

2D point spread function characterization for Prime Focus Spectrograph

Neven Caplar



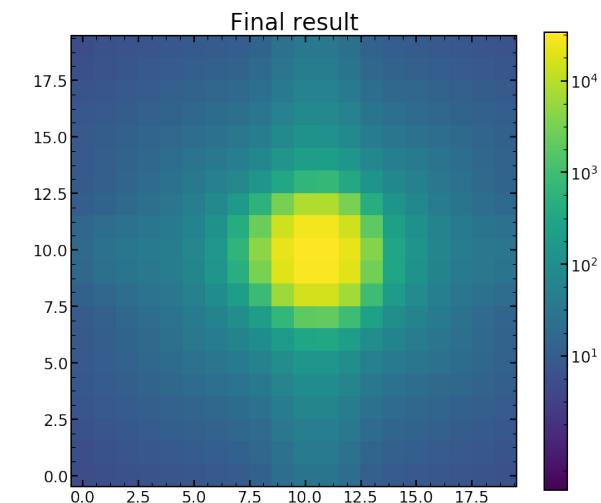
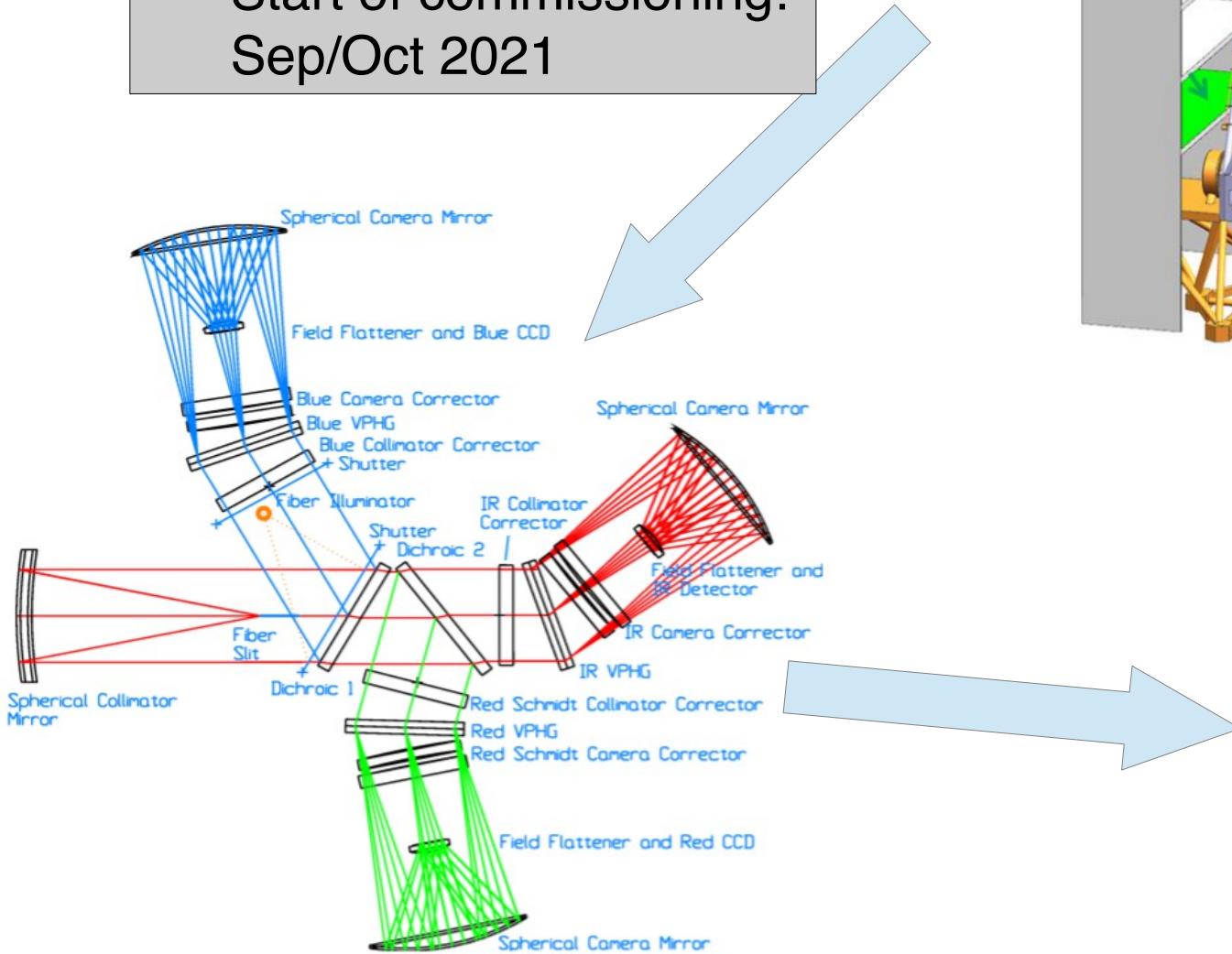
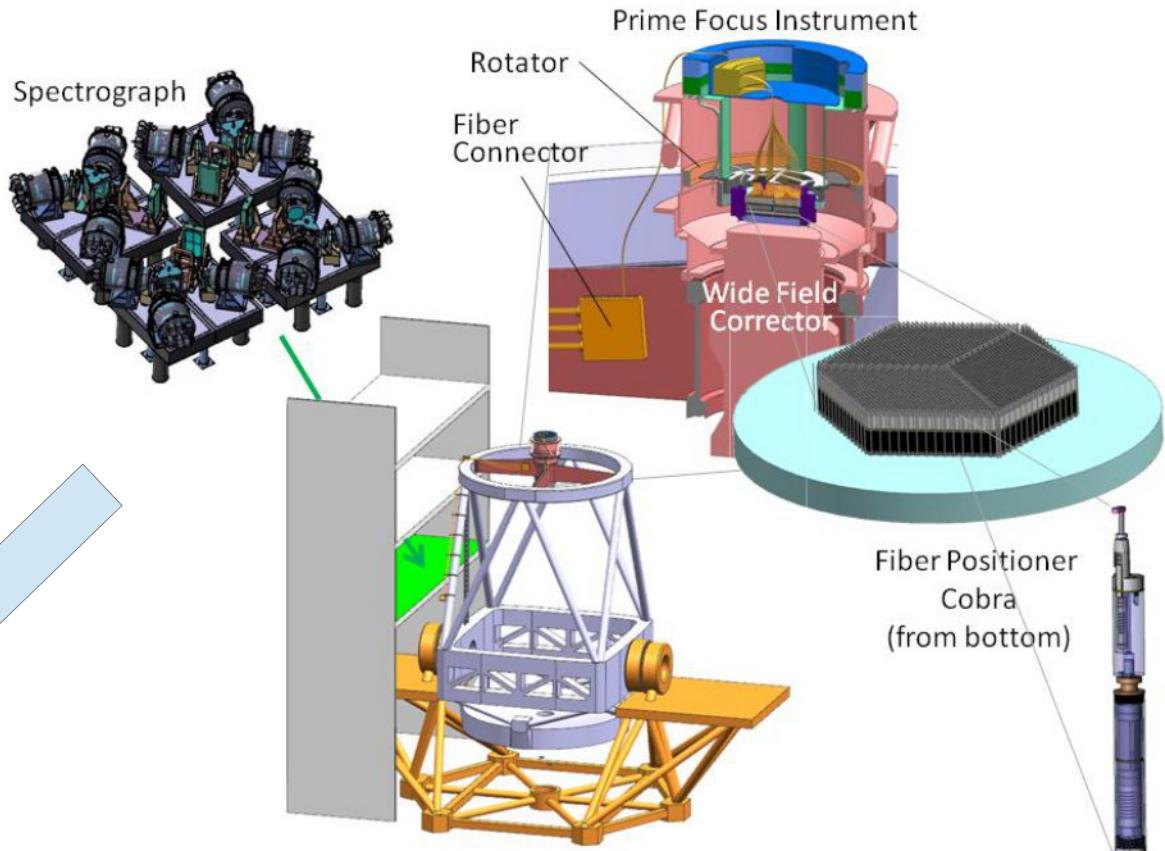
PRINCETON
UNIVERSITY

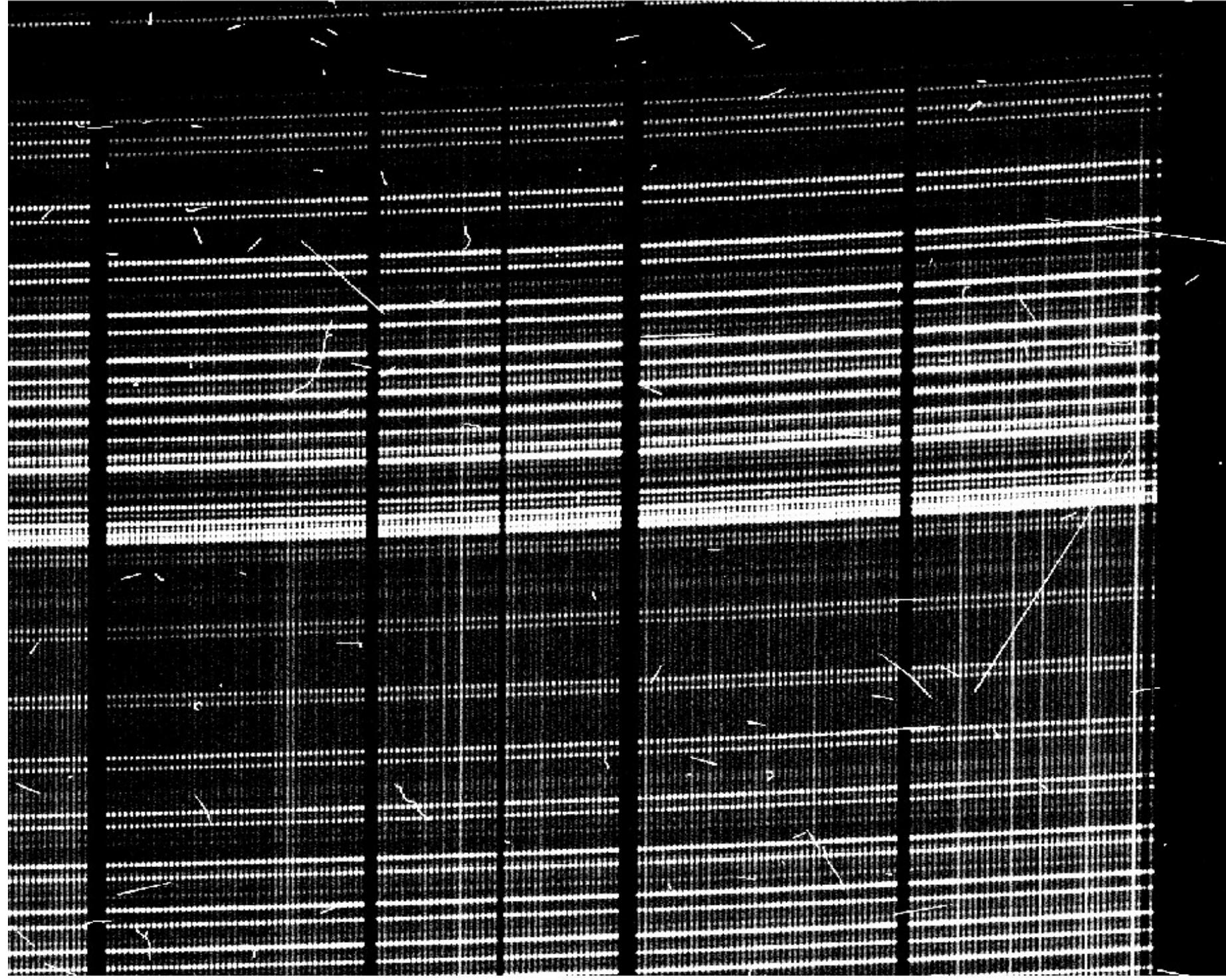


Contents

- Overview of the spectrograph
- Sky subtraction
 - 2d point-spread function algorithm
 - Analysis of defocused images
 - Behavior of wavefront and comparison to Zemax
- Current real world challenges
 - Centering and line properties
 - Problems in red
 - Non continuous solutions

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





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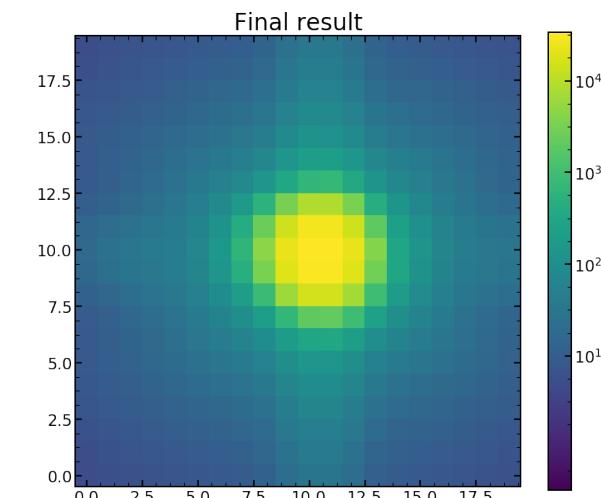
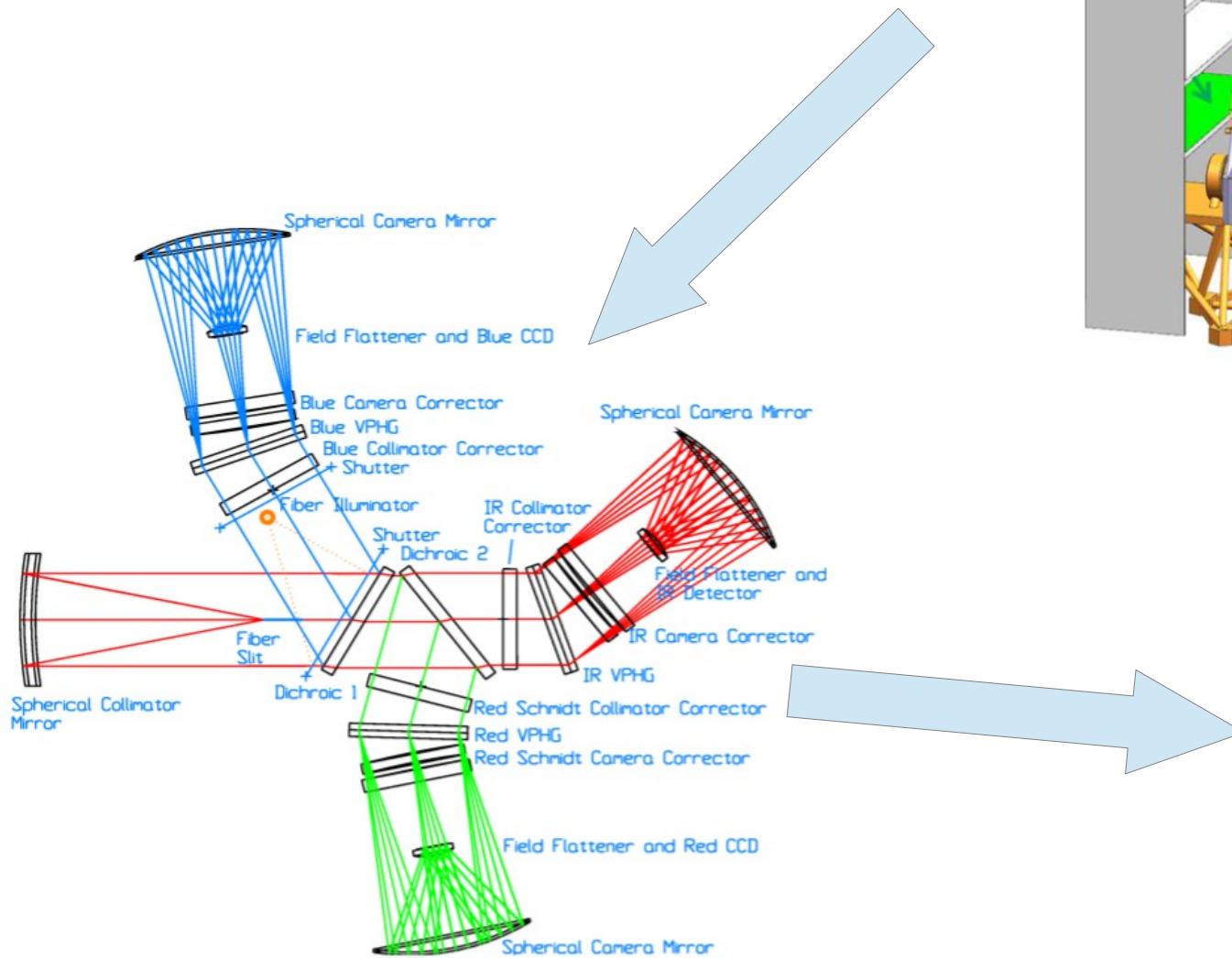
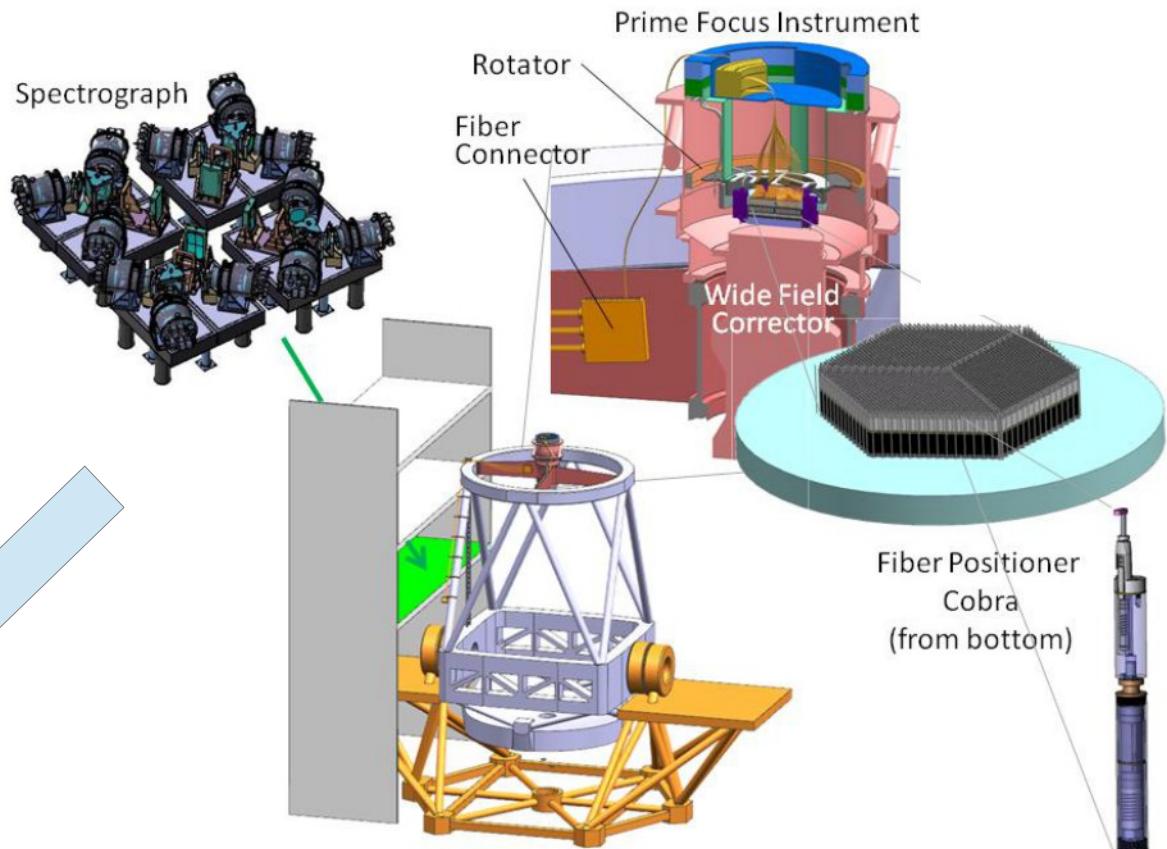
3508



7 21 49 104 215 435 874 1758 3508

3 components to the PSF

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



3 components to the PSF

- Telescope pupil

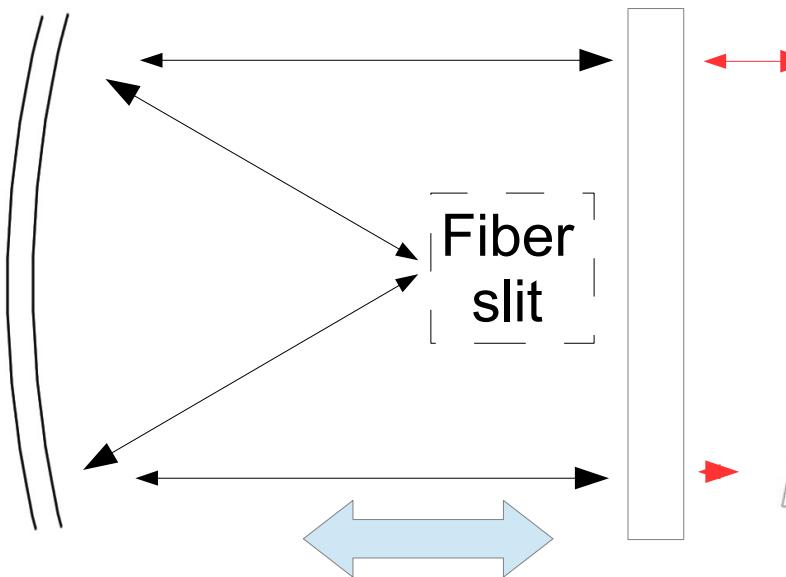
- illumination

- Focal ratio degradation

- in the fibres

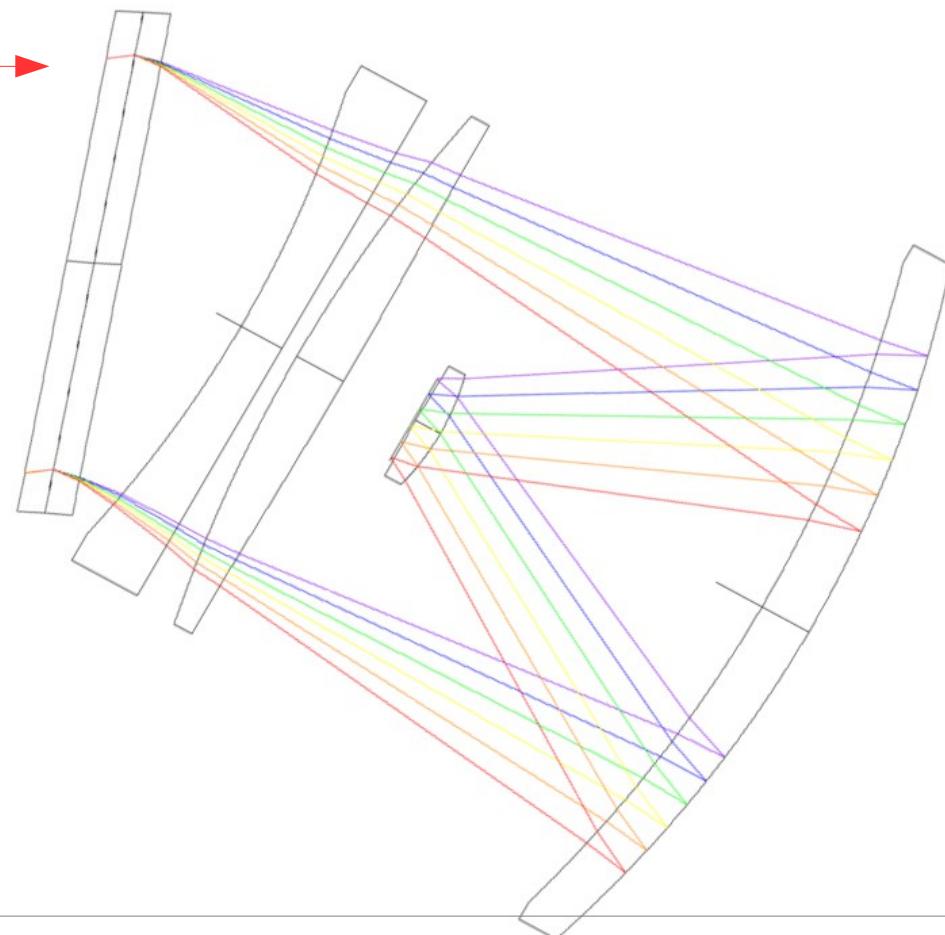
- Spectrograph cameras

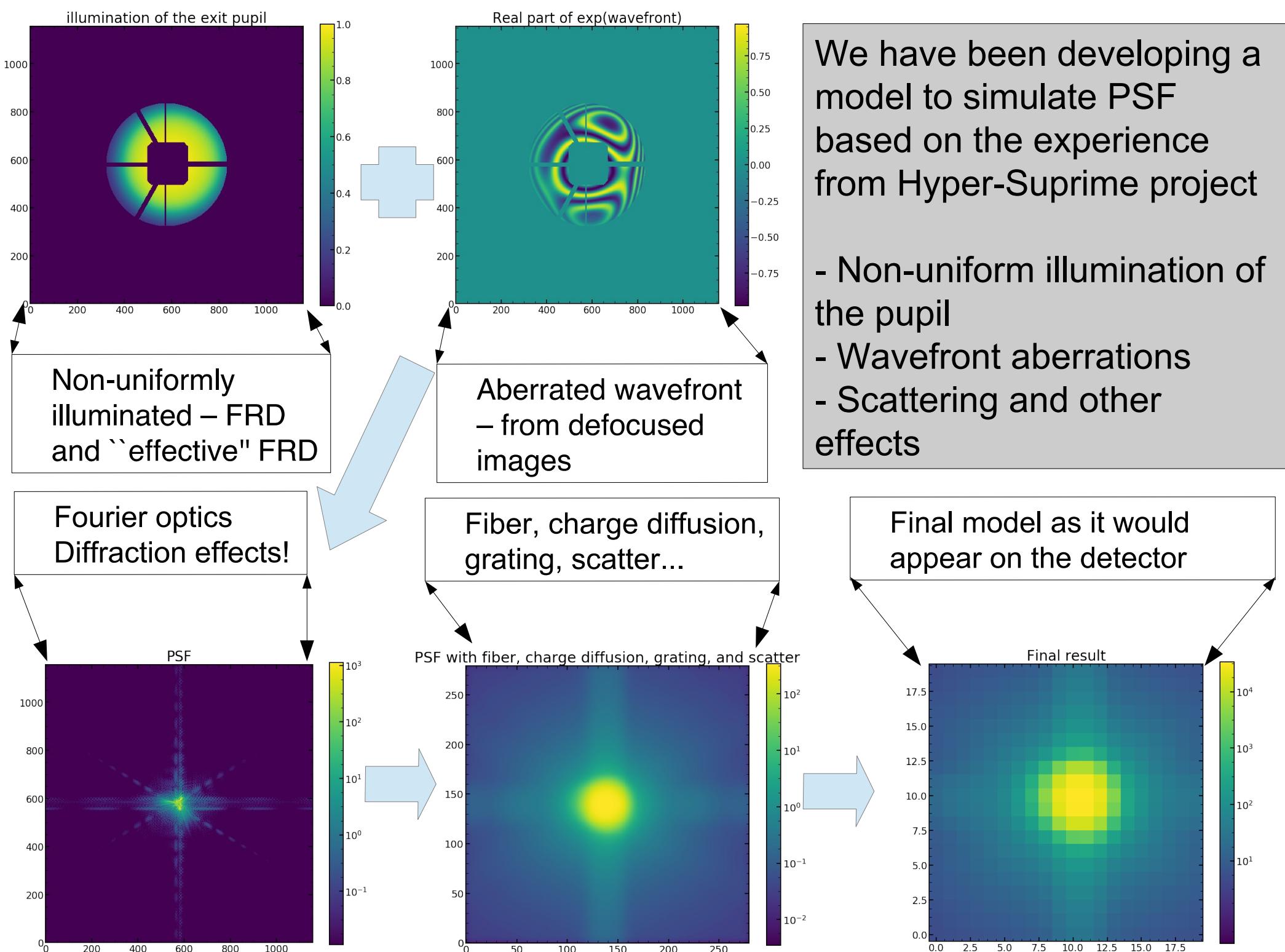
- Separate these 3 components (vignetting, fibers & camera) causing aberrations in the PSF by working in wavefront space
- We aim to characterize contribution of camera imperfections to PSF by modelling optical performance using defocused data



