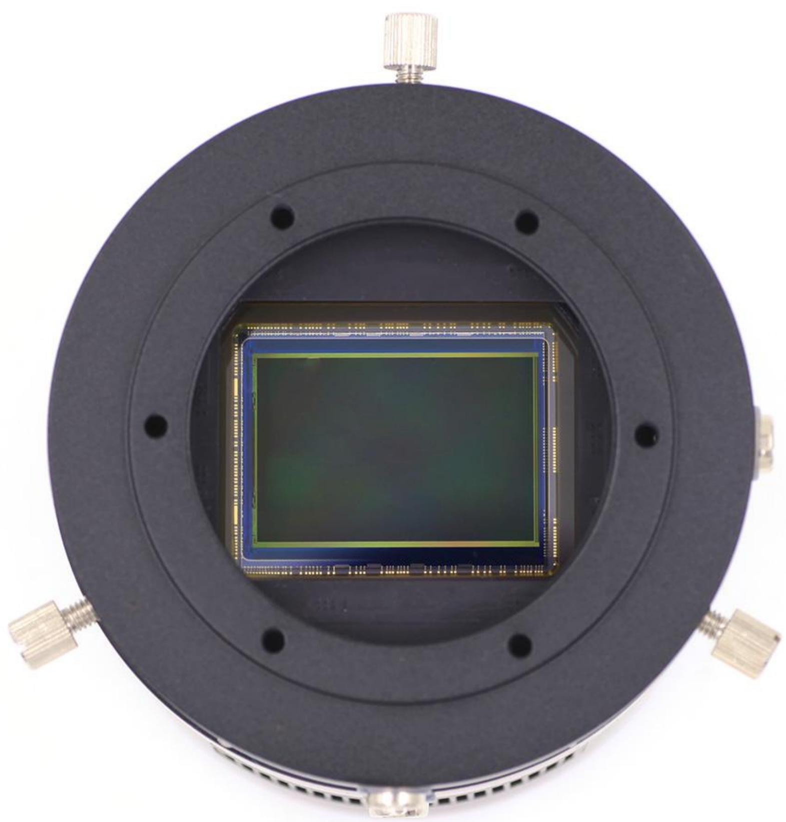
English Version

Dr. Q on astrophotography:

Setting GAIN and OFFSET on cold CMOS camera for deep sky astrophotography



First of all, because of some characteristics of the current CMOS cameras like insufficient AD sampling rate (12bit or 14bit), or higher gain results in lower read-out noise, there is no such thing as “the best GAIN and OFFSET” values. We need to understand about read out noise, full well capacity, system gain , as well as noise from the

background sky cosmic waves, to help us setting the GAIN and OFFSET.
To let everyone start taking pictures, we would like to discuss the principle of setting GAIN and OFFSET for cold CMOS camera. Then, we will explain in detail why we use such principle.

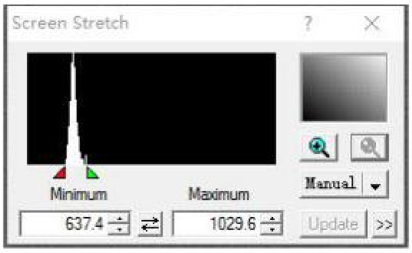
GAIN setting

If you haven't used a cold CMOS camera before, we recommend that you set the gain to "unit-gain" in the beginning. Unit-gain means the gain of which 1 electron per ADU (1e/ADU). In general we give you this number. For example, QHY168C the unit-gain is 10, QHY367C is 2800. You don't need to bother much about this value, increase or decrease a bit doesn't make a big difference.
*Attention: Setting the unit-gain is not the best setting. It is only a beginning
Then we increase or decrease the gain value according to the condition. In general if your optics is a fast one, low F-ratio between F2.2 to F5, long exposure for more than 5 minutes and not using narrowband filters, then you can decrease the GAIN value to achieve a higher dynamic range and make better use of full well capacity. Doing so will avoid overexposure of the stars. You will see overexposed stars as bloated and loss of color saturation.
If you use narrowband filter on a slow optical system between F6 – F10, and short exposure time, then the number of photons received will be lower. In this case you can increase the GAIN value to make better use of characteristics of low read-out noise in high GAIN value. This will increase the signal to noise level of your target.

