

# $C^{18}O(2-1)$ emission from L1527 observed by ALMA

*(uses archived data in open access  
ADS/JAO.ALMA=2012.1.00647.S;  
Better resolution than published earlier:  
beam is  $0.6 \times 0.5$  arcsec<sup>2</sup> FWHM)*

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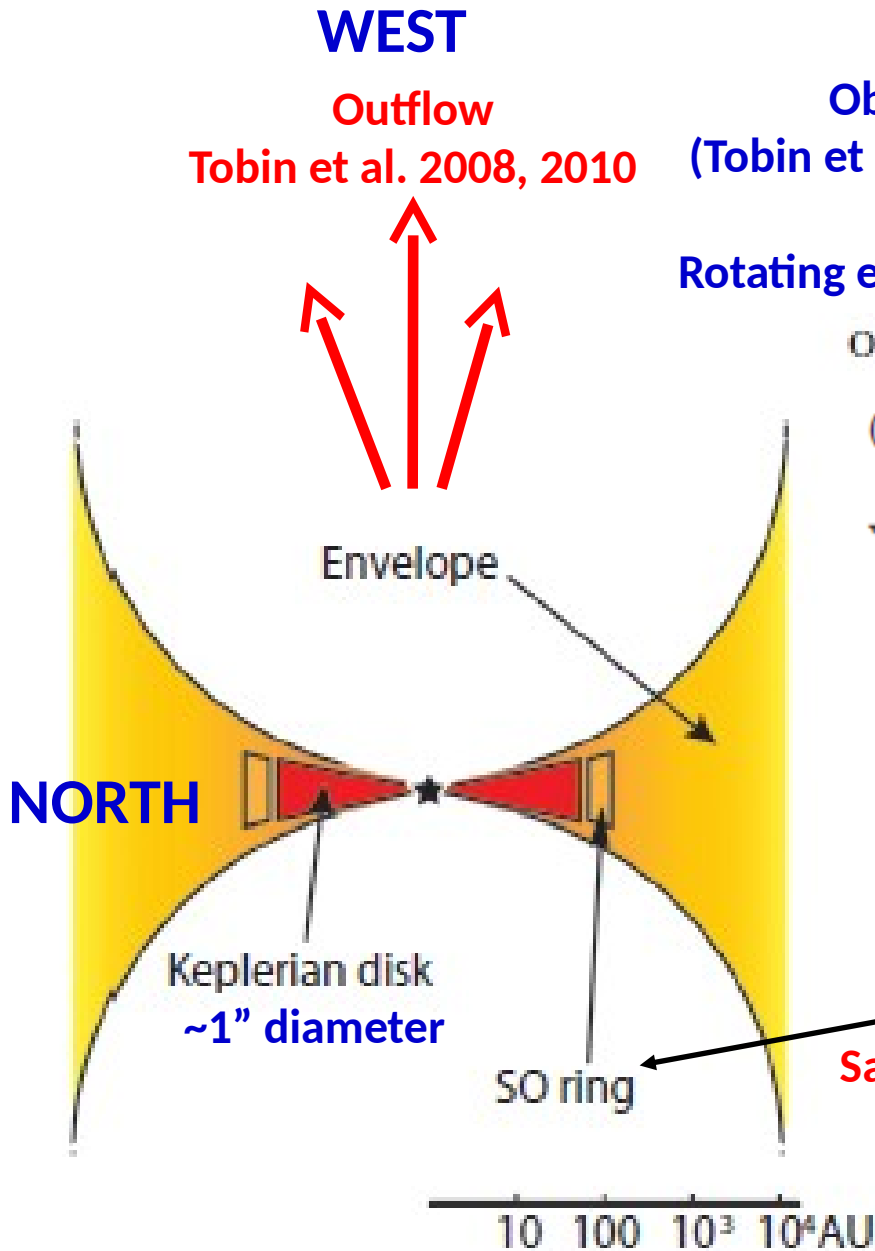
# L1527 IRS

Class 0 protostar at ~140 pc

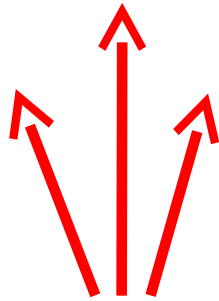
Observed in dust and gas by many authors

(Tobin et al. 2012,2013, Segura-Cox et al. 2015, Davidson et al. 2014, etc.)

Rotating envelope, ~1 solar mass, nearly perpendicular to east-west axis



**WEST**  
**Outflow**  
Tobin et al. 2008, 2010



Envelope

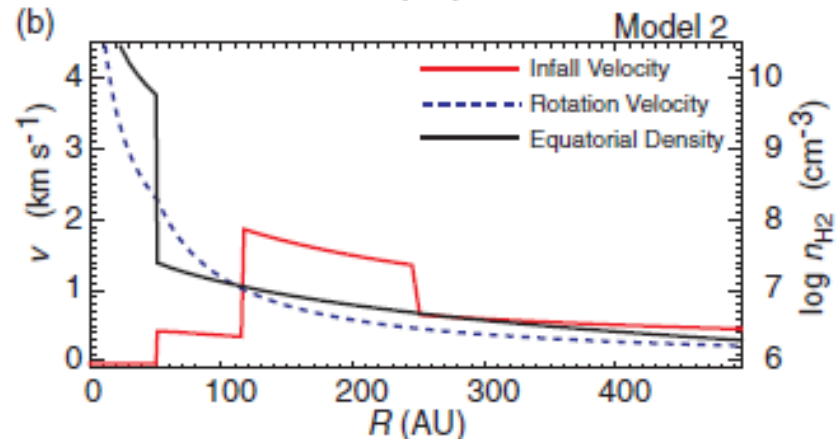
**NORTH**

Keplerian disk  
~1" diameter

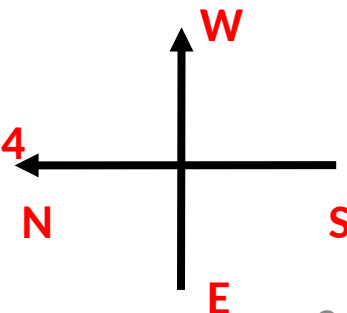
SO ring

10 100 10<sup>3</sup> 10<sup>4</sup>AU

OHASHI ET AL.



