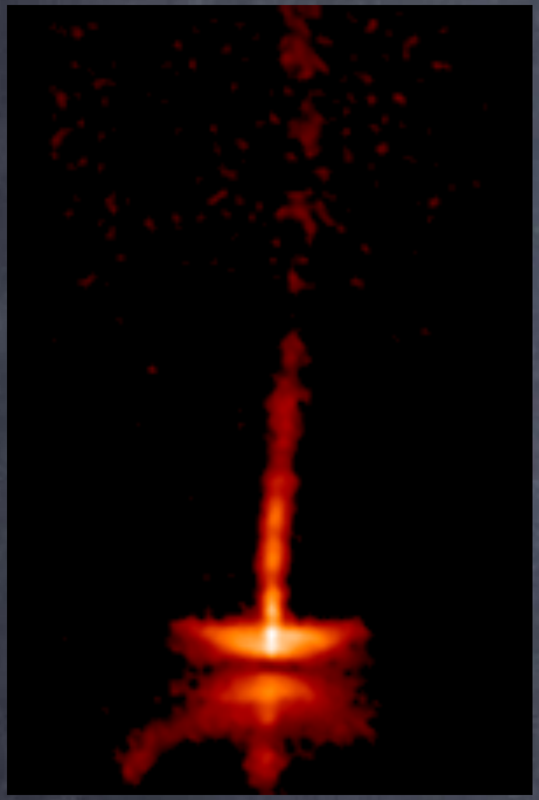
The HH30 T-Tauri Star



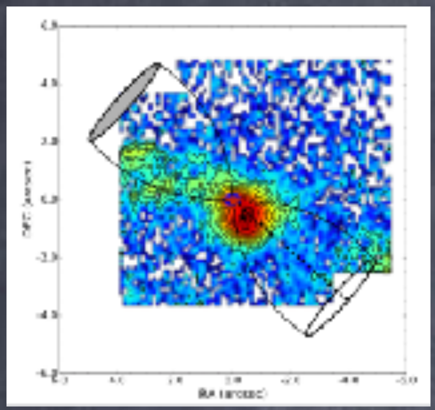
Fabien Louvet
Fellow at U. de Chile,
soon at ENS+CEA

Collaborations:
C. Dougados, N. Cuello, S. Cabrit, R. Nealon, V. Le Gouellec, F. Ménard, D. Mardones, C. Pinte, A. Hales, M. Montesino, F. Bacciotti, D. Coffey, G. Garay, L. Bronfman, C. Arce, P. Cortes, C. Hull, A. Plunket

Outflows: an ubiquitous phenomenon

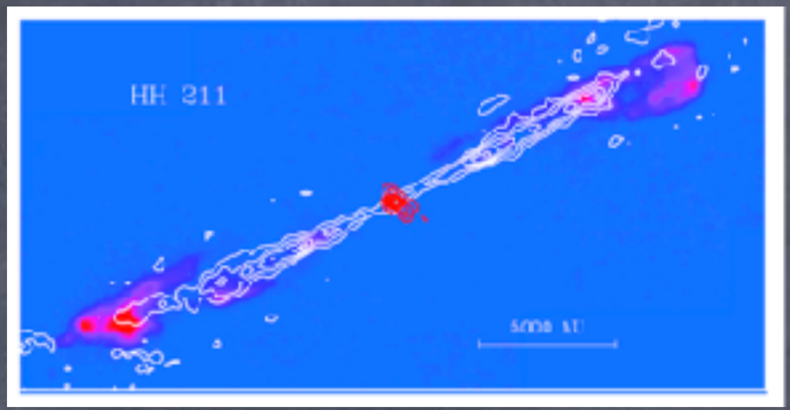
Exist for all masses

(proto) Brown Dwarf



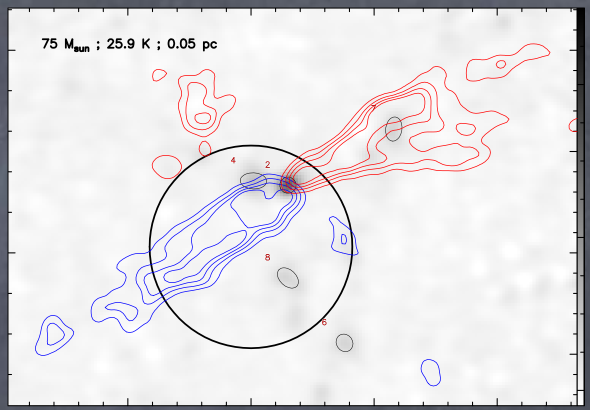
Whelan+ 2018

Solar-type



Gueth+ 1999

Massive



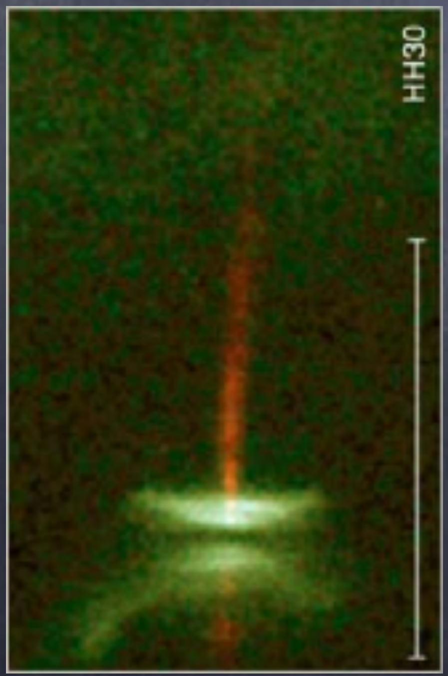
NGC6334

Exist at all stages

Class 0

Bachiller+ 1997

T-Tauri



Burrows+ 1996

Same as?

AGN

X binary

Outflows

For the high-mass star formation community:

- Betray the star-formation
- It is entrained material from the envelope
- They remove the excess of angular momentum in disks
- The ejection/accretion ratio is of 10%

Outflows

For the low-mass star formation community:

- Betray the star-formation at certain stages of evolution.
- It is entrained material from the envelope due to the jet, or due to magneto-centrifugal disk wind, or, or…
- They remove the excess of angular momentum in disks… perhaps. Or it is the jet. Or both. Or none of them. Do they rotate?
- The ejection/accretion ratio mean value is of 10%. It varies from star to star. Somewhere between 1% and 40%.

How to evacuate the angular momentum?

Through the MRI?

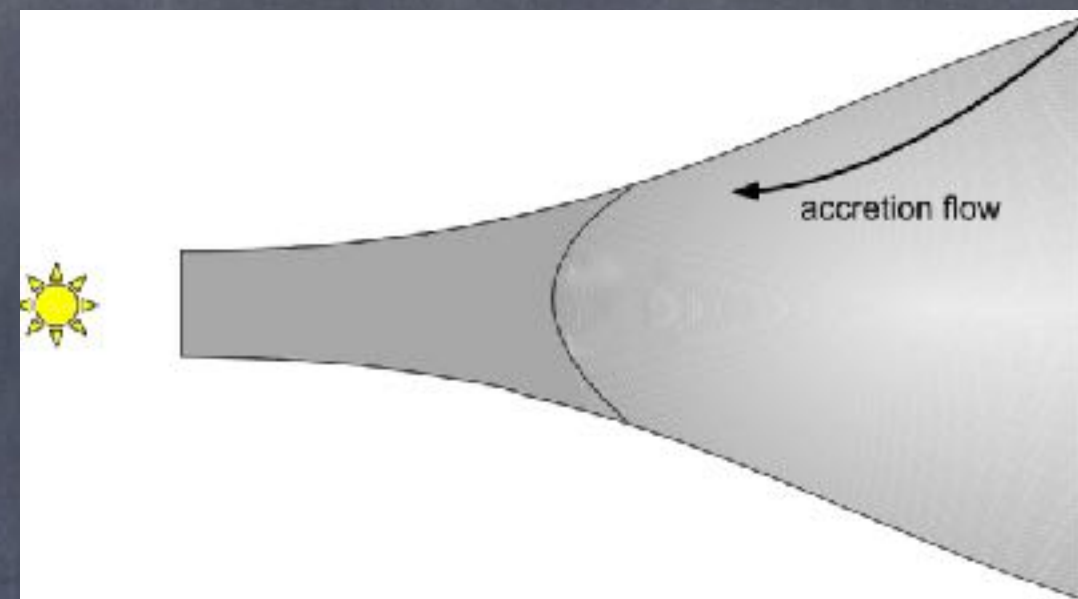

The Astrophysical Journal, 376:214–220, 1991 July 20

A POWERFUL LOCAL SHEAR INSTABILITY IN WEAKLY MAGNETIZED DISKS.
I. LINEAR ANALYSIS

Steven A. Balbus and John F. Hawley
Virginia Institute for Theoretical Astronomy, Department of Astronomy, University of Virginia, P.O. Box 3818, Charlottesville, VA 22903
Received 1990 November 1; accepted 1991 January 15

