C3 Series

Astronomical CMOS Cameras

User's Guide

Version 1.11

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C3 cameras are not authorized for and should not be used within Life Support Systems without the specific written consent of the Moravian Instruments. Product warranty is limited to repair or replacement of defective components and does not cover injury or property or other consequential damages.

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 C3 series of cooled scientific CMOS cameras were developed for imaging under extremely low-light conditions in astronomy, microscopy and similar areas.

Mechanical design of this series inherits from earlier CCD-based G3 Mark II cameras, which makes the C3 camera line fully compatible with vast range of telescope adapters, off-axis guider adapters, filter wheels, Camera Ethernet adapters, guiding cameras etc.

Rich software and driver support allow usage of C3 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 and Linux driver libraries are shipped with the camera, provide the way to integrate C3 camera with broad variety of camera control programs.

The C3 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 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 an x86 or ARM based computer 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.

C3 cameras are designed to be attached to host PC through very fast USB 3.0 port. While C3 cameras remain compatible with older (and slower) USB 2.0 interface, image download time is significantly longer.

Alternatively, it is possible to use the “Moravian Camera Ethernet Adapter” device. This device can connect up to four Cx (and CCD based Gx) cameras of any type (not only C3, but also C1, C2 and C4) 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 C3 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 simple imagers. C3 cameras integrate highly efficient CMOS sensor 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.

C3 Camera Overview

C3 camera head is designed to be easily used with a set of accessories to fulfil various observing needs. Camera head itself is manufactured in several variants.

First, there are variants differing in the cooling performance:

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

Second, there are variants differing if filter wheel control:

- 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.

Figure 1: C3 Camera without filter wheel (left), with Internal filter wheel (middle-left), with “M” size External filter wheel (middle-right), and with “L” size External filter wheel (right)

C3 camera model with Internal filter wheel accepts two sizes of filters:

- Filter wheel with 5 positions for unmounted D50 mm (or 2”) filters or filters in 2” threaded cells.

- Filter wheel with 7 positions for unmounted D36 mm filters.

There are three sizes of the External filter wheels, capable to accept various sizes of filters, available for the C3 cameras:

Small “S” size wheel for:

- 5 square 50×50 mm filters
- 7 unmounted filters D50 mm or filters in 2” threaded cells
- 10 unmounted filters D36 mm filters

Medium “M” size wheel for:

- 5 square 50×50 mm filters
- 7 unmounted filters D50 mm or filters in 2” threaded cells
- 10 unmounted filters D36 mm filters.

Large “L” size wheel for

- 7 square 50×50 mm filters
- 9 unmounted D50 mm or filters in 2” threaded cells

Both Internal and External filter wheels with D36 mm filters can be used with C3 camera equipped with APS size sensors. Cameras with “Full-frame” sensors (24×36mm) cannot use such small filters.

Please note the camera head is designed to either accept Internal filter wheel or to be able to connect to the External filter wheel, but not both. If the Internal filter wheel variant is used, External filter wheel cannot be attached.

And third, there are two sizes of adjustable adapters, which can be used with C3 cameras:

- Small “S” adapters, compatible with C2 cameras, are used for e.g. M48×0.75 and M42×0.75 threaded adapters, Nikon bayonet adapter, 2” barrel adapter etc.
- Large “L” adapters, compatible with C4 cameras, intended for large diameter attachments between camera and telescope, e.g.

M68×1 threaded adapter or C3-OAG, which is also equipped with M68×1 thread.

Adjustable adapters are mounted on adapter base when camera with internal filter wheel or camera without any filter wheel is used or directly on the external filter wheel front surface. This means both “S” and “L” adapter bases can be mounted on any camera, external but filter wheels are made for one particular adapter size only:

- “S” external filter wheels are compatible with “S” adapters
- “M” and “L” external filter wheels are compatible with “L” adapters

Note the “S” and “M” filter wheels are of very similar dimensions and hold the same number of the same filters. They differ in the adjustable adapter size only.

C3 Camera System

C3 camera with “S” size adapter

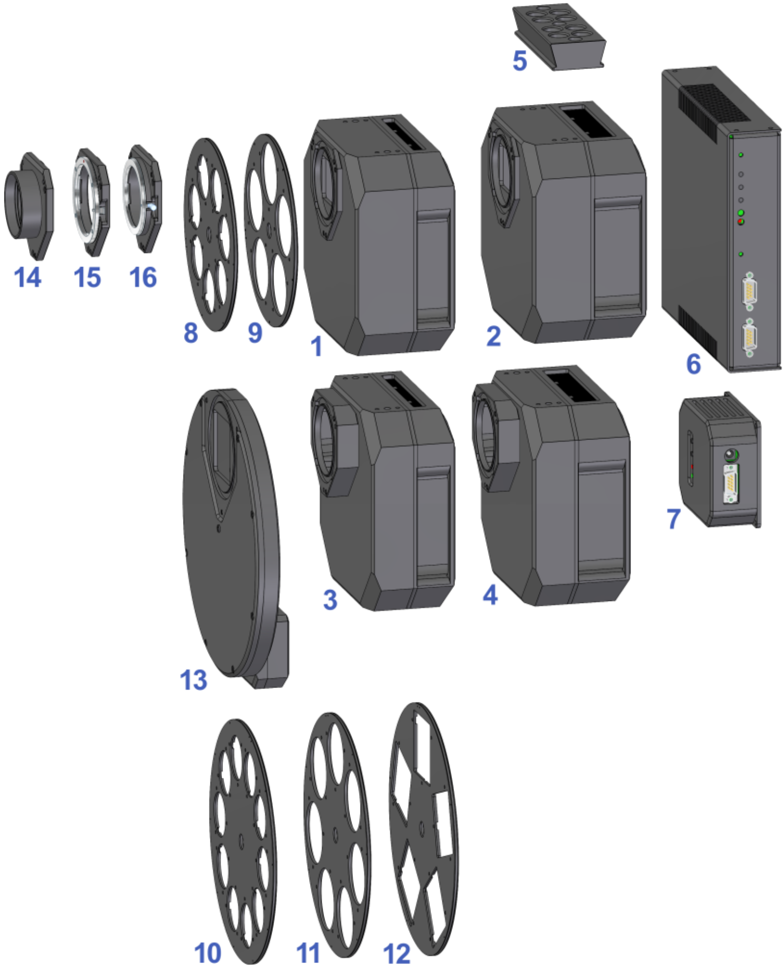


Figure 2: Schematic diagram of C3 camera with “S” size adapter system components

C3 camera with "L" size adapter

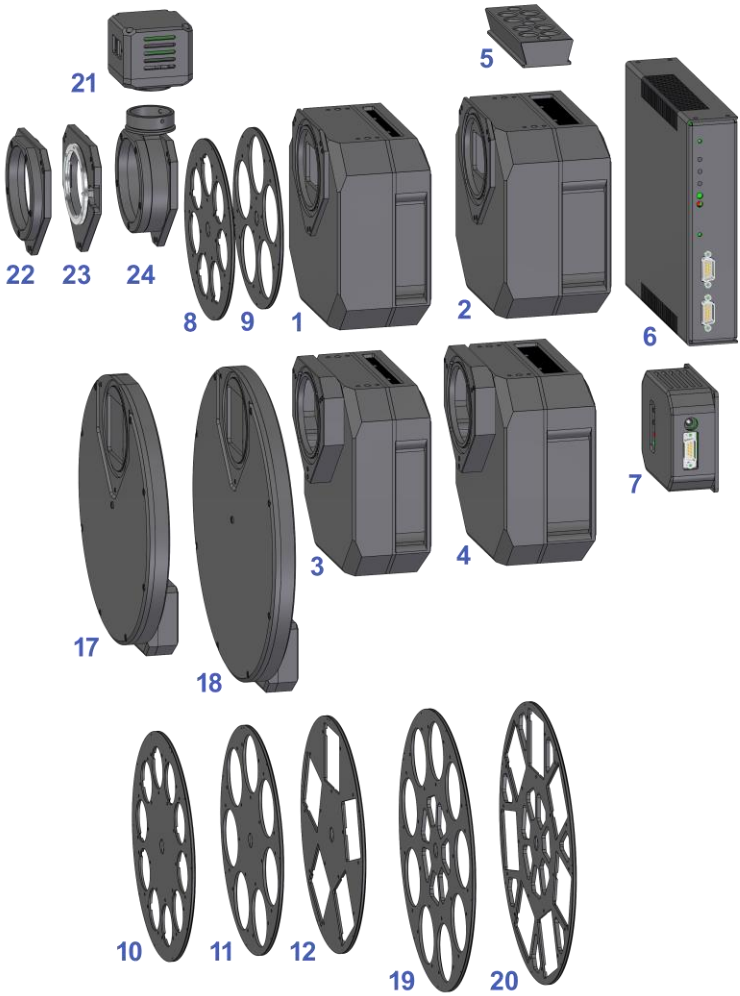


Figure 3: Schematic diagram of C3 camera with "L" size adapter system components

Components of C3 Camera system include:

1. C3 camera head with Internal Filter Wheel
2. C3 camera head with Internal Filter Wheel and Enhanced Cooling
3. C3 camera head capable to control External Filter Wheel
4. C3 camera head capable to control External Filter Wheel with Enhanced Cooling
5. 1.75” dovetail rail for C3 camera head
6. Moravian Camera Ethernet Adapter (x86 CPU)
7. Moravian Camera Ethernet Adapter (ARM CPU)

   The Ethernet Adapter allows connection of up to 4 Cx cameras of any type on the one side and 1 Gbps Ethernet on the other side. This adapter allows access to connected Cx cameras using routable TCP/IP protocol over unlimited distance.

