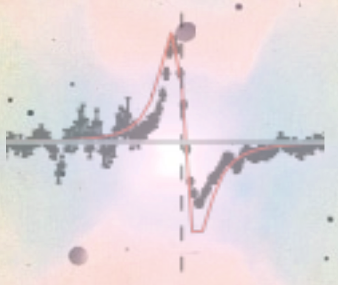
CRIRES-VLT spectro-astrometry: a new tool to search for disks and compact structures at the innermost regions of PNe



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Outline

- Asymmetries in PNe and observational challenges
- High-resolution spectro-astrometry
- How does it works?
- CRIRES-VLT commissioning data
- The Red Rectangle
- Summary and perspectives

Asymmetries in PNe

Asymmetries in PNe = observational challenges to detect, resolve, and interpret the collimating agents (binaries, disks, high velocity jets)

Post-AGB stars ➡ may be obscured by dust + emission of molecules + compact sizes

Proto-PNe ➡ compact central regions + dust + molecules

Young PNe ➡ collimating agents are still compact and obscured

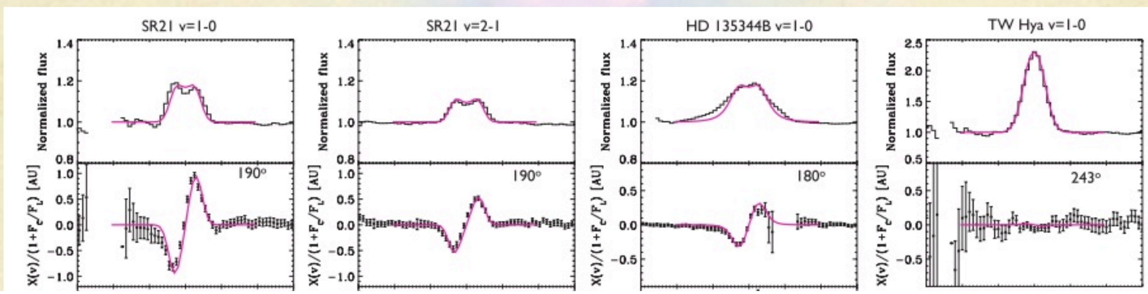
But they are strong IR and radio emitters!

✧ Interferometric studies have provided strong, clear evidences of equatorial disks/rings/torii. In the IR, VLTI may have some observational constraints (baselines, sensitivity).

High-resolution spectro-astrometry

Satisfactory results with a standard instrumental setup, using one telescope

- ✧ Succesful detection of jets in brown dwarfs (Whelan et al. 2005)
- ✧ Disks around Be stars (Wheelwright et al. 2012)
- ✧ Protoplanetary Keplerian gaseous disks (Pontoppidan et al. 2008; 2011) using CRIRES-VLT



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THE STRUCTURE AND DYNAMICS OF MOLECULAR GAS IN PLANET-FORMING ZONES: A CRIRES SPECTRO-ASTROMETRIC SURVEY

