Combining Images for SNR improvement

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Improving SNR by Combining Multiple Frames

- The typical Astro Image is made by combining many sub-exposures (frames) into a single exposure using averaging, median combines etc.
- The SNR is improved by this combining of data, but:
  - Is there a limit to how many frames should be combined?

Signal To Noise Ratio Theory

- Signal to Noise ratio is defined:

$$SNR = \frac{Signal}{Noise} \tag{1}$$

- In the general case there are many noise components: the most commonly encountered significant ones are included in the equation below

$$Noise = \sqrt{\begin{matrix} Signal\_shot\_noise^2 + Read\_noise^2 + Fixed\_pattern\_noise^2 + \\ Dark\_shot\_noise^2 + \ Dark\_fixed\_pattern\_noise^2 \end{matrix}} \tag{2}$$

- Many of these noise components can be made negligible by picking proper operating temperature and performing simple image calibration
  - Fixed Patten Noise is eliminated by proper Flat-Fielding
  - Dark Shot Noise: cooling can render this parameter insignificant
  - Dark Fixed Pattern Noise: dark-subtraction (“despiking”) eliminates what remains of this term that cooling doesn’t directly eliminate
- Applying these techniques the noise equation reduces to:

$$Noise = \sqrt{Signal\_shot\_noise^2 + Read\_noise^2} \tag{3}$$

Signal To Noise Ratio Theory

- Since

$$Signal\_Shot\_Noise = \sqrt{Signal} \tag{4}$$

- Substituting (4) into (3) the noise equation becomes:

$$Noise = \sqrt{Signal + Read\_noise^2} \tag{5}$$

- Substituting (5) into (1) we get

$$SNR = \frac{Signal}{\sqrt{Signal + Read\_noise^2}} \tag{6}$$

- If the read noise is small compared to the signal, it further reduces to

$$SNR = \sqrt{Signal} \tag{7}$$

Implications

- Doubling the SNR:
  - Neglecting read noise, FPN and dark noise components, to double the SNR, we need 4x as much signal

$$SNR_{2x} = 2 * SNR_1 = 2 * \sqrt{Signal_1} = \sqrt{4 * Signal_1} = \sqrt{Signal_2}$$

