Flat fielding for spectra with AuxTel

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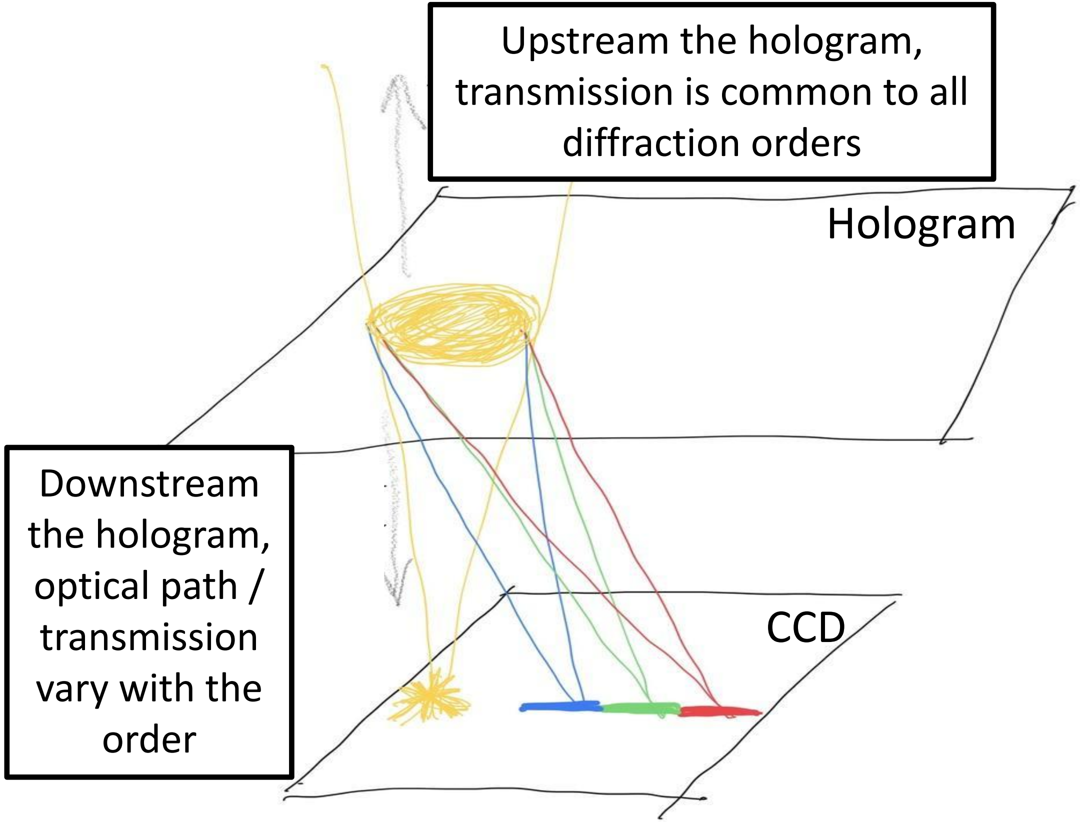
Flat-fielding in spectroscopy



Factorization of the wavelength dependence

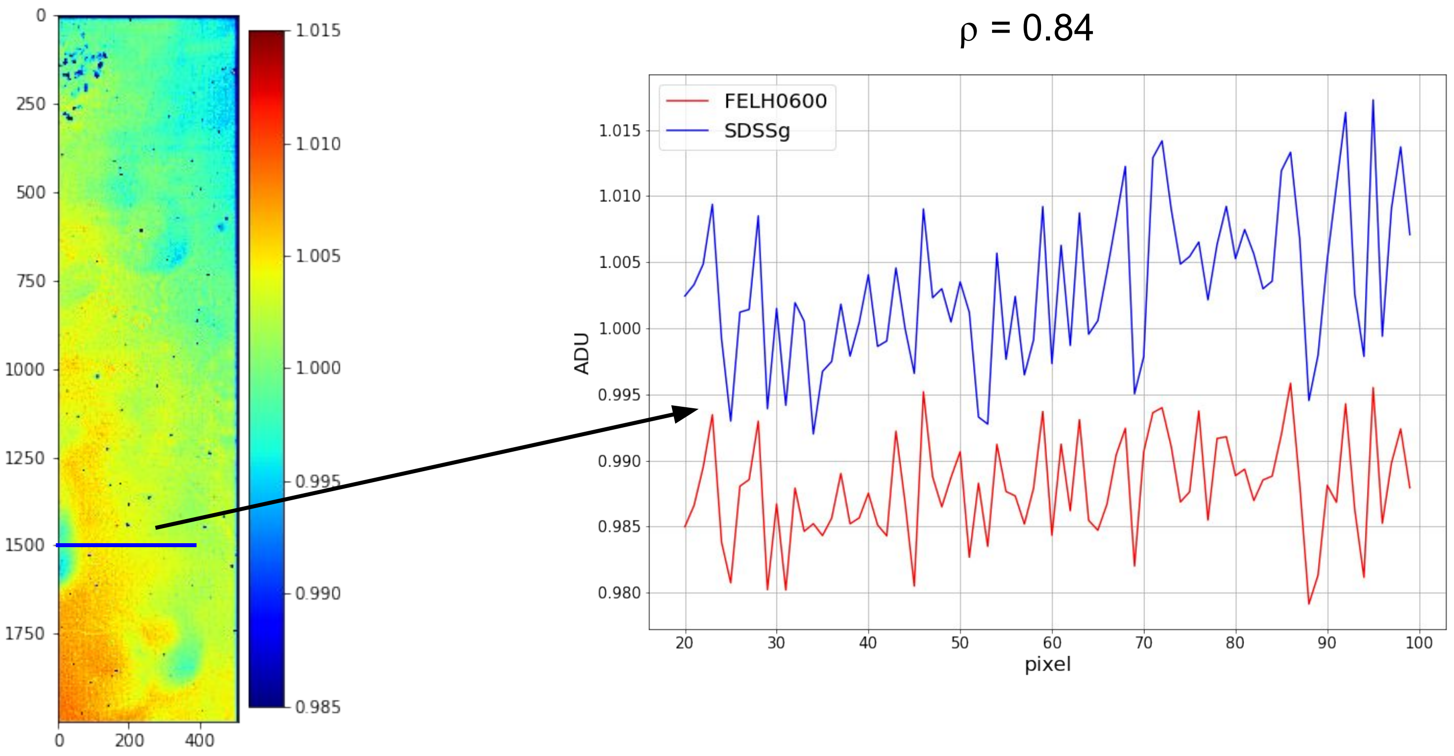
Idea:

- Evaluate spatial correlation between flats with different filters

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

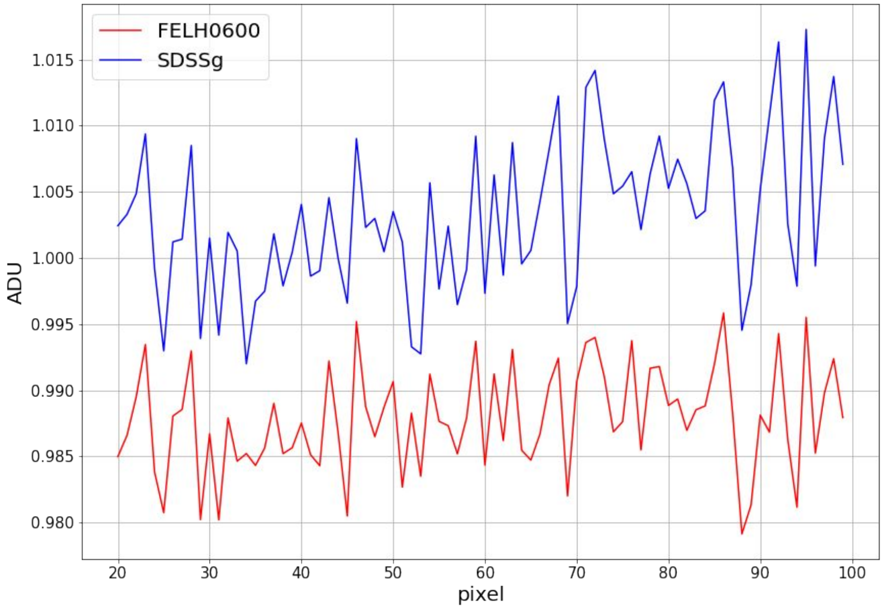
- See if can factorize out the wavelength dependency on the flats:
    - $F_{o.f.}(i,j)$ = **out of focus artifacts** (vignetting, dust on optical components) = **slow** pixel to pixel variation (real space) or **low** spatial frequency (Fourier space)
    - $F_{CCD}(i,j,\lambda)$ = **focused artifacts** (dust on the CCD, pixel surface variations) = **fast** pixel to pixel variation or **high** spatial frequency
    - We examine the **hypothesis** of $F_{CCD}(i,j,\lambda) = G_{CCD}(i,j) \times \varepsilon_{CCD}(\lambda)$
- 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**

