Appendix A

Apendix: SHOCnhelpful

While the main body of the thesis dealt with characterizing SHOC, the focus here will be the commissioning of SHOC. Commissioning SHOC involved absolutely anything from planing and coordinating how to mount SHOC on the telescopes, mounting SHOC and testing hardware and software all the way through too training new users, writing documentation and specifications for future control software and dealing with warranty issues. Consequently, while the previous chapters aimed at exploring all of SHOC's different modes and capabilities, this appendix has a completely different goal. Here the aim is too guide a user in how to use SHOC all the way from selecting which telescope to observe on to opening the control software for the first time, taking data and finally what they should know when reducing their observations. This appendix was therefore not written simply as a chapter in a this thesis but rather to be a free standing document that can be read on its own, thereby serving as a user manual. This will unfortunately result in there being some overlap in content with that already presented, however as concepts will not be explained again but rather only referred to this is kept to a minimum. Without further ado, SHOCnhelpful the user manual to SHOC:

A.1 Introduction

SHOC, the Sutherland High-speed Optical Cameras, are two optical imaging systems each of which consist of an off-the-shelf Andor iXon 888 EM CCD camera, a control computer and a GPS. Each of these systems can be mounted on the South African Astronomical Observatory's 1.9m, 1.0m and 0.75m telescopes* at the Sutherland observatory. While SHOC's primary use is high cadence (subsecond) optical imaging with microsecond frame-by-frame timing, it is also suited to do more general imaging using longer exposures. More information on SHOC and how to apply for time can be found at **http://shoc.saao.ac.za/**, **http://www.saao.ac.za/facilities/instruments/shoc/** and

*The SAAO telescopes are named according to the size of their primary mirrors, either in meters or inches. The 1.9m is also referred to as the 74 inch, 1.0m the 40 inch and the 0.75m the 30 inch.

http://www.saao.ac.za/observing/telescope-time-applications/.

Before starting, a word on the structure of SHOCnhelpful: the manual is divided up into five main sections. In this section, tables containing the main properties of SHOC as well as an experienced user check list for running SHOC is presented. Rather than explain how to use SHOC in detail, the section aims to provide a quick reference for the most commonly needed information as well as operating instructions for experienced users. This is followed in Section A.2 by a step-by-step guide for first-time users. In this section, fleshed out instructions are given which will guide a user in how to log in, run, take data, download their data and shut down SHOC. Next, in Section A.3, important information that users should know about SHOC is given. Rather than writing one long section, this part is divided up into short subsections that are often only a paragraph long, allowing information on a specific topic to be easily found. Amongst other things topics such as timing, problems with the .fits headers, downloading data and image scaling are covered. This is followed by Section A.4 in which instructions on how to choose which telescope, mode, exposure time and under which lunar conditions to observe a star of particular magnitude is given. Finally, in Section A.5, some basic technical information on the system is presented.

Before starting the golden rule to observing: **DON'T PANIC**. Despite the length of this document, SHOC truly is a simple instrument to operate. In the vast majority of circumstances, all that is required to take good data is to start SHOC up, point the telescope at the targets, change the binning, exposure time and number of exposures and hit GO. If something should go wrong, please immediately contact the small telescope's night support staff (contact information can be found on the wall inside the warm room of all of the telescopes).

A.1.1 Characteristics, Properties and Important Information

Logging in: "rdesktop -g 1280x1024 C -u shocT", where C is the control computer (shocnawe, shocndisbelief or shocnhorror), T is the telescope (74in, 40in or 30in), User name: shocT.

Table A.1: Telescope properties.

Telescope	Field of View (arcmin per Side)	Plate Scale (arcsec per Pixel)	GPS Delay (ns)	Binning (1.5" seeing)
1,9m Without Focal Reducer	1.29	0.076	90.90	6×6
1.9m With Focal Reducer	2.79	0.163	90.90	3×3
1.0m	2.85	0.167	45.45	3×3
0.75m	3.73	0.218	35.35	2×2

A.1.2 Checklist for Experienced Users

The aim of this section is to provide a point-by-point checklist for experienced users.

1. Staring Up

Table A.2: Approximate focus values on each telescopes.

Telescope	Telescope Focus
1.9m With Focal Reducer	1938
1.9m Without Focal Reducer	1900
1.0m	990
0.75m	470

(a) Log in via remote desktop: "rdesktop -g 1200x1000 C -u shocT", where C is the control computer (shocnawe, shocndisbelief or shocnhorror), T is the telescope (74in, 40in or 30in). User name: shocT, Password: please contact technical support.

(b) Open the the filter control software, initialize both filter wheels and select the desired filter.

(c) Synchronize the computer and GPS time.

(d) **Open the camera control software and change the cooling temperature to -60°C**.

(e) In the main camera setup, select the required "Triggering Mode", "Exposure Time", "Kinetic Series Length", "Readout Rate" and "Pre-Amplifier Gain". **THE "Output Amplifier" MAY ONLY BE SWITCHED TO "Electron Multiplying" (EM) IF SPECIAL PERMISSION HAS BEEN GRANTED TO DO SO FOR A SPECIFIC TARGET** by either Amanda Gulbis (amanda@salt.ac.za) or Hannah Worters (hannah@saao.ac.za). **SHOC'S EM REGISTER CAN**

Table A.3: Saturation for SHOC 1 (full well 143,838 electrons).

Mode	pre amp gain	Saturation (counts/ADU)	Saturation (electrons)
1 MHz 16bit CON	1.0×	35,428	143,838
	2.4×	65,536	110,754
	4.9×	65,536	41,287
3 MHz 14bit CON	1.0×	13,100	143,838
	2.4×	16,384	69,304
	4.9×	16,384	29,818
1 MHz 16bit EM	1.0×	7,515	143,838
	2.4×	19,229	143,838
	4.9×	39,955	143,838
3 MHz 14bit EM	1.0×	2,798	143,838
	2.4×	7,297	143,838
	4.9×	15,156	143,838
5 MHz 14bit EM	1.0×	2,745	143,838
	2.4×	6,935	143,838
	4.9×	15,077	143,838
10 MHz 14bit EM	2.4×	5,907	143,838
	4.9×	12,431	143,838

EASILY BE COMPLETELY DESTROYED (OR SEVERE PERMANENT DAMAGE DONE) WITHIN A MATTER OF SECONDS IF THE EM MODES ARE USED WITHOUT PROPER TRAINING.

(f) Select the desired binning and subframing.

(g) In the spooling tab change the "File Name" to "YYYYMMDD" and the "Location" to "C:\data\T \YYYY\MMDD" (T as above), Click on 'OK".

(h) Start exposing by clicking on the "Camera" icon.

2. Frame-by-frame GPS triggering

   (a) Ensure that the "Delay of Exposure Period (secs)" in the main camera setup is set to zero when using "External" triggering.

   (b) In the GPS control software, check that the box next to the "Time Valid" label is light blue and that the "User Time Bias" is set to the correct value for the telescope.

Table A.4: Saturation for SHOC 2 (full well 79,169 electrons).

Mode	pre amp gain	Saturation (counts/ADU)	Saturation (electrons)
1 MHz 16bit CON	1.0×	20,888	79,169
	2.5×	51,744	79,169
	5.2×	65,536	44,564
3 MHz 14bit CON	1.0×	7,980	79,169
	2.5×	16,384	64,880
	5.2×	16,384	28,999
1 MHz 16bit EM	1.0×	4,254	79,169
	2.5×	10,655	79,169
	5.2×	23,353	79,169
3 MHz 14bit EM	1.0×	1,786	79,169
	2.5×	4,151	79,169
	5.2×	9,216	79,169
5 MHz 14bit EM	1.0×	1,762	79,169
	2.5×	4,114	79,169
	5.2×	9,205	79,169
10 MHz 14bit EM	2.5×	3,603	79,169
	5.2×	7,877	79,169

Table A.5: Minimum exposure time (in seconds) in each mode under selected binning and subframing. Note that values for 512×512 subframe using 2×2 binning equals those of the full frame 4×4 binning and are not displayed.

Mode	Full Frame (1024 × 1024)		512 × 512 Subframe	
	2 × 2	4 × 4	4 × 4	8 × 8
1 MHz 16bit CON and EM	0.57	0.29	0.15	0.08
3 MHz 14bit CON and EM	0.21	0.11	0.06	0.04
5 MHz 14bit EM	0.13	0.07	0.04	0.03
10 MHz 14bit EM	0.07	0.04	0.03	0.02

(c) Click on the wording "POP Status" and select: "Pulse Polarity" to be "Positive", "POP Mode" to be "POP Repeat" and "Output Pulse Width" to be 10μs. Input the desired exposure time in the "POP Repeat Interval" box (in milliseconds) and the desired start time the "POP Start Time" box (in UT). Click on 'OK".

(d) **Write down the 'POP Repeat Interval" and "POP Start Time"**.

Table A.6: Read noise and electron to ADU gain for SHOC 1.

Mode	Pre-amp Value	Gain (electrons/ADU)	Read Noise (electrons)
1 MHz 16bit CON	1.0×	4.06	9.30
	2.4×	1.69	7.49
	4.9×	0.63	5.84
3 MHz 14bit CON	1.0×	10.98	15.81
	2.4×	4.23	11.59
	4.9×	1.82	10.19
1 MHz 16bit EM	1.0×	19.14	33.69
	2.4×	7.48	19.75
	4.9×	3.60	18.00
3 MHz 14bit EM	1.0×	51.4	61.17
	2.4×	19.71	34.30
	4.9×	9.49	29.99
5 MHz 14bit EM	1.0×	52.40	82.27
	2.4×	20.74	48.53
	4.9×	9.54	39.59
10 MHz 14bit EM	2.4×	24.35	60.14
	4.9×	11.57	51.14

Table A.7: Read noise and electron to ADU gain for SHOC 2.

Mode	Pre-amp Value	Gain (electrons/ADU)	Read Noise (electrons)
1 MHz 16bit CON	1.0×	3.79	8.22
	2.5×	1.53	6.52
	5.2×	0.68	6.03
3 MHz 14bit CON	1.0×	9.92	13.99
	2.5×	3.96	10.85
	5.2×	1.77	9.79
1 MHz 16bit EM	1.0×	18.61	32.20
	2.5×	7.43	19.62
	5.2×	3.39	16.54
3 MHz 14bit EM	1.0×	44.32	51.85
	2.5×	19.07	33.18
	5.2×	8.59	26.29
5 MHz 14bit EM	1.0×	44.92	69.63
	2.5×	19.24	45.02
	5.2×	8.60	35.69
10 MHz 14bit EM	2.5×	21.97	52.07
	5.2×	10.05	46.33

Table A.8: Latitude, longitude and altitude of each telescopes as measured by SHOC's GPS.

Telescope	Latitude	Longitude	Altitude (m)
1.9m	32°27.73' S	20°48.70' E	1822
1.0m	32°22.78' S	20°48.60' E	1810
0.75m	32°22.78' S	20°48.63' E	1811

(e) Stop the GPS after the cube has been taken by opening the POP menu and select "POP Mode" to be "Off".

3. Shutting Down

   (a) **Close the camera control software, click on "File" → "Close".**

   (b) Transfer the data to the server.

   (c) Check that all the data have been transfered to the server.