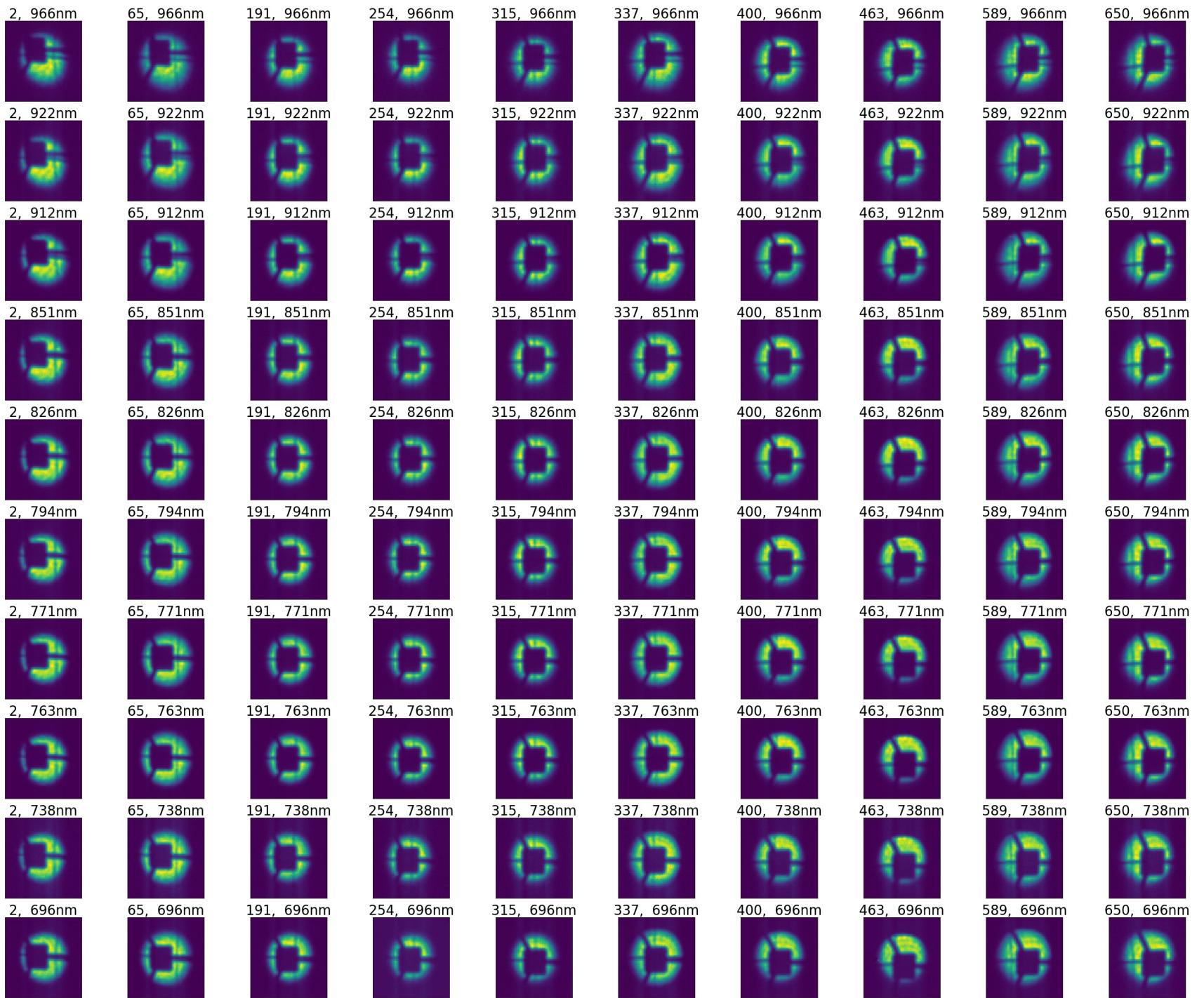
Move slit to defocus

Single camera

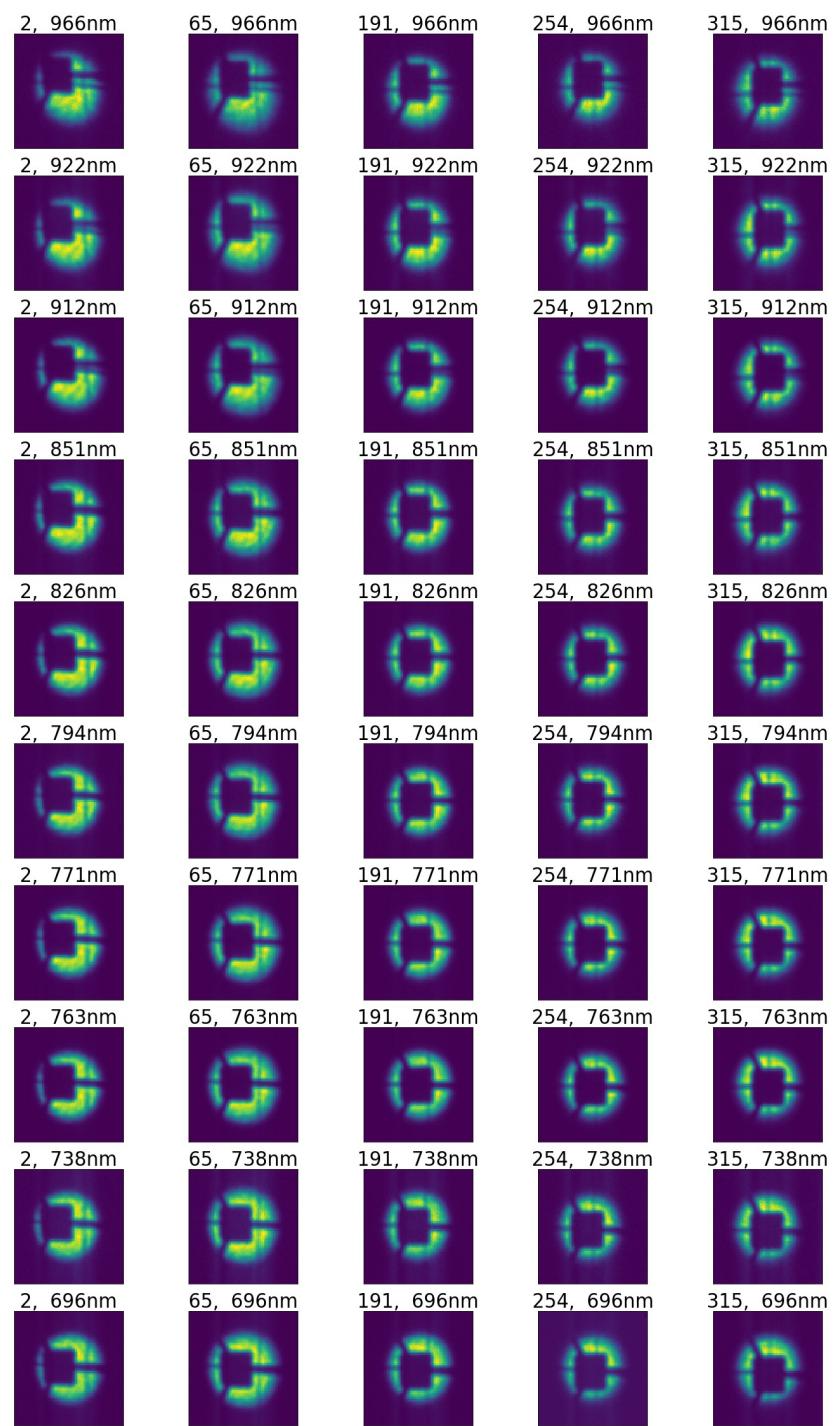




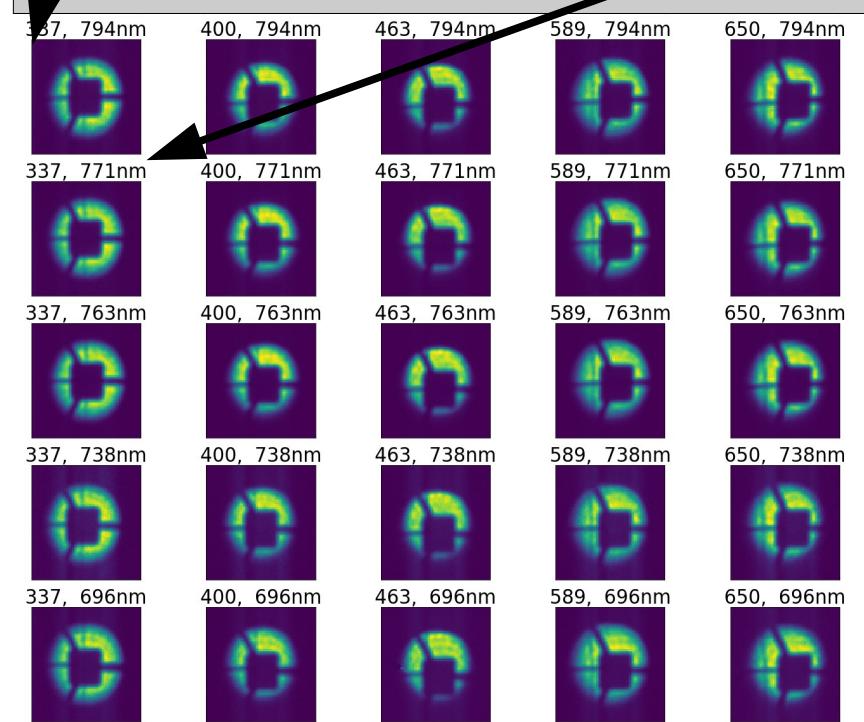
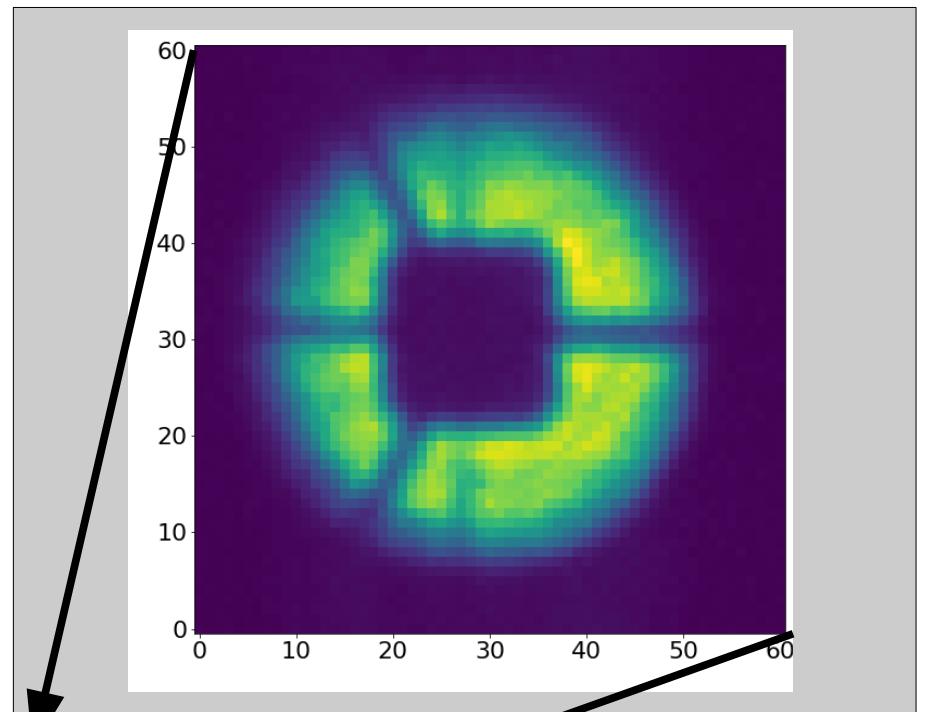
Wavelength

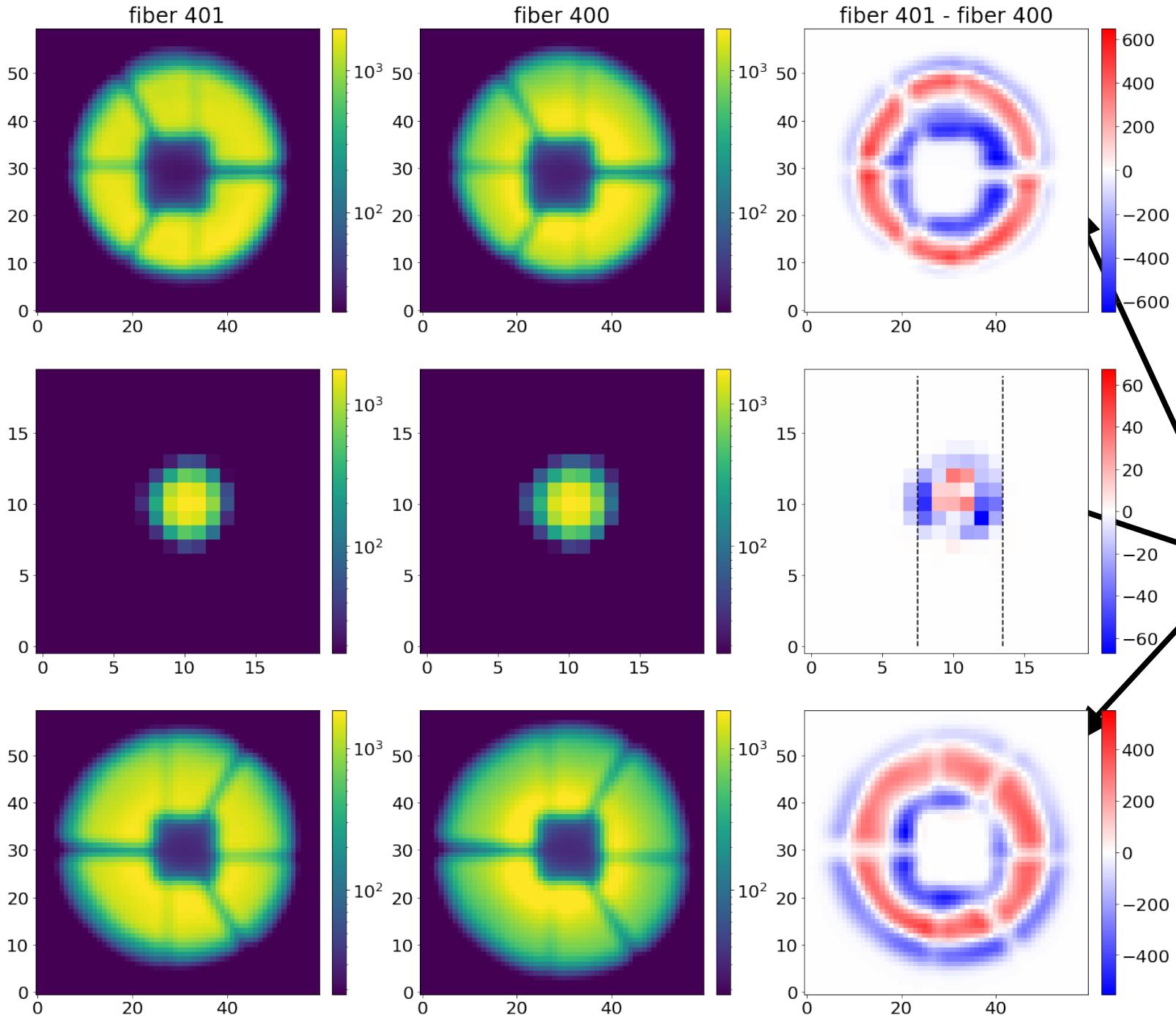


Wavelength



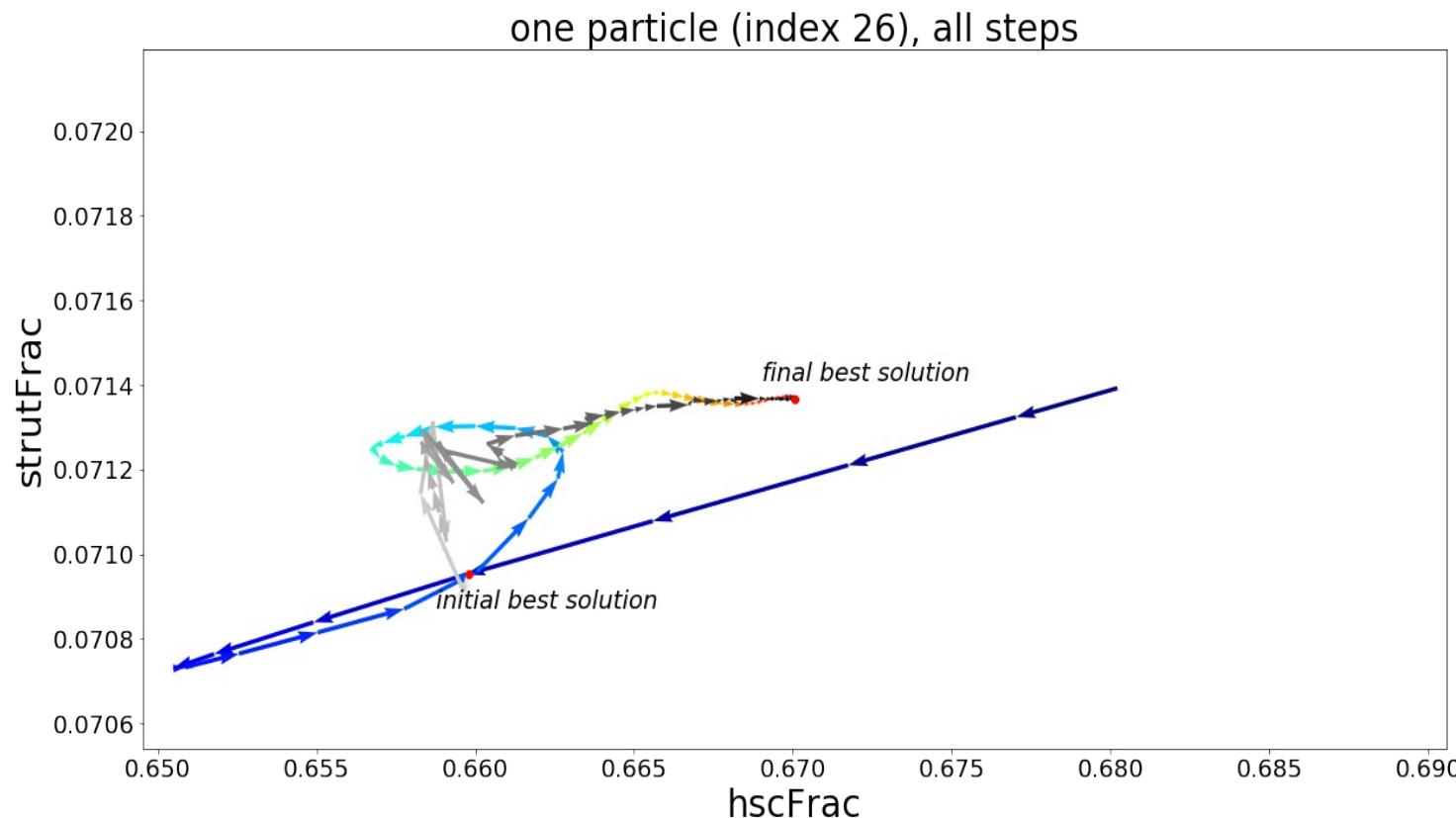
Different fibers



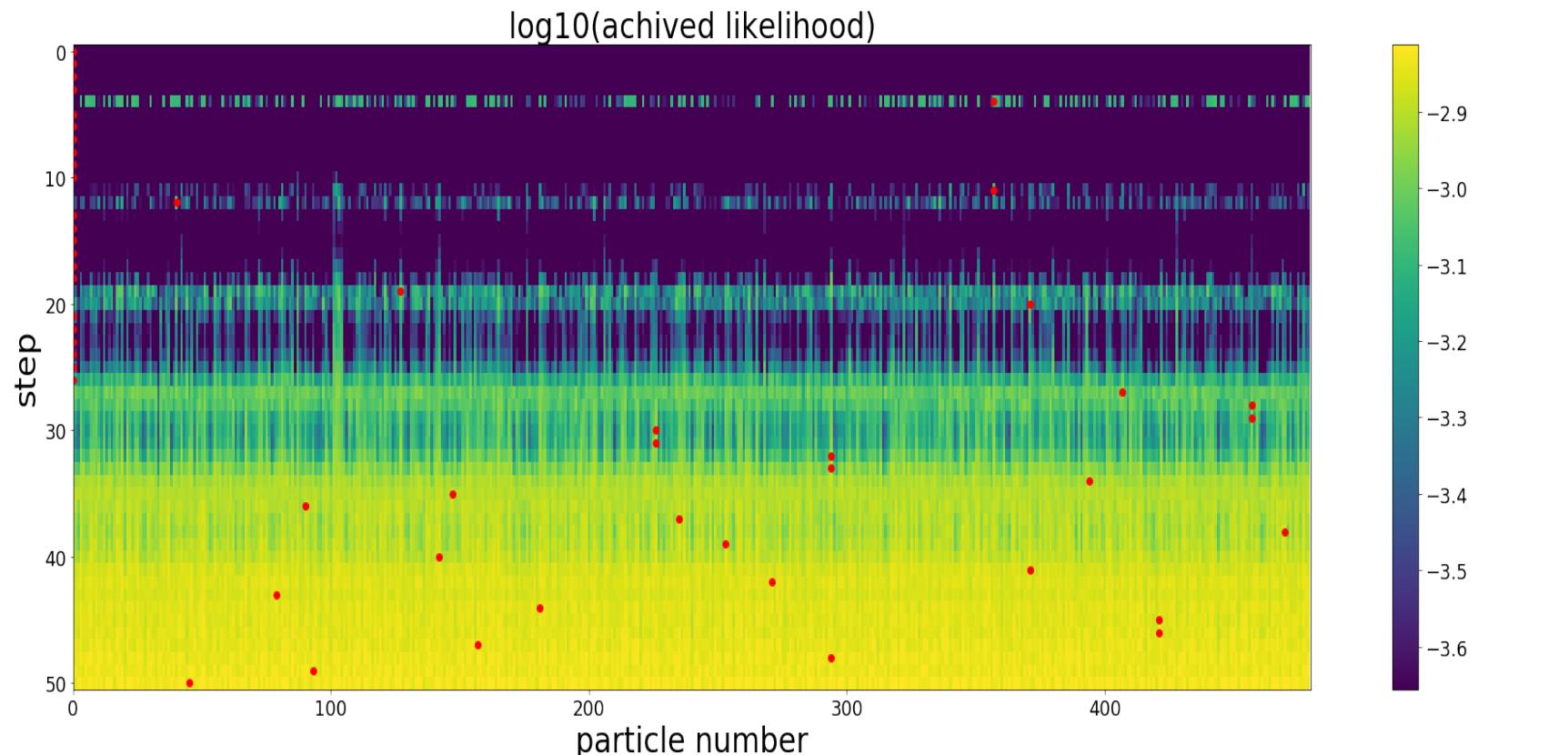


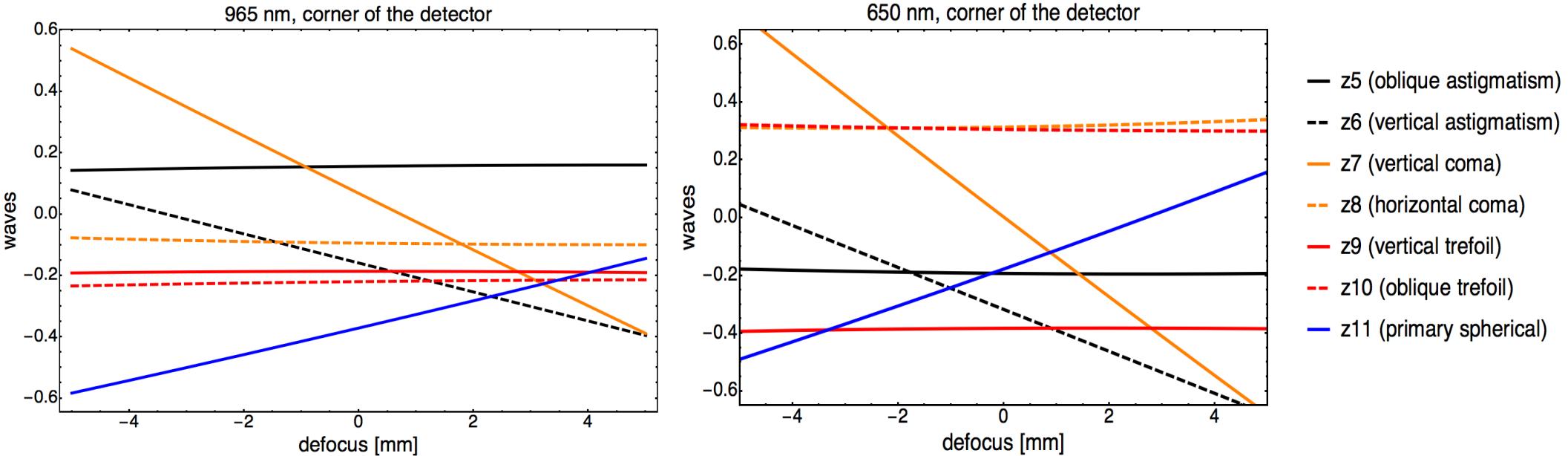
- Neighbouring fibers
- Possible to illuminate and defocus separately
- Wavefront is practically identical
- Only difference is the fiber illumination

