AuxTel flats for spectroscopy

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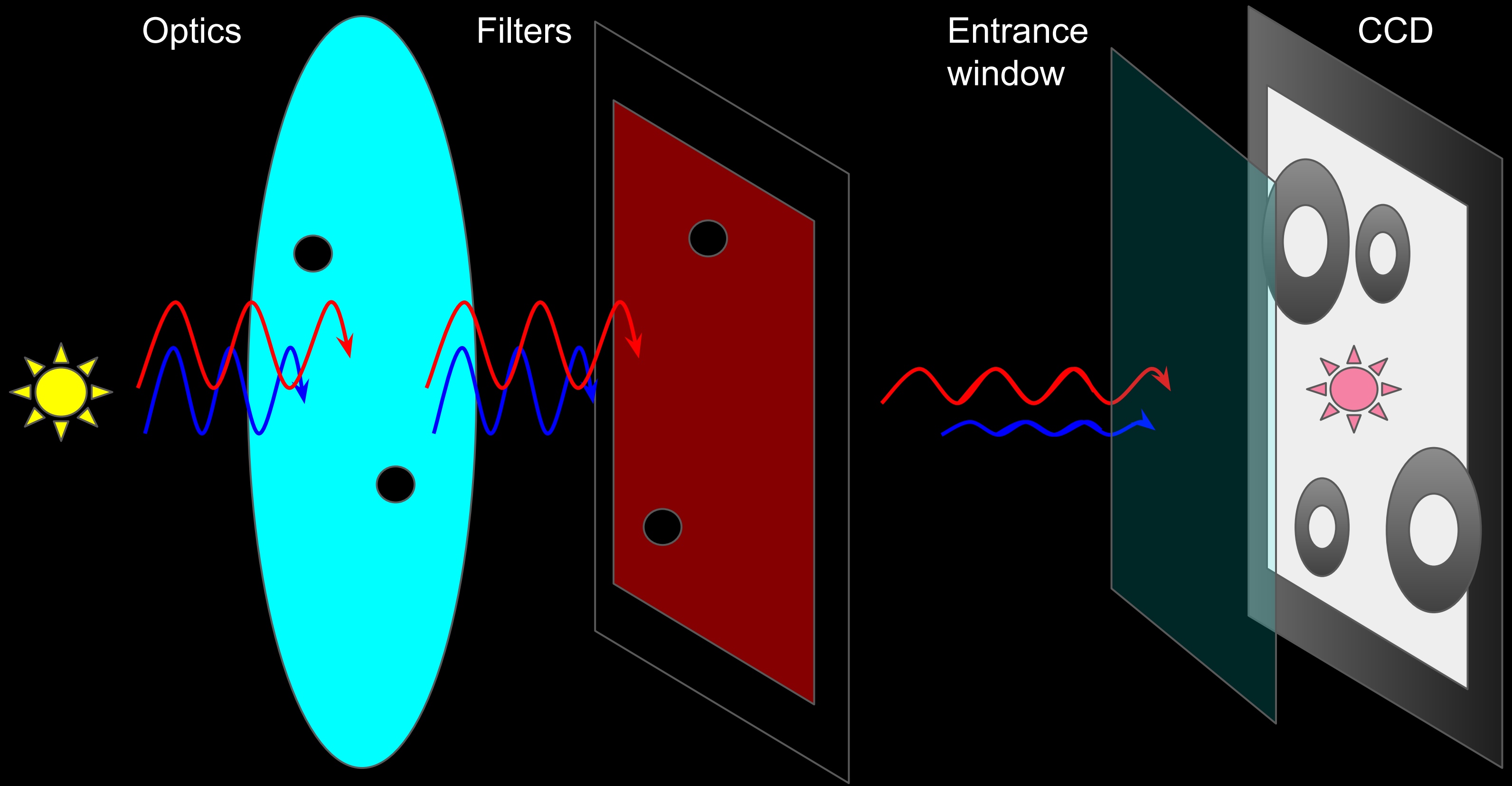
LSST-France meeting

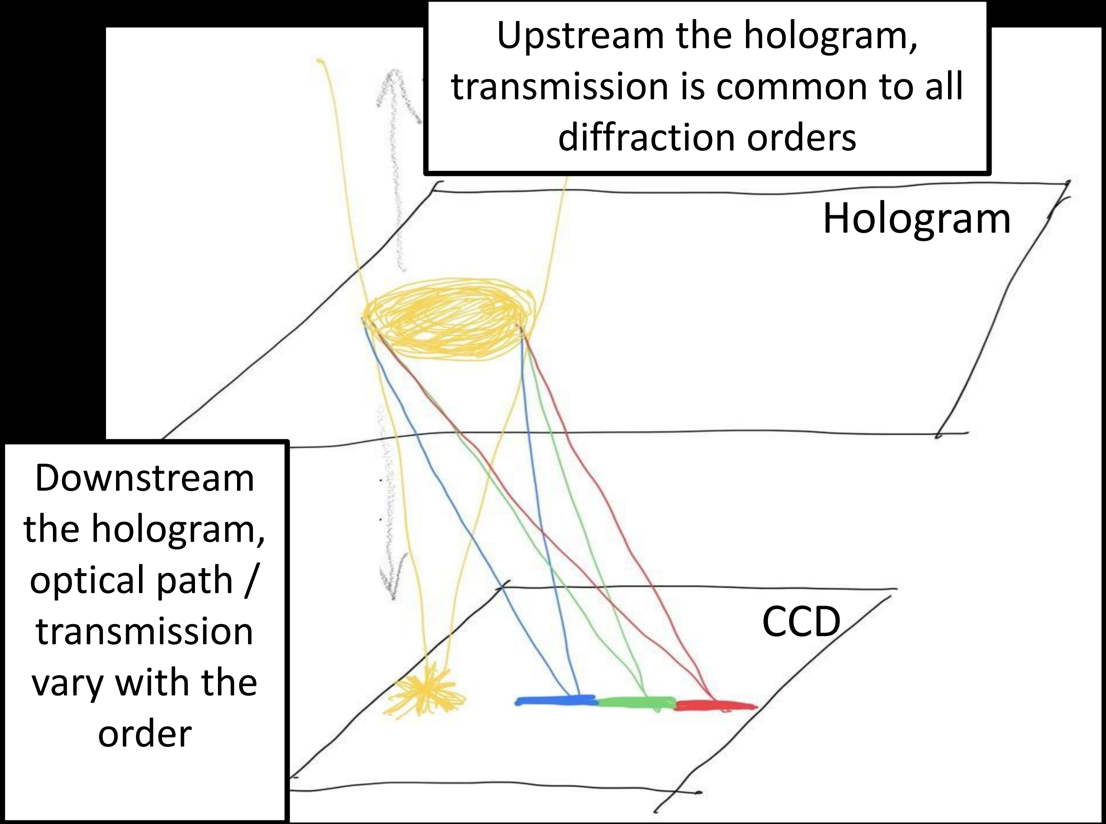
Main goals

- Obtain special master flats for spectroscopy
  - Different requirements from photometric case
  - We want to keep pixel-to-pixel variations (high frequency) while removing large-scale variations (low frequency)
  - Develop methodology to achieve this
- Show that the wavelength dependence of the flats can be factored out from the spatial dependence
  - Each part (wavelength) of the spectrum would need a flat taken at that wavelength
  - If flat values depend separately on spatial coordinates (x,y) and on wavelength (λ), we can use a single filter flat for full spectrum

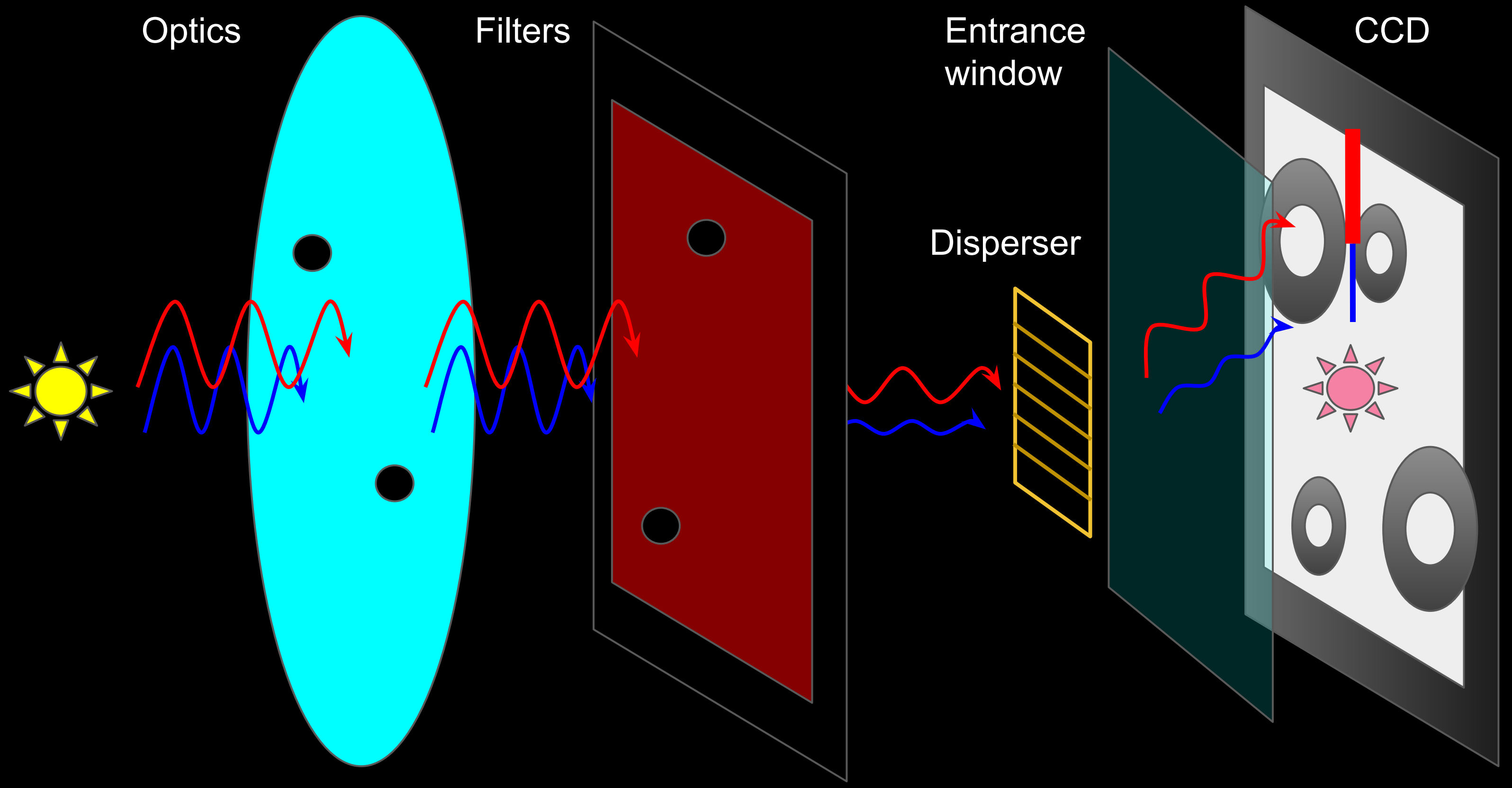
Flat-fielding in photometry



Flat-fielding in spectroscopy



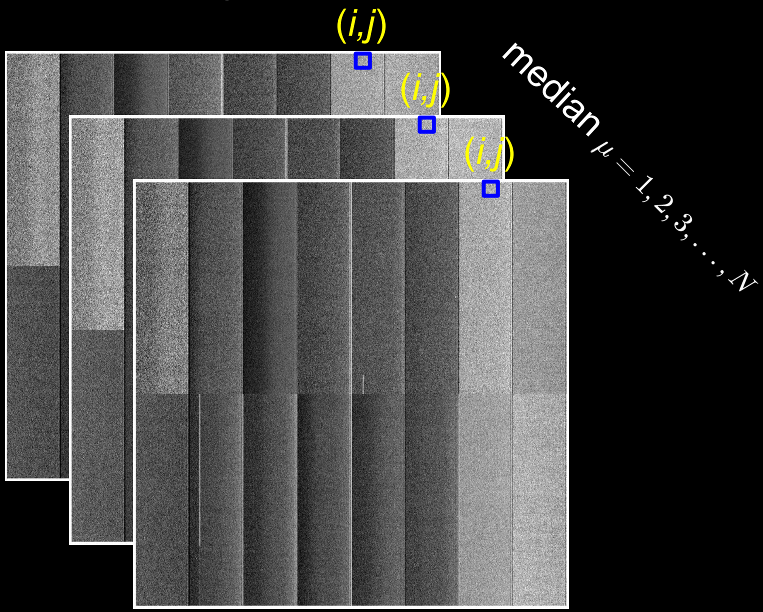
Flat-fielding in spectroscopy

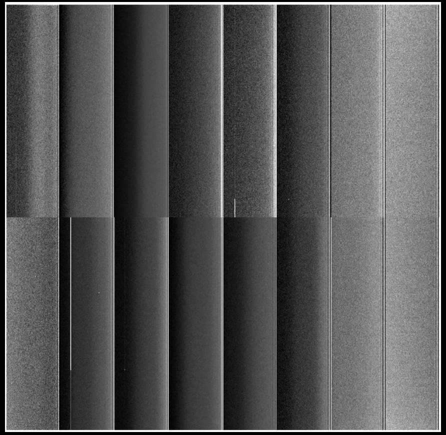


Steps: master bias

- We start with a set of *N* bias images: $B^{(\mu)}(i,j)\,(\,\mu = 1, 2, 3, \ldots, N\,)$
- We create the **master bias,** $\mathcal{B}$, such that the pixel (*i,j*) is the **median** of the *N* images at the same pixel, that is,

$$\mathcal{B}\;\Big|\;\mathcal{B}(i,j) = median_{\mu}\left(B^{(\mu)}(i,j)\right)$$





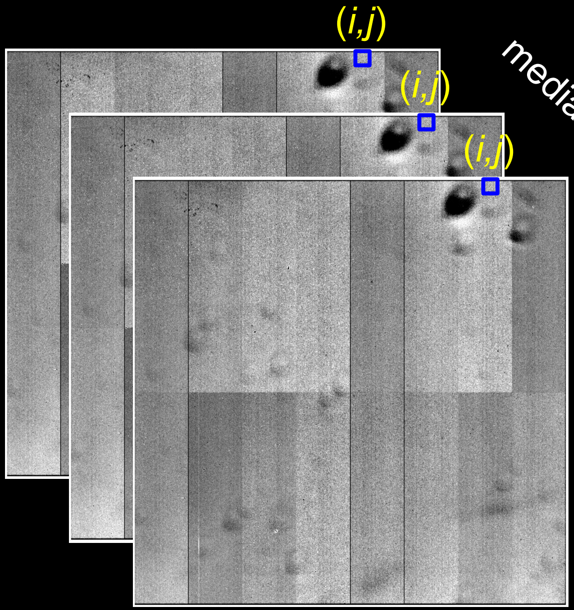
Steps: master flats

- We start with a set of *N* flat images with a given filter *b* (FELH0600, BG40, SDSSg): $F_b^{(\mu)}(i,j)\,(\mu = 1,2,3,\ldots,N)$, where $F_b^{(\mu)}(i,j) = F_b^{(\mu)}(i,j) - \mathcal{B}(i,j)$

$$med^{(\mu)} = median_{(i,j)}\left(F_b^{(\mu)}\right) \;\Big|\; F_b^{(\mu)}(i,j) \;\rightarrow\; F_b'^{(\mu)}(i,j) = \frac{F_b^{(\mu)}(i,j)}{med^{(\mu)}}$$

Steps: master flats

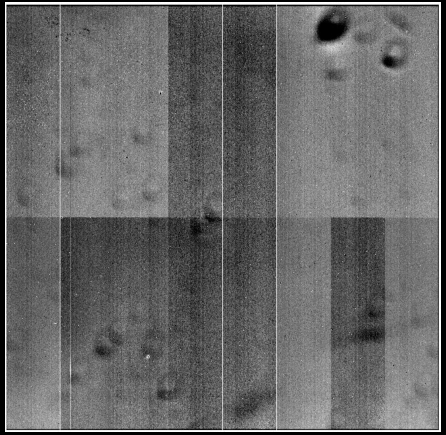
- We start with a set of *N* flat images with a given filter *b* (FELH0600, BG40, SDSSg): $F_b^{(\mu)}(i,j)\,(\mu = 1,2,3,\ldots,N)$, where $F_b^{(\mu)}(i,j) = F_b^{(\mu)}(i,j) - \mathcal{B}(i,j)$
- We take the **median over all pixels** for each image and **normalise** by it: $F_b'^{(\mu)}$



median $_{\mu = 1,2,3,\ldots,N}$

“Master flat”

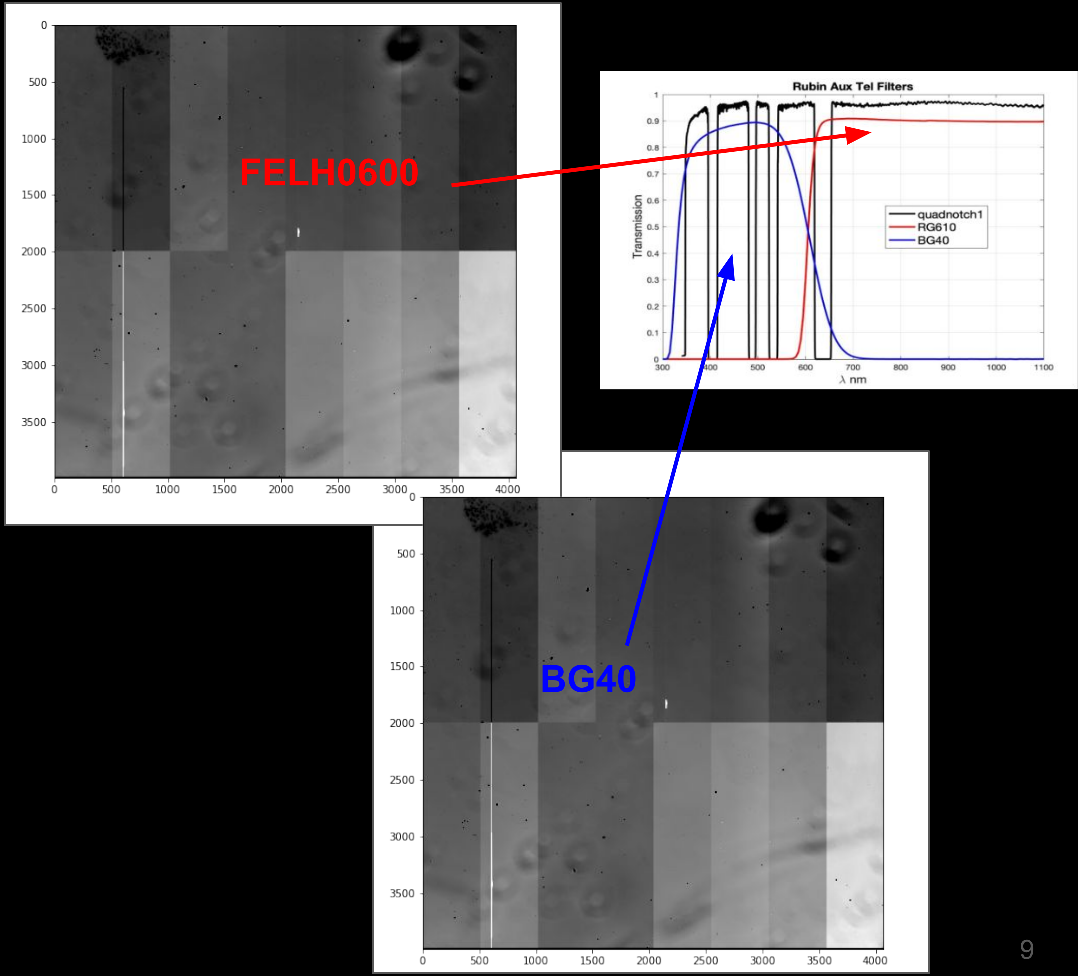
- We take the **median** over the *N* $F_b'^{(\mu)}$ flats at each pixel (*i,j*): $\tilde{F}_b$ | $\tilde{F}_b(i,j) = median_\mu\left(F_b'^{(\mu)}(i,j)\right)$



