Observations of jet and outflow launching regions

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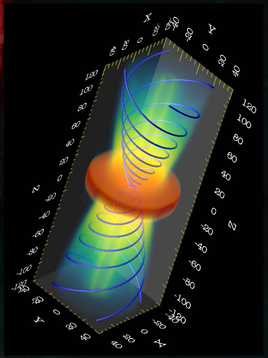

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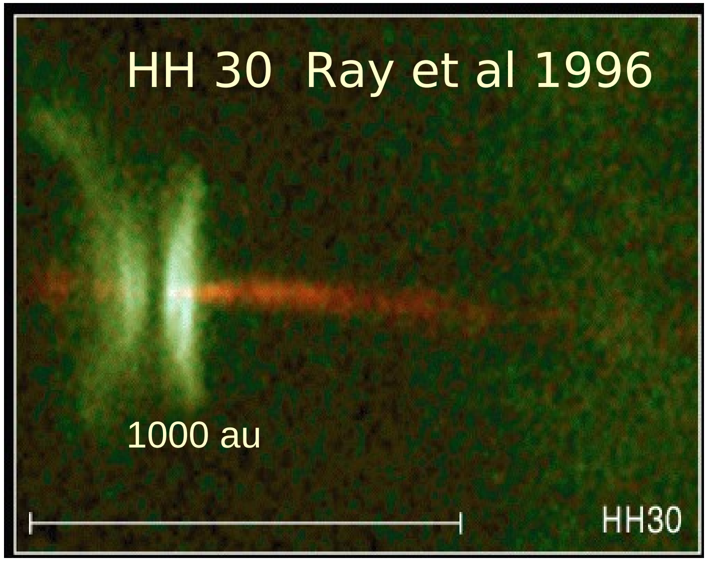
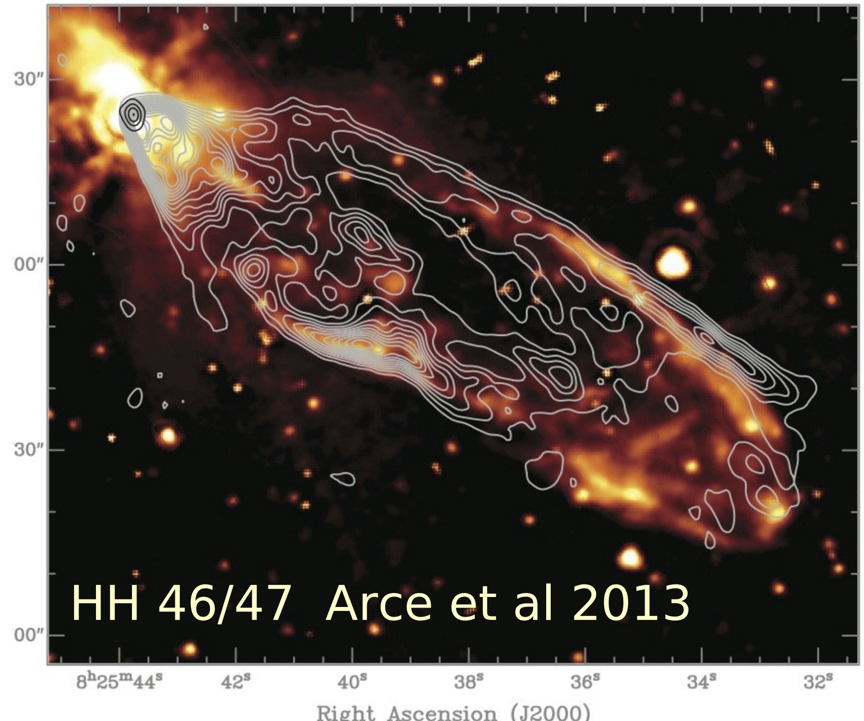
Resolved flow signatures

Fast axial Jets



V = a few 100 km/s
ionic (OI, NII, SII, FeII)
molecular (H_2, SIO)

Low-velocity outflows



V = a few 10 km/s
molecular (^{12}CO)

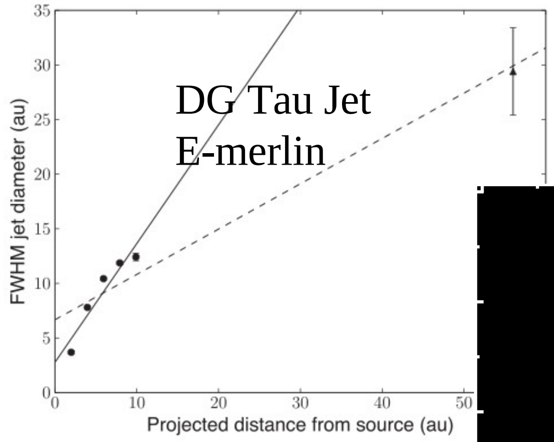
Link between the two components and the role they play in extraction of mass and angular momentum from the envelope/disk are still open issues

I- The origin of atomic jets

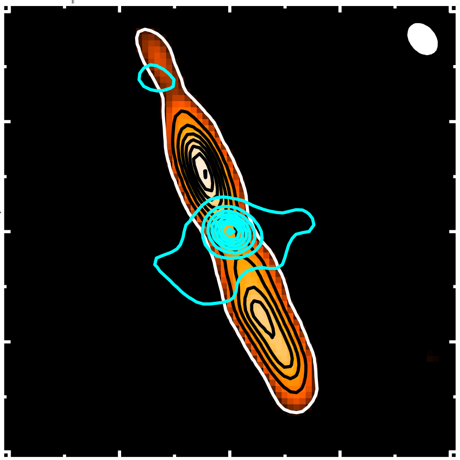
Jets: collimation

- Collimation scale z= 35-50 UA
  r < 5 au Ray et al. 2007 PPV

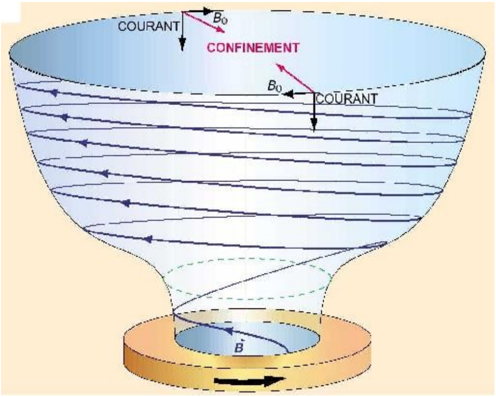
- ✓ DG Tau (cm) r < 2.5 au
  Ainsworth+13



SiO Jet HH 212



Similar in molecular jets from Class 0 sources Cabrit+07, Codella+14, Podio+15



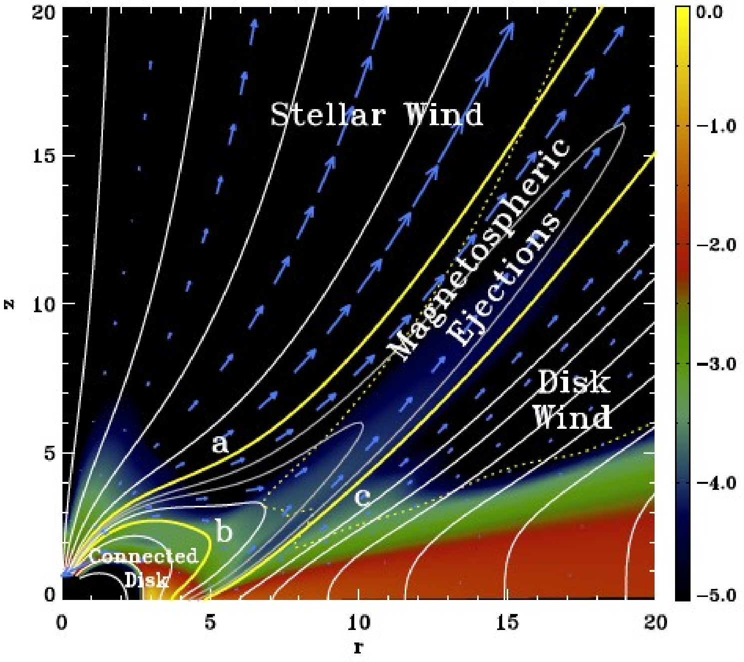
Collimation by large scale outer B field

$J_z \times B_\varphi$: self-collimation

Blanford & Payne 1982

see Cabrit 2007 (JETSET I school proceedings)

The launching site



Unique info on B disk magnetisation in inner aus, impact on:

➔ Angular momentum transport

➔planet formation and photoevaporation models

- density jump, dust trap
- screen inner UV X rays
- migration processes

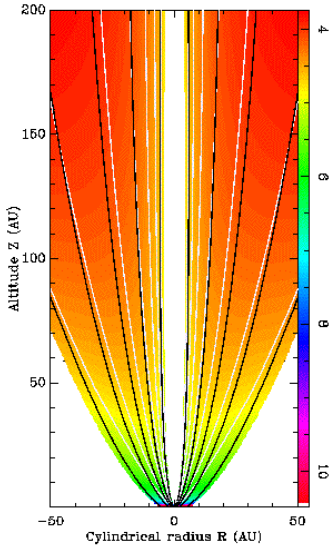
cf Baruteau+14 PPVI, talk by A. Gomez

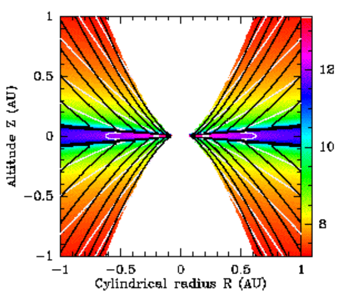
Atomic Jets: onion like structure

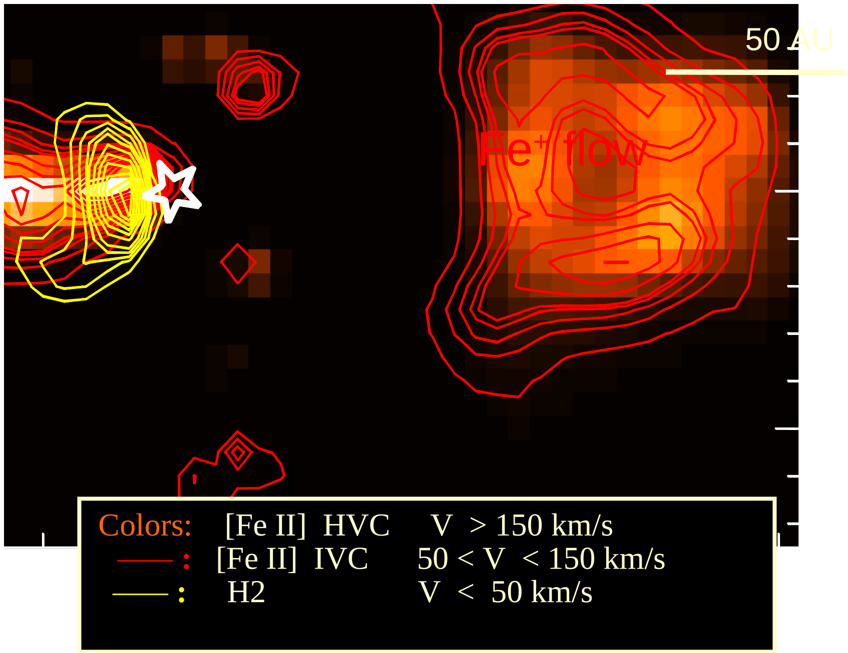
Nested velocity structure in atomic flow Bacciotti et al. 2000

