Moravian Instruments

Filter Wheels

User's Guide

Version 1.1

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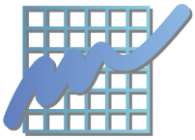

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Table of Contents

Introduction

Astronomical cameras with silicon-based monochrome sensors are sensitive to a wide range of wavelengths, spanning from near ultra-violet (UV) to near infra-red (IR) light. If it is desired to capture only a portion of such a spectral range, it is necessary to place a color filter in front of the sensor. This is why Moravian Instruments cameras are designed to operate with a wide range of Moravian Instruments filter wheels.

Moravian Instruments filter wheels are always computer controlled like cameras themselves, so they can be integrated into complete imaging setups.

There are three classes of Moravian Instruments filter wheels:

- **Internal** filter wheels (IFW)
- **External** filter wheels (EFW)
- **Standalone** filter wheels (SFW)

Figure 1: C2 camera without filter wheel (left), with Internal filter wheel (center) and with External filter wheel (right)

There are fundamental differences among these three filter wheel types:

- **Internal** and **external** filter wheels are always controlled and powered by the camera, there is no power or USB plug. Also,

these filter wheels do not need own drivers; commands, controlling their operation, are passed through the camera driver.

- **Standalone** filter wheels on the other side contain own electronics and thus require standalone power line and communication line to the host PC. They also need own drivers, beginning with USB system driver, user space application driver etc.

Cameras with Internal Filter Wheels

The C2 and C3 camera lines, combining asymmetrical camera head design and relatively small sensors, can incorporate filter wheels directly into the front camera shell, which is then manufactured slightly thicker.

Internal filter wheels bring several advantages:

- Camera head is only slightly thicker and heavier, compared to camera without filter wheel, head width and height remain unchanged.
- Camera with IFW make up a single device without obvious mechanical or electrical connections.
- There is more space for filters inside the camera shell compared to External filter wheel shell – up to 10 mm space is available, compared to just 6 mm in the EFW.

But integrating the filter wheel into camera also brings disadvantages:

- IFW dimension and thus also number of filter positions are limited by the camera head front cross-section.
- IFW cannot be integrated into cameras incorporating large sensors (C4 and C5 lines), despite the asymmetrical design of the camera head.
- Changing filters require opening the camera head, exposing mechanical shutter and camera electronics, which require great care not to damage these components. Also, closing the camera is more demanding as it is necessary to properly arrange internal cabling etc.

So, in general, IFW is suitable for applications using relatively small number of filters, which are exchanged rather exceptionally. For instance, photometric camera operating with Johnson-Cousin UBVRI filters only is a good example.

Cameras with External filter wheels

All Moravian Instruments cameras are equipped with electronics, capable to drive the filter wheel. Also, the camera firmware and command set include instructions to control the wheel.

> Remark:
>
> The only exceptions are the smallest C0 and C1 series cameras, intended as auto-guiders or planetary cameras. If an automatic filter exchange is needed, at last the C1+ series camera must be used.

Cameras without IFW are manufactured with thinner front shell to save weight and to shrink the camera back focal distance (BFD), which means the internal wheel cannot be added later. Filter wheel controlling electronics remains unused in such case.

So, cameras without IFW are equipped with an external connector, containing all signals necessary to control a filter wheel. If an External filter wheel is mechanically attached to the camera head, it is possible to connect it to the camera head using single cable with 8-pin connectors to provide power and control signals to the wheel.

> Hint:
>
> Because the External filter wheels use the power and control provided by the camera, EFWs do not need any additional power and control lines.

From the software point of view, there is no difference between IFW and EFW. Software only sees the filter wheel controlled by the camera, regardless if the wheel is inside camera shell or in a separate shell, bolted to the camera head.

Warning:

Using single electronics to control either IFW or EFW means, that a camera cannot use both filter wheels at once. Decision which filter wheel is to be used must be made upon camera purchase, as the differences between both variants are substantial (different front and back shells, different digital electronics). While modifying the IFW variant to the EFW one and vice versa is in principle possible, it is economically not viable, because of too many parts must be replaced.

Figure 2: Bottom side of the camera with Internal filter wheel (left) and camera without IFW, but with External filter wheel attached (right)

External filter wheels bring many advantages:

- EFWs offer wide range of filter sizes and filter slot positions.
- As EFWs can incorporate very large filters (up to 65 × 65 mm), they are offered also for cameras with large and very large sensors (C4 and C5 series).
- EFWs are compatible with both asymmetrical cameras (C2, C3, C4, and C5A) and corresponding symmetrical models (C1+, C1x, C5S).
- Opening the EFW shell and exchanging filters is easier, as there are no mechanical of electronics devices inside the shell but the wheel motor drive.

Using of an External filter wheel also brings some negatives:

- Camera with EFW is bulkier and heavier compared to the IFW variant.
- While the IFW is accessible from the back side when the camera front shell is removed and filter wheel itself need not to be removed from the shell, EFWs are opened from the front side and filter wheel must be removed from the shell to be able to install or replace filters.
- Only 6 mm space is available for filters inside the EFW shell, compared to 10 mm space in the IFW.

Cameras with Standalone filter wheels

The external filter wheel diameter has construction limits, it is not possible to simply increase both EFW shell and filter wheel itself. The diameter and weight would be so big, that usage of such wheels would not be practical.

Natural solution of this problem is placing of two smaller filter wheels beside each other. The total number of filter positions is lower than the sum of positions in both wheels from obvious reason: one position in each wheel must remain empty (clear) and it is set as an actual position when a filter from the other wheel is to be used not to interfere with it. So, if for instance two filter wheels with five positions each are used, we denote such wheel as “8+Clear” positions. This means four positions in both wheels may be used for any filter, which makes 8 total filter positions. When both filter wheels are set to index 0 (the clear position), one additional clear position is added to the total number of filter positions.

The filter wheel controlling electronics, incorporated into Moravian Instruments cameras, cannot control two independent filter wheels simultaneously. So, the new line of Moravian Instruments filter wheels is equipped with own control electronics and naturally require own control and power lines, fully independent on the camera. This is why the new line is called Standalone filter wheels (SFW).

Figure 3: The SFW-5XL on the C5S camera

Hint:

SFW is the first and only line of Moravian filter wheels, capable to operate without Moravian camera and thus usable also with other brand cameras or without a camera at all.

Using of SFWs brings also changes to the driver structure. While IFWs and EFWs are controlled through a camera, SFWs need own driver stack. This means a Windows or Linux system USB driver must be installed, as well as a new user space libraries (e.g. ASCOM in Windows, INDI or driver libraries in Linux) etc.

Also, client software may handle the SFW differently. For instance, SIPS differentiates between filter wheel drivers handled by camera and fully independent filter wheel drivers:

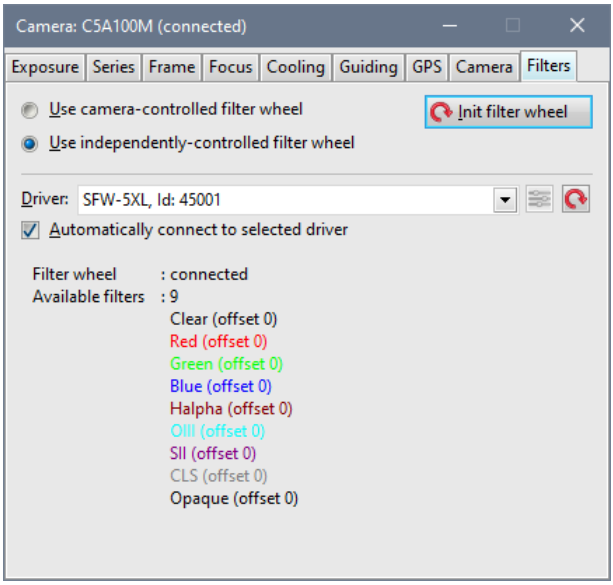


Figure 4: The Filters tab of the SIPS Imaging Camera tool allows selection between camera-controlled and standalone filter wheels

Fixing filters into filter wheel

There are two standards of filter mounting mechanism used in astronomical instruments:

- Filters mounted in **threaded cells** are intended to be screwed into a threaded socket in the filter wheel.
- **Unmounted filters** (either glass-only, or with metal rings around the glass) have to be fixed into the wheel socket using screws.

