



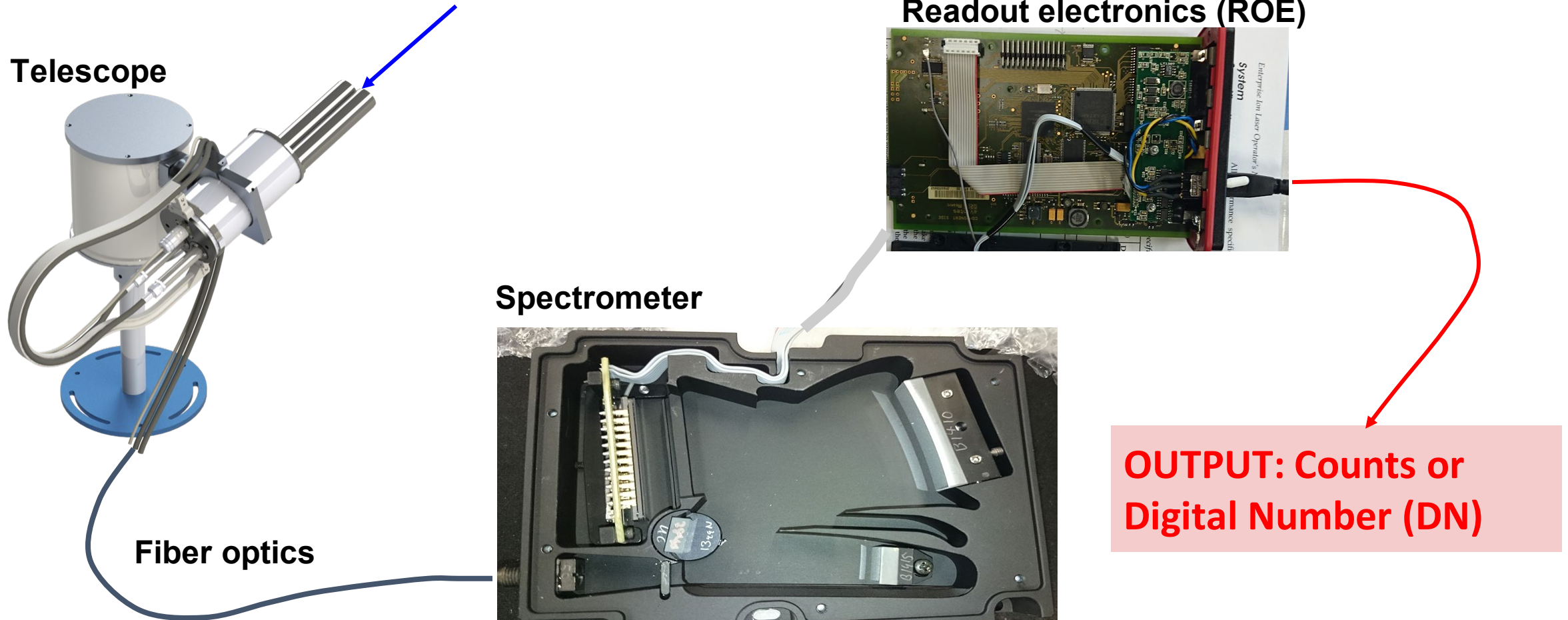
Instrument calibration part 1: Laboratory

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**Fifth Joint School on Atmospheric Composition
September 14 – 29, 2023**

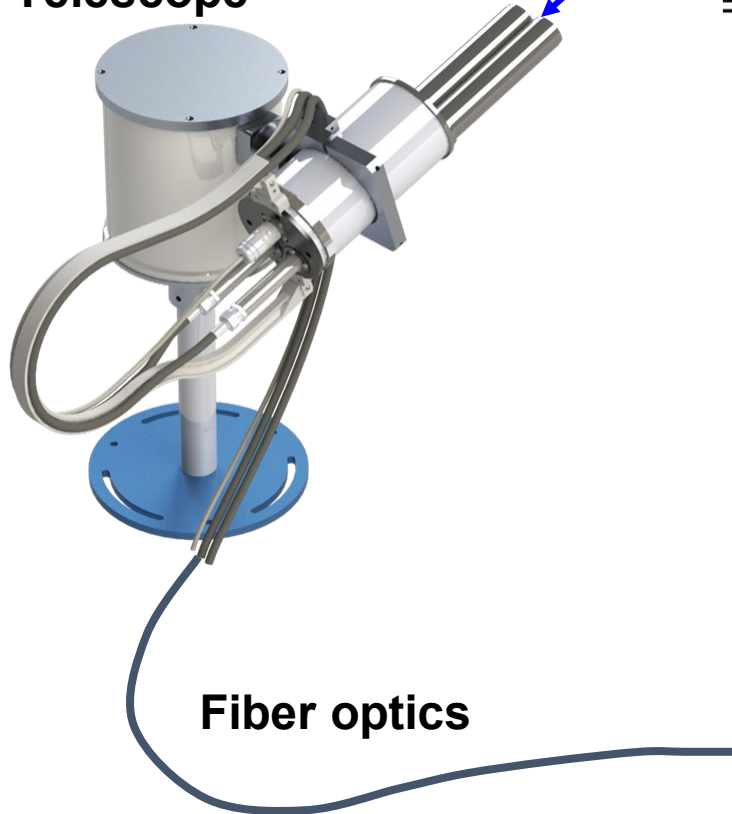
“Forward Direction”: From input flux to digital number

**INPUT: Spectral Irradiance $[W/m^2/nm]$ =
Energy received per time interval ($J/s=W$) per area (m^2) per wavelength interval (nm)**

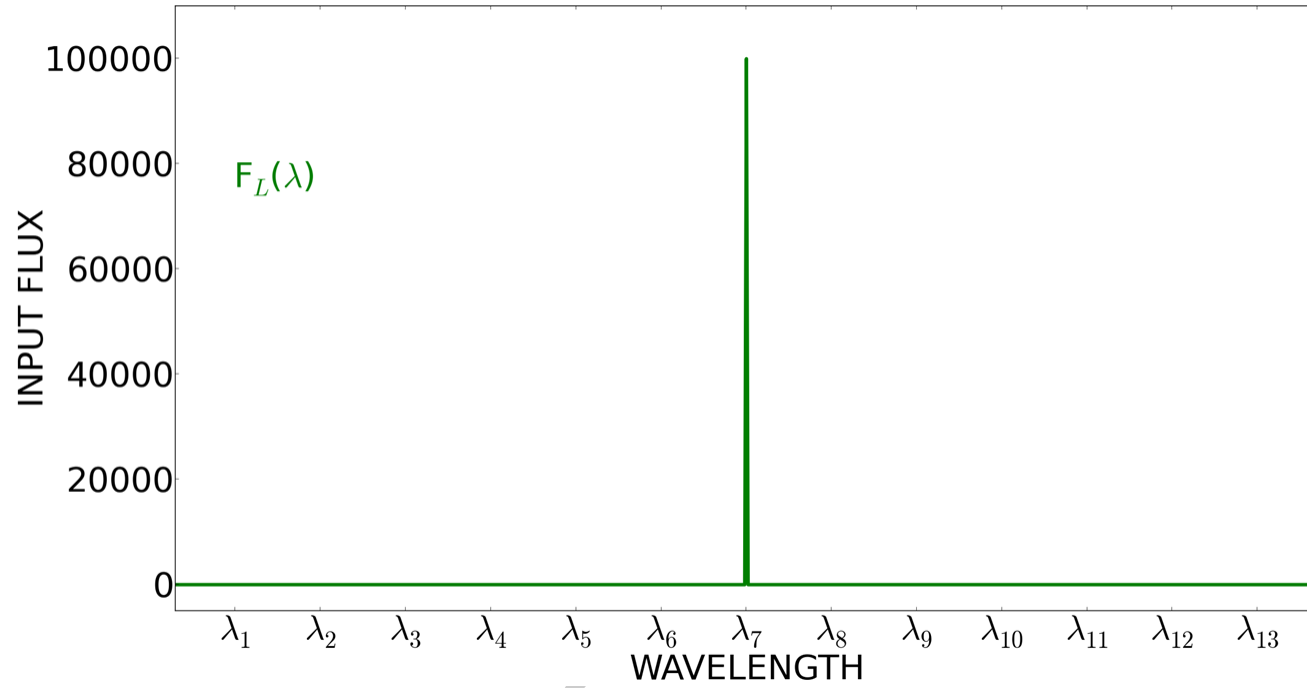


→ Follow a monochromatic input

Telescope



Fiber optics



Spectrometer



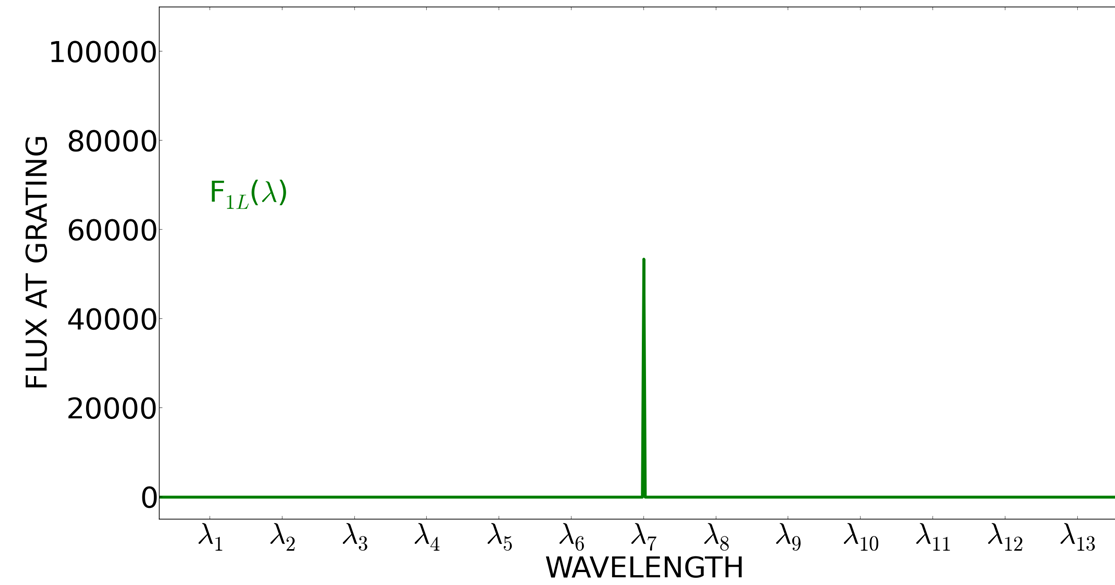
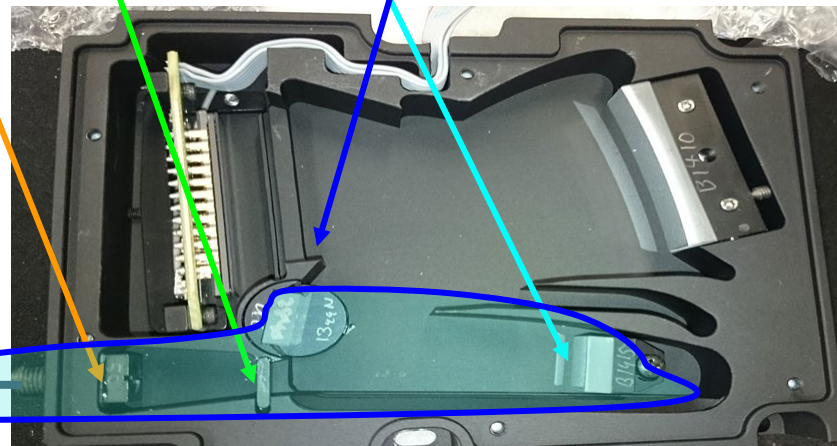
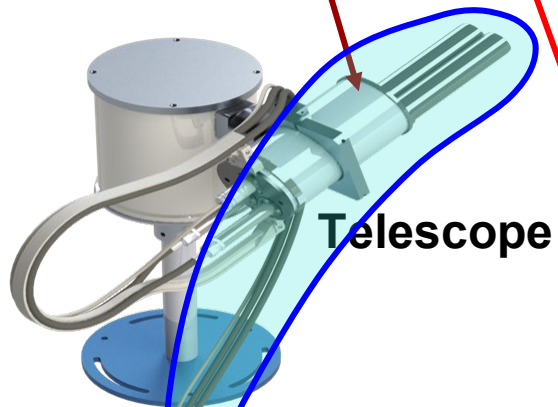
Flux at grating

