

C0, CG, and C1 Series CMOS Cameras



User's Guide

Version 3.1

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Moravian Instruments
Masarykova 1148
763 02 Zlín
Czech Republic

phone: +420 577 107 171

web: <https://www.gxccd.com/>

e-mail: info@gxccd.com

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Introduction

Thank you for choosing the Moravian Instruments camera. The C0, CG, and C1 series CMOS cameras were designed to work as automatic guiders as well as small, lightweight imagers for Sun, Moon, and planets. With proper image calibration, these cameras provide surprisingly good results also in entry-level deep-sky imaging.

The used CMOS sensors response to light is linear up to very close to saturation point, so, especially the C1 line of cameras can be used for scientific applications like variable star research, too.



Rich software and driver support allow usage of C0, CG, and C1 cameras without necessity to invest into any 3rd party software package thanks to included free SIPS software. However, ASCOM (for Windows) and INDI (for Linux) drivers, shipped with the camera, provide the way to integrate these cameras with vast variety of camera control programs.

The C0, CG, and C1 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 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 Apple Macintosh computers is also included.

Only certain software packages are supported on Mac.

C0, CG, and C1 cameras are designed to be connected to the host PC through USB 3.0 interface, operating at 5 Gbps. Cameras are also compatible with USB 2.0 port to communicate with a host PC.

Alternatively, it is possible to use the “Moravian Camera Ethernet Adapter” device. This device can connect up to four Cx (and Gx) cameras of any type (CMOS based Cx or CCD based Gx cameras) 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 that the USB standard allows usage of cable no longer than approx. 5 meters and USB 3.0 cables are even shorter to achieve very fast transfer speeds. On the other side, 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.

Download speed is naturally significantly slower when camera is attached over Ethernet adapter, especially when compared with direct USB 3 connection.

The C0, CG, and C1 cameras do not need an external power supply to operate, they are powered through the USB connection from the host PC.

Note the camera must be connected to some optical system (e.g. the telescope) to capture images. The camera is capable of 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.

C0, CG, and C1 cameras compared

All three camera lines share majority of features, like the used sensors, USB interface, autoguider port, etc. At the first view, the only difference is the size and shape of camera body.

Feature	C0	CG	C1 ¹
Dimensions	50 × 50 × 40.4 mm	50 × 34 × 68 mm	57 × 57 × 46.4 mm
Weight	115 g	138 g	170 g
Cooling fan	No	No	Yes
Tripod thread	No	No	Yes



Figure 1: Comparison of the C0 (left), CG (middle), and C1 (right) cameras

¹ Values are valid for C1 v3 cameras, earlier C1 v1 and v2 models are slightly thicker and heavier. See the [Mechanical Specifications](#) chapter.

The main differentiating feature of the CG series is the flattened camera shape. Sometimes the C0 or C1 camera cannot be used on OAG because of its shape. Both C0 and C1 cameras exceed the front plane, defined by the OAG front thread, and thus they can possibly interfere with the telescope's rear mounting interface. The CG cameras are designed not to exceed the OAG in the front. But otherwise, the CG cameras are essentially the C0 ones in the flat casing.



Figure 2: Side view of the C5 camera, SX-sized filter wheel, and C5-OAG adapter with attached CG camera



Figure 3: The CG camera head is designed to be flat

The greater dimensions of the C1 models allowed adding of some features, not available on the C0 and CG cameras.

Despite neither C0 nor C1 cameras employ active Peltier sensor cooling, exchanging the air inside the C1 camera head can keep the sensor temperature up to 10° C lower compared to closed design of the C0 and the CG. Such temperature drop can almost halve the sensor dark current.

C0, CG, and C1 Camera Overview

The C0, CG, and C1 cameras are equipped with Sony IMX **global shutter** CMOS detectors with $3.45 \times 3.45 \mu\text{m}$ square pixels. Individual models differ in resolution only.

All used sensors utilize global electronic shutter. This means every pixel within the image is exposed in the same time, as opposed to rolling shutter sensors, which exposes individual lines one after another. There is no difference for long exposures of static objects, but imaging of moving objects using short exposure time using rolling shutter leads to image shape distortions.

