RESOLVING THE COLLIMATION ZONE OF INTERMEDIATE- HIGH-MASS PROTOSTELLAR JETS

Science with LLAMA
September 2022, Salta, Argentina

ADRIANA R. RODRÍGUEZ KAMENETZKY[1,2]

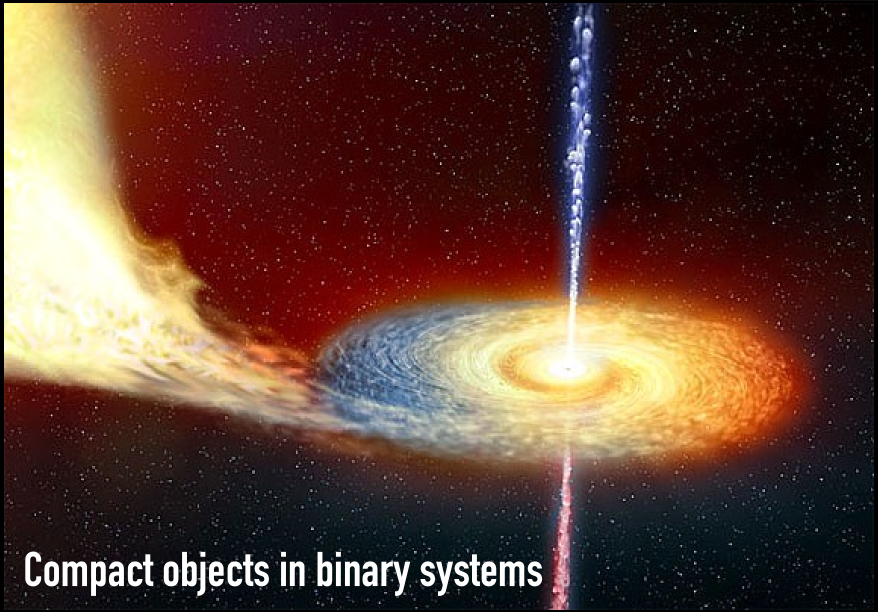
[1]Instituto de Radioatronomía y Astrofísica, UNAM
[2]IATE, CONICET, Argentina (starting in Dic. 2022)

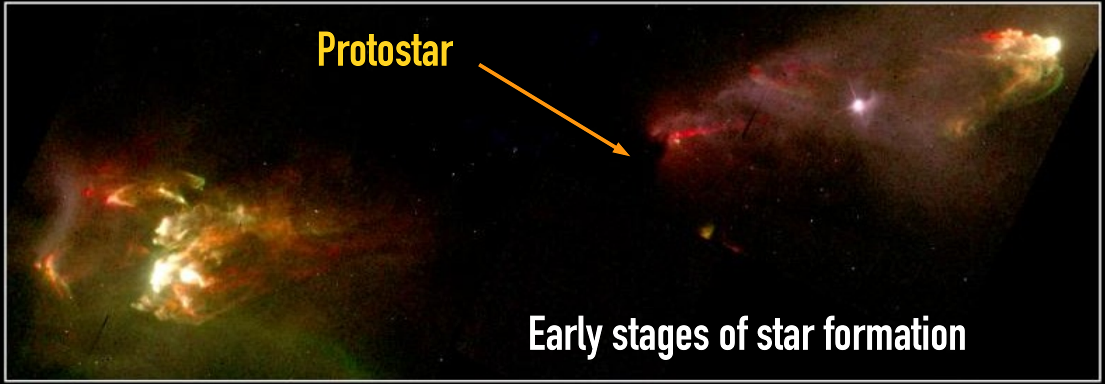
In collaboration with
C. Carrasco-González, L. F. Rodríguez, A. Sanna , J. M. Torrelles +

Image Credits: Bill Saxton, NRAO, AUI, NSF

Astrophysical Jets

play an important role in the evolution of their host systems



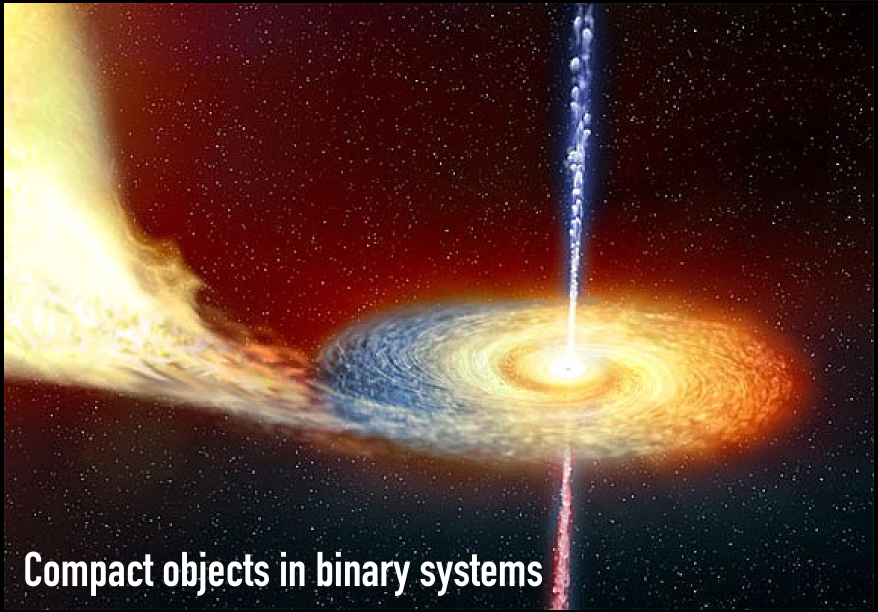


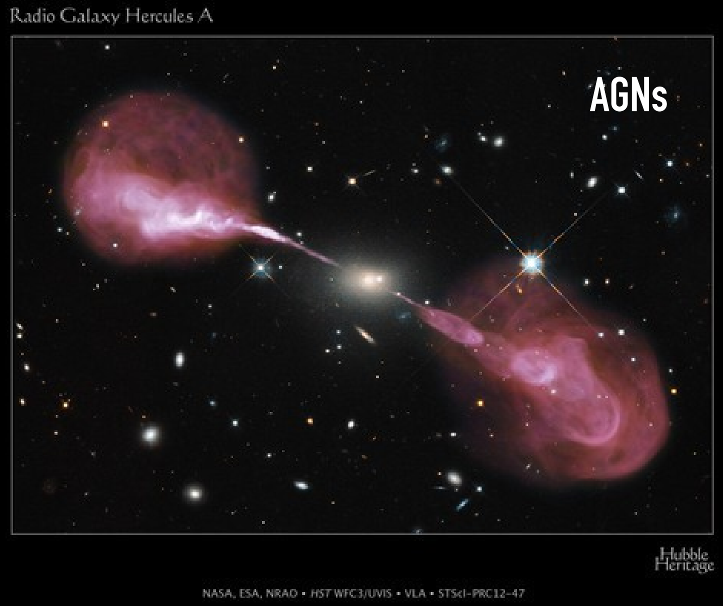
How are they launched and collimated?

