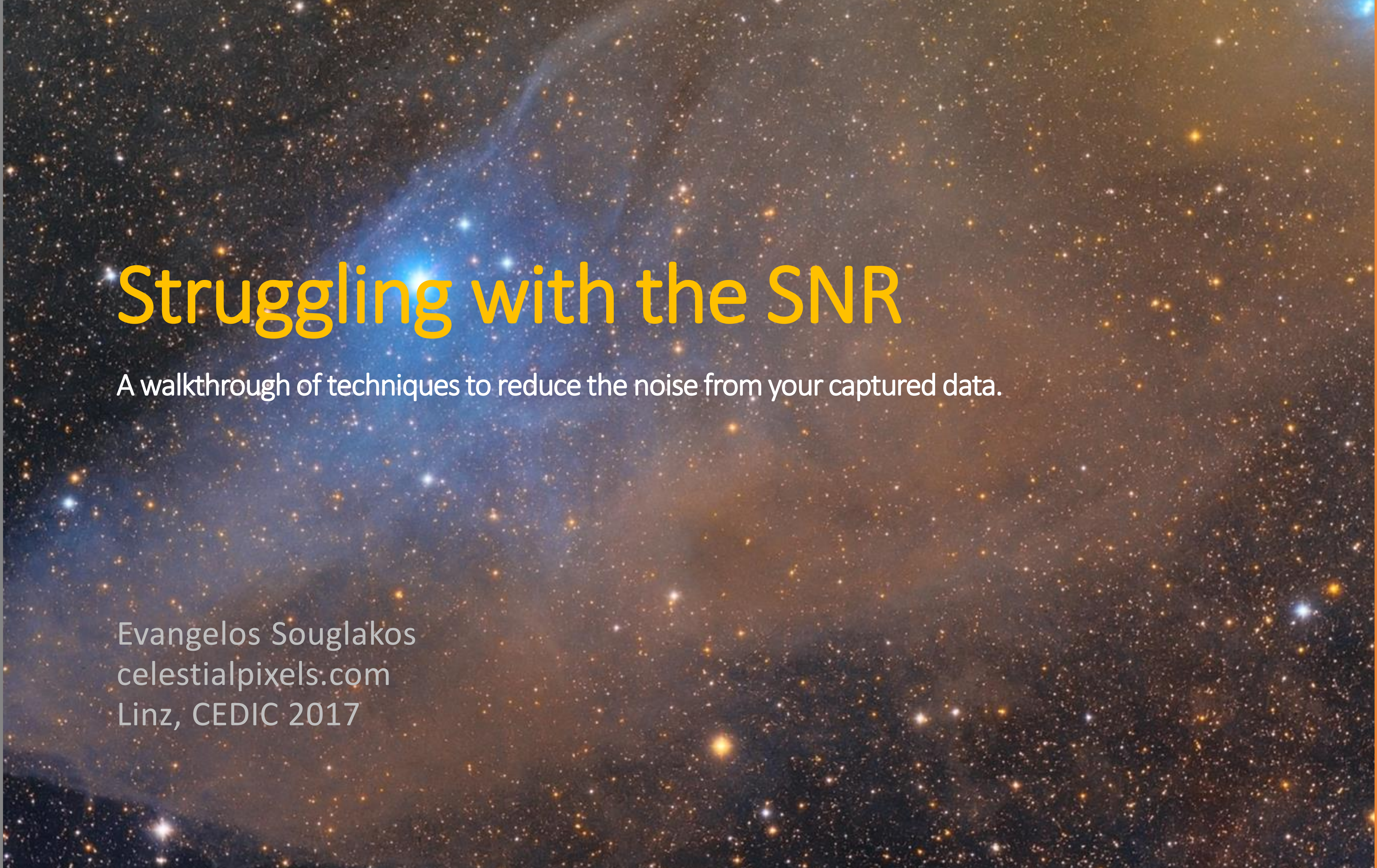


Struggling with the SNR

A walkthrough of techniques to reduce the noise from your captured data.

Evangelos Souglakos
celestialpixels.com
Linz, CEDIC 2017

SNR

Astrophotography of faint deep-sky objects is all about signals and noise

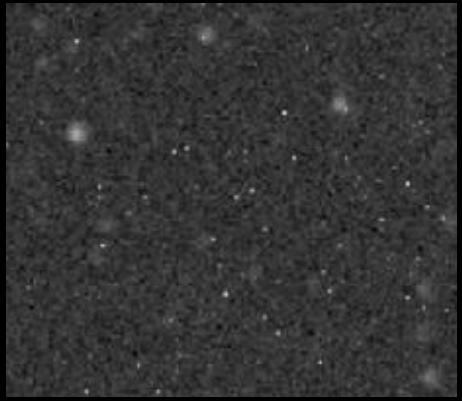
- The more signal you collect the better your photos will be.
- Top priority is always to collect as many data as possible.

SNR

Types of noise

- **Read noise (On Chip) / Camera Noise (Off Chip)**
  - Comes from both the electronics on the sensor itself and from the electronics inside your camera.
- **Dark Current Noise**
  - Intensity should double as you double the exposure duration and it should also double for every 6°C
  - Pattern of fixed, spatial noise
  - Reduced by cooling
- **Electronic Interference / Bias**
  - CCD, CCD preamplifier, ADC, CDS signal processor
- **Pixel Non-Uniformity**
  - Each pixel has a slightly different sensitivity to light, typically within 1% to 2% of the average signal. Can be reduced by calibrating an image with a flat-field image

SNR



- **Shot noise or Photon Noise (target and skyglow)**
  - Random arrival of photons hitting a pixel of your sensor per time
  - Sensor doesn't know if the photons are coming from your target or from the skyglow
  - Skyglow lowers SNR by injecting shot noise into the image without also injecting signal into the image.
- **Hot and Cold Pixels**
  - Defective pixels. No signal is acquired anymore by those pixels
- **Cosmic Rays**
  - High energy particles strike Earth's atmosphere and release a rain of charged particles and photons which are detected as bright specks in an image.

- **Other Artifacts** such as Satellites, Airplanes, Meteors etc.

SNR

Methods to boost our SNR

- Drop the noise
- Boost the signal.
  - aperture of your scope and f ratio.
  - If you keep the aperture constant and vary the f-ratio (by varying the focal length), you're trading off signal and resolution
- Light throughput of the telescope
  - Obstruction
  - Coating of mirrors / lens quality
- Quantum Efficiency of your image sensor
  - Proportion of photons that are recorded out of the total number that hit the sensor

CCD Cameras

Monochrome vs color cameras. Color filters cut your signal down to under a third of what it would have been without the color filters. You've cut the signal and kept the noise the same.

- Quantum Efficiency
- Dark Noise
- Read Out Speed
- Per-pixel SNR is higher with larger pixels

