**QHYCCD QHY 42 Camera : first evaluation and parameters measurements**

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## Part 1 : the QHY CCD QHY 42 on the test-bed

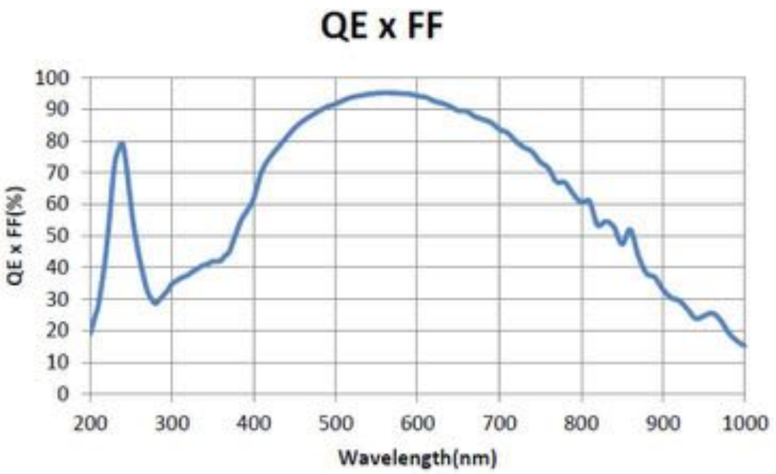
### Introduction

My field of interest is mainly on exoplanets observations and more recently, asteroids. I broke my piggy bank a first time with an Officina Stellare RILA 400 F5.2 telescope and an ASA Direct Drive DDM85. And I broke my piggy bank a second time acquiring a FLI 11002 camera: although other cameras I had before gave me good times (Starlight SX694, QHY10…), the FLI is outstanding by the quality of its design and the stability of the measurements both hardware and software. It is also outstanding by its price!

The famous Kodak 11002 CCD chip is well known by astronomers and appreciated by its pixel size (9µ), the total sensor size (24x36 mm) and a quite low dark current. It has two relative main drawbacks: a quite high read noise, although well controlled in the FLI camera with only 9e- at a 2 Mhz read speed, and a moderate quantum efficiency: 50% at 500 nm, but decreasing rapidly in the IR with only 24% above 700nm.

For making beautiful deep sky astrophotos, the FLI 11002M is perfect, but for exoplanet transit measurement the Sony Exview chip of the SX694 is as good or even better with a much better QE, lower read noise (allowing stacking), lower thermal noise. The only difficulty with the SX694 is to find comparison stars of the same magnitude and colour when star field is poor, but when comparison stars are far (with the 11002), measurements quality decreases rapidly due to atmosphere variation.

When the new BSI chips arrived on the market (especially the GSENSE400BSI by Gpixel which can be found in the new FLI CMOS Kepler camera, and the QHYCCD QHY42) the temptation is great to have a try! The QE of the GSENSEBSI chip is around 95% in V, but still very good in the Near IR (70% at 750nm).




A quick computation gives the mean QE ratio between 300 and 1000 nm : it is 0.24 for the KAI 11002 and 0.65 for the GSENSE400BSI, meaning 2.7 more photons are converted into electrons with the BSI CMOS chip (note an excellent 0.45 for the ICX 694). In the IR (700-1000nm), the 11002 mean QE is 0.07 and the GSENSE400BSI one is 0.36, 5 times more!

At this stage, I had a big problem : this chip is awfully expensive and the piggy bank did not get fat enough to buy the new FLI Kepler KL400 camera! The piggy bank cried a little bit when I broke it and decided to buy the new QHY42 camera by QHYCCD.

I suppose that many of you are interested by the results of these first measurements and my first impressions about this camera.

**Warnings**

First, I am not a professional of chips and CCD camera measurements: I do not guarantee the results you will find below, but I tried to do my best!
My references books :
- Bruce Gary book http://brucegary.net/book_EOA/x.htm page 198 and after
- Signal to noise : Part 3 by Craig Stark
http://www.stark-labs.com/craig/resources/Articles-&-Reviews/CCD_SNR3.pdf

Second, I am not interested in planetary observation and the "lucky imaging" techniques. Obviously, with a very fast data transfer in USB3 and a very low read noise, the QHY 42 is a very interesting candidate for this kind of observation, but I did not measure any parameters in this context. The only measurements you will find here is "long pose" for faint objects, meaning typically more than one second.

**The QHY 42 camera : physical presentation**

The QHY 42 camera arrived directly from China in a well protecting box. The camera itself appears robust and well designed. The back side is very simple with only a USB 3.0 connector and 12v power supply socket (this one is screwable, which is good idea avoiding a cable disconnection when moving the telescope!). The weight is 730 grams which is rather light for such a powerful engine! The diameter is 90mm and the length 110mm. The front side presents a 28x28 mm window glass protecting the CCD. The mechanical interface is a 77mm dovetail and 54mm female adaptor is provided.



**The QHY 42 hardware installation**

I did not find any problem for hardware installation, except you need absolutely an USB 3.0 connection. I tried several USB 2.0 connector scenarios : it is possible to access the camera settings, but as soon as you try to transfer an image, the imaging software crashes (Maxim, but also SharpCap and EZCAP_QT, the QHYCCD home made software).