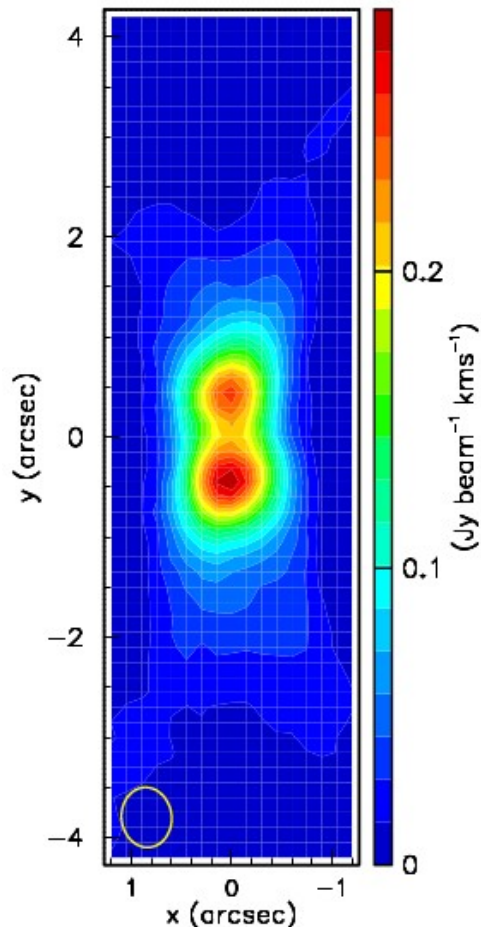
Recent important result :  
R-dependent chemistry  
Sakai et al. 2014, Ohashi et al. 2014



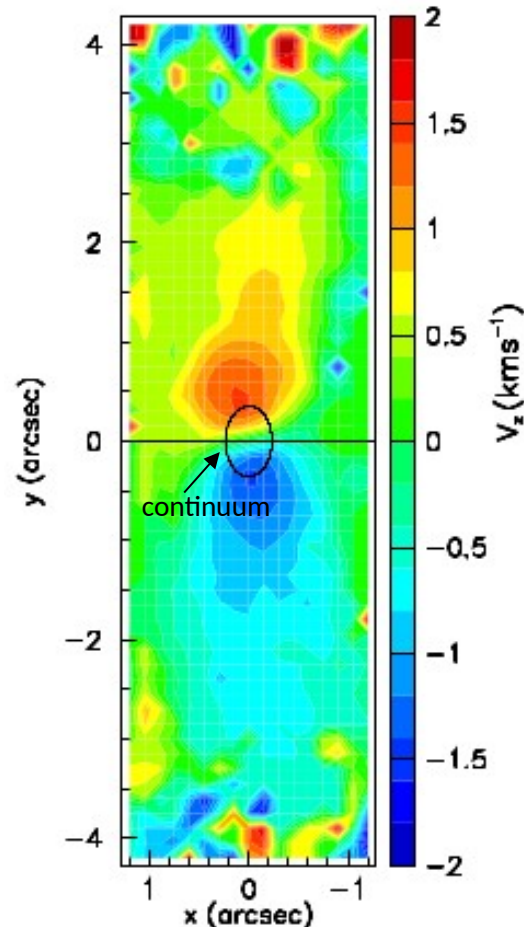
Figures are from Ohashi et al. 2014

# Evidence for typical rotating disc morpho-kinematics with a strong and ubiquitous absorption slightly red shifted with respect to systemic velocity

