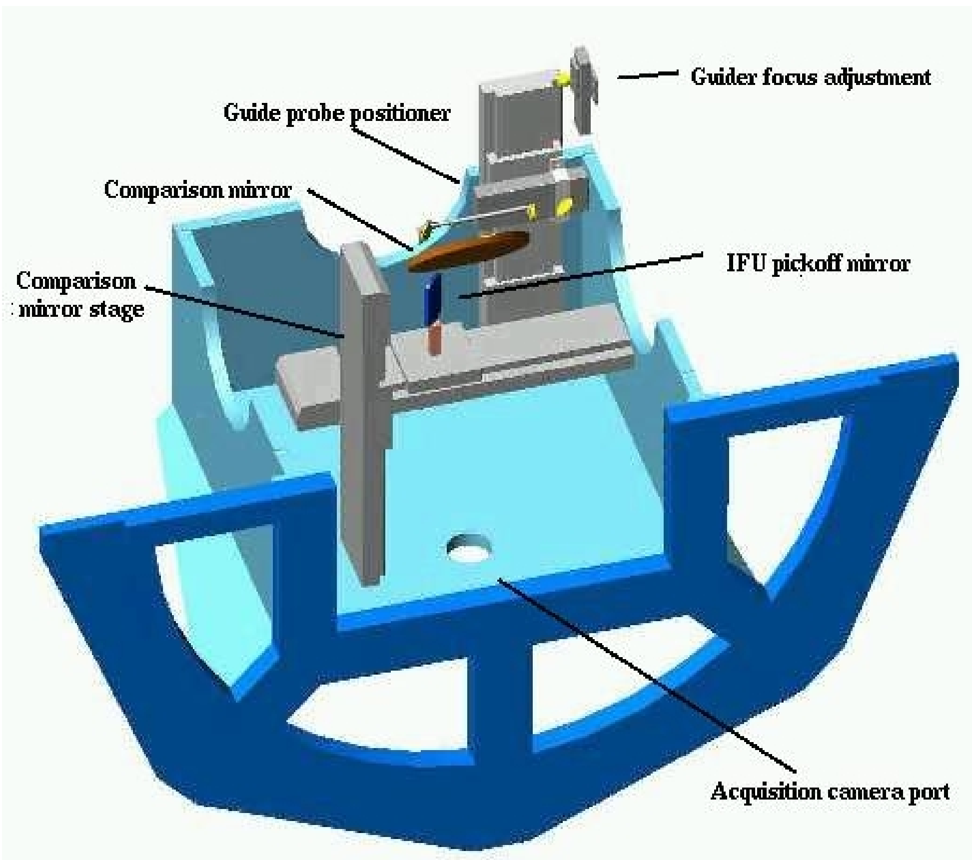
2. DESCRIPTION OF THE SPECTROGRAPH, STEP BY STEP

2.1 The ISB and optical component situated before the fore-optics

The fore-optics of the present instrument will be installed on a side of the optical Instrument Selector Box. Inside the ISB, a moveable pick-off mirror deviates the light towards the fore-optics, at 90^{o} from the beam coming from M3. When the mirror is off, the light enters the High Throughput Spectrograph, in construction at UNC. An ADC (Atmospheric Dispersion Corrector) and a Calibration Lamps System are shared between the two spectrographs. A mirror in form of a ring around the pick-off mirror will be used by the tip-tilt sensor. The ISB is being designed at CTIO, and we do not describe this system here.



2.2 The fore-optics

2.2.1. The interchangeable system

The microlens-fiber IFU is coupled to the telescope via simple fore-optics.The function of the fore-optics is to magnify the focal plane of the telescope to the scale that is required by the microlens array. The fore-optics consists of a magnification lens and a field lens. The field lens is used to provide telecentric correction to the magnified beam; that is, the light must feed the lenses parallel to their axes.

The first goal clearly stated by the SAC is to match 0.15” of the sky, or 49 µm in the focal plane, to 1mm lenses; this corresponds to a magnification of about 20. In the red part of the spectrum, the PSF with tip-tilt correction is expected to be about 0.30”, so that this choice corresponds to ideal spatial sampling by two lenses. It is convenient to have at least two interchangeable fore-optics systems, so that the system is still well adapted for relatively bad seeing conditions (still good for stellar spectroscopy) and/or observations covering a larger field, and for observations in the blue region. The second fore-optics system has a magnification a factor 2 smaller than the first one, resulting in 0.30” per lens. Since the SAC recommends to make provision for a 0.08”/pixel scale to be used with AO, we leave room for a third switchable magnification, on a sliding system with room for three sets of fore-optics lenses. It might be interesting to have an option for 0.60" per pixel, but this cannot be obtained without some loss of light (the image of the pupil at the input of the fibers would be larger than the core diameter, unless we use a different core diameter). For the moment, we leave as future options the possibilities of 0.08" or 0.60" per pixel.

