Calibration of Digital Images

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MAAWS 2011

Digital image is just a set of numbers

Y\X	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	29	30
1	7453	7710	6939	7710	7710	6939	7196	6939	6682	6682	6939	6939	6939	6682	6682	6682	6939	7710		5654	5654
2	6939	7967	6682	6682	8224	7710	7453	7710	6939	6939	7710	7710	7710	6939	6425	6939	7967	7967		6425	5911
3	6939	7710	5911	5397	6939	6939	6939	7196	7710	7967	7967	7967	7967	7967	7710	7967	8738	8481		5911	5911
4	7967	6939	6682	6425	6682	6682	6425	6682	6939	8738	8738	7453	6939	6939	7710	8738	8481	8738		6425	6425
5	6939	6939	6682	6939	6939	6682	6939	6682	5911	6939	7710	6939	6939	6939	7710	8224	8738	7967		7967	7967
6	6939	7710	6939	7710	6939	7710	6939	6682	6425	5911	5911	6682	5911	6939	6939	7196	7453	7710		8738	7967
7	7710	6939	6682	7710	6939	6939	7710	7967	7710	6425	6425	7710	6425	7710	6939	7196	7967	6939		7710	7710
8	8224	7710	6939	6939	6939	7196	6425	7967	7710	6939	6939	6939	7710	7710	6939	7967	7967	6939		6425	6682
9	6939	7967	7710	7710	7710	8481	7453	7453	7967	6939	7453	7453	7453	7453	7453	7967	7967	7967		6682	5140
10	7967	8224	7710	8224	8738	9509	6939	6939	7967	6939	7710	7710	7967	6939	7453	7710	8481	11565		7967	4883
11	9509	8738	8481	8224	9509	7710	6939	6939	7710	6939	6939	6682	7453	7967	7967	8995	10537	24672		7967	6682
12	9766	10023	8738	7453	7453	7453	7453	6939	7453	6939	5911	6425	7453	7453	7967	8995	16448	41634		7710	7710
13	7453	7967	7710	6939	7196	6682	7710	6939	7710	7967	7710	7453	8481	8481	7453	7967	16448	41634		7710	6939
14	7453	7453	6939	6682	6682	6682	6682	[illegible]	7710	8224	7967	7453	7967	7967	6425	7710	13364	24672		7710	7453
15	6425	6425	4883	6682	6682	5911	6682	[illegible]	7710	7710	7710	7710	7710	7710	6939	7453	7710	12850		6682	6682
16	6939	6425	6425	6425	5397	5397	6682	[illegible]	7710	7710	6939	6682	5911	6939	6939	6425	6425	7453		6682	5911
17	7453	6425	6425	5654	5140	5140	6939	[illegible]	7967	7453	7453	6682	6682	6939	7710	6939	6682	7710		6425	6425
18	7967	6939	6939	4883	6425	5911	7710	[illegible]	7967	6939	6939	7196	6939	6939	8738	8481	6939	6939		6939	7453
19	7710	6939	7710	6939	6939	7967	693[illegible]	[illegible]	8738	9509	6939	6682	6939	7710	8738	7453	6425	6425		7710	7710
20	6682	5911	6939	7453	7710	7453	693[illegible]	[illegible]	7967	10023	7710	6682	6682	6682	6939	6425	5140	6939		6939	6682
21	7453	7710	7710	6939	7710	7453	642[illegible]	[illegible]	8738	7967	7453	6682	5911	6682	7453	6425	5911	6939		5911	5911
22	7453	7710	7710	7196	7710	7710	77[illegible]	[illegible]	6939	7453	7967	6939	5397	6939	6939	6425	6682	7196		6425	6425
23	6939	7710	7967	7967	7967	6939	69[illegible]	[illegible]	6939	7710	7710	6939	6682	6682	6939	7710	6939	6682		6682	7967
24	6682	7196	6939	7967	7453	6425	66[illegible]	[illegible]	6939	7710	6939	6939	6939	6682	6939	7967	6939	5911		6939	9509
25	6939	7710	6939	7710	7710	7710	7[illegible]	[illegible]	6939	7196	7710	7967	7453	6682	6939	7710	6682	5911	6939	7710	6682	5911	6682	5911	6682	7710	7710	5911	5911	8224
26	6682	6682	6939	7453	7710	7710	7[illegible]	[illegible]	6682	6939	8224	8738	6939	6939	7710	6682	5911	5911	5911	5911	5140	5911	5911	6682	7967	7967	7196	5397	5911	7453
27	5911	5911	7453	8738	7710	7453	7[illegible]	[illegible]	6682	7196	7710	7967	7453	6425	7453	6682	6425	6682	5911	6682	6682	6682	6939	7710	7967	7967	6939	5911	6939	6939
28	5140	6682	7710	9509	8481	7710	[illegible]	[illegible]	6682	6939	6939	6425	6939	6939	7453	6939	6939	6425	6939	6939	7196	6939	6939	5911	6939	7967	6939	5911	5911	6939
29	5911	6939	7196	7196	7710	7453	[illegible]	[illegible]	6682	6939	5140	5911	5911	5911	5911	6939	6939	6425	7967	8224	7710	7710	6939	5911	5911	6682	6425	5397	7196	7710
30	6939	6425	7196	6939	6939	7967	[illegible]	[illegible]	5911	6682	6425	6425	4883	4883	5911	6425	5397	4883	6939	7710	7967	7967	6939	5911	5911	6939	7710	7196	7196	7710
31	7967	7967	6939	7196	6682	7710	[illegible]	[illegible]	6682	6682	6425	5911	4883	5911	5911	5397	5397	4883	6939	6425	6939	6939	6939	6425	5911	6682	7710	7967	6939	6682
32	7710	7967	7710	7710	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6425	6425	5140	5911	5911	6682	5911	5911	5911	6425	6425	6425	5911	5911	6425	6425	6939	7967	7967	7710	5397
33	7710	7453	6939	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6939	7196	7710	7196	6939	6682	6682	6425	6425	5911	5911	6425	6939	6939	6939	7710	7453	6939
34	6939	6939	591[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8224	7967	7710	7710	6939	6939	5911	6939	6425	5911	6425	6939	6939	6682	5397	5911	6682	6425
35	7710	6939	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10794	8738	7453	6682	6682	5911	6939	6939	6939	6939	6939	7453	7453	6939	6425	5911	6425	6939	6425
36	6939	6682	6682	6939	6682	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10794	8738	7967	5911	5911	5654	7710	7710	6682	6939	7196	8224	8224	7196	6939	6425	7196	7196	5911
37	6939	6425	6939	6939	6939	7453	6425	[illegible]	5911	[illegible]	[illegible]	6939	7453	7453	7453	6939	6939	6425	7710	7710	7710	8738	15163	23901	17219	11565	7967	7710	7967	7967	6682
38	6425	5140	6682	6939	6939	7453	6425	6682	5654	6425	6425	5654	5911	6425	7453	6939	6939	7196	7710	8995	14649	36237	50115	39064	20046	9509	7967	8738	7967	6682
39	6682	6425	6939	7710	6939	6939	6939	6425	5654	6425	6939	6425	6682	7453	7453	7453	7710	6939	7710	7967	18761	44718	56797	51400	29298	12336	8738	7710	7967	6939

Every image contains "artifacts":

Light from the object

↓

Intergalactic/ interstellar space

↓

Atmosphere

↓

Optical system

↓

Camera

↓

Raw image

<u>Optical system effects:</u>

- Selective bandpass
- Diffraction effects
- Distortions
- Reflections and light leaks
- Vignetting / hot spots
- Dust shadows

<u>Detector effects:</u>

- Variations in pixel sensitivity
- Offset level
- Thermal charge
- Amplifier electroluminescence
- Charge overflow and skimming
- Non-linear response

Calibration corrects artifacts which can be "mapped" by the detector:

Optical system effects:

- Selective bandpass
- Diffraction effects
- Distortions
- Reflections and light leaks
- Vignetting / hot spots
- Dust shadows

Detector effects:

- Variations in pixel sensitivity
- Offset level
- Thermal charge
- Amplifier electroluminescence
- Charge overflow and skimming
- Non-linear response

Flat frame

Bias frame

Dark frame

The noise:

Noise results from the uncertainty in measuring any particular value

- Measuring reference voltage of CCD amplifier etc. → readout noise (in every frame)
- Statistical variation in thermal current during exposure → thermal noise (in dark, flat frames and raw image)
- Statistical variation in photon rate during exposure → photon noise (flat and raw image frames)

While the image quality improves during calibration…

the noise never disappears – it actually increases!!!

Final noise = square root $(A^2 + B^2 + C^2 \ldots \text{etc})$

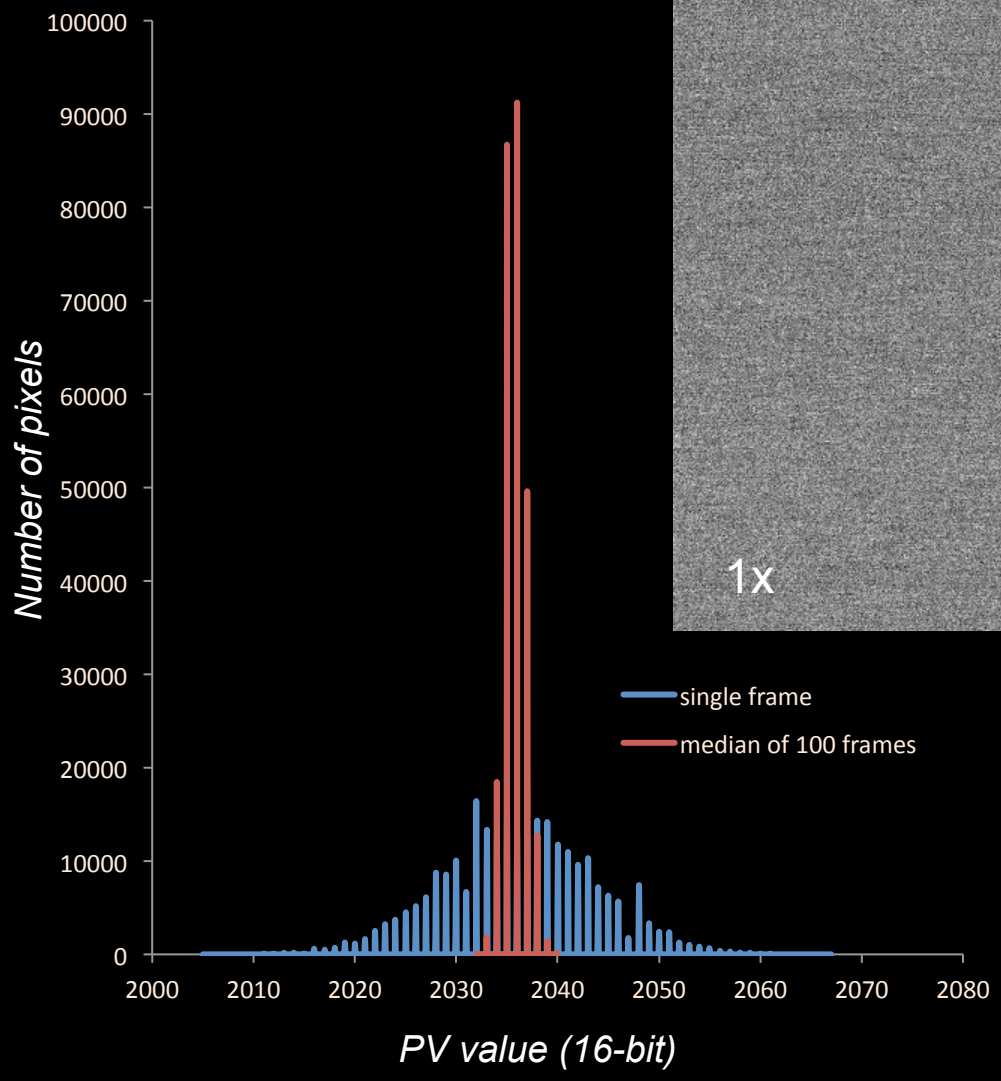
Calibration overview:

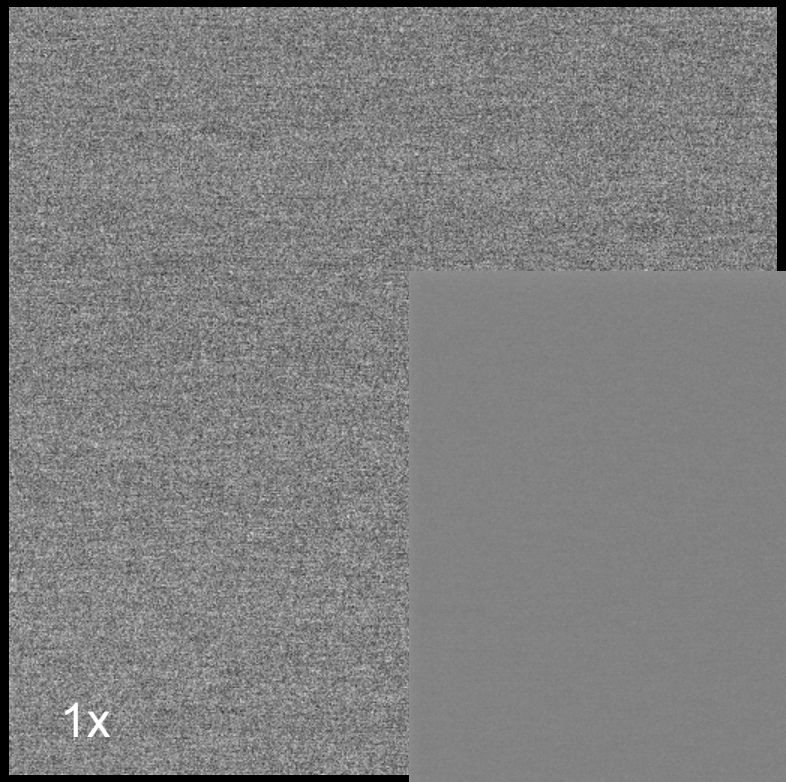
- *Set of images*
- *Set of "dark images"* → *dark frame*
- *Set of "flat bright images" and "flat dark images"* → *flat frame*

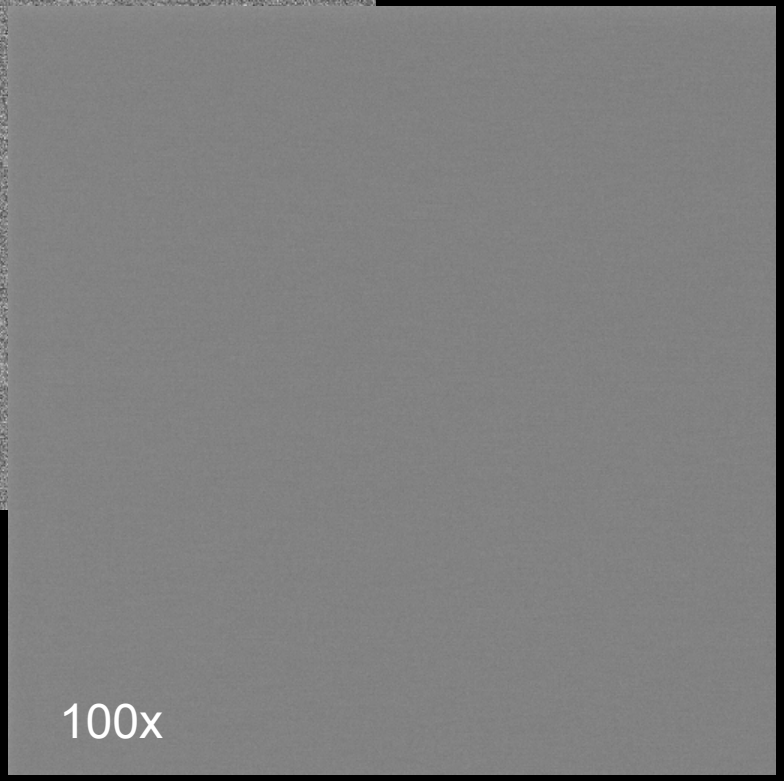
Calibration process:

(image – dark frame) / flat frame → calibrated image

Bias frame contains electronic offset (and readout noise)