Filter in threaded cells

Only two diameters of filter cells standardized over years, in fact copying the standard diameter of telescope focusers and eyepiece mounting barrels (many new filter diameters and formats, introduced with ever increasing size of astronomical camera sensors, remained unmounted):

- 1.25” diameter cells.
- 2” diameter cells.

Filters in 1.25-inch diameter cells

While the outer diameter of these cells is well defined (1.25” or 31.75 mm), attempts to standardize the thread, used on the 1.25” cells, failed:

- The thread diameter converged to 28.5 mm and all filter manufacturers are at or very close to this diameter.
- Thread pitch on the other side quite varies among various companies:
    - Some European companies standardized on 0.5 mm pitch.
    - Some American companies use 40 TPI, which leads to 0.635 mm pitch.
    - Some companies manufacture the cell thread with pitch somewhere between these two extremes.

Luckily, the thread length is typically very small (just 2 mm on Moravian filter wheels) and thus the thread pitch differences play only small role.

Moravian Instruments filter wheels are designed to be as compatible with various standards as possible, using **M28.5 × 0.55** thread. Major filter brands, both European and American, can be used with them.

Filters in 2-inch diameter cells

Luckily, the **M48 × 0.75** thread, used on 2” cells, is the same regardless of the filter manufacturer.

> Remark:
>
> The M48 × 0.75 thread is also widely used on other astronomical equipment, as it gradually replaced the T-thread (M42 × 0.75) as a de-facto standard for focusers, optical correctors etc.

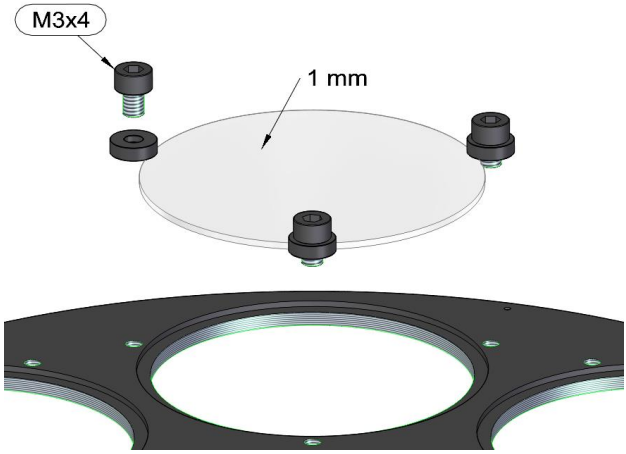
Unmounted filters

Unmounted filters must be fixed in filter wheel socket using screws. Filters are often just a piece of glass, which could be easily damaged if it is tightened only by metallic screw head. Moravian Instruments filter wheels are always accompanied with a set of plastic washers to be used between the filter itself and the fixing screw.

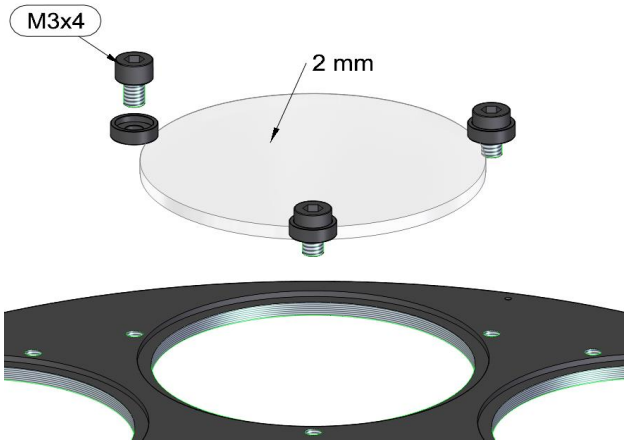
> Remark:
>
> Some manufacturers use a metallic ring around the glass to make the filter more resistant to damage. Still, using a plastic washer under the screw head is recommended also for such filters.

Moravian Instruments filter wheels use socket allowing to fix filters only 1 mm thick. But on the other side, much thicker filters must also remain compatible with the filter wheel. This is why different types of screws and washer orientation is recommended according to the thickness of the used filters:

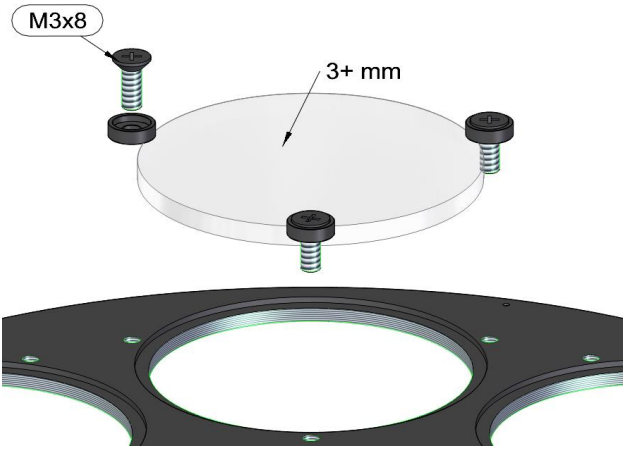
- M3 × 4 screw with cylinder head and a plastic washer oriented “upside down” is recommended for 1 mm thick filters.



- M3 × 4 screw with cylinder head and a normally oriented plastic washer is recommended for 2 mm thick filters.



- M3 × 8 screw with countersunk head and a normally oriented plastic washer is recommended for 3 mm and thicker filters.



Filter Wheel Vignetting

Filter input pupil may block part of the light cone, created by the used optics (telescope or photographic lens). Shielding typically occurs further from the optical axis, which results into darkening of the image closer to the sensor edges or corners. Such darkening is called vignetting.

Remark:

Even ideal optical system naturally suffers from slight vignetting from simple geometric reasons – the telescope input pupil for on-axis image has greater area compared to off-axis image (area of a circle vs. area of an ellipse with major axis equal to the diameter of the circle).

However, also other parts of the telescope may cause additional vignetting, like limited focuser diameter, small secondary mirror of reflecting telescopes or small telescope tube input pupil etc. But the following text concerns only vignetting caused by filter wheels and filters, as they are typically the most prominent source of vignetting.

Vignetting depends on four dimensions:

1. The used optical system f/ratio ($\frac{\text{focal length}}{\text{input diameter}}$), which defines the angle of the light input cone[1].
2. Sensor size (diagonal for round filters, longer edge for square filters).
3. Filter diameter or edge length.
4. Filter or filter wheel distance from the focal plane.

The faster optics (like the f/4 Newtonian) is more prone to vignetting than slower f/8 refractor or even f/10 SCT.

[1] This simple equation is valid for majority of telescopes, but cannot be applied to photographic lenses. The lens distance from focal plane is often greater than effective focal length, which means the ray path is more complex and the angle of the input light cone does not correspond to the lens f/ratio.

Remark:

Note especially the wide field Newtonian telescopes are often equipped with coma-correctors, which alter light cone falling to the sensor. In general, correctors prolonging focal length may lower the vignetting and vice versa. Also, keep on mind the corrector input pupil itself may introduce vignetting, too.

Specific limiting f/ratios for each camera (sensor), filter dimension, and filter wheel class (distance of the input pupil from the sensor) are stated in the respective filter wheel class description.

Internal Filter Wheels

Internal filter wheels are available for C2 and C3 cameras only, as the C4 and C5 camera require 50 × 50 mm or even 65 × 65 mm square filters, which are too big to fit into relatively small internal filter wheel.

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

- **5 positions** for unmounted **D31 mm** filters or filters in **1.25”** threaded cells.
- **6 positions** for unmounted **D26 mm** (or 1”) filters.

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

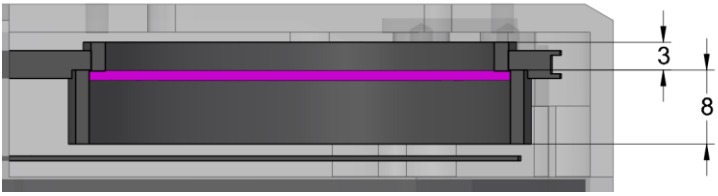
- **5 positions** for unmounted **D50 mm** (or 2”) filters or filters in **2”** threaded cells.
- **7 positions** for unmounted **D36 mm** filters[2].

Filter space

The space available for filters is the same for both C2 and C3 cameras, but it differs depending on the filter wheel type. The 3 mm thickness of the filter wheels designed for both unmounted filter and filter in threaded cells is divided to 2 mm of thread and 1 mm of a deepening for unmounted filter. The same 3 mm thickness of the filter wheels intended only for unmounted filters offer 2 mm deepening. This means the unmounted filters can be up to 1 mm thicker in this filter wheel compared to filter wheel also compatible with threaded cells.