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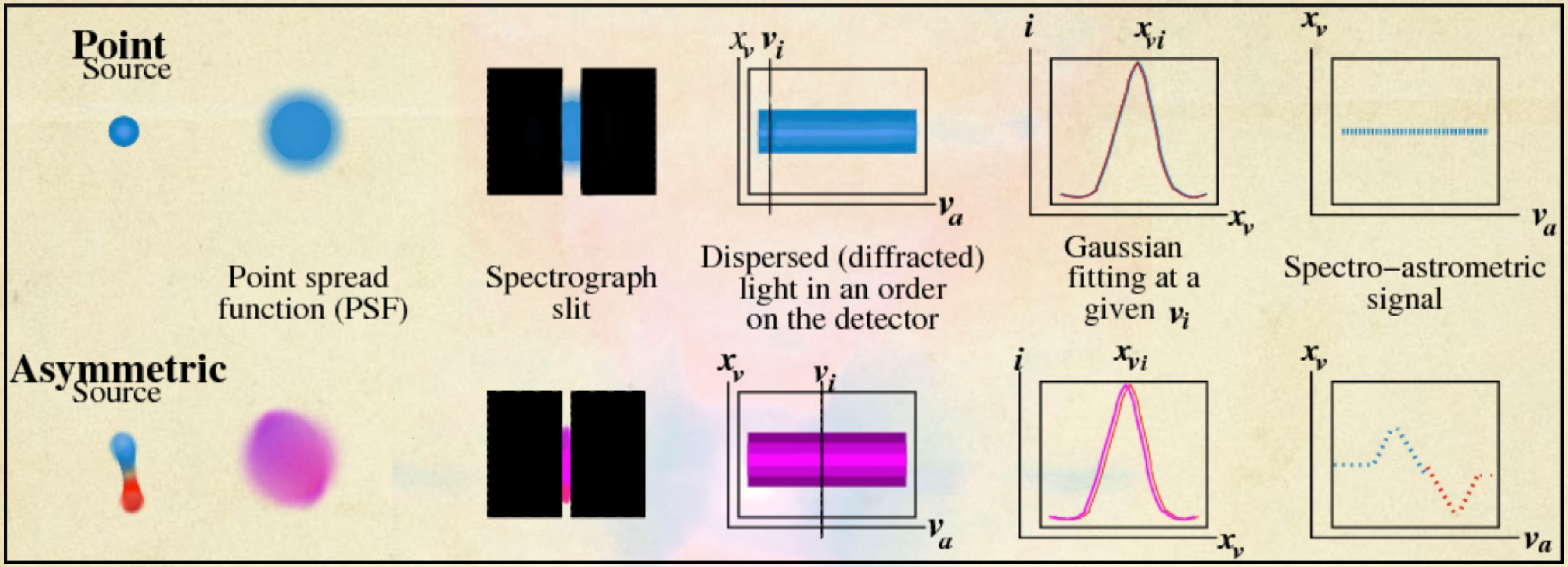
How does spectro-astrometry works?



Sketch of the SA technique for a point source and an asymmetric source, both blurred by the seeing (adapted from Whelan et al. 2008).

- ✓ Gaussian fitting along the dispersion axis (rectangular boxes of 3 km/s × 5.2 arcsecs for our CRIRES data).
- ✓ **We measure the offsets of the centroid wrt the continuum. The spectral signature originally diluted in the spectrum will appear.**
- ✓ A point source will not produce any SA signal. An asymmetrical source will reveal variations in the centroid offsets wrt the continuum emission varying along each PA.

For a spectro-astrometric analysis it is important to consider that:

- At least two PAs must be acquired to measure the variations of the SA signatures. The observation of an antiparallel PA (aPA) is mandatory to validate these signatures.

- The lines/features studied are selected considering the line-to-continuum ratio (the larger the better). If no low-dispersion spectrum is available, the chemistry and excitation of the source are useful as well.

- Continuum correction is important (continuum dilution of the SA signatures).

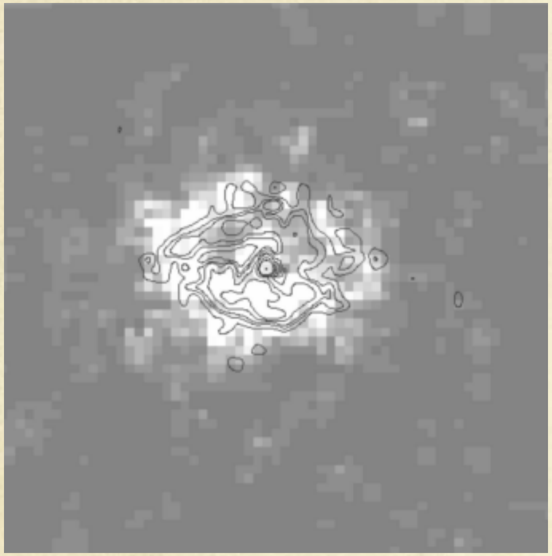
- Model fitting to the SA signatures is crucial to interpret the data (geometrical, radiative tranfer…).

