CCD User’s Manual

Version 1.22 – January 12, 2024

This equipment has been tested and found to comply with the limits for a Class B digital device pursuant to Part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses, and can radiate radio frequency energy, and if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

- Reorient or relocate the receiving antenna.
- Increase the separation between the receiver and the equipment.
- Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.
- Consult the dealer or an experienced radio/TV technician for help.
- Use shielded I/O cables when operating this equipment.
- You are also warned that any changes to this certified device will void your legal right to operate it.

Industry Canada Compliance Statement
This Class B digital apparatus complies with Canadian ICES-003.

European Union - Compliance to the Electromagnetic Compatibility Directive
This product is in conformity with the protection requirements of EU Council Directive 2004/108/EC on the approximation of the laws of the Member States relating to electromagnetic compatibility. This product has been tested and found to comply with the limits for Class B Information Technology Equipment according to European Standard EN 55022. The limits for Class B equipment were derived for typical residential environments to provide reasonable protection against interference with licensed communication devices.

Visit us at:

http://diffractionlimited.com

Diffraction Limited

E-mail: orders@cyanogen.com

33 Roydon Place, Unit 5, Ottawa, ON Canada, K2E 1A3

Telephone: 613-225-2732

Fax: 225-225-9688

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ALUMA CCD User's Manual

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IMPORTANT!

Please read this guide thoroughly before installing and operating your new ALUMA CCD camera. It is important to fully understand and follow all installation, operation, and maintenance procedures as stated to ensure proper functionality. Failure to do so may affect your warranty!

ALUMA Imaging Technology

The ALUMA® CCD Series cooled imaging cameras have been engineered from the ground up to provide the highest performance possible in a compact, lightweight package. ALUMA was designed for a wide variety of imaging sensors to support different low-light imaging applications. All cameras include a high reliability, even-illumination mechanical shutter, which facilitates dark/bias calibration and photometric-quality imaging.

ALUMA features USB 2.0, and some versions have a WiFi 802.11 b/g/n interface. This allows ALUMA cameras to be controlled by Windows®, Macintosh®, and Linux computers.

A range of compatible ALUMA accessories are available. The FW8S-ALUMA filter wheel supports eight 36 mm filters (or 1-1/4" with adapter rings), and features high precision indexing to ensure repeatable flat-field calibration. For autoguiding the StarChaser SC-2 guide camera provides off-axis guiding in front of the filters for optimum sensitivity. ALUMA is also compatible with the AO-8A adaptive optics unit, which provides tip-tilt image stabilization.

The ALUMA CCD Cameras

Our mid-size ALUMA® CCD camera series offers excellent performance, very low noise, and a rich set of features. In addition, all ALUMA camera models include MaxIm LT for Windows. ALUMA also supports third-party applications through ASCOM and native ALUMA drivers.

ALUMA features

- Wide variety of imaging sensors
- Light weight, compact design
- Centered optical axis for optimum instrument balance
- Ultra-reliable even-illumination (photometric) mechanical shutter that facilitates accurate dark/bias calibration frames
- Driver support for Windows, Macintosh, and Linux
- USB 2.0 and optional WiFi 802.11 b/g/n communications interfaces
- Full frame image buffering eliminates readout artifacts and provides 100% reliable wireless download
- Two-stage TE cooling for typical maximum of -50 C delta T
- Twin variable speed fans with SmartCooling™ technology
- High accuracy temperature regulation
- Built-in RBI Pre-flash (full frame front-illuminated sensors only)
- External TTL trigger inputs and output
- Included 110V / 220V power supply and optional 12VDC operation
- User-rechargeable desiccant plug
- Built-in 1/4-20 tripod mount
- Support for high precision 8-position filter wheels
- Support for external guide head, self-guiding filter wheels, and adaptive optics
- Bulletproof firmware update capability – virtually impossible to “brick”

Refer to Appendix A-4 for detailed camera specifications.

Multi-platform operation

ALUMA is designed to operate via USB 2.0, and some versions support WiFi 802.11 b/g/n. Designed from the ground-up to support operation on any modern computing platform, ALUMA is compatible with Windows, Macintosh, and Linux. Fully-documented and supported drivers are available for all platforms, including ASCOM drivers.

1 - Installation

1.1 Components

Camera

Your ALUMA camera and accessories are provided in a foam-lined hard shell protective case. Observe proper handling procedures for sensitive electronic equipment and unpack the contents carefully in a clean, dry area. Inspect the contents to ensure all components are present and in good order. You should find the following:

- ALUMA main camera body (with handles and desiccant plug installed)
  - Refer to Appendix A-4 for camera model specifications
- Camera dust cap (10078)
- Power supply: 12V @ 6A Universal (60014A)
  - Power cable with US plug (51089) (type specified on ordering)
  - Power cable with European plug (50392) (type specified on ordering)
  - Power extension cable (68007)
- USB flash drive
- 2” Nosepiece adapter with cap (50146)
- Ferrite clip (51354)
- Relay cable RJ11-RJ11 (50711)
- USB A Male-to-Mini B 5 pin Male cable, 15 feet (68006)

Filter Wheel

The optional ALUMA filter wheels were designed exclusively for use with the ALUMA cameras. Inspect the supplied contents to ensure all components are present and in good order. You should find the following:

- FW8S-ALUMA 8-position filter wheel
- T-thread adapter plate (40-12051-00) attached to filter wheel
- Ferrite clip (20-12118-00)
- O-rings, 2-027 (8 pieces) (41006)
- Hex wrench 3/32” (51867)

1.2 Installing the Software

NOTE:
If you already have MaxIm DL Pro, **please update to the latest version**.

The MaxIm LT imaging application supplied with your ALUMA camera allows you to operate it using a Windows computer. The application is found on the flash drive included with your camera. Drivers (excluding application software) are also provided for the Mac and Linux operating systems.

System requirements

The following hardware is required for MaxIm LT:

- MS Windows (applicable versions: 7, 8, 8.1, 10)
- Recommended minimum memory size: 1 GB or larger.
  Processing larger images or opening multiple images simultaneously will require correspondingly more memory. 2 GB memory is recommended for processing large arrays, including images larger than 6 megapixels.
- Disk space: 100 MB for program installation
- Video display: 1024x768, 16-bit color or higher
- Mouse

Windows installation

1. Go to the Registration page on the Diffraction Limited website at:
   https://diffractionlimited.com/maxim-lt-registration
2. Enter the requested information and serial number to register the MaxIm LT application. Use your camera's serial number for this. You will then automatically be emailed a license key.
3. Insert the flash drive into an available USB port.
4. Open Windows Explorer and navigate to the DL Imaging Driver (Aluma) folder on the flash drive.
5. Double-click Launcher.exe, then choose Install MaxIm DL. This applies whether you are installing the included MaxIm LT application or a licensed version of the fully-featured MaxIm DL program.
6. Follow the onscreen instructions and enter the license key you received when prompted.

   NOTE:
   The required camera and filter wheel USB drivers are available through Windows Update. The drivers will automatically be downloaded when the camera is plugged and if an internet connection is present. For computers with no internet connection, the drivers are located on the supplied USB flash drive, in a folder named DL Imaging Driver (Aluma). Browse to this folder when prompted during the installation.

7. Refer to Chapter 2 - Operating ALUMA with MaxIm LT for operational details once the software and hardware installations are complete.

1.3 Installing the Hardware

This section details the steps required to assemble the ALUMA camera and FW8S-ALUMA filter wheel hardware. Diffraction Limited recommends that filters are installed as part of the procedure to mate the filter wheel to the camera.

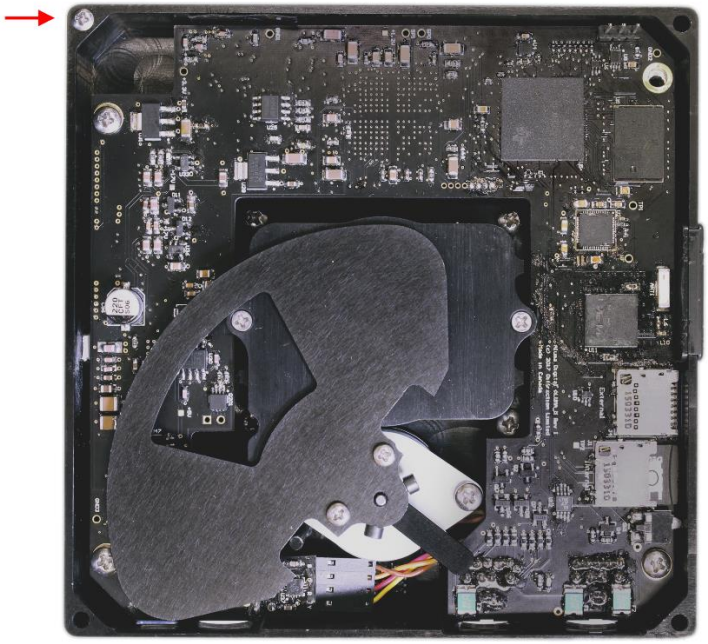
CAUTION:

Do not touch the connectors, wires, or circuit board visible on the exposed inner faces of the camera or filter wheel. Components on the circuit board can be damaged by electro-static discharge.

1. Place the ALUMA camera on a clean dry surface with the sensor side facing up. Orient the camera with its connectors facing you.
2. Remove the front cover plate of the camera by unscrewing the 4-40 x 2" cap screws (use the supplied 3/32" hex wrench) around the perimeter of the plate and lifting it off the camera body.

   The camera's front plate will not be used again when a filter wheel is attached.

   NOTE:
   Once the four screws are removed, the camera's rear plate will be loose so be careful if you need to lift the camera.
3. Reinstall the top left screw (indicated) into the camera. Note that the circuit board is notched in this corner.



Set the camera aside.

4. Place the filter wheel on a clean dry surface with the camera side facing down. Orient it so that the motor is at the top left corner.
5. Remove the four 4-40 cap screws that secure the filter wheel's front plate (FW8S shown) and lift it off the base plate.

Set the front plate aside.

6. Separate the filter retainer from the carousel by removing the eight Philips screws (circled) that attach the filter retainer to the carousel.

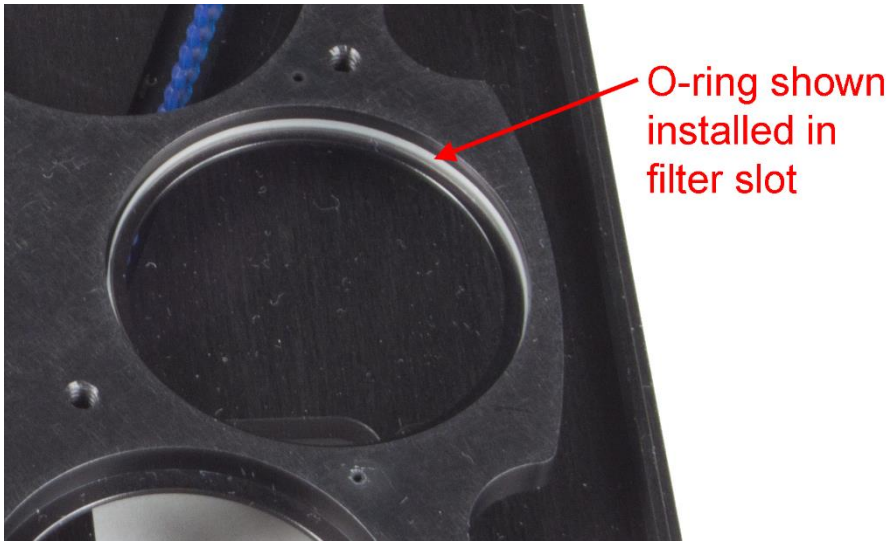
Set the filter retainer aside. Note that the filter retainer is the same size and shape as the carousel and simply attaches to the carousel over the filters to hold them in place.