[2] Only the C3-26000 model with APS-sized sensor can use D36 mm filters.

- The barrel portion of the filter threaded cells, used in the Internal wheel, can be up to 8 mm thick. The thread can be up to 3 mm long. So, the total thickness of the cell can be up to 11 mm.



- Unmounted filters, but fixed in the wheel designed also for threaded filter cells, can occupy up to 8 mm space. Note such space includes not only the filter itself, but also the fixing screw head and washer. As the head and washer thickness typically slightly exceed 2 mm, it is safe to use up to 5 mm thick unmounted filters.

- Filter wheels designed for unmounted filters only (either D26 mm/1” or D36 mm filters) can accommodate up to 1 mm thicker filters.

Installing or exchanging filters

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

Hint:

There are numbers (filter positions) of individual filter slots engraved in the wheel.

Opening the C2 camera head

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

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.

Figure 5: Filters in the Internal filter wheels can be exchanged after removing of the camera front cover

After removing the screws carefully turn the camera head by the telescope adapter upward. Gently pull the front part of the case. Notice there are two cables, connecting the filter wheel motor and the filter position optical bar, plugged into the electronics board. It is not necessary to unplug these

cables to change filters, but if you unplug them, take care to connect them again in the proper orientation!

> Hint:
>
> Moravian Instruments filter wheels are always designed so the aperture manufactured in the wheel, not the inserted filter, faces the incoming light cone. So, the complex shapes like unmounted filter edges, holding screws, etc., possibly causing reflections, are always hidden from the incoming light.
>
> The geometry of the IFW allows to insert or replace filters without removing the filter wheel front the camera front shell.

Opening the C3 camera head

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

Figure 6: Filters can be exchanged after removing of the camera front cover

After removing the screws carefully turn the camera head by the telescope adapter upward. Gently pull the front part of the case. Notice there are two cables, connecting the filter wheel motor and the filter position optical

bar, plugged into the electronics board. It is not necessary to unplug these cables to change filters, but if you unplug them, take care to connect them again in the proper orientation!

Changing the Whole Filter Wheel

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

Internal filter wheel vignetting

The Internal filter wheel input pupil is 24 mm from the sensor[3].

C2 cameras with Internal filter wheel

Limiting telescope f/ratio for C2 camera with internal **6-position** wheel for **D26 mm** unmounted filters or **5-position** wheel for filters in **1.25" cells**. Both filter wheels offer 24 mm input pupil[4].

Camera model	Sensor diagonal	Filter diameter	Limiting f/ratio
C2-3000	8.89 mm	24 mm	1.59
C2-5000	11.07 mm	24 mm	1.86
C2-7000	17.56 mm	24 mm	3.72
C2-9000	15.99 mm	24 mm	3.00

[3] The 24 mm distance does not depend on the camera series, it is valid for both C2 and C3 cameras, despite the illustration shows the C3 camera only.
[4] The pupil of 1.25" filter cell depends on its manufacturer and may slightly vary, but the difference from 24 mm is typically not substantial.

C2-12000	17.58 mm	24 mm	3.74
C2-46000	23.31 mm	24 mm	35.02

Except for C2-46000, other C2 models can be well used even with fast f/4 telescopes. Neither D26 mm (or D1") unmounted filters nor filters in 1.25" threaded cells are recommended for C2-46000.

The **5-position** internal filter wheel accepts also **D31 mm** unmounted filters. Using such filters enlarges the input pupil from 24 to 27 mm.

Camera model	Sensor diagonal	Filter diameter	Limiting f/ratio
C2-3000	8.89 mm	27 mm	1.33
C2-5000	11.07 mm	27 mm	1.51
C2-7000	17.56 mm	27 mm	2.54
C2-9000	15.99 mm	27 mm	2.18
C2-12000	17.58 mm	27 mm	2.55
C2-46000	23.31 mm	27 mm	6.51

Even the C2-46000 can be used with unmounted D31 mm filters in the internal wheel without vignetting with approx. f/7 or slower telescopes.

C3 cameras with Internal filter wheel

A variant of the C3 internal filter wheel for unmounted **D36 mm** filters offer 34 mm input pupil.

Camera model	Sensor diagonal	Filter diameter	Limiting f/ratio
C3-26000	28.27 mm	34 mm	4.19
C3-61000	43.29 mm	34 mm	N/A

The unmounted D36 mm filters in the internal wheel are suitable for almost every telescope when used in the C3-26000 camera, but they are too small for C3-61000 camera regardless of the used optics.

The C3 internal filter wheel for filters in **2" cells** offer 44 mm input pupil. Again, the exact diameter may vary according to manufacturer, but not much.

Camera model	Sensor diagonal	Filter diameter	Limiting f/ratio
C3-26000	28.27 mm	44 mm	1.53
C3-61000	43.29 mm	44 mm	33.61

The 2" filters in cells can be used with C3-61000 camera only at the cost of vignetting in the image corners.

Like in the case of 1.25” vs. D31 mm unmounted filters, using of unmounted **D50 mm** filters in the wheel for 2” filters enlarge the input pupil from 44 to 47 mm.

Camera model	Sensor diagonal	Filter diameter	Limiting f/ratio
C3-26000	28.27 mm	47 mm	1.28
C3-61000	43.29 mm	47 mm	6.46

The D50 mm unmounted filters can be combined with C3-61000 camera without vignetting for slower telescopes.

External Filter Wheels

The External filter wheels are designed for the broad range of Moravian instruments cameras, from the C1+ up to the large sensor C5 series.

> Remark:
>
> The smallest C1+ cameras require 12 V DC power attached to operate the External filter wheel. Other camera types require the 12 V DC power even for basic operation, so they can always control External wheels.

The External filter wheels are manufactured in several sizes, from the smallest “XS” (Extra Small) up to “XL” (Extra Large). But regardless of the filter wheel size, all filter wheels are designed to preserve the same back focal distance.

The most obvious difference among the EFW series is of course the diameter and thus number of filter positions. But individual series also differ in telescope adapter tiltable base dimension.

EFW with “S” (small)[5] adapter base

The “S”-sized adapter base is intended for adapters limited to 2” (50.7 mm) diameter, which include M42 × 0.75 (T-thread), and M48 × 0.75 threads, but also Canon and Nikon lens bayonets.

The External filter wheels with the “S” adapter base are attached to the camera head using four metric M3 screws in the corners of the 44 mm square pattern. Such mounting interface is used on C2 and C3 camera heads, as well as on the C1+ and C1× cameras.

[5] Note that the size-letters are used both to mark adapter base size (S, L, and XL) as well as External filter wheel size (XS, S, M, L, and XL). It is always necessary to properly distinguish if the size-letter denotes the adapter base or the wheel.

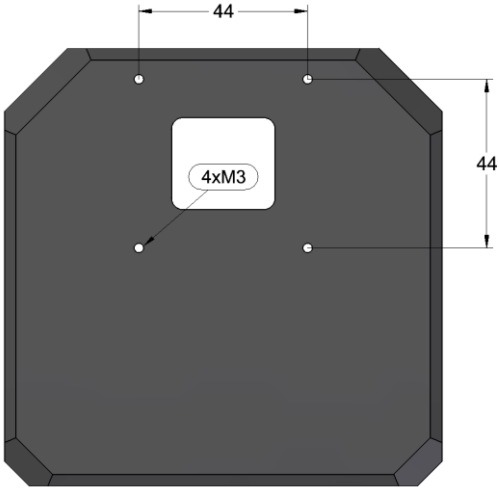


Figure 7: M3 threaded holes, used to mount the EFW, on the C2 camera head

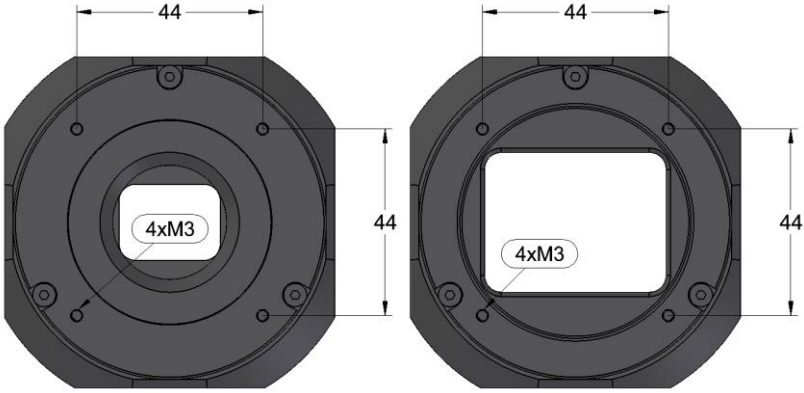


Figure 8: M3 threaded holes, used to mount the EFW, on the C1+ and C1× camera heads

