Solar Camera Comparison Test

by Jim Thompson, P.Eng
Test Report – August 24th, 2022

Introduction:
There are many different areas one can explore in the field of amateur astronomy. Although much of my time is spent on deepsky object observing via Electronically Assisted Astronomy (EAA), I also enjoy imaging solar system objects as it is something that I can easily do from my urban backyard. Of particular interest to me is solar imaging in multiple wavelengths, including: Calcium-K (393.37nm), Solar Continuum (540nm), Helium-D3 (587.56nm), Hydrogen-α (656.28nm), and near infrared (700-1200nm). I find collecting images of the Sun during the same time period using these various wavelengths provides a fascinating broad view of what is going on. To accomplish my goal of imaging at multiple wavelengths I am reliant on a high performance monochrome camera. Monochrome cameras provide superior resolution and sensitivity versus colour cameras, but the question of monochrome versus colour is not the purpose of this test report. The question I try to answer in this report is: "which monochrome camera should I use?"

Objective:
The objective of this test report is to evaluate the performance of various CMOS-based monochrome cameras in the application of narrowband solar imaging. Cameras are compared in terms of their ability to produce a solar image under the same viewing conditions that is sharp and finely detailed. Characteristics that feed into a camera's ability to produce a high quality image include: sensitivity, frame rate, resolution, and pixel size. The cameras considered in this test report include the following (prices in USD):

- ZWO ASI290MM ($269);
- ZWO ASI183MM Pro ($999, ASI183MM $699);
- Mallincam Skyraider DS432M-TEC ($1599, ASI432MM $599); and
- Imaging Source DMK 33UX226 ($574).

The ASI183MM Pro and DS432M-TEC are both cooled cameras (I purchased them for deepsky EAA) but uncooled versions of both are available from ZWO as noted above. Cameras using the IMX226 sensor are uncommon – I had to source mine from an industrial machine vision company. A photo of the four cameras under test is provided in Figure 1.

Before sourcing my most recent camera, the DMK 33UX226, I did a fair amount of research on the Sony website. It would seem that Sony's focus presently is to develop new colour sensors only, so the list of suitable monochrome sensors for use in a solar camera is not very long. Table 1 summarizes Sony's data for the list of monochrome sensors commercially available in cameras today.

Figure 1 Image of Cameras Under Test

Parameter	Sensor							
	IMX035	IMX174	IMX178	IMX183	IMX226	IMX290	IMX432	IMX492
sensor type	Exmor CMOS	Exmor, Pregius CMOS	Exmor R, Starvis CMOS	Exmor R, Starvis CMOS	Exmor R, Starvis CMOS	Exmor R, Starvis CMOS	Pregius CMOS	Exmor R, Starvis CMOS
sensitivity (mV)	460	825	380	388	~250	1200[1]	4050	1500?
pixel area normalized sensivity (mV/sq µm)	*35*	*24*	*66*	*67*	*73*	*143*[1]	*50*	*70*
sensor diagonal size (mm)	6.08	13.4	8.92	15.86	9.33	6.46	17.6	23.1
pixel size (µm)	3.63	5.86	2.4	2.4	1.85	2.9	9.0	4.63[2]
effective pixels	1.3MP	2.35MP	6.44MP	20MP	12.4MP	2.13MP	1.7MP	11.8MP[2]
resolution	1270x1030	1936x1216	3096x2080	5472x3648	4072x3046	1945x1097	1600x1100	4168x2824[2]
shutter type	rolling	global	rolling	rolling	rolling	rolling	global	rolling
frame rate, 10-bit, full res. (fps)	15	165	30	25	40	120	100	24
pixel # normalized frame rate (MP/s)	*20*	*388*	*193*	*499*	*496*	*256*	*176*	*282*
under test				X	X	X	X	

1. I question the Sony published mV sensitivity value for the IMX290 as all the other sensors on this list using the same technologies (1st Gen STARVIS + Exmor R) have mV/sq µm values around 70.
2. The IMX492 has an "unlocked bin 1" mode that splits the on-chip binned pixels into their native 2.32µm size, giving 47.1MP and resolution 8336x5648. Effect of this mode on frame rate is not known.

- Starvis = low light level high sensitivity design for security cameras
- Exmor = on-chip analog/digital signal conversion and two-step noise reduction
- Exmor R = back illuminated version, ~2x as sensitive as original Exmor
- Pregius = global shutter technology

Table 1 Summary of Available Monochrome SONY Sensors

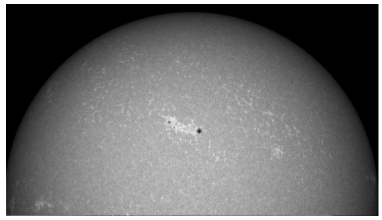
My application involves imaging the Sun using a 98mm f/6.3 refractor. Seeing conditions from my location in the middle of Ottawa are typically below average, so it is uncommon for me to use a Barlow to extend the scope's focal length beyond its native 688mm. With such a short focal length setup, I am looking for a camera with small pixels to give me good spatial resolution. I am also looking for high sensitivity so that I can keep my exposure time as low as possible. Finally, I want a sensor large enough to capture the whole Sun's disk in one frame.