Integrated  
flux

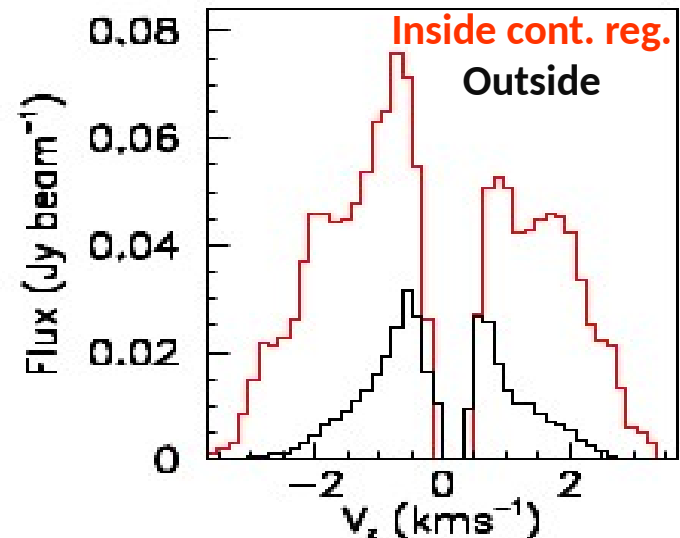


Doppler  
velocity



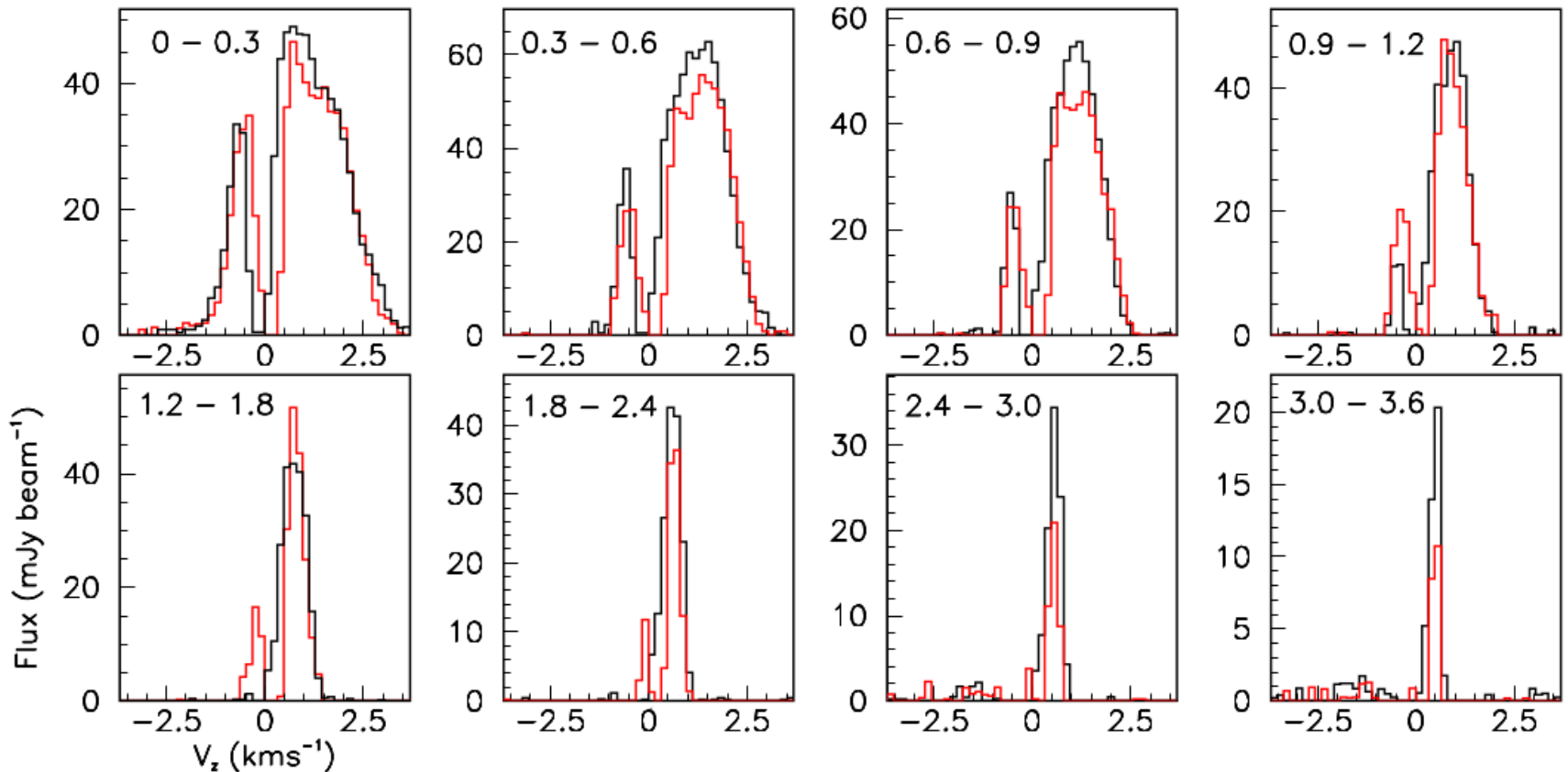
The Doppler velocity spectrum is split in two by a central dip seen both inside and outside the continuum region:

Absorption cannot be exclusively blamed on the continuum, important contribution of extended foreground gas is to be expected.



Our approach is to **ignore the data in the absorption region** rather than attempting a description of their morpho-kinematics. We use a model that assumes **rotation symmetry about the disc axis and symmetry about its median plane.**

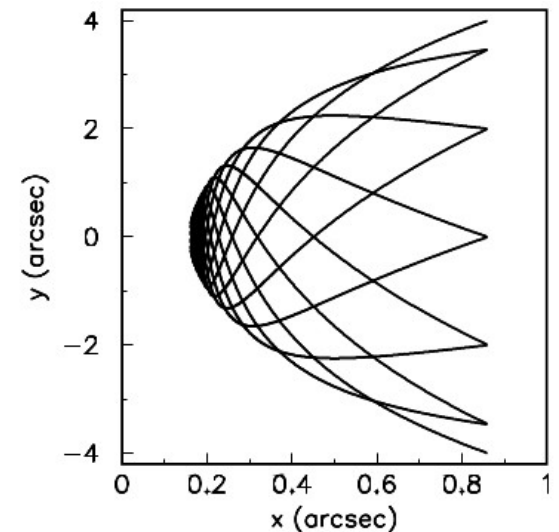
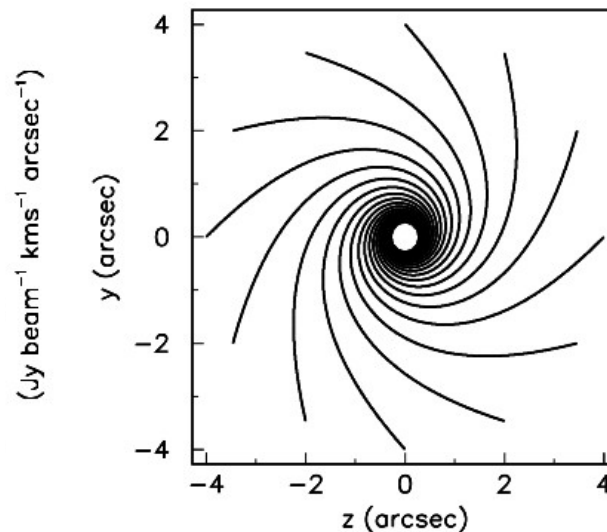
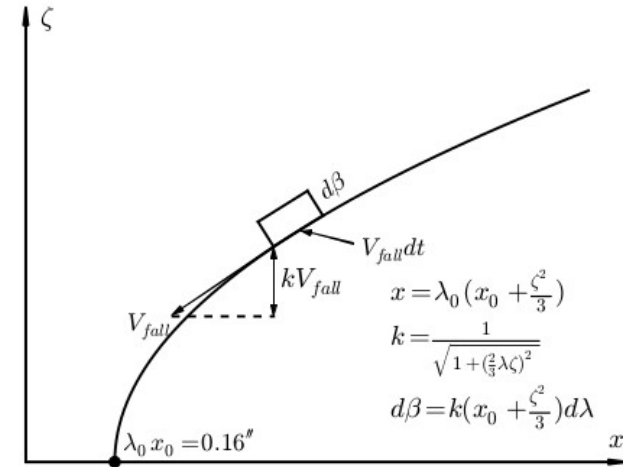
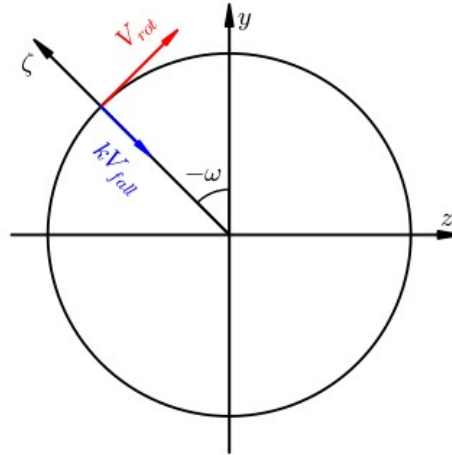
As a result the number of lost velocity bins is reduced from four to two by retaining the blue-shifted part of the direct spectra and the red-shifted part of the reflected spectra (with respect to x axis).