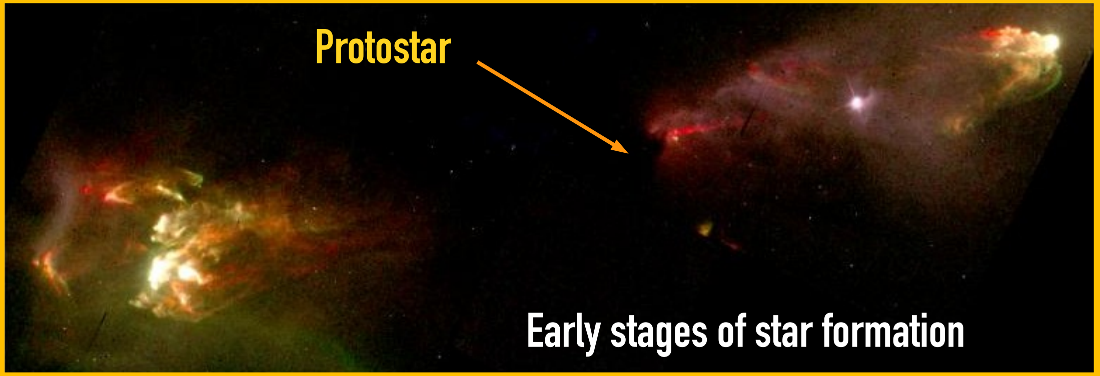
Is there a universal mechanism to explaing all kind of jets?

Astrophysical Jets

play an important role in the evolution of their host systems







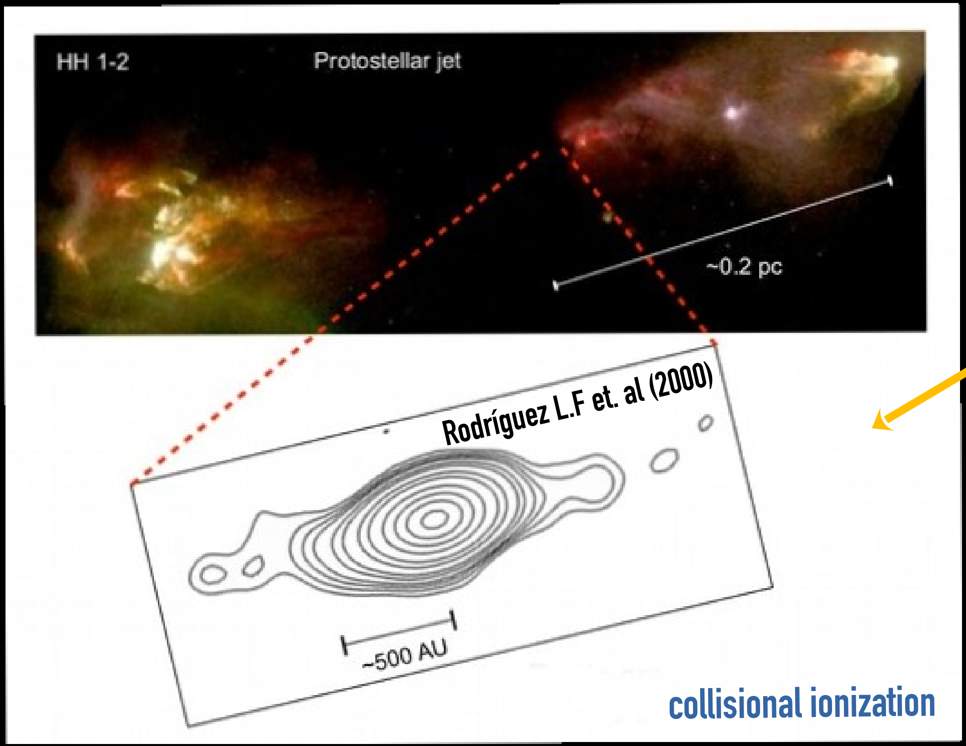
How are they launched and collimated?

Is there a universal mechanism to explaing all kind of jets?

Protostellar jets

Associated with strong accretion stages during the star formation process

(Class 0 and I protostars)



Thermal free-free emission from partially ionized material.

They allow us to probe close to their launching platforms

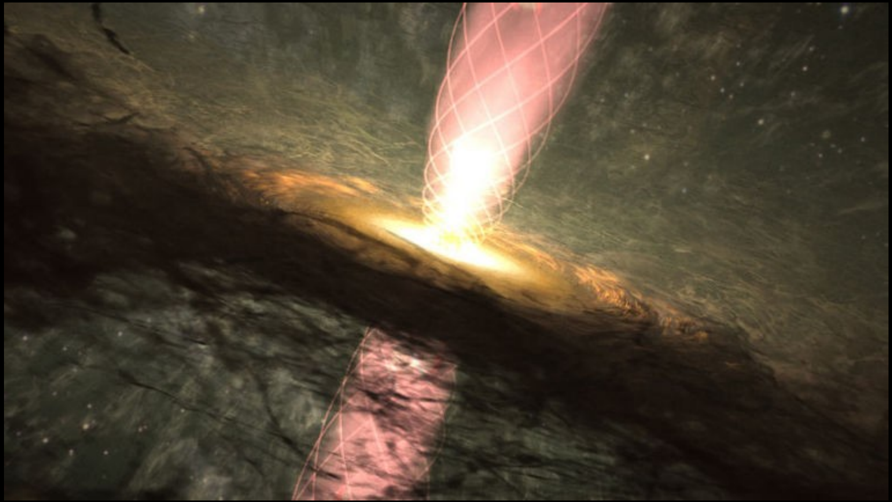
Most internal regions observed at radio frequencies

In the past decades, radio interferometric observations, mainly performed with the VLA at C and X bands, have allowed to set an upper limit of 100 au to the distance from the protostar at which collimation takes place