Method:
Testing consisted of image data collection using each camera on a Williams Optics FLT98 apochromatic refractor with one of the following solar filter configurations:

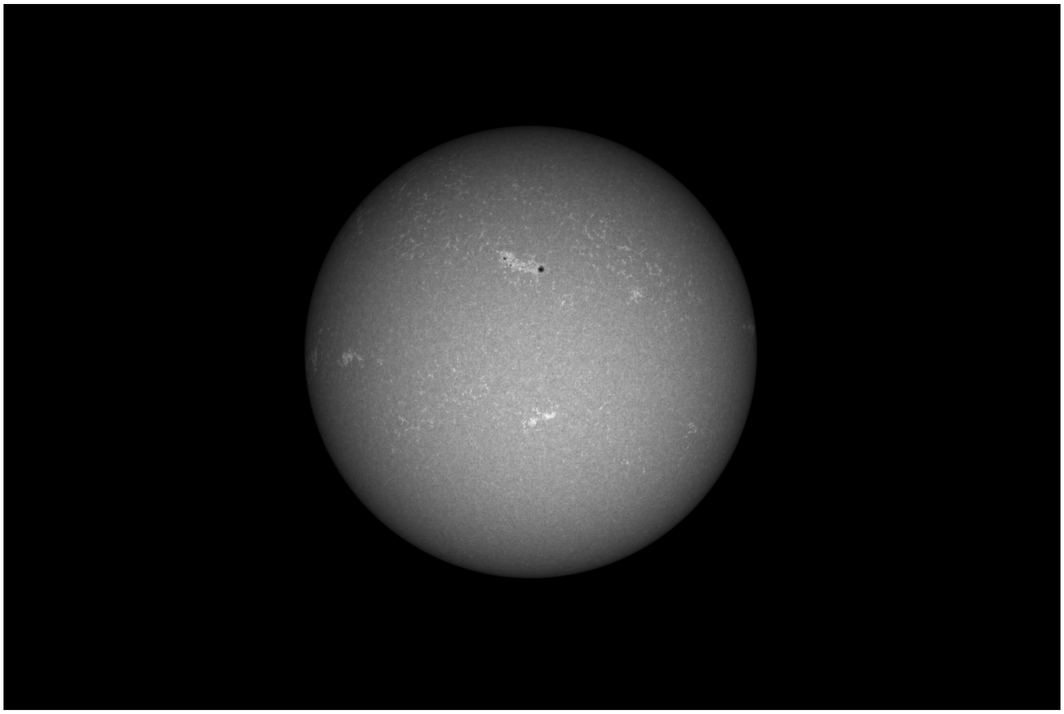
- Baader Planetarium cool-ceramic safety Herschel prism plus:
  - Omega Optics 2Å Calcium-K filter;
  - Baader Planetarium 10nm Solar Continuum filter; or
  - Semrock 2nm Helium-D3 filter.
- Solarscope SF-50 0.7Å H-α etalon + blocking filter.

The scope is mounted on a Skywatcher EQ8-R equatorial mount. All image data presented in this report was collected from my backyard in central Ottawa, Canada. Images using a particular filter arrangement were all collected on the same day within a 30 minute time window. Data collection was in the form of 2000 8-bit frames stored in .SER file format, which was later stacked in Autostakkert!3 and sharpened using wavelets in Registax 6. The best 10% of frames were used in each stack. The same wavelet settings were used for images from each camera for a particular filter arrangement. Note that image data using the DS432 was only collected in H-α, and Solar Continuum filter image data was only collected using the DMK 33UX226. All image data was collected with camera gains at minimum, only exposure time was adjusted to achieve the desired image brightness. Camera gamma was set to max (darkest) on all cameras with the exception of the DMK 33UX226 which has much more gamma adjustability available; only about ½ of the available gamma adjustment was used.

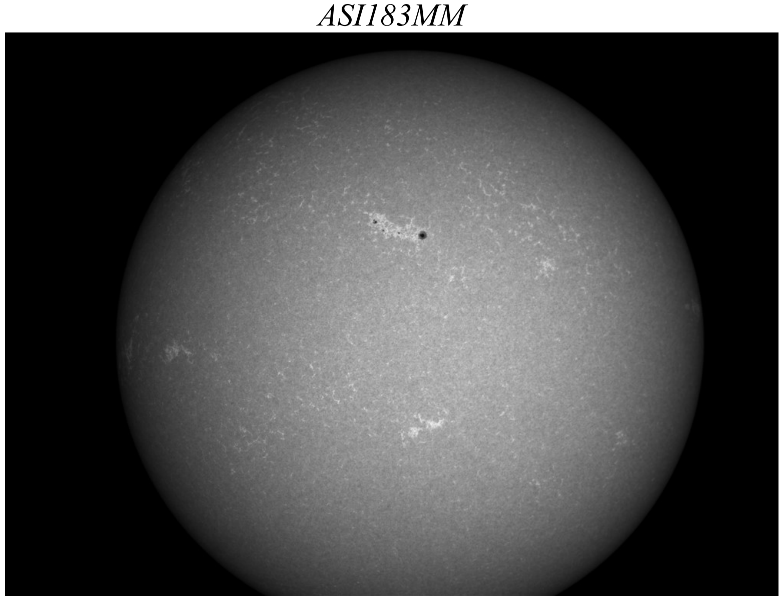
Results – Calcium-K Imaging:
Calcium-K images were captured using the setup described above, around mid-day on August 2nd. Figure 2 presents a sample full resolution image generated by each camera. They are presented in the figure at the same scaling so one can get a sense of both the sensor size and the relative resolution. Figure 3 shows a cropped section from each image in the area around the main sunspot group, again scaled the same to show the relative resolution. The exposure time required by each camera varied as noted in the figure, with the ASI290 requiring the shortest exposure time. All three cameras tested produced a sharp image with no artifacts. The DMK 33UX226 produced a bit blurrier image because its resolution was fine enough to show the limits of the seeing conditions. Additional sharpening of the DMK 33UX226 image using Topaz Sharpen AI helped to compensate for the seeing. Despite the impact of seeing on the DMK 33UX226 image, it is evident that this camera is delivering the image with the most detail visible.