Steps: master flats

- There are two different components on the signal:
  - **Electronics** (which we want to keep) **+ dust on CCD** (focused artifacts)
  - **Smooth gradients** (vignetting) and **extended effects** (dust and out of focus artifacts)

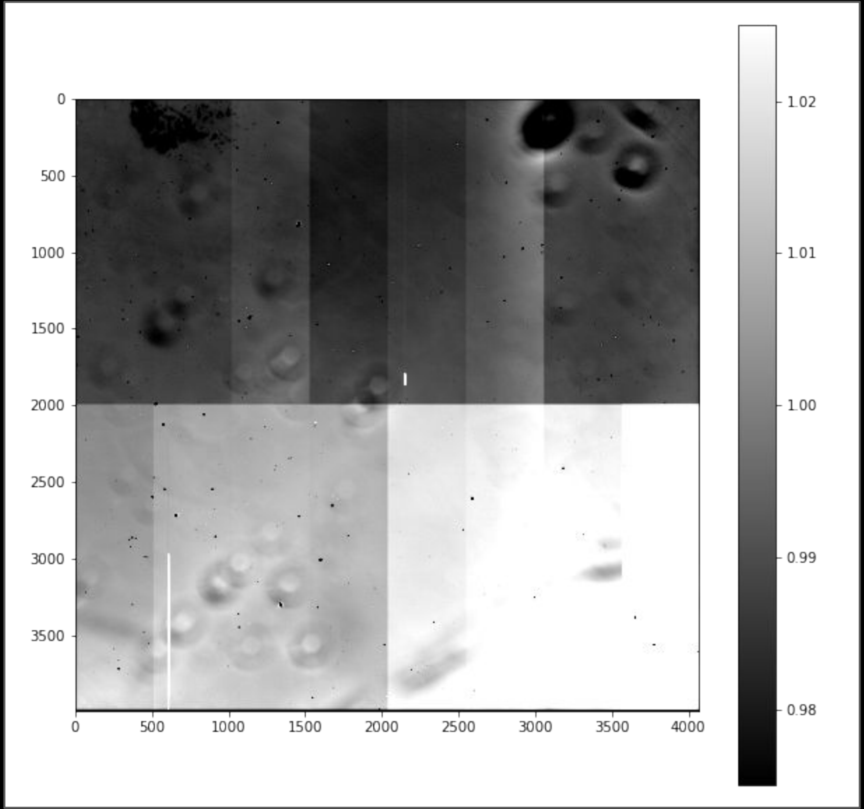
To capture the smooth / extended components, we apply a **median spatial filter** (window of 40x40 pixels)

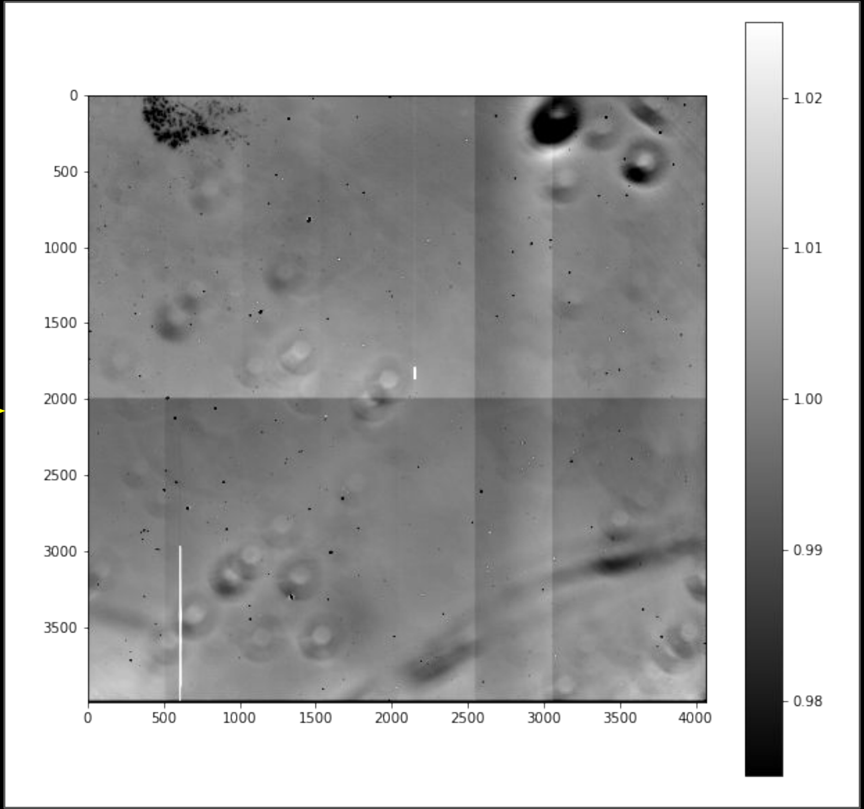


Steps: master flats

- Smoothing:
  - We normalise each segment by their median value (for security, we reject points higher/lower than $\pm 0.5\sigma$)

Steps: master flats

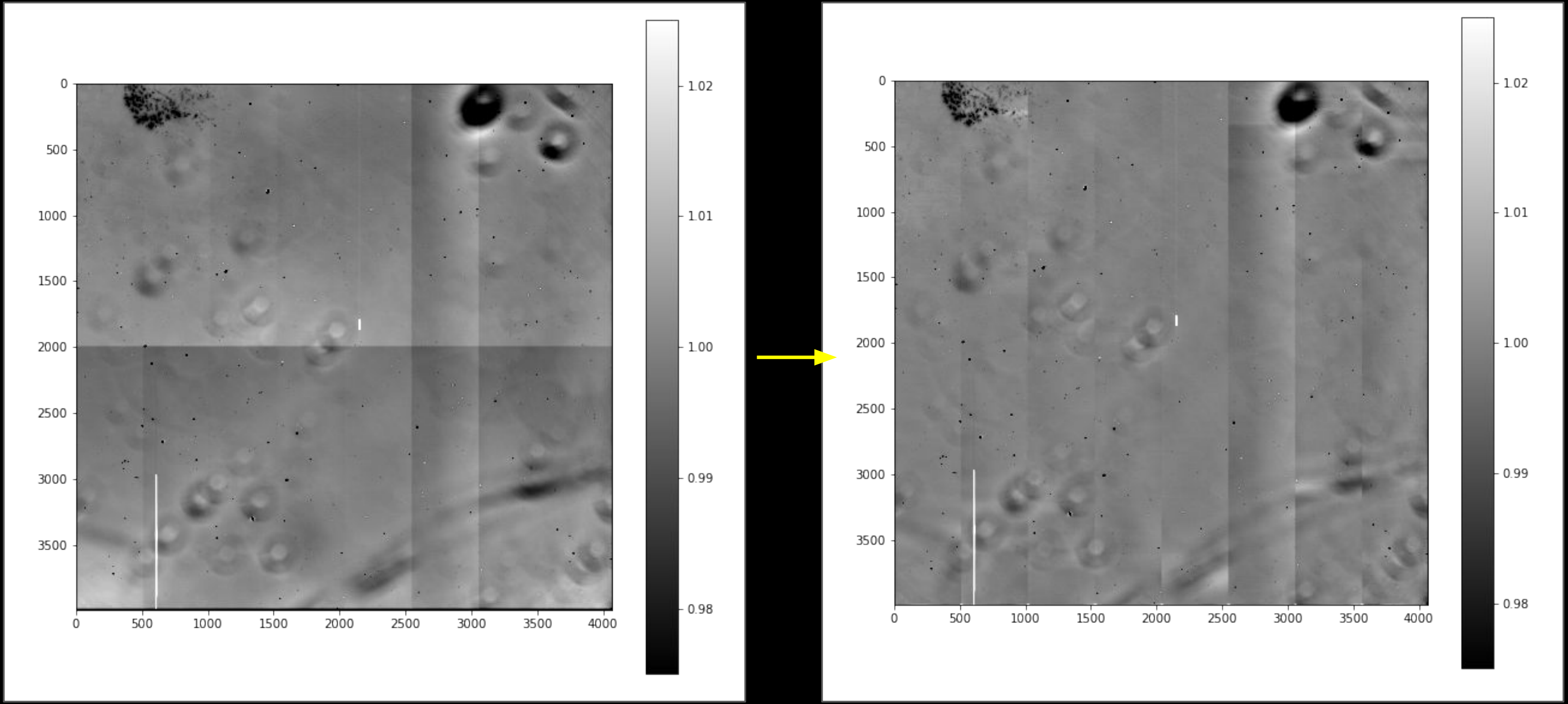




Steps: master flats

- Smoothing:
  - We normalise each segment by their median value (for security, we reject points higher/lower than $\pm 0.5\sigma$)
  - We observe a vertical (also a horizontal) gradient in the upper and lower segments
    - These large-scale variations do not seem to be due to out-of-focus artifacts, but due to electronics
    - We want to remove them while preserving the rest of the large scale variations
    - First approach: divide each row by their median value
      - This removes the gradient but presents some projection issues
      - Work in progress to improve this method (using a fit to the median value per row)

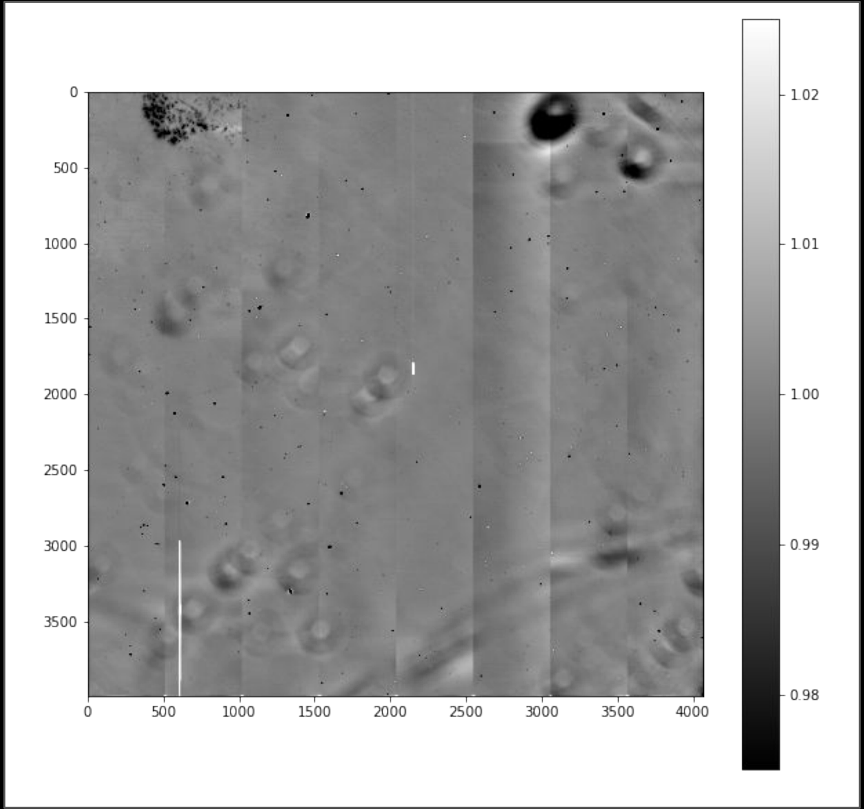
Steps: master flats

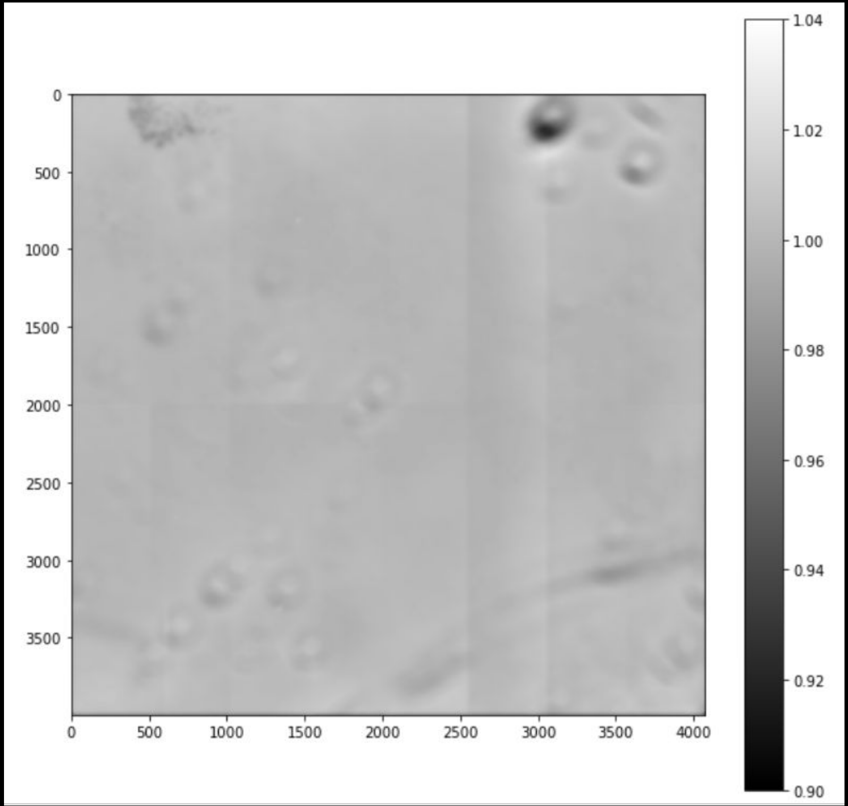


Steps: master flats

- Smoothing:
  - We normalise each segment by their median value (for security, we reject points higher/lower than $\pm 0.5\sigma$)
  - We observe a vertical (also a horizontal) gradient in the upper and lower segments
    - These large-scale variations do not seem to be due to out-of-focus artifacts, but due to electronics
    - We want to remove them while preserving the rest of the large scale variations
    - First approach: divide each row by their median value
      - This removes the gradient but presents some projection issues
      - Work in progress to improve this method (using a fit to the median value per row)
  - After removing the gradient, we apply a median filter with window size 40x40 to the upper and lower segments separately

Steps: master flats



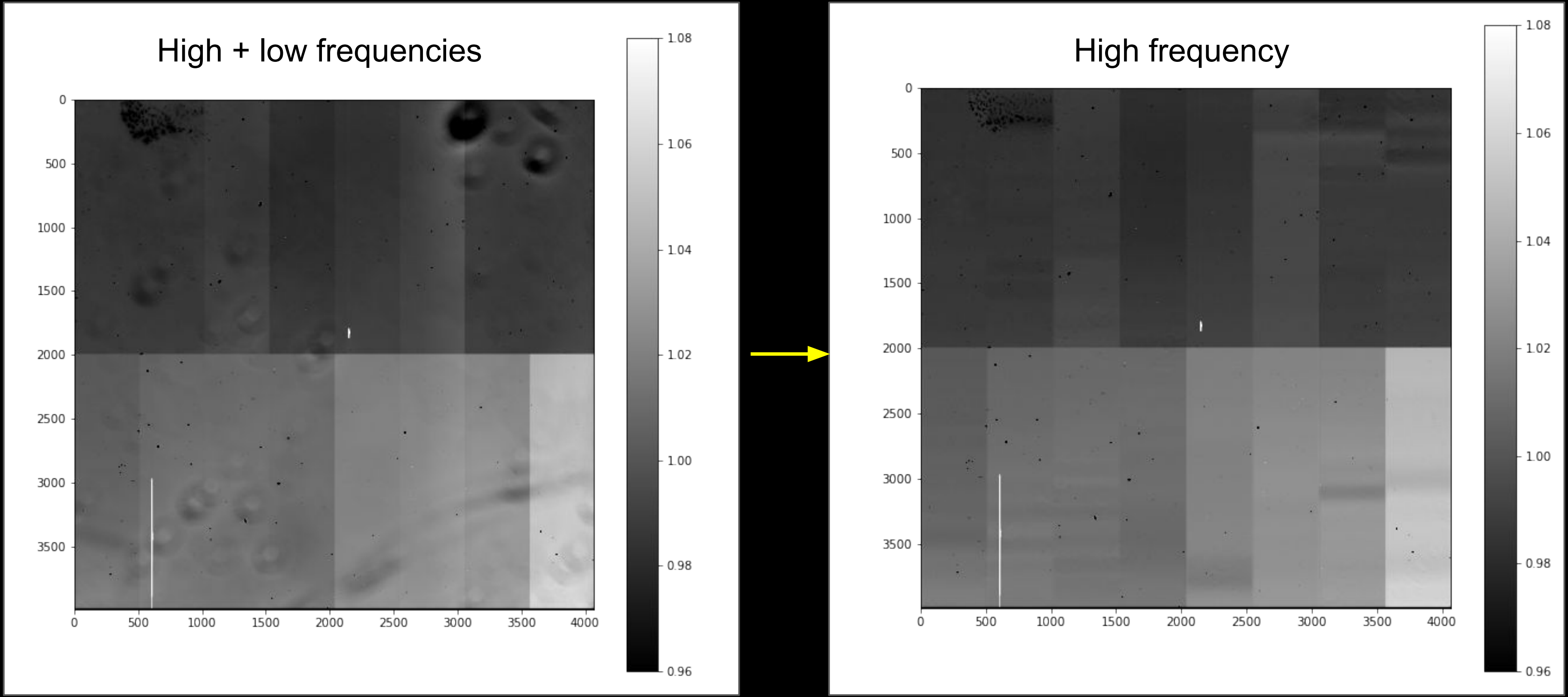


Steps: master flats

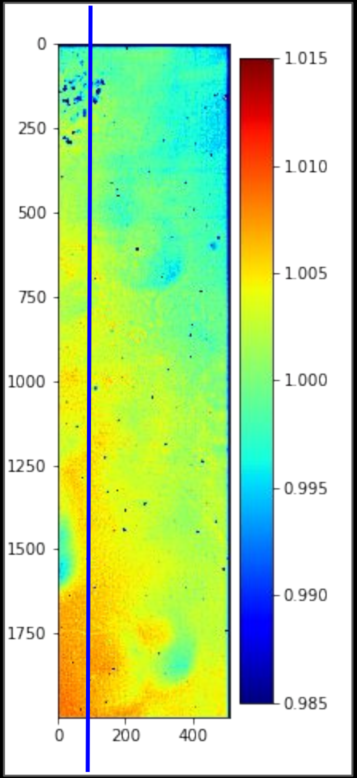
- We start with a set of *N* flat images with a given filter *b* (FELH0600, SDSSr, SDSSg): $F_b^{(\mu)}(i,j)\,(\mu = 1,2,3,\ldots,N)$, where $F_b^{(\mu)}(i,j) = F_b^{(\mu)}(i,j) - \mathcal{B}(i,j)$
- We take the median over all pixels for each image and normalise by it: $F_b'^{(\mu)}$
- We take the **median** over the *N* $F_b'^{(\mu)}$ flat images at each pixel (*i,j*): $\tilde{F}_b$
- We compute the **smooth component,** f_b, by replacing each pixel value by the median in a 40x40 sliding window
- We remove this smooth component:

$$\tilde{F}_b \;\rightarrow\; \mathcal{F}_b \;\Big|\; \mathcal{F}_b^{seg}(i,j) \;=\; \frac{\tilde{F}_b^{seg}(i,j)}{f_b^{seg}(i,j)}$$

