C1× Series

Astronomical CMOS Cameras

User's Guide

Version 1.9

Modified on May 9th, 2025

All information furnished by Moravian Instruments is believed to be accurate. Moravian Instruments reserves the right to change any information contained herein without notice.

C1× 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

Table of Contents

Introduction 5

C1× Camera Overview 8

C1× Camera System 12

C1× camera M56×1 adapter 12

C1× camera with the “S” size adapter 13

C1× camera with the “L” size adapter 14

CMOS Sensor and Camera Electronics 17

Camera Electronics 19

Sensor linearity 19

Download speed 20

Camera gain 21

Conversion factors and read noise 22

Binning 24

Hardware binning 24

Adding vs. averaging pixels 25

Binning in photometry 26

Exposure control 28

GPS exposure timing 28

Hardware trigger input 30

Cooling and power supply 33

Overheating protection 34

Power supply 35

Mechanical Specifications 38

C1× camera head 39

Camera with the “XS” External Filter Wheel 42

Optional accessories 44
Telescope adapters 44
Off-Axis Guider Adapter (OAG) 46
GPS receiver module 47
Attaching camera head to telescope mount 48
Moravian Camera Ethernet Adapter 50
Adjusting of the telescope adapter 51
Camera Maintenance 53
Desiccant exchange 53

Introduction

Thank you for choosing the Moravian Instruments camera. The C1× series of cooled scientific CMOS cameras were developed for imaging under extremely low-light conditions in astronomy, microscopy and similar areas.

The C1× family of cameras combine large APS and Full-Frame sized sensors, used in the C3 series, with a compact body of C1+ cameras. The front cross-section of the C1× camera head is the same like the C1+ one, only its body is a bit longer to accommodate more complex electronics as well as more powerful cooling (here originates the name of the entire series – C1 eXtended). Similarly to the C1+ line, also the C1× cameras lack mechanical shutter.

Figure 1: C1× camera

Using of large sensors up to 24×36 mm required also redesign of the telescope/lens adapters of the C1× line, the M42/M48×0.75 threads, used with C1+ camera adapters, are too small for such large sensors. So, the C1× adapters are equipped with new M56×1 thread. The front plate of the M56×1 adapter also contains four threaded holes, which makes it compatible with C3 camera body and thus the C1× can use the same External filter wheels and other accessories like the C3 line.

Figure 2: C1× cameras are compatible with many accessories for C3 line, like the External filter wheels, OAG adapters etc.

Rich software and driver support allows usage of C1× camera without a 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, shipped with the camera, provide the way to integrate C1× camera with broad variety of camera control programs.

The C1× cameras are designed to work in cooperation with a host Personal Computer (PC). As opposite to digital still cameras, which are operated independently on the computer, the scientific 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.

C1× cameras are designed to be attached to host PC through very fast USB 3.0 port. While C1× 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 C1×, but also C1, C2, C3 and C4) and offers 1 Gbps and 10/100 Mbps Ethernet interface for direct connection to the host PC. Because the host 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 C1× 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. C1× 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.

C1× Camera Overview

C1× camera head is designed to be as small and compact as a cooled camera with large sensor can be.

A special version C1× camera, denoted by the suffix “T”, is equipped with a port for GPS receiver and with a digital input for external triggering. Because majority of C1× usage scenarios (astronomical photography, variable star research, etc.) do not utilize the benefits of the sub-microsecond exposure timing or external exposure triggering, and both the GPS module interface and hardware trigger port increase the price of the C1× camera, standard variant of the C1× cameras are offered without these ports.

C1× cameras are equipped with tiltable telescope interface and tripod mounting threaded holes. They are also compatible with external filter wheels designed for larger C2 and C3 cameras – camera head contains connector to control filter wheel. If the external filter wheel is used, the tiltable mechanism on the camera head is inactive and tiltable adapters for external filter wheels are used instead. Therefore, C1× cameras can utilize vast range of telescope and lens adapters including off-axis guider adapters.

Figure 3: C1× camera head

C1× camera head is designed to be easily used with a set of accessories to fulfil various observing needs. Camera adapter base back focal distance is 16.5 mm and can be used directly to attach the camera to the telescope focuser using the M56×1 thread.

Figure 4: C1× camera with M48, Nikon and Canon lens adapters

The M56×1 thread in the adapter base is also used to attach several adapters for specific mounting standards:

- M42×0.75 (T-thread) long adapter with 55 mm back focal distance.
- M42×0.75 (T-thread) short adapter with 21.5 mm back focal distance.
- M48×0.75 long adapter with 55 mm back focal distance.
- M48×0.75 short adapter with 21.5 mm back focal distance.
- Canon EOS bayonet lens adapter.
- Nikon bayonet lens adapter.

