRI turbulence, implying weak MHD disk winds. The actual value of ν/η in MRI and its scaling with μ are still uncertain, however.

- The anomalous ("turbulent") resistivity η must be large, with $\alpha_m \equiv \eta/(V_A h) \simeq 1$, in order to have a *steady* jet (Casse & Ferreira 2000a). However, numerical simulations show that massive *unsteady* disk winds may still occur for smaller α_m (see below).

- The wind slow point occurs at only a few disk scale heights. A substantial ejection/accretion ratio $\xi = ({\rm d}\dot{M}_{\rm jet}/{\rm dln}r)/\dot{M}_{\rm acc} \simeq 0.01$ is obtained for a vertically isothermal "cold" disk with $\mu \simeq 0.5$, even though the enthalpy launch criterion $\mu \leq 2\ h/r$ proposed by Shu et al. (2008) is not fulfilled. Indeed, in such models, the Poynting flux/magnetic torque plays a more important role than enthalpy in allowing matter to escape from the potential well.

- Disk surface heating enhances the density at the slow point and increases mass loading up to $\xi \simeq 0.1$, even though acceleration remains mostly magnetic (Casse & Ferreira 2000b). The reduced rotation speed in these "warm disk winds" is more compatible with current observational limits (Pesenti et al. 2004; Ferreira et al. 2006).

4.2. *Numerical MHD simulations of disk winds: effect of disk resistivity*

The effect of disk resistivity was investigated by Zanni et al. (2007), using the 2.5D version of the FLASH code with AMR and 7 levels of refinement. The initial disk parameters were $\mu = B_z^2/(4\pi P_0) = 0.6$, a thermal aspect ratio (before magnetic compression) $h/r = 0.1$, and a turbulent resistivity profile $\eta(r,z) = \alpha_m V_A h(r) \exp[-2(z/h)^2]$. The viscous torque was supposed everywhere to be negligible compared to the magnetic torque (i.e. $\nu/\eta \ll r/h$). Figure 2 presents the outcome of two MHD simulations.

When $\alpha_m = 1$ (right panel of Figure 2), a full steady state is reached, with field lines gently wrapped around magnetic surfaces and a steady magneto-centrifugal disk wind flowing off the disk surface.

When $\alpha_m = 0.1$ (left panel of Figure 2), no steady state is reached: the footpoints of the field lines are continuously advected towards the center, and differential rotation along the lines develops a strong B_ϕ gradient which lifts up the matter into an outflow. The ejection/accretion ratio $\simeq 0.6$ is higher than when $\alpha_m = 1$, although it will evolve on the long term as field lines pile up at the disk inner edge.

These results confirm the conclusions of analytical work that a steady, powerful MHD disk wind can be established without the need of a strong enthalpy to overcome the potential well, provided (i) the disk field is close to equipartition, (ii) the magnetic torque dominates the viscous torque (opposite to the situation considered by Shu et al. (2007)), (iii) the resistivity is high, with $\alpha_m \simeq 1$. The simulations further show that massive disk winds still occur for smaller resistivities ($\alpha_m \ll 1$), although the flow will be unsteady (and possibly cyclic).

4.3. *Effect of disk magnetization*

The effect of the disk magnetisation parameter $\mu = B^2/4\pi P_0$ on disk structure and MHD wind launching has been recently explored numerically with the PLUTO code (Tzeferacos et al., in prep.). μ is varied from 0.2 to 6 while the diffusivity parameter α_m is kept equal to 1.

