G2 CCD Camera

User's Guide

Version 2.6

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Introduction

Thank you for choosing the G2 CCD camera. The cooled, slow-scan series of G2 CCD cameras were developed for imaging under extremely low-light conditions in astronomy, microscopy and similar areas. The development team focused to every detail of camera mechanics, cooling, electronics and software to create state-of-the-art product. G2 CCD cameras feature compact and robust construction, rich features, sophisticated software support and easy operation.

G2 cameras can contain filter wheel with 5 positions for 1.25“ filters . Camera variants without internal filter wheel can control external filter wheel with 12 positions for the same filter s or with 10 positions for D36 mm filters.

Please note the G2 CCD cameras are designed to work in cooperation with a host Personal Computer (PC). As opposite to digital still cameras, which are operated independently on the computer, the scientific slow-scan, cooled cameras usually require computer for operation control, image download, processing and storage etc. To operate G2 CCD camera, you need a computer which:

1. Is compatible with a PC standard.
2. Runs a modern 32-bit or 64-bit Windows operating system.

   Drivers for 32-bit and 64-bit Linux systems are also provided, but camera control and image processing software, supplied with the camera, requires Windows operating system.

3. Provides at last one free USB port.

   The current series of G2 CCD cameras are designed to operate with USB 2.0 high-speed (480 Mbps) hosts. Although they are fully backward compatible with USB 1.1 full-speed (12 Mbps) hosts, image download time can be somewhat longer if USB 1.1 connection is used.

   A simple and cheap device called USB hub can expand number of available USB port. Typical USB hub occupies one computer USB port and offers four free ports. Make sure the USB hub is USB 2.0 high-speed compatible.

But keep on mind that if more USB devices connected to one hub need to communicate with a host PC, USB hub shares its single up link line to the host PC. Although G2 CCD cameras can operate through a USB hub, it can negatively affect the camera performance, like download time etc. It is recommended to connect other USB devices through USB hub (e.g. the mouse) and to provide the camera a direct USB connection to the host PC.

4. Alternatively it is possible to use the Gx Camera Ethernet Adapter. This device can connect up to four Gx cameras of any type (not only G3 and G4, but also G0, G1 and G2) and offers 1 Gbps and 10/100 Mbps Ethernet interface for direct connection to the host PC. Because the PC then uses TCP/IP protocol to communicate with the cameras, it is possible to insert e.g. WiFi bridge or other networking device to the communication path.

The G2 CCD camera needs an external power supply to operate. It is not possible to run the camera from the power lines provided by the USB cable, which is common for webcams or very simple imagers. G2 CCD cameras integrate highly efficient CCD chip cooling, shutter and filter wheel, so their power requirements significantly exceed USB line power capabilities. On the other side separate power source eliminates problems with voltage drop on long USB cables or with drawing of laptop batteries etc.

Also note the camera must be connected to some optical system (e.g. the telescope) to capture images. The camera is designed for long exposures, necessary to acquire the light from faint objects. If you plan to use the camera with the telescope, make sure the whole telescope/mount setup is capable to track the target object smoothly during the exposure.

G2 Camera Overview

G2 camera head is designed to be easily used with a set of accessories to fulfill various observing needs. Camera head itself is manufactured in two different variants:

- Camera with internal filter wheel.
- Camera with control port for external filter wheel. This model allows attachment of several variants of external filter wheels with various number of filter positions and sizes.

Illustration 1: G2 camera without filter wheel (left), with internal filter wheel (middle) and with attached external filter wheel (right).

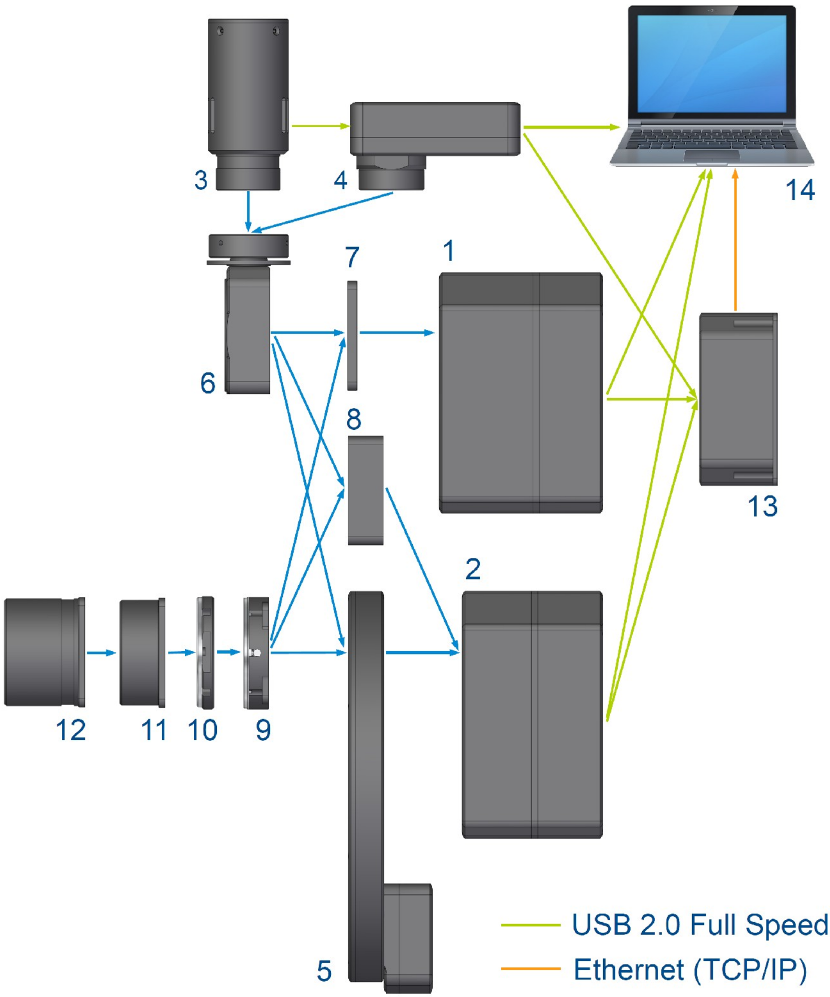


Illustration 2: Schematic diagram of G2 camera system components

Components of G2 Camera system include:

1. G2 camera head with internal filter wheel.
2. G2 camera head without internal filter wheel, ready for attaching of external filter wheel.
3. G0 Guider camera.
4. G1 Guider camera.

G0 and G1 cameras are completely independent devices with their own USB connection to the host PC. They can be used on G2 OAG, on standalone guiding telescope or for any other imaging purpose, like Moon or planetary imaging etc.

Both G0 and G1 camera can share the Gx Camera Ethernet Adapter with up to 3 other Gx cameras to be accessed over network.

5. External filter wheel.
6. Off-axis guider adapter, optionally with M42×0.75 thread (T-thread) or M48×0.75 thread.
7. Thin spacer. Camera with internal filter wheel and this spacer has the same back focal distance as camera with external filter wheel.
8. Thick spacer. Camera without internal filter wheel and this spacer has the same back focal distance as camera with external filter wheel.
9. Nikon bayonet adapter for Nikon compatible lenses.
10. Canon EOS bayonet adapter for Canon compatible lenses.
11. T-thread (M42×0.75) adapter.
12. 2-inch barrel adapter.

Other available adapters are missing from this illustration, e.g. M48×0.75 thread adapter, M42×1 Pentax/Parktica lens adapter etc.

13. Gx Camera Ethernet Adapter allows connection of up to 4 Gx cameras of any type on the one side and 1 Gbps Ethernet on the other side. This adapter allows access to connected Gx cameras using routable TCP/IP protocol over practically unlimited distance.
14. The whole system is controlled from a host PC.

CCD and Camera Electronics

G2 series of CCD cameras are manufactured with two kinds of CCD detectors:

- **G2 cameras with Kodak KAF Full Frame (FF) CCD architecture.** Almost all Full Frame CCD detector area is exposed to light. This is why these detectors provide very high quantum efficiency. FF CCD detectors, intended for research applications, are not equipped with so-called Anti Blooming Gate (ABG – a gate, which prohibits blooming of the charge to neighboring pixels when image is over-exposed) to ensure linear response to light through the whole dynamic range. FF CCD detectors used for astrophotography are equipped with ABG to eliminate disrupting blooming streaks within field of view.

  Cameras with Full Frame, non-ABG detectors are suitable for scientific applications, where linear response is necessary for photometric applications in astronomy, microscopy etc. High quantum efficiency could be used also for narrow-band imaging, where overexposure is a rare exception, and for imaging of small objects without a bright star in the field of view.

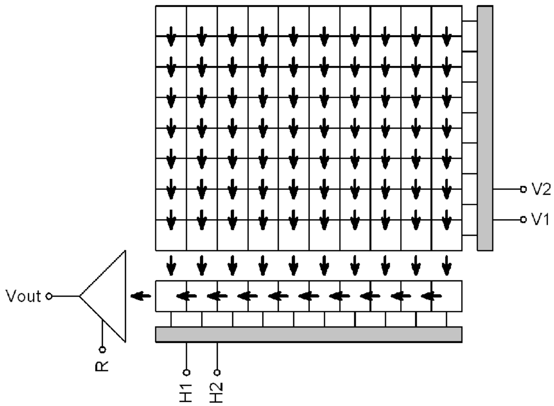


Illustration 3: "Full Frame" CCD schematic diagram

- **G2 cameras with Kodak KAI Interline Transfer (IT) architecture.** There is a shielded column of pixels just beside each column of active pixels on these detectors. The shielded columns are called Vertical registers. One pulse moves charge from exposed pixels to shielded pixels on the end of each exposure. The the charge is moved from vertical registers to horizontal register and digitized in the same way like in the case of Full Frame detectors. This mechanism is also known as “electronic shuttering”, because it allows very short exposures and also digitization of the image without mechanically shielding of the detector from incoming light.

  Also G2 cameras with IT CCDs are equipped with mechanical shutter, because electronic shutter does not allow dark-frame exposures, necessary for proper image calibration etc.

  The price for electronic shutter if lower quantum efficiency (sensitivity) of IT detectors compared to FF ones. Also all IT detectors are equipped with ABG, so they can acquire images of very bright objects without charge blooming to neighboring pixels.

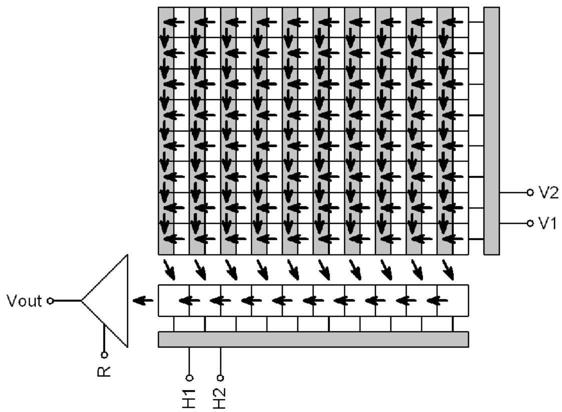
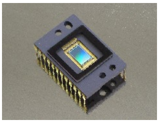
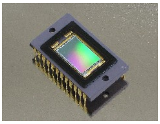
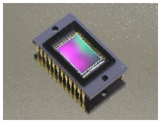
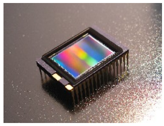


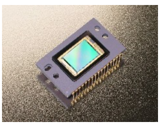
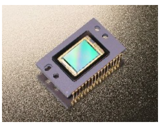
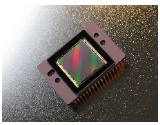
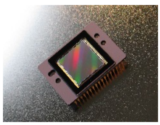
Illustration 4: “Interline Transfer” CCD schematic diagram

G2 camera models with Full Frame CCD detectors:

Model	**G2-0402**	**G2-1600**	**G2-3200**	**G2-8300**
CCD chip	KAF-0402ME	KAF-1603ME	KAF-3200ME	KAF-8300
Resolution	768×512	1536×1024	2184×1472	3358×2536
Pixel size	9×9 μm	9×9 μm	6.8×6.8 μm	5,4×5,4 μm
CCD area	6.9×4.6 mm	13.8×9.2 mm	14.9×10.0 mm	18,1×13,7 mm
ABG	No	No	No	Yes
Color mask	No	No	No	No (see Note)
				

G2-8300 camera is available in the G2-8300C version with color CCD detector (with Bayer mask), capable of single-shot color images.