- ``Global parameters'' (such as illumination details) are fit with Particle Swarm Optimizer (<http://cosmo-docs.phys.ethz.ch/cosmoHammer/>)
- For each particle, at each step run wavefront algorithm from Tokovinin & Heathcote (2006PASP..118.1165T)
 - Compute small changes in the final image by varying Zernike parameters by a small amount
 - Use the same computation for all particles to save time
 - In least square sense, solve for the coefficients which multiply each change made by changing Zernike parameter
 - Continue until no more improvement



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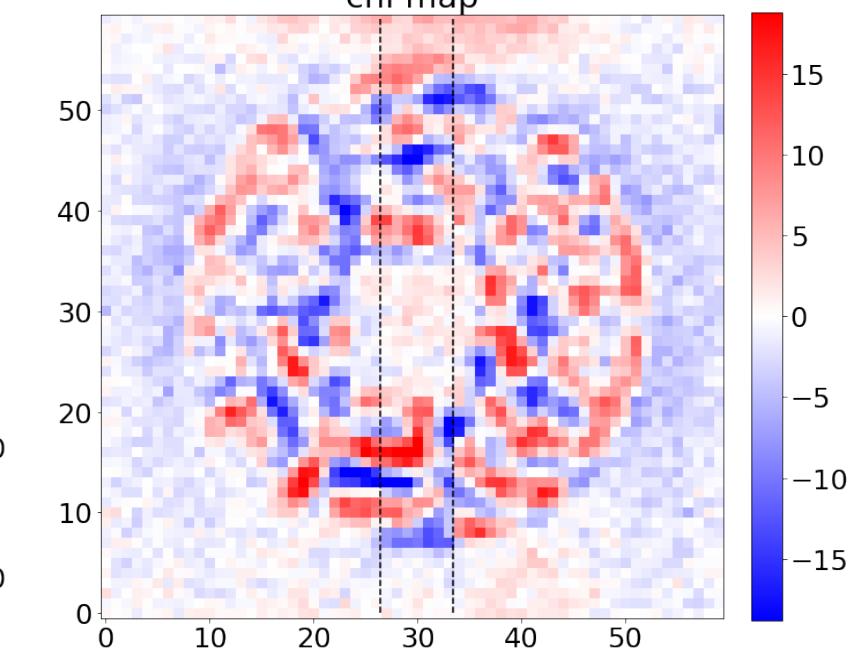
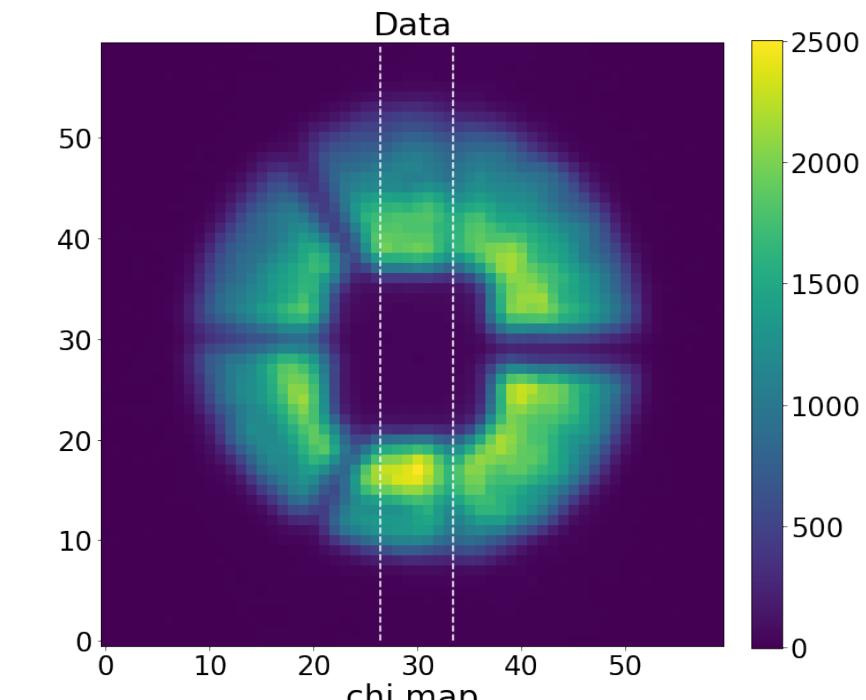
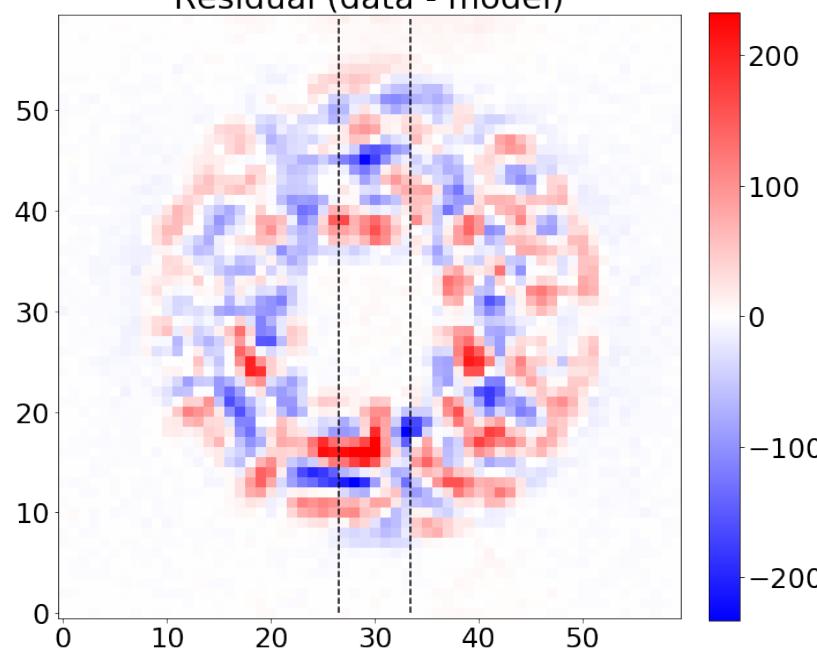
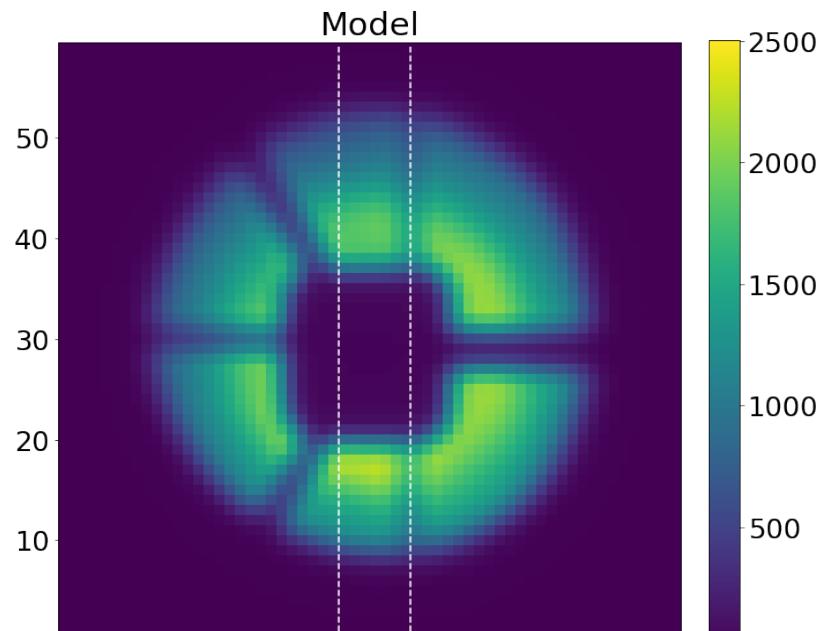




Wavefront aberrations as function of defocus (Zemax)

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

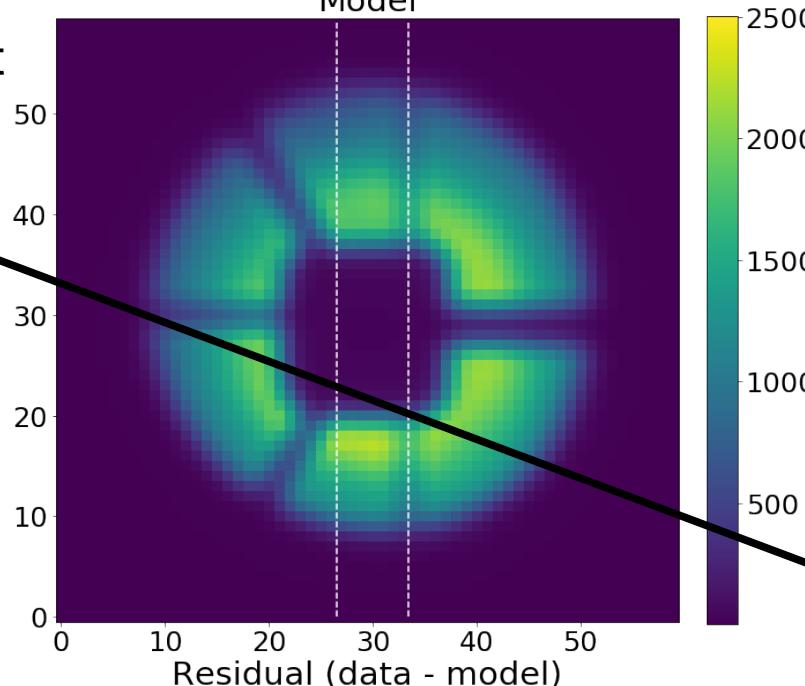
Defocused
data,
example with
linear scaling



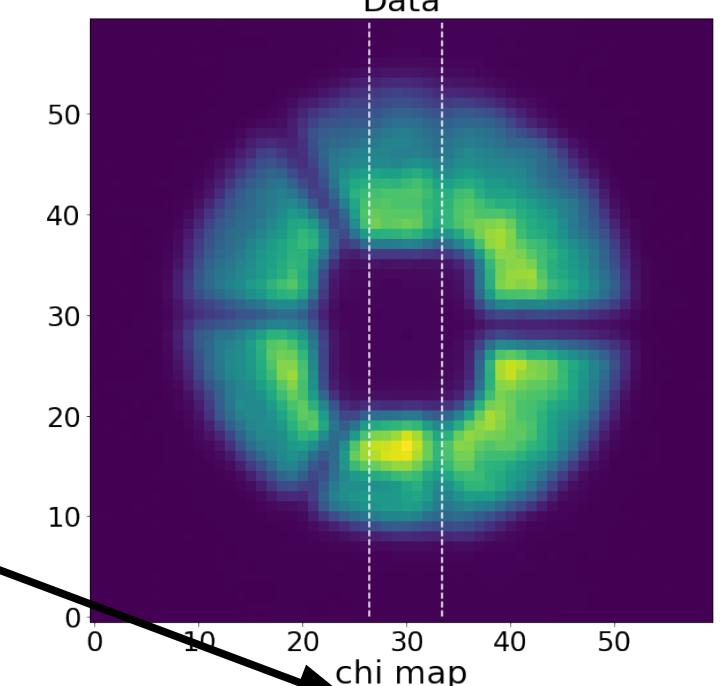
- Next source at the edge of the image, seen in the residual

Defocused data,
example with linear scaling

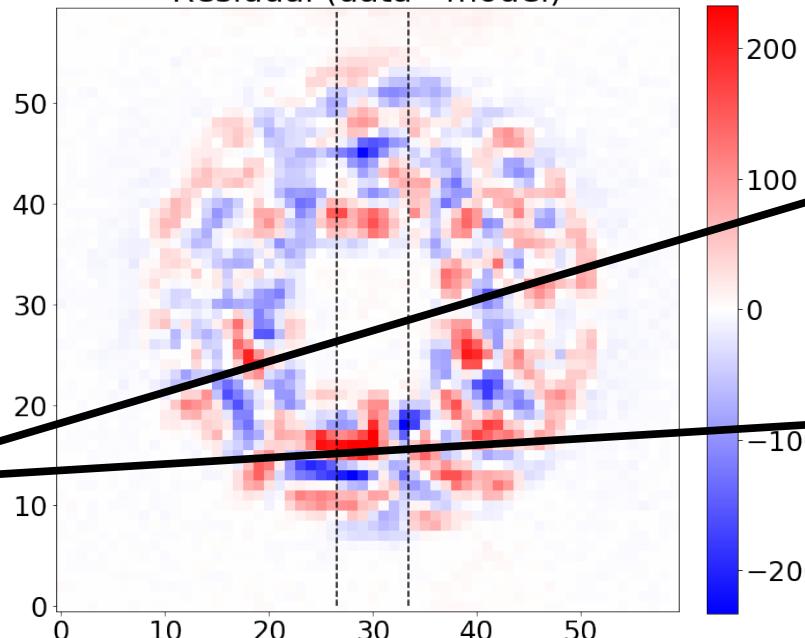
Model



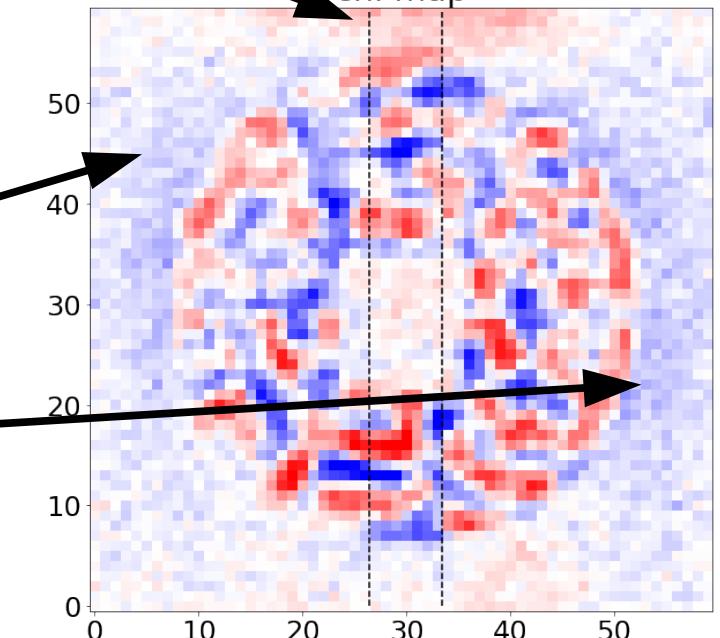
Data



Residual (data - model)

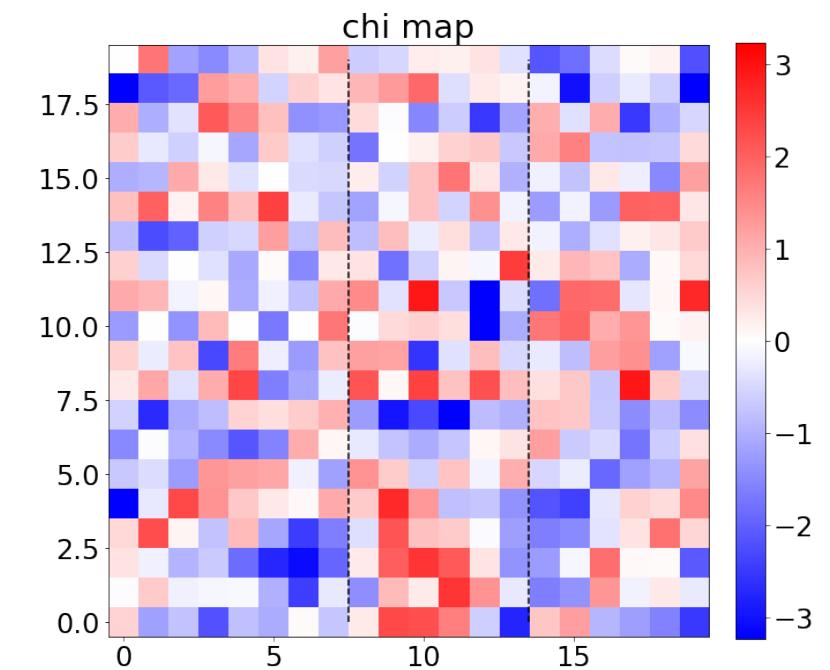
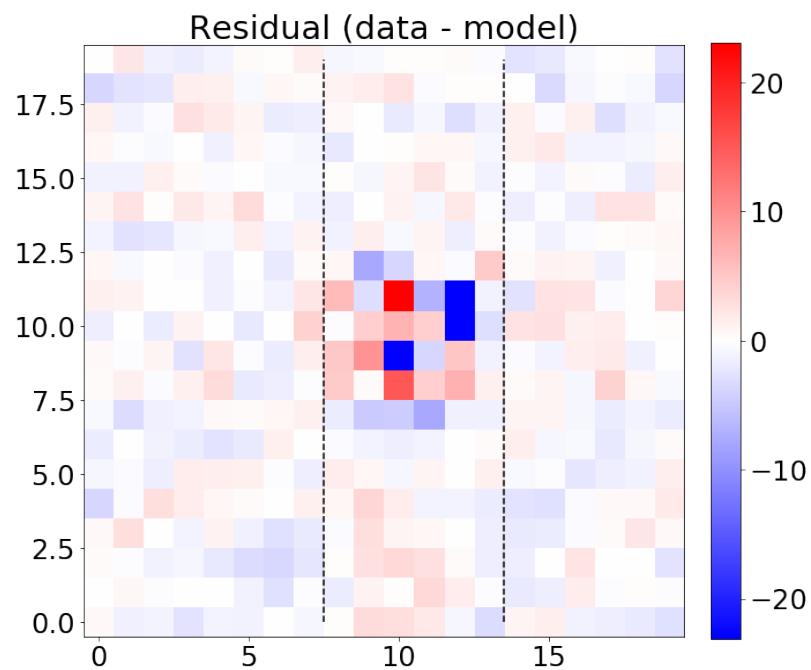
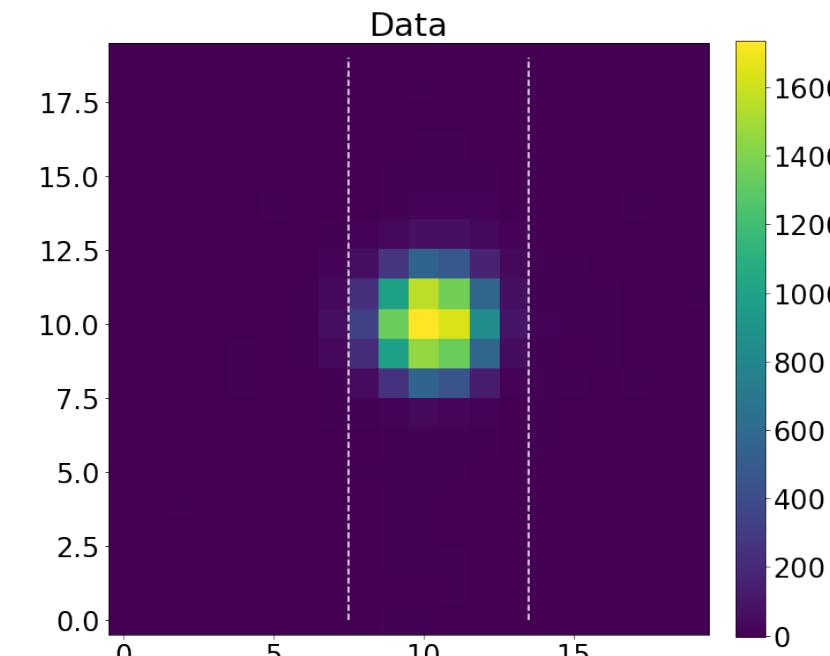
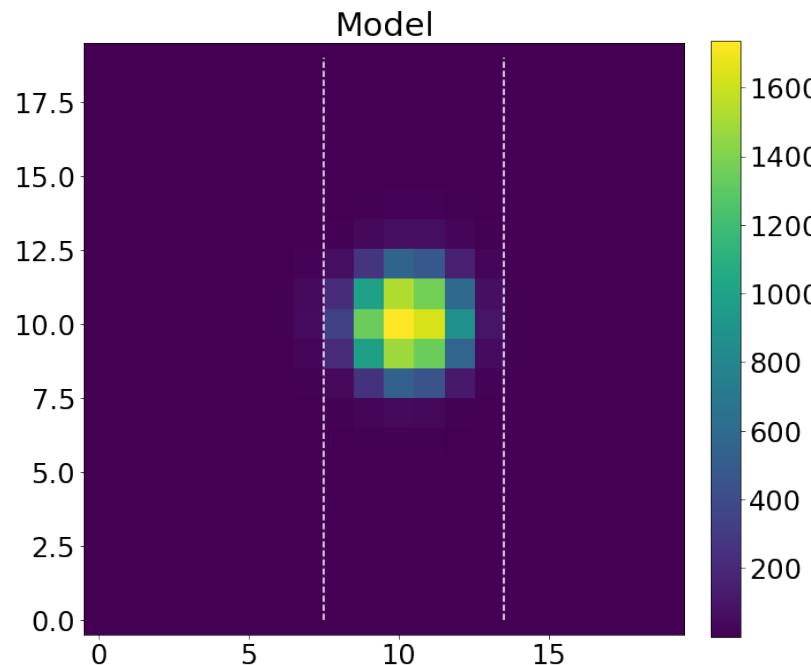


