CO RO-VIB OBSERVATIONS OF HD100546: A SYMMETRIC DISK OR NOT?

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Observations + Model

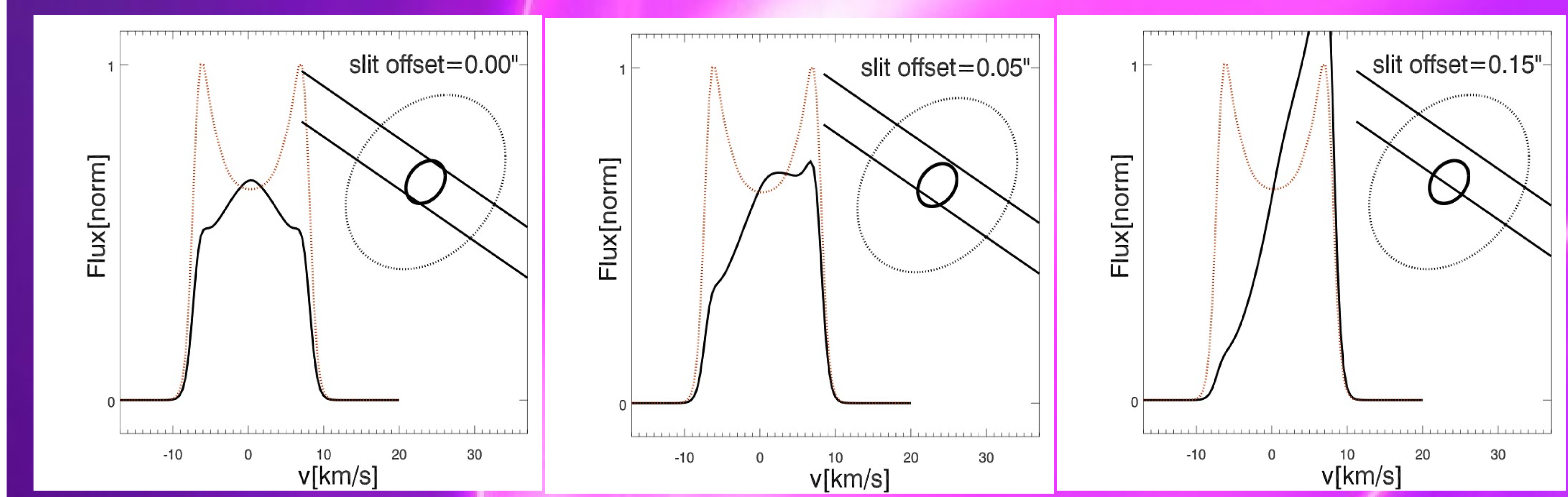
High-resolution CRIRES/VLT spectra (Goto et al. 2012) of the CO ro-vib lines, 4.5-5.0 μm:

* 0.2" slit at 8 orthogonal and antiparallel position angles.
* >50 line identified, various symmetric and asymmetric line shapes.
* Line profile shapes change with slit position.
* High v-bands almost as strong as the fundamental.

ProDiMo (Woitke, Kamp, Thi 2009) model for HD100546:

* Parameterized disk structure fitted to observational data (Thi et al. 2011, Benisty et al. 2010, Tatulli et al. 2011). NOT including the CO ro-vib data.
* Large CO ro-vibrational model molecule (Thi et al 2012) with 2 electronic levels (each 7 vibrational levels containing 60 rotational levels).
* Model CO line data cubes were calculated and treated similarly as the observations through slit filtering.

Fig 1



Output from our slit filtering tool: The 3D data line cubes contain the intensity [erg/cm²/s/Hz/sr] at every spatial position on the 'sky' for 91 velocity channels. The IDL tool applies PSF convolution, velocity convolution, rotation and slit filtering, to generate simulated observations.
In the three plots above the v(2-1)R06 line was filtered through a slit at a position angle of 55° with three different pointing offsets.Shown in red are the unfiltered double peaked line profiles, on top in black, the filtered line profiles, and on the top right of each plot, a sketch of the disk with the slit.