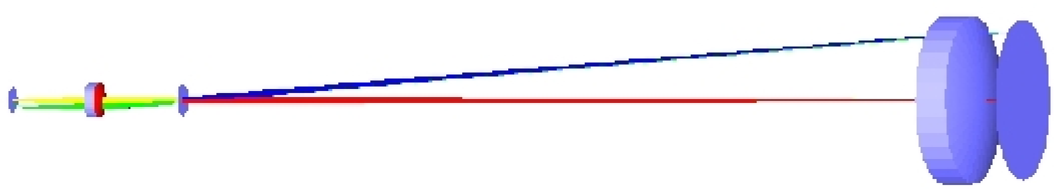


Figure 2.1 The 0.3 arsec/mm fore-optics

The above figure illustrates the optical design of one of the fore-optics; the focal plane of the telescope and the pupil are shown. In the project proposed by Damien Jones, there are two magnification doublets in the 0.15 arcsec/mm unit; the same field lens (in a different position) is used in both units.

Fore-Optics, 0.3 arcsec/1 mm microlens version 1.02

Surf	Ident	z mm	Separation mm	Radius mm	Next medium	Aperture/ Term
-1	EnP	0.000	-	plane	AIR	
0	Sce	-inf	-	plane	AIR	
1	PM	0.000	inf	-13490.260 -1.003100	AIR	4250.0 cc
2	SM	-5829.610	5829.610	-2032.660 -1.520300	AIR	605.0 cc

3	TIS	3400.262	9229.872	plane	AIR	10.0
4	FOL1	3430.191	29.929	44.052	BAK2	12.5
5	FOL2	3431.691	1.500	8.267	CAF2	12.5
6		3436.691	5.000	-13.217	AIR	12.5
7	STOP	3467.659	30.968	plane	AIR	12.0
8	FL1	3768.762	301.103	5720.862	BAK2	62.5
9	FL2	3772.762	4.000	108.771	CAF2	62.5
10		3785.262	12.500	-107.842	AIR	62.5
11	MLA	3800.262	15.000	plane	AIR	60.0

EnP and Sce are Entrance Pupil and Source respectively.

PM, SM and TIS are the telescope primary mirror, secondary mirror and image surface respectively.

FOL1 & 2 are the components of the low mag doublet.

FL1 & 2 are the components of the field lens doublet.

MLA is the microlens array.

The attached ZEMAX listing is "FL102.ZMX" (available at LNA home page)

Fore-Optics, 0.15 arcsec/1 mm microlens version 1.04

Surf	Ident	z mm	Separation mm	Radius mm	Next medium	Aperture/ Term
-1	EnP	0.000	-	plane	AIR	
0	Sce	-inf	-	plane	AIR	
1	PM	0.000	inf	-13490.260 -1.003100	AIR	4250.0 cc
2	SM	-5829.610	5829.610	2032.660 -1.520300	AIR	605.0 cc
3	TIS	3400.262	9229.872	plane	AIR	10.0
4	FOH11	3408.442	8.180	-15.409	BAK2	10.0
5	FOH12	3409.442	1.000	6.841	CAF2	10.0
6		3415.442	6.000	-7.170	AIR	10.0
7	FOH21	3415.942	0.500	20.281	BAK2	10.0
8	FOH22	3417.442	1.500	6.841	CAF2	10.0
9		3421.442	4.000	-17.862	AIR	10.0
10	STOP	3437.937	16.495	plane	AIR	12.0
11	FL1	3739.477	301.539	5720.862	BAK2	62.5
12	FL2	3743.477	4.000	108.771	CAF2	62.5
13		3755.977	12.500	-107.842	AIR	62.5
14	MLA	3800.262	44.286	plane	AIR	60.0

FOH11, 12, 21 & 22 are the components of the two high mag doublets.

The attached ZEMAX listing is “FH104.ZMX”.

2.2.2. The Schott filters

For mechanical reasons, the Schott filters will be placed close to the focus of the telescope, before the magnification lenses of the fore-optics system (see the section on mechanical design). These filters are needed to avoid overlapping of orders, when observations in the redder part of the spectrum are made. For instance, if we observe at λ=800 nm, the second order of λ=400nm must be removed by a filter. Considering that wavelengths shorter than 320 nm are not transmitted by the optics of the spectrograph, a filter cutting wavelengths lower than 2x320= 640 nm would be enough (below this λ, there is no problem of overlap of orders). As discussed in section 1.3, this allows us to observe the range 350nm-1100nm in two steps, one without filter and the other with a filter. However, we intend to offer two more options, with limiting wavelengths about 420 nm and 530nm, for those who want to observe central regions of the range of the spectrograph, without discontinuity in the midle of the spectrum.

2.3 The IFUs

2.3.1 The main IFU

The IFU is composed of the crossed cylindrical lenses from LIMO. The aspect of the array is shown below. The cylindrical lenses can be manufactured with aspheric surface profiles producing diffraction limited performances, and the array can be made achromatic with the use of a high dispersion glass substrate, ensuring high throughput at all wavelengths. But since the technology of IFU construction is evolving rapidly, the team will continue to examine other possibilities for the lenslet construction.

The coupling of fibers to the lenslet arrays will use the technique which was used for the prototype. The fibers extremities are introduced and cemented in steel jackets (steel tubes used for hypodermic needles). The jackets are introduced in an array of holes in a brass block, and are all polished simultaneously. The fibers are fixed on the glass substrate with UV-cured cement.

