2D point spread function characterization for Prime Focus Spectrograph

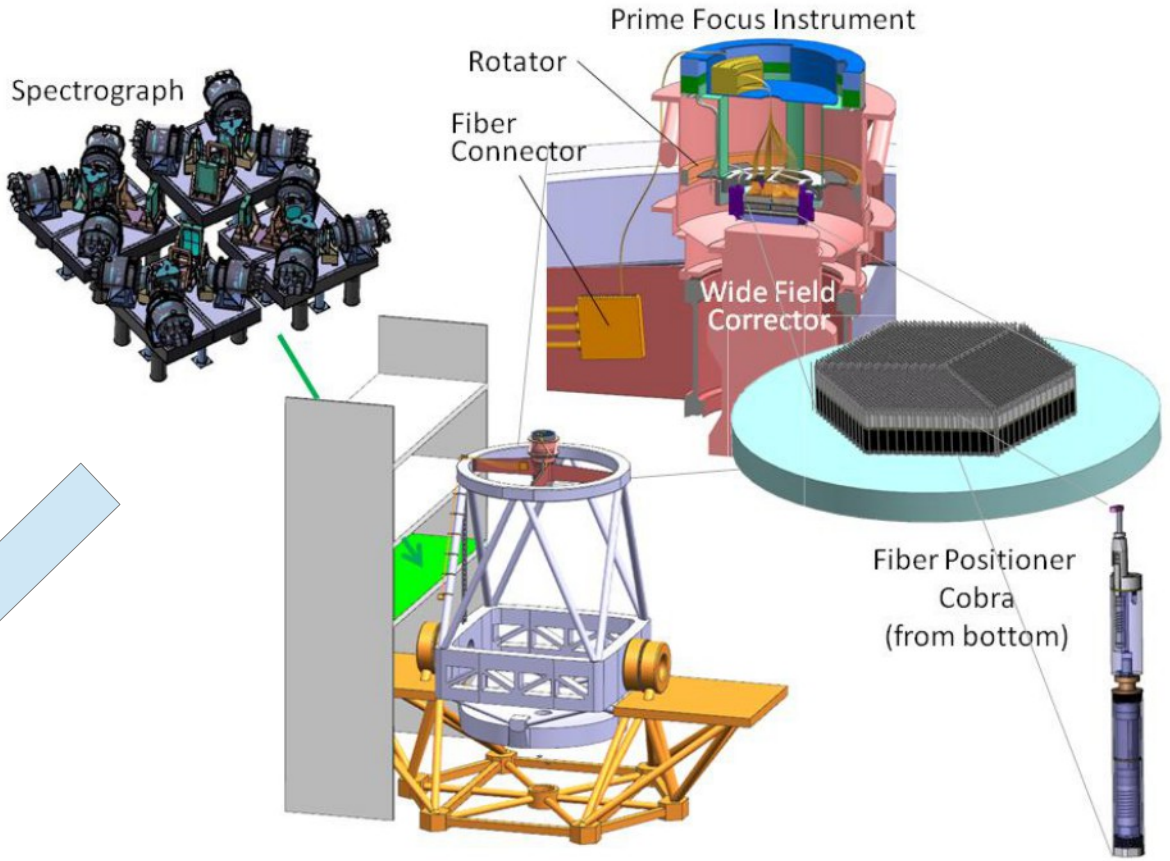
Neven Caplar

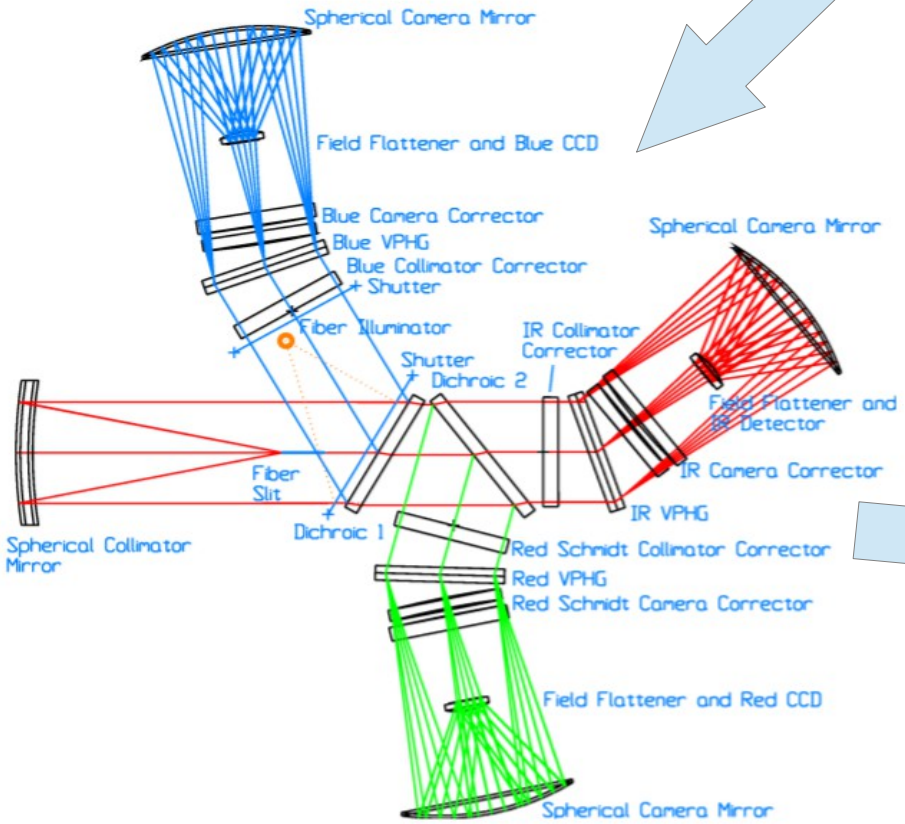
PRINCETON UNIVERSITY

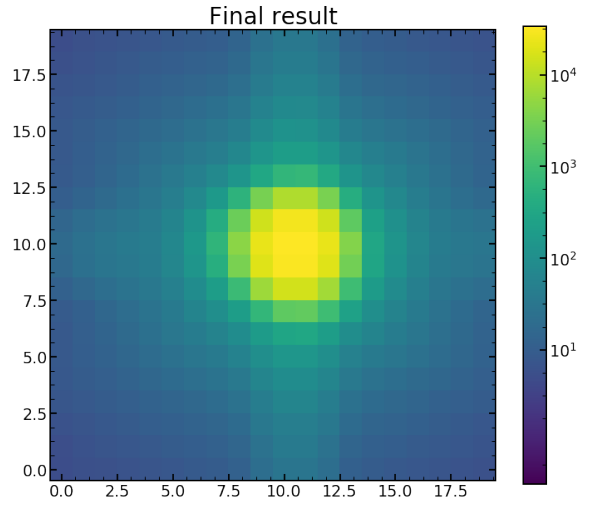
Contents

- 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

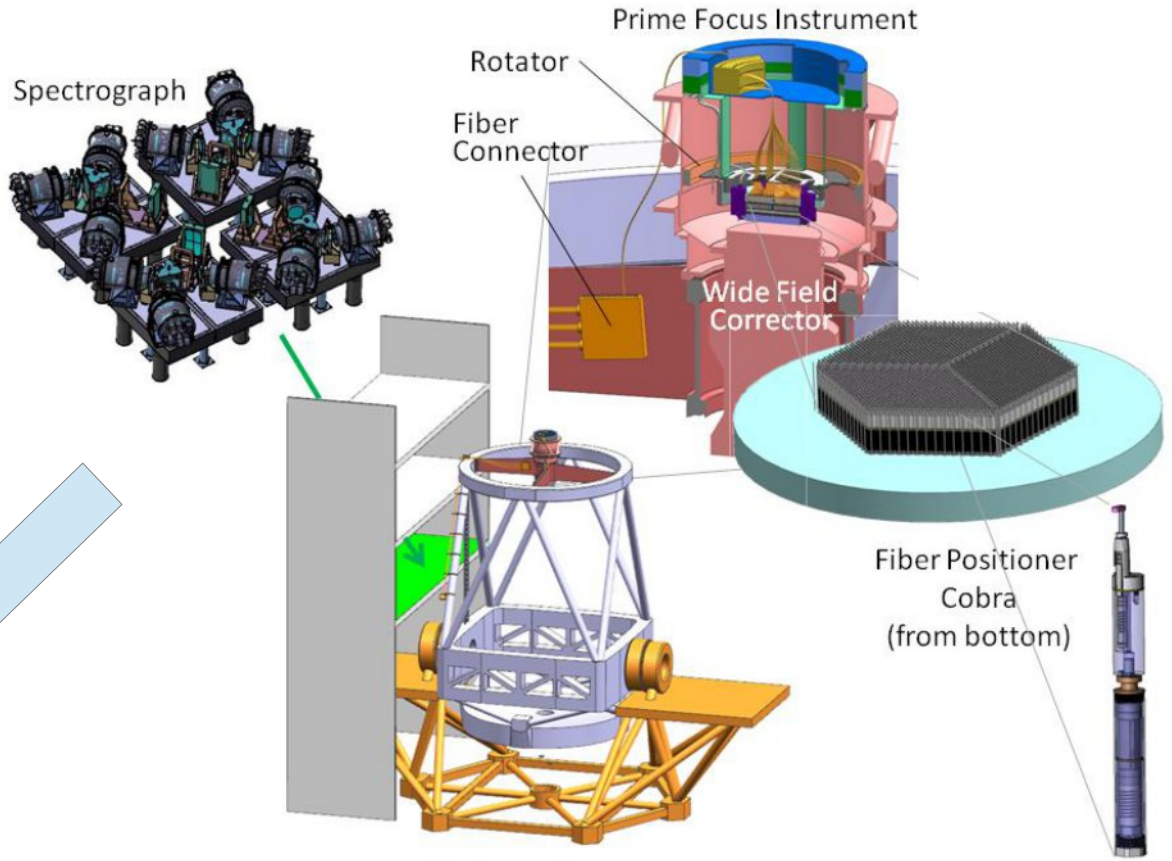
- 2394 fibers on 8.2 meter Subaru Telescope
- 360 nm – 1260 nm
- 1.6 to 2.7 Angstrom resolution
- Start of commissioning: Oct 2021

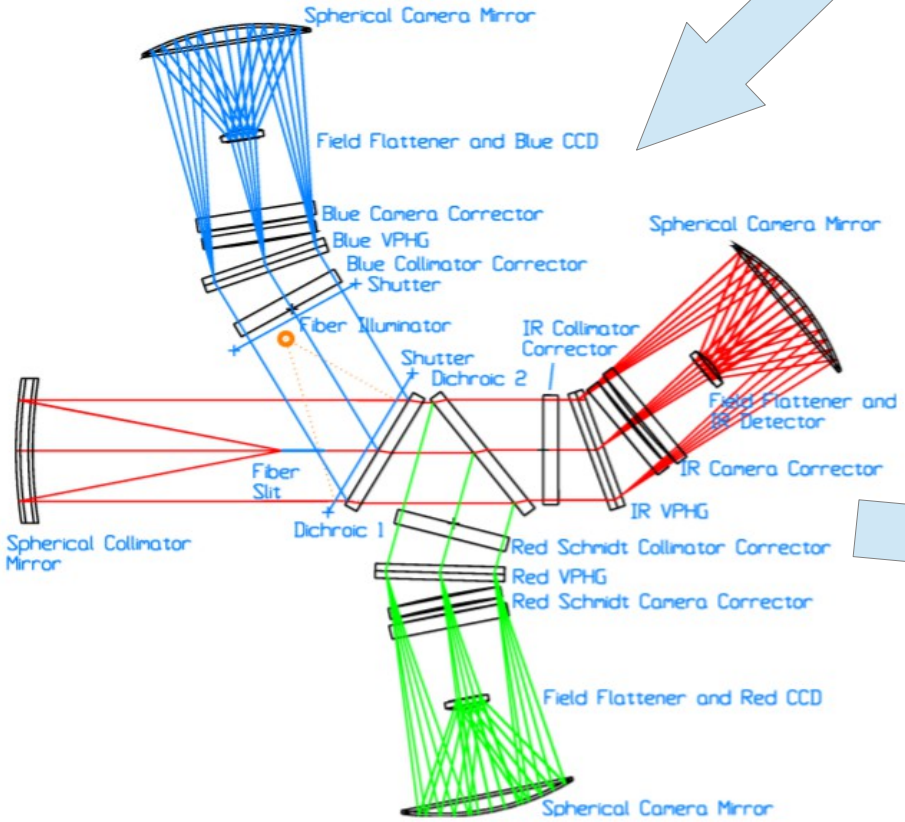


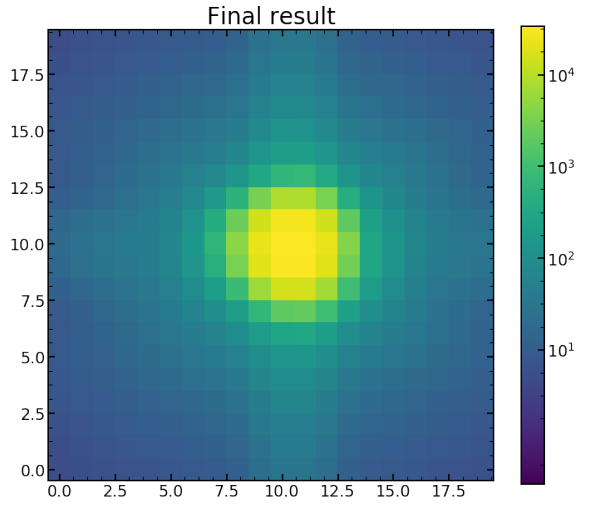




3 components to the PSF
- Telescope pupil illumination
- Focal ratio degradation in the fibres
- Spectrograph cameras

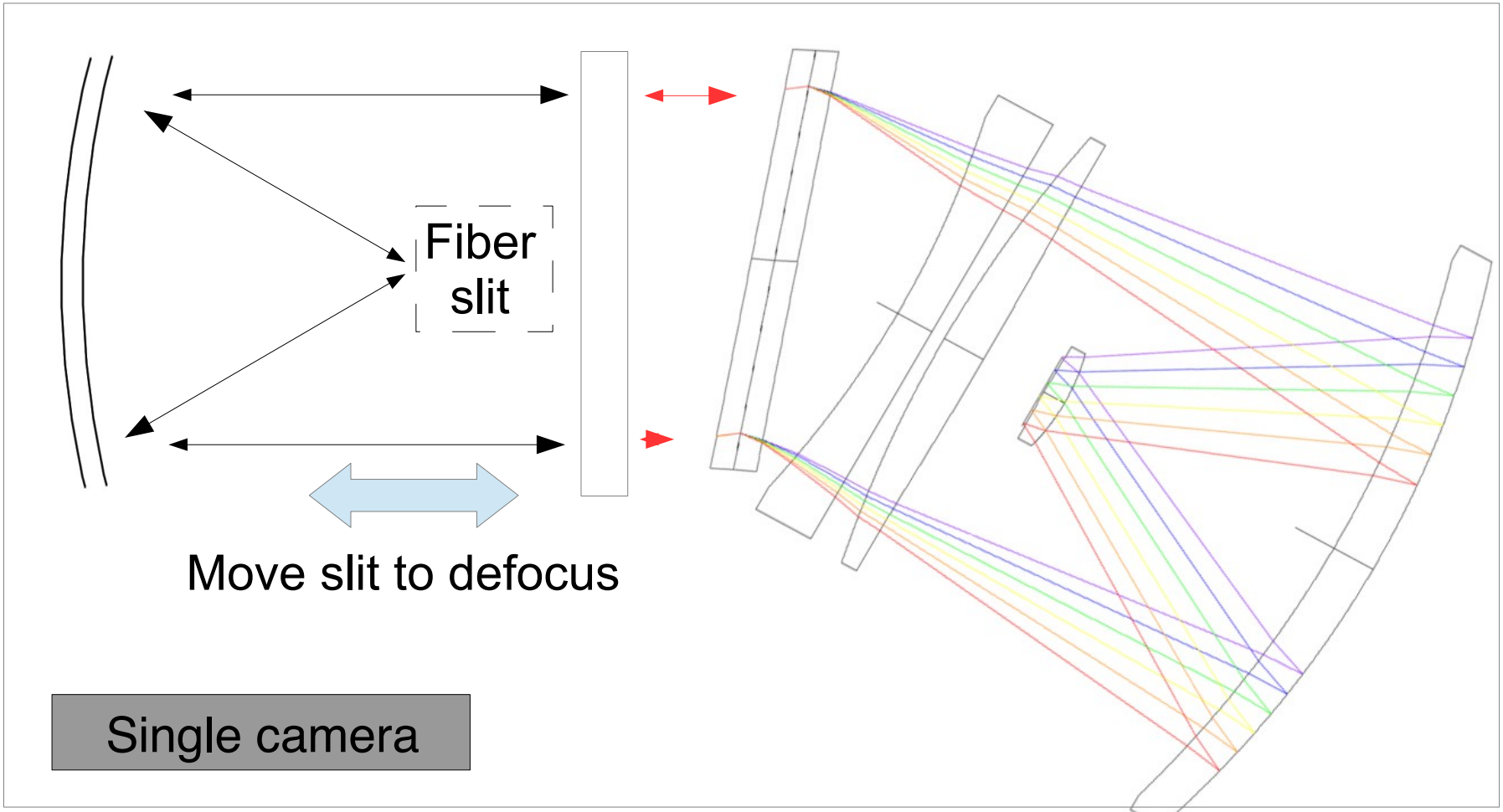


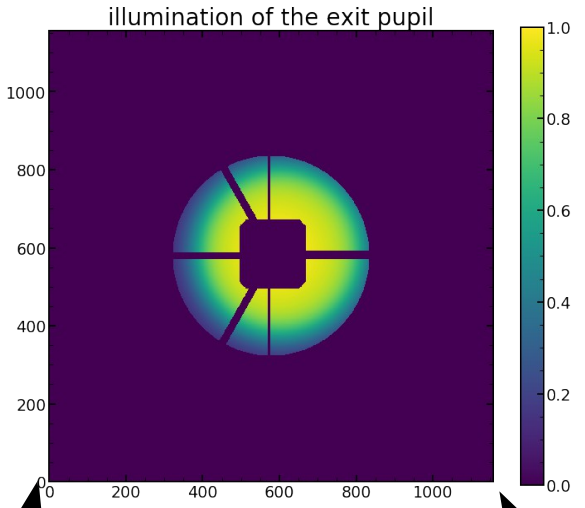


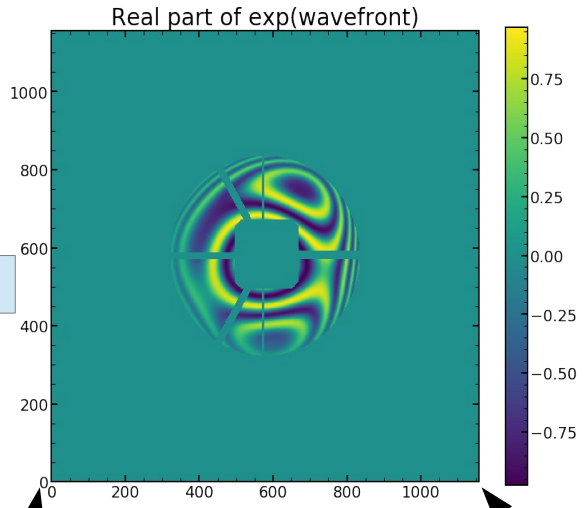


3 components to the PSF
- Telescope pupil illumination
- Focal ratio degradation in the fibres
- Spectrograph cameras

- 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







Non-uniformly illuminated – FRD and ``effective'' FRD

Aberrated wavefront – from defocused images

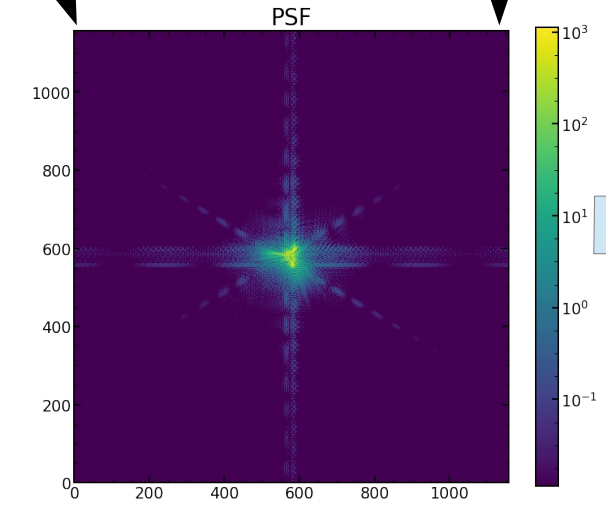
We have been developing a model to simulate PSF based on the experience from Hyper-Suprime project

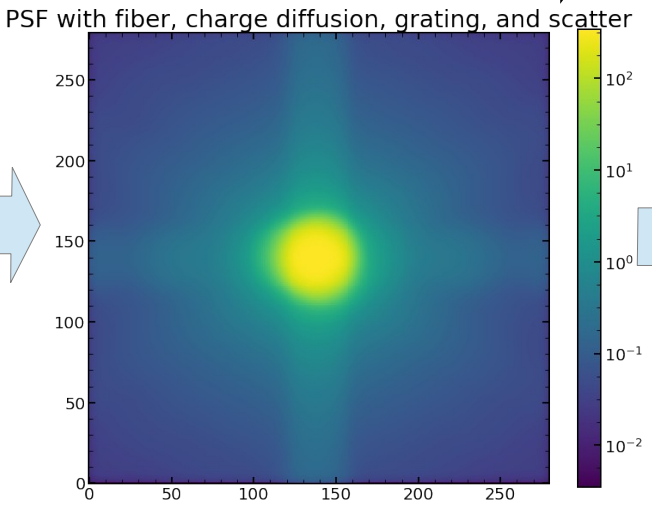
- Non-uniform illumination of the pupil
- Wavefront aberrations
- Scattering and other effects

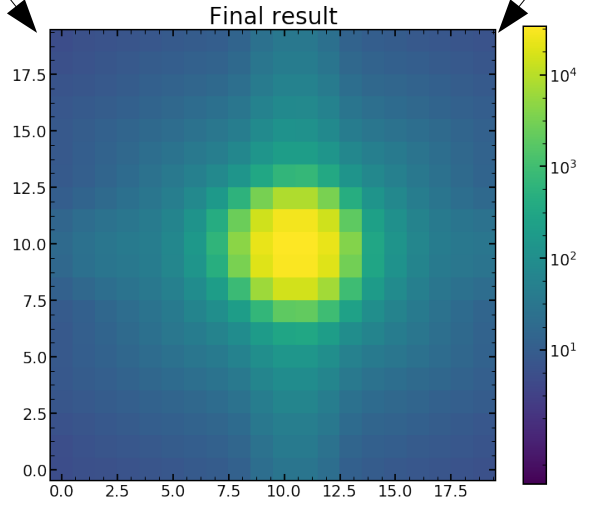
Fourier optics
Diffraction effects!

