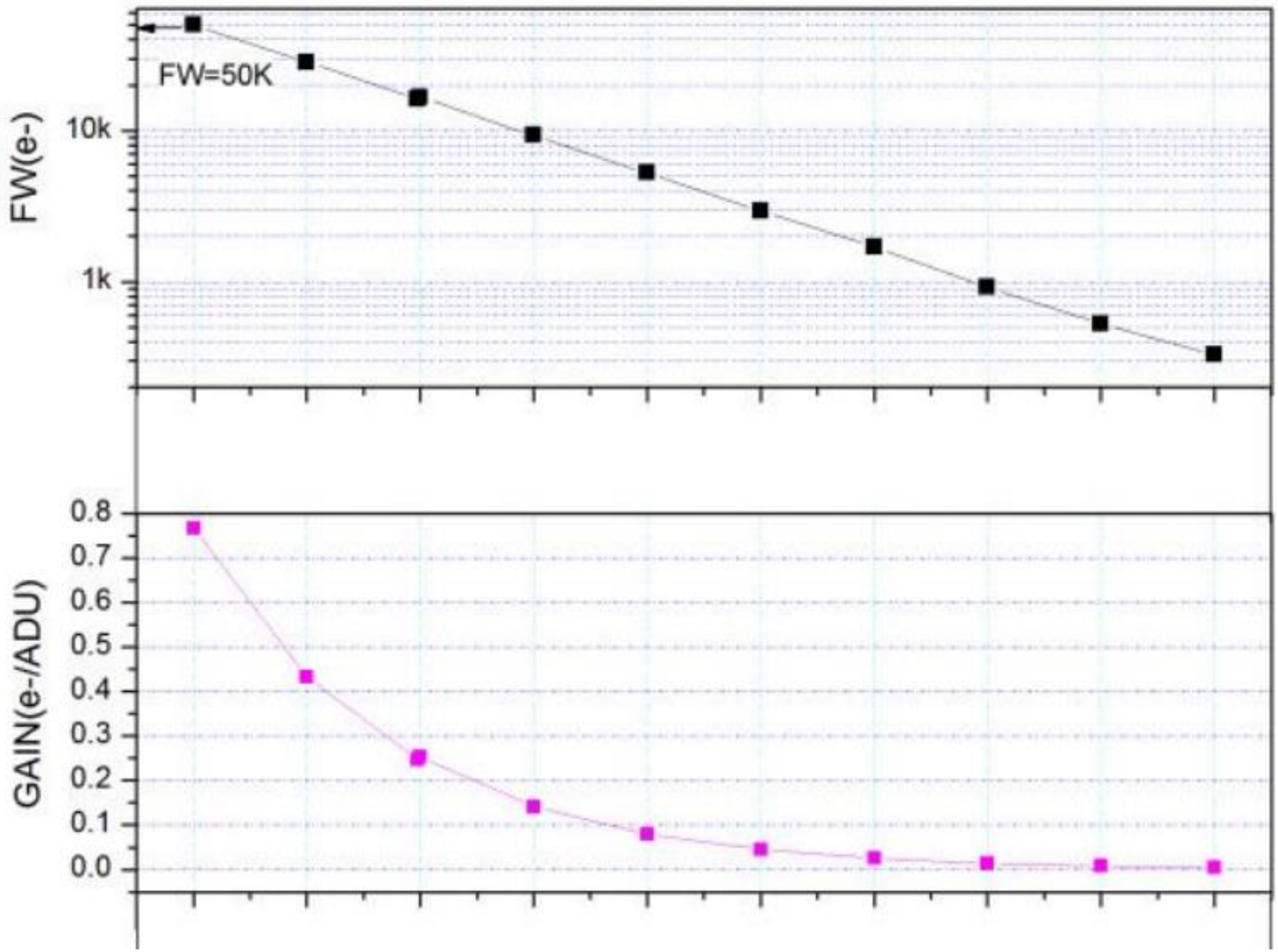
How to choose exposure length

Following Robin Glover (SharpCap)