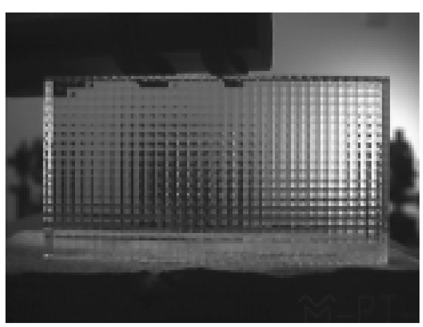


Figure 2.2. The microlens array used in the prototype

SOARS IFU Optics version 1.02

Surf	Ident	z (mm)	Separation (mm)	Radius (mm)	Next medium	Aperture/Term
-1	EnP	324.000	-	plane	AIR	
0	Sce	0.000	-	plane	AIR	
1		0.010	0.010	plane	SILICA	1.0
				-2.631		cylinder
2		1.010	1.000	plane	AIR	1.0
3		1.020	0.010	2.567	SILICA	1.0
				plane		cylinder
4		2.020	1.000	plane	SILICA	1.0
5		9.087	7.067	plane	SILICA	0.1

The attached ZEMAX listing is “IFU102.ZMX”.

2.3.2 The sky IFU fore-optics

For observations of extended objects, sky subtraction is a major concern, since very often, regions of the sky not contaminated by the object are only found at distances larger than the size of the IFU. One mode of observation (see section 3) uses for sky subtraction a separate IFU with a small number of pixels (5 x 5), positioned in the sky at about two arc minutes from the object. The “sky” IFU must be built with the same technology of the main one, since we desire similar transmission for the sky and the object. In our case, due to the relatively small diameter of the pick-off mirror, the sky IFU cannot go far from the main IFU. There was a choice to be made, here. To observe the sky at 2’ from the main IFU, we must install another fore-optics first lens at about 50 mm from the interchangeable ones, and therefore, to have acompletely indendent fore-optics system. Do we need also an interchangeable system, in order to use always the same magnification of the main IFU? For mechanical simplicity, and to avoid too many controls or duplicate optical systems, our choice is to have a fixed position of the sky IFU, and a single magnification (factor 10). A rotation of the plane of the sky, performed by the ISB, will allow in most cases to find a convenient position in the sky for the sky IFU. The question of different magnifications between object and sky, when the factor 20 magnification is used at the main IFU, can be corrected during data reduction, using a correction factor derived from the flat field.

In the chapter on observations and data reduction, we discuss the other option offered to the observer (shuffle-and-node).it does not require additional optical components, except for a mask covering half of the microlens array.

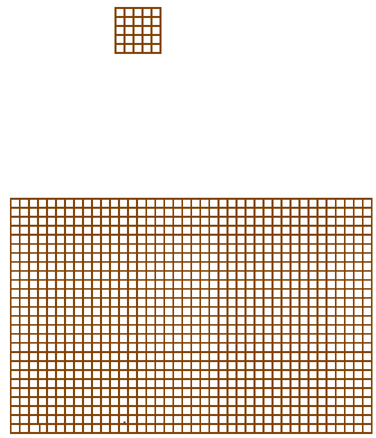


Figure 2.3 Relative sizes of main and sky IFU. The relative distance is much larger than in the figure since they use distinct fore-optics. The size of the main microlens array is 26x50 mm.