Figure 5: M42 and M48 short adapters with 21.5 mm BFD (left) and long adapters with 55 mm BFD (right) for M56×1 thread

The adapter base is also equipped with four M3 threaded holes 44 mm apart. As the adapter base BFD is 16.5 mm – the same BFD like in the case of C2 and C3 cameras – there is a possibility to attach the External Filter Wheel to the C1× camera. Four sizes of the External filter wheels, capable to accept various sizes of filters, are available for the C1× cameras:

Extra small "XS" size wheel for:

- 7 unmounted D36 mm filters

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

The filter wheels with D36 mm filters can be used with C1× cameras equipped with APS size sensors only. Cameras with “Full-Frame” sensors (24×36 mm) cannot use such small filters.

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.

Figure 6: C1× camera with “XS” and “S” sized External filter wheels

If the External filter wheel is used, the tiltable base directly on the camera head stays inactive. Instead, another tiltable base, intended for C3 adapters, is manufactured directly on the External filter wheel front shell. So, if the External filter wheel is used, adapters for the M56×1 thread cannot be used. Instead, adapters designed for C3 cameras, must be used.

There are two sizes of adjustable adapters available, depending of the External filter wheel size:

- Extra small “XS” and small “S” External filter wheels use small “S” adapters, compatible with C2 cameras. These adapters include e.g. M48×0.75 and M42×0.75 threaded adapters, Nikon bayonet adapter, 2” barrel adapter etc.

- Medium “M” and Large “L” External filter wheels use 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.

C1× Camera System

C1× camera M56×1 adapter

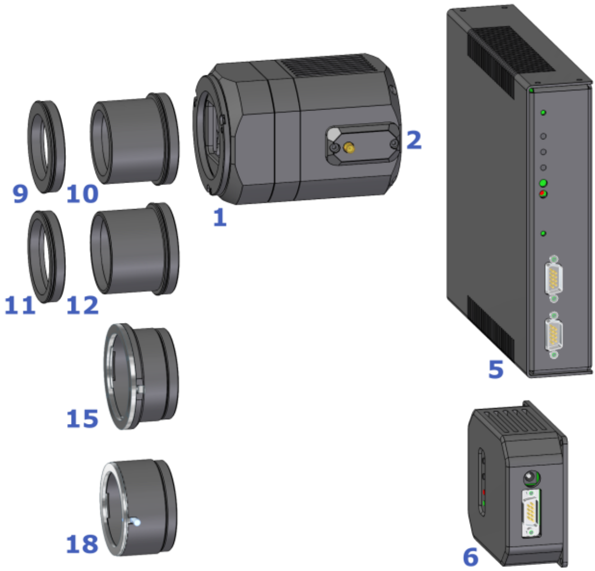


Figure 7: Schematic diagram of C1× camera M56×1 tiltable adapter and telescope adapters using this standard