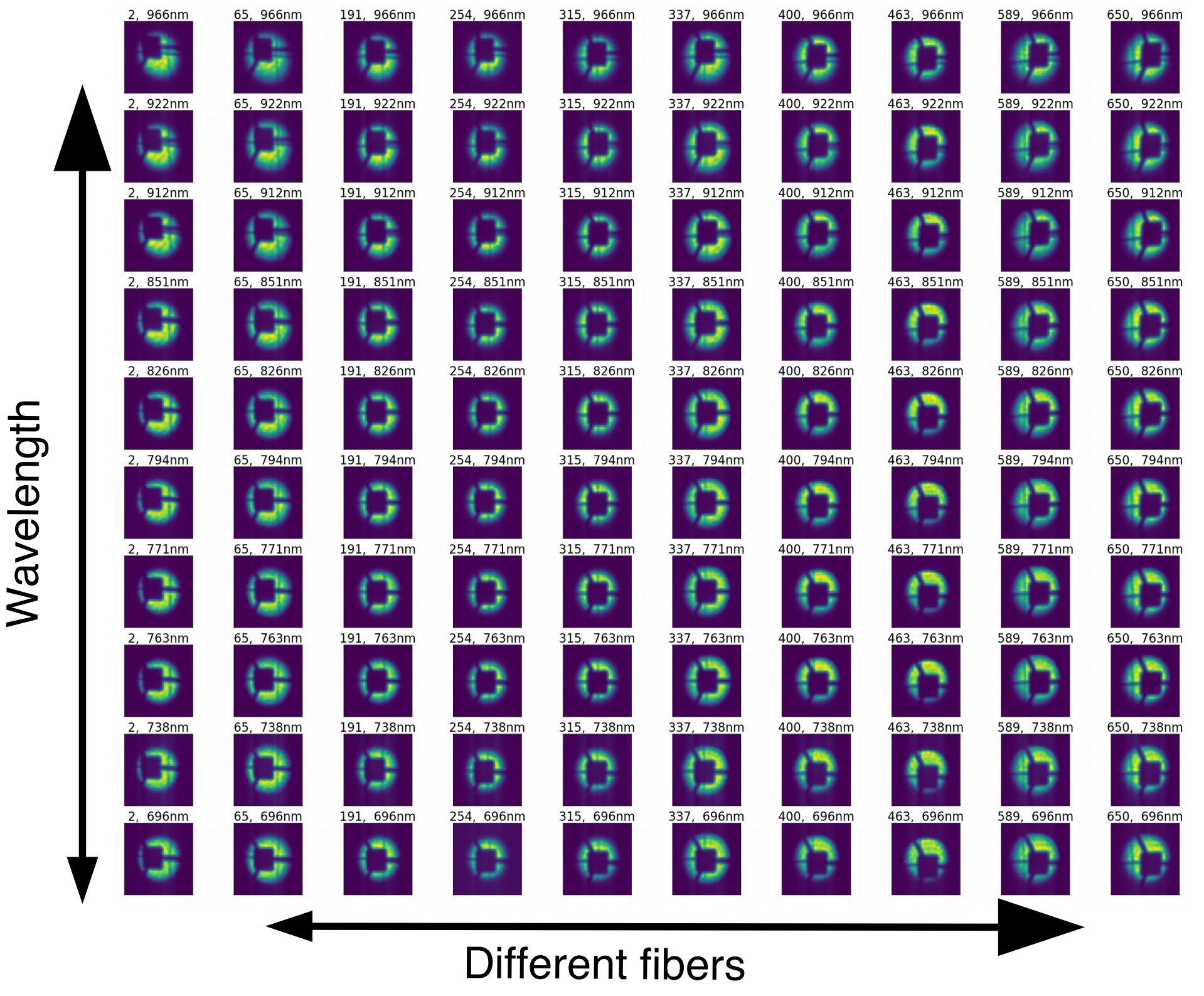
Fiber, charge diffusion, grating, scatter...

Final model as it would appear on the detector





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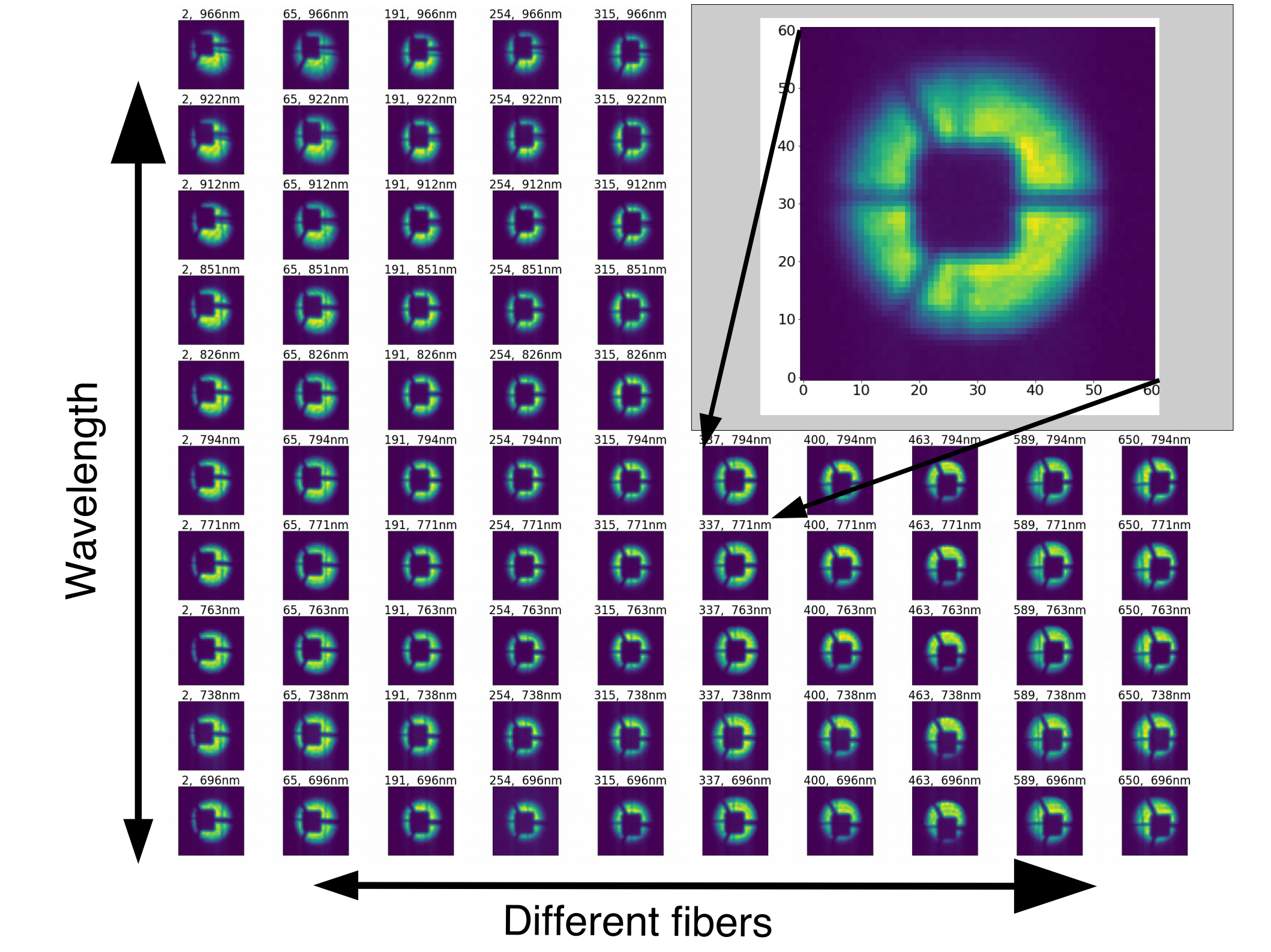
Wavelength
Different fibers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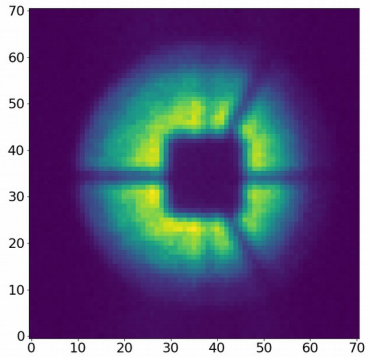
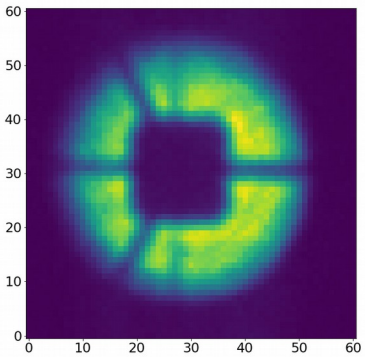
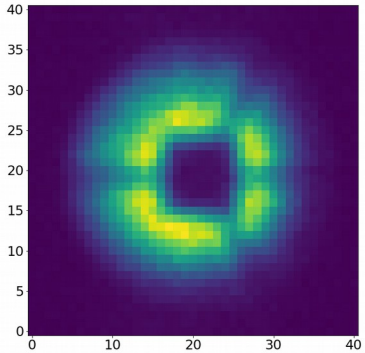
0
10
20
30
40
50
60
Wavelength
Different fibers

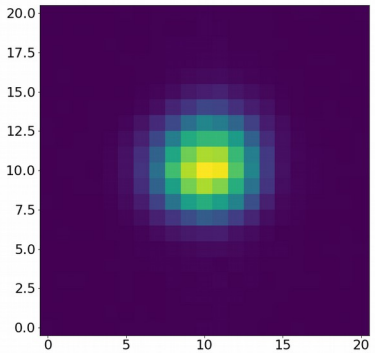
How to decouple the illumination and the wavefront aberrations?

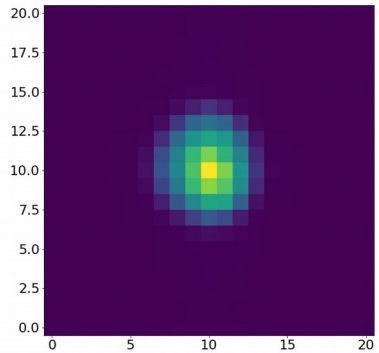


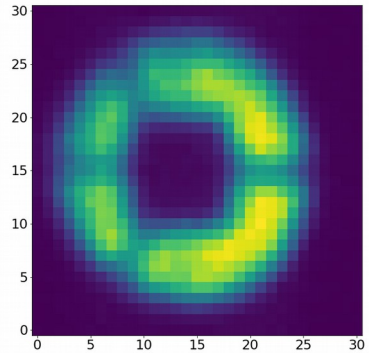


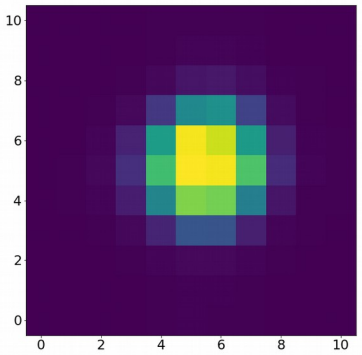
- Images at different value of defocus
- Follow wavefront aberrations as a function of defocus







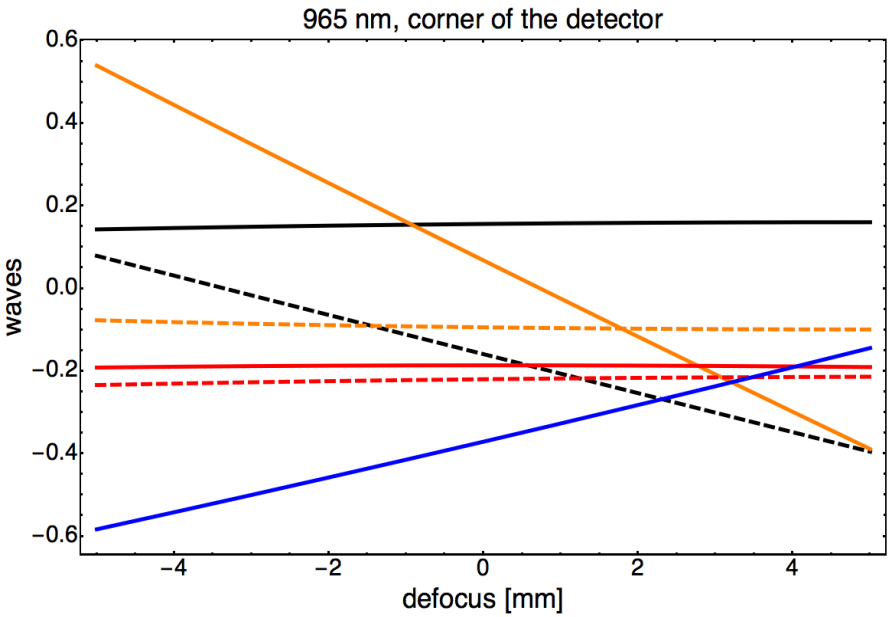


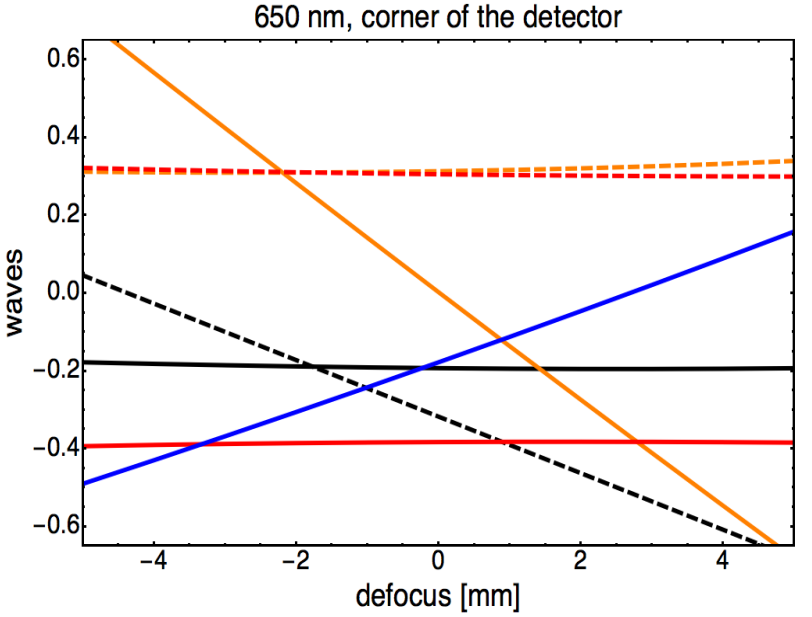


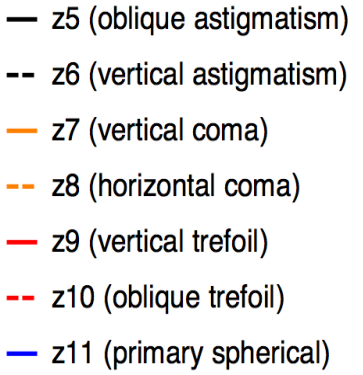
More defocused

In focus

More defocused



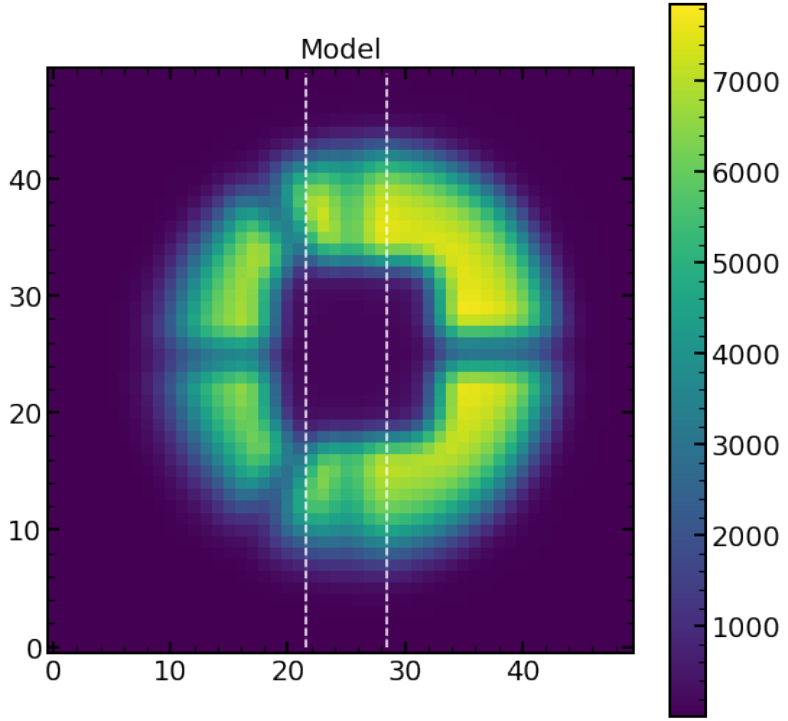


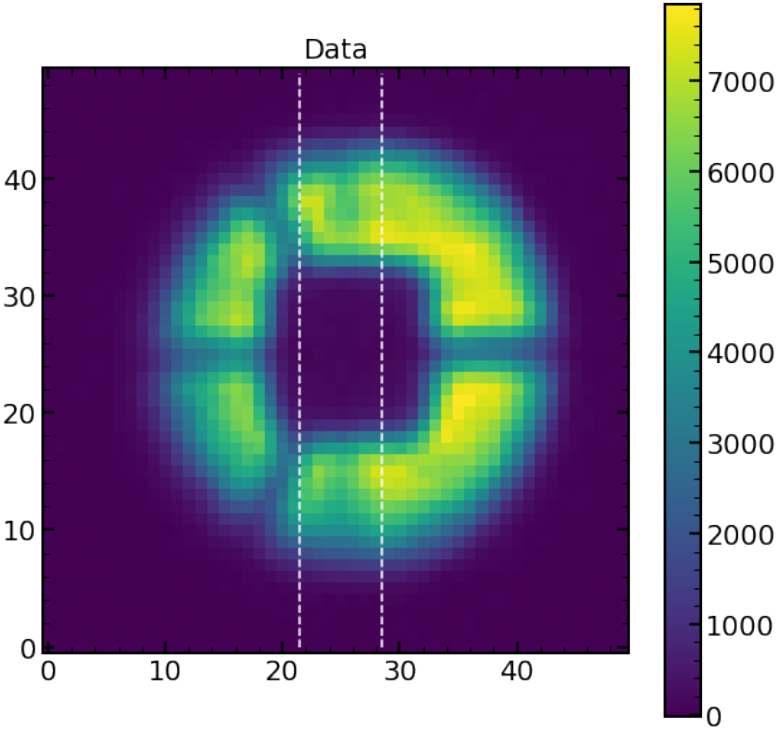


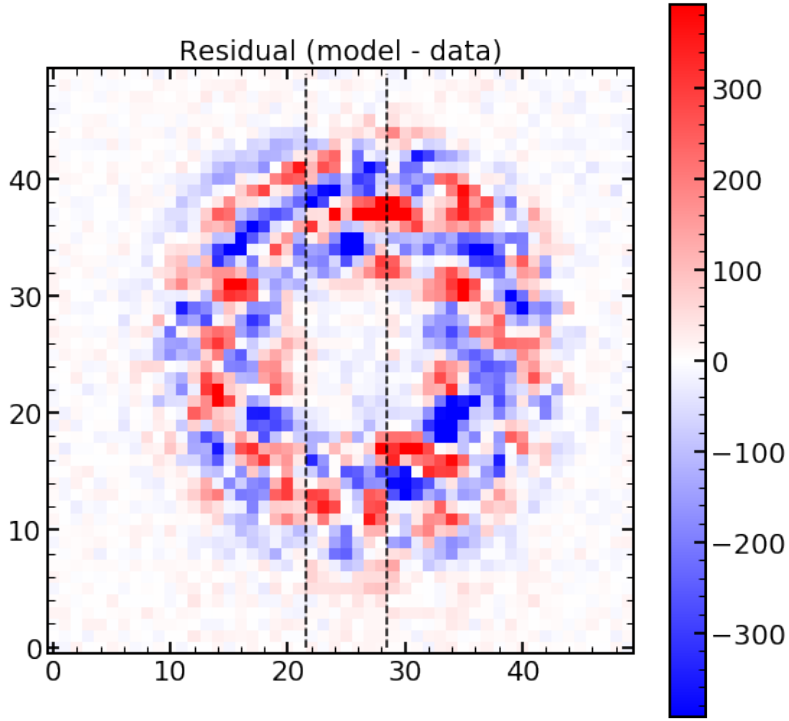
Wavefront aberrations as function of defocus (Zemax)

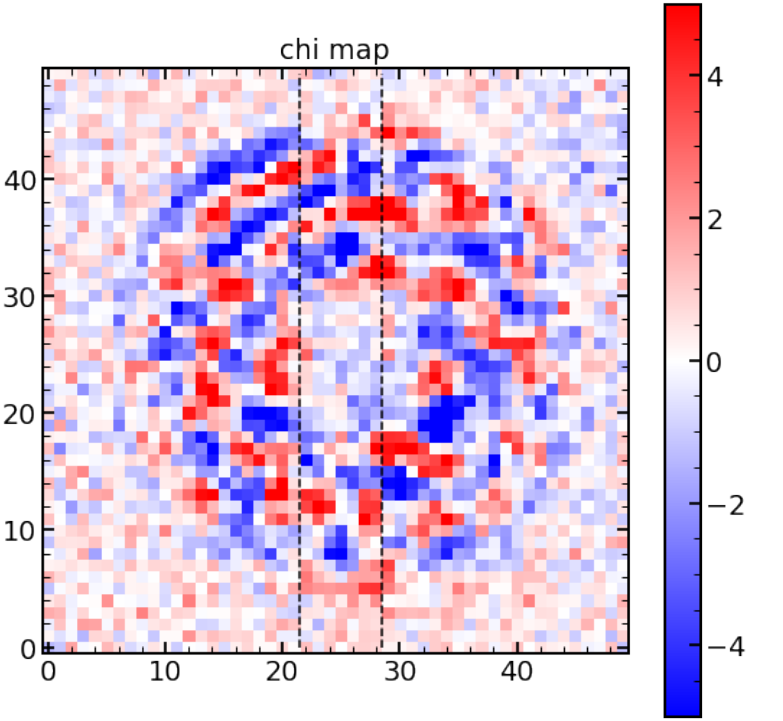
- We wish to deduce/reproduce these curves from the data
- Model wavefront aberrations at each position in the detector

