WYFFOS scattered light analysis

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Introduction

Unidentified scattered light could be seen on the detector of WYFFOS. The problem is known for a long time and a few baffling solution was realized, but none of them solved the problem completely. The present document gives an overview on the work that has been done to reduce scattered light in WYFFOS.
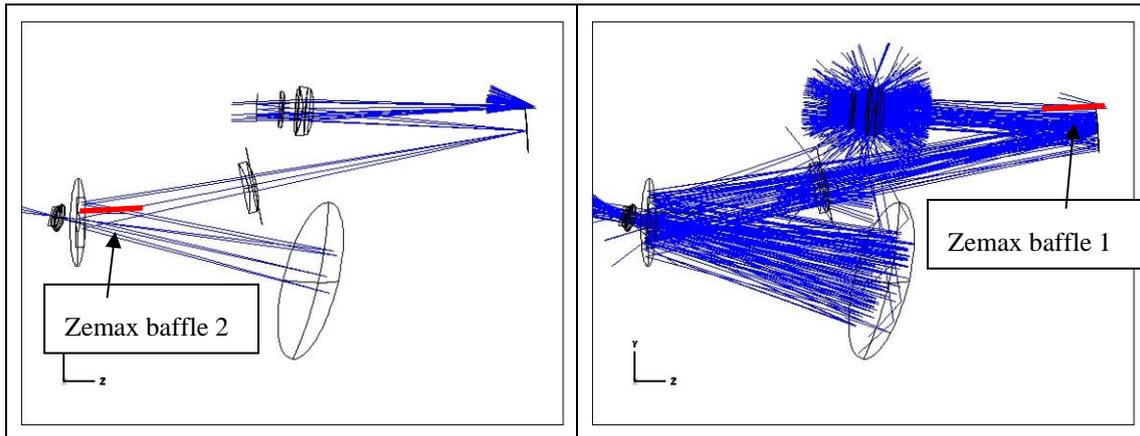
Scattered light analysis in Zemax

The "wyffos06-asbuilt.zmx" file was used for the analysis in Zemax. For the scattered light analysis the file had to be converted in order to be able to use with non-sequential ray tracing (in Zemax terms from SC to NSC). In sequential mode rays are traced from the object surface to each surface in a specific, sequential order, while in non-sequential mode the ray may strike any object in any order, and the ray may even strike the same object multiple times. Also it is possible to define refractive, reflective and scattering properties, so it makes the scatter analysis more accurate.
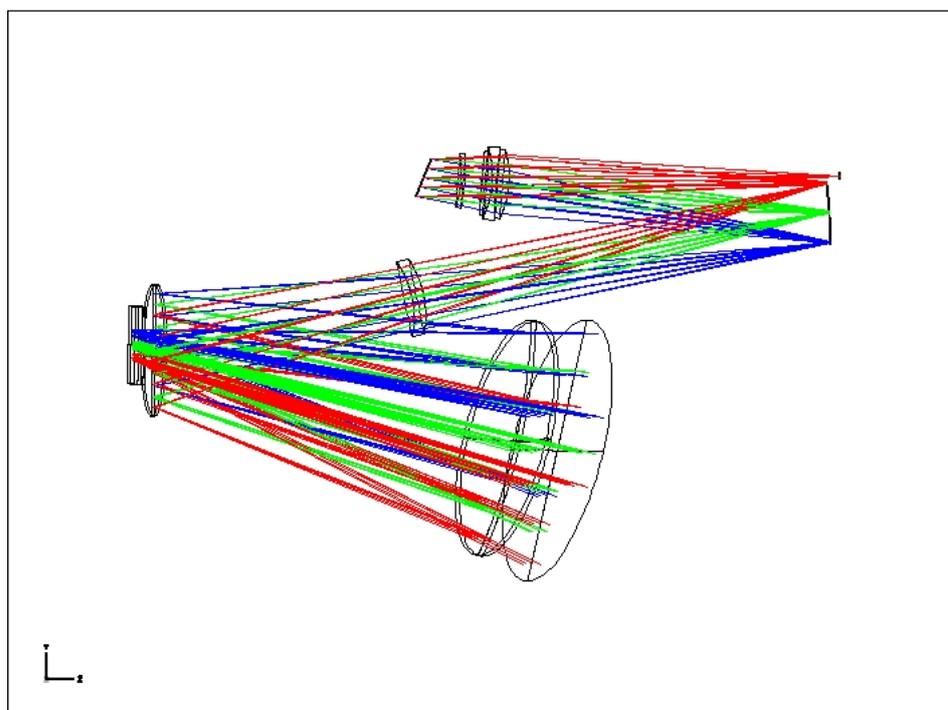
Figure 1 WYFFOS optical layout

The following images (Figure 2) show WYFFOS in Non-Sequential mode after conversion, where the baffles are modelled as well. They show possible light paths for one wavelength only. Left image shows the situation without scatter, the right image with scatter. It can be seen that the source of scattered/reflected light could come from several objects, e.g. from the fibres themselves, from the grating, from the double pass collimator lens or from the negative lens that is positioned between the relay mirror and the flat mirror just in front of the camera.

Double bounce reflections from the internal surfaces of the lenses create ghosts, while light from the fibres or from the grating (unwanted spectrum of light or from other orders) contribute to scattered light.

Figure 2 Scattered light in WYFFOS

According to the Zemax analysis there are two essential places for baffles: "Zemax baffle 1" position is next to the relay mirror and "Zemax baffle 2" position next to the CCD. The first baffle is needed in order to block the light that falls directly from the fibres to the negative lens (and this way entering into the light path) and the second to eliminate light that falls onto the detector directly from the negative lens (it has to be reflected first the two mirrors and only then it should reach the CCD).

Baffle 2 is installed, but it is not fully appropriate. From the Zemax model it became apparent that this currently installed baffle (Zemax baffle 2) has to be larger and tilted more into the direction of the big spherical mirror's optical axis in order to be more efficient. Contrast could be increased and scattered light could be reduced with these modifications.

