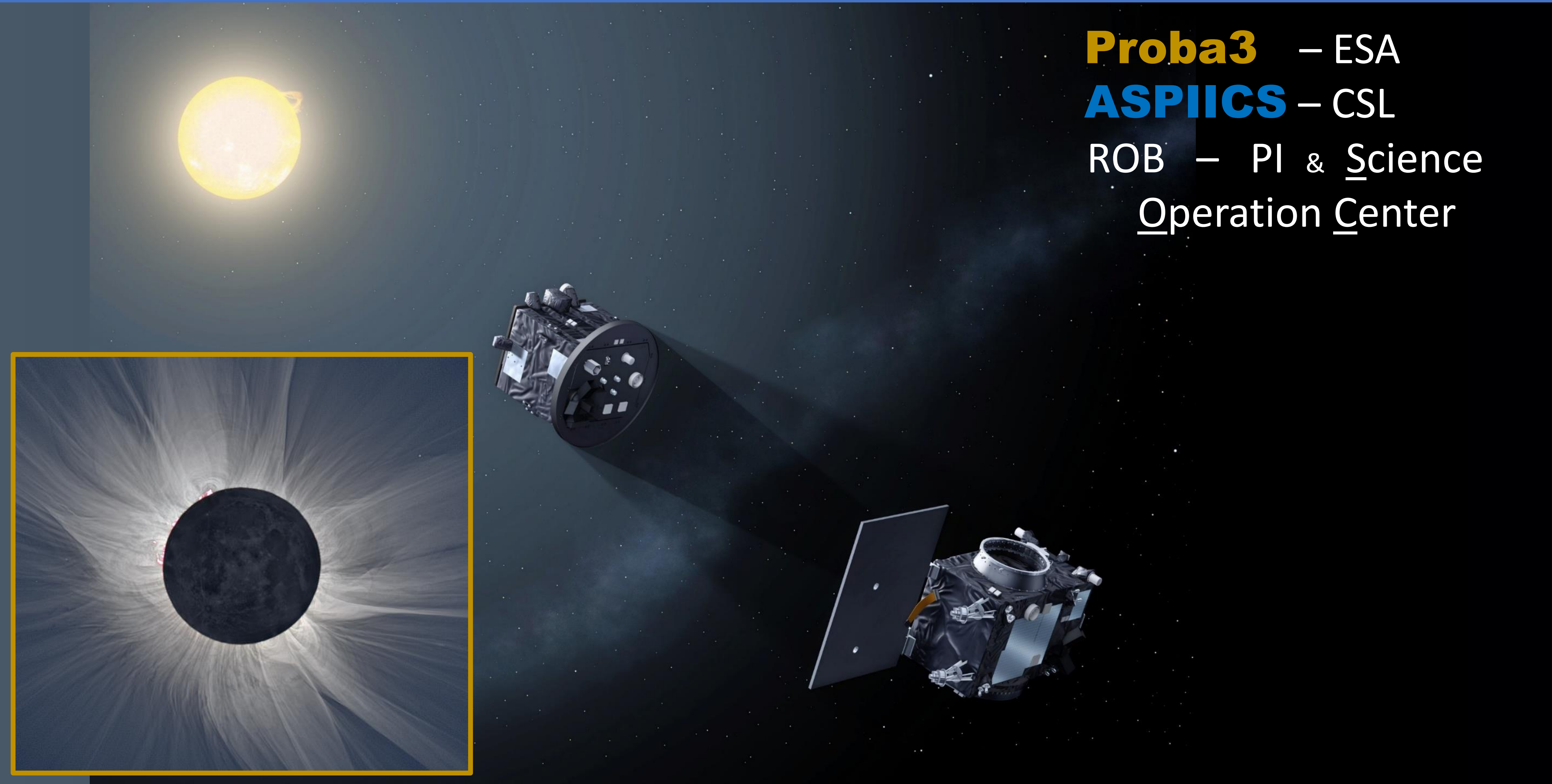
On-ground calibrations of ASPIICS: results and discussion

Sergei Shestov

using measurements and analysis of CSL & INAF & ROB & MPS teams

ASPIICS onboard Proba3



Proba3 – ESA

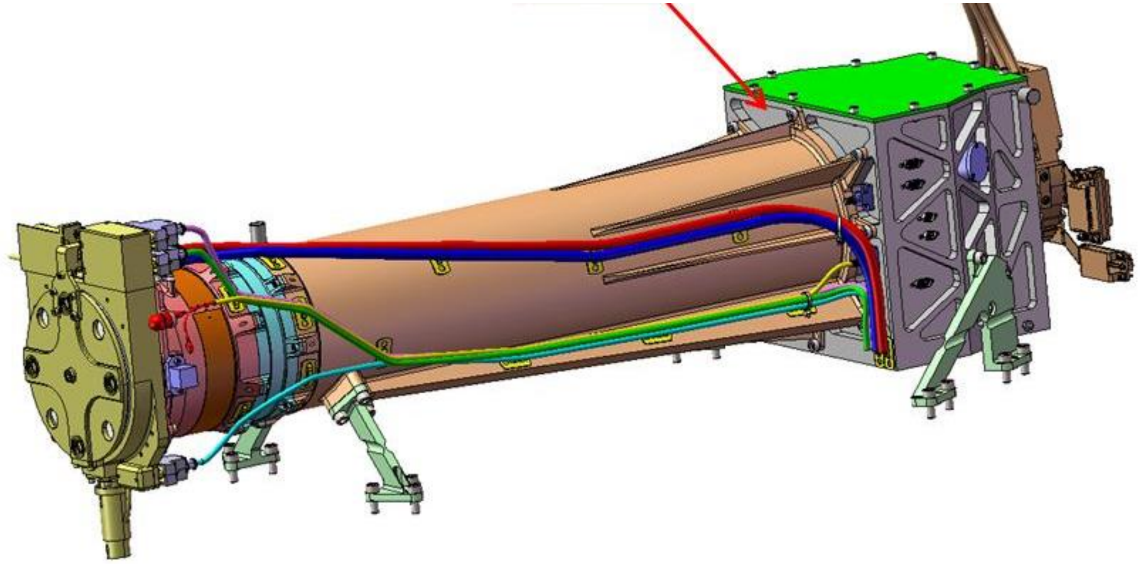
ASPIICS – CSL

ROB – PI & Science Operation Center

Calibration of ASPIICS

ASPIICS calibrations

- CSL/Liege – 2021
- INAF/Turin – Aug/Sept 2021
- ROB & INAF – processing of the calibration data (33Gb archive)



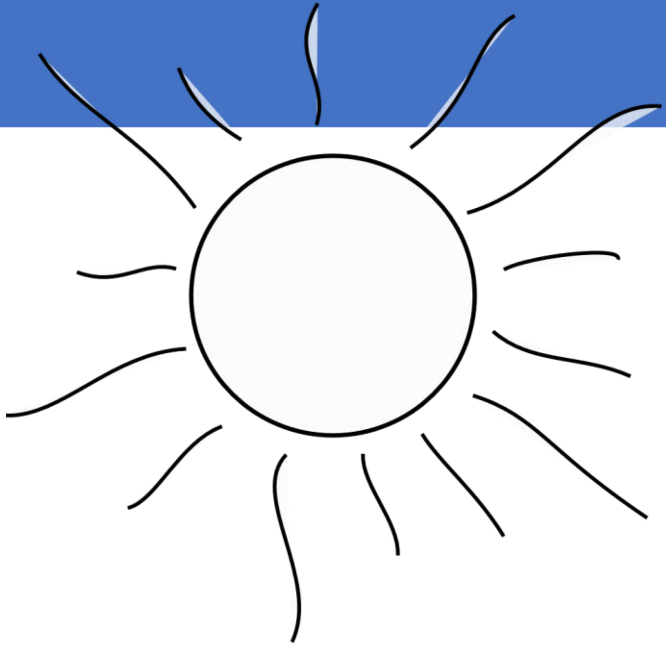
What I did during ~1 year

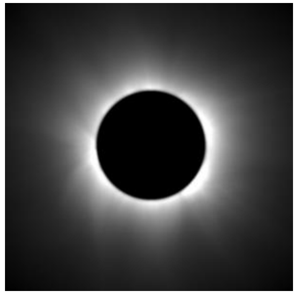
- Dark frames
- Radiometric sensitivity
- Flat field
- Nonlinearity
- Polarization
- IO position
- PTC and gain
- Hot pixels

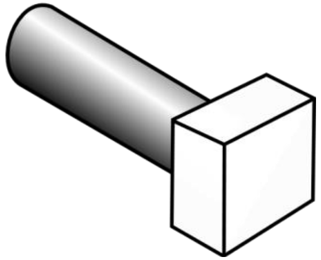
- Stray light – diffraction, scattering

impossible to measure; models Shestov et al. 2018, 2019, 2021

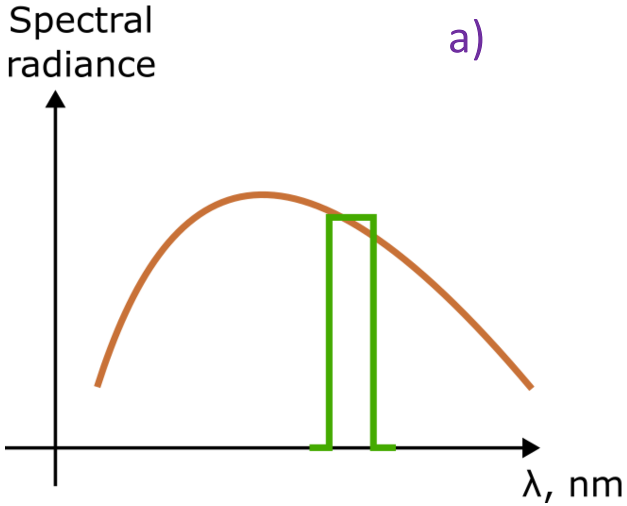
Spectral passband

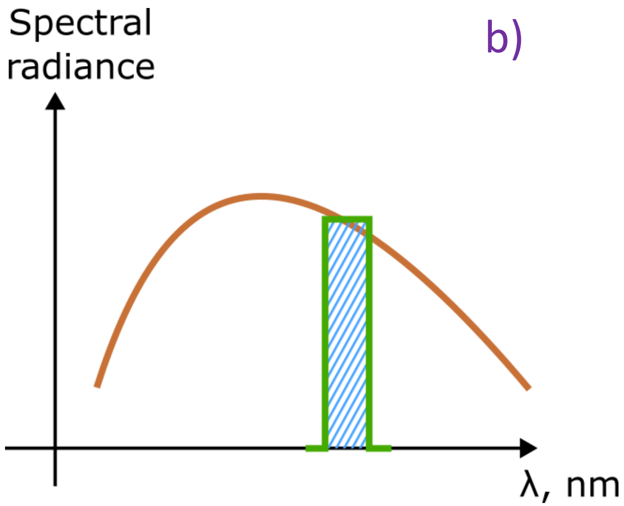


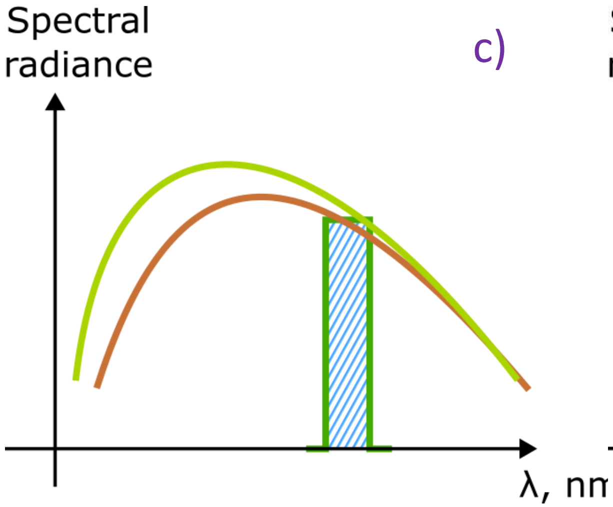


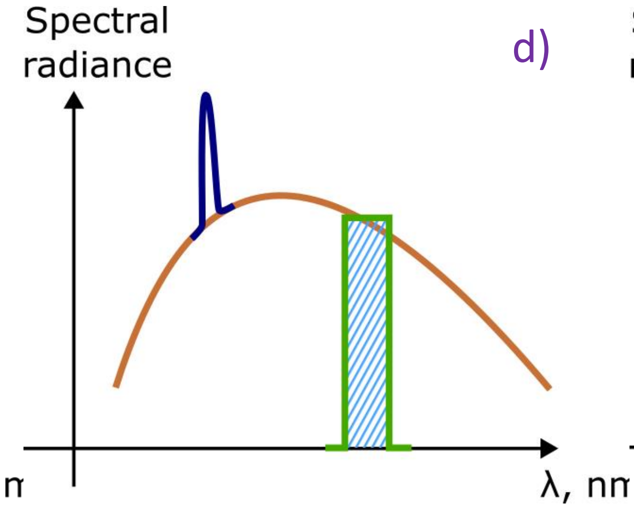


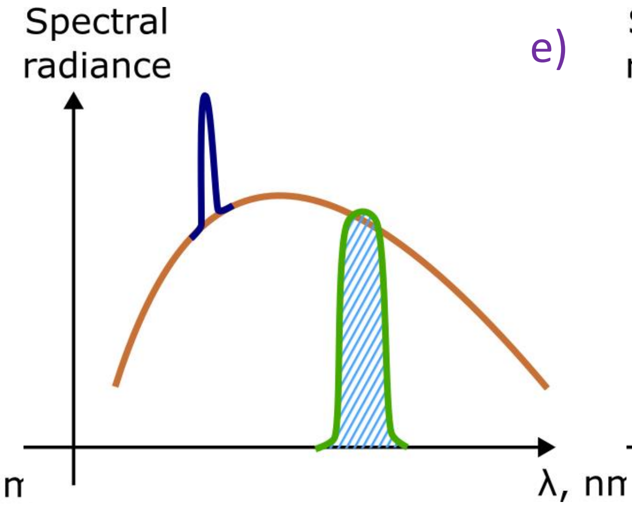
How to define radiometric sensitivity?