8. 7-positions internal filter wheel for unmounted D36 mm filters
9. 5-positions internal filter wheel for 2”/D50 mm filters
10. 10-positions filter wheel for “S” or “M” housing for D36 mm filters
11. 7-positions filter wheel for “S” or “M” housing for 2”/D50 mm filters
12. 5-positions filter wheel for “S” or “M” housing for 50×50 mm filters
13. External Filter Wheel “S” size (5, 7 or 10 positions)
14. M42×0.75 (T-thread) or M48×0.75 threaded adapters, 55 mm BFD
15. Canon EOS bayonet lens “S” size adapter
16. Nikon bayonet lens “S” size adapter
17. External Filter Wheel “M” size (5, 7 or 10 positions)
18. External Filter Wheel “L” size (7 or 9 positions)
19. 9-positions filter wheel for “L” housing for 2”/D50 mm filters
20. 7-positions filter wheel for “L” housing for 50×50 mm filters
21. C1 auto-guiding camera
22. M68×1 threaded “L” size adapter, 47.5 mm BFD
23. Canon EOS bayonet lens “L” size adapter
24. Off-Axis Guider with M68×1 thread, 61.5 mm BFD

CMOS Sensor and Camera Electronics

C3 cameras are equipped with Sony IMX rolling shutter **back-illuminated** CMOS detectors with 3.76 × 3.76 μm square pixels. Despite the relatively small pixel size, the full-well capacity over 50 ke- rivals the full-well capacity of competing CMOS sensors with much greater pixels and even exceeds the full-well capacity od CCD sensors with comparable pixel size.

The used Sony sensors are equipped with 16-bit ADCs (Analog to Digital Converters). 16-bit digitization ensures enough resolution to completely cover the sensor exceptional dynamic range.

> While the used sensors offer also lower dynamic resolution (12 and 14 bit), C3 cameras do no utilize these modes. Astronomical images always use 2 bytes for a pixel, so lowering the dynamic resolution to 14 or 12 bits brings no advantage beside the slightly faster download. But cooled astronomical cameras are intended for very long exposures and a fraction of second saved on image download is negligible compared to huge benefits of 16-bit digitization.

Both IMX571 (used in C3-26000) and IMX455 (used in C3-61000) sensors are supplied in two variants:

- **Consumer grade sensors.** The sensor manufacturer (Sony Semiconductor Solutions Corporation) limits their usage to consumer digital still cameras only with operation time max. 300 hours per year.
- **Industrial grade sensors**, intended for devices operating 24/7.

All sensor characteristics (resolution, dynamic range, …) are equal, sensors differ only in target applications and usage time. C3 is technically digital still camera, only specialized for astronomy. If it is also “consumer” camera strongly depends on users. Cameras used for causal imaging (when weather permits) only rarely exceeds 300 hours of observing time per year. Cameras permanently installed on observatories, utilizing every clear night and possibly located on mountain sites with lots of clear nights exceed the 300 hours/year within a couple of months. This is why C3 cameras are offered in two variants:

- **C3-26000** and **C3-61000** with consumer grade sensors, intended for max. 300 hours a year operation.
- **C3-26000 PRO** and **C3-61000 PRO** with industrial grade sensors.

Monochrome C3 camera models with consumer-grade sensors:

Model	C3-26000	C3-61000
CMOS sensor	IMX571	IMX455
Sensor grade	Consumer	Consumer
Color mask	None	None
Resolution	6252 × 4176	9576 × 6388
Pixel size	3.76 × 3.76 µm	3.76 × 3.76 µm
Sensor size	23.51 × 15.70 mm	36.01 × 24.02 mm

Monochrome C3 camera models with industrial-grade sensors:

Model	C3-26000 PRO	C3-61000 PRO
CMOS sensor	IMX571	IMX455
Sensor grade	Industrial	Industrial
Color mask	None	None
Resolution	6252 × 4176	9576 × 6388
Pixel size	3.76 × 3.76 µm	3.76 × 3.76 µm
Sensor size	23.51 × 15.70 mm	36.01 × 24.02 mm

Color C3 camera models with consumer-grade sensors:

Model	C3-26000C	C3-61000C
CMOS sensor	IMX571	IMX455
Sensor grade	Consumer	Consumer
Color mask	Bayer RGBG	Bayer RGBG
Resolution	6252 × 4176	9576 × 6388
Pixel size	3.76 × 3.76 µm	3.76 × 3.76 µm
Sensor size	23.51 × 15.70 mm	36.01 × 24.02 mm

Color C3 camera models with industrial-grade sensors:

Model	C3-26000C PRO	C3-61000C PRO
CMOS sensor	IMX571	IMX455
Sensor grade	Industrial	Industrial
Color mask	Bayer RGBG	Bayer RGBG
Resolution	6252 × 4176	9576 × 6388
Pixel size	3.76 × 3.76 µm	3.76 × 3.76 µm
Sensor size	23.51 × 15.70 mm	36.01 × 24.02 mm

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 C3 cameras show very good linearity in response to light. This means the camera can be used for advanced research projects, like the photometry of variable stars and transiting exoplanets etc.

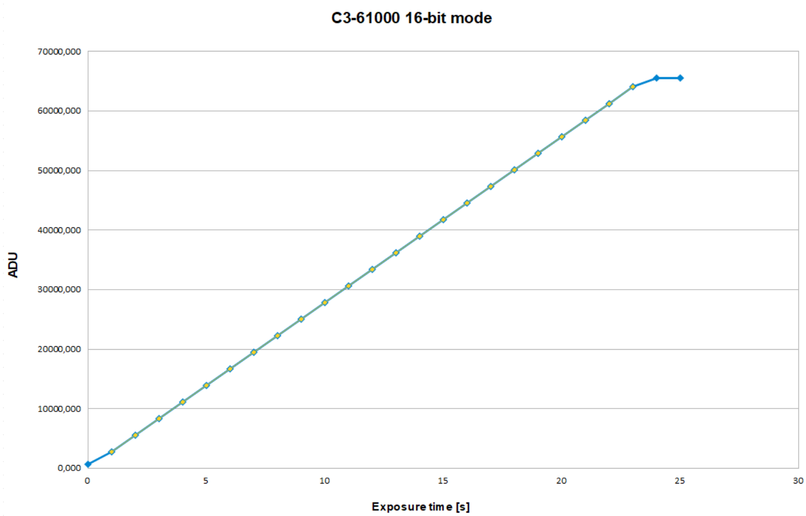


Figure 4: Response of IMX455 sensor in 16-bit mode

Download speed

C3 cameras are equipped with on-board RAM, capable to hold several full-resolution frames. Downloading of the image to the host computer thus does not influence image digitization process, as the download only transfers already digitized images from camera memory.

Time needed to digitize and download single full frame depends on USB connection type.

Camera model	C3-26000	C3-61000
Full-frame, USB 3.0 (5 Gbps)	0.22 s	0.44 s
Full-frame, USB 2.0 (480 Mbps)	1.16 s	2.73 s

If only a sub-frame is read, time needed to digitize and download image is naturally lower. However, the download time is not cut proportionally to number of pixels thanks to some fixed overhead time, independent on the sub-frame dimensions.

Camera model	C3-26000	C3-61000
1024×1024 sub-frame, USB 3.0 (5 Gbps)	0.03 s	0.05 s
1024×1024 sub-frame, USB 2.0 (480 Mbps)	0.06 s	0.06 s

Download times stated above are valid for cameras with firmware version 3.3 and newer. Older firmware download times were approximately 30% longer.

The driver is sometimes forced to read bigger portions of the sensor than the user defined because of a sub-frame position and dimension limitations imposed by the sensor hardware. Sometimes it is even necessary to read a whole sensor.

It is recommended to click the **Adjust Frame** button in the **Frame** tab of the SIPS camera control tool. The selected frame dimensions are then adjusted according to sensor limitations. Adjusted frame is then read from the sensor, without a necessity to read a bigger portions or even whole sensor and crop image in firmware.

C3 camera electronics supports in-camera 2×2 binning. If this binning mode is used, download speed increases because of less amount of data read from camera.

Camera model	C3-26000	C3-61000
Full-frame 2×2 binning, USB 3.0 (5 Gbps)	0.16 s	0.30 s
Full-frame 2×2 binning, USB 2.0 (480 Mbps)	0.29 s	0.69 s

The in-camera binning is supported by firmware version 3.3 and later.

Download speed when using the Moravian Camera Ethernet Adapter depends if the 100 Mbps or 1 Gbps Ethernet is used, if USB 2 or USB 3 is used to connect camera to Ethernet Adapter device, but also depends on the particular network utilization etc.

When the camera is connected to the Ethernet Adapter using USB 3 and 1 Gbps Ethernet is directly connected to the host PC, download time of the C3-61000 full frame is approx. 2.5 s.