the telescope ...

the fiber ...

the entrance slit ...

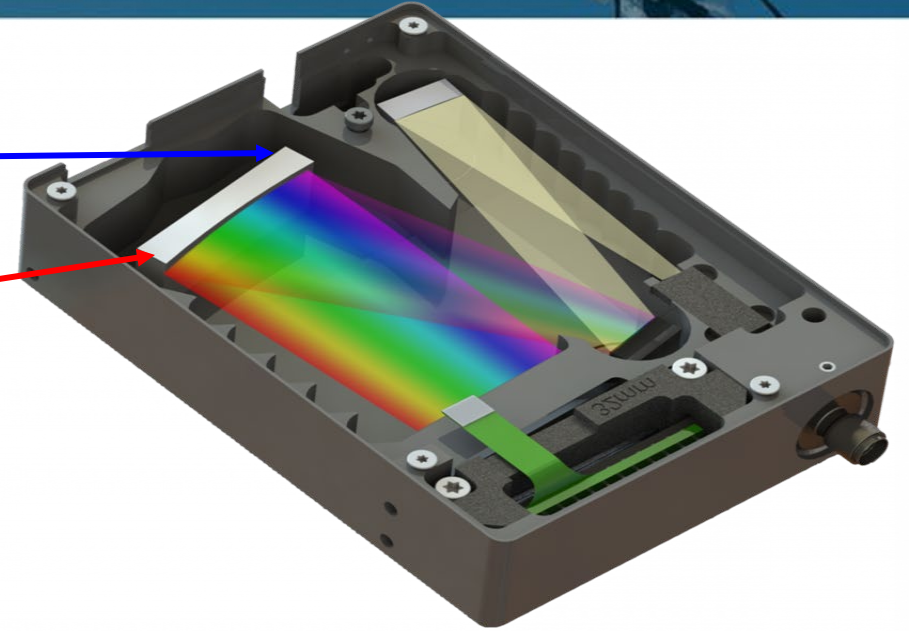
an aperture ...



Dispersion

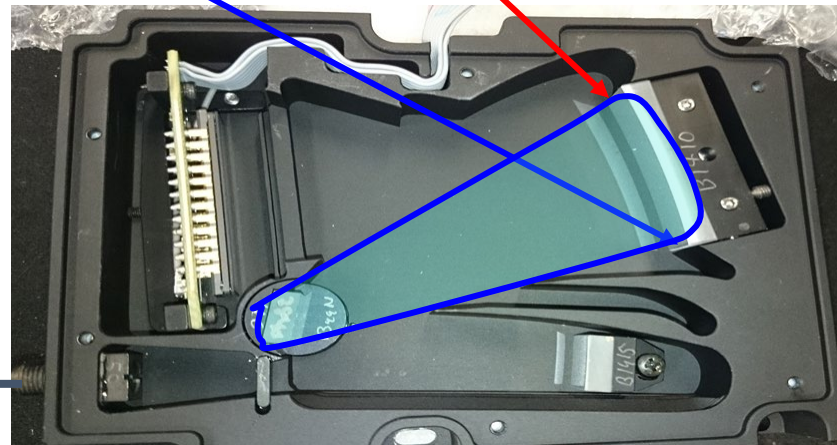
Lower wavelengths reach the 2nd mirror at one end.

Higher wavelengths reach the 2nd mirror at the other end.



Telescope

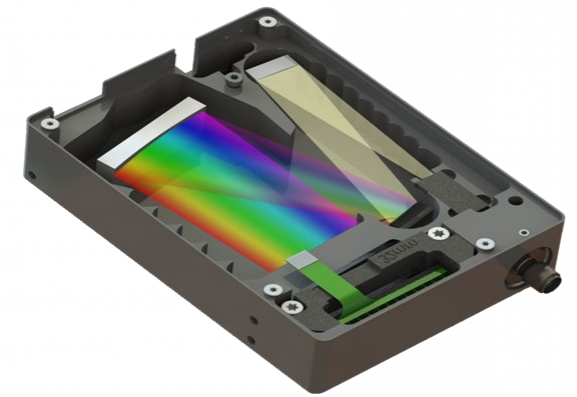
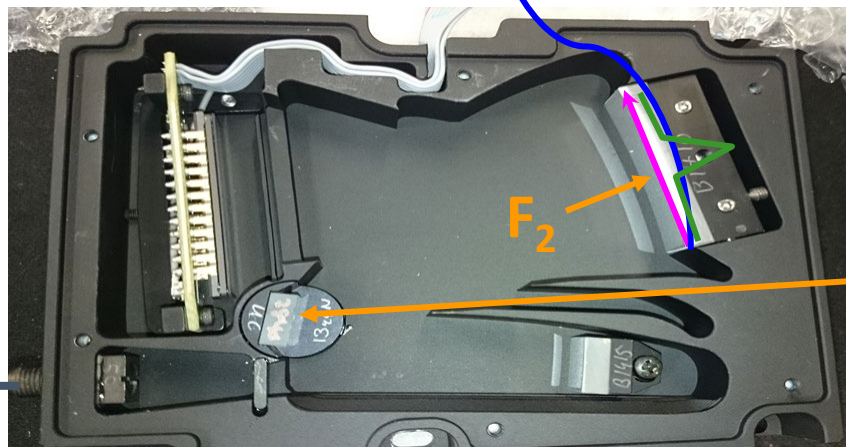
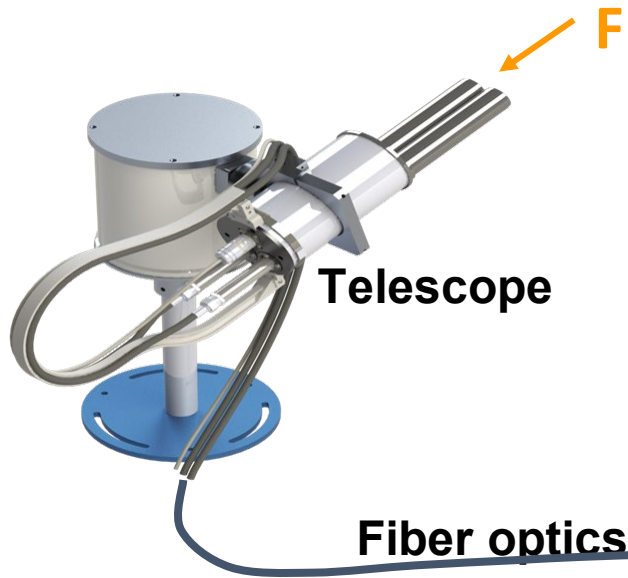
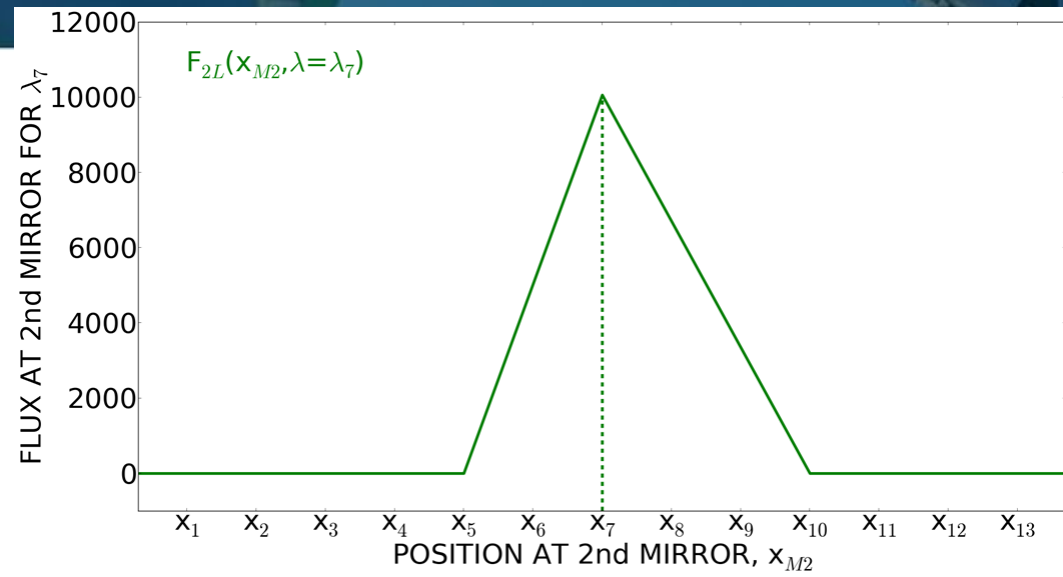
Fiber optics