chi map

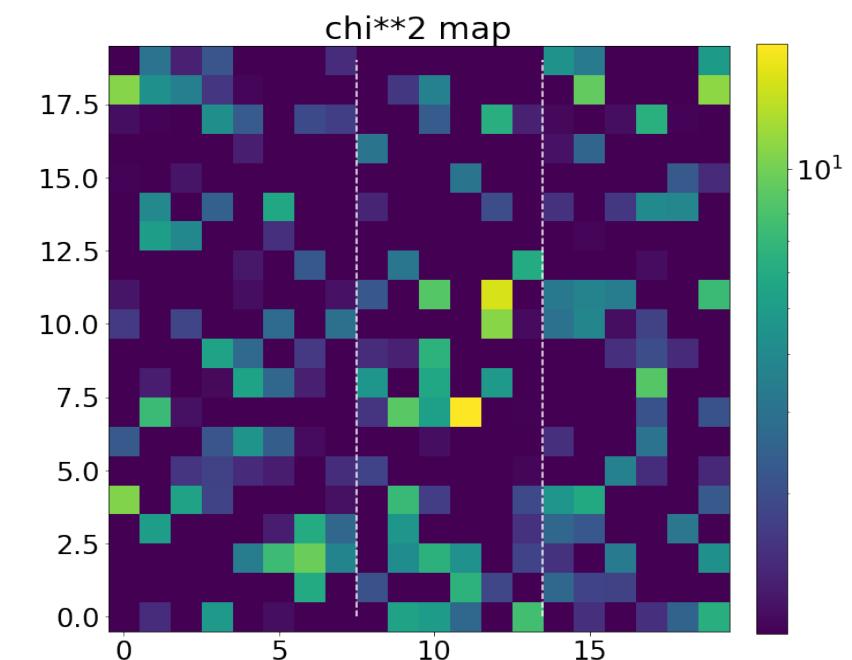
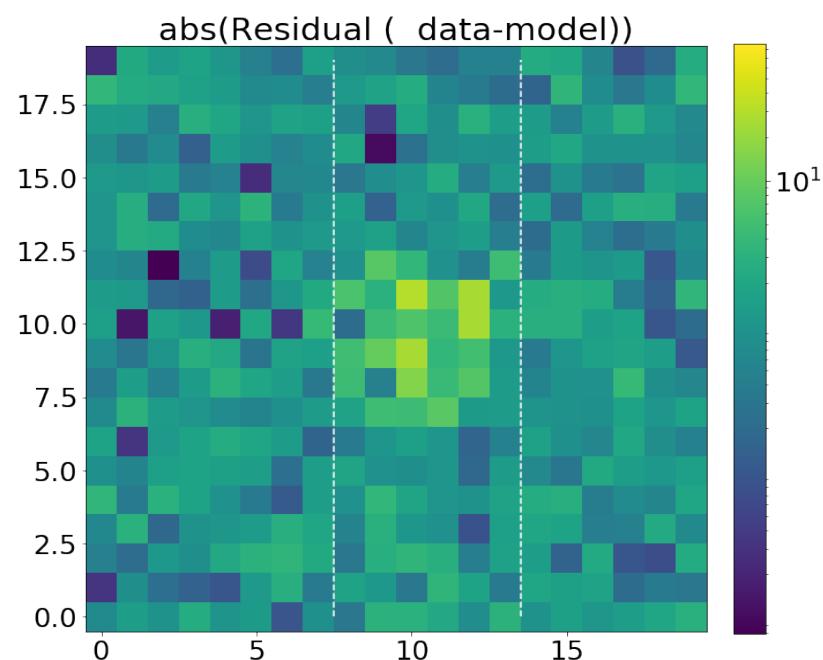
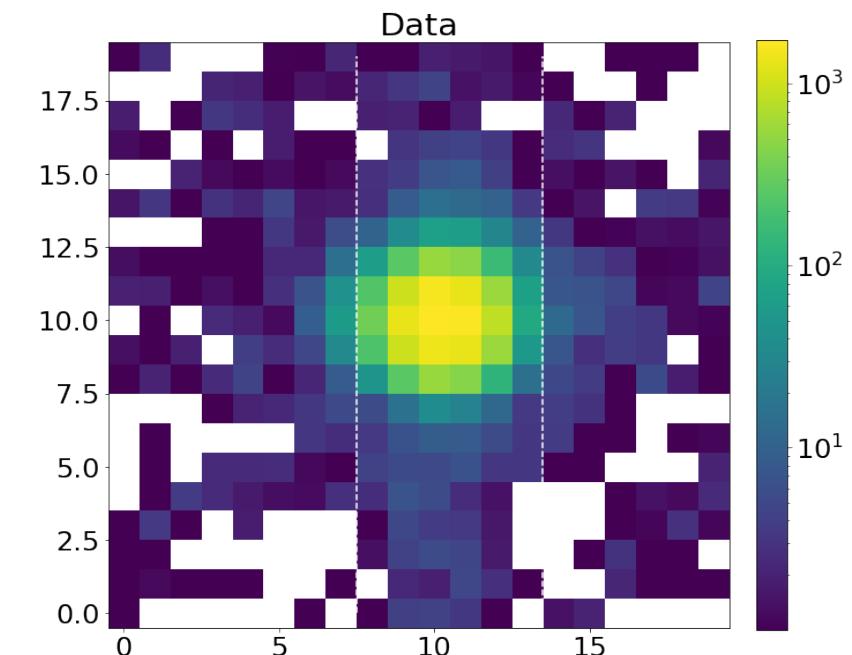
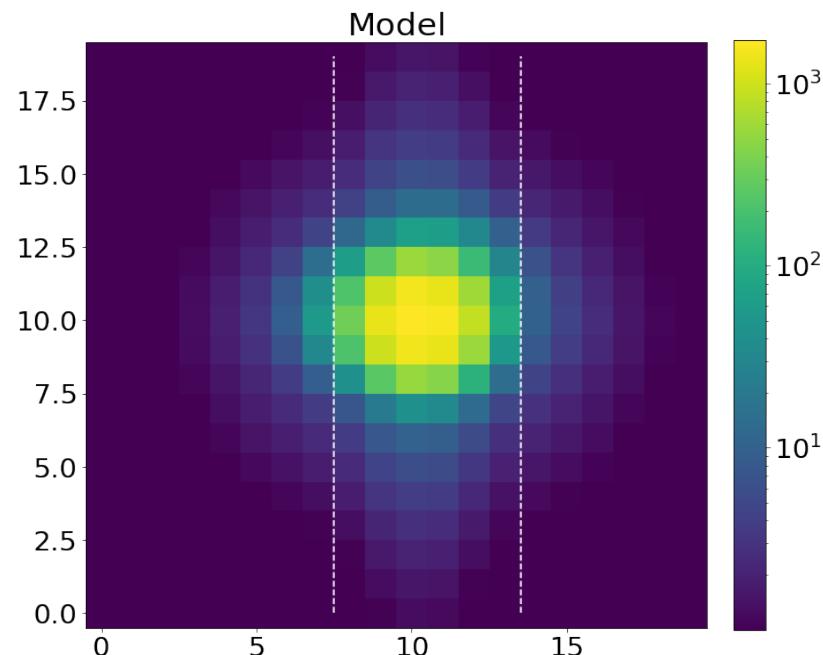


- Too much scattering for defocused image?

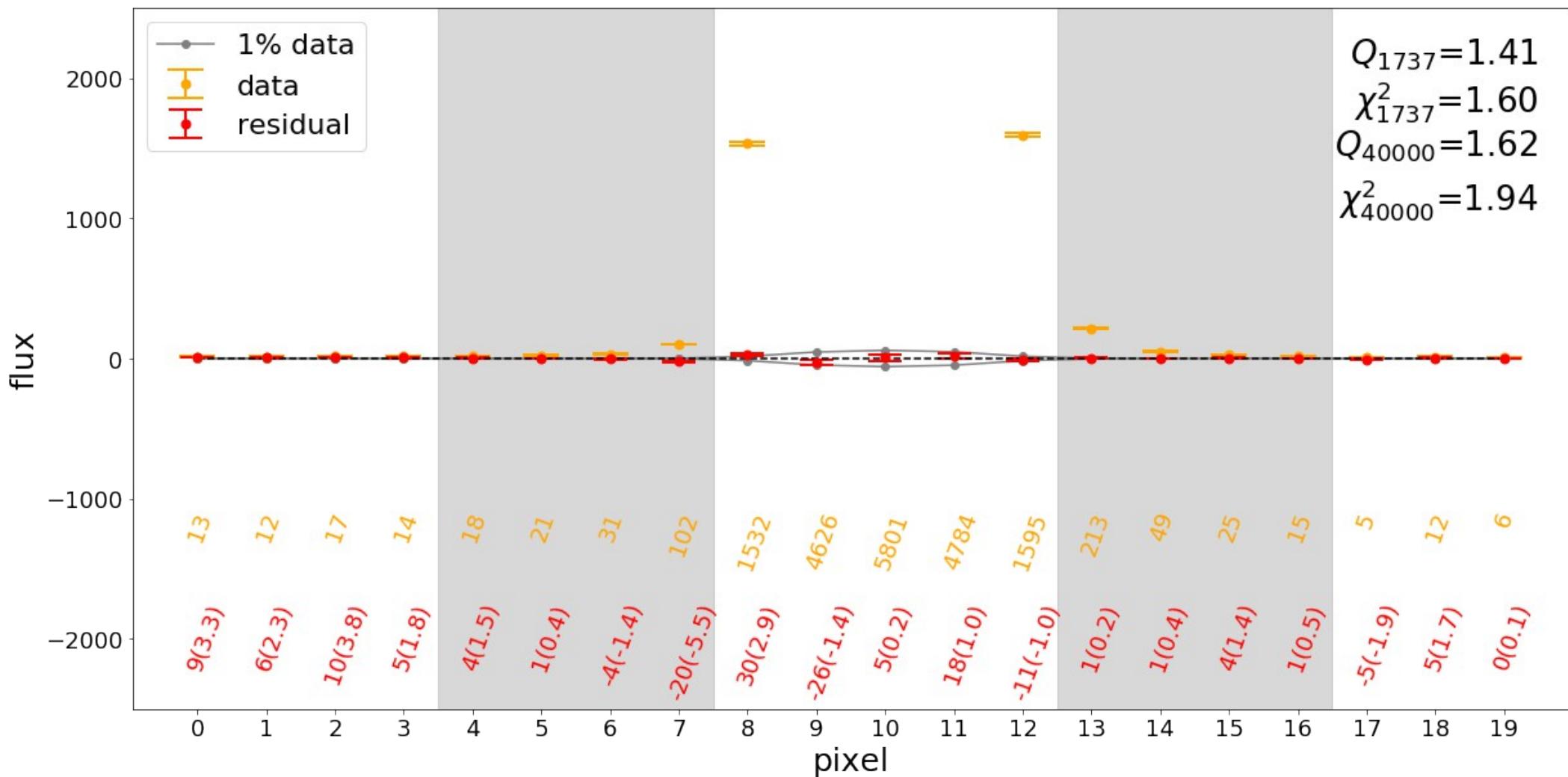
Focused
data,
example with
linear scaling



Focused
data,
example with
log scaling

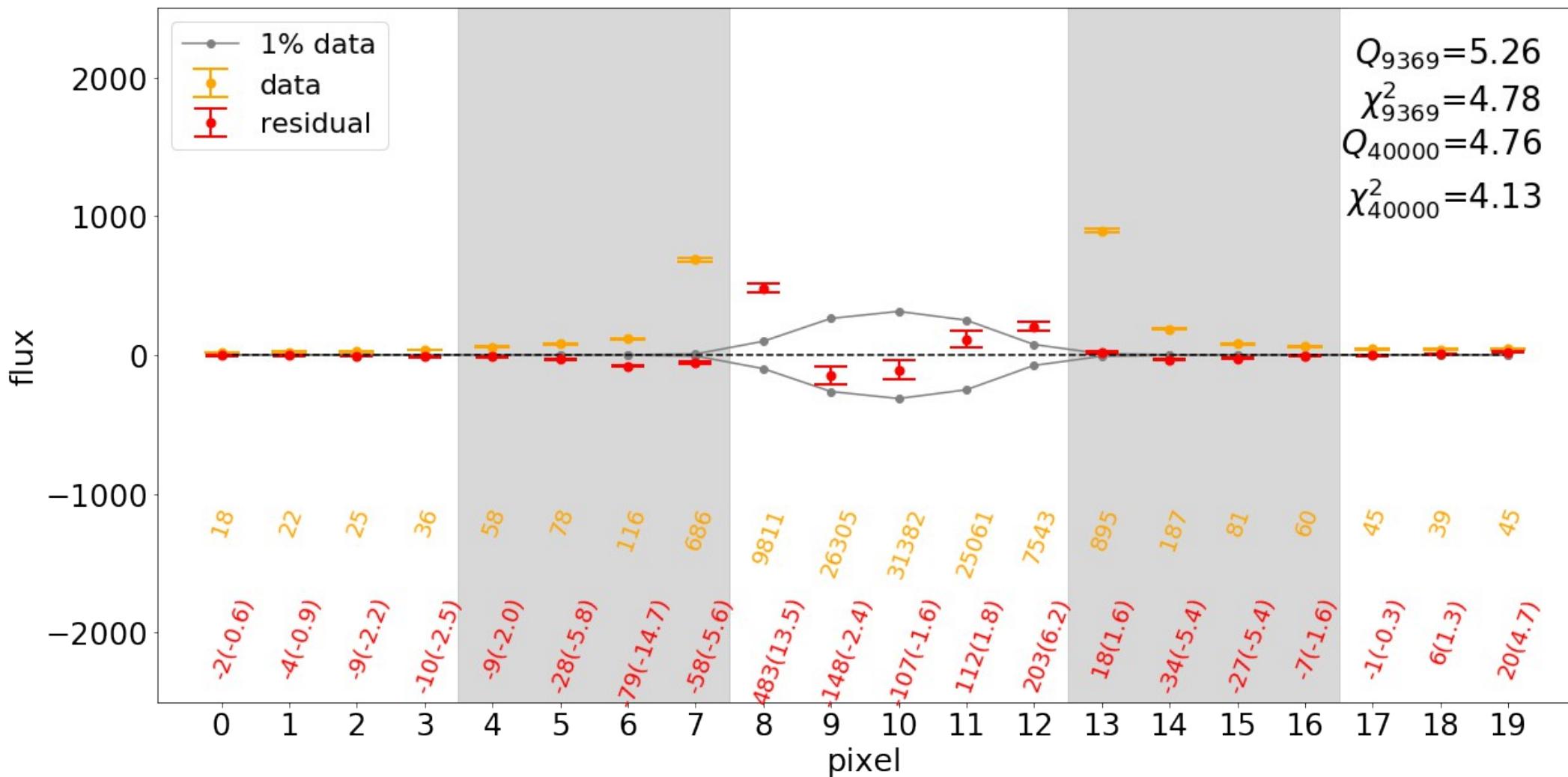


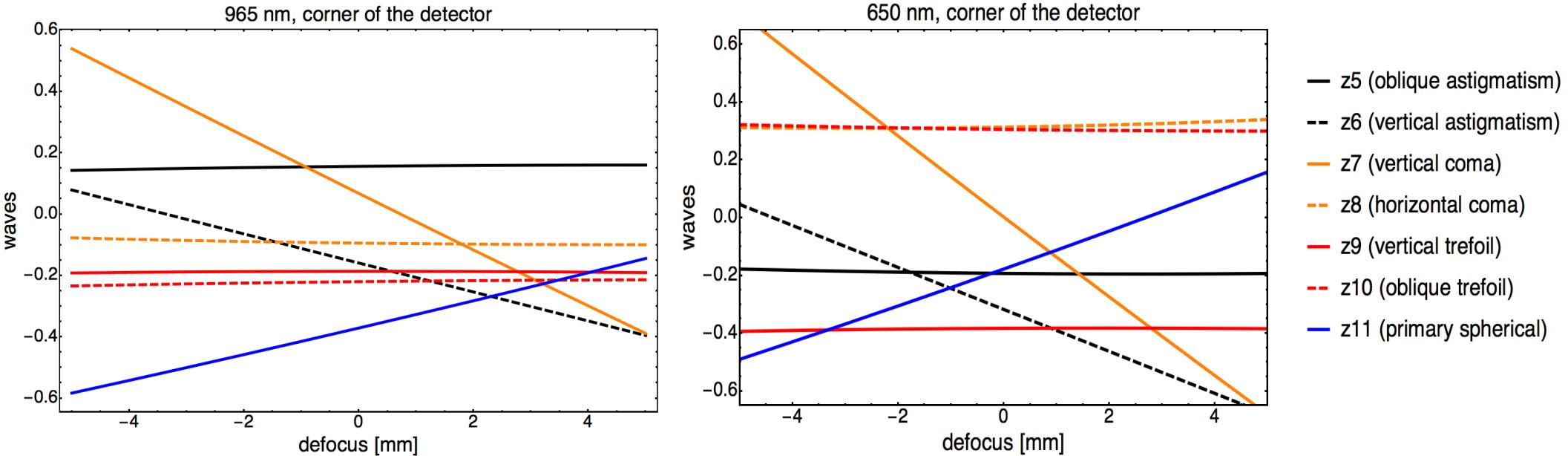
- Ultimate goal is quality of 1d extraction (closely related but not necessarily completely equivalent to the quality 2d subtraction)
- Provisional goal is 1% subtraction
 - In particular, outside of the core of the lines (gray areas below)



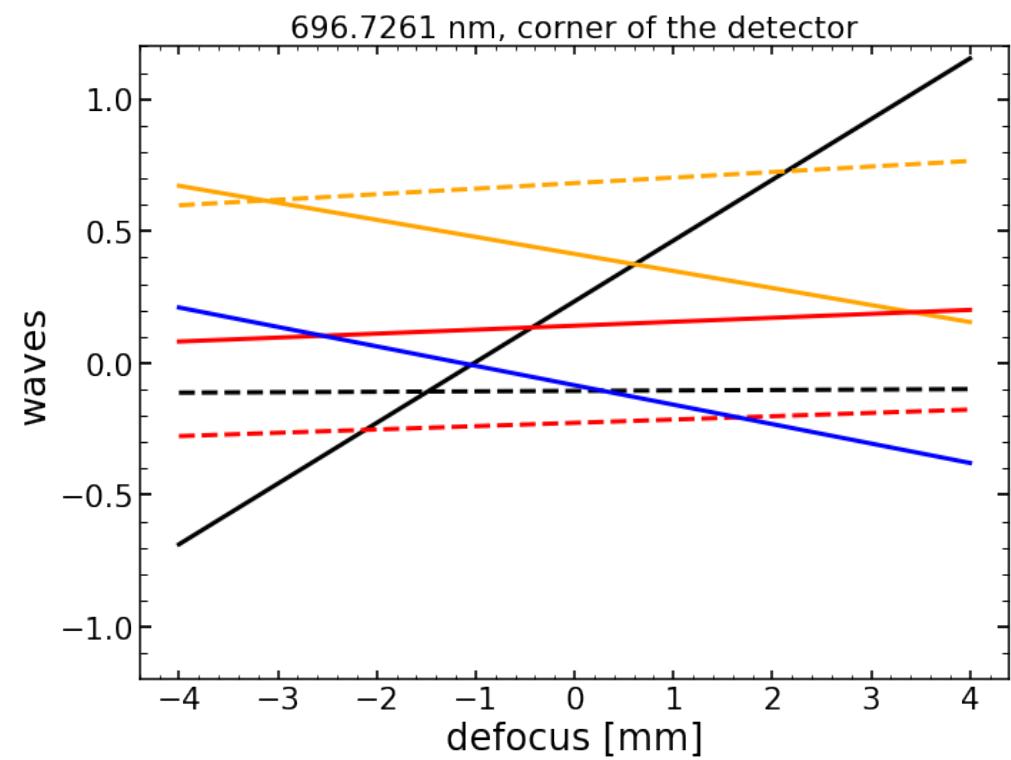
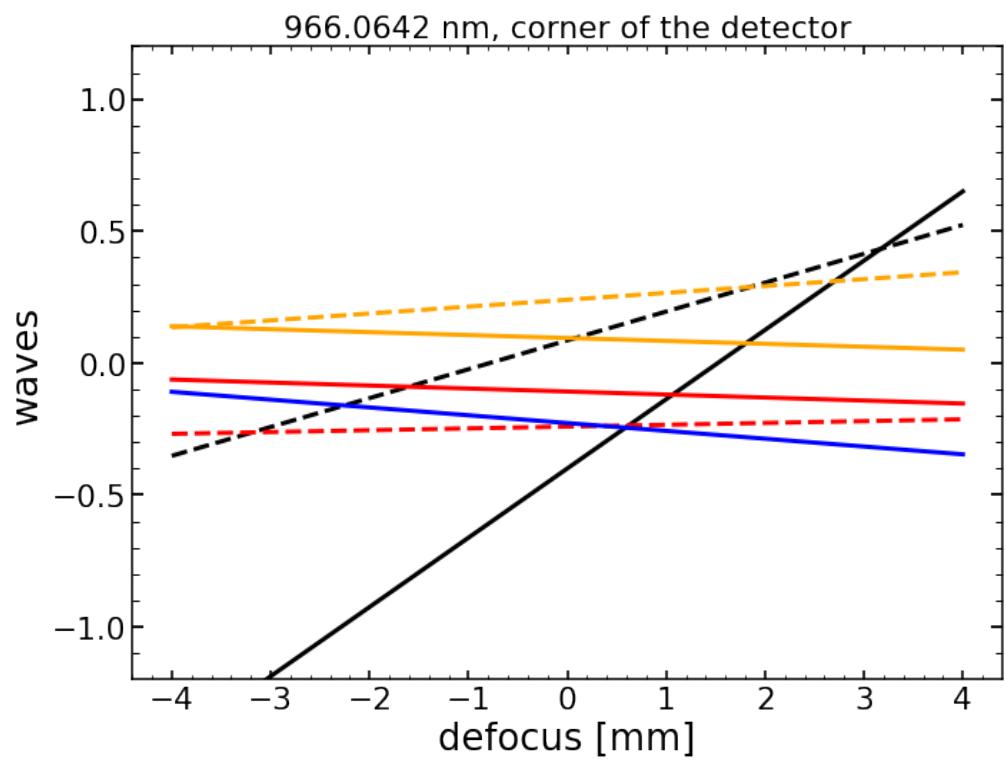
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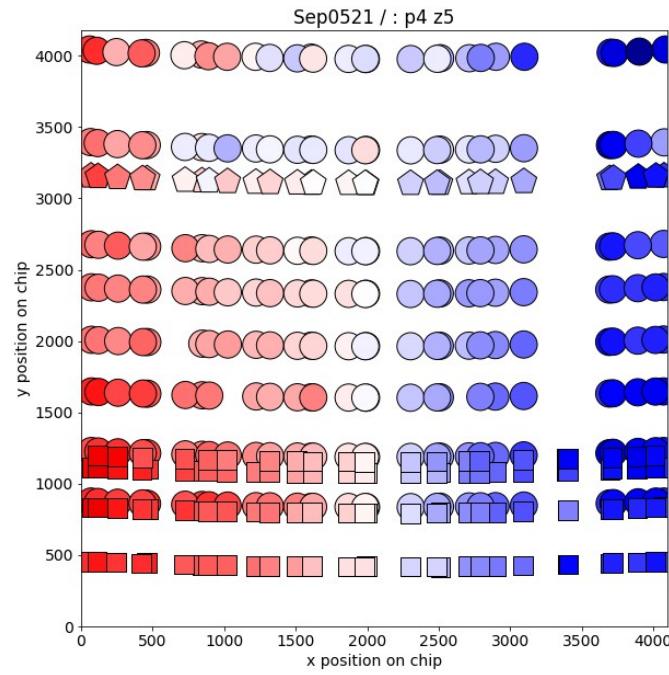
Higher flux example



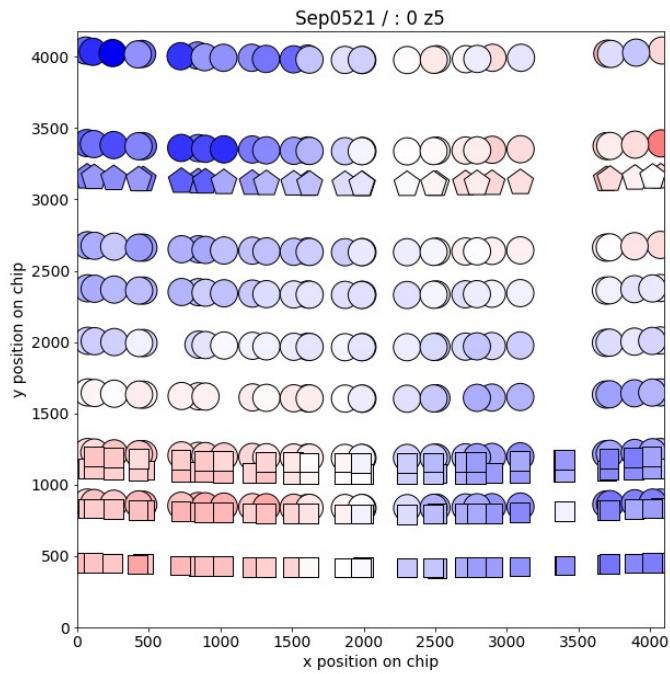
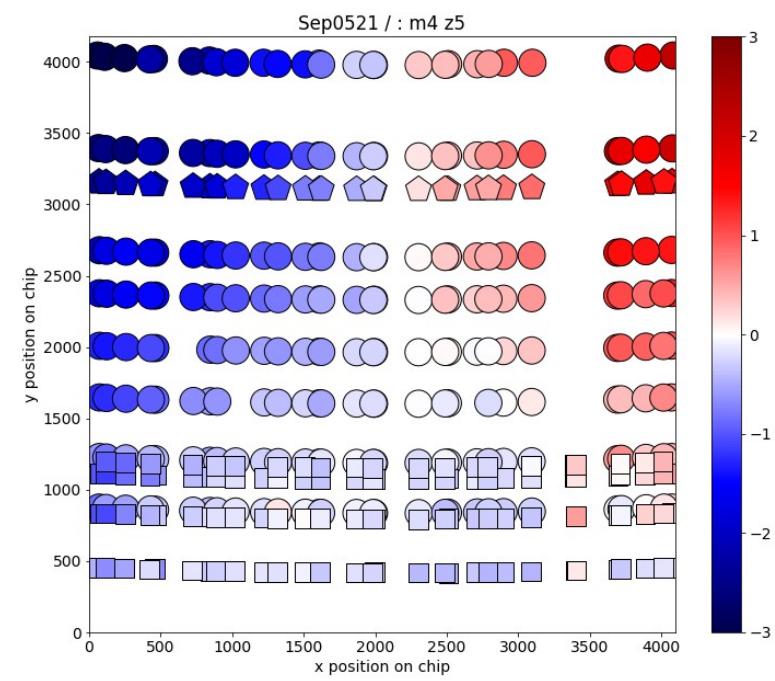


- Example from modelling of the experimental data below
(not exactly the same location as above, but observe large difference)



