The ASI120MM camera

Nicolas Dupont-Bloch, March 2017

Overview

The ASI120MM is one the most affordable, all-purpose ASI cameras. It has long proved to be one of the very first CMOS cameras capable of high-resolution, megapixel images of astronomical objects of all kinds and scales, with some extra features.

Here are its main capabilites at a glance :

- planetary, lunar and solar imaging at high speed (high speed helps to drastically diminish the blurring effect due to natural instability of air)
- deep-sky imaging limited to planetary nebulae (e.g. Ring Nebula M57, Crab Nebula M1), high-contrast galaxies (Whirlpool Galaxy M51, Cigar Galaxy M82), open and globular clusters (Wild Duck Cluster M11, Hercules Great Cluster M13), bright diffuse nebulae (Orion Nebula M42, Lagoon Nebula M8)
- all-sky imaging (with enclosed lens : a field of view of 140°, relatively close to human vision) to record meteors, or to image the Milky Way or entire constellations
- autoguiding (this helps a lot for deep-ky imaging)
- 1,2 megapixels

Despite the release of more recent sensors, the monochrome ASI120MM remains appreciated for its very moderate cost, its extreme versatility and the quality of the 8-12 bits images it delivers at high speed in various sizes and formats, including movies and time lapses. 8 bits (256 possible different gray shades) are to image the Solar System while 12 bits can help to differentiate more subtle shades (more than 4 000) for deep-sky imaging. The camera now exists in four variants : with USB2 port and color (ASI120MC) or monochrome (ASI120MM) sensor or with USB3 port and color (ASI120MC-S) or monochrome sensor (ASI120MM-S). The USB3 version offers a higher frame rate to take advantage of the spare time intervals where the air remains steady, allowing to quickly record series of accurate images of planets at high magnification ; then the images are sorted depending on their accuracy, re-aligned then processed with the help of dedicated software such as AutoStakkert !2 : that is « lucky imaging ». The color version is designed to easily image main bodies of the Solar System and some bright, deep-sky objects, at the price of lesser sentivity and lesser accuracy in final images (all due to the Bayer matrix and the process of interpolation to reconstruct the colors). Monochrome sensors have a greater sensitivity, they provide unaltered raw images for better image processing, they have a larger bandwidth including near ultraviolet and near infrared, and they are able to precisely differentiate information with the help of specialized filters. They also may provide color images at the price of three more work per image and greater expense : filters with a filter wheel. Efficiency and accuracy are the keys for why professional, astronomical cameras are always fitted with monochrome sensors. We will also see that the innovative, sturdy housing of the ASI120 offers a number of unexpected possibilities, such as DIY cooling or direct compatibility with various optics and mechanical adaptations. Owing to its performance, its moderate cost and its surprisingly wide range of features, the monochrome ASI120MM is, in my opinion, the best, all-purpose ASI camera for beginners who wants to go further in the aftermath.

Sensor and possible applications

Once released by Aptina and then by ON Semiconductor, the CMOS MT9M034 monochrome sensor is sensitive in the range of near ultraviolet to near infrared, including of course all visible colors seen as undifferentiated, white light. Since celestial objects reflect or emit a large spectrum, including visible light, ultraviolet and infrared, the sensor is able to gather more information than our eye. Relative to previous CMOS sensors, the MT9M034 shows an impressive efficiency, up to 75% (75% of incoming light is converted to digital signal), with relatively low undesired, parasite noise even during exposures of some tens of seconds. Some other sensors released at the same time but devoted to planetary imaging have a superior sensitivity at the price of much smaller images and possibly more noise (amplified by the sensor's own heat at high speed). A peculiar feature of the MT9M034 is the high sensitivity in blue, meaning that the camera can provide accurate planetary images with short exposures in the three fundamental colors when exploited with filters (trichromy), at the time when other sensors demand longer exposures in blue. The high sensitivity in blue is also interesting because this color, in terms of physics, has a short wavelength, and telescopes provide sharper images at short wavelengths. This is not equivalent to keeping the blue component only of a color image, because imaging filters are much more performing - and expensive - than the built-in filters of a color sensor, and because in a monochrome sensor, all photosites receive the filtered, blue light, while in a color sensor, only one photosite out of four receive the blue light. In addition, imaging filters have 25-30% better transmission than the in-built filters of a color sensor. When the air is calm and cold, imaging the Moon with a blue filter means that we can see craters almost two times smaller than in deep red. The blue also offers additional information on planets, such as ice clouds on Mars at martian spring. On the other hand, the blue is more scattered by atmospheric turbulence, when the air is warm. Another drawback is that blue filters absorb a large amount of incoming light : we can see the absorption by swapping red and blue filters when we directly observe a planet or the Moon. To keep the advantage of imaging in blue, we need the sensor to be capable of short exposures in all colors, and this is the case with the MT9M034. Other non-negligible qualities of the sensor are its insensitivity to radioelectric disturbances from the environment, its insensitivity to irregularities of the power supply from the USB port controller (especially with laptops), and its built-in software automatic reduction of a parasite signal called the Fixed Pattern Noise : static bands superimposed to the image due to the structure of CMOS image sensors. Now let us examine how the sensor may be exploited at best.

- Monochrome, large-bandwidth imaging for contrasted, deep-sky objects such as Cigar Galaxy M82, Whirlpool Galaxy M51, Hercules Globular Cluster M13, Omega Centauri Globular Cluster NGC5139, Ring Nebula M57. This is quite simple and efficient as long as the exposures remains reasonable at low gain. Even with a basic, motorized equatorial mount with no autoguiding, exposures of 15 seconds are sufficient to show the nucleus of numerous galaxies, if not the arms. Since the sensor is permanently exposed to ambiant temperature, winter is the best season because coldness naturally lowers parasite noise. My advice is not to use the ASI120MM with a light-pollution filter, nor with a narrow-band filter, because faint objects may not be detected unless exposures are too long for the sensor (this leads to excessive parasite signal), if not under the detectivity threshold level. The best thing to do is to image under dark skies, far from cities. Fortunately, numerous, contrasted deep-sky objects such as M57, even M51, are easily detectable by the camera even from urban sky with no filter.

- Planetary imaging in monochrome.
- Planetary imaging in colors with a filter wheel and red, green and blue filters.
- The Moon is one of the best targets for the megapixel, monochrome ASI120MM because it is able to take very short exposures to « freeze » the turbulence (lucky imaging), and because the Moon is mainly grayish. Lunar imaging is feasible with no filter, or with a red filter to minimize the blurring effect of atmospheric turbulence, or with a blue filter for better accuracy when the air is calm. The filter has to be designed for imaging : at the contrary of filters for observation, filters for imaging have to suppress invisible but prejudiciable ultraviolet and infrared light. However, imaging the subtle colored shades of the Moon, due to different ages and material of the soil, is feasible with the help of color filters, then the color saturation has to be exaggerated with the help of an image editor software.
- Near-infrared imaging for more advanced amateur astrophotographers. This requires longer exposures than in visible light, seconds up to tens of seconds, telescopes having a diameter of 6 inches / 150 mm or more, and dedicated filters. There are a number or relatively unexplored and exciting applications of near-infrared imaging : underlying clouds of methane in Jupiter (CH4 filter), clouds on Uranus (e.g. 610, 685, 742 or 807 filters – the number indicates the wavelength, or « color » : a 610 filter fits to small-aperture telescopes while a 807 filter requires 12-in / 300-mm or larger telescopes). Note that a more advanced camera such as the ASI224MC (while beeing a color camera) provides much more « clean » images even if near-infrared imaging requires relatively long exposures.
- Near-ultraviolet imaging, especially interesting to image the Sun with a set of two filters : for instance an Astrosolar filter (neutral density 3.8) in front of the telescope to prevent the telescope from damaging due to the huge amount of energy from the Sun, and a CaK (calcium) filter. This set of filters shows a peculiar, fascinating layer just above the solar photosphere (which emits visible light) and just below the chromosphere (where solar prominences occur). Since this layer emits in near ultraviolet, it is barely visible to human eye, while the monochrome ASI120MM is able to image it.