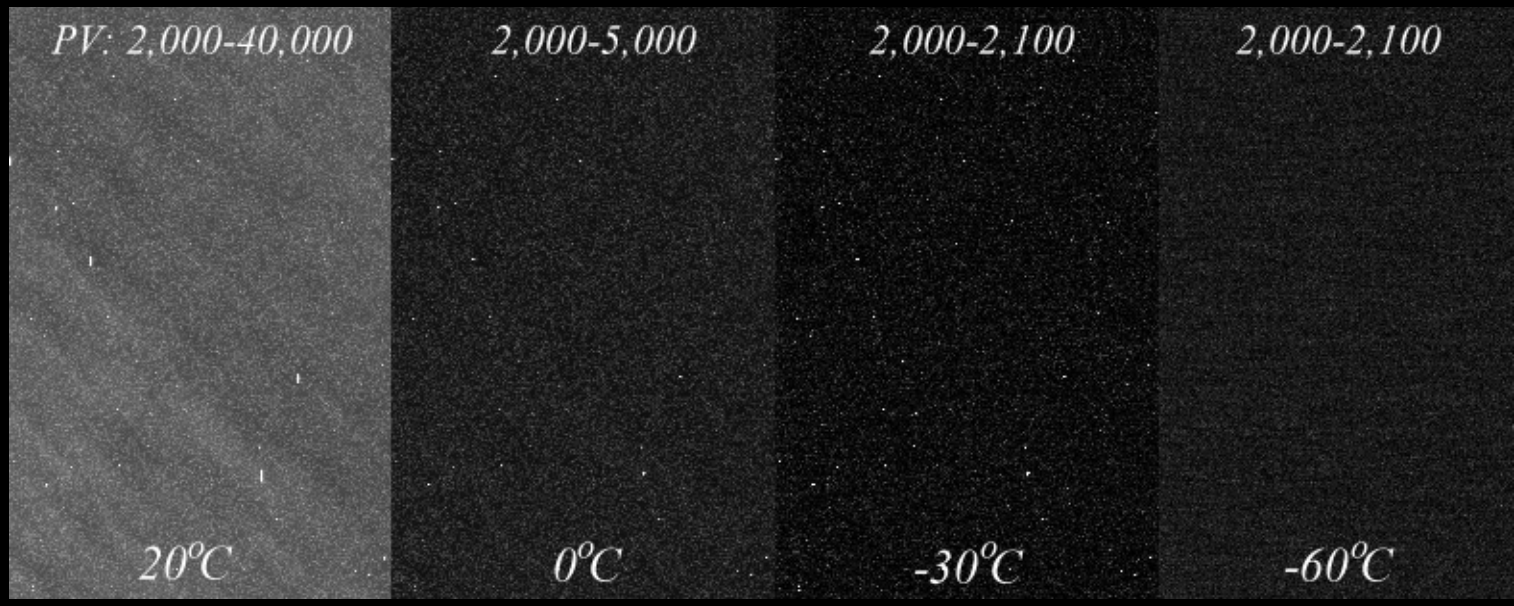


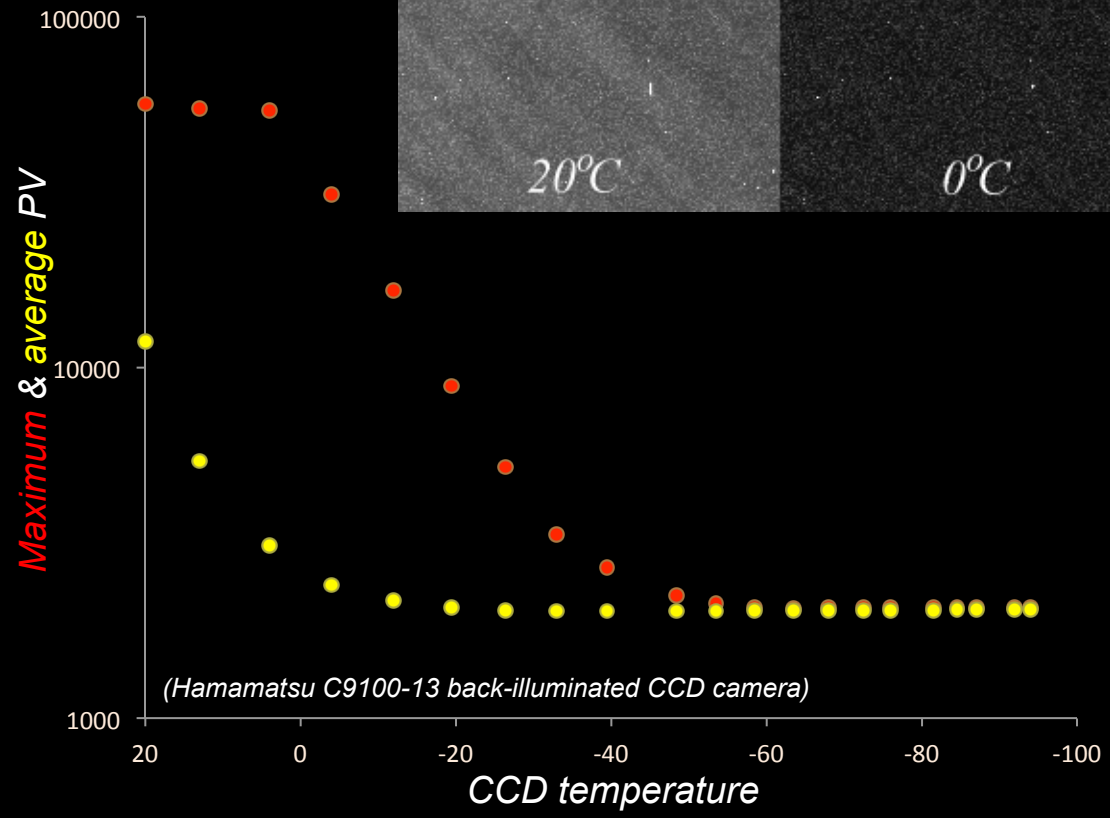




- A pattern in a bias frame indicates RFI problem

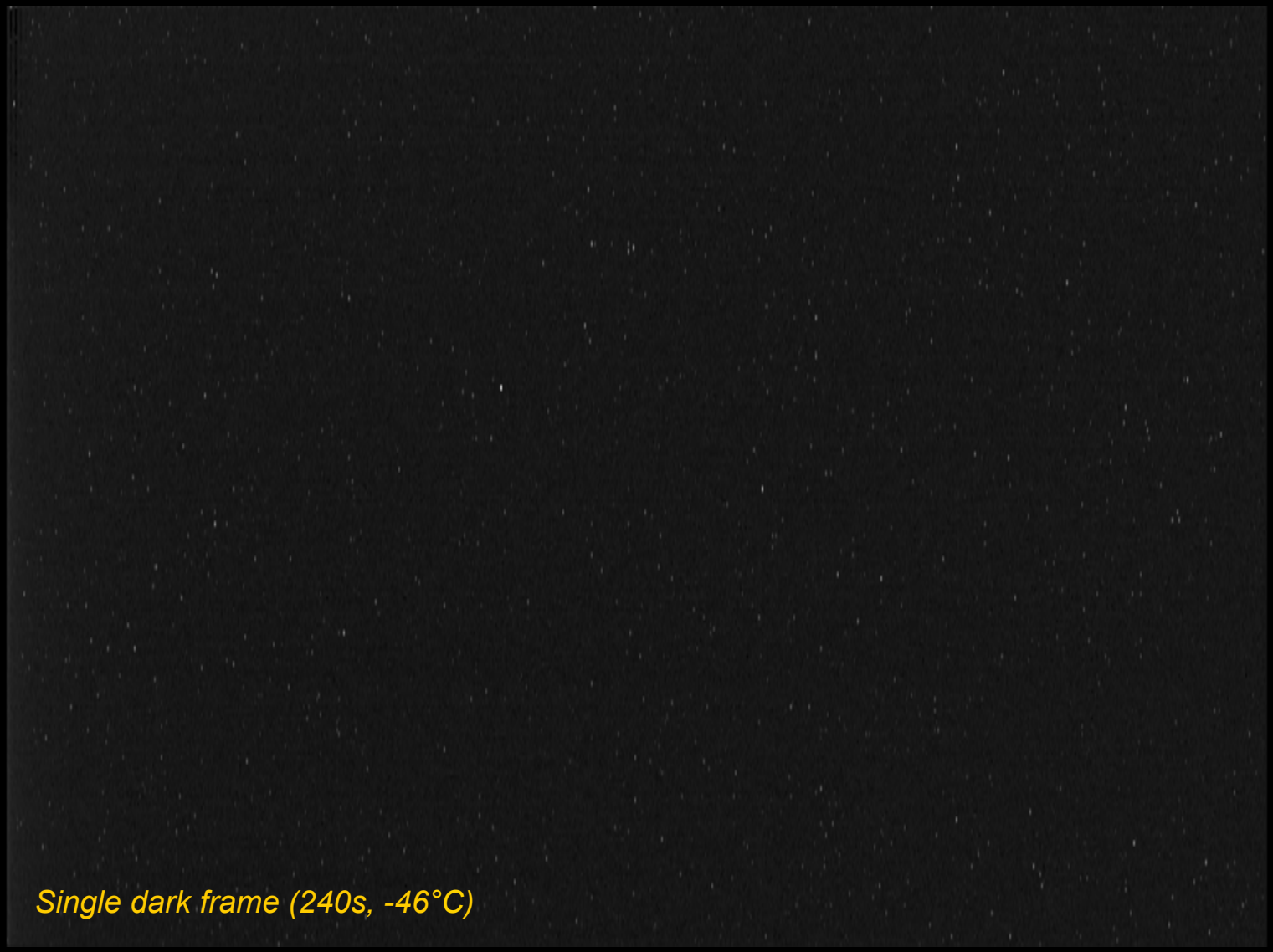
Detector temperature and dark current





- Thermal charges drop 2x / 7°C
- Hot pixels are suppressed
- Dark frames are temperature-specific

Preparing dark frame



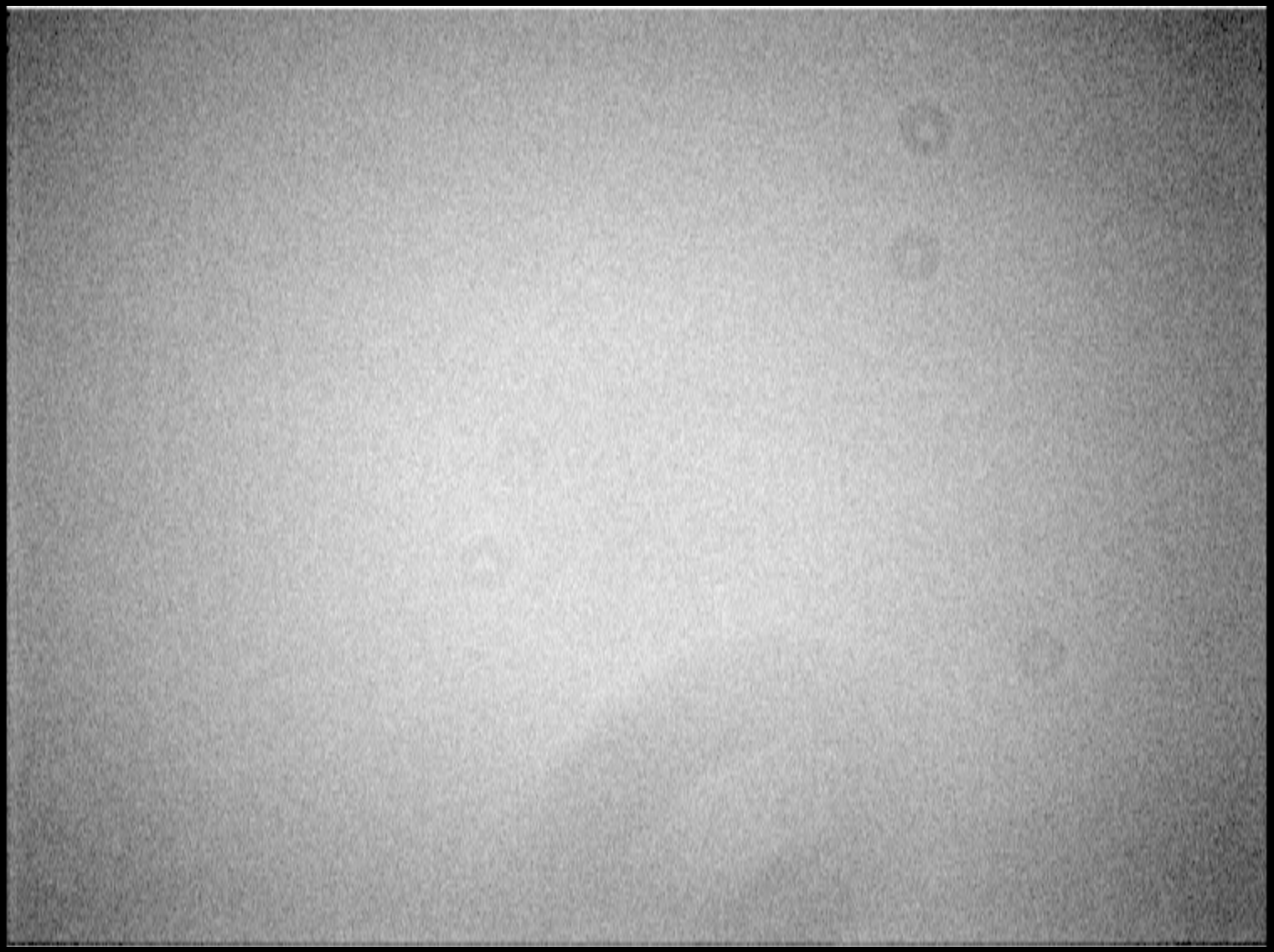
Preparing dark frame

Flat frame is derived from the image of the uniform light source

- Twilight sky
- Dome / wall flat
- Electroluminescent panel
- Light box

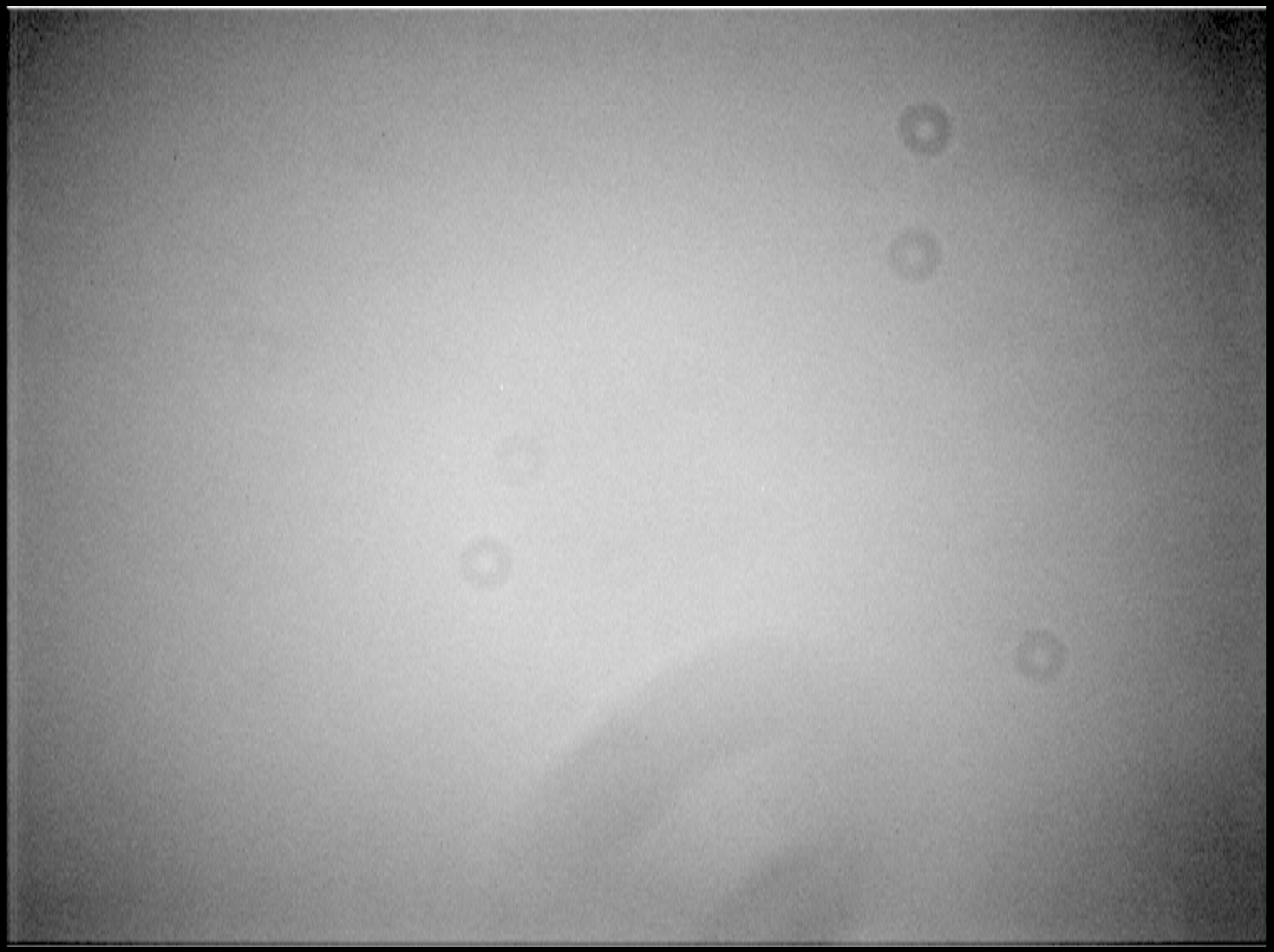
- Flat frame is setup specific – any movement of components (or dust) will ruin it …