   (d) Log off the remote desktop by clicking on the Windows "Start" button at the lower left and selecting "Log Off".

A.2 A Step-By-Step Guide for First-Time Users

In this section, a point-by-point recipe, with explanations, is presented to lead first-time users through starting and setting up SHOC, taking science images, copying the data to their computer and shutting down.

A.2.1 Starting Up

1. SHOC is controlled via remote desktop. Clients exist on each of the thin client computers installed in each dome (from which SHOC is normally run), Windows, Mac OSX, Linux, Android, and other operating systems. Any computer with remote desktop capability that is on the SAAO network can be used to connect to SHOC. Under Linux: go to the "Applications" drop down menu in the top left of the screen, select "Accessories" and then "Terminal". Under Mac OSX: open a terminal window, either under "Applications" → "Utilities" → "Terminal", or one that is installed (e.g. Xterm).

2. At the command prompt, type **"rdesktop -g 1200x1000 C -u shocT"** where:

   (a) **C**: is the control computer mounted on the telescope. Either "shocnawe", "shocndisbelief" or "shocnhorror". The telescope support staff will be able to tell you which computer is mounted on your telescope.

   (b) **T**: is the telescope being used. Either "74in", "40in" or "30in".

   (c) The **1200x1000** should be replaced with a window size suitable for your monitor. These values are applicable to the the thin client monitors in the domes.

3. The user will now be prompted for a user name and password:

(a) User name: shocT (T is as above).

(b) Password: please contact technical support.

4. A screen as shown in Figure $A.1$ will now appear.

5. The icon at the very top left of the screen labeled "Andor SOLIS" opens the control panel to SHOC. Next to this, the "TM4 GPS" icon opens an interface to the GPS. Although it is not required, it is recommended that the GPS be used to sync the computer clock to the GPS time at the start of every night. Please refer to Section A.3.18 for more information on different triggering methods and their effect on the absolute and relative timing accuracy and Section $A.3.17$ for the GPS operating instructions.

6. Note: Please do not close the sticky note at the bottom of the screen as it will be used later. It can be minimized by double clicking on it.

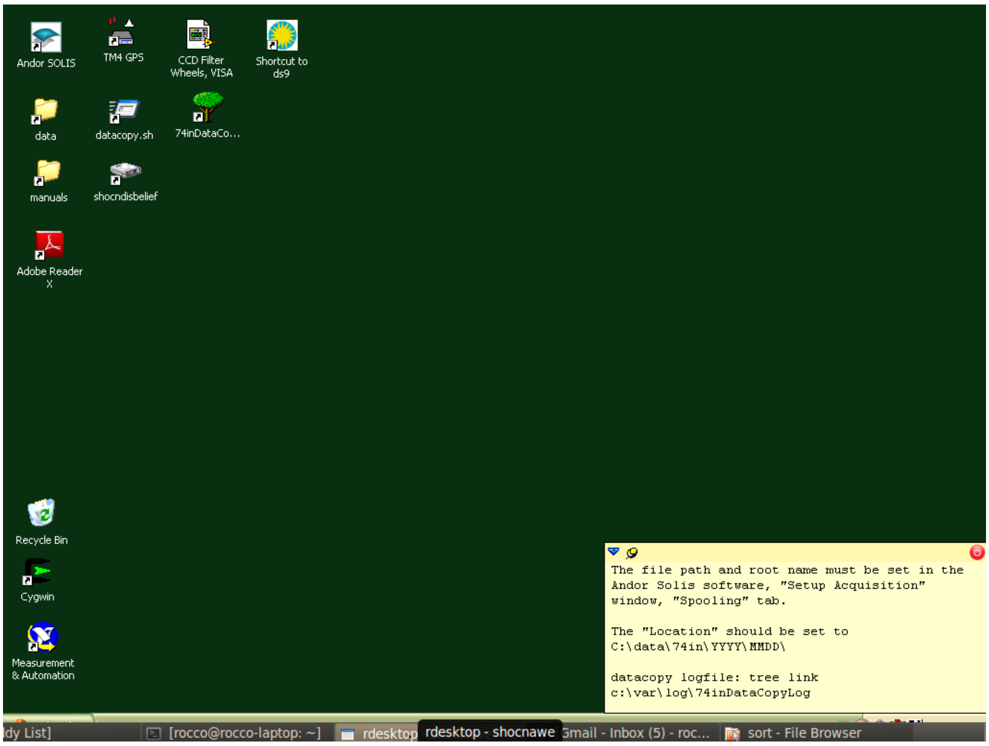


Figure A.1: SHOC desktop that appears after successful login.

A.2.2 Setting Up the Camera Control Software

1. Open the camera control software by double clicking on the "Andor SOLIS" icon on the main Desktop. The user will now be presented with the screen shown in Figure $A.2$.

2. **Click on the temperature indicator (labeled temperature control in Figure A.2) at the bottom left of the screen and change it to -60^{o}C**. Note that the camera will automatically start cooling to the set temperature when the control software is opened. Once the temperature has stabilized at the set temperature, the temperature indicator box will turn from red to blue. This typically takes less than five minutes although it can be as much as ten minutes. A temperature of -60^oC is used as it gives adequate cooling under normal operating conditions to provide negligible dark current and low read noise. If ambient temperatures are high ($> 25^o$C), this value should be increased to -50^oC which will have a limited effects on data quality and will reduce stress on the cooler.

3. Open the wrench icon on the main menu bar (the first bar with icons, icon number seven; labeled in Figure A.2). The user will be presented by a screen as shown in Figure A.3.

   (a) In the first tab "Setup Camera", the camera parameters should be set for each exposure. Figure A.3 shows the standard settings: the "Exposure Time" (in seconds) and "Kinetic Series Length" (the number of frames in a single data cube) are typically the only parameters that need to be changed between exposures. Details on other parameters are provided in Section A.3, for advanced users.

   (b) Note: Data are stored as a .fits file that is a three-dimensional data cube - every cube consists of a user-defined number of single frames (if "Kinetic Series Length" is set to one, the cube has a single frame and the length of the third axis, denoted by the key word "NAXIS3" in the .fits header, will be equal to one).

   (c) **THE "Output Amplifier" MAY ONLY BE SWITCHED TO "Electron Multiplying" (EM) IF SPECIAL PERMISSION HAS BEEN GRANTED TO DO SO FOR A SPECIFIC TARGET** by either Amanda Gulbis (amanda@salt.ac.za) or Hannah Worters (hannah@saao.ac.za). **SHOC'S EM REGISTER CAN EASILY BE COMPLETELY DESTROYED (OR SEVERE PERMANENT DAMAGE DONE) WITHIN A MATTER OF SECONDS IF THE EM MODES ARE USED WITHOUT PROPER TRAINING.**

   (d) If binning and subframing are desired, those parameters can be specified under the second tab, "Binning". Note that if a custom binning is selected, the camera may be forced to use a subframe (for example if 5x5 binning is selected there will be $1024/5 = 204$ rows and 4 extra pixels). If a pre-set binning is then selected, the software will not revert to the largest possible imaging area but will remain subframed. The user needs to then re-select "1024x1024(Full)".

   (e) In the fourth tab "Spooling" change the "File Name" to "YYYYMMDD" and the "Location" to "C:\data\T \YYYY\MMDD", where "T" is once more the telescope used ("74in", "40in" or "30in") and YYYYMMDD is the current date. An example is shown in Figure A.4. Please ensure that the settings entered match those prescribed in order to have the standard data format. If this standard is not followed, the data will NOT be copied correctly and may be inaccessible. This information is also provided on the sticky note.

(f) Close the window by clicking on “OK” at the bottom.

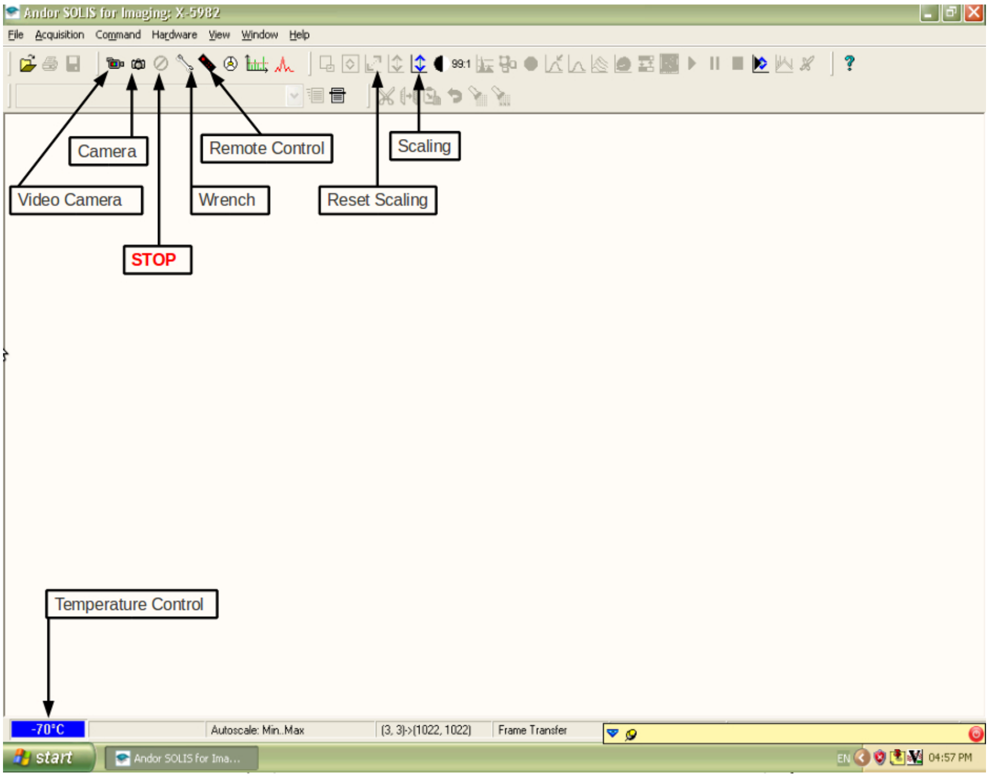


Figure A.2: The SHOC start up interface.

A.2.3 Filter Wheel Control (Labview)

At the moment, the filter wheels are run from a separate PC set up by IT in the warm room. If no PC was set up, please contact the SAAO’s on-site IT support (contact information can be found posted on the wall inside the telescope warm room).

1. In order to run the program, go to the filter wheel control computer (technical support staff will be able to tell you which computer it is) and open the “CCD, Filter wheels, VISA” program.

2. A screen as shown in Figure $A.5$ will now appear.

3. Check that the “VISA Resource Name” drop down menu (located below the red stop button) is set to ASRL1: (or any other value that results in the indicators “Filter A/B Centered” turning from dark green to light green when running the program).

