

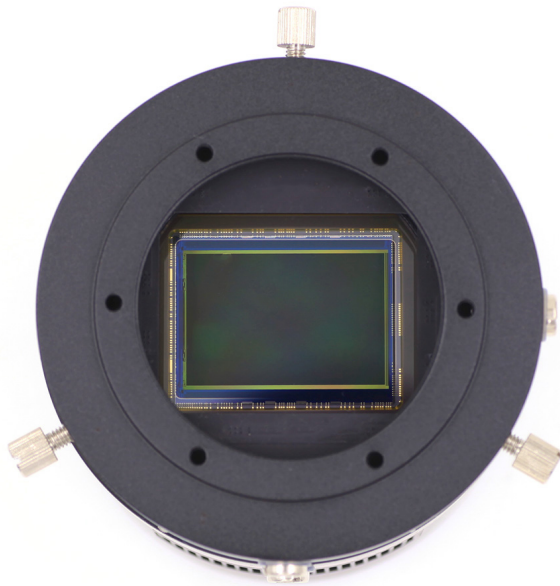
Setting GAIN and OFFSET on cold CMOS camera for deep sky astrophotography



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.

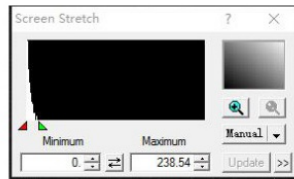
OFFSET

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.

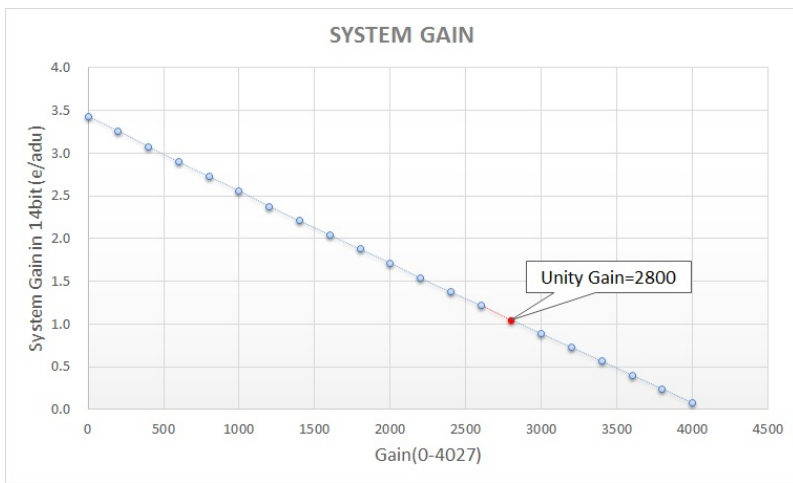
When the GAIN increases, the system gain of the CMOS will decrease. To certain level the system gain will be 1e/ADU. This is "unit-gain". However, increasing the GAIN value will limit the full charge of the well. If the system gain is 1 for a 12bit CMOS camera, the pixel will be saturated at only 4096 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.

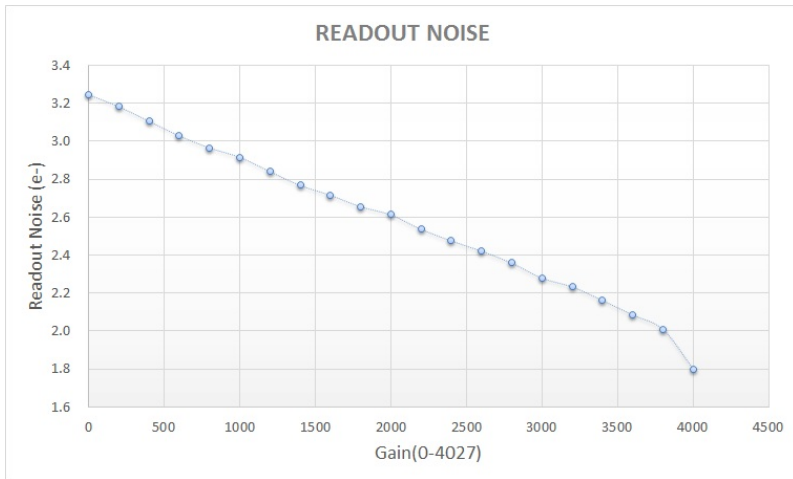
If the number of received photons is limited, like using narrowband filters or short exposures, we can increase the GAIN value. It is because the stars will not be easily saturated. At the same time, we limit the noise from the background cosmic radiation. Under this condition, the readout noise and 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