Two lines of cameras are available depending on the available dynamic range (bit-depth of the digitized pixels):

- **Models with Sony IMX sensors supporting 8- and 12-bit digitization.** Because every 12-bit pixel occupies two bytes when transferred to host PC, 12-bit image download time is longer compared to 8-bit image. Maximal FPS in 8-bit mode is then significantly higher.
- **Models with Sony IMX sensors supporting 12-bit digitization only.** As the 12-bit read mode is always used for long-exposure applications (astronomical photography, scientific research) either way, lower theoretical download time in 8-bit mode brings no limitations for real-world scenarios. All other parameters being same (sensor size, resolution, pixels size, noise, ...), lower price of these cameras may be then very attractive.

C0, CG and C1 camera models with 8- and 12-bit digitization:

Model	C0/CG/C1-1500
CMOS sensor	IMX273
Resolution	1456×1088
Pixel size	$3.45 \times 3.45 \mu\text{m}$
Sensor size	$5.02 \times 3.75 \text{ mm}$

Model	C0/CG/C1-3000	C0/CG/C1-5000	C0/C1-12000
CMOS sensor	IMX252	IMX250	IMX253
Resolution	2064 × 1544	2464 × 2056	4112 × 3008
Pixel size	3.45 × 3.45 μm	3.45 × 3.45 μm	3.45 × 3.45 μm
Sensor size	7.12 × 5.33 mm	8.50 × 7.09 mm	14.19 × 10.38 mm

Note the CG series do not offer the largest 12 MPx sensor variant, as it is primarily designed for auto-guiding, not imaging.

C0, CG and C1 camera models with 12-bit digitization only:

Model	C0/CG/C1-3000A	C0/CG/C1-5000A	C0/C1-12000A
CMOS sensor	IMX265	IMX264	IMX304
Resolution	2064 × 1544	2464 × 2056	4112 × 3008
Pixel size	3.45 × 3.45 μm	3.45 × 3.45 μm	3.45 × 3.45 μm
Sensor size	7.12 × 5.33 mm	8.50 × 7.09 mm	14.19 × 10.38 mm

Cameras limited to 12-bit read mode are marked with letter A, following the model number. For instance, if the C1-3000 offers both 8- and 12-bit read modes, the C1-3000A model employs only 12-bit read mode. All other parameters (sensor size, pixel resolution) are equal.

C0 and C1 Camera System



Figure 4: Schematic diagram of the C0 and C1 camera system components

Components of the C0 and C1 Camera system include:

1. C0 camera head with CS-mount adapter
2. C1 camera head with CS-mount adapter
3. C0 camera head with combined T-thread (M42×0.75) and CS-mount adapter
4. C1 camera head with combined T-thread (M42×0.75) and CS-mount adapter
5. C/CS-mount to 1.25" barrel adapter

6. Short (10 mm) variant of C/CS-mount to 1.25" barrel adapter, intended for usage with OAG
7. Off-Axis Guider adapter (OAG), intended for large cooled cameras (C1+, C1x, C2, C3, C4, and C5)

OAG shown here is not exactly a part of the C0/C1 camera system. It is intended for cooled cameras (C2 to C5) and only accommodates C0 or C1 camera for guiding.

To allow the C0 or C1 camera to work with OAG, it is necessary to use the CS-mount adapter. C0 or C1 camera with T-thread adapter is not compatible with OAG.

The C0 and C1 cameras are also compatible with larger OAGs for C3/C4 and C5 cameras, not shown here.

8. Extension tube with M48×0.75 thread and 55 mm back focal distance
9. Extension tube with M42×0.75 thread and 55 mm back focal distance (standard T-thread adapter)
10. Adapter for Canon EOS bayonet lens
11. Adapter for Nikon bayonet lens

C1 camera versions

C1 cameras underwent several innovation cycles through its lifetime. Versions 1 and 2 differ only internally and they are undistinguishable from the user point of view. The 3rd iteration of the C1 camera design allowed to make the camera head 7 mm thinner and 45 g lighter. Beside the smaller and lighter body, all other features (used sensors, USB and autoguider interfaces, download time, ...) are the same.



Figure 5: Comparison of the C1 v3 (left) and v1/v2 (right) models shows the difference in camera thickness

CMOS Sensors and Camera Electronics

CMOS camera electronics primary role, beside the sensor initialization and some auxiliary functions, is to transfer data from the CMOS detector to the host PC for storage and processing. So, as opposite to CCD cameras, CMOS camera design cannot influence number of important camera features, like the dynamic range (bit-depth of the digitized pixels).

