ALMA studies of the disk-jet-outflow connection

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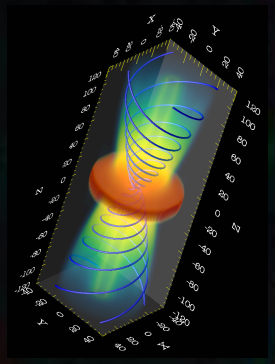
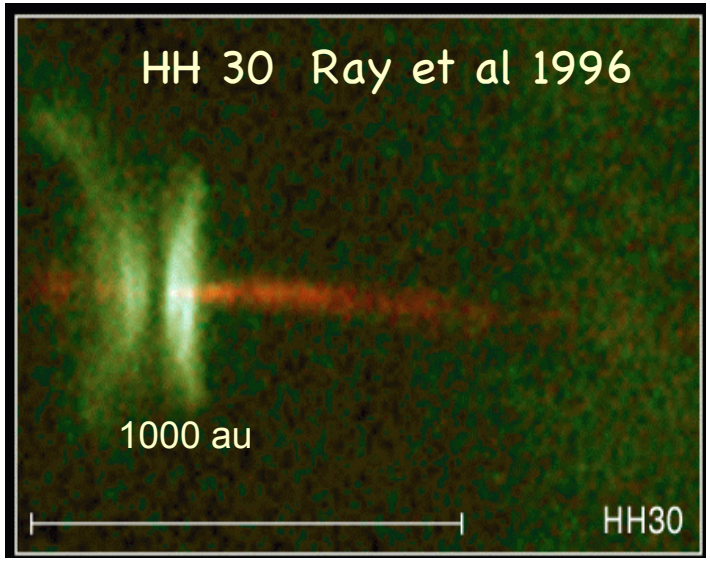


F. Louvet, D. Mardones (DAS Calan Obs)
S. Cabrit & B. Tabone (Obs. Paris) B. Dent & A. Hales (JAO)
F. Ménard & C. Pinte (IPAG) F. Gueth, E. Chapillon (IRAM)

IPAG
Institut de Planétologie et d'Astrophysique de Grenoble

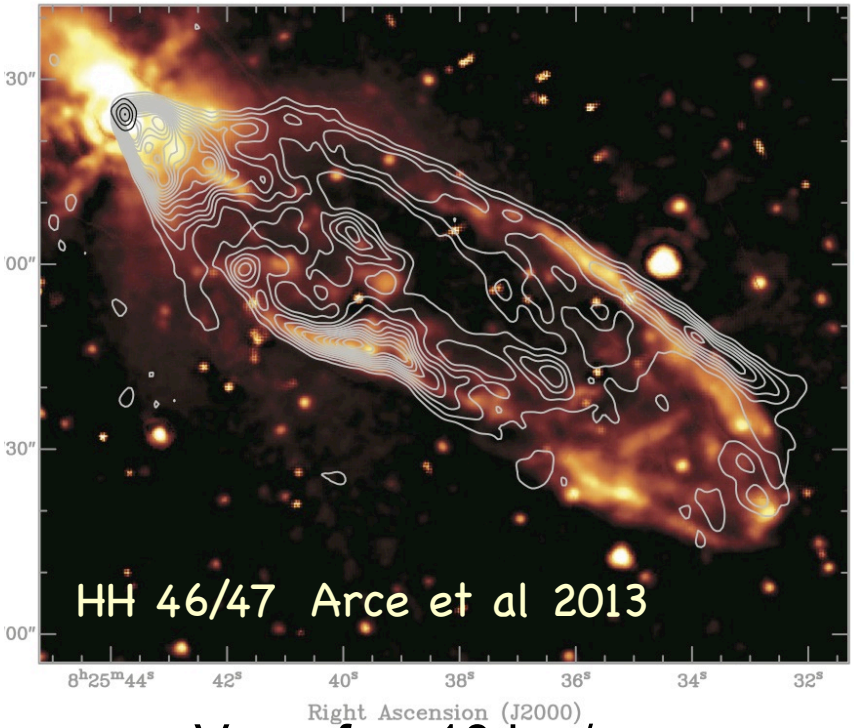
Protostellar jets/outflows

Fast axial Jets



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

Low-velocity outflows

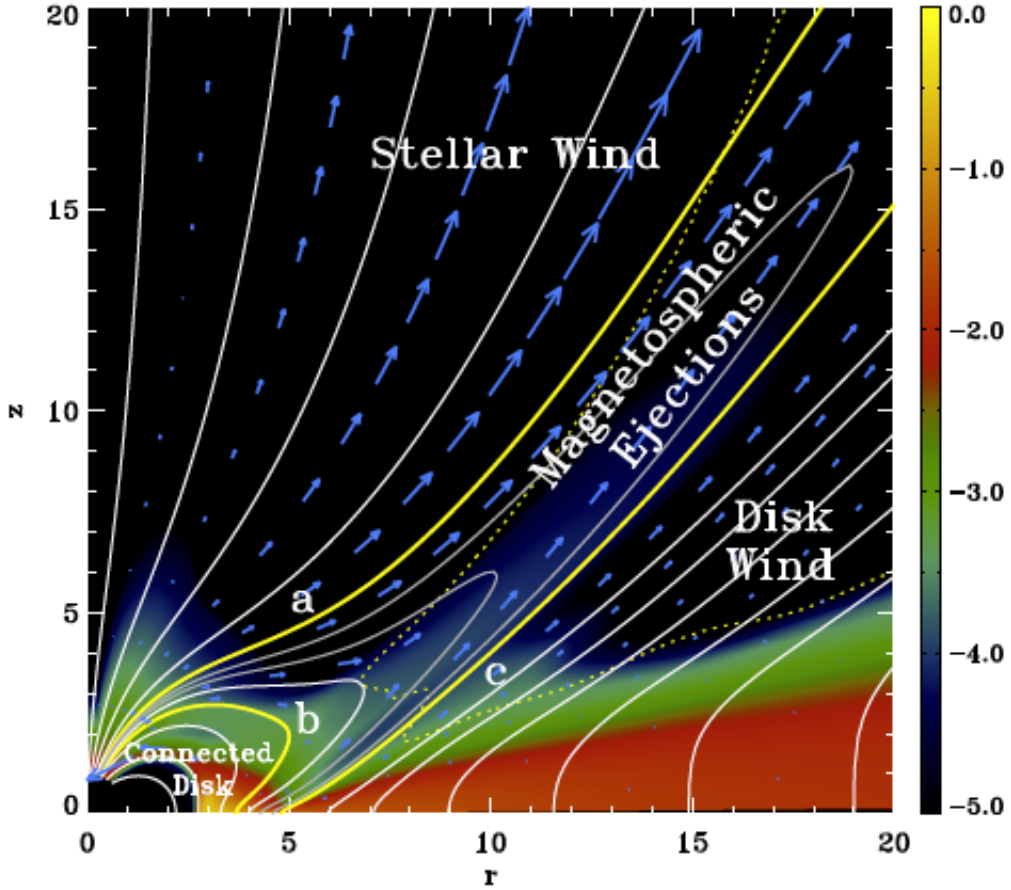


V = a few 10 km/s
molecular (^{12}CO)

