The ASI224MC camera

Nicolas Dupont-Bloch, March 2017

Images of Saturn and Jupiter : courtesy of William Pellissard and Christophe Pellier

Overview

Initially released as a planetary camera, the ASI224MC also quickly reveals itself to be a fantastic tool to image compact, bright deep-sky objects with unprecedent accuracy. The secret is that, it embeds one of the most efficient and low-noise color sensors designed by Sony for low-light environments. At a time where the cost of professional, ultra-high speed, ultra-efficient, short-lifetime EMCCD cameras starts at 60 000$, ZWO picks up Sony's ultra-low-noise IMX224 sensor to offer amateur astronomers a somewhat comparable tool at a fraction of the cost of an EMCCD. The ASI224MC indeed paves the way for high-resolution, deep-sky imaging. In some months, the camera convinces very experienced, planetary astrophotographers sticked to monochrome sensors that a color sensor is able to provide – for the first time – comparable or better results on planets, including advanced applications such as near-infrared imaging. The price to pay for is a limited number of photosites ; nonetheless the camera offers no less than 1,2 megapixel.

The camera is available in non-cooled or cooled version, with some differences in mechanics and options.

Sensor and possible applications

Sony's IMX224 is based on a classic technology (front-side illuminated) but it provides the best of it, with twice the sensitivity of comparable, HD color sensors at the time of its release. This is because the IMX224 sensor is designed to operate under dark sky, with no moonlight. The most impressive charateristics are an extended efficiency in near infrared, a uncommonly low noise (SNR1s[1] is 0.13 lx, almost two times better than the IMX290), and the possibility of huge gain of 72 dB, or 4000x, to be compared to other sensors typically limited to 43dB, or 150x. However the gain of the ASI224MC is voluntarily limited to a more reasonable value of 60 dB, in accordance to its astronomical use. The readout noise is only 0.75-1.5^{e}-, the lowest of all ASI camera as of March 2017.

Applications :

- Planetary imaging in color at very high frame rate ; this greatly helps to acquire numerous, accurate images at the moment when air is calm (lesser turbulence).
- Near-infrared imaging of planets (with a filter).
- Planetary nebula imaging.
- Compact galaxies offering good contrast, and globular clusters.

The cooled version is capable of long exposures with ultra-low noise.

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

Because it is also designed for near-infrared applications, the Bayer matrix (color filters on the surface of the sensor) is intentionnally transparent beyond 750 nanometers, that is from deep red to near infrared. This is a new performance for a color sensor ; it can be exploited for peculiar applications on planets.

The camera offers 8-bit or 12-bit images (the 12-bit mode is often labelled « 16 bits » in image acquisition software). The latter is more suited to deep-sky imaging because it differentiates four times more shades (refer to review of the ASI178mm). The sensor theoretically may operate in HDR mode with 70-dB dynamics but this requires a optional image processor which was not released by Sony at the time of the release of the sensor itself. Anyway, with planetary imaging as main scope, the camera is to be exploited in 8-bit mode in most cases ; this is consistent with the relatively limited full well capacity of a little more than 19 000^{e-} (refer to the chapter about the ASI178MM for comparison). The camera is capable of deep-sky imaging too, with very low shot noise, but we have to keep in mind that the readout noise abruptly diminishes when the system gain is more than 50^{e-}/ADU, typically corresponding to bright objects such as globular clusters or planetary nebulae. Another solution is to lenghthen the exposure (up to 1000 seconds, or 16 minutes !) to gather more light, but, in such a case, the turbulence may seriously damage the accuracy of the images, hence the camera is definitely best exploited with relatively bright objects and exposures shorter than 0.5-1 second. At the other side of the exposure range, e.g. when imaging the full Moon or the Sun in white light (with an Astrosolar filter) down to 600 microseconds, absolutely no Fixed Pattern Noise was detected. The camera can operate at exposures as short as 32 microseconds, largely exceeding our mean needs.

