

# SBIG Astronomical Instruments

## Memo

### The Capabilities of the ST-7XEI and ST-9XEI Series Cameras

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SBIG has recently announced new low prices for USB based ST-7XEI and ST-9XEI cameras. Our intent here is to make quality, scientific grade sensors available at minimal cost. Before in an application note I discussed the importance of self guiding, but I have since realized that several types of observations, mostly neglected by amateurs, do not require critical guiding. The beauty of these types of observations is that not only can the CCD camera be less expensive, but also the telescope. These days telescopes of substantial aperture are really quite inexpensive, but a good, high quality mount is not. In this memo I discuss these types of observations, and show some results I have obtained from my backyard sea level site, where the Milky Way is just barely detectable on a good night. You will be amazed at what is possible!

#### TDI Techniques – Turn off the Guiding!

Professional astronomers performing sky surveys or asteroid searches often build instruments that employ time delay integration (TDI) with a CCD. This powerful technique is not only gives good results, but it can be done with a very simple telescope system. In essence, the telescope is fixed, and as the stars drift across the CCD the CCD is clocked at exactly the right rate to keep the accumulating charge underneath the star's image until the star reaches the edge of the CCD, and the readout register. An SBIG user, Christoph Flohr, has written a very capable program for doing this kind of imaging with SBIG cameras, particularly the ST-7/8/9/10 series. The program can be downloaded for free from [www.driftscan.com](http://www.driftscan.com).

Figure One shows a large mosaic image to illustrate this technique. The data was captured from my suburban back yard here in Santa Barbara. I used an ST-7XEI, uncooled, on an 8 inch F/4 Newtonian tube assembly I bought from Hardin Optical for \$300. The mount was a Losmandy G11. Data is collected with the mount turned off. I would find the starting point with the drive running, turn off the mount right when I started collecting the data, and 26 minutes later increment the declination position manually by 0.33 degree and shift the telescope by 30 minutes (to an earlier setting) in right ascension. At the 30 minute mark I would start the next 26 minute swipe. I collected 9 swipes, each with 765 x 7500 pixels of data, in each data set. I had to do this over two nights. The data was assembled in Photoshop and cropped and manually touched up to get rid of the diffraction spikes and "tails". When a bright star passes over the CCD it leaves a little residual charge that leaks out over the next few seconds, leaving a tail. If I cooled the CCD the tail would be less prominent, but also longer. I didn't cool the CCD just to prove a point with others here at SBIG that it is less important with TDI

imaging, since the hot pixels are averaged over the entire height of the CCD. The Kodak full frame devices are quite low in dark current. I used a red filter over the CCD to reduce my considerable light pollution. The final cropped imaged shown was assembled from 45 megapixels of data!

Figure One: Mosaic of TDI images of the North American Nebula: ST-7EI  
(Captured without cooling, dark frames, flat fields, or clock drive, using a \$300 optical system)



One has to accurately align the columns of the CCD with the drift of the star to get good star images. I would drive the system back in forth in RA while taking a 10 second exposure, and then tweak the camera rotation to get vertically streaked stars to within a pixel. I rotated the camera by loosening the setscrew, rotating the camera, and retightening the screw – nothing fancy. This task is comparable in difficulty to focusing the camera. If one has an equatorial mount, you only have to do this alignment once. SBIG now has a precision camera rotator to facilitate this task.

With my telescope and CCD, the drift time for a star to cross the CCD was about 120 seconds. When one is not on the celestial equator, the stars follow a curved path, and you can get some elongation at the edges of the field of view. At the 45 degree declination of the North American Nebula this effect is a few pixels at the edges.