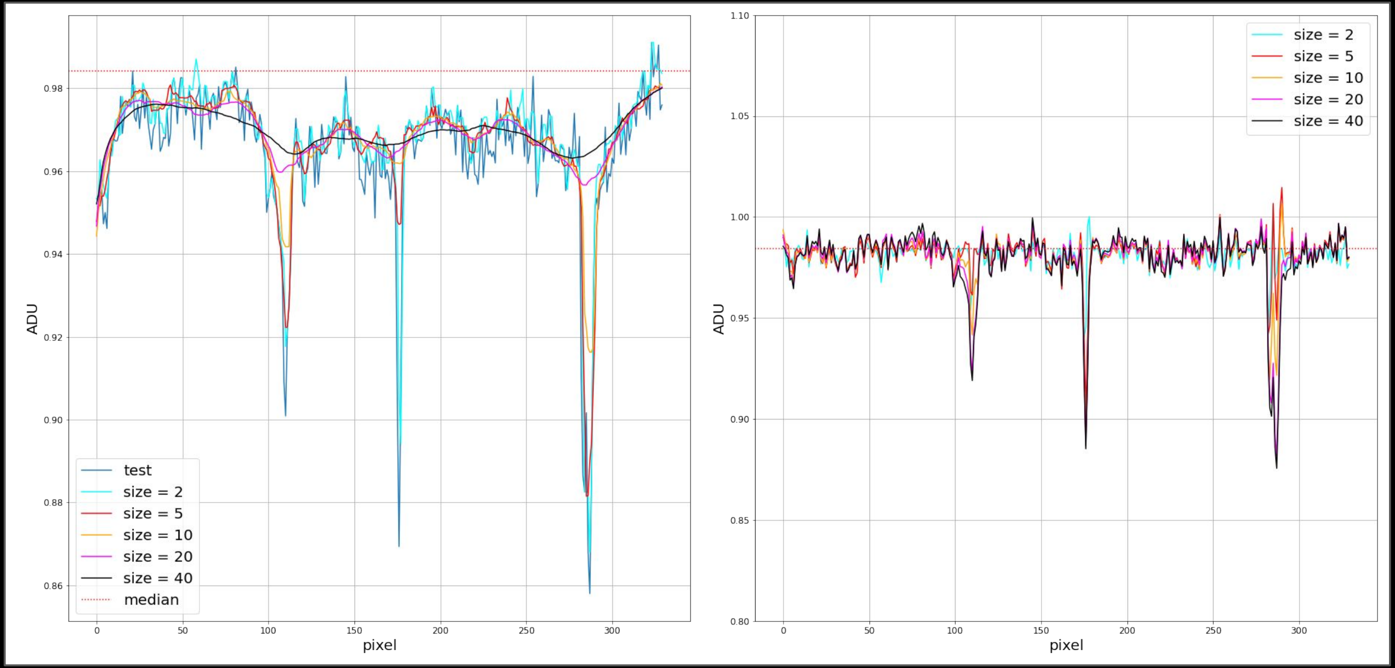
2D median smoothing: FELH0600



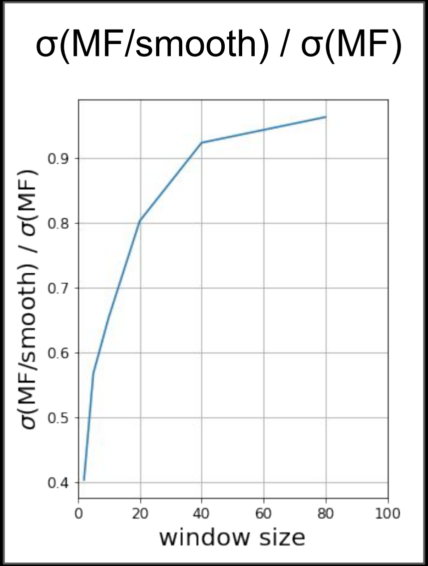
2D median smoothing

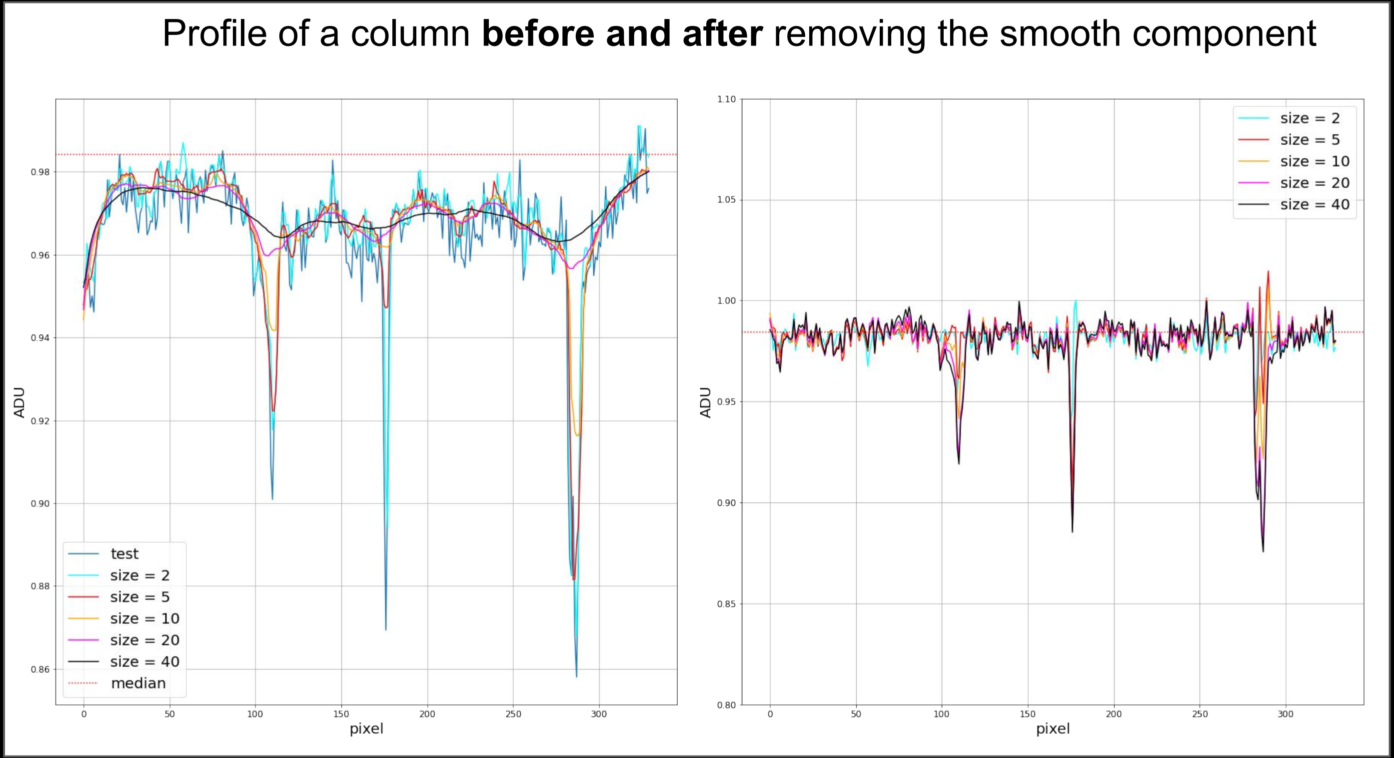


Profile of a column **before and after** removing the smooth component



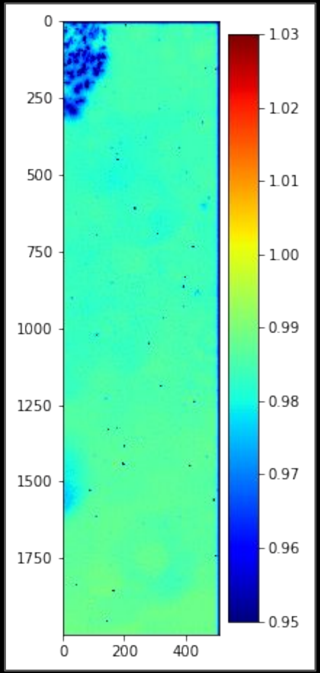
2D median smoothing



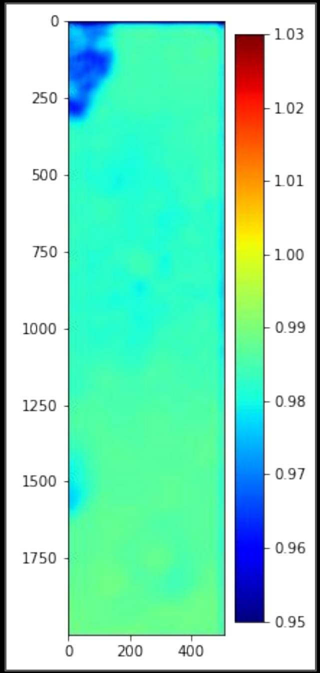


2D median smoothing

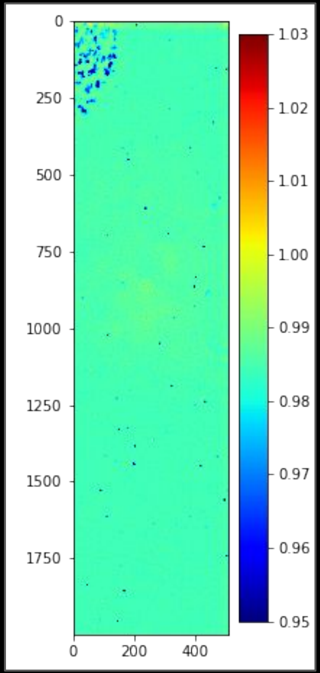
Master flat



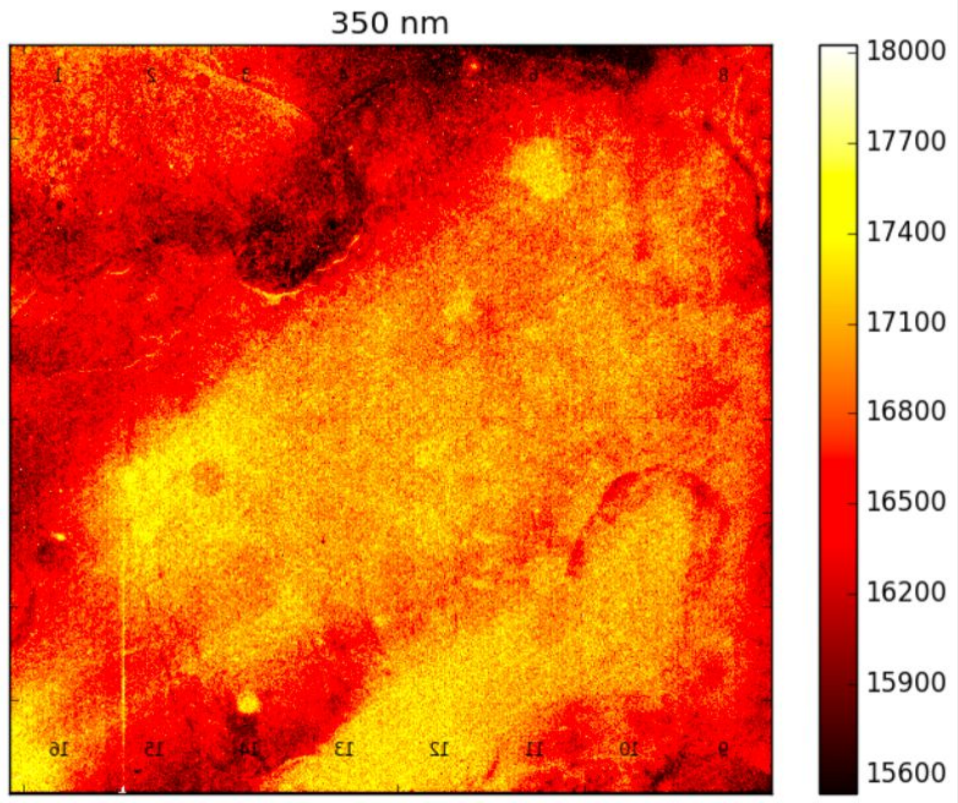
Smoothed



Master flat / smoothed

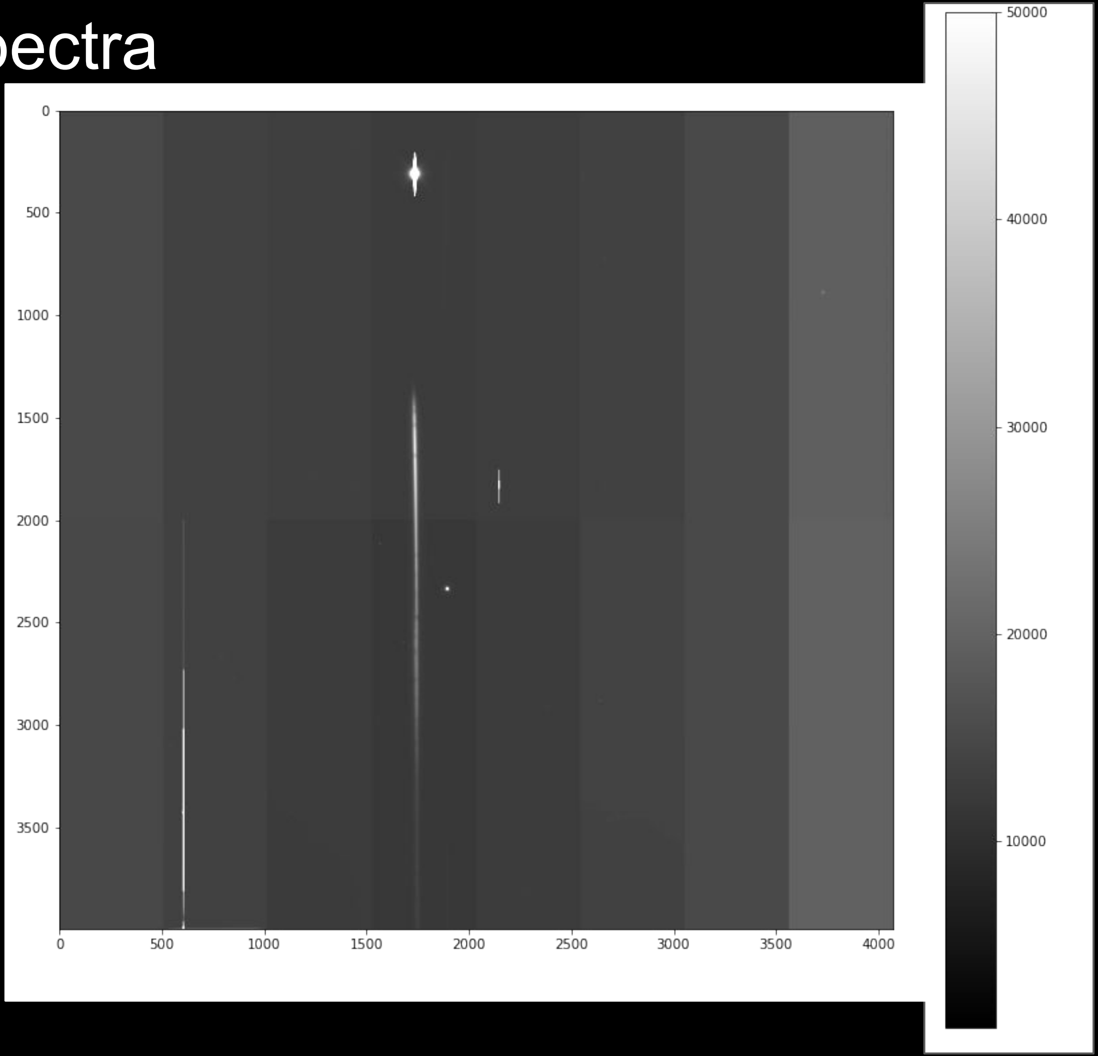


CCD response at 350 nm (laboratory flat)



