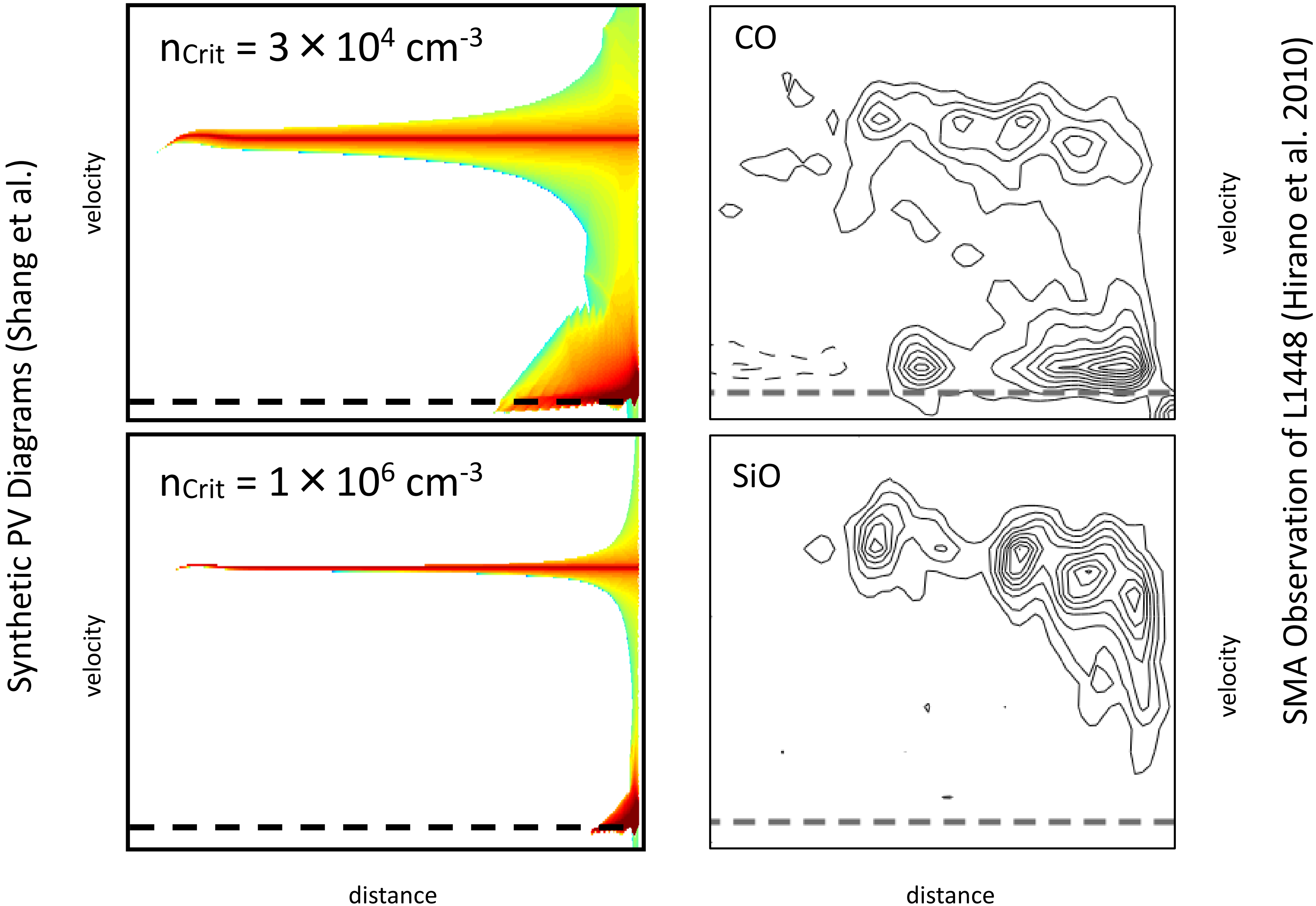
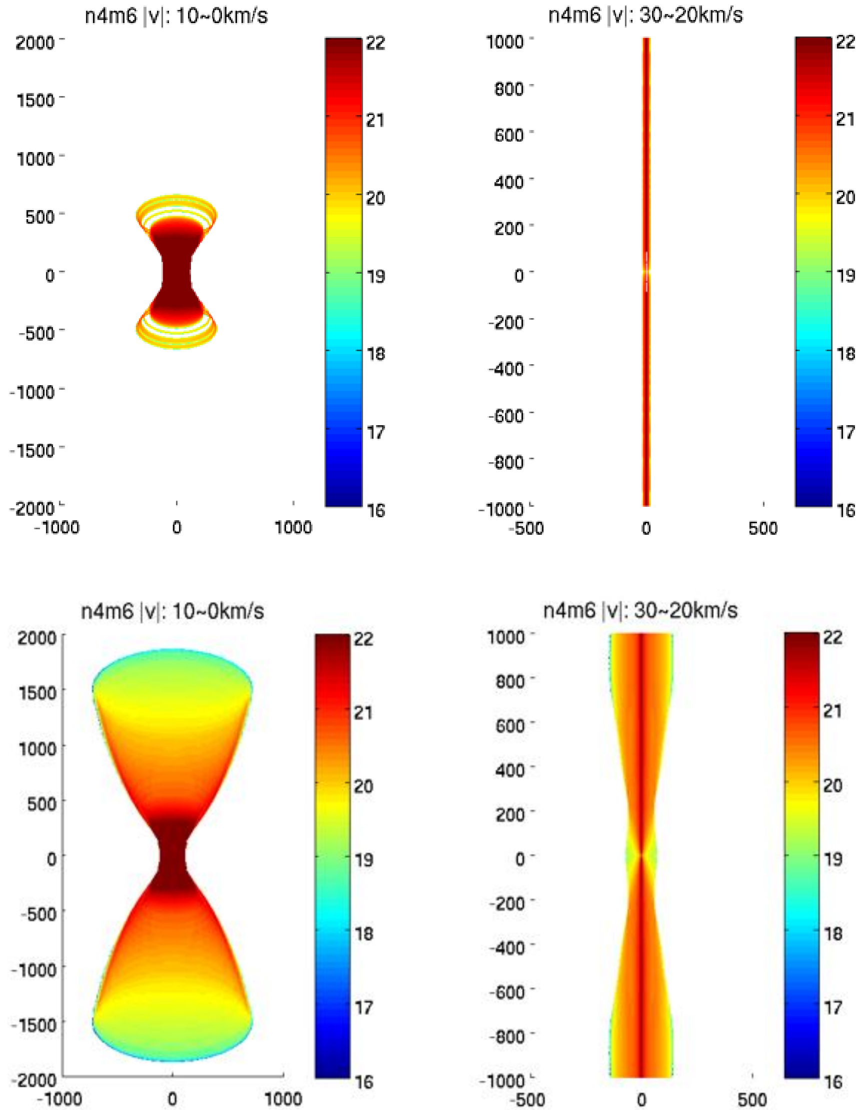
Synthetic Cold Molecular Outflows from Protostars

