# Surface structure of AGB stars: complementing interferometry with spectro-astrometry

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## Summary

We present MIDI and CRIRES observations of the "normal" C-star TX Psc. The MIDI data show no evidence for deviations from circular symmetry or circumstellar dust. The spectro-astrometry with CRIRES points to the presence of a bright/dark region in the NE/SW very close to the star. Since this angular range is not covered by the MIDI observations, the results are consistent with each other but not necessarily with older adaptive optics data.


## 1. The normal(?) carbon star TX Psc

TX Psc is one of the brightest and nearest optical carbon stars and has been extensively observed from the visual to mm-waves. Its small variability, simple near IR spectrum, and weak gas mass loss made it a good test case for classical model atmospheres (Jørgensen et al. 2000). However, adaptive optics images (Fig. 3), lunar occultation data and mm-CO line profiles all indicate deviations from the simple picture (Richichi et al. 1995; Cruzalebes et al. 1998; Heske et al. 1989). Herschel-PACS data (Fig. 1) show an asymmetry in the same direction as indicated by the above observations but at a much larger scale and along the proper motion direction. Interaction with the ISM plays a major role here (Jorissen et al. 2011) but the reasons for the similarity in the orientations at different scales are still unclear. Possibilities range from a strongly asymmetric mass loss event to the presence of a companion.

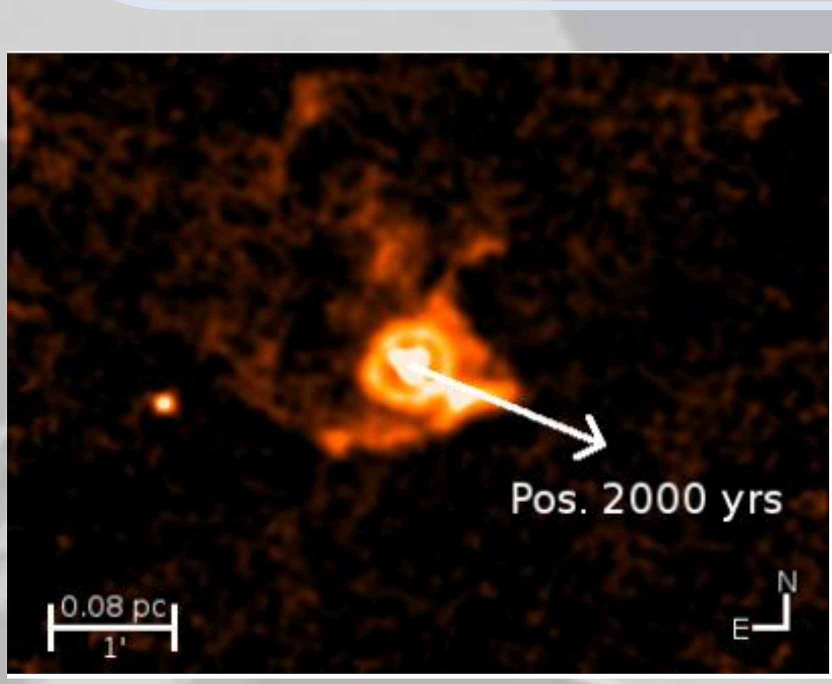


***Figure 1:*** Herschel PACS image of TX Psc at 70μm. (Jorissen et al. 2011). The arrow indicates the direction of the proper motion which is similar to the elongation seen with adaptive optics (cf. Fig. 3).

## 2. Spectro-astrometry

This technique measures the position of the photocenter as function of wavelength and can reach accuracies much better than the angular resolution of the telescope. The accuracy depends only on the S/N and the width of the PSF. The method is regularly used for YSOs (e.g. Pontoppidan et al. 2008) and a first application to cool giants was presented in Voigt (2009). Object mapping is performed by long-slit exposures with several slit position angles (PA). The main concern are artefacts caused by the shape of the PSF and internal instrumental effects. A simple and quite effective way to detect these artefacts is to obtain spectra at PA and PA+180° (e.g. Brannigan et al. 2006) since real signatures should show up with opposite sign.

