Winter Star Party 2013
Finer points of imaging

Richard Crisp

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rdcrisp@earthlink.net

www.narrowbandimaging.com

Agenda

- Flat Fielding with confidence
- RBI: Swirls in Darks?
- Blocky and other odd shapes in flats
- Halpha: bad choice for luminance

Key Issues for Flat Fielding

- How many flat exposures?
- What signal level for the exposures?
- How do we take the exposures: what method should be used?

How do you know what signal level to use for the flats?

- A Master flat is simply an image of the “fixed patterns” observed by the sensor when mated to an optical system imaging a uniform background
- Like any image, for a good image: we want high signal levels and many such images to combine together
- But how many is enough: how do we know we are right?

Practical Matters

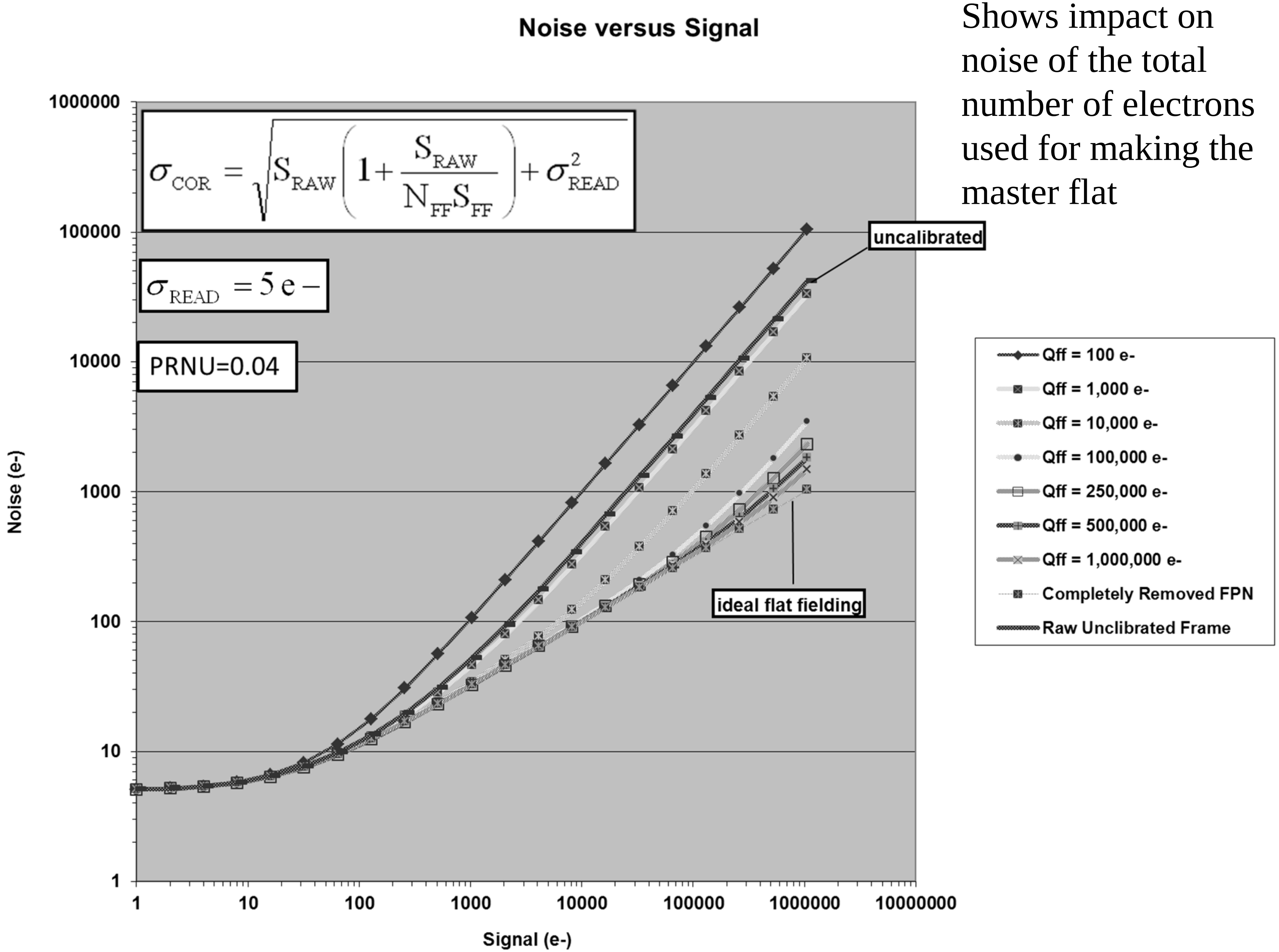
- Easier to get a good “image” (aka high SNR) of the FPN if the camera is operated in the FPN-Limited region: fewer flats needed at high signal level
- The signal level should be high enough so that read noise is inconsequential;
  - ex: 10e- read noise = shot noise of 100e- signal
    - To be inconsequential, should be less than 1-2%: signal levels
    - Signal level at least 10,000 e- or more for 10e- read noise camera
- Signal levels for the flats should be as high as practical to maximize the FPN and to reduce the total number of flats needed
- The signal level should be low enough so that no pixels saturate
- Ignoring FPN, the SNR of Flat is proportional to SQRT(#Frames) and proportional to SQRT(signal level in frame).

How do you Quantify the Integrity of the Flat Fielding Process?

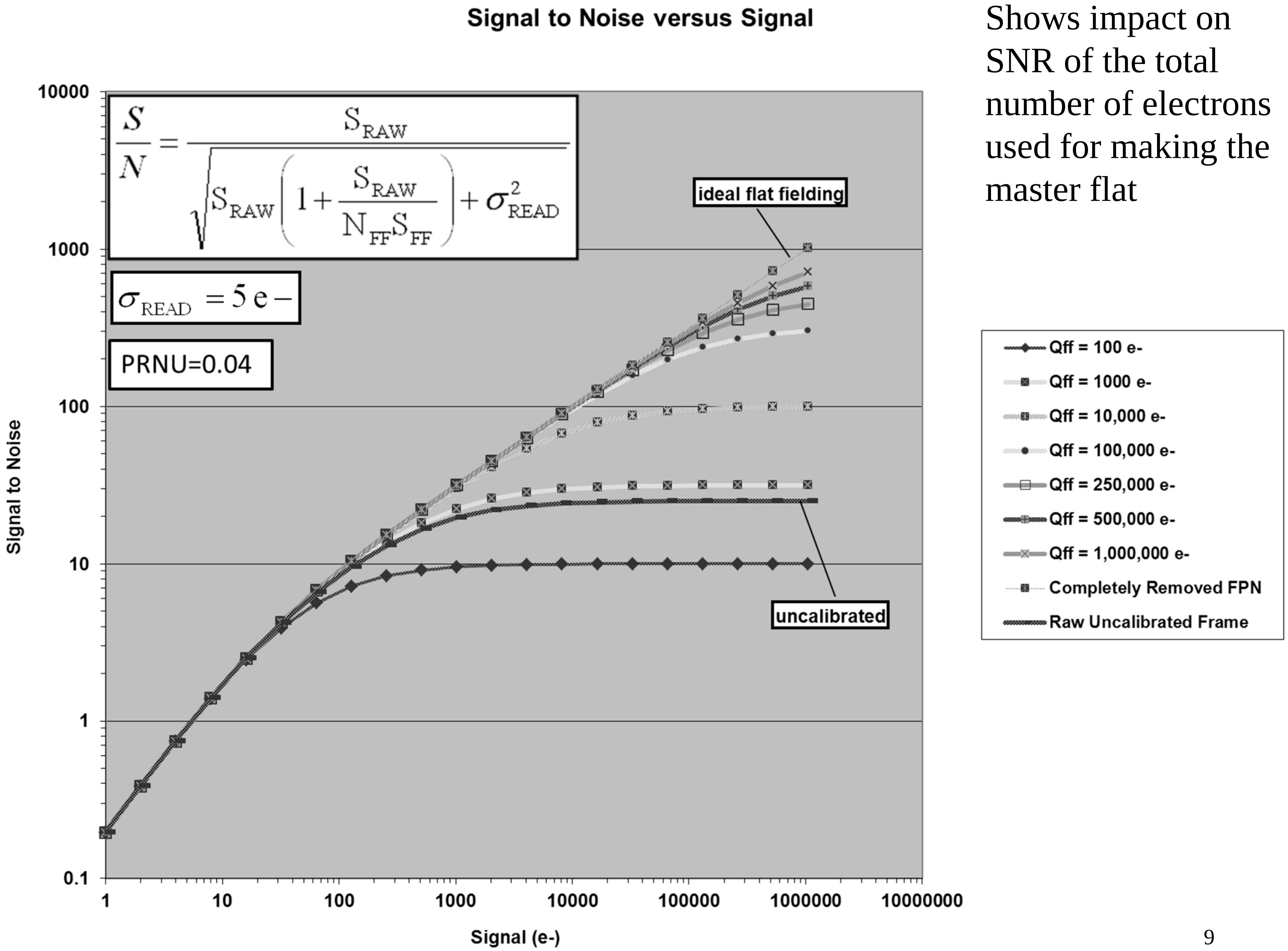
- You create a Flat Field Photon Transfer Plot
  - It plots noise against signal for a sequence of flat-fielded images
  - It clearly shows the relationship between signal in the flats and noise in the flat-fielded result

FFPTC: Testing how many flats is enough

- You combine varying numbers of the flat frames to make several master flats and apply to the test data to see how many flats are actually necessary to reach a given noise performance level



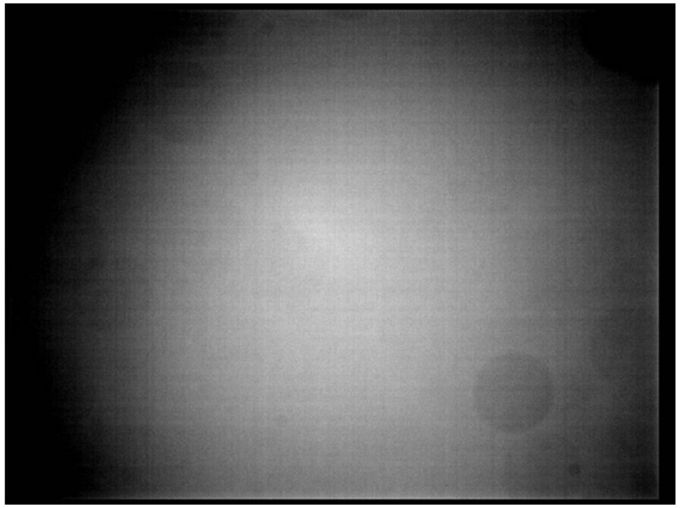
Shows impact on noise of the total number of electrons used for making the master flat

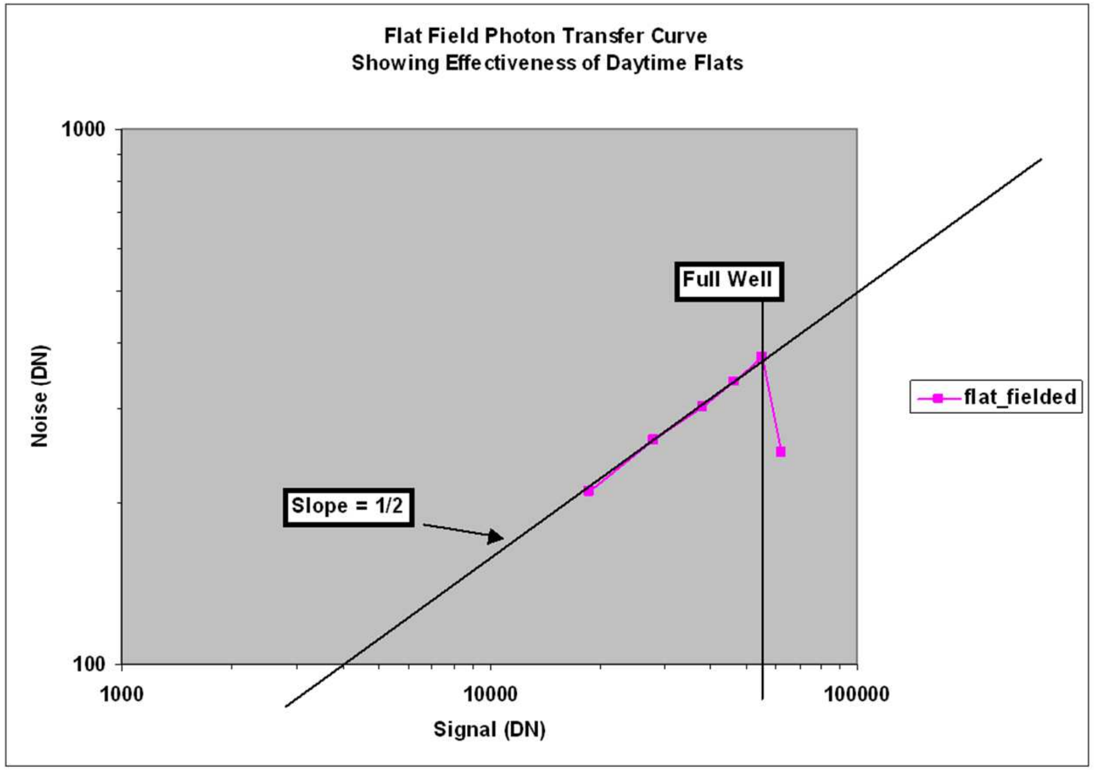


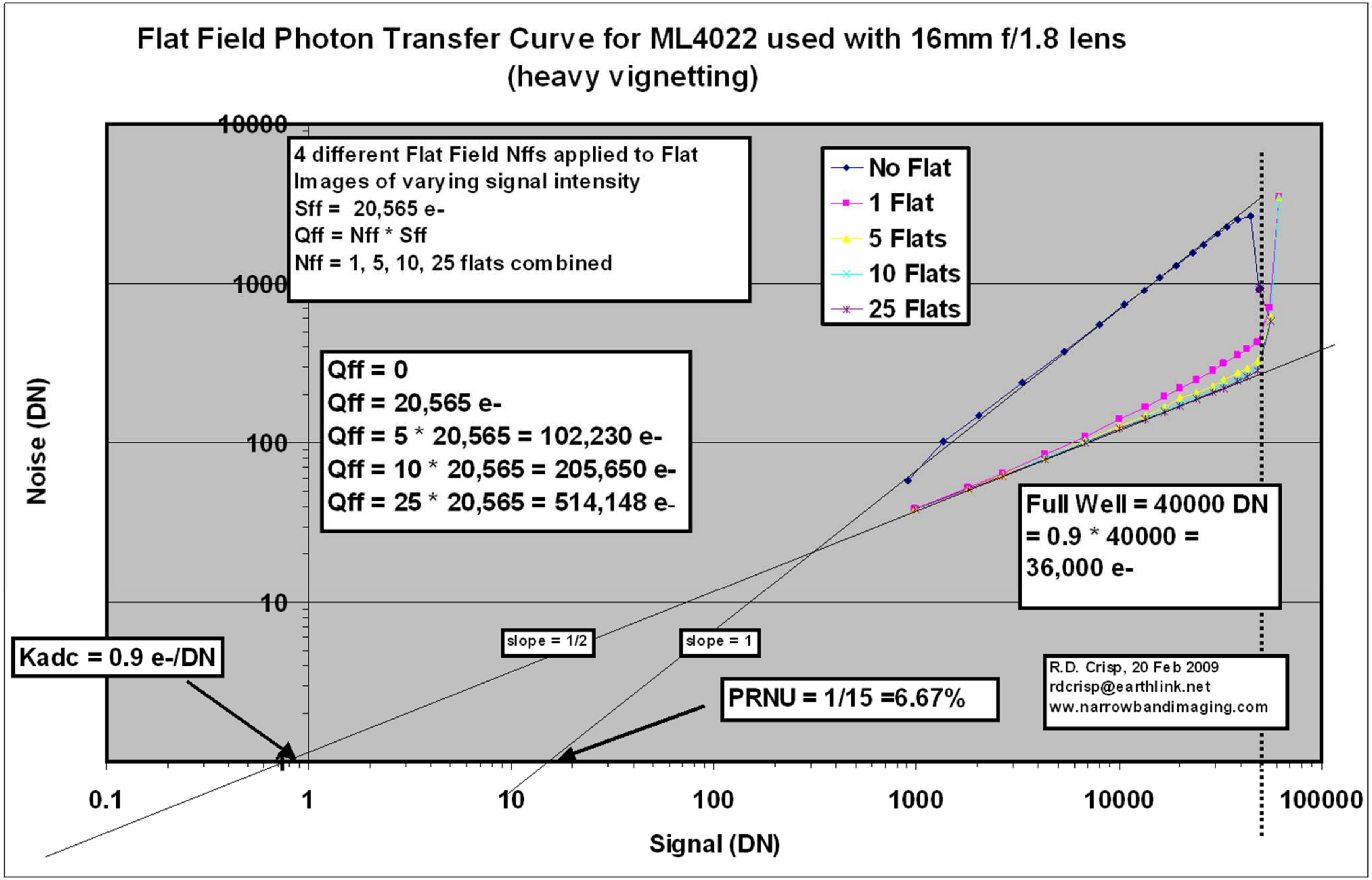
Shows impact on SNR of the total number of electrons used for making the master flat

Testing Master Flat

- Once you have prepared a master flat, you can test it by making a FFPTC (flat field photon transfer curve)
- If the slope of the FFPTC is +1/2 then the FPN is completely removed



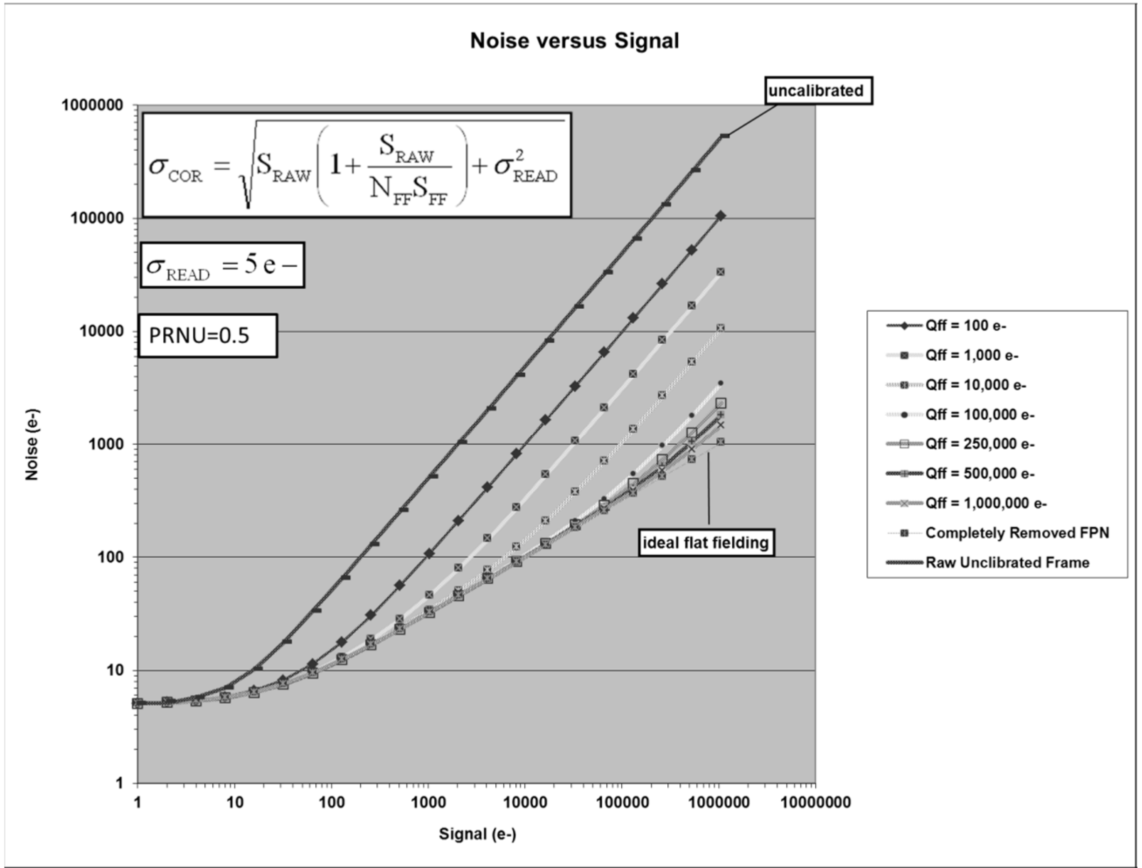




For modest signal levels, 5-10 frames seems sufficient for this system

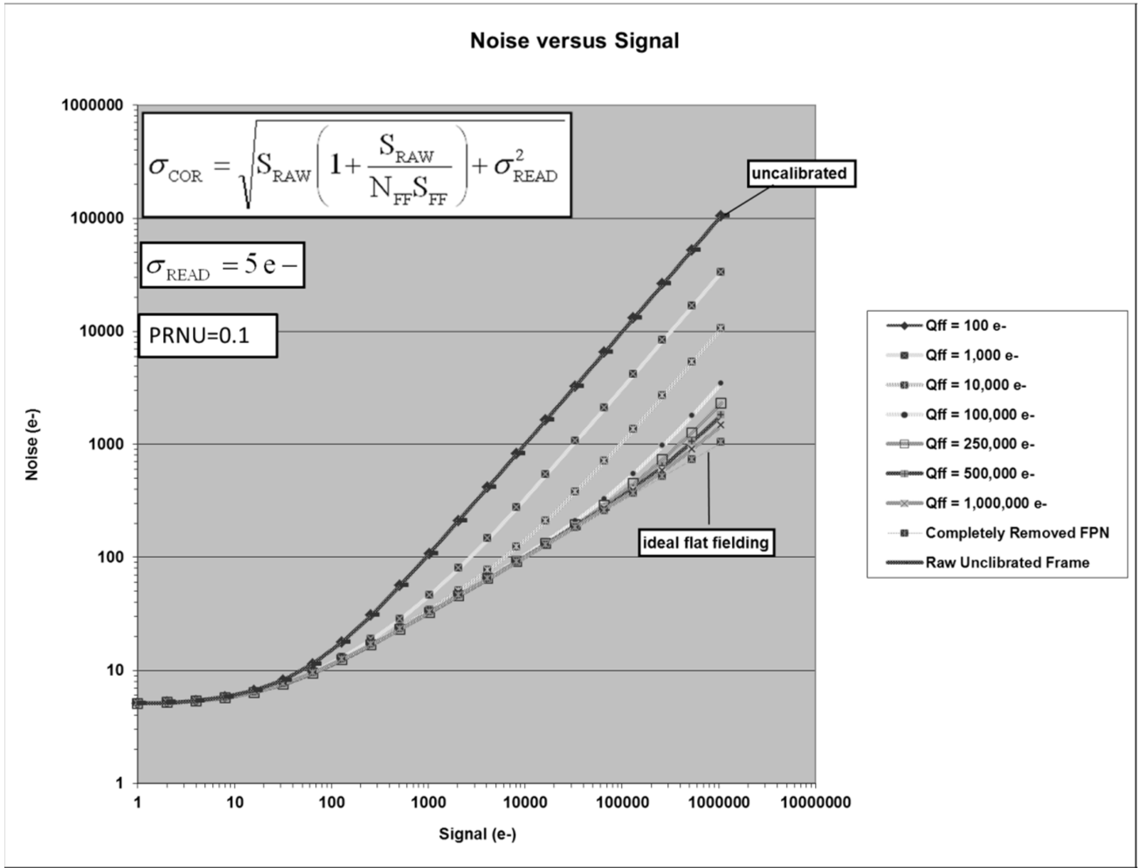
Noise vs Signal

PRNU = 0.50



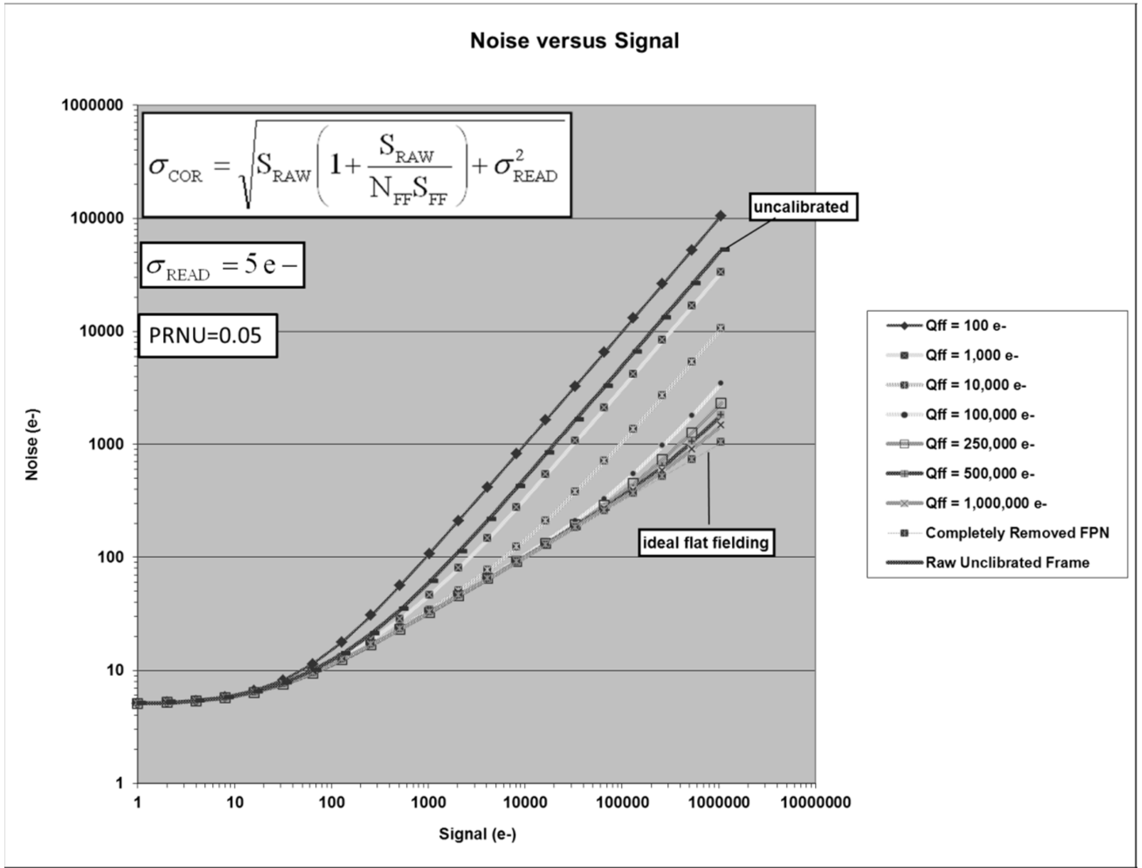
Noise versus Signal
uncalibrated
$$\sigma_{COR} = \sqrt{S_{RAW}\left(1+\frac{S_{RAW}}{N_{FF}S_{FF}}\right)+\sigma^2_{READ}}$$
$\sigma_{READ} = 5\,e-$
PRNU=0.5
ideal flat fielding
Noise (e-)
Signal (e-)
1
10
100
1000
10000
100000
1000000
10000000
Qff = 100 e-
Qff = 1,000 e-
Qff = 10,000 e-
Qff = 100,000 e-
Qff = 250,000 e-
Qff = 500,000 e-
Qff = 1,000,000 e-
Completely Removed FPN
Raw Unclibrated Frame

