Flat-fielding

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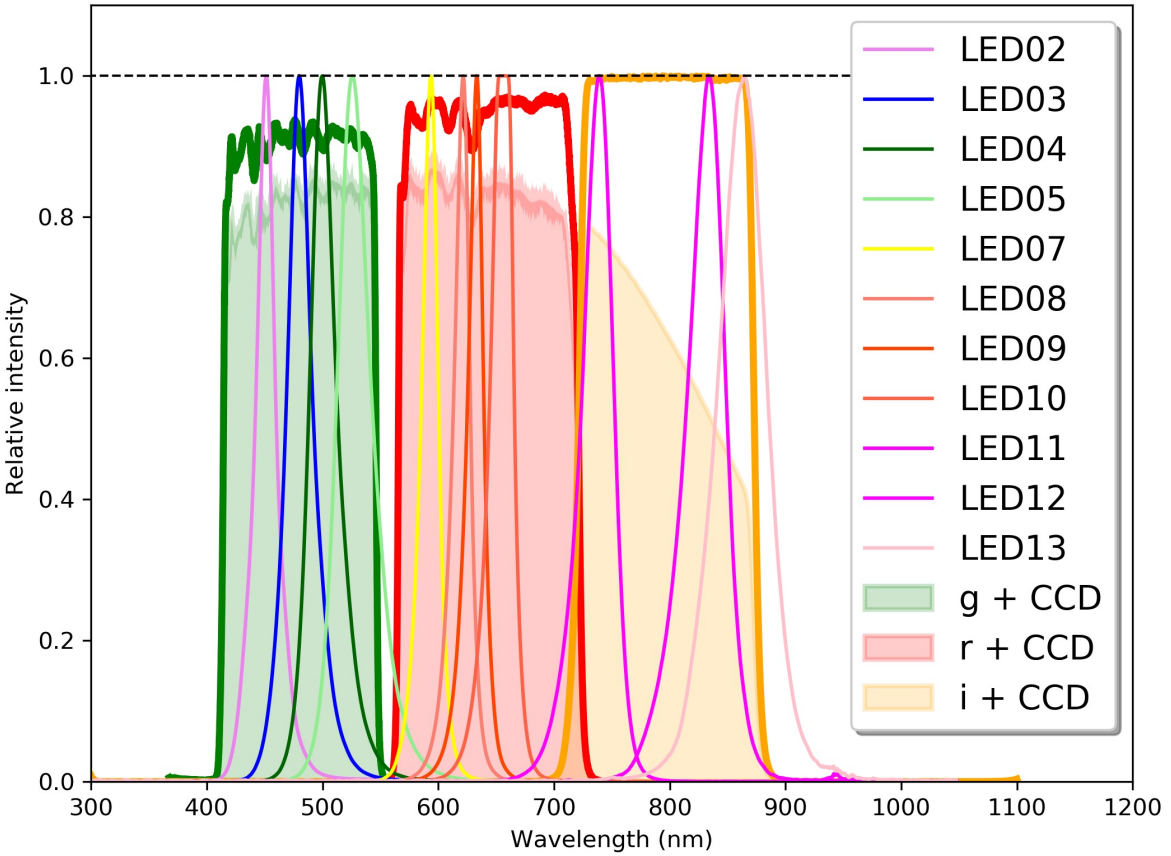
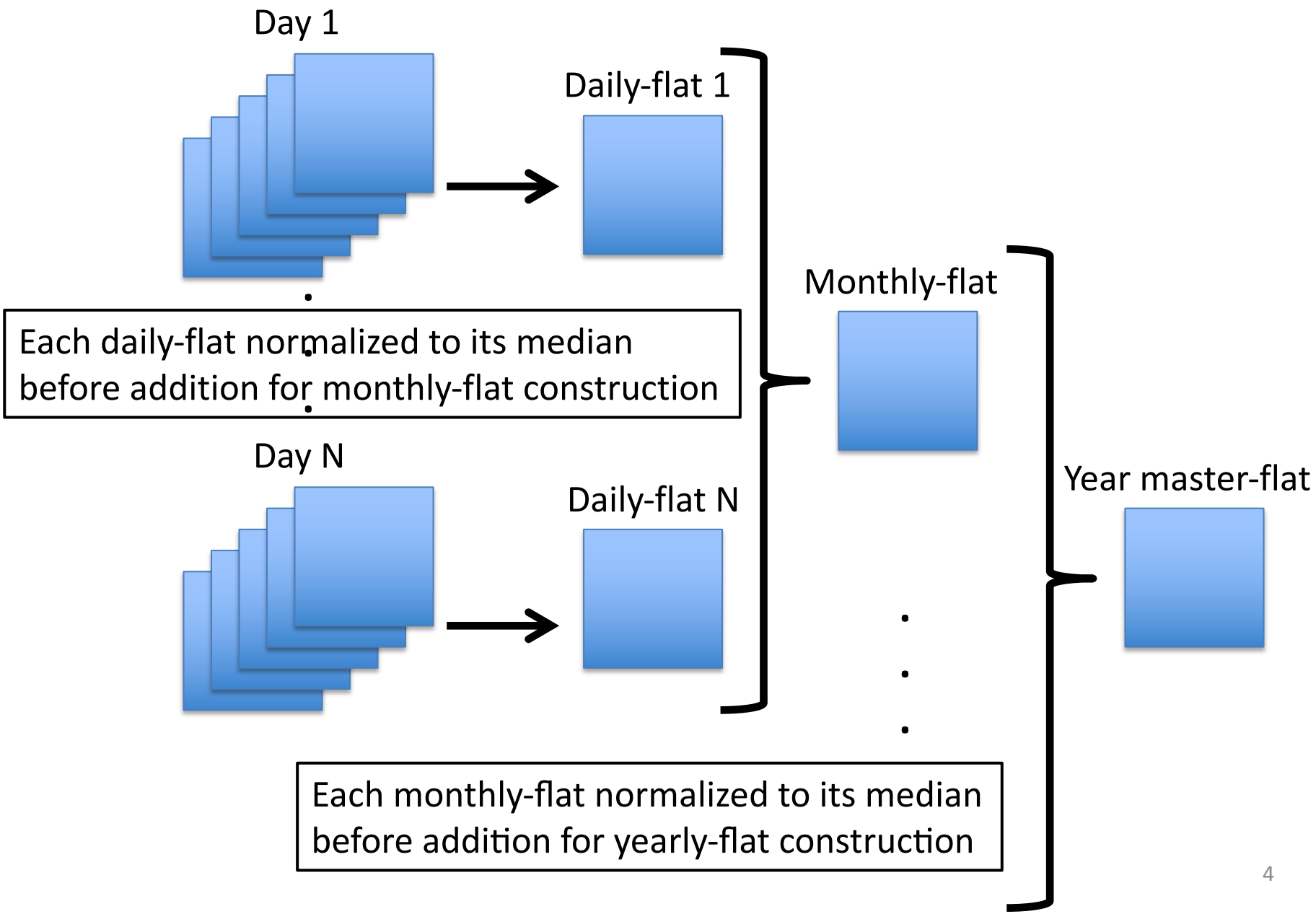
Master-flat

Filter and LED spectra

Flat-field illuminator
(32 pulsed LEDs per colour)