Camera gain

Sensors used in C3 cameras offer programmable gain from 0 to 36 dB, which translates to the output signal multiplication from 1× to 63×.

> Note the C3 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.

Camera driver accepts gain as a number in the range 0 to 4030, which corresponds directly to sensor's register value. This number does not represent gain in dB nor in multiply value. However, the driver offers a function, which transforms the gain numerical value to gain expressed in dB as well as multiply. Some selected values are shown in the table:

Gain number	Gain in dB	Gain multiply
0	0.00	1.00×
500	1.13	1.14×
1000	2.43	1.32×
1500	3.96	1.58×
2000	5.82	1.95×
2500	8.19	2.57×
3000	11.46	3.74×
3500	16.75	6.88×
4000	32.69	43.11×
4030	35.99	63.00×

Conversion factors and read noise

Generally, many sensor characteristics depend on the used gain. Also, the used sensors employ two conversion paths. One path offers very low read noise, but cannot utilize full sensor dynamic range. Another conversion path offers maximum pixel capacity, but at the price of higher read noise. The cross point is set to gain 3× (approx. 10dB), where the full well capacity drops from more than 50 ke- to ~17 ke-. The read noise then drops from ~3.2 e- RMS to ~1.5 e- RMS.

Gain number	0	2749	2750	4030[1]
Sensor gain	0.0 dB	9.7 dB	9.7 dB	36 dB
	1×	3×	3×	63×
Full well capacity	52800 e-	17000 e-	17000 e-	800 e-
Conversion factor	0.80 e-/ADU	0.26 e-/ADU	0.26 e-/ADU	0.01 e-/ADU
Read noise	3.51 e- RMS	3.15 e- RMS	1.46 e- RMS	1.28 e- RMS

Sensor dynamic range, defined as full well capacity divided by read noise, is greatest when using gain 0, despite somewhat higher read noise:

- At gain = 0, dynamic range is 52800 / 3.51 = 15043×
- At gain = 2750, dynamic range is 16900 / 1.46 = 11575×

Also, it is worth noting that in reality the noise floor is not always defined by read noise. Unless the camera is used with very narrow narrow-band filter (with FWHM only a few nm) and under very dark sky, the dominant source of noise is the sky glow. When the noise generated by sky glow exceeds approximately 4 e- RMS, extremely low read noise associated with gain set to 2750 or more is not utilized and dynamic range is unnecessarily limited by the lowered full well capacity.

So, which gain settings is the best? This depends on the particular task.

- Gain set to 2750 can be utilized if imaging through narrow-band filter with appropriately short exposures, so the background noise does not exceed the read noise. This is typical for aesthetic astro-photography, where the lowered full well capacity does not negatively influence the result quality.
  But even without narrow-band filters, the extremely low read noise allows stacking of many short exposures without unacceptable increase of the stacked image background noise, caused by accumulation of high read noise of individual exposures.
- Gain set to 0 offers maximum full well capacity and the greatest sensor dynamic range, which is appreciated mainly in research

[1] The 36 dB (63×) gain at register value 4030 is properly implemented only in the firmware version 10.x and later.

applications. Pass-bands of filters used for photometry are relatively wide and dominant source of noise is the sky glow. But also, for RGB images, used for aesthetic astro-photography, higher dynamic range allows longer exposures while the bright portions of the nebulae and galaxies still remain under saturation and thus can be properly processed.

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.

Binning

The camera driver and user's applications offer wide variety of binning modes up to 4×4 pixels as well as all combinations of asymmetrical binning modes 1×2, 1×3, 1×4, 2×4 etc. To allow such flexibility, binning is performed only in the camera driver (software binning) and does not rely on the limited capabilities of the hardware binning.

The negative side of software binning is the same download time like in the case of full-resolution 1×1 mode. For typical astronomy usage, the small fraction of second download time is irrelevant, but for applications sensitive to download time, the hardware 2×2 binning can be useful.

Hardware binning

C3 camera implements 2×2 binning mode in hardware in addition to the normal 1×1 binning.

Hardware binning is supported by camera firmware version 3.3 and later. The Windows SDK supports the hardware binning from version 4.11 and the SIPS software package from version 3.33.

Hardware binning can be turned on and off using the parameter **HWBinning** in the 'cXusb.ini' configuration file, located in the same directory like the 'cXusb.dll' driver DLL file itself.

```
[driver]
HWBinning = true
```

When the **HWBinning** parameter is set to true, the in-camera hardware binning is used and software binning is no longer available. This mode brings faster download time, but also introduces several restrictions:

1. Maximal binning is limited to 2×2, higher binning modes are not available.
2. Asymmetrical binning modes (1×2, 2×1, …) are not allowed.

Despite the number of pixels in the 2×2 binned image is ¼ of the full resolution image, the download time is not four-times lower.

Adding vs. averaging pixels

The traditional meaning of pixel binning implies adding of binned pixels. This originated in CCD sensors, where pixel charges were literally poured together within the sensor horizontal register and/or the output node.

For CMOS sensors with full 16-bit dynamic resolution, the negative side of binning is limiting of the sensor dynamic range, as for instance only ¼ of maximum charge in each of the 2×2 binned pixels leads to saturation of resulting pixel. CCDs eliminated this effect to some extend by increasing of the charge capacity of the output node and also by decreasing of the conversion factor in binned modes. But such possibilities are not available in CMOS detectors.

CMOS sensors with less than 16-bit precision often just add binned pixels to fulfil the available resolution of 16-bit pixels. For instance, camera with 12-bit dynamic range can sum up to 4×4 pixels and still the resulting binned pixels will not overflow the 16-bit range.

In theory, the resulting S/N ratio of binned pixel remains the same regardless if we add or average them. Let us take for example 2×2 binning:

- If we add 4 pixels, signal increases 4-times and noise increases 2-times – three additive operations increase noise by $\sqrt{(\sqrt{2})^2 + (\sqrt{2})^2}$. Resulting S/N increases 2-times, but only until the sum of all pixels is lower than the pixel capacity.

- If we average 4 pixels, signal remains the same but the noise is lowered to ½ as noise is averaged $\frac{\sqrt{(\sqrt{2})^2+(\sqrt{2})^2}}{4}$. Resulting S/N also increases 2-times, but only until the noise decreases to lowest possible 1-bit of dynamic range.

As the C3 camera read noise in the maximum dynamic range (gain 0) is around 3.5 ADU, halving it in 2×2 binning mode still keeps the read noise above the lower 1-bit limit and at the same time binned pixel will not saturate. For higher binning modes, the noise approaches lower limit, but averaging pixels still protects from pixel saturation, which is more important than limiting of S/N.

If we consider that the image background noise is only rarely defined by the read noise of the sensor, as the noise caused by background sky glow is typically much higher, for 16-bit camera averaging pixels is definitely the better way to bin pixels compared to just adding them. This is why both software and hardware binning modes in the C3 cameras are by default implemented as averaging of pixels, not summing.

However, both software and hardware binning modes can be switched to sum binned pixels instead of average them by the **BinningSum** parameter in the 'cXusb.ini' configuration file:

```
[driver]
BinningSum = true
```

Let's note there is one more possibility to bin pixels – in the application software. This time binning is not performed in camera hardware nor in the camera driver. Full resolution 1×1 image is downloaded from the camera and software itself then performs binning. The SIPS software adds pixels instead of averaging them, but at the same time SIPS converts images from 16-bit to 32-bit dynamic range. This means S/N of the binned images always increases, pixels never saturate and read noise never approaches lower limit. The negative side of this option is two-time bigger images.

Binning in photometry

Saturated pixels within bright stars are no issue for aesthetic astro-photography, but photometry measurement is invalid if any pixel within the measured object reaches maximum value, because it is not possible to determine the amount of lost flux. Software performing photometry (e.g. the SIPS Photometry tool) should detect saturation value and invalidate entire photometric point not to introduce errors.

But binning efficiently obliterates the fact that any of the binned pixels saturated (with the exception of all binned pixels reached saturation value). So, using of binning modes for research applications (photometry and astrometry) can lead to errors caused by lost flux in saturated pixels, which cannot be detected by the processing software due to binning.

This is why the behavior of both software and hardware binning modes is user-configurable through the **BinningSaturate** parameter in the ‘cXusb.ini’ configuration file:

```
[driver]
BinningSaturate = true
```

If the **BinningSaturate** parameter is set to true, resulting binned pixel is set to saturation value if any of the source pixels is saturated. For aesthetic astro-photography, keeping this parameter false could result into slightly better representation of bright star images, but for research applications, this parameter should always be set to true.

Note the **BinningSum** and **BinningSaturate** parameters have any effect if the camera firmware version is 5.5 or later. Prior firmware versions just averaged binned pixels and the pixel saturation was not taken into account when hardware (in camera) binning was used.

The earlier camera drivers, performing software binning, also used pixel averaging for binning, but handled the saturated pixels like the **BinningSaturate** parameter is true.

Both above mentioned configuration parameters require at least the software/drivers version:

- SIPS version 3.33

- Moravian Camera SDK version 4.11
- ASCOM drivers version 5.13
- Linux INDI drivers version 1.9-2
- Linux libraries version 0.7.1
- macOS libraries version 0.6.1
- TheSkyX Windows/Linux/macOS version 3.4
- AstroArt drivers version 4.3

If the camera is used through the Moravian Camera Ethernet Adapter, it’s firmware must be updated to version 53 or newer.

