C2 Series

Astronomical Cameras

User's Guide

Version 1.9

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C2 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.

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Introduction

Thank you for choosing the Moravian Instruments camera. The cooled C2 series 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 G2 Mark II cameras, which makes the C2 series fully compatible with vast range of telescope adapters, off-axis guider adapters, internal or external filter wheels, Camera Ethernet adapters, guiding cameras etc.

Rich software and driver support allows usage of C2 camera without necessity to invest into any 3rd party software package thanks to included free SIPS software package. However, ASCOM (for Windows) and INDI (for Linux) drivers, shipped with the camera, provide the way to integrate C2 camera with broad variety of camera control programs.

The C2 cameras are designed to work in cooperation with a host Personal Computer (PC). As opposite to digital still cameras, which are operated independently on the computer, the scientific slow-scan, cooled cameras usually require computer for operation control, image download, processing, and storage etc. To operate the camera, you need a computer which:

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

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

3. Support for x64 and ARM64 based Apple Mac computers is also included.

   Only certain software packages are currently supported on Mac.

C2 cameras are designed to be attached to host PC through very fast USB 3.0 port. While C2 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 Gx) cameras of any type (not only C2, but also C1, C3 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 while the USB standard allows usage of cable no longer than approx. 5 meters, the TCP/IP communication protocol used to connect the camera over the Ethernet adapter is routable, so the distance between camera setup and the host PC is virtually unlimited.

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

The C2 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. C2 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.

C2 Camera Overview

C2 camera head is designed to be easily used with a set of accessories to fulfil various observing needs. Camera head itself is manufactured in two different variants:

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

Figure 1: C2 Camera without filter wheel (left), with Internal filter wheel (middle) and with attached External filter wheel (right)

C2 camera model with Internal filter wheel accepts two sizes of filters:

- Filter wheel with 5 positions for unmounted D31 mm filters or filters in 1.25" threaded cells.
- Filter wheel with 6 positions for unmounted D26 mm (or 1") filters.

There are two sizes of the External filter wheels, each capable to accept two sizes of filters, available for the C2 cameras:

- Extra small “XS” size wheel for 8 unmounted filters D31 mm or filters in 1.25” threaded cells.
- Extra small “XS” size wheel for 7 unmounted filters D36 mm.
- Small “S” size wheel for 12 unmounted filters D31 mm or filters in 1.25” threaded cells.
- Small “S” size wheel for 10 unmounted filters D36 mm.

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.

C2 cameras are manufactured with a wide range of CMOS sensors. Probably the most important differentiating factor, fundamentally affecting camera operation, is an electronic shutter implemented in the sensors. C2 cameras support sensors with:

- **Global shutter**, allowing capturing of the whole frame in the very same instance of time. This means all pixels are reset and start to capture light simultaneously. Global shutter is particularly suitable for capturing fast moving scenes, because they ensure image does not suffer from motion distortion, caused by rolling shutter sensors. On the other side, frame rate of global shutter sensors is lower compared to rolling shutter ones, because each frame must be fully digitized prior to start of next exposure.
- **Rolling shutter**, which resets individual image rows in a sequence. The exposure of each image row is delayed typically by a few tens of microseconds. Depending on this delay and number of rows, the first and last row exposure time may be shifted by up to several tenths of a second. The inherent feature of rolling shutter sensors is a distortion of fast-moving scenes, when image moves within the time individual rows are exposed. Luckily, such fast moving scenes are very rare in astronomy. The plus side of rolling shutter is much higher FPS, as each image is already exposed while the previous image is digitized.

C2 Camera System

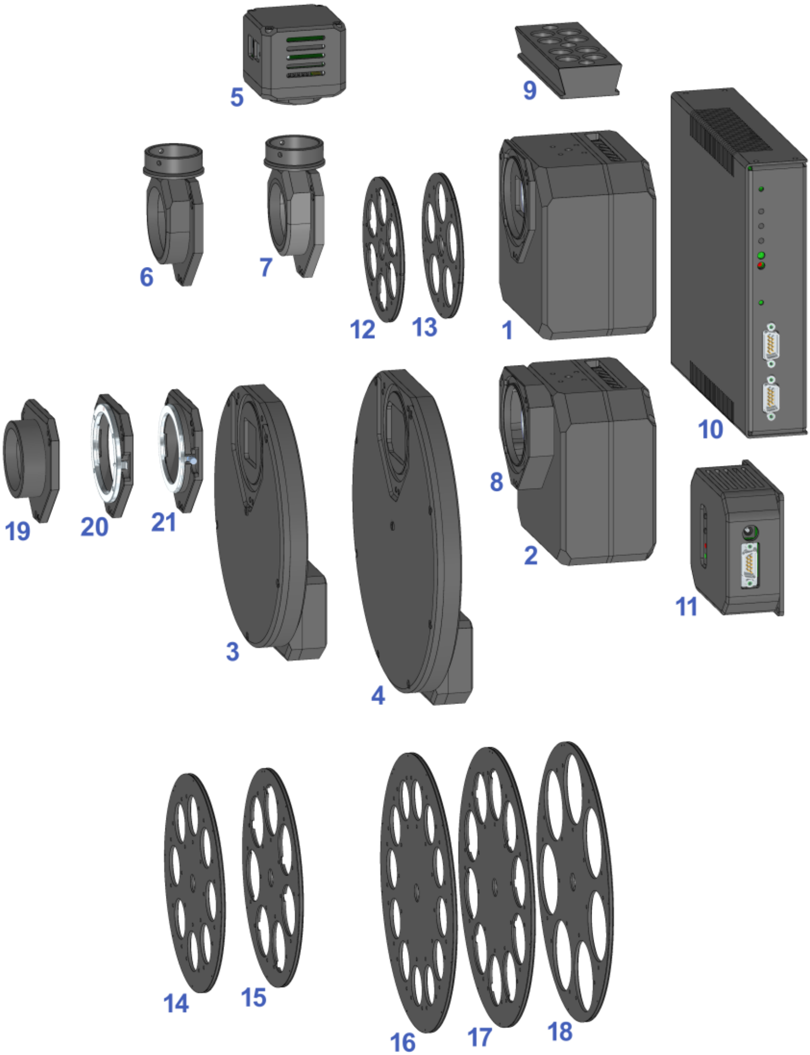

Figure 2: Schematic diagram of C2 camera system components

Components of the C2 Camera system include:

1. C2 camera head with Internal Filter Wheel (5 or 6 positions)
2. C2 camera head capable to control External Filter Wheel
3. External Filter Wheel "XS" size (7 or 8 positions)
4. External Filter Wheel "S" size (10 or 12 positions)
5. C1 guider camera

> C1 cameras are completely independent devices with their own USB connection to the host PC. They can be used either on C2 OAG or on standalone guiding telescope.
>
> C1 camera can share the Moravian Camera Ethernet Adapter with up to 3 other Cx or Gx cameras to be accessed over network.