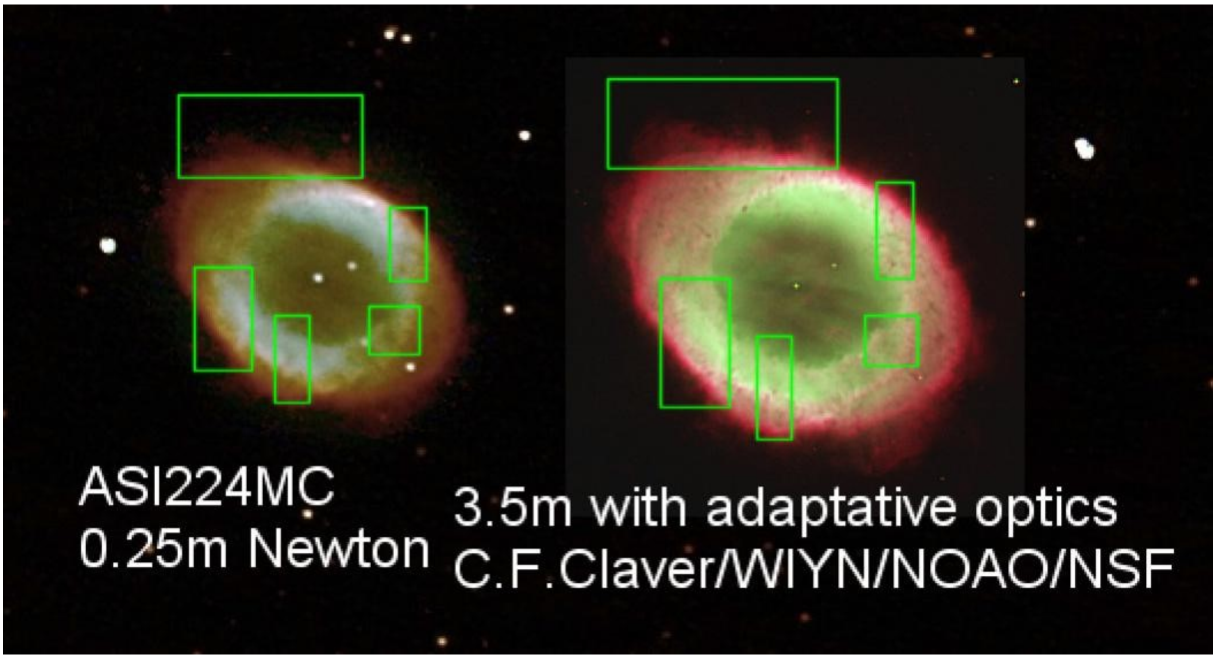

Figure 1 – An early test of the camera, colors uncalibrated, shows that the equivalent detection threshold level could be considered as somewhat limited for a deep-sky camera. The neighbouring IC1296 spiral galaxy (not framed here) is barely detected with the 10-in/254-mm F/4.7 telescope but its shape is undoutbly revealed : this is a performance for a color, planetary camera. On the other hand, the correlation of the relatively faint, peripheral extensions of the Ring Nebula M57 taken with the small telescope and a very large, cutting-edge, professional telescope is excellent. The image at right is severely sized down. Of course, the larger the telescope, the more accurate the image.

Housing, connectors, setup

The front side offers a standard, female M42 x 0.75 thread (for photographic adapters) and a 1.25-in/31.75-mm adapter to insert the camera into a eyepiece holder or a Barlow lens. Directly inserting the camera into the eyepiece holder, with no eyepiece, is the recommended solution for beginners, prior to playing with stronger magnification with a Barlow lens or a tele-extender for eyepiece projection. Note that the front side of the naked housing forms a 2-in/50-mm tube ring to be directly inserted into a large eyepiece holder. Despite the voluntarily short length, it is sufficient to securely maintain the camera with no tilt, thanks to its light weight. The sensor is small enough to be exploited with 1.25-in/31.75-mm, eyepiece adapter with no vignetting at all.

