

# 2D point spread function characterization for Prime Focus Spectrograph

Neven Caplar



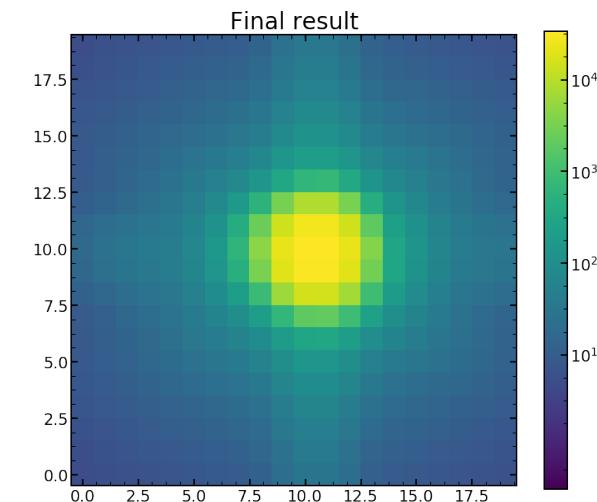
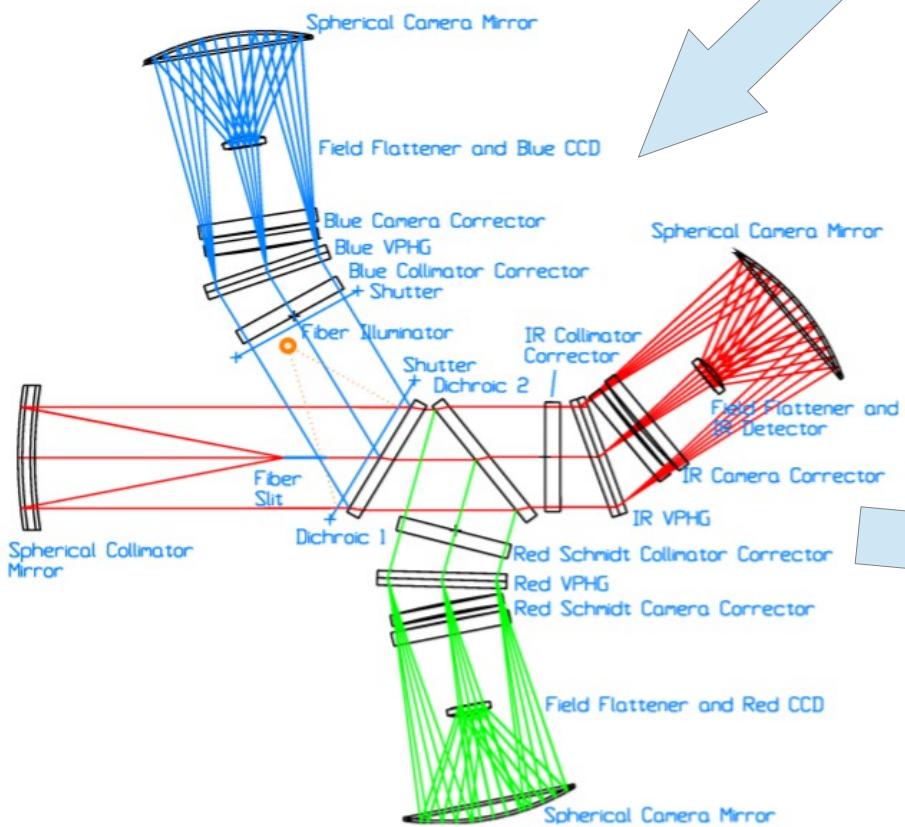
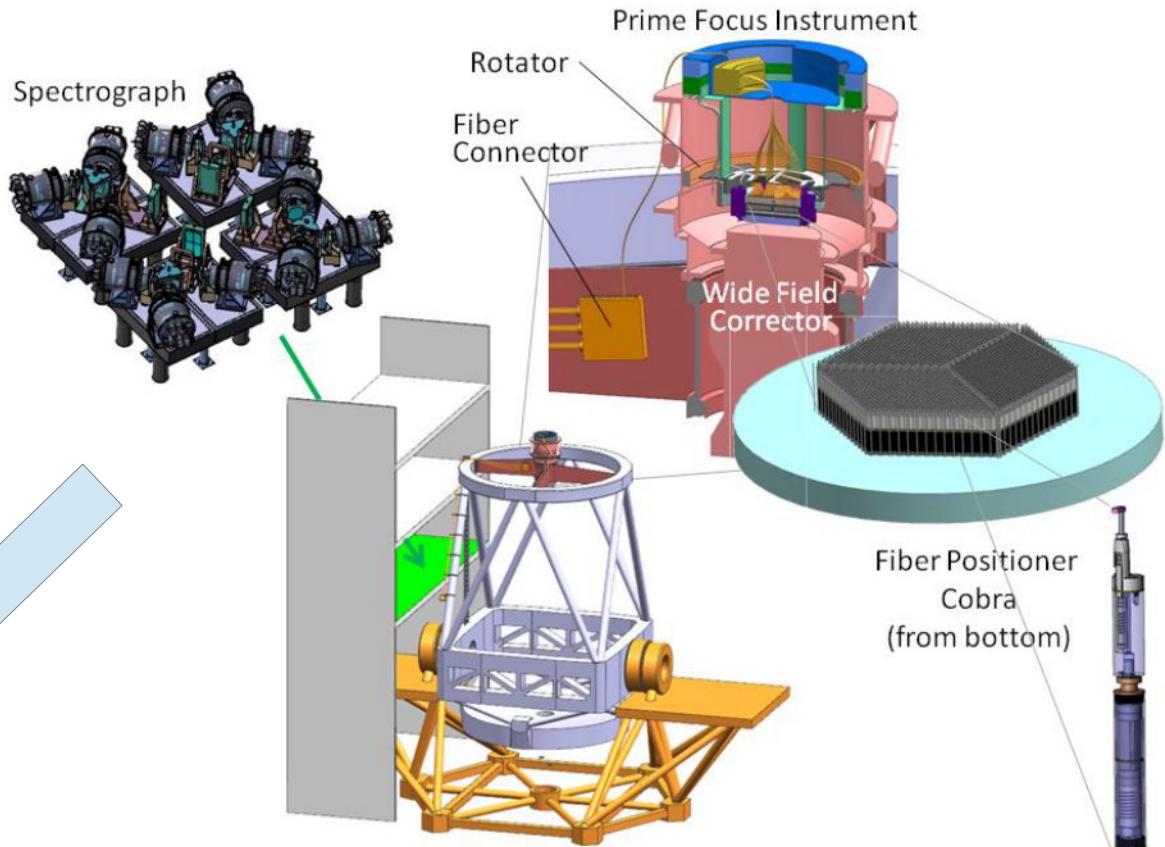
PRINCETON  
UNIVERSITY



## Contents

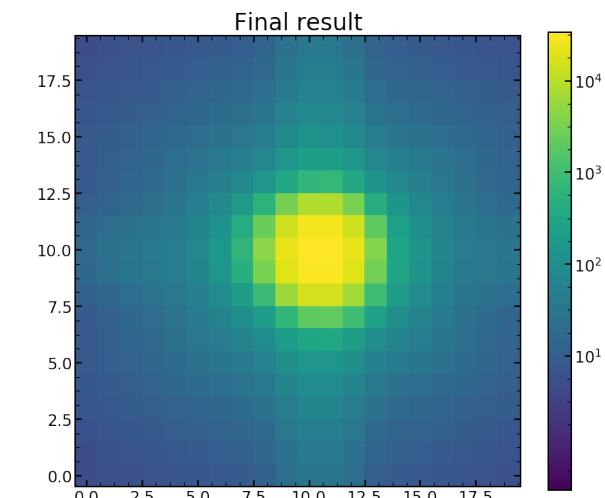
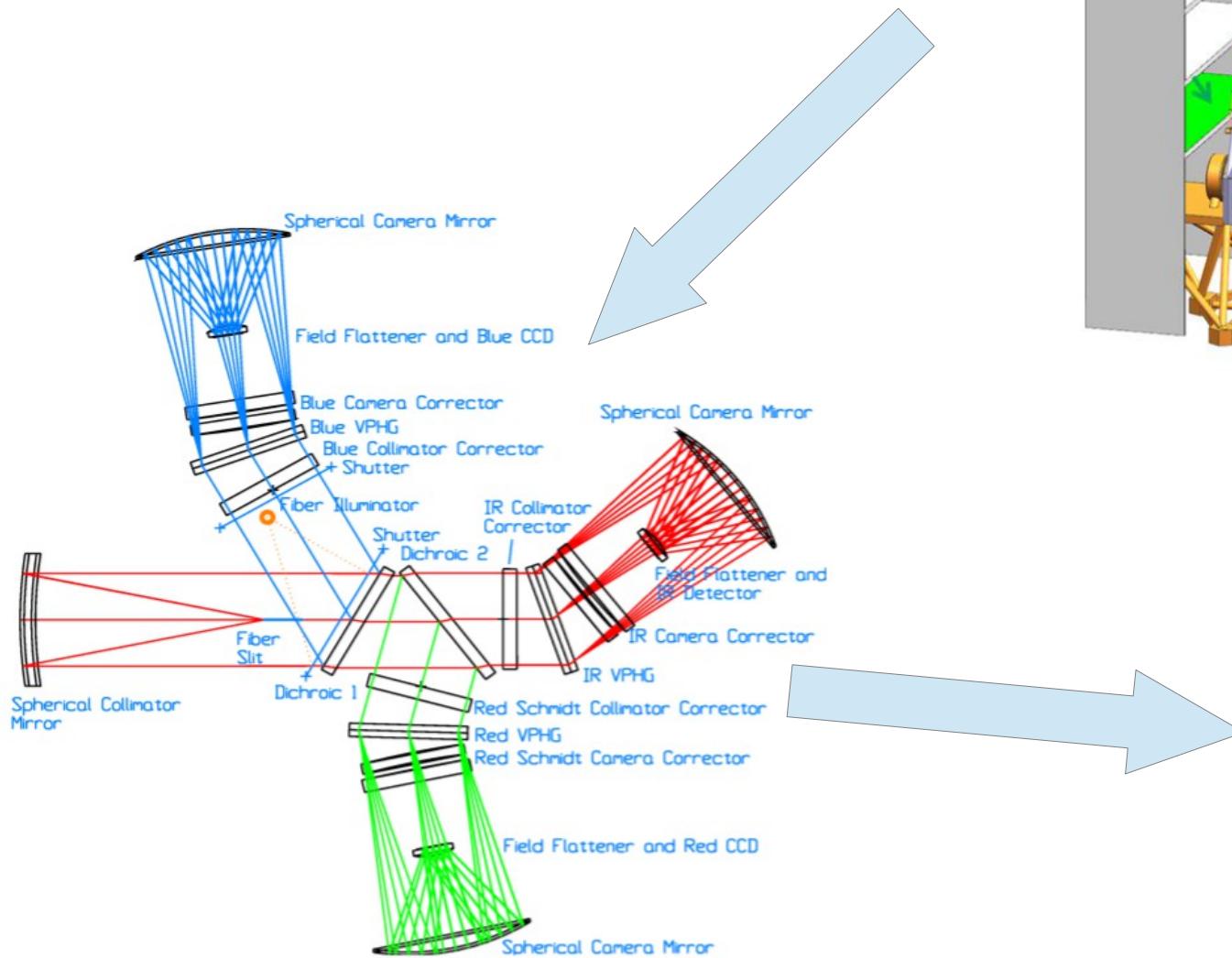
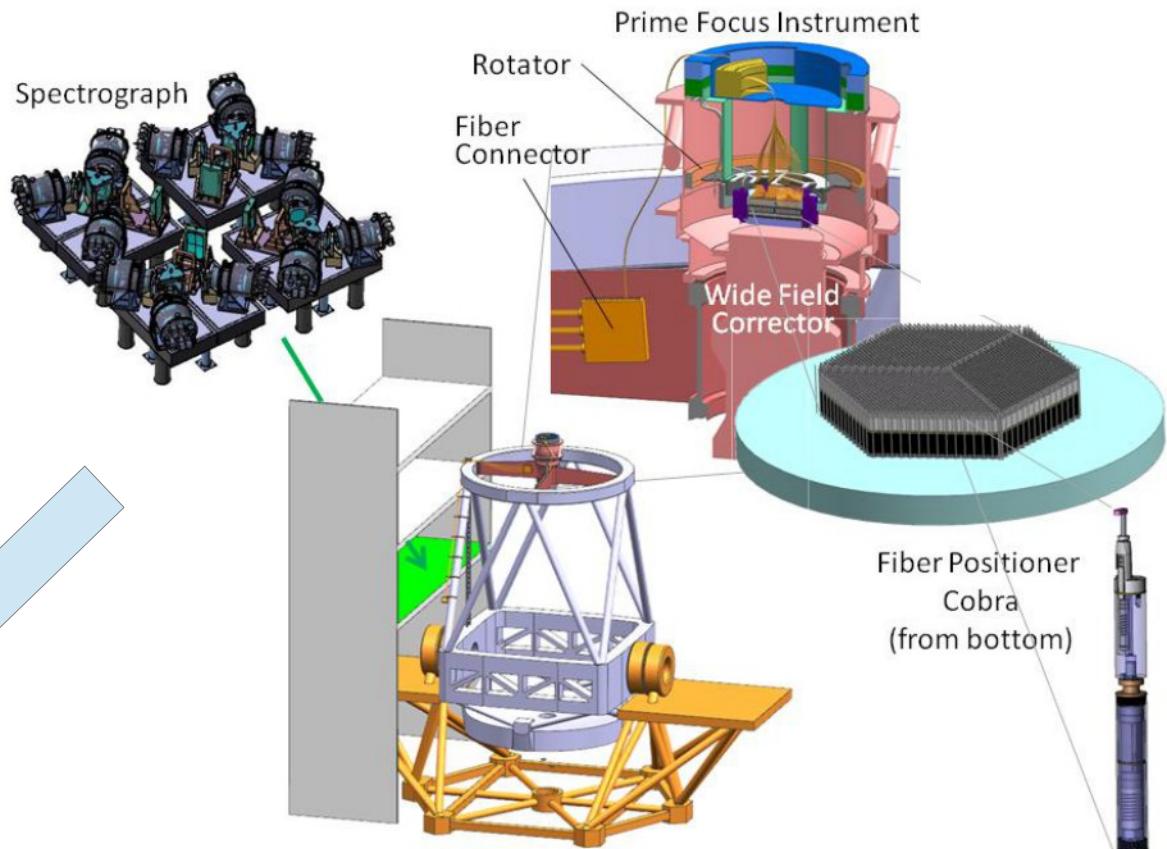
- Overview of the spectrograph
- Sky subtraction
  - 2d point-spread function algorithm
  - Analysis of defocused images
  - Behavior of wavefront
- Some interesting topics/problems (optional)
  - Overlap
  - Wings

- 2394 fibers on 8.2 meter Subaru Telescope
- 360 nm – 1260 nm
- 1.6 to 2.7 Angstrom resolution
- Start of commissioning: Oct 2021



# 3 components to the PSF

- Telescope pupil illumination
- Focal ratio degradation in the fibres
- Spectrograph cameras



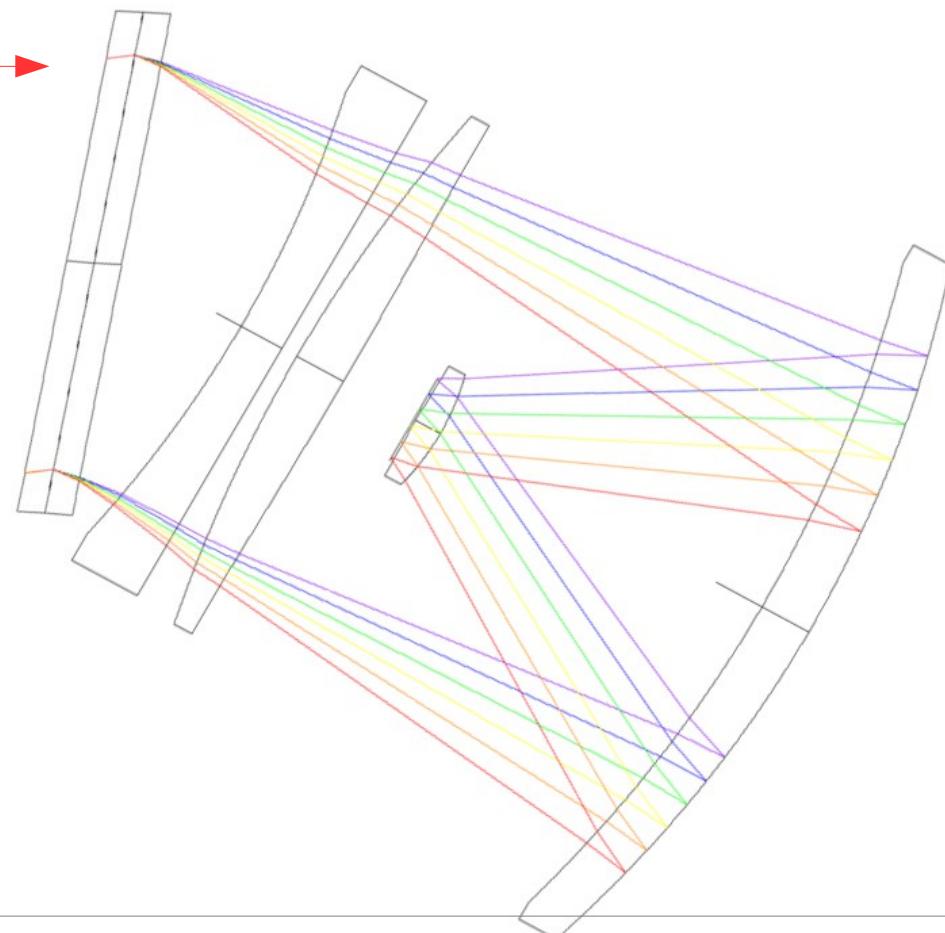
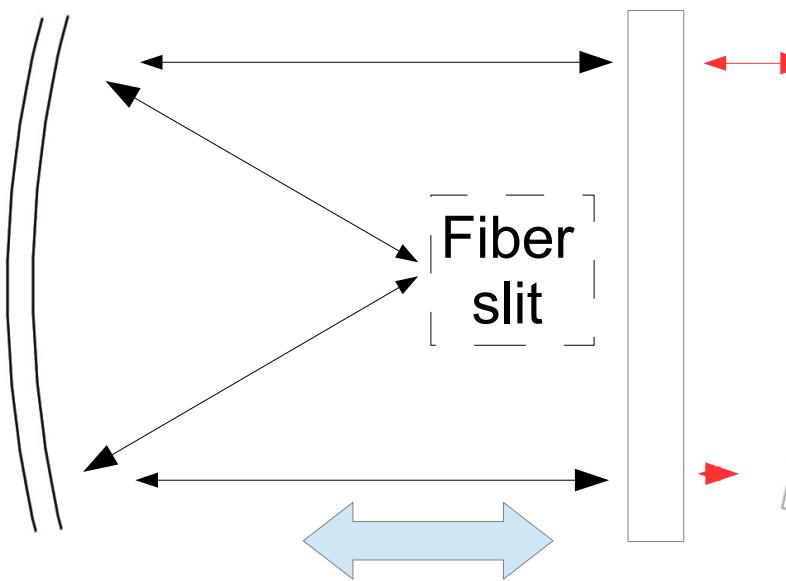
3 components to the PSF