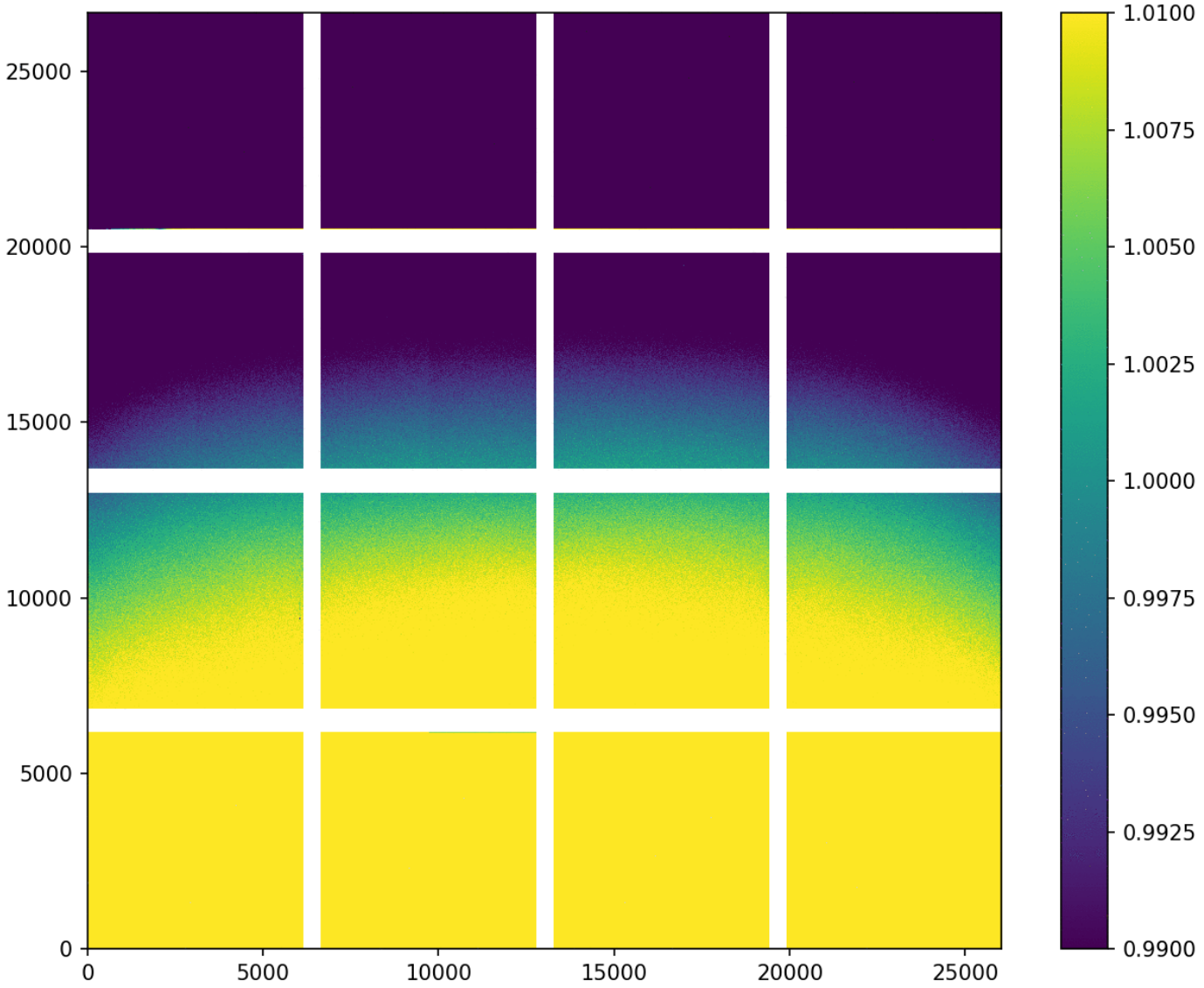


Master-flat construction

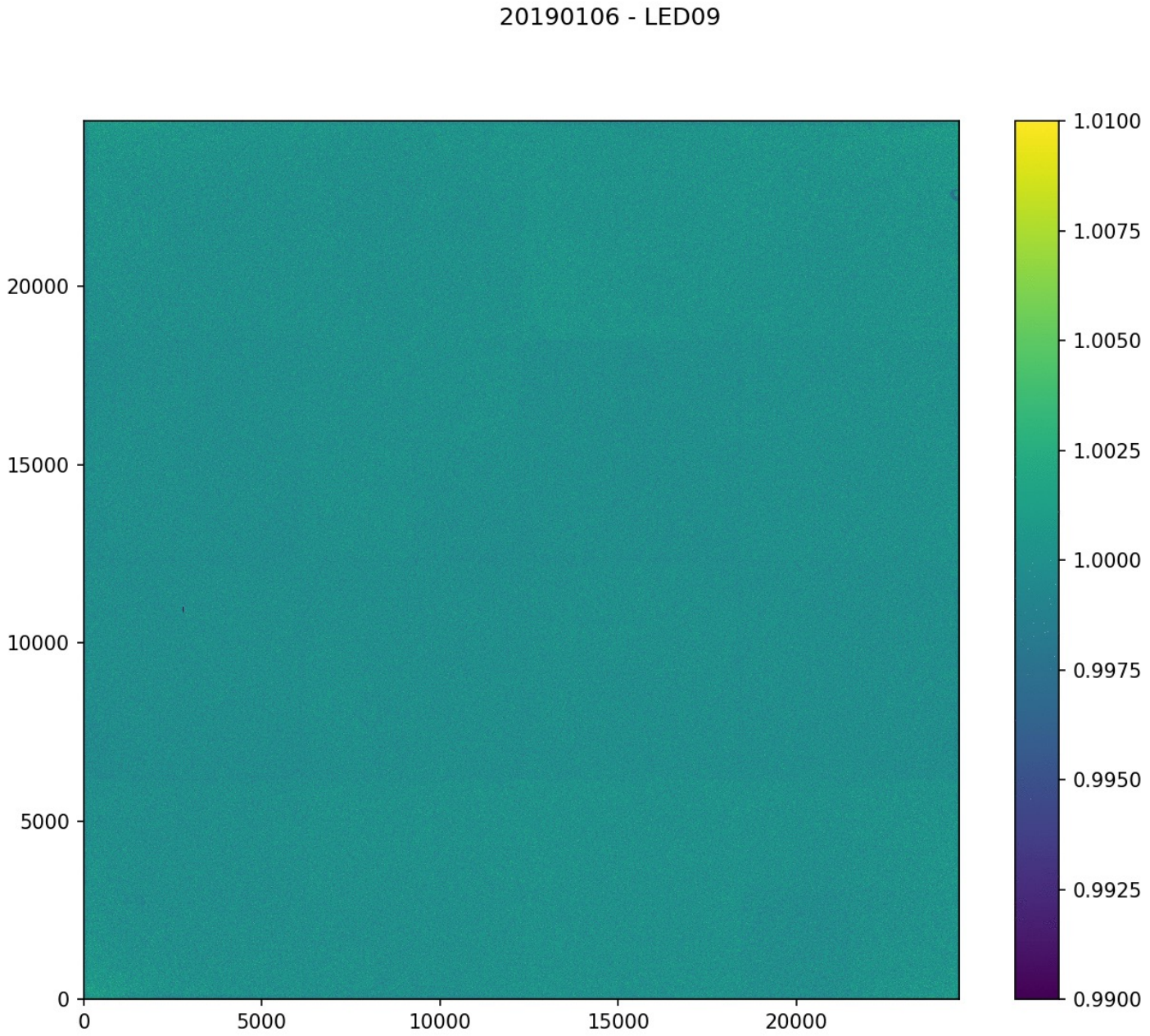


January 2019 (LED09) : daily-flat / monthly-flat

Before removing “bad” daily-flat

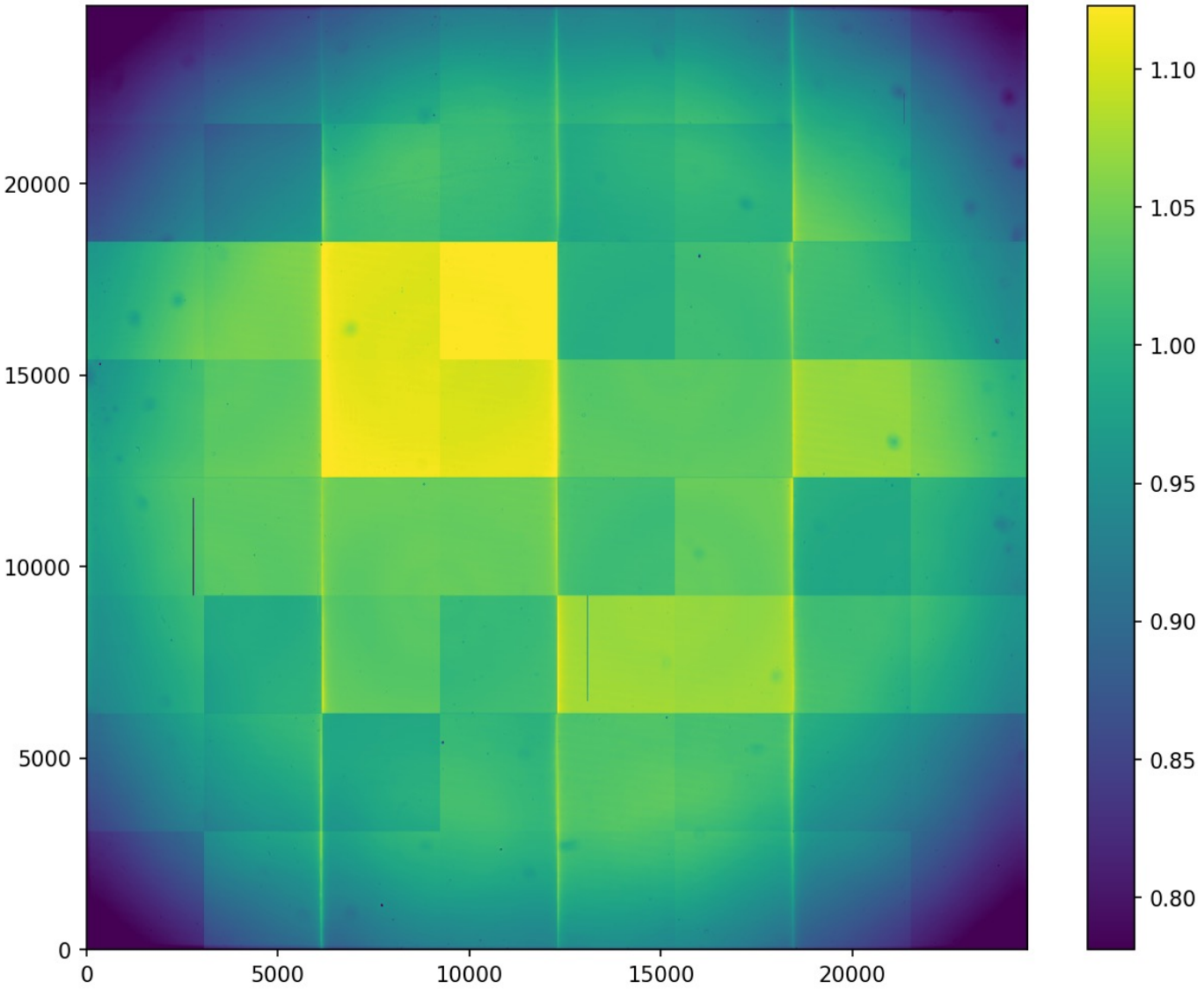


January 2019 (LED09) : daily-flat / monthly-flat

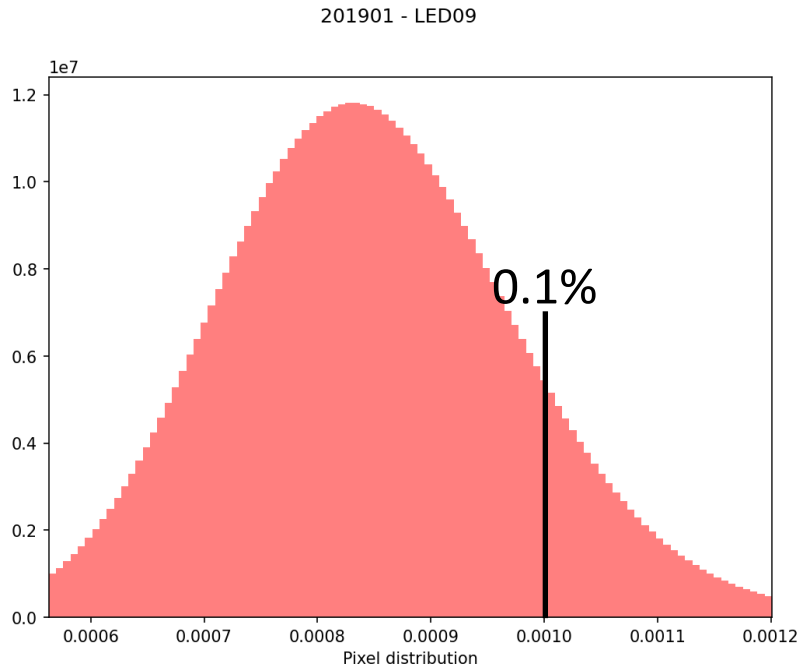


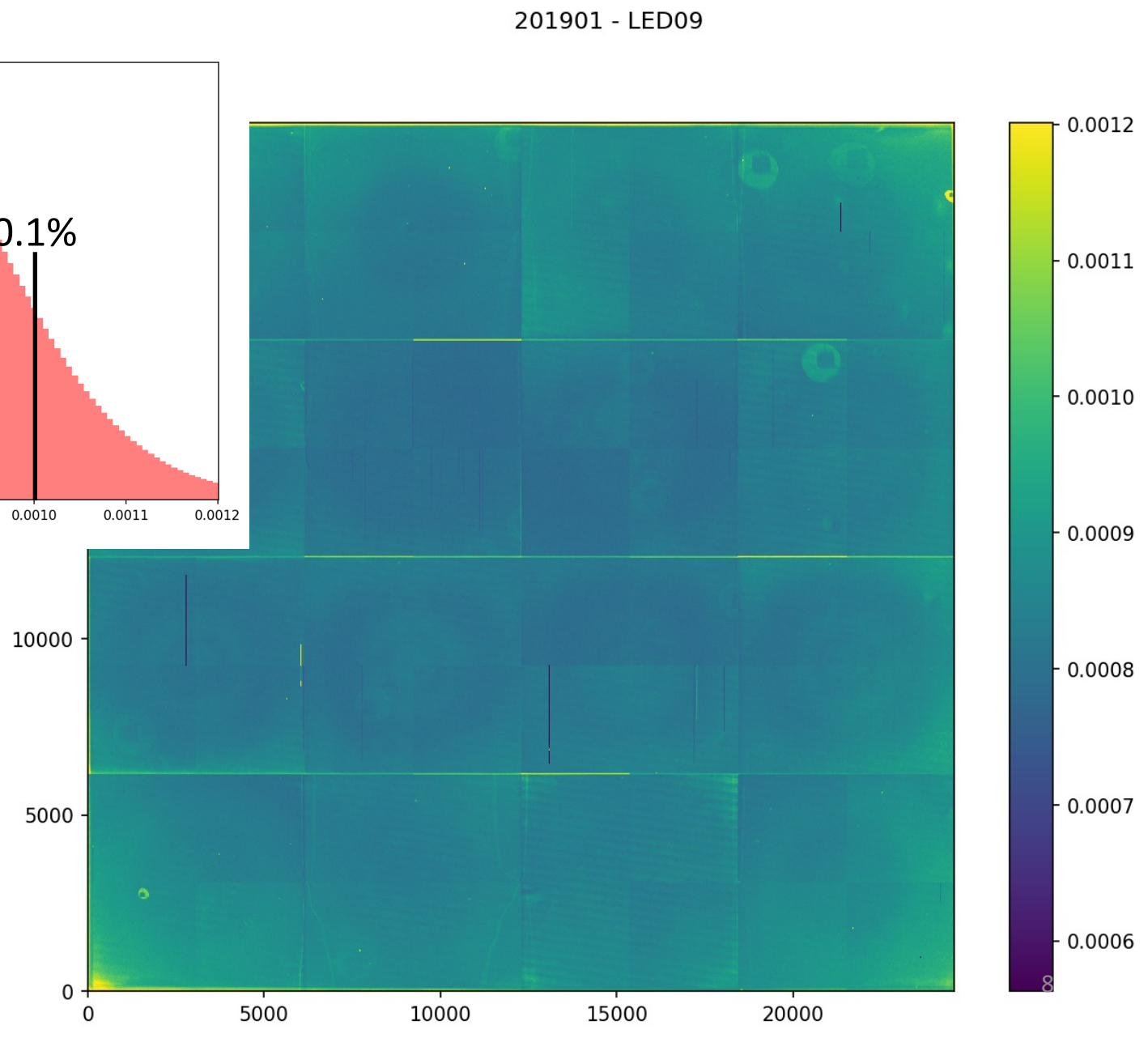
January 2019 (LED09) : master-flat

After removing “bad” daily-flat



January 2019 (LED09) : master-flat residual



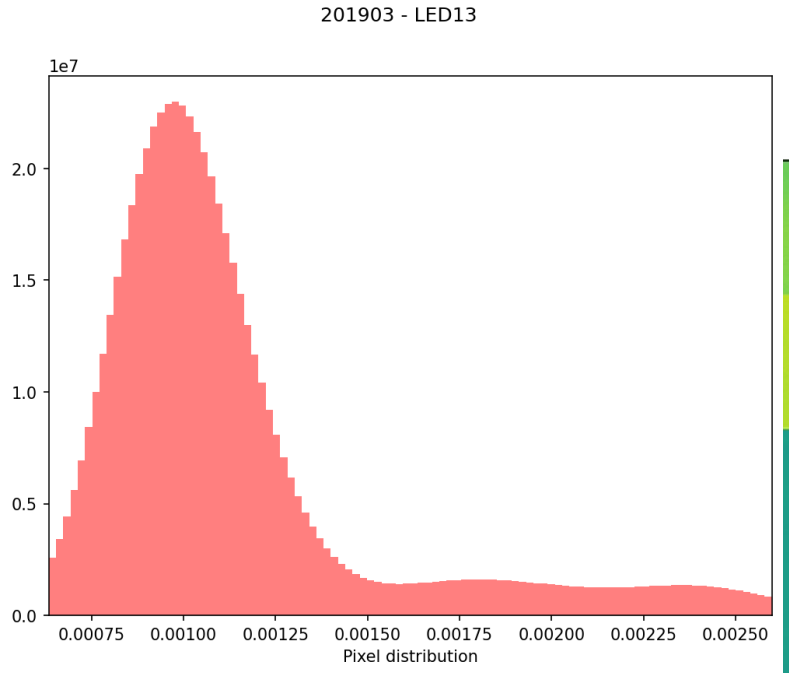