ABSTRACT

In this paper and a companion work, we show that a broad class of astrophysical accretion disk is dynamically unstable to axisymmetric disturbances in the presence of a weak magnetic field. Because of the ubiquity of magnetic fields, this result bears upon gaseous differentially rotating systems quite generally. This work presents a linear analysis of the instability. (The companion work presents the results of nonlinear numerical simulations.) The instability is local and extremely powerful. The maximal growth rate is of order the angular rotation velocity and is *independent* of the strength of the magnetic field, provided only that the energy density in the field is less than the thermal energy density. Unstable axisymmetric disturbances require the presence of a poloidal field component, and are indifferent to the presence of a toroidal component. The instability also requires that the angular velocity be decreasing outward. In the absence of a powerful dissipation process, there are no other requirements for instability. Field motions associated with the instability directly generate both poloidal and toroidal field components. We discuss the physical interpretation of the instability in detail. Conditions under which saturation occurs are suggested. The *nonemergence* of the classical Rayleigh criterion for shear instability in the limit of vanishing field strength is noted and explained. The instability is sensitive neither to disk boundary conditions nor to the constitutive fluid properties. Its existence precludes the possibility of internal (noncompressive) wave propagation in a disk. If present in astrophysical disks, the instability, which has the character of an interchange, is very likely to lead to generic and efficient angular momentum transport, thereby resolving an outstanding theoretical puzzle.
Subject headings: accretion — hydrodynamics — hydromagnetics — instabilities



Balbus & Hawley 1991

- Used for ~20 years to explain the accretion in disks
- MRI works only in the inner part (0.1-1au) when AD, ohmique diffusion and Hall effect are taken into account.

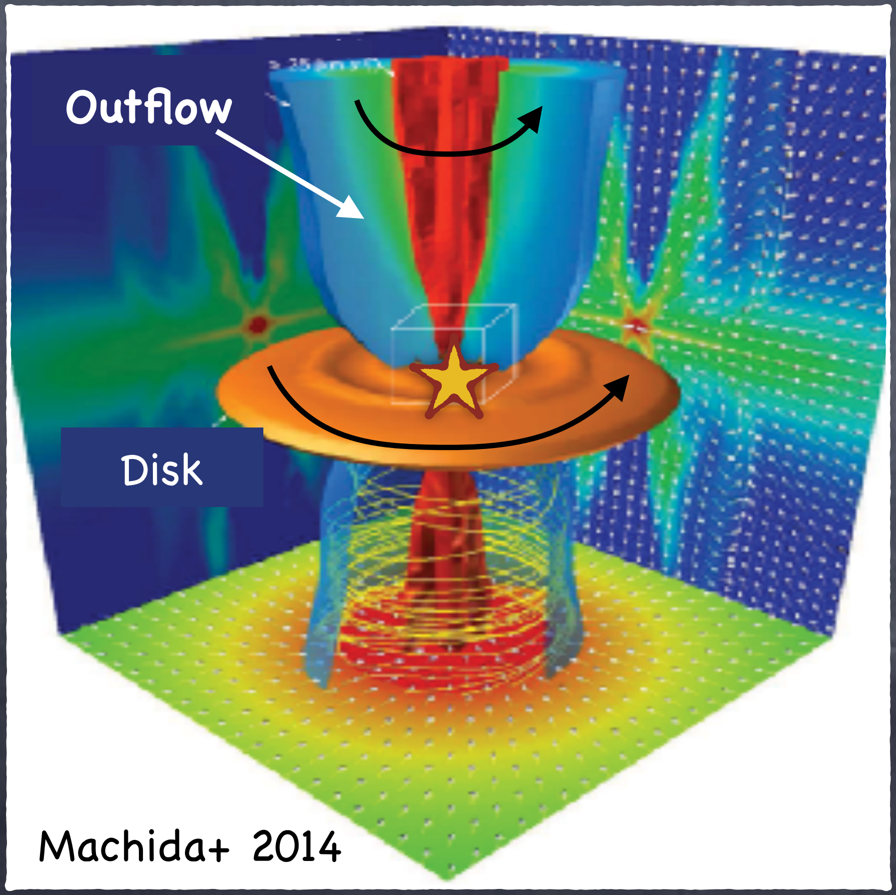
Bai 2013 ; Lesur, Kunz, Fromang 2014 ; Bai 2015

How to evacuate the angular momentum?

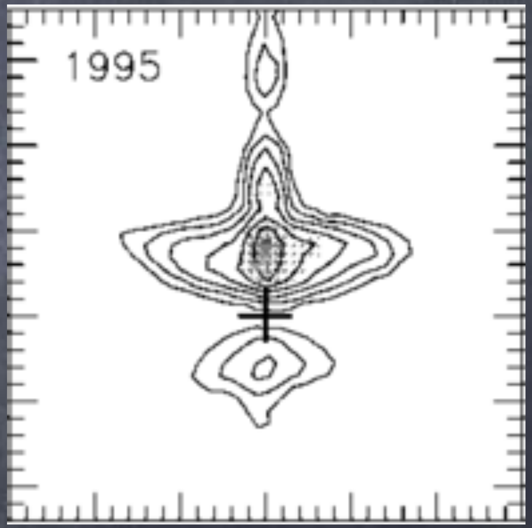
Through jets and outflows?

First proposed by Norman & Pudritz+ 1983, Ferreira+ 1997, MHD numerical models by Machida+ 2014, Hirano+ 2019

Numerical model



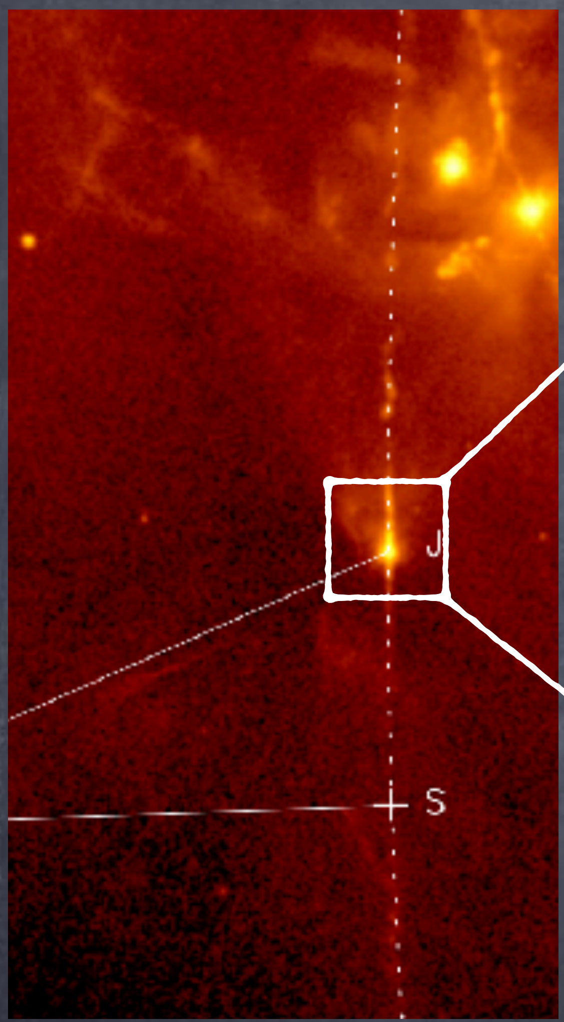
HH30 with the HST



Stapelfeldt + 1999

Outflow - disk: case study of HH30!