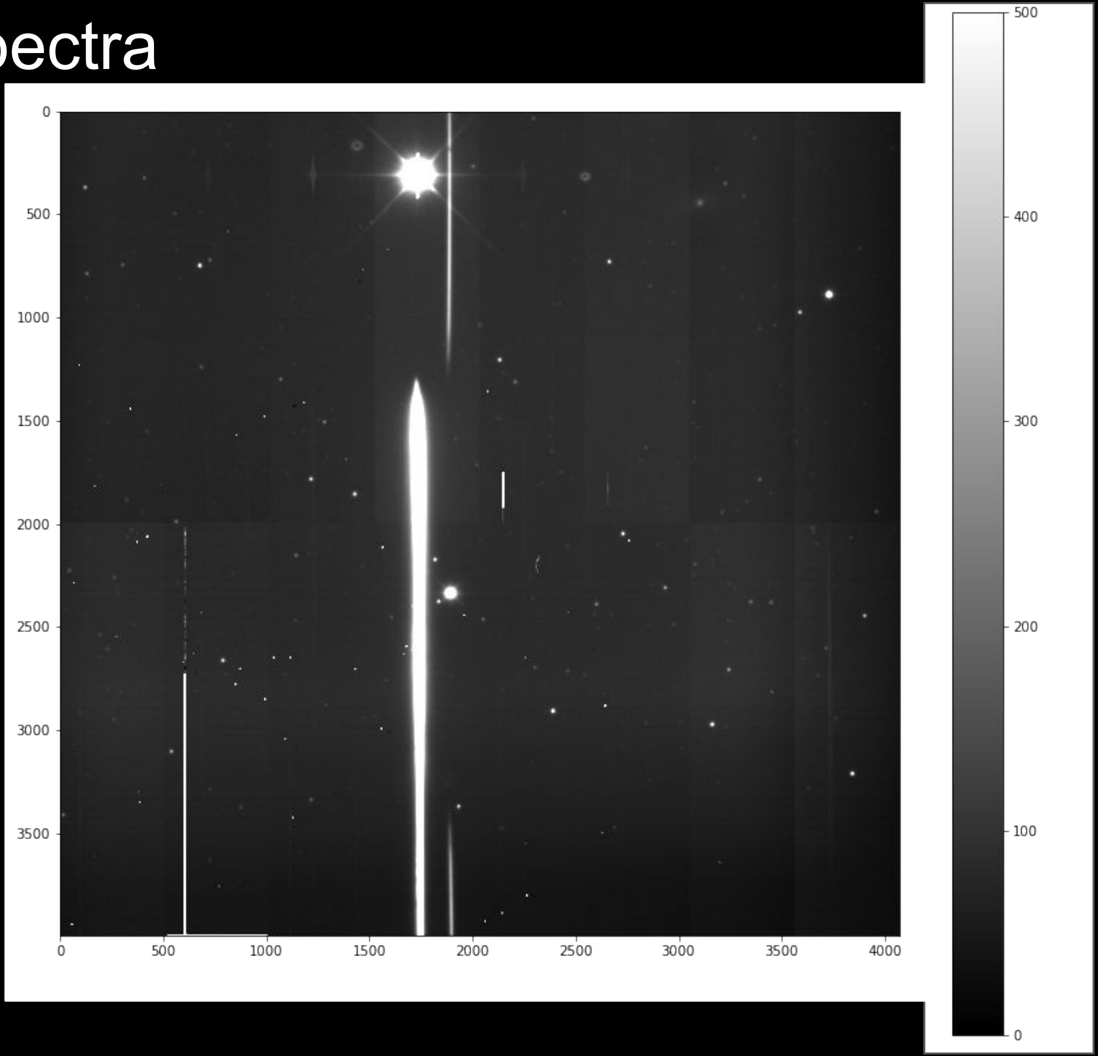
Impact on spectra

Raw



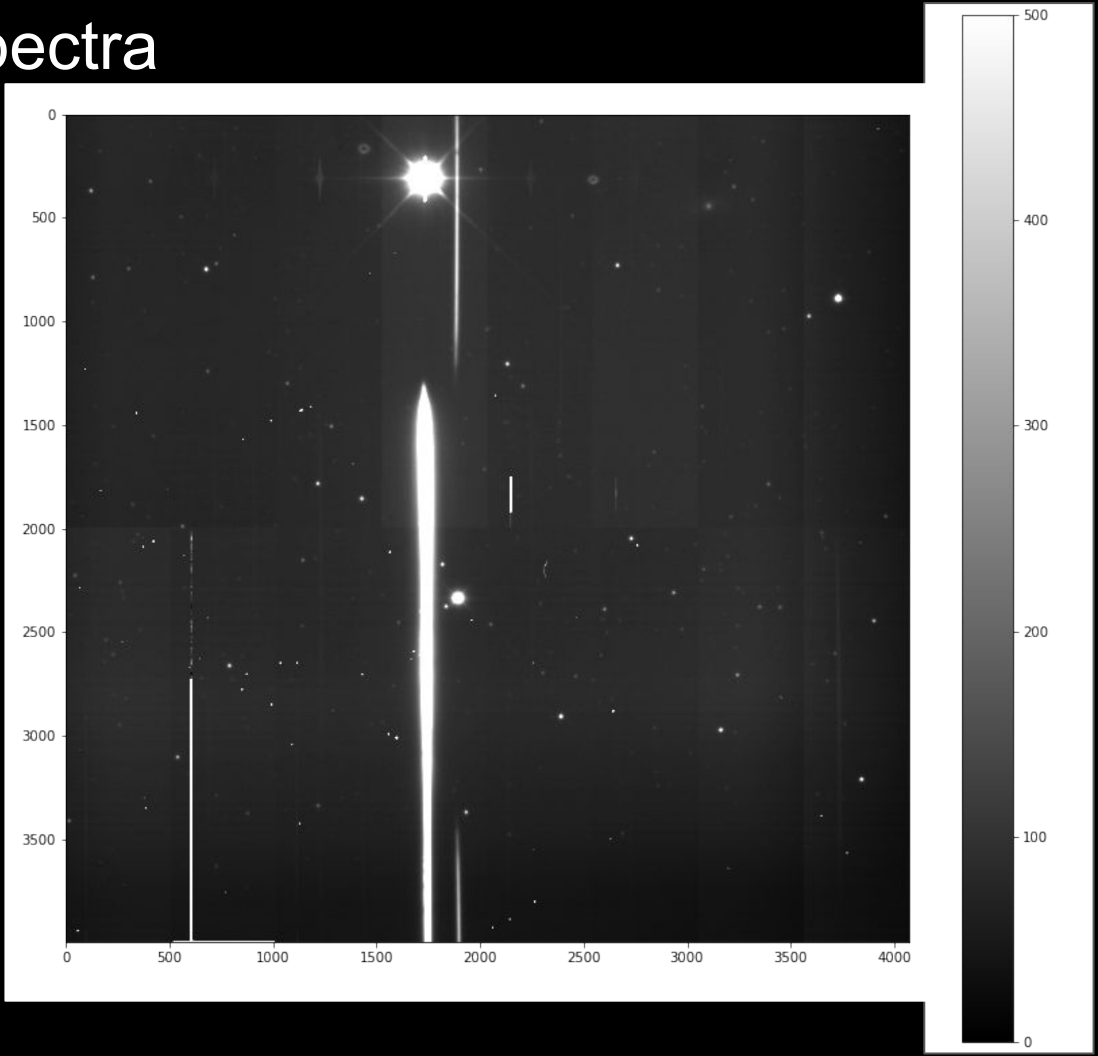
Impact on spectra

Raw-bias



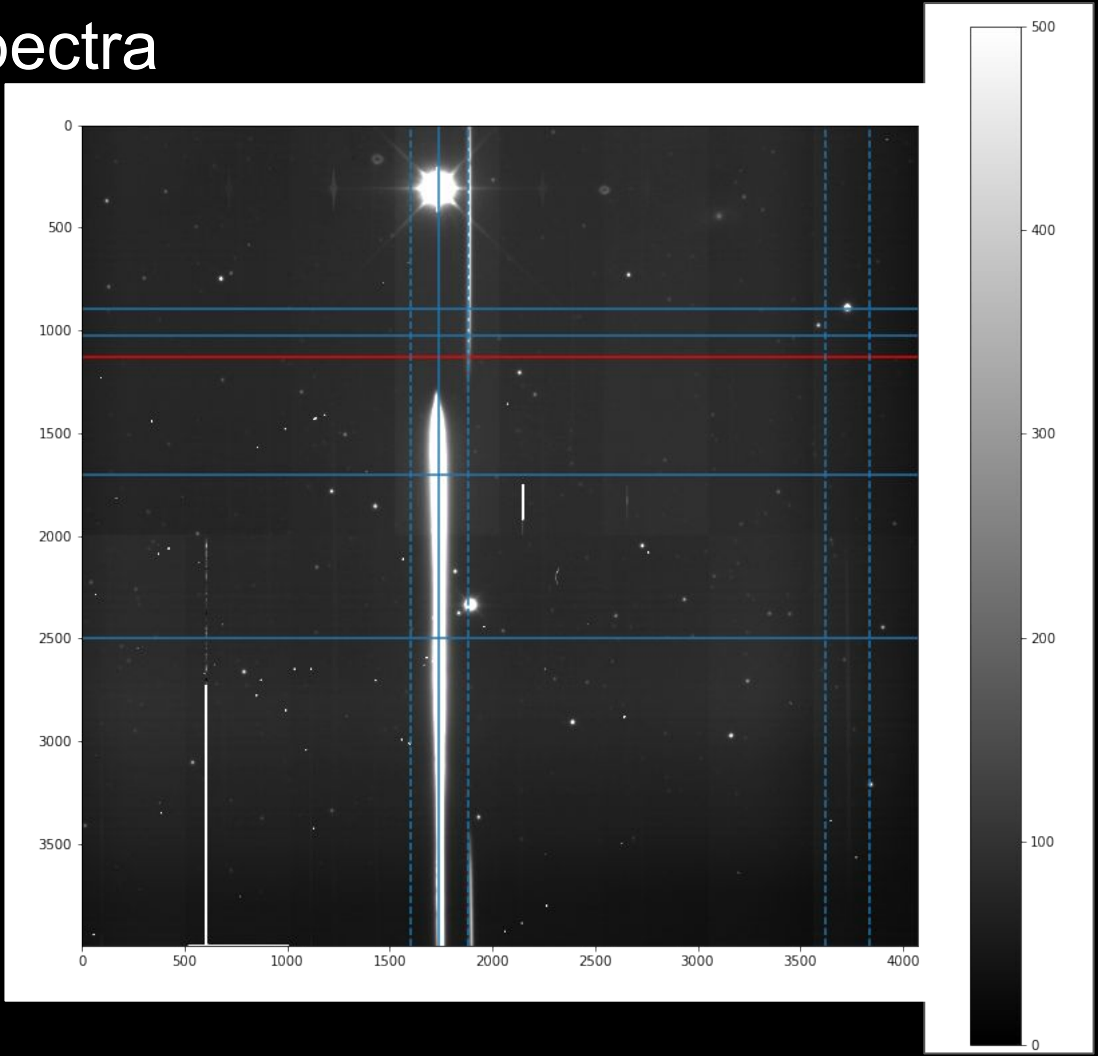
Impact on spectra

(Raw-bias)
/flats

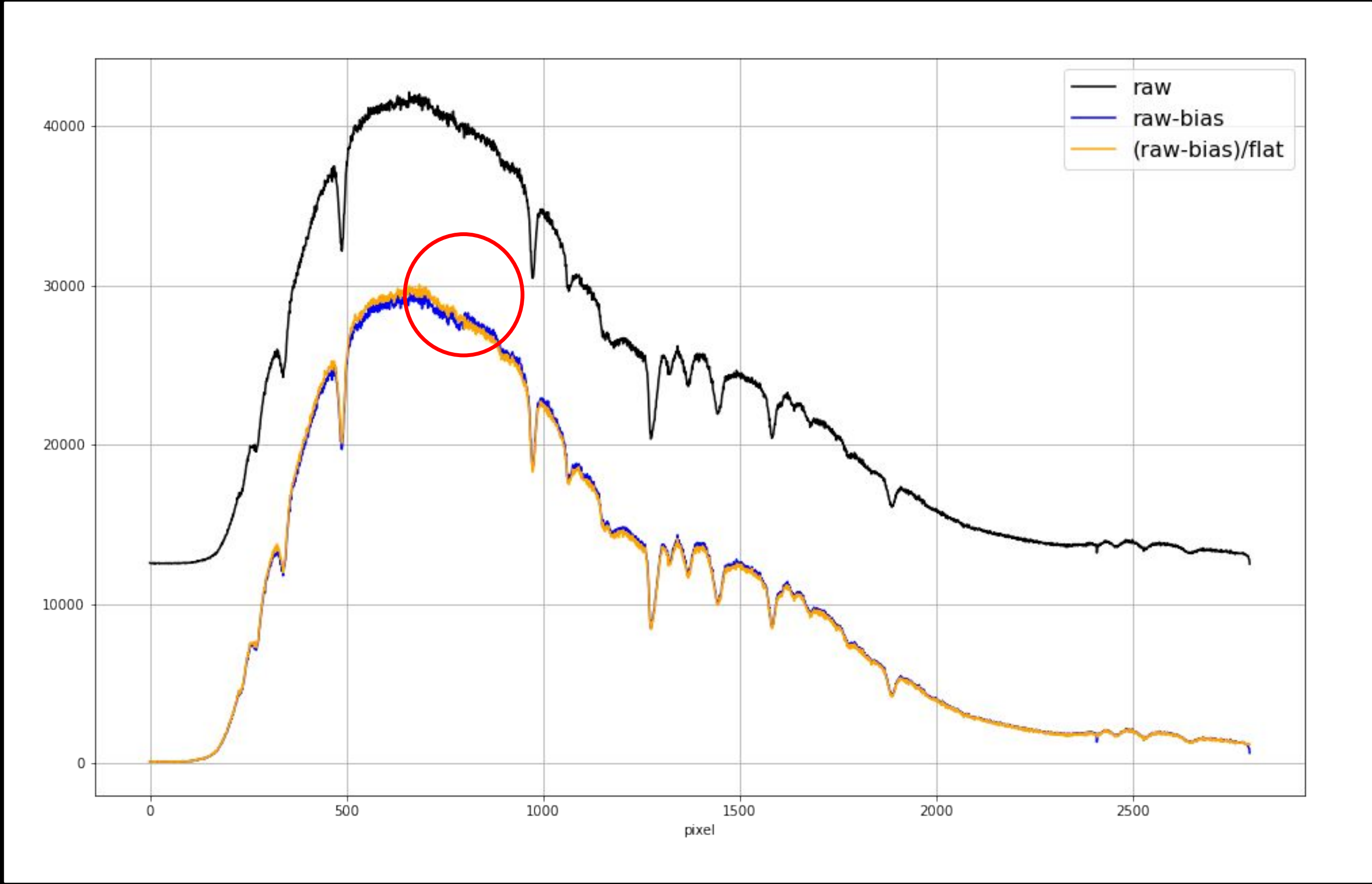


