G4 Series Mark II

Cooled CCD Cameras

User's Guide

moravian instruments

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Introduction

Thank you for choosing the Moravian Instruments camera. The cooled G4 series Mark II CCD cameras were developed for imaging under extremely low-light conditions in astronomy, microscopy and similar areas.

Design of this series inherits from earlier G4 Mark I cameras, but brings some significant enhancements. G4 cameras employ precise electronics providing uniform frames and extremely low read noise limited only by CCD detector itself. G4 camera head is large enough to contain detector up to 37×37 mm in size.

Modular mechanical construction allows various camera variants to be combined with rich set of accessories, including telescope adapters, off-axis guider adapters, external filter wheels (there are external filter wheels with 5 or 7 positions for 50×50 mm square filters available for G4 cameras), Ethernet adapters, guiding cameras etc.

> Please note the internal filter wheel is not available for G4 cameras, because a filter wheel capable to carry 50×50 mm square filters is too big to fit inside camera head.

Rich software and driver support allows usage of G4 camera without necessity to invest into any 3rd party software package thanks to included free SIPS software package. However, ASCOM (for Windows) and INDI (for Linux) drivers, shipped with the camera, provide the way to integrate G4 camera with vast variety of camera control programs.

The G4 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 the camera, you need a computer which:

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

2. Is compatible with a PC standard and runs 32 or 64-bit Linux operating system.

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

3. Support for x64 based Apple Macintosh computers is also included.

   Only certain software packages are currently supported on Mac.

G4 cameras require at last one free USB 2.0 port to communicate with a host PC.

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 or seven additional USB ports. Make sure the USB hub is USB 2.0 high-speed compatible.

Alternatively, it is possible to use the “Gx Camera Ethernet Adapter” device. This device can connect up to four Gx cameras of any type (not only G4, but also G0, G1, G2 and G3) 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 WiFi adapter or other networking device to the communication path.

Please note while the USB standard allows usage of cable no longer than approx. 5 meters, the TCP/IP communication protocol used to connect the camera over the Ethernet adapter is routable, so the distance between camera setup and the host PC is virtually unlimited.

The G4 cameras need 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. G4 cameras integrate highly efficient CCD chip cooling, shutter and possibly 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 long exposures.

G4 Camera Overview

G4 camera head is designed to be easily used with a set of accessories to fulfil various observing needs. The cameras do not allow usage of internal filter wheel as the large sensors require large 50×50 mm filters. External filter wheel is then the only option for G4 camera.

There are two sizes of the External filter wheel available for the G4 cameras:

- Medium “M” size wheel for 5 square filters 50×50 mm
- Large “L” size wheel for 7 square filters 50×50 mm

Figure 1: G4 camera without filter wheel (left) and with "M" (center) and "L" (right) External filter wheels

G4 camera heads are manufactured in two variants, differing in the cooling performance:

- Standard cooling
- Enhanced cooling (11 mm thicker due to increased heat sink)

