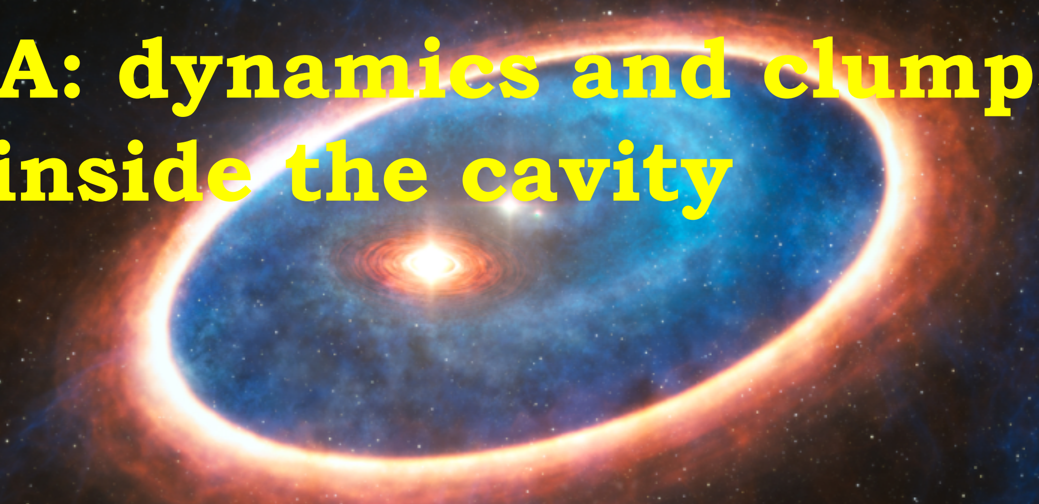
GG Tau A: dynamics and clumps inside the cavity



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in collaboration with
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SFDE17, Quy Nhon, August, 2017

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1. INTRODUCTION

GG TAU

140 pc, 2-3 Myr

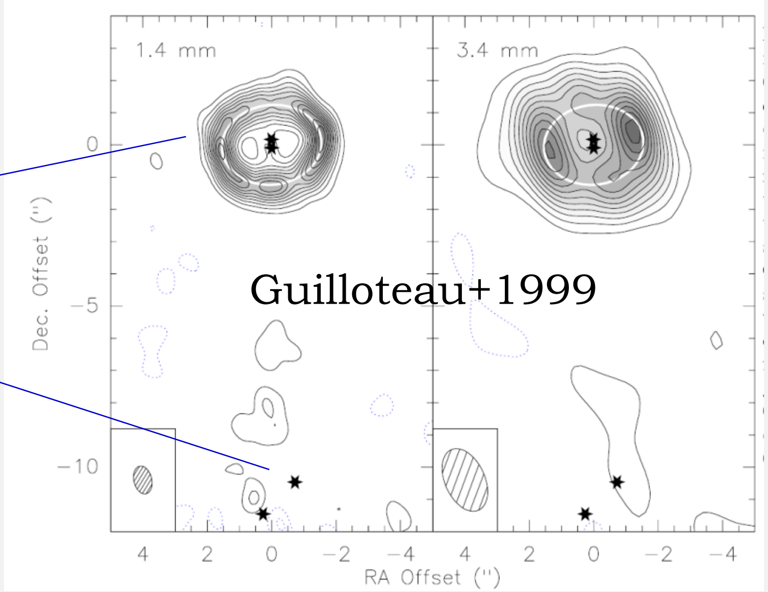
GG Tau A (a binary, 0.26” or 38 au - 1.3 M_{sun})

GG Tau A/B (10” or 1400 au)

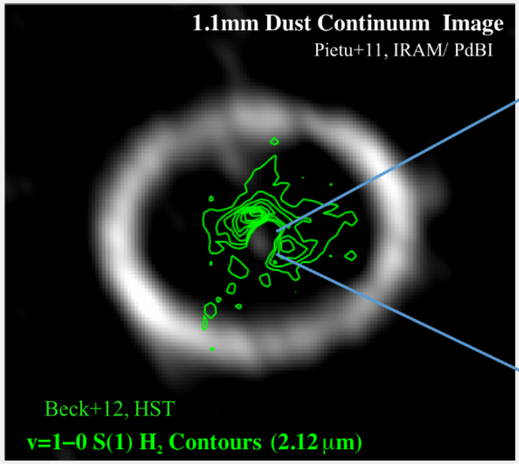
GG Tau B (a binary, 1.4” or 180 au – 0.17 M_{sun})

→ proto-type of the TTauri binary system

GG TAU A - a triplet system itself
cavity of 190 au, i~ 37 degrees, PA ~8°



Guilloteau+1999



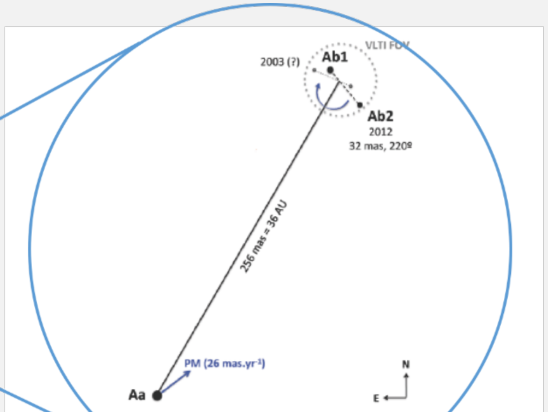
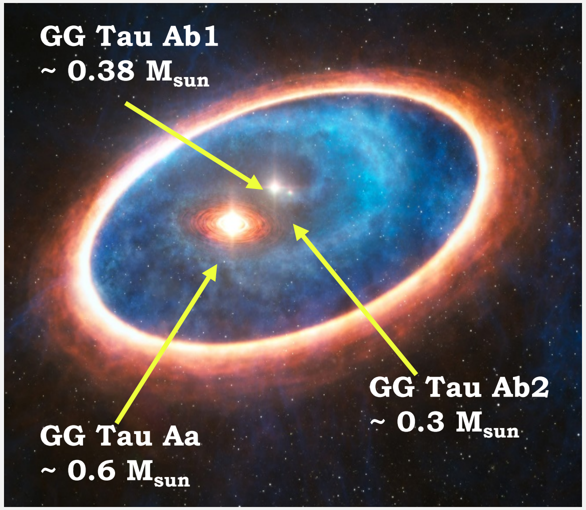
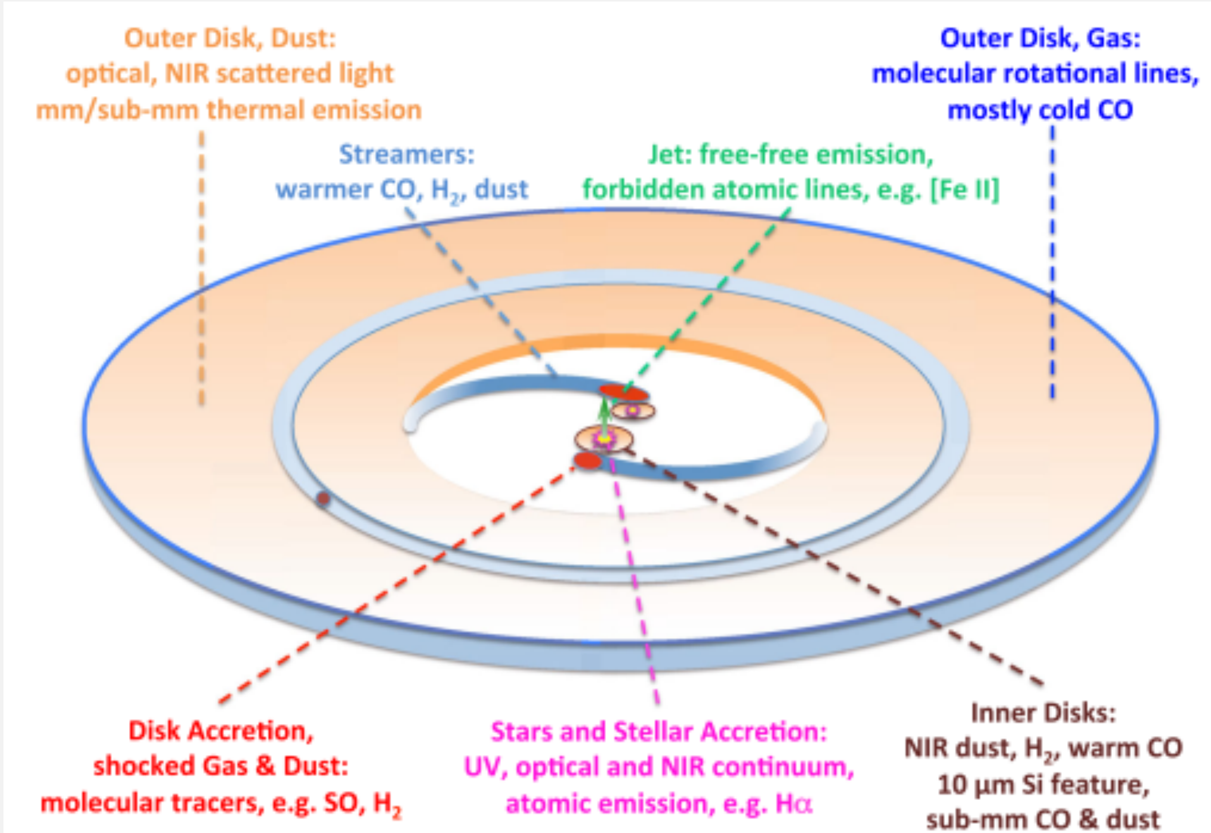


