Plasma jets from young stars: shocks and molecules

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Outline

- Introduction: Plasma jets from young stars
- Molecular jets from protostars
- Interaction of a time-variable jet with a surrounding disk wind (collaboration of Ph.D. student B. Tabone with A. Raga, invited by Plas@Par in June 2016)
- Conclusions
Plasma Jets from young stars

Main tracers in visible T Tauri stars
- Lines $10^4$ K plasma: H, O, S+, N+, F+, ...
- free-free radio continuum
- In a few cases: Xrays, synchrotron

- Vaxial ~ 100-400 km/s
- Onion-like V => 10 km/s

- Accretion-Powered: Mej/Macc ~ 10% (Cabrit +90, Hartigan+95, Ellerbroek+15)

- Collimated within 10-50 AU ➔ disk magnetic field (Hartigan+04, Cabrit07, Ciardi+15)
Protostellar jets are more nearby and have spectral line emission: good laboratory to understand jet origin in accreting systems.
Jet / wind origin?

- Possibly a combination of several flows
  - Stellar and/or magnetospheric (to brake down star below break up)
  - Disk wind (to extract ang.mom. from accretion disk, explain universality, collimate inner wind)
Jet velocity variability

- Fast moving knots, bipolar $\rightarrow$ internal shocks caused by velocity variability (Raga+90)

- Line ratios: shock-excited plasma $\Delta V \sim 20-140$ km/s, $X_{\text{ion}} \sim 1-10\%$, $n_e \sim 100-10^5$ cm$^{-3}$ (Hartigan+94; Lavalley-Fouquet+00)

- Knot spacing : 3 time scales
  $\approx 3$-10 yrs, $\approx 100$ yrs, $\approx 1000$ yrs
  
  $Raga+2002,2011; Hartigan+2007; Agra-Amboage+2011\ldots$
Molecular Jets from protostars

- Bright in molecules: H$_2$, SiO, CO, SO
- Mdot(atomic) $\sim$ 10% Mdot(molecular) 
  ($Spitzer, Herschel$; Dionatos+10, Nisini +15);
- Proper motion, collimation, knot spacing, identical to T Tauri atomic jets; but 10-100 x higher Mdot and Macc (Cabrit 02, Cabrit+07, Codella+14, Podio+15)

Dusty MHD disk wind becomes molecular at high Macc (Panoglou+12, Yvart+16)

→ can feed molecular jet?
Questions motivating our study

Assume a 2-component flow: disk-wind + time-variable axial magnetospheric wind:

- How would the disk wind be perturbed by inner jet bowshocks?
- Where could be still observe the « pristine » disk wind flow, to test MHD disk wind models (eg. rotation, chemical composition)?
- Could disk wind material enter the atomic bowshocks and explain fast molecular knots?

As a first step: simple HD cylindrical model
Analytical solution of interaction of jet bow-shock with uniform wind
Kinematics (analytical)

Immediate Postshock wind

Fully mixed jet+wind
Numerical simulations

- to test analytical predictions, and study long term interaction between several successive internal working surfaces.
- 2.5D cylindrical HD code *Coyotl* (Tabone & Raga)
  - second order Godunov method with HLLC Riemann solver
  - Atomic cooling function from Raga & Canto (1989)
  - 2000 x 350 domain, 1 AU /cell, Rj = 20 AU
  - Vary Vw/Vj
Numerical simulation with $V_w = 0.4V_j$

Similarities and *differences* with analytical predictions:

- **Shape and kinematics of bowshock agree with model**
- **Refilling from below by disk wind:**
  - *On-axis*: at predicted distance
  - *off-axis*: pushed outwards by weak shock (driven by cavity edge)
- **Refilling from above:**
  - Due to thermal re-expansion of (hot) shocked gas into emptied cavity
Long term evolution

\[ V_w = 0.4 \, V_j \]

Successive weak shocks create a conical quasi-stationary cavity of angle

\[ \tan(\alpha) \approx V_0 / V_j \]
Long term evolution

$V_w = 0.1 \ V_j$

Broader opening angle for smaller $V_w$

$$\tan(\alpha) \approx \max \left( \frac{V_0}{V_j}, \frac{2C_s}{V_w} \right)$$
Molecules in jet shocks?

Little disk wind material at bowshock apex beyond second shock

- Cannot feed molecules in axial jet knots far from source

Alternatives (future work):

- Fast molecular jet
- Postshock chemistry
ALMA observations of CO conical cavity in HH30

No residual envelope to confine jet bowshocks
Small cavity footpoint < 20 AU ➔ Interaction of jet with slow disk wind?

Vr ~ 5 km/s ➔ Vw ~ 9 km/s
Opening angle 35° close to simulation (25°)

Model of expanding ring
Vr ~ 5 km/s

Louvet et al. 2017
Conclusions

- Interaction between slow disk wind and faster time-variable jet:
- Pristine disk wind remains only between first few knots, and outside conical cavity
- HH30 may be example of conical cavity confined by slow disk wind; detailed comparison ongoing.
- Refilling of bowshocks by disk wind material not efficient beyond a few knot spacings: need other origin for molecules in jet knots: postshock chemistry? Initially molecular inner jet?