6. Off-Axis Guider with M48×0.75 thread
7. Off-Axis Guider with M42×0.75 thread (T2)
8. Thick adapter base, compensating EFW thickness to achieve proper back focal distance for cameras without filter wheel
9. 1.75" dovetail rail for C2 camera head
10. Camera Ethernet Adapter (x86 CPU)
11. Camera Ethernet Adapter (ARM CPU)

> 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 unlimited distance.

12. 6-positions internal filter wheel for D27.5 mm filters
13. 5-positions internal filter wheel for 1.25"/D31 mm filters
14. 8-positions external filter wheel "XS" for 1.25"/D31 mm filters
15. 7-positions external filter wheel "XS" for D36 mm filters
16. 12-positions external filter wheel "S" for 1.25"/D31 mm filters
17. 10-positions external filter wheel "S" for D36 mm filters
18. 7-positions external filter wheel "S" for 2"/D50 mm filters
19. M42×0.75 (T-thread) or M48×0.75 threaded adapters, 55 mm BFD
20. Canon EOS bayonet lens adapter
21. Nikon bayonet lens adapter

C2 with global shutter CMOS Sensors

C2 series of CMOS cameras with Sony IMX **global shutter** CMOS detectors have pixel size 3.45 × 3.45 µm or 4.50 × 4.50 µm.

Three lines of C2 cameras with global shutter are available depending on the available dynamic range (bit-depth of the digitized pixels) and pixel size:

- **C2 cameras with Sony IMX sensors with 3.45 × 3.45 µm pixels, 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.
- **C2 cameras with Sony IMX sensors with 3.45 × 3.45 µm pixels, 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 speed 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 “A” cameras may be then very attractive.
- **C2 cameras with Sony IMX sensors with 4.50 × 4.50 µm pixels and 12-bit digitization only.** Greater pixels mean higher dynamic range (more electrons can be stored in each pixel before it saturates), but also higher read noise. Still the theoretical S/N is almost the same because of higher signal camera can accumulate. This camera is more suitable for longer focal length telescopes, where small pixels provide oversampled images, and also for research applications, where dynamic range is important.

C2 camera models with 3.45 × 3.45 µm pixels and 8- and 12-bit digitization:

Model	C2-3000	C2-5000	C2-12000
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

C2 camera models with 3.45 × 3.45 µm pixels and 12-bit digitization only:

Model	C2-3000A	C2-5000A	C2-12000A
CMOS sensor	IMX265	IMX246	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

C2 camera models with 4.50 × 4.50 µm pixels and 12-bit digitization only:

Model	C2-7000A
CMOS sensor	IMX428
Resolution	3216 × 2208
Pixel size	4.50 × 4.50 µm
Sensor size	14.47 × 9.94 mm

Cameras limited to 12-bit read mode are marked with letter A, following the model number. For instance, if C2-3000 marks camera with both 8- and 12-bit read modes, C2-3000A denotes camera model with only 12-bit read mode. All other parameters (sensor size, pixel resolution) are equal.

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 C2 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.

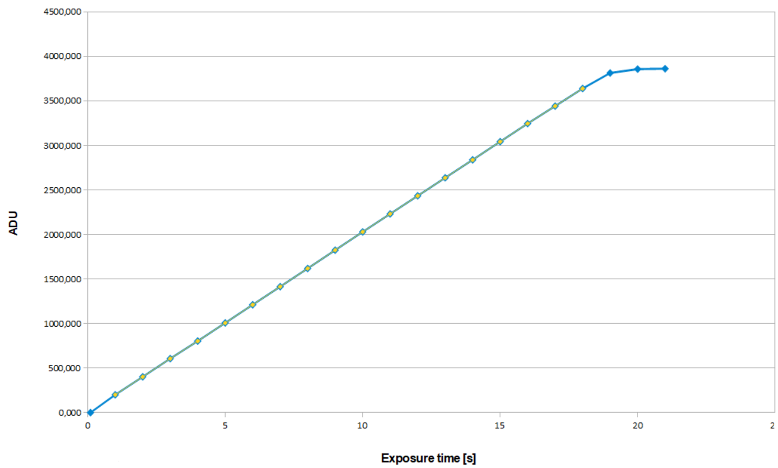

Figure 3: Response of the Sony IMX sensors with 3.45 × 3.45 µm pixels (IMX252)

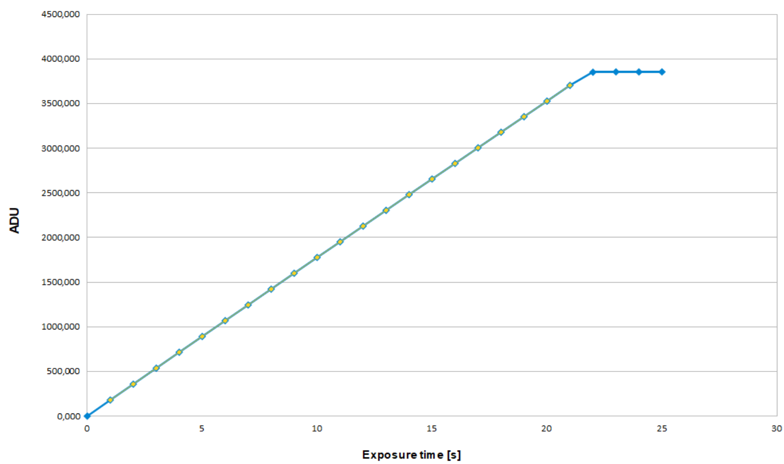

Figure 4: Response of the Sony IMX sensors with 4.50 × 4.50 µm pixels (IMX428)

Download speed

As already noted, there are two lines of C2 camera series, differing in the used sensor. The first series with 3.45 × 3.45 µm pixels 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 C2 cameras with 3.45 × 3.45 µm pixels offers only single read mode:

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

And the “A” version of C2 cameras with 4.50 × 4.50 µm pixels offers also only one read mode:

- **12-bit fast** mode with ~151 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 C2 cameras offer programmable gain from 0 to 24 dB, which translates to the output signal multiplication from 1× to 15.9×. Gain can be set with 0.1 dB step.

Note the C2 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.

Camera/sensor parameters for sensors with 3.45 × 3.45 µm pixels:

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

Camera/sensor parameters for sensors with 4.50 × 4.50 µm pixels:

Digitization	12-bit	12-bit
Sensor gain	0 dB	24 dB
Full well capacity	26000 e-	2100 e-
Conversion factor	6.3 e-/ADU	0.5 e-/ADU
Read noise	5.3 e- RMS	3.9 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

C2 cameras are capable of very short exposures. The shortest exposure time is 125 μs (1/8000 of second). This is also the step, by which the exposure time is expressed. So, the second shortest exposure is 250 μs 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).