Spectrometer

Flux at 2nd mirror

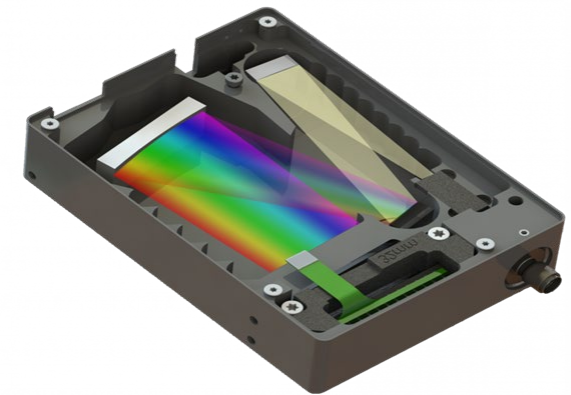
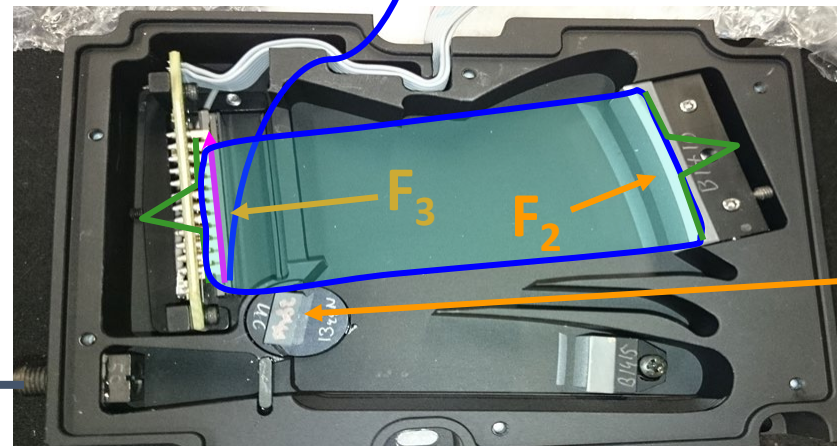
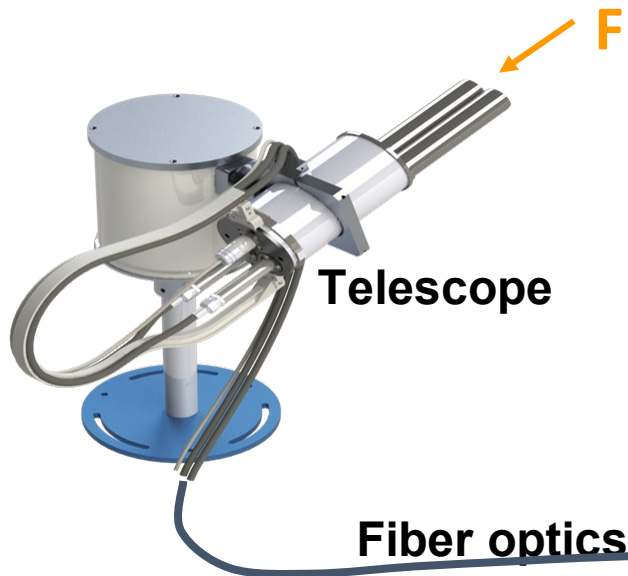
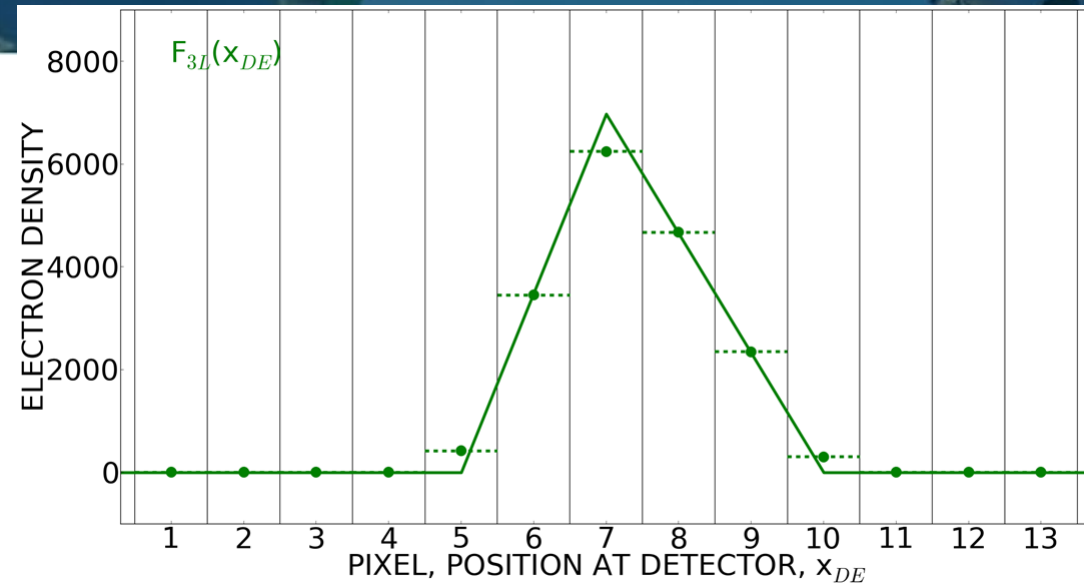
Monochromatic light distributes over “some region” on the 2nd mirror.
Not a Delta-function anymore ...



Spectrometer

Flux at detector and electrons in detector

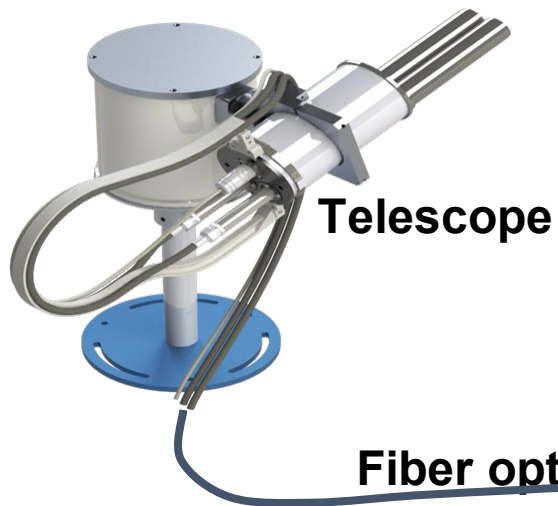
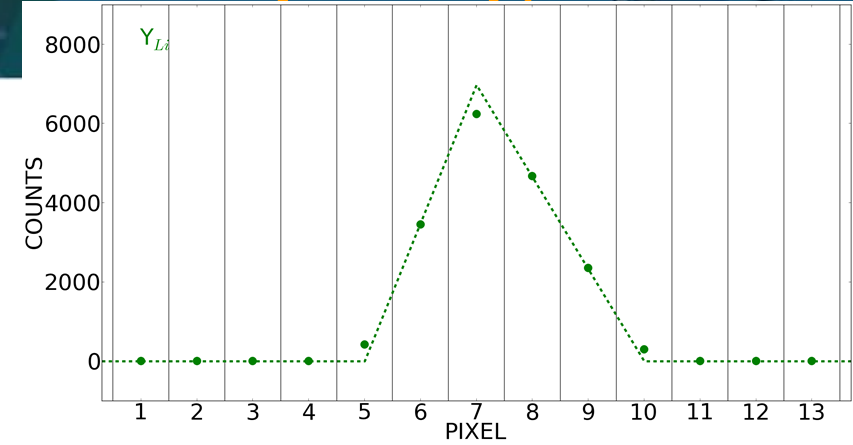
Flux at detector is binned into pixels



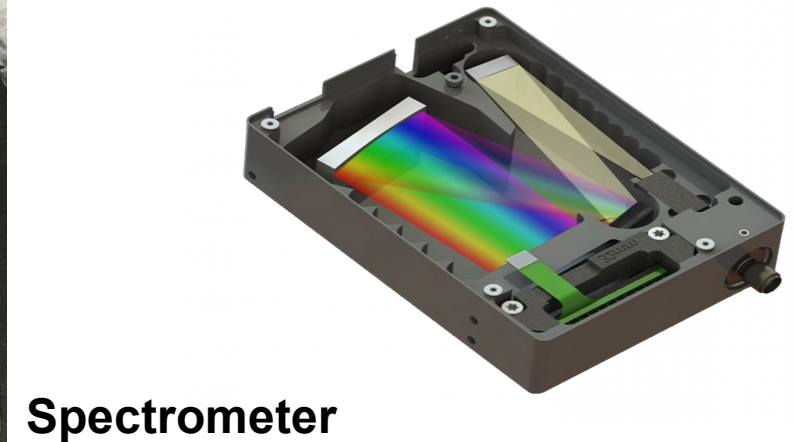
Spectrometer

Transmission from detector to output signal

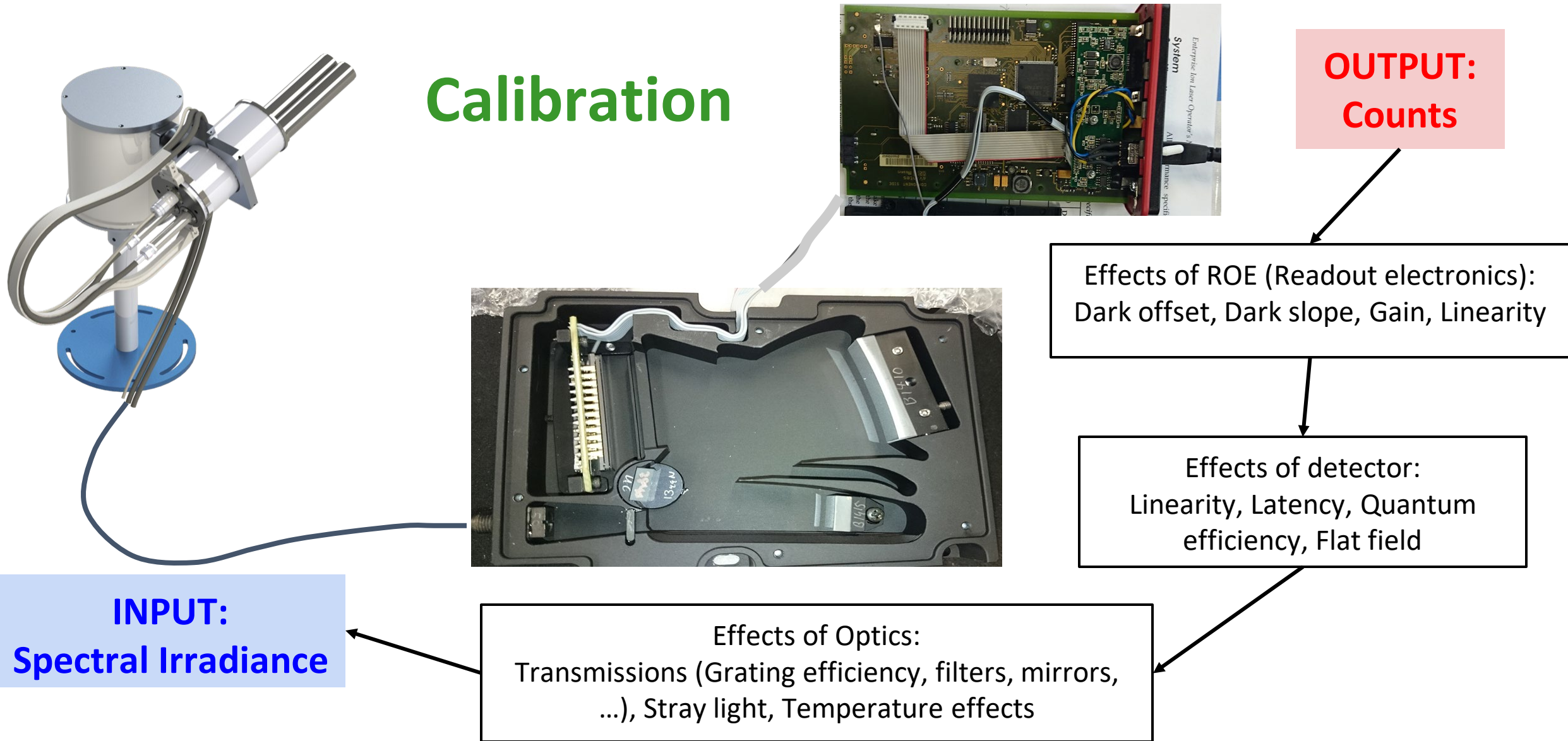
Counts for monochromatic input give
“Slit (scatter) function”.