Defocused data, example with linear scaling

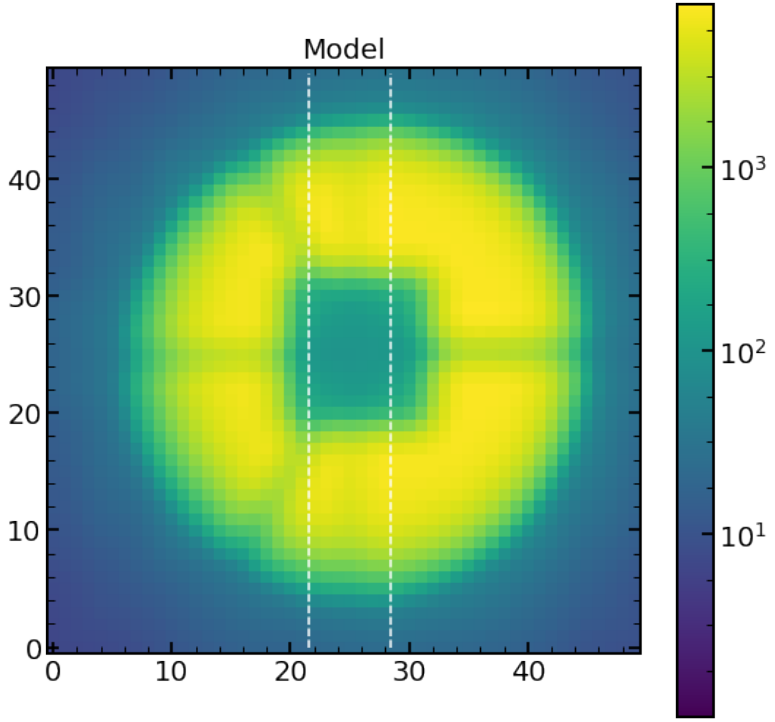


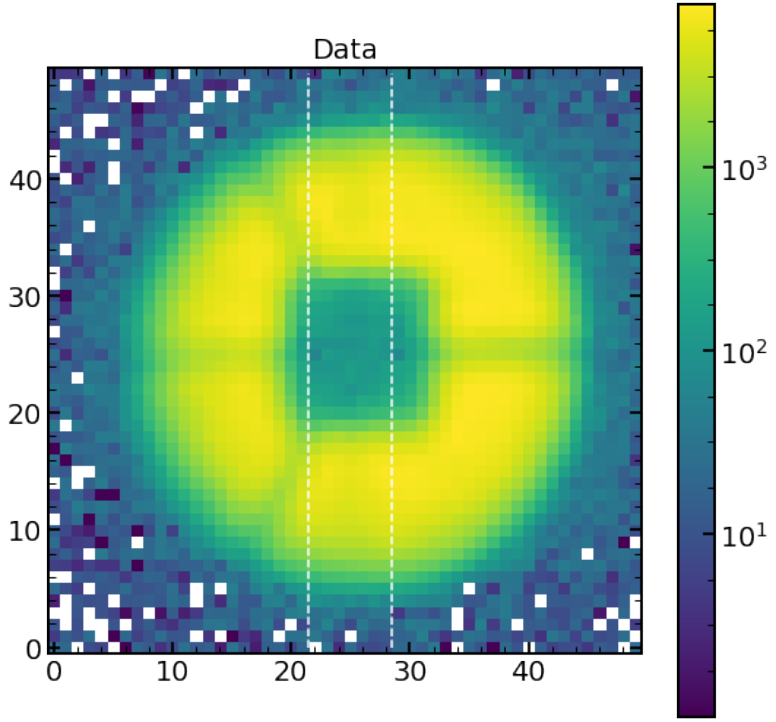


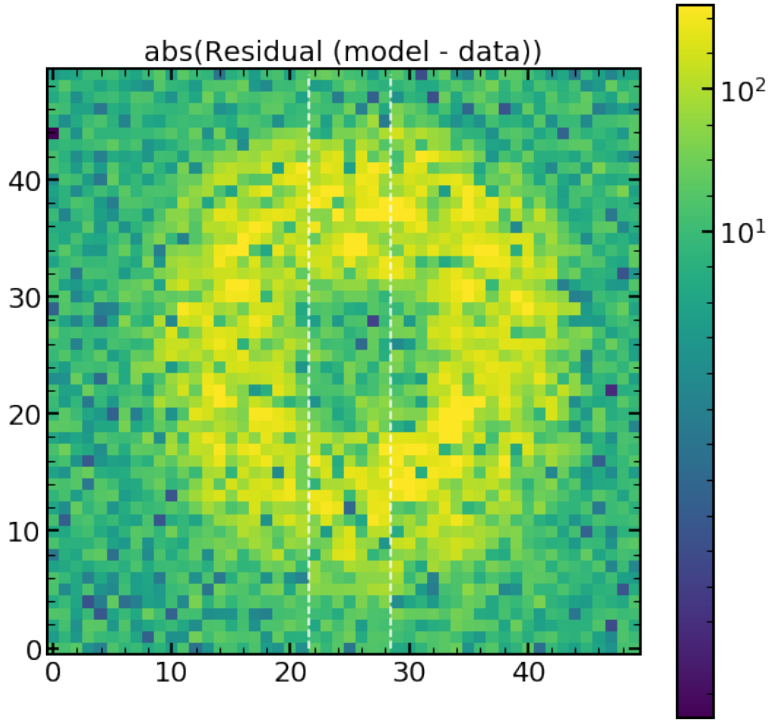


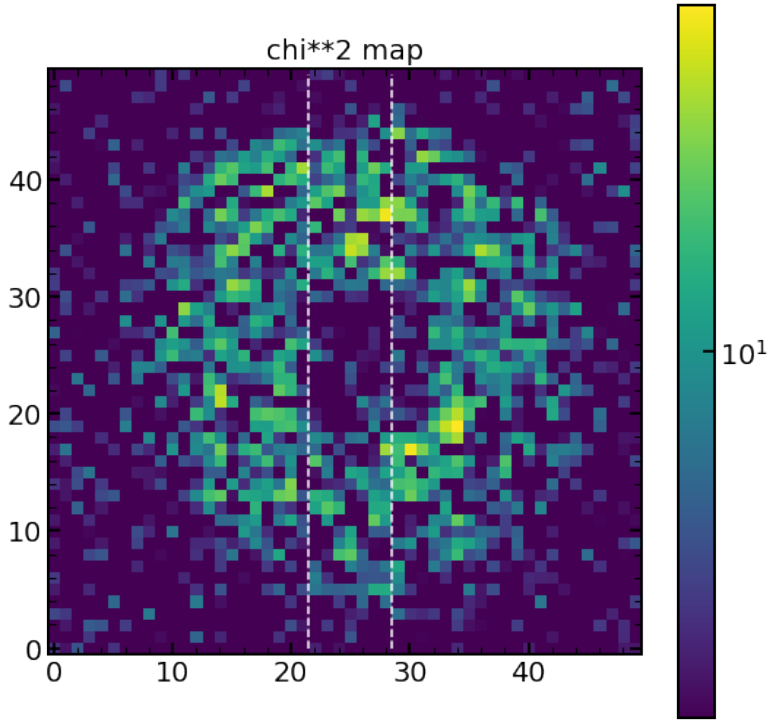


Defocused data, example with log scaling

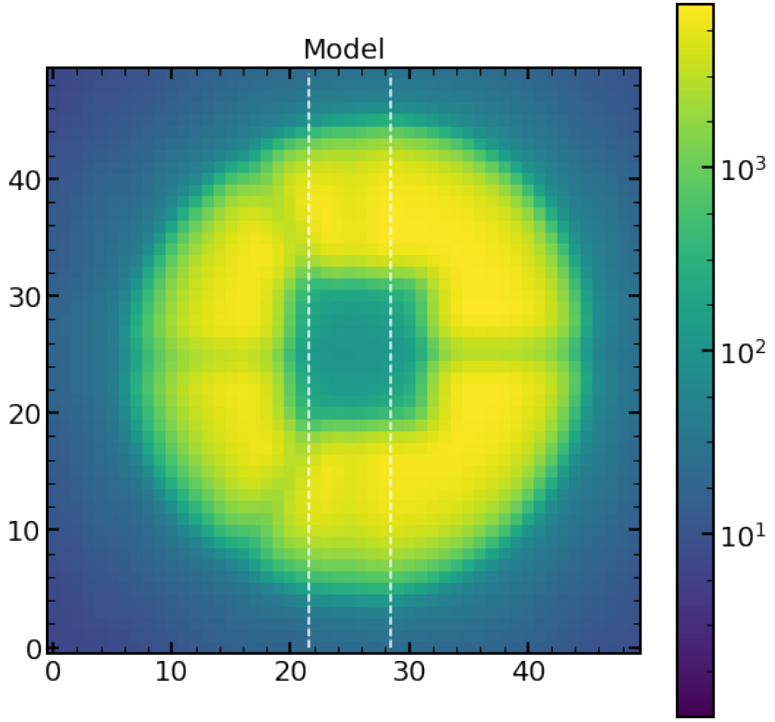


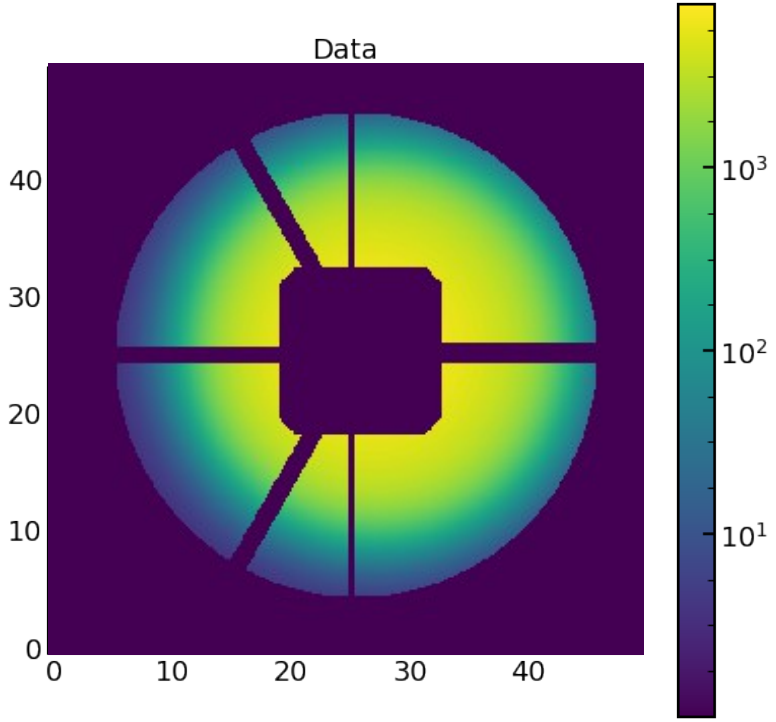


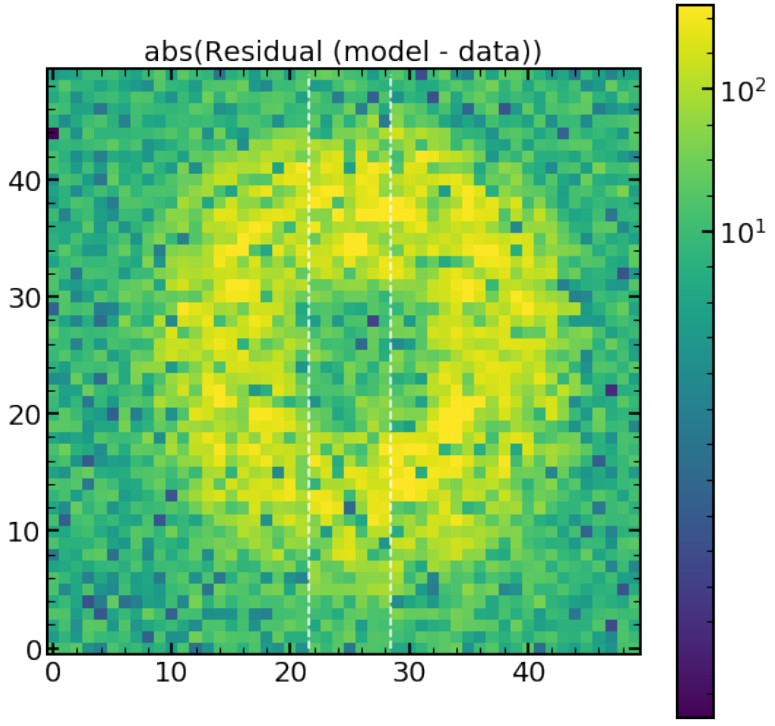


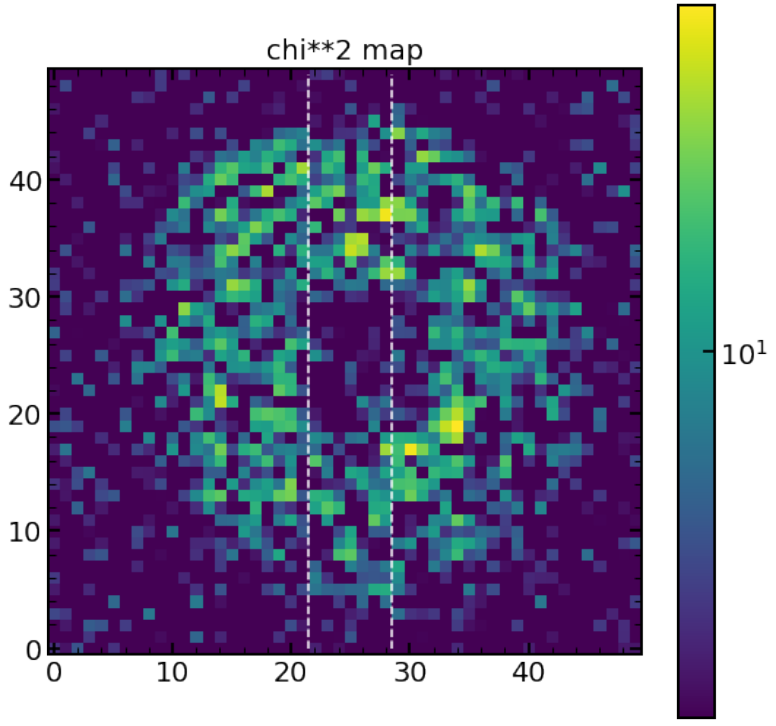


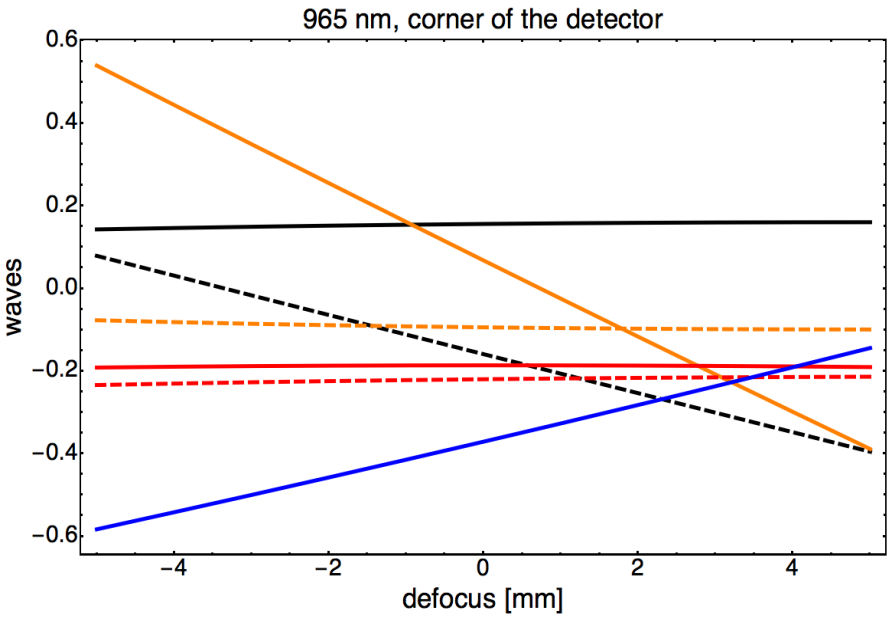
Defocused data, example with log scaling

