Removing the Affects of Residual Bulk Image (RBI) at the Sierra Stars Observatory

By Rich Williams

I bought one of the very first ProLine PL09000 CCD cameras with the Kodak KAF-09000 CCD chip manufactured by Finger Lakes Instrumentation (FLI) back in October, 2006. The FLI PL09000 had the best large-area, high-quantum efficiency front-illuminated CCD chip to fit the specifications and our needs for our Sierra Stars Observatory 0.61-meter f/10 Classical Cassegrain telescope.

A 6,100mm (6.1 meter!) focal length telescope produces a large image scale, which requires relatively large pixels to achieve a pixel resolution that does not grossly oversample the image data. The pixel size of the KAF-09000 is 12 microns, which gives a pixel resolution of 0.4 arc-seconds. This pixel resolution oversamples even the best of seeing conditions at our site and we bin the pixels 2x2 to achieve an effective pixel resolution of 0.8 arc-seconds. This has the added benefit of quadrupling the effective well depth compared to unbinned pixels.

The KAF-09000 chip has a matrix of 3,056 x 3,056 pixels (1,528 x 1,528 pixels binned 2x2). This big CCD chip is 36.7mm x 36.7mm square and even at the large image scale of the 0.61-meter telescope provides a field of view of over 20 x 20 arc-minutes. The chip's combination of pixel size, area, high-quantum efficiency, and cost made it an ideal choice for our needs at the time and it is in my opinion still the best choice available today.

Another reason for choosing the FLI ProLine camera is that I believe it offered the best cooling in the market. According to the specifications the camera is capable of cooling up to -65C below the ambient temperature depending on the size of the CCD chip. Our camera is consistently capable of maintaining stable temperatures of -60C below the ambient temperature. Also FLI's technician, Jim Moronski, worked closely with us (even evenings and during the weekend!) to develop the *Linux* driver we would need for the camera to work with our observatory control software.

The Discovery of RBI on Images Taken with the SSO Telescope

The FLI camera has very low noise in both bias and thermal calibration frames and together with the excellent flat field technique I developed produces very clean, high-quality data. Even so occasionally I would see strange faint persistent ghosts or "smudges" when greatly stretching images searching for faint asteroids or processing images to bring out the faintest and subtlest details in some object for my image gallery. These affects were intermittent and variable. Because of the care I take in producing the best possible calibration frames I was pretty sure that they were not a cause of the problem. I figured that it must be something inherent in the chip.

My hunch proved to be correct. I read a post by Richard Crisp on the FLI user group forum about his work on Residual

Image 1 is a 60-second image of Vega taken with the Sierra Stars Observatory telescope using the FLI PL09000 camera. Even at the fastest exposure times the camera can take (0.01 seconds) Vega is too bright to image without over exposing.

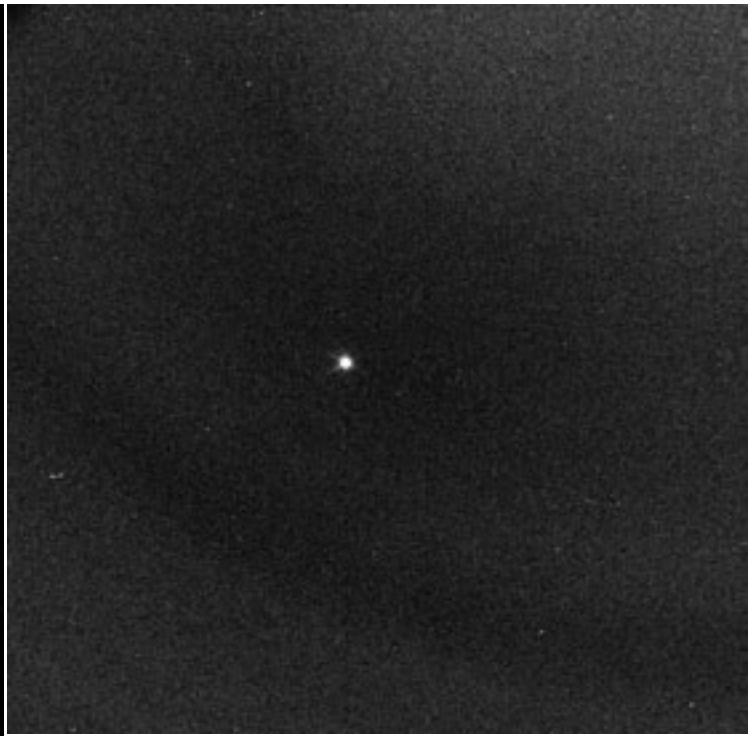

Image 2 is a 60-second dark frame (shutter closed) taken immediately after the image in Image 1. The ghost image of Vega is clearly visible and pronounced. This artifact would appear in some form in subsequently taken images.