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

The origin of atomic jets

Jets are likely magnetically driven Pudritz+07 Ferreira&Pelletier93 Shu+94
Sauty&Tsinganos94,00, Romanova+10 see also review by Cabrit JETSET school I



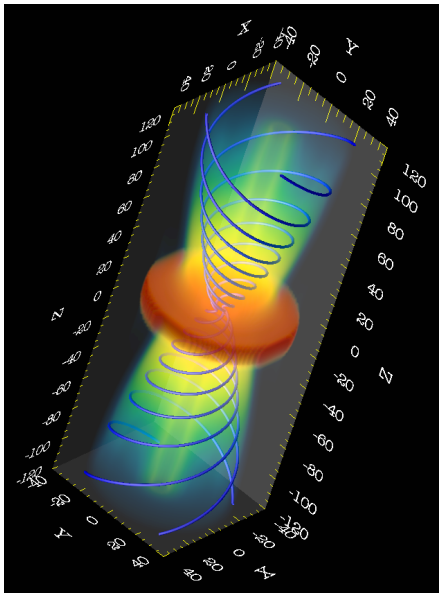
Zanni & Ferreira 2013

Powerful disk-winds require large scale B field close to equipartition

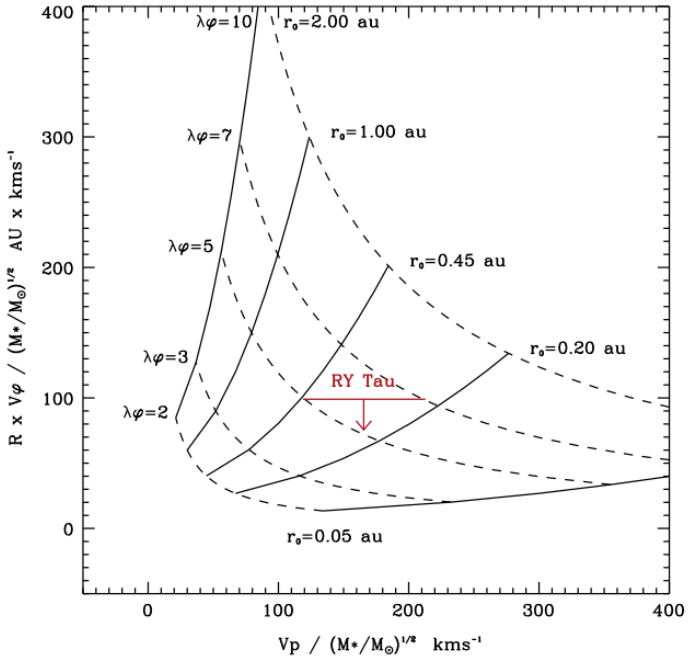
Strong impact on inner disk eolution and planetary formation

cf Baruteau+14 PPVI

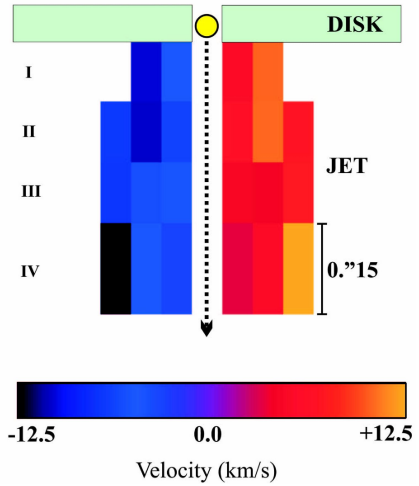
Rotation



DISK WIND MODELS



OBSERVATIONS



HST/STIS

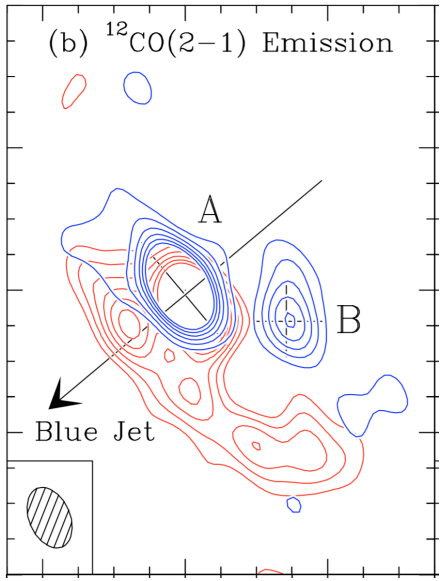
Steady Magnetically driven disk winds:
Bacciotti+02,Anderson+03,Ferreira+06

$$r v_\phi = \Omega_0 r_0^2 \lambda_\phi$$

$$v_p = \Omega_0 r_0 \sqrt{2\lambda_\phi - 3}$$

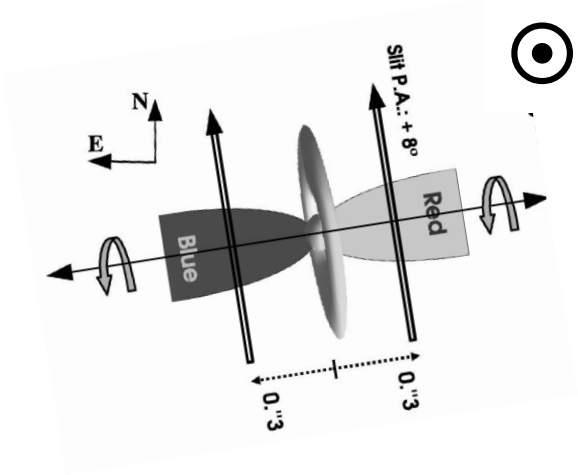
- Transverse ΔV = 10-15 km/s in 6 T Tauri jets Bacciotti+02 Coffey +04,07,11,12 Woitas+03 ➔ rlaunch ≈ 0.1 – 5 au

But are we really tracing rotation in jets ?