Figure 2 - The small-sized sensor is compatible with 1.25-in/31.75-mm equipment (adapter at right) with no vignetting. It opportunely corresponds to the very central part of the image field, where possible optical flaws of the telescope (such as coma, field curvature, spherochromatism or astigmatism) are limited or inexistent. The USB3 port (blue) may be connected to a USB2 port at the price of lesser frame rate. The RJ11 socket (black) is for the autoguider port of the mount. The ring (bottom) is the adapter for C/S lenses (the cooled version is compatible with C lenses only). The front side of the housing forms an internal, female, M42 x 0.75 thread for T2 photographic adapters, even for direct connection with compatible photolenses (with a spacer). The flange of the body also may directly enters a 2-in/50.8-mm drawtube. The back side of the uncooled version shows four M4 threads and a Kodal thread.

The uncooled version is compact (62 x 35mm) and lightweight (100 grams). On the side of the housing stands a standard, RJ11 connector for autoguiding (ST4 standard), and a USB3 port. The enclosed, M42 x 0.75-to-C/S thread ring adapter is needed to screw up the 2.1-mm, wide-field lens. Since the sensor is closer to the surface than the cooled version, only the uncooled version is compatible with the enclosed, wide-field lens (not included in the cooled version). The back side offers four female, M4 threads and a Kodak female thread for a photo tripod or a gimball (comparable to the ASI120MM for instance).

Due to a more complex housing, the cooled version does not offer room enough for a Kodak, female thread on the back, nor M4 threads. Since this forbids the use of a gimball for all-sky survey or quick attachment for autoguiding with a telelens, ZWO has designed a optional, sturdy, holder ring (compatible with all cooled ASI cameras). The other connectors for autoguiding and USB are placed on the back side, along with a connector for a optional power supply for the cooler. Alongside all cooled ASI cameras, the fan is maintained with no contact, thanks to magnetic levitation

(« MagLev »), hence it causes absolutely no vibration. This is very important when imaging at high magnification. The cooler needs a 12-V, 2-Ampere power supply. Tests showed that a 3-A power supply allows to reach the maximum efficiency in case the ambiant temperature is hot, in summer. The camera may operate even it the cooler is off. The weight of the cooled version is 410 grams. One could argue that a planetary camera does not need cooling, but since the ASI224MC also can image deep sky, the regulated cooler is welcome for long exposures and easy image calibration with dark frames.

On the sky

All-sky

This refers to the uncooled version only. The same applications as with the ASI120MM and the same 2.1-mm lens are possible, at the difference of color rather monochrome images, a much lesser readout noise and shot noise, and undetectable Fixed Pattern Noise. Please see the chapter about all-sky imaging in the ASI120MM review for the various applications : meteors, Milky Way, constellations...

The cooled version, anyway, may be equipped with a C-lens (longer focal length). The performance of the sensor deserves high-quality optics and we have to avoid cheap C-lenses intended to consumer, videosurveillance camera.

The Moon

While the camera is primarily intended to planetary imaging in colors, it can easily image the Moon. Numerous combinations have been tried, especially various output image/movie formats with or without color decoding.

Beginners should select « RGB » and « 8 bits », and BMP image or AVI movie formats. The AVI format is for 8-bit color ; it is recognized by all movie players, at the price of cumbersome files. BMP images contain only 256 possible levels for each primary color, red, green, and blue.

More advanced users advantageously choose more performing SER movie format. SER movies are intended to software such as Registax, AutoStakkert !2, Avistack, IRIS or other software to stack and re-align raw images. SER movies may be recorded either in non-debayered or debayered formats. Debayering consists in decoding the colors during acquisition, prior to stacking, or in the aftermath, with the help of Registax, IRIS, FitsWork, PIPP and other software. Acquiring SER movies with no debayering saves computer performance while reading images at high frame rate. The 12-bit mode showed no noticeable improvement on the Moon.

