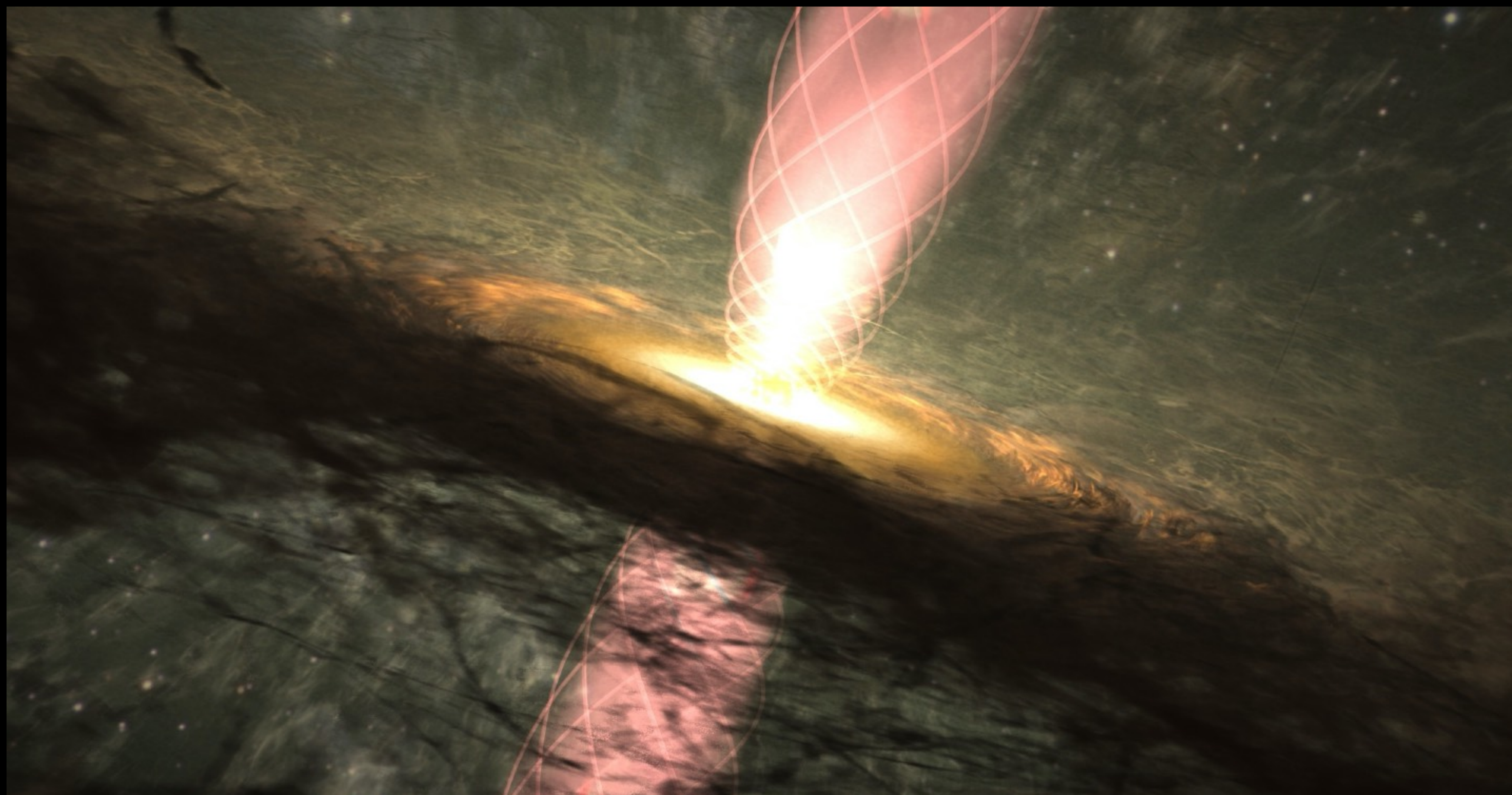
Observational Constraints on Launching and Collimation of Protostellar Jets



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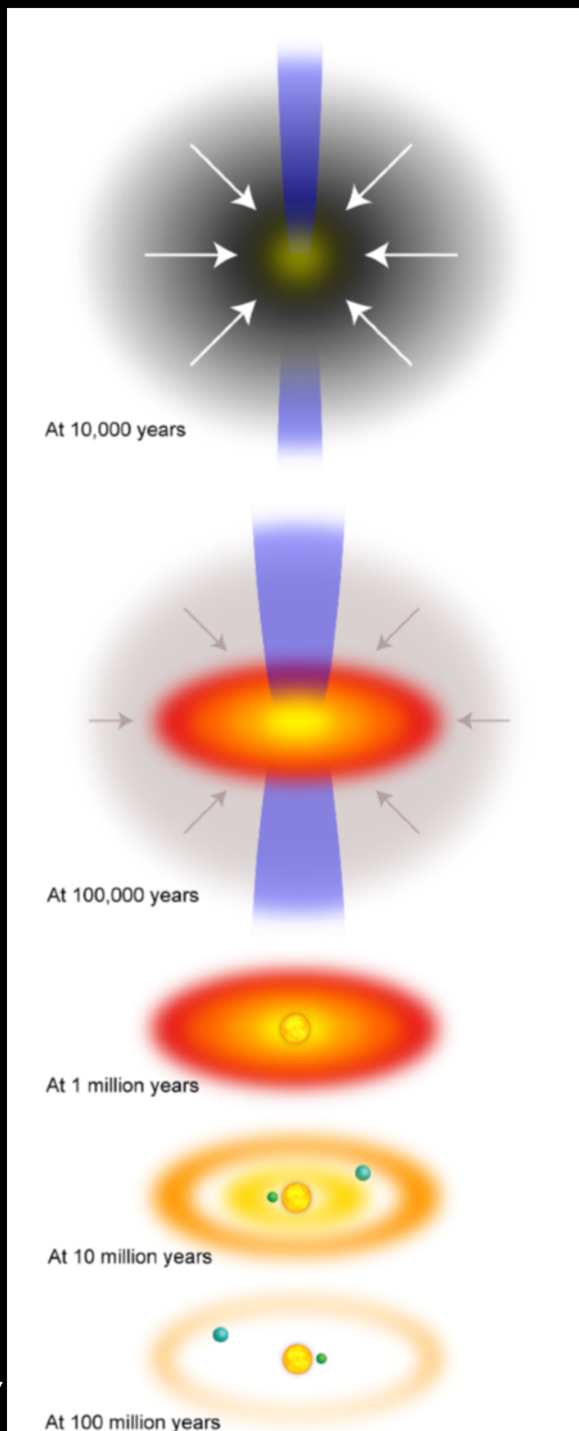
Protostellar Jets

forming-star

time



Early Stages → accretion disks + jets

Jets regulates accretion onto the protostar. Jets are fundamental to understand how a protostar evolves.

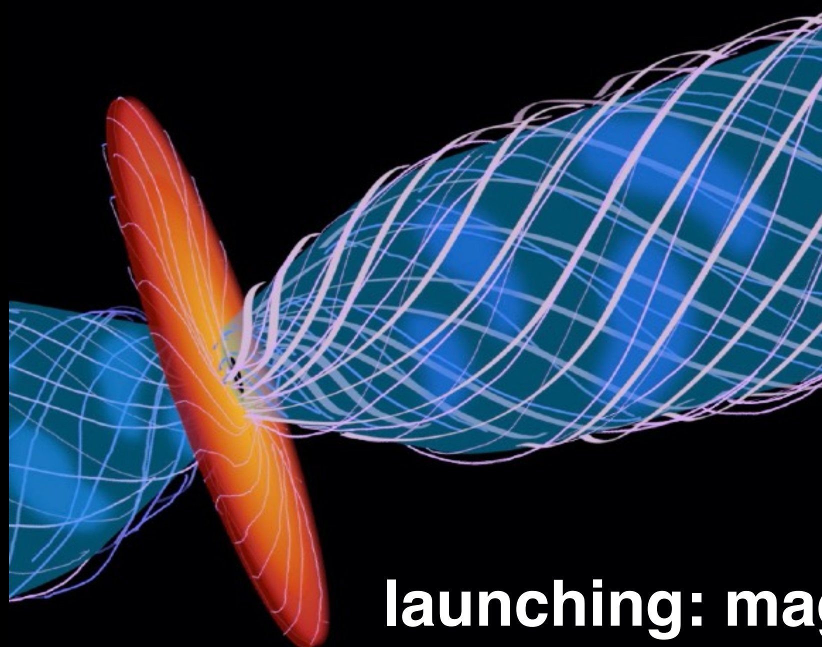
Low-mass vs Massive stars

~ 1 Msun	Star Mass	> 8 Msun
~ 0.01 Mstar	disk mass	~ Mstar?
Slow & ordered	accretion	High & violent
Strong	B	Weak?

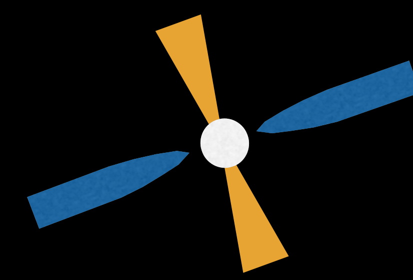
Jets and winds ARE present in both,
But, is it the same phenomenon?