**The QHY 42 software installation**

Clearly, software installation is not the stronger point of this camera. Fist of all, no documentation at all is provided, which is surprising considering the prices of the camera. May be I am the first (or second?) customer.

Happily, Dr Qin has helped me a lot and efficiently to get the correct drivers and also the correct ASCOM driver from the SDK.

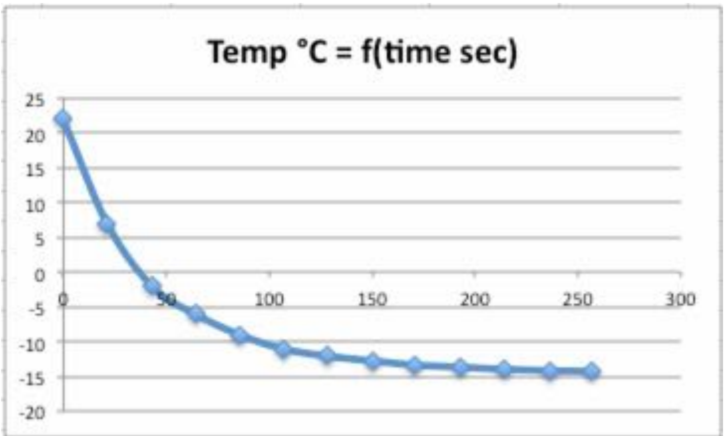
Although, I used Maxim DL 6 to proceed all measurements, the QHY 42 software is still buggy and among identified bugs :

- Maxim DL (and all other software also) crashes when “disconnecting” the camera
- The offset of the camera is not always taken into account or disappear when reconnecting the camera (if noted 100 in the settings, it is like it is zero on the image; putting the offset to 250 and back to 100, then the offset is correct on the image !)
- Due to the native use of an internal buffer within the camera, the image you get is not always the last one which has been taken by the camera! This might be confusing, and remember you have to flush the camera buffer before recording images.

Software quality and reliability is to day the main default of the QHY 42, hoping it will improve soon.

**QHY 42 Cooling**

The ambient temperature being 22°C, I set up the target temperature at -15°C.




The temperature went down to -10°C in less than 2 minutes, but reached only -14°C, not succeeding to cool the camera at -15°. During the night, with an external temperature of 15°C in summer, a -15°C setting should be ok, but there is no margin. With a quite important thermal noise (see later), the cooling power might be insufficient, especially in warm countries.

When the temperature is reached (-10°C for all following measurements) the stability is good, with plus or minus 0.1 °C (if you believe in the internal sensor!).

**QHY 42 AD converter**

The internal AD converter is 12 digit size : it is able to measure numbers only from 0 to 4095 ! And even if you read 65535 onto your favourite software, it is important to understand that in fact it corresponds in 64535/16 : 4095 “real” ADUs. This is the main limitation of this chip, because you have to find a compromise between a low gain (3 e-/ADU for instance) which limits the precision of the measure (a digit won’t make the difference between 1 or 3 e-) or a high gain (0.5 e-/ADU) which reduces the full well capacity and the dynamic range, but gives a better sensibility.

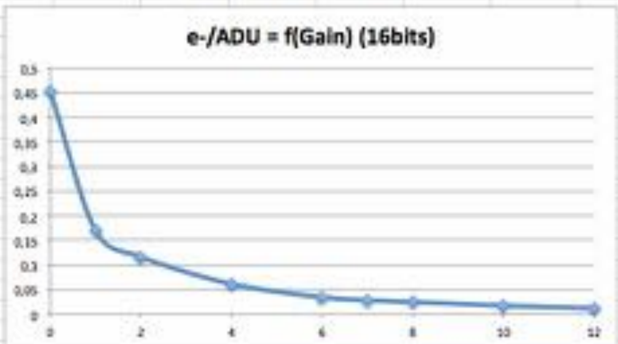
**QHY 42 : Effect of the Gain setting**

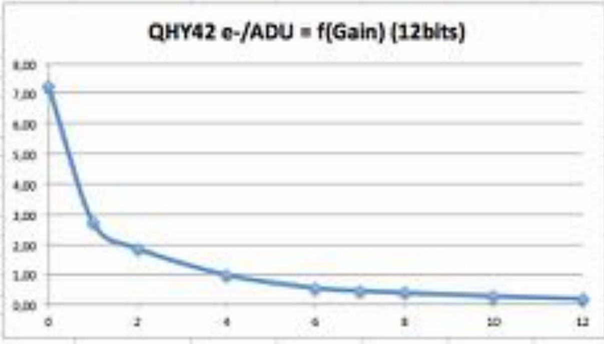
The internal gain can be adjusted from zero to 24.
The gain 00 corresponds to 7e-/ADU (12 bits), and a 30 000 e- approximate Full well.
Unity gain of one e-/ADU corresponds to the G=04 setting. The full well is 4000 e-.
For G=07, the gain is 0.45 e-/ADU, the full well is 1800 e- and the read out noise drops at 1.4 e- (which is quite low).
From this measures, it seems that a gain of 1 to 4 should be correct for contrasted objects, and a gain of 6-8 should be correct for faint objects, to keep a good precision (#0.001).

