

# The SAC8

## Imaging faint fuzzies for the masses?

By Craig Stark [click to email author](#)

**Author notes:** I have had the SAC8 for over a year now and have gotten a lot of images off it by now both under the stars and on the test bench. Before the SAC8, I used a digital camera (Nikon CP5000) and an “SC-1” long-exposure modified webcam to image. I am currently one of the co-owners of the SAC Users Yahoo Group and I maintain [a site with more technical details on the SAC8](#) that part of this review was drawn from. However, I am not tied to SAC directly and have no financial interest in the company. All photos in this review are mine (except as noted, the final shots). My shots should not be taken as evidence of the best the SAC8 can do by any means.

– Craig Stark

### Overview

The SAC8 is a TEC-cooled, monochrome CCD camera. At only \$539 it costs half as much as a 12-bit StarlightXpress MX-512 and is even less expensive than the popular Stellacam video system. Thus, despite being SAC’s most expensive camera, it clearly represents an “entry level” imaging system from the perspective of price. From my use of a SAC8 over the last year, if the SAC8 represents entry level performance, this is a very grand age of amateur astrophotography that we live in. It’s a great camera that has let me take pictures I never thought I’d be able to take. It’s also let me “see” faint DSOs, I’d never see otherwise, learn a lot about astro-imaging, and have a lot of fun in the process.



### What's included

In the package, you get the camera head unit, a control box, a cable to connect the two, and a CD of software. The head unit includes a removable T-thread to 1.25" adapter so that it can be attached to the telescope either way and has a 1/4" threaded hole to attach directly to a camera tripod if you so choose. The head unit and the control box are

connected by a single DB-15 cable that plugs into the back of the head unit, where a small fan sits as well. The control box is connected to the computer via a USB cable and a parallel port cable and to a 12V source via a standard male cigarette lighter plug (current draw is well under 1A, even with the TEC on). Images are downloaded via the USB cable for rapid viewing, but the camera is controlled via signals sent to the parallel port (a version of the SAC8 that does away with the need for a parallel port is in the works).

The CD includes a registered copy of AstroVideo and FitsX from [COAA](#), driver software, and, for basic photo manipulation, 30-day trials of PhotoImpact and Picture Window. AstroVideo is the main program for image capture and some amount of pre-processing, while FitsX provides additional image processing capabilities. Both are designed with the SAC8 in mind and work very well with it. Not included, but a second option for capture and processing is version 2 or better of [K3CCDTools](#).

### **The Camera: Technical details**

The camera itself uses a 1/3" Sony EXview HAD CCD™ chip (ICX254-AL). These Sony CCDs are extremely sensitive (thanks to an array of microlenses over the CCD wells and sensitivity into the infrared) and have very low noise characteristics. Unlike many conventional cameras for astrophotography, the SAC8 is a marriage of a low-light video camera and a video frame capture device (it is related to the 1004x-JG camera developed on the QCUIAG Yahoo group, but has been substantially refined and developed by the folk at SAC, William Behrens in particular). Unlike video cameras, however, the SAC system is designed with long-exposure imaging at its core. This design does add a few quirks, but most certainly contributes to its low cost. Having had as much fun with the SAC8 as I've had, I'd probably say, "It's not quirky – it has 'character'."

The first thing that comes from this design is the resolution. The CCD itself has a native resolution of 510x492 with a pixel size of 9.6 $\mu$ m x 7.4 $\mu$ m. This resolution can be halved vertically with on-chip binning to increase the sensitivity twofold. Either way, the image that is read out of the camera is 640x480. In this resampling, the pixels become nicely square. Thus, you have two modes: high-res (640x480, resampled from 510x492) and low-res (640x480, resampled from 510x246 with 2x the sensitivity).

The second thing that comes with this is the fact that there are two "modes" of operation. In "short exposure mode", the SAC8 acts like a video camera, with exposures that range from 1/60 – 1/100,000 of a second. This video signal is streamed to the computer at 320x240 at up to 30 FPS (lower FPS rates yield better quality images, thanks to less compression) when either the "VFW" or "WDM" drivers are used in AstroVideo. One very nice feature of the SAC8 is that this short exposure mode can be shown in a live preview window. This makes focusing a breeze (or as much of a breeze as CCD focusing can ever be). You don't need to wait a long time between downloads to see the effect of your focus changes on the image (you do have to use a fairly bright star if you do it this way, though). Additionally, this short exposure signal

can be captured by the “TWAIN” driver at 640x480 in AstroVideo at high quality, but at a much slower framerate.