Launching and Collimation Mechanisms

Self-collimation

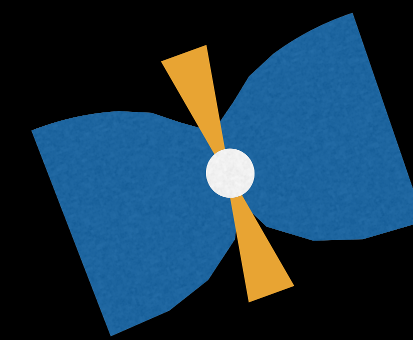


X-wind



Shu et al. (1994)

Disk-wind

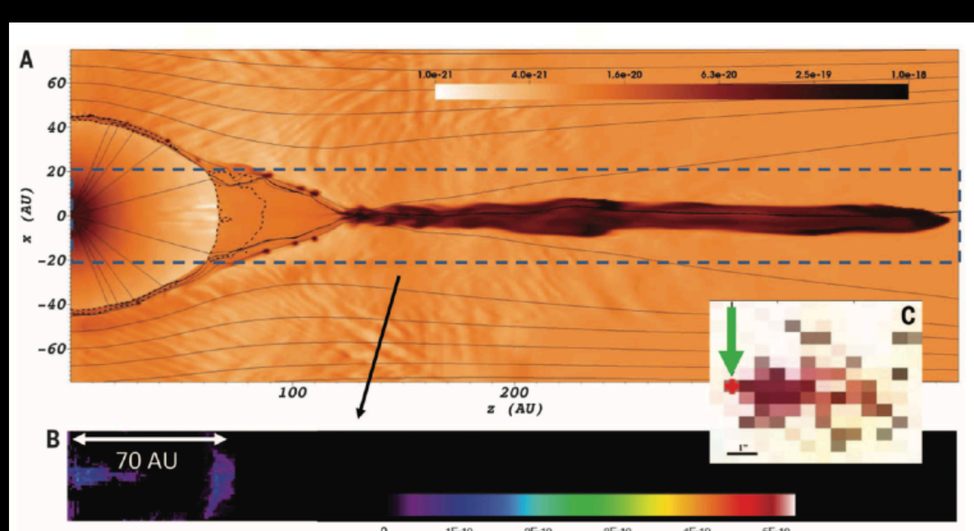


Pudritz & Norman (1983)

launching: magneto centrifugal forces
collimation: helical B
(Blandford & Payne 1982)

Jets are already collimated near (~au) the protostar/disk system

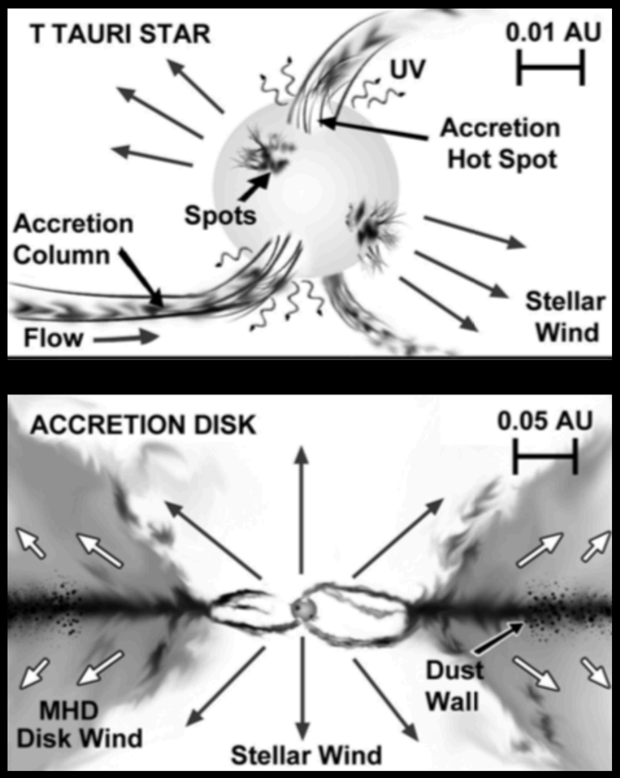
External collimation



launching: ?
collimation: ordered B + high density
(e.g. Albertazzi et al. 2014)

Protostar launches wide-angle wind, which is collimated into a jet at large (~10-100 au) distances

Observing Launching and Collimation Regions



LAUNCHING

Disk-wind / X-wind models

(Blandford & Payne)

Magneto-centrifugally launching from the innermost regions (<10 au) of the accretion disk

