Morphology and kinematics of the gas envelope of Mira Ceti

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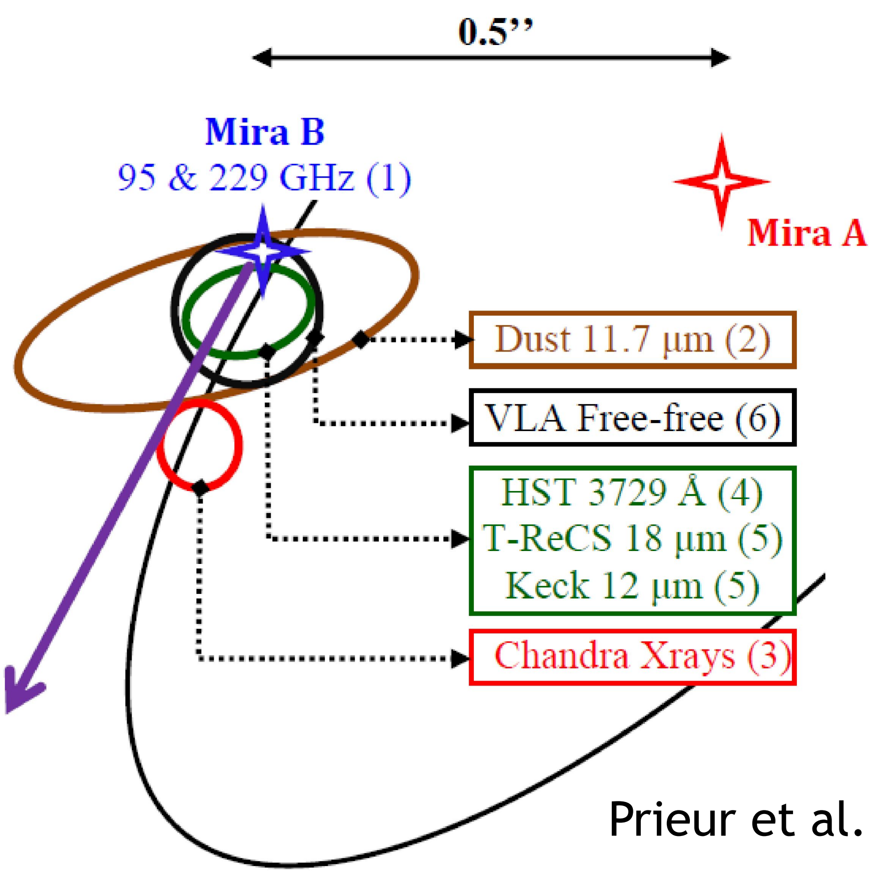
Mira Ceti is one of the most studied binary stars.

Mira A, is a long period variable, displaying Tc in its spectrum. It is an M type, oxygen rich star with a mass loss rate ~10^{-7} $M_{\odot}$/yr.

Mira B, is probably a white dwarf with T~10^4 K, at a projected distance on the plane of the sky of ~ 0.5" from Mira A. The orbital period is of at least 500 yr.

Mira B is known to accrete matter from Mira A, with a connection between the two stars having been observed in multiwavelength.



Prieur et al. 2002

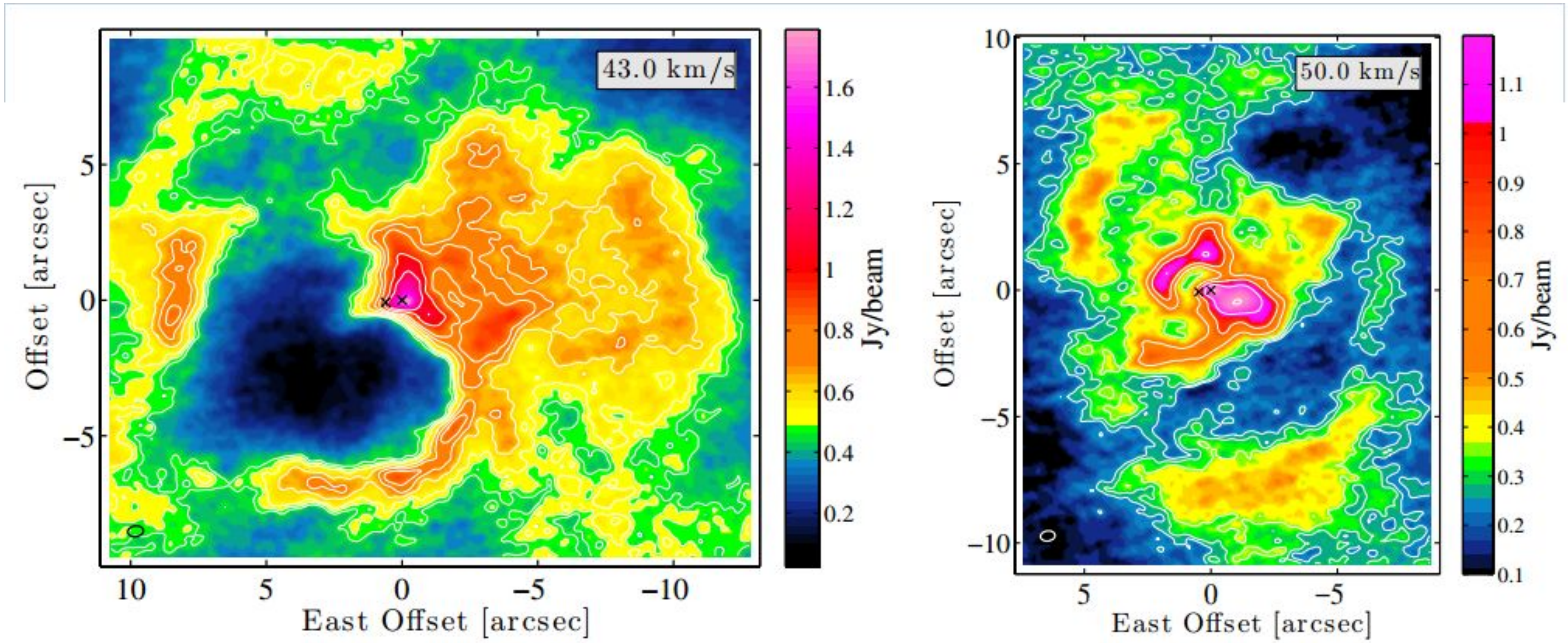
References:

1. Ramstedt et al. 2014;
   Vlemmings et al. 2015,
2. Marengo et al. 2001,
3 &4. Karovska et al. 2005,
5. Ireland et al. 2007,
6. Matthews & Karovska 2006.

The short distance environment of Mira A+B has been observed using the ALMA.

The $^{12}CO(3-2)$ line emission has been mapped with an spatial resolution of ~0.5" up to a distance of ~10" from the central star by ***Ramstedt et al. (2014)***.

The map reveals the presence of a bubble and of a complex pattern of arcs. The authors suggest an interpretation in terms of Mira A's slow wind filling its Roche lobe and being accreted by Mira B in the orbital plane.



In the present work we analyse other ALMA observations that offer a slightly better resolution.

The better spatial resolution of the data makes it possible for us to study the short distance environment of the binary in considerably more detail.

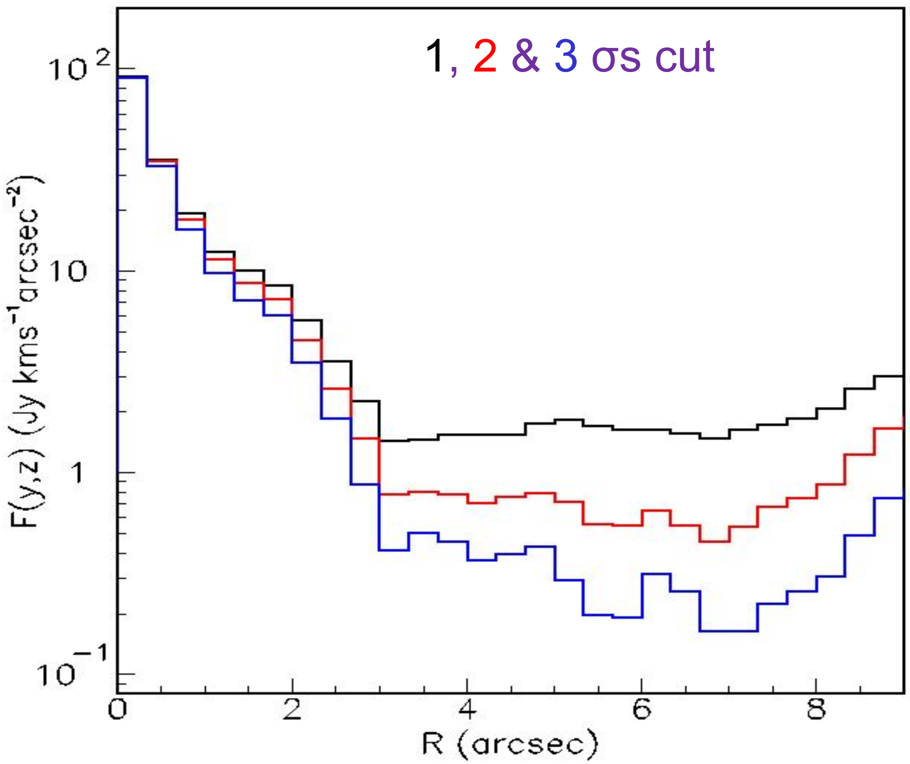
Observation

Using archived data in open access ADS/JAO.ALMA/2013.1.00047.S

CO(3–2) line; observed between 2014 June 12 & 15, including 34-36 antennas, maximal baseline of 650 km; Total time on source ~11 min.

Beam of 0.325×0.309 $arcsec^2$ (FWHM) at position angle of 83.2°; pixel sizes of 0.06×0.06 $arcsec^2$.