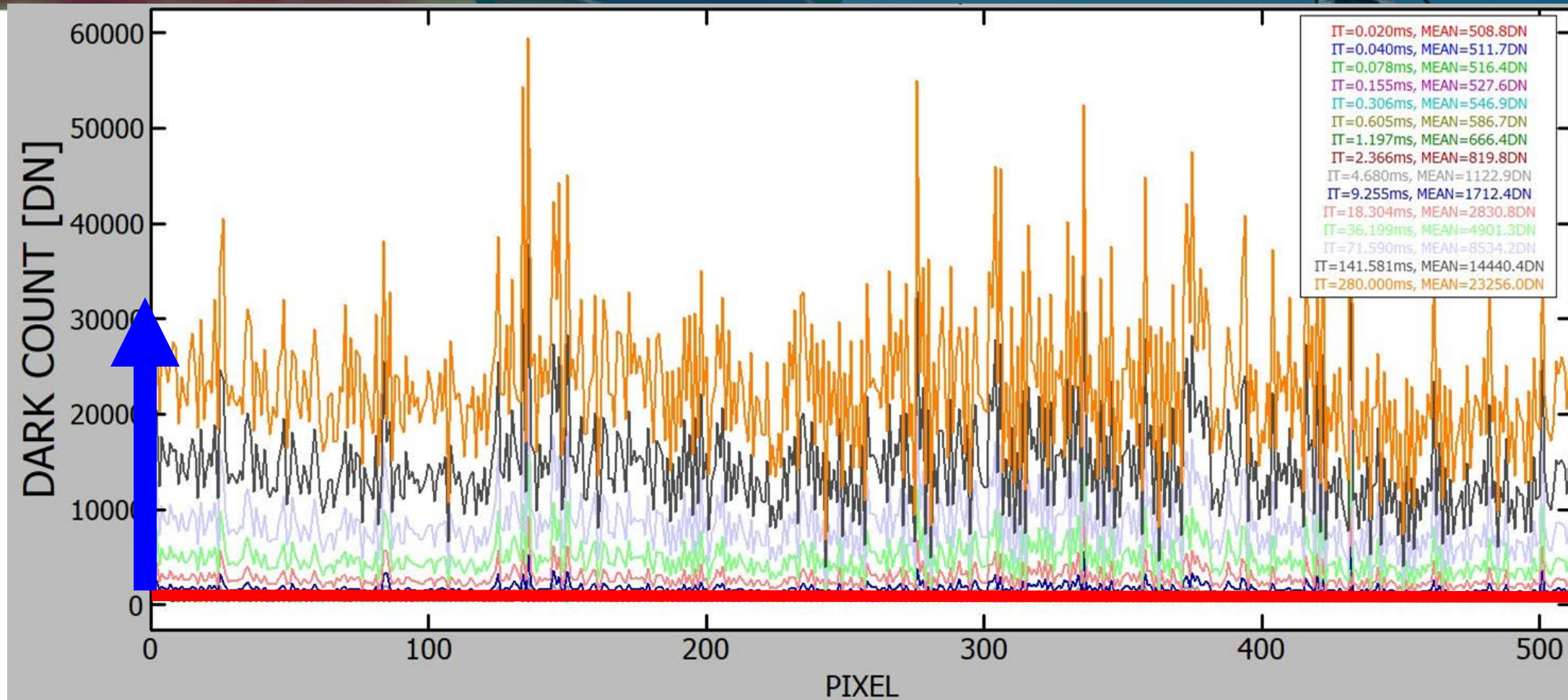
Readout
electronics



“Backward Direction”: From digital number to flux



Dark offset and slope



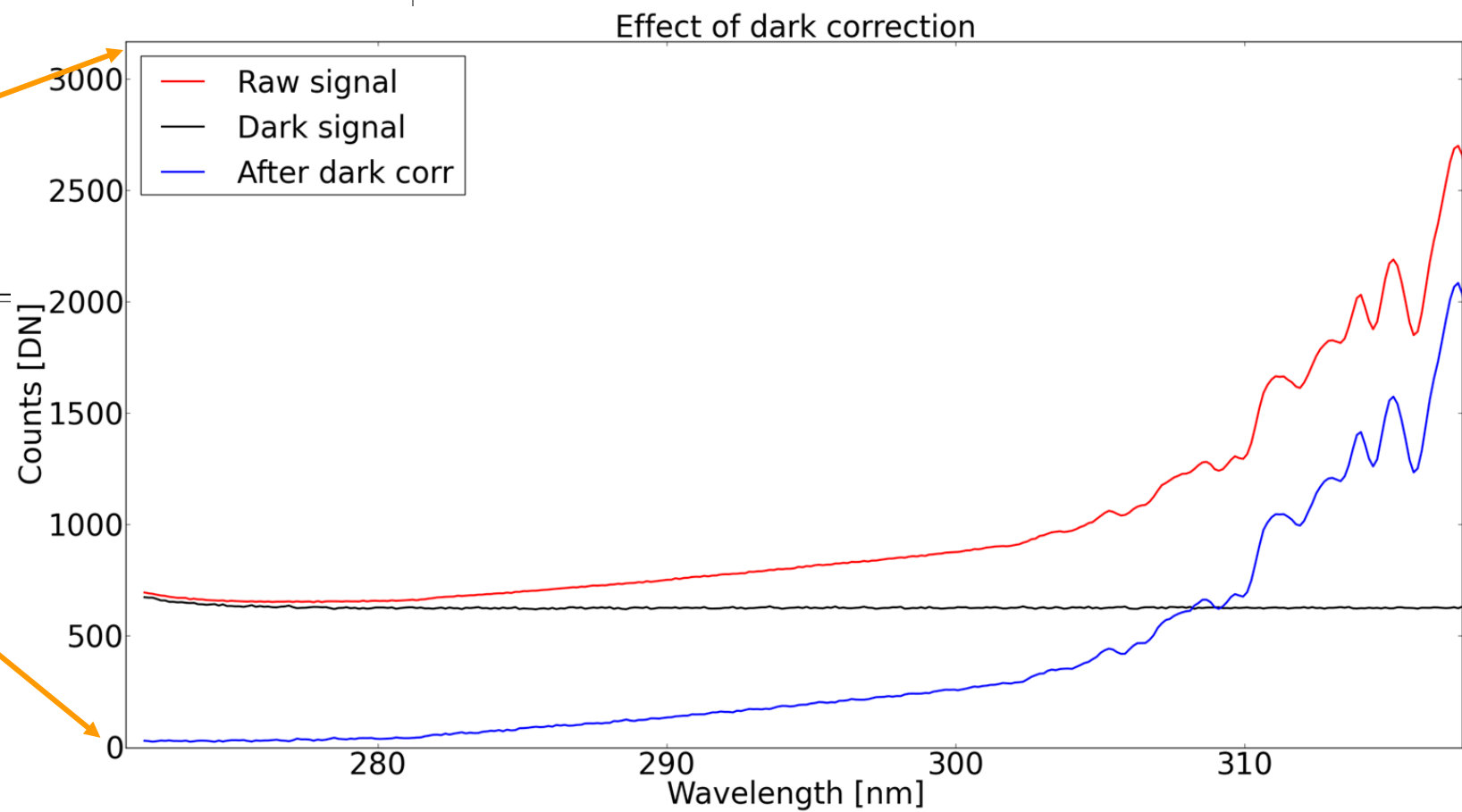
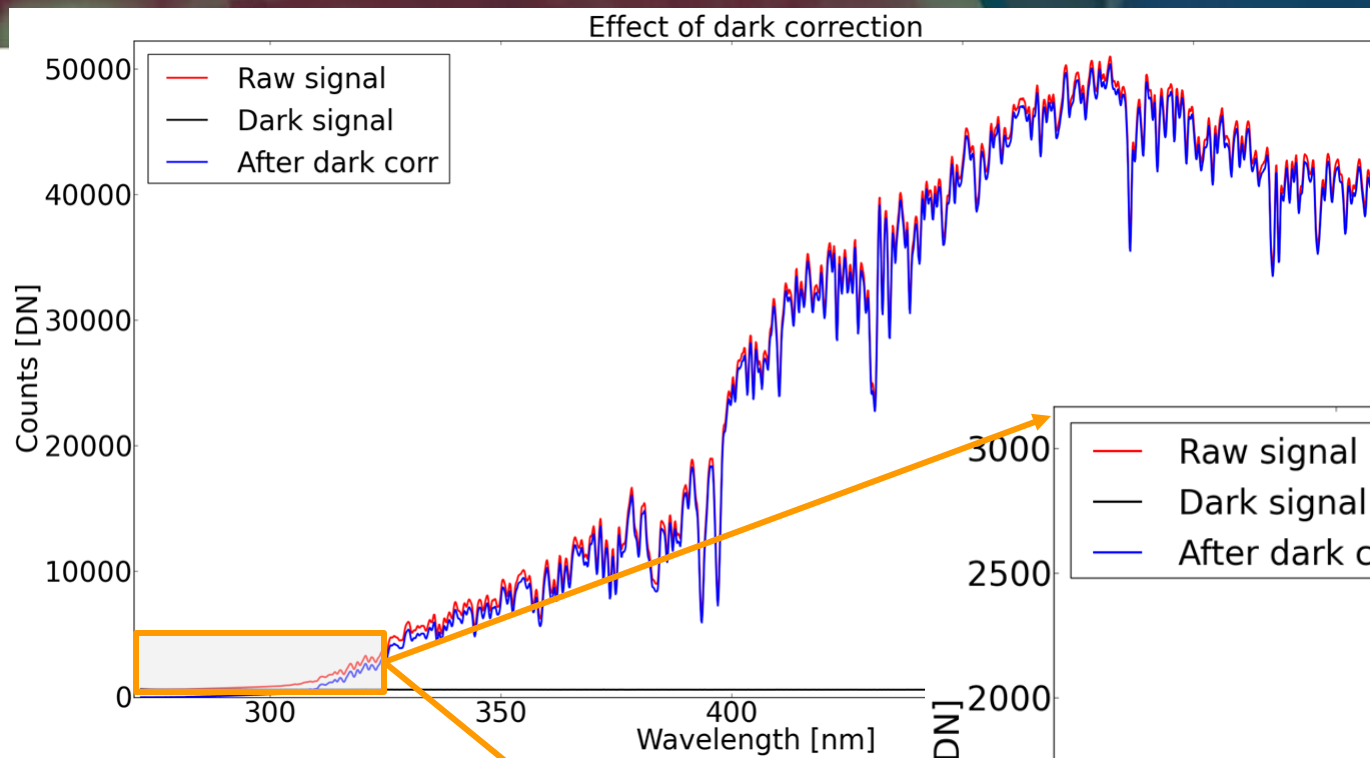
Dark Slope

