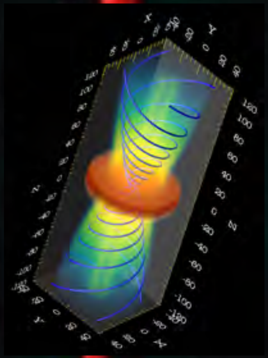
The accretion-ejection connexion in Herbig Ae/Be stars



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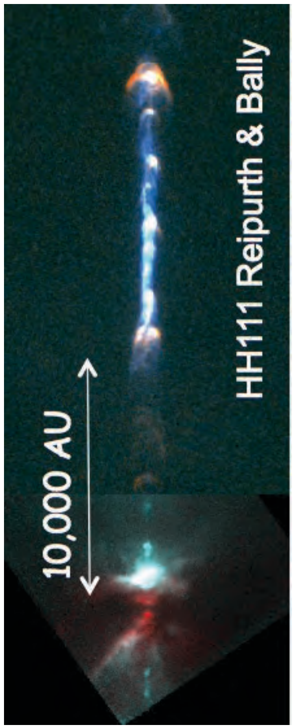
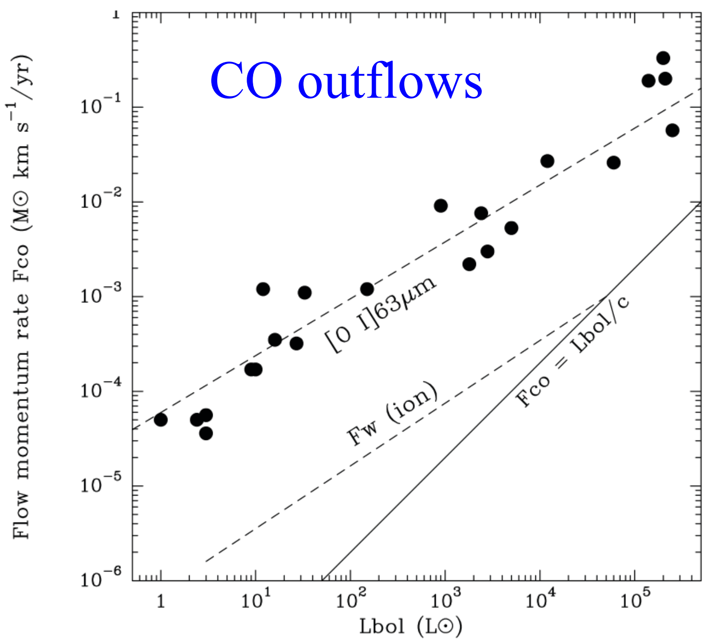
The accretion-ejection connexion

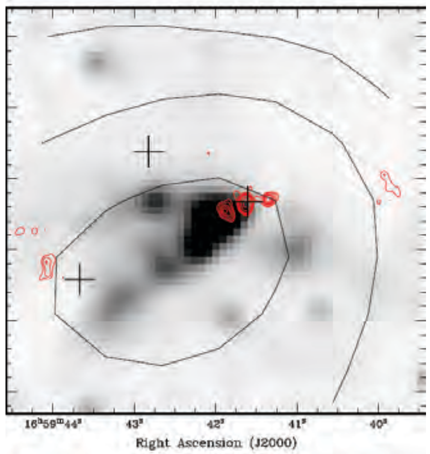
Low-mass jet





Richer et al 2000, Beuther 2002
see also posters by Caratti o Garatti, Pomohaci, Maud

High-mass jet

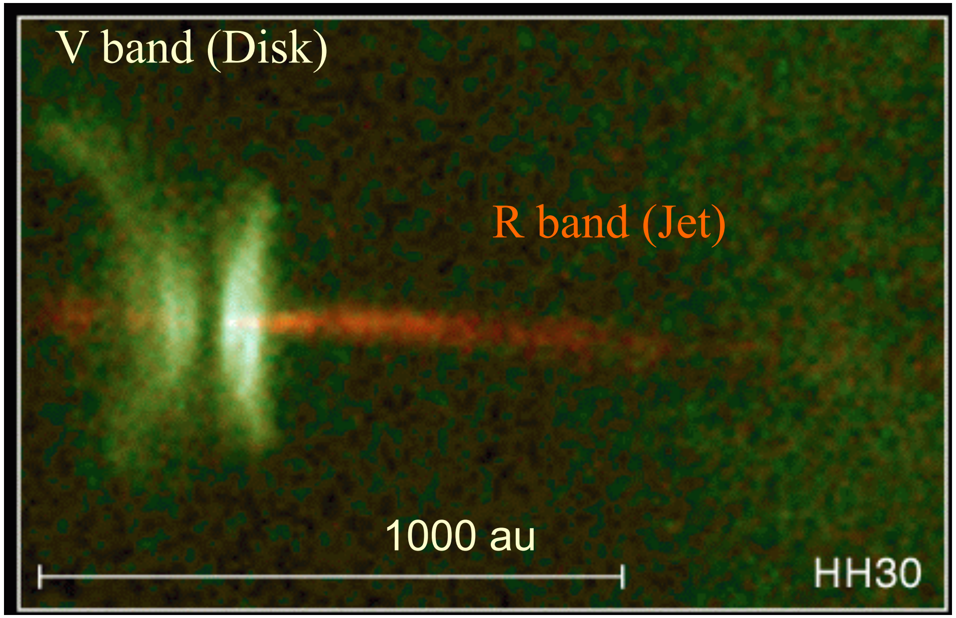


Guzman et al 2010

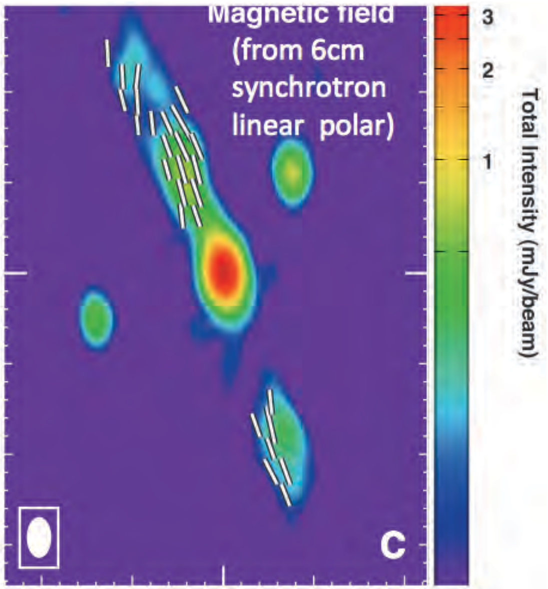
- Correlation F_{CO}, FH_2 vs L_{bol}
- Collimated jets up to L_{bol} = a few 10^5 $L_\odot$ (30 $M_\odot$ ZAMS) for tdyn < 10^4 yrs e.g. Kraus et al. 2010 Cesaroni et al. 2007 Guzman et al. 2010, 2012 …

Same ejection mechanism up to 20 $M_\odot$?

Low-mass atomic jets



Ray et al. (1997)



Carrasco-Gonzalez et al 2010, Science **330**, 1209 (2010)

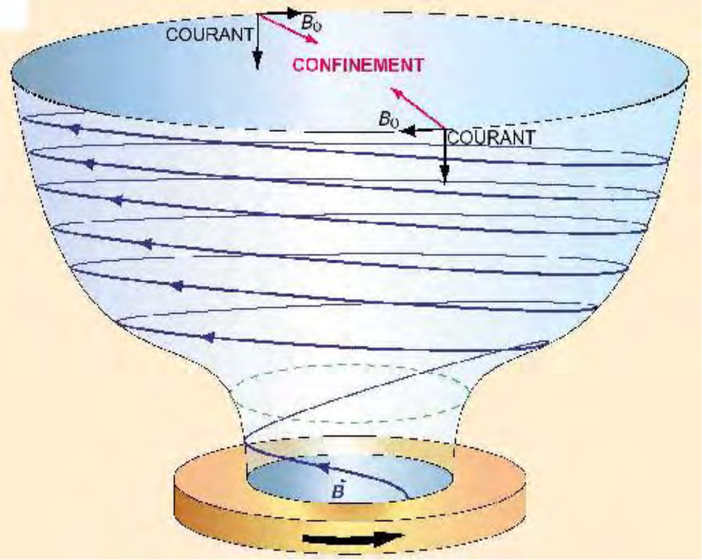
Current observational constraints:

- $R_0 < 5$ au
- Small collimation scale < 30 au
- does not depend on evolution

Ray, Dougados et al. 2007 PPV, Cabrit 2007

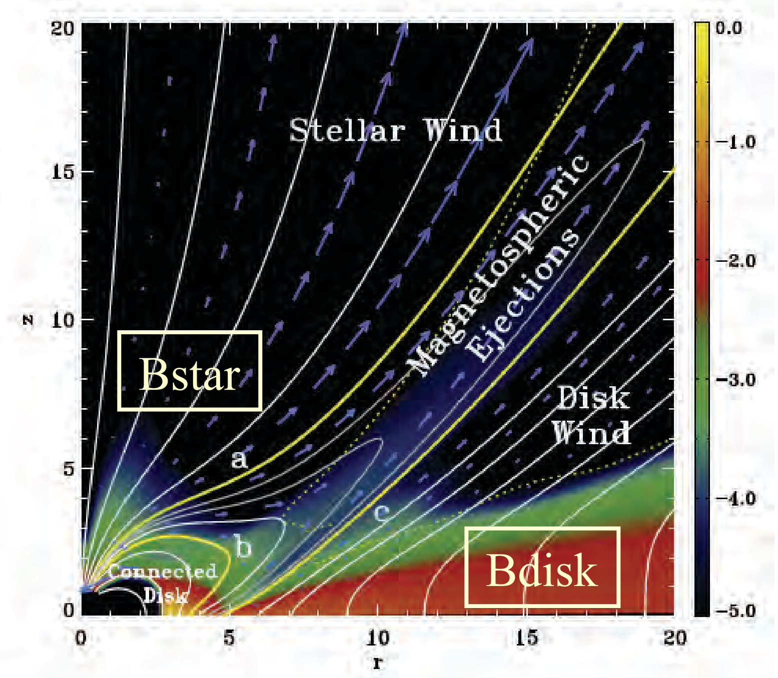
Low mass case: the role of Bstar and/or Bdisk

Magneto-centrifugal ejection



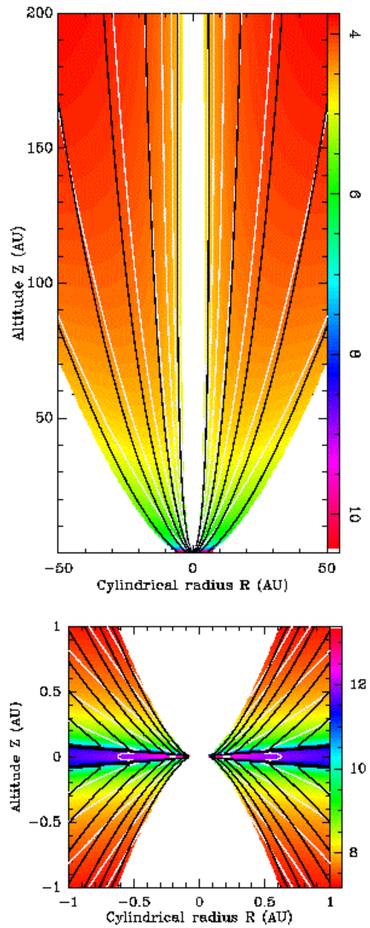
Blandford & Payne 1982

3 possible ejection sites



Zanni & Ferreira 2013

Magnetic Disk winds



Ferreira 1997

see e.g. Stepanovs et al. (2014) for recent numerical simulations

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*

- Optically revealed 1-8 $M_\odot$ PMS stars: system well constrained
- Direct constraints from $R_\star$ up to large scales
- Different internal structure (expected different $B_\star$)

(Stellar) Magnetic fields in Herbig stars

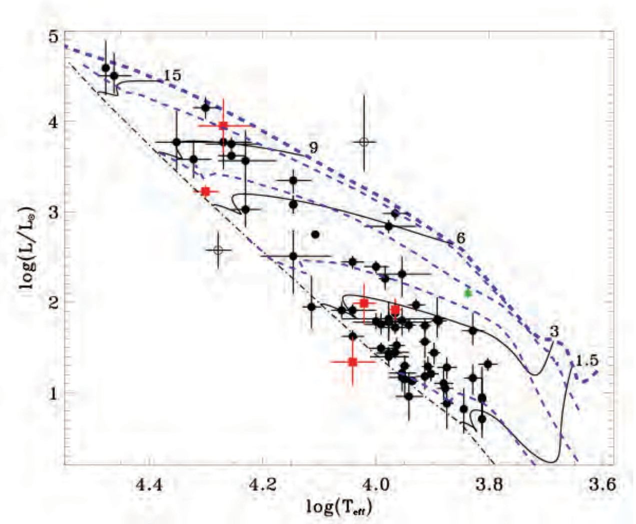
< 10 % of Herbig Ae/Be stars with kG large scale magnetic fields

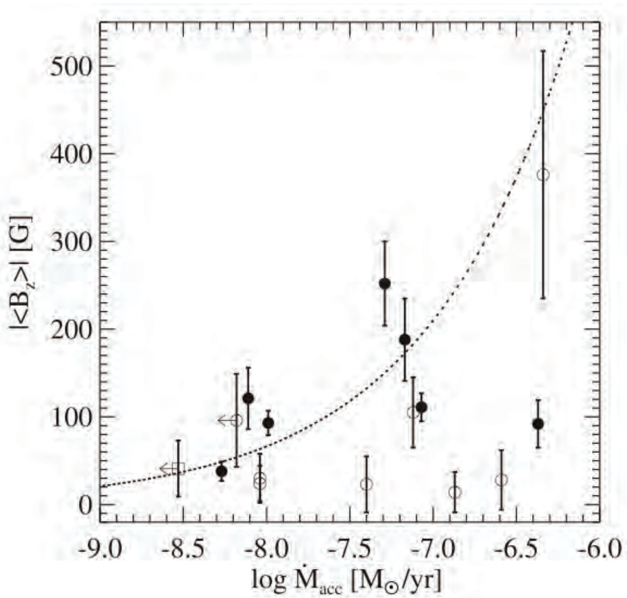
Wade et al. 2007, Alecian et al. 2013,

similar to MS Ap/Bp stars

+ decrease of magnetic flux with age

Fossil field origin ?





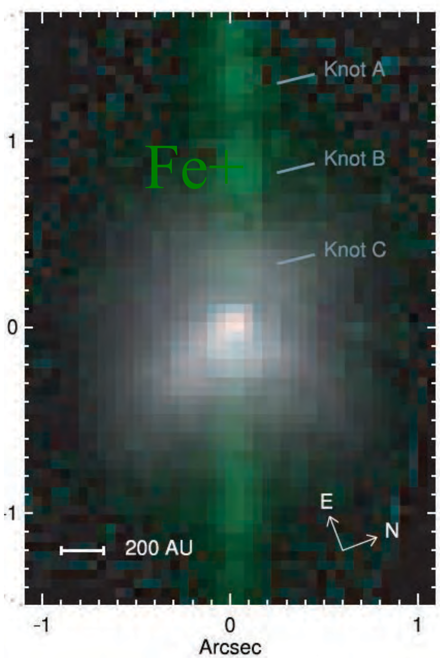
BUT

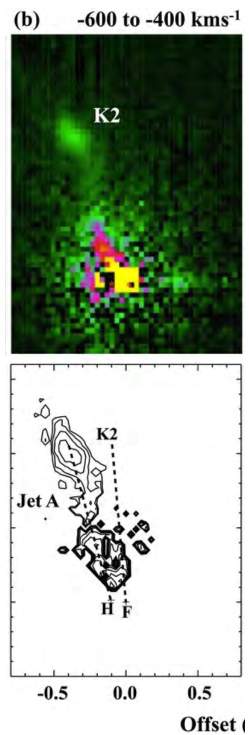
- B=100-500 G required to form accretion funnels at Mac=10^{-8} Msun/yr Wade et al 2007, Bessolaz et al 2008, Hubrig et al. 2009,2013
- *Detection of 100 G field in 2 O MS stars* Fossati et al. (2015)