Although the number of photosites is relatively limited, the sensor offers no less than 1.2 megapixels : this is enough to image relatively large areas on the Moon such as main craters with their blanket of ejectas, systems of rilles, or the entire Moon in color during lunar eclipses (with a 135-mm telelens or other short-focal optics). By saturating colors with the help of a image editing software, various compositions and ages of the lunar soil can be emphasized, e.g. some fresh craters show a bluish tint. We also may break the limit of 1.2 megapixels by composing mosaics. FireCapture offers a convenient way to compose mosaics by helping the astrophotographer to take several movies starting from a reference point, managing shared portions of images to avoid blank parts in the final, reconstructed image[2].

Planets

Planets in color are the main application of the camera (especially in its uncooled version). As for the Moon, beginners may record color, AVI movies : this ensures the maximal compatibility with movie players and easily allows sharing movies on Internet. The best combination is, once again, recording undebayered (RAW8), SER movies, then the stacking software reconstructs the colors. As with most Sony sensors, several readout speeds are available[3]. In image acquisition software, e.g. SharpCap or FireCapture, the default choice is « normal » to ensure the sensors is prone to minimal noise during internal readout phase. « High-speed » mode is for acquisition at very high frame rate but we have to set a moderate gain because readout noise is more important.

The good surprise is that, the ASI224MC is the first ever color camera able to capture color images of planets with the same accuracy as monochrome cameras with no need at all for expensive imaging filters and filter wheel (this also saves backfocus). This is due to the astonishing sensitivity and low noise of the sensor. As a color sensor exploits groups of four photosites (one red, two green and one blue) per pixel, experienced astrophotographers are used to more limited resolution in color images than in monochrome ones, in which each sensor photosite corresponds to each image pixel. To compensate for the drawback of color sensors, the only solution is to increase the magnification, theoretically by four[4], leading to a reduction of incoming light flux by surface unit of 16 ! Fortunately, owing to the unconventional characteristics of the IMX224 sensor, very high magnification is in the reach of the camera : we can rise twofold or threefold the magnification while keeping reasonable exposure durations by increasing the gain, with little extra noise. For instance, with the same telescope, while a ordinary color camera reaches its limits with a 2x Barlow lens, the ASI224MC still operates well with a 3-4x Barlow lens, resulting in about the same final image resolution as a monochrome camera. Facing the complexity of trichromic imaging with successive filters, both beginners and experienced planetary photographers greatly appreciate the simplicity of one-shot-color (OSC) imaging – at the condition where results are as satisfying as trichromy, and this is the case here.

[2] See example at http://www.cambridgeblog.org/2017/01/announcing-the-winner-of-our-shoot-the-moon-photo-competition/
[3] Four speeds, from 27 to 74 MHz.
[4] Thanks to software interpolation, reconstructing colors leads to a loss of about 45% in accuracy, depending on the algorithm and the Color Filter Array (Bayer matrix or variants).

Figure 3 - Saturn shot through a Celestron C14 XLT equipped with Astro-Physics Barcon Barlow lens, Astronomik uv-ir cut filter, Optec TCF-S focuser, Pierro-astro Atmospheric Disperson Corrector MKII. 6662 frames, 428-second derotation with the help of WinJupOs. Processing with PIPP, AutoStakkert !2, Registax 6 then PhotoShop. Histogram filled up to 74%. The telescope was installed at the 15th floor in Paris, France, and the planet was only 19° above the horizon ! Image by William Pellissard.