CCD Cameras

Readout Speed vs Noise

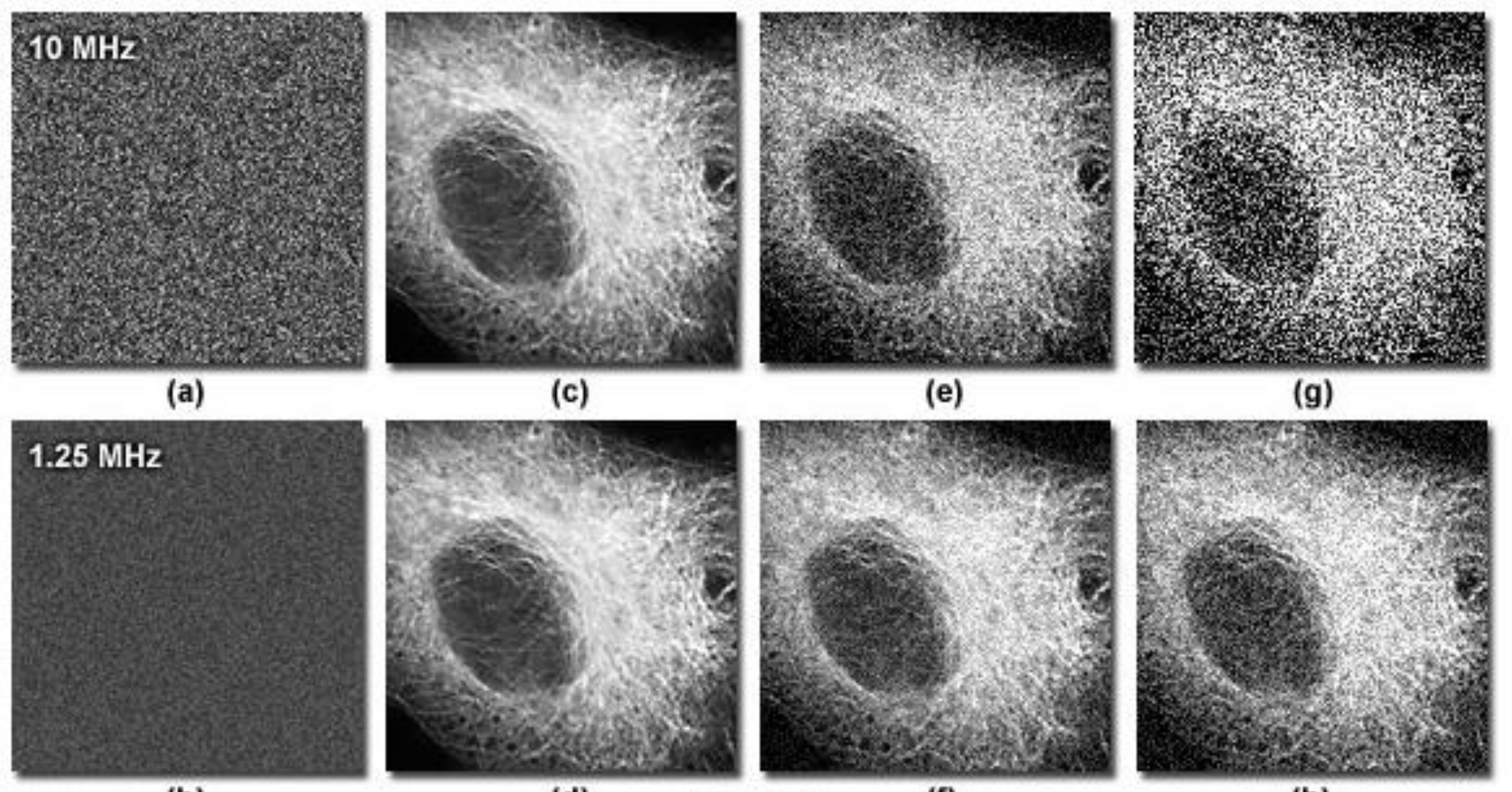


Figure 2

at low light levels, the readout noise can dominate other sources of noise

Sub exposures

- Increases signal-to-noise ratio

The number sequence image.

The ramp sequence image.

Single frame with noise. The noise profile was designed to simulate the condition where sensor read noise + photon noise gives a S/N = 1 for the number 10.

Sub exposures

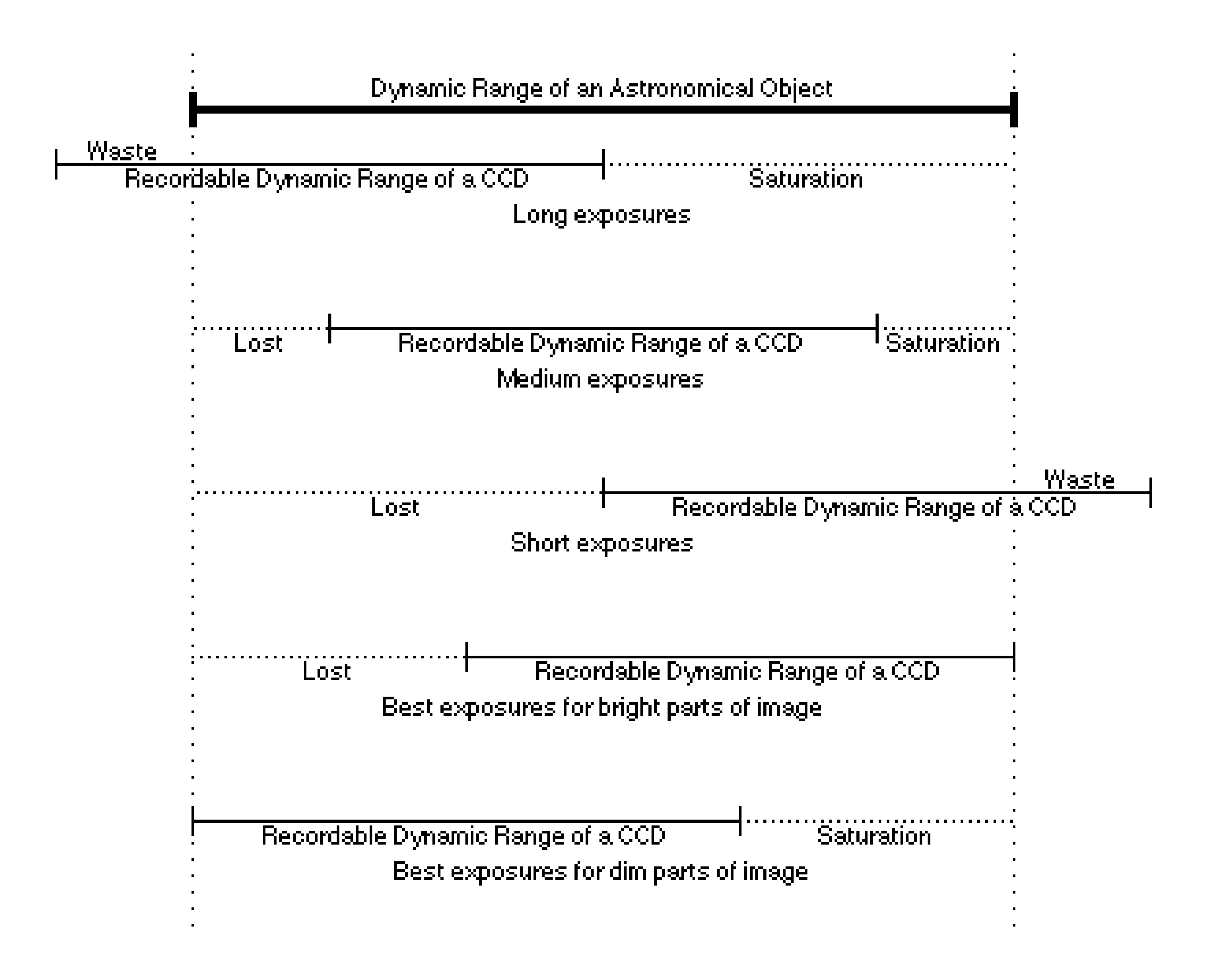
- Increases signal-to-noise ratio

100 image median combine on 16-bit data.

100 image Sigma-Clipped average combine on 16-bit data.
Clipping was set to 2.45 standard deviations.

Sub exposures

- Increases dynamic range
  - Objects have a range of brightness (actual dynamic range) that exceeds the range of brightness that can be recorded by the CCD (recordable dynamic range)
  - Stacking increases the number of possible digitized values linearly with the number of images stacked.