The choice of a telescope is actually a complicated tradeoff. In Table One below I have tabulated the resolution, elevation field of view, maximum exposure time at the celestial equator, limiting magnitude, and image smear at +/- 60 degrees declination due to the TDI drift rate varying with declination angle. An F/4 optical system is assumed. Longer focal lengths have better resolution and less image smear, but at the expense of field of view. Note that since longer focal lengths result in shorter exposure times, sensitivity to starlight only increase linearly with aperture. The volume and cost of the optics and mechanics tend to scale with the cube of the aperture, though, compelling one to favor shorter focal lengths. However, short focal lengths will have more elongation due to differential velocity at the edges of the field of view. This effect varies as the tangent of the declination being viewed, so it will be only 58% of the tabulated value at 45 degrees declination. The 8 inch F/4 Newtonian is a good choice with an ST-7XEI.

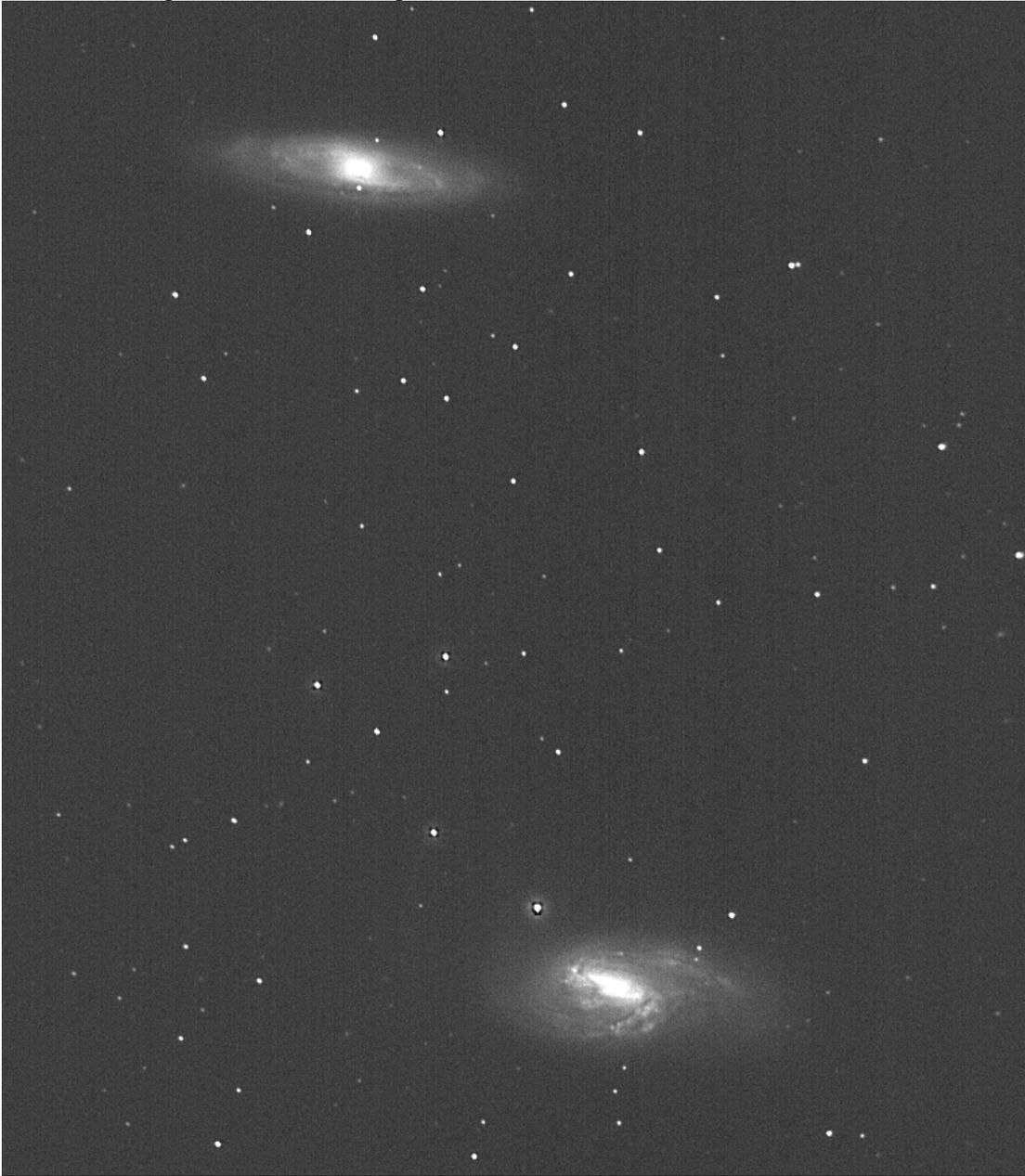
Table One: ST-7 TDI Tradeoffs with Focal Length