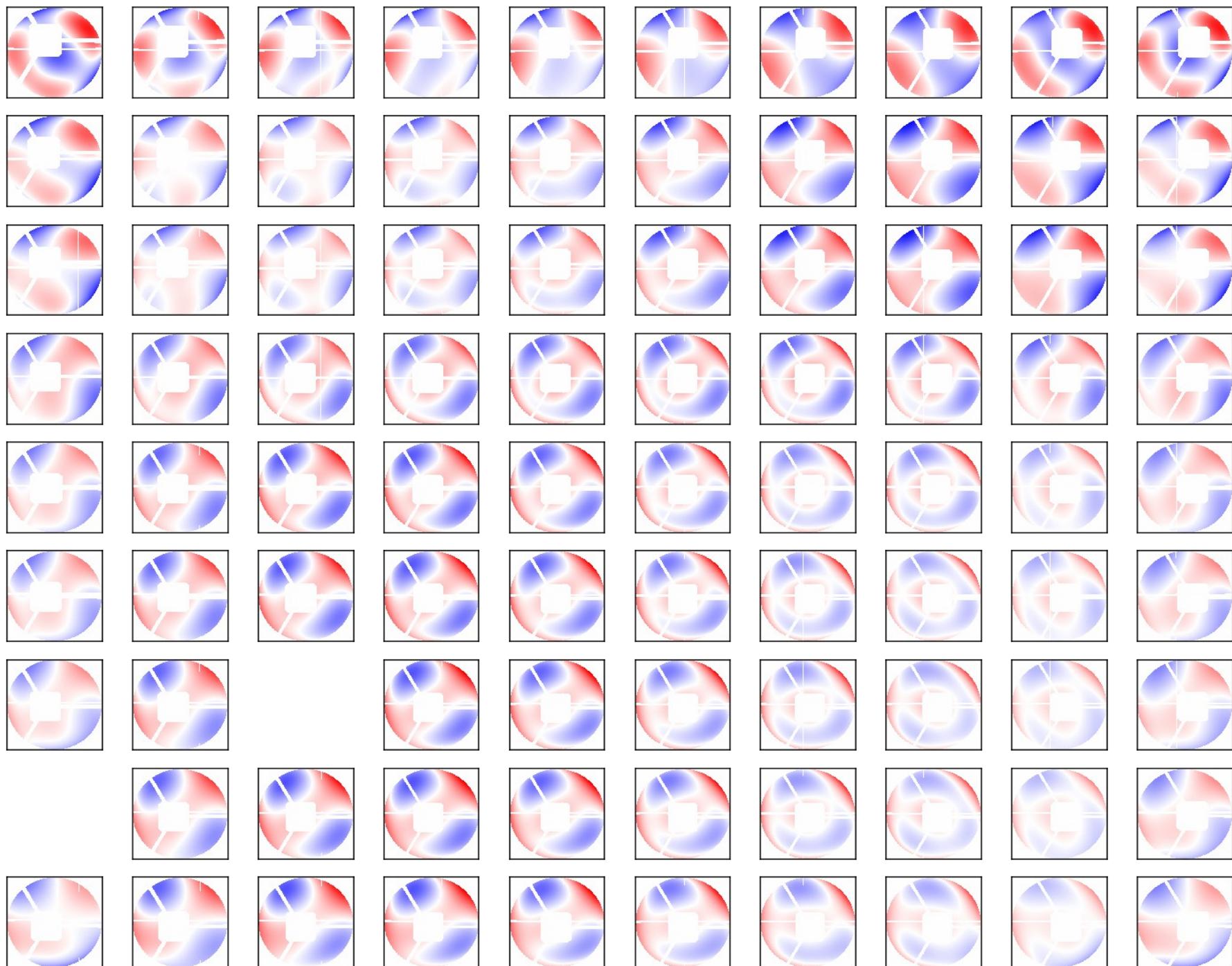


Change of single component
(oblique astigmatism)

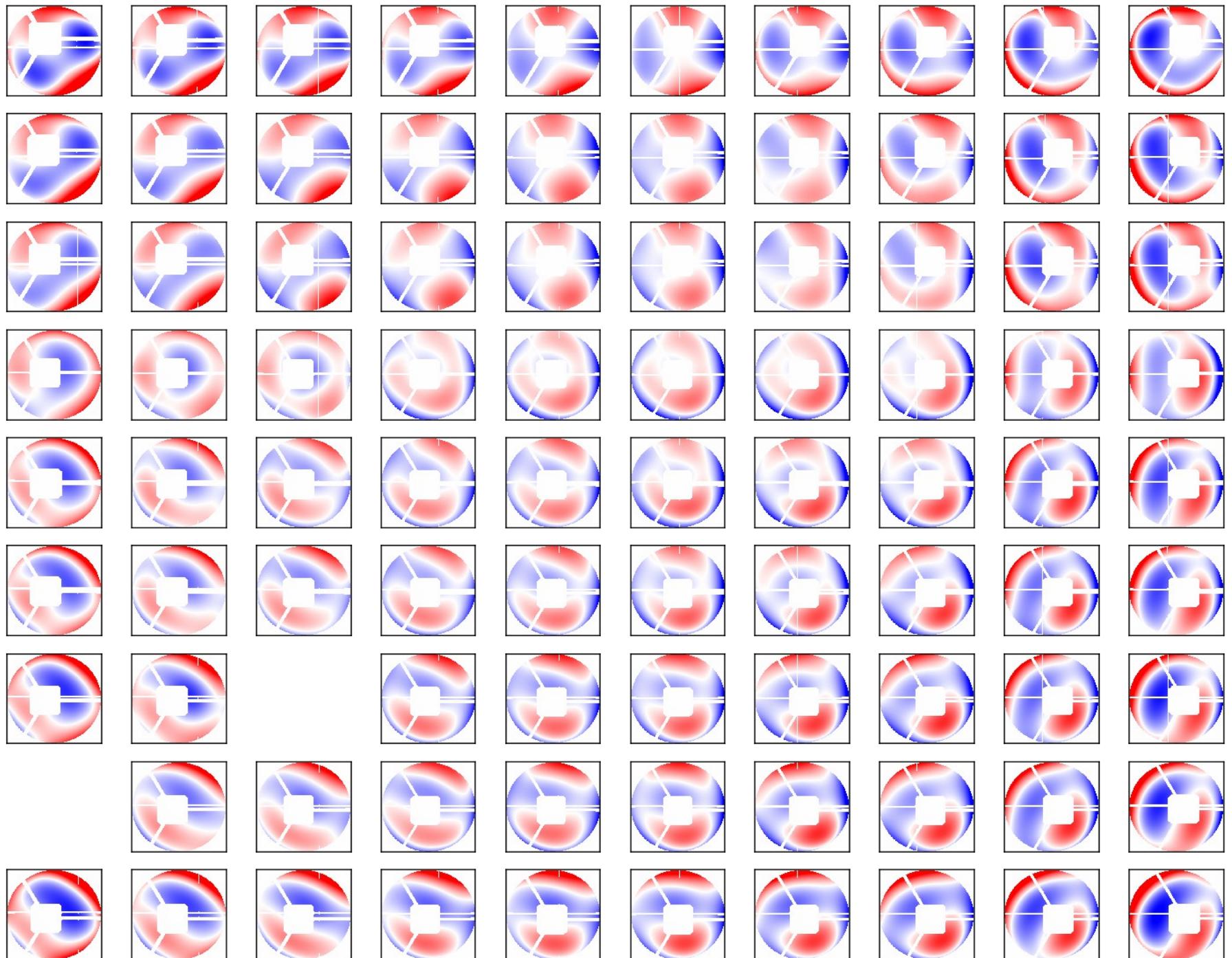


Changing defocus

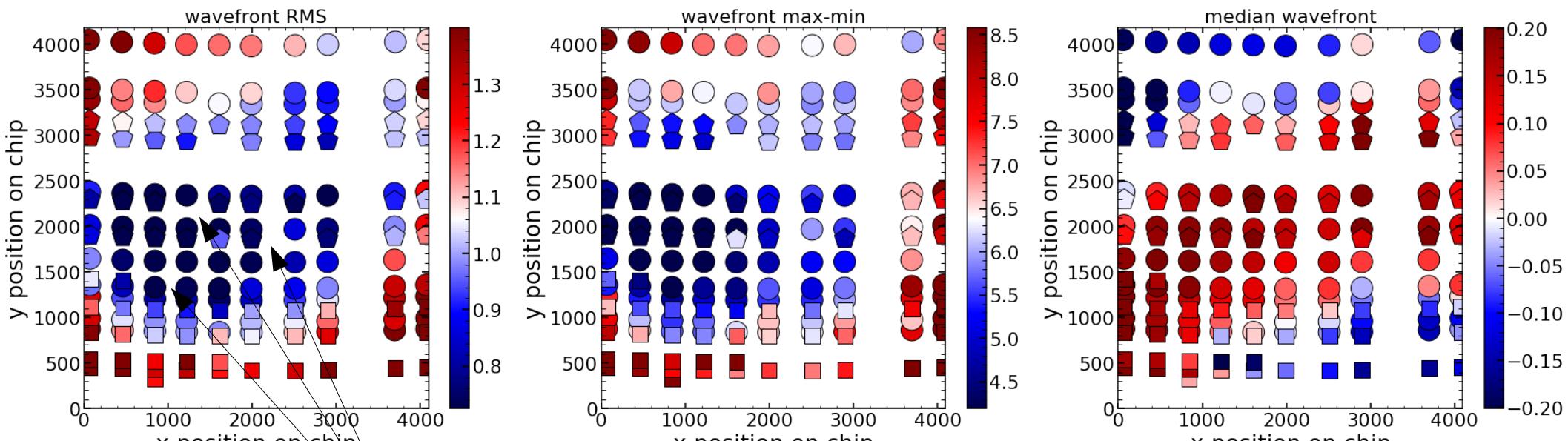
Wavefront - Zemax



Wavefront – reality

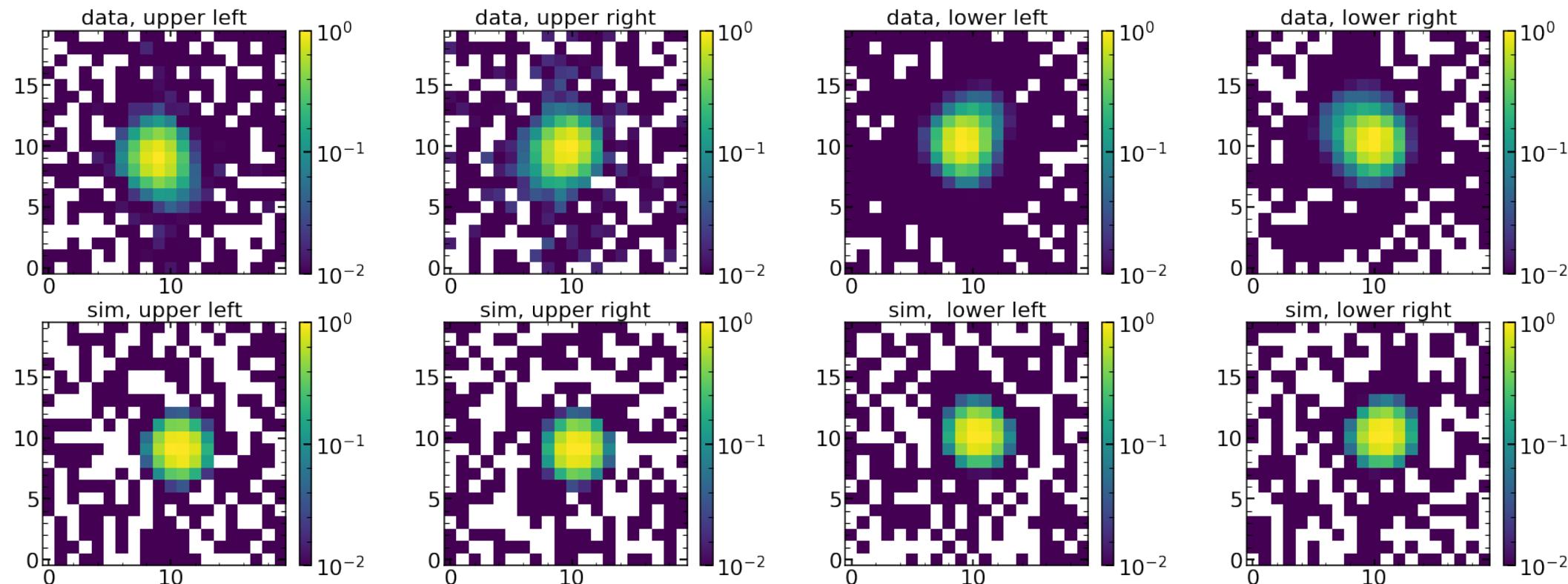


Wavefront rms across the detector

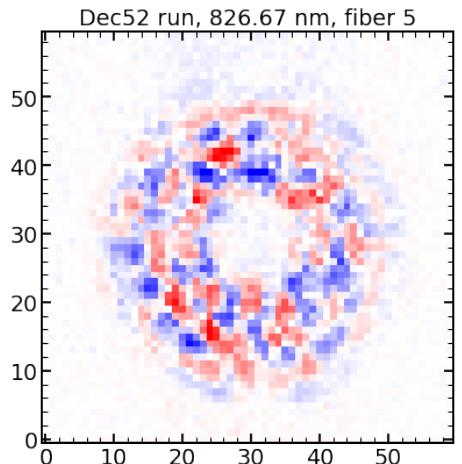


Not in the center of the detector –
probably because it was centered from
available data

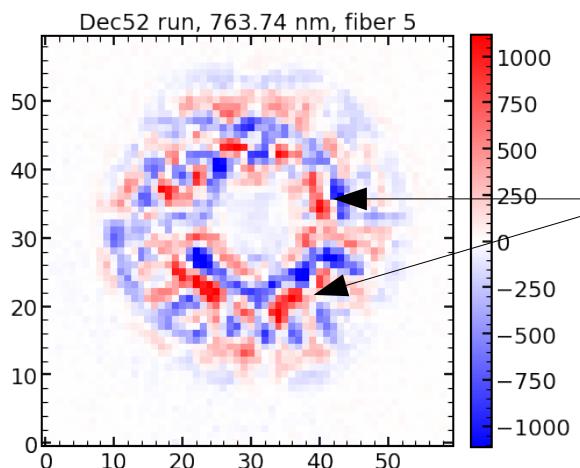
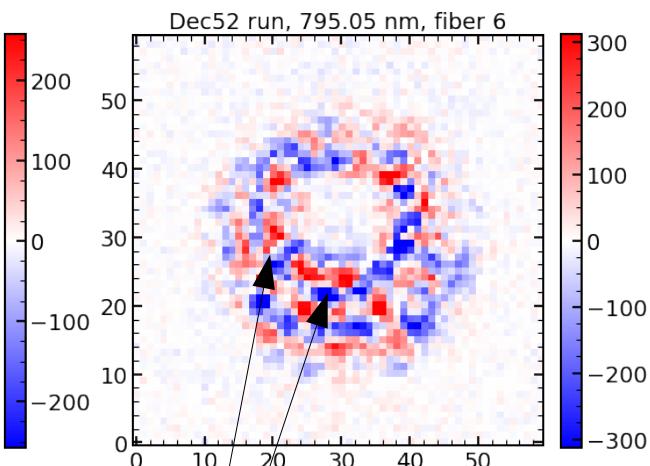
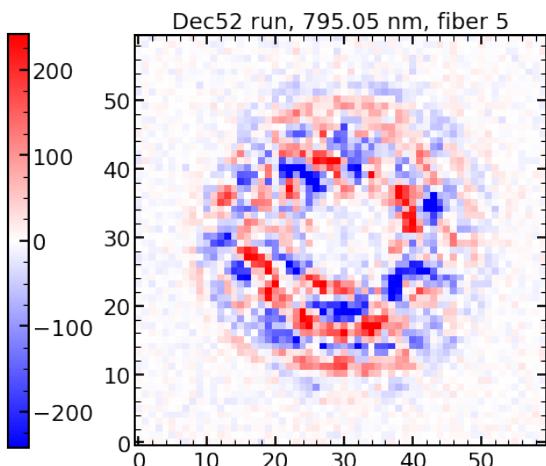
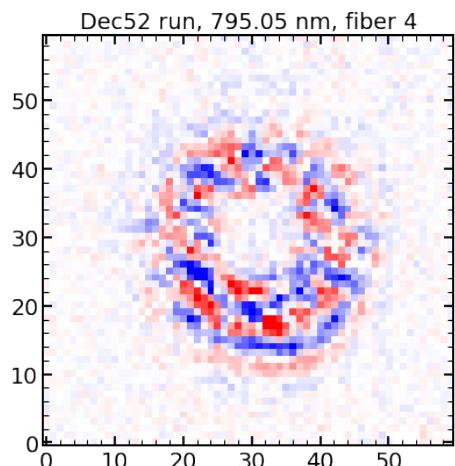
Zemax & real data



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

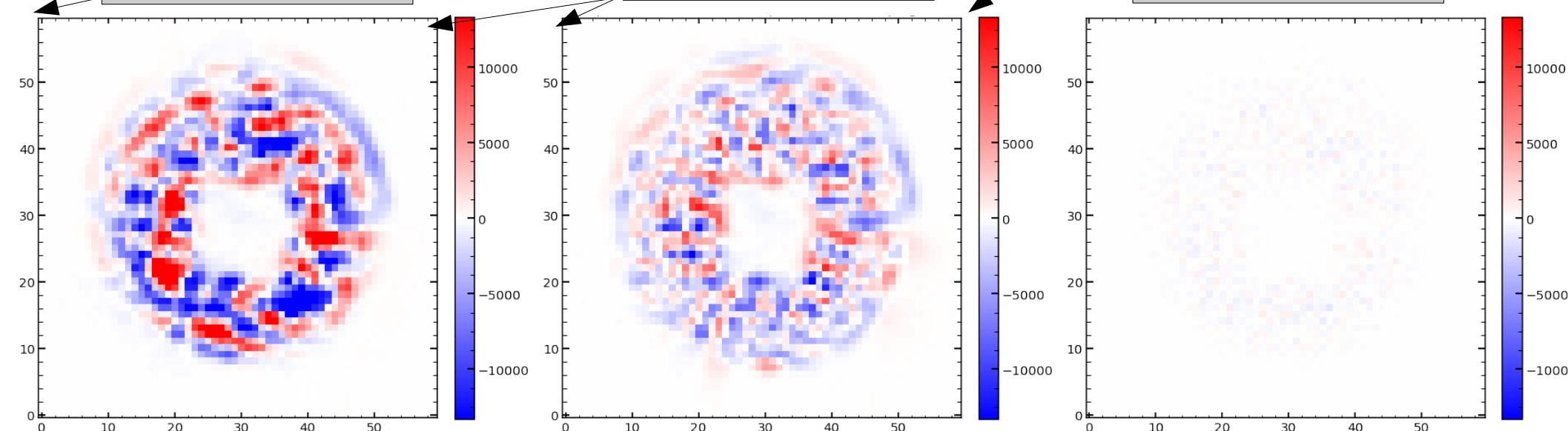
Direct Fits

Up to z22

Up to z254

Perfection

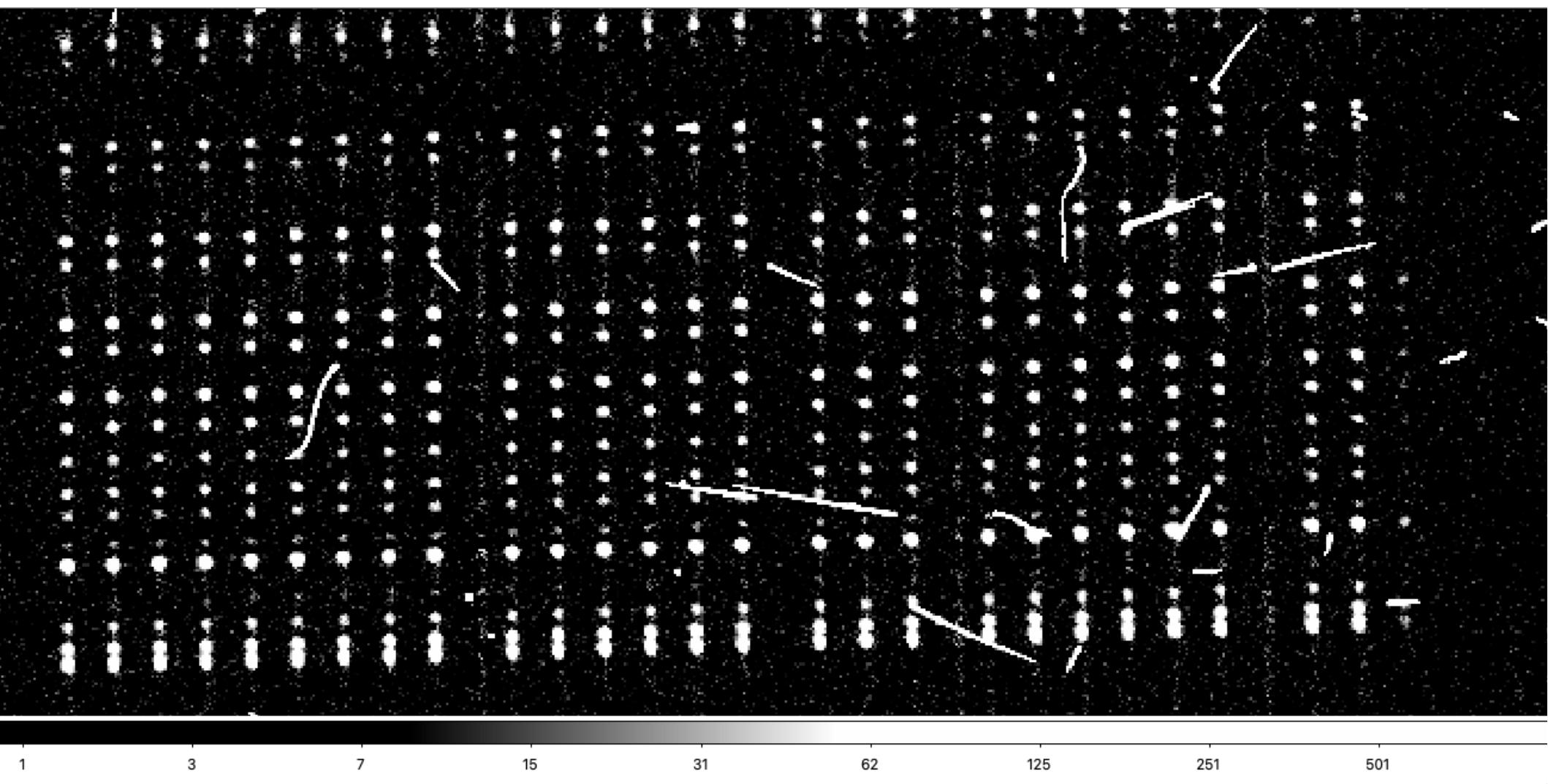
Residuals scaled to
5% of the maximal flux
in the data



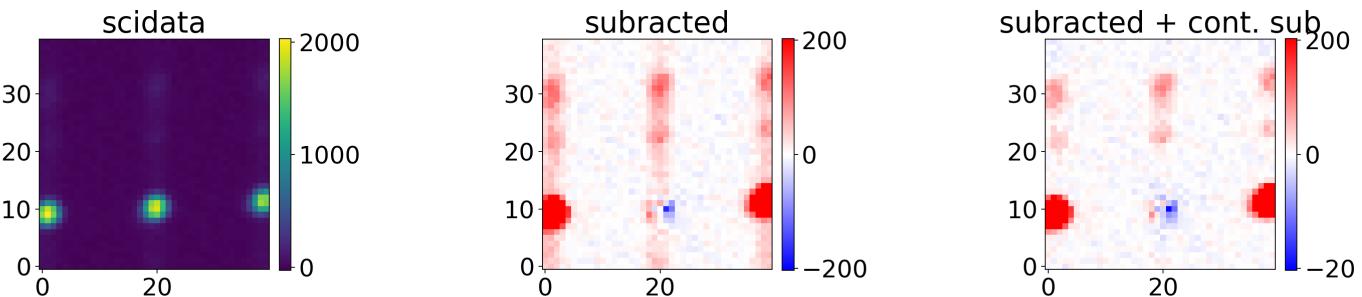
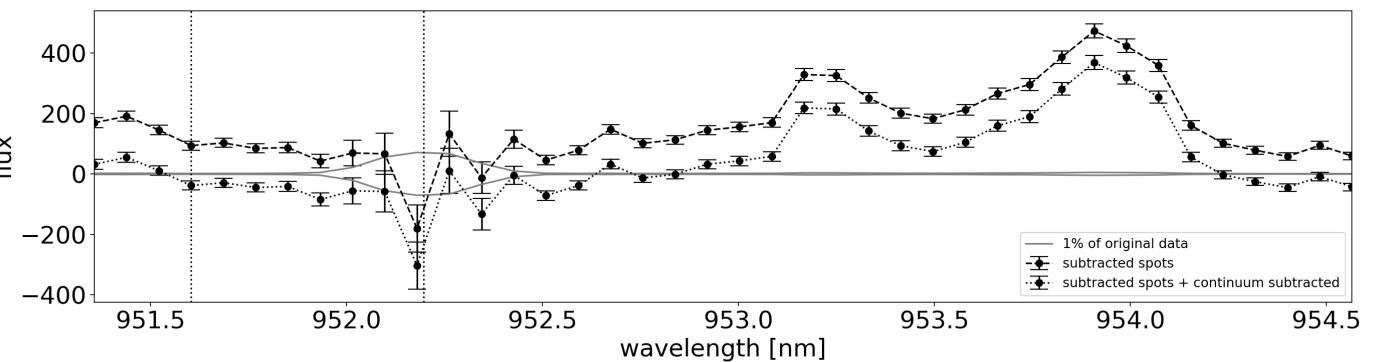
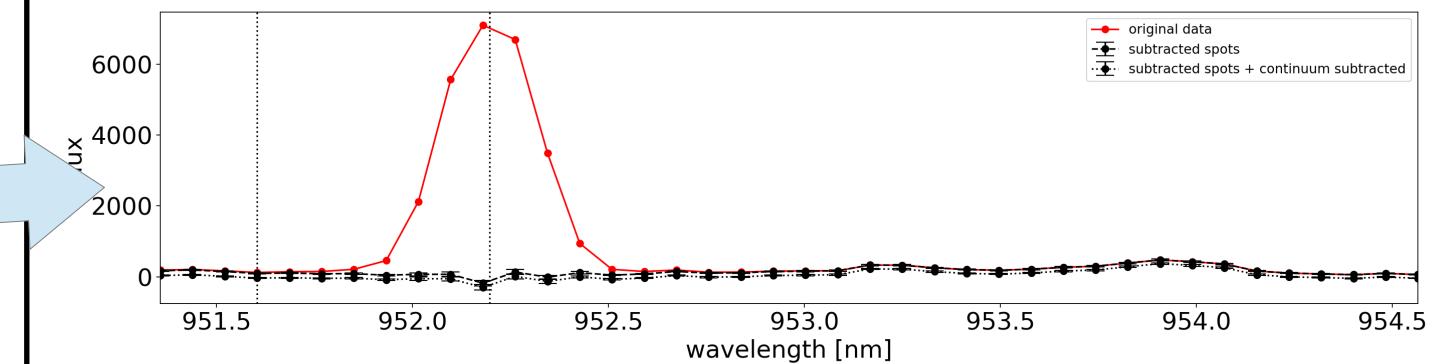
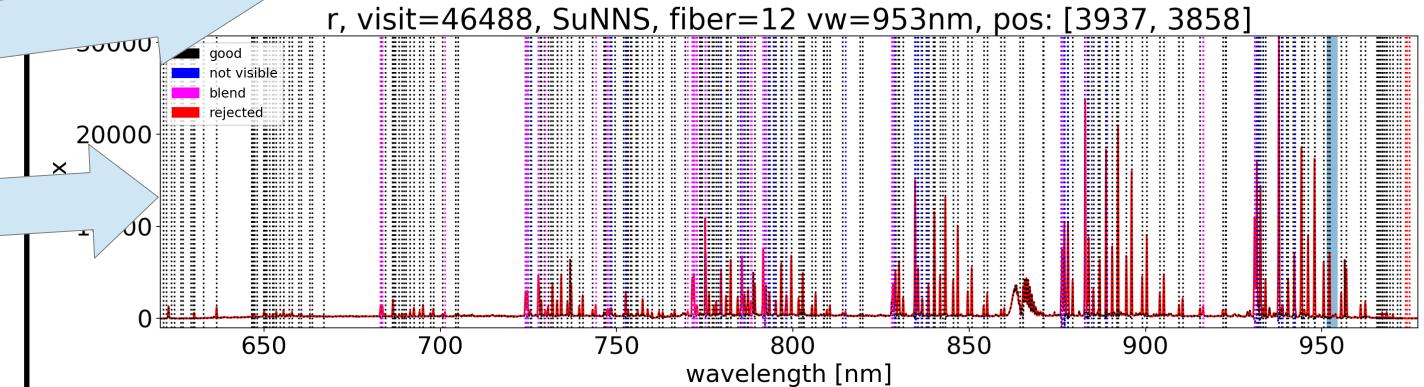
High order
aberrations do not
vary as a position of
the detector? (if they
come from glass
imperfections)