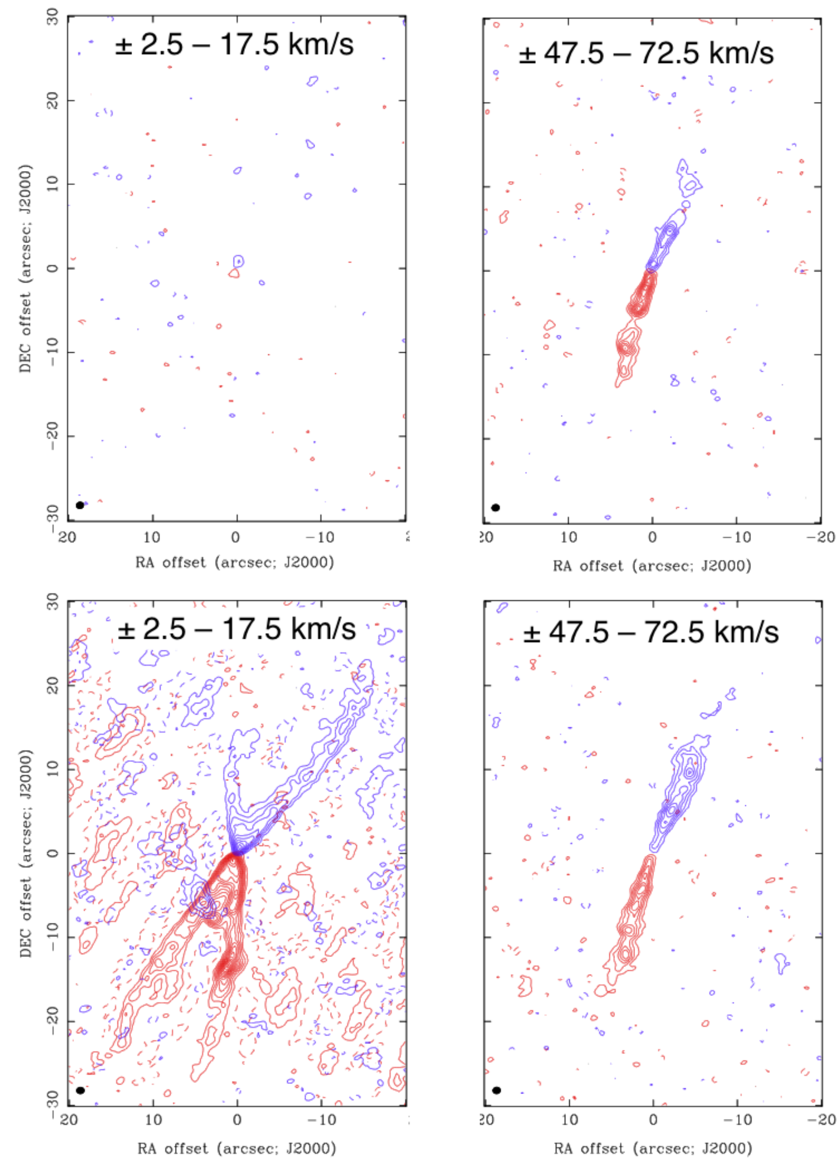


Synthetic Cold Molecular Outflows

H. Shang, L.-Y. Wang, T.-Y. Chiang & C.-M. Shen



L1448 Data (Hirano et al. 2010)



Comparisons with SMA Observation of L1448

SMA Observations of Young Protostellar jets:

Searching for Jet Rotation

Chin-Fei Lee (ASIAA)

Naomi Hirano, Aina Palau, Paul Ho, Sienny Shang,Tyler Bourke, Qizhou Zhang

Picture: Derek Kubo

Current findings of Protostellar Jets

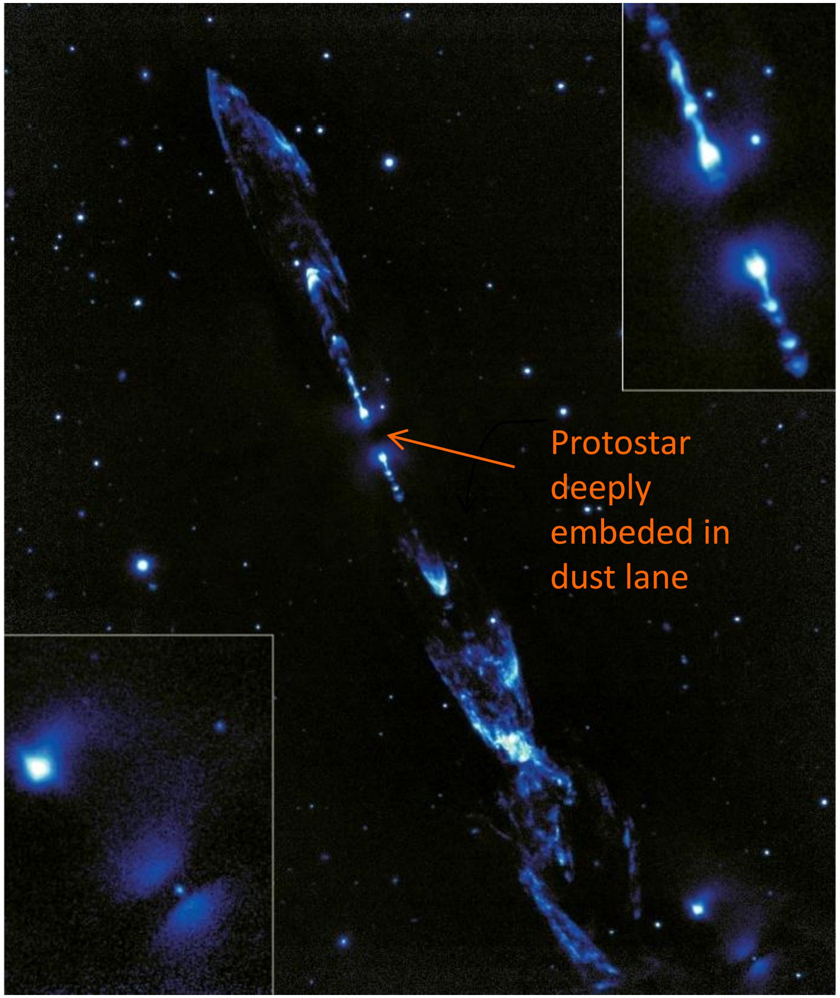
- Jets are extracting a considerable fraction (10% -- 30%) of the accretion power
- Jets appear collimated on small scales independent of circumstellar density ➔ intrinsic magnetic collimation process (Stellar wind, Disk wind and X-wind models)
- Evidence for dust and molecules in Jets
  - stellar wind would not be dense enough to produce the dust and molecules
  - Disk winds and X-winds seem promising to explain dust and molecules

From Cabrit

Why study Protostellar Jets?

