



Diffraction Limited

SBIG[®] STF Series *Imaging Cameras*



User's Manual

Version 1.01 - October 09, 2019

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.

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IMPORTANT!

Please read this guide thoroughly before installing and operating your new SBIG STF 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!

SBIG STF Imaging Cameras

The SBIG STF series of imaging cameras is an evolution of the previous ST series, where the “F” stands for “Fast”, signifying the substantial performance improvements of these cameras over their predecessors. Indeed, the STF series provides a superior cost versus performance ratio, with low noise and fast readout speeds. The family includes both monochrome and colour sensors and supports filtered imaging with the optional FW8-8300 filter wheel.



SBIG STF models include:

- STF-3200W is the ultimate in sensitivity, with 85% peak quantum efficiency. The KAF-3200 is one of the most sensitive front-illuminated Charge Coupled Devices (CCD) sensors available.
- STF-4070 and STF-8050 are interline cameras with very strong cooling, and are capable of both very short and very long exposures. Both cameras feature an all-electronic shutter and are available as either monochrome imagers (STF-4070M and STF-8050M), one-shot colour imagers with a standard Bayer filter pattern (STF-4070C and STF-8050C), or as enhanced one-shot Luminance, Red, Green, Blue (LRGB) imagers utilizing the Truesense Sparse Color Filter Pattern (STF-4070SC and STF-8050SC).
- STF-8300M utilizes the large and very popular 8.3 megapixel KAF-8300 sensor. The camera boasts very good sensitivity along with low noise.

Camera Features

Our STF series cameras offer excellent performance, very low noise, and a rich set of features. All STF camera models include the MaxIm LT application for Windows for image acquisition and processing. The series features:

- Four different CCD imaging sensors by ON Semiconductor™
- Light-weight, compact design
- Centered optical axis for optimum instrument balance
- Support for Windows, Macintosh, and Linux
- USB 2.0 communications interface
- Full-frame image buffering eliminates readout artifacts
- Thermoelectric Peltier cooling with accurate temperature regulation
- Included 110V / 220V power supply and optional 12VDC operation
- User-rechargeable desiccant plug
- Built-in 1/4-20 tripod mount
- Support for 8-position filter wheel FW8-8300

Refer to [Appendix A-2 Specifications](#) for detailed camera specifications.

Multi-platform operation

The STF cameras are compatible with Windows (versions 7 through 10), MacOS 10.14.4 (32-bit), and Canonical Ubuntu Linux 18.04LTS.

The STF camera interface specification is also fully documented, supporting the development of custom interfaces.

1 - Installation

1.1 Supplied Components

Camera

Your STF 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, static-free area. Inspect the contents to ensure all components are present and in good order. You should find the following:

- STF main camera body, with desiccant plug installed
- Camera dust cap
- Power for models STF-4070 or STF-8050:
 - +12V 6A Power supply (60012A)
 - Power cable with US plug (51089), European plug (50392), or Australia/New Zealand plug (50390) (type specified on ordering)
 - Power extension cable
- Power for models STF-3200W or STF-8300M:
 - +12V 3A Power supply (60013)
 - Power cable with US plug (51089) or European plug (50392), or Australia/New Zealand plug (50390) (type specified on ordering)
- +12 VDC Battery power cable (CA-ST402BATTERY). Note that this cable is an option in lieu of the AC power supply and works with all STF camera models.
- USB flash drive
- 2" Nosepiece adapter
- Camera handles (qty 2) and 8-32 x 5/16" socket head cap screws (qty 4)
- Ferrite snap-on chokes to reduce radio frequency interference (qty 2)
- Guider-to-telescope mount interface cable (TIC) RJ11-RJ11.
NOTE: This cable has its pin connections flipped from one end to the other – they are not straight-through connections.
- USB cable, 15 feet (4.6 meters)
- Allen key, 9/64"

FW8-8300 Filter Wheel

The optional FW8-8300 filter wheel is designed for use with the monochrome STF cameras, including the STF-3200W, STF-8300M, STF-4070M, and STF-8050M.

The one-shot colour cameras are not usually used with a filter wheel. However, the FW8-8300 will mechanically fit and operate with the STF-4070C, STF-4070SC, STF-8050C and STF-8050SC cameras. Since these cameras do not employ a mechanical shutter, this is useful for customers who wish to capture dark frames without having to manually cover the camera. With an FW8-8300 filter wheel in place, such captures can be performed remotely by using a blackened filter slot as a mechanical shutter to cover the sensor.

Inspect the supplied contents to ensure all components are present and in good order. You should find the following:

- FW8-8300 - 8-position filter wheel with I²C cable
- 2" Nosepiece adapter with cap
- O-rings, 2-027 (qty 8) (41006)
- Allen key, 9/64"

1.2 Installing the Software

The MaxIm LT imaging application allows you to operate your STF camera using a Windows computer. A MaxIm LT license is now included at no cost with purchases made after October 1, 2019. CCDOPS software is available at no cost for older cameras, or you can purchase a MaxIm LT license at a discounted price. For previous purchases, refer to [Appendix F: Compatible software products](#). Drivers only are provided for the MacOS and Linux operating systems.

System requirements

The following hardware and software 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
- Internet browser

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 for the MaxIm LT application. Use your camera's serial number for this. If your camera is authorized for a free license you will be automatically emailed a license key.
3. Insert the supplied flash drive into an available USB port.
4. Open Windows Explorer and navigate to the flash drive's root folder.
5. Double-click **Launcher.exe**, then click *Install SBIG* to install the SBIG Driver Checker. When the installation is completed, launch the SBIG Driver Checker.
6. Click the *Update* button to install the drivers.
7. Return to the Launcher and click the *Install MaxIm DL* button. Follow the onscreen instructions to install the Maxim LT application and then enter the license key you received when prompted.

NOTE:

To enter your license key properly, you must select all the text from the email you receive and copy it to the clipboard. You then start MaxIm LT and open the Enter License dialog. The license key will be entered automatically – there is no need to paste it since MaxIm LT finds it on the clipboard and pastes it for you.

8. Click **OK** to finish. You can then proceed to the next section to install your hardware.

1.3 Installing the Hardware

This section details the steps required to connect an STF camera and FW8-8300 filter wheel. Diffraction Limited recommends that filters are installed as part of this procedure when mating the filter wheel to the camera.

Note that these installation instructions are illustrated showing an STF-8300M camera body but are also applicable to the STF-3200W, STF-4070M, and STF-8050M cameras. However, most of this procedure is not applicable to the one-shot colour camera models STF-4070C, STF-4070SC, STF-8050C and STF-8050SC since these do not normally require the use of a filter wheel. For those cameras you can proceed directly to step 15, unless you've chosen to install the filter wheel for use in collecting dark frames.

➔ 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. Use of an anti-static wrist-strap and an anti-static mat with proper grounding is recommended.

