ALMA SV data: The Unexpected Disk Wind

Based on data presented in:
Klaassen et al. 2013

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Outline

- Protostellar Disks
- Dispersal Mechanisms
- What We've Seen
  - ALMA Science Verification Data
- What comes next
  - More ALMA data?

Protostellar Disks

Are very useful things...

Winds are blown off of it

Material infalls onto it

Planets form in it

Accretion happens through it

But at the end of the day...

Something has to disipate it

The solar system doesn't really look like this!

How to remove the disk

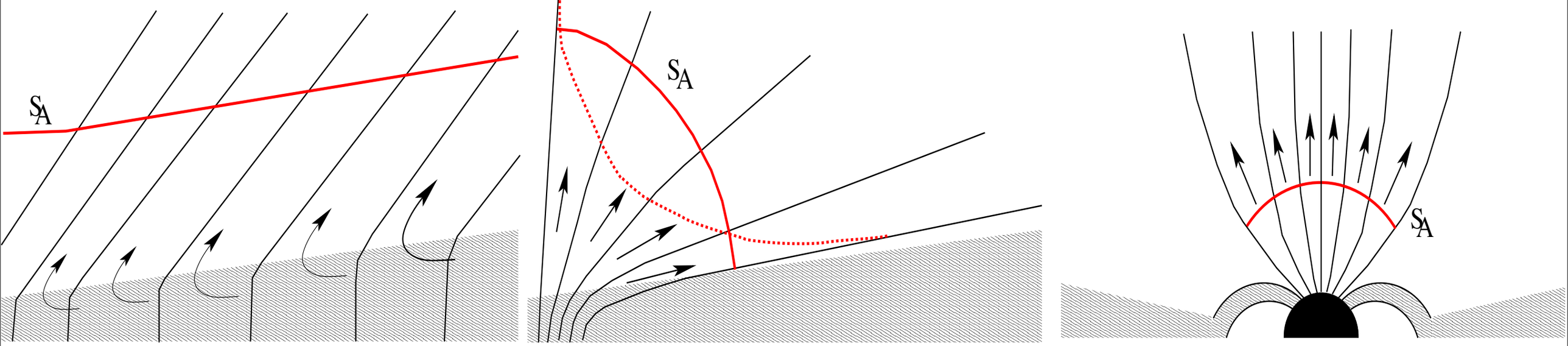
Accretion Driven

Pressure Driven

(a) Extended disc–wind: $r_e >> r_i$

(b) X–wind: $r_e > r_i$

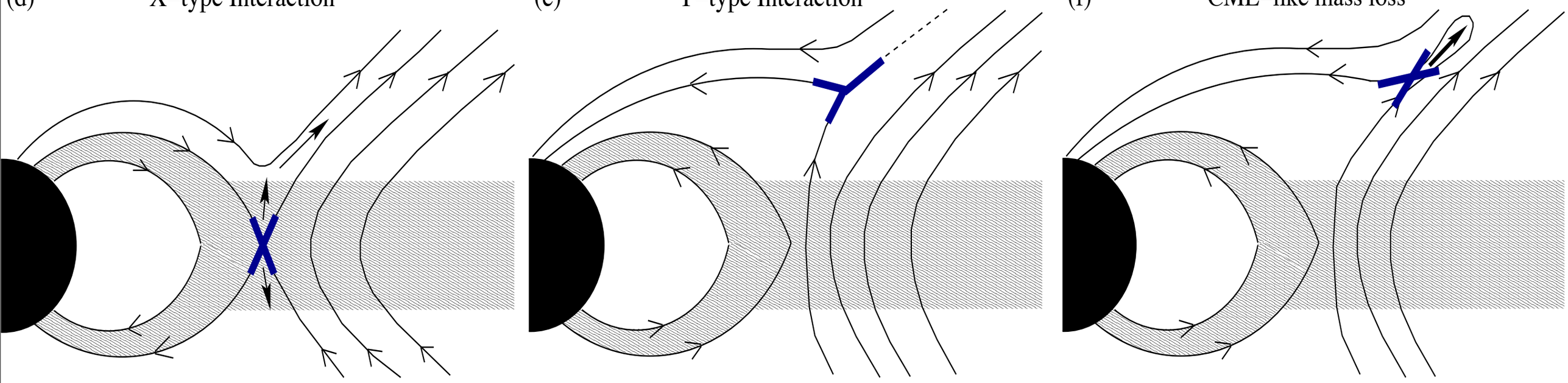
(c) Stellar wind



(d) X–type Interaction

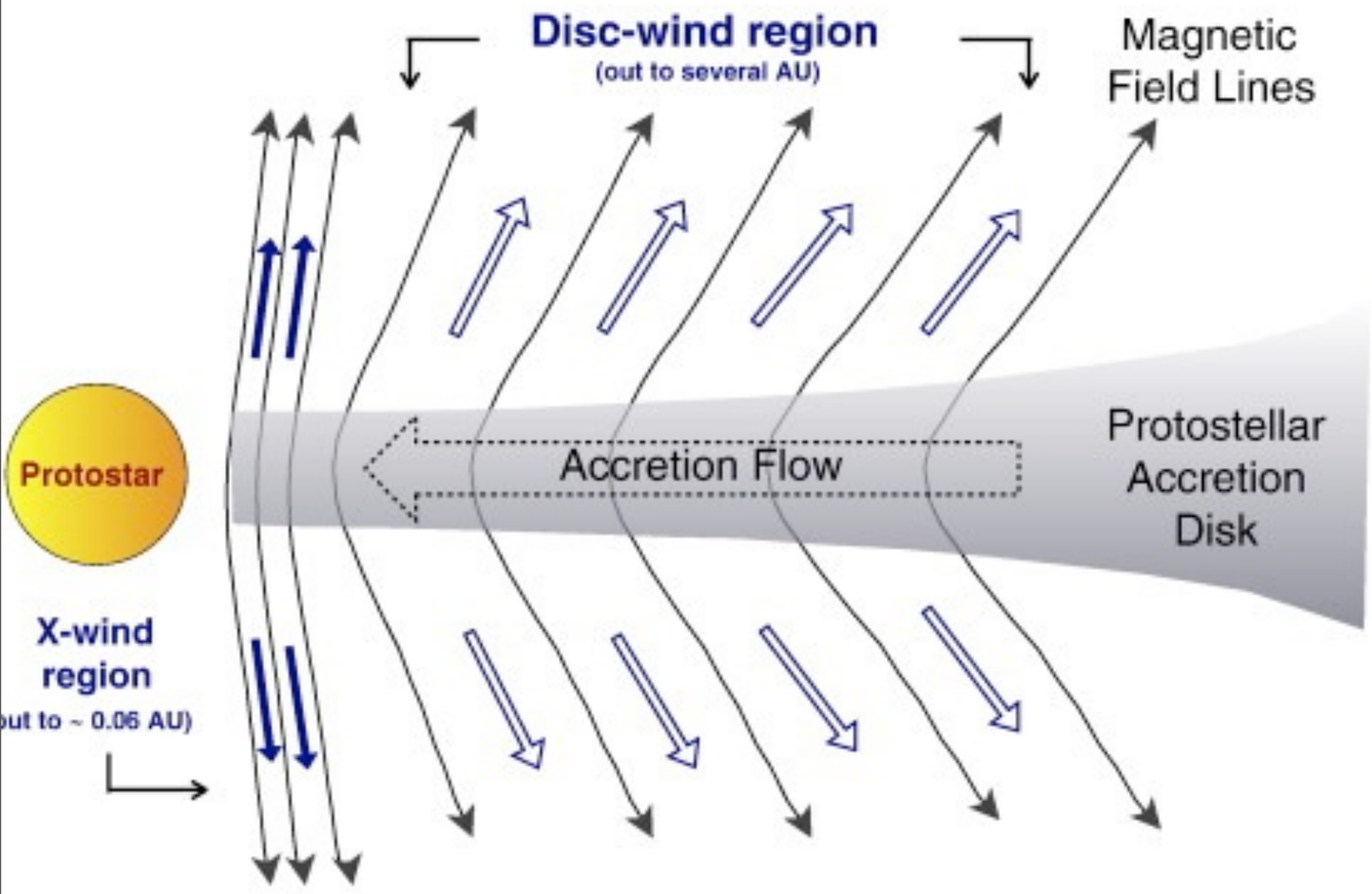
(e) Y–type Interaction

(f) CME–like mass loss

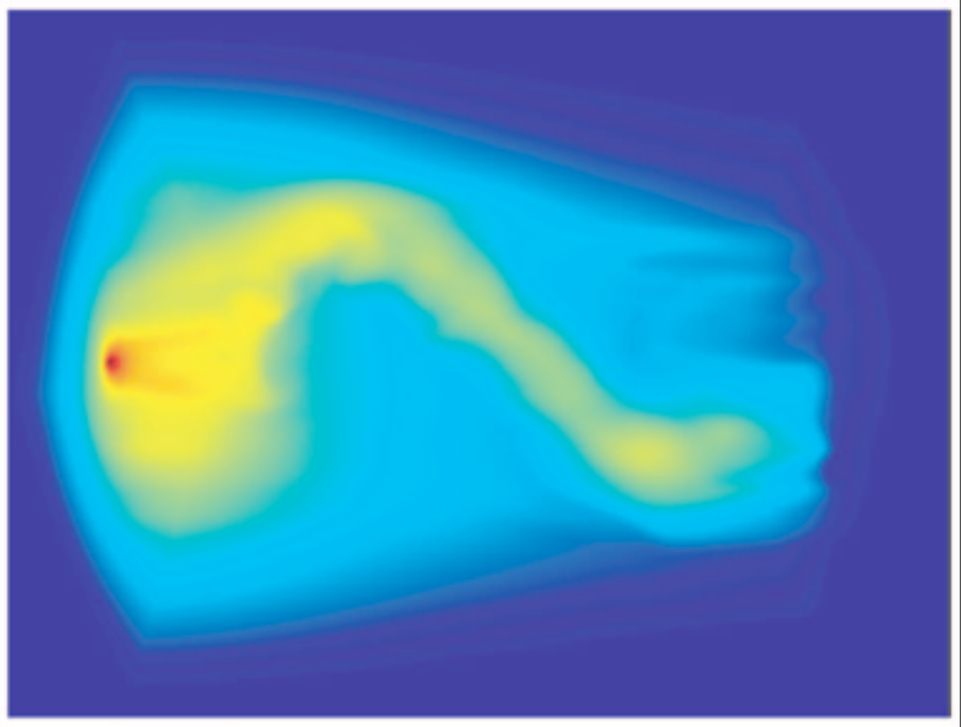


Ferreira et al. 2006

Disk Wind Theory



Ouyed, Clark & Pudritz (2003)
Salmeron & Ireland (2011)