This limit does not allow to rule out any launching/collimation mechanism

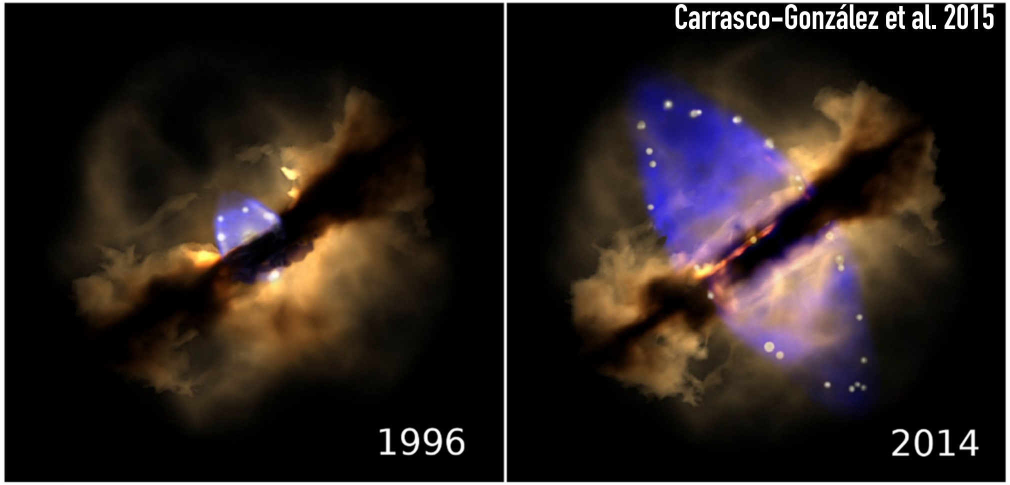
Collimation mechanisms (Basics)

SELF COLLIMATION



Entail plasma confinement by a self-generated helical magnetic field in the protostar/disk system (e.g., X-wind, Disk-wind)

EXTERNAL COLLIMATION



Imágenes de la simulación en 3D de la evolución del flujo de gas ionizado en W75N(B)-VLA 2. Créditos: Wolfgang Steffen, Instituto de Astronomía, UNAM.

Poorly collimated winds might be externally collimated by Strong ambient medium pressure at large (≥ 10-100 au) distances from the protostar or large-scale ordered magnetic field

But... different mechanisms could dominate the jet collimation on different scales (Frank+2014), and even jet launching might depend on the mass and/or evolutionary stage of the protostar (Hoare 2015).

We need to zoom into the launching and collimation zone

HIGH SENSITIVITY & HIGH ANGULAR RESOLUTION
observations at radiofrequencies

Eg., considering the Taurus molecular cloud, one of the closest to us, located at ~140 pc

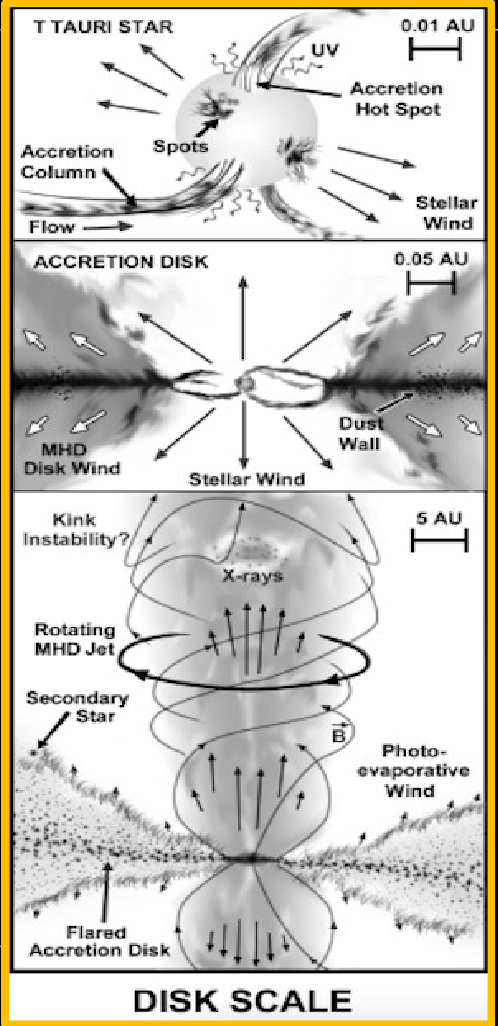
1 au is equivalent to 7 mas

We need 1mas angular resolution
to study launching/collimation at au scales

Not posible with current interferometers, e.g.:

- We achieved 30mas (at 7mm) with VLA-A and 37mas (at 6cm) with eMERLIN

- VLBA can resolve 1 mas but lacks the sensitivity to detect free-free emission from these objects at this resolution.



Frank et al. 2014

FEW OBJECTS HAVE BEEN RESOLVED UNDER 100 AU at radiofrequencies

(Resolution ~40/50 mas)

Consistent with self-colliamtion

- (low-mass) DG Tau A at 6cm with eMERLIN (Ainsworth et al. 2013)

- (low-mass) HL Tau at 7mm with VLA- A (Carrasco-González et al. 2019)

- (low-mass) The multiple protostellar system L1551 IRS 5 at 7mm VLA-A (Lim & Takakuwa 2006, Lim et al. 2016), VLA-A 1.3cm (Feeney-Johansson et al. In prep)

Reviewed in This Talk

First time to be resolved under 100 au. We found important results

- (high-mass) Cep A HW2, at 7mm VLA-A (Carrasco-González et al. 2021)

- (intermediate-mass) The Serpens radio jets at 7mm with VLA-A (Rodríguez-Kamenetzky et al. 2022)

Cep A HW2

THE ASTROPHYSICAL JOURNAL LETTERS, 914:L1 (8pp), 2021 June 10 https://doi.org/10.3847/2041-8213/abf735

CrossMark

Zooming into the Collimation Zone in a Massive Protostellar Jet

Carlos Carrasco-González[1], Alberto Sanna[2,3], Adriana Rodríguez-Kamenetzky[1], Luca Moscadelli[4], Melvin Hoare[5], José M. Torrelles[6,7], Roberto Galván-Madrid[1], and Andrés F. Izquierdo[8,9]

[1] Instituto de Radioastronomía y Astrofísica (IRyA-UNAM), Morelia, Mexico; c.carrasco@irya.unam.mx
[2] INAF—Osservatorio Astronomico di Cagliari, Selargius, Italy
[3] Max-Planck-Institut für Radioastronomie (MPIfR), Bonn, Germany
[4] INAF—Osservatorio Astrofisico di Arcetri, Firenze, Italy
[5] School of Physics & Astronomy, University of Leeds, Leeds, UK
[6] Institut de Ciències de l'Espai (ICE, CSIC), Barcelona, Spain
[7] Institut d'Estudis Espacials de Catalunya (IEEC), Barcelona, Spain
[8] European Southern Observatory, Garching, Germany
[9] Leiden Observatory, Leiden University, Leiden, The Netherlands

Received 2021 March 29; revised 2021 April 10; accepted 2021 April 13; published 2021 June 7

We imaged the radio emission at projected distances of only ~20 au from the protostar, resolving the innermost 100 au of a massive protostellar jet for the first time.