Disk Winds: $V_p = (2\lambda-3)^{1/2} \times V_{kep}(r_0)$ (with $2 < \lambda < 10$) $\lambda = (r_A/r_0)^2$

warm solutions (heating disk surface)

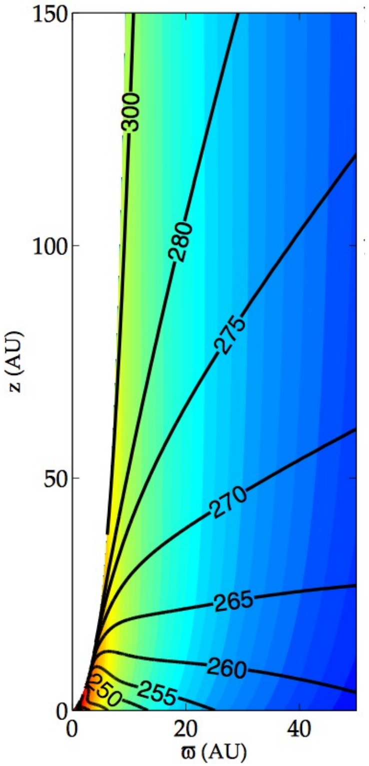




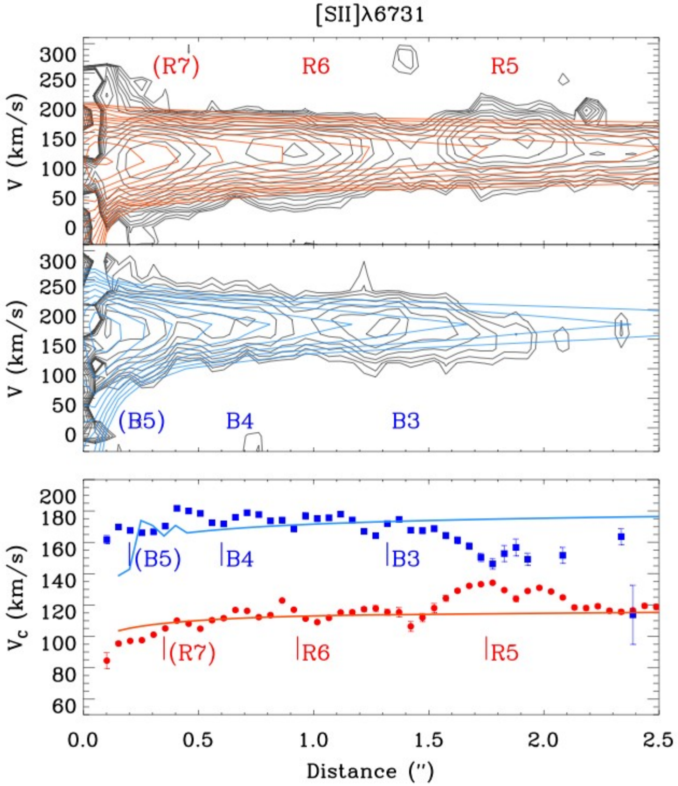


Agra-Amboage et al. (2011)

Jets with narrow line widths



Shang+02



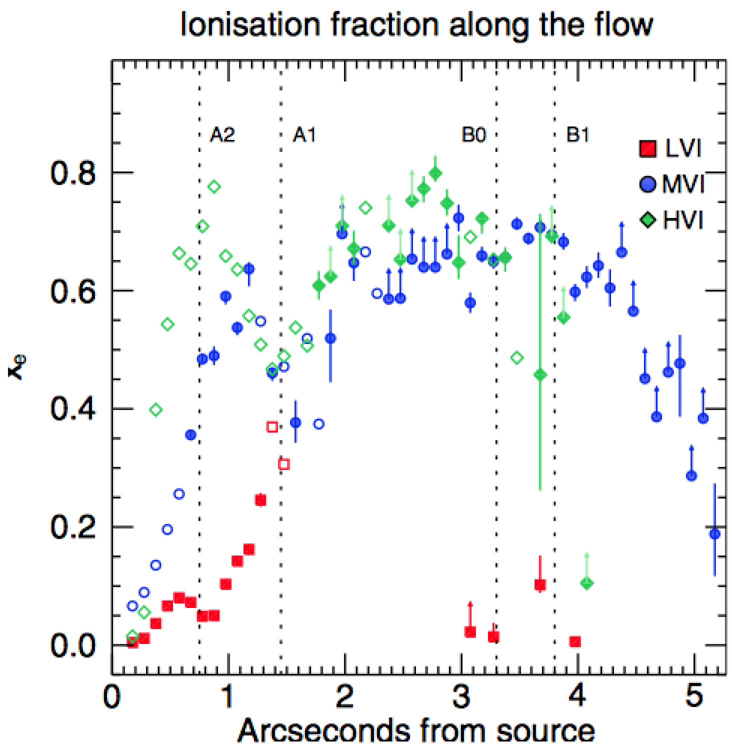
Liu & Shang 2012

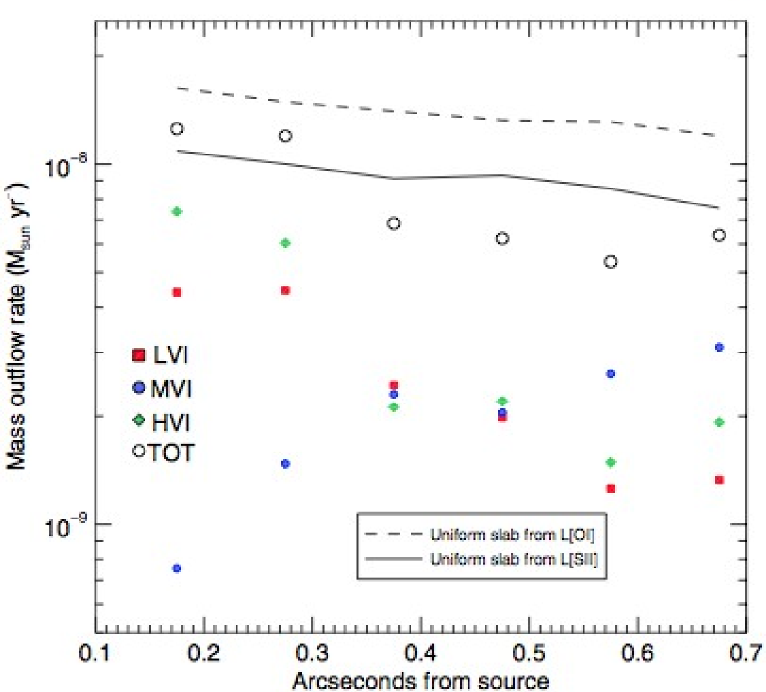
Some jets show narrow line widths at the base more compatible with X-wind models. e.g. RW Aur Statistics ?

Atomic Jet mass fluxes

- Multi-line resolved studies of jet launching regions critical

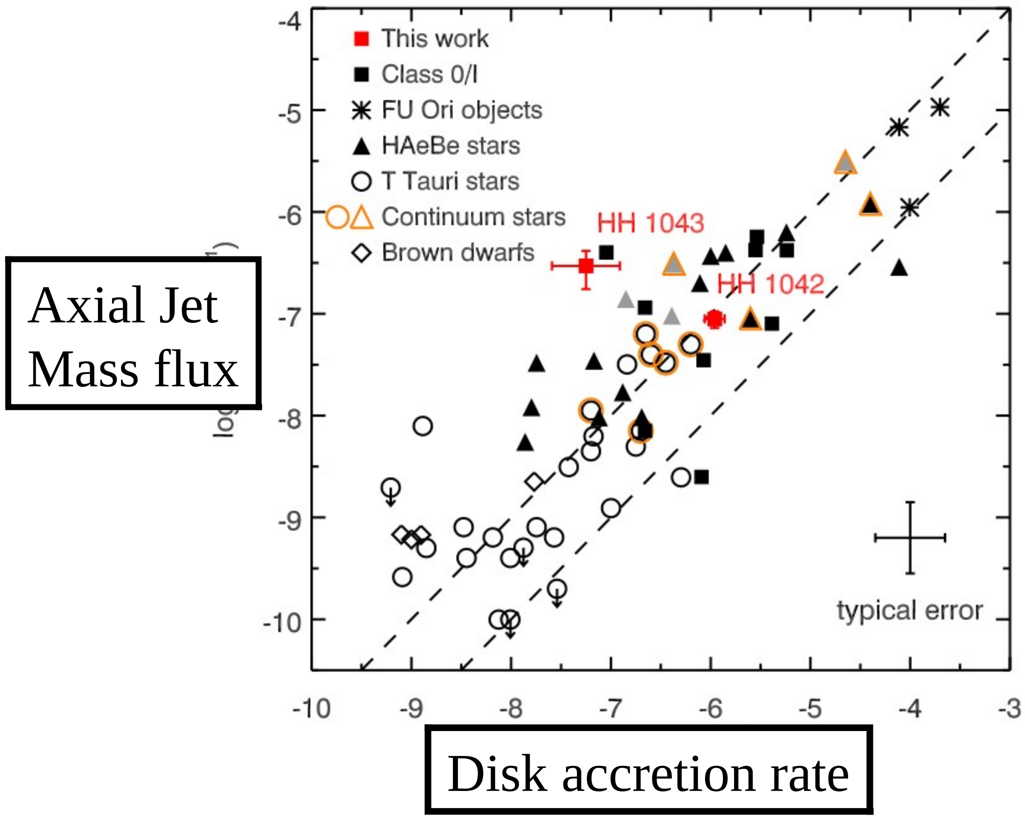
  cf HST study of the DG Tau jet by Maurri+14 (also Lavalley-Fouquet+2000)