7. Carefully place the filter wheel bottom plate over top of the camera. Ensure that the connector side is facing in the same direction as the camera connectors.

   The filter wheel motor shaft will be located within the notched corner of the camera's top circuit board. Carefully align the two and gently press together. The filter wheel bottom plate should fit snugly and flush against the front of the camera.

8. Reinstall the remaining three screws (circled) through the bottom plate of the filter wheel.
9. Double-check that all pieces are properly seated and tighten the screws.
10. Determine the location you want for each filter. The carousel slots are numbered 1 to 8. You can later configure the MaxIm LT application to correspond to your chosen filter order.
11. The filter wheel supports eight 36 mm filters (or 1-1/4" filters with adapter rings). Ensure that your filters are clean prior to installation.

12. If you are using filters that are 3 mm thick, then put one of the supplied O-rings into the filter slot before placing the filter into the slot.



If the filters are less than 3 mm thick (e.g., Baader), then place the filter into the slot first, followed by the O-ring. For filters over 3 mm thick, do not use the O-rings.

13. Replace the filter retainer plate over the filters and fasten it to the carousel using the eight Philips screws and washers that you removed in step 6.
14. Replace the filter wheel front plate being careful not to pinch any wires or the I2C cable.
15. Fasten the front plate to the base plate using the four 4-40 cap screws that you removed in step 5.
16. Mount the camera and filter wheel assembly to your optical device. You can use the supplied 2" nosepiece or other proprietary adapter for this, as required.
17. Attach the cabling:

CAUTION:

Never "hot plug" the cables into or from the units. Always disconnect power before connecting or disconnecting any cables.

- The ALUMA filter wheel has a short cable extending from it with a Mini-DIN connector. Plug this connector into either of the I2C/FW/AO sockets on the camera. This cable is the same for both the standard and self-guiding filter wheels and supplies power and control signals to the filter wheel.
- If you have the FW8G-ALUMA Self-Guiding Filter Wheel, also attach the supplied HDMI cable between the HDMI port on the self-guiding filter wheel cover and the GUIDE HEAD port on the camera.
- If you are using the FW8G-ALUMA with an AO-8A Adaptive Optics unit, plug this into the remaining I2C/FW/AO socket on the camera.
- If you are using a StarChaser SC-2, the unit attaches directly to the front plate of the filter wheel.
- TIC RJ11-RJ11 cable – if equipped. This cable is only required for auto-guiding purposes in astronomical imaging. It plugs into the GUIDE OUT connector on the ALUMA camera and connects to the guide port on a telescope mount.
- Attach the USB cable between the USB connector and your computer. This is only required for non-wireless camera operations.
- Install the ferrite clamp in a convenient position along the camera power cable, preferably close to the camera, then plug the cable into the POWER connector.

The camera is now ready to be powered up.

1.4 Applying Power

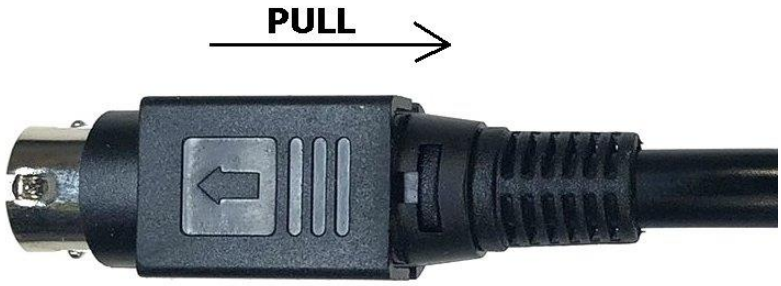
1. Connect the cable between the power supply and the camera.
2. Plug in the power supply to turn it on.

NOTE:
The ALUMA camera comes with a power supply capable of operating from 90 to 264 VAC, and supplies 80W maximum. Actual power requirements are +12 VDC at 5A.

The camera may also be powered directly from a capable +12 VDC source using an appropriate cable (not supplied). Refer to the power jack pinout diagram in Appendix A-3 to source or create such a cable.

IMPORTANT NOTE:

The power connectors have a locking mechanism – both the power brick connector and the extension cable connector. The lock is engaged by pressing the plug into the socket. It is unlocked by pulling back on the shell. If you experience difficulty latching it, try pulling on the shell a couple of times to loosen it up.



Pull to Unlatch

1.5 Testing the Camera and Filter Wheel

Once the camera hardware has been assembled and MaxIm LT is installed and configured, Diffraction Limited recommends that you conduct a simple bench test of the system to verify the functionality of all components.

You should review Chapter 2 - Operating ALUMA with MaxIm LT to familiarize yourself with the basic software connection and operating instructions prior to performing this test.

Proceed with the bench test as follows:

1. Verify that all cabling is properly connected.
2. Apply power to the camera.
3. Open MaxIm LT and connect to the camera (refer to Section 2.1).
4. Set the camera cooler to ON.

   NOTE:
   Operating the camera at very high ambient temperatures (in excess of +40 degrees C) or within a sealed enclosure can lead to overheating. Under these conditions, it is possible that the heat generated by the camera cooler could heat the camera body to the point that the electronics might malfunction. To prevent that, overheating protection has been implemented in the camera firmware. If the camera's internal temperature rises above +75 degrees C, the camera will turn off the cooler completely. No warning of this is provided. However, since the sensor temperature is recorded in the FITS header, you will be able to determine if the cooler stopped working for a particular image.

5. Take a set of exposures including both dark and light frames. Set your exposure length to a very short duration to avoid saturation if you are conducting this bench test under bright lighting conditions. Alternatively, you can limit the light entering the camera by covering the sensor opening using a piece of cardboard with only a pinhole opening in it.
6. If you are using a filter wheel, also take a set of light exposures using each of the available filters to ensure proper operation of the wheel.

2 - Operating ALUMA hardware with MaxIm LT

The MaxIm LT application allows full configuration and control of the ALUMA cameras and filter wheels as well as Diffraction Limited adaptive optics units. Calibrating files, automating imaging sequences, logging, and various image processing tasks can all be performed. Please note however that since MaxIm LT and MaxIm DL both share the same Help file, not all features detailed in that file will be enabled in MaxIm LT. Full feature access requires MaxIm DL Pro.

The procedures in this chapter are intended as a basic introduction to connecting and operating the ALUMA hardware. Consult the Help file for further information on specific parameters, detailed procedures, and various tutorials.

2.1 Connecting the ALUMA Camera to MaxIm LT

The following is the basic MaxIm LT procedure used to configure and connect to the ALUMA camera and an optional filter wheel.

1. Launch the MaxIm LT application.
2. Click the Camera Control icon or press Ctrl-W to open the Camera Control window and click the Setup tab.
3. Click the Setup Camera button under Camera 1. The Setup DL Imaging form opens.
4. Click the Camera Model drop-down. Three choices are available: Simulator, DL Imaging, and SBIG Universal. Select DL Imaging.
5. Configure the IP Address parameter on the form, if required.
6. Click the Advanced button. The DL Config form opens. This form allows you to check camera parameters and also to perform firmware updates and additional camera configuration.
7. Select your camera from the Devices list. Various camera parameters will auto-populate the display fields in the form. Also note that the next time you open MaxIm LT, your serial number will appear in the Camera dropdown in the Setup DL Imaging form.
8. Click the Settings button. The DL :: Settings form opens to allow access to additional camera settings. Configure as required and click OK to accept the settings and close the form.
9. Click OK to accept the settings in the DL Config form and close it Your preferences will also be saved.
10. Click OK to accept the settings and close the Setup form.
11. Click the Options button under Camera 1. The Options form opens.
12. Configure any of the optional camera parameters if required or use the default values as a starting point.

13. Click OK to accept the settings. The Options form closes.
14. Click the Setup Filter button under Camera 1 if you are using an ALUMA filter wheel controlled by MaxIm LT. The Setup Filter form opens. Otherwise, go to step 15.

    NOTE:
    Controlling filter wheels from other manufacturers requires a fully-featured application such as MaxIm DL Pro or other supportive software.

15. Select DL Imaging+FW from the drop-down menu.

    NOTE:
    You can edit a filter's name in this form by double-clicking the existing name in the list.

16. Configure any other parameters that appear on the form or use the default values as a starting point.
17. Click OK to accept the settings. The Setup Filter form closes.
18. The settings under Camera 2 are used to connect to a second separate camera for guiding purposes.

    NOTE:
    If you are using the self-guiding FW8G-ALUMA filter wheel (for astronomical imaging), you must select the Dual Chip Mode for Camera 1 instead. Camera 2 is not used for this purpose.

    Repeat steps 3 to 17 if required for Camera 2.

19. Click the Connect button to establish camera communications.
20. Enable the camera cooler(s) by clicking the On button.
21. Click the Cooler button under Camera 1. The Set Camera Cooler form opens.
22. Set the desired cooler temperature (in degrees Celsius) and click OK. The Set Camera Cooler form closes.
23. Click the Cooler button under Camera 2, if applicable. The Set Autoguider Cooler form opens.
24. Set the desired cooler temperature (in degrees Celsius) and click OK. The Set Autoguider Cooler form closes.

The ALUMA camera and filter wheel are now connected and ready to begin imaging.

NOTE:
When attaching the ALUMA camera to your operational equipment such as a telescope, consider looping the USB and power cables around the camera handle to provide strain relief. Cable tie wraps can also be used for this purpose.

2.2 Basic Imaging Procedure

After setting up the ALUMA camera and filter wheel as stated above, the Expose tab in the Camera Control window allows you to set the exposure parameters and initiate imaging. This procedure details the basic approach to imaging with the ALUMA camera.

1. Click the Expose tab.
2. Configure the parameters as follows:
   - Click on the Camera 1 radio button.
   - Exposure Preset: The presets allow you to quickly configure the exposure parameters for different types of imaging. Use the Standard exposures option for this introductory imaging procedure.
   - Readout Mode: Normal
   - Frame Type: Light
   - Filter Wheel: Luminance
     You can only set this parameter if you configured a filter wheel for the camera. A Luminance filter allows full visible spectrum illumination of the sensor, but you can select another filter type if you wish. If one of your filter slots is empty, you can also use that instead.
   - X Binning: 1
     When binning greater than 1 is selected, the electronic charge from groups of adjacent 2x2 or 3x3 pixels is electronically summed in the camera before readout. This process adds no noise and effectively increases sensitivity at the cost of lower spatial resolution. Binning of the X and Y axis of the sensor can be configured individually.
   - Y Binning: Same or 1
   - Subframe: Deselect the On checkbox. This will ensure that you capture the entire frame, rather than just a part of it.
   - Seconds: Set the desired exposure time in seconds. You can use the scroll arrows or type in a value into the field. Exposures of less than a second must be entered as decimal values.
3. Click the Options arrow. A fly-out menu is displayed. This is used to access and configure a number of imaging parameters to customize your imaging requirements.

   For this introductory imaging procedure, set the following:
   - Click on No Calibration.
   - Click on Set Image Save Path. The Select Folder form opens. Use this to specify where to save your images.
   - Click on Exposure Delay. Use this if you want to set a delay time (in seconds) prior to beginning an exposure. If you are taking a continuous sequence, this delay will be applied between each image.
   - Click on Show Tool Tips if you want to display pop-up tips on form options.