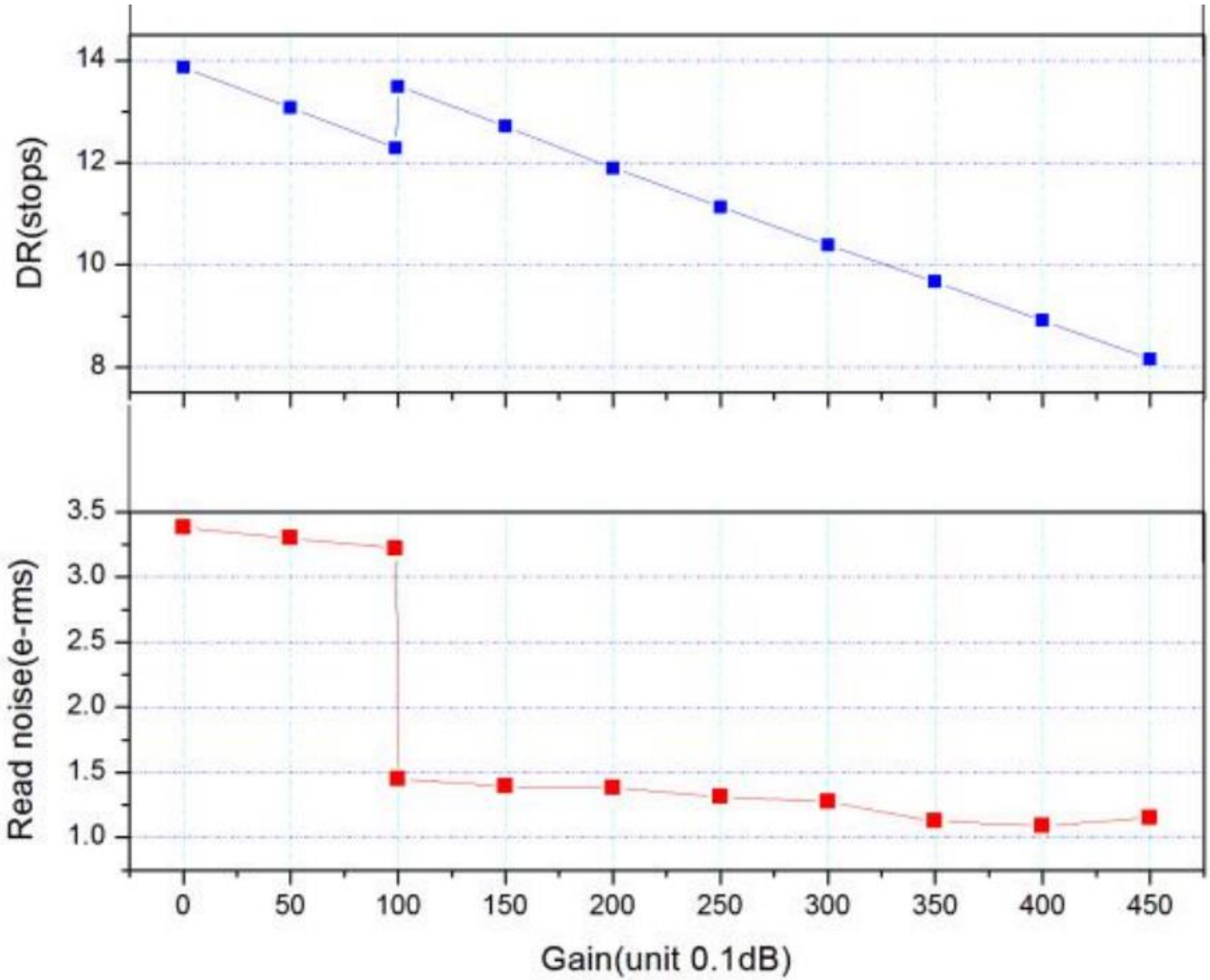
[Deep Sky Astrophotography With CMOS Cameras by Dr Robin Glover – YouTube]