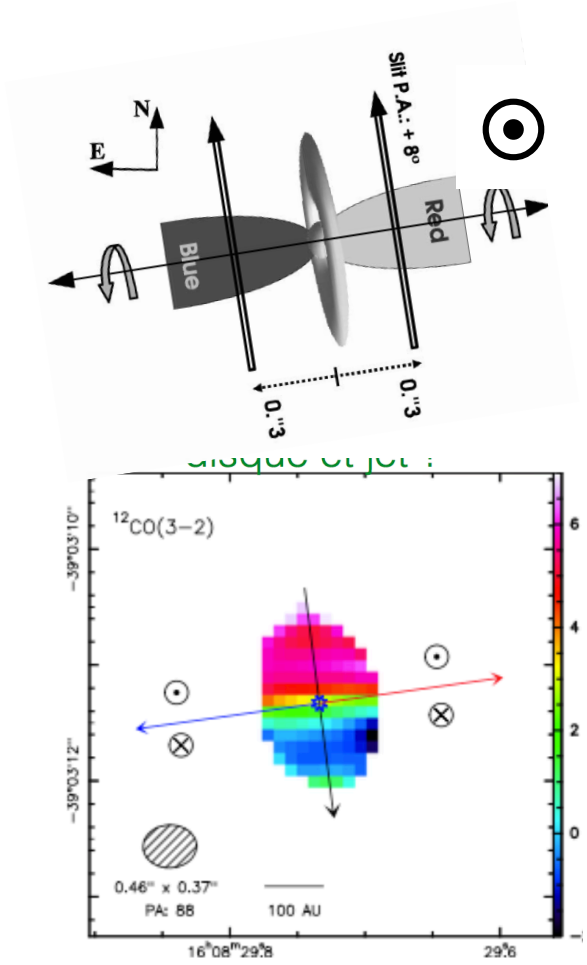
	Jet rotation	Disk rotation	
DG Tau	✔	✔	Testi+2002
RW Aur	✔	✔	Cabrit+2006
CW Tau	✔	✔	Cabrit in prep

- Th 28: best convincing case of jet rotation detection Coffey+2004,2007



- ✓ Sense of jet rotation agree between: different lines, jet and counter-jet
- ✓ Edge-on source
- ✓ No signature of binarity

But are we really tracing rotation in jets ?



Th 28 ALMA Cycle 1
Disk and jet counter-rotating
Louvet, Dougados et al. 2016

	Jet rotation	Disk rotation
DG Tau	✔	✔
RW Aur	✔	✔
CW Tau	✔	✔
Th 28	✔	✔

In 2 jets (out of 4) rotation sense of disk **NOT** consistent with rotation sense of jet ! Cabrit+06, Louvet+16

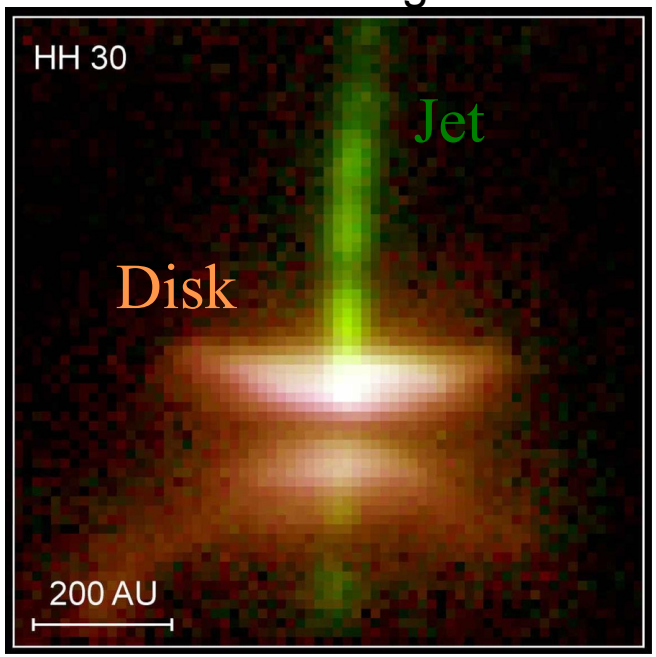
→ Cannot derive r_0 from optical jet rotation studies (perspective in UV) ?

