AstroPhoto Insight Magazine
www.astrophotoinsight.com

Guider Roundup

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Introduction
One of the side effects of writing PHD Guiding is that I get a lot of guide cameras sent to me so that I can include them in PHD. Most of the time, the only photons these cameras see are those that are bouncing off of my ceiling or off of something near my desk. So, when people ask me how well a certain camera works for guiding, I'm not able to say a heck of a lot other than to take an educated guess based off of the sensor and what I saw in quick test shots. This doesn't make for a very satisfying answer and after giving this answer a few dozen times, I felt it was time to address this and say something a bit more constructive.

What Makes a Good Guider?
If I had to design a guider, it would have the following properties. First, it would use a monochrome sensor with a decent size and QE (quantum efficiency). It would also be capable of exposures of a few seconds without a ton of noise. Finding a guide star can be a challenge and the more sensitive, bigger, and less noisy your camera is, the more guide stars you can find. Next, it would be in a lightweight package so that it's not stressing the guide scope's focuser. Flex throws a wrench into anyone's attempt to accurately guide and one place I've hit it often is in the guide scope's focuser. The heavier the camera, the more leverage it puts on the focuser, making lighter cameras a real plus. Next, it would have an ST-4 output so that I could be assured of getting the guide signals out to my mount. Guiding via the serial port either directly or via ASCOM works for many mounts but not all and sharing the serial port connection between programs is sometimes a challenge even if this way of guiding works well. The ST-4 / autoguide port bypasses both of these issues. Finally, ideally, it wouldn't cost an arm and a leg. I'm perennially cheap and at first blush can't see spending vast sums of money on a guide camera.

The Contenders
On the table here are 9 cameras, all of which can be considered good guide cameras. All are capable of several second-long exposures and all but one use monochrome sensors. They range in price from under $250 for the Opticstar PL-130M and Orion Autoguider to about $800 for the Starlight Xpress Lodestar and to about $1400 for the Meade DSI III Pro. Here they are in alphabetical order:

Atik 16-IC: The Atik 16-IC was reviewed here (volume 3, issue 7) last year. It uses a Sony ¼" ICX424AL monochrome CCD sensor and sports a full 16-bit ADC, T-mount and 1.25" mounting options, and an onboard ST-4 output. It is the only one here that also sports TEC to cool the CCD. Current street price is about $650.

Top row: Meade DSI III, DSI III Pro, DSI II Pro, and Atik 16 IC (note: production units are black)
Bottom row: Orion guider, TIS DMK 31, Opticstar PL-130, Starlight Xpress Lodestar, Fishcamp Starfish
25 mm Plossl shown for size

Fishcamp Starfish: The Fishcamp Starfish has been my go-to guider for some time now and was reviewed here alongside the CCD Labs QGuider last year (volume 3, issue 4). The version tested here is the $700 uncooled version (a TEC-cooled option is available). It uses the ½" Micron MT9M001 monochrome CMOS sensor and sports a host of onboard processing to clean up the full 10 bits per pixel possible with the sensor (the other cameras using this sensor here use only 8 bits). It has ST-4 output, an RS-232 serial port, and LED status indicators. Mounting options include both T-mount and 1.25".

Meade DSI II Pro, III, and III Pro: The Meade DSI series is a perennial favorite with a loyal following. A lot of DSI users have picked up newer cameras (e.g., a DSI III) and turned their old DSIs into guiders. Unfortunately, I did not have one of the original DSI (color) or DSI Pro (monochrome) cameras here for the star tests. Although discontinued and not available new, these represent a solid choice for guide cameras on the used market. Tested here are a DSI II Pro (monochrome) and color and monochrome versions of the DSI III series. The DSI II Pro uses the tried-and-true Sony ICX429-AL sensor and the DSI III series uses the excellent Sony ICX-285 sensor. All use 16-bit ADCs and have T-mount and 1.25" mounting options, but none have ST-4 output. The DSI II Pro currently goes for about $650 whereas the DSI III series goes for about $1400. Few would consider the DSI III series for a guide camera, but I had them here and felt it would be of interest to see what $1400 would do for guiding.

Opticstar PL-130: The Opticstar PL-130 comes in two versions, the PL-130 and AG-130 with the latter bundling a ShoeString GPUSB adapter to provide ST-4 output. Both use the same camera head with a Micron MT9M001 ½" monochrome CMOS sensor outputting 8-bit data. The camera comes with C-mount, T-mount, and 1.25" mounting options and is very compact and lightweight. Current pricing on the PL-130 is about $230 with the AG-130 going for about $300.