Mechanical shutter

C2 cameras are equipped with mechanical shutter, which is an 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 C2 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 subsequent light images. If the next image is a dark or bias frame, shutter closes prior to 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 approx. 5 seconds while the shutter is open, camera firmware closes the shutter to cover the sensor from incoming light.

GPS exposure timing

The C2 cameras with global shutter 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.

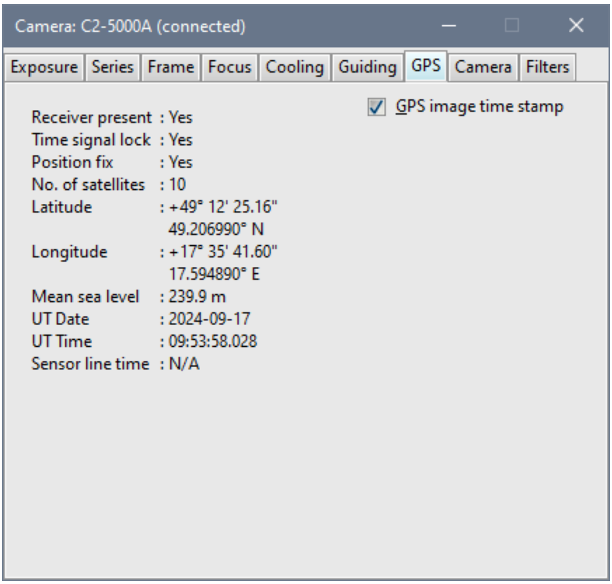

Figure 5: SIPS offers GUI to determine the state the GPS receiver

A huge advantage of the global-shutter CMOS sensors, compared to rolling-shutter ones, is very simple and straightforward way to determine the exact exposure time of every pixel. As opposed to rolling-shutter sensors, all pixels are exposed at exactly the same time, returned by the GPS receiver, and there is no need to calculate with line time and pixel y-coordinate.

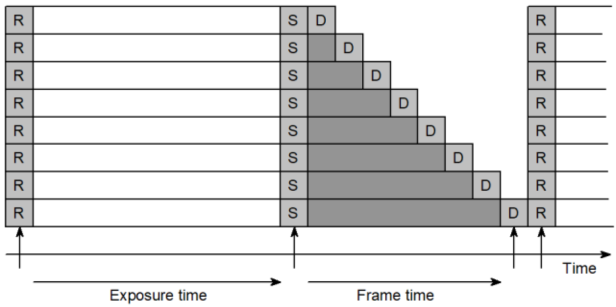

Figure 6: Illustration of the CMOS global shutter operation

Remember to always use the latest version of SIPS or 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.

C2 with rolling shutter CMOS Sensors

C2 series of CMOS cameras with Sony IMX **rolling shutter** CMOS detectors employs sensors of two different sensor families, differing in pixel size and dynamic range:

Model	**C2-9000**	**C2-46000**
CMOS sensor	IMX533	IMX492
Resolution	3008 × 3008	8336 × 5648
Pixel size	3.76 × 3.76 µm	2.315 × 2.315 µm
Digitization	14-bit	12-bit
Sensor size	11.31 × 11.31 mm	19.30 × 13.08 mm

The IMX533 sensor (C2-9000) belongs to the same family like sensors used in the C1×, C3 and C5 camera lines, only the digitization precision is 14-bit instead of 16-bit of the larger sensors.

The IMX492 sensor (C2-46000) offers the smallest pixels of all Moravian camera lines and it is unique for the C2 and C1+ camera lines.

Camera Electronics

Controlling of the rolling shutter sensors differs significantly from controlling of the global shutter sensors. The camera internals differ significantly according to different electronic shutter

The C2 cameras with rolling shutter contain 256 MB of onboard memory, capable to store up to 14 full-resolution frames of the C2-9000 camera or 2 full-resolution frames in the case of C2-46000 camera. Camera API allows for sequential exposures, during which short-exposure images are stored into memory possibly faster than the host computer is able to read them. Sequential exposures are paused when the internal memory is filled with images, not yet read by the host PC. As explained earlier, rolling shutter sensors are capable to perform image exposure while digitizing the previous image.

Sensor linearity

The IMX sensors used in the C2 cameras show very good linearity in response to light. This means C2 cameras can be used for advanced research projects, like the photometry of variable stars and transiting exoplanets etc.

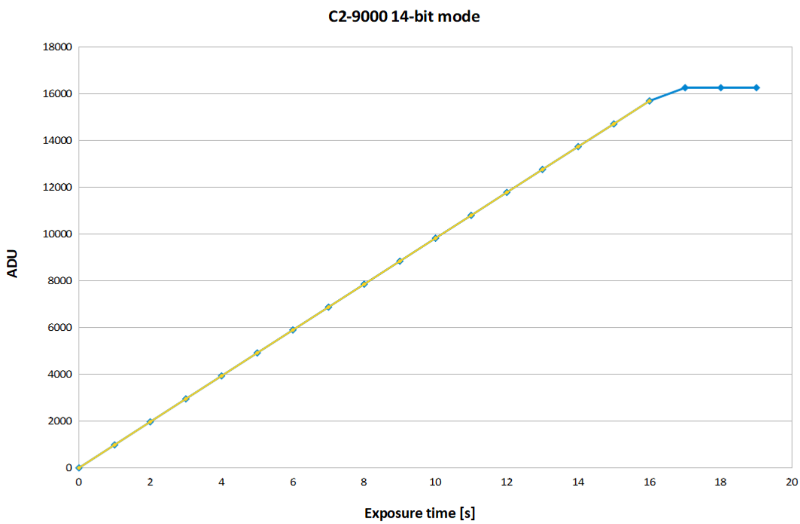

Figure 7: Response of the Sony IMX rolling-shutter sensor (IMX533)

Download speed

Thanks to C2 camera onboard RAM, downloading of the image to the host computer 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 the USB connection type.

Camera model	C2-9000	C2-46000
Full-frame, USB 3.0 (5 Gbps)	0.06 s	0.30 s
Full-frame, USB 2.0 (480 Mbps)	0.40 s	2.06 s

The C2-9000 camera significantly speeds up the download if only a sub-frame is read. However, the download time is not cut proportionally to number of pixels thanks to some fixed overhead time, independent on the sub-frame dimensions.

The download speedup is not as proportional to the downloaded area in the case of C2-46000 camera because of the sensor-imposed limitations, but it is still significant.

Camera model	C2-9000	C2-46000
1024×1024 sub-frame, USB 3.0 (5 Gbps)	0.02 s	0.08 s
1024×1024 sub-frame, USB 2.0 (480 Mbps)	0.05 s	0.14 s

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.

The C2 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	C2-9000	C2-46000
Full-frame 2×2 binning, USB 3.0 (5 Gbps)	0.03 s	0.19 s
Full-frame 2×2 binning, USB 2.0 (480 Mbps)	0.11 s	0.52 s

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 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 C2-9000 full frame is less than 0.5 s.