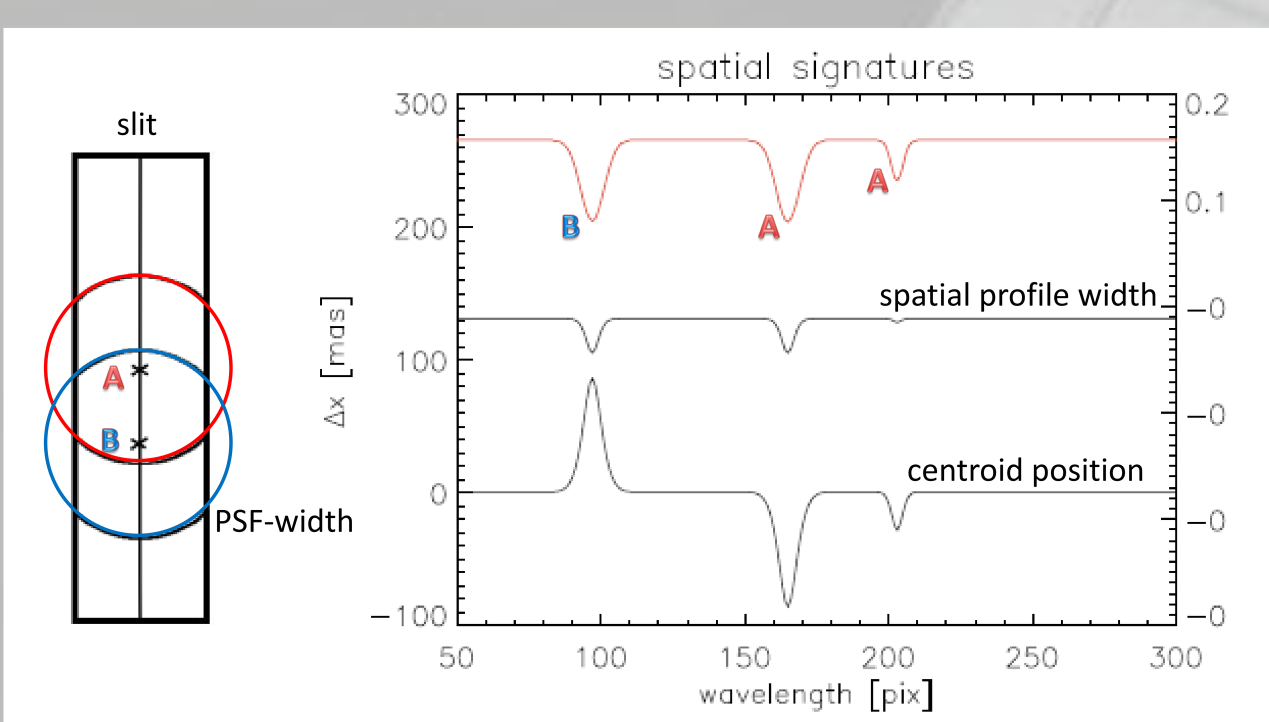


***Figure 2:*** The principle of spectro-astrometry based on simulations (from Voigt, 2009). The crosses indicate the position of the binary components A and B, the circles give the size of the PSF and the spectral lines belonging to them are marked in the spectrum. For a slit rotated by 180°, the signatures in the centroid position should point in the opposite direction. A slit inclined to the separation vector introduces also a wavelength shift.

## 3. CRIRES observations

We have obtained spectro-astrometry in several wavelength regions and for 4 PAs. The PAs were chosen to check for any asymmetries in the directions indicated by AO (Fig. 3) and the observations were repeated with PA+180°. The wavelengths covered quasi-continuum regions around 2.15μm and 3.6μm, HCN and $C_2H_2$ lines around 3.1μm and CO Δv=1 lines near 4.6μm. The slit width was 0.″15 and to avoid detector saturation, the windowed read-out mode was used (only 2 of the 4 chips could be used). The observing conditions were very good (0.″6 seeing). In addition, we observed a standard star with the same setup and PAs. Data were reduced with the CRIRES pipeline, the centroid positions were derived from Gauss-fits.