Exposure control

The shortest theoretical exposure time of the C3 cameras depends on the used sensor type:

- C3-26000 shortest exposure is 139 µs
- C3-61000 shortest exposure is 156 µs

However, such short exposures have no practical application, especially in astronomy. The camera firmware rounds exposure time to a multiply of 100 µs intervals, so in reality the shortest exposure time of both camera models is 200 µs.

> Note the individual lines are not exposed at the same time, regardless of how short the exposure is, because of the rolling-shutter nature of the used sensors. The difference between the first and last line exposure start time is 0.15 s for the C3-26000 and 0.25 s for the C3-61000.

There is no theoretical limit on maximal exposure length, but in reality, the longest exposures are limited by saturation of the sensor either by incoming light or by dark current (see the following chapter about sensor cooling).

> Please note the short exposure timing is properly handled in the camera firmware version 6.7 and later.

Mechanical shutter

C3 cameras are equipped with mechanical shutter, which is very important feature allowing unattended observations (fully robotic or just remote setups). Without mechanical shutter, it is not possible to automatically acquire dark frames, necessary for proper image calibration etc.

Mechanical shutter in the C3 cameras is designed to be as reliable as possible, number of open/close cycles is virtually unlimited, because there are no surfaces rubbing against each other. The price for high reliability is slow shutter motion. Luckily, mechanical shuttering is not necessary for exposure control, only for taking dark frames and possibly bias frames — all used CMOS sensors are equipped with electronic shuttering.

Camera firmware optimizes the shutter operation to avoid unnecessary movements. If a series of light images is taken immediately one after another, the shutter remains open not to introduce quite significant delay of the close/open cycle between each pair of subsequent light images. In the case next image has to be dark or bias frame, shutter closes prior to dark frame exposure and vice versa — shutter remains closed if a series of dark frames is acquired and opens only prior to next light frame. If no exposure is taken for a few seconds while the shutter is open (this means after a light image exposure), camera firmware closes the shutter to cover the sensor from incoming light.

GPS exposure timing

C3 cameras can be equipped with GPS receiver module (see the Optional Accessories chapter). The primary purpose of the GPS receiver is to provide precise times of exposures taken with the camera, which is required by applications dealing with astrometry of fast-moving objects (fast moving asteroids, satellites, and space debris on Earth orbit, …).

The GPS module needs to locate at least 5 satellites to provide exposure timing information. Geographic data are available if only 3 satellites are visible, but especially the mean sea level precision suffers if less than 4 satellites are used.

The camera SDK provides functions, allowing users to access precision exposure times as well as geographics location. The SIPS software package main imaging camera control tool window contains the GPS tab, which shows the state of the GPS fix.

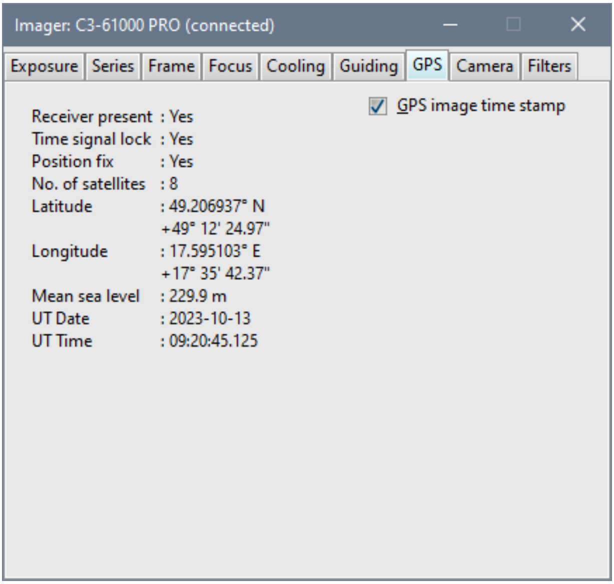


Figure 5: SIPS offers GUI to determine the state the GPS receiver

Determination of exact exposure time is quite complicated because of the rolling-shutter nature of the used sensors. Camera driver does all the calculations and returns the time of the start of exposure of the first line of the image. Still, users interested in precise exposure timing need to include several corrections into their calculations:

1. Individual image lines are exposed sequentially. The time difference between start of exposure of two subsequent lines is fixed for every sensor type:
    i. C3-26000 line exposure takes 34.667 µs
    ii. C3-61000 line exposure takes 39.028 µs
2. If the image is binned, single line of resulting image contains signal from multiple added (or averaged) lines, each with different exposure time start. The exposure start of individual lines of the binned images differs by the single line time difference, multiplied by the vertical binning factor.

3. If only a sub-frame is read, it must be considered that the sensor imposes some restrictions to the sub-frame coordinates. If the required sub-frame coordinates violate the sensor-imposed rules, camera driver enlarges the sub-frame region to fully contain desired sub-frame and then crops it by software. The provided start exposure time then concerns the first line actually read from the camera, not the first line of the resulting (software cropped) image.
   For instance, the y-coordinate of the sub-frame must not be lower than 15 lines. If a sub-frame with lower y-coordinate is asked by the user, whole frame is read and cropped by software.
   Note the camera SDK offers function **AdjustSubFrame**, which returns the smallest sub-frame, fully containing the requested sub-frame, but also fulfilling the sensor-imposed sub-frame coordinate restriction. If adjusted sub-frame is read, no software cropping occurs and image exposure time concerns the first line of the image. The SIPS software offers the “Adjust Frame” button, which adjusts defined sub-frame.

Please note the precise exposure timing is properly handled in the camera firmware version 7.10 and later.

Always use the latest camera drivers (ASCOM or Camera SDK DLLs in Windows, INDI or libraries in Linux) available on the web. Also, always update the firmware in the Moravian Camera Ethernet Adapter if the camera is connected over Ethernet.

Cooling and power supply

Regulated thermoelectric cooling is capable to cool down the CMOS sensor from 40 to 45 °C below ambient temperature, depending on the camera type. The Peltier hot side is cooled by fans. The sensor 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.

C3 cameras are available in two variants, differing in the cooling performance:

- **Standard cooling** cameras achieve regulated temperature difference up to 40 °C below environment temperature.
- **Enhanced cooling** cameras can regulate temperature up to 45 °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 6: Standard cooling camera (left) and Enhanced cooling model (right) with thicker back shell containing greater heat sink

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.

Sensor cooling	Thermoelectric (Peltier modules)
Standard cooling ΔT	40 °C below ambient maximum
	35 °C below ambient typical
Enhanced cooling ΔT	45 °C below ambient maximum
	40 °C below ambient typical
Regulation precision	±0.1 °C
Hot side cooling	Forced air cooling (two fans)
	Optional liquid coolant heat exchanger

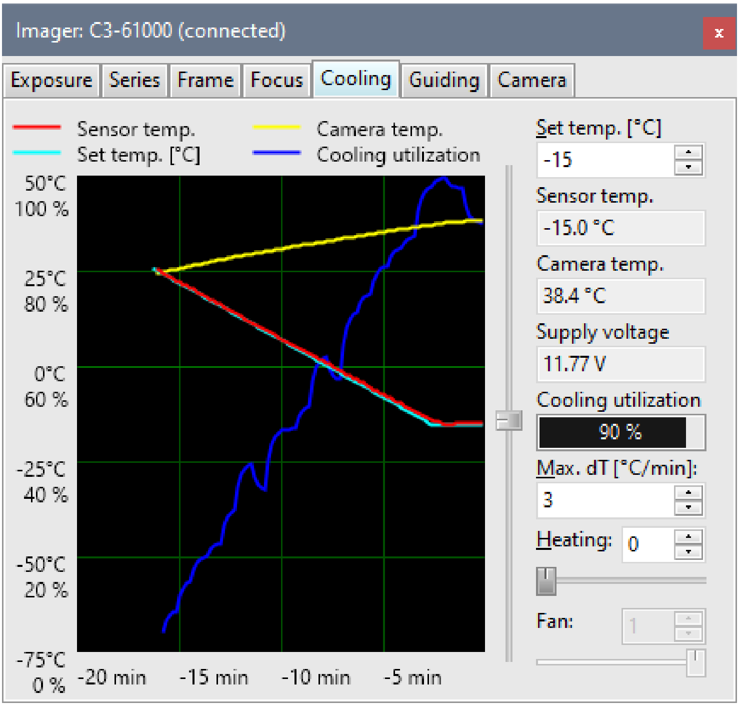


Figure 7: Standard cooling C3-16000 camera reaching -40°C sensor temperature below ambient temperature

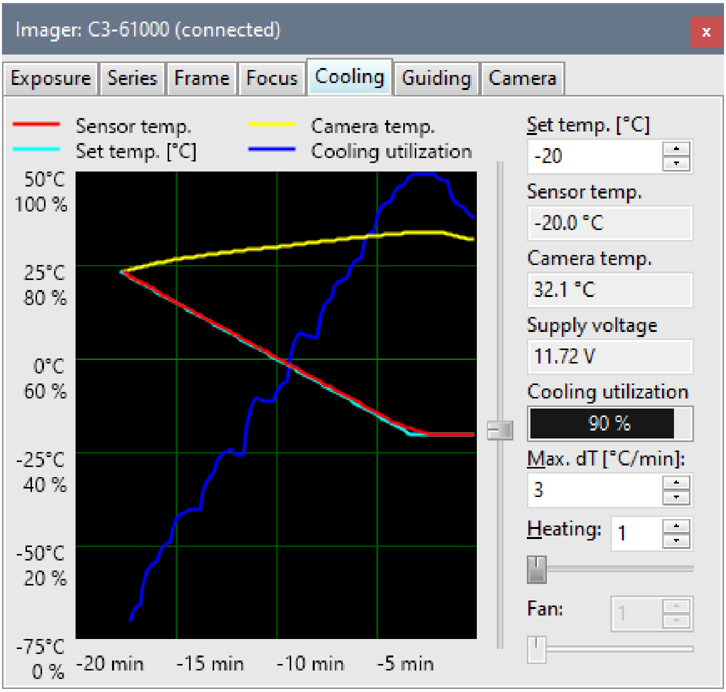


Figure 8: Enhanced cooling C3-16000EC camera reaching -45°C sensor temperature below ambient temperature

Maximum temperature difference between sensor 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 sensor temperature when the ambient temperature rises. Typical temperature drop can be achieved with cooling running at approx. 90% power, which provides enough room for regulation.