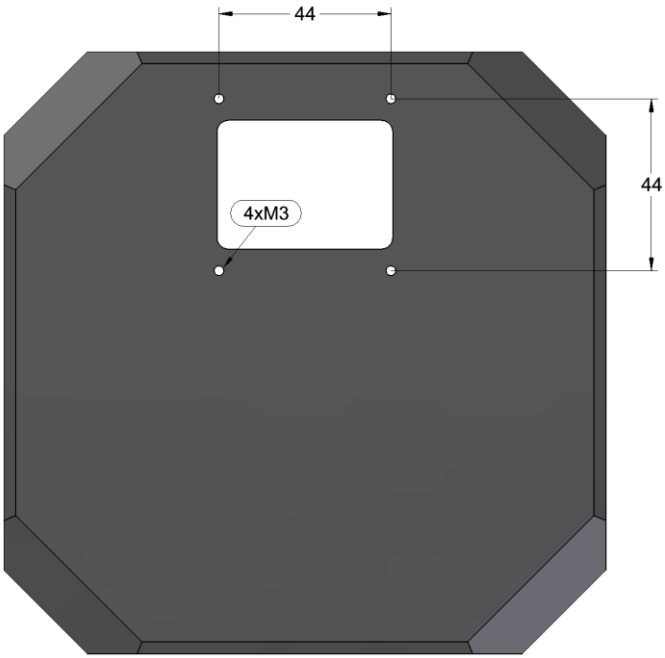


Figure 9: M3 threaded holes, used to mount the EFW, on the C3 camera head

Remark:

While the C2 and C3 cameras always use the M3 threaded holes to attach either the tiltable adapter base or filter wheel, the C1+ and C1× use a threaded adapter base, into which various telescope adapters screw. So, in the case of C1+ and C1× cameras, the M3 holes are used to mount the EFW only. If no External filter wheel is used, the M3 holes remain empty and can cause light leak. This is why the C1+ and C1× camera adapters are shipped either with M3 holes if the is supplied with EFW or the M3 holes are missing if no EFW is used.

The “XS” filter wheels

The **“XS”** filter wheels are compatible with **C1+**, **C1×**, and **C2** cameras:

- **8 positions** for unmounted filters **D31 mm** or filters in **1.25”** threaded cells.
- **7 positions** for unmounted **D36 mm** filters.

The “S” filter wheels

The **“S”** filter wheels are compatible with **C1+**, **C1×**, **C2**, and **C3** cameras:

- **12 positions** for unmounted filters **D31 mm** or filters in **1.25”** threaded cells[6].
- **10 positions** for unmounted **D36 mm** filters[7].
- **7 positions** for unmounted filters **D50 mm** or filters in **2”** threaded cells.
- **5 positions** for unmounted square **50 × 50 mm** filters.

EFW with “L” (large) adapter base

The “L”-sized adapter base is intended for greater adapters based on M68 × 1 thread, offering more robust connection between the camera and telescope. The Canon and Nikon lens bayonets are available also with the “L”-sized adapter base.

The “M” filter wheels

The **“M”** filter wheels correspond to the “S”-sized ones, only offer the “L” adapter base instead of the “S” adapter base. So, these filter wheels are compatible with the same camera series **C1+**, **C1×**, **C2**, and **C3** and accommodate the same filters:

- **12 positions** for unmounted filters **D31 mm** or filters in **1.25”** threaded cells.
- **10 positions** for unmounted **D36 mm** filters.
- **7 positions** for unmounted filters **D50 mm** or filters in **2”** threaded cells.
- **5 positions** for unmounted square **50 × 50 mm** filters.

[6] D31 mm or 1.25” filters cannot be used with C1× or C3 cameras.
[7] D36 mm filters cannot be used with C1×61000 or C3-61000 cameras.

The “L” filter wheels

The **“L”** filter wheels are always equipped with the “L” adapter base. They accommodate these filters:

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

Both “M” and “L” sized EFW are made compatible with **C2/C3** camera series as well as the **C4** series, designed for greater sensors. However, while the C4 cameras also use four M3 threaded holes to attach EFW to camera head, these holes are 52 mm apart, compared to 44 mm of the C2/C3 series. Breaking the mechanical compatibility was necessary because of the size of sensors, used in C4 line.

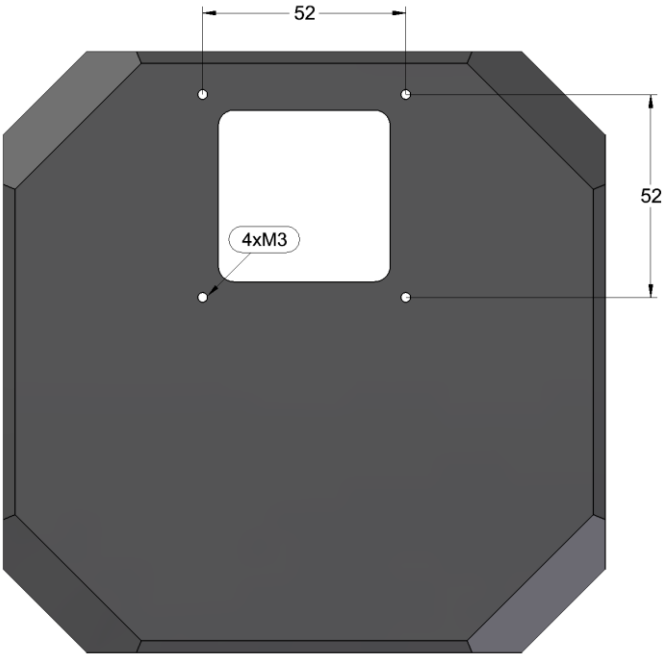


Figure 10: M3 threaded holes, used to mount the EFW, on the C4 camera head

So, both “M” and “L” wheels are offered in -3 version, compatible with C2 and C3 cameras, and -4 version, intended for C4 cameras.

EFW with “XL” (extra-large) adapter base

The “XL”-sized adapter base is designed for the M85 × 1 thread, used solely on C5 series cameras. Also, the Canon and Nikon lens bayonets are available with “XL”-sized adapter base, but photographic lenses always cause vignetting on very large C5 sensors.

The “XL” filter wheels

The **“XL”** filter wheels roughly equal to the “L”-sized ones, only offer the “XL” adapter base:

- **7 positions** for unmounted square **50 × 50 mm**[8] filters.
- **5 positions** for unmounted square **65 × 65 mm** filters.

The “XL” filter wheels use a pattern of six M3 threaded holes on the camera head, spaced by 60° around the 70 mm diameter circle:

[8] The 50 × 50 mm filters are offered for C5-100M cameras only and they still can cause some vignetting on the sensor shorter edges.

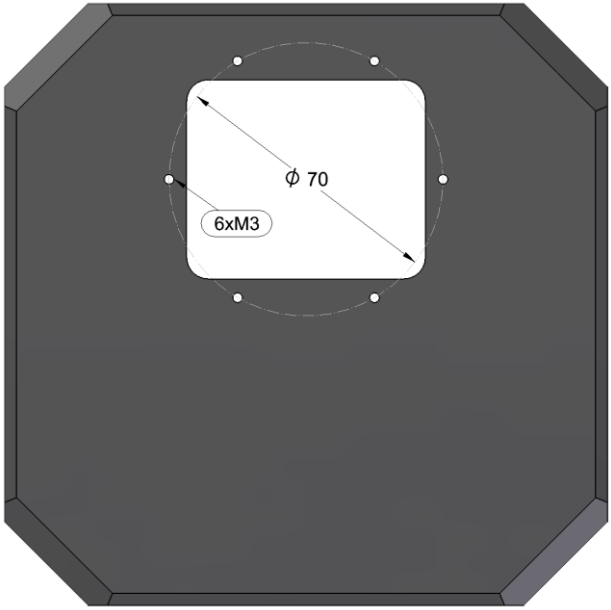


Figure 11: M3 threaded holes, used to mount the "XL" sized EFW, on the asymmetrical C5A camera head

The pattern is the same on both asymmetrical C5A and symmetrical C5S camera versions.