(From thermal electrons)

Dark Offset

(From electronics)

Dark correction



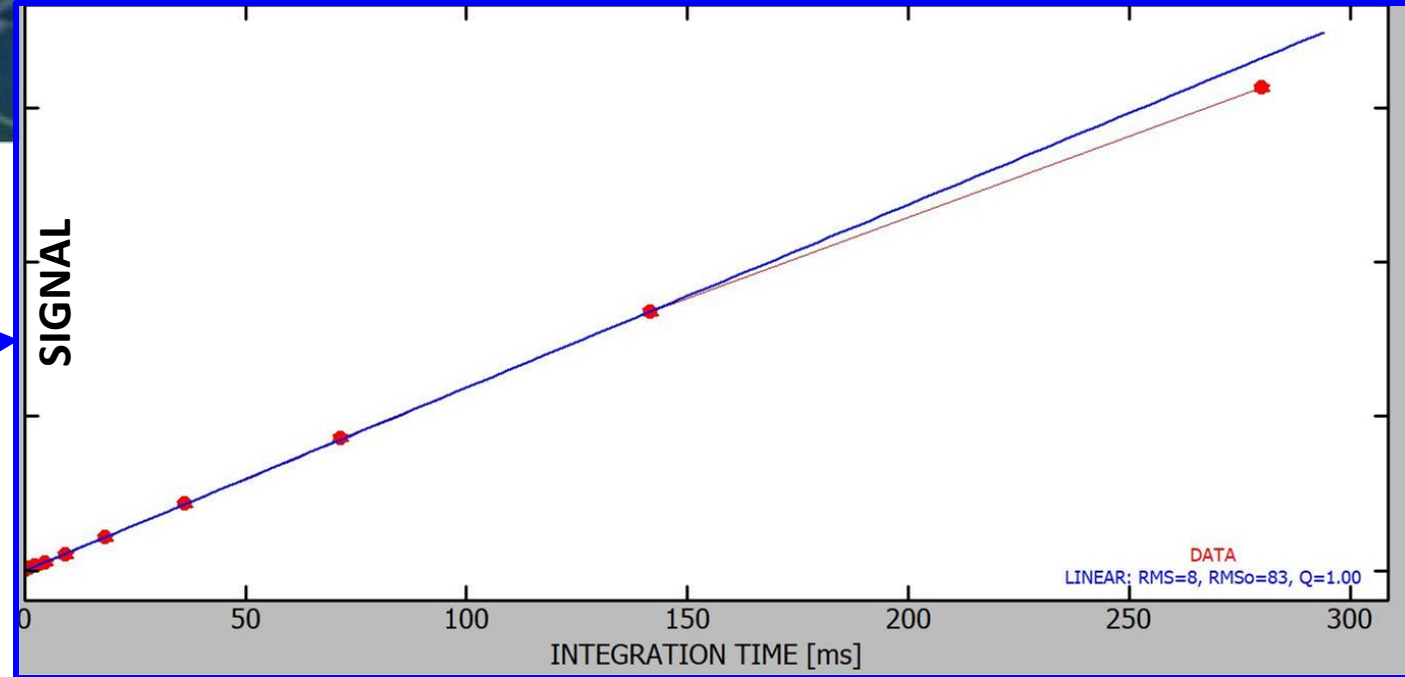
Linearity

(If you are lucky ...)

Dark & bright signals increase
~ linearly with light input

(If you are less lucky ...)

Your system is strongly non-linear

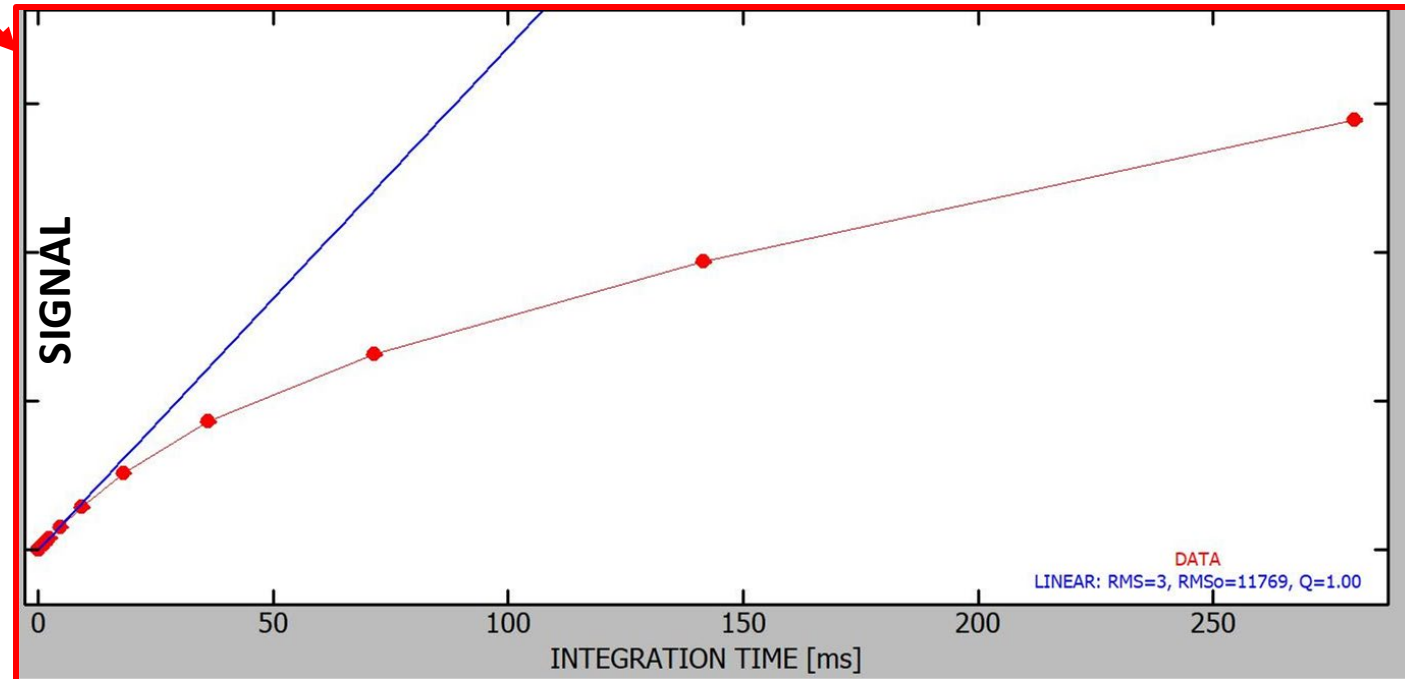


Non-linearity in Detector:

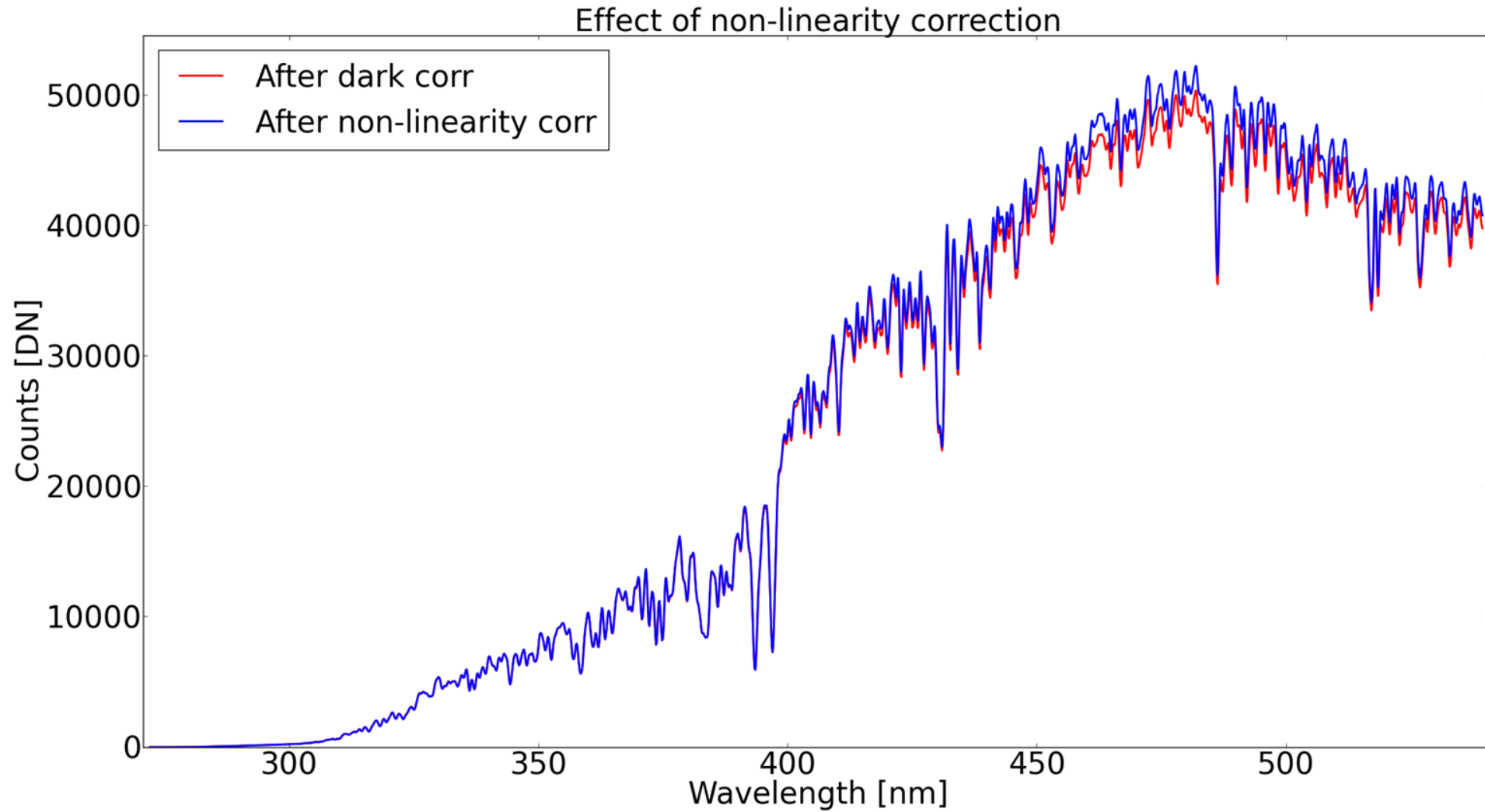
(Photon-induced or thermal) electron (e^-) accumulation differs from the e^- generation due to saturation and/or recombination.