Jets around Herbig stars

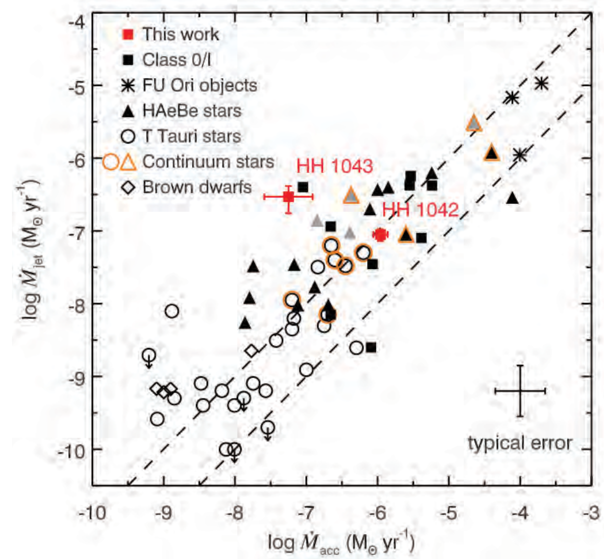
- Spectroscopic evidence: rare but observational bias (Fe^+ > 50% in embedded masisve YSOs, cf posters)
- When detected: properties very similar to TTS jets

Collimation





Ejection efficiencies



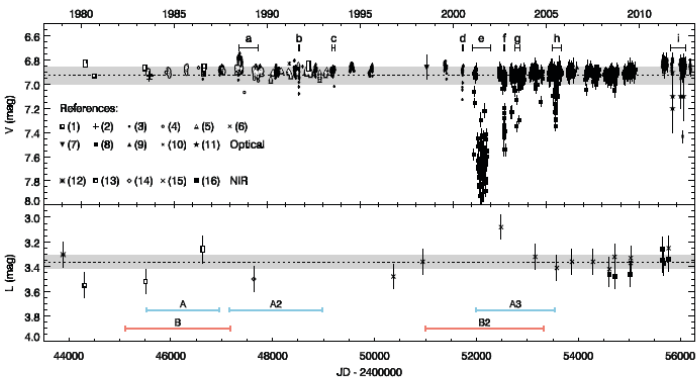
(dMjet/dt) / (dMac/dt) = 10 %

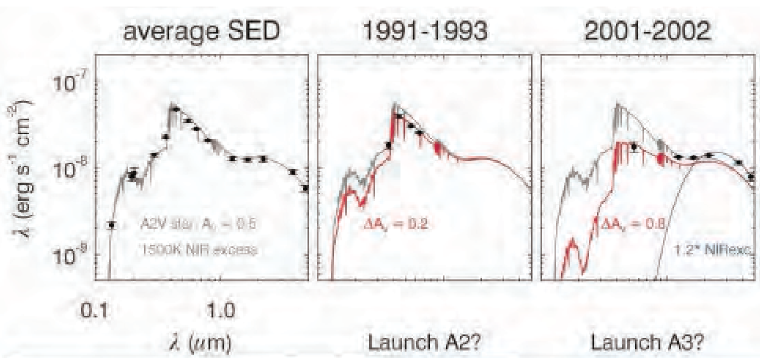
atomic jet

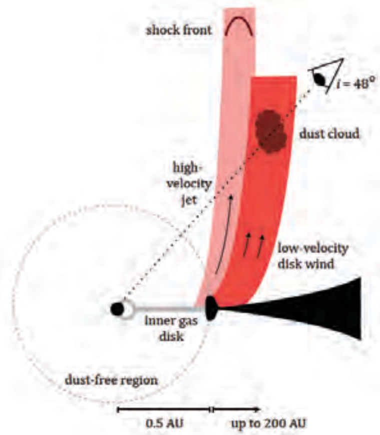
disk accretion rate

Perrin et al. (2007) Corcoran & Ray (1998) Melnikov et al. (2008)
Whelan et al. (2010) Ellerbroek et al. (2013, 2014) Reiter & Smith (2014)

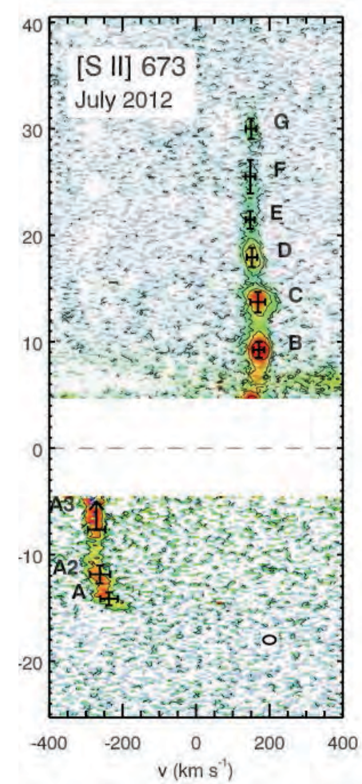
Dust in atomic jets ?







HD 163296



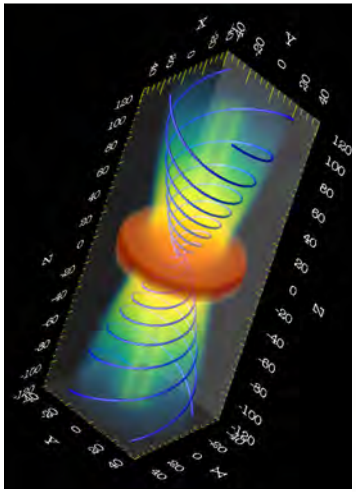
Δt=15 yrs

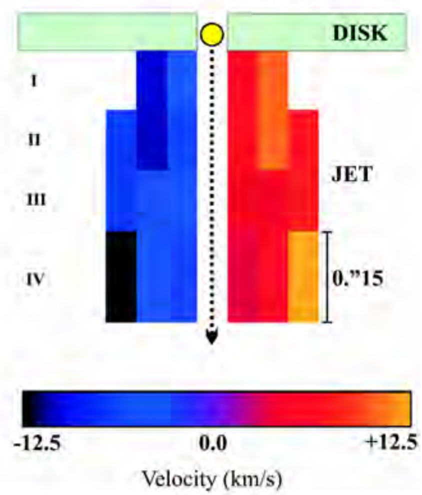
Ellerbroek et al. (2014)

- 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$_\star$ detected (dipolar < 50 G) Alecian et al 2014

→ **Origin in disk wind ?**

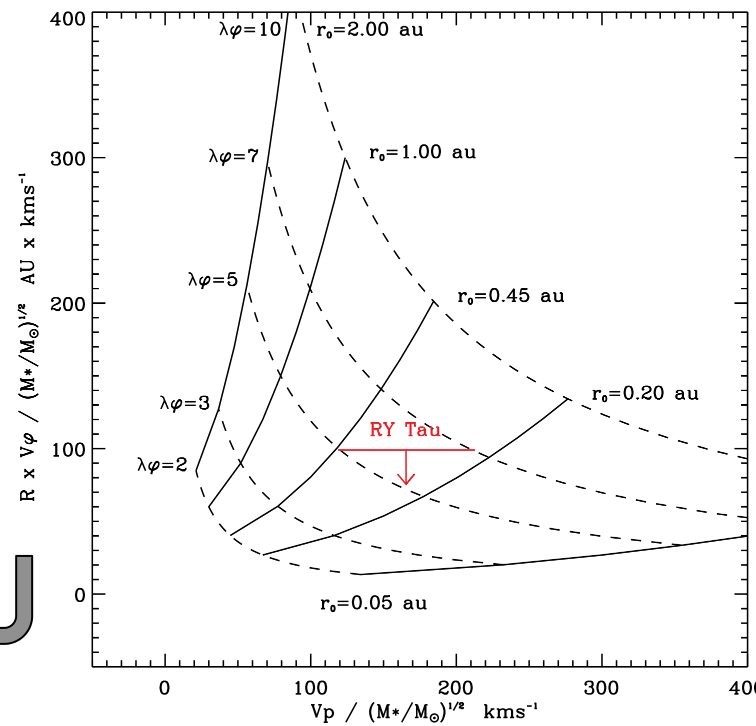
Do jets rotate ?