The sensor has a analog-to-digital converter capable of delivering either 8-bit ot 12-bit images. 8-bit are perfect for bright bodies of the Solar System. Tests performed by capturing movies of planets and Moon in 12 bits, while providing more subtle and detailed raw images, showed no obvious improvement in final images in most cases for the Moon, and in no case on planets. The great interest of having a 12-bit converter is its ability to detect low levels of light, just above the natural brightness of the sky and light pollution. This greatly help to image galaxies and diffuse nebulae.

Figure 1 – playing at daytime with the 12-bit (left) and 8-bit (right) modes. The posterization effect is dramatically diminished in 12 bits. This has no effect on planetary and lunar imaging (at the exception of delicate features such as dark, lunar domes near the terminator), but the 12-bit mode is a serious advantage to image deep-sky objects such as diffuse nebulae or galaxies which show limited contrast.

The drawback of 12-bit imaging is the increased bulk of data. While 12 bits represent 1.5 times more than 8 bits, technical constraints of computers lead to embed the 12 bits into a 16-bit format, with obvious consequences such as needing larger storage capacity, slowering data tranfer and increasing computing time when stacking images. The reduction in speed also has consequences at acquisition time when we image planets or the Moon at low speed in 12 bits. Another feature to be taken in consideration is the dynamic range, or full well capacity / readout noise. Facing more recent ASI cameras, the ASI120MM shows the less favorable performance (67 dB), while the ASI1600MM has 2.5 times better results (75 dB). In addition, situations of low enlightment (< 50 e-/ADU) are defavorable to the MT9M034 sensor which shows abruptly increasing readout noise, about twofold the noise of the ASI1600MM or ASI290MM.

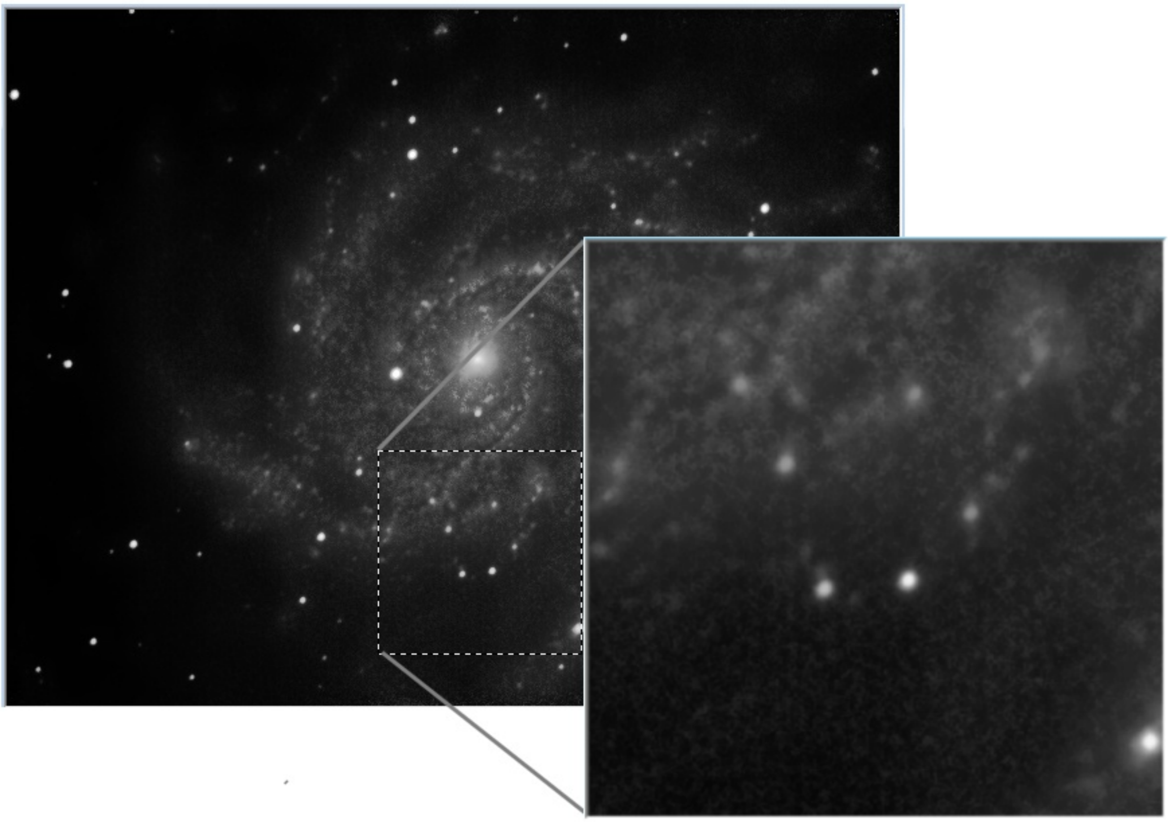

Figure 2 – in extreme cases, such as the pale, poorly contrasted, M101 Pinwheel Galaxy, some bands appear, mixed to the signal. This is a trace of the Fixed Pattern Noise, one of the sources of noise in a CMOS sensor, due to the structure in columns (columns of photosites sharing the same amplifier and converter). The image can be partially corrected by subtracting offset frames, but it is hard to separate the real image and the noise when the light flux from the galaxy is so faint. More advanced ASI cameras such as the ASI178MM show a even background, resulting in a far better image quality. Anyway, imaging M101 with a planetary camera is a performance. The telescope used for this image is a 10-in/254-mm Newton at F/4.7. Image N. Dupont-Bloch.

To conclude, the ASI120MM is the most affordable all-purpose, monochrome ASI camera but this is at the price of lesser performance, especially for faint galaxies and diffuse nebulae. However, beginners on a budget will be delighted with the camera for a long while.

Image field

Because the ASI120MM is intended to beginners, some explanations may be necessary prior to entering into technical details. The width of the image, or image field, depends on the combination of a sensor of a certain size and the focal length of the telescope or the photolens. The MT9M034 has a diagonal of only 1/3 inch, or 6 mm, comparable to a compact still camera or a consumer camcorder. This implies that imaging an entire constellation, for instance some tens of degrees large like the Big Dipper, requires a very short focal-length objective – this is why a wide-field lens is enclosed with the ASI120MM. When used with a telescope, the sensor delivers a relatively narrow image, albeit it offers more pixels than numerous dedicated, planetary cameras.

At this point, it is necessary to not confuse the field of wiew, the resolution, and the number of pixels.

- The field of view is the angular width of the image. The Moon is 0.5-degree large and it is easily masked out by our thumb when we observe it with naked eye. Many deep-sky objects are much wider, such as the Pleiades (about 2 degrees, or 2°). When we increase the magnification, we reduce the field of view. This is why many large, celestial subjects do not require a strong magnification.
- The resolution is the size of the tiniest detail in the image. It primarily depends on the telescope (the larger the optics, the finest the details). The magnification enlarges the image produced by the telescope prior to casting it onto the camera's sensor. A too weak magnification does not allow the telescope to cast the optical image so that each detail of the image corresponds to each pixel ; details merge on the same pixel and the resolution is reduced. At the contrary, if the magnification is too strong, each detail of the optical image is spread on several neighbour pixels : we are wasting light and the best resolution is exceeded. When we get the appropriate magnification, not too strong nor to weak, each detail in the optical image is cast on each pixel : the situation is optimal, and the resolution depends only on the telescope (and, of course, the stability of air). A small telescope may easily distinguish 2-km details of the Moon. The appropriate magnification is to be determined either empirically (the simpliest way, recommended to beginners), or theoretically by calculating the sampling rate (this is explained in astrophotography books). When we are able to recognize 2-km details on our image and on a detailed, lunar map, we can say that the resolution of the image is perfect, because the camera was able to record the finest details the telescope is able to produce. After some early tries on the Moon, we are ready to image Jupiter or Saturn in the limits of the possibilities of the telescope.
- The number of pixels of the MT9M034 sensor is 1260 x 980. The megapixel images from the ASI120MM are large enough to record both Jupiter and its main moons, entire globular clusters, or areas on the Moon, while the final image can pleasantly fill the screeen of a laptop. Another important thing to know is that the ASI120MM has a monochrome sensor ; this means that each photosite (a photosite is a light-sensitive tile, and the MT9M034 contains 1.2 million of them) exactly corresponds to each pixel of the final image. This is not the case with the color version (ASI120MC), where four photosites are needed to reconstruct one color pixel in the final image (anyway we will see in the chapters about color ASI cameras that the final resolution is much better than a fourth of a monochrome camera !).