Orion Autoguider: The Orion Starshoot Autoguider was reviewed here (volume 3, issue 4) in its CCD Labs QGuider form. It also goes by several other names from various vendors (e.g., QHY5, MagZero MZ-5m, etc.) and it also uses a Micron MT9M001 ½" monochrome CMOS sensor with an 8-bit ADC. Like the Opticstar, this is a very compact and lightweight unit. The Orion also has an ST-4 output and has a current street price of about $250.

Starlight Xpress Lodestar: The Lodestar uses a 1/3" Sony ICX429-AL sensor (the same sensor as in the DSI II Pro) mounted in a unique case. The case is a 1.25" tube making the camera look a lot like a basic eyepiece and it weighs very little. In addition to mounting in a standard 1.25" drawtube, it has C-mount threads. Despite its diminutive size, it sports a full 16-bit ADC and an ST-4 output. Current pricing on the Lodestar is about $800.

The Imaging Source DMK-31AF: The Imaging Source sells a range of cameras using Sony CCD sensors. These have been very popular for lunar and planetary work in both the monochrome (DMK) and color (DMF or DBK) versions. All of the cameras are compact units and use the C-mount standard. The DMK-31AF here uses a 1/3" Sony ICX204AL monochrome CCD and costs about $630.

Guiding Accuracy vs. Star SNR

Modern guide software is capable of determining where a star is to a small fraction of a pixel. The ability to do "sub-pixel guiding" rests on the ability to look at a star's light as it is spread over a set of pixels and determine from the spreading of the light just where the center of the star is. The figure here shows how this works. On the left, we have an example of a star (red circle) that is centered exactly at the intersection of four pixels. The light from the star is then evenly balanced across the four pixels. If this star moves a fraction of a pixel to the right (middle panel), more of the star's light hits the two pixels on the right and they are brighter as a result. Since the star is evenly centered up-down here, the upper-left and lower-left pixels are the same brightness and the upper-right and lower-right pixels are the same brightness. If the star moves a bit down now, its light is disproportionately hitting the lower-right pixel and avoiding the upper-left pixel.

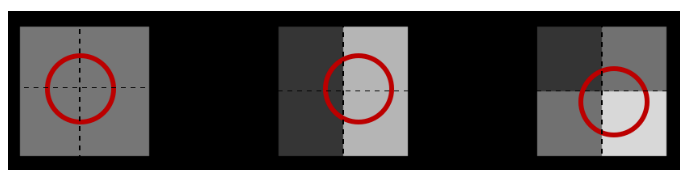


Figure 1

By looking at how the star's light hits a patch of pixels and using logic like this, we can determine where the center of the star is to a fraction of a pixel. In practice, we use more than a 2x2 patch of the array, of course and we don't just look at "brighter" and "darker". The most common method of doing this is to find the star's "centroid" or "center of mass". Done well, this can accurately determine the star's location, but it does rely on a few things. First, it relies on the star's light being spread over a number of pixels. This isn't usually a problem, but if you have very large pixels and a very short focal length guide scope and you focus perfectly, you'll be in trouble. (If you run such a setup, defocus a bit). Second, it relies on the star having a clean profile. In particular, the star should not be clipped (saturated). If the

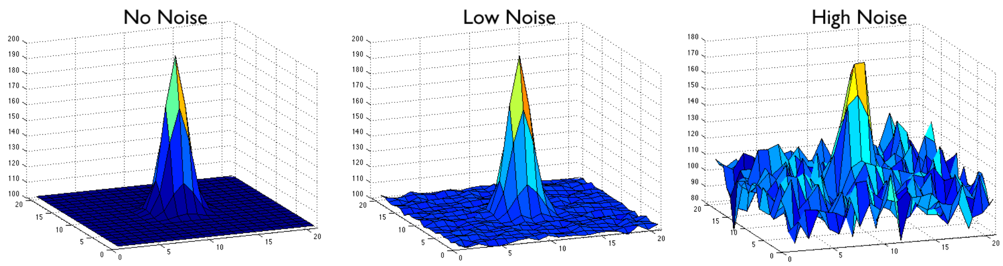


Figure 2

middle 4x4 grid around the star has pixels that all report 65,535 (the maximum intensity in a 16-bit camera), you're not going to be able to know exactly where the star is. By saturating the star, you've lost a lot of valuable information. Finally, accurate estimation of the star's location depends on having a decent signal to noise ratio for the star. If your guide star is just barely poking out from the background noise, you'll have a tougher time figuring this center of mass accurately.