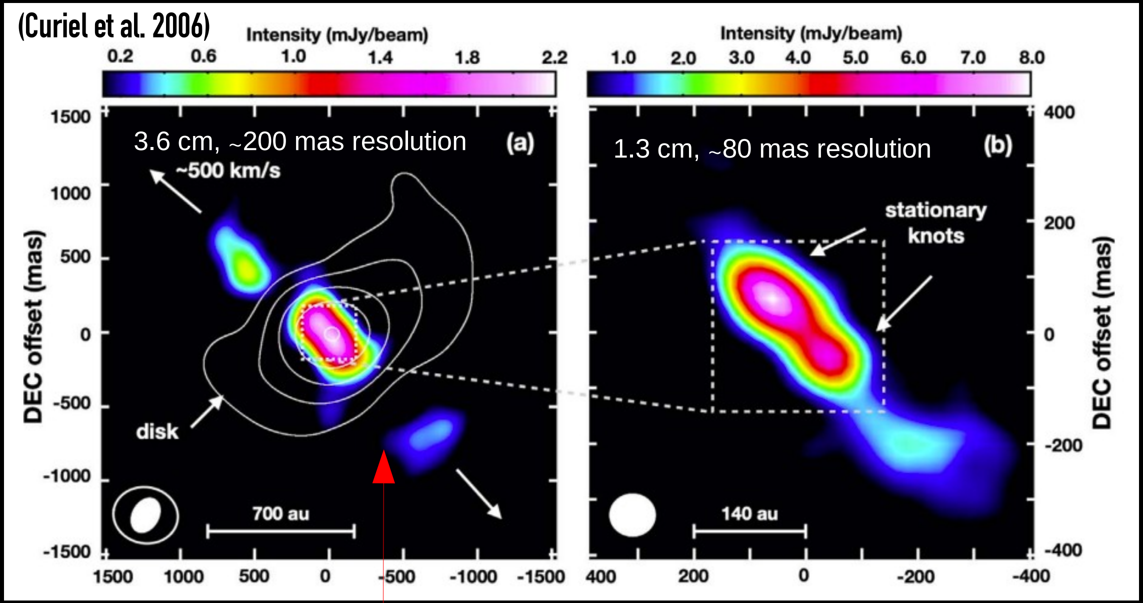
The morphology of the radio jet emission is very different than what is usually observed in jets from low-mass protostars.

Our study suggests the presence of a wide-angle wind launched from the protostar/disk system, and a highly collimated jet starting at 20–30 au from the protostar.

Cep A HW2

Located at 700 pc in the Cepheus A high-mass star-forming region,
is one of the best known examples of a disk/jet system associated with a massive protostar

(Curiel et al. 2006)



Emission from the dusty disk is resolved by NOEMA 1.3 mm high angular resolution observations (Beuther et al. 2018)

Earlier observations

Multi-scale view of the Cep A HW2 disk/jet system

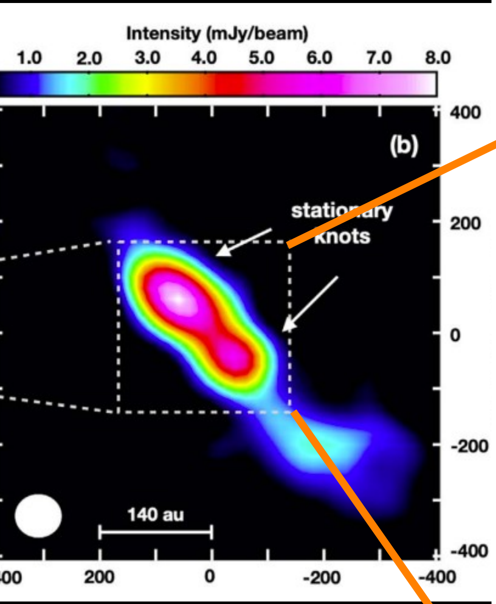
- (a) Radio jet morphology at scales of ~1000 au, with a central, bright, elongated core, and two separated knots either side of the core, moving away in opposite directions (Curiel et al. 2006).

- (b) Stationary knots. Interpreted as not being ejected by the powering source

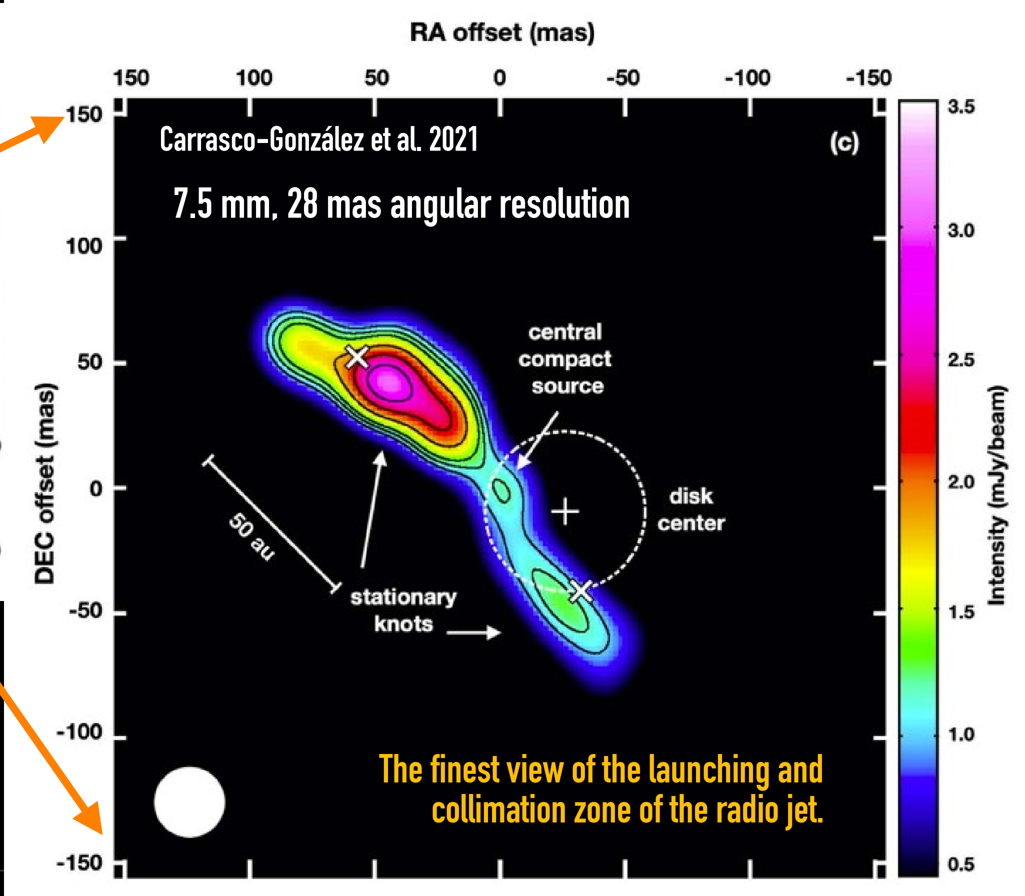
They speculate that “the knots could be associated with the outer part of the cavity evacuated in the infalling gas by the wind, being shocked by the wind”