Preparing flat frame – step 1



Single image of uniform source

Preparing flat frame – step 2



10 images combined

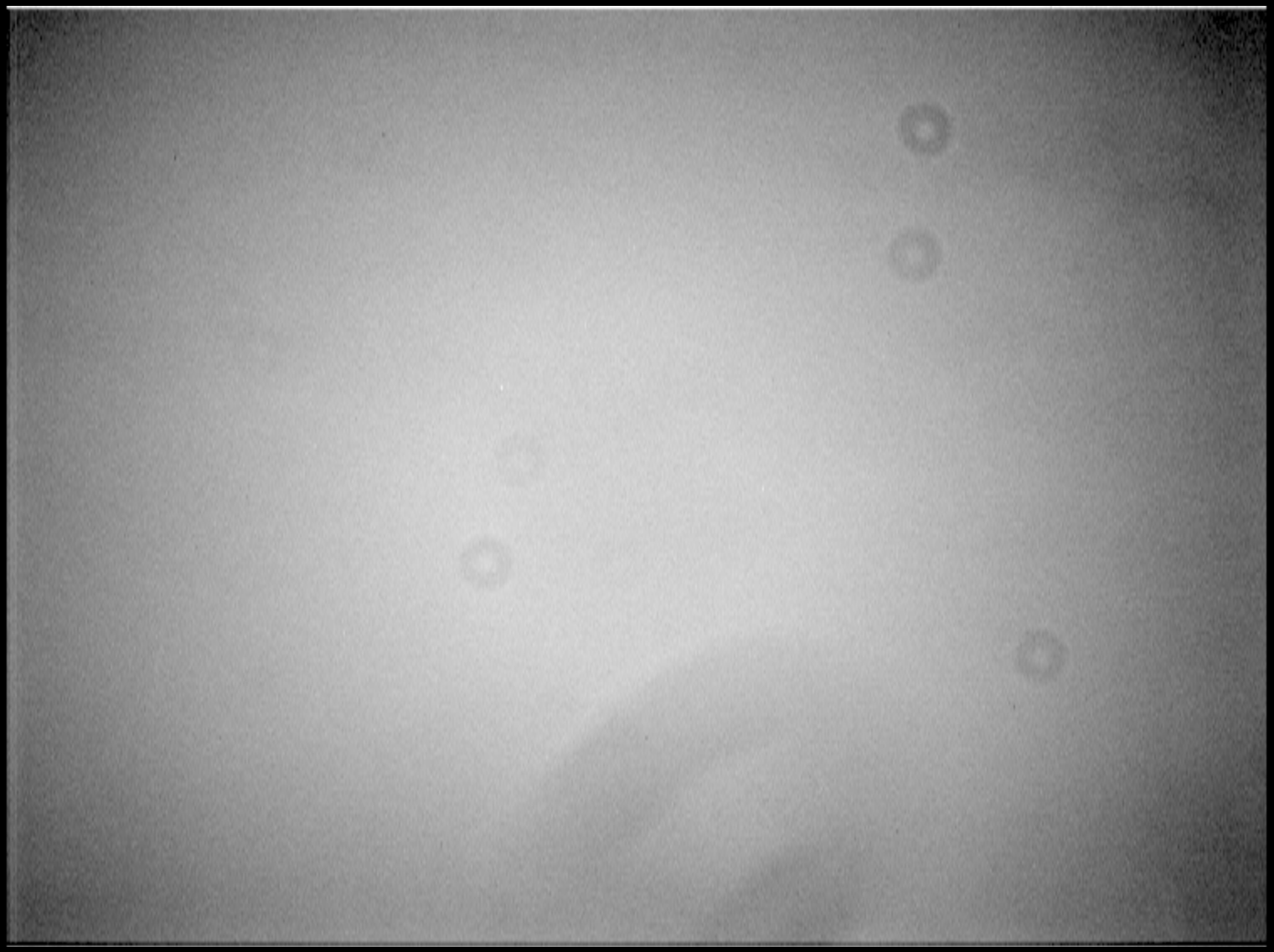
Preparing flat frame – step 3

Single "dark flat" image

Preparing flat frame – step 4

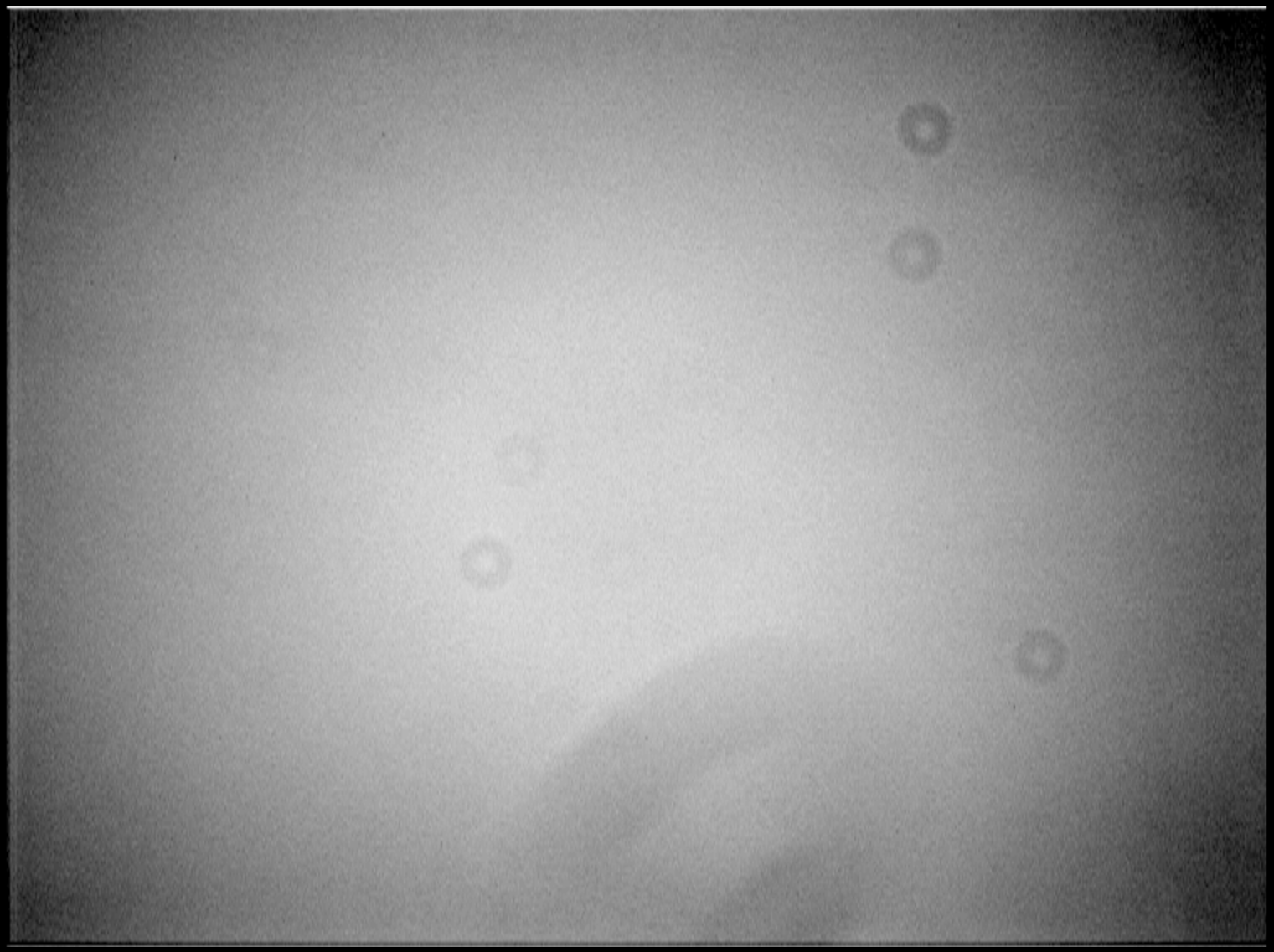
Median of 10

Preparing flat frame – step 5

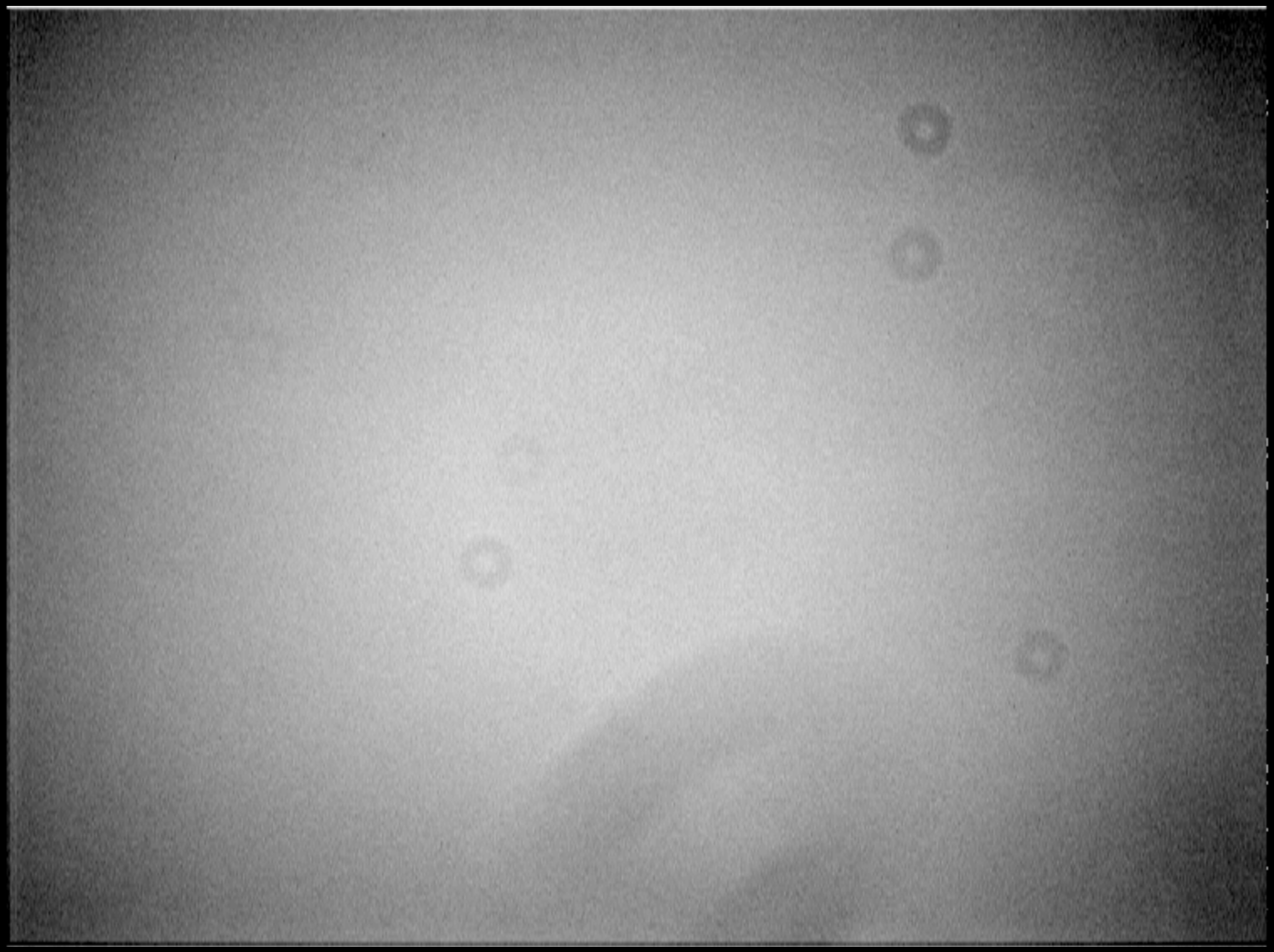


Then subtract combined dark from combined bright flat image …

Preparing flat frame – step 6

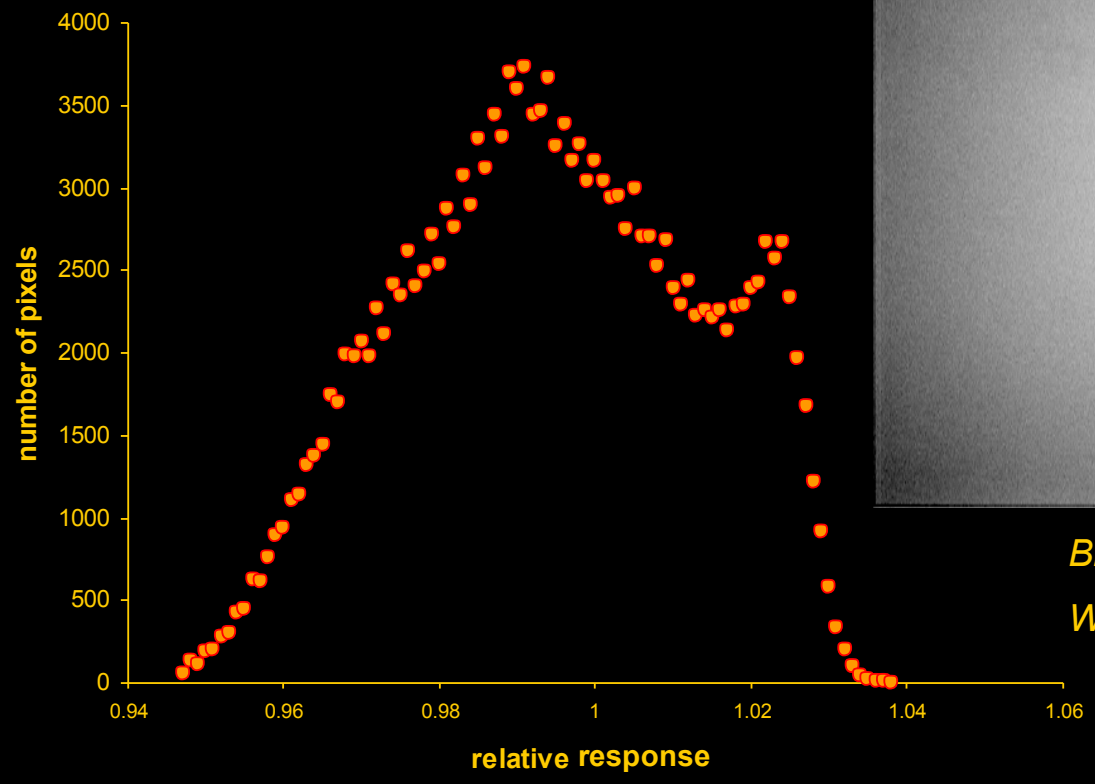


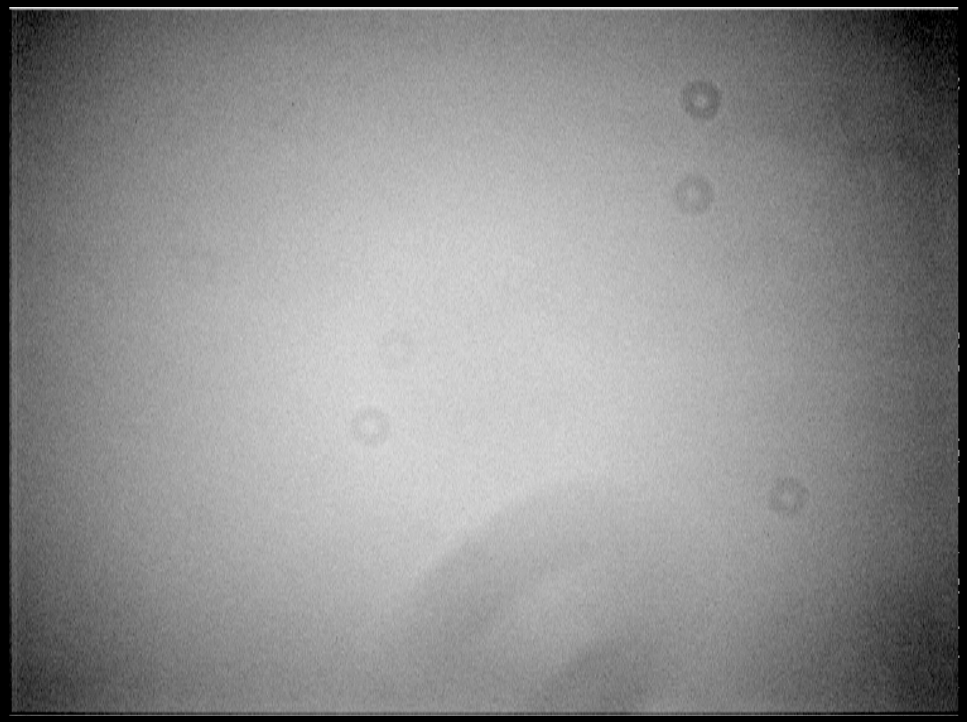
Preparing flat frame – final step



Divide PV of each pixel by average value …

Flat frame is not an image - it is a map of detector's relative response to light !