The following figures show images of the WYFFOS detector with and without baffles ("Zemax baffle 1 & 2") in linear and logarithmic (log5) visualization. Approximately the 80% of the slit could be seen and only one wavelength is visualized at a time. The scattered light analysis was done with three wavelengths range: 365-467 nm, 513-674 nm and 725-974 nm. The images have to be mirrored vertically in order to get the image that is shown normally in ds9.

Scattered light for the 365-467 nm range
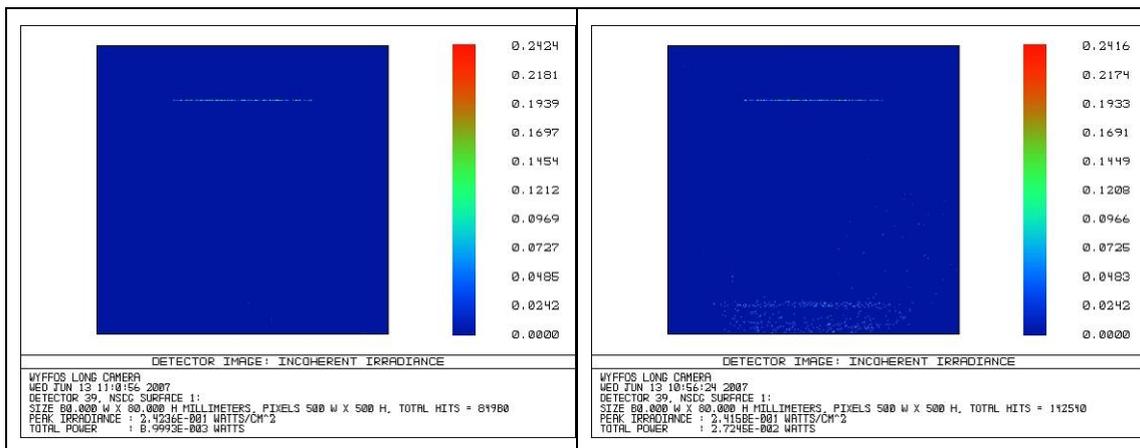
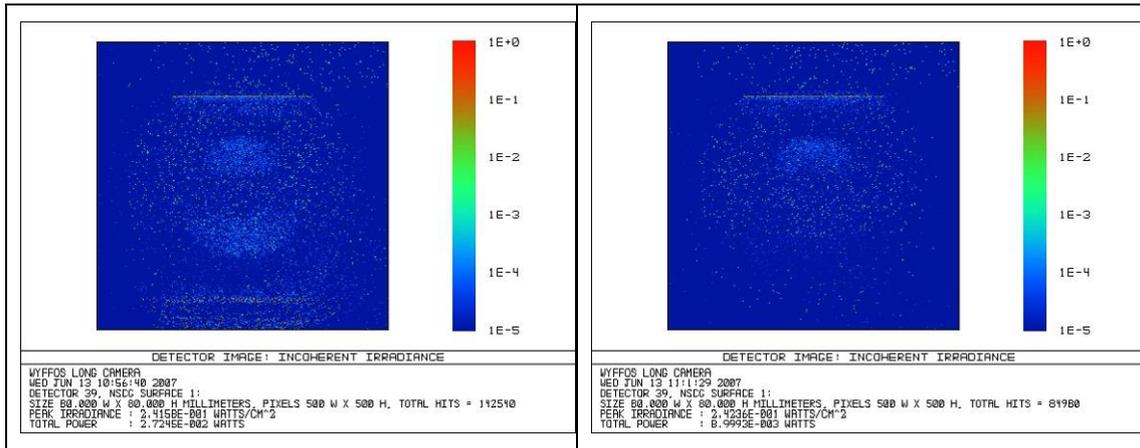**Figure 3 Scattered light for the 365-467nm range, left without baffles, right with baffles (linear scale)**

Figure 4 The same as above but the data is shown in log5 scale

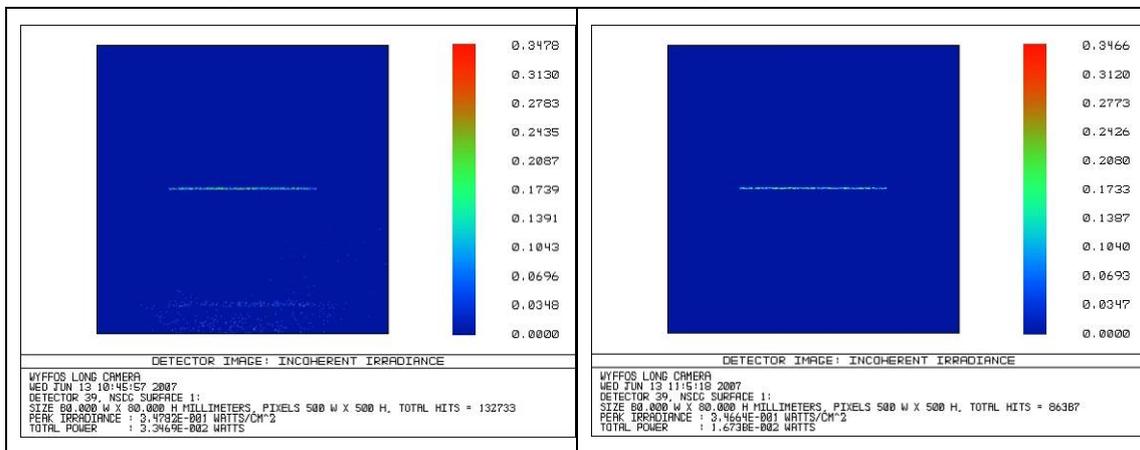## *Scattered light for the 513-674 nm range*