High extinction

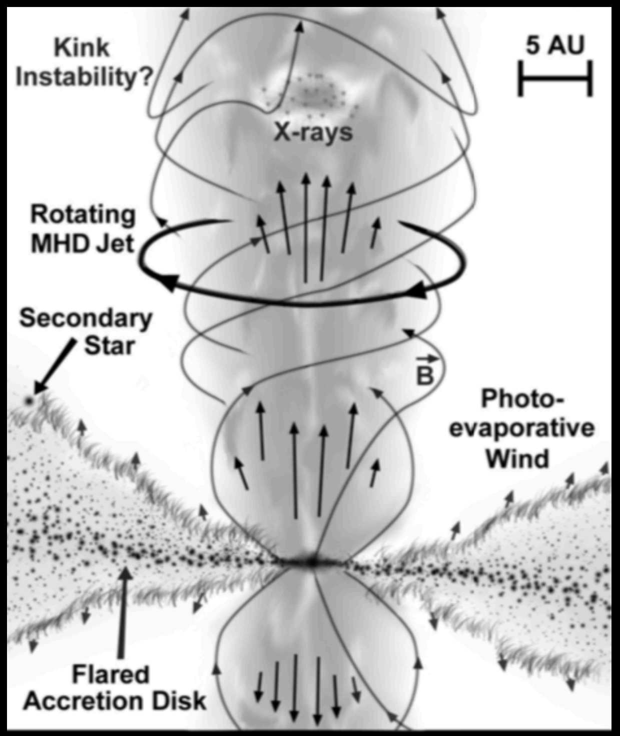
Small scales

Radio interferometers

Magnetic fields

Extremely difficult

Polarization, weak



COLLIMATION

Helical magnetic field
Dynamo in the disk/protostar

Helps for initial collimation

~100 au

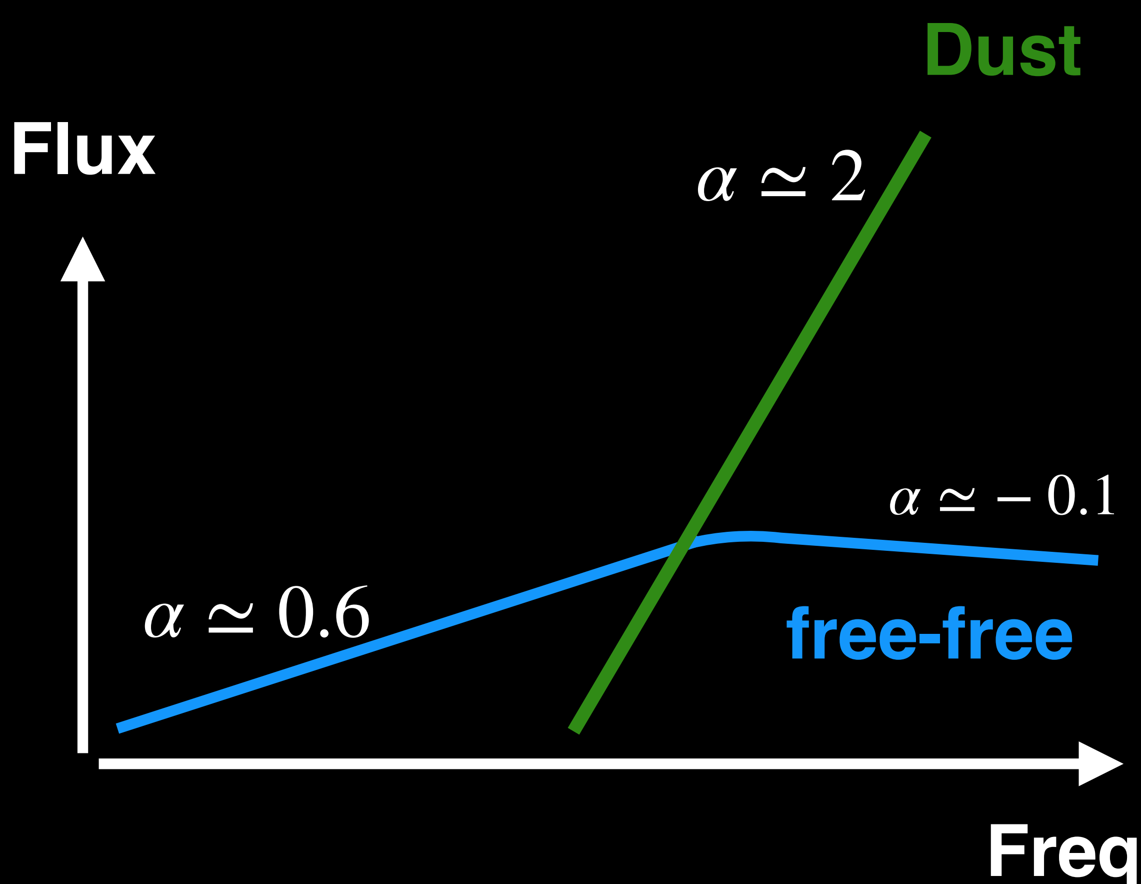
see review by Frank+2014

Astron Astrophys Rev (2018) 26:3
https://doi.org/10.1007/s00159-018-0107-z

REVIEW ARTICLE

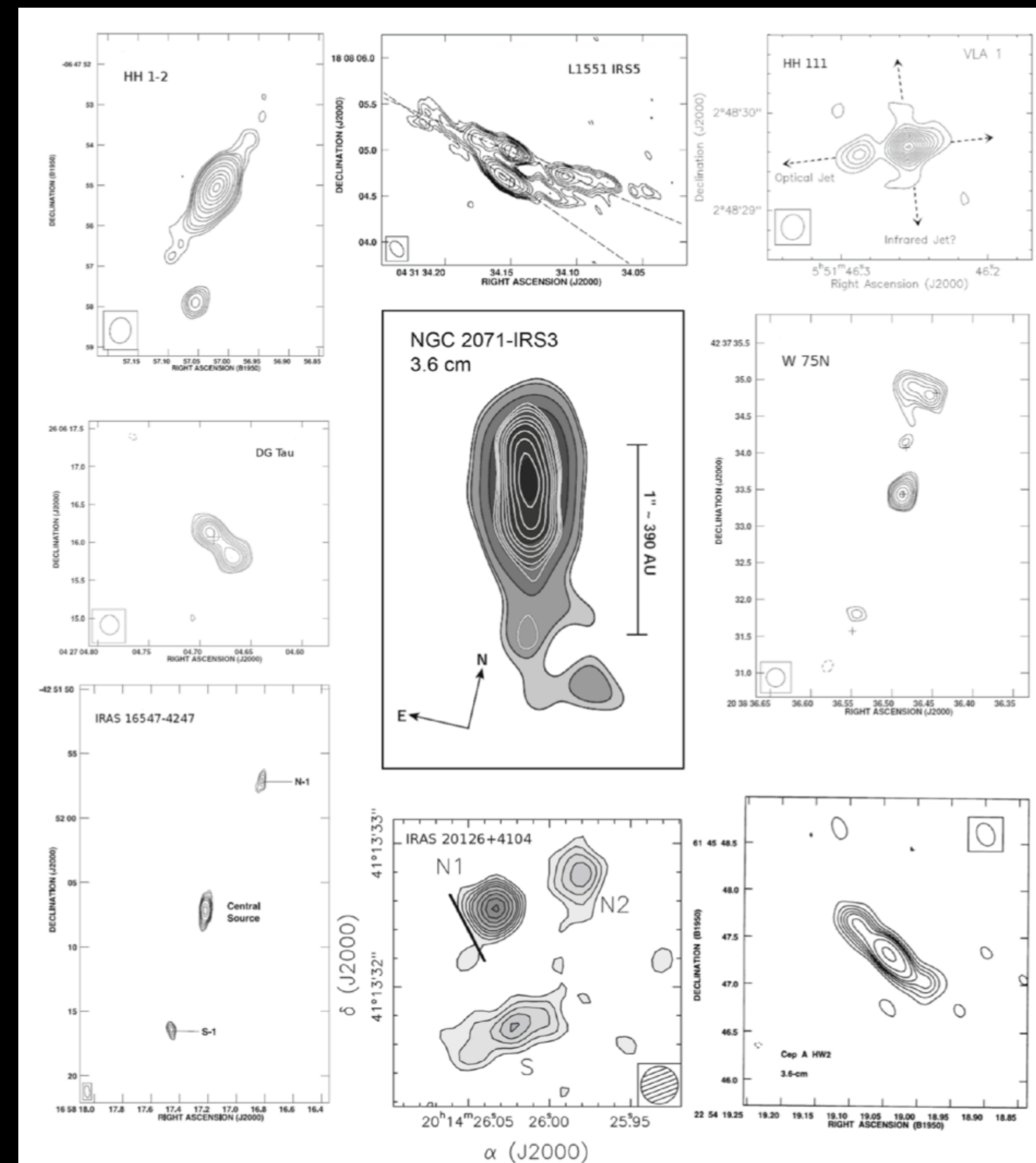
Radio jets from young stellar objects

Guillem Anglada[1] · Luis F. Rodríguez[2] ·
Carlos Carrasco-González[2]



weak (<1 mJy) emission at cm
difficult to observe at mm due to dust

Some of the best resolved radio jets
Material some hundreds of au
from the protostar

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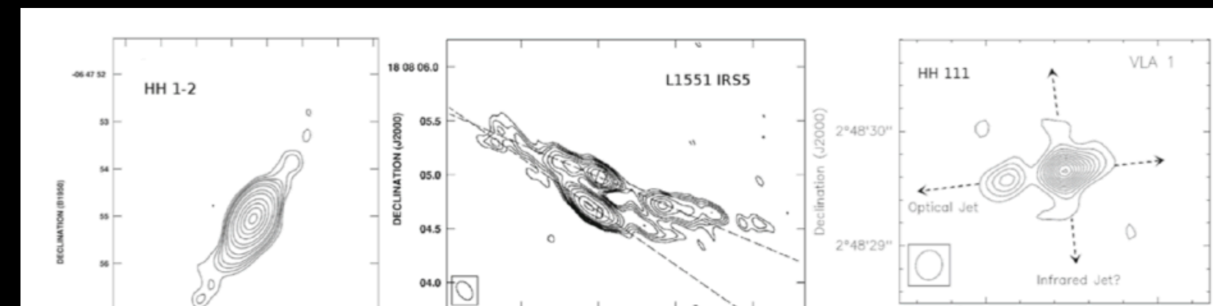


F

Radio Obs. during 1990s and early 2000s

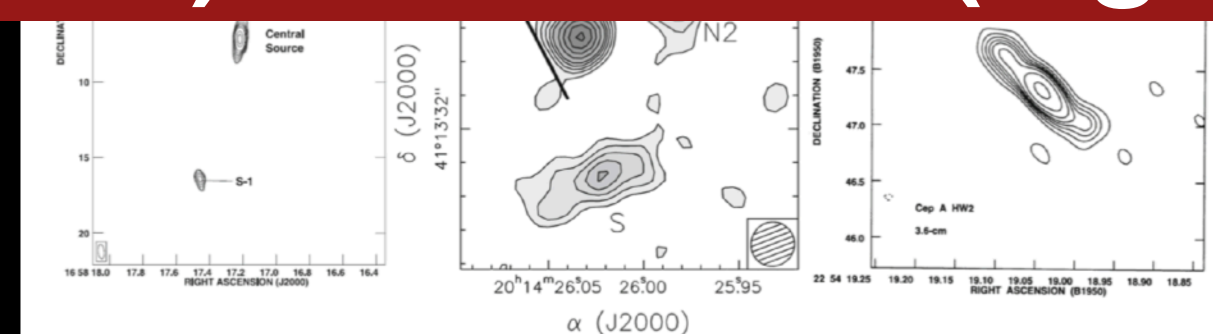
CONSTRAINTS:

Collimation Distance: <100 au

Velocities: 100 km/s (low-) ~1000 km/s (high-)

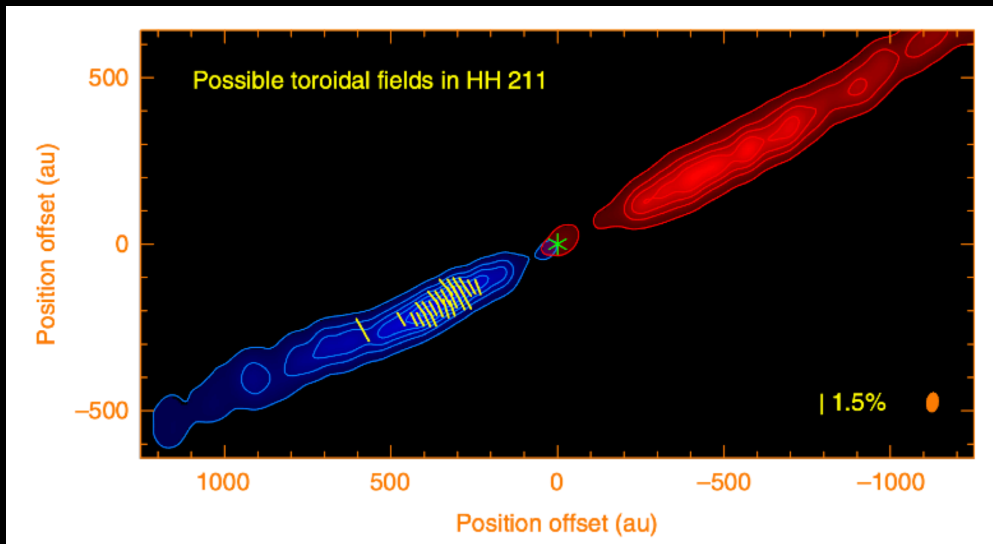
Freq

weak (<1 mJy) emission at cm
difficult to observe at mm due to dust



Magnetic Fields

One low-mass jet



Goldreich-Kylafis effect (polarized molecular lines)

ALMA Observations

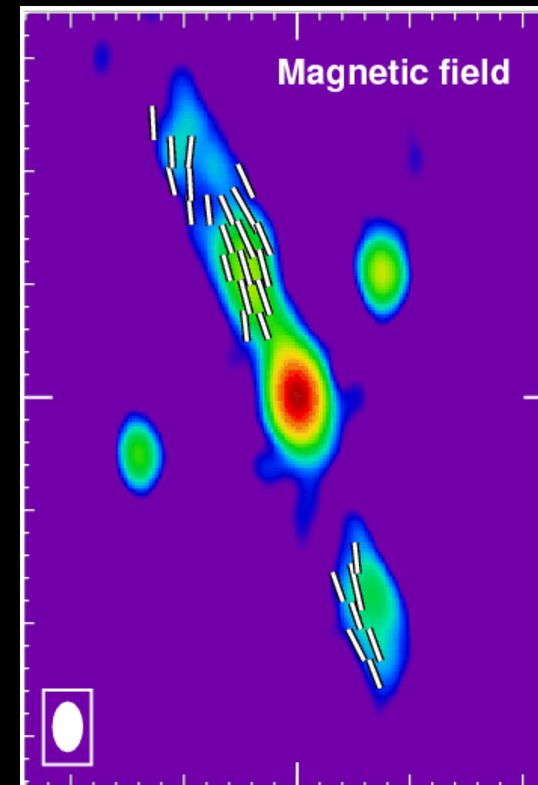
Toroidal (helical?) ; B~15 mG

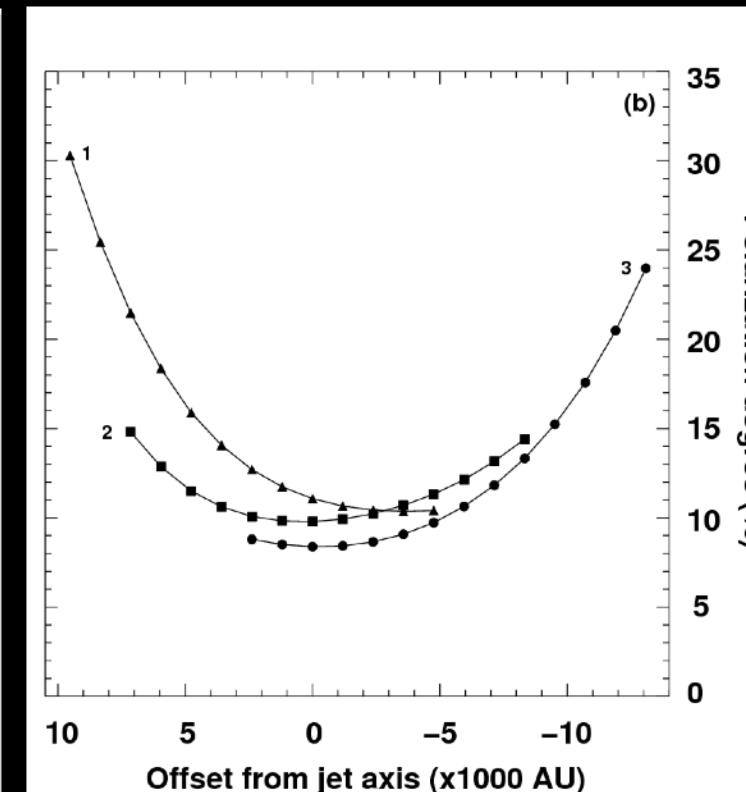
Lee et al. (2018), Nature Comm.