PRNU = 0.10



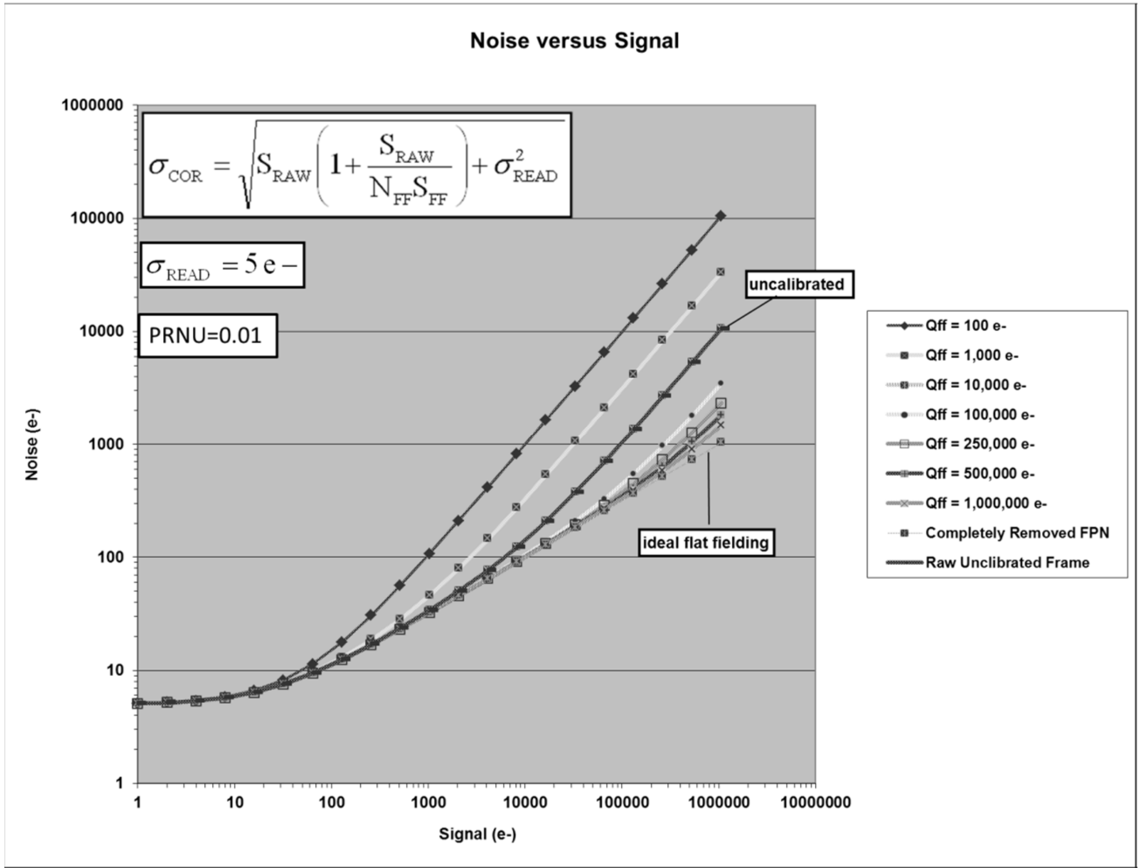
Noise versus Signal
$\sigma_{COR} = \sqrt{S_{RAW}\left(1+\frac{S_{RAW}}{N_{FF}S_{FF}}\right)+\sigma^2_{READ}}$
$\sigma_{READ} = 5\,e-$
PRNU=0.1
uncalibrated
ideal flat fielding
Noise (e-)
Signal (e-)
Qff = 100 e-
Qff = 1,000 e-
Qff = 10,000 e-
Qff = 100,000 e-
Qff = 250,000 e-
Qff = 500,000 e-
Qff = 1,000,000 e-
Completely Removed FPN
Raw Unclibrated Frame

PRNU = 0.05



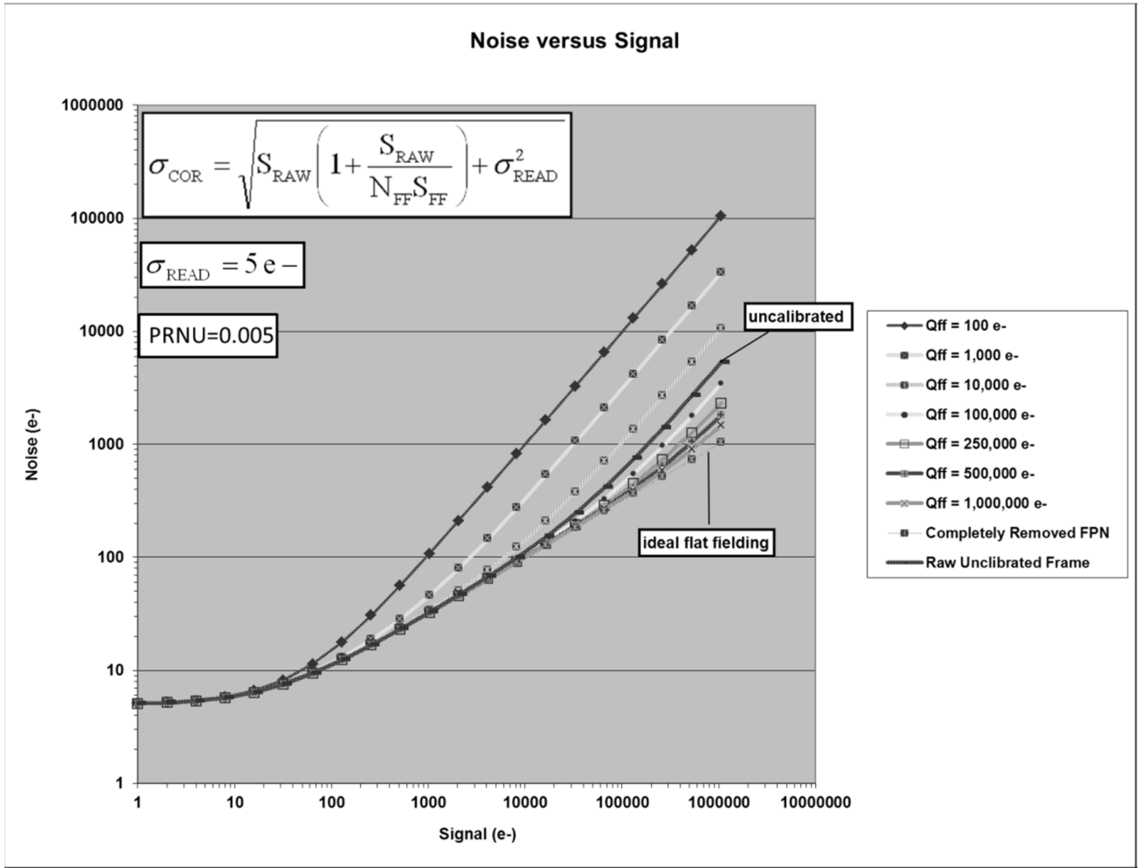
Noise versus Signal
$\sigma_{COR} = \sqrt{S_{RAW}\left(1+\frac{S_{RAW}}{N_{FF}S_{FF}}\right)+\sigma_{READ}^2}$
$\sigma_{READ} = 5\ e-$
PRNU=0.05
uncalibrated
ideal flat fielding
Qff = 100 e-
Qff = 1,000 e-
Qff = 10,000 e-
Qff = 100,000 e-
Qff = 250,000 e-
Qff = 500,000 e-
Qff = 1,000,000 e-
Completely Removed FPN
Raw Unclibrated Frame
Noise (e-)
Signal (e-)
1
10
100
1000
10000
100000
1000000
10000000

PRNU = 0.01



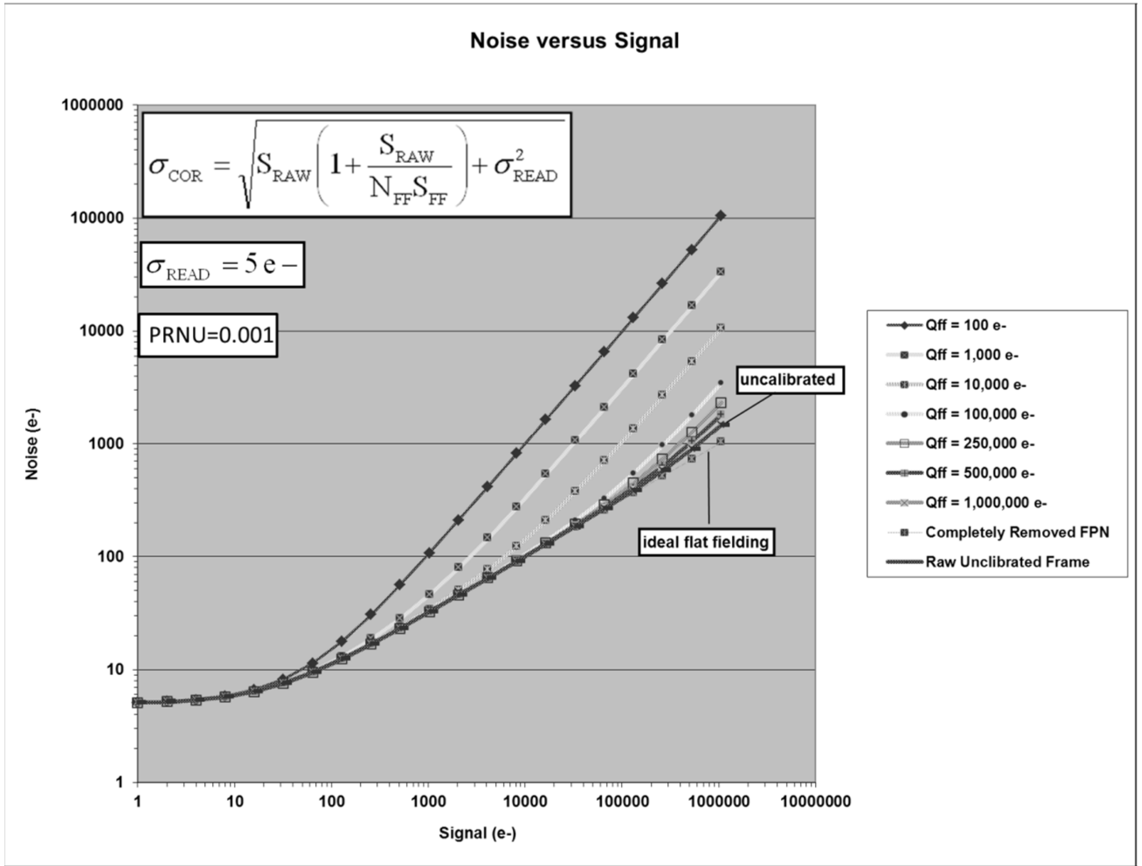
Noise versus Signal
$\sigma_{COR} = \sqrt{S_{RAW}\left(1+\frac{S_{RAW}}{N_{FF}S_{FF}}\right)+\sigma_{READ}^2}$
$\sigma_{READ} = 5\,e-$
PRNU=0.01
uncalibrated
ideal flat fielding
Qff = 100 e-
Qff = 1,000 e-
Qff = 10,000 e-
Qff = 100,000 e-
Qff = 250,000 e-
Qff = 500,000 e-
Qff = 1,000,000 e-
Completely Removed FPN
Raw Unclibrated Frame
Noise (e-)
Signal (e-)
1
10
100
1000
10000
100000
1000000
10000000

PRNU = 0.005



Noise versus Signal
$\sigma_{COR} = \sqrt{S_{RAW}\left(1+\frac{S_{RAW}}{N_{FF}S_{FF}}\right)+\sigma^2_{READ}}$
$\sigma_{READ} = 5\,e-$
PRNU=0.005
uncalibrated
ideal flat fielding
Qff = 100 e-
Qff = 1,000 e-
Qff = 10,000 e-
Qff = 100,000 e-
Qff = 250,000 e-
Qff = 500,000 e-
Qff = 1,000,000 e-
Completely Removed FPN
Raw Unclibrated Frame
Noise (e-)
Signal (e-)
1
10
100
1000
10000
100000
1000000
10000000

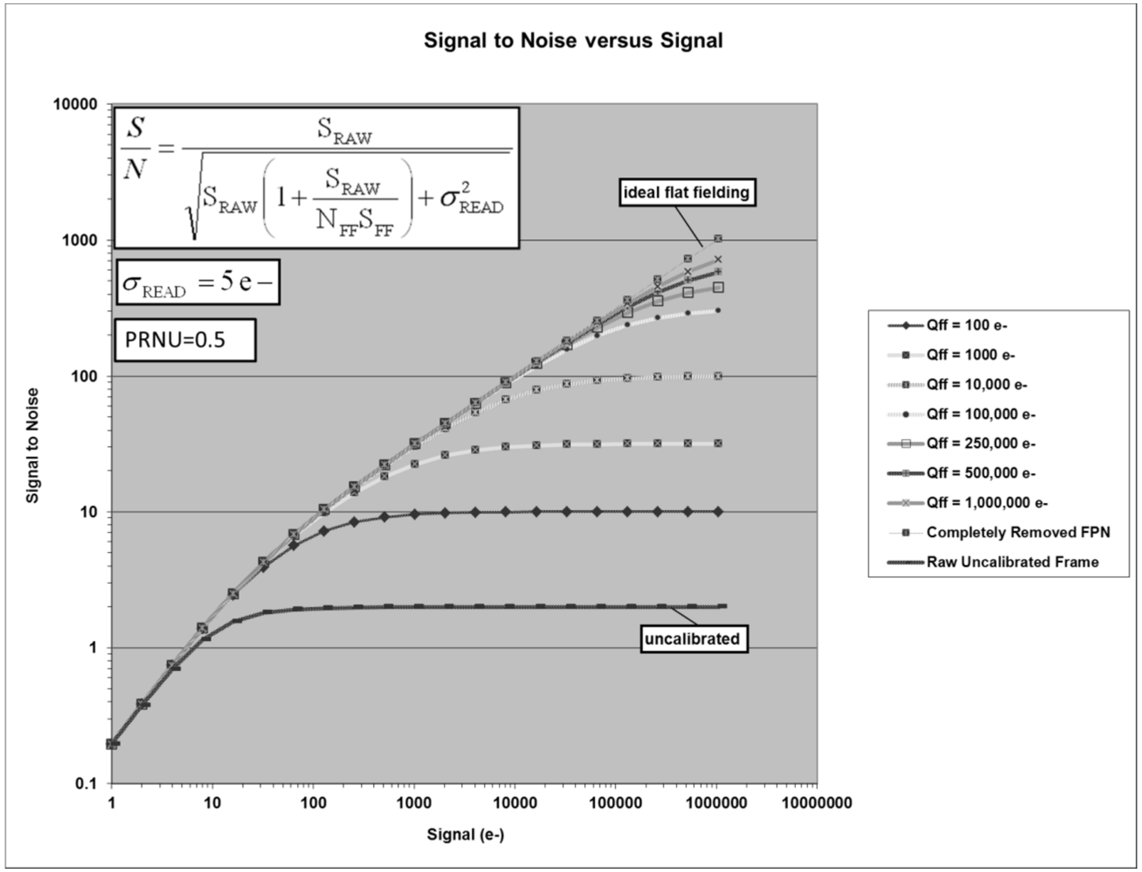
PRNU = 0.001



Noise versus Signal
$\sigma_{COR} = \sqrt{S_{RAW}\left(1+\frac{S_{RAW}}{N_{FF}S_{FF}}\right)+\sigma_{READ}^2}$
$\sigma_{READ} = 5\,e-$
PRNU=0.001
uncalibrated
ideal flat fielding
Noise (e-)
Signal (e-)
1000000
100000
10000
1000
100
10
1
1
10
100
1000
10000
100000
1000000
10000000
Qff = 100 e-
Qff = 1,000 e-
Qff = 10,000 e-
Qff = 100,000 e-
Qff = 250,000 e-
Qff = 500,000 e-
Qff = 1,000,000 e-
Completely Removed FPN
Raw Unclibrated Frame

SNR vs Signal

PRNU = 0.5



Signal to Noise versus Signal
$\frac{S}{N} = \frac{S_{RAW}}{\sqrt{S_{RAW}\left(1+\frac{S_{RAW}}{N_{FF}S_{FF}}\right)+\sigma_{READ}^2}}$
$\sigma_{READ} = 5\,e-$
PRNU=0.5
ideal flat fielding
uncalibrated
Signal to Noise
Signal (e-)
10000
1000
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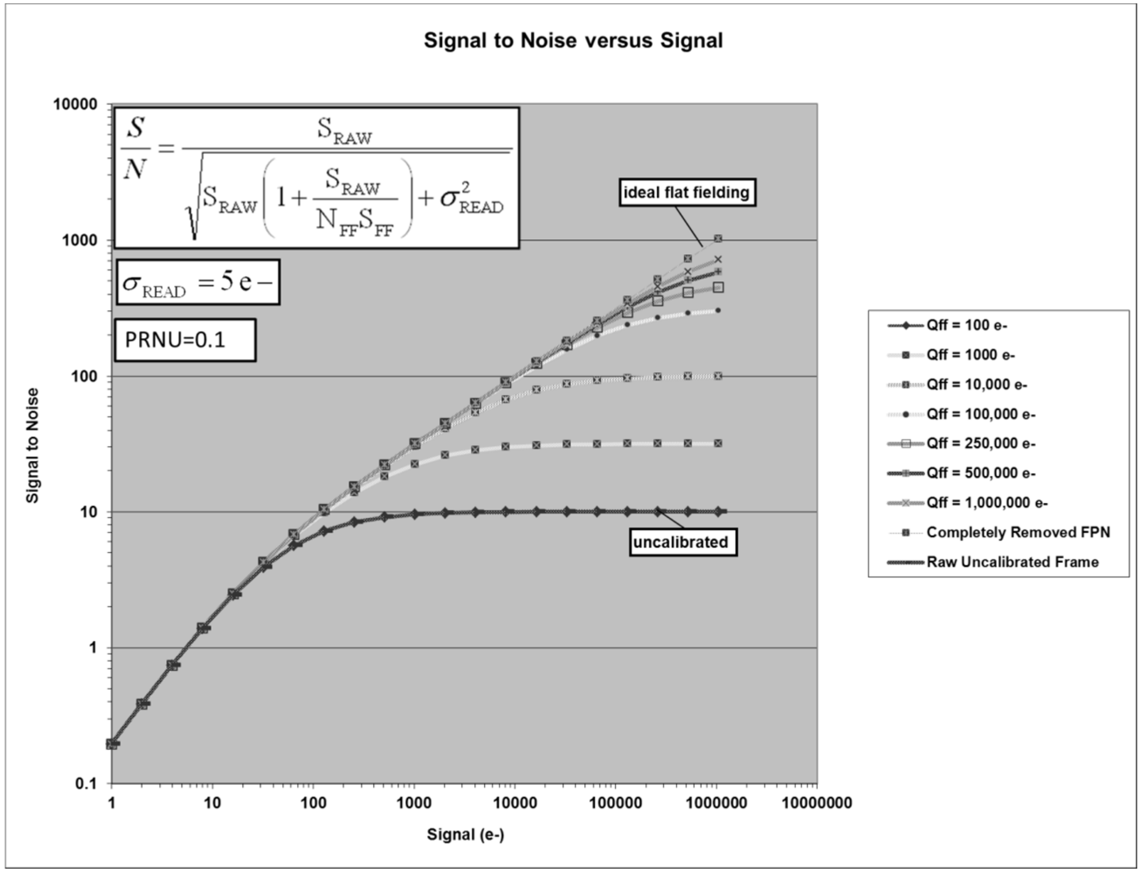
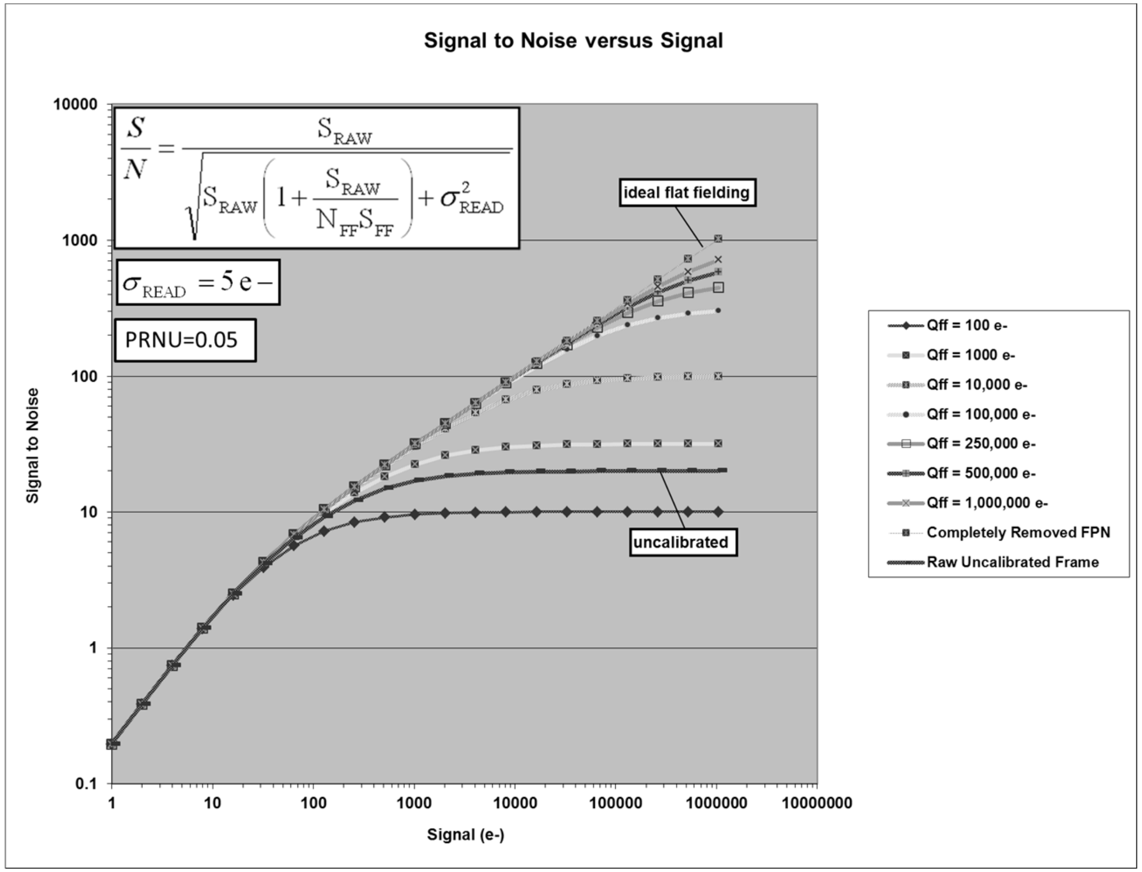
10000000
Qff = 100 e-
Qff = 1000 e-
Qff = 10,000 e-
Qff = 100,000 e-
Qff = 250,000 e-
Qff = 500,000 e-
Qff = 1,000,000 e-
Completely Removed FPN
Raw Uncalibrated Frame