- However still large uncertainties ! (x2)

Atomic Jet mass fluxes



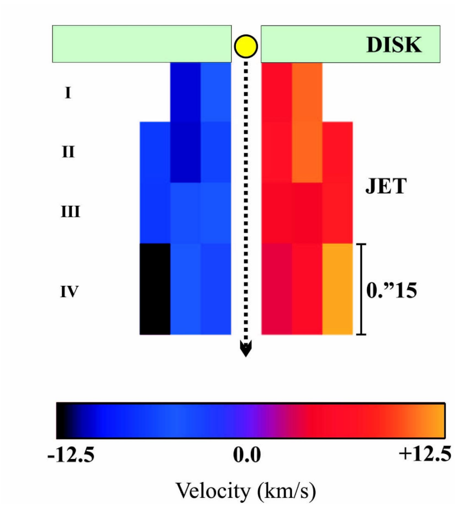
Mjet/Macc = 0.1

Cabrit+90
Hartigan+95
Antoniucci+08
Ellerbroek+13 …

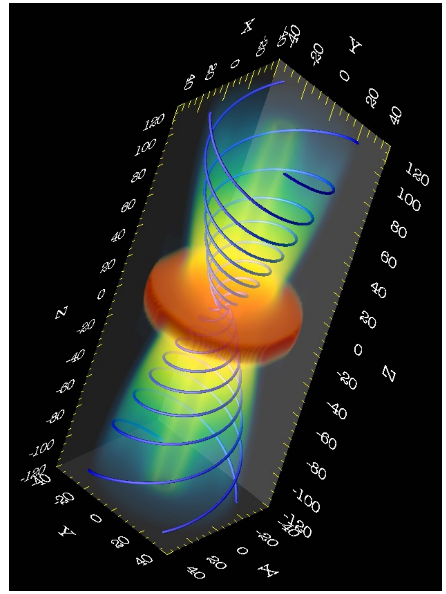
- Universal accross evolutionary stages and stellar masses
  - can be accounted for by extended D-winds
  - (may be) difficult to explain with stellar winds Cranmer09

Atomic jets: rotation

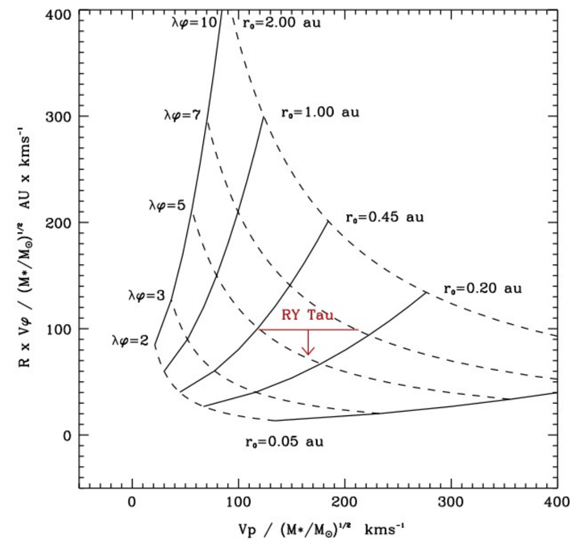
OBSERVATIONS



HST/STIS



DISK WIND MODELS



- Transverse ΔV = 10-15 km/s in 6 T Tauri jets
  Bacciotti+02 Coffey+04,07,11,12 Woitas+03

- Magnetically driven disk winds predict: Bacciotti+02,Anderson+03,Ferreira+06

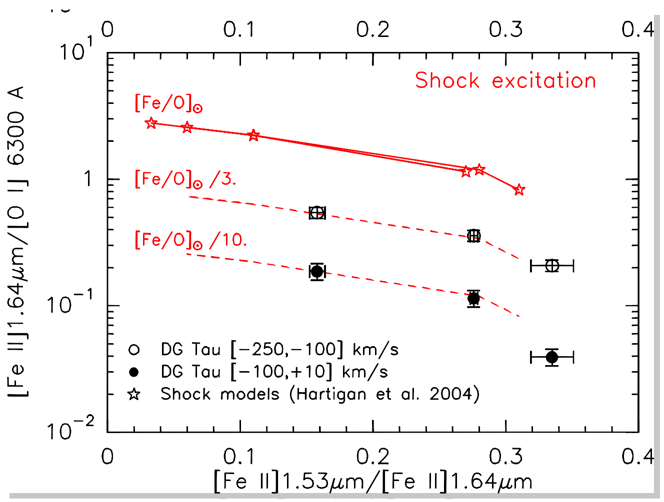
$$2rV_\phi\Omega_0 = V_p^2 + 3\Omega_0^2 r_0^2$$

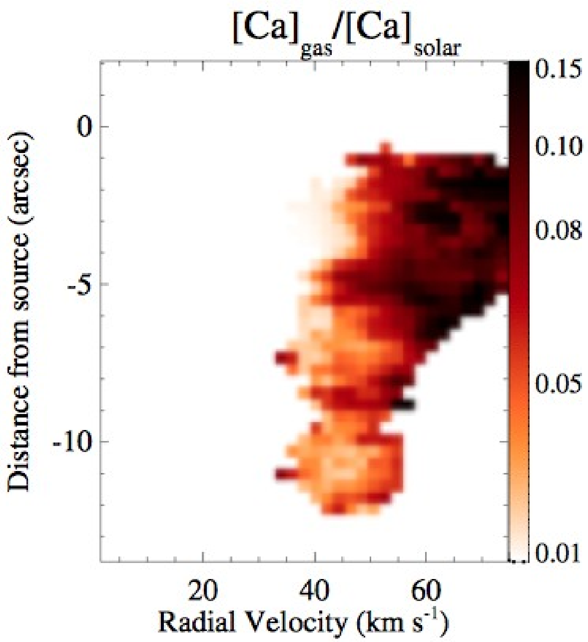
➔ suggests rlaunch ≈ 0.1 - 5 AU for all candidates so far

Dust in the launching regions of jets ?

Podio+11 DG Tau B

Agra-Amboage+11 DG Tau





- Under-abundance of refractory elements (Fe, Ca, Ni, …) > when V <
  - seen on larger scales in younger HH jets: Podio+09
  - depletion of Fe on dust grains + partial destruction of dust grains in shocks

→ R_{launch} > Rdust in disk

But few studies so far …

A very robust launching mechanism

- Jets around BDs Whelan+04 and massive protostars up to 15 Msun Guzman+10 and over > 5 orders of magnitude in Macc Whelan+10
- Jets from Herbig stars: test of the influence of Bstar cf Gregory+14

HD163296: a case study

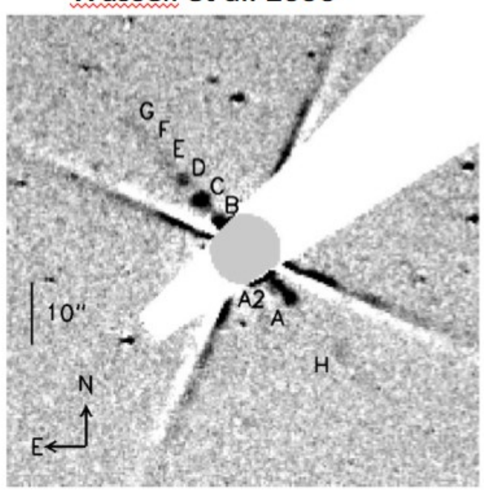
Ellerbroek+14:

Jet similar to TTs jets

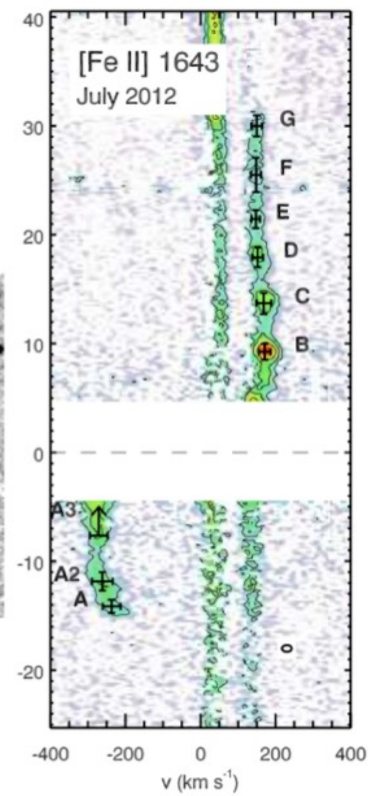
BUT
no strong Bstar
detected

Alecian+13

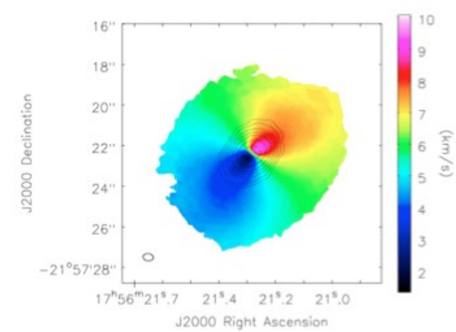
Jet HST
Wassell et al. 2006



Jet X-SHOOTER
Ellerbroek et al. 2014

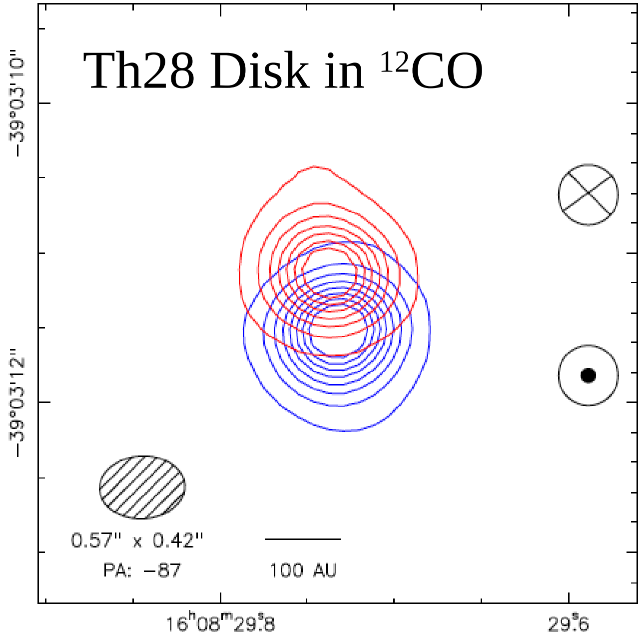


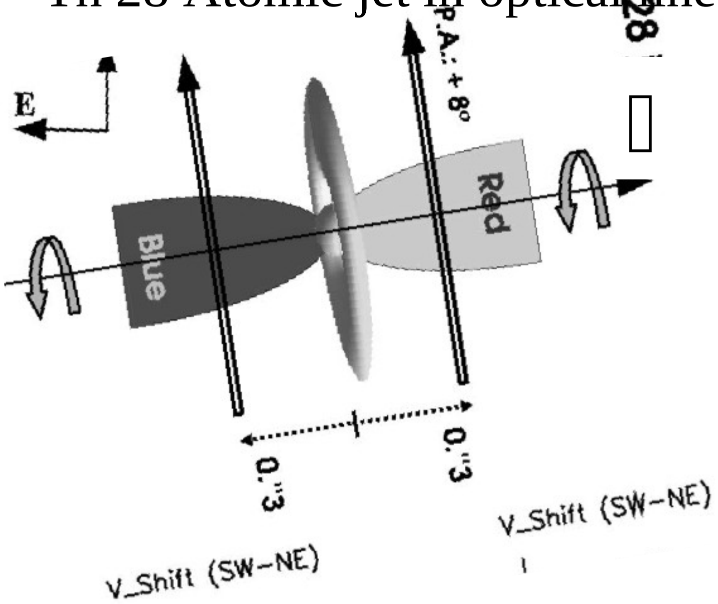
Disk CO(3-2) ALMA
de Gregorio-Monsalvo et al. 2013



II- Atomic jets: Open Issues

Puzzle 1: Do atomic jets rotate ?





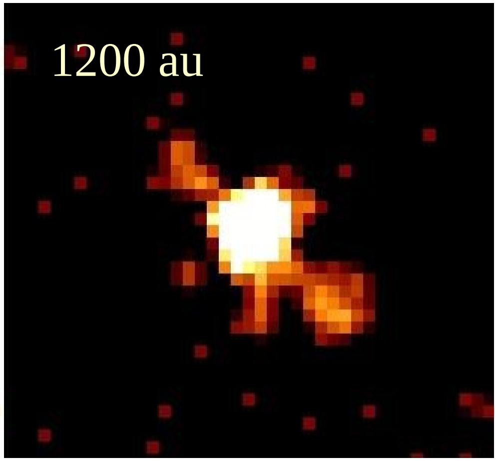
- In 2 jets (out of 4) Rotation sense of disk **NOT** consistent with rotation sense of jet Cabrit et al. 2006, Louvet et al. in prep
- no consistent ΔV **along the jet** found in the 3 sources with spectro-imaging techniques White+2014, Coffey+2015 (see poster), Hodapp+14

Either upper limits or steady assumption not valid

Shocks can blur rotation signatures Sauty2012, Fendt2011

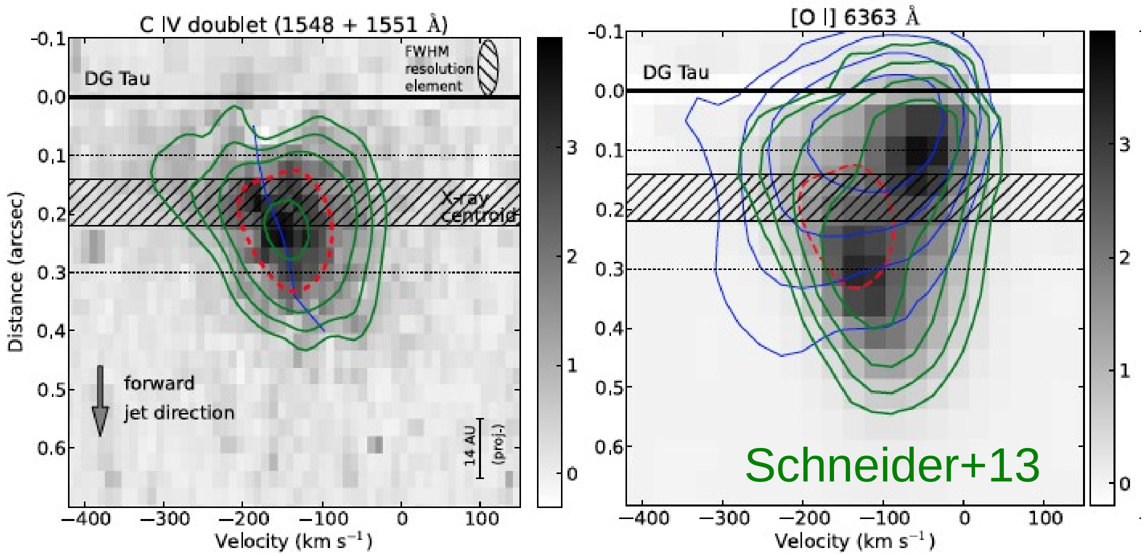
Puzzle 2: Inner X-ray emission

DG tau Jet in X-rays



Gudel+08,12

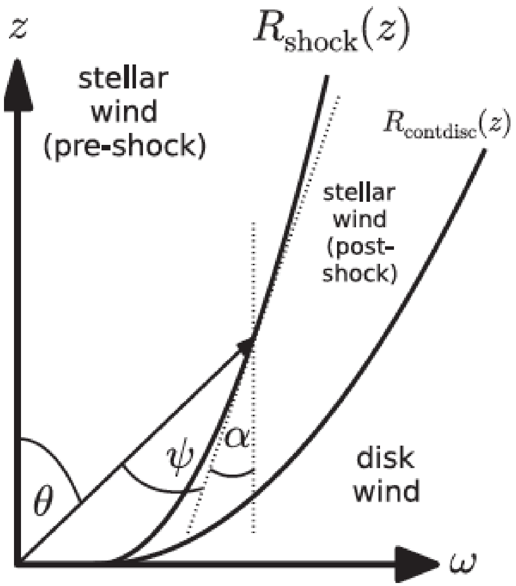
Inner 1'' in DG Tau Jet with HST/STIS



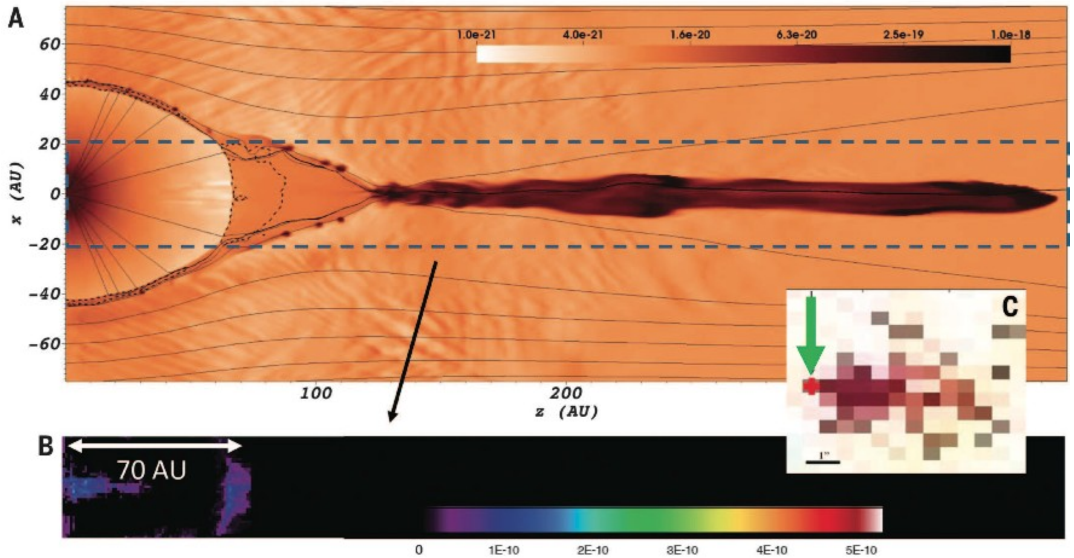
- Soft X-ray along jet axis (40-1200 au)
  Gudel+08 Skinner&Gudel14 Skinner+11 Favata+02
- Tx= 3-4 x10^6 K → **If shocks: Vs > 450 km/s**
  - ✓ dM/dt ≈10^{-10} Msun/yr reproduces Lx Gunther+09
  - ✓ Other heating processes: magnetic heating ?
- Inner X-ray knot stationary

Puzzle 2: the inner X-ray emission

Recollimation shock in an inner tenuous fast stellar wind ?
Bonito+10



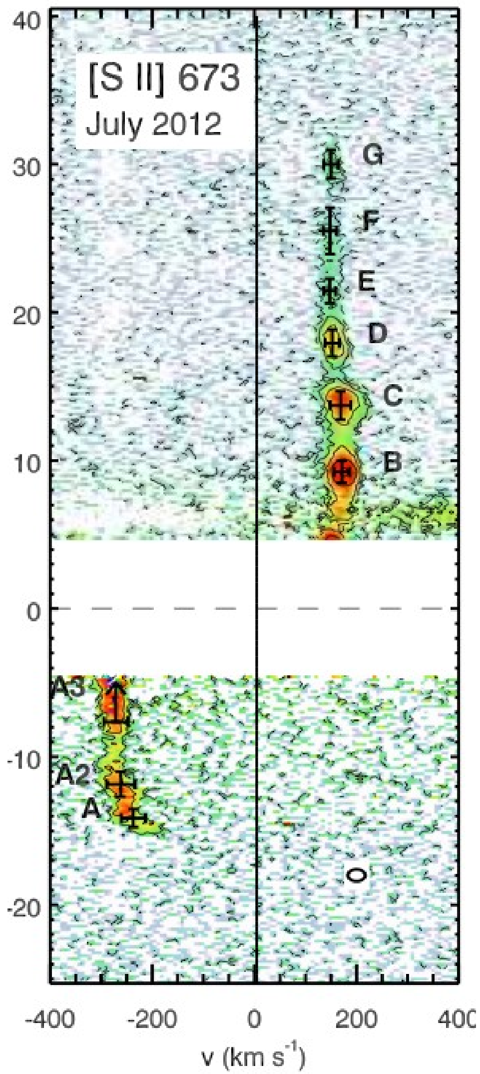
Gunther+14



Albertazzi+14

Link with unresolved signatures of stellar winds ?