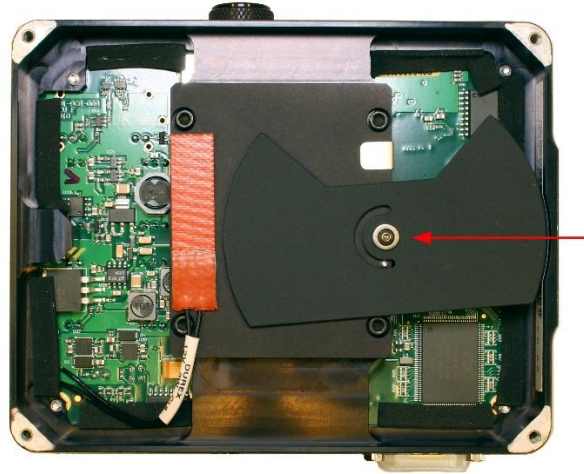
1. Place the STF camera on a clean dry surface with the sensor side facing up.
2. Remove the front cover plate of the camera by unscrewing the four cap screws (use the supplied 3/32" Allen wrench) around the perimeter of the plate and lifting it off the camera body.



The camera's front plate is not used when a filter wheel is attached. Retain this plate for possible future use and set the camera aside.

NOTE:

If you are installing an STF-3200W or STF-8300M camera, note the position of the round recess inside the front plate that allows for the height of the camera's shutter spindle, indicated below.



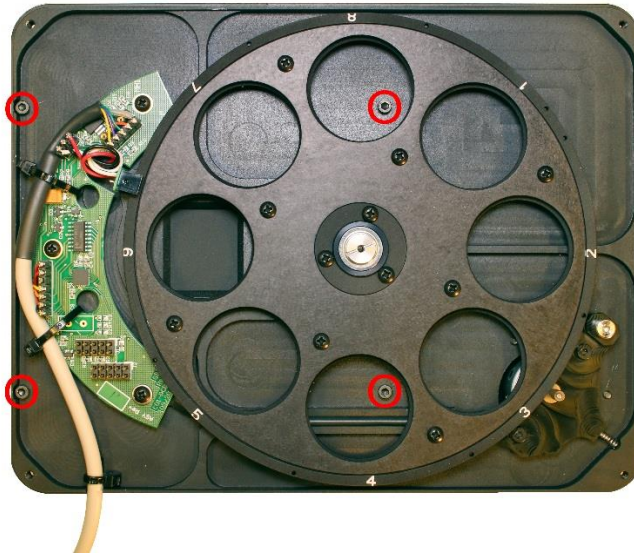
If you wish to re-attach the camera's front plate in the future, you will need to remove the filter wheel and orient the plate in the same way. There is a similar recess in the filter wheel's back plate that will replace the camera front plate and it must be oriented over the shutter spindle in the same way.

3. Place the filter wheel on a clean dry surface with the camera side facing down.
4. Remove the four 4-40 cap screws (indicated) that secure the filter wheel's front plate and lift it off the base plate.

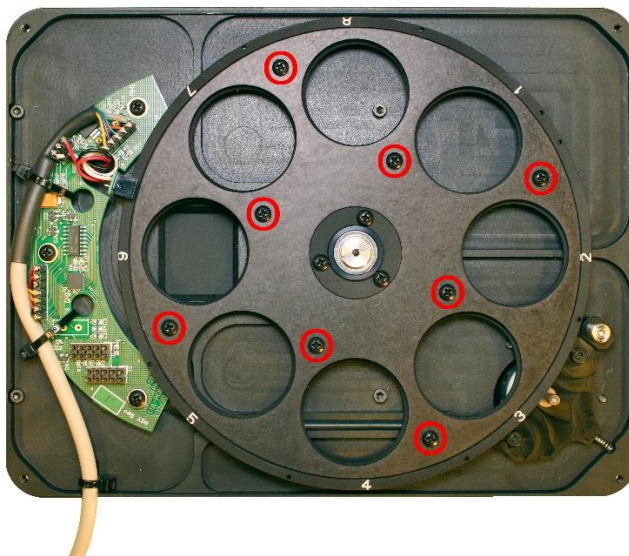


Set the front plate aside.

- Carefully place the filter wheel base plate over the top of the camera. For STF-3200W or STF-8300M cameras, ensure that the top of the camera's shutter spindle goes into the round recess on the camera side of the filter wheel's base plate. The filter wheel bottom plate should fit flush against the front of the camera.
- Reinstall the four screws (circled) that you removed in step 2 through the bottom plate of the filter wheel and into the camera.



- Double-check that all pieces are properly seated and tighten the four screws.
- Separate the filter retainer from the carousel by removing the eight Philips screws (circled) that attach the retainer to the carousel. 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.



Set the filter retainer aside.

9. Determine and record the location you want for each filter. The carousel slots are numbered 1 to 8. Although you can install the filters in any order you wish, you should note what that order is for your software setup later on. We suggest the following typical order:
 - Slot 1: Luminance
 - Slot 2: Red
 - Slot 3: Green
 - Slot 4: Blue
 - Slot 5: H-alpha
 - Slot 6: Sulfur II
 - Slot 7: Oxygen III
 - Slot 8: Other type or empty
10. The filter wheel supports 36 mm filters (or 1.25 inch filters with adapter rings). Ensure that your filters are clean prior to installation.
11. 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.



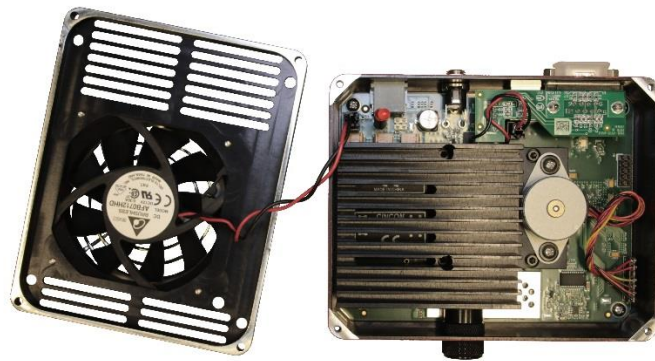
If the filters are less than 3 mm thick (e.g., Baader), then place the filter into the slot **first**, followed by the O-ring. For filters over 3 mm thick, do not use the O-rings.

12. 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 8.
13. Replace the filter wheel front plate being careful not to pinch any internal wires or the outgoing I²C cable.
14. Fasten the front plate to the base plate using the four 4-40 cap screws that you removed in step 4.

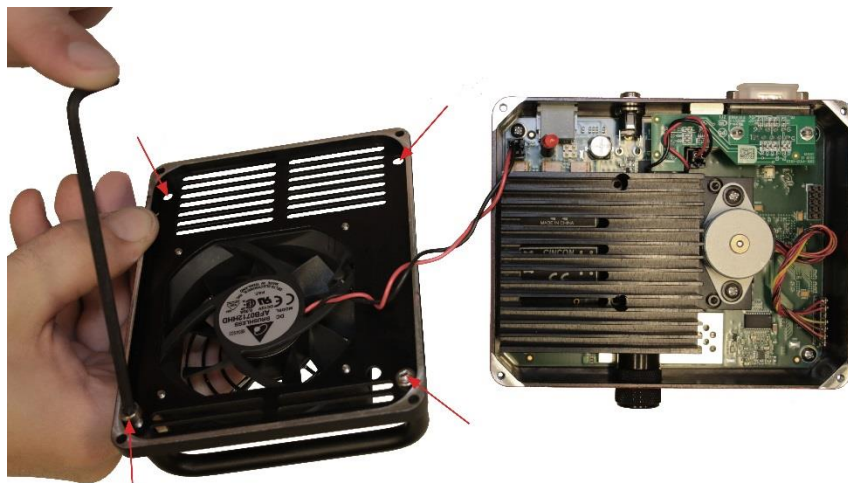
15. To install the camera handles, place the camera on a clean dry surface with the rear cover plate facing up. If you are not installing the handles, proceed to step 19.