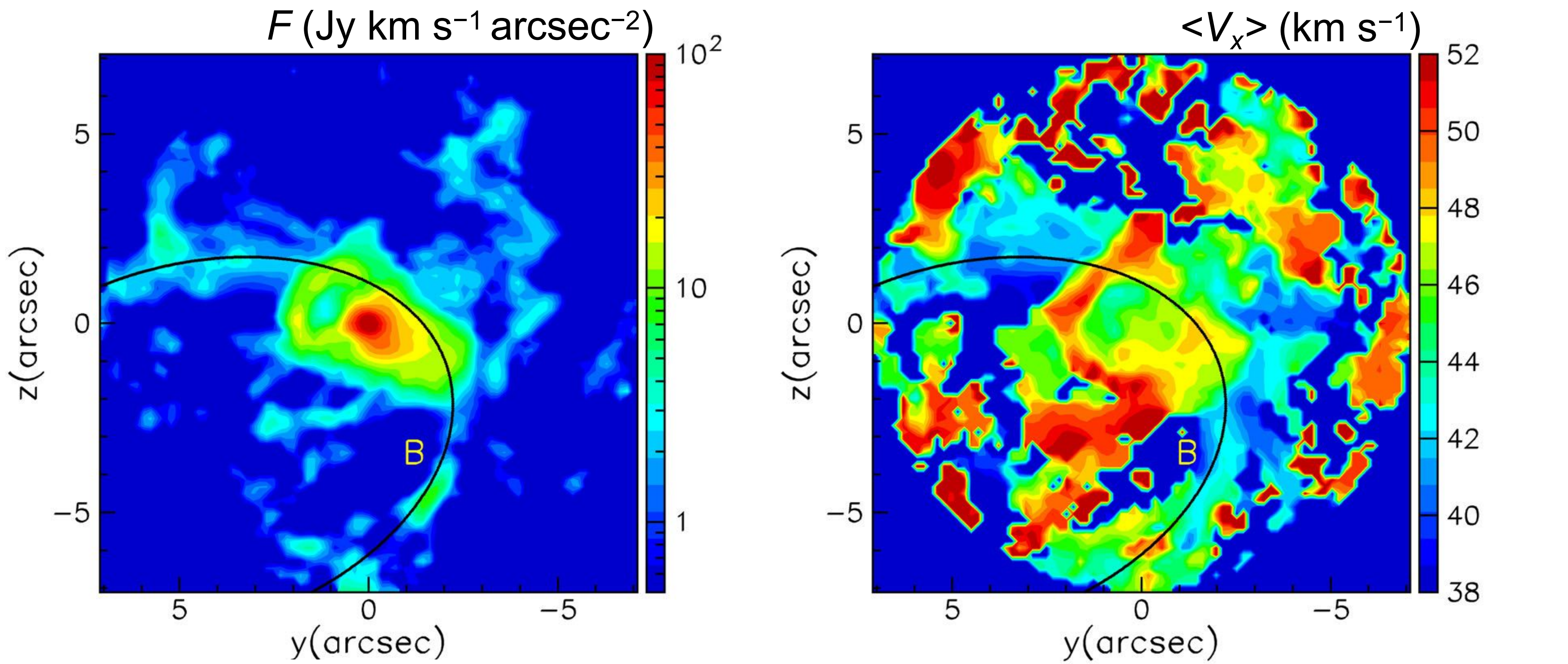
Doppler velocity spectrum: from 25 to 65 km s^{-1} , in channels of 0.4 km s^{-1}.

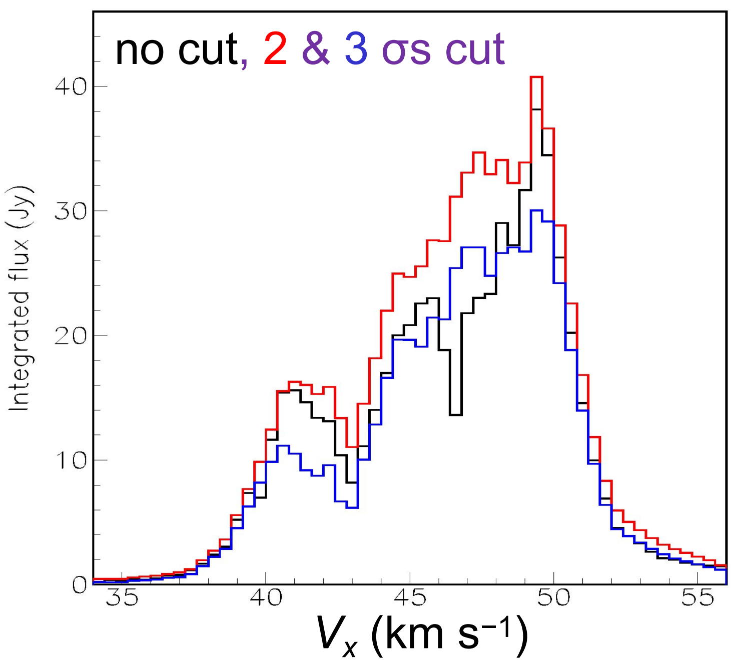


We restrict the analysis to pixels having R<7" in order to be free of problems related with the lack of large distance coverage.

In practice, most of the results are confined to the interior of a circle of radius R=3".

Mophology and kinematics of the circumbinary envelope: an overview





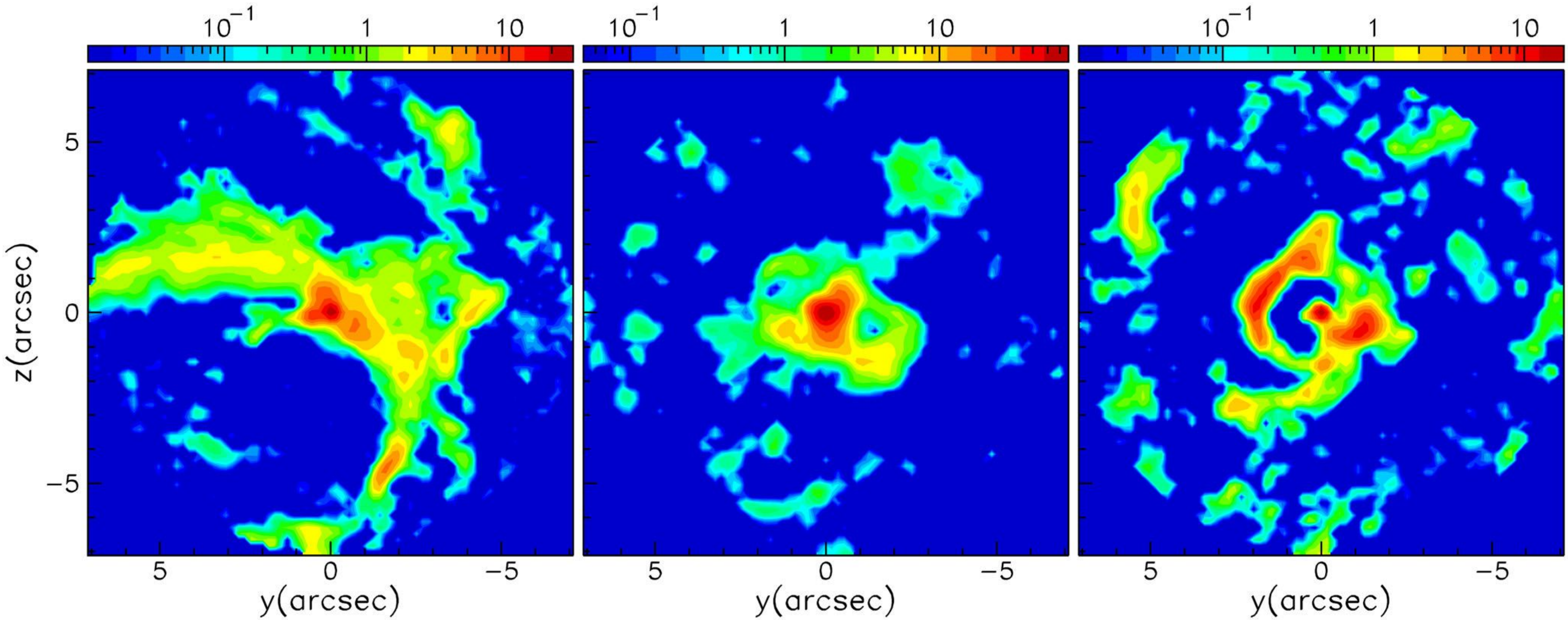
A distinctive feature is the existence of regions separated by several arcsec but sharing similar Doppler velocities.