C2-9000 camera gain

Sensors used in the C2-9000 camera offer programmable gain from 0 to 36 dB, which translates to the output signal multiplication from 1× to 63×.

> Note the C2 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×

C2-46000 camera gain

The C2-46000 camera offers programmable gain from 0 to 16 dB, which translates to the output signal multiplication from 1× to 6.5×.

> Note the C2 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 500. 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×
100	1.61	1.20×
200	3.59	1.51×
300	6.15	2.03×
400	9.81	3.09×
500	16.25	6.49×

C2-9000 conversion factors and read noise

Generally, many sensor characteristics depend on the used gain. Also, the sensor used in C2-9000 employs two conversion paths[1]. 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 e- RMS to ~1.5 e- RMS.

Gain number	0	2749	2750	4030[2]
Sensor gain	0.0 dB	9.7 dB	9.7 dB	36 dB
	1×	3×	3×	63×
Full well capacity	50800 e-	16500 e-	16500 e-	880 e-
Conversion factor	3.10 e-/ADU	1.02 e-/ADU	1.02 e-/ADU	0.054 e-/ADU
Read noise	3.81 e- RMS	3.03 e- RMS	1.55 e- RMS	1.18 e- RMS

[1] The C2-9000 firmware must be updated to version at least 10.x to be able to utilize the High Gain Conversion.

[2] The 36 dB (63×) gain at register value 4030 is properly implemented only in C2-9000 firmware version 12.x and later.

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 50800 / 3.81 = 13333×
- At gain = 2750, dynamic range is 16500 / 1.55 = 10645×

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 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.

C2-46000 conversion factors and read noise

The sensor read noise and full well capacity depend on the used gain.

Gain number	0	500
Sensor gain	0.0 dB	16.25 dB
	1×	6.49×
Full well capacity	18500 e-	2900 e-
Conversion factor	4.53 e-/ADU	0.71 e-/ADU
Read noise	7.11 e- RMS	5.29 e- RMS

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

C2 cameras implement 2×2 binning mode in hardware in addition to normal 1×1 binning. This mode can be turned on and off using the **HWBinning** parameter 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. Binnig with CMOS sensors can behave differently, pixels can be either added or averaged.

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 also 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.

But resulting S/N ratio can be affected either by overflow (saturation) of resulting pixel when adding binned pixels or by read noise underflow (dropping below 1 bit) when averaging them.

While the bigger siblings of the C2 cameras (C1×, C3, and C5) utilize CMOS sensors with full 16-bit dynamic resolution, the sensors used in C2 models offer only 14-bit or even 12-bit conversion. So, up to 4 pixels (2×2 binning) can be added and still the resulting pixel cannot overflow the 16-bit dynamic range of each 2 bytes long pixel. This is why the default binning behavior of the C2 cameras uses pixel adding instead of averaging on both software binning and in-camera (hardware) binning.

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

```
[driver]
BinningSum = false
```

Let us 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 (except for 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.

Exposure control

The shortest theoretical exposure time is 49 μs for the C2-9000 camera and 108 μs for the C2-46000 model. 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 C2-9000 shortest exposure time is also 100 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 37 ms for the C2-9000 camera and 154 ms for the C2-46000 model.

There is no theoretical limit on maximal exposure length, but 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).

Mechanical shutter

Mechanical shutter of the rolling-shutter C2 cameras works the same way like in the case of global-shutter C2 variants.

GPS exposure timing

C2 cameras with rolling-shutter 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.

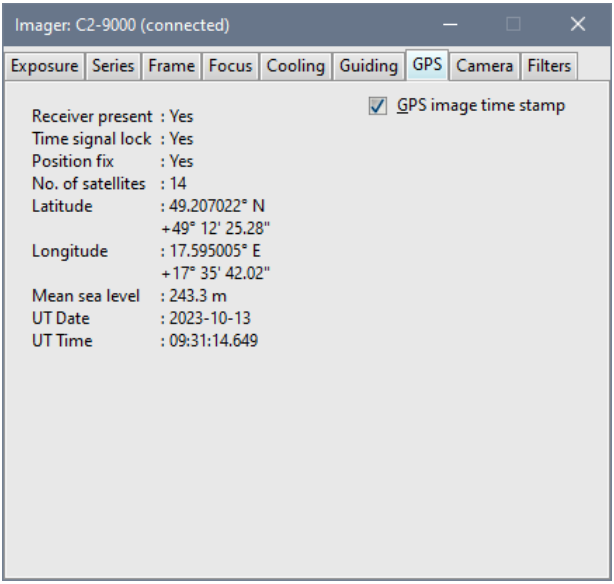

Figure 8: SIPS offers GUI to determine the state the GPS receiver

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

12.194 µs (this time is determined by the IMX533 sensor) or 26.985 µs (again determined by the IMX492 sensor).

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.
   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.

The illustrations below show how individual lines of the rolling shutter CMOS sensor are reset and exposed.

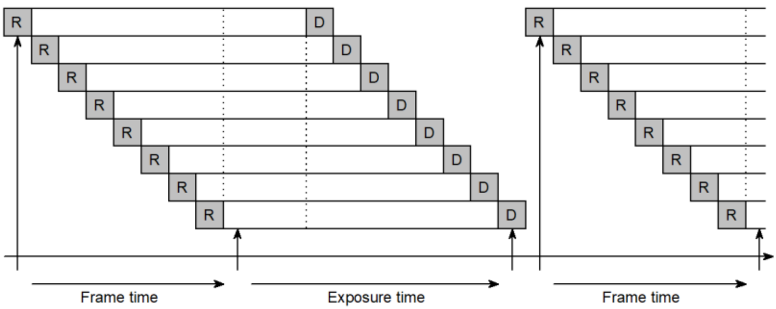

Figure 9: Illustration of the CMOS rolling shutter operation for individual exposures

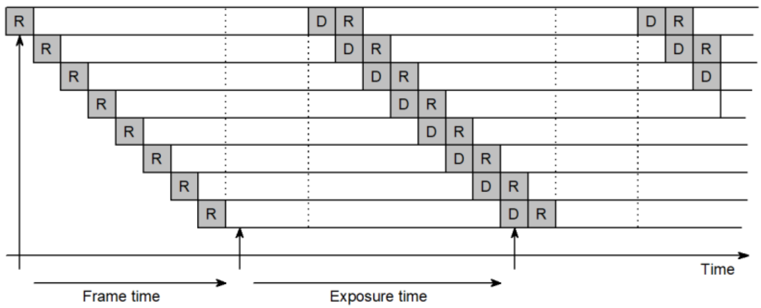

Figure 10: Illustration of the CMOS rolling shutter operation for serial exposures

Remember to always use the latest version of SIPS or 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.

Please note the GPS-based exposure timing is properly handled in the C29000 camera firmware version 7.10 and later.

The C2-46000 supports GPS timed exposures from the time of the camera release.