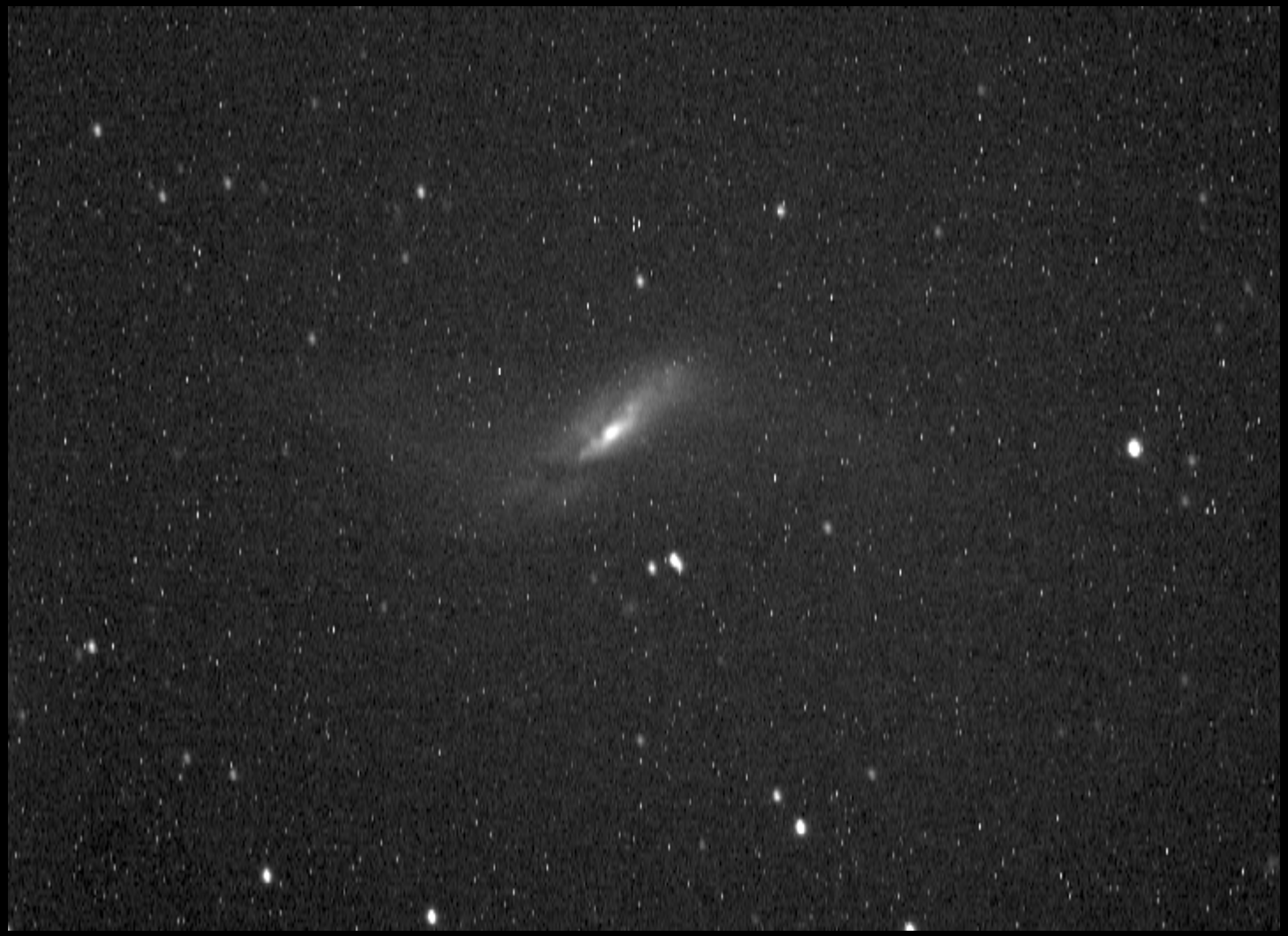


Black = 4.3% lower response

White = 3.8% higher response than average

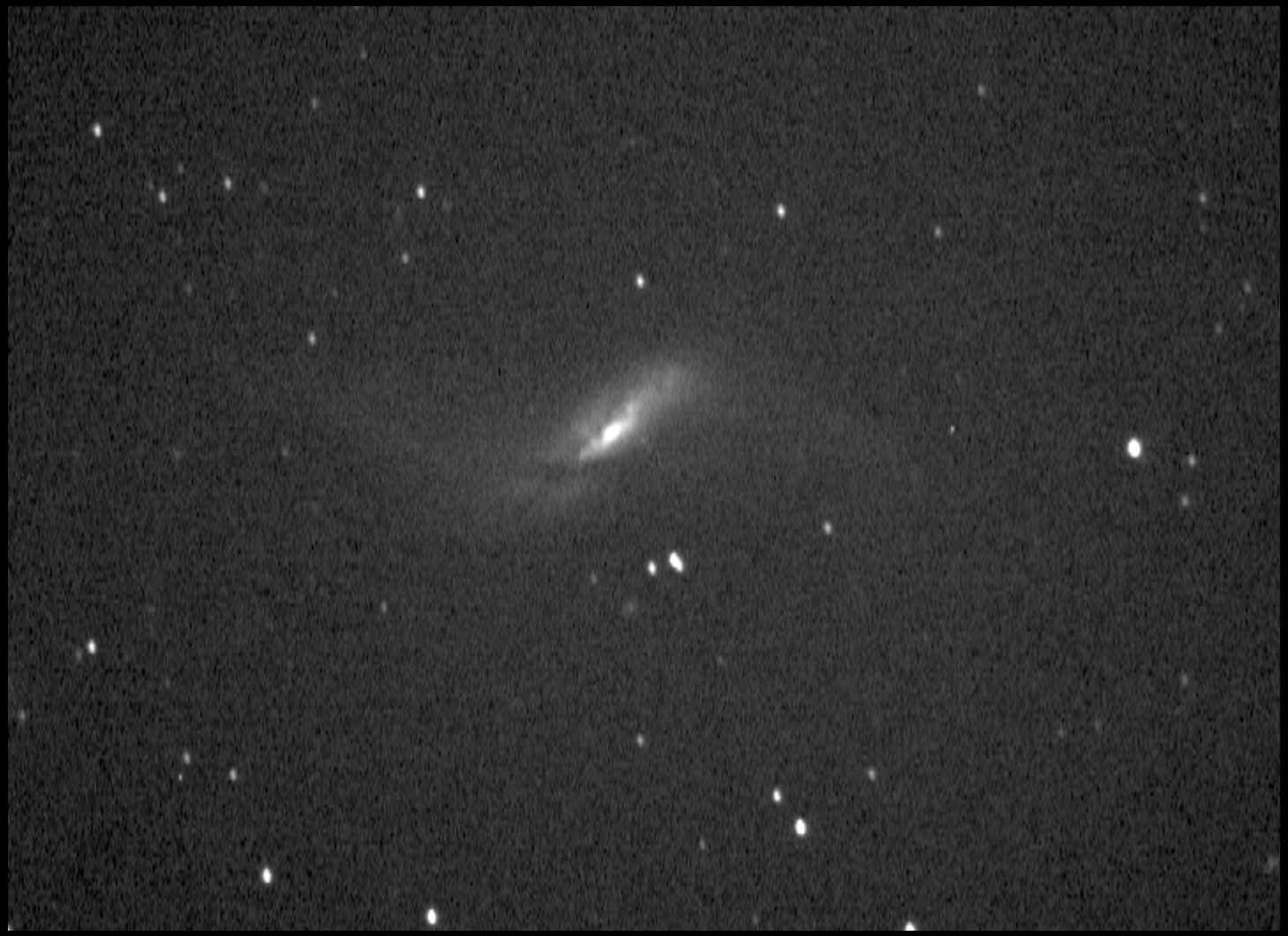
- That's why it is important to preserve fractions !

Calibration example:



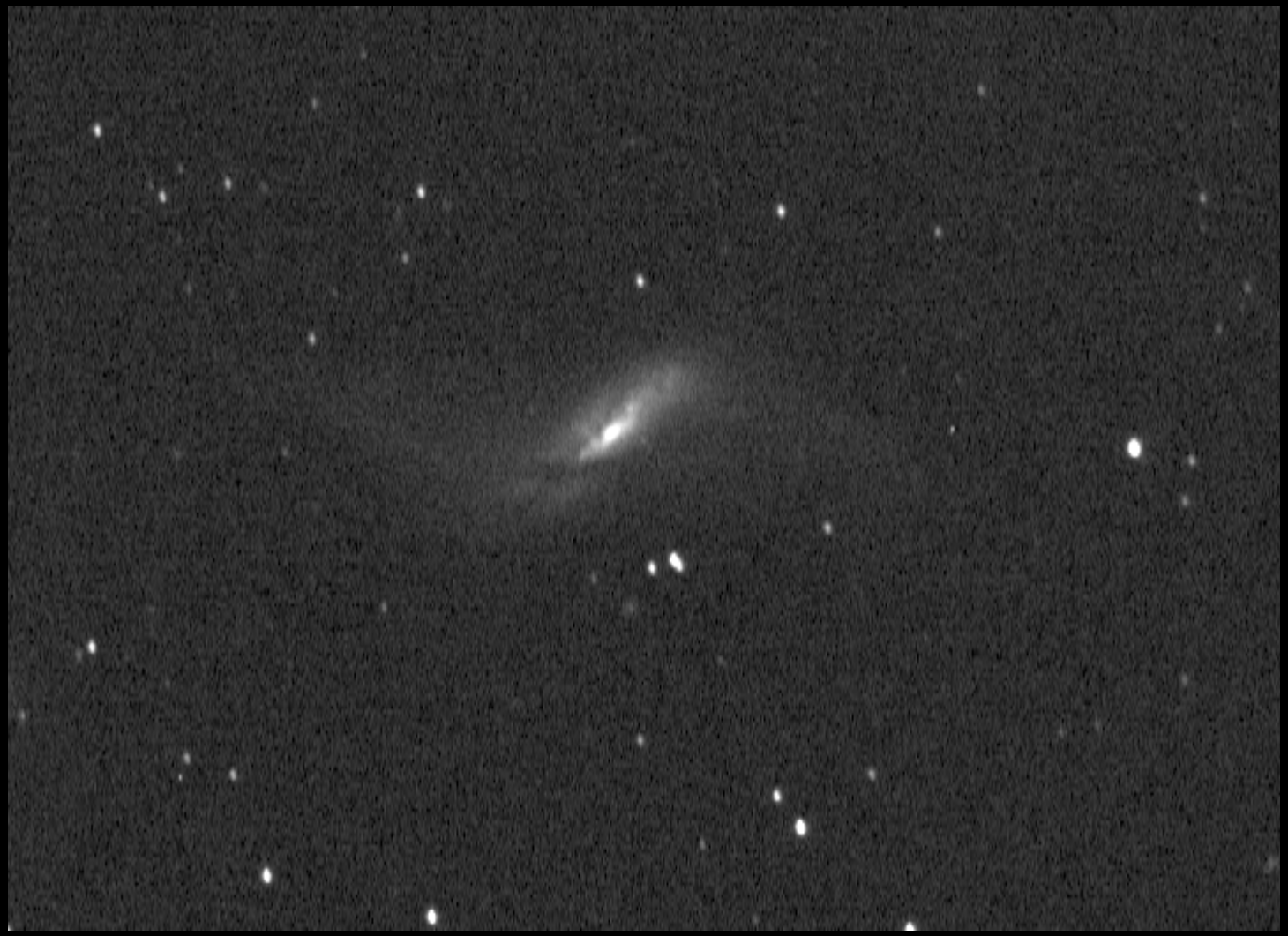
Raw CCD image (PV: 827 → 2617)

Step 1: Dark frame subtraction



Dark-corrected image (PV: 715 → 2132)

Step 2: Division by flat frame



Calibrated CCD image (PV: 724 → 2119)