CRIRES-VLT commissioning data

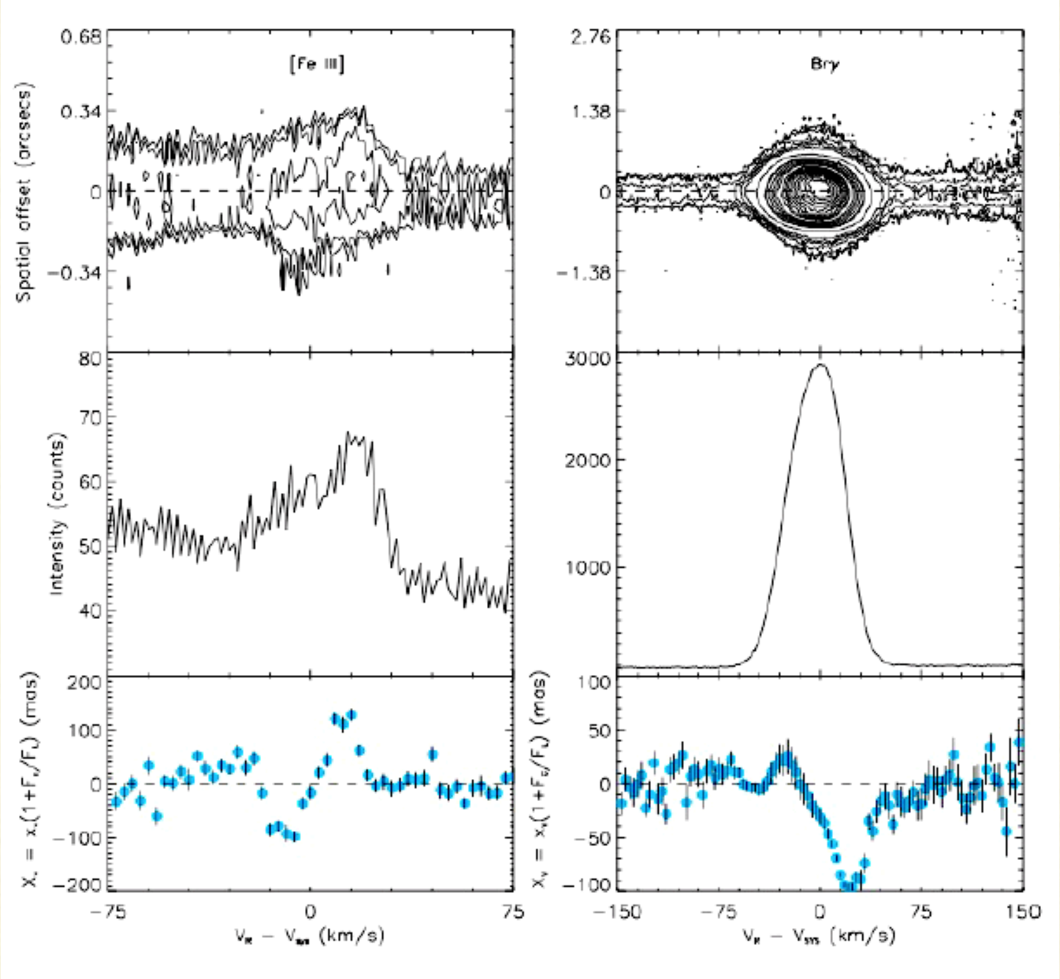
We have used commissioning data to develop the methology and the software to perform the spectro-astrometric analysis.

- 1 proto-PN (IRAS 17516-2525) and 1 young PN (SwSt 1).
- In previous studies both lacked for the resolution to fully unveil their morphological characteristics.