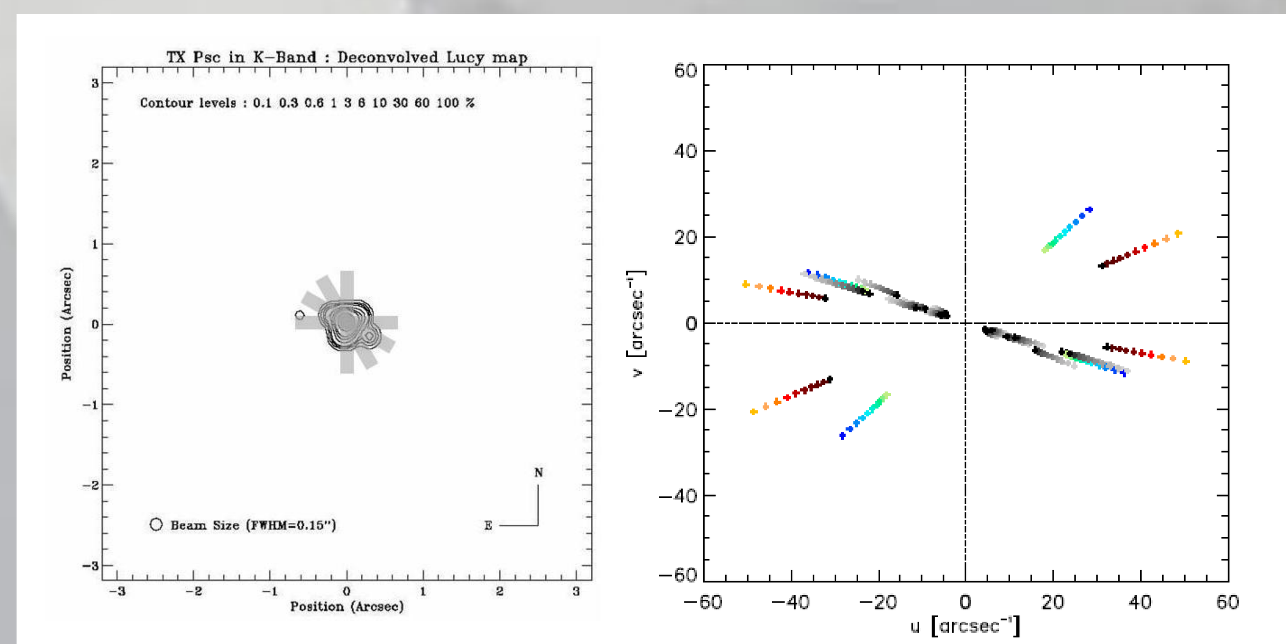


***Figure 3 (left):*** Reconstructed map obtained with COME-ON+ at the ESO 3.6m telescope in the K-band (Cruzalebes et al. 1998). The slit positions are superposed with the actual slit width used.
***Figure 4 (right):*** uv-coverage of the MIDI observations used. The colors distinguish different wavelengths and observing epochs. The orientation is the same as in Fig. 3.

## 4. MIDI observations

TX Psc was observed with VLTI/MIDI between 2004 and 2009 using ATs and UTs. Baseline lengths range from 11.9m to 90.3m with PAs between 66 and 133 . The observations were reduced with MIA+EWS and only the ones obtained under good atmospheric conditions and with good agreement between the MIA and EWS results were used for further analysis (Fig. 4). Calibrated visibilities are the averages of the results obtained using different calibrators. The visibility errors correspond to the standard deviation of the results derived with different calibrators in the same night. If the error was lower than 10% a standard error of 10% was used instead.