4. To begin an individual exposure, click the Single radio button and then the Start button. You can end the exposure manually at any time by pressing Stop. You must save this image manually if you want to keep it.
5. To begin a continuous sequence of identical exposures, click the Continuous radio button and then the Start button. The sequence only ends when you press Stop. This mode is generally used for focusing and framing purposes, and acquired images are not saved.
6. To configure a custom sequence of exposures, click the Autosave button. The Autosave Setup form opens.

   For this introductory imaging procedure, set the following:

   - Autosave Filename: Enter the base filename (e.g. “M27”) you want to use for the sequence of images. Each image file taken will use this name, appended with an individual frame number, for example, "M27-001.fit".
   - Dither: Off
   - Delay First: Specify a delay time (in seconds) prior to taking the first exposure, if desired.
   - Delay Between: Specify a delay time (in seconds) between exposures, if desired.
   - Click the Slot 1 button and configure each of the parameters on the line as you require. The Repeat parameter allows you specify how many of these particular exposures will be taken. An optional Suffix can also be automatically applied to the end of the filename to aid you in identifying the image later on. For example, if you configured a Red filter slot, you might want to add a Suffix of "R". This will produce a filename such as "M27-001R.fit". If you use only one imaging slot then you don’t really need a suffix. However, if you set up multiple slots and want to add a suffix, then each suffix must be unique. You can configure up to 32 slots when setting up an Autosave sequence.
   - Click OK when you are finished configuring the sequence.
7. To begin the custom sequence, ensure that the Autosave radio button is selected and click Start. You can end the Autosave sequence at any time prior to its completion by pressing Stop.

3 - Image Calibration

Image calibration, also known as image reduction or pre-processing, applies corrections for tiny defects and variations in the camera sensor and optical system. Proper image calibration is of the utmost importance in producing the highest-quality images possible.

No electronic imaging device is perfect. Each sensor has a unique response in the following three areas:

- Bias level
- Dark current
- Raw sensitivity to light levels

These effects don't just vary from sensor to sensor, they also vary from pixel to pixel within the same sensor. Each response affects the intensity represented in every pixel of the image in a specific way. The combined effect of these pixel variations may be relatively small on brightly-lit images, but under low-light conditions, they can become extremely important.

The majority of the problems caused by these variations can be readily removed by calibrating the raw image. Performing basic image calibrations can provide a huge improvement in the signal-to-noise ratio, resulting in much greater sensitivity. Nominalizing these variations also provides a truer representation of the subject in the working image. This provides the best possible basis for any subsequent image processing.

The basic calibration steps are termed Bias, Dark, and Flat-Field calibration. These are detailed below. A general workflow is then provided for image calibration and the subsequent combining of multiple light frames, if required.

Refer to the online Help file for further information and more detailed procedures, as required.

3.1 Bias Frame Calibration

Bias is an offset that occurs when a pixel is read from the camera. Unfortunately, bias can vary across the image. Also, if bias is not corrected, then flat-field calibration will not work correctly.

A bias frame is essentially an exposure with a duration of zero (or in reality, as close as possible to zero length) and taken with the shutter closed. Each pixel will have a slightly different value, but except for a small amount of noise, the value for any one pixel will be consistent from image to image. Since the bias is consistent from image to image, it can be subtracted.

The bias frame itself contains a small amount of readout noise. This readout noise is produced inside the electronics that read the pixels. It can be very low in sophisticated cameras, but it is never zero. This noise can be easily suppressed by combining a number of bias frames together.

Ideally, the other types of calibration frames should also be bias-frame calibrated. MaxIm LT does this automatically when bias frame files are selected.

The bias for a particular camera is generally constant over a substantial period of time. This means that you can take bias frames just once, and use them on all your images for many months to come. Note that some cameras may have a small bias dependency on temperature. Small bias offsets are not important of themselves, but they can degrade the effectiveness of flat-fielding calibration.

It should be mentioned that bias is also included in dark frames. As such, it actually is possible to perform accurate calibration without using bias frames. That said, you should *always* use bias frames if either of the following are true:

- You are using exposure scaling to match dark frames to light frames
- You are using flat-field frames but are not using matching dark frames ("flat-darks")

Bias frames are extremely easy to acquire, so there is little reason to skip them. You can quickly acquire 10 or 20 frames to average, so the read noise in the bias frames will not be contributing to your overall noise level.

Taking Bias frames

1. Connect to the camera (as per section 2.1) and click the Expose tab.
2. Configure the tab's parameters as follows:
   - Click on the Camera 1 radio button.
   - Exposure Preset: irrelevant
   - Subframe: Deselect the On checkbox. MaxIm DL will extract the appropriate subframe from the calibration full frame if required.
3. Click the Options arrow and set the following:
   - Click on No Calibration.
   - Click on Set Image Save Path and specify the file location.

4. Click the Autosave radio button to configure a sequence of 10 to 20 identical exposures. You only need to configure one slot with the required parameters:
   - Type: Bias
   - Filter: irrelevant
   - Exposure: Set to the shortest possible value for your camera
   - Binning: Set to same as your Light frames
   - Readout Mode: Normal
   - Repeat: Set to the number of exposures you want

   Click OK when done.
5. Click the Start button to begin the sequence.

When the sequence completes, you will have a set of bias frames that can subsequently be used to create a calibration group and apply a bias calibration to your light frames.

3.2 Dark Frame Calibration

Every camera sensor produces a certain amount of dark current, which accumulates in the pixels during an exposure. The dark current is produced by heat, and high-performance cameras cool their sensors to minimize this effect.

The main problem with dark current is that it accumulates at a different rate in every pixel. Some pixels are "hot" and others are "cold". Unfortunately there is usually a spattering of pixels that are especially hot, which degrade the image a great deal. Fortunately, the effect of hot and cold pixels can be easily removed by subtracting a dark frame.

A dark frame is an exposure taken under the same conditions as the light exposure, but with no light striking the sensor array. Since each pixel is consistent in its dark current at any one temperature, the dark frame can be subtracted from the light frame to remove the fixed pattern from the image. For most sensors this produces a striking improvement in the image.

Unfortunately, while the rate of dark current is constant, the actual accumulation of dark current is random. Anything that is random in imaging is noise, which is the enemy of sensitivity. Doubling the dark current increases the random noise produced by the square root of 2 (approximately 1.414). This means the hot pixels produce significantly more noise. Since the noise is random and therefore unpredictable, it cannot be removed; in some calibrated images they will be brighter than normal, and in others they will be darker than normal. You can improve the hot pixels, but you cannot completely fix them.

So subtracting a dark frame eliminates noise because it gets rid of the gross pixel-to-pixel variations in dark current. Unfortunately, and perhaps counterintuitively, subtracting a dark frame also adds noise to the image. Every pixel has random read noise, plus the residual dark current noise. This noise does not subtract, but rather adds in a root-sum-square fashion. Therefore simply subtracting one dark frame increases the noise level 41%.

The way to get rid of this noise is to remove it by averaging multiple dark frames. Every time you quadruple the number of averaged dark frames, you drop the noise contribution in half.

Suppressing Hot Pixels

Although you can greatly improve the hot pixels by calibration, there will still be a residual speckle of hot and cold pixels in the image. For astronomical applications, you can “dither” the pointing of the camera slightly between exposures, thus distributing the noise contribution of each hot pixel to a slightly different position on the image. You can then combine a number of images together using the Median, Sigma Clip, or SD Mask algorithm, which will reject the hot pixel contributions altogether.

Dark Frame Scaling

The longer the exposure you take, the more dark current accumulates. This means that the dark frame and light frame must have the same exposure time in order for calibration to work. They must also be taken at exactly the same temperature as nearly as possible, because the rate of dark current accumulation varies strongly with temperature. The TE coolers in the camera allow high precision temperature regulation which greatly simplifies management of the dark frames.

If a dark calibration frame that precisely matches the exposure duration and/or temperature of an image is not available, you can employ Dark Frame Scaling as an alternative. Use a dark frame whose temperature and exposure duration are as close to those of your light frames as possible, and configure the Set Calibration command to perform scaling. Using a bias frame is strongly recommended in this situation (bias is constant and does not scale with exposure time).

There are two types of automatic scaling available: Auto Scale and Auto Optimize. Auto Scale will adjust the scaling based on the exposure times listed in the FITS header. This is useful for situations where the exposure time changes, but the temperature does not. If exposure time information is not available, or the images were taken at different temperatures, the Auto Optimize algorithm will perform an iterative adjustment of the scaling until the noise is minimized.

With a temperature-regulated camera, you can create a library of "master frames" by shooting sets at various temperature settings and exposure lengths. These can then be used to calibrate any matching exposure taken with the same camera. Dark Frame Scaling can then be used if an exact match is not available. If you enter multiple sets of calibration frames into Set Calibration, MaxIm LT will automatically choose the frames that best match the exposure conditions.

Some users just take a single set of long dark frame exposures and use the exposure compensation feature for shorter light exposures. Most cameras are highly linear, so this technique works very well.

Taking Dark frames

1. Connect to the camera (as per section 2.1) and click the Expose tab.
2. Configure the tab's parameters as follows:
    - Click on the Camera 1 radio button.
    - Exposure Preset: irrelevant
    - Subframe: Set to same as your Light frames
3. Click the Options arrow and set the following:
    - Click on No Calibration.
    - Click on Set Image Save Path and specify the file location.

4. Click the Autosave radio button to configure a sequence of 10 to 20 identical exposures. You only need to configure one slot with the required parameters:
   - Type: Dark
   - Filter: irrelevant
   - Exposure: Set to the same length as your Light frames
   - Binning: Set to same as your Light frames
   - Readout Mode: Normal
   - Repeat: Set to the number of exposures you want

   Click OK when done.
5. Click the Start button to begin the sequence.

When the sequence completes, you will have a set of dark frames that can subsequently be used to create a calibration group and apply a dark calibration to your light frames.

3.3 Flat-Field Frame Calibration

Each pixel in the camera has a slightly different sensitivity to light. These sensitivity differences add another noise component to the image (known as flat-fielding error) unless steps are taken to compensate. While flat-fielding correction is important for achieving high quality images, it is absolutely essential for accurate photometric measurements.

Pixel-to-pixel variations in light sensitivity are imprinted into an image, with the more sensitive pixels showing up as brighter dots. When long exposures are used to image extremely faint subjects, such as in astronomical applications, the ultimate sensitivity limit is determined by how precisely the flat-fielding error can be removed.

There are several common sources of flat-fielding variations. Typical sensors have pixel-to-pixel variations on the order of 1%. Vignetting in the optical system can reduce the light flux at the corners of the sensor. Dust on optical surfaces near the sensor can cast shadows (often called “dust donuts” due to their appearance in centrally-obstructed optical systems). Compressed air can help reduce dust donuts, but it is often difficult to completely eliminate them.

To create a flat-field frame, the optical system must be illuminated by a uniform light source and an exposure is taken. To avoid non-linearity at the top and noise at the bottom of the camera's range, the exposure is usually chosen to get an average value of 30% to 50% of the saturation level. The flat-field is then renormalized by dividing each pixel into the average value in the array. Any pixel that is more sensitive is assigned a number slightly below 1 and any pixel that is less sensitive is assigned a number slightly above 1. When this frame is multiplied by a raw image, it removes the sensitivity variations.

Methods for acquiring Flat-Fields

Flat-fielding is by far the most troublesome calibration method. The entire aperture of the optical system must be evenly illuminated with light – if this is not done very carefully, then the flat-field will be wrong. Light leaks will ruin the calibration by adding unfocussed light that did not pass through the optical system. In addition, once calibrated, the camera cannot be moved or even refocused. Finally, some sensors have significant flat-field variation as a function of wavelength (color), and it can be difficult to create a reasonable facsimile of the normal illumination spectrum.