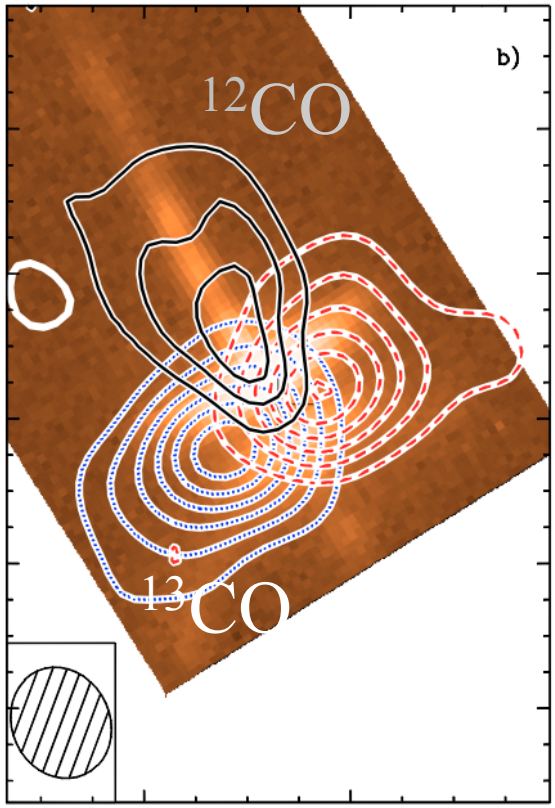
Small scale molecular flows/cavities

Edge-on Class II source in Taurus (d=140 pc), Mstar=0.45 Msun

Ray+1997

HST image





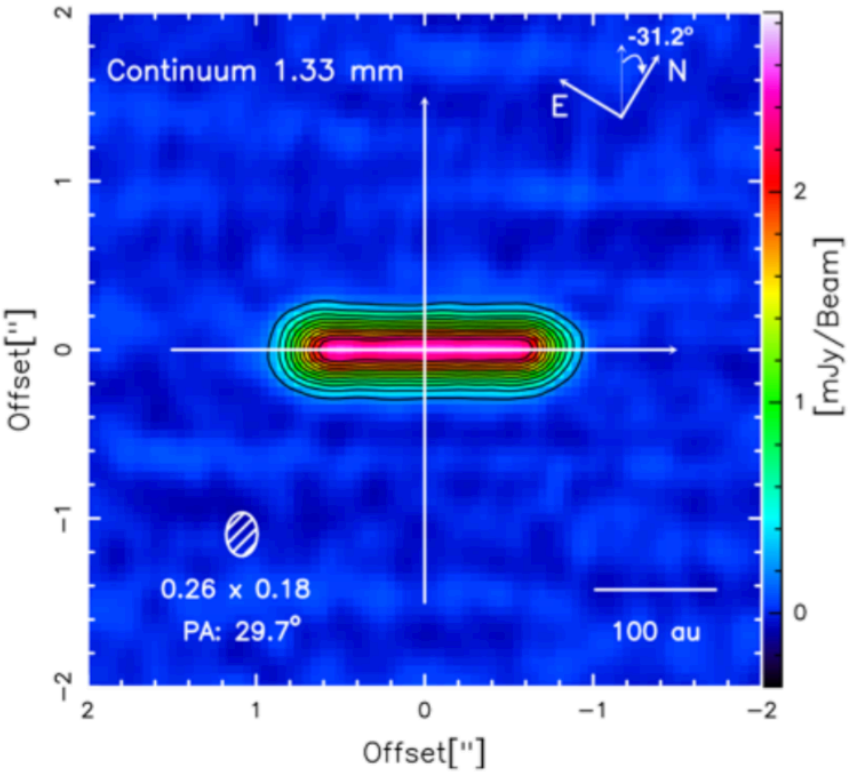
Pety+06

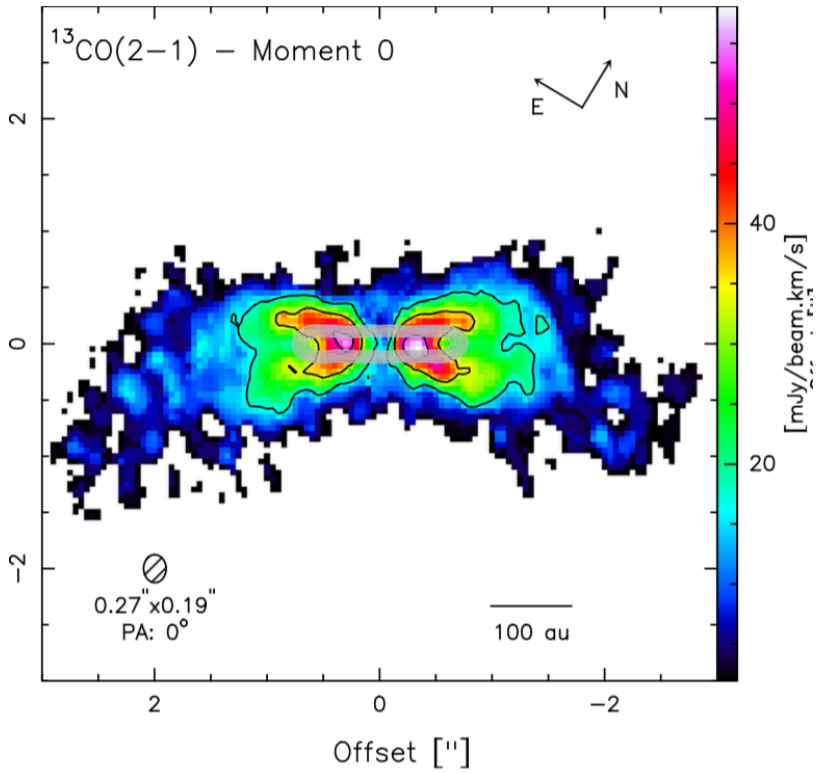
IRAM/PdBI beam1.8”x1.1”