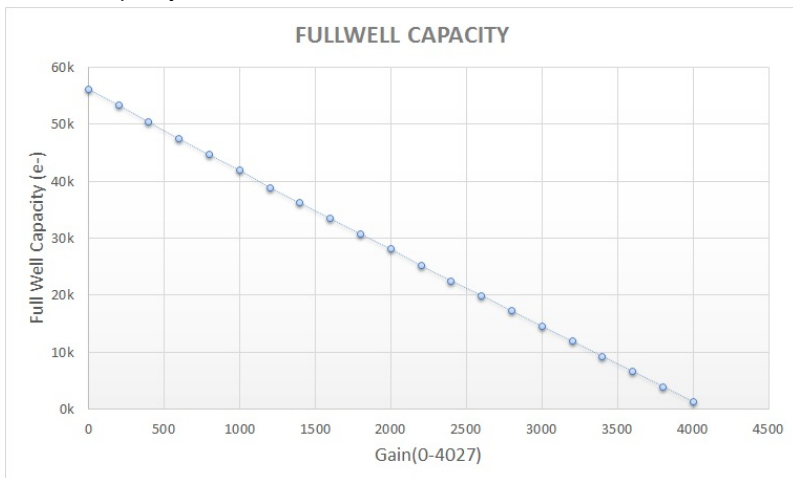
QHY367C system gain values, found in product manuals



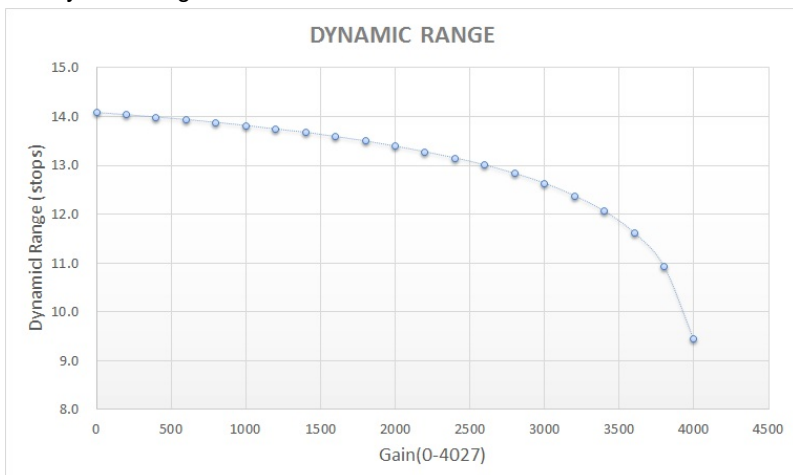
Graph of readout-noise vs GAIN value (noise decreases as GAIN increases)



