The ASI178MM-Cool camera

Nicolas Dupont-Bloch, March 2017 – Revised on August 2022.

Overview

The ASI178MM-cool is an all-purpose, HD monochrome camera for planets, the Moon, the Sun, and deep-sky objects of all kinds, and it is an autoguider with in-built, ST4 port. Since the camera concentrates 16 megapixels on a small-sized sensor (barely 9 mm in diagonal), it is particularily suited to wide-field imaging in HD 2K even if the image field of the telescope is not perfectly corrected on a large surface, such as a F/6 doublet ED refractor with no field corrector, a F/5-F/6 Newton with no coma corrector, a Ritchey-Chrétien with a 0.75x focal reducer, a Schmidt-Cassegrain with a 0.63x reducer-corrector, a Fastar/Hyperstar Schmidt-Cassegrain or other comparable situations. The camera is also perfectly compatible with narrow-field telescopes such as Maksutov-Cassegrain. It may be fitted to various DSLR photolenses with the help of adapters (only the uncooled version is compatible with C/S lenses). The drawback of the tiny, 2.4-micron wide photosites is that, any optical flaw which is negligible with larger photosites may become visible with the ASI178MM, e.g. coma, spherochromatism, astigmatism. The accurate camera indeed is demanding in terms of optical quality. On the other hand, it offers 14-bit images to distinguish four more shade levels than the ASI290 or ASI1600 cameras for half the cost of the larger ASI1600. It has less sensitivity[1] than the ASI290MM but it offers three more pixels. The ASI178 delivers images by far larger than a computer screen, although it is also capable of high frame rate for planetary imaging with reduced field of view, or Region Of Interest. In my opinion, above all, it is remarkably suited to lunar imaging with oversampling and large field, and deep-sky imaging with high-quality optics and short focal length.

Another non-negligible advantage of such a small-sized sensor is its full compatibility with affordable, 1.25-in/31.75-mm filters and filter wheels, along with widespread devices of the same diameter (Barlow lens , tele-extender for eyepiece projection, small-telescope eyepiece holder).

Figure 1 – The ASI178MM-cool ready for planetary or lunar imaging, with a Barlow lens and a optional filter wheel which directly accepts the M42 x 0.75, female thread of the camera body. As illustrated, the narrow sensor is compatible with 1.25-in/31.75-mm filters and accessories. Planetary imaging does not need cooling at all. To image deep-sky objects, the regulated cooler is on, the power supply cable is connected and the Barlow is removed or replaced by a coma corrector at the right distance from the sensor. Image N.Dupont-Bloch.

[1]The sensitivity of the 178 is rated at 2 Volt per square micron to be compared to 4,5 Volt for the 290.

Sensor and possible applications

Keeping a high sensitivity despite the small surface of the photosites is achieved by the STARVIS technology, that is back-illuminated sensors. At the contrary of classic, front-illuminated sensors, light directly enters the potential well (the « bucket » which accumulates electric charges proportionally to incoming light) with no obstacle apart from the necessary microlenses which concentrate light. This leads to lesser internal light loss, reflection and diffusion, and greater effective surface (fill factor) of the photosites. The well capacity, that is the limit for accumulation of charges, is comparable to the IMX290 or the ASI120MM's MT9M034 (about 15 000^{e}-) : this is one of the smallest ones amid ASI cameras. The small capacity leads to relatively quick saturation of bright stars in a stellar field during long exposures. In terms of signal on noise ratio, the 6-megapixel IMX178 is two times less performing than the 2-megapixel IMX290 (SNR1s values respectivly 0.46 and 0.23 lx[2]) and 3.5 times less than the 1-megapixel IMX224 (0.13 lx). The lesser performance is to be compensated for with a lower gain and 2-3 more longer exposures than the other cameras ; anyway the IMX178 is very well suited to long exposures. In case of very low enlightment[3], such as faint galaxies or elusive, diffuse nebulae, the IMX178 shows 30 percent, or better, less readout noise than the aforementioned cameras plus the ASI1600MM and the ASI071MC. The readout noise of 2.2^{e}- at system gain = 0 is better than all other ASI cameras, truly favorising long exposures. As of March 2017, the dynamic range (77 dB) is as good or better than all other ASI cameras at the exception of the color ASI071MC.

The 14-bit converter can distinguish a little more than 16 000 different gray shades. This is four times more accurate than the 12-bit ASI224MC, ASI290, ASI1600 or ASI120MM (4 096 different shades). At this moment, only the ASI071MC has such a precision. This is essential to image the very subtle light gradients in the faint arms of galaxies or the extensions of planetary or diffuse nebulae while other cameras show a posterisation effect (steep transitions of shades, like office laser printers – refer to the ASI120MM review). This is also important because the brightness of diffuse, deep-sky objects is always very close to natural glowing of the sky and light pollution ; hence distinguishing a pale object in a bright background requires a better converter resolution than a planetary camera. 14 bits represents the exact balance between planetary cameras and specialized, deep-sky, CCD cameras. The feature has no visible consequence on planetary or lunar images if we stack a sufficient number of frames (300-3 000, up to 15 000 in case of strong turbulence). Note that the precision of the converter (16 384 possible levels or ADU for Analog-to-Digital Unit) perfectly matches the potential well capacity (15 000^{e}-).

Owing to its characteristics in terms of image size, spectral sensitivity, converter resolution, and low noise, the IMX178 is suited to HD, deep-sky imaging with no filter or with selective filters for light-pollution rejection, trichromy, or specific bands such as hydrogen alpha, sulfur or oxygen. Since concentrating so many pixels in such a small surface leads to tiny, 2.4-micron-wide photosites, we will need a telescope with 30% shorter focal length to keep the same magnification as with an ASI1600MM. If we have a too long focal length relative to the size the the photosites, the sampling rate (magnification, in arc-seconds per pixel) is too small, resulting into dark, uselessly oversized images. The solution is to use the IMX178MM with a photolens, a small Newton or a short-focal, apochromatic refractor. Another consequence of the 2.4-micron photosites is that the image

[2] http://www.sony-semicon.co.jp/products_en/IS/sensor0/technology/snr1s.html

[3] Especially, for the considered cameras, when the system gain is less than 50^{e}-/ADU.

resolution is better than the diffraction spot, or Airy disk. Thus, the image of a focused, unsaturated star with moderate turbulence occupies 2-3 photosites at F/D=2.8, 4-6 photosites at F/D=4, and twofold at F/D=8. The early tests I had performed with various photolenses (58 mm F/2, 300 mm F/4.5, 180 mm F/2.3) always showed otherwise negligible spherochromatism. Indeed, the ASI178MM demands precision optics such as high-quality photolenses and fine, short-focal telescopes at F/D=6 or less.