Focal Length (mm); F/4 System	Field of View in Elevation (minutes of arc)	Exposure Time (Seconds)	Resolution (angular width, 2 pixels, in arcseconds)	Limiting Magnitude, Unfiltered	Smear at edge of Field of View, Pixels (60 deg Dec)
400	59.2	158	9.27	17.2 (est)	7.6
500	47.3	126	7.42		6.1
600	39.4	105	6.18	17.5 (est)	5.1
700	33.8	90	5.30		4.3
800	29.6	79	4.64	18.0 (Meas.)	3.8
900	26.3	70	4.12		3.4
1000	23.7	63	3.71	18.2 (est)	3.0

With my images, the lack of cooling caused the hot pixels to form hot streaks in the image. SBIG has a utility in CCDOPS, called FIX UNCOOLED TDI IMAGE, that corrects this line-to-line offset nicely. I also had one image that showed a 30 count variation in sky brightness from side to side (I have no idea why, the images before and after were fine). Matt Longmire added another utility to CCDOPS that adds a wedge to one's image data to flatten this out.

In Figure Two I show an image of M65 and M66 captured using a Celestron 8 inch SCT. I used our FR-4 focal reducer to get the F/number down to around F/5 for a wider field of view. It is amazing how much detail can be captured in a single 56 second pass of the scene across the CCD.

Figure Two: TDI Image of M65 and M66 with an ST-7EI and a C8



I encourage everyone to experiment with this technique. I hope my example of what can be done with no cooling, no clock drive, no dark subtraction, no flat field, and a very modest optical system encourages others to try this out! The technique is great for huge mosaics, asteroid hunting, and for users with inexpensive mounts. The ST-9EI is even better for this technique, since the larger device results in longer transit times across the CCD, increasing the exposure. Below I show an ST-9EI strip captured showing NGC7331. Huge portions of the sky can be imaged! The small scale below simply does not do the image justice.



### Real Science: Exo-Solar Planet Detection from your BackYard!

Another field of study where accurate guiding is not that important is photometry. This may come as a shock to some, but for photometry of brighter objects a little wander of the star image is a good thing, as it averages out sub-pixel, and pixel-to-pixel variations that would otherwise limit the data accuracy. Also, for brighter objects short exposures are desired since otherwise the stars saturate, and data accuracy is degraded. Brighter is a relative term here. CCD cameras have such great sensitivity that exposures of only 30 seconds are adequate for stars down to 14<sup>th</sup> or 15<sup>th</sup> magnitude with an 8 inch scope. As a result, many objects can be studied by taking a long series of unguided (but with a clock drive running) 10 to 30 second exposures. Guiding is used to bring the star back to the starting point occasionally, but the guide information is derived from the image data from the imaging CCD. Guide stars are very easy to find under these conditions. What can you do with bright star photometry? You can find planets around distant stars!