[Choosing the right gain for Deep Sky imaging with CMOS cameras - YouTube]

ASI2600 (X-axis = gain in 0.1 dB)



ASI2600 (X-axis = gain in 0.1 dB)



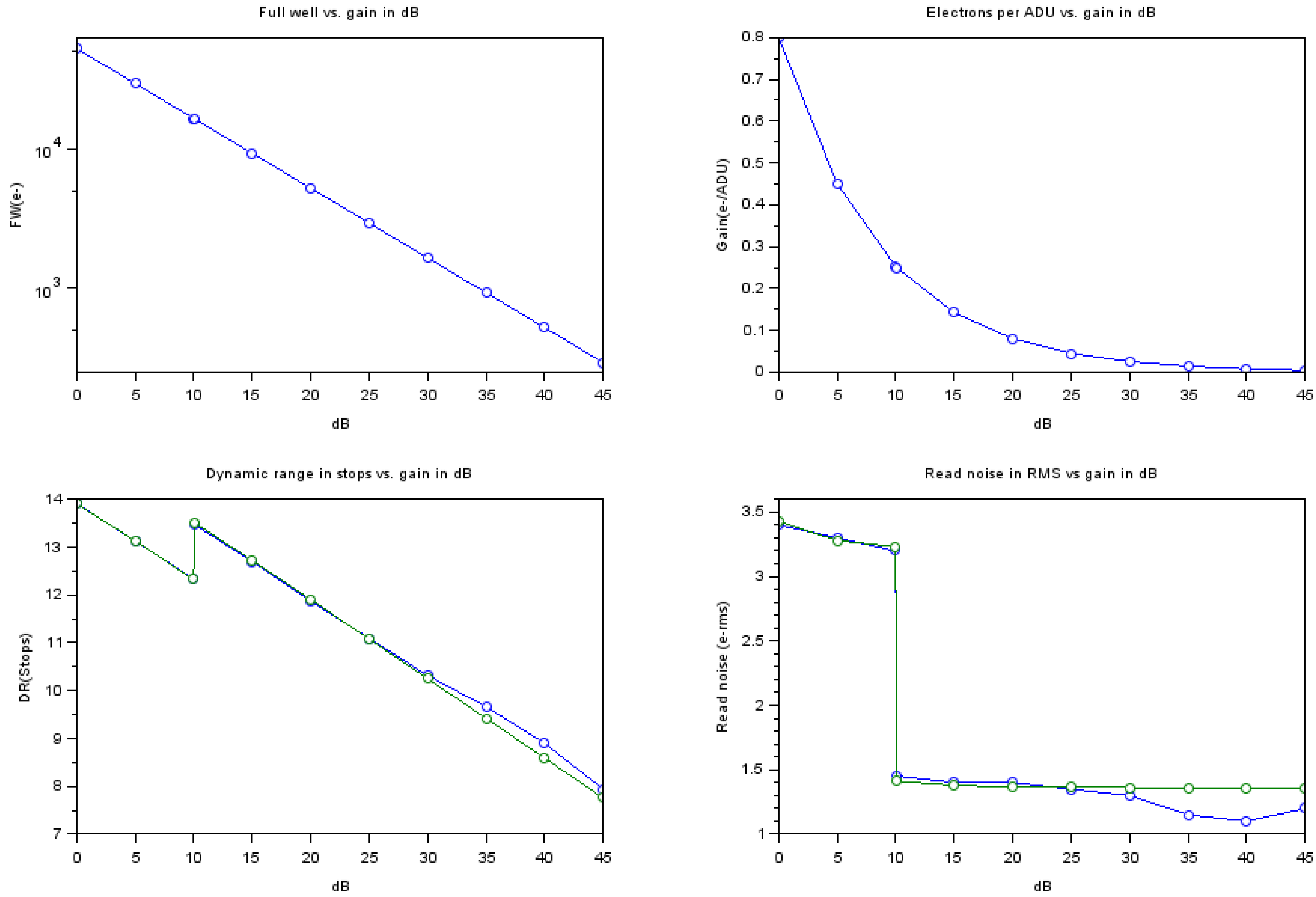
CMOS amplification

- Conversion amplifier (e- charge to ADC voltage):
  - Some sensors (ASI2600 for instance) use dual gain conversion where the charge to voltage conversion gain can be 1 (LCG=low conversion gain) or higher (HCG=high conversion gain) above a certain user-selected gain level.
  - HCG significantly reduces digitization noise but also reduces the full well depth (in e-)
- ADC amplifier (user facing Gain):
  - Also expressed in dB:
    - $dB = 20\log_{10} Gain$ and $Gain = 10^{\frac{dB}{20}}$
    - Note: ZWO uses 0.1 dB units
  - Full well (e-): $FW = \frac{eMax}{Gain}$ where $eMax$ = maximum e- charge
  - e- per ADU: $eGain = \frac{FW}{2^{nBits}}$
  - Read noise (RN, in e- RMS): Obtained from measurements
  - Dynamic range in stops: $DR = \log_2(FW/RN)$

CMOS dual conversion noise model

- Model proposed by Bill Claff for Sony A7s
  - Sony A7S DR-Pix Read Noise (photonstophotos.net)
- Conversion gain amplifier (e- to V):
  - $rmsOut_1 = \sqrt{(convGain \times rmsIn_1)^2 + addNoise_1{}^2}$
- ADC amplifier (V to V):
  - $rmsOut_2 = \sqrt{\left(\frac{Gain \times rmsOut_1}{convGain(Gain)}\right)^2 + addNoise_2{}^2} =$
    $\sqrt{(Gain \times rmsIn_1)^2 + \left(\frac{Gain \times addNoise_1}{convGain(Gain)}\right)^2 + addNoise_2{}^2}$
- Divide $rmsOut_2$ by $Gain$ to convert to e- rms
- ASI2600 parameters that match the graphs:
  $rmsIn_1 = 1, HCG = 3.3, addNoise_1 = 3.05$ and $addNoise_2 = 1.2$.