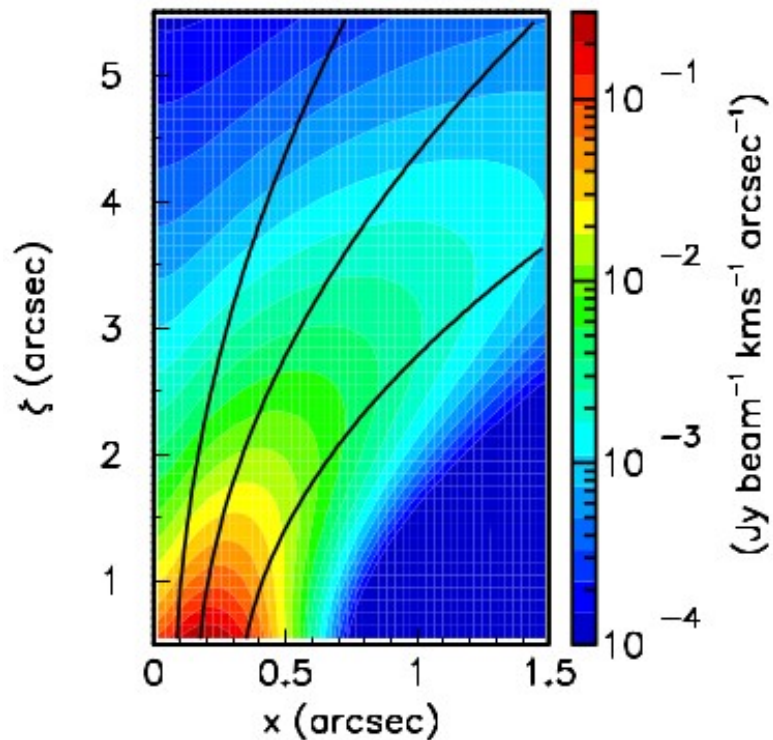


We do not fit the density and temperature distributions separately but absorb them in a single effective emissivity  $\rho(x, y, z)$ , defined such that:  $F(x, y) = \int \rho(x, y, z) dz = \int f(x, y, V_z) dV_z$

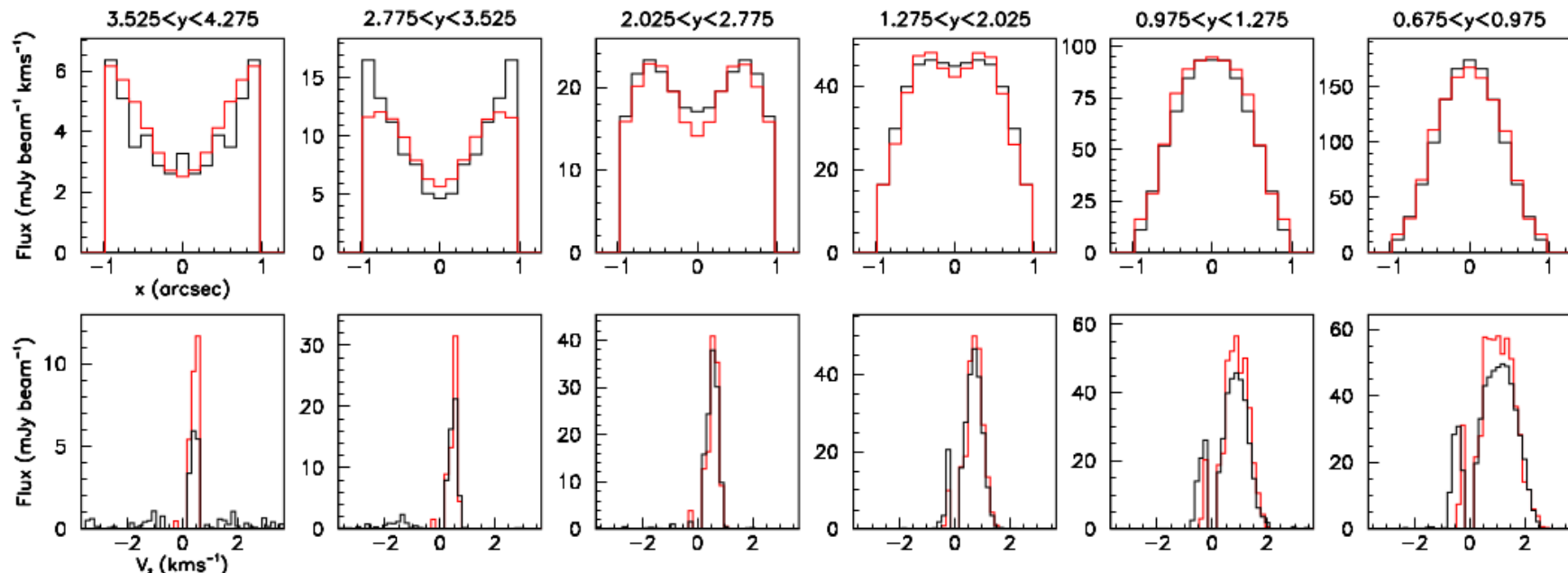
We model the trajectories of the gas molecules as spiralling on paraboloids of equation  $x = \lambda(x_0 + \zeta^2/3'')$  with  $\zeta = (y^2 + z^2)^{1/2}$

The velocity is parameterized as the sum of a component  $V_{rot}$  perpendicular to the  $(\zeta$  vs  $x)$  plane and a velocity  $V_{fall}$  tangent to the parabola in the  $(\zeta$  vs  $x)$  plane.