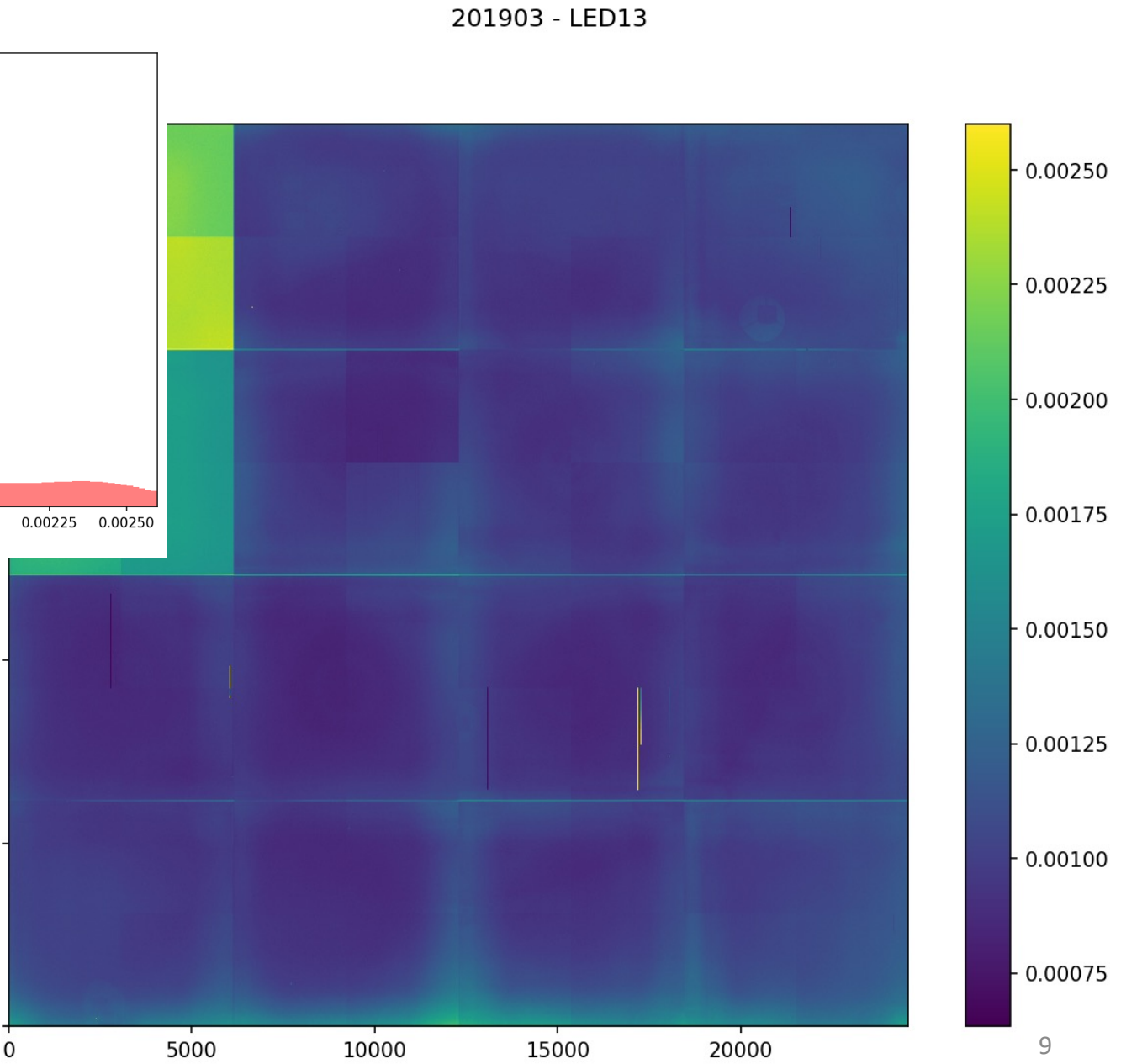
$$\frac{\sigma_n}{\langle n \rangle} = \frac{\sqrt{\langle n^2 \rangle - \langle n \rangle^2}}{\langle n \rangle}$$

N = pixel counts

$$n = \frac{\text{pixel counts}}{med(\text{flat})}$$

LED13 : master-flat residual from normed counting



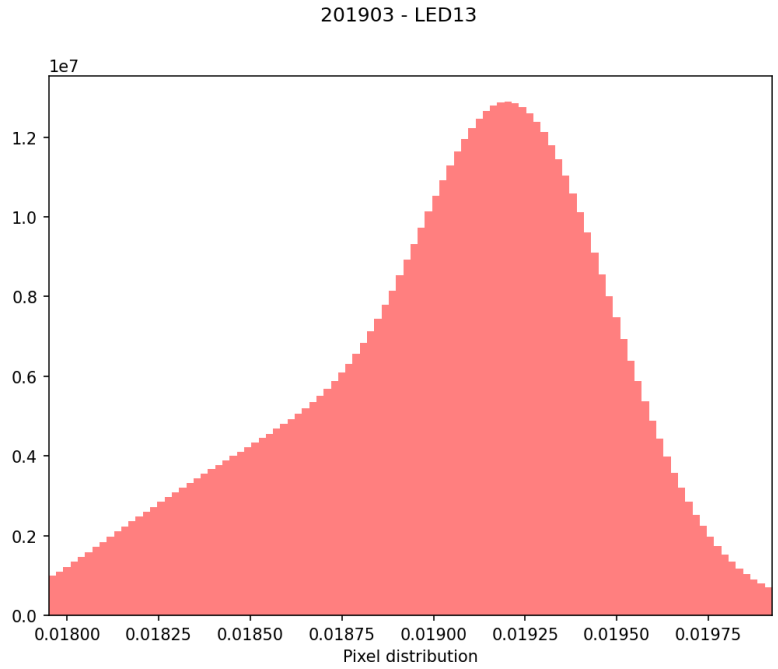


$$\frac{\sigma_n}{\langle n \rangle} = \frac{\sqrt{\langle n^2 \rangle - \langle n \rangle^2}}{\langle n \rangle}$$

$N = \text{pixel counts}$

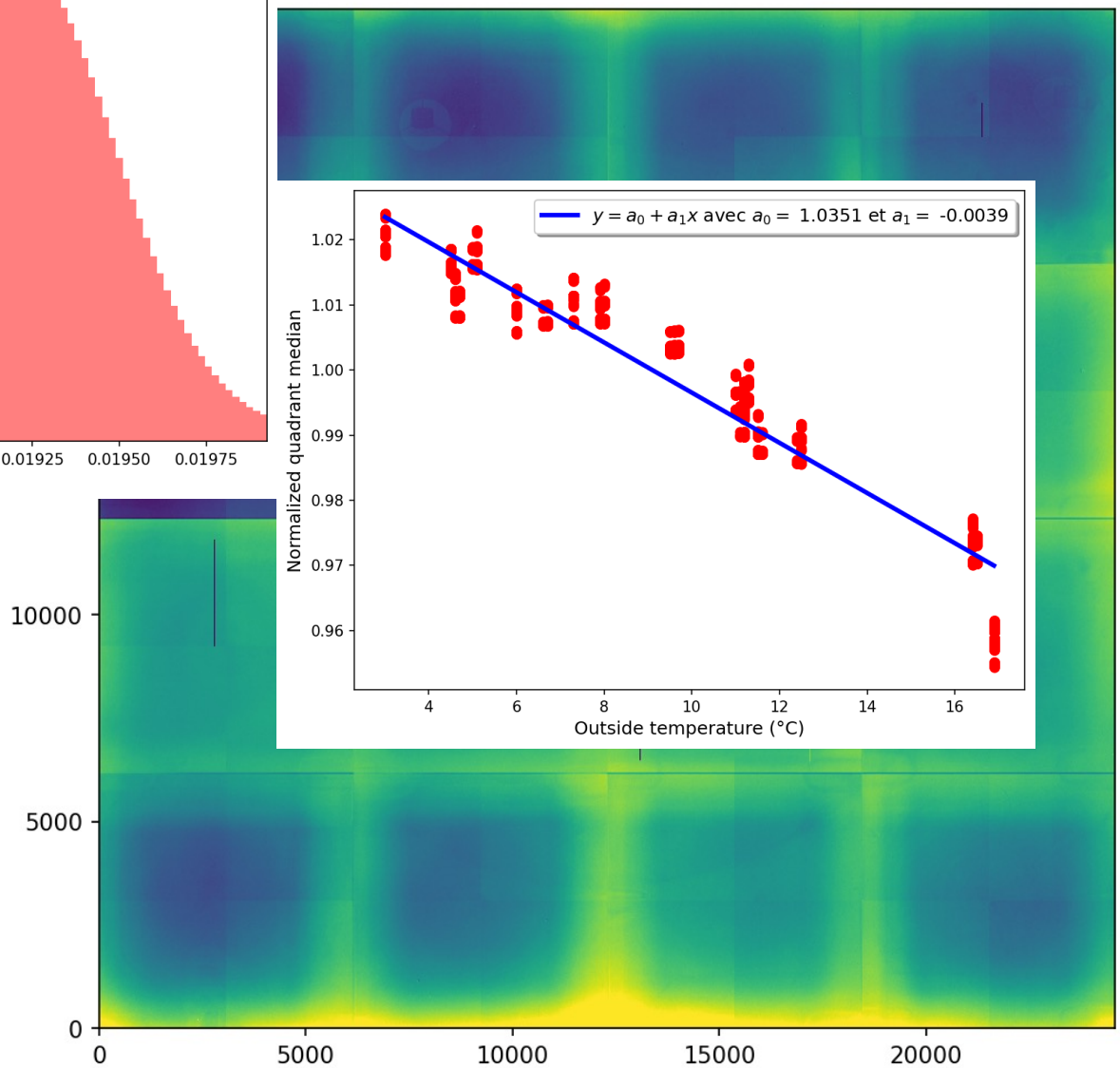
$$n = \frac{\text{pixel counts}}{med(\text{flat})}$$