16. Remove the rear cover plate of the camera by unscrewing the four indicated cap screws (use the supplied 3/32" Allen wrench) around the perimeter of the plate and lifting it slowly off the camera body. Be careful not to strain the cooling fan wires.



17. Attach the handles to the outer face of the rear cover plate using the four supplied 8-32 x 5/16" socket head cap screws inserted through the plate from the inner face, as indicated.



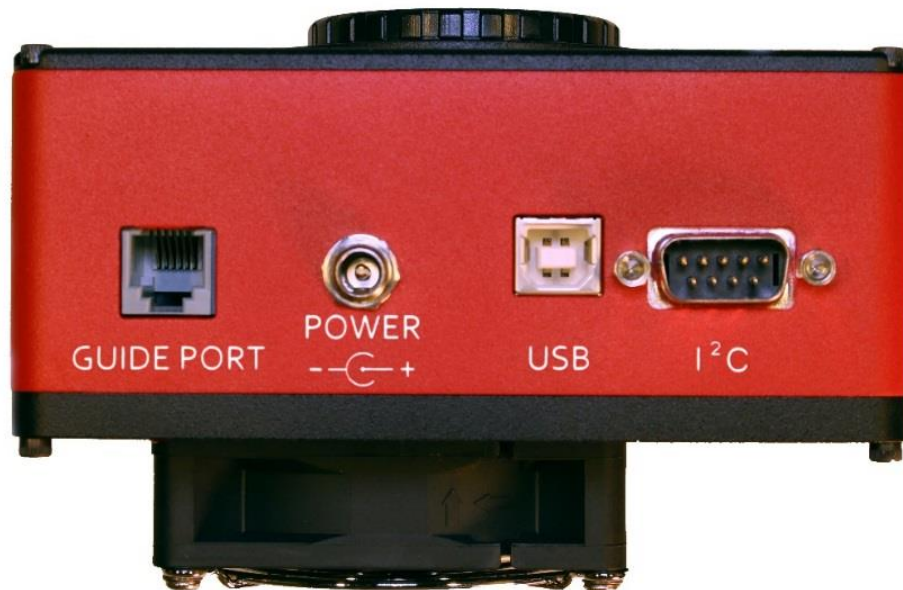
18. Replace the rear cover plate onto the camera. Be careful not to pinch the cooling fan wires and secure the plate using the four cap screws around the perimeter.
19. Install the ferrite snap-on chokes at convenient positions along both the USB cable and the TIC cable, preferably close to the camera ends of these cables. Open a choke and lay the cable into the channel, then snap the choke halves together.



20. Attach the cabling:

➡ CAUTION:

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



- The FW8-8300 filter wheel has a short cable extending from it with a DB-9 connector. If you are installing this filter wheel with your camera, plug the DB-9 connector into the I²C port on the camera. This cable supplies power and control signals to the filter wheel.

➡ CAUTION:

If you are not using the FW8-8300 filter wheel, keep the supplied protective cover on the I²C port to protect the circuitry from electrostatic discharge.

- The Telescope Mount Interface cable (TIC) (RJ11-RJ11) is only required for auto-guiding purposes in astronomical imaging. It plugs into the GUIDE PORT connector on the STF camera and connects to the guiding port on a telescope mount.
- Attach the USB cable between the USB connector and your computer.
- Attach the power supply cable between the POWER connector and the power supply, but do not turn the power supply on yet. You must thread the cable's power connector outer knurled shell down onto the camera connector to ensure that the cable does not come loose.

The camera is now ready to be powered up and tested. Refer to [Section 1.4 Testing the Camera and Filter Wheel](#).

1.4 Testing the Camera and Filter Wheel

Once MaxIm LT is installed and the camera hardware has been assembled, Diffraction Limited recommends that you perform a simple bench test of the system. This should be done prior to mounting your camera on your optics.

You should read Chapter 2 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.

NOTE:

The STF cameras come with a power supply capable of operating from 90 to 264 VAC. Actual power requirements are +12 VDC at 3A maximum for the STF-3200W or STF-8300M models and 6A maximum for the STF-4070 or STF-8050 models.

The camera may also be powered directly from a capable +12 VDC source using an appropriate cable. The optional CA-ST402BATTERY cable is available for this purpose. You can also refer to the power jack pinout diagram in [Appendix A-1 Connector pinouts](#) to create such a cable.

3. Open MaxIm LT and connect to the camera by following the procedure in [Section 2.1 Connecting the STF Camera to MaxIm LT](#).
4. 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 amount of light entering the camera by covering the sensor opening using a piece of cardboard with only a small hole in it.
5. 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.
6. If your testing is successful, you are now ready to mount the camera to your telescope or other optical device. You can use the supplied 2" nosepiece or other proprietary adapter for this, as required.

NOTE:

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


2 - Operating your SBIG STF camera with MaxIm LT

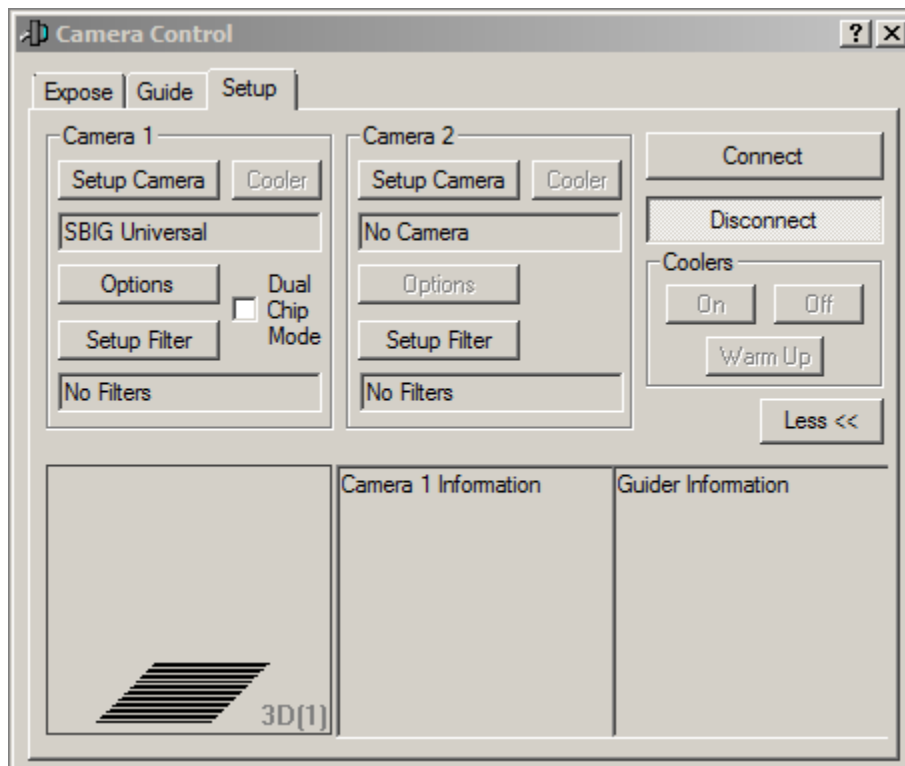
The MaxIm LT application allows full configuration and control of the SBIG STF cameras and filter wheel. Calibrating files, automating imaging sequences, logging, and various image processing tasks can all be performed. Please note however that since MaxIm LT and MaxIm DL both share the same Help file, 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 STF hardware. Consult the Help file for further information on specific parameters, detailed procedures, and various tutorials.