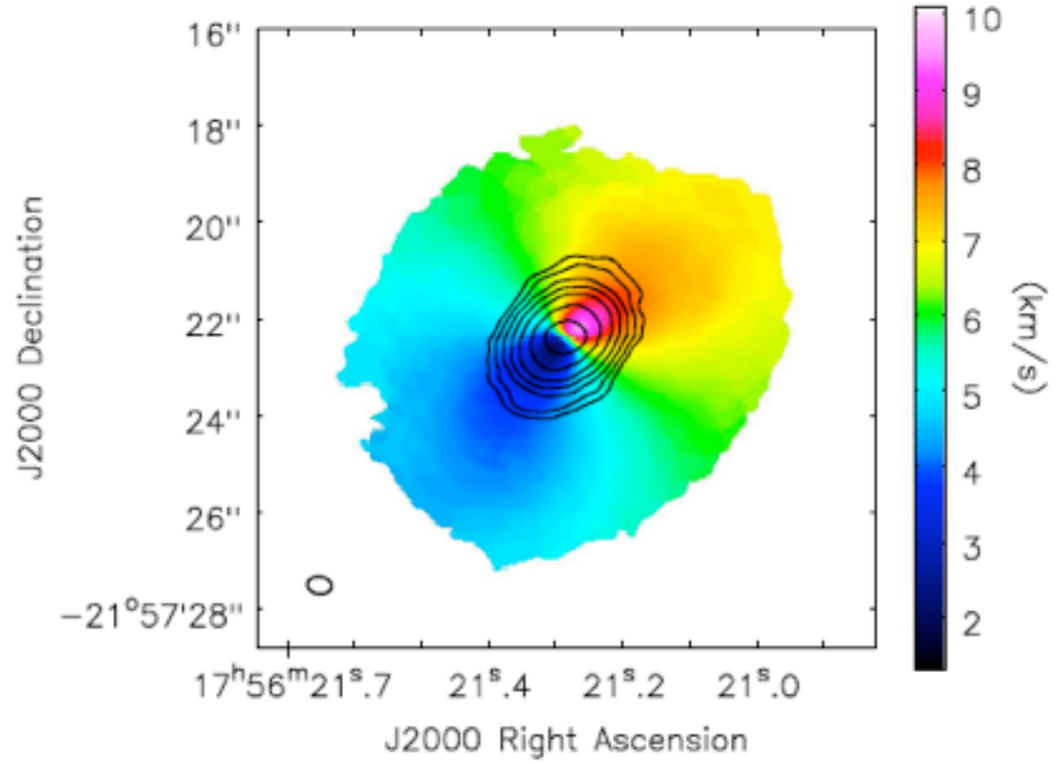


- Launched from a few AU
- Collimated by the magnetic field

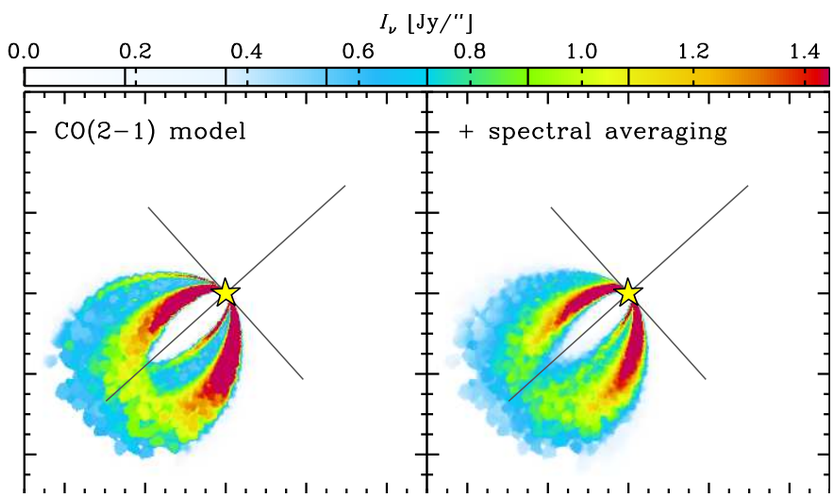
Disk winds should show signs of rotation

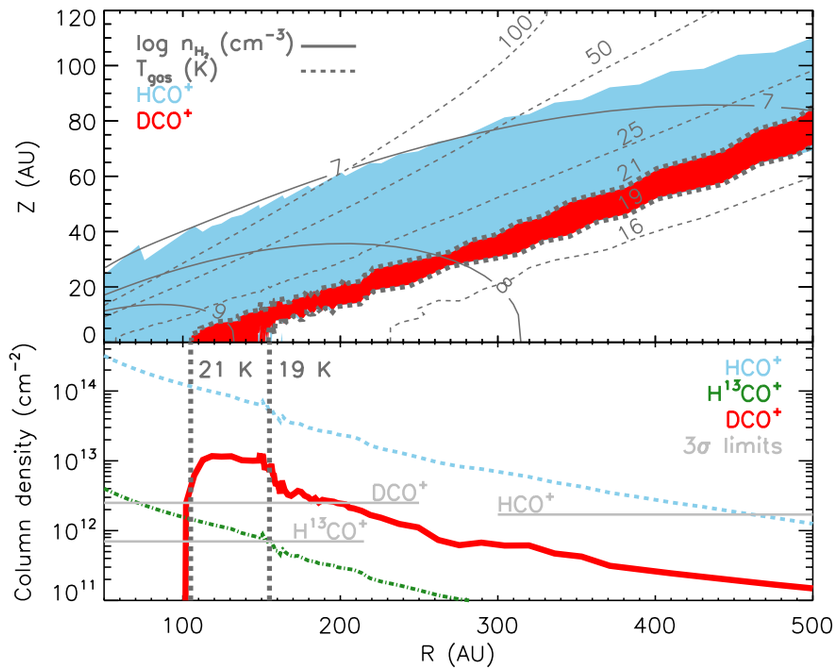
HD 163296

- Herbig Ae star (2.3 $M_\odot$)
- 4-5 Myr old
- Good testbed for disk modelling (a lot of lines)
- Evidence for variability



- HH 409 comes from this star

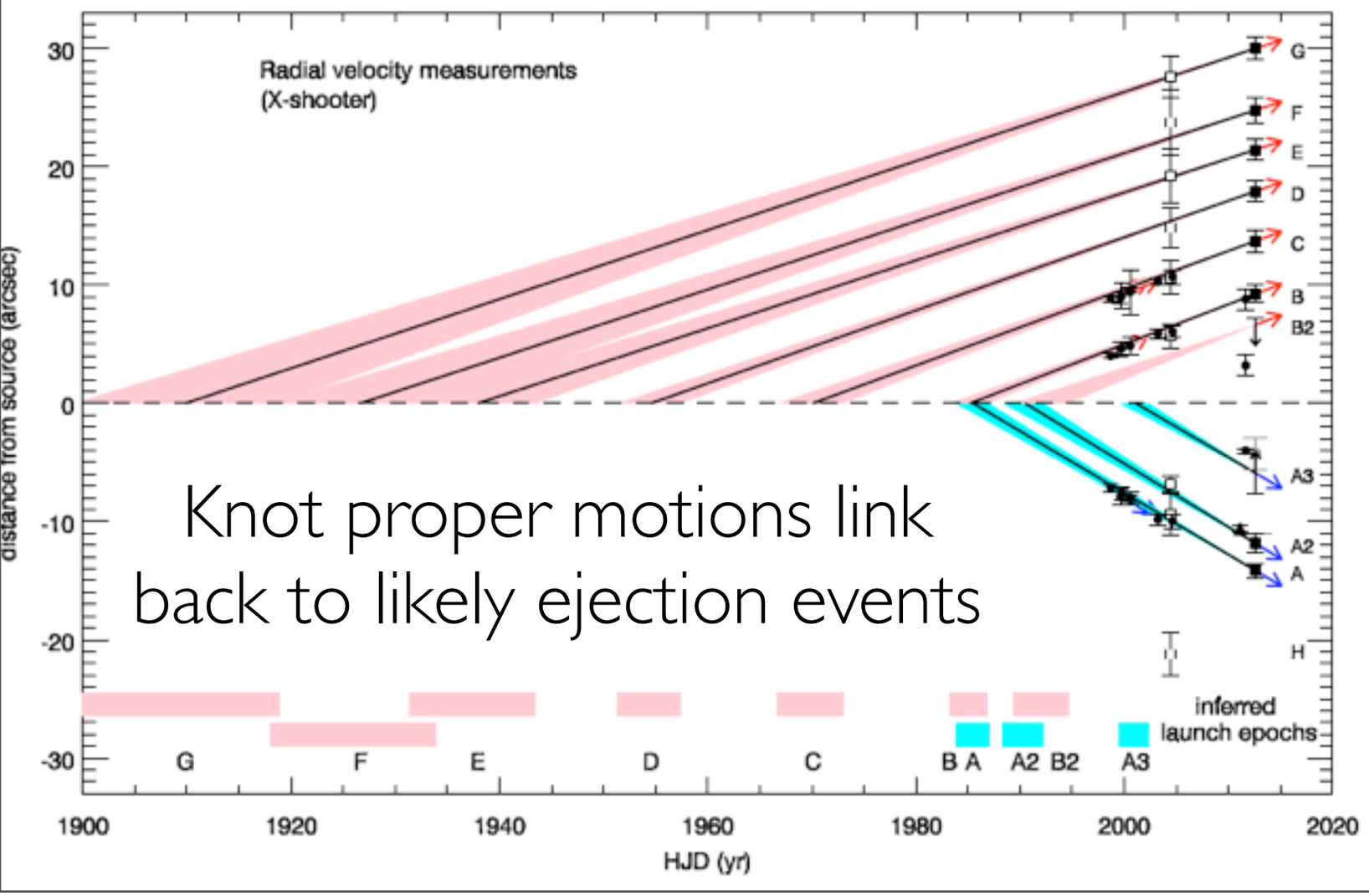




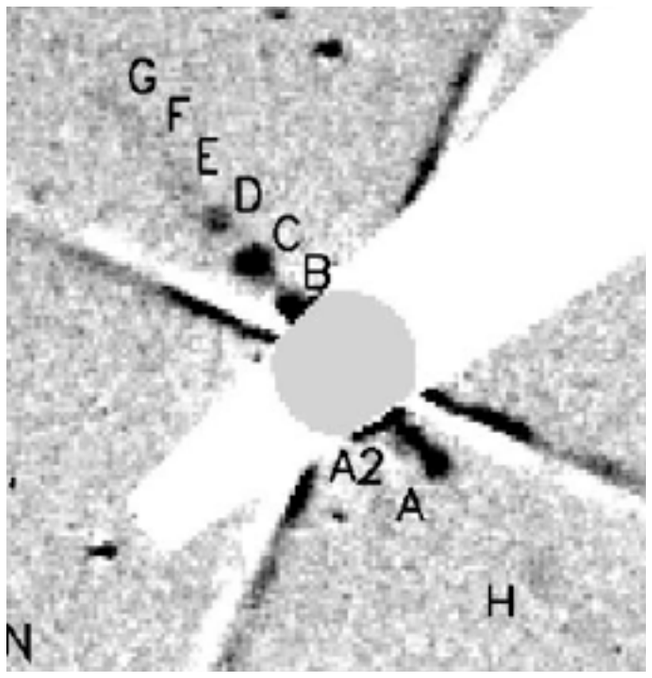
De Gregorio-Monsalvo et al., Mathews et al. (both submitted)
Rosenfeld et al. (in press)