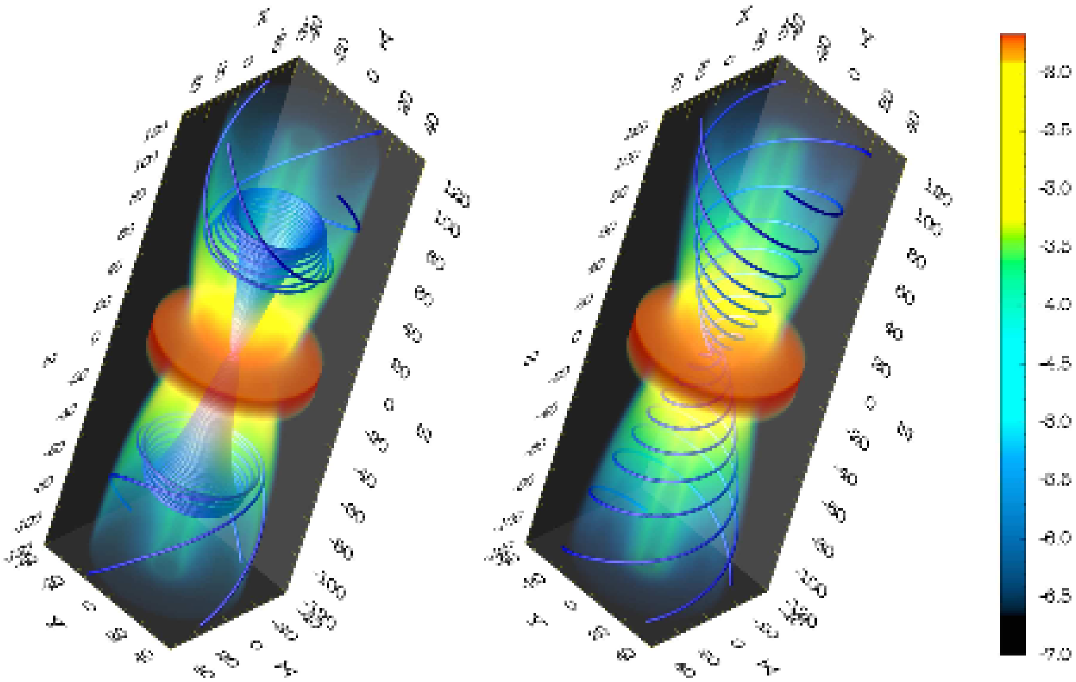

Fig. 2. 3D rendering of the density and field topology above a magnetized resistive disk with equipartition field. For a resistive parameter $\alpha_m = 1$ (right) a steady magneto-centrifugal disk wind is formed. For $\alpha_m = 0.1$ (left), a massive unsteady outflow driven by the toroidal pressure gradient results (Zanni et al. 2007).

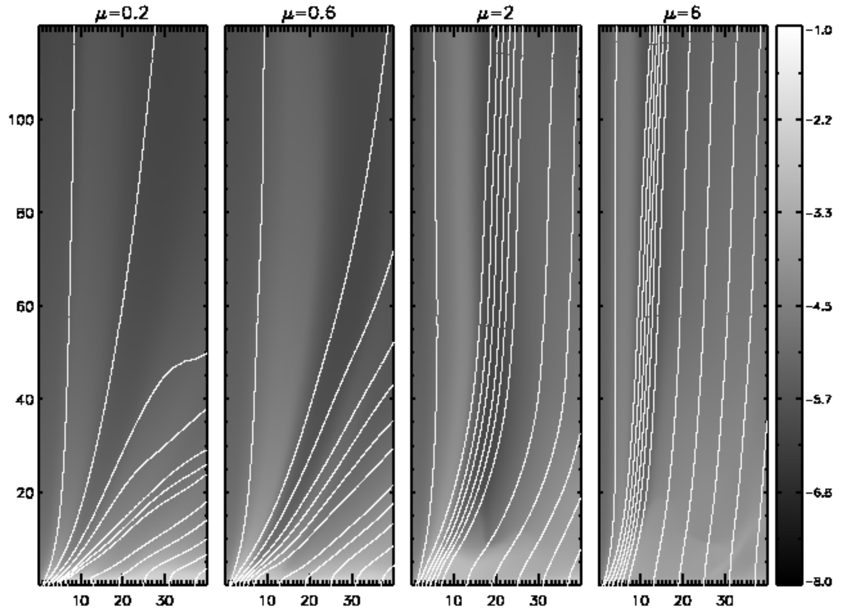

Fig. 3. Logarithmic density in greyscale with sample magnetic field lines after ~ 63 inner disk rotations for values of the disk magnetization $\mu = B^2/4\pi P_0 = 0.2$, 0.6, 2, and 6 (see text).