To give an idea of how much this affects guiding, I created several synthetic star-field images using Matlab. Each image contained 400 "stars" displaced by known, small fractions of a pixel in both directions. Each image was degraded by one of three levels of Gaussian noise: none, low, and high. The "low" and "high" noise levels were estimated from the SNR of the test star taken from two different cameras in the results described below, so that we might draw rough conclusions on how these cameras' images might affect guiding accuracy. In Figure 2, we have 3D profiles of sample stars in each noise condition (stars having no shift in either direction). Intensity in these plots is "up".

These arrays of simulated, slightly shifted stars were passed into *PHD Guiding* (version 1.8.5) and it was used to estimate the stars' centroids. The mean difference between PHD's reported position and the true position built into the image was measured. This way, we can see how much the presence of noise affects the accuracy of the star localization routine.

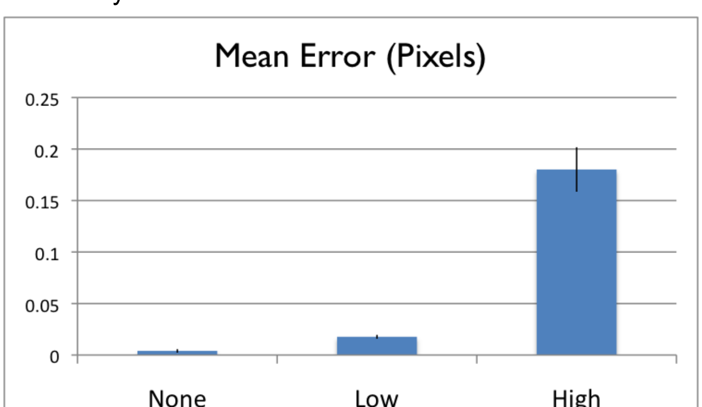


Figure 3

With no noise in the image, *PHD Guiding* had an average error of 0.004 pixels (1/250th of a pixel). This represents the highest level of accuracy possible given the internal precision of *PHD's* calculations and the quantization of our simulated star's intensity. With small amounts of noise, comparable to the best camera in the tests, PHD Guiding had an average error of 0.0177 pixels (1/56th of a pixel) and with the high level of noise it had an average error of 0.18 pixels (1/5.5th of a pixel).

Thus, the star's SNR certainly affects our guiding accuracy. However, one should note that even with quite noisy stars, guiding software can still locate the star's position to a fraction of a pixel.

Test Protocol

There is no absolute answer to the basic question, "How deep can I go with this guide camera?" as this will be affected by your guide scope, your light pollution, the guide image's exposure duration (which will be affected by both of the above and by your mount's accuracy and your imaging scale), the ambient temperature, etc. What we can say is how well the cameras perform relative to each other. Shown here are the results of imaging the same target through the same scope from the same location with the same duration using each of the guide cameras at hand. While ideally this would be done on the same night, a few technical difficulties got in the way and I had to spread the test images over two nights. I collected data from one camera, the Starlight Xpress Lodestar on both nights to serve as a stable reference and help ameliorate this problem.

I used as a test rig my Celestron CPC 1100XLT with a 0.63x reducer aimed at M3. The tests were done in my suburban locale in Irvine, CA (not too far from both Meade and Celestron's headquarters). Each camera was placed with its focal plane in roughly the same location as all of the other cameras and fine focused. A series of three exposures at typical guide durations of 1 second (left images) and three at 2 seconds (right images) were taken. For the DSI III cameras, images were taken with the onboard amplifier either on during the exposure (which induces some amp glow in longer exposures) or off. The best guide frame from each set was chosen and linear stretching in Nebulosity and PhotoShop was done to equate the histograms across images. Images were rotated 90 or 180 degrees to bring them into near alignment and cropped to show the same portion of M3.