- Telescope pupil illumination

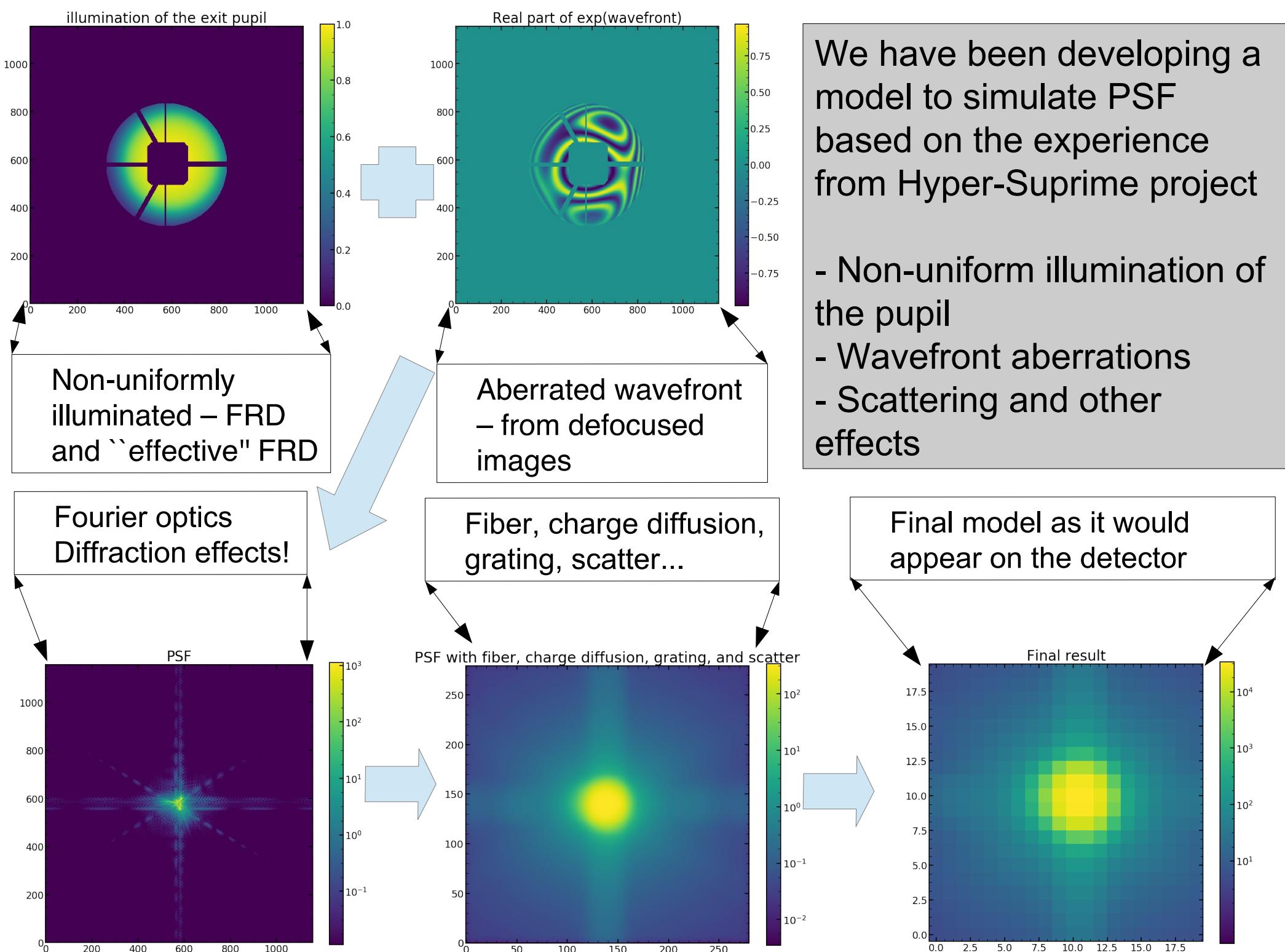
- Focal ratio degradation in the fibres

- Spectrograph cameras

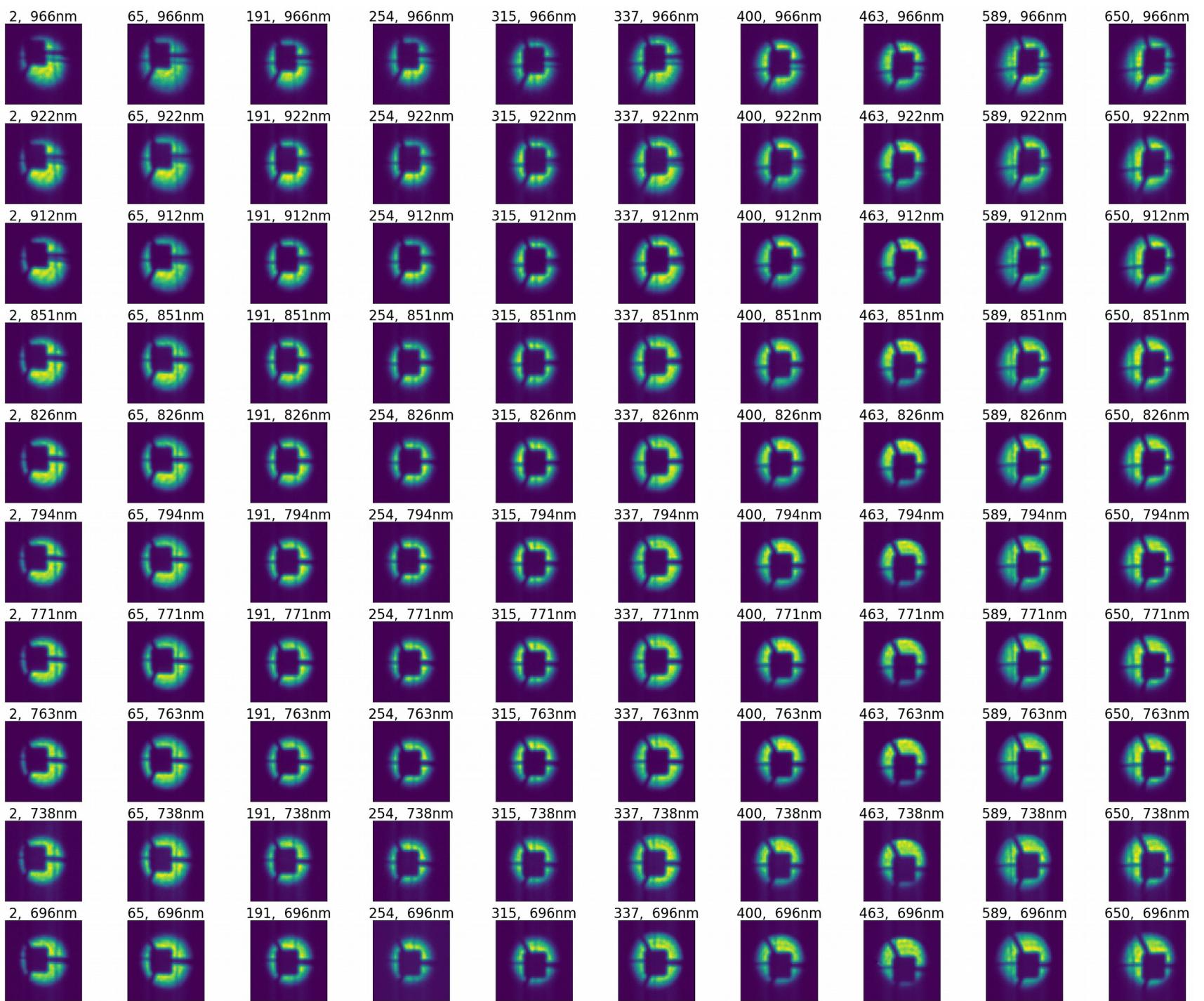
- Separate these 3 components (vignetting, fibers & camera) causing aberrations in the PSF by working in wavefront space
- We aim to characterize contribution of camera imperfections to PSF by modelling optical performance using defocussed data



Single camera

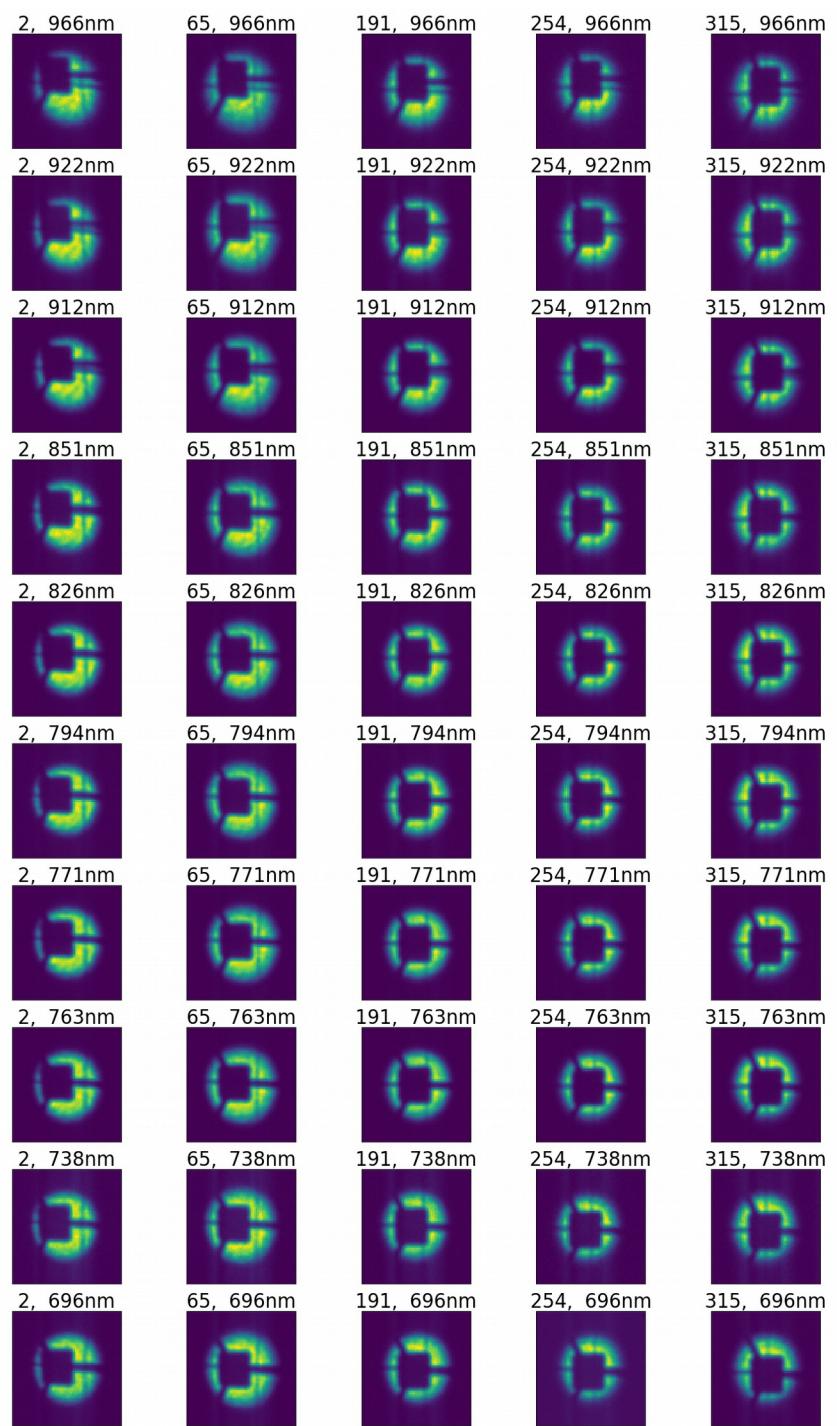


Wavelength

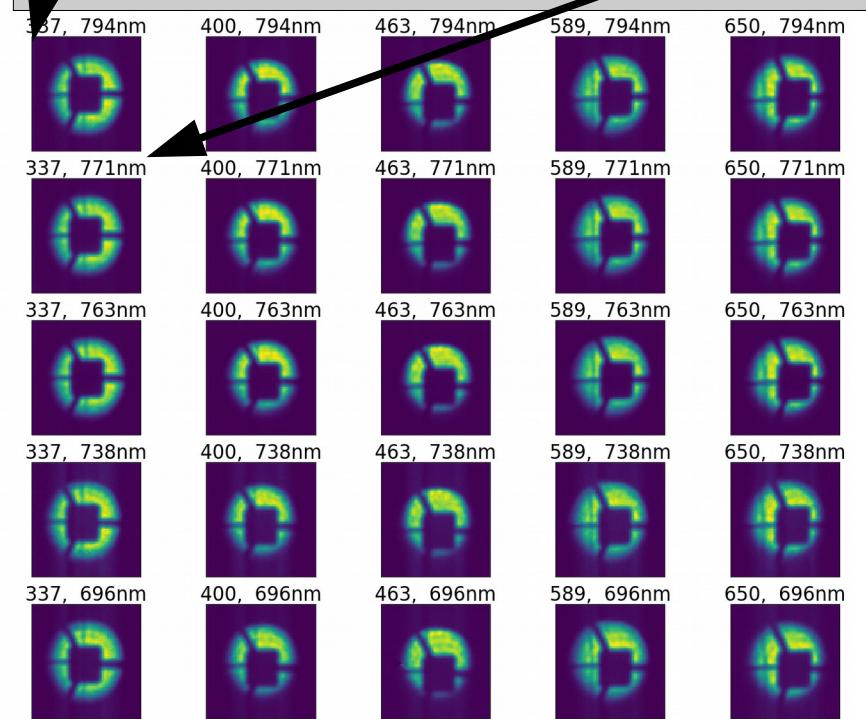
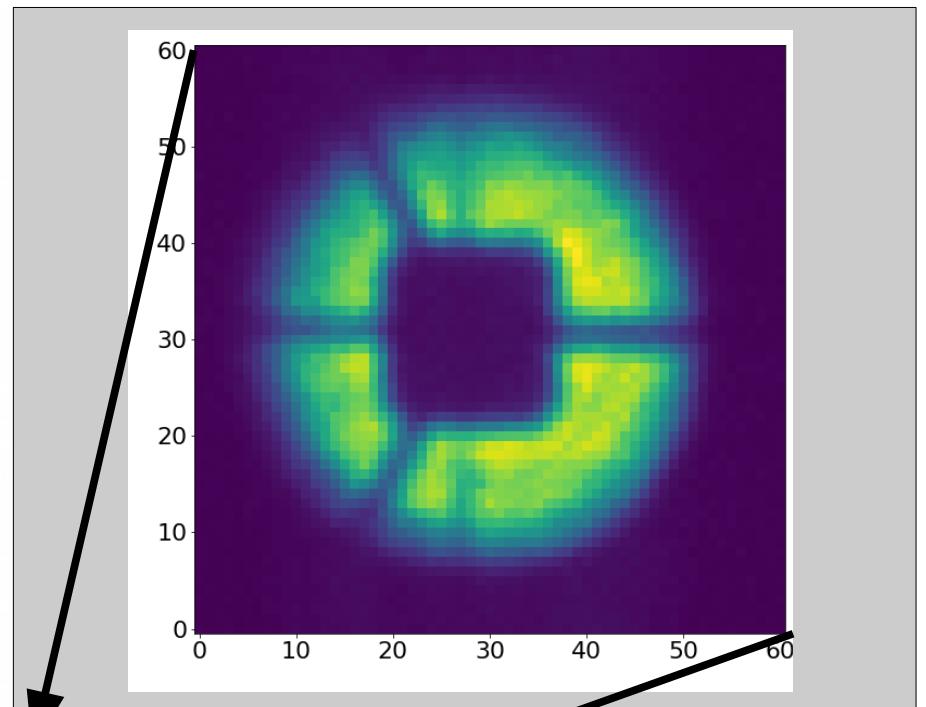


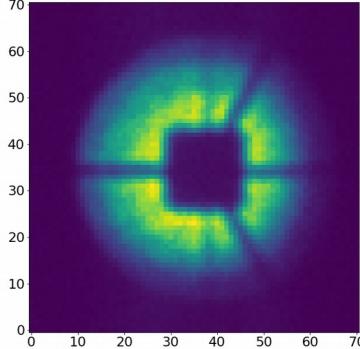
Different fibers

Wavelength



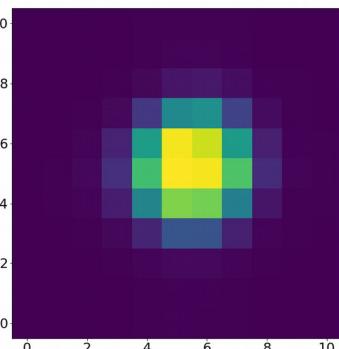
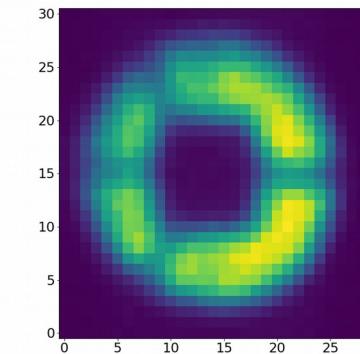
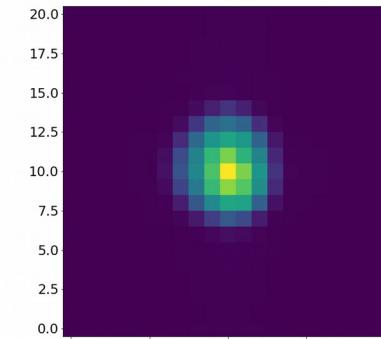
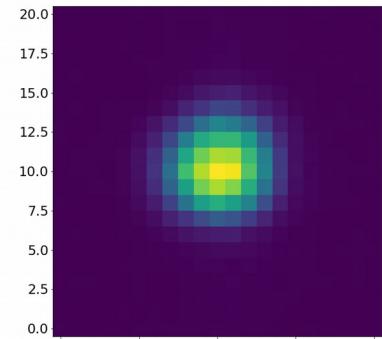
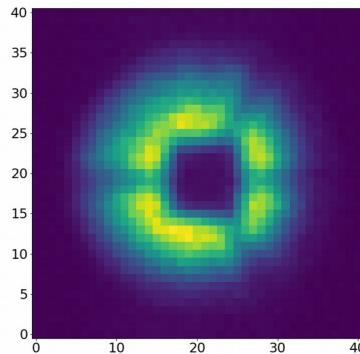
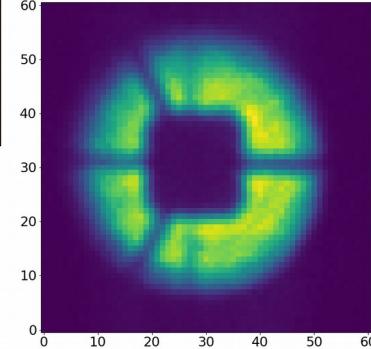
Different fibers