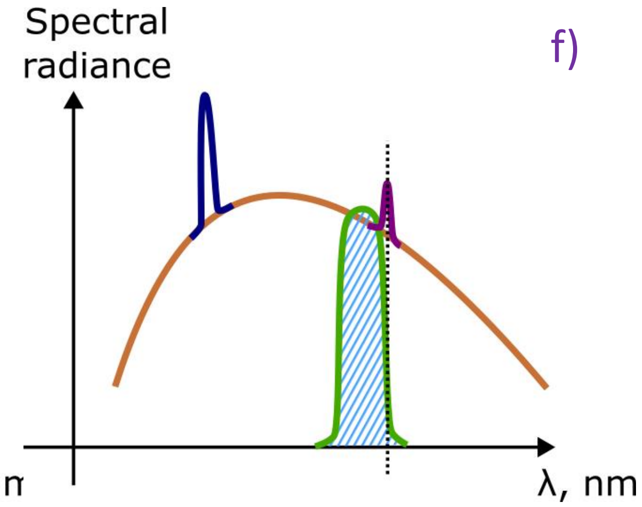




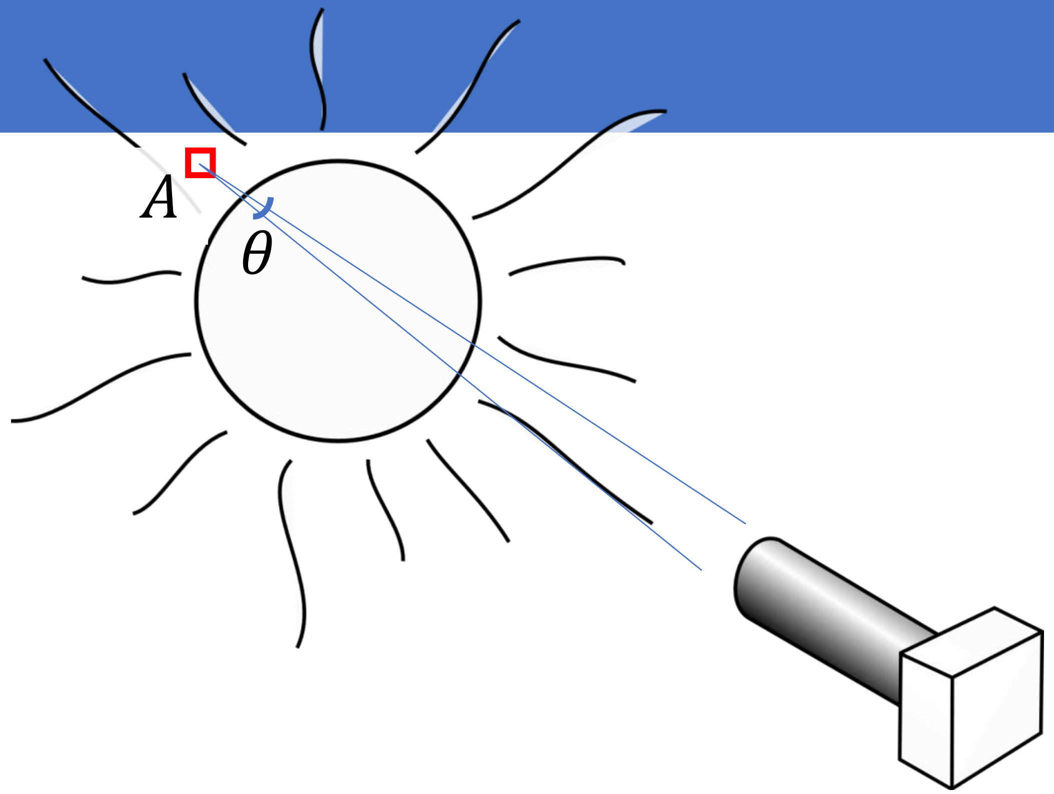


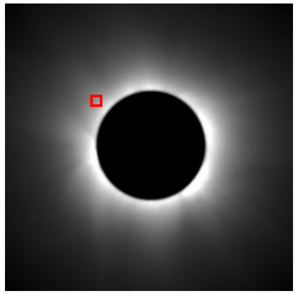






Geometric factor





Number of
photons per pixel

$$N' = B \cdot \theta \cdot A$$

Aperture area S_{ap}

Pixel solid angle Ω_{pix}

$$\boldsymbol{N'} = \boldsymbol{B} \cdot \frac{\pi D^2}{4} \left(\frac{dx}{f}\right)^2$$

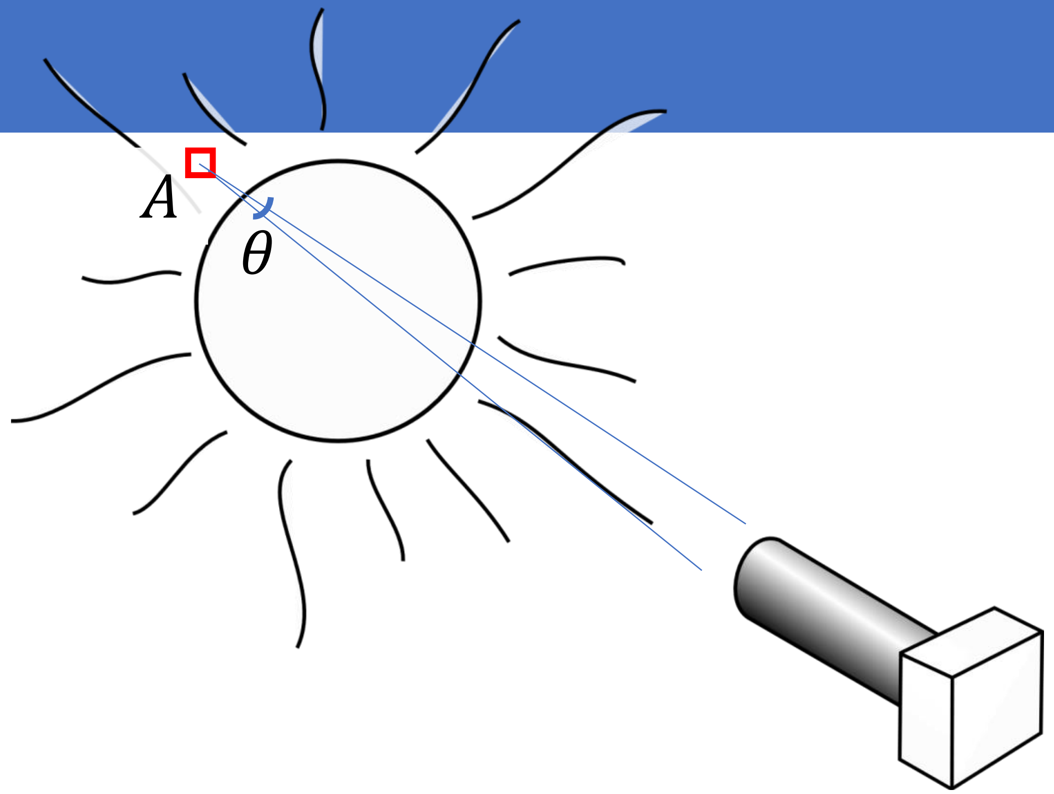
units

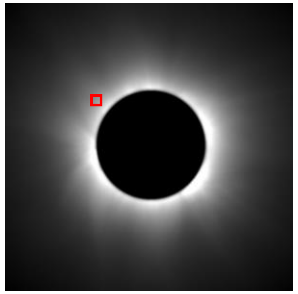
$$\left[\frac{\text{photon}}{\text{s}}\right] \qquad \left[\frac{\text{photon}}{\text{s sr cm2}}\right][\text{cm2}][\text{sr}]$$

$$A = \left(\frac{dx \cdot L}{f}\right)^2 \qquad \theta = \frac{\left(\frac{\pi D^2}{4}\right)}{L^2}$$

dx – pixel size, ~ 10 μ
f – focal length, ~ 780 mm
D – aperture, ~ 5cm
L – distance, ~ 1 a.u.

Geometric factor





Transmissivity %

Detector counts

Detector sensitivity DN/photon

$$N = B \cdot \theta \cdot A \cdot T \cdot s$$

$$A = \left(\frac{dx \cdot L}{f}\right)^2 \qquad \theta = \frac{\left(\frac{\pi D^2}{4}\right)}{L^2}$$

$$\boldsymbol{N} = \boldsymbol{B} \cdot \frac{\pi D^2}{4}\left(\frac{dx}{f}\right)^2 \cdot T \cdot s$$

A_k

units

$\left[\frac{\text{DN}}{\text{s}}\right]$ $\left[\frac{\text{photon}}{\text{s}}\right]$ $[\%]$ $\left[\frac{\text{DN}}{\text{photon}}\right]$