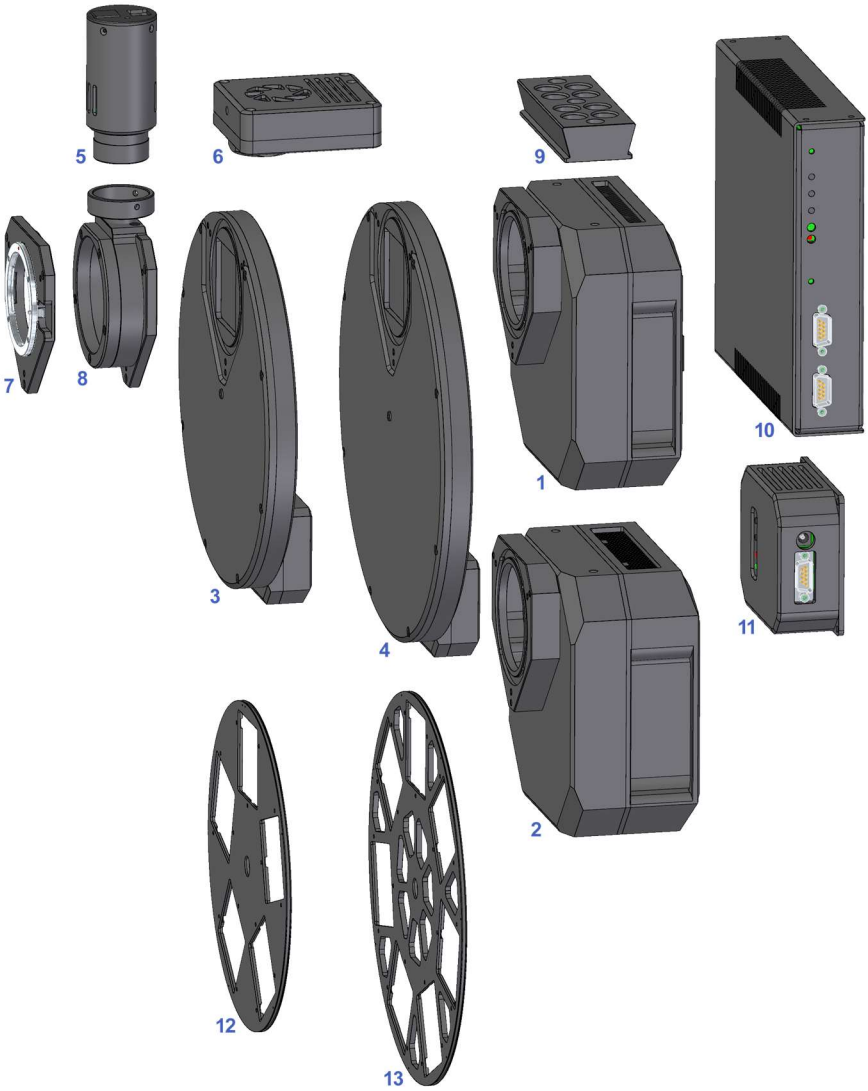


Figure 2: Schematic diagram of G4 camera system components

Components of G4 Camera system include:

1. G4 camera head with standard cooling
2. G4 camera head with Enhanced Cooling (EC) option

   Both variants of camera head are capable to control the External Filter Wheel

3. External Filter Wheel “M” size (5 positions)
4. External Filter Wheel “L” size (7 positions)
5. G0 Guider camera
6. G1 Guider camera

   G0 and G1 cameras are completely independent devices with their own USB connection to the host PC. They can be used either on G2 OAG or on standalone guiding telescope.

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

7. Canon EOS bayonet adapter for Canon compatible lenses
8. Off-Axis Guider with M68×1 thread adapter
9. 1.75” dovetail rail for G4 camera head
10. Gx Camera Ethernet Adapter (x86 CPU)
11. Gx Camera Ethernet Adapter (ARM CPU)

    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.

12. 5-positions “M” size filter wheel for 50×50 mm filters
13. 7-positions “L” size filter wheel for 50×50 mm filters

CCD and Camera Electronics

G4 series of CCD cameras are manufactured with “Full Frame” CCD sensors manufactured by On Semiconductor (formerly Kodak).

Almost all Full Frame CCD detector area is exposed to light, which ensures quantum efficiency provided but these sensors. Modern FF CCD detectors are suitable also for scientific applications, even if equipped with so-called Anti Blooming Gate (ABG – a gate, which prohibits blooming of the charge to neighboring pixels when image is over-exposed) with linear enough response to light within the full dynamic range.