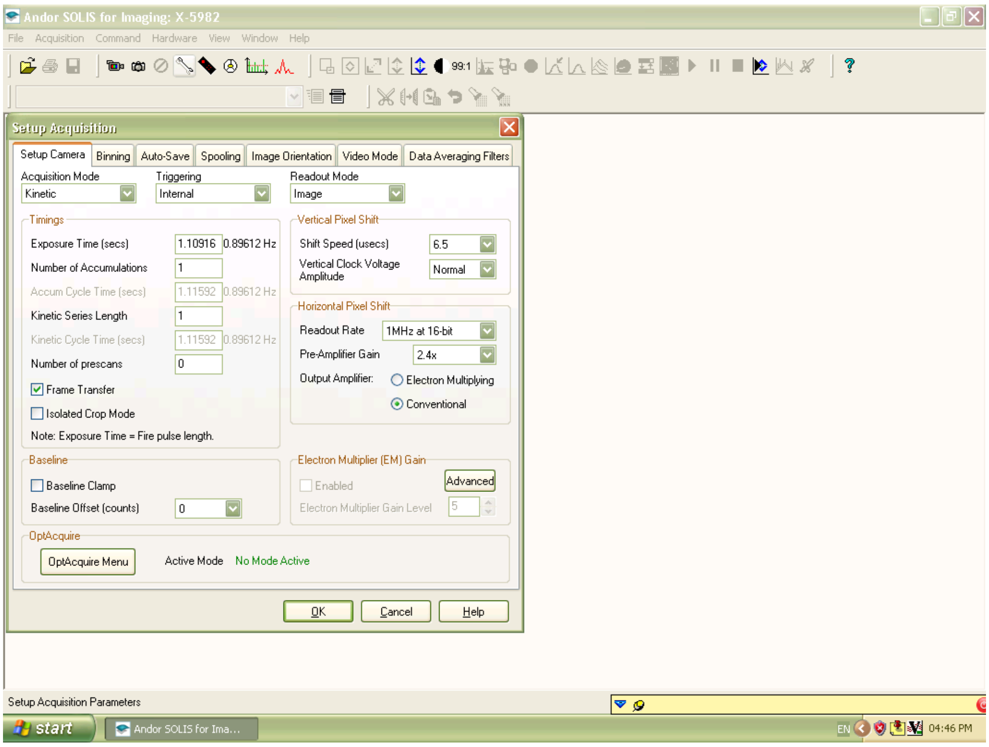


Figure A.3: SHOC's main setup window.

4. Run the program by clicking on the the arrow button located below the edit tab on the main menu bar, causing it to change to a black "moving" arrow as indicated in Figure *A*.5.

5. Initialize both wheels (or in the case of the 30", which only has a single filter wheel, the wheel) by clicking on the "OK" button below the "Initialize Filter A/B" wheel button.

6. **When clicking on buttons inside the program, the mouse button needs to be held in for 2 seconds in order for the software to detect the click.**

7. The user can now select which position they would like the wheel to be in and move it by typing the selected position in the box below the label "Filter A/B Required Position (1-8)" and clicking on OK.

8. The wheel will be in the requested position if the number in the "Filter A/B Position" has changed to the desired value (**make sure to check this after every movement**), the light indicating that the wheel is moving has gone off and the light indicating that the wheel is centered has come on.

9. Note:

   (a) **The filter wheel position needs to be hand recorded for every file, as this information is currently NOT saved in the .fits header.**

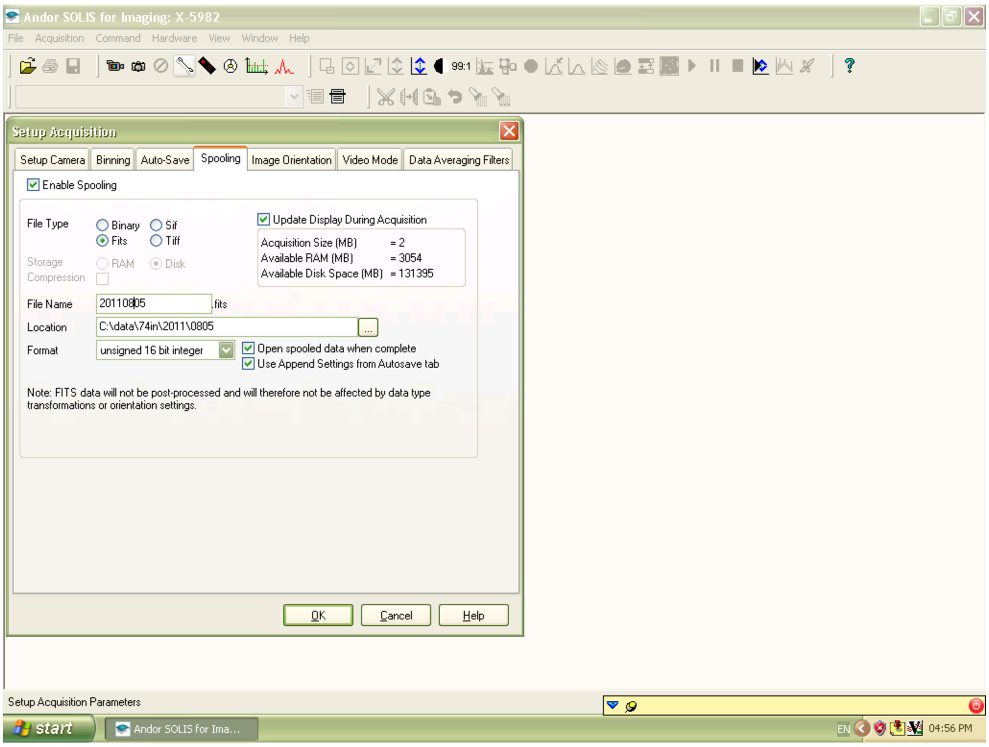


Figure A.4: The spooling tab in the main camera setup.

(b) **After every filter change, a Light Emitting Diode (LED) will shine inside the filter box for a few seconds to check that the wheel has moved to the correct position. It is therefore advisable to wait for ten seconds after the filter wheel has stopped moving before resuming observations.**

(c) **The filter wheels have been observed to sporadically move to the incorrect position or be at a different position to what is displayed on the software. When doing filter sequences, it is therefore advised that the wheel is initialized during every sequence.**

(d) Information about which wheels are in the telescope and which filter is in each position of each wheel is displayed on sheets typically located on the observing floor wall. If you are unable to find this information, please contact the telescope support staff.

(e) The light indicating that the wheel is at its reference position will only come on when the wheel is at position one.

A.2.4 Taking Data

1. Exposures are stopped by clicking on the ⊘ icon (located two icons to the right of the video camera, labeled as "STOP" in Figure A.2).

2. **Real-time imaging:** Click on the video camera icon (three icons to the left of the wrench; labeled in Figure A.2). The camera will now take and display images, but not save them. This allows the user to check that the exposure time, count levels, binning, telescope position, etc. are as desired.

3. There is a cursor (in the shape of a cross) on the image can be moved to a different location by clicking on the desired location. The x, y spatial values of that pixel, number of counts/ADUs of the pixel and X- and y- cross sections, centered on the cursor, are displayed at the bottom and sides of the frame. Note: image contrast can be adjusted as described in Section A.3.5.

4. The exposure time can be changed by clicking on the remote control icon to the right of the wrench. This will bring up a small window in which the exposure time can be adjusted in real time, while taking images in video mode. Once a new exposure time has been entered, simply click outside the box to activate it. Note that changing the exposure time in this way is equivalent to changing it in the main setup window (opened using the wrench icon). Saturation is apparent as either smearing in the image or no variation in count levels between pixels. Saturation values are also presented for each camera and mode in Tables A.3 and A.4.

5. To start taking and storing data, click on the camera icon to the right of the video

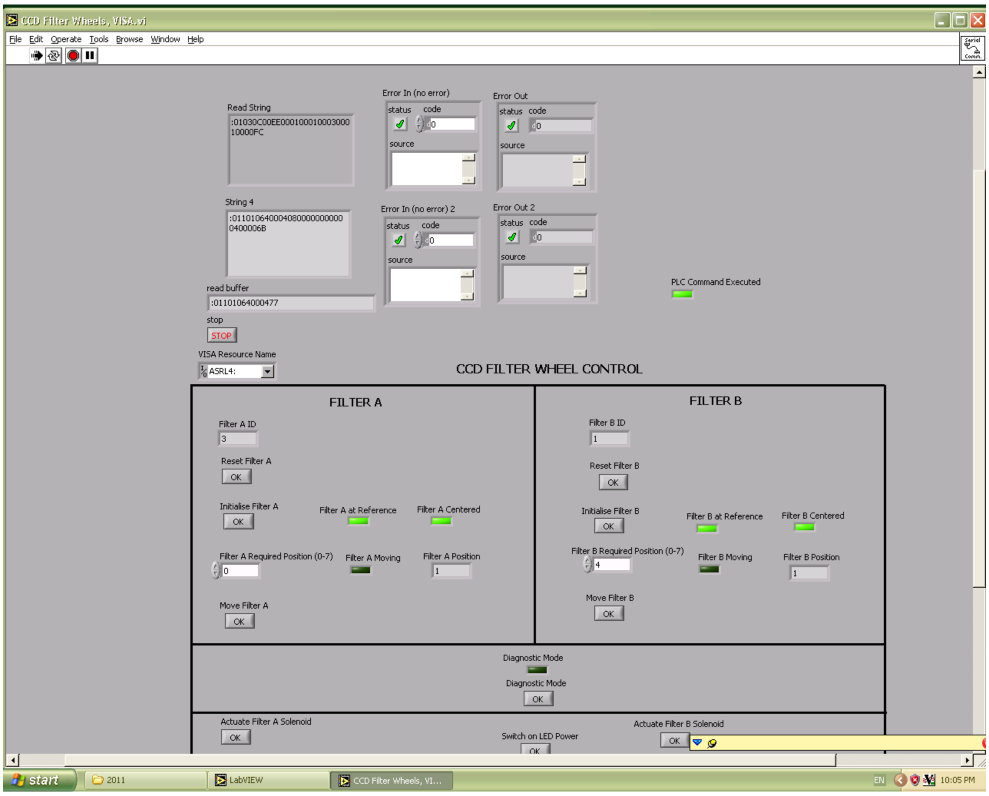


Figure A.5: The filter wheel control panel.

camera icon. Clicking on this icon will execute the settings stored in the "Setup Camera" tab and save each cube as a .fits file according to the information in the "Setup Acquisition" tab. Each individual cube will be saved with a 3 digit number appended to the end of the set file name (for more information please refer to Section $A.3.13$). Finally, note that if the camera is stopped while taking science images (using the ⊘ icon), the images already taken will be saved and that SHOC will never overwrite data. If it should happen that the cube being should have the same name as an existing cube, the new cube will be saved with an additional element in the file name, please refer to Section A.3.13 for more information on this.

6. While a cube is being taken, the number of frames already taken is displayed in the bottom left hand corner of the software, next to the temperature indicator.

7. The most recent data are displayed in the "Andor SOLIS" software. To open an older file, a link to ds9 is provided on the desktop (images are stored in the data folder set up in Section $A.2.2$). Alternatively, older files can also be opened in SOLIS by selecting "File"→"Open" and once again navigating to the appropriate data folder. **Please do not attempt to open a cube before all of the images in the cube have been completed.**

A.2.5 Using the GPS

1. Synchronizing the Computer and GPS Time (recommended at the start of each night to ensure header time stamps with accuracy of $\pm 0.5s$):

    (a) Make sure that the dome is open and the telescope is pointing at the sky.