2.4. The fibers

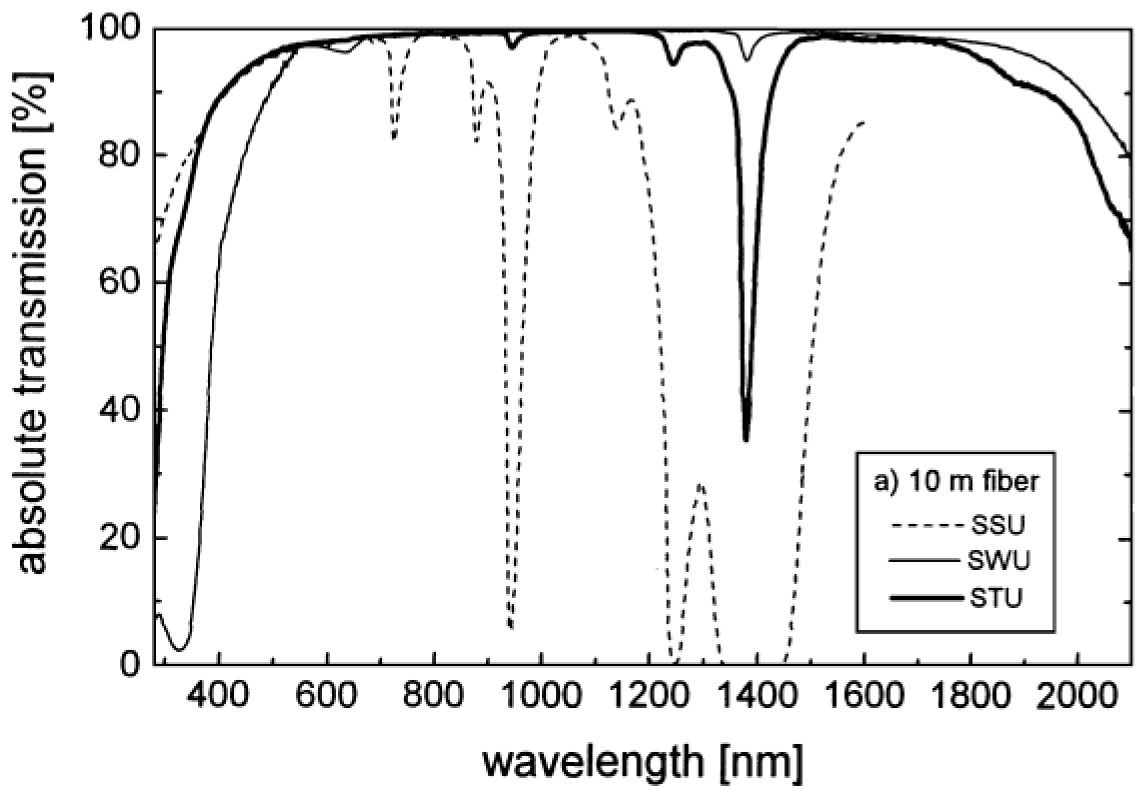


Figure 2.4. transmission of high-OH or "blue" fibers (SSU), low-OH or "red" fibers (SWU) from Polymicro, and fluosil fibers (Heraeus).

We shall use Polymicro "blue" fibers, the same used in the prototype. Their transmission curve is shown by the dashed curve in the figure above. The reason for this choice is that they are much better in the blue than low-OH fibers, which would turn impossible observations at 350 nm. The Heraeus fluosil fibers are not fabricated with the core-cladding diameter ratio that we desire. We need at least 5 μm cladding thickness, to avoid light loss at the longest wavelength (1 μm).

The "blue" fibers present a deep absorption at about 950 nm. Since it coincides with an atmospheric absorption, it is not a region of interest for observations. We intend, after the start of the use of the spectrograph, to construct a second fiber bundle optimized for the red-near infrared region.

The focal ratio degradation of the "blue" fibers, measured by Cesar de Oliveira is shown in Figure 2.5.

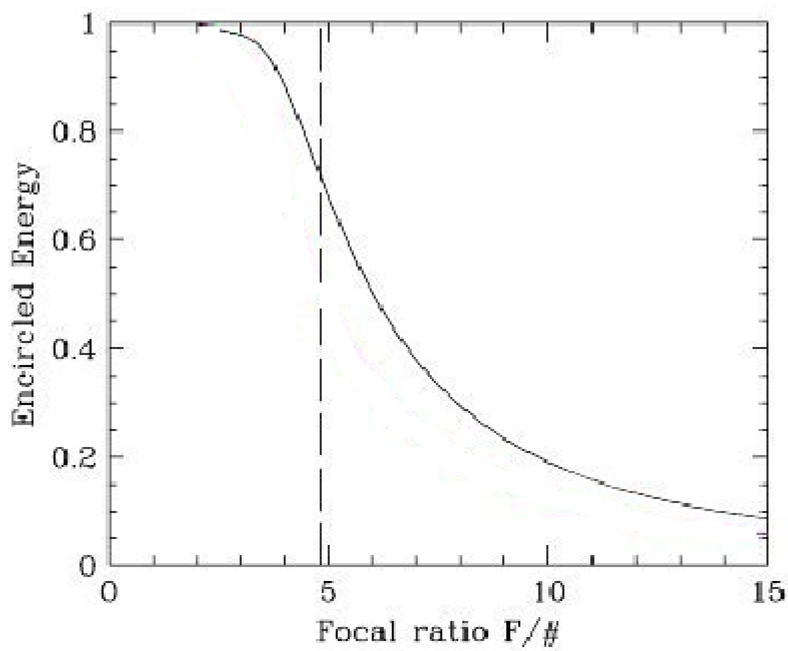


Figure 2.5 The focal ratio degradation of Polymicro 50 μm core diameter fibers

In the experiment, the fiber is fed with light with a focal ratio f5.5, and at the output we measure what fraction of the light is collected within a beam of variable f#. The length of the fibers was 17m, longer than we are going to use at the SOAR spectrograph. We can see that 70% of the light is collected in an aperture of f5 (the input f# of the collimator that we are going to construct). This is one of the largest sources of light loss in the project.

2.4. The optical design of the bench spectrograph

2.4.1 The slit and the collimator

In this section the report written by Damien Jones is reproduced, with only minor adaptations.

After many efforts to optimize a dioptric collimator, a new catadioptric collimator has been developed to circumvent the chromatic problems. This collimator delivers near diffraction-limited imagery over almost the entire slit field from a wavelength of 290 nm to 2500 nm. It is used in an off-axis, unobscured, mode that is identical, in principle, to the 2dF spectrograph collimators on the AAT. The slit surface is now *convex* to the collimator with a radius of curvature of about 500 mm. There is a fused Silica cover plate that also contributes to aberration control.