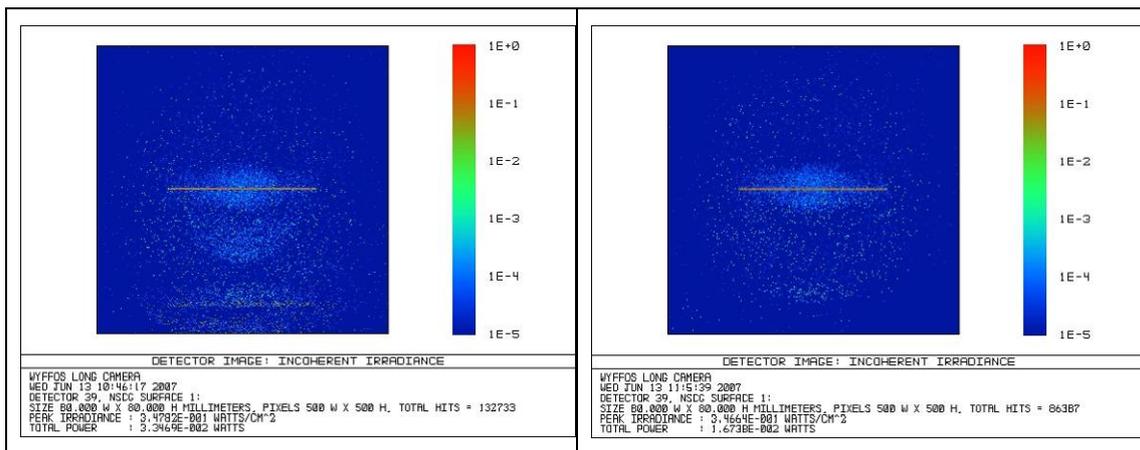**Figure 5 Scattered light for the 513-674nm range, left without baffles, right with baffles (linear scale)**

Figure 6 The same as above but the data is shown is log5 scale

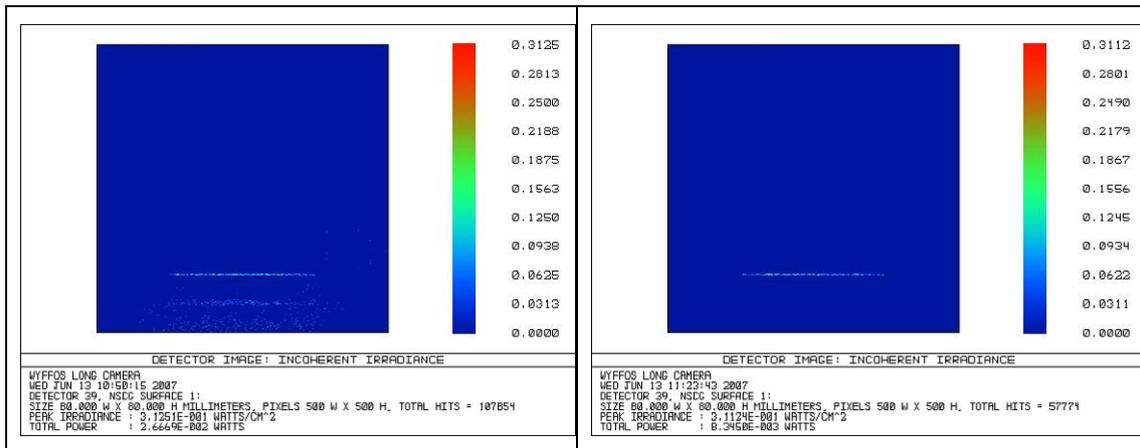## *Scattered light for the 725-974 nm range*

Figure 7 Scattered light for the 725-974nm range, left without baffles, right with baffles (linear scale)
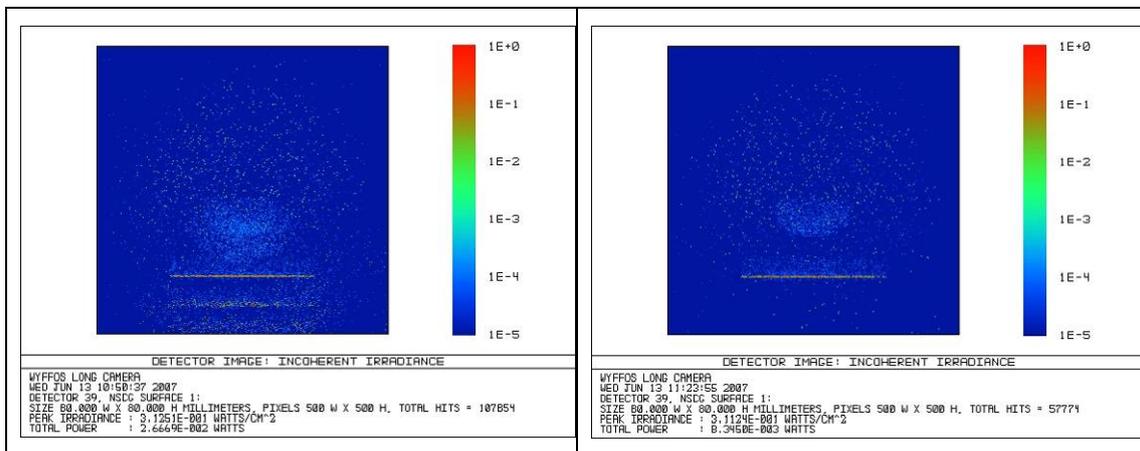

Figure 8 The same as above but the data is shown in log5 scale

Scattered light test with WYFFOS

After the analysis had been done in Zemax, the next step was to check the results calculated in Zemax in the practice. Exposures were taken with the WYFFOS detector and the images were compared to the ones that were from Zemax. Several baffling solutions were installed and then the scattered light was identified.

The R600R grating was used during the tests, its characteristics could be seen below. The grating was used with the "WY_8830 filter", which was inserted in the optical path in filter B position. This configuration was appropriate to visualize the scattered light in WYFFOS.