HST

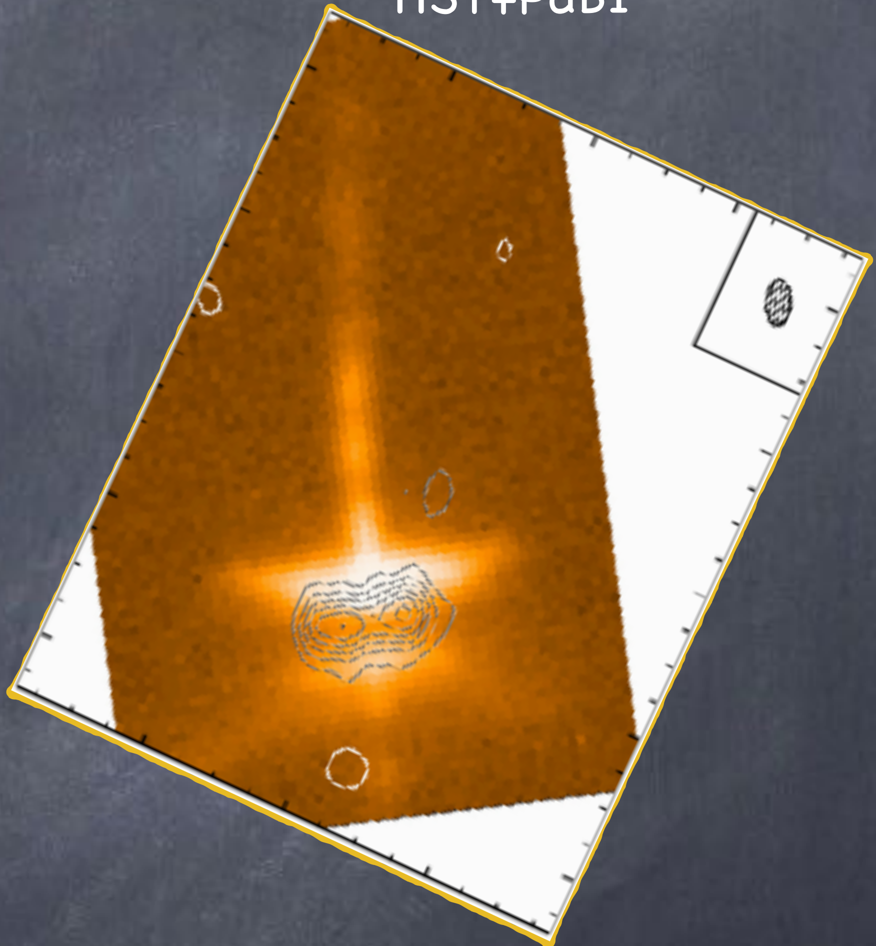


Estallela+ 2012

HST+ALMA

Burrows+ 1996 &
Louvet+ 2018

HST+PdBI

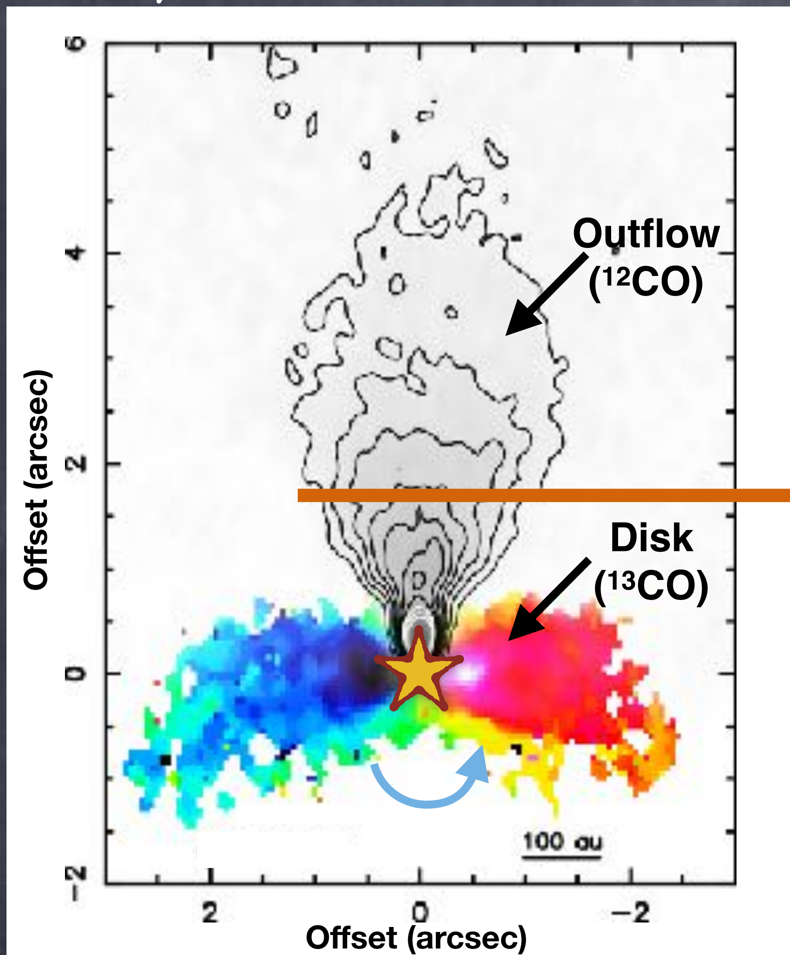


Guilloteau+ 2008

- Edge-on system
- Monopolar outflow
- d = 140pc

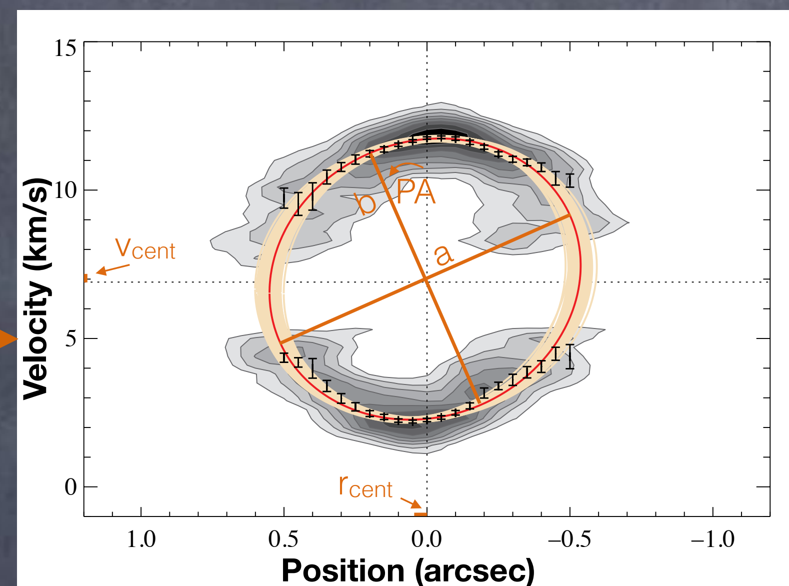
HH30 with the ALMA interferometer

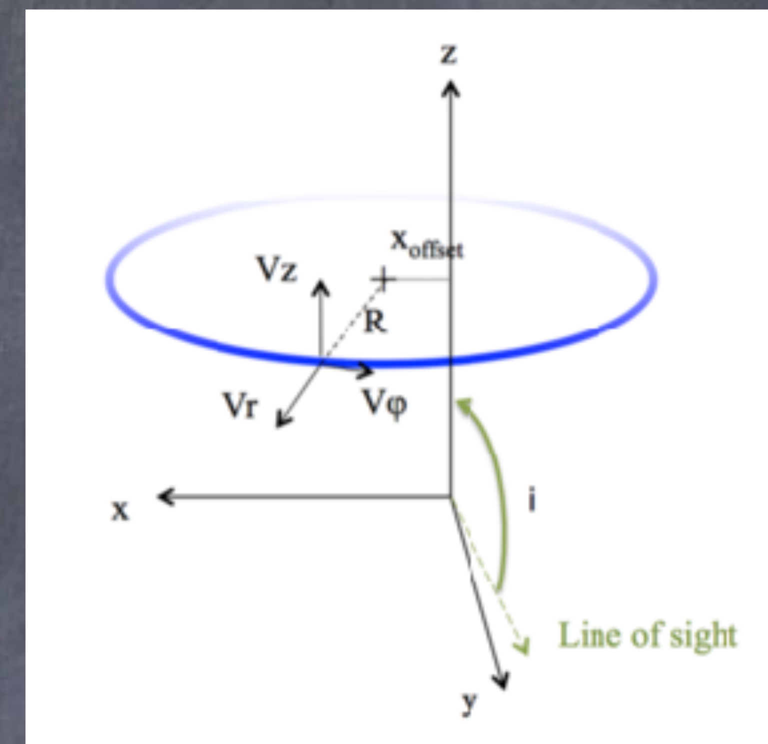
Only accessible since ALMA



Louvet+ 2018

Position-Velocity Diagram





$$x_{\rm offset} = r_{\rm cent}$$
$$V_z = -(V_{\rm cent} - V_0)/\cos i$$
$$(V_r \sin i)^2 = \left((\cos {\rm PA})^2/a^2 + (\sin {\rm PA})^2/b^2\right)^{-1}$$
$$(V_\phi \sin i)/R = 0.5 \times (V_r \sin i)^2 \times \sin 2{\rm PA} \times (1/b^2 - 1/a^2)$$
$$1/R^2 = \left((\cos {\rm PA})^2/b^2 + (\sin {\rm PA})^2/a^2\right) - (V_\phi/R)^2/V_r^2.$$

- The disk is rotating
- The outflow is rotating
- There is conservation of the angular momentum (RxVφ)
    - ➡ Launching radius of 1-7 au