Difficult to detect and to interpret
B perpendicular or parallel to Pol. Vec.?

> Both cases are consistent with helical magnetic fields…
> …but also consistent with other configurations
>
> Understanding B only possible with new instrumentation (SKA, ngVLA, ALMA)

One high-mass jet





Synchrotron (polarized continuum)

VLA observations

Poloidal + Pol. gradients —> helical?
B ~ 0.2 mG

Carrasco-González et al. (2010), Science

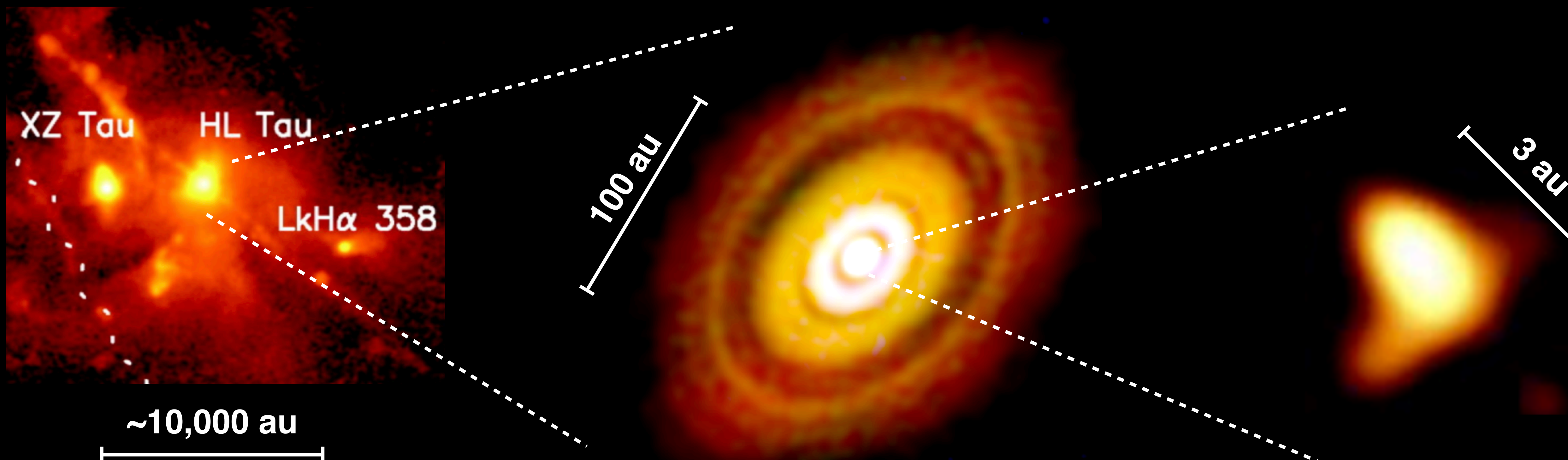
Synchrotron only possible in strong shocks —> embedded and fast jets ~ very young and massive protostars

(see Rodríguez-Kamenetzky et al. 2016, 2017, 2019)

Launching and Collimation Region

Radio observations (90s and 2000s) —> launching and collimation takes place < 100 au from protostar

Highest angular resolution observation of a low-mass jet (HL Tau)



Optical

Anglada et al. (2007)

ALMA+VLA

VLA

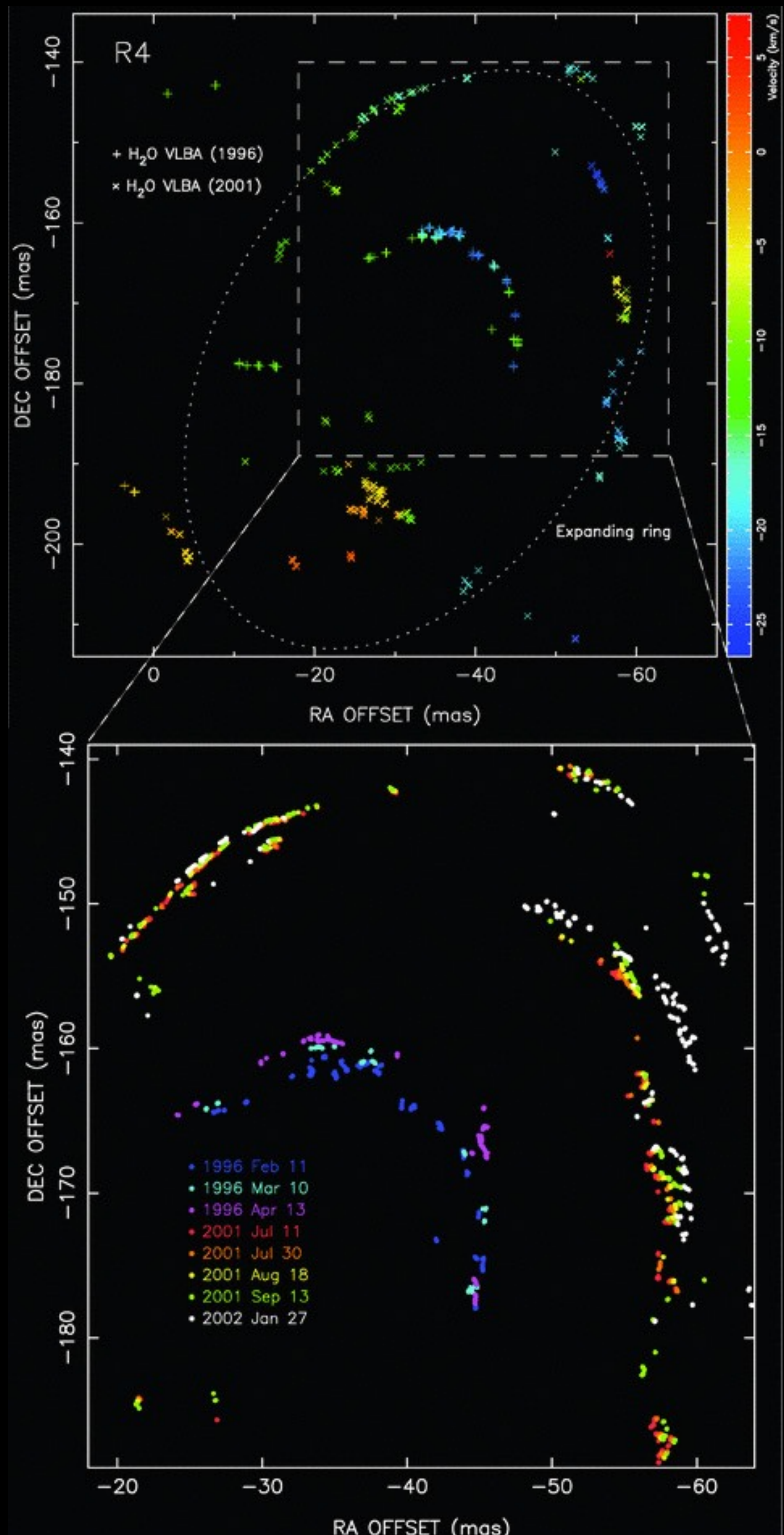
Carrasco-González et al. (2019)

Class I/II (not the earliest stage; near the end of jet's life)

The jet is already collimated at ~1 au

Well agreement with X-wind, probably also Disk-wind

COLLIMATION IN HIGH-MASS JETS



Torrelles et al. (2011)

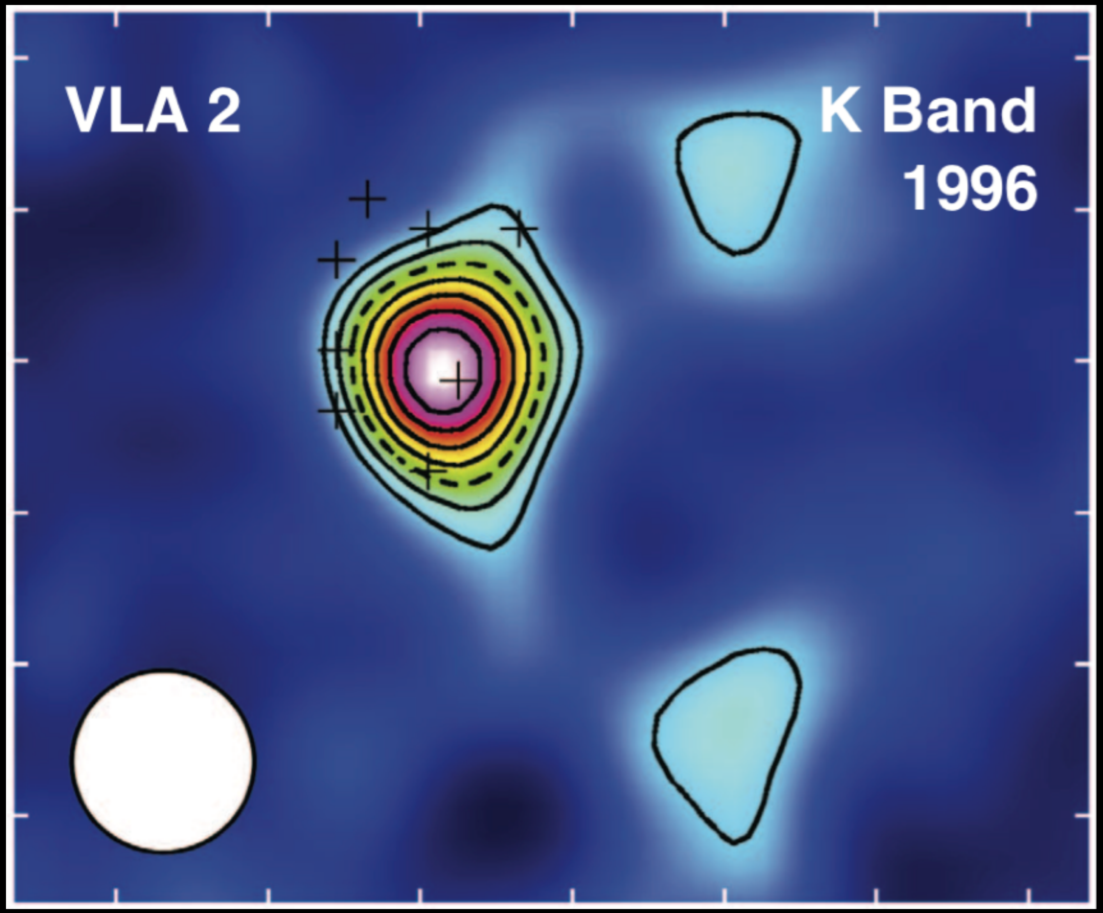
Today, it is well accepted that jets are also associated with high-mass protostars