Table 1 R600R grating characteristics in WYFFOS

Grating	Wavelength blaze (ang)	Dispersion (ang/pix)	Resolution (ang)	Spectral coverage (ang)
R600R	7000	0.8	4.4	3000

Original baffle configuration

Table 2 shows information on the exposures that were taken during the initial step of the scattered light tests. The images themselves are shown in Table 3; the spectra are shown on the left side with linear scaling, on the right logarithmic (log5).

On r976455.fit the spectra is centred and the rest of the images up to r976458.fit show when the spectra is shifted to the red region, then from r976459.fit to r976464.fit when it is shifted to the blue.

It is important to mention that in all of the cases the scattered light could only be seen when the data was visualized with logarithmic scaling (log5). Also in many cases some part of the spectra was saturated, so exposure times were close to the limit. Consequently the ratio of the scattered light/spectra was really low. The main objective of these tests was to find the reason of the scattered light and so essentially the effect of the new baffle instalments were examined and not the quantification of the scattered light was the main objective.

Table 2 Exposures and corresponding notes

File	Central wavelength (ang.)	Integration time (sec)	Filter B – WY_8830	Notes
r976455.fit	8000	0.5	IN	Spectra in the middle of the imaging area
r976456.fit	8400	0.5	IN	
r976457.fit	8800	0.5	IN	
r976458.fit	9200	0.5	IN	

r976459.fit	7600	0.5	IN	
r976460.fit	7200	0.5	IN	
r976461.fit	6800	0.5	IN	
r976462.fit	6400	0.5	IN	
r976463.fit	6400	0.5	IN	Screw covered next to the relay mirror
r976464.fit	6400	0.5	IN	Longer baffle used next to the detector (Zemax baffle 1)