Cooling and power supply

Regulated thermoelectric cooling is capable to cool the CMOS sensor up to 40 °C below ambient temperature. The Peltier hot side is cooled by fan. 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.

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

Figure 11: Back side of the C2 camera head contains vents for a fan, cooling Peltir hot side

The cooling performance also 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.

CMOS sensor cooling	Thermoelectric (Peltier modules)
Maximal cooling ΔT	~40 °C below ambient (~95% cooling)
Regulated cooling ΔT	35 °C below ambient (~90% cooling)
Regulation precision	±0.1 °C
Hot side cooling	Forced air cooling (fan)

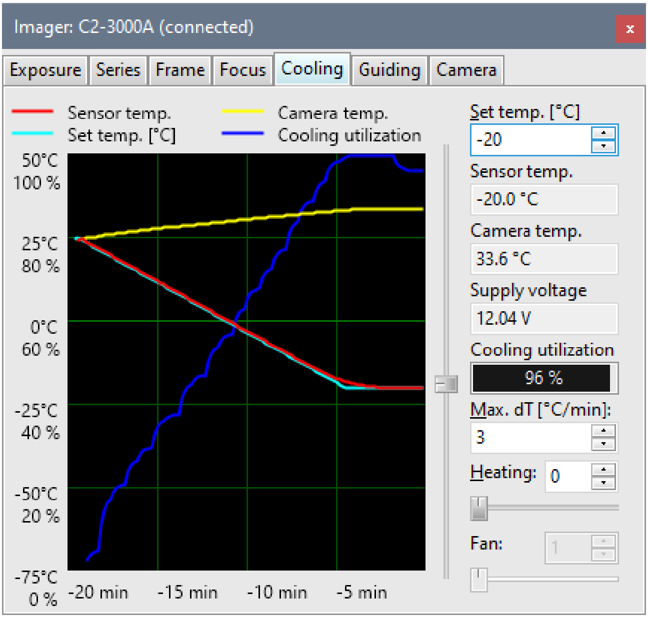

Figure 12: C2-3000A camera reaching -45°C sensor temperature below ambient

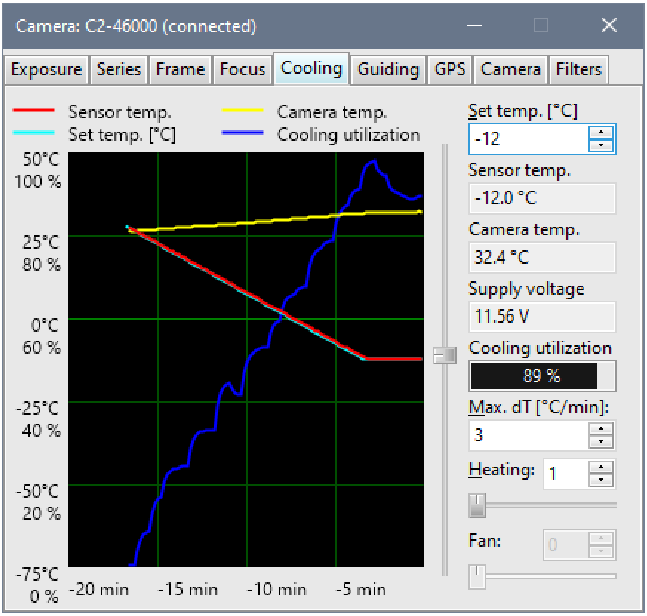

Figure 13: Approx. -40°C C2-46000 sensor temperature below ambient

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 C2 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 55 W, the 60 W power supply ensures noise-free operation.

Warning:

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

Camera head supply	12 V DC
Camera head power consumption	<4 W without cooling
	26 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.

C2 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 14: 12 V DC/5 A power supply adapter for C2 camera

Mechanical Specifications

Compact and robust camera head measures only 114×114×65 mm (approx. 4.5×4.5×2.6 inches). The head is CNC-machined from high-quality aluminum and black anodized. The head itself contains USB-B (device) connector and 12 V DC power plug. Integrated mechanical shutter allows streak-free image readout, as well as automatic dark frame exposures, which are necessary for unattended, robotic setups.

Figure 15: Bottom side with connectors of the camera without filter wheel (left) and with internal filter wheel (right)

Camera head with integrated Internal filter wheel is 77.5 mm thick. Filter wheel offers 5 positions for standard 1.25-inch threaded filter cells. A variant of filter wheel with 6 positions for unmounted D26 mm filters is also available.

Internal mechanical shutter	Yes, blade shutter
Shortest exposure time	125 μs (electronic shutter)
Longest exposure time	Limited by chip saturation only
Internal filter wheel	5 positions for 1.25” threaded cells or for D31 mm unmounted filters
	6 positions for D26 mm unmounted filters
Head dimensions	114×114×77.5 mm (Internal filter wheel)
	114×114×65 mm (without filter wheel)

Back focal distance	33.5 mm (base of adjustable adapters)
Camera head weight	1.15 kg (with Internal filter wheel)
	1.00 kg (without filter wheel)
	1.70 kg (with “XS” External filter wheel)
	1.95 kg (with “S” External filter wheel)

C2 cameras use electronic shuttering to control exposures. Mechanical shutter is used only to cover the sensor when acquiring dark or bias frames.

Back focus distance is measured from the sensor to the base on which adjustable adapters are mounted. Various adapters then provide back focal distance specific for the particular adapter type (e.g. M48 threaded adapter back focal distance is 55 mm).

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

When the adjustable adapter base, intended for camera with Internal Filter Wheel, is mounted on camera without filter wheel, the resulting back focal distance is only 21 mm.

