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MMP, the Multi Mini Prism device for ESPRESSO APSU: prototyping, and integration

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ABSTRACT

The multi mini prism device is a crucial component of the Espresso Anamorphic Pupil Slicer (APSU). At the end of the slicer, is necessary to differently fold each field to correctly illuminate the echelle and this is made by cylindrical prisms glued onto a silica window. We present the integrated robotic system conceived to reach the required tolerances in term of alignment and integration. It consists in a tip/tilt stage to select the wedge angle, a rotational stage to select the right clock angle, coupled to an x-y stage to position the elements on the window and a z axis to perform the gluing.

Keywords: Extra-solar Planet Atmospheres, High Resolution Spectroscopy, Espresso, front End.

1 INTRODUCTION AND GENERAL DESCRIPTION

Espresso and its detailed proposal was endorsed by the ESO Council at its 111th meeting in December 2007. Among the recommended instruments, a High Resolution, Ultra Stable Spectrograph for the VLT combined Coudè focus arose as a cornerstone to complete the current 2nd generation VLT instrument suite. Following these recommendations, ESO issued on March 2008 a call for proposal, open to member state Institutes or Consortia, to carry out the Phase A study for such instrument. Our Consortium was successfully selected to carry out the Phase A and later to conduct the ESPRESSO project. The Instrument will be located in the Combined-Coudè Laboratory (CCL) of the VLT and will be the first instrument able of using a 16-m equivalent telescope. A detailed description of the ESPRESSO Project can be found in [1][2][3].

The main scientific drivers for this instrument have been defined by ESO as follows:

- Measure high precision radial velocities for search for rocky planets;
- Measure the variation of physical constants;
- Analyse the chemical composition of stars in nearby galaxies.

For the capital and human investment, the Consortium will be awarded Guaranteed Time Observations. 80% of the observing nights will be invested for the search and characterization of rocky planets in the habitable zone of G, K, and M stars in the *SUT* mode. A 10% of the time will be dedicated to the determination of possible variability of fundamental constants. Depending on the magnitude of the target, this programme will be carried out partially in the *SUT*, partially in the *MUT* mode. The remaining 10% will be reserved for outstanding science cases and allocated as a function of topical questions arising at the moment of the GTO Observations.

The pupil slicer increases the resolving power of the spectrograph effectively decreasing slit width. Two cylindrical objective with different focal length (1:3) introduce anamorphism. An elliptic pupil 30 X 10mm is realized. Pupil slicing is done with two (almost) achromatic identical couple of prisms likely configured as Risley prisms pair. A pick off system centred onto a first pupil extract useful light for the Exposure Meter (Landoni [4]).
Due to the slicing of the pupil the illumination of the echelle is not optimal with a result of losing throughput. For this reason, on the spectrograph focal plane it was necessary to fold the pupil.

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This paper describes in detail a component of the Anamorphic pupil slicer: the multi prism folding system. In order to proper illuminate the echelle, is necessary to differently fold each field of the APSU. The solution is made by gluing cylindrical prisms with proper bending low angle onto a support double plate silica window. In particular, it is shown the integration system which has been conceived.

2 APSU: GENERAL DESCRIPTION

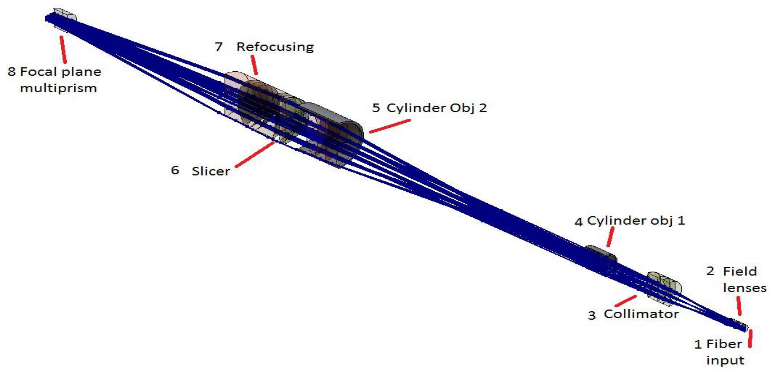


Figure 1. APSU overall view.

The APSU has an on-axis configuration, as respect to the PDR one. It is also more tolerant in terms of alignment requirement. Resolving power is increased by mean of a pupil slicer, effectively decreasing slit width.
The field lens realizes a pupil 24 mm after its vertex (18.5mm before the collimator). Collimation of light is done by a quadruplet (BSL7Y & S-FPL53) with all spherical surfaces; it creates a circular collimated beam of 10mm diameter.