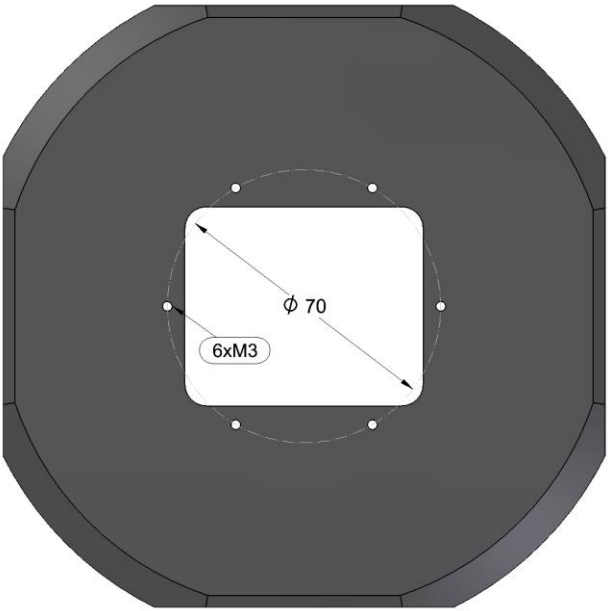


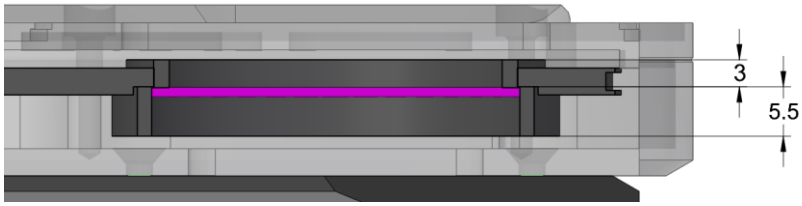
Figure 12: M3 threaded holes, used to mount the "XL" sized EFW, on the asymmetrical C5A camera head

Filter space

The space available for filters is the same, regardless of the EFW size. However, comparing to internal filter wheels, external filter wheels are thinner and thus also the space for filters is narrower.

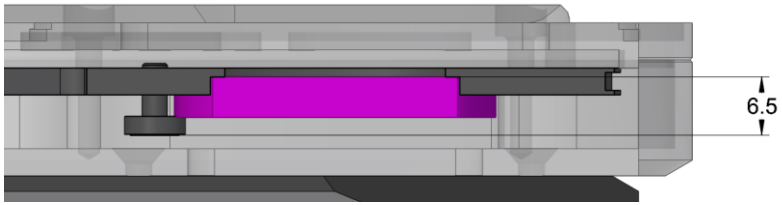
The difference between filter wheels designed for both unmounted filters and filters in threaded cells, and filter wheels intended only for unmounted filters, also apply. This means the filters can be up to 1 mm thicker if the filter wheel is designed for unmounted filters only.

- The barrel portion of the filter threaded cells, used in the external wheel, can be up to 5.5 mm thick. The thread can be up to 3 mm long. So, the total thickness of the cell can be up to 8.5 mm.



- Unmounted filters, but fixed in the wheel designed also for threaded filter cells, can occupy up to 5.5 mm space. Note such space includes not only the filter itself, but also the fixing screw head and washer. As the head and washer thickness typically slightly exceed 2 mm, it is safe to use up to 3.5 mm thick unmounted filters[9].

- Filter wheels designed for unmounted filters only (either D26 mm/1” or D36 mm filters) can accommodate up to 1 mm thicker filters.



[9] Standard photometric Johnson-Cousin filters typically can be used in the EFW, despite they are defined as 4 mm thick glass. The space between the screw head and EFW shell is stated very conservatively and also, the fixing screw head and washer are typically thinner than 2 mm.

Installing or exchanging filters

Installing or exchanging filters requires opening of the EFW shell. As there are no mechanical of electronics devices inside the shell but the wheel motor drive, opening the EFW shell and exchanging filters is easier compared to IFW.

Moravian Instruments filter wheels are always designed so the aperture manufactured in the wheel, not the inserted filter, faces the incoming light cone. So, the complex shapes like unmounted filter edges, holding screws, etc., possibly causing reflections, are always hidden from the incoming light.

The geometry of the EFW requires to remove the filter wheel from the shell to insert or replace filters. Otherwise, when the filter wheel is removed, fixing of individual filter types in the wheel remains the same like in the case of IFW.

External filter wheel vignetting

The External filter wheels allow usage of bigger filters, but at the same time filter wheel input pupil is filter wheel input pupil is 28.5 mm[10] from the sensor, further than in the case of internal wheels.

[10] All External filter wheels, from XS to XL size, are designed to provide the same BFD and also the distance of the wheel to the sensor is the same. This is valid for all camera classes, from C1+ to C5.

C1+ and C2 cameras with External filter wheel

The smallest filters available in the external wheels are mounted in **1.25" threaded cells**. Typically, these filters have 24 mm input pupil.

Camera model	Sensor diagonal	Filter diameter	Limiting f/ratio
C1+/C2-3000	8.89 mm	24 mm	1.89
C1+/C2-5000	11.07 mm	24 mm	2.20
C1+/C2-7000	17.56 mm	24 mm	4.42
C1+/C2-9000	15.99 mm	24 mm	3.56
C1+/C2-12000	17.58 mm	24 mm	4.44
C1+/C2-46000	23.31 mm	24 mm	41.59

C2-46000 would suffer from vignetting with 1.25" filters with virtually every telescope used.

When the unmounted **D31 mm** with 27 mm input pupil are used, vignetting starts to be less prominent.

Camera model	Sensor diagonal	Filter diameter	Limiting f/ratio
C1+/C2-3000	8.89 mm	27 mm	1.57
C1+/C2-5000	11.07 mm	27 mm	1.79
C1+/C2-7000	17.56 mm	27 mm	3.02
C1+/C2-9000	15.99 mm	27 mm	2.59
C1+/C2-12000	17.58 mm	27 mm	3.03
C1+/C2-46000	23.31 mm	27 mm	7.73

The C2-46000 start to be usable with unmounted D31 mm filters in the external wheel from approx. f/8.

The external filter wheels for unmounted **D36 mm** filters with 34 mm aperture are no barrier for any C2 camera, including the C2-46000 model.

Camera model	Sensor diagonal	Filter diameter	Limiting f/ratio
C1+/C2-3000	8.89 mm	34 mm	1.14
C1+/C2-5000	11.07 mm	34 mm	1.24
C1+/C2-7000	17.56 mm	34 mm	1.73
C1+/C2-9000	15.99 mm	34 mm	1.58
C1+/C2-12000	17.58 mm	34 mm	1.74
C1+/C2-46000	23.31 mm	34 mm	2.67

C1× and C3 cameras with External filter wheel

An external filter wheels for unmounted **D36 mm** filters offer 34 mm input pupil, but further from the sensor compared to Internal variant.

Camera model	Sensor diagonal	Filter diameter	Limiting f/ratio
C1×/C3-26000	28.27 mm	34 mm	4.97
C1×/C3-61000	43.29 mm	34 mm	N/A

The unmounted D36 mm filters in the external wheel are suitable for the C1×26000 and C3-26000 cameras only if combined with relatively slow optics. The C1×61000 and C3-61000 cannot be used with such small filters.

The external filter wheels for filters in **2" threaded cells** offer 44 mm input pupil, but again the exact diameter depends on the manufacturer.

Camera model	Sensor diagonal	Filter diameter	Limiting f/ratio
C1×/C3-26000	28.27 mm	44 mm	1.81
C1×/C3-61000	43.29 mm	44 mm	39.92

The vignetting in the image corners is unavoidable with 2" filters and C3-61000 camera.

The unmounted **D50 mm** filters in the wheel for 2" filters enlarge the input pupil from 44 to 47 mm.

Camera model	Sensor diagonal	Filter diameter	Limiting f/ratio
C1×/C3-26000	28.27 mm	47 mm	1.52
C1×/C3-61000	43.29 mm	47 mm	7.67

Usage of the unmounted D50 mm filters with the C1×/C3-61000 camera results into vignetting with all but quite slow telescopes.