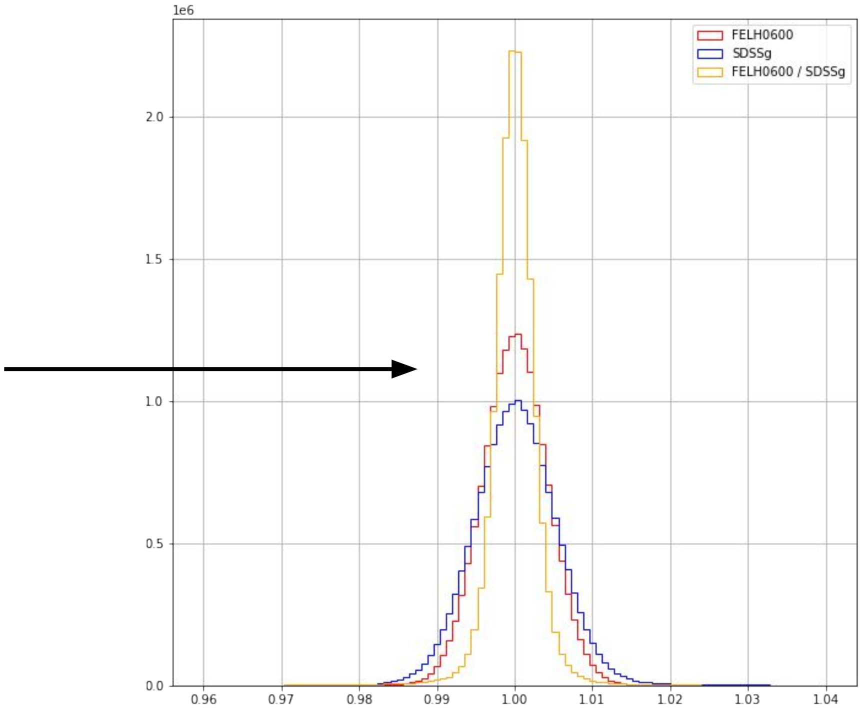
Factorization of the wavelength dependence: pixel correlation



Factorization of the wavelength dependence: pixel correlation

ρ = 0.84

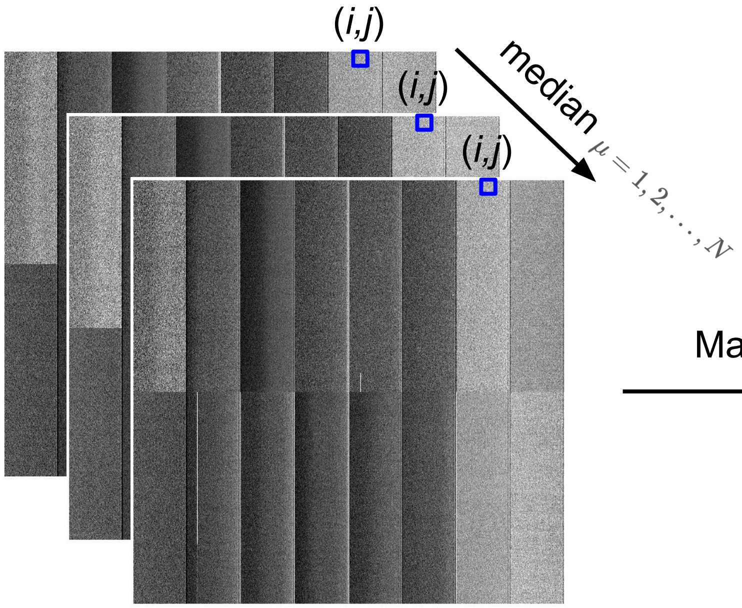




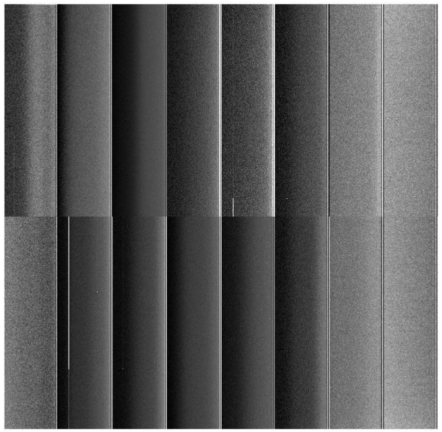
Steps: master bias

- We start with a set of *N* bias images: $B^{(\mu)}(i,j)$ ($\mu = 1, 2, \ldots, N$)
- 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,

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



Master bias →



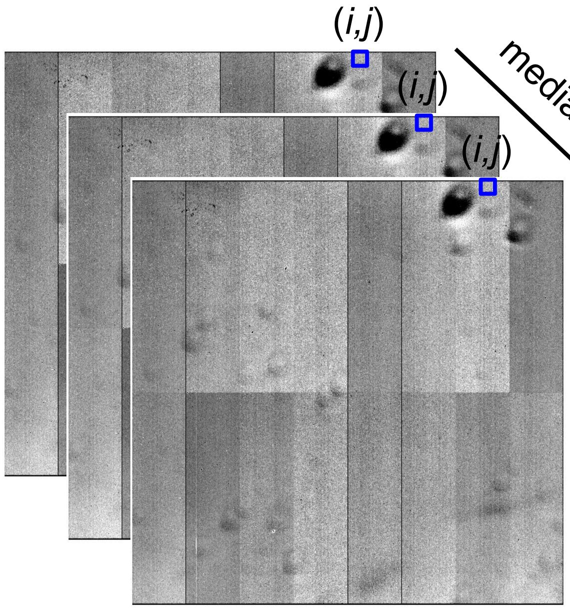
Steps: master flats

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

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

Steps: master flats

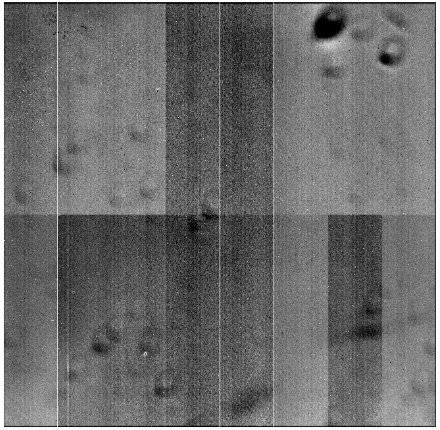
- We start with a set of *N* flat images with a given filter *b* (FELH0600, SDSSr, SDSSg): $F_b^{(\mu)}(i,j)$ ($\mu = 1, 2, \ldots, N$), where $F_b^{(\mu)}(i,j) = F_b^{(\mu)}(i,j) - \mathcal{B}$
- We take the **median over all pixels** for each image and **normalise** by it: $F_b^{\prime(\mu)}$



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

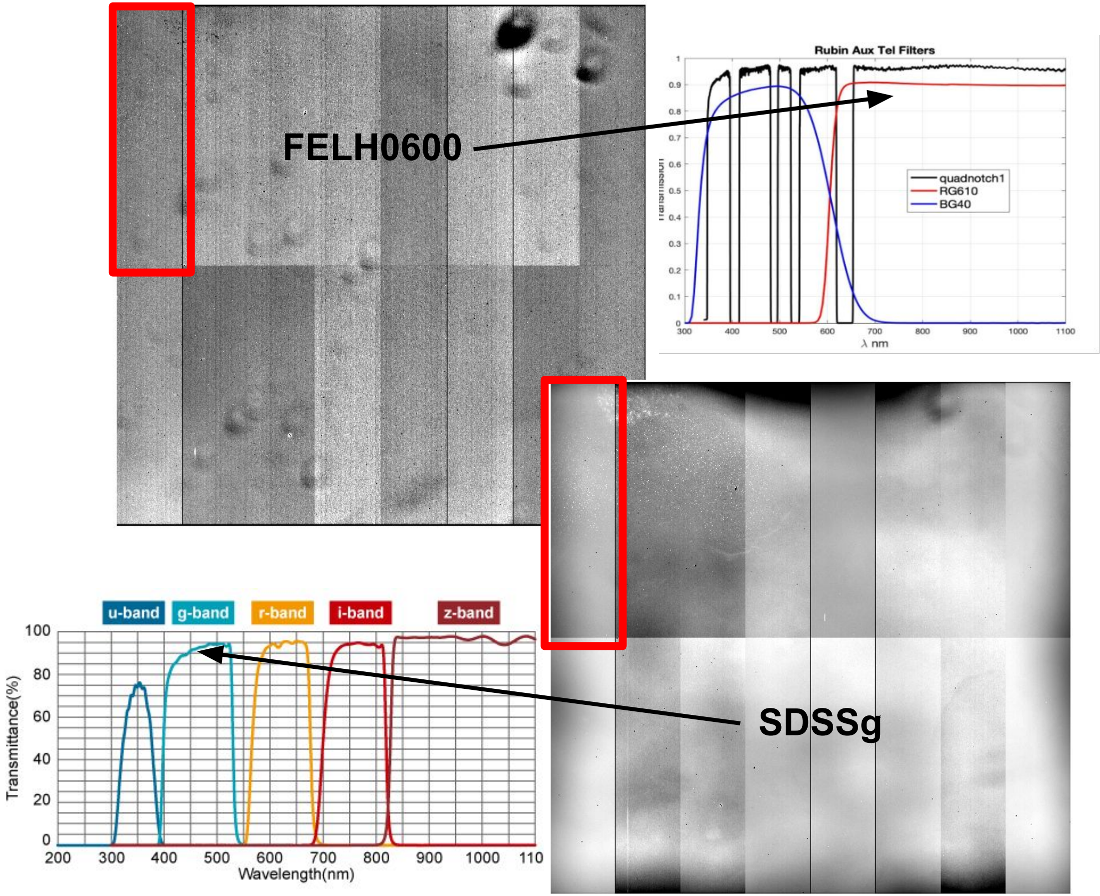
- We take the **median** over the *N* $F_b^{\prime(\mu)}$ flats at each pixel (*i*,*j*): $\tilde{F}_b \quad | \quad \tilde{F}_b(i,j) = median_\mu\left(F_b^{\prime(\mu)}(i,j)\right)$

