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Integration and test activities for the SUMIRE Prime Focus Spectrograph at LAM

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ABSTRACT

The Prime Focus Spectrograph (PFS) of the Subaru Measurement of Images and Redshifts (SuMIRe) project for Subaru telescope consists in four identical spectrographs feed by 600 fibers each. Each spectrograph is composed by an optical entrance unit that creates a collimated beam and distributes the light to three channels, two visible and one near infrared. We present here the integration process of the first spectrograph channel.

The verification requirements, the specific integration requirements and the product tree are the main drivers from the top plan for the Assembly Integration and Test (AIT) development process. We then present the AIT flow-down, the details for the AIT processes as well as opto-mechanical alignment procedures and tests setup.

In parallel, we are developing and validating dedicated tools to secure and facilitate the AIT activities, as we have to assemble eight visible cameras, integrate and align four fiber slits, integrate and align the components of four spectrographs.

Keywords: Assembly, Integration, test, AIT, PFS, SUMIRE

1. INTRODUCTION

The Prime Focus Spectrograph (PFS) [1] of the Subaru Measurement of Images and Redshifts (SuMIRe) project for Subaru telescope is developed by a large consortium over the world lead by the Japanese of IPMU divided into two main systems, a fiber positioner placed at the prime focus of SUBARU telescope and a spectrograph composed by four identical spectrographs feed by 600 fibers each. A spectrograph module [2][3] covers a spectral range between 380 to 1260nm splitted in 3channels, the blue, the red and the near infrared (NIR) one. A module, as shown on Figure 1 is fed by a pseudo slit placed at the focal plane of a Schmidt collimator, the beam is split into three channels by two dichroics followed the Schmidt corrector of the collimator and the Volume Phase Holographic Gratings (VPHG). The beam, then enters into the camera, first composed by the two Schmidt correctors, followed by the Schmidt-Mangin mirror, the field lens and the focal plane composed by either two detector for the visible camera or a single H4RG for the near infrared camera.

The spectrograph system integration is performed at LAM from dewars, focal plane assemblies and NIR cameras received from JHU, the fiber slit from LNA and other opto-mechanical parts from a French vendor, Winlight System.

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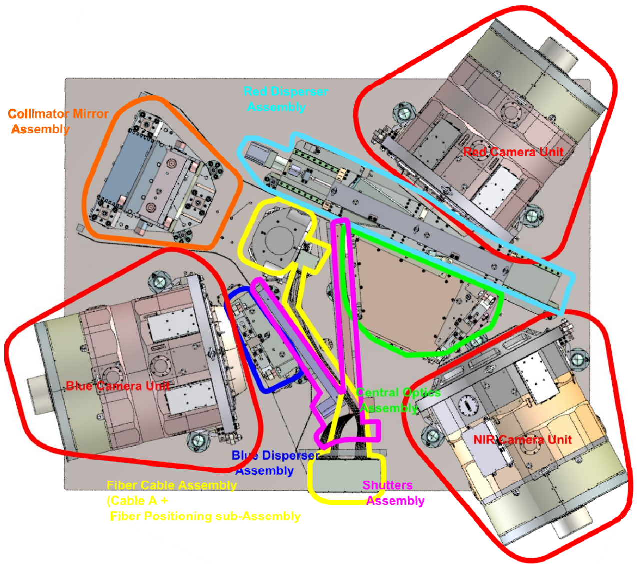

Figure 1 Overview of a Spectrograph Module

2. AIT DEVELOPMENT PROCESS

2.1 AIT overall approach

The verification requirements, the product tree, the optical design sensitivity study and the alignment strategy are the main drivers for the Assembly Integration and Test development process.

One goal of the product tree regarding AIT constraint is to split the instrument into products that can be assembled, tested and verified independently. In general, this breakdown appears during discussion on work package and responsibility. Another point of attention is interfaces: as different parts of the instruments are made by different institutes in the consortium, the interface definition becomes critical and the AIT has to be involved in this definition to add, if needed, some constraints regarding the entire integration process. Some specific interface can also be added for the integration. An important aspect in the development of an instrument is to think to the AIT during the design phase: while some small changes can be easily implemented to facilitate AIT during this design phase, it would become a difficulty to handle changes during later phases (request for change, change of interfaces, impact on on-going fabrication, etc.).

The verification requirements documented by the system group define how the instrument will be validated. The technical validation of each partner's contribution and of the full instrument should be clearly defined. These verification requirements become the main entry to define tests that will be performed by each partner and at LAM for final integration. The AIT response to these requirements is a set of test procedures and the definition of the tools required to perform these tests. For PFS performance tests at LAM, we identified the need of a dedicated illumination source, to measure, for example, the image quality over the field of view.