Overheating protection

The C3 cameras are equipped with an overheating protection in their firmware. This protection is designed to prevent the Peltier hot side to reach temperatures above ~50°C – sensor cooling is turned off to stop heat generation by the hot side of the Peltier TEC modules.

Please note the overheating protection uses immediate temperature measurement, while the value of camera temperature, presented to the user, shows temperature averaged over a longer period. So, overheating protection may be engaged even before the displayed camera temperature reaches 50°C.

Turning the overheating protection on results in a drop in cooling power, a decrease in the internal temperature of the camera and an increase in the temperature of the sensor. However, when the camera cools its internals down below the limit, cooling is turned on again. If the environment temperature is still high, camera internal temperature rises above the limit an overheating protection becomes active again.

Please note this behavior may be mistaken for camera malfunction, but it is only necessary to operate the camera in the colder environment or to lower the desired sensor delta T to lower the amount of heat generated by the Peltier modules.

The overheating protection is virtually never activated during real observing sessions, even if the environment temperature at night reaches 25°C or more, because camera internal temperature does not reach the limit. But if the camera is operated indoors in hot climate, overheating protection may be activated.

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 50 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 you use own power source.

Camera head supply	12 V DC
Camera head power consumption	<8 W without cooling
	47 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

Power consumption is measured on the 12 V DC side. Power consumption on the AC side of the supplied AC/DC power brick is higher.

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.

C3 camera measures its input voltage and provides it to the control software. Input voltage is displayed in the Cooling tab of the Imaging Camera tool in SIPS. This feature is important especially if you power the camera from batteries.

Figure 9:Figure 8: 12 V DC/5 A power supply adapter for the C3 camera

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 automatic dark frame exposures, which are necessary for unattended, robotic setups.

Internal mechanical shutter	Yes, blade shutter
Standard cooling head dimensions	154×154×65 mm (without filters)
	154×154×77.5 mm (internal wheel)
Enhanced cooling head dimensions	154×154×76 mm (without filters)
	154×154×88.5 mm (internal wheel)
Standard cooling weight	1.6 kg (without filter wheel)
	1.9 kg (with Internal filter wheel)
	2.5 kg (with “S” External 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)
	2.1 kg (with Internal filter wheel)
	2.7 kg (with “S” External filter wheel)
	2.7 kg (with “M” External filter wheel)
	3.0 kg (with “L” External filter wheel)

Camera front view

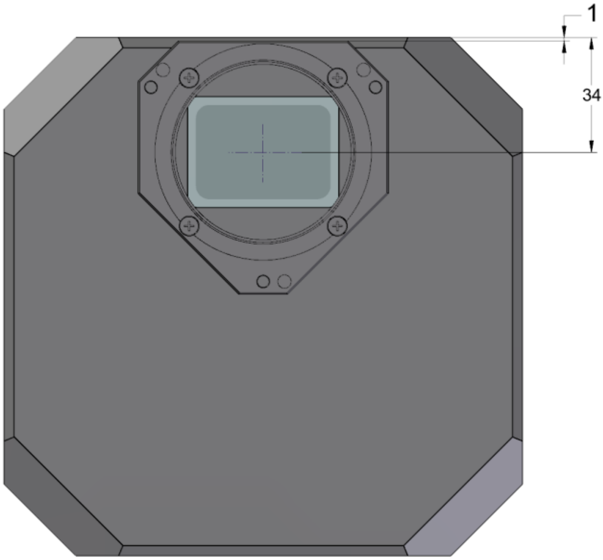


Figure 10: C3 camera head front view dimensions

Camera without filter Wheel

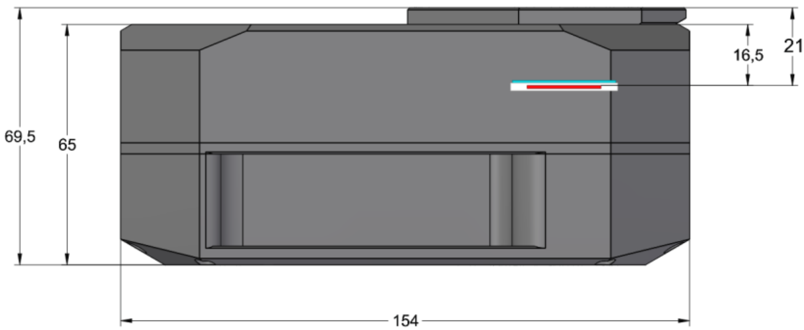


Figure 11: C3 camera head side view dimensions

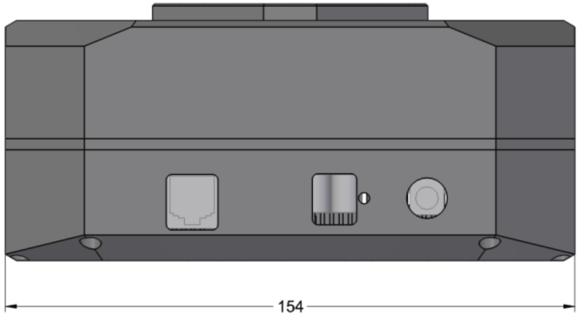


Figure 12: C3 camera head bottom view dimensions

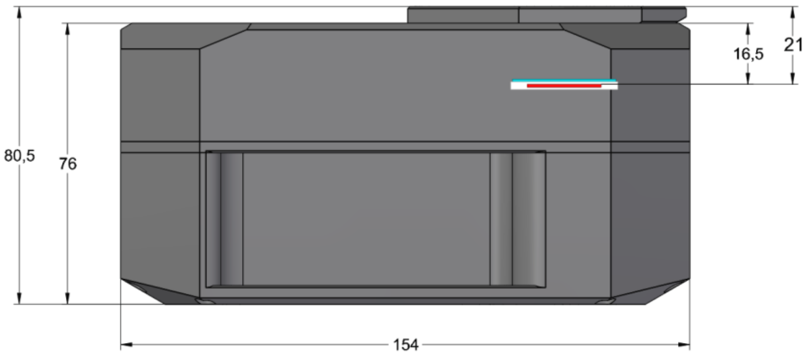


Figure 13 C3 camera head with Enhanced Cooling side view dimensions

Camera with Internal Filter Wheel

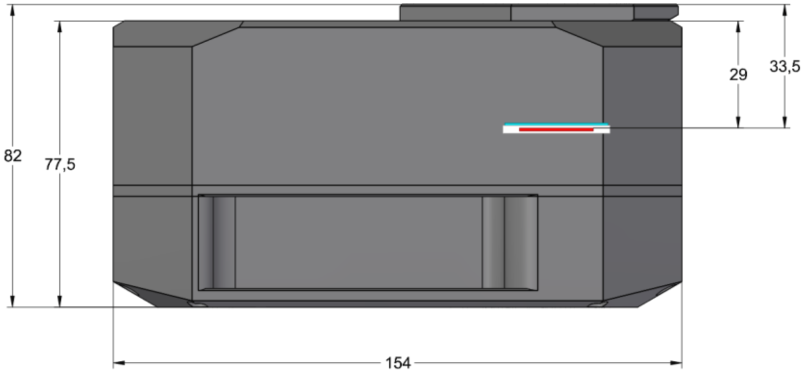


Figure 14: C3 camera head with Internal Filter Wheel side view dimensions

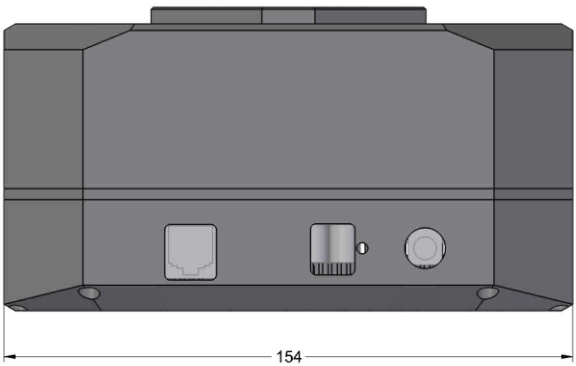


Figure 15: C3 camera head with Internal filter wheel bottom view dimensions

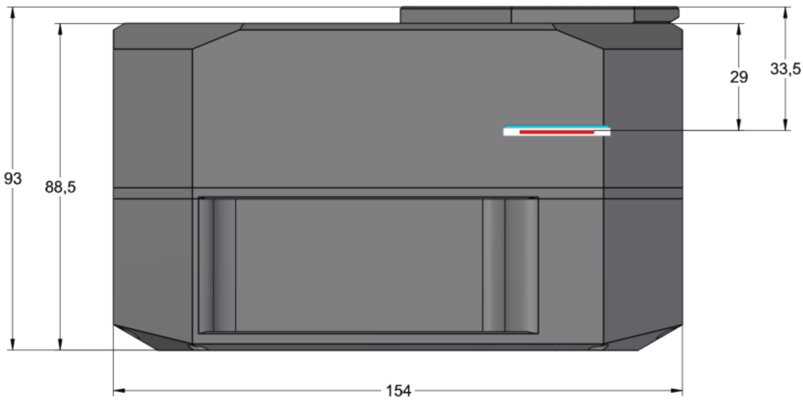


Figure 16: C3 camera head with Enhanced Cooling and Internal Filter Wheel side view dimensions