Given these problems, a good flat-field can be very difficult to achieve for certain types of optical equipment, and so this calibration step is sometimes skipped. However, if there is no vignetting and dust donuts are not an issue, calibrating the camera alone may be sufficient. Cover the end of a roughly six-inch long opaque tube with a translucent material (a few layers of white photocopy paper will do in a pinch). Place this over the front of the camera, gently illuminate the assembly with white light (natural or incandescent, not fluorescent or LED), and take an exposure with a duration that produces a brightness level of roughly 30% of full scale. The resulting images can be used to flat-field the camera, regardless of the optics used. Note that the camera’s window must be very clean (that is, no dust spots) for this to work properly.

The flat-field frames themselves must be calibrated to remove bias, and for longer exposures, dark frame correction must also be performed. It is essential that both the flat-field frames and light frames are properly bias corrected, otherwise the flat-field operation will not work correctly (mathematically, subtraction and division are not commutative).

The calibration tools in MaxIm LT handle the mechanics of bias correction and renormalization automatically.

Taking Flat-Field frames

1. Configure your optical system to acquire flat-fields, as suggested above.
2. Connect to the camera (as per section 2.1) and click the Expose tab.
3. Configure the tab's parameters as follows:
   - Click on the Camera 1 radio button.
   - Exposure Preset: irrelevant
   - Subframe: Set to same as your Light frames
4. Click the Options arrow and set the following:
   - Click on Full Calibration. When you configure your calibration schema, include Bias frames and if required, dark frames as well.
   - Click on Set Image Save Path and specify the file location.
5. Click the Autosave radio button to configure a sequence of 10 to 20 identical exposures for each filter you used in your light exposures. Configure one slot per filter with the required parameters and number of repeat exposures you want. Click OK when done.
   - Type: Flat
   - Filter: This must be set to use the same filter as your light exposures. So if you are performing tri-color or narrowband imaging, you must take a set of flat-field images for each filter used.
   - Exposure: Set this to produce an image with 30% to 50% of the saturation level
   - Binning: Set to same as your Light frames
   - Readout Mode: Normal
   - Repeat: Set to the number of exposures you want

   Click OK when done.
6. Click the Start button to begin the sequence.

When the sequence completes, you will have a set of flat-field frames that can subsequently be used to create a calibration group and apply a flat-field calibration to your light frames.

3.4 Understanding Calibration Groups

MaxIm LT allows you to set up the calibration frames into multiple groups of files to provide a high level of calibration automation and flexibility, including:

- Automatic creation of master calibration frame libraries
- Fully-automatic calibration of images sequences involving different exposures, filters, and binning
- Autoguider per-filter exposure scaling without needing new dark frames
- Eliminating the need to shoot autoguider dark frames during a session
- Automatic selection of flat-darks

As previously discussed, calibration requires bias, dark, and flat files. In practice, users can often take exposures with different settings in a single imaging session. Individual exposures may vary by exposure time, sensor temperature, binning, filter band, subframing, and different cameras may even be in use (e.g. an autoguider versus the main camera).

MaxIm LT can perform exposure scaling to account for exposure duration (Auto Scale) and to some extent temperature (Auto Optimize). The software can also automatically extract a subframe from the calibration frames. But differences in binning, exposure bands, filters, and of course cameras cannot be accommodated except by using multiple calibration frames. Switching back and forth manually can be time consuming, particularly if complex exposure sequences are taken with different filters and binning, as is typically done for LRGB imaging and photometry.

A Calibration Group is simply a set of one or more calibration frames that are taken under the same conditions. For instance, a set of 10 dark frames taken at -20C with a specific camera would be one group. A set of flat frames taken with a green filter would be another.

These groups can be automatically generated by scanning a folder or folder tree. All image files with matching characteristics are grouped together, based on the information in their FITS headers. Alternatively, the user can choose to manually create calibration groups.

All the files in a group are combined using an average, median, sigma combine, or SD Mask algorithm to make an internal "master frame" that is used to calibrate images. This master frame is not visible to the user.

However, some users prefer to generate and save the master calibration frames so they can be quickly reloaded and used at a later date. The Set Calibration command allows you to do this. Note however that this step is completely optional and is not required for the calibration process to work properly.

When master calibration frames are generated and saved to disk, the list of groups in the Set Calibration window is automatically replaced by these master frame files. If bias subtraction is enabled and suitable groups are available, the darks and flat masters will automatically be bias-subtracted. Similarly, the flat masters will be dark-subtracted if dark subtraction is enabled and suitable groups are available.

When the masters are saved to disk, they are tagged with header flags to indicate whether these subtractions have been done. In that way when they are loaded again later, MaxIm LT will know whether they need to have these subtractions performed or not.

3.5 Calibrating and Combining Images

While calibration reduces or removes the majority of the problems caused by bias, dark current, and light sensitivity variations in a camera sensor, there is still random noise remaining in the actual scene that the sensor records. If a pixel receives 100 photons of light from a target, there will be 10 photons of quantum photon noise due to the statistical nature of light. Some additional noise will be present due to camera read noise and dark current noise.

The key thing to note here is that this noise is random in nature and varies from frame to frame, whereas the object of interest, such as a distant galaxy, generally does not. By combining numerous individual frames of the same subject, the subject's signal steadily increases in a linear fashion. However, since the noise in a single image is random, its increase in a combined image follows a Poisson statistical distribution and so it increases more slowly. Combining images therefore increases the overall signal-to-noise ratio in the final result, yielding both smoother subject and background appearances.

Combining files (also known as "stacking") is not limited to your light frames, but is also applicable to your calibration frames, since all imaging frames include noise.

When you add or subtract images, the noise is always additive. Subtracting a single dark frame from a light frame will remove large pixel-to-pixel variations in the average accumulation of dark current, but it will also increase the random noise in the light frame by 41%. If instead you averaged sixteen dark frames together prior to subtraction, the noise will only be increased by 10%.

The standard combine method is to Average the frames. This produces the best results for purely random Gaussian noise. Unfortunately if there is an "outlier" pixel on one frame (e.g., a cosmic ray hit) then it will be included in the average.

Median combine is much more effective at suppressing outlier pixels. Unfortunately, median combining increases the noise level 25% compared to averaging. When median combining flat-field frames, renormalization is also required. This ensures that each frame is at the same average brightness. MaxIm LT does this automatically.

An alternative to Median combine is to use Sigma Clipping or Standard Deviation Masking. These techniques throw out outlier pixels and then average the remaining. They are in effect a compromise between median and average, combining the noise reduction advantages of Average with the outlier pixel rejection of Median combine. You can also select renormalization options for these methods.

General workflow for calibrating and combining images

The following is a general summary of the basic workflow used in MaxIm LT to calibrate and combine images. As such, consider it an overview. Numerous parameters not cited here are available to tailor the process to specific imaging types and requirements. Refer to the MaxIm DL Help file for full tutorials, further information, and more detailed procedures, as required.

Under Automatically Generate Groups click the Folder button to browse to a folder containing your calibration images.

1. Use the **Set Calibration** command to set up calibration groups that will be used to calibrate your individual raw light frames. Proceed as follows:
   a) Click Process > Set Calibration. The Set Calibration form opens.
   b) Click the Folder button in the Automatically Generate Groups section to browse to the folder containing your calibration images.
   c) Select Auto-Generate (Clear Old) using the Auto-Generate dropdown button. A set of Calibration Groups will appear in the list, with images pre-sorted by calibration type, exposure, sensor temperature, etc.
   d) To adjust the settings for an individual group, click on the group to highlight it. You can then set the parameters such as Dark Frame Scaling and Combine Type in the Group Properties section as desired. You can also change the Name of a group by double-clicking it in the list.
   e) If you want to create a master calibration file for this group of files, click the Replace w/ Masters button. MaxIm LT will combine the files and display the master file name in the Group Membership field. The master file will automatically be saved in the same folder that contains the individual calibration files. If you choose not to create such master calibration files, MaxIm LT will stack the calibration frames on-the-fly when you calibrate your light frames.
   f) Click OK when you are done.

2. Use the **Stack** command to calibrate and combine your raw light frames. Proceed as follows:
   a) Click Process > Stack. The Stack form opens.
   b) On the **Select** tab, turn on Classify by FILTER if your images were acquired using filters and then click the FILTER button to set up the filter mapping. This will determine what filters are mapped into which LRGB color channels. To change a row, click once on the row, then click once on the Filter Color(s) item, and enter a new value. This will make sure that your filters are automatically assigned to the correct group.
   c) Enable the Mark added images as Auto Calibrate checkbox. Each image will automatically be calibrated as it is needed, using the settings from the Set Calibration command.

d) Click the Add Files button to select the desired files. You can also use the drop list adjacent to the Add Files button to select entire folders of files to add. Browse to the folder where your images are located. When you add individual files or folders, they will appear in the Groups tree at left. You can also deselect individual files from the tree so that they will not be included in the stacking process.

e) Configure the parameters in the Stack form's remaining tabs as required:

- Select the **Quality** tab to configure parameters that limit which files will be stacked, based on various quality criteria.
- Select the **Align** tab to enable precise alignment of images. This is particularly useful in astronomical imaging, where a certain amount of shift from image to image is usually present.
- Select the **Color** tab to customize the color balance settings if desired. Otherwise click the Defaults button, which assumes 1:1:1 color balance.

The parameters contained in these tabs are explained in detail in the Help file. Refer to the *Image Processing – Stacking* tutorial.

f) Select the **Combine** tab and set the Combine Method. For large numbers of images, try using Sigma Clip - a Sigma Factor of 3 is a good starting point. If you have a modest number of images, the SD Mask mode will produce a better result but will take more time - a good starting point is a Sigma Factor of 0.5 and Number of Passes set to 3.

The remaining Combine parameters and options are detailed in the Help file. Set these as required.

g) Click Go to start the stacking process. This may take some time, so you can interrupt and restart the process if needed. If you have multiple image groups, they will be stacked separately. Color sets will automatically be color combined.

When the combining process completes, the final product is a calibrated master light frame that can be used as a basis for any further image processing.

You can save this image in a number of different formats. The FITS (Flexible Image Transport System) file is the standard file format used in astronomical applications. It includes extensive support for header information to describe the image, along with the equipment and procedures used to produce it.

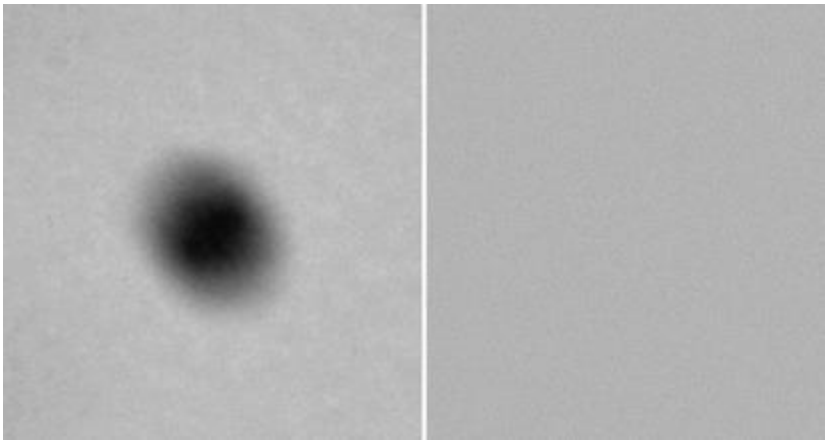
For other applications, we recommend using 16-bit TIFF images. If you are using the supplied MaxIm LT software, the choice of TIFF or FITS can be set under: File menu > Settings > Files tab > Default File Extensions
Setting this will determine the default file type created when MaxIm LT takes images.