However, poorly collimated or even spherical winds are also commonly found associated to high-mass protostars

Are they related?
Is the outflow phenomenon similar at all masses?

Torrelles+1997

W75N VLA 2
A very young massive protostar with a spherical wind



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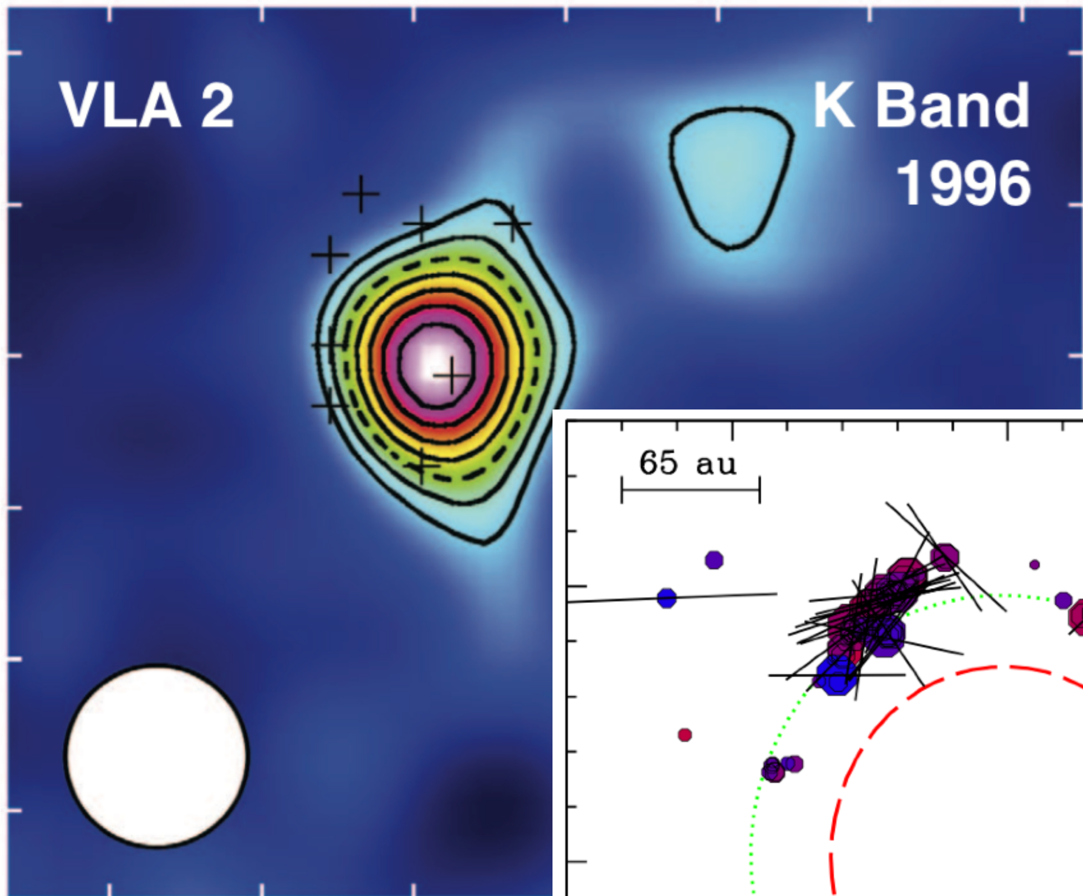

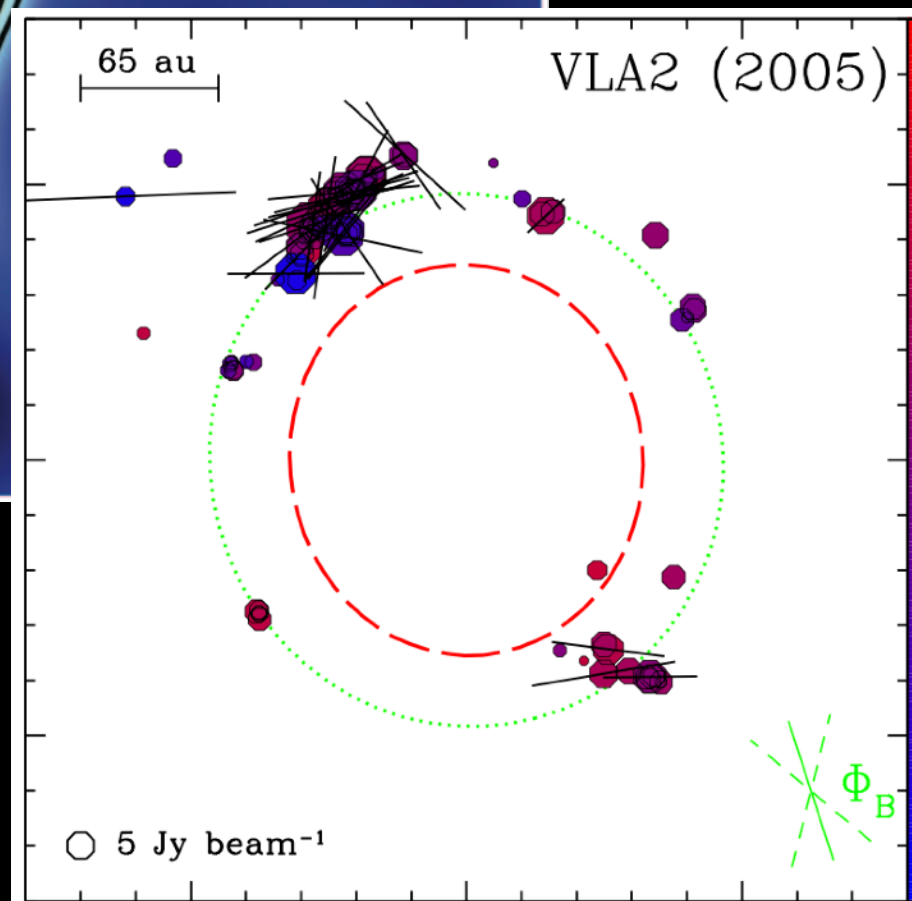

Surcis+2014

Water masers trace shocks

yes, spherical

Torrelles+1997

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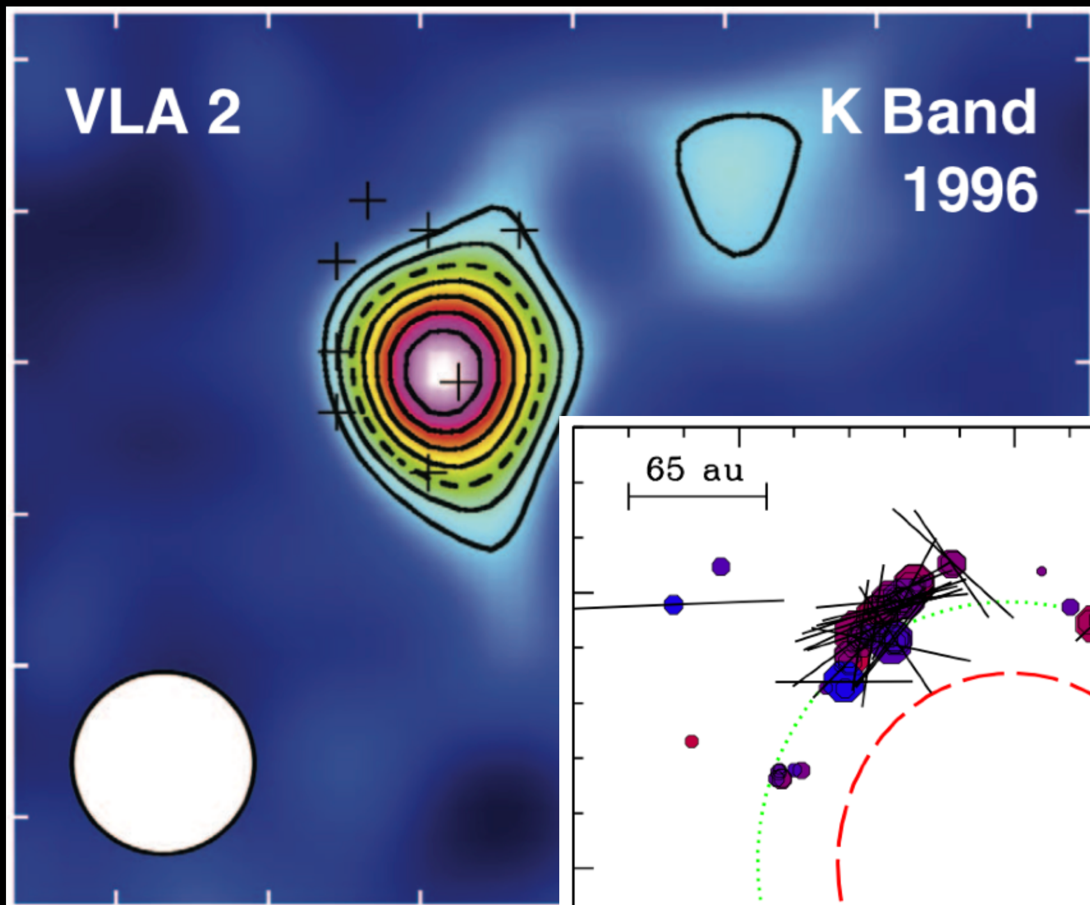