Contour plot of the CO abundance in the disk model. The gap stretches from ~4-13 AU, most of the CO ro-vib emission is coming from the puffed up wall. Blue contour lines are gas temperatures, 200 K, 800 K and 2k=2000 K. White dashed lines indicate the radial region where the CO is emitted from.

Main disk parameters of the outer disk:

M_*:	2.0 $M_\odot$
R_*:	1.54 $R_\odot$
L_*:	26 $L_\odot$
T_{eff}:	10500 K
log(g):	4.37
apow:	3.5
amin:	0.1
amax:	5.0
dust/gas:	0.71
Mdust:	3.82 $10^{-4} M_\odot$
Mgas:	5.37 $10^{-4} M_\odot$
Rin:	0.19 AU
Rout:	500 AU
β:	1.0

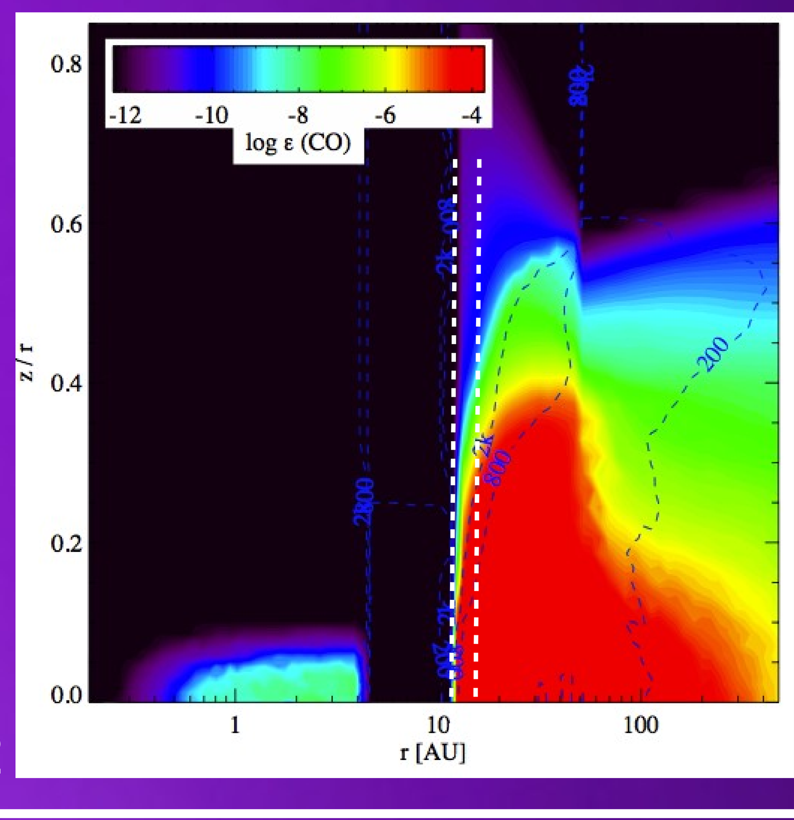
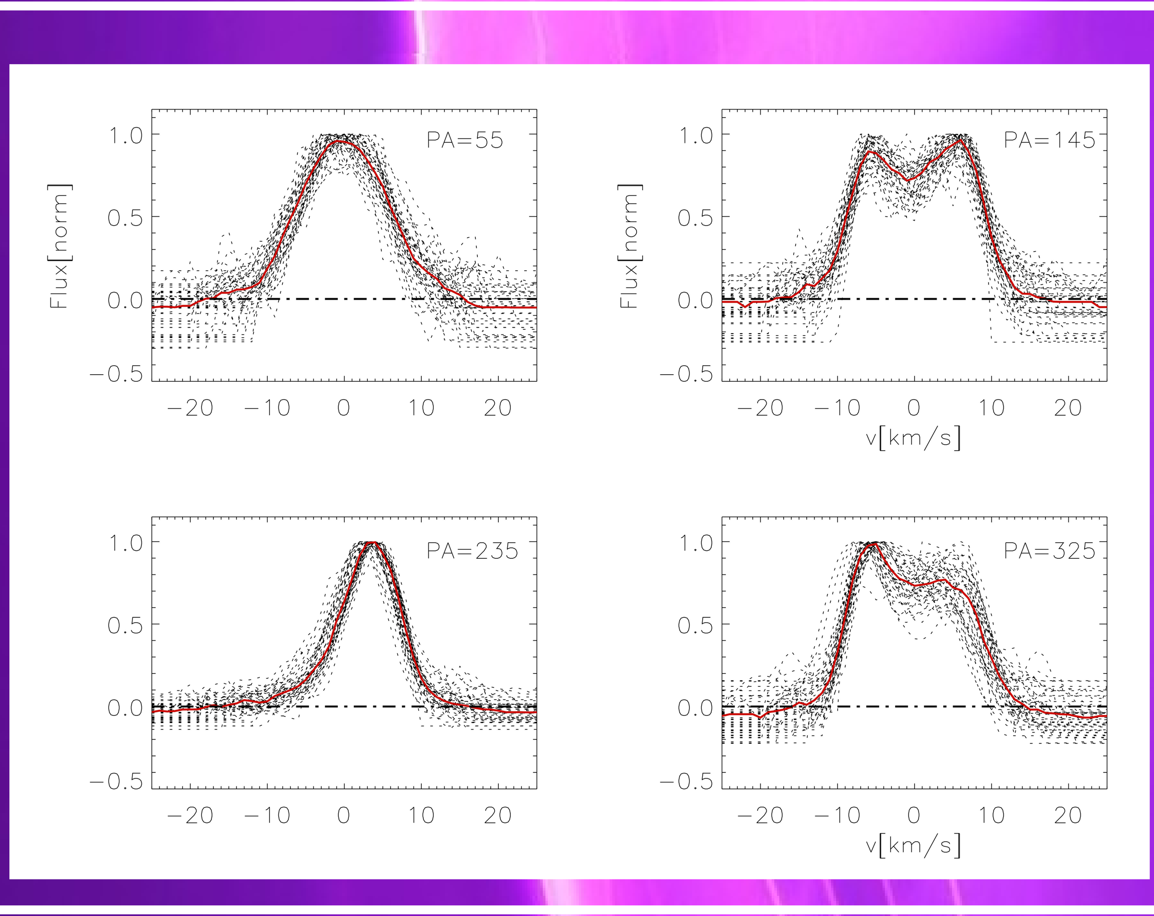