The young PN SwSt 1

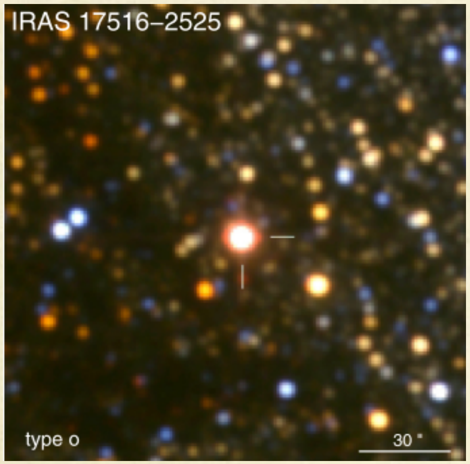


Deconvolved HST Hβ image over-plotted by [O III] contours (De Marco et al. 2001).

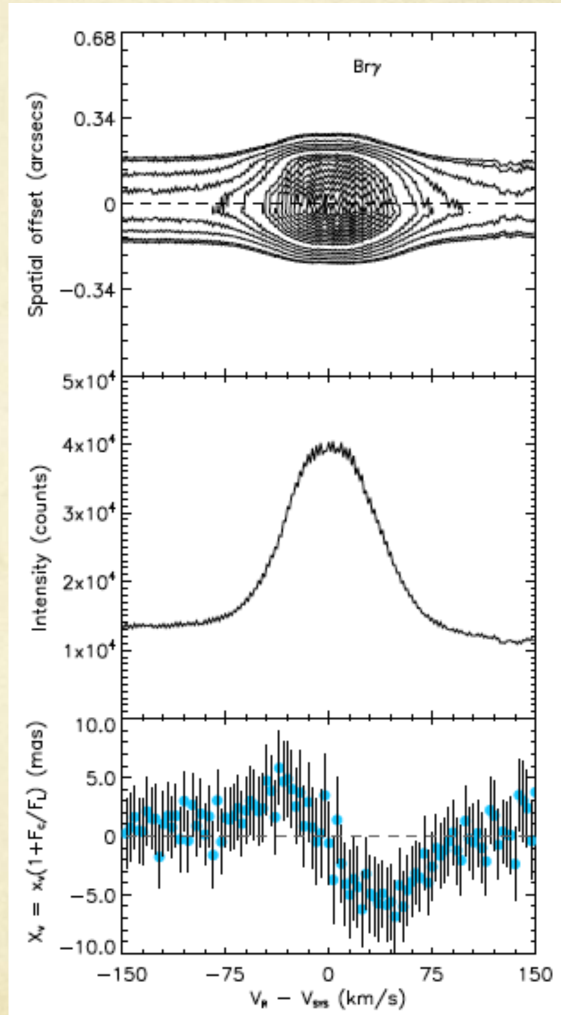


CRIRES spectra and spectro-astrometry of the [Fe III] and Brγ lines. The SA signatures detected for each line seems to trace different structures: a disk of 230 mas in the case of the [Fe III] infrared line at 2.145 microns and smaller bipolar lobes of 130 mas in size are probably detected in the Brγ line.

Proto-PN IRAS 17516-2525



(Left) RGB composite image of IRAS 17516-2525 with near-IR filters (JHK) of 2MASS (Ramos-Larios et al. 2009)



CRIRES spectrum and spectro-astrometry of the Br γ line. This structure are likely small bipolar lobes of 12 mas in size only revealed after the SA analysis.