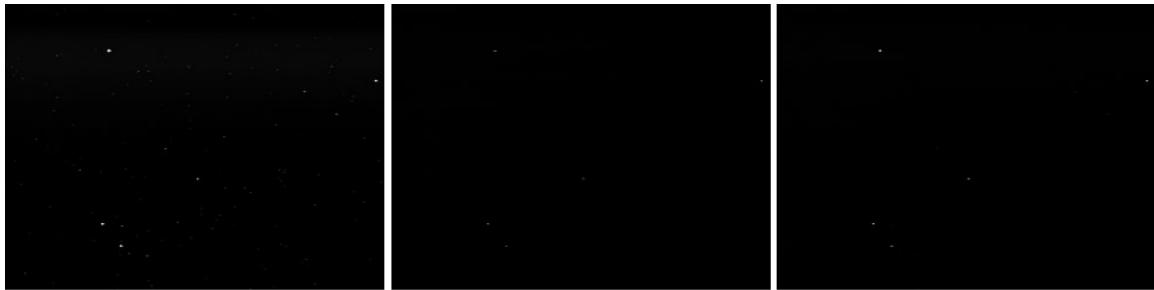
The second mode, “long exposure mode”, has the SAC8 operate like a more conventional astro CCD camera. In this mode, the CCD amplifier and the shutter are controlled by the computer so that the amp can be shut off, the exposure started, a delay enforced, the amp turned back on, and the shutter closed (shutting off the amplifier during the exposure eliminates “amp glow” – the significant brightening of one corner and mild brightening of the whole image). Here, exposure durations can range from ~100ms (there’s some variability in the exact timing – you can specify 1ms, but it takes some time to actually go through the process) to longer than you’d ever care to image. The video signal is captured by the control box using the TWAIN driver so that a 640x480 image can be read without the compression required for a continual video feed. One thing to note is that when capturing an un-binned, high-res image, it actually takes two passes to read the image (one pass for the odd lines of the image and one for the even lines). This means it takes a bit longer overall and does introduce one artifact (see “*Interlacing artifact*” below).

### **Artifacts (the downsides)**

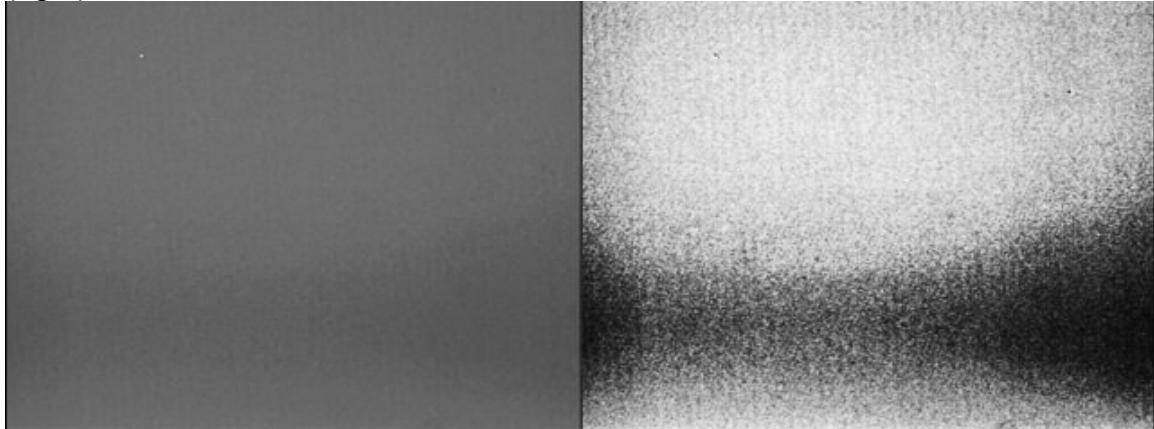
When asked whether I want the good news or the bad news first, I usually choose the bad news. So, I’m going to give you the bad news on the SAC8 first by going through the artifacts that the camera has. An ideal CCD camera would have no noise, have CCD wells (pixels) that are both linear and have response characteristics that are identical to every other CCD well and are independent from signals in other CCD wells. Further, the camera would be very sensitive and have sufficient bit depth (resolution in intensity) to capture very faint and very bright signals with no distortion in their recorded intensity.

Is the SAC8 an ideal CCD camera? No. Then again, even a very nice SBIG isn’t ideal (it’s closer, of course) and the SAC8 only costs \$539. The real question is whether the SAC8’s artifacts can be dealt with well enough that you can make nice images with it. In my mind, the answer is a very clear “yes”. There are artifacts in the camera, but most are very easily dealt with in a way that corrects the artifacts cleanly (hot pixels, flatness of field, and interlacing). One is less easily dealt with, but do-able (bit depth limitations), and one is easily dealt with, but in a less-than-clean way (“ear” artifact). All in all, this bad news is really not very bad at all, making it very easy to be happy with the camera and to have fun with it. So, what are the artifacts?