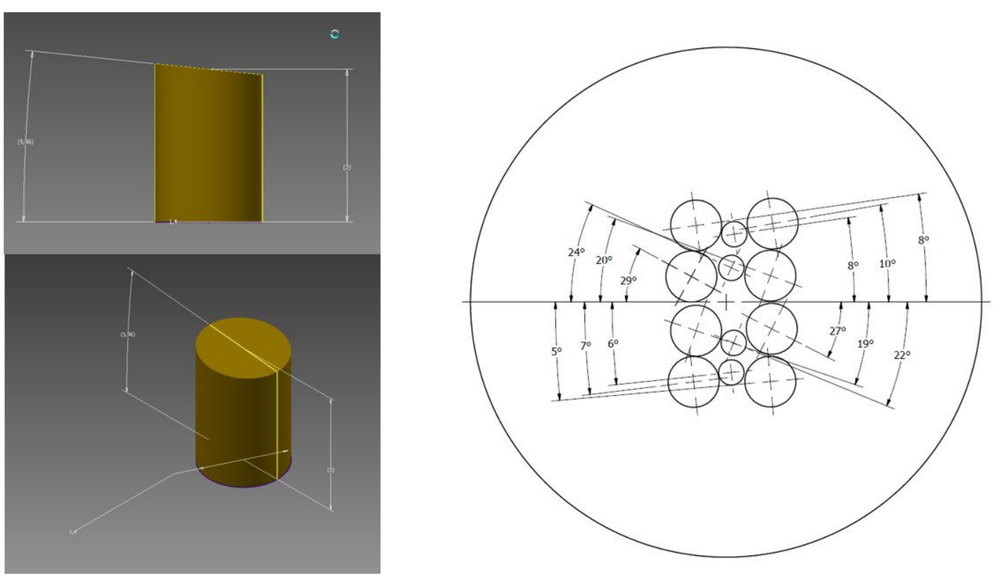


Figure 2. On the left is shown an example of a prism side and isometric view, on the right is shown the overall position of the prisms inside the silica window

2 cylindrical objectives introduce anamorphism. Pupil slicing is done with two (almost) achromatic identical couple of prisms (BSL7-Y & S-FPM2) likely configured as Risley prisms pair. They are adjacent and rotated by 180° (see figure below). A prism angle of ±3.5° is necessary to obtain a bending angle of ±0.25° that is required to properly locate the two parent spectra onto the CCD within the required separation. Before and after the slicer it has been necessary the use of a planoconvex and a planoconcave lens to avoid ghosts. These elements are made by BSL7Y and S-FPM2. After the slicer is located a quadruplet focusing system (N-ZK7 & S-FPL53) that illuminate the Focal Plane multifolding system which is composed by twelve mini-prism and direct the light onto the echelle [6]. The mini-prisms are 2 mm high and have a round section with a diameter of 1 or 2 mm (Table 1). One of the two round faces has an antireflection coating and is tilted by a specific angle (All the prisms were realized and coated by Wisag).

Table 1. Multi mini prism requirements summary

Prisms Requirement	
Radius of curvature surf 1	Infinity
Radius of curvature surf 2	Infinity
Clear Aperture (Type A)	ϕ 2.0 mm+0/-0.1
Clear Aperture (Type B)	ϕ 1.0 mm+0/-0.1
Substrate	Fused Silica
Substrate Thickness	
Surface tolerances	λ/6 p.t.v.
Surface micro-roughness	<1 nm rms
Surface quality	20/10
Coating Transmission (surf 2)	>99.5% [380-780 nm] average >99% [375-780 nm] absolute
Angle (Type A1)	5° 46’ (ϕ 1 mm)
Angle (Type A2)	4° 55’ (ϕ 2 mm)
Angle (Type A3)	7° 6’ (ϕ 2 mm)
Angle tolerances	±1’
Assembly Requirement	
Prism positioning tolerances (x,y)	±5 μm
Prism positioning tolerances (z)	±5μm
Prism positioning tolerances tip tilt (x,y)	± 1’
Prism positioning tolerances clock (z)	± 0.5°

3 INTEGRATION

3.1 Overall description

Because of the high precision request for the positioning of the mini-prisms it was necessary to develop a custom-made instrumentation to control the assembly process. The double plate silica window is positioned into a holder to prevent any motion during the assembly procedure and fixed to a stage which controls the motion along the z axis. Each prism is then positioned upside down (in order to expose the gluing surface) onto a thin holder. It is aligned in its angular position in terms of clock, tip and tilt. All this procedure is performed by proper stages and controlled by an optical system, tracing the relative positions of the reflections of a collimated light beam reflected by the surfaces of the window and the prism. Afterwards, a micro-drop of glue (NOA 63) is deposited onto the exposed surface of the prism, and the prism is moved to its final xy position by two stages with micrometric precision. Finally, the window is moved towards the prism until the glue covers all the prism surface. The last step is the glue curing with a UV led source.
In the next sections the detailed procedure will be described, focusing on the solutions adopted in order to satisfy the requested precision for each degree of freedom.