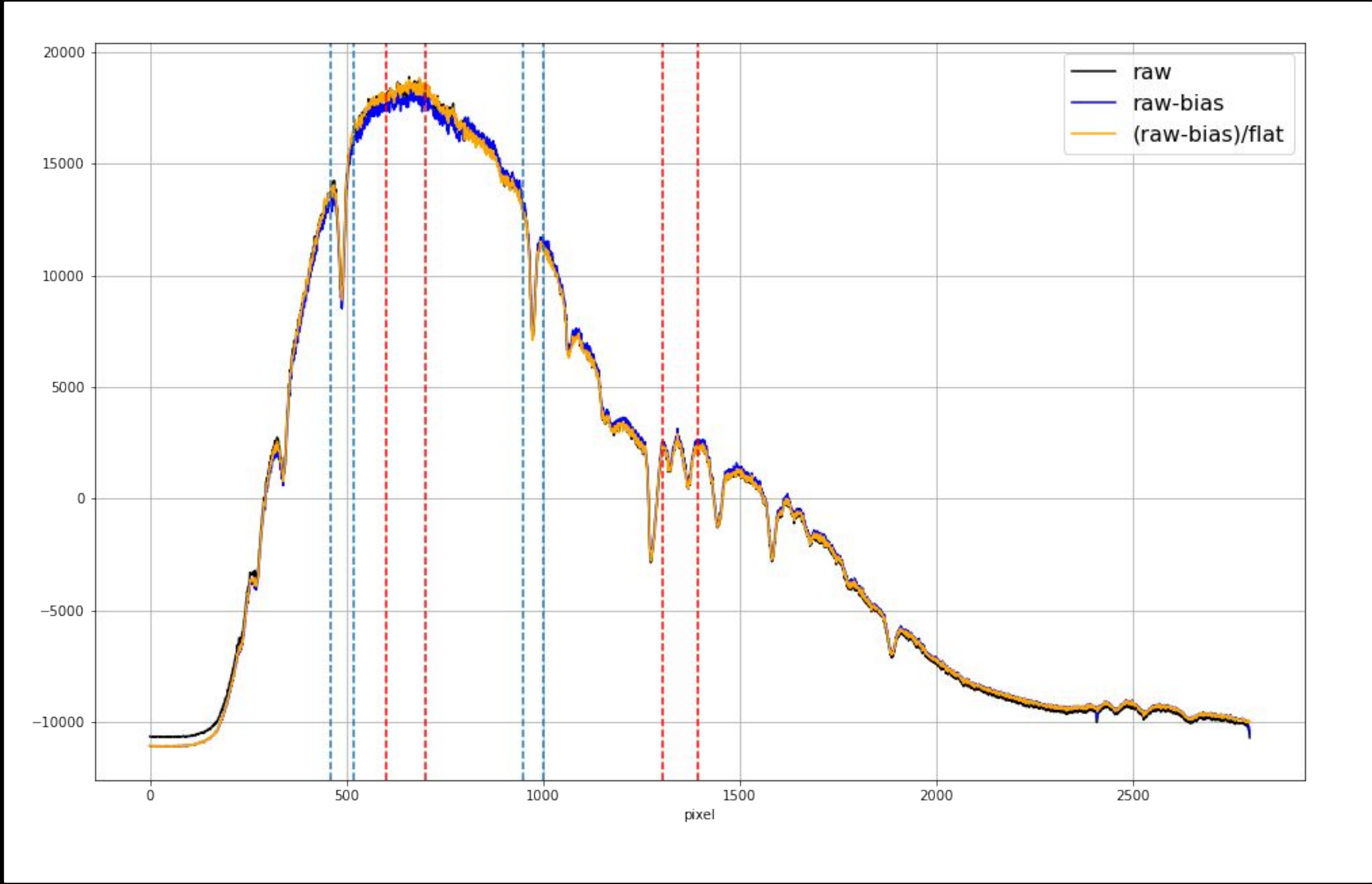
Impact on spectra

(Raw-bias)
/flats



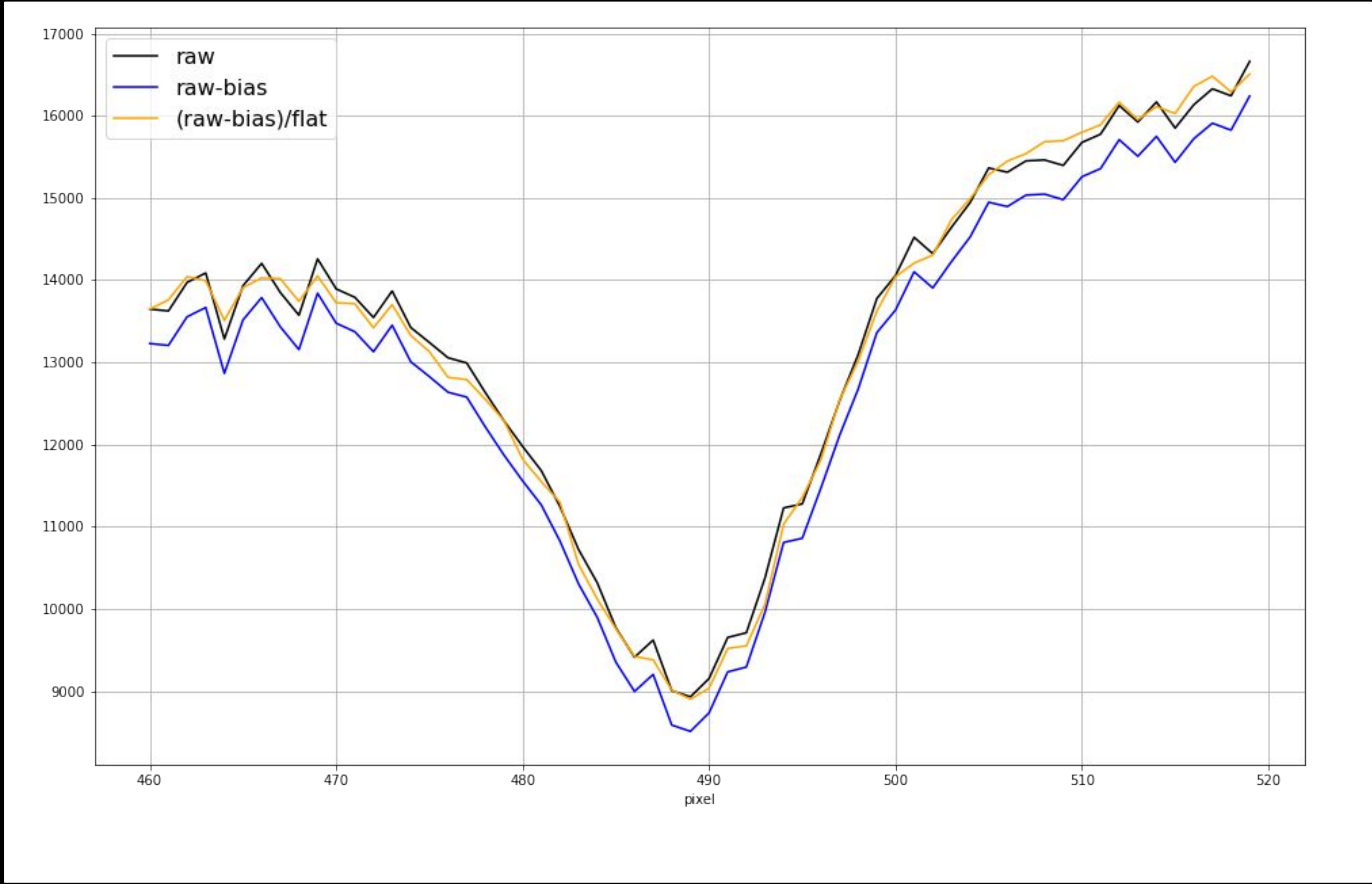
Impact on spectra



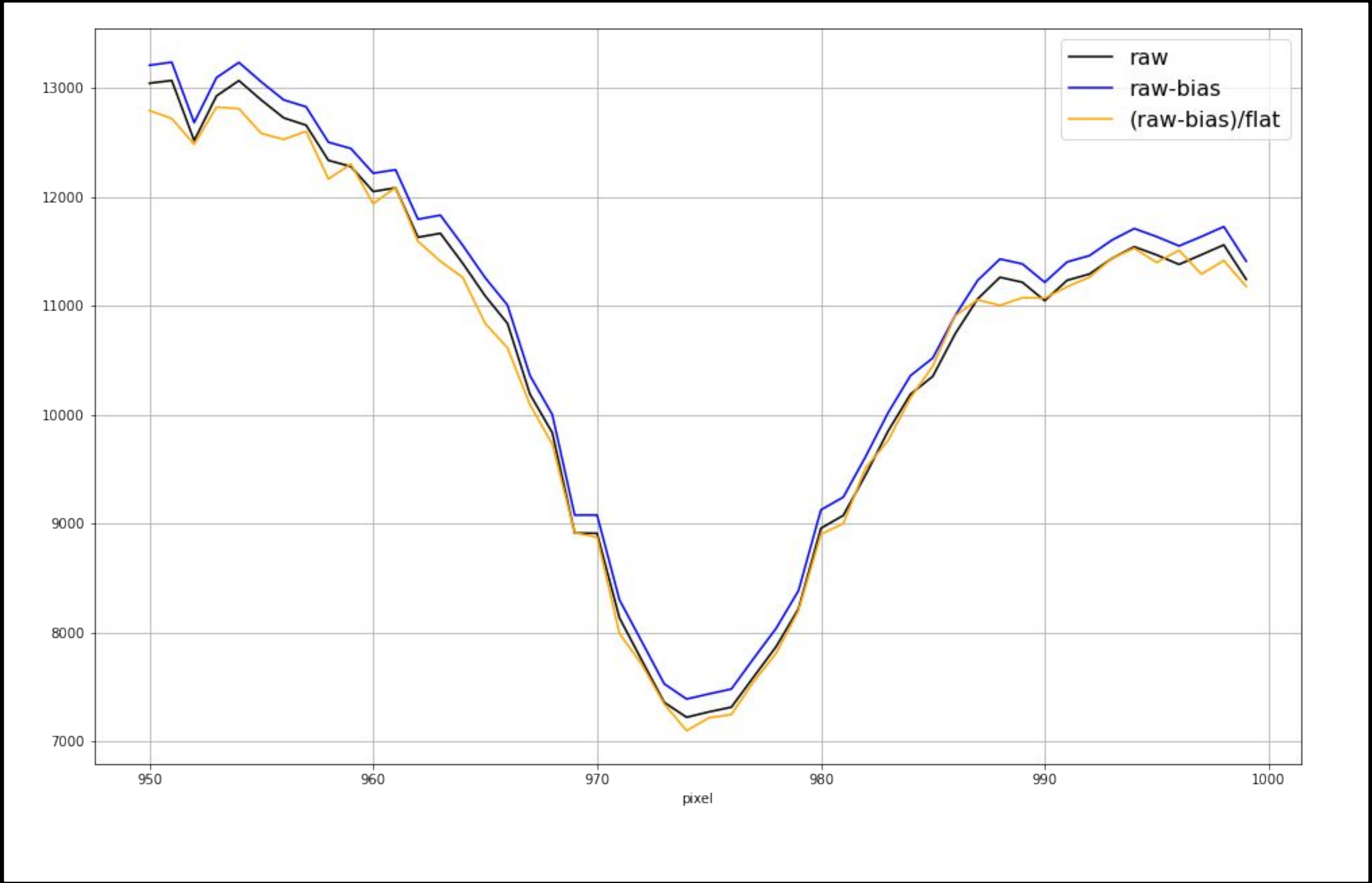


raw
raw-bias
(raw-bias)/flat
20000
15000
10000
5000
0
−5000
−10000
0
500
1000
1500
2000
2500
pixel