HST/STIS

MHD disk wind



specific angular momentum

poloidal velocities

Steady ejection

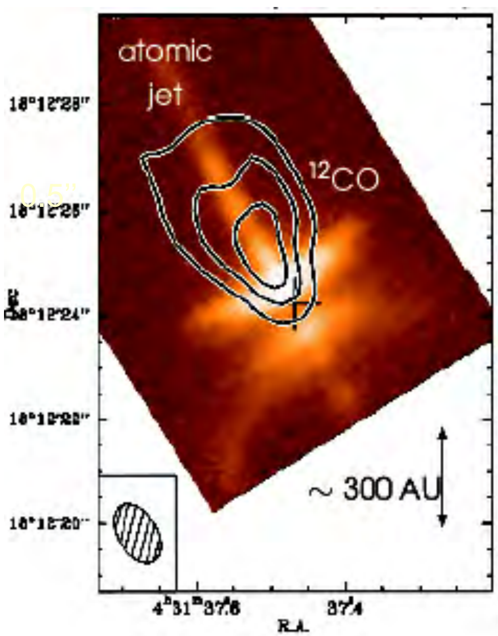
Ferreira et al. (2006)

- Rotation detections in TTs jets at limit of current instrumentation e.g Coffey et al. (2015)
- Vφ propto Mstar$^{1/2}$ easier to measure in more massive jets

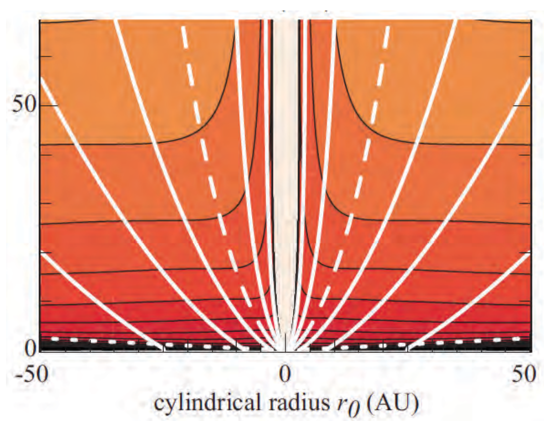
Small scale wide molecular flows

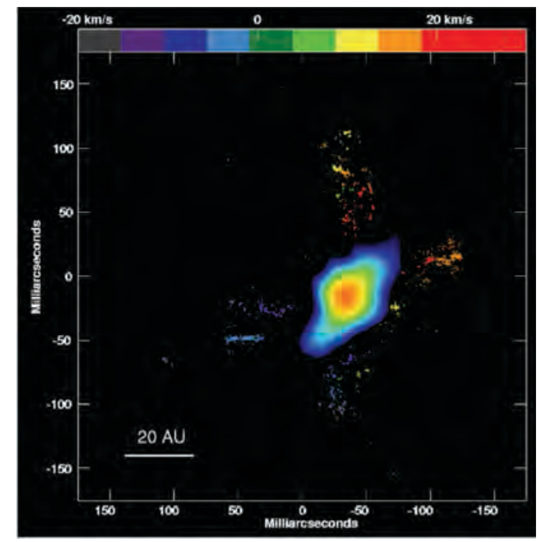
Low-mass

High-mass



HH 30 Pety et al. 2006





Orion source I
Vaidya & Goddi 2013

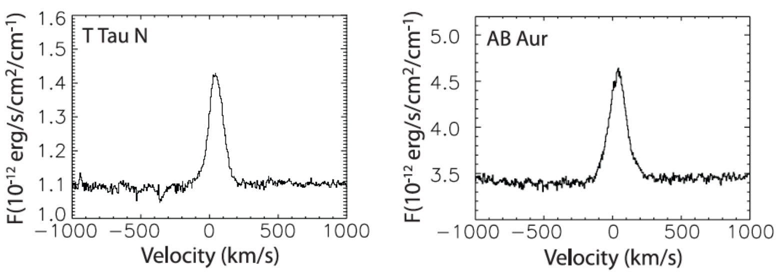
- **Outer streamlines of MHD disc wind** $r_0 > 1$ AU Panoglou et al 2012

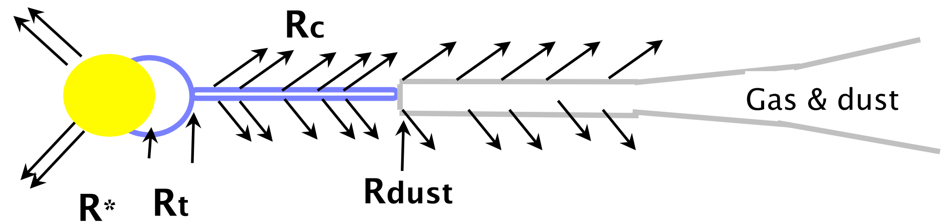
  Crucial tests to be performed with ALMA (angular momentum)

  wide-angle wind component ?

Probing the central engine: the HI lines

Brγ

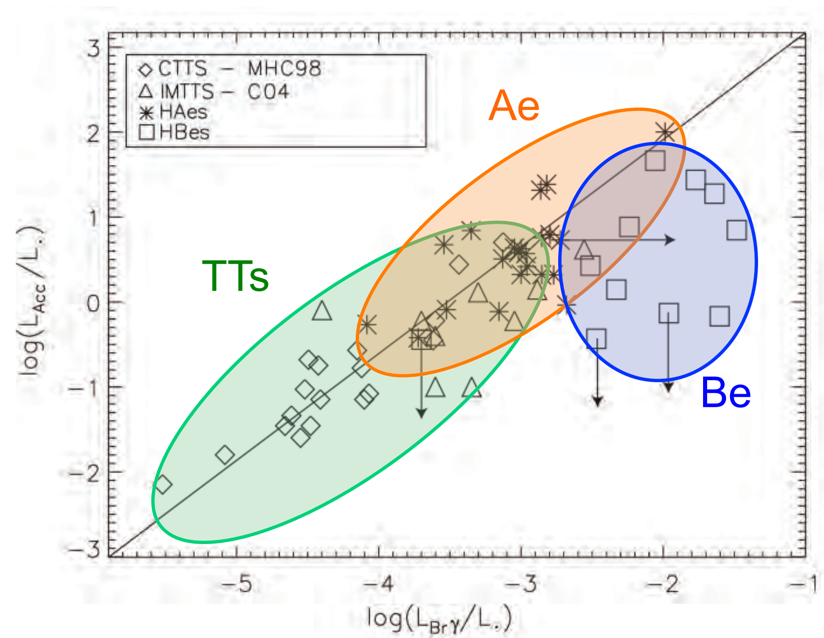




- HI Brγ - Macc correlation

van den Acker 2005, Garcia-Lopez et al. 2006 Donehew & Brittain 2011

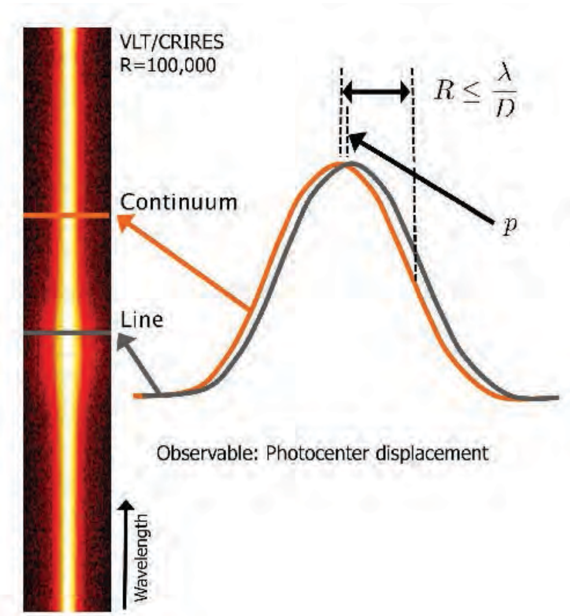
Break at A0/B9 SpT ?