Sensor linearity

The sensors used in the C0, CG, and C1 cameras show very good linearity in response to light. This means the camera can be used also for entry-level research projects, like for instance photometry or brighter variable stars etc.

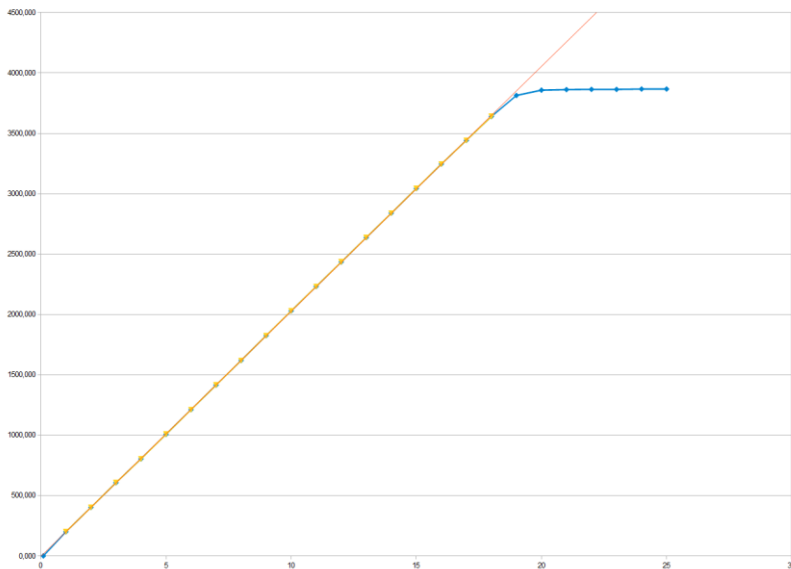


Figure 6: Response of the Sony IMX252 sensor used in C1-3000 camera

Download speed

As already noted, there are two lines of C0, CG, and C1 camera series, differing in the used sensor. The first series offers four different read modes:

- **8-bit slow** mode with ~ 132 MPx/s digitization speed
- **12-bit slow** mode with ~ 72 MPx/s digitization speed
- **8-bit fast** mode with ~ 263 MPx/s digitization speed
- **12-bit fast** mode with ~ 132 MPx/s digitization speed

The slow variant of both read modes can be used to slightly lower the amount of heat generated by the sensor, as the communication interface operates at half speed compared to fast mode. Also, when the camera is connected using USB 2.0 interface, fast read mode provides data at higher speed than the USB 2.0 can handle and thus causes more interruptions of image digitization process.

The “A” version of C0, CG, and C1 cameras offers only single read mode:

- **12-bit fast** mode with ~ 132 MPx/s digitization speed

The digitization speeds mentioned above are valid for USB 3.0 connection. Also please note the digitization speeds do not necessarily lead to corresponding FPS, because every image downloaded has to be processed and displayed, which also consumes time. This time is negligible, if slow-scan camera needs many seconds for image download, but in the case of fast CMOS cameras, time for image processing in the PC (e.g. calculation of image standard deviation etc.) can be longer than image download itself.

Despite one byte per pixels is transferred from camera to PC in the 8-bit read mode, many astronomical processing software packages work with 16-bit or 32-bit images only (e.g. SIPS). So, images occupy the same space in the computer memory regardless of the read mode.

Also, standard format for image storage in astronomy is FITS. While this format supports 8-bit per pixel, this variant is rather unusual and 16 or 32-bit integer or 32-bit floating-point pixels are typically stored to disk files to achieve as wide compatibility as possible.

Camera gain

Sensors used in C0, CG, and C1 cameras offer programmable gain from 0 to 24 dB, which translates to the output signal multiplication from $1\times$ to $15.9\times$. Gain can be set with 0.1 dB step.

Note the camera firmware supports only **analog gain**, which means real amplification of the signal prior to its digitization. The used sensors support also **digital gain** control, which is only numerical operation, bringing no real benefit for astronomical camera. Any such operation can be performed later during image processing if desired.

Conversion factors and read noise

Generally, all sensor characteristics depend on the used gain. So, we provide two list of parameters for both minimal and maximal gain.