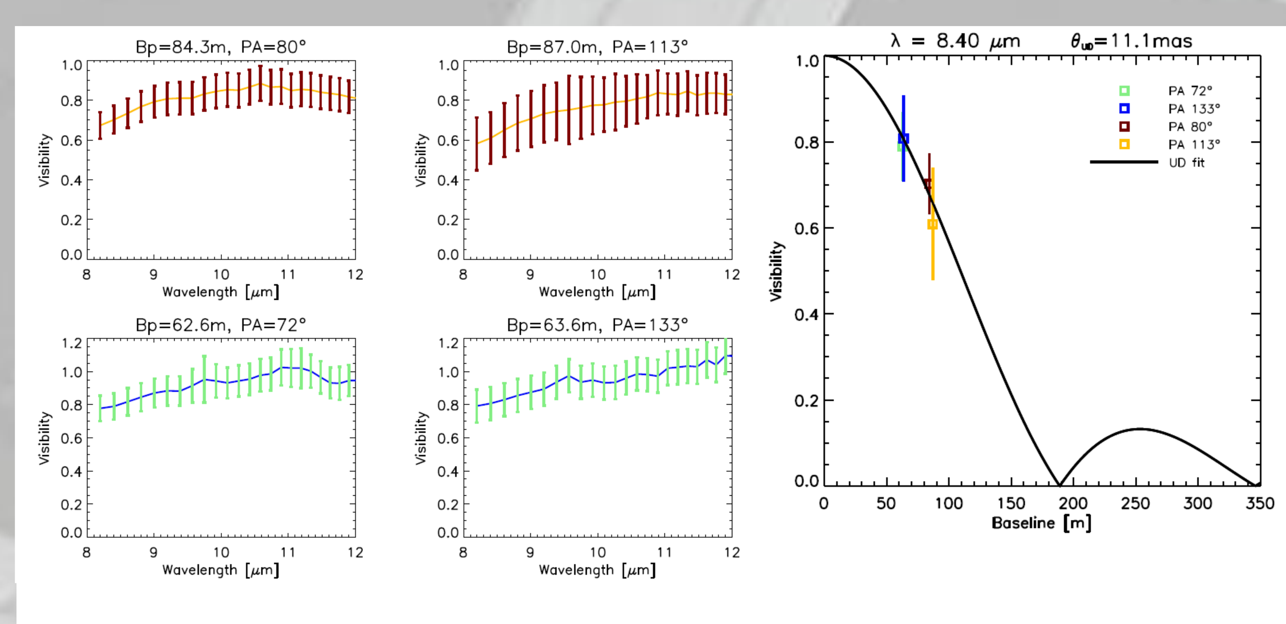


***Figure 5 (left):*** Visibilities for the selected MIDI data sets. Colour coding as in Fig. 4.
***Figure 6 (right):*** Uniform disk fit to the data sets of Fig. 5 at 8.4μm.

## 5. MIDI results

Most of the observations were taken at a position angle of ~70 in order to be able to study the different layers of the circumstellar environment. Different position angles, on the other hand, taken at the same baseline length allow to study the symmetry of the circumstellar surroundings. Two such data sets (Upper panel: ~85 m; Lower panel: ~63 m) were available for TX Psc and are shown in Fig. 5. Comparing the calibrated visibilities of the left plots with the ones of the right plots yields no change in the profile and spectral shape within the errors. This strongly suggests that the **atmosphere of TX Psc is spherically symmetric** (at these PAs and baselines). There is also no signature of SiC dust as expected from the available IR-spectra. The derived **UD diameters** (Fig. 6) range between 8.5mas and 11.4mas but agree within their errors. These numbers are practically **identical to** those found by Quirrenbach et al. (1994) from **interferometry between 0.7 and 0.8μm.** This confirms that there is **no circumstellar dust around TX Psc.**

## 6. CRIRES results

The results can be summarized as follows:

- The FWHM of the spectra along the slit is about 2 pixels or 0.″17 at 4.6μm (2.6 pixels at 2μm), indicating the good AO performance of CRIRES
- The **flux spectra** extracted for different PAs and nodding positions **agree to within better than 1% (Fig. 7)**
- The **position spectra** (i.e. photocenters as a function of λ) for different PAs and nodding positions **in the K-band** generally **are identical** within a few 0.01pixels.
- However, the **position spectra of most CO-lines** around 4.6μm and several **$C_2H_2$ lines** around 3.1μm show **systematic differences between PA and PA+180° (Fig. 8)**.
- The differences are **weakest for the v=3-2** transitions.
- The systematic differences are strongest for PA=0-30° and disappear for PA=90° (Fig. 9) **indicating the presence of a bright region in the NE or a dark region in the SW**.
- This asymmetry is consistent with the MIDI results but probably not with the AO image. To clarify this, a deeper analysis needs to be carried out.