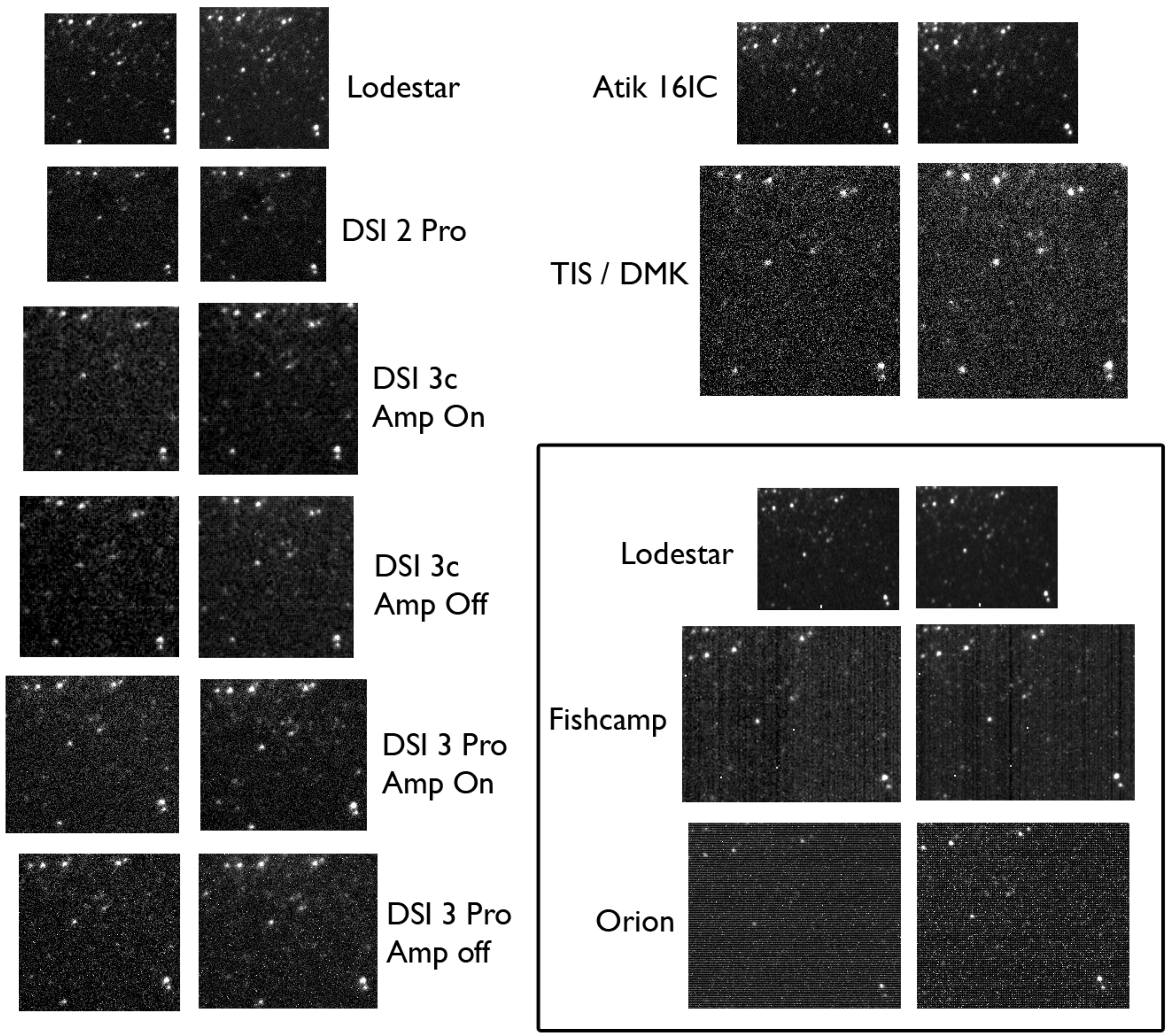
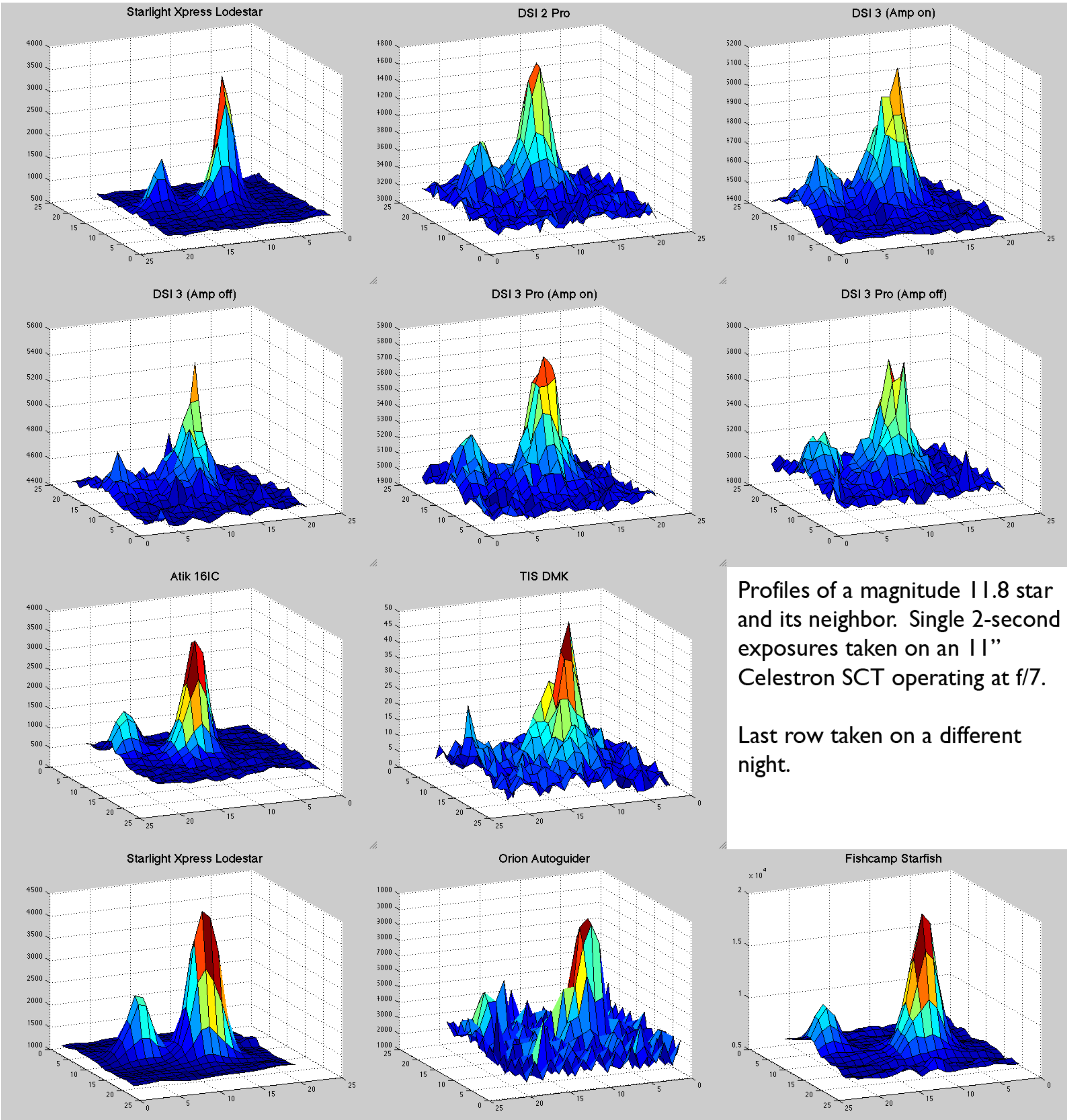