ASI290MM

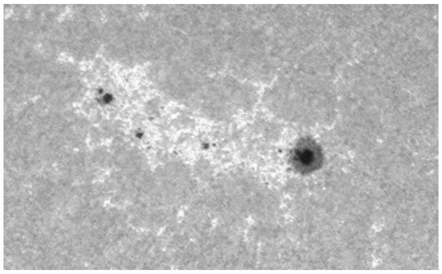


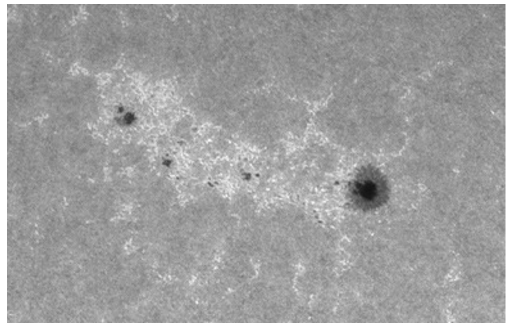
ASI183MM



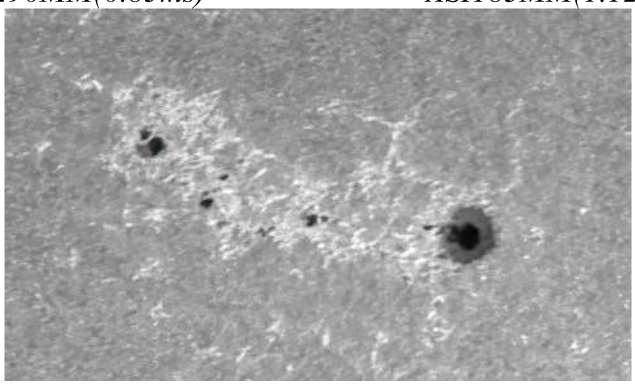
DMK 33UX226

Figure 2 Image Size Comparison Between Tested Cameras

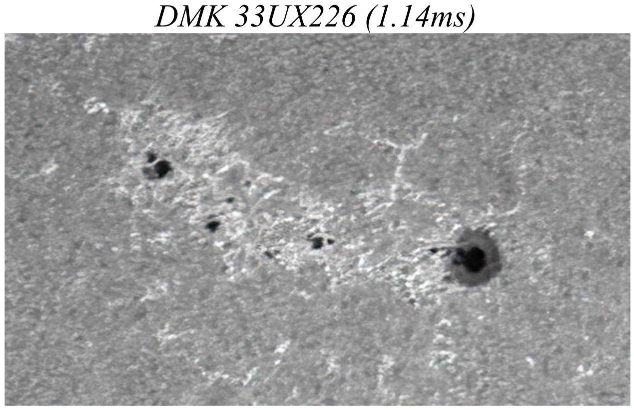




ASI290MM(0.85ms) *ASI183MM(1.12ms)*



DMK 33UX226 (1.14ms)



DMK 33UX226 w/additional sharpening in Topaz Sharpen AI

Figure 3 Calcium-K (393.37nm) Imaging Comparison Between Tested Cameras

Results – Solar Continuum Imaging:

Images using the Solar Continuum filter were collected using the DMK 33UX226 camera in the late morning of August 13th. Increasing cloud did not allow me to collect image data in this wavelength with the other cameras. Figure 4 presents some cropped samples from the images that were captured using the DMK 33UX226 in this band. The images are some of the sharpest I have ever captured in this band from my backyard. No additional sharpening has been added outside of a light application of wavelets in Registax 6.