The ASI224MC has a clear window to protect the sensor ; it prevents from reflections and protects against dust. As previously mentionned, the IMX224 is sensitive to near infrared. Usually, near infrared is considered as damaging for planetary imaging, especially on Mars. Not only the color balance is disturbed, but mixing infrared and visible light reduces the accuracy of the optical image, as if we were listening to two different musics at the same time. This is why color cameras require a IR/UV cut filter, that is a filter which lets pass all visible light but removes the near infrared and near ultraviolet[5]. Nonetheless, since the IMX224 is sensitive to near infrared, we can exploit the feature to explore new ways to image the planets. Infrared filters, which pass the infrared while cutting visible light and ultraviolet, are available in different bandwidths, e.g. a Baader 685 is perfect for 6-in/150-mm telescopes ; PlanetPro 742 or Planet Pro 807 are more efficient but strongly dims light and demand larger telescopes. Other filters such as the CH4 (methane) are intended to image giant planets like Jupiter or Uranus. Here are some advanced applications of near-infrared imaging for planets :

- Relative height of clouds of Jupiter revealed by absorption of light by methane (the brighter in CH4, the higher the atmosphere)
- details on Uranus and Neptune
- calcium-rich pyroxenes on the soil of Mars

[5] Refer to http://www.planetary-astronomy-and-imaging.com/en/ir-cut-filter-asi224mc/

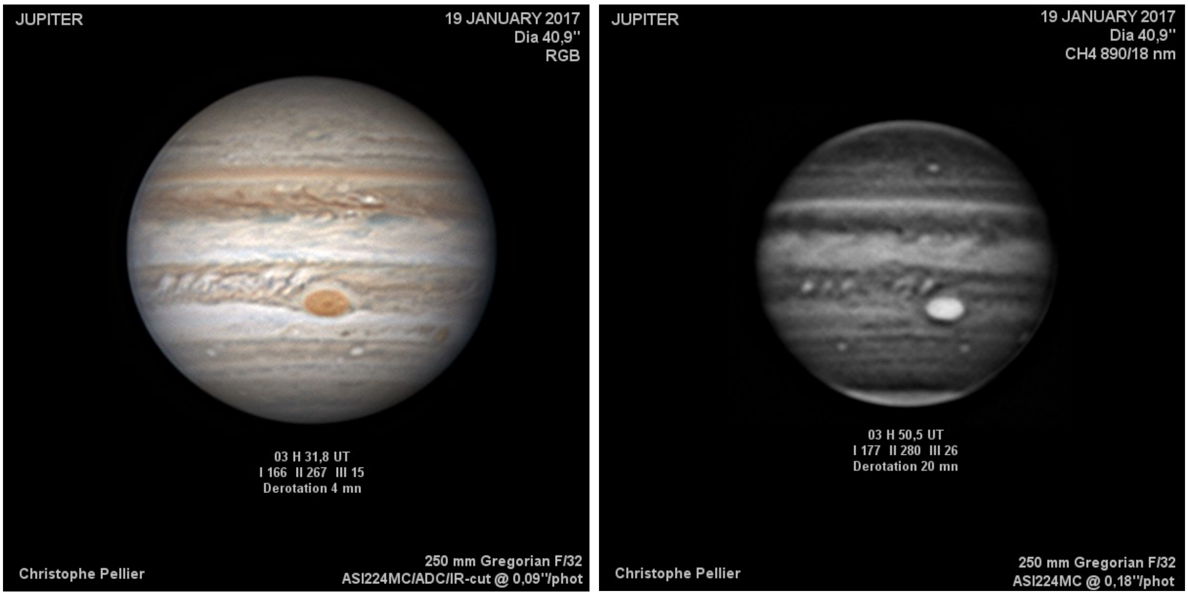

Figure 4 – Left : color image of Jupiter taken with an Atmospheric Dispersion Corrector. Right : image taken through a near-infrared, methane (CH4) band filter. As Jupiter rotates very quickly, the movies are processed with the help of WinJupOs for derotation, that is software shifting of individual images prior to stacking. Derotation cancels motion blurring. The technique dramatically improves the accuracy of final images, especially when using a near-infrared or near-ultraviolet filter resulting in drastic absorption of light, leading to long-duration exposures, hence long-duration movies. 10-in/250-mm Gregory telescope. Note the strong magnification of left image, with a sampling rate of 0.09 arcsecond per pixel : this is necessary to overcome possible artifacts from debayerisation (see text). Images by Christophe Pellier (Société Astronomique de France).