    (b) Open the GPS software by clicking on the icon labeled "TM4 GPS" in Figure $A.1$, this will open a window as shown in Figure $A.6$.

    (c) Wait until the box next to the "Time Valid" label in the bottom right of the window turns from dark to light blue (this will take a few minutes while the GPS locates a sufficient number of satellites).

    (d) At the very bottom of the window, in the rows of icons, click on the clock (third from the right). In the window that opens, click on "Set PC Clock" to synchronize the computer and GPS time. The window will automatically close when the times have been successfully synchronized. Note that this is typically not instantaneous but takes a few seconds after the "Set PC Clock" button was clicked.

2. **The following steps are only applicable in the case that the GPS is used to trigger frames (please refer to Section A.3.18 for details on triggering methods).**

3. To trigger only the start of the data cube using the GPS:

    (a) Set the camera up as described in Section $A.2.2$.

Figure A.6: The GPS Start up screen.

(b) In the main camera setup window, under the "Setup Camera" tab, select "External Start" in the "Triggering" drop down menu.

(c) Close the setup window and click on the camera icon. Because the triggering is external, the camera will now wait for a trigger from the GPS before executing the observation.

(d) In the GPS control software, ensure that the box next to the "Time Valid" label is light blue and that the "User Time Bias" is set to the correct value for the telescope (see Table A.1). To change the "User Time Bias", simply click on the wording.

(e) Click on the wording "POP Status" and select: "Pulse Polarity" to be "Positive", "POP Mode" to be "One-shot" and "Output Pulse Width" to be 10μs (these parameters are also shown in Figure A.7).

(f) Set the "POP Start Time" to the desired start time **in UT (UT = SAST - 2)**, and click on "OK".

(g) **Note: The start time saved under the keyword "FRAME" in the .fits header is not the GPS time at which the first frame was triggered but rather the trigger time plus an unknown offset. Accordingly the "POP Start Time" should be hand recorded for every file.**

(h) The "POP status" light will now turn orange, turning to green at the time of the trigger. The trigger should be obvious in the SOLIS software as well, since data should start being displayed. If the trigger does not obviously occur at the correct time, confirm that the time entered in UT is correct.

4. To trigger each frame of the data cube using the GPS (microsecond timing accuracy):

   (a) Set the camera up as described in Section *A*.2.2.

   (b) In the main camera setup window, under the "Setup Camera" tab, select "External" in the "Triggering" drop down menu.

   (c) The user will note that the display shown in Figure *A*.2 will change slightly. In the "Timings" section, the tab labeled as "Exposure Time (secs)" changes to "Delay of Exposure Period (secs)", and "Kinetic Cycle Time (secs)" changes to "Minimum Triggering Period (secs)".

   (d) **Set the "Delay of Exposure Period (secs)" to zero seconds.** If this is not done it will effect the exposure time that will be input into the GPS as well as the start time of the individual frames, for a detailed explanation please see Section A.3.18.

   (e) Close the setup window and click on the camera icon. Because the triggering is external, the camera will now wait for a trigger from the GPS before starting the observation.

   (f) In the GPS control software, ensure that the box next to the "Time Valid" label is light blue and that the "User Time Bias" is set to the correct value for the telescope (see Table *A*.1). To change the "User Time Bias", simply click on the wording.

   (g) Click on the wording "POP Status" and select: "Pulse Polarity" to be "Positive", "POP Mode" to be "POP Repeat" and "Output Pulse Width" to be 10μs. These parameters are shown in Figure *A*.7.

   (h) Input the desired exposure time in the "POP Repeat Interval" box in milliseconds, selecting a value that is larger than the "Minimum Triggering Period (secs)" displayed in the main camera setup. This value is the exact time between output pulses and thus the exposure time.

   (i) Set the "POP Start Time" to the desired start time **in UT (UT = SAST-2)**, and click on 'OK".

   (j) **Note: The "POP Repeat Interval" value (exposure time) is not recorded in the .fits headers and must be hand recorded. Similarly, the start time saved under the keyword "FRAME" in the .fits header is not the GPS time at which the first frame was triggered but rather the trigger time plus an unknown offset. Accordingly the "POP Start Time" should be hand recorded for every file.**

(k) The "POP status" light will now turn orange, turning to green once the GPS starts triggering SHOC (which should be obvious in the SOLIS software as well, since frames should start being displayed). If the trigger does not obviously occur at the correct time, confirm that the time entered in UT is correct.

(l) **After the cube has been taken, once more open the POP menu and select "POP Mode" to be "Off".** If this is not done, the GPS will continue to send triggers to the camera and the next time that the camera is asked to wait for a GPS trigger, it will immediately start.

Figure A.7: The GPS Programed Output Pulse (POP) menu.

A.2.6 Transferring Data to the Server

Data from the SHOC computers are transferred to the Sutherland servers from where it will automatically be copied to Cape Town once a day. Copying data to the servers is done via a user-run data copy script. We have opted to have the user choose when to copy the data in order to avoid automatic scripts possibly compromising data acquisition. Note that because of the amount of data that can be taken on any given night, the SHOC computers are locally purged of data every two weeks. Please make sure your data is copied throughout the night, or at the end of each night!

1. As shown in Figure $A.1$, double click on the "datacopy.sh" icon and wait for the program to finish running (indicated by the window that opens automatically, closing again).

2. To check which files were transferred, double click on the folder labeled "log", scroll to the appropriate date, right click and open using "Word Pad". A list of all of the files that were copied during the last transfer will be shown.

3. Should any problems occur during data transfer please contact the SAAO's on-site IT support.

A.2.7 Downloading Data

To access your data, you can transfer the files from the ltsp server to your local machine. One method to do this is to open a terminal window on any computer that is connected to the network.

1. Start the secure file transfer protocol by typing "sftp ccdX@ltsp.suth.saao.ac.za", please contact technical support for the password, where X is the size of the telescope, "74", "40", or "30".

2. Change directories into your filepath by typing "cd /data/T/C/YYYY/MMDD" where T="74in", "40in" or "30in"; C="shocnawe", "shocndisbelief", or "shocnhorror"; YYYY is the year and MMDD are month and day.

3. Copy all files to the current directory on the local machine by typing "get *".

A.2.8 Shutting Down

1. **To close the camera control software, in SOLIS simply click on "File" → "Close". It is extremely important to do this at the end of every night. If the control software is not closed, the camera will continue to cool (even when the remote desktop is closed) which can strain the cooler if the ambient temperature rises too high during the day.**

2. Make sure that no other programs are running inside the remote desktop window.

3. Click on the Windows "Start" button at the lower left and log off the remote desktop OR close the remote desktop window on your local machine (e.g. clicking the X in the upper left corner) OR hit the CTRL and D keys simultaneously in the terminal from which the remote desktop was started.

4. There is no need to stop or close the filter control software at the end of the night.

A.3 What You Should Know About SHOC

In this section a more in-depth explanation will be given on certain aspects of SHOC, amongst other things, frame timing (and how to calculate the start time of each frame), taking flat fields and biases, and incorrect values in the .fits headers will be discussed.

A.3.1 Telescope Focus

Since the chances are good that another instrument was mounted on the telescope during the previous week, the telescope focus will likely need to be adjusted by a significant amount at the start of the run. The values in Table $A.2$ can be used as a starting point in order to focus. Since the focus will change depending on the humidity, seeing and temperature, the above values should be treated as a starting point only. The best idea is to first focus SHOC by adjusting the telescope focus. After this the guiding camera can be focused as described in the TCS manual.

A.3.2 Known Defects

A known defect occurs on SHOC 2 in the form of a hot pixel located at x,y position (10,1010).

A.3.3 Linearity

SHOC 1 CCD were found to be linear to within 0.5% for counts between the bias level and saturation in all modes. In the case of SHOC 2, the 1MHz CON, 3MHz CON, 1MHz EM and 3MHz EM modes were found to be linear to within 0.5% for counts between the bias level and saturation, while the 5 and 10 MHz EM modes were found to be linear to within 1.5% and 3.0% for counts between the bias level and saturation.

A.3.4 Duration of an Observation

The "Kinetic Series Length" is the number of consecutive frames that is to be taken and saved into a single data cube, while the "Kinetic Cycle Time" is the amount of time between the start of two frames (this includes both exposure time and dead time). Accordingly, to find out how long the observation will take, multiply the kinetic cycle time with the number of exposures in the data cube. Note that the kinetic cycle time is always (irrespective of the binning used) 0.00676s longer than the exposure time in the case that internal (no GPS) triggering is used.

A.3.5 Image Scaling and Zooming

The scaling icon, labeled in Figure A.2, is used to activate and deactivate automatic scaling of displayed images. When the icon appears as displayed in the Figure, the display will be automatically rescaled after each image is taken. Although this sounds good, the problem is that the images are always scaled linearly between the brightest and faintest object on the frame, resulting in fainter objects being hard to see. In order to see fainter background stars, the display can be adjusted by either clicking and dragging the scaling bar at the top of the image or using the arrows at either end of the bar to increase/decrease the minimum and maximum counts between which the scaling is done. If the user would like to adjust the scaling once and then not have it change after every image taken is displayed (the scaling will revert to default as each new image is displayed), the scaling icon can be clicked.

After each image is taken, the display will update to show the most recent image. After a cube has been taken, a new window will open showing all of the images in the cube, and allowing the user to scroll through them using a scroll bare on the left of the window. Additionally the user can zoom into any particular section of an image by simply clicking and dragging a box around the area of interest. In order to get out of the zoomed in area, simply click on the "Reset Scaling" indicated in Figure A.2.

A.3.6 Number of Accumulations

When the number of accumulations is set to a number other than one, successive images will be co-added. Accordingly what will happen is that the first frame will be taken and readout. After exposing the second frame, the counts from this exposure will be added to those of the first to form the second frame etc..

A.3.7 Prescan

The final box sets the number of prescans. Please be aware that **prescans do not simply clear the CCD of charge by reading out the CCD before starting an exposure**. If the number of prescans is, for example, set to five, five full exposures will be taken and deleted before the the images that were asked for are taken.

A.3.8 Frame Transfer

Please ensure that the "Frame Transfer" box is checked, as the camera has not been tested in non-frame transfer mode.

A.3.9 Vertical Pixel Shift Speed

The "Vertical Pixel Shift" box in Figure A.3 can be used to change the speed at which charge is shifted vertically through the part of the CCD that is exposed to light. The default setting (of 6.5μs) is recommended as this allows for the highest shift speed without significant decreasing the charge transfer efficiency. Values of the "Vertical Pixel Shift" at which the charge transfer efficiency will be significantly reduced are indicated in the software by []. Note that by increasing the vertical shift speed, shorter exposure times will be possible in a given mode, however the amount by which the exposure time can be decreased is at maximum six milliseconds.