Digitization	12-bit	12-bit	8-bit	8-bit
Sensor gain	0 dB	24 dB	0 dB	24 dB
Full well capacity	11000 e-	1100 e-	2600 e-	1100 e-
Conversion factor	2.8 e-/ADU	0.3 e-/ADU	10.0 e-/ADU	4.4 e-/ADU
Read noise	2.2 e- RMS	2.0 e- RMS	4.2 e- RMS	9.7 e- RMS

Please note the values stated above are not published by sensor manufacturer, but determined from acquired images using the SIPS software package. Results may slightly vary depending on the test run, on the particular sensor and other factors (e.g. sensor temperature, sensor illumination conditions etc.), but also on the software used to determine these values, as the method is based on statistical analysis of sensor response to light.

Exposure control

The C0, CG, and C1 cameras are capable of very short exposures. The shortest exposure time is $125\ \mu\text{s}$ ($1/8000$ of second). This is also the step, by which the exposure time is expressed. So, the second shortest exposure is $250\ \mu\text{s}$ etc.

Long exposure timing is controlled by the host PC and there is no upper limit on exposure time. In reality the longest exposures are limited by

saturation of the sensor either by incoming light or by dark current (see the following sub-chapter).

Sensor Cooling

Dark current is an inherent feature of all silicone circuits. It is called “dark”, because it is generated regardless if the sensor is exposed to light or not. Dark current, injected into individual pixels, appear in image as noise. The longer exposure, the greater amount of noise is present in every image. As it is generated by random movement of particles, it depends on the temperature exponentially (this is why the noise generated by dark current is also denoted “thermal noise”). Typically, lowering the sensor temperature by 6 or 7 °C halves the dark current.

While none of the C0, CG, or C1 cameras are equipped with active thermo-electric (Peltier) cooling, the C1 models employ a small fan, exchanging air inside the camera body. What is more, a small heat sink is located directly on the sensor to remove as much heat as possible². So, the C1 sensor cannot be cooled below the ambient temperature, but its temperature is kept as close to environment as possible. Compared to closed designs of the C0 and CG cameras, the sensor temperature in the C1 can be between 7 and 10°C lower and resulting dark current may be less than a half.



Figure 7: Cooling air intake is on the right side of the C1 camera (left image), while the output vents are on the opposite side (right image)

The fan operation can be controlled from the software. SIPS directly offers a slider controlling fan in the “Cooling” tab of the main camera

² The heat sink is used in the C1-3000(A), C1-5000(A), and C1-12000(A) models. The C1-1500 sensor is too small for a heat sink.

control tool window. Drivers for other software must rely on driver configuration dialog box to control fan.

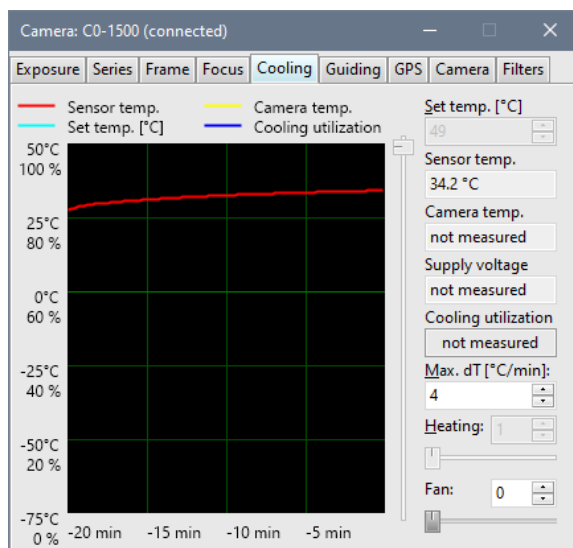


Figure 8: Without fan, the sensor in the C0-1500 camera reaches temperature approx. 7°C above ambient

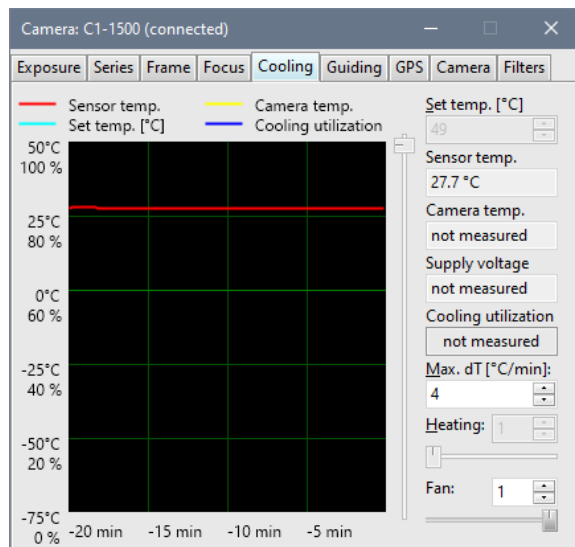


Figure 9: The sensor in the C1-1500 camera with running fan is kept very close the ambient temperature