Cep A HW2

A B-type massive protstar



(Curiel et al. 2006)



- The new image resolves the innermost region of the radio jet

-We confirm the absence of proper motions 12 yrs after the previous 10-yr monitoring

- The compact 7.5 mm source is detected at the center whose position is consistent with the center of the massive dusty disk.

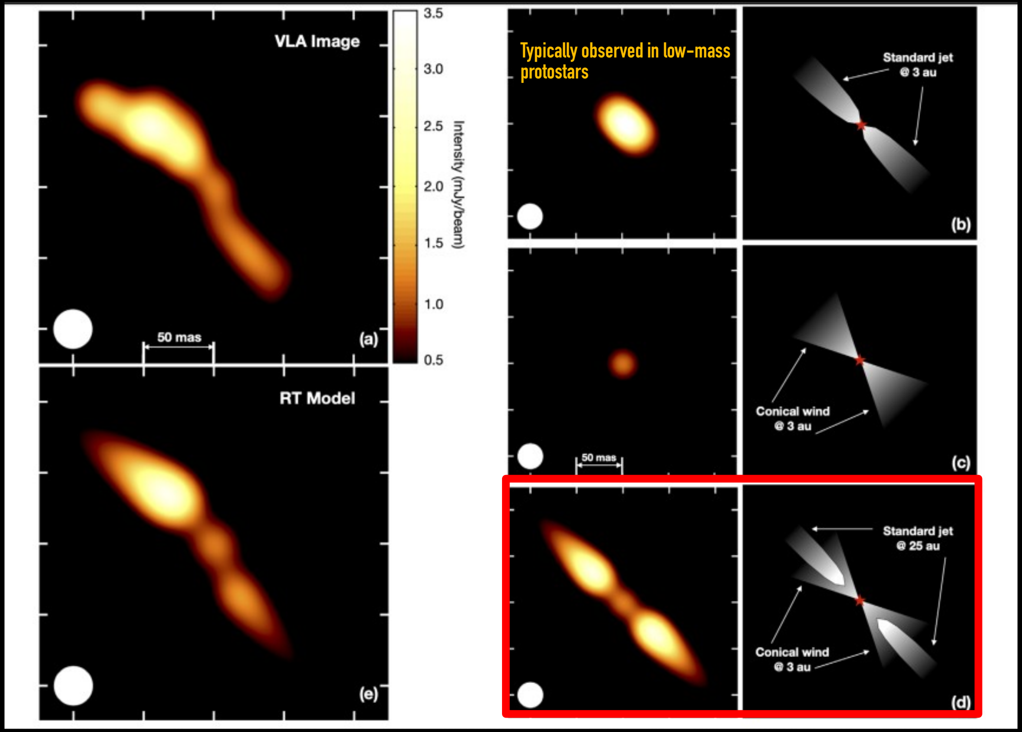
The two stationary elongated knots are tracing high density material at the base of the jet

The compact source would be tracing the most recently ejected gas by the protostar/disk system.

Cep A HW2

Radiative transfer models

To better understand the underlying physical structure traced by the 7.5 mm emission, we produced a number of radiative transfer models for several combinations of wind parameters



- Models were created with *sf3dmodels Package* (Izquierdo et al. 2018), based on Reynolds 1986 models.

- Synthetic continuum images (*RADMC-3D*, Dullemond et al. 2012)

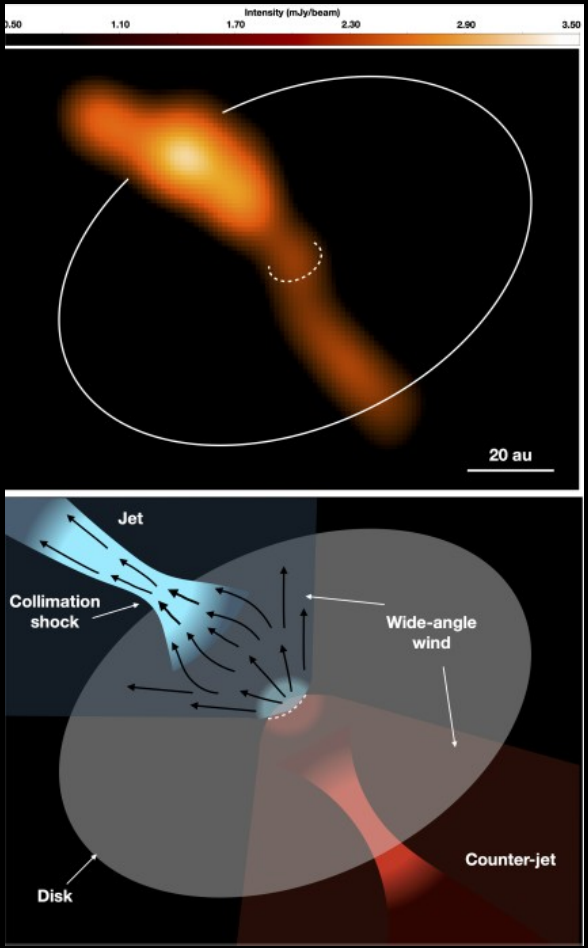
The standard collimated (isothermal, constant velocity, constant ionization fraction) jet does not reproduce the morphology observed

The central compact source is only reproduced with a wide-angled wind

In this case the electron density and ionization fraction would decrease much faster than in a collimated jet. Therefore, only the densest part at the very center of the flow can be detcted

The two elongated knots are reproduced by adding to the conical wind a standard collimated jet.