### Detecting Extra-Solar Planets by Timing Eclipsing Binaries

Laurance Doyle (SETI Institute) has pioneered a new technique for detecting planets around eclipsing binaries. An eclipsing binary is a pair of stars orbiting each other so closely that their atmospheres are in contact, and have periods ranging from a few hours to a day or two. The timing of mid-eclipse can be measured to a matter of a few seconds. If a planet is orbiting the combined system it will shift the center of mass of the binaries back and forth as it orbits, and the additional light travel time can be measured. What one will see after years of measurement is a cyclically varying variation in the time of mid eclipse. The technique is quite sensitive, and has the potential to detect earth-sized planets. However, one does not have to spend years observing the star since the individual cycles are only a matter of hours, and observations from multiple amateurs are easily coordinated if all have accurate timing. Russell Genet is quite active in measuring eclipsing binaries, and is eager to coordinate the activities of individual amateurs. He can be reached at [russmgenet@aol.com](mailto:russmgenet@aol.com). Russell is well known due to his book on Microprocessor Control of Small Telescopes.

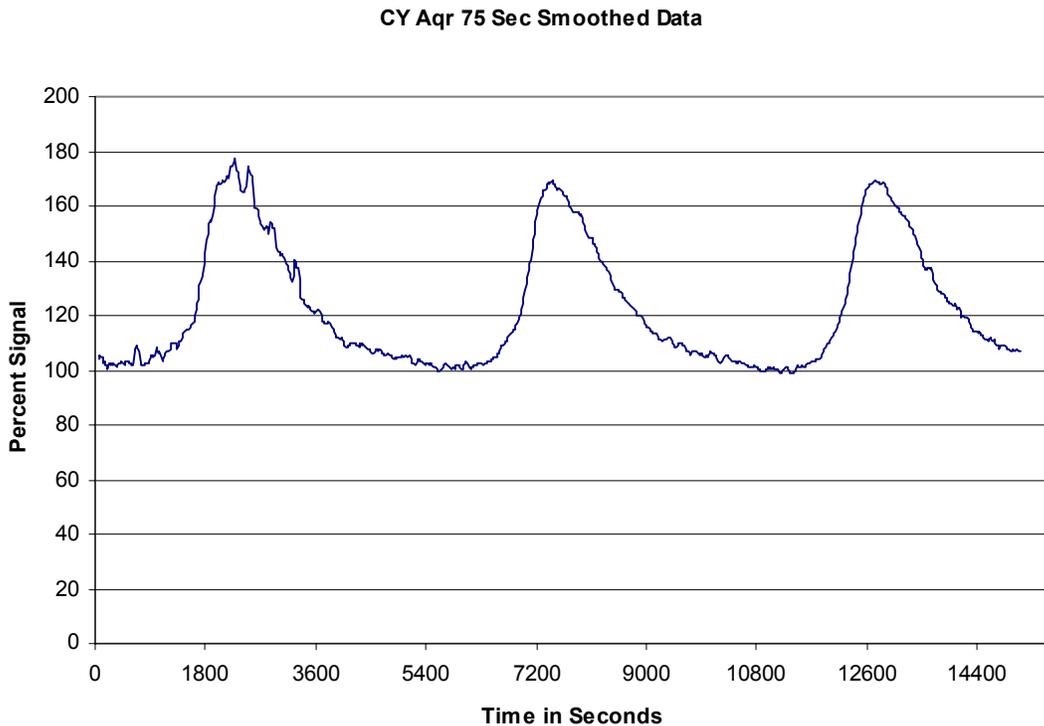
To illustrate this technique I used an ST-7XEI to monitor CY Aquarii one night for a few hours, once again with my \$300 8 inch F/4 Newtonian. I love it – I think its Chinese made, but the quality is good, the optics are fine and the steel tube means I didn't have to refocus for a month. I used a G11 mount from Losmandy, which has also given me years of good performance. Below I show the star field including CY AQR. It is the brightest star near the upper right edge in this 15 second exposure.

Figure Four: CY Aquarii Field



Figure Five shows the brightness fluctuations of this star. It varies by 70% every 88 minutes, which is very fast. I captured three cycles in one evening by midnight. While it is not an eclipsing binary, it makes my point that there are objects in the sky that vary quite fast. This star increases 30% in brightness in only 4 minutes right before maximum. You can see it changing on the computer screen. At minimum it is around magnitude 11.2. Also, you don't need photometric filters. I used a red filter to minimize light pollution and atmospheric variation as the star rose in the sky, but what is really important here are the times of minima, and the period. This is a relative measurement, derived by comparing the star brightness with nearby stars. The data shown is derived from 800 frames captured automatically by MilliMag, a new SBIG program that makes this type of data collection very easy. It will be described further on our web site when it becomes available.