C1× camera with the “S” size adapter

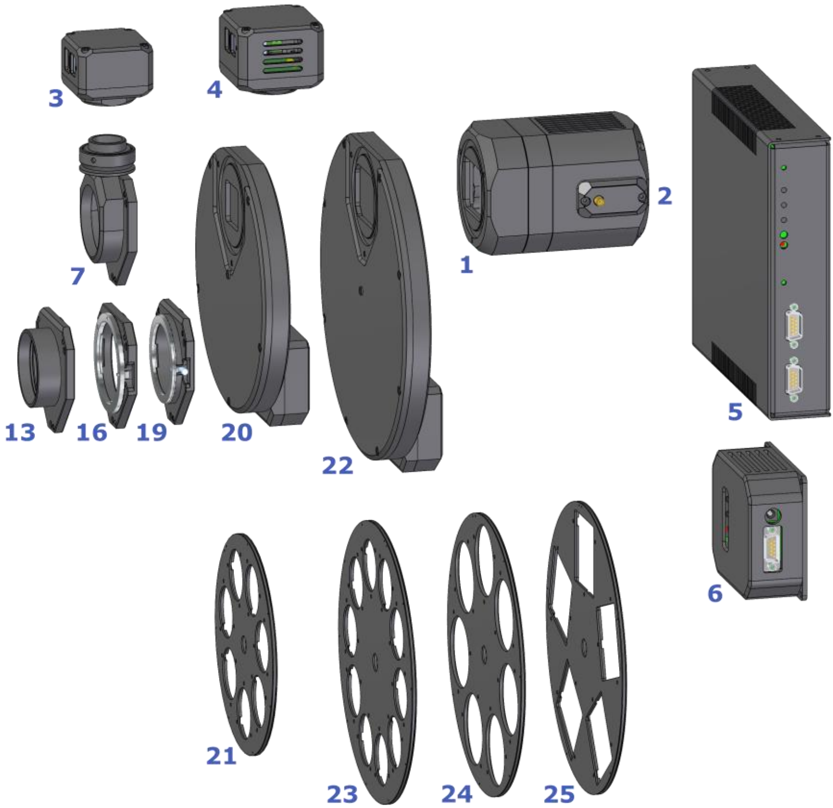


Figure 8: Schematic diagram of C1× camera with the “S” size adapter system components

C1× camera with the “L” size adapter

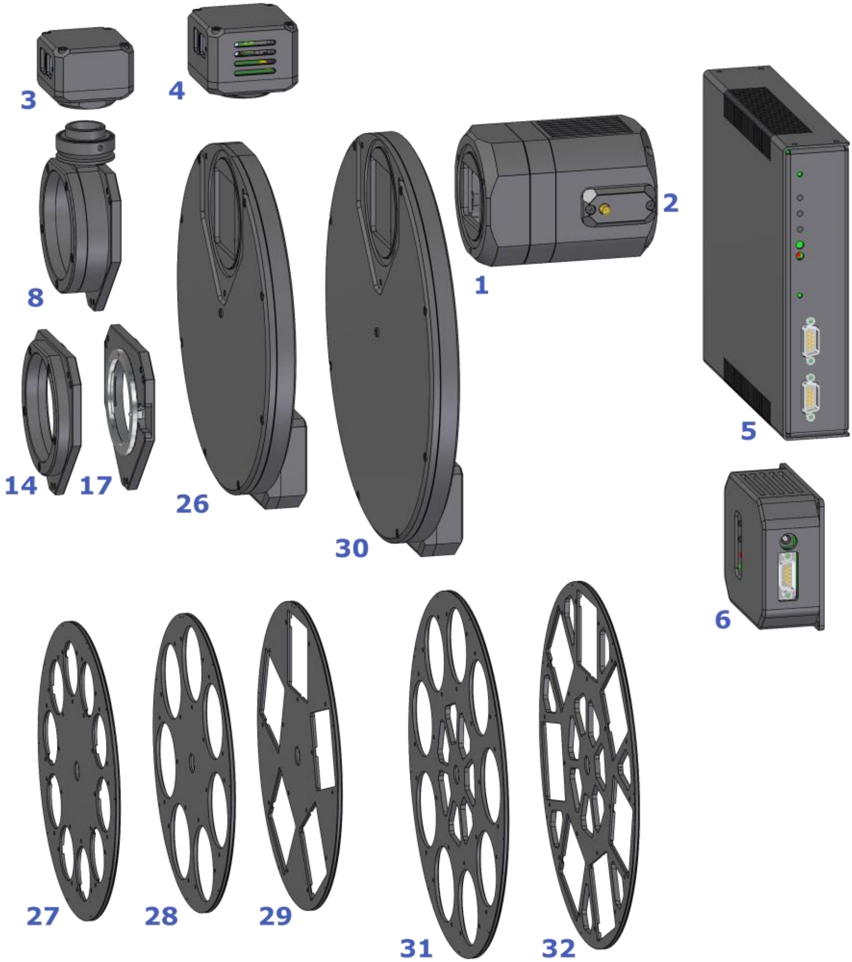


Figure 9: Schematic diagram of C1× camera with the “L” size adapter system components

Components of C1× Camera system include:

1. C1× camera head with M56×1 tiltable adapter base
2. Optional GPS receiver module
3. C0 auto-guiding camera
4. C1 auto-guiding camera

    C0 and C1 cameras are completely independent devices with their own USB connection to the host PC. They can be used either on the OAG or on standalone guiding telescope.