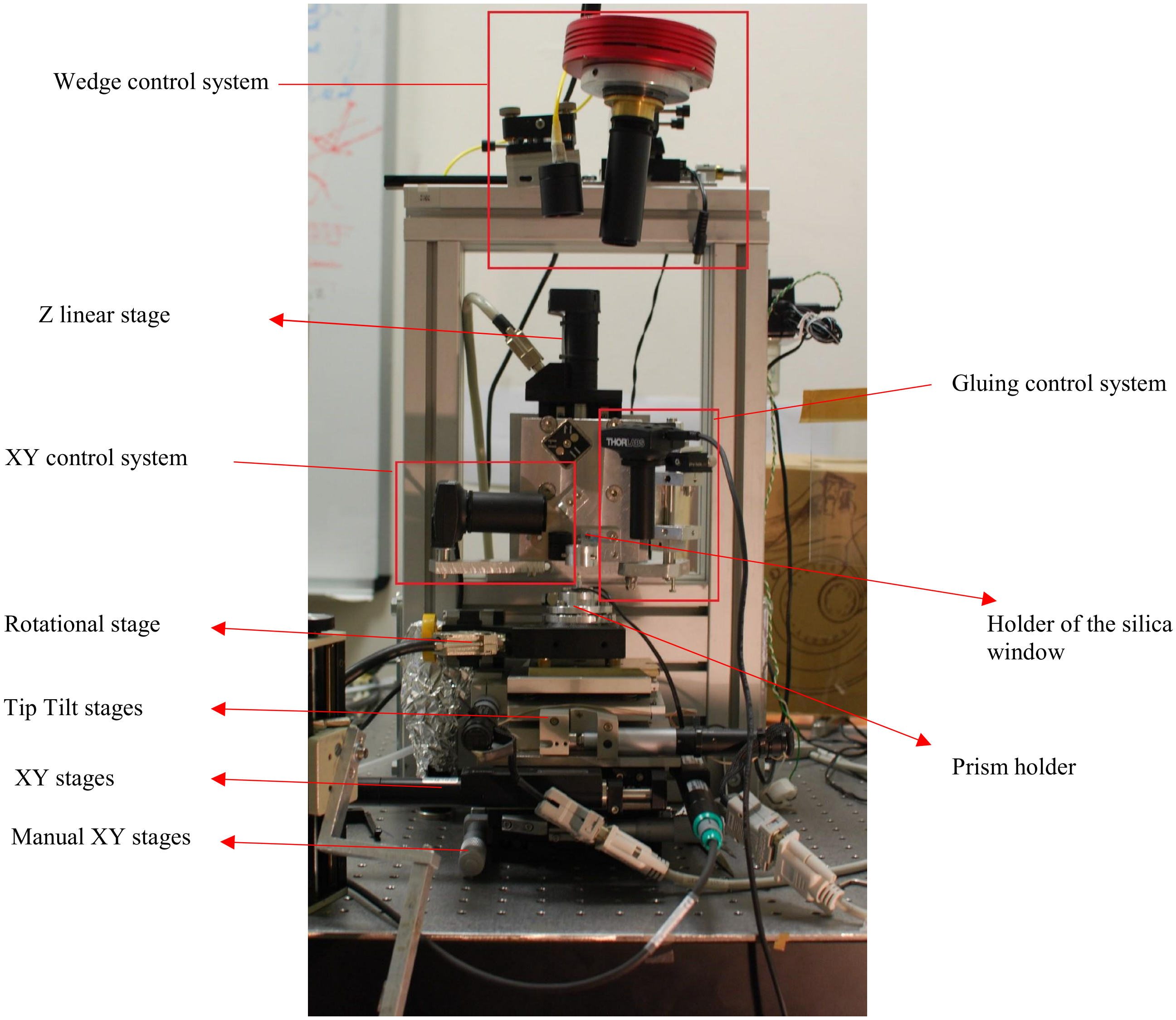


Figure 3. Overall picture of the integration system.

3.2 Gluing optimization process

In order to avoid light abortion by the glue layer in the working window of the telescope, it was used the Norland Optical Adhesive 63 ("NOA63") which has an excellent transmission in the near UV (fig. 4) and a refractive index close to the fused silica's one.