The other extreme side of the bandwitdh is near ultraviolet. What could be an obstacle for the camera is its limited sensitivity to such a color (about 30% of the quantum efficiency) to image the clouds of Venus with a ultraviolet-pass filter. The ASI224MC can do it, but it is not the very best choice for that, facing cameras such as the ASI174MM or the ASI290MM.

High-resolution, planetary imaging, especially with a color camera, may suffer from aiming at a low altitude above the horizon. Due to a differential refraction by the atmosphere of the Earth, colors are gradually shifted. The shifting on the final image can be roughly fixed by re-centering the colors in Registax (« RGB shift ») but, when the planets are at low elevation, this is unsufficient[6]. To fully compensate for the differential refraction of colors, a device, based on a prism, preventively shifts the colors : the Atmospheric Dispersion Corrector, or ADC (not to be confused with Analog-to-Digital Converter), such as ZWO's.

Deep-sky

Here is the second breakthrough of the color IMX224 sensor. At the time when we were testing the camera prior to its relase, it quickly apperead that is was capable of acquiring numerous, short-exposure images of bright and compact planetary nebula such as the Ring Nebula M57. When the exposure is shorter than one second or so, the blurring effect ot the turbulence by warm air vanishes. Of course, this is much more than tenfold the usual exposures for planetary imaging at strong magnification. Traditional deep-sky imaging requires tens of seconds, preferentially minutes, because deep-sky objects are often large, but very faint. Thanks to the particularly low noise from the sensor,

[6] Refer to http://www.planetary-astronomy-and-imaging.com/en/asi224mc-adc/

the camera is able to gather light enough in less-than-a-second exposures at « moderate » gain, up to 400-450. This is the definitive advantage of CMOS sensors relative to CCD sensors. The latter have less noise during long exposures (shot noise), but more noise when reading the image (readout noise). Since the shot noise of the IMX224 is relatively low for exposures of seconds (even much more !) while the readout noise is extremely low, we can advantageously acquire hundreds, or thousands of short-exposure, color images to be stacked, resulting in a low-noise final image of relatively bright and compact objects, with no blurring effect from turbulence. This is relatively close to photon-counting cameras, and EMCCD sensors. In other words, the ASI224MC opens the way for high-resolution, deep-sky imaging, offering an accuracy of less than one arc-second, often meeting the theoretical resolving power of the telescope – like planetary imaging.

The best targets are bright and compact, deep-sky objects such as planetary nebulae, but globular clusters and some galaxies also are in the scope, even the core of some diffuse nebulae. Indeed, the ASI224MC has triggered the re-discovery of planetary nebulae and other compact objects in amateur imaging.

Figure 5 – Hercules Great Cluster M13. From left to right : single, raw frames of 0.1 second (!), 0.25 second, 0.5 second, gain 500, 8 bits. Best results are obtained by stacking hundreds or, better, thousands of short-exposure images. 10-in/254-mm Newton at F/D=4.7.

Figure 6 – Stacking 350 frames of 0.5 second each, 8 bits, gain 500. 10-in /254-mm Newton (stars at image corners suffer from coma due to the use of a newtonian telescope with no coma corrector). Exposures longer than 1 second are prone to blurring from atmospheric turbulence and the final accuracy severely diminishes.

The camera offers binning mode ; that is grouping photosites. The grouped photosites share then add incoming light, as if they consist in a giant photosite. Binning 2x is grouping photosites by four, binning x3 is grouping them by 9. Actually results are quite different from a monochrome camera, because the photosites of a color camera are already grouped by four due to the Bayer matrix and this requires interpolation. Anyway binning always diminishes the accuracy but the feature is extremely handfull to detect then to frame very faint objects prior to shooting, even to image objects with poor contrast. Binning with CMOS sensors is achieved by software and this does not lower shot noise.