Puzzle 3: Jet asymetries and variability



- Velocity asymetries BUT similar mass-fluxes
  Melnikov+09 Podio+11 Ellerbroek+14
  → ≠ momentum flux and kinetic energy flux
- ✓ B misalignement and external pressure Matsakos+12
- ✓ asymmetric disks (H, corona) Fendt+13

- Origin of knots

  Internal shocks due to time variable ejection

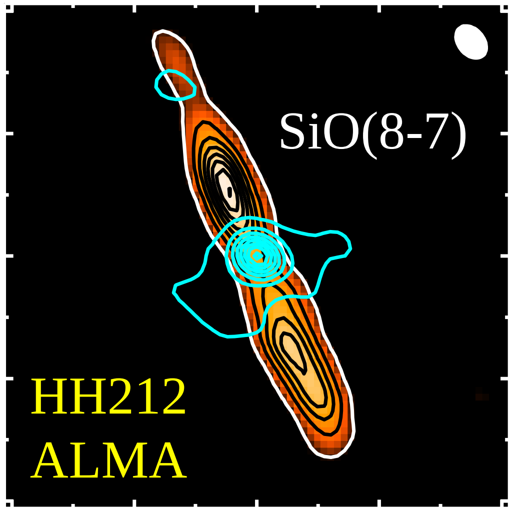
  Variability at the base Δt=2-15 yrs:
  - ✓ Stellar or disk dynamo cycle ? Stepanovs+14
  - ✓ perturbations in the disk ?

III- The origin of the molecular jets/outflows

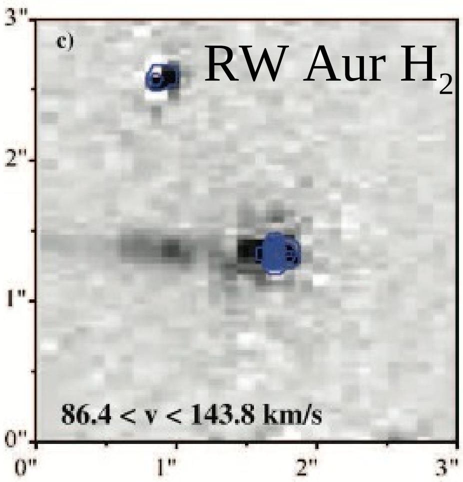
Molecular Jets

- Bright in molecules: SiO, CO, SO, H_2
- Velocities up to ~ 50-100km/s
- HV highly collimated ~ Class 2 jets (Cabrit+ 07, Codella+14, Podio+15)
- Class 0: Mdot(atomic) ~ 10% Mdot(HV molecular) *Spitzer*, *Herschel;* Dionatos+10, Nisini+15)
- Are the molecules ejected from the disk ? Formed inside dust-free stellar wind ? Entrained from the envelope ?

Class 0



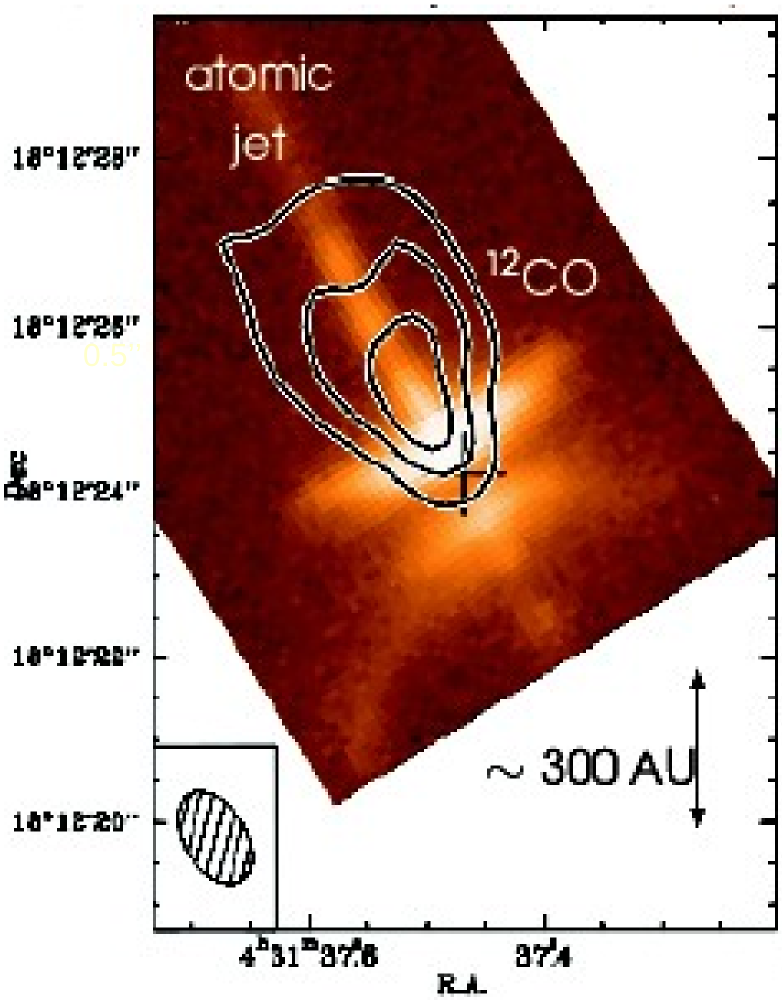
Class 2



cf. posters B. Tabone on HH212 with ALMA; Cabrit+Yvart on predicted H_2O profiles vs *Herschel*.

ALMA ideal to look for predicted rotation signatures !

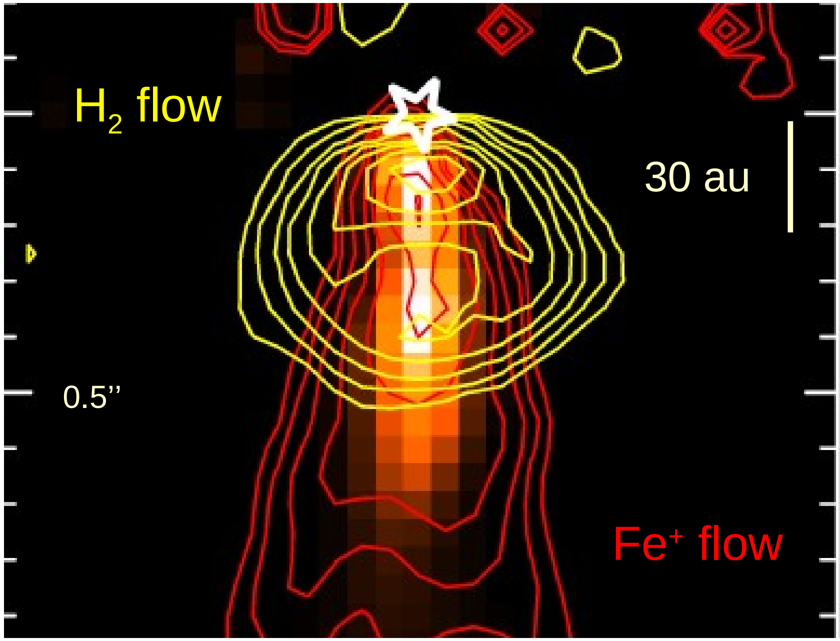
Small scale molecular *cavities*



Pety+06

see also Lauhnardt+09

Zapata+14,13 Arce+13, Codella+13

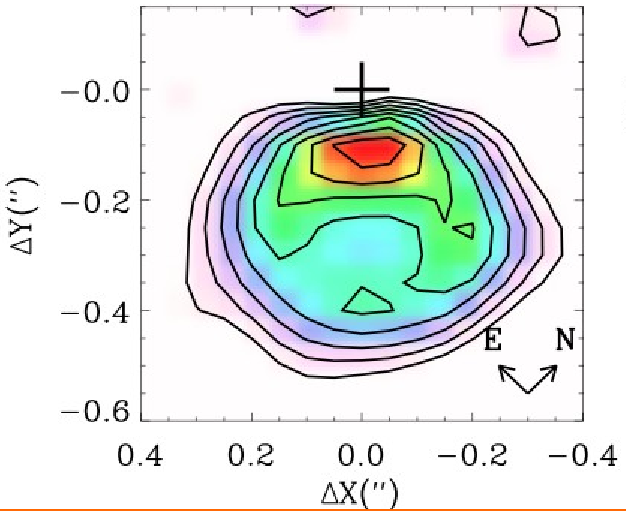


Agra-Amboage+14 Schneider+13

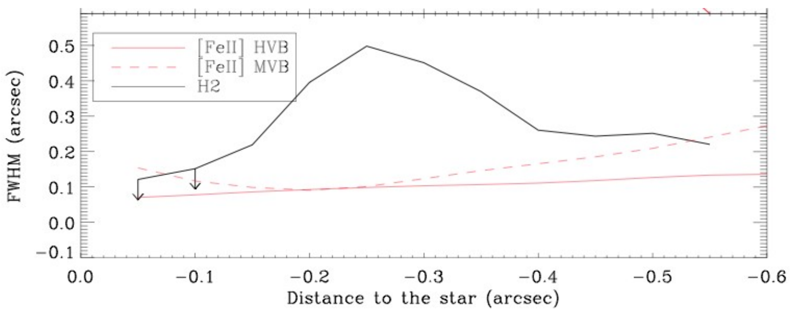
see also Beck+08 Takami+07

- Slow ($V < 20$ km/s) broad cavities: CO (mm) , H_2 (NIR, UV)