Almost unavoidable vignetting of the C1×/C3-61000 camera combined with round filters, regardless if in 2" threaded cells or unmounted D50 mm, often causes users opt for **square 50×50 mm** filters.

Camera model	Sensor long side	Filter side	Limiting f/ratio
C1×/C3-26000	23.51 mm	48 mm	1.16
C1×/C3-61000	36.01 mm	48 mm	2.38

The square 50×50 mm filters allow usage of the C1×/C3-61000 camera without vignetting with virtually any telescope.

C4 cameras with External filter wheel

Only the **square 50×50 mm** filters in the external filter wheel are offered with the C4 cameras.

Camera model	Sensor side	Filter side	Limiting f/ratio
C4-16000	36.86 mm	48 mm	2.56

These filters place no restrictions on using the C4-16000 camera with virtually any telescope in terms of vignetting.

C5 cameras with External filter wheel

A variant of the XL-size external filter wheel for **square 50×50 mm** filters is available for the C5 cameras[11].

Camera model	Sensor long side	Filter side	Limiting f/ratio
C5-100M	43.86 mm	48 mm	6.88
C5-150M	53.42 mm	48 mm	N/A

The square 50×50 mm filters can be used with C5-100M only with very slow telescopes or at the cost of vignetting along the sensor shorter edge.

Another variant of the external filter wheel for the C5 cameras is intended for **square 65×65 mm** filters.

Camera model	Sensor long side	Filter side	Limiting f/ratio
C5-100M	43.86 mm	63 mm	1.49
C5-150M	53.42 mm	63 mm	2.97

The square 65×65 mm filters can be used with the C5 cameras with any telescope.

[11] This applies for both asymmetrical C5A and symmetrical C5S variants.

Standalone Filter Wheels

While the external filter wheels can accommodate more filters compared to the internal ones, even the external filter wheel diameter has construction limits. It is not possible to simply increase both EFW shell and filter wheel itself. The diameter and weight would be so big, that usage of such wheels would not be practical.

Natural solution of this problem is placing of two smaller filter wheels beside each other. The total number of filter positions is lower than the sum of positions in both wheels from obvious reasons: one position in each wheel must remain empty (clear) and it is set as an actual position when a filter from the other wheel is to be used not to interfere with it. So, if for instance two filter wheels with five positions each are used, we denote such wheel as 8+Clear positions. This means four positions in both wheels may be used for any filter, which makes 8 total filter positions. When both filter wheels are set to index 1 (the clear position), one additional clear position is added to the total number of filter positions.

The Moravian Instruments Standalone Filter Wheel (SFW) comes in the "XXL" flavor, which indicates it is even greater than the larges "XL" sized EFW available. Number of available positions depends on filter size:

- **8+Clear** positions for **65 × 65 mm** square filters, suitable for C5 cameras (both asymmetrical C5A and symmetrical C5S variants).
- **12+Clear** positions for **50 × 50 mm** square filters, suitable for C5-100M cameras (with some vignetting over the sensor short edge), but also for C4 and C3 cameras, also using 50 × 50 mm filters.
- **16+Clear** for unmounted filters **D50 mm** or filters in **2"** threaded cells for C3 cameras.

While the SFW filter wheels are always equipped with the "XL" sized telescope interface, offering M85 × 1 or M68 × 1 threaded adapter, as well as the Canon EOS and Nikon lens adapters, the SFW back plate is manufactured in three versions:

- The -5 version with six holes for M3 screws for C5 cameras.
- The -4 version with four holes for M3 screws 52 mm apart for C4 cameras.
- The -3 version with four holes for M3 screws 44 mm apart for C3 cameras.

Power and control interface

As opposed to IFW and EFW, the SFW filter wheels need separated power and control lines. The SFW control unit is equipped with 12 V DC 5.5/2.5 mm power plug as well as USB 1.1 data connection.

The SFW control can be also handled by the Moravian Camera Ethernet Adapter together with a main imaging, guiding, and context cameras. Only make sure the Moravian Camera Ethernet Adapter device is updated with the latest firmware available.

> Remark:
>
> The SFW is supported in the SIPS v4.1 and later software, as well as in the latest ASCOM drivers for Windows, Linux libraries and INDI/INDIGO drivers are available etc. Also, the Moravian Camera SDK contains libraries, headers and API description allowing to control the SFW from other software packages as well as from Python etc.

Back focal distance

While all EFWs from “XS” to “XL” size are designed to preserve the very same BFD on all Cx cameras, the SFW naturally increased the BFD because of the design using two overlapping wheels. The resulting BFD depends on

the adapter used.

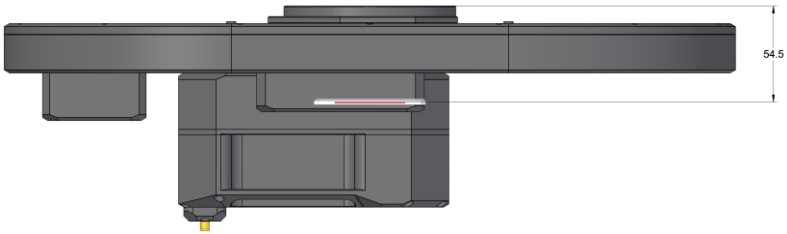


Figure 13: The C5 camera with SFW and M85 × 1 adapter offers 54.5 mm BFD

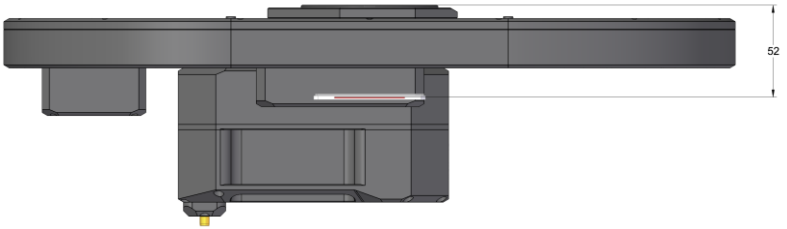
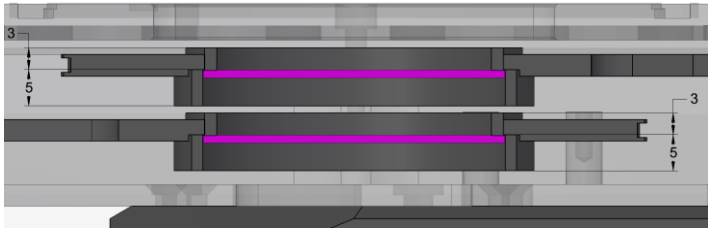


Figure 14: The C5 camera with SFW and M68 × 1 v2 adapter offers 52 mm BFD

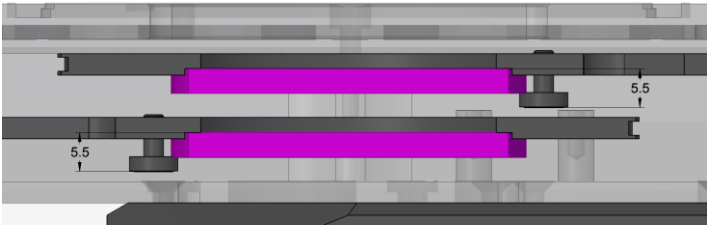
Filter space

The space for filters in the SFW corresponds to the space available in EFW wheels.

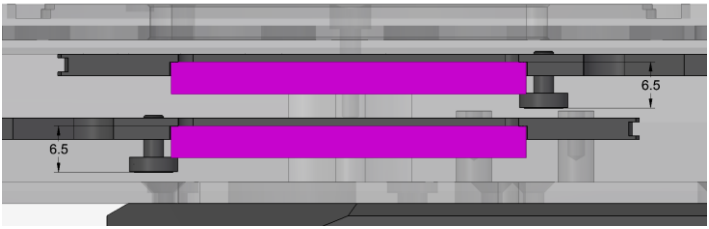
- The barrel portion of the filter threaded cells, used in the standalone wheel, can be up to 5 mm thick. This is 0.5 mm less compared to EFW; the reason is up to 1 mm space of the threaded part of filters in the second wheel. The thread can be up to 3 mm long. So, the total thickness of the cell can be up to 8 mm.



- Unmounted filters, but fixed in the wheel designed also for threaded filter cells, can occupy up to 5.5 mm space. Note such space includes not only the filter itself, but also the fixing screw head and washer. As the head and washer thickness typically slightly exceed 2 mm, it is safe to use up to 3.5 mm thick unmounted filters[12].