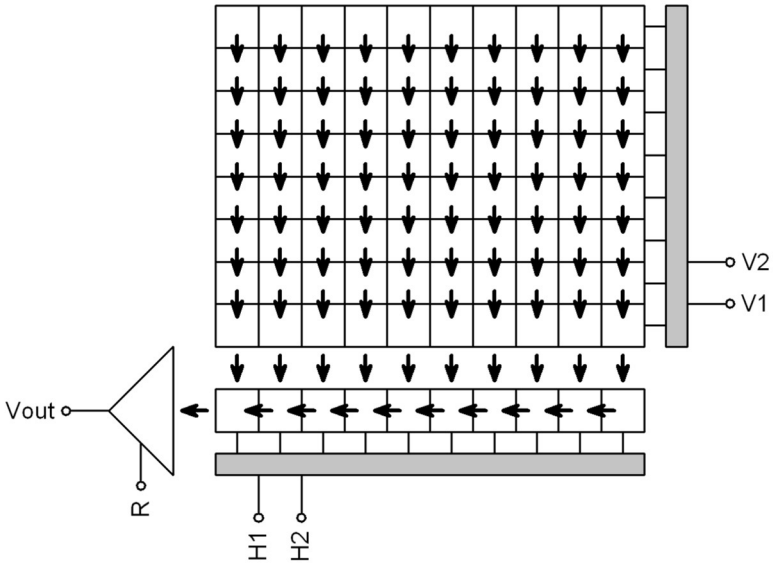
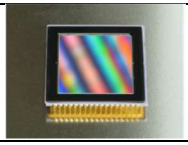
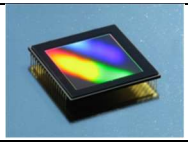


Figure 3: “Full Frame” CCD schematic diagram

G4 camera models:

Model	G4-9000	G4-16000
CCD sensor	KAF-09000	KAF-16803
Resolution	3056 × 3056	4096 × 4096
Pixel size	12 × 12 µm	9 × 9 µm
Sensor area	36.8 × 36.8 mm	36.9 × 36.9 mm
ABG	Yes	Yes
Color mask	No	No
		

CCD sensor

Quantum efficiency (sensitivity) of CCD detectors used in G4 cameras depends on the particular camera model.

Figure 4: Quantum efficiency of CCD detectors used in G3 and G4 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.

Model G4-9000

G4-9000 uses 9 MPx CCD OnSemi KAF-09000.

Resolution	3056 × 3056 pixels
Pixel size	12 × 12 µm
Imaging area	36.8 × 36.8 mm
Full well capacity	Approx. 110 000 e^-
Dark current	0.5 e-/s/pixel at 0°C
Dark signal doubling	7 °C

Model G4-16000

G4-16000 uses 16 MPx CCD OnSemi KAF-16803.

Resolution	3056 × 3056 pixels
Pixel size	9 × 9 µm
Imaging area	36.9 × 36.9 mm
Full well capacity	Approx. 100 000 e^-
Dark current	0.3 e-/s/pixel at 0°C
Dark signal doubling	6.3 °C

Camera Electronics

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.

Maximum length of single USB cable is approx. 5 m. This length can be extended to 10 m or 15 m by using single USB hub or active USB extender cable. Up to 5 hubs or active extenders can be used in one connection.

Gx Camera Ethernet Adapter device allows connection of up to four Gx cameras of any type through Ethernet interface and TCP/IP network. Because TCP/IP protocol can be routed, the distance between camera and host PC can be virtually unlimited.

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 as well as on the camera read mode.

- **Preview** read mode provides system read noise approx. 1 or 2 e^- above CCD chip read noise.
- **Low Noise** read mode is somewhat slower, but ensures system read noise roughly equal to the manufacturer-specified chip read noise.

Model G4-9000

Gain	1.5 e^-/ADU (1×1 binning)
	1.7 e^-/ADU (other binnings)
System read noise	10 e^- RMS (Low noise)
	11 e^- RMS (Preview)
Download time	5.8 s (Low noise)
	4.2 s (Preview)

Model G4-16000

Gain	1.6 e^-/ADU (all binnings)
System read noise	11 e^- RMS (Low noise)
	12 e^- RMS (Preview)
Download time	10.0 s (Low noise)
	7.2 s (Preview)

Stated read noise is measured on particular CCD sensor, evaluated during camera design. Actual read noise of different sensors varies within sensor manufacturing batch and also among various manufacturing batches. The camera read noise is determined by the sensor itself and the camera manufacturer cannot affect it.