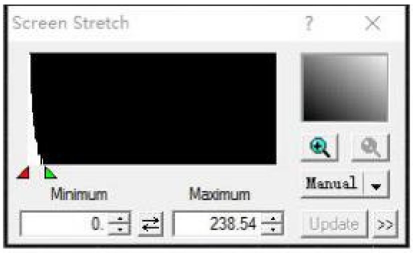
OFFSET

There is no such thing as the best value for OFFSET. This is how you should set the OFFSET value: Take the bias frame and dark frame at a certain GAIN value, then study the histogram of the frames.
You can see that the histogram distribution is a peak-like curve. By changing the OFFSET value, this curve will move left or right. We have to make sure the range of the whole curve is greater than 0. It cannot be chopped off at the end. At the same time, we need to have a bit of residue on the left side, just a bit greater than 0. Difference of 100 to couple hundreds ADU, even thousands is ok. However, it cannot be too huge that it takes a good portion of the effective dynamic range between 0-65535.

We have to pay attention to that fact that under different GAIN values, the width of this peak varies. The higher the GAIN, the wider the distribution. Thus the OFFSET value of the low GAIN will not be suitable for high GAIN as it is very likely to have the left side of the curve being chopped off at 0.



Correct



Wrong

Advanced level

We all know that there is no 16-bits sampling rate for current CMOS camera. As a result, the AD sampling accuracy cannot match perfectly with the full well capacity. At the low GAIN level, the CMOS system gain will be couple electrons per ADU. The camera loses the ability to distinguish the strength of the signal because of such sampling error.

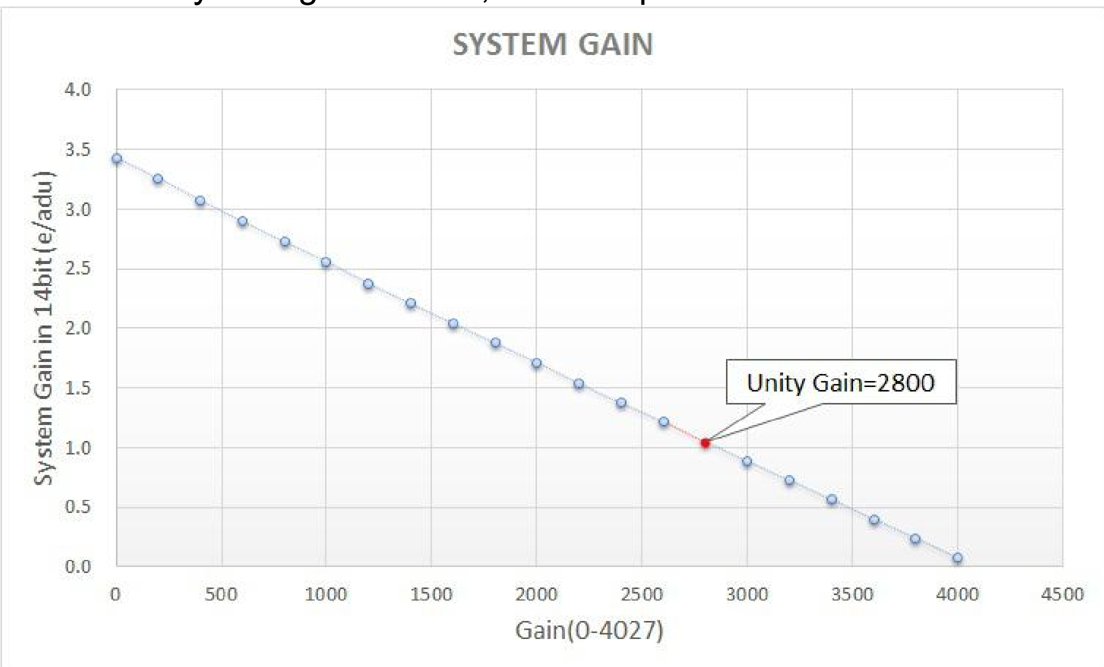
When the GAIN increases, the system gain of the CMOS will decrease. To certain level the system gain will be 1e/ADU. This is “unit-gain”. However, increasing the GAIN value will limit the full charge of the well. If the system gain is 1 for a 12bit CMOS camera, the pixel will be saturated at only 4096 electrons (full well capacity). If you have bright objects in the picture, like majority of stars, they will be saturated. This problem will be worse if your optics is a fast one or you have long exposure. Once the stars are saturated, they will be very bloated and cannot be fixed in post processing (unless you have tools to shrink the stars, like Pixinsight). At the same time, the color saturation of the star will be affected. At the end, the stars will be huge and white washed. This gives a very “dry” feeling to the picture. We can only decrease the gain value in this case, to gain a higher full well capacity.