Figure 3 shows the density and field after ~ 63 inner disk rotations for the various values of magnetization. Steady-state is reached only for $\mu = 0.6$, again confirming the analytical results (cf. § 4.1). It may be seen that the collimation of field lines is much tighter as μ increases, straying away from the analytically expected "open" topology. The ejection/accretion ratio also increases for stronger mag-

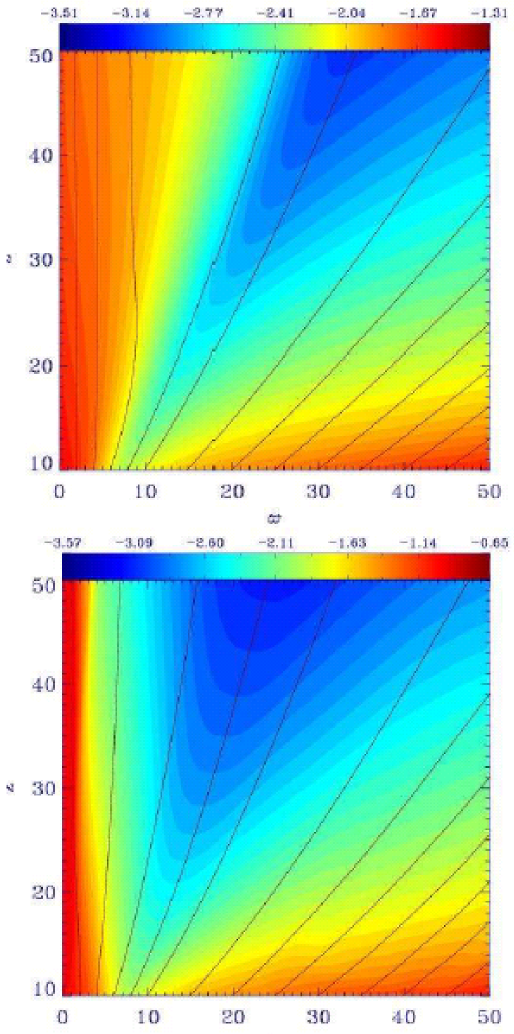

Fig. 4. Density (colour scale) and magnetic field (curves) of a two-component stellar wind + disk wind model. Top: initial set-up. Bottom: steady-state (note the enhanced stellar wind collimation).

netic fields, in agreement with the trend found in the steady analytical models of Ferreira (1997).

4.4. *Effect of an outer cutoff in radius*

The stability and structure of analytical MHD jet models with a finite outer disk radius has been recently investigated by Stute et al. (2008) through numerical simulations with the PLUTO code. In this case the disk is treated as a boundary condition, allowing to study the jet evolution on longer time scales. The reduced external thermal and magnetic pressures change the perpendicular force balance at the "surface" of the flow, affecting the radial expansion. A steady-state is reached, where the inside region remains similar to the initial analytical solution. Truncated, exact MHD disk-wind solutions thus appear to be topologically stable. Synthetic map predictions, and their comparison with observed jet widths, are under way.

5. TWO-COMPONENT MHD MODELS: STELLAR + DISK WIND

Theoretical considerations on collimation (Bogovalov & Tsinganos 2001) and energetics (Ferreira et al. 2006, see § 4.1) argue that jets from YSOs may have at least two components: an inner, pressure-driven stellar wind responsible, e. g., for the broad P Cygni Blue absorption in HeI lines (Edwards et al. 2006; Kwan et al. 2007), and an outer disk-wind providing the large observed jet mass flux. Studying the interaction between these two flows requires suitable, two-component MHD models.