See the review of the ASI178MM-cool to compare the relative surfaces of the sensors.

Housing, connectors, setup

Our first thought, when we unpack the camera, is that it is small (only 62 mm x 28 mm) and lightweight (100 grams). This is welcome in case of use with a debut telescope, with possibly fragile mechanics and lightweight focuser. While beeing one of ZWO's very first cameras, the ASI120MM already shows a sturdy, machined-aluminum housing. The naked camera offers a M42 x 0.75 female thread, one of the most spread standard for astrophotography (also called « T2 »). In case we are not equipped with M42-compatible connectors, the package encloses a 1.25-in (31.75-mm) adapter to be screwed into the camera, while the other side is to be directly inserted into the eyepiece holder of the telescope, once the eyepiece is removed. This quite simple adaptation is called « prime focus » : the telescope is exploited as a photolens. This provides the greatest luminosity, the widest field of view, the minimal magnification, and the easiest use. It is perfect to image entire regions of the Moon, bright star clusters such as the Pleiades (which are easily visible from cities), or the disk of Jupiter with its main moons in the neighbourhood (up to four visible at a time). Later, after we have gained experience, the same direct adaptation will be exploited to image more delicate subjects such as some galaxies or planetary nebulae.

The camera also may be exploited with no telescope at all. In the package, we find a wide-field, 2.1-mm lens (2.1 mm is the focal length of the lens), along with a thick, threaded ring. The ring is to be screwed into the M42 thread of the camera, then the lens can be screwed into the internal thread of the ring. The ASI120MM now is turned to an all-sky camera, capable of acquiring images at very wide field. On the back of the housing, we find a standard, Kodak female thread. The Kodak thread is to directly screw the camera on a photo or video tripod, or on a photo gimball. This is a perfect mean to image the Milky way in seconds, entire constellations, or to survey meteors. Thanks to the absence of magnification, the diurnal motion if the Earth is negligible, so there is no need for a motorized mount. The stars appear to be somewhat distorted at the extreme edges of the image ; this is due to the « extreme » optics. The internal female thread of the thick ring is a « C/S » (C/Small) format, a standard thread widely used in surveillance and industrial cameras, thus a huge number of small lenses are compatible with the ASI120MM. Beware of another standard called « C » : C objectives have longer focal length and they need a 5-mm long spacer to correctly focus on the ASI120MM. This is a difference with other ASI cameras which only accept C objectives while the ASI120MM offers a wider compatibility. The problem is that, numerous C or C/S objectives are very cheap and their low optical quality do not meet the requirements of astronomy imaging, especially with a megapixel camera.

The backside of the housing also shows four M4 female threads, 39 mm apart. We are completely free to exploit the threads ; for instance to screw the camera oriented toward the sky to survey meteors, to take movies or time lapses (e.g. one image per minute) of the rotating constellations while the Earth rotates. Another interesting possibility is to add a Do-It-Yourself cooler to diminish the noise in case we want to image deep sky with long exposures, especially during summer, because heat increases the level of undesired parasite signal in the sensor.

Experimental, DIY cooling (for experienced users)

A bane of all sensors (CCD or CMOS) is their inclination to spontaneously generate parasite noise. A part of the parasite signal cannot be totally diminished, such as the Fixed Pattern Noise, along with inevitable small defects such as a certain dispersion in the sensitivity of the different photosites, some dead photosites, possibly dead columns of photosites, or hot pixels (spontaneously lit even if no light reach them). You'd be surprised when examining the dramatic and numerous defects in raw images from professional astronomy cameras, including aboard the Hubble Space Telescope ! All these drawbacks may not appear at all with exposures ranging from milliseconds to seconds, even tens of seconds at moderate gain. During long exposures (up to 1000 seconds with the ASI120MM), a great part of additional parasite noise is generated when the sensor heats. This is why deep-sky cameras in professionnal observatories are severely cooled with liquid nitrogen (-195,8°C). This is not a convenient solution for amateurs. Another, more simple solution is to add a electric cooler, based on Peltier effect. We can find a Peltier module in an ice box, or at a electronic parts dealer. The good surprise is that, the sensor of the ASI120MM is in thermal contact – through a internal, metal finger - with the back of the housing. This is for passive, heat dissipation. Thus, we may cool the sensor by simply cooling the housing. Prior to the release of advanced, cooled ASI cameras, some people tried to build a low-cost, though relatively efficient, cooling system. The idea was to allow the ASI120MM to gather light for minutes instead of tens of seconds, with low parasite noise, in order to image fainter and fainter galaxies and nebulae. This has no interest at all when we image the brighter bodies of the Solar system (even in infrared) because they only require reasonable exposure duration, so thermally-generated noise has no time enough to dramatically increase.

We don't recommend the construction of a Peltier cooler to beginners unless they are familiar to basics of electronics or electricity. Nonetheless, the results are encouraging – until we pick up a more sophisticated, cooled ASI. Adding a DIY cooler is the most unexpected possibility of evolution of the ASI120MM (the expected benefits for color version are less interesting because the sensor is less sensitive).

Here are the necessary parts :

- A Peltier module for ice box
- A regulated, 12-Volt, 3-Ampere power supply
- Thermal paste
- 2 meters of wire (at least as thick as the Peltier's ones)
- Four M4 threaded rods (or four M4 screws, about 6-cm long) with four nuts
- A soldering iron, and possibly a driller with 4-mm, soft-metal drill bits
- A fan and its associated radiator for desktop computer (CPU cooler)