$\dot{M}$ approximately reproduces the maximum intensity seen for the northern knot.



Our results suggest that:

- The outflowing material is ejected very near the protostar over a wide angle (namely, a wind)

- and, farther away, it is collimated into a narrow stream (namely, a jet)

Serpens jet

The Astrophysical Journal Letters, 931:L26 (10pp), 2022 June 1 https://doi.org/10.3847/2041-8213/ac6fd1

Resolving the Collimation Zone of an Intermediate-mass Protostellar Jet

Adriana R. Rodríguez-Kamenetzky[1], Carlos Carrasco-González[1], Luis F. Rodríguez[1], Tom P. Ray[2], Alberto Sanna[3,4], Luca Moscadelli[5], Melvin Hoare[6], Roberto Galván-Madrid[1], Hsien Shang[7], Susana Lizano[1], Jochen Eislöffel[8], Jeremy Lim[9], José M. Torrelles[10,11], Paul Ho[7,12], and Anton Feeney-Johansson[13,14]

We studied the collimaiton zone with an unprecedented physical resolution of 15 au at 7mm.

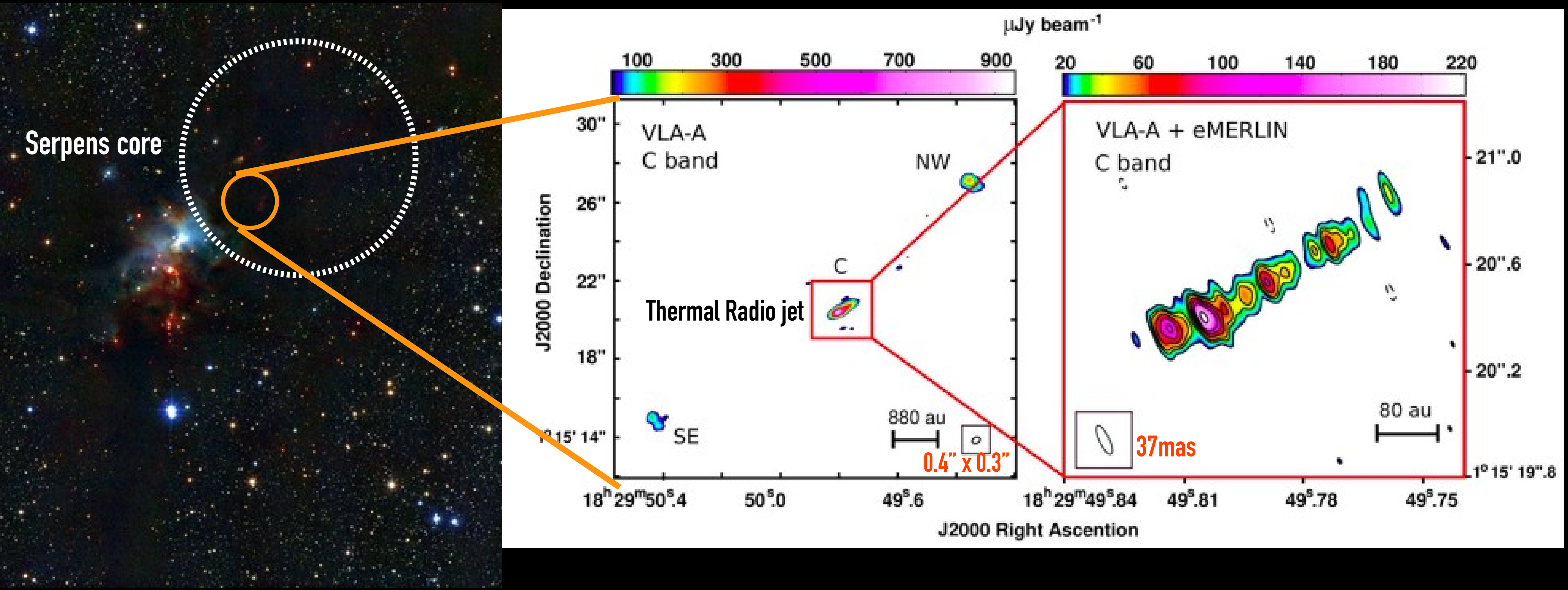
We detected a highly collimated ionized stream that would be launched from most internal regions of th disk, and a narrow (~28 au wide) ionized cavity

We propose the scenario in which both a highly collimated jet and a wide-angle wind coexist