G2 camera models with Interline Transfer CCD detectors::

Model	**G2-2000**	**G2-2000C**	**G2-4000**	**G2-4000C**
CCD chip	KAI-2020	KAI-2020	KAI-4022	KAI-4022
Resolution	1604×1204	1604×1204	2056×2062	2056×2062
Pixel size	7,4×7,4 μm	7,4×7,4 μm	7,4×7,4 μm	7,4×7,4 μm
CCD area	11,8×9,0 mm	11,8×9,0 mm	15,2×15,2 mm	15,2×15,2 mm
ABG	Yes	Yes	Yes	Yes
Color mask	No	Yes	No	Yes
				

Cameras with “C” suffix contains CCD detector covered with so-called Bayer mask. Color filters of three basic colors (red, green, blue) cover all pixels, so every pixels detects only light of particular color.

These cameras are able to acquire color image in single exposure, without the necessity to change color filters. On the other side color mask brings lower sensitivity and limits the capability to perform exposures using narrow-band filters etc.

Because each pixel is covered by one of three basic color filters, it is necessary to compute (interpolate) remaining two colors for each pixel, which of course limits resolution of color image. Imaging using color detectors is described in the “Color images” chapter.

CCD Chip

Quantum efficiency (sensitivity) of CCD detectors used in G2 cameras depends on the particular camera model.

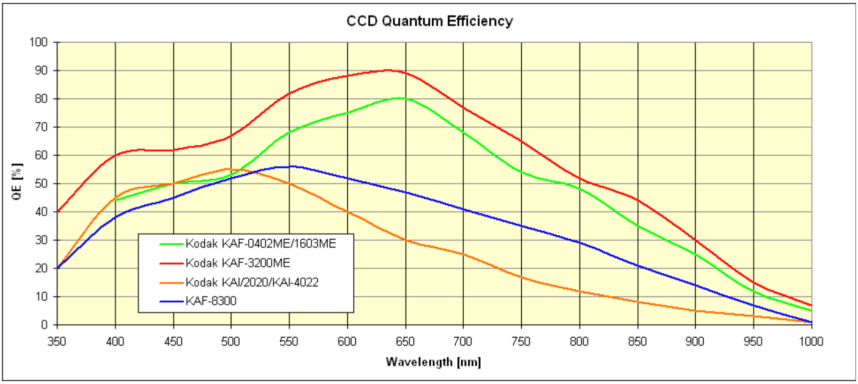


Illustration 5: Quantum efficiency of Kodak CCD detectors used in G2 cameras

Inherent dark current of these detectors is quite low compared to other CCD detectors, suitable for scientific applications, which results into very good signal/noise ratio.

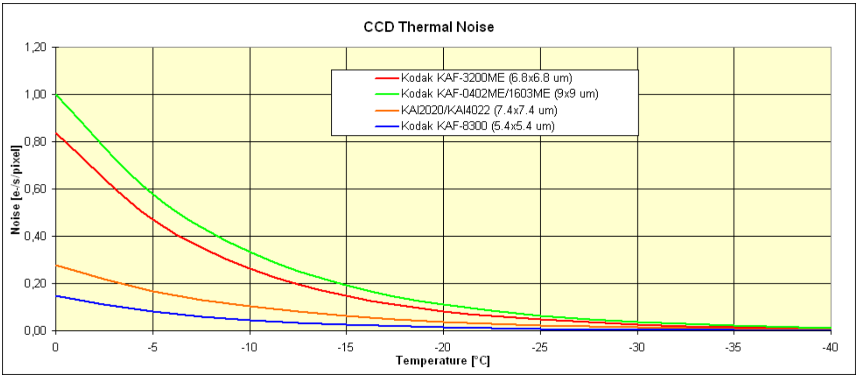


Illustration 6: Dark current of Kodak CCD detectors, used in G2 cameras

Model G2-0402

G2-0402 model uses 0.4 MPx Kodak KAF-0402ME.

Resolution	768×512 pixels
Pixel size	9×9 μm
Imaging area	6.9×4.6 mm
Full well capacity	Approx. 100 000 e^-
Output node capacity	Approx. 220 000 e^-
Dark current	1 e^-/s/pixel at 0°C
Dark signal doubling	6.3 °C

Model G2-1600

G2-1600 model uses 1.6 MPx Kodak KAF-1603ME.

Resolution	1536×1024 pixels
Pixel size	9×9 μm
Imaging area	13.8×9.2 mm
Full well capacity	Approx. 100 000 e^-
Output node capacity	Approx. 220 000 e^-

Dark current	1 e^-/s/pixel at 0°C
Dark signal doubling	6.3 °C

Model G2-3200

G2-3200 model uses 3.2 MPx Kodak KAF-3200ME.

Resolution	2184×1472 pixels
Pixel size	6.8×6.8 μm
Imaging area	14.9×10.0 mm
Full well capacity	Approx. 55 000 e^-
Output node capacity	Approx. 110 000 e^-
Dark current	0.8 e^-/s/pixel at 0°C
Dark signal doubling	6 °C

Model G2-8300

G2-8300 model uses 8 MPx Kodak KAF-8300.

Resolution	3358×2536 pixels
Pixel size	5,4×5,4 μm
Imaging area	18,1×13,7 mm
Full well capacity	Approx. 25 000 e^-
Output node capacity	Approx. 55 000 e^-
Dark current	0.15 e^-/s/pixel at 0°C
Dark signal doubling	5.8 °C

KAF-8300 CCD detector with color (Bayer) mask can be used in the G2-8300C camera.

Model G2-2000

G2-2000 uses 2 MPx CCD Kodak KAI-2020.

Resolution	1604×1204 pixels
Pixel size	7.4×7.4 μm
Imaging area	11.9×8.9 mm

Full well capacity	Approx. 40 000 e^-
Output node capacity	Approx. 80 000 e^-
Dark current	0.3 e^-/s/pixel at 0°C
Dark signal doubling	7 °C

KAI-2020 CCD detector with color (Bayer) mask can be used in the G2-2000C camera.

Model G2-4000

G2-2000 uses 4 MPx CCD Kodak KAI-4022.

Resolution	2056×2062 pixels
Pixel size	7.4×7.4 μm
Imaging area	15.2×15.2 mm
Full well capacity	Approx. 40 000 e^-
Output node capacity	Approx. 80 000 e^-
Dark current	0.3 e^-/s/pixel at 0°C
Dark signal doubling	7 °C

KAI-4022 CCD detector with color (Bayer) mask can be used in the G2-4000C camera.

Camera Electronics

Remark

Stated values are valid for G2 cameras revision 4. Previous revisions could differ in some parameters. Refer to chapter “G2 Camera Revisions” for differences among individual revisions.

Some parameters (e.g. camera gain) are defined by the used system driver, so they depend on the version of actually used driver. If the Gx Camera Ethernet Adapter is used, system driver is defined by the firmware version of the Ethernet Adapter device.

16-bit A/D converter with correlated double sampling ensures high dynamic range and CCD chip-limited readout noise. Fast USB interface ensures image download time within seconds.

ADC resolution	16 bits
Sampling method	Correlated double sampling
Read modes	Preview
	Low-noise
Horizontal binning	1 to 4 pixels
Vertical binning	1 to 4 pixels
Sub-frame readout	Arbitrary sub-frame
Computer interface	USB 2.0 high-speed
	USB 1.1 full-speed compatible

Binning can be combined independently on both axes.

Image download time and system read noise depends on the CCD chip used in particular camera model.

Model G2-0402

Gain	1.5e$^-$/ADU (1×1 binning)
	2.0e$^-$/ADU (other binnings)
System read noise	15 e$^-$ (Low Noise mode)
	17 e$^-$ (Preview mode)
Full frame download	0.7 s (Low Noise mode)
	0.5 s (Preview mode)

Model G2-1600

Gain	1.5e$^-$/ADU (1×1 binning)
	2.0e$^-$/ADU (other binnings)
System read noise	15 e$^-$ (Low Noise mode)
	17 e$^-$ (Preview mode)
Full frame download	2.6 s (Low Noise mode)
	1.8 s (Preview mode)

Model G2-3200

Gain	0.8 e^-/ADU (1×1 binning)
	1.3 e^-/ADU (other binnings)
System read noise	7 e^- (Low Noise mode)
	10 e^- (Preview mode)
Full frame download	5.5 s (Low Noise mode)
	3.8 s (Preview mode)

Model G2-8300

Gain	0.4 e^-/ADU (1×1 binning)
	0.8 e^-/ADU (other binnings)
System read noise	8 e^- (Low Noise mode)
	9 e^- (Preview mode)
Full frame download	14.2 s (Low Noise mode)
	9.8 s (Preview mode)

Model G2-2000

Gain	0.4 e^-/ADU (1×1 binning)
	0.8 e^-/ADU (other binnings)
System read noise	7 e^- (Low Noise mode)
	9 e^- (Preview mode)
Full frame download	3.1 s (Low Noise mode)
	2.1 s (Preview mode)

Model G2-4000

Gain	0.4 e-/ADU (1×1 binning)
	0.8 e^-/ADU (other binnings)
System read noise	7 e^- (Low Noise mode)
	9 e^- (Preview mode)
Full frame download	6.7 s (Low Noise mode)
	4.5 s (Preview mode)

CCD Cooling and Power Supply

Regulated two-stage thermo-electric cooling is capable to cool the CCD chip up to 50 °C below ambient temperature. The Peltier hot side is cooled by a fan. The CCD chip temperature is regulated with ±0.1 °C precision. High temperature drop and precision regulation ensure very low dark current for long exposures and allow image proper calibration.

The camera head contains two temperature sensors – the first sensor measures directly the temperature of the CCD chip. The second one measures the temperature of the air cooling the Peltier hot side.

The cooling performance depends on the environmental conditions and also on the power supply. If the power supply voltage drops below 12 V, the maximum temperature drop is lower.

CCD chip cooling	Thermoelectric (Peltier modules)
TEC modules	Two stages
Maximal ΔT	>50 °C below ambient
Regulated ΔT	48 °C below ambient (85% cooling)
Regulation precision	±0.1 °C
Hot side cooling	Forced air cooling (fan)
	Optional heat exchanger for liquid coolant

Maximum temperature difference between CCD and ambient air may exceed 50 °C when the cooling runs at 100% power. However, temperature cannot be regulated in such case, camera has no room for lowering the CCD temperature when the ambient temperature rises. The 45 °C temperature drop can be achieved with cooling running at approx. 85% power, which provides enough room for regulation.