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

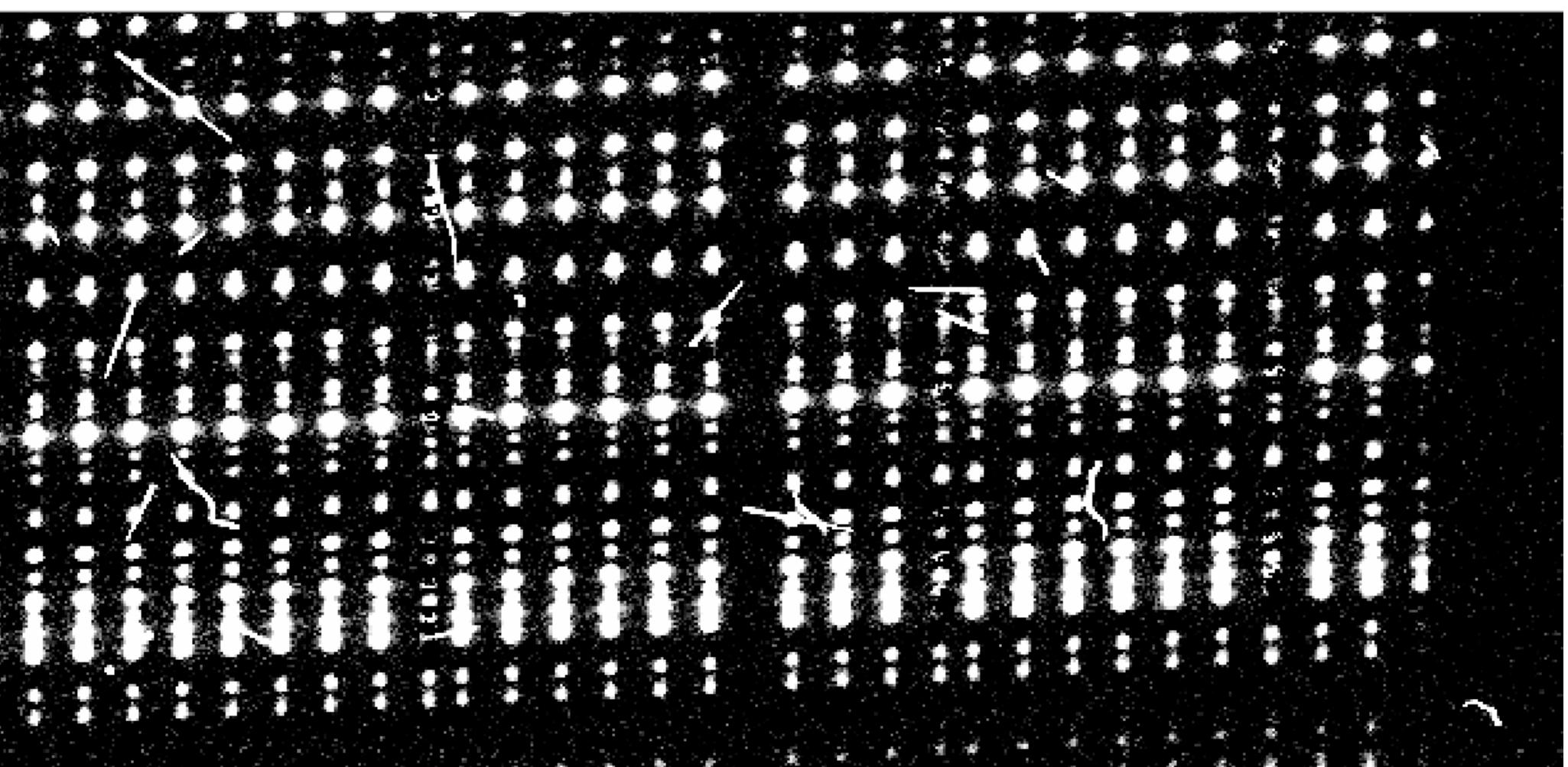
Problems – centering, full
list of lines, strength of
lines....



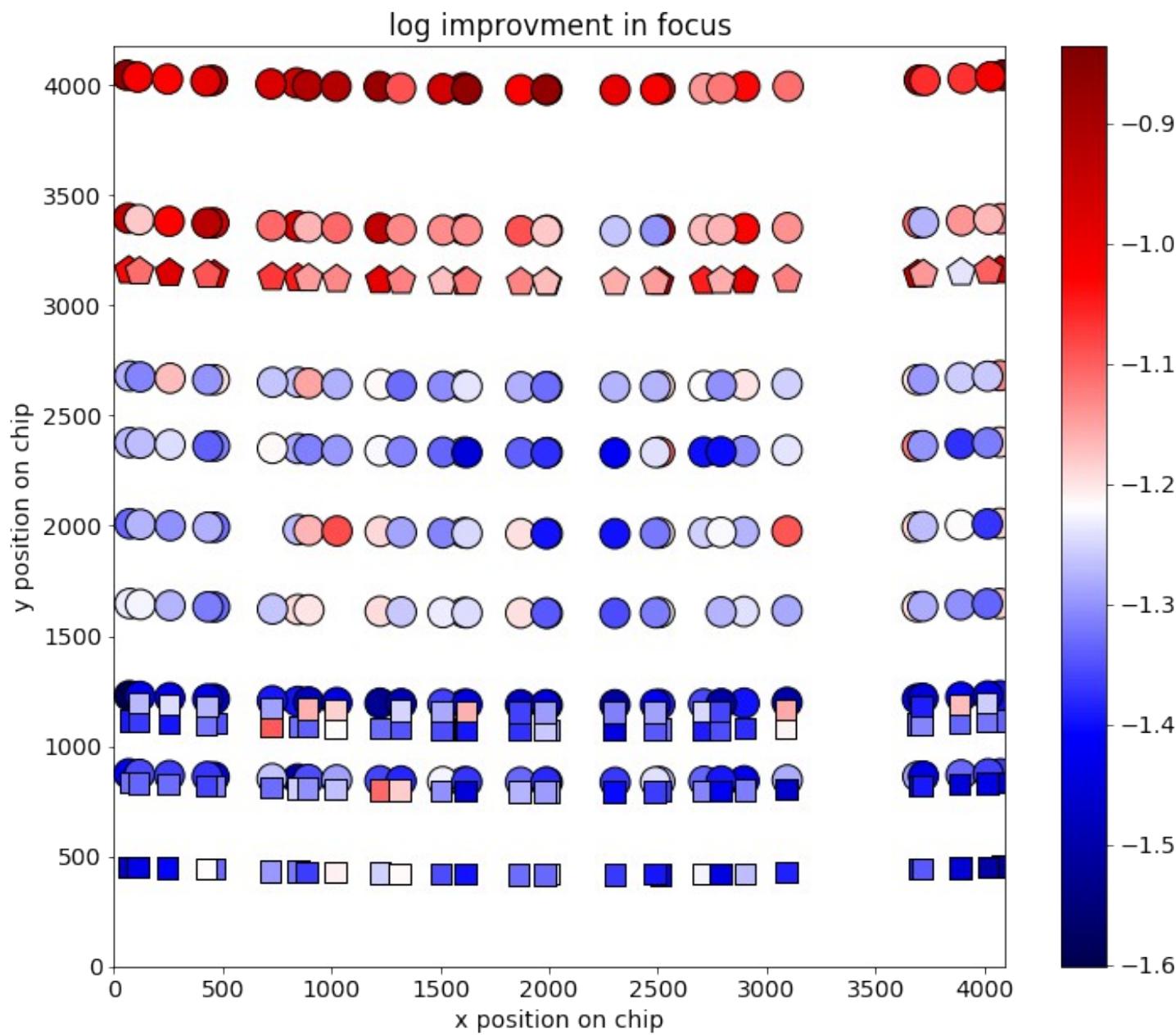
- Example
- Fiber, wavelength
- Full spectrum with all lines
- Shaded region shows the region of interest
- Zoom in on the region of interest. Red shows the data, dashed after subtraction of spots dotted after continuum subtraction as well.
- Zoom in on the region of interest, on the subtracted spectrum. The gray line shows $\pm 1\%$ of the data.
- 2d images of the region of interest. Left: original data, middle after spot subtraction, right after cont sub as well. Scaled to 10% of original image.



Problems – re



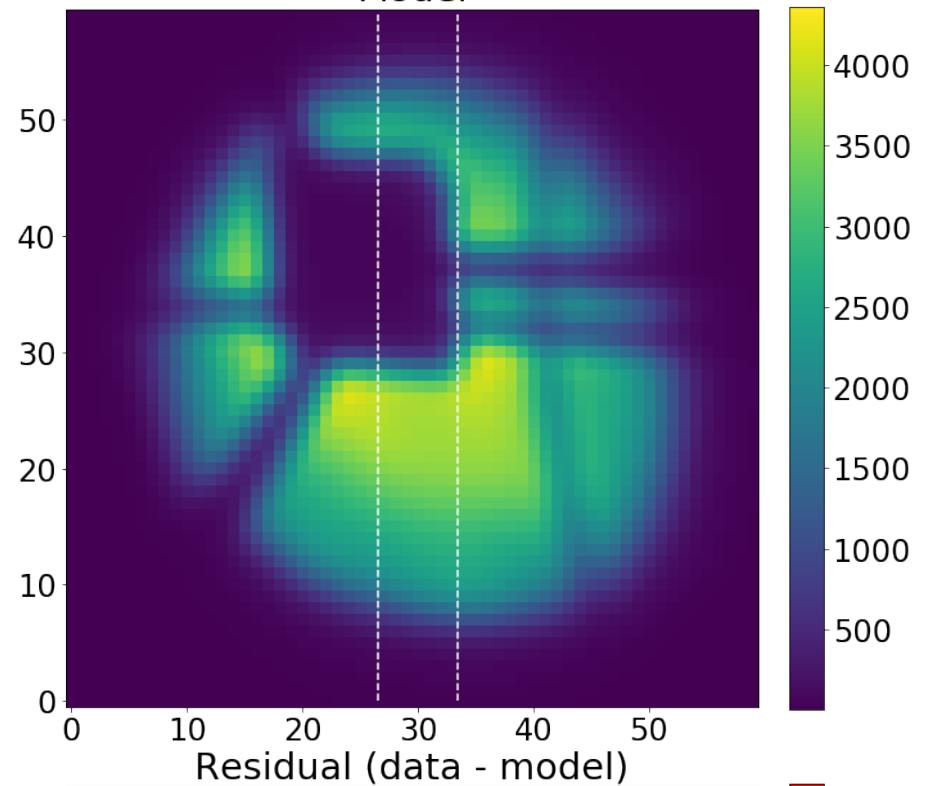
Problems in red



Measure of the quality of the fit, for images in focus

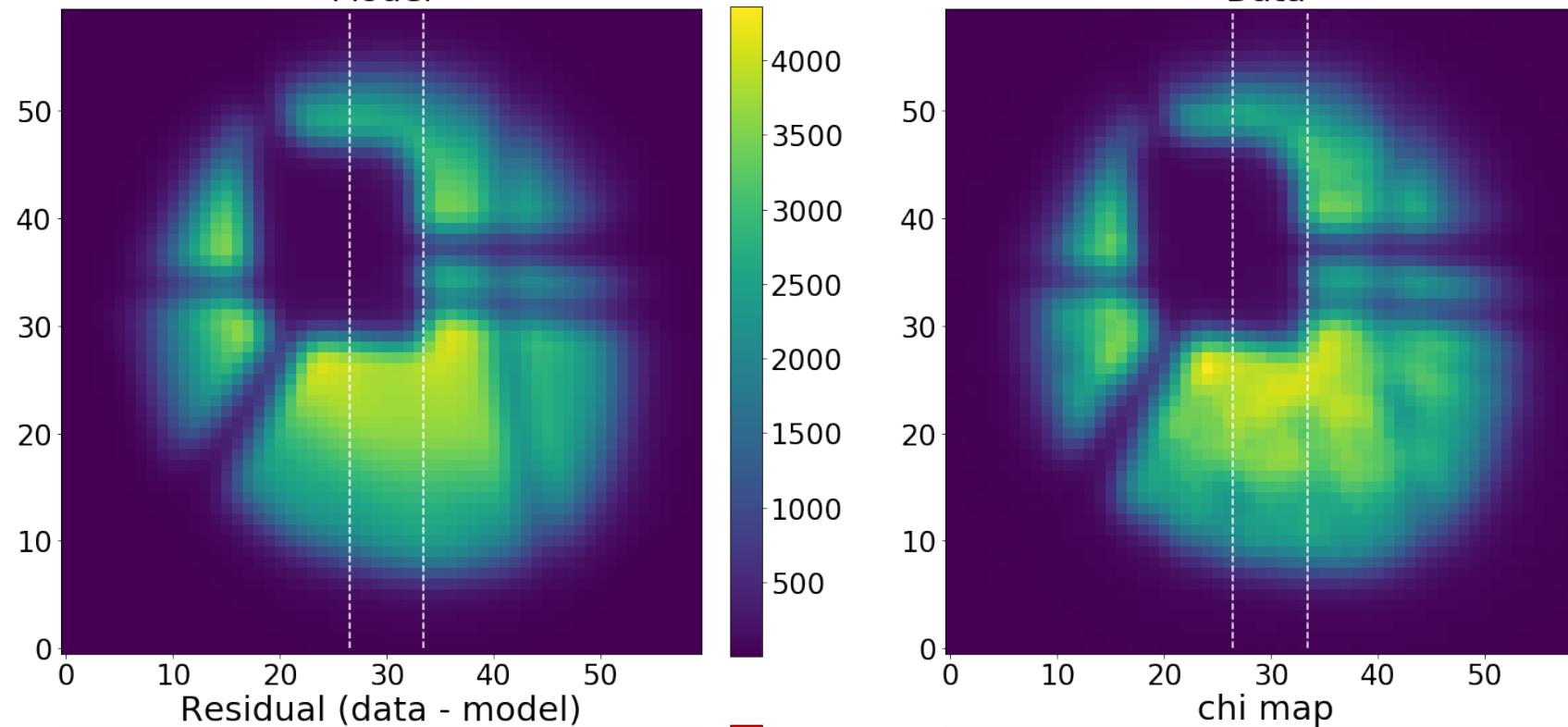
Clearly worse fits for images at the top of the detector (redder wavelengths)

Model

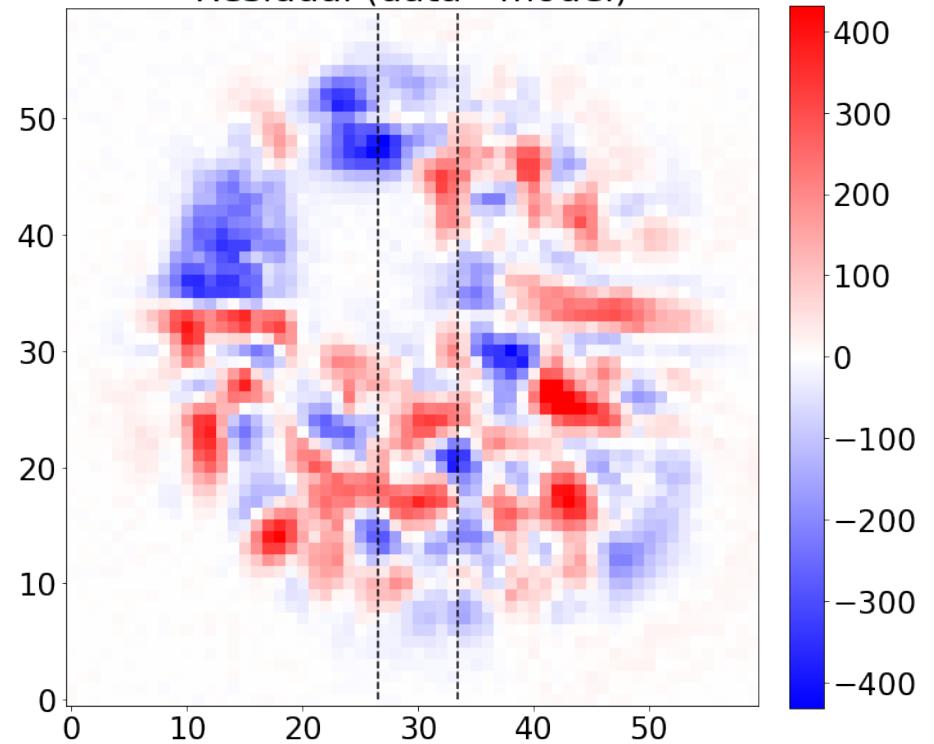


Residual (data - model)

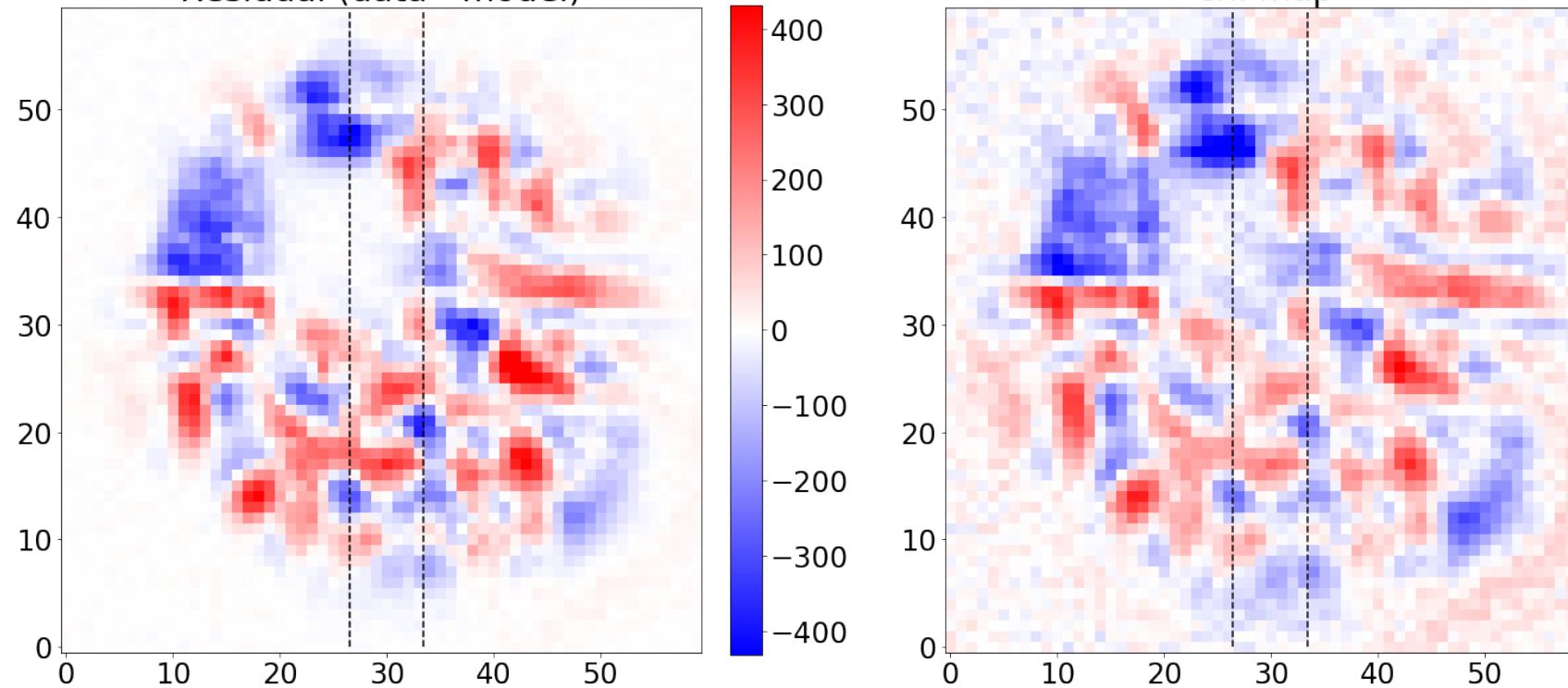
Data



chi map

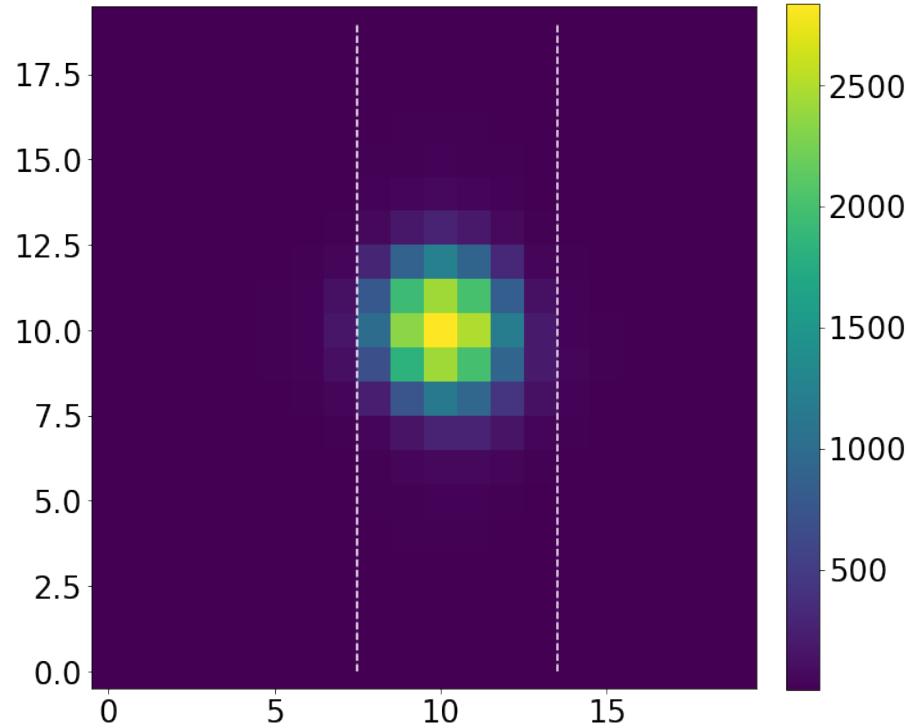


Residual (data - model)