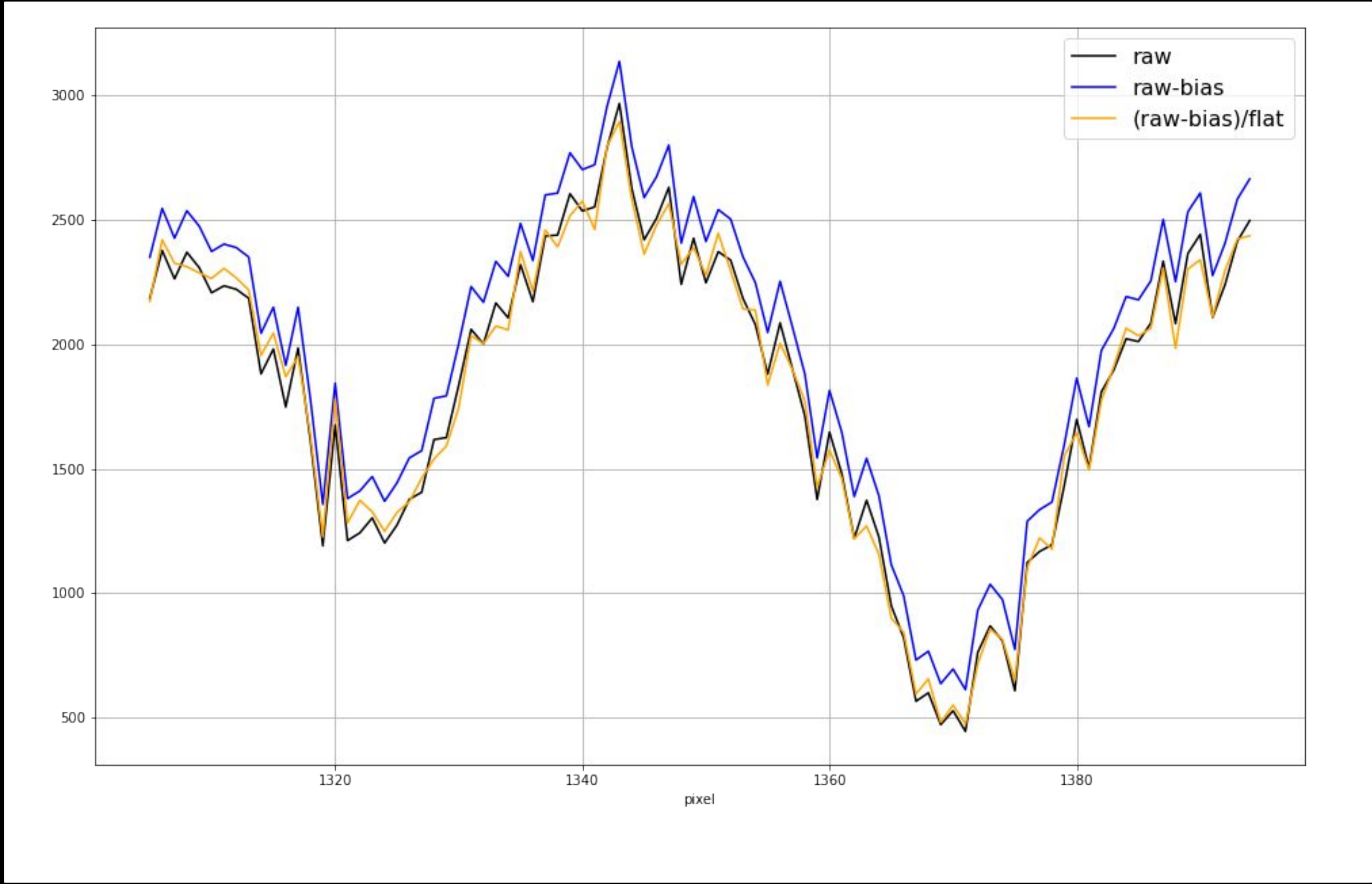
Impact on spectra



Impact on spectra

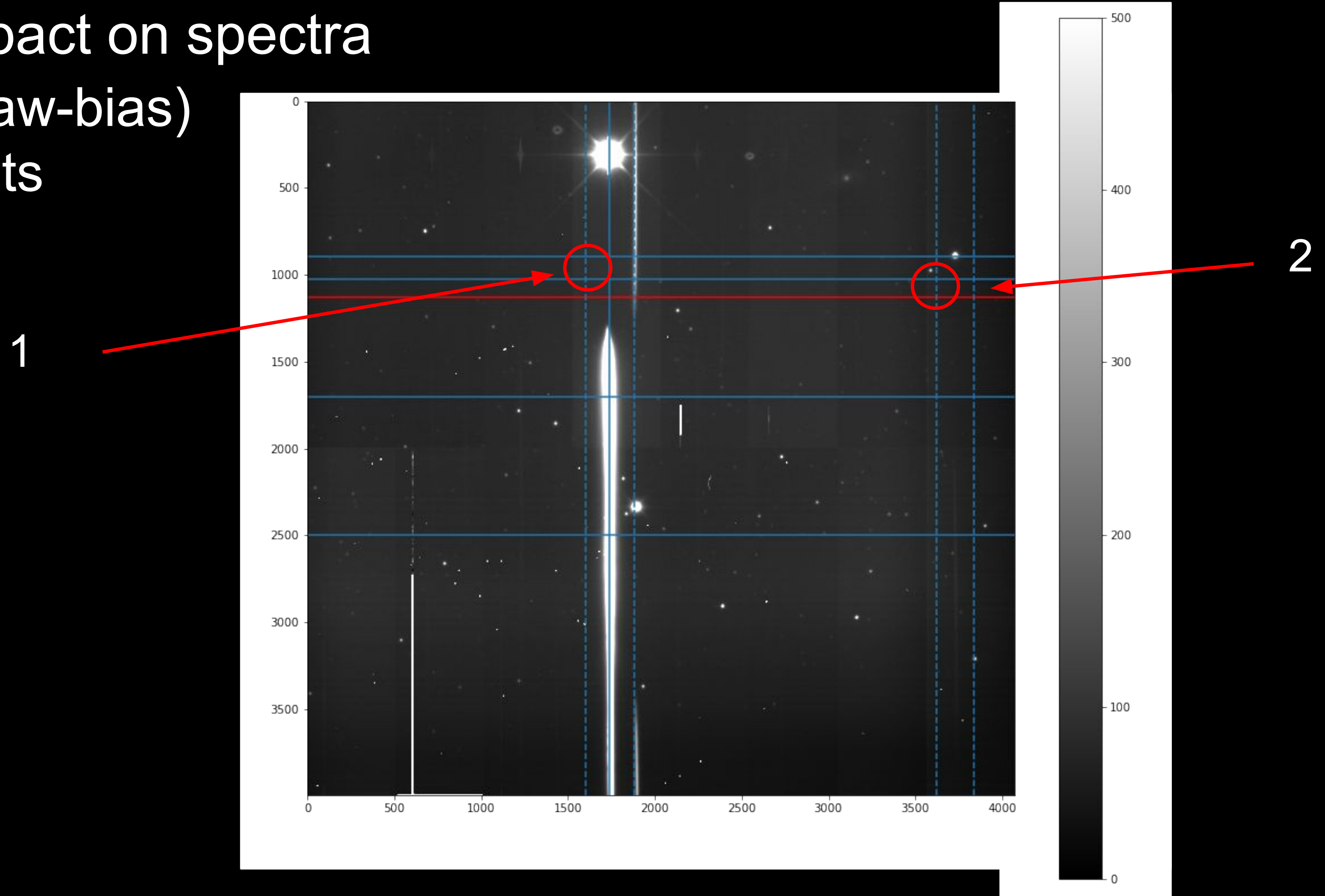


Impact on spectra



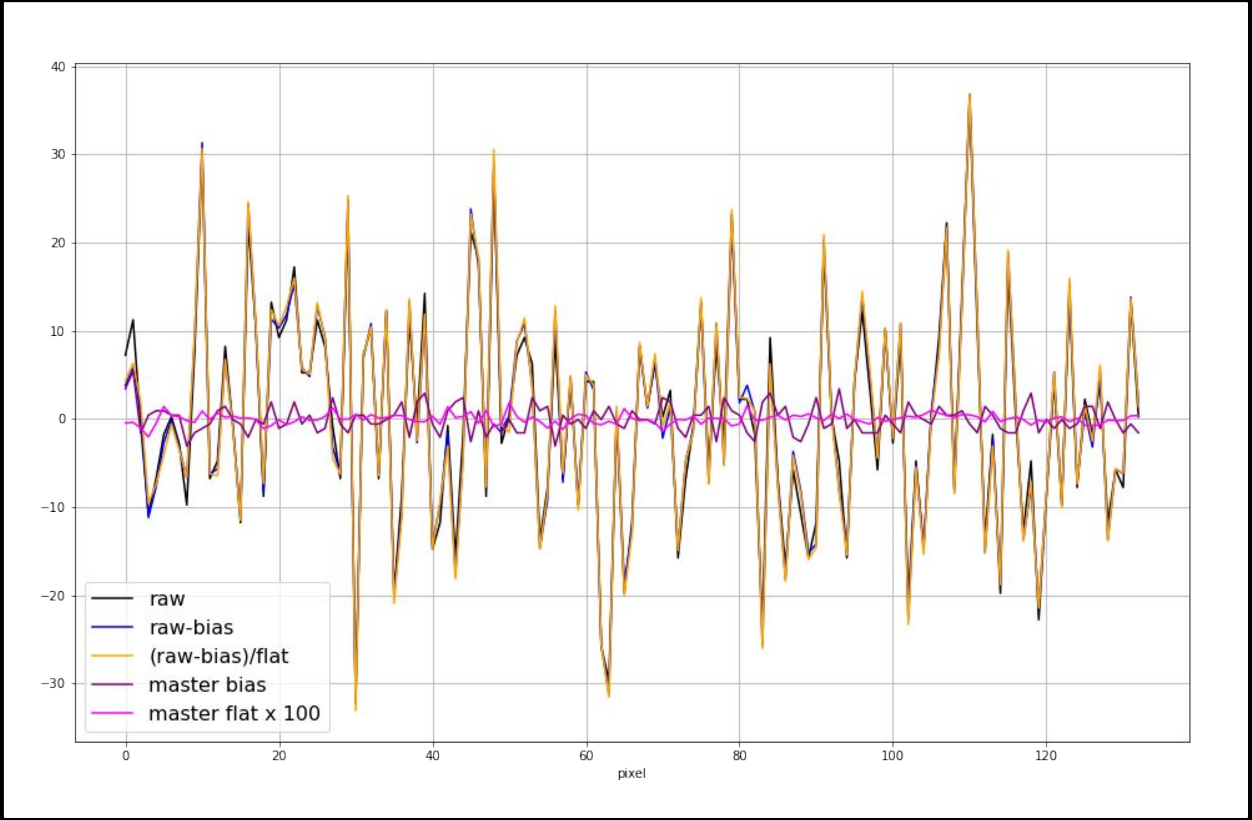
Impact on spectra

(Raw-bias)
/flats



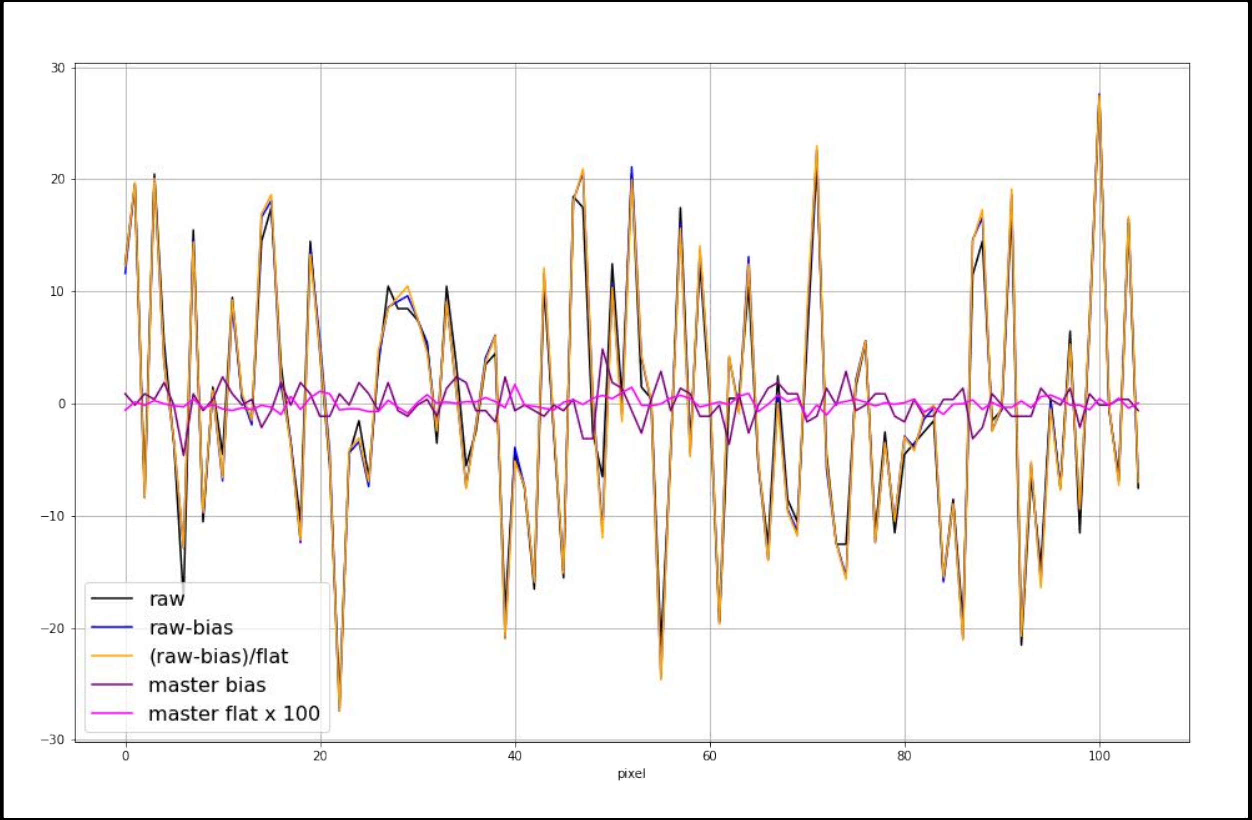
Impact on spectra

1



Impact on spectra

2



Factorization of the wavelength dependence

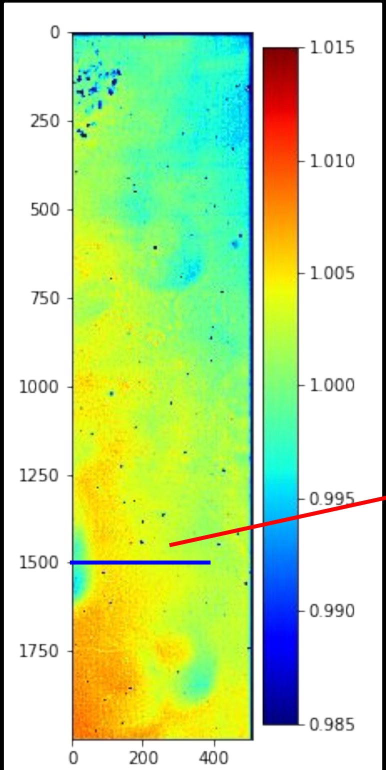
Idea:

- Evaluate spatial correlation between flats with different filters

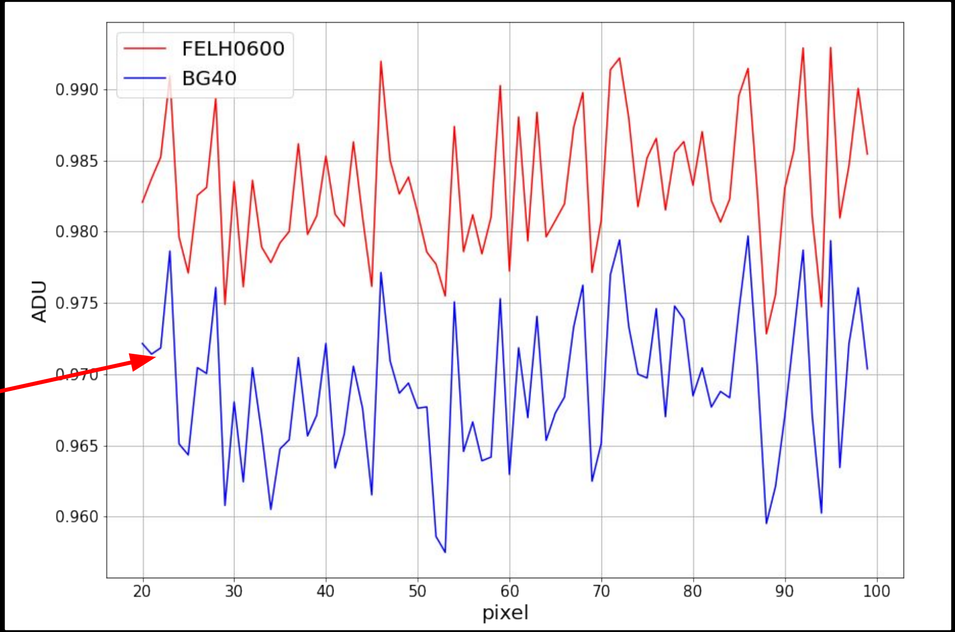
$$ADU(i,j,\lambda) = F_{o.f.}(i,j) \times F_{CCD}(i,j,\lambda) = F_{o.f.}(i,j) \times G_{CCD}(i,j) \times \varepsilon_{CCD}(\lambda)$$

- See if can factorize out the wavelength dependency on the flats:
  - $F_{o.f.}(i,j)$ = **out of focus artifacts** (vignetting, dust on optical components) = **slow** pixel to pixel variation (real space) or **low** spatial frequency (Fourier space)
  - $F_{CCD}(i,j,\lambda)$ = **focused artifacts** (dust on the CCD, pixel surface variations) = **fast** pixel to pixel variation or **high** spatial frequency
  - We examine the **hypothesis** of
- If ~ true, then we could preliminary use a single flat for spectra reduction
- How can we test this?
  - By examining the **ratio** of flat images **at different wavelengths (with different filters)**

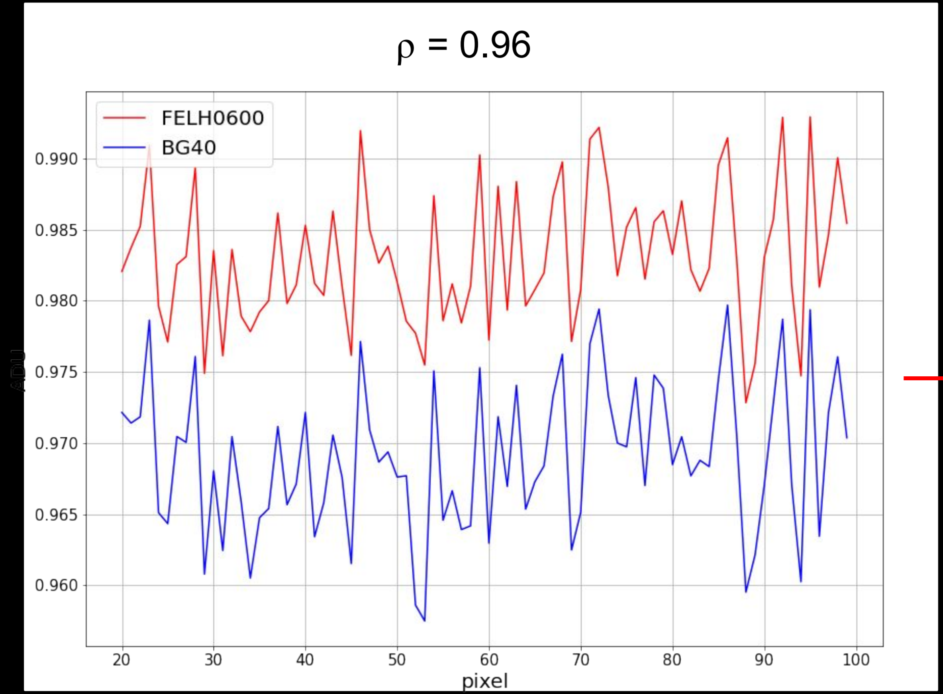
Factorization of the wavelength dependence: pixel correlation

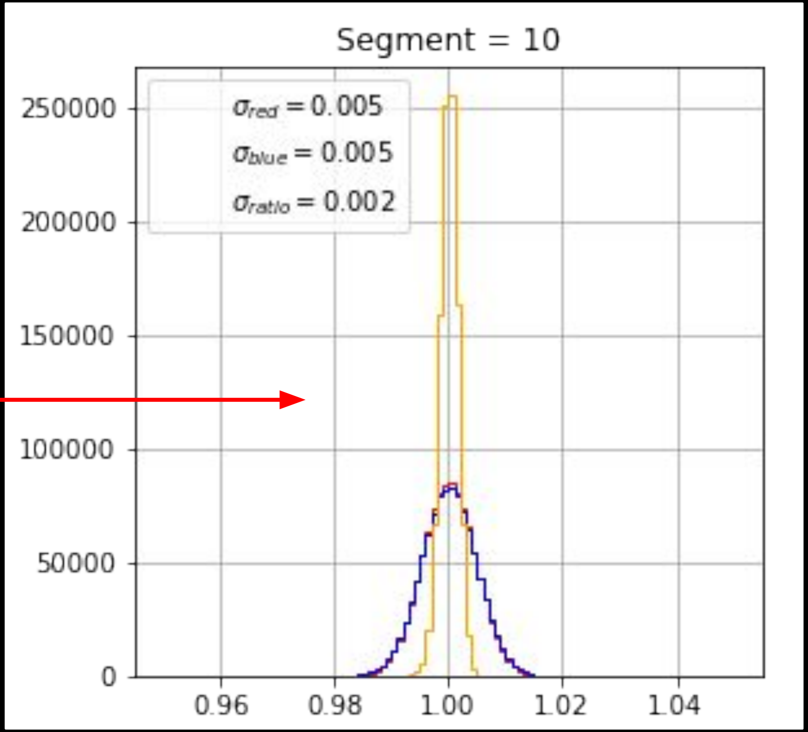


$\rho = 0.96$

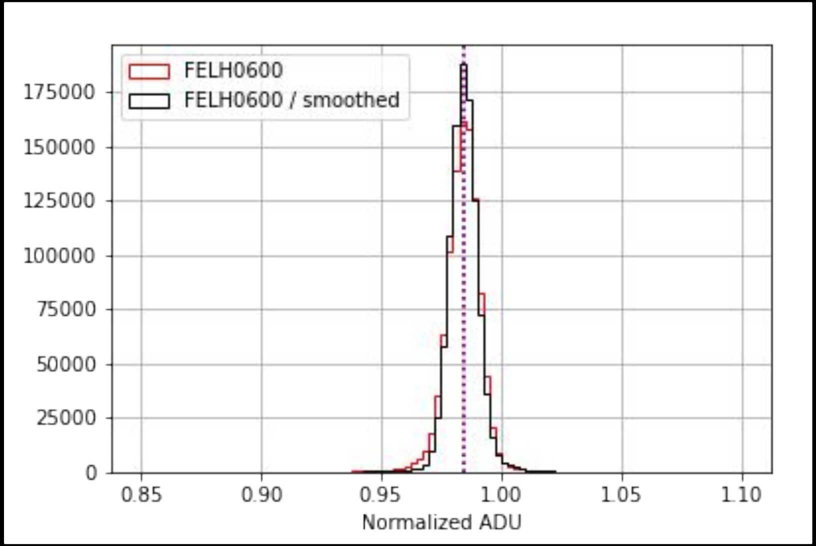


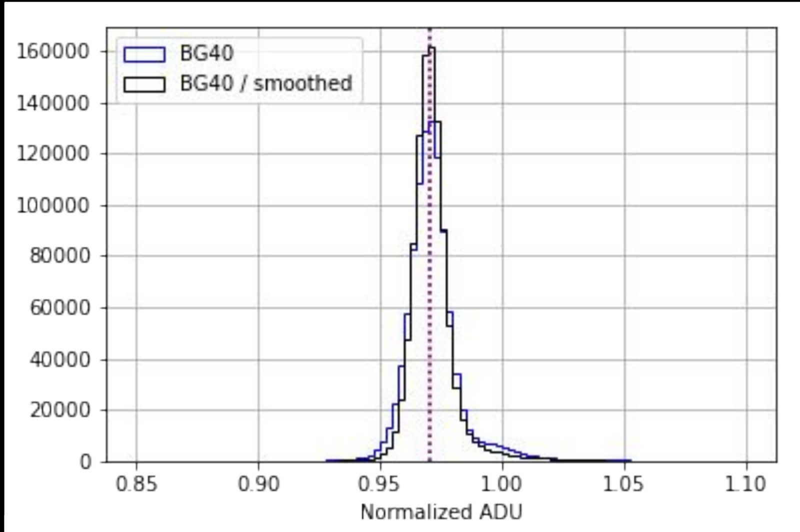
Factorization of the wavelength dependence: pixel correlation