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

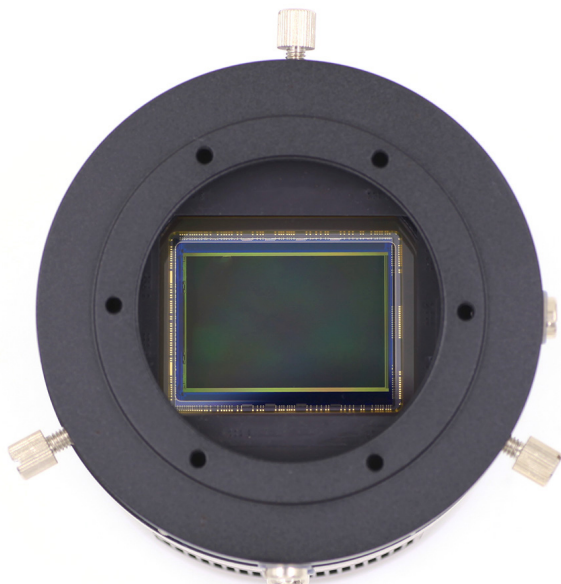


QHY163M, 16million pixel 4/3 format, part of the North America Nebular in Cygnus



Q博谈天文摄影之

CMOS相机拍摄深空如何设置GAIN和OFFSET



首先，并没有一个所谓的"最佳的GAIN和OFFSET值",由于当前CMOS相机的一些特性，例如不足的AD采样率（12位或者14位），以及读出噪声随增益提高而降低的特性。我们需要稍微理解一下相机的读出噪声，满阱，系统增益，以及天光背景的光子噪声等，才能更好的帮助我们确定应该使用的GAIN和OFFSET.

为了方便大家更好的能开始拍摄，我们这里给出一个针对制冷CMOS相机深空拍摄的GAIN和OFFSET的设置原则。然后再详细讲述为什么要采取这个原则。

GAIN设置

如果您以前没有制冷CMOS相机的使用经验，那么我们建议您刚开始的时候，增益可以设置为"单位增益”。单位增益是指相机的系统增益为 $1e/ADU$ 的时候的GAIN设置值。通常我们会在相机的页面直接给出该值。例如QHY168C的是10，而QHY367C的则为2800. 注意单位增益的设置也不必要纠结一定要刚好是系统增益，增加一点或者减少一点影响其实并不大。

请注意：单位增益并不是最好的设置！只是一个起始点

然后根据拍摄的具体情况，再进一步确定是增加或者减少这个值。通常情况下，如果您的光学系统是快速光学系统，大光圈，例如F2.2-F5之间的望远镜，曝光时间又比较长，比如5分钟以上，同时又没有使用窄带滤镜，那么可以考虑进一步减少GAIN. 以便获得更大的动态范围，更好的利用相机的满阱值，以避免恒星过曝。（过曝的恒星会导致星点肥大，同时恒星的颜色饱和度受到损失）。

如果您使用了窄带滤镜，或者你的望远镜焦比在F6-F10，曝光时间又比较短，那么在曝光时间周期内接受到的光子数有限，这种情况下，您可以提高增益，以期充分发挥在CMOS高增益下读出噪声低的特性，提高目标的信噪比。

使用情况	增益值	目的
入门值	系统增益	提供一个初始值给入门用户使用
使用快镜，曝光时间较长	降低增益	充分发挥动态范围，避免星点饱和
使用窄带，慢镜，曝光时间短	提高增益	光子数有限情况下，获得更低读出噪声

OFFSET设置

OFFSET的设置也并没有一个最佳值。OFFSET设置的正确方法是：在某一个增益下，分别拍摄偏置场和暗场，然后观察图像的直方图分布。

可以看到直方图分布是一个峰。通过改变OFFSET，可以使得这个峰向左或者向右平移。我们需要确保整个这个峰都要大于0，不能被0给截掉。同时，为了能有所冗余，因此需要比零略大一些，比如大100到几百个ADU，甚至几千ADU都是可以的。但是也不能太大，否则会占用掉0-65535中有效的动态范围。

需要注意，不同增益下，这个峰的宽度是不相同的，在高增益下这个峰就会变宽。因此在低增益下合适的OFFSET值，在高增益下未必合适。很可能由于这个峰变宽了导致这个峰的部分被0给截掉。



正确



错误

进阶篇

众所周知现阶段还没有16位采样的CMOS相机，因此就会导致AD的采样精度不能与CMOS的满阱电荷数很好的匹配。在低增益下，CMOS的系统增益往往会达到若干个电子对应一个ADU。这样会带来采样误差。损失了相机对信号强度的分辨能力。