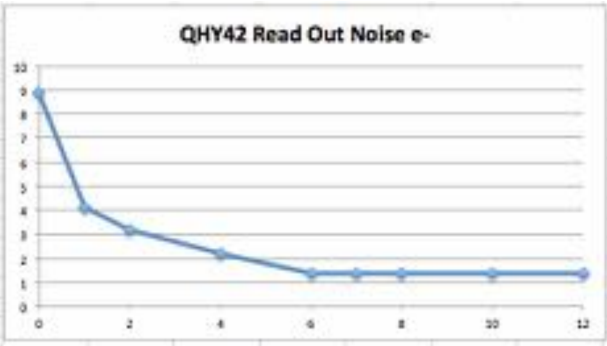
e-/ADU = f(Gain) (16bits)

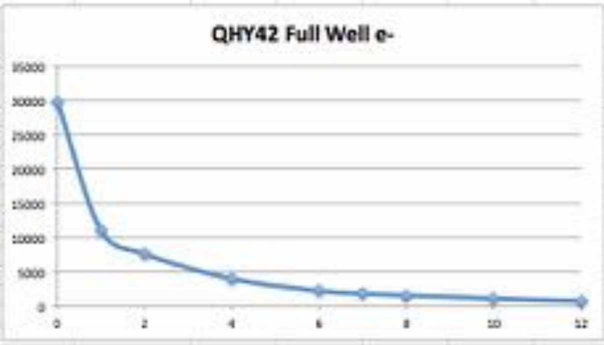
**Mesures synthesis :**

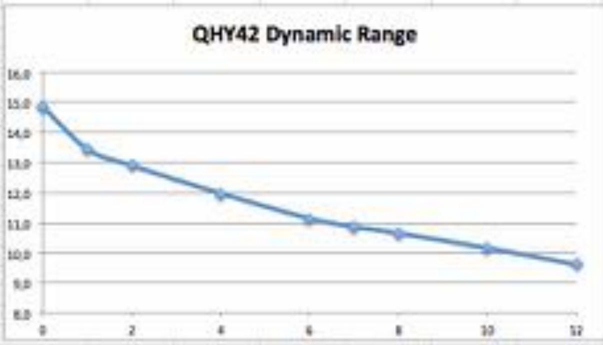
| Gain | e-/ADU 16b | e-/ADU 12b | Full Well | Stop | Read Noise |
|---|---|---|---|---|---|
| 0 | 0,4535 | 7,26 | 29720 | 14,9 | 8,9 |
| 1 | 0,1699 | 2,72 | 11134 | 13,4 | 4,1 |
| 2 | 0,1162 | 1,86 | 7615 | 12,9 | 3,2 |
| 4 | 0,0613 | 0,98 | 4017 | 12,0 | 2,2 |
| 6 | 0,0344 | 0,55 | 2254 | 11,1 | 1,37 |
| 7 | 0,0284 | 0,45 | 1861 | 10,9 | 1,36 |
| 8 | 0,0245 | 0,39 | 1606 | 10,6 | 1,37 |
| 10 | 0,0174 | 0,28 | 1140 | 10,2 | 1,38 |
| 12 | 0,0119 | 0,19 | 780 | 9,6 | 1,37 |












QHY 42 Gain for G=07 Offset=261   (initial setting for DSO)

The test is made with 5 images exposed from 0.1 sec to 0.3 sec.

The correlation is excellent with an error less 0.2 %

The gain is 0.454 e-/ADU (12bits) or 0.0284 e-/ADU (16 bits).

The full well is 1851 e-

QHY42 Gain - G= 07 Offset = 261

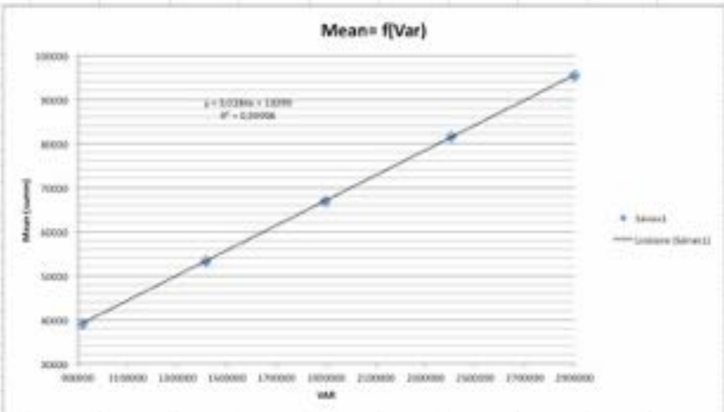
| T | Var | Mean | Std Dev | Mean (comp | Error % |
|---|---|---|---|---|---|
| 0,1 | 919489,21 | 39278 | 958,9 | 39212 | 0,17 |
| 0,15 | 1415826,31 | 53247 | 1189,885 | 53308 | -0,12 |
| 0,2 | 1896938,76 | 67003 | 1377,294 | 66972 | 0,05 |
| 0,25 | 2403538,61 | 81560 | 1550,335 | 81359 | 0,25 |
| 0,3 | 2898318,98 | 95405 | 1702,445 | 95431 | -0,01 |