Properly calibrated image

- *Bias, thermal charges and non –uniform sensitivity are corrected*

- *Minimal increase in noise*

  → *readout and photon noise dominate*

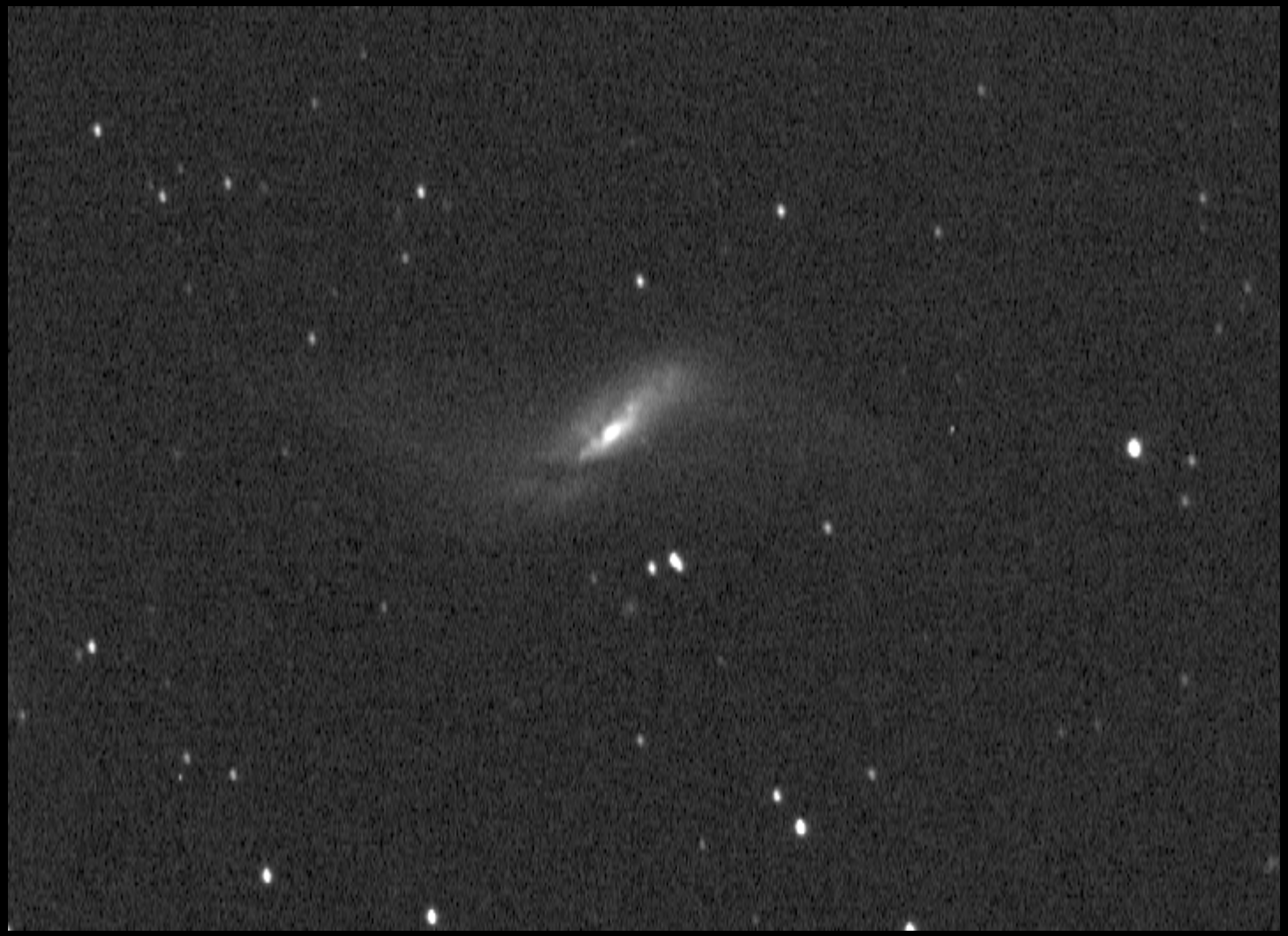
- *Dealing with both:*

  1. *Longer exposures*
     AND (not or!)
  2. *Combining many images*

- *Sky background contributes to photon noise as well !*

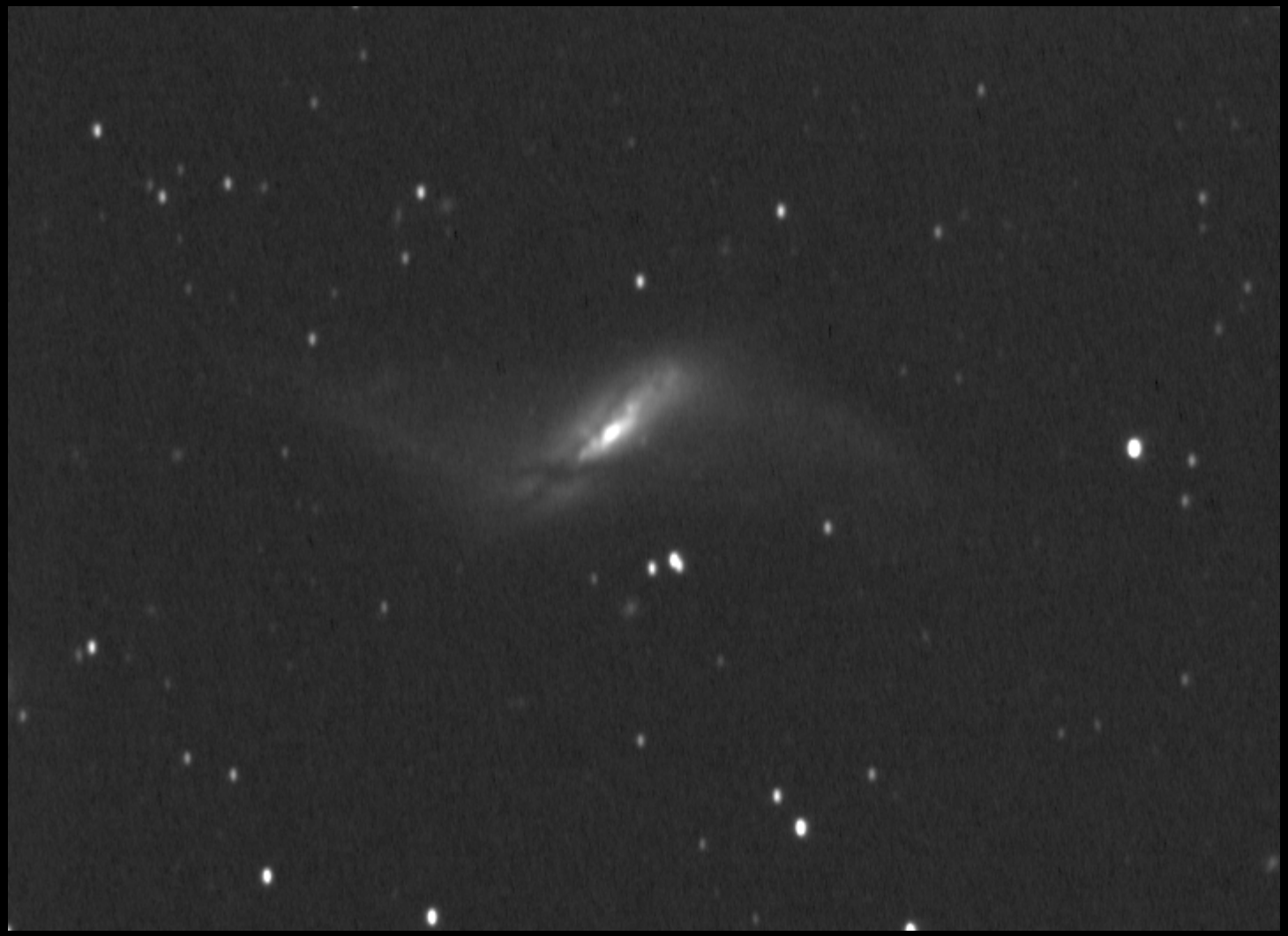
  → *darker skies*
  → *selective filters*

Combining multiple calibrated images



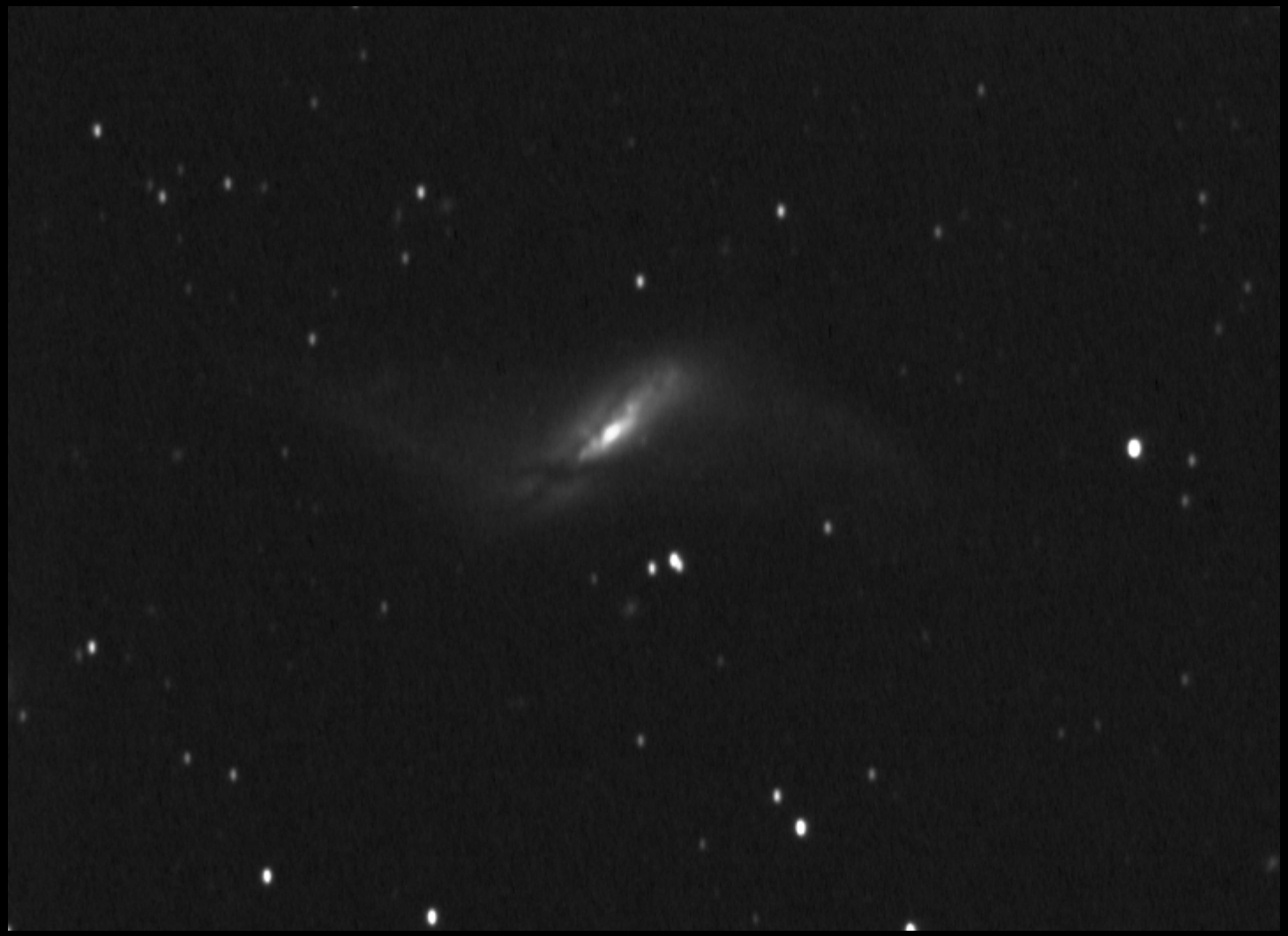
Single calibrated image

Combining multiple calibrated images



Median of 10 calibrated images

Brightness scaling – Background cannot turn black !



Clipped background means that the calibration was not done properly.

There is always information in the background !

Cookbook CCD + 8”SCT (10 x 4 min.)

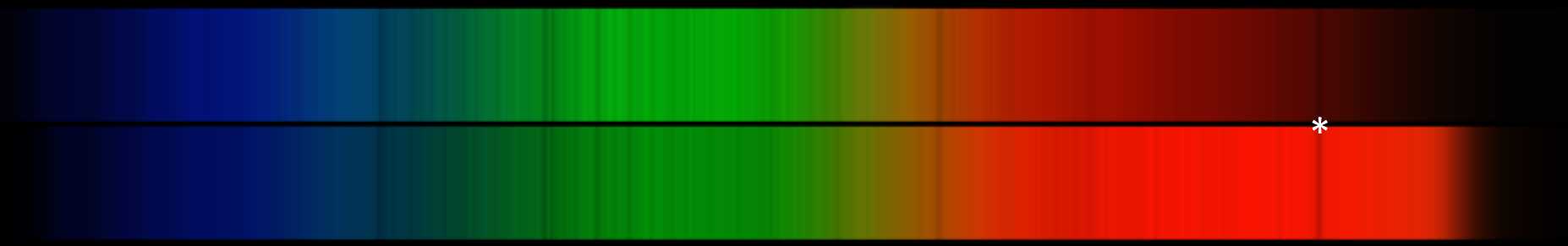
POSS II (red plate)

Challenges of calibrating DSLR image ..

0. Internal filter blocks far red (including Ha and SII lines)

- Off the shelf DSLRs have filter suppressing very red end of the spectrum
- Very little transmission of Ha emission line (and S II)

original Canon sensor filter: Ha(656nm)

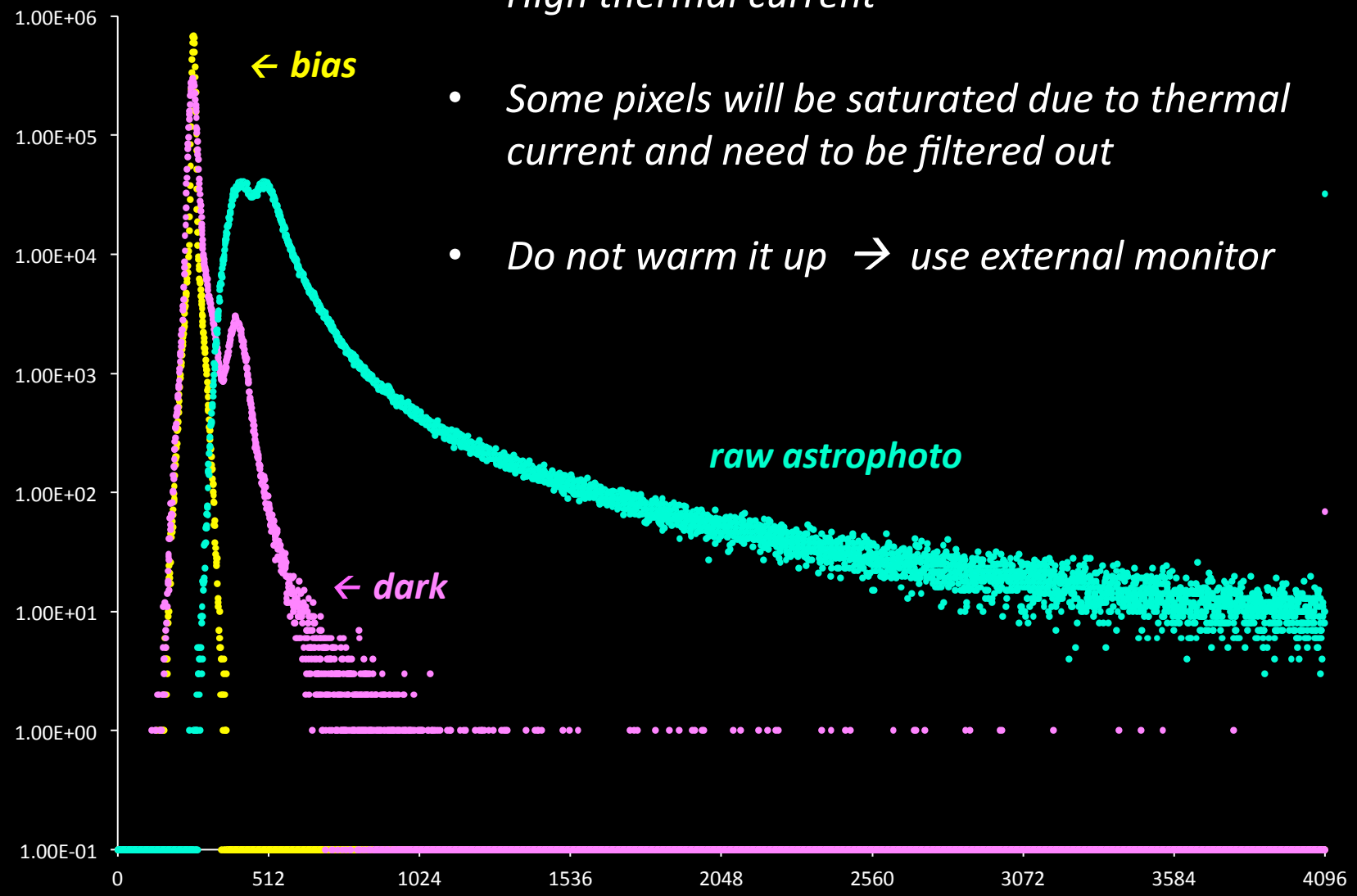


after replacement with Baader -UV/IR filter: ~ 6x increase

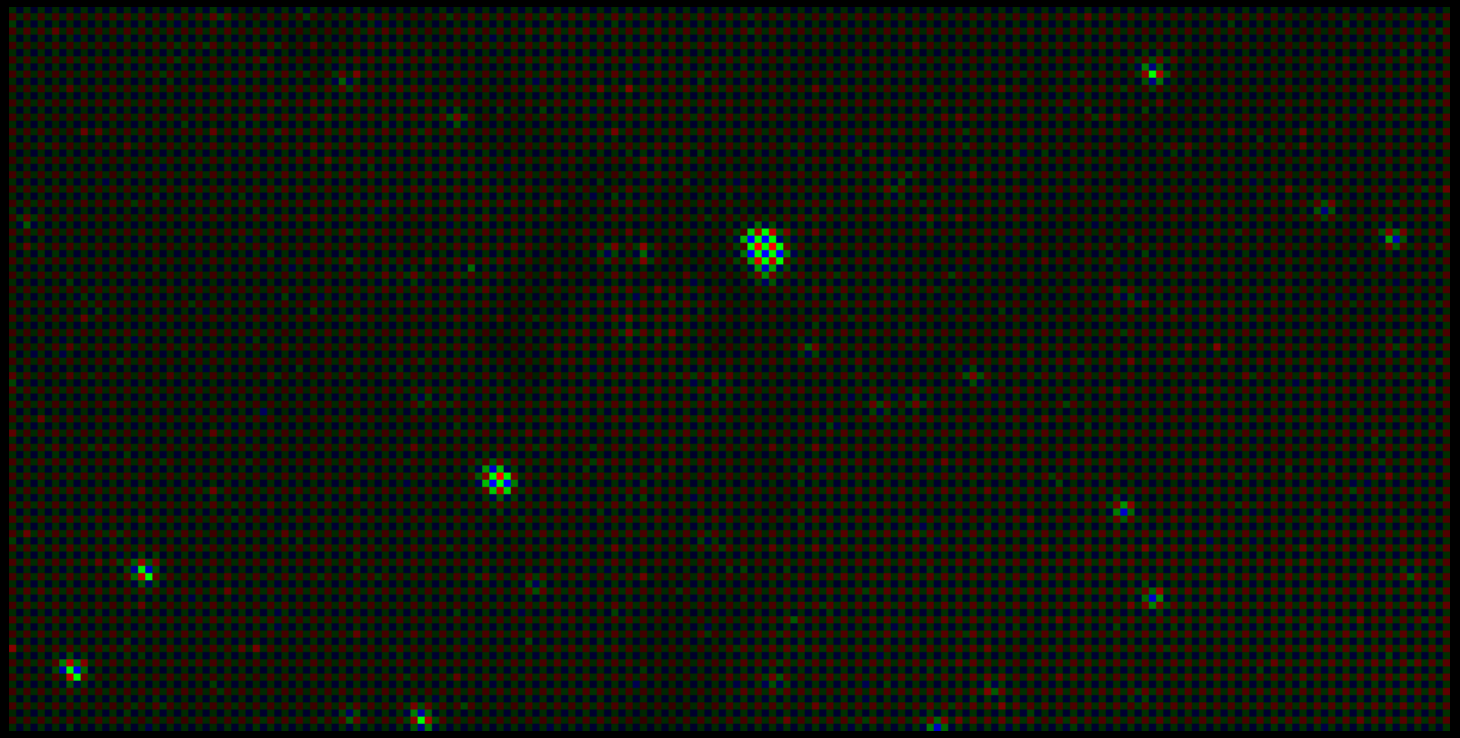
→ *For best results DSLR camera needs to be modified …*