2.1 Connecting the STF Camera to MaxIm LT

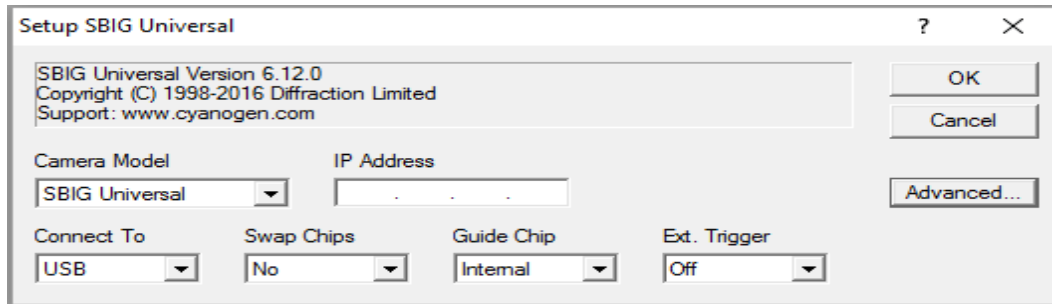
The following is the basic MaxIm LT procedure used to configure and connect to the STF camera and an optional FW8-8300 filter wheel.

1. Launch the MaxIm LT application.
2. Click the Camera Control icon  or press Ctrl-W to open the *Camera Control* form and click the *Setup* tab.



3. Click the *Setup Camera* button under Camera 1 to open the *Setup* form.

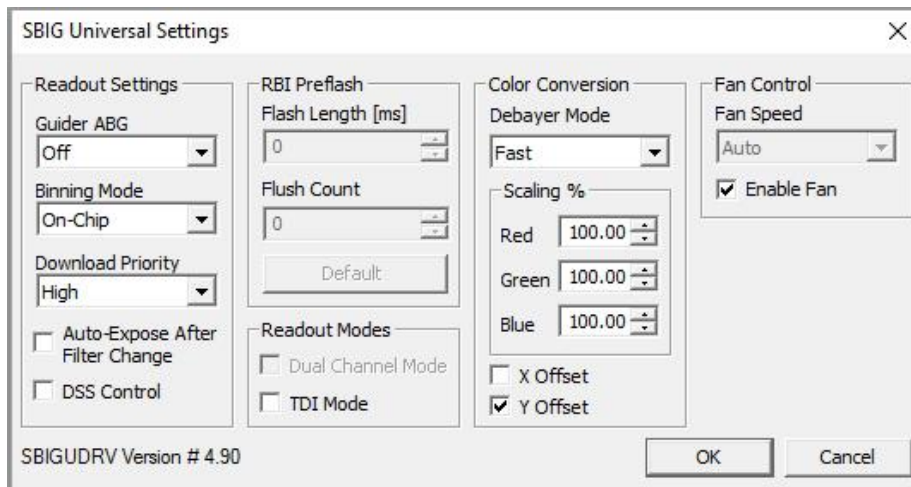
- Click the *Camera Model* drop-down. Three choices are available: Simulator, DL Imaging, and SBIG Universal. Select SBIG Universal.



- Configure the remaining parameters as follows:
 - Connect To*: USB. If the camera is already plugged in, the Connect To field will show the actual camera model instead of USB. This allows you to set up one of multiple cameras, if present.
 - Swap Chips*: No
 - Guide Chip*: not applicable (setting is ignored)
 - IP Address*: not applicable (setting is ignored)
 - Ext. Trigger*: This is set to Off by default. Refer to [Appendix A-1 Connector pinouts](#) for information on using the Trigger In/Trigger Out function.

Note that the next time you open MaxIm LT, your option selections will automatically appear in the *Setup SBIG Universal* form.

- Click the *Advanced* button. The *SBIG Universal Settings* form opens.

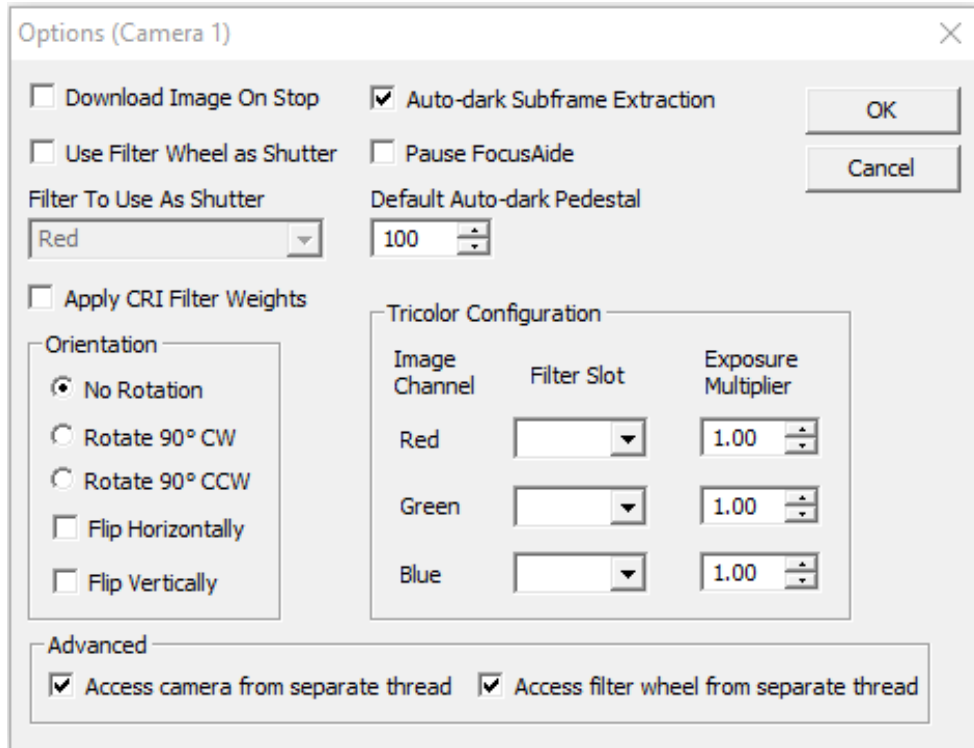


This form allows you to check and set additional camera parameters. The default settings should be fine for your initial connection - reconfigure them if required. Full details on these parameters are available in the MaxIm DL Help file and at:

https://diffractionlimited.com/help/maximdl/HIDD_SETUPST7.htm

Click **OK** to accept the settings and close the *SBIG Universal Settings* form.

7. Click **OK** to accept the settings and close the *Setup SBIG Universal* form to return to the Camera Control form.
8. Click the *Options* button under Camera 1. The *Options (Camera 1)* form opens.



Configure the optional camera parameters as shown. Full details on these parameters are available in the MaxIm DL Help file and at:

https://diffractionlimited.com/help/maximdl/HIDD_SETUPST7.htm

9. Click **OK** to accept the settings and close the *Options (Camera 1)* form to return to the *Camera Control* form.
10. Click the *Setup Filter* button under Camera 1 in the *Camera Control* form if you are using an FW8-8300 filter wheel controlled by MaxIm LT. The *Setup Filter* form opens. Otherwise, go to step 17.