The velocity distribution: several peaks giving evidence for distinct families of sources, making it easier to cope with the complexity of the observed patterns.

blueshifted region, $34 - 44 \text{ km s}^{-1}$

central velocities $44 - 50 \text{ km s}^{-1}$

redshifted region, $50 - 56 \text{ km s}^{-1}$

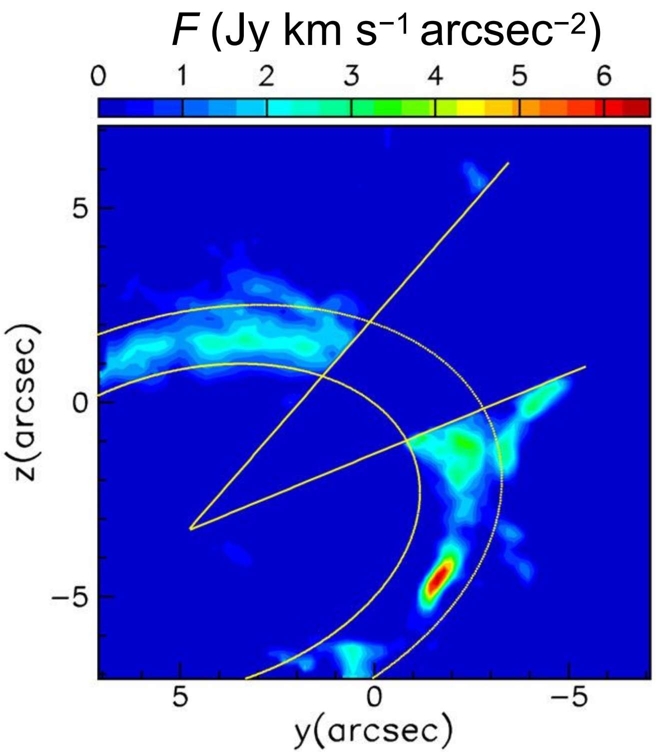


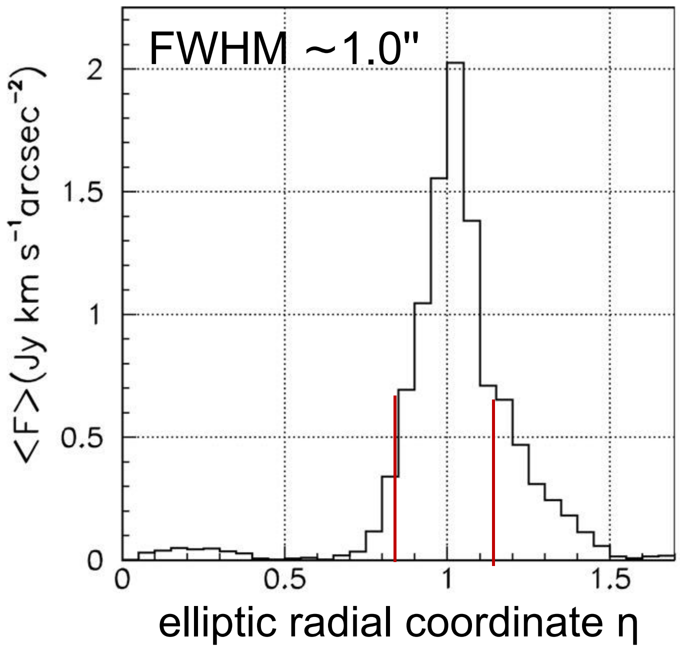
The three velocity intervals are not perfectly separated, which complicates the analysis in the overlap regions.