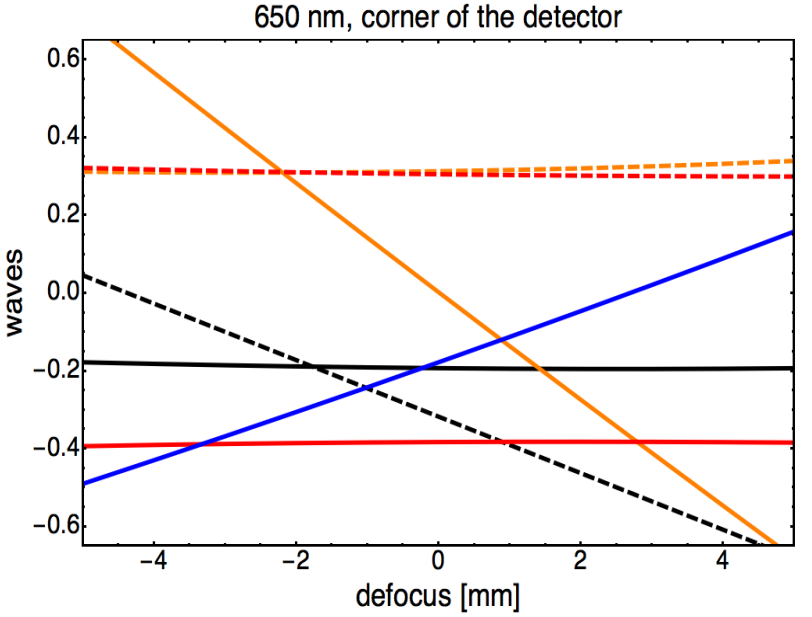


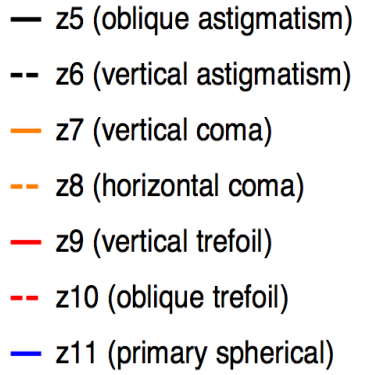




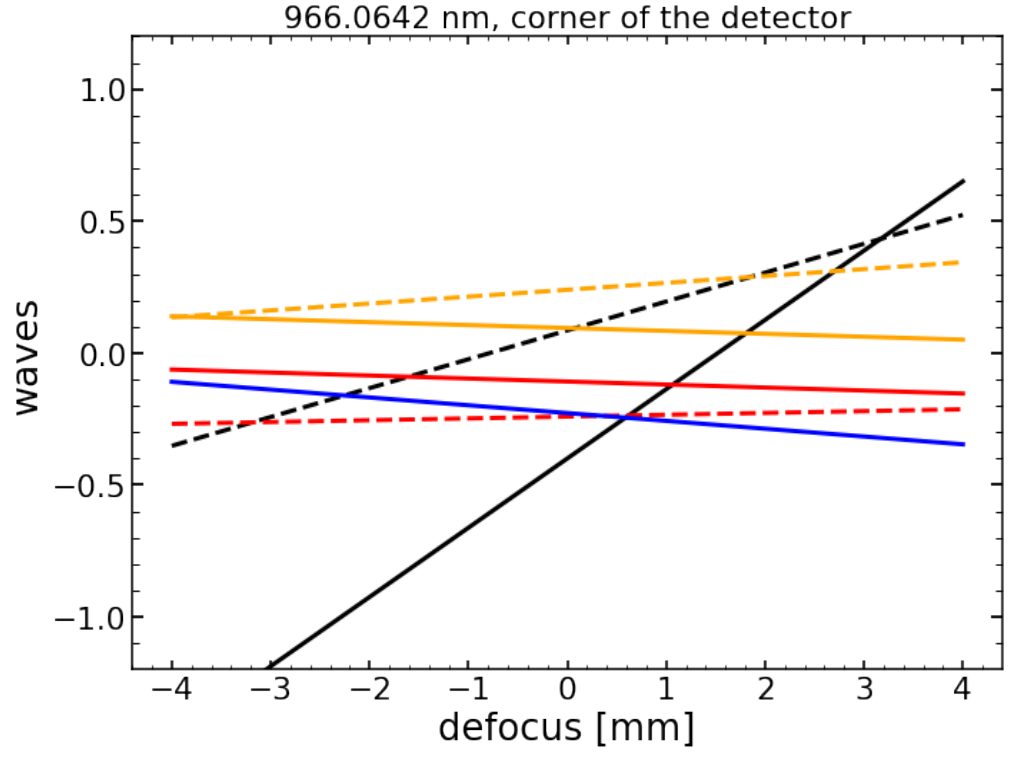


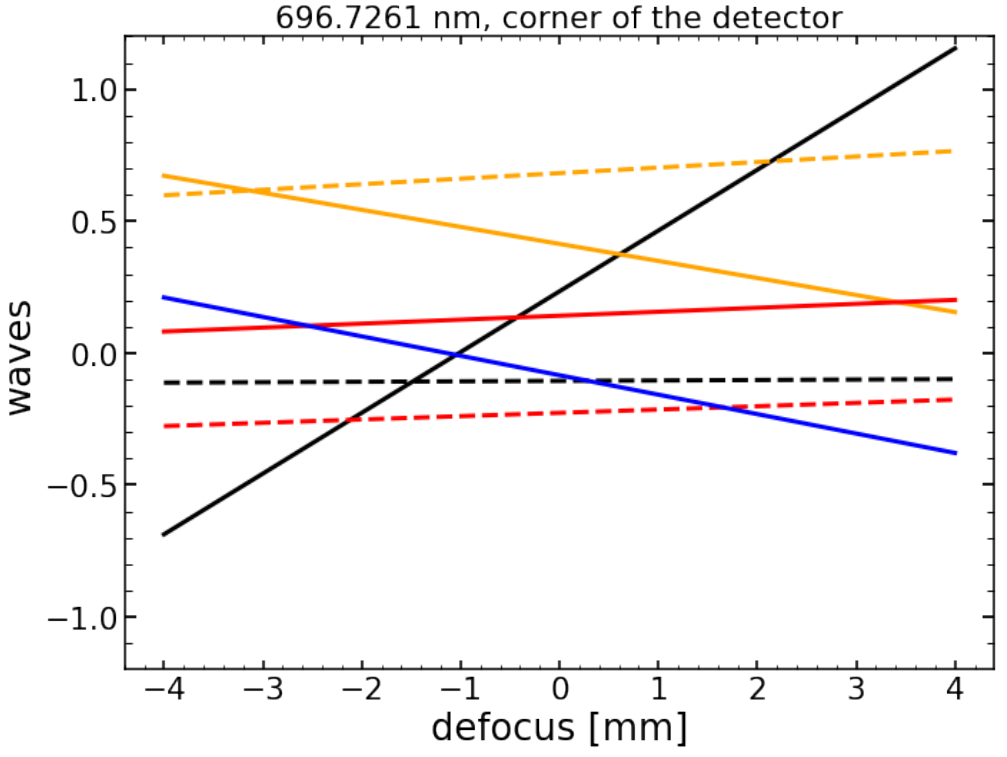


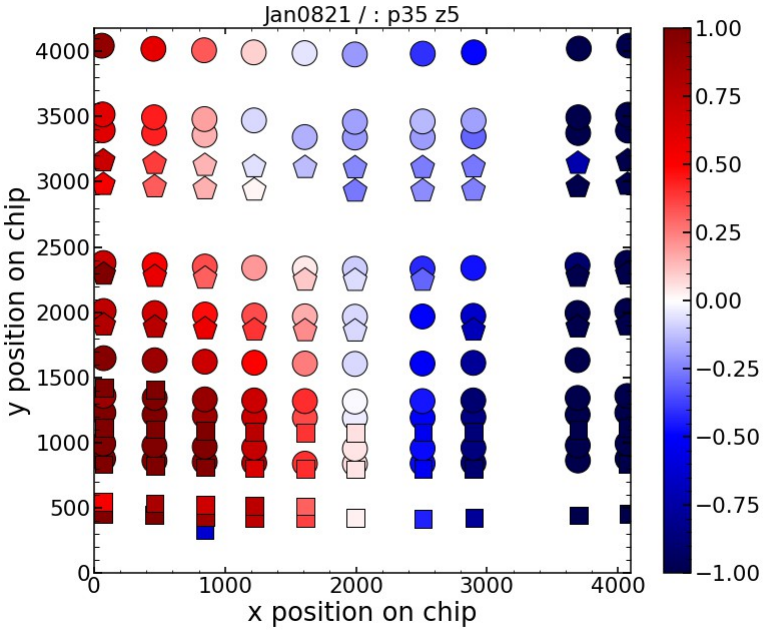




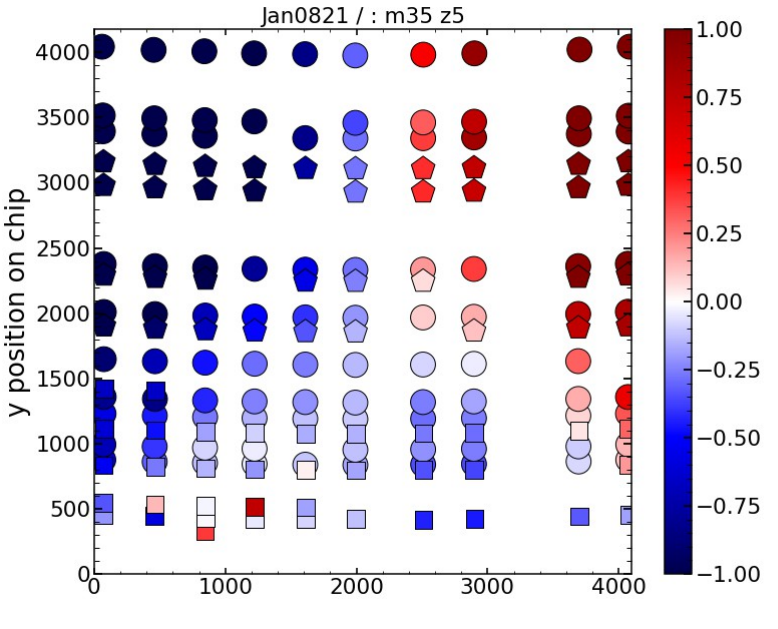
- Example from modelling of the experimental data below
  (not exactly the same location as above, but observe large difference)

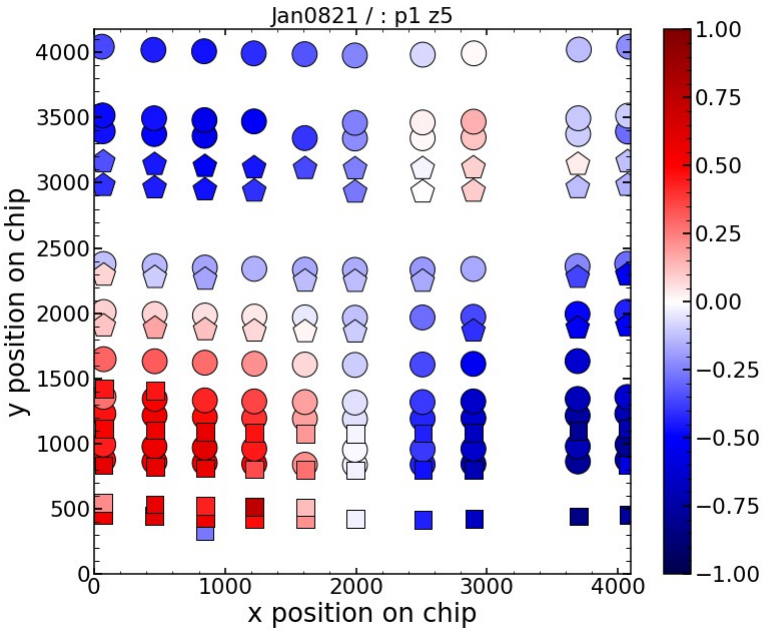


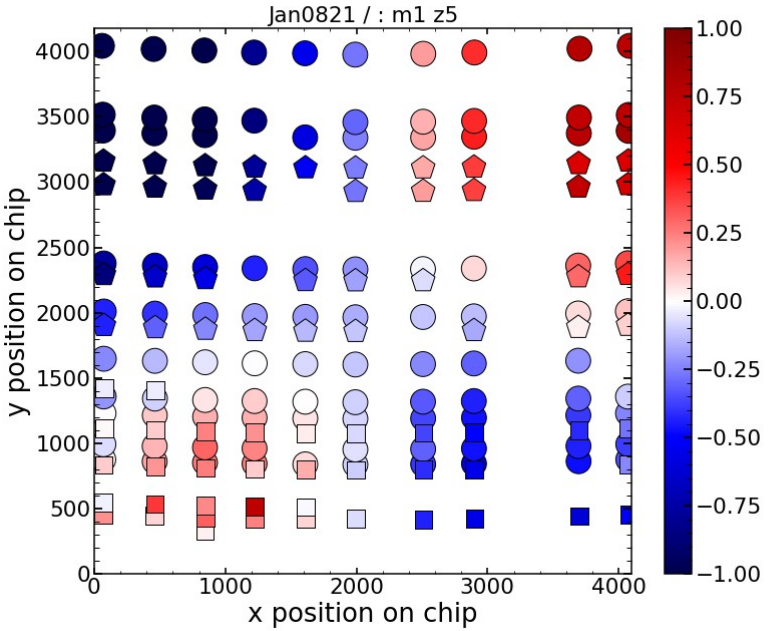




Change of single component (oblique astigmatism)

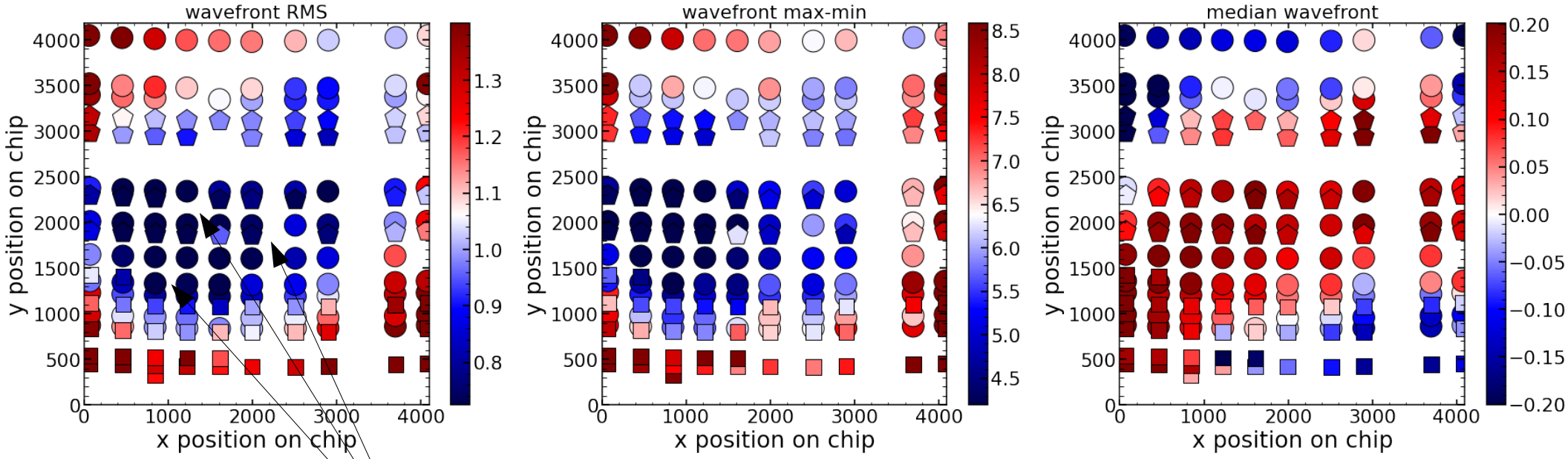






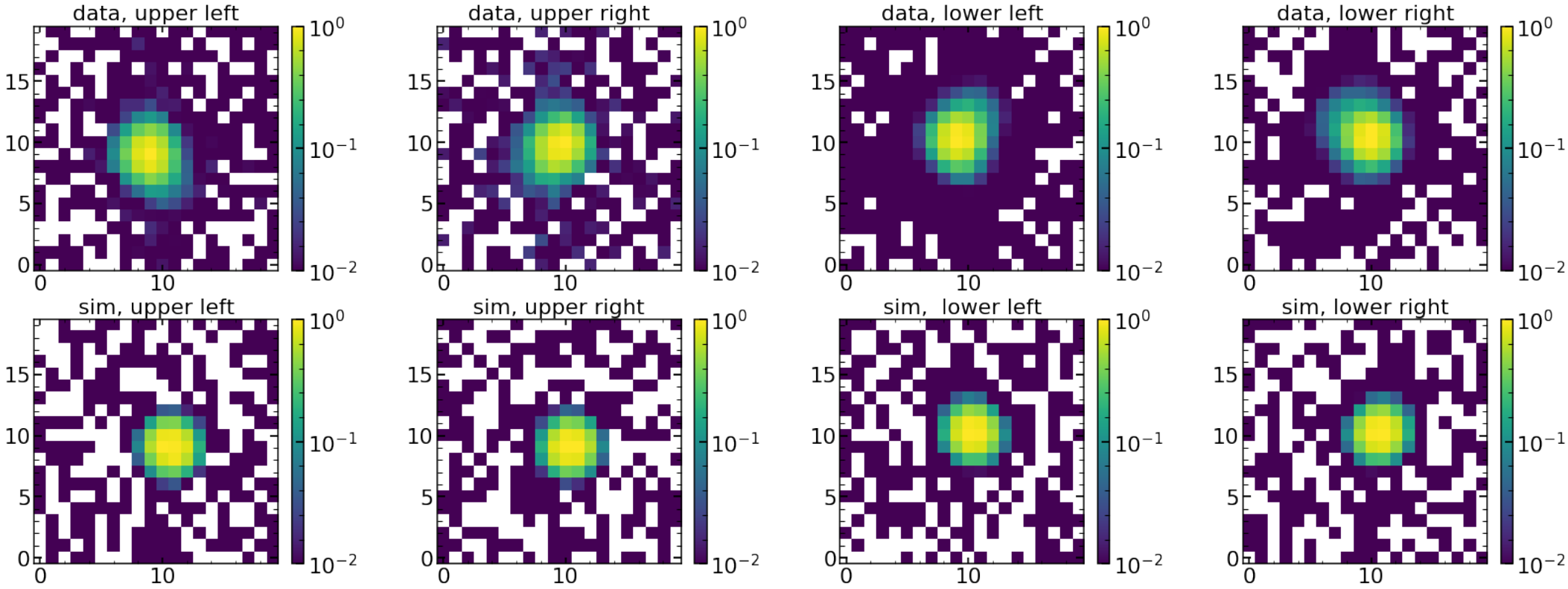
Changing defocus

Wavefront rms across the detector

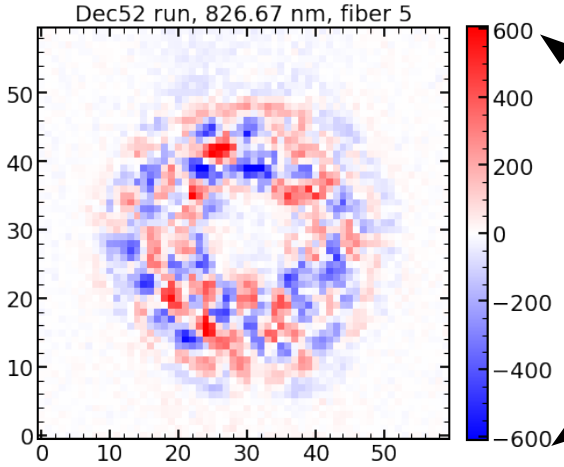


Not in the center of the detector – probably because it was centered from available data

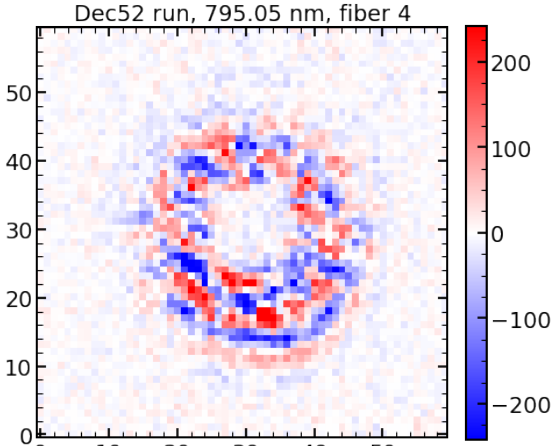
Zemax & real data

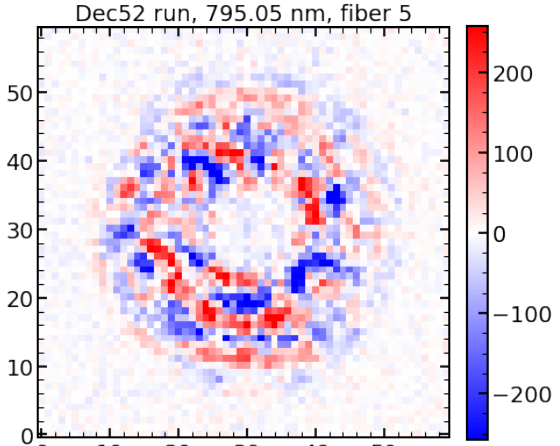


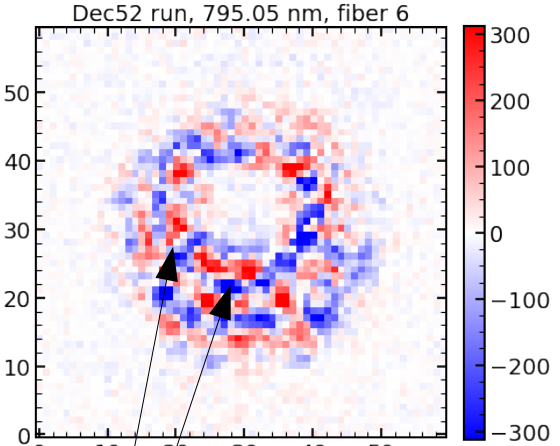
Residuals of fits to the data - defocus

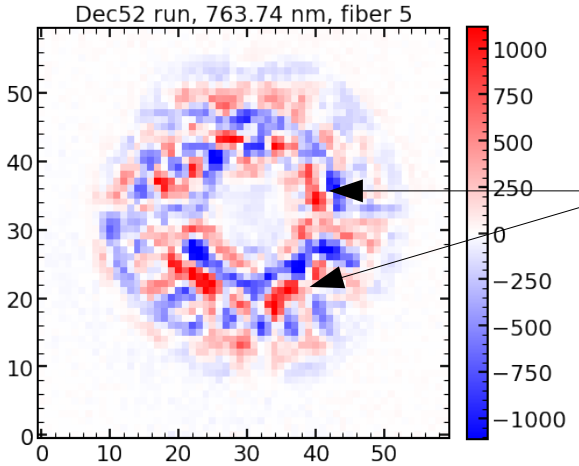


Residuals scaled to 5% of the maximal flux in the data









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

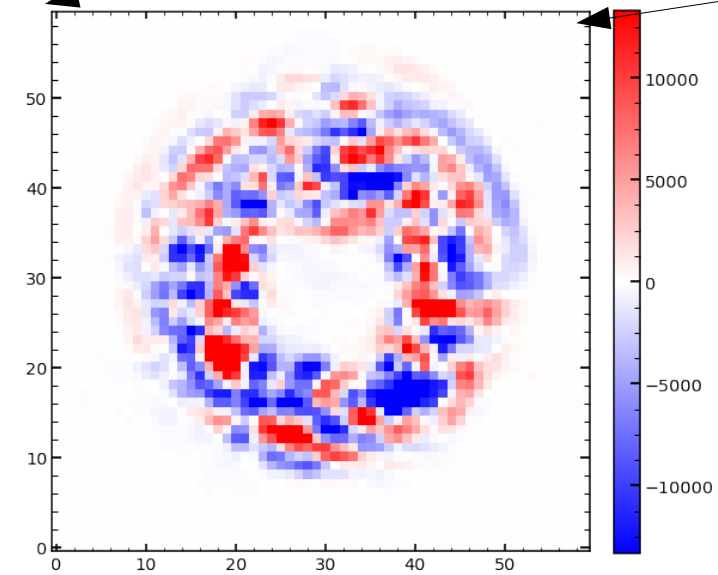
Direct Fits

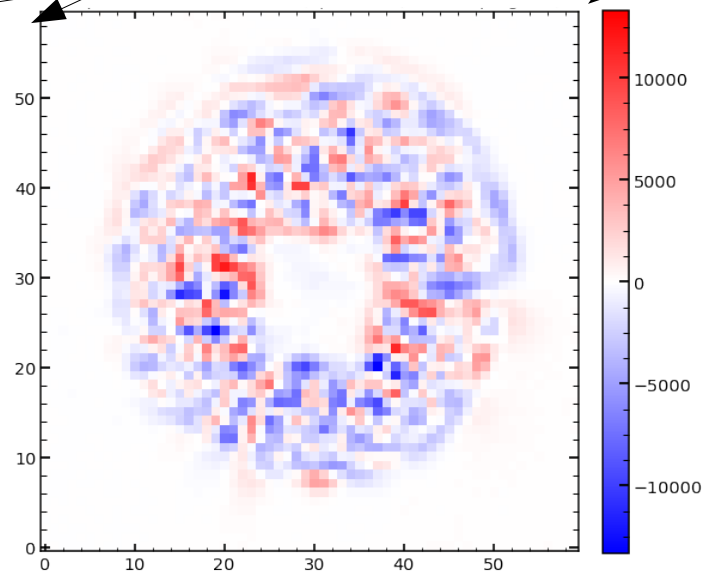
Residuals scaled to 5% of the maximal flux in the data