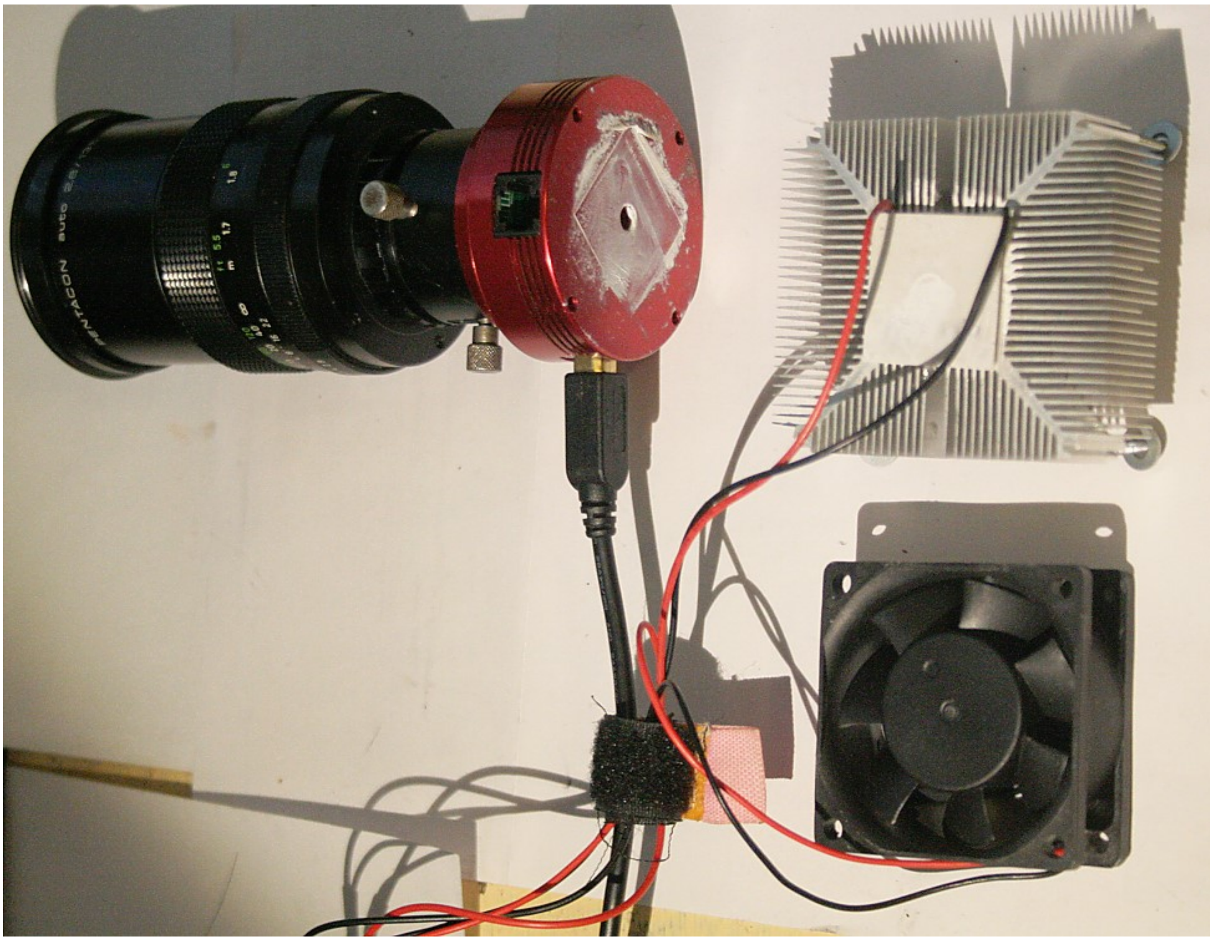

Figure 3 – The necessary parts to build a Peltier cooler for the ASI120MM. We can see thermal paste on the back of the housing. Paste also has been spread of the two sides of the Peltier module (the white square). The Peltier module is simply but firmly maintained between the radiator and the camera housing. Then the fan is placed on top of the radiator. The whole stack is eventually attached to the camera with four M4 threads. A drill may be necessary to pierce the radiator if it is larger than the fan, but, in my experience, it is unnecessary because the space between the female M4 threads of the ASI120MM intentionnally correspond to computer parts.

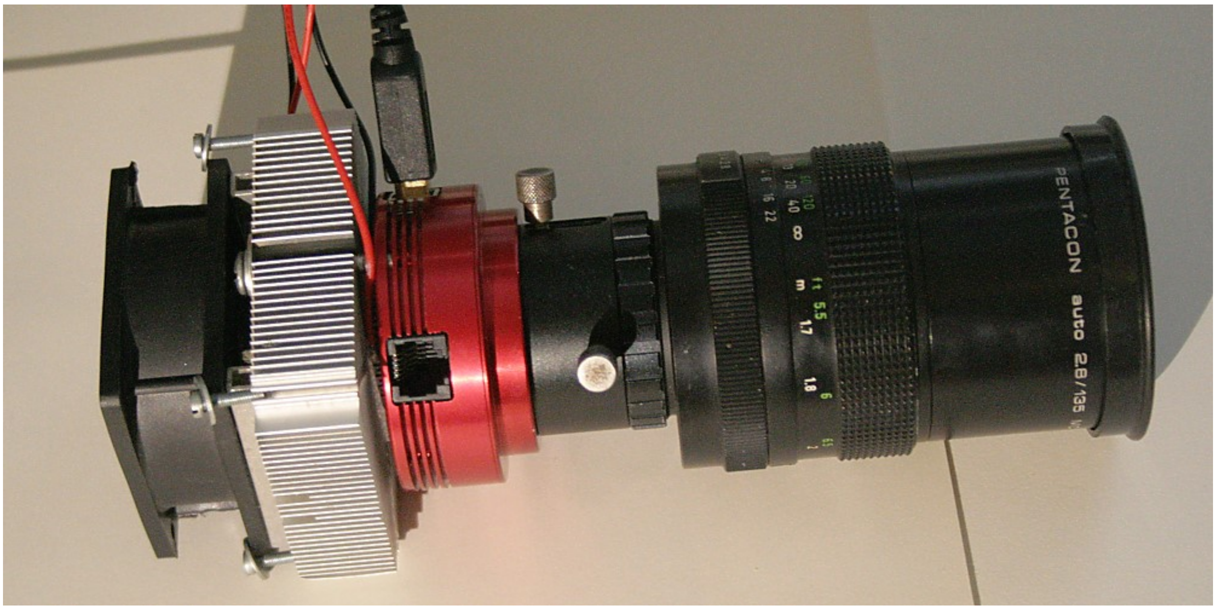

Figure 4 – From right to left: a M42-thread telelens, a M42-thread spacer directly screwed into the M42, female thread of the camera, the Peltier module (not visible on the image, inserted between the housing and the radiator and covered on

two sides by thermal paste), the radiator, then the fan. The M4 screws maintain the whole assembly. Images N. Dupont-Bloch.

Since the MT9M034 image sensor has a built-in thermal sensor, software such as FireCapture or Sharpcap are able to display its temperature in real time. As soon as we supply the Peltier, noise lowers while the sensor starts to cool down. The problem is, the system is so efficient that, during winter, frost forms not only on the housing, but also in the chamber of the sensor because of air humidity. The system has not to be cooled under 2-3°C, and reveals itself to be unnecessary when the weather is really cold. But in summer, exposures of tens of seconds or more become noiseless when cooling is on. While common Peltier modules accept up to 4 Ampere, a modest power supply with an output of 1.5-2 Ampere is sufficient, unless we have a current-regulated power supply for laboratory. Once the camera is reasonably cooled, exposures may last minutes with much lesser noise.

The ambiant temperature may vary during the night, and we have to survey the temperature of the sensor displayed by the software, because the sensor follows the air temperature on top of the effect of the Peltier cooler. Since this simple cooling system does not take in account the variable, ambiant temperature, the cooling has to be manually – subsequently roughly – regulated to not reach near-zero or negative temperatures which triggers apparition of frost. Moreover, if we take dark frames (see next chapter) at a given temperature, we have to acquire a new set of dark frames once the temperature has changed. This is why a regulated, advanced cooling system was asked by a number of deep-sky photographers, and eventually led to the release of cooled ASI cameras (see chapters on cooled ASI).