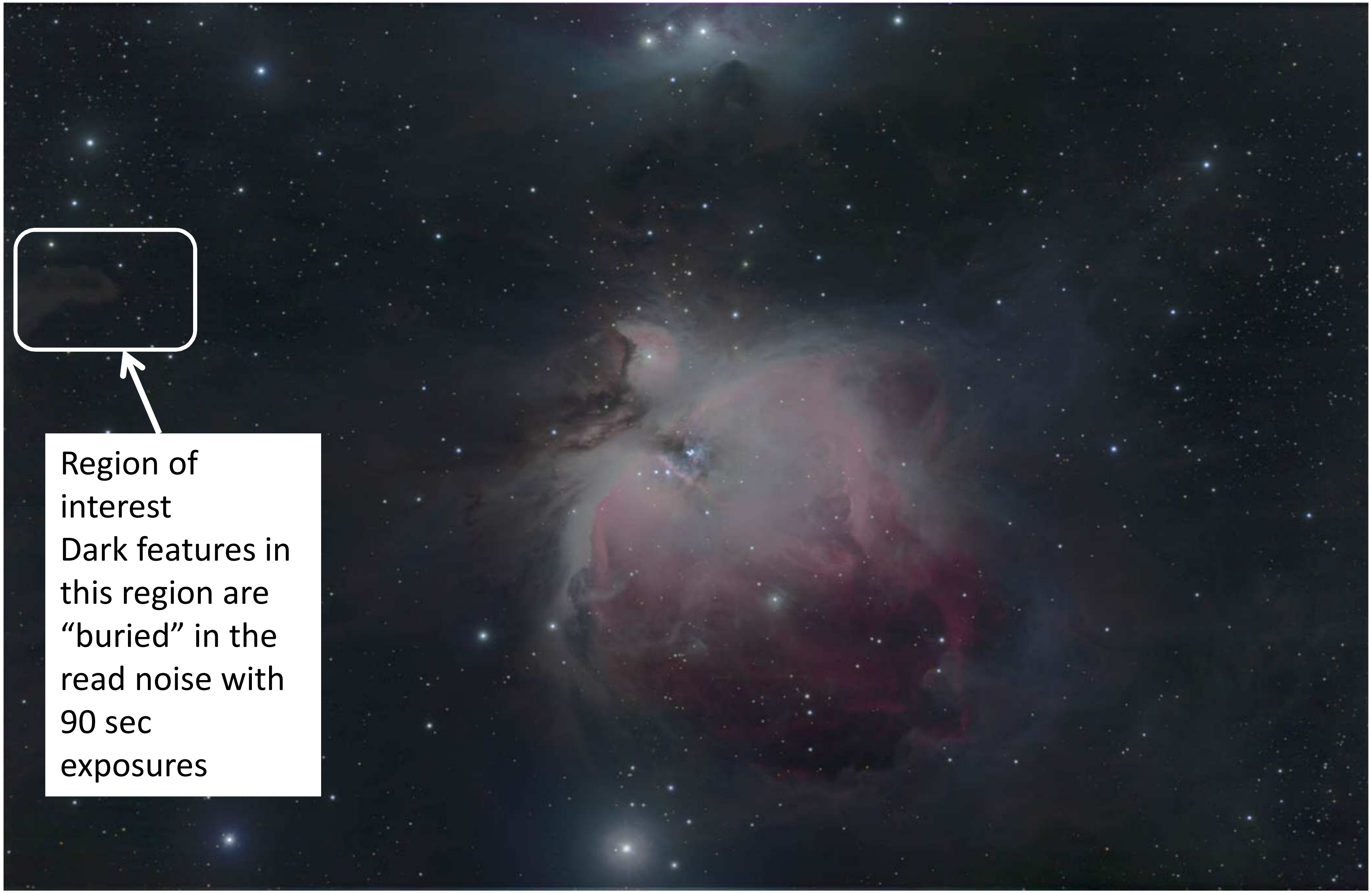
$therefore$: $Signal_2$ = 4* $Signal_1$

- While doubling the number of exposures does not have any limit, there are practical considerations given to the total amount of time available for taking the image data
- One situation where a very large number (> 200) of exposures may be beneficial is when capturing the faint nebulosity surrounding a very bright object that you wish to avoid excessively saturating.
  - Example: Trapezium/M42 from camera with ABG and 20,500 e- saturation signal: up to 233 exposures of 90 sec.

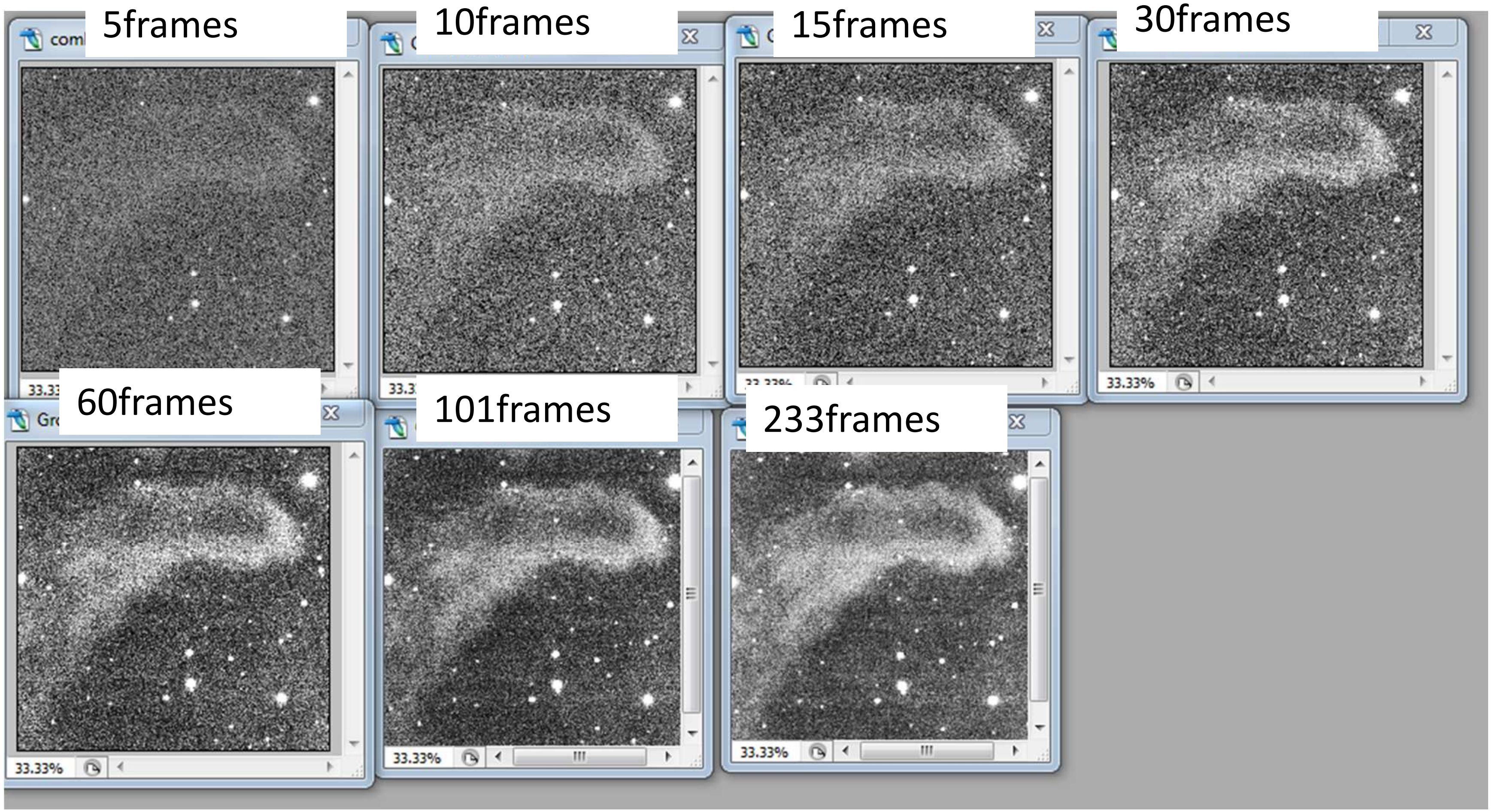
Example HDR Image taken with large # of exposures