## How to decouple the illumination and the wavefront aberrations?

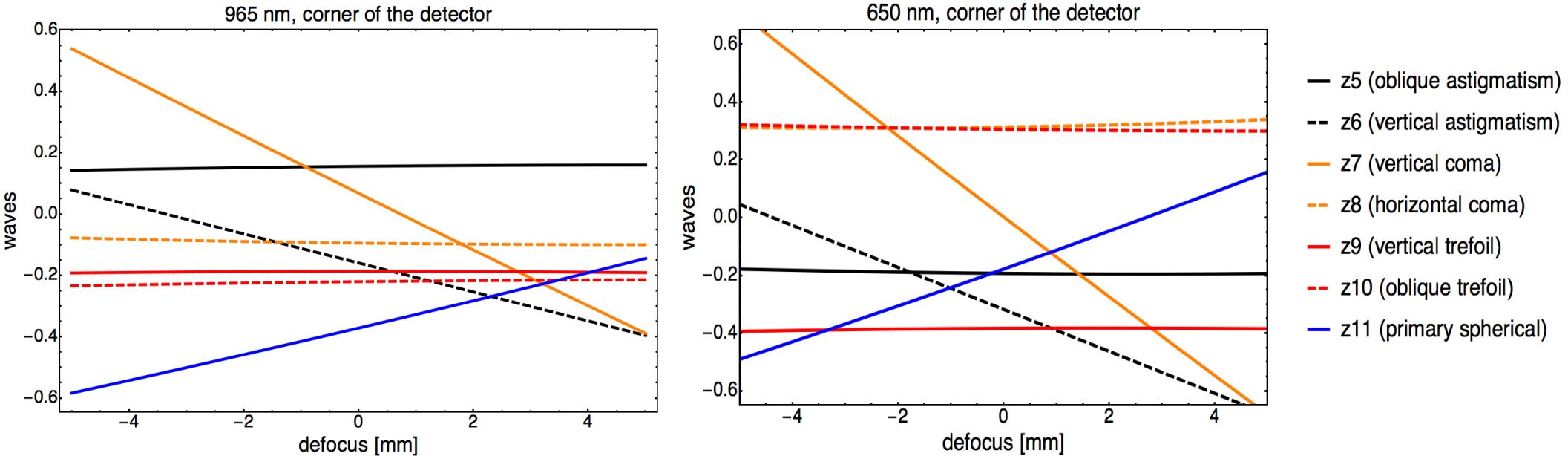
- Images at different value of defocus
- Follow wavefront aberrations as a function of defocus



More defocused

In focus

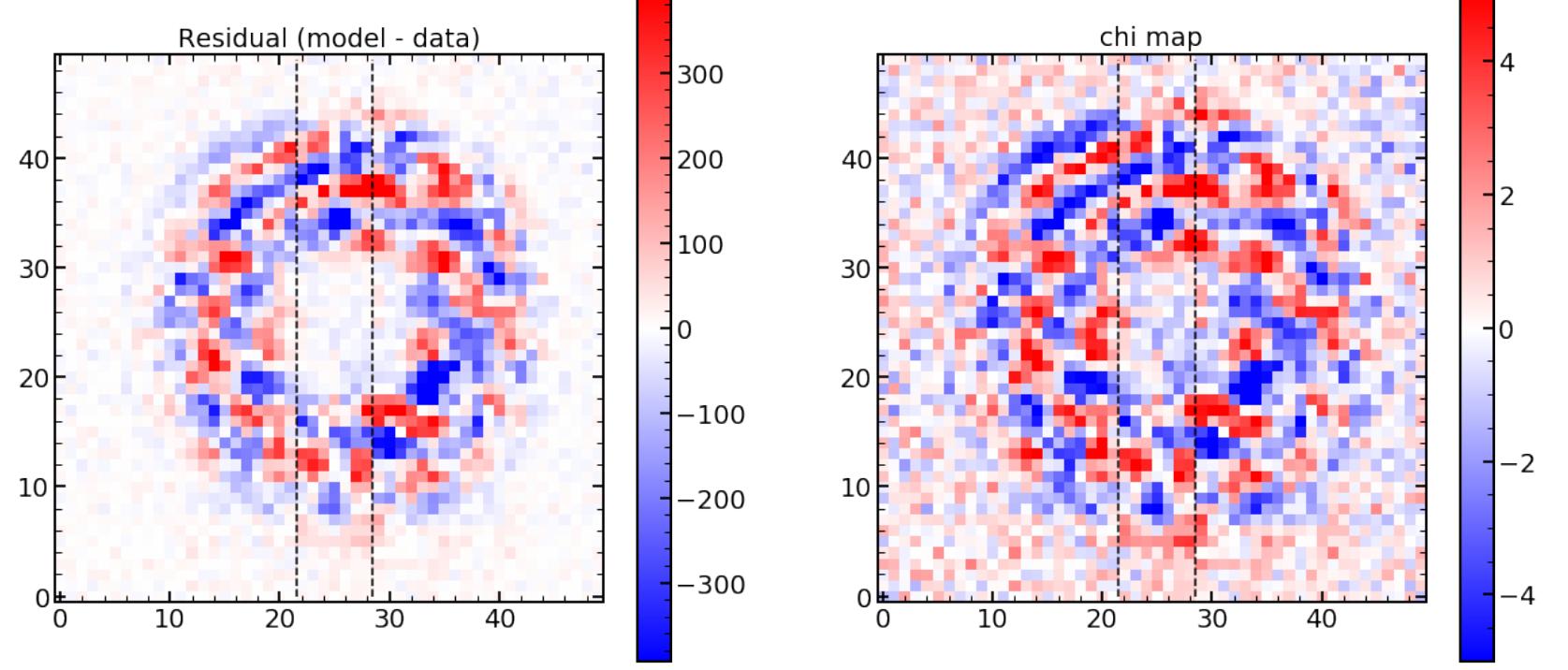
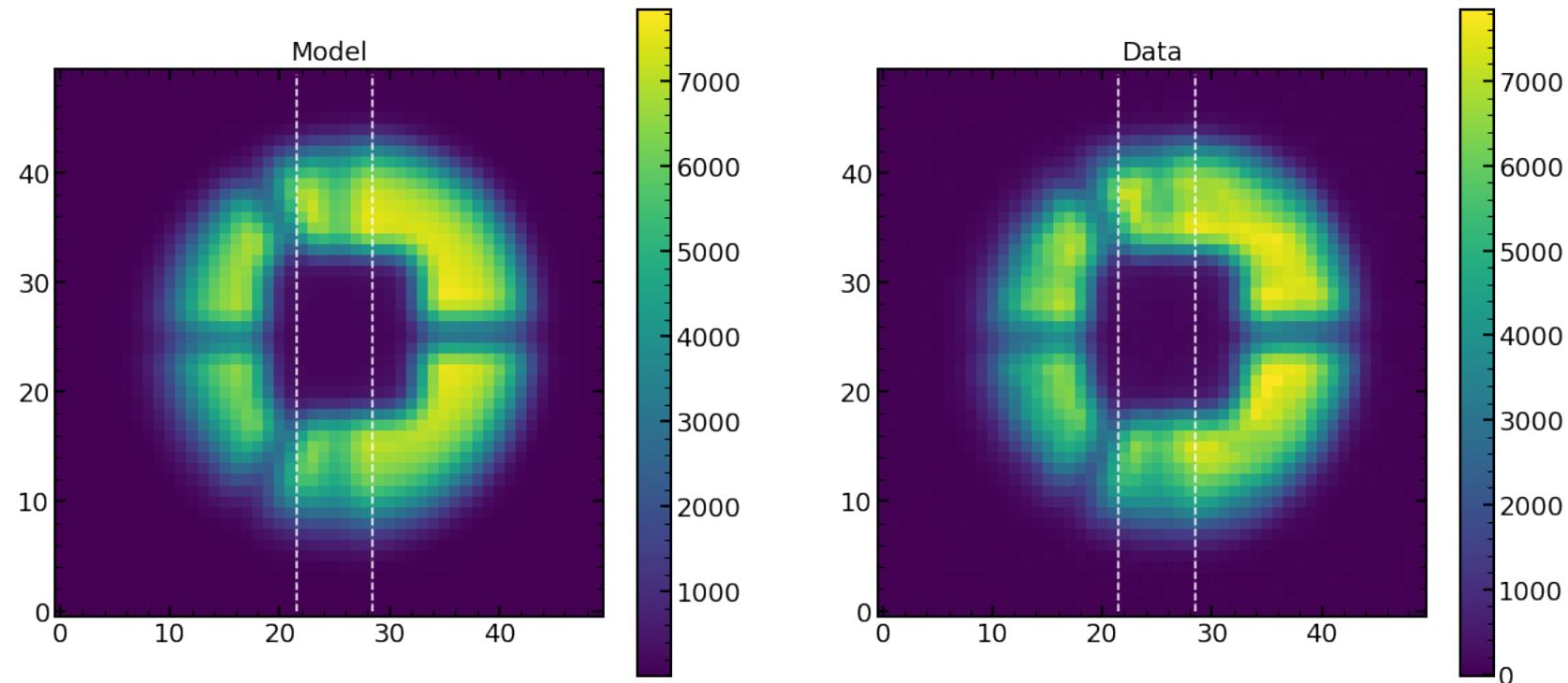
More defocused



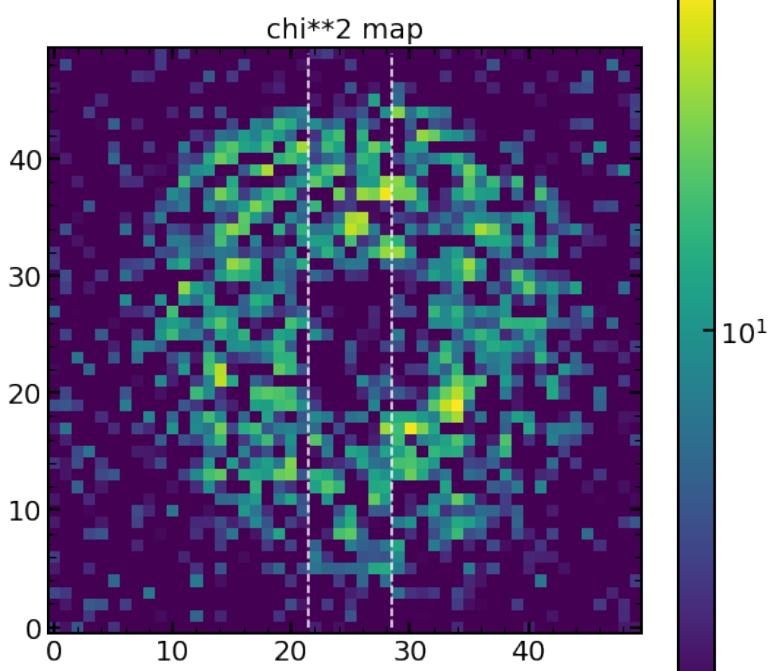
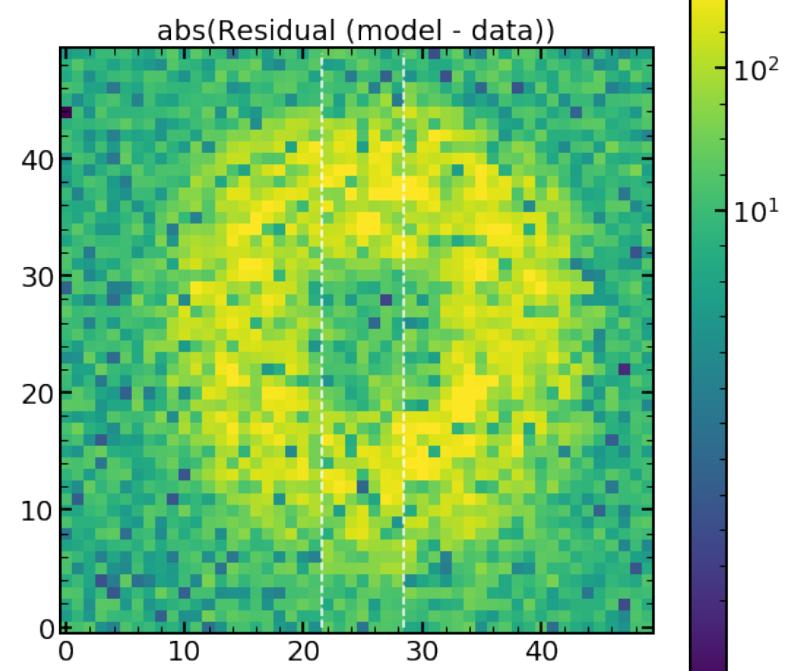
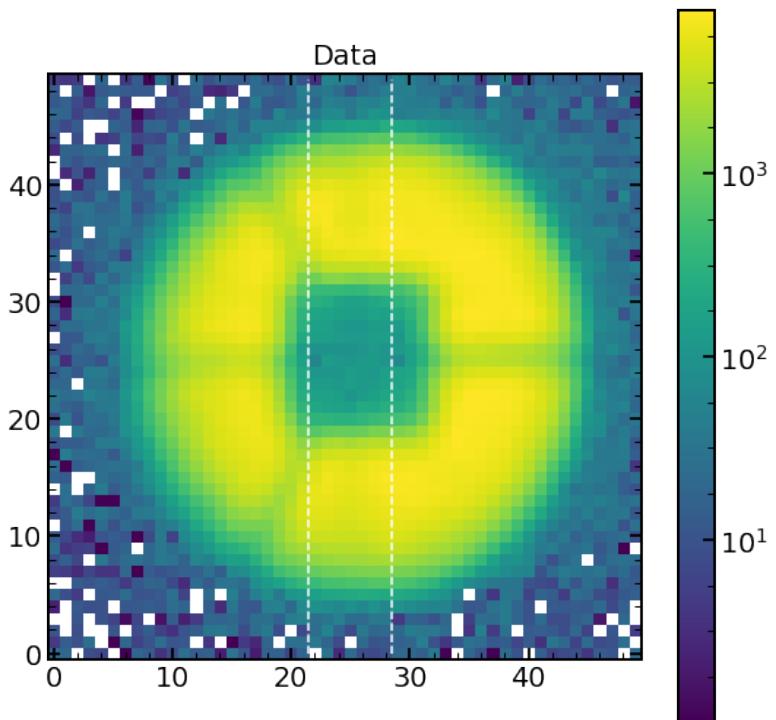
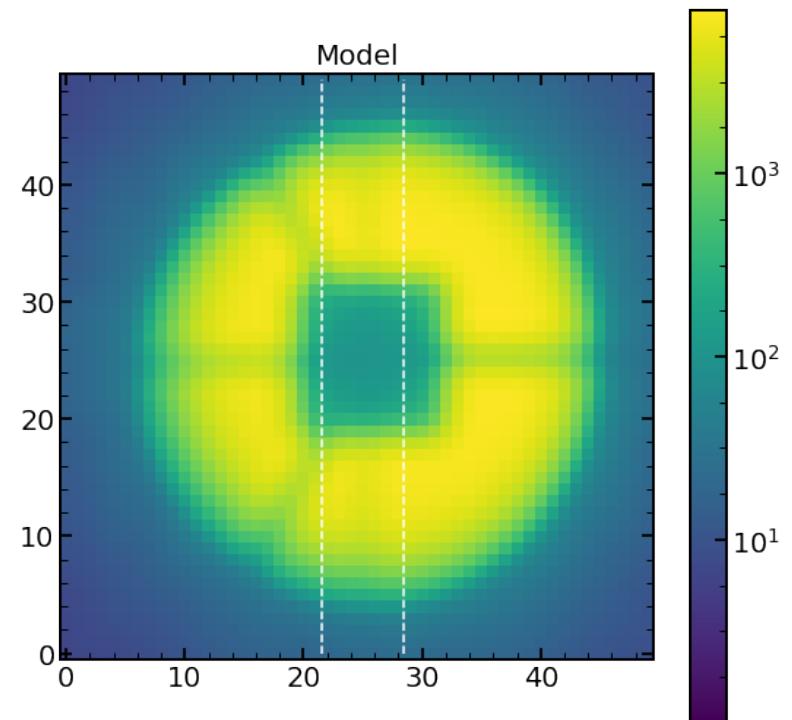
## Wavefront aberrations as function of defocus (Zemax)

- We wish to deduce/reproduce these curves from the data
- Model wavefront aberrations at each position in the detector

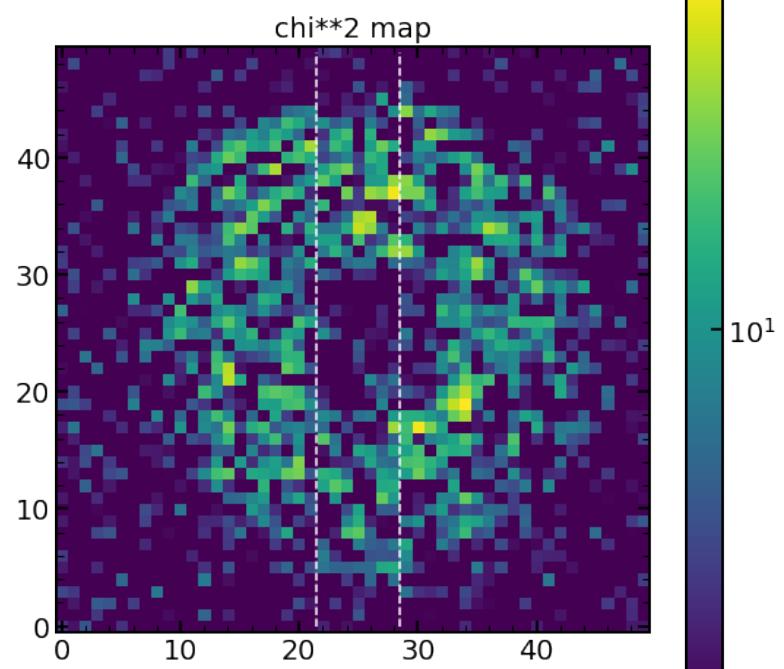
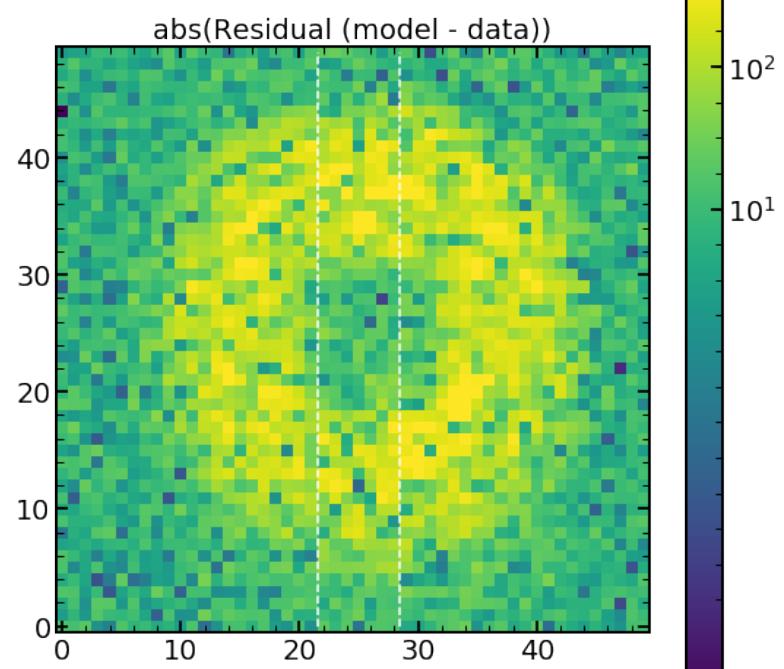
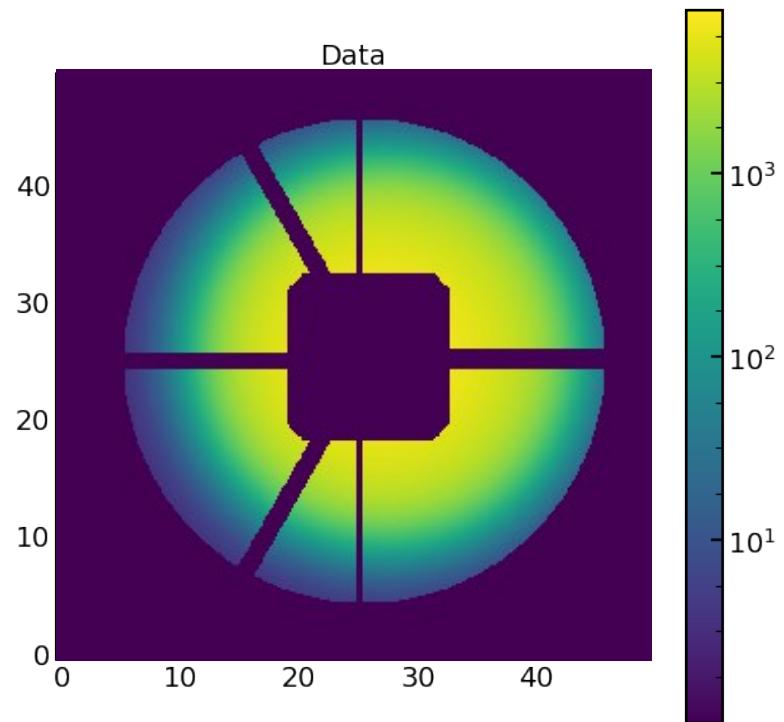
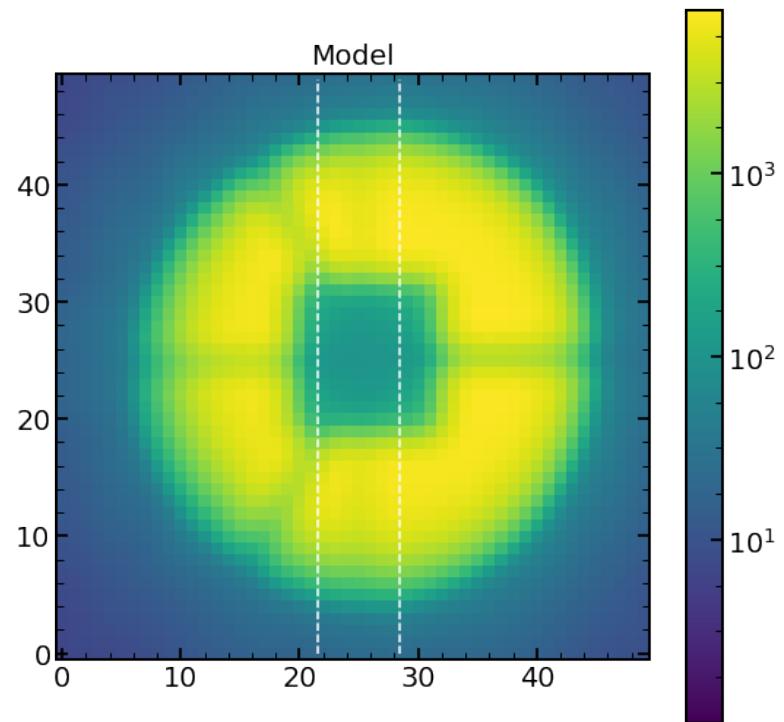
## Defocused data, example with linear scaling