Serpens jet

Driven by a deeply embedded Class 0 intermediat-mass (3 M_sun) protostar

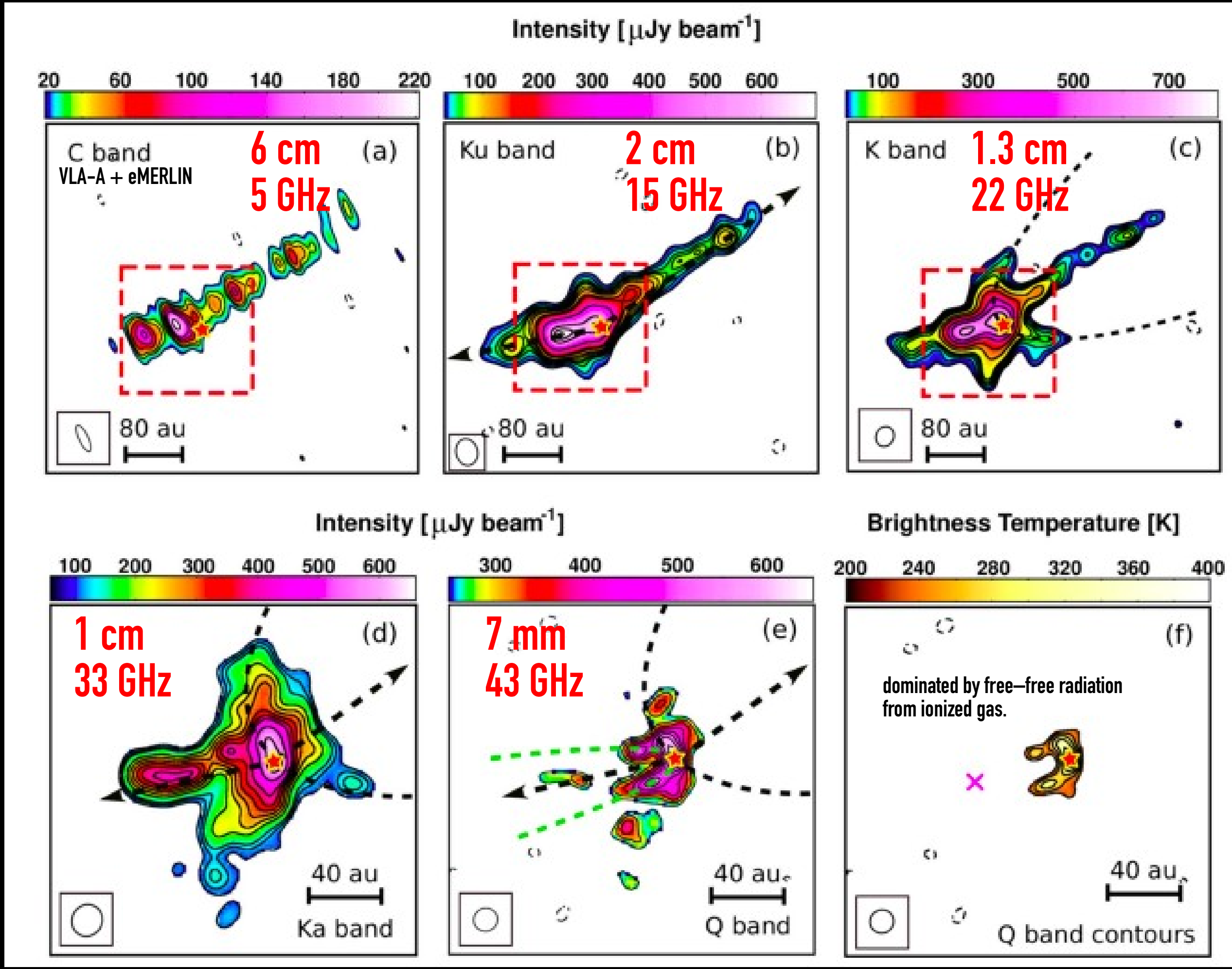
@436 pc



External shocks move at ~300 km/s and are synchrotron emiters (e.g.,Rodríguez-Kamenetzky et.al 2016)
It was found to harbor a massive disk (e.g., Hogerheijde et al. 1999; Enoch et al. 2009)
The estimated envelope mass is ~16 M_sun (Kristensen et al. 2012).

Serpens jet

Approaching the collimation zone



MULTIFREQUENCY OBSERVATIONS

1.3cm: Jet + cavity (see Hull et. al 2016)

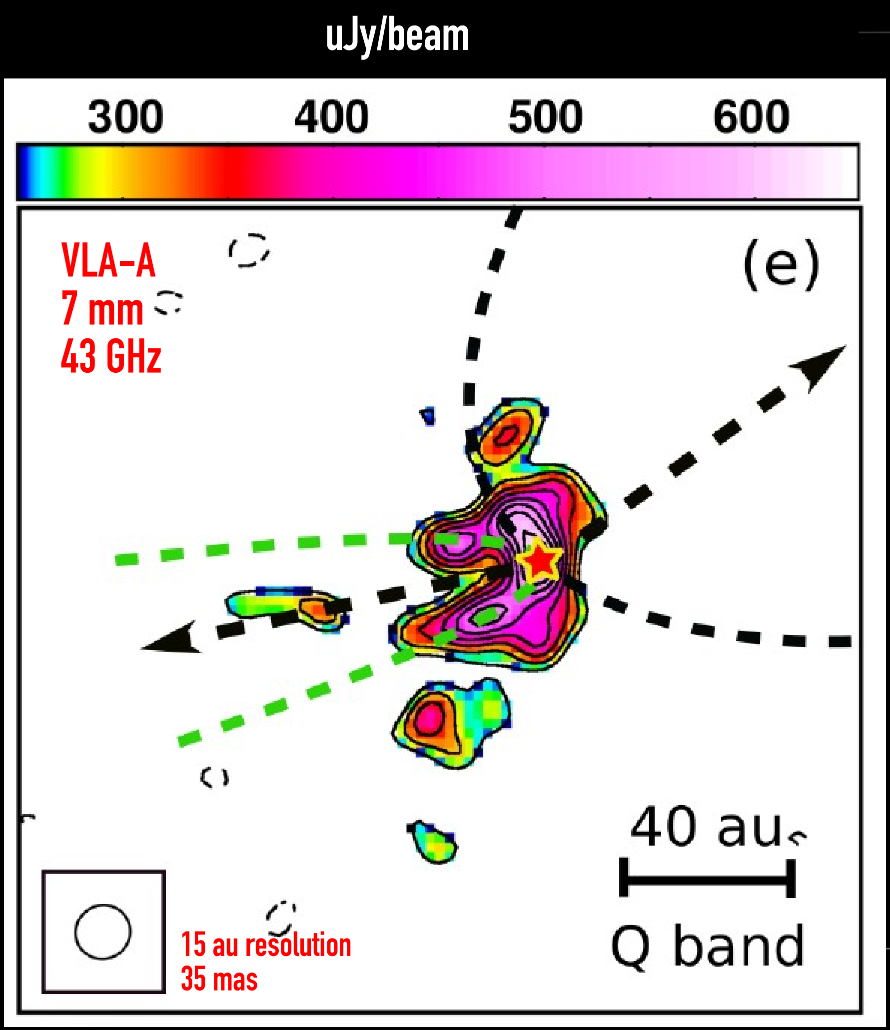
At higher frequencies, the contribution of free–free emission from the jet is much lower and only its most compact structures are detected:

1cm: extended component reminiscent of a disk+ jet

7mm: A highly collimatd stream at ~60au from the protostar + a narrow (~28 au wide) ionized cavity

The brightness temperature is very high compared to the brightness temperature that would be expected at 7mm for thermal emission from a dusty disk up to ~40 au from the protostar (e.g., Carrasco-González et al. 2019).

Serpens jet



According to our kinematic analisys, the jet would be launched from internal regions of the disk, and becomes visible where the first substantial ionizing shock occurs.