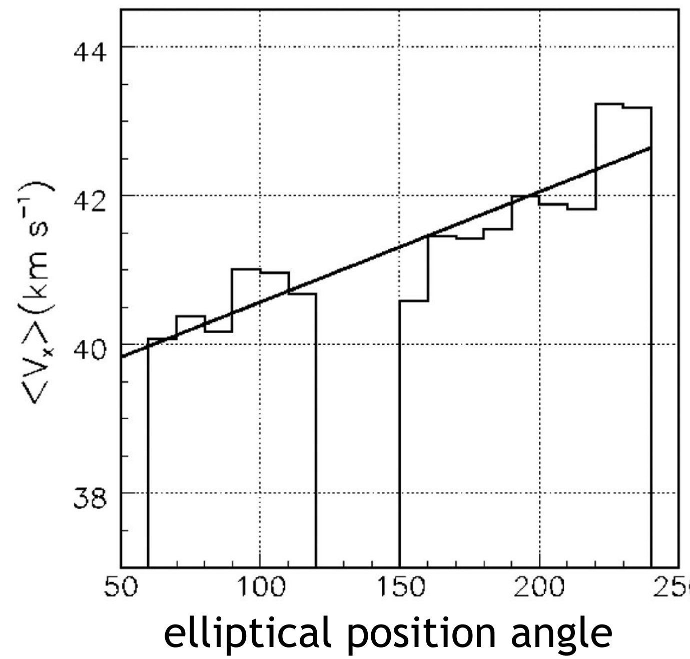
We shall aim at giving as objective as possible a description of what has been observed, without relying on a priori preconceptions.

The blueshifted south-eastern bubble

$34 < V < 44$ km s^{-1}







The bubble region sticks out very clearly.

The inner edge is sharper than the outer edge (opposite is expected from a bubble).

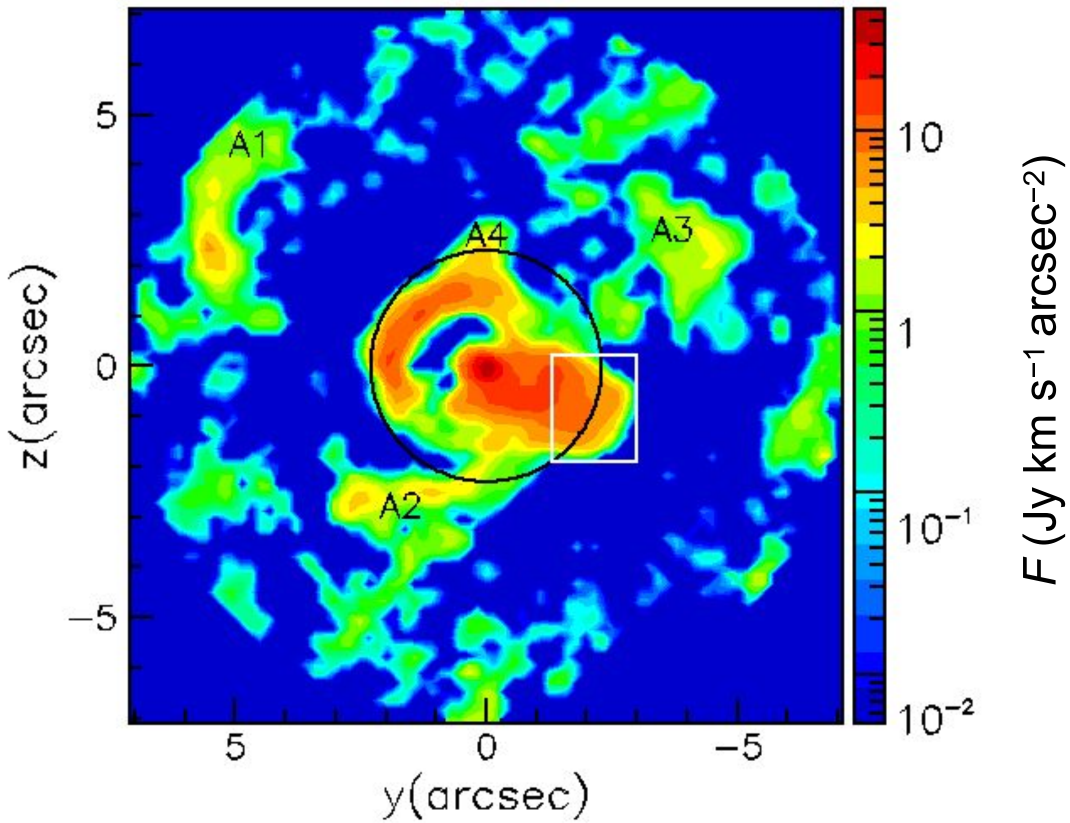
In the arc region, the velocity increases from ~40 (NE) to ~42.5 km s^{-1} (SW).

If the ellipse is interpreted as the projection of a circular ring in space, its angle with the sky plane is ~50^{o}. If the ring is expanding radially at constant velocity, V~ 1.3 km s^{-1} on the line of sight, ~1.7 km s^{-1} in space -->