C0 and CG cameras are not equipped with a cooling fan nor the vents. The camera head is closed, which enhances the resistance to the environment (for instance, salty air close to the seashore etc.), but at the cost of higher sensor operating temperature.

Autoguider port

A lot of astronomical telescope mounts (especially the mass-manufactured ones) are not precise enough to keep the star images perfectly round during long exposures without corrections. Cooled astronomical cameras and digital SLR cameras allow perfectly sharp and high-resolution images, so even a small irregularity in mount tracking appears as star image deformations. C0, CG, and C1 cameras were designed especially with automatic mount guiding on mind.

Guiding cameras are designed to operate without any mechanically moving parts (except for magnetically levitating fan in the case of C1 models). Electronic shutter allows extremely short exposures and also obtaining thousands of images in a short time, which is necessary for quality guiding.

C0, CG, and C1 cameras work in connection with a host computer (PC). Guiding corrections are not calculated in the camera itself, it only sends acquired images to the PC. The software running on the PC calculates the difference from required state and sends appropriate corrections to the telescope mount. The plus side of using a host PC CPU to process images is the fact, that current PCs provide overwhelming computational power compared to any embedded processor inside the guiding camera. Guiding algorithms then can determine star position with sub-pixel precision, can match multiple stars to calculate average difference, which limits the effects of seeing, etc.

Calculated corrections can be sent back to mount using PC-to-mount link, but more accurate guiding can be achieved using so called “Autoguider” port. It is enough to connect the camera and the mount using standard 6-wire cable and guide the mount through the camera.

The maximum sinking current of each pin of the camera is 400 mA. If the mount does not treat the autoguider port as logical input only, but switches the guiding motors directly by these signals, a relay box must be inserted between the camera and the mount. The relay box ensures switching of currents required by the mount.

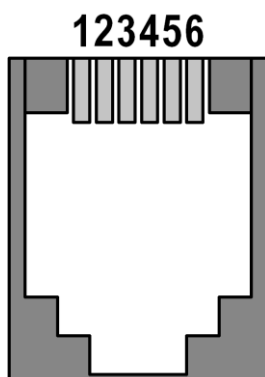


Figure 10: Standard 6-pin Autoguider Port is located beside the USB3 port on the top side of C1 (left) and C0 (right) cameras



Figure 11: CG camera USB and Autoguider ports are located on the camera back side

The Autoguider port follows the de-facto standard introduced by SBIG ST-4 autoguider. The pins have the following functions:



1. R.A. + (Right)
2. Dec + (Up)
3. Dec – (Down)
4. R.A.– (Left)
5. Common (Ground)
6. Not connected

Mechanical Specifications

C0, CG, and C1 cameras are designed to be lightweight and compact to be easily attached even to small telescopes or finders.

The head is CNC-machined from high-quality aluminum and black anodized. The head itself contains USB-B 3.0 (device) connector and standard 6-pin “autoguider” connector.

Internal mechanical shutter	No
Shortest exposure time	125 μ s
Longest exposure time	Limited by sensor saturation only
C0 head dimensions	50 × 50 × 40.4 ³ mm
CG head dimensions	50 × 34 × 68 ⁴ mm
C1 head dimensions	57 × 57 × 46.4 ⁵ mm
Back focal distance	12.5 mm (CS-mount compatible) 18.5 mm (T-thread)
C0 camera weight	115 g
CG camera weight	138 g
C1 camera weight	170 ⁶ g

Telescope/lens adapter

C0 and C1 cameras are supplied with two types of telescope/lens adapters:

- Adapter with 1/32 UN thread and 12.5 mm Back Focal Distance (CS-mount).
- Adapter with M42×0.75 thread (T-thread) and 18.5 mm Back Focal Distance. This adapter also contains inner thread 1/32 UN with 12.5 mm Back Focal Distance (CS-mount).