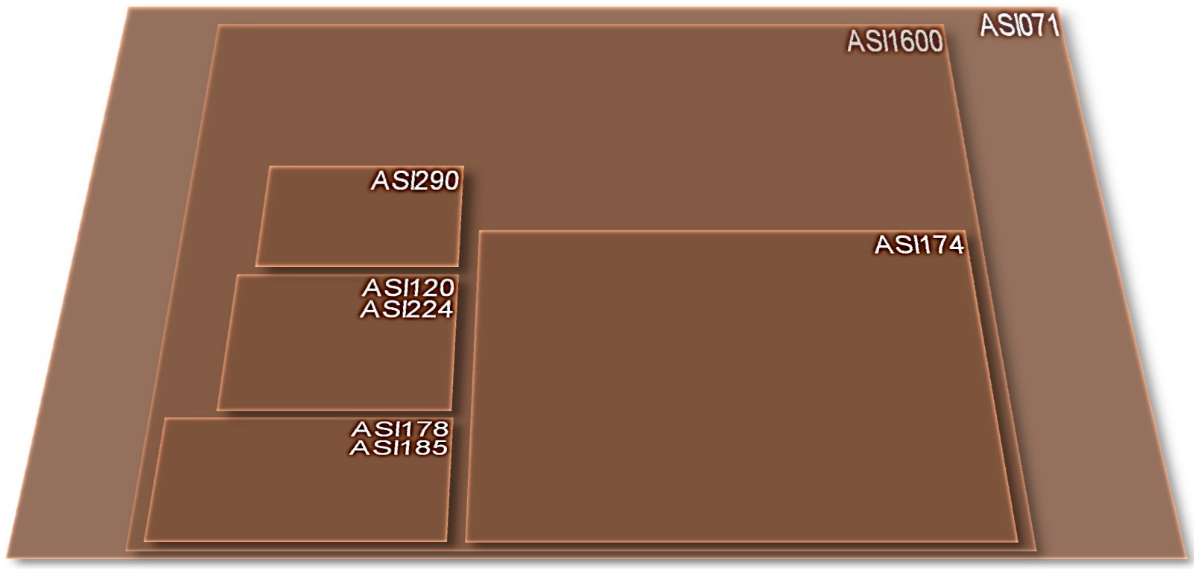


Figure 2 – Comparison of the sizes of the sensors of some ASI cameras. The ASI178MM is not the largest one but it concentrates the tiniest photosites. For deep-sky imaging, employing a 30% shorter focal length results in the same horizontal field as the ASI174MM, because the sensors have different surfaces. For lunar or planetary imaging, keeping the same focal length as with the ASI174MM increases the magnification by 140% or by 30% relative to the ASI120MM, because the sensors have different sizes of photosites. Image N.Dupont-Bloch.

Planetary imaging requires high frame rates. The ASI178 reaches 479 frames per second (FPS) if we accept to take a small part only of the sensor, this is 320 x 240 pixels (Region Of Interest). This is quite enough to image a large planet such as Jupiter with a 8-in/200-mm telescope. The extra magnification offered by the small photosites means that in case we have a relatively important focal length, e.g. 1400 mm or more at prime focus of a small Maksutov-Cassegrain, not to speak of a large, 14-in/355-mm Schmidt-Cassegrain having a focal length of 3900 mm, the use of Barlow lens or eyepiece projection is even unnecessary. If we are mainly looking for ease of use in color planetary imaging, the ASI224MC or the ASI178MC are more convenient choices, but the ASI178MM has other advantages. Its sensitivity in near ultraviolet is a real asset to image the clouds of Venus. For more advanced users, it is excellent in trichromy, with a large bandwidth and low noise. It shows a uncommonly wide field to frame both Jupiter and some distant moons or large planetary conjunctions while keeping a great magnification.

All monochrome, HD sensor are ideal to image the Moon. But let us examine the impact of the tiny, 2.4-micron photosites. If we keep the same resulting focal length as with a classic, planetary sensor, that is 4-5-micron-wide photosites, the magnification is almost two times greater. Owing to its brightness, the Moon accomodates to oversampling, that is when the magnification is twofold or more the necessary value to reach the visual resolving power of the optics. The advantage is that, when the atmosphere is cold and steady, oversampling allows the camera to acquire details smaller than in usual seeing conditions. Oversampling is especially usefull with color sensors such as the IMX224, but it also works very well with some monochrome sensors as long as they are sensitive and noiseless. This is the case when I image the Moon with the ASI178MM, and the extra magnification brings substantial improvement. Relative to the monochrome ASI120MM, the final accuracy is 20-30% better. If we try to shoot the Moon in near infrared, the loss in resolution (due to the nature of light) could lead to waste light unless we decrease the magnification. Another solution is grouping the photosites by four or nine to simulate giant photosites : that is binning, respectively x2 and x3. Based on tests performed with different cameras, binning with monochrome sensors give better results than color ones because no interpolation occurs. Even if binning reduces the number of pixels in the final image, the IMX178 has 6 millions of them, hence it can produce megapixel, near-infrared lunar images even with binning.