Camera with "S" External Filter Wheel

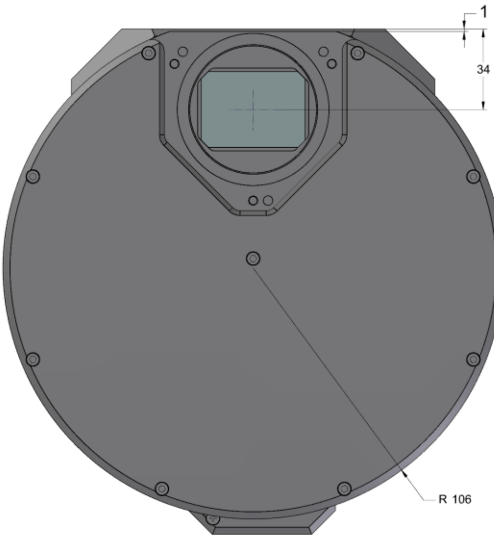


Figure 17: C3 camera head with External filter wheel front view dimensions

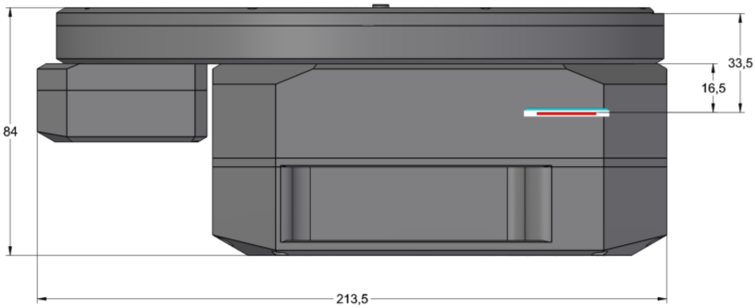


Figure 18: C3 camera head with External filter wheel side view dimensions

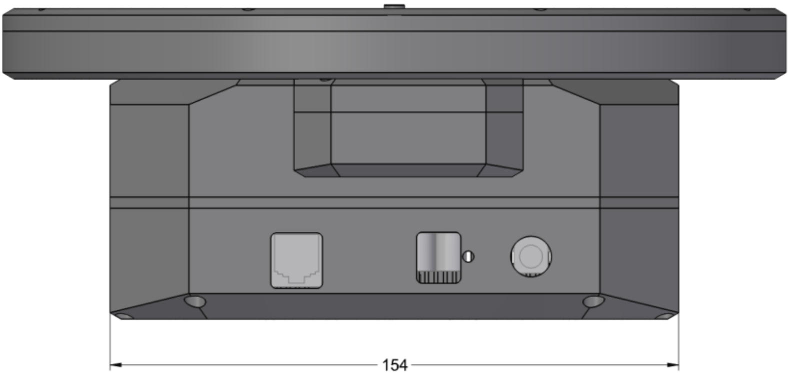


Figure 19: C3 camera head with External filter wheel bottom view dimensions

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

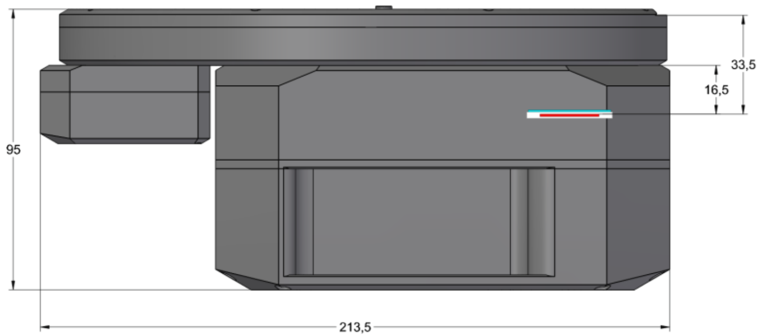


Figure 20: C3 camera head with Enhanced cooling and External filter wheel side view dimensions

Back focal distance

The stated back focal distances (BFD) include corrections for all optical elements in the light path (cold chamber optical window, sensor cover glass, ...), fixed in the camera body. So, stated values are not mechanical, but optical back focal distances. However, no corrections for filters are included, as the thicknesses of various filters are very different.

C3 cameras are manufactured in many variants and can be connected with various accessories, which leads to many possible back focal distance values.

There are two groups of the telescope and lens adapters, differing in back focal distance definition:

- Adapters **without strictly defined BFD**. These adapters are designed to provide as low BFD as possible.
- Adapter **with defined BFD**. These adapters are typically intended for optical correctors (field flatteners, coma correctors, ...) and also for photographic lenses. Keeping the defined BFD is necessary to ensure proper functionality of correctors or to be able to achieve focus with photographic lenses.

Adapters without back focal distance defined

Most commonly used adapters without strictly prescribed back focal distance are M48 × 0.75 thread for C3 cameras with the "S" adapter base or the "S" sized External Filter Wheel and M68 × 1 thread for C3 cameras with the "L" adapter base or the "M" and "L" sized External Filter Wheel.

Let us note the M48 × 0.75 threaded adapter is sometimes used with 55 mm BFD, e.g. when used with optical correctors. This is why two models of this adapters are available — "short" variant with as low BFD as possible and "long" variant, which preserves the 55 mm BFD.

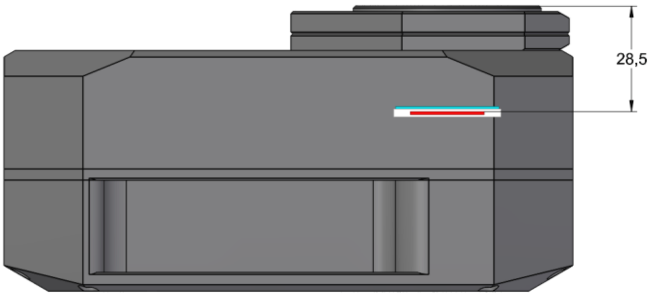


Figure 21: C3 camera with "S" adapter base back focal distances with short M48 × 0.75 adapter

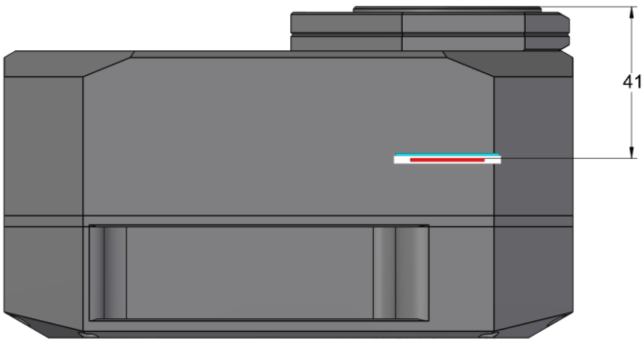


Figure 22: C3 camera with Internal Filter Wheel and "S" adapter base back focal distances with short M48 × 0.75 adapter

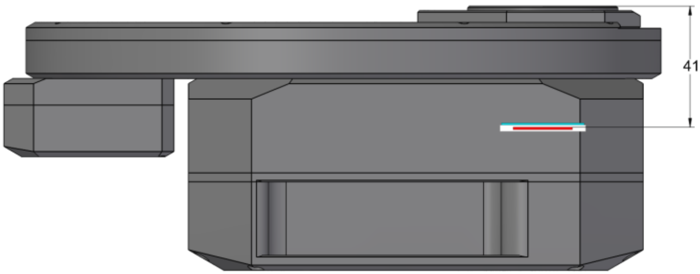


Figure 23: C3 camera with “S” External Filter Wheel back focal distances with short M48 × 0.75 adapter

There are two variants of the M68 × 1 adapter. The version 1 consists of two parts (the base and the M68 threaded ring attached with 5 screws) and thus its total height is greater.