Gain = 0,0284 e-/ADU 16bits  Full Well= 1851e-

Gain = 0.454 e-/ADU 12bits

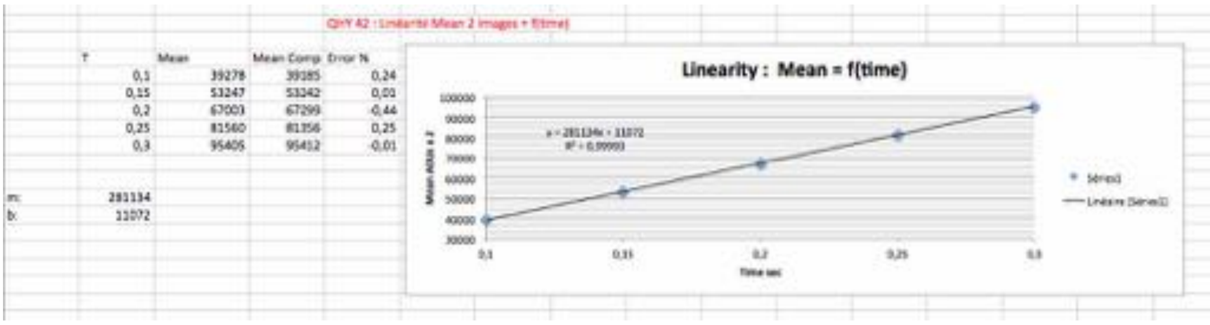
m: 0,0284

b: 13099




QHY 42 Linearity for G=07 Offset=261

From the previous measures, it is possible to check the linearity, which is also excellent (< 0.5%) :



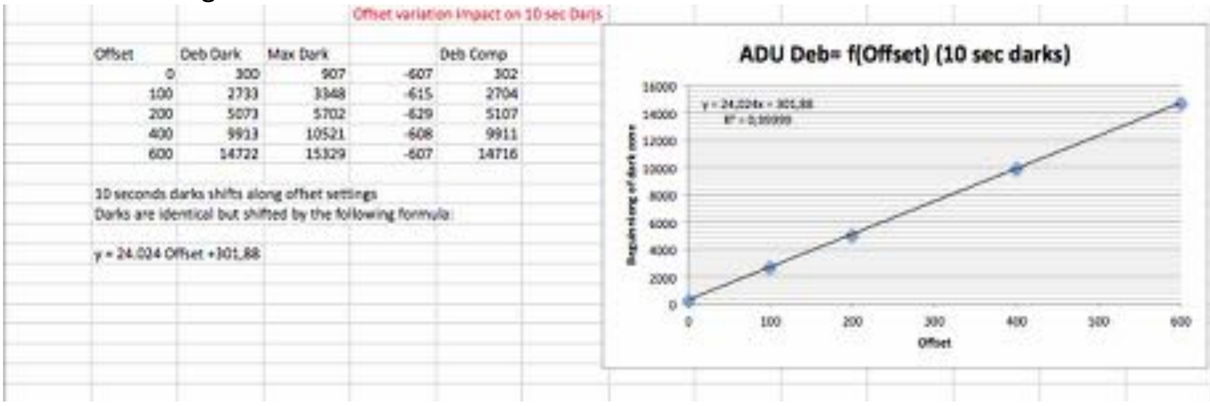
QHY 42 : Linéarité Mean 2 images = f(time)

| T | Mean | Mean Comp | Error % |
|---|---|---|---|
| 0,1 | 39278 | 39185 | 0,24 |
| 0,15 | 53247 | 53242 | 0,01 |
| 0,2 | 67003 | 67299 | -0,44 |
| 0,25 | 81560 | 81356 | 0,25 |
| 0,3 | 95405 | 95412 | -0,01 |

m: 281134
b: 11072



<u>QHY 42 Influence of Offset on Fixed ADU</u>
10 sec Darks at different Offset
Adding 100 of Offset pushes on the right by 2400 ADU (16bits) (or 150 ADU 12 bits) the curve of the dark image



Offset variation impact on 10 sec Darks

| Offset | Deb Dark | Max Dark | | Deb Comp |
|---|---|---|---|---|
| 0 | 300 | 907 | -607 | 302 |
| 100 | 2733 | 3348 | -615 | 2704 |
| 200 | 5073 | 5702 | -629 | 5107 |
| 400 | 9913 | 10521 | -608 | 9911 |
| 600 | 14722 | 15329 | -607 | 14716 |

10 seconds darks shifts along offset settings
Darks are identical but shifted by the following formula:

y = 24.024 Offset +301,88



**Read Noise :**

As seen below, the read out noise drops from 9e- to 1.4e- as soon as G > 6

<u>Dark current (in ADU and electrons) (G=07 Offset=100)</u>

The dark current is a difficult topic for this camera.