LED13 : master-flat residual from raw counting

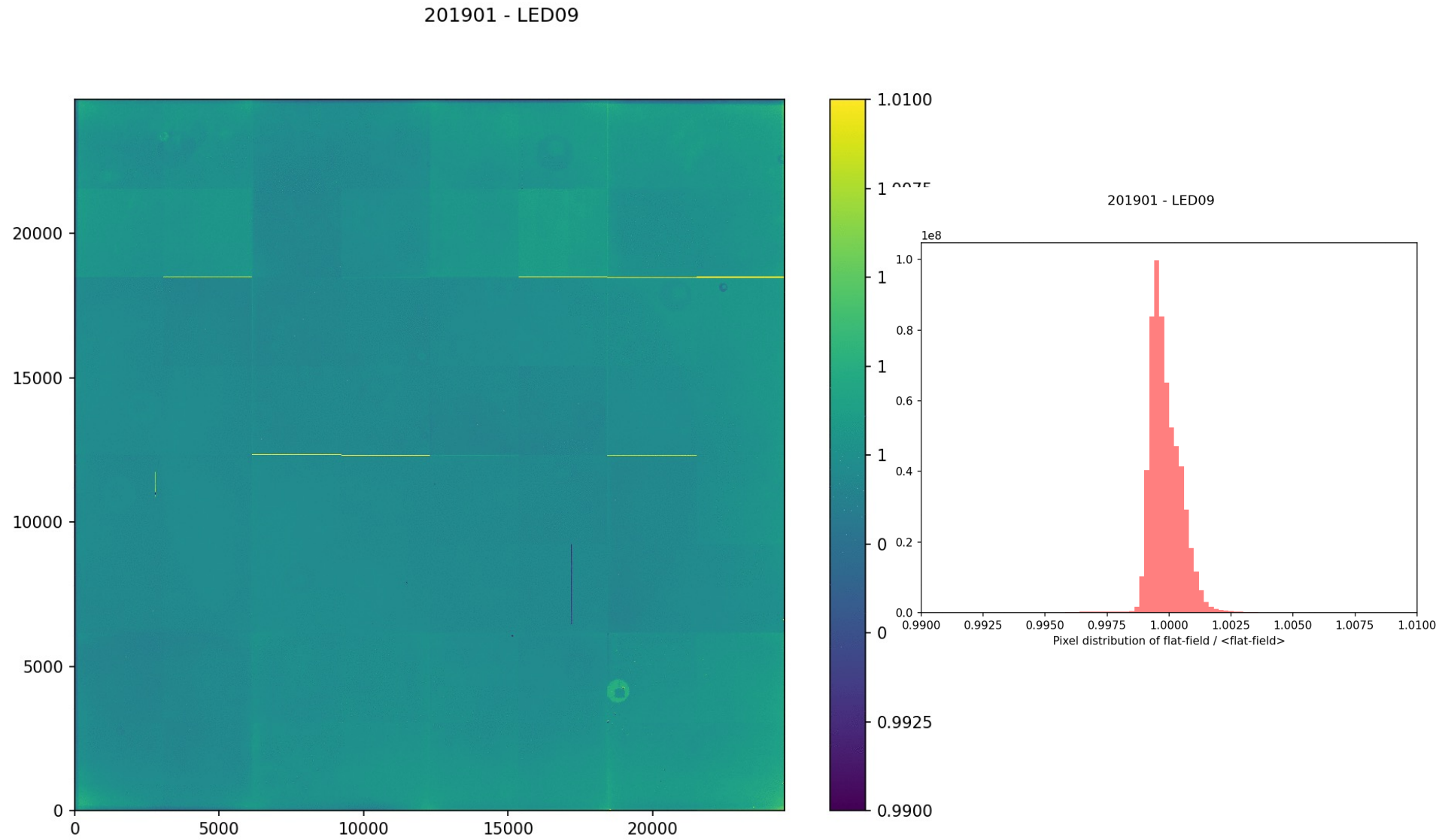


$$\frac{\sigma_N}{\langle N \rangle} = \frac{\sqrt{\langle N^2 \rangle - \langle N \rangle^2}}{\langle N \rangle}$$

N = pixel counts



2019 (LED09) : monthly-flat / yearly-flat



LED weighting

https://www.oir.caltech.edu/twiki_ptf/pub/ZTF/Calibration/ZTFnote_SED-LED.pdf

LED weighting : methodology

- Based on star SEDs through ZTF filters with QE

$$S(\lambda) = \mathrm{SED}(\lambda) \times T^{\mathrm{QE}}_{\mathrm{Filter}}(\lambda)$$

- Build LED combination associated to each filter (3 or 4 LEDs) with CCD QE

$$L(\lambda) = \sum_{i=1}^{3-4} k_i \times \mathrm{LED}_i(\lambda) \times \mathrm{QE}(\lambda) \quad \text{with} \quad \int \mathrm{LED}_i(\lambda)\, d\lambda = 1$$

- Minimize chi-2 function: k_i are free parameters with $\sum_i k_i = 1$
  - Based on SED amplitude

$$\chi^2_{\mathrm{Amp}} = \sum_{\lambda}^{N_\lambda} (S(\lambda) - L(\lambda))^2$$

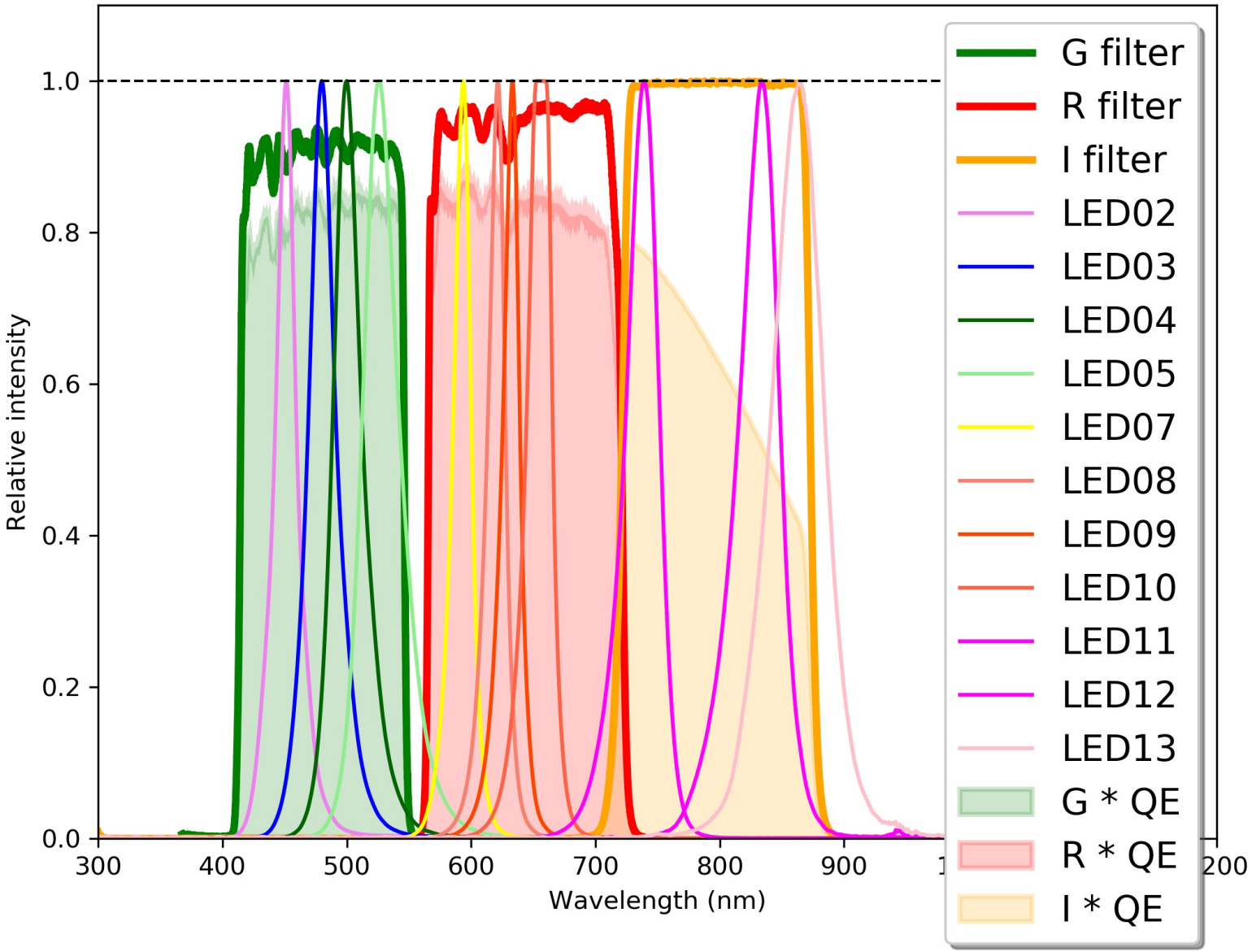
  - Based on SED amplitude and first moment $\langle \lambda_S \rangle = \frac{\int S(\lambda)\, \lambda\, d\lambda}{\int S(\lambda)\, d\lambda}$

$$\chi^2_{Amp+|Mean|} = \sum_{\lambda}^{N_\lambda} (S(\lambda) - L(\lambda))^2 + N_\lambda \times |\langle \lambda_S \rangle - \langle \lambda_L \rangle|$$

$$\chi^2_{Amp+l*|\mathrm{Mean}|} = \sum_{\lambda}^{N_\lambda} (S(\lambda) - L(\lambda))^2 + l \times |\langle \lambda_S \rangle - \langle \lambda_L \rangle|$$