in a passband k

dx – pixel size, ~ 10 µ

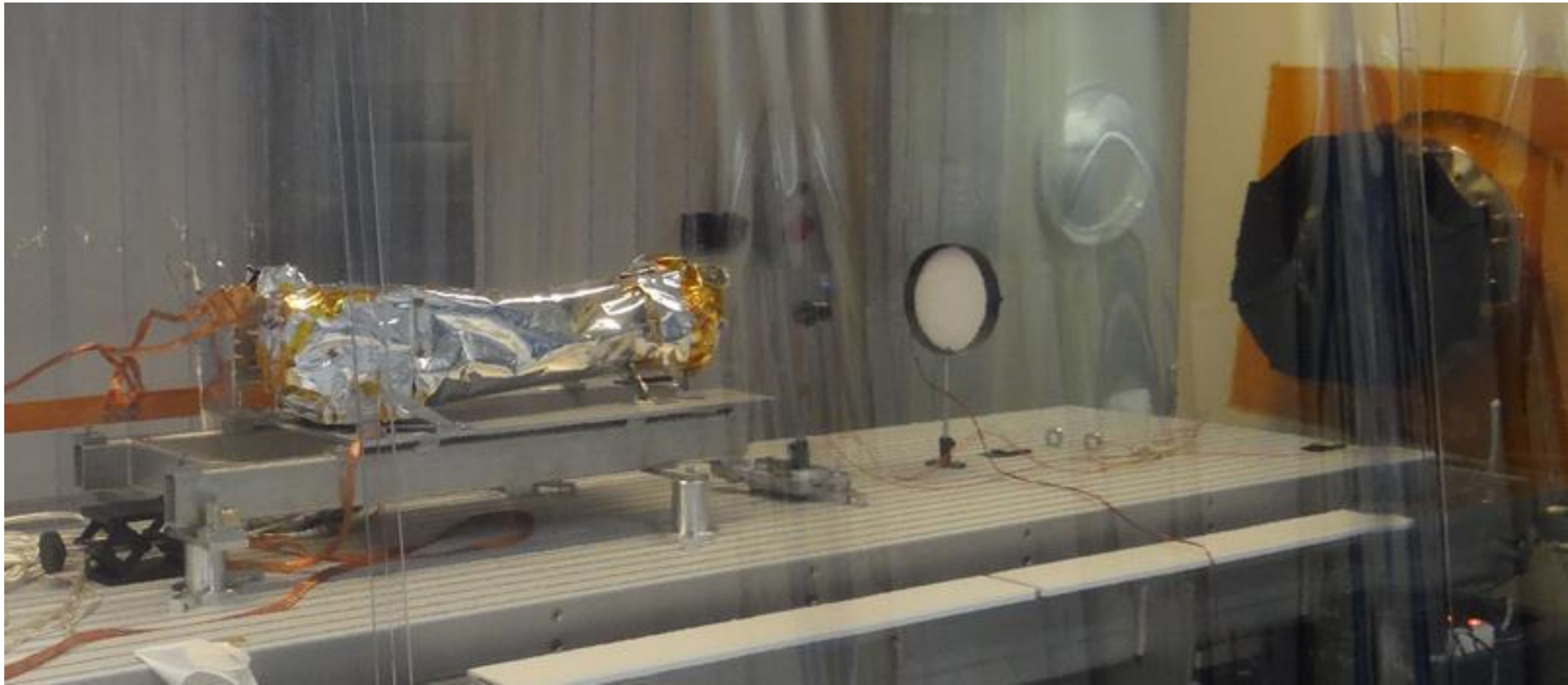
f – focal length, ~ 780 mm

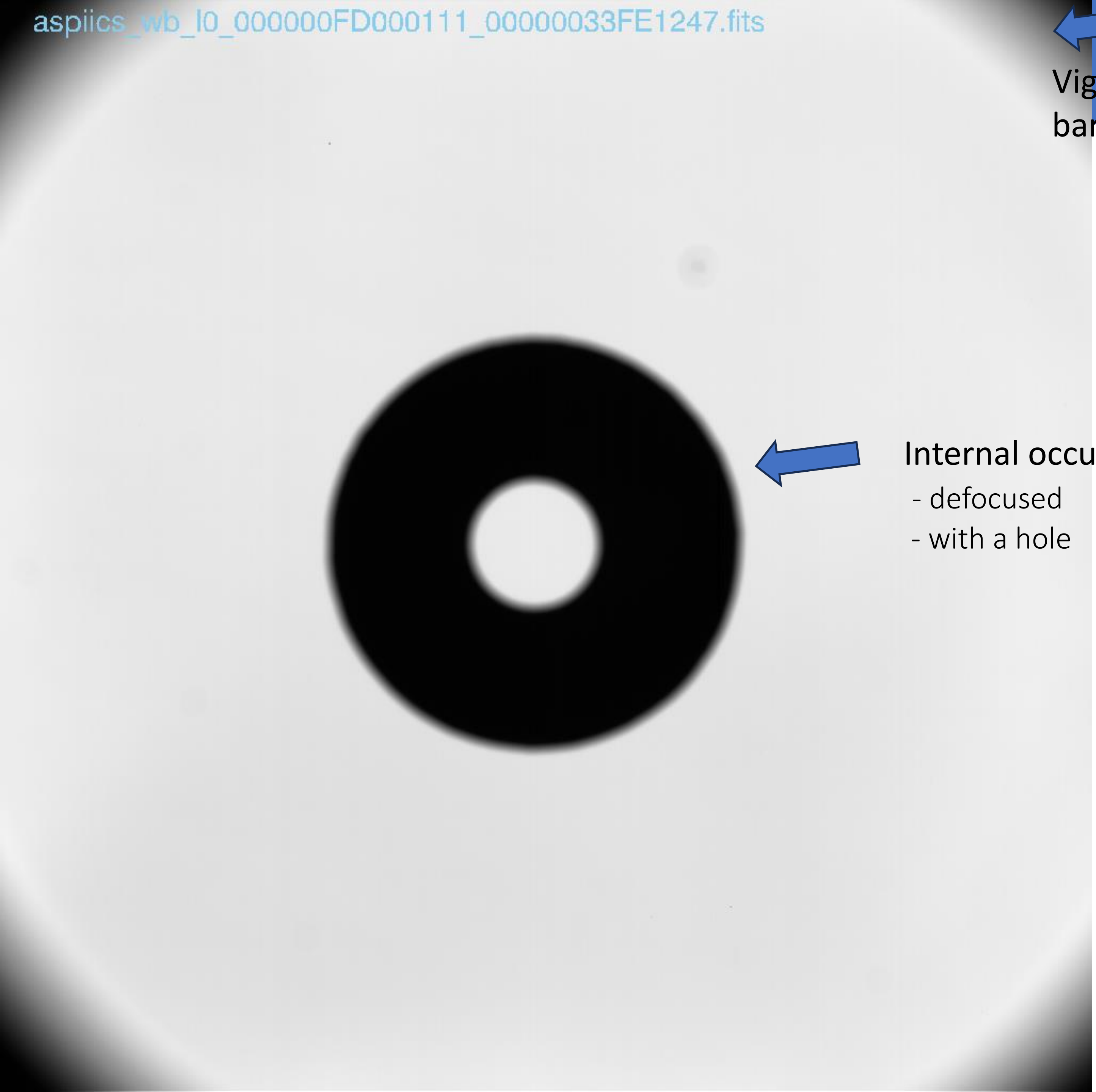
D – aperture, ~ 5cm

L – distance, ~ 1 a.u.

Radiometric sensitivity of ASPIICS

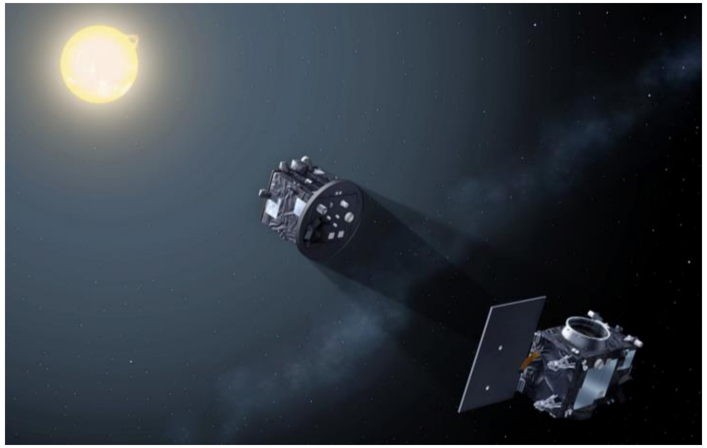
- Flat Field Panel (white LEDs)
- Calibrated photodiode
- ASPIICS takes images with different t_{exp} in different filters

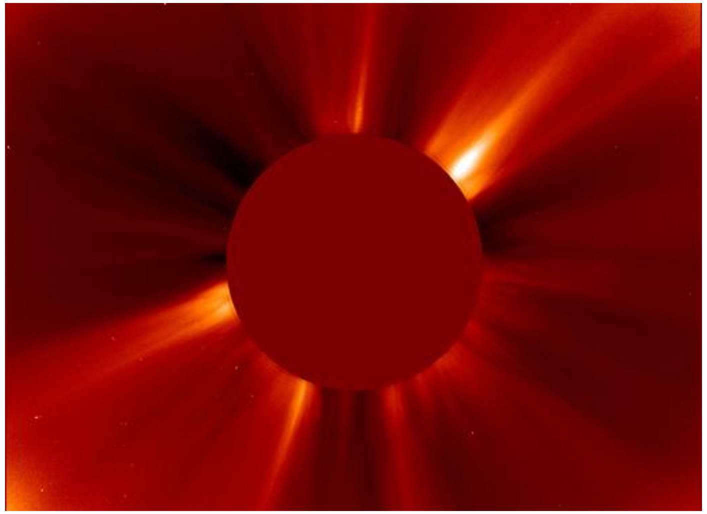


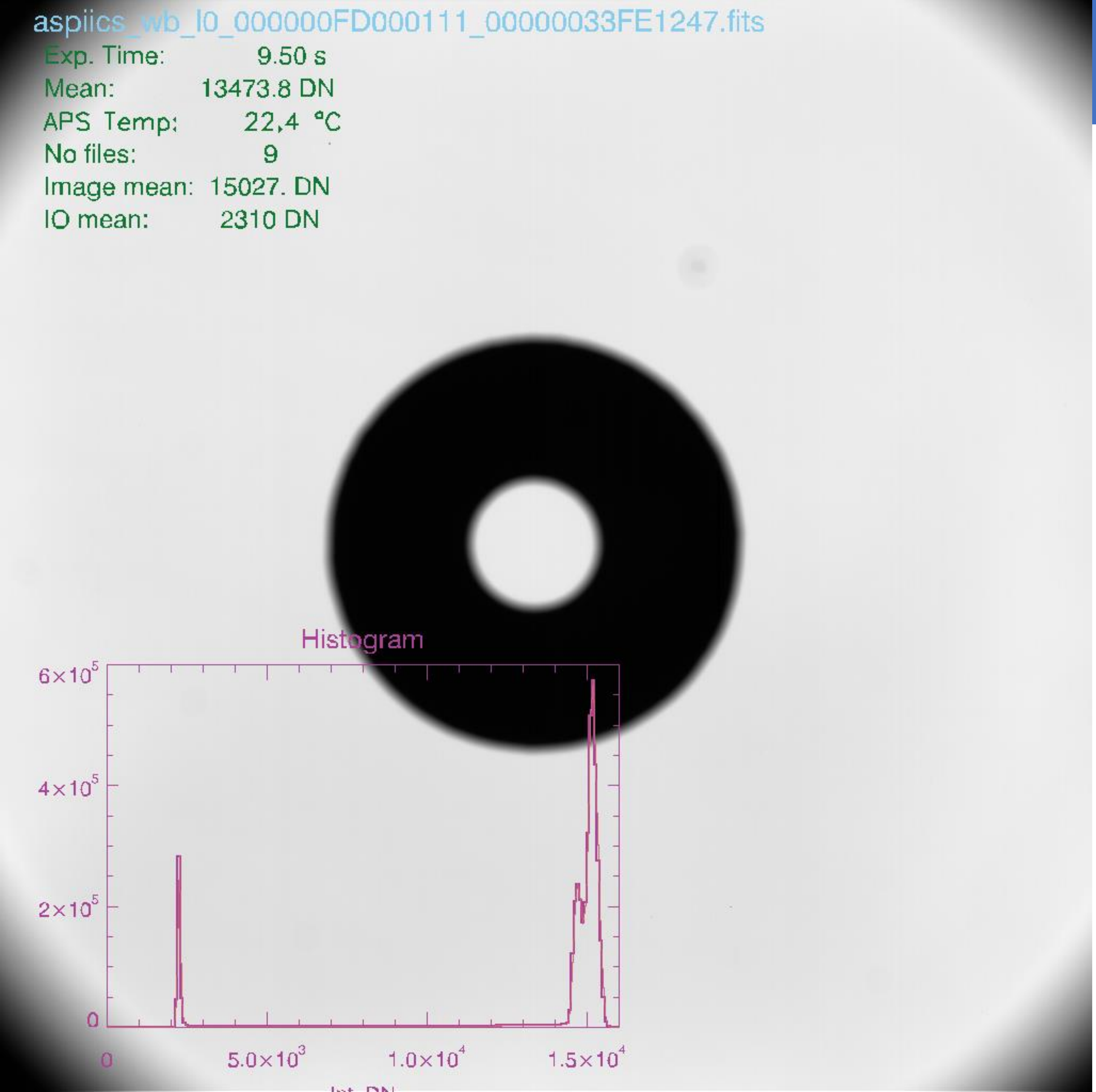


Vignetting by the barrels & holders

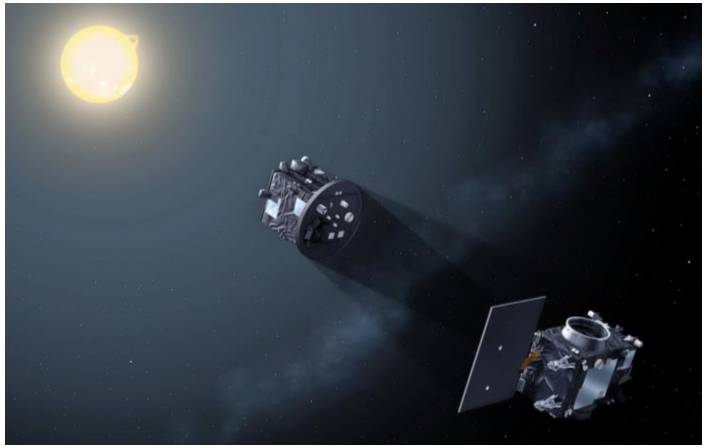
Internal occulter
- defocused
- with a hole