NOTE:

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

11. Select SBIG Universal from the *Filter or Controlling Camera Model* drop-down menu.
12. Select FW8-8300 from the *Model* drop-down menu. The *COM Port* setting is not applicable and can be ignored.
13. Edit any of the eight filter names that you want to by double-clicking an existing name in the list to make changes.

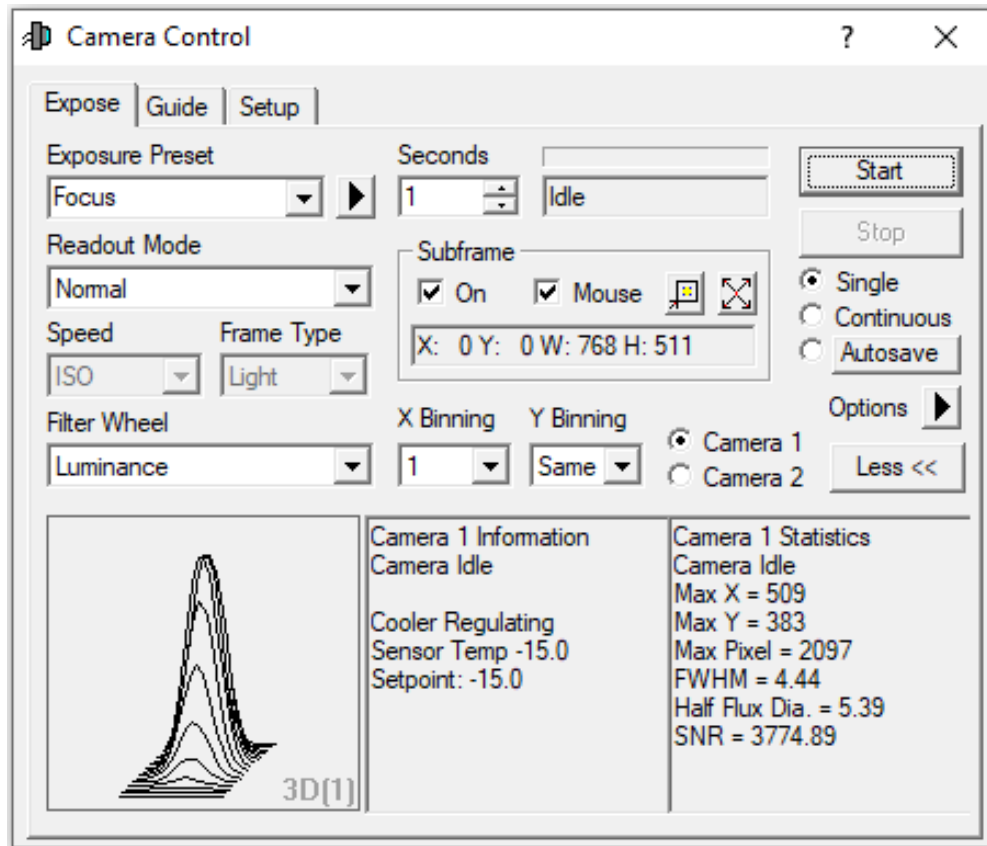
14. If your filters vary in refractive properties, a Focus Offset can be entered for each filter. This causes the focus position to be offset appropriately every time an exposure is taken with a new filter position. If this feature is used, absolute positioning focusers are strongly recommended to ensure accurate repeatability. The offset is expressed in focuser steps.
15. Configure any other parameters that may appear on the *Setup Filter* form using the default values as a starting point. Full details on these parameters are available in the MaxIm DL Help file and at:
https://diffractionlimited.com/help/maximdl/HIDD_SETUPST7.htm
16. Click **OK** to accept the settings. The *Setup Filter* form closes.
17. The settings under Camera 2 are typically used to connect to a separate astronomical guiding camera, if required.
Repeat steps 3 to 16 for Camera 2.
18. Click the *Connect* button to establish camera communications.
19. Enable the camera cooler(s) by clicking the *On* button.
20. Click the *Cooler* button under Camera 1. The *Set Camera Cooler* form opens.
21. Set the desired cooler temperature (in degrees Celsius) and click **OK**. The *Set Camera Cooler* form closes.
22. Click the *Cooler* button under Camera 2, if applicable. The *Set Autoguider Cooler* form opens.
23. Set the desired cooler temperature (in degrees Celsius) and click **OK**. The *Set Autoguider Cooler* form closes.

The STF camera and FW8-8300 filter wheel are now connected and ready to begin imaging.

2.2 Basic Imaging Procedure

After setting up the STF camera and FW8-8300 filter wheel as stated in [Section 2.1 Connecting the STF Camera to MaxIm LT](#), 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 an STF camera.

1. Click the *Expose* tab. The form displays the following:



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, but 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 list of choices is displayed. This menu 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*. This sets a delay time (in seconds) prior to the start of 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 the 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 vary from sensor to sensor, and 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. Normalizing 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 desired 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 thermoelectric (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 desired 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 wantClick **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 desired 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 wantClick **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. 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.

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. 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 FITS Header Keywords 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 which filters are mapped into the 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 ensure 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.

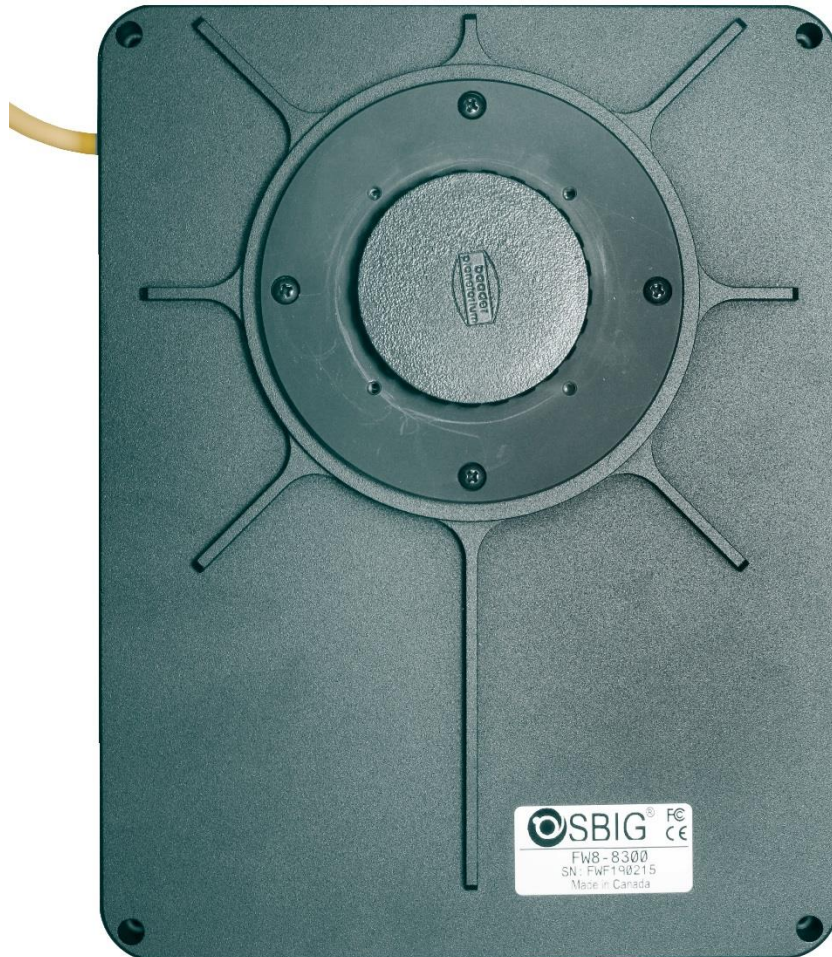
When the combining process completes, the final product is a calibrated master light frame that can be used as a basis for any further image processing.