Although the slit surface is coaxial with the rest of the system, the eccentric entrance pupil means that the fibre ensemble must be inclined by nearly 6 degrees with respect to the plane containing the slit itself and the system optical axis. This is identical in principle, again, with 2dF.

New Catadioptric Collimator Proposal

The new catadioptric collimator (version 2.01) is tabulated below.

SOARS Catadioptric Collimator (reversed), version 2.01

Surf	Ident	z mm	Separation mm	Radius mm	Next medium	Aperture/ Term
1	Pupil	y= 75.000 z= 0.000	inf	plane	AIR	100.0
2	CCL1	200.000	200.000	1516.554	SILICA	280.0
3		220.000	20.000	2106.191	AIR	280.0
4	CCL2	270.000	50.000	-240.650	SILICA	280.0
5		285.000	15.000	-243.933	AIR	280.0
6	CCL3	435.000	150.000	-316.691	SILICA	280.0
7		450.000	15.000	-350.724	AIR	280.0
8	CCLM	1060.000	610.000	-1020.146	AIR	350.0
9	Slit +	553.396	506.604	617.880	SILICA	120.0
10	Cover	538.396	15.000	507.868	SILICA	108.3
11	Exit Pupil	y=-51.933 z= 33.231	507.827	plane	SILICA	108.3

The pupil and exit pupil are *offset* in the y-direction. The near collimated beam from the mirror is designed to clear the slit by nearly 25 mm. Thus off-axis portions of CCL1, 2, 3 & CCLM are to be utilized.

Surfaces 9 and 10 are *convex* to the *incoming light* (in this *reversed* collimator) from the main mirror and their sign is thus positive (this is the convention that Damien uses with his software). Some optical design software (such as ZEMAX) uses the opposite convention in that the sign of a surface curvature is set in relation to the *optical axis*.