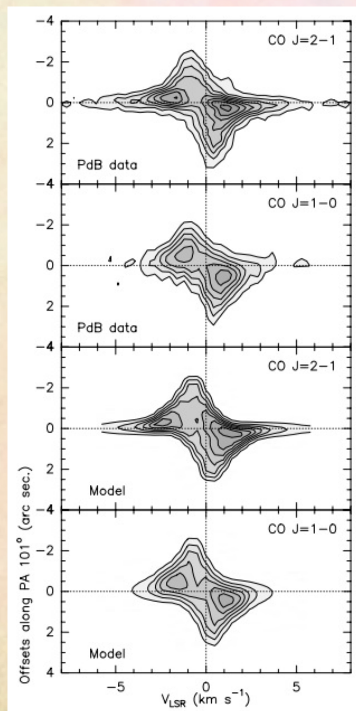
THESE DATA HAVE HELPED US TO DEVELOP THE METHOLOGY FOR THE SA ANALYSIS. HOWEVER, WE HAVE FOUND TANTALIZING SMALL-SIZED STRUCTURES

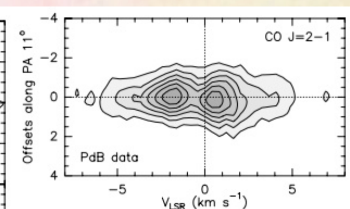
(from ≈12 mas up to ≈200 mas)

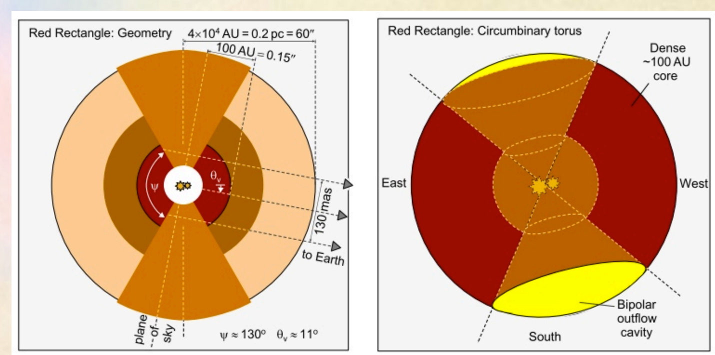
The Red Rectangle (AFGL 915)

What's going on?

- ✧ Close binary (common envelope)
- ✧ Dusty disk of crystalline silicates (Waters et al. 1998)
- ✧ Keplerian CO gaseous disk ≤ 560 AU (Bujarrabal 2003, 2005, 2007, 2013)
- ✧ Dusty massive and thick disk, likely accreting, at its innermost regions (150 mas = 100 AU, Men'shchikov 2002)