Other very interesting applications are small solar instruments having a very narrow field of view. Simple, solar imaging with a neutral density filter (e.g. Astrosolar) is perfectly in the scope of the camera, even if the sensor has a rolling shutter, theoretically less convenient than the global shutter of the ASI174. A noticeable feature is the extension of the bandwidth to short wavelengths, hence solar imaging with calcium filters (Ca-K) is easier than with the ASI120MM, even the ASI290MM, along with imaging Venus in near ultraviolet. Last but not least, the IMX178 shows an excellent sensitivity (95% of relative quantum efficiency) around 656 nanometers, that is the light emitted by both hydrogen clouds of nebulae and solar chromosphere, including solar prominences.

Housing, connectors, adapters

I have purchased the first batch of ASI178-cool, with no refinements as with the newer ASI071 : no USB hub, no possibility to replace dessicant tablets without opening the housing. On the other hand, the ASI178-cool has a autoguider, RJ11 port. The power supply for the cooler is standard, 12 Volt, 2 Ampere, while it accepts up to 3 Ampere. The camera can operate with cooler off. A usual with cooled ASI cameras, the silent fan is maintained by magnetic levitation to totally suppress vibrations.

The front side shows a sturdy, 2-in/50.8-mm tube to be directly inserted to a corresponding eyepiece holder to access prime focus. An adapter for 1.25/31.75-mm eyepiece holder is included in the package. The body also shows a standard female, M42 x 0.75 thread for T2-equipped, imaging accessories like a Barlow lens, a tele-exender, a focal reducer, a field corrector and so on. Since the sensor is narrow, the large, M48 standard is not necessary because no vignetting may happen. In case we have different standards, various M48-to-M42 x 0.75 adapters are available.

The cooled version has a depth of 17.5 mm and it is compatible with C lenses but not with C/S lenses. The cooled camera can be equipped with a M42 x 0.75-To-C adapter to fit C lenses. The uncooled version is delivered with a M42 x 0.75-to-C/S thread to attach the enclosed, 2.5-mm lens for all-sky imaging : meteors, Milky Way, entire constellations. A optional, 5-mm spacer is available to adapt C lenses to the C/S-compatible, uncooled version. I have performed compatibility tests with various C and C/S lenses provided by third-party manufacturers. I must admit, sometimes, the focal length is not adapted and correct focusing to infinite is unreachable ; this is due to the optics. We must ensure that the focal length of the C or C/S lens perfectly matches the expected standard.

Once again, it is important to keep in mind that all 1.25-in/31.75-mm imaging filters and accessories are compatible with the small-sized IMX178, at the contrary of cameras with larger sensors such as the ASI1600 or ASI290.

On the sky

The Moon

This is the main reason for why I picked up the ASI178MM (I ordered the cooled version to image both the Moon and deep-sky). I have imaged the Moon with various magnifications with photosites of 5.6, 4.75, then 2.4 microns. It's easier to get higher magnifications with smaller photosites than with more powerfull eyepiece projection or Barlow lens. With increasing sensitivity and decreasing noise, the successive sensors provide cleaner images, with more magnification and shorter exposure duration, hence more details. I have to admit, my best lunar images were taken with the ASI178MM with a red filter (the filter cuts UV and IR), without need for changing my 1.25-in/31.75-mm equipment : barlow lens, filters and filter wheel. Of course, cooling is not necessary at all for lunar imaging.

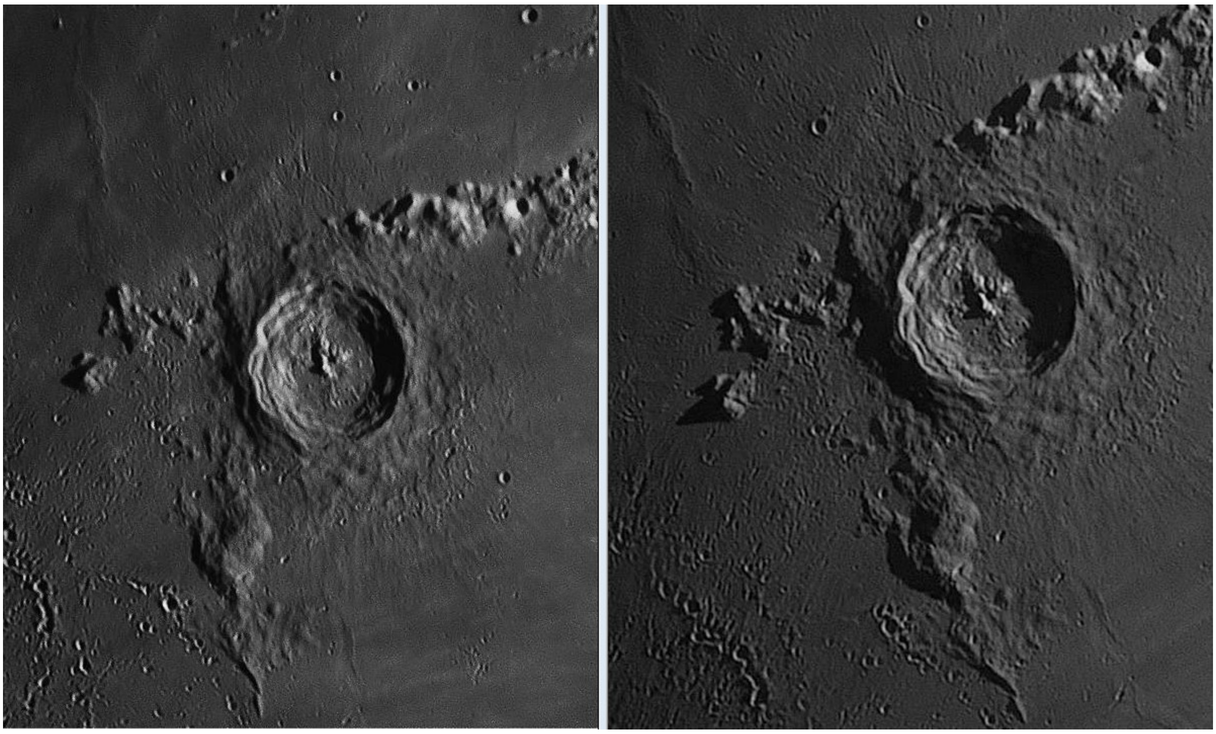


Figure 3 - Comparing details at same scale taken with same instrument and same focal length. Left : ASI120MM, right : ASI178MM. The images result from SER movies of 300 8-bit images each. The movies were stacked then processed with wavelets. The images are cropped. The 2.4-micron photosites of the ASI178MM bring nearly 30% more magnification and lesser noise while exposure durations were comparable. Images N.Dupont-Bloch.