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 determines the default file type created when MaxIm LT takes images.

4 - Accessories

4.1 FW8-8300 Filter Wheel



The FW8-8300 8-position filter wheel holds standard 36 mm drop-in filters, and inserts are available for 1-1/4" filters, which are suitable for smaller format imaging sensors. The 36 mm filters provide un-vignetted imaging at any f/ratio with cameras such as the STF-8300. The wheel's thin design adds only 20 mm of back focus to the imaging train. Power and control signals to the filter wheel are provided by the fixed I²C cable which connects directly to the STF camera. No additional power or computer cable is required. The filter wheel also allows the use of optional Canon and Nikon lens adapters to enable the use of such lenses with the STF camera.

Refer to the Diffraction Limited website for details at:

<http://diffractionlimited.com/products/cameras-accessories/filter-wheels/>

4.2 Other Accessories

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

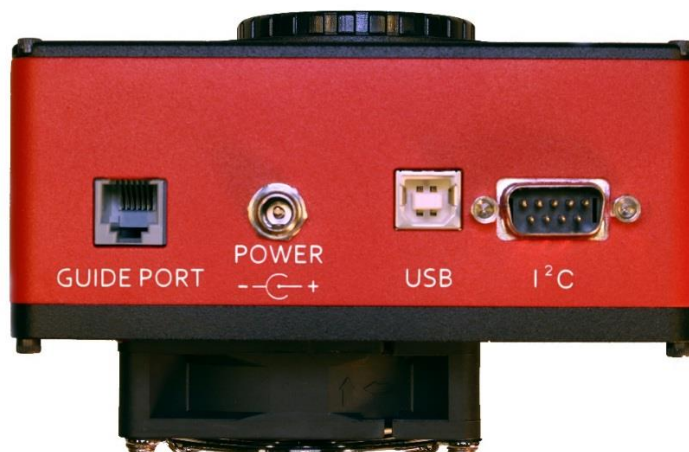
- Canon and Nikon lens adapters
- Filters
- Mounting plates and nosepieces
- Adapter plates and inserts
- Desiccant plugs
- Cables
- Power supplies
- and more ...

Refer to the Diffraction Limited website for details at:

<http://diffractionlimited.com/products/cameras-accessories/accessories/>

Appendix A: SBIG STF Camera Details

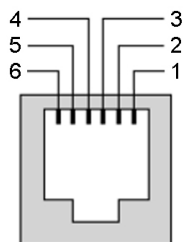
A-1 Connector pinouts



The STF-8300M camera connectors are shown above, but the pinout data provided below is applicable to all the STF series cameras.

USB connector pinout is to the USB standard.

GUIDE PORT (RJ-12), female connector. The diagram shows the pin number identification when looking into the camera's connector.



- Pin 1: AUX
- Pin 2: COMMON
- Pin 3: X- (for the Right Ascension axis)
- Pin 4: Y- (for the Declination axis)
- Pin 5: Y+ (for the Declination axis)
- Pin 6: X+ (for the Right Ascension axis)

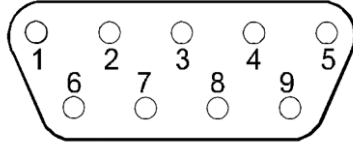
Note: AUX is normally not connected

POWER

This barrel connector is centre-positive and requires an input of +12.0 VDC (range: 10.0 to 14.5 VDC) at 3 amps for most models, and 6 amps for the STF-4070 and STF-8050 models. The recommended mating connector is a Switchcraft S760K, available from DigiKey.

I²C connector (DB-9 Male)

The diagram shows the pin number identification when looking into the camera's connector.



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-2 Specifications

STF-3200W

Imaging sensor	KAF-3200
Peak QE	85%
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 MPix/sec
Total pixel count	3.2 million pixels
Full well capacity	55,000 e-
Read noise	11.0 e- typical
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	0.09 sec
Full frame download	< 1 sec
Internal tracking sensor	No
Power	12 VDC, 3A max
Shutter	Electro-mechanical
Temperature regulation	Yes
Cooling delta below ambient	Typical maximum -30° C
Dimensions	5" x 4" x 3.1" (12.7 x 10.1 x 7.9 cm) (without handles)
Weight	1.7 lbs (0.77 kg)
Computer interface	USB 2.0
OS compatibility	Windows 32 and 64 bit, Macintosh, Linux
<i>Supported options:</i>	
Adaptive optics	No
Filter wheel	Yes
Self-guiding filter wheel	No
Filter size	36 mm or 1.25"
Off-axis guiding	Yes
Remote guide head	No

STF-4070M, STF-4070C, STF-4070SC

Imaging sensor	KAI-04070
Peak QE	52% (STF-4070M) 42% (STF-4070C) 42% (STF-4070SC)
Sensor size	14.6 mm x 12.8 mm
Imaging pixel array	2048 x 2048 pixels
Pixel size	7.4 μm (square)
Pixel digitization rate	10/20 MPix/sec
Total pixel count	4.1 million pixels
Full well capacity	44,000 e-
Read noise	12.0 e- typical
Dark current e/p/s at 0° C	3.0 e-/p/s typical
Anti-blooming	Yes
A/D converter	16-bit
Exposure duration minimum	0.001 sec
Full frame download	0.5 sec
Internal tracking sensor	No
Power	12 VDC, 6A max
Shutter	Electronic
Temperature regulation	Yes
Cooling delta below ambient	Typical maximum -50° C
Dimensions	5" x 4" x 3.75" (12.7 x 10.1 x 9.5 cm) (without handles)
Weight	2.15 lbs (0.98 kg)
Computer interface	USB 2.0
OS compatibility	Windows 32 and 64 bit, Macintosh, Linux
<i>Supported options:</i>	
Adaptive optics	No
Filter wheel	Yes
Self-guiding filter wheel	No
Filter size	36 mm or 1.25"
Off-axis guiding	Yes
Remote guide head	No

STF-8050M, STF-8050C, STF-8050SC

Imaging sensor	KAI-08050
Peak QE	49% (STF-8050M) 36% (STF-8050C) 36% (STF-8050SC)
Sensor size	18.3 mm x 13.6 mm
Imaging pixel array	3296 x 2472 pixels
Pixel size	5.50 μm (square)
Pixel digitization rate	8 MPix/sec
Total pixel count	8.1 million pixels
Full well capacity	20,000 e-
Read noise	12 e- typical
Dark current e/p/s at 0° C	7.0 e-/p/s typical
Anti-blooming	Yes
A/D converter	16-bit
Exposure duration minimum	0.001 sec
Full frame download	0.5 sec
Internal tracking sensor	No
Power	12 VDC, 6A max
Shutter	Electronic
Temperature regulation	Yes
Cooling delta below ambient	Typical maximum -50° C
Dimensions	5" x 4" x 3.75" (12.7 x 10.1 x 9.5 cm) (without handles)
Weight	2.15 lbs (0.98 kg)
Computer interface	USB 2.0
OS compatibility	Windows 32 and 64 bit, Macintosh, Linux
<i>Supported options:</i>	
Adaptive optics	No
Filter wheel	Yes
Self-guiding filter wheel	No
Filter size	36 mm or 1.25"
Off-axis guiding	Yes
Remote guide head	No