- Filter wheels designed for unmounted filters only (either square 50 × 50 or 65 × 65 mm filters) can accommodate up to 1 mm thicker filters.



Filter positions

Distinguishing to which position should be each wheel rotated is handled by the filter wheel driver and from the user's perspective such wheel acts as one wheel with 9 positions, filters are indexed from 1 to 9.

It is necessary to open the SFW front shell prior to installing filters. There are two filter wheels inside, one is on top (closer to the telescope), another is on the bottom of the shell.

[12] Standard photometric Johnson-Cousin filters typically can be used in the EFW, despite they are defined as 4 mm thick glass. The space between the screw head and EFW shell is stated very conservatively and also, the fixing screw head and washer are typically thinner than 2 mm.

Figure 15: Top and Bottom filter wheels in the SFW shell

8+Clear filter wheel

Final position	Filter wheel	Wheel position
1 (clear)	Bottom/Top	1
2	Bottom	2
3	Bottom	3
4	Bottom	4
5	Bottom	5
6	Top	2
7	Top	3
8	Top	4
9	Top	5

12+Clear filter wheel

Final position	Filter wheel	Wheel position
1 (clear)	Bottom/Top	1
2	Bottom	2
3	Bottom	3
4	Bottom	4
5	Bottom	5
6	Bottom	6

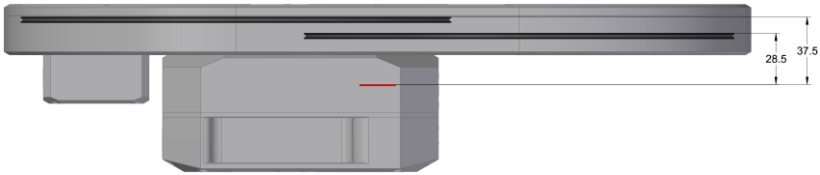
7	Bottom	7
8	Top	2
9	Top	3
10	Top	4
11	Top	5
12	Top	6
13	Top	7

16+Clear filter wheel

Final position	Filter wheel	Wheel position
1 (clear)	Bottom/Top	1
2	Bottom	2
3	Bottom	3
4	Bottom	4
5	Bottom	5
6	Bottom	6
7	Bottom	7
8	Bottom	8
9	Bottom	9
10	Top	2
11	Top	3
12	Top	4
13	Top	5
14	Top	6
15	Top	7
16	Top	8
17	Top	9

Standalone filter wheel vignetting

The Standalone filter wheels contain two wheels, one above another. The “bottom” wheel (closer to the camera) keeps the same distance 28.5 mm from the sensors like the External filter wheels. But the input pupils of both wheels are the same and thus only the “top” wheel (closer to the telescope) affects vignetting and the distance 37.5 mm between input pupil and sensor must be counted. So, SFWs cause greater vignetting compared to EFWs.



C1× and C3 cameras with Standalone filter wheel

A standalone filter wheel for unmounted **D50 mm** filters offer 47 mm input pupil, but further from the sensor compared to the External variant.

Camera model	Sensor diagonal	Filter diameter	Limiting f/ratio
C1×/C3-26000	28.27 mm	47 mm	2.00
C1×/C3-61000	43.29 mm	47 mm	10.10

The unmounted D50 mm filters in the standalone wheel are suitable for the C1×26000 and C3-26000 cameras, but usage with C1×61000 and C3-61000 will always lead to some vignetting in the image corners.

The **square 50×50 mm** filters are more suitable for the usage in the SFW.

Camera model	Sensor long side	Filter side	Limiting f/ratio
C1×/C3-26000	23.51 mm	48 mm	1.53
C1×/C3-61000	36.01 mm	48 mm	3.13

These filters do not impose limitations for the C1×/C3-61000 camera with SFW with virtually any telescope.

C4 cameras with Standalone filter wheel

Only the **square 50×50 mm** filters in the standalone filter wheel are offered with C4 cameras.

Camera model	Sensor side	Filter side	Limiting f/ratio
C4-16000	36.86 mm	48 mm	3.37

Even with SFW, the 50×50 mm square filters do not cause vignetting even with quite fast telescopes.

C5 cameras with Standalone filter wheel

A variant of the standalone filter wheel for **square 50×50 mm** filters can be used with C5 cameras.

Camera model	Sensor long side	Filter side	Limiting f/ratio
C5-100M	43.86 mm	48 mm	9.06

C5-150M	53.42 mm	48 mm	N/A

However, the square 50×50 mm filters in the SFW cause vignetting along the sensor shorter edge even with the C5-100M camera.

The **square 65×65 mm** filters offer much wider input aperture 63 mm.

Camera model	Sensor long side	Filter side	Limiting f/ratio
C5-100M	43.86 mm	63 mm	1.96
C5-150M	53.42 mm	63 mm	3.91

These filters do not limit usage with any C5 camera combined with SFW.

Filter wheel software tools

Definition of filters in the filter wheel

Every camera driver for SIPS has to provide information about available filters (if the particular camera has the integrated or external filter wheel). But the user can order camera with various filters, it is possible to change individual filters or the whole filter wheel etc. There is no way how to determine the actual filter types (colors) in the filter wheel automatically. So, the user must define such information.

Standalone utility program, contained in the SIPS installation version 3.0 and later, is provided to allow definition of filters installed in the particular camera (or cameras).

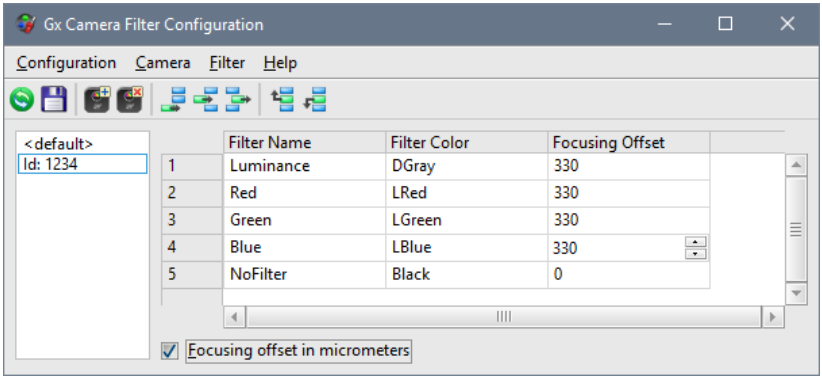


Figure 16: Main window of the filter configuration program

This program is named 'GxFWConfig.exe' and can be run either but clicking of its desktop icon or from the Start menu.

The utility handles filter information, located in the user-specific (HKCU) portion of the Windows Registry (a database containing configuration information for applications and operating system services).

> Please note that because the filter configuration is held individually for every user, definition created by one user is not accessible if another user is logged into the operating system.

The filter description information is read from the Registry upon the program start-up. When the program finishes and modified configuration is not saved back, the user is asked whether to quit the program either way and abandon all performed changes. Read and Write operations can be invoked also manually:

 – refresh (read) the configuration according to current content of the Registry

 – write the current state to the Registry

The configuration tool allows definition of filters used in any particular camera, identified by its Id number:

 – add new camera Id

 – remove currently selected camera Id

Cameras are listed in the left part of the application window. What's more, there is a possibility to define one global <default> configuration, which is used if a camera with Id not listed in the camera list is connected.

Individual filters are described in the sheet on the right side of the application window. Sheet lines, representing individual filters, can be manipulated by the following commands:

 – append new filter description

 – insert new filter description

 – remove currently selected filter description

 – move currently selected filter description one position up

 – move currently selected filter description one position down

If there are more filters in the camera than the configuration describes, other filters will be added with undefined name. And if the configuration describes more filters than the number of filters in the camera, superfluous descriptions will be omitted.

Each filter definition consists of three values:

- **Filter name**: This name is returned to the client application, which can use it to list available filters in the filter wheel.
- **Filter color**: This color can be used by client application to display the filter name with a color, hinting the filter type. The color can be expressed by a name (White, Red, LRed, etc.) or directly by number representing the particular color (0 represents black).
- **Filter offset**: Distance to move the focuser to refocus upon filter change. Plan-parallel glass shifts the actual focus position back for 1/3 of the glass thickness (exact value depends on the glass refraction index, but for almost all glasses 1/3 is very close to exact value). Refocusing is useful when changing filters of different thickness among exposures or when some exposures are performed through filters and other without filters at all.