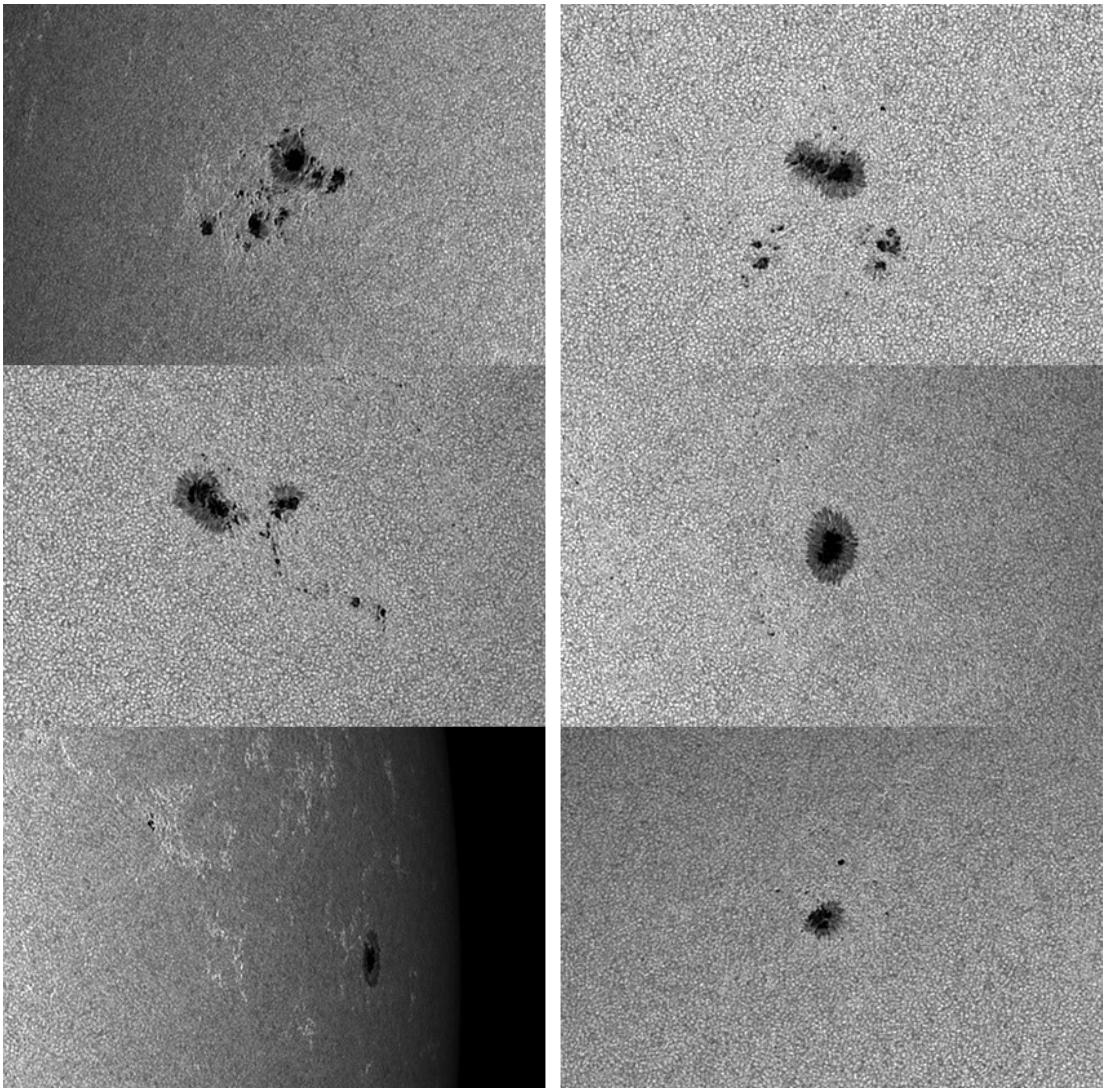
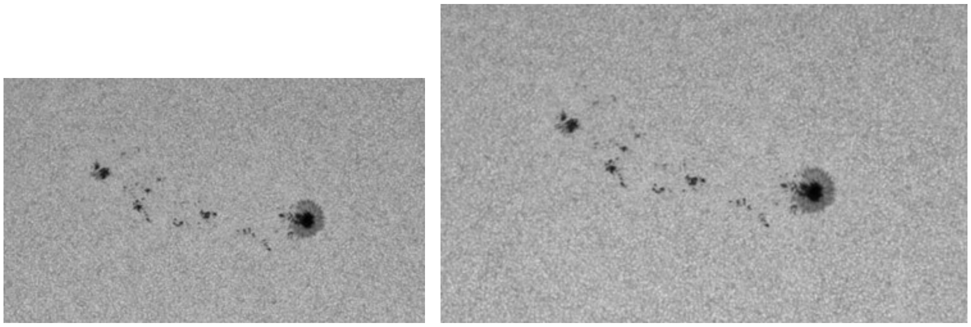


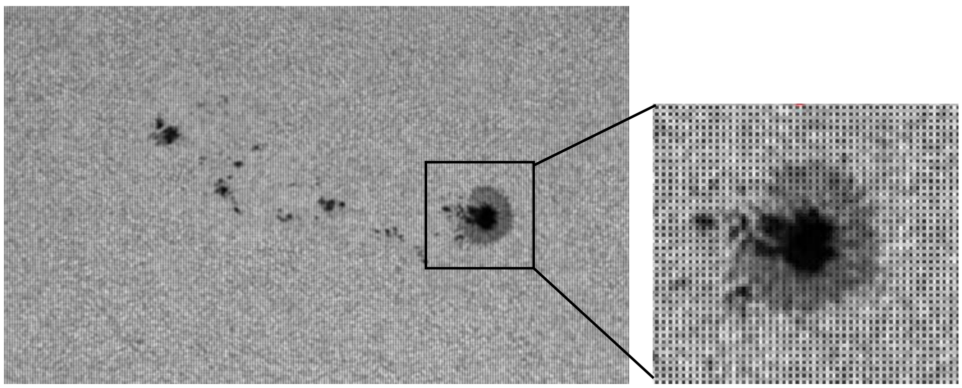
Figure 4 Solar Continuum (540nm) Images Captured Using DMK 33UX226

Results – Helium-D3 Imaging:

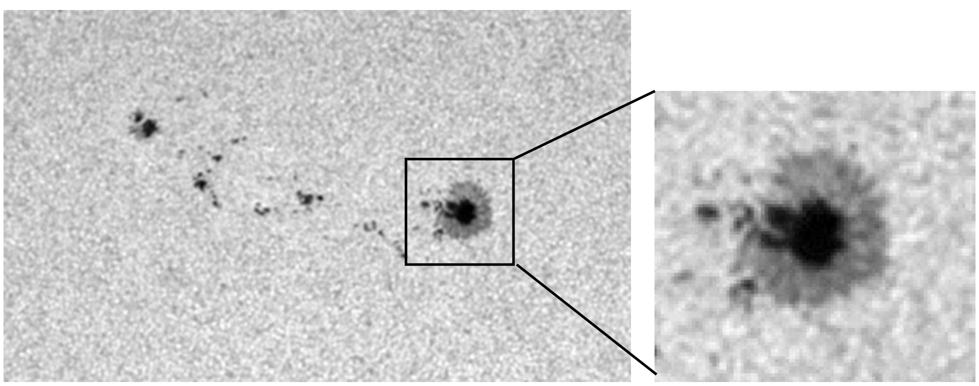
Images captured using the Helium-D3 filter were captured around mid-day on August 2nd. A crop of the main sunspot, as captured by each camera, is shown in Figure 5. During data capture the ASI183MM showed a faint overlay of a grid pattern, the so called "screen door" effect that has been noted by many other users of this camera. In this particular case the screen door pattern was effectively blurred out by the stacking process and is not visible in Figure 5. However in the past when I have tried the ASI183MM with my Helium-D3 filter the artefact has been more pronounced and was still present in the stacked image. The DMK 33UX226 showed a very obvious grid artefact during the data collection. This artefact was further enhanced by the stacking and wavelet sharpening process as can be seen in Figure 5. Close examination of this artefact revealed that it was a repeating pattern every-other pixel across the entire sensor. This is



ASI290MM(0.09ms) *ASI183MM(0.16ms)*



DMK 33UX226 (0.19ms)



DMK 33UX226 w/convolve filter before wavelets

Figure 5 Helium-D3 (587.56nm) Imaging Comparison Between Tested Cameras

rather different than the pattern observed with the ASI183MM which repeats on a scale of 10 to 20 pixels and is rectangular in shape, the pattern having a longer period in the vertical direction. After researching image processing tools for removing artefacts I came across the "convolve" filter. It allows the user to define a matrix of integer values that directs how the output image is to be constructed from the pixels of the source image. Not knowing what I would get I simply played around with this filter in AstroImageJ and by trial and error very quickly settled on the convolve matrices listed below. The convolve filter works by combining pixels in the source image as directed by the matrix to create a new output pixel. So in the case of my first matrix, the output pixel is a weighted average where: the original pixel has a weighting of 2, the pixels immediately to the left and right have a weighting of 1, and the pixels in the row above and below are ignored (weighting = 0). The first matrix removes (smooths out) the vertical lines in the image, and the second matrix removes the horizontal lines.

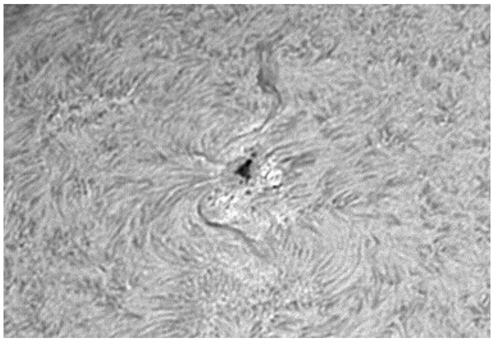
Convolve Matrix #1:	0	0	0
	1	2	1
	0	0	0
Convolve Matrix #2	0	1	0
	0	2	0
	0	1	0

I tried the convolve filter on some past images captured with the ASI183MM containing the sensor artefact, but it did not work to remove the artefact.

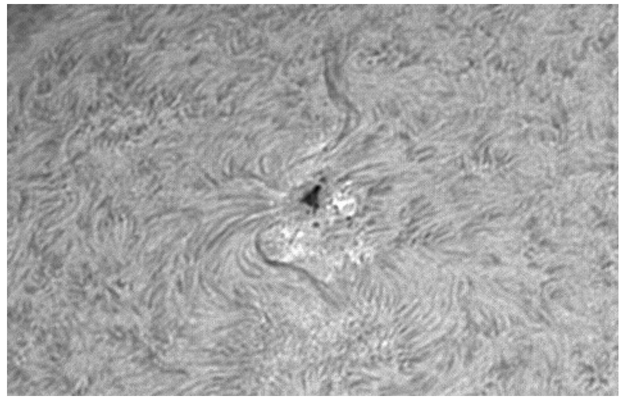
Results – H-α Imaging:

Images in the H-α band were collected on August 20th. A crop from two different areas on the solar disk, as captured by each camera, is shown in Figures 6 and 7. Images with the DS432M were collected both at the native focal length of the scope, and with a 2.5x Barlow. During the data collection the screen door artefact was evident with the ASI183MM camera. Figure 8 is a screen capture of a single frame from the .SER file showing the general appearance of the artefact. In this particular instance I was lucky that the artefact was smoothed out by the stacking process. In my experience it is more often that the pattern is maintained through the stacking process and enhanced by wavelets. During data collection with the DMK 33UX226 camera its sensor artefact was not visible. It was only after stacking and wavelets application that the pattern was visible. The pattern was much less pronounced than what was observed in the Helium-D3 band, minor enough in fact to almost ignore, but I chose to apply the convolve filter anyway.