Slow (V = 10 km/s) conical flow

$(dM/dt)_{CO} = 10^{-7}$ Msun/yr ≈ 50 (dM/dt)Jet

ALMA Observations of HH 30

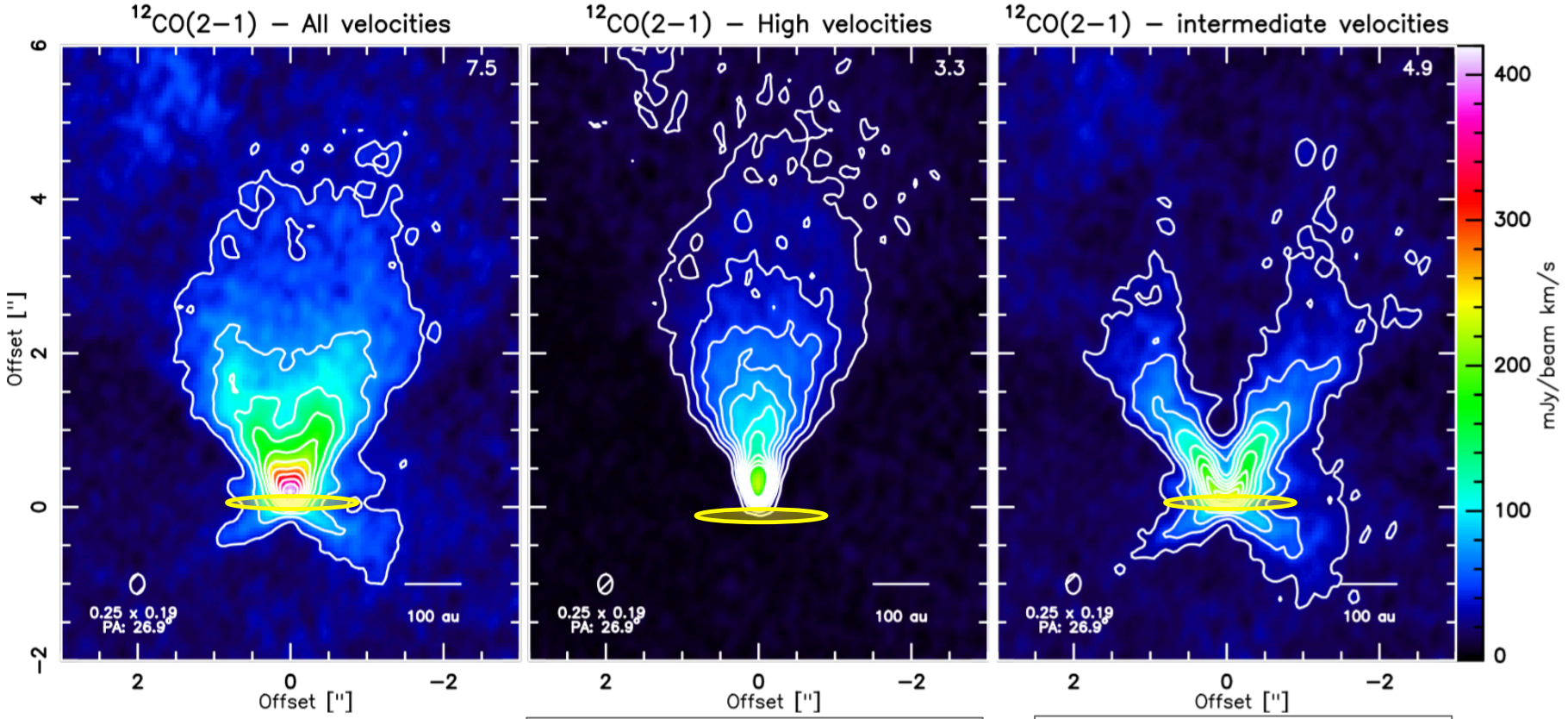




$i > 83^{o}$

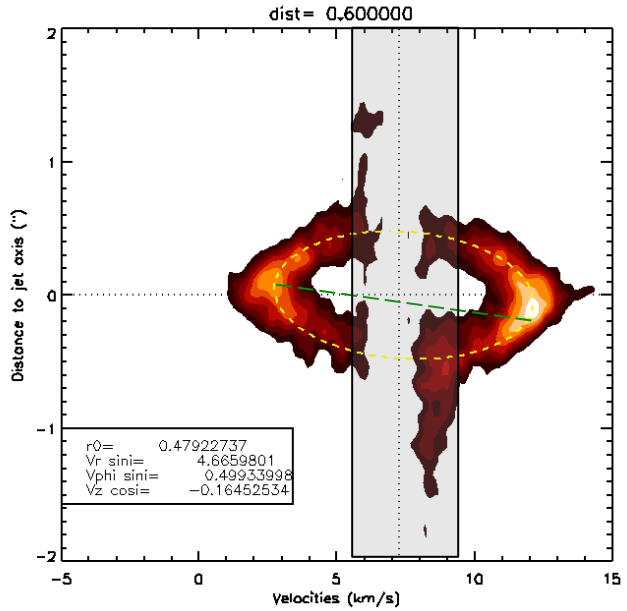
Louvet, Dougados et al. in prep

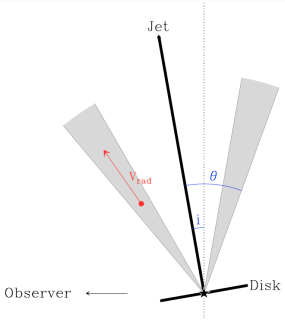
ALMA Observations of HH 30

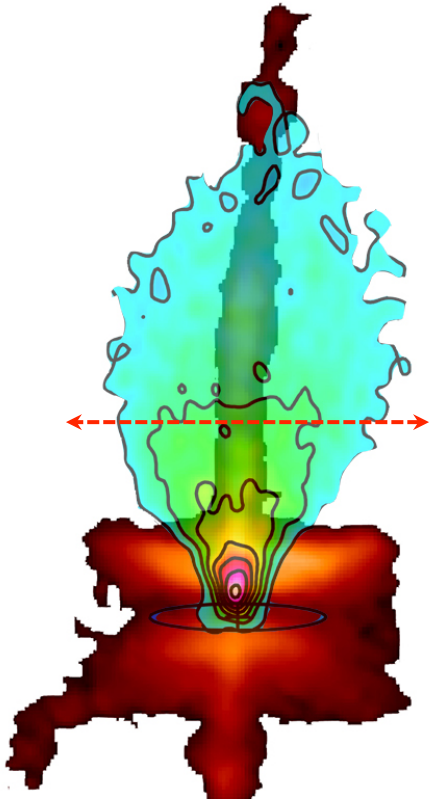


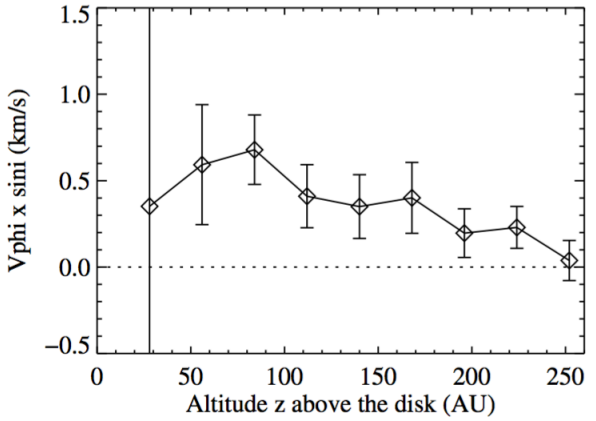
Louvet, Dougados et al. in prep

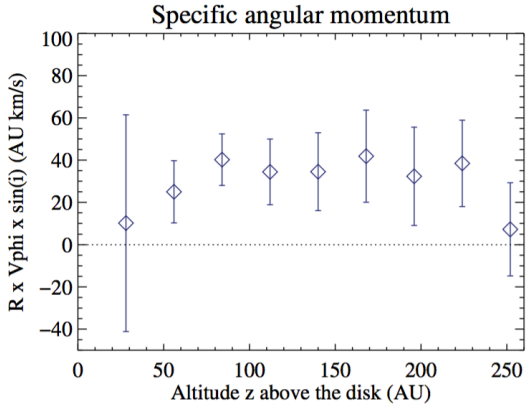
ALMA observations of HH 30: rotation









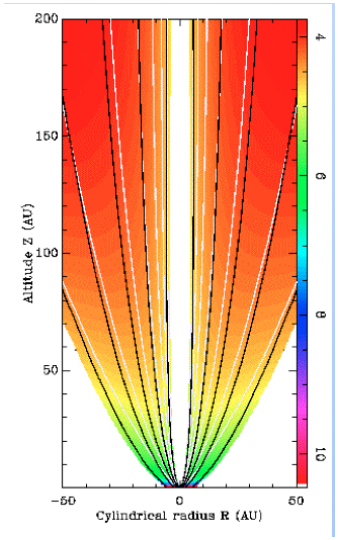


Low rotation detected (Vφ < 0.7 km/s)

Conservation of angular momentum over central 200 au

Origin in disk wind ?