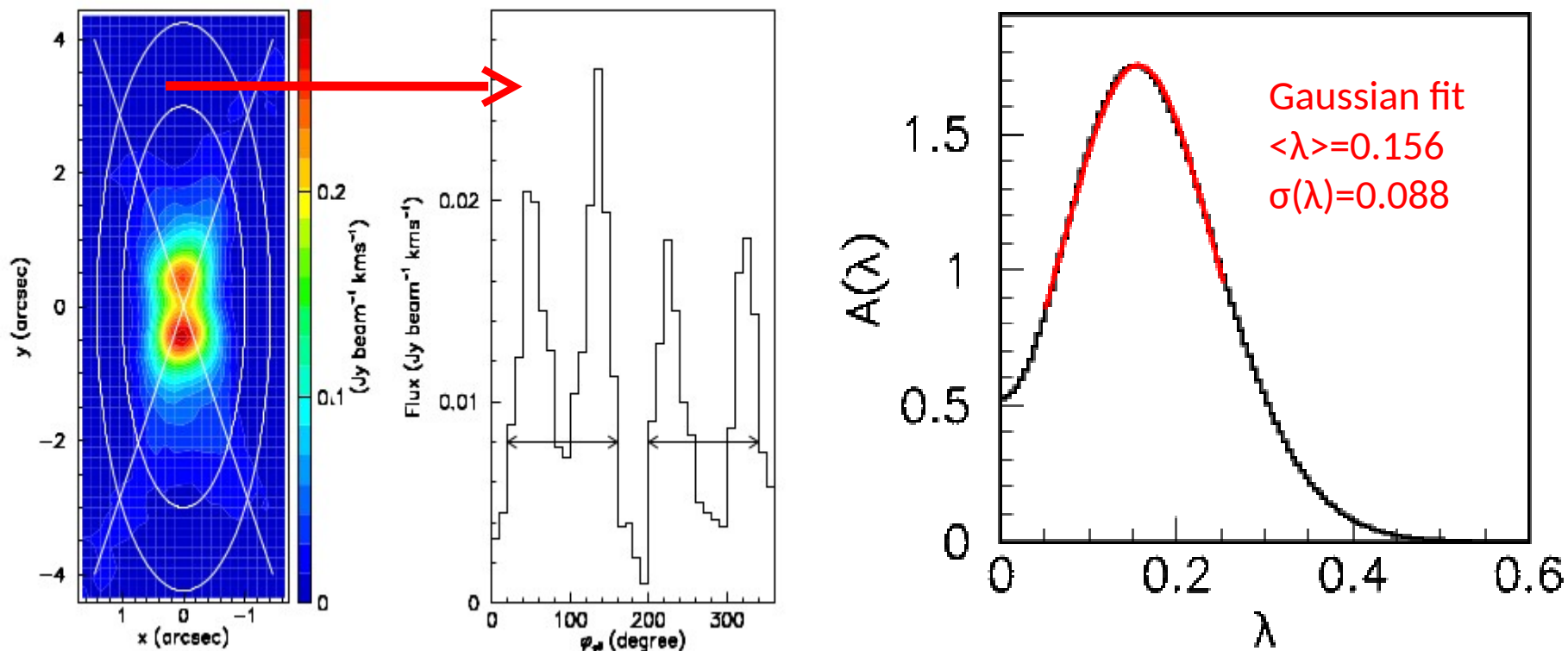




Fits are limited to  $|y| > 80$  au,  $|x| < 140$  au and exclude velocity bins between 0 and 0.32 km/s. Both effective emissivity and velocity are reconstructed in space. Good fits are obtained.

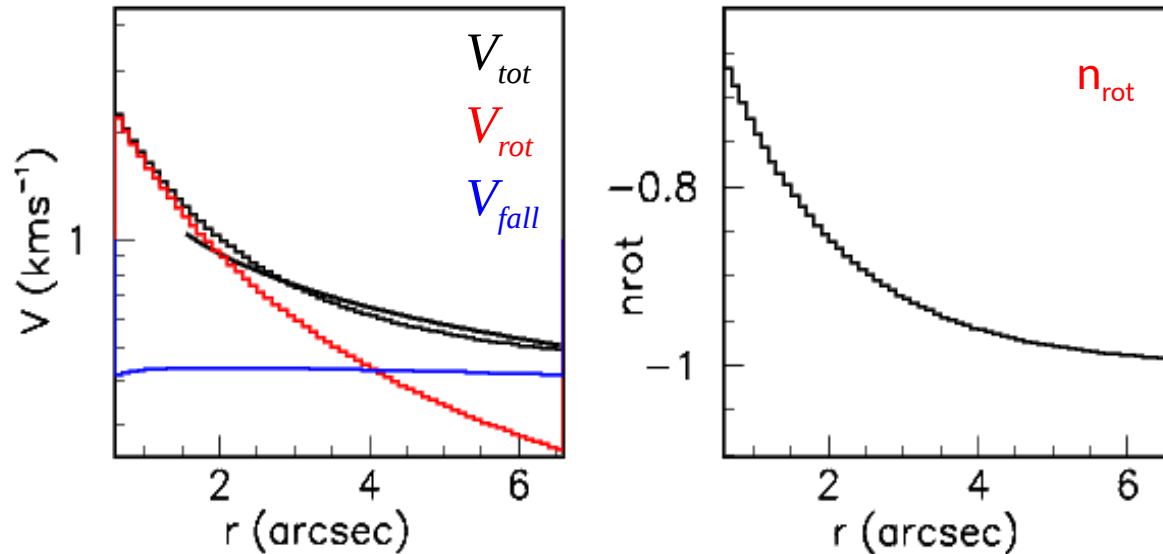


# Angular dependence of the in-falling flux



Direct evidence for an X-shaped in-falling flux (meaning a depression along the disc axis [outflow] and a depression in the neighbourhood of the disc plane), is described by the model as a dependence of the flux on  $\lambda$ , the parameter that labels paraboloids. Disc plane depression is probably due to CO molecules freezing out on cold dust grains.