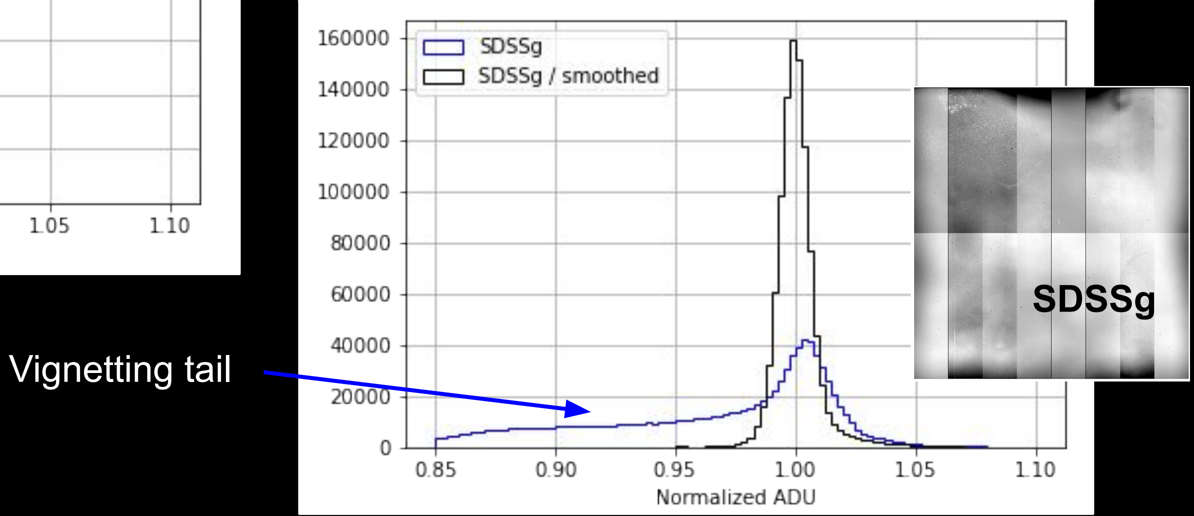




Master flats ratio

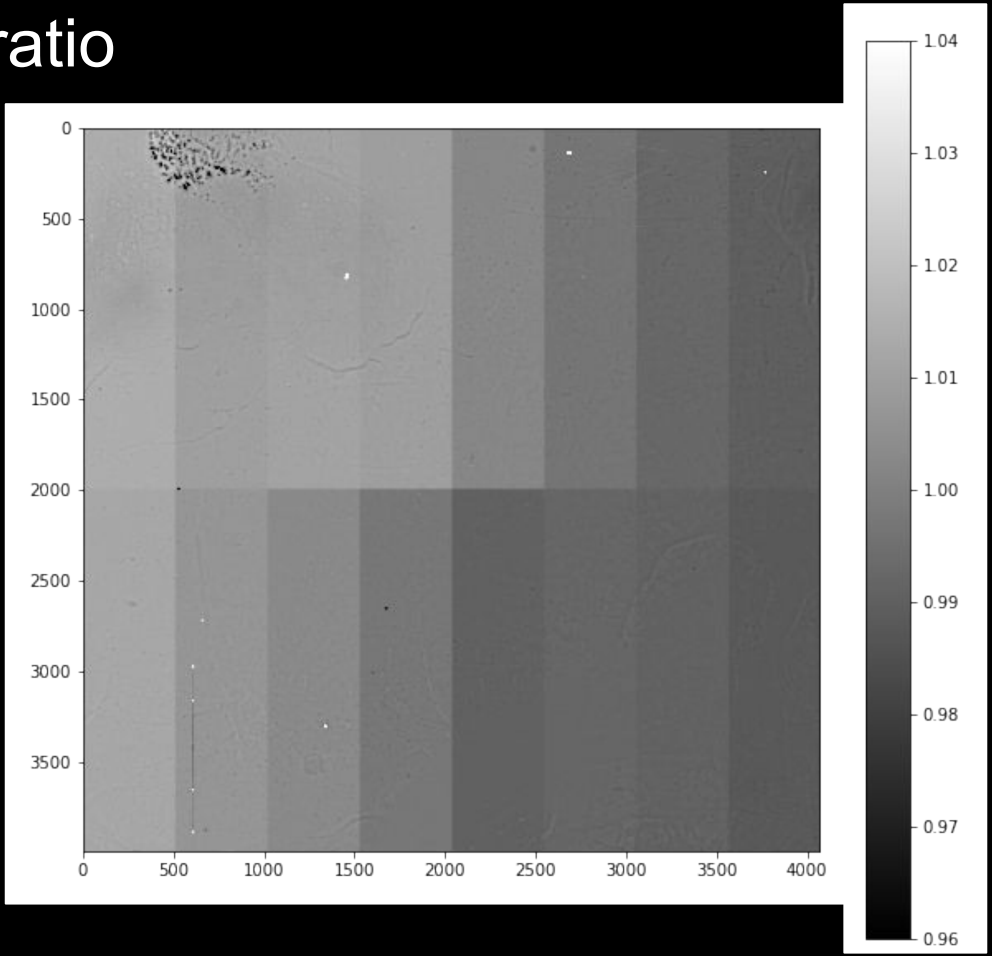




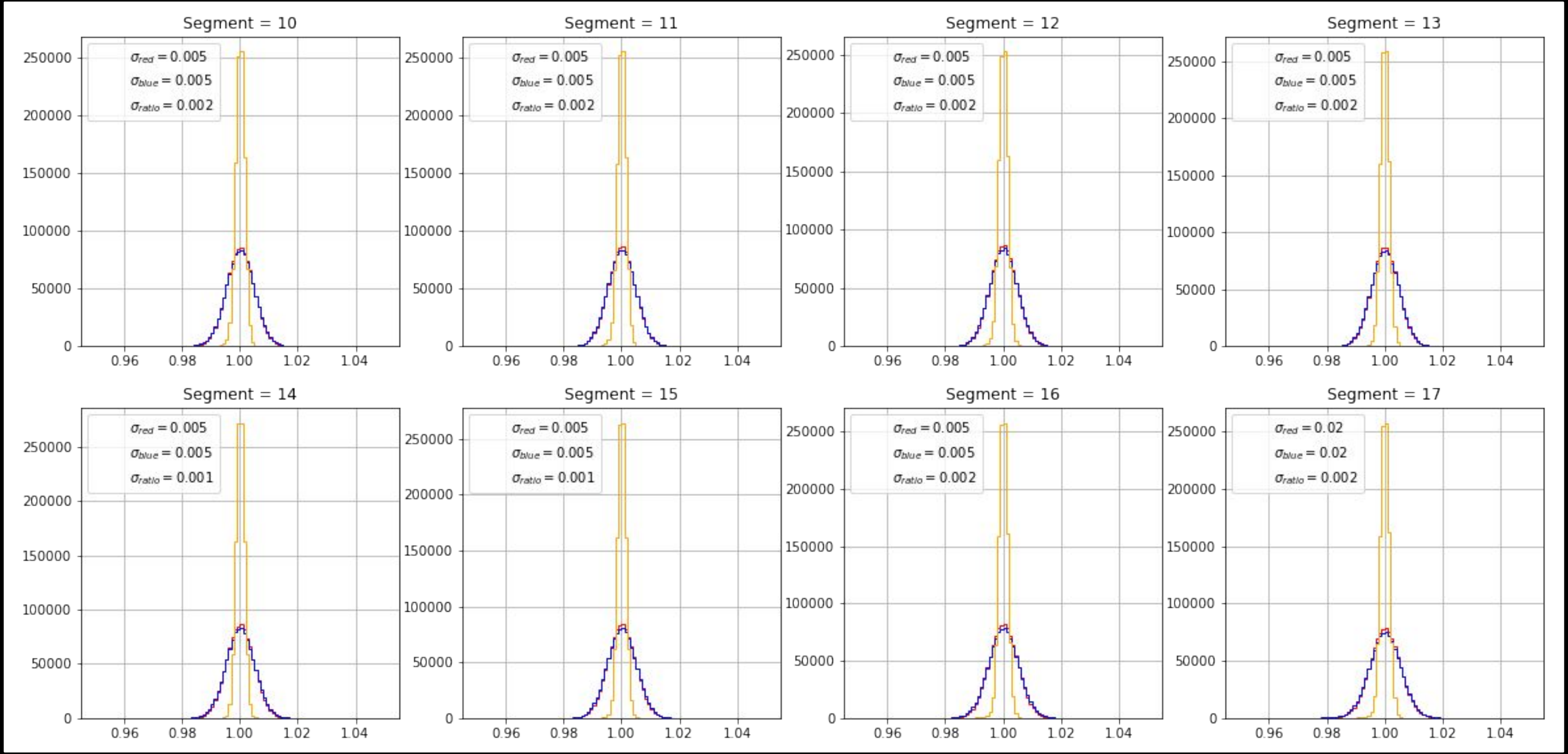


Master flats ratio

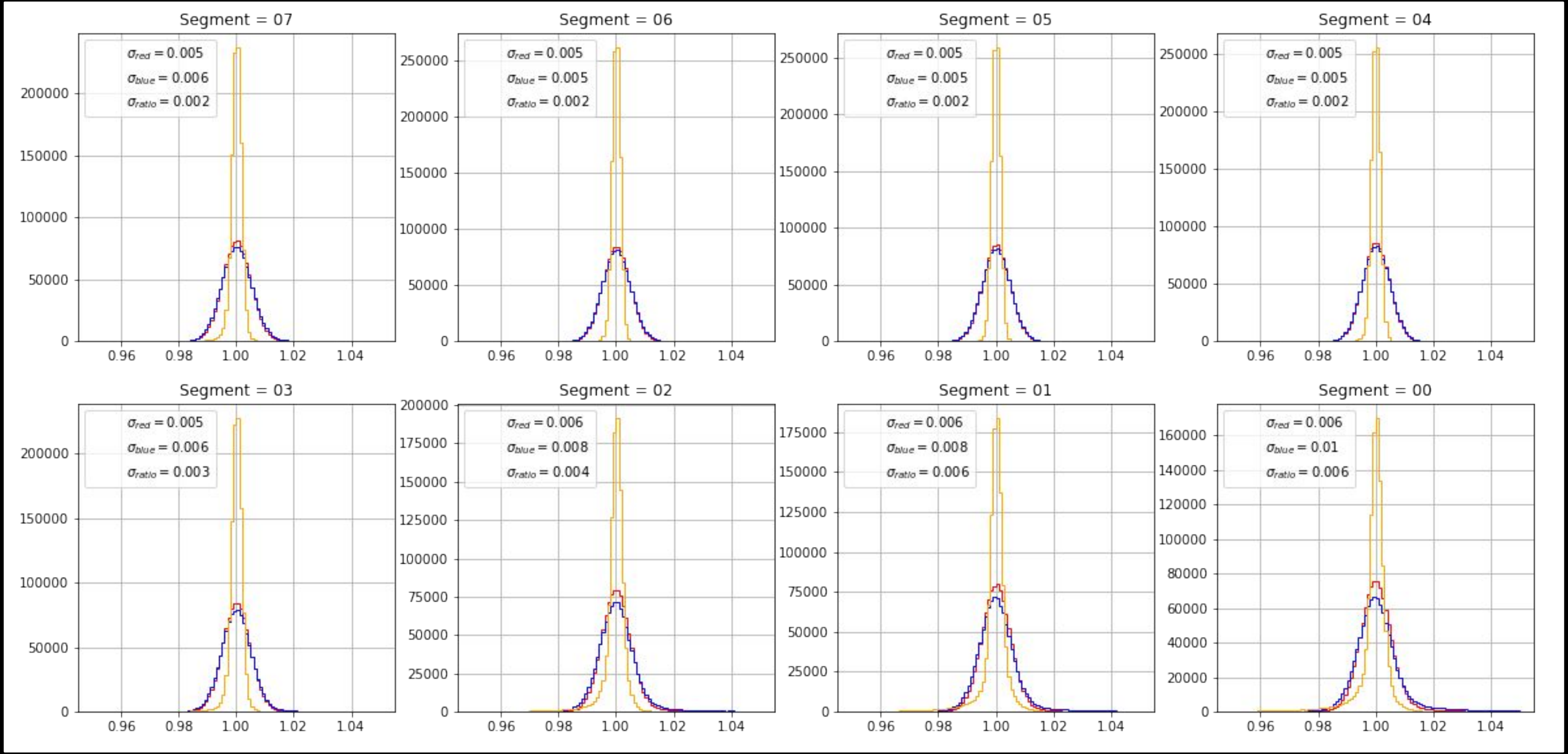
FELH0600 / BG40



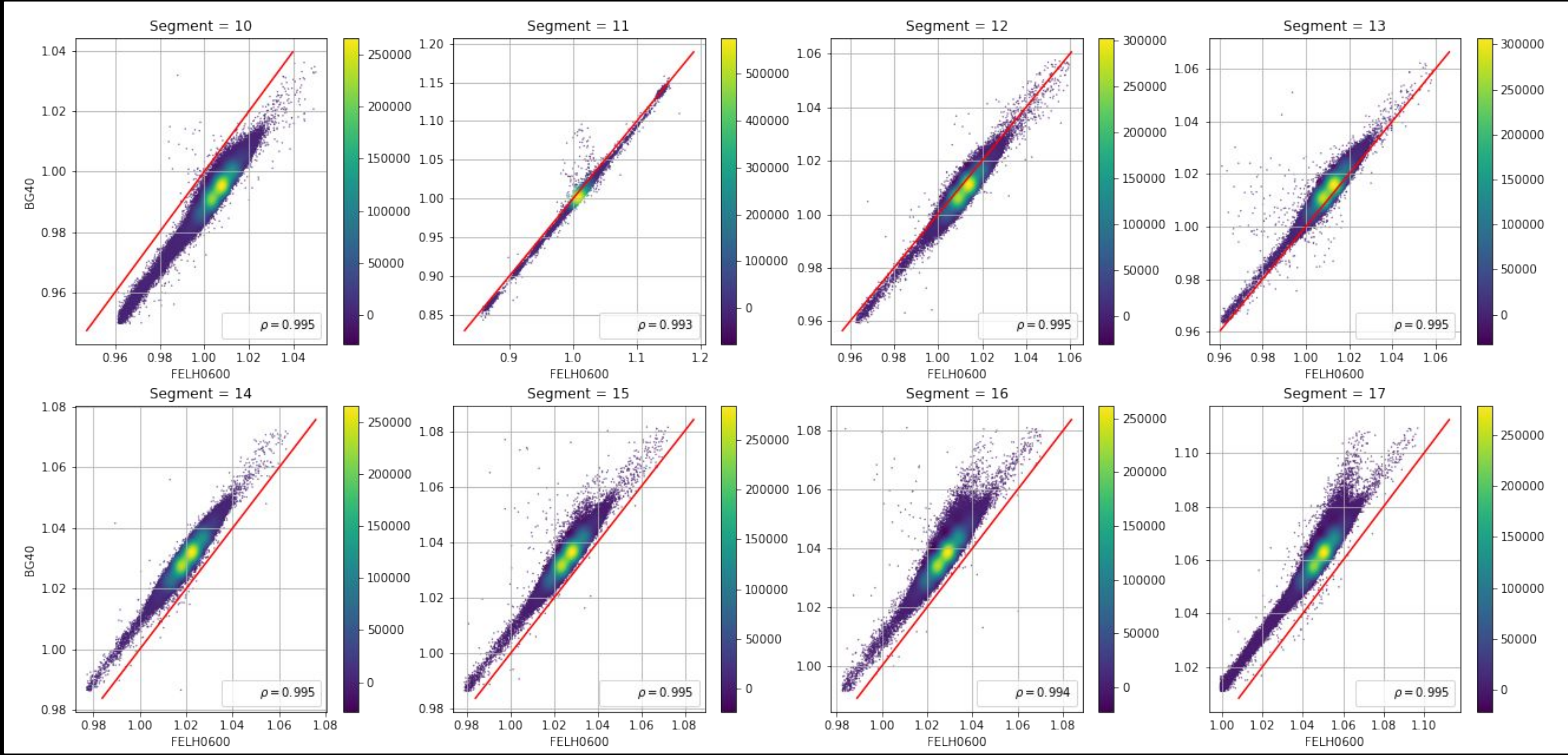
Master flats ratio



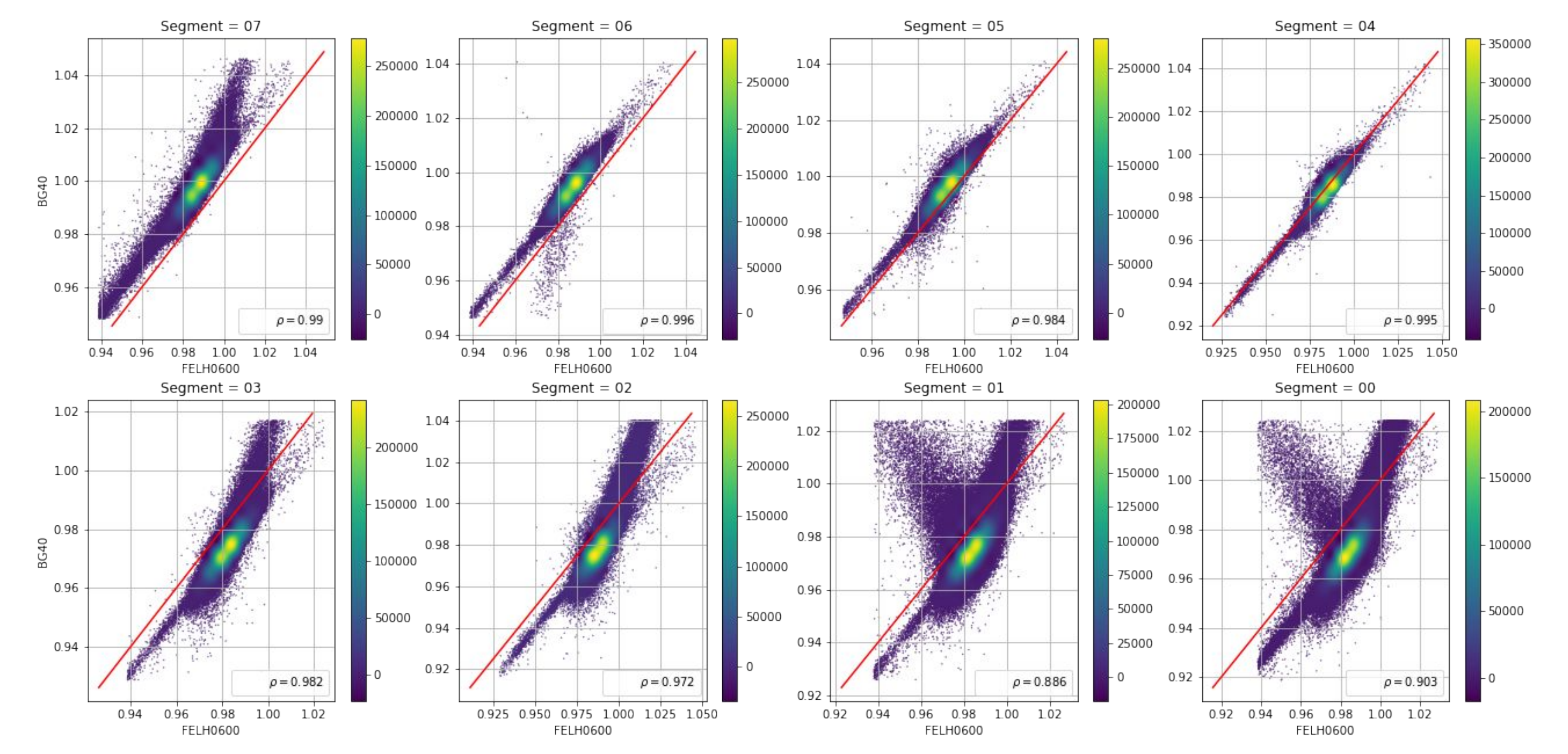
Master flats ratio



Master flats ratio: spatial correlation of pixel content



Master flats ratio: spatial correlation of pixel content



Conclusions and work in progress

- Pixel-to-pixel variations improved (smoothed) on top of the spectrum
  - Effect of the master flats noticeable where we are dominated by light from source (top of spectrum)
  - Negligible effect on zones dominated by sky background
  - Need to know typical fluctuation of individual bias images
- First results on spectra are encouraging
- Work in progress
  - Some refinements are still required (transition between segments)
  - Important for second order sustraction
  - Need to compare with lab flats to evaluate large-scale electronic variations (no out-of-focus artifacts)
  - Estimate impact on the measurement of **equivalent width (EQW)** for stellar lines

Conclusions and work in progress

- We find a good enough spatial correlation (ρ > 0.9) between pixels in flat fields of different colours (FELH0600 and BG40) to **factor out the λ dependence**

$$ADU(i,j,\lambda) = F_{o.f.}(i,j) \times F_{CCD}(i,j,\lambda) = F_{o.f.}(i,j) \times G_{CCD}(i,j) \times \varepsilon_{CCD}(\lambda)$$

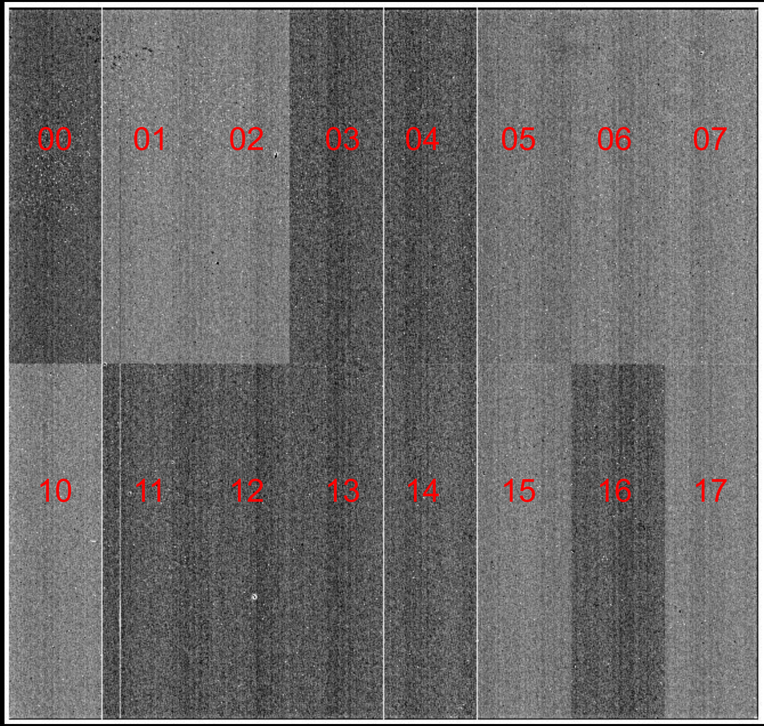
- We propose to preliminary **use a single high spatial frequency master flat** (as previously created) for AuxTel spectra deflatening