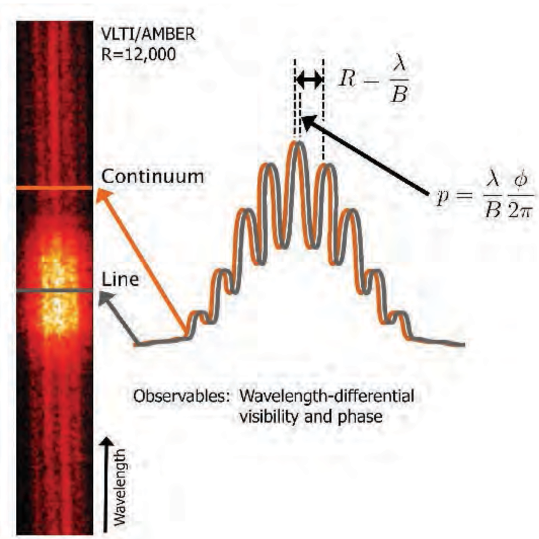
Probing sub-au scales

milli-arcsecond angular resolution

Spectro-astrometry



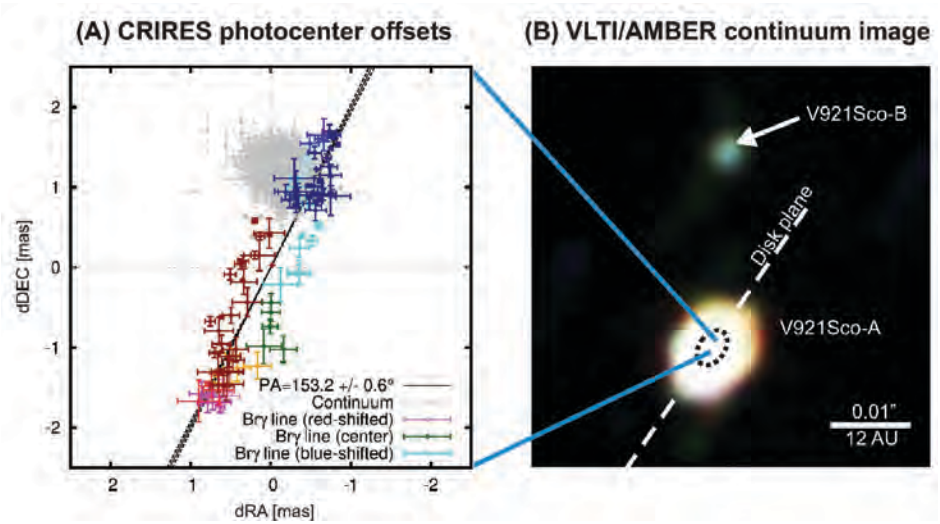
Spectro-interferometry



Kraus 2014

20-30 µas precision on relative photocenter displacement

Inner keplerian gaseous disk



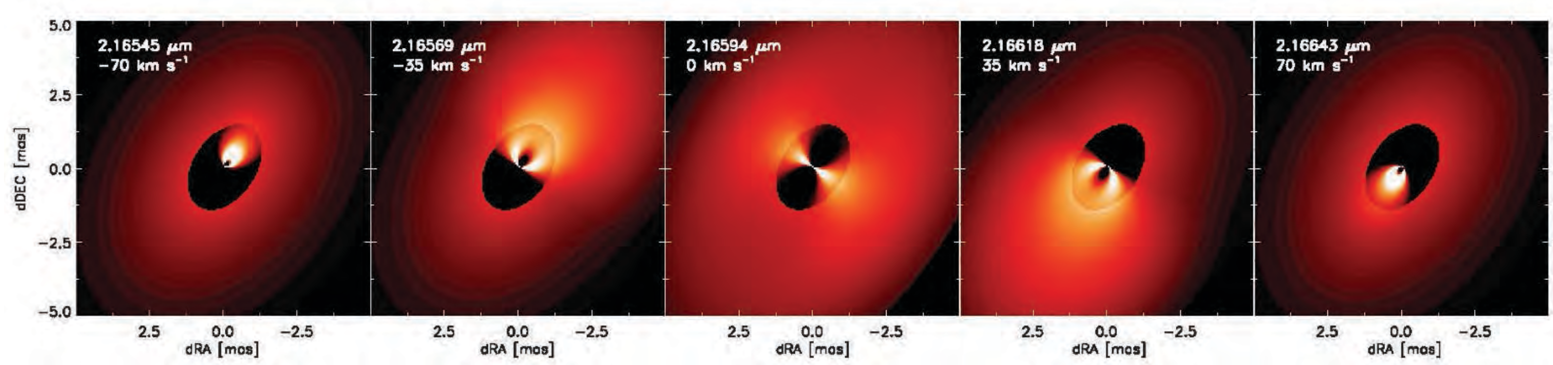
V921 Sco (Be)

CRIRES/VLT+AMBER/VLTI

Kraus et al. (2012)

HI Brγ originates from a keplerian gaseous disk inside Rsub

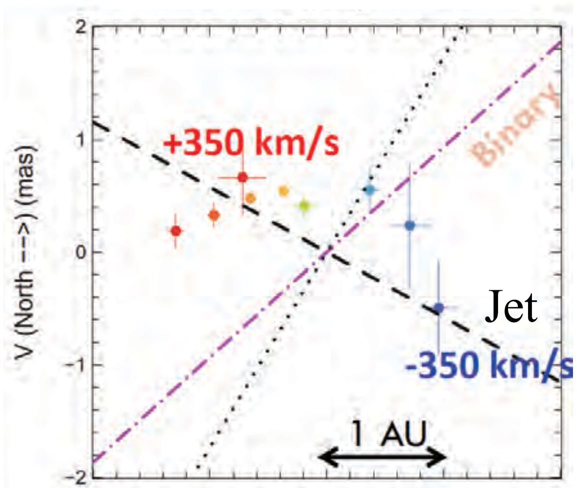
also Eisner et al (2010)



Formation in inner (disk?) winds

VLTI

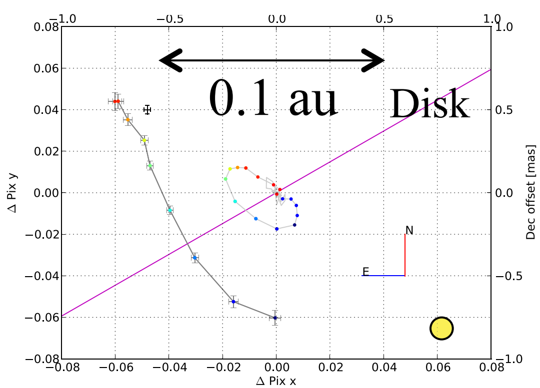
embedded Be star



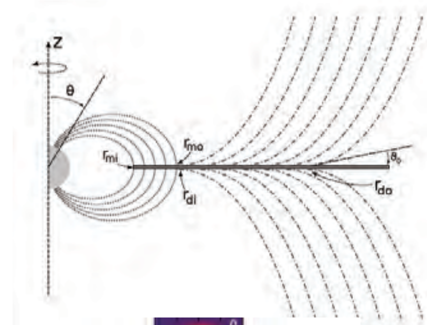
Benisty et al. (2010)

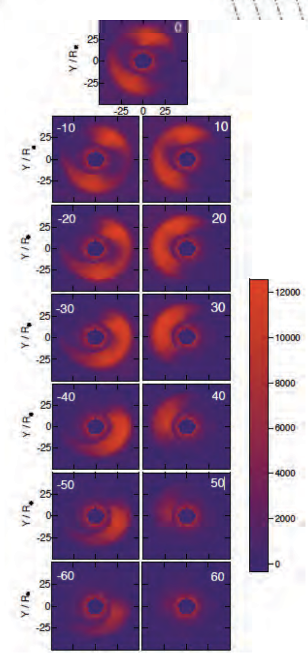
VLT

Transition B star



Ramirez et al in prep





also: Weigelt et al. (2011),
Garcia-Lopez et al. (2015),
Rousselet-Peraut (2010)

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 !