- Could be a central core of Magneto-centrifugal winds emanating from the inner regions of accretion disks, probing the accretion process very close to the protostars.
- thus, could be the keys to removing excess angular momenta from the disks, allowing material to fall onto the protostars?
- To answer these questions, we need to measure the jet rotation, ie, how much angular momentum can be carried away by the jets.
- Moreover, the specific angular momentum and energy can be assumed to be conserved along any field line → Measuring v_p & v_φ + stellar mass ➔ launching radius.

HH 212 Jet in H_2 in Orion at 400pc

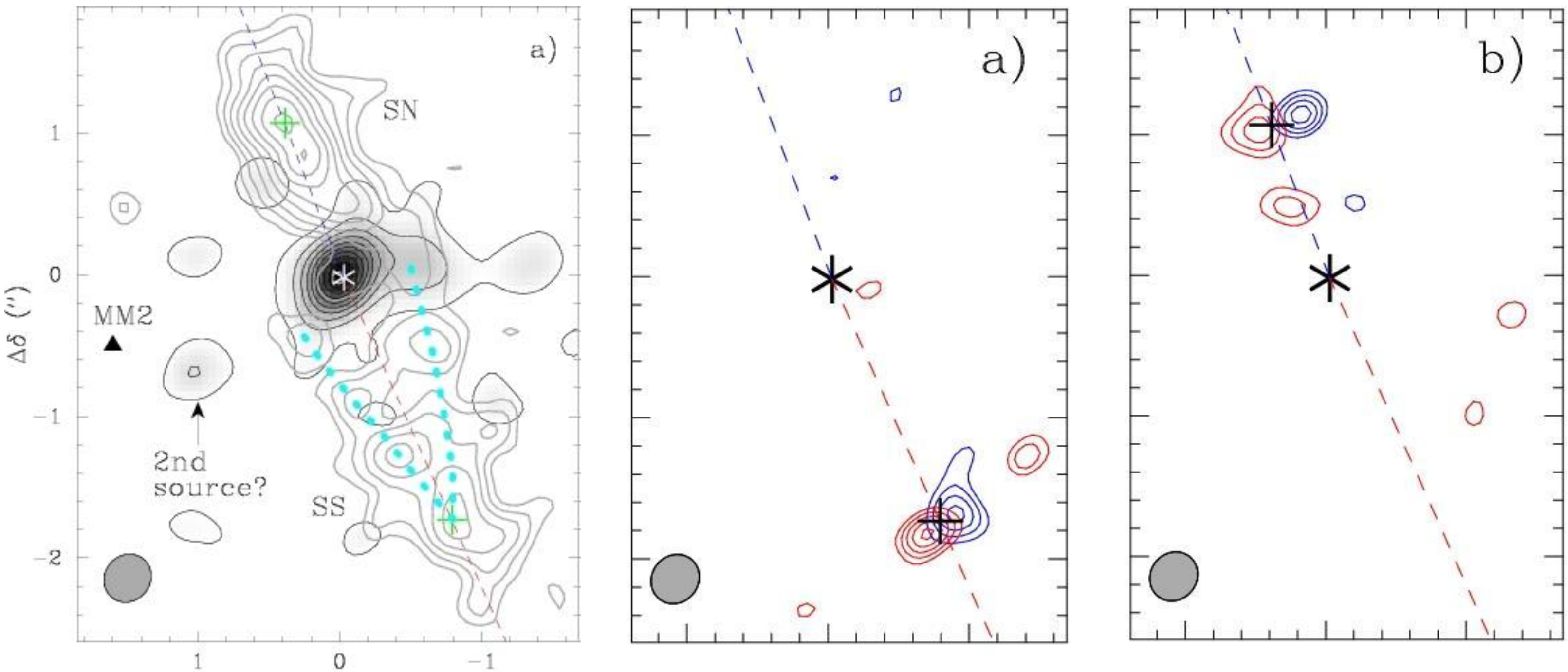


- Molecular jet by Class 0 protostar (12 Lsun)
- ~7’ (0.8 pc) long
- Collimated, symm.
- Knots, bow shocks
- North: blueshifted, South: redshifted
- Vj: 150-250 km/s
- Reflection Nebulae

VLT image at 0.34” resolution McCaughrean et al. 2002

Zoom in at 0.35" res. in SiO + dust cont

Jet Rotation?



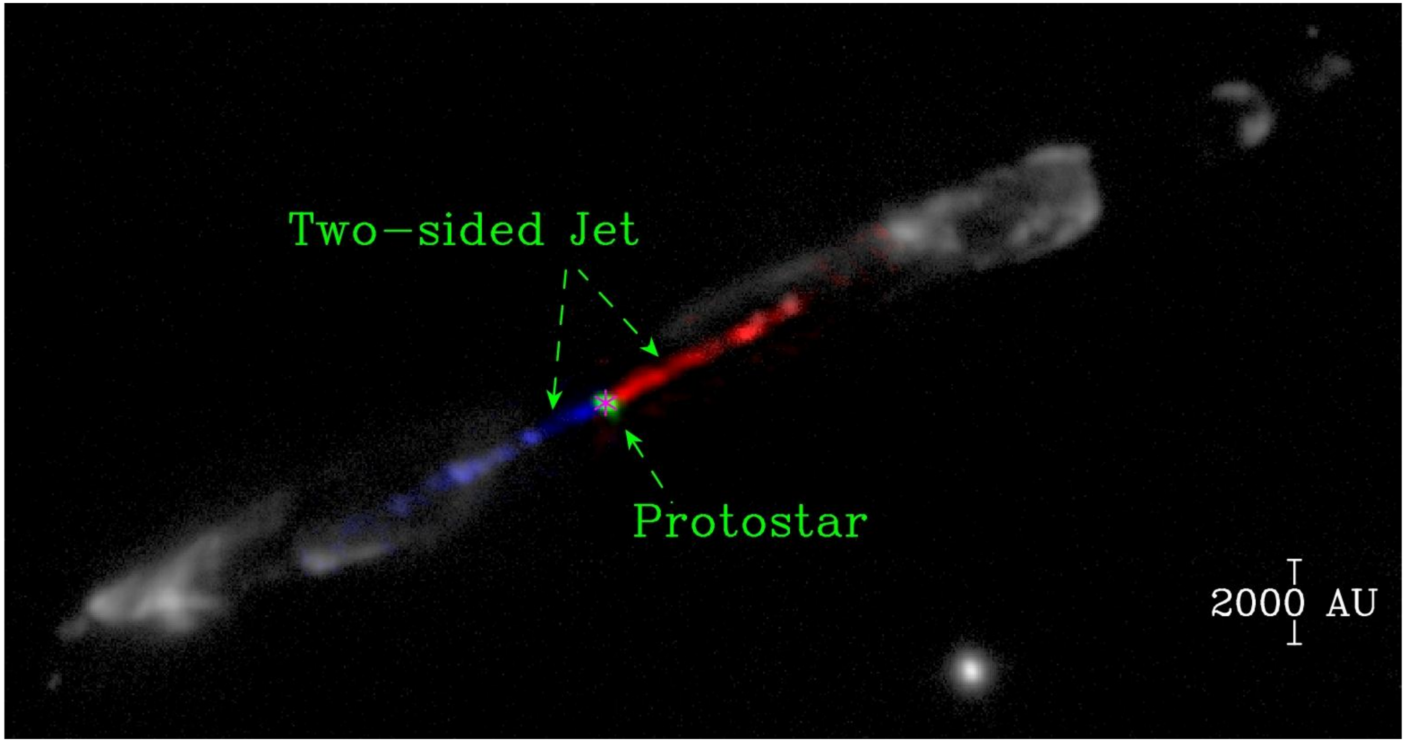
~ 2 km/s at 40AU (0.10")