"Master flat"



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)
- We do this process for each register / segment separately
  - To account for gain variations



Steps: master flats

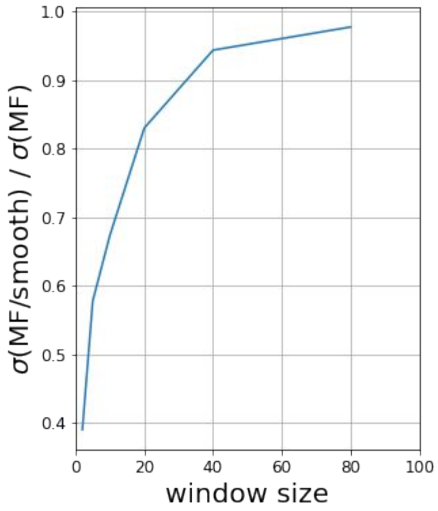
- We start with a set of *N* flat images with a given filter *b* (FELH0600, SDSSr, SDSSg): $F_b^{(\mu)}(i,j)$ ($\mu = 1, 2, \ldots, N$), where $F_b^{(\mu)}(i,j) = F_b^{(\mu)}(i,j) - \mathcal{B}$
- We take the median over all pixels for each image and normalise by it: $F_b'^{(\mu)}$
- We take the **median**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

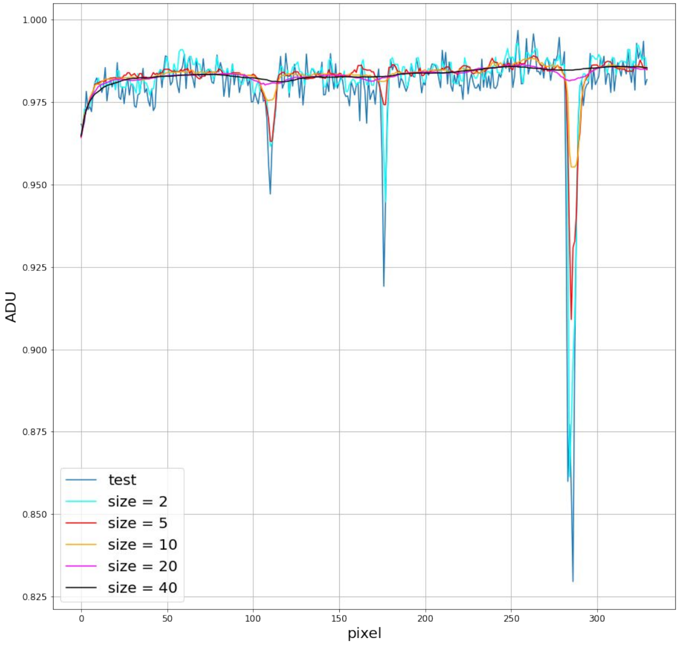
$$\tilde{F}_b \rightarrow \mathcal{F}_b \quad | \quad \mathcal{F}_b(i,j) = \frac{\tilde{F}_b(i,j)}{f_b(i,j)}$$

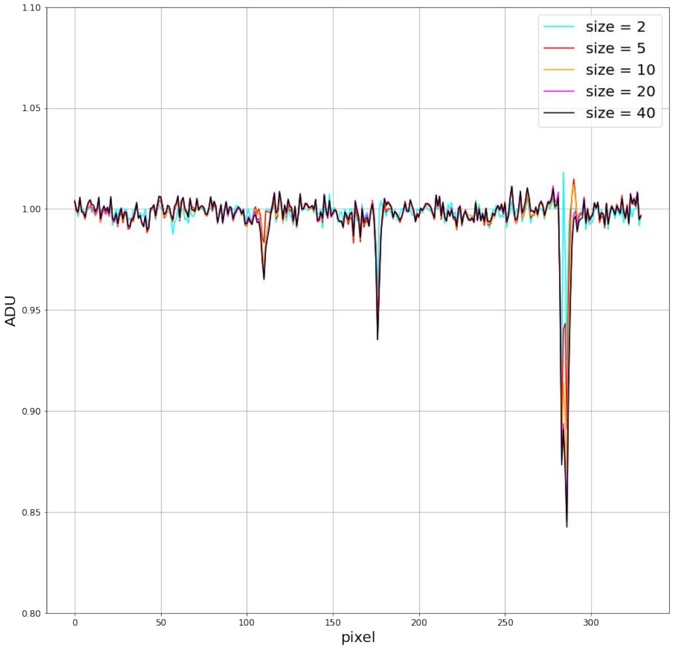
2D median smoothing

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

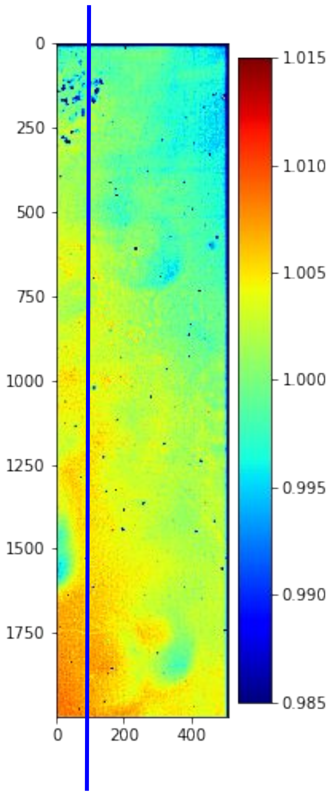
σ(F/smooth) / σ(F)



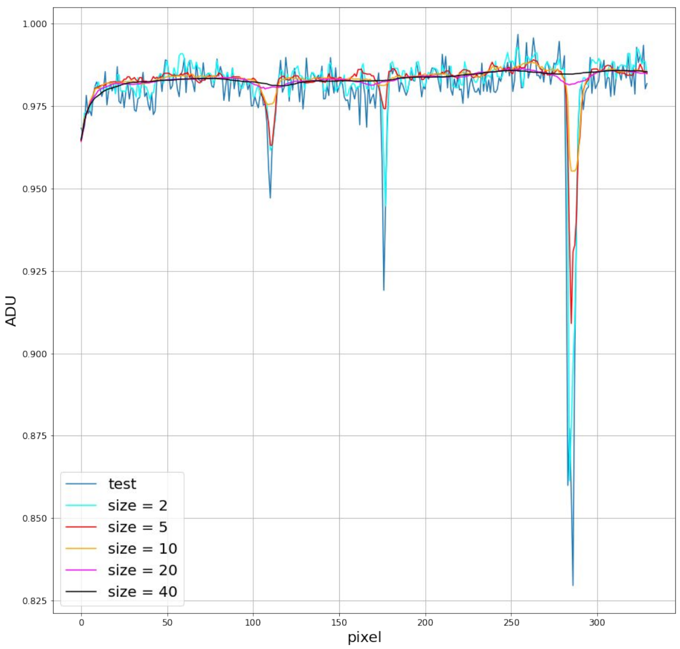


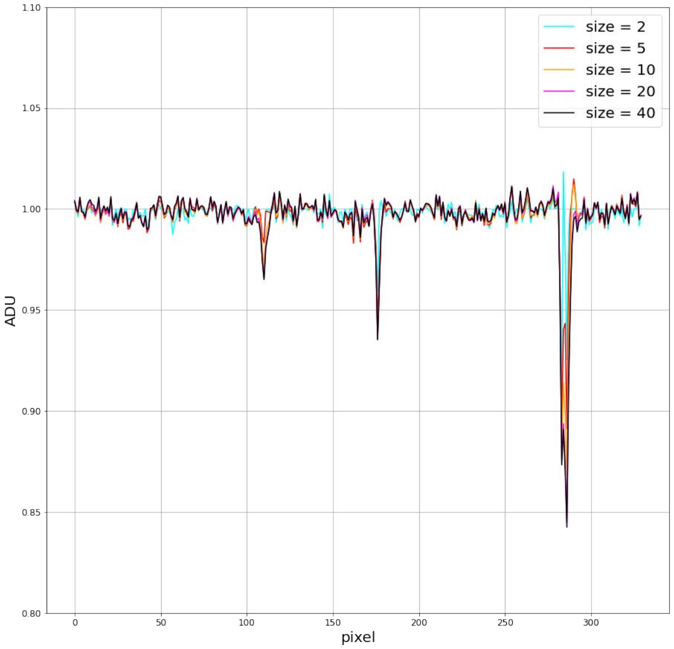


2D median smoothing



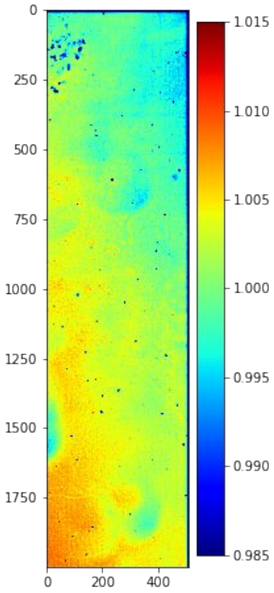
Profile of a column **before and after** removing the smooth component