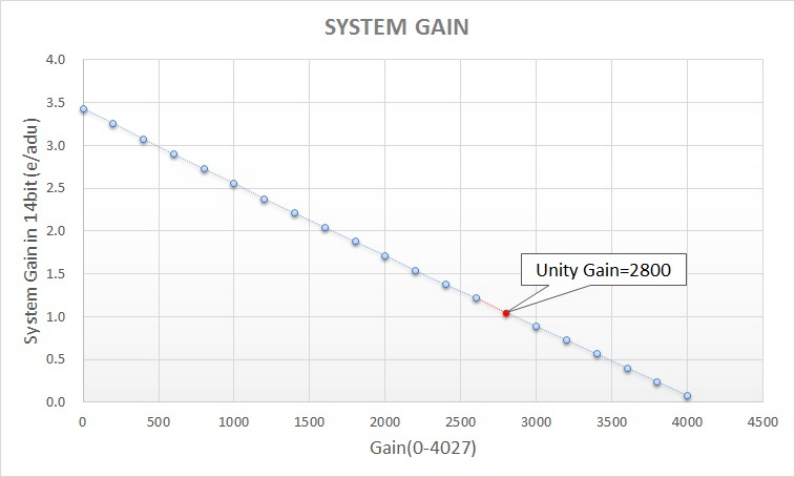
当提高增益的时候，CMOS的系统增益值会降低，当达到某一个增益时，对应 $1e/ADU$ ，这就是系统增益。但是提高增益会带来一个问题，就是限制了输出图像的满阱电荷数。比如12位的CMOS，当系统增益为1的时候，图像达到饱和的时候，对应的满阱就只有4096电子。这样如果图像中有比较亮的目标，例如大多数的恒星等，就会出现饱和。特别是如果您的望远镜是快镜，或者曝光时间比较长，这个问题就会特别的突出。一旦恒星饱和，星点就会变粗，而且后期是无法补救的(除非用软件缩星大法)。同时，星点的颜色信息也会受到影响，星点的颜色饱和度会下降。最终图像感觉星点很粗，大部分星点很白。感觉图像非常干涩。因此这种情况下，只能通过降低增益，来获得图像更大的满阱。

降低增益是在没有16位AD情况下采用的一个不得已的折中方法。这时候采样误差（量化噪声）会增加。但是，由于在长曝光，以及快镜下，像素的光子数比较多，光子数自身的量子噪声，会带来超过量化噪声的起伏（可以理解作为一种在亮度上自然实现的“抖动”算法），因此量化噪声增加带来的影响会有所减小。通过一定的叠加，也可以在一定程度上弥补因为量化噪声引起的图像层次不够的问题。

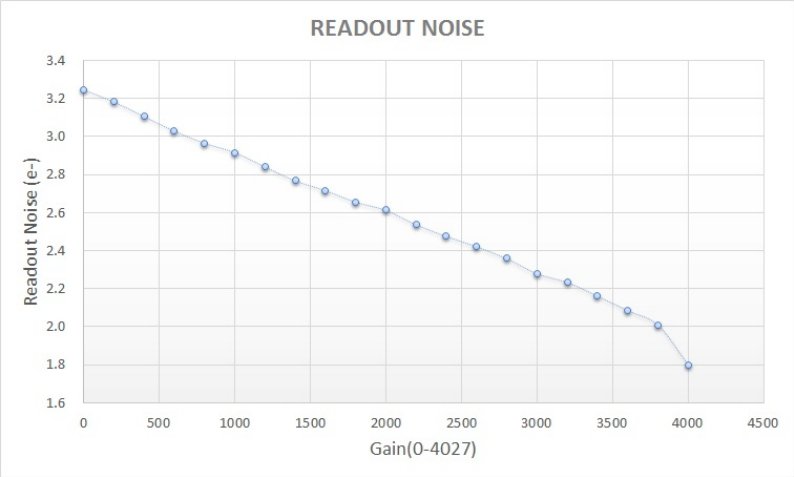
在光子数受限的情况下，例如在窄带摄影，曝光时间短，以及使用的镜子是“慢镜”的情况下，那么可以提高增益。因为这种情况下不容易出现目标饱和问题，同时，背景天光几乎没有，此时读出噪声和量化噪声是影响弱光探测能力的主要因素，提高增益获得更低的读出噪声和更低的量化噪声，对于提高信噪比是非常有意义的。