1. DSLR's detector is warm …

- *High thermal current*
- *Some pixels will be saturated due to thermal current and need to be filtered out*
- *Do not warm it up → use external monitor*



3. Bayer array complicates calibration …

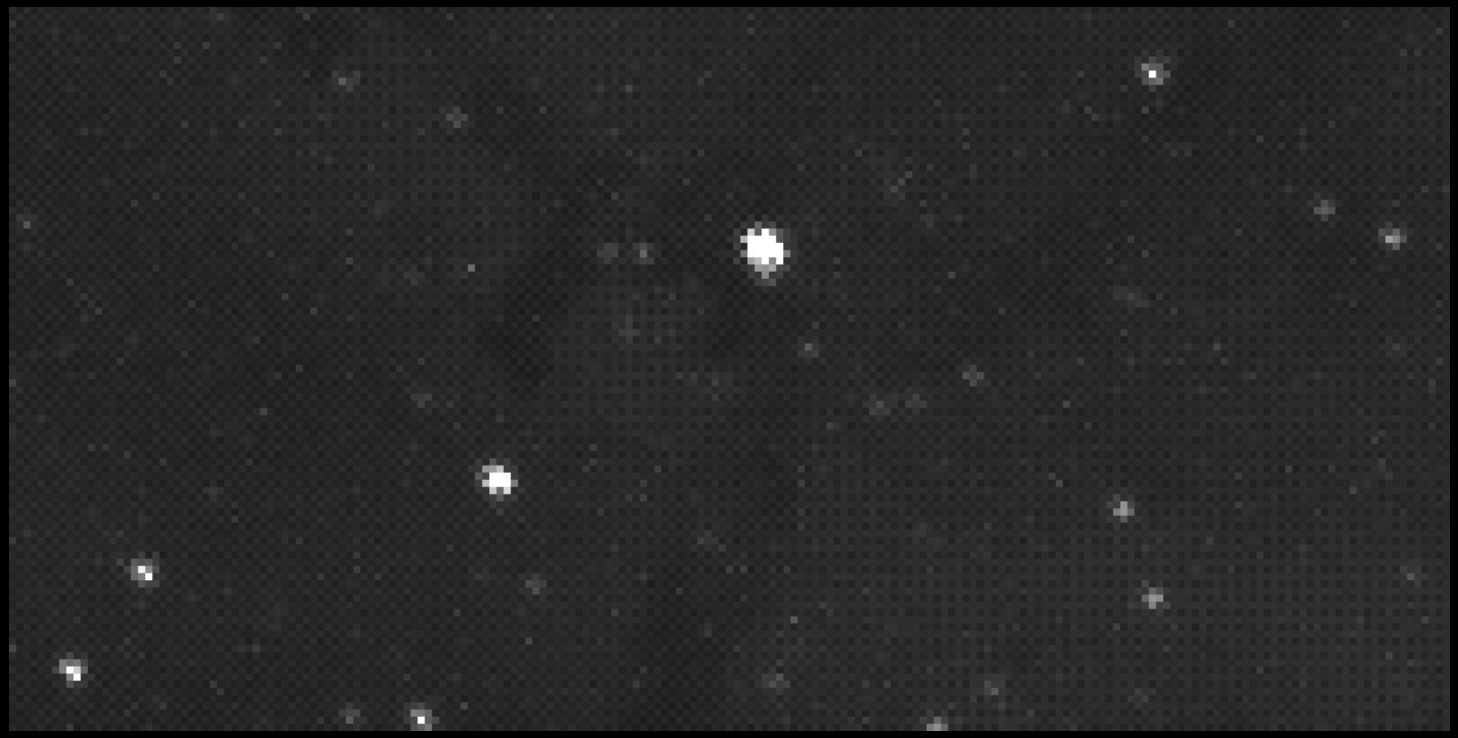


- *Bayer array:* G B
  R G

3. Bayer array complicates calibration …

- *Bayer array:* G B / R G
- *Direct color conversion averages neighboring pixels to "smooth" color*

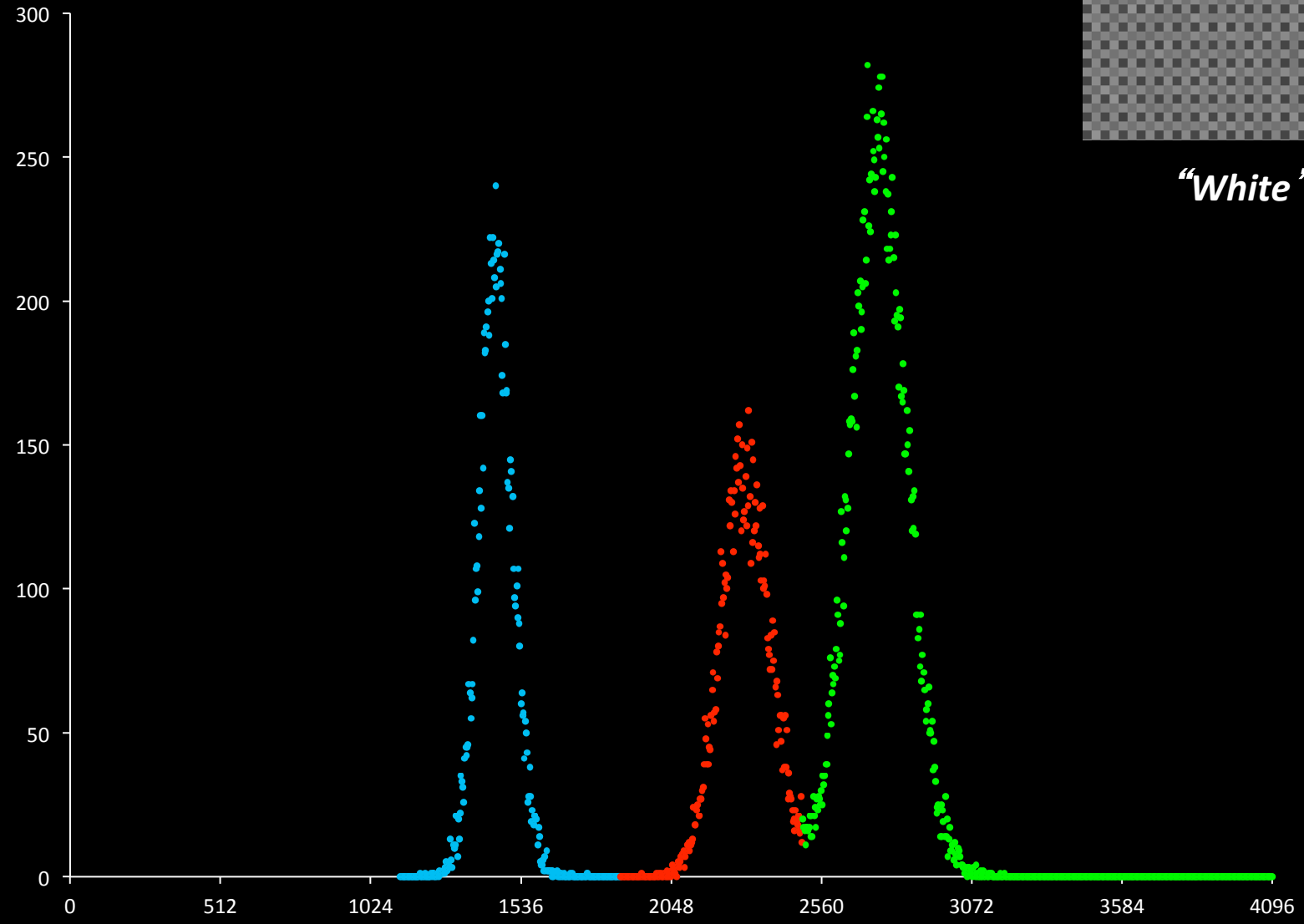
3. Bayer array complicates calibration …

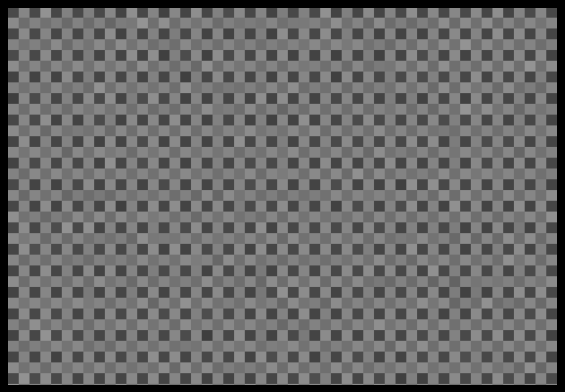


- *Bayer array:* G B / R G
- *Grid has to be preserved throughout calibration*

→ *Use RAW format (also keeps the original 12-bit pixel depth)*

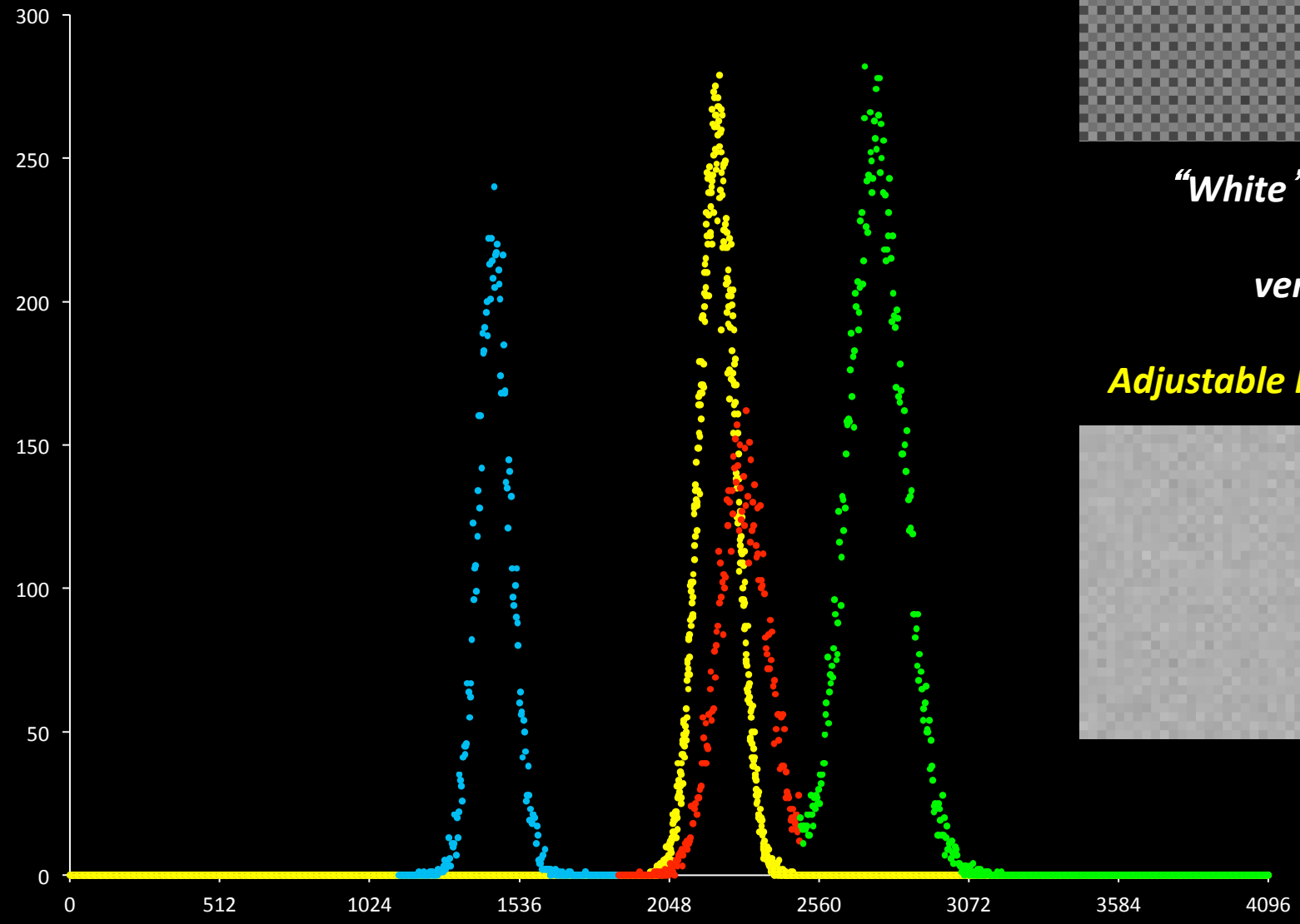
"Flat" sources for DSLR need to be corrected for Bayer filters