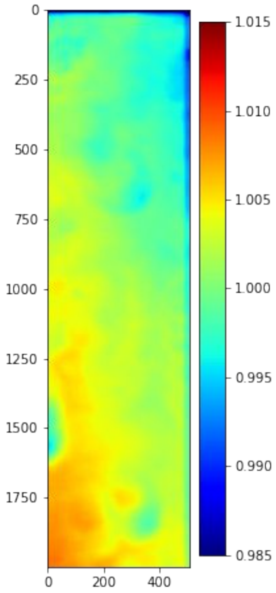


2D median smoothing

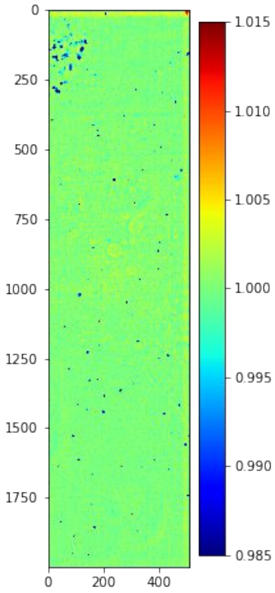
Master flat



Smoothed

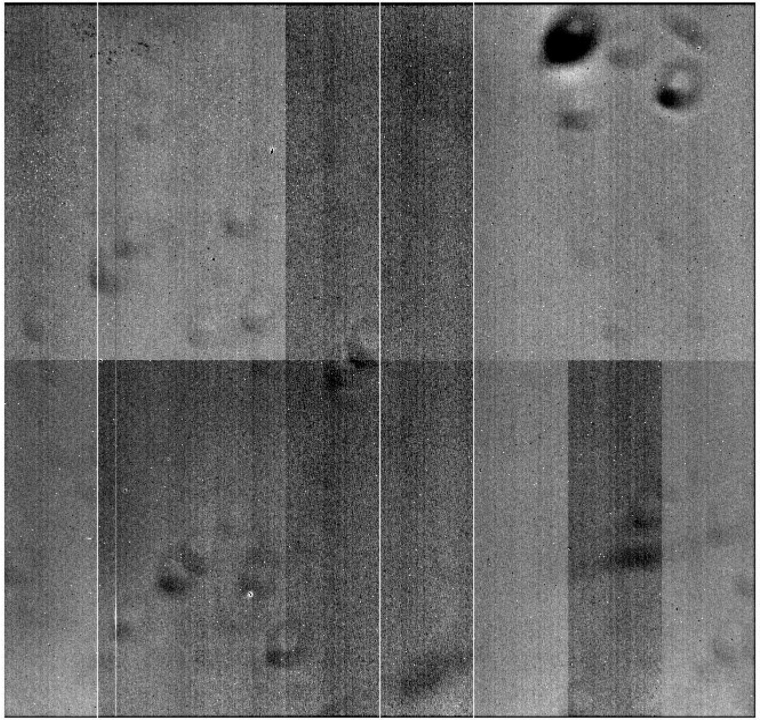


Master flat / smoothed

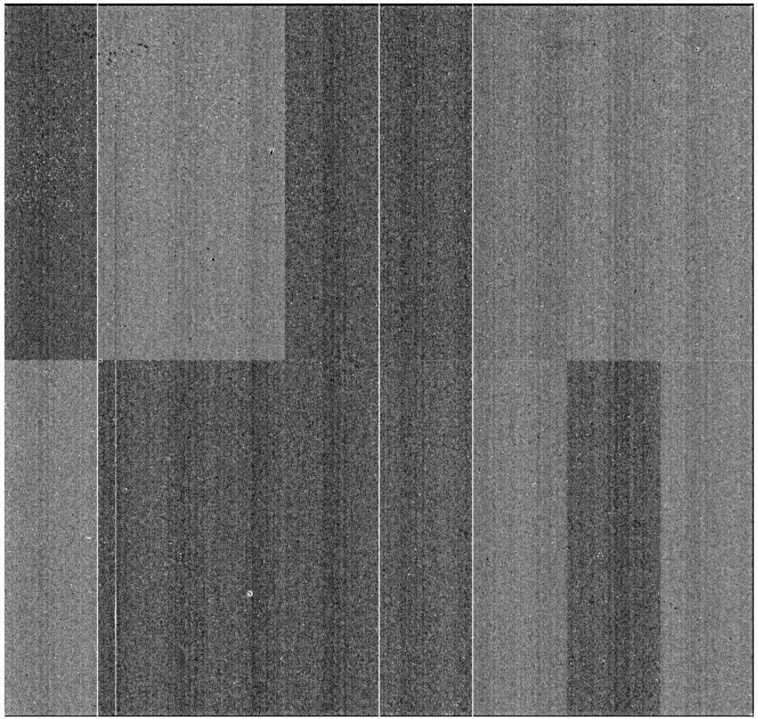


2D median smoothing

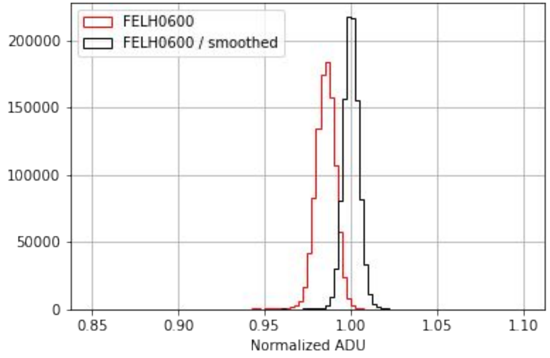
Master flat (low + high frequency)

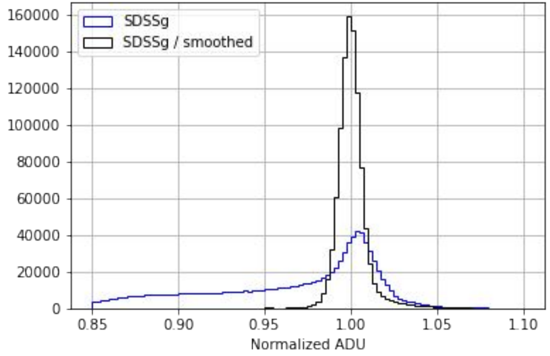


Master flat (high frequency)