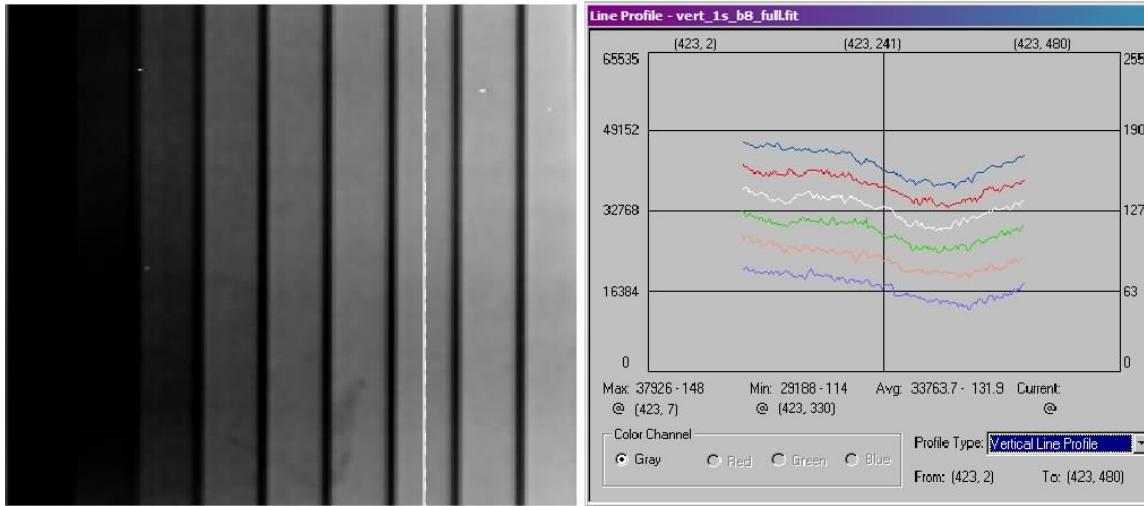
**1) Hot pixels:** Every CCD has some thermal noise. As you increase the exposure, you’ll start to see “hot pixels” appear. The Sony CCD is extremely good in this regard. Below is a 30 s dark frame showing the hot pixels with the TEC cooler off (left, ambient temp ~80°F), a 30 s dark frame with the TEC cooler on (middle), and a 1 minute dark frame with the TEC on (right). Removing these hot pixels by subtracting a dark frame isn’t going to leave a whole bunch of noisy holes in your final image, making this con more like a pro of the SAC8.



2) **Flatness of field:** Most CCD cameras aren't *perfectly* flat in their response in that there is an uneven bias signal in the frame or there are slight variations in the sensitivity across the detector. The SAC8 has no bias signal to deal with (none that reaches the computer), but its field isn't flat. There is a clear "banding", making a horizontal bright-dark-bright artifact appear when the contrast is stretched and this isn't something that's small enough to be ignored. Below is a raw shot of what should be a flat field (left) that shows the artifact a bit, a version that has been stretched a lot to accentuate the artifact (right).

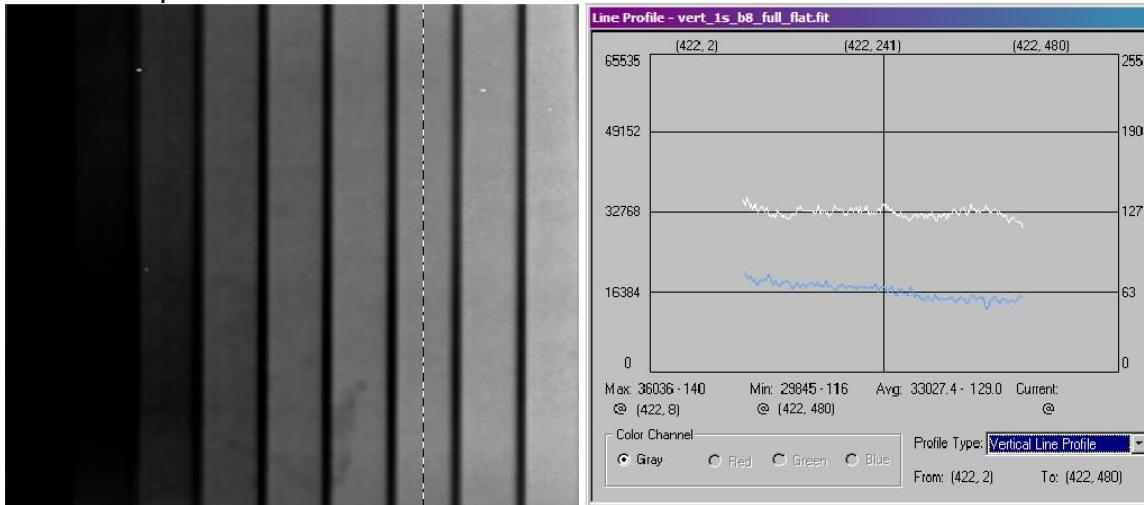


Here's another way to look at the artifact. Here, I shot some greyscale bars (left) and used [ImagesPlus](#) to plot the response within a bar as a function of the vertical position of the pixel (right). For the third bar from the right (white line added to greyscale bars to show the location of the data), the vertical response is shown as the white line in the graph on the right. The signal from other bars is shown as the colored lines.