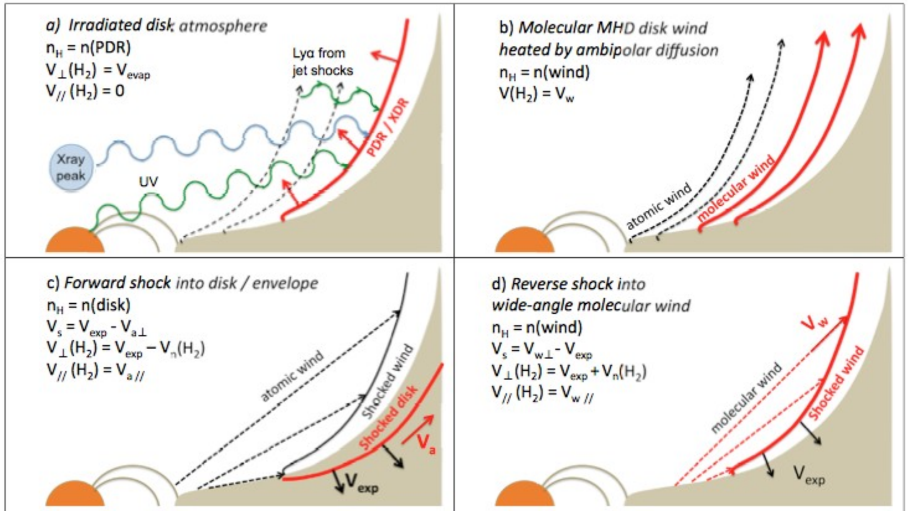
The H_2 in DG Tau



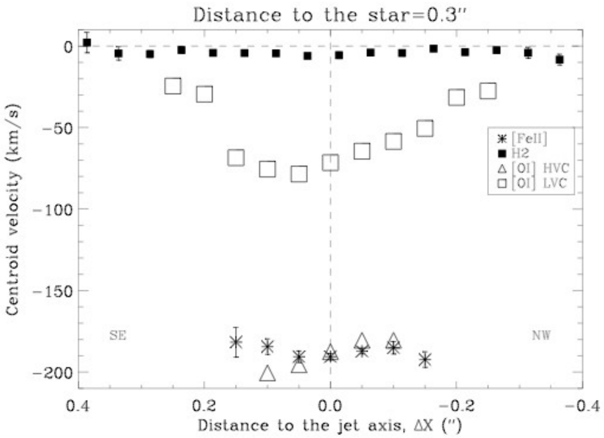
- No connection with FeII jet



Vexp < 12 km/s from comparison to FUV image
Schneider+2013



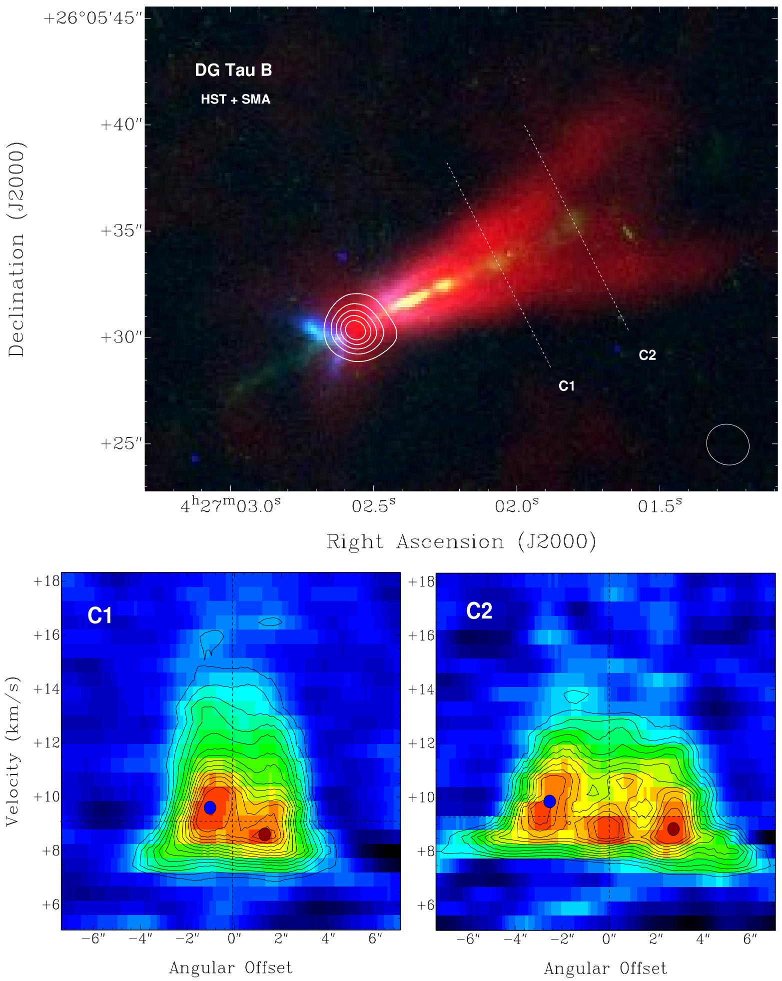
- Connection with OI LVC ?



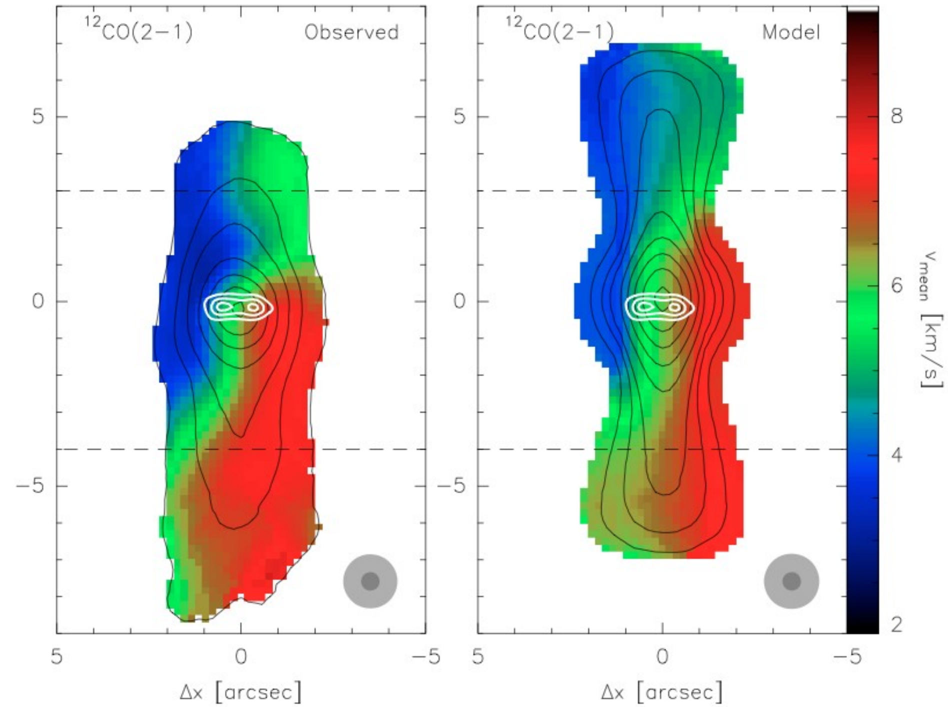
Agra-Amboage+2014

V-shaped CO cavities

Zapata+14 DG Tau B



CB 26 Launhardt+09



ΔV=1-2 km/s at r=100 au

consistent with disk wind from r_0=10-50 au

But $(dM/dt)_{outflow}$ = $10^{-6} – 10^{-7}$ $M_{\odot}$/yr !

Soon ALMA observations !

Summary

- Atomic jets launched from inner AU regions: MHD disk winds most promising scenario but
  - requires additional observational tests (dust)
  - Statistical studies of jet properties still critically missing
  - Realistic modelling of the impact of SW and MEs on structure of DW

    + explore alternative models (magnetic tower jets cf Ciardi+09)

- ALMA will soon provide very interesting constraints on the origin of molecular outflows

- Potentially a strong impact on mass and angular momentum extraction in disks

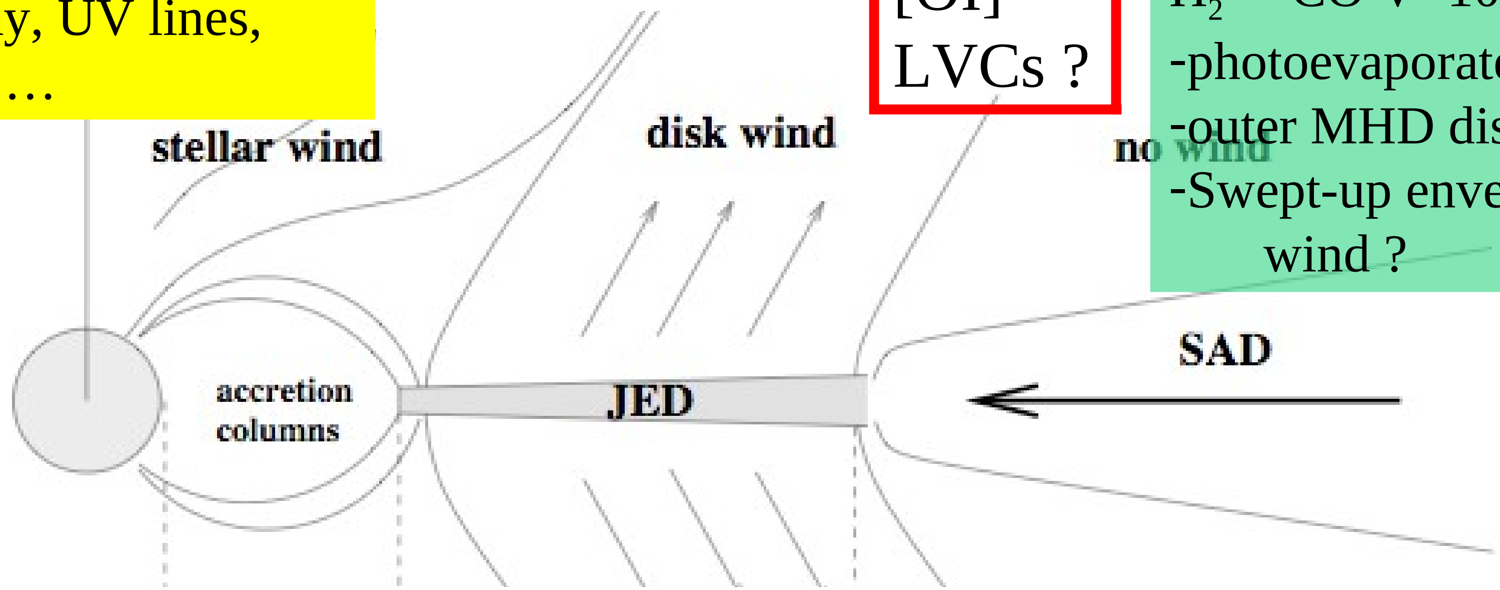
Multi-component flows

ME sources of
variability ,
Eruptive events ?