Camera with Internal Filter Wheel

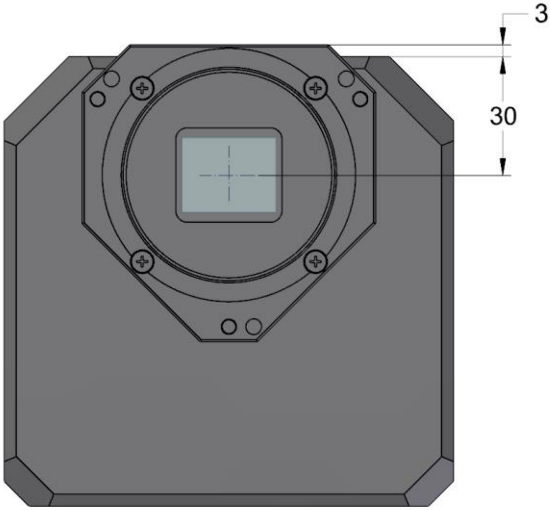

Figure 16: C2 camera head front view dimensions

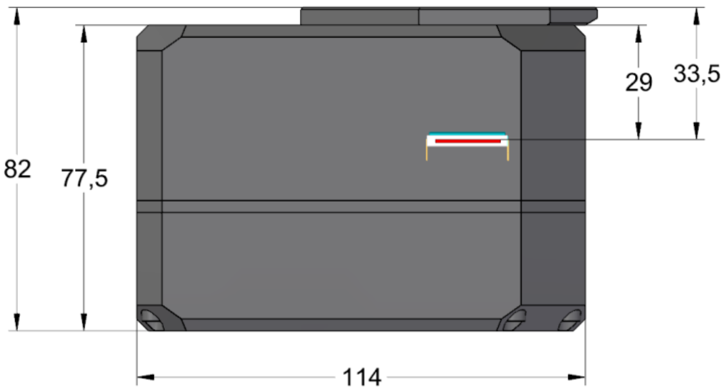

Figure 17: C2 camera head with Internal Filter Wheel side view dimensions

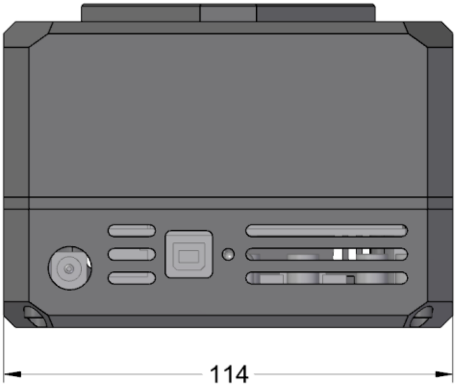

Figure 18: C2 camera head bottom view dimensions

Camera with “XS” External Filter Wheel

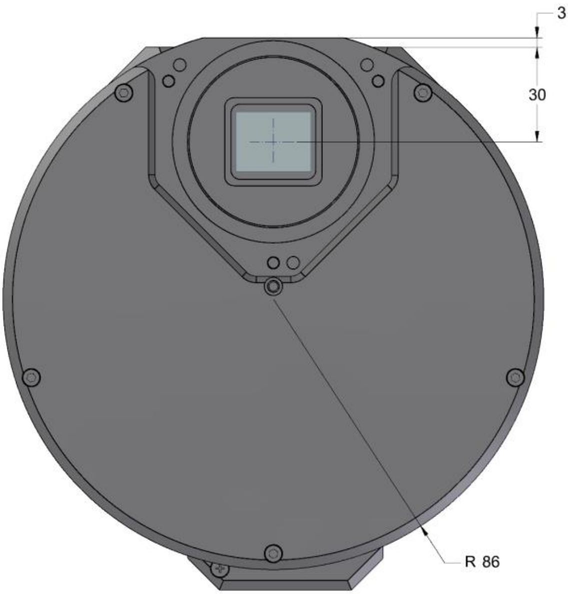

Figure 19: C2 camera head with External filter wheel front view dimensions

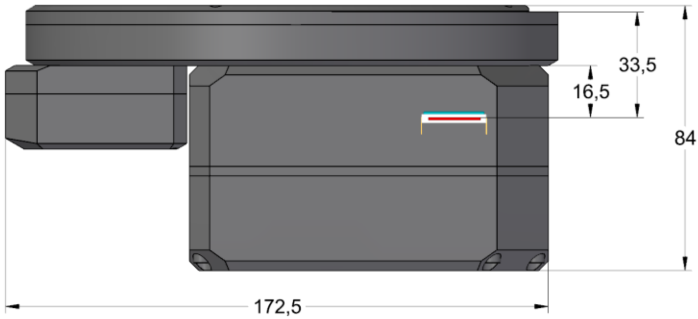

Figure 20: C2 camera head with External filter wheel side view dimensions

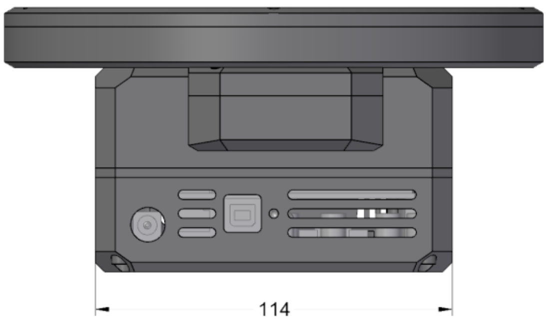

Figure 21: C2 camera head with External filter wheel bottom view dimensions

The “S” 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.

Camera without filter wheel

If the camera model, intended for usage with External filter wheel, is used without filter wheel at all, two types of adjustable adapter bases can be used.

When a “thin” adapter base, intended for camera with Internal filter wheel, is used, the back focal distance is only 21 mm.

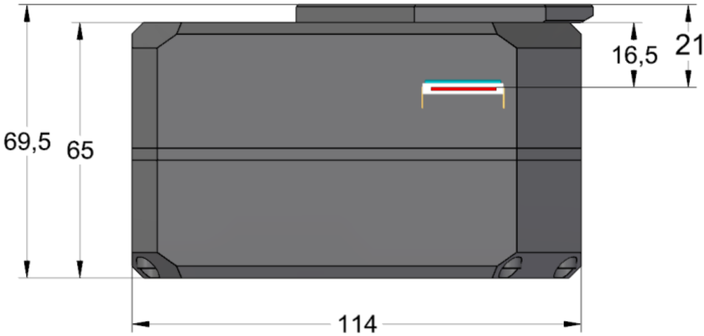

Figure 22: Camera without filter wheel with "thin" adapter base

“Thick” adapter base has the same thickness like the External filter wheel. This means all adapters, attached to this thick base, keep the same 33.5 mm back focal distance like the camera with External filter wheel attached or camera with Internal filter wheel and “thin” adapter base.

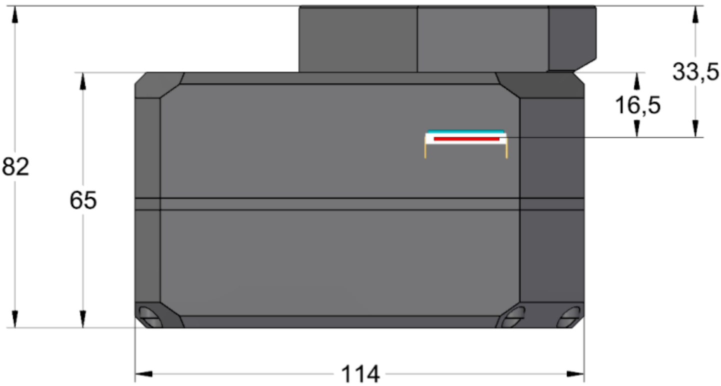

Figure 23: Camera without filter wheel with "thick" adapter base

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.

C2 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 adapter without strictly prescribed back focal distance is M48 × 0.75 thread.

> Let us note the M48 × 0.75 threaded adapter is also 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.