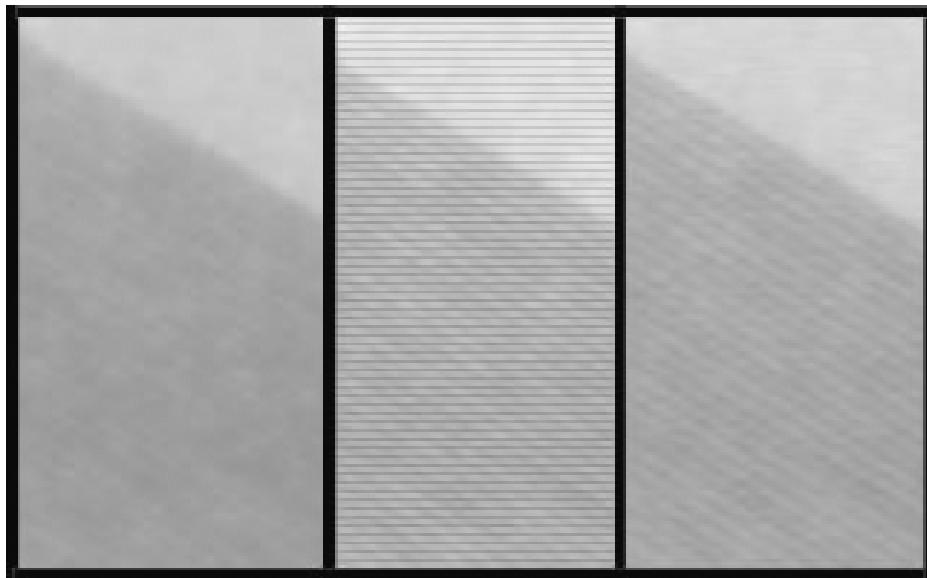
From this, you can see the artifact clearly. These should be horizontal lines. As we look at the other bars (plotted as the different colored lines), we see the same response, shifted vertically, of course, indicating the overall difference in brightness across the bars (the brighter two bars to the right of the indicated bar and the dimmer three immediately to the left are plotted). [Note for the keen-eyed. The lines are not perfectly shifted versions of each other. These data were collected on an earlier generation of the SAC8 which passed a gamma function over the data which made the response a bit non-linear. This is likely the source of the slight change in the response across the colored lines. Current versions of the SAC8 (which mine has been updated now to) do not pass this gamma function over the data.]

So, the SAC8 has this artifact in that it does not have a flat field. Fortunately, this artifact is largely fixed with ease. I use a single flat frame (average of about 50 frames) collected many months ago. Despite being taken on a different scope, with a different focal reducer setup, at a different time, this "master flat" can do a very nice job at removing this artifact (remember, the artifact is not vignetting – it's something endemic to the SAC8). Here is that same shot after flat frame removal, along with a plot of the vertical response of two of the bars.



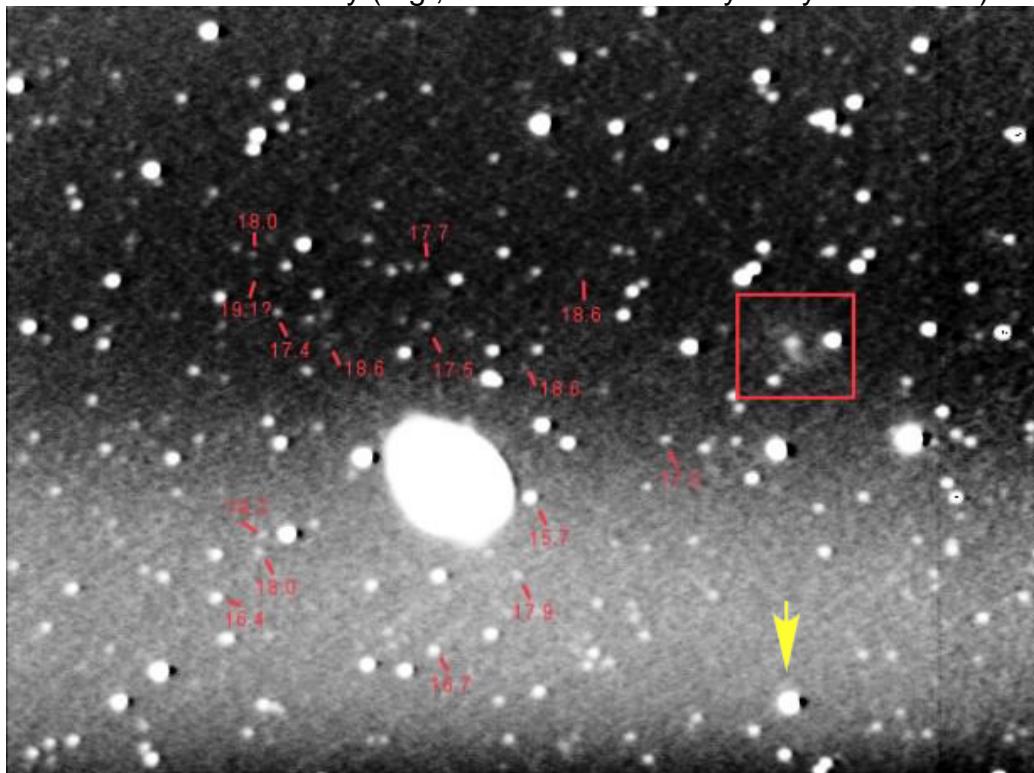
So, the fact that it doesn't have a perfectly flat field isn't that huge of an issue after all. I should note that FitsX has a nice tool to remove the artifact even if you didn't acquire a flat field (or to touch up what flat field correction left behind) that creates a mathematical model of the y-axis of the image that's geared towards this artifact specifically and removes it.