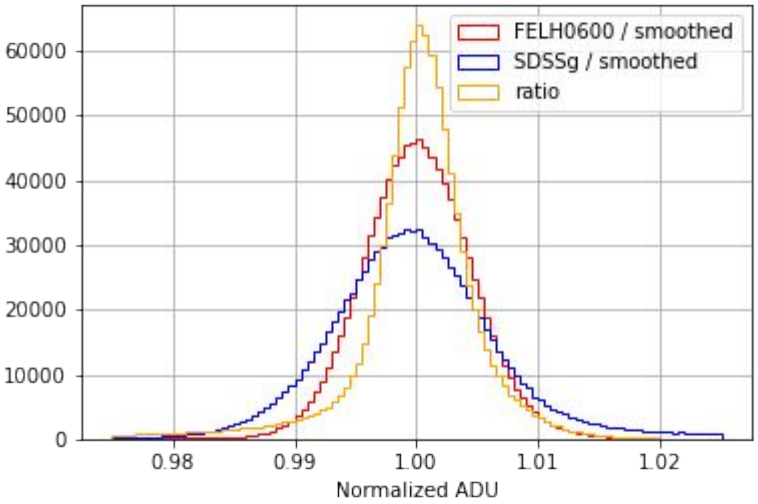


Master flats ratio

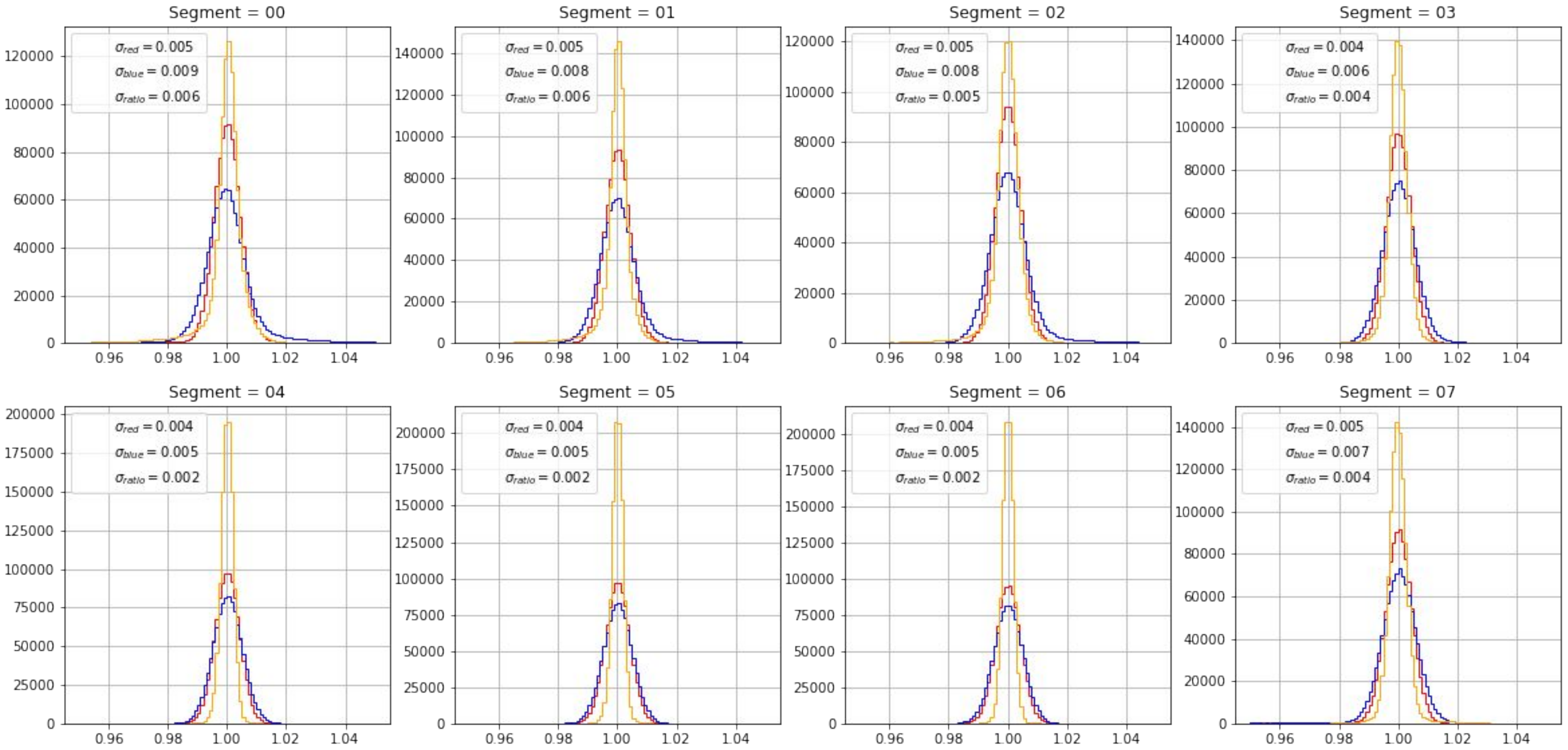




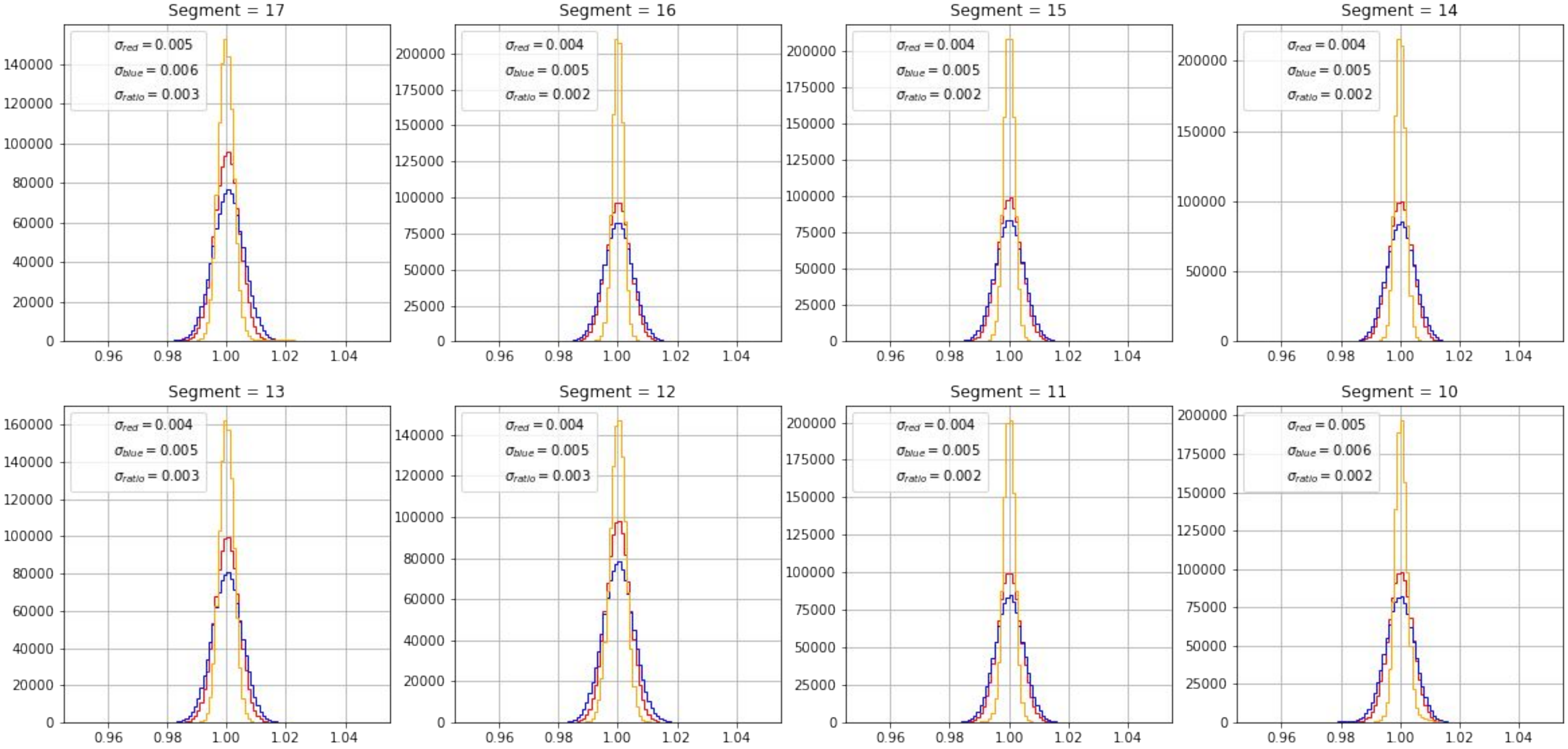
Ratio of the (high frequency only) master flats