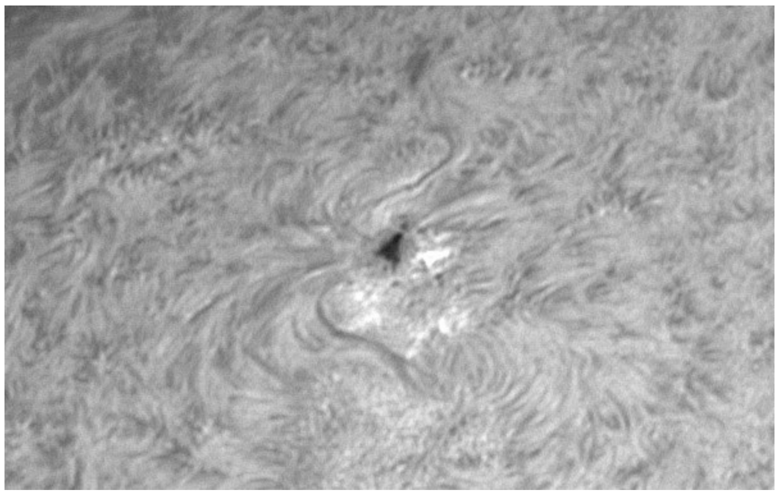
The DMK 33UX226 images are again slightly blurrier than those from the other cameras due to its resolution being a bit beyond what the seeing conditions supported. Application of additional sharpening in Topaz Sharpen AI helps to compensate for the effects of seeing, as illustrated in Figure 9. In my opinion the DMK 33UX226 delivered the images with the most detail visible. The images produced by the DS432M with 2.5x Barlow, are no better than what I can achieve using the ASI290MM. This is true in terms of resolution, sensitivity, and field of view.



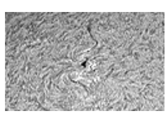
ASI290MM(2.60ms)



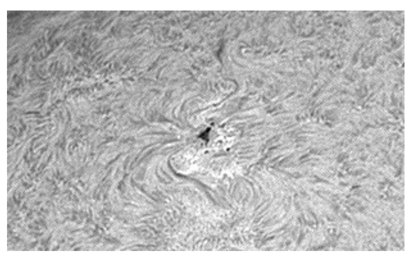
ASI183MM(4.90ms)



DMK 33UX226 w/convolve filter before wavelets (7.04ms)

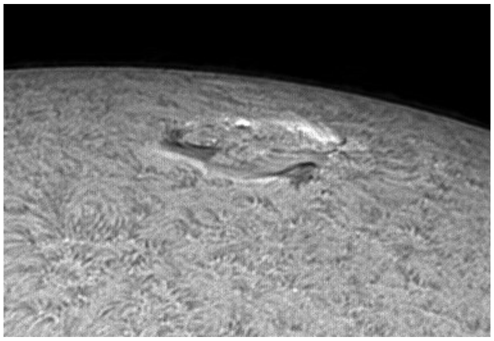


DS432M (0.40ms)

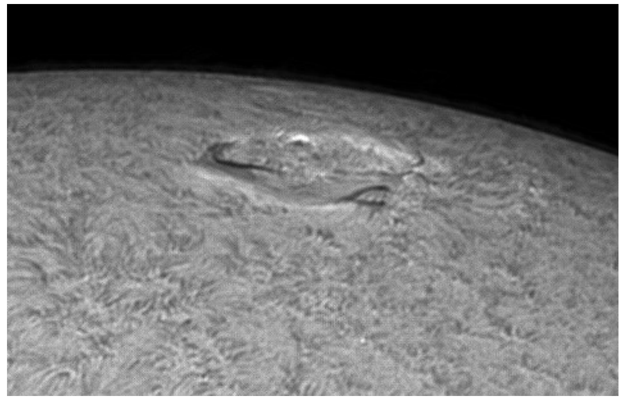


DS432M + 2.5x Barlow (2.50ms)

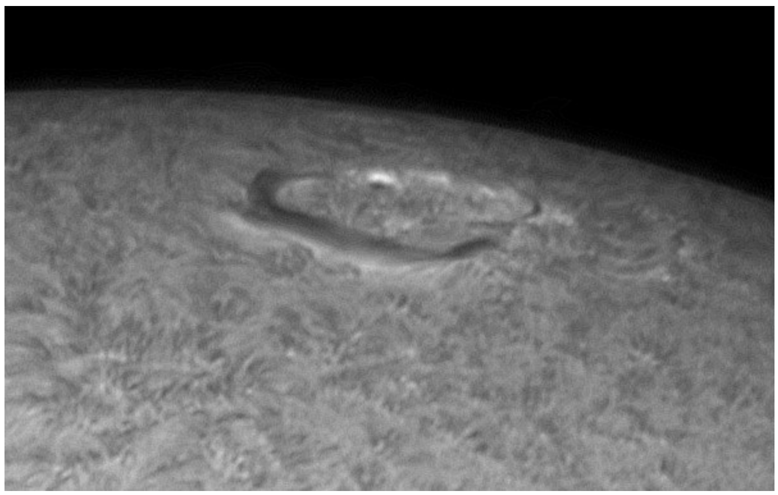
Figure 6 Hydrogen-α (656.28nm) Imaging Comparison Between Tested Cameras, View 1



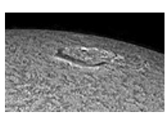
ASI290MM(2.60ms)



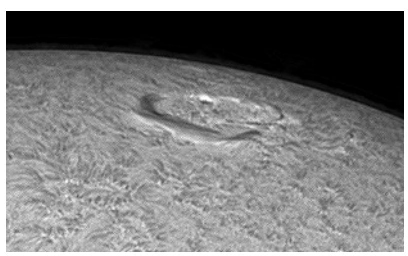
ASI183MM(4.90ms)