As a first step, the PLUTO code was used to investigate the topological stability of two analytical MHD steady solutions: a meridionally self-similar (describing stellar outflows) and a radially self-similar flow (describing disk winds). Both were extended to all space by removing their singularities (Matsakos et al. 2008). In a second step, the two solutions were combined, with different relative contributions. Figure 4 shows that a steady-state is reached, where the disk wind solution is essentially unmodified while the stellar wind is being collimated by the disk wind component (Matsakos et al., in prep.). Interaction between the two flows thus affects the asymptotics of stellar winds (see also Meliani et al. 2006).

6. MRI SIMULATIONS

Bodo et al. (2008) have investigated the effect of different aspect ratios R/Z (radial extension/disk height) in 3D simulations of MRI-driven compressible turbulence in the shearing box approximation.

In computational shearing boxes of aspect ratio $R/Z = 1$, the transport coefficient of angular momentum α is strongly intermittent and dominated by the channel solution. As R/Z increases to values of 4–8, the intermittent behavior disappears, and the solution tends to become size independent, with $\alpha \simeq 0.01$. Therefore, care must be exercized when evaluating transport coefficients in MRI using simulations in the shearing box approximation. Global disk MRI simulations are under way.

7. MHD JET INSTABILITIES

Kelvin-Helmholtz instabilities in magnetized YSO jets have been recently investigated by several JETSET members:

Viallet & Baty (2007) describe a partial stabilization mechanism for weakly magnetized transonic flows, through the formation of a stabilizing sheath of enhanced B-field.

Another recent study by Shadmehri & Downes (2007) shows that the finite thickness of a weakly ionized layer can stabilize the two dominant growing KH modes. Charged dust particles in the partly ionized flow also have a stabilizing effect (Shadmehri & Downes 2008).

Finally, Matteo Bocchi (JETSET PhD in Heidelberg) with H. Baty and M. Camenzind, is modelling the formation of knots by KH instability in a jet with a reversed Field Pinch configuration (cf. poster at this conference).

8. LARGE SCALE SIMULATIONS OF JET PROPAGATION

8.1. *Turbulence injection by jets into parent cloud*

The injection of turbulence in clouds by protostellar jets is a crucial issue to understand feedback mechanisms in star formation. Several JETSET teams have recently investigated the problem with numerical simulations, with mixed results:

De Colle & Raga (2005) studied the interaction of Herbig-Haro jets with a molecular cloud in the presence of magnetic fields. They found that the magnetic field facilitates the transport of momentum and energy to ambient cloud, thanks to the propagation of Alfvén waves perpendicular to the jet motion. This could efficiently feed turbulence into the cloud.

JETSET associate Adam Frank and his group found that a single jet in a turbulent medium repowers turbulence, while multiple jets can drive turbulence in initially quiescent media, with a mean turbulent velocity greater than 5 times the sound speed. (Frank 2007; Carroll & Frank 2007; Cunningham et al. 2007, and Frank 2009).

Contrasting results were found by Banerjee et al. (2007), who find a quick damping of supersonic fluctuations away fom the jet beam, suggesting that jets are not able to drive turbulence in molecular clouds. More work is needed to settle this important issue.

8.2. *Swept-up molecular outflows*

Downes & Cabrit (2007) conducted very long-term hydrodynamical simulations (> 1500 yrs) of the outflow cavity driven by a jet bowshock into the ambient cloud, including H_2 dissociation and H_2 cooling. As the bow head propagates at ≥ 50 km/s, H_2 is dissociated at the bowshock apex and surviving molecules are mostly in the slow bowshock wings. Because of this, the intensity-weighted speed $<V>$ in simulated CO lines profiles underestimates the true bow advance speed by a factor > 10. Using $<V>$ to get the flow dynamical age (as done by many observers) will thus overestimate the trueage and underestimate the jet momentum injection rate by an order of magnitude or more.

Using the "maximum" speed in CO profiles, and correcting for inclination, gives more accurate estimates of the flow energetics in the simulations. The high ratio of momentum flux to $L_{\rm acc}$ obtained by the latter method on observed outflows (Cabrit & Bertout 1992; Beuther et al. 2002) thus appears to be robust, and an efficient jet mechanism is required also in very young embedded protostars, with an ejection/accretion ratio of order 10%.