4 - Accessories

4.1 ALUMA Micron-Precision Filter Wheel

The optional FW8S-ALUMA 8-position filter wheel includes a positive centering mechanism that precisely centers each filter in the exact same position every time. This single-pixel accuracy completely eliminates ghost images of dust spots and other artifacts after flat-fielding.

Positive detent mechanism provides single-pixel filter position accuracy



Precision flat-fielding with ultra-accurate indexing

The left-hand image shows a dust spot on the filters. A flat-field calibration frame was taken, then the filter wheel was rotated several times before taking a second picture, which was flat-field calibrated, at right. No evidence of the dust spot is visible. This high precision results in the highest quality images and excellent photometric accuracy.

The ALUMA wheel holds standard 36 mm filters, and inserts are available for 1-1/4″ filters, which are suitable for smaller format imaging sensors.

The ALUMA filter wheel replaces the camera's front plate, resulting in the minimum possible back-focus, ensuring that the camera / filter wheel combination will reach focus on the widest possible variety of optical systems.

4.2 AO-8A Adaptive Optics

Diffraction Limited is the market leader in Adaptive Optics tip-tilt guiding systems. Our adaptive optics units provide fast, precise positioning control without the lag, backlash, stiction, and other problems associated with telescope mounts. The AO units can reduce the impact of seeing, resulting in tighter star images and higher resolution.

All ALUMA models can operate with the AO-8A Adaptive Optics accessory. The AO-8A uses a tip-tilt window to quickly and precisely adjust the image position in response to autoguider feedback. With Adaptive Optics there is no backlash, stiction, or lag, and the movements are extremely precise and accurate. This allows the AO-8A to not only remove the effects of periodic error, drift, and wind gusts, but also reduce the effects of atmospheric seeing. The AO-8A requires an off-axis guide camera behind the device. Diffraction Limited recommends using the FW8G-ALUMA filter wheel. The AO-8A can also be used with a Remote Guide Head if you have a custom Off-Axis Guider.

Refer to the Diffraction Limited website for details at:
http://diffractionlimited.com/product/ao-8a/

4.3 StarChaser SC-2

Diffraction Limited's SBIG StarChaser guiders are the world's first all-in-one independent off-axis guiding cameras with adaptive optics support. The StarChaser operates independently of the main camera. It combines a pick-off mirror, guider camera, guide port and adaptive optics control. Off-axis guiding eliminates the problem of flexure between the imaging camera and a separately mounted guider by using the same optical path for both the main camera and the guider.

The StarChaser SC-2 is compatible with all ALUMA CCD series cameras. It directly supports the AO-8A Adaptive Optics unit.

4.4 Other Accessories

Numerous other accessories are available to enable a wide variety of user configurations, including:

- Filters
- Mounting plates and nosepieces
- Adapter plates and inserts
- Tripod mounts
- Cables
- Power supplies
- and more …

Refer to the Diffraction Limited website for details at:
http://diffractionlimited.com/products/cameras-accessories/accessories/

Appendix A: ALUMA Camera Details

A-1 Supplied components

- ALUMA main camera body (with handles and desiccant plug installed)
- Camera dust cap (10078)
- Power supply: 12V @ 6A Universal (60014A)
  - Power cable with US plug (51089) (type specified on ordering)
  - Power cable with European plug (50392) (type specified on ordering)
  - Power extension cable (68007)
- Flash drive
- 2” Nosepiece adapter with cap (50146)
- Ferrite clip (51354)
- Relay cable RJ11-RJ11 (50711)
- USB A Male-to-Mini B 5 pin Male cable, 15 feet (68006)

A-2 LED Power indicator

The LED on the camera indicates the power input levels as follows:

- GREEN when the power input voltage is good, above 11.4V.
- AMBER when the power input voltage is low, dropping below 11.4V.
- RED when the voltage is very low, dropping below 10V. The lowest possible voltage necessary to run the camera is 9V.

The LED turns off whenever exposures are in progress.

For WiFi-equipped cameras, if you power up the camera with the USB cable not plugged in, the LED will blink slowly (once per second) instead of glowing steadily. Normally, the blinking indicates that the WiFi communication processor is booting up, and then either establishing the Ad Hoc network or trying to connect to the WiFi Access Point, depending on the camera WiFi settings. This normally requires approximately 30 seconds. While the LED is blinking and the WiFi processor is booting up, you cannot connect to the camera wirelessly.

When the LED stops blinking, the camera is ready. However, this does not necessarily mean that the camera has successfully connected to the provided WiFi network. If you cannot connect wirelessly, this likely indicates that the WiFi network parameters you supplied are incorrect, such as the wrong SSID or password.

The LED will also remain blinking whenever you power up the camera while an external micro SD card has been plugged in to update the WiFi communications processor firmware. This process takes approximately three minutes, after which the LED will stop blinking. Do not unplug the camera while this update is in progress.

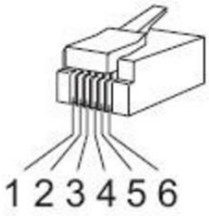
A-3 Connector pinouts

The first-generation ALUMA CCD camera front panel is shown below.

Please note that second generation ALUMA CCD cameras do not have the Guide Out, Guide Head, and secondary I2C ports, as these functions are all provided directly by the compatible StarChaser SC-2 guide camera.

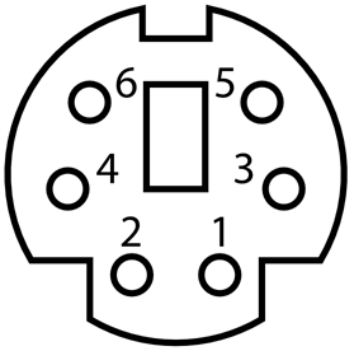
USB connector pinout is to USB standard.

GUIDE OUT (RJ-12), pins left to right:



Pin 1: AUX
Pin 2: COMMON
Pin 3: X-
Pin 4: Y-
Pin 5: Y+
Pin 6: X+
Note: AUX is normally not connected

POWER connector (6-pin mini-DIN)
The diagram shows the pin number identification when looking into the camera connector.



Pins 1, 3, 5: +12V
Pins 2, 4, 6: GND

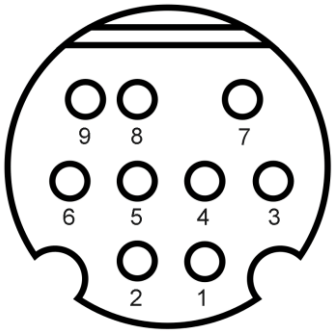
NOTES:

- Maximum recommended input voltage is 14V DC
- The shell of the connector is connected to ground via 1 Megaohm in parallel with 100 pF, and should be connected to the cable shield.
- Power ground is connected to the chassis of the camera through a low impedance.
- For a positive retention power connection we recommend using locking connector Kycon 806-KMDLAX-6P.

GUIDE HEAD (HDMI style) connector is proprietary. It is only included on first generation ALUMA CCD cameras.

I2C/FW/AO connectors (9-pin mini-DIN)

This diagram shows the pin number identification when looking into the camera connector. Please note that first generation ALUMA CCD cameras include two of these connected in parallel. For second generation cameras this functionality is provided instead by the optional StarChaser SC-2 guide camera.



Pin 1: GND	Pin 6: 3.3V Out
Pin 2: I2C SDA	Pin 7: 12V Out
Pin 3: I2C SCL	Pin 8: Trigger Out 0
Pin 4: Trigger Out 1	Pin 9: Trigger In
Pin 5: N/C	

NOTE: The *Trigger In* and *Trigger Out* functions are enabled via this connector. The functions must be configured in the MaxIm LT application software when you set up the camera.

CAUTION:

The *Trigger In* input voltage must not exceed 5.5V maximum.

Trigger In used to initiate exposures via an external control signal. The *Trigger In* signal must be floating or connected to the camera's GND (or TTL Low Level) before starting the Trigger Mode. If the signal is at the TTL High Level instead, the exposure will begin as soon as Trigger Mode is started, just like a regular (non-Trigger Mode) exposure. When *Trigger In* is properly configured, the camera will periodically flush the CCD sensor while waiting for the TTL High Level input signal on pin 9 of the connector. When you click Start to begin an exposure, the camera will flush the CCD one last time and then start the actual exposure, with a possible delay of up to 200 ms. Note that the *Trigger In* signal can be switched back to the TTL Low Level at any point after the beginning of the exposure.

The *Trigger Out* function can be used to control an external shutter, for activities such as precision timing measurements or similar. For such purposes, the same signal appears on Trigger Out 0 (pin 8) and Trigger Out 1 (pin 4), and the trigger output signal remains active during the exposure.

Note that *Trigger Out* is an open collector output, which means that it needs to be pulled up to between 3.3 to 12V maximum (or requires an external pull-up resistor) while the camera is inactive, and conversely, is active when low (at GND) only during an exposure.

A-4 Specifications

ALUMA 694

Imaging sensor	ICX-694
Peak QE	75%
Sensor size	12.5 mm x 10.0 mm
Imaging pixel array	2750 x 2200 pixels
Pixel size	4.54 µm (square)
Pixel digitization rate	8 MPix/sec
Total pixel count	6 million pixels
Full well capacity	18,000 e-
Read noise	4.5 e- typical
Dark current e/p/s at 0° C	0.025 e-/p/s typical
Anti-blooming	Yes
A/D converter	16-bit
Exposure duration minimum	0.001 sec
Full frame download	~1 sec via USB
Internal tracking sensor	No
Power	12 VDC, 5A max
Shutter	Mechanical, Electronic
Temperature regulation	Yes
Cooling delta	Typical maximum -50° C
Dimensions	4.5″ x 4.5″ x 4″ (with handles)
Weight	2.2 lbs
Computer interface	USB 2.0
OS compatibility	Windows 32 and 64 bit, Macintosh, Linux

Supported options:	
Adaptive optics	Yes
Filter wheel	Yes
StarChaser SC-2 Guider	Yes
Filter size	36 mm / 1.25″

ALUMA 814

Imaging sensor	ICX-814
Peak QE	75%
Sensor size	12.5 mm x 10.0 mm
Imaging pixel array	3388 x 2712 pixels
Pixel size	3.69 µm (square)
Pixel digitization rate	8 MPix/sec
Total pixel count	9 million pixels
Full well capacity	15,000 e-
Read noise	4.5 e- typical
Dark current e/p/s at 0° C	0.025 e-/p/s typical
Anti-blooming	Yes
A/D converter	16-bit
Exposure duration minimum	0.001 sec
Full frame download	~1 sec via USB
Internal tracking sensor	No
Power	12 VDC, 5A max
Shutter	Mechanical, Electronic
Temperature regulation	Yes
Cooling delta	Typical maximum -50° C
Dimensions	4.5″ x 4.5″ x 4″ (with handles)
Weight	2.2 lbs
Computer interface	USB 2.0
OS compatibility	Windows 32 and 64 bit, Macintosh, Linux

Supported options:	
Adaptive optics	Yes
Filter wheel	Yes
StarChaser SC-2 Guider	Yes
Filter size	36 mm / 1.25″