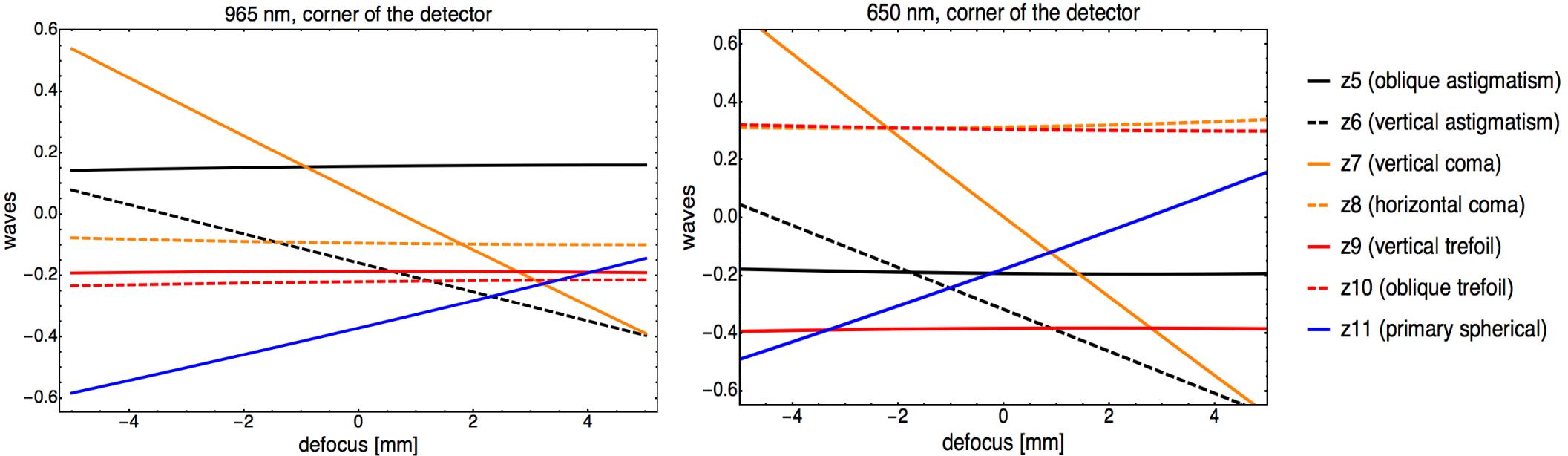


Defocused  
data,  
example with  
log scaling

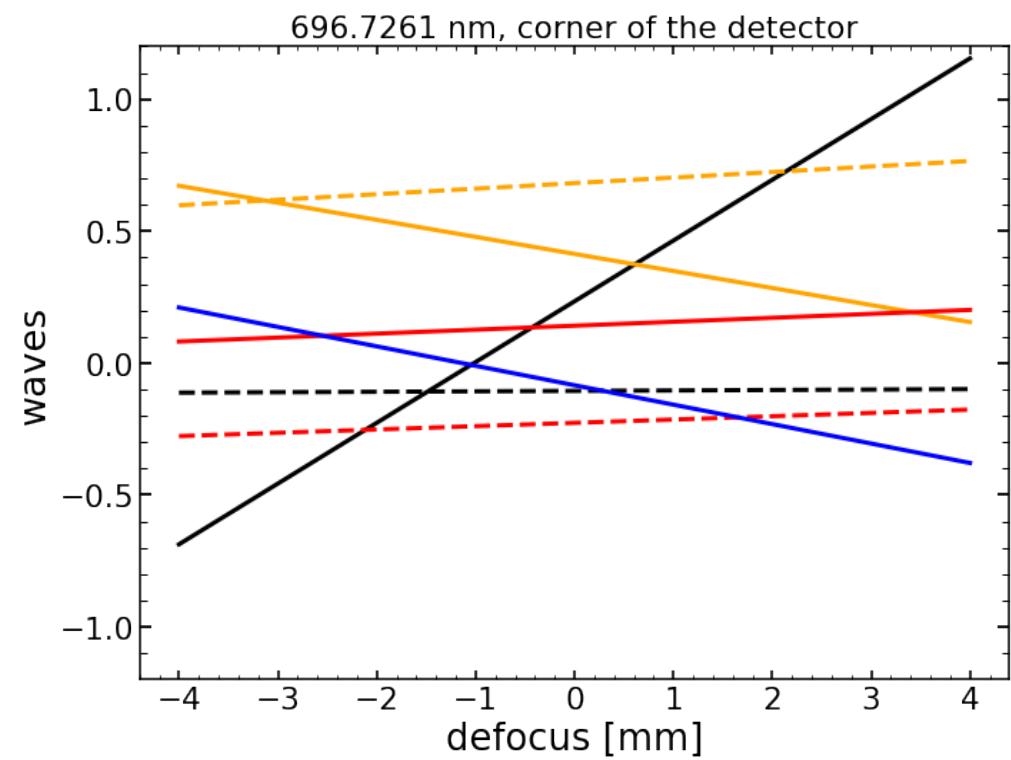
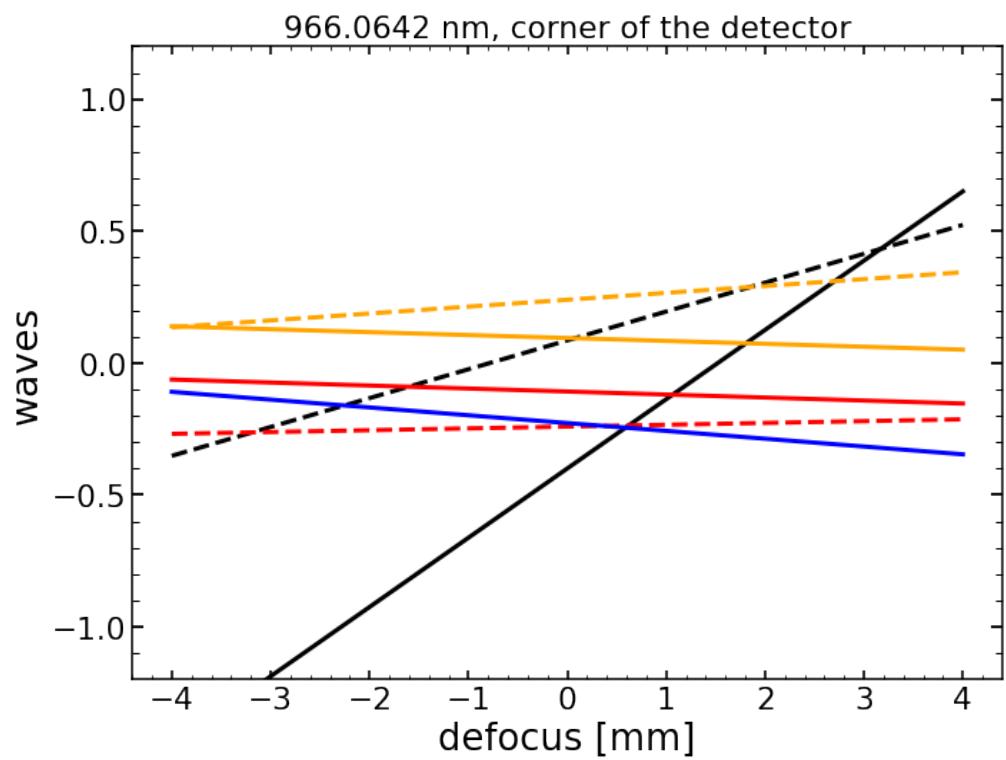


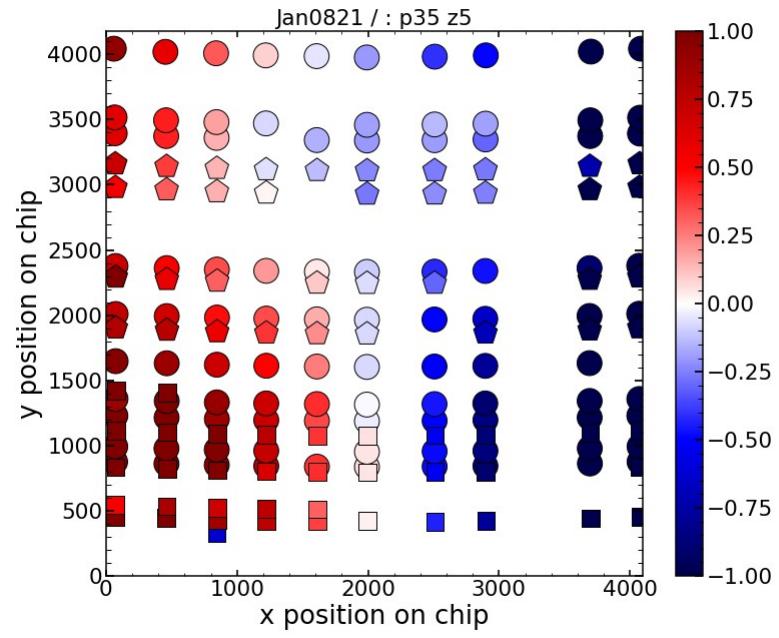
Defocused  
data,  
example with  
log scaling



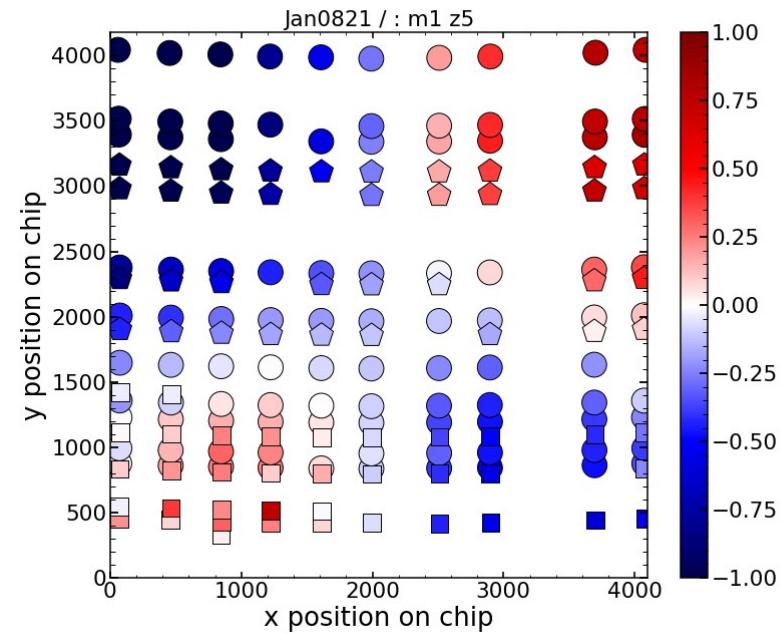
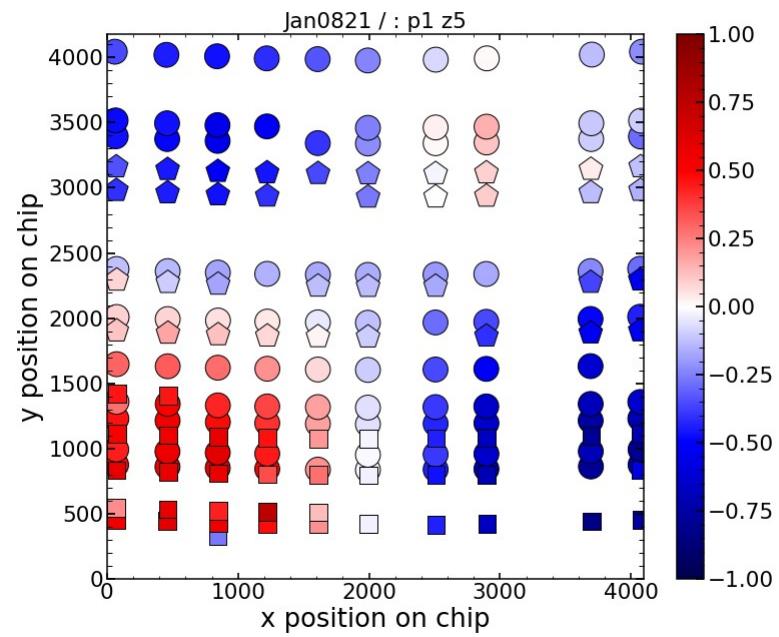
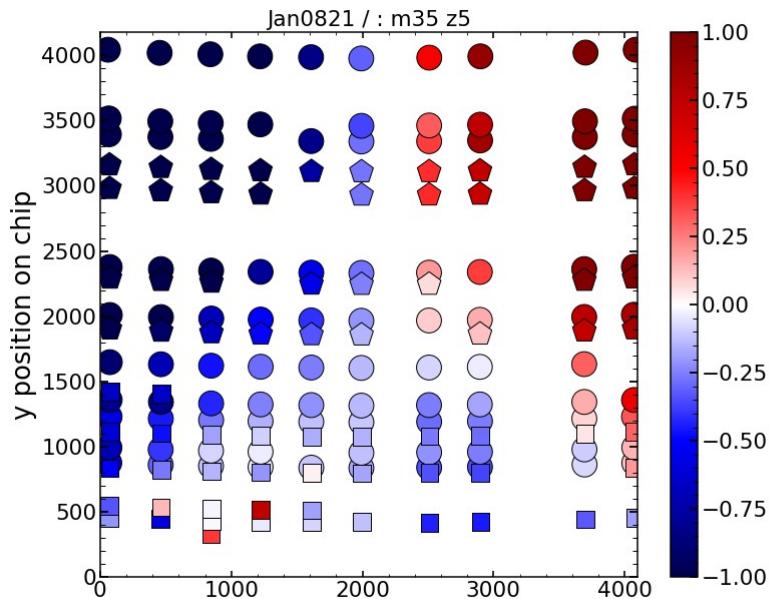


- Example from modelling of the experimental data below  
(not exactly the same location as above, but observe large difference)



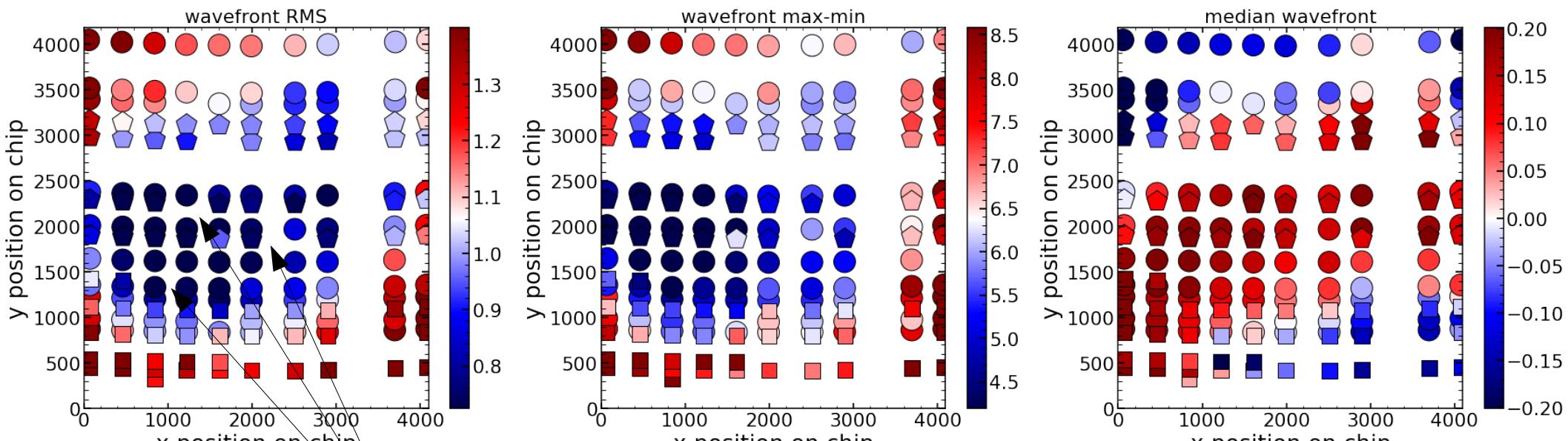


Change of single component  
(oblique astigmatism)