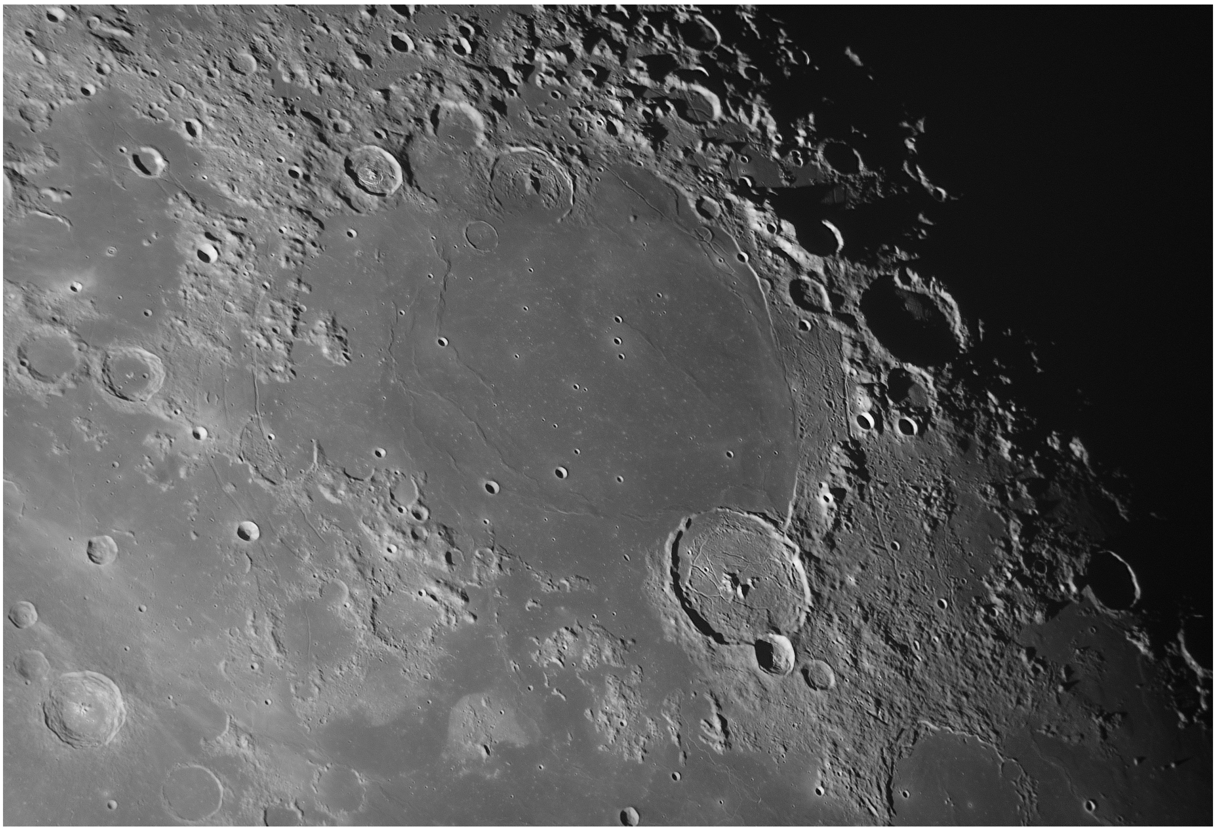
Figure 4 – Left : the ASI178MM has an aspect ratio of 3 :2, that is the standard for classic 35-mm still photography. It is also capable of other formats and aspect ratio, such as Full HD 16 :9. Right : the ASI120MM has an aspect ratio of 4 :3, the standard for TV, 35-mm silent films, and video (e.g. 720p60, videosurveillance). The figure only depicts the aspect ratio, with no consideration for relative scale, magnification, and field width. Images N.Dupont-Bloch.

Convenient acquisition parameters are 8 bits, SER movie ; histogram filled up to 80%. I acquire 500 frames with gain set to about 60% and the shorter exposure duration as possible, depending on the magnification and possible filter. I use a blue filter when the atmosphere is very steady. The image format is set to the maximal value, 6 megapixels, and this drastically reduces the frame rate down to 60 FPS. Given the magnification and the filter, I slow down the camera to 10-20 FPS, that is 50-100-millisecond exposures. With no filter, when the Moon is high, or if we use an Atmospheric Dispersion Corrector, the exposure may be reduced to some ten milliseconds, not to speak of wide-field, low-magnification, prime-focus imaging wich allows extremely short exposures at low gain.

In case the air is warm with important turbulence, I have discovered that, by reducing somewhat blurred final images then applying a slight unsharp mask, I can get accurate images at any time, whatever the turbulence, at the price of having images of 2-3 megapixels rather than 6 megapixels. When I was exploiting the 1.2-megapixel ASI120MM on the Moon with noticeable turbulence, 30-60% of the movies were definitively damaged by motion blurring. The ASI178MM allows to get relatively accurate images despite turbulence by direct imaging at prime focus, thanks to its tiny photosites. This also can be normal conditions when imaging with a long-focus, Schmidt-Cassegrain or Maksutov telescope. Other solutions can be binning, using a focal reducer compatible with a 9-mm diagonal sensor, and software reduction of the size of the final image.

When the air is steady, resulting in accurate and stable images at high magnification, imaging the Moon with the ASI178MM is someting like using the ASI224MC on planets : the cameras easily tolerate a high sampling rate, for instance 0.1 ''/px (arcsecond per pixel) with a 10-in/254-mm telescope rather than usual values of 0.2-0.3''/px with the ASI120MM. In practice, swapping the cameras is roughly equivalent to getting a 15-30% larger telescope but we have to keep in mind that when I performed the comparison, the sensors differed by their release date, technology, and cost. Surprisingly, I experienced the same leap in performance with both front-side-illuminated IMX224 and back-side-illuminated IMX178 relative to older sensors, no matter they are CMOS or CCD.