PRNU = 0.1



Signal to Noise versus Signal
$$\frac{S}{N}=\frac{S_{RAW}}{\sqrt{S_{RAW}\left(1+\frac{S_{RAW}}{N_{FF}S_{FF}}\right)+\sigma_{READ}^2}}$$
$\sigma_{READ} = 5\,e-$
PRNU=0.1
ideal flat fielding
uncalibrated
Signal to Noise
Signal (e-)
10000
1000
100
10
1
0.1
1
10
100
1000
10000
100000
1000000
10000000
Qff = 100 e-
Qff = 1000 e-
Qff = 10,000 e-
Qff = 100,000 e-
Qff = 250,000 e-
Qff = 500,000 e-
Qff = 1,000,000 e-
Completely Removed FPN
Raw Uncalibrated Frame

PRNU = 0.05



Signal to Noise versus Signal
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$\sigma_{READ} = 5\,e-$
PRNU=0.05
ideal flat fielding
uncalibrated
Signal to Noise
Signal (e-)
10000
1000
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10
1
0.1
1
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100
1000
10000
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1000000
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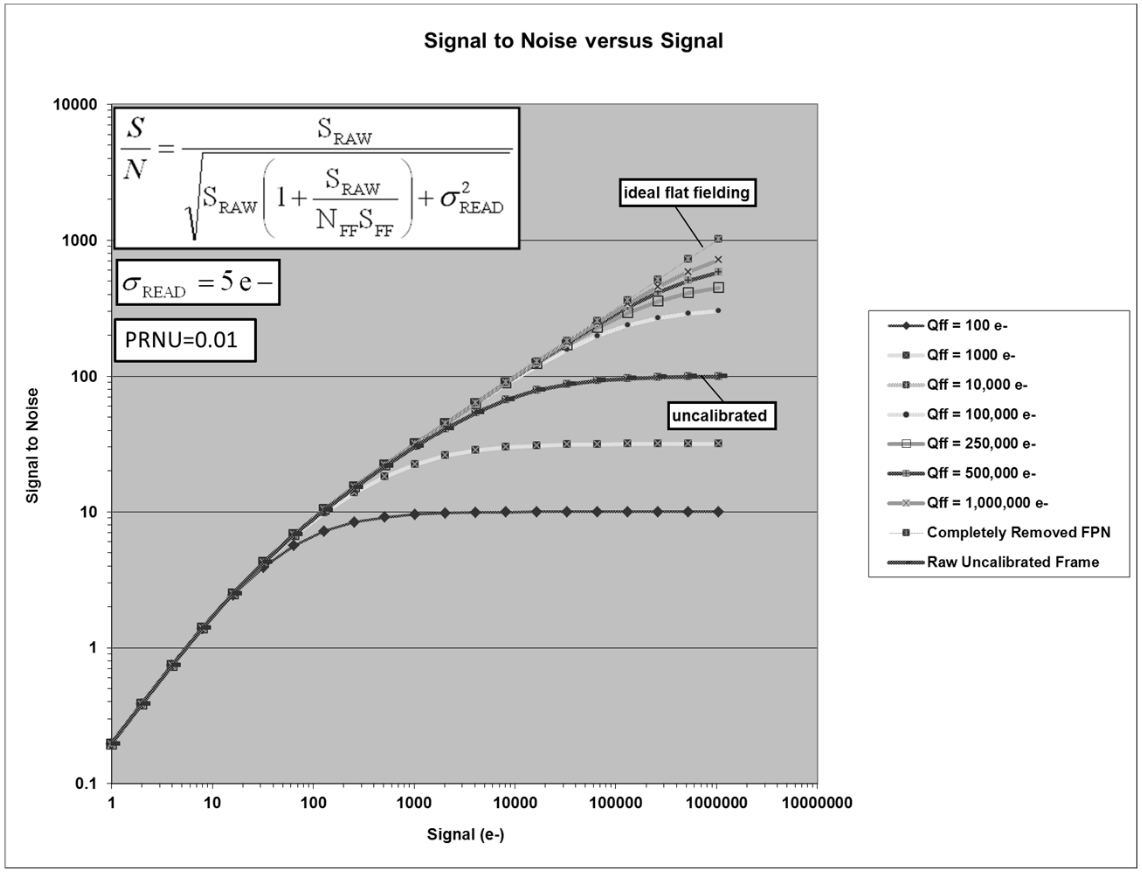
Qff = 100 e-
Qff = 1000 e-
Qff = 10,000 e-
Qff = 100,000 e-
Qff = 250,000 e-
Qff = 500,000 e-
Qff = 1,000,000 e-
Completely Removed FPN
Raw Uncalibrated Frame

PRNU = 0.01



Signal to Noise versus Signal
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$\sigma_{READ} = 5\,e-$
PRNU=0.01
ideal flat fielding
uncalibrated
Signal to Noise
Signal (e-)
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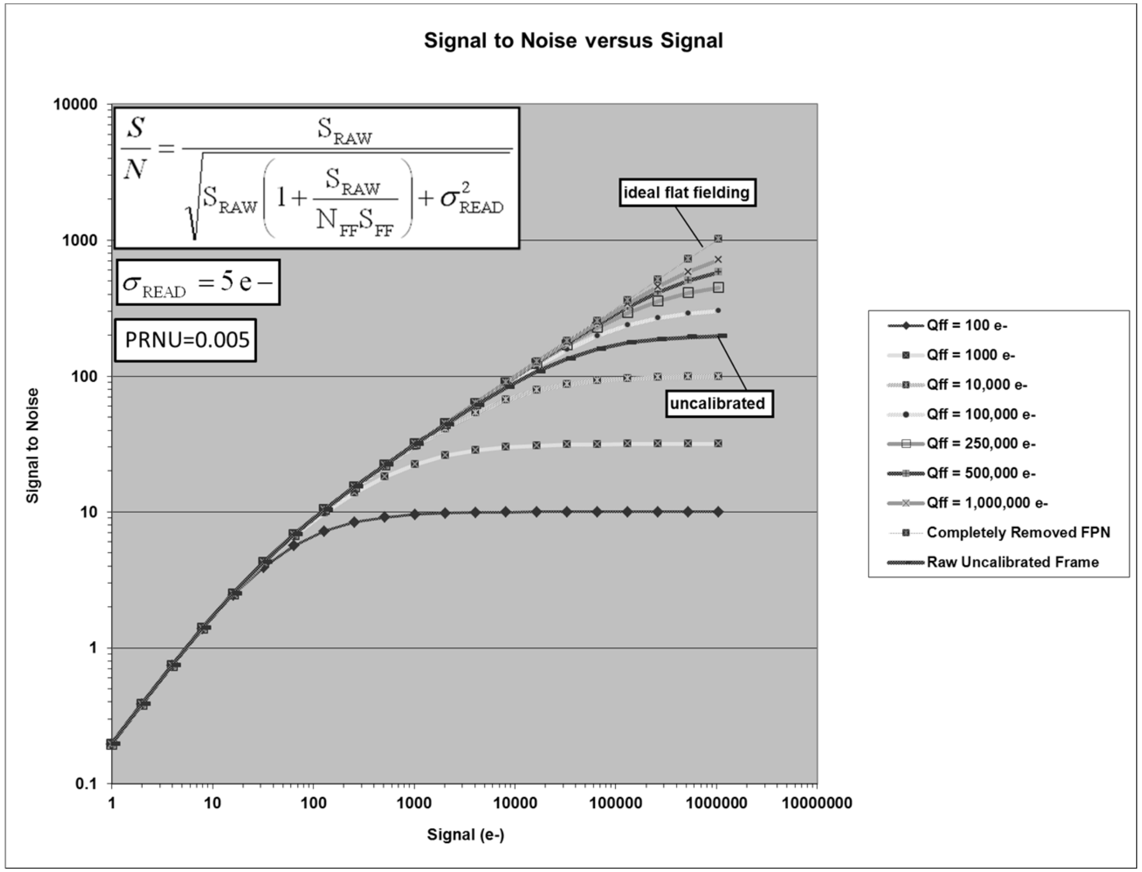
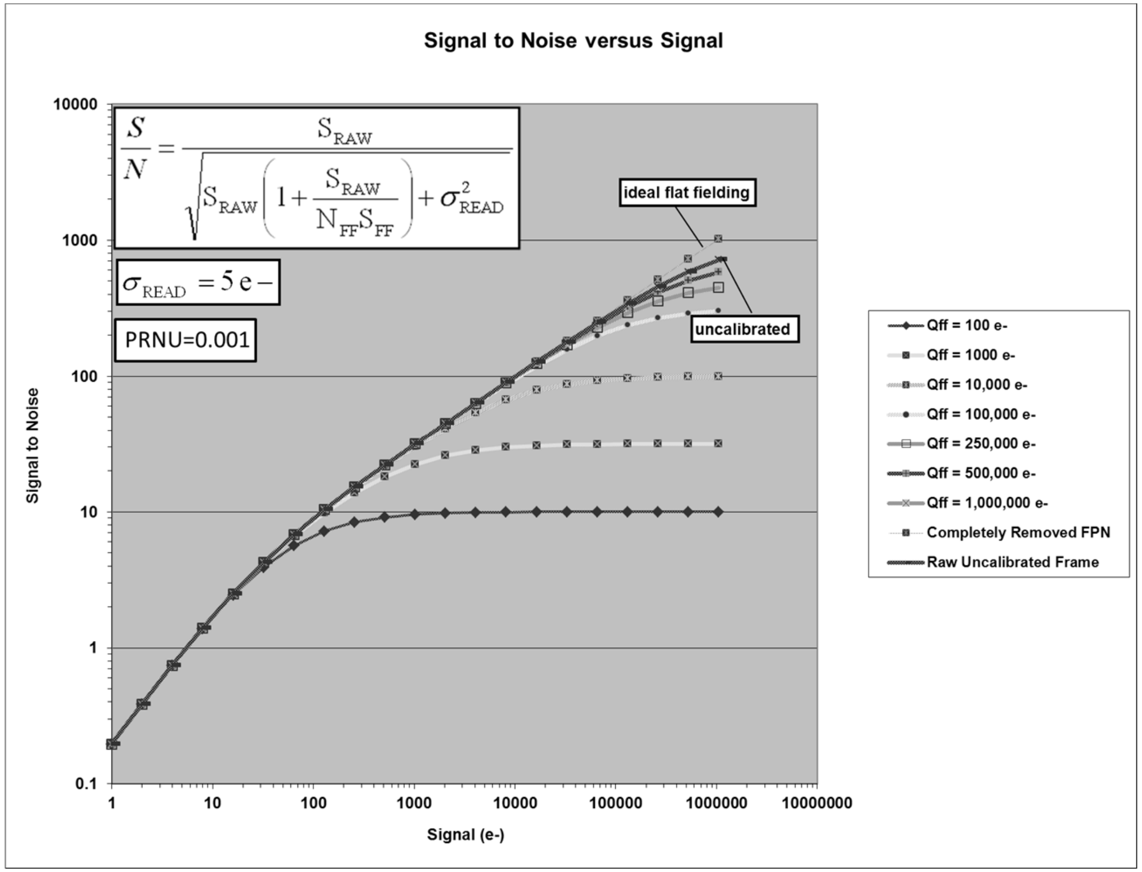
Qff = 1000 e-
Qff = 10,000 e-
Qff = 100,000 e-
Qff = 250,000 e-
Qff = 500,000 e-
Qff = 1,000,000 e-
Completely Removed FPN
Raw Uncalibrated Frame

PRNU = 0.005



Signal to Noise versus Signal
$$\frac{S}{N}=\frac{S_{RAW}}{\sqrt{S_{RAW}\left(1+\frac{S_{RAW}}{N_{FF}S_{FF}}\right)+\sigma_{READ}^2}}$$
$\sigma_{READ}=5\,e-$
PRNU=0.005
ideal flat fielding
uncalibrated
Signal to Noise
Signal (e-)
Qff = 100 e-
Qff = 1000 e-
Qff = 10,000 e-
Qff = 100,000 e-
Qff = 250,000 e-
Qff = 500,000 e-
Qff = 1,000,000 e-
Completely Removed FPN
Raw Uncalibrated Frame

PRNU = 0.001



Signal to Noise versus Signal
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$\sigma_{READ} = 5\,e-$
PRNU=0.001
ideal flat fielding
uncalibrated
Signal to Noise
Signal (e-)
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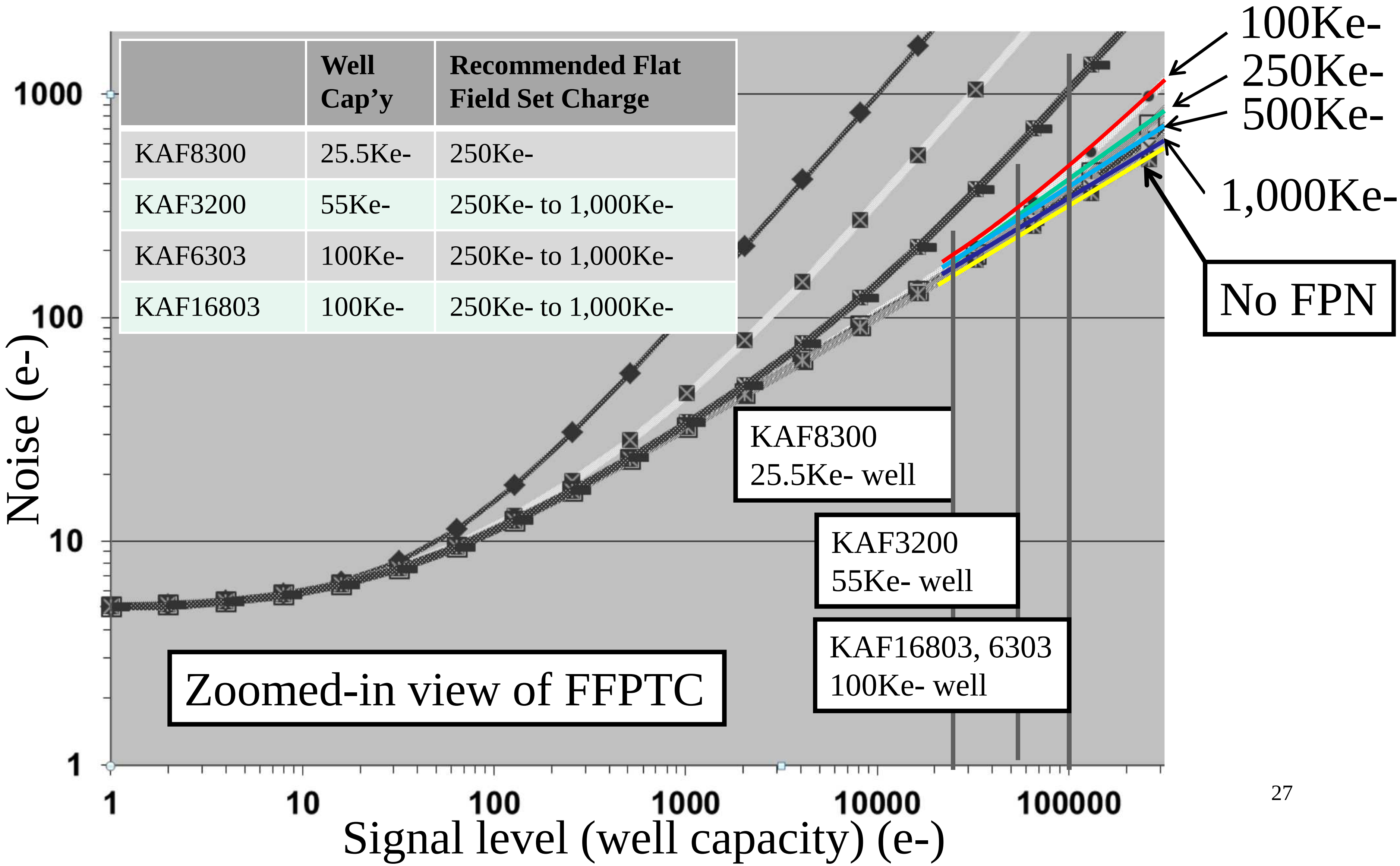
Qff = 1000 e-
Qff = 10,000 e-
Qff = 100,000 e-
Qff = 250,000 e-
Qff = 500,000 e-
Qff = 1,000,000 e-
Completely Removed FPN
Raw Uncalibrated Frame

The relationship between well capacity and optimum electron-count in flat-field set

- For good flat-fielding, the signal level in the flats needs to be higher if the signal level in the raw image is higher
  - This is shown in each of the FFPTCs we have seen
  - As signal increases, more electrons are needed in the flat set to remove the FPN (images of the moon are nearly worst case!)
  - The limit to the signal is the well capacity

Finding recommended electron-count for flat-field set for selected sensors

	Well Cap'y	Recommended Flat Field Set Charge
KAF8300	25.5Ke-	250Ke-
KAF3200	55Ke-	250Ke- to 1,000Ke-
KAF6303	100Ke-	250Ke- to 1,000Ke-
KAF16803	100Ke-	250Ke- to 1,000Ke-



Shooting Flats

Why shoot sky flats in broad daylight?

- Light intensity doesn't change from frame to frame: easy to get high quality flats of near-constant signal level
- Can take your time and get all the filters done in a single sitting
  - Don't have to rush at twilight
  - Don't have to stay up after dawn when you are tired
- No need for questionable and expensive flat boxes, undesirable EL panels and so on:
  - Tools needed: Aluminum foil, white toweling, bungee cord, patience

Key Challenges to Address

- Light leaks
- Focusing
- Avoiding shutter shading and saturation

Fixing Light Leaks

- Light Leaks are not allowed!
- I put a clear filter in place and take a 5 second 4x4 binned exposure and carefully compare it to a dark (frame differencing via pixel math for example)
- If they look different it is time to find and fix the light leaks

Fixing Light Leaks

Use lots of aluminum foil

Wrap edges of filter wheel and focuser

Wrap filter pocket in camera lens

Cover aperture tightly to test

Fixing Light Leaks cont'd

The foil can look ugly

But the result is what counts

Focusing

- The telescope needs to be pretty close to focused at infinity
- But how can you do that in the daytime?
  - Use a far away power pole or building
  - Use a mountain top
  - Trees don’t work so well; the wind moves them around
- The first quarter moon is a good choice if it is up
- But the sky is so bright: how do you prevent saturation with clear or broadband filters, or even emission line filters?

Focusing: Saturation Prevention

Make a pinhole in the foil covering the aperture to “stop down” the lens or telescope

This will help avoid saturation.

Once focused remove aperture cover!

Focusing: Target

Once focused, remove the pinhole aperture cover!

If it is up, the first quarter moon is a great focusing target

Otherwise try for a building or a mountain’s rocky edge or a transmission tower, radio tower etc a few miles away

Avoiding Shutter Shading and Saturation

- An interline sensor can often be used with the mechanical shutter open (if you have a mechanical shutter) by using “video mode”
  - Not all camera makers support this mode (FLI does)
  - This relies on the electronic “snap shutter” so there is no mechanical shutter to shade the sensor
  - You can take very short exposures (0.01 to 0.1 seconds)
- If you have a mechanical shutter and a non-interline sensor, make sure the shutter is open for at least 3 seconds: longer for a big sensor
  - Avoids “shutter shading” artifacts in the flat (causes “dark middles” in the calibrated image due to the middle of the flat being too bright)
  - But the sky is really bright, so how do you avoid saturating the sensor with clear filter and a shutter open for 3-4 seconds?

Attenuating the Light

I use white towels folded over many times and bungee corded to the aperture end

No creases over the aperture allowed !

But we still aren’t ready: what about gradients?