First, looking at the chip manufacturer, there are two very different figures for the thermal noise:

- If the "FD Node in Reset mode" (anti blooming on), then the dark current is 20e-/p/s at -10°C
- If the "FD Node is floating", then the dark current is 0.15 e-/p/s.

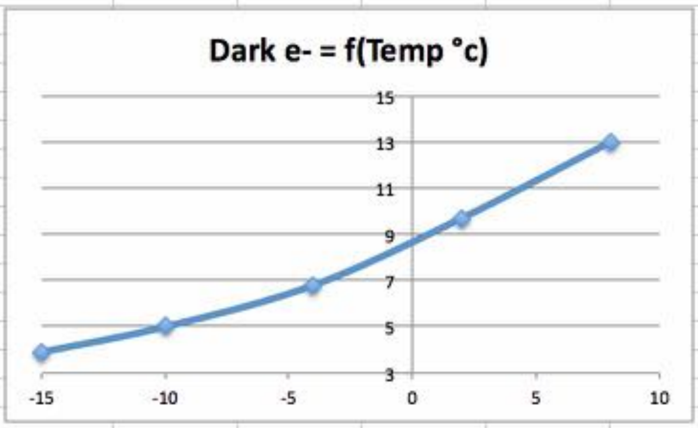
(information from: http://www.imagesensors.org/Past%20Workshops/2015%20Workshop/2015%20Papers/Sessions/Session_10/10-05_X-Wang.pdf )

In the same idea, the Kepler 400 camera by FLI has implemented a "Low Dark Current" options for long exposures (dim objects) not to be used for short exposures (because limiting full well capacity and dynamic range).

Measuring the Dark noise of the QHY42 as a function of temperature, at G07Offset100 setting, gives the following results:

Dark current measurements e- = f (temperature) G=07 Offset=100

| Temp °C | Dark e- |
|---|---|
| 8 | 13 |
| 2 | 9,7 |
| -4 | 6,8 |
| -10 | 5 |
| -15 | 3,9 |



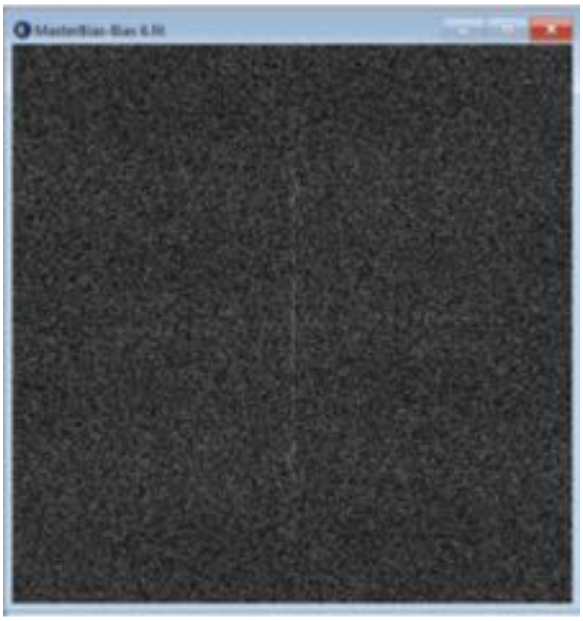

Even at -15°c , the 3.9 e-/p/sec dark noise and the error associated to it, limits the exposition time : typically, exposition time should be around 10 seconds (but can be easily stacked due to low read-out noise) and should not exceed 60 seconds.

Read Noise stability (G=07 Offset=100)

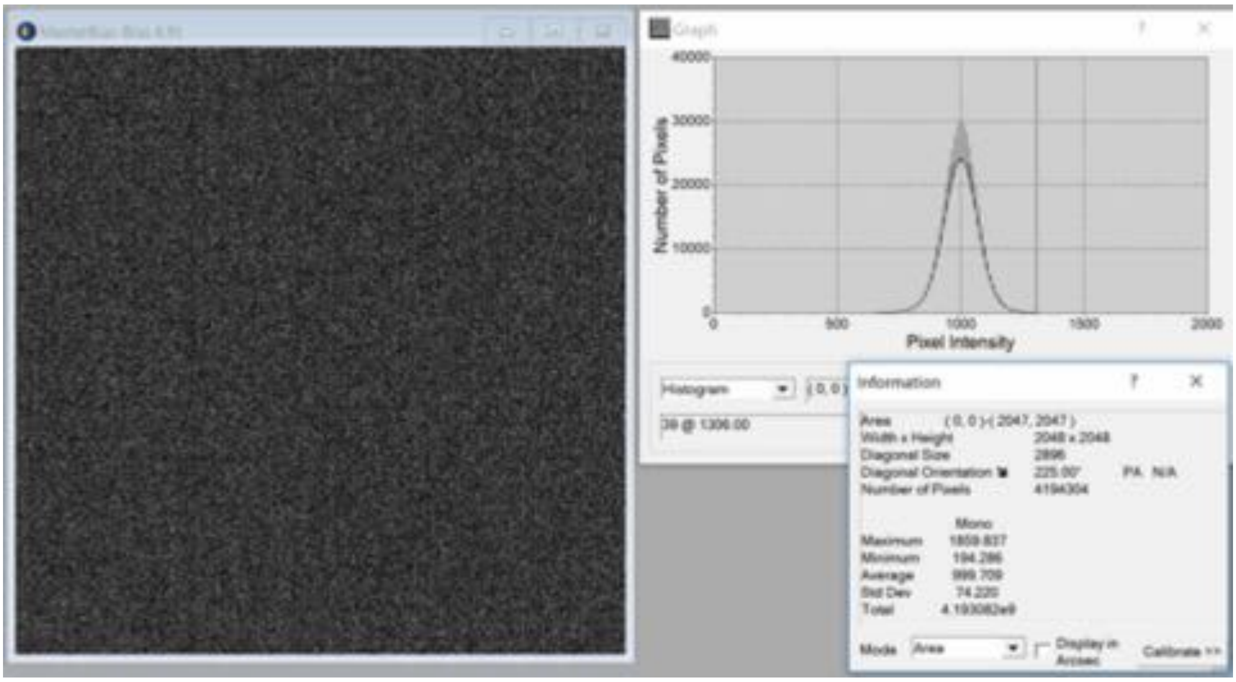
The master bias image shows very well the “structure” of vertical reading of the pixel. It is possible also to see a defective line at y=597 (grade 2 CCD).