~ 0.5 km/s at 50AU (0.13")

Sense of velocity gradient is the same as that of envelope

==> jet rotation! angular momentum likely ≤ 25 AU km/s!!

HH 211 Jet in Perseus (280pc)

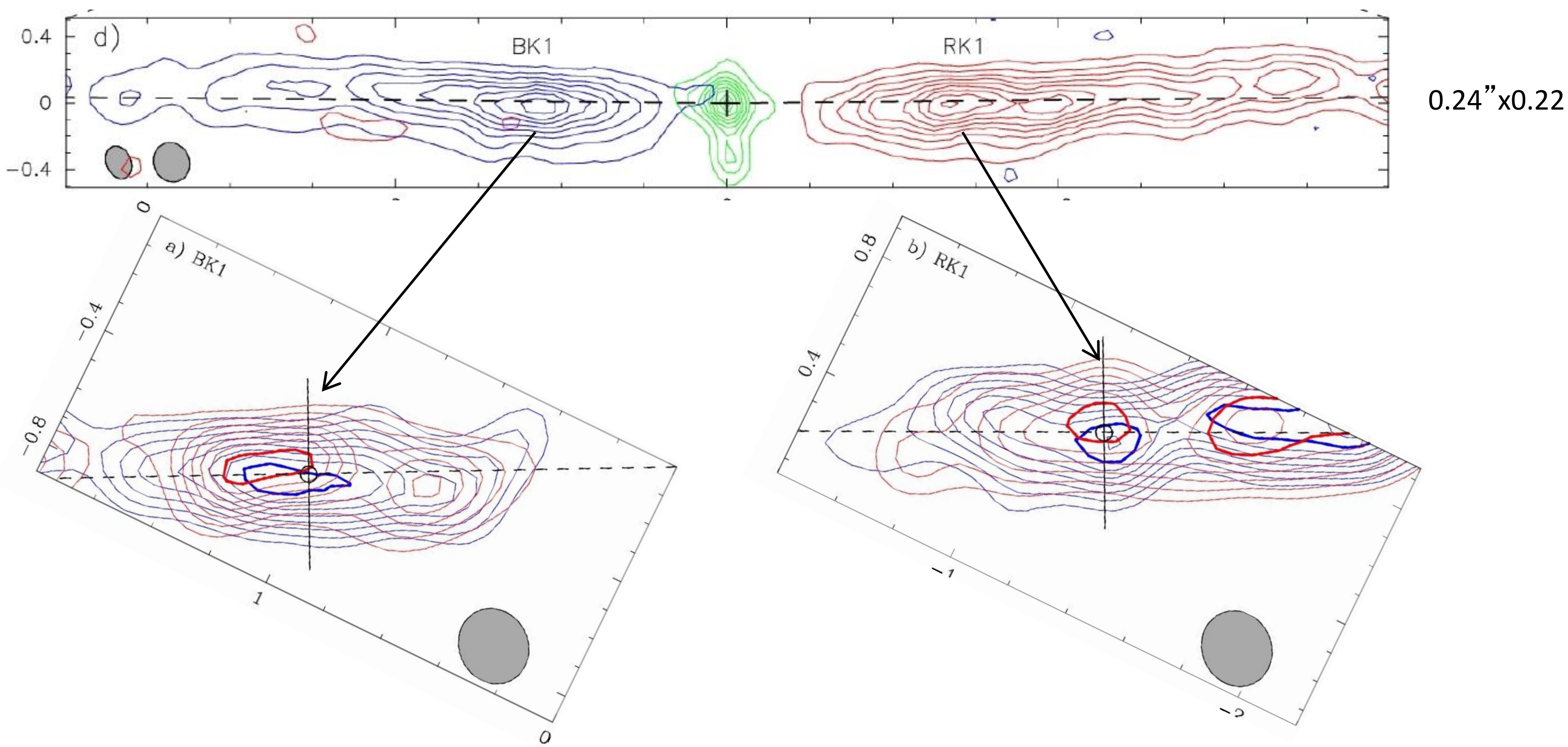


H_2 (VLT at 0.35" resolution, Hirano et al. 2006)

(Class 0 protostar with 3 Lsun)

(SMA at ~1" resolution) 345GHz Cont. + SiO (Red+Blue).

Jet rotation?



Same sense of gradient with the HCO+ disk/envelope since not well resolved
==> upper limit of jet rotation
==> angular momentum ≤ 5 AU km/s !