After the definition of the glue, we proceed defining the glue deposition process on the mini-prisms. The main issue is to control the amount of glue deposited. An excess would drop outside the surface of the prism during the positioning, covering the area of a nearby prisms; on the contrary, too little glue would not cover all the prism area, modifying the light path. Moreover, the glue thickness must be less than 10/20 µm in order to avoid tip/tilt misalignments during the curing procedure. As a result, the gluing process must provide the right amount of glue with extreme precision. Thus a syringe was adopted together with a micrometer pusher.

The syringe is fixed to a translational stage in order to control the distance from the tip and the prism. The procedure is to push the piston until a drop covers the needle tip, then the syringe is lowered and when the drop touches the prism, it is transferred by means of surface tension.

Typical Properties of NOA 63

Solids	100%
Viscosity at 25° C	2000 cps
Refractive Index of Cured Polymer	1.56
Elongation at Failure	6%
Modulus of Elasticity (psi)	240,000
Tensile Strength (psi)	5,000
Hardness - Shore D	90

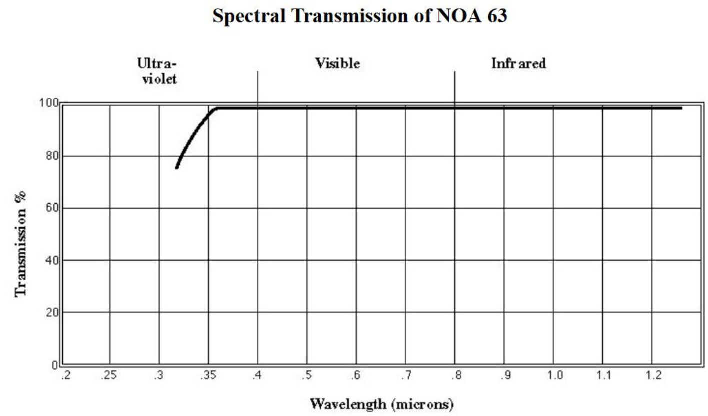


Figure 4. On the left Specification of Norland Optical Adhesive 63, on the right its transmission spectra at the solid state

3.3 Prism holder

Because the positioning of each prism must be done without interfering with the others, we must handle each of them touching only their top surface. The solution was to design an holder as shown in figure 5 on top of which is fixed an hollow tip, connected to a void pump.

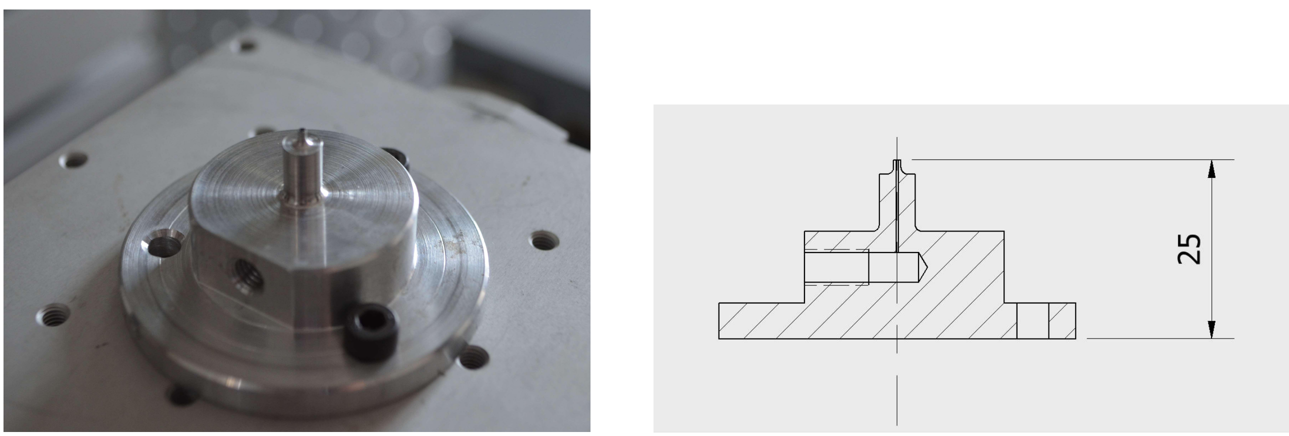


Figure 5. Picture and technical draw of the prism holder.

3.4 Positioning system

The positioning system has been developed in order to place the prism with the minimum error in position. In figure 3 is shown the pile of stages needed to control 5 degree of freedom: x, y, tip, tilt, clock. On the bottom, a manual linear stage enables to make a first rough xy positioning, above it is fixed another xy stages (PImicos - KT120) to achieve the correct position with an accuracy of about 5 microns. Then is placed a tip tilt stage (PImicos - M043) and finally a rotational stage (Owis). Because the largest value of wedge (7° 6’, see table 1) is greater than the range of the tip-tilt stages, it was necessary to give an extra-tilt to the holder of about 3° with respect to the plane of the rotational stage. The holder with such a tilt, is fixed on the top of the pile; the z degree of freedom is handled by another linear stage (PI MICOS, LS65) on which the silica window is placed. The whole system has been placed on an optical bench.