Avoiding Gradients in the Flats

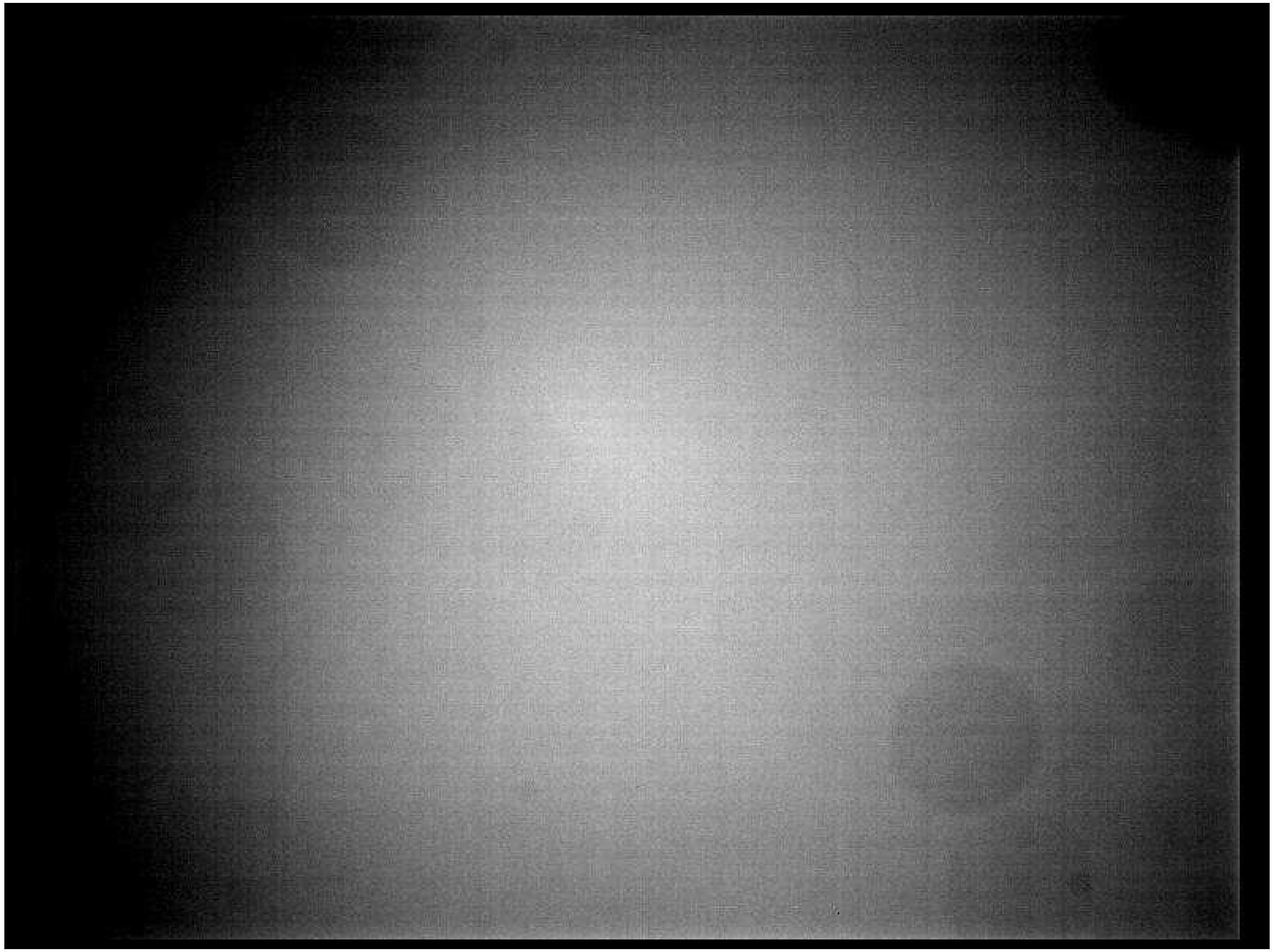
I use aluminum foil to create a sun shield around my towels to keep the sun from hitting the side of the towels and having a built-in gradient

Now the telescope is ready to shoot flats

How I read my laptop screen in the daytime

I put my telescope cover over my laptop and stick my head inside to let me see the display

Results

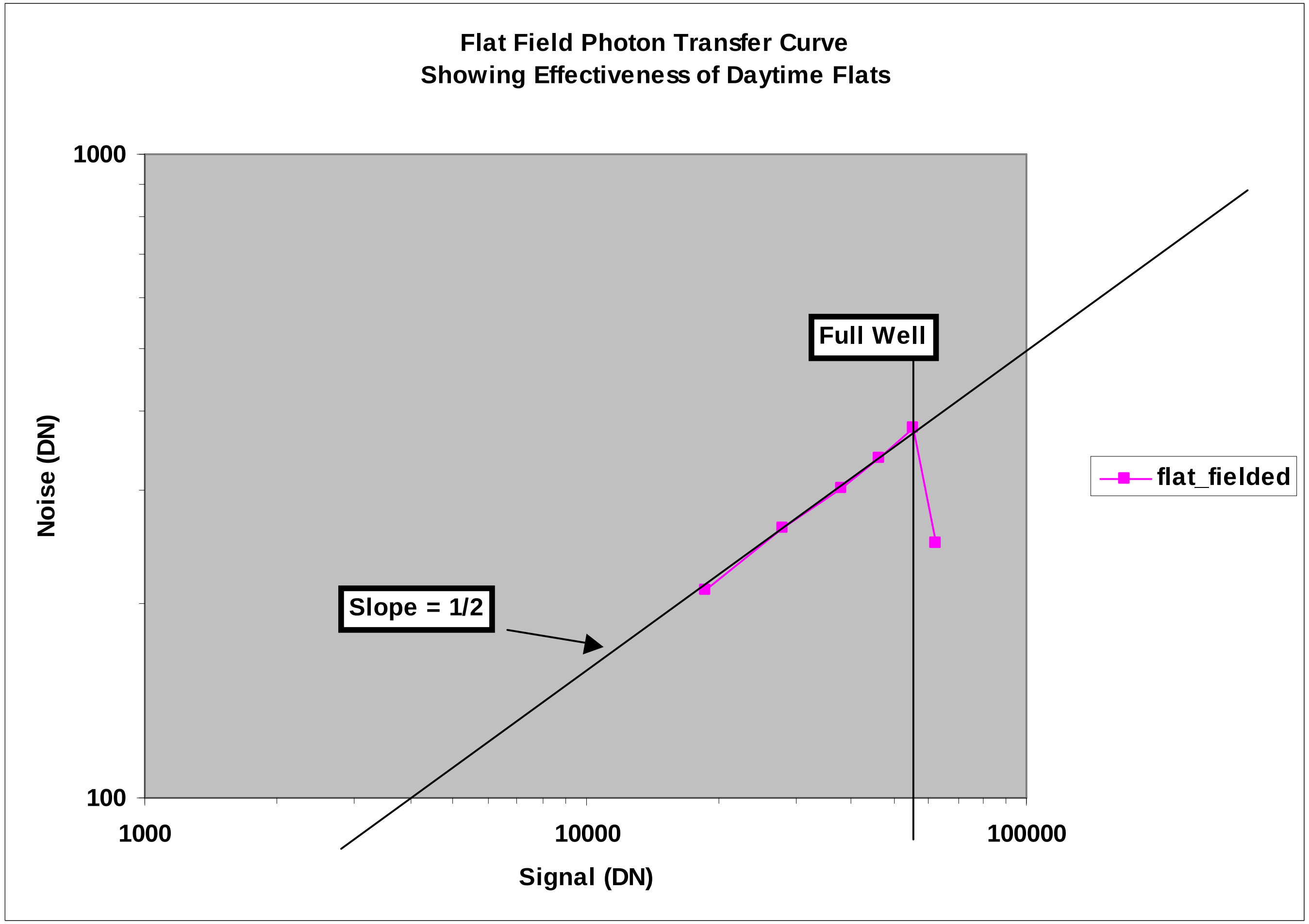


The crosshatch pattern is classic fixed pattern noise from the sensor

The circular shapes are dust motes

The dark column to the right is overscan

Flat Field Photon Transfer Curve Showing the Flats Work Correctly



Backgrounder on Photon Transfer analysis:
http://www.narrowbandimaging.com/incoming/flats_part1_part2_part3_expanded.pdf

Image calibrated with the flats

First light Pentax 6x7 400mm f/4 ED(IF) with FLI ML8300
7 hours RGB+Ha

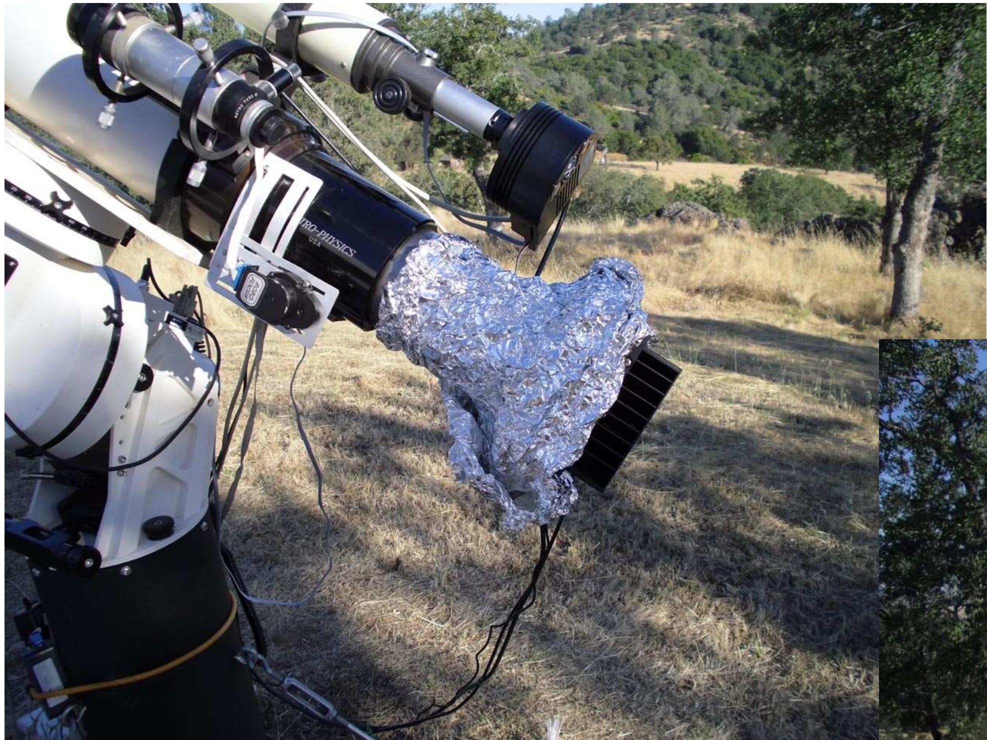
(old style (2009) camera window)

Image calibrated with the flats

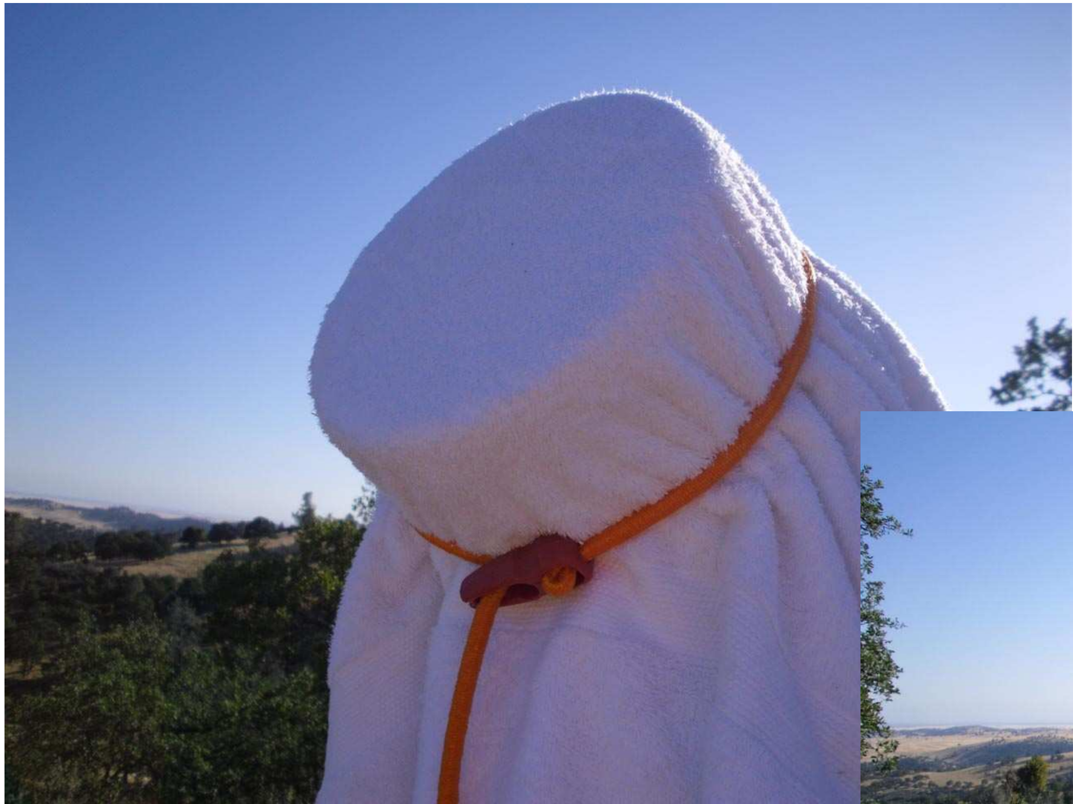
Pentax 6x7
400mm f/4 ED(IF)
with FLI ML8300
2.5 hours Ha +
[OIII]

Red = Ha
Green = [OIII]
Blue = [OIII] +
Hbeta ≅ [OIII] +
0.3 Ha

AP155EDF

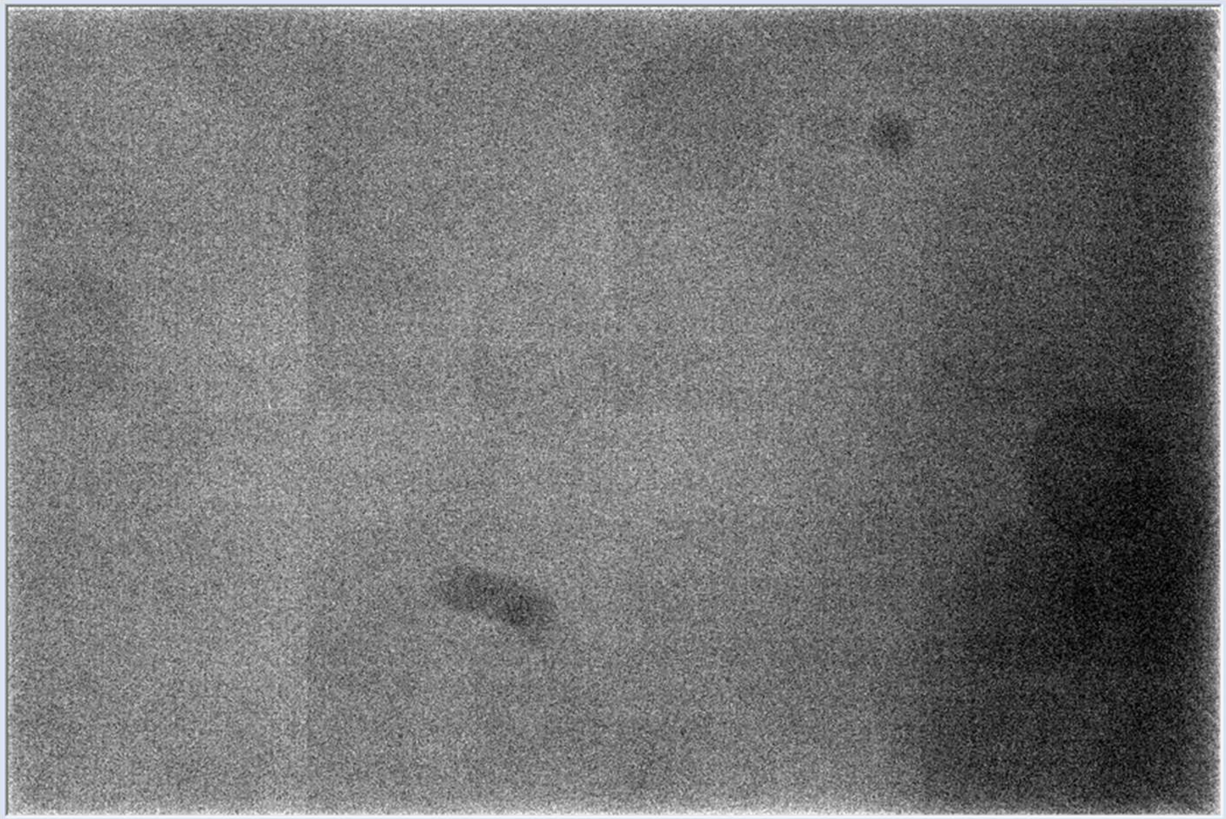


AP155EDF



AP155

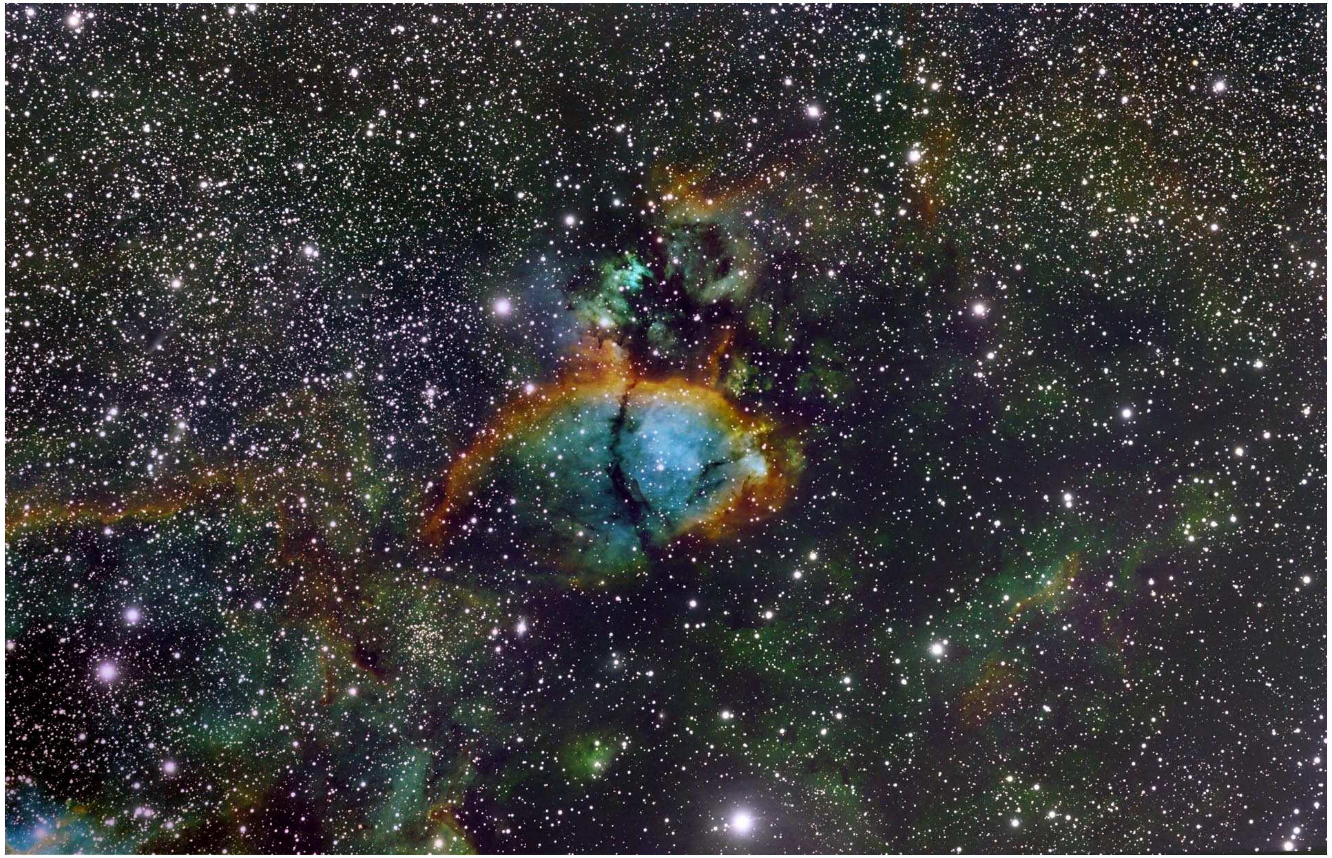
Results AP155/ML29050 Luminance



The blocky shapes is classic fixed pattern noise from the sensor manufacturing (photomask making artifacts)

The circular shapes are dust motes

Image calibrated with the flats



AP155EDF f/7
with 4” flattener
FLI ML29050
Lum + S2/Ha/O3
37.5 hours total

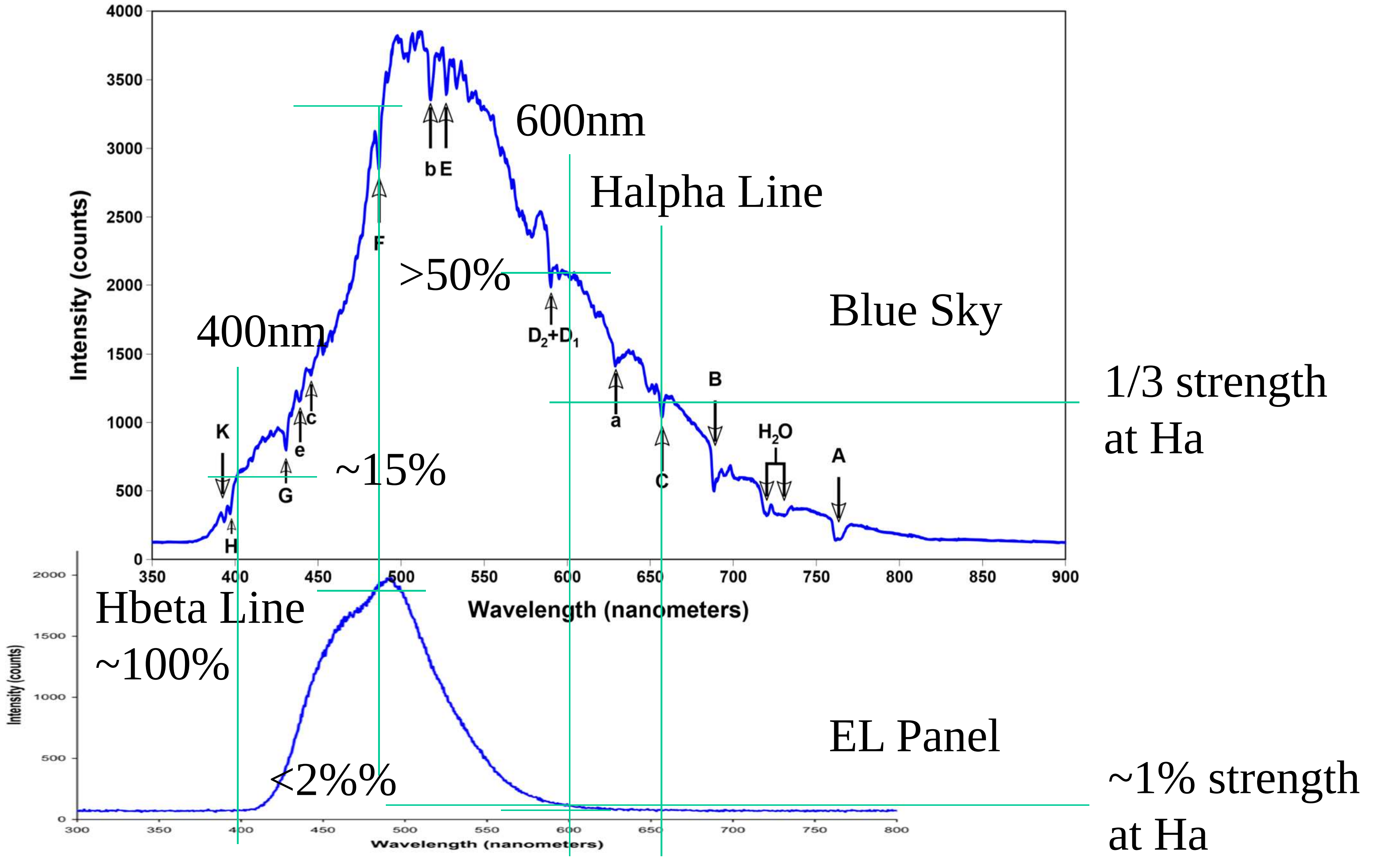
Why are EL Panels Not Recommended?