Fig. 3. Sketch of the new triple system GG Tau Aa (M0V), Ab1 (M2V) and Ab2 (M3V) in their 2012 orbital configuration.

Di Folco+14, A&A Letter



Morphology? Kinematics? Planet formation in multiple stellar system?



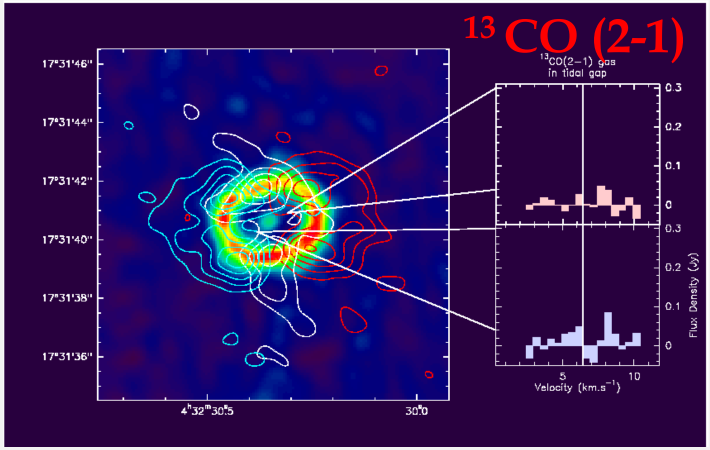
Dutrey et al, 2016

A scheme of the environment of a young binary system showing the expected origin of the various dust and gas emissions; outer disk, streamer, inner disk, jet, and accretion tracers. In the outer disk, an accreting CB planet can eventually open a gap.

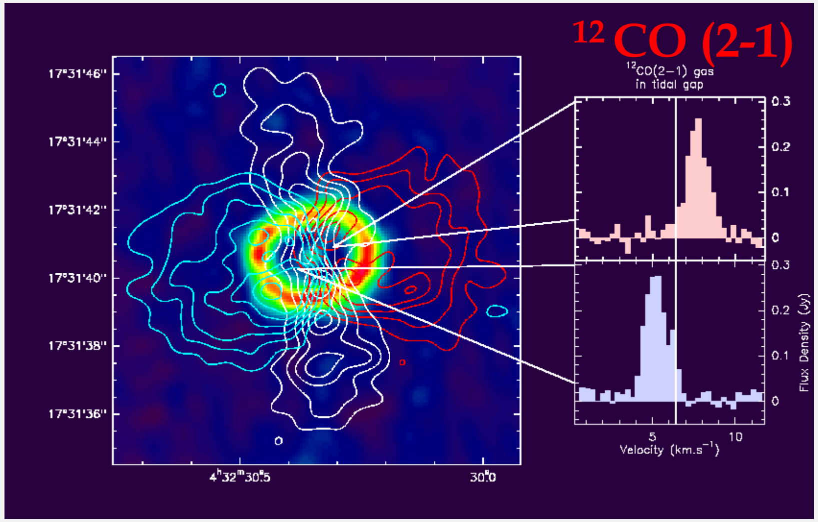
GG Tau A: Early Observations

Is there a gap or it is really empty?

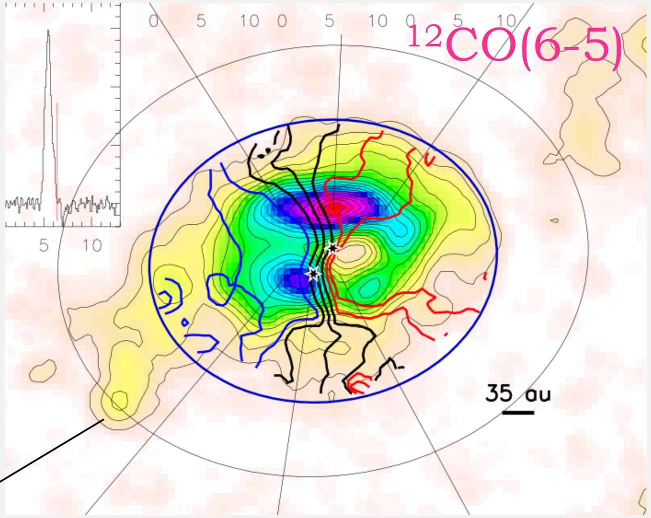
PdBI observations



Dutrey and Guilloteau, 2001



ALMA cycle 0



Dutrey + 2014

Hot spot -> Planet formation?

2. DATA

Cycle 1
(Tang + 2016)

ALMA#2012.1.00129.S

-November 18 and 19, 2013.
-29 antennas
-Longest baselines 1282 m.
-Observing time: ~ 37 mins on source.
-Beam: 0.40×0.29, PA= 53°
-Noise: 7.0 mJy/beam

We use a 3-σ cut for CO(3-2) emission and a 2-σ cut for ^{12}CO(6-5) emission on each data cube element. Also we clean the ^{12}CO(6-5) data by ignoring data cube elements that contain noise far away from the mean Doppler velocity of the corresponding pixel.