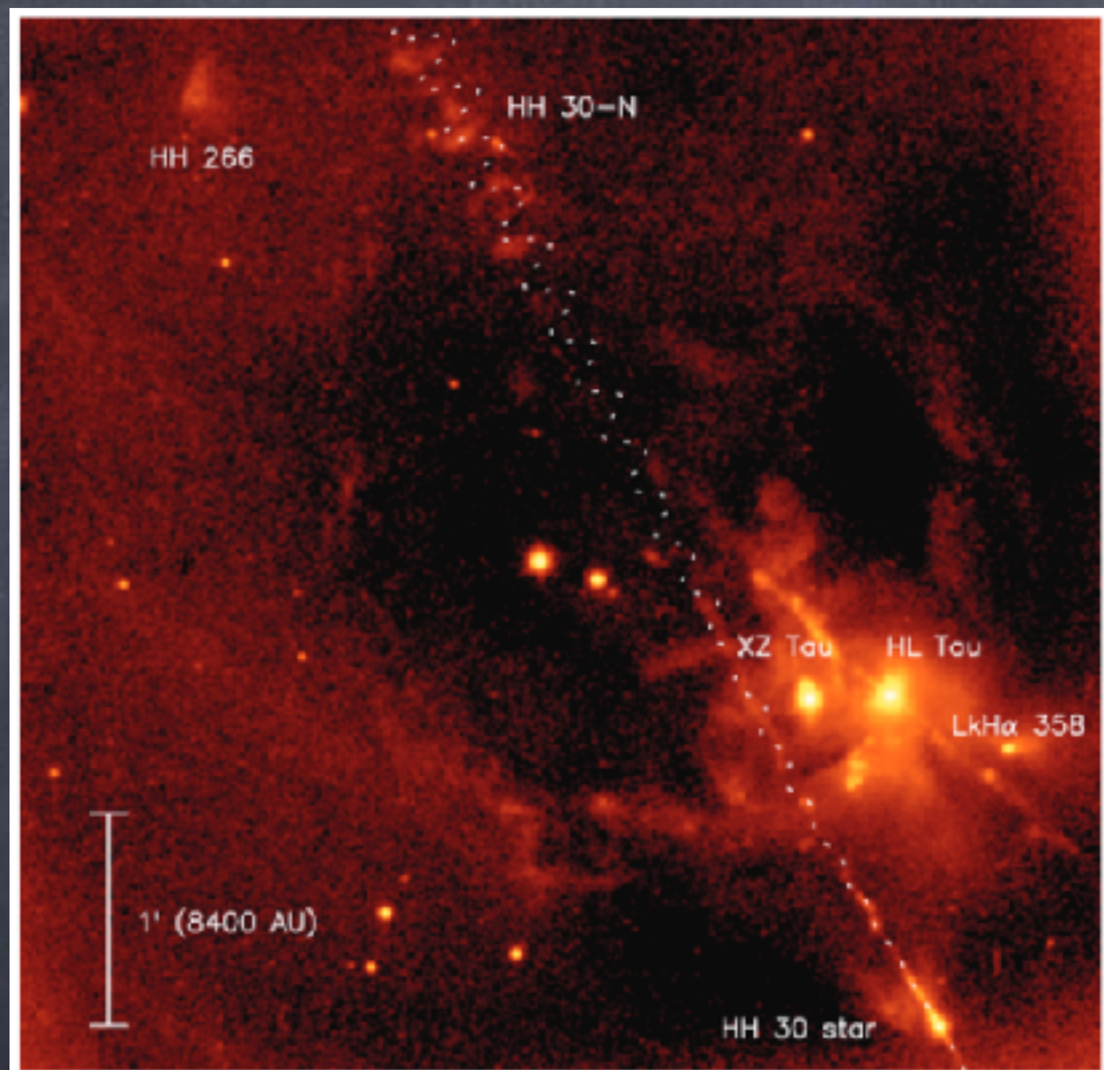
}

Good agreement with MHD disk wind

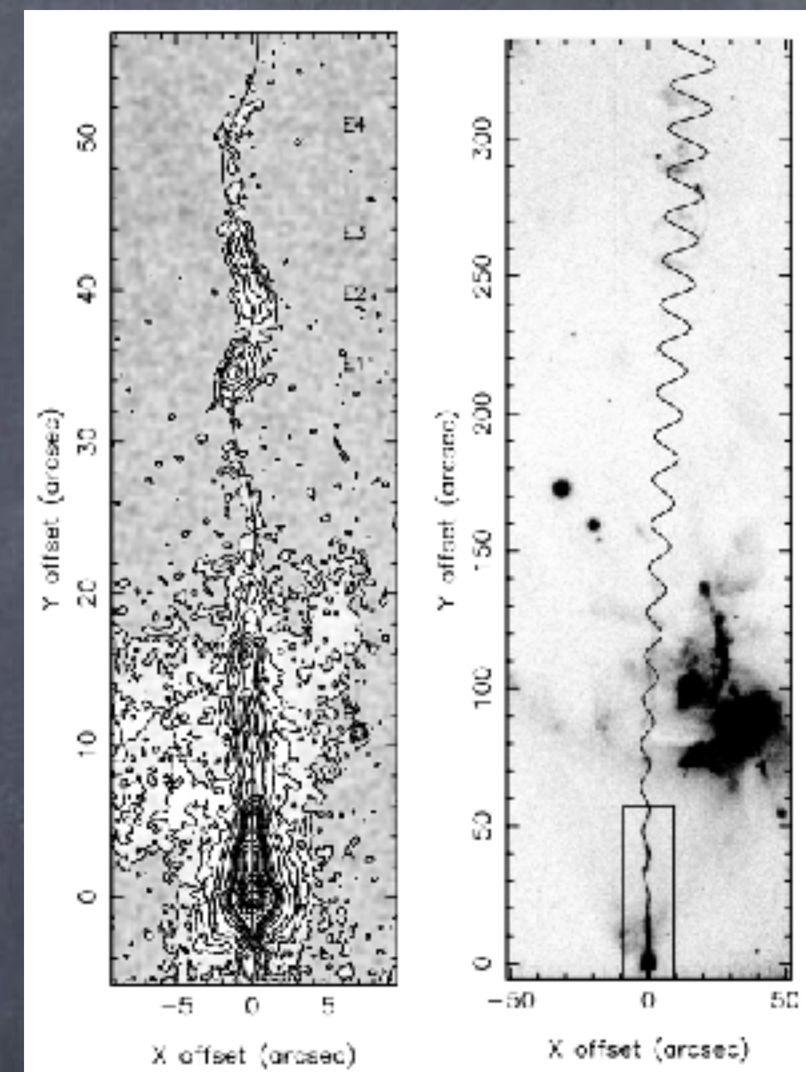
Second opportunity

Constrain the binaries by studying the jet/outflow features

HH30: wiggling of the jet



Anglada+ 2007