Lagrange multiplier

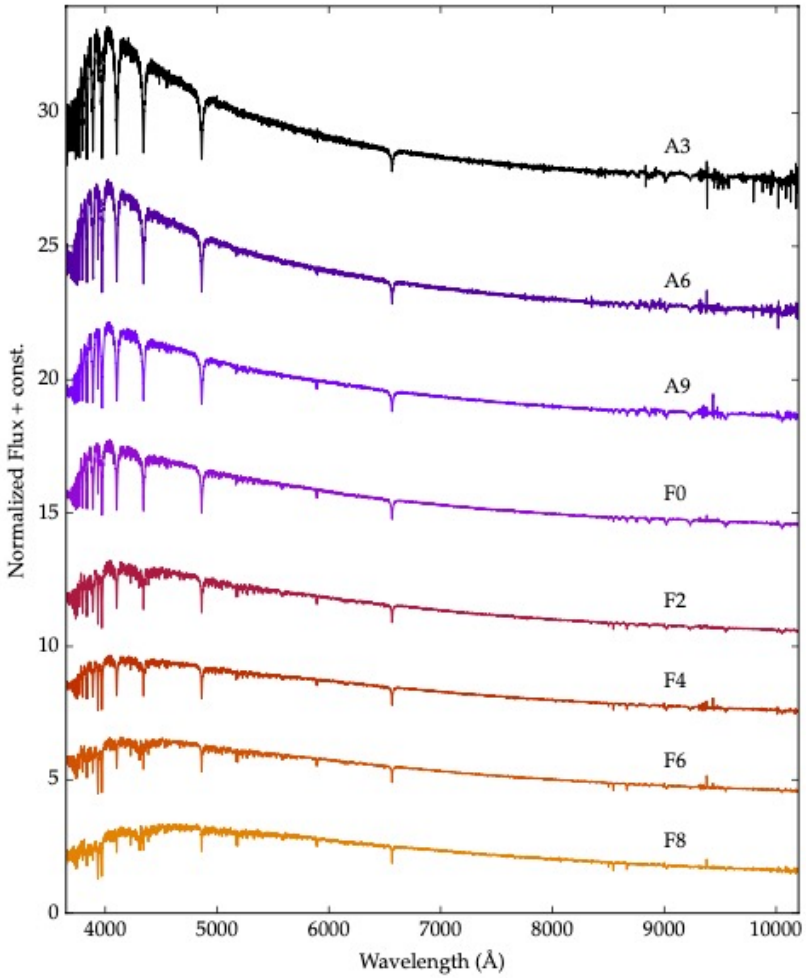
Filter & LEDs


Relative intensity
1.0
0.8
0.6
0.4
0.2
0.0
300
400
500
600
700
800
900
Wavelength (nm)
G filter
R filter
I filter
LED02
LED03
LED04
LED05
LED07
LED08
LED09
LED10
LED11
LED12
LED13
G * QE
R * QE
I * QE

Set of SED's

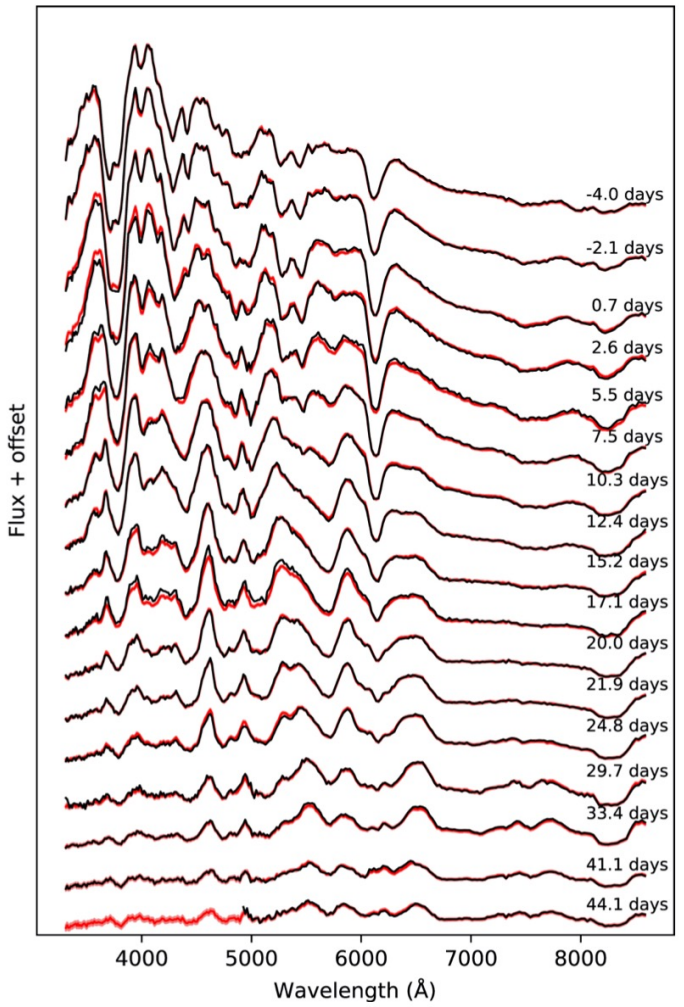
SDSS-BOSS stellar templates

- 322 spectra
- All star type

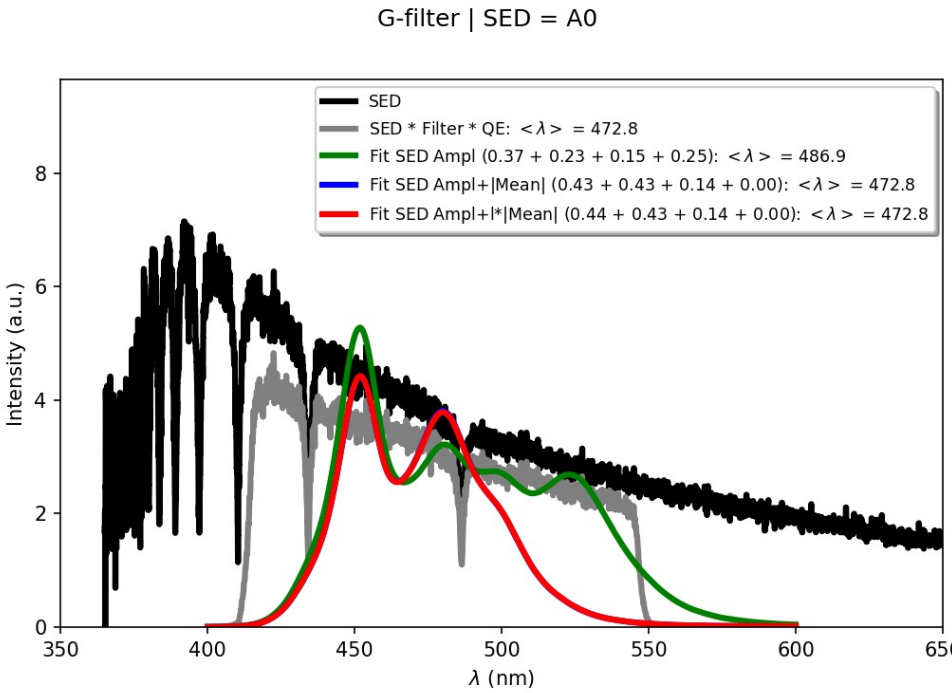


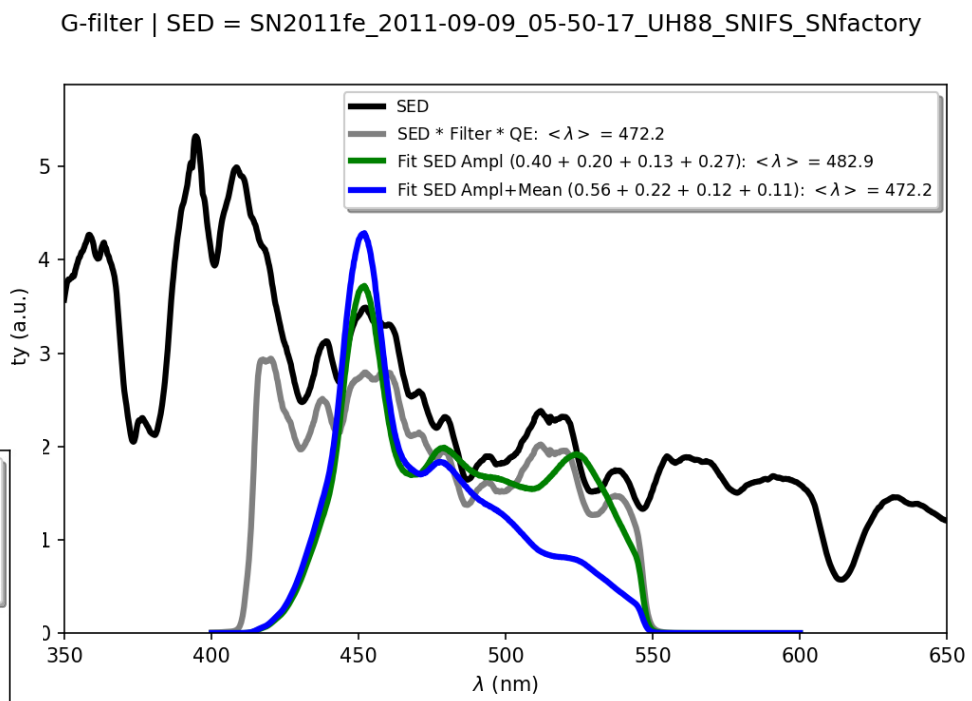
SN factory

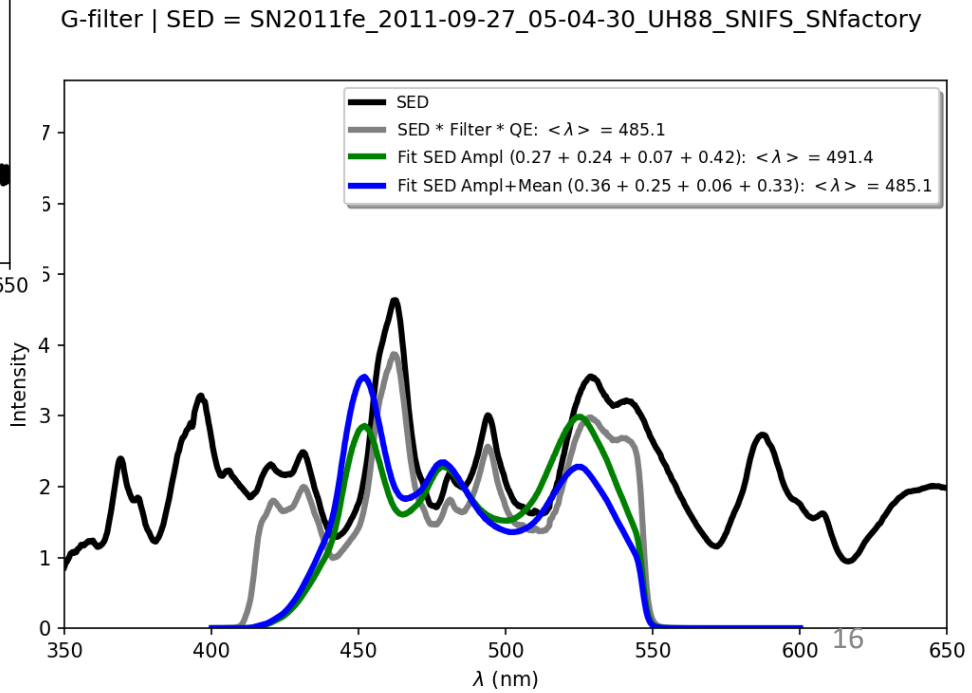
- 172 SNe Ia time series
- More than 2000 spectra