Happily, the read noise image (difference between master bias and a bias image) shows à very “clean” structure, which is confirmed by the its FFT.

Master Bias Image



FFT : Master Bias – Single Bias




Master Bias – Single Bias (offset : 1000)

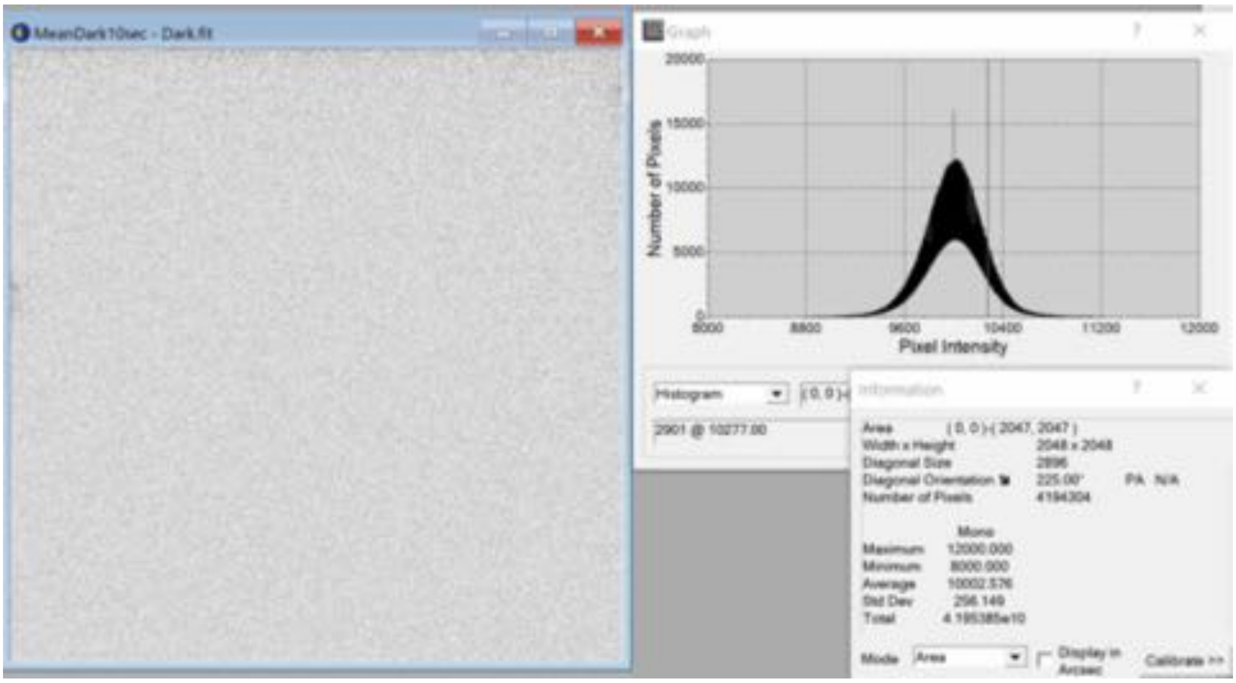
Dark Noise stability (G=07 Offset=100)

The 10 seconds master dark noise image is a bit frightening showing several “hot regions” in the image.

Happily, when a dark noise single image is subtracted to the masterdark, the corrected image becomes very clean. And the FFT confirms it.