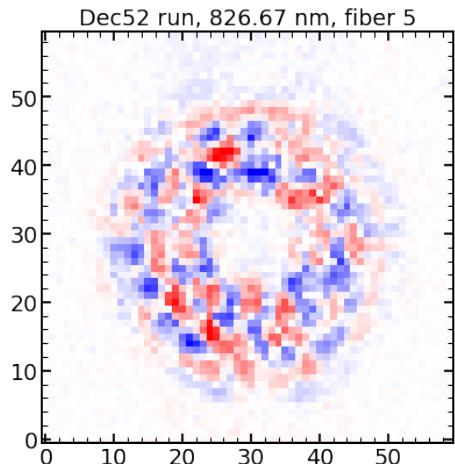
Changing defocus

# Wavefront rms across the detector

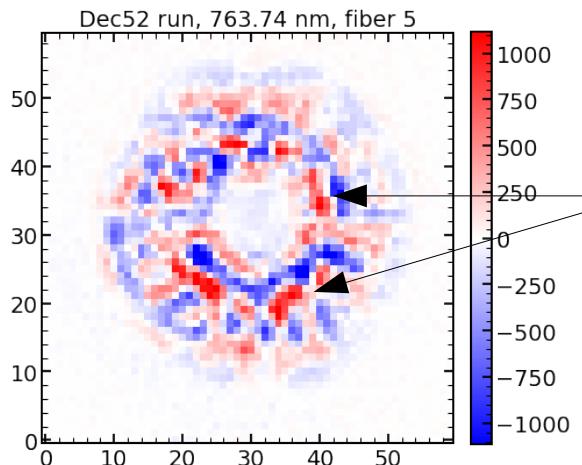
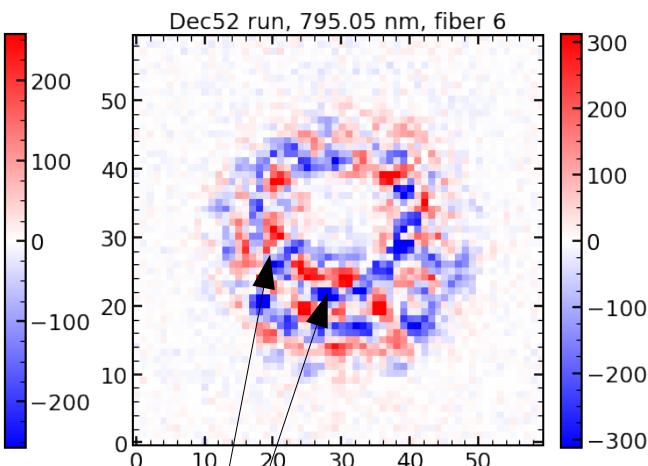
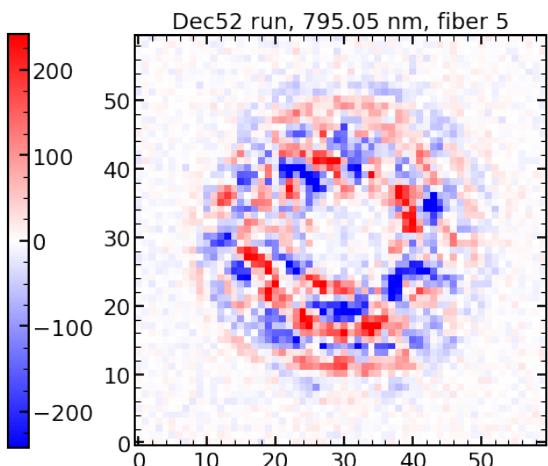
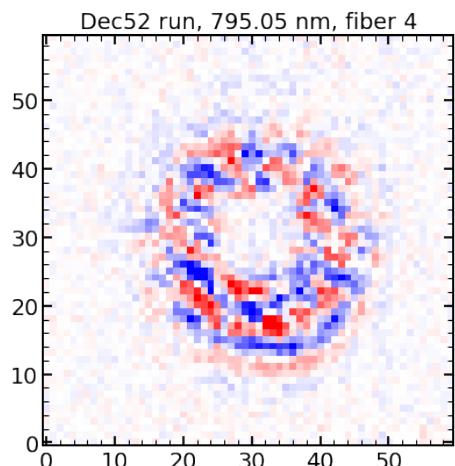


Not in the center of the detector –  
probably because it was centered from  
available data

## Residuals of fits to the data - defocus



Residuals scaled to  
5% of the maximal flux  
in the data



Speckles – can be  
"removed" by fitting  
higher order  
wavefront  
abberations

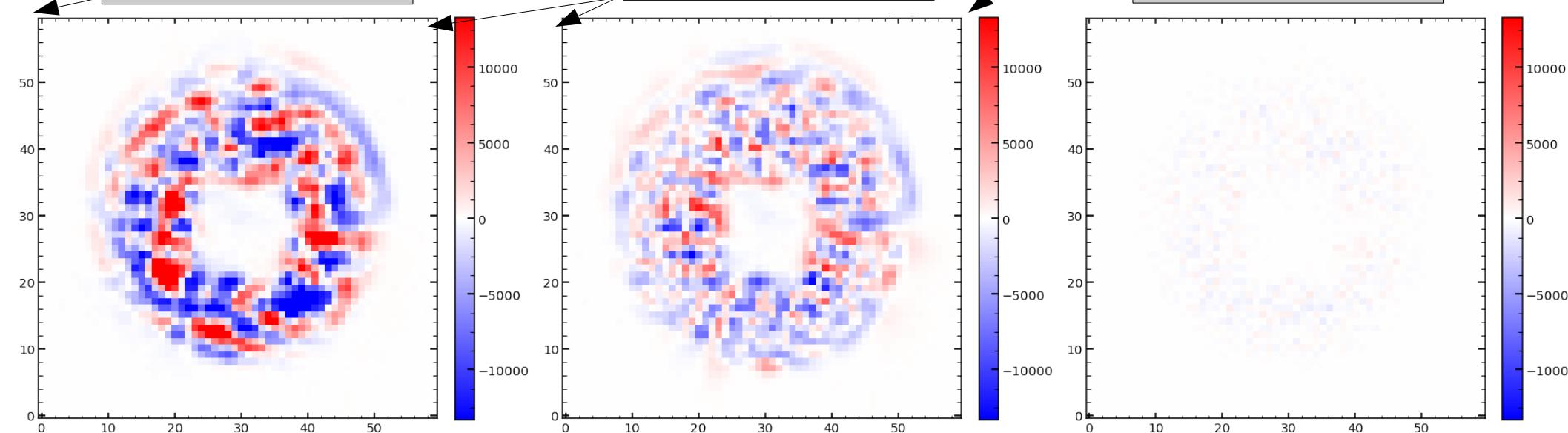
## Direct Fits

Up to z22

Up to z254

Perfection

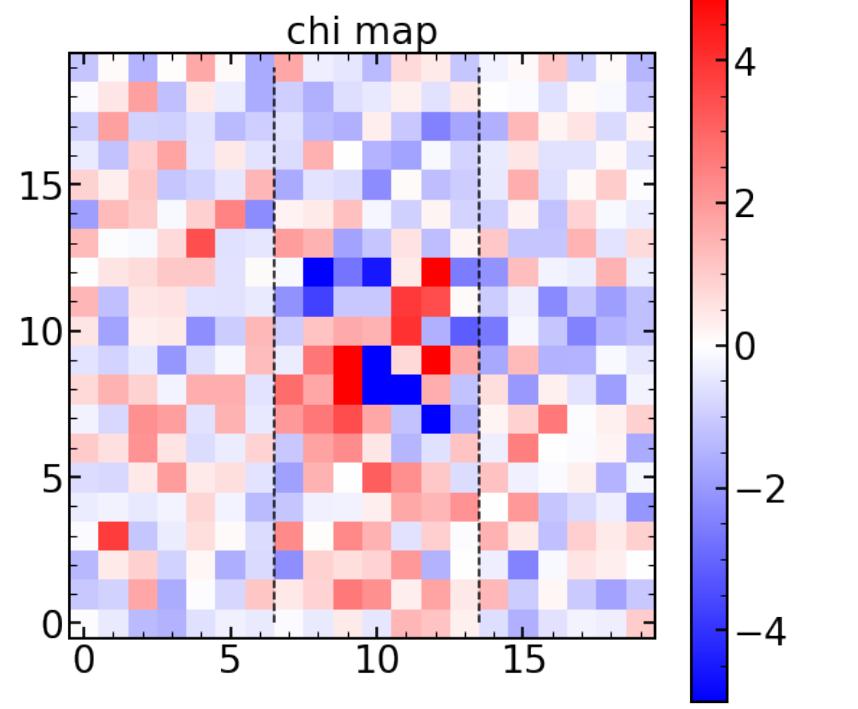
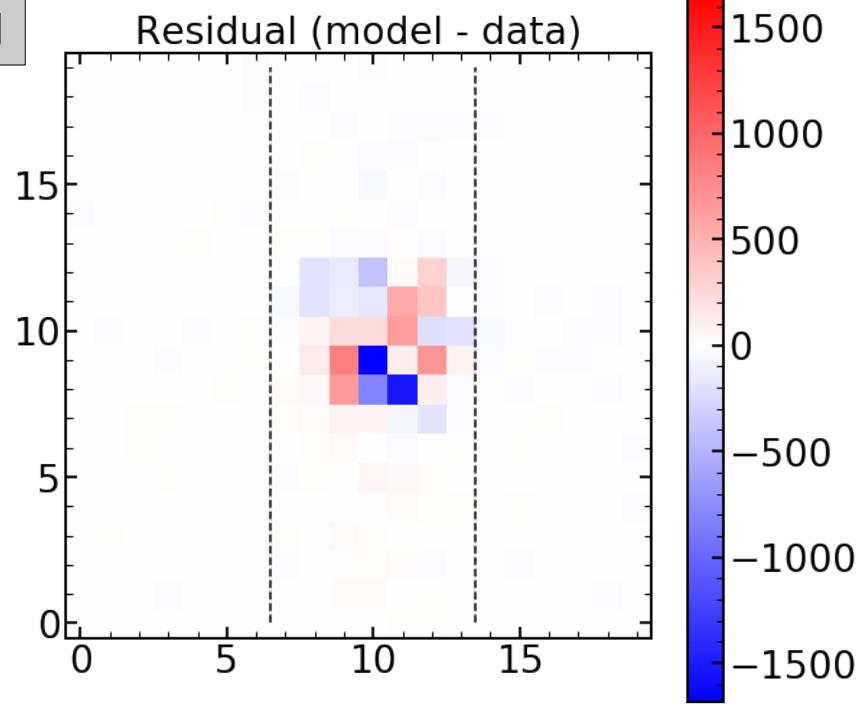
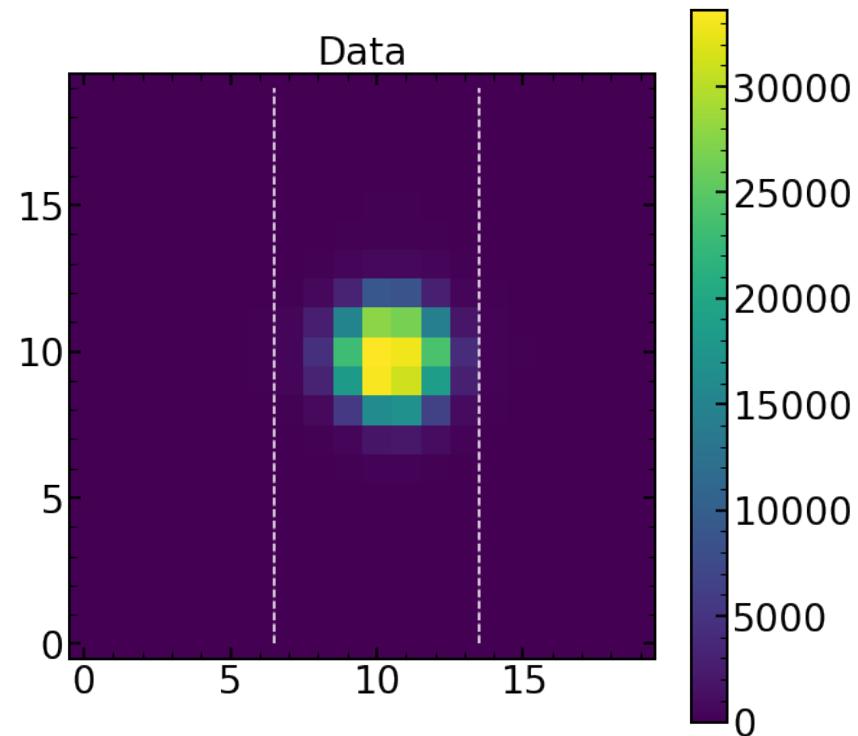
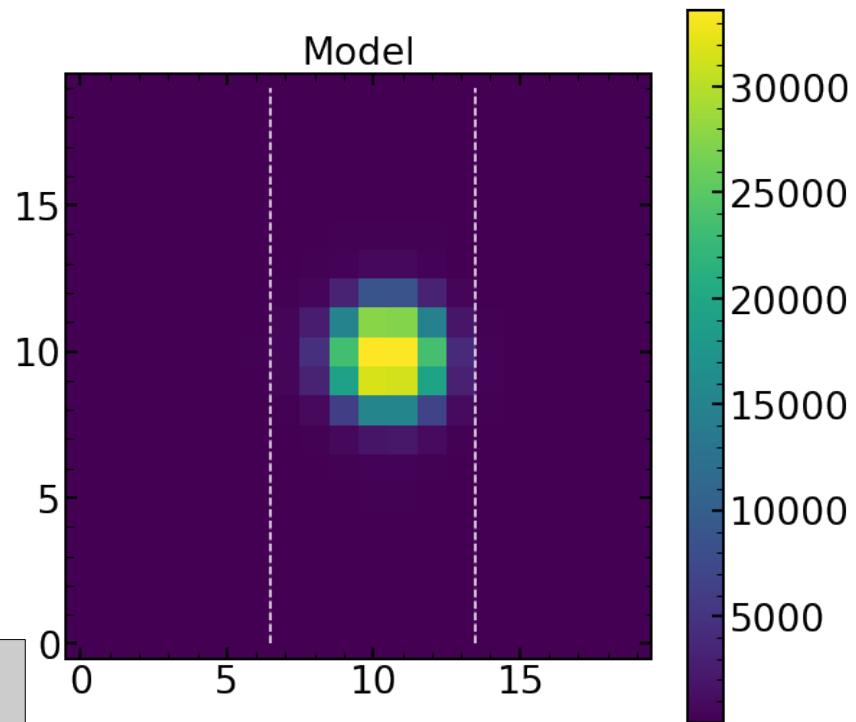
Residuals scaled to  
5% of the maximal flux  
in the data

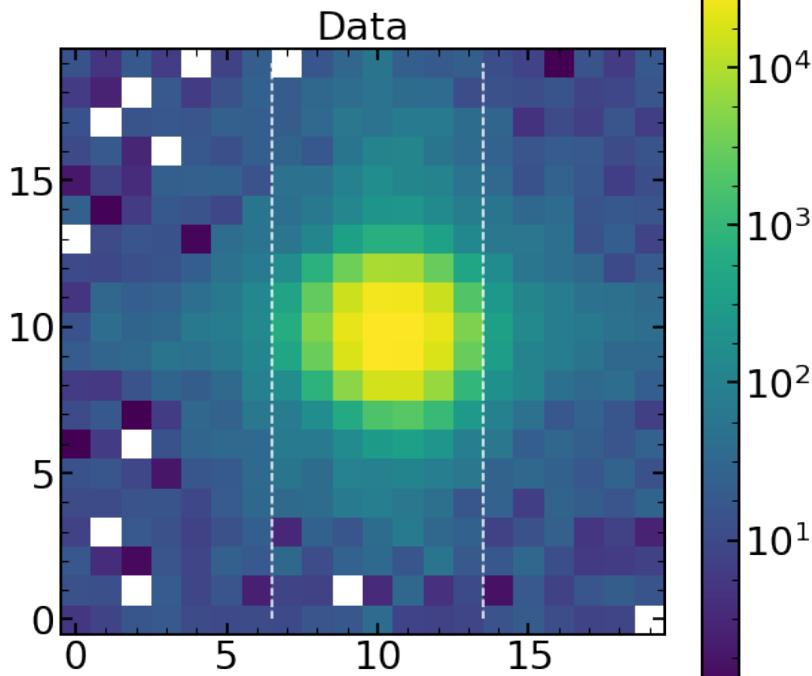
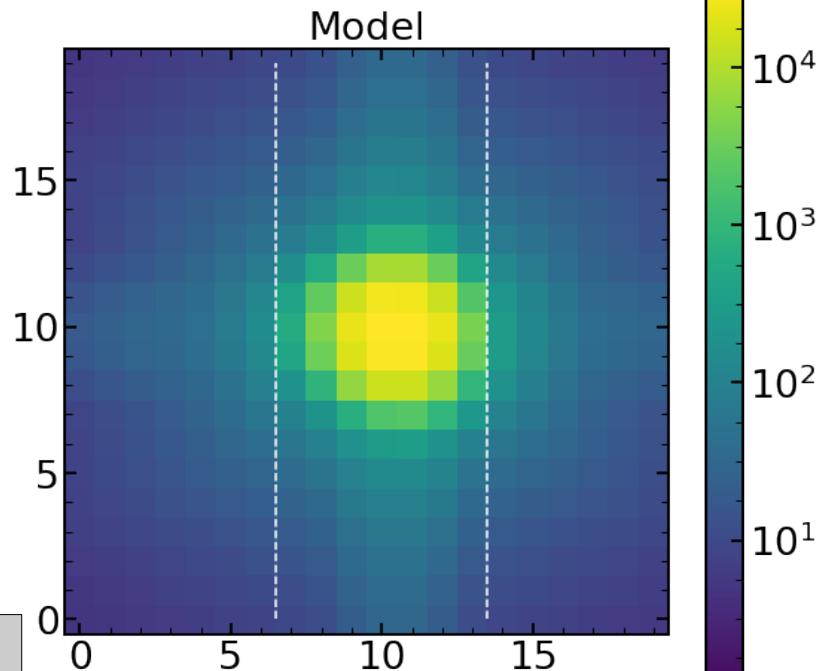


High order  
aberrations do not  
vary as a position of  
the detector? (if they  
come from glass  
imperfections)

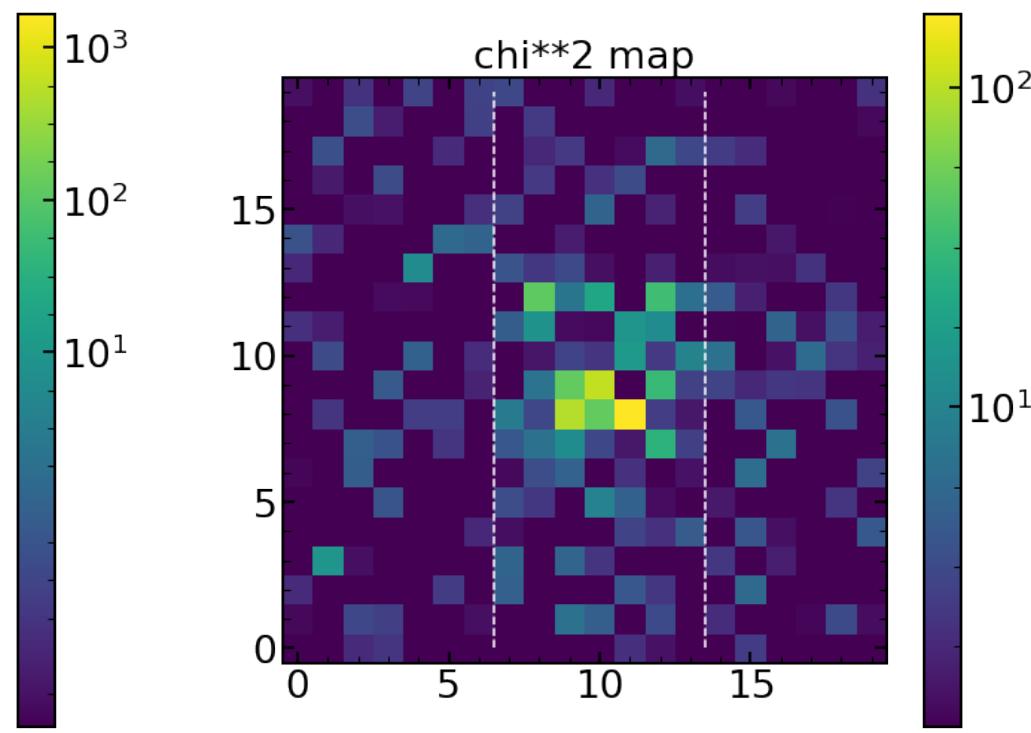
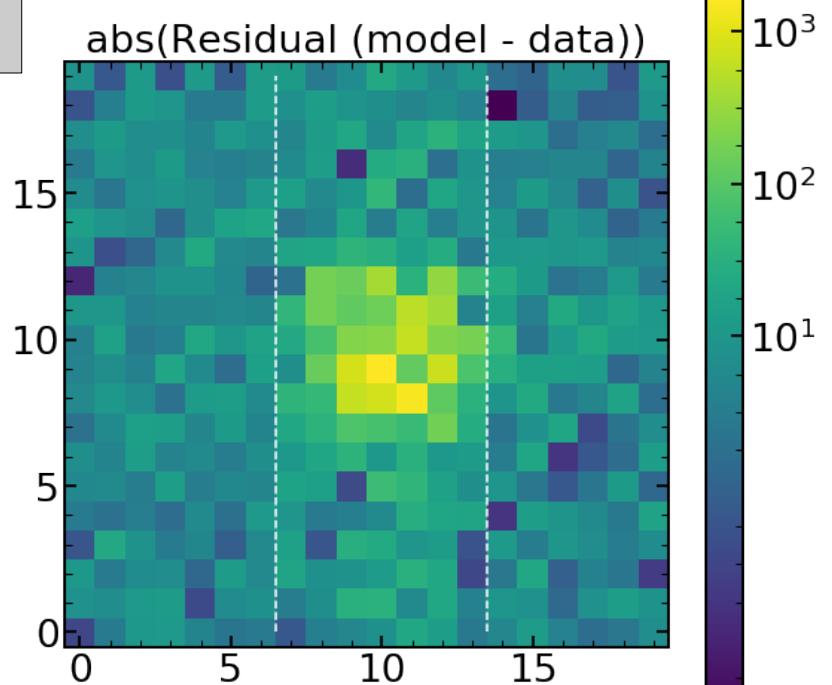
Speckles – can be  
``removed" by fitting  
higher order  
wavefront  
abberations