HH 409

- The variability in the disk can be traced back to HH knot ejections



Knot proper motions link back to likely ejection events



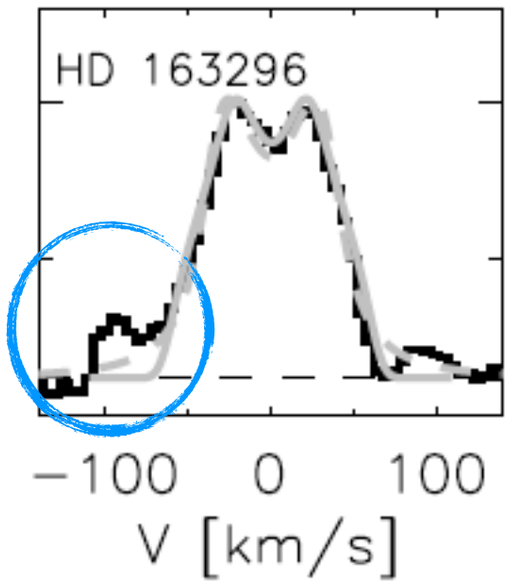
So there's a jet.. What about the wind?

Wassell et al. (2006), Ellerbroek et al (in prep)

Disk Wind

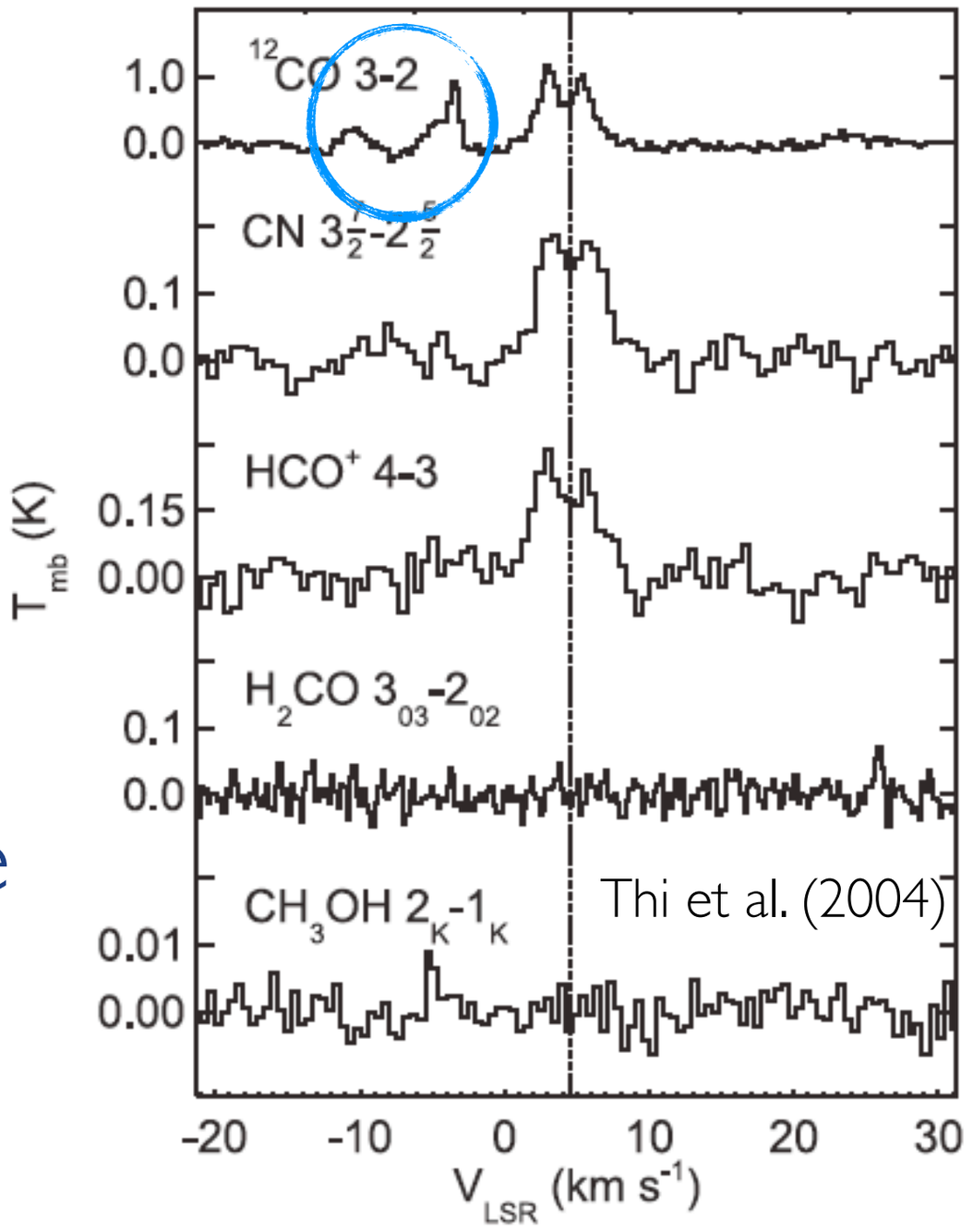
- This wind hasn't been imaged before because previous observations weren't sensitive enough at high resolution

Ro-vibrational CO



Salyk et al. (2011)

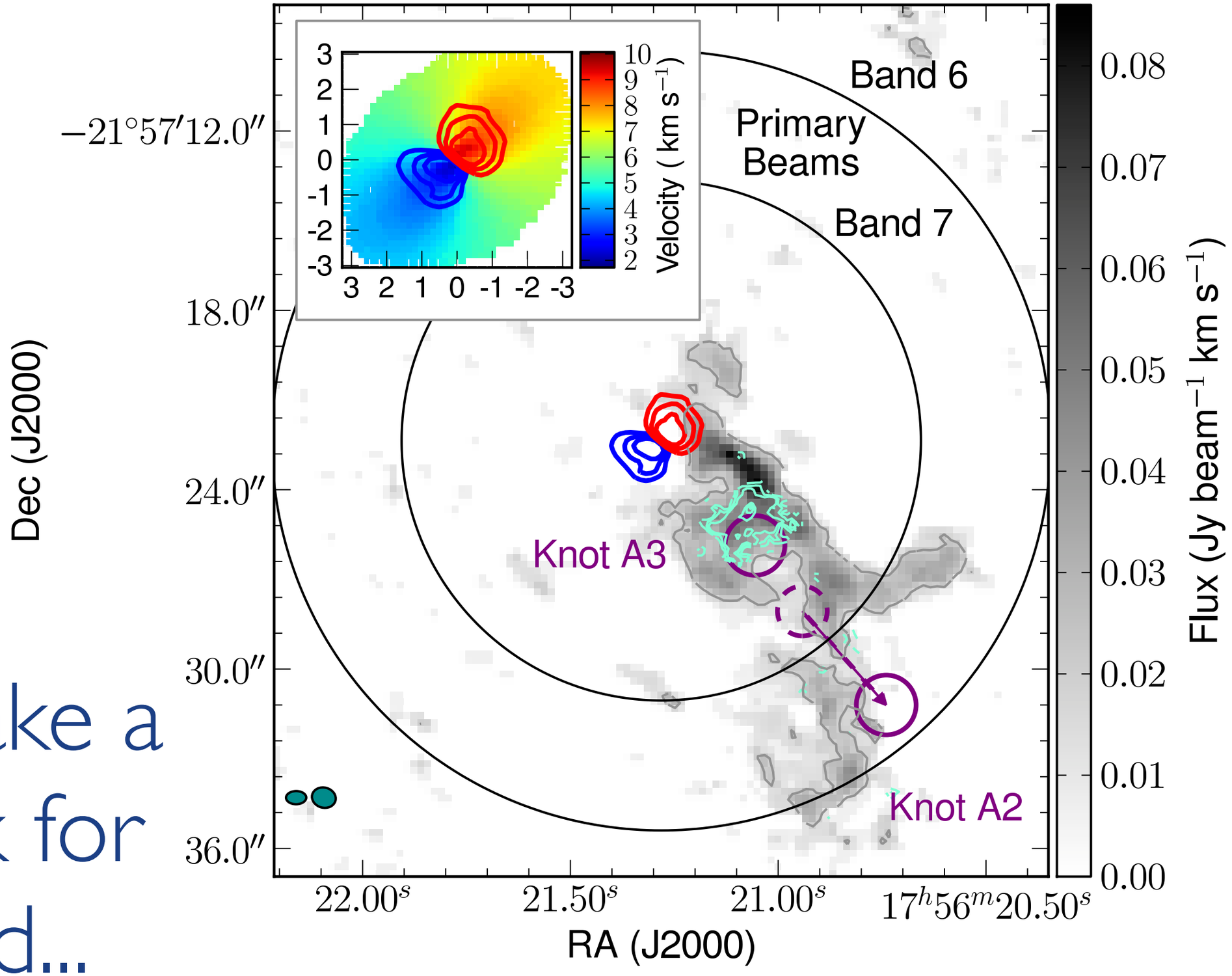
It has been seen in CO with single dish telescopes