A possible problem is the huge size of the movies. The 16-megapixel images reduce the maximal frame rate to 60 FPS. Acquiring series of 6-megapixel movies may lead to occupy 10-25 gigabytes per night on the computer disk. This also results in long-duration, albeit automated, stacking process with AutoStakkert!2 or other software. My modest-CPU, long-autonomy laptop often needs twenty hours to complete the process of stacking the entire set of movies. Final processing requires a performing computer with a large screen, such as for HD- and DSLR-image edition.



One of the best use of the uncooled ASI178mm is lunar imaging. The 6-megapixel sensor shows very good capabilities to acquire a confortable field-of-view while the tiny, 2.4-micron photosites reveal fine details in the same image. 10-in Newton, Barlow, red filter, ASI178mm. 300 images were stacked. Image N.Dupont-Bloch.

A crop of the previous image. A very interesting point with the ASI178mm is the ability to reframe a region afterwards with no loss in quality, as if it were shot with a medium-format DSLR. Image N.Dupont-Bloch.

The Sun

As previously mentionned, not only the ASI178MM is very sensitive to the deep red light emitted by the chromosphere, but in addition, the size of the sensor perfectly matches small solar telescopes. It is not suited to solar, wide-field imaging with large output filter and long focal length. I have performed successfull tests with a Lunt LS60 BF600 and a Coronado PST BF5. In white light (Astrosolar ND5 in front of the aperture ot the telescope plus CCD, green filter), exposures as brief as 780 microseconds were reached at prime focus of the 10-in/254-mm Newton. If we use a more transmitting filter (ND3.8), the ASI178 may speed up to 32 microseconds. Successfull tests were also performed in white light with a 90-mm Maksutov with Astrosolar. The long focal length of the Maksutov (F/D=14) may prevent from adjusting the best magnification with the very small, 2.4-micron photosites. Note that absolutely no parasite frame (Fixed Pattern Noise) appeared, at the contrary of older CMOS sensors during extremely short exposures. The noticeable sensitivity to near ultraviolet offers the attractive opportunity to image in calcium (Ca-K filter).

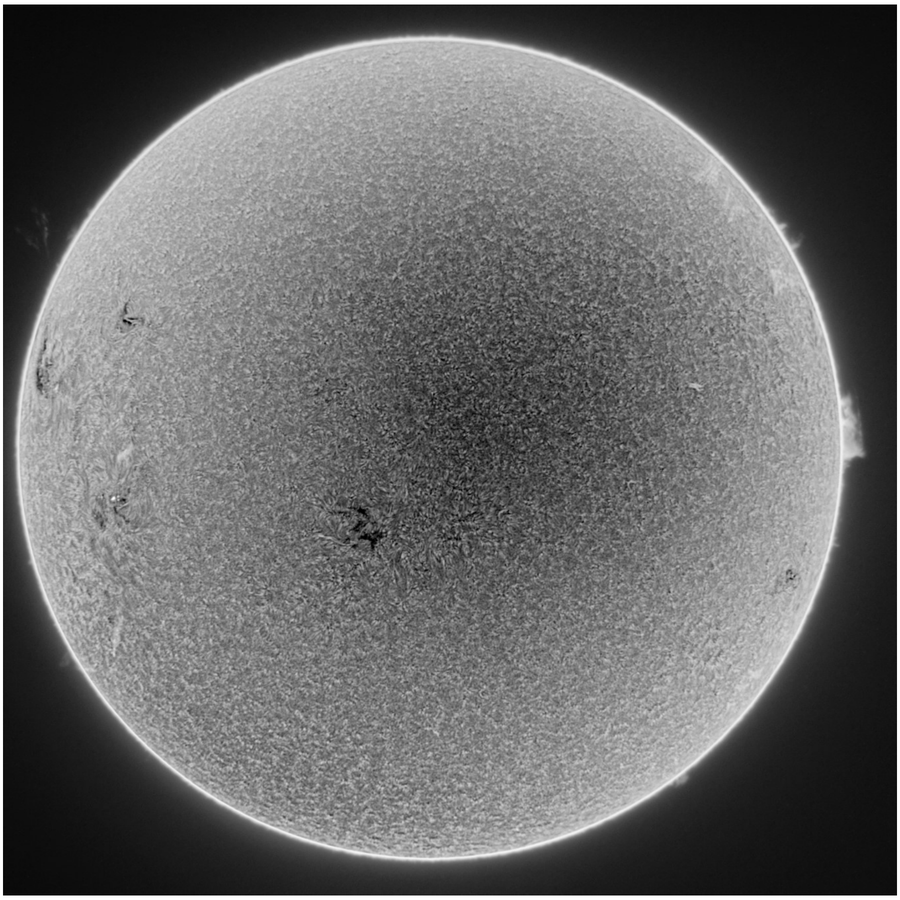


Figure 5 – The entire Sun at prime focus of a Lunt LS60 BF600. The two-phase processing emphasizes both the surface (negative rendering) and the peripheral prominences (brightness increase). Thanks to the 14-bit converter, the camera easily manages the huge contrast of the features of the Sun : the prominences (bright loops at the border as well as in front of the surface), the chromosphere viewed from side-on (bright circle at the border), the surface, a tiny sunspot (white spot at left) and active regions (dark spots over the surface), even the very dim, V-shaped, swirling prominence at top left. Image N.Dupont-Bloch.