STF-8300M

Imaging sensor	KAF-8300
Peak QE	54%
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	25,500 e-
Read noise	9.3 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
Internal tracking sensor	No
Power	12 VDC, 3A max
Shutter	Electro-mechanical, even-illumination
Temperature regulation	Yes
Cooling delta below ambient	Typical maximum -30° to -40° C
Dimensions	5" x 4" x 3.1" (12.7 x 10.1 x 7.9 cm) (without handles)
Weight	1.7 lbs (0.77 kg)
Computer interface	USB 2.0
OS compatibility	Windows 32 and 64 bit, Macintosh, Linux
<i>Supported options:</i>	
Adaptive optics	No
Filter wheel	Yes
Self-guiding filter wheel	No
Filter size	36 mm or 1.25"
Off-axis guiding	Yes
Remote guide head	No

STF-402M

Imaging sensor	KAF-0402
Peak QE	77%
Sensor size	6.9 mm x 4.6 mm
Imaging pixel array	765 x 512 pixels
Pixel size	9.0 μm (square)
Pixel digitization rate	5 MPix/sec
Total pixel count	0.3 million pixels
Full well capacity	100,000 e-
Read noise	13.0 e- typical
Dark current e-/p/s at 0° C	1.0 e-/p/s typical
Anti-blooming	No
A/D converter	16-bit
Exposure duration minimum	0.09 sec
Full frame download	0.25 sec
Internal tracking sensor	No
Power	12 VDC, 3A max
Shutter	Electro-mechanical
Temperature regulation	Yes
Cooling delta below ambient	Typical maximum -20° C
Dimensions	5" x 4" x 3.1" (12.7 x 10.1 x 7.9 cm)
Weight	1.25 lbs (0.57 kg)
Computer interface	USB 2.0
OS compatibility	Windows 32 and 64 bit, Macintosh, Linux
<i>Supported options:</i>	
Adaptive optics	No
Filter wheel	Yes - internal
Self-guiding filter wheel	No
Filter size	22 mm (0.85")
Off-axis guiding	Yes
Remote guide head	No

STF-1603W

Imaging sensor	KAF-1603
Peak QE	77%
Sensor size	13.8 mm x 9.2 mm
Imaging pixel array	1536 x 1024 pixels
Pixel size	9.0 μm (square)
Pixel digitization rate	5 MPix/sec
Total pixel count	1.5 million pixels
Full well capacity	100,000 e-
Read noise	15 e- typical
Dark current e-/p/s at 0° C	0.6 e-/p/s typical
Anti-blooming	No
A/D converter	16-bit
Exposure duration minimum	0.09 sec
Full frame download	0.5 sec
Internal tracking sensor	No
Power	12 VDC, 3A max
Shutter	Electro-mechanical
Temperature regulation	Yes
Cooling delta below ambient	Typical maximum -30° C
Dimensions	5" x 4" x 3.1" (12.7 x 10.1 x 7.9 cm) (without handles)
Weight	1.7 lbs (0.77 kg)
Computer interface	USB 2.0
OS compatibility	Windows 32 and 64 bit, Macintosh, Linux
<i>Supported options:</i>	
Adaptive optics	No
Filter wheel	Yes
Self-guiding filter wheel	No
Filter size	36 mm or 1.25"
Off-axis guiding	Yes
Remote guide head	No

Appendix B: Maintenance

B-1 Cleaning the sensor window

The design of the STF cameras allows for cleaning of the window covering the sensor chamber. The camera body is not evacuated and is easy to open. When opening or reassembling the camera (see [Section 1.3 Installing the Hardware](#)), you must be careful not to damage any of the structures contained inside. Treat the instrument delicately.

For the STF models that use a mechanical shutter, ensure that the power to the camera is off before cleaning. Carefully rotate the shutter by hand to access the window for cleaning.

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

The sensor 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.

B-2 Regenerating the desiccant

This section describes the regeneration procedure for the desiccant used in the STF 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 or used in high humidity conditions, you are advised to regenerate the desiccant every six months, or even sooner if frosting is noticed.

➡ CAUTION:

Failure to regenerate the desiccant regularly can lead to expensive corrosion damage inside the camera body and will void your warranty. Do not ignore this procedure!

To regenerate the desiccant:

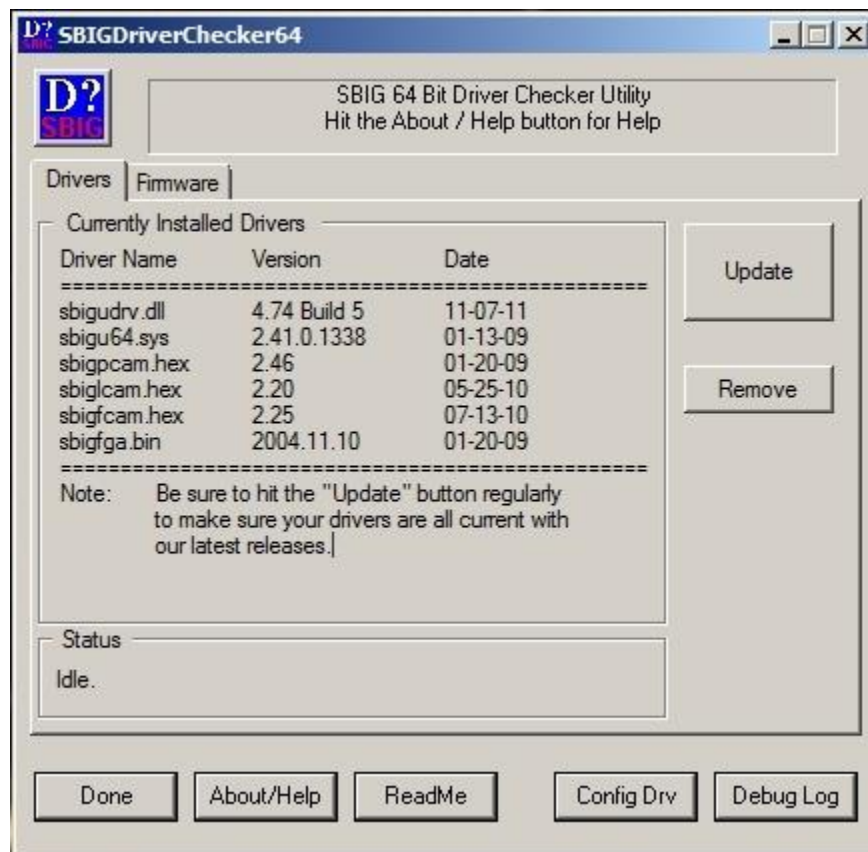
1. Place the camera on a clean dry surface with the knurled aluminum desiccant knob facing upwards.
2. The container screws into the side of the camera body. Use your fingers and turn it counter-clockwise to extract it.
3. Remove the O-ring from the container and place it aside.
4. Set the camera aside 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 the container into the camera. Insure that the O-ring does not get pinched.
7. Turn the container clockwise by hand to tighten it. Do not use tools.
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.