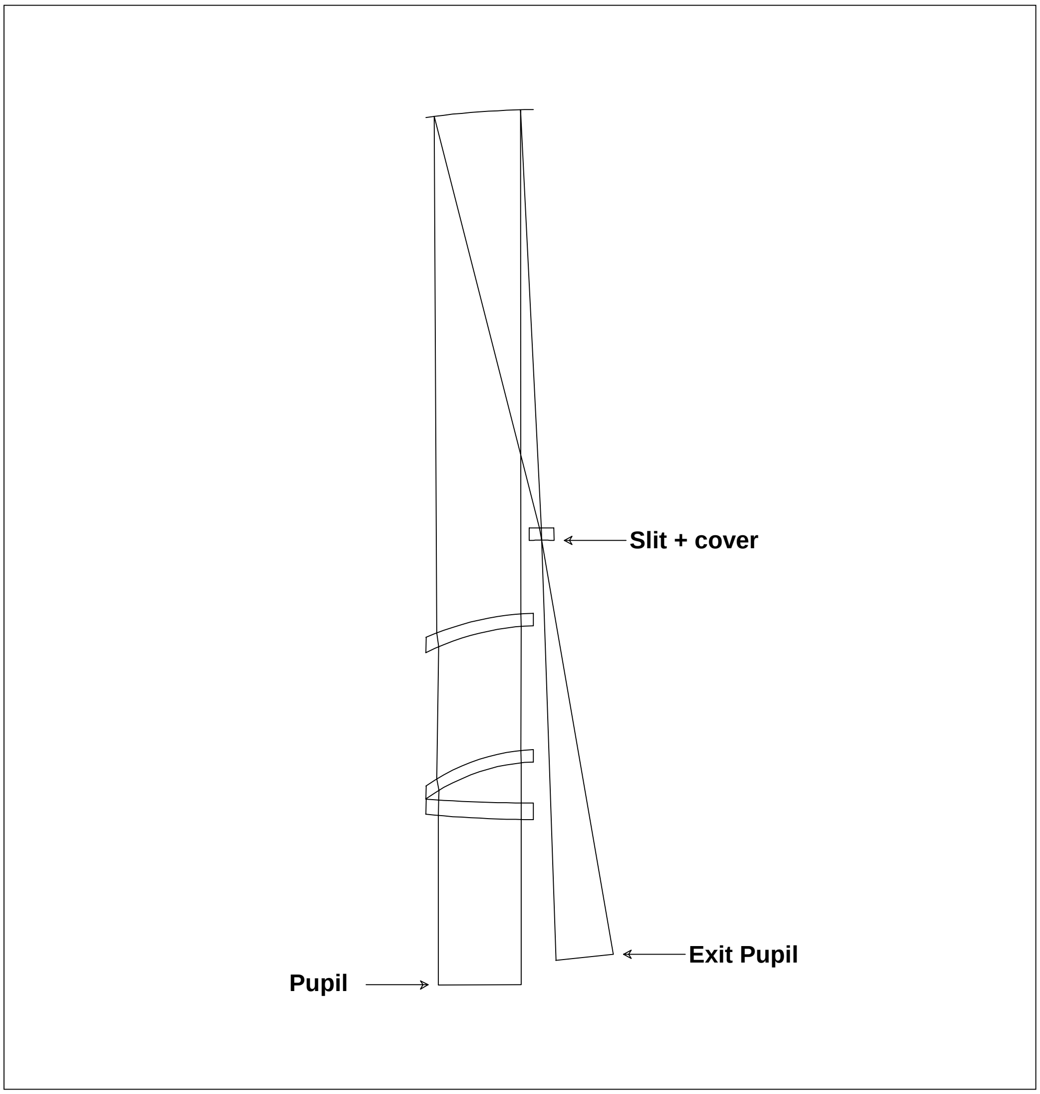
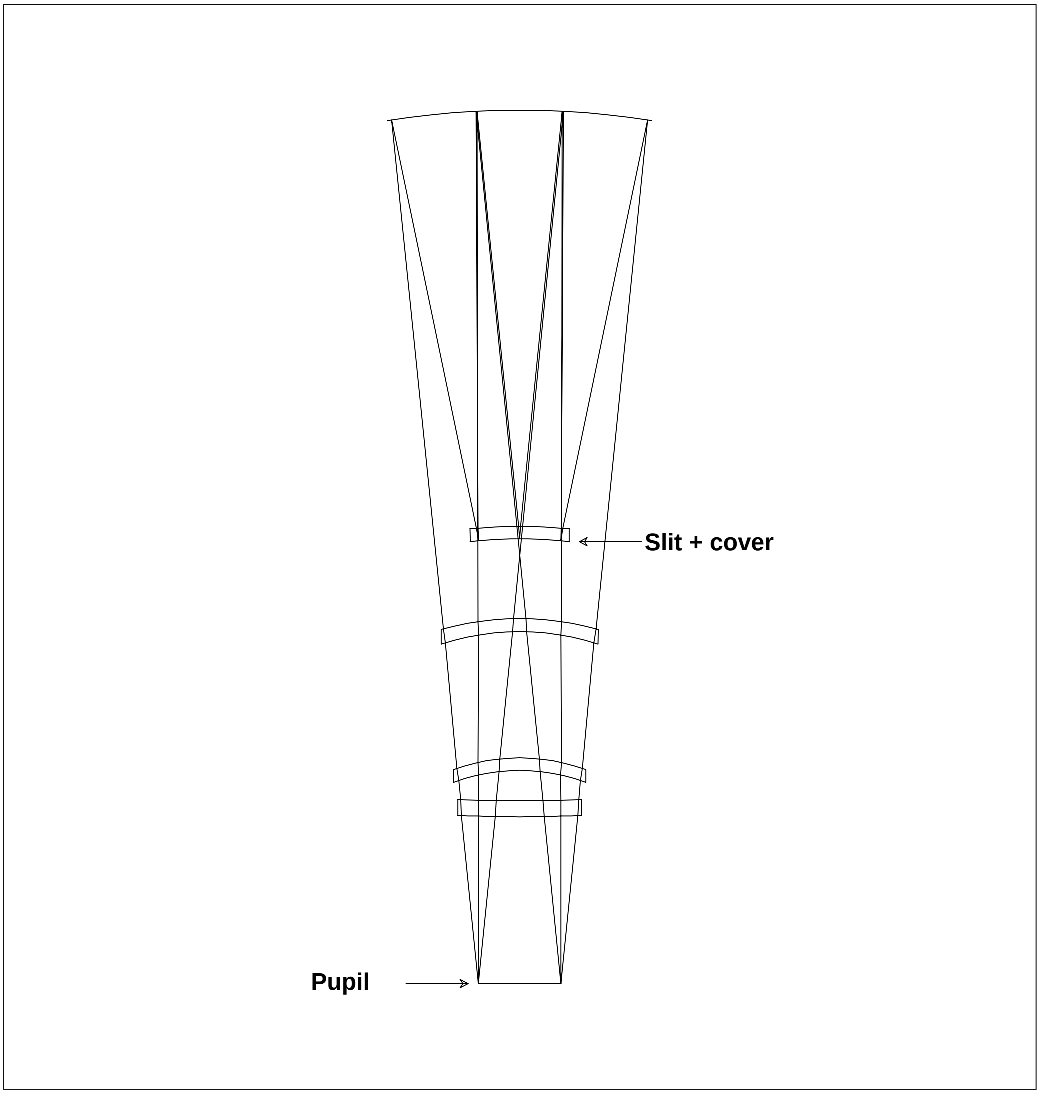


Fig. 2.6 SOARS Catadioptric Collimator (reversed), version 2.01 "Side" view

The attached ZEMAX listing is “H3CX201.ZMX”. It will probably need some editing and adjustments before it is useable. Damien has not attempted to list a *non-reversed* collimator because of the confusion that would arise from the initial offsets and tilts. A “H3CX201-REVERSED.ZMX” file was prepared by Militão at IAG and is available at the LNA home-page.