Power Supply

The 12 V DC power supply enables camera operation from arbitrary power source including batteries, wall adapters etc. Universal 100-240 V AC/50-60 Hz, 60 W “brick” adapter is supplied with the camera. Although the camera power consumption does not exceed 30 W, the 60 W power supply ensures noise-free operation.

Camera head supply	12 V DC
Camera head power consumption	30 W
Adapter input voltage	100-240 V AC/50-60 Hz
Adapter output voltage	12 V DC/5 A
Adapter maximum power	60 W

Power consumption is measured on the AC side of the supplied 12 V AC/DC power supply. Camera consumes less energy from 12 V power supply than state here.

The camera contains its own power supplies inside, so it can be powered by unregulated 12 V DC power source – the input voltage can be anywhere between 10 and 14 V. However, some parameters (like cooling efficiency) can degrade if the supply drops below 12 V.

G2 CCD camera measures its input voltage and provides it to the control software. Input voltage is displayed in the Cooling tab of the CCD Camera control tool in the SIPS. This feature is important especially if you power the camera from batteries.

Illustration 7: 12 V DC/5 A power supply adapter for G2 CCD Camera

Warning:

The power connector on the camera head uses center-plus pin. Although all modern power supplies use this configuration, always make sure the polarity is correct if you use own power source.

Mechanical Specifications

Compact and robust camera head measures only 114×114×65 mm (approx. 4.5×4.5×2.6 inches). The head is CNC-machined from high-quality aluminum and black anodized. The head itself contains USB-B (device) connector and 12 V DC power plug. Integrated mechanical shutter allows streak-free image readout, as well as automatic dark frame exposures, which are necessary for unattended, robotic setups. Integrated filter wheel contains 5 positions for standard 1.25-inch threaded filter cells. A variant of filter wheel with 6 positions for the same filters without cells (only a glass) is also available.

Internal mechanical shutter	Yes, blade shutter
Shortest exposure time	0.1 s
Longest exposure time	Limited by chip saturation only
Internal filter wheel	5 positions for 1.25" threaded filter cells or for 31 mm glass-only filters
	6 positions for 26.5 mm glass-only filters
Head dimensions	114×114×77.5 mm (with internal filter wheel)
	114×114×65 mm (without filter wheel)
Back focal distance	29 mm (with internal filter wheel)
	16.5 mm (without filter wheel)
	33.5 mm (with external filter wheel)
Camera head weight	1.15 kg (with internal filter wheel)
	1.05 kg (without filter wheel)
	1.95 kg (with external filter wheel)

Filter wheel with 6 positions cause vignetting (shielding of the detector corners) if large CCD detector is used.

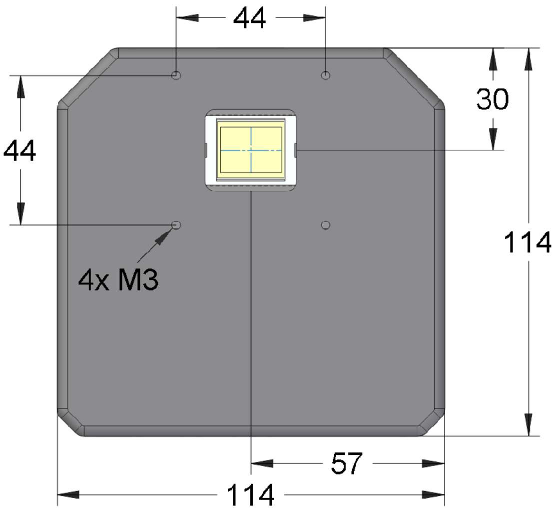


Illustration 8: G2 camera head front view dimensions

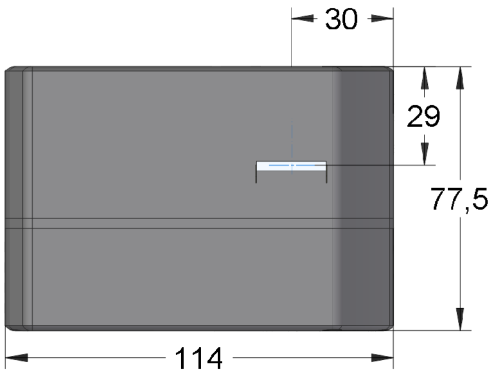


Illustration 9: G2 camera head with internal filter wheel side view dimensions

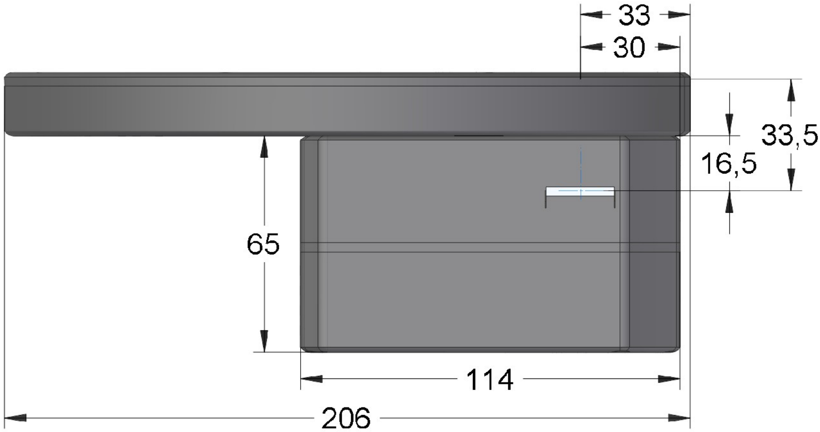


Illustration 10: G2 camera head with external filter wheel side view dimensions

Telescope adapters

The camera is supplied with standard 2" barrel adapter by default, but the user can choose any other adapter he/she prefers. Another adapters can be ordered separately.

It is possible to choose among various telescope/lens adapters:

2" barrel adapter		Adapter for 2" focusers.
T-thread short		M42×0.75 mm inner thread, 7.5 mm thick.

T-thread with 55 mm BFD		M42×0.75 mm inner thread, preserves 55 mm back focal distance.
M48×0.75 thread short		Adapter with inner thread M48×0.75, 7.5mm thick
M48×0.75 thread with 55 mm BFD		Adapter with inner thread M48×0.75, preserves 55 mm back focal distance.
Pentax (Praktica) lens adapter		M42×1 mm inner thread, preserves 45.5 mm back focal distance.
M68×1 thread adapter		Adapter with inner thread M68×1
Canon EOS lens adapter		Standard Canon EOS bayonet adapter.
Canon EOS clip lens adapter		Canon EOS bayonet adapter with the possibility to insert “clip” filter. Can be used on cameras with internal filter wheel only.

Nikon F lens adapter		Standard Nikon F bayonet adapter.

If the mounting standard defines also back focal distance (distance from adapter front plane to detector), the particular adapter is constructed to preserve defined distance (for instance T-thread defines back focal distance to 55 mm, but certain distance is defined also for Pentax (Praktica) thread, for Canon EOS and Nikon bayonets etc.).

Adapters are attached to the camera body using four M3 (3 mm metric) screws, placed on the corners of 44 mm square. Custom adapters can be made upon request.

Getting Started

Although the camera is intended for operation at night (or for very low-light conditions at day), it is always better (and highly recommended) to install software and to make sure everything is working OK during day, before the first night under the stars.

The G2 CCD cameras can be in principle operated under various CCD control software packages (refer to our web site for available drivers), this manual demonstrates camera operation under the SIPS (Scientific Image Processing System) – camera control and image processing software suite supplied with the camera.

Camera System Driver Installation

Every USB device requires so-called “system driver”, incorporated directly into the operating system kernel. Some devices (for instance USB Flash Disk dongles) conform to some predefined class (USB mass-storage device class in this case), so they can use the driver already present in the operating system. But this is not the case of the G2 CCD camera – it requires its own system driver to be installed.

Although 64 bit operating system can run 32 bit application without any problems, it is basically impossible to combine e.g. 64 bit process with 32 bit dynamic link library. The same is valid for operating system kernel - 64 bit kernel cannot use 32 bit system driver. This is why all G2 camera drivers are supplied in two versions, one for 32 bit systems (marked x86 according to Intel 386, 486 CPUs) another for 64 bit systems, marked x64 (according to CPUs supporting 64 bit instructions marked x86-64 or only x64).

The simplest way to install Gx CCD camera system driver is to run driver pre-installation package (“GxCam Drivers 32bit EN.exe“ or “GxCam Drivers 64bit EN.exe”, provided with the camera or downloaded from a web site) on the target computer. This package installs the driver for all Gx cameras on the particular computer. Then it is enough to plug in the camera and the operating system already knows which driver to use.

Pre-installation is the recommended way how to install system drivers. It is not necessary to deal with differences among individual versions of operating systems, described in subsequent chapters. If the user decides not to use pre-installation, it is necessary to take into account different implementation of the „Plug-and-play" mechanisms of driver installation in different Windows versions.

Due to differences in KAF and KAI CCD handling, there are two drivers for cameras utilizing the respective detectors. Driver names are distinguished by the last letter 'F' and 'I'.

Also individual camera revisions may require different drivers depending on the used digital electronics. Older cameras use "g3ccdF.sys" and "g3ccdI.sys" drivers, while newer use "gXccdF.sys" a "gXccdI.sys" drivers.

Windows 7 and 8 System Driver Installation

Windows 7 and 8 do not offer users the possibility to install system drivers using Plug-and-Play, like in the case of older Windows 2000, Windows XP and Windows Vista. It is necessary to pre-install all drivers, else the operating system only informs user that it cannot find appropriate driver for newly connected device.

We can only estimate reasons for this limitation of system functionality, probably it has something common with the inability of many hardware vendors to provide drivers complying to Plug-and-play standards (notification requiring installation of the software first and plugging of the device later was present on many devices).

Although the Plug-and-Play mechanism is hidden in Windows 7/8, it is possible to use it. Newly connected device appears in the "Device Manager" as "Unknown Device" (such device is usually marked by a question mark on yellow background icon). It is enough to click on such device by right mouse button to invoke pop-up menu and choose "Update Driver..." menu item. Operating system then opens driver installation wizard, basically identical to the one in Windows XP and Windows Vista.

Let us note that 64 bit versions of Windows 8, Windows 7 and Windows Vista require digitally signed drivers. Drivers without digital signature cannot be installed on these systems.

All Gx camera drivers supplied by Moravian Instruments are digitally signed from the beginning of the year 2010.

Windows XP and Windows Vista System Driver Installation

The operating system notifies the new USB device was plugged in the “Found new hardware bubble”. The system then opens the “Found New Hardware” Wizard.

1. The wizard offers searching for suitable driver on Windows Update site. Reject this offer (choose “No, not this time”) and click “Next” button.

2. Choose the “Install the software automatically” in the next step.

   Insert the USB Flash Drive into the drive and the wizard will continue by the next step.

   It is not necessary to install files from USB Flash Drive. It is possible to copy the folder containing driver files e.g. to shared network volume etc. Then it is necessary to choose the “Install from a list or specific location” and to define the path to driver files.

3. The wizard starts to copy files. But Windows XP checks for driver file digital signature. If it cannot find the signature, it notifies the user by a message box. Click “Continue Anyway”, the digital signature is only an administrative step and does not influence the proper functionality.