- M42/Trapezium Region
- LRGB image
  - KAI29050 sensor: saturation signal is 20,500 e-
  - 4 hours of R, G, B total (1H 20M/channel), 120 second exposures
  - 7.25 hours of Luminance, 90 second exposures

Example HDR Image



ABG Sensor (KAI29050) with 20,500 e- saturation signal on HDR object (M42)



Very faint parts of image are buried in read noise: use large numbers of frames to improve SNR (ie 90 second exposures in Orion Nebula)

Examination of Noise using Bias Frames

- Since a Bias frame is a zero length exposure it is largely a measure of the system read noise
- It does take a finite time to readout/download from the sensor so dark signal is accumulated during that time.
- Cooling can make the dark signal less important
- Examining stacks of cooled bias frames therefore is a way to estimate the impact of read noise contribution to the overall noise in a stack of short exposures such as in the M42 example
- Theory says that a quadrupling of # of frames is needed for a 2x reduction of noise.

<u>Let's confirm by experiment</u>

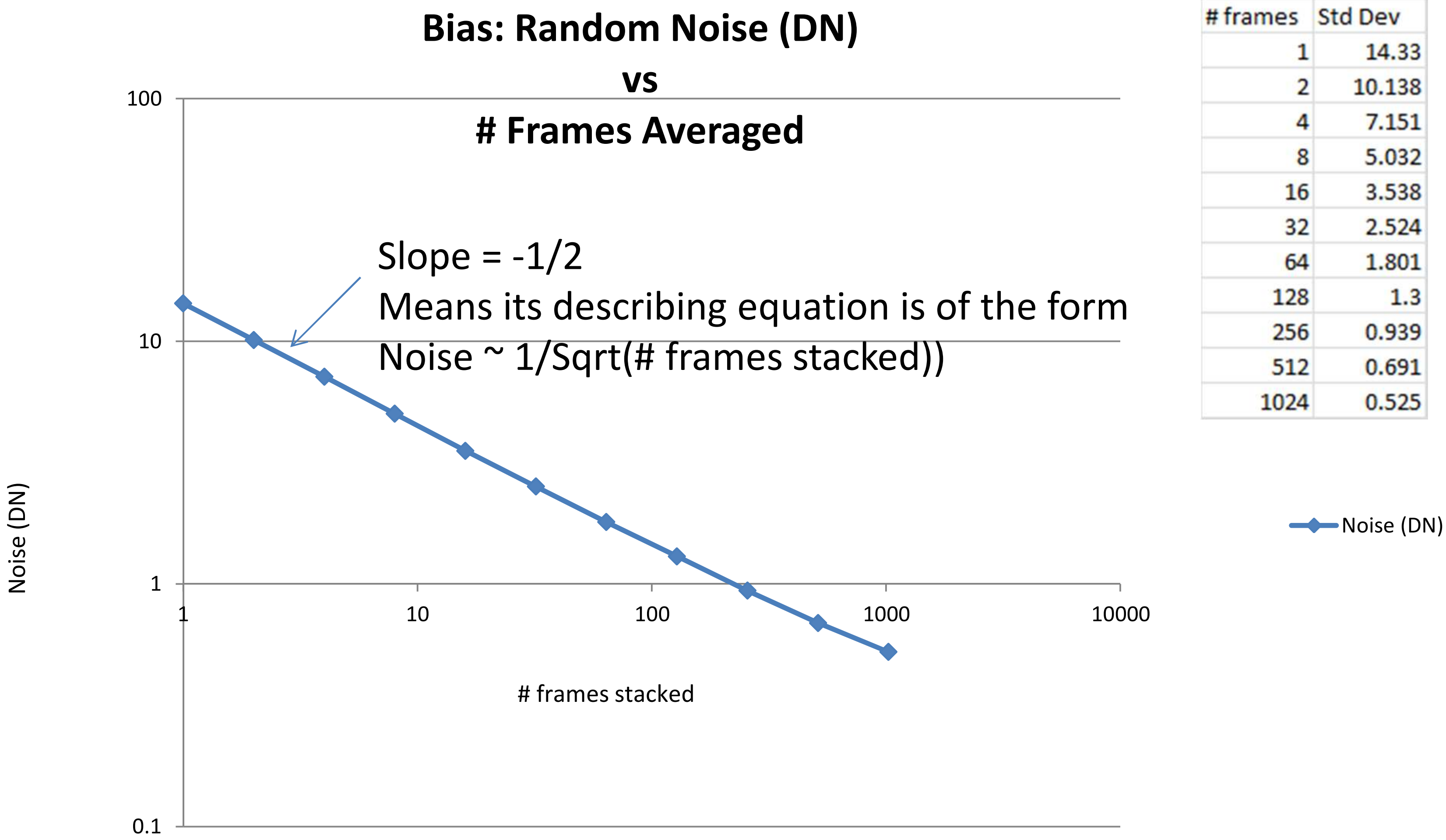
Experimental verification of Theory

- Procedure:
  - Take 1024 identical bias frames