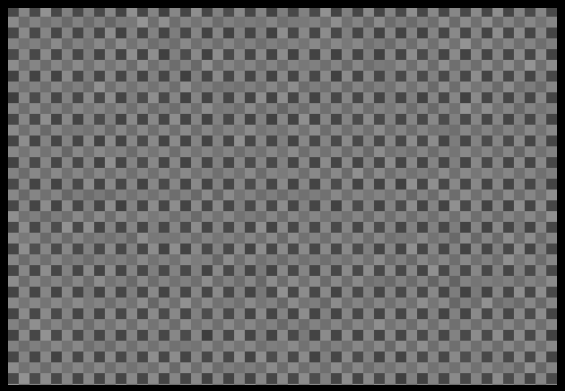




"White" LED box

"Flat" sources for DSLR need to be corrected for Bayer filters

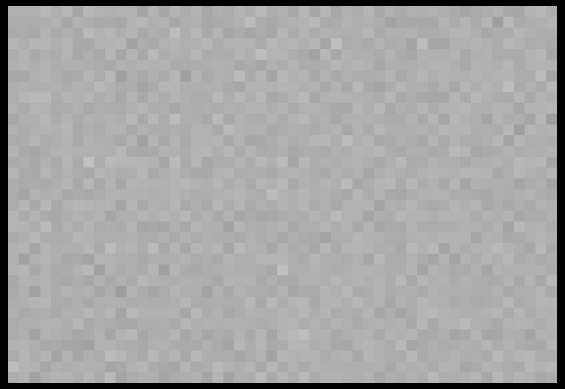




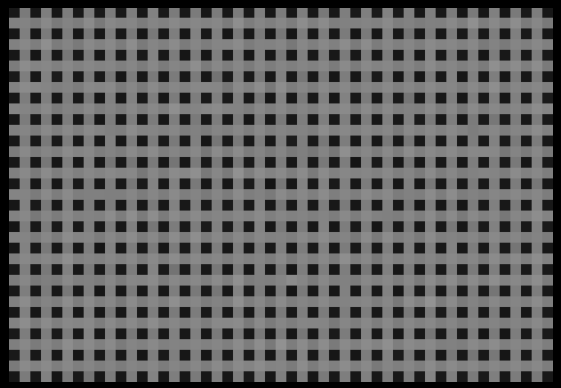
"White" LED box

versus

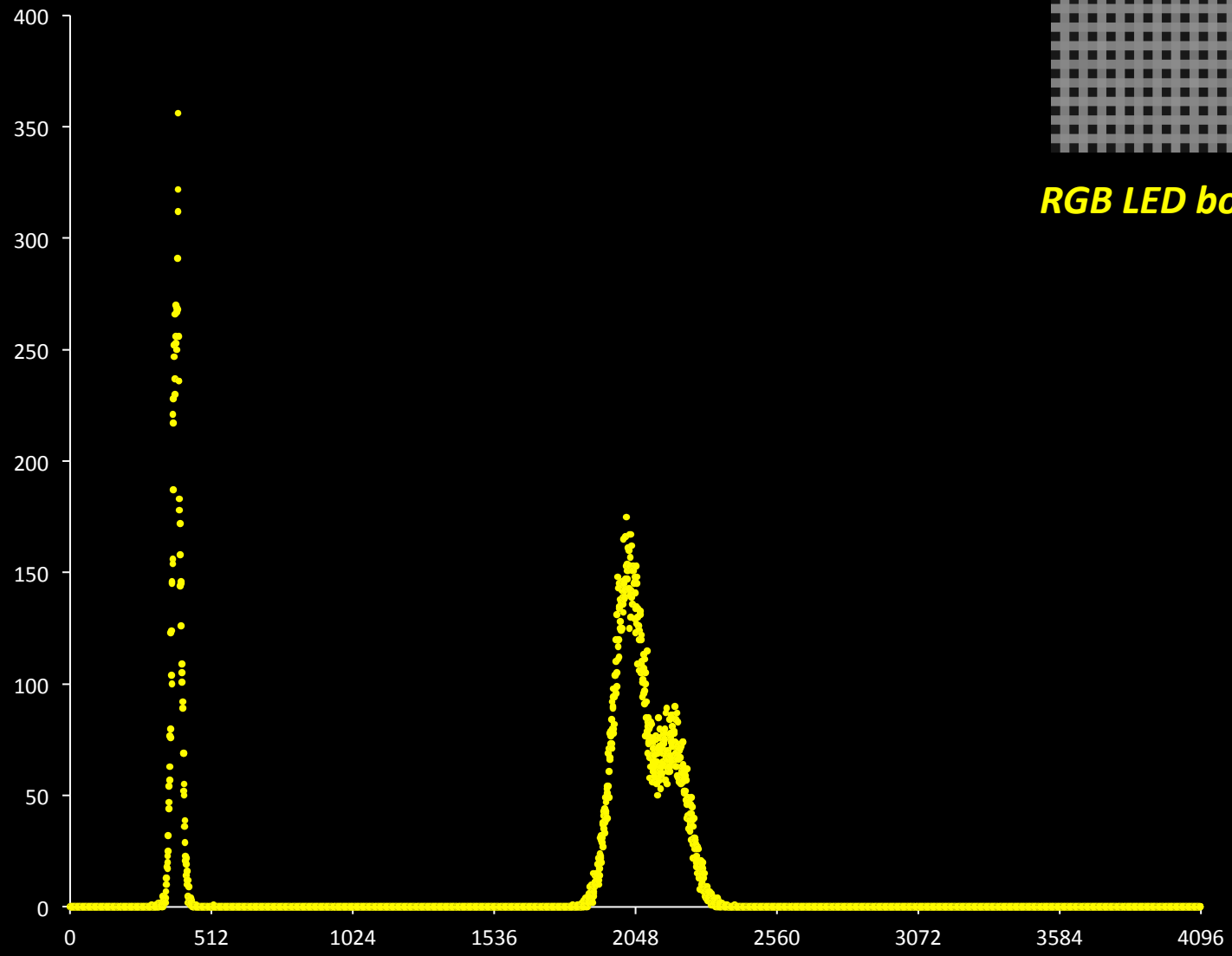
Adjustable RGB LED box



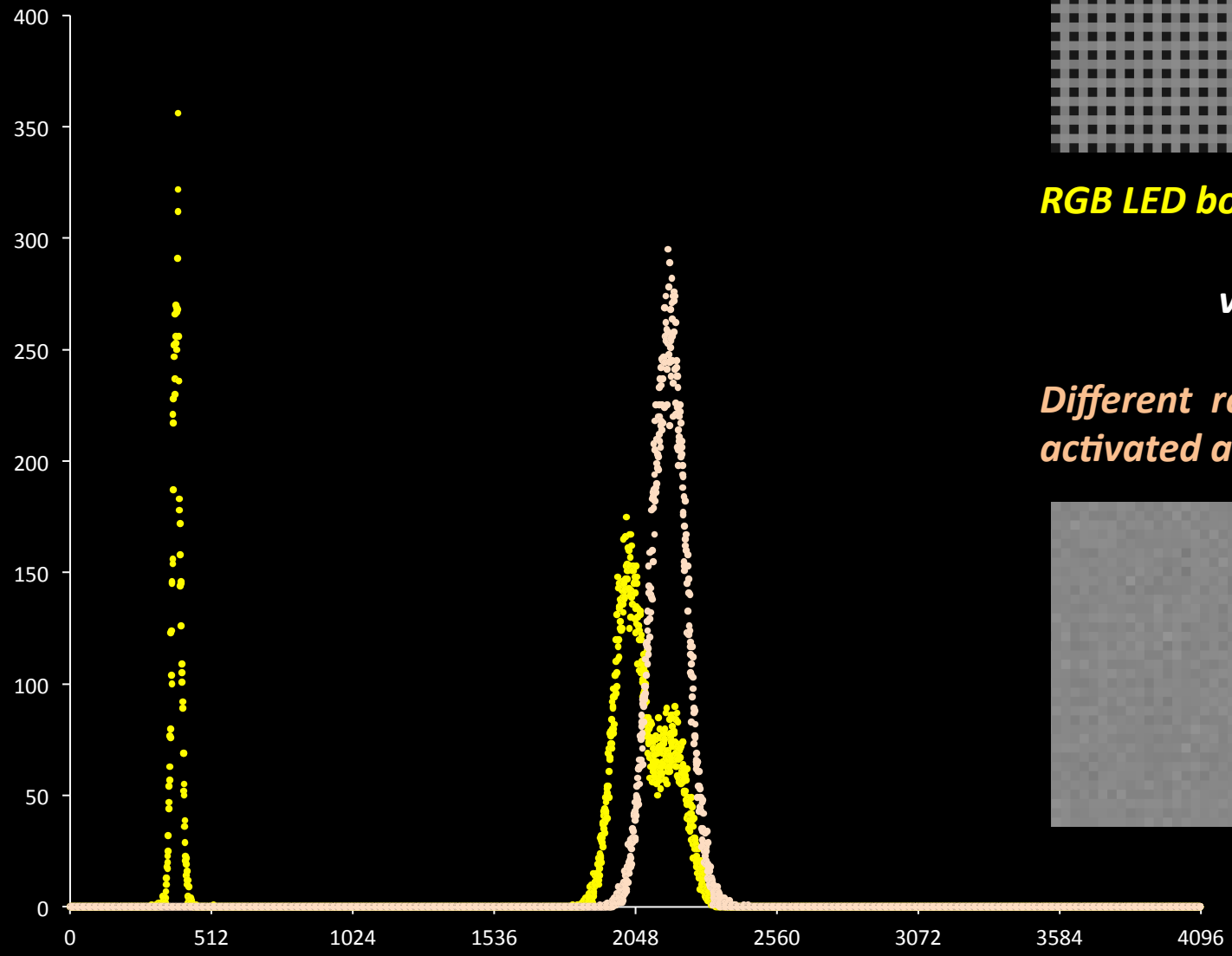
Such correction needs to be applied to filters as well…

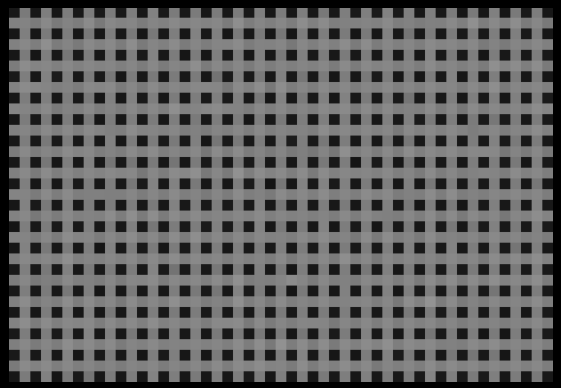


RGB LED box with CLS filter



Such correction needs to be applied to filters as well…

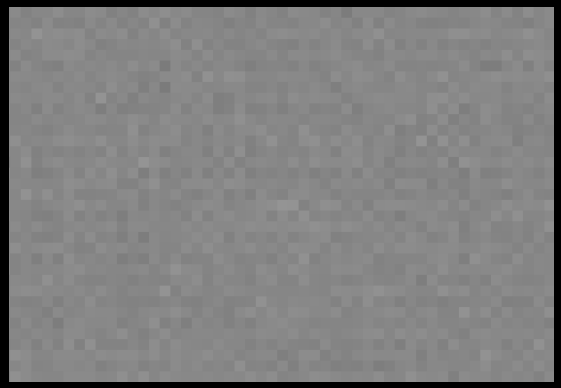




RGB LED box with CLS filter

versus

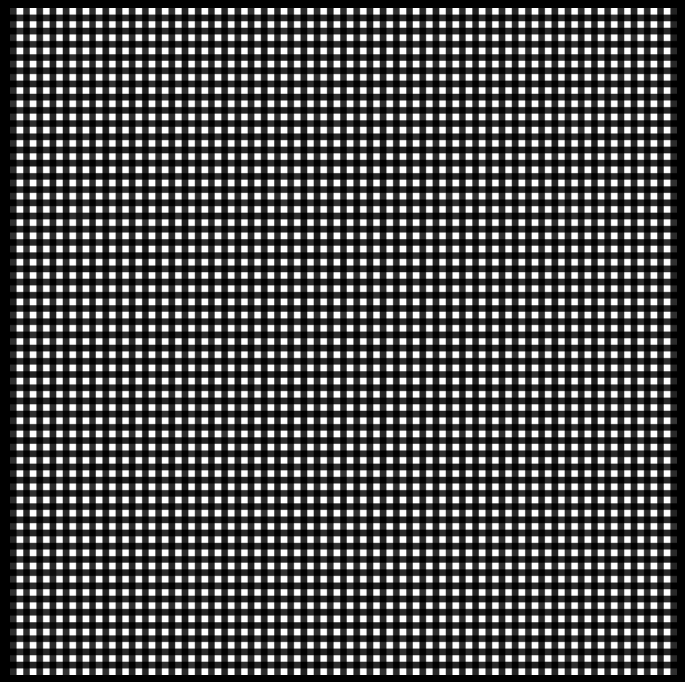
Different red LED (660nm) activated and adjusted



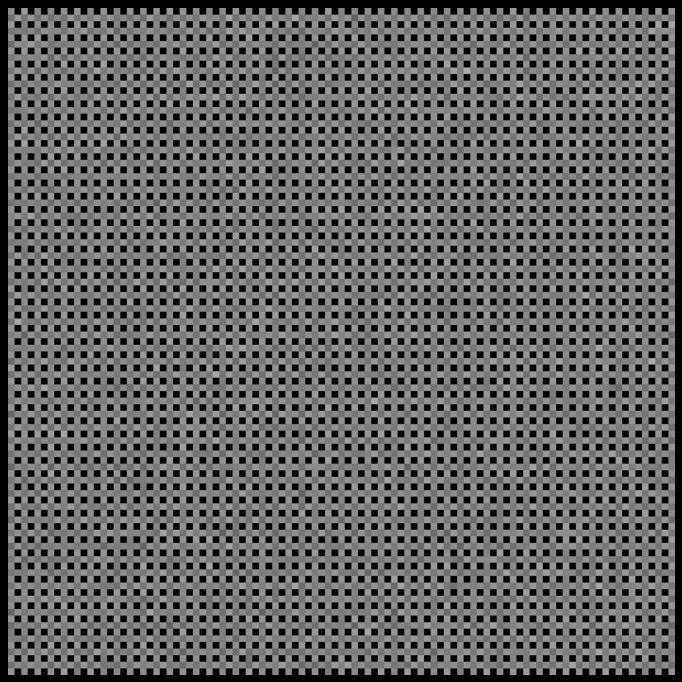
However, that does not work for narrowband filters …

Just discard unused channels

→ they contribute no information, just artifacts amplified during flat frame correction



DSLR + Hα filter
→ keep red "channel" only

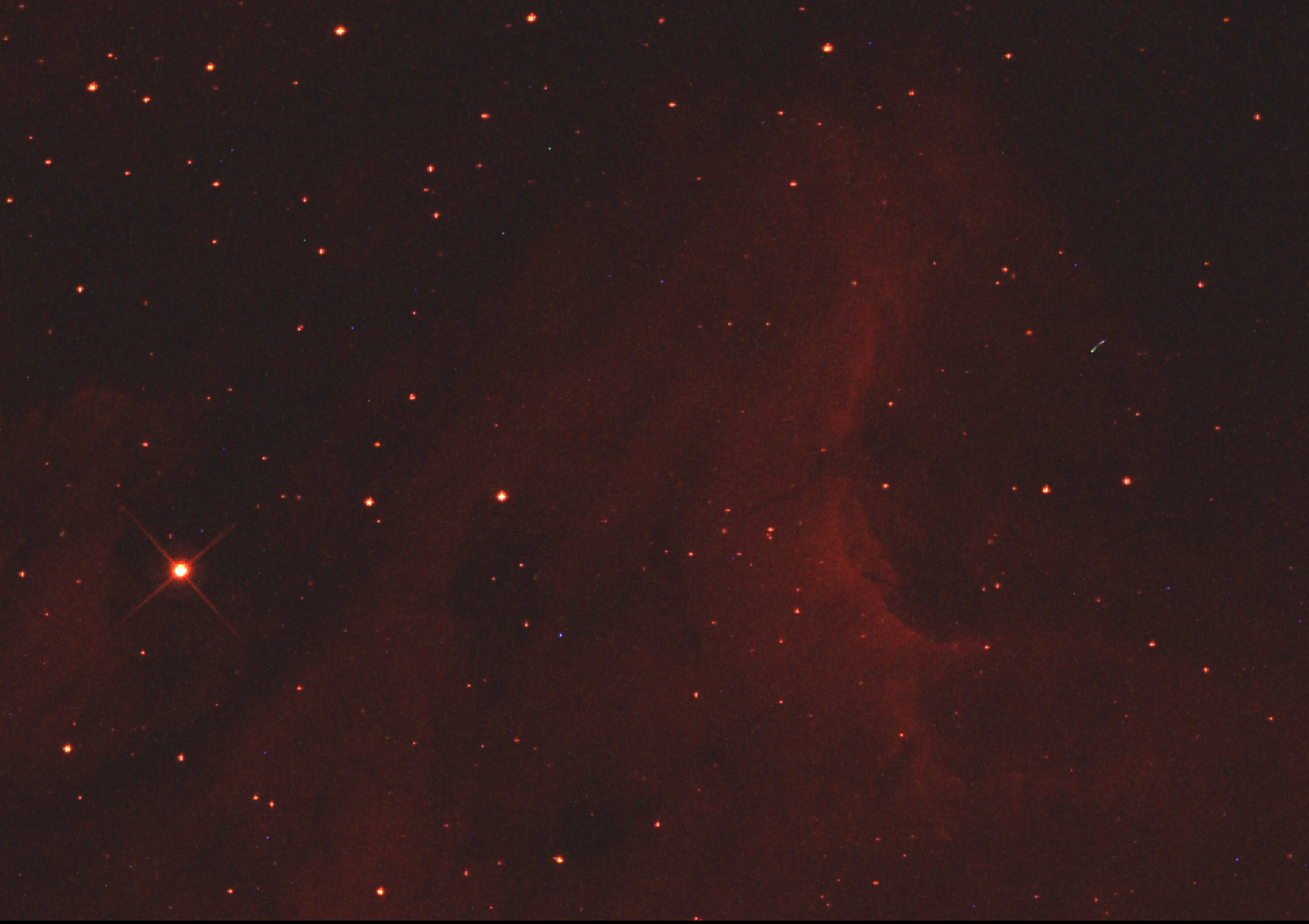


DSLR + OIII filter
→ keep green & blue "channels"