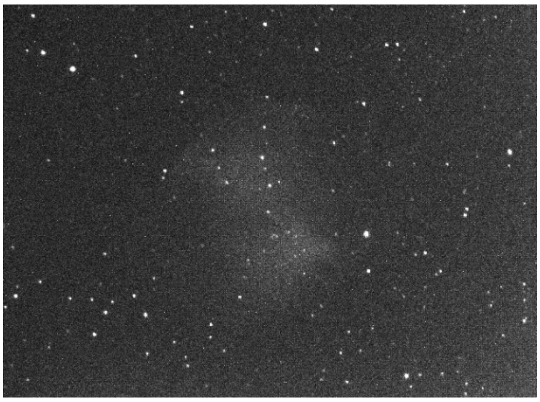

Figure 7 -Detecting Dumbbell Nebula M27 with binning. This is a single frame, binning 2x, one-second exposure, gain = 450. The purpose was only to locate the object prior to shoot it in binning x1 and 12 bits. The frame is not debayered yet. The nebula is clearly detected even in one second.

Figure 8 – The Dumbbell M27 planetary nebula, taken from light-polluted, suburban sky, two nights after summer solstice. 187 exposures of 5 seconds with gain = 76 (that is no amplification). 10-in/254-mm Newton F/4.7. uncooled camera. The purpose of this early image was to play with the zero-gain mode ; best results could have been obtained with shorter exposures, more gain, and more frames.

I also tried to image a peculiar object, the elusive Pickering's Triangle in Cygnus constellation. It is a faint diffuse nebula, and the best way to detect it was through a very selective, H-alpha filter, with a narrow bandwith of 6 nanometers. This only passes a peculiar, deep red, emitted by glowing, hydrogen clouds. The test was performed during a very warm night, close to summer solstice. The camera was uncooled. The supposedly planetary camera was able to detect the cloud even in the worst imaginable conditions for deep-sky imaging.