Conclusions

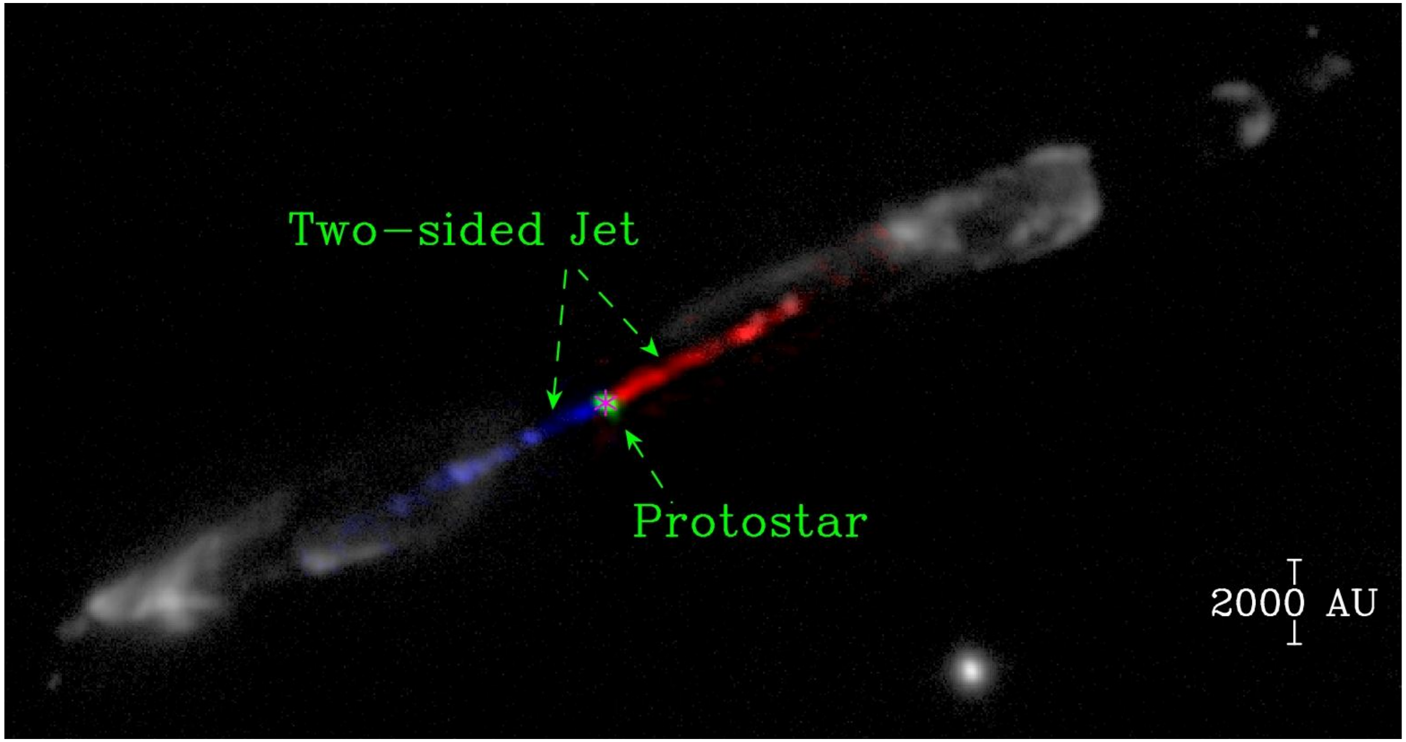
Strong hints of jet rotation for two SiO jets associated with low-mass (0.05-0.15 $M_{\odot}$) Class 0 protostars!!

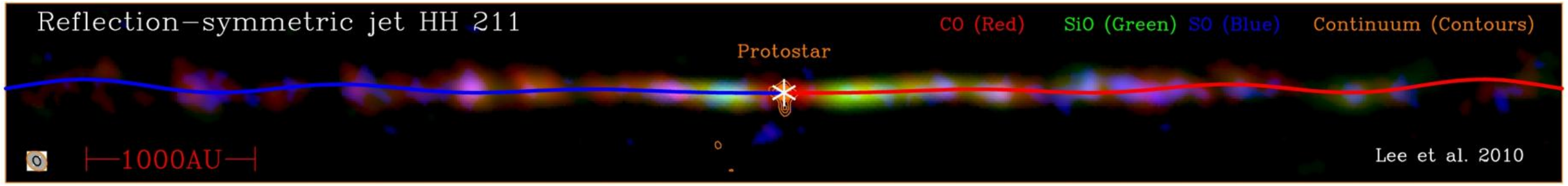
Angular momentum likely ≤ 5 -25 AU km/s!

==> Launching radius ~ 0.014 -- 0.05 AU (3-10 $R_{\odot}$)!!
==> Seems to support the X-wind models!

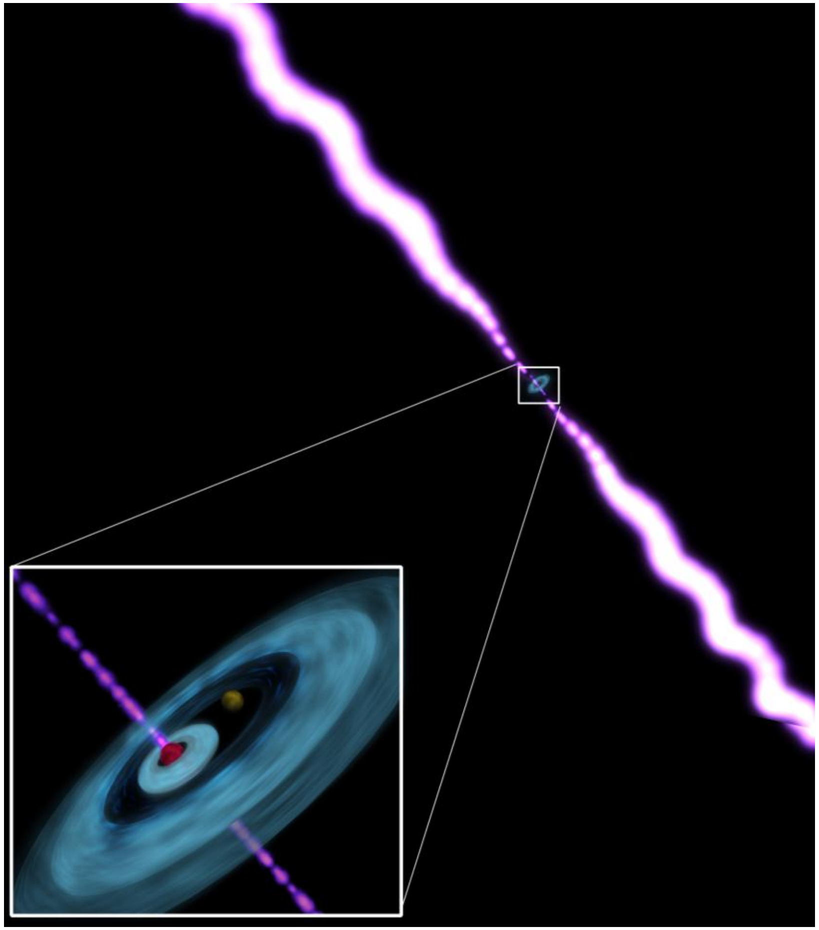
However, ALMA observations at higher resolution (< 0.1") are needed to confirm our results.