Sub exposure duration

- **Time of exposure**
- **Number of Exposures**
- **Sky Background Flux (Sky Limited)**
- **Object Flux**
- **Focal Ratio**
- **Resolution / Aperture**
- **Binning**
- **QE of your CCD**

Sky Limited Exposures

"Sky limit is the zone where the sky noise overpowers the readout noise"

Ideal Exposure Calculator	
Select a CCD Camera	SBIG ST-8300
Enter Test Exposure Time in Minutes	5
Enter Measured Background Value	3000
Select Percent Contribution from Readout Noise	5%
Calculate.	
Ideal Subframe Exposure Time: 3.93 minutes	

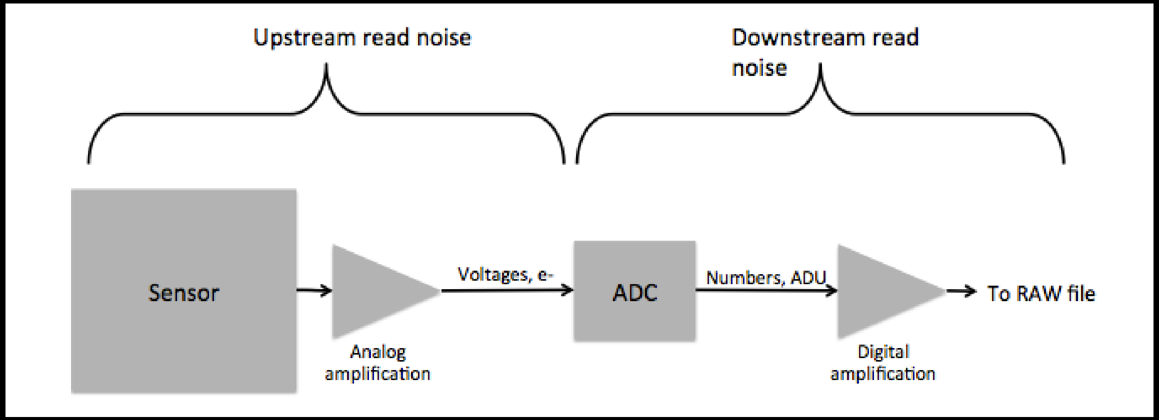
Best ISO for your DSLR

The ISO setting does not affect your cameras sensitivity to light!

The ISO setting determines the amplification factor that the camera applies to the signal that represents the amount of photons captured in a pixel.

When you increase ISO:

1. you increase read noise, the noise that inherent to the electronics of the camera
2. You decrease dynamic range



Best ISO for your DSLR

- Depends on your particular model
- Increasing the ISO increases SNR until upstream read noise surpasses downstream read noise