- Key issues:
  - Uniformity
  - Spectral purity

Uniformity

- An EL Panel typically has nonuniformity of 1-5% across the surface
- It may look uniform to the eye but it may not be if measured using a photometer
- Flat boxes may have even worse uniformity

Spectrum: Blue sky vs EL Panel

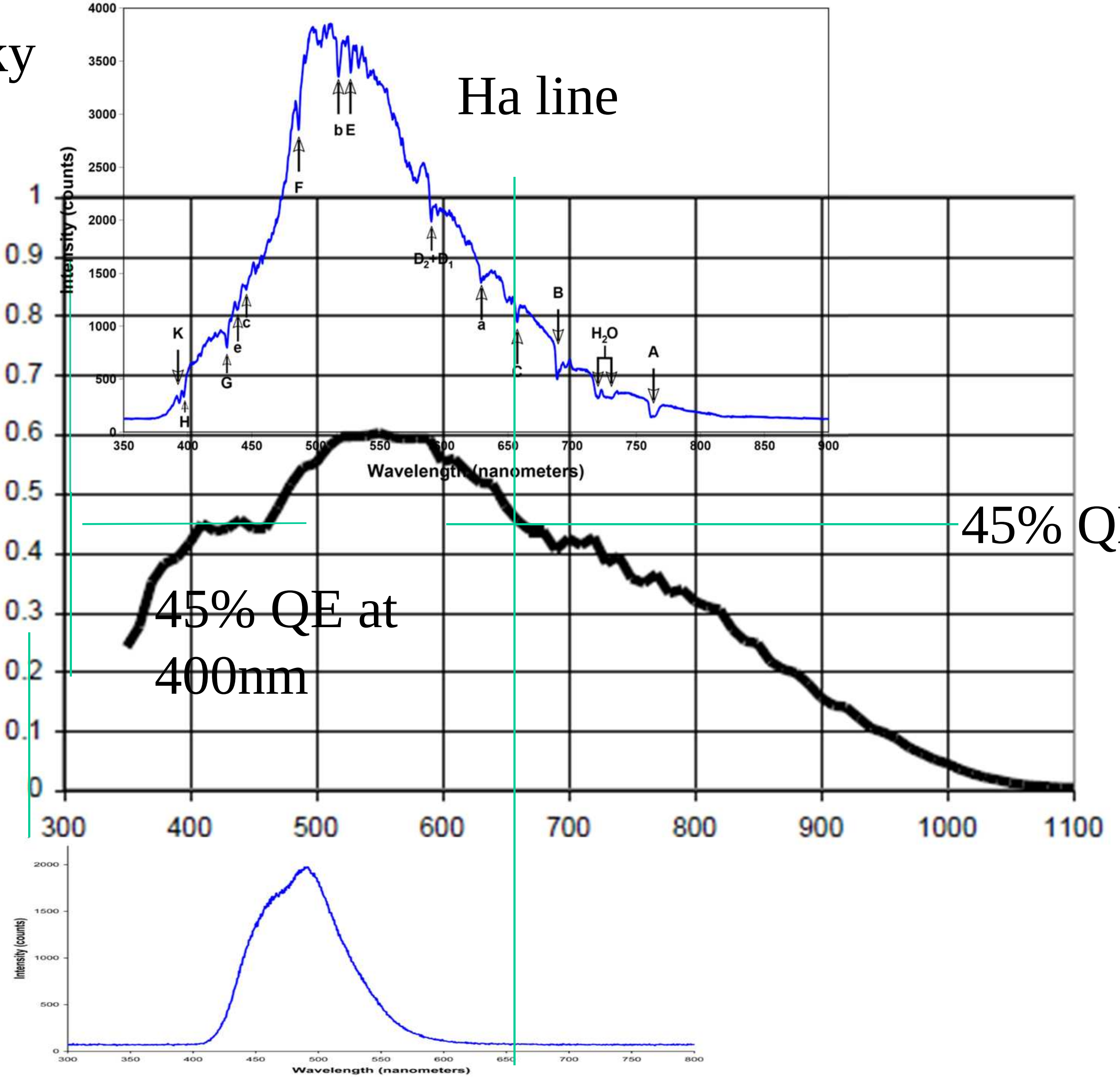


QE + spectral response

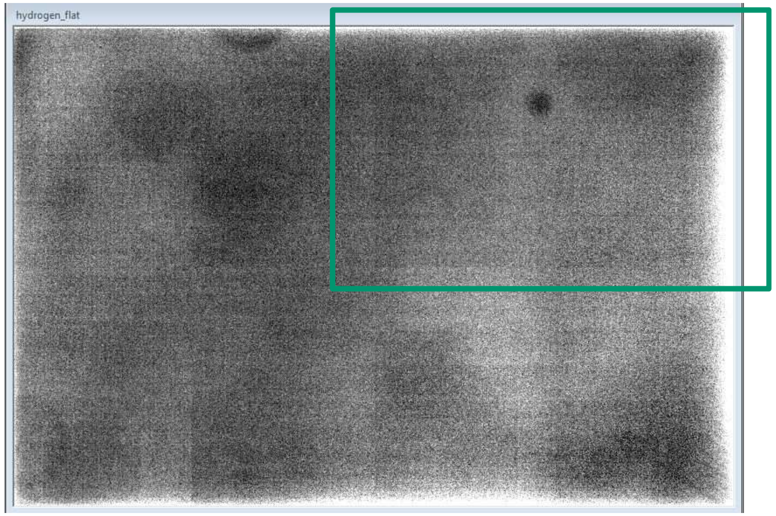
Blue Sky

KAF16803

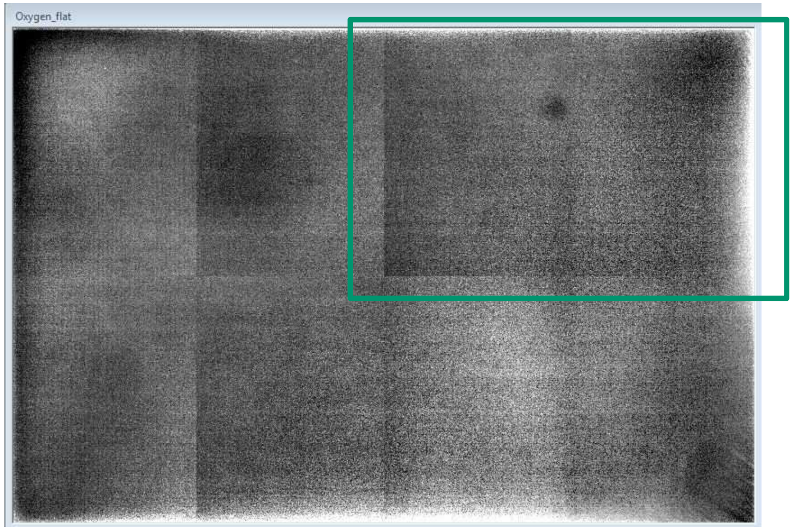
EL Panel



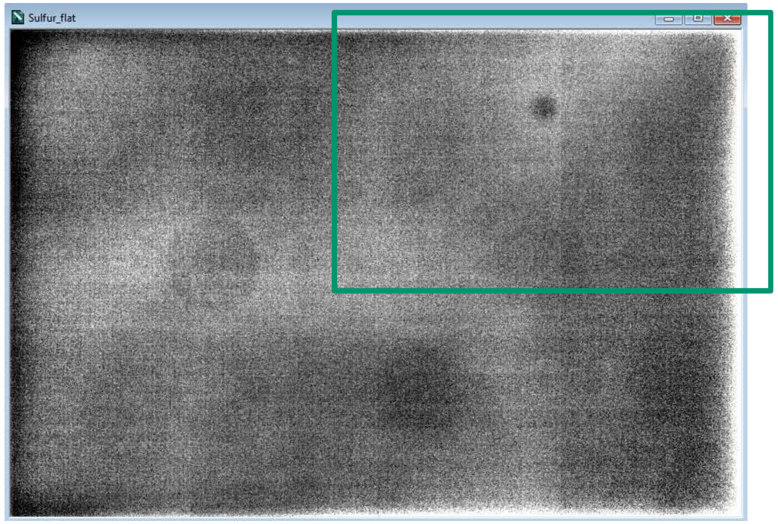
Eline Sky flats (AP155/ML29050)



Ha



[OIII]



[SII]

Note difference in definition of blocky shapes in oxygen vs other wavelengths

If we used a broadband filter with a non-physical (EL) spectrum we could have problems with the flats!

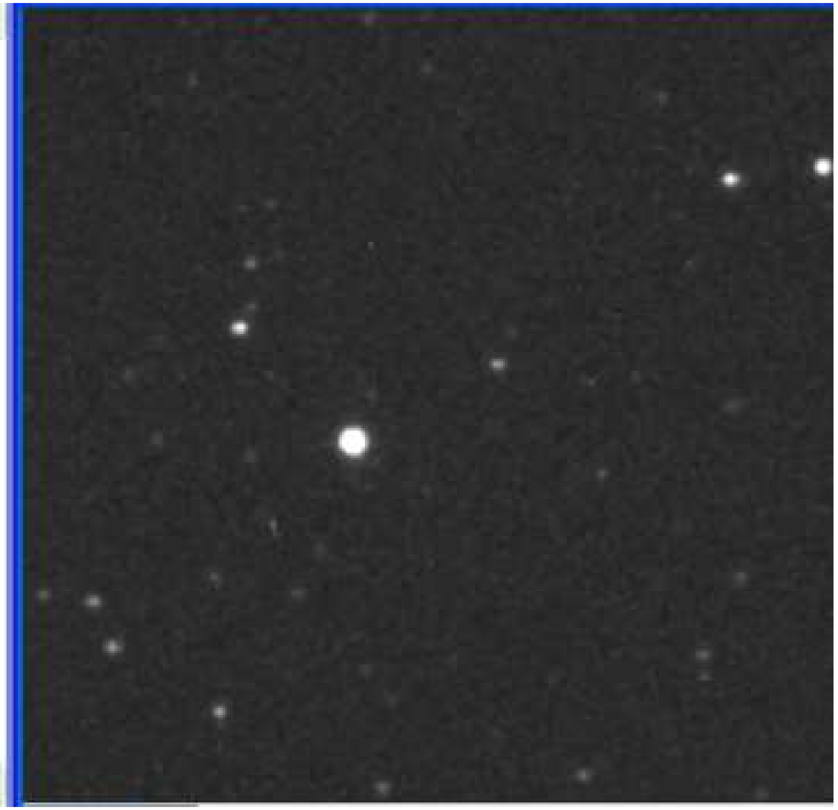
RBI and Dark FPN

RBI example in scientific image (Halpha)

Image with RBI
(is that a nebula beside the bright star?)

RBI example in scientific image (@ 656 nm)

Image with RBI
(dithered images with
RBI from focusing)



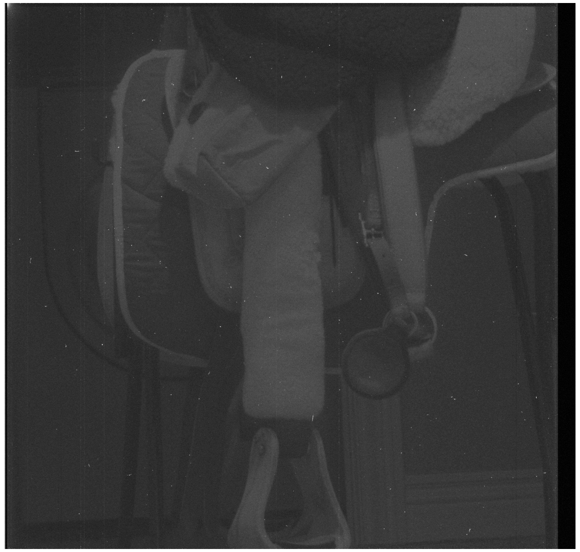
Actual starfield
(the “nebula” was RBI)

Meanwhile that twilight moon image just trashed your images

- Long exposures: RBI issue
  - Use “light-flood” and deep cooling to remedy: same as Cassini/Galileo

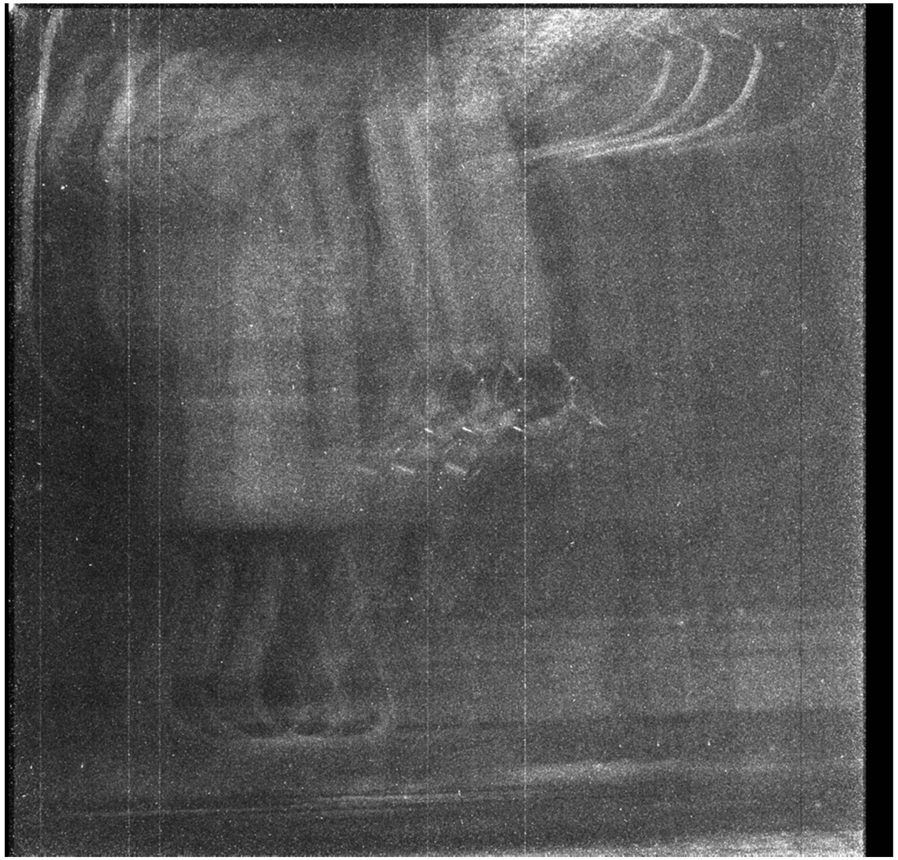
Image

5 Minute Dark Immediately following image



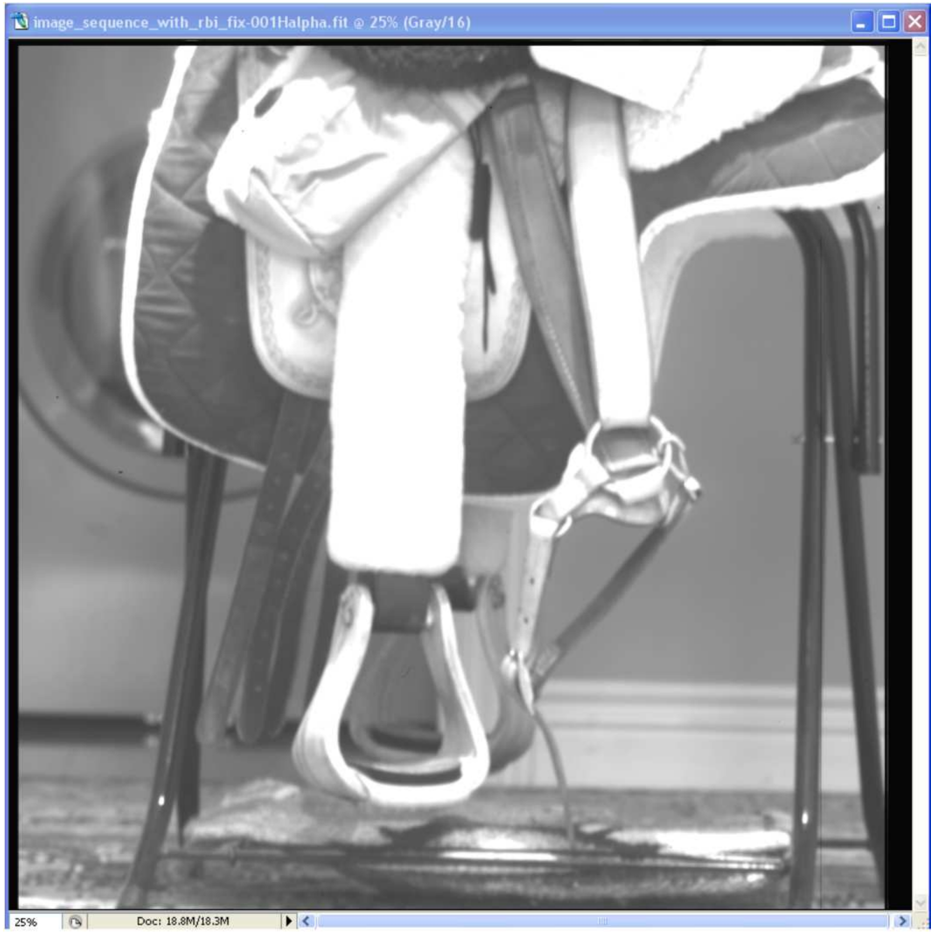
5 Minute Dark One hour following image

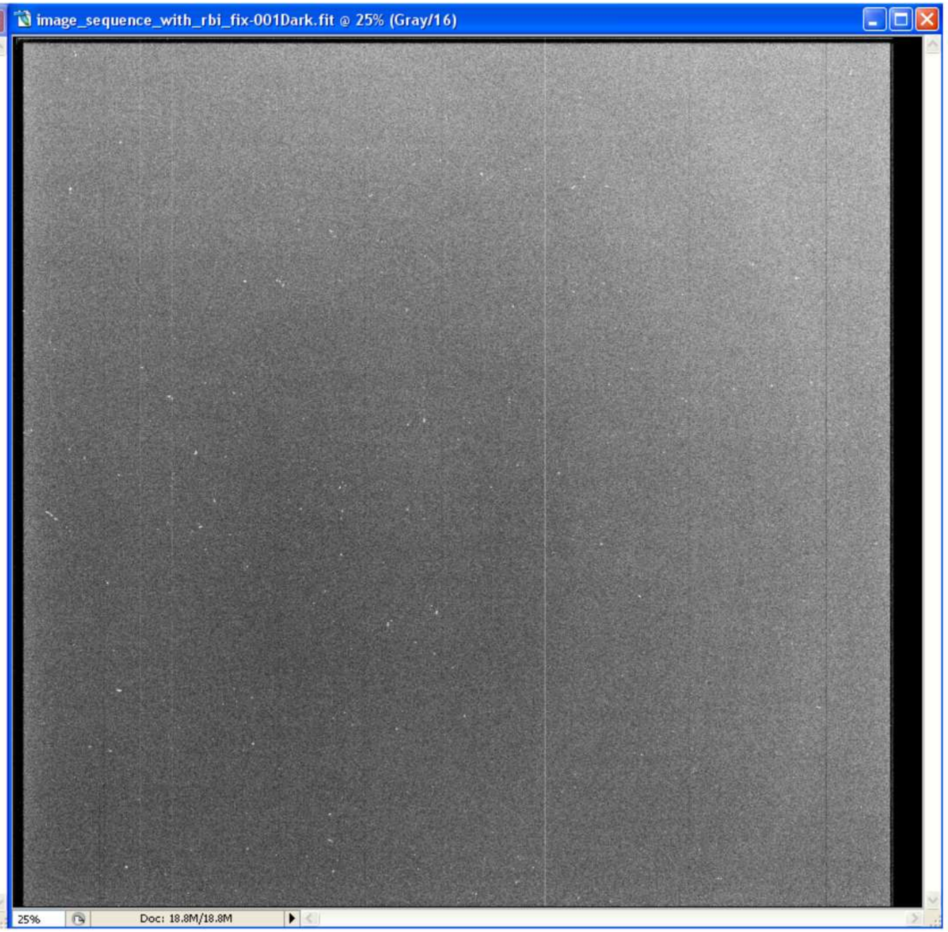
Another RBI example at 656 nm



Five minute dark exposure
following
four dithered light exposures

Management of RBI: Flood-Flush-Integrate protocol

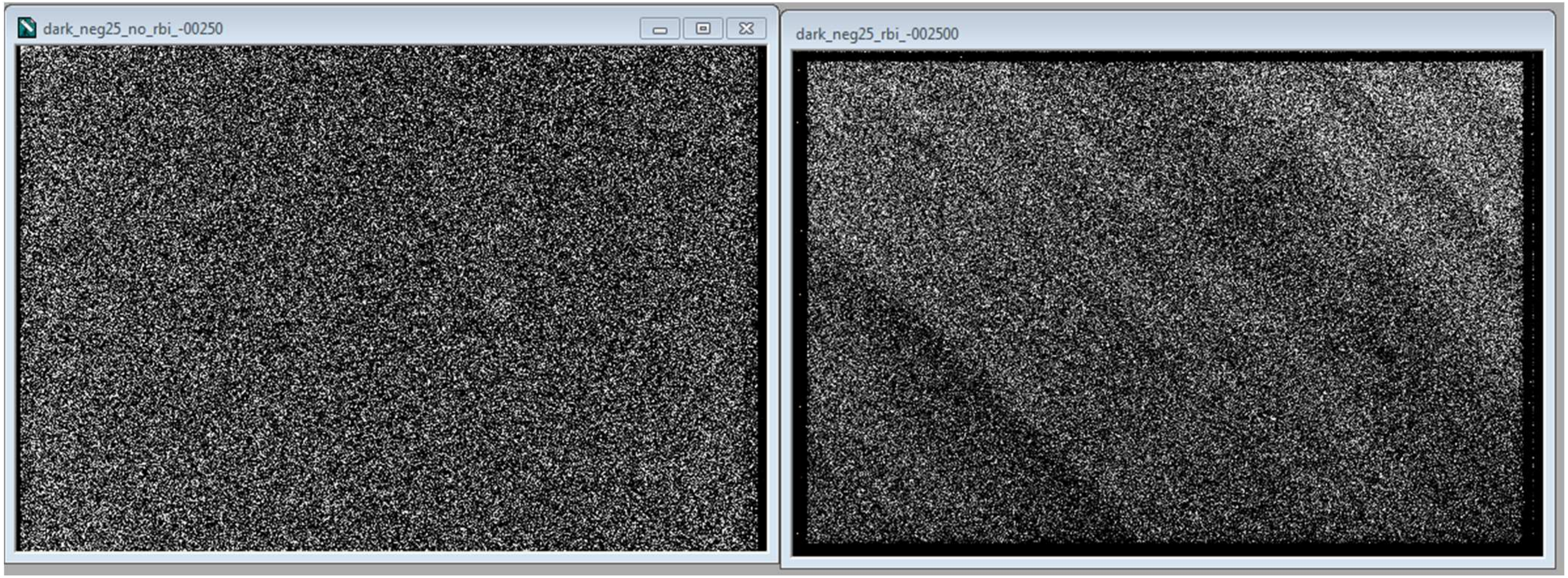




Image

Subsequent dark

DARK FPN: without and with light flood

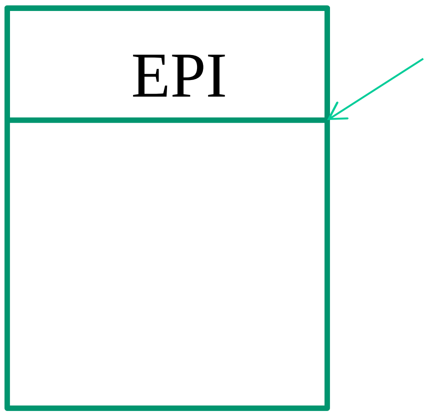


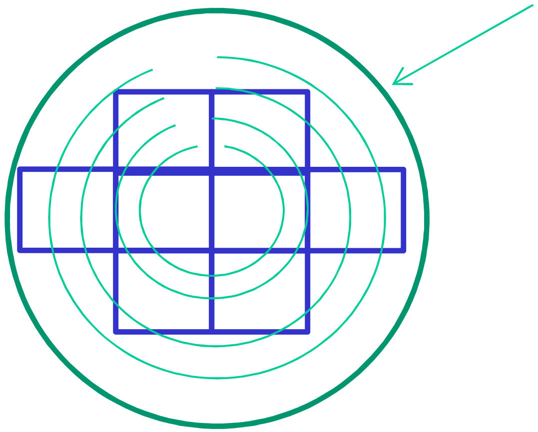
No Light Flood
(900 second dark)

With Light Flood
(900 second dark)