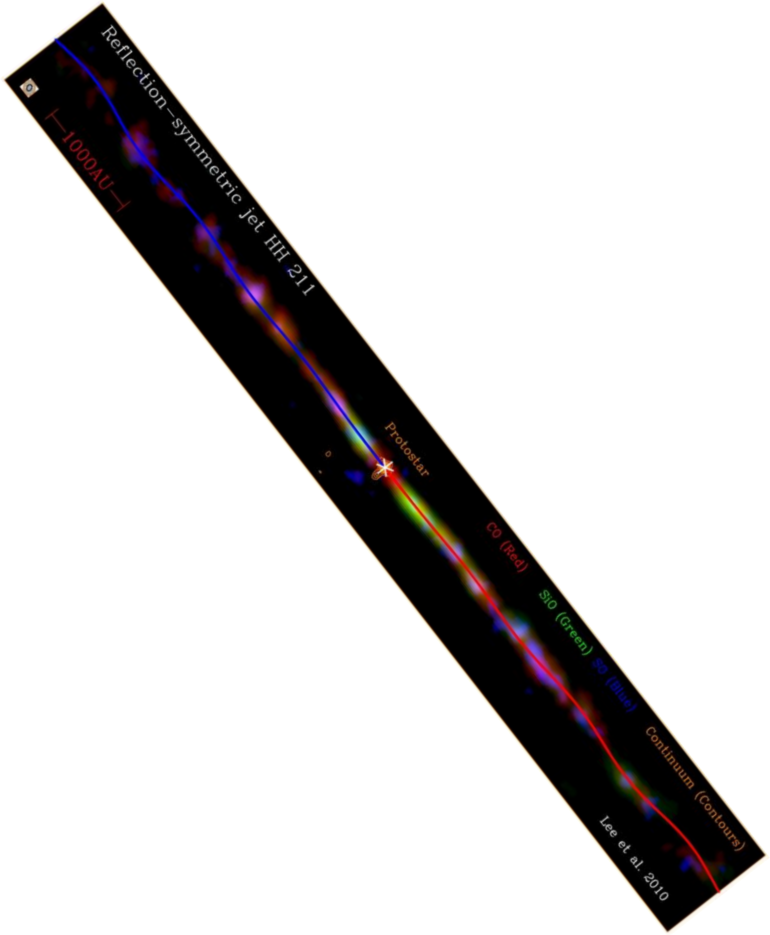
Reflection Symmetry – Orbiting Jet source





Reflection Symmetry – Orbiting Jet source





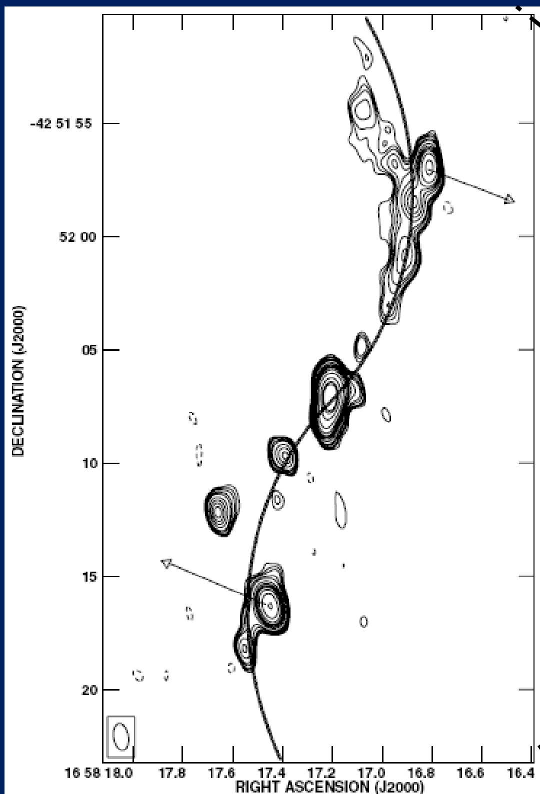
A binary of 60 M_{Jup} with 30 M_{Jup} each

Binary separation 4.6 AU, Orbital Period~43 yrs

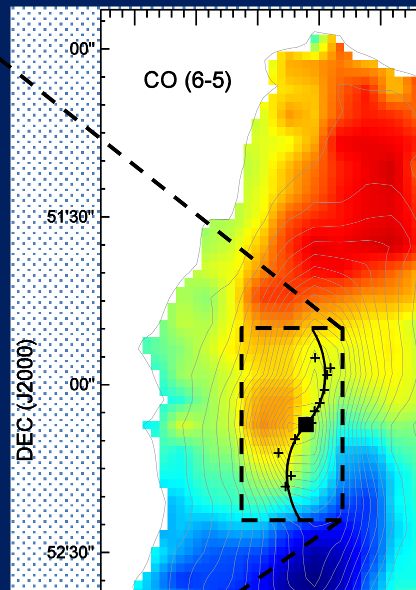
Searching for a molecular counterpart of the most luminous YSO radio jet in our Galaxy

by Keping Qiu (MPIfR)

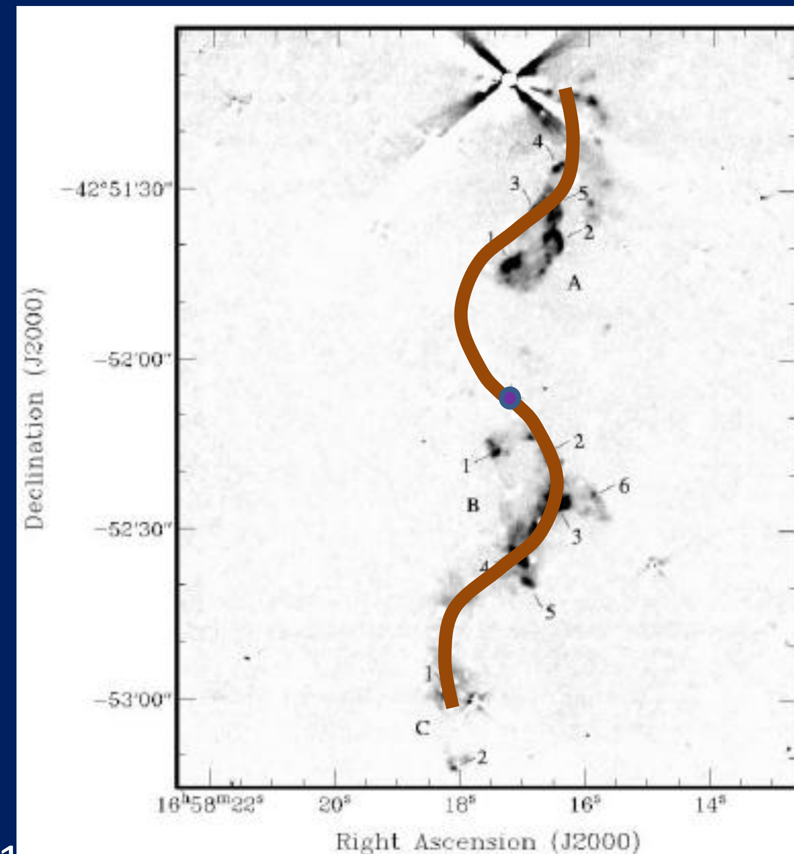
IRAS 16547-4247: $6.4\times10^4 L_\odot$ (Garay et al. 2003), equivalent to an O8 star at ZAMS



VLA 3.6 cm (Rodriguez+ 2008)



APEX CO(6-5) Moment-1



VLT H_2 2.12μm (Brooks et al. 2003)

A ~2pc, collimated CO outflow roughly parallel with the radio jet;
The wiggling pattern seen in CO velocity field & shocked H_2 in contrast with the radio jet!