5. Moravian Camera Ethernet Adapter (x86 CPU)
6. 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.

7. Off-Axis Guider for “S” base with M48×0.75 thread, 55 mm BFD
8. Off-Axis Guider for “L” base with M68×1 thread, 61.5 mm BFD
9. M42×0.75 (T-thread) threaded short adapter, 21.5 mm BFD
10. M42×0.75 (T-thread) threaded long adapter, 55 mm BFD
11. M48×0.75 threaded short adapter, 21.5 mm BFD
12. M48×0.75 threaded long adapter, 55 mm BFD
13. M42×0.75 (T-thread) or M48×0.75 threaded adapters for “S” base, 55 mm BFD
14. M68×1 threaded adapter for “L” base, 47.5 mm BFD
15. Canon EOS bayonet lens adapter for M56 thread
16. Canon EOS bayonet lens adapter for “S” base
17. Canon EOS bayonet lens adapter for “L” base
18. Nikon bayonet lens adapter for M56 thread
19. Nikon bayonet lens adapter for “S” base
20. External Filter Wheel “XS” size (7 positions)
21. 7-positions filter wheel for the “XS” housing for D36 mm filters
22. External Filter Wheel “S” size (5, 7 or 10 positions)
23. 10-positions filter wheel for the “S” housing for D36 mm filters
24. 7-positions filter wheel for the “S” housing for 2”/D50 mm filters

25. 5-positions filter wheel for the “S” housing for 50×50 mm filters
26. External Filter Wheel “M” size (5, 7 or 10 positions)
27. 10-positions filter wheel for the “M” housing for D36 mm filters
28. 7-positions filter wheel for the “M” housing for 2”/D50 mm filters
29. 5-positions filter wheel for the “M” housing for 50×50 mm filters
30. External Filter Wheel “L” size (7 or 9 positions)
31. 9-positions filter wheel for the “L” housing for 2”/D50 mm filters
32. 7-positions filter wheel for the “L” housing for 50×50 mm filters

CMOS Sensor and Camera Electronics

C1× 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), C1× 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 C1×26000) and IMX455 (used in C1×61000) 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. C1× 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 the C1× cameras are offered in two variants:

- **C1×26000** and **C1×61000** with consumer grade sensors, intended for max. 300 hours a year operation.
- **C1×26000 PRO** and **C1×61000 PRO** with industrial grade sensors.

Monochrome C1× camera models with consumer-grade sensors:

Model	C1×26000	C1×61000
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 C1× camera models with industrial-grade sensors:

Model	C1×26000 PRO	C1×61000 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 C1× camera models with consumer-grade sensors:

Model	C1×26000C	C1×61000C
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 C1× camera models with industrial-grade sensors:

Model	C1×26000C PRO	C1×61000C 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 the C1× 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.

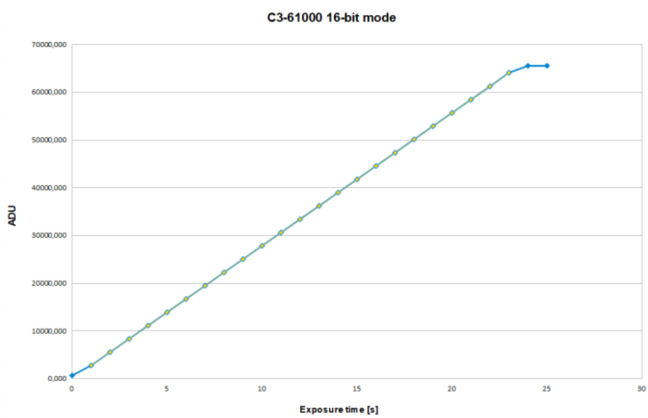


Figure 10: Response of IMX455 sensor in 16-bit mode

Download speed

C1× 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	C1×26000	C1×61000
Full-frame, USB 3.0 (5 Gbps)	0.22 s	0.47 s
Full-frame, USB 2.0 (480 Mbps)	1.16 s	2.74 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	C1×26000	C1×61000
1024×1024 sub-frame, USB 3.0 (5 Gbps)	0.03 s	0.04 s
1024×1024 sub-frame, USB 2.0 (480 Mbps)	0.06 s	0.05 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.

C1× 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	C1×26000	C1×61000
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 C1×61000 full frame is approx. 2.5 s.

Camera gain

Sensors used in C1× cameras offer programmable gain from 0 to 36 dB, which translates to the output signal multiplication from 1× to 63×.

> Note the C1× 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×

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

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.

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

C1× 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 4.10 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's 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 C1×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 take into account 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 C1× 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 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 (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:

- C1×26000 shortest exposure is 139 μs
- C1×61000 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 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 C1×26000 and 0.25 s for the C1×61000.

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.

GPS exposure timing

C1× cameras in the “T” version 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.