  Filter offsets can be defined in the focuser dependent units (steps) or in micrometers (µm). If the micrometers are used, it is necessary to inform driver by checking the “Focusing offset in micrometers” check-box, located below the filter description sheet.

The above-mentioned information will be used e.g. to display the filter-choosing combo-box of the SIPS “Imaging Camera” tool:

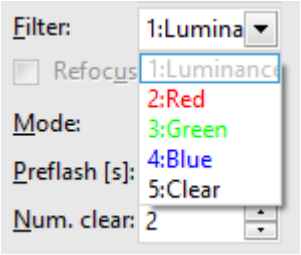


Figure 17: Filters offered by the SIPS Imager tool

Definition of filters using configuration file

If the filter definition is not found in the Registry, the Gx camera driver for SIPS uses alternate way to describe used filters – the 'gxusb.ini' file.

The 'gxusb.ini' file is placed in the same directory where the camera driver and the SIPS itself is installed.

> Note that when no portable version of SIPS, which can be located in arbitrary directory, is used, but SIPS is installed into the “Program Files” directory, this particular directory is protected by UAC (User Access Control) mechanisms in Windows. When the file INI is opened into editor (e.g. notepad) and modified, it cannot be just saved into the same directory. It is necessary to save it elsewhere and then copy it back to its original location in the “Program Files”, because it is necessary to confirm UAC dialog box during file copy operation.

Configuration file is ordinary text file following the .INI files conventions. Here is the example of the 'gxusb.ini':

```
[filters]
Luminance, Gray, 330
Red, Lred, 330
Green, Lgreen, 330
Blue, Lblue, 330
Clear, 0, 0
```

Filters are described in the **[filters]** Section. Every line in this section describes one filter position. Filter description is a comma-separated list of three values, identical to items described in the previous chapter.

Filter offsets can be defined in the focuser dependent units (steps) or in micrometers (µm). If the micrometers are used, it is necessary to inform driver by the **MicrometerFilterOffsets** parameter in the **[driver]** section of the ini file.

```
[driver]
MicrometerFilterOffsets = true

[filters]
Luminance, Gray, 660
...
```

Value of the **MicrometerFilterOffsets** parameter can be expressed as keywords **true** or **false** as well as numbers **0** (for false) or **1** (for true).

Using of multiple configuration files for different cameras

It is sometimes necessary to work with multiple cameras, sharing single driver on the computer (whole series of Gx cameras share 'gxusb.dll' or 'gxeth.dll' drivers). If multiple cameras have different filter wheels with different filters, it is rather complicated to adopt the 'gxusb.ini' configuration file to currently connected camera. If there are multiple cameras connected at once, adopting of configuration file is not possible.

This is why SIPS camera drivers (and also Gx/Cx camera drivers for other programs) allows enhanced naming convention of driver configuration file. Every Gx and Cx series camera has unique identification number, stated on the camera shell (this number is also displayed in the list of all connected cameras in the SIPS “Imaging Camera” tool).

Camera driver tries to open configuration file, which name is extended with the camera ID number first. If for instance camera ID is 1234, driver tries to open configuration file named 'gxusb.1234.ini'. Only if such file does not exist, general configuration file 'gxusb.ini' is used. So, it is possible to create separate configuration files describing filters in every connected camera.

Number of filters definition tool

If the camera is equipped with internal or external filter wheel then the number of filters in the wheel is stored in the camera permanent memory. Similarly, in the case the camera is not equipped with filter wheel at all, number of filters 0 indicates to the firmware that the filter wheel initialization routine should be skipped and camera start-up time is reduced significantly.

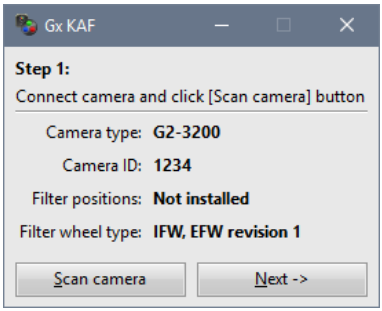
If the number of filers in the attached filter wheel changes (e.g. 5-positions filter wheel is replaced with 7-positions one), it is necessary to change the camera permanent memory.

Similarly, if the filter wheel is added to the camera, which was not configured to control filter wheel (number of filters was 0) or filter wheel is completely removed from the camera (number of filters should be 0), camera permanent memory must be changed, too.

> If a filter wheel is attached to camera configured not to use filters, the newly added wheel simply does not work. On the other side, if the filter wheel is removed from the camera, configured to use filters, camera firmware tries to initialize the filter wheel upon startup. Initialization sequence fails and camera then continues to operate, the time needed to start the camera is unnecessarily long.
>
> This is also the reason to store number of filters in camera permanent memory. In principle camera firmware would be able to check the filter wheel presence and to count the number of filters if the filter wheel is connected, but the start-up sequence would be much longer.

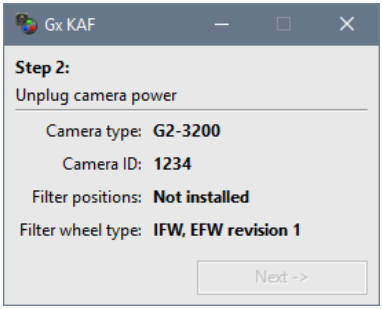
Number of filters configuration tool is located in the folder '\Tools\GxNumFilters\ GxNumFilters.exe' on the accompanying Flash Drive.

Please note the GxNumFilters utility needs administrative permissions to run. Windows indicates it by displaying of the small shield on the bottom-right corner of the program icon and users are prompted to allow it to run with administrative rights upon launch.

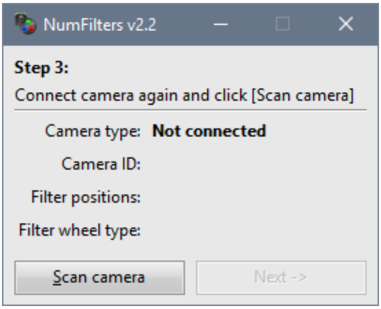


When the tool is run, it checks whether some camera is connected. If yes, it connects to it and shows its ID. If not, user have to connect camera and click “Scan camera” button.

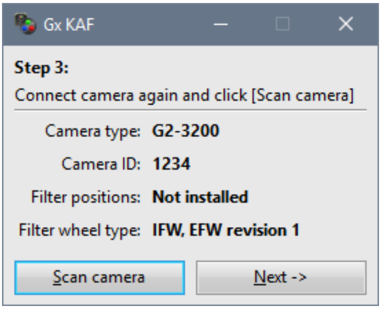
Always run this utility with one camera connected only. If multiple cameras are connected, the utility may fail.



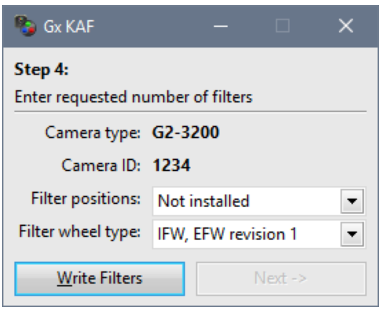
Then it is necessary to un-plug and plug again the camera.



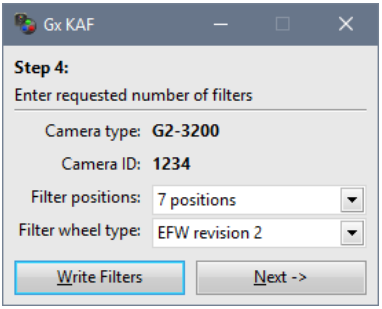
When camera is again plugged, click the “Scan camera” button.



Note the tool shows the information about number of filter positions as well as about type of filter wheel.



Information texts are replaced with edit controls, allowing to change current status.



Choose the desired values and click the “Write Filters” button.

Please note changes in the camera permanent memory will be applied only after the camera is powered off and on again.

The “Filter wheel type” allows selection of two types:

- IFW, EFW revision 1
- EFW revision 2

If internal filter wheel is used, always choose the first option.

All new Mark I as well as all Mark II external filter wheels are manufactured as revision 2 only.

To distinguishing legacy external filter wheel revision 1 and 2, check the size of the motor box on the bottom of the external filter wheel housing. Revision 2 motor boxes are bigger and slightly extends the filter wheel shell outline.

Figure 18: External filter wheel revision 2 (left) and revision 1 (right)