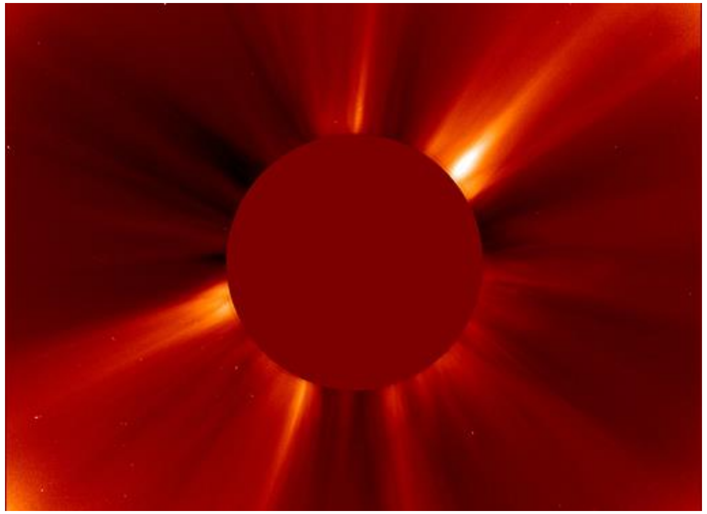






aspiics_wb_l0_000000FD000111_00000033FE1247.fits
Exp. Time: 9.50 s
Mean: 13473.8 DN
APS Temp: 22,4 °C
No files: 9
Image mean: 15027. DN
IO mean: 2310 DN
Histogram
6×10^5
4×10^5
2×10^5
0
0
5.0×10^3
1.0×10^4
1.5×10^4





Difference with EUV calibrations

$$N = B \cdot \frac{\pi D^2}{4}\left(\frac{dx}{f}\right)^2 \cdot T \cdot s$$

1. Large & divergent source
2. Finite distance

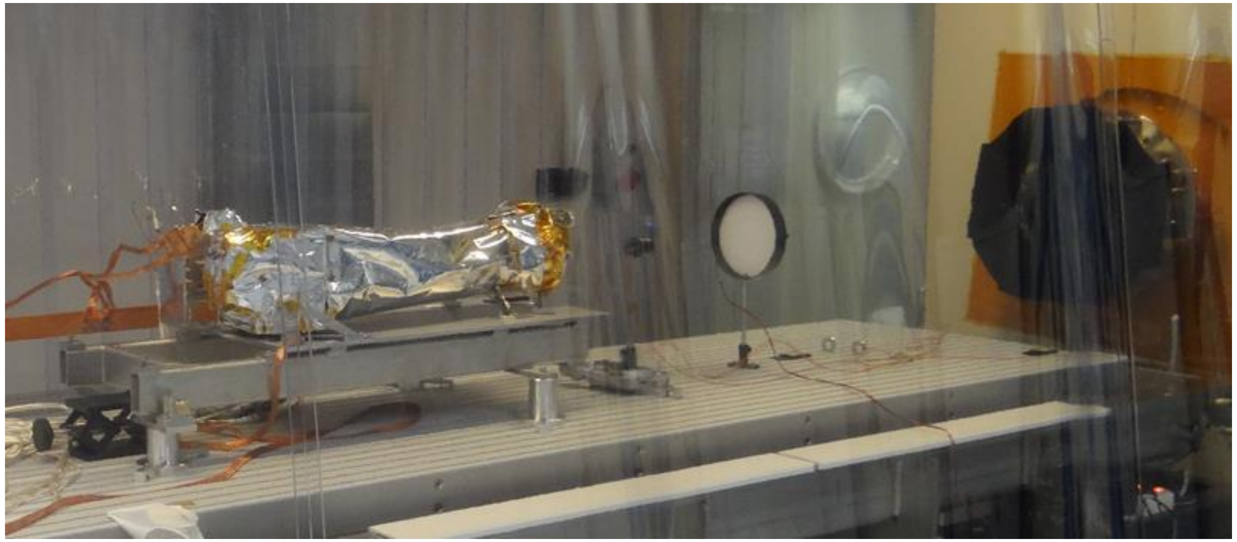
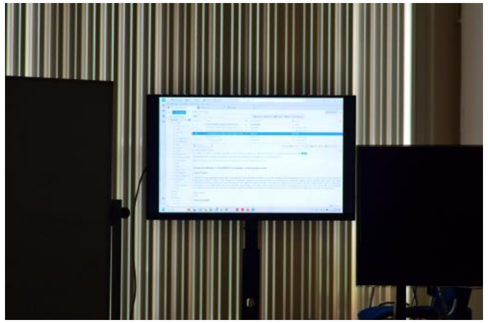
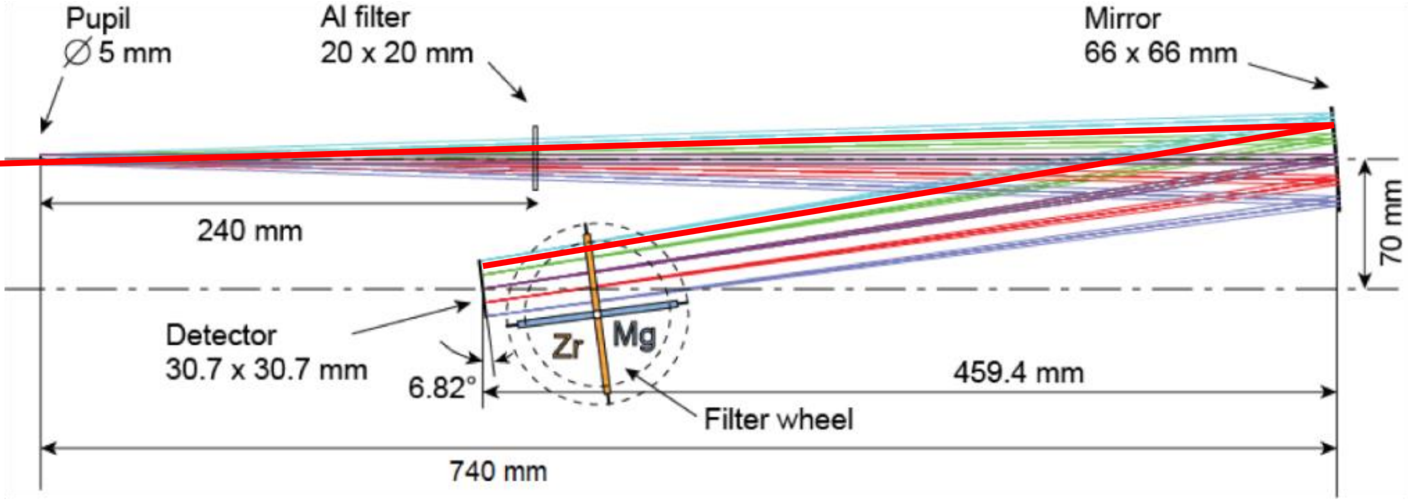


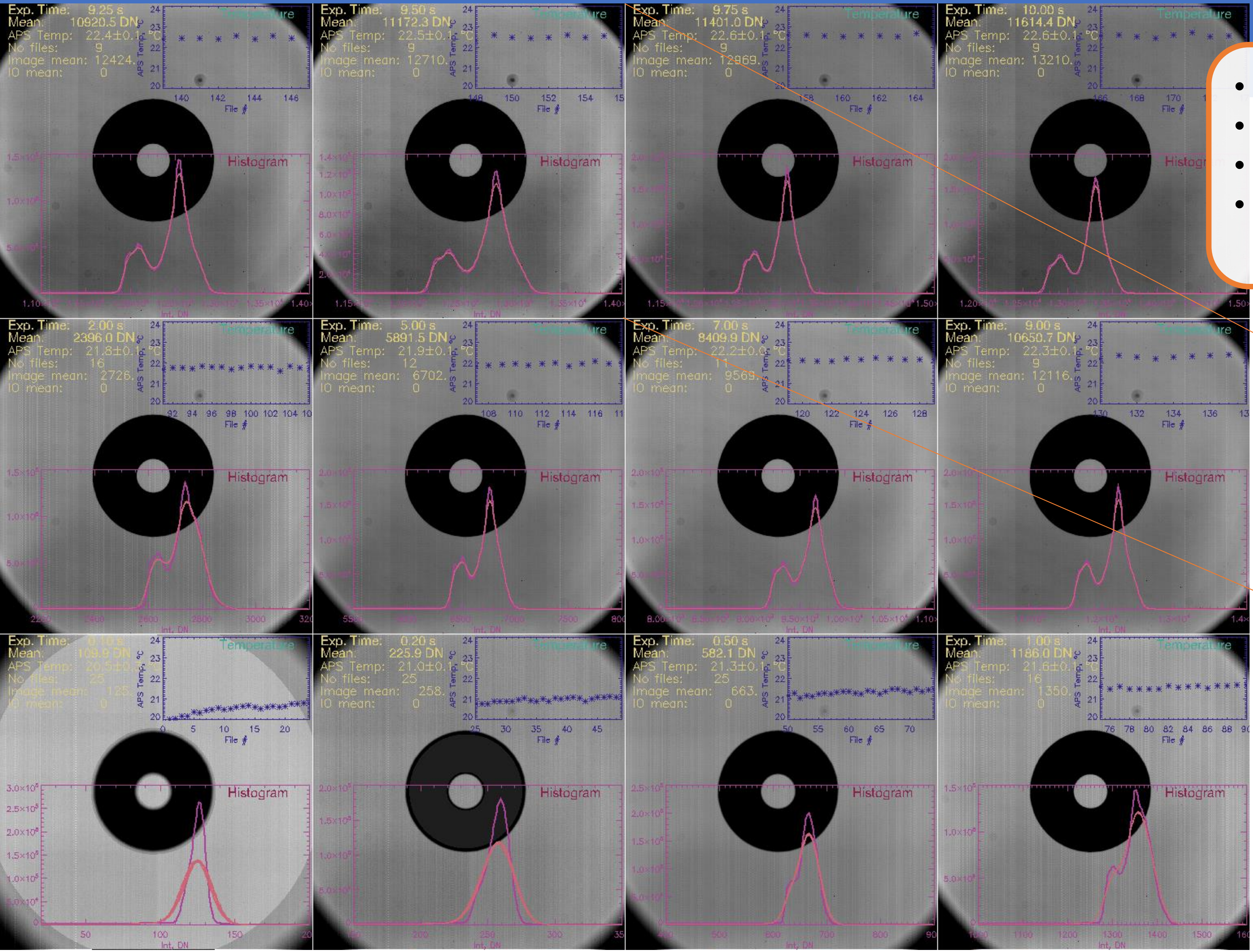
Photo of the same monitor:
out-of-focus and in-focus



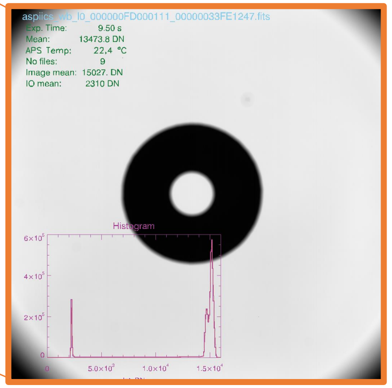
Synchrotrons:

- extremely high intensity
- tunable wavelength via monochromators
- very collimated beam (i.e. ESFR – 20 urad or 4 arcsec)
- small crossection of the beam – few mm