9. LABORATORY JETS

Several JETSET teams are involved in laboratory studies, with the goal of (i) studying scaled astrophysical systems at higher resolution and with more complete diagnostics than possible in astrophysical observations, (ii) providing a benchmarking of theories and numerical codes.

9.1. *MHD Jet launching*

The Z-pinch installation MAGPIE at Imperial College (London) has been successfully used to perform experiments of episodic "magnetic towers" driven by a toroidal field, producing an axial dense clumpy jet surrounded by an expanding magnetized cavity (Lebedev et al. 2005). Resistive 3D numerical MHD simulations remarkably reproduce the temporal evolution of the jet and cavity (Ciardi et al. 2007). Recently, repetitive eruptions have also been produced (PhD theses of F. Suzuki-Vidal and A. Marrochino, JETSET students). More details can be found in the contribution of Frank et al. (2009).

9.2. *Jet propagation (hydro): jet bending*

The bending of a supersonic jet by a side-wind, and the effect of jet rotation on this process, have been studied for the first time in the laboratory by the JETSET team at Imperial College. The experiment is in a similar regime to that believed to apply in observed HH jets, namely $V_{\rm jet}/V_{\rm wind} = 2-6, n_{\rm jet}/n_{\rm wind} = 0.1-100$, Mach number $M > 20$, Reynolds number $> 10^4$.

The formation of a new inclined working surface is observed in the experimental jet (Ampleford et al. 2007), as predicted by numerical simulations (see Figure 5). Simulations further allow to investigate the longer term evolution; it is predicted that knots form in the beam by RT and KH instabilities, and

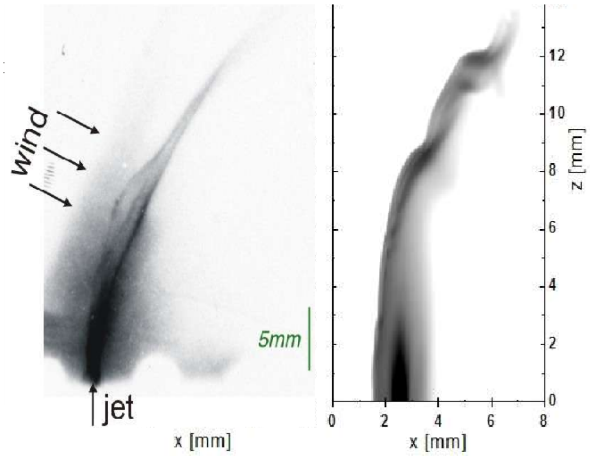

Fig. 5. Left: Experimental XUV image of a Z-pinch jet bent by a side wind. Right: Synthetic XUV image from a numerical simulation, from Ciardi et al. (2008).

that the bent jet may become fully turbulent on large scale. The growth of instabilities is affected by jet rotation (Ciardi et al. 2008).

9.3. *Radiative shocks (Hydro)*

The JETSET team of Observatoire de Paris, lead by C. Stehlé, has been conducting laser-driven shock experiments at the Prague Laser facility (PALS) to investigate the dynamics of fast radiative shocks, and the effect of 2D radiative losses. The experiments are confronted with numerical simulations performed by the JETSET associate team of Edouard Audit at CEA/Saclay, using the HERACLES hydro 2D-3D code, which includes a new radiative transport module (Gonzalez et al. 2007).

The precursor in the radiative shock experiment is slower than predicted by 1D shock models, while an excellent fit to experimental data is obtained in 2D assuming 60% radiative side losses through the walls of the shock tube. This effect had been neglected so far by experimentalists. Shock curvature is also observed (Gonzalez et al. 2006; Busquet et al. 2007). These results have direct applications to study X-ray/UV emission in fast shocks at the head of jets, and in accretion shocks.