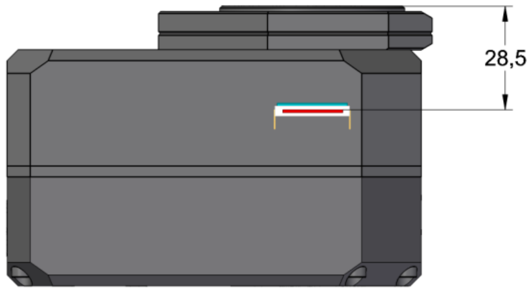

Figure 24: C2 camera with “S” adapter base back focal distances with short M48 × 0.75 adapter

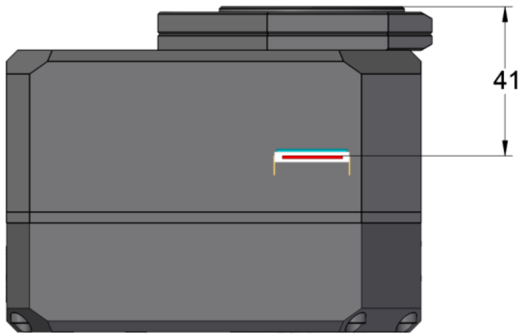

Figure 25: C2 camera with Internal Filter Wheel and “S” adapter base back focal distances with short M48 × 0.75 adapter

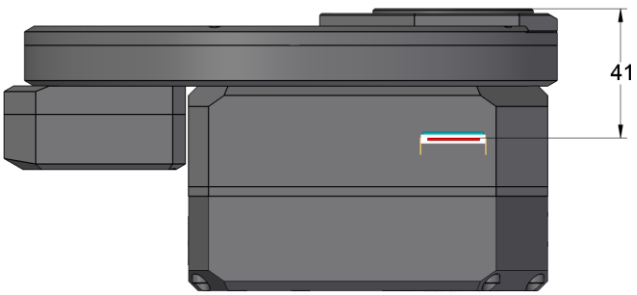

Figure 26: C2 camera with “XS” External Filter Wheel back focal distances with short M48 × 0.75 adapter

Adapters with defined back focal distance

There are three basic variants of C2 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.

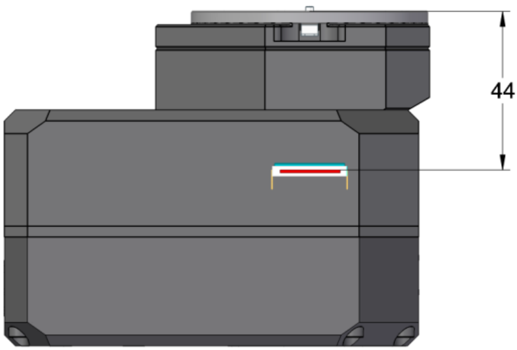

Figure 27: C2 camera without filter wheel, the Canon EOS adapter is on the thick adapter base to preserve defined BFD (the thick adapter base adds the same BFD like the External filter wheel)

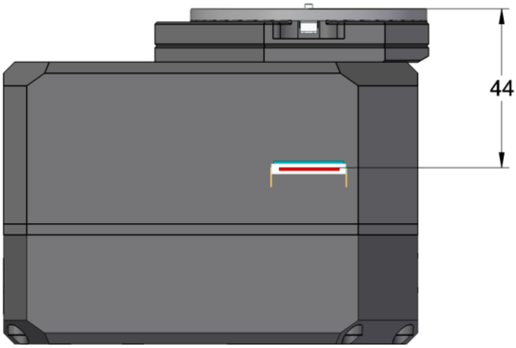

Figure 28: C2 camera with Internal filter wheel, the Canon EOS adapter is on the thin adapter base to preserve defined BFD

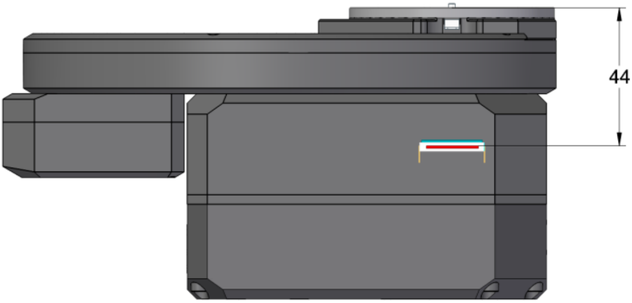

Figure 29: C2 camera with External filter wheel, the Canon EOS adapter is attached to adapter base on the External filter wheel

Off-Axis Guider Adapter

The OAG for C2 cameras uses M42×0.75 or M48×0.75 threaded adapter with 55 mm back focal distance.

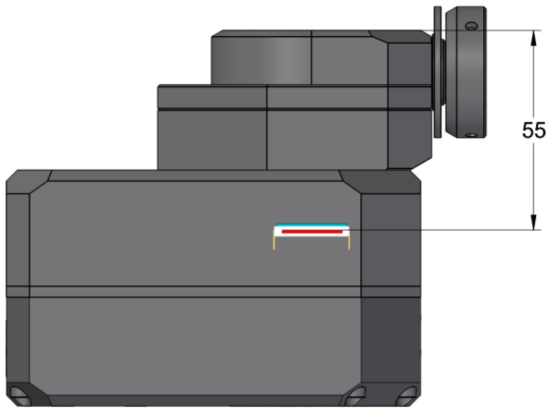

Figure 30: C2 camera without filter wheel, the OAG is on the thick adapter base to preserve defined BFD (the thick adapter base adds the same BFD like the External filter wheel)

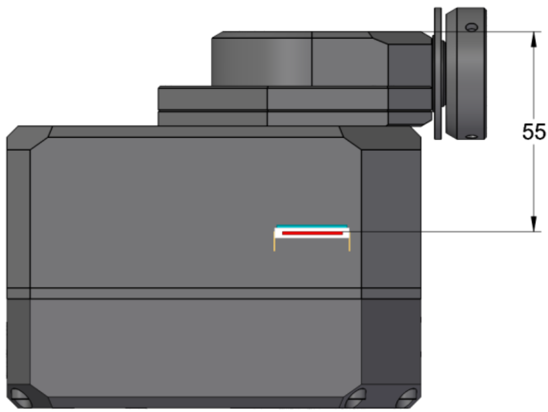

Figure 31: C2 camera with Internal filter wheel, the OAG is on the thin adapter base to preserve defined BFD

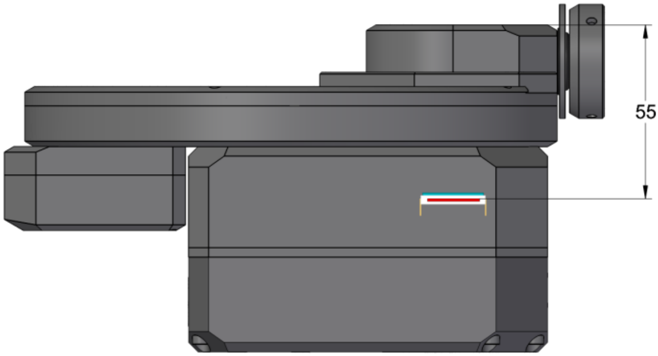

Figure 32: C2 camera with External filter wheel, the OAG is attached to adapter base on the External filter wheel

Optional accessories

Various accessories are offered with C2 cameras to enhance functionality and help camera integration into imaging setups.