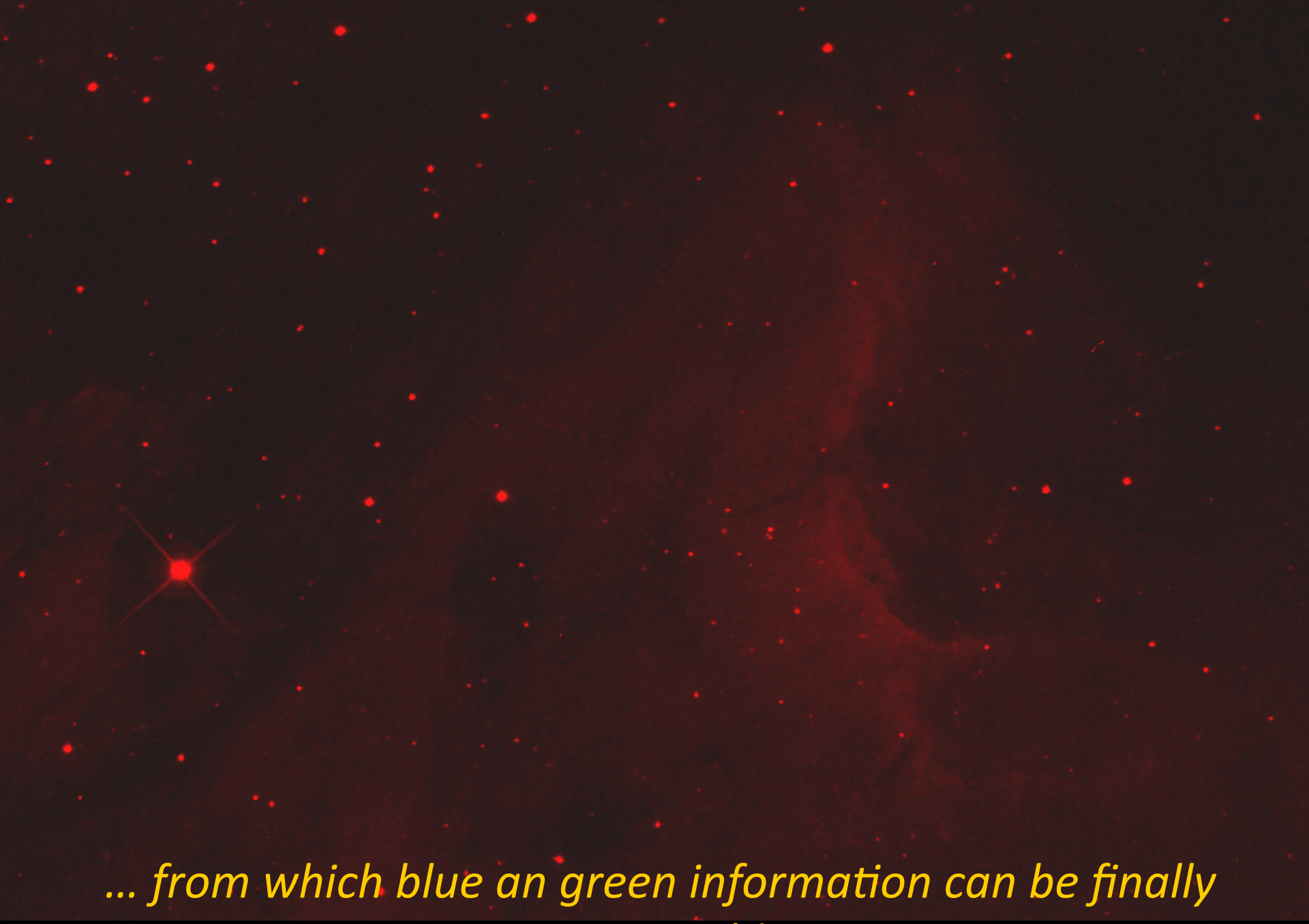
Example of DSLR image calibration:

Raw image taken through Ha filter (fragment) ...

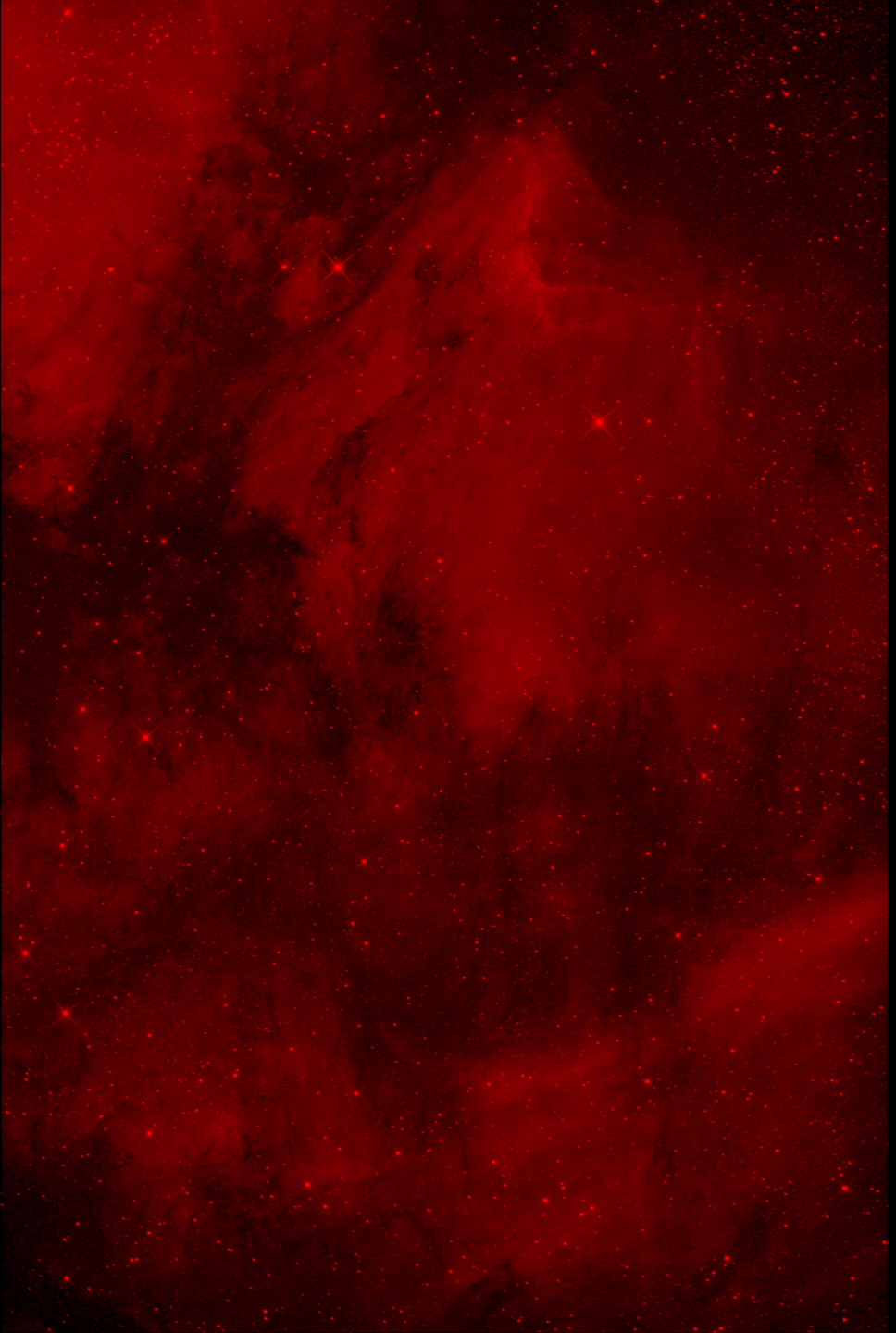
… dark frame was subtracted, hot pixels replaced and them divided by flat frame …



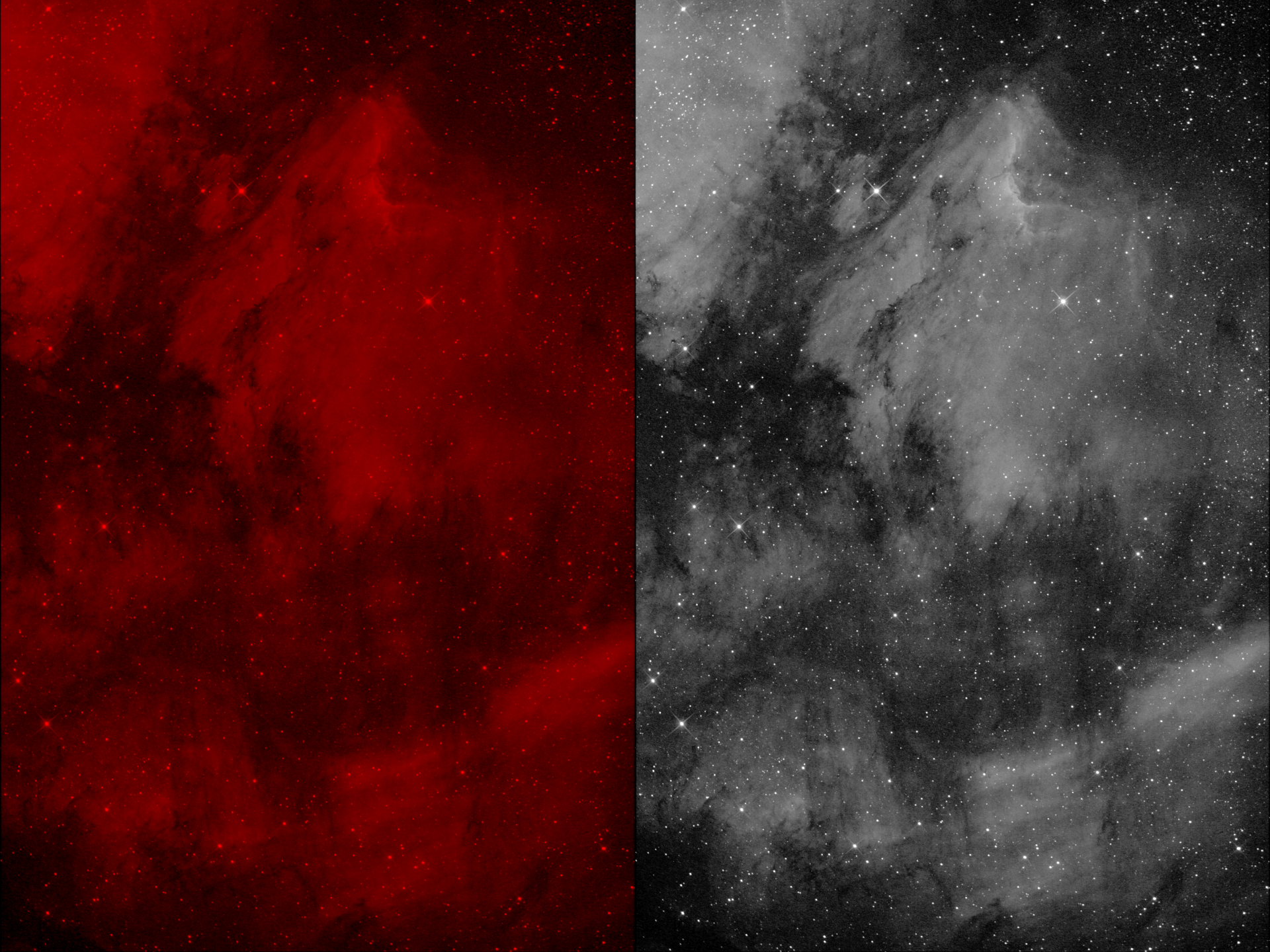
… then converted into RGB image …



… from which blue an green information can be finally removed !

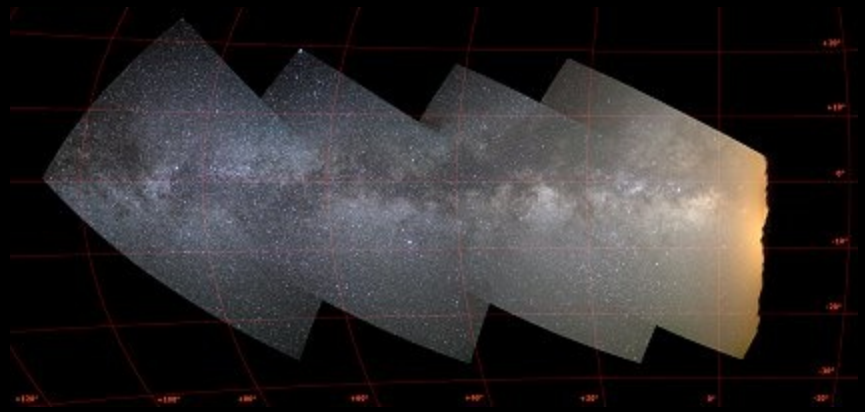


Full frame view of seven Ha images
combined and scaled:

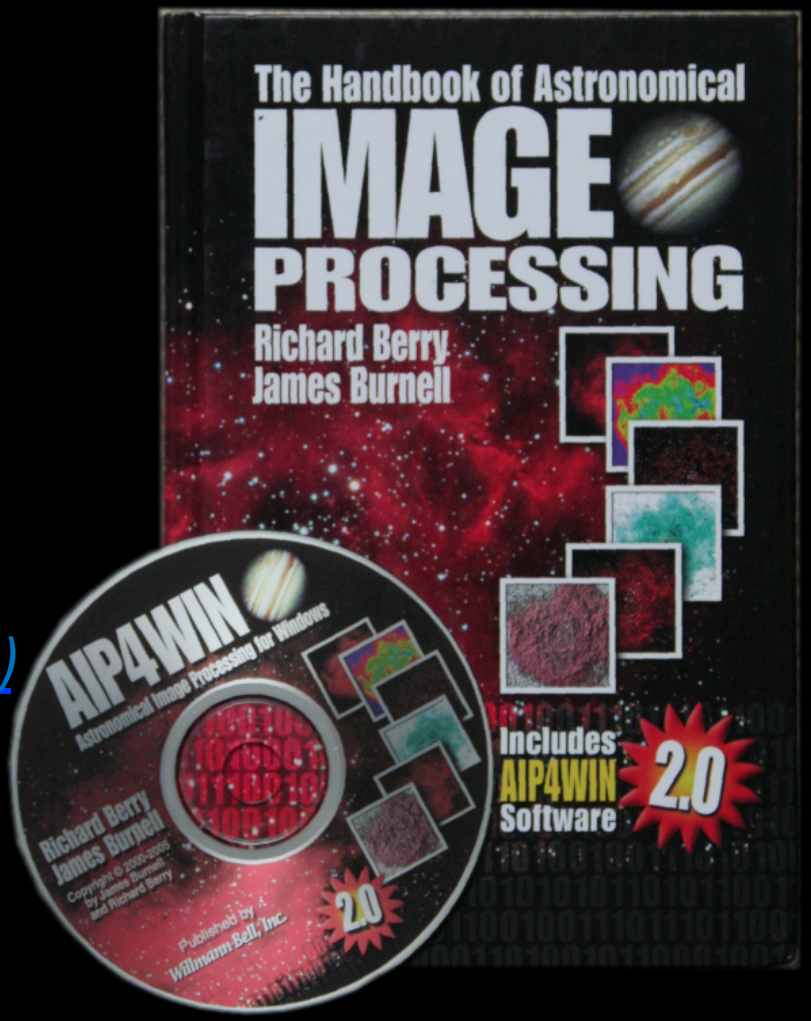


Recommended software:

- *IRIS (http://astrosurf.com/buil)*



- *AIP4WIN (www.willbell.com)*



- *other …*