3) **Interlacing:** I mentioned above that in high-res mode, the camera makes two passes at reading the data. This causes an "interlacing" artifact in that fine horizontal lines can be seen in the high-res images. This results from the fact that half of the lines get a bit longer exposure than the other half of the lines (remember, one set is read off before the other). With very long exposures, this effect is negligible. With shorter exposures, the difference in exposure time between the odd and even lines is apparent. Below are tightly cropped in shots of fine grey diagonal lines on a light grey background. On the left is a shot taken in low-res mode, where no banding is present, but the fine diagonal lines have turned into a solid grey. In the middle is the same area taken in high-res mode (2x the exposure duration), clearly showing the fine horizontal banding.



AstroVideo has the option to "match odd/even lines" either immediately after acquiring each high-res frame or as a post-processing step (K3CCDTools has a similar option). This tool creates histograms of the odd and the even lines and matches the histograms at 20 points. The result is shown on the right, where the interlacing artifact is gone and the fine diagonal lines in the image can now just be resolved. So, we have another artifact of the camera that isn't really a big deal after all, as it can be easily remedied. I should note that as your mount lets the target drift in the frame a bit across images, the alignment of images in a big stack is likely to reduce this artifact a lot as well, as the odd and even lines will likely randomly align on top of each other in the stack, canceling out the brightness differences between the two.

4) “**Ears**” or “**Shadows**”: Image a very bright star with the SAC8 and have the background of the image such that it isn’t totally black and what you’ll see is the bright star and a black “shadow” or “ear” to the right of the star. The artifact from some of the inner workings of the SAC8. In particular, when a signal comes in that is bright enough to drive the analog-to-digital converter (or “A/D” or “ADC”) to its full level (full white), it seems that it takes some time for the A/D to recover to normal operation. So, a saturated pixel (or a few saturated ones in a row) will peg the A/D enough that the next few near-black (background sky) pixels end up black. The shot below is intentionally only barely processed. It’s a shot of M57 taken as a stack of 30, 10 s exposures. No flats or darks were applied to remove those artifacts and M57 itself is clearly well saturated. I took this shot actually to show how deep one can go (8” SCT at f/6), but it shows this artifact clearly (e.g., the star indicated by the yellow arrow).



There are two popular methods for dealing with this artifact and neither are perfect, as neither really let you get back the data that should be there. The first uses the aptly-named “VanGogh” tool in FitsX, which automatically identifies such dark spots and fills them in with data from the surrounding area. The second is to use an image editing program’s rubber-stamp or smudge tool to do this manually.

By the way, note that this is a stack of 30 10s exposures with an 8” SCT at f/6. Those are mag 18 stars being picked up and that’s IC1296, the faint mag 15 barred spiral galaxy in red box.

5) **Bit depth**: Like webcams, the SAC8’s capture device for turning the CCD’s signal into data for your computer is a 24-bit color device. Sounds great! 24 bits is a lot of