Table 3 Scattered light tests with the original baffle configuration

File	*Lin*	*Log*
r976455.fit		
r976456.fit		
r976457.fit		

r976458.fit		
r976459.fit		
r976460.fit		
r976461.fit		
r976462.fit		
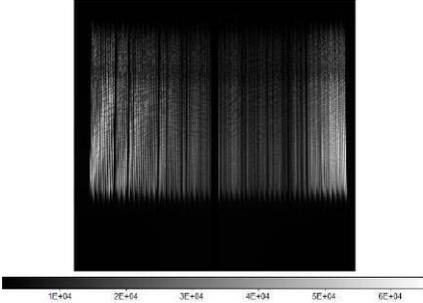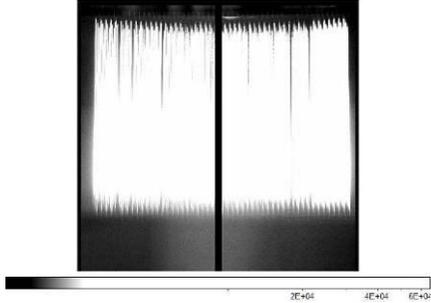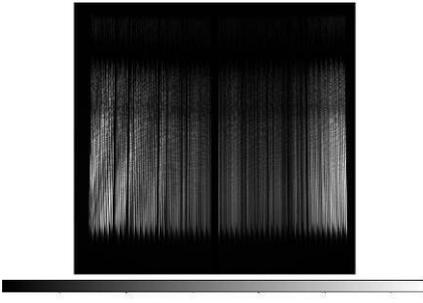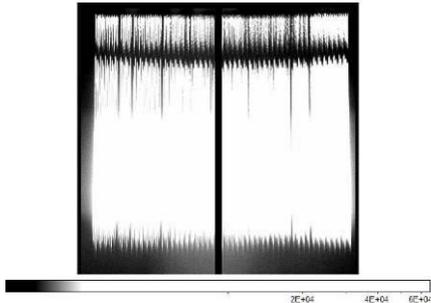
r976463.fit		
r976464.fit		
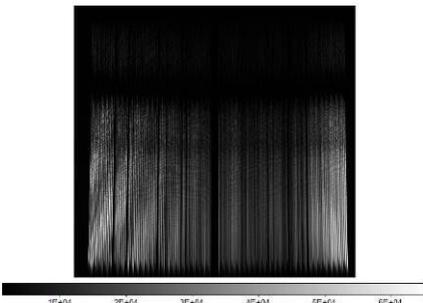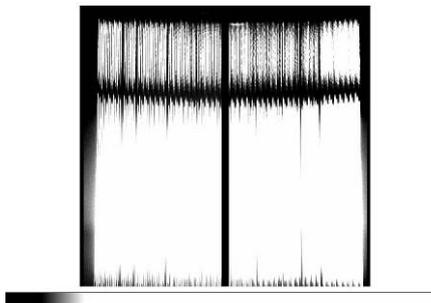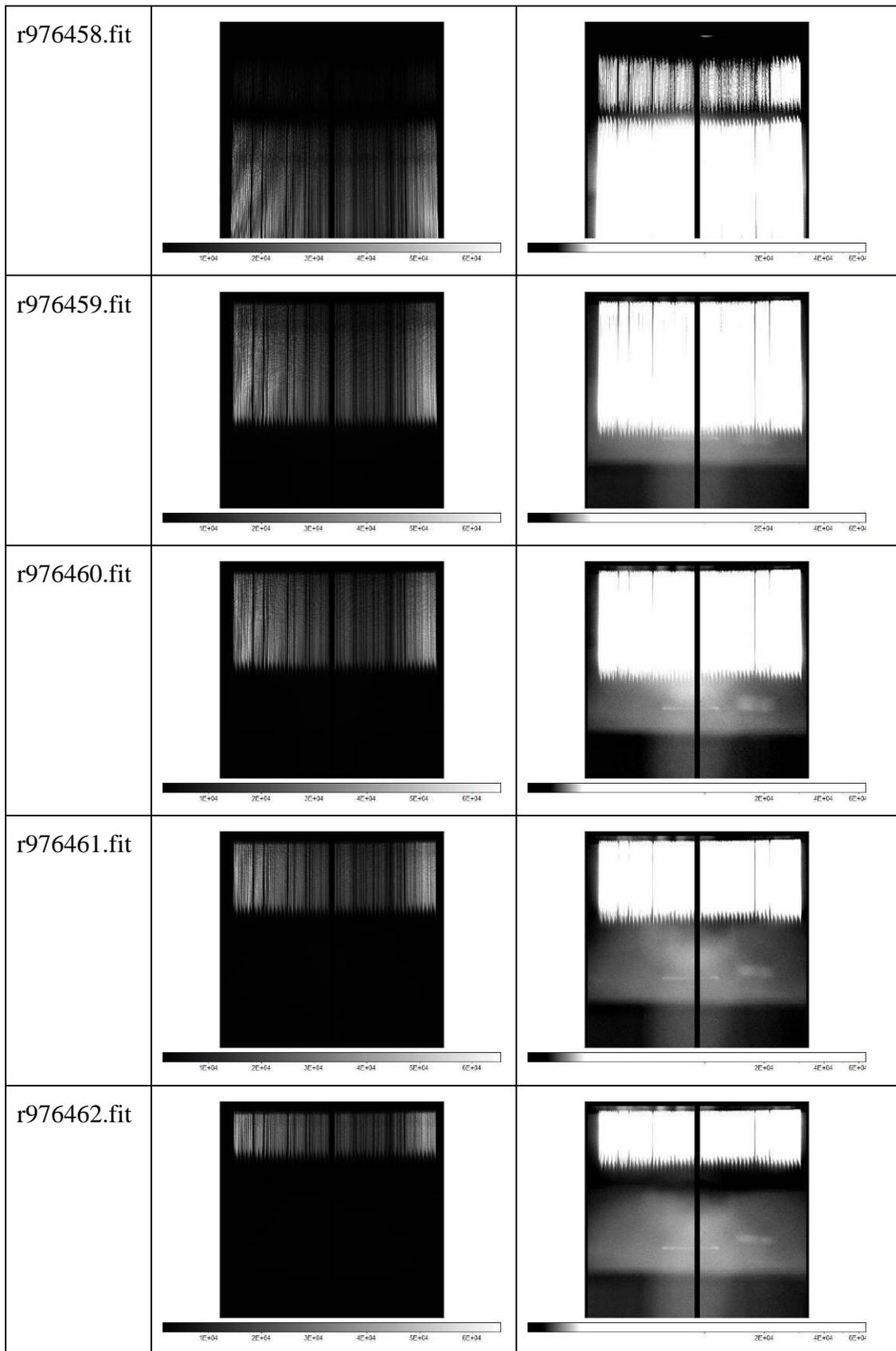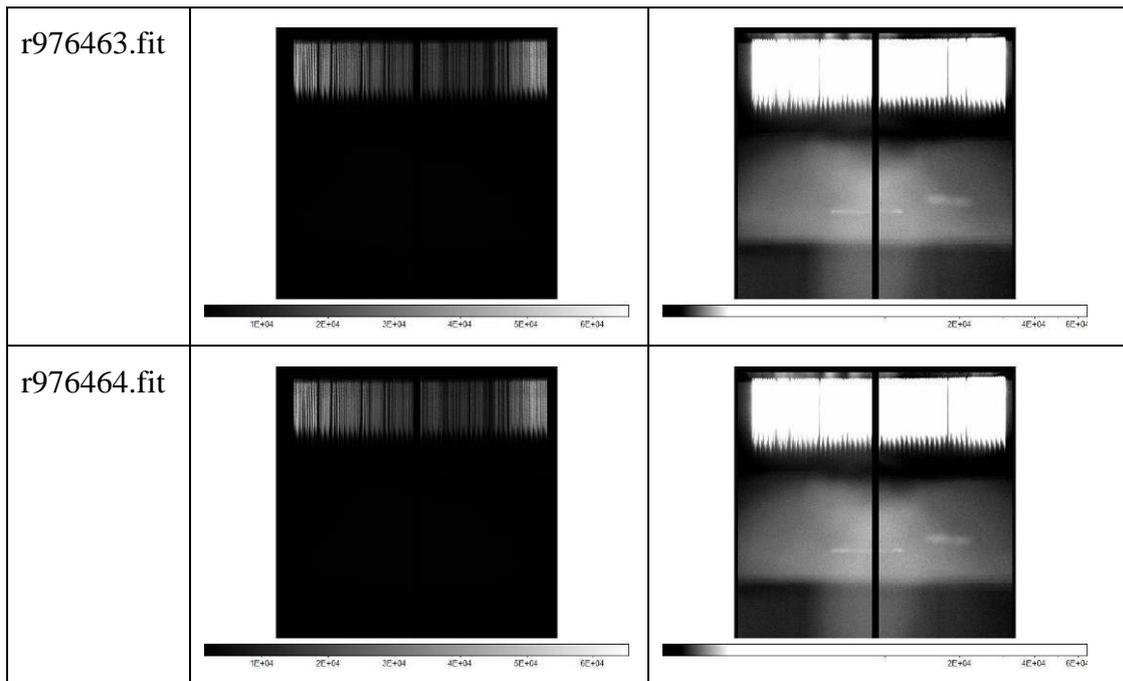
New baffle configuration