# KINEMATICS



Rotation dominates:  $V_{rot} = V_{rot0} r^{n_{rot}}$ ,  $V_{rot0} = 1.66 \pm 0.08 \text{ km/s}$ .

Strong evidence for  $n_{rot}$  to decrease with  $r$  but precise shape poorly constrained. Cut in  $y$  prevents observation of Keplerian disc.

In-fall velocity  $V_{fall} \sim 0.43 \pm 0.10 \text{ kms}^{-1}$  over the explored range, smaller than free-fall velocity, with no evidence for a significant  $r$ -dependence, in particular no evidence for the sudden jump to  $\sim 1.5 \text{ kms}^{-1}$  required by Ohashi et al. to describe the absorption-dominated central region



# CENTRAL MASS AND ACCRETION RATE

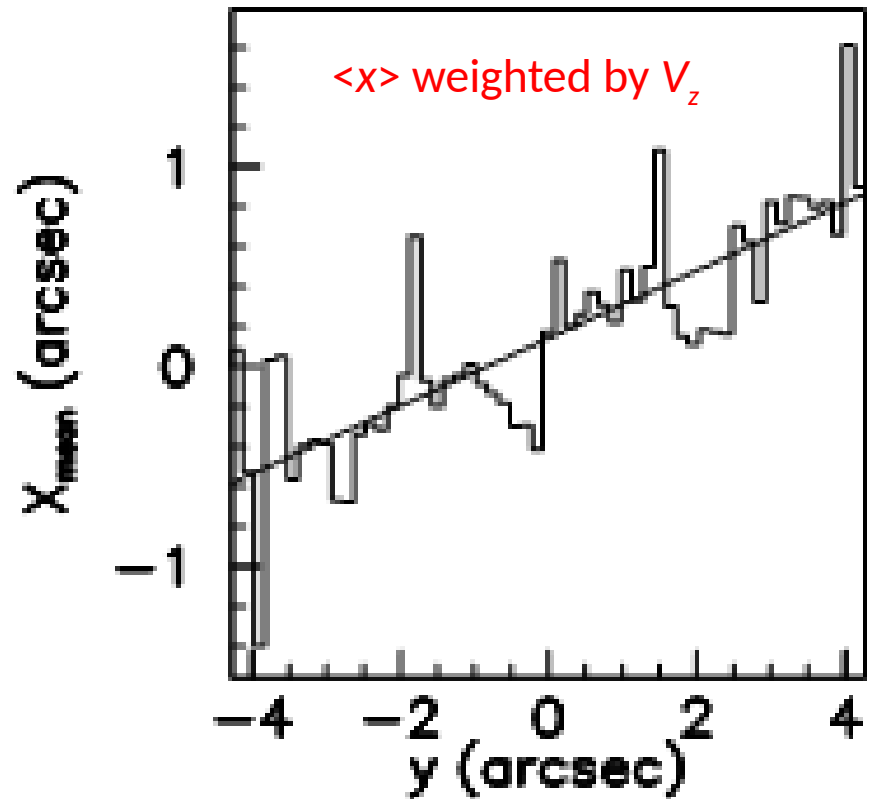
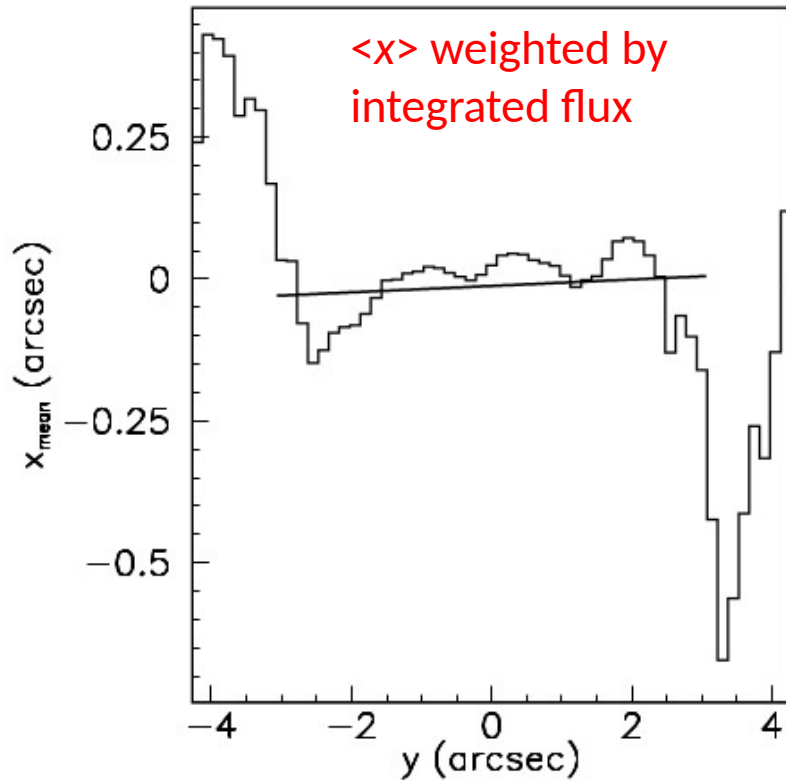
Writing that the total energy is conserved and cancels at infinity implies for the velocity  $V_{\text{tot}} = \sqrt{2GM/r}$  giving  $M \sim 0.20 M_{\text{sun}}$  for  $r < 1.5''$ , in agreement with earlier estimates but obtained from a different range of  $r$ .