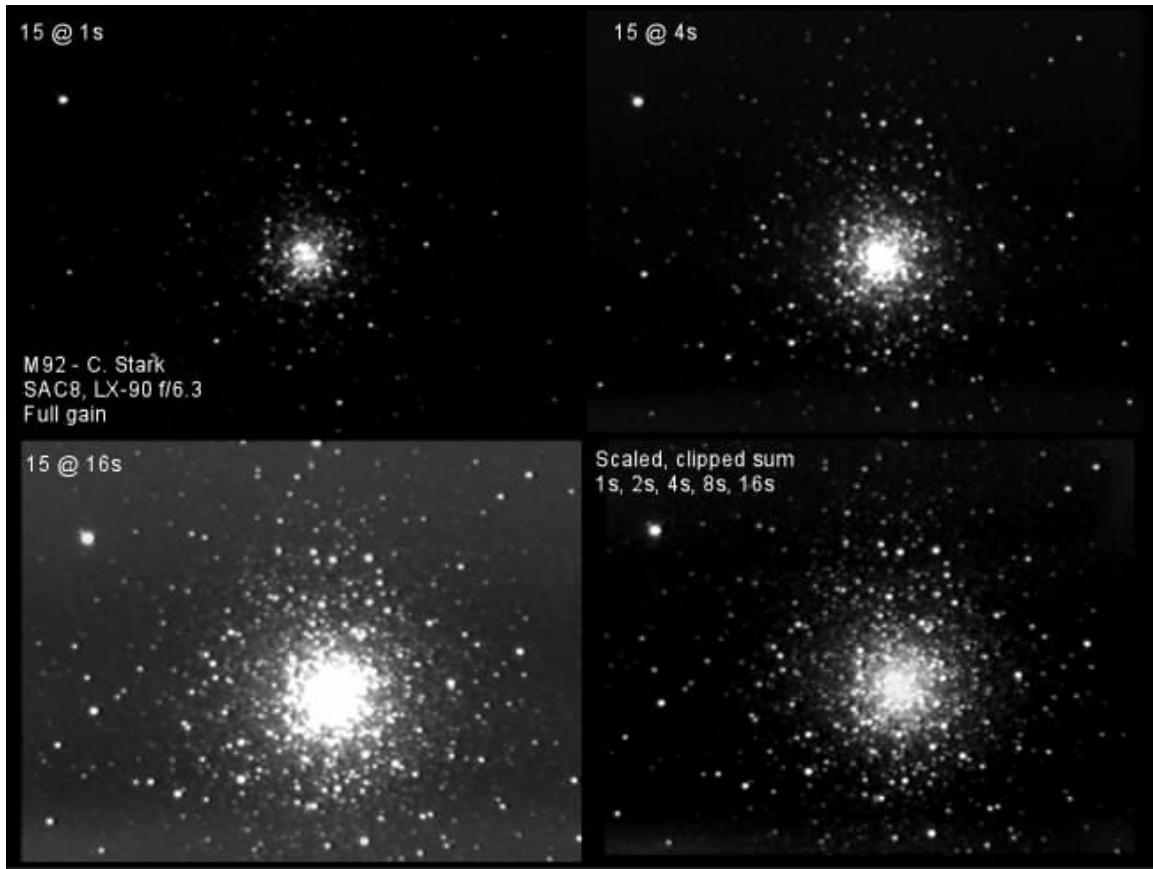
intensity resolution. The problem is the SAC8 is a monochrome CCD and that 24 bits of color equates to 8 bits per color. Thus, the signal off of the SAC8 is quantized into 8 bits or 256 levels of grey. While that's fine and good in the finished product (the monitor you're now looking at probably does no better than 256 grays – remember, that's 24 bits of color), it's not so fine and good in the raw data for a lot of targets.

In the image above, to pull out those mag 18 stars, all of M57 is saturated. It sure would be nice to have both the mag 18 stars and the details of M57, but that's not going to happen in 8 bits. 256 levels of grey (8 bits) corresponds to ~6 magnitude range under ideal conditions. Thus, when you want to shoot for very faint stars, you're going to saturate the brighter stars. A 12-bit imager has a ~9 mag. range and a 16-bit imager has a ~12 mag range. As skyglow starts to enter our image, the lowest level of signal is raised off of black and into grey. Grey to white is not as big a range as black to white, and so we've lost bit depth, meaning we may not even have 8 bits under real conditions.

All is not lost, however. There are two ways in which we can increase the bit depth. First, stacking many 8-bit images will result in a final image that has greater than 8 bits (as long as you've got a bit of noise in each and as long as you're stacking in something that'll hold the extra data, like 32-bit integers). Briefly, the small bit of noise helps you resolve signals that are less than one bit in magnitude, as the small signal will bias you one way or the other (e.g., no signal with a bit of noise might have a 50-50 chance of reading a "1" and a faint signal on that noise may shift it to 60-40. Stack a lot of those and you've read your faint signal.) This will get you a few bits back in reasonable stack sizes, but just a few.

There's a second technique to getting around the problem and one that's also included within AstroVideo. If we take multiple sets of exposures at different exposure lengths, we could have one set that gets the bright parts well (but loses the dim aspects), one set that gets the dim parts well (but washes out the bright parts), and potentially several sets inbetween. A demo of this on M92 is shown below. The upper-left shows the shortest single exposure and the lower left shows the longest single exposure. The lower-right shows the combination of several of these.

AstroVideo has a nice option to automatically collect a series of exposure durations (the "log exposure" option) and to combine them intelligently (that latter part is key – you can't simply add the sets of images). The demo above was done manually before AstroVideo had this option, but I now use AstroVideo to do the combination as its results are at least as good as my manual combination.



### Summary of “cons”

So, the SAC8 has its flaws. Like all cameras, it has hot pixels, but it's got very few of them. Its field isn't flat, but that's easily fixed. When shooting in high-resolution mode, you can see the effects of interlacing, but that's also easily fixed. Bright stars produce dark ears to the right. That's easy to fill in, but the fill-in process can't recover lost data. Finally, the camera has only 8 bits of intensity resolution, but with a little bit of work, one can extend this through stacking and through combining multiple exposure durations. Once you've got your SAC8 up and going (this sometimes does take people a few tries to get drivers, etc. sorted out), these are the problems you'll face.