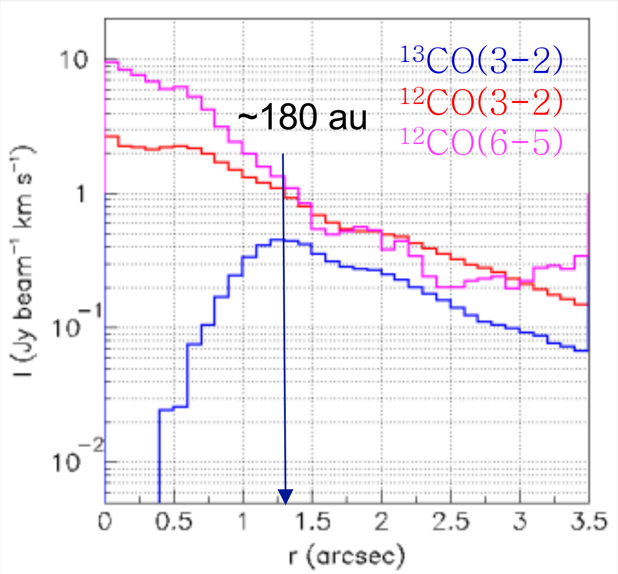
Cycle 0
(Dutrey + 2014)

ALMA#2011.1.00059.S

-August 12 and 13, 2012
-23 antennas
-Longest baseline: 402.3 m.
-Observing time: ~25.4 mins on source
-Beam: 0.29×0.27, PA= 53°
-Noise: 70 mJy/beam

3. MORPHOLOGY AND KINEMATICS

Morphology



Radial profiles of effective emissivity

r>1.3 arcsec (180 au)

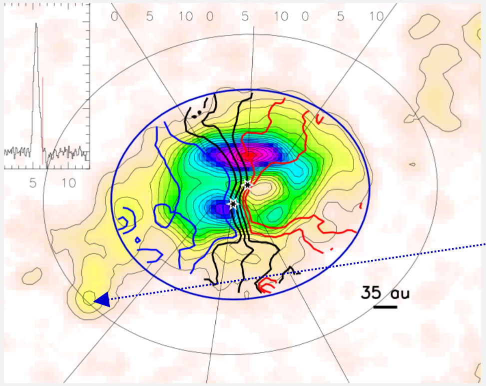
all three distributions decrease by a factor of 2.2 to 2.3 per arcsec.

r <1.3 arcsec (~180 au):

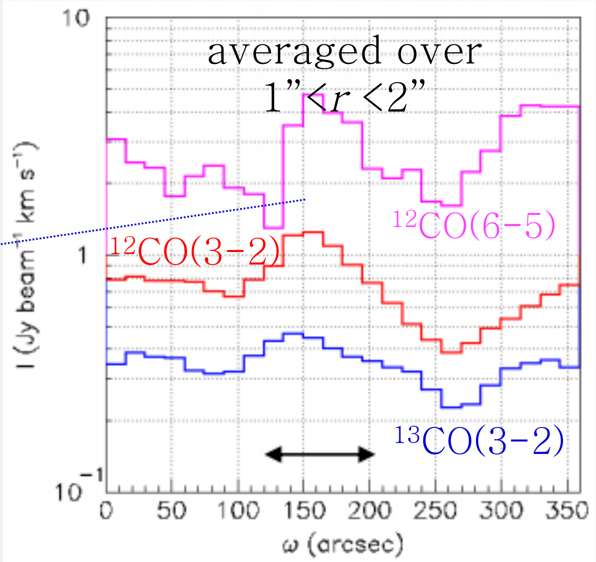
^{13}CO(3-2) emission drops to zero.

^{12}CO(J=3-2 & J=6-5) emissions remain high.

← probably a result of higher temperatures in the centre or different optical thicknesses.



Dutrey et al, 2014

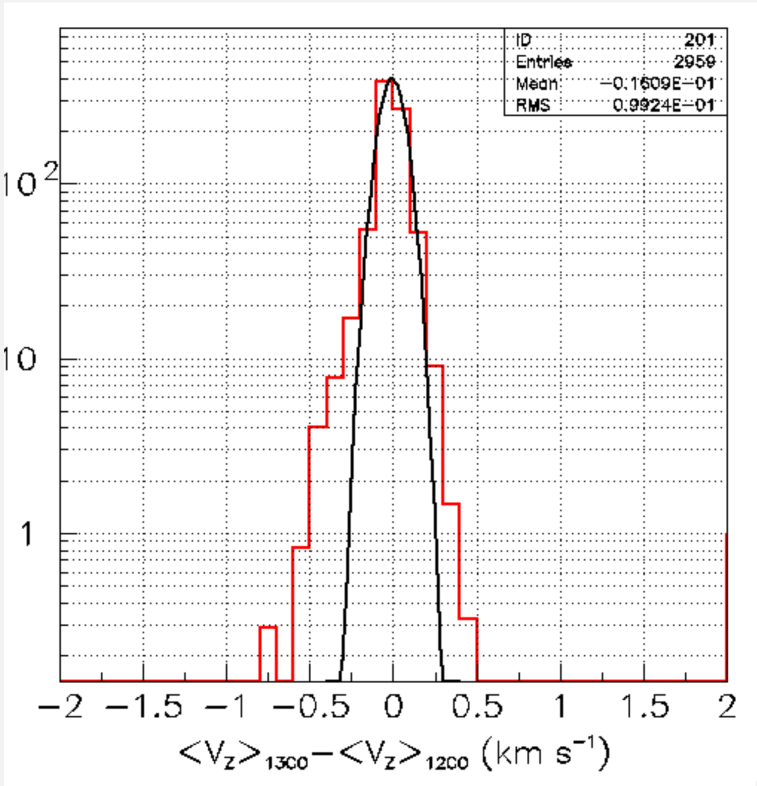


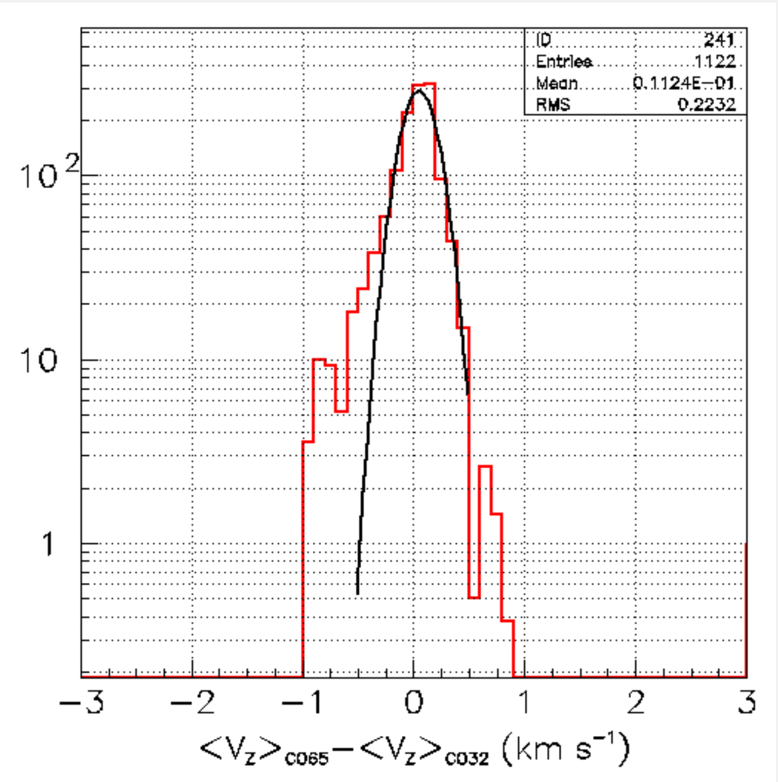
Azimuth profiles of effective emissivity

Both the emissions display a south-eastern excess for 120º<ω<210º, which corresponds to the hot spot.