After images were taken with the original baffle configuration, new baffles were installed in specific places within WYFFOS (the new instalments are listed in the notes column of the following tables). These positions were in correspondence with the Zemax analysis.
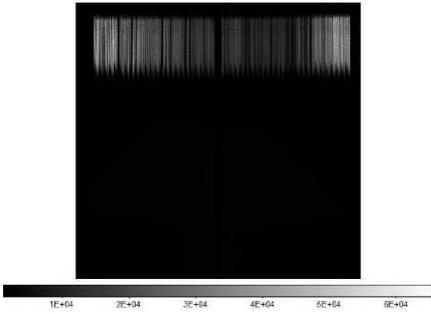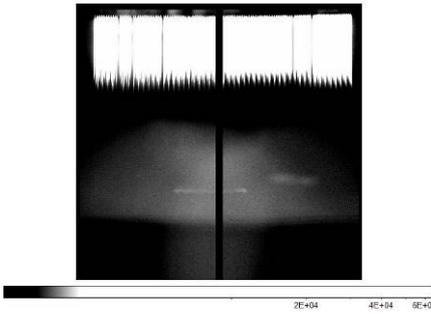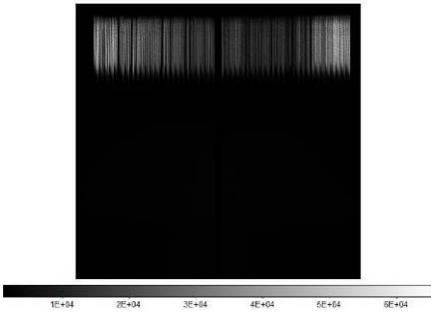
Table 4 shows information on the exposures that were taken during the new baffle instalments. The images themselves are shown in Table 4; the spectra are shown on the left side with linear scaling, on the right logarithmic (log5).

Table 4 Information on the exposures that were taken with WYFFOS during the new baffle instalments

File	Central wavelength (ang.)	Integration time (sec)	Filter B – WY_8830	Notes
r977820.fit	6400	0.5	IN	
r977821.fit	6400	0.5	IN	Baffle next to the relay mirror (Zemax baffle 1)
r977822.fit	6400	0.5	IN	Longer baffle next to the CCD (Zemax baffle 2)
r977823.fit	6800	0.5	IN	
r977824.fit	6800	0.5	IN	Longer and wider baffle next to the CCD (Zemax baffle 2)

r977825.fit	6800	0.5	IN	Filter A IN
r977826.fit	6800	0.5	IN	Small folded baffle next to the CCD (Zemax baffle 2)
r977827.fit	6800	0.5	IN	Big folded baffle next to the CCD (Zemax baffle 2)
r977828.fit	6800	0.5	IN	Small folded baffle + wider baffle next to the CCD (attached to the inner side of the existing baffle to eliminate reflections from the baffle itself) - (Zemax baffle 2)
r977829.fit	6400	0.5	IN	
r977837.fit	7900	1	IN	
r977838.fit	8000	1	IN	
r977839.fit	8000	0.5	IN	