### Advantages (the upsides)

What are the upsides to the SAC8 that set it apart? Well, the price is clearly one, but I'm going to suggest that even if the price were higher, the SAC8 would still be a great buy. The major reason is that quite simply, the SAC8 is ridiculously sensitive. One of my favorite examples comes from a time in which I was testing the camera on the bench and placed a black plastic lenscap over the nosepiece. The only light came from a 15W halogen lamp on the desk. At its most sensitive setting, a 1s exposure was enough to produce a midlevel grey from the few photons (IR most likely) that made it through the black plastic (a metal lenscap yielded a black image). This sensitivity has a number of serious benefits to anyone and to beginners in particular. The sensitivity will

allow you to go deeper, use darker specialty filters (e.g., O-III, H-alpha, etc), and/or use shorter exposures.

Shorter exposures not only mean less time per target, but less time that you need to have your mount operate without error. Not many beginners thinking of a \$539 camera have mounts that'll hold you within an arcsecond or so over the course of several minutes. Generally, this requires some combination of an expensive mount, periodic error correction, autoguiding, or manual guiding. On my mounts, typical of many amateurs (LX-90 and LXD-55), I've measured periodic error rates that give a maximum rate of change of about 0.1"/s. So, it would take about 10s to drift 1 arcsecond, 20s for 2", etc. Therefore, if you've got pixels that are covering a few arcseconds of sky, you should be able to run unguided exposures of 10, 20, or 30 s without worrying about loosing any frames from star trails (exact numbers will depend on mount, scope focal length, etc.)

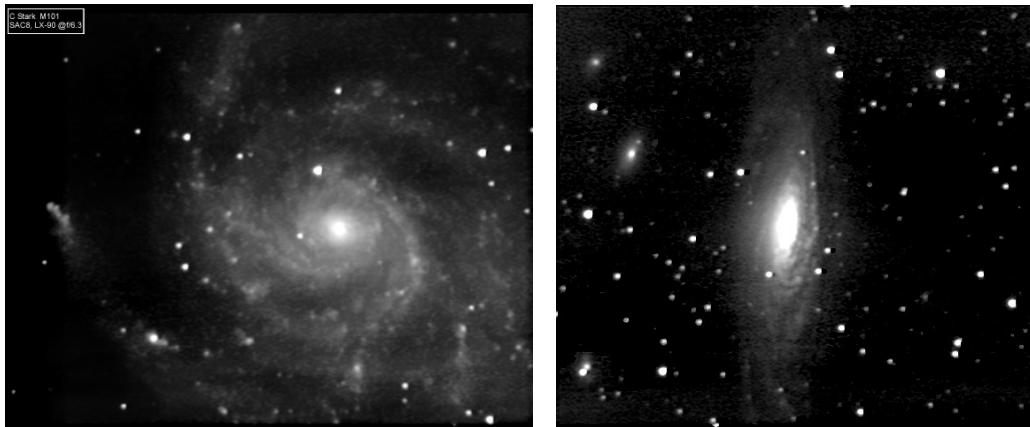
What can you do in 10-30s? A lot. In fact, even running without filters at my mag-6+ dark sky site under moonless skies, skyglow becomes a problem before drift. In low-res mode at f/3, 6 seconds and I'm getting appreciable glow. Move that to high-res mode at f/6 and 30 seconds is all I could ever hope for before skyglow starts to eat up my bit depth. Under my suburban skies, 2 s is often all I can do before skyglow sets in at f/3.

Before this sounds like a bug rather than a feature (2 s is all you can do?), an image of just what you can do in a stack of 2 s exposures (here at f/6 from suburban skies, 8"



SCT, shot in low-res mode). For reference, the magnitude of several nearby stars has been added to the image. Processing is quite basic with nothing fancy (simple linear stretching) only.

Here, the 2 s exposures gives a very nice image and gets you well past mag 15 stars. In the prior image of M57 (under "Ears or Shadows"), remember that 10 s turned the whole nebula into one over-exposed blob, hit mag 18, and showed the faint mag 15 nearby galaxy as well (4s exposures at f/3 are needed to hit IC1296 from my suburban skies). Here's a dimmer target, M101 shot at f/6 as 100 frames of 15 s each and NGC 7331/ 7336, 7335, and 7337 as 70 frames of 15 s each (both low-res again).



In no way should these shots be taken as the best one can do with the SAC8. In fact, both were taken only a few months after I got the camera and these days others are routinely putting better shots than any of mine up on the SAC Users Yahoo Group. They do show, however, just how deep one can begin to go as a result of the SAC8's extreme sensitivity.

As a side-note, I should say that the SAC8's sensitivity comes from two sources. First, by being monochrome and by using the Sony EXview HAD CCD chip, you get a big boost in sensitivity over many CCDs. However, the SAC8 has another trick. It has a "gain knob" on the control box that controls the gain (amount of amplification) of a small preamplifier that sits between the output of the CCD and the analog-to-digital (A/D) converter. The gain knob therefore, can control how much or how little boost the signal off the CCD gets before the signal gets digitized and sent to the computer.