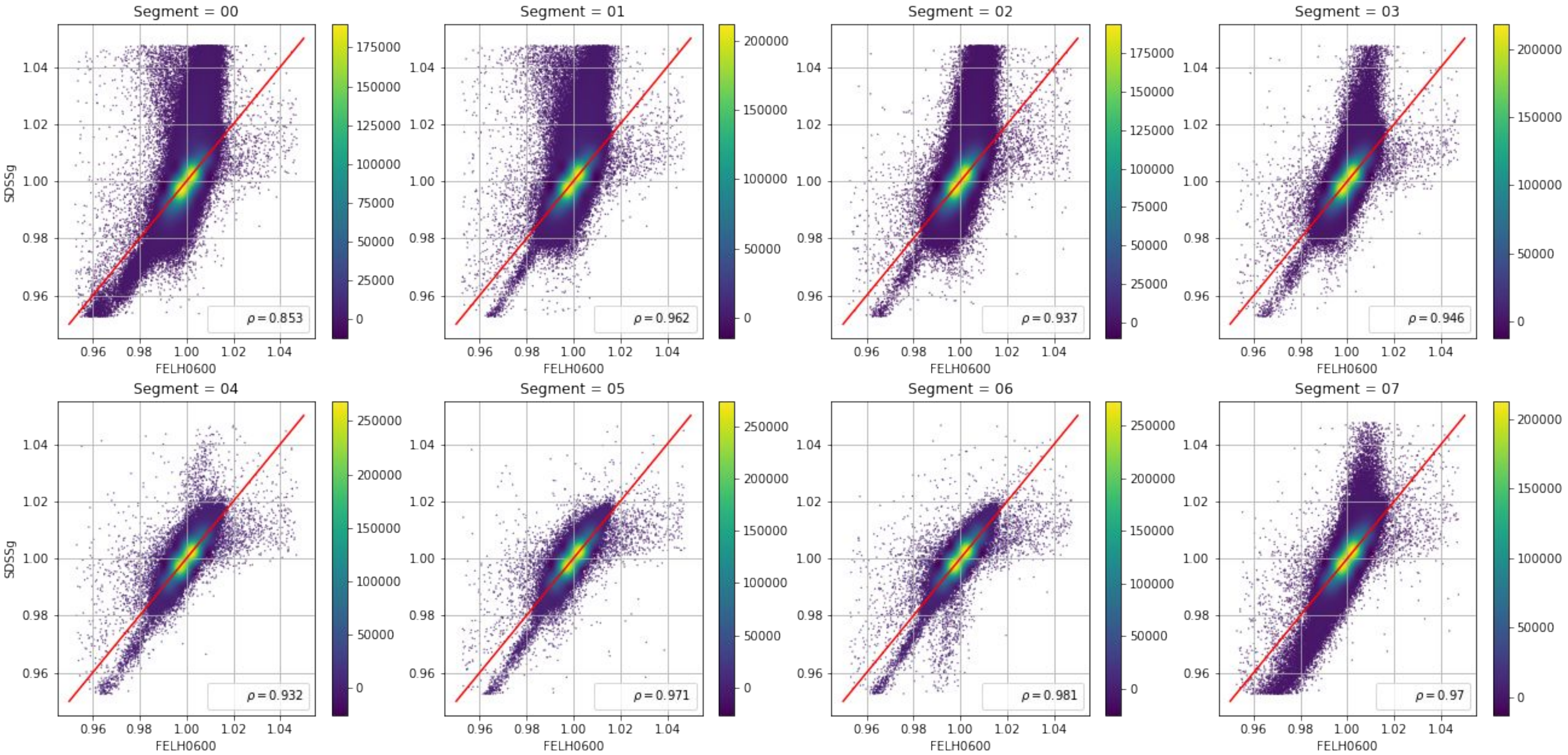
Master flats ratio



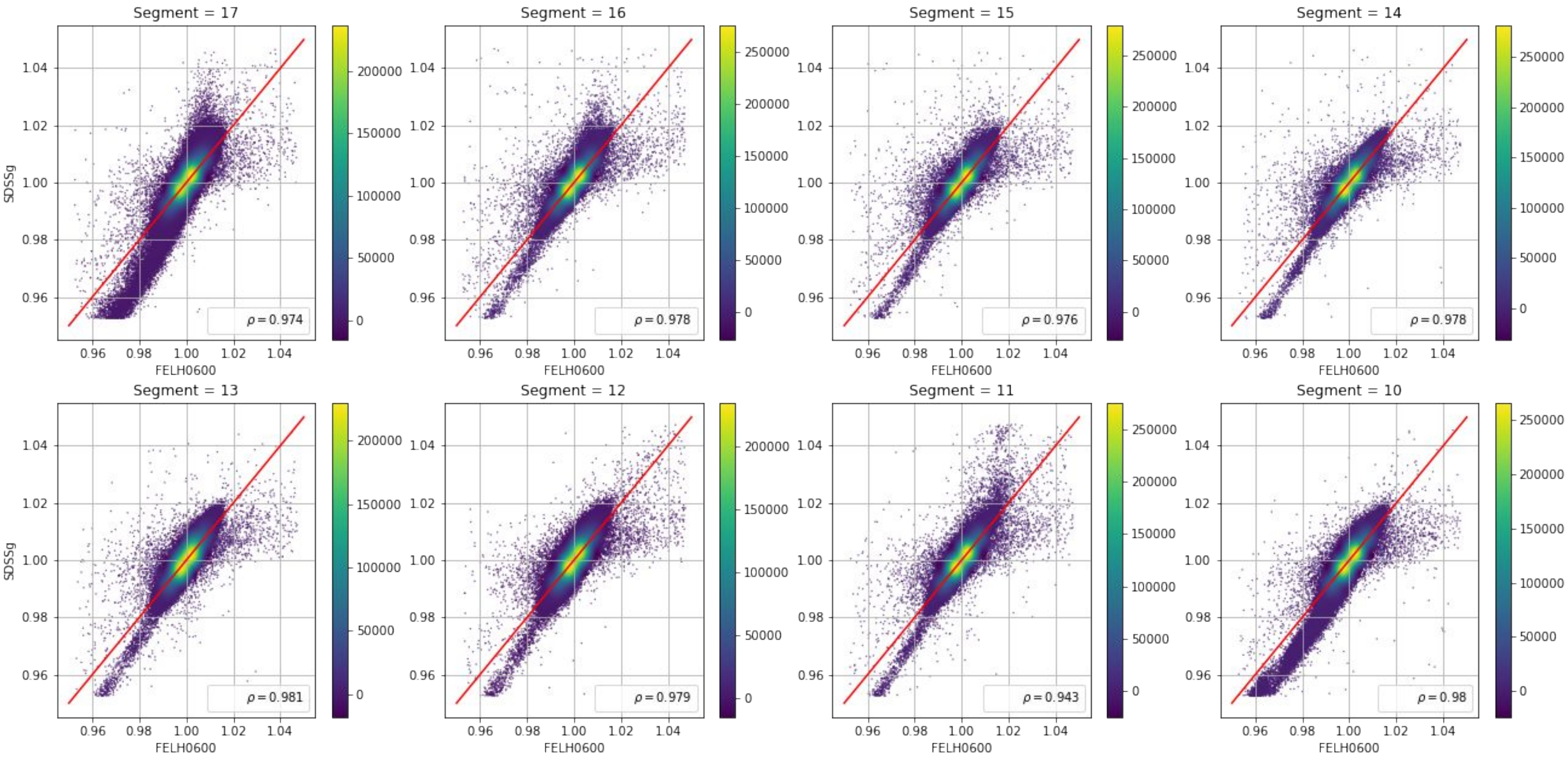
Master flats ratio



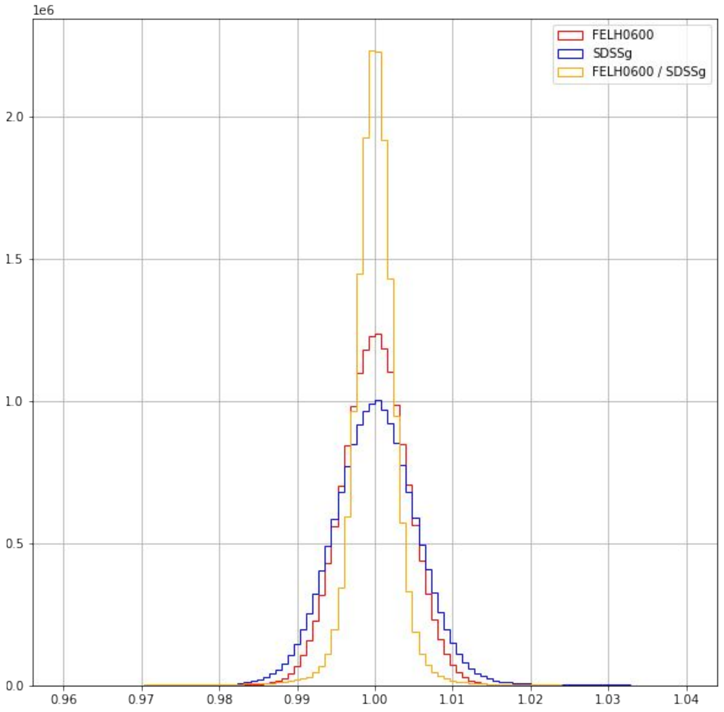
Master flats ratio: spatial correlation of pixel content