Non-linearity in ROE:

Caused by operational amplifier and AD-Converter

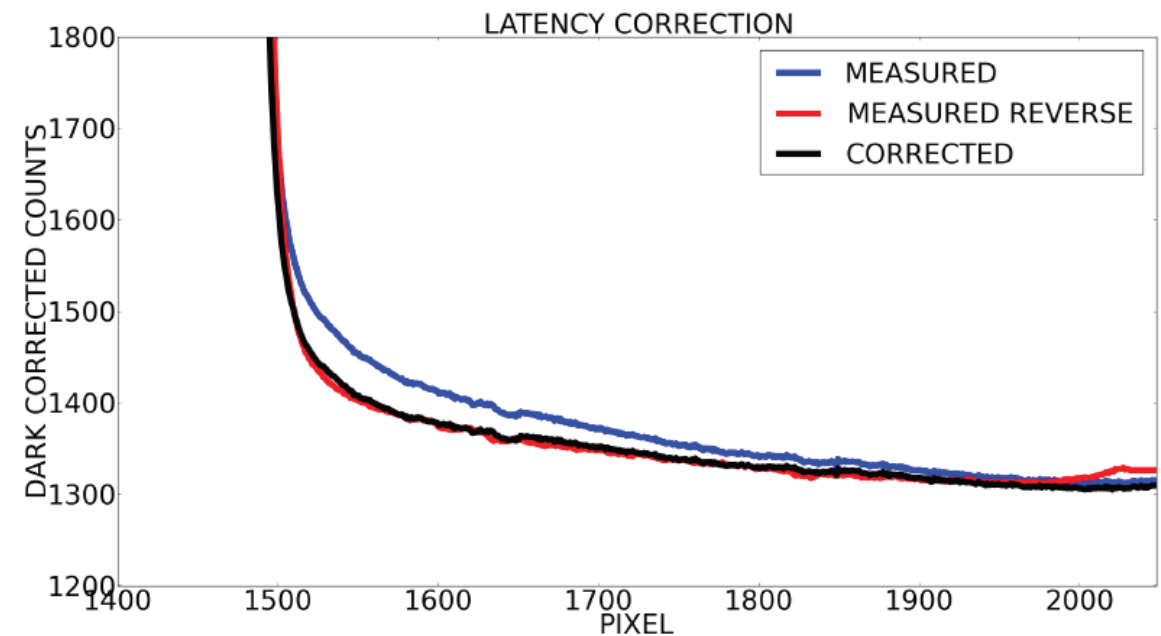
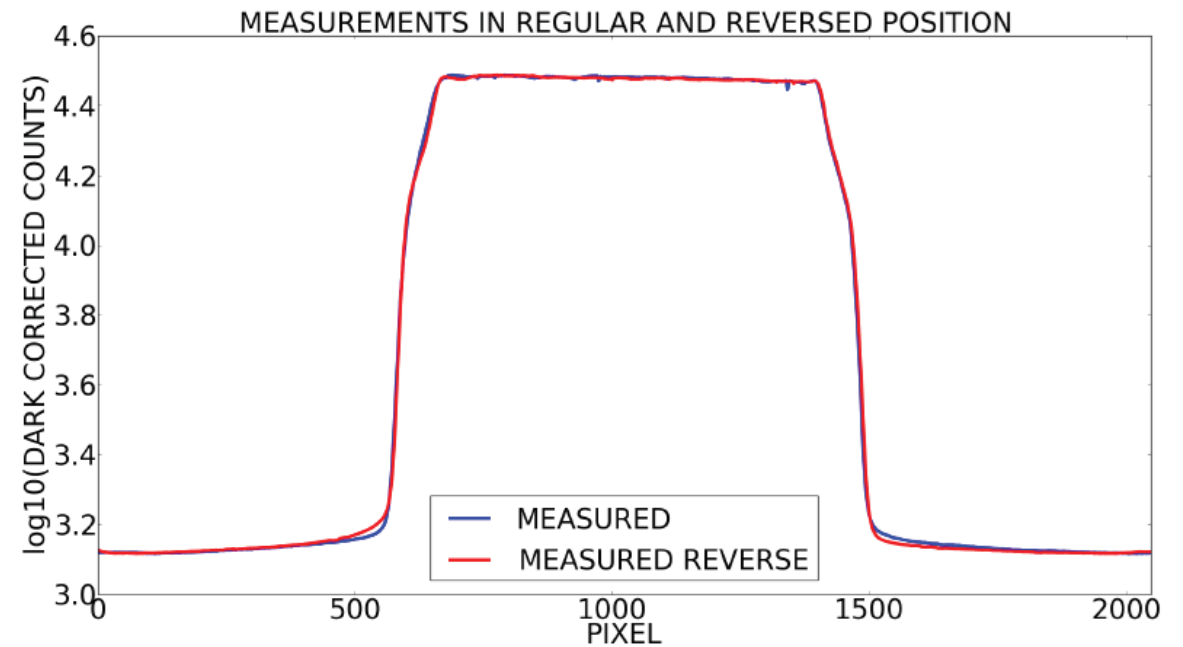
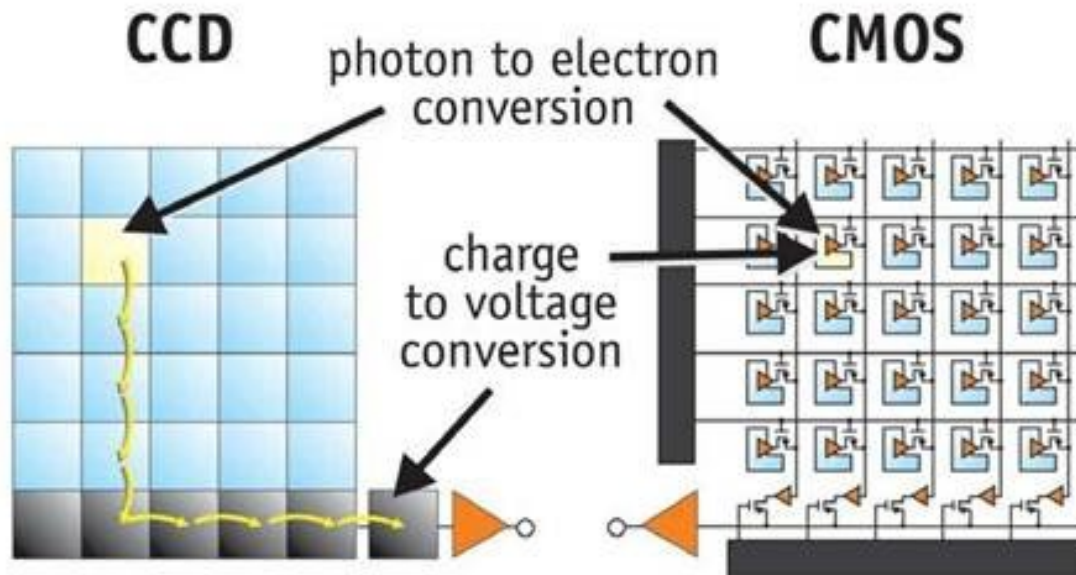