The upside of using the gain knob is that boosts the sensitivity and the SAC8 allows for a lot of gain. The downside of the gain knob is that that amplification introduces some more noise into the image. Technically, that's not quite right, but if you take a 1s exposure at full gain and a 13s exposure at zero gain, you'll have images that are about equally bright but the 1s full-gain shot will have more noise in it. In this way, the shorter-exposure, full-gain shots are noisier than the longer-exposure zero-gain shots. Using this knob lets you control the trade-off between sensitivity and noise in each shot. The great feature is that this noise is nicely uncorrelated from image to image. So, when you stack a large number of sensitive, but noisy images, the noise cancels out and you're left with a clean averaged image. Interestingly, it even turns out that if you equate total imaging time, running full-gain and very short exposures does at least as

well as running without this additional gain and longer exposures. All the while, you're taxing your mount a lot less by using shorter exposures.

The images shown so far have all been monochrome. While this may be considered a limitation of the SAC8, it's actually a plus, in my opinion. Not only do you get a sensitivity boost over one-shot color (if you're not imaging in color), but you also get more flexibility. If you want to make an image that's all based on light from Hydrogen-alpha, or make a tri-color image based on UV, O-III, and IR, you can have all your pixels tuned to those wavelengths (with the appropriate filters, of course) and not have to worry about other filters being in the way (the filters over a color CCD chip). Further, your final resolution in each color will be the true resolution of the CCD chip. One-shot color CCDs have to divide their pixels among three colors, cutting the resolution for each color by a third. On a monochrome CCD like the SAC8, each color (shot through an appropriate color filter) gets the full resolution of the CCD if you so choose. Alternatively, one can shoot a luminance (L) channel at full resolution and color (RGB) channels at low resolution, using the added sensitivity of the low resolution mode to offset the light lost through the color filters. Quite simply, monochrome CCDs allow for more control and more flexibility (at the cost of more difficult processing and the monetary expense of additional filters).

Finally, there has been a lot of interest in "real time video astronomy" and "electronic eyepieces" that allow you to see an image on a computer screen in real time while observing. This sort of thing is very useful for showing groups what the scope is aiming at (i.e., what are we doing standing here in the dark?) When sensitive enough, this sort of thing can even allow one to see fainter details than might be visible through the eyepiece. The SAC8 certainly isn't as easy to setup as an electronic eyepiece, as one needs to hook up a computer, plug in a few cables, and fire up some software to get the SAC8 going. Once done, however, the SAC8 can operate as a nice real-time astronomy device. Using either AstroVideo or K3CCDTools (where it works a bit more smoothly), one can have the camera take a "long exposure", display it on the screen, take another exposure, display, etc. automatically. In the extra-sensitive low-res mode, this loop takes about 1s to complete, plus whatever exposure time you select. That exposure time can, of course, be whatever one selects and is unlimited (unlike traditional electronic eyepieces). In fact, one can even set it up to automatically correct for hot pixels and the flat field on the fly and even align multiple frames and stack on the fly. The net result is a near real-time view that can show a lot more detail in those faint fuzzies.

## Conclusions

The SAC8 is an exceptional value. For \$539, you get an extremely sensitive, low-noise, cooled monochrome CCD camera. The objects I grew up seeing shots of in the back of popular magazines are within my reach with the SAC8. Not only is the camera sensitive enough to pick up really faint fuzzies, but it's sensitive enough to do it with exposure durations I can actually manage with my mounts – something that never seemed to be the case using a digital camera (and one capable of 30-60s exposures) or a long-exposure modified webcam. It's not without a few quirks, but processing steps that fix

most of the quirks seemingly perfectly are painless. The 8-bit limitation is problematic, but not as problematic as one might believe. Many objects work reasonably well in 8-bit raw images and those that don't can have a final image composed of multiple exposure durations that do a good job of adding real bits to the image.

Knowing all that I know about the SAC8 now, would I buy it again? No question, I would. If given the choice between free use of the SAC8 and the more expensive StellaCam (which I've used) or Starlight Xpress MX-512 (which I admit I haven't used personally), what would I pick? The SAC8 without hesitation. At this point in the hobby, I could certainly justify buying an SBIG ST-7XME or a Starlight Xpress MX-716 / MX-916 as an upgrade, having "gotten my feet wet" with the SAC8. These are all excellent cameras that I would be proud to own and use, but I'm having way too much fun with the SAC8 and know I haven't gotten the best shots I can get out of it.

As a parting shot so to speak, I'll include two pictures, each worth more than the 4,000 words in this review. I surely wish either were mine, but they're not. The first is by Stephen Hamilton and the second by Michael Garvin and both represent some of what others have been able to do with the SAC8.



Rosette Nebula in H-alpha, captured on a SAC-8 and an 8" SCT. Image by Stephen Hamilton.

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M16: Eagle Nebula  
H-a, O-III, and H-b false  
color  
SAC8 and 8" SCT  
Image by Michael Garvin