Focused  
data,  
example with  
linear scaling



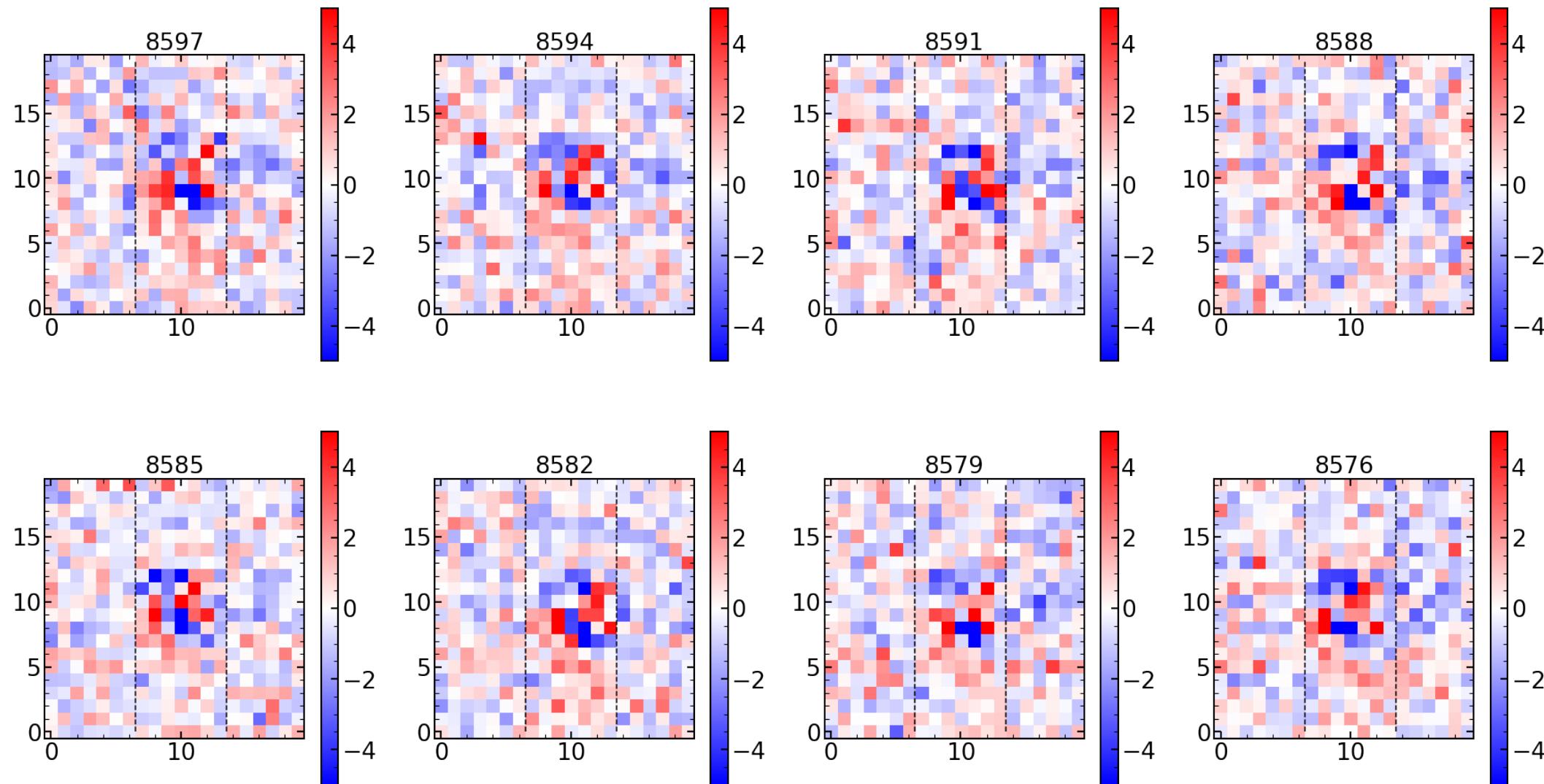


Focused  
data,  
example with  
log scaling



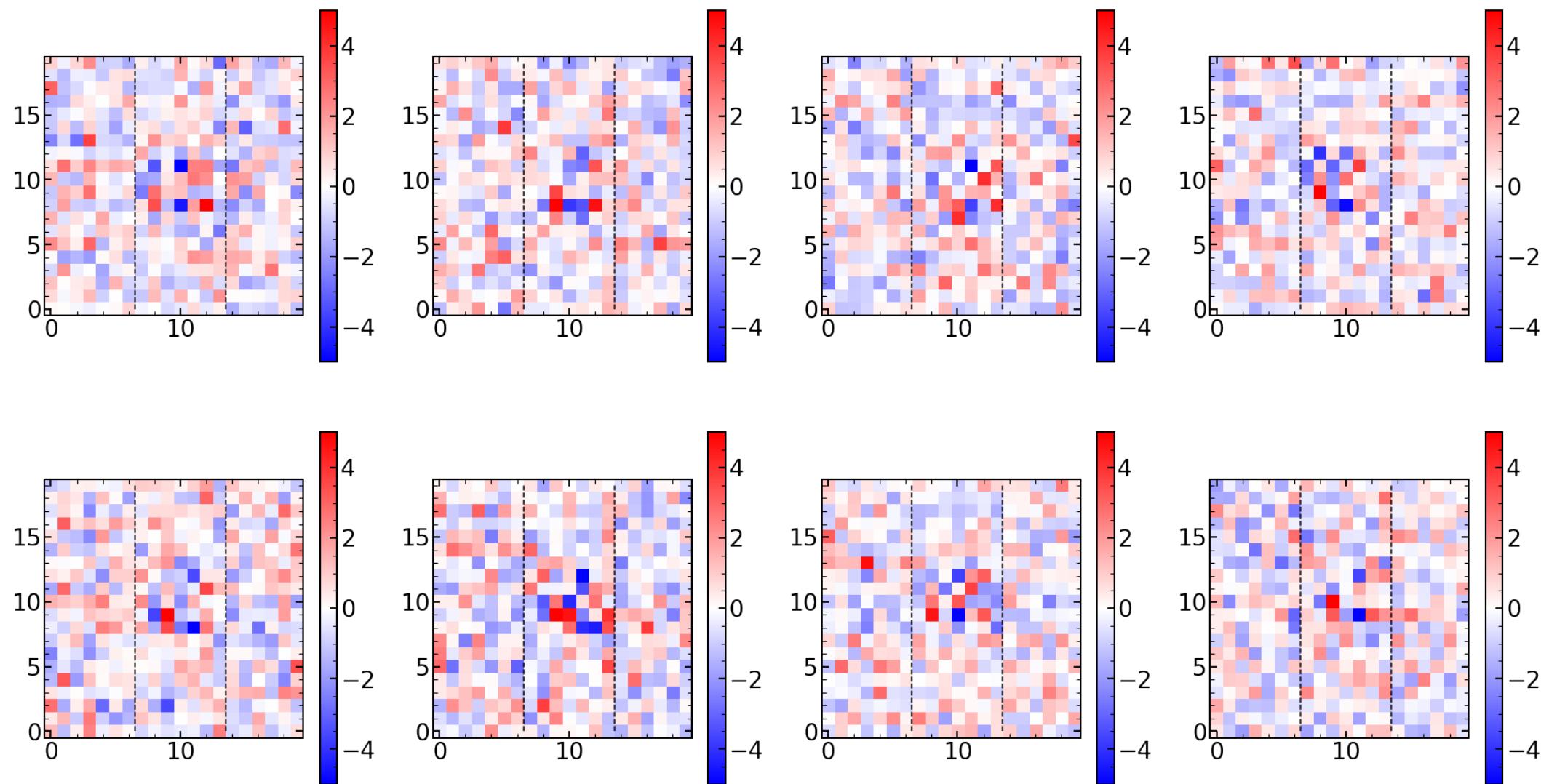
# Residuals in the focused data, 8 different dithering positions

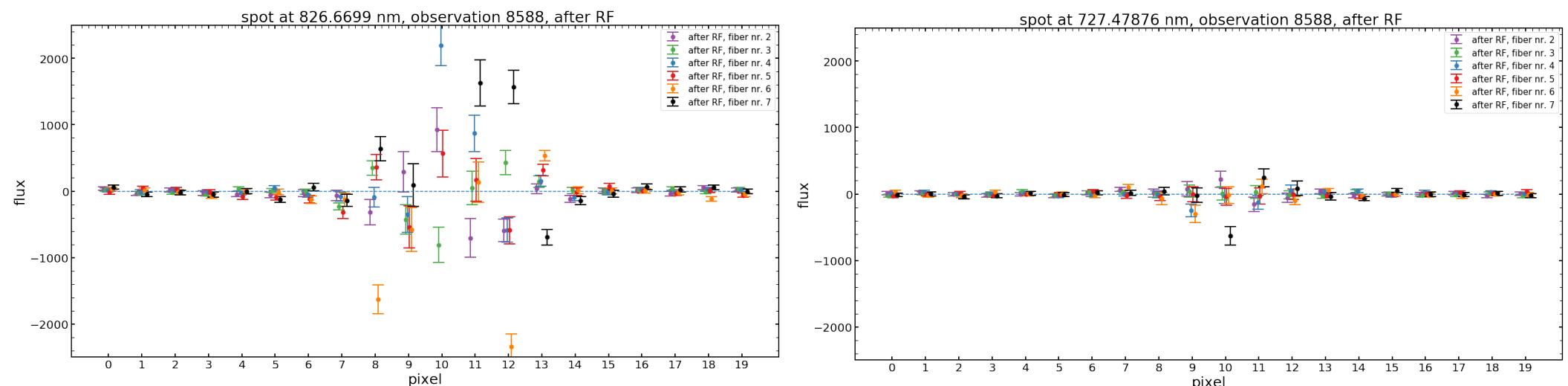
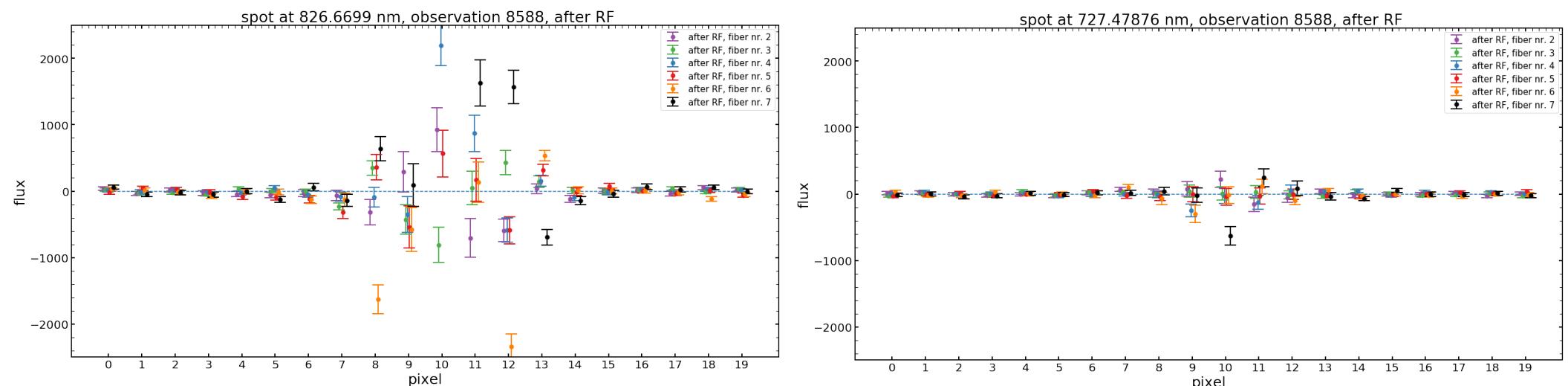
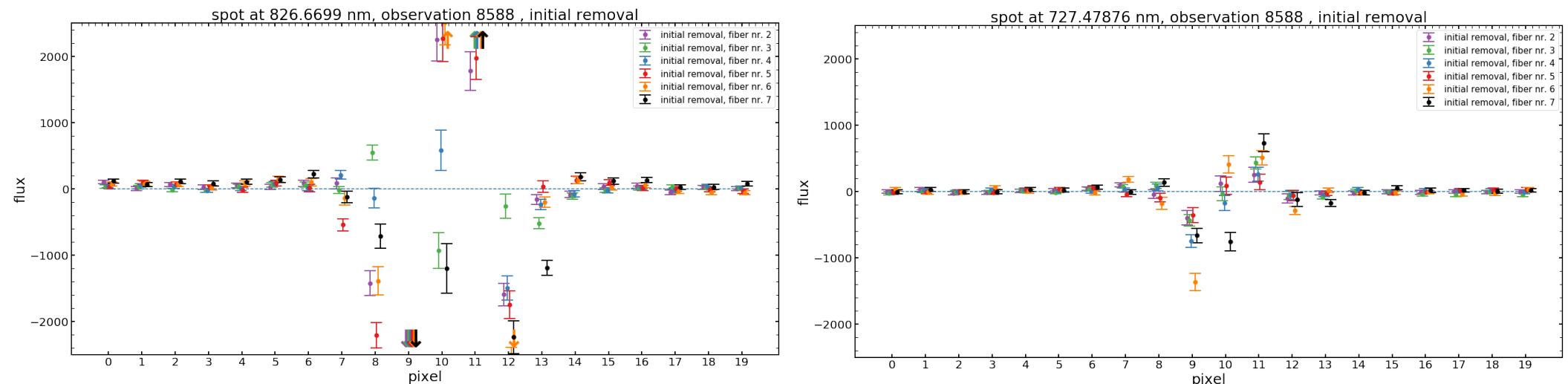
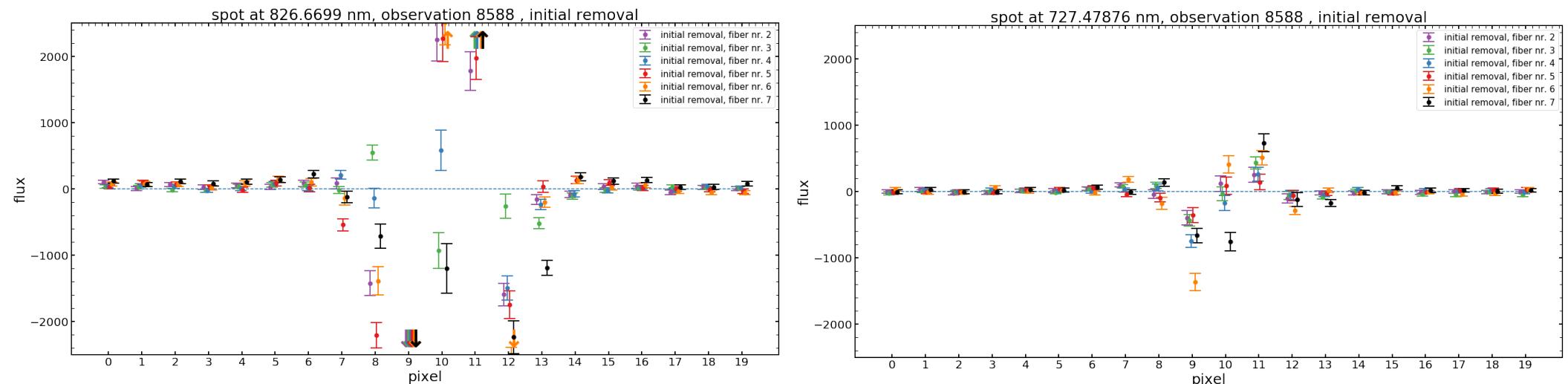
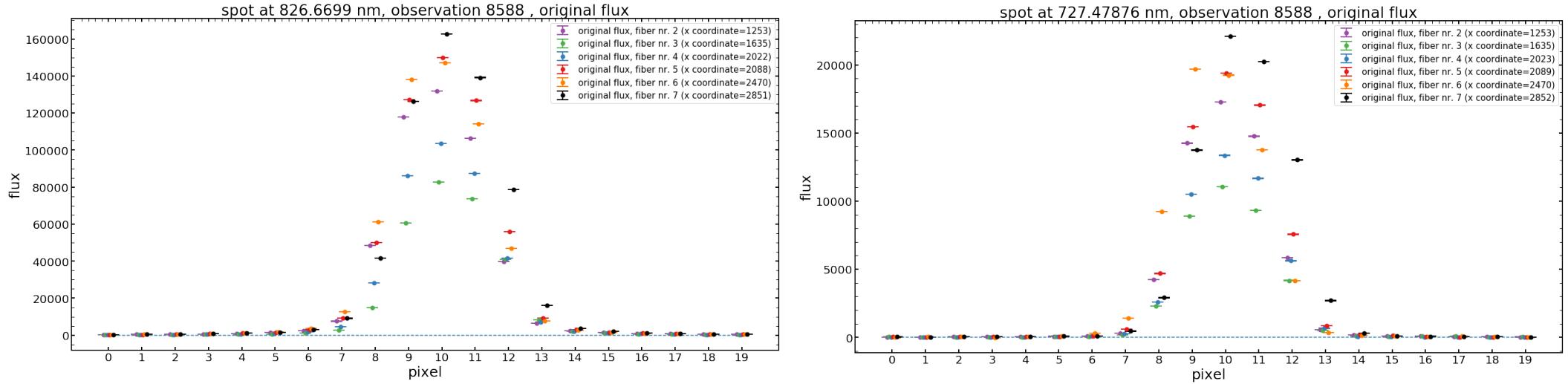
Residuals, up to Zernike 22 and Jan 15 modifications to centering