Planets

Unfortunately planets were very low on my horizon at the time of writing and all I got was some images of Jupiter damaged by turbulence. However, owing to the extended bandwidth and good FPS rate of the sensor, there is absolutely no reason for what the camera could not shoot planets as successfully as the Moon. Planets are small, and resolution of 320x200 are often enough to acquire Jupiter ; this allows to increase the frame rate up to 479 frames per second with USB3. Note that the ASI178MM may also operate with USB2 ; this potentially decreases the frame rate, but this primarily depends on the exposure duration (frame rate = 1 / exposure in seconds). Based on the sensor's peculiar characteristics, I would recommend the ASI178MM for trichomy, near-ultraviolet imaging on Venus and near-infrared imaging on Jupiter, Mars and Uranus. FireCapture is perfect to manage a set of configurations comprising exposure time, gain and other parameters according to the selected filter, and many other features such as reframing and direct compatibility with the WinJupOs file format. Facing the relative complexity of trichromy, I would say that color, planetary imaging is more fun, less expensive (no filter needed) and more performing with the ASI224MC. However, the ASI178MM performs well for planets, and it has the advantage of providing 3000-pixel large images to capture large scenes comprising Jupiter and its moons, or large conjunctions.

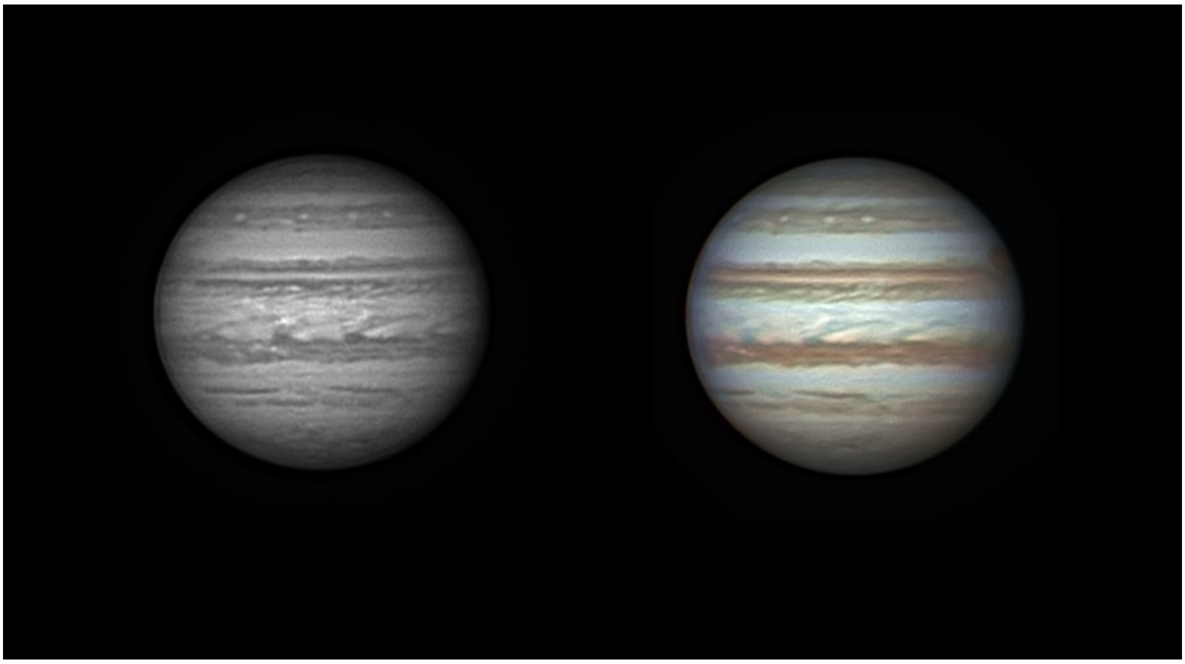


Figure 6 – Jupiter in red (left) and in trichromy (right) with a 254-mm/10-in Newton and a Barlow lens. The shooting conditions were not good. At right, the three, successive images with red, green then blue filter were realigned with the help of WinJupOs. Images N.Dupont-Bloch.

Deep-sky

This is the second reason for what I ordered the ASI178MM-cool. A significant advantage of a monochrome sensor is its ability to image at full sensitivity through any selective filter, including light-pollution rejection, or narrow bandwidth such as hydrogen alpha (Horesehead Nebula), oxygen III (Dumbbell Nebula) or sulfur II (parts of Rosette Nebula). Such filters are rather expensive, especially in a large diameter : one of the great advantages of the ASI178 is its compatibility with affordable, 1.25-in/31.75-mm filters and filter wheel. The maximal efficiency is with no filter at all, although this requires fine optics and moderate light pollution.

Figure 7 – The small-sized, 3:2 aspect ratio sensor demands foresighted framing. Bode's Galaxy M81, 10-in/254-mm Newton at F/4.7, 500 x 5-second exposures, 14 bits (tagged « 16 bits » in image acquisition software). No dark, no offset, even no flat, cooling steady at -15°C. The image is geometrically altered by the coma of the telescope while stars inflated due to my processing devoted to emphasize the galaxy. The 14-bit converter distinguishes numerous, subtle details in the arms. The raw frames are as clean as if they came from a CCD sensor under the limitation of a much smaller potential well. The image is taken under a light-polluted sky in suburbs with no filter. Dark frames were acquired next day at same temperature, same exposure, same gain, then subtracted with DeepSkyStacker. Image N.Dupont-Bloch.