Telescope adapters

Various telescope and lens adapters for the C2 cameras are offered. Users can choose any adapter according to their needs and other adapters can be ordered separately.

- **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, preserves 44 mm back focal distance.
- **Nikon F bayonet** – standard Nikon F lens adapter, preserves 46.5 mm back focal distance.

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

Off-Axis Guider Adapter (OAG)

C2 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.

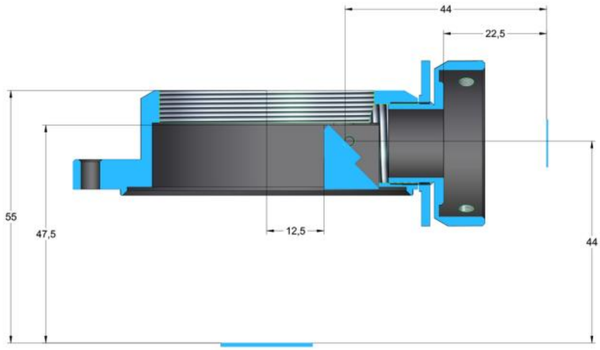

Figure 33: Position of the OAG reflection mirror relative to optical axis

C2-OAG is manufactured in two variants, one with M42×0.75 thread (T-thread) and another with M48×0.75 thread. Both variants are designed to be compatible with external filter wheels and to preserve 55 mm distance from the sensor.

If the OAG has to be used on camera with internal filter wheel, the OAG is mounted to adapter base like any other adapter. Resulting Back focal distance remains the same.

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

OAG guider port is compatible with CMOS based C1 cameras or older CCD based G0 and G1 cameras. It is necessary to replace the CS/1.25” adapter with short, 10 mm variant in the case of G1 cameras. Because 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 C2-OAG.

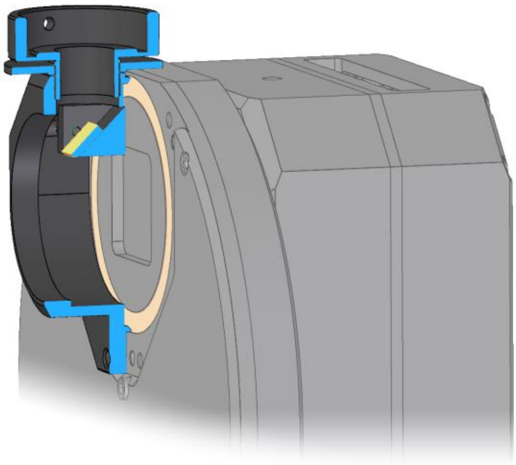

Figure 34: C2-OAG sectional rendering illustrating reflecting mirror

GPS receiver module

The C2 cameras, both global-shutter and rolling-shutter variants, 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 35: The C2 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

C2 camera heads are equipped with “tripod” thread (0.25”) as well as four M4 threaded holes on the top side of the camera head.

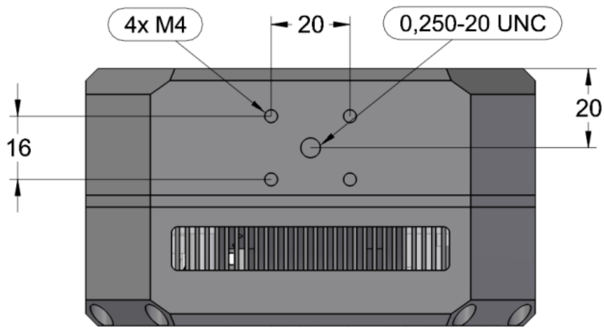

Figure 36: Threaded mounting holes on the camera head top side

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: C2 camera color variants

Camera Ethernet Adapter

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

Figure 39: The Camera Ethernet Adapter with two connected cameras

Adjusting of the telescope adapter

All telescope/lens adapters of the C2 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 Mark II camera telescope adapters are attached using three "pulling" screws. As the adapter tilt is adjustable, another three "pushing" screws are intended to fix the adapter after some pulling screw is released to adjust the tilt.

> **Warning:**
>
> Both pulling and pushing screws, used on the C2 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.

- C2 camera 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 External filter wheel front plate is already designed to hold the spring and it also contains threads to fix respective adapters.

Figure 42: External filter wheels are already designed to for adjustable telescope adapters

Camera Maintenance

The C2 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 C2 camera cooling is designed to be resistant to humidity inside the CMOS sensor chamber. When the temperature decreases, the copper cold finger crosses freezing point earlier than the sensor 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 CMOS 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 C2 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.

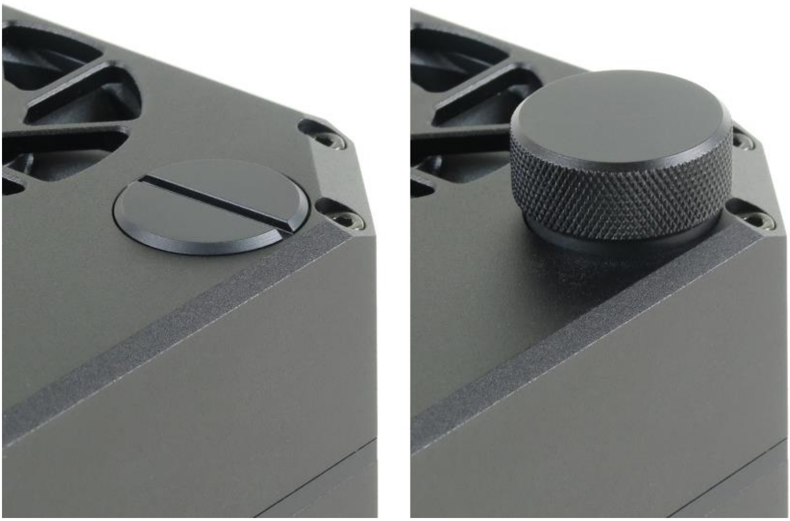

Figure 43: Silica-gel container is accessible from the camera back side

Exchanging the silica-gel

C2 cameras employ the same desiccant container like the larger C1+, C1x, C3 and C4 cameras as well as the cooled Gx CCD 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 CCD cold chamber itself. It is intended only to hold possible dust particles from entering the front half of the camera head with the CCD chamber optical window, shutter, and possibly internal filter wheel. While the O-ring material should sustain the high temperature during silica-gel baking, it is possible to remove it and put it back again prior to threading the contained back to the camera.

This design also allows usage of some optional parts:

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

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

Figure 45: Optional cap, standard container, and the tool-less variant of the container

Changing Filters

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

Opening the camera head

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

Warning:

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

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

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

Changing the Whole Filter Wheel

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

Changing the Telescope Adapter

All adapters of the C2 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 C2 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: Removing 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 fan on the back side of the camera does 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.