Figure Five: CY AQR Light Curve



### Detecting Extra-Solar Planets by Observing a Transit

Tim Castellano of NASA-AMES is seeking amateur participation in a project to detect planets orbiting other stars by looking for the reduction of the star's brightness when the planet passes in front of the star. So far I know of 4 separate groups of amateurs who have successfully measured the 1.7% drop in brightness of HD209458 using commonly available equipment (including me). Other stars are suspected of harboring planets based on radial velocity measurements but no other eclipsing planets have yet been detected. SBIG's MilliMag software simplifies and automates this photometric measurement specifically for the ST-7XEI or ST-9XEI, achieving a relative brightness measurement accuracy of 2 millimagnitudes per 5 minute interval with an 8 inch F/4 scope. For more information please visit [www.transitsearch.org](http://www.transitsearch.org), or contact Tim ([tcastellano@mail.arc.nasa.gov](mailto:tcastellano@mail.arc.nasa.gov)).

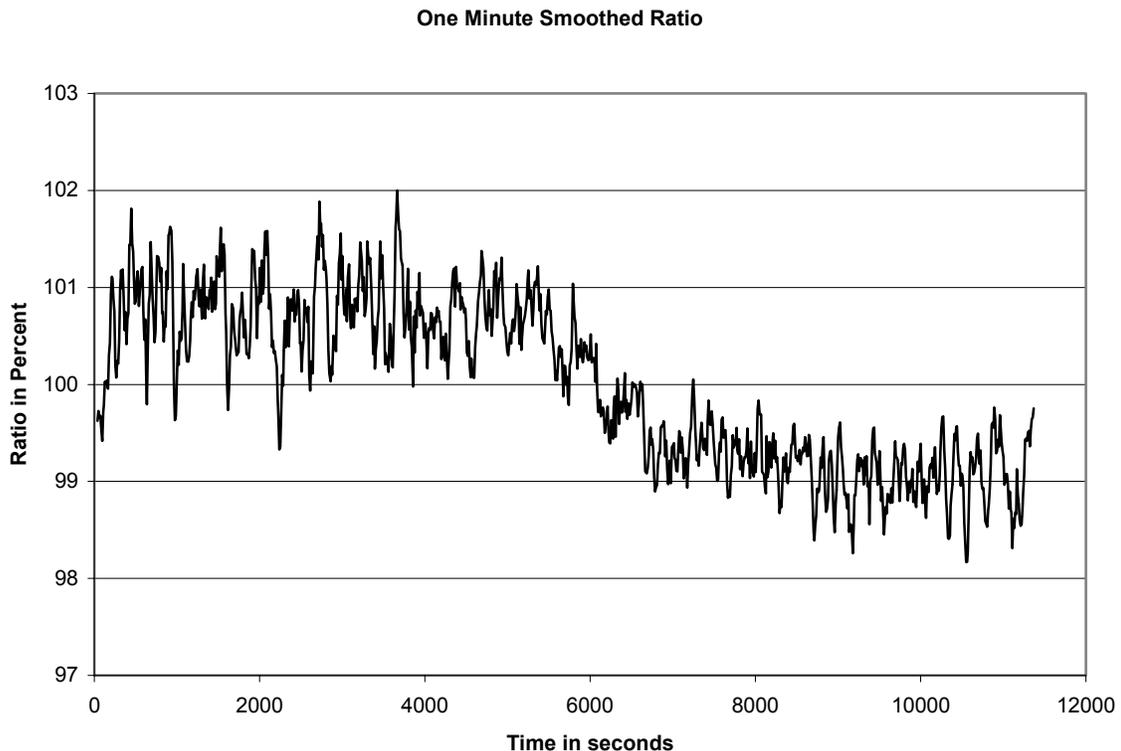
My measurement of this object is illustrative of what can be achieved. The star field including HD209458 is shown below in Figure Six. Once again, an unremarkable star, below the center (the brightest one), is the one most conclusively proven to show planet transits in the sky.