Table 5 Scattered light tests with the new baffle configuration

File	*Lin*	*Log*
r977820.fit		
r977821.fit		

r977822.fit		
r977823.fit		
r977824.fit		
r977825.fit		
r977826.fit		

r977827.fit		
r977828.fit		
r977829.fit		
r977837.fit		
r977838.fit		

r977839.fit		
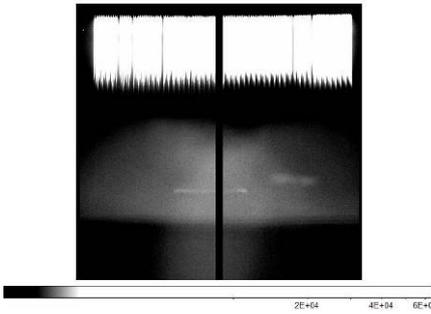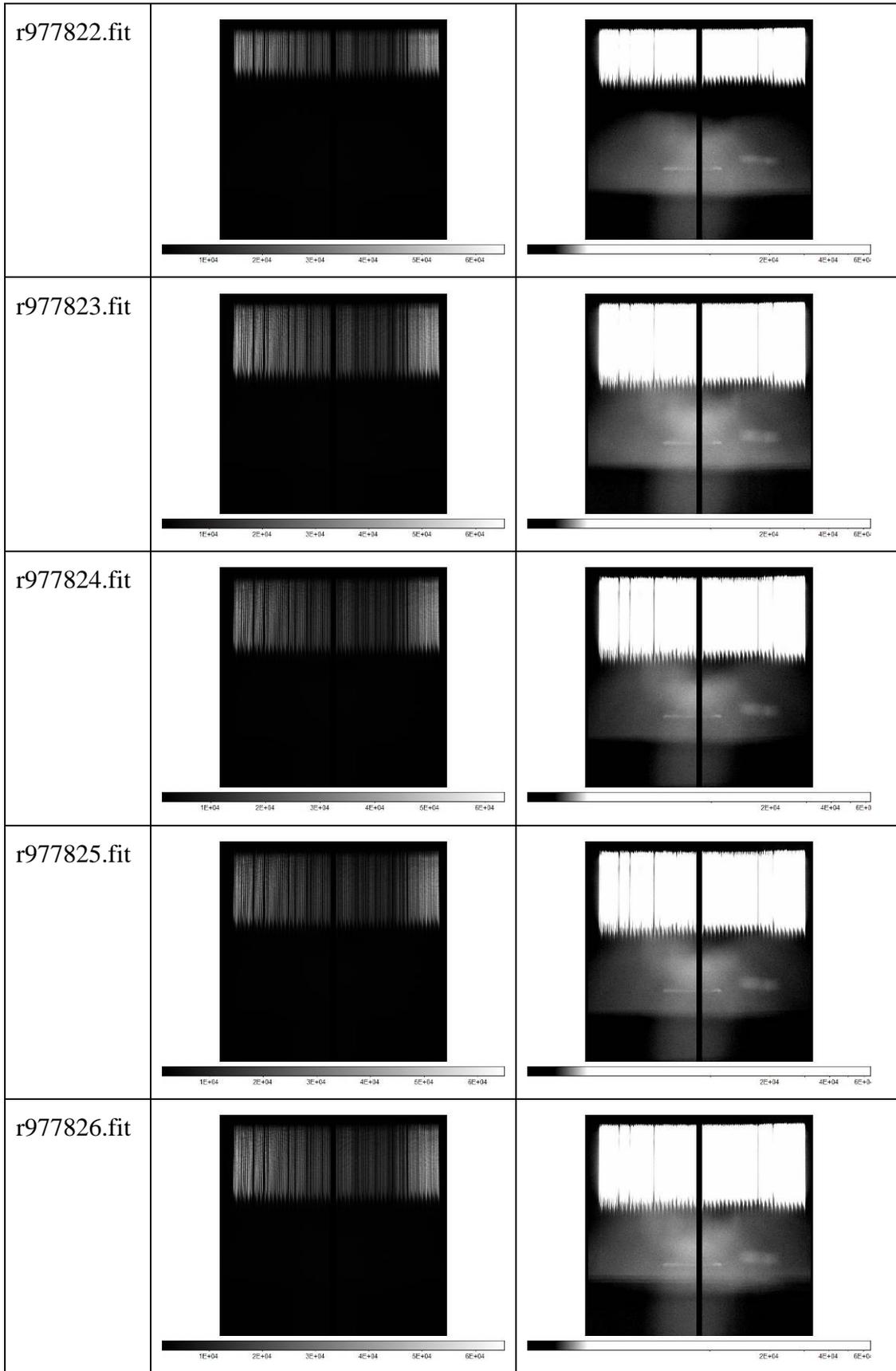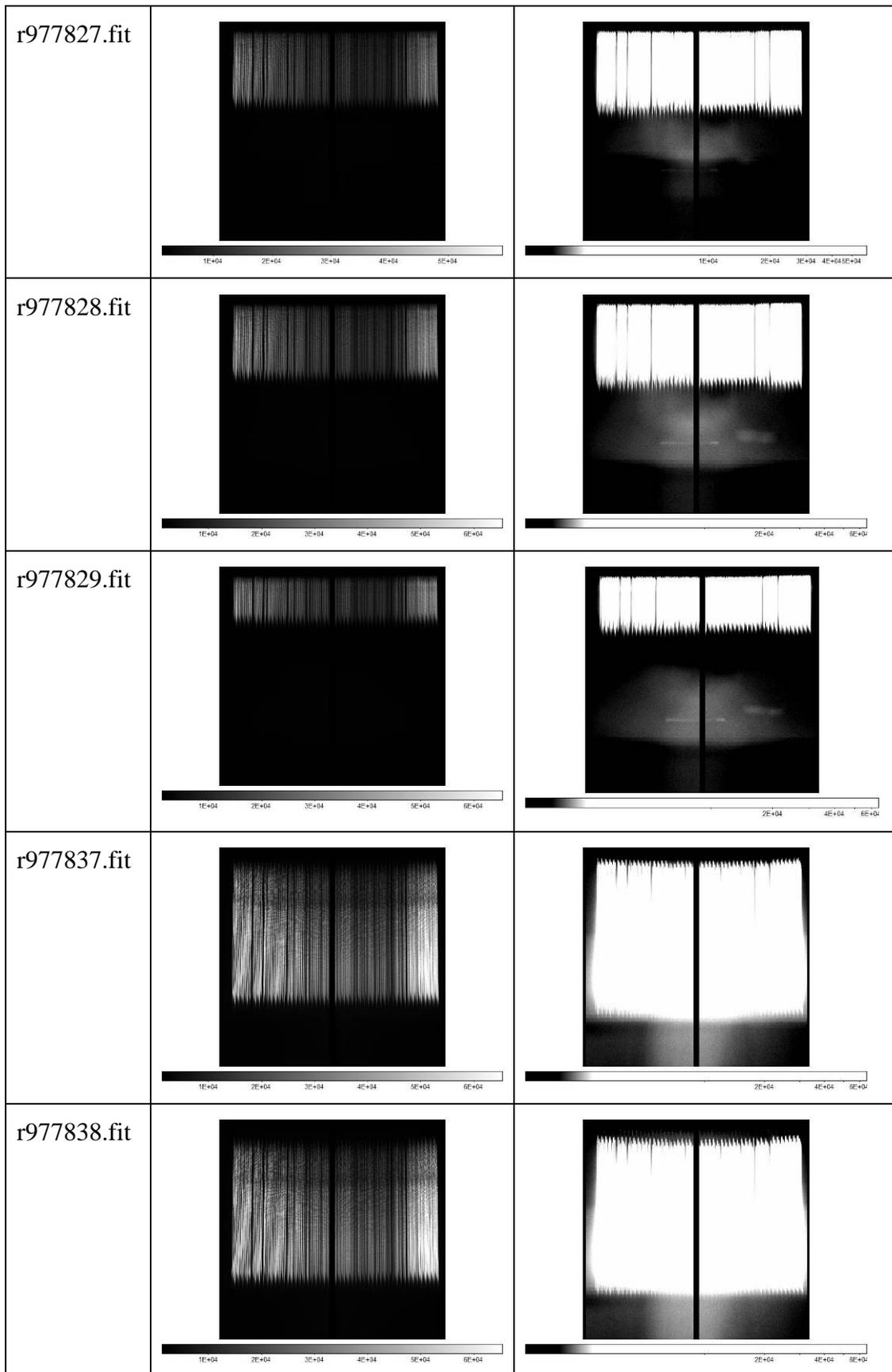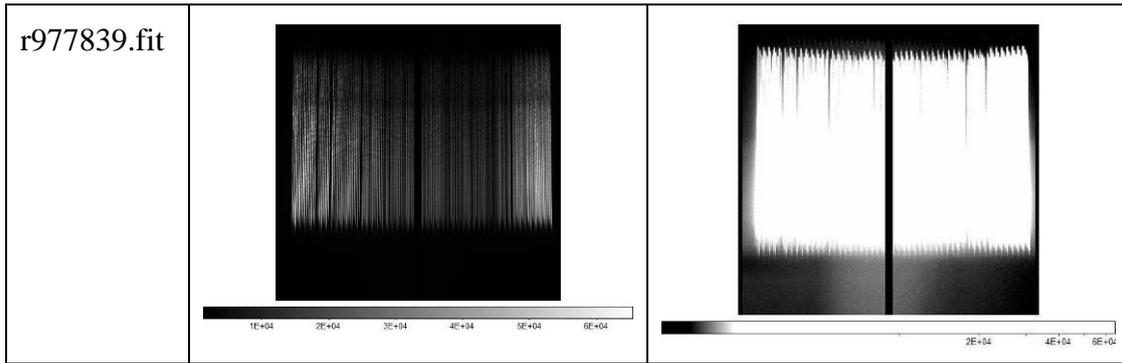
After the new baffles were installed new images were taken when filter WY_8830 was out of the optical path. Table 6 lists the information on these images.