A.3.10 Horizontal Pixel Shift Speed and Pre-amplifier Gain

The "Horizontal Pixel Shift" box in Figure A.3 contains three parameters that can be adjusted, these are "Readout Rate", "Pre-Amplifier Gain" and "Output Amplifier". Together these parameters set what has up to now been referred to as the mode of the camera. Starting at the bottom, **THE "Output Amplifier" MAY ONLY BE SWITCHED TO "Electron Multiplying" IF SPECIAL PERMISSION HAS BEEN GRANTED TO**

DO SO FOR A SPECIFIC TARGET by either Amanda Gulbis (amanda@salt.ac.za) or Hannah Worters (hannah@saao.ac.za). **SHOC'S EM REGISTER CAN EASILY BE COMPLETELY DESTROYED (OR SEVERE PERMANENT DAMAGE DONE) WITHIN A MATTER OF SECONDS IF THE EM MODES ARE USED WITHOUT PROPER TRAINING.**, please refer to Section A.3.11 for more information on this. Next the electron to ADU gain can be adjusted by selecting a different 'Pre-Amplifier Gain", the following options are available: 1.0×, 2.4×, 4.9× (SHOC 1), 1.0×, 2.5×, 5.2× (SHOC 2) the values corresponding to these settings are given in Tables A.6 and A.7. Finally the speed at which the storage area is readout can be changed to one of the following options: 1 MHz 16bit CON, 3 MHz 14bit CON, 1 MHz 16bit EM, 3 MHz 14bit EM, 5 MHz 14bit EM or 10 MHz 14bit EM) in the "Readout Rate" menu.

When choosing in which mode to operate the camera, the user should take into consideration that faster readout rates will allow shorter exposure times (Table A.5), but incur higher read noise, while higher electron to ADU gain values decrease the dynamic range. Read noise and electron to ADU gain values for each mode are provided in Tables A.6 and A.7. In addition to this it should be noted that as it takes about 6 milliseconds for the top most pixel in the frame to be shifted to the storage area and SHOC does not have a shutter, the top row of pixels in each frame will have an exposure time of about six milliseconds longer than the bottom row. Consequently although it is possible (with enough subframing and binning) to expose for less than a hundredth of a second, this is inadvisable due to the above reason. Finally as indicated above, the 1MHz CON and EM modes are both 16 bit. What this means is that the mode will reach saturation at $2^{16} = 65536$ counts. On the other hand, the 3 MHz CON and EM and 5,10 MHz EM modes are all 14-bit modes and saturate at $2^{14} = 16384$ counts. As the saturation limits of each mode will also depend on the electron to ADU gain, Tables A.3 and A.4 give the saturation limit in both counts and electrons for each mode.

A.3.11 The EM Modes

THE "Output Amplifier" MAY ONLY BE SWITCHED TO "Electron Multiplying" IF SPECIAL PERMISSION HAS BEEN GRANTED TO DO SO FOR A SPECIFIC TARGET by either Amanda Gulbis (amanda@salt.ac.za) or Hannah Worters (hannah@saao.ac.za). **SHOC'S EM REGISTER CAN EASILY BE COMPLETELY DESTROYED (OR SEVERE PERMANENT DAMAGE DONE) WITHIN A MATTER OF SECONDS IF THE EM MODES ARE USED WITHOUT PROPER TRAINING.**

In the case that special permission has been granted for the EM modes to be used, the "Output Amplifier" can be set to Electron Multiplying (EM) and the box directly below used to first enable and then set the EM Gain. **NOTE: IF THE EM GAIN IS PUSHED TOO HIGH, THE EM REGISTER CAN BE COMPLETELY DESTROYED (OR SEVERE PERMANENT DAMAGE DONE) WITHIN A MATTER OF SECONDS. ACCORDINGLY THE EM GAIN SHOULD NEVER BE SET TO**

VALUES HIGHER THAN 100 AND SHOULD BE SLOWLY INCREASED IN SMALL STEPS FROM 5 UPWARDS. IN THE CASE THAT DAMAGE IS BEING DONE, A WARNING BOX WILL APPEAR IN THE BOTTOM RIGHT OF THE SCREEN. IF THIS HAPPENS, THE USER MUST IMMEDIATELY STOP EXPOSURES AND DECREASE THE EM GAIN AND/OR EXPOSURE TIME. WHEN TAKING FLAT FIELDS FOR THE EM MODES, EM MAY UNDER NO CIRCUMSTANCE BE ENABLED.

The EM mode can be used with EM disabled when observing science targets, however, it is inadvisable to do so (or with very low EM gain) as the EM gain needs to be high enough to compensate for the higher read noise generated by the EM register. When using the EM modes, EM gain should be set equal to the read noise in the mode (Tables A.6 and A.7) plus five (for example if the read noise in a particular mode is 20 electrons per pixel, an EM gain of 25 should be used) as this will ensure that the effective read noise is less than one electron per pixel. Increasing the EM gain beyond this point only serves to decrease dynamic range and increase the risk of damaging to the EM register without increasing the signal-to-noise (SNR) ratio of a star (i.e. if the read noise in a particular mode is 20 electrons per pixel using an EM gain of 25 or 250 will result in the same SNR).

When using the EM modes, with EM switched on, users should be aware that the EM gain will effectively change the read noise and electron to ADU gain of the images. The effective read noise and electron to ADU gain can be calculated by dividing the read noise and electron to ADU gain of the mode with EM off* (given in Tables A.6 and A.7) by the EM gain. NOTE: in the .fits headers the key word GAIN gives the EM gain and is given a value of zero when EM is switched off or the CON mode is used. Neither the effective read noise nor electron to ADU gain are recorded in the .fits headers.

A.3.12 Subframing and Binning

The "Binning" tab in Figure A.3 allows the user to select a binning and sub-framing. Note that there are five possible pre-selectable size subframes, with the final custom setting allowing the position of the sub-frame to be changed from the default at the center of the CCD. By moving the subframe to the bottom of the CCD, the kinetic cycle time can be reduced slightly (of the order of a few hundredths of a second) as compared to when it is placed at the top.

When a custom binning is selected, (for example 5x5) SHOC may be forced to work in a sub-frame mode (there are 1024 pixels across the CCD hence 5x5 binning will result in 204 rows of 5 pixels each, with 4 pixels left over). When a pre-set binning is once more selected, SHOC will not revert to full frame mode automatically, but will remain in a sub-frame mode. The user needs to manually re-select full frame.

*Technically this does mean that in the example at the end of the previous paragraph, using an EM gain of 250 will result in an effective read noise of $20/250 = 0.08$ electrons per pixel while using an EM gain of 25 will only result in an effective read noise of 0.8 electrons per pixel. However, as the effective read noise is added as the square of the value when calculating SNRs, this has a negligible effect on the SNR.

A.3.13 Auto Saving and Spooling

In Figure A.3, the “Auto-Save” and “Spooling” (shown in Figure A.4) tabs are used for selecting how and where the data are saved. Spooling ensures that every frame is saved, when taking a very large data cube this prevents total data loss should a mid-cube crash occur. When the “Use Append Setting” from “Auto Save” tab is selected, the spooled data are complied into a data cube and named via the pattern selected in the “Auto-Save” tab. In the “Auto-Save” tab, all of the settings should be left as is, with only the “Auto Increment” box checked.

The “Start Value” indicates the number that will be assigned to the next image name, while the “Pad Width” changes the number of digits in the number. For example setting the “Pad Width” to three means that a maximum number of 999 cubes can be taken. In the case that the spooling is disabled, an image taken should be displayed and give you the option to save and name it.

Finally, a word on naming conventions. First, data cubes that are bigger than 2Gb will be broken up into separate files (with maximum size 2Gb) labeled in the format date.number.-X1.fits. Secondly, in the case that the computer crashes or the user quits during the night, the “Start Value” will reset to one and needs to be changed to the correct value. You can however rest easy, knowing that in case this is not done data will not be overwritten. In stead, an additional “.01” will be appended to the file name, hence images will have the format date.number.01.fits

A.3.14 Image Orientation

The “Image Orientation” tab in Figure A.3 can be used in order to rotate and flip the display, however the images will be saved using the default settings. Something that can also create a lot of confusion is that due to the physical setup of SHOC’s readout registers, an image taken in the EM mode will be, displayed and saved, flipped along the y-axis as compared to an image taken in the CON mode.

A.3.15 Flat Fields

Flat fields are normally taken just after sunset or just before sunrise under photometric conditions (when the sky is cloudless) using the same settings as that of the science images (filter, binning and mode). In order to take flat fields using SHOC, point the telescope at the twilight sky and take between ten and twenty individual flats using an exposure time such that the number of counts in each pixel is roughly equal to the saturation limit in that mode (Tables A.3 and A.4) divided by two. If no sky flats can be obtained during an observing week, dome flats can be taken using the same method and pointing the telescope at a uniformly illuminated white screen inside the dome.

WHEN TAKING FLAT FIELDS FOR THE EM MODES, EM MAY UNDER NO CIRCUMSTANCE BE ENABLED.

When taking flat fields with SHOC, users may notice structure such as shown in the example flat field in Figure A.8. Two distinct structures have been observed to appear on the flats (both of which are visible in Figure A.8). The first are lines running diagonally across the frame, forming diamond shapes. This structure is the result of the thinning process used during manufacturing of the CCD. This typically is only visible on the flat fields (not science images) and then only if the signal level in the flat field is high enough. The second structure, which can often also be seen on science images, is that the center of the image is brighter than the edges. The cause for this is unknown, although it is likely the result of either vignetting or how the light is brought to a focus. Both of these structures are completely normal and are removed by flat fielding.

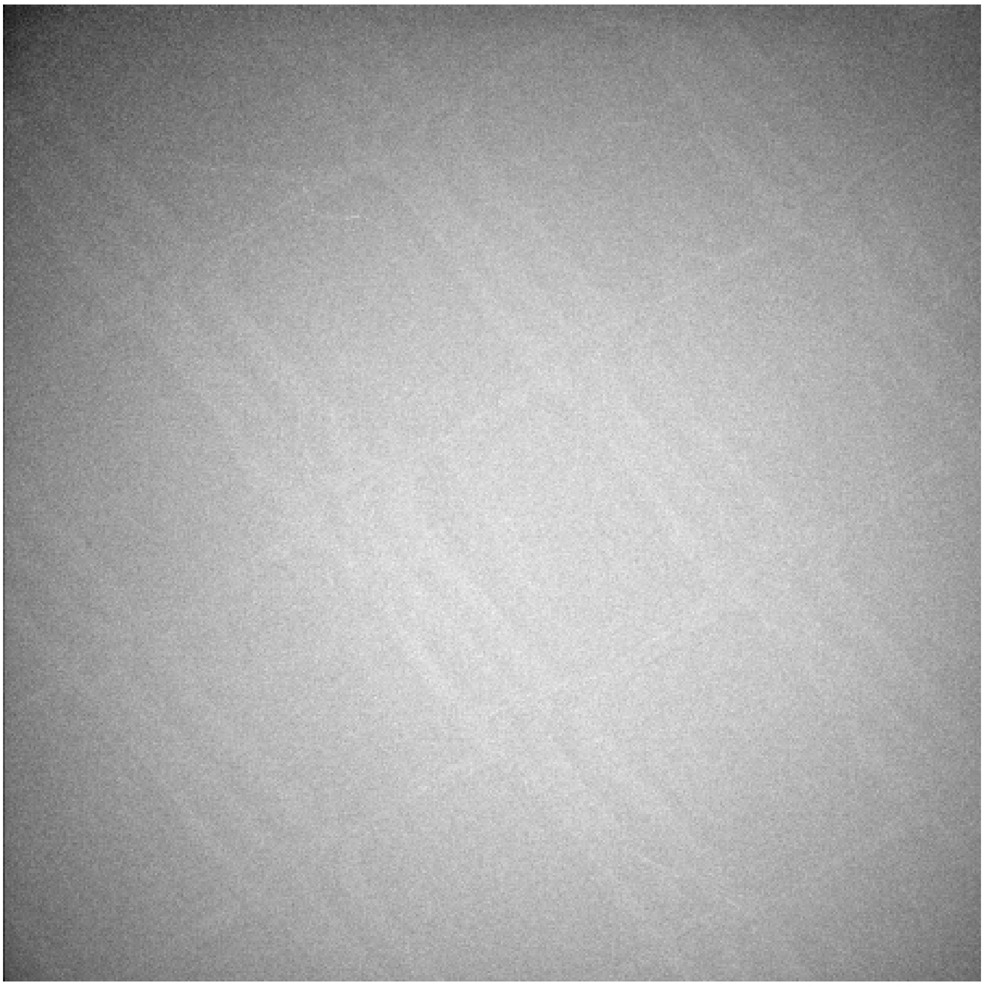


Figure A.8: Example of a flat field taken with SHOC.