4. The wizard then finishes the installation and the camera is ready to work.

Please note the Windows XP system keeps the information about installed devices separately for each USB port. If you later connect camera to a different USB port (different USB connector on the PC or through the USB hub), Windows reports “found new hardware” again and asks you to install the software. Repeating the installation again brings no problem, just choose “Install automatically” option and Windows will reuse already installed drivers.

SIPS Software Installation

The Scientific Image Processing System (SIPS) software package is designed to operate without the necessity to be installed in any particular folder. The package can be even run directly from USB Flash Drive.

SIPS needs the Microsoft Visual C++ 2008 libraries to work. These libraries are already installed on many Windows PCs, because they are used by a lot of other applications. But if they are not present, it is necessary to install them first. The best way how to do it is to run the “Microsoft Visual C++ 2008 SP1 Redistributable Setup” package (executable file 'vcredist_x86.exe'). This package can be downloaded from the Microsoft web site and it is also supplied on the USB Flash Drive shipped with the camera,

SIPS package is distributed in the two forms:

1. In the form of the executable installation package 'SIPS_EN.exe'. Running of this package installs SIPS similarly to any other Windows application. The user does not need to care whether other libraries or packages are installed, the setup process installs everything necessary.

   If the SIPS is installed this way, then it can be easily uninstalled from the application management of the Windows operating system.

2. In the form of so-called “portable version” on the USB Flash Drive. The directory called “SIPS” contains SIPS image (set of EXE and DLL files, as well as auxiliary INI files etc.), which can be directly executed. The image can be copied to computer local drive into the (possibly newly created) directory chosen by the user.

   The portable version can be also downloaded in the form of ZIP archive (file 'sips.zip') from the web site. Again it is enough to unzip the archive into chosen directory.

   Uninstalling of the SIPS portable version is also quite easy – just delete the SIPS folder.

No matter how is the package installed, the software is run by launching the 'SIPS.exe' main program file.

SIPS configuration files

The software package distinguishes two types of configuration:

- Global configuration, common for all users.
- User-specific configuration.

Global configuration defines which hardware is used and which drivers controls it. The configuration is stored in the simple text file "sips.ini", which must be placed in the same folder as the "sips.exe" main executable. The file may look for example like this:

```
[Camera]
Gx Camera on USB = gxusb.dll
Gx Camera on Ethernet = gxeth.dll
Legacy G2 camera = g2ccd2.dll
ASCOM Camera = ascom_camera.dll

[GPS]
GarminUSB = gps18.dll
NMEA = nmea.dll

[Telescope]
NexStar = nexstar.dll
Meade = meade.dll
ASCOM = ascom_tele.dll

[Focuser]
ASCOM = ascom_focuser.dll

[Dome]
ASCOM = ascom_dome.dll
```

Individual sections define which driver would be loaded and asked to enumerate all connected devices of particular type (CCD cameras, GPS receivers, telescope mounts).

SIPS package already contains this file containing all included drivers. This file is not modified programmatically, it is necessary to edit it manually if new device driver, not included into basic package, is installed.

User-specific configuration is stored in the file named also "sips.ini", but this file is placed in the "\Documents and Settings\%user_name%\Application Data\SIPS\" folder. Number of setting is stored in this text file, beginning from the position and open state of individual tool windows, to the preferred astrometry catalog and parameters for searching stars in images.

G2 CCD Camera Driver for SIPS

SIPS is designed to work with any CCD camera, providing the driver for the particular camera is installed. The driver for G2 CCD camera is included into the basic SIPS package and is not necessary to install it separately.

All Gx cameras use common driver 'gxusb.dll' when connected directly to the host computer or 'gxeth.dll' when connected trough the Gx Camera Ethernet Adapter.

Common drivers for all Gx cameras were introduced in SIPS version 2.3, previous SIPS versions used different drivers for G0/G1 and for G2/G3/G4 cameras. G2 cameras used the 'g3ccd.dll' driver (g3 name prefix had historical reasons, G2 cameras inherited electronics originally developed for G3 series and because thy were software compatible, they used the same driver), but it was replaced with the 'gxusb.dll' common driver.

Every CCD camera driver for SIPS (including the G2 CCD drivers) is required to provide information about available filters (if the particular camera has the integrated filter wheel, of course). But the user can order camera with various filters, or he or she can change individual filters or the whole filter wheel etc. There is no way how to determine the actual filters in the filter wheel automatically. This is why the G2 CCD camera driver for SIPS reads the 'gxusb.ini' file to determine actual configuration of filters, which will be then reported to SIPS.

The 'gxusb.ini' file is placed in the same directory where the camera driver and the SIPS itself is installed. This file is ordinary text file following the .INI files conventions. Here is the example of the 'gxusb.ini':

```
[filters]
Luminance, Gray, 0
Red, Lred, 330
Green, Lgreen, 330
Blue, Lblue, 330
Clear, 0, 330
```

Filters are described in the `[filters]` Section. Every line in this section describes one filter position. Filter description is a comma-separated list of three values:

- **Filter name**: This name is returned to the client application, which can use it to list available filters in the filter wheel.

- **Filter color**: This color can be used by client application to display the filter name with a color, hinting the filter type. The color can be expressed by a name (White, Red, LRed, etc.) or directly by number representing the particular color (0 represents black).
- **Filter offset**: Distance to move the focuser to refocus upon filter change. Plan-parallel glass shifts the actual focus position back for 1/3 of the glass thickness (exact value depends on the glass refraction index, but for almost all glasses 1/3 is very close to exact value). Refocusing is useful when changing filters of different thickness among exposures or when some exposures are performed through filters and other without filters at all.

Filter offsets can be defined in focuser dependent units (steps) or in micrometers (μm). If the micrometers are used, it is necessary to inform driver by the “MicrometerFilterOffsets” parameter in the “[driver]” section of the ini file.

```
[driver]
MicrometerFilterOffsets = true

[filters]
Luminance, Gray, 660
...
```

Value of the “MicrometerFilterOffsets” parameter can be expressed as keywords “true” or “false” as well as numbers “0” (for false) or “1” (for true).

The above mentioned information will be displayed e.g. in the filter-choosing combo-box this way:

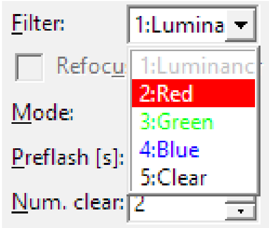


Illustration 11: Filters offered by the CCD Camera tool

If there are more filters in the camera than the configuration file describes, another filters will be added with undefined name. And if the configuration file describes more filters than the number of filter in the camera, last descriptions will be omitted.

Using of multiple configuration files for different cameras

It is sometimes necessary to work with multiple cameras, sharing single driver on the computer (whole series of Gx cameras share 'gusb.dll' or 'gxeth.dll' drivers). If multiple cameras have different filter wheels with different filters, it is rather complicated to adopt the 'gxusb.ini' configuration file to currently connected camera. If there are multiple cameras connected at once, adopting of configuration file is not possible.

This is why SIPS camera drivers (and also camera drivers for other programs) introduced enhanced naming convention of driver configuration file. Every Gx series camera has unique identification number, stated on the camera shell (this number is also displayed in the list of all connected cameras in the SIPS “CCD Camera” tool). Camera driver tries to open configuration file, which name is extended with the camera ID number. If for instance camera ID is 1234, driver first tries to open configuration file named 'gxusb.1234.ini'. Only is such file does not exists, general configuration file 'gxusb.ini' is used. So it is possible to create separate configuration files describing filters in every connected camera.

Cropping of the CCD area

The Gx camera drivers is able to crop the image matrix even before the image is passed to SIPS. Although it is possible to define sub-frames directly in SIPS camera control tool, limiting camera resolution this way is not very convenient when multiple frames of different types (light, dark, flat) are acquired. If for instance the user wants to use only center area of a large CCD because the optics used cannot utilize such large CCD detector, it is possible to read only a sub-frame (sub-frame 256, 0, 1024, 1024 converts 1.5Mpx G2-1600 camera into 1MPx camera). But different sub-frame is used e.g. when focusing the camera and it is necessary to properly restore above mentioned subframe before each dark, light of flat field is acquired. And 1 pixel difference between light and dark frame harms the possibility to properly calibrate images.

This is why the 'gxusb' and 'gxeth' drivers allow definition of sub frame in the appropriate .ini file in the “[crop]” section:

```
[crop]
x = 256
y = 0
w = 1024
h = 1024
```

Such camera will report resolution 1024× 1024 pixels to SIPS and all other sub-frames, defined in the SIPS camera control tools, will be related to the above defined subframe.

Camera Connection

Camera connection is pretty easy. Plug the power supply into the camera and connect the camera to the computer USB port using the supplied USB cable. Note the computer recognizes the camera only if it is also powered. Camera without power act the same way as the unplugged one from the computer point of view.

When the camera is powered and connected to the computer (with appropriate drivers installed), it starts to initialize filter wheel. The internal filter wheel starts to rotate and the camera control unit searches for the filter wheel home position. This operation takes a few seconds, during which the camera does not respond to computer commands. Camera indicates this state by flashing the orange LED. See the “Camera LED state indicator” chapter for details.

Illustration 12: Camera without internal wheel on left, with internal filter wheel on right. USB connector is on left side and power connector on right side of the camera head.

The camera is fully powered by the external power supply, it does not use USB cable power lines. This means it does not draw laptop batteries and long USB cables with thin power lines (which can cause voltage drops and power-related problems for USB-powered devices) does not affect the G2 CCD camera operation.

Camera LED state indicator

There is a two-color LED on the camera body, close to the USB connector. The LED is functional only upon camera startup not to influence observations.

The LED starts blinking orange when the camera starts to initialize filter wheel. Orange blinks are not always the same – they depend on the filter position when the camera is powered up.

If the case the camera control unit cannot find the filter wheel origin, the camera notifies the user by 2 s long red flash immediately after filter initialization failed (orange blinking terminates). Please note the while filter wheel initialization is skipped by the firmware when the camera is supplied without the filter wheel. So if you notice orange blinks followed by 2 s red blink, the filter wheel failed to initialize. Although the camera continues operation like the model without filter wheel, it is not recommended to start work with such camera – it is not clear which filter is behind the CCD or the wheel can be in the inter-filter position. Return the camera to manufacturer for maintenance in such case.

Camera firmware finishes initialization by signaling the USB speed, on which it is currently operating.

- USB 2.0 High Speed (480 Mbps) is signalized by 4 short green blinks.
- USB 1.1 Full Speed (12 Mbps) is signalized by 4 short red blinks.

Working with Multiple Cameras

It is possible to connect multiple CCD cameras to single computer, be it directly to USB ports available on the computer I/O panel or through the USB hub. The operating system assigns unique name to every connected USB device. The name is rather complex string derived from the device driver GUID, USB hub identifiers, USB port number on the particular hub etc. Simply put, these identifiers are intended for distinguishing USB devices within operating system, not to be used by computer users.

But the user always needs to distinguish individual cameras – for instance one camera should be used for pointing, another for imaging. This is why every camera has assigned unique identifier (ID number). This number is printed on the sticker on camera body and it is also displayed in the list of all available cameras in the CCD Camera tool in SIPS. This enables the user to select the particular camera he or she needs.