To span 7.2" (~720 au), it takes ~2000 yr

Redshifted arcs

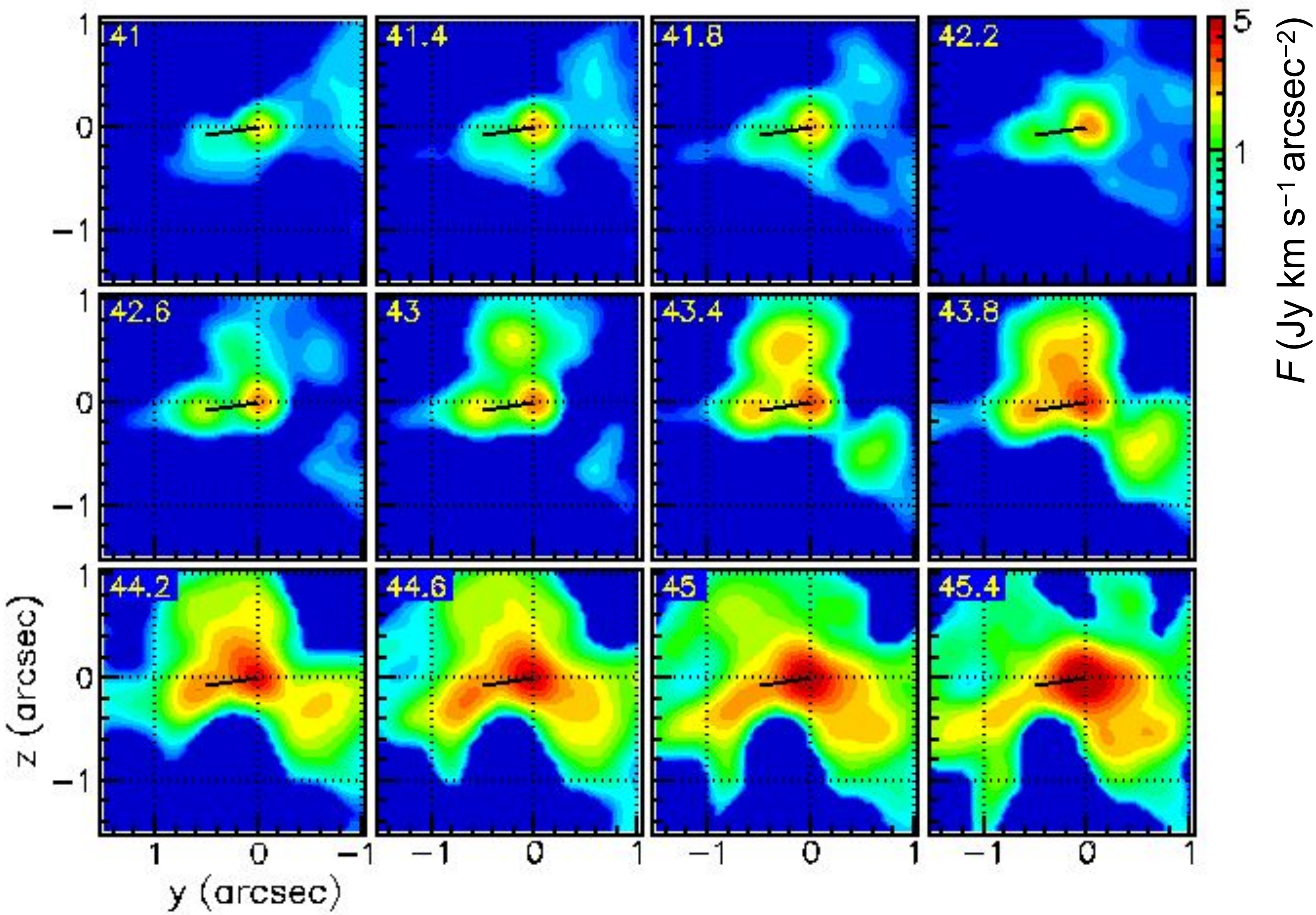
V > 48 km s^{-1}



We have considered various possible associations of these sources (spiral arms, large circles or ellipses), but unable to unravel them from the present data.

The data used by Ramstedt et al. (2014), having a better coverage at large distances, are more suitable for this purpose.

The close environment of the Mira A+B pair



The gas flow emitted by Mira A in a solid angle facing Mira B concentrates towards Mira B very much as predicted by ***Mohamed & Podsiadlowski (2012)*** in the framework of their WRLOF picture.

At larger scale

a radius of 3" around Mira A

Two outflows in the north-eastern and south-western hemispheres

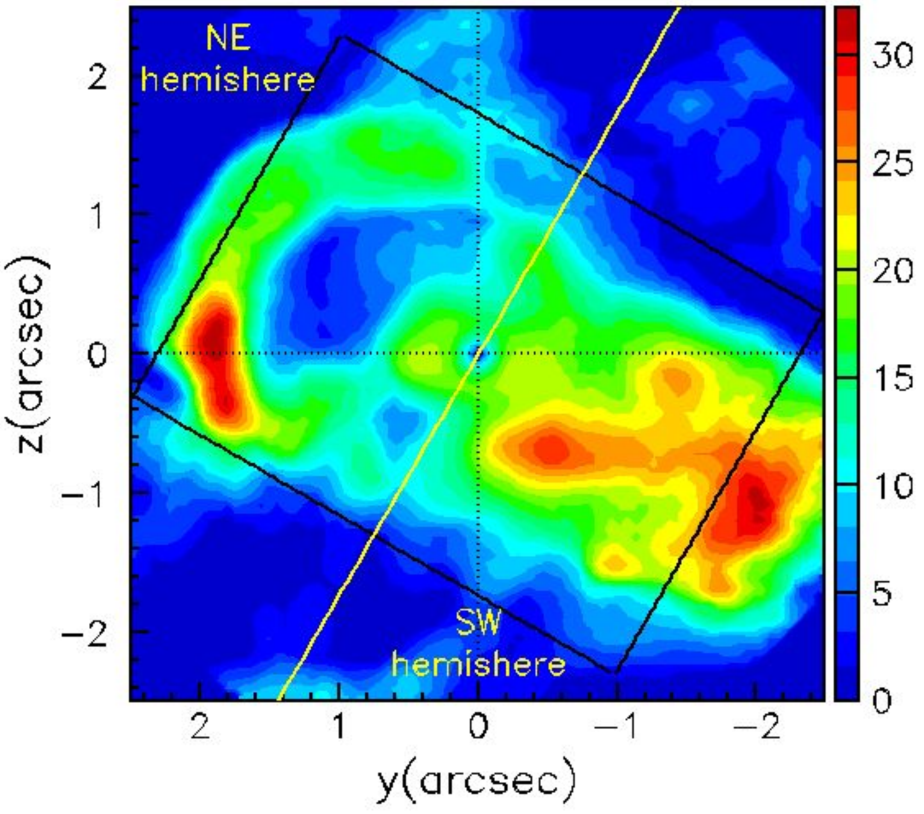
At short distances, up to ~1.5":
very different morphologies

SW outflow: broad solid angle, expands radially at a rate ~5 to 10 km s^{-1} and slightly redshifted.