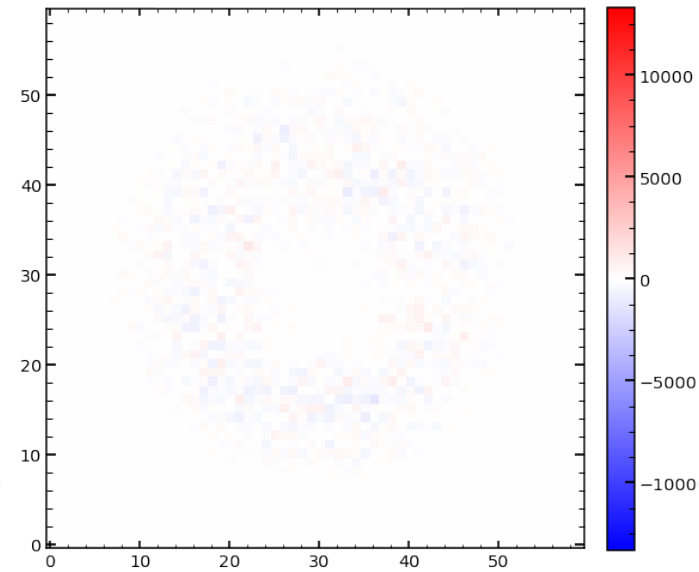
Up to z22

Up to z254

Perfection



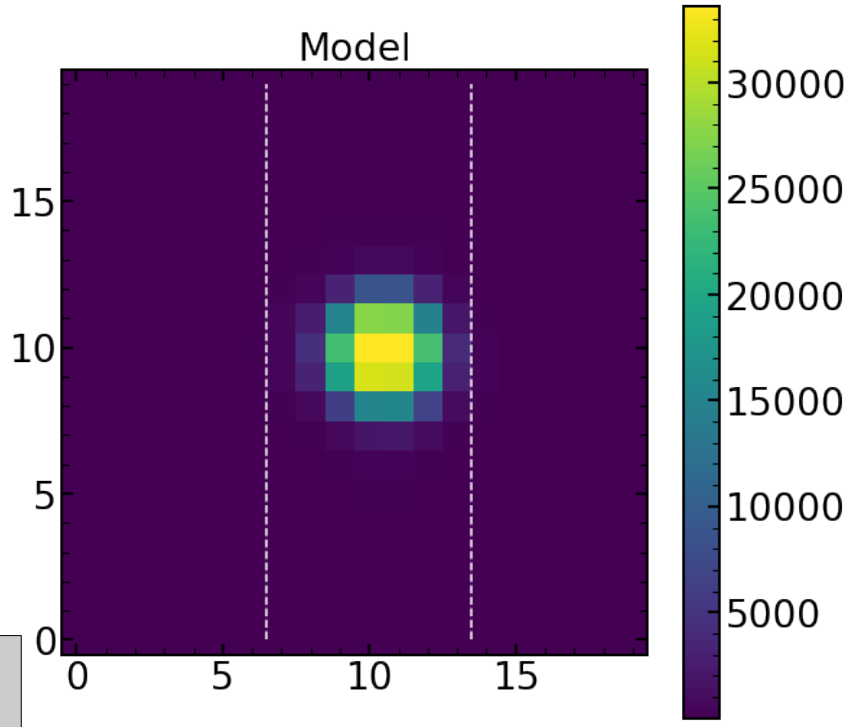


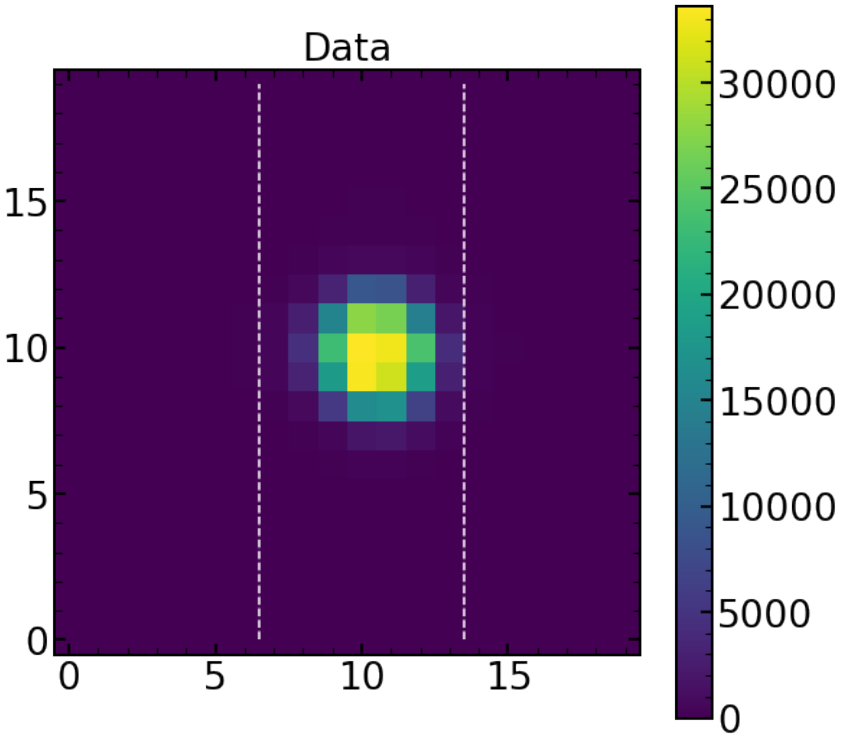


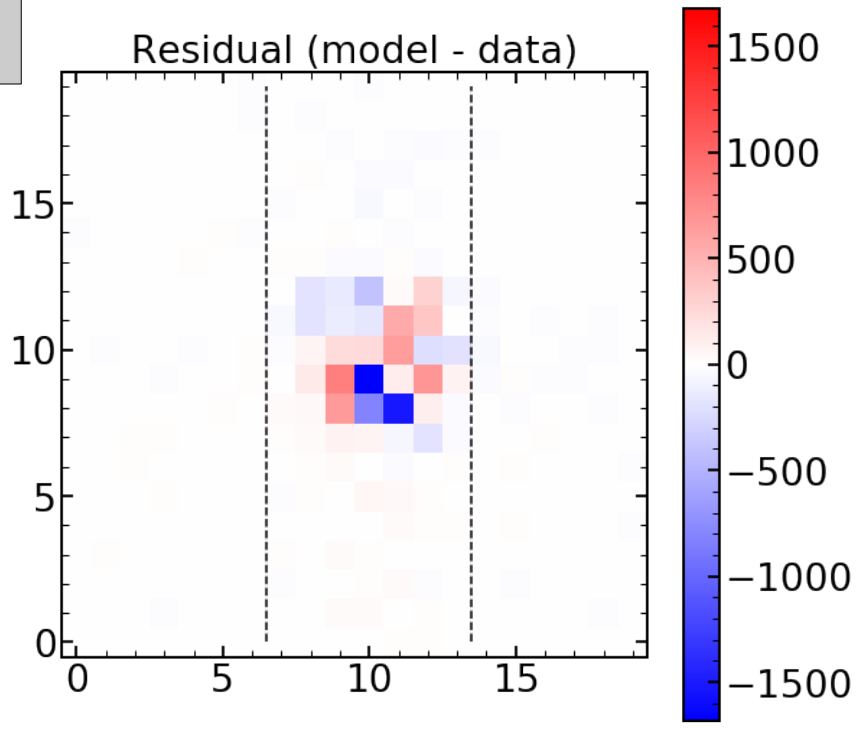
High order aberrations do not vary as a position of the detector? (if they come from glass imperfections)

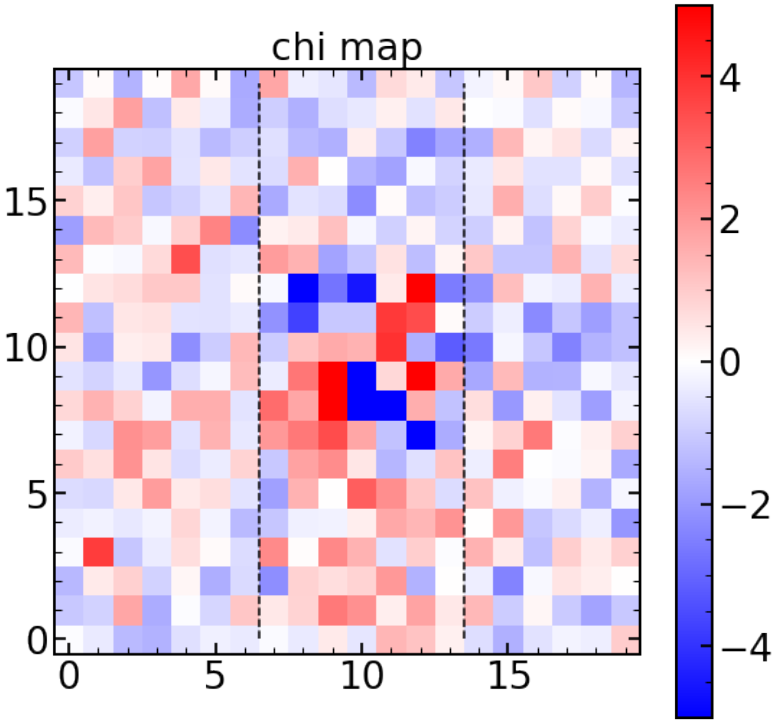
Speckles – can be ``removed'' by fitting higher order wavefront abberations

Focused data, example with linear scaling

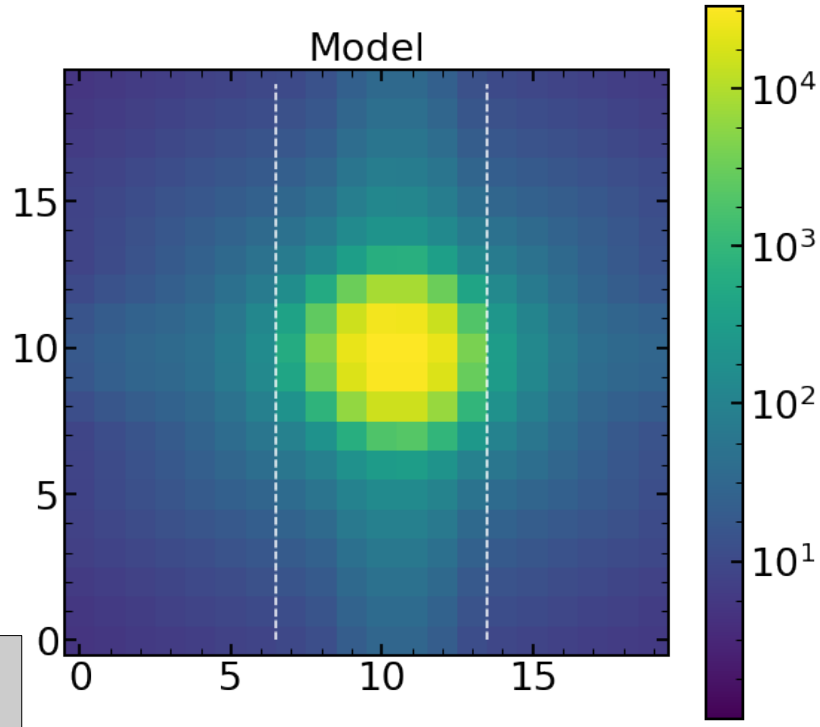


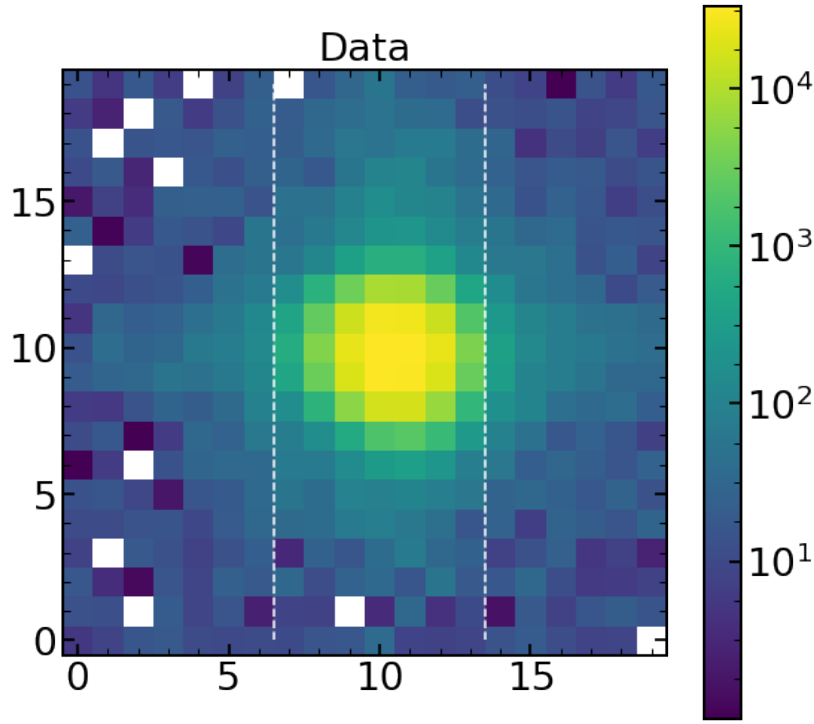


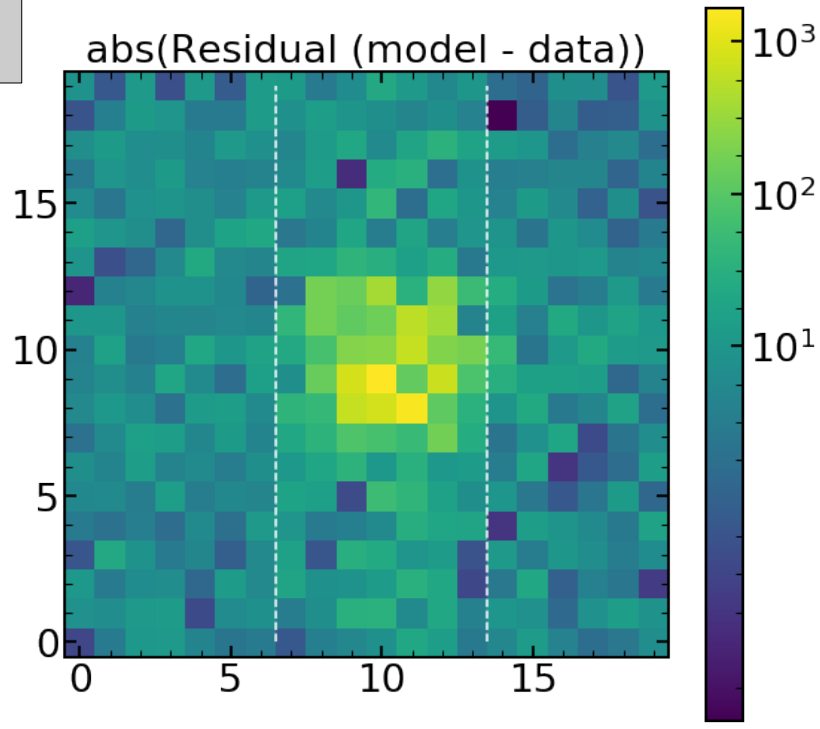


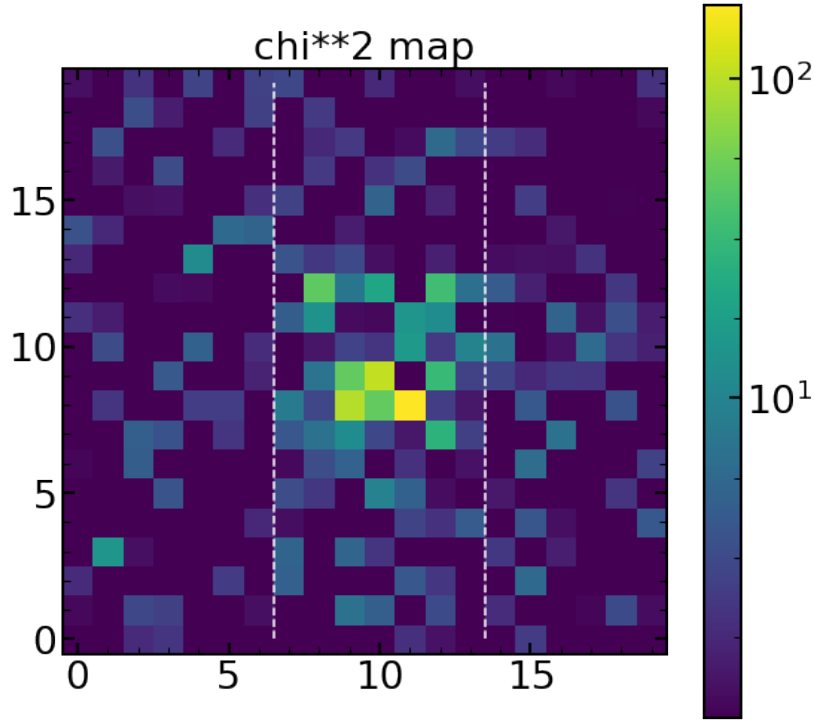


Focused data, example with log scaling

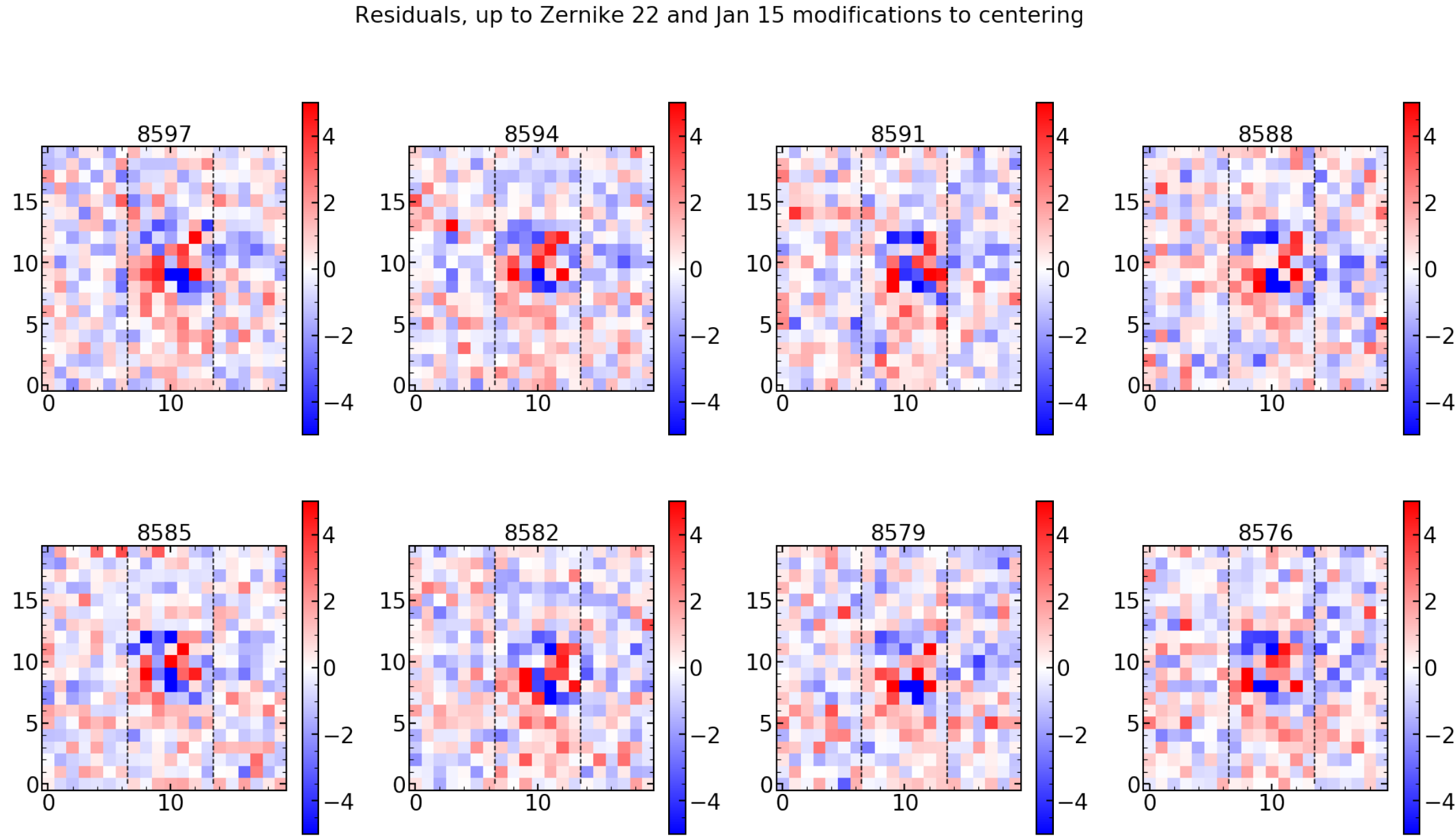






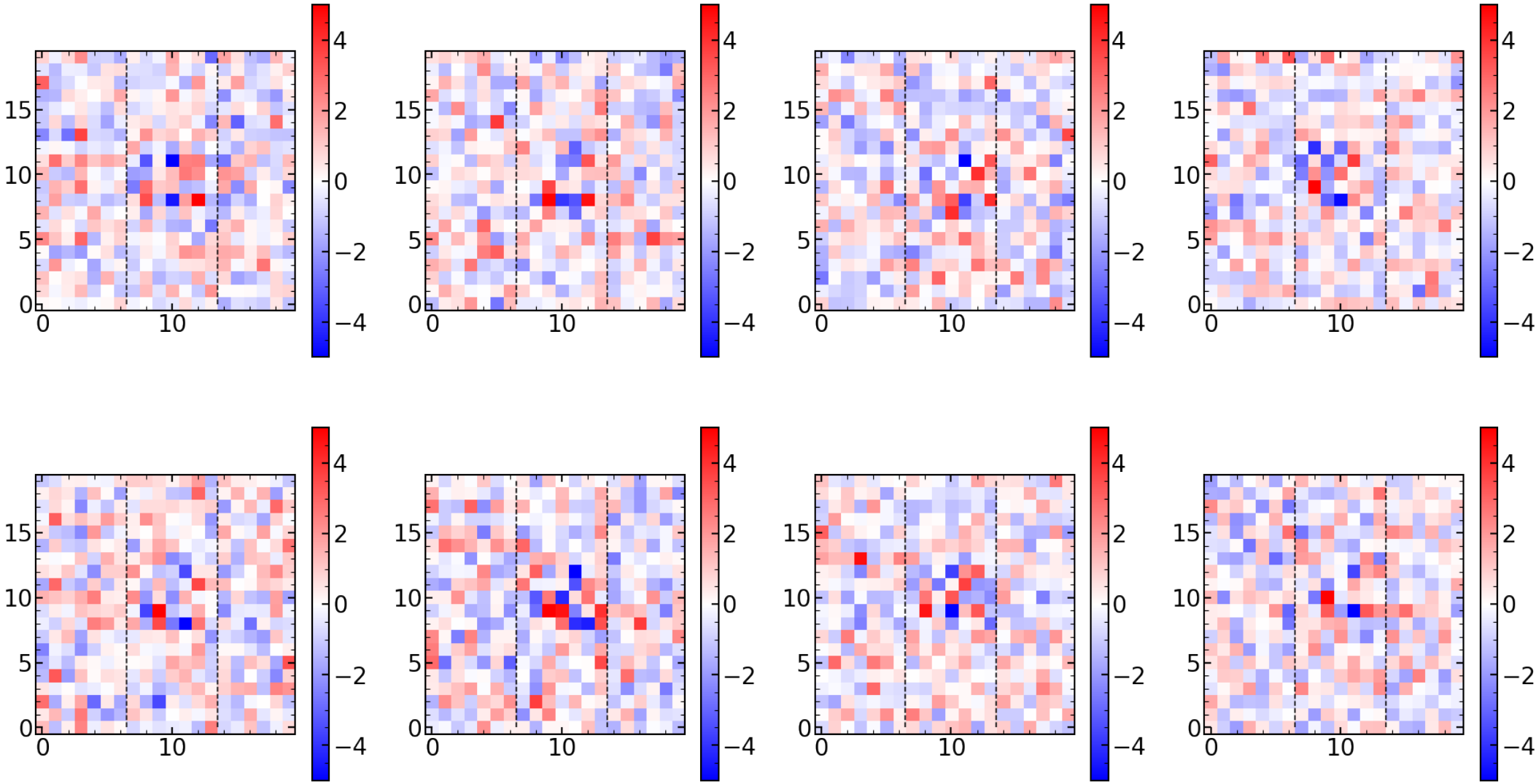


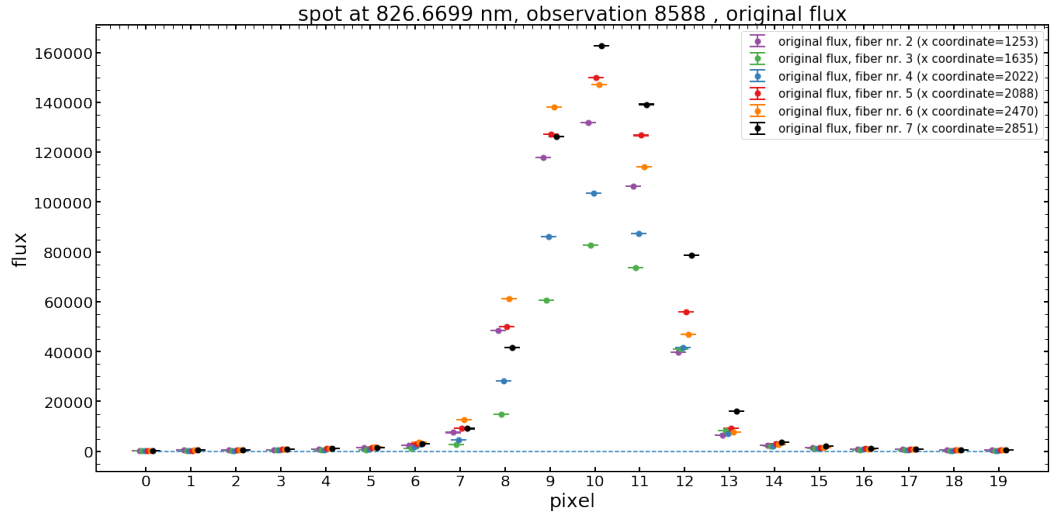
Residuals in the focused data, 8 different dithering positions