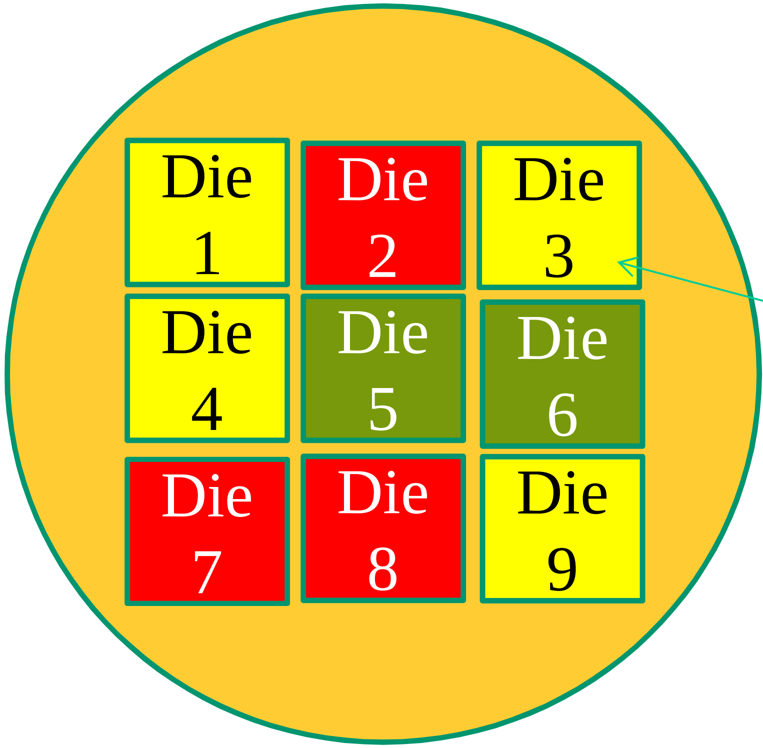
RBI Mechanisms

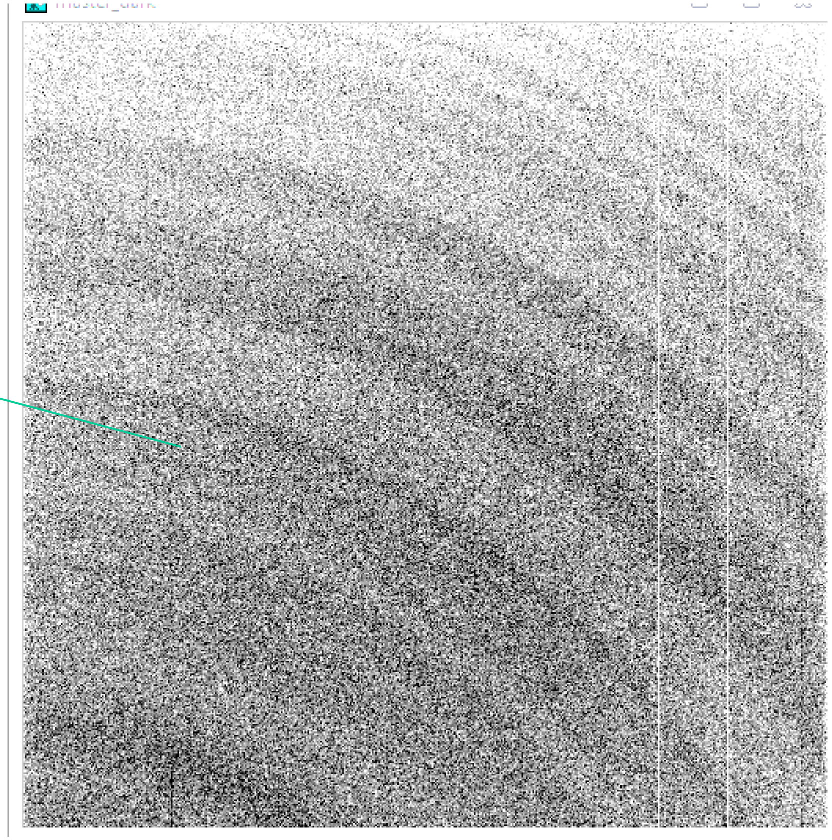
- Epi interface trapping sites
  - Spectral dependence
- Stress-induced trapping sites in lattice from crystal growth process
  - Swirling shapes in darks
- Random bulk defects in crystal lattice
  - No spectral dependence or swirling shapes





Wafer Mapping example





DARK FPN: Before and after Calibration

Not Calibrated
(900 second exposure)

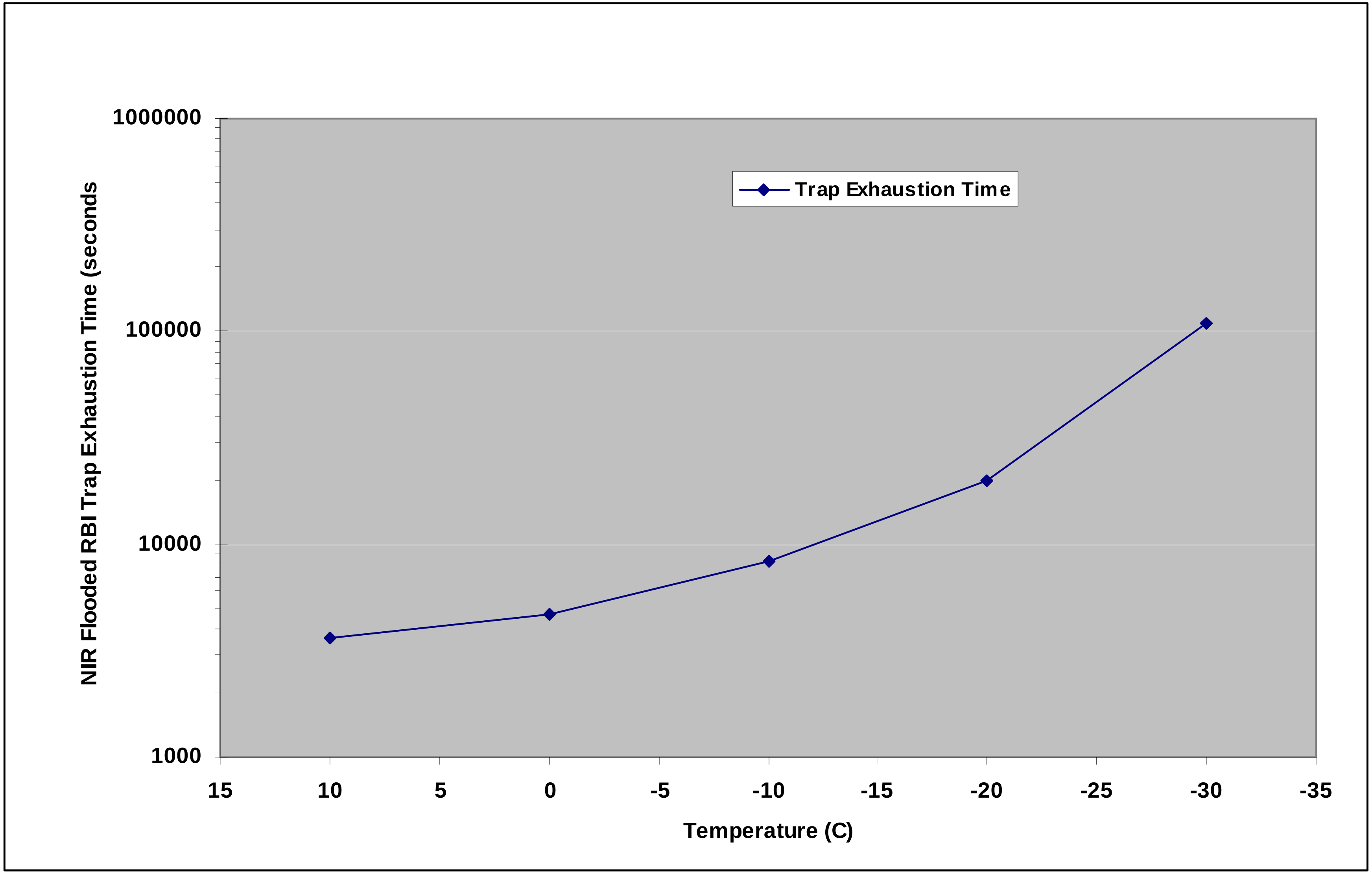
Calibrated
(900 second exposure)

RBI Hazard

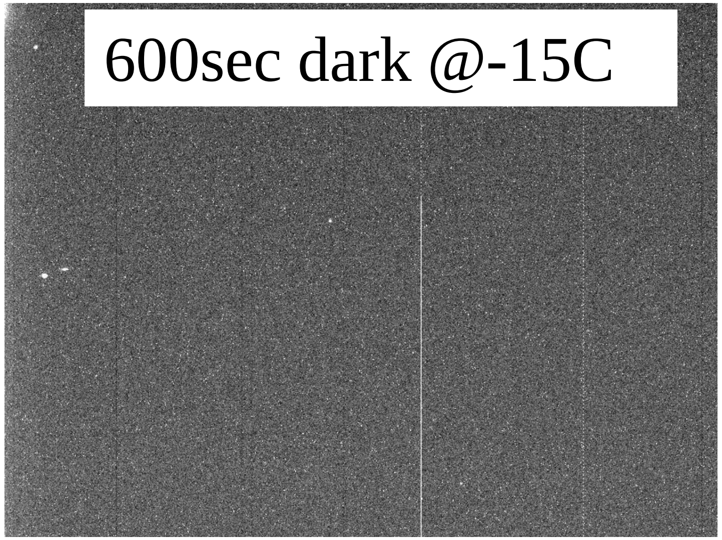
- Incompletely filled traps
  - Cannot calibrate: you get some of the DFPN but not a known quantity… How can you calibrate that?
- Can happen with evening flat shots
  - Traps get loaded up during flat-taking
  - Traps not fully filled and not fully empty: subsequent images are not calibrateable because state is unknown!

Time for full Trap Exhaustion

(Once you load the traps, they take a long time to fully decay)

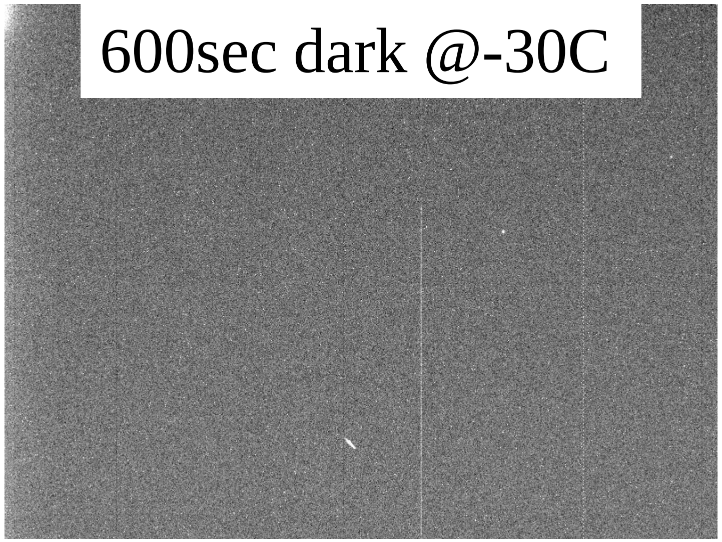


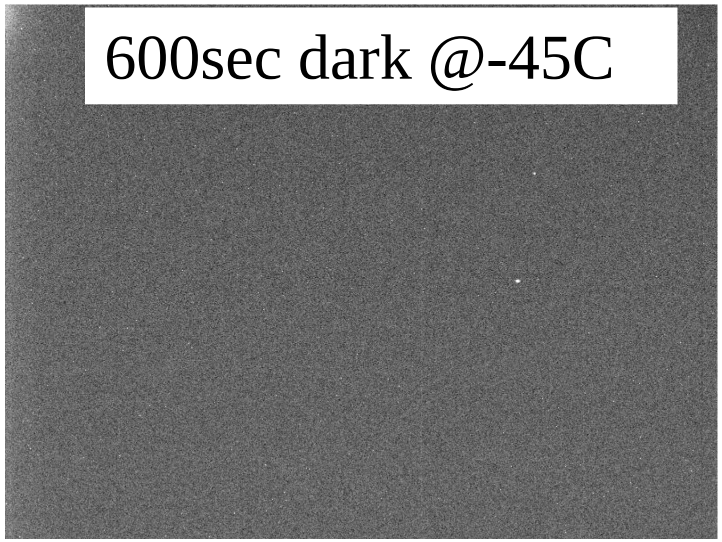
Sensor Issues: Managing Cosmetic Defects via Cooling



A major benefit of deep cooling is management of cosmetic defects

It is NOT solely about dark shot noise minimization!



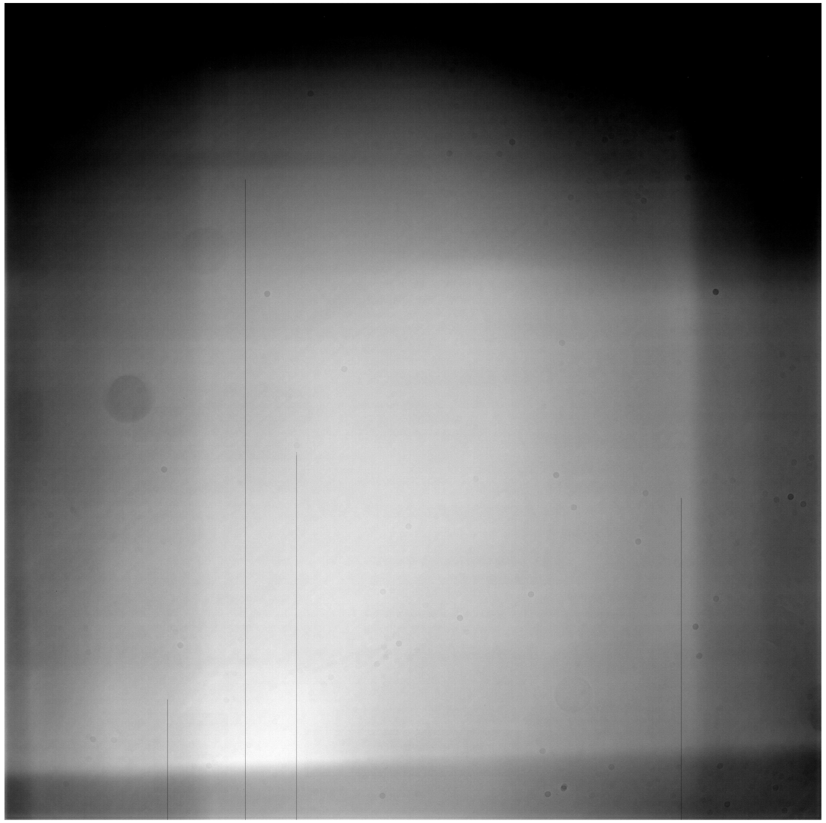


Diagnosing Flat Field Anomalies

Key Points

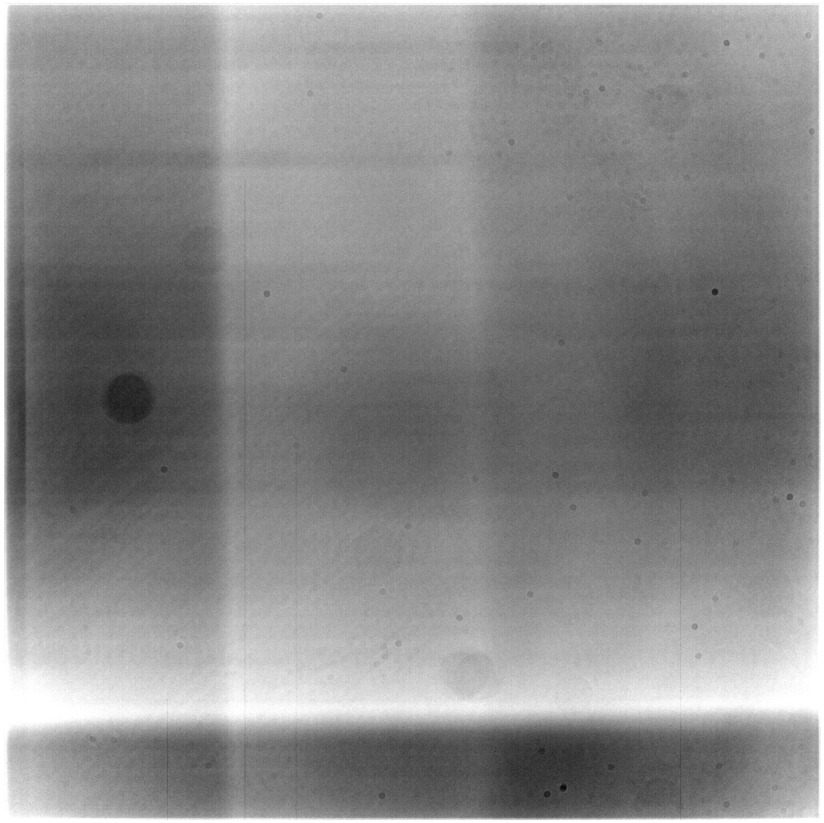
- Flats taken using CCDs and square filters with unpainted edges exhibit anomalies
  - Straight line ‘blocky-shadows’ and straight lines demarcating lighter versus darker regions appear in some flats
- Filter Edge Artifacts were eliminated by blackening edges of filters using a Testor’s brand Flat Black Enamel Pen
- Other artifacts are due to CCD Photoresponse non-uniformity and Mitigated Residual Bulk Image (RBI) Trap Leakage
- Proper calibration eliminates all artifacts except for filter edge artifacts, which are eliminated by edge painting

Examples
(non-edge blackened square filters)



Ha Flat

KAF16803



[SII] Flat

Edge Blackening

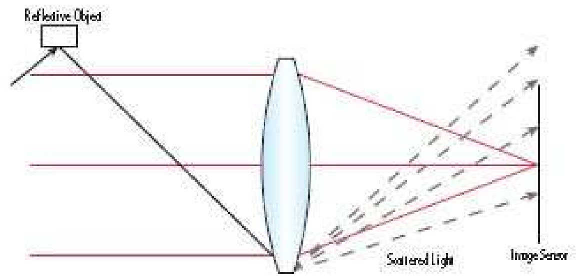


Figure 1: Light reflected by an object outside FOV being scattered from the edges of a lens without edge blackening

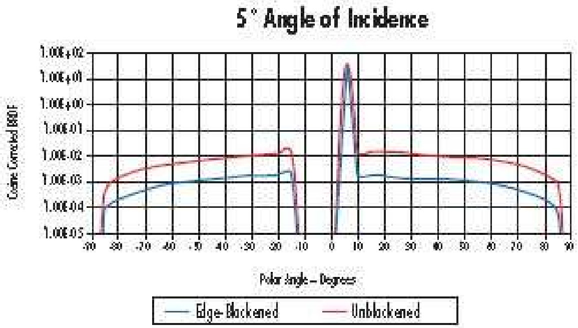


Figure 2: BRDF Plot of unblackened and blackened lenses

Figure 3: Line profile of the irradiance distribution through the center of an imaging sensor where the lens edges are not blackened.

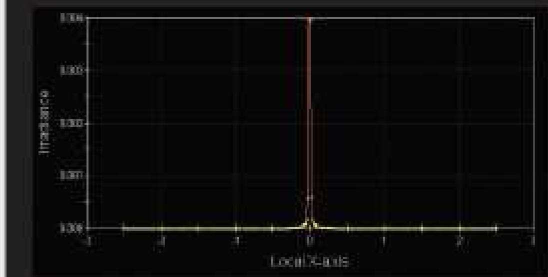


Figure 4: Line profile of the irradiance distribution through the center of an imaging sensor where the lens edges are blackened.

Source: Edmund Industrial Optics “Why Use Edge-Blackened Optics?”

Blackening the Edges

2549C Enamel Paint Marker Flat Black
by Testor Corp.

Be the first to review this item

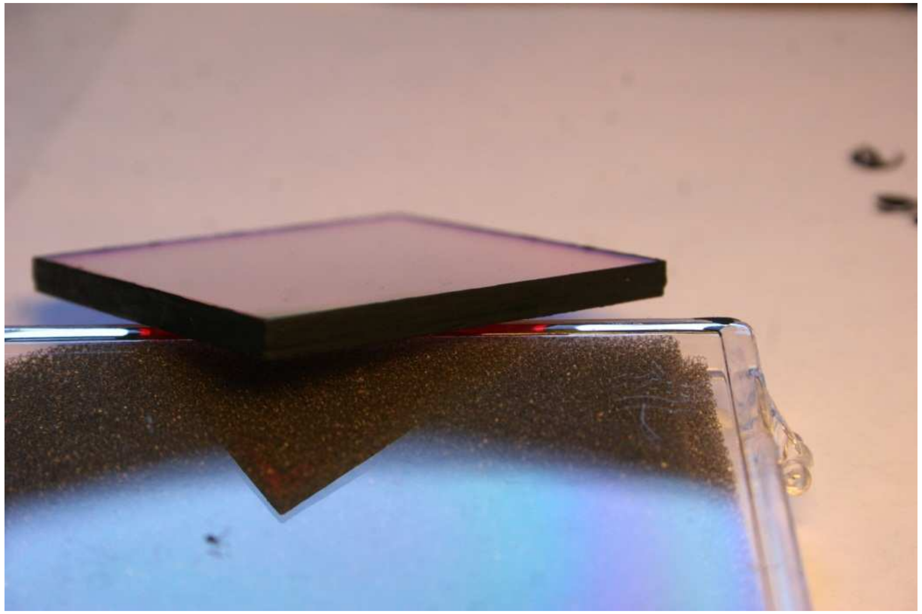
Price: $3.70

In Stock.
Ships from and sold by **Best Service Stores**.

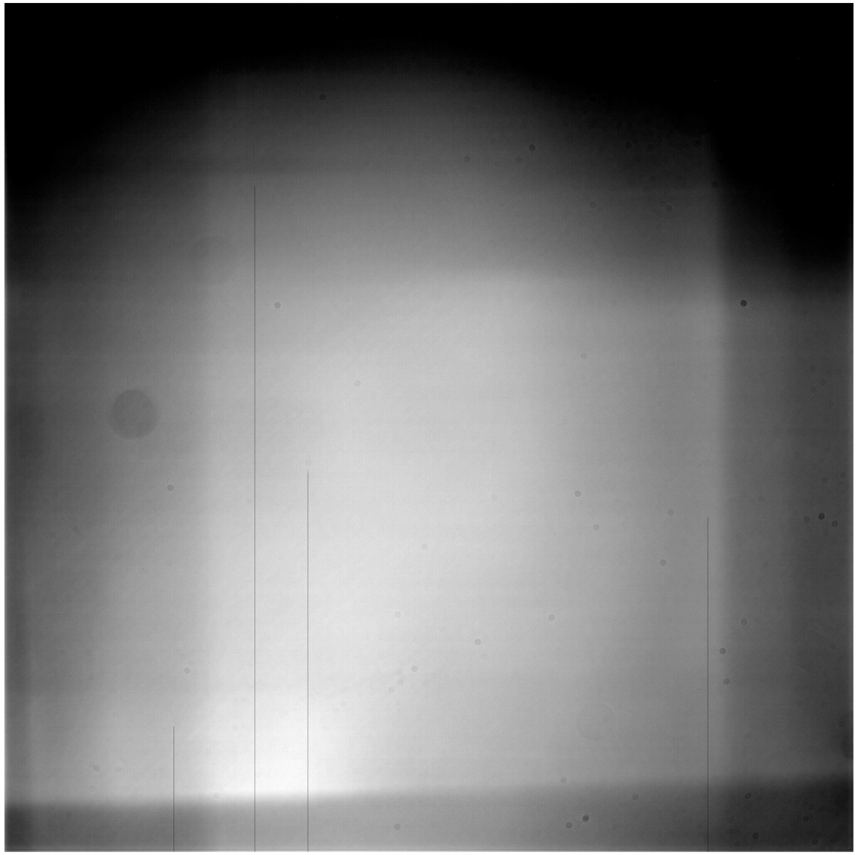
Only 2 left in stock--order soon.