DMK 33UX226 (7.04ms)



DS432M (0.40ms)



DS432M + 2.5x Barlow (2.50ms)

Figure 7 Hydrogen-α (656.28nm) Imaging Comparison Between Tested Cameras, View 2

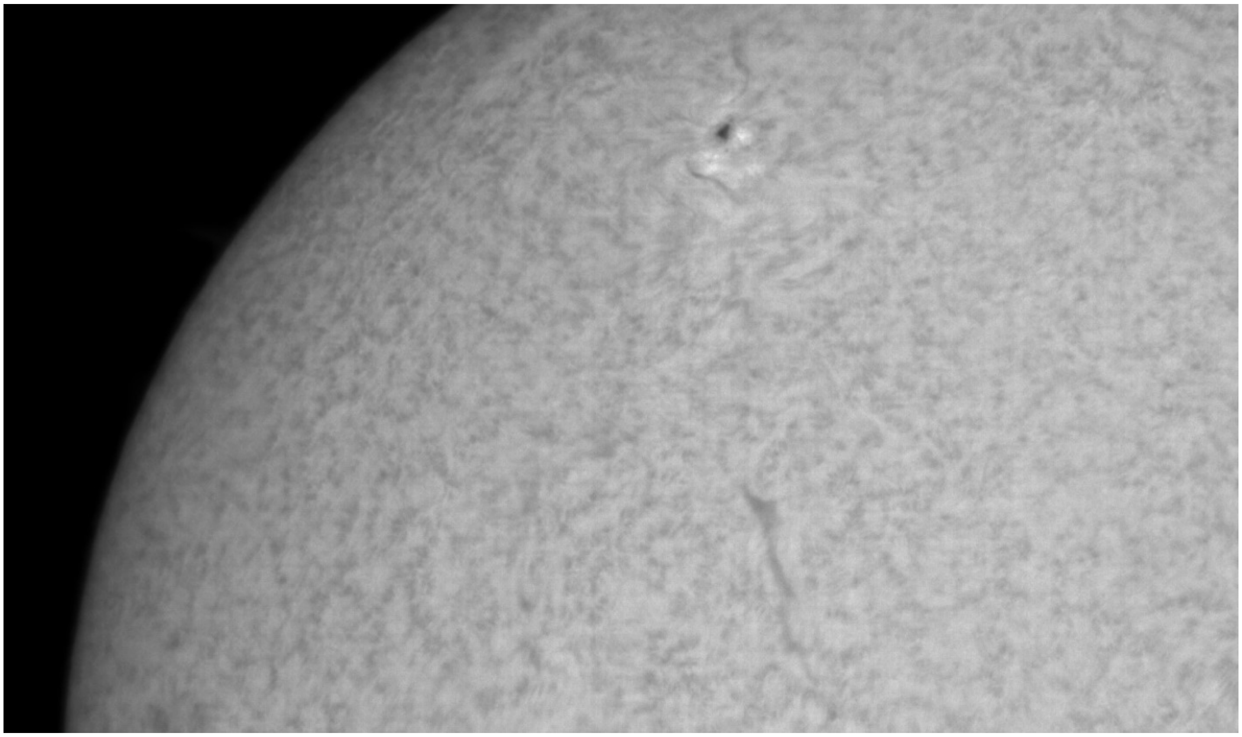


Figure 8 Hydrogen-α (656.28nm) Imaging w/ ASI183MM, Single Frame Illustrating Grid Artefact

Discussion:
I have been using the ASI290MM for many years and have been happy with its performance. The only thing it has left me wanting for is a larger sensor with the same pixel size. To produce an image of the full Sun's disk using the ASI290 requires me to tile four images together during post processing – an effort I'd rather not spend. I purchased the ASI183MM a few years ago with the hopes it would fill my need for a higher resolution sensor, but very quickly I ran into the screen door sensor artefact issue. The artefact is minimally invasive when imaging in Calcium-K or Solar Continuum, so I have been using the ASI183 in those situations. It is also my primary lunar imaging camera in infrared, a role it has filled very well. This has left me limited to using the ASI290 whenever I want to image in Helium-D3 or H-α. I briefly considered the ASI178MM camera, but quickly found online that it suffers from the same sensor artefact as the ASI183MM. The ASI174MM has a long history of being used for solar imaging, but it has much larger pixels than the ASI290 and is half as sensitive. In the past year or so there have been a number of new solar imaging cameras released by different vendors, but none that have fit my requirements – many are colour cameras or have large pixels. It is this relatively recent activity in new cameras for solar imaging that inspired me to look at the problem again and ultimately purchase the DMK 33UX226 and put it to the test.

A visual comparison of each camera's relative imaging performance is presented above. During the image data gathering process I took note of a number of important parameters such as exposure times and frame rates. These parameters are summarized in Table 2.