Linearity correction



Latency

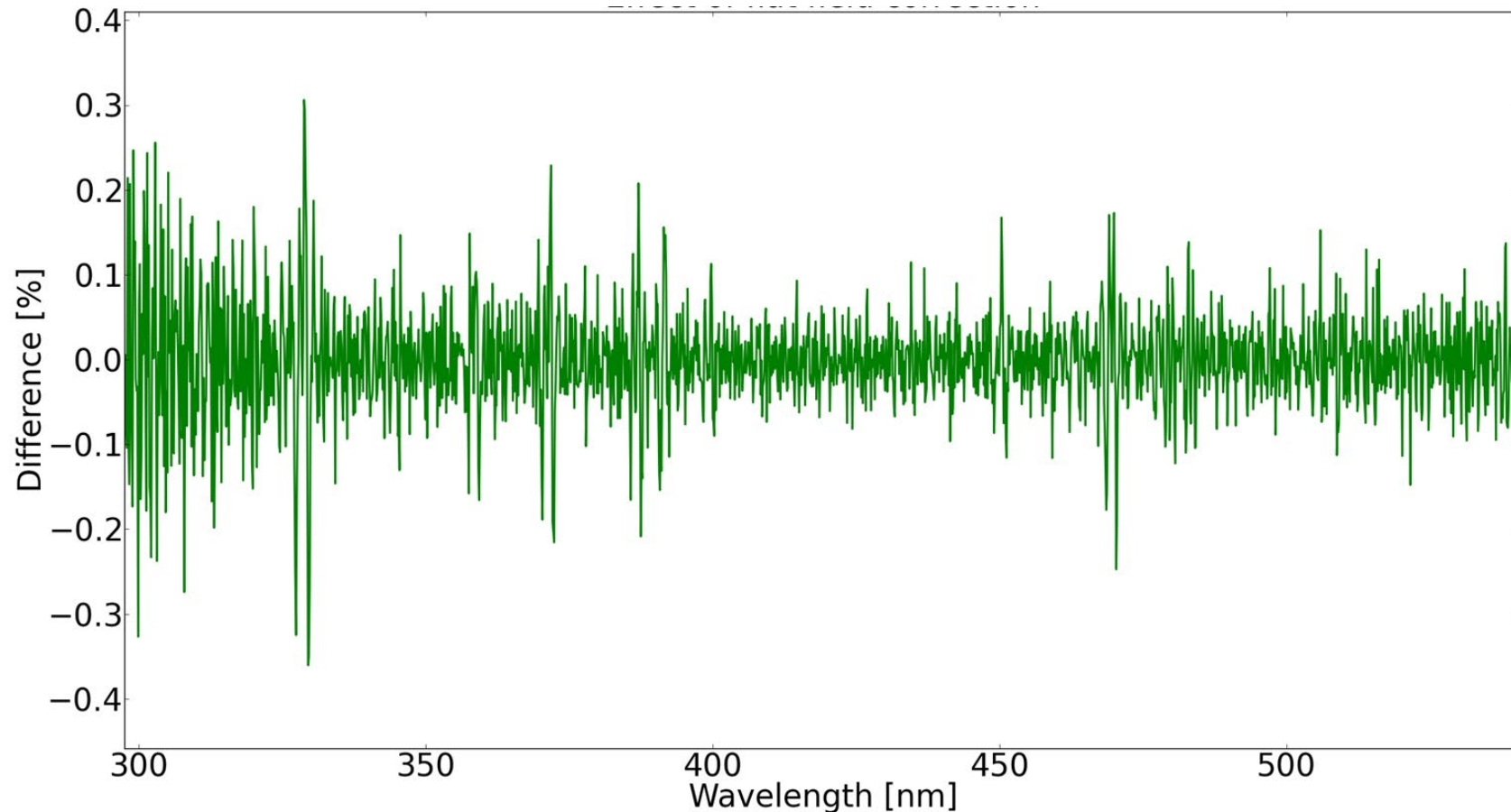
Readings in a pixel are influenced by the readings in the previously read pixel



Pixel Response Non Uniformity (PRNU)

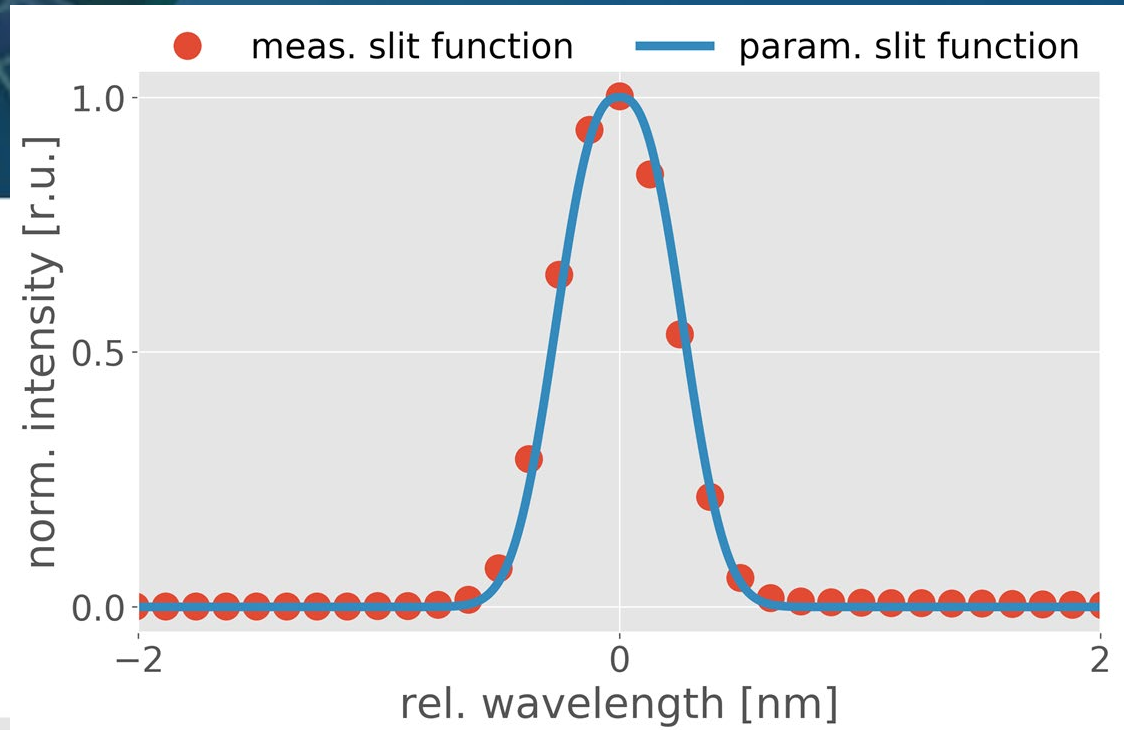
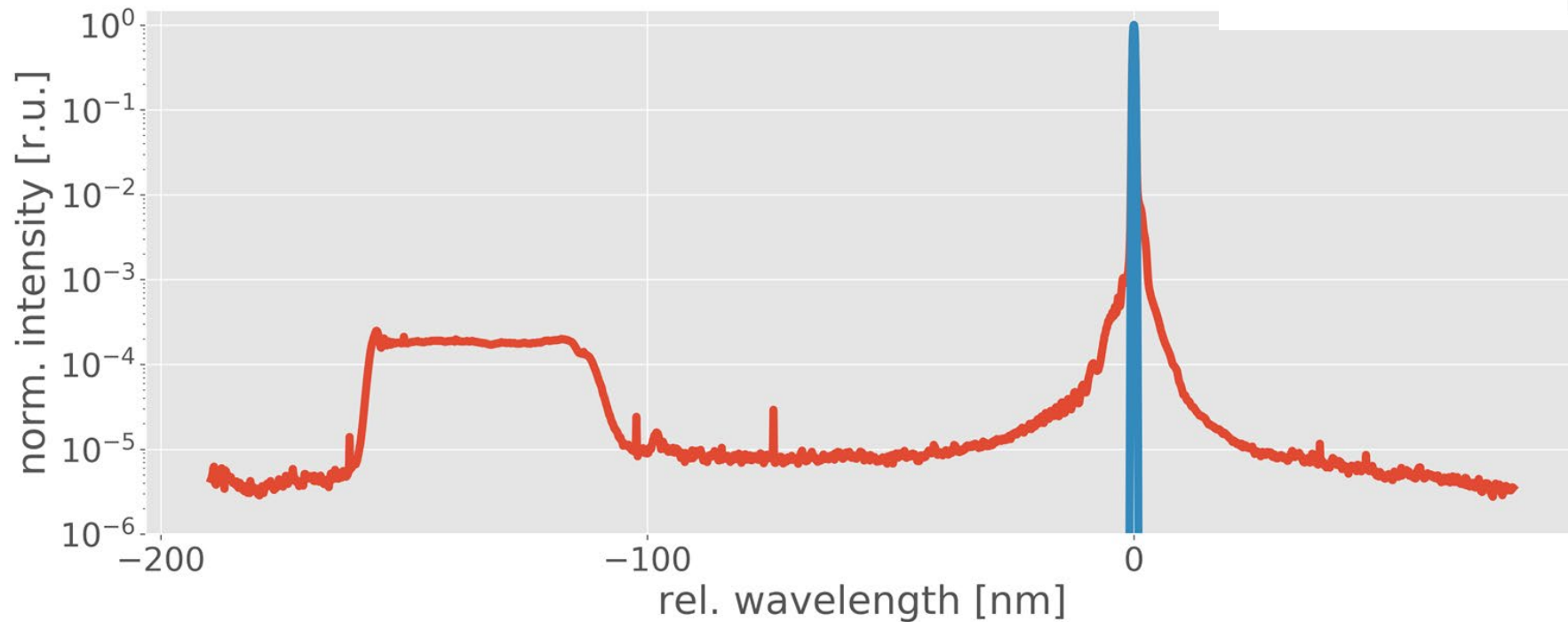
“What is the difference in the readings, if every pixel gets exactly the same input?”

For single pixels the PRNU is actually an effect of about $\pm 1\%$. Here it is reduced since for this CCD 64 single pixels are averaged in the reading.