Table 2. Stages specifications.

Name	Degree of freedom	range	Precision
PImicos - KT120	X, Y	40 mm	2 µm
PImicos - LS65	Z	50mm	0.5 µm
PImicos - M043	Tip, Tilt	+/- 7°	0.046 arcsec
Owis	Clock	360°	0.1°

Particular attention was put on the alignment of the tip-tilt stage with respect to the xy stage. Indeed, the clock angle of each prism is defined with respect to the xy axes, but the alignment procedure of the clock (see section 3.5.1) is done with the tip-tilt stages and referred its x'y' coordinate system. An eventual misalignment of the xy and x'y' coordinate systems would introduce a systematic error in the clock of the prism.

3.5 Control system

For each degree of freedom, we had to solve two main issues: define a zero and control the final positioning. In the following sections we discuss one by one the solutions adopted in each cases.

3.5.1 Prism clock angle

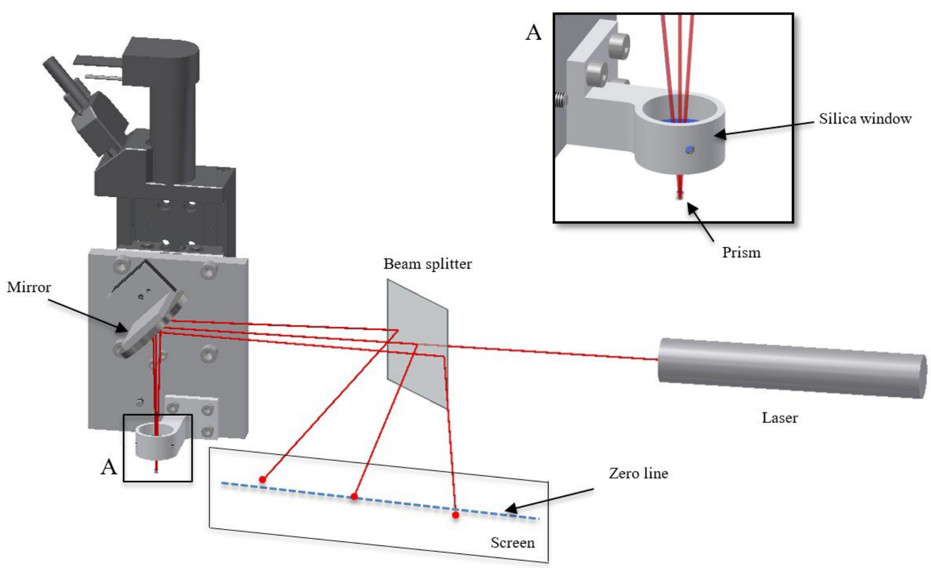


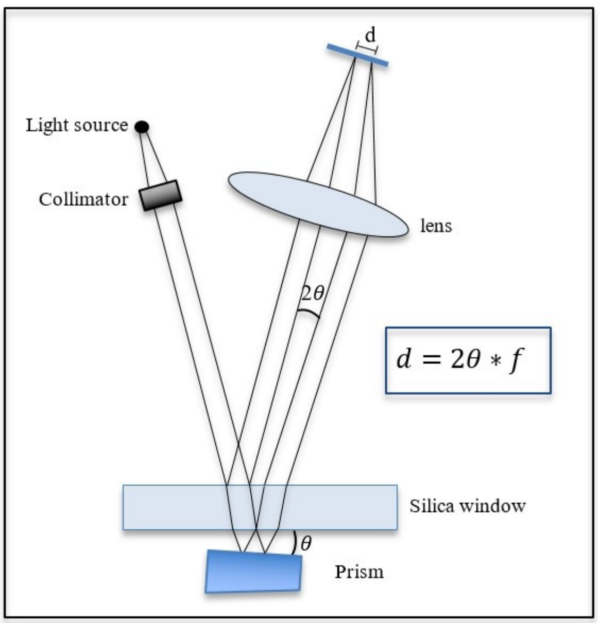
Figure 6. Overall picture of the clock control system.