Master Dark 10 sec

FFT Master Dark – Single Dark




Master Dark – Single Dark (offset 10000)

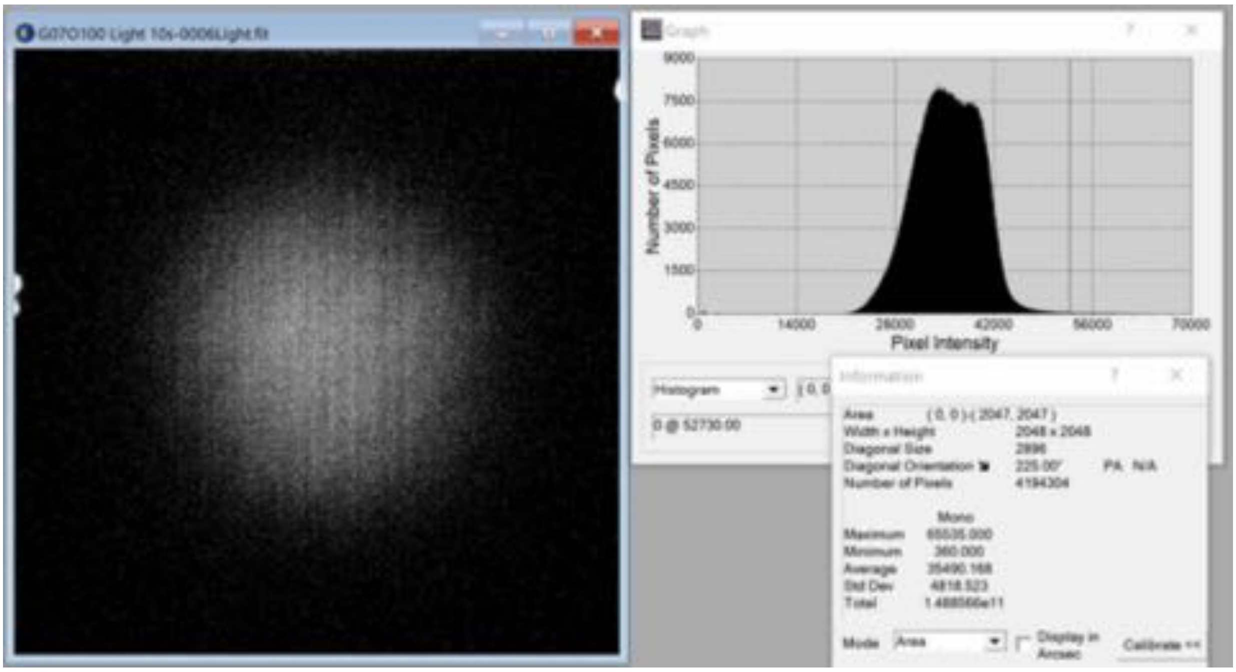
**Summary and FLI 1102 comparison :**

| | FLI 11002 2Mhz | QHY 42 mes G=7 G=7 Offset=100 | QHY 42 mes G=7 G=4 Offset=100 |
|---|---|---|---|
| Size pix µ | 9µ | 11µ | 11µ |
| Dim pix | 4008x2672 | 2048 x 2048 | 2048 x 2048 |
| Dim mm | 24 x 36 | 22.53 x 22.53 | 22.53 x 22.53 |
| Read Out | Electronic | Progressive | Progressive |
| Peak QE | 50% | 95% | 95% |
| AD Converter | 16b | 12b | 12b |
| Read Out Noise | 9e- | 1.3e- | 1.3e- |
| Full Well | 51 ke- | 1860 e- | 4017 e- |
| Gain (16bits) | 0.80 | 0.0284 | 0.0613 |
| Gain (12bits) | na | 0.45 | 0.98 |
| Dark @-10°c | 0.01e- | 5 e- | 6e- |

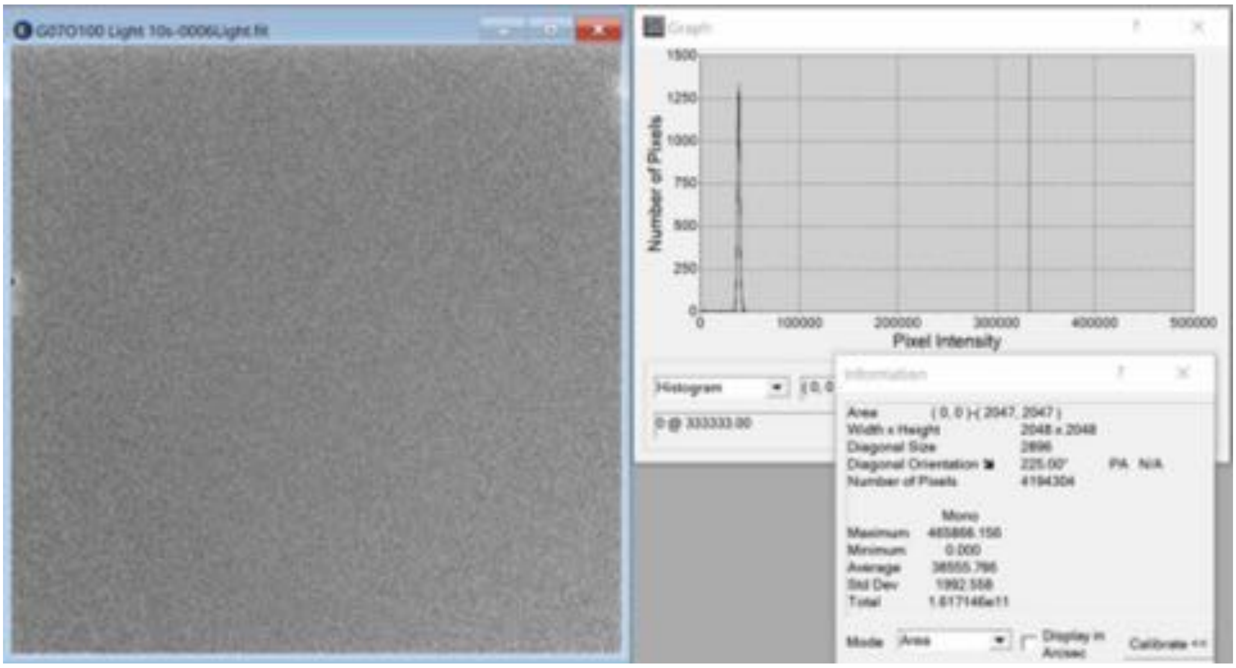
**Experimenting QHY42 with very dim uniform light**