Writing instead that the kinetic energy increase is compensated by an equal decrease of the gravitational potential energy at  $r = 1.5''$  gives  $M \sim 0.28 M_{\text{sun}}$ .

This is because  $V_{\text{tot}}$  is observed to vary as  $r^{-0.7}$  rather than  $r^{-0.5}$  as expected for a stationary regime. Indeed the best fit requires a strong deviation of the flux from a stationary flux, parameterized by dividing the stationary effective density by  $r^q$  with  $q = 0.93 \pm 0.25$  instead of 0. We retain  $M = 0.23 \pm 0.06 M_{\text{sun}}$  for  $r < 1.5''$ .

The normalisation between data and model effective emissivity gives an accretion rate of  $3.5 \pm 1.0 \cdot 10^{-7} M_{\text{sun}}/\text{yr}$  at  $r = 1''$  assuming a constant temperature of 30 K and a  $\text{C}^{18}\text{O}$  to molecular hydrogen ratio of  $4.9 \cdot 10^{-8}$ . This is a factor of  $\sim 2$  smaller than measured from the luminosity, which is not very surprising as the two methods measure different things.

# ORIENTATION IN SPACE



An upper limit of **22°** is placed on a possible tilt between the disc plane and the  $yz$  plane with respect to the  $y$  axis.

The tilt from North about the line of sight ( $z$  axis) **cancels** for the integrated flux when  $|y| < 3$  arcsec but increases to **~10°** when  $|y|$  increases beyond this value. **A same 10° tilt is observed in in the Doppler velocity map and in the infrared (Tobin et al.).** Possibly an effect of magnetic field or binarity?

# Summary (1)

We have reconstructed in space the morphology and kinematics of the gas envelope of protostar L1527 using the  $\text{C}^{18}\text{O}(2-1)$  line emission from regions that are not dominated by absorption. Our model contributes a significant improvement but confirms the general picture obtained from earlier analyses.

We find evidence for rotation with a power law requiring an index decreasing with increasing distance from the star, as expected from Keplerian regime to inverse distance law. Evidence for the rotation velocity to decrease when moving away from the median ( $z$  vs  $y$ ) plane has been obtained.

Very strong absorption slightly above systemic velocity prevents a reliable exploration at distances from the protostar smaller than  $\sim 1''$ .

We measure a mean in-fall velocity of  $0.43 \pm 0.10 \text{ km s}^{-1}$  over the explored range, smaller than free fall velocity, with no evidence for a significant  $r$ -dependence.

# Summary (2)

The accretion rate is evaluated as  $3.5 \cdot 10^{-7} M_{\odot} \text{yr}^{-1}$  at  $r \sim 1''$ .

We measure a central mass of  $0.23 \pm 0.06 M_{\odot}$  contained within  $r = 1.5''$ , in agreement with earlier estimates but obtained from a different range of  $r$ .

Evidence is found for a strong depression near the disc plane probably caused by the freeze-out of CO molecules on cold dust grains. It comes in addition to the depression along the disc axis where the outflow takes place.

We give an upper limit of  $\sim 22^{\circ}$  on a possible tilt of the disc plane about the south-north ( $y$ ) axis. A tilt of  $\sim 10^{\circ}$  about the line of sight is observed at large distances ( $|y| > 3''$ ), but cancels at smaller distances. A same tilt of  $10^{\circ}$  is observed on the map of the mean Doppler velocity and in infrared data.

# ACKNOWLEDGEMENTS

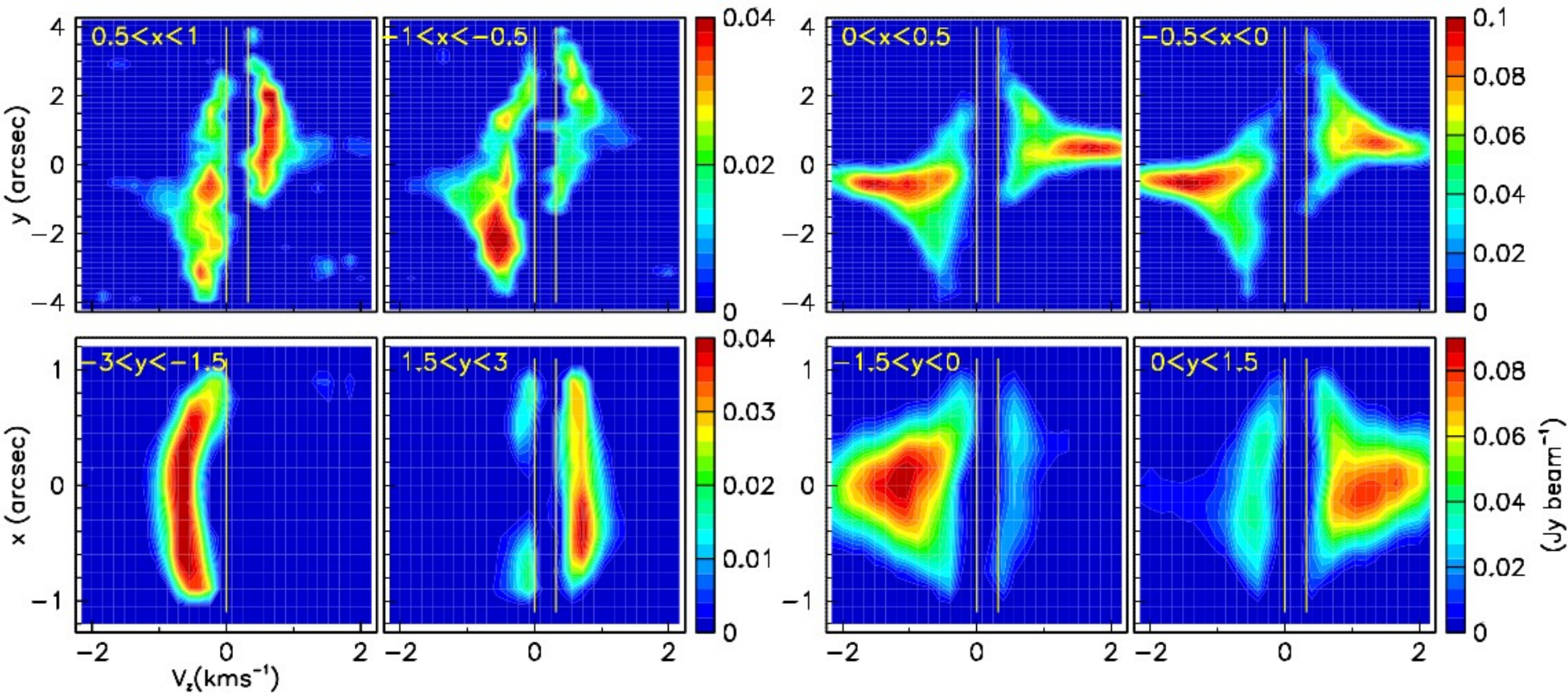
The data are retrieved from the JVO portal operated by NAOJ. We are indebted and very grateful to the ALMA partnership, who are making their data available to the public after a one year period of exclusive property, **an initiative that means invaluable support and encouragement for Vietnamese astrophysics**. We particularly acknowledge friendly support from the staff of the ALMA Helpdesk.