Magneto-centrifugal DW



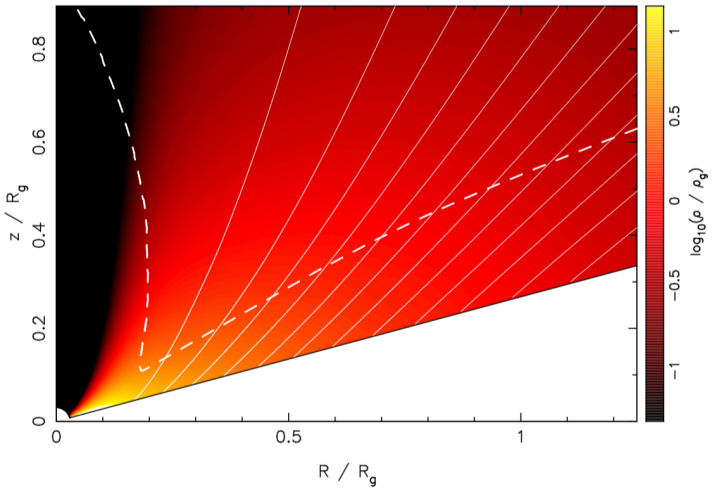
λ=1.6, r_0=1 au

compatible with CO survival

Panoglou+2012

Photo-evaporated DW

Alexander+14 PPVI

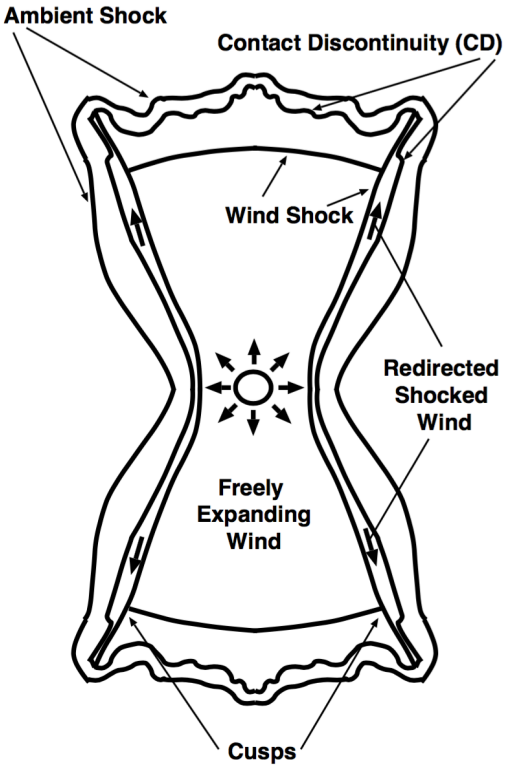


r_0=3-4 au from conservation of specific angular momentum

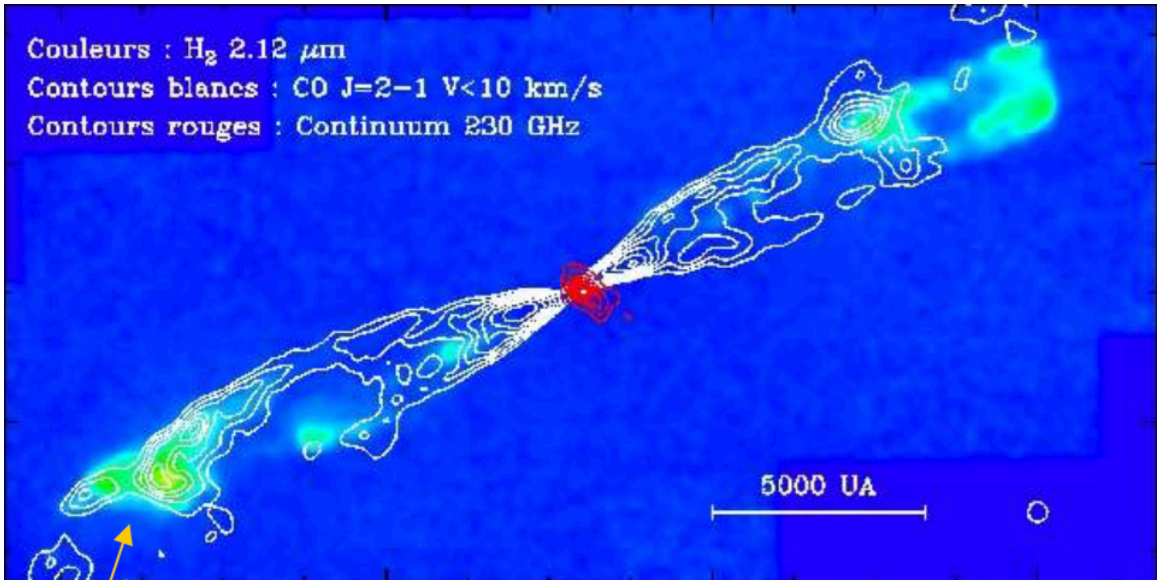
- But pb to account for the large mass flux of $\approx 10^{-7}$ Msun/yr
- PDW requires warm CO at the surface of disk (T $\approx$ 2000 K)

Observational predictions required

Interaction with envelope/disk and/or bow-shock wings ?



Delamarter+2000



- But Hubble-like law (Vr propto r, Vz propto z Lee+2000) NOT observed
- Detailed modelling required

Summary

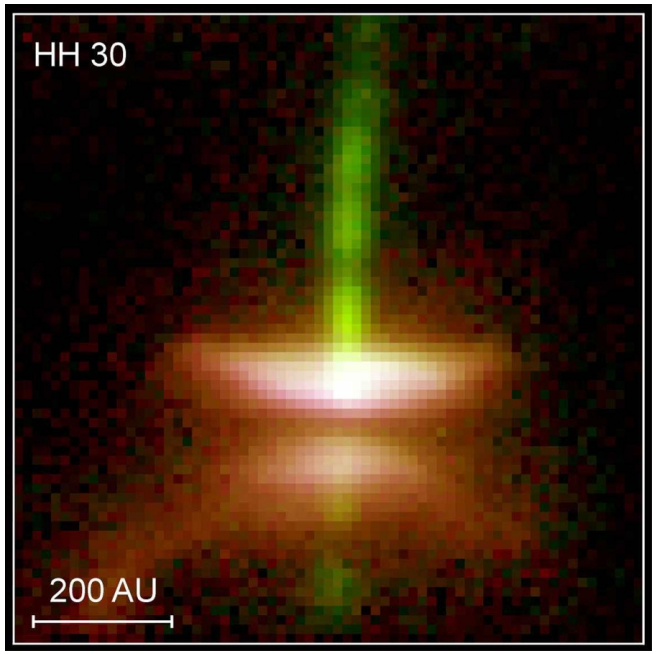
- ALMA is revolutionizing our view of molecular jets/cavities:
  - jet/flow rotation challenge current disk wind models
  - Role of outflow disruption for core-to-star efficiency potentially crucial