We made the following experiment: the camera is illuminated by a luminescent flat plane placed at about 20 cm from the camera window. Approximately 5 sheets of cardboards are used to measure the flat field (0.4 second) and 20 sheets to measure the light (30 x 10 seconds exposures).
The difference between an image before and after calibration shows the importance of the calibration process with this camera to eliminate dark noise :

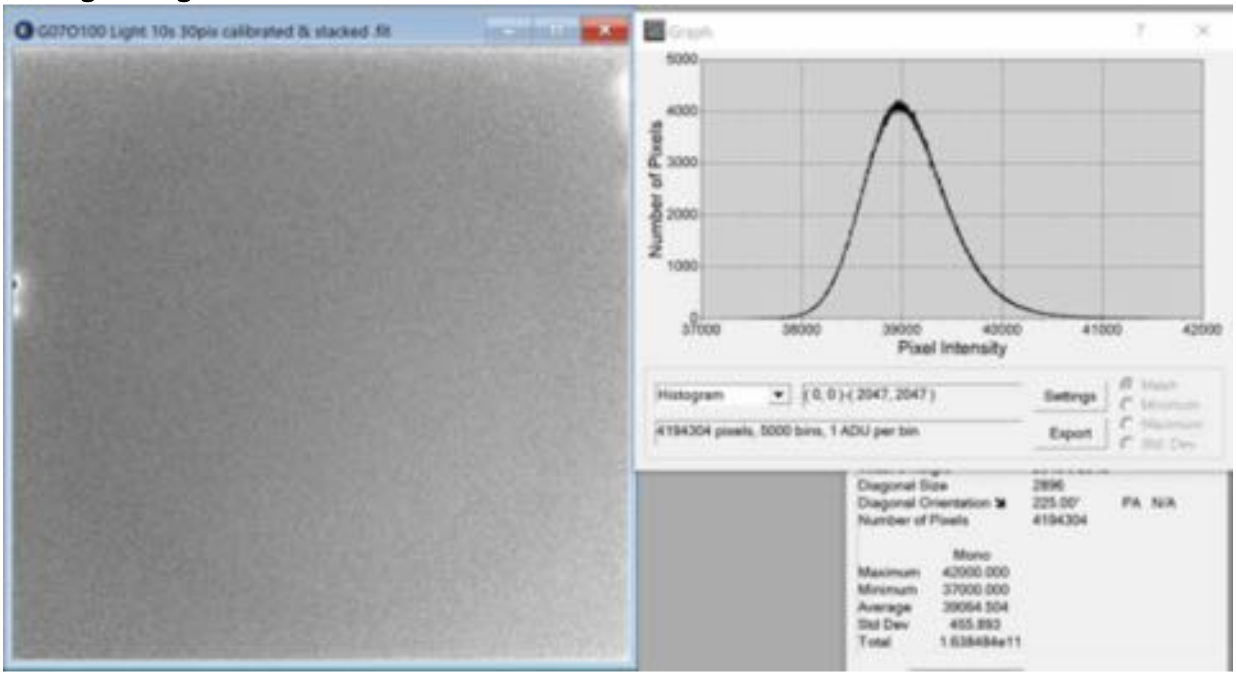
**Before calibration :**




**After Calibration :**




**30 single images calibrated and stacked:**




The image corresponding to 30 single images calibrated and stacked, shows different structures :

- the hot regions of the camera begin to appear (which is not a great problem, this regions could be clipped easily by post processing, without loosing much information)
- the image appears to be a little lighter in the right down corner : this is due to the fact the card boards where not perfectly and homogeneously pressed and some more light (a few e-!) arrived into this corner

The number of e- by pixel on the stacked image varies from 1080 to 1150, with a mean of 1109 e-. The measured standard deviation is only 13 e- (instead of 55 e- for a single frame), showing the interest of stacking process with this low read noise camera.

**Conclusion:**

QHY42 is a non typical camera with a very high efficiency, low read noise but an important, although stable, dark noise. Now the question is how it is going to perform on real objects like astrophotography on DSO objects, and precisely measuring star light fluxes. We shall see that in the second part of this document.