We express our deep gratitude to Pr A. Dutrey, S. Guilloteau and P. Lesaffre for helpful comments and suggestions.

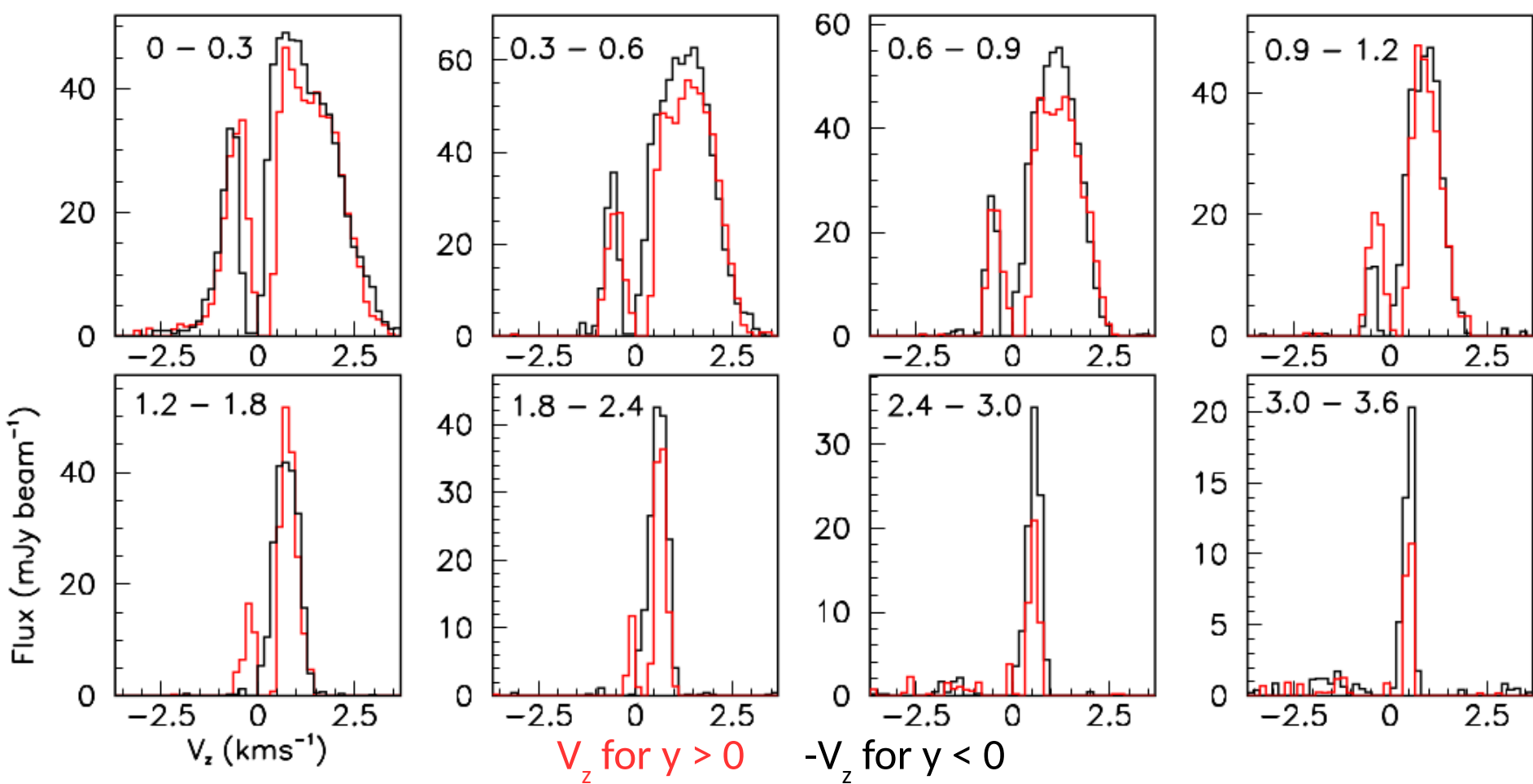
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**THANK YOU FOR  
YOUR ATTENTION**

# PV diagrams



PV diagrams show characteristic of a rotating disk having its axis along the  $x$  axis and displaying symmetries in  $x$  (changing  $x$  in  $-x$  leaves both Doppler velocity and flux densities invariant) and in  $y$  (changing  $y$  in  $-y$  changes the sign of the Doppler velocity and leaves the flux density invariant).



From the data, at least four central velocity bins are essentially lost. However, if one assumes symmetry under both  $x$  and  $y$  reflections about the origin, the number of lost velocity bins can be reduced to two by retaining the blue-shifted part of the direct spectra and the red-shifted part of the reflected spectra.

If symmetry in  $y$  is obeyed spectrum in the southern hemisphere with the reflected spectrum in the northern hemisphere would be identical. However, absorption being red-shifted breaks the symmetry: it suppresses the red-shifted part of the direct spectrum and the blue-shifted part of the reflected spectrum.