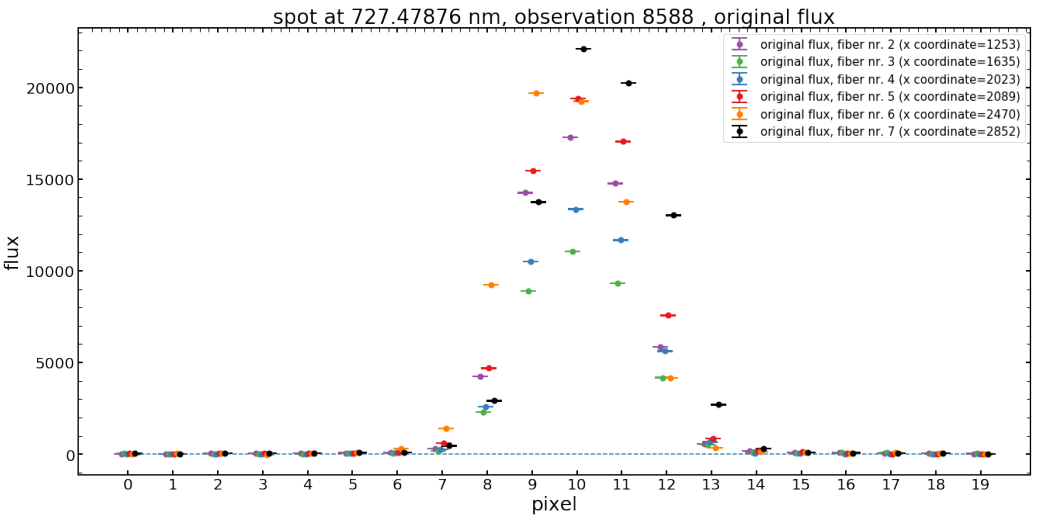


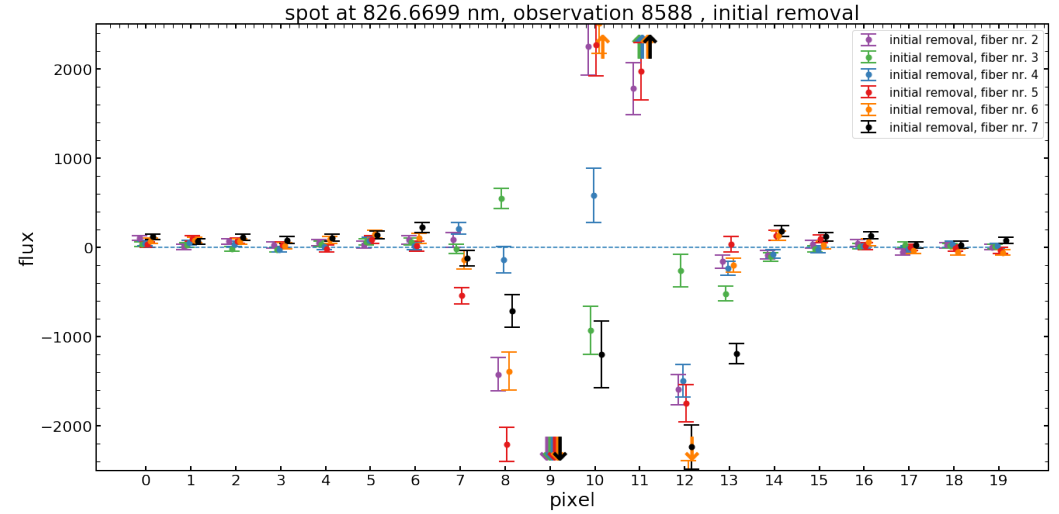
Residuals in the focused data, 8 different dithering positions, after Random forest cleaning applied

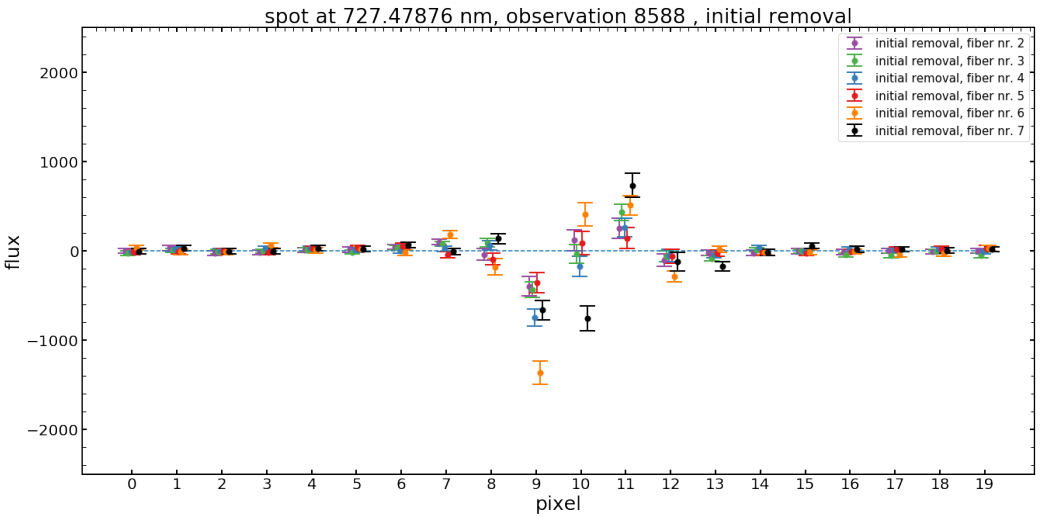
up to Zernike 22, Jan 15 modifications to centering, and Random Forest postprocessing

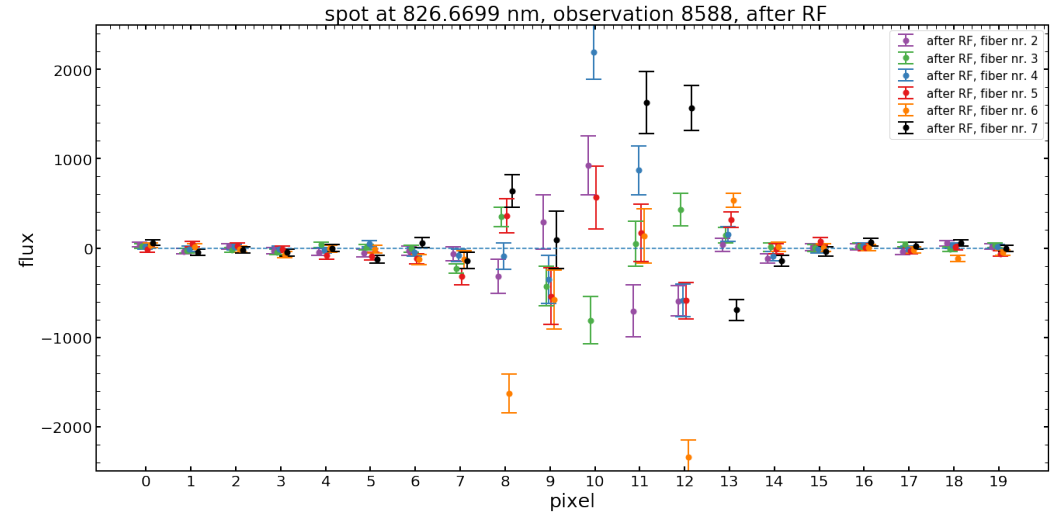


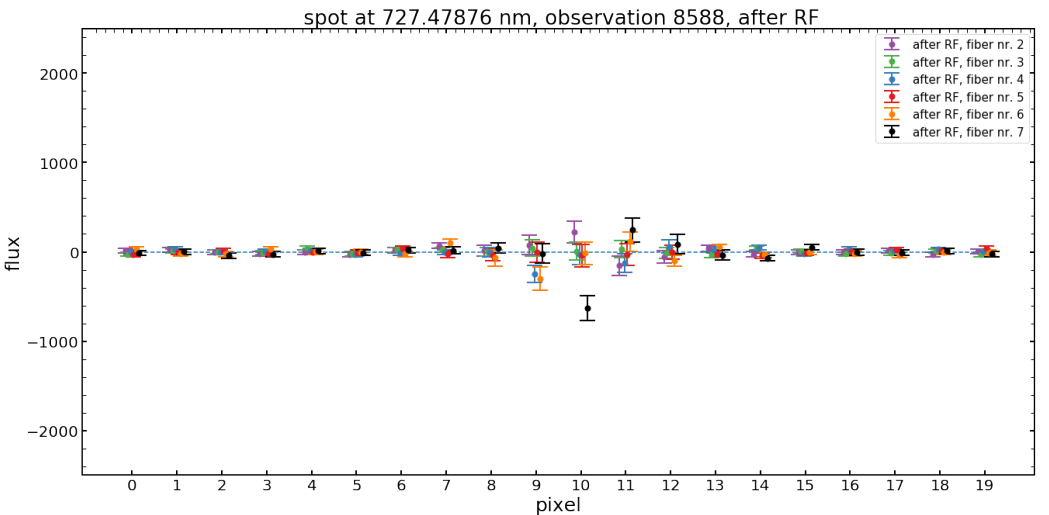

spot at 826.6699 nm, observation 8588 , original flux
original flux, fiber nr. 2 (x coordinate=1253)
original flux, fiber nr. 3 (x coordinate=1635)
original flux, fiber nr. 4 (x coordinate=2022)
original flux, fiber nr. 5 (x coordinate=2088)
original flux, fiber nr. 6 (x coordinate=2470)
original flux, fiber nr. 7 (x coordinate=2851)
flux
pixel


spot at 727.47876 nm, observation 8588 , original flux
original flux, fiber nr. 2 (x coordinate=1253)
original flux, fiber nr. 3 (x coordinate=1635)
original flux, fiber nr. 4 (x coordinate=2023)
original flux, fiber nr. 5 (x coordinate=2089)
original flux, fiber nr. 6 (x coordinate=2470)
original flux, fiber nr. 7 (x coordinate=2852)
flux
pixel

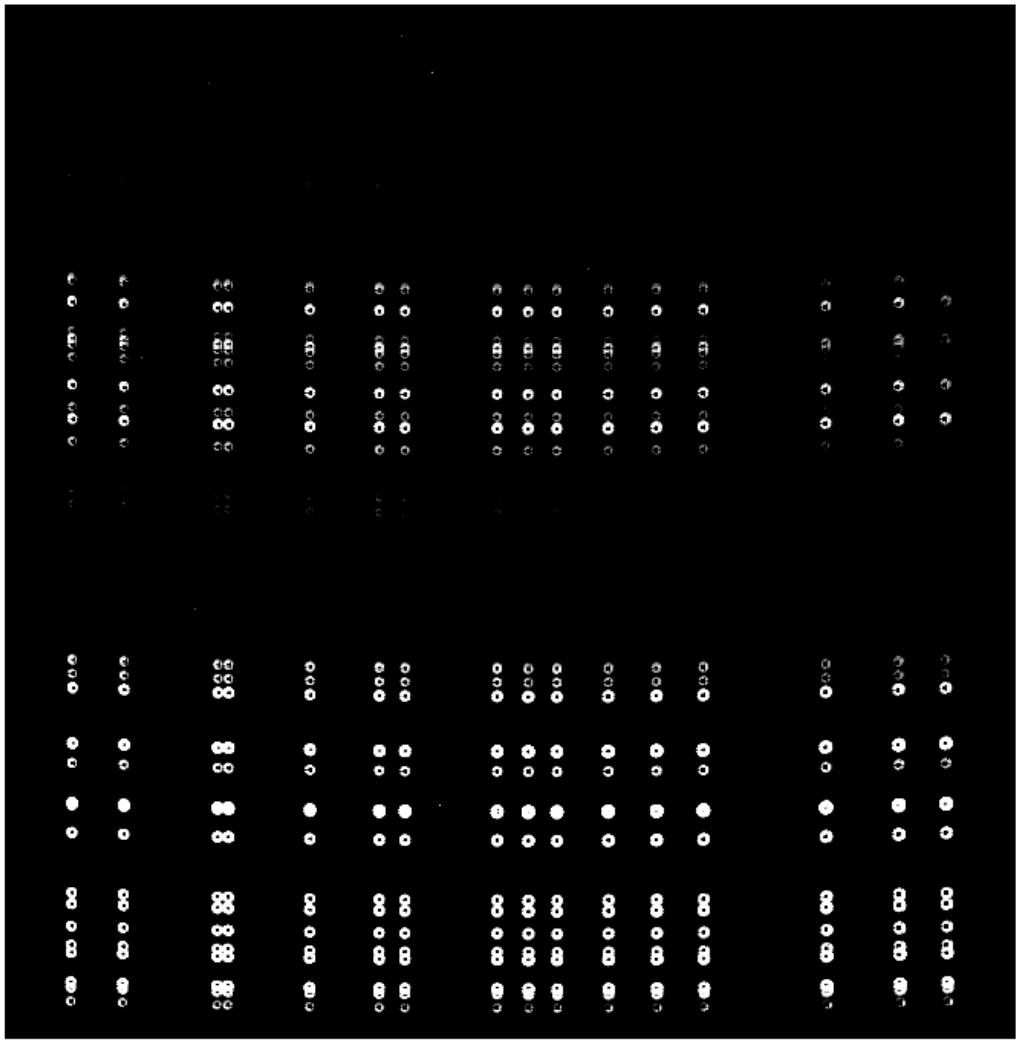

spot at 826.6699 nm, observation 8588 , initial removal
initial removal, fiber nr. 2
initial removal, fiber nr. 3
initial removal, fiber nr. 4
initial removal, fiber nr. 5
initial removal, fiber nr. 6
initial removal, fiber nr. 7
flux
pixel

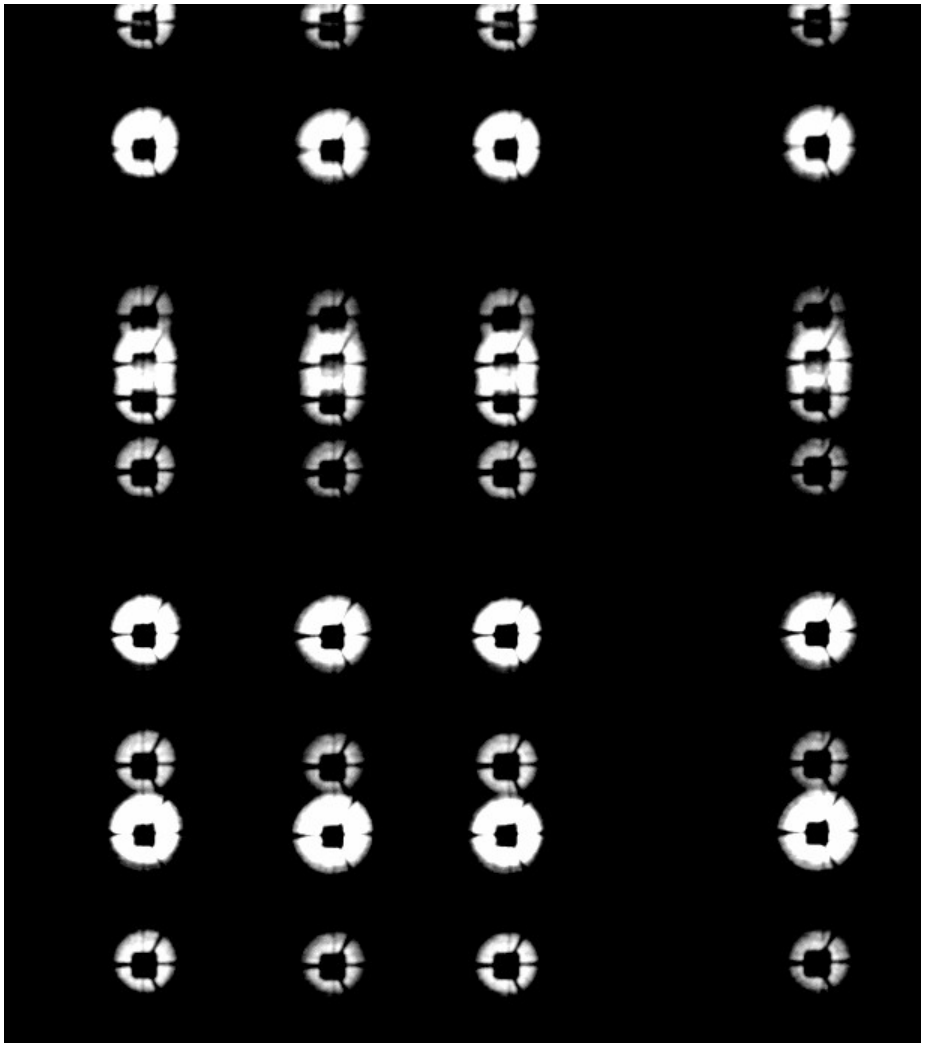

spot at 727.47876 nm, observation 8588 , initial removal
initial removal, fiber nr. 2
initial removal, fiber nr. 3
initial removal, fiber nr. 4
initial removal, fiber nr. 5
initial removal, fiber nr. 6
initial removal, fiber nr. 7
flux
pixel


spot at 826.6699 nm, observation 8588, after RF
after RF, fiber nr. 2
after RF, fiber nr. 3
after RF, fiber nr. 4
after RF, fiber nr. 5
after RF, fiber nr. 6
after RF, fiber nr. 7
flux
pixel


spot at 727.47876 nm, observation 8588, after RF
after RF, fiber nr. 2
after RF, fiber nr. 3
after RF, fiber nr. 4
after RF, fiber nr. 5
after RF, fiber nr. 6
after RF, fiber nr. 7
flux
pixel

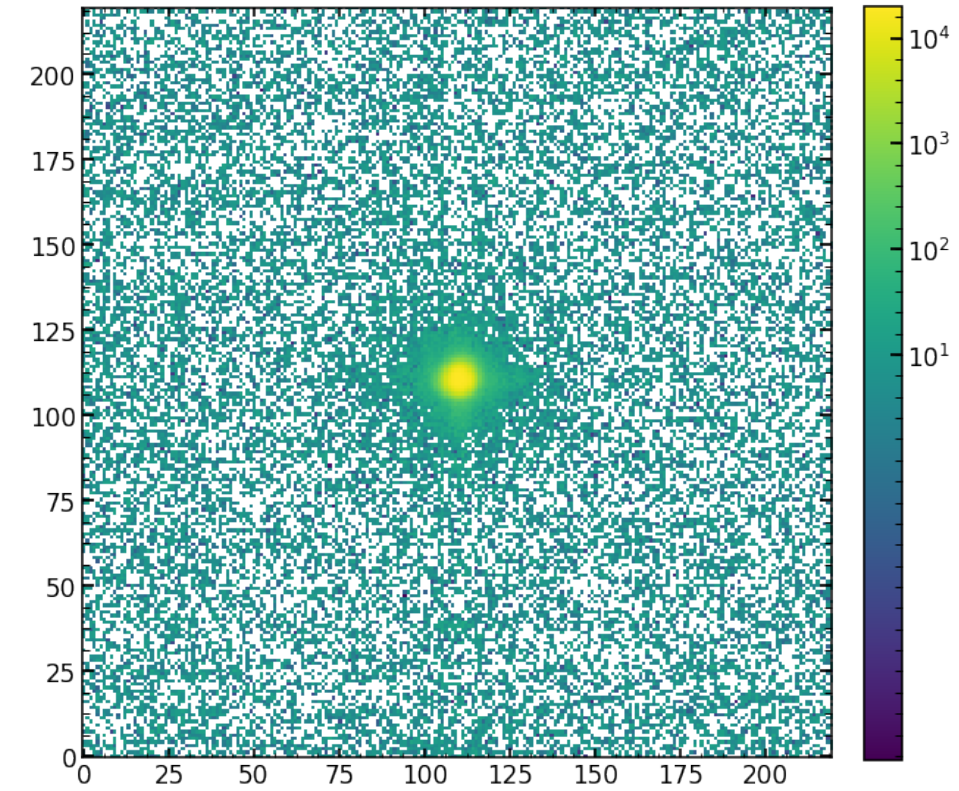
Selected topics – Overlap of spots

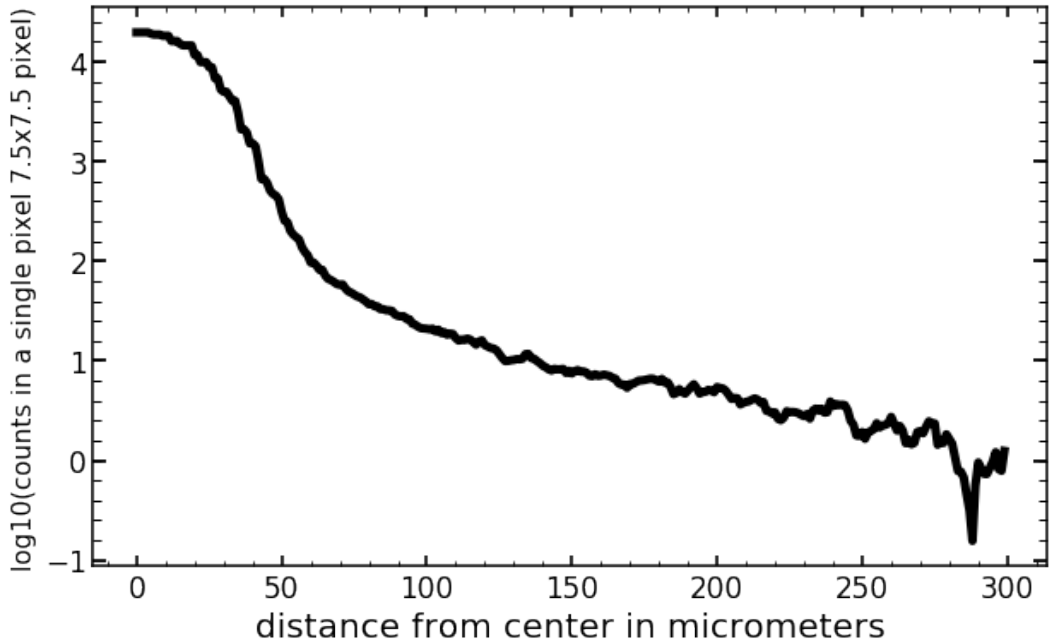




Partially mitigated by algorithm improvement, creating two identical models with an offset and adding them together