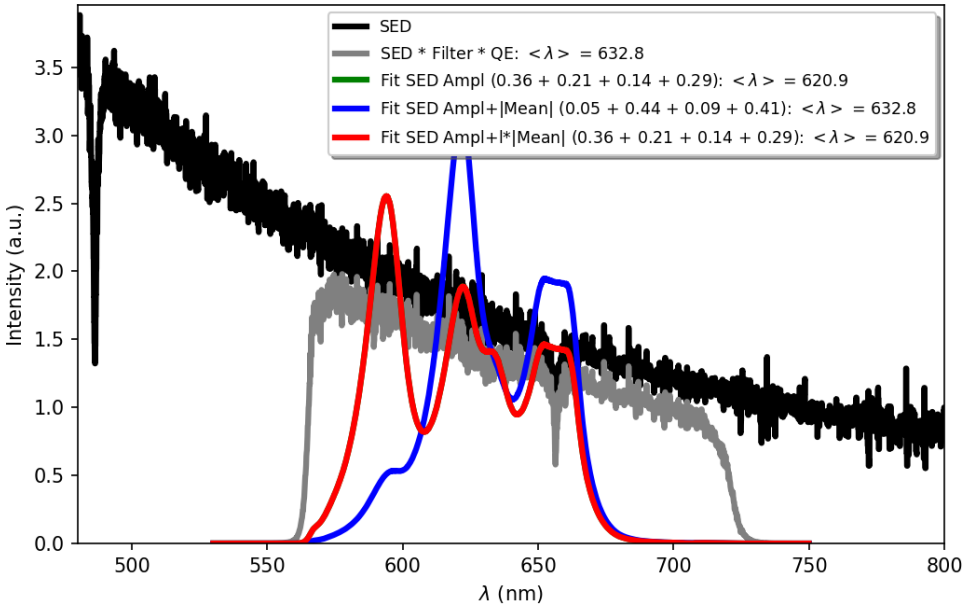
g-filter

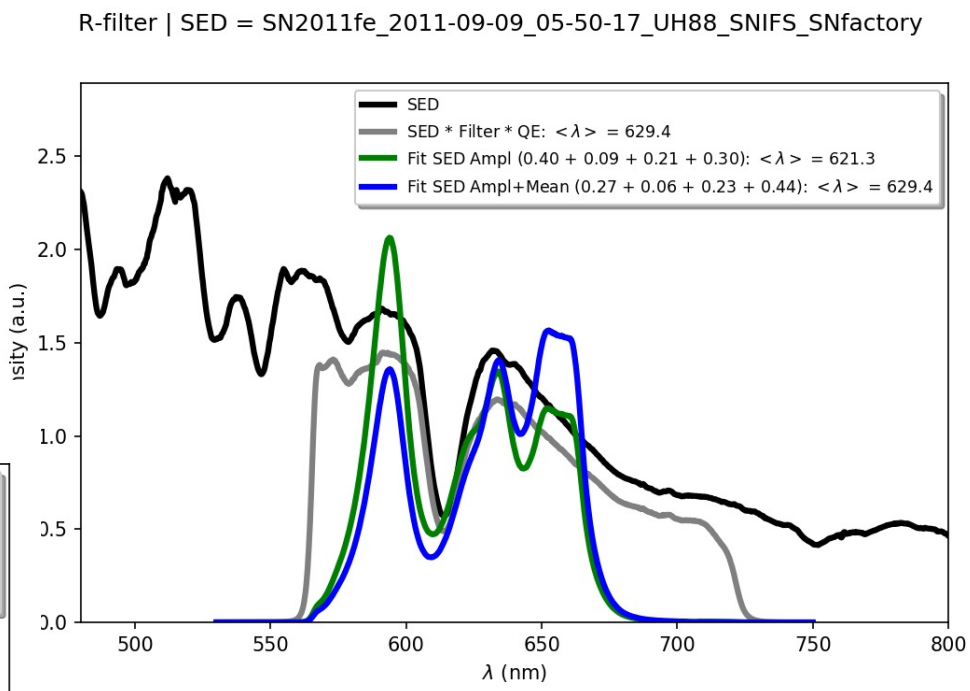

G-filter | SED = A0
SED
SED * Filter * QE: <λ> = 472.8
Fit SED Ampl (0.37 + 0.23 + 0.15 + 0.25): <λ> = 486.9
Fit SED Ampl+|Mean| (0.43 + 0.43 + 0.14 + 0.00): <λ> = 472.8
Fit SED Ampl+l*|Mean| (0.44 + 0.43 + 0.14 + 0.00): <λ> = 472.8
Intensity (a.u.)
λ (nm)

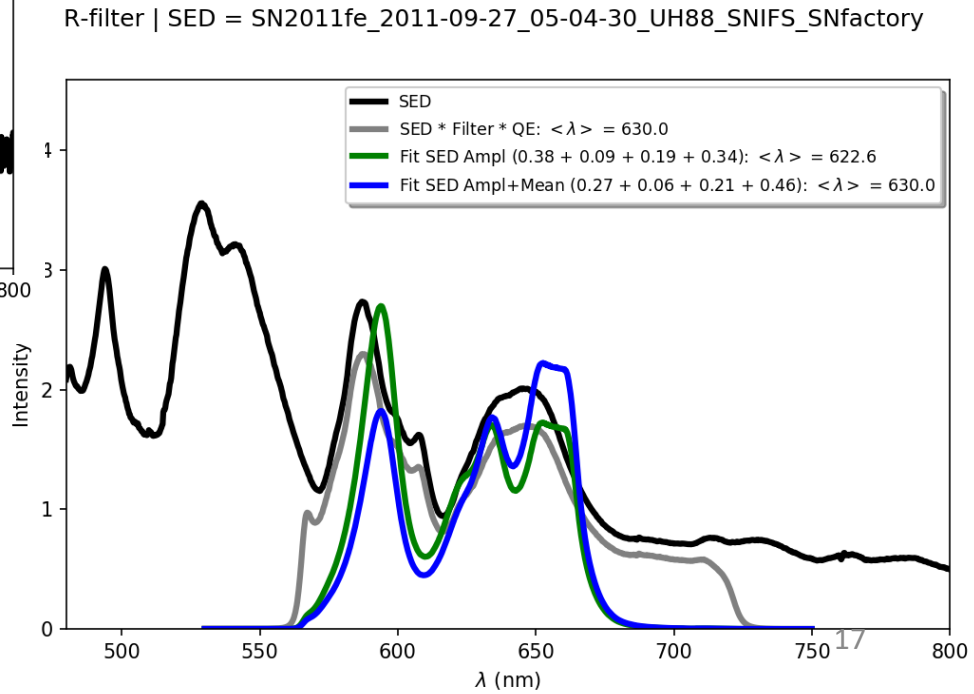

G-filter | SED = SN2011fe_2011-09-09_05-50-17_UH88_SNIFS_SNfactory
SED
SED * Filter * QE: <λ> = 472.2
Fit SED Ampl (0.40 + 0.20 + 0.13 + 0.27): <λ> = 482.9
Fit SED Ampl+Mean (0.56 + 0.22 + 0.12 + 0.11): <λ> = 472.2
λ (nm)


G-filter | SED = SN2011fe_2011-09-27_05-04-30_UH88_SNIFS_SNfactory
SED
SED * Filter * QE: <λ> = 485.1
Fit SED Ampl (0.27 + 0.24 + 0.07 + 0.42): <λ> = 491.4
Fit SED Ampl+Mean (0.36 + 0.25 + 0.06 + 0.33): <λ> = 485.1
Intensity
λ (nm)

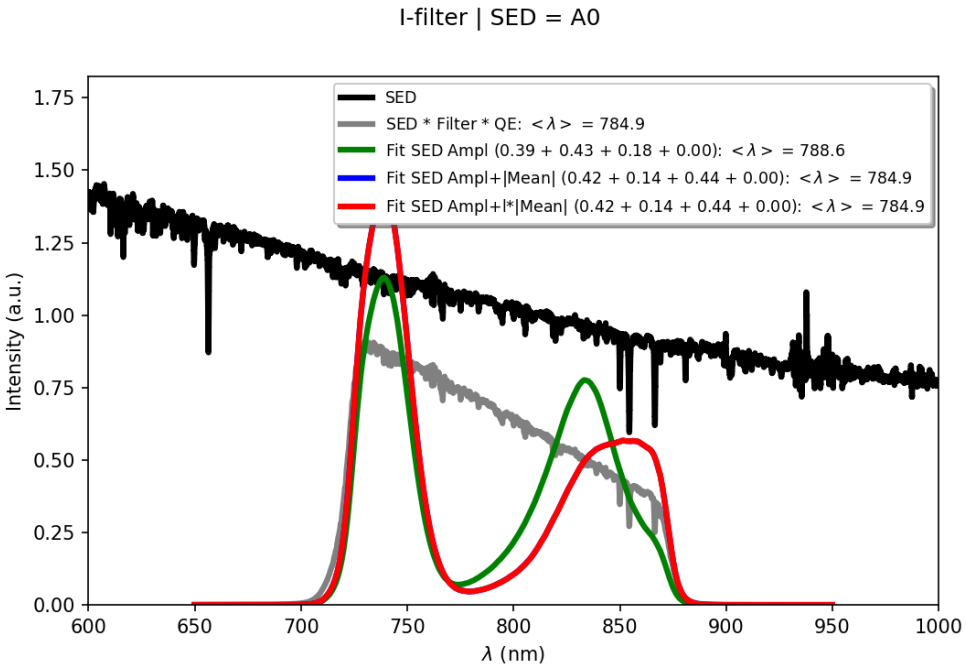
r-filter

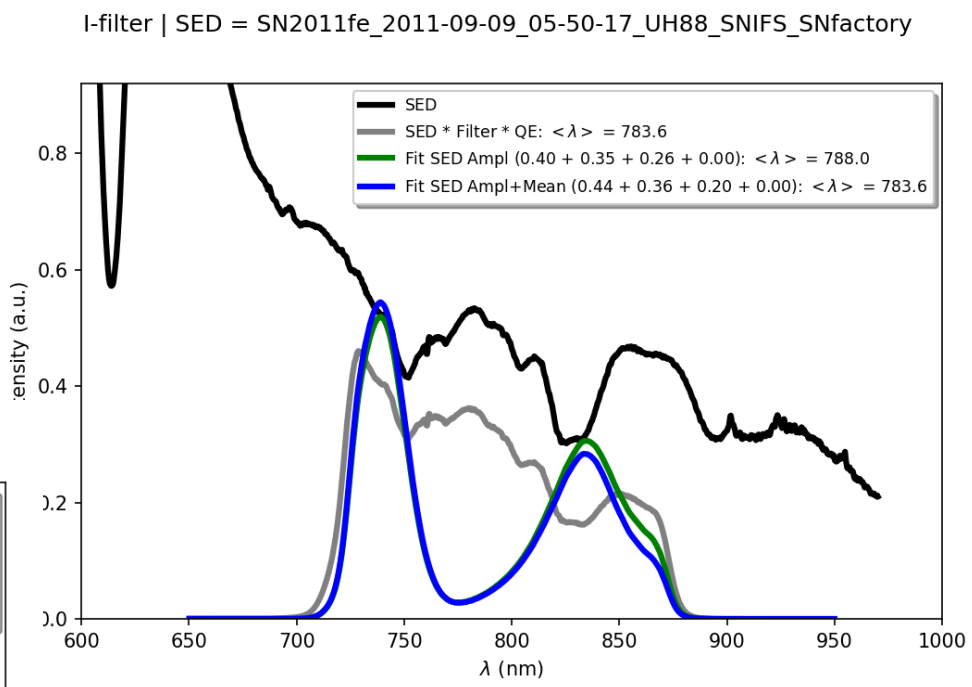

R-filter | SED = A0
SED
SED * Filter * QE: <λ> = 632.8
Fit SED Ampl (0.36 + 0.21 + 0.14 + 0.29): <λ> = 620.9
Fit SED Ampl+|Mean| (0.05 + 0.44 + 0.09 + 0.41): <λ> = 632.8
Fit SED Ampl+l*|Mean| (0.36 + 0.21 + 0.14 + 0.29): <λ> = 620.9
Intensity (a.u.)
λ (nm)