Cooling and power supply

Regulated thermoelectric cooling is capable to cool down the CCD chip from 42 to 47 °C below ambient temperature, depending on the camera type. The Peltier hot side is cooled by fans. 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 proper image calibration.

G4 cameras are available in two variants, differing in the cooling performance:

- **Standard cooling** cameras achieve regulated temperature difference up to 42 °C below environment temperature.
- **Enhanced cooling** cameras can regulate temperature up to 47 °C below environment temperature. Compared to standard variant, enhanced cooling cameras are somewhat bulkier due to bigger heat sink, slightly heavier and somewhat noisier because of more powerful fans.

Figure 5: Standard cooling camera (left) and Enhanced cooling model (right) with thicker back shell containing larger heat sink

The camera head contains two temperature sensors – the first sensor measures directly the temperature of the CCD chip. The second one measures the temperature inside the camera shell.

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)
Standard cooling ΔT	47 °C below ambient maximum
	42 °C below ambient typical
Enhanced cooling ΔT	50 °C below ambient maximum
	45 °C below ambient typical
Regulation precision	±0.1 °C
Hot side cooling	Forced air cooling (two fans)
	Optional liquid coolant heat exchanger

Maximum temperature difference between CCD and ambient air may be reached 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. Typical 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 55 W, the 60 W power supply ensures noise-free operation.

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 other than the supplied power source is used.

Camera head supply	12 V DC
Camera head power consumption	15 W without cooling
	52 W maximum cooling
Power connector	5.5/2.5 mm, center +
Adapter input voltage	100-240 V AC/50-60 Hz
Adapter output voltage	12 V DC/5 A
Adapter maximum power	60 W

Figure 6: 12 V DC/5 A power supply adapter for G4 camera

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.

G4 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.

Mechanical Specifications

Compact and robust camera head measures only 154×154×65 mm (approx. 6×6×2.6 inches) for the model with standard cooling. Enhanced cooling increases camera depth by 11 mm.

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, no other parts (CPU box, USB interface, etc.), except a “brick” power supply, are necessary. Another connector allows control of optional external filter wheel. Integrated mechanical shutter allows streak-free image readout, as well as automatic dark frame exposures, which are necessary for unattended, robotic setups.

Internal mechanical shutter	Yes, blade shutter
Shortest exposure time	0.2 s
Longest exposure time	Limited by chip saturation only
Head dimensions	154×154×65 mm (standard cooling)
	154×154×76 mm (enhanced cooling)
Back focal distance	33.5 mm (base of adjustable adapters)
Standard cooling weight	1.6 kg (without filter wheel)
	2.5 kg (with “M” External filter wheel)
	2.8 kg (with “L” External filter wheel)
Enhanced cooling weight	1.8 kg (without filter wheel)
	2.7 kg (with “M” External filter wheel)
	3.0 kg (with “L” External filter wheel)

Back focus distance is measured from the sensor to the base on which adjustable adapters are mounted. Various adapters then provide back focal distance specific for the particular adapter type (e.g. Canon EOS bayonet adapter back focal distance is 44 mm).

Stated back focal distance already calculates with glass permanently placed in the optical path (e.g. optical window covering the CCD cold chamber).