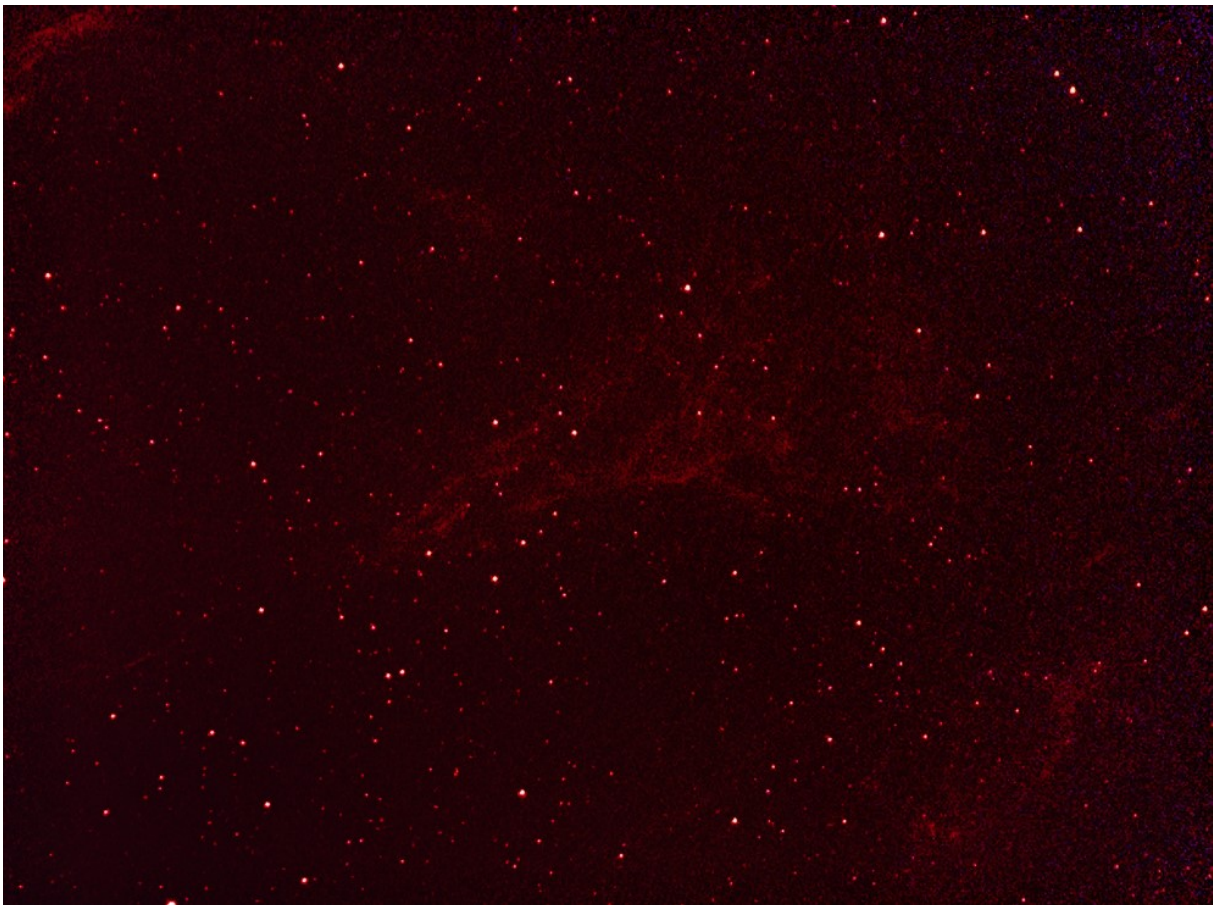

Figure 9 – This test image represents a performance for a color, uncooled planetary camera. Detecting a faint, hydrogen cloud in Cygnus through a very absorbing filter and two-minute exposures, close to summer solstice during a warm night was a great surprise. 180-mm F/2.3 telelens, Ha, 6-nm filter. 24 x 120 seconds, on-the-fly subtraction of dark frames with FireCapture. A slight blurring effect was applied to get a slightly more aesthetic image. Note that no amp glow appears despite the fact that the sensor temperature was more than 20°C.

Figure 10 – The compact, NGC4449 irregular galaxy. I was searching another, much brighter galaxy when the camera detected a halo while the telescope was slewing. 75 x 15 seconds, gain 250, 8 bits, with a 10-in/254-mm Newton F/4.7. The galaxy is not so often imaged, especially with a uncooled, color, planetary camera. Stars are enlarged due to amplification of low lights with the image editing software ; raw frames show pinpoint stars.

To conclude, the ASI224MC is, as of 2017, a thrilling tool to image planetary nebula and other compact, bright, deep-sky objects. Not only turbulence vanishes at such short exposures, but, in addition, the telescope settles for a ordinary mount, with no autoguiding, while correct sidereal tracking for no longer than 5-15 seconds is sufficient.

Autoguiding

Like the ASI120MM, the sensor has a limited size, suited to autoguiding with an off-axis guider (OAG). While beeing in color, the camera is sensitive enough to detect guide stars with low noise. Hence, there is no confusion with possible hot pixels, especially with typical exposures of one second (i.e. default duration in PHD2). Tests were performed with 1200-mm focal length for the imager (Newton + DSLR) while the autoguiding ASI224MC was equipped with a humble 135-mm telelens ; the camera was attached by its kodak thread to a gimball screwed on the dovetail of the telescope. Refer to the review of the ASI120MM for more information. We would not pick up such a capable camera for autoguiding only, but, in case we later purchase a cooled ASI with a larger sensor, the ASI224MC does the job wery well.