³ C0 thickness includes CS-mount lens adapter.

⁴ CG thickness includes CS-mount lens adapter.

⁵ C1 thickness includes CS-mount lens adapter. The dimension 46.4 mm is valid for C1 v3, version 1 and 2 thickness is 53.4 mm.

⁶ Camera weight 170 g is valid for C1 v3, version 1 and 2 weight is 215 g.

The CG cameras are supplied with CS-mount adapter only.

The CS-mount thread with Back Focal Distance is 12.5 mm makes C0 and C1 cameras compatible with vast number CS-mount compatible of CCTV lenses. If C-mount lens is to be used (with 17.5 mm Back Focal Distance), simple 5 mm thick adapter ring should be used.



Figure 12: Comparison of C1 camera with CS- mount only adapter (left) and C1 camera with combined T-thread (M42×0.75) and CS-mount adapter (right)



Figure 13: CG camera with CS-mount threaded lens adapter

C-to-1.25" barrel adapter, compatible with standard 1.25" eyepieces, is included into camera package. So, the C0, CG, or C1 camera can be easily mounted into virtually every astronomical telescope instead of an eyepiece.

If the camera should be used with OAG for cooled Cx or Gx cameras, short 10 mm C-to-1.25" barrel adapter must be used. This adapter,

shipped with respective OAG, is fully compatible with C0 and C1 cameras.

Note the C0 and C1 cameras with T-thread adapter cannot be used with OAG. While the short (10 mm) CS-to-1.25" barrel adapter can be threaded into internal CS-mount thread, the large-diameter M42 adapter interferes with screws fixing the camera in the OAG guider port. This is why C0 and C1 variants with CS-mount only adapter are still supplied.

The T-mount interface (also known as T-thread adapter) is defined by thread dimensions M42×0.75 as well as by 55 mm Back focal Distance. T-thread adapter for C0 or C1 cameras does not comply to the second parameter, its BFD is only 18.5 mm. The 55 mm BFD is not required in all applications and keeping such relatively large BFD would make the adapter quite bulky.

Still, an extension tube with male M42×0.75 thread is available. This extension tube converts the C0 or C1 camera BFD to 55 mm, required by numerous focal-reducers, field-flatteners, coma-correctors, and other optical elements.



Figure 14: C1 camera (left), 55 mm BFD extension tube with M42×0.75 thread (center) and with M48×0.75 thread (right)

There are two variants of the threaded extension tubes with 55 mm BFD:

- Extension tube with M42×0.75 (T-thread) on the telescope side.

- Extension tube with larger M48×0.75 thread on the telescope side.

Also, extension tubes with bayonet interfaces for standard photographic lenses are available:

- Extension tube with Nikon bayonet adapter.
- Extension tube with Canon EOS bayonet adapter.



Figure 15: Extension tubes for C1 cameras with M42×0.75 adapter: T-thread with 55 mm BFD (far left), M48×0.75 thread with 55 mm BFD (left), Nikon bayonet (right) and Canon EOS bayonet (far right)

Threaded extension tubes outer diameter is exactly 2 inches (50.8 mm), so it can allow using of the C0 or C1 camera with any 2" focuser instead of 2" eyepiece.



Figure 16: C1 camera with Canon EOS lens attached

Tripod and metric threads



Figure 17: C1 camera bottom contains standard 0.25" (tripod) thread and 4 metric M3 threaded holes

If the C1 camera is not attached to the telescope focuser through its telescope/lens adapter, it can be attached to standard photographic tripod using 0.25" thread. Another possibility is to use 4 metric M3 threaded holes, also located on the bottom side of the C1 camera head.

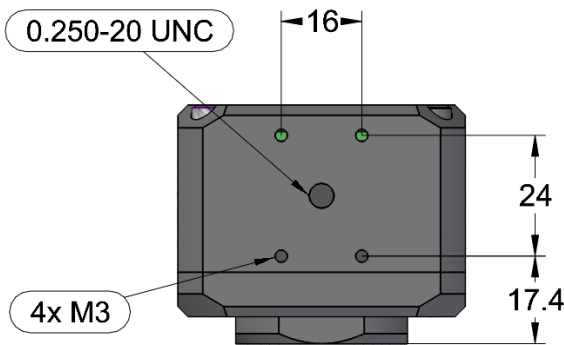


Figure 18: Position of the tripod 0.25" thread and four M3 threaded holes on the bottom of the C1 v3 camera head

The threaded hole pattern (thread diameter as well as hole mutual distances) is the same for all versions of C1 cameras. Only the holes are 1 mm further from the camera front side on C1 cameras version 1 and 2.