Maybe we should have seen this coming

A Disk Wind

- CO J=3-2
- CO J=2-1

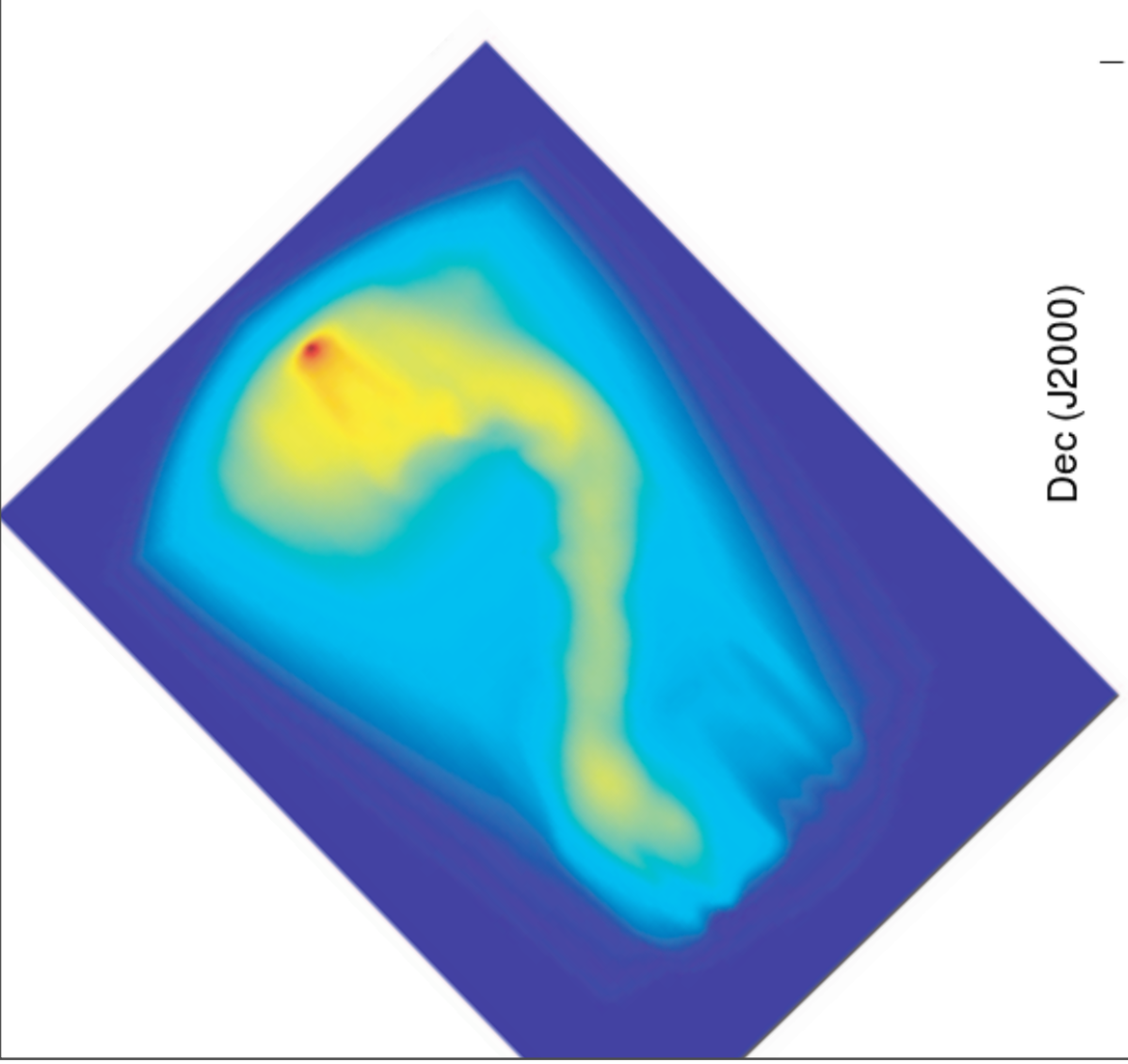


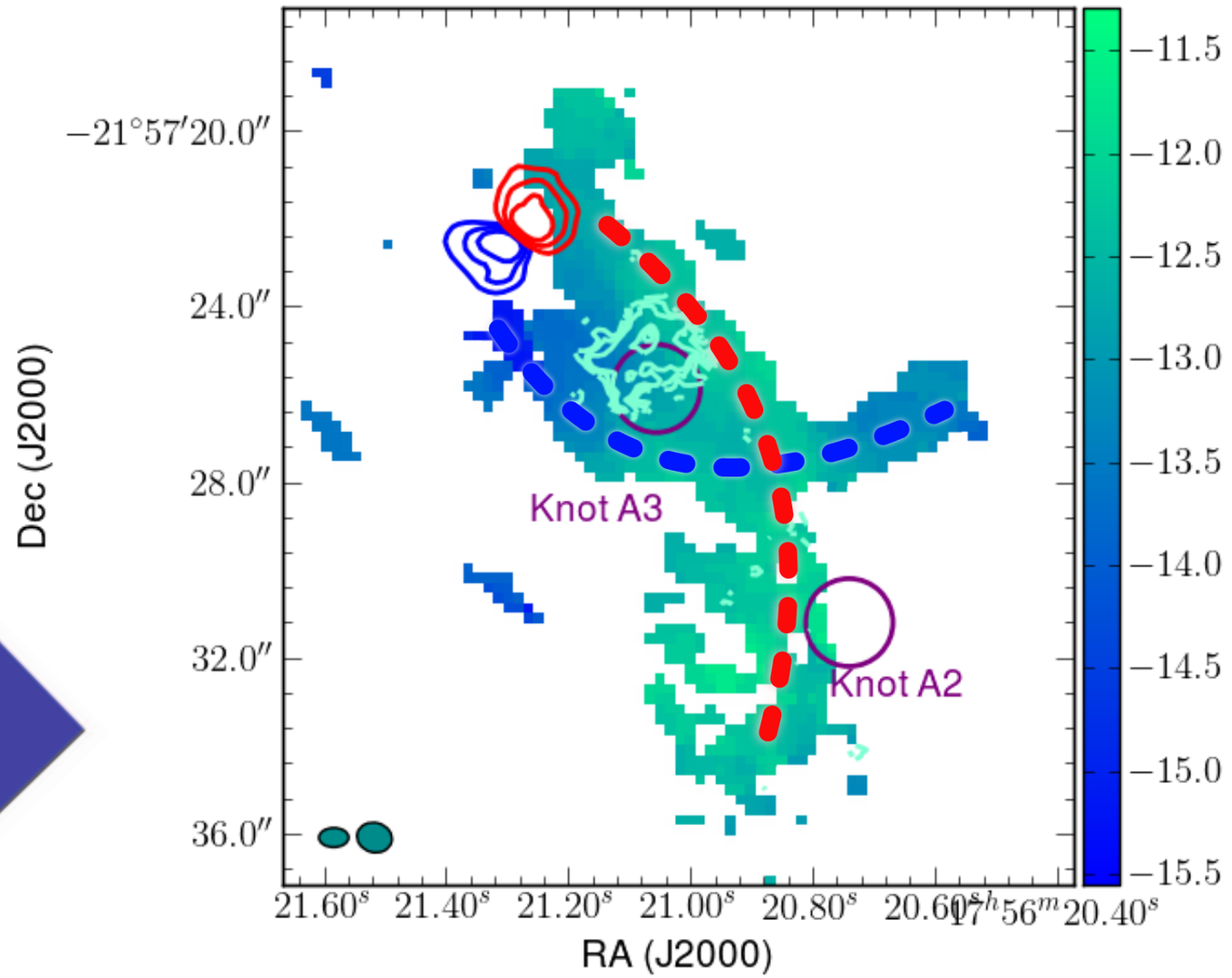
But lets take a step back for a second...

Klaassen et al. 2013

Wind Rotation

- Has requisite corkscrew morphology
- Likely with two footpoints in the disk





Ouyed, Clark & Pudritz (2003),Klaassen et al. (2013)

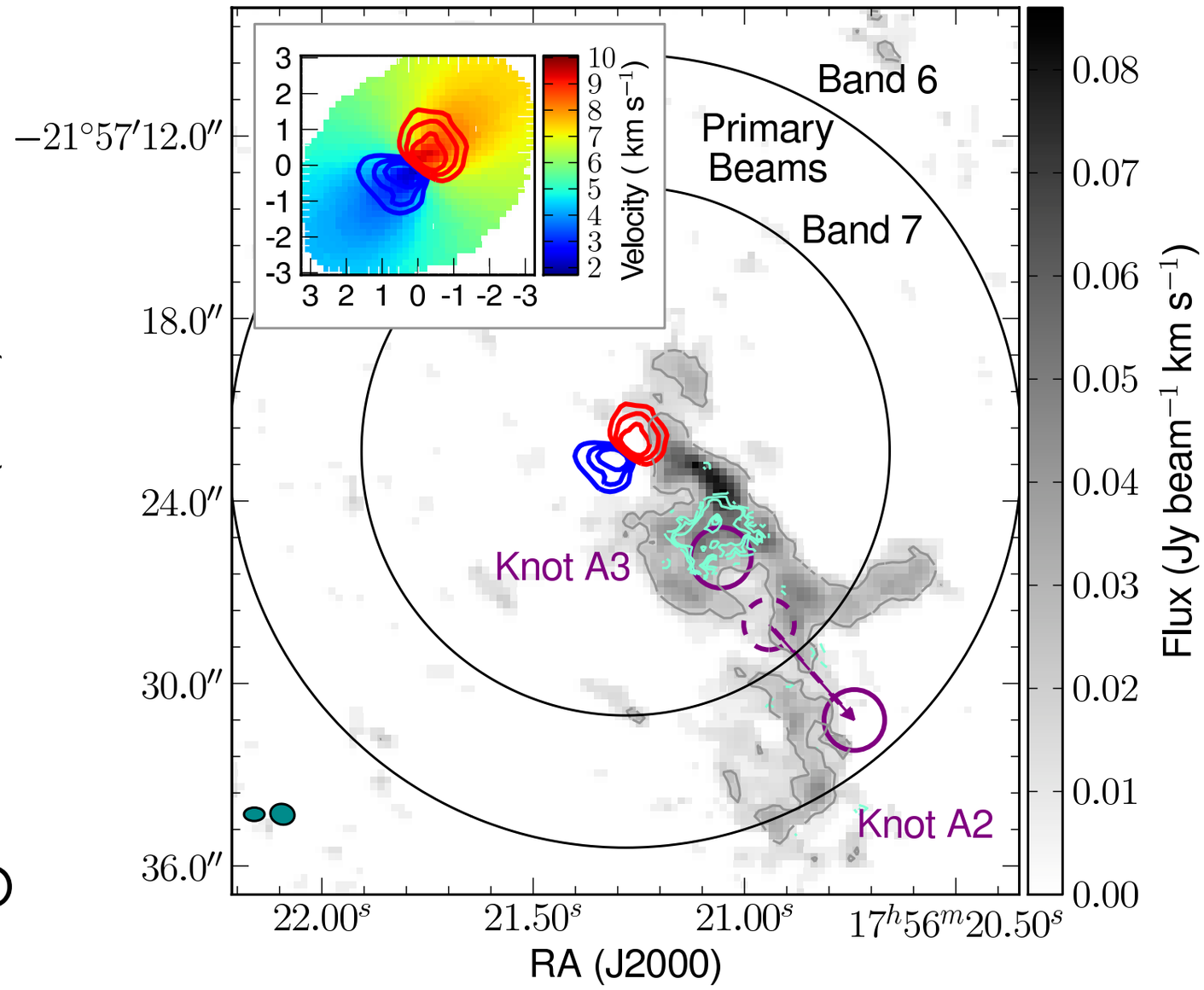
HD 163296

- Why do we see only one lobe?
- Why is the CO J=3-2 so sparse?