To decrease the GAIN in this case because of lack of 16bit sampling ADU, is the only work around. At this time, the sampling error will increase. However, under long exposure or using fast optical system, the pixel will receive more photons. The variation of quantized noise from the photon which you can consider as natural dithering of the light intensity, will be greater than the “noise” from the sampling error. Therefore the effect of the sampling error will diminish. By averaging multiple exposures, this will compensate the lack of depth of the picture because of the sampling error.

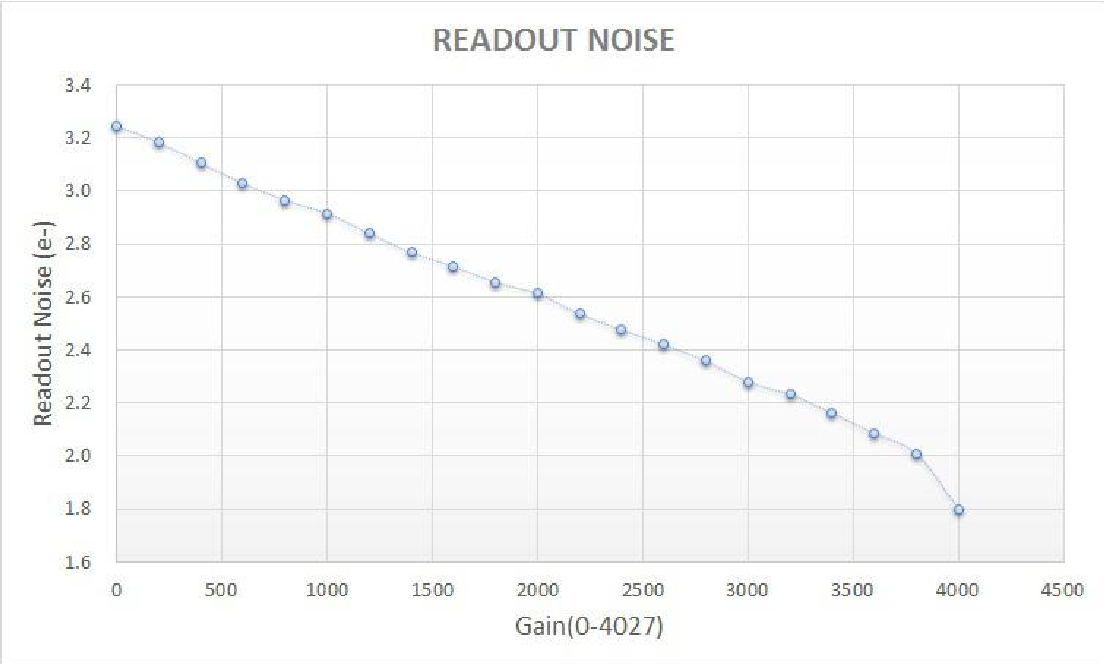
If the number of received photons is limited, like using narrowband filters or short exposures, we can increase the GAIN value. It is because the stars will not be easily saturated. At the same time, we limit the noise from the background cosmic radiation. Under this condition, the readout noise and quantized noise are the major factors that affect the ability to distinguish dim light or objects. By increasing the GAIN value in order to decrease the readout noise and quantized noise from sampling error, this would greatly increase the signal to noise ratio.