The NE outflow: two arms, with a separation of ~90∘ on the sky plane, both blueshifted, bracketing a broad dark region.

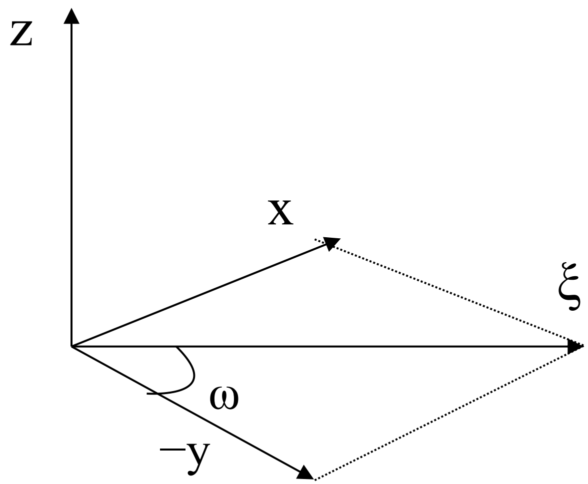
At larger distances, ~1.5 to 2.5":
the asymmetry between the two hemispheres is significantly smaller and both display evidence for detached arcs

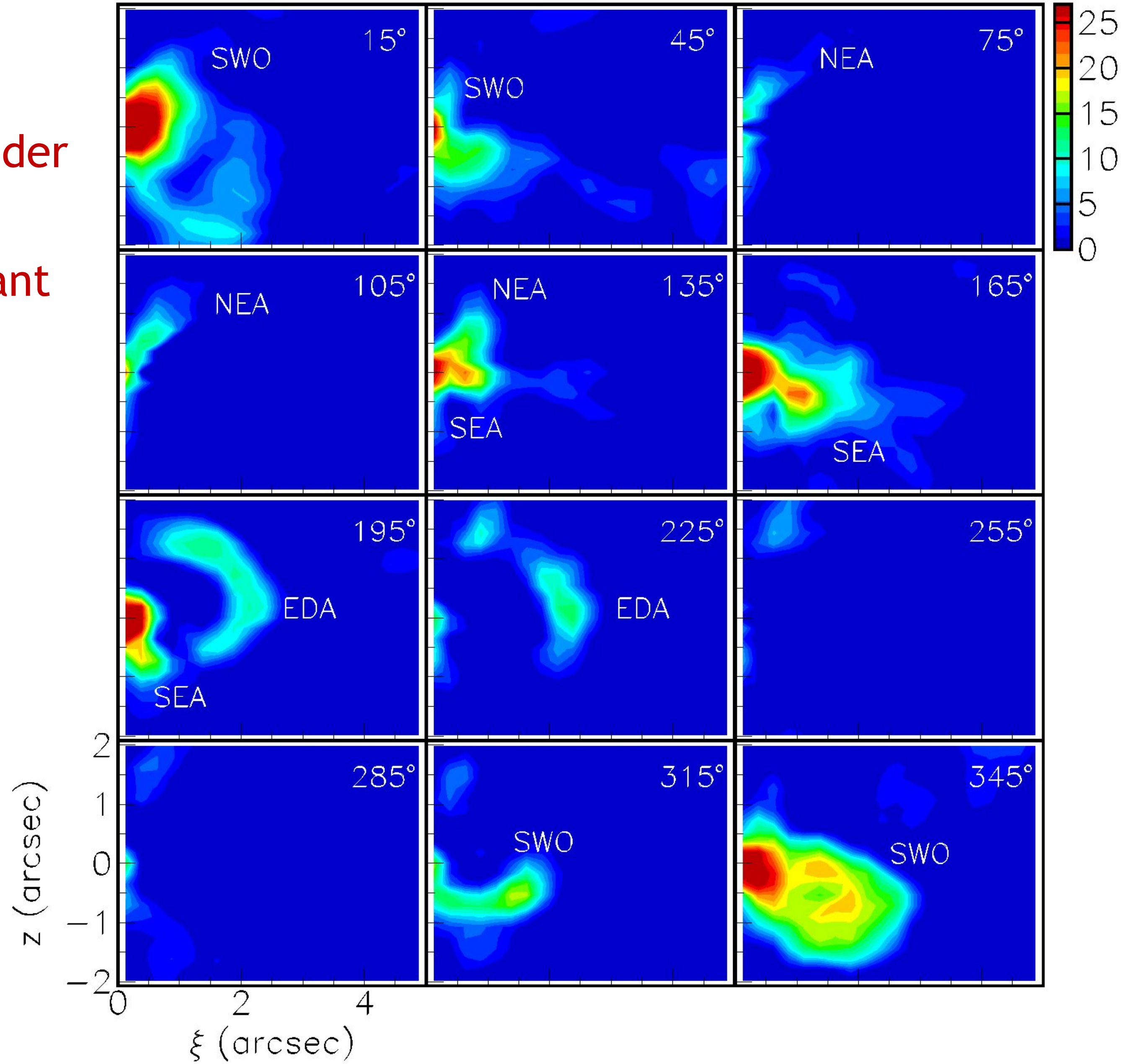
$F \times R$ (Jy km s^{-1} $arcsec^{-1}$)



$42 < V < 53$ km s^{-1}

Effective emissivity is reconstructed in space under the assumption of a pure radial expansion at constant velocity of 7 km s^{-1}.





The model may have nothing to do with reality, but it provides a useful visualization of the morphology, in particular of its topology.