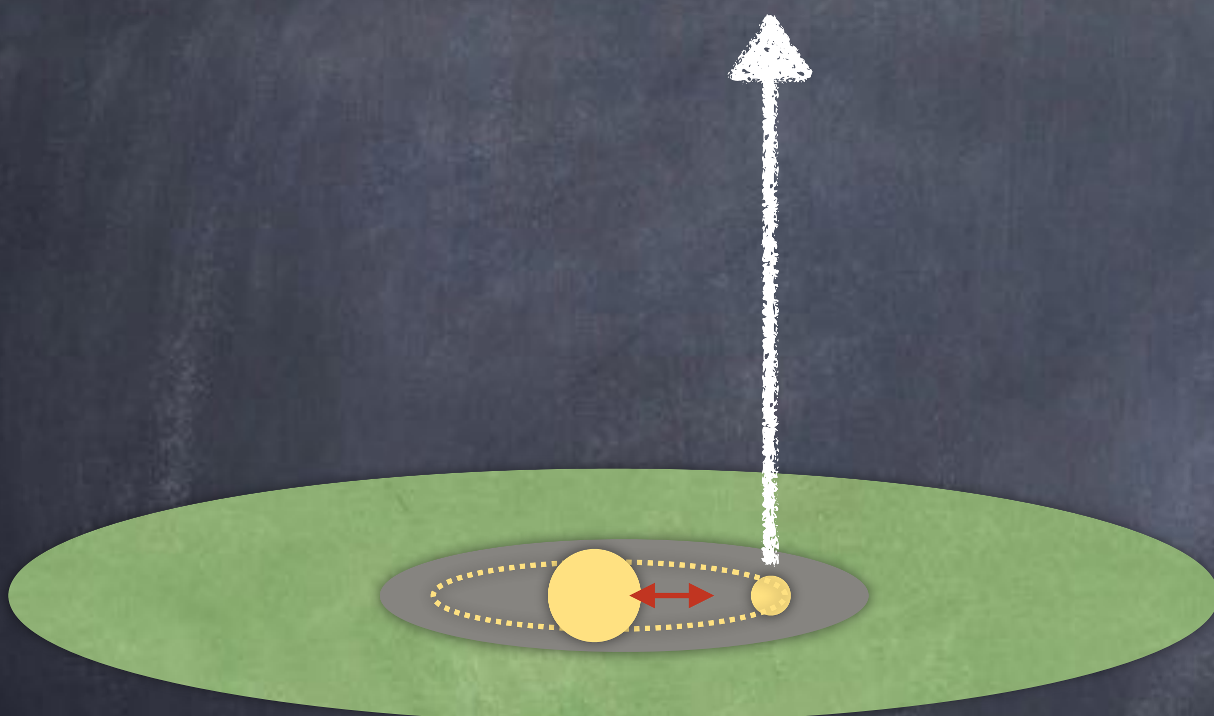


Anglada+ 2007

—> HH30 is a binary system

HH30: wiggling of the jet

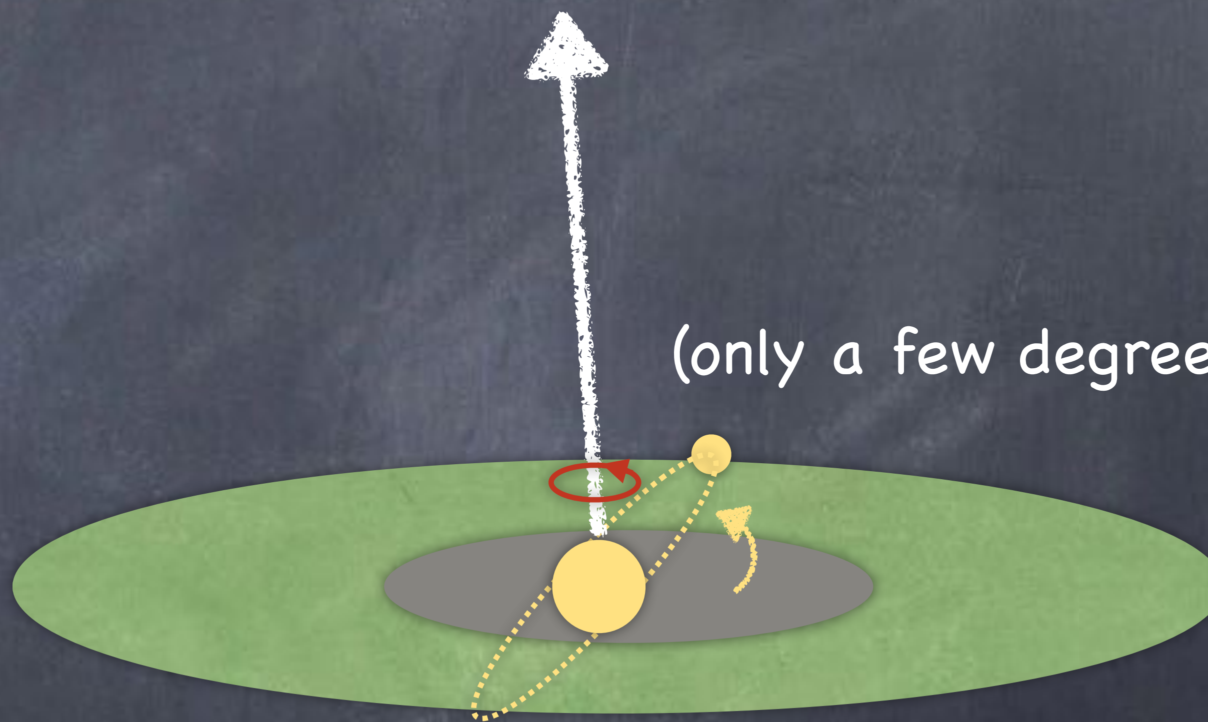
Orbital motions



separation ~18 au

Precession

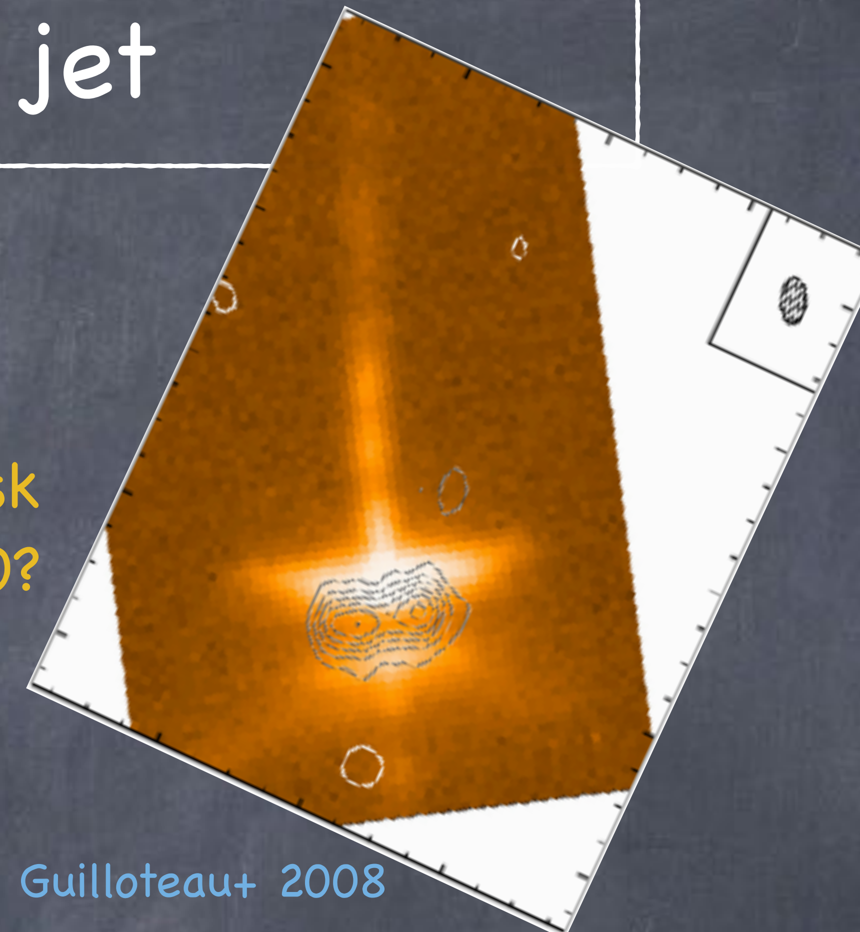
(only a few degrees)