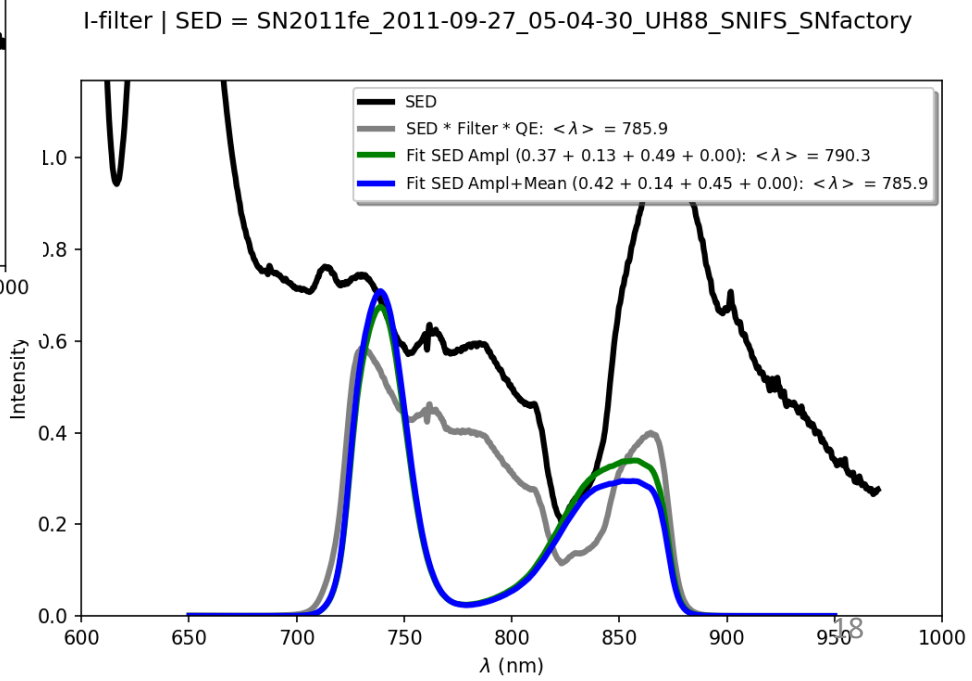

R-filter | SED = SN2011fe_2011-09-09_05-50-17_UH88_SNIFS_SNfactory
SED
SED * Filter * QE: <λ> = 629.4
Fit SED Ampl (0.40 + 0.09 + 0.21 + 0.30): <λ> = 621.3
Fit SED Ampl+Mean (0.27 + 0.06 + 0.23 + 0.44): <λ> = 629.4
λ (nm)


R-filter | SED = SN2011fe_2011-09-27_05-04-30_UH88_SNIFS_SNfactory
SED
SED * Filter * QE: <λ> = 630.0
Fit SED Ampl (0.38 + 0.09 + 0.19 + 0.34): <λ> = 622.6
Fit SED Ampl+Mean (0.27 + 0.06 + 0.21 + 0.46): <λ> = 630.0
Intensity
λ (nm)

i-filter


I-filter | SED = A0
SED
SED * Filter * QE: <λ> = 784.9
Fit SED Ampl (0.39 + 0.43 + 0.18 + 0.00): <λ> = 788.6
Fit SED Ampl+|Mean| (0.42 + 0.14 + 0.44 + 0.00): <λ> = 784.9
Fit SED Ampl+I*|Mean| (0.42 + 0.14 + 0.44 + 0.00): <λ> = 784.9
Intensity (a.u.)
λ (nm)


I-filter | SED = SN2011fe_2011-09-09_05-50-17_UH88_SNIFS_SNfactory
SED
SED * Filter * QE: <λ> = 783.6
Fit SED Ampl (0.40 + 0.35 + 0.26 + 0.00): <λ> = 788.0
Fit SED Ampl+Mean (0.44 + 0.36 + 0.20 + 0.00): <λ> = 783.6
λ (nm)

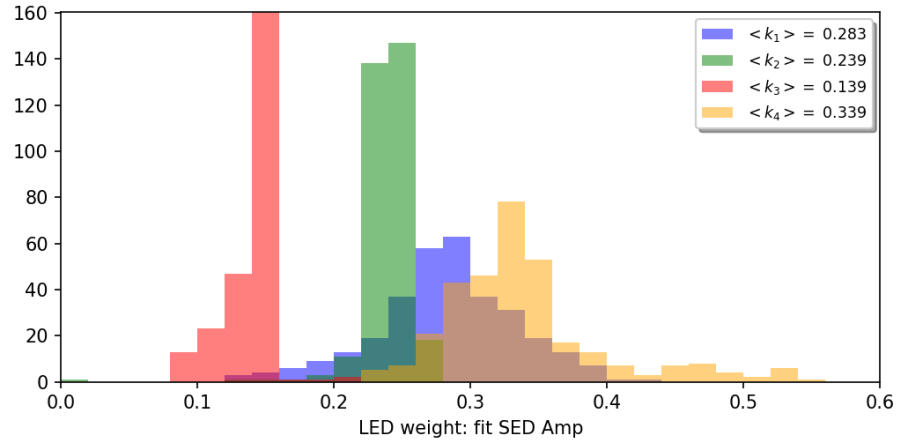

I-filter | SED = SN2011fe_2011-09-27_05-04-30_UH88_SNIFS_SNfactory
SED
SED * Filter * QE: <λ> = 785.9
Fit SED Ampl (0.37 + 0.13 + 0.49 + 0.00): <λ> = 790.3
Fit SED Ampl+Mean (0.42 + 0.14 + 0.45 + 0.00): <λ> = 785.9
Intensity
λ (nm)