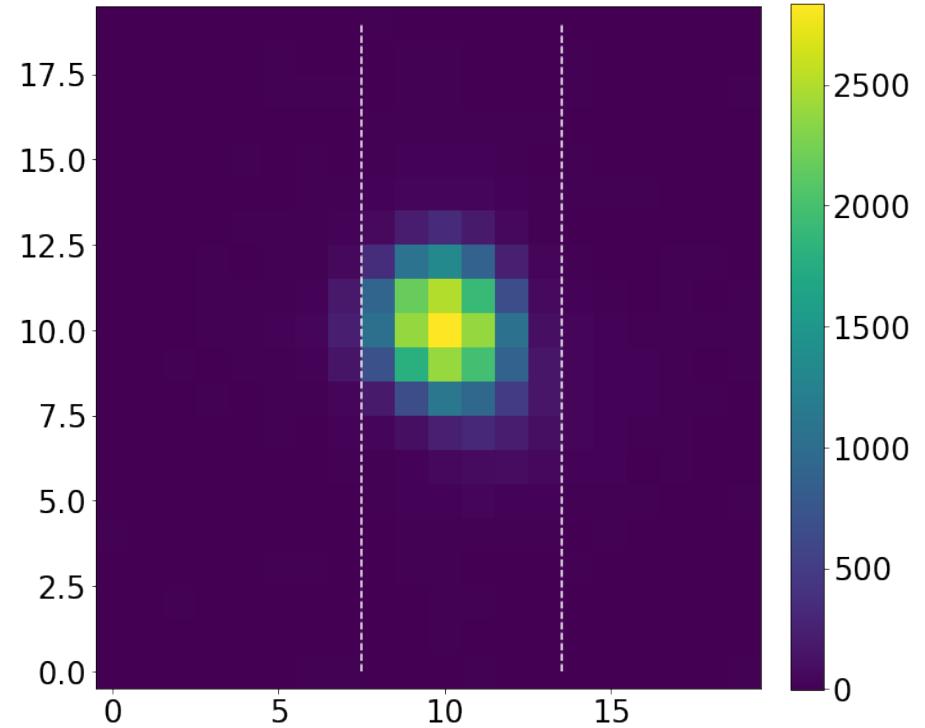


chi map

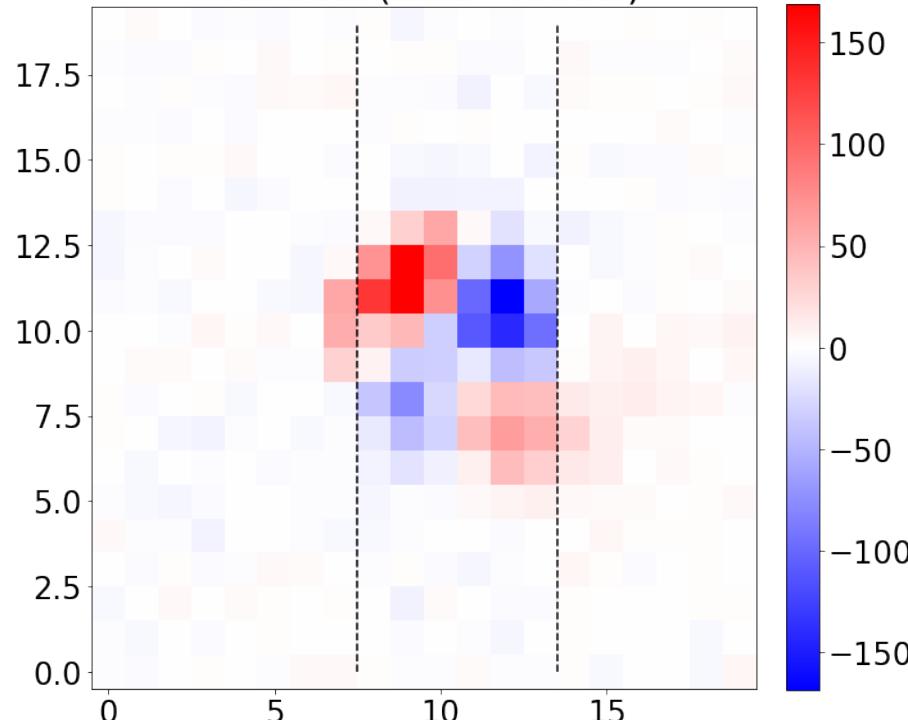
Model



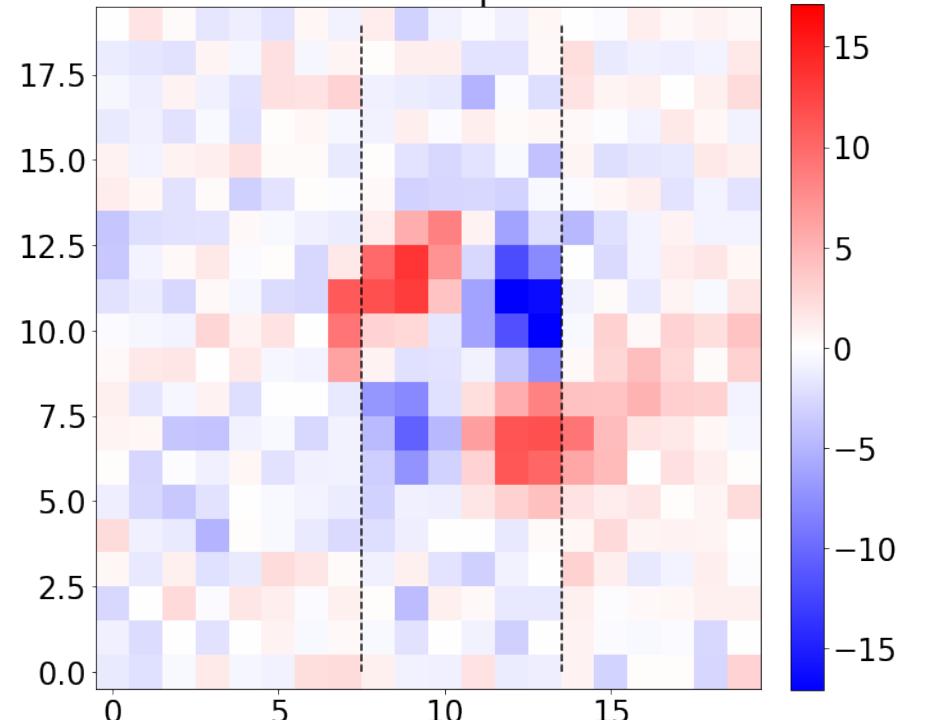
Data



Residual (data - model)

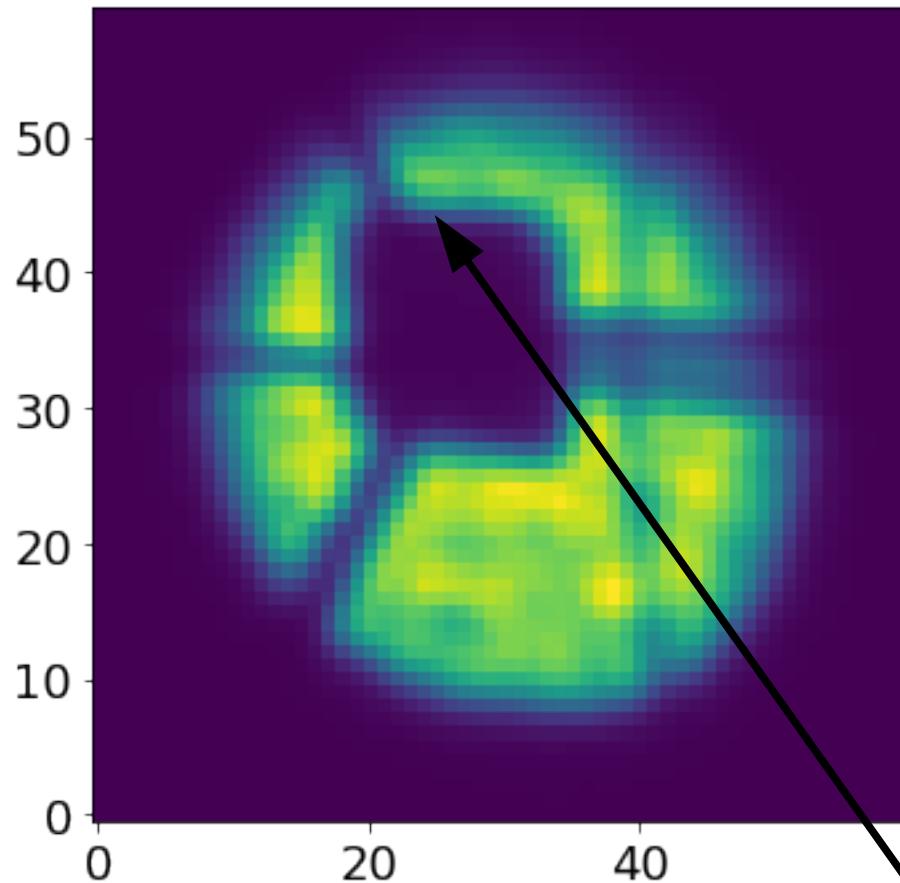


chi map

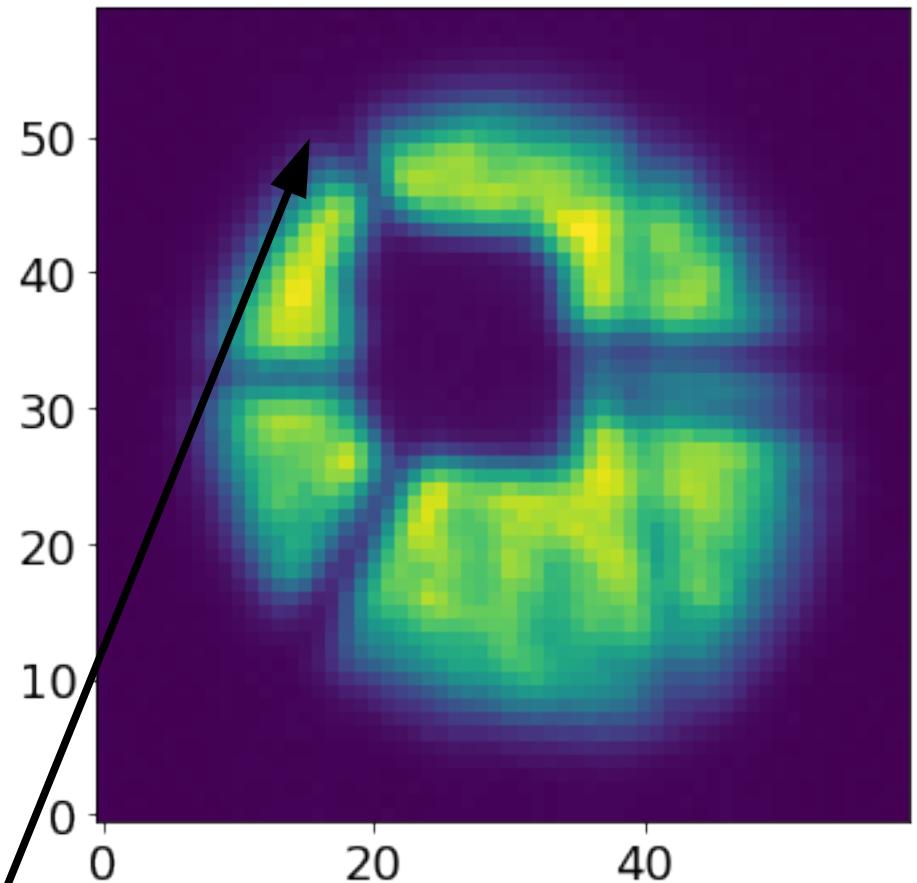


Problems in red

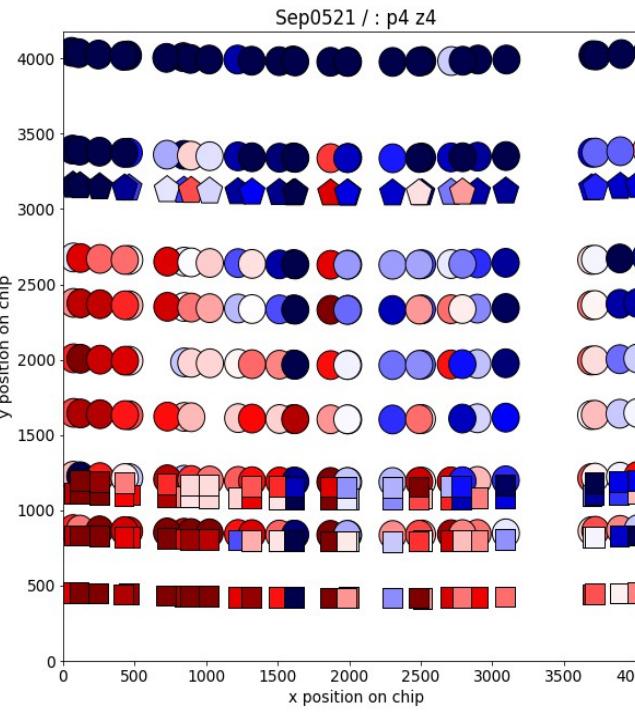
SM1



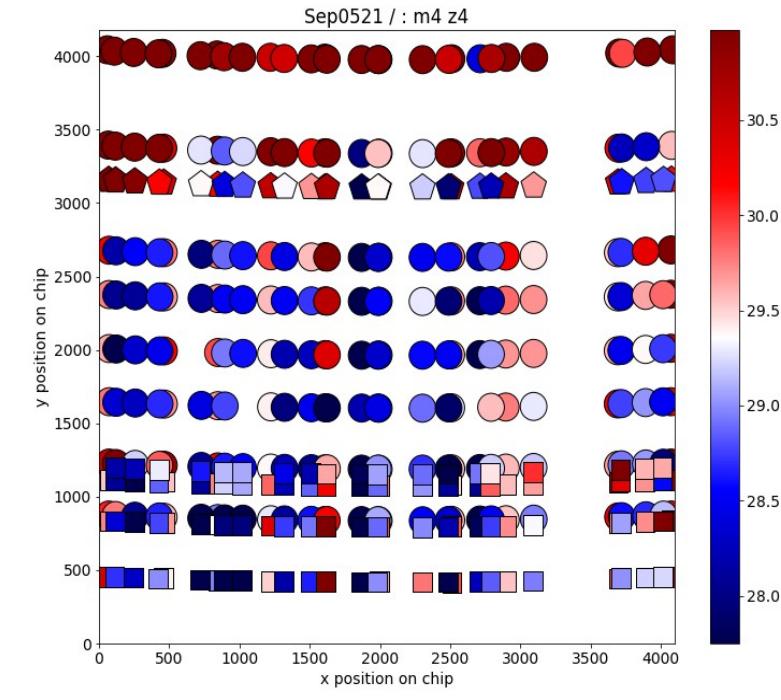
SM2



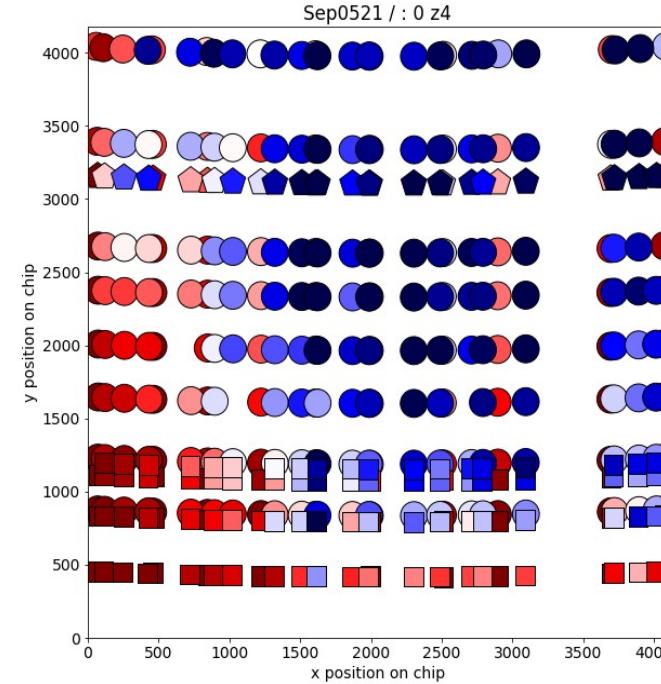
- Soon – data from spectrograph modules 2 and 3
- Same spot, same defocus, same optics



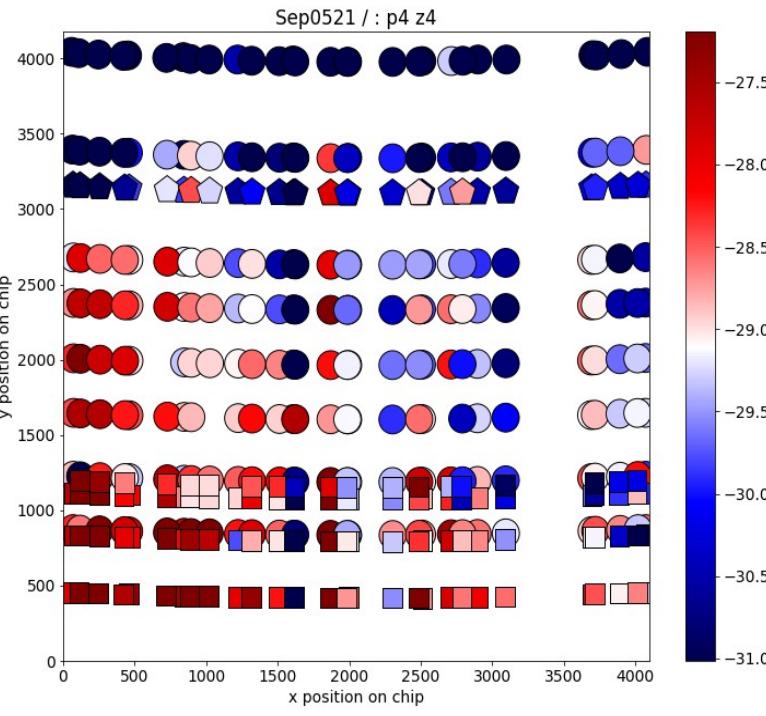
Change of single component (z4, defocus)



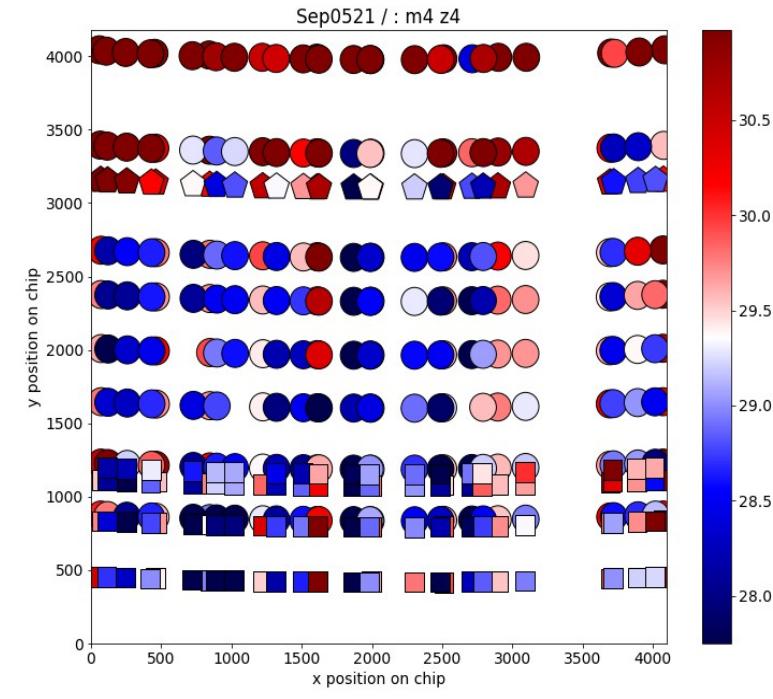
Problem – non continuous solutions



Changing defocus



Change of single component (z4, defocus)



Problem – non continuous solutions

- First step – fit multiple spots in the same fiber, with illumination pattern same in all spots
- Ultimate step - Global solution of Zernike parameters across the whole detector plane

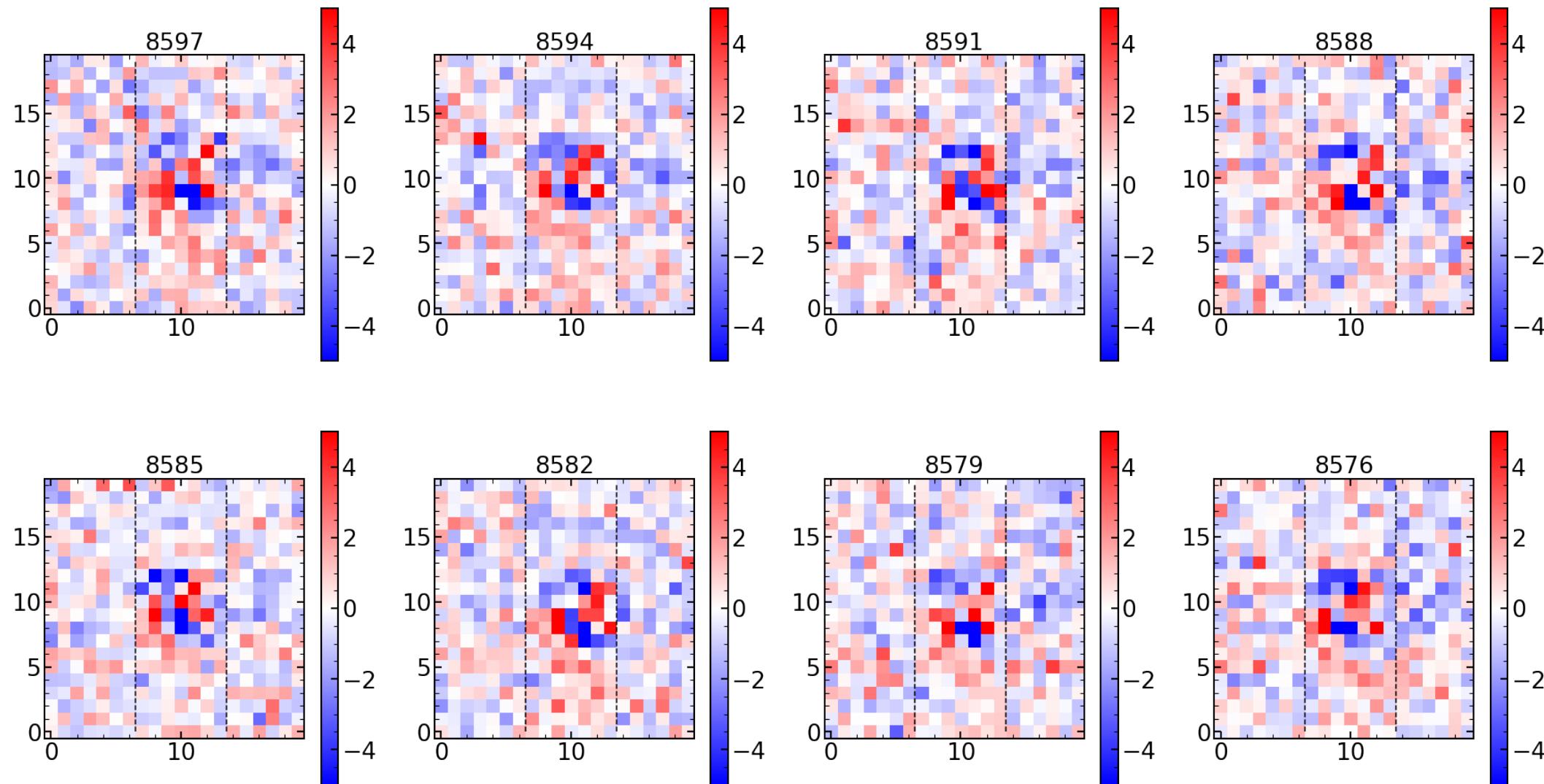
Summary

- 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/

Extra slides

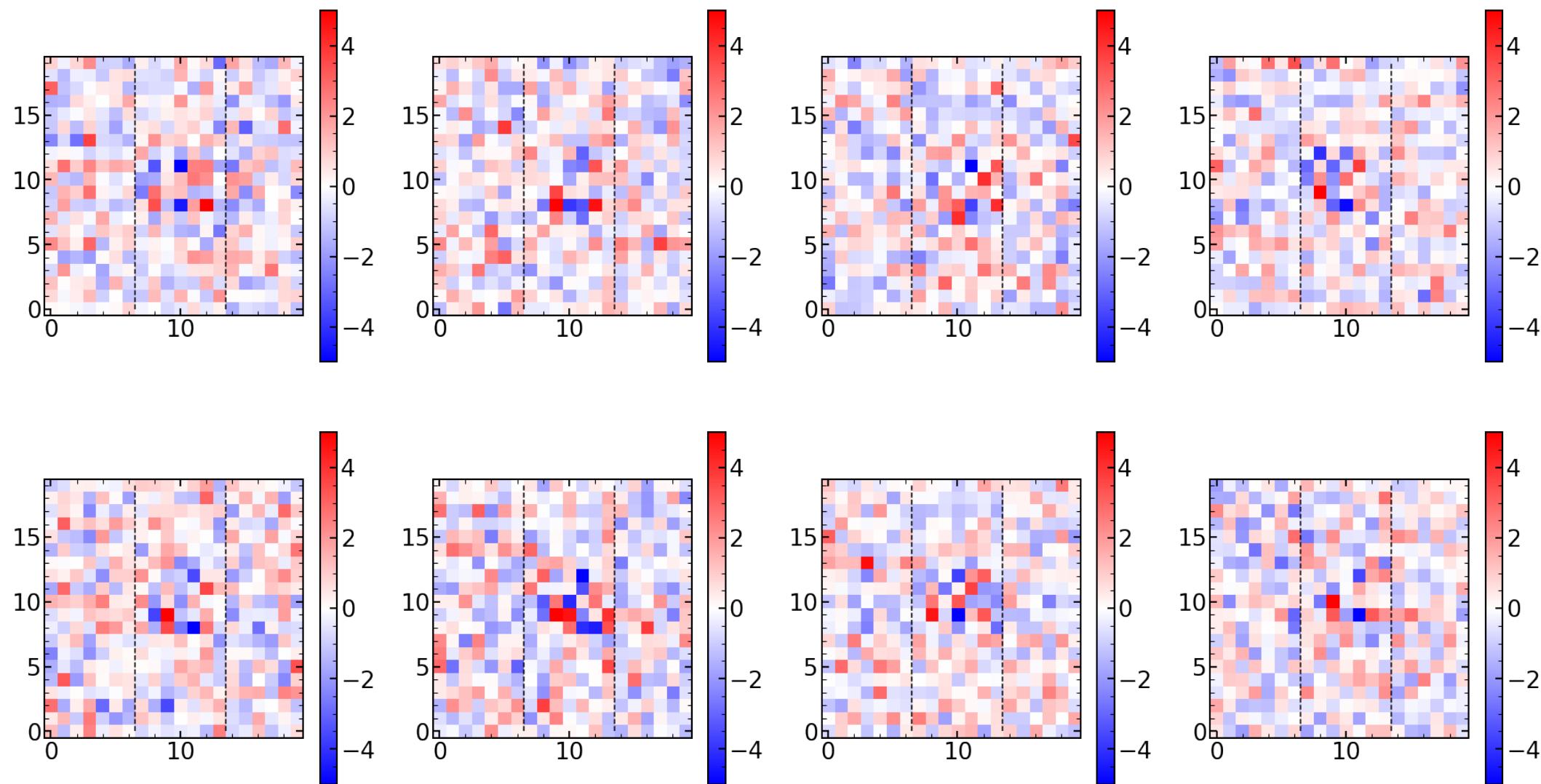
Residuals in the focused data, 8 different dithering positions