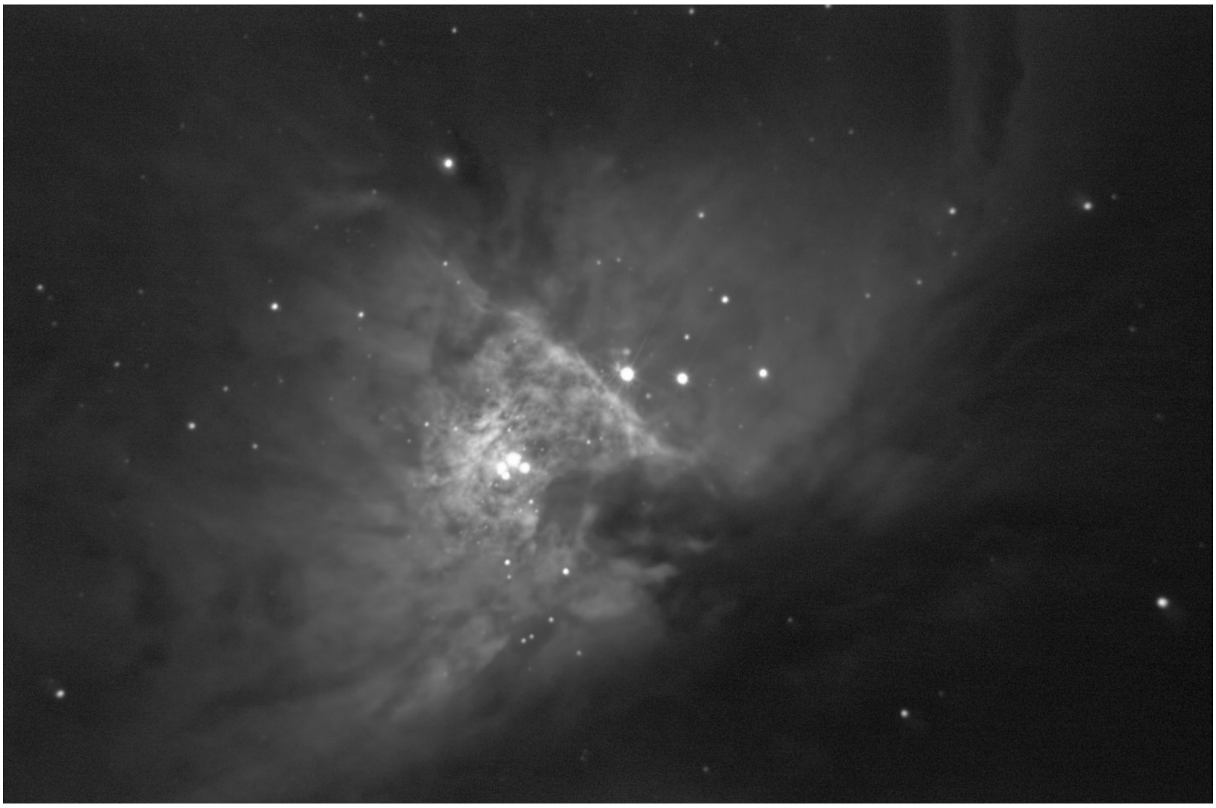


Figure 8 – The core of the Great Orion Nebula M42 with a narrow-band (6 nm), hydrogen-alpha filter and a 10-in/254-mm Newton at F/4.7 with no coma corrector. Addition of 1000 frames of 500 milliseconds. The sensitivity of the ASI178MM allows unguided exposures when imaging the brightest galaxies and nebulae. Prior to the necesssary, global contrast adjustment, raw images show sharp, unsaturated stars. Image N.Dupont-Bloch.

The small-sized sensor allows – to not say implies - the use of a small telescope, such as 6-in/150-mm Newton, a 80ED refractor, or a short-focal photolens for diffuse objects. This is welcome when we are a bit tired of moving a 65-kg telescope to countryside. At the contrary, with a large telescope, very compact objects like planetary nebulae or small galaxies perfectly fit the sensor with no need for a Barlow lens.

Figure 9 – A composite, test image of Pelican Nebula (center right) and North America Nebula (up) with a 58-mm F/2 photolens and a filter wheel. The red is acquired through a H-alpha, 6-nm filter and 44 exposures of 60 seconds, green = 44 x 60 seconds, and blue = 31 x 5 seconds, all with gain = 400. The sensor is cooled down to -20°C. The asymetric halos around bright stars are due to the optical flaws of the photolens. Image N.Dupont-Bloch.

Figure 10 – A raw frame of the Horsehead Nebula Barnard 33 through a H-alpha filter, single 240-second exposure at minus 15°C with a 6-in/150-mm Newton at F/4 with coma corrector. The contrast is increased by software. The bright areas at corners are due to spontaneous electroluminescence of non-imaging parts of the sensor (amp glow). This is normal, even very limited in the case of the IMX178. This is easily fixed, as well as hot pixels, by subtracting dark frames. Dark frames may come from reusable files or they can be taken on the fly, for instance with the help of SharpCap. I have saved reusable darks (-15°C, gain 350, 16 bits, binning x1) for 20, 60 and 240 seconds, covering most of my needs. Sensors evolve with time and the set of dark frames should be renewed several months apart.

Figure 11 - The final image after re-combinating four stacked images in H-alpha as red (30 x 240 s), green (8 x 60 s), blue (9 x 60 s), luminance (60 x 30 s), dark frames are subtracted. Image taken under suburban, light-polluted sky. Autoguiding was performed by an ASI120MM and a 70/420 achromatic refractor. Images N.Dupont-Bloch.

My first tests were disappointing because the coma of my newtonian telescopes severely damaged the edges of the images at F/4 and F/4.7. I was not aware of the however predictible flaw because I imagined that such a small sensor (less than 9 mm in diagonal), ideally placed at the center of the image field of the telescope, should get the best of the optics. The ASI178MM has very small photosites relative to many flaws of various telescopes, especially if they have a fast (<7 or so) F/D ratio. Since the sensor is monochrome, each detail of the optical image correspond to a photosite and to a monochrome pixel, at the contrary of a color sensor which requires four photosites per color pixel. Hence the monochome IMX178 is very accurate and it really needs a small but correct image field, and good optics with no chromatism, or achromats with green, red or H-alpha filter. Binning 2x or 3x, that is grouping photosites by 4 or 9, may be a temporary solution to diminish image field flaws while this noticeably increases brightness with no additional noise, though this reduces the resolution. In my experience with the camera, finest images always result from binning x1.

Figure 12 – A part of the Veil Nebula with a 6-in/150-mm Newton at F/4 with no coma corrector. H-alpha 6 nm = 16 x 300 seconds, green = 4 x 30 seconds, blue = 8 x 30 seconds. Gain set to 300, binning x2, sensor temperature -15°C. Image N.Dupont-Bloch.