Camera without filter wheel

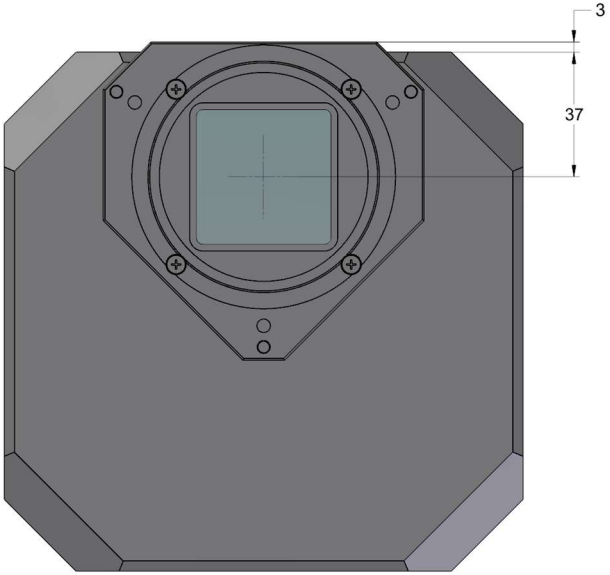


Figure 7: G4 camera head front view dimensions

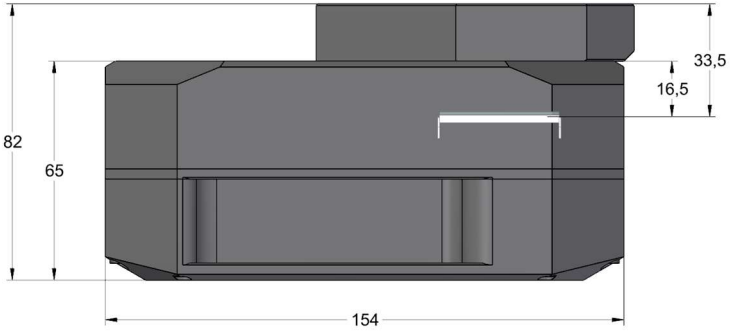


Figure 8: G4 camera head side view dimensions

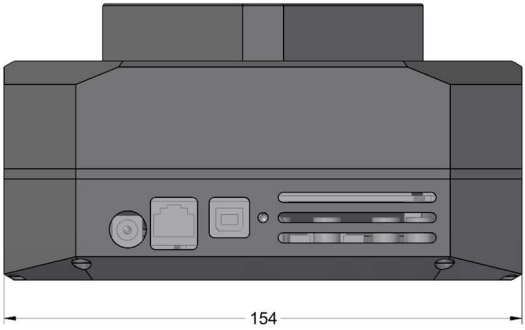


Figure 9: G4 camera head bottom view dimensions

Enhanced cooling variant

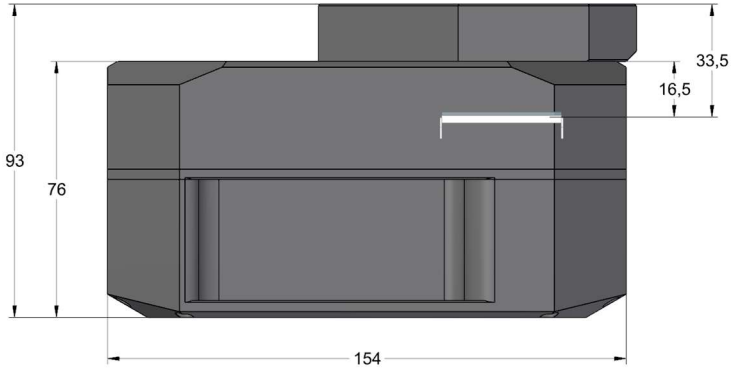


Figure 10: G4 camera head with Enhanced cooling side view dimensions

Camera with “L” External filter wheel

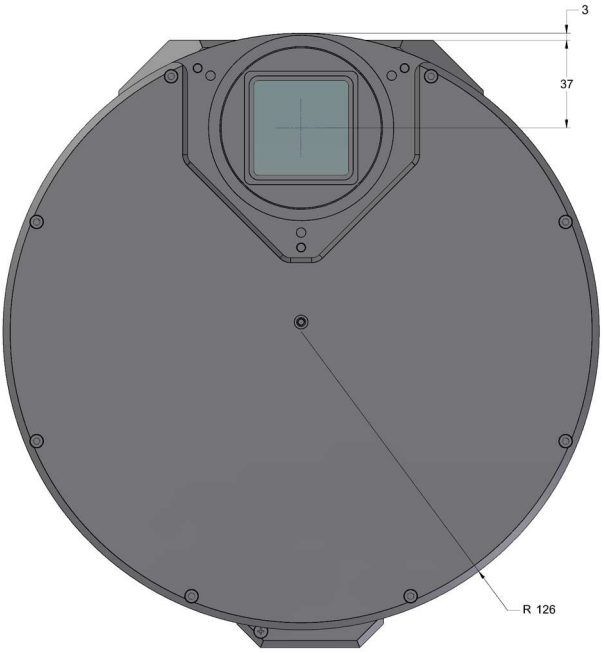


Figure 11: G4 camera head with External filter wheel front view dimensions

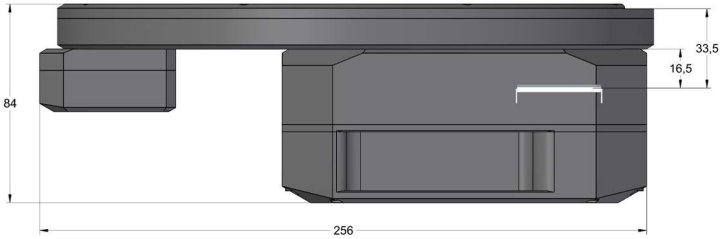


Figure 12: G4 camera head with External filter wheel side view dimensions

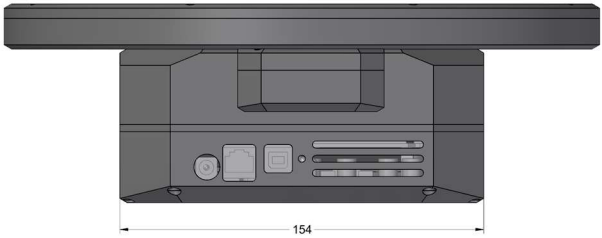


Figure 13: G4 camera head with External filter wheel bottom view dimensions

The “M” sized External Filter Wheel diameter is smaller (see External Filter Wheel User's Guide), but the back focal distance of all external filter wheels is identical.

Enhanced cooling with External filter wheel variant

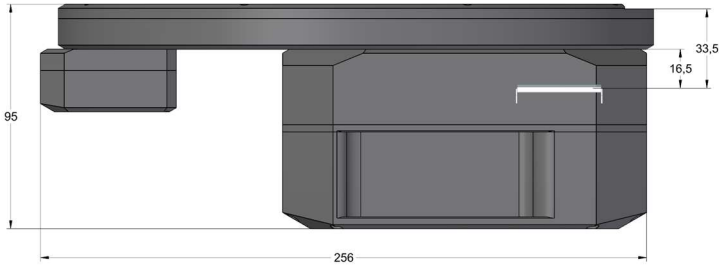


Figure 14: G4 camera head with Enhanced cooling and External filter wheel side view dimensions

Optional accessories

Various accessories are offered with G4 Mark II cameras to enhance functionality and help camera integration into imaging setups.

Telescope adapters

Usage of many common types of telescope and lens adapters are ruled out by very large sensor used in G4 Mark II cameras. The CCD diagonal dimension of G4 cameras is 52 mm, which is greater than outer dimensions of many adapter kinds. Only the M68 threaded and Canon EOS bayonet adapters are large enough not to cause vignetting.

- **M68×1** – adapter with M68×1 **inner thread**.
- **Canon EOS bayonet** – standard Canon EOS lens adapter ("L" size"). Adapter preserves 44 mm back focal distance.

Mark II adapters are attached either directly to the External filter wheel front plate or to the adjustable adapter base mounted on the camera head.

Off-Axis Guider Adapter (OAG)

G4 camera can be optionally equipped with Off-Axis Guider Adapter. This adapter contains flat mirror, tilted by 45° to the optical axis. This mirror reflects part of the incoming light into guider camera port. The mirror is located far enough from the optical axis not to block light coming to the main camera sensor, so the optics must be capable to create large enough field of view to illuminate the tilted mirror.