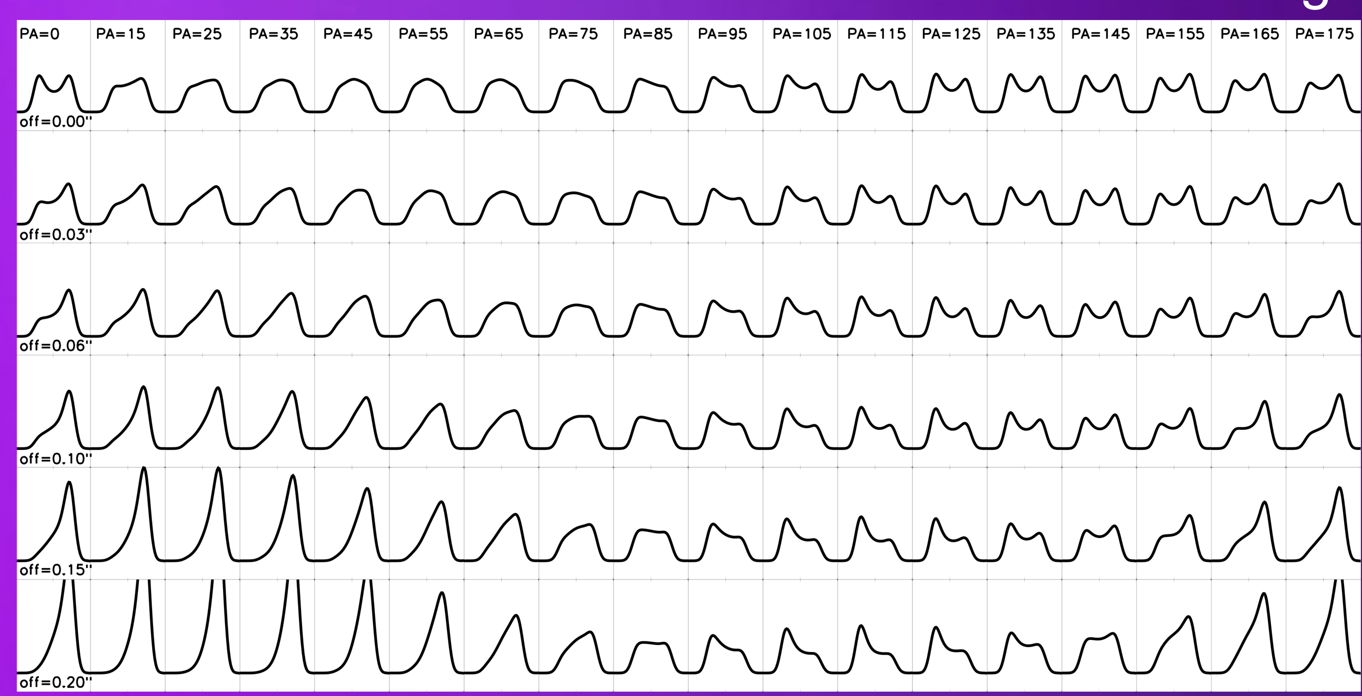
Fig 2

Fig 3



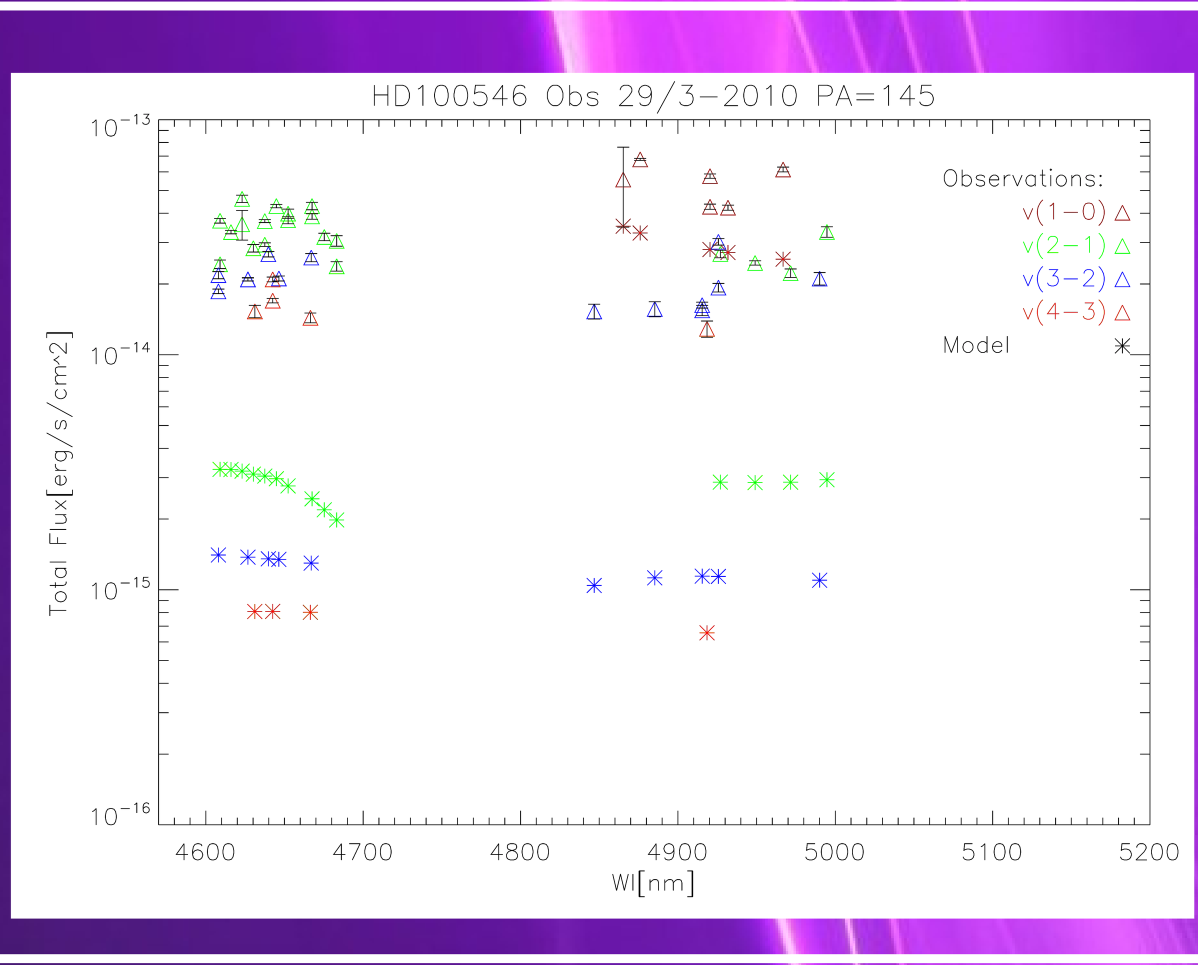
Averaged and normalized CO ro-vibrational line profiles observed with the CRIRES/VLT with a slit at 4 different position angles. Transitions from the four lowest v levels and from J=4 to J=30 are included in the average. The black dotted lines are the individual transitions while the red line is the median. Amazingly within each PA these transitions show the same line profiles shapes, indicating that they originate in the same narrow region around the disk wall.