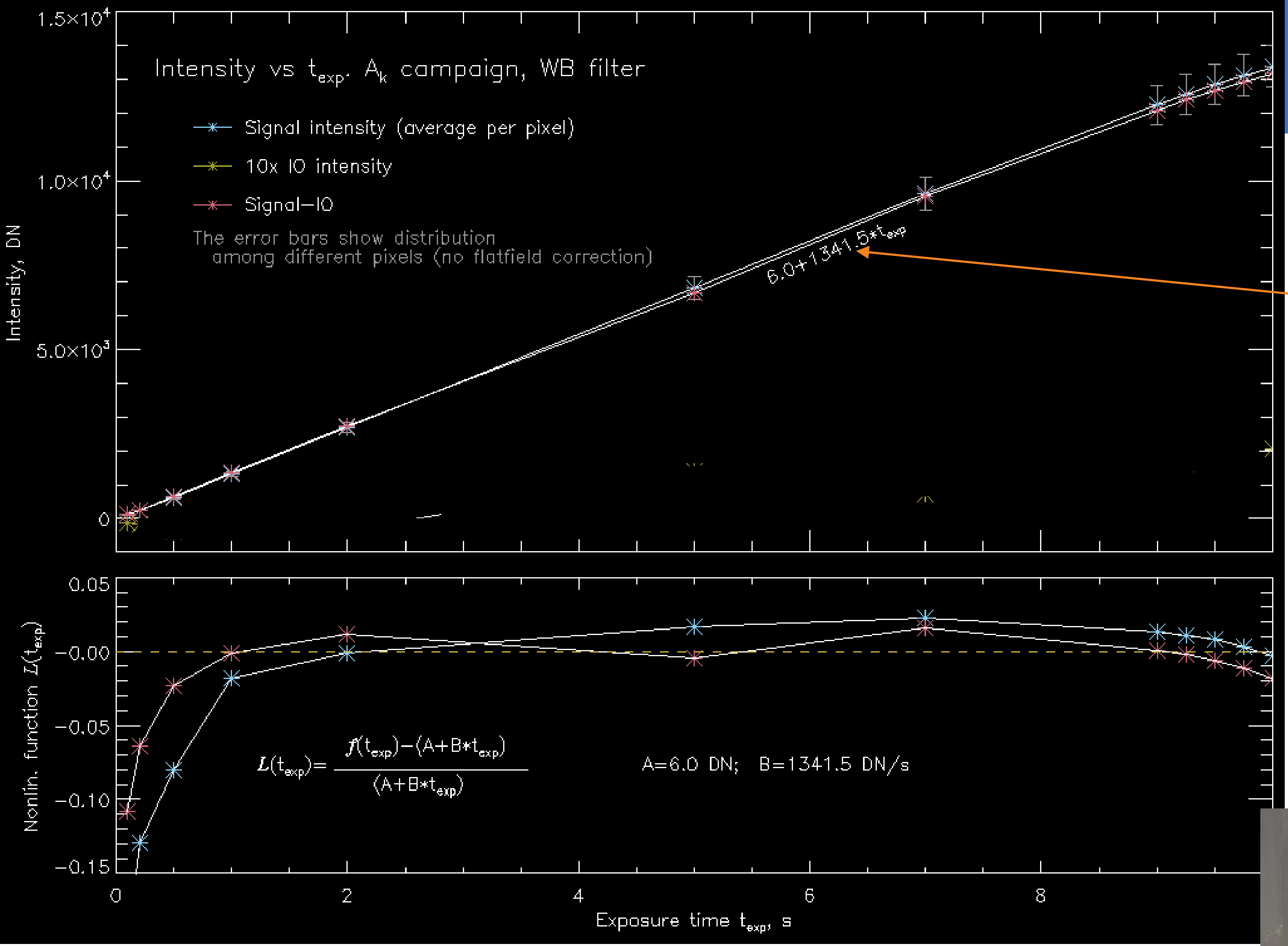




- Wideband filter
- 12 panels: for t_{exp} from 0.1 to 10 s
- Average over N files is shown
- Color table is adjusted for every panel



Same data, different color scale



This number goes to the radiometric formula

$$\boldsymbol{N} = \boldsymbol{B} \cdot \mathrm{A_k}$$

Nonlinearity

Radiometric sensitivity and provisional data

1343

Real filter	Measured flux I, DN/s	Diode flux: Diode current, A	Diode flux: Filter Transmission * **	Diode flux: renormalized to filter peak transmission, A	Diode flux: Diode flux, W	FFP brightness: W mm^{-2} sr^{-1}	FFP brightness: W cm^{-2} sr^{-1}	FFP brightness: photon s^{-1} cm^{-2} sr^{-1}	Photometric sensitivity A_k: DN sr cm^2 photon^{-1}	Provisional P3-SOC-ROB-TN-012***: --//--	Ratio
Pol 0	1347.1	3.10E-07	0.72	4.32E-07	1.53E-06	7.34E-08	7.34E-06	2.02E+13	6.67E-11	7.50E-11	0.89
Pol 60	1333.7	3.10E-07	0.72	4.32E-07	1.53E-06	7.34E-08	7.34E-06	2.02E+13	6.61E-11	7.50E-11	0.88
Pol -60	1337.4	3.40E-07	0.72	4.74E-07	1.68E-06	8.05E-08	8.05E-06	2.21E+13	6.04E-11	7.50E-11	0.81
Fe	231.8	1.20E-07	0.90	1.33E-07	4.90E-07	2.35E-08	2.35E-06	6.23E+12	3.72E-11	9.02E-11	0.41
He	924.9	3.00E-07	0.96	3.13E-07	1.03E-06	4.96E-08	4.96E-06	1.46E+13	6.36E-11	8.95E-11	0.71
WB	1341.5	3.25E-07	0.97	3.35E-07	1.19E-06	5.69E-08	5.69E-06	1.57E+13	8.57E-11	1.04E-10	0.82

* average transmittance in peak is taken from corresponding xls file

** polarizers are described in Optical model

*** obtained as T*dS_{pix}*Ap*QE*g

ed without nonlinearity	
Pol 0	1347.1
Pol 60	1333.7
Pol -60	1337.4
Fe	231.8
He	947.7
WB	1343

	Diode coeff. (NIST 568nm), A/W	0.294
	Diode coeff. (NIST 530nm), A/W	0.271
	Conversion E/B, W/(W mm^{-2} sr^{-1})	20.83 see sergei's numerical calculation
Photon energy e=hc/lambda, J	550 nm	3.636E-19
	530 nm	3.774E-19
	587 nm	3.407E-19
	hc, J*m	2.00E-25

Photodiode sensitivity, A/W		NIST sensitivity, A/W	Datasheet IRD
	wavelength, nm		
	531	0.271	0.274
	568	0.294	0.300
	674	0.348	0.3
'=> calculated for ASPIICS filters			
	530.45	0.272	
	550.00	0.282	
	587.70	0.303	

$$A_k = \Omega_{pix} \cdot S_{ap} \cdot T \cdot QE \cdot g$$

for example

$$\Omega_{pix} = 1.8 \cdot 10^{-10}\,[sr] \qquad (2.81 arcsec)^2$$

$$S_{ap} = \pi R^2 \approx 18.52\,[cm^2]$$

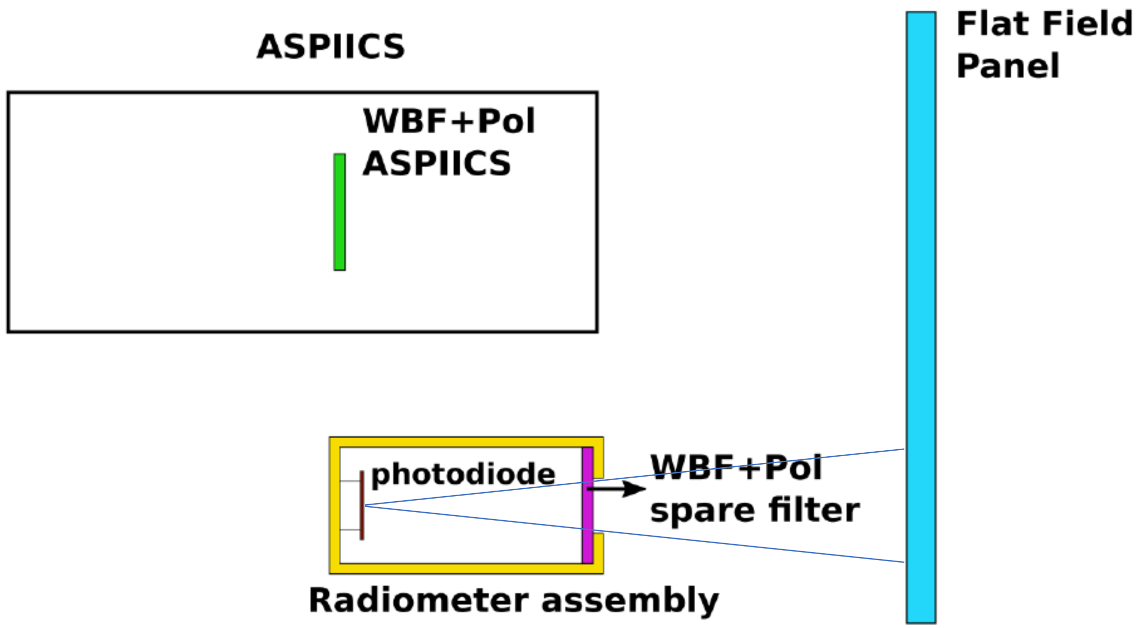
$$T \approx 0.39 \qquad (0.79 + ND50\%)$$

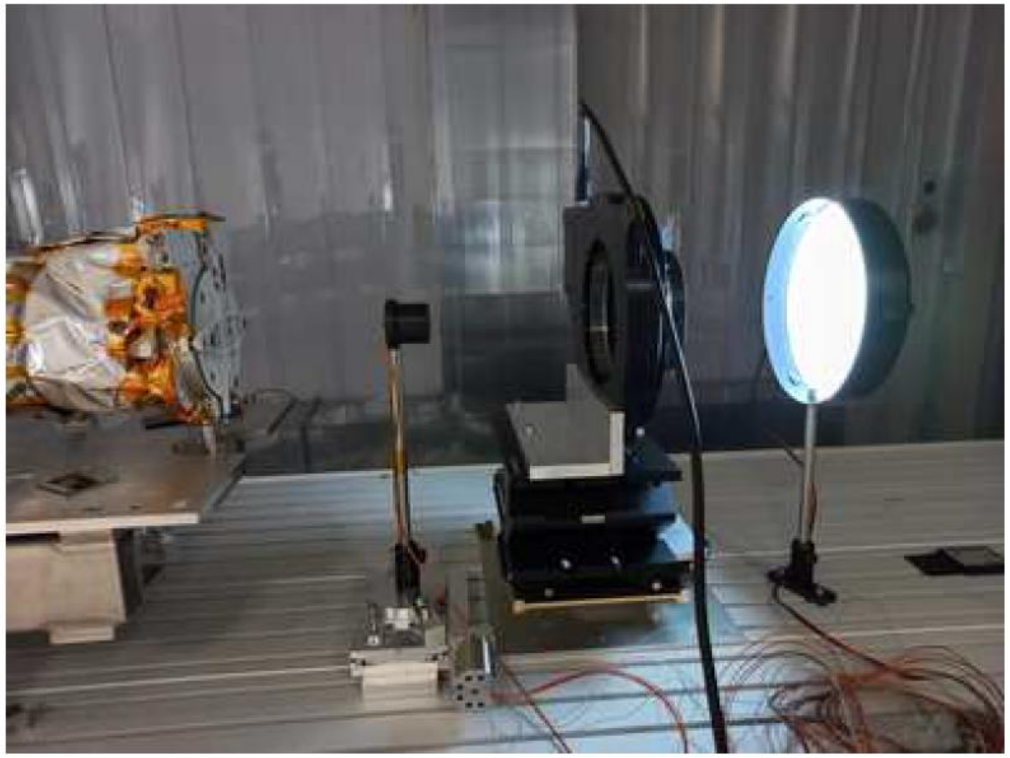
$$QE \approx 0.65$$

$$g \approx 0.12\,[DN/el^-]$$

Shestov et al. 2021

How to measure FFP brightness





$$I_{ph} = B \cdot A_{ph} \cdot \Omega_{ph} \cdot D$$

A_{ph} – photodiode area
Ω_{ph} – subtended angle
D – sensitivity [Ampere/Watt]

- Photodiode has the same filter
- Biggest error – subtended angle / photodiode entrance (!!!)
- Big discrepancy in the case of NBF filters
- Origin is not clear; B(V) has been used