4 new from $3.70

Source: Amazon.com

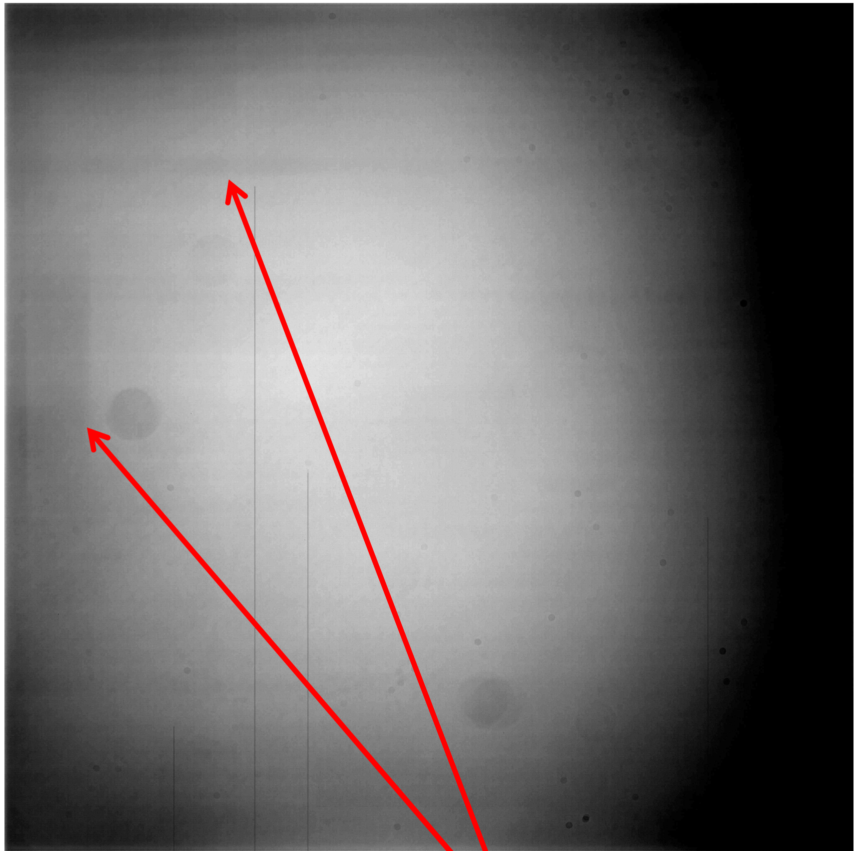


Before/After Edge Blackening



Before

KAF16803



After

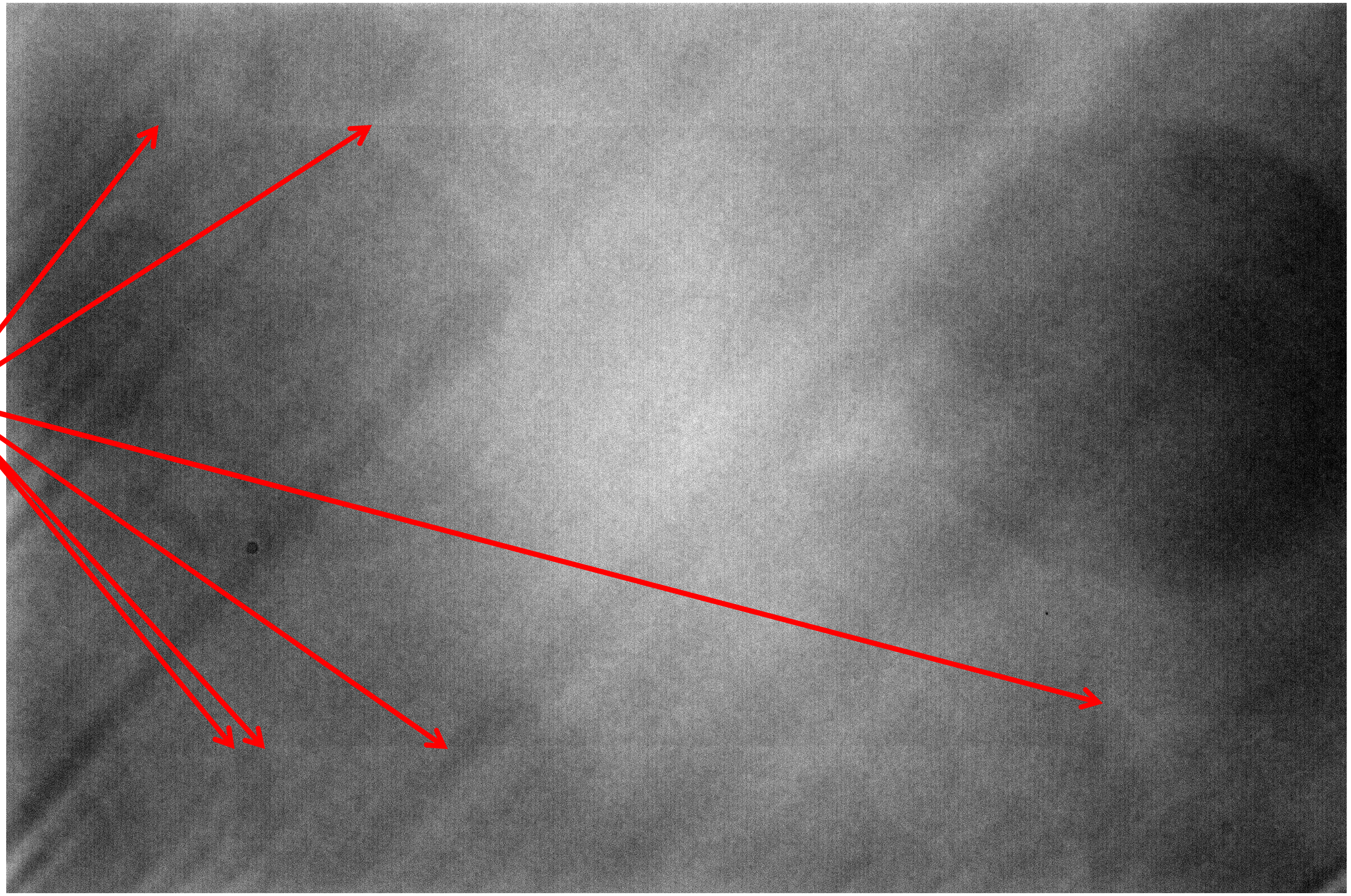
Remaining anomalies are discussed next

PRNU Anomalies

- Fabrication processes for CCDs use photolithography for making required structures on the silicon wafer
- The wafers are coated with a photosensitive thin film, exposed via a photomask and then processed creating the CCD's circuitry on the silicon wafer
- The photomasks are made using an electron-beam with a finite spot size
- Minor variations in line widths on the photomask arise from the finite spot size and the need for the beam to "snap to grid" to cut the design features
  - The features to be etched may not lie perfectly on Ebeam grid boundaries
  - This causes dimensional variation in the resulting etched features on the photomask
- These result in linewidth variations on the CCD that cause some pixels to be slightly larger than others
- This leads to visible artifacts in images arising from Photo Response Non Uniformity (PRNU), an important CCD performance specification
- These artifacts are completely removed by proper flat fielding

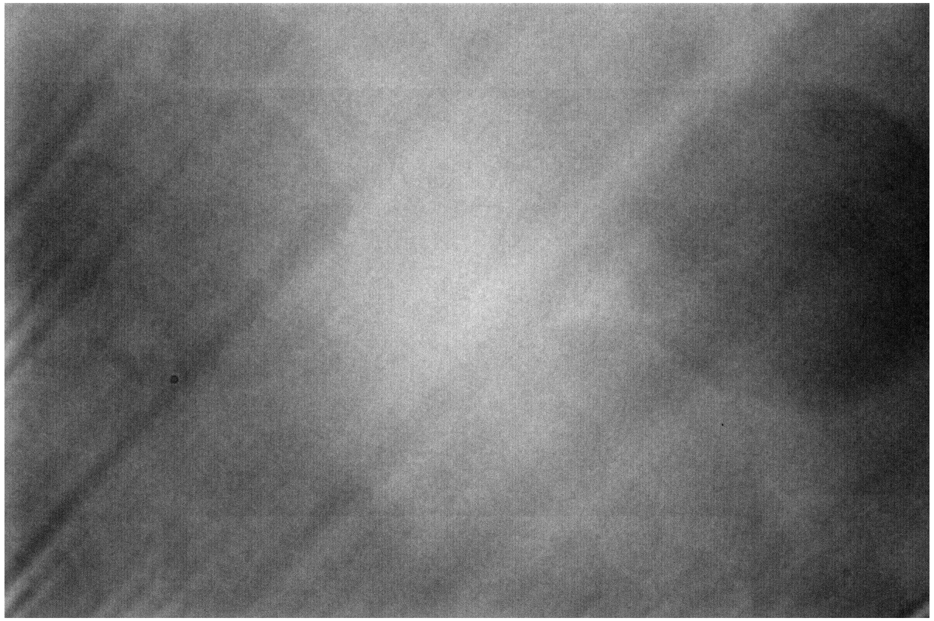
Examples of Photomask-Induced PRNU Artifacts

Caused by photomask linewidth variation



KAF3200ME Halpha flat using 50mm ROUND filter

Multiple PRNU Artifacts
(all are removable by flat-fielding)



KAF3200ME Halpha
flat using 50mm
ROUND filter

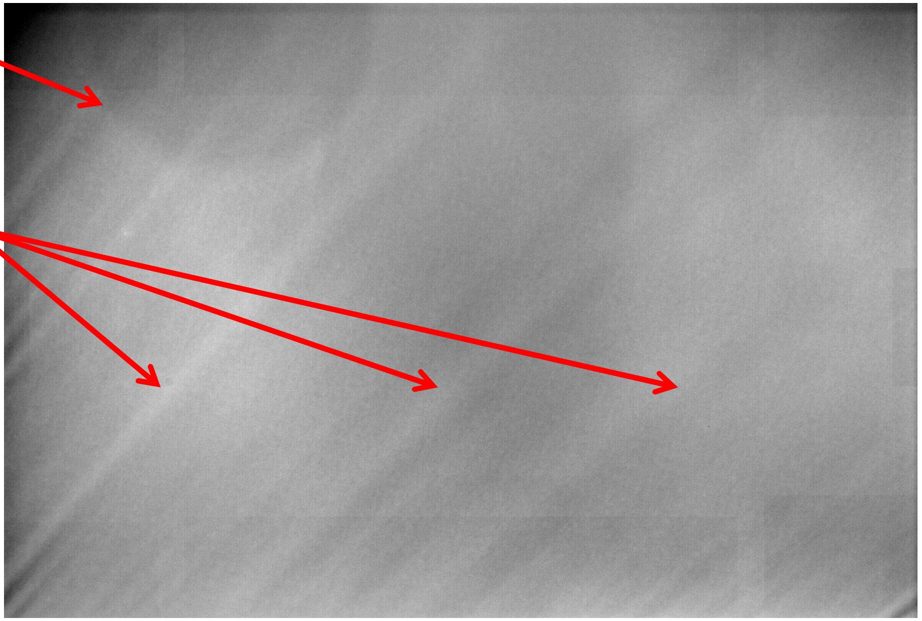
KAF3200ME [OIII]
flat using 50mm
ROUND filter

Note the photomask-induced artifacts are identical
(the blocky shapes with straight edges oriented horiz and vert)
NOT CAUSED BY FILTER EDGES

Non-Photomask Artifacts
(all are removable by flat-fielding)

Dust Mote
on filter

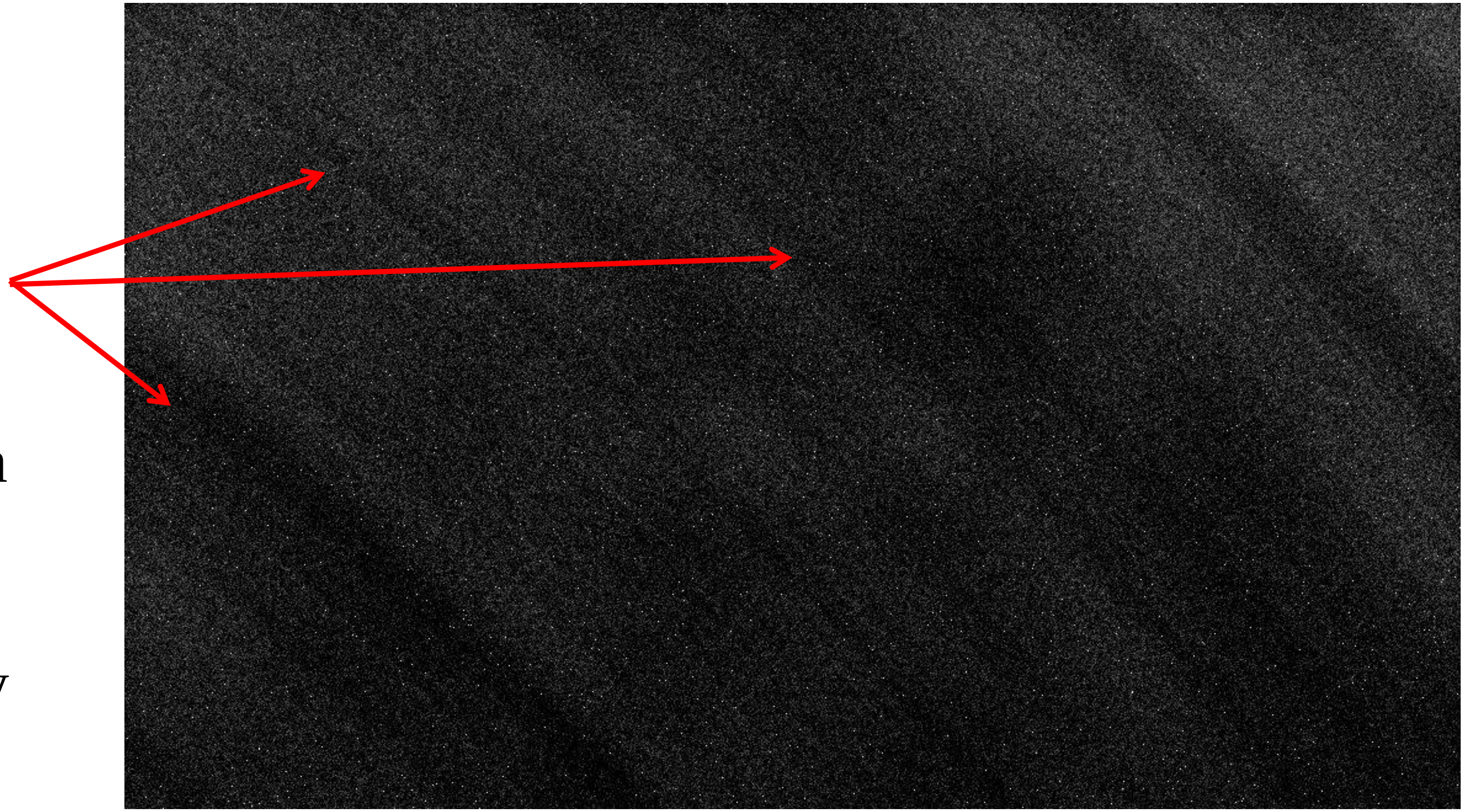
Wafer Polishing Artifacts (in silicon wafers prior to CCD fabrication steps) cause CCD Photo-Response Non-Uniformity



KAF3200ME [OIII] flat using 50mm ROUND filter

Dark Signal Non-Uniformity (DSNU)
For RBI Mitigated Camera

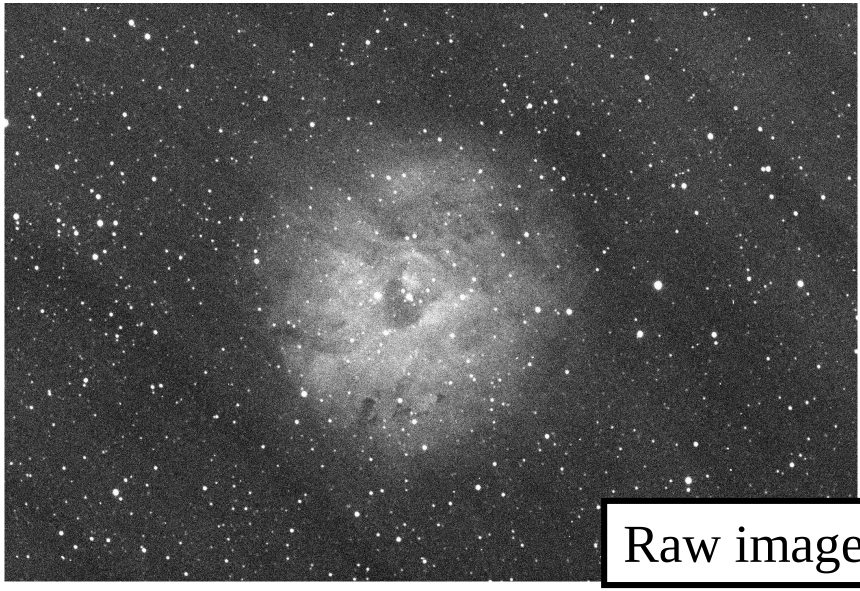
DSNU component caused by non-uniform RBI Trap distribution (removed by dark-subtraction)

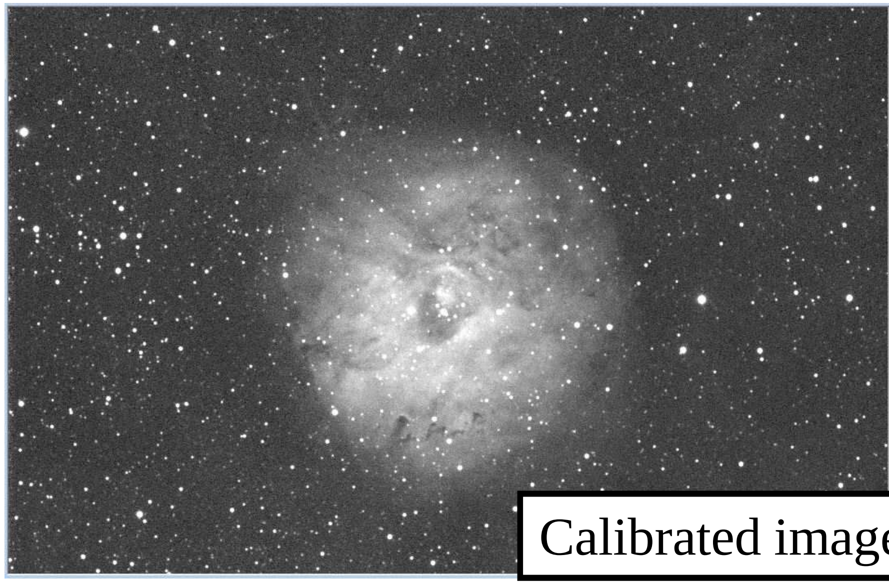


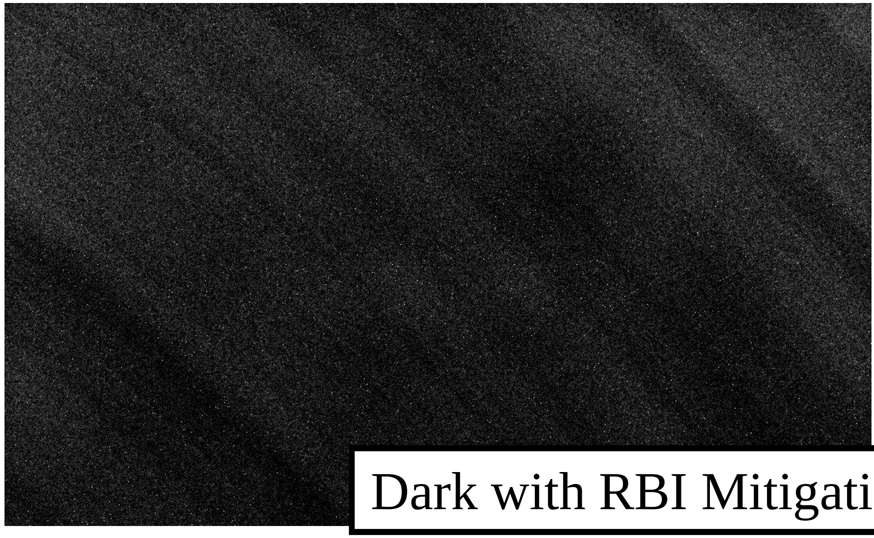
KAF3200ME
Dark

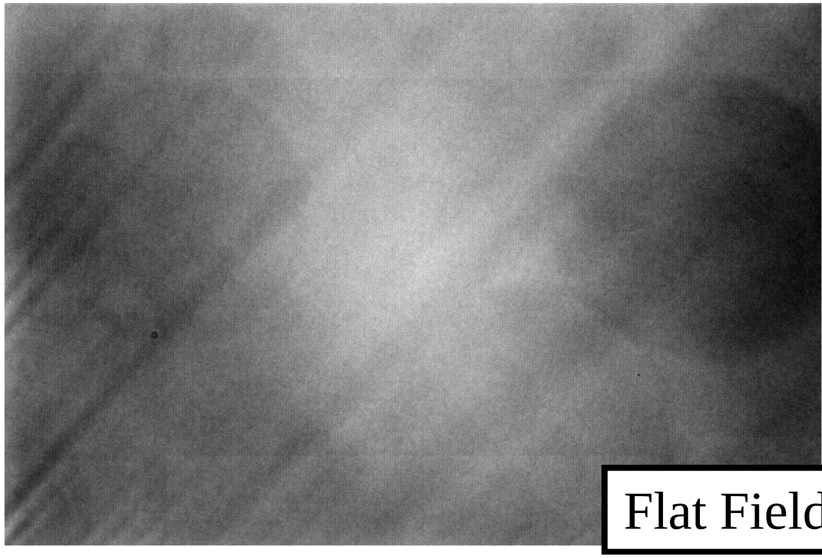
Classic DSNU “Dark Spikes” (salt and pepper features)(removed by dark-subtraction)

Before/After Calibration


Raw image


Calibrated image


Dark with RBI Mitigation


Flat Field

Why it makes no sense to use Halpha for luminance for a tricolor emission line image

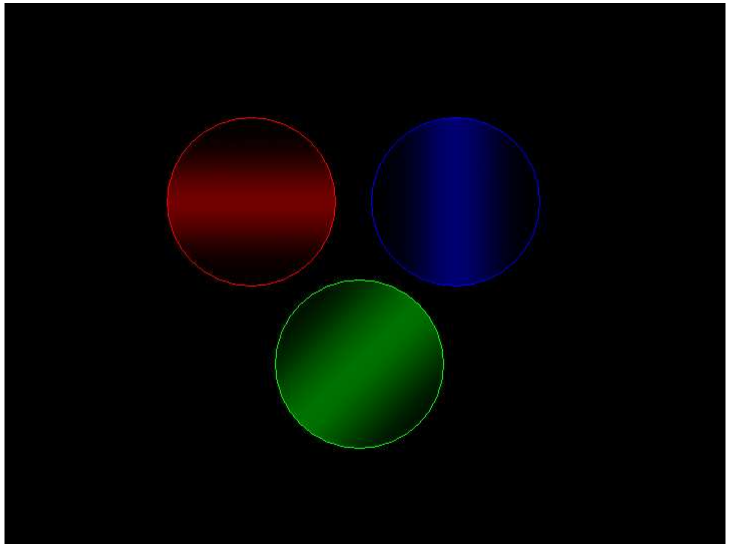
R.D. Crisp

28 July 2009

www.narrowbandimaging.com

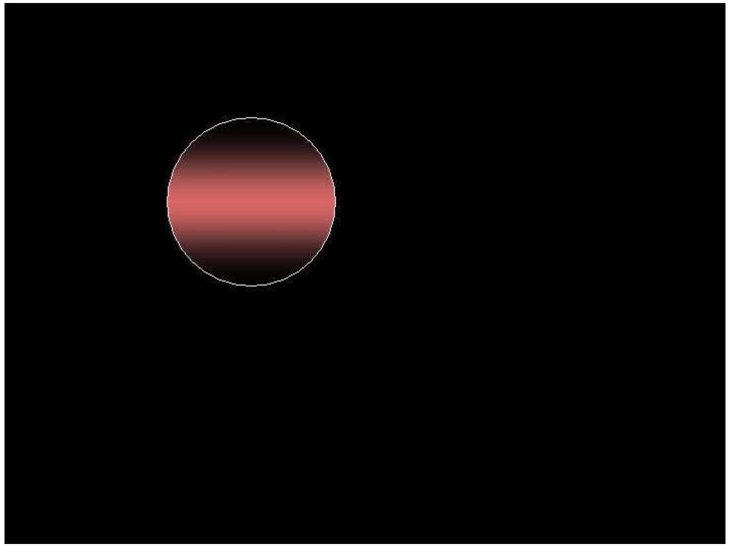
Luminance operation

- Adding a luminance layer above an image essentially multiplies the image data with the luminance data.
- Where there is both luminance data and image data, the image survives. Where either is lacking, the image is attenuated to the degree of the luminance applied: 100% luminance means 100% extinction if there's no signal below the luminance.
- See the two following pages: first uses one channel only for luminance (equivalent to Halpha in an Ha/S2/O3 or an RGB image) the second uses all three colors as luminance; equivalent to using clear data for luminance