Fig 4



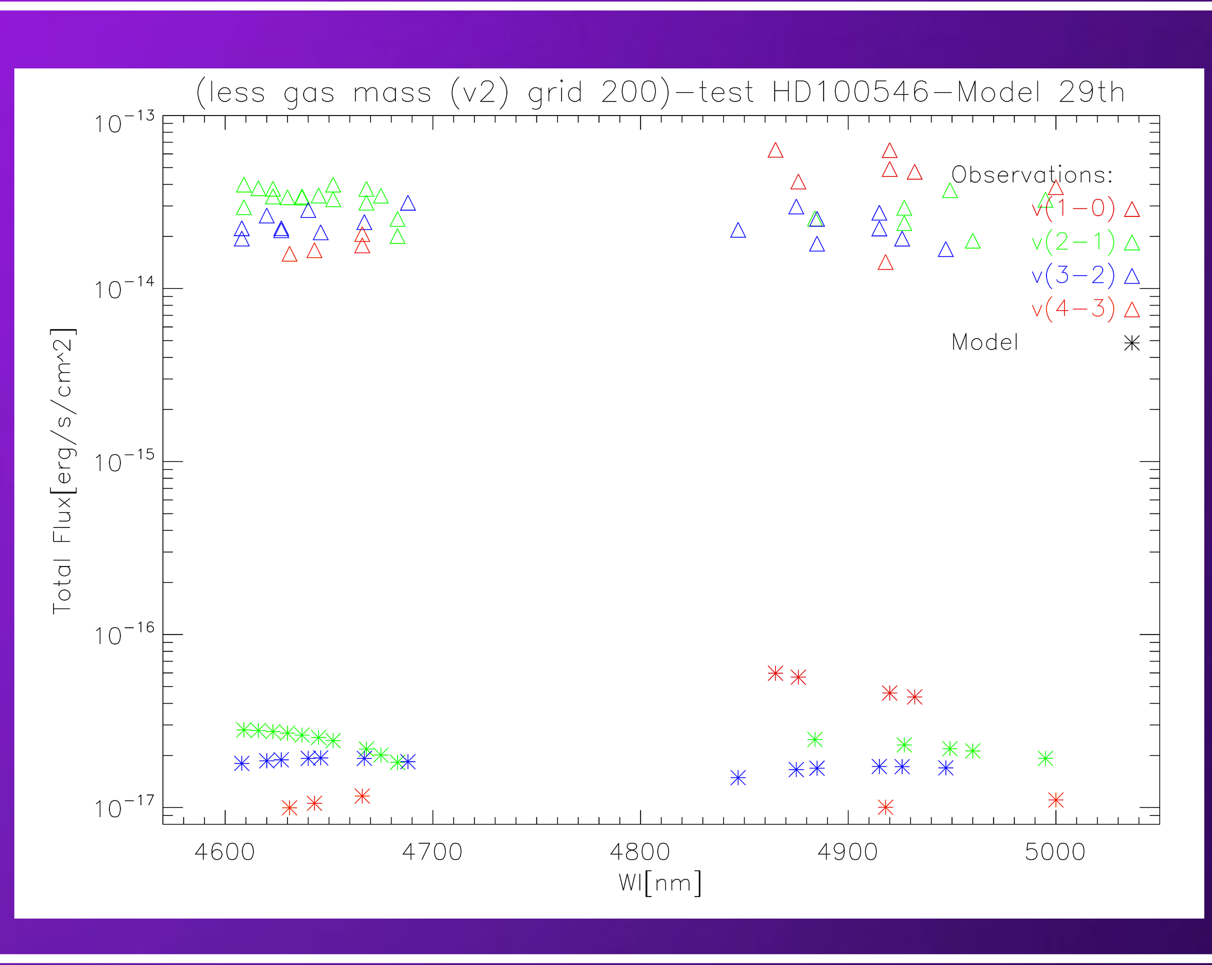
Slit filtering simulation done with one representative line v(2-1)R06. We shifted the slit position through 18 different position angles (0°-175°) and six different pointing offsets (0.00", 0.03", 0.06",0.10",0.15",0.20"). The y values are normalized fluxes running from 0.99 to 1.05, while the x values correspond to velocities from -15 km/s to +15 km/s.
This gives an overview of possible line shapes in our observations if an offset is present. The corresponding negative offsets would lead to mirrored versions of these profiles. Comparing this to Fig. 3 we see that all line asymmetries can be explained with offsets.