separation < 1au

Mass ratio 2e-3

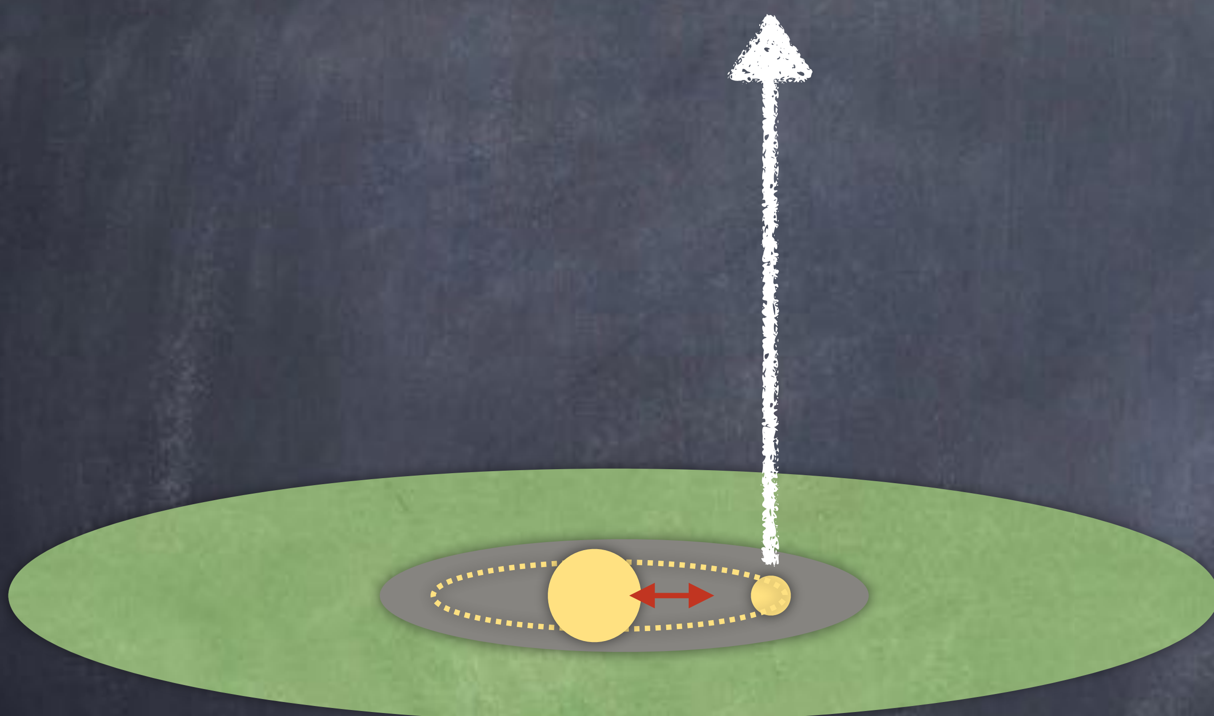
HH30: wiggling of the jet



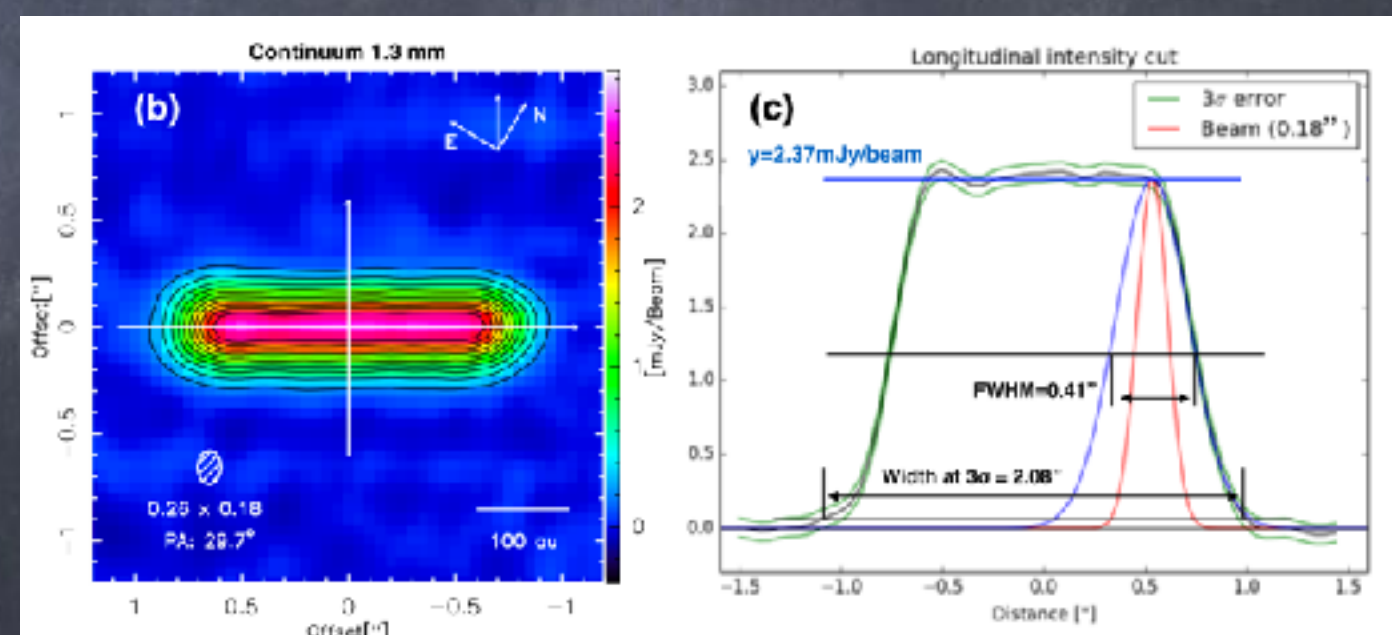
Guilloteau+ 2008

Orbital motions

—>Is there a gap in the disk of HH30?