A critical point is the validation of the optical design: an alignment strategy has to be elaborated based on the sensitivity study. The alignment procedure provides its set of constraints for the mechanical design and also and the assembly plan. The sequence of assembly can be heavily constrained by an alignment strategy, so the AIT needs also to have a global view on all these elements to minimize the constraints on the design and the integration activities.

2.2 PFS main drivers

The number of identical parts in the PFS instrument, and the important size of the optical components was a significant reason to study solution and tools to minimize the integration activities.

One main goal early identified in the project was to minimize the integration activities at the summit of Mauna Kea. In consequence, we identified that the assemblies shall be repositionable without any alignment on the main bench and that

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assemblies shall not be dismounted nor disassembled. Taking into account the size of the components and the restricted available space between them, we spent a particular attention on the handling tools and on the guiding tools. In addition a global metrology method was proposed based on the laser tracker system, to check the correct mechanical integration.

The LAM has the responsibility to assemble in Marseille the 8 visible cameras, from different parts coming from consortium members or vendor. In particular, we need to dis-assemble the opto-mechanicals part aligned to integrate the focal plane then re-assemble the parts and finally close the dewar. We designed a dedicated tool to facilitate the AIT operations and securely handle the assembly of the camera. The tool is detailed in the section 3.2.

Another key point is the time constraint that does not allow us to make a complete prototype or first module and then fabricate the 3 others with modification if needed. This is not possible because of a serialization manufacturing process choice to save time and cost. Yet, in order to mitigate any development risk, it was decided to first build a single channel spectrograph. This one channel spectrograph will be used to validate the thermal design of the visible camera and the image quality. It will also help us to validate and finalizing the assembly procedures and the AIT tools

2.3 AIT plan

The main AIT documents are the AIT plan that describes each activity with the procedure, the AIT flow chart that gives an overview of each activity with the dependency and the activities sequence and the planning that gives the timescale of the AIT activities and the needed resources.

In Figure 2 below is shown the AIT flow of the one channel spectrograph of PFS, one can see all parts and assemblies to be delivered to LAM in red, the AIT tools in grey, the software required in blue. The type of activity is also identified by colors: green for mechanical integration and assembly, alignment in light green and yellow for test. There is a distinction between integration and assembly: the assembly is to put together mechanical parts to make a whole, while the integration is to place an assembly with on other assembly. Moreover for each test the acceptance list is detailed with the corresponding requirement that will be verified.