  Because we need better data

- What is the relation to HH 409?

  This is pretty neat actually



Klaassen et al. 2013

Spatial Filtering

- A brief interlude into Interferometry..

An interferometer is only sensitive to structures on size scales comparable to its longest and shortest baselines

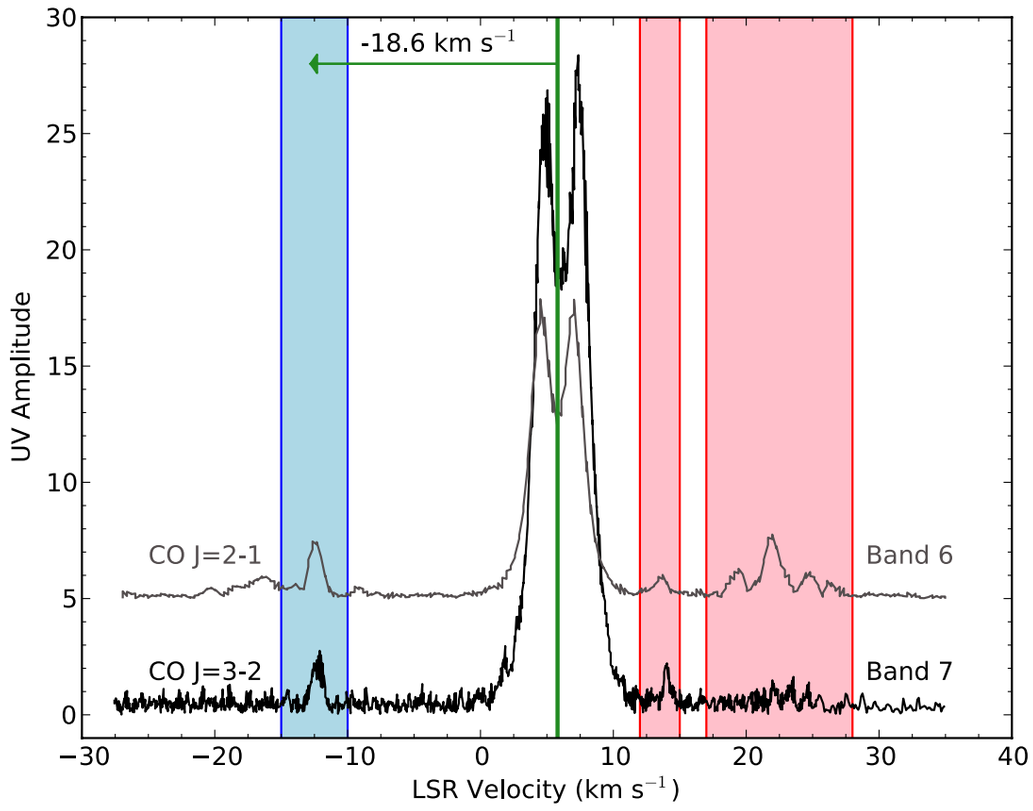
$$\theta = \frac{1.2\lambda}{L}$$

Baseline length = L

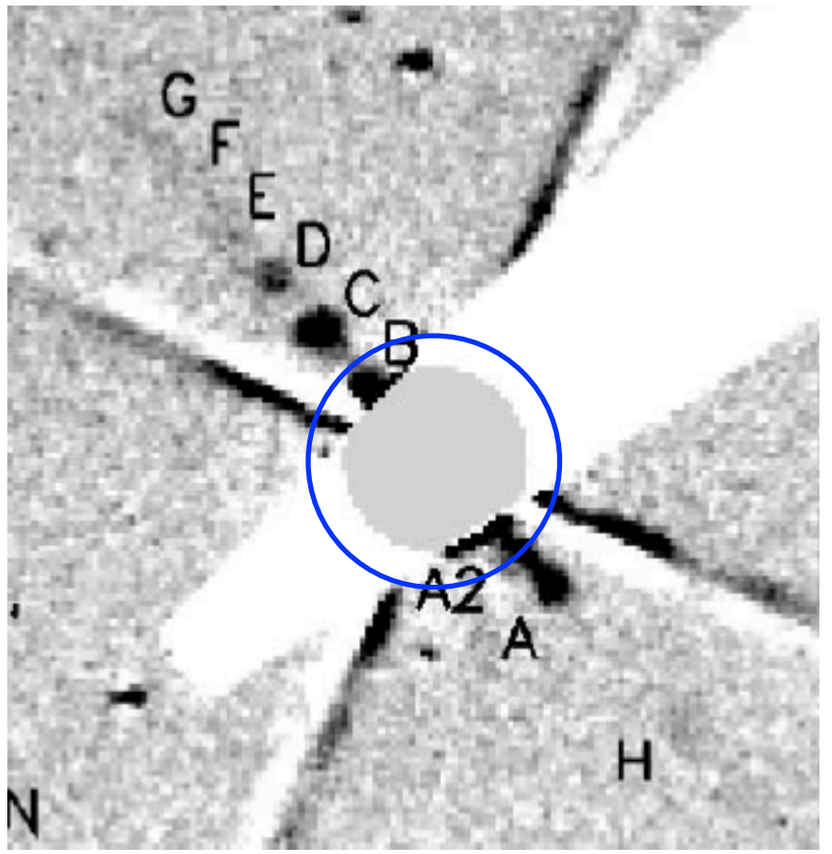
The largest scale structures you can see depends on how tightly you can pack the antennas

Where's the red lobe?

- We can see the full wind on the shortest baselines
- There are not enough short baselines to image the red lobe properly