Image Registration

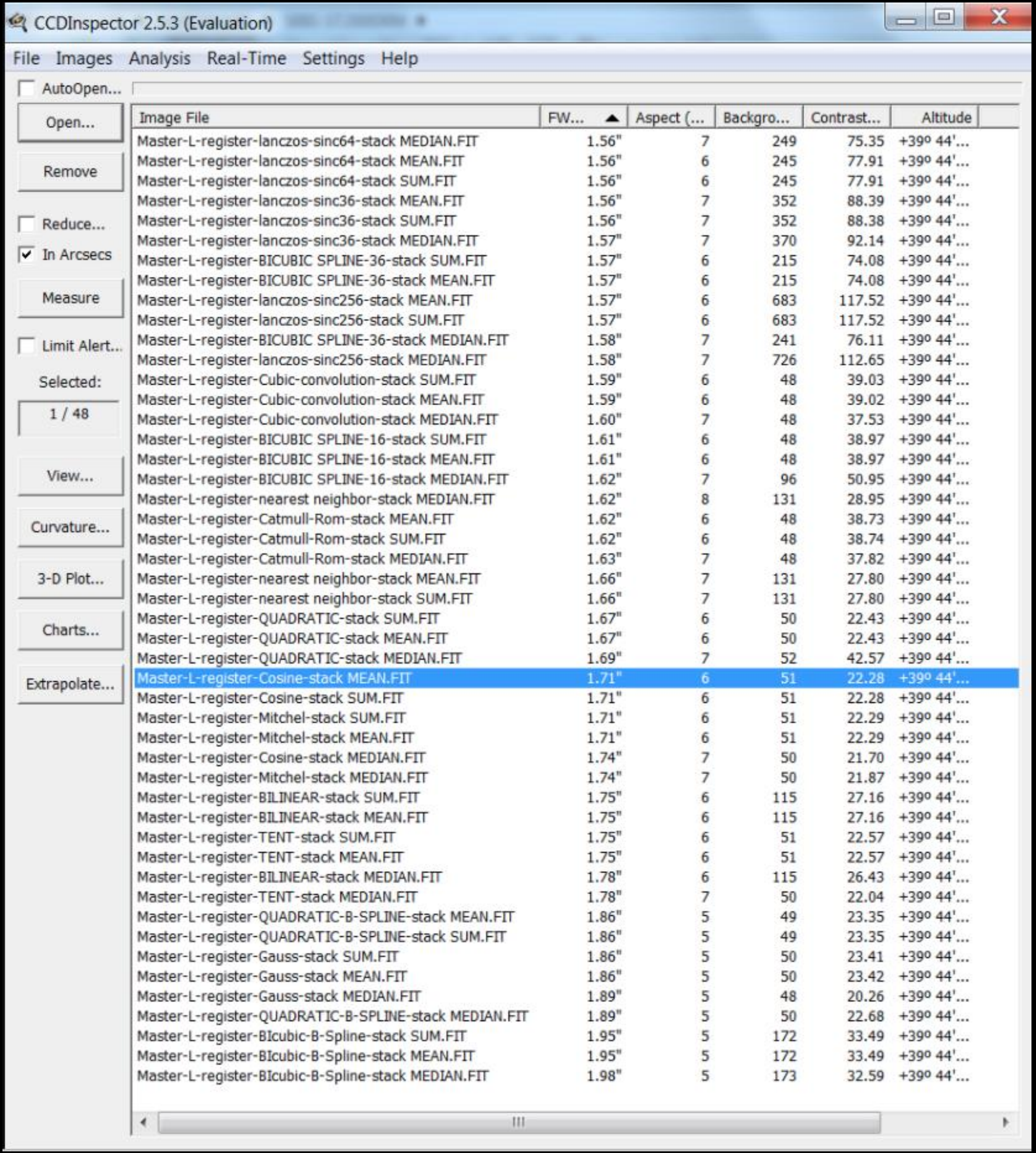


Image File	FW...	Aspect (...	Backgro...	Contrast...	Altitude
Master-L-register-lanczos-sinc64-stack MEDIAN.FIT	1.56"	7	249	75.35	+39º 44'...
Master-L-register-lanczos-sinc64-stack MEAN.FIT	1.56"	6	245	77.91	+39º 44'...
Master-L-register-lanczos-sinc64-stack SUM.FIT	1.56"	6	245	77.91	+39º 44'...
Master-L-register-lanczos-sinc36-stack MEAN.FIT	1.56"	7	352	88.39	+39º 44'...
Master-L-register-lanczos-sinc36-stack SUM.FIT	1.56"	7	352	88.38	+39º 44'...
Master-L-register-lanczos-sinc36-stack MEDIAN.FIT	1.57"	7	370	92.14	+39º 44'...
Master-L-register-BICUBIC SPLINE-36-stack SUM.FIT	1.57"	6	215	74.08	+39º 44'...
Master-L-register-BICUBIC SPLINE-36-stack MEAN.FIT	1.57"	6	215	74.08	+39º 44'...
Master-L-register-lanczos-sinc256-stack MEAN.FIT	1.57"	6	683	117.52	+39º 44'...
Master-L-register-lanczos-sinc256-stack SUM.FIT	1.57"	6	683	117.52	+39º 44'...
Master-L-register-BICUBIC SPLINE-36-stack MEDIAN.FIT	1.58"	7	241	76.11	+39º 44'...
Master-L-register-lanczos-sinc256-stack MEDIAN.FIT	1.58"	7	726	112.65	+39º 44'...
Master-L-register-Cubic-convolution-stack SUM.FIT	1.59"	6	48	39.03	+39º 44'...
Master-L-register-Cubic-convolution-stack MEAN.FIT	1.59"	6	48	39.02	+39º 44'...
Master-L-register-Cubic-convolution-stack MEDIAN.FIT	1.60"	7	48	37.53	+39º 44'...
Master-L-register-BICUBIC SPLINE-16-stack SUM.FIT	1.61"	6	48	38.97	+39º 44'...
Master-L-register-BICUBIC SPLINE-16-stack MEAN.FIT	1.61"	6	48	38.97	+39º 44'...
Master-L-register-BICUBIC SPLINE-16-stack MEDIAN.FIT	1.62"	7	96	50.95	+39º 44'...
Master-L-register-nearest neighbor-stack MEDIAN.FIT	1.62"	8	131	28.95	+39º 44'...
Master-L-register-Catmull-Rom-stack MEAN.FIT	1.62"	6	48	38.73	+39º 44'...
Master-L-register-Catmull-Rom-stack SUM.FIT	1.62"	6	48	38.74	+39º 44'...
Master-L-register-Catmull-Rom-stack MEDIAN.FIT	1.63"	7	48	37.82	+39º 44'...
Master-L-register-nearest neighbor-stack MEAN.FIT	1.66"	7	131	27.80	+39º 44'...
Master-L-register-nearest neighbor-stack SUM.FIT	1.66"	7	131	27.80	+39º 44'...
Master-L-register-QUADRATIC-stack SUM.FIT	1.67"	6	50	22.43	+39º 44'...
Master-L-register-QUADRATIC-stack MEAN.FIT	1.67"	6	50	22.43	+39º 44'...
Master-L-register-QUADRATIC-stack MEDIAN.FIT	1.69"	7	52	42.57	+39º 44'...
Master-L-register-Cosine-stack MEAN.FIT	1.71"	6	51	22.28	+39º 44'...
Master-L-register-Cosine-stack SUM.FIT	1.71"	6	51	22.28	+39º 44'...
Master-L-register-Mitchel-stack SUM.FIT	1.71"	6	51	22.29	+39º 44'...
Master-L-register-Mitchel-stack MEAN.FIT	1.71"	6	51	22.29	+39º 44'...
Master-L-register-Cosine-stack MEDIAN.FIT	1.74"	7	50	21.70	+39º 44'...
Master-L-register-Mitchel-stack MEDIAN.FIT	1.74"	7	50	21.87	+39º 44'...
Master-L-register-BILINEAR-stack SUM.FIT	1.75"	6	115	27.16	+39º 44'...
Master-L-register-BILINEAR-stack MEAN.FIT	1.75"	6	115	27.16	+39º 44'...
Master-L-register-TENT-stack SUM.FIT	1.75"	6	51	22.57	+39º 44'...
Master-L-register-TENT-stack MEAN.FIT	1.75"	6	51	22.57	+39º 44'...
Master-L-register-BILINEAR-stack MEDIAN.FIT	1.78"	6	115	26.43	+39º 44'...
Master-L-register-TENT-stack MEDIAN.FIT	1.78"	7	50	22.04	+39º 44'...
Master-L-register-QUADRATIC-B-SPLINE-stack MEAN.FIT	1.86"	5	49	23.35	+39º 44'...
Master-L-register-QUADRATIC-B-SPLINE-stack SUM.FIT	1.86"	5	49	23.35	+39º 44'...
Master-L-register-Gauss-stack SUM.FIT	1.86"	5	50	23.41	+39º 44'...
Master-L-register-Gauss-stack MEAN.FIT	1.86"	5	50	23.42	+39º 44'...
Master-L-register-Gauss-stack MEDIAN.FIT	1.89"	5	48	20.26	+39º 44'...
Master-L-register-QUADRATIC-B-SPLINE-stack MEDIAN.FIT	1.89"	5	50	22.68	+39º 44'...
Master-L-register-BIcubic-B-Spline-stack SUM.FIT	1.95"	5	172	33.49	+39º 44'...
Master-L-register-BIcubic-B-Spline-stack MEAN.FIT	1.95"	5	172	33.49	+39º 44'...
Master-L-register-BIcubic-B-Spline-stack MEDIAN.FIT	1.98"	5	173	32.59	+39º 44'...

Combining Algorithms

- **Mean / Average**
  - Best SNR but worse at removing artifacts / non random noise (e.g hot / cold pixels)
- **Median**
  - Rejects the highest and lowest pixel values
  - Removes extremely bright semi-random artifacts such as cosmic rays
  - Bad for hot and cold pixels as they remain the same place in all images
  - Better at artifact removal but it reduces SNR in terms of random noise.

Combining Algorithms

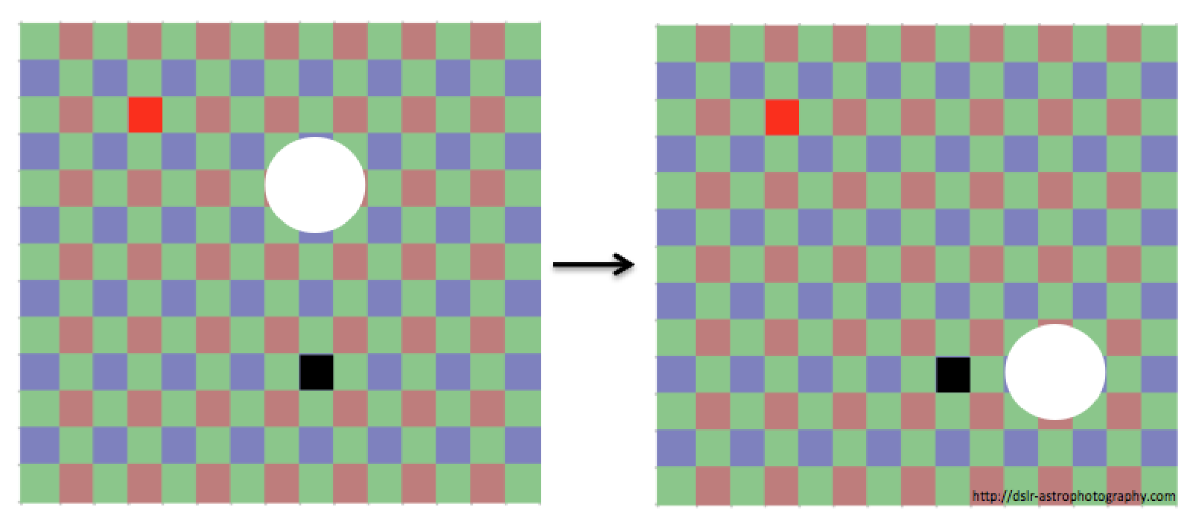
- **Min/Max-Clip**
  - best non-random noise reduction
  - less SNR loss than median combine.
  - Rejects the highest or lowest value before taking a median value from the remaining pixel values.
    This eliminates extreme pixel values from contributing to the median value.
- **Sigma Clip**
  - Reduces extreme pixel values by using data from surrounding pixels.
  - Best choice when combining a large number of subframes (> 20)

How to detect faintest details

- Dark Skies
- Large Aperture and quality lens / mirror
- Fast f/ratio and large aperture are key because you gather the most light in the shortest time.
- Dark current suppression
- Good Quantum Efficiency
- ISO selection in DSLRs / Dynamic Range
- Well Depth – Dynamic Range (Ability of a camera to record simultaneously very low light signals alongside bright signal)

Dithering

- A method of shifting the telescope slightly between exposures to offset each image slightly.
- This results in fixed pixel defects like hot and cold pixels being misaligned in the final composite image and thus removed by median or Sigma Clip combine methods.



Filters

- Comparing filter total transmissions in units of 65535

	Lum	Red	Green	Blue	
Astrodon	5500	1173	1743	1510	(2E series)
Astronomik	5524	2099	2098	1979	(L2, DeepSky RGB)
Baader	5448	2596	2496	1579	

- Astrodon gives the lowest counts in RGB, especially R is very weak at almost half count.