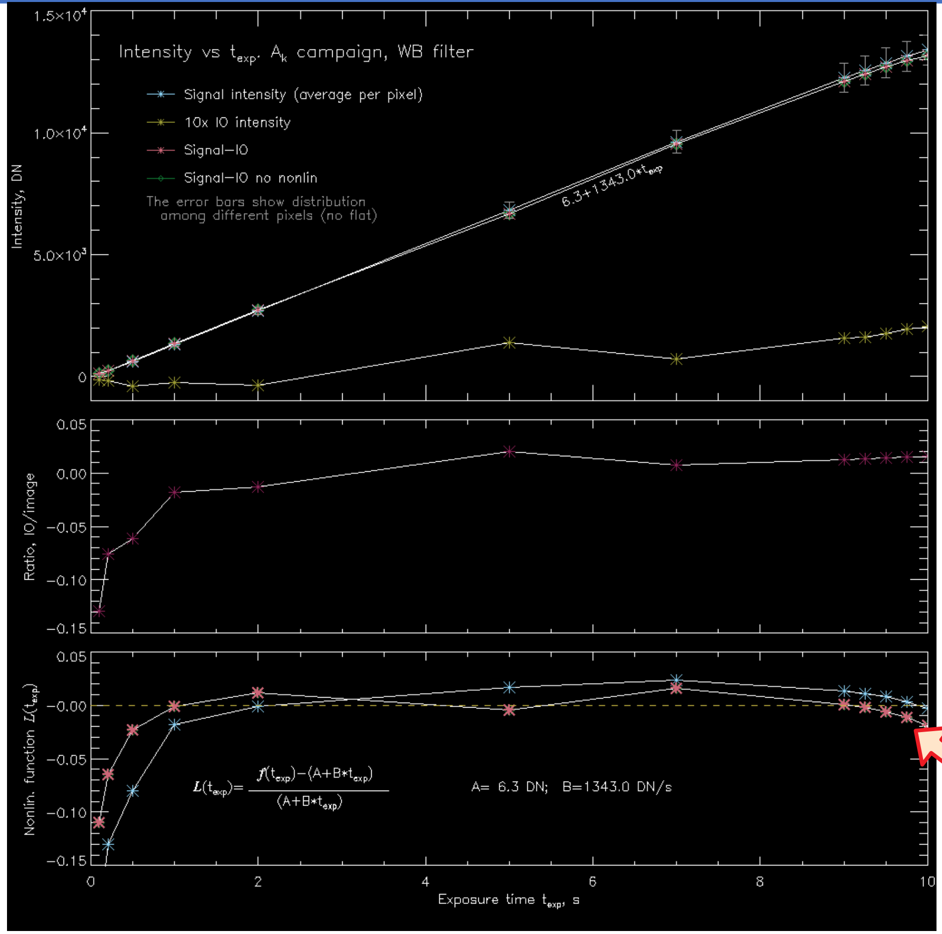
Radiometric sensitivity

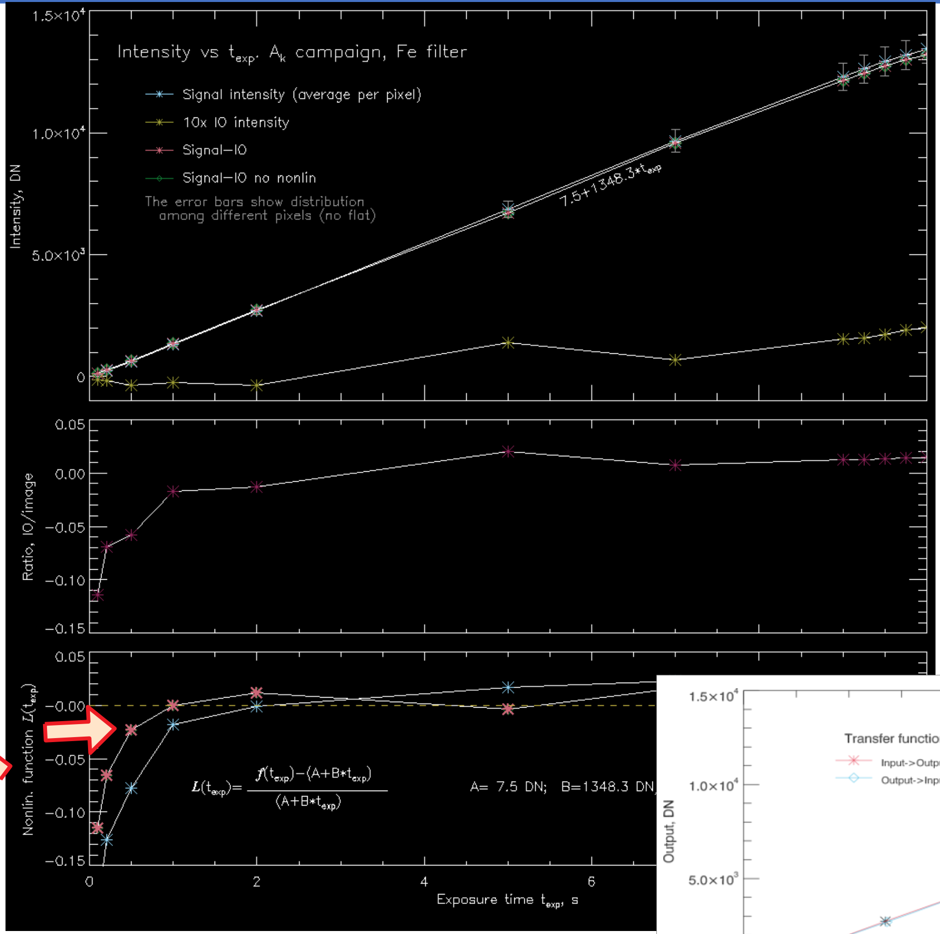
Conclusions:

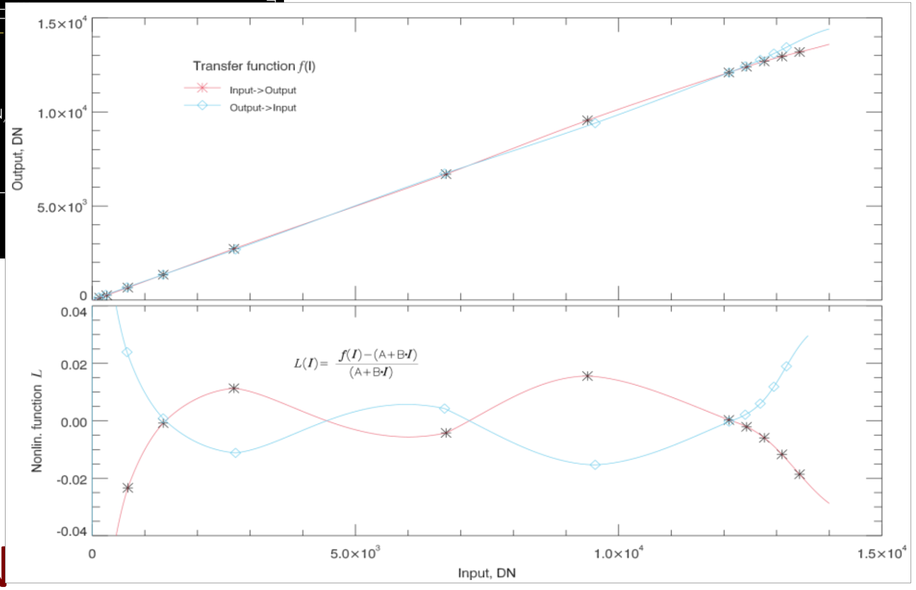
- A_k measured for 6 filters
- 80-90% correspondence to theory
- Nonlinearity of DN vs t_{exp}

- Advantage in using extended diverging light source
- Biggest uncertainty – photodiode stability & solid angle
- Unknown effect for narrow-passband filters

Nonlinearity





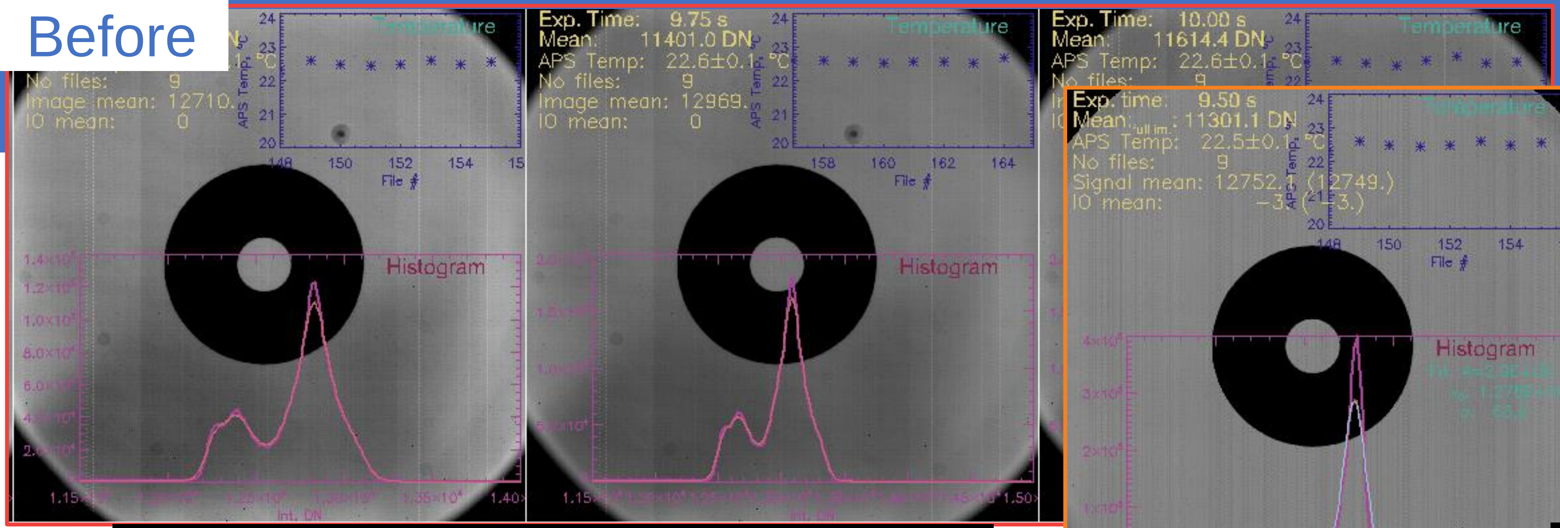


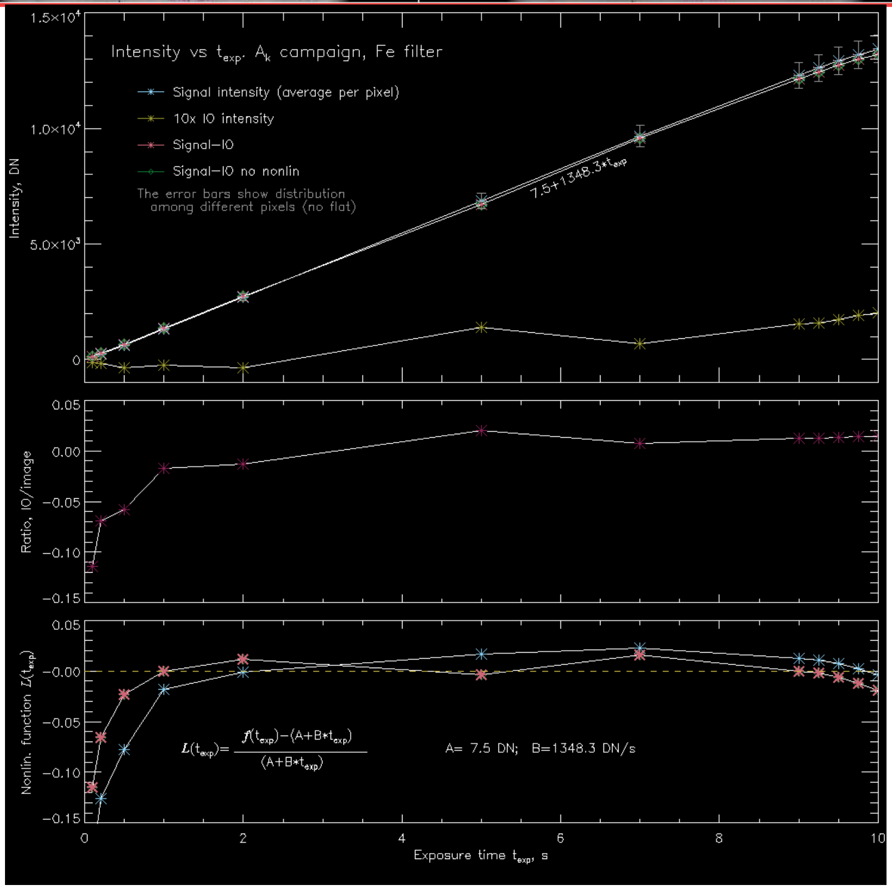
$$N = B \cdot \Omega_{pix} \cdot S_{ap} \cdot T \cdot s = B \cdot A_k$$

$$s \rightarrow QE \cdot g$$

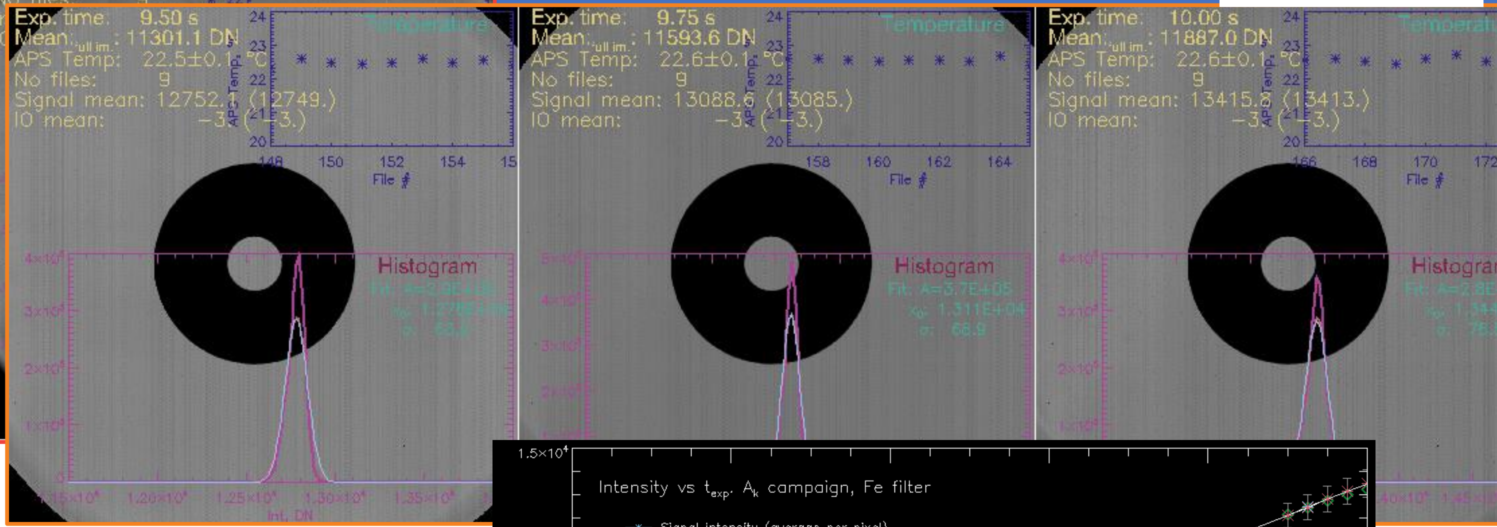
Source of nonlinearity – conversion from electrons to DN