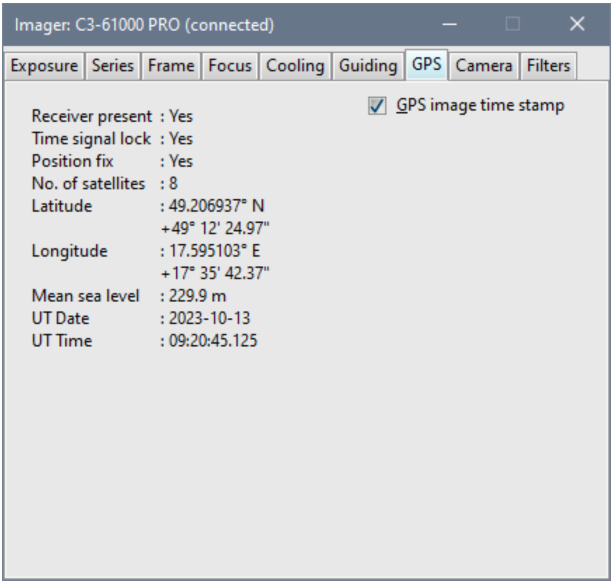


Figure 11: SIPS offers GUI to determine the state the GPS receiver

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. C1×26000 line exposure takes 34.667 μs
   ii. C1×61000 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

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 25 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.

Hardware trigger input

The C1× cameras marked with the “T” suffix (the ones also compatible with GPS receiver modules) are equipped with a hardware trigger input port.

The trigger input allows for external hardware to determine the exact time of exposure start.

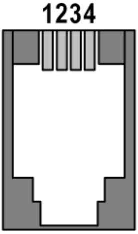
Note:

The external exposure triggering is supported by a variant of the **StartExposure** function named **StartExposureTrigger**, available for the user of the Camera SDK for Windows as well as Linux and Mac libraries and drivers. However, the SIPS software does not support triggered exposures.

The hardware trigger input port is available on the back side of the C1× cameras.

Figure 12: back of the C1× camera with trigger input port, the GPS port on the camera side is covered

The port uses RJ9 (4P4C) four-pin connector. Pins 1 and 2 are connected and have a function of positive pole, pins 3 and 4 are connected to negative pole. The trigger is activated when an external hardware connects (short-circuit) pins 1 and/or 2 with pins 3 and/or 4. The trigger input port is electrically isolated from the rest of the camera – power and USB grounds etc.



Pin	Function
1	Positive (+) pin No. 1
2	Positive (+) pin No. 2
3	Negative (-) pin No. 1
4	Negative (-) pin No. 2

The maximum current, consumed by the short-circuited trigger port, does not exceed 1 mA.

Cooling and power supply

Regulated thermoelectric cooling is capable to cool down the CMOS sensor by approx. 35 °C below ambient temperature, depending on the camera type. 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.

Figure 13: C1× air inlet with fan is on the bottom side of the camera head (left), air outlet vents are on the camera top side (right)

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)
Cooling ΔT	30 °C below ambient
Regulation precision	±0.1 °C
Hot side cooling	Forced air cooling (fan)

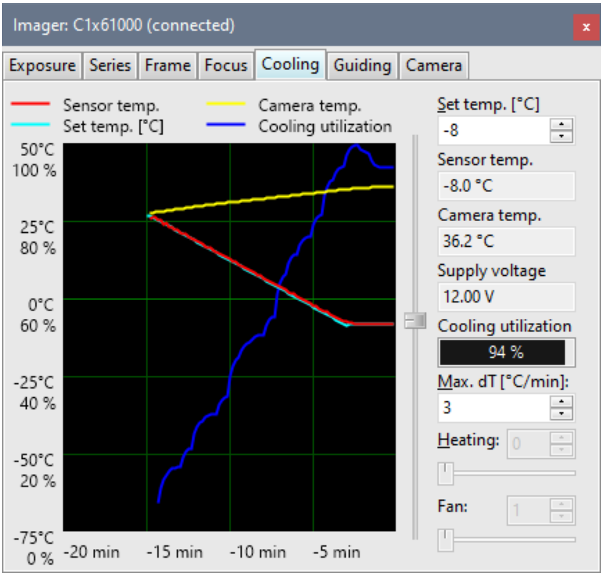


Figure 14: C1×61000 camera reaching -35 °C sensor temperature below ambient temperature 27 °C

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 C1× 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.

Figure 15: Back side of the C1× camera with the 12 V DC power plug, as well as USB and External filter wheel connectors

Camera head supply	12 V DC
Camera head power consumption	<6 W without cooling
	34 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.

C1× 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 16:Figure 8: 12 V DC/5 A power supply adapter for the C1× camera

Mechanical Specifications

Compact and robust camera head measures only 78×78×108 mm (approx. 3.1×3.1×4.4 inches). The head is CNC-machined from high-quality aluminum and black anodized. The head itself contains USB-B (device) connector, connector for External Filter Wheel and 12 V DC power plug.