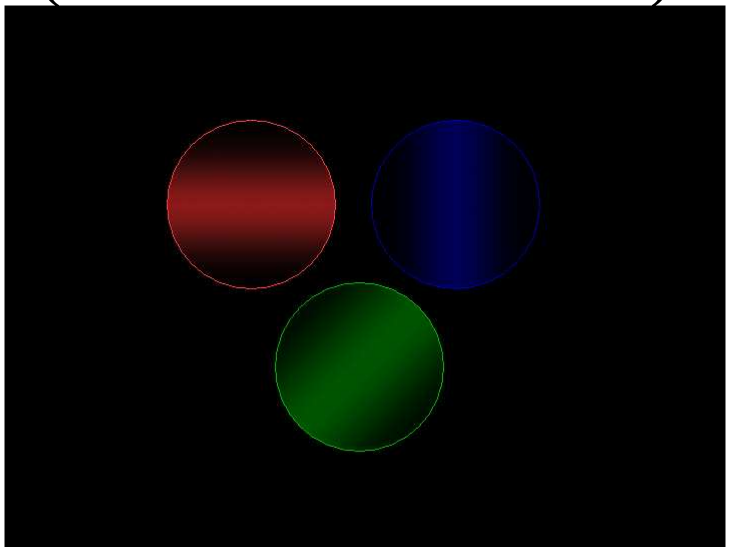


0% luminance
(red used for luminance)

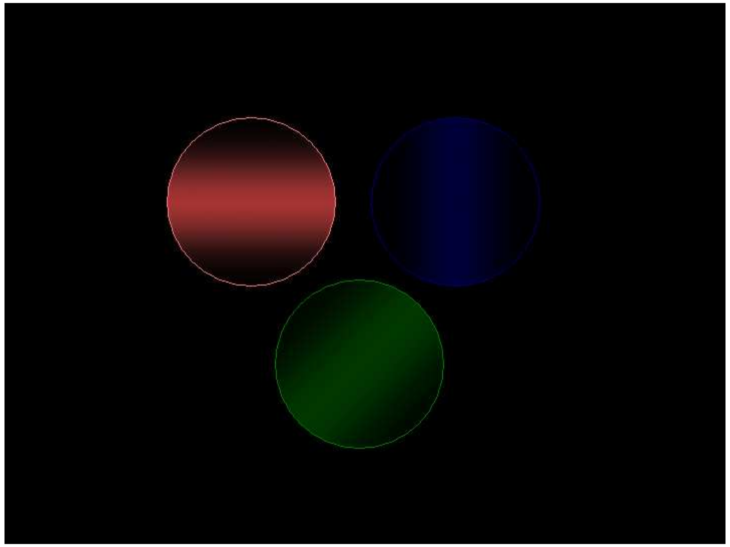
Red used as Lum



100% luminance
(red used for luminance)



25% luminance
(red used for luminance)



50% luminance
(red used for luminance)

R.D.Crisp
28 July 2008
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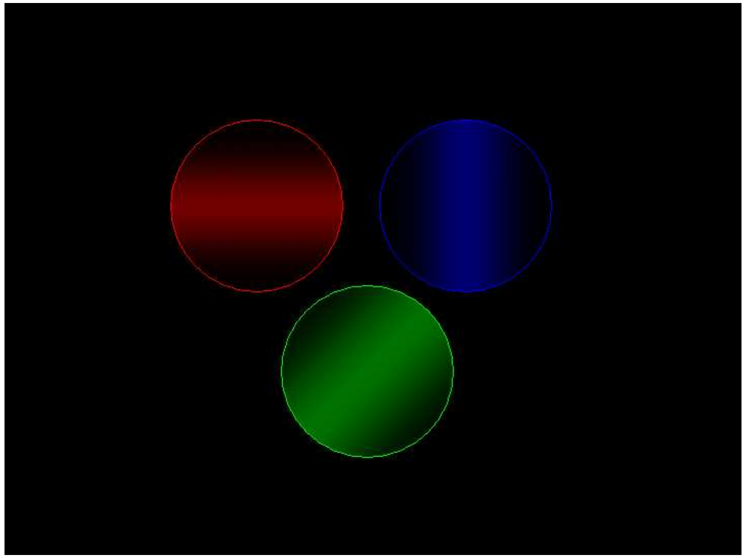
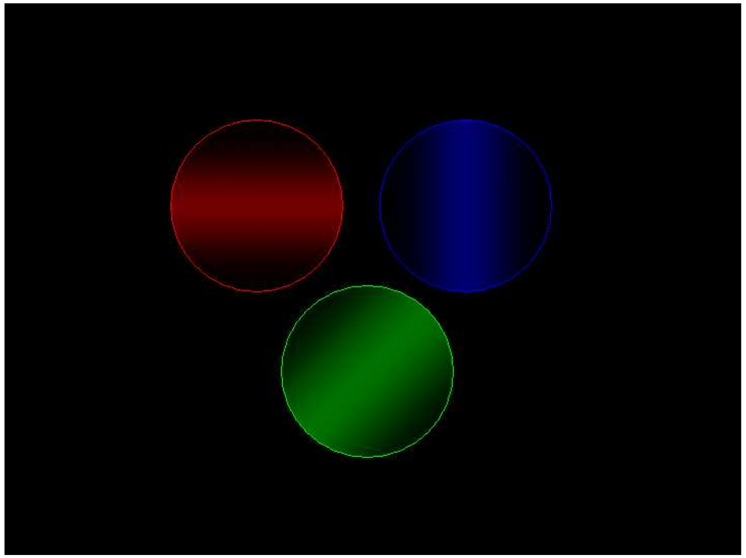
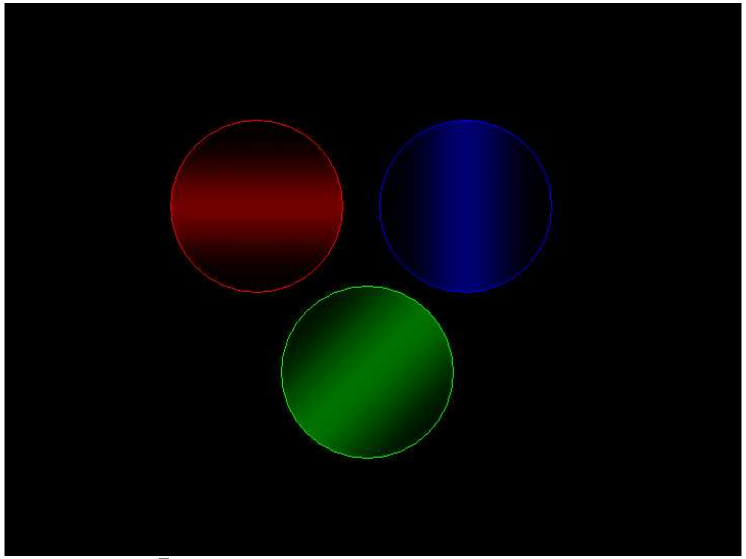


0% luminance
(RGB used for luminance)

RGB used as LUM



100% luminance
(RGB used for luminance)



25% luminance
(RGB used for luminance)

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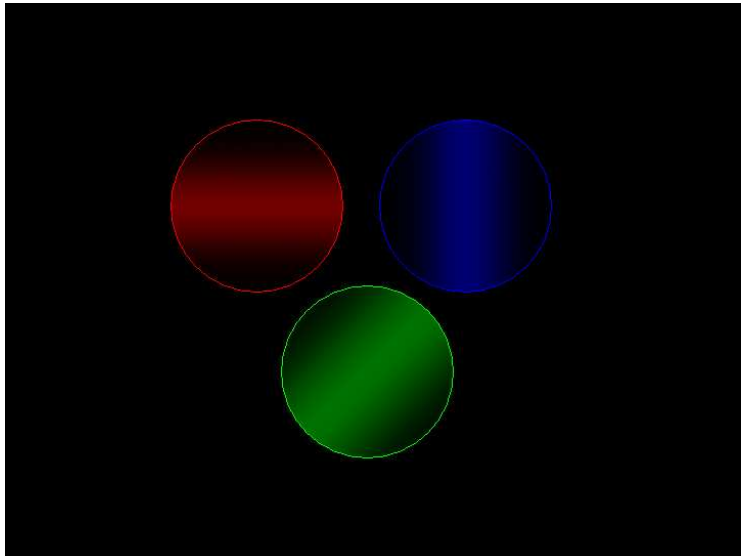


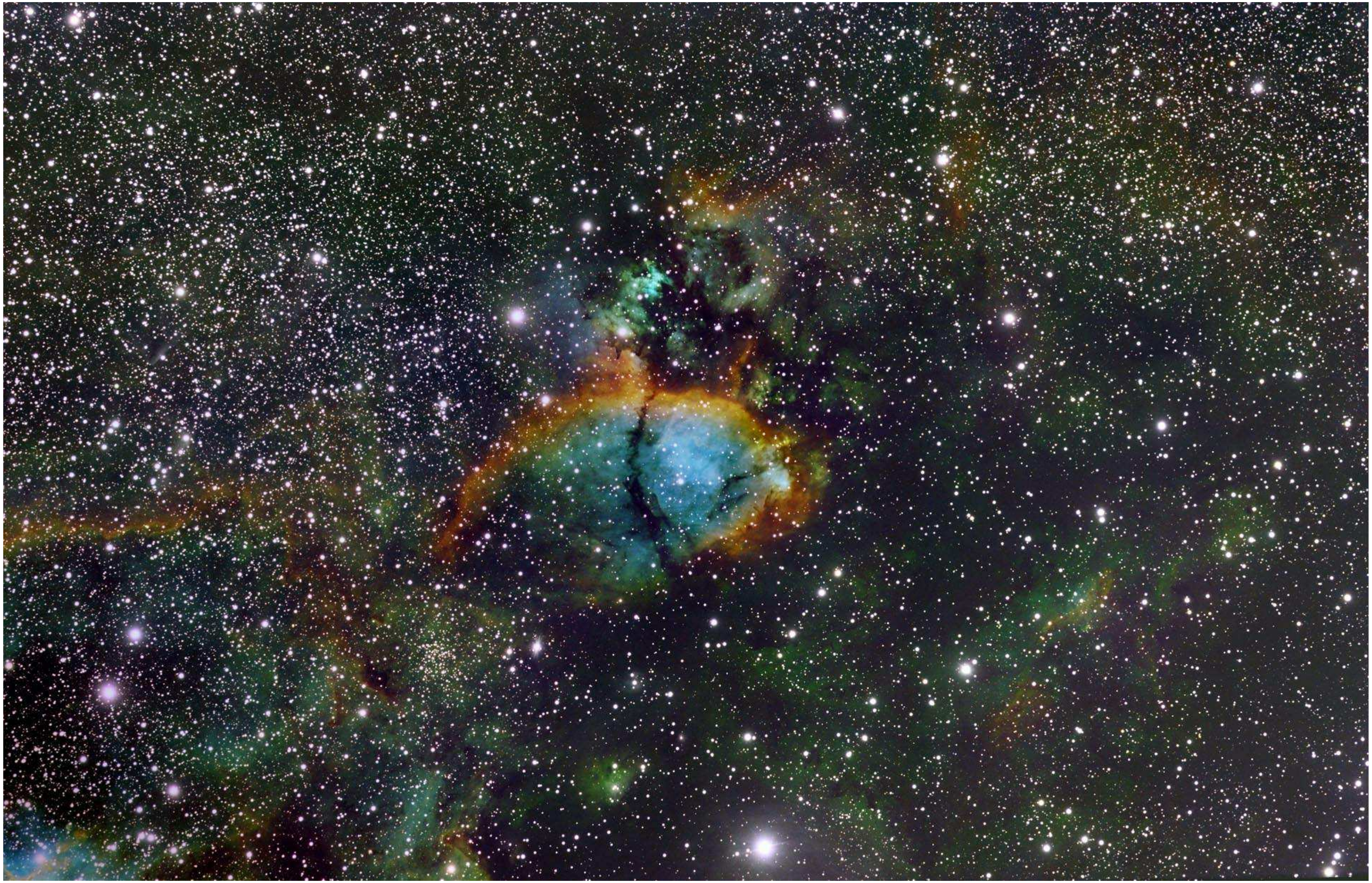
50% luminance
(RGB used for luminance)

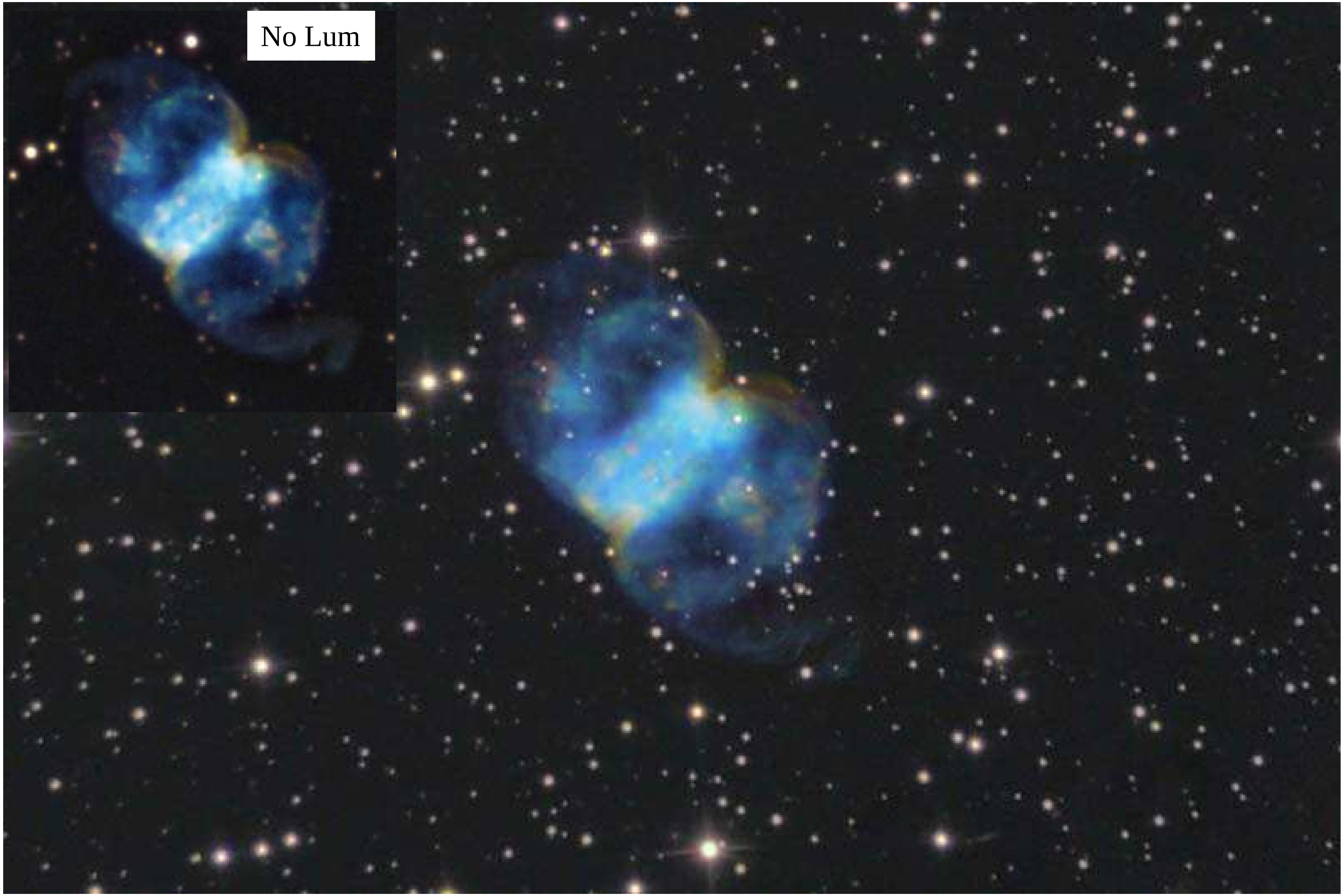
Why do we use Luminance?

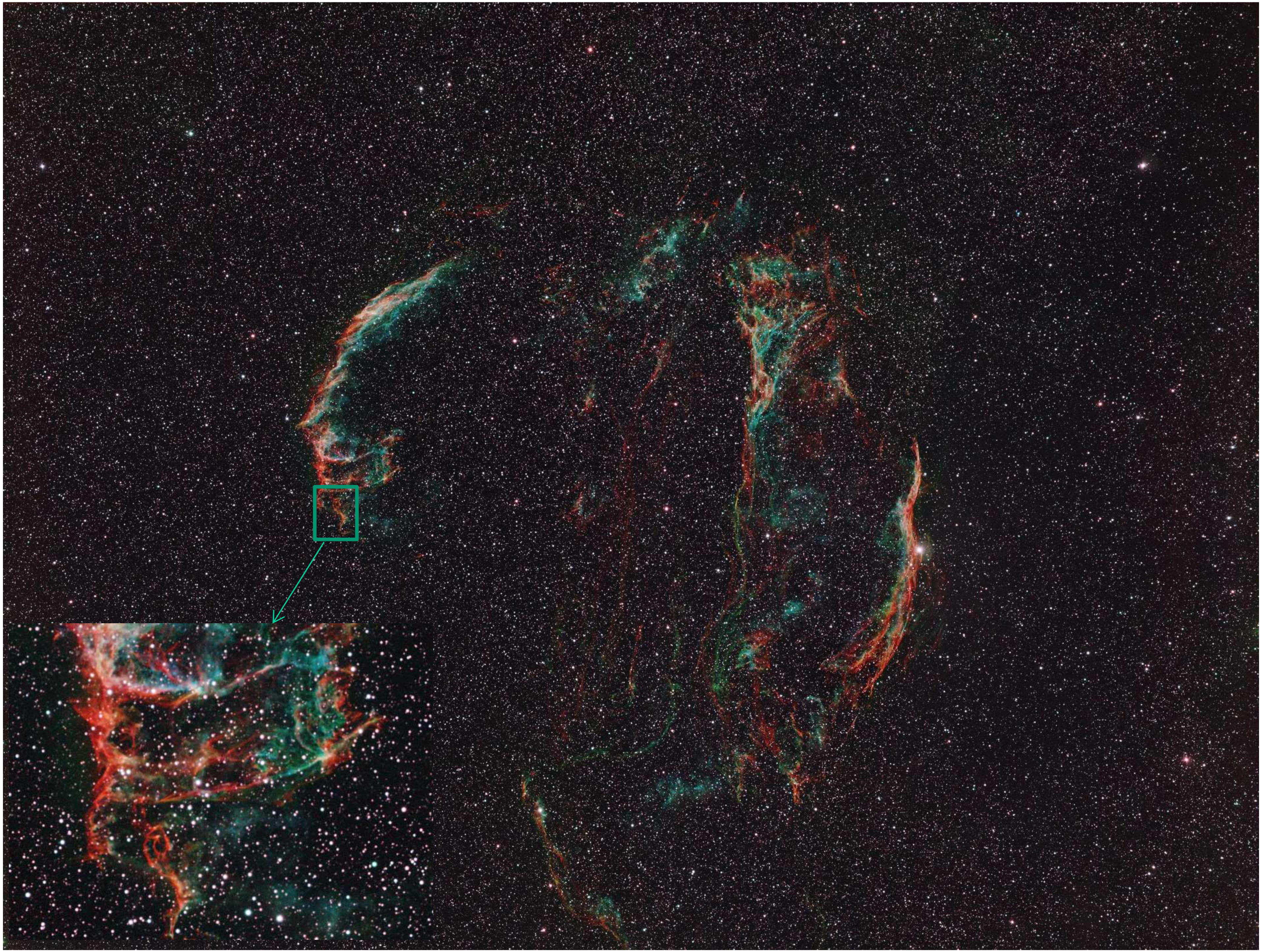
- To smoothen the background
- To enhance contrast

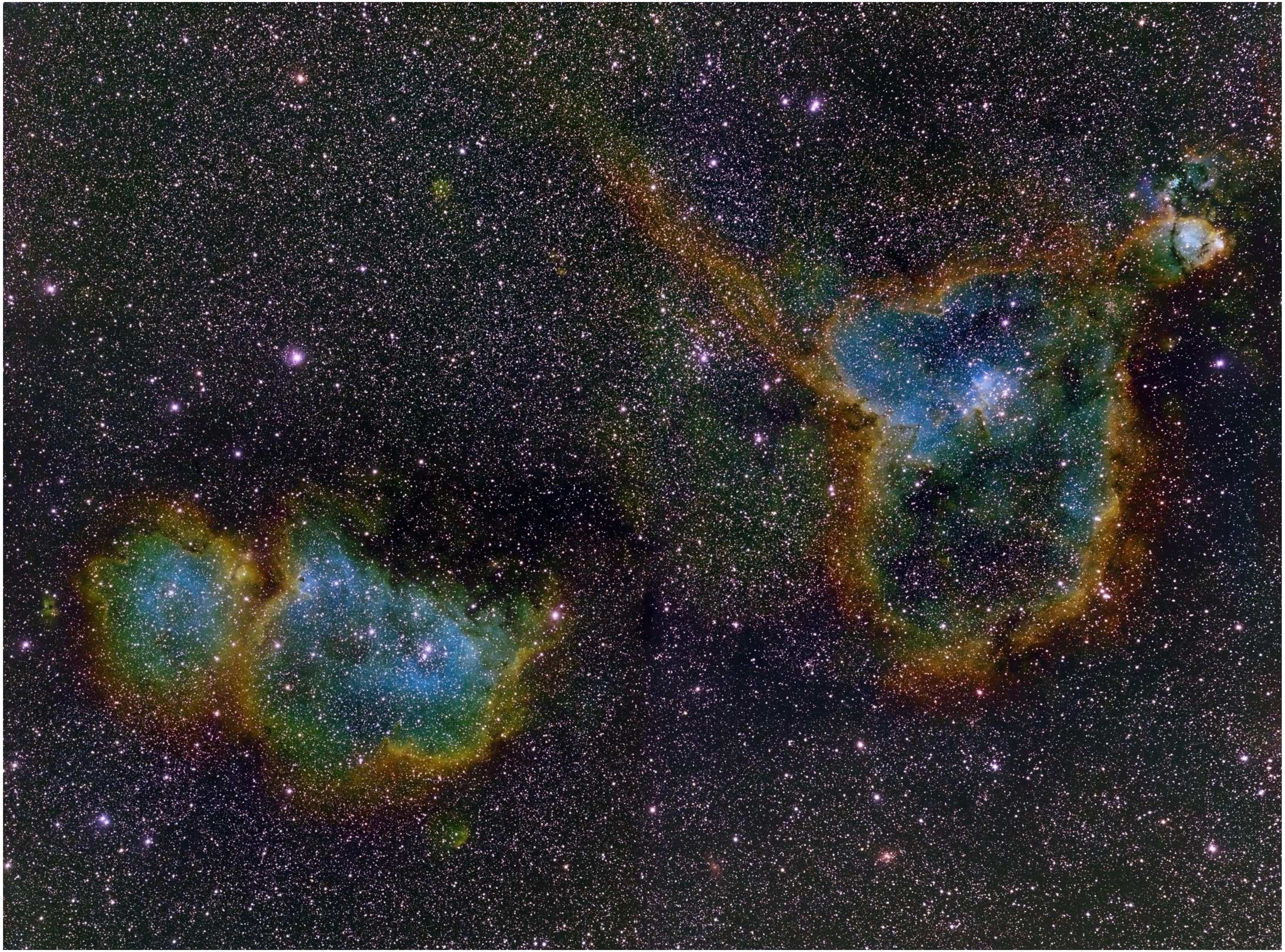
- Classic Luminance use: broadband “clear”* luminance applied atop RGB image.
  - The clear luminance data contains ALL of the data in the underlying color image
  - Applying the clear luminance data does NOT alter the color balance

- Mistake: using Halpha as luminance over a color image (either emission line or RGB)
  - Issue: alters color balance
    - Makes RGB images turn that sick salmon color
    - Attenuates Sulfur and Oxygen data in S2/Ha/O3 emission line images
      - Again fouls color balance
- Alternative
  - Take more S2/Ha/O3 data…. Never can take too much…. Better way to smoothen the data, more signal ALWAYS wins
  - Use clear luminance data…. Works fine with RGB obviously and works nicely with S2/Ha/O3 emission line data. Examples to follow




No Lum





Thank You