A.3.16 Bias and Dark Frames

As SHOC does not have a shutter, it is recommended that when bias frames are taken, the dome shutter and mirror covers are closed, all lights inside the dome are switched of and a U filter is placed in the beam to prevent light from reaching the CCD. In order to take bias frames, once more use the same binning and mode used for science images, selecting the shortest possible exposure time in the mode before taking between ten and twenty images. When taking bias frames in the EM modes, it is suggested that the EM gain be set to the value used for the science images.

During lab tests no dark current could be detected in either SHOC 1 or 2 in 20-minute exposures with the CCD cooled to -40^{o}C. As SHOC is typically run at -60^{o}C using much shorter exposures, there is no need to take dark frames.

A.3.17 The GPS

In Figure $A.6$, the start up window of the GPS software is shown. This window is divided into five boxes. The top left "Receiver Status" box shows the signal strength received from each of the satellites that is currently being used. The receiver mode is also displayed, and should be set to "Static Position" to ensure the highest timing accuracy. Below this, the "Time and Date" box displays the the local and UTC time. The "Local Time" should be set to South African Standard Time (SAST), where SAST = UTC + 2. This can be checked/changed by clicking on the label "Local Time" and entering the correct offset from UTC. The Local date is changed similarly.

The "Position Data", box shows the latitude, longitude and altitude above sea level of the observer. Default values displayed in Figure $A.6$ are for the 1-meter telescope at Sutherland. In the case that these values do not display, they can be re-entered using the values given in Table $A.8$.

In the middle box, labeled as "Timing Status", the "Timing Mode" should be set to "static". If the observer wishes to get an accurate position, the "Timing Mode" can be changed to "Auto Survey". This will recalculate the position of the GPS, **note that this takes about three and a half hours to complete**. The "User Time Bias" tab takes into account the time delay caused by the signal traveling via cable between the receiver, GPS and camera. Negative values cause the timing function to occur later in absolute time while positive values cause them to occur earlier. Note that changing the time bias can cause the time valid status to drop out momentarily. The correct input values for each telescope are displayed in Table $A.1$ and need to be set by the user at the start of each run.

Finally in the "Alarms and Indicators" box; if the "Antenna Fault" is orange, it most likely indicates that the GPS antenna has not been connected to the GPS correctly. In the case that this happens, please call the standby electronics technician.

A.3.18 Timing

When using SHOC, individual frames can be triggered in one of two ways, either using the computer clock or by means of the GPS. If high precision timing is not required frames can be triggered by means of the computer clock (Section A.3.18). In this case individual frames will have a absolute timing accuracy of ± 0.5s. If, however, high accuracy timing (in the order of microseconds in both absolute and relative timing) is desired frames should be triggered by means of the GPS.

Internal Trigger

The user has a number of different options of how to trigger the camera. The first is simply using internal triggering. This method uses the internal computer clock to trigger and write time stamps on the headers. The problem with this is that the accuracy of the time stamp (record in the "FRAME" keyword at the very bottom of the .fits header) is not very high. There are a number of reasons for this, however the most important is that **the time stamp recorded on the headers is rounded to the nearest second. As a consequence, the absolute time accuracy is at best ± 0.5 seconds when the computer clock is synchronizing with the GPS at the start of each night, as described in Section $A.3.17$.** The relative time accuracy (between frames) is expected to be higher than the absolute, however how much higher is unknown.

Additionally the start time record in the "FRAME" keyword is the time when the file was created (at the end of the first exposure) and not the start of the first exposure. Finally, the time recorded in the "FRAME" keyword is in UT not SAST. The user should at this point be aware that science images are saved as cubes, only one header gets written for the entire cube. Hence the start time of the first frame is equal to the time recorded on the header, minus the exposure time. The start time of the second frame equals the start time of the first plus the Kinetic cycle time, the start of the 3rd frame equals the start of the second plus the kinetic cycle time, ...

External Trigger

When the camera is triggered externally using the GPS (either when each frame in the cube is triggered separately using the GPS or the cube is started using the GPS), the absolute and relative timing accuracy is in the order of a few microseconds. When making use of external trigger, there are a number of things to be aware of and take into account when setting up an exposure and reducing the data.

1. As above, only one .fits header gets written per cube.
2. The time recorded on the "FRAME" keyword in the .fits header is not the GPS time at which the first frame was triggered but rather the trigger time plus an unknown offset **Accordingly the start time put into the GPS needs to be hand recorded by the user.**

3. A trigger from the GPS will cause the camera to readout (not start an exposure). Essentially what happens is that the camera exposes continuously until a trigger is received and then reads out.

4. When the camera is placed in external trigger mode, a series of "keep clean" cycles are run. These cycles are aimed at preventing charge build up in the CCD and involve the CCD and readout register being readout continuously. These cycles will take apoximatly 23 microseconds to complet after the first trigger have been recieved.*

5. When switching from internal trigger mode to external, the display shown in Figure $A.2$ will change slightly. In the "Timings" section, the tab labeled as "Exposure Time (secs)" changes to "Delay of Exposure Period (secs)" and "Kinetic Cycle Time (secs)" changes to "Minimum Triggering Period (secs)".

6. The first two frames of any data cube should always be ignored when using external triggering, for reasons to be explained below.

7. When the camera is placed in "External" triggering mode, the .fits header key word "EXPOSURE" still appears, this is incorrect and should be "READOUT DELAY".

Keeping the above in mind, let's look at what actually happens: when the camera is placed in external trigger, the "Delay of Exposure Period (secs)" (which is recorded in the header as "EXPOSURE") should be set to zero seconds (the case when delay is set to a non-zero value will be discussed later in this section). When "Delay of Exposure Period (secs)" is set to zero seconds, the exposure time equals the time between GPS pulses (i.e the "POP Repeat Interval" which is set in the GPS software). Note that the exposure time will not be exactly equal to the pulse frequency. This is due to the time it takes each frame to readout. This readout time will be equal to the number of pixels readout (which is always 1024 as binning occurs in the readout register) times the shift speed (which is normally set to 6.5 microseconds). Accordingly the exposure time will actually be 0.00676s less than the time between pulses (regardless of the binning and subframing used) and what has and will be referred to as the exposure time is technically not the exposure time but rather the cycle time.

To illustrate how the timing works, consider the following example: the user sets the GPS to start sending pulses at 00:00:00 UT and the pulse interval is one second. When the camera is placed in external trigger, the CCD and readout register start running a "keep clean" cycle. Pulse number one arrives at 00:00:00, however the camera will first finish the current "keep clean" cycle before the CCD is readout (remember that a GPS pulse causes a readout of the CCD). Hence frame number one should be deleted since the exposure time will equal the time between the "keep clean" cycle finishing and the readout starting (which should be simultaneous) and the frame was not readout at 00:00:00. The second pulse arrives at 00:00:01 UT and starts readout of frame two. However since the readout of frame

*Personal communication with Chris O'Kane, Product Support Engineer at Andor Technology.

number one commenced late due to the “keep clean” cycle, frame number two will not have an exposure time of 1s but a value less than 1s and needs to be deleted for this reason. Keep in mind that the GPS continues to send pulses independent of the camera, accordingly the pulses will arrive every one second irrespective of what the camera is doing. At 00:00:02 pulse number 3 arrives to start readout of frame number three. Since frame number two was readout at the correct time, frame number 3 will have exposure time of 1s and can be used.

The final thing to then take into account is that the start time of frame number n equals the time that pulse number *n-1* was sent, since readout of frame number n is also the start time of frame number *n+1*. Hence if the GPS was set to start sending pulses at time T with an interval of dt between the pulses then the start time of frame number n equals $T + (n - 2)dt$.

External Trigger with a None-Zero Delay

Moving on to the case where the “Delay of Exposure Period (secs)” is not set to zero, the start of each exposure will be delayed by the value entered into the “Delay of Exposure Period (secs)” box. As an example, suppose the “Delay of Exposure Period (secs)” is set to one second and the trigger period to two seconds (just longer than the value displayed in the ”Minimum Triggering Period (secs)” box in the main camera setup). The first trigger is received, the camera waits for the current cleaning cycle to complete before reading out the imaging area. An additional one second elapses during which time the imaging area is cleared by running “keep clean” cycles, before starting the exposure. The second trigger is received one second later starting the process again. This means that the exposure time will be equal to one second (not two) since the GPS triggers come in every two seconds regardless of what the camera does and after each trigger the camera waits for one second before starting the exposure. It is very important to note that during the delay the camera will run “keep clean” cycles and will at the end of the delay period first finish the current cycle before staring the exposure. As a result there will be an uncertainty in the exposure and start time of each frame of aproximatly 23 microseconds, with the start time of frame number n will equal the time that trigger number *n-1* was received plus the “Delay of Exposure Period (secs)” value.

External Start

This mode is essentially a combination of the internal and external triggering modes. What happens is that the camera will run “keep clean” cycles until the first trigger is received. When this happens, the current “keep clean” cycle is fished before the exposure for frame one starts. Note that the GPS trigger in this case does not cause the imaging area to readout but rather stops the “keep clean” sequence, thereby staring the first exposure. The camera now switches to internal triggering and continue as described in Section $A.3.18$ using the parameters set in the main camera setup window.

A.3.19 Downloading Data

Note that because of the amount of data that can be taken on any given night, the SHOC computers are locally purged of data every two weeks. Please make sure your data is copied throughout the night, or at the end of each night!

At the Telescope

Data that have been transfered to the server can be copied onto any computer connected the the network using 'sftp ccdX@ltsp.suth.saao.ac.za", please contact technical support for the password. Once this has been done type cd /data/Tin/shocnawe/YYYY/MMDD where YYYY and MMDD is the year, month and day on which the sought after observations was done and T is once more the the size of the telescope ('74", "40", or "30"). The files can now be downloaded by typing "get *", all files in that directory will then be saved to the computer used, in the current directory.

In Cape Town

Using the same method as at the telescope, data can be copied onto a computer in Cape Town using: sftp username@ltsp.suth → enter password → cd /data/telescopedata/74in/shocnawe/YYYY/ → cd into MMDD folder → get *. Where "username" is your SAAO username.