Many Thanks to

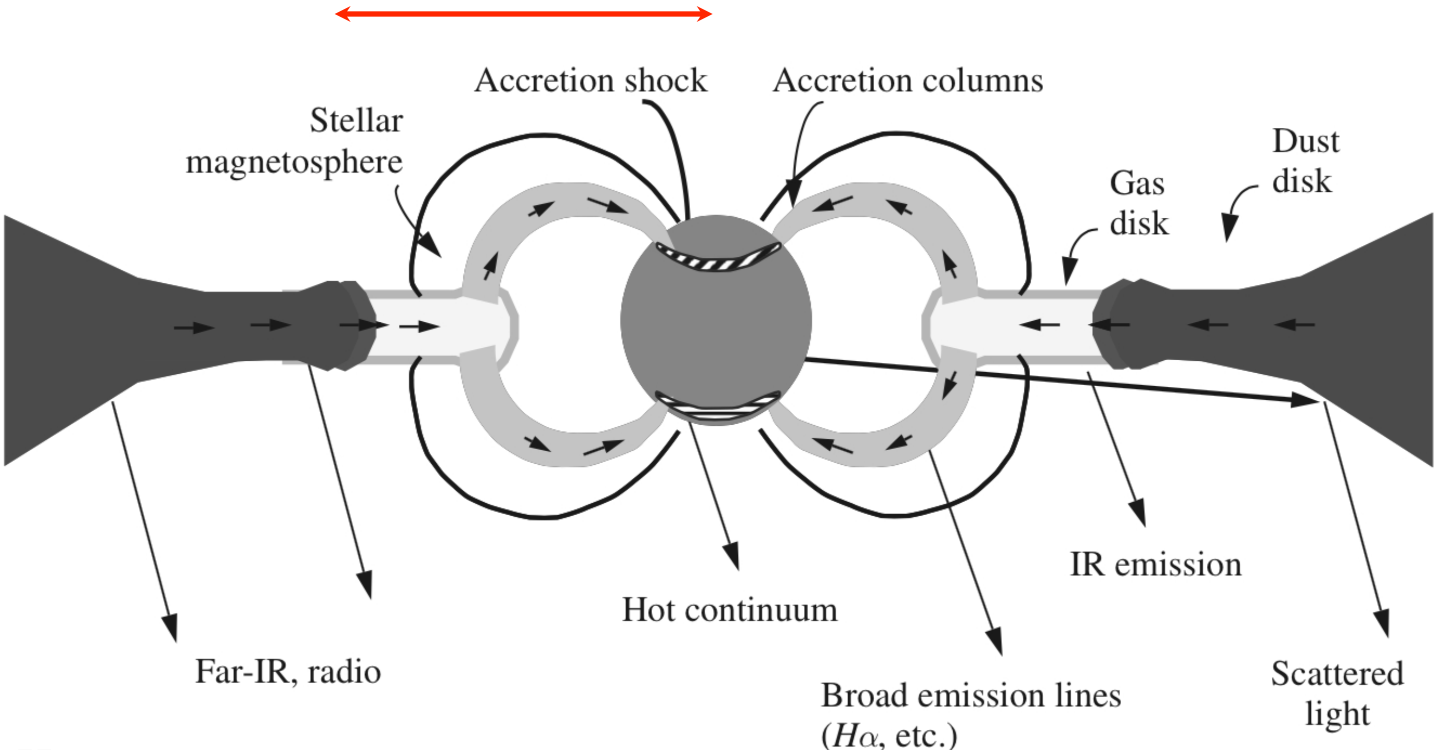
R. Ramirez, S. Casassus, D. Mardones, G. Garay (Dept. astronomia Universidad de Chile) A. Dunhill, J. Cuadra (PUC Santiago) A. Hales (Alma-Santiago)

P. Garcia, V. Agra-Amboage (Porto) E.Whelan (Tubingen) S. Brittain, C. Adams (Clemson Univ. USA) S. Alencar, G. Lima (Belo Horizonte Brasil) M. Bonnefoy (MPIA-Heidelberg) L. Ellerbroek (Amsterdam)

S. Cabrit (LERMA/Obs. Paris) J. Ferreira, J. Bouvier , M. Benisty, K. Rousselet-Perraut, J. Bouvier (IPAG) J.F. Donati (OMP)