To control the clock positioning we develop an optical system (figure 6) able to track the reflections of the surfaces of the prism and the silica window. A light coming from a laser (λ=633nm) is reflected by a mirror and directed towards the silica window. Part of the light is reflected back to the same path, while the other part passes through the window and hit the prism (properly placed) so that other two back reflections due to its tilted faces are produced. All these beams are deflected by a beam splitter placed between the laser and the mirror and projected on a screen (figure 6). The two spots coming from the reflections of the prism faces are moved by means of the tip, tilt and rotational stages, in order to lay them on a line which represent the zero position of the clock. This zero line is defined placing a glass plate instead of the prism, aligning the reflected spot with the one due to the silica window, then moving the tip (or the tilt) stage alone and tracing the line described by the spot in its movement. With this system we are able to correct the angular position with an accuracy of 0.2°.

3.5.2 Prism wedge angle

For wedge positioning we mean the minimization of the angle between the two faces to be glued, i.e., the prism base and the window. Because of the high accuracy requested (less than 60 arcsec) we built an optical control system together with a semi-automatic algorithm. As shown in figure 7, a monochromatic light is collimated by a lens (f=20mm) and directed towards the silica window and to the prism below. The reflections are focused by another lens (f=100mm) on a CCD camera (ATIK 314 L). After the focusing, the collimated beams appear as points on the CCD with a relative position related to the relative angle between the surfaces of reflection.

Figure 7. Scheme of the wedge control system



With a focal length (f) of 100 mm and a CCD with pixels of 4.65 µm the minimum angle detectable is:

$$d\theta = \frac{l_{pixel}}{f} = 9.6\, arcsec$$

The angle $d\theta$ correspond to twice the angle of the reflecting surface as shown in figure 7, hence the minimum angle variation detectable is 4.8 arcsec.

Finally, we had to consider the dimension of the focalized spot, that is related to both the collimator and the focuser focal lengths and to the wavelength of the light beam.

$$\left.\begin{aligned} d &= 1.22\,\lambda\, F_{\#} \\ F_{\#} &= \frac{f_1}{d_f} \\ d_f &= 2 f_2 NA \end{aligned}\right] \rightarrow \quad d = 1.22\,\lambda \frac{f_1}{2 f_2 NA}$$

Where d is the dimension of the spot on the CCD, f_1 and f_2 are the focal length of the focusing lens and the collimator lens, d_f is the dimension of the collimated beam, λ is the wavelength of the light and NA is the numerical aperture of the fiber. With $f_1 = 100mm, f_2 = 20mm,\ \lambda \sim 0.5$ and NA=0.12 the expected dimension is d = 12.7 µm.

The final alignment is made automatically by a custom made software which detect the spots and superpose them moving the tip tilt stages.

3.5.3 In plane control

Another optical system is adopted to define the zero of the xy coordinates system. It is a simple microscope made by two doublets to ensure the right magnification, a mirror placed between the lenses to fold the field of 90° and a camera to collect the image (figure 8). Everything is fixed to the vertical linear stage.

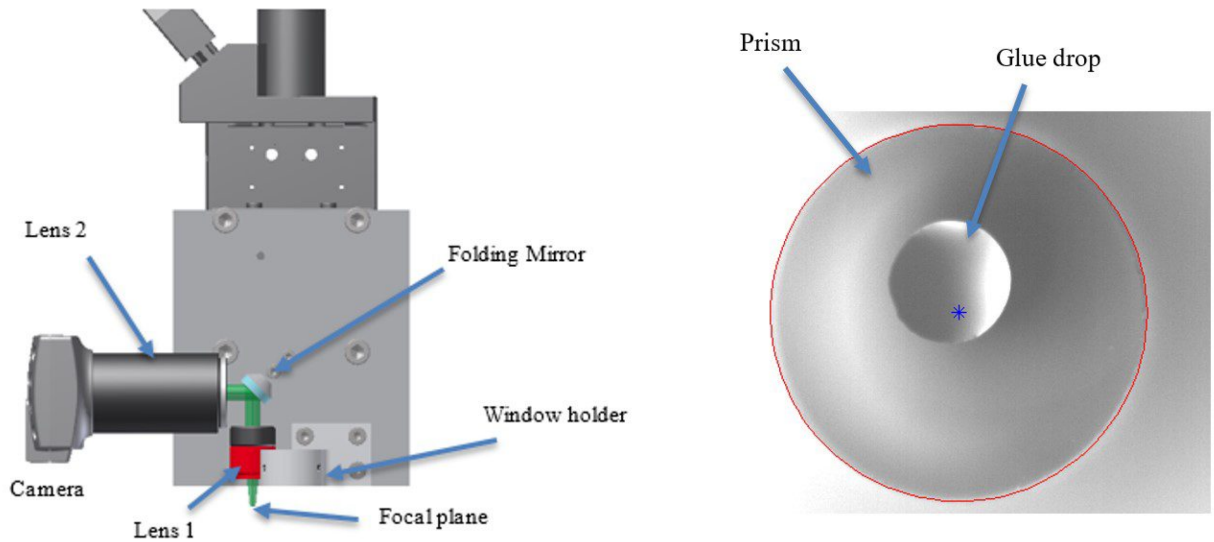


Figure 8. On the left is shown the microscope used to define the zero xy position, on the right an example of a prism recognition done by the software.