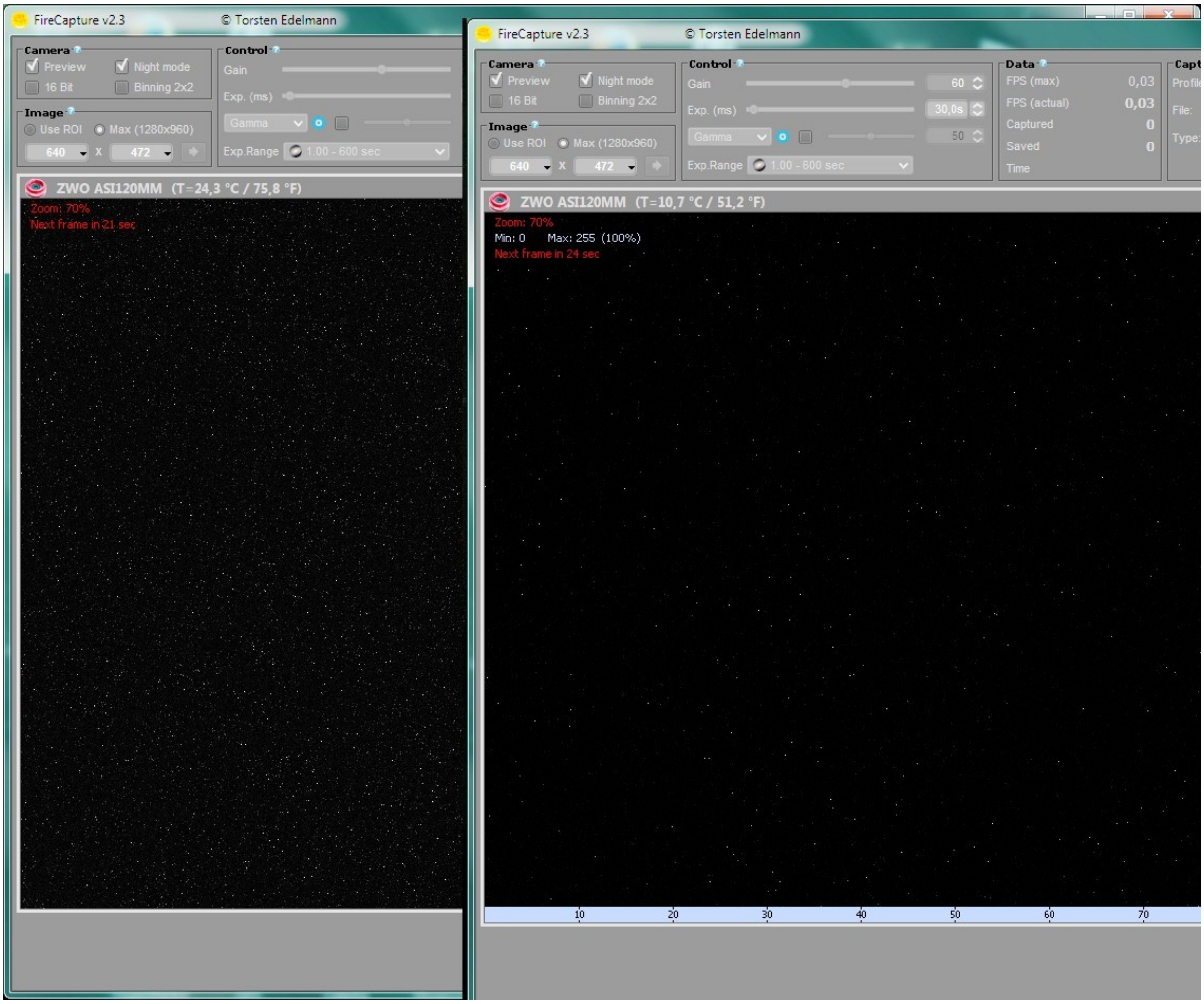

Figure 5 – The images were taken while the cover was in place (« dark frames »). Right : cooler is on, left : cooler is off. The exposures lasted 30 seconds. The thermal noise significantly lowered, even with a difference of 15°C. At this time, a cooled ASI is much more performing. Note that series of dark frames are not sufficient to separate the noise from the signal from faint celestial objects : during summer, thermal noise reaches then exceeds the signal. Image N. Dupont-Bloch.

On the sky

All-sky

Playing with the enclosed, 2.1-mm lens offers a first opportunity to discover and experiment the camera and the software, and interesting images are to be expected. By placing the camera equipped with the lens behind the window, we already can realize time lapse of passing clouds. At night, meteor showers can be recorded by programming a infinite sequence of 30-second images (Figure 5). If the meteors are not awaited to be bright, the binning mode may seriously help to gather more light, at the price of the reduction of the number of pixels.

Figure 6 – A Geminid meteor captured with the 2.1-mm lens. Exposure 30 s, gain 20. The Full Moon was rising. Image N. Dupont-Bloch.

Imaging the Milky Way or several constellations in a single shoot are other exciting subjects. Since the female thread of the intermediate, thick ring is a standard, C/S mount, other lenses for industry are directly compatible. The optical quality is essential because the camera has tiny photosites, which are very sensitive to possible optical flaws.

Figure 7 – The Milky Way was very low on the horizon when I imaged several constellations in a single shot of 10 seconds. The Big Dipper is at top of the image. Image N. Dupont-Bloch.

The Moon

The Moon is a perfect subject to start astrophography, because is is bright, large, and it contains numerous details showing high contrast. I had already gained experience in lunar imaging with older CCD and CMOS sensors when I purchased the ASI120MM. I must admit, this was my first ASI camera and I was both excited and worrying about purchasing another CMOS sensor-equipped camera. My first tries were dedicated to searching traces of bands or noise in raw frames of the Moon. The search was unsuccessfull for weeks : images were very clean, including the darkest areas near the terminator. Relative to my older, favourite CMOS camera, the magnification was boosted, thanks to newer sensor and electronics with low noise, smaller pixels, and higher sensitivity. Moreover, the full-aluminium housing was seriously build, with no tilt at all of the sensor (the image was accurate in all corners). The last classic problem I was afraid of is that, CMOS sensors do not like very much extremely short exposures, such as solar imaging or lunar imaging at low magnification, especially when the Moon is gibbous of full. In such cases, bands tend to appear (due to the structure of a CMOS sensor), but the camera worked very well.

Beginners should try to take still images in BMP, PNG or TIF format. In my opinion, SharpCap is perfect for lunar imaging because it offers total control of the camera's features while beeing easy to use. Best results are obtained by acquiring SER movies of 300-500 images to be automatically stacked in the aftermath (with the help of AutoStakkert !2, Avistack or other software). The exposure may vary depending on the lunar brightness : height relative to the horizon, phase, possible color filter, magnification. The 16-bit (indeed 12 bits) mode revealed itself to be useless for lunar imaging, at the possible exception of very dark areas at high magnification. In most situations, not only the 8-bit mode is sufficient ; in addition, it saves space on the hard disk (half the space needed for 16-bit mode), the computer has less data to transfer from the camera, and the frame rate (Frame Per Second or FPS) is higher. I obtain good images with a correct balance between gain and exposure duration : the exposure should be as short as possible to minimize the blurring effect of warm, turbulent air, while the gain has to be set in the range of 40-60%. If the exposure is longer than 100 milliseconds (ms), the turbulence strongly affects image accuracy. If the incoming light is not sufficient, the best thing to do is to lower the magnification rather than increasing the gain (this would lead to noisy images). The best setting is achieved when the histogram is filled at about 80 percent.

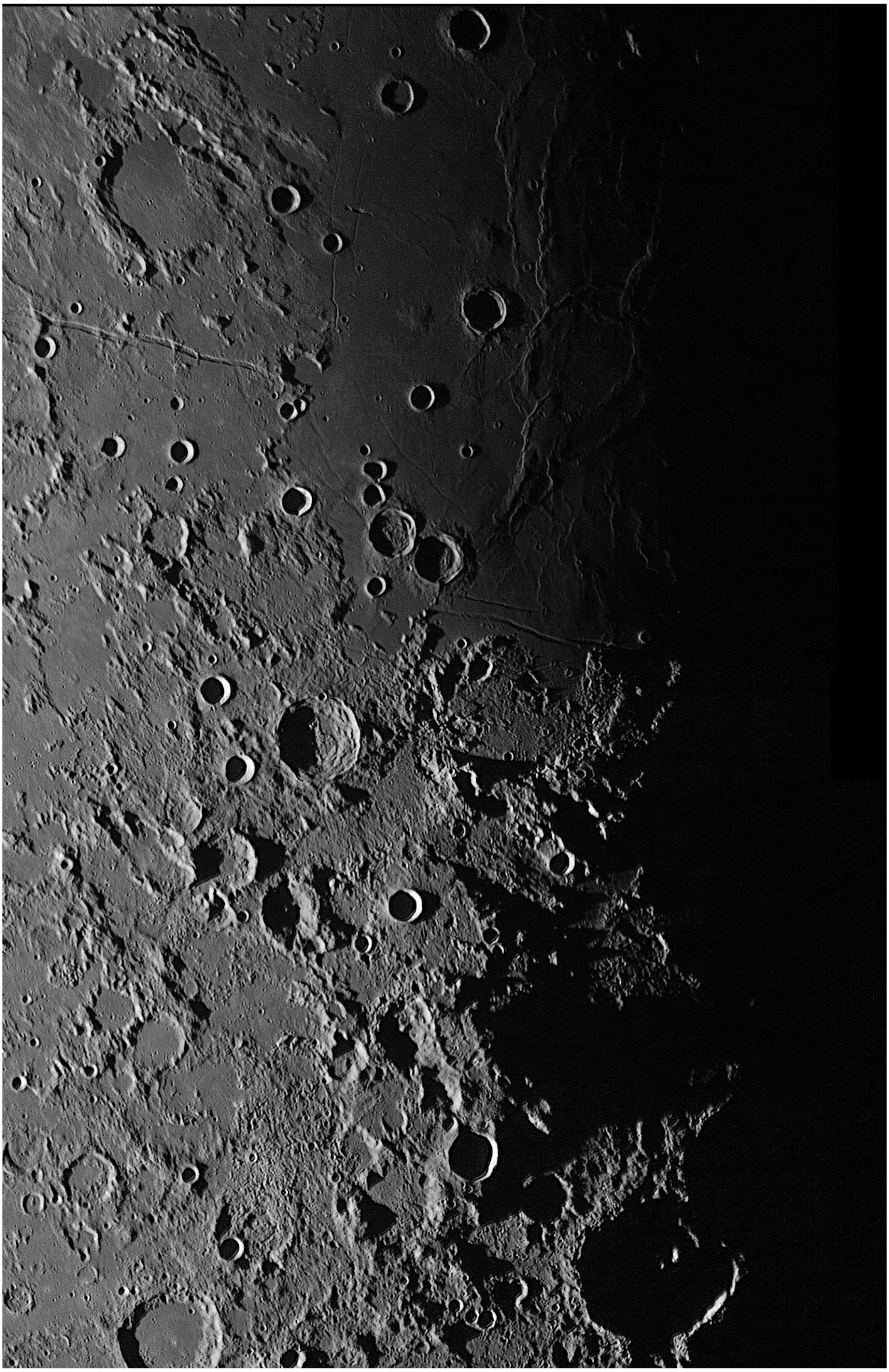

Figure 8 – Lunar terminator, mosaic of 3 images vertically assembled. Each image come from a 8-bit, SER movie, acquired with FireCapture, and then processed with AviStack and PhotoShop. 10-in/254-mm Newton with 2.3x Barlow, red filter, ASI120MM. Image N. Dupont-Bloch.