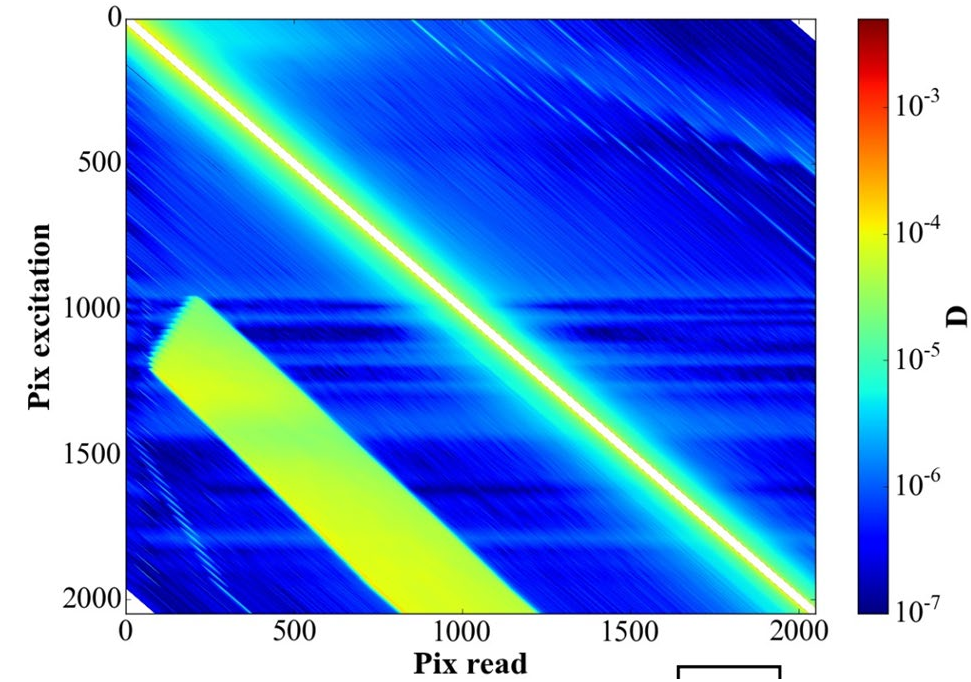
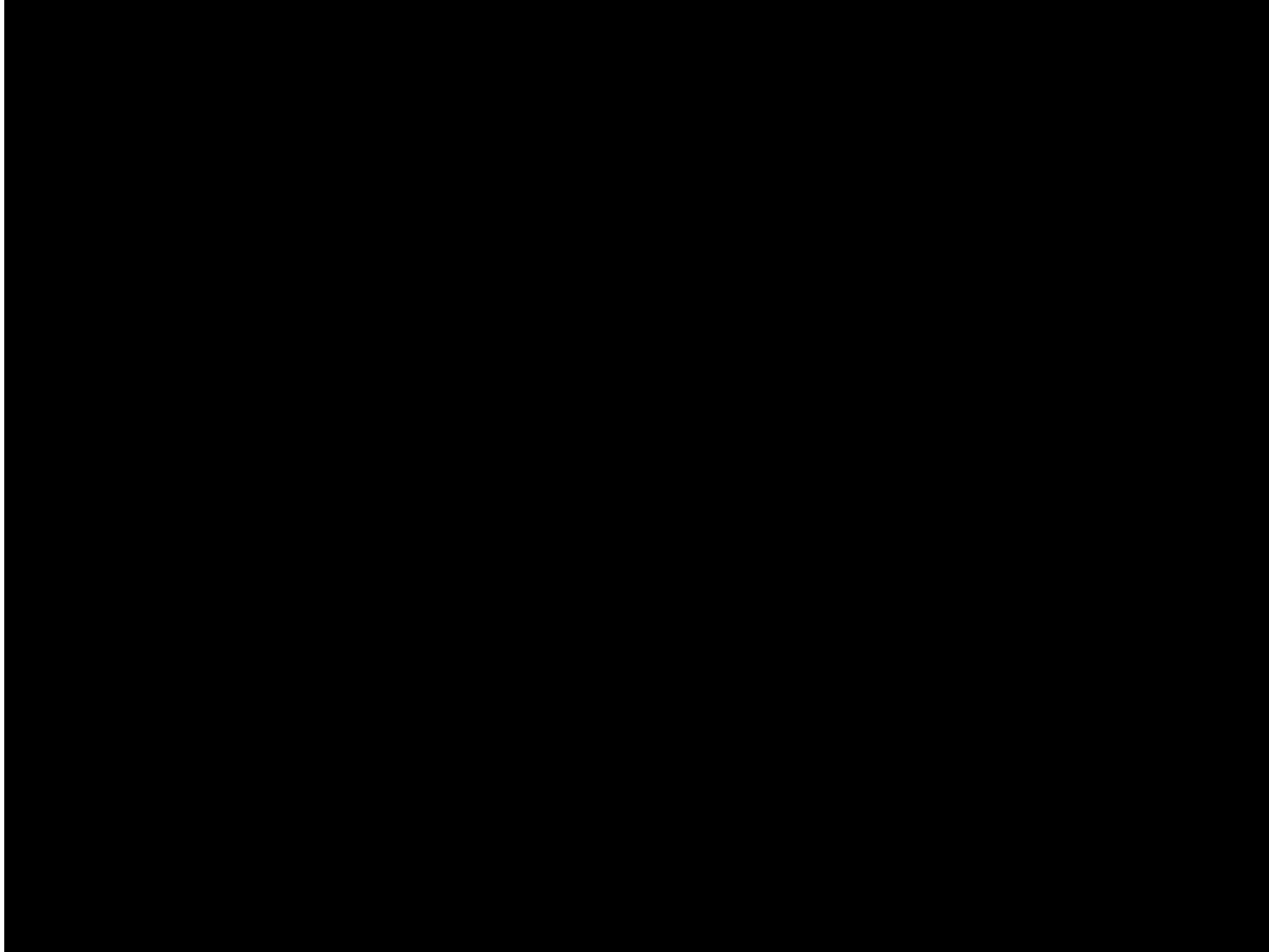


Spectral stray light

“Not all photons necessarily end up where they should.”



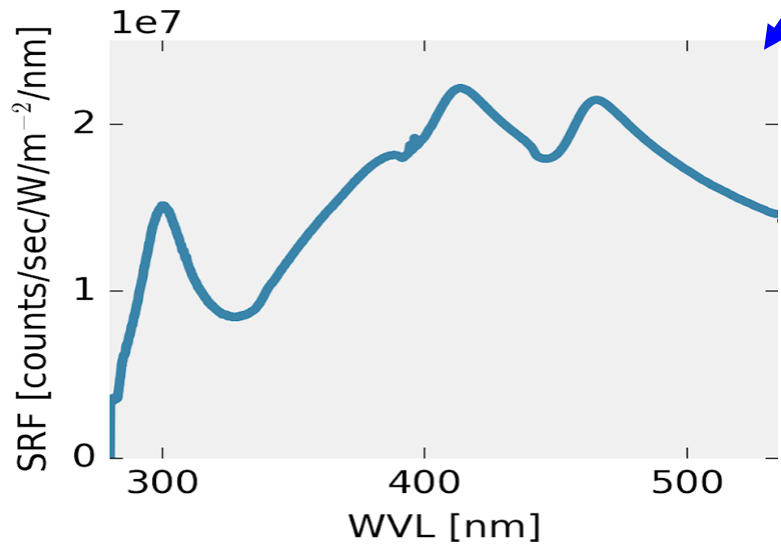
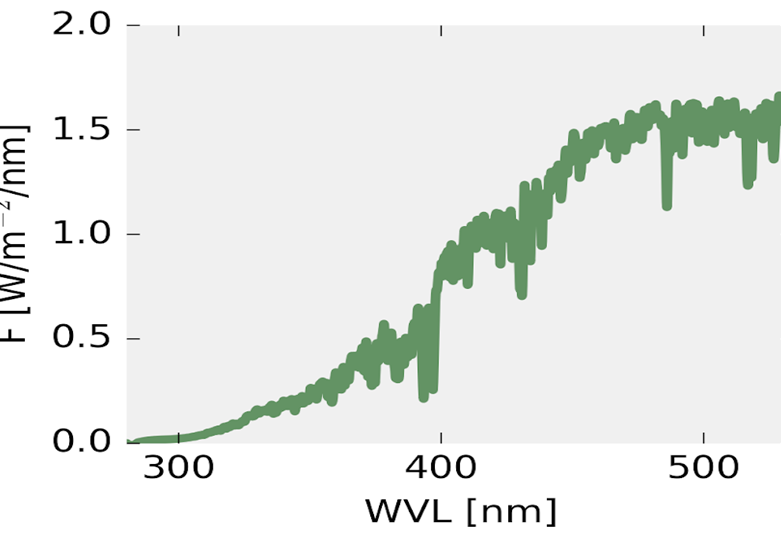
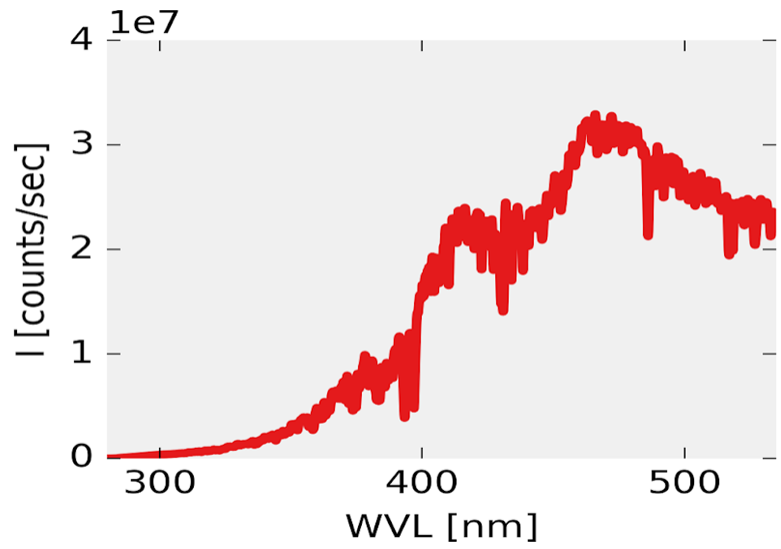
Full slit (scatter) function



Video compiled and thankfully provided by

- Julian Gröbner and
- Natalia Kouremeti

Spectral sensitivity

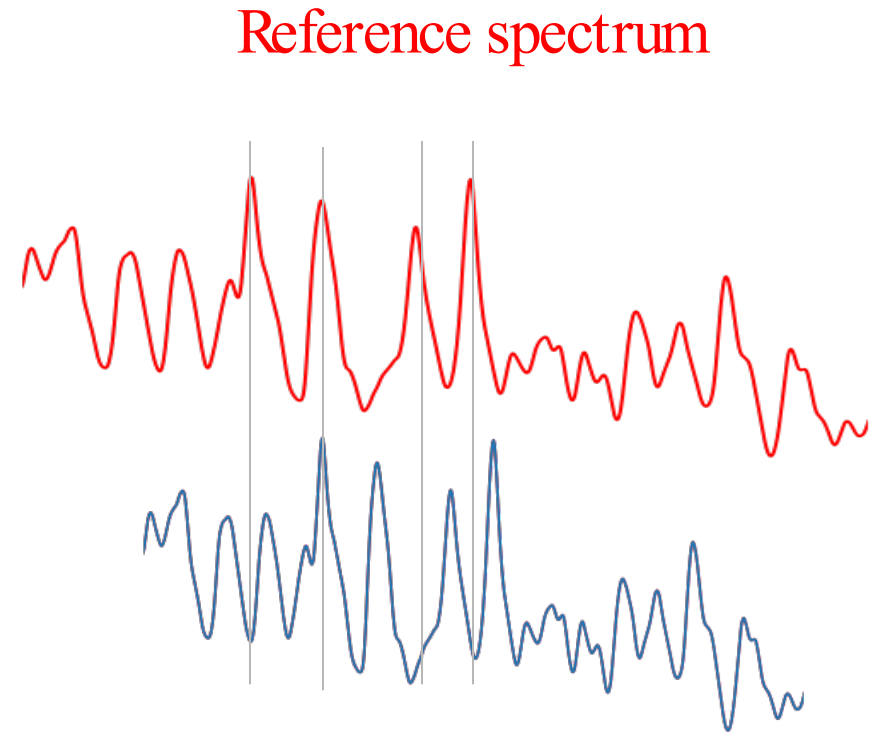


Combined effect
on transmission of
all optical
elements

- Windows
- Filters
- Fiber
- Mirrors
- Grating
- Detector
- ...

Dispersion and resolution changes

- In the lab we can determine the dispersion (which pixel corresponds to which wavelength) and resolution (width of slit function) of the system.
- However these **parameters usually change in the field** (temperature, instrument setup, ...).
- Due to the known structure of the solar spectrum, we can correct for this to some extent in the retrievals.
- More in Michel's talk about calibration techniques applied in the field ...



Measured spectrum