A.3.20 .fits Header Key Words

In the above sections it has already been mentioned a few times that care should be taken when dealing with the .fits headers as there is information that is recorded incorrectly, missing or can easily be misinterpreted. In this section additional problems that users should be aware of will be mentioned and those already mentioned repeated (to allow easy reference).

1. Only one header is written per data cube, if a cube is split into separate images in IRAF, the headers for all of the individual frames are identical to that of the cube.

2. No filter, GPS or telescope or target information is recorded.

3. EXPOSURE: When the camera is placed in "External" triggering mode, the .fits header key word "EXPOSURE" should be "READOUT DELAY". A value of 1.0E-05 is equivalent to zero.

4. FRAME:

   (a) The time is in UT not SAST.

   (b) Internal Trigger: The time recorded as start of exposure time is rounded to the nearest second.

   (c) Internal Trigger: The start time record in the "FRAME" keyword is not the start time of the first exposure but the time when the file was created (at the end of the first exposure).
   (d) External trigger: The time recorded on the "FRAME" keyword in the .fits header is not the GPS time at which the first frame was triggered but rather the trigger time plus an unknown offset.

5. GAIN: The key word "GAIN" gives the EM gain and is recorded as zero when EM is switched off or the CON mode is used. Neither the preamplifier gain, read noise, effective read noise or effective electron to ADU gain are recorded in the .fits headers. Values for the electron to ADU gain and read noise (from which the effective values can be calculated by dividing by the EM gain) are given in Tables A.6 and A.7.
6. SERNO:
   (a) If "SERNO" = 5982 then SHOC 1 was used.
   (b) If "SERNO" = 6448 then SHOC 2 was used.
7. READTIME:
   (a) If READTIME = 1.0E-06 then the 1MHz 16bit mode was used.
   (b) If READTIME = 3.0E-06 then the 3MHz 14bit mode was used.
   (c) If READTIME = 5.0E-06 then the 5MHz 14bit mode was used.
   (d) If READTIME = 1.0E-07 then the 10MHz 14bit mode was used.

A.3.21 Handling Data Cubes

SHOC saves images in data cubes which are three dimensional .fits files which contain multiple images saved as a single file. The data cubes produced by SHOC can be handled by splitting them up into single .fits files. This is done by using the "imslice" command in IRAF, see the in built help command for more details. The user should however note that when a cube is sliced, the new .fits headers created for each image will be identical to the original header for the cube.

A.3.22 Trouble Shooting

1. If asked for an administrative password, please contact technical support.
2. In the case that the computer crashes:
   (a) Restart the computer and following the normal start up procedure.
   (b) In the main camera setup (Figure A.3), under the "Auto-Save" tab, change the value in the box marked "Start Value" to one higher than that of the final cube taken before the crash. Note, if this is not done, images will not be overwritten, rather the new images will have an additional .01 appended to the file name.

3. Should the camera over heat (this normally results from the air outlets being blocked), an alarm will sound from the camera. Unfortunately no indication or reason for the alarm will be given on the control software. In the case that this happens please shut the instrument down and contact electrical support immediately, **THE CAMERA MAY NOT BE USED WHILE THE ALARM IS SOUNDING.**

A.3.23 Additional Notes and Warnings

1. **The camera does not have a shutter.** Consequently please stop exposures when slewing, when the telescope is not tracking a target, before any lights are switched on in the dome or the dome shutters are opened during the day.

2. **UNDER NO CIRCUMSTANCES SHOULD ANY CABLES BE PLUGGED IN OR OUT OF EITHER SHOC 1 AND 2, SHOCNAWE, SHOCNDISBELIEF OR SHOCNHORROR WHEN THERE IS POWER ON THEM, OR THE CONTROL COMPUTER IS POWERED UP. THIS IS IN ORDER TO PREVENT DAMAGE TO THE ELECTRONICS AND CONTROL CARDS.**

A.4 Choosing Observing Settings

A.4.1 Electron to ADU Gain, Readout Rate, EM Gain and Camera

Please see Section A.3.10 and A.3.11 on how to select the optimal gain, readout rate and EM gain.

While the read noise and electron to ADU gain of SHOC 1 and 2 are very similar (Tables A.6 and A.7), the full well saturation differ significantly (143,838 and 79,169 electrons for SHOC 1 and 2 respectively) which does make a difference to the saturation limits and dynamic range that can be attained (please see Tables A.3 and A.4).

A.4.2 Choosing a Telescope, EM or CON and Lunar Condition.

In order to select with which telescope, EM or CON mode, exposure time and under which lunar conditions to observe a star of particular magnitude, predicted SNR curves in the V filter for the EM and CON modes can be plotted as a function of exposure time, sky brightness and telescope. From these curves, an observer can determine how to, and under which conditions, to observe their target.

The first thing that is required is a value for the magnitude of the sky inside the aperture in which the SNR is measured (it is recommended that an aperture radius of $3 \times FWHM$ is used as 98% of the stellar signal will be contained inside the aperture) which can be obtained using

$$M_{sky} = B - 2.5 \log(A), \tag{A.1}$$

where B is the sky surface brightness in magnitudes per square arcsecond ($mag/arcsec^2$) and A is the area inside the aperture. While $A = aparure\ radius \times binning \times plate\ scale$, a value of 21.7* $mag/arcsec^2$ and 19.7† $mag/arcsec^2$ can be used for the sky surface brightness in the V filter under dark and bright conditions respectively.

Equations A.2 and A.3 can now be used to calculate SNRs for the V filter in the EM and CON modes, where t is exposure time in seconds, M_* is the V magnitude of the target star, $n_{pix} = \Pi(aparure\ radius)^2$ is the number of pixels inside the aperture, N_R is the read noise in electrons per pixel, EM_{gain} is the EM gain and $s_F\ and\ c_F$ are the coefficients given in Table A.9. By plotting predicted SNRs as a function of exposure time and sky brightness (such as the example shown in Figure A.9), an observer can decide on the best way in which to observe their target.

$$SNR_{CON} = \frac{t10^{s_F M_* + c_F}}{\sqrt{t10^{c_F}(10^{s_F M_*} + 10^{s_F M_{sky}}) + n_{pix} N_R^2}} \tag{A.2}$$

$$SNR_{EM} = \frac{t10^{s_F M_* + c_F}}{\sqrt{2t10^{c_F} 10^{s_F M_{sky}} + n_{pix} \frac{N_R^2}{EM_{gain}^2}}} \tag{A.3}$$

Table A.9: SNR coefficients.

Telescope	s_F	c_F
1.9m Without Focal Reducer	-0.400 ± 0.001	9.750 ± 0.004
1.9m With Focal Reducer	-0.400 ± 0.001	9.483 ± 0.006
1.0m	-0.400 ± 0.001	9.277 ± 0.005
0.75m	-0.400 ± 0.002	9.140 ± 0.186

When looking at Figure 3.8 it is important to realize that although curves are only plotted for the 1MHz EM mode, curves for the 3,5 and 10 MHz EM modes will be identical to those of the 1MHz EM as long as an appropriate EM gain is used for the specific mode. The cause of this is that although the different EM modes have different read noises (which is the only difference between the modes in terms of noise), the effective read noise can be decreased to the same value in each mode by using an appropriate value for the EM gain.

Finally it should be stated that the SNR values obtained above should be treated as a guide and not a guarantee. The SNR values that will be obtained on a specific night will differ from the predicted values due to different seeing, extinction, humidity, cloud cover, filter band pases, sky surface brightness, lunar phase, lunar cloud illumination, CCD QE and telescope throughput. The only way to know for sure what SNR will be obtained on a given night and whether or not a higher SNR will be obtained in th EM or CON mode is to take a few frames and measure the SNR. It should be mentioned that in order to test the accuracy of the predicted SNR, this was done and it was found that the SNR values

*The average dark sky background measured at Sutherland between 1986 and 2012. Measurements were performed under dark moon conditions in an area of the sky in which no visible stars were present.

†Krisciunas & Schaefer (1991) found that under a three quarters moon, the sky brightness in the V band increases by about 2 magnitudes at a position angle of 90 degrees from the moon.

Table A.10: Hardware specifications

	Model	Serial Number
SHOC 1	DU-888E-C00-UVB	X-5982
SHOC 1 CCD	E2V TECH CCD201	10011-03-01
PCIe Card 1	CCI-24	C-5986 (SHOCnawe)
SHOC 2	DU-888E-C00-UVB	X-6448
SHOC 2 CCD	E2V TECH CCD201	20-1-139
PCIe Card 2	CCI-24	C-5915 (SHOCndisbelief)
PCIe Card 3	CCI-24	C-6400 (SHOCnhorror)

obtained were withing 15% of the predicted values.

A.5 Technical Information

The following section will give technical specifications for the camera and other hardware (GPS, computer, cables, connectors etc.). The user manuals for SHOC (labeled Andor), computer and GPS can be found on the link labeled manuals on the desktop once logged into the control computer, as well as on the SHOC website (http://shoc.saao.ac.za/).

A.5.1 Systematics

Figures A.10 and A.11 are two line diagrams showing the position of the various sub components relative to the telescope and wiring between them.

A.5.2 The SHOC System

Each SHOC system consists of an off-the-shelf Andor iXon 888 EM CCD cameras, a control computer, and a Spectrum Instruments, Inc. Intelligent Reference/TM-4^{TM} GPS . The CCD is a back-illuminated, frame-transfer CCD with UVB coating and 1024 x 1024 pixels each of which is $13\mu m$x$13\mu m$ in size.

In total there are two cameras (SHOC 1 and 2) and three identical control computers (each of which has its own GPS). While SHOCnawe and SHOCndisbelief are normally used with SHOC 1 and 2 respectively, SHOCnhorror serves as a backup system. In the case of a hardware failure any of the three control computers can simply be swapped out with each other.

A.5.3 Cooling

The camera housing contains a thermoelectric cooler. The cooler is powered by a 2.1 mm Jack connector which goes through an adapter (Input: 100-250 V, 47-63 Hz, 0.4 A, Output: 7.5V, 4.0A) and to a standard 120 V U.S. Plug. The cooling cable has a length of 1.2m, setting the maximum distance that SHOC can be separated from the control computer.

Additional cooling is possible via water cooling; however, this method is not used and has not been tested.

A.5.4 PCI Interface

The controller card for the camera is a PCIe card. The camera-computer cable is 3-m long and has proprietary 36-way connectors. Both PCI card and cable are provided by Andor Technology.