SOARS Catadioptric Collimator (reversed), version 2.01
“Top” view

Figure 2.7. The catadioptric collimator “top”view

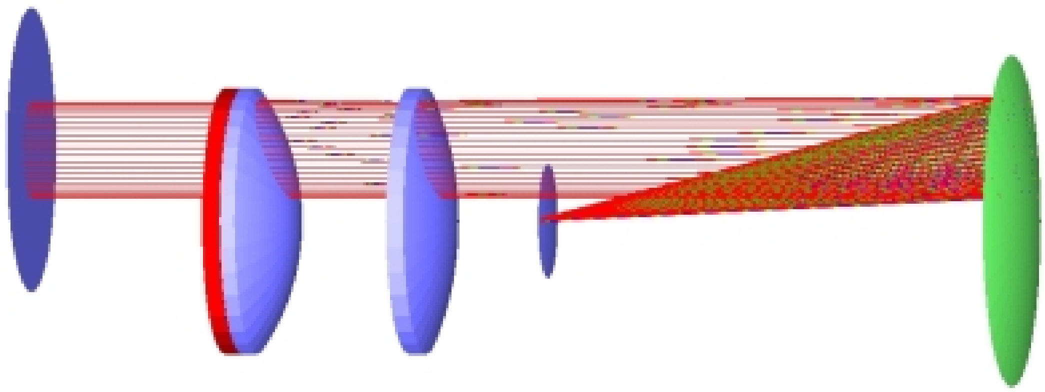


Figure 2.8 The figure shows ray-tracings, with the lenses shown in their entire form for clarity. Only the portion the lenses that are effectively needed will be fabricated.

2.4.2 Camera Proposal

The latest camera (version 6.05) is tabulated below. The camera design incorporates 2 conic surfaces.

SOARS Camera, version 6.05

Surf	Ident	z mm	Separation mm	Radius mm	Next medium	Aperture/ Term
-1	EnP	0.000	-	plane	AIR	
0	Sce	-inf	-	plane	AIR	
1	Pupil	0.000	inf	plane	AIR	100.0
2	CM11	200.000	200.000	495.927	CAF2	181.6
3	CM12	217.000	17.000	1451.736	BAK2	181.6
4	CM13	226.000	9.000	161.258	CAF2	181.6
5	CM14	280.000	54.000	-206.597	FK5	181.6
6		289.000	9.000	plane	AIR	181.6
7	CM2	294.000	5.000	230.477	FK5	188.5
8		319.000	25.000	plane	AIR	188.5

9	CM3	570.321	251.321	112.263	CAF2	156.8
10		603.321	33.000	plane	AIR	156.8
11	CM41	606.321	3.000	349.911	BAK2	146.0
				-7.941013		cc
12	CM42	615.321	9.000	68.061	CAF2	118.0
13	CM43	668.321	53.000	-104.905	SILICA	118.0
14	CM44	675.321	7.000	97.324	FK5	97.6
15		687.321	12.000	311.289	AIR	95.7
				12.177440		cc
16	FF	702.321	15.000	-131.710	SILICA	93.7
17		709.321	7.000	291.702	AIR	91.1
18	D	719.321	10.000	plane	AIR	79.1

Note that the Entrance Pupil (EnP) and Surface 1 (pupil) coincide.
Source is collimated.
D is detector.
The attached ZEMAX listing is “CAM605.ZMX”.