Attachment

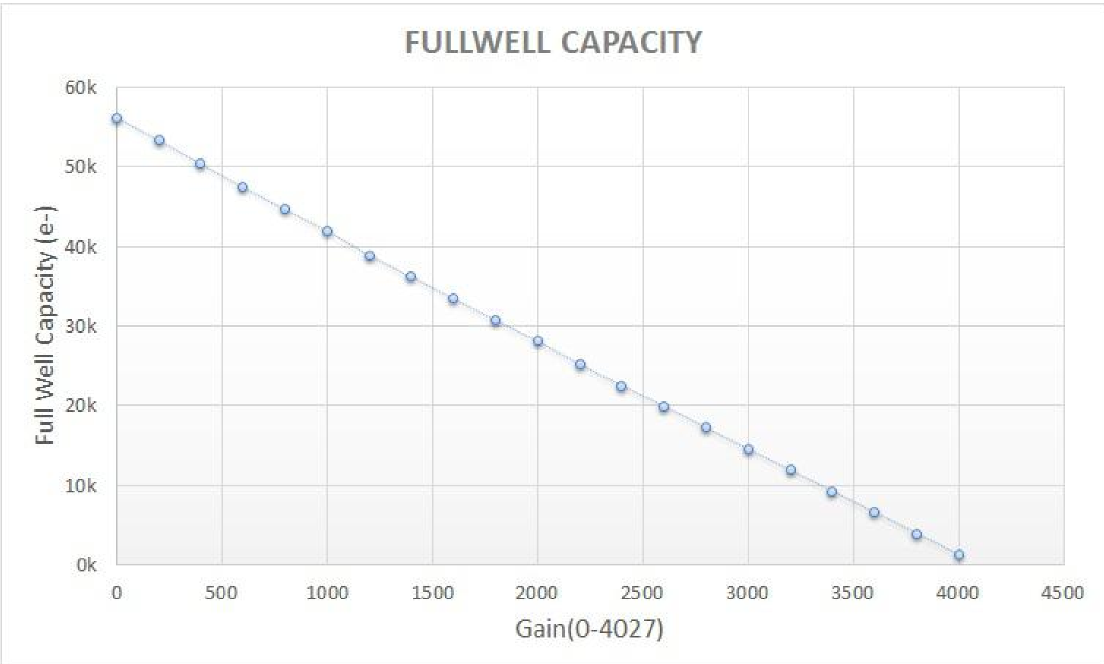
QHY367C system gain values, found in product manuals



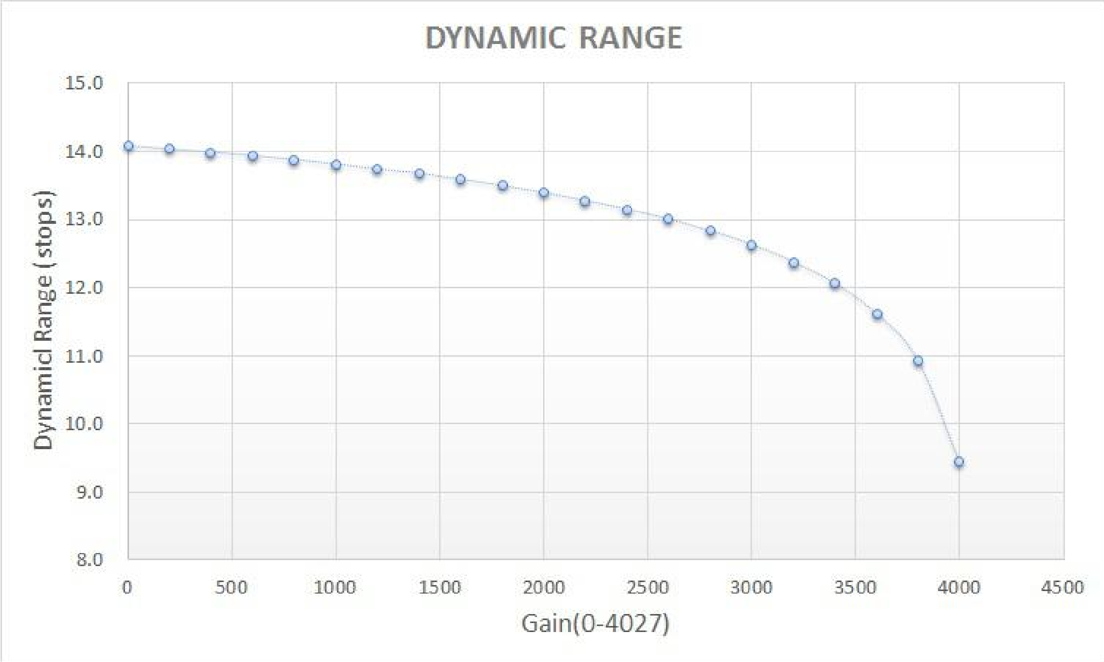
Graph of readout-noise vs GAIN value (noise decreases as GAIN increases)



Full well capacity decreases as the GAIN increases



The dynamic range decreases as the GAIN increases



QHY168C, 16million pixel APS-C cold CMOS for the Blue Horsehead nebula

QHY367C, 36million pixel full frame cold CMOS, the Rho Ophiuchi cloud complex

QHY128C, 24million full frame cold CMOS for Horsehead nebula at the Orion’s belt, making use of F2.2 Celestron RASA and 10min exposure, with lowest GAIN value

QHY163M, 16million pixel 4/3 format, part of the North America Nebular in Cygnus