ASI2600 dual conversion model fit



Ideal sensor and peripherals

- The ideal sensor is a photon counter for a telescope in perfect operating conditions
  - Long or short subs makes no difference in this case
    - The sum of independent Poisson-distributed random variables (aka shot noise) also has a Poisson distribution with a mean and variance that is the sum of the means and variances of the individual ones.
  - The variance and SNR of the stacked data is the same regardless of the sub exposure length.

Non-ideal operating conditions

- Read noise (analog electronics, ADC)
- Thermal noise
- Light pollution
- Saturation
- Pattern noise (amp glow, banding)
- Quantum efficiency (QE)
- Tracking errors, seeing, satellite trails, etcetera
  - For this, shorter is better. How short can we go?

Light Pollution

- Expressed in electrons per pixel per second
- Photon rate follows from F ratio, sensor hardware (pixel pitch, QE), camera (RGB/Mono), narrowband filter width, Bortle number, atmosphere, dark current (sensor temperature)
- Sky background calculator at
  Sky Background Calculator (sharpcap.co.uk)
- Balance the LP against the thermal noise
  - Cool it such that thermal is 5% or 10% of LP
  - Thermal noise is otherwise similar to LP
    - During post-processing we can remove it using darks but the electronics cannot filter it out when taking data

SharpCap sky calculator

Calculate Sky Background Electron Rate

This tool will calculate the sky background electron rate you can expect.
Just enter details of your light pollution levels and imaging system.