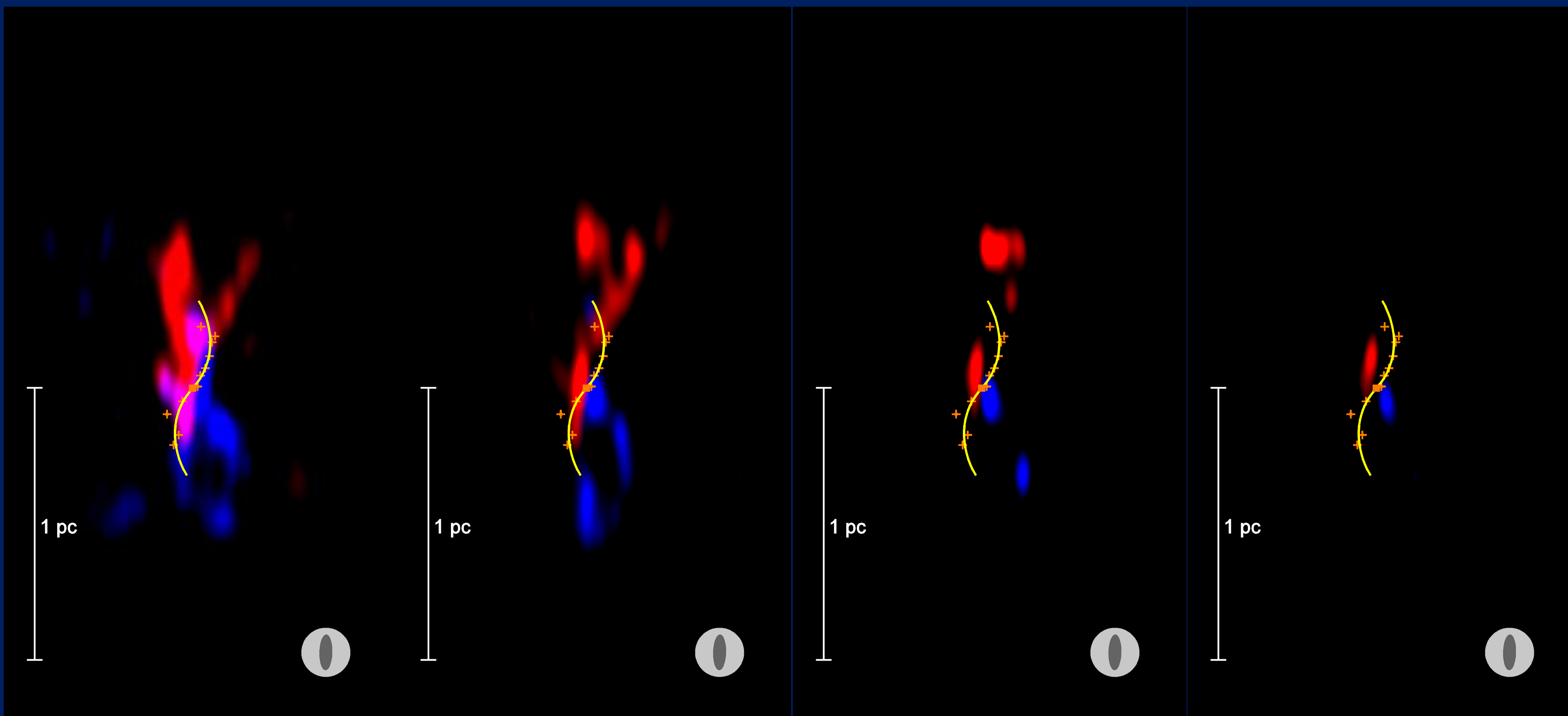
SMA CO (2-1): picking up compact structures, in general consistent with the wiggling pattern seen in CO(6-5)

|ΔV|= 5 – 13 km/s
11 – 21 km/s

|ΔV|=14 – 26 km/s
22 – 34 km/s

|ΔV|= 27 – 36 km/s
35 – 45 km/s

|ΔV|= 37 – 46 km/s
46 – 55 km/s



APEX CO 6-5 (contours) overlaid on SMA CO 2-1 (colored image)

|ΔV|= 5 – 13 km/s
11 – 21 km/s

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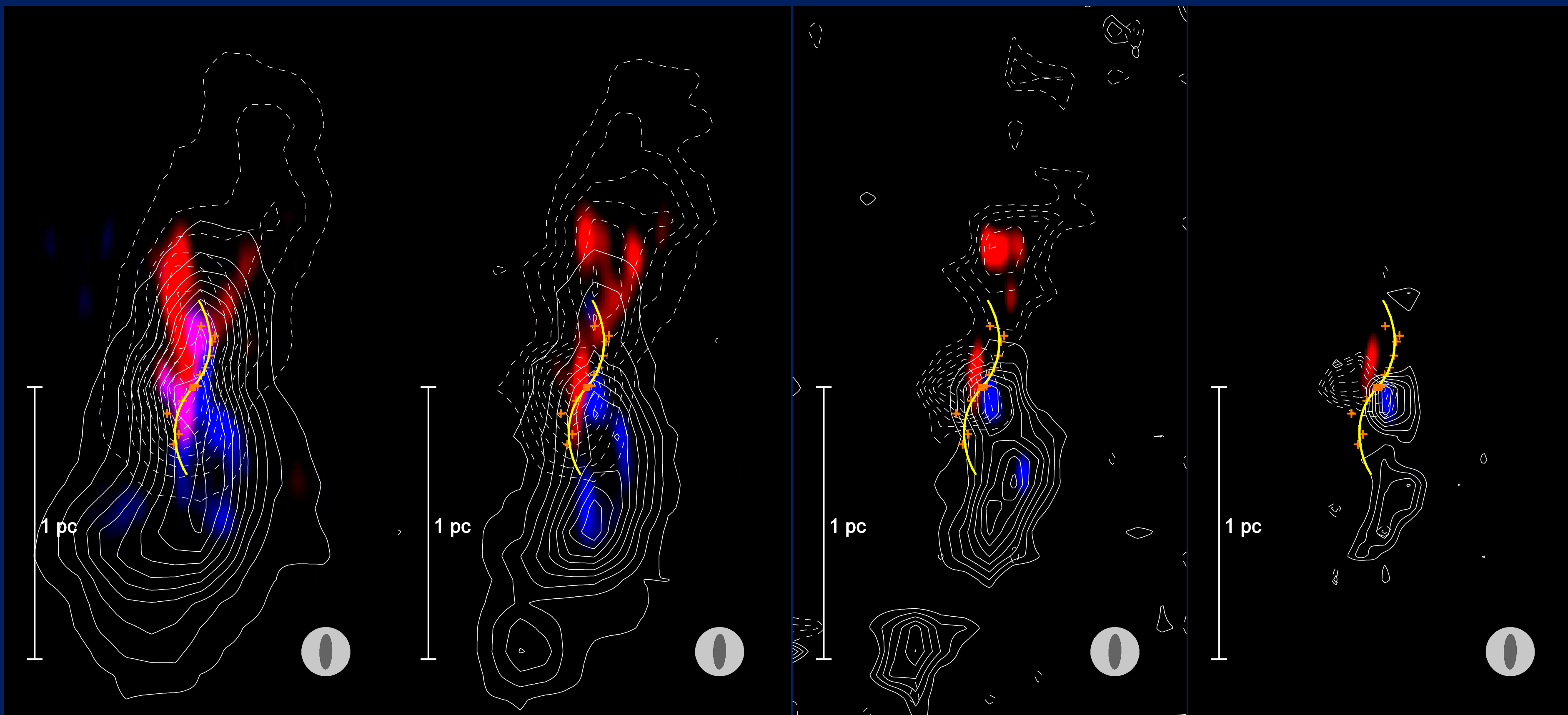