Planets, monochrome

Planetary imaging is perfectly in the scope of the ASI120MM, with the difference of a larger field relative to more specialized cameras. I was initially surprised by the softness of the images, due to relatively low noise. The best acquisition parameters are 8 bits, gain 40-60%, histogram filled to 80%. We may record images, but the most efficient way to quickly acquire numerous images when the turbulence is low, is to save images in a .SER movie file. When imaging in monochrome, I usually use SharpCap. The series of images, or the movies, have to be aligned and stacked with the help of AutoStakkert !2, Avistack, or other software. Then the stacked image (to be recorded as a TIFF or FITS file) may be processed with wavelets in Registax.

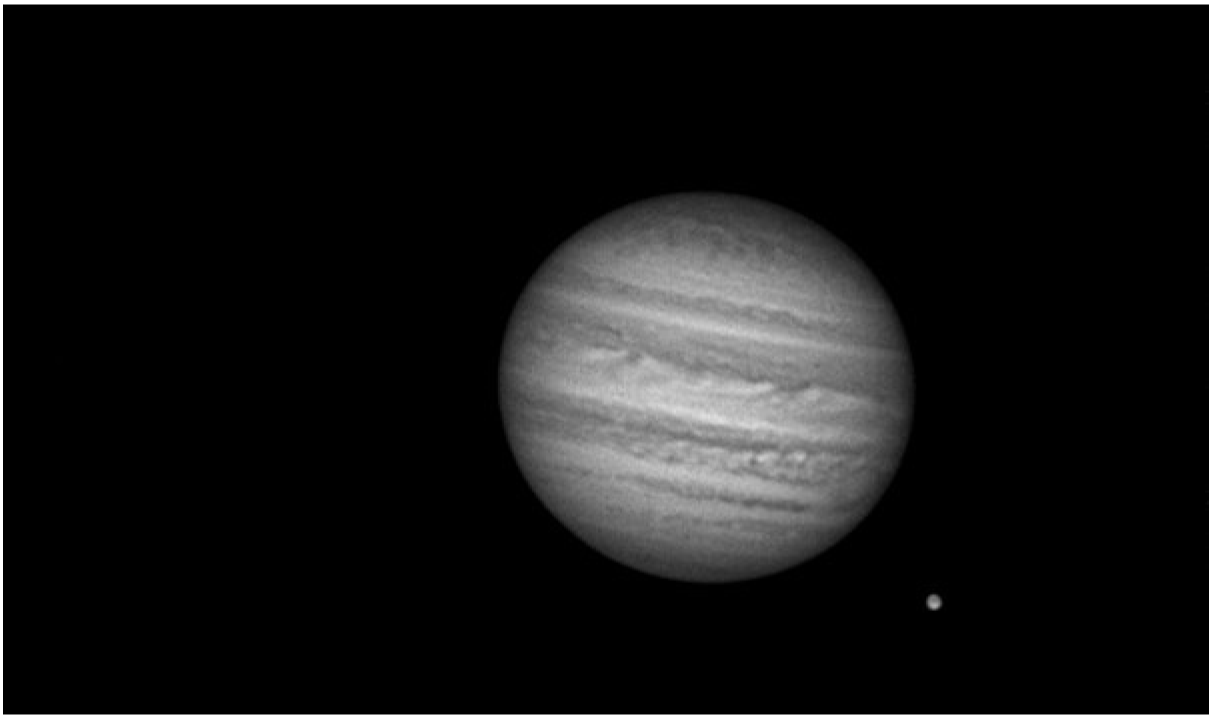

Figure 9 – Jupiter and Ganymede. ASI120MM, red filter, 254-mm/10-in Newton, Barlow 2.3x. Image N. Dupont-Bloch.

Figure 10 - Another pleasing capability of the ASI120MM (and other ASI120 cameras) is the direct acquisition of megapixel images, such as Jupiter and its main moons at large. From right to left : Ganymede, Io, Jupiter, Europa. Color is acquired with successive red, green and blue filters. Image N. Dupont-Bloch.

Planets, trichromy (for experienced users)

Trichromy requires a filter wheel and three imaging filters : red, green and blue. ZWO also manufactures this equipment, and a kit comprising an ASI120MM, a filter wheel and imaging filters (red, green, blue and luminance – that is full spectrum, all filters cut undesired ultraviolet and infrared) is available in a complete package. Images have to be separately processed, as three monochrome images, then re-assembled in an image editing software, as a TIFF image (RGB combination). Colors have to be reagligned in most cases ; Registax provides a very handfull RGB-align function. Even if the efficiency of the MT9M034 sensor perfectly matches RGB filters, I prefer using FireCapture because not only it can save reusable, quick « profiles » (whole set of acquisition parameters) per color, but it also can save movies in WinJupOs file name format for easier processing. WinJupOs is a software to compensate for the rotation of planets such as Jupiter (Jupiter allows a 2-mn exposure before motion blurring appear). It requires extra work, but the results are by far more accurate. My advice is to slowly evolve from monochrome to the more demanding, but more rewarding, trichomy imaging.

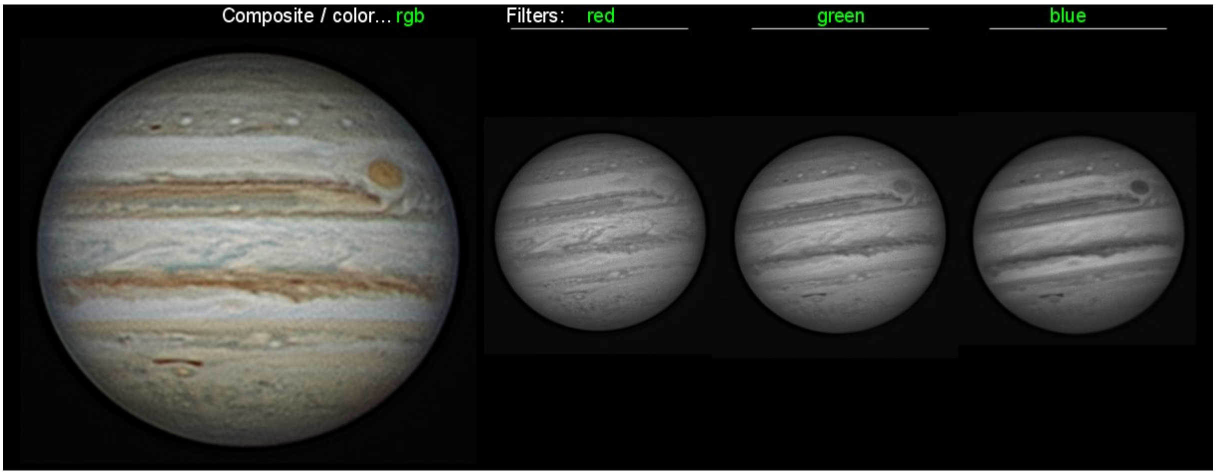

Figure 11 – Jupiter in trichromy. From right to left : successive, monochrome images in blue, green, red, then final image. Note the differences in the cloud belts and how the Great Dark Spot appears in the different colors. The images have been un-drifted (« de-rotated ») to compensate for the quick rotation of the planet (a jovian day lasts only 10h 55mn) with the help of WinJupOs prior to assembling the color image. 254-mm/10-in Newton, 2.3x Barlow and CCD filters for trichromy. Image N. Dupont-Bloch.