Summary

- description of the morphology and kinematics of the gas envelope of Mira Ceti using high spatial resolution observations of CO(3–2) emission made by ALMA.

- The observed Doppler velocity distribution is made of three components:

a blueshifted south-eastern arc, described as a ring in slow radial expansion, born some 2000 years ago;

a few redshifted arcs, all sharing velocities by ~ 3±2 km s^{-1} with respect to the main star;

a central region dominated by the circumbinary envelope, displaying two outflows in the south-western and north-eastern hemispheres.

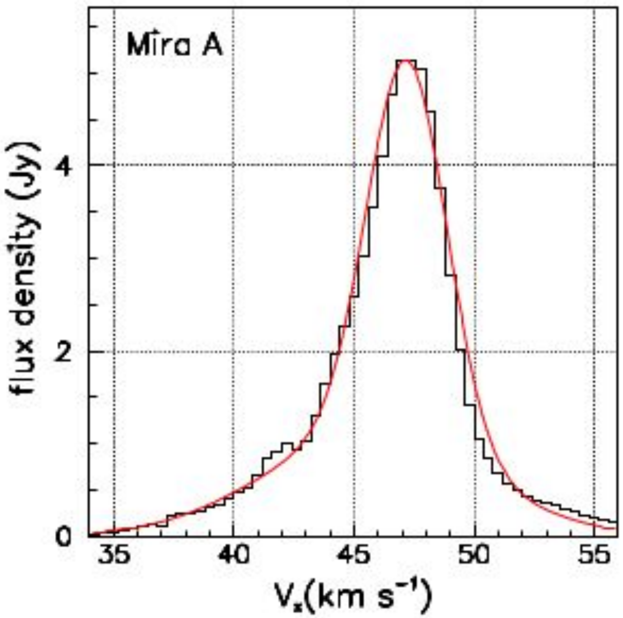
- Close to the stars, we observe a mass of gas surrounding Mira B, and having Doppler velocities with respect to Mira B reaching ±1.5 km s^{-1} , which interpreted as gas flowing from Mira A towards Mira B.

- The present work is emphasised on giving as simple and yet as reliable a picture of what has been observed, with the aim of helping with the conception of models that would allow for a deeper understanding of the physics at play.

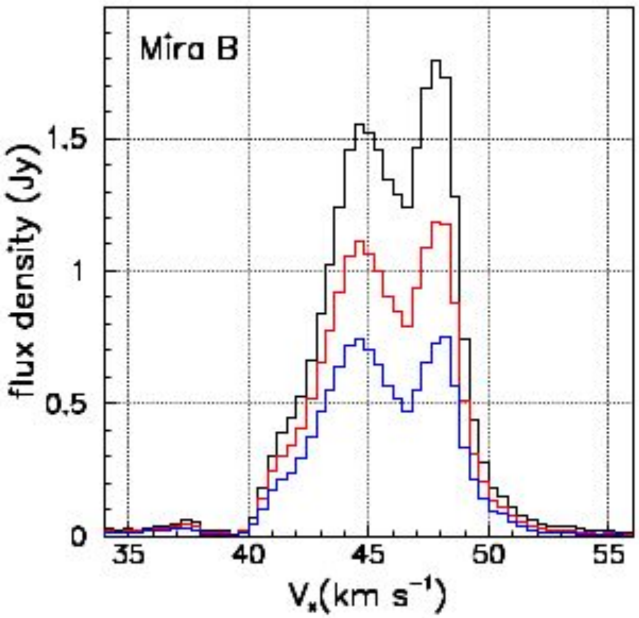
ACKNOWLEDGEMENTS

We are indebted and very grateful to the ALMA partnership, who are making their data available to the public after a one year period of exclusive property, an initiative that means invaluable support and encouragement for Vietnamese astrophysics.

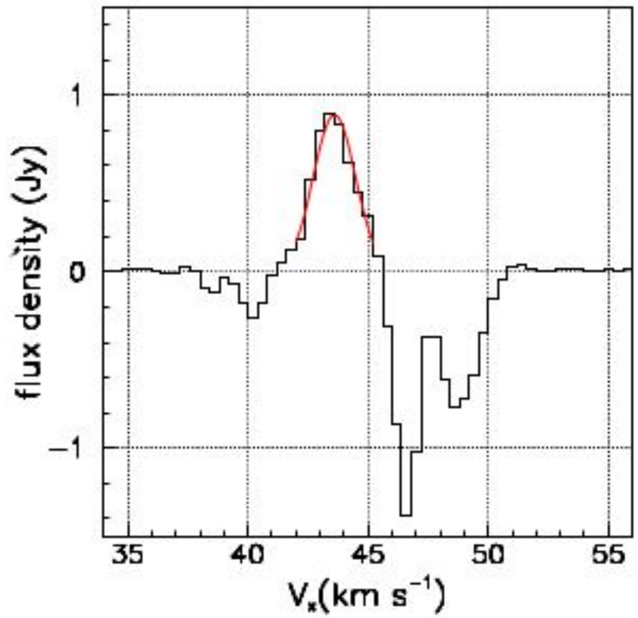
We particularly acknowledge friendly support from the staff of the ALMA Helpdesk.



Velocity distribution integrated in a circle of radius 0.3" centred on Mira A. The fit is the sum of two Gaussians, centred at 47.2 km s^{-1} and centred at 45.7 km s^{-1}



Velocity distributions integrated in circles of radius 0.20 (blue), 0.25 (red) and 0.3" (black) centred on Mira B.



Difference between the velocity distributions integrated in circles of radius 0.3" and centred on Mira B and on the symmetric of Mira B with respect to Mira A.

PV diagram in a circle centred on Mira A for distances to Mira A between 0.5 and 2.5".