A Unified Model for Bipolar Outflows from Young Stars

Hsien Shang
Institute of Astronomy and Astrophysics, Academia Sinica
Taiwan
International Collaborators

Tony Allen, Jimmy Liu
(ASIAA)
Zhi-Yun Li, Mei-Yin Chou, Jeffrey Anderson
(U Virginia)
Jet-Driven versus Wind-Driven

- Jet Driven Bow Shocks
  - Raga & Cabrit 1993
  - Masson & Chernin 1993
  - Chernin et al 1994
  - Ostriker et al 2001
- Noticeable Features:
  - High velocity jet-like emissions; CO bullets

- Wind-Driven Shells
  - Shu et al 1991 (SRLL)
  - Li & Shu 1996
  - Shu et al 2000
- Low-velocity emissions from cavities near the sources
Kinematic Features of Jet-Driven Shells in Position-Velocity Diagrams in CO (J=1-0) and H$_2$

- A convex spur feature at the tips of high velocity H$_2$ bow shocks $\rightarrow$ Jet-Driven
- Examples: HH212, HH240/241, HH111

HH212, Lee et al (2000)
Kinematic Features of Wind-Driven Shells in Position-Velocity Diagrams in CO (J=1-0) and H₂

- A parabolic structure near the base of the driving sources \( \rightarrow \) Wind-shells
- Examples: VLA 05487, HH111, RNO 91
Extremely High Velocity Components

• Associated significantly with extremely young sources of protostars
• Carrying out approximately one order of magnitude or higher in mechanical luminosity than sources without EHV components (classical outflow sources)
• Examples: Class 0 sources → HH211, HH212, L1448…
The Power of X-Wind

• Optical illusion of the very cylindrically stratified density structures formed by magnetic hoop stress → Density Collimation in Jets

• Logarithmically slow streamline and magnetic fieldline collimation (conventional sense) → Wide-Angle Wind

• Best combination of creating a wide-angle wind and a jet component needed to explain lobe structures and PV diagrams observed in CO outflows
Fig. 1.—Geometry for shell of molecular gas, moving at speed $v_s(\theta)$ at position $r_s(\theta)$, as swept up by a protostellar wind moving at speed $v_w(\theta)$ into a molecular cloud core with the density profile given by eq. (1). The observer views the system at an inclination angle $i$ with respect to the rotation axis of the protostellar disk, and residual infall of cloud material onto the disk occurs in those directions near the equatorial plane not affected by the outflow.

Shu, Ruden, Lada, & Lizano (1990)
A Free Wind Simulating the X-Wind
**Isodensity Contours of Isothermal Magnetized Toroids Viewed Edge-On**

Li & Shu (1996) 
Allen, Li, & Shu (2003) 

The Choices of $Q(\theta)$

\[ M_{H_0} = (1 + H_0) \frac{a^3}{G}, \]
n=4
M=6
Shang et al (2005)
**Structures of Outflows**

- The lobes produced by an X-wind like wide angle wind interacting with a series of magnetized toroids can produce the right lobe shapes with different collimation ratios.
- The density structure as a result of very cylindrically stratified momentum input display cylindrically stratified layers.
- The central jet cores are surrounded by less dense material inside the lobes.
- Onion-like entrainment layers— the central jet may escape intact for slightly opened toroids.
• PV diagrams at 4 different inclination angles using Li & Shu (1996), equivalent to n=2

• The PV produced by a thin-shell may represent the outermost shell first encountering the ambient toroids

Position-Velocity Diagram from HH211

- PV in CO (2-1) display clearly wind-shell like behavior
- But, what is SiO 5-4 tracing?
- Clearly, SiO high-J transitions display different characteristics established by CO
- New SMA result: Hirano et al (2005), in preparation
Position-Velocity Spectrogram of RW Tau Jet

Woitas, Ray, Bacciotti, Davis, & Eisloffel 2002
Summary

- X-Wind combined with the series of toroids from magnetic collapsing envelopes can provide the right momentum input and ambient density environment needed to explain a variety of molecular outflow sources and their associated properties, together with intrinsic properties revealed by Herbig-Haro objects.
- The PV produced assumed by SRLL a thin-shell may represent the outermost shell first encountering the ambient collapsing toroids.
- Different layers of material may naturally display different PV and MV behavior—to be investigated in the near future—establishing different characteristics from historical CO low-J observations.
- Different density tracers such as SiO multi-transition lines can probe different density and excitation regions produced by both the primary jet and entrained material.
- New characteristics from the high-J transitions tracing high density and high temperature from models and observations.
- If SiO can exist in situ in the primary wind, maybe SiO high J transition can probe the naked jet near the base of outflows for youngest protostars?