Tests performed by Tommy Nawratil
www.teleskop-austria.com

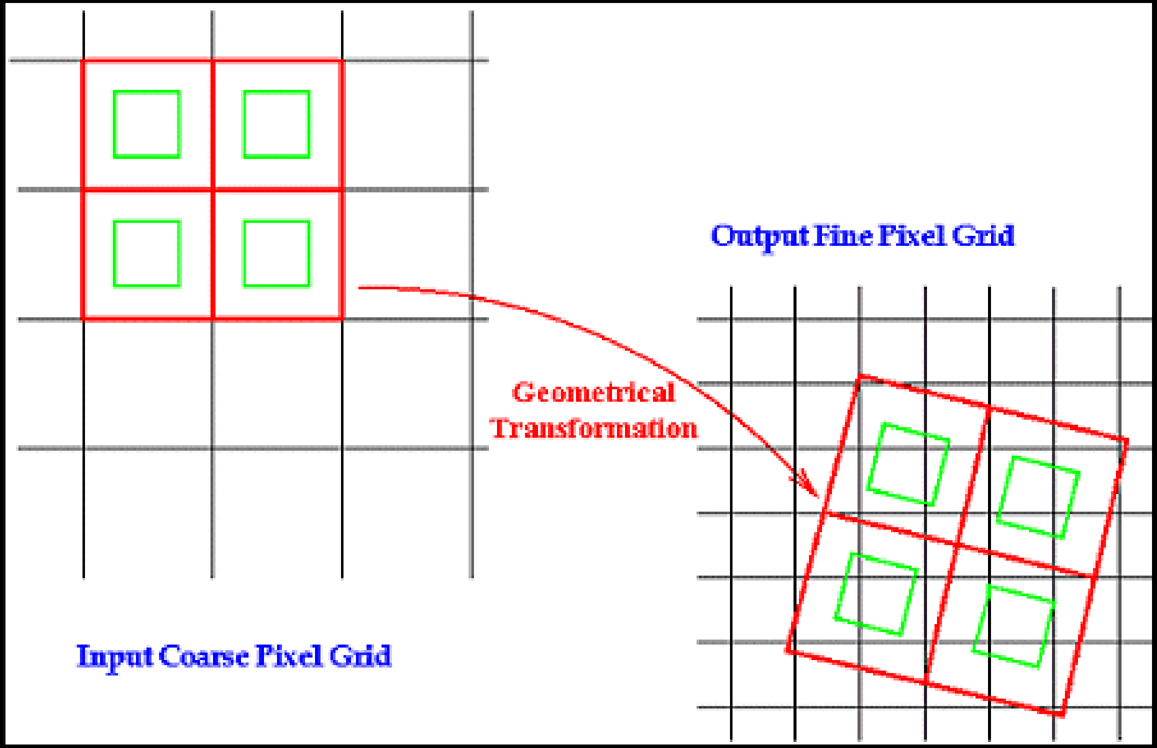
Binning for Color Data

When there is not enough time to capture everything in bin1x1

- Color data require 3x time to be equivalent to Lum
- Bin color data (RGB) to 2x2.
- Always set Luminance at 1x1 (full resolution)
- When combined with the L, the final LRGB will have the same level of detail as the Luminance image.
- Pay attention to color (RGB) sensitivity of your CCD and capture
  - Uneven sub frame time duration per color
  - More frames when you use a “less sensitive for your camera” color filter
  - Try to reach background to max 2/3 of your sky limit ADUs

Drizzle

- Variable Pixel Linear Reconstruction Algorithm, better known as “Drizzle” was created for NASA to correct for undersampled images taken by the Hubble Space Telescope



Drizzle

Image sample from deepskywest

Drizzle integration

Undersampled Data taken with 135mm lens – 8 arcsecs

Capturing Data Guidelines

- Measure and calculate your sky limited exposures
- Aim for shorter exposures except you are in a very dark location
  (if something goes wrong less data lost)
- Short exposures VS long exposures in terms of SNR loss is very small
- Divide your sky limit / 2 and take as many number of exposures you can
- Use Sigma Clip combine algorithm to stack
- Always use random dithering in all direction
- Bin color filters in 2x2 when there is not enough time.
- Use Drizzle when you are undersampling

Calibration Frames

Darks / Flats / Bias

- Always take **Flats** to correct uneven illumination
- Advise not to take darks on low dark current sensor (**Sony)**, Just do aggressive dithering / sigma clipping algorithm and it wipe out any hot/cold pixel
- Amp glow is reduced in Sony sensors when you cool them under -5°C
- **Any issue with glow requires calibration of your light/flat frames with darks**