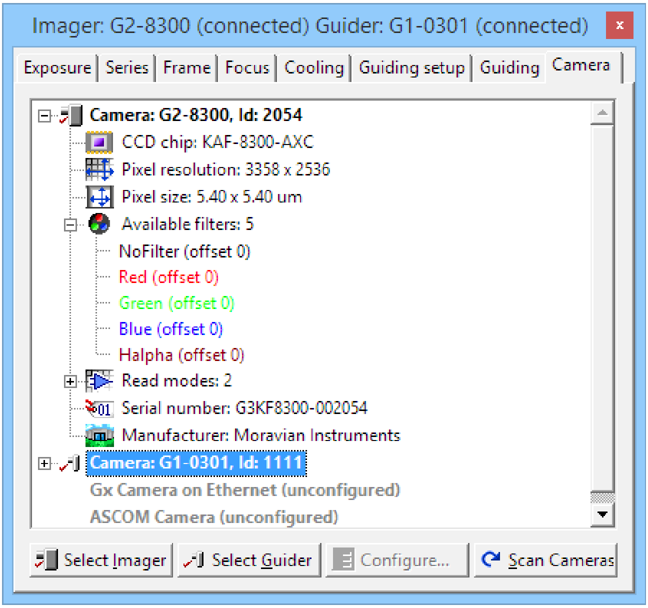


Illustration 13: Camera Id number is displayed in brackets after camera name in SIPS

Camera Operation

Camera operation depends on the software used. Scientific cameras usually cannot be operated independently on the host computer and G2 CCD also needs a host PC (with properly installed software) to work. Camera itself has no displays, buttons or other controls. On the other side, every function can be controlled programmatically, so the camera is suitable for unattended operation in robotic setups.

Plug the camera into computer and power supply and run the SIPS program. Open the “CCD Camera” tool (choose the “Tools” menu and click the “CCD Camera...” item or click the  tool button). The camera name (e.g. “G2-1600”) should be displayed in the title bar of the tool window.

If you run the SIPS before the camera was plugged and powered, SIPS does not know about it and it is necessary to scan for available cameras. Select the “Camera” tab and press the “Scan Cameras” button. The G2 CCD camera should appear in the displayed tree. Select it (click its name by mouse – its name should be highlighted) and press “Select Camera” button.

If the G2 CCD does not appear in the tree of available cameras, check the following items:

1. Check the USB cable – make sure both connectors are properly inserted to PC (or USB hub) and to camera head.
2. Check the camera power – the power adapter should be plugged to AC source (the green LED on the adapter should shine) and the power output cable connector must be properly inserted to camera head connector.
3. Check if the camera system driver is properly installed. Refer to the “Camera System Driver Installation” chapter for information about system driver installation.

Camera and the Telescope

The camera needs some optical system to capture real images. It depends on the telescope adapter to which telescopes (or lenses) the camera can be connected. Standard 2" barrel adapter is recommended if your telescope is equipped with 2" focuser. But the best way to attach a camera to the telescope is threading the camera to the focuser (be it T-thread, M48×0.75 thread or other standard).

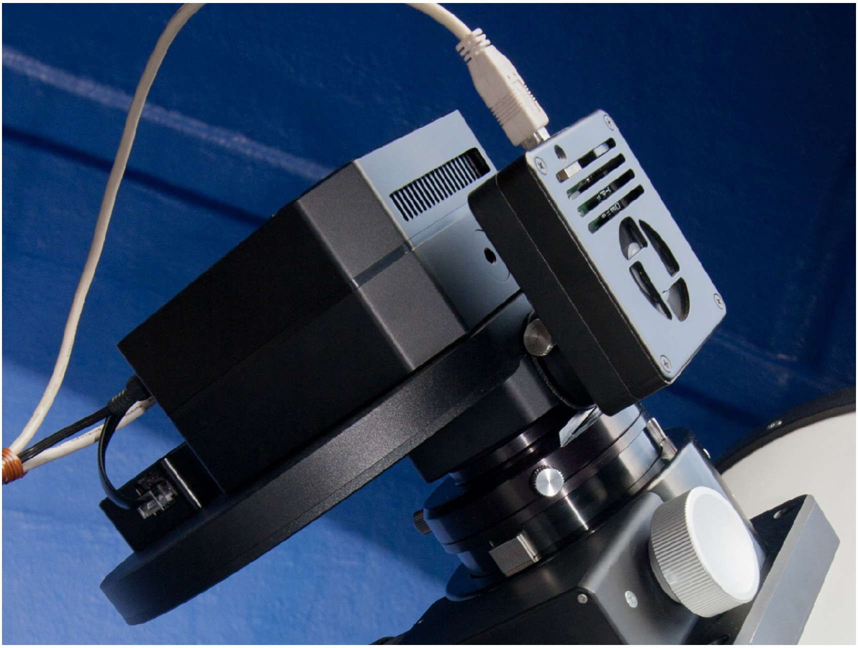


Illustration 14: Complete system consisting of G2 camera, External Filter Wheel, Off-Axis Guider adapter and G1 guider on the Newtonian reflector telescope

Photographic lens or some small refractor is the best optical system to start experimenting with the camera. If you are using some bigger telescope at home for the first experiments, make sure the telescope can be focused to relatively nearby objects in the room.

It is better to start experimenting at night, because it is very easy to saturate the camera at daylight. The shortest exposure can be around 0.1 s, which can be too long at daylight conditions.

The following chapters provide only a brief description of camera operation under SIPS (Scientific Image Processing System) program, supplied with the camera. Refer to the SIPS User's Guide (click “Help” and “Contents” from the SIPS main menu) for thorough description of all SIPS features.

Temperature Control

Active chip cooling is one of the basic features of scientific CCD cameras (SIPS User's Guide explains why cooling is important to reduce thermal noise). If you plug the G2 CCD to power supply, you may notice the fan on the back side of the camera head starts operation. This fan take away the heat from the hot side of the Peltier modules, which cool the CCD chip. Fan is running continuously when the camera is plugged to power supply, independently on the Peltier cooler (it is also used to cool down the camera power supplies etc.).

Peltier cooler can be controlled from the “Cooling” tab of the SIPS CCD Camera tool.

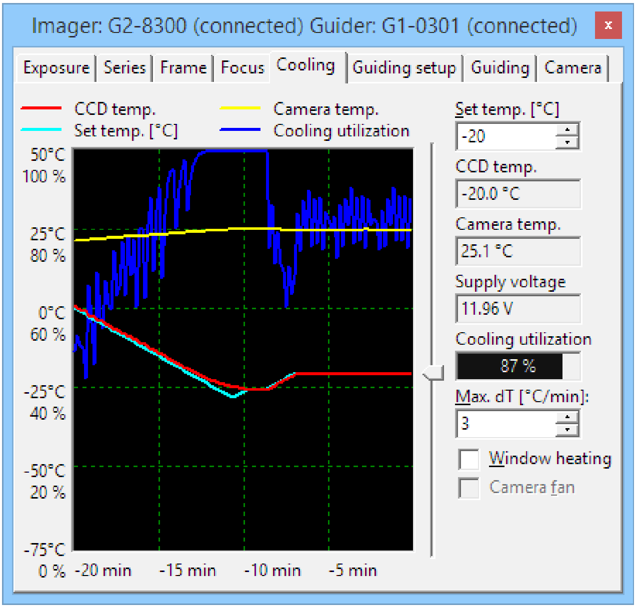


Illustration 15: Cooling tab of the CCD Camera Control tool

Although the Cooling tab displays number of values and graphs, only two values can be modified by the user. The “Set Temperature” count-box defines required CCD chip temperature and the “Max. dT” count-box defines the maximum speed, with which the temperature can change. If the required temperature is greater or equal to the current CCD chip temperature, the Peltier cooler is off. The “Cooling utilization” indicator displays 0% and the camera consumes minimum energy.

To cool down the CCD chip, set the required temperature to target value. Camera does not switch the Peltier cooler to 100% immediately, but starts changing of the target temperature according to defined maximal speed. The target temperature is displayed in cyan color on the graph. The current chip temperature is displayed in red. Also notice the blue line, which displays the cooling utilization – it starts to grow from 0% to higher values.

Also notice the yellow line in the graph – it displays camera internal temperature. This temperature also somewhat grows as the cooling utilization grows. The hot air from the Peltier hot side warms up the camera interior slightly.

How fast can be the chip cooled? Can be the chip damaged, if it is cooled too fast? Unfortunately the maximum speed of temperature change is not defined for Kodak CCD chips (at last the author does not know about it). But in general slow temperature changes cause less stress to electronic components than rapid changes. The SIPS temperature change speed default value is 3 °C per minute. It is usually no problem to switch the camera earlier and to provide time for slow cooling. However, if it is necessary to cool the camera rapidly, alter the “Max. dT” value.

It is also easier to achieve higher temperature differences if the temperature is changed only slowly. Switching the Peltier cooler from zero to 100% immediately provides a lot of heat and, especially in the case of air-cooled Peltier, the overall camera temperature can raise more than necessary. The result is the chip temperature is higher in absolute numbers, because the hot-side temperature is also higher. It takes long time before the hot side slowly settles.

What is the best temperature for the CCD chip? The answer is simple – the lower the better. But the minimum temperature is limited by the camera construction. The G2 CCD cameras are equipped with two-stage cooler, which can cool the chip up to 50 °C below ambient temperature with air cooling. But it is not recommended to use maximum possible cooling. If the environment conditions change, the camera may be unable to regulate the temperature if the environment air temperature rises. Set the target temperature, which requires approx. 85% of the cooling utilization. This provides enough room for e.g. environment temperature changes etc.

The power supply voltage is also displayed in the “Cooling” tab. Especially when the camera is powered from 12 V battery, this information can be used to estimate when the battery should be replaced and recharged. Note that working with less intensive cooling can significantly prolong the battery life.

First Images

Actual exposure is performed from the “Exposure” tab of the CCD Camera tool.

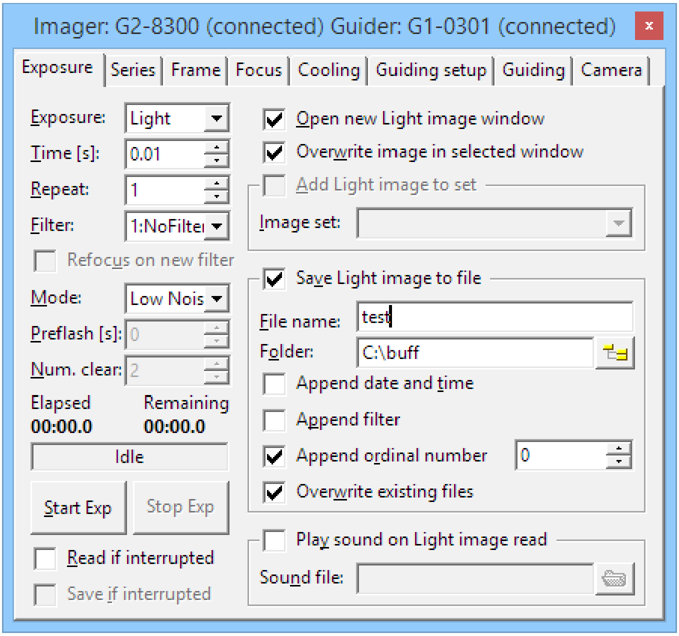


Illustration 16: Exposure tab of the CCD Camera Control tool

It is necessary to define few parameters before the first shot. First, it is necessary to define the image type – choose “Light” from “Exposure” combo box. Then choose the exposure time. If you experiment with exposures in the dark room with a camera connected to some f/6 refractor, start with 1 second. Do not forget to review the image handling options on the right side of the “Exposure” tab. Let the “Open new Light image window” and “Overwrite image in selected window” check-boxes checked, uncheck other options for now (we do no plan to save our first images).