Red Lobe



Approx ALMA B7 beam

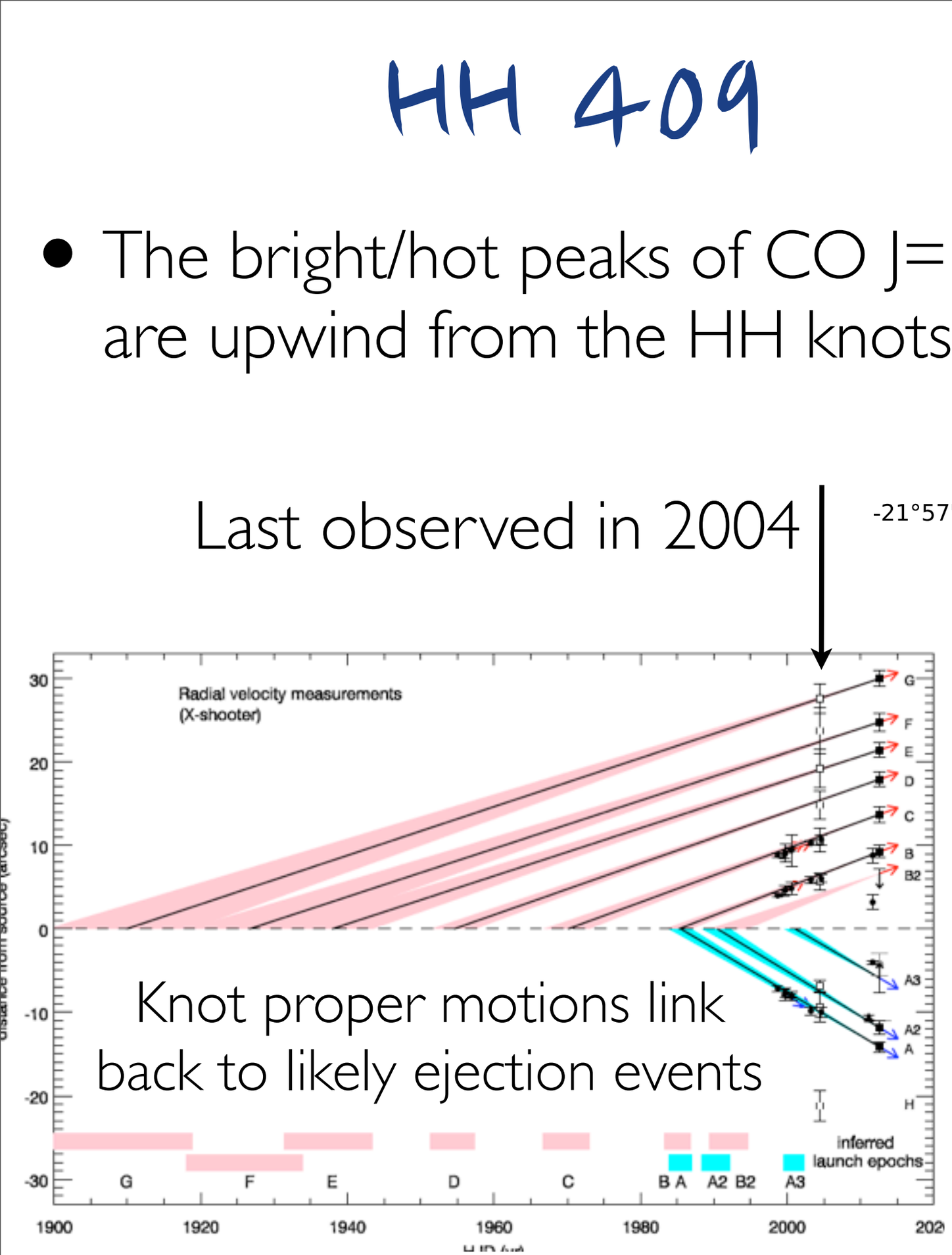
Blue Lobe

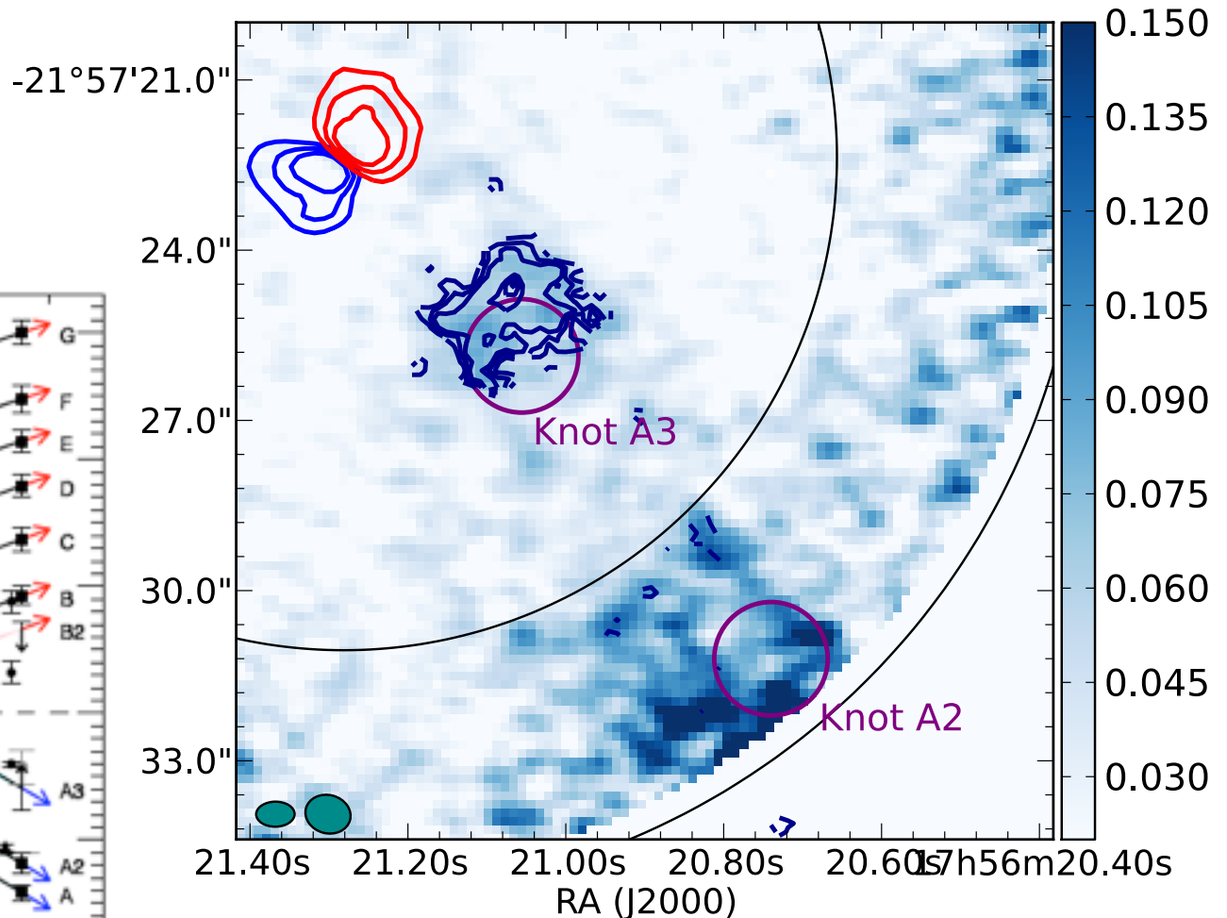
Wassell et al. (2006), Klaassen et al. (2013)

HH 409

- The bright/hot peaks of CO J=3-2 are upwind from the HH knots

Last observed in 2004





Klaassen et al. (2013)
Ellerbroek et al (in prep)

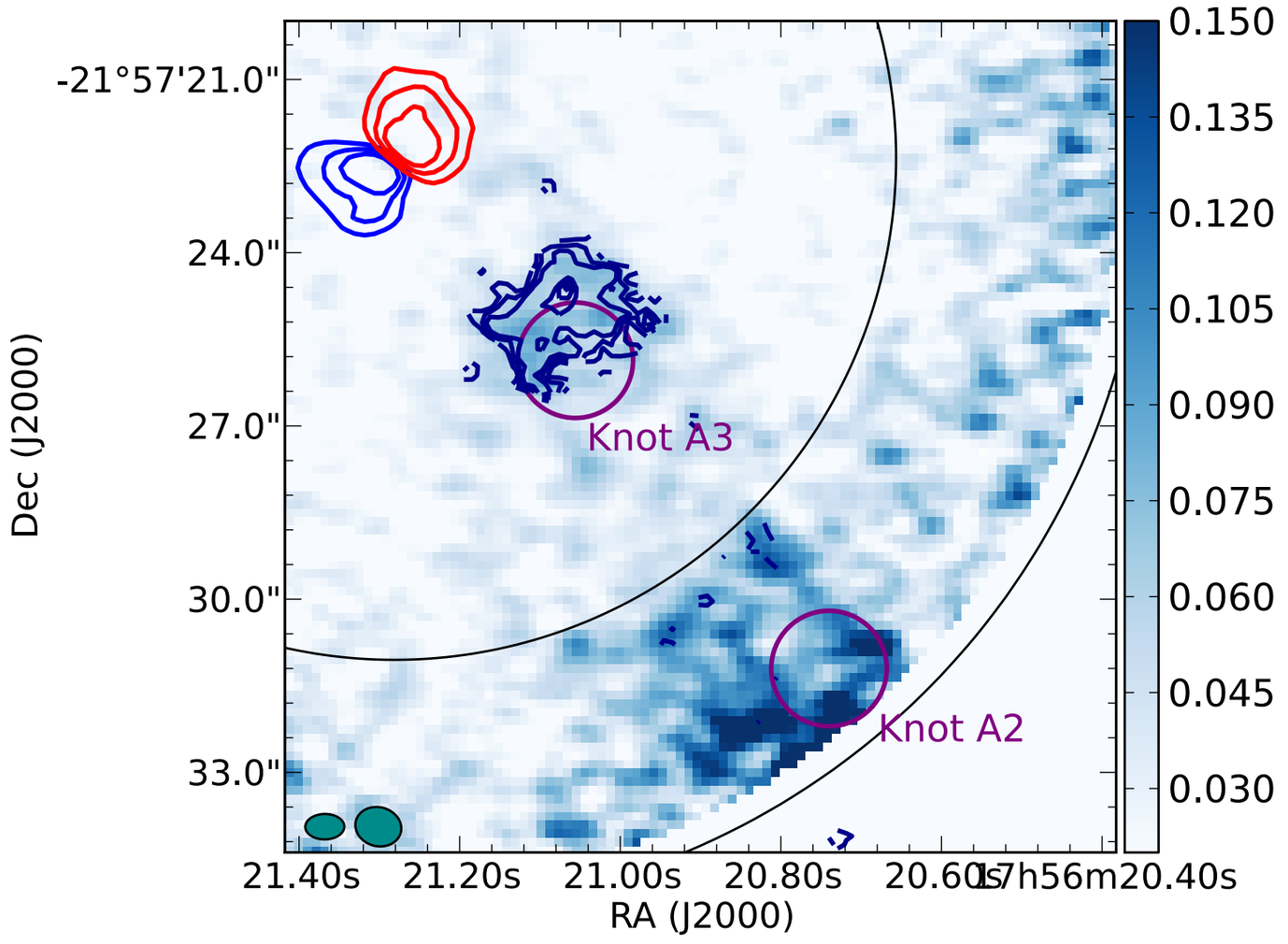
The J=3-2 emission

Klaassen et al. (2013)

- Spatial Filtering is also why we can't really see the J=3-2 emission very well

$$\theta = \frac{1.2\lambda}{L}$$

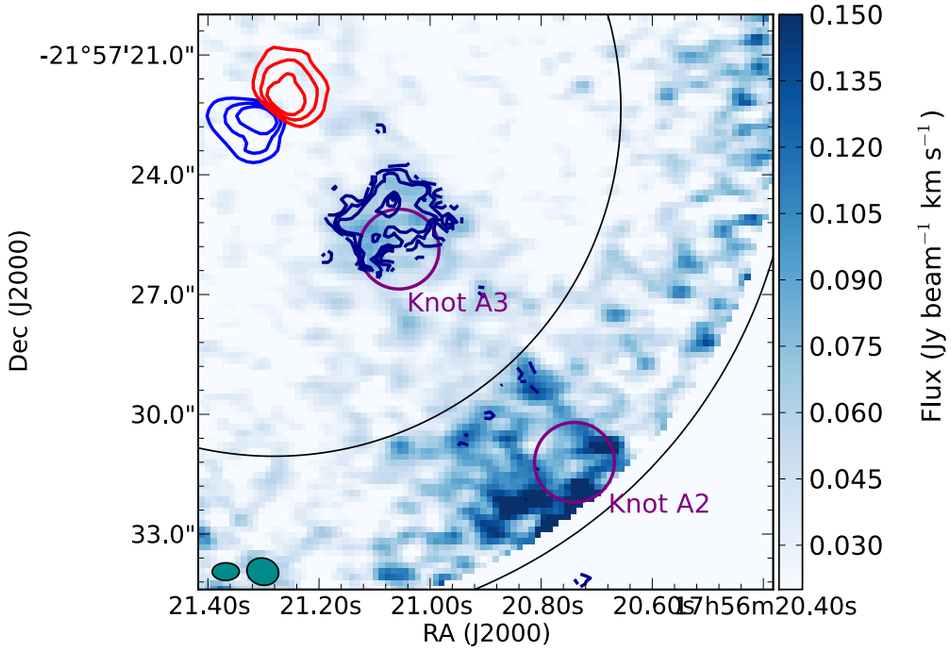
We can only see bright (compact) knots of emission in the J=3-2 transition