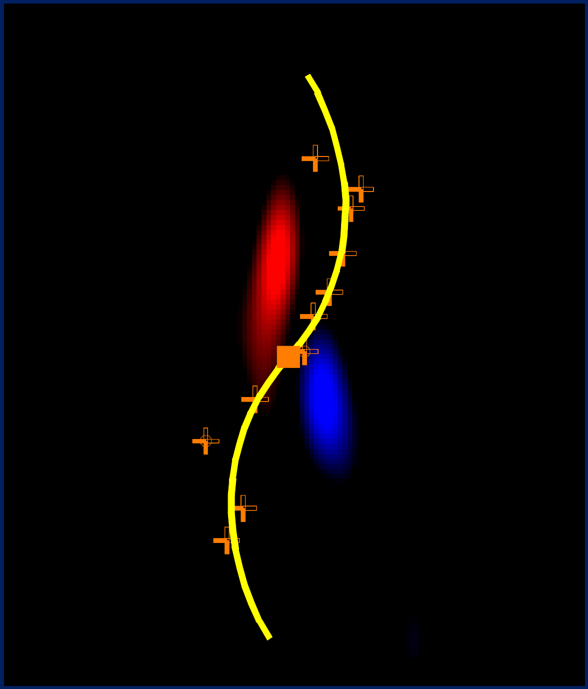
A large and collimated CO jet sharing its central source (a hot core) with a luminous radio jet.

The CO jet is young ($t_{dyn} \sim 10^4$ yr), very massive (reaching 100 $M_\odot$), harboring extremely high-velocity clumps closest to the central source.

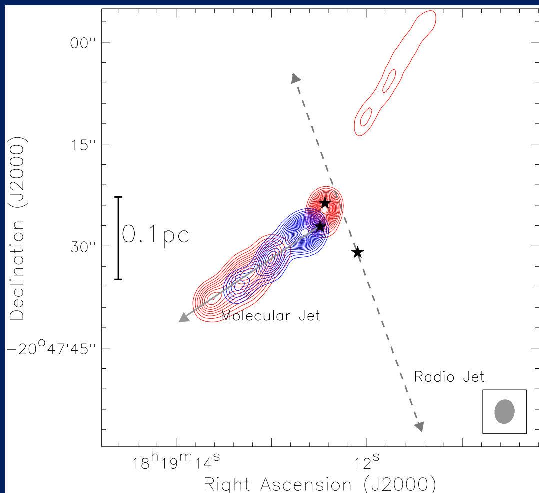
The CO jet is clearly wiggling, but in a manner very different from that of the radio jet.

The difference is hard to be understood as due to ejections with different ages, provided the innermost (youngest) CO clumps having a PA significantly offset from the radio jet.

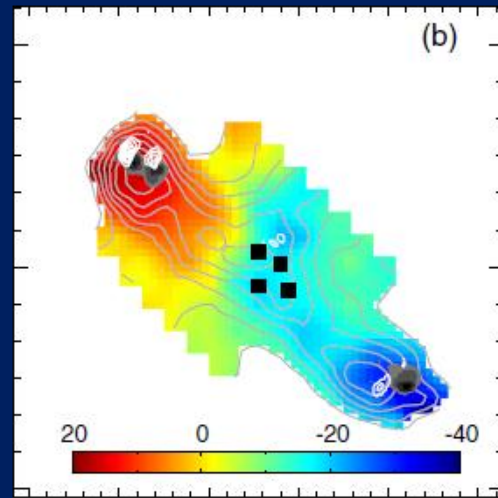
A twin-jet in precession from a massive binary? ALMA is needed for a more definitive answer.



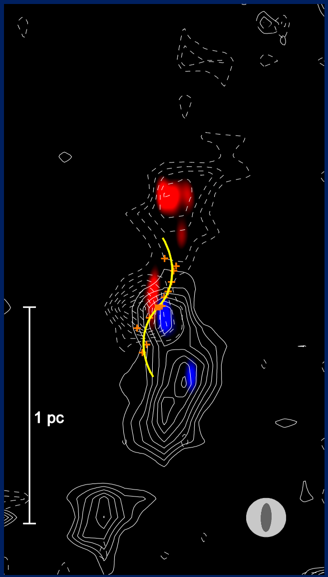
Putting it in the context: Molecular Jets in Massive YSOs



A CO Jet in a cool massive core (HH80-81MM2, Qiu+2009)



A CO (9-8) Jet in a radio-quiet Hot Core (NGC6334I, Qiu+2011)



A CO jet in a radio-loud Hot Core

Molecular jets in massive star formation:

from earliest protostellar stages (core a few 10 K) to hot core (>100 K) stages;

All show EHV features, with discrete, bullet-like clumps seen at the earliest stages;

Time scale: ~10^3 to 10^4 yr; Size: ~0.1 pc to a few pc; Mass: ~1 $M_\odot$ to 100 $M_\odot$;

Roughly constant mass and momentum rates.

Mass	Dynamical time	Mass loss rate	Momentum loss rate
~1 to 100 $M_\odot$	a few10^3 to ~10^4 yr	~10^{-3} $M_\odot$/yr	~10^{-2} ($M_\odot$km/s)/yr