ALUMA 47-10

Imaging sensor	E2V CCD 47-10 AIMO, available in: Midband, Broadband, Enhanced UV
Peak QE	93%
Sensor size	13.3 mm x 13.3 mm
Imaging pixel array	1056 x 1027 pixels
Pixel size	13 µm (square)
Pixel digitization rate	1 MPix/sec
Total pixel count	1 million pixels
Full well capacity	100,000 e-
Read noise	5 e- typical
Dark current e/p/s at 0° C	20 e-/p/s typical
Anti-blooming	No
A/D converter	16-bit
Exposure duration minimum	0.1 sec
Full frame download	~1 sec
Internal tracking sensor	No
Power	12 VDC, 5A max
Shutter	Mechanical, even-illumination
Temperature regulation	Yes
Cooling delta	Typical maximum -50° C
Dimensions	4.5″ x 4.5″ x 4″ (with handles)
Weight	2.2 lbs
Computer interface	USB 2.0
OS compatibility	Windows 32 and 64 bit, Macintosh, Linux

Supported options:	
Adaptive optics	Yes
Filter wheel	Yes
StarChaser SC-2 Guider	Yes
Filter size	36 mm / 1.25″

ALUMA 77-00

Imaging sensor	E2V CCD 77-10
Peak QE	93%
Sensor size	12.3 mm x 12.3 mm
Imaging pixel array	512 x 512 pixels
Pixel size	24 µm (square)
Pixel digitization rate	1 MPix/sec
Total pixel count	262,000 pixels
Full well capacity	300,000 e-
Read noise	7 e- typical
Dark current e/p/s at 0° C	60 e-/p/s typical
Anti-blooming	No
A/D converter	16-bit
Exposure duration minimum	0.1 sec
Full frame download	~1 sec via USB
Internal tracking sensor	No
Power	12 VDC, 5A max
Shutter	Mechanical, even-illumination
Temperature regulation	Yes
Cooling delta	Typical maximum -50° C
Dimensions	4.5″ x 4.5″ x 4″ (with handles)
Weight	2.2 lbs
Computer interface	USB 2.0
OS compatibility	Windows 32 and 64 bit, Macintosh, Linux

Supported options:	
Adaptive optics	Yes
Filter wheel	Yes
StarChaser SC-2 Guider	Yes
Filter size	36 mm / 1.25″

ALUMA 3200 (discontinued)

Imaging sensor	KAF-3200
Peak QE	80%
Sensor size	14.85 mm x 10.26 mm
Imaging pixel array	2184 x 1472 pixels
Pixel size	6.8 µm (square)
Pixel digitization rate	4 or 1 MPix/sec (selectable)
Total pixel count	3.2 million pixels
Full well capacity	55,000 e-
Read noise	11.5 e- typical at 4 MHz 10.0 e- typical at 1 MHz
Dark current e/p/s at 0° C	0.5 e-/p/s typical
Anti-blooming	No
A/D converter	16-bit
Exposure duration minimum	0.1 sec
Full frame download	< 1 sec via USB
Internal tracking sensor	No
Power	12 VDC, 5A max
Shutter	Mechanical, even-illumination
Temperature regulation	Yes
Cooling delta	Typical maximum -50° C
Dimensions	4.5″ x 4.5″ x 4″ (with handles)
Weight	2.2 lbs
Computer interface	USB 2.0
OS compatibility	Windows 32 and 64 bit, Macintosh, Linux

Supported options:	
Adaptive optics	Yes
Filter wheel	Yes
StarChaser SC-2 Guider	Yes
Filter size	36 mm / 1.25″

ALUMA 8300 (discontinued)

Imaging sensor	KAF-8300
Peak QE	56%
Sensor size	17.96 mm x 13.52 mm
Imaging pixel array	3326 x 2504 pixels
Pixel size	5.4 µm (square)
Pixel digitization rate	10 MPix/sec
Total pixel count	8.3 million pixels
Full well capacity	25,000 e-
Read noise	10 e- typical
Dark current e/p/s at 0° C	0.15 e-/p/s typical
Anti-blooming	Yes
A/D converter	16-bit
Exposure duration minimum	0.1 sec
Full frame download	~1 sec via USB
Internal tracking sensor	No
Power	12 VDC, 5A max
Shutter	Mechanical, even-illumination
Temperature regulation	Yes
Cooling delta	Typical maximum -50° C
Dimensions	4.5″ x 4.5″ x 4″ (with handles)
Weight	2.2 lbs
Computer interface	USB 2.0
OS compatibility	Windows 32 and 64 bit, Macintosh, Linux

Supported options:	
Adaptive optics	Yes
Filter wheel	Yes
StarChaser SC-2 Guider	Yes
Filter size	36 mm / 1.25″

Appendix B: Advanced Operations for Astronomy

B-1 Autoguiding

An autoguider is essentially a secondary camera that operates alongside the main imaging camera. Its function is to correct for small drive errors and long term pointing drift. It does this by repeatedly taking short-duration images of a guide star and then sending these to a host computer to measure that star's position to a fraction of a pixel accuracy. The computer then sends correction signals to the telescope mount in order to maintain and correct the pointing position as required. Some autoguiders are standalone systems and perform all these functions internally, with no external computer required.

No telescope mount is perfect and even high-end configurations can show some motion drift over time if not corrected. However, while autoguiding can maintain precise pointing over long intervals, it is by no means a cure for marginal telescope drive performance or poorly-prepared setups. Having a good polar alignment, rigid tubes that are free of flexure, and locating your mount on a solid, vibration-free surface or pier are equally important factors in maintaining accurate tracking.

Off-axis guiding is a good way to eliminate all of these problems, including flexure. The StarChaser SC-2 Guide Camera can be mounted in front of your FW8S-ALUMA filter wheel, to provide self-guiding in front of the filters. A pick-off mirror in the StarChaser is situated in front of the filters and sends light to an internal CMOS autoguider camera. In this way, optimum guiding sensitivity is provided for all filter slots, regardless of the filter type in use. The StarChaser provides all autoguiding control fully independent of the main camera and filter wheel, but mechanically integrates to ensure there is no flexure in the system.

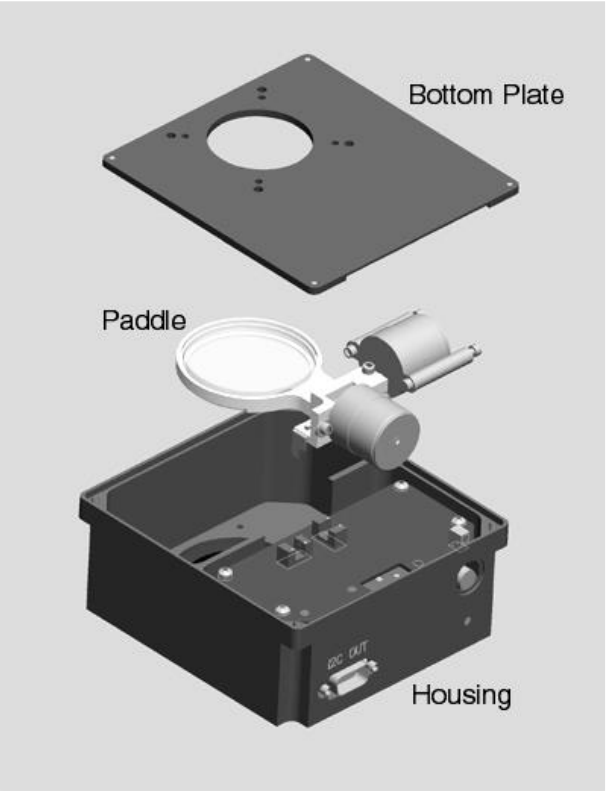
Older units may utilize an FW8G-ALUMA filter wheel, which includes a pick-off mirror and guider sensor inside the filter wheel itself. This also provides excellent autoguider performance.

When setting up the guider, a calibration star should be selected that is relatively bright and isolated. The calibration software can get confused if another star of comparable brightness moves onto the tracking sensor during a move. Once guiding calibration is complete, the unit can self-guide on much fainter stars. If a suitable guide star cannot not found, the telescope position should be adjusted, or preferably, the camera head should be rotated. Rotating the camera requires recalibration of the tracking function.

B-2 Adaptive optics

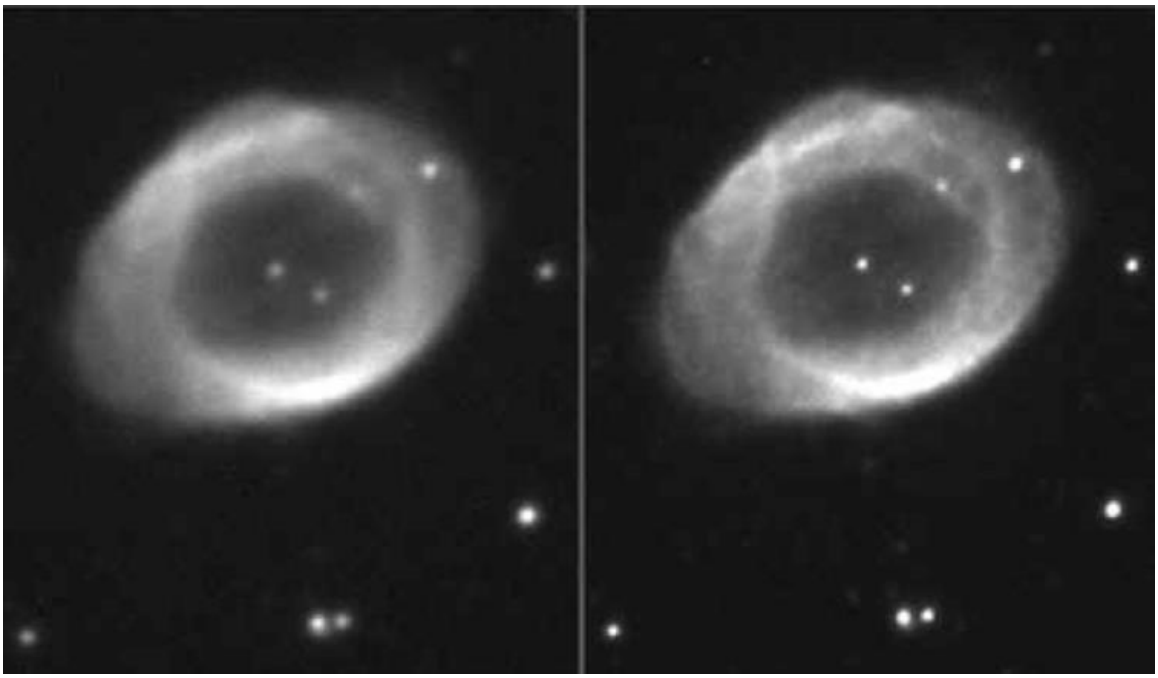
Adaptive optics (AO) is a general term used to describe technology that enables the correction of incoming starlight in order to minimize the effects of atmospheric distortion. The atmospheric stability at an observing site is referred to as the "seeing" condition. When the seeing is poor, turbulence in the atmosphere causes stars to twinkle noticeably. This results in bloated stars and reduced resolution in an image. The use of an adaptive optics system can reduce these distortions by reshaping the light's wavefront prior to it reaching the camera's sensor. On meter-class instruments wavefront sensors and rubber mirrors are used to perform corrections on light from multiple zones of the primary mirror.

Smaller instruments can benefit from fast tip-tilt systems. Diffraction Limited has adaptive optics units that perform this function, allowing for real-time correction of slow seeing effects as well as correcting for wind loading, short-term drive errors, etc. An exploded view of the SBIG AO-8 Adaptive Optics unit is shown here.