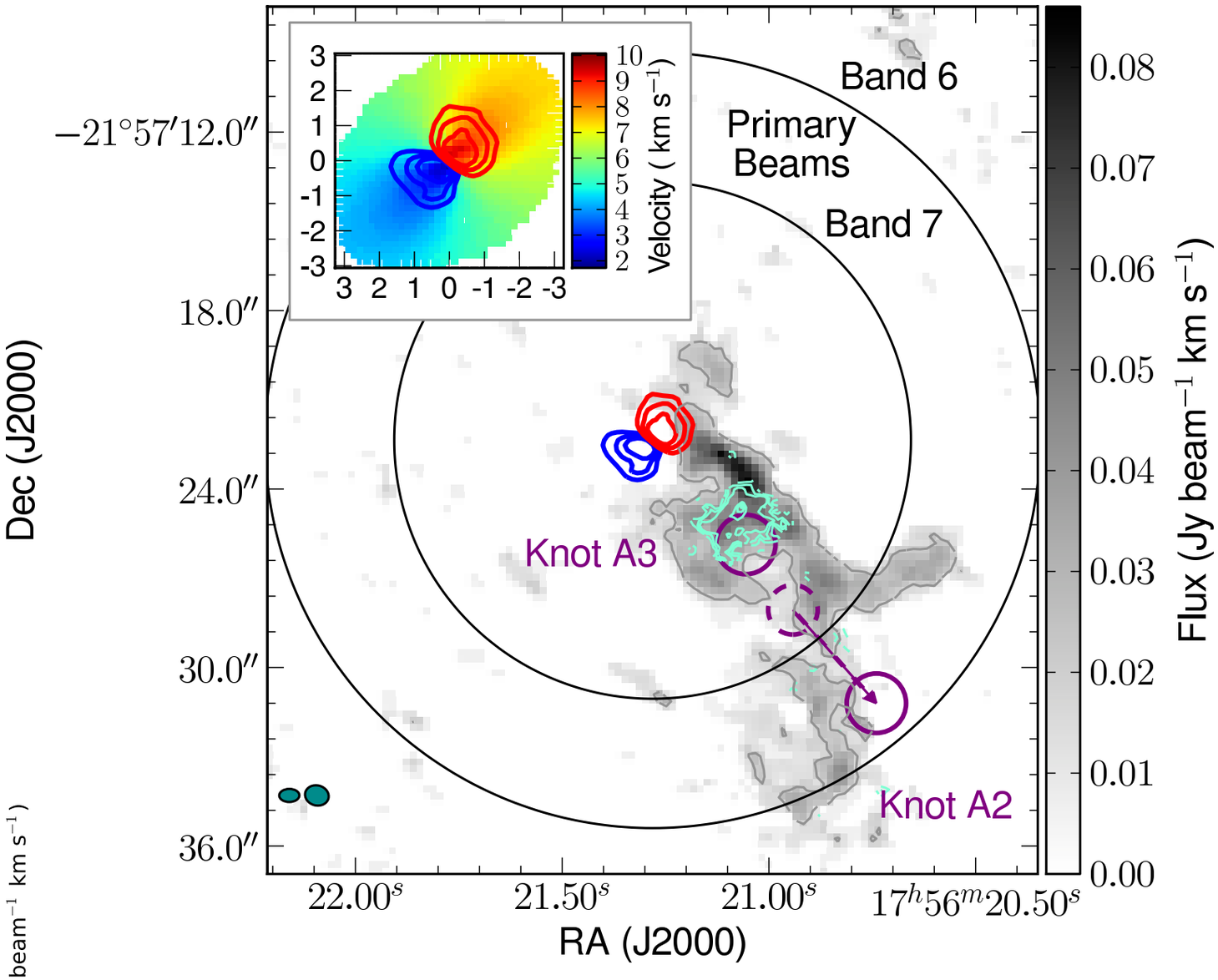


Primary beam correction shows we're seeing two knots of J=3-2 emission

The bright knots

- The knots are upwind from the HH knots
- The gas here is shocked and heated (960 K)



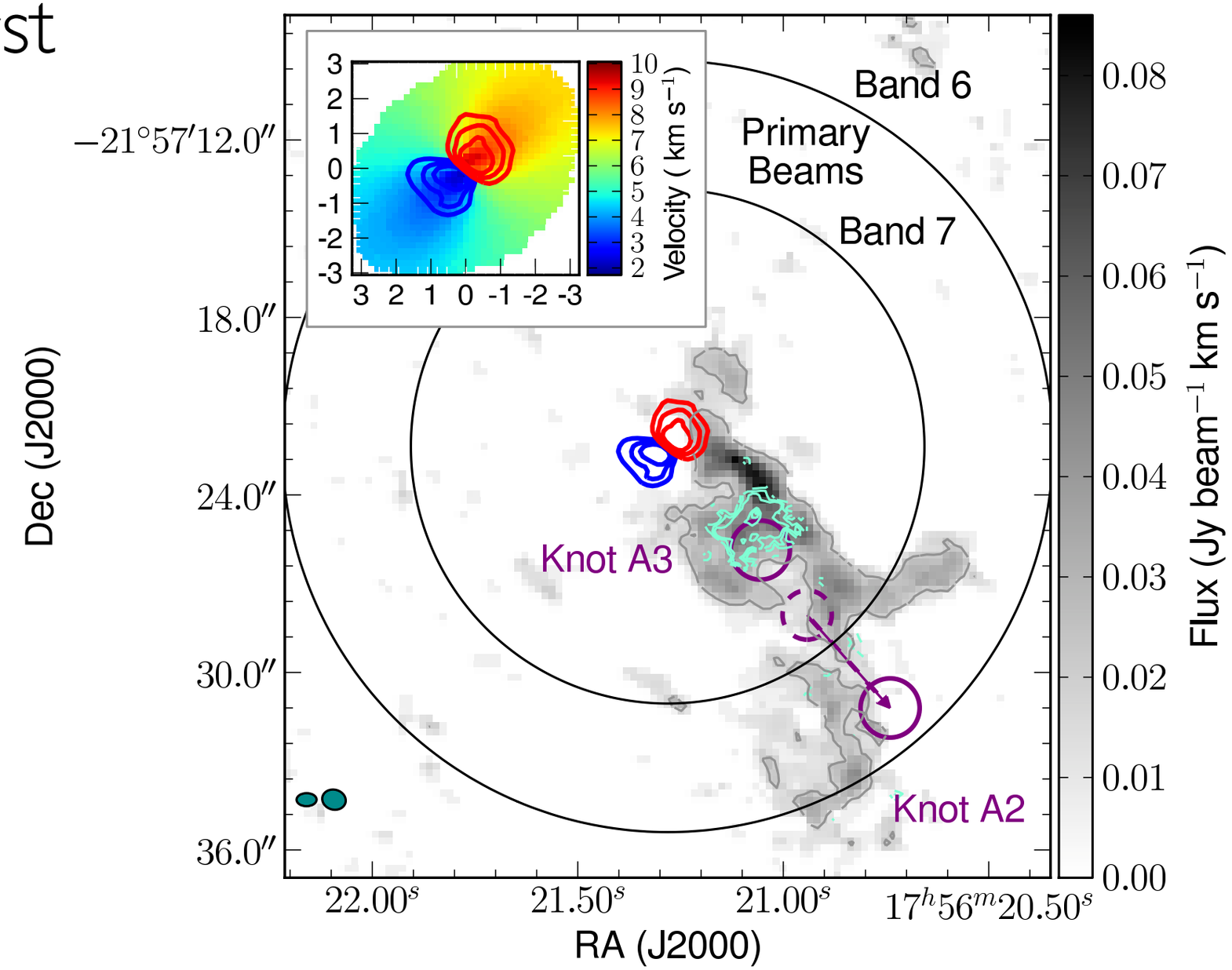


This analysis takes the proper motions of the HH knots into account

Klaassen et al. (2013)

Summary

- We detected the first evidence for a disk wind from a protostar
- The wind is 'interacting' with the HH knots
- We've opened up new avenues to explore



Klaassen et al. 2013

Looking ahead

- Need more data to:
  - See the red lobe
  - Incorporate in the larger scale emission
  - Fully characterise the wind and its properties

ALMA Cycle 2, here I come!

HD 163296

(In just this one source)

De Gregorio-Monsalvo et al., Mathews et al. (both submitted)

HD 163296

What else can ALMA dig up?
(In just this one source)

De Gregorio-Monsalvo et al., Mathews et al. (both submitted)

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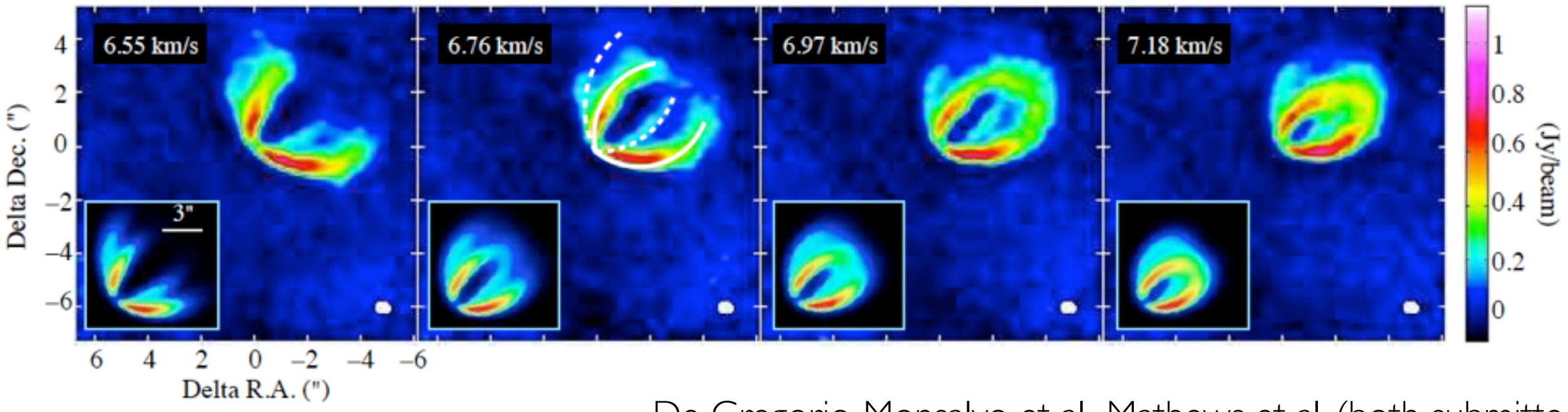