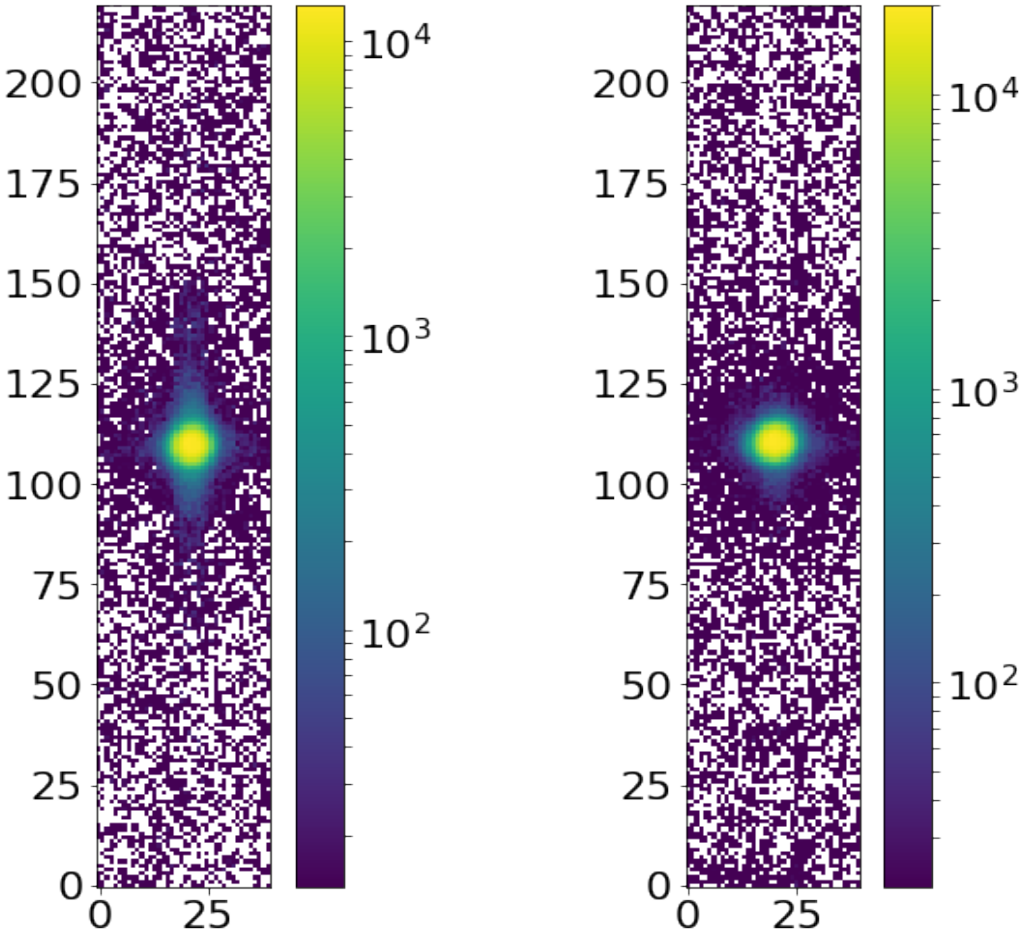
Selected topics - wings





852.40 nm

795.05 nm



Additional possible topics:

- more Zemax comparisons
- more HgAr problems
- 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

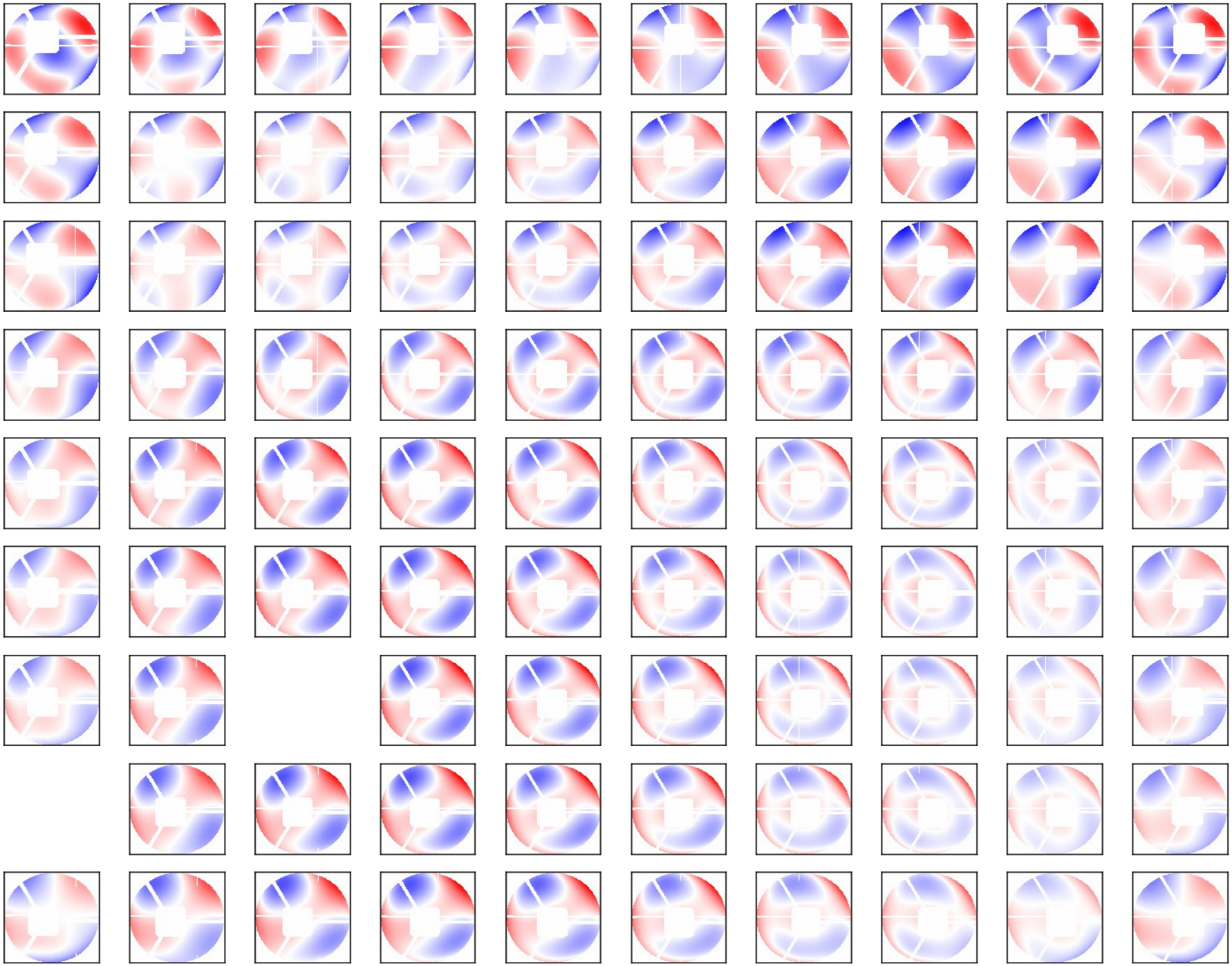
- Characterize contribution of camera imperfections to the point spread function by modelling optical performance using defocused data

- Defocused images on both sides of focus allow to decouple the illumination and the wavefront aberrations

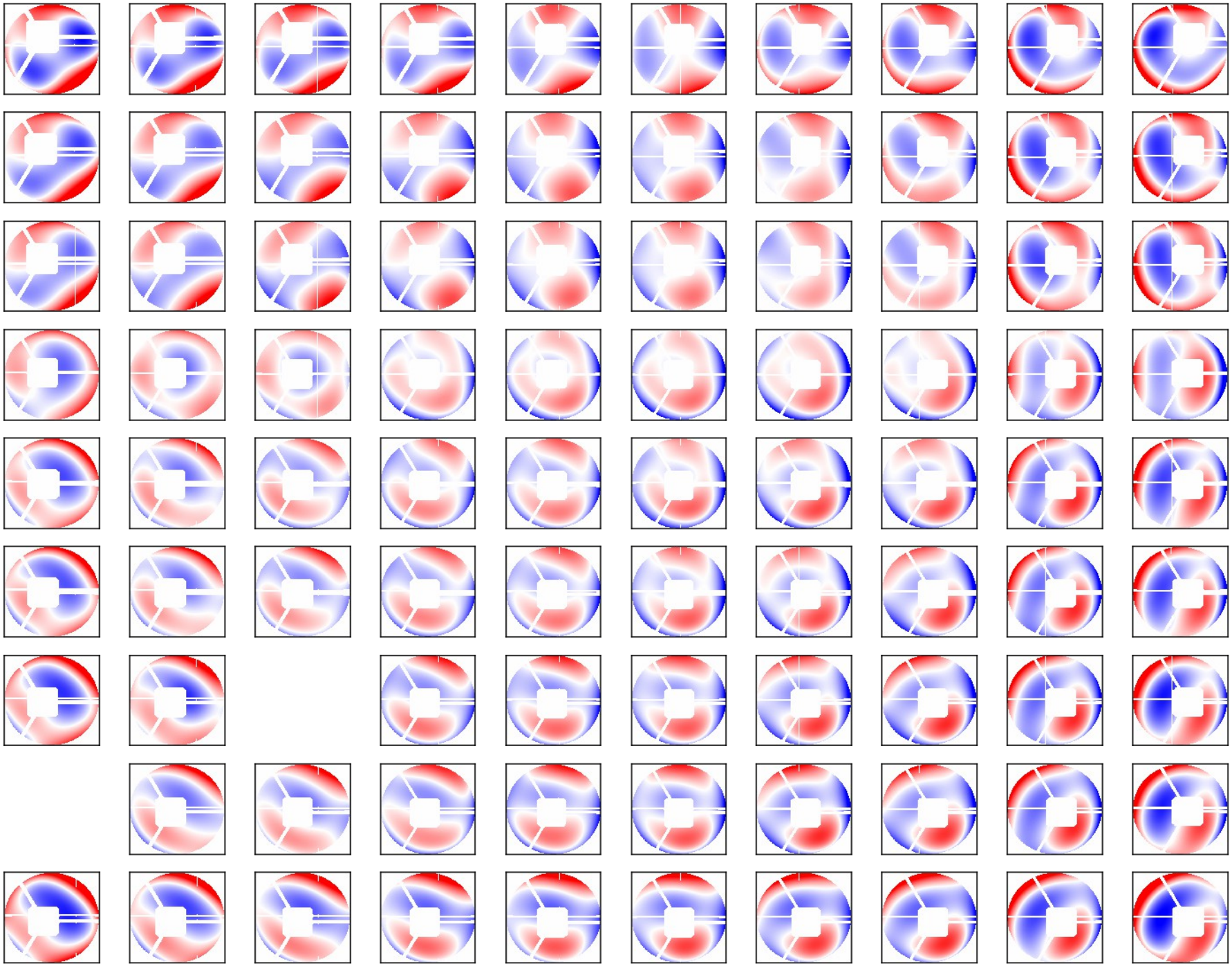
- github.com/nevencaplar/Presentations/BerkleyLab_PFS_Jan21_2021