Table 6 Exposures when filter WY_8830 was out of the optical path

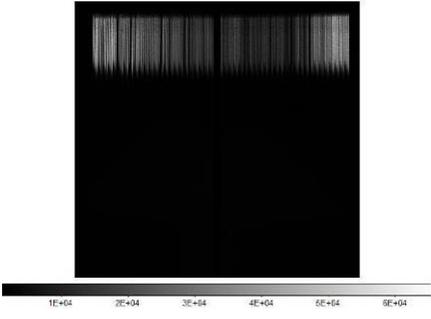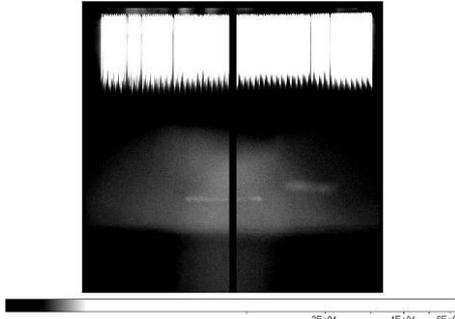| *File*	*Central wavelength (ang.)*	*Integration time (sec)*	*Filter B – WY_8830*	*Notes*
r977830.fit	6400	0.5	OUT	
r977831.fit	6400	1	OUT	
r977832.fit	6800	1	OUT	
r977833.fit	6800	0.5	OUT	
r977834.fit	6000	0.5	OUT	
r977835.fit	7000	0.5	OUT	
r977836.fit	7600	0.5	OUT	
r977840.fit	8000	0.5	OUT	
r977841.fit	8400	0.5	OUT	
r977842.fit	8800	0.5	OUT	
r977843.fit	9200	0.5	OUT	
r977844.fit	7600	0.5	OUT	
r977845.fit	7200	0.5	OUT	
r977846.fit	6800	0.5	OUT	
r977847.fit	6400	0.5	OUT	
r977848.fit	6000	0.5	OUT	

Comparison of the original and new baffle instalments

The following images in Table 8 show the effect of the newly installed baffles. It is not as significant as expected, but some scattered light at the top of the image is eliminated. It is mainly because of the baffle that is positioned next to the relay mirror (Zemax baffle 1). The other larger scattered light area in the middle of the image is slightly decreased, but it is not fully eliminated. Probably it is ghost scattered light from the lens elements.

Table 7 Information on the exposures that were taken before and after the new baffle instalments

File	*Central wavelength (ang.)*	*Integration time (sec)*	*Filter B – WY_8830*	*Notes*
r977820.fit	6400	0.5	IN	BEFORE
r977829.fit	6400	0.5	IN	AFTER

Table 8 Exposures taken before and after the new baffle instalments

File	*Lin*	*Log*
r977820.fit Before baffles		
r977829.fit After baffles		
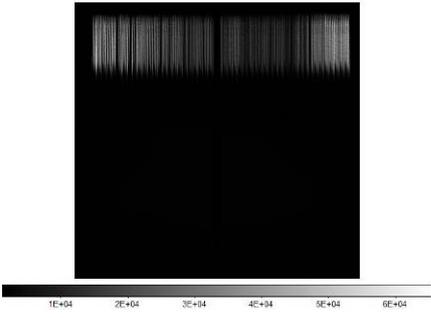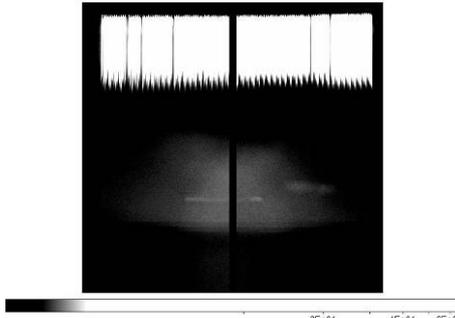
Conclusions

Due to the new baffle instalments some of the scattered light could be successfully reduced but there is still some noticeable scattered light in the middle part of the image. It could be further reduced by using more appropriate baffles; at the moment the baffles are made of black carton paper. Preferable material is plastic or metal, probably aluminium. Also the baffles should be positioned more precisely in order to eliminate scattered light without blocking the desired spectrum for spectroscopy.

Most probably the light contamination in the middle part is ghost scattered light that is generated by the surfaces of the lens elements in the optical path. It is more likely that they are produced by the surfaces of the double-pass collimator lens than by the negative lens. Further investigation is possible regarding ghosting, but with using baffles that part cannot be eliminated.

It is important to mention that in all of the investigated cases the scattered light could only be seen when the data was visualized with logarithmic scaling (log5). Also in many cases some part of the spectra was saturated, so exposure times were close to the limit. Consequently the ratio of the scattered light/spectra was really low. The main objective of these tests was to find the reason of the scattered light and so essentially the effect of the new baffle instalments were examined and not the quantification of the scattered light was the main objective.