  - Average 2, 4, 8, 16, 32, 64, 128, 256, 512, 1024 frames together
  - Crop a 10,000 pixel box in a clean area
  - Measure Std Dev in this box and record
  - Plot Std Dev vs # frames on Logarithmic axes

Bias Frames Analyzed

Standard Deviation of the entire cropped image is measured and recorded for each image

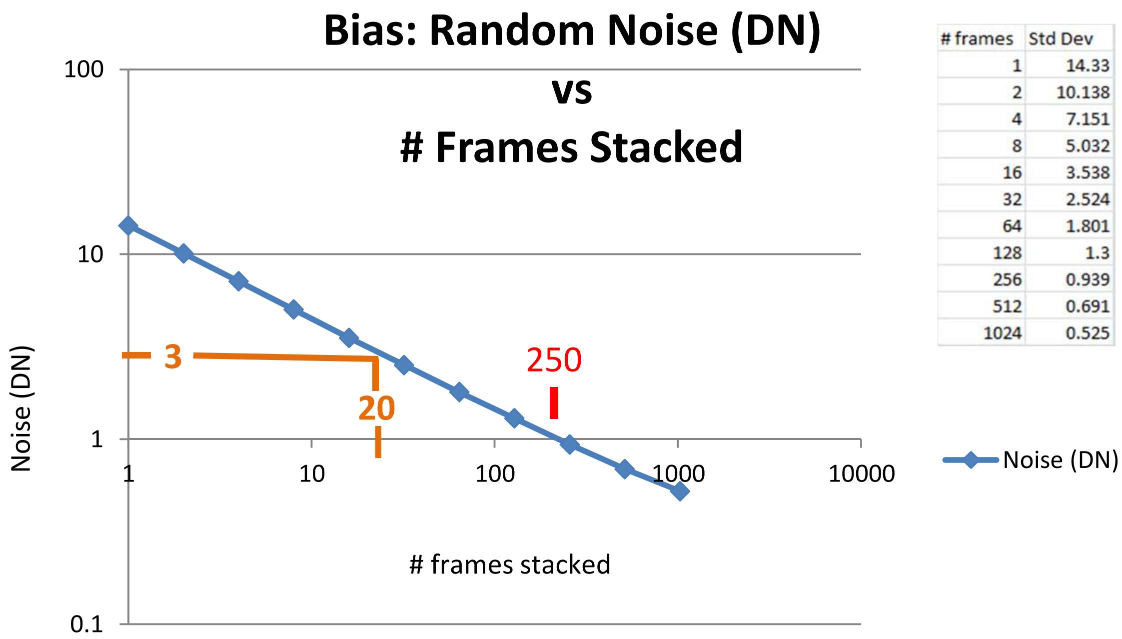
Noise Reduction by Stacking



# frames	Std Dev
1	14.33
2	10.138
4	7.151
8	5.032
16	3.538
32	2.524
64	1.801
128	1.3
256	0.939
512	0.691
1024	0.525

Practical Observations

- In this example with 1 image, the effective read noise contributed by the camera is 14.33 DN. Stacking 20 frames it is reduced to about 3 DN. To reduce below 1 DN requires around 250 frames
- For images of very faint objects it may be necessary to take a large number of exposures, particularly if the exposure time is limited out of dynamic range considerations. For M42, the Trapezium stars limit the exposure time so many exposures are needed to get the faint nebulosity with acceptable SNR



# frames	Std Dev
1	14.33
2	10.138
4	7.151
8	5.032
16	3.538
32	2.524
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