Calibration Frames

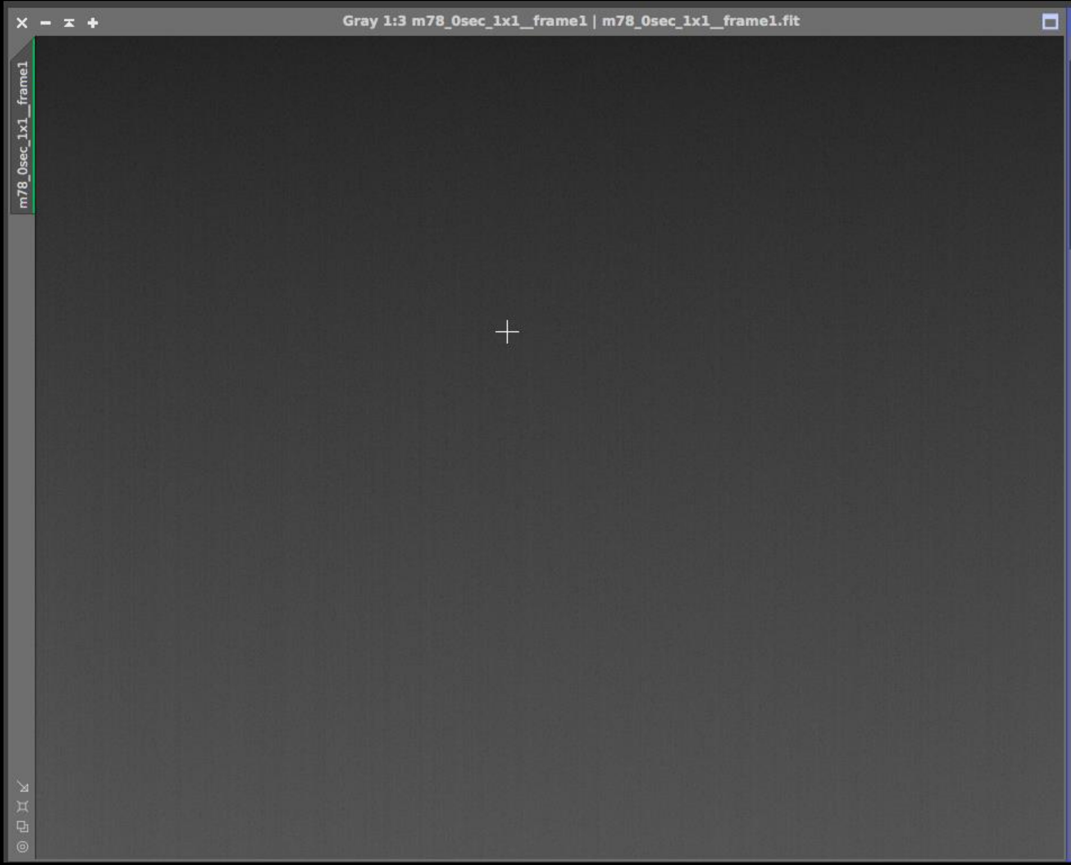
Effect of how many frames

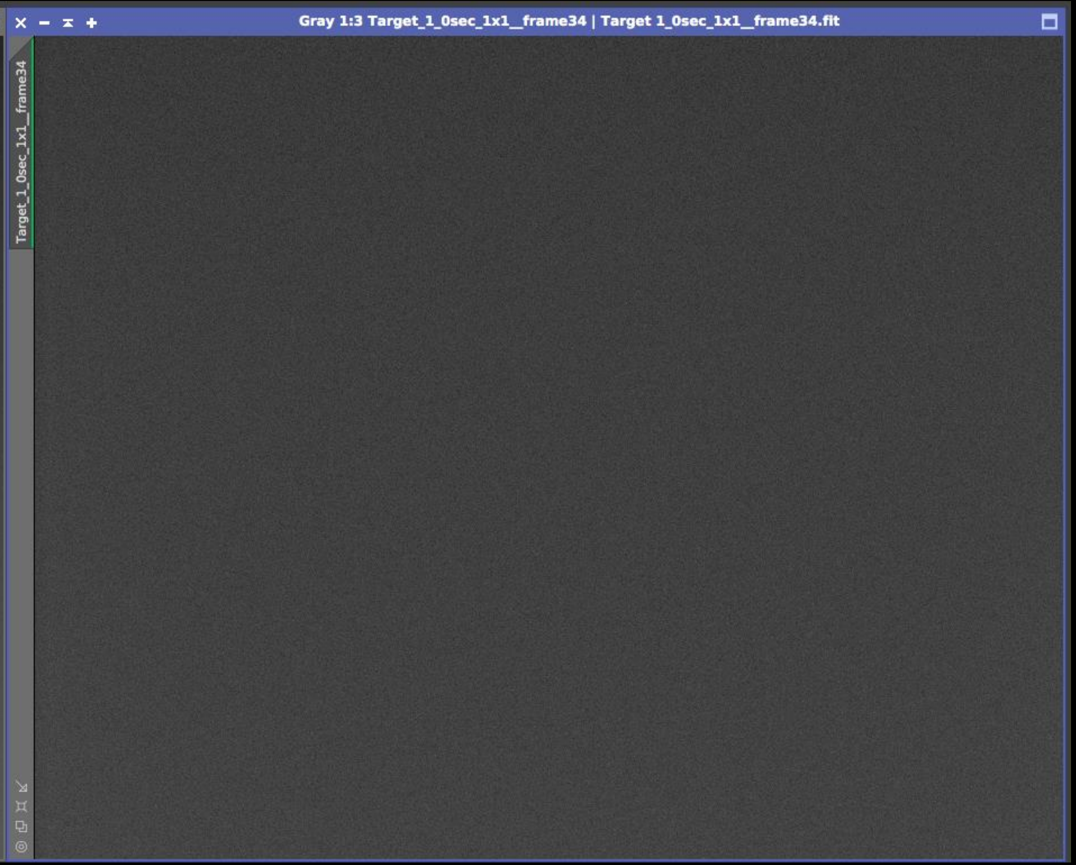
- Take **at least 30 calibration frames** and average stack to improve SNR. After 40 frames the difference is not visible.
- **ADU count in flats**
  - Don’t take flats less than 10k ADUs. You will increase noise
  - Don’t take flats more than 50k ADUs. You will create artifacts due to light saturation
  - 25k-35k is the best option here
  - Never seen a difference when I didn’t use odd number of frames. (median calculation)
  - Trial and Error for every CCD model. Check what suits in your case

Calibration Frames

Bias are very depended from temperature

BIAS of SONY ICX694 @15 °C vs BIAS of SONY ICX694 @ -5 °C





Synthetic Luminance

A good option if you have weak Luminance data (not enough time)

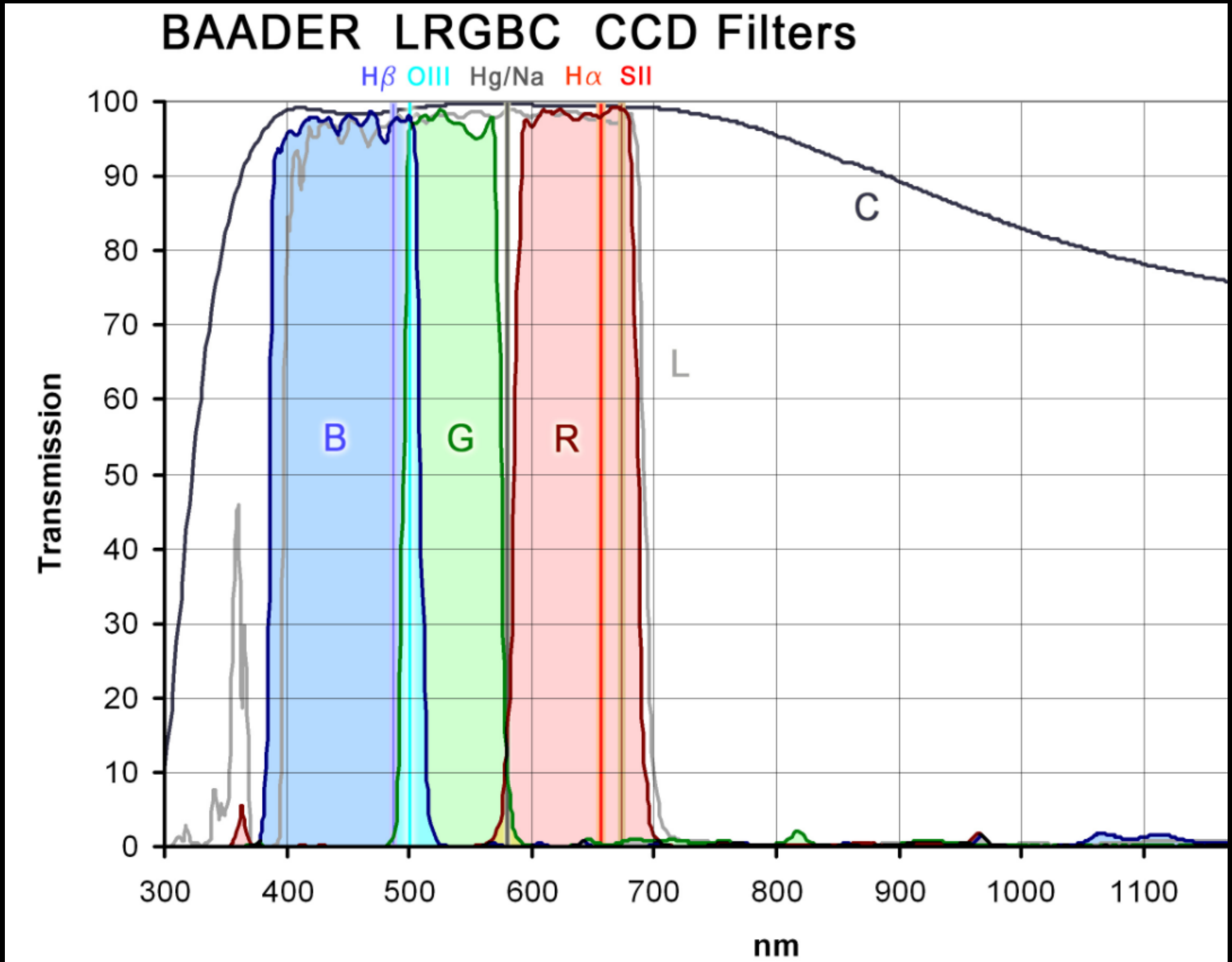
Combine **RGB + Ha data** and then **extract the luminance channel**

- Pixel math
- Average them in **ImageIntegration** tool of Pixinsight

Make sure you have taken care color gradients before the extraction

ImageIntegration : $L + L_{synthetic}$

Synthetic Luminance



Warning:

Actual Lum gives you higher SNR as it spans on all the visible spectrum.

RGB depends from your filters.

(Baader vs Astrodon have different results in SNR)

Synthetic Luminance

Multi Luminance Layering

… or how to enhance your RGB data (Introduced by Robert Gendler)

Our target: Acquire sufficient signal for good color data

- Low signal/noise ratio with reasonable exposure times
- Luminance tends to overwhelm and washout the RGB data
- **Do not increase saturation**
- **Do not lowering the opacity of the luminance**
- Both of them result in excessive noise and sacrifice of detail and an unsatisfying aesthetic result.

Multi Luminance Layering

Process

1. Create an LRGB composite image from your data
2. Reduce opacity to 50%
3. Add saturation and apply a small gaussian blur filter
4. Use this modified LRGB as your new enhanced RGB image
5. Do a final LRGB composite as you always do

Improvement of color S/N and resolution compared to the original RGB composite

The final result is an LRGB image with richer color and full preservation of detail.

Repeat process several times on demand and you can enrich more the color data.