Kinematics

$\langle V_z \rangle_{13CO32}$ - $\langle V_z \rangle_{12CO32}$ $\langle V_z \rangle_{12CO65}$ - $\langle V_z \rangle_{12CO32}$



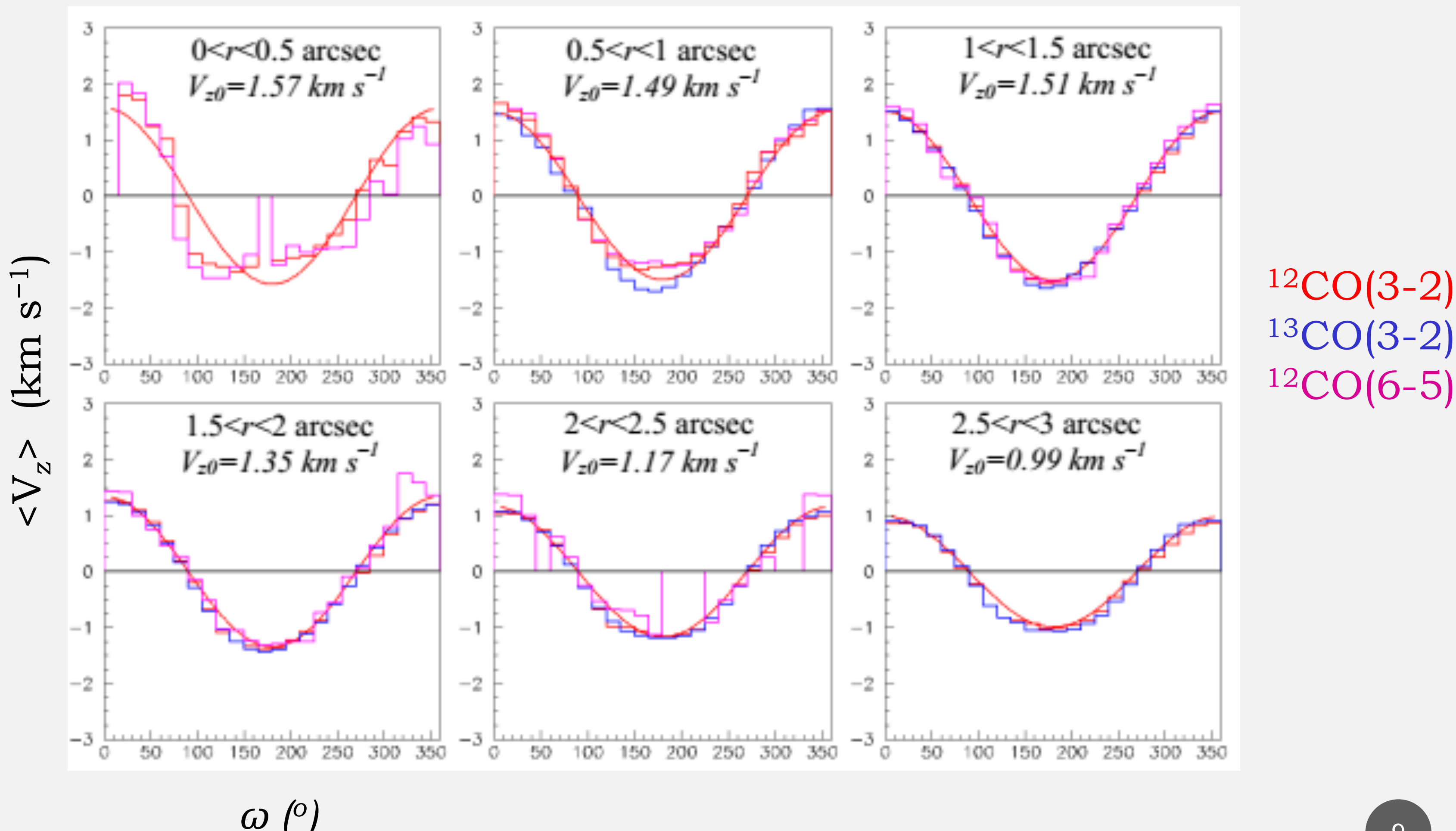


All three sets of observations measure nearly identical mean Doppler velocities in any given pixel

Weight ~ the geometrical mean $(I_1 I_2)^{1/2}$

We assume the source to be a thin flat disc with i=37° inclination namely we define space coordinates that are (x, $y/\cos 37^o$).
We define therefore a space radius $r=[x^2+(1.25y)^2]^{1/2}$
and a space azimuth $\omega=\tan^{-1}(1.25y/x)$.

$$V_z = \sin i(V_{rot}\cos\omega + V_{fall}\sin\omega)$$



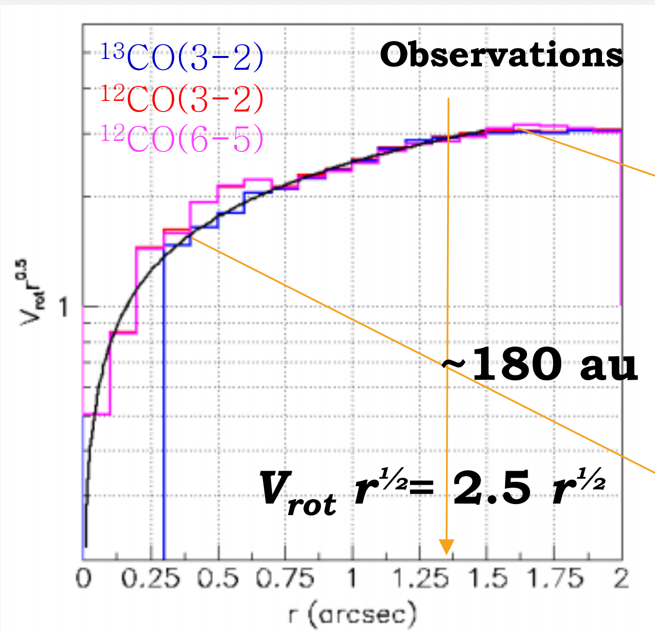
The curve is a fit of the ^{12}CO(3-2) data to a form $V_{z0}\cos\omega$

$V_{rot}=V_z(\sin i \cos\omega)^{-1}$

Both the emissions follow the same rotroation curve, approximately Keplerian down to r~1.3 arcsec.