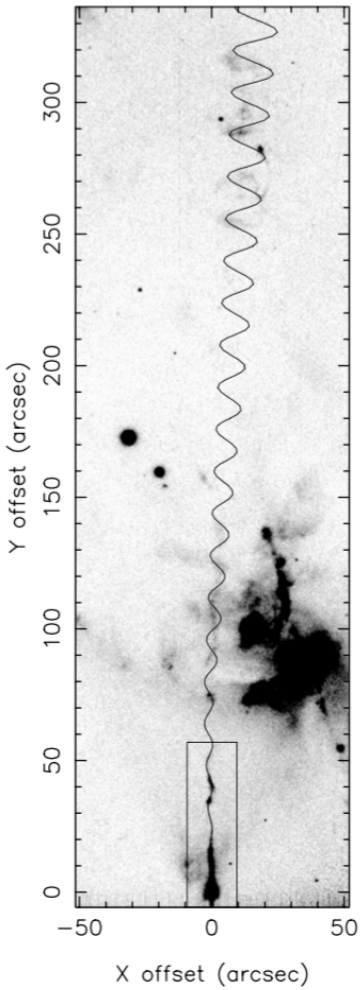
- ✓ Detailed modeling of cavity structure and dynamics needed to firmly establish their nature.

- ✓ More ALMA observations coming

The HH 30 edge-on system

Edge-on Class II source in Taurus (d=140 pc), Mstar=0.45 Msun





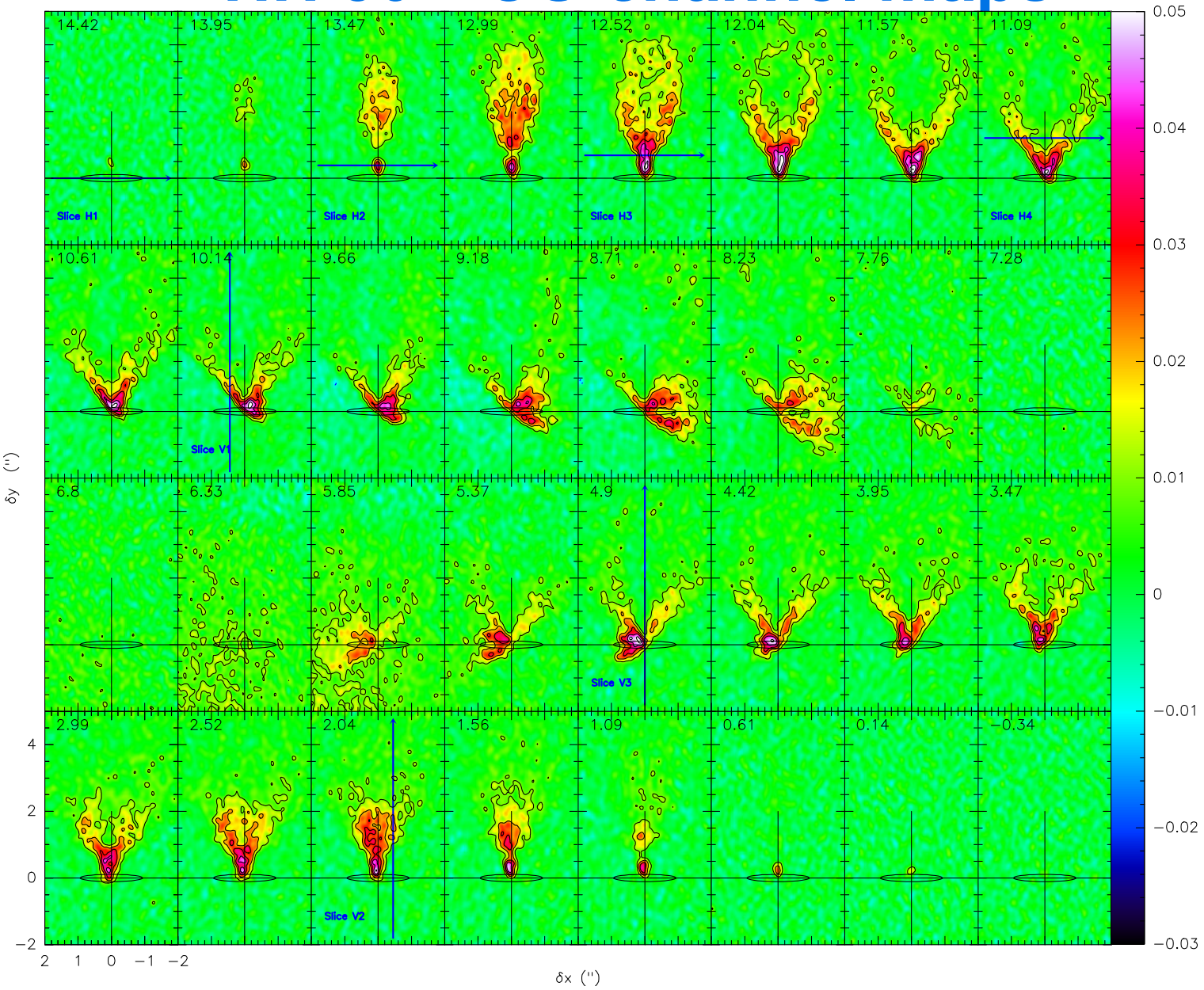
A central binary ?
Large scale jet wiggling