The procedure is to place the prism in the focal plane of the microscope, then a custom made software analyses the picture, detects the prism fitting the image with a circle, finds the centre with a precision of about 1μm and finally aligns the prism to the zero position moving the xy linear stages. This procedure is made iteratively until the alignment is correct within the micron.

3.5.4 Gluing

To monitor the gluing process, we use a camera together with a lens as shown in figure 9. The camera images the glue drop and its growth in dimension during the approach of the prism towards the silica window. Once the drop touches the window, the illumination light is scattered by the edges of the drop, making it detectable by the camera. As we move up the stage, the area covered by the glue increases and by following the increasing in size, it is possible to give an estimation of the final glue thickness.

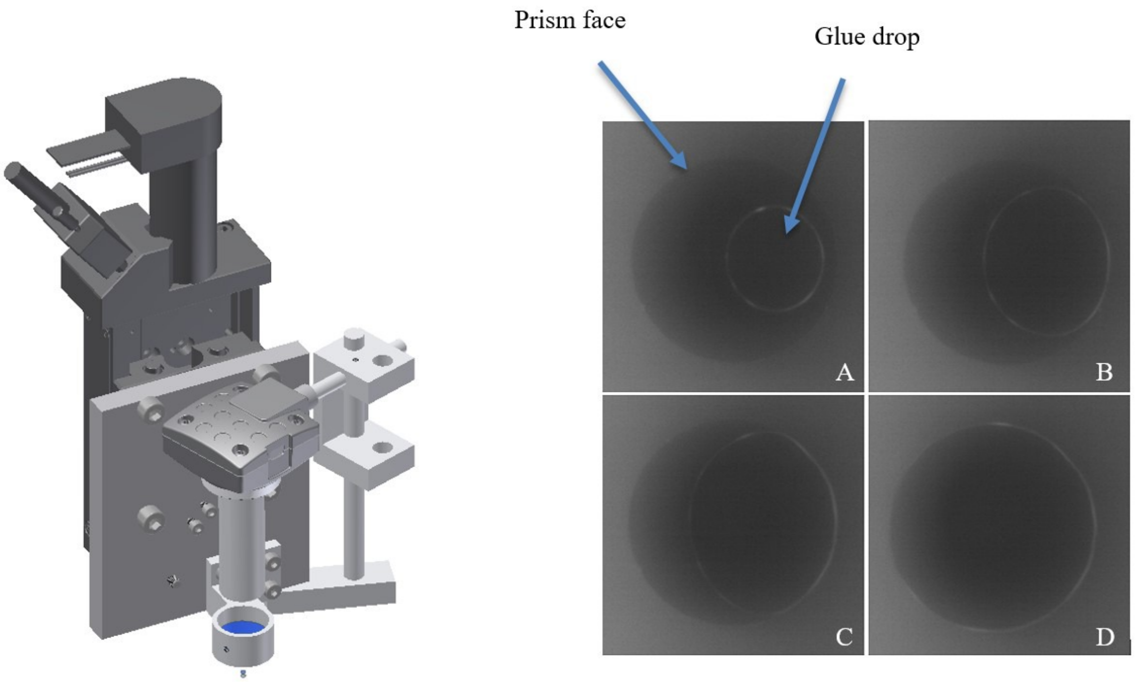


Figure 9. On the left is shown the camera used to monitor the gluing process, on the right an example of the increasing of the drop size detected by the camera during the lowering of the stage.

3.6 Results of the integration and test

The final integration must follow a proper assembly sequence in order to ensure the right final position for every degree of freedom. Here we briefly summarize the steps followed during the assembly procedure for the MMP system:

1. Alignment of the control systems;
2. Definition of the zero clock line (see section 3.5.1);
3. Positioning of the first prism onto the holder;
4. Clock alignment and positioning;
5. Wedge alignment;
6. Glue deposition;
7. XY positioning;
8. Gluing and curing.
9. repetition of points 3-8 for the other mini prisms

The first prototype has been realized and it is shown in figure 10. In order to test the performances, we direct a collimated beam towards the prototype and focus the deflected beams produced by the twelve prisms on a CCD (figure 10 C). Theoretical and the experimental results are shown in figure 10 C and D.