Master flats ratio: spatial correlation of pixel content

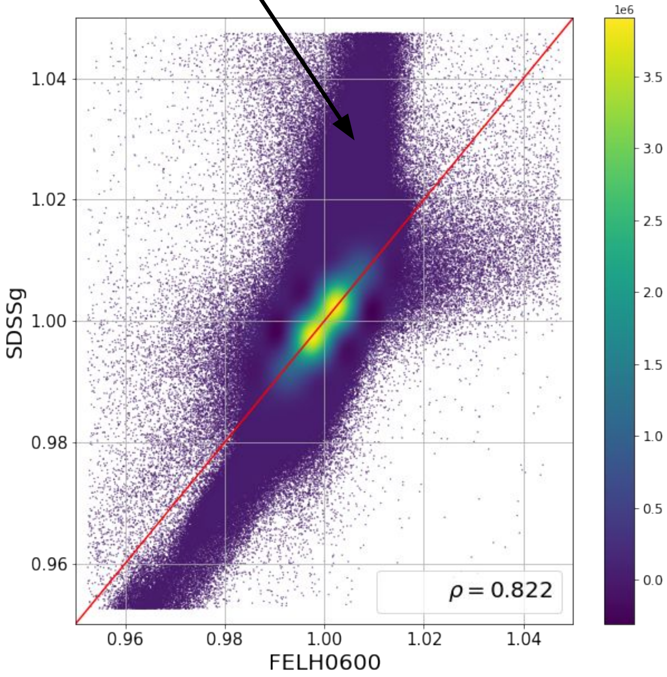


Master flats ratio: spatial correlation of pixel content

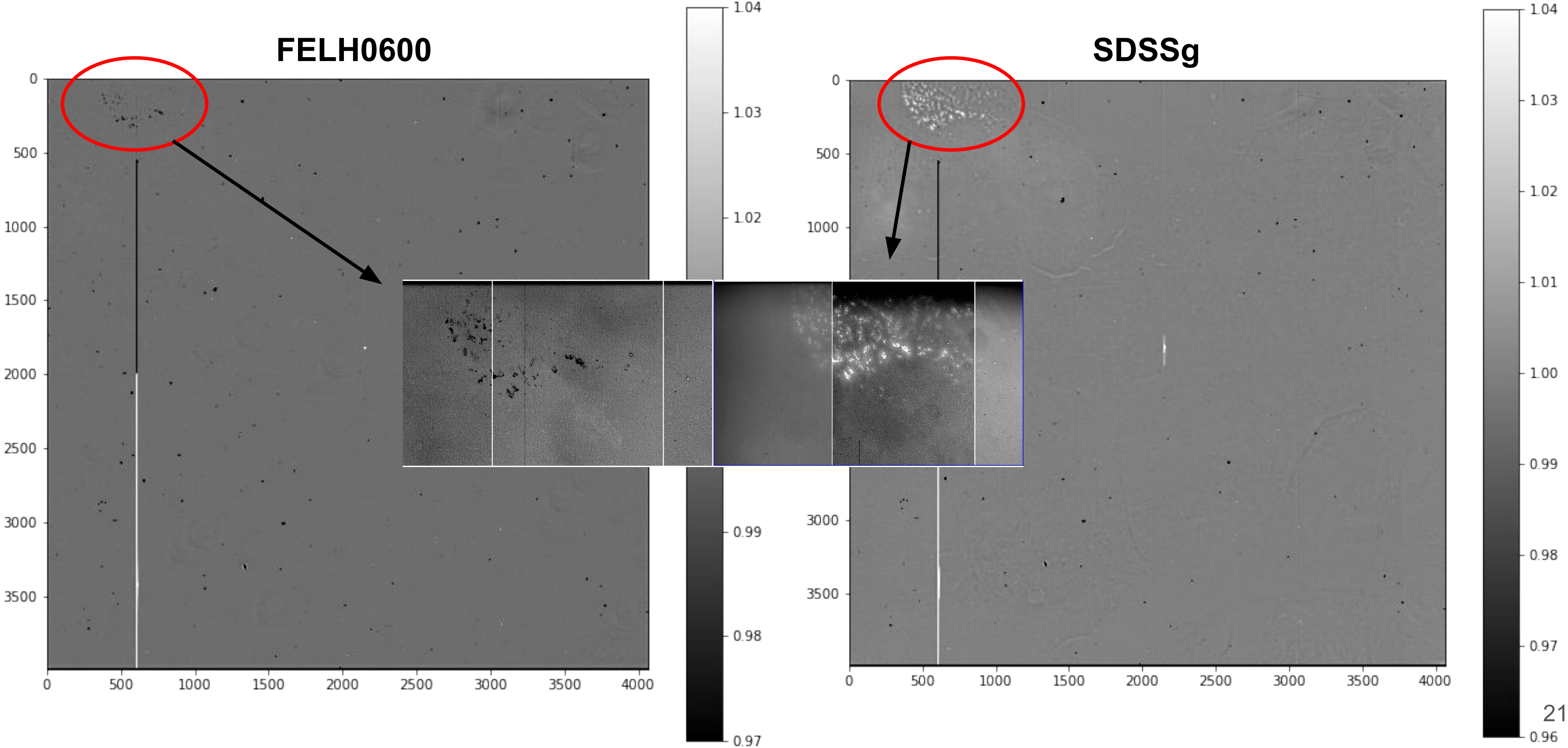


Full CCD

This seems to be due to an issue on some segments of the CCD



Master flats ratio: spatial correlation of pixel content



Conclusions and next steps

- We find a good enough spatial correlation (ρ > 0.8) between pixels in flat fields of different colours (FELH0600 and SDSSg) to **factor out the λ dependence**

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

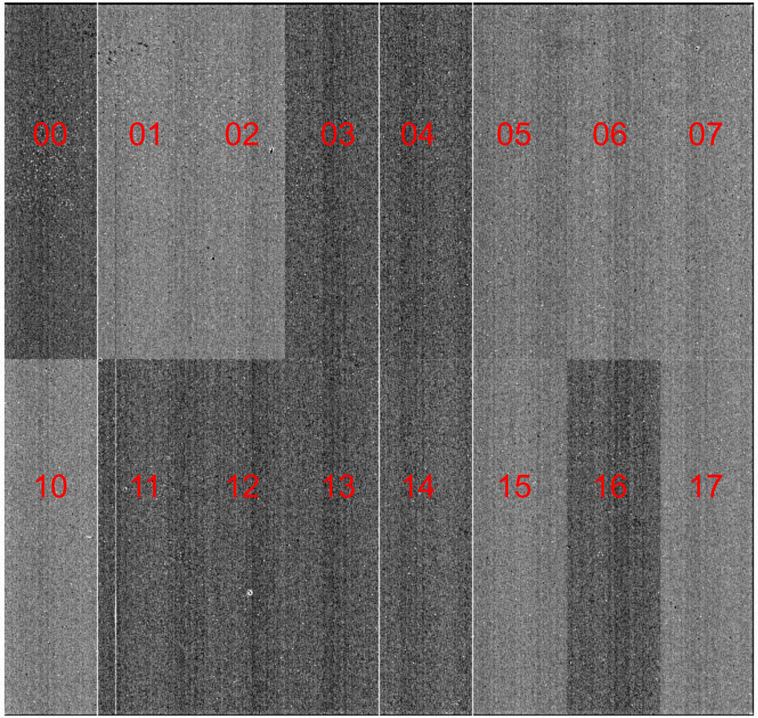
- We need to repeat this with **more filters** (more separated in wavelength)
- If results are consistent, we propose to preliminary **use a single high spatial frequency master flat** (as previously created) for AuxTel spectra deflatening

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

Merci

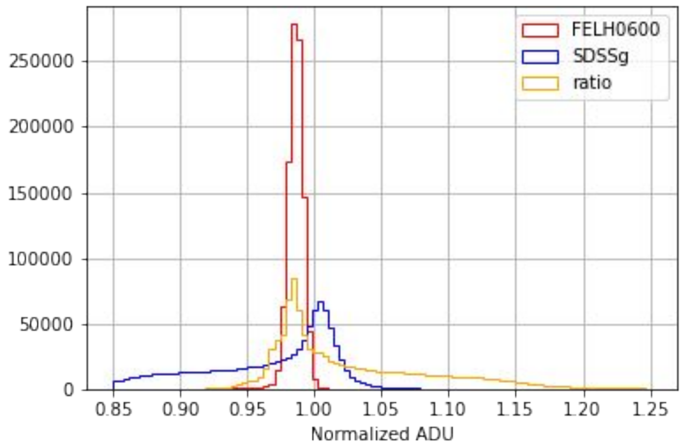
Back-up

Segment numbering convention

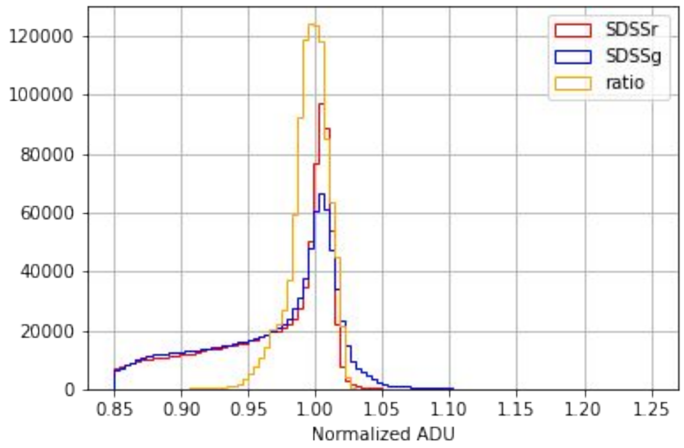


λ independence of $F_{o.f.}(i, j)$

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



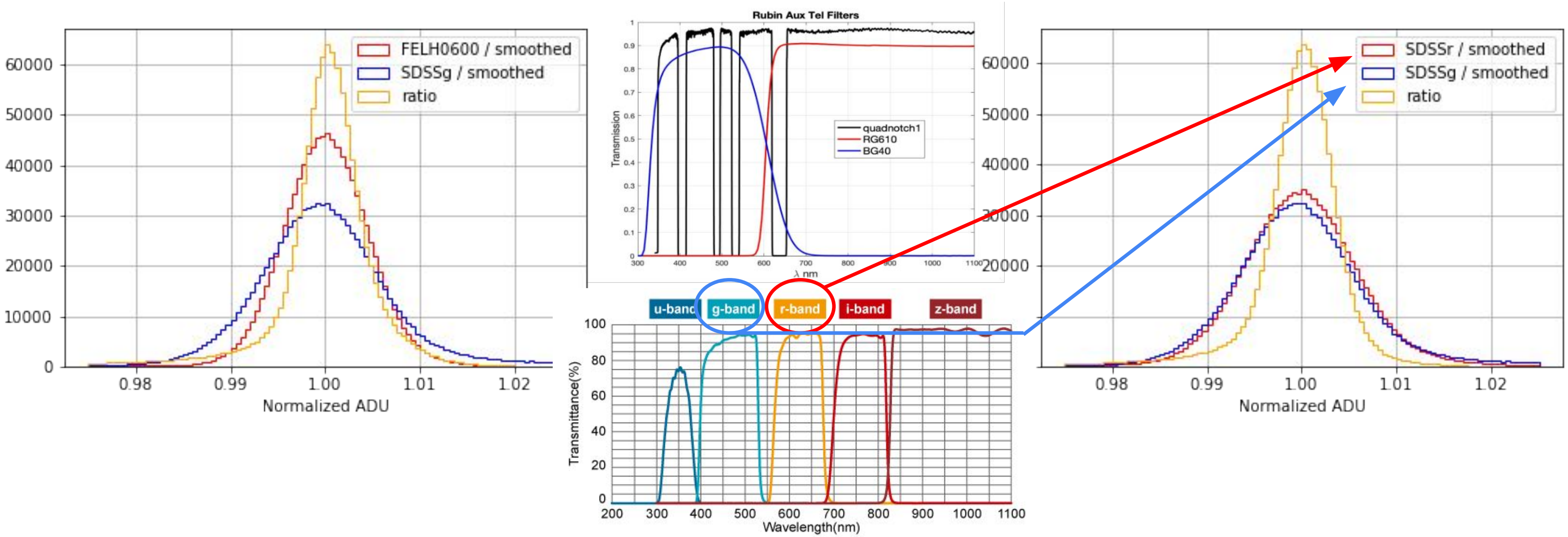
FELH0600 is bigger, so there is less vignetting coming from its frame