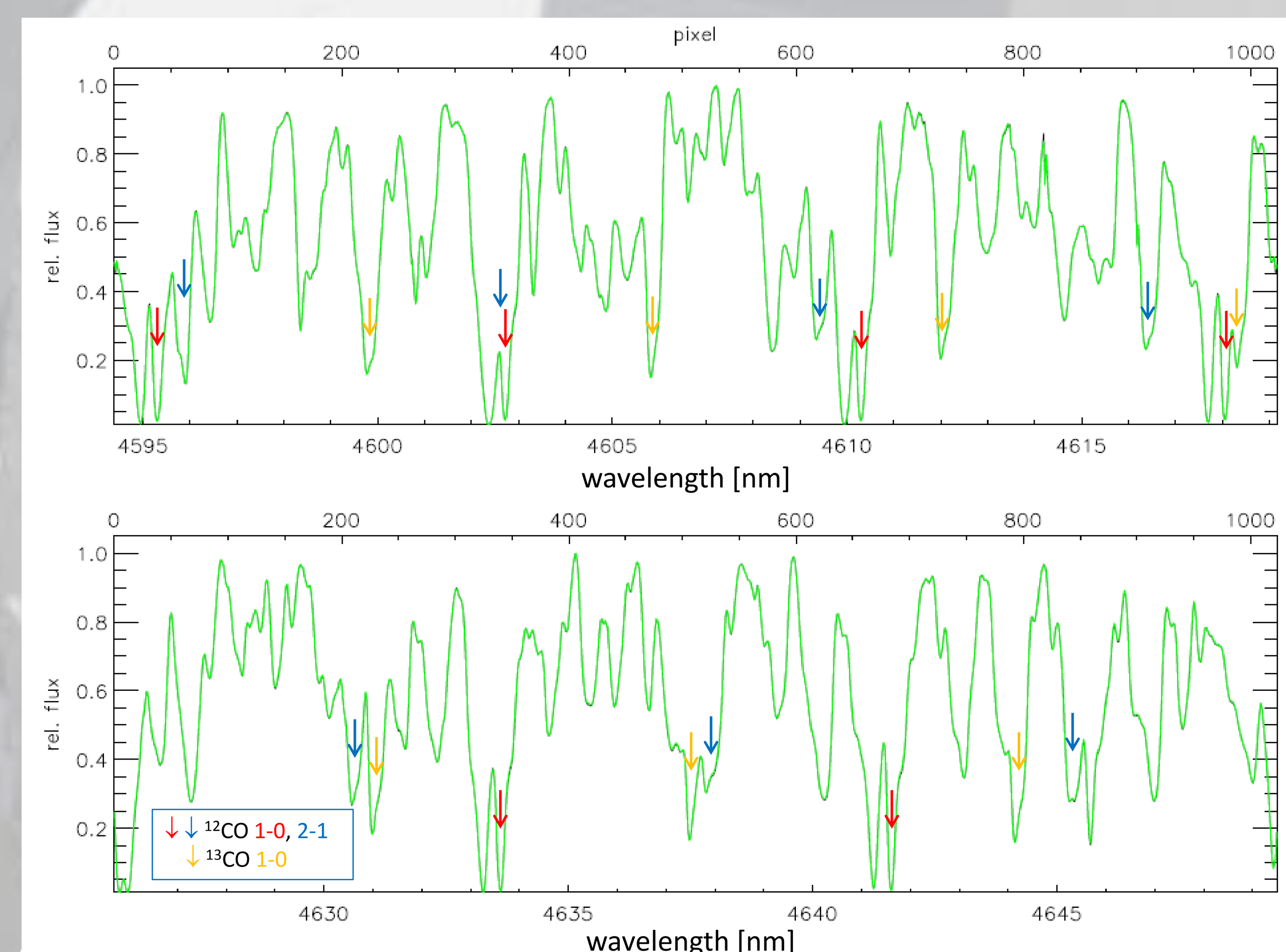


***Figure 7:*** Pipeline extracted spectra near 4.6μm for PAs 0°(black) and 180° (green). The spectra are basically indistinguishable. Some CO-lines are indicated.