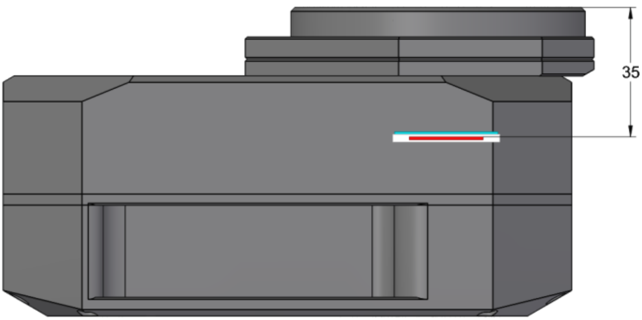


Figure 24: C3 camera with “L” adapter base back focal distances with M68 × 1 version 1 adapter

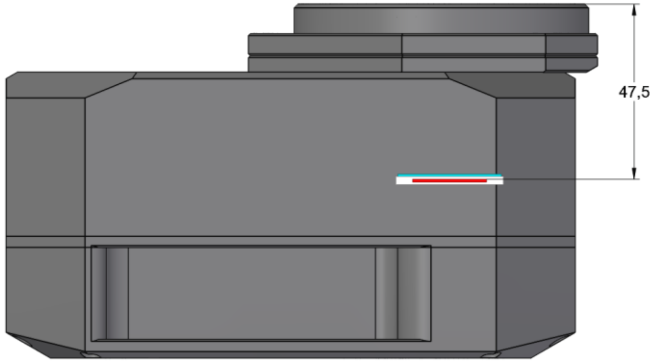


Figure 25: C3 camera with Internal Filter Wheel and “L” adapter base back focal distances with M68 × 1 version 1 adapter

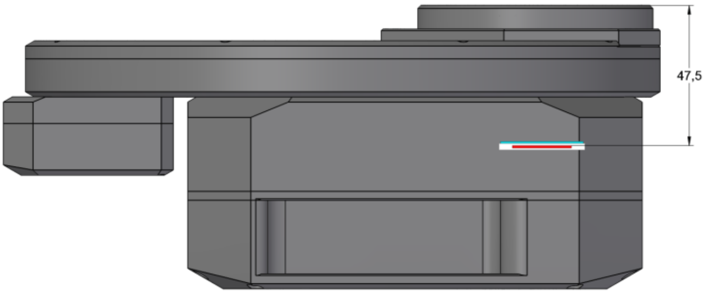


Figure 26: C3 camera with “M” External Filter Wheel back focal distances with M68 × 1 version 1 adapter

The newer M68 × 1 adapter version 2 is machined from one piece and its total height is the same like the M48 adapter and also the resulting BFD is the same.

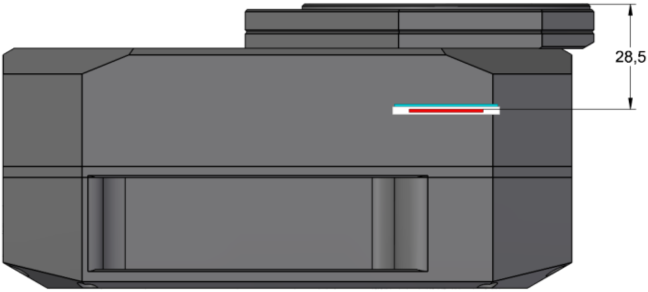


Figure 27: C3 camera with "L" adapter base back focal distances with M68 × 1 version 2 adapter

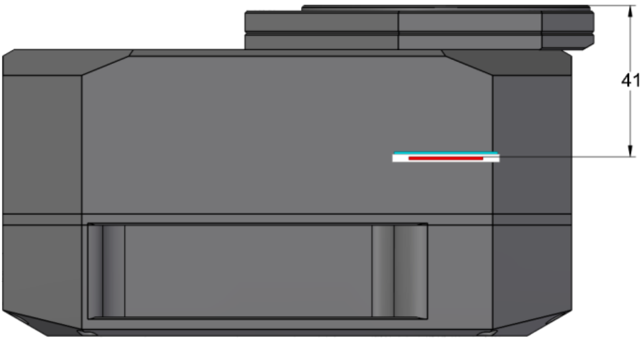


Figure 28: C3 camera with Internal Filter Wheel and "L" adapter base back focal distances with M68 × 1 version 2 adapter

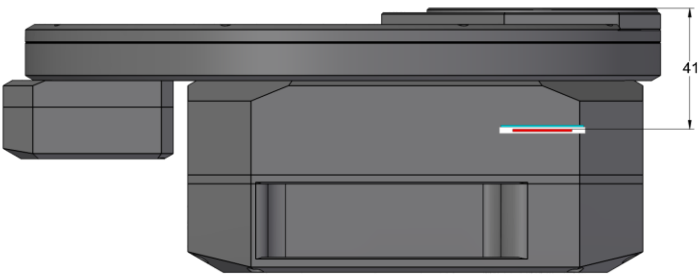


Figure 29: C3 camera with "M" External Filter Wheel back focal distances with M68 × 1 version 2 adapter

Adapters with defined back focal distance

There are three basic variants of C3 camera, differing with back focal distance of the camera head front shell — camera without internal filter wheel, with Internal Filter Wheel with External Filter Wheel. But adapters preserving back focal distance are always designed with the same thickness. Their dimension counts with the BFD of the tiltable adapter base 33.5 mm, which corresponds with BFD of the camera with External Filter Wheel.

However, adapters not mounted on the External Filter Wheel tiltable base must be mounted on standalone tiltable adapter base attached to the camera head. Such adapter base is designed to provide exactly the same 33.5 mm BFD when mounted on camera with Internal Filter Wheel.

If a camera without filter wheel is to be used with adapter preserving the defined BFD, it is necessary to use a thick tiltable adapter base, which also provides the 33.5 mm BFD. Thickness of this adapter base equals the thickness of the External Filter Wheel shell.

The following illustrations show variants with Canon EOS bayonet adapters, preserving 44 mm BFD in all three cases. Similar situations are with Nikon bayonet or M48 × 0.75 threaded adapter with 55 mm BFD.

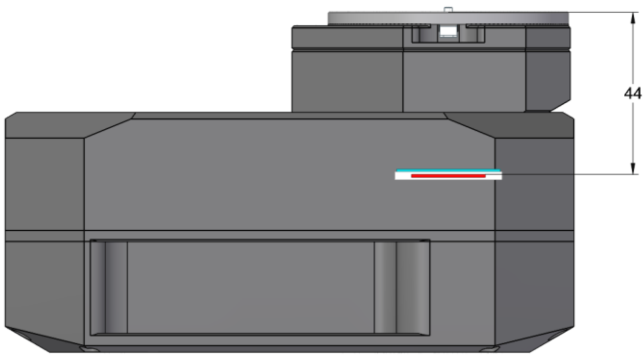


Figure 30: C3 camera without filter wheel, the Canon EOS adapter is on the thick adapter base to preserve defined BFD (the thick adapter base adds the same BFD like the External filter wheel)

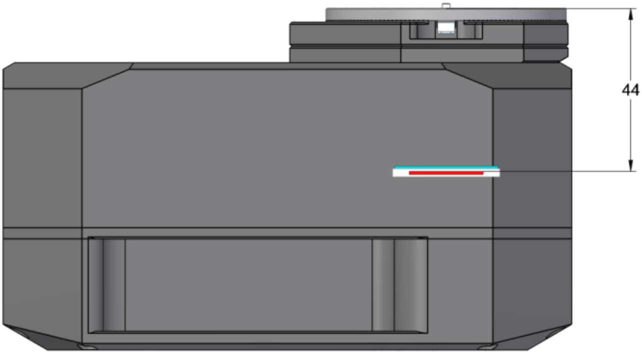


Figure 31: C3 camera with Internal filter wheel, the Canon EOS adapter is on the thin adapter base to preserve defined BFD

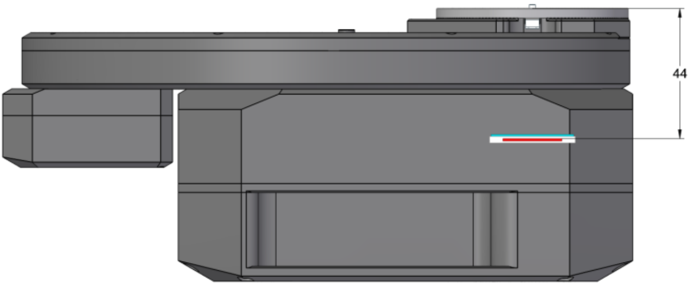
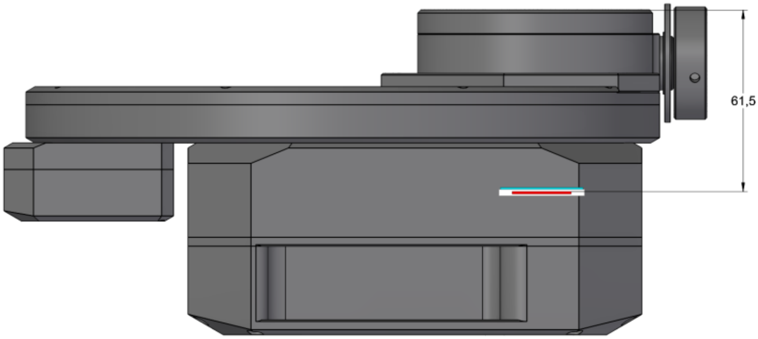


Figure 32: C3 camera with External filter wheel, the Canon EOS adapter is attached to adapter base on the External filter wheel

Off-Axis Guider Adapter

The OAG for C3 cameras use M68×1 threaded adapter with 61.5 mm back focal distance.