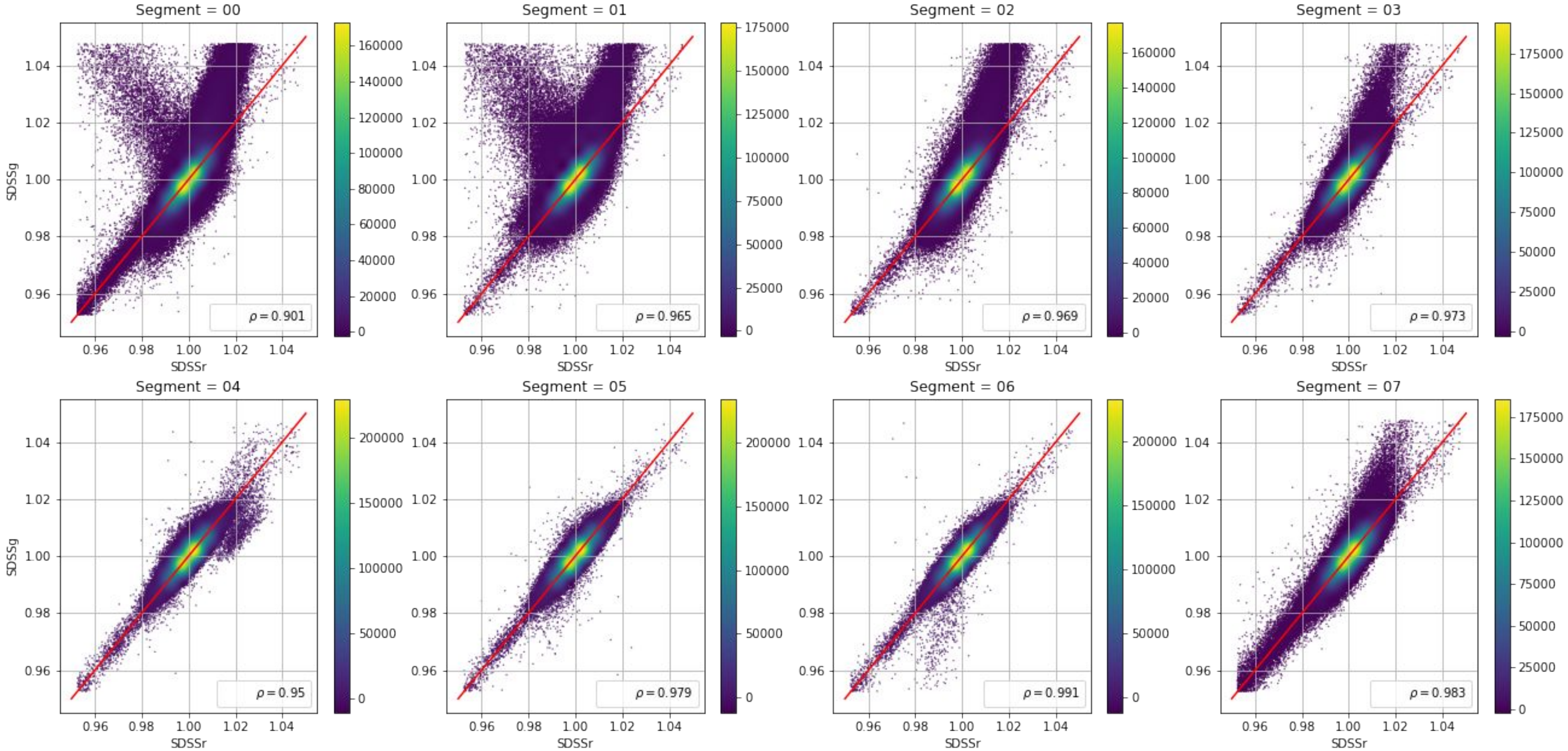
Identical distributions (vignetting tails) for SDSSg (bluer) and SDSSr (redder)

λ independence of $F_{o.f.}(i, j)$

- 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

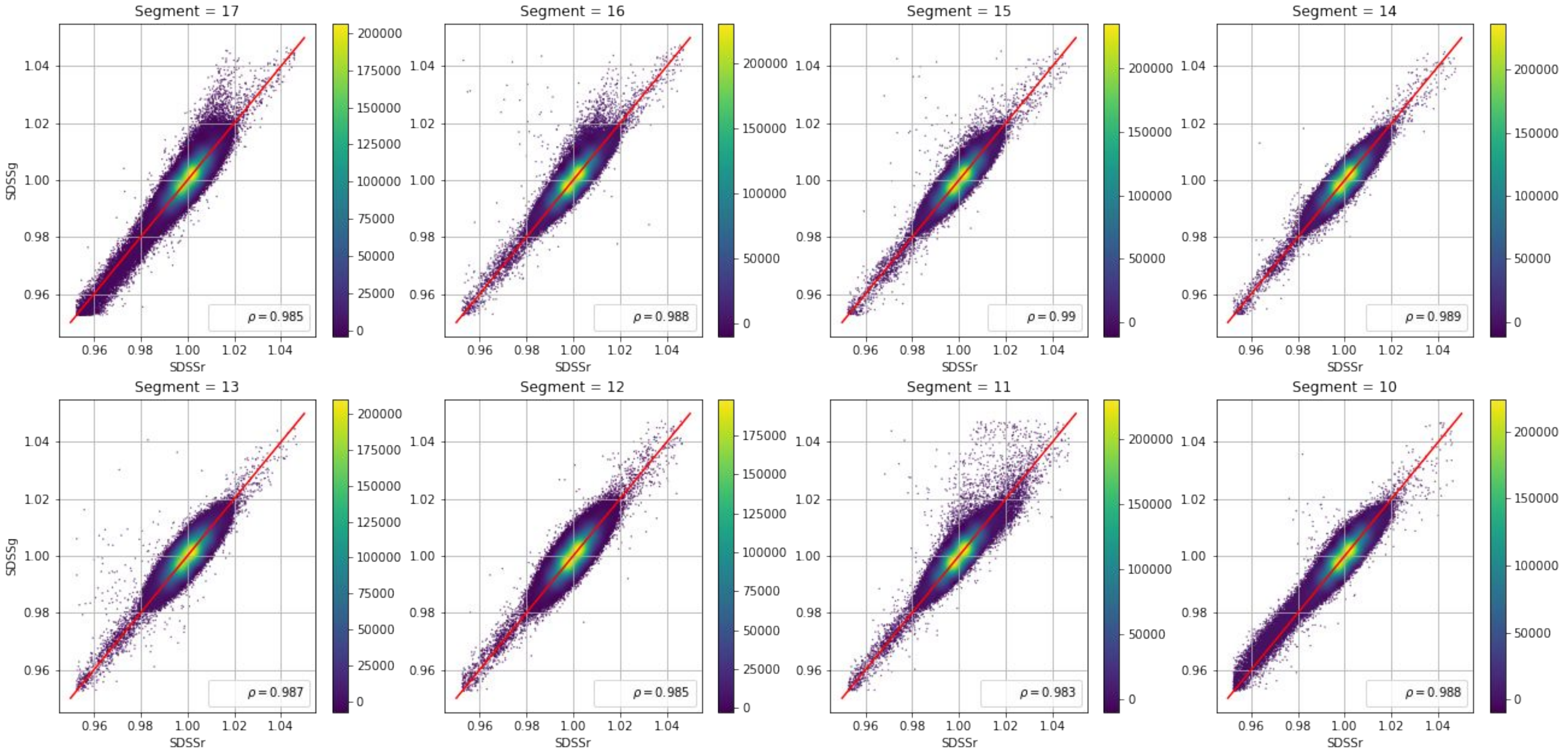


Master flats ratio: spatial correlation of pixel content
(SDSSg - SDSSr)



Master flats ratio: spatial correlation of pixel content

(SDSSg - SDSSr)



Master flats ratio: spatial correlation of pixel content

(SDSSg - SDSSr)

Full CCD