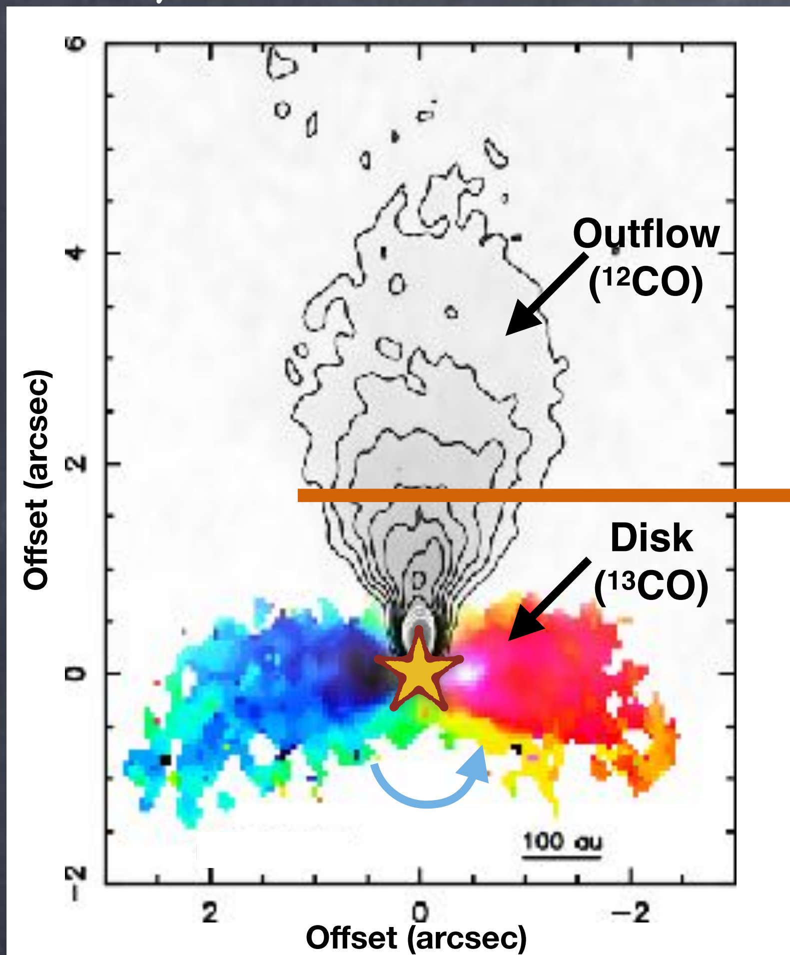
separation ~18 au



Louvet+ 2018

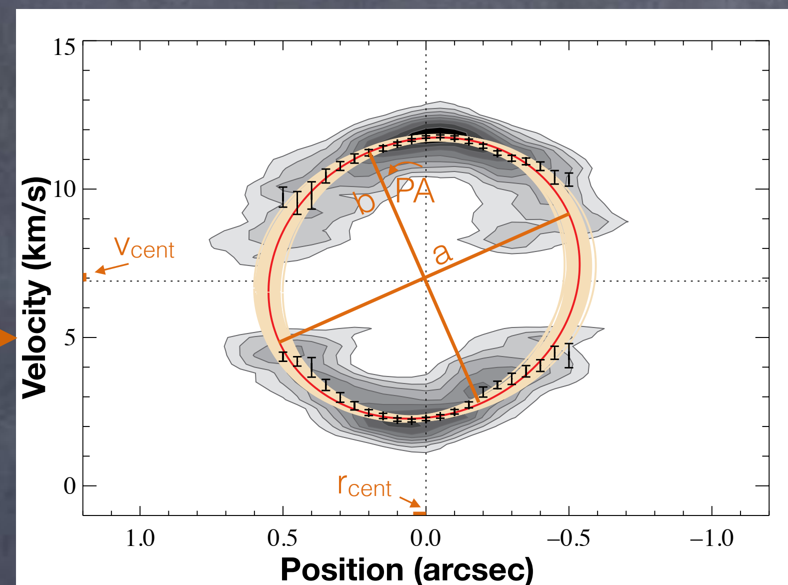
HH30: wiggling of the jet

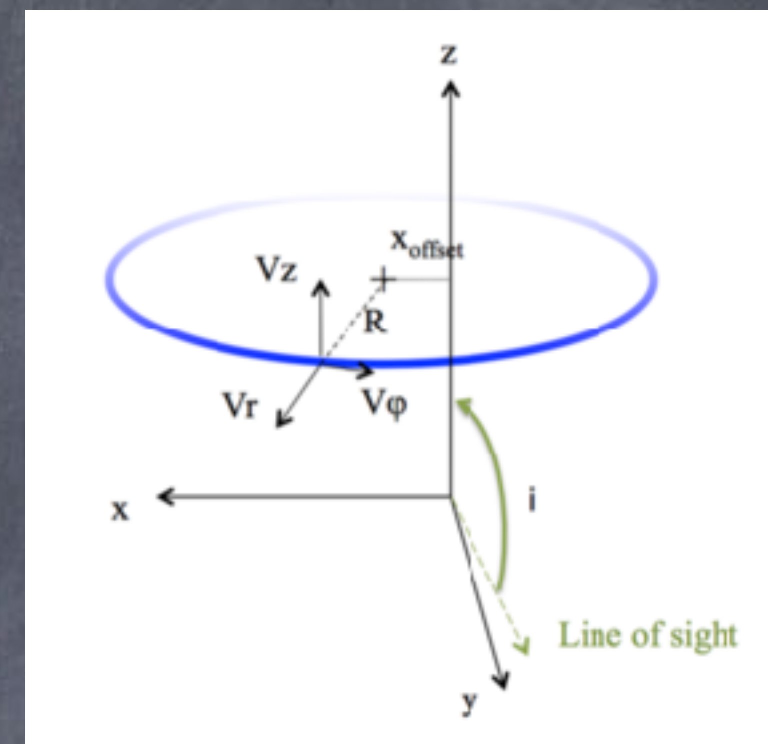
Only accessible since ALMA

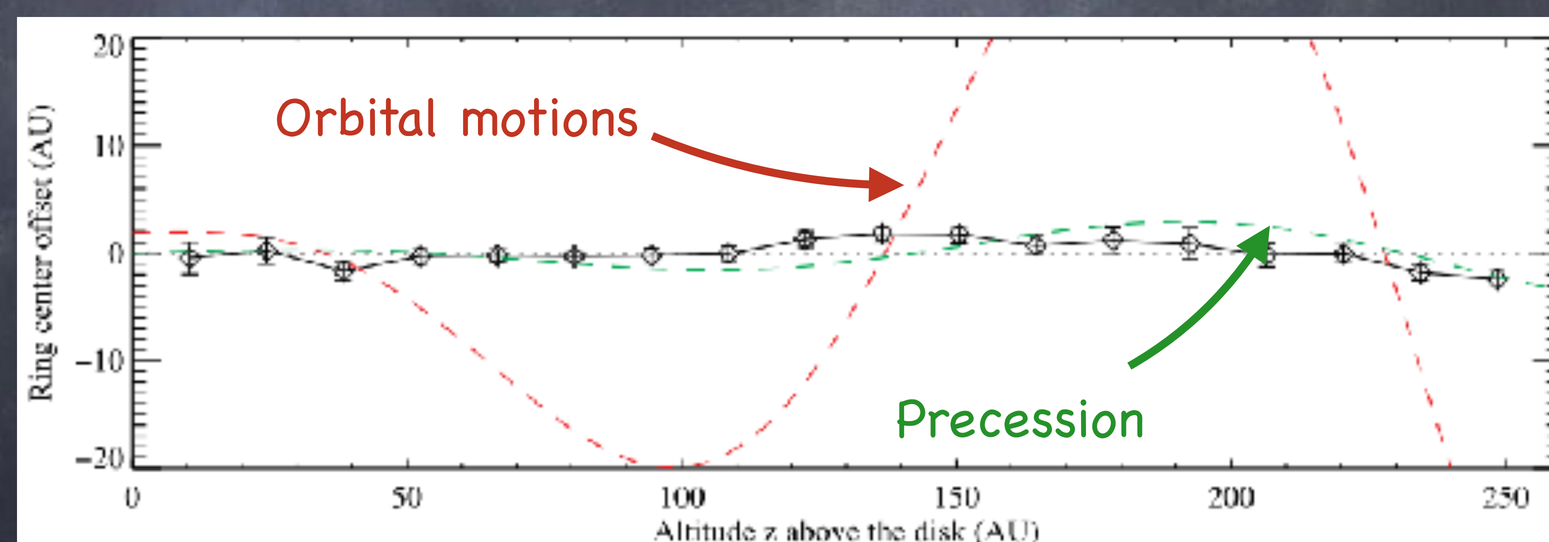


Louvet+ 2018

Position-Velocity Diagram

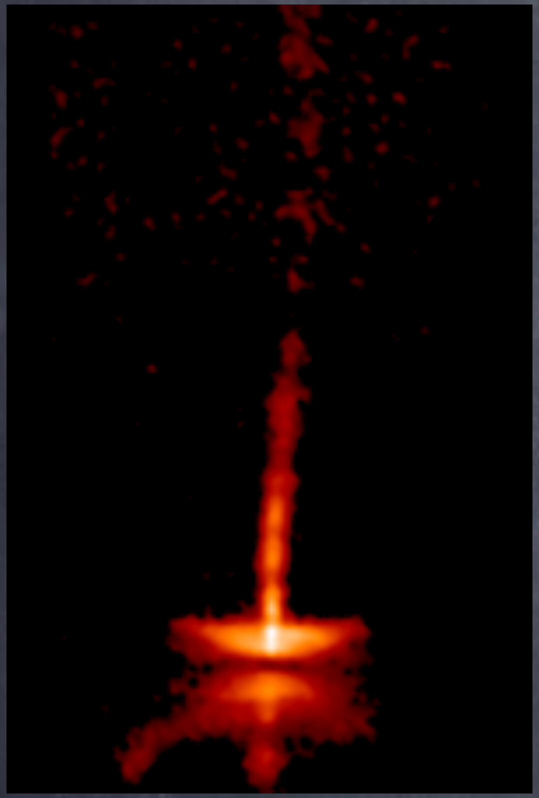






Conclusion: orbital motions are unlikely and the wiggling must be due to precession

Conclusions



- Outflows rotate!