10. MHD CODE DEVELOPMENT BY JETSET TEAMS AND MEMBERS

JETSET teams are heavily involved in the development of several MHD codes:

PLUTO: a modular Godunov-type MHD code optimized for astrophysical flows in the presence of discontinuities (Mignone et al. 2007) is publicly available at `http://plutocode.to.astro.it`. Several improvements have been recently implemented and tested by JETSET trainees:

- Non-equilibrium ionisation and cooling (with a dynamically selected integration algorithm for greater accuracy when $t_{\rm cool} > t_{\rm dyn}$) was introduced by O. Tesileanu (Torino JETSET PhD).
- molecular cooling and an H_2 chemistry module was introduced by Jamie O'Sullivan (Heidelberg JETSET PhD).
- Thermal conduction (Spitzer or user-defined, isotropic or directional) was introduced by Titos Matsakos (Athens/Torino JETSET PhD).

GORGON: a resistive 3D MHD code for laboratory astrophysics, was developed by A. Ciardi (Paris JETSET postdoc) in collaboration with Imperial College. It is now parallelised, and includes hydrogen ionisation and cooling to model astrophysical jets.

MARCOS: a numerical tool for the simulation of multiple time-dependent non-linear diffusive shock acceleration, was developed by Ferrand et al. (2008).

HYDRA: an explicit 3D MHD code for weakly-ionized plasmas (treating both ambipolar diffusion and the Hall effect) was developed by O'Sullivan & Downes (2006, 2007).

Finally, a numerical MHD algorithm comparison is being conducted, lead by Fabio De Colle (Dublin JETSET postdoc). The purpose is to (i) serve as a cross-validation by identifying the qualities and limitations of each code, (ii) provide reference tests for further developments, (iii) estimate the intrinsic errors present in a "standard" jet simulation. A test suite has been defined, with 1D, 2D, & 3D tests and benchmark examples. Tests have been run with AstroBear, Nirvana, Pluto, DeColle's code, and T.Downes's code, and the comparison is under way. For more information contact `fdc@cp.dias.ie`. A multi-purpose "pipeline" for computing synthetic emission maps and line profiles from numerical simulations is also being developed by Jose Gracia (Dublin JETSET postdoc).

11. CONCLUSIONS

The transdisciplinary approach of JETSET has been very fruitful.

Comparisons of observations and theoretical predictions have set new constraints on the jet launch radius and collimation agent (see Ray 2009). The large observed ejection/accretion ratio suggests that a magnetically driven outer wind from the disk and/or star-disk interaction zone is present in addition to the inner stellar wind.

MHD simulations confirm analytical results on the disk magnetisation ($\mu \simeq 0.5$) and turbulent resistivity ($\alpha_m \simeq 1$) needed to launch steady super-Alfvénic disk winds from accretion disks. They have also confirmed the stability of analytical solutions of steady stellar winds and disk winds, extended to more realistic boundary-conditions (disk truncation, removal of singularities). They further show that an outer MHD disk wind can significantly recollimate an inner stellar wind.

Thanks to both numerical studies and laboratory experiments, the study of unsteady ejection mechanisms (magnetospheric reconnection outflows, magnetic tower jets) has made spectacular progress and shows very promising properties. Their ejection efficiency and asymptotic collimation need to be investigated, as well as their interaction with an outer disk field (possibly carrying a wind).

On a larger scale, the effect of jet bending, jet rotation, weak ionisation, and B-field reversals on KH instabilities have been clarified by laboratory experiments and/or numerical simulations, and various stabilizing effects identified. 2D radiative effects have been shown to be important in fast shocks.

The potential of jets to stir up cloud turbulence appears potentially promising, although discrepancies between various workers remain to be clarified. An MHD code benchmarking effort has been started, which should serve as reference for future developments.

More results will be presented at the international conference on "Protostellar Jets in Context" organized by JETSET in July 2008 in Rhodes, where they will be compared with those of other teams and with current studies of jets from other astrophysical sources (AGNs, compact objects, evolved stars...).

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