Fig 5



Left: is a line flux versus wavelength plot of our selected sample of lines. The observational data is plotted as triangles and the modelled data as stars. The different vibrational levels are colour coded (see legend). For the first vibrational level the model underestimates the fluxes by a factor two and for the rest by a factor 10. Also the model predicted line flux ratio between vibrational bands is off.
Right: Line flux to wavelength plot of a modified model where the gas mass is reduced by a factor 100. Here we get the line flux ratio between v levels right but we underestimate the line fluxes by a factor 1000. The solution could be that the same gas mass as in the original model is just vertically more extended at the inner rim (large scale height), thus leading to lower volume densities and more efficient fluorescent pumping.

Fig 6



Conclusions

* All vibrational bands have the same profile shape and thus originate in the same narrow region (Fig. 3 & 2).
* The line flux ratios between v=1-0 and the other bands are 0.5-0.2 (Fig. 5).
* The line asymmetries in our data can be explained by a symmetric disk with slit correction and pointing offset (Fig. 3 & 4).
* The model does without any modification produce the correct width and peak separation of the profiles and the similarity in profiles between all v-bands.
* We reproduce the v=1-0 fluxes (within a factor two) (Fig. 5).
* We underestimate the higher v-band fluxes by a factor 10 and do not find the right ratios between v-bands. This points toward a solution where the same gas mass is spread out vertically leading to lower volume densities and thus more efficient fluorescent pumping (Fig. 5 & 6).
* For this type of nearby disk with a substantial gap it is very important to consider carefully the choice of the slit width and the positioning of the slit in near-IR observations (Fig. 4).

References

M. Benisty et al 2010, A&A, 511, id.A75; M. Goto et al, 2012, A&A, 539, id.A81; E. Tatulli et al 2011, A&A, 531, id.A1; W.-F. Thi et al 2011, A&A, 530, id.L2; W.-F. Thi et al. 2012, A&A, 551, id.A49; P. Woitke, I. Kamp, W.-F. Thi, 2009, A&A, 501, 383.