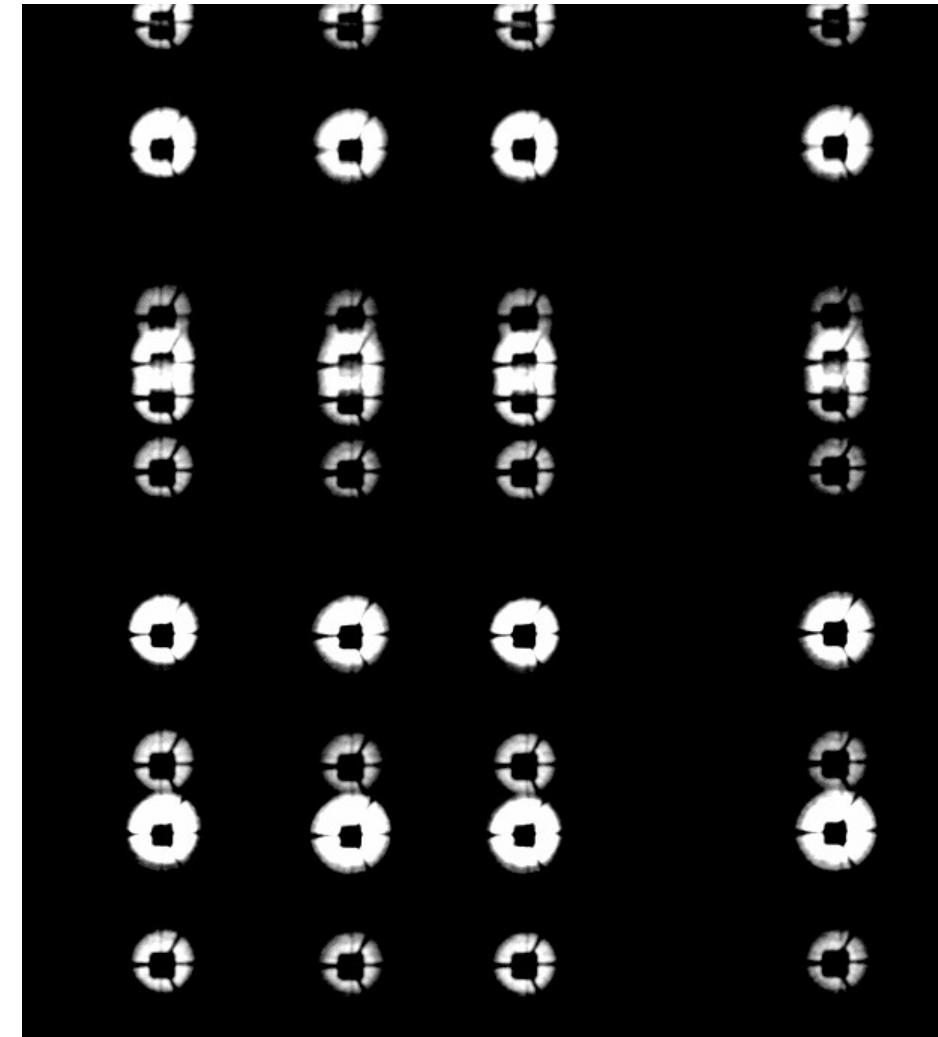
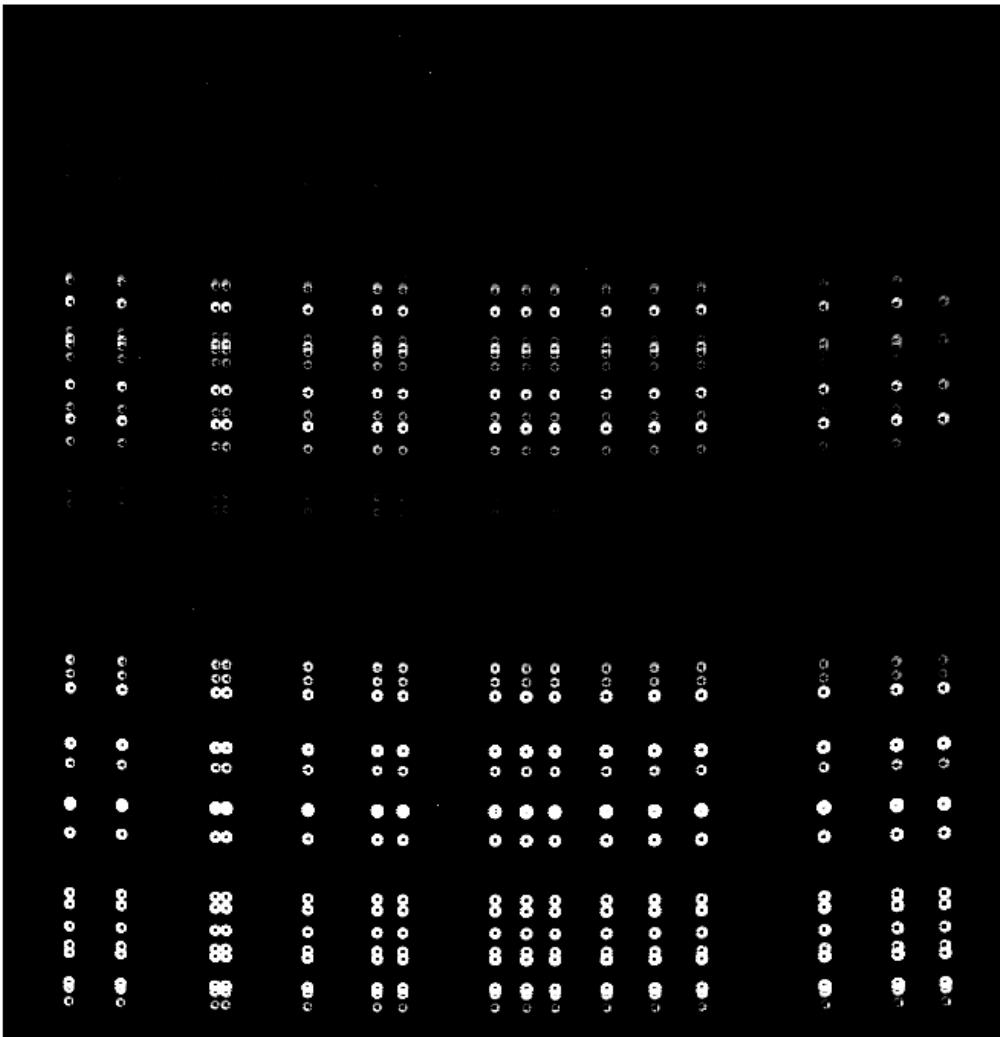
# Residuals in the focused data, 8 different dithering positions, after Random forest cleaning applied

up to Zernike 22, Jan 15 modifications to centering, and Random Forest postprocessing



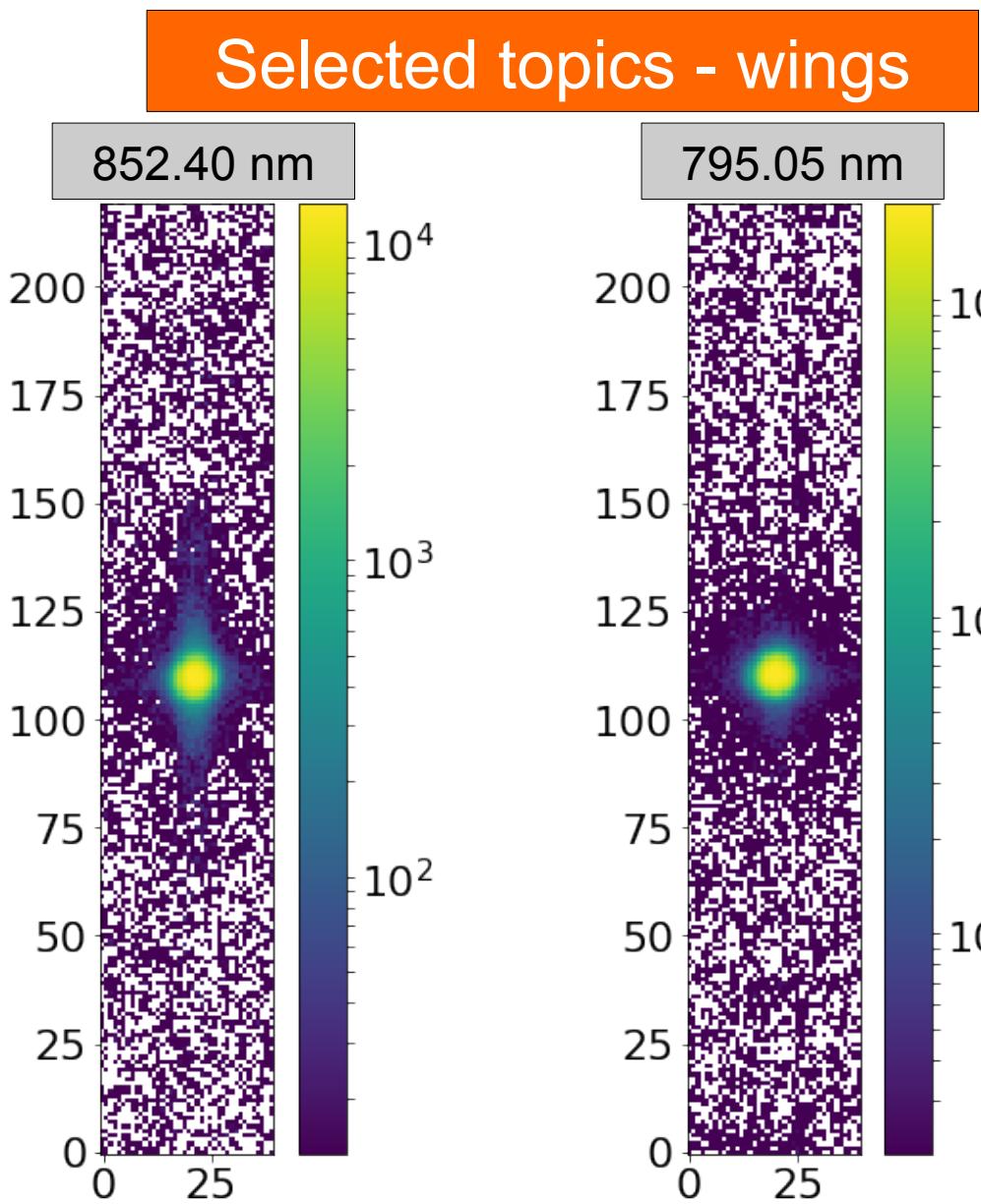
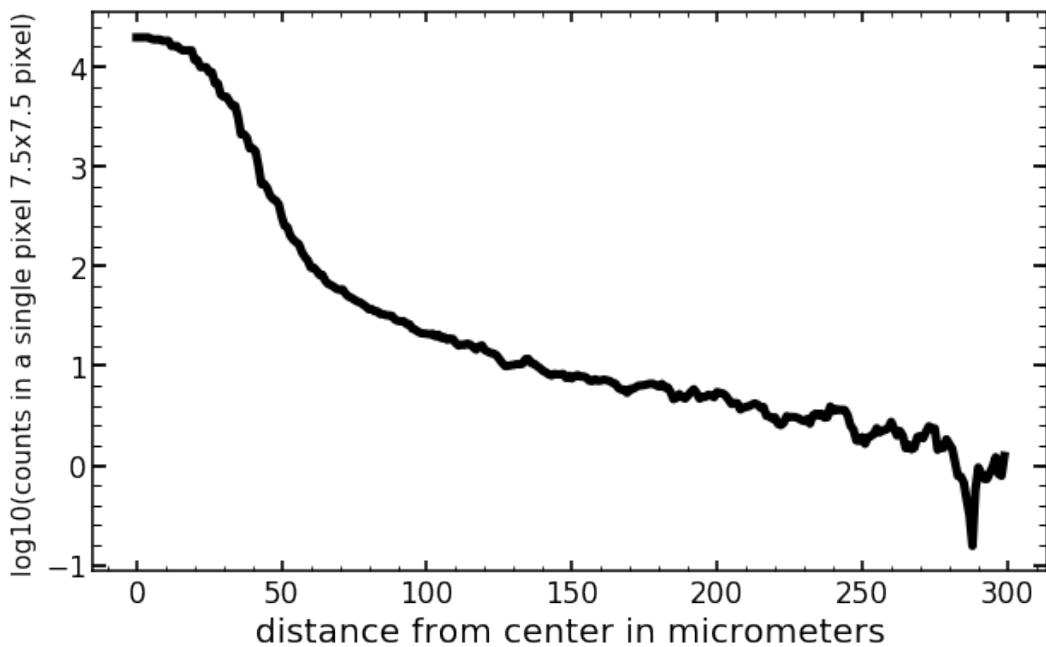
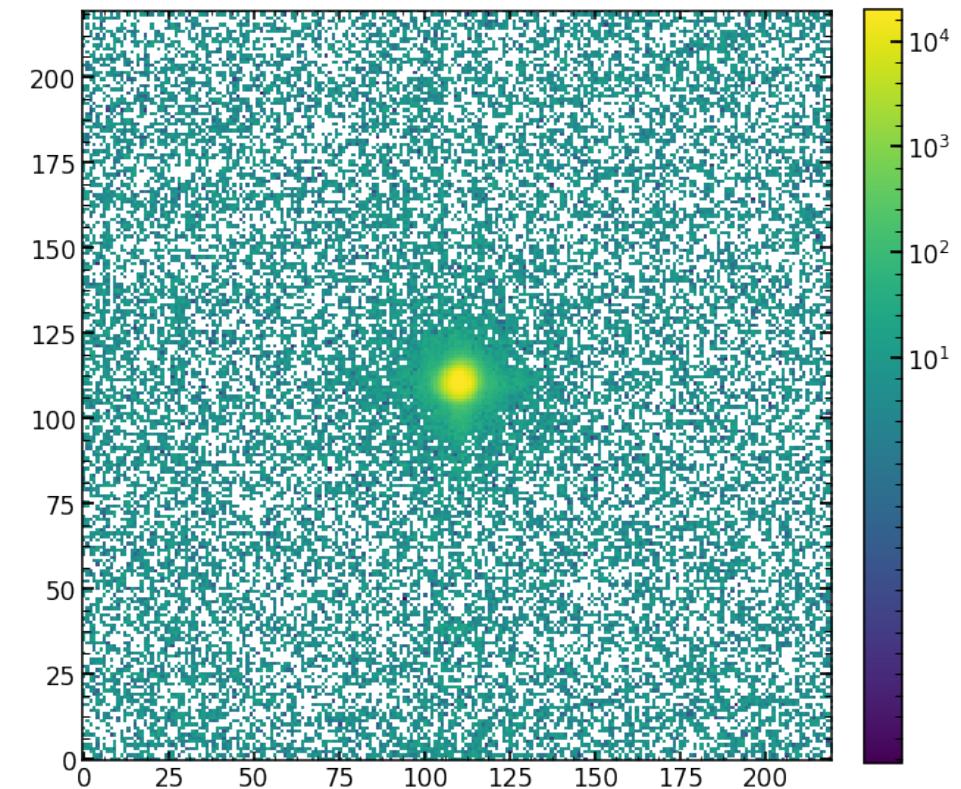


## Selected topics – Overlap of spots



Partially mitigated by algorithm improvement, creating two identical  
models with an offset and adding them together

# Selected topics - wings



Additional possible topics:

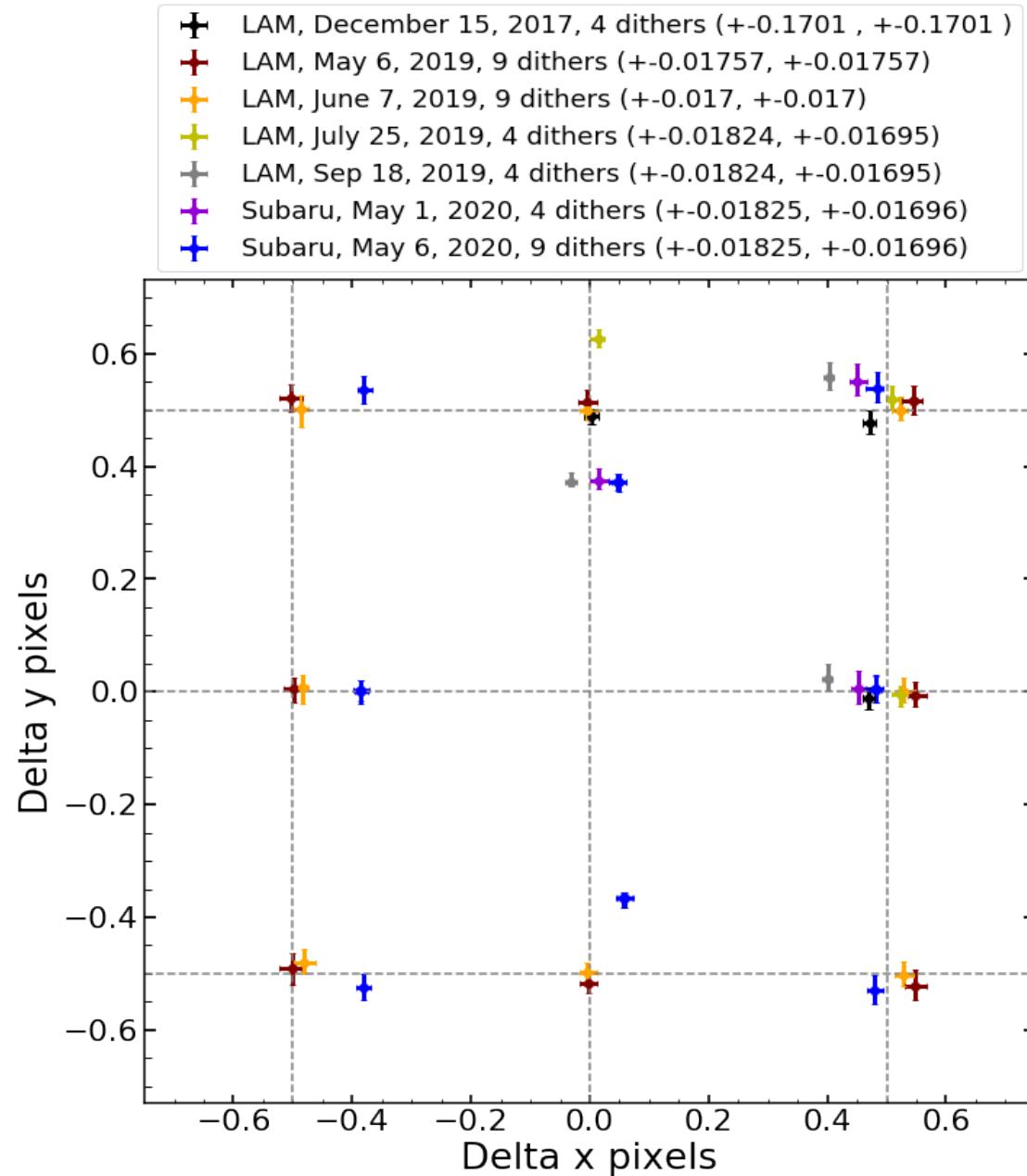
- dithering problems
- attenuator, shutter and flux control
- FRD and different collimator F-ratios