G4-OAG is manufactured with M68×1 thread with the back focal distance 61.5 mm.

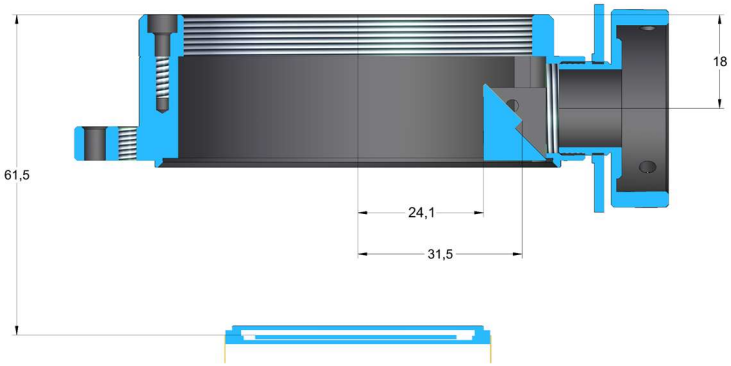


Figure 15: Position of the OAG reflection mirror relative to optical axis

Figure 16: OAG on G4 camera with thick adapter base

If the OAG is used on camera without filter wheel, thicker adapter base must be used to keep the Back focal distance and to allow the guiding camera to reach focus.

OAG guider port is compatible with G0 and G1 cameras. It is necessary to replace the CS/1.25” adapter with short, 10 mm variant in the case of G1 cameras. Because G1 cameras follow CS-mount standard, (BFD 12.5 mm), any camera following this standard with 10 mm long 1.25” adapter should work properly with the G4-OAG.

Attaching camera head to telescope mount

G4 camera heads are equipped with two “tripod” thread (0.25”) on the top side. These threads can be used to attach 1.75 inch “dovetail bar” (Vixen standard). It is then possible to attach the camera head, e.g. equipped with photographic lens, directly to various telescope mounts supporting this standard.

Figure 17: 1.75" bar for standard telescope mounts

Camera head color variants

Camera head is available in several color variants of the center plate. Visit manufacturer's web pages for current offering.

Figure 18: G4 camera color variants

Gx Camera Ethernet Adapter

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.

Figure 19: The Gx Camera Ethernet Adapter with two connected cameras

Adjusting of the telescope adapter

All telescope/lens adapters of the G4 Mark II series of cameras can be slightly tilted. This feature is introduced to compensate for possible misalignments in perpendicularity of the telescope optical axis and sensor plane.

Figure 20: Releasing of the "pushing" screw

The Mark II camera telescope adapters are attached using three "pulling" screws. As the adapter tilt is adjustable, another three "pushing" screws are intended to fix the adapter after some pulling screw is released to adjust the tilt.

Warning:

Both pulling and pushing screws, used on the G4 camera adapter, are fine-pitch M4×0.5 thread screws, not standard M4 thread ones. Always

use only screws supplied with the adapter, using of normal M4 screws damages the adapter.

Because the necessity to adjust two screws (one pushing, one pulling) at once is inconvenient, the adapter tilting mechanism is also equipped with ring-shaped spring, which pushes the adapter out of the camera body. This means the pushing screws can be released and still slight releasing of the pulling screw means the distance between the adapter and the camera body increases. The spring is designed to be strong enough to push the camera head from the adapter (fixed on the telescope) regardless of the camera orientation.

When all three pulling screws are fully tightened, releasing of just one or two of these screws does not allow adapter to move, or at last only very slightly thanks to deformation of the adapter body. If the adapter has to be adjusted, it is necessary to slightly release all three pulling screws, which makes room for tilt adjustment.

Figure 21: Adjusting of the "pulling" screw

Only after the proper tilt is reached, the pushing screws should be slightly tightened to fix the adapter in the desired angle relative to camera head. This ensures long-time stability of the adjusted adapter.

Adjustable telescope/lens adapters are attached slightly differently depending if the adapter is attached directly to the camera head (e.g. when camera is equipped with internal filter wheel) or to the External filter wheel case.