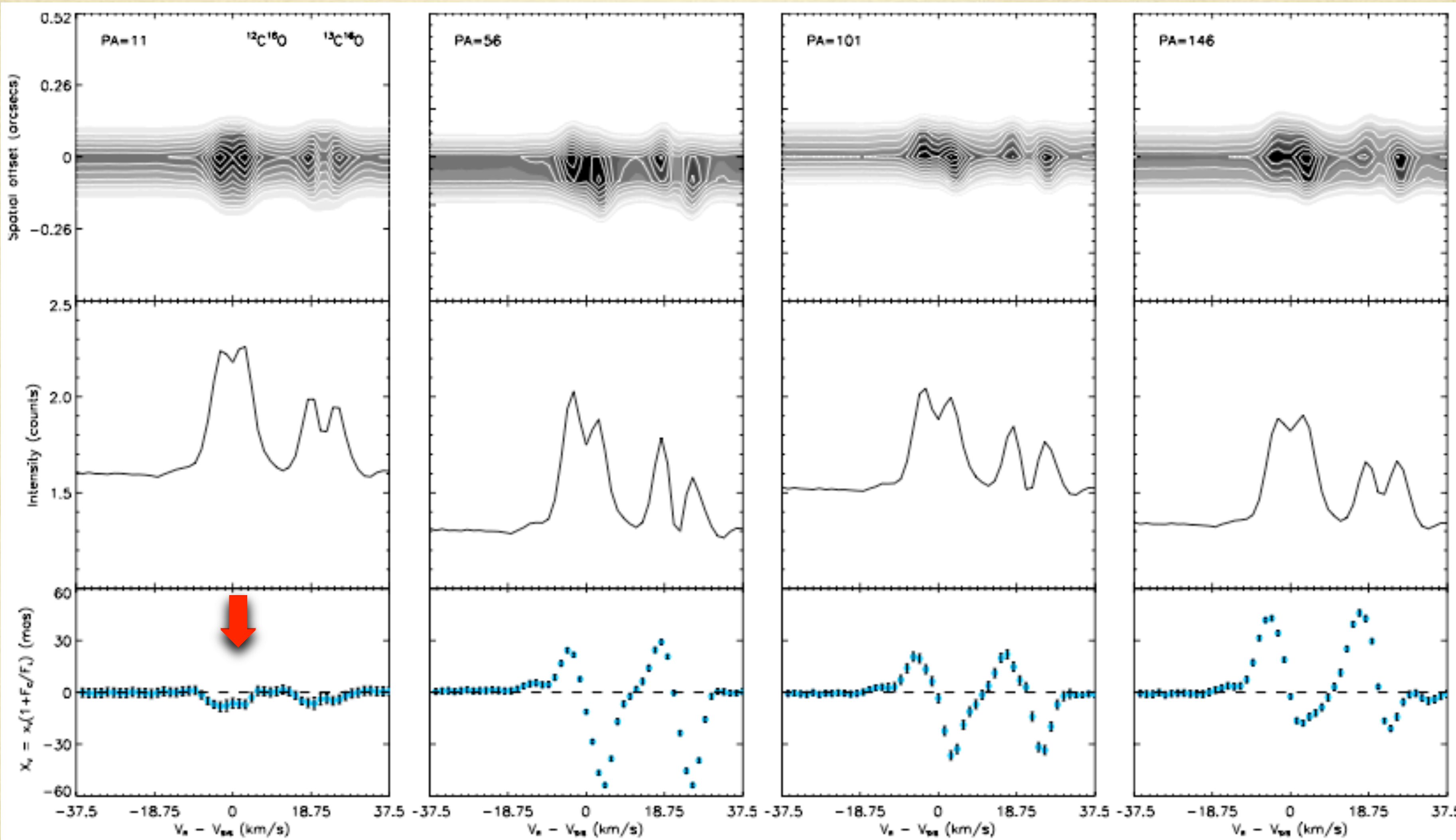


(*Left*) HST Image of the Red Rectagle (Koning et al. 2011). (*Center*) PV diagrams of the detected Keplerian disk of AFGL 915 (Bujarrabal et al. 2005). (*Right*) Innermost small–sized torus theoretically predicted by Men'shchikov et al. (2002).