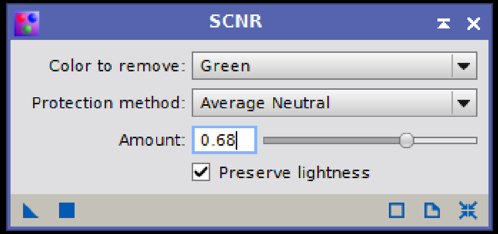
Multi Luminance Layering

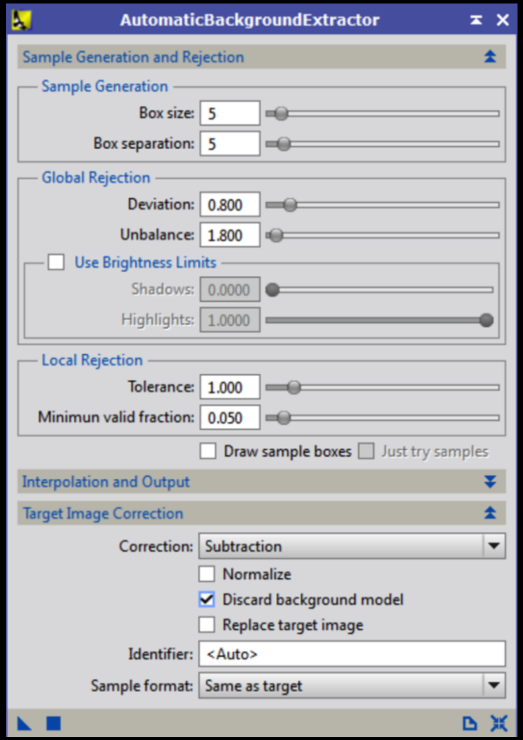
Before

After Multi LL + Star Reduction

Chrominance Noise Reduction

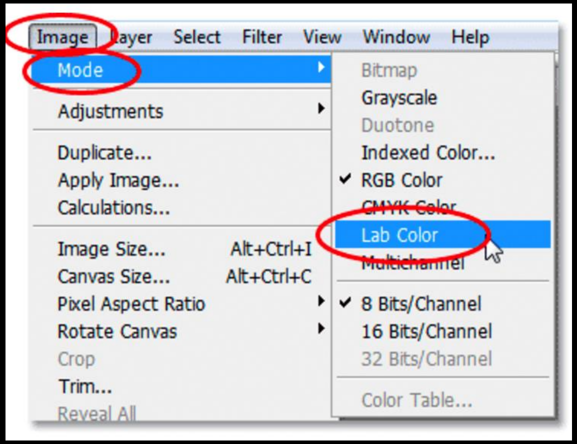
- Remove patterned color noise (ACDNR Color) or use Chromatic noise in LRGB Combination
- Remove any color gradient (Dynamic Background Extraction)
- Remove green noisy pixels (SCNR)

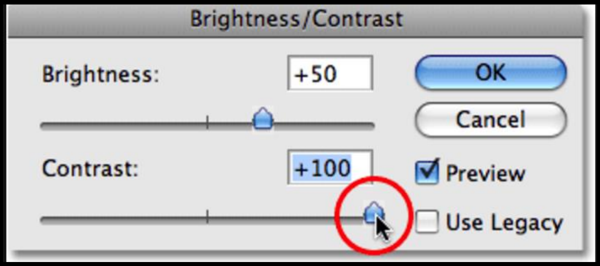




Chrominance Noise Reduction

- Saturation
  - Boost Saturation
  - Use Lab Color in Photoshop, Select A or B channels and Increase Contrast in each one of them.





After that combine Color with Luminance Data

Reduce Noise

ALWAYS USE MASKS

Never apply noise reduction without a mask. You will loose details and most of the times the result will look like pastel / plastic

- Use a star mask to reduce stars and exclude them from N/R
- Use a large mask to apply N/R to your background
- Always use a lightness mask to protect your objects
- Do not exaggerate the N/R! Image looks like a fake one!
- If you have time take more shots to increase SNR.

Reduce Noise

- Most of the errors are done during N/R process

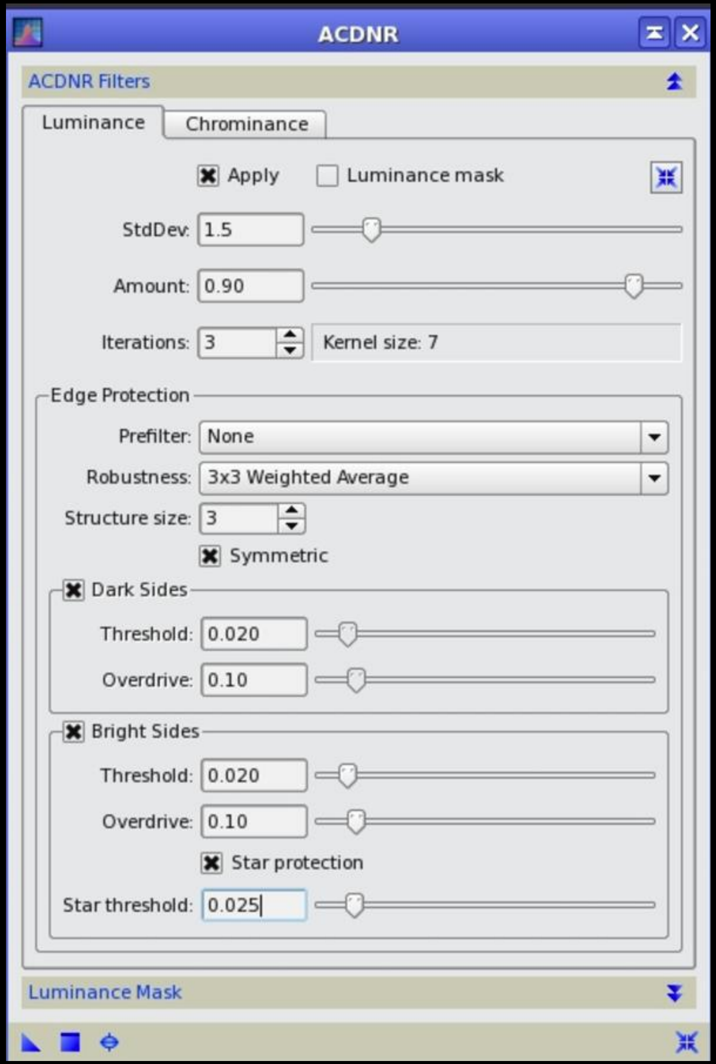
Again, pay attention and never apply a noise reduction filter without a **luminance** mask

- Noise Ninja
- Noiseware
- Topaz DeNoize
- Neat Image

Tends to create a plastic feeling and a strange washout pattern in the background of your final image

ACDNR

- Applies to pixel structure sizes via individual wavelet layers
- Good for Linear or not Linear images
- Smooth noise reduction
- Can be applied in Lum or Color data separately
- Always use a mask or else it can blur details in edges



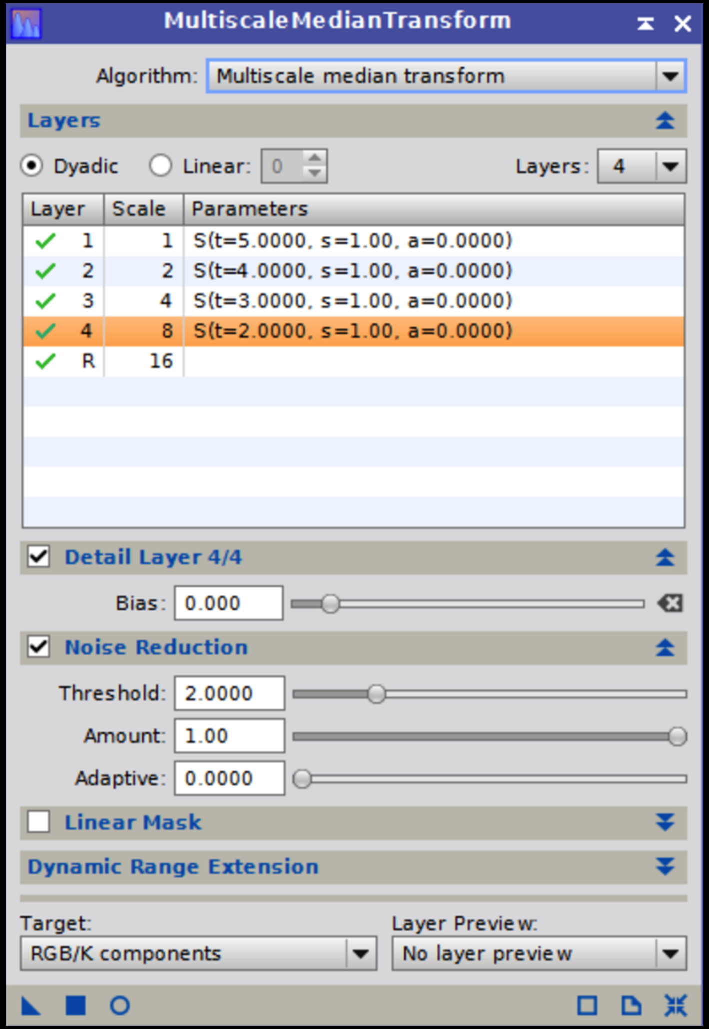
ACDNR

Original RGB

RGB Stack applying Luminance + Chrominance N/R with Lum Mask

Multiscale Median Transform

- Good for linear & non linear images
- Noise reduction can be done smoothly
- Smooth noise reduction
- Can be applied in Lum or Color data
- It leaves behind black noise pixels over background that need some smoothing