-> Universal process?

-> Stationary ejection (?)

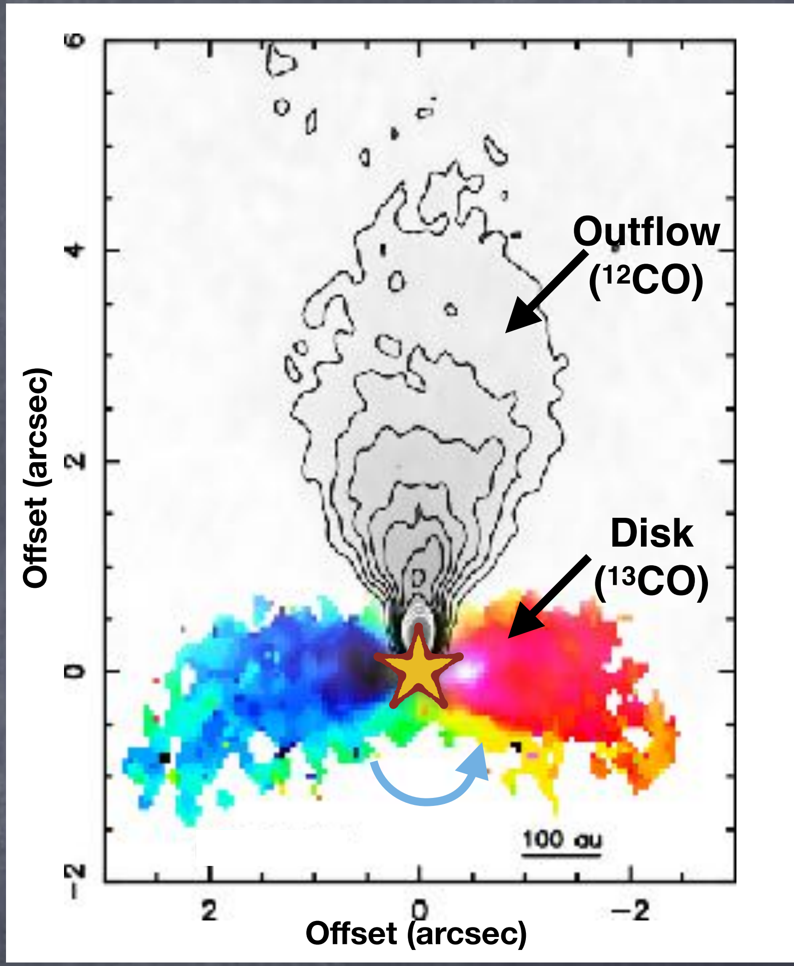
-> Best candidate: MHD disk wind

-> Efficient at removing AM?

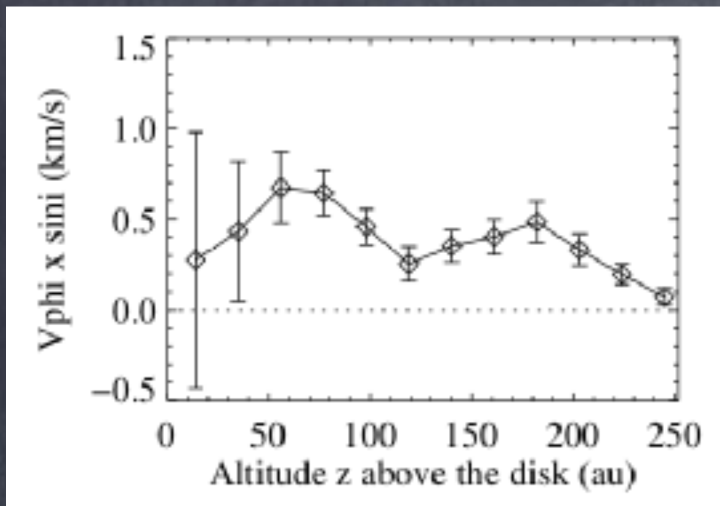
- Outflows/jets wiggle!

-> Betray multiplicity

-> Give constraints on the smallest scales



Conservation of the angular momentum



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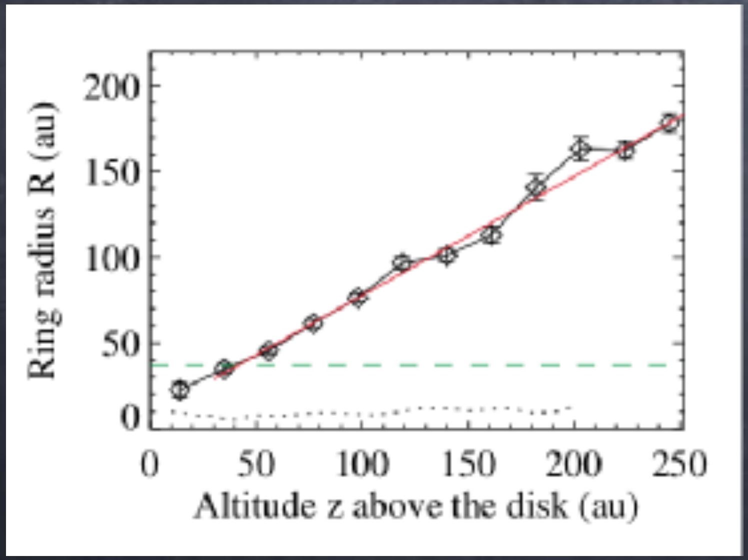

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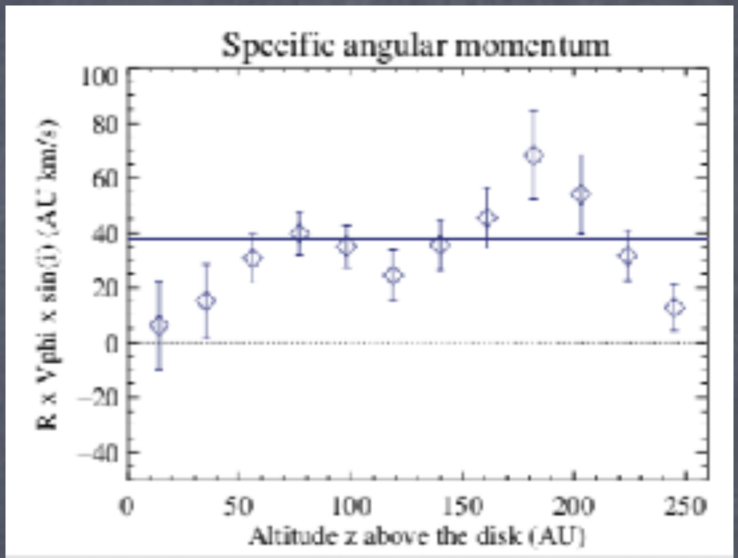

$$
\begin{aligned}
x_{\text{offset}} &= r_{cent} \\
V_z &= -(V_{cent} - V_0)/\cos i \\
(V_r \sin i)^2 &= \left((\cos PA)^2/a^2 + (\sin PA)^2/b^2\right)^{-1} \\
(V_\phi \sin i)/R &= 0.5 \times (V_r \sin i)^2 \times \sin 2PA \times (1/b^2 - 1/a^2) \\
1/R^2 &= \left((\cos PA)^2/b^2 + (\sin PA)^2/a^2\right) - (V_\phi/R)^2/V_r^2.
\end{aligned}
$$