Figure 4

Visual Inspection of Guide Frames

Visual inspection showed the Starlight Xpress Lodestar produced the cleanest, deepest images. When I was starting out in this hobby, I would have been excited to have a final image that looked as good as the two second frame the camera produced. The bulk of M3 isn't shown in these crops but it really looked wonderful on the screen and were I looking for something simple to toss in a bag and show "real time" views with, this would have to be a contender.

Next up and not far behind at all was the Atik 16IC, the only cooled camera in the round-up. It too put up a wonderful image of M3. At these very short exposure durations its amplifier control isn't enabled and there was a slight glow in the upper-left corner but this in no way would affect its use as a guide camera. At longer exposure durations, the amplifier is turned off and the camera produces an excellent image. Behind this and not too far back was the Fishcamp Starfish. The Starfish resolved almost as many stars in the halo of M3 as the Atik did but had a bit more noise in the form of fine horizontal lines (that are vertical in the image shown here as the frame was rotated 90 degrees).



Profiles of a magnitude 11.8 star and its neighbor. Single 2-second exposures taken on an 11" Celestron SCT operating at f/7.

Last row taken on a different night.

Figure 5

Next up were the monochrome "Pro" versions of the Meade DSIs. Both the DSI II Pro and III Pro were free of artifacts but didn't resolve quite as many stars as the top three cameras. I've used a DSI II Pro myself on a few outings and had no issues at all as it serves very well as a guider. The DSI III with its color filters over the chip came in behind the two monochrome counterparts showing fewer stars still owing to the lower SNR that results from these filters (each pixel has roughly a third as much light hitting it).