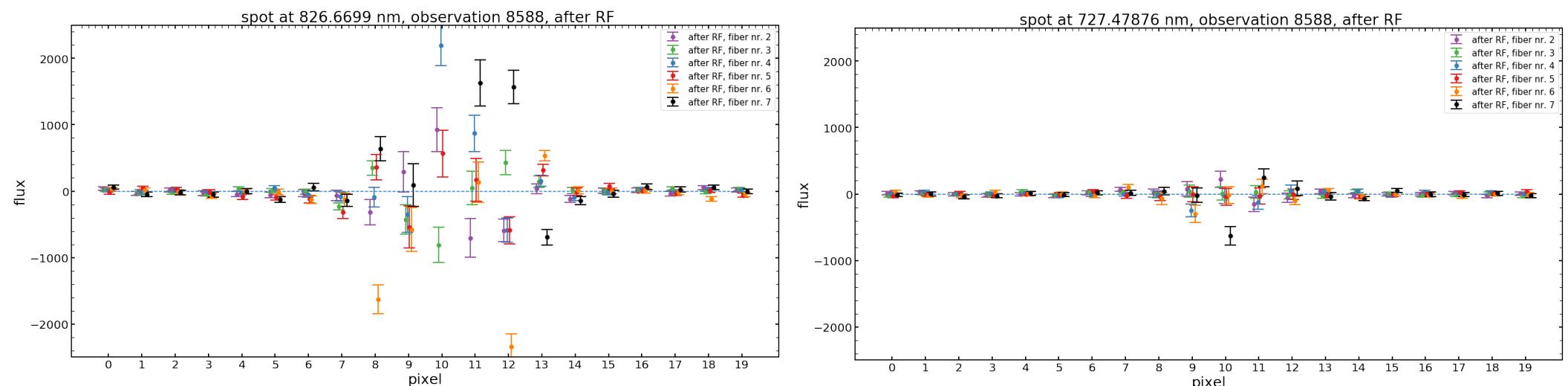
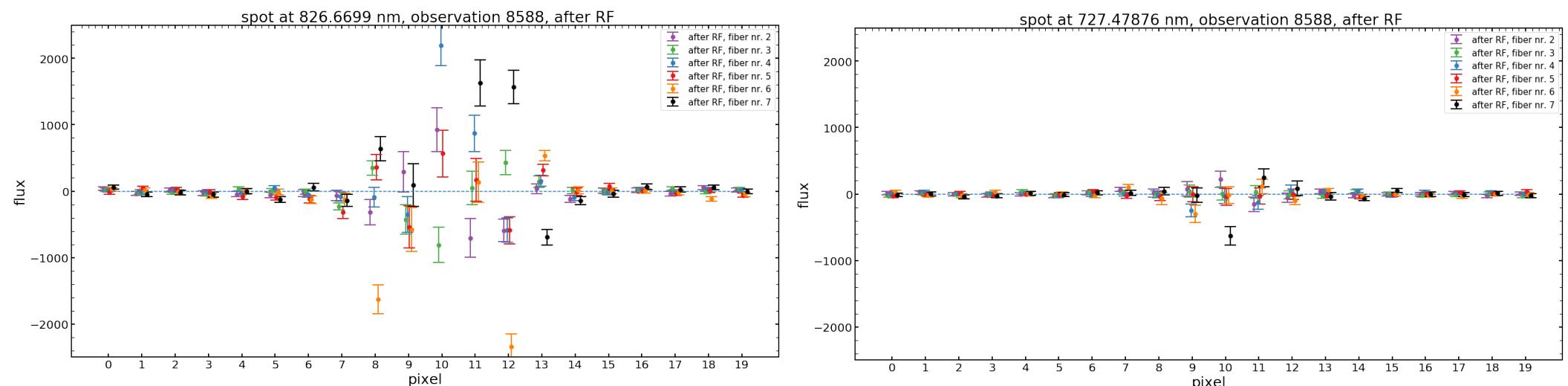
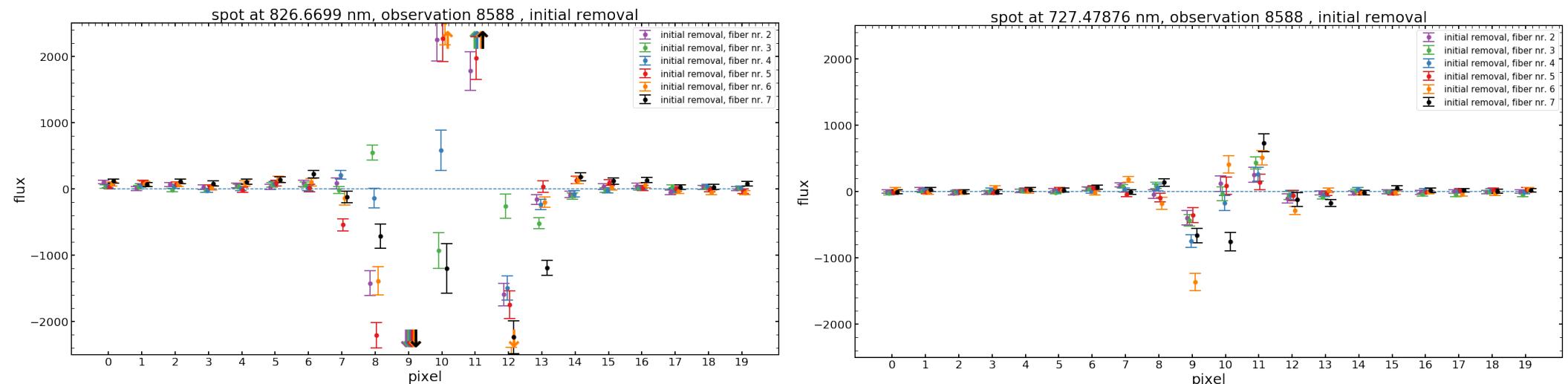
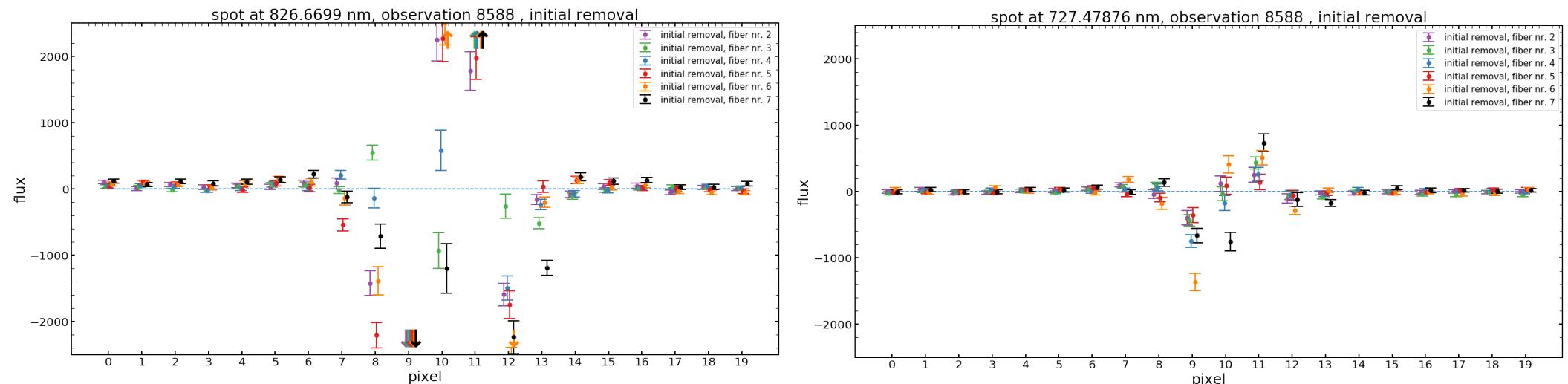
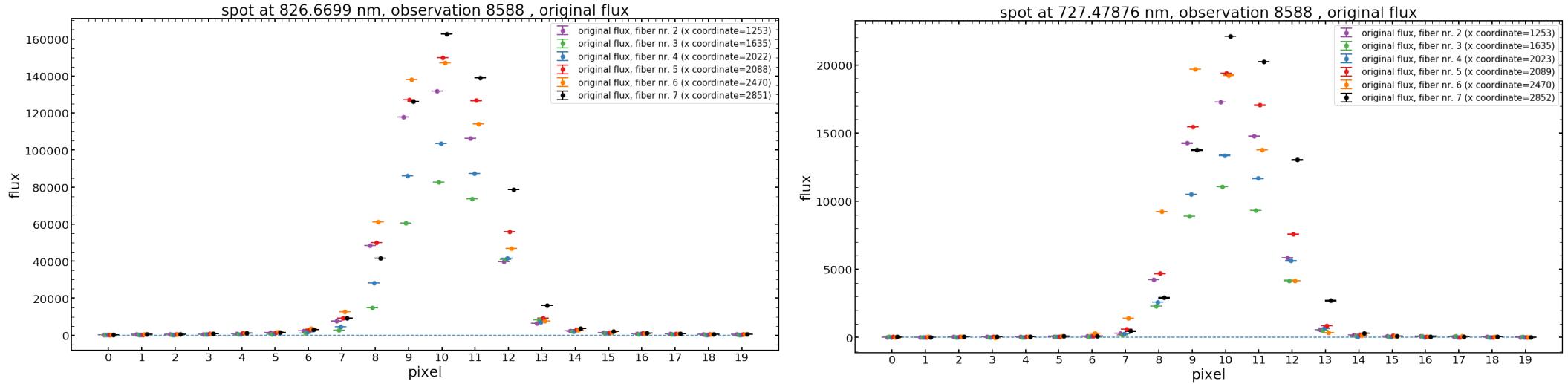
Residuals, up to Zernike 22 and Jan 15 modifications to centering



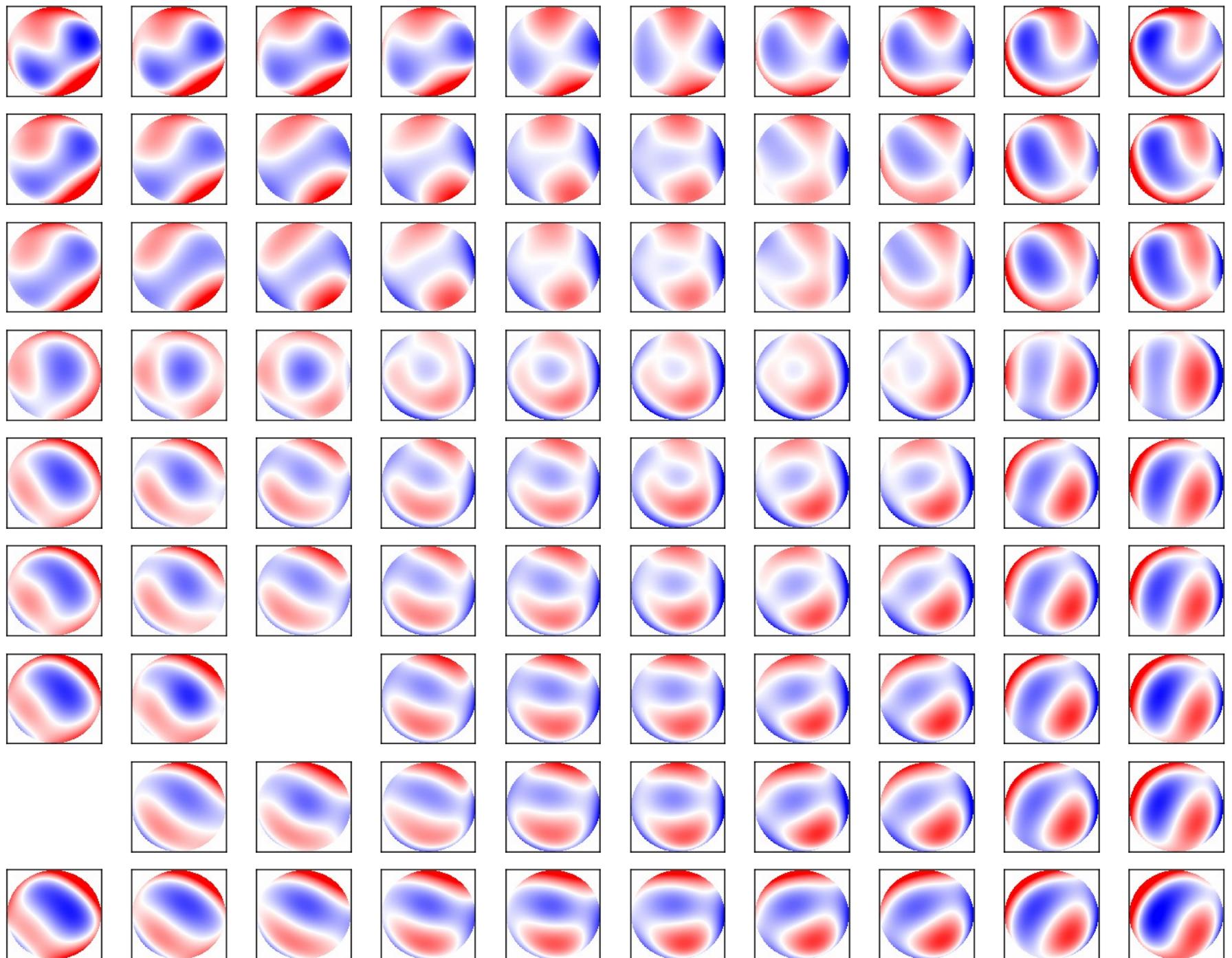
Residuals in the focused data, 8 different dithering positions, after Random forest cleaning applied

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

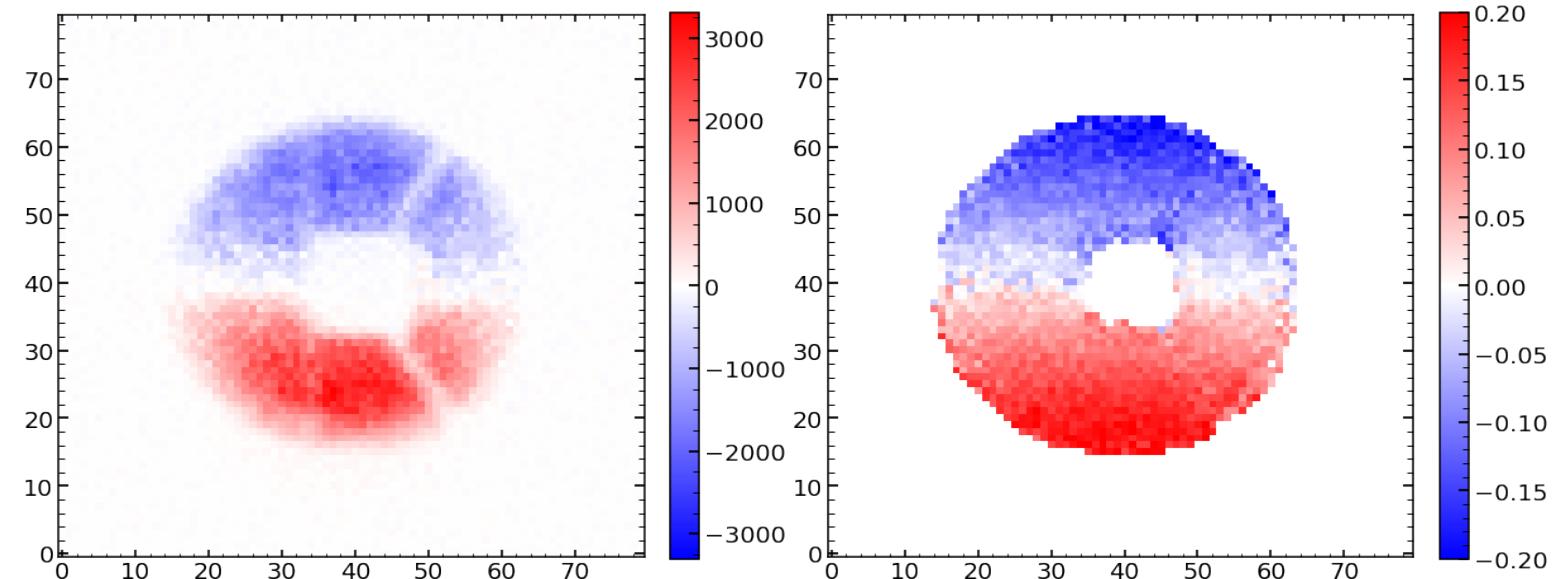
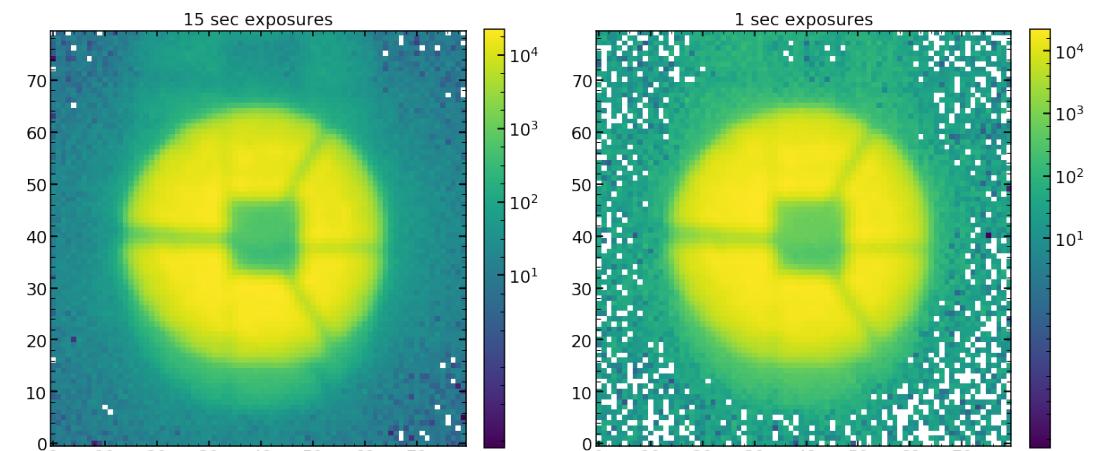
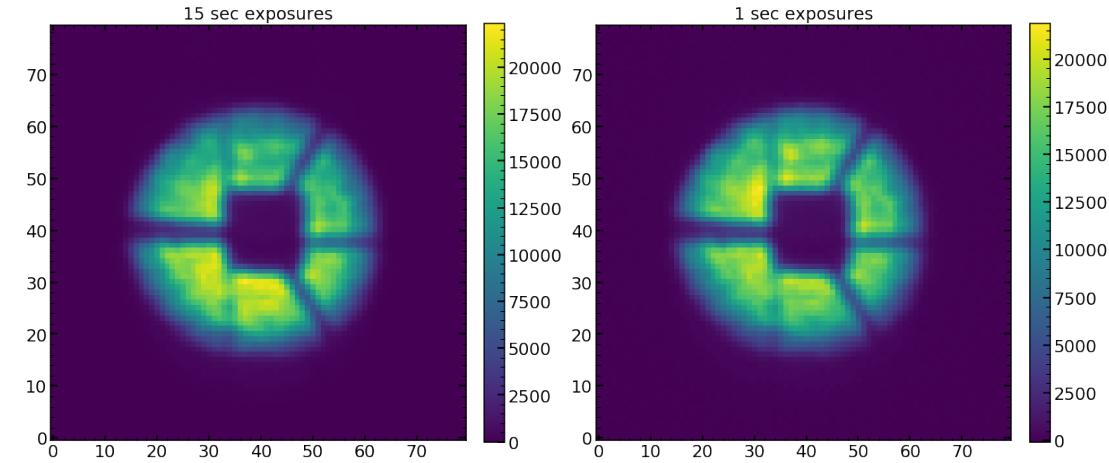




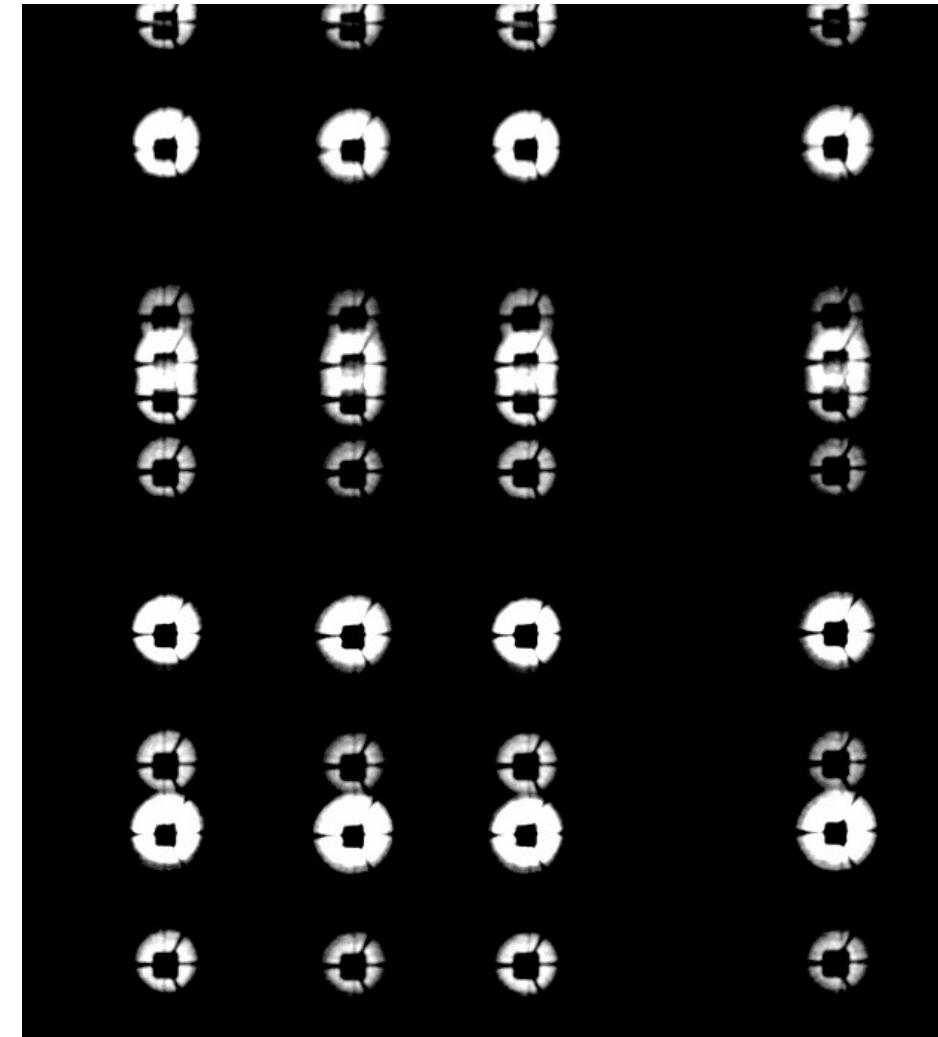
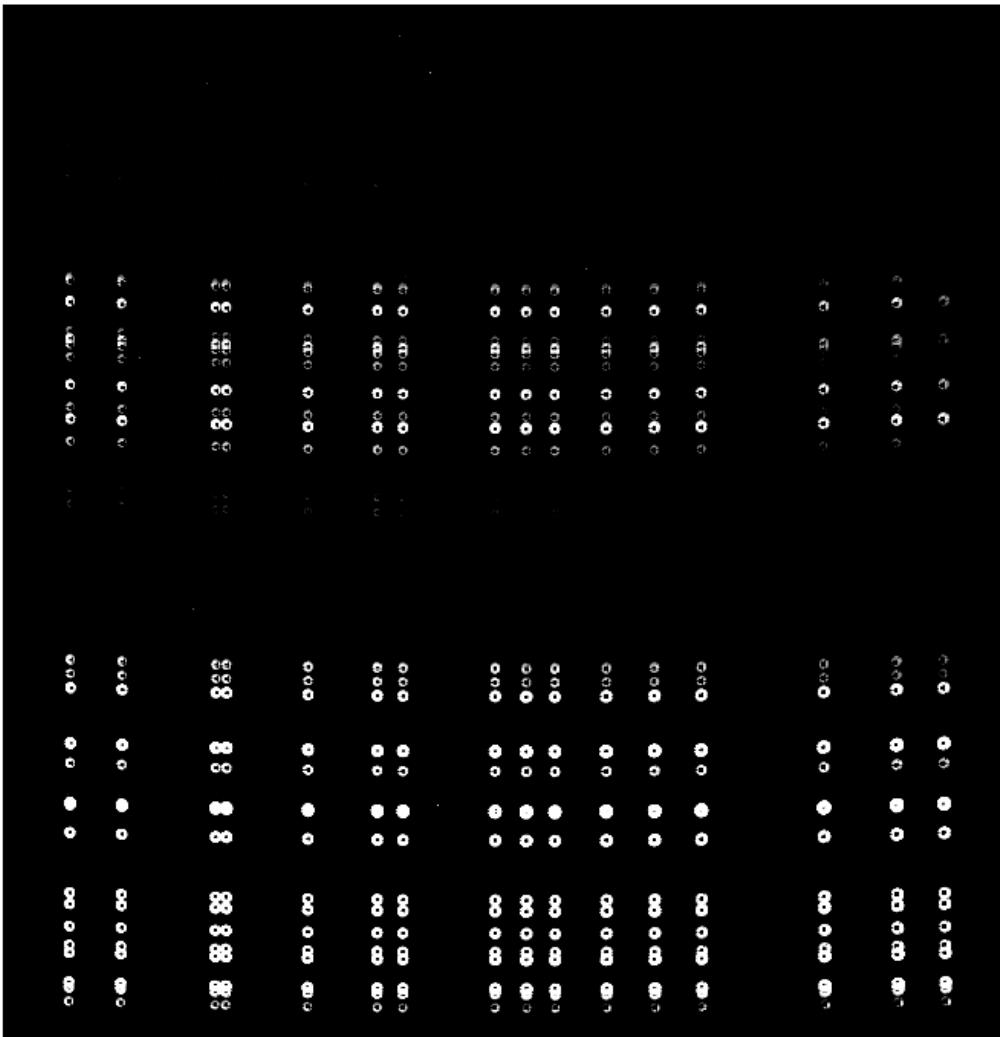
wavefront



Shutter and flux control



Selected topics – Overlap of spots



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

Parameter fitting