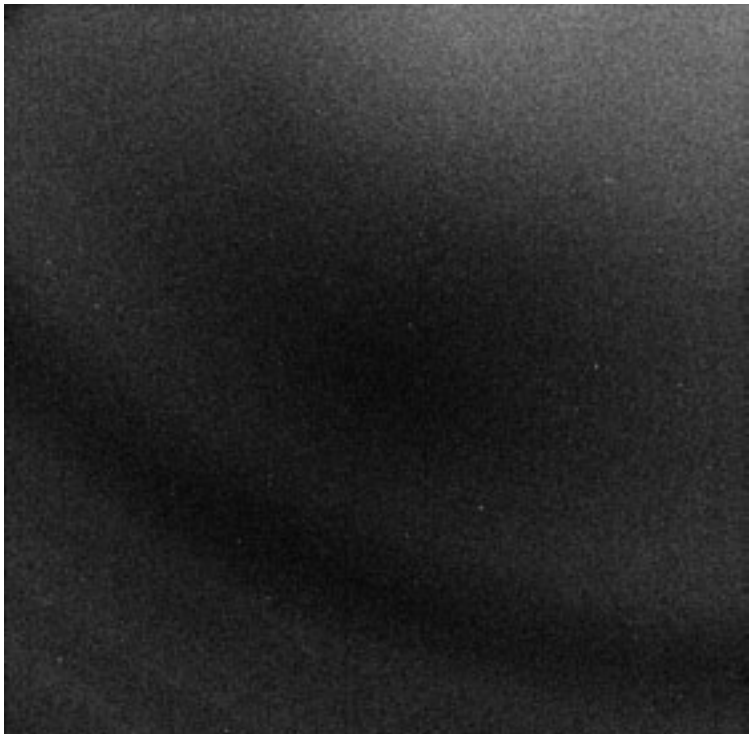

Image 3 is a 60-second dark frame taken immediately after taking another 60-second image of Vega and running the RBIFlush routine before taking the image. The effect of RBI is completely eliminated.

Bulk Image (RBI) affects in CCD chips. He explained that RBI was a characteristic of certain types of the new front-illuminated CCDs – one of which was the KAF-09000 chip. In simple terms an RBI is a ghost image of a bright area of a previously taken image that is carried over and appears in subsequent images. The latent images are caused by electrons trapped in the chip that can take time to "bleed off." The time it takes depends on the temperature of the chip. The cooler the chip the fewer electrons are trapped and the faster they dissipate.

The technical description of what causes RBI is rather longer and is best explained by the references at the end of this article.

The good news is that there is a solution for eliminating RBI. If you flood all of the pixels to their maximum well depth (65k+ ADU for the KAF-09000 chip) with a bright light and then flush the pixels by running one or more bias images, you can completely eliminate the RBI residing in the chip. FLI acted quickly on this information and were one of the first companies to develop a technique to eliminate the RBI affects in their cameras that contain chips susceptible to RBI. Their solution was to add a diode to the cameras to flood the chip with light making some firmware changes to accommodate this change. In addition they created a software routine called *RBIFlush* that sets programmable times for illuminating the diode and for setting the number of bias frames to flush the electrons from the chip.

The compromise for adding this very important feature is that it adds a few to several seconds of time between images. However, the FLI Proline cameras have remarkably fast download times and the overall time with the RBI feature implemented is still faster than many camera's download times for similarly large mega pixel chips.

I bought the SSO ProLine camera before FLI developed the RBI feature and made it a standard feature of their cameras. I called Greg Torrance at FLI in late spring and asked him if we could update our camera to add the RBI capability. He said that yes they could, but it would require me to send in the camera to do the upgrade and that they would turn it around quickly. Because our camera runs on a *Linux*-based control system we also needed to have a new *Linux* driver to run the RBI routine on our system. Once again Jim Moronski at FLI acted quickly and developed and recompiled the *RBIFlush* code to run on *Linux*. Steve Ohmert, who does all the *Linux* programming for SSON projects, developed code to integrate the new *RBIFlush* routine into our observatory control system.

A quick turnaround to upgrade our camera was very important as our observatory would be down during this time. Because the SSON Rigel telescope in the Winer Observatory in southern Arizona is down from late June into early September for the southwestern U.S. monsoon season, this would mean that SSON would not be able to serve its customers while the SSO camera was being retrofitted. My plan was to wait until Rigel was back up and running so at least one of our observatories was avail-

able to our customers for their projects. Up until then no one seems to have noticed or complained about any affects caused by RBI on our SSO telescope so I figured we could wait until Rigel was back in operation to send in the camera.

Then I received an email from Rob Matson asking me about some artifacts/smudges in his recent images he got from schedules he ran on our SSO telescope. Rob uses SSON extensively for his asteroid discovery work. Because our SSO telescope is capable of detecting and getting astrometry data of objects 20+ magnitude in 120-second exposures, he is very successful and has discovered 10 new asteroids in the past several months. I checked his images from the night in question and checked what other images were run before his images ran. I found that before Rob's jobs ran another job in the schedule ran twelve 300-second images of a field with very bright stars, many of which were greatly bloomed. The "smudges" in Rob's images aligned with positions of the brightest stars in the previous images. I knew this was caused from RBI and the repeated exposures reinforced the effect. I emailed Rob to tell him what I found.

Now that RBI was affecting our SSON customers I felt I couldn't wait until September to upgrade the camera. I called Greg at FLI and arranged to send the camera to their shop during the time around the full moon in July when it would least affect our customers. The turnaround time from sending in the camera and getting it back on the telescope was less than a week. The programming work that Jim and Steve did worked flawlessly the first time I tried imaging with the camera on the sky! After running his first jobs on our SSO telescope with the *RBIFlush* routine implemented, Rob emailed me to tell me his data was very clean with no hint of RBI.

Results of Eliminating RBI on the SSO Telescope

The best way to see what a difference eliminating the affects of RBI has on image quality is to compare images (**See Images 1, 2, 3**) of a bright object taken with and without using *RBIFlush*. I used Vega as a test image to clearly demonstrate the effect of RBI. While it is unlikely that anyone will take such long exposures of Vega longer exposures of much dimmer objects can still produce similar RBI ghosts.

For more information about RBI there are several links to point you to more technical information about Residual Bulk Image.

Listed are three here:

1) http://www.narrowbandimaging.com/residual_bulk_image_ccd_orig_page.htm,
2) http://www.ptbmagazine.com/features/2009/feat1_0409.html
3) http://www.physics.pdx.edu/~d4eb/ccd/RevScInstr_73_2002_2028.pdf

I'll be glad to answer any further questions on the subject. You can contact me using the Sierra Stars Observatory Network website at www.sierrastars.com. ATT