Your Sky Brightness

Sky Magnitude	19.00	magnitude per arcsec^2
or Bortle Number	5.8	(Bright suburban sky)
or Naked Eye Limiting Magnitude	5.4	

Your Telescope

F Ratio	4.5

Your Camera

Pixel Size	3.75	microns
Quantum Efficiency	80	%

○ Monochrome ◉ Colour

Your Filter

Selected Filter	None (Luminance)	
Bandwidth	100	nm

The Result

Sky Electron Rate **4.66 e/pixel/s**

LP table by Robin Glover

LIGHT POLLUTION RATES (ELECTRONS PER PIXEL PER SECOND)

	Bortle 9 Inner City	Bortle 7 Urban	Bortle 5 Suburban	Bortle 3 Rural	Bortle 1 Excellent Dark
f/4	175	22	5.3	1.2	0.80
f/5	112	14	3.7	0.81	0.51
f/6	78	9.6	2.6	0.56	0.36
f/7	57	7.1	1.9	0.41	0.26
f/10	28	3.4	0.85	0.19	0.13

- Data for mono sensor, 50% QE, 3.75 micron pixels
- For a colour sensor or RGB filters, divide by 3
- For a narrowband filter, divide by 25 (12nm) to 100 (3nm)
- http://tools.sharpcap.co.uk

Sensor + stacker model

- R = read noise mean rate in electrons/pixel/second
- P = LP rate in electrons/pixel/second
- T = integration time
- s = sub-exposure time
- n = #subs
- E = noise tolerance in % over best possible level
  - Add no more than E % RMS due to read noise
- Stack total noise = $\sqrt{nR^2 + TP}$ =$\sqrt{n}\sqrt{R^2 + sP}$
- Optimum $s = C\,\frac{R^2}{P} = \frac{1}{\left(\frac{100+E}{100}\right)^2 - 1}\frac{R^2}{P}$
  - Say, $C = 10$ for $E = 5\%$
  - R depends on the camera specific gain
  - This model does not account for saturation!

Optimizing gain and exposure

- Stay above the noise floor to pull out the LP background and above including nebulosity
  - $s \geq C\frac{R^2}{P} = \frac{1}{\left(\frac{100+E}{100}\right)^2 - 1}$ (with $C = 10$ for $E = 5\%$)
- Stay below the full well to prevent star clipping
  - For typical bright targets, LP is at 0-5% of the histogram, nebulosity is at 5-8% and the brightest stars are at 90-100%
  - If we know the LP in e-/pixel/s then the brightest stars will be roughly 30x that: $s \times 30 \times P \leq FW$
- This is all per sub. The stacker will improve the SNR for n subs by a factor $\sqrt{n}$