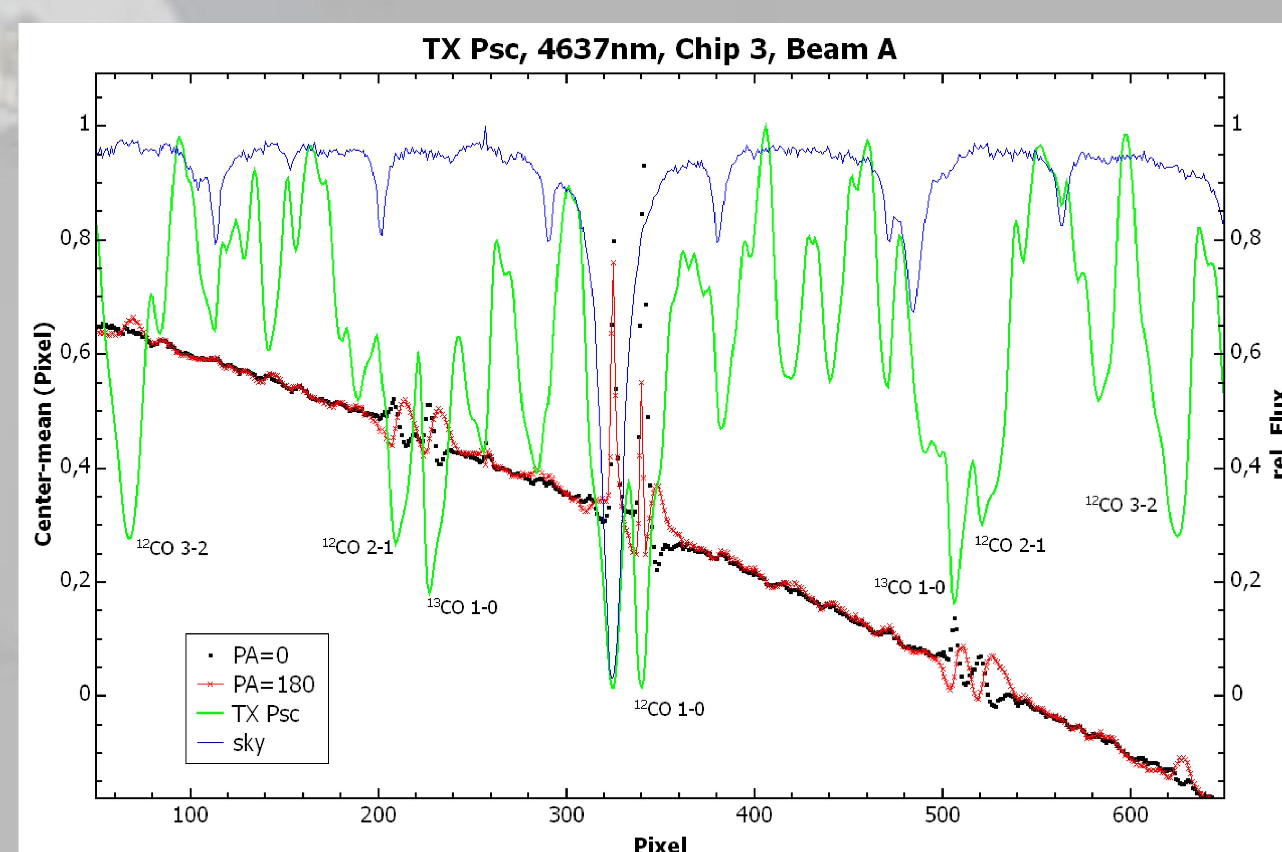


***Figure 8:*** A comparison of flux and position spectra for a selected region of Fig. 7. The green and blue lines are the flux spectra of TX Psc (green) and a standard star (blue) at PA 0°, respectively (right Y-axis). The black and red lines are the position spectra for PA 0° and 180°, respectively (left Y-axis). Some CO lines are identified. Note the clear signatures for asymmetries at X ~ 210, 230, 350, 510, 530 pixels.

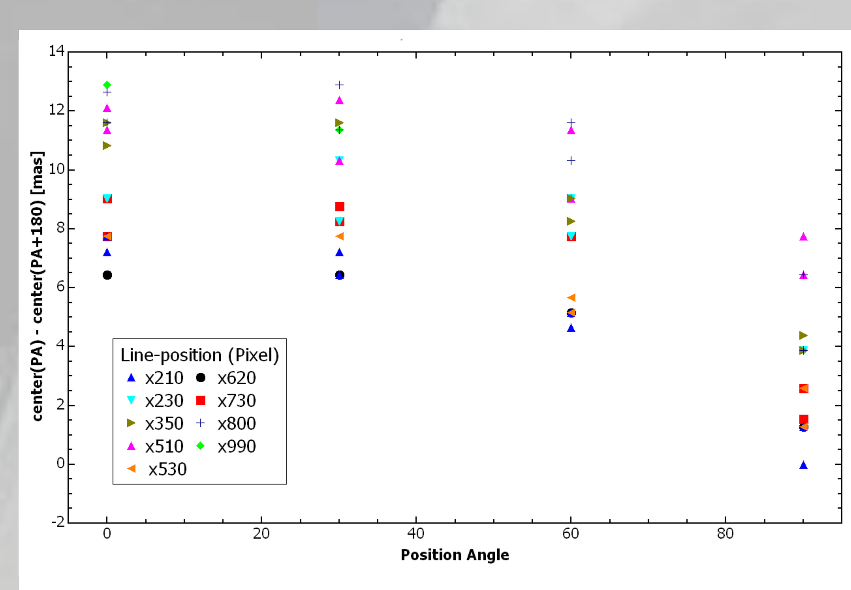


***Figure 9:*** Differences in position spectra between PA and PA+180° for selected lines (identified by their pixel position) near 4.6μm versus PA. The maximum effect is seen at PA≲30°. Note that two measurements are plotted for each spectral line and PA corresponding to the two nodding positions.

## Questions?

Meet me here or mail to josef.hron@univie.ac.at


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