The accretion-ejection connexion in Herbig Ae/Be stars

Catherine Dougados
UMI-FCA Dept. Astronomia, Universidad de Chile Santiago & Institut de Planétologie et d’Astrophysique de Grenoble

R. Martinez, S. Casassus, D. Mardones (UdeChile)
V. Agra-Amboage (Porto univ.), S. Cabrit (Obs. Paris), J. Ferreira, D. Coffey (Dublin Univ.), M. Benisty (IPAG) L.Podio (INAF) L. Ellerbroek, E. Whelan (Tubingen Univ.), S. Brittain, C. Adams (Clemson Univ.)
The accretion-ejection connexion

Low-mass jet

High-mass jet

Correlation $F_{\text{CO}}, FH_2$ vs $L_{\text{bol}}$

Collimated jets up to $L_{\text{bol}} = \text{a few } 10^5 L_{\odot}$ (30 M$_{\odot}$ ZAMS) for $t_{\text{dyn}} < 10^4$ yrs e.g. Kraus et al. 2010 Cesaroni et al. 2007 Guzman et al. 2010, 2012

Same ejection mechanism up to 20 M$_{\odot}$?
Low-mass atomic jets

Current observational constraints:
- \( R_0 < 5 \) au
- Small collimation scale < 30 au
- does not depend on evolution

Ray, Dougados et al. 2007 PPV, Cabrit 2007

Ray et al. (1997)
Low mass case: the role of Bstar and/or Bdisk

Magneto-centrifugal ejection

3 possible ejection sites

Blandford & Payne 1982

Zanni & Ferreira 2013
Magnetic Disk winds

Ferreira, Dougados, Cabrit 2006
- Reproduce collimation, kinematics mass flux of TTs jets

BUT
- cannot account for low vsini
- require large disk magnetization ($\mu \approx 1$)

Towards hybrid models including the star-disk interaction

Ferreira 1997
see e.g. Stepanovs et al. (2014) for recent numerical simulations
Herbig Ae/Be stars

The missing link in star formation
The workshop will take place in honour of the life and works of George H. Herbig

- Optically revealed 1-8 M☉ PMS stars: system well constrained
- Direct constraints from $R_*$ up to large scales
- Different internal structure (expected different $B_*$)
(Stellar) Magnetic fields in Herbig stars

< 10 % of Herbig Ae/Be stars with kG large scale magnetic fields

Wade et al. 2007, Alecian et al. 2013,
similar to MS Ap/Bp stars
+ decrease of magnetic flux with age
Fossil field origin ?

BUT

❖ Detection of 100 G field in 2 O MS stars
Fossati et al. (2015)
Jets around Herbig stars

- Spectroscopic evidence: rare but observational bias (Fe+ > 50% in embedded massive YSOs, cf posters)
- When detected: properties very similar to TTS jets

Collimation

Ejection efficiencies

\[
\frac{(dM_{\text{jet}}/dt)}{(dM_{\text{ac}}/dt)} = 10 \%
\]

Dust in atomic jets?

- Jet launch accompanied by dust occultation events and NIR flares
  - dust lifted in outer streamlines of disk wind? Podio et al. (2009), Agra-Amboage et al. (2011)
  - No B* detected (dipolar < 50 G) Alecian et al. 2014

$\Delta t=15\text{ yrs}$
Do jets rotate?

Steady ejection
Ferreira et al. (2006)

Rotation detections in TTs jets at limit of current instrumentation e.g
Coffey et al. (2015)

\( V \phi \propto M^{1/2} \) easier to measure in more massive jets
Small scale wide molecular flows

Outer streamlines of MHD disc wind \( r_0 > 1 \text{ AU} \) Panoglou et al 2012

Crucial tests to be performed with ALMA (angular momentum)
wide-angle wind component?
Probing the central engine: the HI lines

\[ \text{HI Br} \gamma \]

- **HI Br\(\gamma\) - Macc correlation**
  - van den Acker 2005, Garcia-Lopez et al. 2006 Donehew & Brittain 2011
  - Break at A0/B9 SpT?
Probing sub-au scales

milli-arcsecond angular resolution

Spectro-astrometry

Spectro-interferometry

Kraus 2014

20-30 μas precision on relative photocenter displacement
Inner keplerian gaseous disk

V921 Sco (Be)
CRIRES/VLT+AMBER/VLTI
Kraus et al. (2012)
HI Brγ originates from a keplerian gaseous disk inside Rsub

also Eisner et al (2010)
Formation in inner (disk?) winds

**embedded Be star**

Benisty et al. (2010)

**Transition B star**

VLT

0.1 au

Disk

Ramirez et al. in prep

VLTI

+350 km/s

-350 km/s

Transition B star

1 AU

Summary

- Low-mass T Tauri stars: atomic jets launched from inner AU regions
  - MHD disc winds most promising scenario but
    ★ don’t account for TTs low rotation rates
    ★ may pose pbs to disk physics

- Jets from intermediate-mass Herbig stars
  ➢ more rare than T Tauri case (observational bias ?)
  ➢ very similar properties to TTs jets
  ➢ weaker Bstar
  Seem to support disk-wind origin but low statistics yet!

- Next:
  ➢ Statistical studies of jet signatures vs stellar/disk properties
  ➢ Linking all scales on a few sources

Global view over the whole stellar mass spectrum is highly desirable!
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Magnetospheric accretion in T Tauri stars

Magnetospheric cavity: a few $R_{\text{star}} < 0.1$ AU

$R_{\text{trunc}} = f(B_{\text{star}}, M_{\text{acc}}) \approx R_{\text{cor}}$

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Camenzind 1990
Edwards et al. 1994
Hartmann et al. 1994
Jets in Herbig Stars

- Embedded B star (ZCMa-Be) driving collimated jet

Whelan et al. (2010)
The Accretion-Ejection connexion

Class 0 Protostar

Evolved Class I Protostar

- Universal accross evolutionary stages  \( \frac{dM_{\text{jet}}}{dt}/\frac{dM_{\text{ac}}}{dt} \approx 0.1 \)

Accretion-Powered

Hartigan et al. 1995; Antoniucci et al. 2008

- Universal in \( M_{\text{star}} \): from 24 M\( \text{Jup} \) to 20 M\( \text{\bigodot} \)
MHD Disk winds: A natural outcome of disk physics?

- Expectations from both numerical simulations of collapse and of MRI in disks (→ disk wind)

Ciardi & Hennebelle 2010

Lesur & Ferreira 2013
Impact for transport of angular momentum

Magneto-centrifugal wind can play a major role in angular momentum transport from $r = 0.3-5-10$ AU (Bai et al. 2013, Bai & Stone 2011) see also Baruteau et al. 2014 PPVI
Rotation measurements in Jets?

MODELS

OBSERVATIONS

HST/STIS

Transverse $\Delta V = 10-15$ km/s observed in 6 T Tauri jets with HST/STIS

Rotation signatures in jet body?

2- The origin of HI lines

Spectrally resolved interferometric observations (R=5000, 10^4)
AB Aur VEGA/CHARA observations in Hα (Rousselet-Peraut et al 2010) modelling with 2D radiative transfer of disk wind
Lima, Rousselet, Dougados et al. in prep

Variation of V across Hα