Then click the “Start Exp” button. Camera will open the shutter, perform 1 s exposure, close the shutter and download the image. Image is then opened in new image window. If this is the first shot, it will probably be far from sharp focused image. Alter the focuser and try again.

Notice that options determining the new image handling on the right side of this tab changes with every change of the exposure type. SIPS remembers these options for every exposure type separately. So it is possible e.g. to define separate folders for dark frames and for flat fields.

Always check whether new image processing options are defined properly before you start any exposure.

If you choose “Dark” from “Exposure” combo box (remember the image handling options on the right side changes – make sure they are properly defined), image will be captured without opening the shutter. The captured image will represent the thermal noise, generated by the CCD chip itself, combined with the CCD chip and camera electronics read noise. Such images are subtracted from normal images during image calibration to reduce the dark current effects.

Brightness and Contrast – Image Stretching

The G2 CCD dynamic range spans 65 536 levels. But only imaging of perfectly illuminated and perfectly exposed scenes can result in images with pixels spanning this range. Usually only a fraction of this range is used, e.g. the black background can have values around 500 counts and the brightest part of the image can have around 10 000 counts. If we assign the black to white range to the full possible range (0 to 65 535), the image with 500 to 10 000 counts will be displayed only in dark gray tones. This is why image brightness scale should be “stretched” before they are displayed.

Open the “Histogram and Stretch” tool .

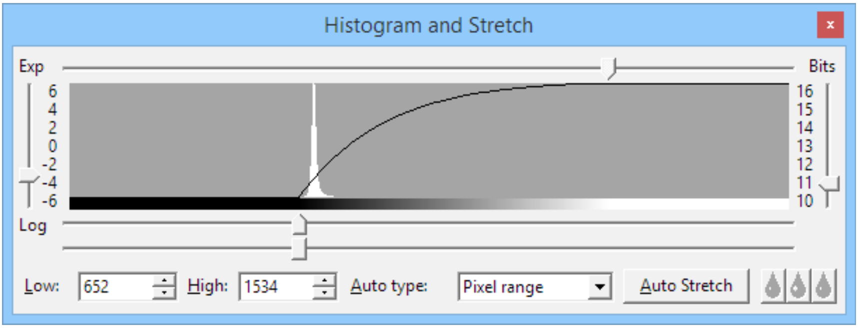


Illustration 17: Histogram and Stretch tool

The exact meaning of the histogram chart is explained in the SIPS software documentation. Now only try to play with “Low” and “High” count-boxes or better with the related horizontal sliders. Observe how the image view is changed when you alter these values.

The best positions of Low and High control are as follows: the Low count should be on the count value representing black on the image. Any pixel with value lower than this count will be displayed black. The High count should be on the count value representing white on the image. Any pixel with value higher than this count will be displayed white.

Similar adjustments are usually called brightness and contrast adjustments.

- Brightness is changed by moving both Low and High values together up and down. Try to move both values using the second slider below the histogram chart.
- Contrast is changed if the relative distance between Low and High values changes. Try to narrow or widen the distance between Low and High values.

But astronomers often need precise control of Low and High values so the terms brightness and contract are not used within SIPS.

Calibration

If you preform short exposure of bright object, the signal to noise ratio of the image is very high. Image artifacts related to CCD chip (like hot/cold pixels or thermal noise) almost do not affect the image. But all unwanted effects of unevenly illuminated field, CCD thermal noise etc. significantly degrade image quality when imaging dim deep-sky objects for many minutes.

This is why every CCD image should be calibrated. Image calibration basically consists of two steps:

1. **Dark frame** subtraction
2. Applying **flat field**

Image calibration is supported by the "Calibration" tool in SIPS .

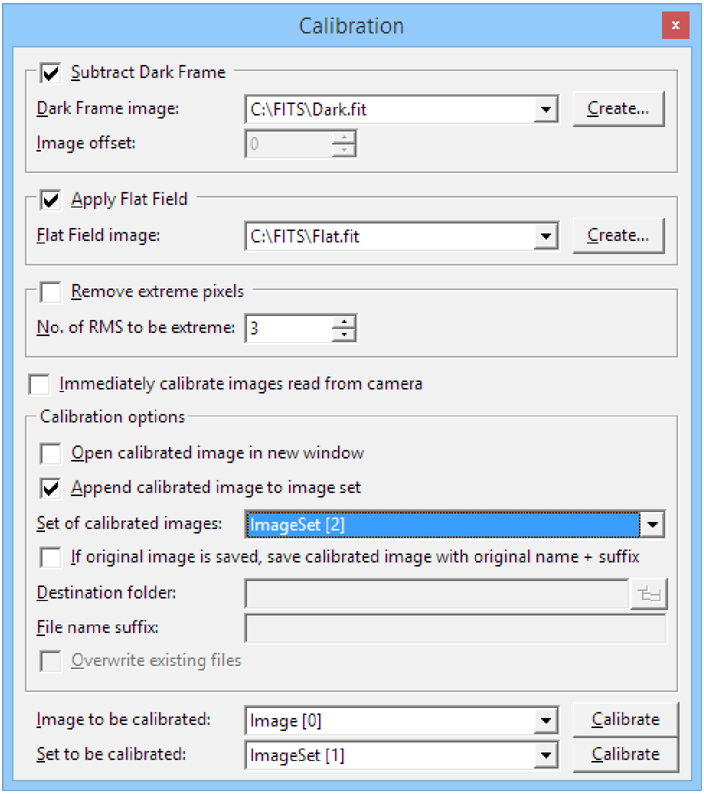


Illustration 18: Calibration tool

The raw image downloaded from the camera contains not only the information desired (the image of the target field), but also CCD chip thermal noise and artifacts caused by unevenly illuminated field (vignetting), shadows of dust particles on camera cover glass and filters etc.

Illustration 19: The raw image downloaded from the camera

The Dark frame is taken with the same exposition time at the same CCD chip temperature. Because hot pixels are less stable than normal pixels, it is always better to take more dark frames (at last 5) and to create resulting dark frame as their average or better median.

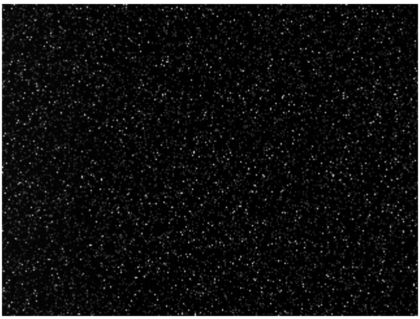


Illustration 20: The dark frame corresponding to the above raw image

Illustration 21: The raw image with subtracted dark frame

Subtraction of the dark frame eliminated majority of thermal noise, but unevenly illuminated field is still obvious. Image center background is much brighter than the border parts.

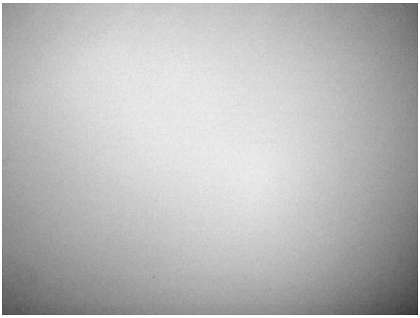


Illustration 22: Flat field represents the telescope/camera response to uniformly illuminated field

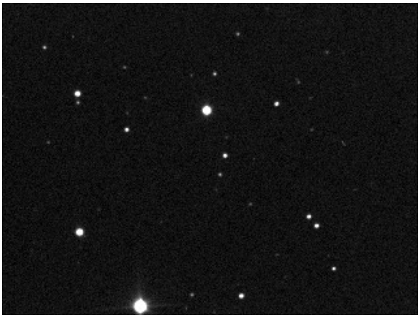


Illustration 23: Fully calibrated image with dark frame subtracted and applied flat field

CCD image calibration is described in detail in the SIPS User's Guide. Refer to the "Introduction to CCD Imaging" and "Calibrate Tool" chapters for calibration description in theory and in practice.

Color Images with monochrome camera and filters

Color images are definitely more appealing than black and white ones. It is also easier to gather more information from color images – for instance it is possible to distinguish which part of the nebula is emission (red) and which is reflection (blue). But astronomical cameras are only rarely equipped with color CCD chips from number of reasons. The color and monochrome chips are discussed in the SIPS User's Guide – refer to the "Introduction to CCD Imaging" chapter.

Although the G2 CCD camera is equipped with monochrome CCD chip, it is definitely capable to capture color images, at last when the internal filter wheel contains RGB filters. Instead of shooting single color image, three images – each for Red, Green and Blue colors, must be obtained and combined. This process is not suitable for fast moving/changing objects, but astronomical objects usually do not change so fast.

Taking three images and combining them is undoubtedly more complex procedure than shooting simple color image. But using of monochrome chip brings so important advantages for astronomical usage, that bothering with multiple images is definitely worth the effort:

- Color CCD chips have one fixed set of filters without the possibility to exchange them or to completely remove them. Monochrome chip is capable to take images with narrow-band filters like Hα, OIII, etc.

- Color chips have less Quantum Efficiency (QE) then monochrome ones. Limiting QE from around 80% to around 30% by color filters only wastes light in number of applications.
- Interpolation of pixel luminance from surrounding pixels, necessarily performed when processing images from color chips, introduces significant error and prohibits precise measurement of position (astrometry) and brightness (photometry).
- Color CCD chips do not allow reading of binned images.
- Color CCD chips do not allow so-called Time Delay Integration (or Drift-Scan Integration).

Another huge advantage of monochrome chip is the possibility to combine color images from three color images and one luminance image. Luminance image is captured without filter, using maximum chip sensitivity. This technique is often called LRGB imaging.

Inserting the color filter into the light path significantly reduces the amount of light captured by the chip. On the other side the human eye is much less sensitive to changes of color than to changes of brightness. This is why the CCD chip can be binned when capturing color images to 2×2 or 3×3 to significantly increase its sensitivity. Luminance image is taken without binning so the image resolution is not degraded.

Let us note that imaging through separate color filters is close to impossible in some cases. For instance taking images of some fast evolving scenes, like planet occultation by Moon, imaging of fast moving comet etc. There is no time to take separate exposures through filters, because the scene changes between individual exposures. Then it is not possible to combine red, green and blue images into one image. In such cases using a single-shot color camera is necessary.

The color images can be combined in the (L)RGB Add Tool  in SIPS. This tool is thoroughly described in the SIPS User's Guide.