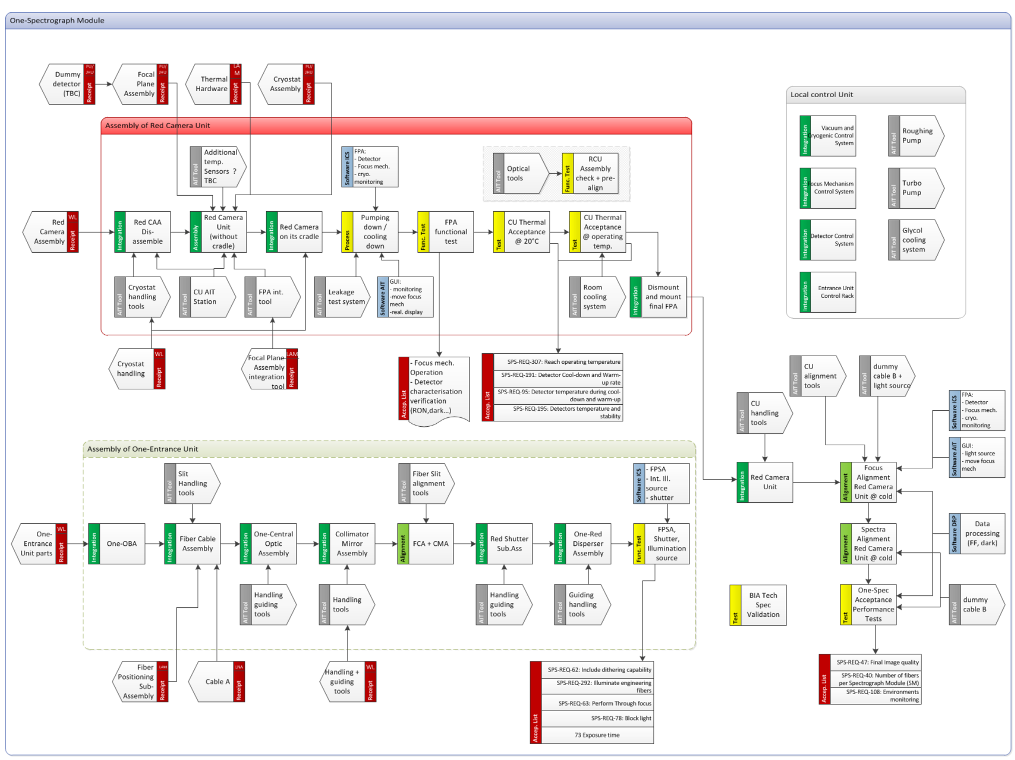

Figure 2 PFS LAM AIT flow chart of the one-channel spectrograph

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3. AIT TOOLS

3.1 Assembly on the bench and metrology

As mentioned previously, a particular attention of the mechanical design was focused on the repositioning capabilities. The overall repositioning budget of all elements on the optical bench is +/-50microns in each direction at the slit plane and +/-15arcsec in roll. The solution adopted is to have a common mounting feature based on spherolinder mount. In addition each component is equipped with at least four reflector supports to allow a measure using a laser tracker system before and after the dismounting/remounting. This 3D metrology will be used to detect any mechanical assembly positioning error as soon as possible. Indeed the space available around each element is very restricted so an early detection on the position of mechanical assembly will save to time.

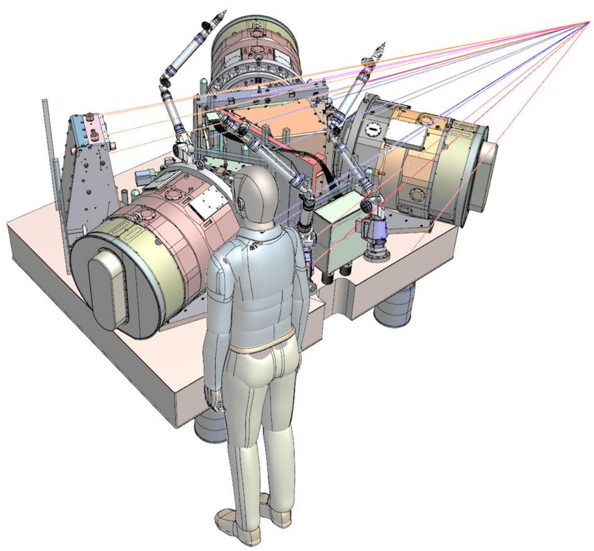

Figure 3 3D view of Spectrograph Module with metrology mapping.

One specific point of PFS is the combination of large parts and restricted space. So it was necessary to have dedicated handling tools and mounting guiding system for each element. For example the Central Optics Assembly is about 800x500x730mm3 for 150kg and one can see on the Figure 1 the accessibility to this part is limited. The mounting tool consists in guiding/landing bars taller than the height of the assembly that are placed in ring attached to the part itself in order to securely move it down using a slow-speed crane.

3.2 Camera Unit AIT station

The main specification of the CU AIT Station is to facilitate the assembly of the visible camera unit with the required repositioning performance, i.e. without the need for an optical alignment. There are two main functions, the first one is the integration of the focal plane assembly inside the camera and the second one is to close the cryostat and finalize the assembly of the camera unit.

The camera assembly is received from Winlight System with the optics aligned. LAM has to integrate the focal plane. As it is a Schmidt camera, one first needs to dis-assemble the opto-mechanical parts. The camera optics assembly is removed from the cradle and put on the unit station with a dedicated handling tool. The rear part of the camera composed by the Mangin mirror, its support and the focal plane is decoupled from the front bell using the Camera Optics Integration Tool (COT).