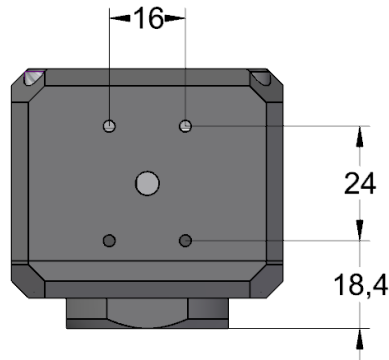


Figure 19: Position of the four M3 threaded holes on the bottom of the C1 v1 and v2 camera head

Note the threaded mounting holes are not available on the C0 cameras.

Camera Dimensions

Both C0 and C1 cameras are supplied with two variants of the telescope/lens adapters:

- CS-mount only adapter.
- Universal adapter combining T-thread (M42×0.75) and CS-mount thread (1/32 UN). Thanks to 1/32 UN thread this adapter remains compatible with all CCTV lenses and other equipment.

Note if the camera is to be used in combination with OAG, the CS-mount only adapter must be used as the universal T-thread/CS-mount adapter is not mechanically compatible with OAG.

C0 Dimensions

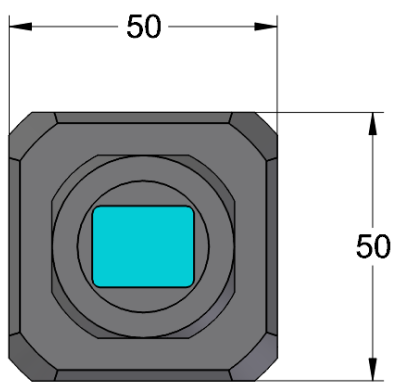


Figure 20: C0 camera with CS-mount only adapter front view

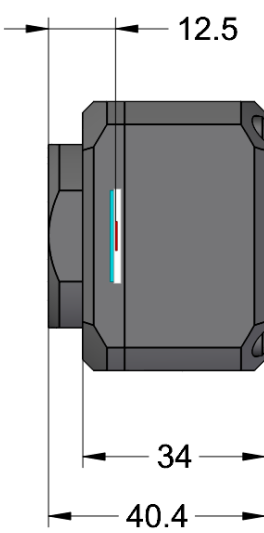


Figure 21: C0 camera with CS-mount only adapter side view

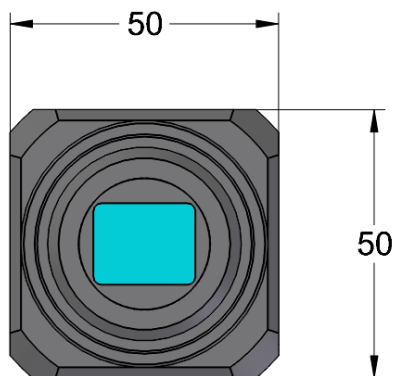


Figure 22: C0 camera with combined T-thread/CS-mount adapter front view