Tenuous stellar
wind
X ray, UV lines,
HeI …

[OI]
LVCs ?

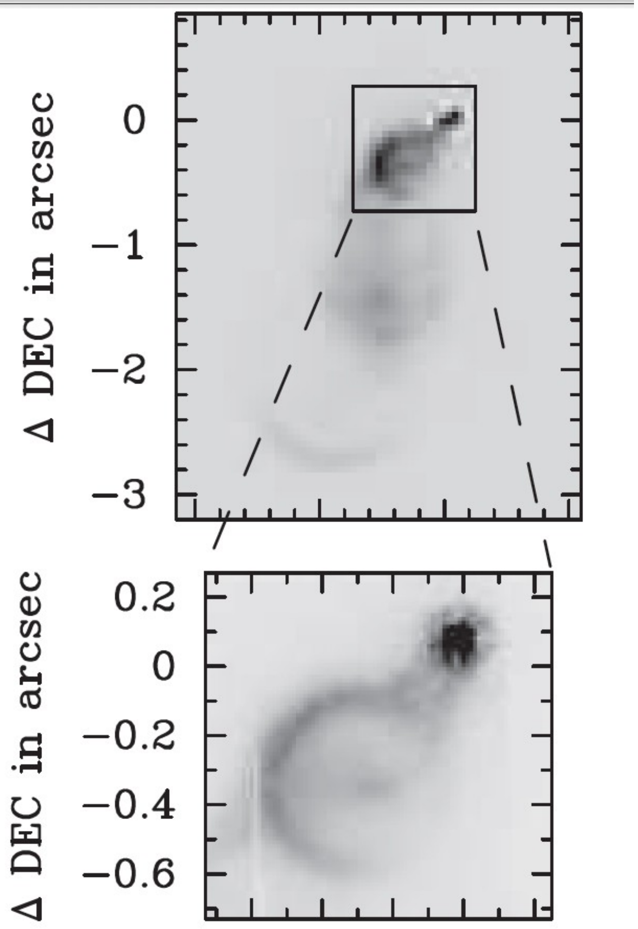
Slow molecular
wind → a few 10’s AU?
H_2 CO V=10-20 km/s
-photoevaporated wind
-outer MHD disk wind
-Swept-up envelope/outer
wind ?



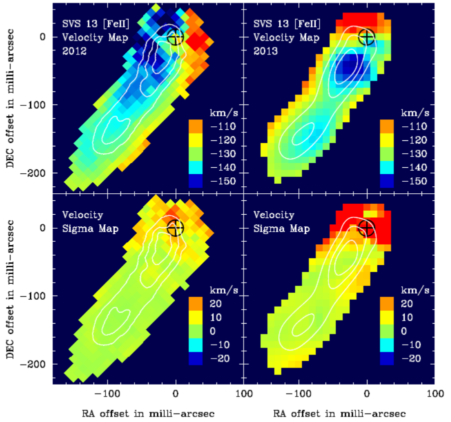
Atomic+ molecular jets
V > 50 km/s
ME+Extended MHD
D-wind → a few AU

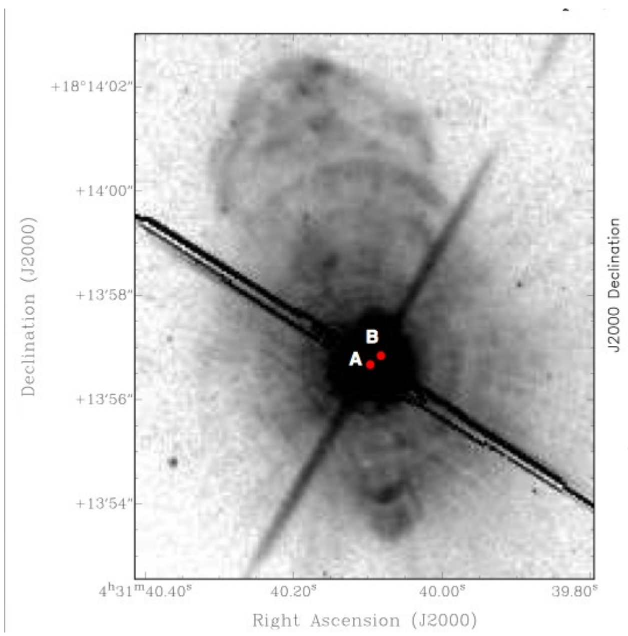
Bubbles ?

SVS 13 H_2



Hodapp+14





Many Thanks to

S. Cabrit, D. Coffey, V. Agra-Amboage (Porto) L. Podio (Arcetri) E.Whelan (Tubingen)
L. Ellerbroek (Amsterdam)

The warm H2 cavity in DG Tau

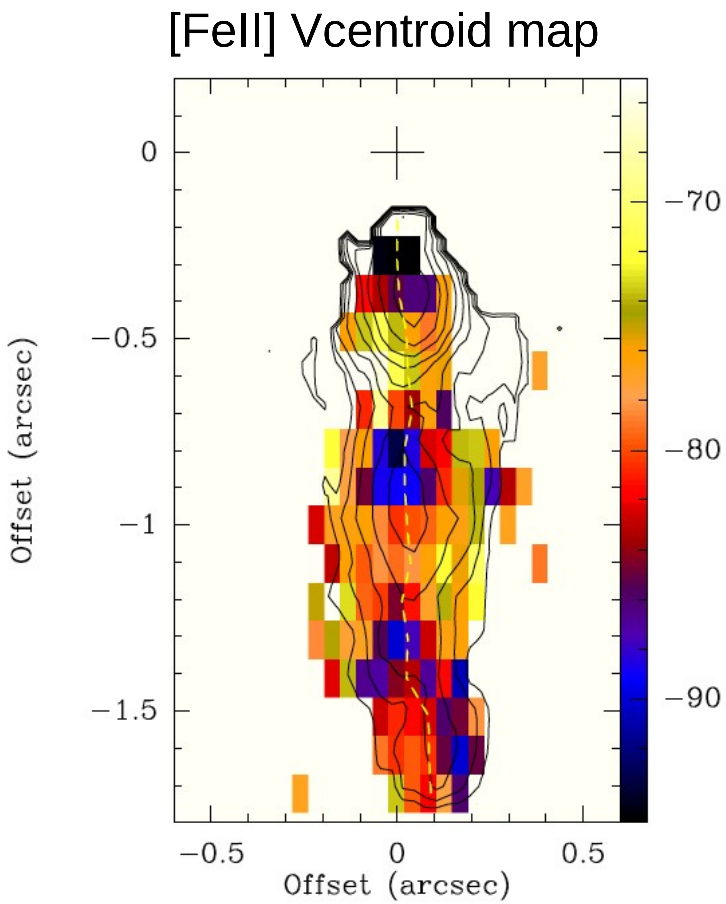
- Shocks unlikely: not compatible with geometry and/or
- Photo-evaporated or MHD disk wind **but** detailed predictions required

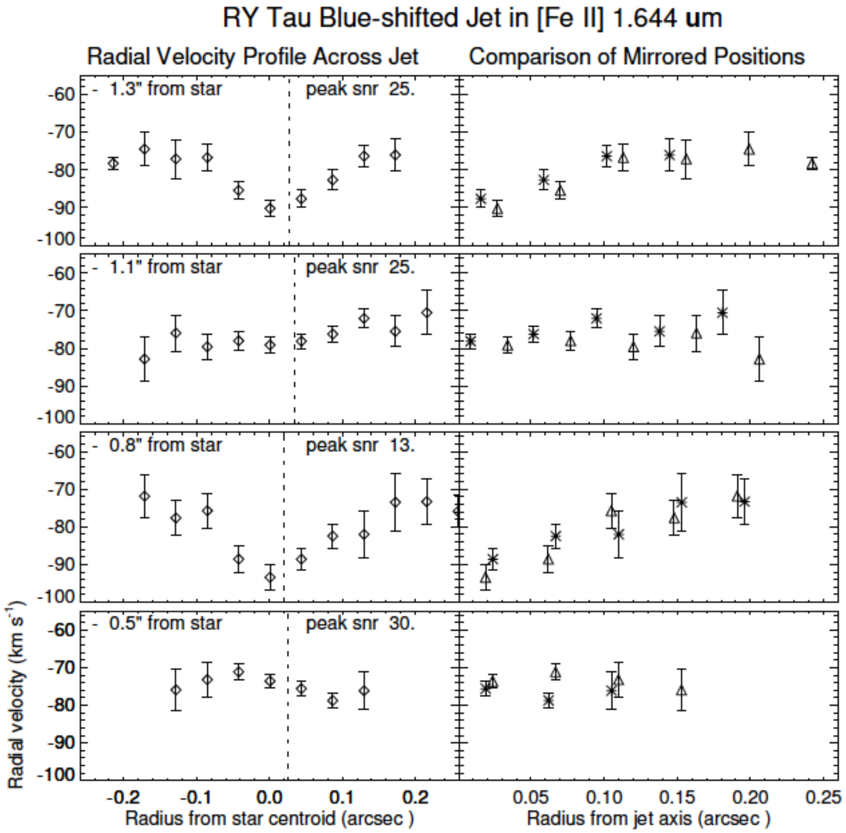
Detection of Jet magnetic Field

- Synchrotron linear polarisation:
  - B aligned with jet in HH80-81
- Synchrotron knot in DG Tau (see talk by Ainsworth et al.)
  - More to come with eVLA, LOFAR

Carrasco-Gonzalez et al 2010, *Science*

Puzzle 1: Do atomic jets rotate ?