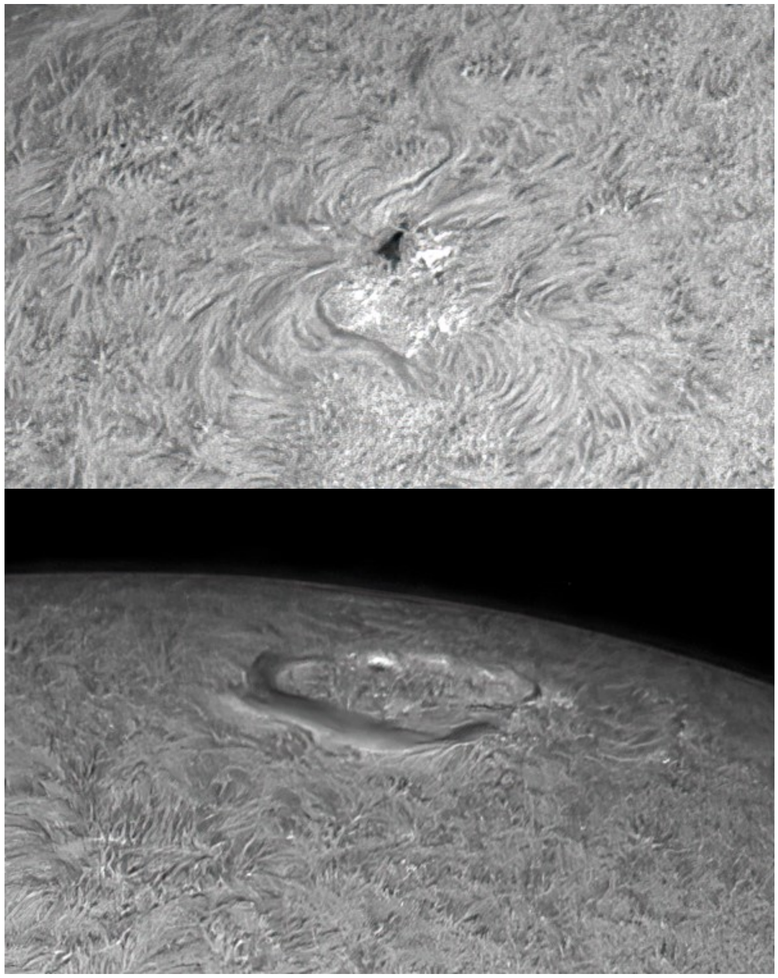


Figure 9 Hydrogen-α (656.28nm) Imaging w/ DMK 33UX226 – Additional Sharpening in Topaz Sharpen AI

Parameter		**ASI290MM**	**ASI183MM Pro**	**DMK 33UX226**	**DS432M-TEC**	**DS432M-TEC + 2.5x**
Exposure Time (ms)	Calcium-K	0.85	1.12	1.14		
	Helium-D3	0.09	0.16	0.19		
	H-α	2.60	4.90	7.04	0.40	2.50
AOI Size for Same FOV		Full Frame (1936x1096)	2339x1324	3035x1718	624x353	Full Frame (1600*1100)
Frame Rate for AOI (fps)		78	42	29	58	13
Time to Collect 2000 Frames (sec)		26	47	67	35	155
Resulting File Size (Gb)		4.0	5.9	9.9	0.4	3.7

Table 2 Summary of Image Data Collection Parameters

The ASI290 and ASI183 delivered the highest frame rates, but the DMK 33UX226 frame rate was acceptable considering the size of the frames it was streaming to the computer. The DS432 did not deliver frame rates as fast as I expected based on the Sony sensor data. It is possible I did not have the MallincamSky software configured correctly for high-speed acquisition. One curious observation was that there isn't a frame rate benefit to using an Area-of-Interest (AOI) on the DMK 33UX226 camera. The max frame rate is pegged at 30fps for this camera regardless of the AOI size. For all the other cameras tested the frame rate increases with decreasing AOI size.

In terms of exposure time, it was interesting that the disparity between cameras varied depending on what waveband was being imaged. The difference in exposure time was much less between cameras when imaging in Calcium-K then for the other bands. The difference in exposure time between cameras was the largest when imaging in H-α, more in line in fact with what would be suggested by the sensor data. My imaging results are consistent with my earlier assertion that the sensitivity of the IMX290 is not 1200mV as suggested by Sony but is more like 600mV.

Conclusions:

Based on the results of the testing described above, I have made the following conclusions:

1. The very high sensitivity offered by the IMX432 sensor does not make up for its large pixel size and low resolution. The amount of tele-extension required (i.e. Barlow) to achieve the same spatial resolution as the ASI290 entirely negates the sensitivity benefit. Although usable for solar imaging, in my opinion there is no compelling argument to purchase a camera with this sensor versus the ASI290.
2. The ASI290 was the only camera able to deliver artefact free imaging in all of the bands considered. The DS432 was not tested in multiple bands so I can't say for sure if it is free of artefacts (it probably is). The ASI290 also delivered the highest frame rates and shortest exposure times. In almost all regards it was the best all-round performing camera tested. The only shortcoming of the ASI290 is its low resolution/small FOV.
3. The ASI183 performed as well or slightly better than the ASI290 in terms of image quality, but only in specific bands. It is prone to the grid artefact when imaging at longer wavelengths (eg. H-α). The artefact may or may not be blurred out by the stacking process depending on the seeing conditions and your scope tracking.
4. The DMK 33UX226 delivered images with the highest spatial resolution, but as a result the images it produced suffered the most from the effects of the poor seeing conditions at my location. With the application of additional software sharpening tools, the images produced by the DMK 33UX226 were in my opinion superior to those of all the other cameras tested.
5. The sensor artefact produced by the DMK 33UX226 was observed to be most pronounced while imaging in Helium-D3, but was still visible in H-α. Application of a convolve filter post-stacking appears to be an affective way of resolving the artefact issue on this camera. No comparable solution has been found for the ASI183.

If you have any questions, please feel free to contact me.

Cheers!

Jim Thompson (top-jimmy@rogers.com)