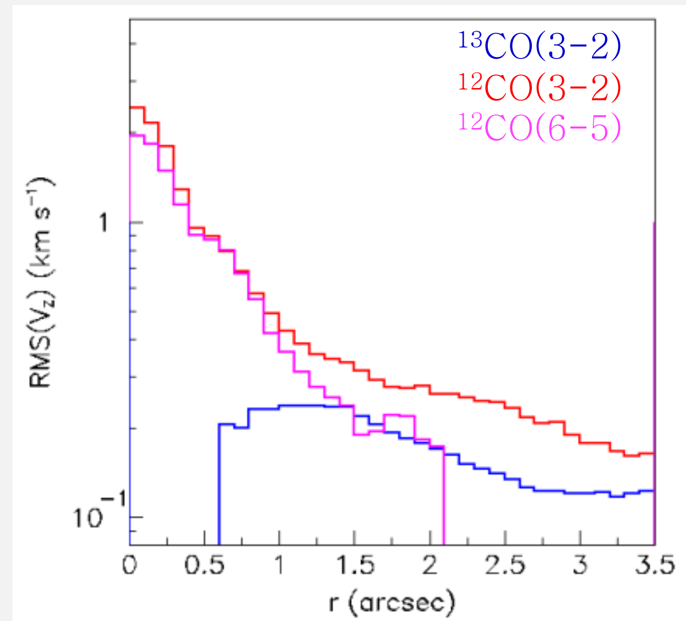
$V_{rot}\times r^{1/2}$

Rms(V_z)



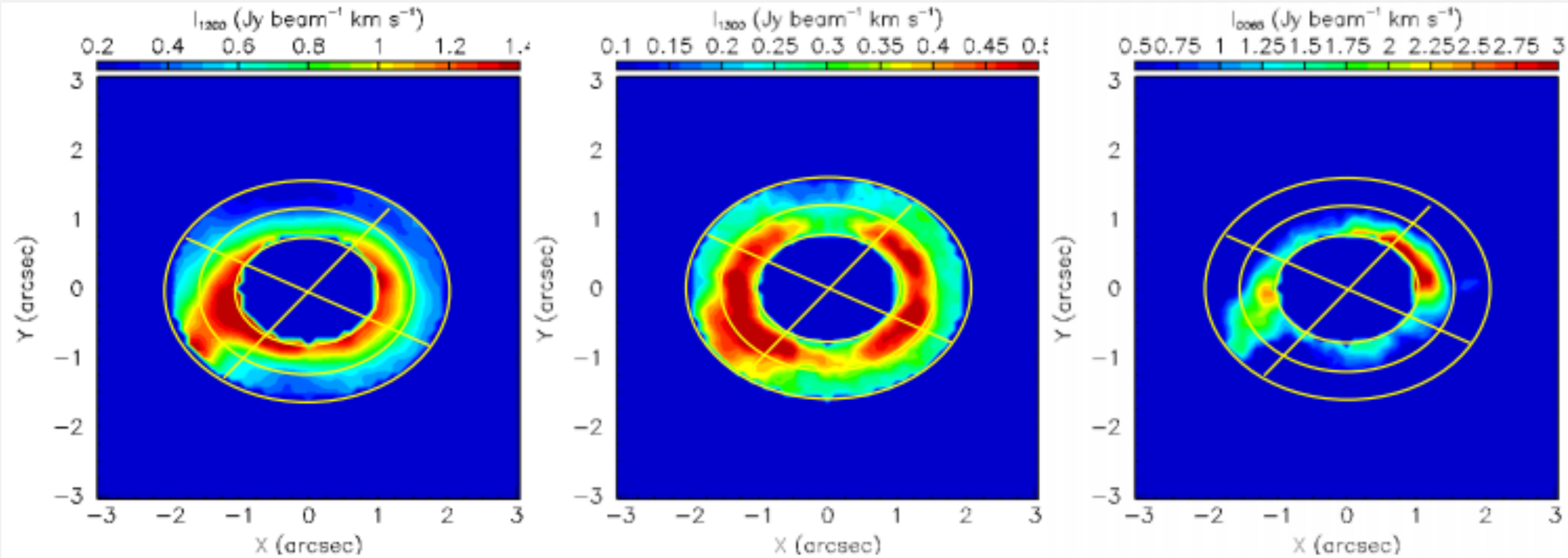
Flat = Keplerian

Constant Velocity < 1.3”



At small r-values, both $^{12}CO(3-2)$ and $^{12}CO(6-5)$ line widths increase suddenly to very high values, up to 2 kms^{-1}, a result of the configuration of the gravity field of the binary

Outer region



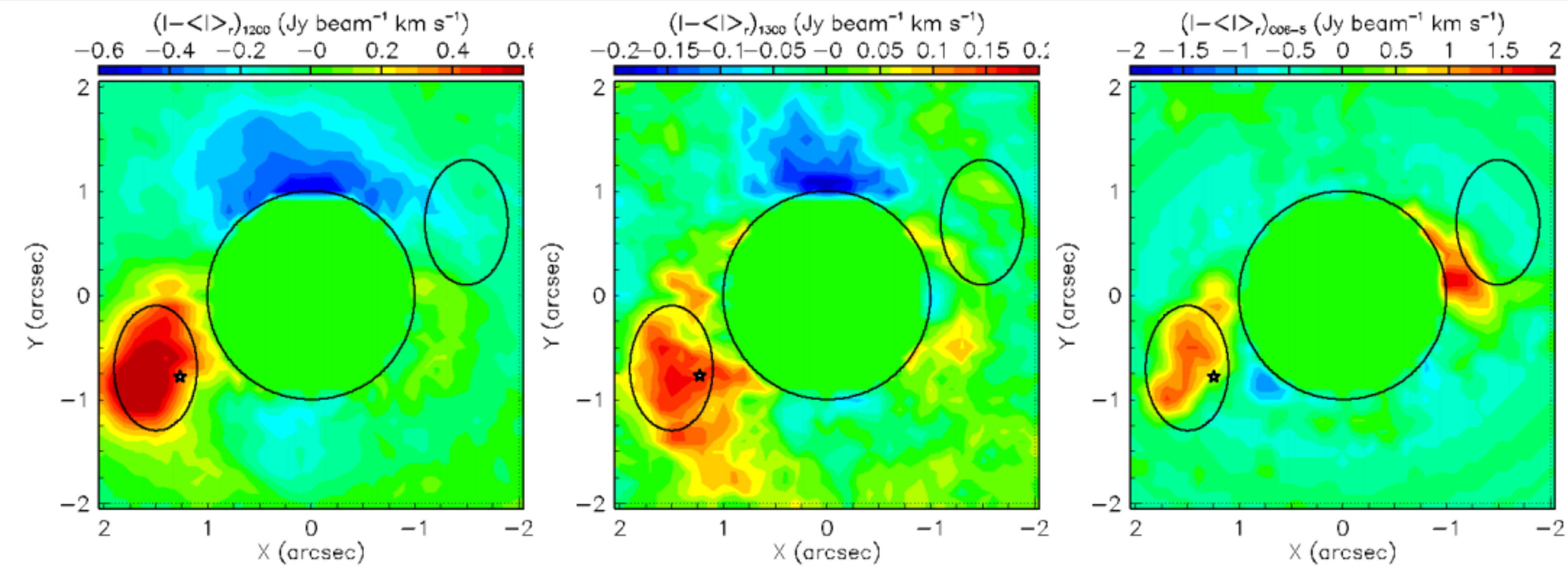
Rms values (km/s) of the line widths

		120°<ω<210°	210°<ω<300°	–60°<ω<30°	30°<ω<120°
1”<r<1.5”	^{12}CO(3-2)	0.36	0.39	0.39	0.40
	^{13}CO(3-2)	0.24	0.23	0.25	0.25
	^{12}CO(6-5)	0.24	0.31	0.39	0.26
1.5”<r<2”	^{12}CO(3-2)	0.28	0.28	0.33	0.28
	^{13}CO(3-2)	0.21	0.20	0.21	0.19
	^{12}CO(6-5)	0.26	0.14	0.17	0.16