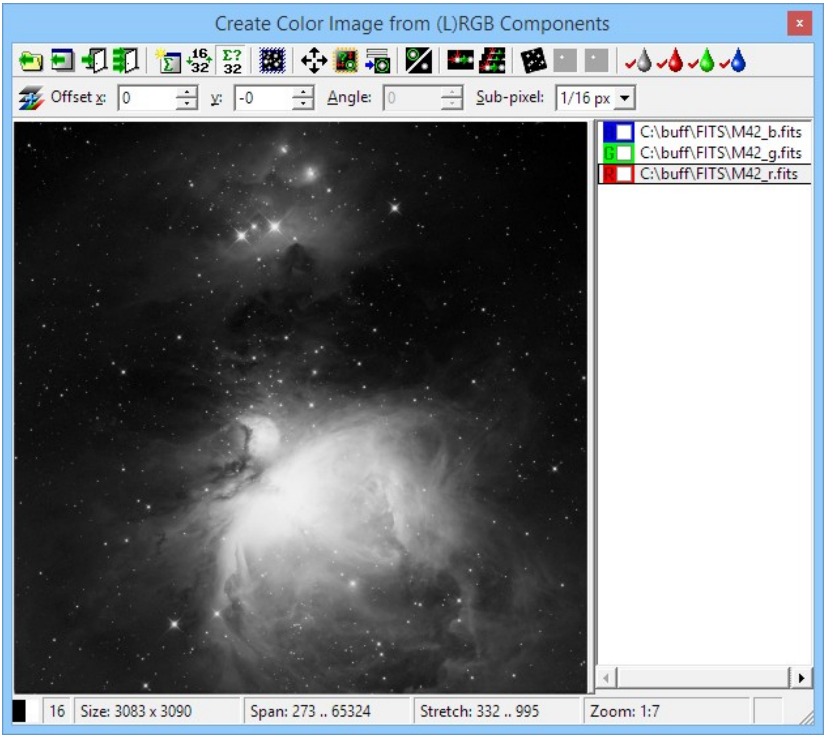


Illustration 24: "(L)RGB Image Add" tool in SIPS...

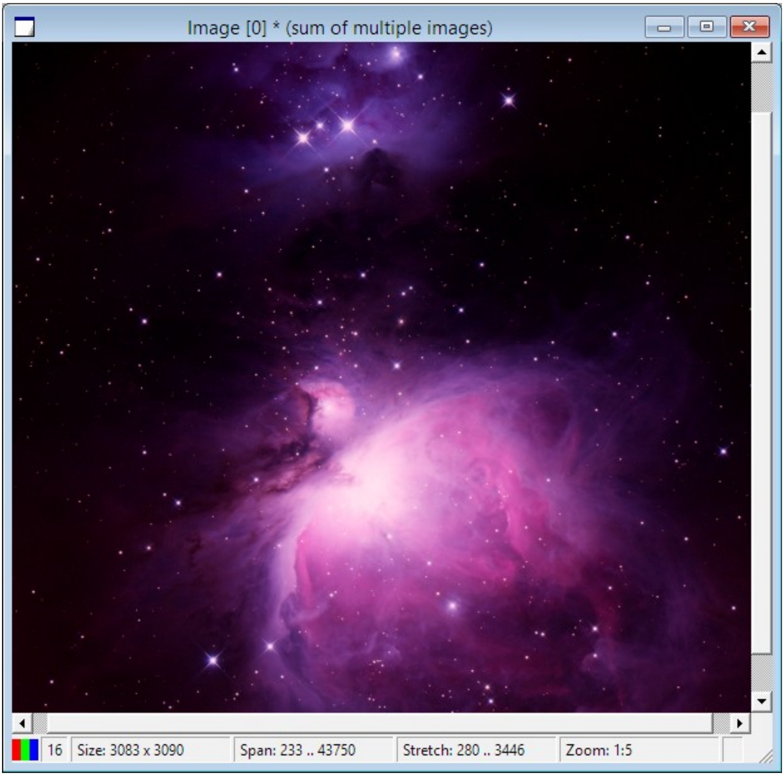


Illustration 25: ...and a resulting image

If we take images for individual colors and also luminance image, possibly with different binning and exposure times, the calibration starts to be relatively complex. We need dark frame for every exposure time and binning. We need flat field for every filter and binning. We need dark frames for every flat field. This is the price for beautiful images of deep-sky wonders.

Color images with color camera

Single-shot color cameras use special CCD detectors with red, green and blue color filters applied directly on individual pixels. G2 CCD cameras can be equipped with such detectors (the name of the camera is then followed by the letter “C” to indicate color CCD).

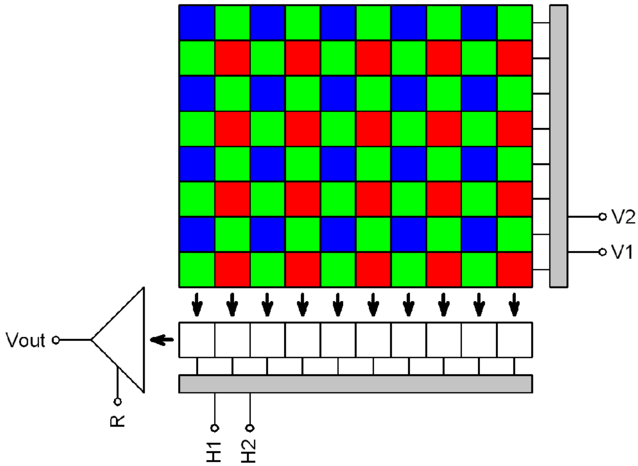


Illustration 26: Schematic diagram of color CCD detector

Every pixel receives light of particular color only (red, green or blue). But color image consists of pixels with all three colors specified. So it is necessary to calculate other color from the values of neighboring pixels.

Covering pixels with such color mask and subsequent calculations of remaining colors was invented by Mr. Bayer, engineer working at Kodak company. This is why this color mask is called Bayer mask and the process of calculation of missing color is called Debayer processing.

There are several algorithms for calculating missing color components of individual pixels – from simply using of color from neighboring pixels (this method provides quite coarse images) to more accurate methods like bilinear or bicubic interpolation. There are even more sophisticated algorithms like pixel grouping etc.

No G1 camera performs the Debayer processing itself. The raw image is always passed to the host PC and processed by control software. It is also possible not to perform Debayer filtering and save images in the raw form for processing by some other software packages.

SIPS software implements bilinear Debayer interpolation. It is possible to perform Debayer processing immediately when the image is downloaded from the camera (color image is then immediately displayed and/or saved and no raw monochrome image is shown) or to perform this processing anytime later.

Debayer processing can be performed from “Image Transform” tool (to open this tool click  button in the tool-bar or choose “Image Transform” from the “Tools” menu). Check box “Debayer new images” allows immediate Debayer processing of images downloaded from the camera. The  button performs Debayer processing of currently selected image.

The Bayer mask displayed on the schematic image above begins with blue pixel. But there are no rules specifying the color of the first pixel – in principle there can be also green pixel from the blue-green line on the upper-left corner as well as green pixel from the green-red line or red pixel.

There is no way how to determine the Bayer mask organization from the image. This is why the “Image Transform” tool provides two check-boxes called “Bayer X odd” and “Bayer Y odd”. Combination of these check-boxes allows specification of Bayer mask organization on the particular CCD.

State of “Bayer X odd” and “Bayer Y odd” check-boxes are always updated when you connect camera with color CCD according to the information provided by the driver. Is is necessary to update them manually only if the raw color image is loaded from the disk file and needs to be processed without connected camera.

Wrong definition of these two flags results in wrong color calculation. Proper settings can be easily determined by the try-and-error method. But Debayer processing discards the original raw image so it is always necessary to backup the original raw image.

Also please note the settings of the “Bayer X odd” and “Bayer Y odd” check boxes must be altered when any geometric transformations are applied to the raw image (e.g. mirroring, rotation, etc.). Some transformations (e.g. soft binning or resampling) cannot be performed on raw image at all. It is always better to Debayer images first and process them later.

Also note that stacking of raw color images results in loss of color information. Stacking algorithms align images regardless if the particular pixel is red, green or blue. SIPS allows also sub-pixel stacking, which can mix pixels of different colors. Images must be Debayer processed first and then stacked.

Balancing colors

CCD chip sensitivity to red, green and blue light is different. This means the exposure of uniformly illuminated white surface does not produce the same signal in pixels covered with different color filters. Usually blue pixels gather less light (they have less quantum efficiency) then green and red pixels. This results into more or less yellowish images (yellow is a combination of red and green colors).

The effect described above is compensated by so-called “white balancing”. White balancing is performed by brightening of less intensive colors (or darkening of more intensive colors) to achieve color-neutral appearance of white and/or gray colors. Usually is one color considered reference (e.g. green) and other colors (red and blue) is lightened or darkened to level with the green.

Automatic white balancing can be relatively easy on normal images, where all colors are represented approximately uniformly. But this is almost impossible on images of deep-space objects. For instance consider the image of emission nebula, dominated by deep-red hydrogen alpha lines – any attempts to lighten green and blue color to create color-neutral image result to totally wrong color representation. Astronomical images are usually color balanced manually.

As already described in the “Brightness and Contrast – Image Stretching” chapter, image can be visually brightened by altering its stretch limits. SIPS “Histogram and Stretch” tool displays and also enables altering of stretching curve limits and shape for red, green and blue color individually.

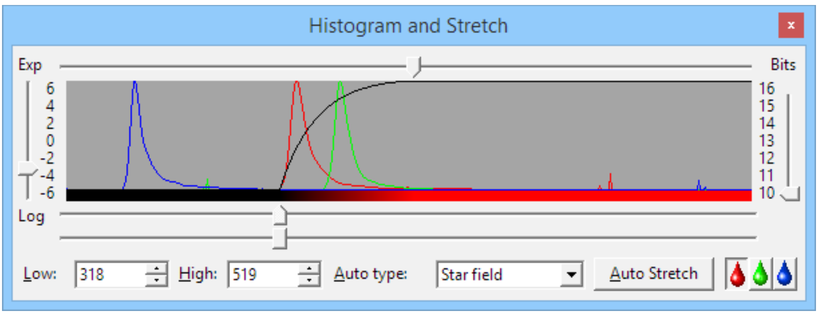


Illustration 27: Histogram and Stretch tool shows histograms of individual colors

Some General Rules for Successful Imaging

Advanced CCD cameras caused a revolution in amateur astronomy. Amateurs started to capture images of deep-sky objects similar or surpassing the ones captured on film by multi-meter telescopes on professional observatories. While the CCD technology allows capturing of beautiful images, doing so is definitely not easy and straightforward as it may seems. It is necessary to gain experience, to learn imaging and image processing techniques, to spend many nights mastering the technology.

Although CCD camera can convert majority of incoming light into information, it is not a miracle device. Keep on mind that laws of physics are sill valid.

- CCD camera does nothing more than converting image created on the chip by telescope (or objective lens) into information. A quality telescope and quality “photographic-class” mount is absolute must for successful imaging. If the mount cannot keep the telescope on track or the telescope cannot create perfectly focused image, result is always distorted and blurred.
- Ideally the exposures should be automatically guided using guiding CCD camera or at last webcam or similar device. Tracking errors caused by drive periodic error, mount polar misalignment or other mechanical issues (often unnoticeable by eyes) cause streaking of star images. Note the exposure time for each color often reaches tens of minutes or even hours if the really high quality images are taken.

> The G1 series of CCD cameras are especially designed with guiding on mind. G1 CCD cameras are equipped with “autoguider” connector, which allows direct connection between the G1 camera head and telescope mount. 16-bit digitization and using of sensitive Sony EXview HAD CCDs provide higher sensitivity and dynamic range compared to typical video or web cameras. The SIPS software package supports both imaging and guiding cameras and implements sophisticated guiding algorithms.

- Focus image properly. Almost unnoticeable focuser shift affects star diameter. Focusing, especially on fast telescopes, is critical for sharp images. Electrical focuser is a huge advantage, because it allows focusing without shaking the telescope by hand and with precision surpassing the manual focusing.