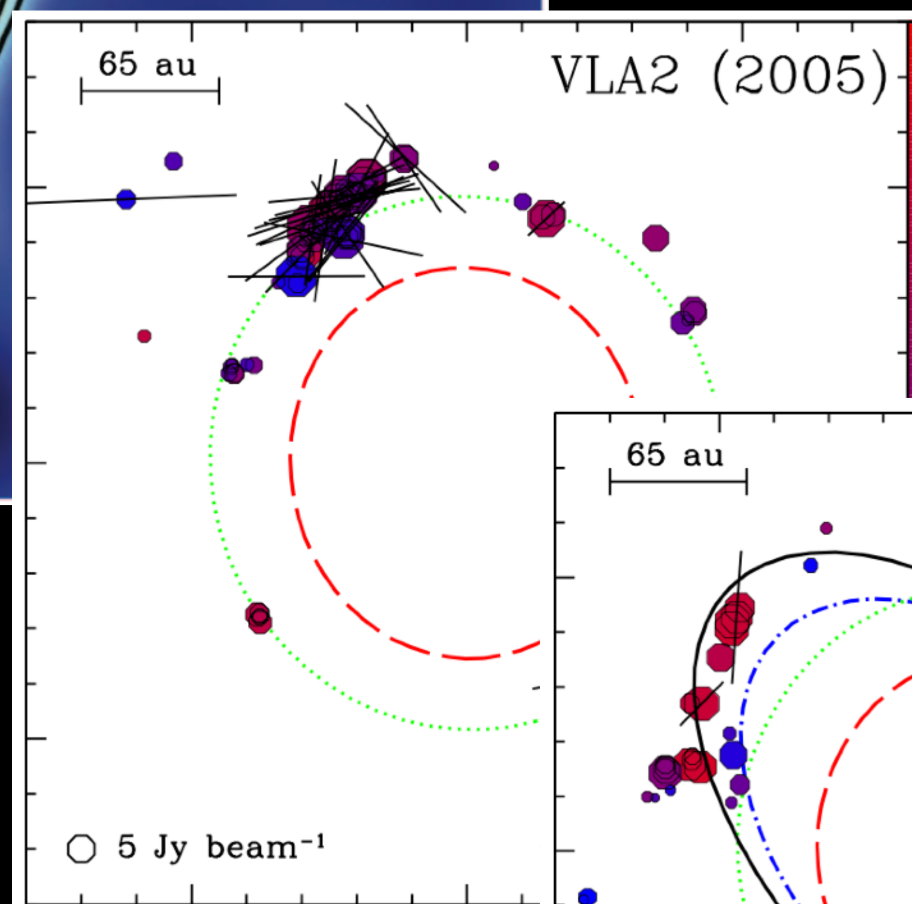

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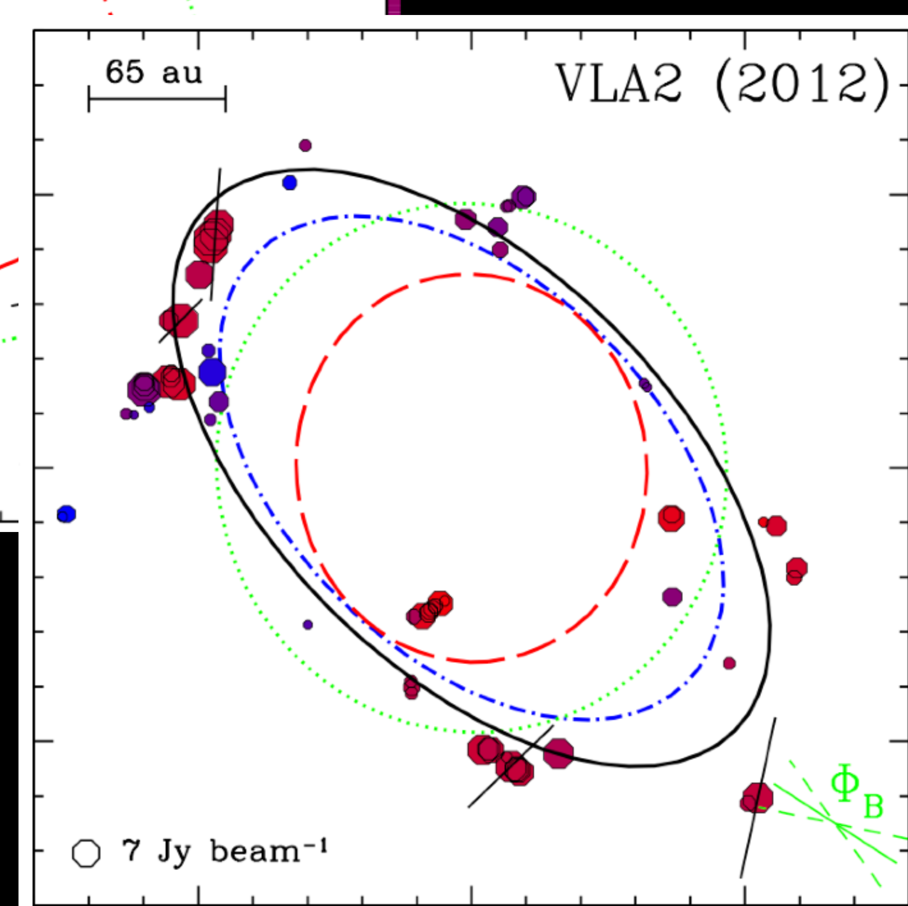
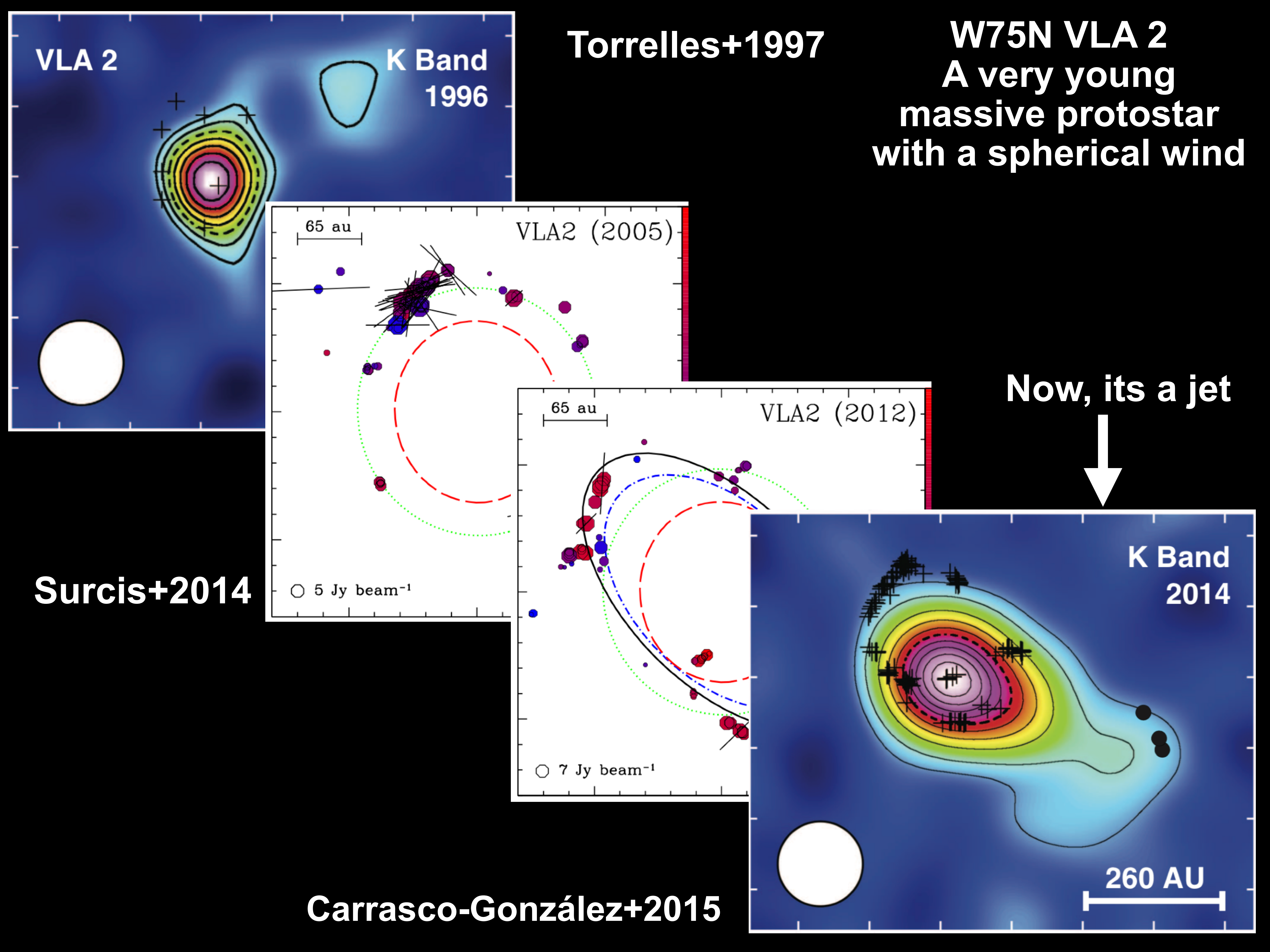
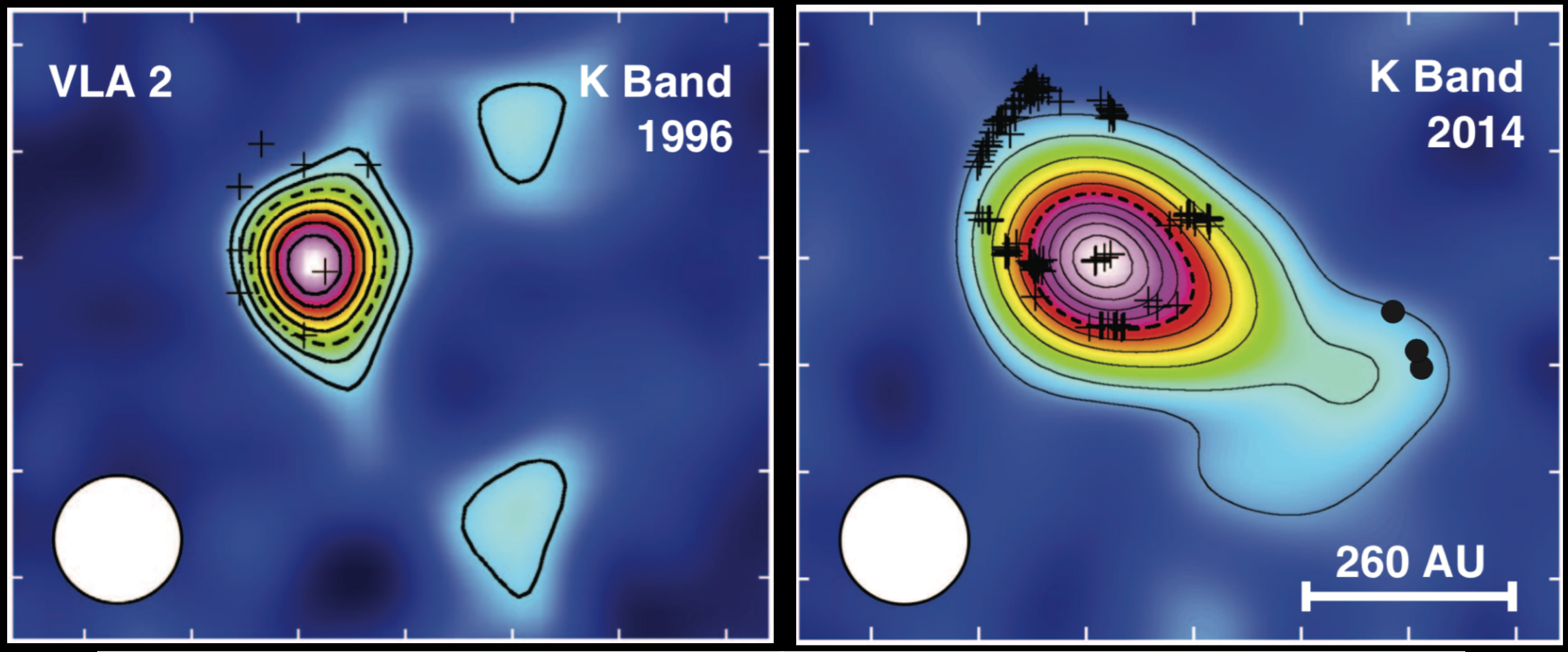
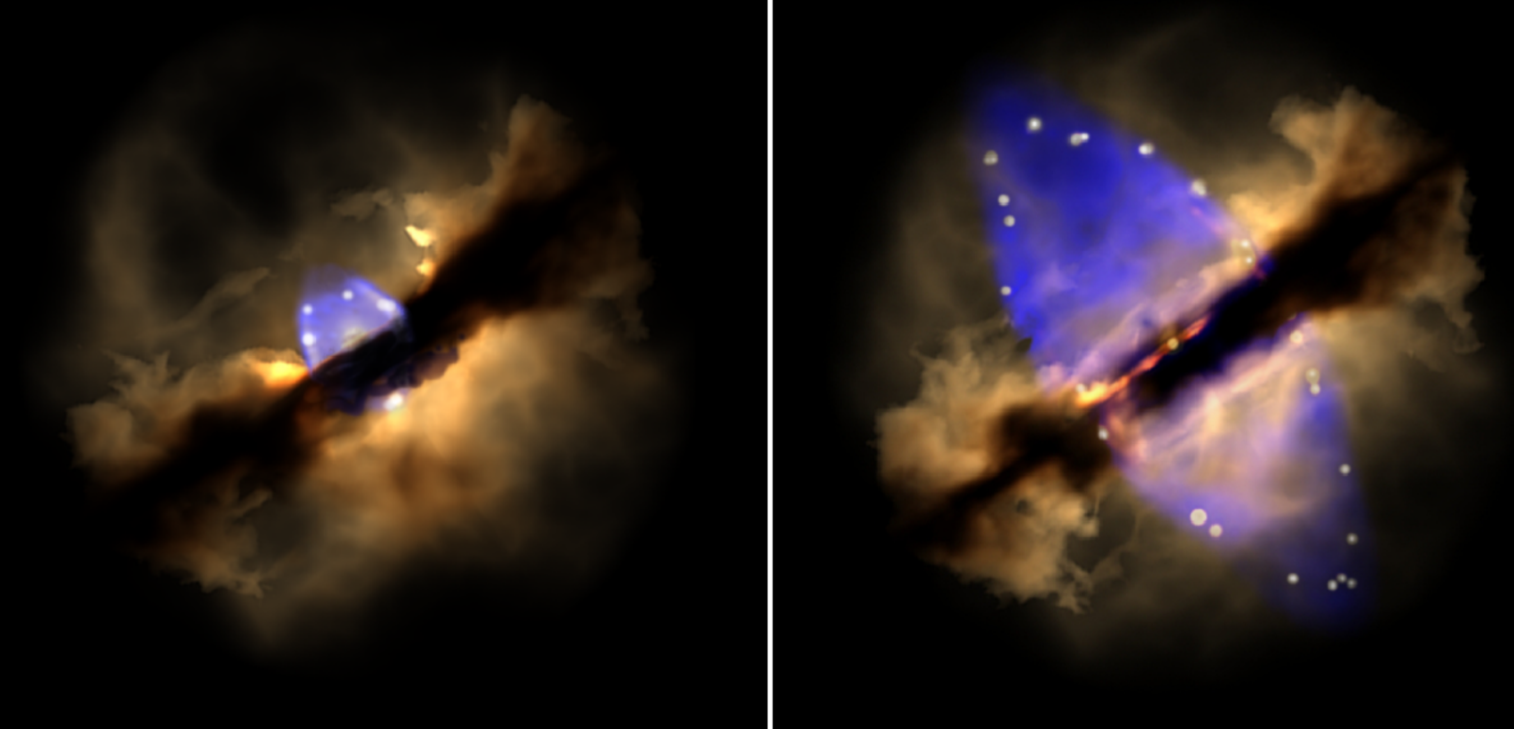
Surcis+2014



Now, elongated


W75N VLA 2
A very young