CRIRES-VLT observations of The Red Rectangle

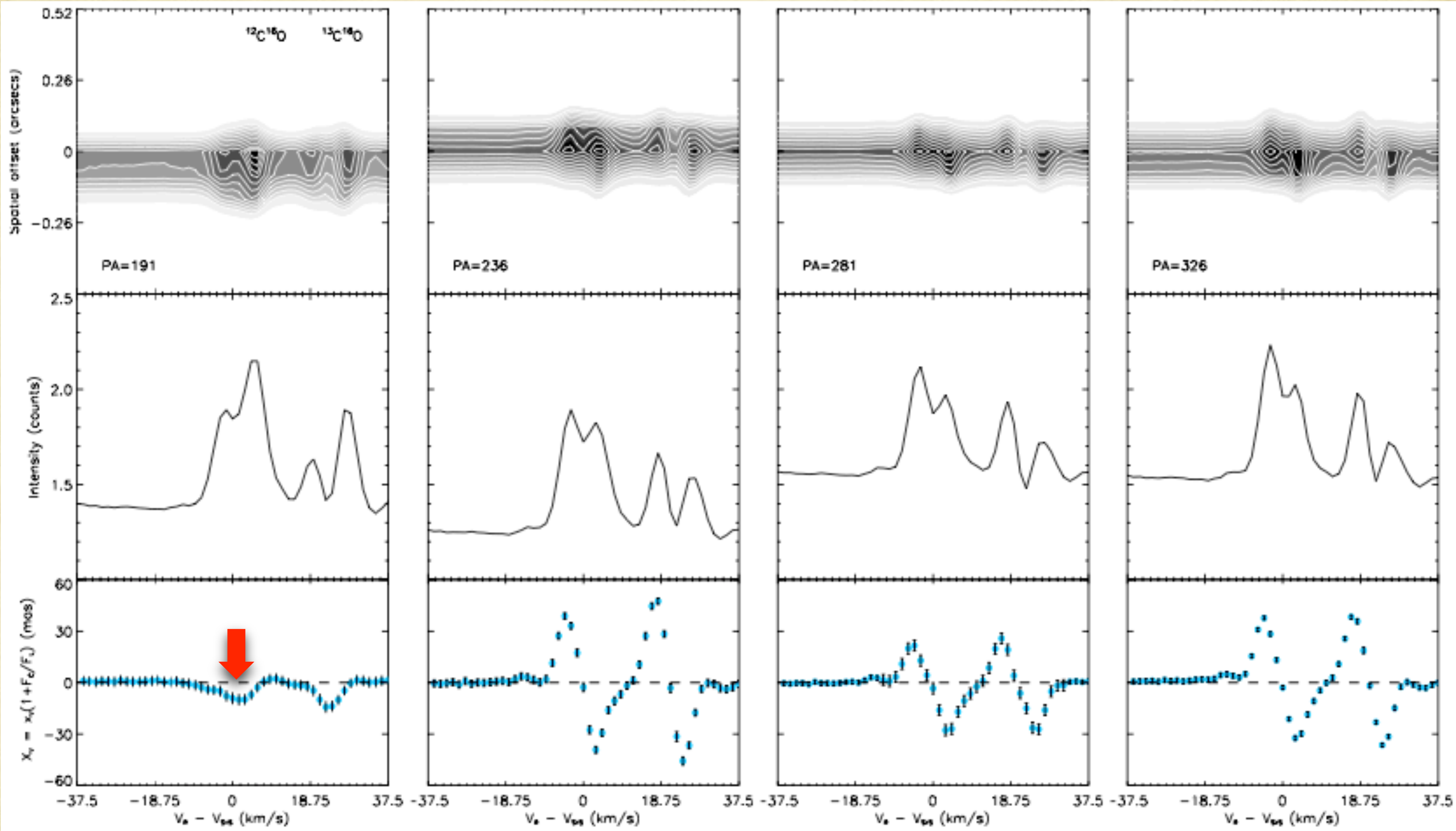
- Long-slit high-resolution spectra (AO loop closed) of the $^{12}C^{16}O$ (J= 1-0) fundamental band at 4.99 μm (Program 090.D-0761(A), P.I. M.W. Blanco)
- 4 PAs (11°, 56°, 101°, 146°) and their respective aPA (191°, 236°, 281°, 326°)

AFGL 915: CRIRES SA analysis (parallel PAs)



(*Upper*) Position-Velocity diagrams without spectroastrometry. (*Middle*) Double-peaked line intensity profiles, characteristic of Keplerian sources. (*Bottom*) Anti-symmetric velocity field after the SA analysis and varying with every PA acquired, also typical of Keplerian sources.