- If the External filter wheel is used, the adapted base is not necessary, as the Mark II External filter wheel front plate is already designed to hold the spring and it also contains threads to fix respective adapters.
- G4 Mark II adapters are not mounted directly on the camera head. Instead a tilting adapter base, holding the circular spring, is always used.

Figure 22: Off Axis Guider adapter on the adapter base, attached to the G4 camera without External filter wheel (left) and directly on the External filter wheel (right)

Camera Maintenance

The G4 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 G4 camera 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 container, filled with silica-gel desiccant, is placed inside the camera head. This cylindrical chamber is connected with the insulated cooled CCD chamber itself.

Warning:

High level of moisture inside the CCD cold chamber can cause camera malfunction or even damage to the CCD sensor. 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 desiccant. 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 dry the wet silica-gel by baking it in the oven (not the microwave one!) to dry it again. Dry the silica-gel for at last one or two hours at temperature between 120 and 140 °C.

The silica-gel used in G4 cameras changes its color according to amount of absorbed water – it is bright yellow or orange when it is dry and turns to

transparent without any color hue when it becomes wet. It is recommended to shorten replacement interval if the silica-gel is completely transparent upon replacement. If it is still yellow-orange, it is possible to prolong the replacement interval.

Figure 23: Silica-gel container is accessible from the camera back side

Exchanging the silica-gel

G4 Mark II cameras employ the same desiccant container like the G3 and G2 cameras. The whole container can be unscrewed, so it is possible to exchange silica-gel without the necessity to remove the camera from the telescope.

Silica-gel is held inside the container with a perforated cap. This cap is also screwed into the container body, so it is easy to exchange the silica-gel inside the container after it is worn out or damaged e.g. by too high temperature etc.

The container itself does not contain any sealing (the sealing remains attached to the CCD cold chamber inside the camera head), it consists of

aluminum parts only. So, it is possible to heat the whole container to desired temperature without risking of the temperature-induced sealing damage.

Figure 24: Desiccant is held inside container by perforated cap

Note:

New containers have a thin O-ring close to the threaded edge of the container. This O-ring plays no role in sealing the CCD cold chamber itself. It is intended only to hold possible dust particles from entering the front half of the camera head with the CCD chamber optical window, shutter and possibly internal filter wheel. While the O-ring material should sustain the high temperature during silica-gel baking, it is possible to remove it and put it back again prior to threading the contained back to the camera.

This design also allows usage of some optional parts:

- Threaded hermetic cap, which allows sealing of the dried container when it is not immediately attached to the camera head.
- Alternate (somewhat longer) desiccant container, modified to be able to be screw in and tightened (as well as released and screwed out) without any tool.

The sealing cap as well as the tool-less container are not supplied with the camera, they are supplied only as optional accessory.

Figure 25: Optional cap, standard and tool-less container variants for both standard cooling and enhanced cooling (prolonged) cameras

Desiccant containers for Standard cooling and Enhanced cooling cameras

The difference between Standard and Enhanced cooling cameras is the thickness of the camera back shell, containing heat sink. Naturally, the silica-gel container of Enhanced cooling variants must be longer. Otherwise the containers are the same and the longer variant can be used with standard cooling cameras, it then only extends from the camera back.

Changing the Telescope Adapter

All adapters of the Mark II cameras are attached using three “pulling” screws. As the adapter tilt is adjustable, another three “pushing” screws are intended to fix the adapter in place.

If the adapter has to be replaced for another one, it is necessary to unscrew the three pulling screws. The adapter then can be removed and replaced with another one.

Warning:

Both pulling and pushing screws, used on the G4 camera adapter, are fine-pitch M4×0.5 thread screws, not standard M4 thread ones. Always use only screws supplied with the adapter, using of normal M4 screws damages the adapter.

Always make sure to carefully locate the ring-shaped spring prior to attaching the adapter.

Figure 26: Replacing of the adjustable telescope adapter

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.