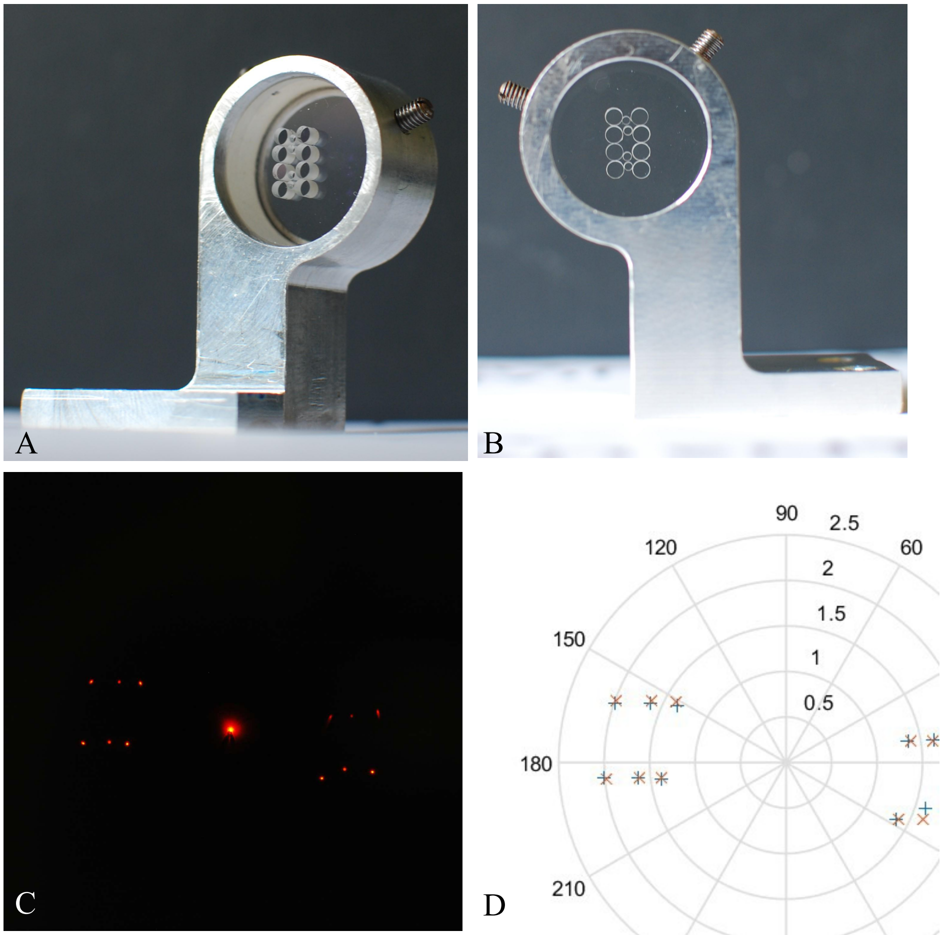


Figure 10. A, B: final results of the integration process. C: image focused on a CCD camera coming from a collimated beam deflected by the mini prism device. D: theoretical (x) and experimental (+) refraction angles for the twelve prisms.

Table 3. Results of the first integration.

	P1	*P2*	*P3*	*P4*	*P5*	*P6*
Δ_{clock}	0.2°	1.0°	0.1°	0.9°	0.8°	1.1°
Δ_{wedge}	0.2′	0.1′	1.5′	0.3′	0.0′	1.6′
	P7	P8	P9	P10	P11	P12
Δ_{clock}	4.0°	0.2°	0.2°	0.2°	2.8°	0.7°
Δ_{wedge}	0.8′	0.7′	1.0′	1.0′	0.9′	1.1′

Each point in the polar graph of figure 10 D corresponds to one prism, and its radius and angle values are directed related with the prism wedge and clock. After a global clock subtraction, we calculated the errors between the theoretical and experimental refraction angles (table 3). The RMS error in the overall clock positioning is 1.3°, while in the wedge is

1.0’. The worst errors are in the clock position of P7 and P11, due to a problem in the integration sequence of the prisms. The clock error, considering all prism except P7 and P11 is 0.56°.

4. CONCLUSIONS

The strict optical requirements of the APSU unit strongly affect the manufacturing process of the APSU focal plane. Hence, the positioning of the prisms composing the Multi Mini Prism at the focal plane must be produced with an extreme precision. An appropriate instrumentation to perform the assembly process has been designed, assembled, and verified, along with the control software to ensure a proper alignment of the single prisms. A first prototype was assembled and tested, showing results well within the specifications.
The system promises to be exploited for future applications in mini optics, like micro lens array and micro prism array for pupil and field slicing.

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