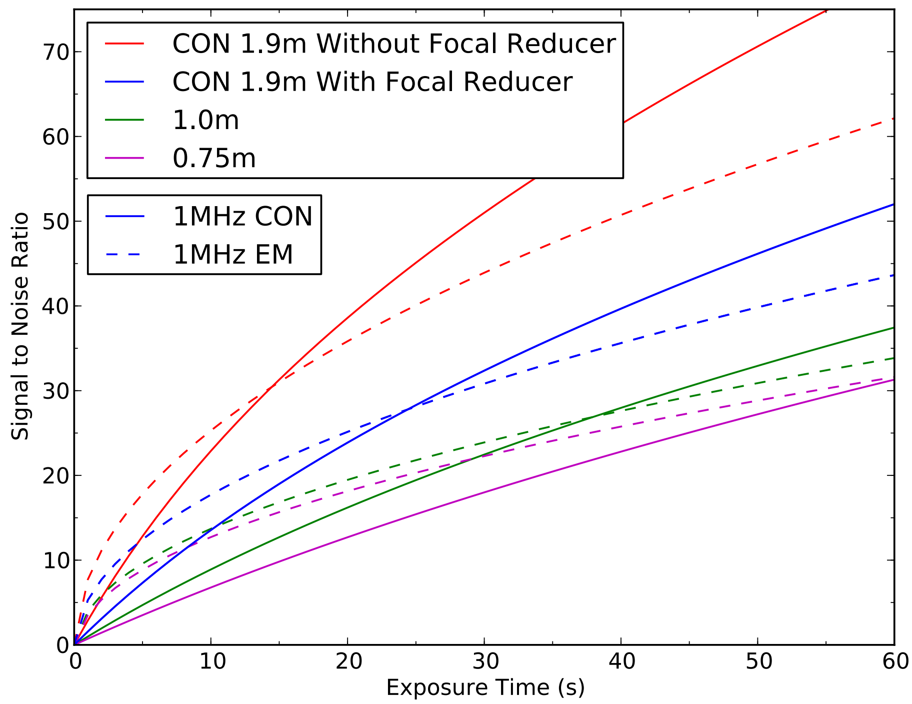
A.5.5 GPS, GPS Trigger and Antenna Cable

The GPS is a Spectrum Instruments, Inc. Intelligent Reference/TM-4^{TM}. A complete user manual can be found either on the SHOC website or in the Manuals link on one of the control computers.

The trigger cable running between the GPS and camera is a 3m RG-174U cable with 5.05ns/m delay, 50Ω resistance. A SMB connector is fitted to the end of the cable that connects to the camera, and a BNC connector to the other. The input is TTL level and CMOS compatible and has 470Ω impedance.

The cable running between the GPS and GPS receiver is a RG-58 co-axial cable with 5.05ns/m delay and length depending on the telescope (see Table A.1). The GPS is connected to the computer, trigger cable, and power via an octopus serial cable. A serial connection goes to the computer, a BNC connection from the "output" octopus cable goes to the "external trigger" SMB on the camera, and power comes from an adapter (Input: 120-140 V, 0.4 A, Output: 24 V, 0.4 A) with a standard 120 V U.S. plug. A BNC cable runs from the "antenna" GPS port to the GPS antenna mounted at the top of the telescope.

In addition to power, three cables need to be disconnected whenever SHOC is dismounted: BNC from the antenna to the GPS, trigger cable between GPS and camera and PCIe between the computer and camera.



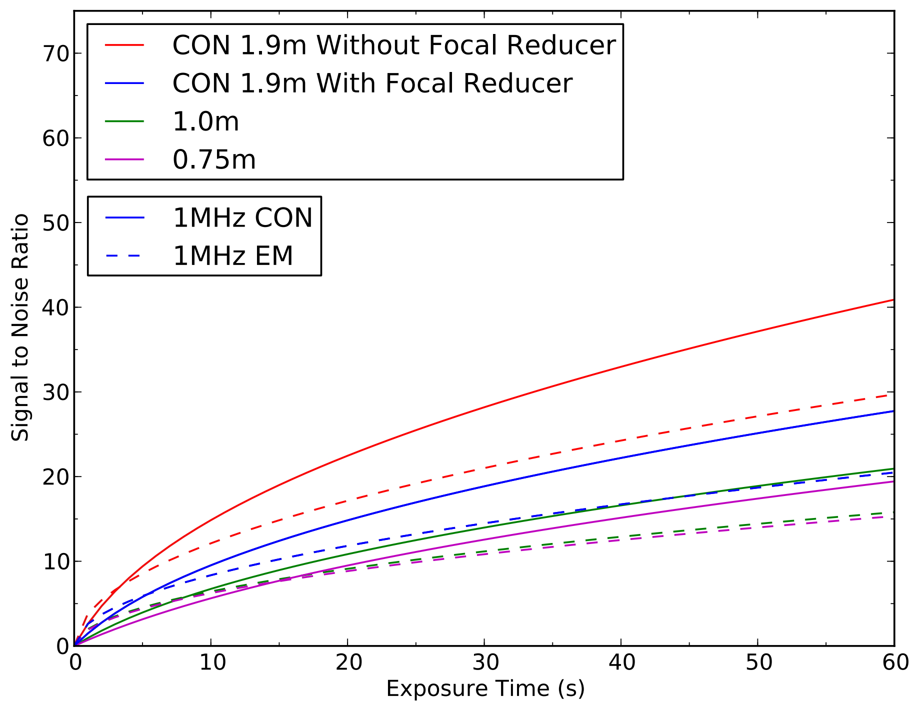


Figure A.9: Predicted SNRs for an V $= 18^{th}$ magnitude star on the 0.75m, 1.0m and 1.9m with and without the focal reducer in SHOC 1's 1MHz EM and CON modes under dark (top) and bright (bottom) conditions (surface brightness of 21.7 $mag/arcsec^2$). In order to calculate the values, a seeing of 1.5 arcsec were assumed, that an appropriate binning (1.9m without focal reducer: 6×6, 1.9m with focal reducer: 3×3, 1.0m: 3×3 and 0.75m: 2×2) is used on each telescope (two to three super pixels across the seeing disk), the EM gain is set to 25 (just above the read noise of 19.75 electrons per pixel) and all stars are extracted inside an aperture of radius nine pixels (which corresponds to just more or less than $3 \times FWHM$ depending on the binning used in each telescope).

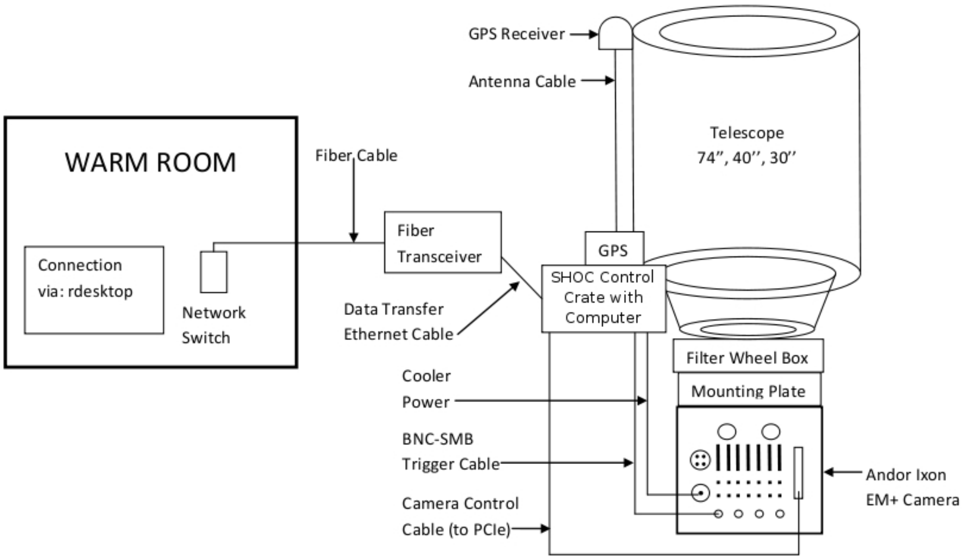


Figure A.10: Schematic of SHOC when mounted on the Telescope.

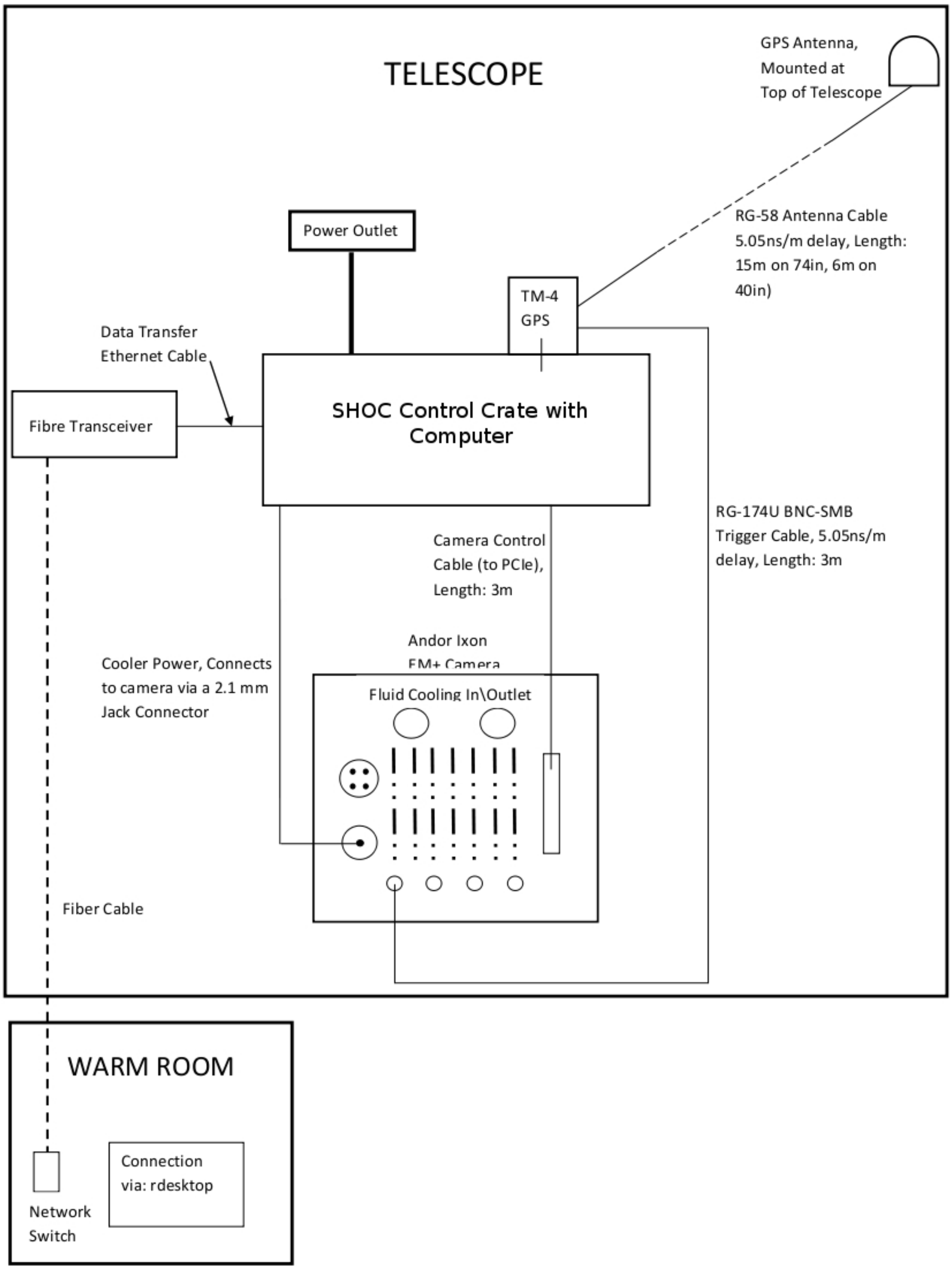


Figure A.11: Schematic of SHOC, Including Technical Information.