The front side of the C1× camera body is not intended for direct attachment of the telescope/lens adapter. It is instead designed to accept tiltable adapter base, on with the telescope and lens adapters are mounted.

Figure 17: The M56×1 thread and four M3 threaded holes creates the telescope/lens interface of C1× cameras

Head dimensions	78×78×108 mm
Back focal distance	16.5 mm (adapter base with M56×1)
Camera head weight	0.85 kg

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

C1× camera head

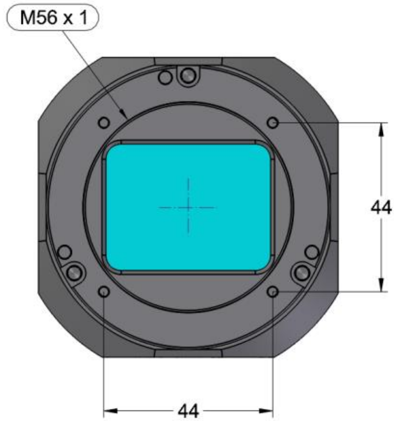


Figure 18: C1× camera head with a tiltable adapter base with M56×1 inner thread and four M3 threaded holes front view

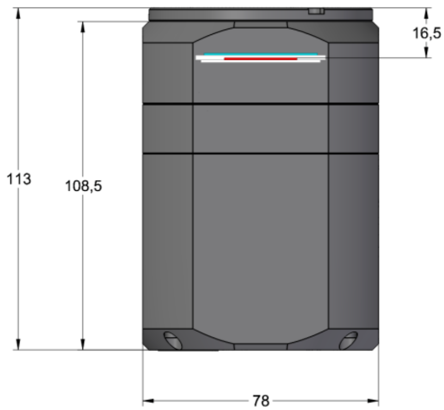


Figure 19: C1× camera head with a tiltable adapter base side view

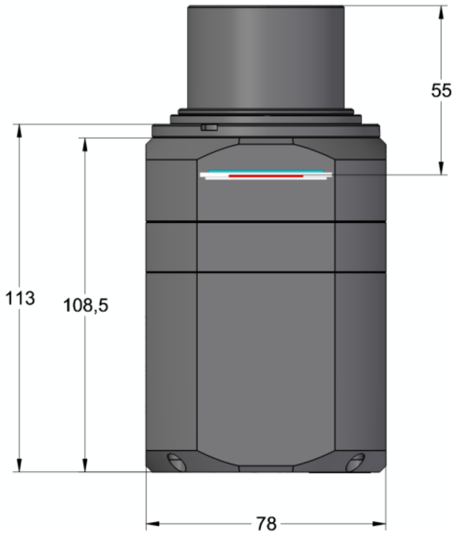


Figure 20: C1× camera head with M42×0.75 (T-thread) or M48×0.75/2-inch adapter with 55 mm BFD

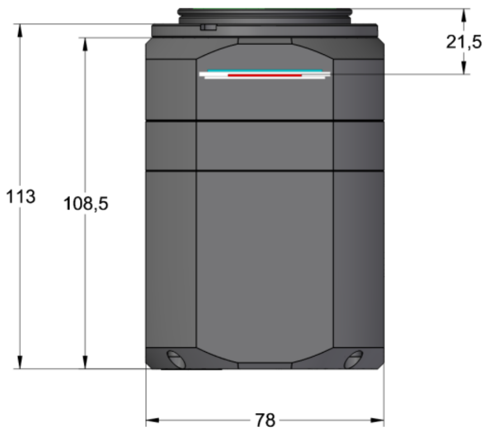


Figure 21: C1× camera head with M42×0.75 (T-thread) or M48×0.75 adapter with 21.5 mm BFD

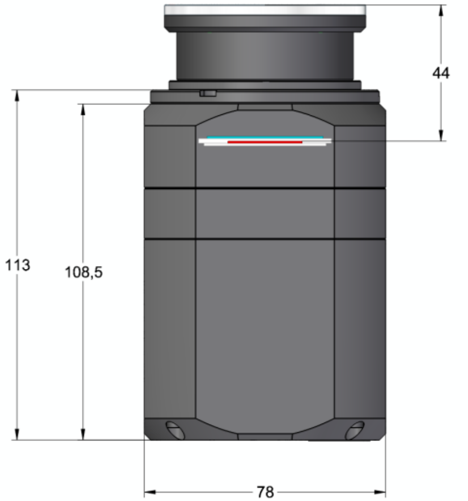


Figure 22: C1× camera head with Canon EOS bayonet adapter for photographic lenses