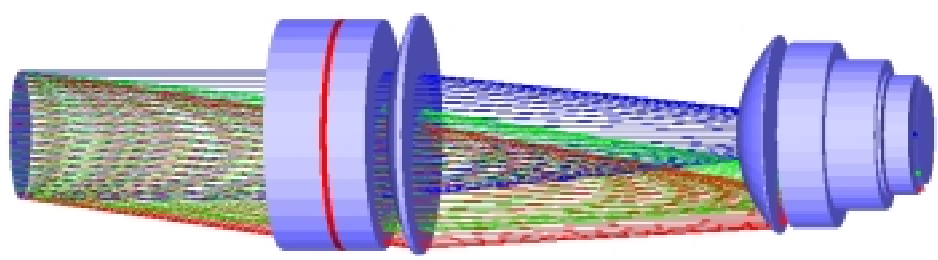


Figure 2.9 The camera

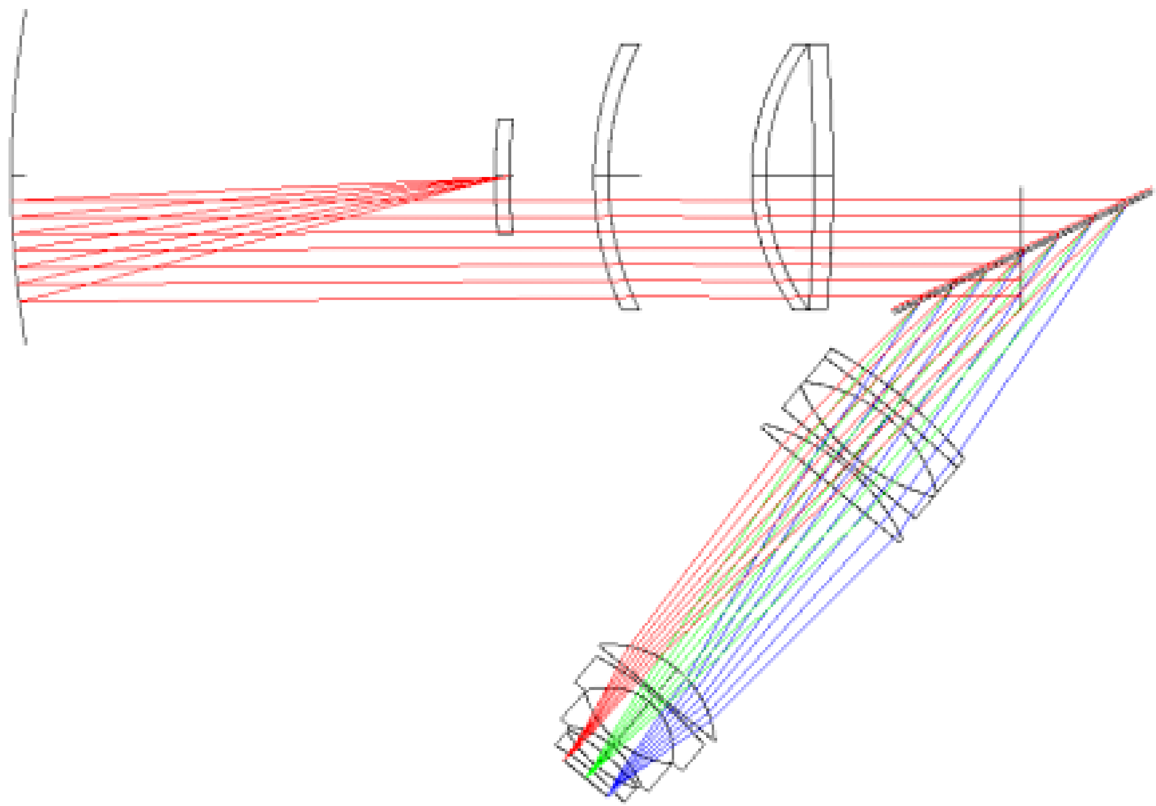


Figure 10. Collimator, grating and camera together

2.4.3 The spot diagram.

Figure 2.11 shows the spots that are obtained, at different wavelengths and different positions of the CCD, for the system collimator + camera. The side of the squares is 100 µm. The spots are smaller than 30 µm (2 pixels of the CCD) and are satisfactory.

The performance of the system in terms of transmission efficiency is discussed in section 2.6.

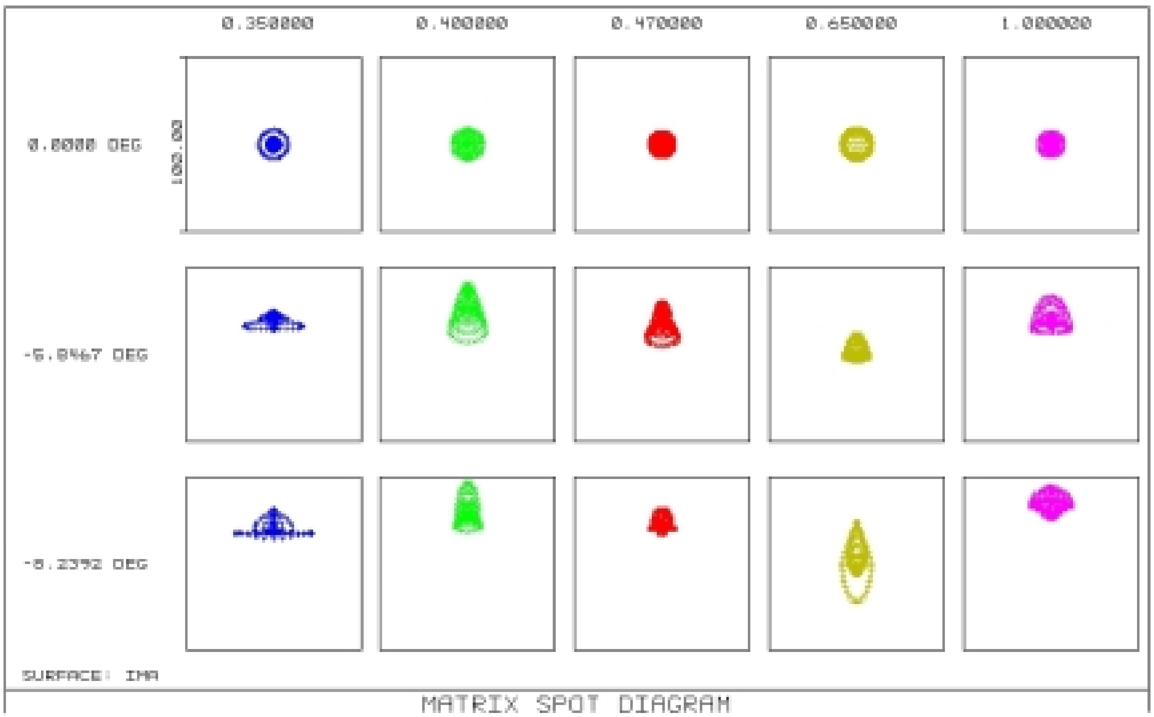


Figure 2.11 The spot diagram of the system collimator + camera