The narrow cavity could be excited by the interaction of either a wide-angled X-wind or a disk-wind with the toroid of infalling material from the envelope, as predicted by theoretical stydies (e.g., Shang et al. 2006, 2020)

Highly collimated jet + wide-angle wind

either launched by the X-wind or X-plus-disk-wind mechanism.

So far...

- We have detected YSO dominated by free-free emission from the jet at 7 mm, although a small contribution from disk emission would be expected.
- This is ideal to study two intimately related phenomena such as the jet and disk, at the same time
- We have started to approach the collimation zone at 7mm. This makes Band 1 a very interesting target.

ALMA + LLAMA Band 1

Some numbers

ALMA SPATIAL RESOLUTION

The resolution in arcsec can be approximated as:

$$\mathrm{FWHM}('') = 76/\mathrm{max\_baseline(Km)}\ /\mathrm{frequency(GHz)}$$

Considering a basline of 16 km (ALMA's most extended) at 40 GHz we get ~120 mas resolution

Considering ALMA+ LLAMA, with an approximate baseline of 180 km and at 40 GHz we get ~10 mas resolution

Thus, LLAMA would improve the angular resolution of ALMA by a factor 12 at 7mm

With VLA-A we achieved an angular resolution of 35 mas, so ALMA+LLAMA would also improve the resolution achieved by a factor ~3

ALMA + LLAMA

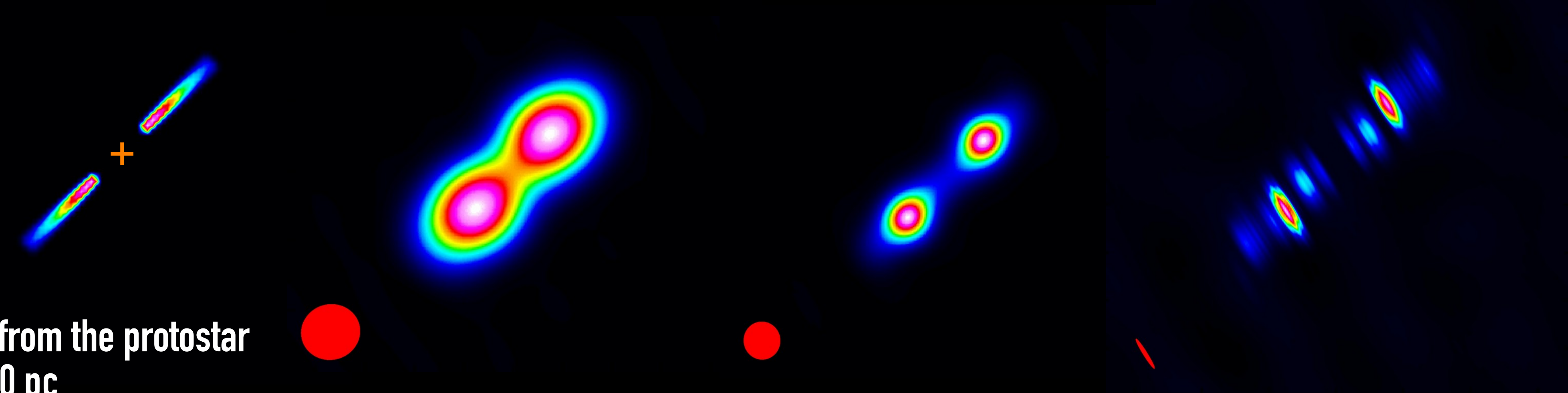
Illustrative simulations using the *Common Astronomy Software Applications package*

Jet model

ALMA Robust= 0
Resolution ~80 mas

ALMA+LLAMA Robust= 0
Resolution ~50 mas

ALMA+LLAMA Uniform
Resolution 37 mas x 4 mas



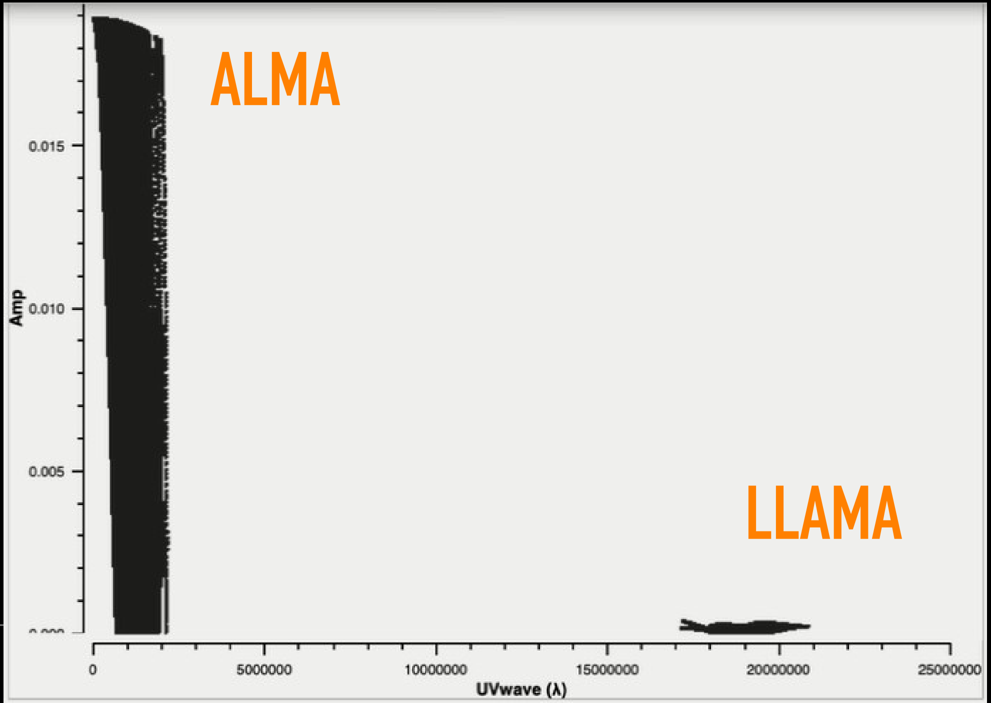
40 au from the protostar
At 1000 pc

artifact probably due to low coverage of the uv plane at high spatial frequencies
??

We need to start simulating observations to know the scope of the interferometer.

- In the interfrometric future of ALMA+LLAMA it would be possible study jet collimation in southern protostellar jets at BAND 1

- Moreover, points in the uv-plane provided by the interference with LLAMA could be useful to constrain disk models in the uv-plane.



THANK YOU