  Keep on mind that the star images are affected not only by focusing, but also by seeing. Star images will be considerably bigger in the night of poor seeing, no matter how carefully you focus.

- Master image calibration (dark frame subtraction and flat fielding) and carefully calibrate all images. Various artifacts (thermal noise, hot pixels, gradients, telescope/lens vignettation, dust particles on filters etc.) degrade the image and properly calibrated image always looks better. Take care to obtain dark frames and flat fields for all filters used, for all resolutions/binnings etc.

- If the image is processed to be as aesthetic as possible, other processing than basic calibration can significantly improve its appearance. Nonlinear stretching (called “curves” in some image-editing packages), special filters (hot/cold pixels removal, noise reduction etc.) and other processing (e.g. deconvolution) enhances the image.

  Never perform these enhancing filters on images intended for data reduction processing. It is always good idea to store original image and to enhance only its copy. Scientific information can be significantly degraded by various noise filters, deconvolution etc. If for instance the image of some galaxy contains newly discovered supernova, photometric reduction of the original image can be scientifically very important.

- A common saying “there is a science in every astronomical picture” is especially true for CCD images. Examine your images carefully, blink them with older images of the same object or field. There is always a chance some new variable star, new asteroid, new nova or supernova appear in the image.

- Be patient. Although many advertisements proclaim “capture images like these your first night out”, they probably mean your first successful night out. Nights can become cloudy or foggy, the full Moon can shine too much, the seeing can be extremely bad… Number of things can come wrong, but the bad luck never lasts forever. Start with bright objects (globular clusters, planetary nebulae) and learn the technique. Then proceed to more difficult dimmer objects.

If you are new to CCD imaging and terms like “dark frame”, “read noise” and “image binning” sound strange to you, refer to the “Introduction to CCD Imaging” chapter of the SIPS software documentation. This chapter explains basic principles of CCD operation and their usage in astronomy, discusses color imaging, CCD chip dark current and camera read noise, chip resolution and pixel scales in relation to telescope focal length, explains basic image calibration etc.

Camera Maintenance

The G2 CCD camera is a precision optical and mechanical instrument, so it should be handled with care. Camera should be protected from moisture and dust. Always cover the telescope adapter when the camera is removed from the telescope or put the whole camera into protective plastic bag.

Desiccant exchange

The G2 CCD cooling is designed to be resistant to humidity inside the CCD chamber. When the temperature decreases, the copper cold finger crosses freezing point earlier than the CCD chip itself, so the water vapor inside the CCD chamber freezes on the cold finger surface first. Although this mechanism works very reliably in majority of cases, it has some limitations, especially when the humidity level inside the CCD chamber is high or the chip is cooled to very low temperatures.

This is why a cylindrical chamber, filled with silica-gel desiccant, is placed inside the G2 CCD camera head. This cylindrical chamber is connected with the insulated cooled CCD chamber itself.

Warning:

High level of moisture in the CCD chip chamber can cause camera malfunction or even damage to the CCD chip. Even if the frost does not create on the detector when the CCD is cooled below freezing point, the moisture can be still present. It is necessary to keep the CCD chamber interior dry by the regular exchange of the silica-gel. The frequency of necessary silica-gel exchanges depends on the camera usage. If the camera is used regularly, it is necessary to dry the CCD chamber every few months.

It is possible bake the wet silica-gel in the oven (not the microvawe one!) to dry it again. Dry the silica-gel for at last one hour at 150 to 160 °C. Exceeding the 170 °C can damage the silica-gel and its ability to absorb moisture will be limited.

The silica-gel used in G2 cameras changes its color according to amount of water absorbed – it is bright yellow or orange when it is dry and turns to transparent without any color hue when it becomes wet.

Changing the silica-gel

G2 cameras have the container accessible from the back side of the camera head.

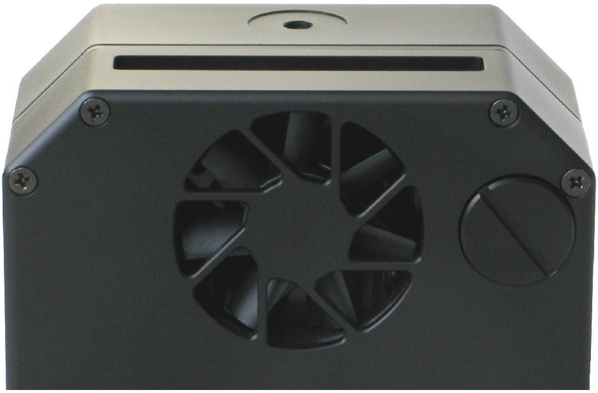


Illustration 28: Silica-gel container is under the screwed cap with slot, right of the fan vents

The slotted desiccant chamber cap can be unscrewed e.g. by a coin. Pour out wet silica-gel and fill the chamber with a dry one. The desiccant chamber can be filled with a hot silica-gel without a danger of damaging of the container.

The desiccant container can be left open without the fear from contamination of CCD chamber interior by dust. There is a very faint stainless steel grid between the CCD chamber and the desiccant container, so dust particles cannot enter the chamber itself. It is even recommended to keep the desiccant container cap off for a couple of hours when the camera is in the room with low humidity. This helps drying the CCD chamber interior and prolongs the silica-gel exchange interval.

G2 cameras revisions 1 and 2 employed desiccant container accessible only from inside of the camera. It was necessary to open the camera head before the desiccant could be replaced.

Changing Filters

It is necessary to open the camera head to change filters or the whole filter wheel. To open the head unscrew the six bolts holding camera head together.

Opening the camera head

The blade shutter rotates 180° between individual snapshots. Camera cover could be opened only when the shutter fully closed (covers the CCD). If for instance the camera is unplugged from power adapter while exposing, the shutter remains open. Camera cannot be opened in such case.

Warning:

Shutter can be damaged while removing the camera cover if not in proper position.

After removing the screws carefully turn the camera head by the telescope adapter upward. Gently pull the front part of the case. Notice there are two cables, connecting the filter wheel motor and the filter position optical bar, plugged into the electronics board. It is not necessary to unplug these cables to change filters, but if you unplug them, take care to connect them again in the proper orientation!

Illustration 29: Filter positions are marked on the filter wheel

Illustration 30: Filters cane be exchanged after removing of the camera front cover

Changing the Whole Filter Wheel

The whole filter wheel can be changed at once. It is necessary to remove the front part of the camera case the same way as in the case of changing filters. The filter wheel can be removed when you unscrew the bolt on the center of the front part of camera case. Take care not to damage the horseshoe-shaped optical bar when replacing the filter wheel.

Changing the Telescope Adapter

The camera head contains bolt square. The telescope adapter is attached by four bolts. If you want to change the adapter, simply unscrew these bolts and replace the adapter with the new one.

Power Supply Fuse

The power supply inside the camera is protected against connecting of inverted-polarity power plug or against connecting of too-high DC voltage (above 15 V) by a fuse. If such event happens and the cooling fans on the back side of the camera do not work when the camera is connected to proper power supply, return the camera to the service center for repair.

G2 Camera Revisions

G2 series of CCD cameras underwent several revisions, each implementing various enhancements, new printed circuits boards with latest electronics components and utilizing all gained experience and new ideas.

Revision 1

The first introduced G2 camera. Only G2-0400 model with KAF0402ME CCD was available in this revision.

- Cameras used USB 1.1 interface working at 12 Mbps transfer speed.
- Camera driver was called “g2ccd”.
- Image download time was approx. 3-times longer compared to revision 4.
- Peltier hot side was cooled by two fans.
- Desiccant container was hidden inside the camera head, it was necessary to open the head to exchange it.
- Internal filter wheel has 98 mm diameter.

Revision 2

The second revision of G2 cameras added models G2-1600 and G2-3200 and the original model changed name to G2-0402.

- Digital electronics was completely overhauled and upgraded to USB 2.0 interface with 480 Mbps transfer speed.
- The air intake vents shaping was slightly changed to make the camera somewhat quieter. This revision still used two fans.
- Camera driver was named “g2ccd2”, the digit “2” in the suffix signalized USB interface version.

Revision 3

Yet another version of the digital electronics was developed for the new G3 series of CCD cameras with detectors up to 36 × 24 mm (digital electronics board is the same for various models of the same series, individual models differ in analog electronics, designed for every particular type of CCD). The same electronic module was later reused also in G2 cameras and even later in the even bigger G4 series. The third revision of G2 cameras was introduced.

- The most prominent visual difference of revision three is the usage of a single and slightly larger (and again slightly more quiet) cooling fan instead of two smaller fans employed by previous revisions.

Information on the camera head (Camera Id, Serial number etc.) was placed on the sticker at first, but later it was laser engraved directly to the aluminum shell. But this difference is only visual and does not define new revision.

- The enlarged desiccant barrel allowed much easier desiccant exchange without opening of the camera head (accessible from the outside).
- Number of models of G2 cameras were offered – KAF detector variants (G2-0402, G2-1600, G2-3200), KAI detector variants (G2-2000, G2-4000) and also “astrophotographic” model with ABG KAF detector (G2-8300).
- Internal filter wheel diameter was shrunk to 95.5 mm.
- Camera driver was named “g3ccd”. The slightly confusing naming of G2 and G4 camera drivers originated here – all three series (including the G3 one) used the same, software compatible electronics and thus also the same driver.

More exactly two drivers for two versions of these cameras were introduced, one for Full-Frame KAF CCD based cameras (g3ccdF) and the second for Interline-Transfer detectors KAI CCD based cameras (g3ccdI). Differentiation is necessary because of fundamental differences in driving of CCD chips of the above mentioned architectures.

Number of internal updates were performed on G2 cameras revision 3, for instance variants for external filter wheel were developed, additional heating of the cold CCD chamber front optical window was added, near-IR preflash capability was introduced for KAF based models etc. But cameras were the same from the outside and they were software compatible and used the same driver.

Revision 4

Development of another version of digital electronics, using modern electronics circuits, required introduction of new revisions of G2, G3 and G4 cameras. G2 series advanced from revision 3 to 4 and G3 and G4 series are now in revision 2.

- The G2 revision 4 shell underwent a slight facelift. Camera is less "boxy" and more similar to bigger G3 and G4 models. Air intake vents are better protected against unwanted interference of rotating fans with either fingers of various wires (hitting a rotating fan with finger is not dangerous, only somewhat unpleasant).

  Basic mechanical dimensions (width, height, depth) of the camera heads did not change. Only the distance of the optical axis relative to camera body center axis is slightly shifted by 2 mm.

- Desiccant container of the G2 cameras was enlarged, it is now identical to the container used on G3 and G4 models.
- CCD cold chambers of all models were significantly redesigned. New chambers bring better CCD insulation from the environment and thus require less frequent desiccant exchanges. They also allow usage of CCDs without cover glass, which are much more demanding to insulation, absence of moisture etc.
- New digital electronics uses 480 Mbps USB 2.0 interface (Gx cameras use only a small fraction the transfer capacity of this interface, so moving to 4.8 Gbps USB 3.0 brings no advantages, only problems with bigger connector, shorter and less flexible cables etc.), still it brings numerous important improvements, like faster image download (especially in the Preview mode), much bigger internal memory buffers or more precise temperature regulation.
- New drivers were unified and named "gXccdF" and "gXccdI" (for FF and IT detectors). G2 cameras employing Back-Illuminated E2V detectors use new driver "gXccdBI".