No significant difference between the 4 quadrants of a same sub-ring

Hot spot:

accounting for the strong radial dependence of the intensity



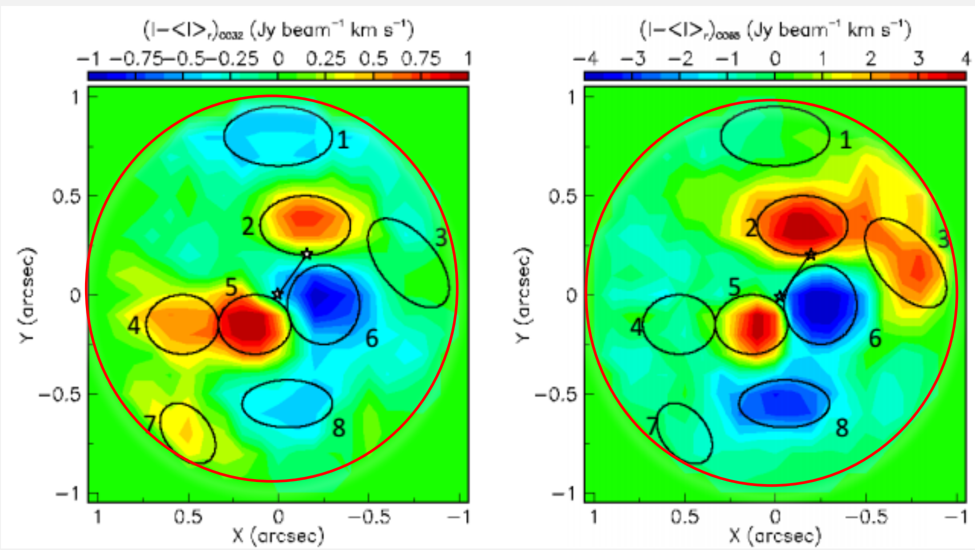
	Hot spot ellipse		Diametrically opposite ellipse	
	$\langle V_z \rangle$ [km s^{-1}]	Rms(V_z) [km s^{-1}]	$\langle V_z \rangle$ [km s^{-1}]	Rms(V_z) [km s^{-1}]
^{12}CO(3-2)	–1.3	0.27	1.1	0.38
^{13}CO(3-2)	–1.3	0.22	1.1	0.24
^{12}CO(6-5)	–1.2	0.25	1.6	0.28

No spectacular effect to be seen!

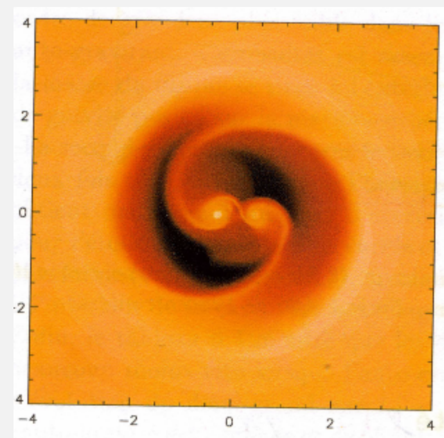
4. Clumps inside cavity and accretion arms ?!?

We have started to study the CO clumps inside the cavity
Differences in excitation conditions between CO (J=3-2) and CO (J=6-5)

$^{12}CO(3-2)$ $^{12}CO(6-5)$



Arnaud Pierens PhD 2004



difference between the measured intensity and its azimuthal average at the same radius

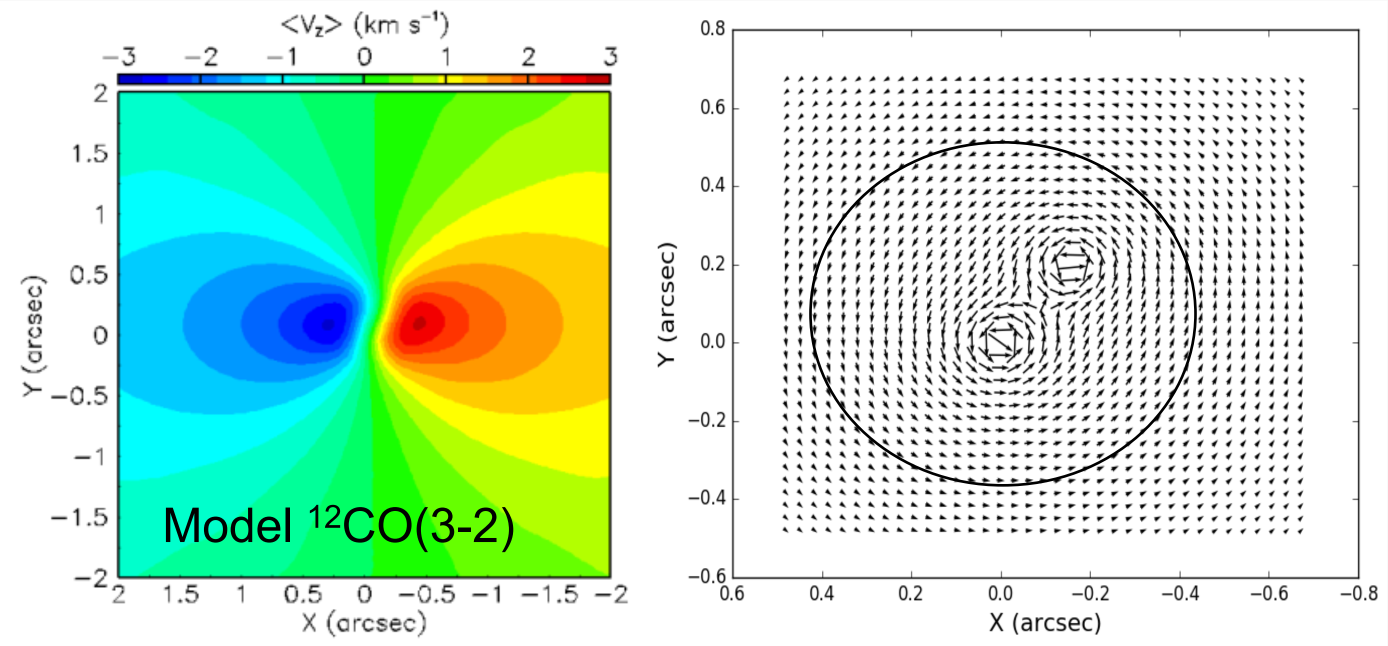
Binary gravity field – a simple model

→ It suggests that the binary gravity field plays an important role in shaping the kinematics close to the stars:

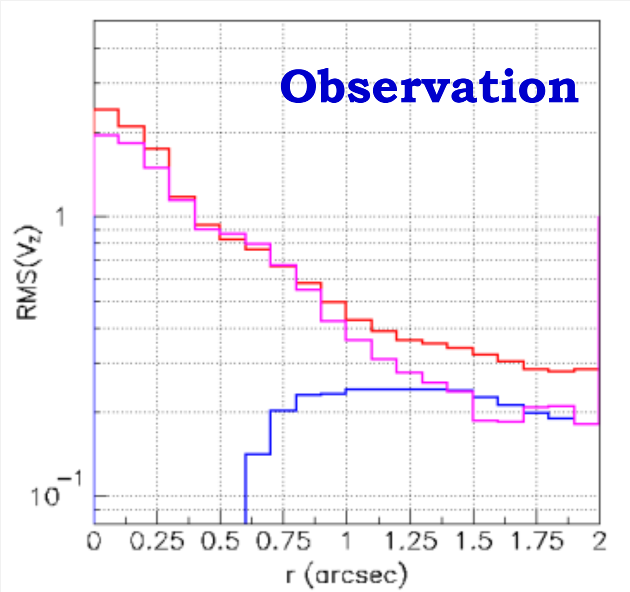
A simple model:

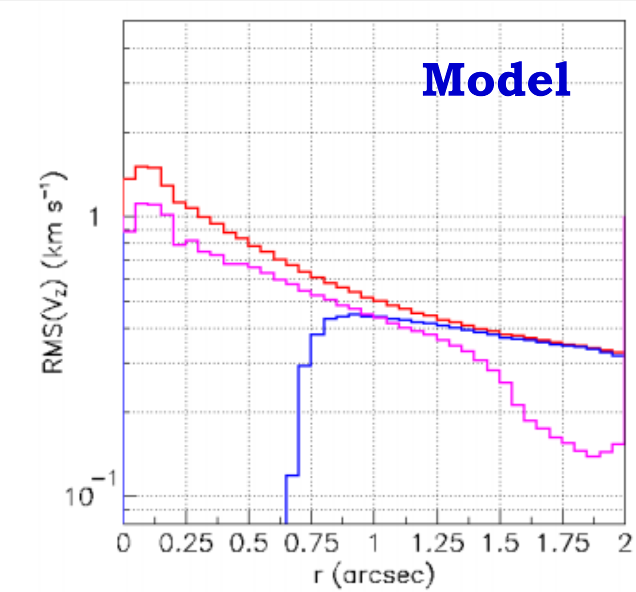
- Infinitely thin and flat disc.
- The orbits are at constant velocity in the cavity -> constant potential -> circular orbits in the case of a single star.

The model is far from reality but it provides useful reference to compare with the data !!!



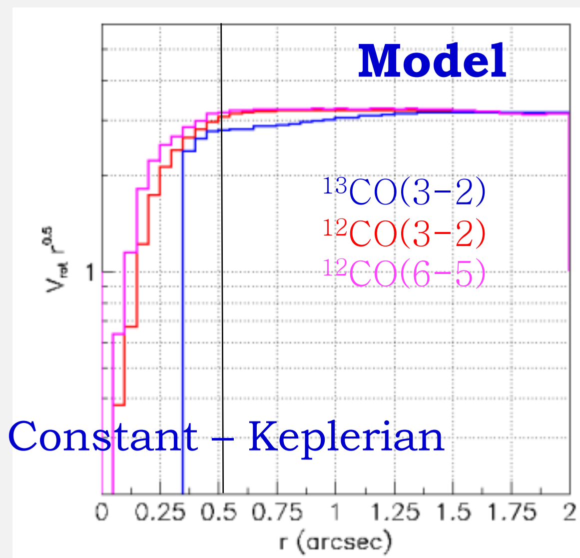
Results

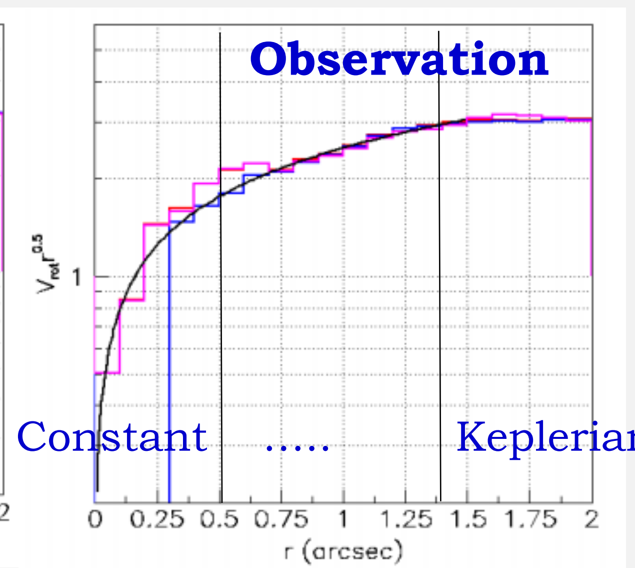




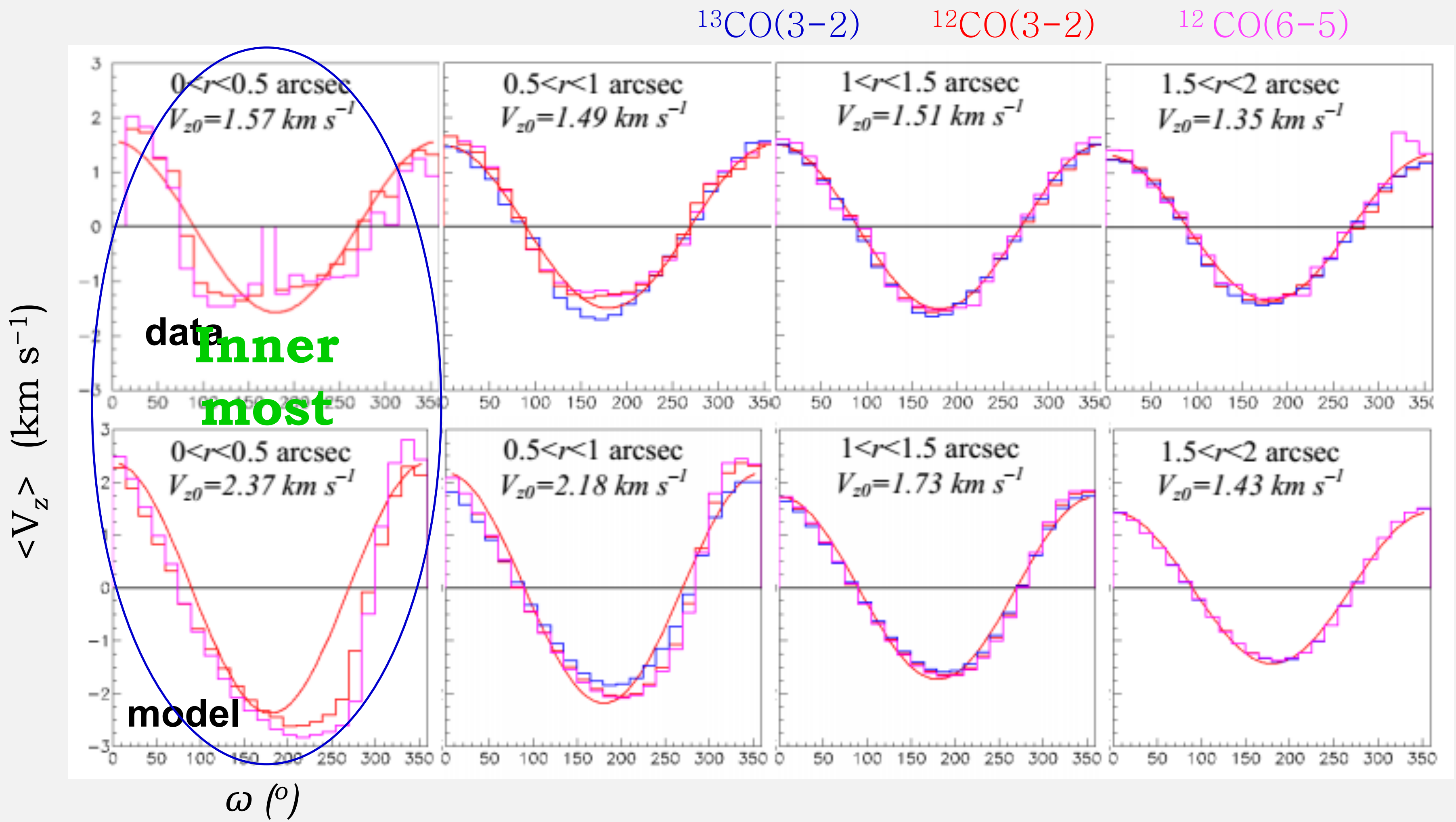
Line broadening results exclusively from beam convolution.