Incoming starlight is monitored by a separate autoguiding camera, such as Diffraction Limited's StarChaser SC-2, an FW8G-ALUMA Self-guiding Filter Wheel, or a Remote Guide Head. This sends a constant stream of guide star images to an attached host computer for analysis. The degree of displacement in a guide star's image is calculated and corrective signals are continually sent to the AO unit. These signals cause the unit's tip-tilt mirror to move in minute

increments to counteract wavers in the light path at up to 10 corrections per second.



Uncorrected image AO-corrected image

Telescope mounts cannot typically be corrected faster than about once per second. The 10 Hz correction rate of the AO unit can clearly result in improved image resolution under the right conditions. Fine details lost in an uncorrected image can be captured in an AO-corrected image.

Appendix C: Maintenance

C-1 Cleaning the sensor window

The design of the ALUMA cameras allows for cleaning of the chamber window. The optical head is not evacuated and is easy to open. When opening or reassembling the camera (see Section 1.3), you must be careful not to damage any of the structures contained inside. Treat the instrument delicately.

Do not open the sensor chamber. If internal chamber maintenance is required, please return the camera for service. Opening the sensor chamber will void your warranty.

The chamber window can be cleaned with a cotton-tipped swab and isopropyl alcohol. Do not get alcohol on the shutter or other components. Dust on the window should be blown off if possible. Use alcohol only if necessary. Use one end of the swab it with alcohol and the other end to dry it. Never re-use a swab and do not scrub with it – use gentle pressure.

Filters can be cleaned in the same way.

If you have a few small dust specs remaining, don't worry. Sometimes it is almost impossible to remove them all. Performing a flat field calibration can remove them effectively.

NOTE:
Cans of compressed air may be used to remove dust, but be cautious. Some types may leave a residue if used with too much vigor or improper proximity. Keep the can vertical to avoid expelling the propellant. Follow the manufacturer's instructions, but also test it on another surface prior to using it on the camera.

C-2 Regenerating the desiccant

This section describes the regeneration procedure for the desiccant used in the ALUMA cameras. The desiccant absorbs moisture inside the camera body, lowering the dew point below the operating temperature of the cooled imaging sensor and thereby preventing the formation of frost. The desiccant is contained in a small cylindrical container that screws into the side of the camera chamber. In normal operation, the useful life of the desiccant is over a year. However, if the camera body is opened often, the desiccant should be regenerated whenever frosting is noticed.

Note: When using a domestic oven with self-cleaning capability, please run a self-cleaning cycle before attempting to recharge the desiccant. Otherwise, the desiccant could become contaminated.

CAUTION:

Failure to regenerate the desiccant when required can lead to corrosion inside the camera body and will void your warranty. Do not ignore this procedure.

To regenerate the desiccant:

1. Place the camera on a clean dry surface with the black anodized aluminum desiccant container facing upwards.
2. The container twists into the side of the camera body. Use a coin to turn the container 90° counter clockwise to extract it.
3. Remove the O-ring from the container and place it aside.
4. Set the camera aside with the container opening facing down. This will prevent dust from falling into the opening.
5. Heat the desiccant container in an oven at 350° F (175° C) for 4 hours. The adhesive used to seal the can will melt at very high temperatures, so be sure to keep the oven temperature below 400° F (205° C). Preheating the oven to avoid hot spots is advised.
6. Remove the container from the oven when done and as soon as it has cooled enough to handle, reinstall the O-ring and insert it into the camera. Insure that the O-ring does not get pinched.
7. Rotate the container 90° clockwise to lock it.
8. The camera may take up to 24 hours to reach a stable frost-free state after inserting the container. If you need to capture images prior to this time and it frosts again, reduce your cooling to the 0° C range - the dark current will still be quite low.

   Additional desiccant plugs are available from Diffraction Limited.

C-3 Updating the camera firmware

There are two firmware elements in the camera that can be updated. The first is the main firmware, which operates the camera and handles USB communications. For cameras that support WiFi communications, there is a second processor with additional firmware.

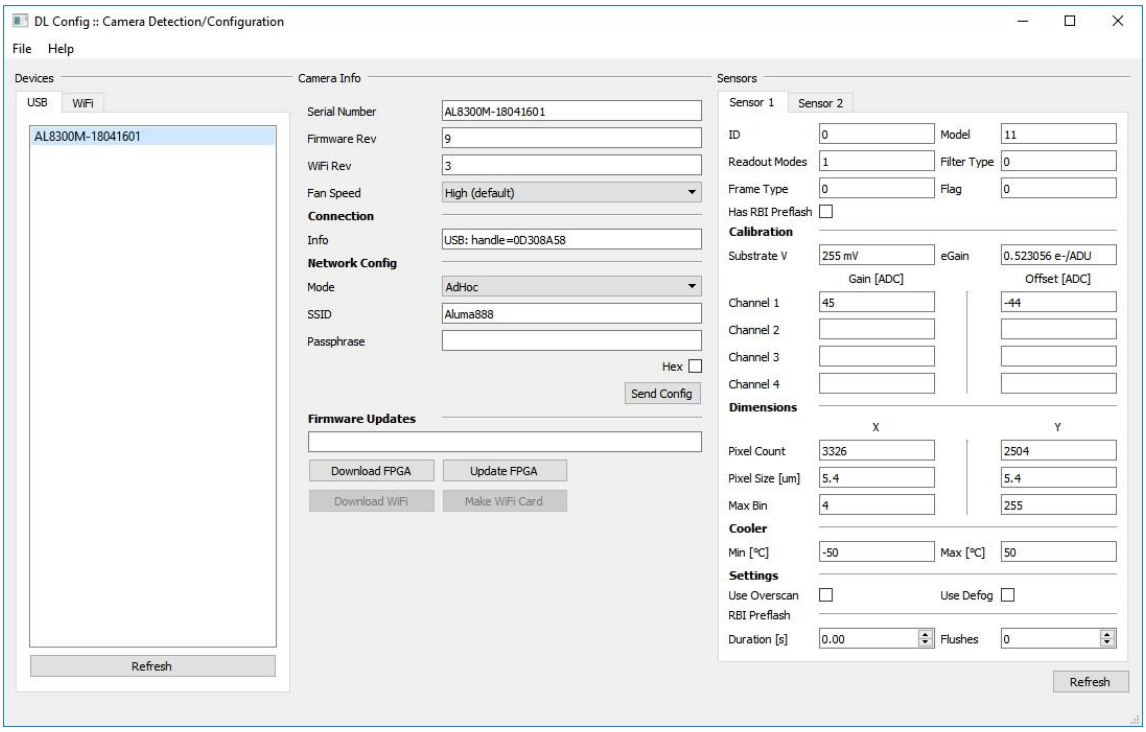
Diffraction Limited supplies a software utility program named “DL Config” that will update both firmware elements in the camera, either via USB or WiFi. This is a standalone version of the “DL Config” form mentioned in Section **2.1 Connecting the ALUMA Camera to MaxIm LT**. The program requires a PC with an internet connection and it can be freely downloaded from the Diffraction Limited website at:

https://diffractionlimited.com/products/cameras-accessories/aluma-series/

Click the READ MORE button for your specific camera model and then the DOWNLOADS tab on that page. There you will find a link to the latest version of the Utility Program. Download and run the program. All further instructions are accessible from the application itself.

Note that in rare cases when the WiFi communications processor requires an update, a micro SD card will be necessary.

The DL Config utility screen is shown below.



To update the camera firmware, proceed as follows:

1. Start the DL Config utility program on your computer and connect to the camera you want to update. It will display the current firmware version and inform you if it is up-to-date or not.
2. If your firmware version is current, you can exit the utility.
3. If your firmware version is not current, click Download FPGA to have the utility automatically download the latest version of the camera's firmware that your driver will support. Wait for the program to report that the download to your computer is complete.
4. Click Upload FPGA to have the utility upload the newly-downloaded version of the firmware to the camera. This will take a few minutes. Wait for the process to complete, then power cycle the camera, and reconnect to it.
5. If the procedure fails, the camera may revert back to the original firmware that was programmed at the factory. If that happens, simply make sure you have a solid connection to the camera and retry this procedure.

Once the main firmware has been successfully updated, you may resume normal camera operations.

For WiFi-equipped models only:

The procedure for updating your WiFi communications processor firmware is documented here:

https://paper.dropbox.com/doc/Updating-Your-Aluma-Cameras-Wireless-Software-3SGPgkfrKkZSXZgw5y4Kc

Appendix D: WiFi Connectivity (if equipped)

Some ALUMA CCD cameras can optionally operate via WiFi connectivity either through an existing WiFi network or with the camera acting as an independent WiFi hotspot. We advise connecting to your camera via USB first, so you can customize your network connection details via a guaranteed connection.

1. To modify the network configuration, open DL Config (either the standalone utility or in MaxIm LT) and consult the Network Config section of the form.
2. The Mode dropdown menu contains the security/connection mode of the camera. The default mode is hotspot operation and is called the Ad Hoc. This has the ALUMA create an Ad Hoc WiFi network that you can connect to directly. The camera will appear on your computer or device as an available network named Aluma888. No password is required. Connect to this network in the usual manner for your device. The other options under the dropdown menu are Unsecured, WPA, WPA2, and WEP.
3. Alternatively, the camera can be configured to log into a WiFi network by using the DL Config standalone utility or from within MaxIm LT. You must supply the network SSID, passphrase, and encryption type when prompted. You can also choose to use the USA/Canada mode (which limits the number of used channels) and allows the passphrase to be a hex key.

   NOTE:
   SSID is the name of the wireless network to connect to (in unsecured, WPA, WPA2, WEP mode), or that the ALUMA generates in Ad Hoc mode.

   Passphrase is the passphrase to use when connecting to a secured network.

   Hex allows the user to enter a hex passphrase for use with secured networks.

4. The camera can be reset to the default hotspot mode by using a paperclip to press the Reset switch. The switch is located through a small opening beside the WiFi antenna. With the camera powered on, insert the paperclip into the opening to push the switch.

   Resetting to hotspot mode is required if you change your network password or if you move your camera into another network area. Once it is reset, you can reprogram the camera to connect to the new network or continue using it as a hotspot.

Appendix E: Troubleshooting

If you experience problems with the ALUMA CCD camera operations, check the following areas:

Check power:

The LED on the camera indicates power input levels as follows:

- RED when the voltage is very low. Check cable connections and the condition of the power supply, especially if you are using a portable (battery) source.
- AMBER when the power input is low. Check the condition of the power supply, especially if you are using a portable (battery) source.
- GREEN when the power input is good.

The LED turns off whenever exposures are in progress.

Refer to Appendix A-2 for detailed information on the camera LED behavior.

Check the USB interface:

Follow these recommendations to ensure good USB connectivity:

- Use only good quality USB cables.
- Avoid using a USB hub if possible. If you do need a hub, try to avoid putting two cameras on the same hub.
- If you are operating in outdoor ambient temperatures, be aware that commercial-quality hubs often do not work well in freezing temperatures. You should use an industrial-quality USB hub in such conditions.
- Avoid using front panel USB jacks on desktop computers. They have internal wiring that will degrade USB signal quality.
- Diffraction Limited suggests tie wrapping the USB cable and power cable together near the camera in order to minimize risk of the USB connector coming loose or being pulling out.

Check the WiFi interface:

If equipped, follow these recommendations to ensure proper WiFi connectivity:

- Confirm that you have selected WiFi when configuring the Connect To drop-down item in Section 2.1.
- Ensure that you have sufficient WiFi signal strength. You can check this with your smartphone or tablet.
- The camera requires approximately 30 seconds to boot up and connect to WiFi, during which time the LED will be blinking. If the LED is on steadily and you still cannot connect, plug in the USB cable and make sure that the network parameters you supplied (SSID and password) are correct.