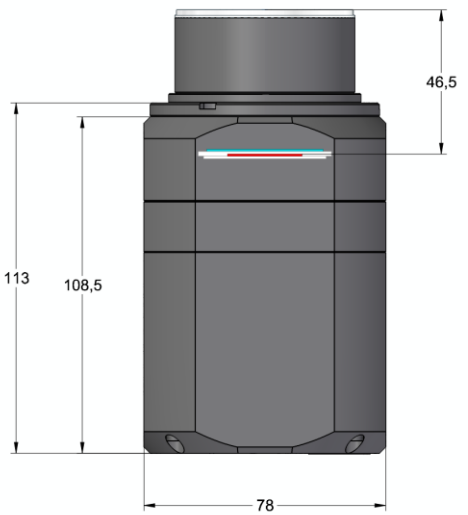


Figure 23: C1× camera head with Nikon bayonet adapter for photographic lenses

Camera with the “XS” External Filter Wheel

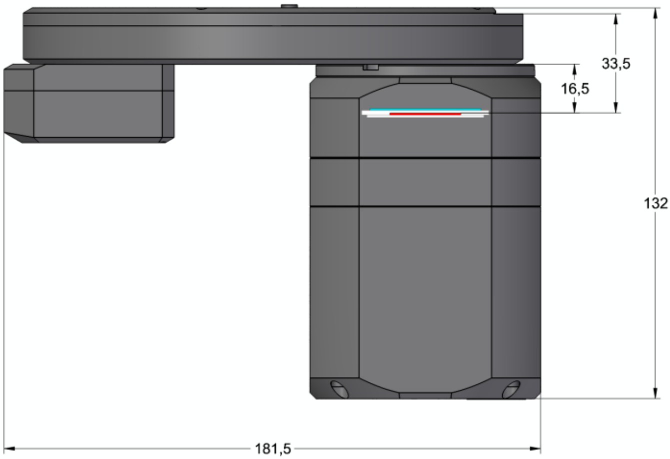


Figure 24: C1× camera head with External filter wheel side view dimensions

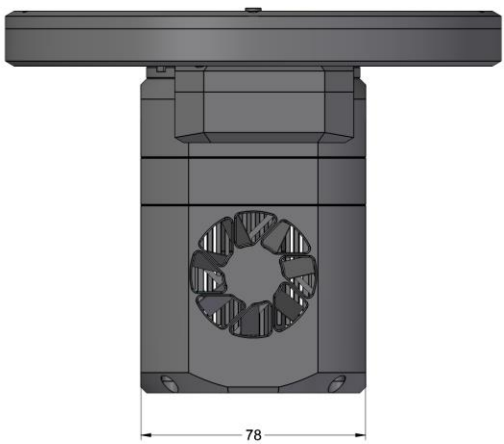


Figure 25: C1× camera head with External filter wheel bottom view dimensions

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

The M48, Canon and Nikon adapters, intended for the M56×1 thread, cannot be used with the External filter wheels. However, the External filter wheel is equipped with adapter base for C2 and C3 adapters and thus all adapters, designed for these cameras, can be used with C1× and External filter wheel.

Optional accessories

Various accessories are offered with C1× cameras to enhance functionality and help camera integration into imaging setups.

Telescope adapters

Various telescope and lens adapters for the C1× cameras are offered. Users can choose any adapter according to their needs and other adapters can be ordered separately.

There are two means of connection between the tiltable adapter base on the C1× camera head and actual adapter:

- The **M56×1 inner thread** with 16.5 mm BFD. Adapters for Canon EOS and Nikon lenses and standard M42×0.75 (T-thread) and M48×0.75 threaded adapters with 55 mm BFD uses this thread for connection with the camera.

  The M56×1 thread can of course act as a camera adapter itself, providing the used telescope system also offers such thread.

Figure 26: Canon (left), Nikon (middle) and M48×0.75 adapters

- Four **M3 threaded holes** 44 mm apart. The back focal distance of the front side of the tiltable adapter base is 16.5 mm, which is the BFD if the front surface of C2 and C3 cameras without filter wheel. This makes the C1× cameras compatible with a vast set of accessories, intended for C2 and C3 cameras, including External filter wheels, off-axis guiding adapters etc.

If the External filter wheel is attached to the C1× base, telescope/lens adapters are attached to the External filter wheel. In such case adapters compatible with the C2 or C3 cameras are used.