Coming in just behind or perhaps tied with the color DSI III was the The Imaging Source DMK 31AF. The image intensity here is quite low and the 8-bit data format, very small pixels, and design aimed for speed (this is really meant for lunar / planetary work) are likely sources of why the camera didn't pull in as many stars as the others. The Orion Autoguider came in next putting up fewer stars still.

One item worth noting is that the Opticstar PL-130's results are not shown here. The reason why comes down to a few factors, one of which was entirely out of the camera's control. Technical difficulties prevented it from being tested the first night and on the second night it was tested last. In the test, it showed no image of M3 at all. Before anyone dismisses the camera, it is not that the camera is less sensitive than the others, at least than those that use the same Micron chip. Rather, it is that the designers have set the offset and gain such that it will provide a clean image when it provides an image. But, very low signals will get cut off and given the value of 0 rather than small, nearly-random numbers. On brighter guide stars, the camera gave a nicely clean image that could be easily guided off of. On this faint target however, the signal was cut off. Had this camera been chosen at the outset, I would probably have ended up on a brighter target. The net result would have been a perfectly even background of zeros with brighter stars poking through to guide off of.

Star Profiles

We can also get a feel for what a guiding package has to work on by looking at the profiles of stars. In these plots, height (and color) represent the intensity of the star and noise in a small area of the image. Here, a magnitude 11.8 star (and a fainter neighbor) were cropped from each camera's two-second frame (crop centered on the star +/- 10 pixels) and the 3D profile plotted. We can use these to evaluate the SNR and to compare to the simulated star images used to test PHD Guiding's accuracy above.

Conclusions

What can we conclude from these results?

First, it should be noted that all of the above cameras produced images that had stars one could easily guide on. We should not loose sight of this fact. Even the Orion Autoguider that came in last place here in image quality had a number of stars in the field that one could easily guide on. One should not dismiss this as a guide camera option as the goal of a guide camera is to get you a star to guide on. Although there were fewer to choose from with the Orion and they were lower in their SNR, they were there, the camera is affordable, it has an ST-4 output, and it is lightweight. Likewise, the DMK 31AF wasn't a stand-out winner in this test but it had plenty of stars to guide on and if the rules were changed to assess the ability to serve as a lunar / planetary camera as well and not be relegated only to guider duty, the rankings here would surely change. I should note here as well that there are also plenty of other cameras I could have tossed into the mix here that wouldn't have done as well as any of these (e.g., any color webcam).

That said, we can also conclude that the cameras clearly differ from each other, even when the imaging chip is the same. The Starlight Xpress Lodestar produced the cleanest images of the lot that were markedly nicer than the DSI II Pro that shares the same chip. Likewise, the Fishcamp Starfish produced better images than the Orion Autoguider or Opticstar PL-130 that use the same chip. The chip is one component of the system, but not the only one. The electronics behind the chip matter.

Third, we can also conclude that while the best performing cameras were more expensive than the lowest, there isn't a perfect correlation here. The Atik 16IC did a great job and is a fantastic choice even if one ignores the fact that it costs less than a lot of the competition. We don't often entirely discount cost.

Fourth, we should not loose sight of the fact that signal to noise is the name of the game. Guiding accuracy is affected by the star's SNR and that SNR is affected by a number of factors. You can get that SNR by using a cleaner camera, by choosing a brighter star, or by exposing longer on that same star. If your guide camera can't do that mag-11 star in 1 second, choose something brighter or expose longer. You'll get a better SNR and better guiding. If you're routinely hitting problems with this (e.g., you're using an off-axis guider and are very constrained in your choice of stars) step up to a higher SNR (lower noise) camera.

Finally, tying these together, there is no one-size-fits-all answer to the question "What guide camera should I choose?" If you've got any one of these and it's working for you, the answer is probably to stick with what you have. If it's not working for you or you don't have one already, I hope that these data can help guide your decision. Any of these will work and let you guide. If the budget is tight, something like the Orion Autoguider is a great choice. If nothing but the best will do, the Lodestar may be your camera. If you're in the market for a good lunar / planetary camera that can stream frames blisteringly fast, the The Imaging Source may be your ticket. The upshot is that differences do exist between guide cameras but amongst the models presented here, you can let other constraints you may have enter into the equation when figuring out which one to buy. ♦

By day, Craig Stark, Ph.D. is a professor whose research involves trying to pull faint signals out of noisy, moving images of people's brains. By night, he is an amateur astrophotographer and operates Stark Labs. Stark Labs provides software to help users pull faint signals out of noisy, moving images of the heavens.
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