massive protostar
with a spherical wind
Torrelles+1997
VLA 2
K Band
1996
65 au
VLA2 (2005)
5 Jy beam⁻¹
Surcis+2014
65 au
VLA2 (2012)
7 Jy beam⁻¹
Now, its a jet
K Band
2014
260 AU
Carrasco-González+2015





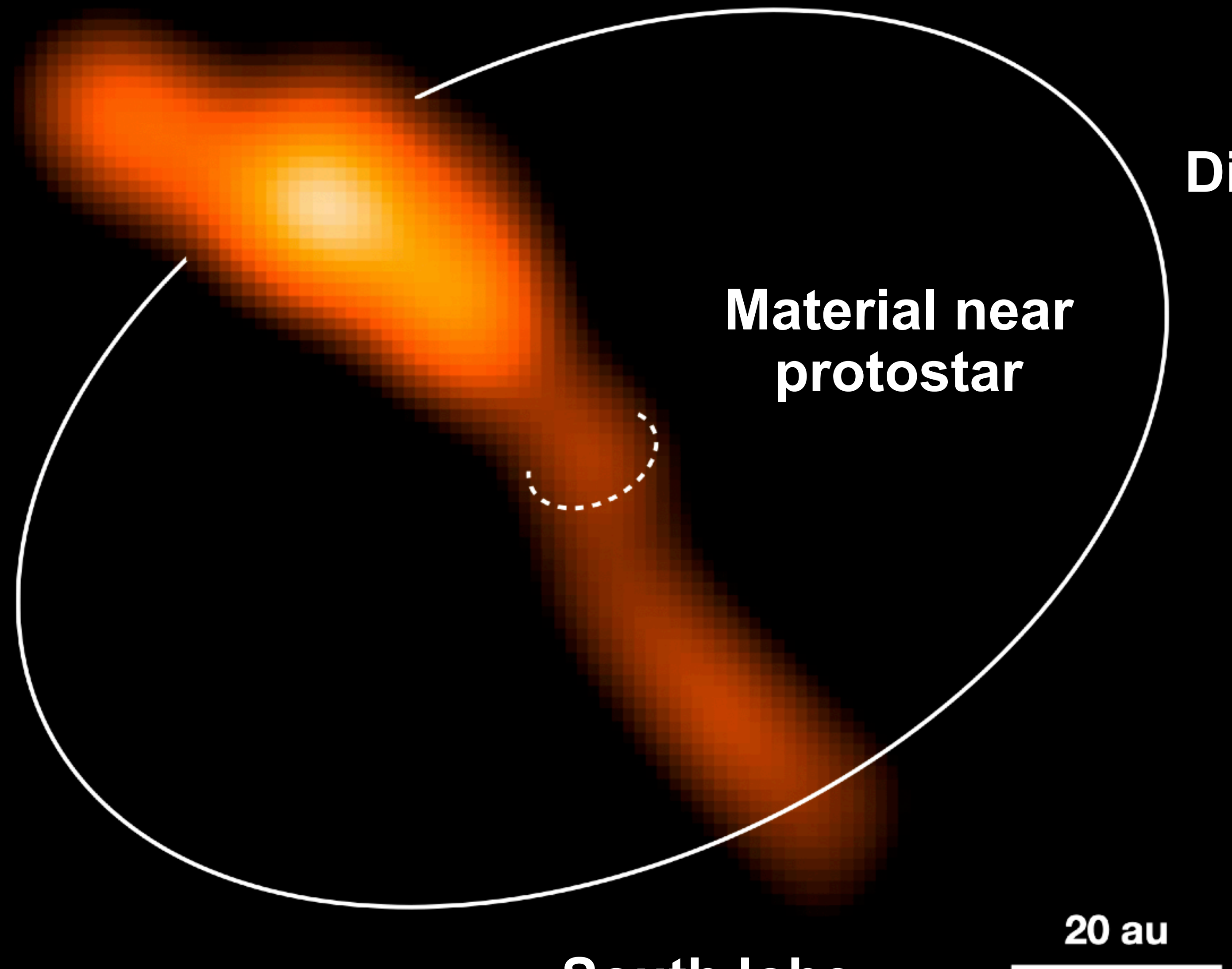
"External" collimation due to interaction with dense ambient medium??