Figure 27: C1× camera with M48×0.75 (left) and Canon EOS (right) adapters

There are two sizes of the adjustable adapter base, depending on the size of the External filter wheel used:

- “XS” and “S” external filter wheels are compatible with “S” adapters (also used with C2 cameras)
- “M” and “L” external filter wheels are compatible with “L” adapters (also used with C4 cameras)

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.
- **M42 (T-thread) short** – adapter with inner thread M42×0.75.
- **M42 (T-thread) with 55 mm BFD** – adapter with inner thread M42×0.75, preserves 55 mm back focal distance.
- **M48 short** – adapter with inner thread M48×0.75.
- **M48 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)

The Off-Axis Guider Adapter can be used with the C1× camera only if the External filter Wheel is used. Then the OAG for C3 cameras with M68×1 thread can be attached to the "M" or "L" External filter wheel.

> Technically also the C2-OAG with M48×0.75 thread can be attached to the "XS" and "S" External filter wheels, but C2-OAG mirror is positioned too close to the optical axis with respect to relatively small sensors of the C1+/C2 camera lines. So, the C2-OAG mirror would partially shadow large sensors use in the C1× cameras.

OAG 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.

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

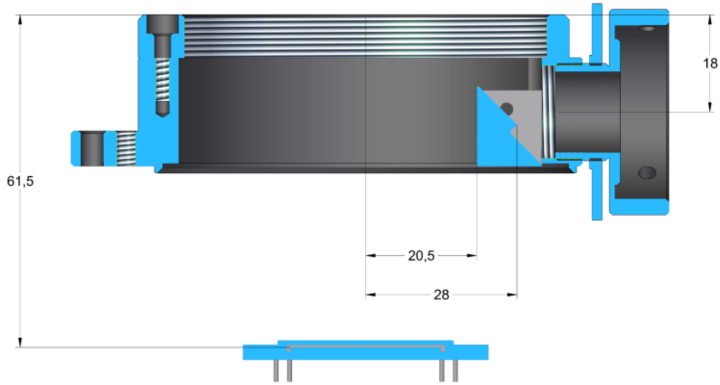


Figure 28: Position of the OAG reflection mirror relative to optical axis

The OAG guider port is compatible with C0 and 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.

GPS receiver module

The C1× variants marked “T” (for Trigger Input) 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 side of the camera head. If the GPS module is removed, the GPS port is covered with a flat black cover.

Figure 29: The C1× camera with GPS receiver module with external antenna

Please note only camera variants marked with “T” suffix are compatible with GPS modules. So, it is necessary to choose GPS-ready variant upon camera ordering.

Attaching camera head to telescope mount

C1× camera heads are equipped with “tripod” thread (0.25”) as well as four M4 threaded holes on the bottom side of the camera head.

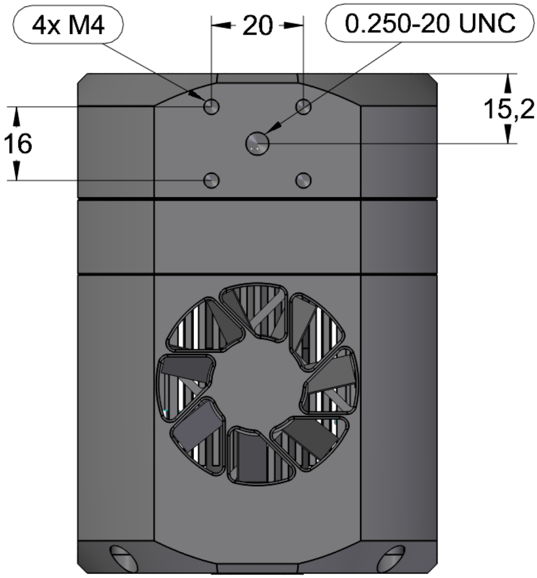


Figure 30: Threaded mounting holes on the C1× camera head bottom side

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 31: 1.75" bar for standard telescope mounts

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 32: The Moravian Camera Ethernet Adapter with two connected cameras

Adjusting of the telescope adapter

The telescope/lens adapters of the C1× 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.

The camera adapter base is 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.

Figure 33: Releasing of the “pushing” screw (left) and adjusting of the "pulling" screw

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.

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.

If the External filter wheel is used, the adjustment screws on the camera body are not accessible and they are not used to adjust the tilt. Instead, an adjustable adapter base on the External filter wheel is used to correct possible tilt.

Figure 34: External filter wheels are already designed to for adjustable telescope adapters compatible with C3 cameras

Camera Maintenance

The C1× 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 C1× 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 C1× 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 35: Silica-gel container is accessible from the camera back side

C1× cameras employ the same desiccant container like the C1+, C2, C3 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 36: Desiccant is held inside container by perforated cap

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