## Summary

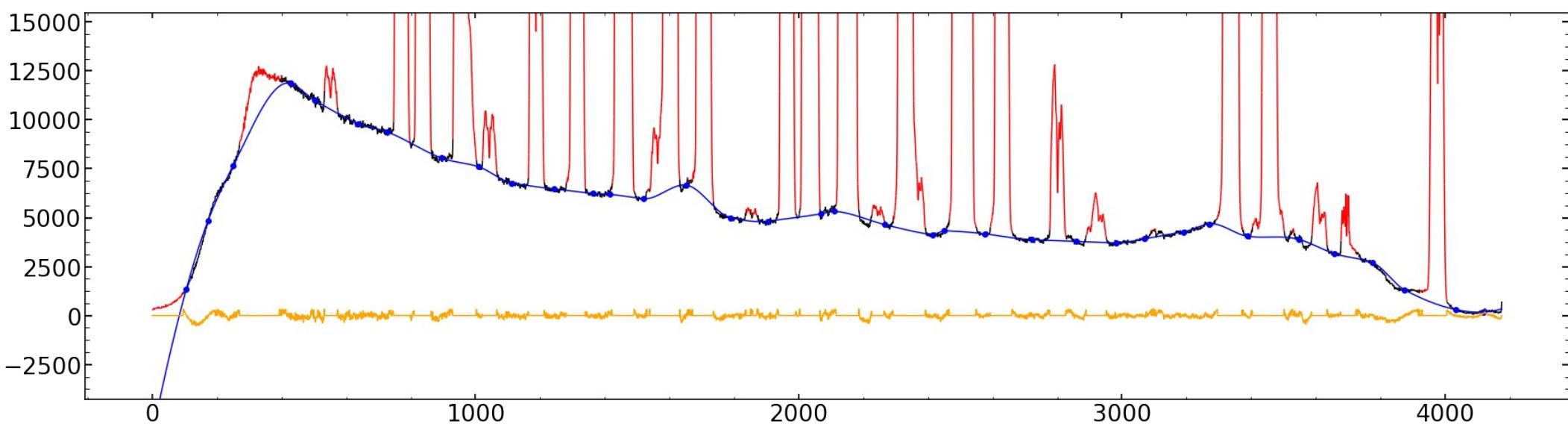
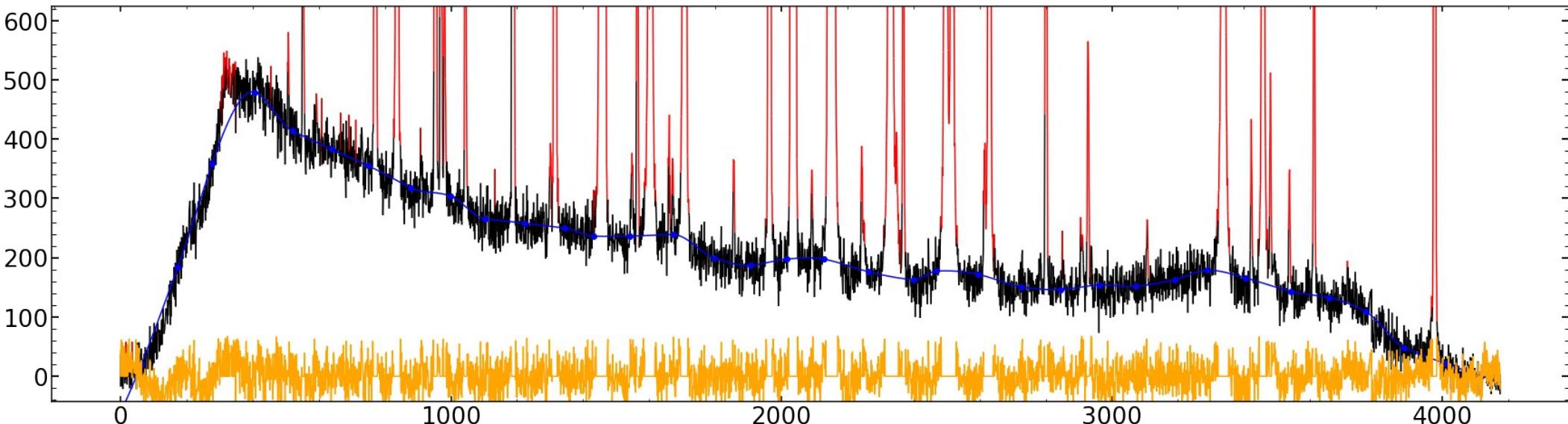
- Prime Focus Spectrograph – 2394 fibers, 380nm-1260nm, to be installed on Subaru
- 3 components of the point spread function
  - Telescope pupil illumination
  - Focal ratio degradation in the fibres
  - Spectrograph cameras
- Characterize contribution of camera imperfections to the point spread function by modelling optical performance using defocused data
- Defocused images on both sides of focus allow to decouple the illumination and the wavefront aberrations

## Extra slides

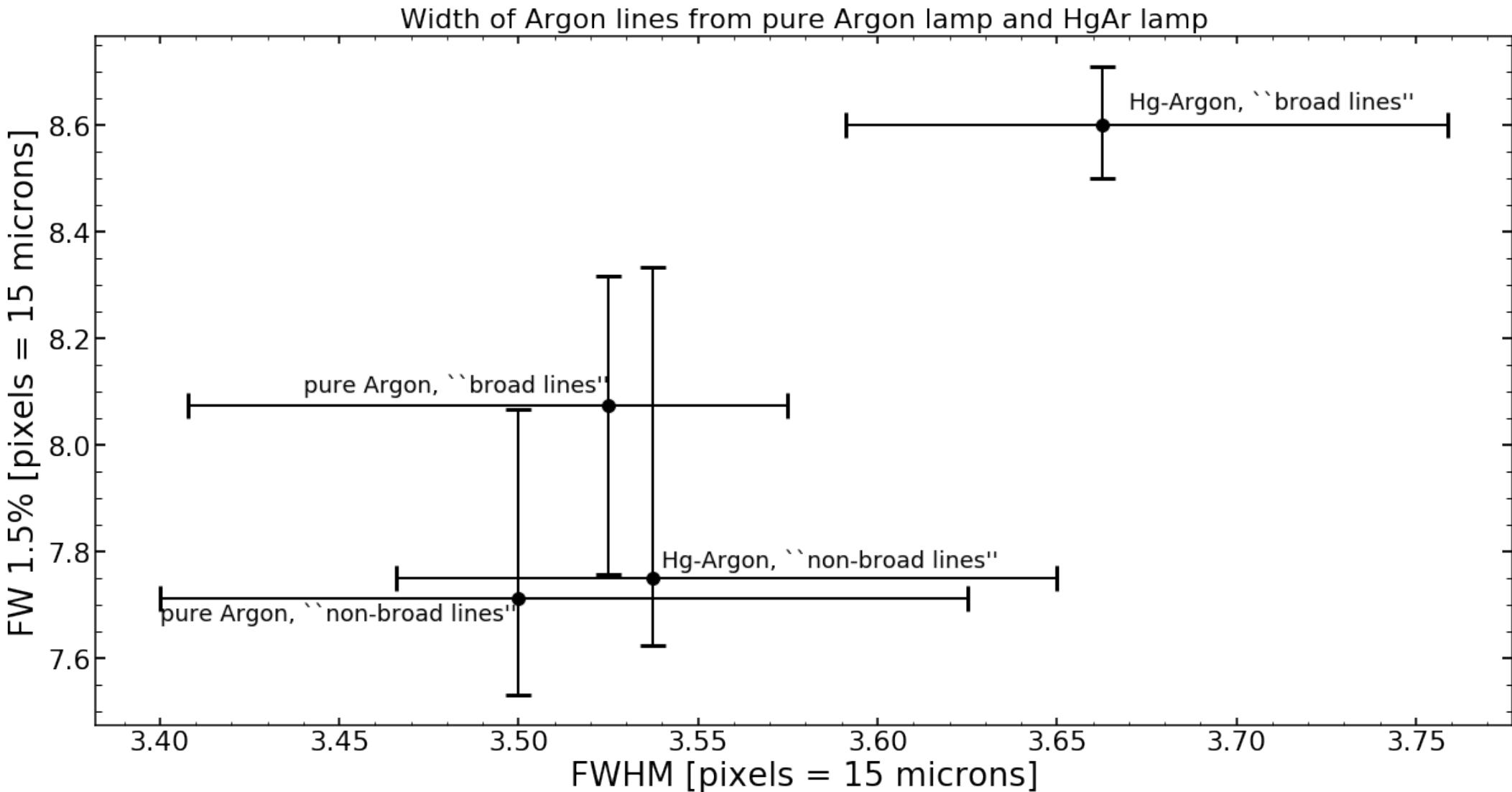
# Dithering



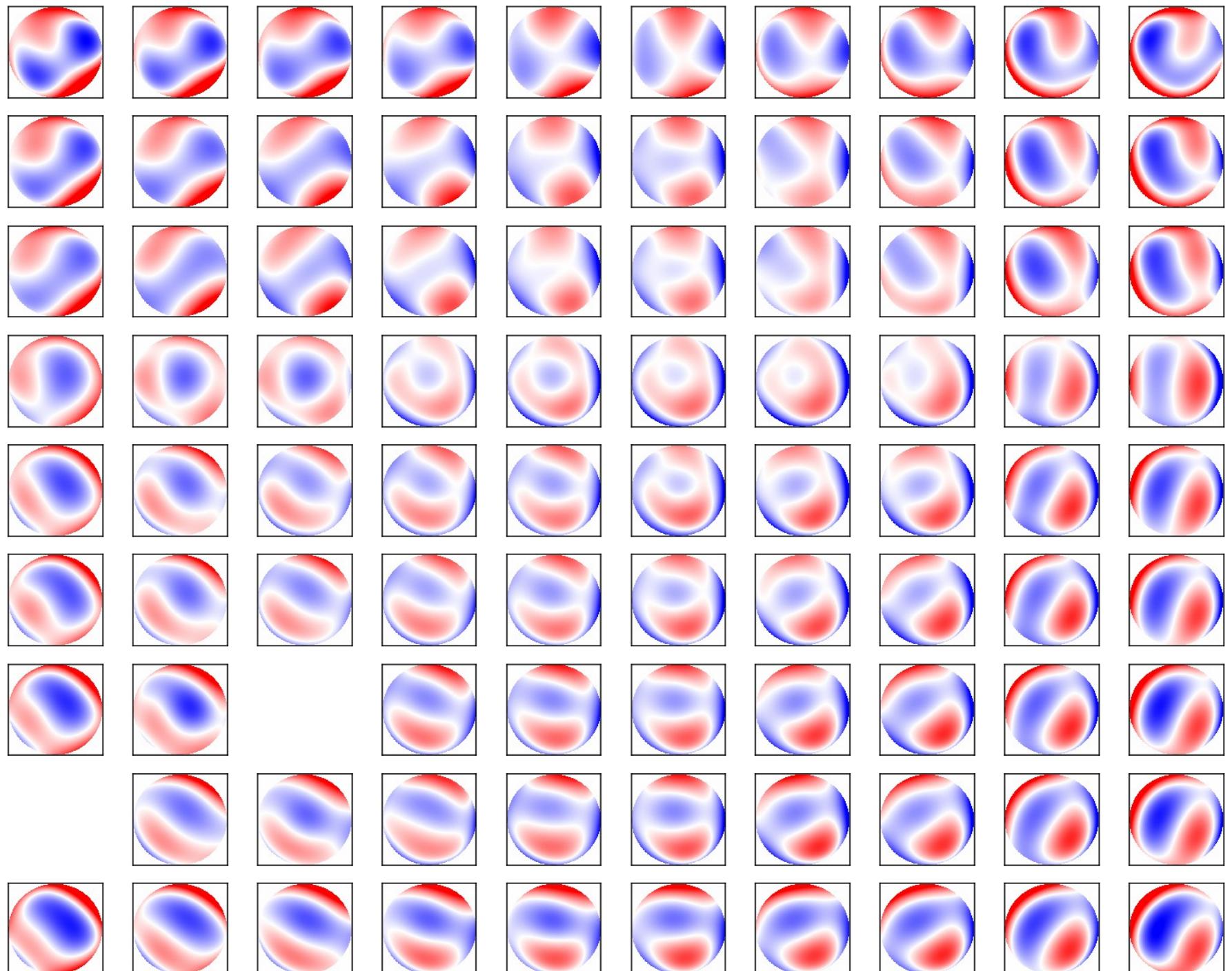
# HgAr continuum



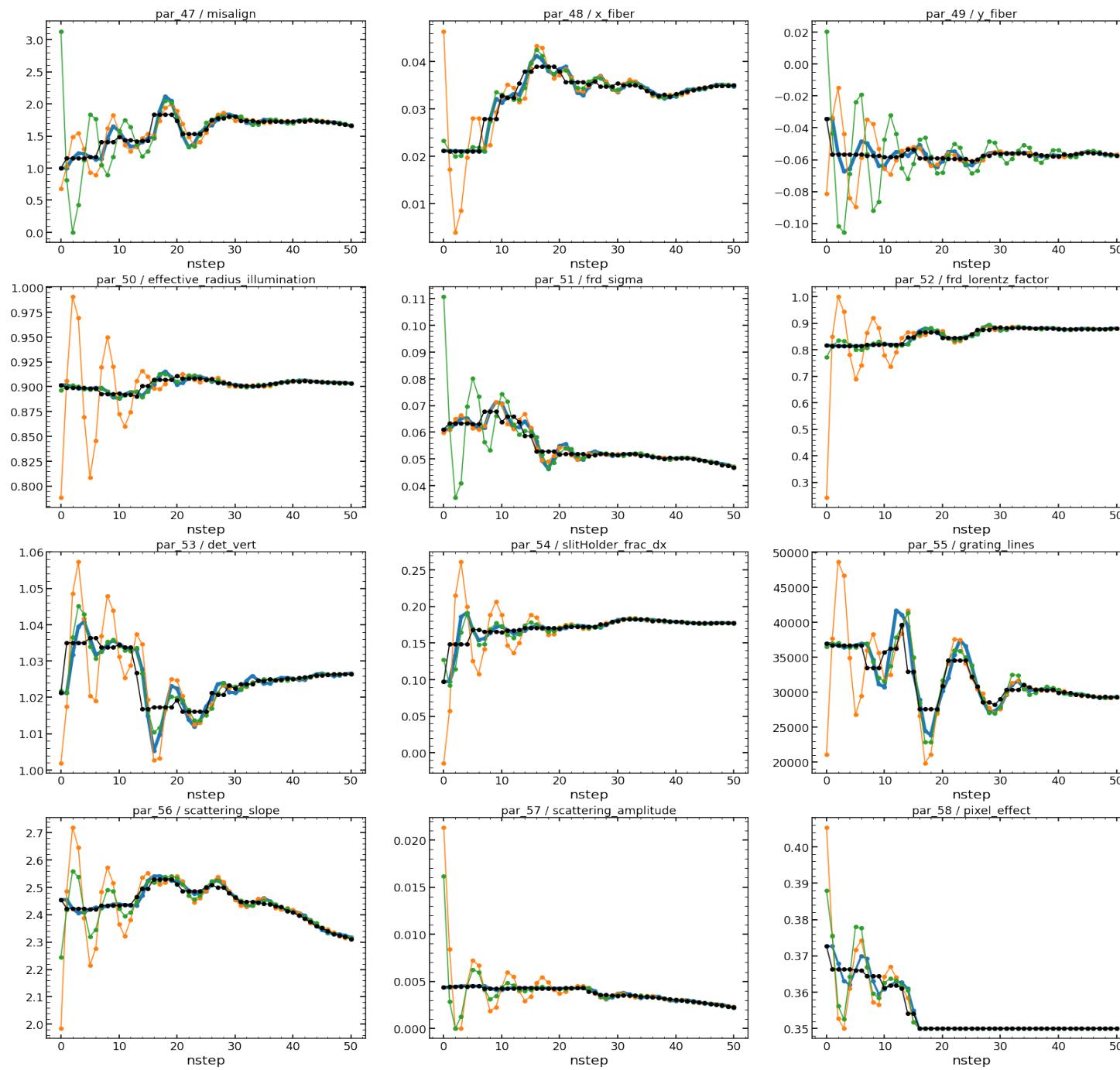
# Broad lines of HgAr



# wavefront

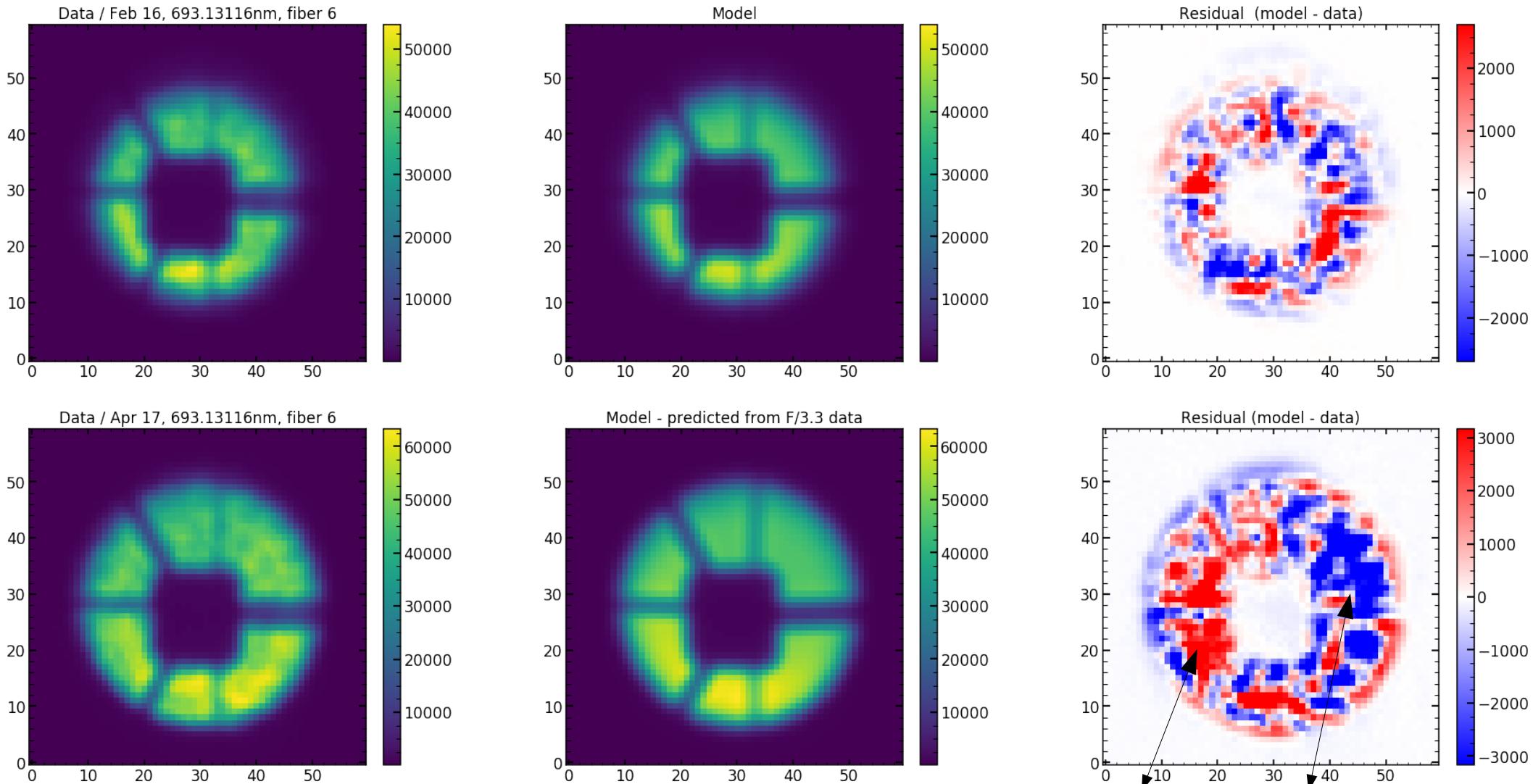


# Parameter fitting



# Different stops

a) only illumination of the full pupil gives full information



b) experiment for the quality of the approach

Mistakes in the non-illuminated region!