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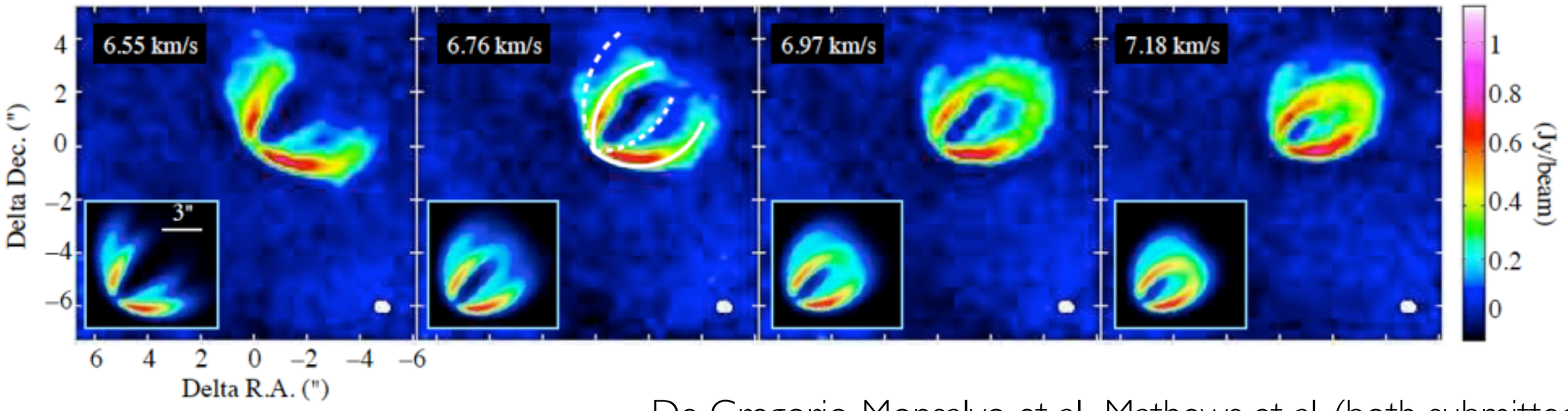
HD 163296

What else can ALMA dig up?
(In just this one source)

✓ The vertical structure in a disk?



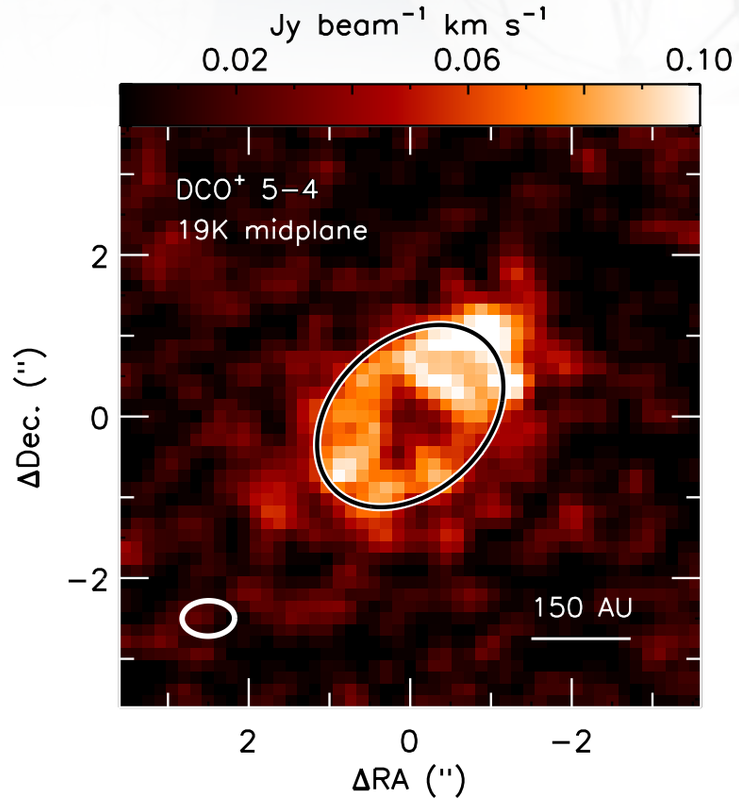
De Gregorio-Monsalvo et al., Mathews et al. (both submitted)

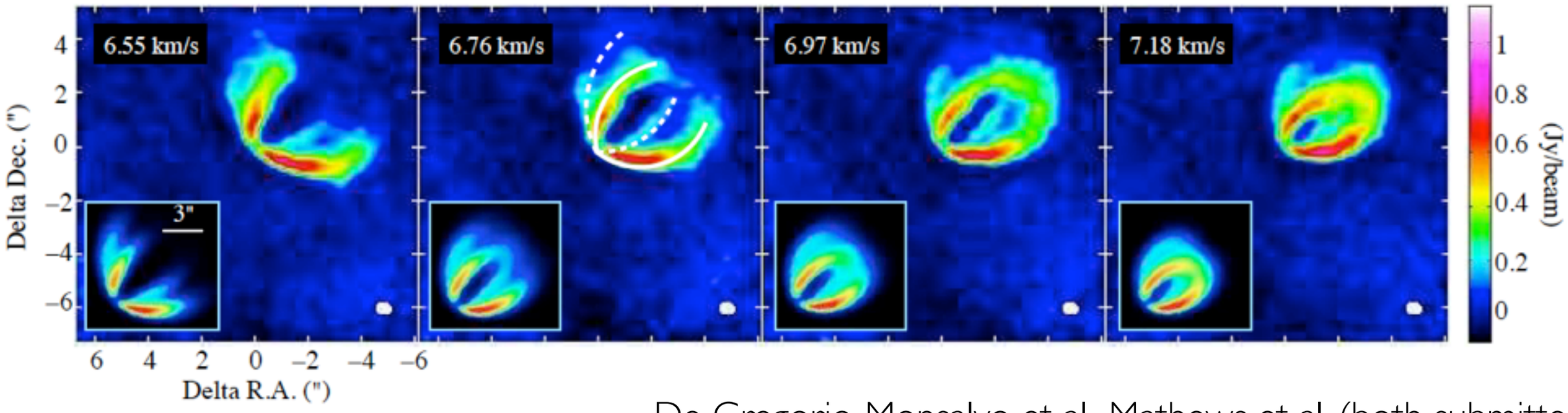
HD 163296

What else can ALMA dig up?
(In just this one source)

✓ The vertical structure in a disk?

✓ The CO snowline?



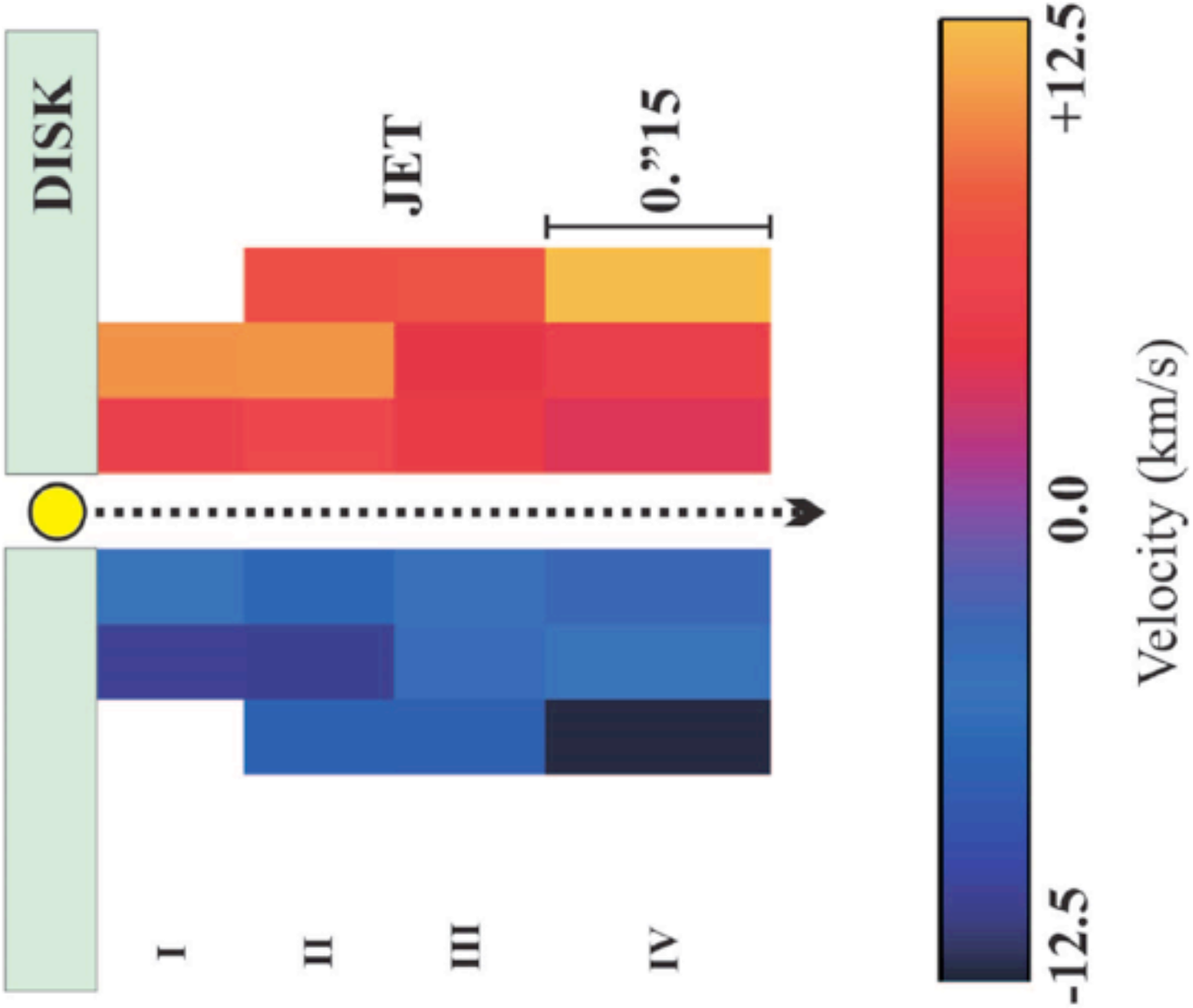


De Gregorio-Monsalvo et al., Mathews et al. (both submitted)

A few False Starts

- People thought they saw the rotating jet components

i.e. Testi et al. (2002) Bacciotti et al. (2002)



But it turns out the rotation may be in the opposite direction

cf. Cabrit et al. (2005)