Magnetospheric accretion in T Tauri stars

Magnetospheric cavity: a few Rstar < 0.1 AU

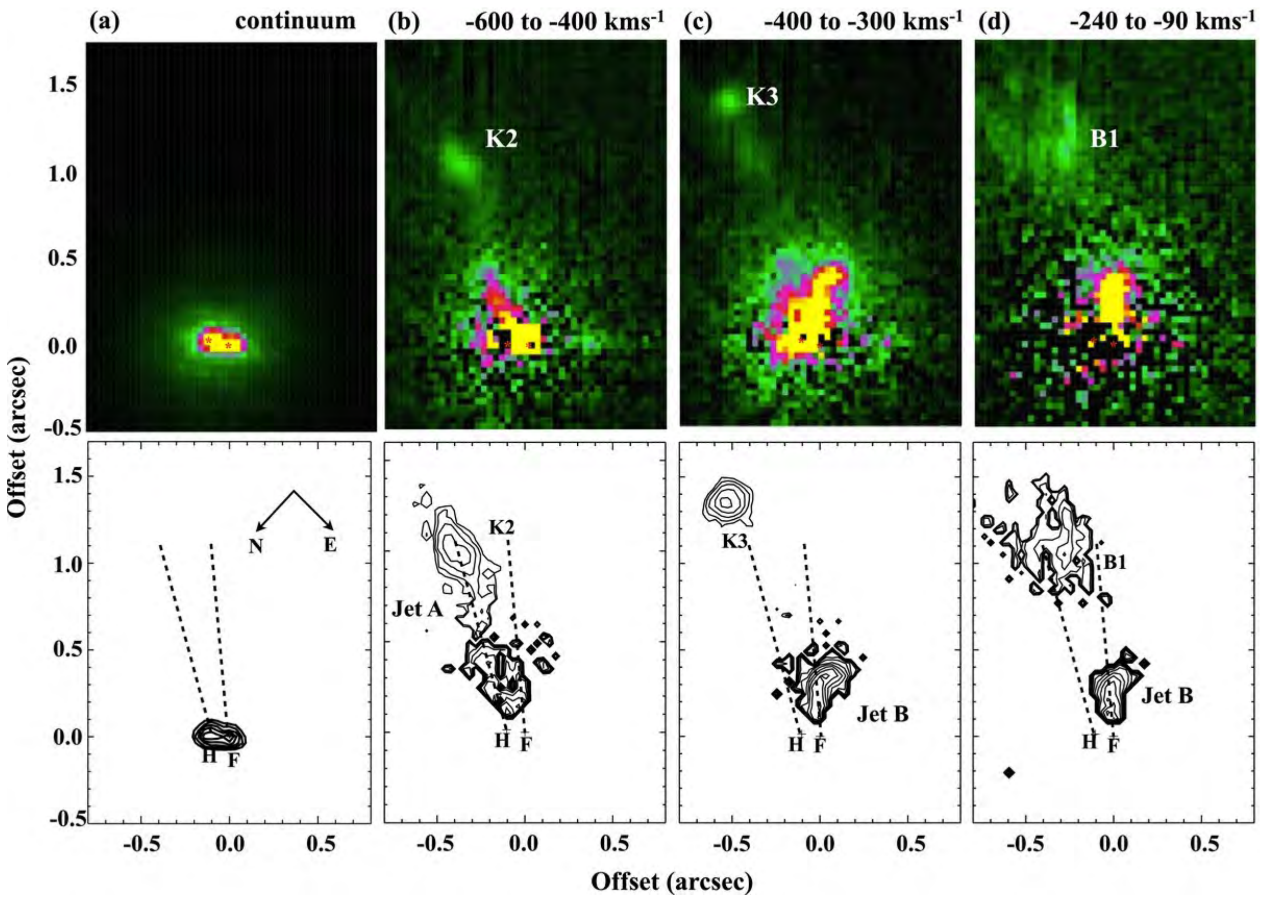


Rtrunc = f(Bstar,Macc) ≈ Rcor

Camenzind 1990
Edwards et al. 1994
Hartmann et al. 1994

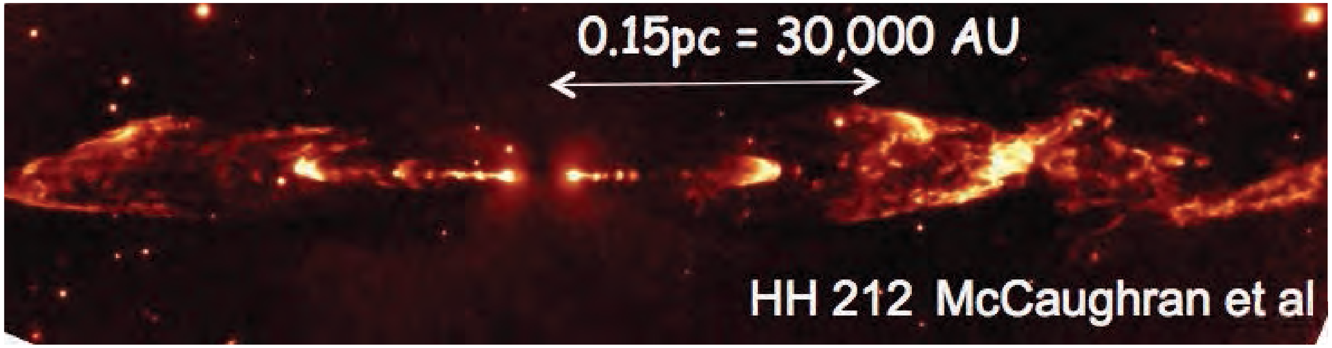
Jets in Herbig Stars

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

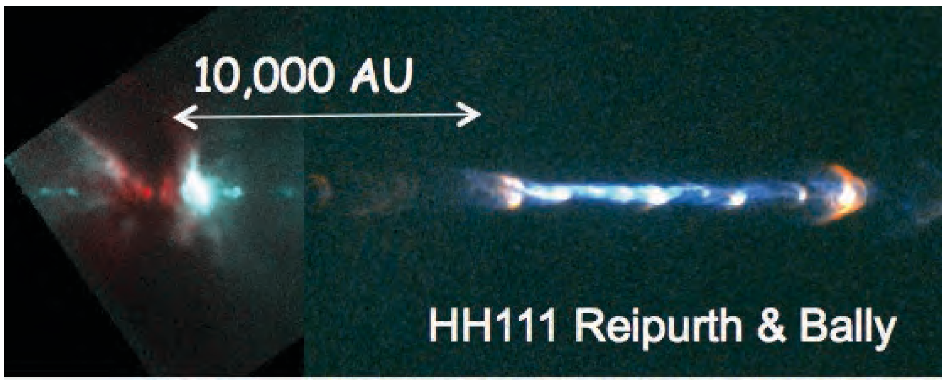


Whelan et al. (2010)

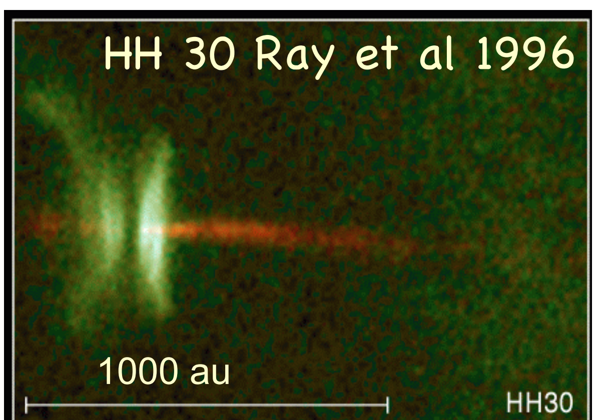
The Accretion-Ejection connexion



Class 0 Protostar



Evolved Class I Protostar



Class II
Disk only

- Universal accross evolutionary stages dMjet/dt/dMac/dt ≈ 0.1

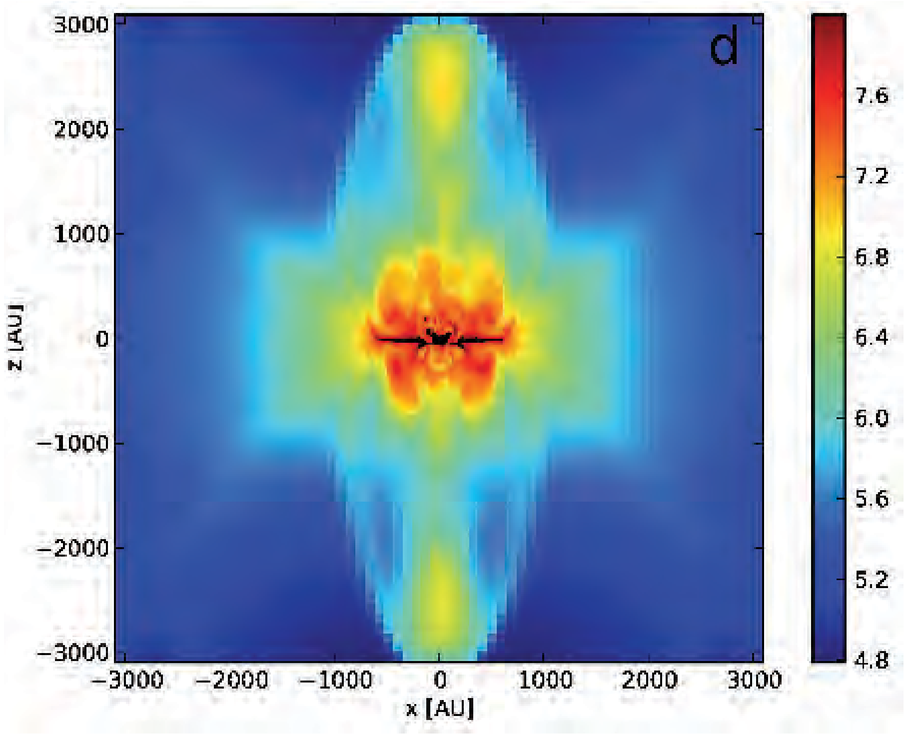
  Accretion-Powered

  Hartigan et al. 1995; Antoniucci et al. 2008

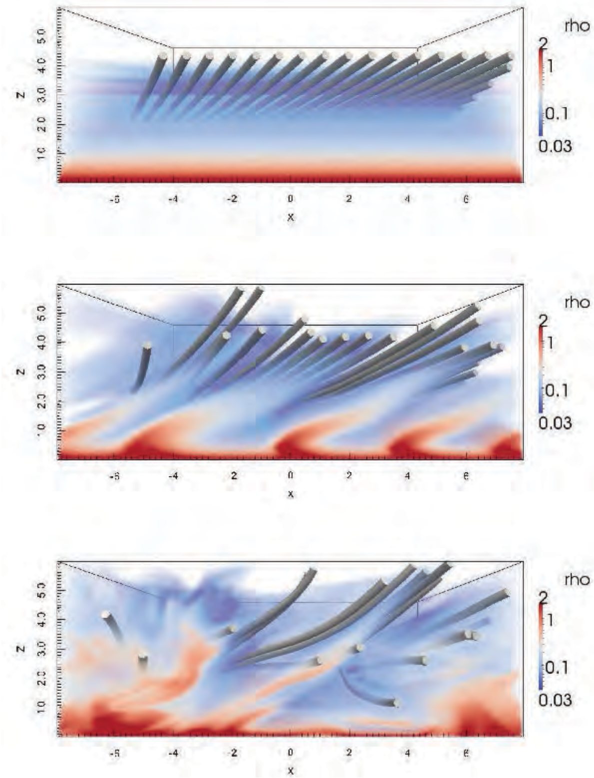
- **Universal in Mstar**: from 24 Mjup to 20 $M_\odot$

MHD Disk winds: A natural outcome of disk physics ?