Note also that the following WiFi encryption modes are supported:

  - Open (no password)
  - WEP
  - WPA
  - WPA2

- Virtual network interfaces and adapter bridges can mask UDP broadcast messages and block WiFi operation. If you can't discover your camera despite the connection details being correct, try disabling the interfaces and bridges one by one until only your physical adapters remain.

Appendix F: Technical and Warranty Support

Software Downloads

Downloads are included on the Diffraction Limited website product pages:

http://diffractionlimited.com/

Navigate to your product and click the Downloads tab. Software utilities, drivers, user documentation, and a Software Development Kit are available here.

Technical Support

Technical Support: http://forum.diffractionlimited.com/

Technical Support Phone: (613) 225-2732

Diffraction Limited Address

Note: You must request an RMA number before returning equipment for repair.

Diffraction Limited
59 Grenfell Crescent, Unit B
Ottawa, ON K2G 0G3, Canada

Appendix G: Compatible software products

MaxIm LT

MaxIm LT is a limited version of MaxIm DL, and is specifically for controlling the ALUMA series cameras and other Diffraction Limited cameras and autoguiders that use Gen 2 USB drivers. A license is available at no cost to the original owner of the camera. The program can operate on Windows computers only.

Please refer to the Windows Installation section in this guide for details.

MaxIm DL

MaxIm DL is a full-featured camera control and processing program available from Diffraction Limited. It can control all Diffraction Limited cameras and most third-party CCD camera models. ALUMA camera control requires Version 6.17 or higher.

Please note that a discount is available for MaxIm LT license owners.

ASCOM

The ALUMA cameras and filter wheels include fully-documented and supported drivers for all platforms, including ASCOM drivers. ASCOM is in turn, is a standard supported in a wide variety of third-party software.

Appendix H: Concepts and Terminology

Anti-blooming Gate - When a sensor's pixel has reached its full well capacity, electrons can effectively spill over into an adjoining pixel. This is referred to as blooming. Sensors with the anti-blooming option can be used to help stop or at least reduce blooming when the brighter parts of an image saturate.

Astrometry - Astrometry is the study of stellar positions with respect to a given coordinate system.

Autoguider - An autoguider a secondary camera that operates alongside the main imaging camera. Its function is to take a continual stream of short duration exposures of the sky that contains a suitably bright guide star. These images are used to monitor if the selected star moves at all. If it does, then signals are sent to the telescope mount to correct for small drive errors and long-term pointing drift. This ensures that stars in the main image remain stationery and perfectly round.

CCD - A CCD (Charged Coupled Device) sensor is a flat, two dimensional array of very small light detectors referred to as pixels. Each pixel acts like a bucket for electrons. The electrons are created by photons (light) absorbed in the pixel. During an exposure, each pixel fills up with electrons in proportion to the amount of light entering the pixel. After the exposure is complete, the electron charge for each pixel is shifted one at a time to an amplifier in one corner of the chip. The resulting voltage is transferred to an external amplifier, filter, and digital converter. When a pixel is displayed at the computer screen, its displayed brightness is proportional to the number of electrons that had accumulated in the pixel during the exposure.

CMOS - A CMOS (Complementary Metal-Oxide Semiconductor) sensor is a flat, two dimensional array of very small light detectors referred to as pixels. Each pixel acts like a bucket for electrons. The electrons are created by photons (light) absorbed in the pixel. During an exposure, each pixel fills up with electrons in proportion to the amount of light entering the pixel. After the exposure is complete, the electron charge at each pixel is amplified and converted to a voltage by a tiny circuit at the pixel. The voltages from each pixel are read out by built-in digital converters, often with one converter per column, and the brightness values are read out from the sensor via a high-speed digital interface. When a pixel is displayed at the computer screen, its displayed brightness is proportional to the number of electrons that had accumulated in the pixel during the exposure.

Color imaging with a monochrome camera - One-shot Color (OSC) cameras with a built-in Bayer matrix are handy for shooting quick color pictures However, imaging with a monochrome camera provides the best quality, sensitivity, and resolution.

A filter wheel with appropriate filters is used to create color images using a monochrome camera. The simplest method is to use three filters, one for Red, Green and Blue. Once the three images are captured, calibrated, aligned and stacked, it is very simple to create the color composite image. That is because

images are *normally* stored as three red, green, and blue planes. Your computer monitor simply displays the three colors directly and your brain interprets different combinations of those three colors as a full gamut of different colors. It works because the retina in the human eye itself is based on red, green, and blue light-sensitive cells.

Dark Frame - A Dark frame is an image taken completely in the dark. The camera shutter must cover the sensor or the optical system must be capped to prevent any light from reaching the sensor. Dark frames are subtracted from normal exposures (light frames) to eliminate fixed pattern and dark current noise from the image. Dark frames must typically be of the same integration time and temperature as the light frame being processed.

Dark Current –Dark Current is the result of thermally-generated electrons building up in the sensor's pixels during an exposure. The number of electrons due to Dark Current is related to two parameters, namely the integration time (exposure length) and the temperature of the sensor. The longer the integration time, the greater the dark current buildup. Conversely, the lower the operating temperature, the lower the dark current. This is why the sensor is cooled for long integration times. Dark Current is a mostly repeatable noise source, therefore it can be subtracted from the image by taking a Dark Frame exposure and subtracting it from the light image.

Dark Noise - Dark Noise is Poisson shot noise from the Dark Current. It results from exactly the same process and statics as photon shot noise, just with thermal electrons instead of photo electrons. Hot pixels are noisier due to higher Dark Noise, and that noise is not subtracted when you subtract a Dark Frame.

Double-Correlated Sampling – Double-Correlated Sampling (DCS) is a technique employed to lower the digitization errors due to residual charge in the readout capacitors of the camera. This results in lower readout noise.

False Color - False Color images are images that have had colors assigned to different intensities instead of gray levels.

FITS Image File Format – The FITS image file format (which stands for Flexible Image Transport System) is a common format supported by astronomical image processing programs. MaxIm LT can save and read image files in this format.

Flat Field - A Flat Field is an image with a uniform distribution of light entering the optical system. An image taken this way is called a flat field image and is used to correct images for vignetting and minor obscurations caused by dust particles on the sensor or camera window. It also corrects pixel-to-pixel variations in light sensitivity within the sensor.

Focal Reducer - A focal reducer reduces the effective focal length of an optical system, and thereby provides a larger field of view to the camera sensor. While this reduces image resolution, it also decreases exposure times since it decreases the system's effective focal ratio. It consists of a lens mounted in a cell and is usually placed in front of an eyepiece or camera. Focal reducers are often used in electronic imaging.

Full Well Capacity - Full Well Capacity refers to the maximum number of electrons that a sensor's pixel can hold. This number is usually directly proportional to the area of the pixel.

Histogram – A histogram is a simple bar graph that shows the range of brightness in an image. Each bar in the graph represents a range of brightness. The leftmost bar represents the dimmest pixels, and the rightmost bar is for the brightest pixels. The height of the bar is the total number of pixels in that particular brightness range of the image. Every image has a different histogram depending on how much of the image is bright or dark.

A typical histogram will have a peak that shows the most common brightness in the image. For astronomical images this is often the sky background.

Interline Transfer CCD –This is a CCD sensor with an architecture that masks alternate columns of the sensor for storage. This requires a shift of only one pixel to occur to transfer information from the active image area to the storage area and permits extremely short shutter times. It also virtually eliminates any image smear, also known as "blooming". Some designs add microlenses on the sensor surface to direct light from the masked columns into the active imaging columns and thereby increase the overall sensitivity of the sensor.

Light Frame - A Light Frame is the image of an object or scene before a Dark Frame has been subtracted.

Photometry - In astronomical applications, photometry is the measurement of the flux or intensity of an object's radiation. Typically this measurement is performed in defined wavelength bands to facilitate comparison and analysis

Pixel Size - The smallest resolution element of an electronic camera sensor is the pixel. Its size is usually specified in microns, such as the ALUMA 8300's 5.40 micron pixels. The term is a contraction derived from "picture element".

Quantum Efficiency - Quantum Efficiency (QE) refers to the fractional number of electrons formed in a sensor pixel for a given number of impinging photons. Quantum Efficiency is usually plotted as a function of wavelength.

Readout Noise - Readout noise is a combination of various noise sources within the sensor plus a small contribution from the camera readout electronics. Sources of noise include reset noise, Johnson noise, thermal noise, and flicker noise.

Resolution and binning - The resolution of a camera sensor is determined by its pixel size. Pixel size can be increased by combining or "binning" more than one pixel and displaying the combined light received as a single pixel. Doing so decreases the effective resolution but increases relative sensitivity. It also shortens the image download time. Maximum absolute resolution is determined by the size of an individual unbinned pixel and the characteristics of the optical system you are using.

Saturation - Saturation refers to the full well capacity of a sensor's pixel as well as the maximum counts available in the A/D converter. A pixel is said to be saturated when the number of electrons accumulated in the pixel reaches its full well capacity. The A/D converter is saturated when the input voltage exceeds the maximum permissible.

Sky Background - The sky background illumination or brightness is the number of counts in an image in areas free of stars or nebulosity and is due to primarily to city lights and natural sky glow. High levels of sky background can increase the noise in images just like dark current. For some objects, filters can be used to reduce the sky background level.

Seeing - Seeing in the astronomical sense refers to the steadiness of the atmosphere during an observing or imaging session. Poor seeing is caused by air mass turbulence and atmospheric temperature variations. Seeing quality is often determined by measuring the Full Width Half Maximum (FWHM) diameter of recorded star images. Refer also to "Transparency".

TE Cooler - A TE cooler is a thermal electric cooling device used to cool the camera sensor down to a low operating temperature. Every camera sensor produces a certain amount of dark current, which accumulates in the pixels during an exposure. This unwanted dark current is produced by heat, and high-performance cameras such as the ALUMA series cool their sensors to minimize this effect. The sensor is mounted to the TE cooler, which in turn, is mounted to a heat sink, usually the camera head housing. A TE cooler is also often referred to as a Peltier cooler.

TIFF Image File Format - The TIFF image file format (which stands for Tagged Interchange File Format) was developed jointly by Microsoft and Aldus Corporations to allow easy interchange of graphics images between programs in areas such as presentation and desktop publishing. MaxIm LT can save and read image files in this format.

Transparency – Transparency in the astronomical sense refers to the total transparency of the atmosphere from the ground to the edge of space. It is largely dependent on the amount of water vapor in the air, but not entirely analogous to the amount of the cloud cover present in a location. There can be isolated clouds in a finely transparent air mass, and conversely, poor transparency can occur when there is little or no cloud present. Man-made light pollution and aerosols (i.e. industrial pollutants, volcanic ash, pollen, sea salt, and forest fire smoke) also degrade transparency. Refer also to "Seeing".

Tri-Color - Tri-Color refers to color images created using three different colors mixed into a balanced color image using red, green and blue filters. An object is imaged three times, once with each color filter. The three images are then co-added and color balanced using appropriate software, such as MaxIm LT.

Vignetting - Vignetting is the obstruction of portions of the incoming light path by parts of an optical system. It usually occurs in the off-axis portions of the image and is seen as an uneven illumination of the image plane. When imaging using a vignetted optical system, the corners of the camera sensor will receive less light. This can be compensated for by using flat-fielding calibration, but it is usually preferable to physically avoid vignetting if possible.

Diffraction Limited