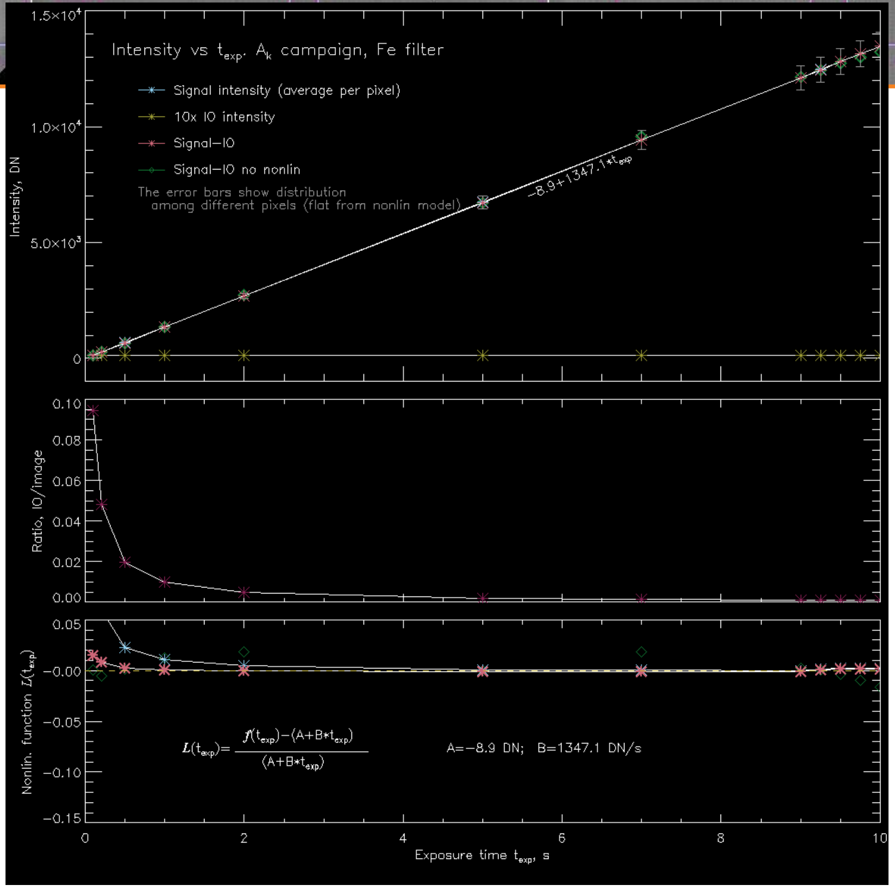
Before



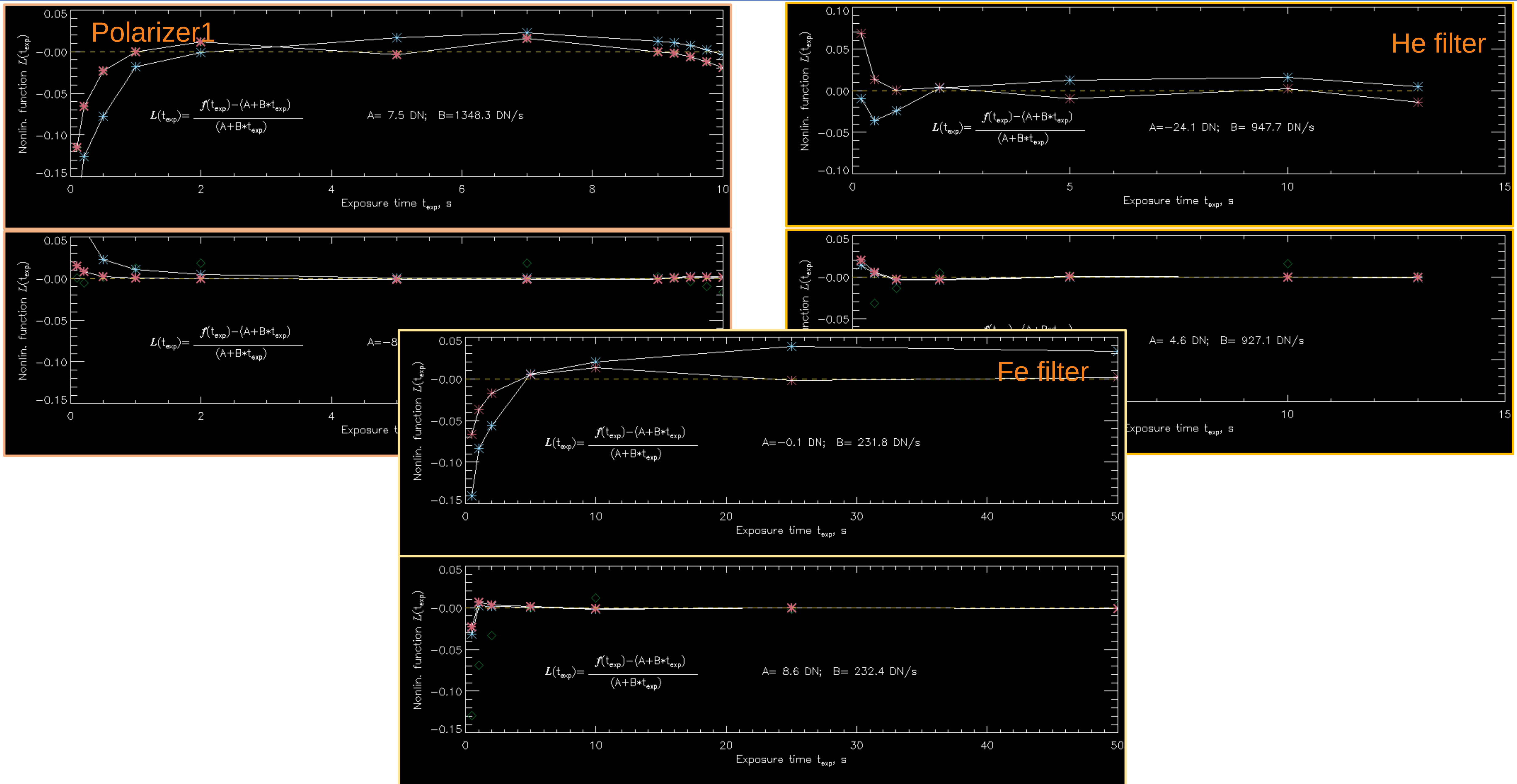


After





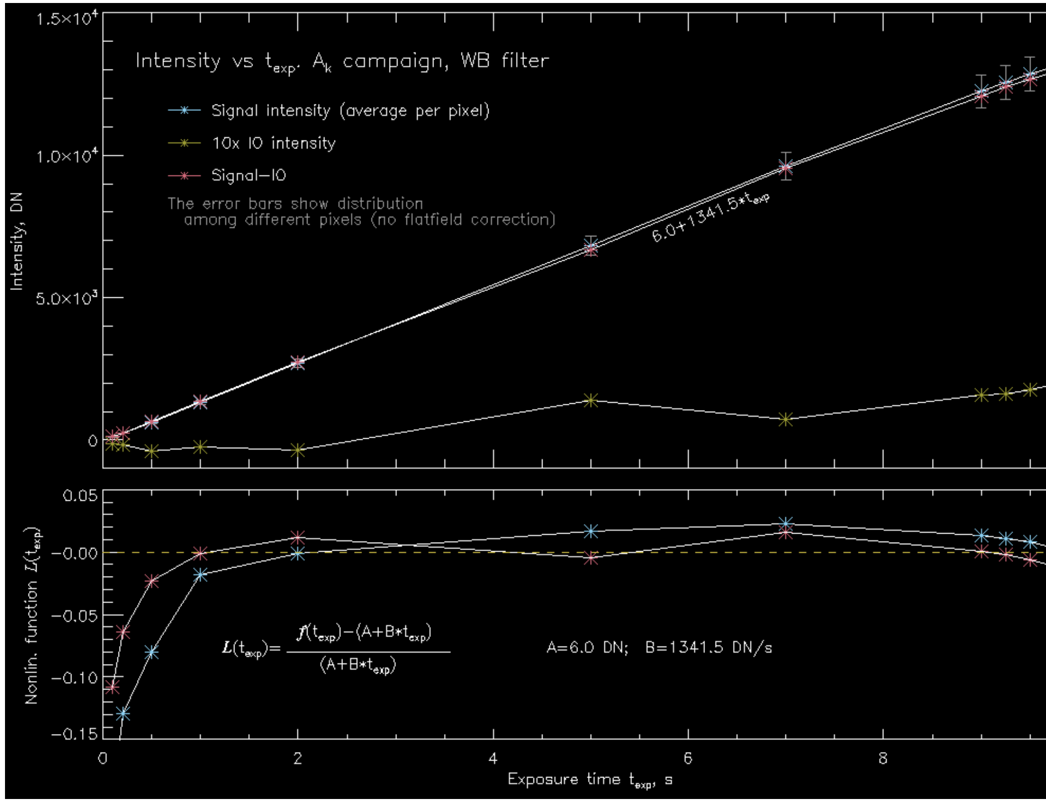
Nonlinearity corrected



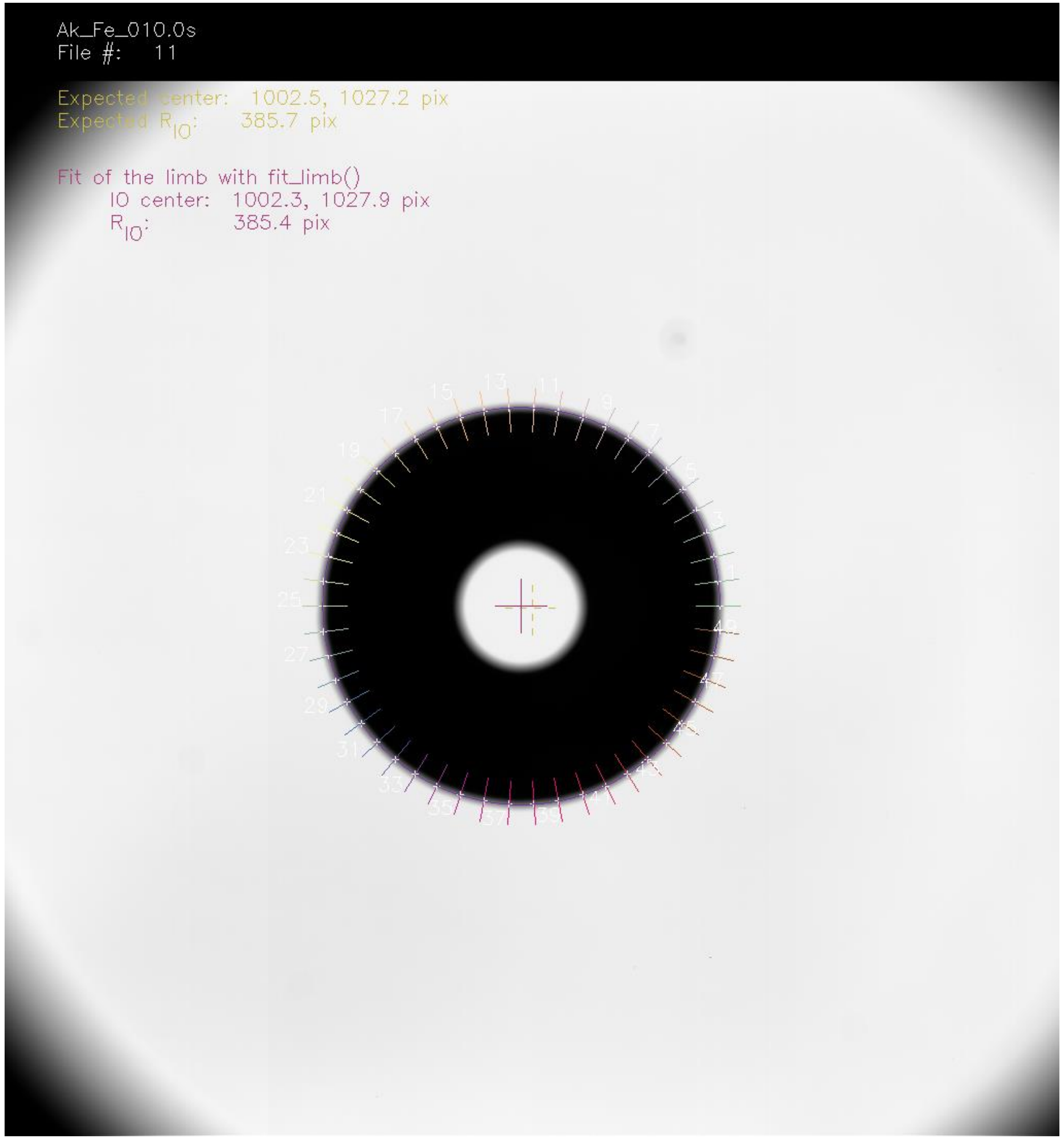
Nonlinearity

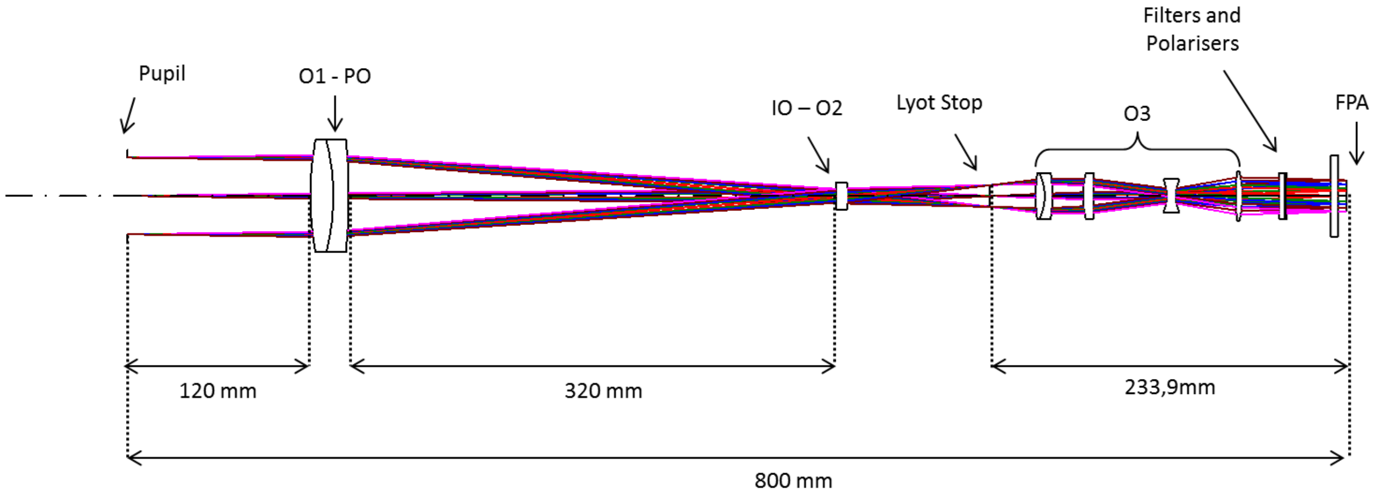
Conclusions:

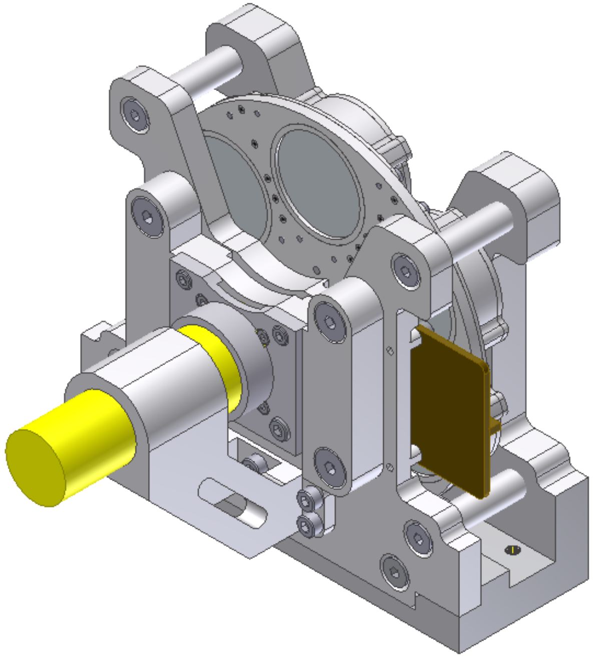
- The nonlinearity is attributed to the process of electron → DN within the detector
- The nonlinearity function is within ±2%, below -5% at smaller signal;
- It was measured using WBF data
- Excellent results for other filters

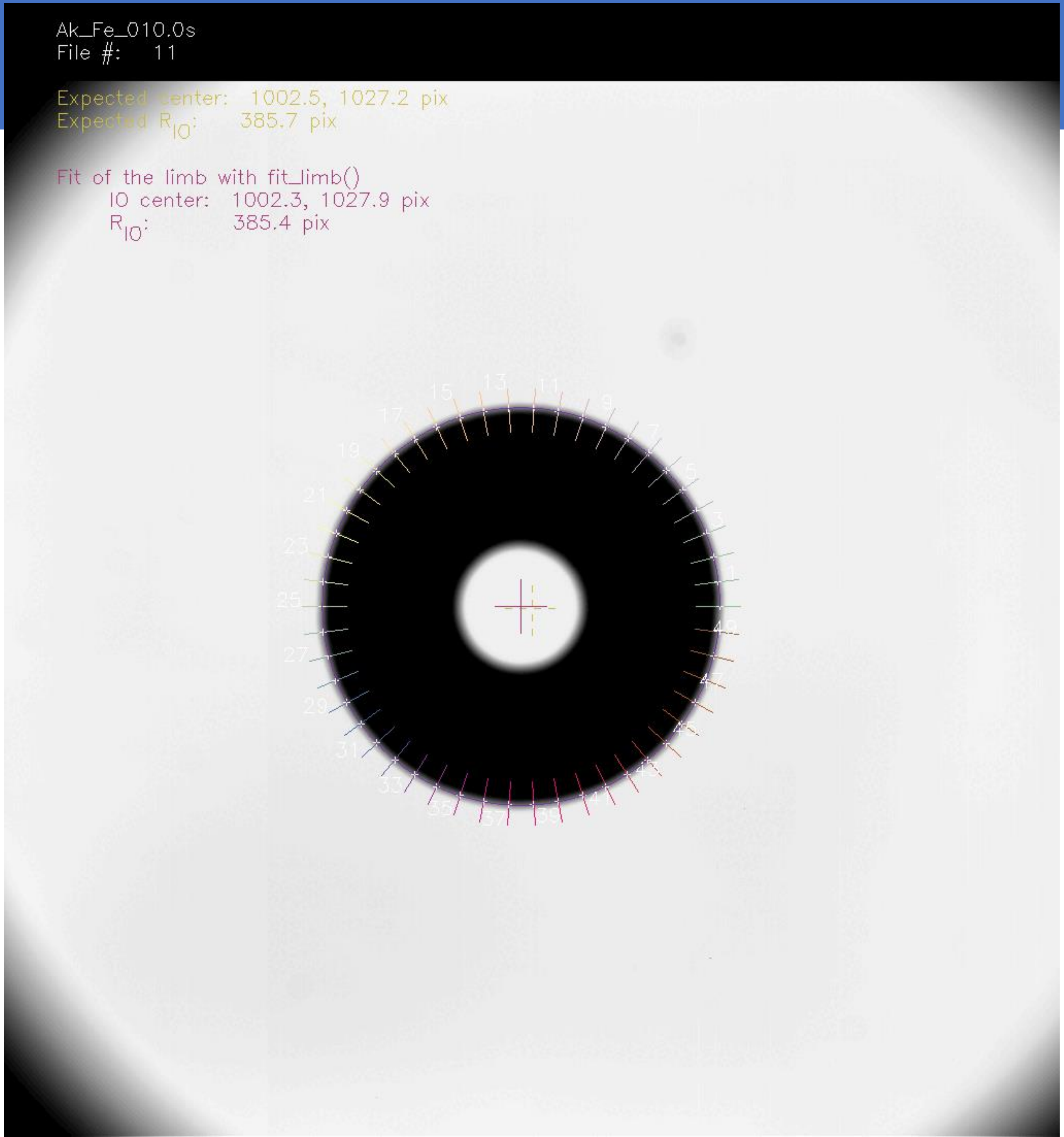


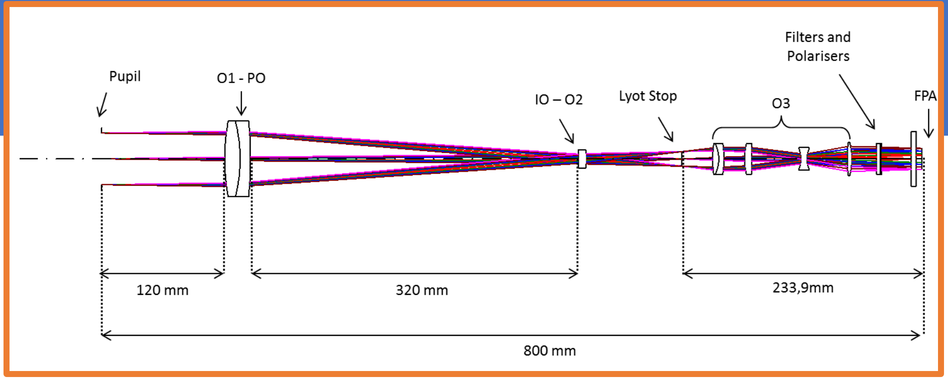