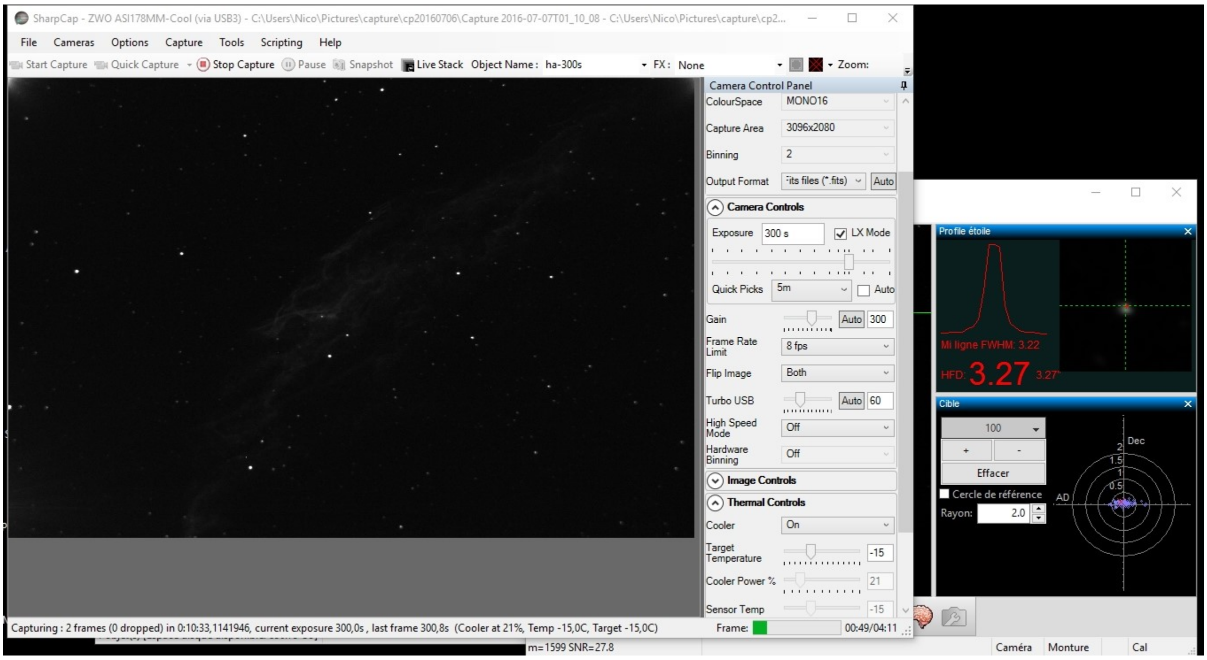


Figure 13 – Acquiring a raw frame with the help of SharpCap. The user-friendly software offers a total control of the camera's features. Beneath at right is the PHD2 software running the ASI120MM as an autoguider with an unfiltered, 70/420 achromatic refractor. Images were saved as FITS files, a specialized format for professional and advanced amateur astronomy. More classic, TIFF images are also supported. BMP images support 8 bits only and they drastically reduce the number of shades. JPG images would reduce both the accuracy and the number of shades.

I must warn about the necessity to use a good coma corrector for a « fast » (F/D=4-5) Newton or a good focal reducer/field corrector for a fast, apochromatic refractor. Once the optical image field is correct, images are near perfect. Adding a field corrector needs the distance to the sensor to be precisely adjusted. We must take into account the depth of the camera, that is 17.5 mm for the ASI178MM-cool (the distance is shorter for the uncooled version : 12.5 mm). The optimal distance is indicated by the manufacturer of the field corrector. The setup is quite simple because correctors are mostly intended to DSLR with a distance of about 54 mm (variations exists, e.g. Canon or Nikon). ZWO provides different spacers with various lengths to achieve the correct distance.

In case we use a filter wheel, its length has to be taken into account, and the filter also slightly lengthen the optical path. In extreme cases, such as F/4 or less, the adjustment may require a precision of a tenth of a millimeter (in my case : 51.66 mm for the 6-in newton, 54.66mm for the 10-in Newton). Other optics are more tolerant, e.g. my Celestron reducer-corrector settles for a back focus of about 115mm but it accepts 90mm. This is not due to the camera but to the optics, and all experienced astrophotographers are used to such adjustments. The other solution is to choose a more reasonable F/D ratio, e.g. 6.5 or more, which offers less optical flaws (especially field curvature, sperical aberration, coma) at the price of longer exposures. Given the sensitivity of the IMX178 and its very discrete sources of noise (FPN, hot pixels, amp glow), this is not a problem.

A substantial advantage of the two-stage, regulated cooling of the ASI cameras is that, like deep-sky, CCD cameras, the device maintains a constant temperature, hence a constant amount of thermal noise. We can acquire dark frames prior to image acquisition, then the software subtracts the dark frames during image acquitition ; this also can be done in the aftermath with DeepSkyStacker and other software. The best idea is to acquire some 10-20 dark frames with different settings, e.g. -15°C, binning 1x, 60 seconds, gain 300 and a second series at a different exposure duration, and so on. The procedure should be repeated from time to time, for instance 2 times per year, because all CCD or CMOS sensors show an increasing number of hot pixels with time. Preparing a full library of reusable dark frames avoids the acquisition of dark frames at each imaging session ; this saves a very appreciable amount of time, especially when we have to acquire 15 dark frames of 5 minutes each. The dark frames may be acquired at daytime, but I have detected some light leaks in my filter wheel and from behind the cell of my open-air primary mirror ; so it is better to acquire the dark frames at night or when the complete assembly is fully covered by opaque fabric. The temperature of -15°C was choosen because the noise is strongly reduced and because this temperature is in the range of the cooler whatever the season in my country ; see also the review of the ASI071MC-cool. As for now, the sensor reaches the desired temperature in minutes with a switching-mode power supply powered by a 12V-220V converter plugged to a car battery. The battery also supplies the laptop, the dew heater for the guide scope, and the GOTO mount.

M3 globular cluster shot with a 6-in F/4 Newton, GPU coma corrector, 39x60s + 135x1s, ASI178mmc. Only the cooled version of the camera is able to capture long exposures with no noise. Fortunately the uncooled version also may capture deep-sky images with numerous, short exposures, as long as the object shows a good contrast, such as clusters or planetary nebulae. The image is taken with no binning. Image N.Dupont-Bloch.