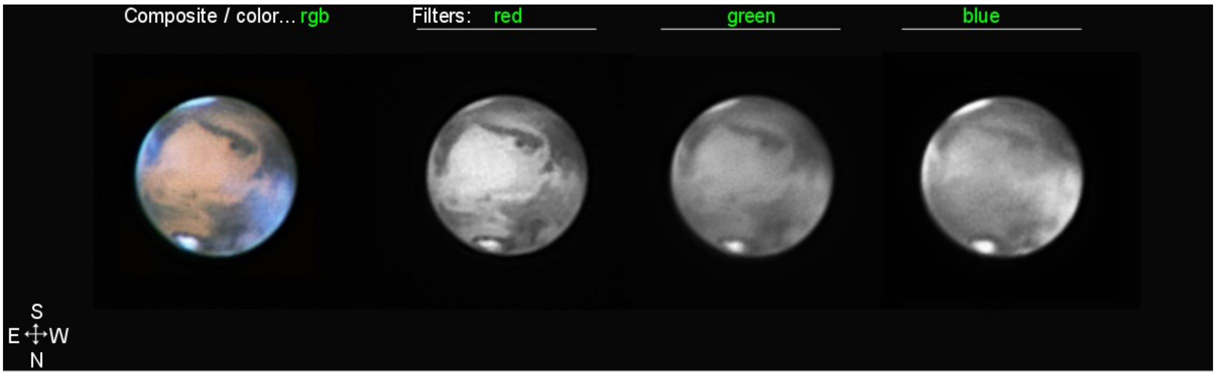

Figure 12 – Mars : ice clouds above the equator and in Hellas basin at top ; polar cap at bottom. Acquisition and processing are the same as with Jupiter. Since Mars rotates slowly (24h 37mn), no « de-rotation » with WinJupOs was necessary. Same instrument as above. Image N. Dupont-Bloch.

Deep-sky

Galaxies, nebulae and star clusters are not necessarily small objects - they often span more than the Moon - but they are faint. While CCD sensors are perfect devices for long exposures (with a greater readout noise than CMOS), my tests performed with a previous monochrome, CMOS sensor had revealed classic weaknesses of the technology : hot pixels or spontaneously lit photosites, random noise, limited exposure duration, noticeable offset with variations in sensivitiy of photosites and columns of photosites, and a high detectivity threshold level. I only have performed tests with no filter at all, to preserve incoming light ; the telescopes were a Celestron 5 at F/6.3, a 70/420 achromatic refractor, and a 10-in/254-mm Newton at F/4.7, installed on my terrace in town, in backyard or at countryside. The good news was some 5-20 seconds were enough to capture star clusters and galaxies with relatively little noise. After some tries, it quickly appeared that best settings are not too long exposures, gain in the range of 40-60%, and dark frame subtraction. A dark frame is an image taken while the telescope objective - or aperture in case of a reflector - is simply covered, with the same parameters as during acquisition (refer to the explanations about DIY cooling for questions about temperature variation). FireCapture and other acquisition software help to capture dark frames. They also automatically subtract one (preferentially 10-20) dark frame to each image during acquisition ; hence frames are already cleaned up from the most important source of noise in CMOS sensors (other sources are electroluminescence enlighting corners – cancelled with the help of dark subtraction, and readout noise - much lower than CCD sensors, and that is why CMOS are better used with limited exposure duration and many frames to stack, at the contrary of CCD).

The exposure is the last parameter to be carefully adjusted. The limited dynamics of the MT9M034 (potential well of 14 500^{e}- and 12-bit converter) tend to enlarge bright stars while gathering sparse light from the arms of galaxies. Star clusters suffer less from the effect if we take care of not saturating the real-time histogram (the right part indicates the number of pixels totally lit) of the acquisition software. In most cases, for non-stellar, diffuse objects, the best choice is to set the exposure so that the faintest levels in the histogram are just beyond absolute darkness, at left part. if the object is too faint to be detected, we can click on « binning 2x » to group the photosite by four. This reduces the resolution by four but the sensitivity is multiplied by four, hence shorter exposures can reveal otherwise elusive objects. The spiral arms of M66 Galaxy were easily detected with a Celestron 5 at f/6.3, gain 60%, binning 2x and exposures of 20 seconds.

Thanks to its small housing and low thermal emission, the ASI120MM also may be placed into a Fastar or Hyperstar adapter to image deep-sky objects at F/2.

A good thing to do is to set « high-speed » to off (default value) : this divides the sensor's internal readout speed by two and lowers thermal noise while keeping acceptable image transfer duration (always faster and less noisy than a CCD). The option is available by SharpCap and FireCapture, and other image aquisition software.

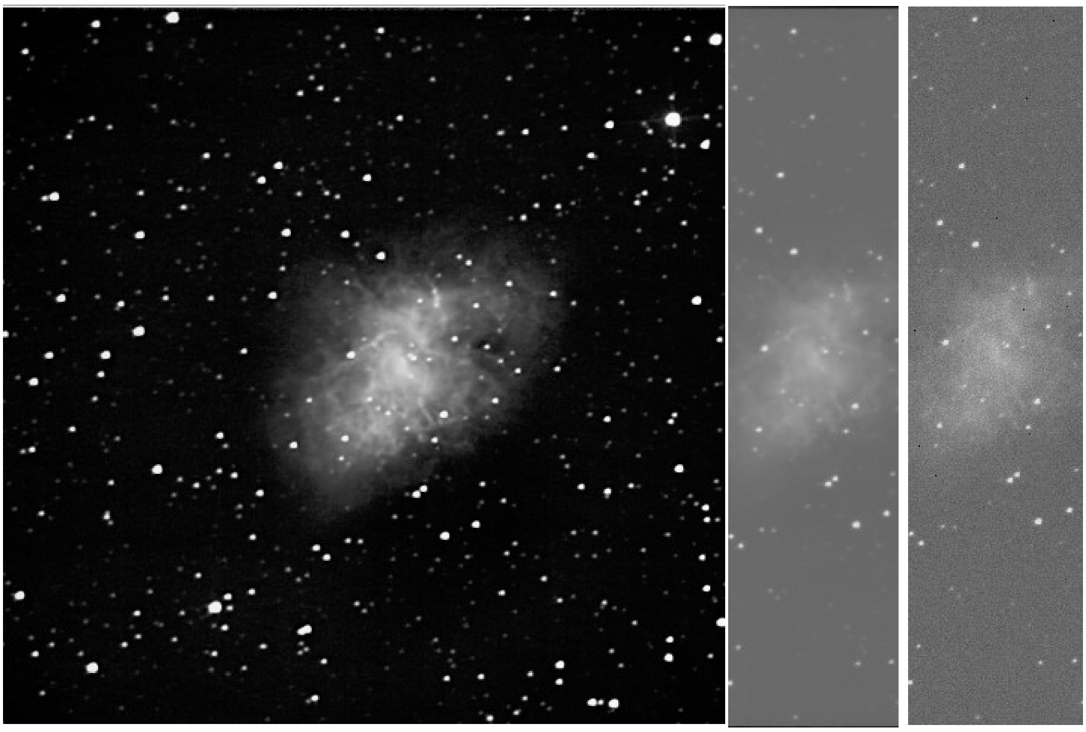

Figure 13 – The Crab Nebula M1. Left : final image. Right : a raw frame of the Crab Nebula M1 with binning 2x, 254-mm Newton at f/2.9, gain 60, exposure 20 seconds, 12 bits. A less extreme, 200-mm F/5 Newton or other classic instrument gather sufficient light to image such a nebula with an ASI120MM. Center : stacking 170 frames with Autostakkert !2, Avistack or DeepSkyStacker, softens the image prior to final, levels adjustment. Image N. Dupont-Bloch.

Figure 14 – Whirlpool Galaxy M51, 205 frames of 15 seconds, gain 60%, sensor at 5°C. Image taken with a 10-in/254mm Newton at f/4.7 from suburbs ; the air was cold and calm. Note the small, 15.7-magnitude galaxy viewed edge-on at bottom left. This is a nice performance for a CMOS, planetary camera. Image N. Dupont-Bloch.