Influence of the filter

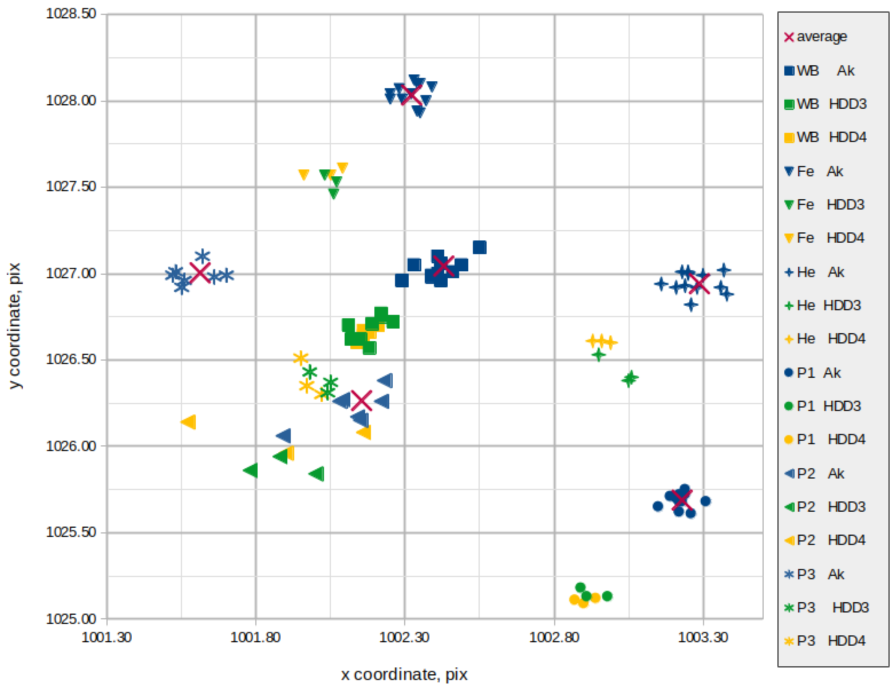












- ~2 pixel shift of the IO center (!)
- slight wedge-shape of the filters

Summary

- Dark frames
- Radiometric sensitivity
- Flat field
- Nonlinearity
- Polarization
- IO position
- PTC and gain
- Hot pixels

- Calibrations in Aug/Sep 2021 during ~3 weeks
- A-posteriory analysis of the calibration data
- Surprises in every characteristic
- It would be better to discover them during the calibration campaign
- Comparison with theoretical model is essential
- Now we are aware of all these pitfalls & effects

- Radiometric calibration using large & divergent source

Thank you!