$$I = \frac{D - \mathcal{B}}{\mathcal{F}}$$

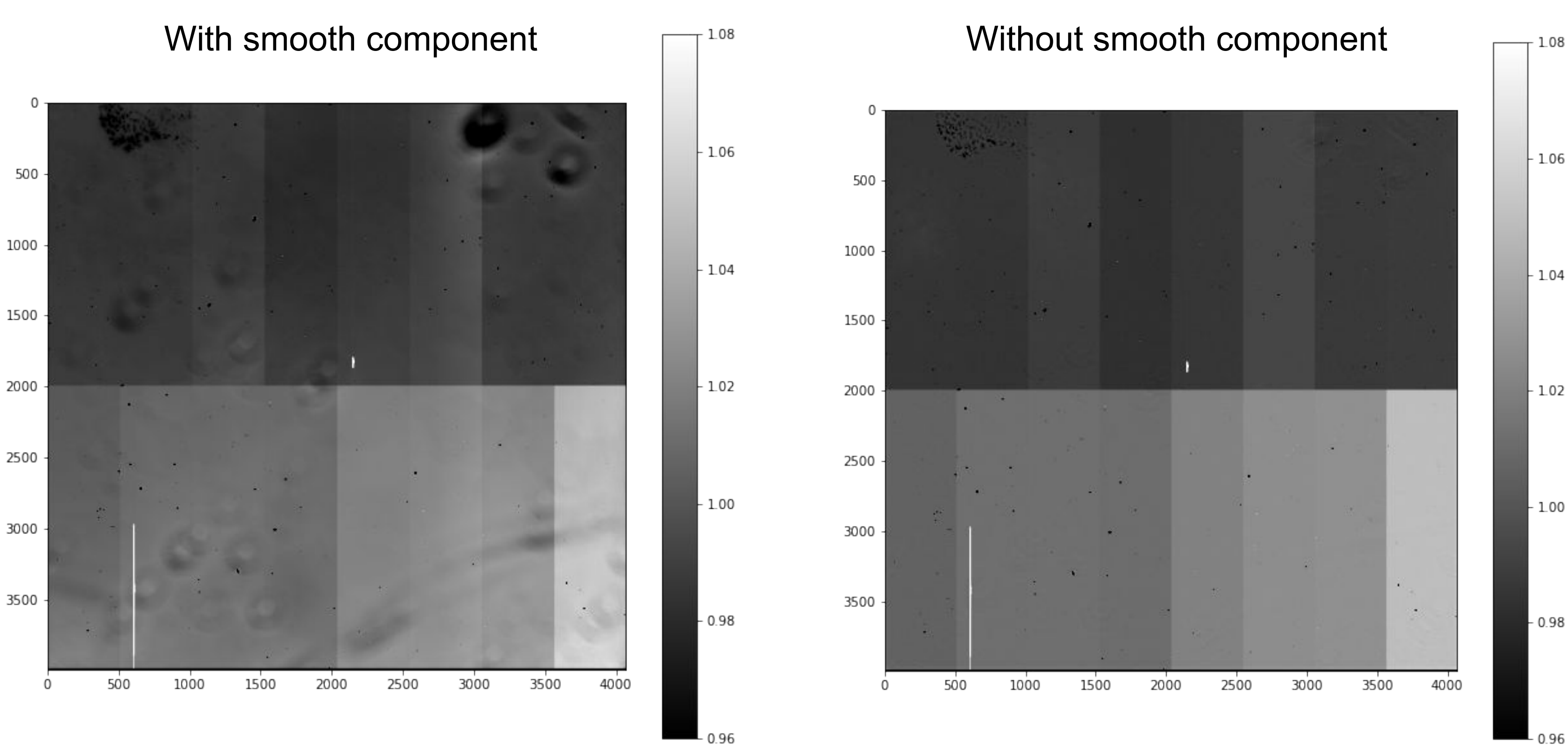
Merci beaucoup

Back-up

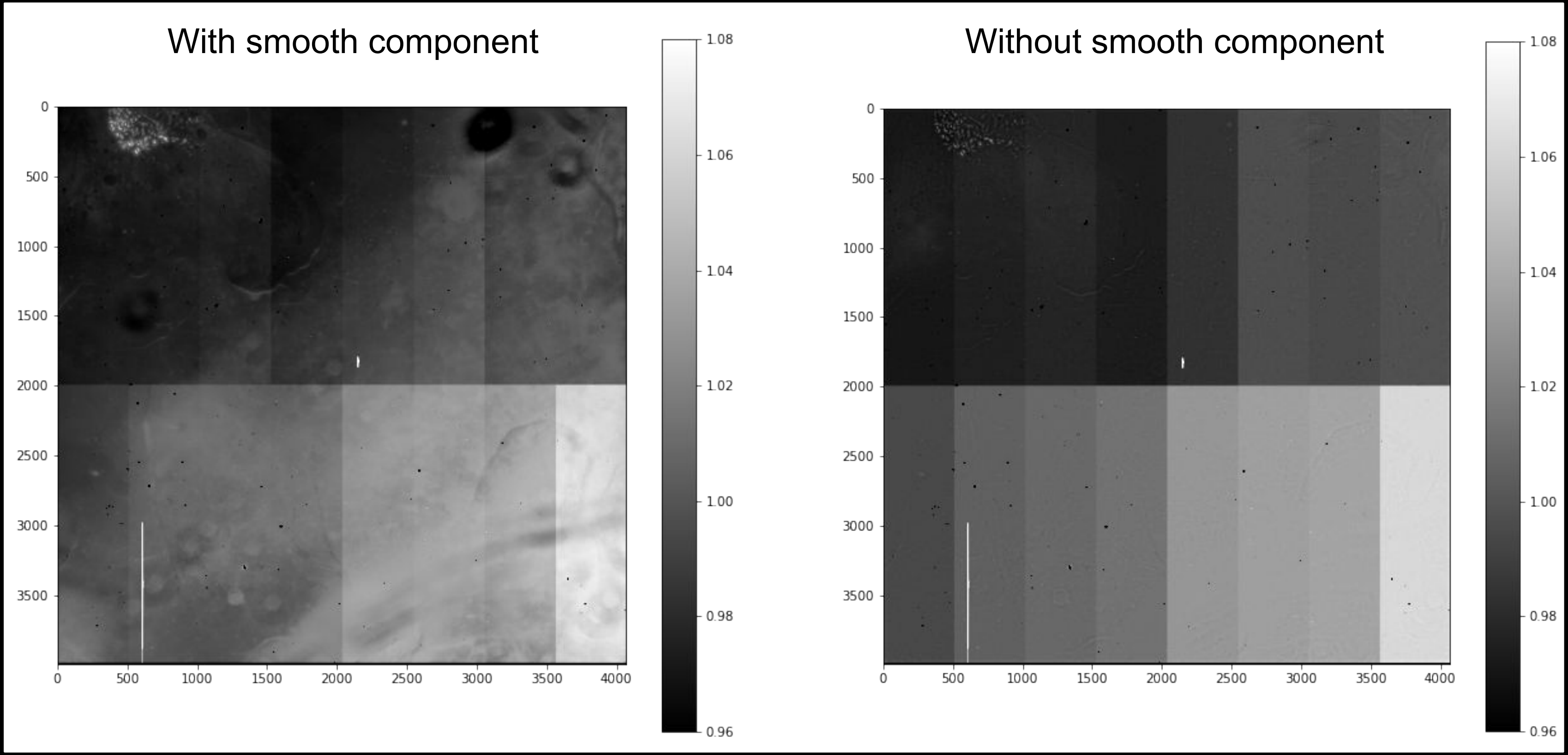
Segment numbering convention



2D median smoothing: FELH0600

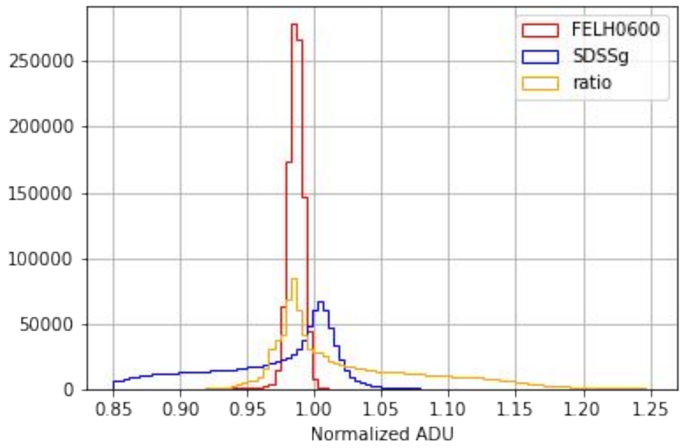


2D median smoothing: BG40

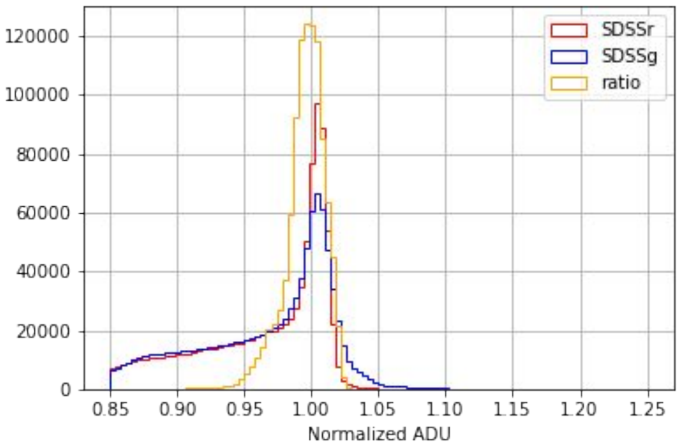


λ independence of

- The optical system is supposed to be **achromatic**
- We check the histograms **before removing** the smooth component:



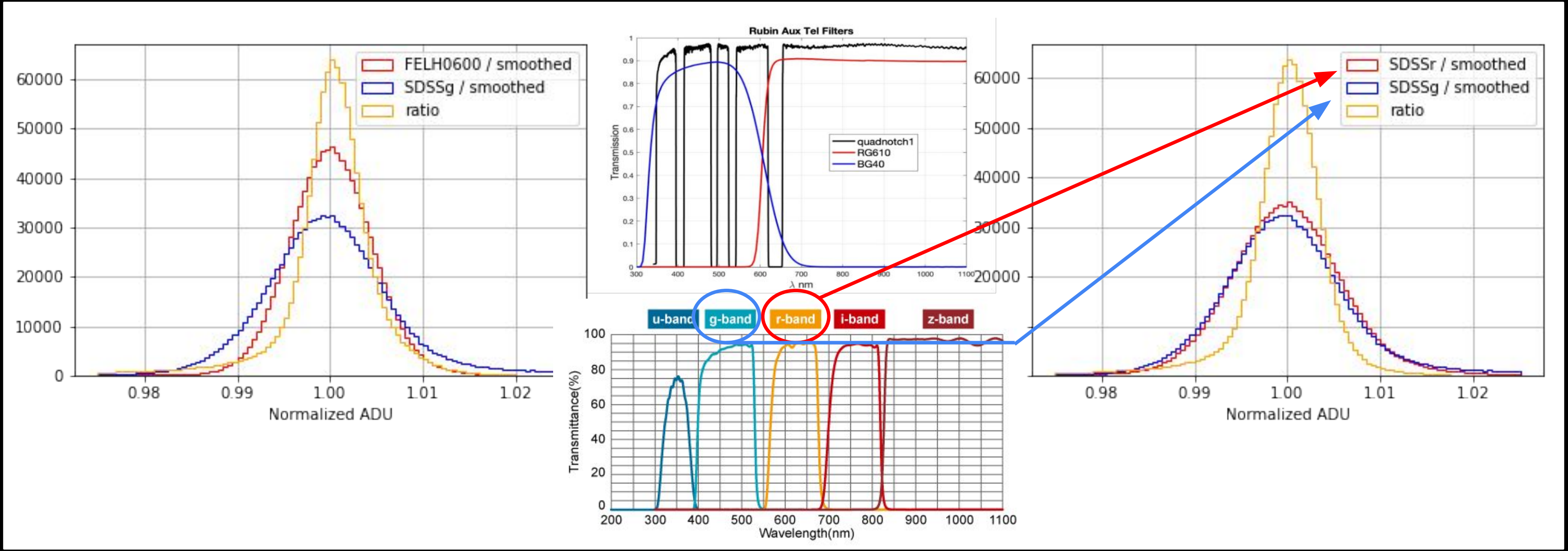
FELH0600 is bigger, so there is less vignetting coming from its frame



Identical distributions (vignetting tails) for SDSSg (bluer) and SDSSr (redder)

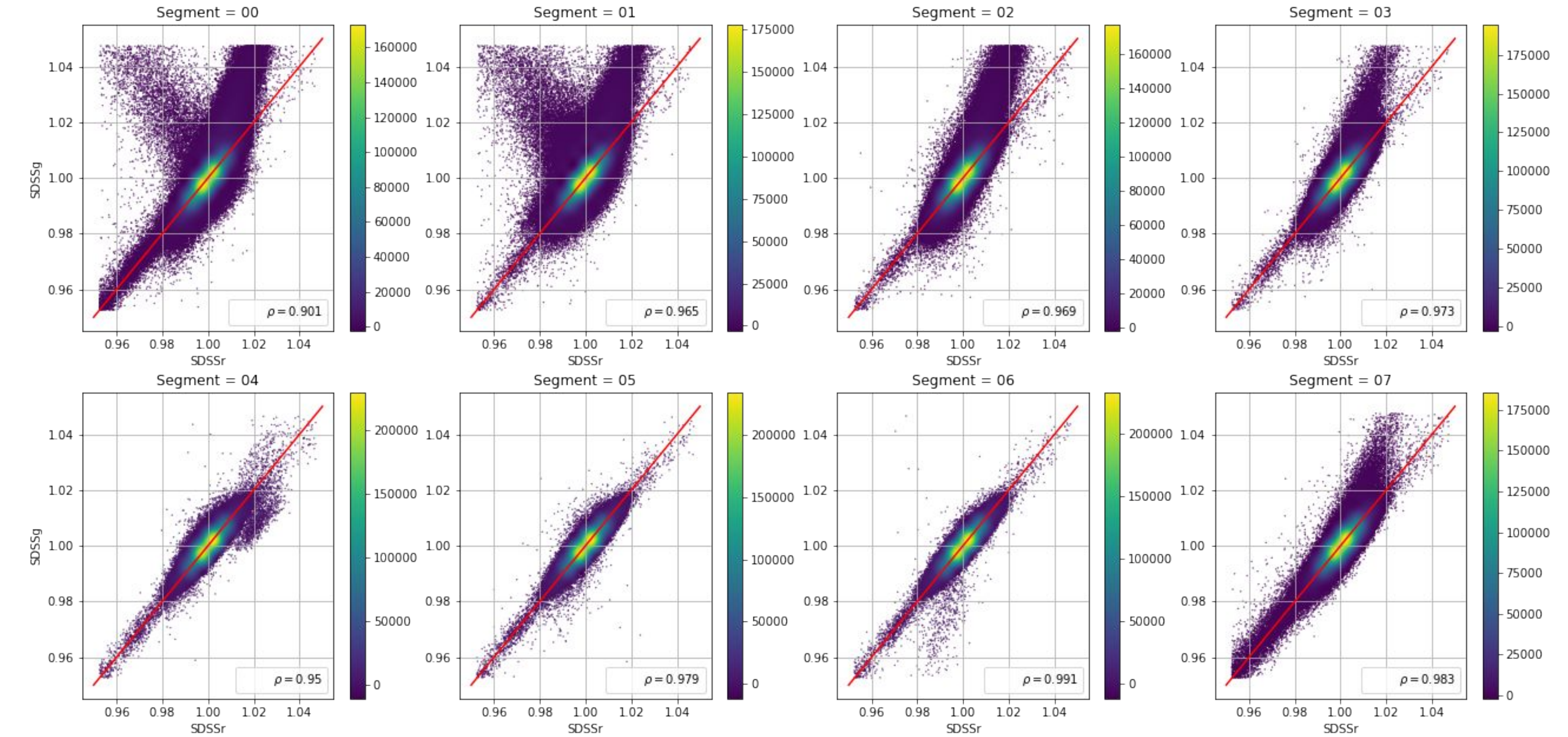
λ independence of

- The optical system is supposed to be **achromatic**
- We check the histograms **before removing** the smooth component
- **Equivalent results** for SDSSr are found after removing the smooth component



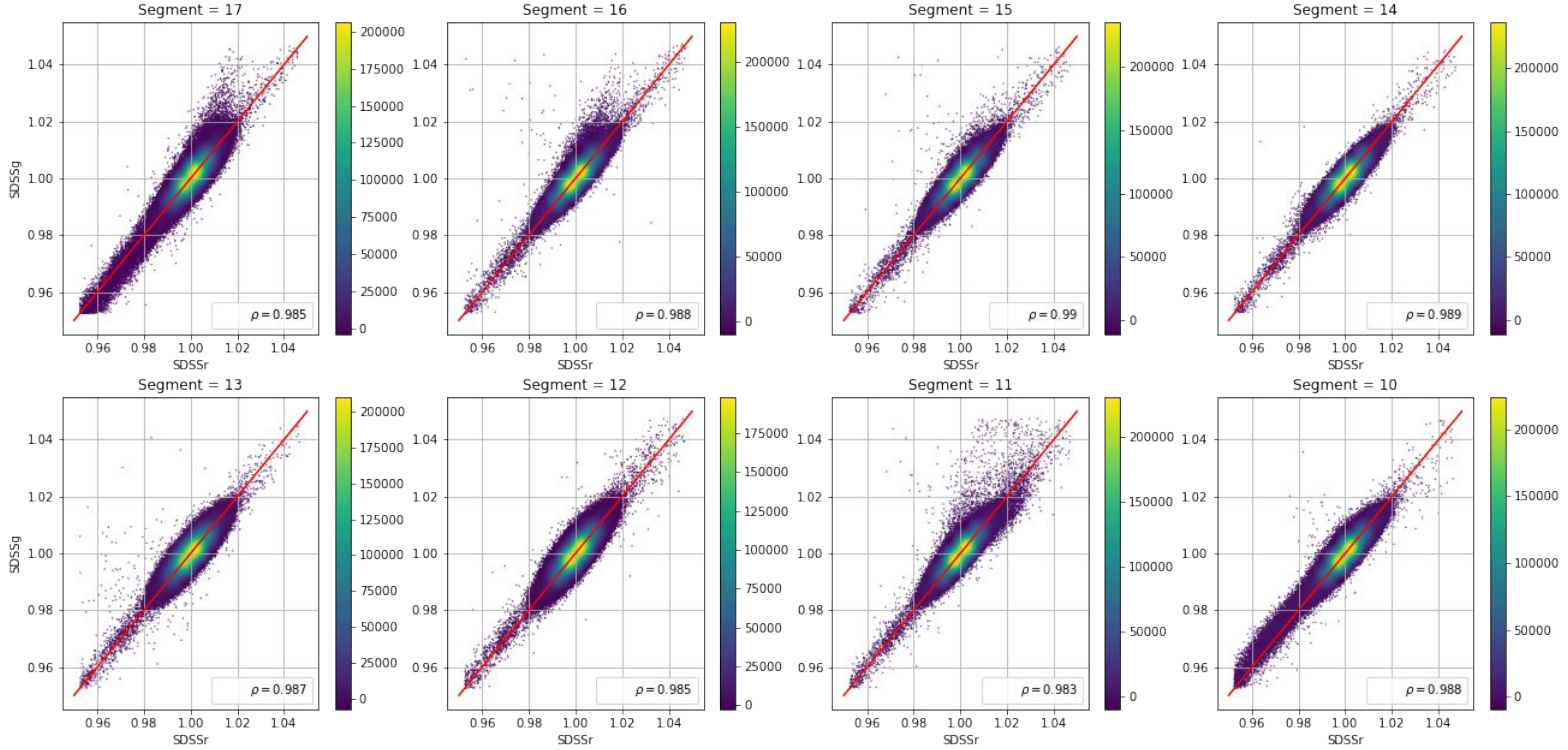
Master flats ratio: spatial correlation of pixel content

(SDSSg - SDSSr)



Master flats ratio: spatial correlation of pixel content

(SDSSg - SDSSr)



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