✧ orbital motion in a 18 au binary

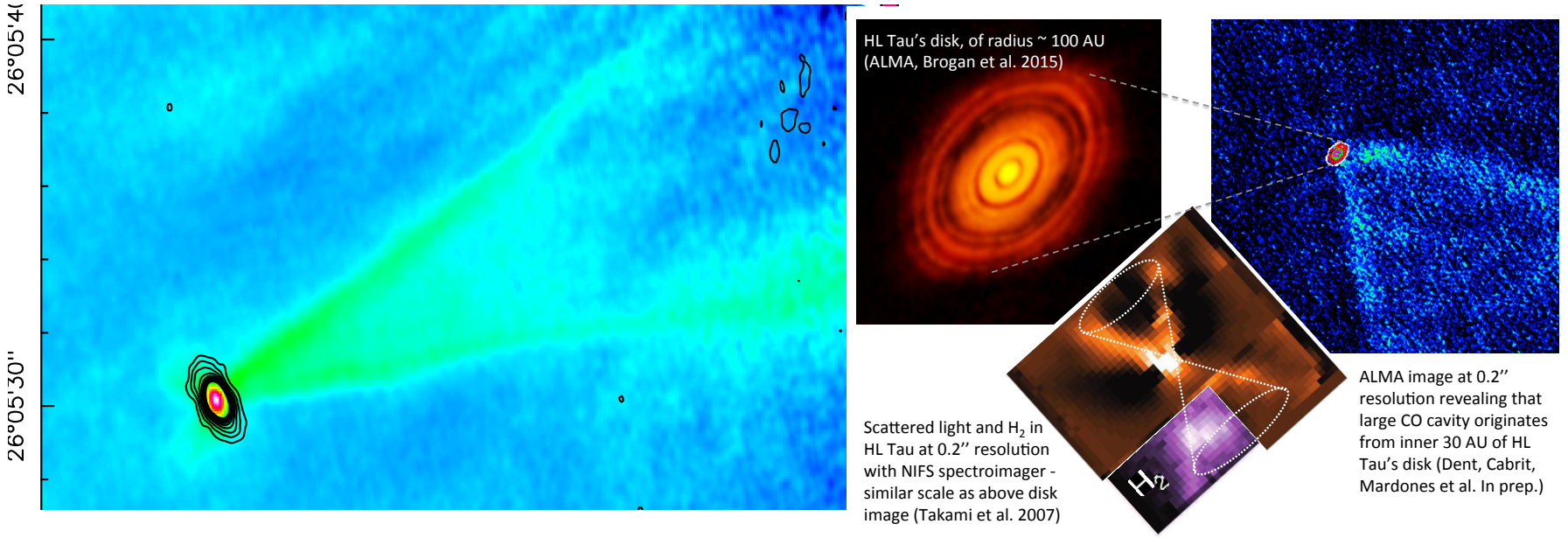
✧ disk precession in < 1 au binary

Anglada+2007
Estallela+2012

HH 30 ^{12}CO channel maps



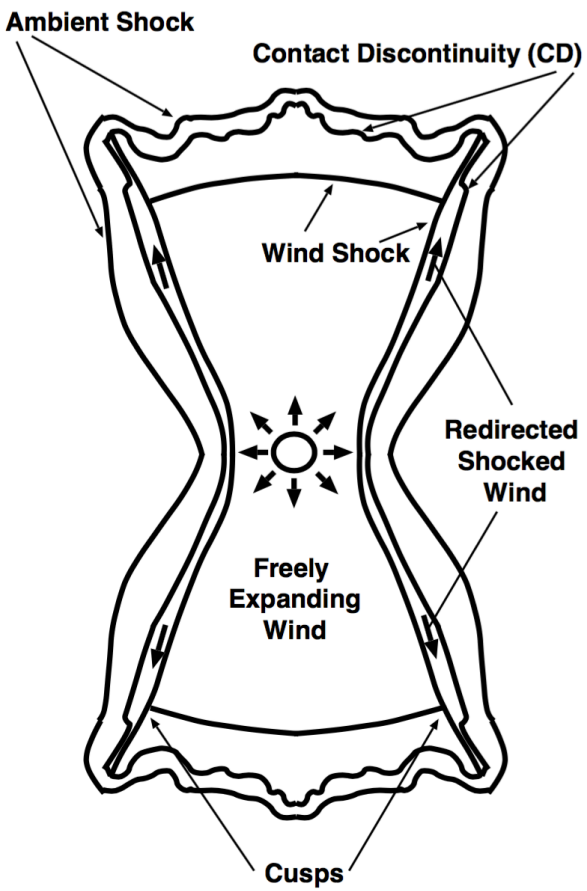
ALMA Observations CO cavities



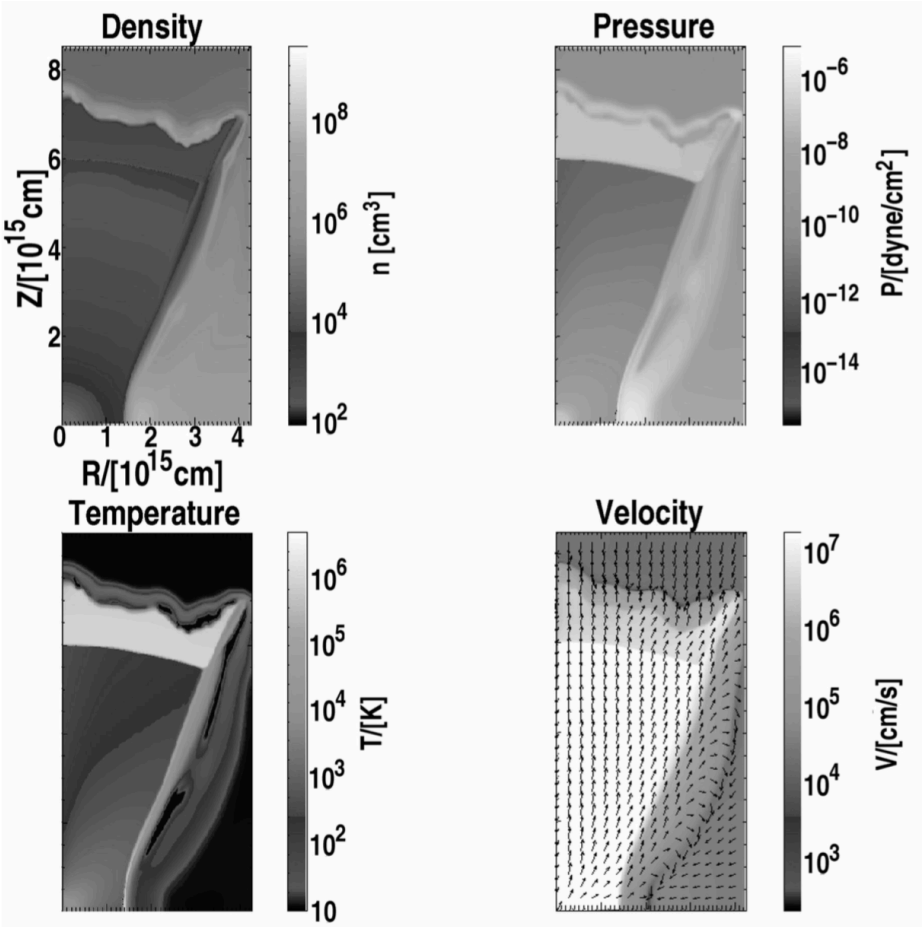
- HL Tau, Cycle 3 DG Tau B, Cycle 4 HH 30

- ALMA observations will also provide constraints on underlying disk at wind launching site

Interaction with envelope/disk ?



Delamarter+2000



Detailed modelling required (on going work by B. Tabone & S. Cabrit)