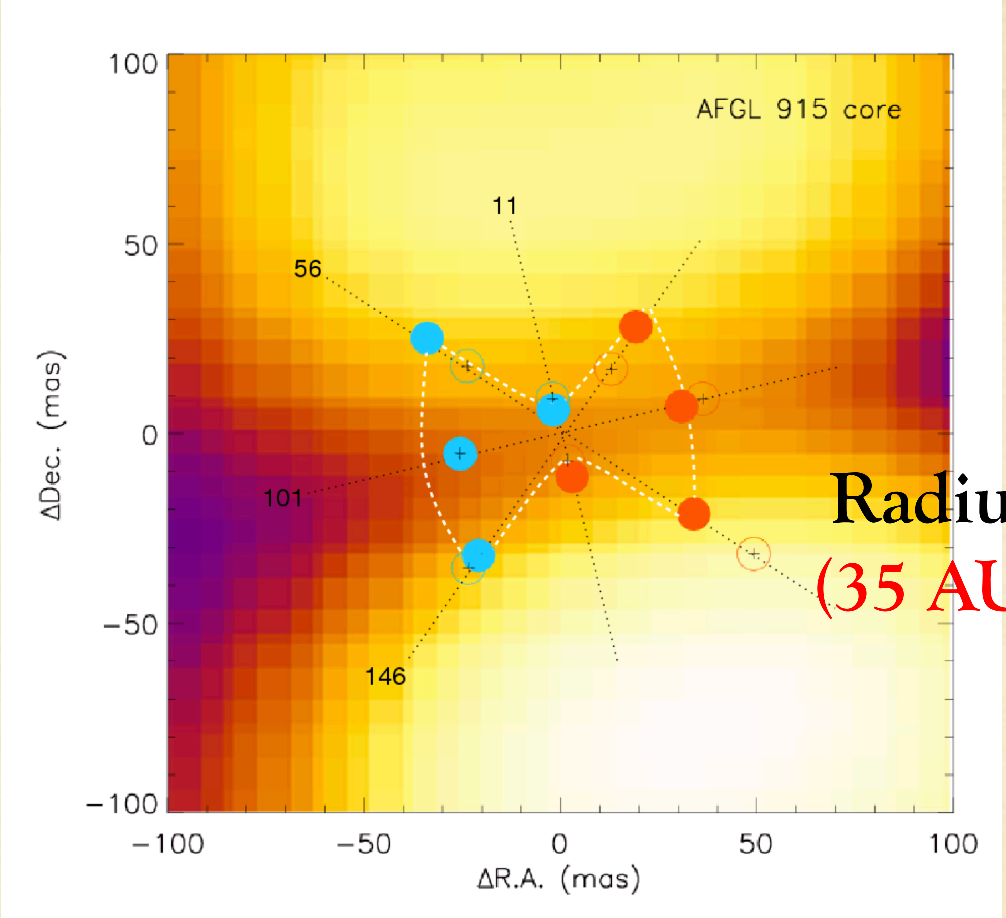
AFGL 915: CRIRES SA analysis (anti-parallel PAs)



(*Upper*) Position-Velocity diagrams without spectroastrometry. (*Middle*) Double-peaked line intensity profiles, characteristic of Keplerian sources. (*Bottom*) Anti-symmetric velocity field after the SA analysis and varying with every PA acquired, also typical of Keplerian sources.

The Red Rectangle

What else..?



Radius ≈ 50 mas
(35 AU at 710 pc)

Offsets superimposed in an H-band image (Men'shchikov et al. 1998). **A Keplerian toroidal structure of warmer CO gas along PA 101?** The blue and red filled circles represent the blue- and red-shifted velocities, respectively, per each PA and anti-parallel PA studied.

Summary & perspectives

- The SA technique offers a feasible alternative to dig deep into the innermost regions of asymmetric PNe (where the action takes place).
- **Small-sized structures can be seen in near-IR wavelengths!**
- A proper model fitting is crucial to a better comprehension and parameterize the structures found. Work is in progress.
- SA analyses of Mz 3 and M2-9 is in progress as well, stay tuned!
- We plan to extend our exploratory program to a survey using CRIRES-VLT and VISIR-VLT to study atomic and molecular gas, and dust.
- We expect to find disks and high velocity jets to add to the valuable information provided by the powerful IR and radio interferometers.