Please note when the OAG has to be used with a camera without filter wheel, it is necessary to use a thick adapter base of the same thickness like the External filter wheel to keep the distance from OAG to sensor constant. Otherwise, the guiding camera cannot reach focus.

Optional accessories

Various accessories are offered with C3 cameras to enhance functionality and help camera integration into imaging setups.

Telescope adapters

Various telescope and lens adapters for the C3 cameras are offered. Users can choose any adapter according to their needs and other adapters can be ordered separately.

Adjustable telescope/lens adapters are attached slightly differently depending if the External filter wheel is used or not:

- If no External filter wheel is used, C3 adapters are not mounted directly on the camera head. Instead, a tilting adapter base, holding the circular spring, is always used.
- 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.

C3 cameras are offered with two sizes of adjustable adapter base:

- Small “S” adapters (also used with C2 cameras)
- Large “L” adapters (also used with C4 cameras)

Adjustable adapters are mounted on adapter base when camera with internal filter wheel or camera without any filter wheel is used or directly on the external filter wheel front surface. This means both “S” and “L” adapter bases can be mounted on any camera, external but filter wheels are made for one particular adapter size only:

- “S” external filter wheels are compatible with “S” adapters
- “M” and “L” external filter wheels are compatible with “L” adapters

Figure 33: Comparison of the "S" size external filter wheel with "S" adapter (left) and "M" size external filter wheel with "L" adapter (right)

Small “S” size adapters:

- **2-inch barrel** – adapter for standard 2" focusers.
- **T-thread short** – M42×0.75 inner thread adapter.
- **T-thread with 55 mm BFD** – M42×0.75 inner thread adapter, preserves 55 mm back focal distance.
- **M48×0.75 short** – adapter with inner thread M48×0.75.
- **M48×0.75 with 55 mm BFD** – adapter with inner thread M48×0.75, preserves 55 mm back focal distance.
- **Canon EOS bayonet** – standard Canon EOS lens adapter (“S” size”). Adapter preserves 44 mm back focal distance.
- **Nikon F bayonet** – standard Nikon F lens adapter (“S” size”), preserves 46.5 mm back focal distance.

Large “L” size adapters:

- **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.
- **Nikon F bayonet** – standard Nikon F lens adapter (“L” size”), preserves 46.5 mm back focal distance.

Off-Axis Guider Adapter (OAG)

C3 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.

C3-OAG is manufactured with M68×1 thread with the back focal distance 61.5 mm.

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.

> Note the C3-OAG is manufactured for “L” size adapter base, so it is compatible with “M” and “L” external filter wheels only.
>
> While C2-OAG (with M48×0.75 or M42×0.75 inner thread) for “S” size adapter base can be technically mounted to “S” size external filter wheel, the mirror is so close to optical axis, that it partially shields sensors used in C3 cameras and C2-OAG is not recommended for C3-61000 camera.

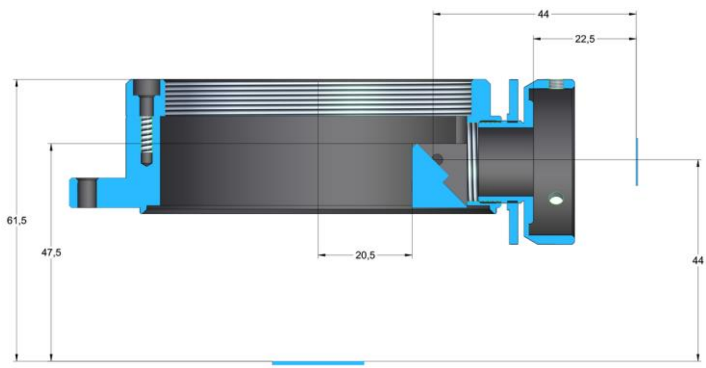


Figure 34: Position of the OAG reflection mirror relative to optical axis

OAG guider port is compatible with C1 cameras with CS-mount adapter. It is necessary to replace the CS/1.25” adapter with short, 10 mm variant in the case of C1 cameras. Because C1 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 C3-OAG.

Figure 35: OAG on C3 camera with Internal filter wheel, attached to thin adapter base

GPS receiver module

The C3 cameras can be equipped with an optional GPS receiver module, which allows very precise timing of the exposure times. Geographic location data are also available to the control software through specific commands.

The used GPS receiver is compatible with GPS, GLONASS, Galileo and BeiDou satellites.

The GPS receiver can be attached to the back side of the camera head. If the GPS module is removed, the GPS port is covered with a flat black cover.

Figure 36: The C3 camera with GPS receiver module with external antenna

> Please note the camera must be equipped with a different back shell as well as internal electronic circuits to be compatible with GPS modules. So, it is necessary to choose GPS-ready variant upon camera ordering. Adding a GPS later requires the camera to be sent to manufacturer.

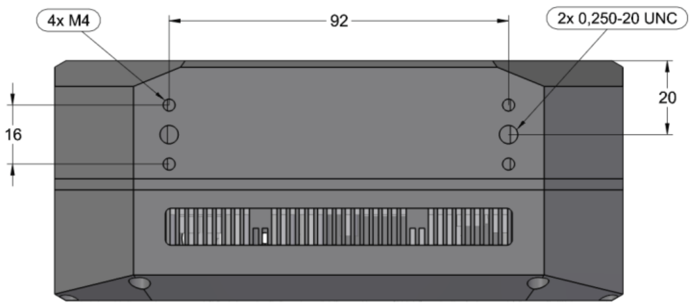
GPS receiver module handling

GPS antenna is shipped with the GPS module. Antenna cable is 3 m long and the antenna is equipped with a magnet, allowing it to be attached to any ferromagnetic surface. Please note the antenna must have a good view to the sky to be able to acquire signal from GPS satellites. Placing the antenna e.g. under metal covered dome may significantly limit the GPS signal reception.

GPS module is handled through camera command set. Its main purpose is to provide very precise timing of the exposure times with µs precision (the GPS module provides time pulses with 30 ns tolerance). Geographic location data are also available to the control software through specific commands.

Attaching camera head to telescope mount

C3 cameras are equipped with two “tripod” 0.250-20UNC threaded holes on the top side of the camera head, as well as four metric M4 threaded holes.



These threaded holes 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 37: 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 38: C3 camera color variants

Moravian Camera Ethernet Adapter

Moravian Camera Ethernet Adapter allows connection of up to 4 Cx cameras of any type on the one side and 1 Gbps Ethernet on the other side. This adapter allows access to connected Cx cameras using routable TCP/IP protocol over practically unlimited distance.

Figure 39: The Moravian Camera Ethernet Adapter with two connected cameras

Adjusting of the telescope adapter

All telescope/lens adapters of the C3 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 40: Releasing of the “pushing” screw

The 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 C3 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 least 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 41: 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 External filter wheel front plate is already designed to hold the spring and it also contains threads to fix respective adapters.
- C3 adapters are not mounted directly on the camera head. Instead, a tilting adapter base, holding the circular spring, is always used.

Figure 42: Off Axis Guider adapter on the adapter base, attached to the C3 camera without External filter wheel (left) and directly on the External filter wheel (right)

Camera Maintenance

The C3 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 C3 camera cooling is designed to be resistant to humidity inside the sensor chamber. When the temperature decreases, the copper cold finger crosses freezing point earlier than the sensor chip itself, so the water vapor inside the sensor 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 sensor 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 sensor chamber itself.

Warning:

High level of moisture inside the sensor cold chamber can cause camera malfunction or even damage to the sensor. Even if the frost does not create on the detector when the sensor is cooled below freezing point, the moisture can be still present. It is necessary to keep the sensor 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 sensor chamber every few months.

It is possible to 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 least one or two hours at temperature between 120 and 140 °C.

The silica-gel used in C3 cameras changes its color according to amount of absorbed water – it is yellow-orange when it is dry and turns to green or transparent without any color hue when it becomes wet, depending on the silica-gel type (manufacturer). It is recommended to shorten replacement interval if the silica-gel is completely green or transparent upon replacement. If it is still yellow-orange, it is possible to prolong the replacement interval.

Figure 43: Silica-gel container is accessible from the camera back side

Exchanging the silica-gel

C3 cameras employ the same desiccant container like the C1+, C1x, C2 and C4 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 sensor 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 44: 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 sensor cold chamber itself. It is intended only to hold possible dust particles from entering the front half of the camera head with the sensor chamber optical window and shutter. 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 45: 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 Filters in the Internal Filter Wheel

It is necessary to open the camera head to change filters or the whole filter wheel.

Opening the camera head

To open the head, unscrew the eight bolts holding camera head together.

Figure 46: Filters can be exchanged after removing of the camera front cover

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!

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

All adapters of the 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 C3 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 47: 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 electronic sensors. So, camera just remains unpowered when wrong polarity or wrong voltage plug is connected.

Still, there is a fuse inside the camera head, adding one more layer of protection. 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 (12 V DC, center + plug), return the camera to the service center for repair.