附图

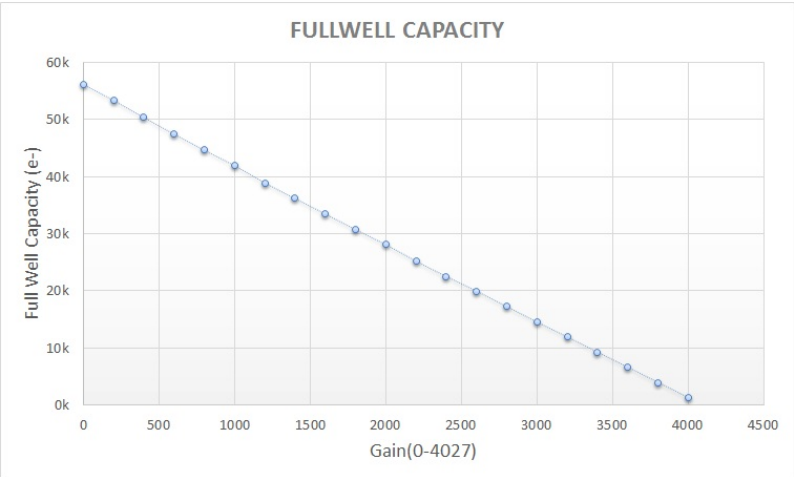
QHY367C的系统增益，在产品页面的特性图里面可以找到



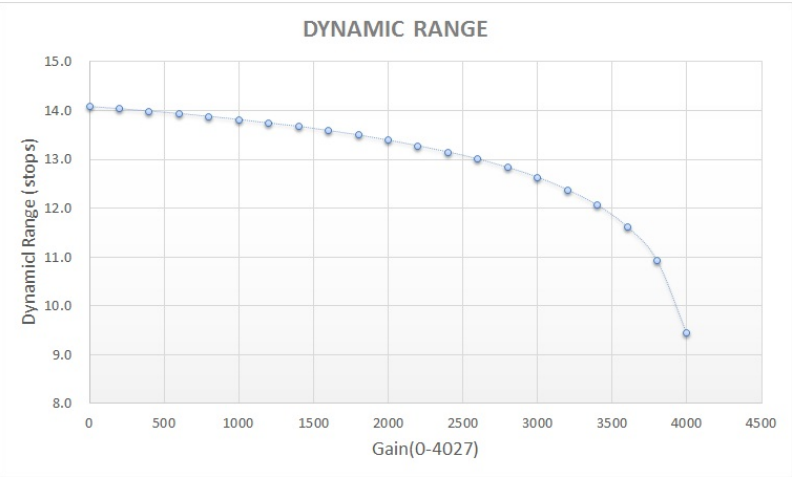
读出噪声随着增益增加而减小的曲线。



输出图像的满阱电荷值随着增益增加而降低



从动态范围角度而言，增益升高会降低动态范围。



QHY168C 1600万像素APS-C画幅制冷CMOS相机拍摄的蓝色马头



QHY367C 3600万像素全画幅制冷CMOS相机拍摄的天蝎座调色盘区域



QHY128C 2400万像素全画幅CMOS相机拍摄的猎户座马头星云，采用了F2.2 RASA快镜和10分钟长曝光，使用了最低增益



QHY163M 1600万像素4/3英寸黑白相机拍摄的天鹅座北美洲星云的局部