Figure 15 – The Flame Nebula in trichromy with a 300-mm 1 :4.5 telelens and a filter wheel. Thanks to the short focal length of the optics, autoguiding was not necessary, allowing deep-sky imaging with minimal equipment. Image in 12 bits (no cooling !), dark frames subtracted during acquisition with FireCapture. 6-nm H-alpha filter, 107 x 60s and 37 x 120s. Green and blue 23 x 10s with binning x2 to save time. Gain set to 60% for all frames. Image N. Dupont-Bloch.

To conclude, the ASI120MM is capable of imaging relatively bright, deep-sky objects at low ambiant temperature and relatively short exposures. The sensor was not designed for such an application, but beginners on a budget should be excited by knowing that, this planetary camera by far exceeds its main scope.

Autoguiding

Autoguiding ensures the mount to accurately track a star if we want long exposures, that is more than 15 seconds with a common, motorized equatorial mount. The ASI120MM, with its sensitive, monochrome sensor, is well suited to this task. While the ASI120MM tracks stars, a second imager (a DSLR or a deep-sky camera) patiently accumulates light from faint galaxies, star clusters or nebulae with no limit in time. The first thing to do is to is to have a dedicated software, such as PHD2. In order to ensure a wide compatibility with guiding software, ZWO provides a software component compatible with the standard, ASCOM astronomy communication protocol. PHD2 accepts both native drivers and ASCOM drivers for the ASI cameras. ASCOM is slower, but it is more compatible. First, we have to plug the Rj11 cable to the ASI120MM's ST4 port, then on the Autoguider port of the mount (many other options exist, even if the mount lacks an autoguider port). In PHD2, we have just to click on the first button at bottom left to select the camera then choose ASI120MM-8 bits, click on « connect camera », then « connect interface » and « close ». PHD2 is very user-friendly and offers only four other buttons : « loop » (to see stars then to select a guide star), « calibrate » (automatic processing to examine how the mount operates – this requires some minutes), then « guide » and « stop ». To be honest, I already have used autoguiders with CCD sensors (very clean raw images) or larger sensors (to get much more chances, in a wider field, to see a guide star bright enough). The ASI120MM is not a CCD, nor has a large sensor, but it is a very reliable autoguider and I still exploit it successfully. The most interesting part is that, thanks to its extreme compatibility (Kodak thread for a gimball or other mechanical connection, M42 lens, adapter for 1.25-in / 31.75-mm eyepiece holder, C/S lens adapter), the ASI120MM can exploit absolutely all kinds of lens, telescope, telelens, or finder, as a guide telescope. When screwed into a gimball, the camera and its optics can be installed on one of the telescope rings, or at front of the dovetail. To image with a Newton or a Schmidt-Cassegrain, I exploit the ASI120MM as an autoguider with a 70/420 achromatic, guide refractor, parallel to the imaging telescope ; the two tubes are screwed on a assembly plate. The guiding scope also may be screwed on a intermediate dovetail, or maintained by rings with adjusting screws 120° apart ; the main telescope's rings often offer two female, Kodak threads for the dovetail on the rings. The most reliable solution, in terms of mechanics, is to insert a off-axis guider (OAG). The device comprises a tiny prism to sample a small, peripheral part of the image field. The image is cast onto the autoguiding ASI120MM, while the remaining- and main - part of the image field reaches the imaging camera. The solution is very elegant and has long proved to be efficient even when imaging at long focal, but it shows some drawbacks : the very narrow field of view may not contain a guide star, and it extends the back focus (by 16.5 mm in the case of ZWO's OAG).

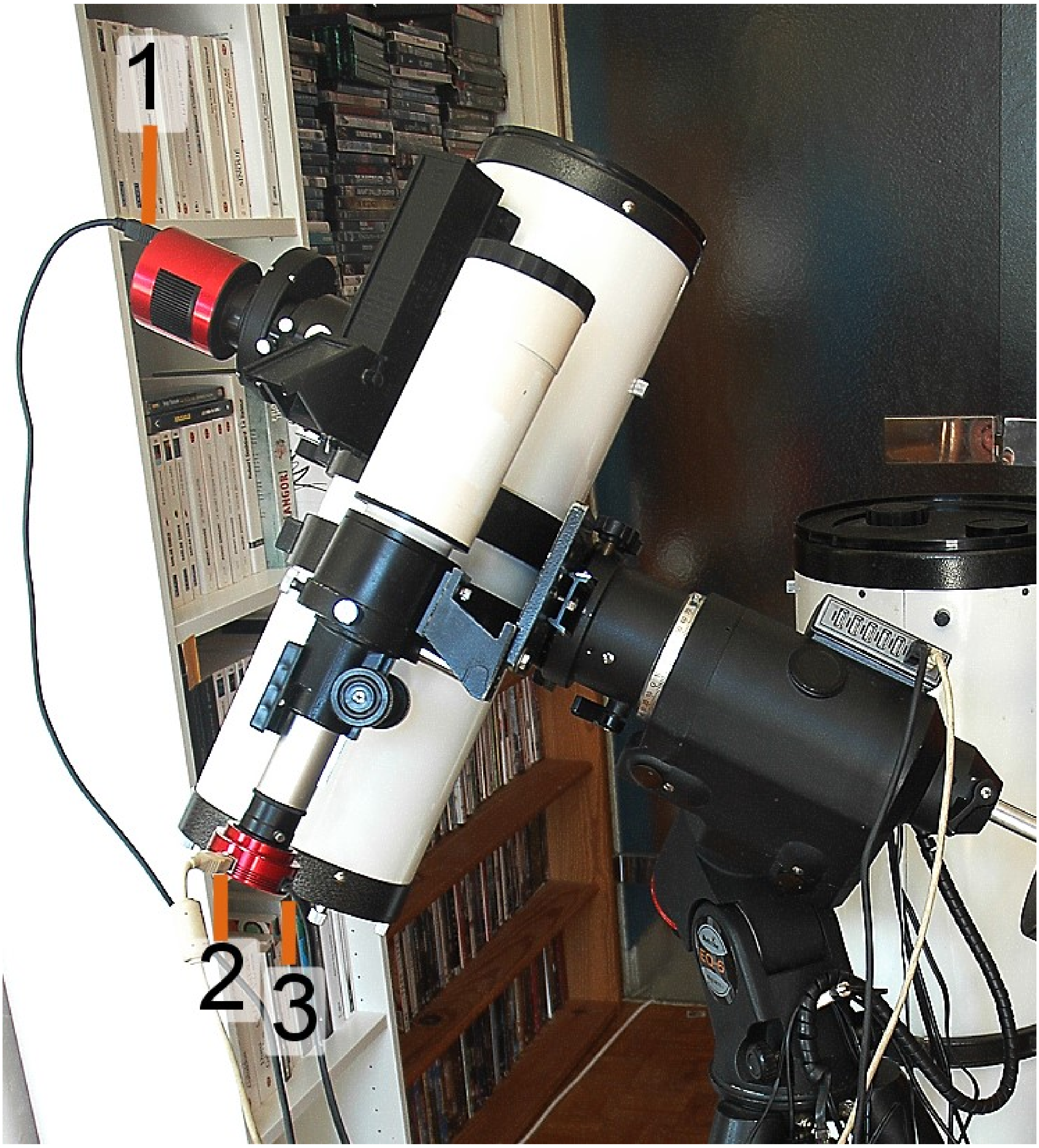

Figure 16 – The ASI120MM as an autoguider. (1) a cooled ASI with its USB cable (the power supply cable for cooling is not represented). The ASI120MM has two connectors : (2) the USB2 cable to the laptop with autoguiding software such as PHD2, and (3) a RJ11 cable for the corresponding connector on the mount, labelled « autoguider ». This is only one possibility amid many others. It is better to rotate the ASI120MM so that it the image is aligned horizontally with the right ascension. When the motors of the mount are off, the guide stars hava to drift horizontally. Then the motors are set on, the software completes an automatic calibration, and the autoguiding is operational. Despite its small sensor, the ASI120MM is sensitive enough to detect guide stars even if the guide scope cannot be orientated independently from the imaging telescope. The ASI120MM runs with PHD2 with the ASCOMV2 driver, RAW8 mode. Image N. Dupont-Bloch.