Carrasco-González et al. (2015), Science

COLLIMATION IN HIGH-MASS JETS

First time we resolve the innermost 100 au in a massive protostellar jet

Cep A HW 2

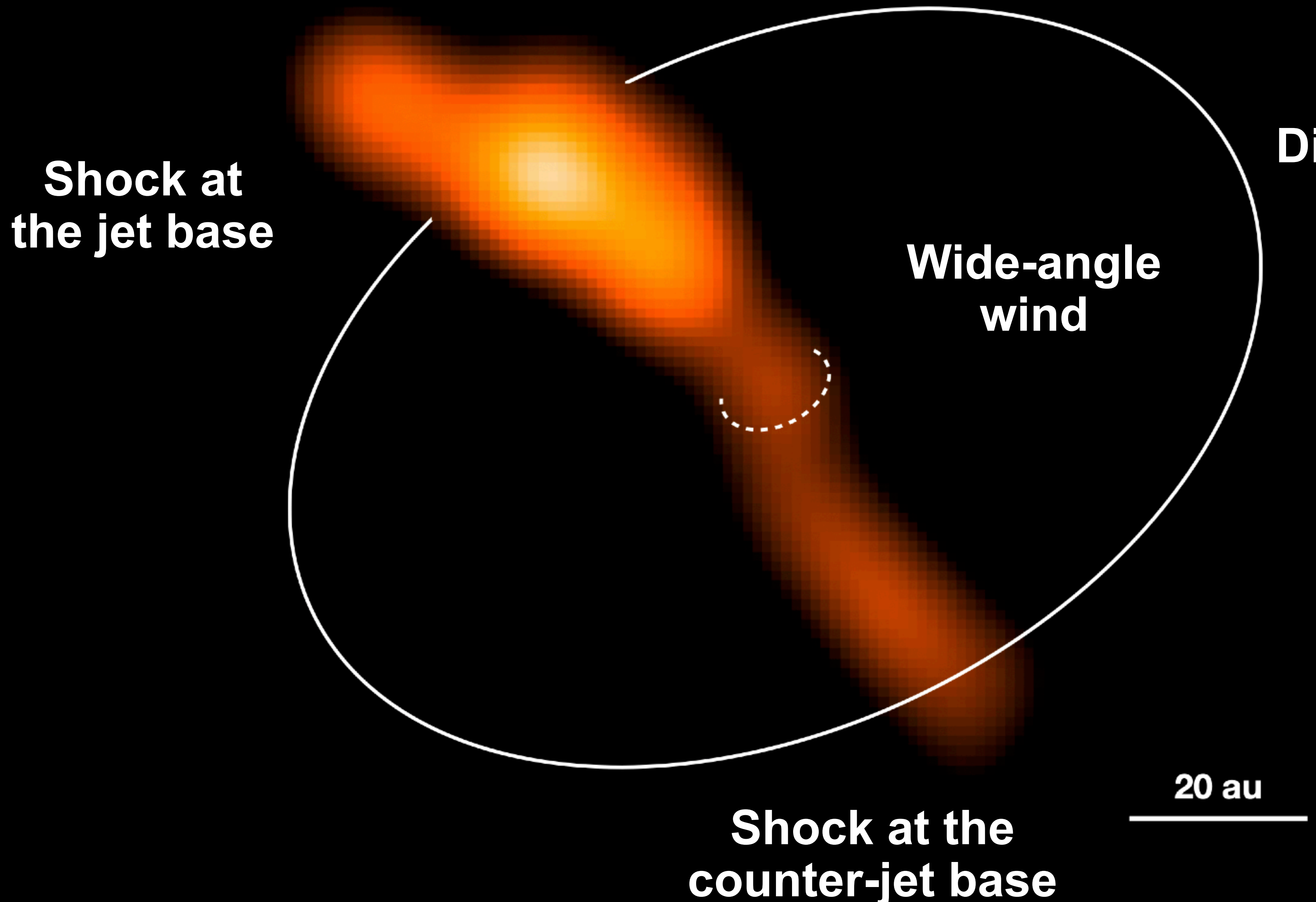


Carrasco-González et al. (2021)

Collimation in high-mass Jets

Cep A HW 2

First time we resolve the innermost 100 au in a massive protostellar jet



Carrasco-González et al. (2021)

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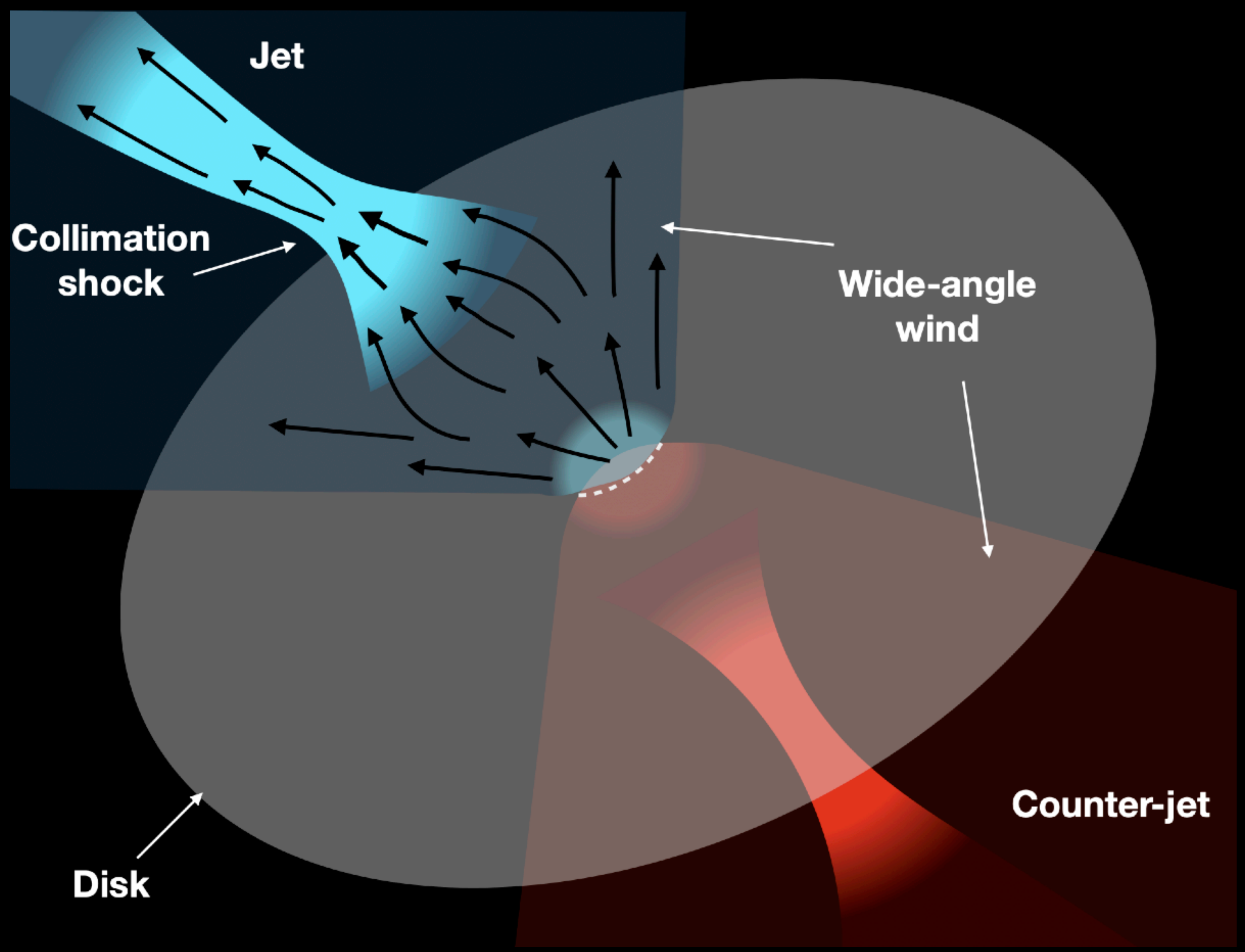

Launching and collimation could be very different in the case of high-mass protostars

Carrasco-González et al. (2021)

SUMMARY

- Protostellar jets are fundamental at early stages in the star formation process

- We still do not know what's the exact mechanism

- Radio observations in the 90s and 2000s imposed an important constraint to the distance at which the jet is collimated (<100 au)

- We need to map magnetic fields and the region near the protostar. Extremely difficult at the moment, giant step with future planned instrumentation (SKA, ngVLA, improved ALMA)

- Current instrumentation has recently allowed to take a look at the launching and collimation zone in both, low- and high-mass protostars.

- We found that the jet phenomenon might be strongly dependent on the mass of the protostar