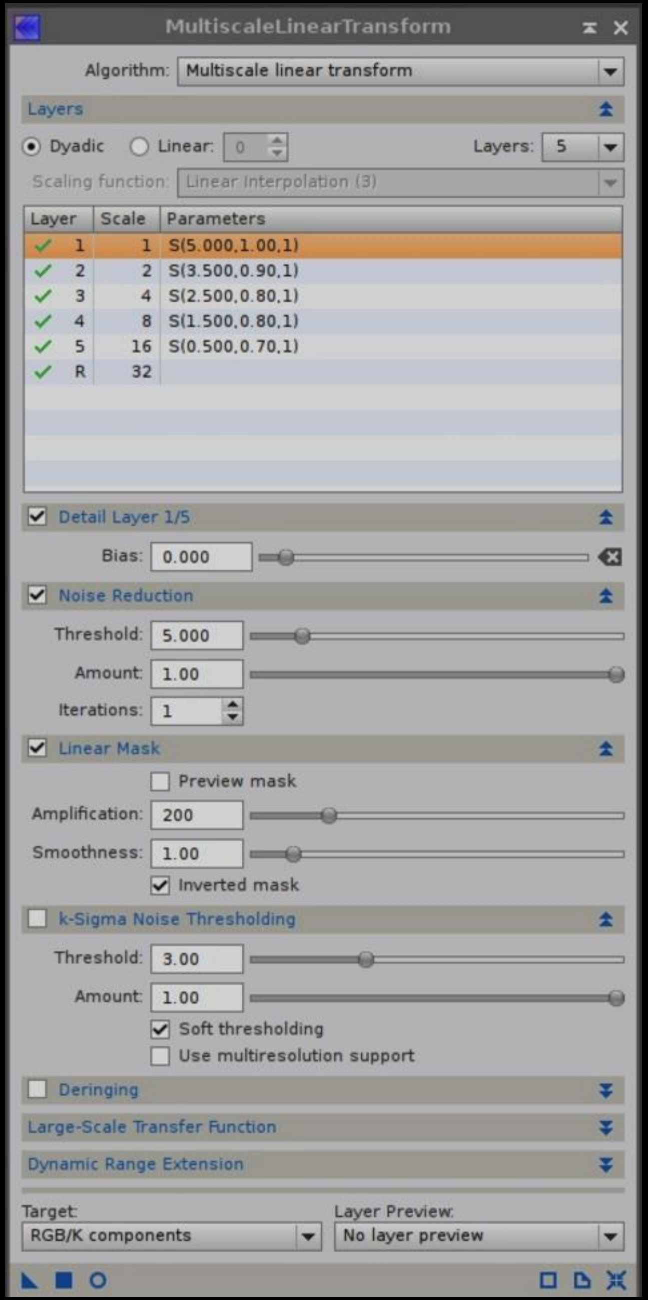
Multiscale Median Transform

Original RGB

Multiscale Median Transform

Multiscale Linear Transform

- Applies to pixel structure sizes via individual wavelet layers
- Good for Linear or non Linear images
- Smooth noise reduction
- Can be applied in Lum or Color data
- Always use a mask or else it can blur details in edges



Multiscale Linear Transform

Original RGB

No mask

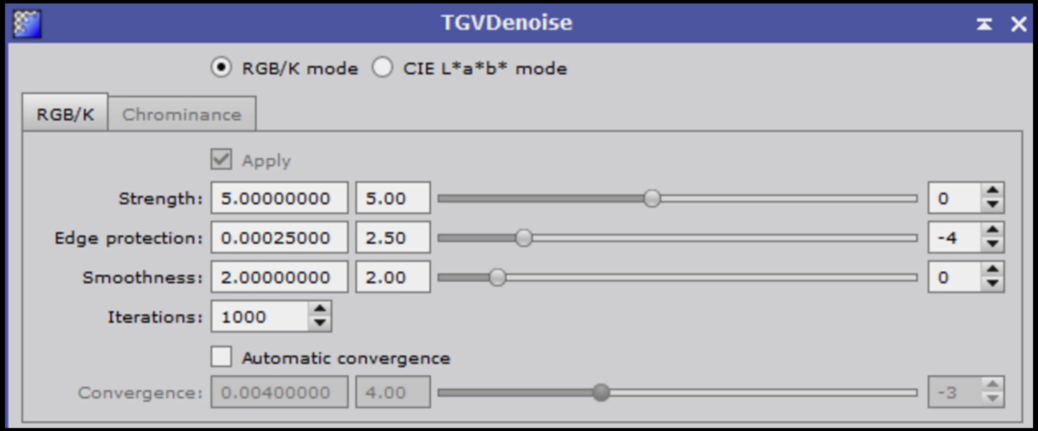
Multiscale Linear Transform

Original RGB

Reverse Mask Applied

TGV Denoise

- Applies to pixel structure sizes via individual wavelet layers
- Good for Linear or not Linear images
- Smooth noise reduction
- Can be applied in Lum or Color data
- Always use a mask or else it can blur details in edges



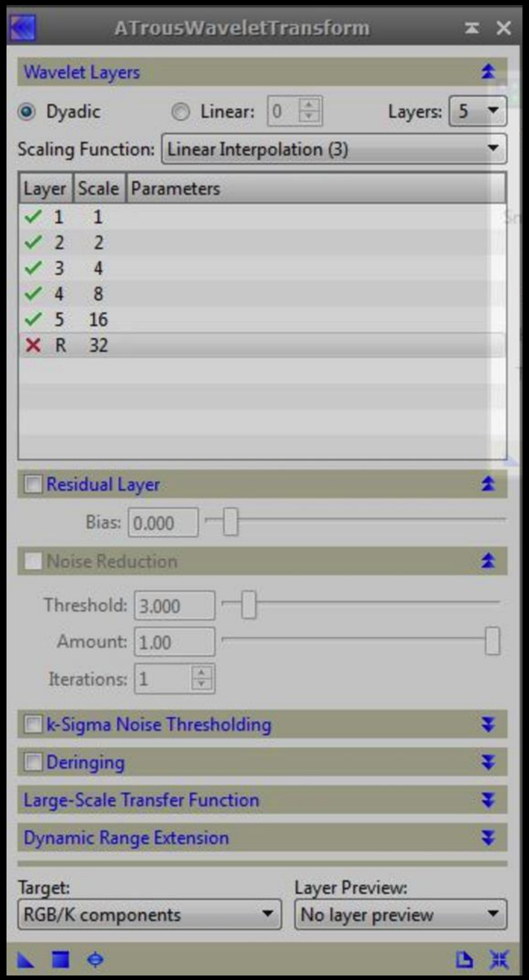
TGV Denoise

Original RGB

Reverse Mask Applied

Multi Scale Processing

- Try to reveal faint large structures such as Integrated F lux Nebulae (IFN) which are very close to the noise floor
- Introduced by Rogelio Bernal Andreo
- Breaks the image into small, and large scale structures
- Lightly stretches the image with the large scale structures
- Creates a mask so the process only happens on the darkest areas of the image
- Adds everything back together



Multi Scale Processing

Final LRGB

Large Scale Structures Processing

Thank you

Celestialpixels.com

Evangelos Souglakos