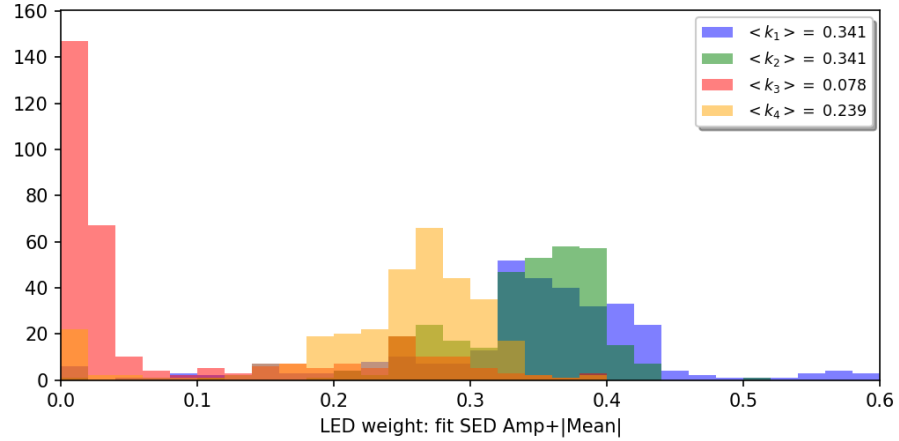
g-filter LED weights

k_1 = LED02
k_2 = LED03
k_3 = LED04
k_4 = LED05

SDSS-BOSS

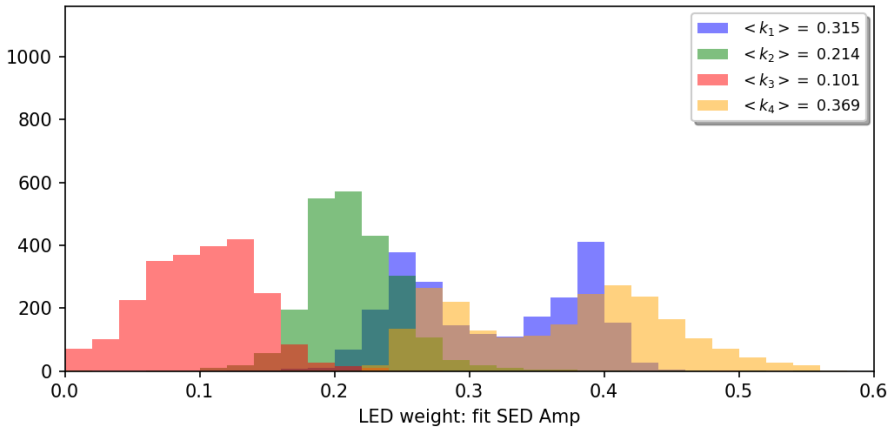
G-filter with fON SED

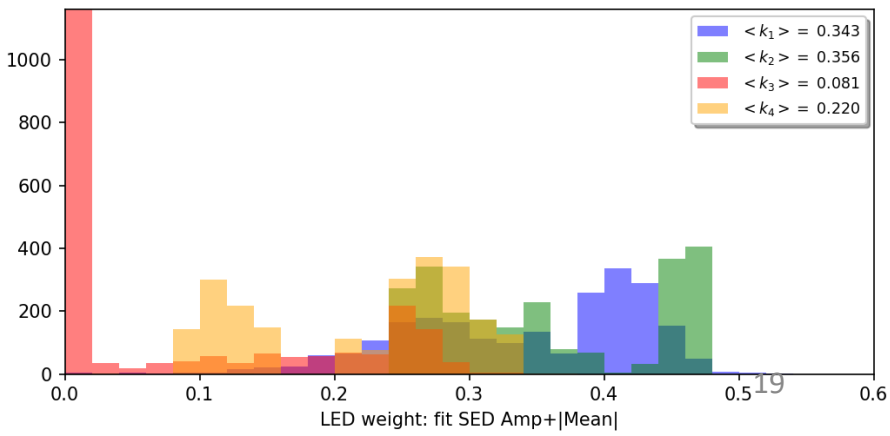




SNFactory

G-filter with fON SED



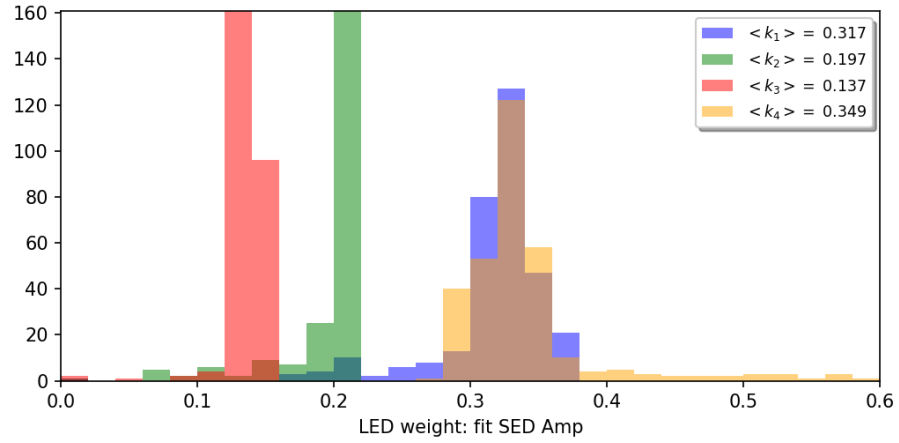


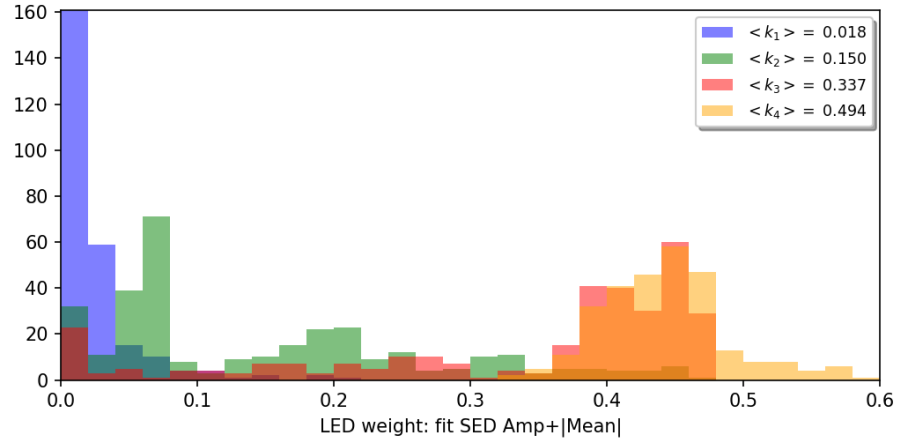
r-filter LED weights

k_1 = LED07
k_2 = LED08
k_3 = LED09
k_4 = LED10

SDSS-BOSS

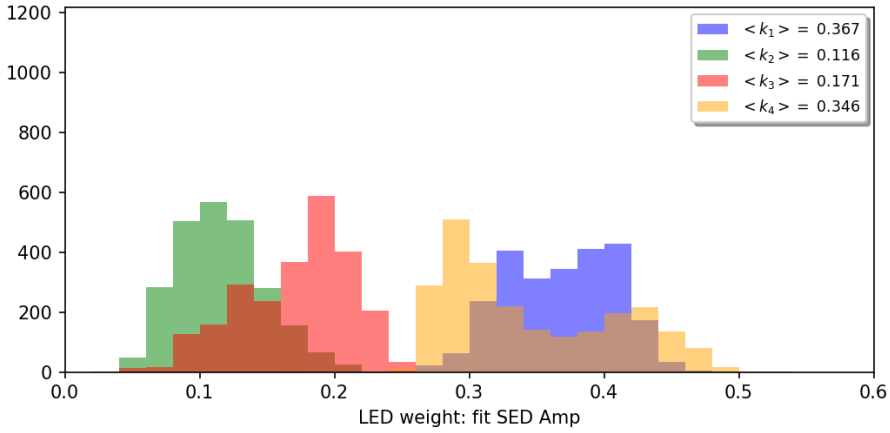
R-filter with fON SED

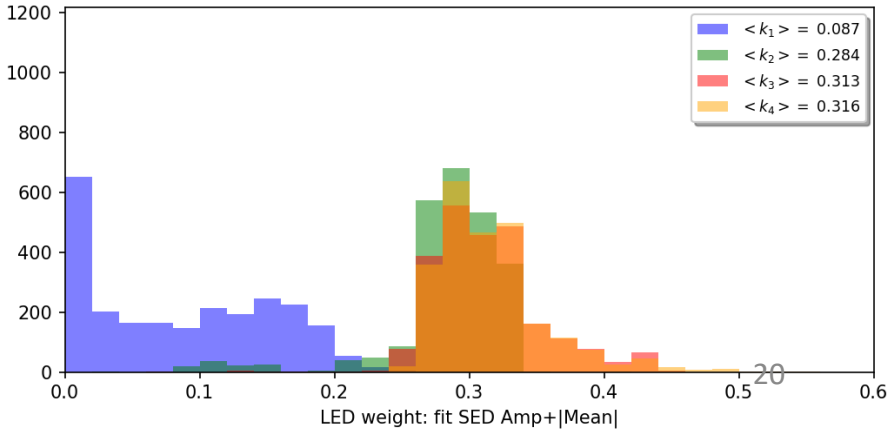




SNFactory

R-filter with fON SED



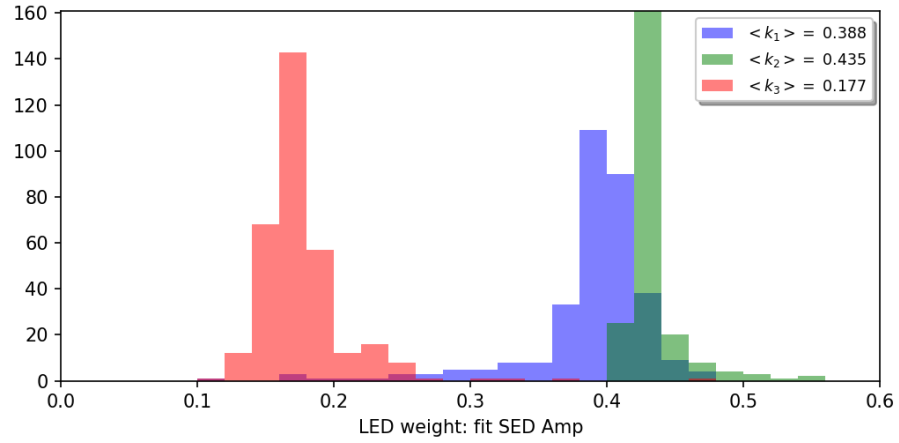


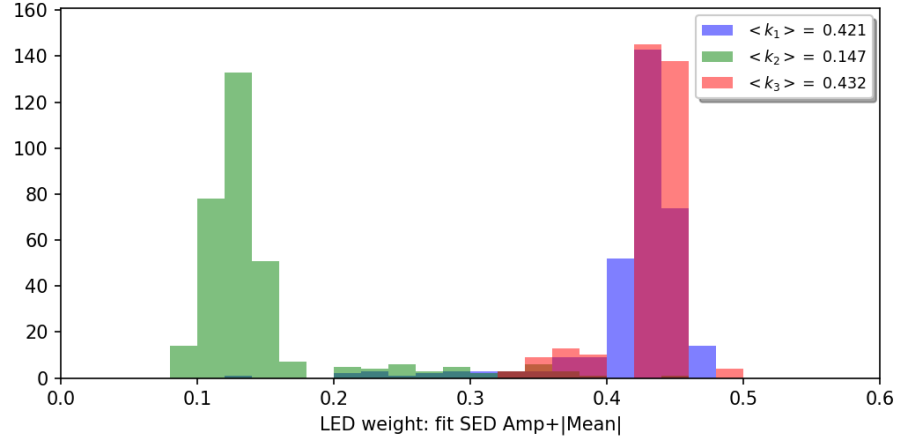
i-filter LED weights

k_1 = LED11
k_2 = LED12
k_3 = LED13

SDSS-BOSS

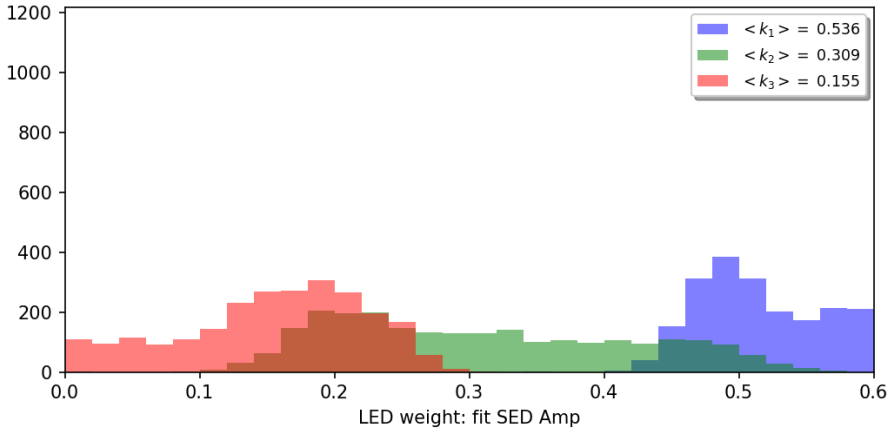
I-filter with fON SED

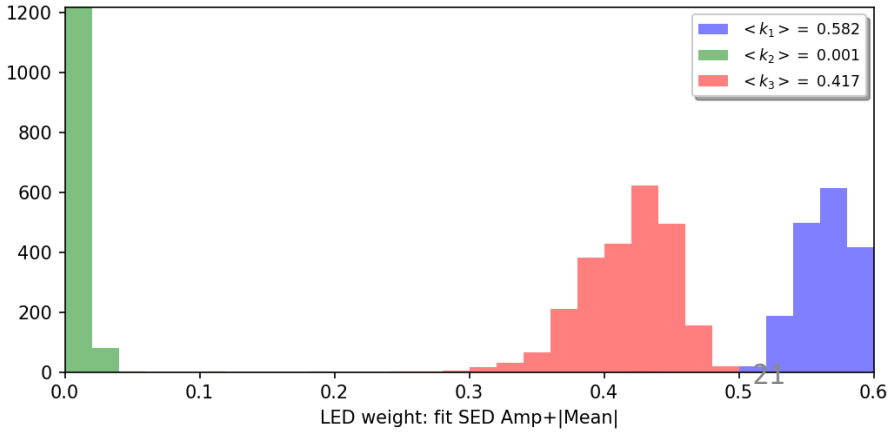




SNFactory

I-filter with fON SED





LED weights

Table 3: LED weights with filter in place from SED fit of SDSS-BOSS stellar templates (BOSS) and SN Factory time series (SNF), and the mean value of both data samples, for each ZTF filter. For each data set and their average the sum rule $\sum_i k_i = 1$ is applied. The third row reports the LED scaling factor to account for differences in initial intensity computed from LED flat-fileds recorded on June 2nd, 2020.

Filter	LED	Scaling factor	$\chi^2_{\rm Amp}$			$\chi^2_{\rm Amp+Mean}$		
			BOSS	SNF	BOSS+SNF	BOSS	SNF	BOSS+SNF
G	**02**	**0.98691**	0.283	0.315	0.299	0.341	0.343	**0.342**
	03	**0.99593**	0.239	0.214	0.227	0.341	0.356	**0.349**
	04	**0.98706**	0.139	0.101	0.120	0.078	0.081	**0.079**
	05	**0.84069**	0.339	0.369	0.354	0.239	0.220	**0.230**
R	**07**	**1.03225**	0.317	0.367	0.342	0.018	0.087	**0.053**
	08	**1.05036**	0.197	0.116	0.156	0.150	0.284	**0.217**
	09	**1.03757**	0.128	0.171	0.154	0.337	0.313	**0.325**
	10	**1.05238**	0.349	0.346	0.347	0.494	0.316	**0.405**
I	**11**	**1.00242**	0.388	0.536	0.462	0.421	0.582	**0.501**
	12	**0.69836**	0.435	0.309	0.372	0.147	0.001	**0.074**
	13	**0.61039**	0.177	0.155	0.166	0.432	0.417	**0.425**

Conclusions and perspectives

Master-flat

- Stability over one month ~ 0.1%
- Require day-by-day inspection to remove ”bad” daily-flat
- Next step:
  - Master-flat over one year (2019)
  - Check CCD steps in flats versus sky-noise in the coming night

LED weighting

- Preliminary study based on SED fitting
- Two set of weights:
  - SED shape fitting
  - SED + 1st moment fitting
- What next…