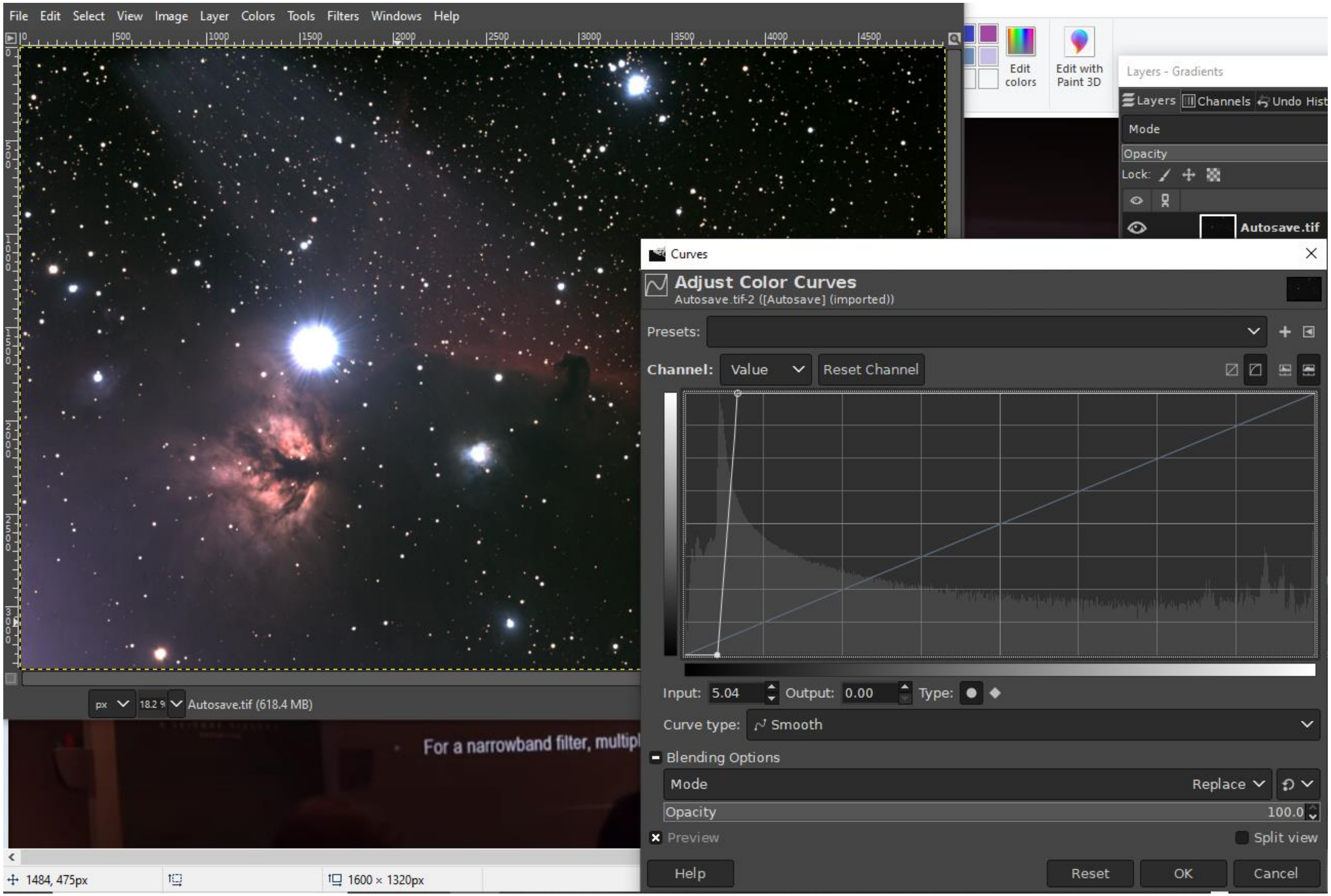
Exposure length by Robin Glover

RECOMMENDATION: OPTIMUM SUB LENGTHS
(NOISE 5% ABOVE MINIMUM LEVEL)

	Bortle 9 Inner City		Bortle 7 Urban		Bortle 5 Suburban		Bortle 3 Rural		Bortle 1 Excellent Dark	
f/4	0.3	2.7	2.8	22	12	90	51	400	76	600
f/5	0.5	4.3	4.4	34	17	130	75	590	120	940
f/6	0.8	6.1	6.4	50	24	180	110	850	170	1330
f/7	1.1	8.4	8.6	67	32	250	150	1170	240	1840
f/10	2.2	17	18	140	72	560	320	2520	470	3680

- Black for 2.5e Read Noise, Red for 7e Read Noise
- Data for mono sensor, 50% QE, 3.75 micron pixels
- For a colour sensor or RGB filters, multiply by 3
- For a narrowband filter, multiply by 25 (12nm) to 100 (3nm)

Example: Horsehead RGB



Example: Horsehead RGB

- Histogram typical of bright DSOs:
  - LP is at 0-5%
  - Brightest stars are at 90-100% (about 30 x P e-/pixel/s)

- Exposure (s):

Bortle\Gain	0 dB	9.99 dB	10.1 dB
5.8	24.8 s	22.0 s	4.2 s
1.0	340 s	301 s	66.2 s

- Stars at s x 30 x P (e-):

Bortle\FW	0 dB FW=52428	9.99 dB FW=16580	10.1 dB FW=16580
5.8	3467 e-	3187 e-	587 e-
1.0	47532 e-	42080 e-	9255 e-