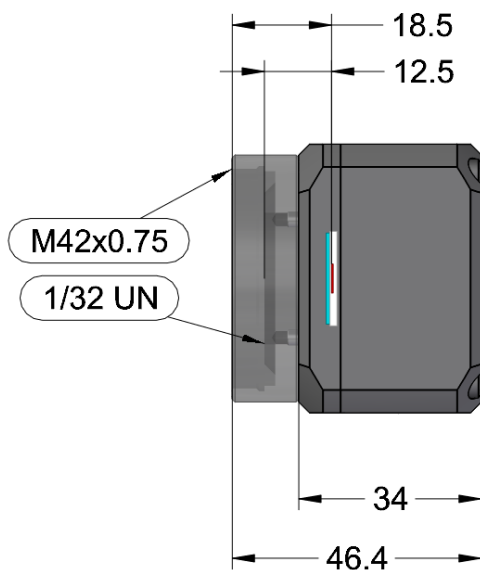


Figure 23: C0 camera with combined T-thread/CS-mount adapter side view

CG Dimensions

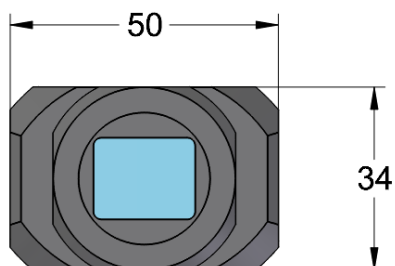


Figure 24: CG camera with CS-mount adapter front view

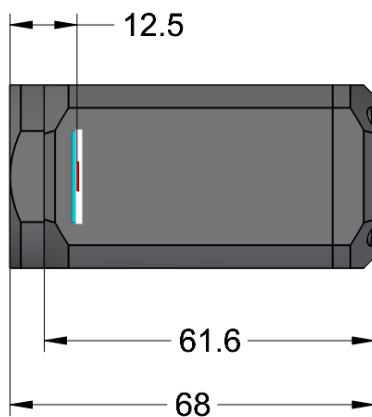


Figure 25: CG camera with CS-mount adapter side view

C1 Dimensions

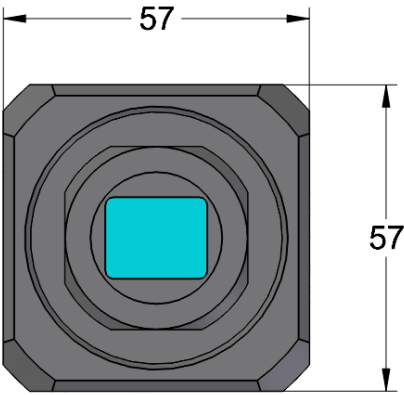


Figure 26: C1 camera with CS-mount only adapter front view

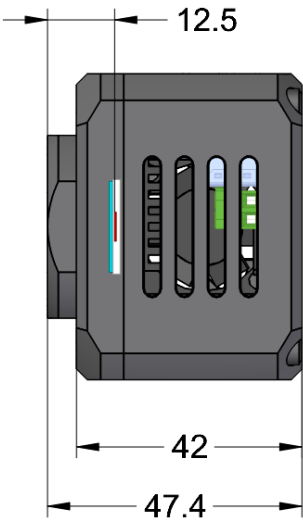


Figure 27: C1 v3 camera with CS-mount only adapter side view⁷

⁷ The C1 camera v1 and v2 total length is 54.4 mm.
32

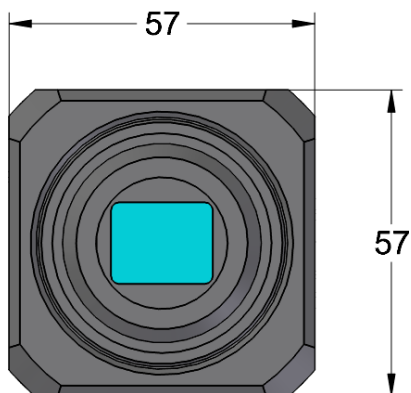


Figure 28: C1 camera with combined T-thread/CS-mount adapter front view

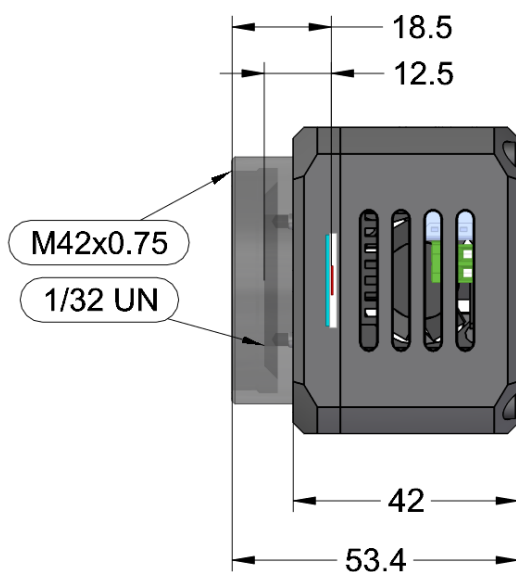


Figure 29: C1 v3 camera with combined T-thread/CS-mount adapter side view⁸

⁸ The C1 camera v1 and v2 total length is 60.4 mm.

Camera Maintenance

C0, CG, and C1 cameras require no special maintenance. Still, it 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.