Extra slides

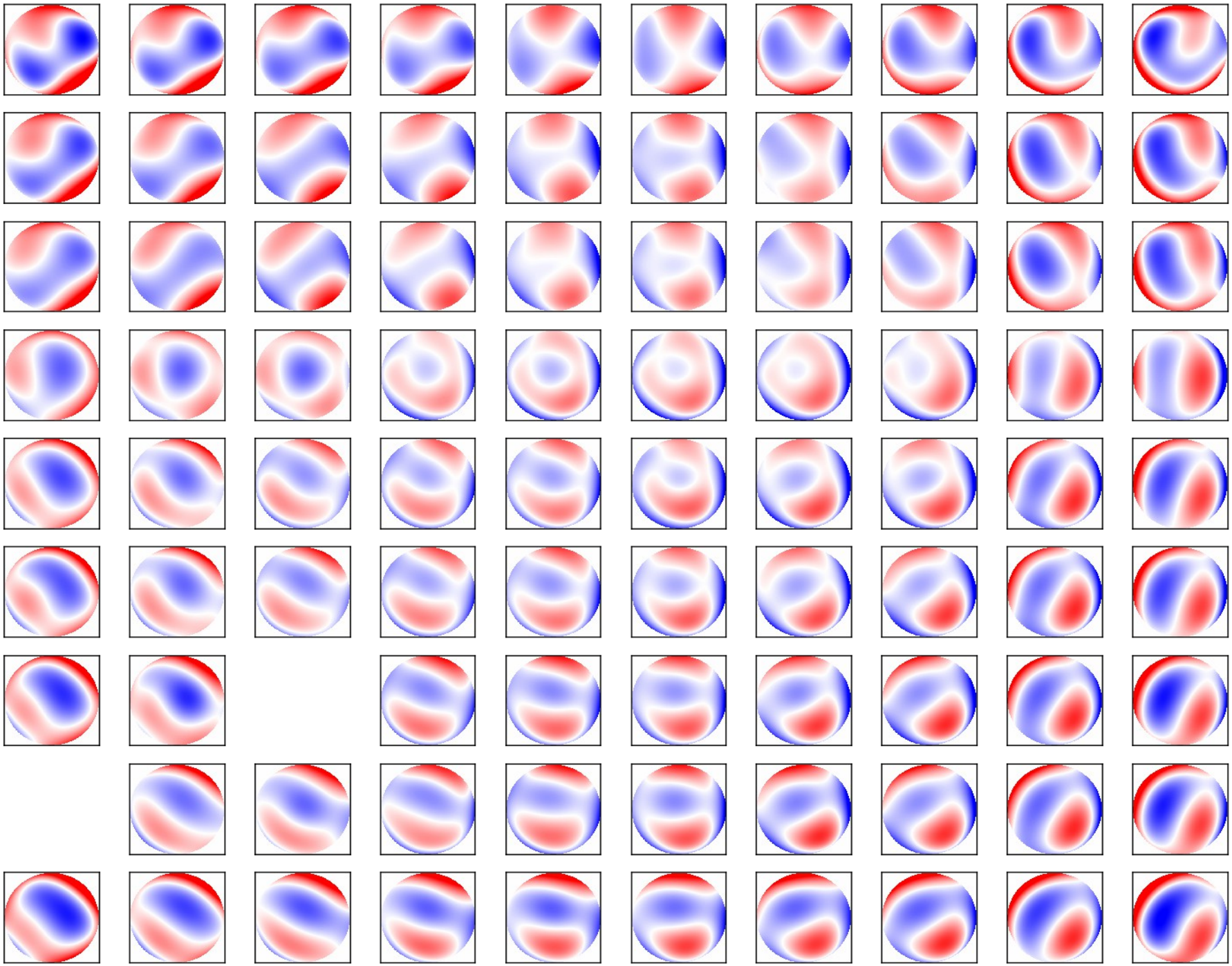
wavefront



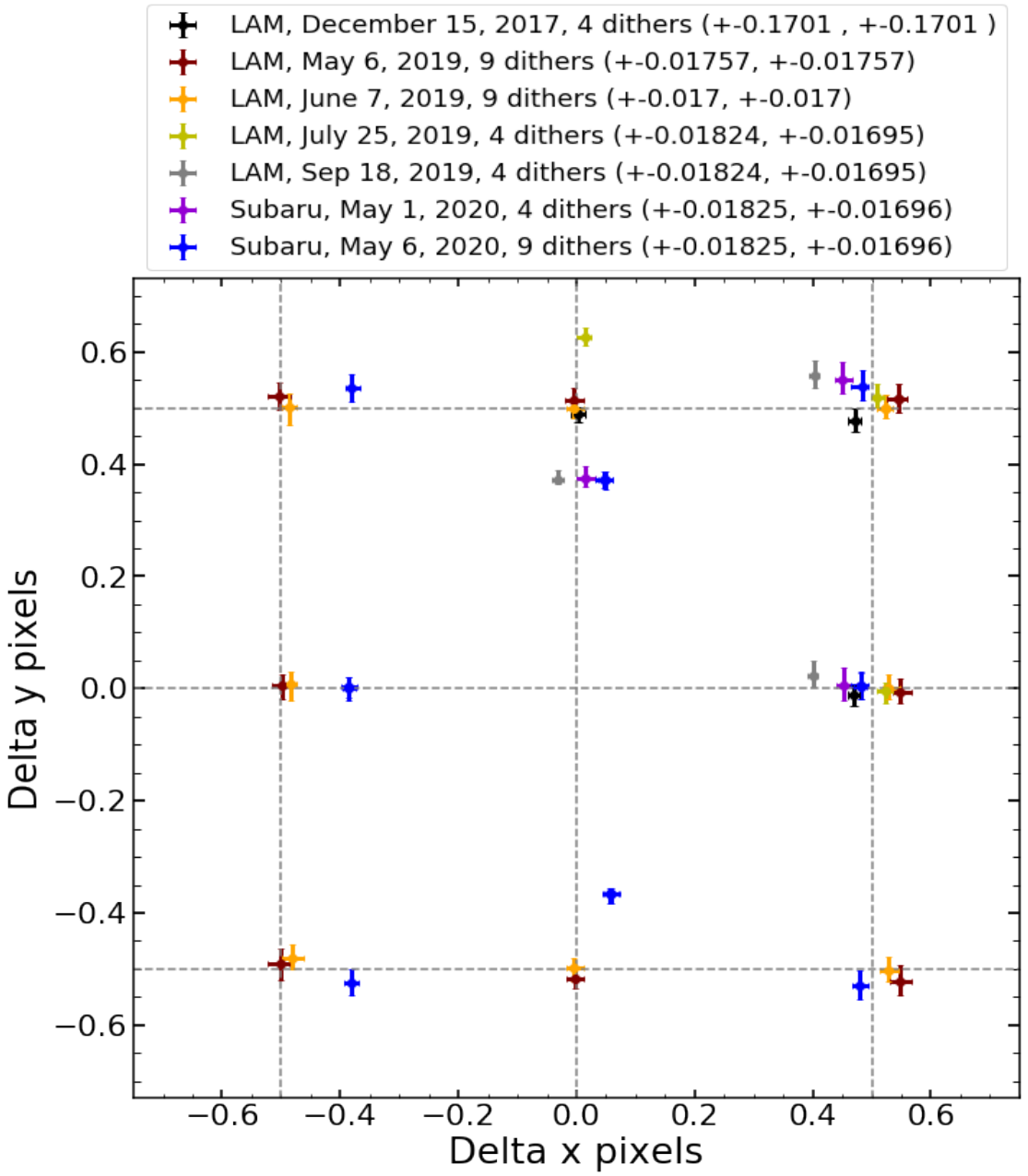
wavefront



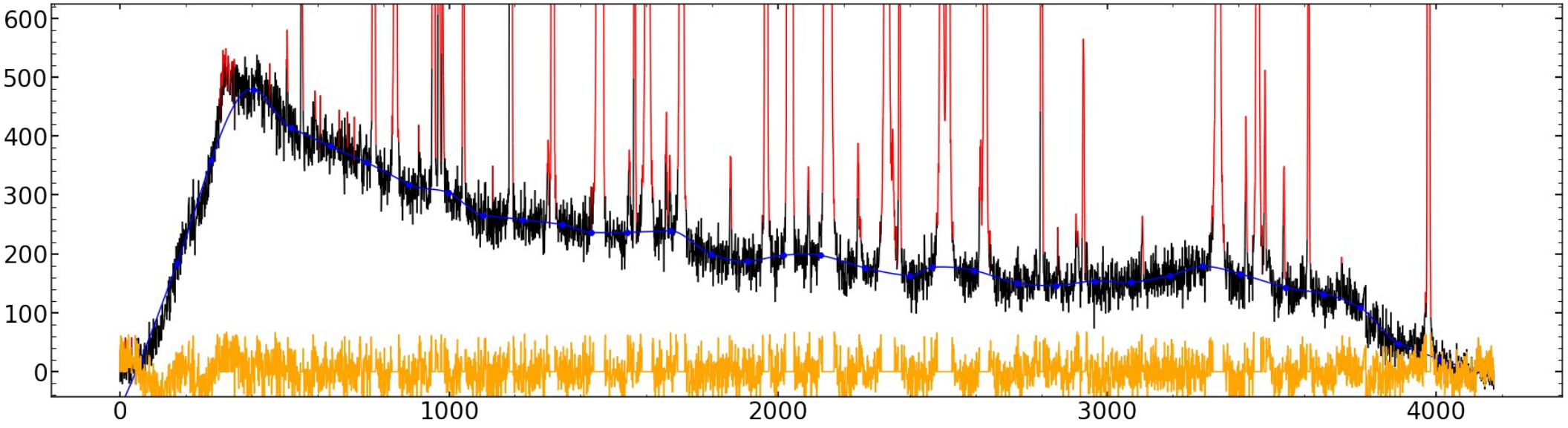
wavefront

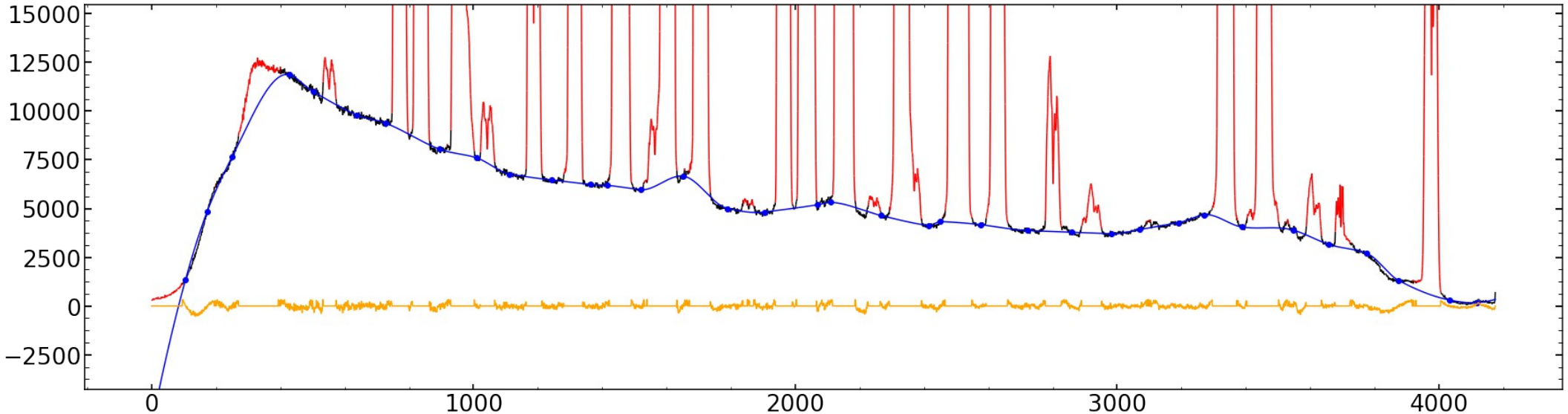


Dithering

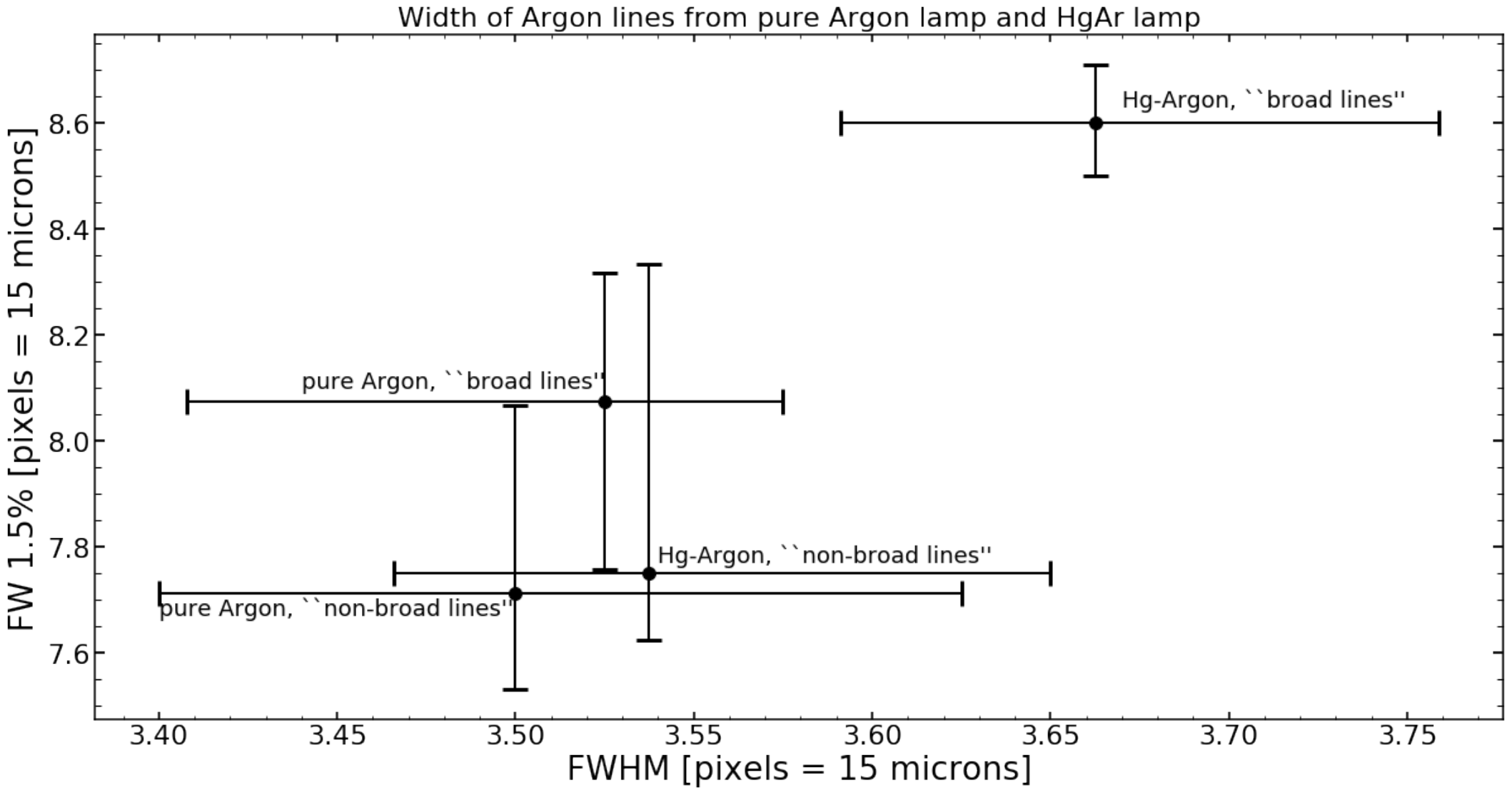

LAM, December 15, 2017, 4 dithers (+-0.1701 , +-0.1701)
LAM, May 6, 2019, 9 dithers (+-0.01757, +-0.01757)
LAM, June 7, 2019, 9 dithers (+-0.017, +-0.017)
LAM, July 25, 2019, 4 dithers (+-0.01824, +-0.01695)
LAM, Sep 18, 2019, 4 dithers (+-0.01824, +-0.01695)
Subaru, May 1, 2020, 4 dithers (+-0.01825, +-0.01696)
Subaru, May 6, 2020, 9 dithers (+-0.01825, +-0.01696)
Delta y pixels
Delta x pixels
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.6
−0.4
−0.2
0.0
0.2
0.4
0.6

HgAr continuum

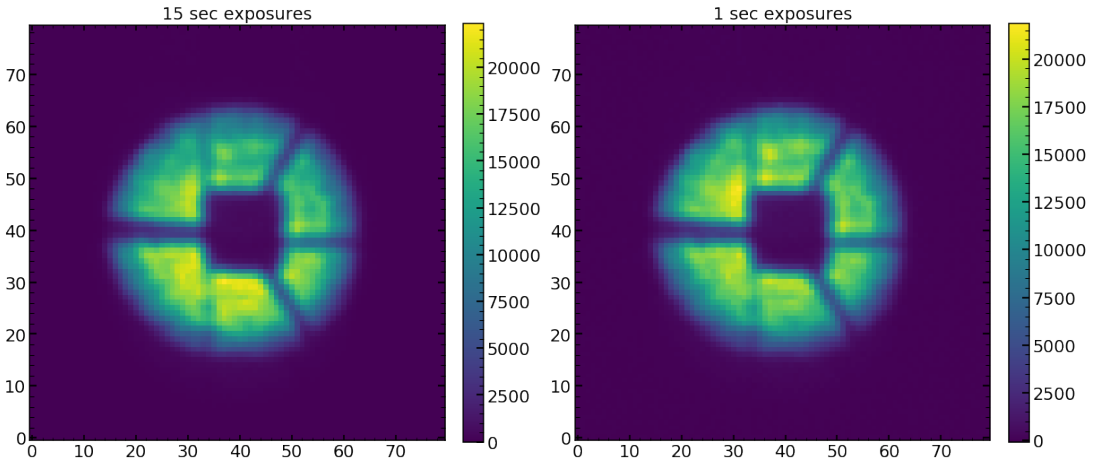


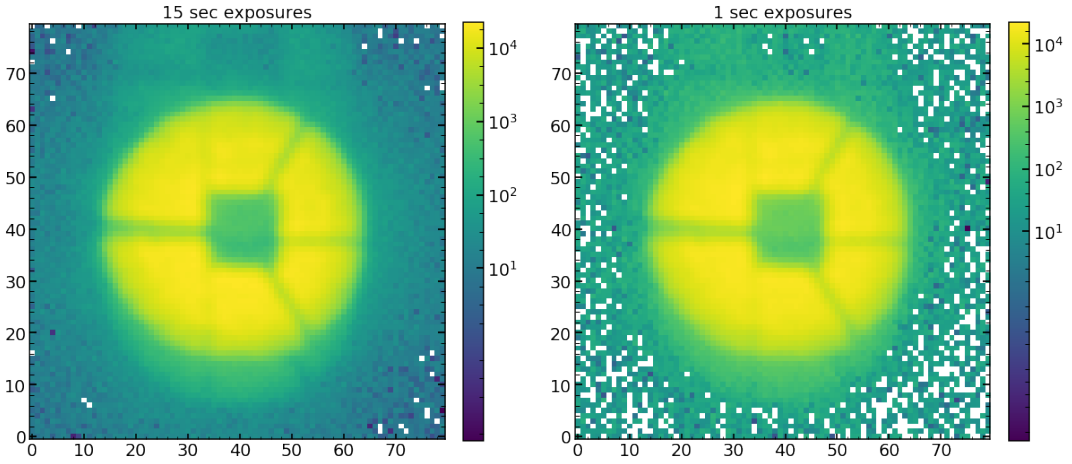


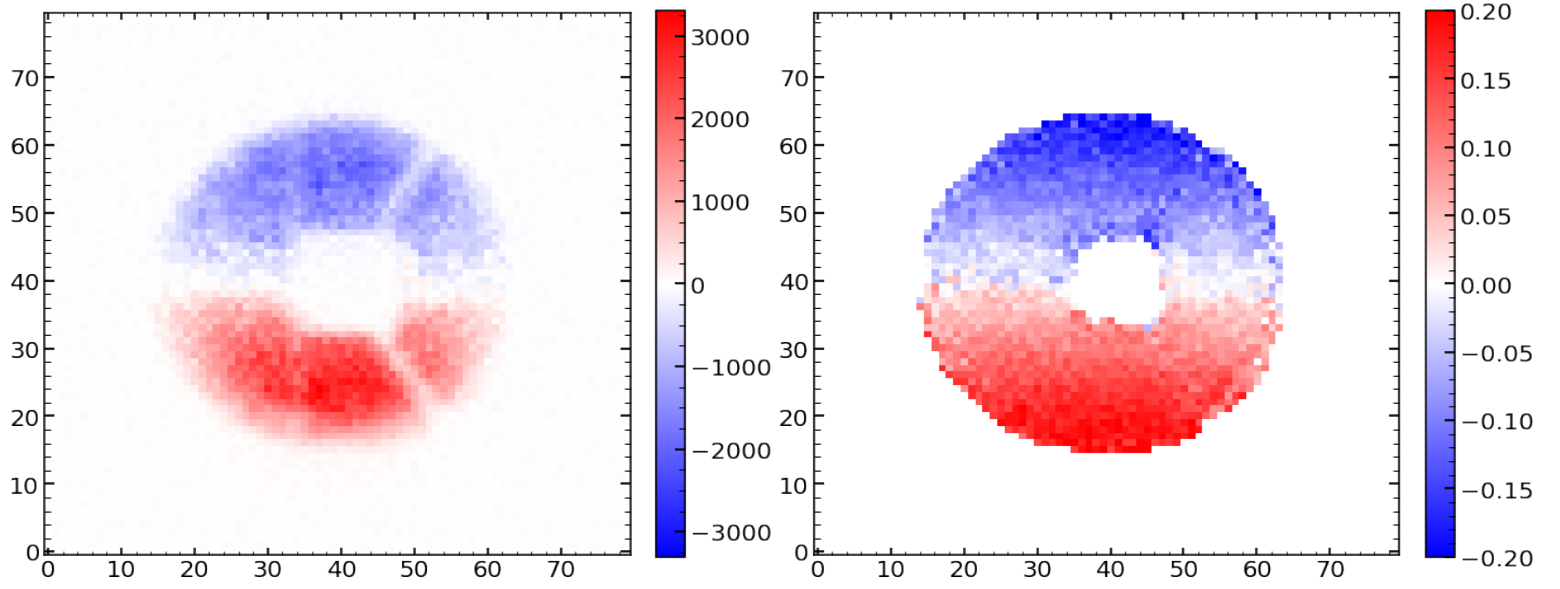
Broad lines of HgAr



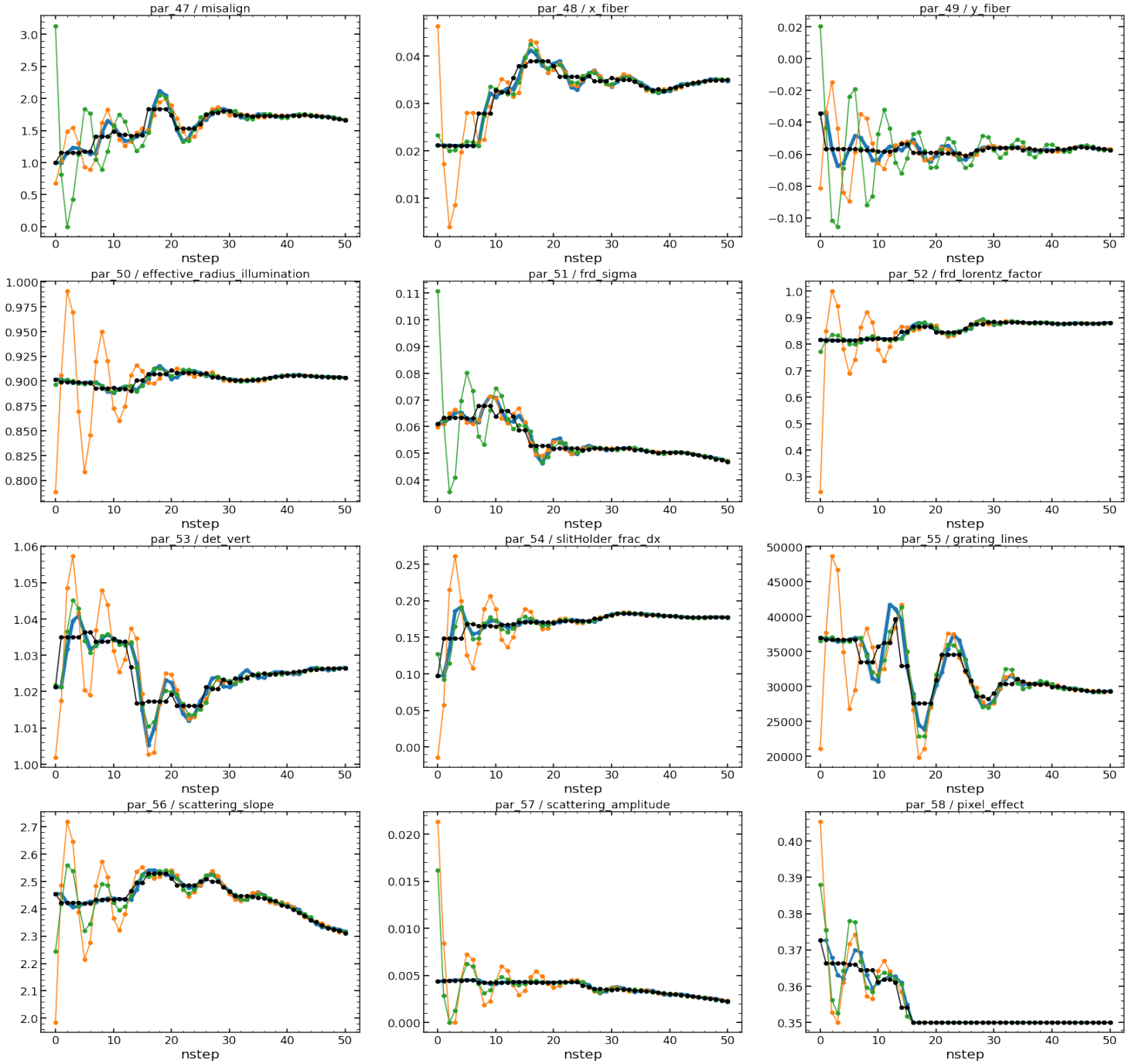
Shutter and flux control





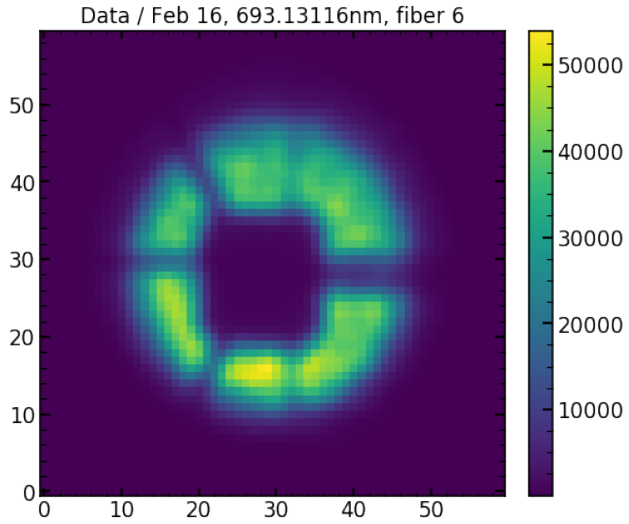


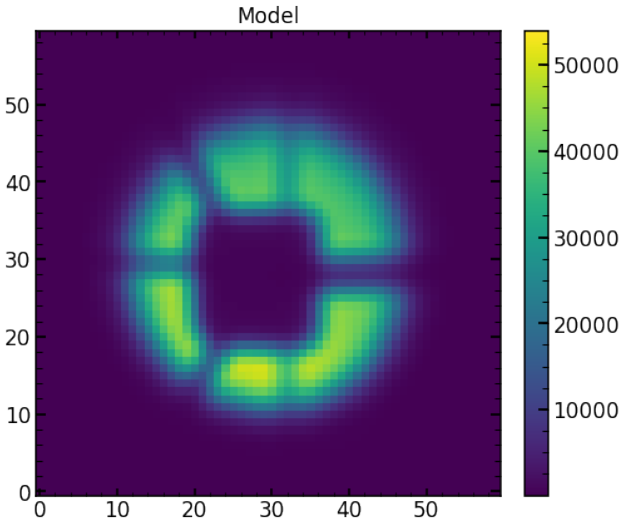
Parameter fitting

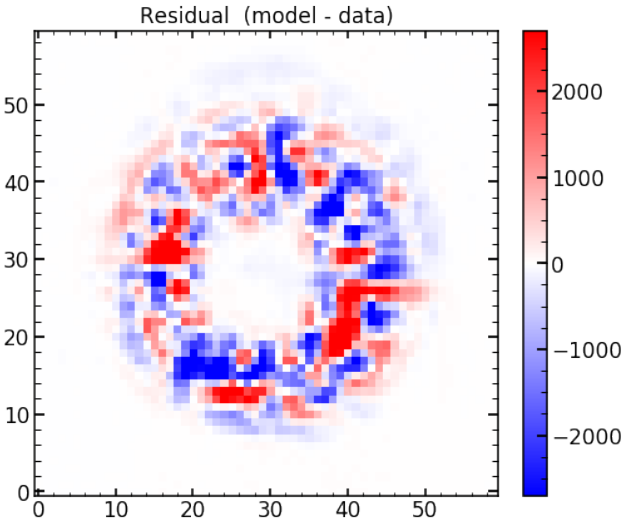


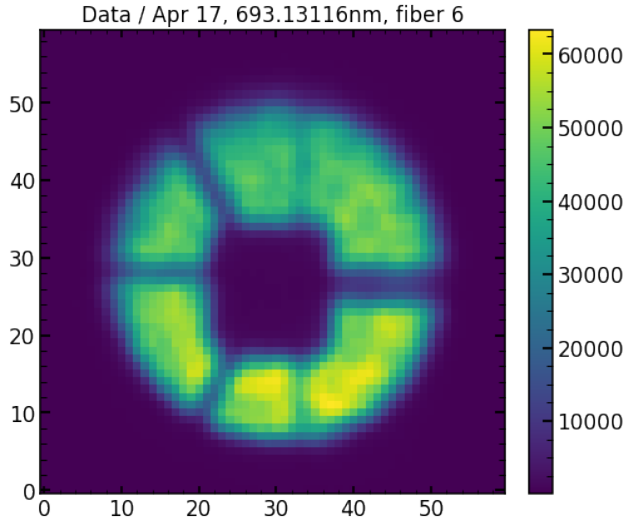
Different stops

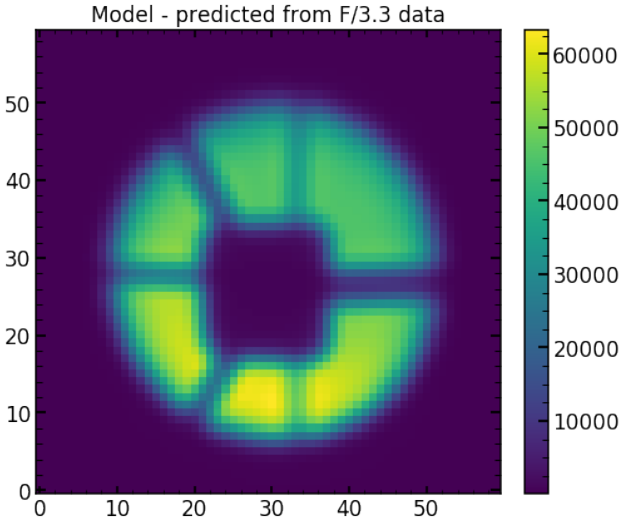
a) only illumination of the full pupil gives full information

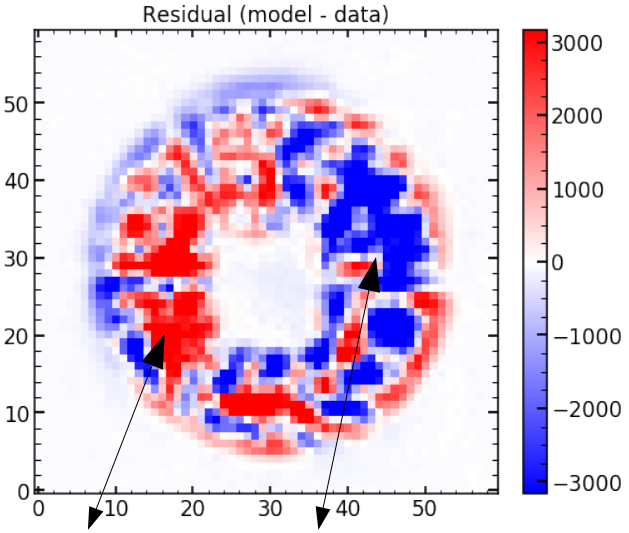












Mistakes in the non-illuminated region!

b) experiment for the quality of the approach