B-3 Updating the camera drivers and firmware

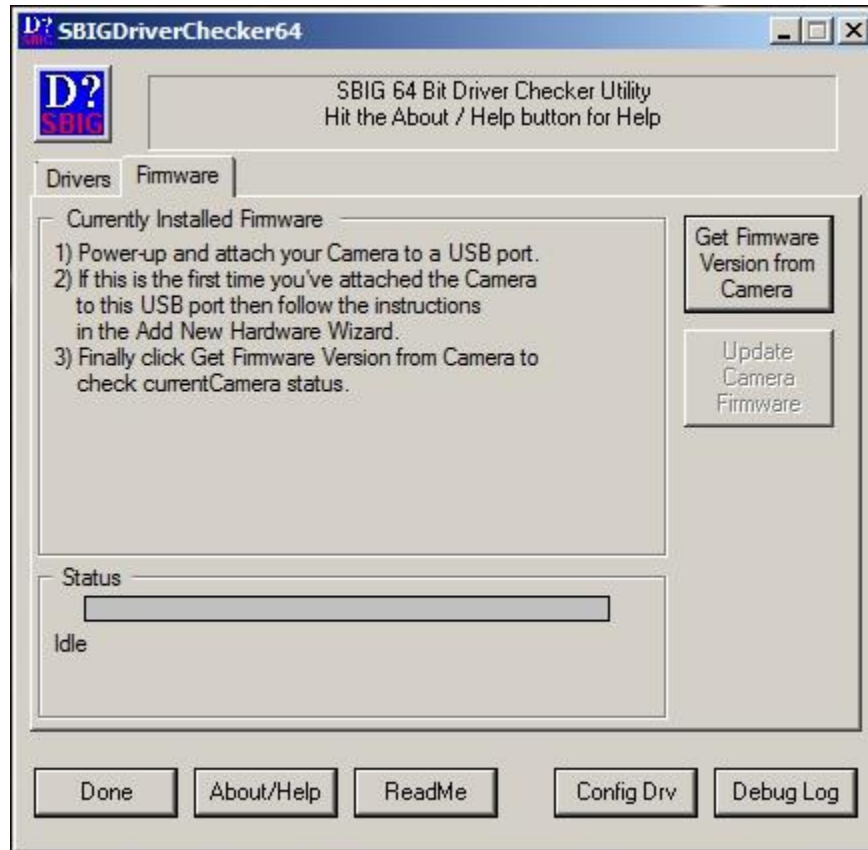
You should periodically check for updates to your camera's drivers and firmware to ensure the best possible performance. Diffraction Limited supplies a software utility program named the SBIG 64-Bit Driver Checker Utility that will update both of these elements. The program can be freely downloaded from the Diffraction Limited website. Use the following procedure to update the STF camera drivers and firmware.

1. Go to the Diffraction Limited website at:
<http://diffractionlimited.com/>
2. Navigate to the Products page for your camera and click the *Downloads* tab.
3. Under the Software section, click the appropriate *Download* button for SBIGUDrv. The download begins automatically.
4. Go to your local Downloads folder and double-click the *SetupDriverChecker64.exe* file to install the program. Follow the onscreen instructions.
5. Start the SBIG 64-Bit Driver Checker Utility when the installation completes. The utility opens on the *Drivers* tab.



6. Click the *Update* button to update to the latest drivers.

7. Click the *Firmware* tab.



8. Apply power to your camera and connect it to a USB port.
9. If this is the first time you have attached the camera to this particular USB port then the Windows Add New Hardware Wizard may open. Follow the onscreen instructions to proceed.
10. Click the *Get Firmware Version from Camera* button. The utility informs you of the camera's current firmware status.
11. If your firmware version is current, you can exit the utility.
12. If your firmware version is not current, click the *Update Camera Firmware* button. The utility will download the most current firmware version for your camera. Follow any onscreen instructions that may appear and wait for the program to report that the update to your camera is complete.

➡ CAUTION:

Do not interrupt the firmware upgrade process or your camera may become unresponsive, which will require it to be returned to the factory for service.

13. Once the main firmware has been successfully updated, you can exit the utility.

Appendix C: Troubleshooting

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

Check the power:

- Ensure that your camera's power cabling is undamaged and securely attached.
- If you are using a portable power supply such as a 12V battery, check the voltage to ensure that it is operating at a proper level.
- Ensure that the camera is receiving power. All STF cameras employ thermoelectric cooling and a fan to remove heat. When your camera is powered up, you should hear the fan operating.

Check the USB interface:

Follow these recommendations to ensure good USB connectivity:

- Use only good quality USB cables.
- Ensure that the USB cable is undamaged and securely attached.
- 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 ports 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 firmware and SBIG drivers:

Use the SBIG 64-Bit Driver Checker Utility program to ensure the camera's firmware is up to date and that the latest drivers are installed. Refer to [Appendix B-3 Updating the camera drivers and firmware.](#)

Appendix D: Legacy SBIG STF camera models

Certain SBIG STF camera models have been discontinued or superseded, including:

- STF-402M is discontinued due to sensor obsolescence. The STF-402M lacked the user-rechargeable desiccant plug and the I²C port. It was not compatible with the FW8-8300 filter wheel. Instead, it incorporated an optional built-in four-position filter wheel, which could include either BVI or RGB filters.
- STF-1603W is discontinued due to sensor obsolescence. It included the I²C port, external filter wheel support, and user-rechargeable desiccant plug.
- STF-1603M was an older version of the STF-1603W. It did not include the I²C port, external filter wheel support, or user-rechargeable desiccant plug.
- STF-3200M was superseded by the current STF-3200W. The "W" version includes the I²C port, external filter wheel support, and user-rechargeable desiccant plug.
- Previous generation cameras include the ST-402ME, ST-1603ME, ST-3200ME, ST-8300M, and ST-8300C. These were slower USB 1.1 versions of the STF cameras.

For more information on discontinued SBIG STF models, please see:

<http://diffractionlimited.com/products/obsolete/>

For more information on discontinued SBIG ST models, please see:

<http://diffractionlimited.com/support/sbig-archives/>

Appendix E: 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

Authorized Repair Center

Bill Lynch – SBIG Service & Repair Center

3769 Constellation Road, Unit D
Lompoc, CA 93436

Bill Lynch – email via:

<http://diffractionlimited.com/about-us/contact-us/#contact-form>

NOTE: You must contact our authorized service & repair center for an RMA number prior to returning your equipment.

Phone: (805) 308-6979

Diffraction Limited Main Address

For non-repair purposes & enquiries only:

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

Appendix F: Compatible software products

MaxIm LT

MaxIm LT is a limited version of MaxIm DL, and is specifically for controlling SBIG STF, STXL, STX, and Aluma cameras. The program operates on Windows computers only. Refer to the [Windows Installation](#) section in this guide for details installation.

The program is supplied on the USB flash drive included with your camera. A license is available at no cost to the original owner of the camera for any purchase made after October 01, 2019. Owners of cameras that were purchased previously may buy a license for a discounted price of \$99 USD.

MaxIm DL

MaxIm DL is a full-featured camera control and image processing program available from Diffraction Limited. It can control all SBIG camera models and a wide variety third-party cameras. For product details, refer to the Software page of the Diffraction Limited web site at:

<http://diffractionlimited.com/products/software-products/>

CCDOPS

The CCDOPS program and user manual are available for controlling older SBIG cameras. These can be freely downloaded from the Legacy Product Support page of the Diffraction Limited web site at:

<http://diffractionlimited.com/support/sbig-archives/>

Appendix G: 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 is 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 stationary 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 STF-8300M'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 thermoelectric 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 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