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



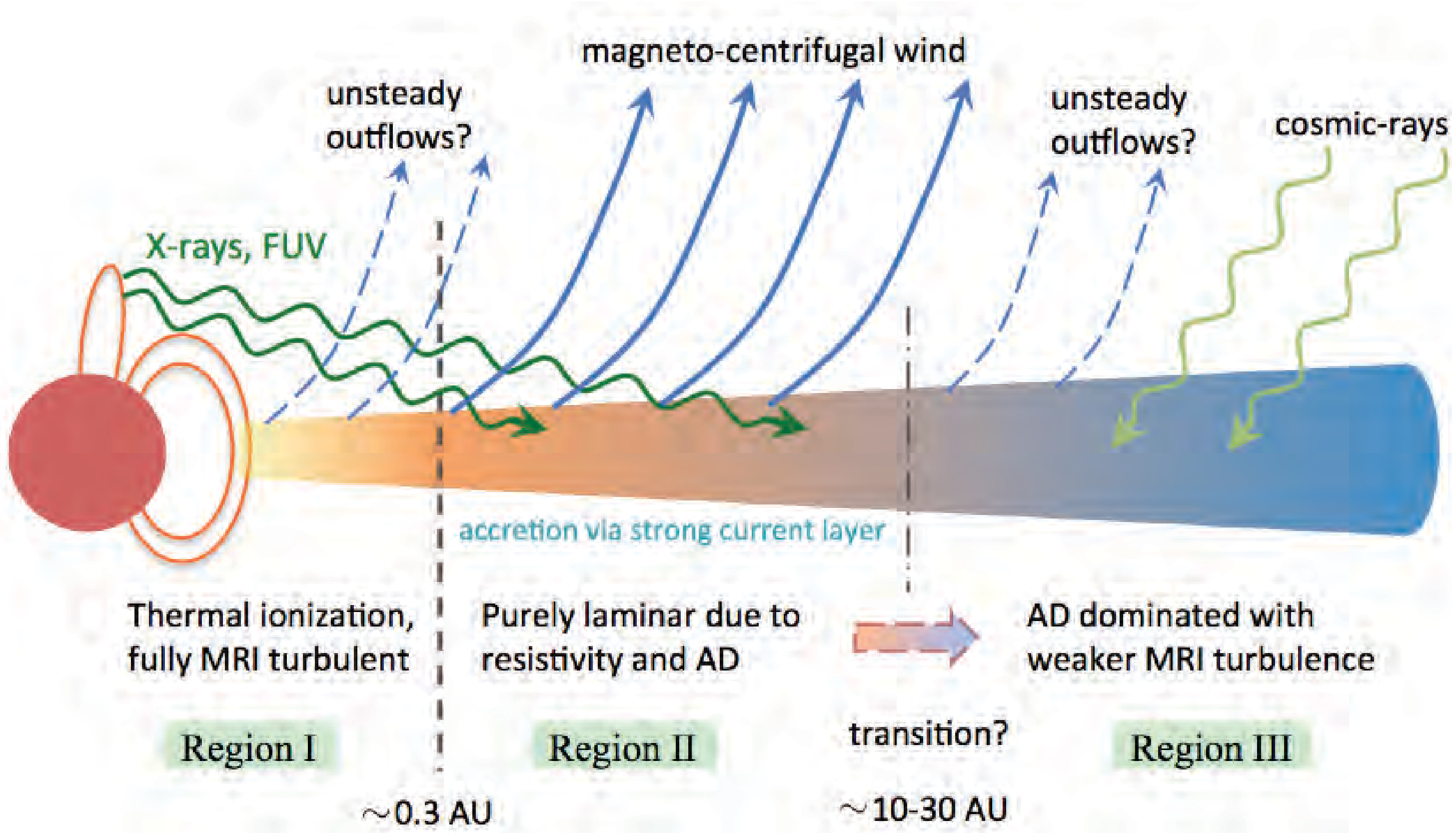
Ciardi & Hennebelle 2010



Lesur & Ferreira 2013

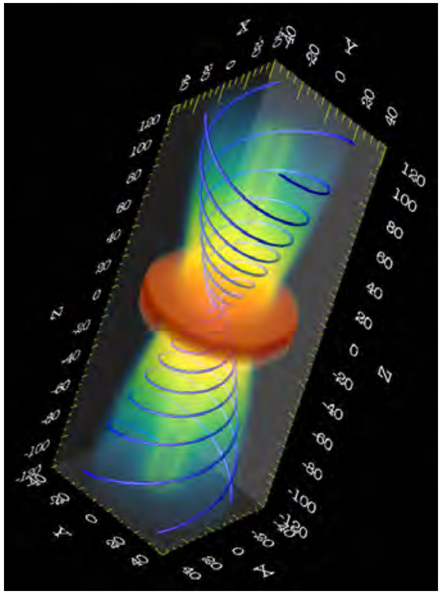
Impact for transport of angular momentum

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

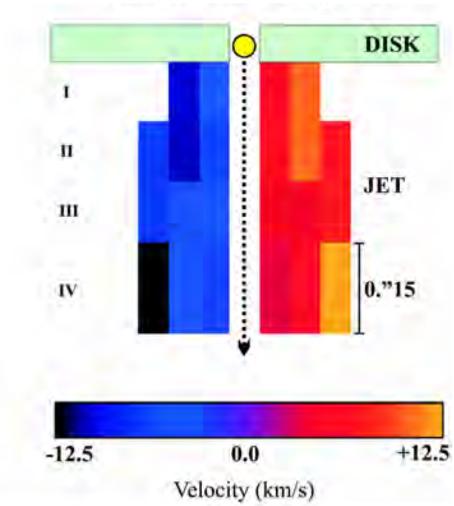


Rotation measurements in Jets ?

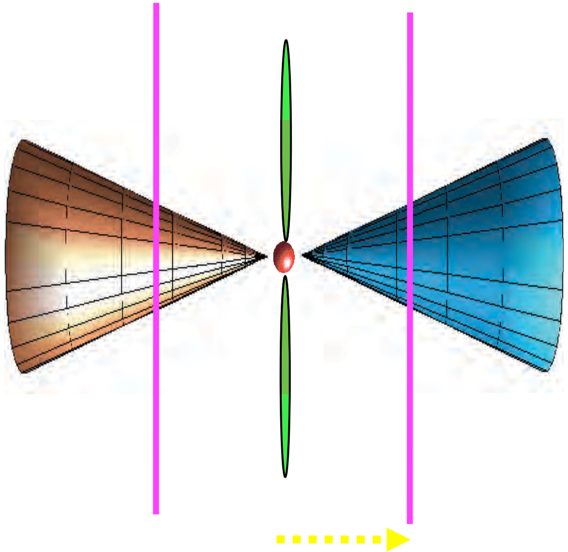
MODELS



OBSERVATIONS



HST/STIS



Transverse ΔV = 10-15 km/s observed in 6 T Tauri jets with HST/STIS

Rotation signatures in jet body ?

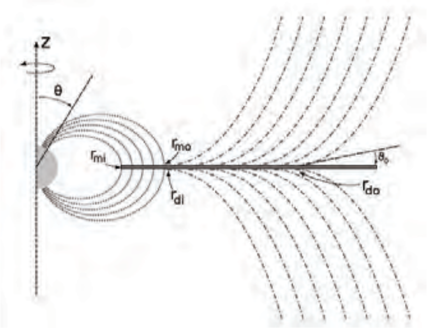
Bacciotti et al. (2002) Coffey et al (2004, 2007) Woitas et al (2003)

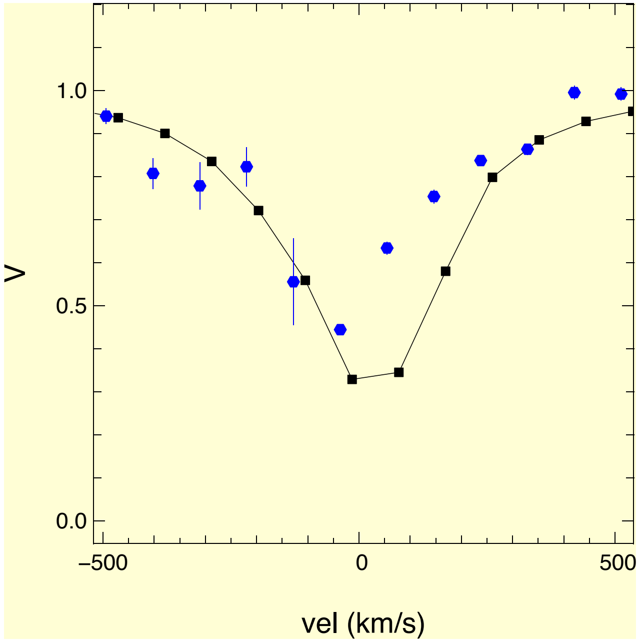
2- The origin of HI lines

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

See also: Benisty et al (2010) Weigelt et al. (2011) Be stars