Deviation from Keplerian occurs at much smaller distance from the stars in the model than in reality, ~0.5 rather than ~1.3 arcsec.





Azimuthal dependence of the mean Doppler velocity



Rotation dominance is clearly evidenced, we note that at low *r* values the model predicts higher |V_z| values than observed.

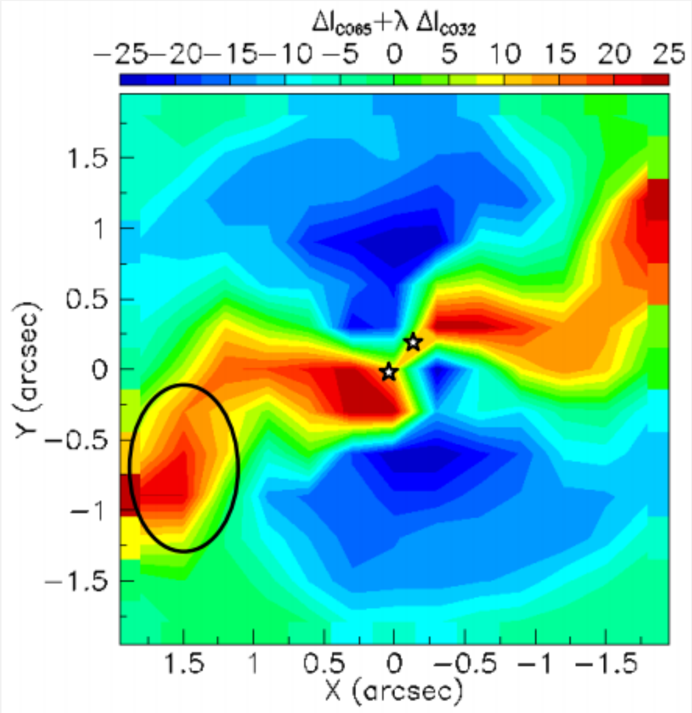
5. Summary

1. Evidence for a remarkable overall agreement between the kinematics observed in $^{12}CO(3\text{-}2)$, $^{13}CO(3\text{-}2)$ and $^{12}CO(6\text{-}5)$
2. Evidence for a general dominance of rotation reaching below the cavity radius.
3. All three sets of observations reveal the presence of an excess of emission in the hot spot region. Line widths do not display spectacular variations in this region
4. In the inner region, evidence is obtained for excesses of emissions aiming at the two stars, Aa and Ab, with shapes reminiscent of what can be expected for accretion arms.
5. The structure of the gravity potential around the binary plays an essential role in shaping the kinematics of the gas in the cavity. Beam convolution is a major factor of apparent line broadening. The availability of new high resolution observations of ~0.15 arcsec (Cycle 3 ALMA #2015.1.00224.S) will greatly improve our understanding of the physics at play.

THANK YOU FOR YOUR ATTENTION!

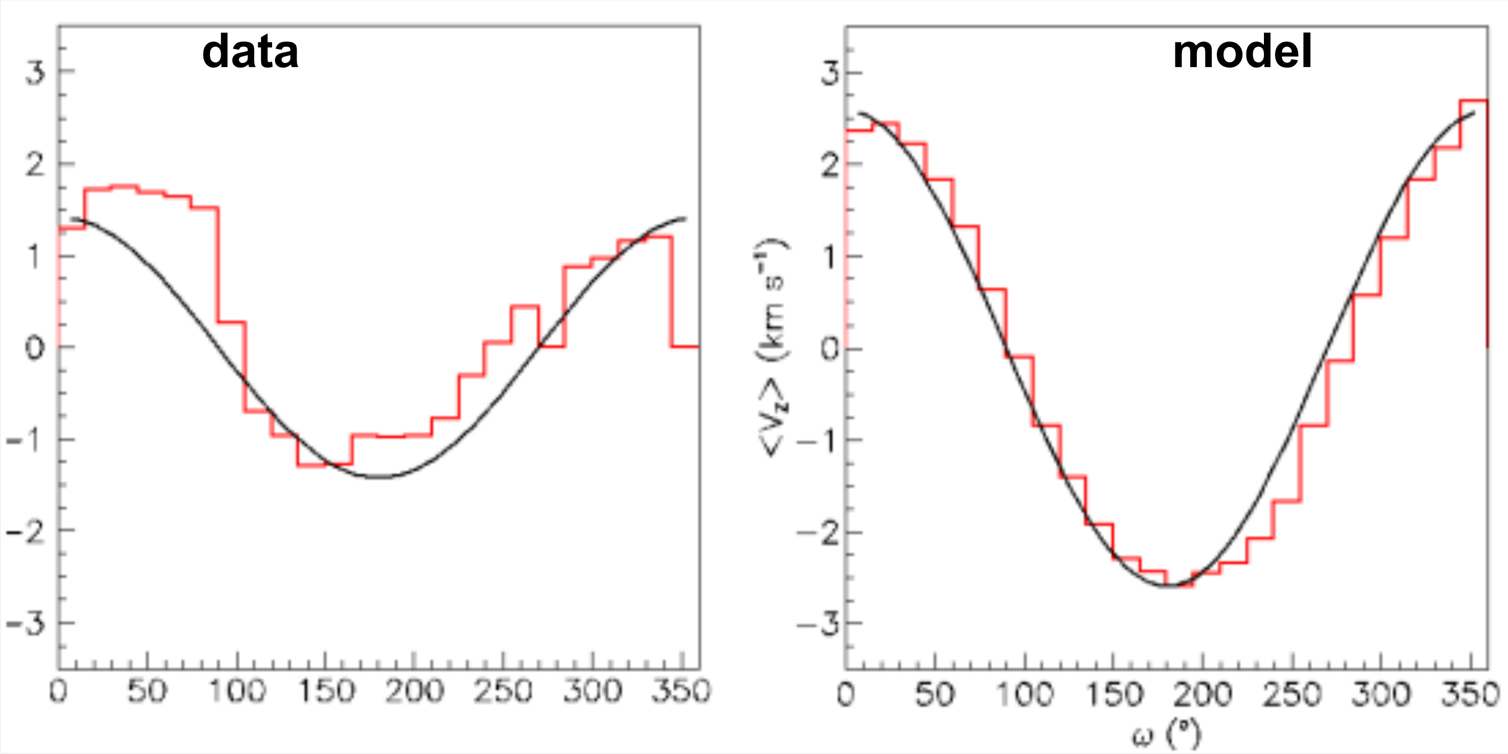
Two puzzling questions require an answer:

1. Is the hot spot connection to one of the accretion arms the result of pure coincidence or does it have a physical cause?



2. Do the size of the cavity and the deviation from a $r^{-1/2}$ law of the rotation velocity suggest a larger binary separation than actually observed?

In the first r bin (r<0.5 arcsec) the deviation from a cosine law predicted by the model does not reproduce the observed shape.



We replot the first r bin result, for both model and data, using the centre of mass of the two stars as origin of coordinates to define ω. The model now looks more cosine-like, as expected.