Figure Six: HD209458 Star Field – 7.5 Second Exposure



I was able to capture the beginning of a transit as the planet starts to partially block the starlight, as shown below in Figure Seven. The noise in this type of observation is mostly due to the twinkling of starlight, still an effect even with an 8 inch aperture. Averaging over a minute's worth of observations helps. Over 1000 frames of data were collected for this graph. The total obscuration is only 1.7%, so this is a tough observation.

Figure Seven – Drop in Brightness as Planet passes before Star



There is a common thread to the photometric research opportunities detailed above. All involve sitting on an object for hours with a telescope looking for a brightness change. This type of research is very difficult for the major observatories, since it ties up so much equipment and staff, night after night. It is also difficult for NASA, for the same reasons.

Another common thread to these opportunities is that in all cases the events that are being monitored are only hours long. In the case of transits and eclipsing binaries, the stars are bright, and location and detection of the object is easy with an 8 inch (20 cm) telescope. One does not need long spells of clear weather to gather useful data. Also, our free MilliMag program does most of the data analysis for you!

In this day and age, when automated professional instruments are sweeping up asteroids, and checking thousands of galaxies for supernovae every night, it is heartening to find that there are still arenas where the amateur can contribute. These opportunities summarized here are also easiest for the amateur since his equipment can run with little attention. Finding planets around other star systems! This is significant research! Five years ago humans speculated whether or not there were planets around other star systems, and now amateurs with a \$1000 telescope and a \$1495 CCD camera can prove that there are!

Many other photometric observation opportunities can be pursued with an ST-7XEI or ST-9XEI. An interesting one is measuring asteroid rotation rates. Brian Warner

([www.MinorPlanetObserver.com](http://www.MinorPlanetObserver.com)) and Robert Stephens have spearheaded amateur involvement in determining rotation rates of asteroids based on measurements of their brightness as they tumble. The rotation rate is quite often only a few hours, enabling an amateur to get a preliminary determination in a single night. Follow up observations can pin down the rotation rate to high accuracy, and measurements of the asteroid over a period of time can reveal the orientation of its rotation axis as the earth-sun-asteroid geometry changes. Once again, this is a straightforward relative measurement not requiring photometric filters or a sophisticated setup. For more information please contact Brian ([brian@MinorPlanetObserver.com](mailto:brian@MinorPlanetObserver.com)). Brian has also written an excellent amateur oriented book describing light curve collect and analysis in general, entitled [A Practical Guide to Lightcurve Photometry and Analysis](#). It details both stellar and asteroid photometry.

SBIG also recommends the interested amateur check out the American Association of Variable Star Observers (AAVSO) web site, as they also welcome new observers. As one of the oldest amateur-professional collaborations around, they have a well developed program to monitor variable stars of all types around the world. They are an excellent source for locator maps and known target stars for verifying one's technique. Their web site can be found at [www.aavso.org](http://www.aavso.org).

#### Of Course, One can also Image the Sky!

This discussion so far has ignored the most obvious use of our cameras, taking images of the night sky. The ST-7EI and ST-9EI will work quite well for that, even with short exposures. As an example, I have some more 8 inch scope images using an ST-7XEI. Figure Eight shows a 10 second image of M13. Figure Nine shows a 4x30 second track and accumulate image of M101. Compare to this to what you see through the eyepiece!

Figure Eight: M13 – 10 Seconds with a ST-7XEI and 8inch F/4 Telescope



Figure Nine: M101 – 4x30 Seconds with an 8 inch F/4 Telescope