Spectro-imaging required, 3 sources investigated so far

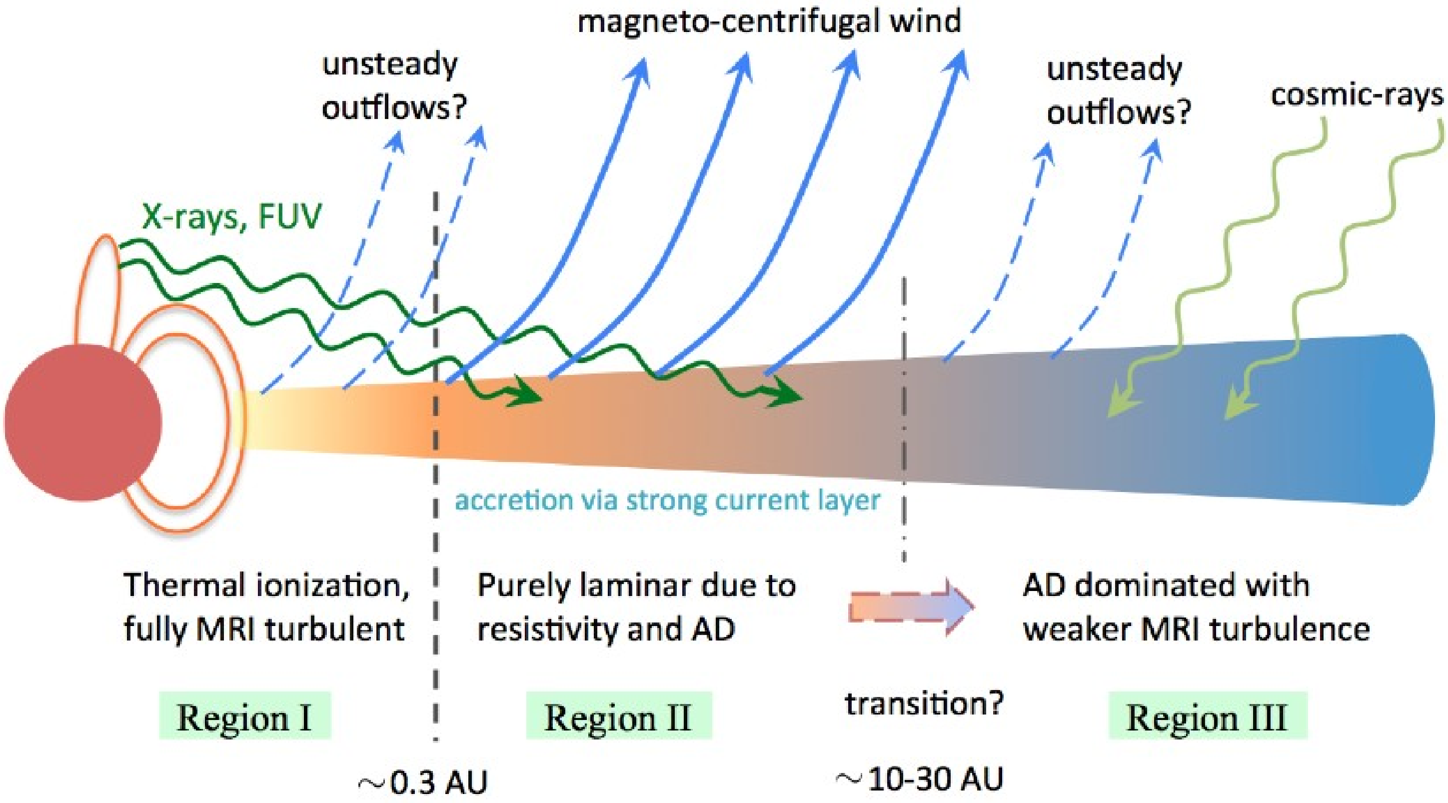
- No consistent rotation signatures along the jet in 2 cases

BUT sensitivity reduced Vphi < 10 km/s

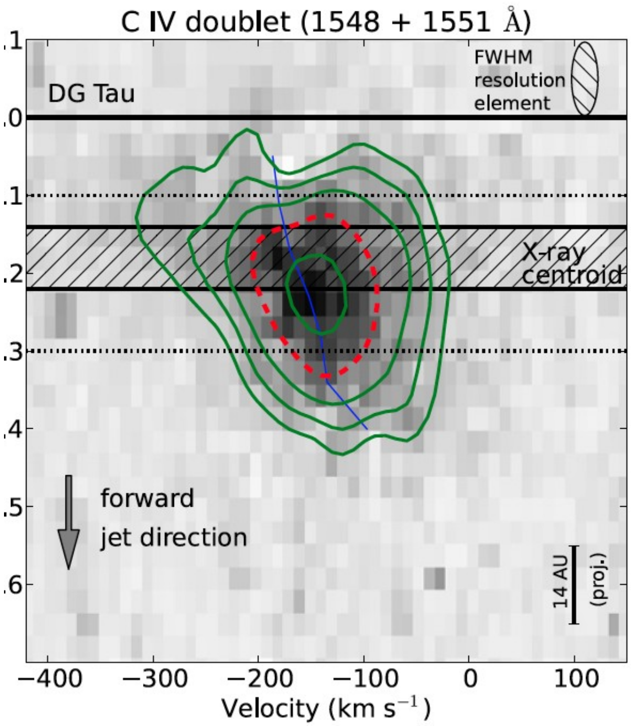
White+2014, Coffey+2015

Impact for transport of angular momentum

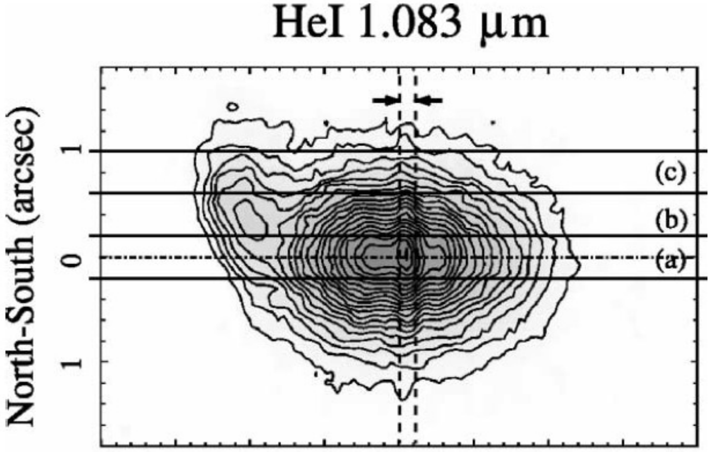
Magneto-centrifugal wind can play a major role in angular momentum transport from r= 0.3-5-10 AU Bai et al. 2013, Bai & Stone 2011 see also Baruteau et al. 2014 PPVI



Hotter inner wind signatures



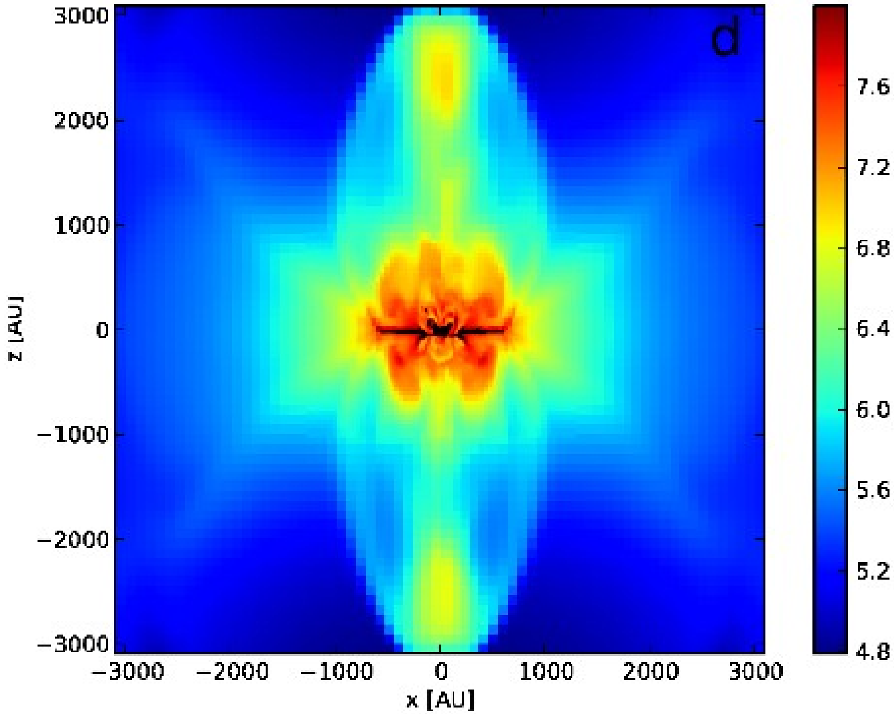
Schneider+13



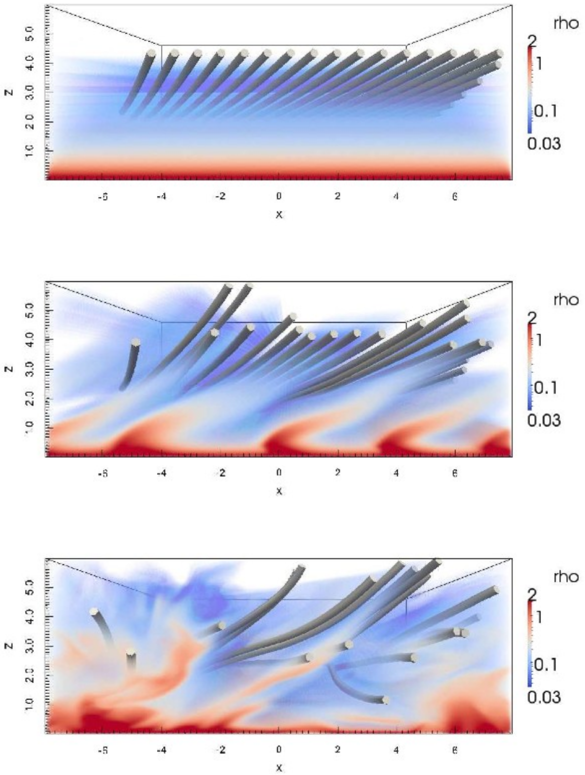
Takami+02

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

Why should we care about jets/outflows ?

Invoked to solve several major issues in SF:

- Low SFE and SFR in turbulent clouds
- 30% Core to Star efficiency
- Removal of star/disk/envelope angular momentum

Also:

- Unique info on B disk magnetisation in inner aus
- May affect planet formation and photoevaporation
  - Density jump, dust trap
  - Screen inner UV X rays
  - Halt migration processes

cf PPVI chapters