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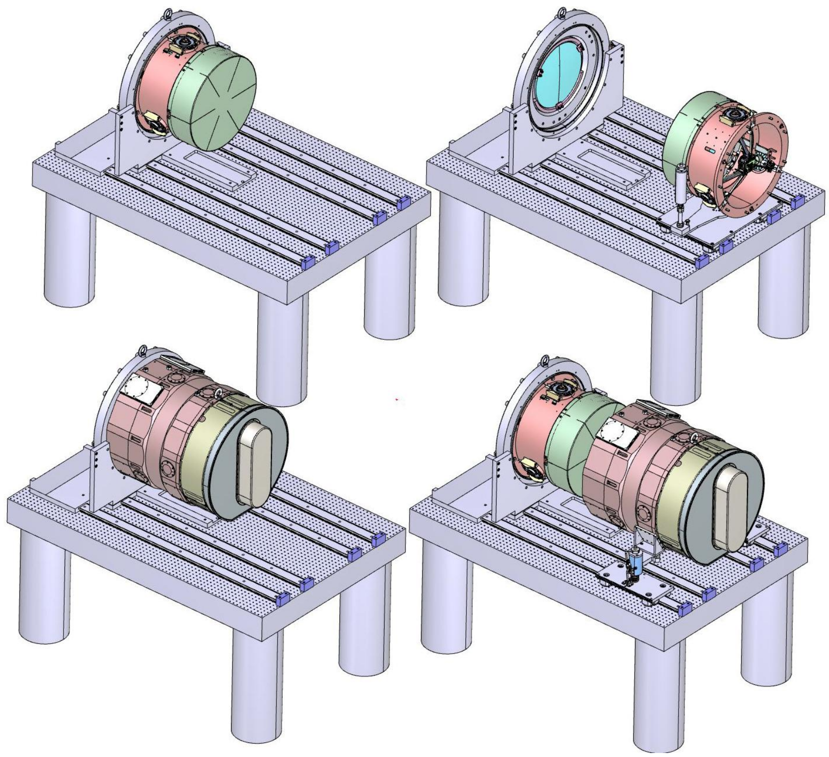

Figure 4 Assembly of the CU using the AIT Station

The COT tool is composed of four functional elements, a guiding system, made by two precision trolleys and rails, a rotation system, with two tapered roller bearings, an axis and a plate to support the mass compensation system, with an adjustable axis, a compression spring with a nut system to set the value of the compression, a cylinder guided by a bearing, and a knurled nut to adjust the height of the assembly and an interface plate removable, used to fix the Mangin Cell on the COT.

The rotation system allows for an easy and secure integration of the focal plane assembly composed by two detectors side by side mounted on motorized stage with 3 degrees of freedom, tip tilt and focus. The three motors are mounted on the external tube linked by three legs to the focal plane assembly.

When the integration is complete, one can rotate the part and move it back to fix it on the front bell using precise interfaces that minimize repositioning errors.

The cryostat is then placed on the unit station using a tool designed to easily plug the cryostat on the front bell. The tool is composed of two functional elements, a guiding system, made with two precision trolleys and rails and a mass compensation system, with an adjustable axis, a compression spring with claw for a quick compression of the springs. A set of flexible parts allows for small movements on every axis during the final positioning.

3.3 CU Focus Alignment

The focus alignment method was studied using theoretical simulations with Zemax and Matlab. The idea is to model images obtained on the detector during alignment process, considering all the effects involved (pixelisation, charge diffusion, fiber...).

The alignment method is based on a through focus. So the simulation consists in applying a shift on the detector in Z-direction (in Zemax) and look at the corresponding spot obtained with the representative optical model. We measure the

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value of the pixel of maximal intensity and the ensquared energy in 3, 4 or 5 pixels. To see the impact of pixelisation, we consider the two extreme cases: the center of the spot is at the center of a pixel (I), and the center of the spot is at the intersection of four pixels (P). At the end we can have the image of the pixelized spot and the corresponding ensquared energy.

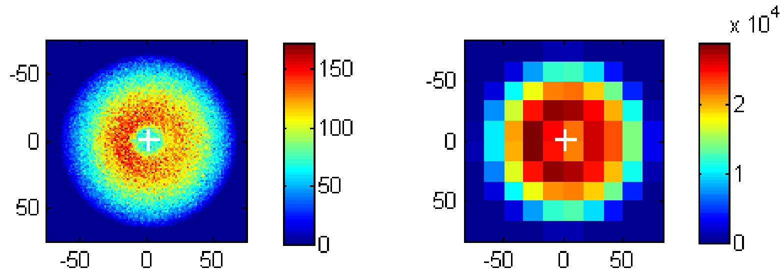

Figure 5 Spot for a defocus of +100um (P) obtained with science fibers

A few criteria for best focus determination were explored to find the best focus position looking at the TF curves. We compared the curves obtained with the Ensquared Energy in 3 by 3 pixels, 4 by 4 pixels and 5 by 5 pixels parameters (Y-axis parameter)

The value of the pixel with the maximal intensity was also considered but appears to not be appropriate; it is strongly dependent on the pixel position relative to the centroid.

The Figure 6 plot compares the results of ensquared energy measurement in 3 by 3, 4 by 4 and 5 by 5 pixels with science fibers. The measurement area of 3 by 3 pixels appears to most appropriate to find the best focus, it gives a sufficient sampling of the spot even with low defocus and the relation EE-Defoc vary faster than with larger areas.

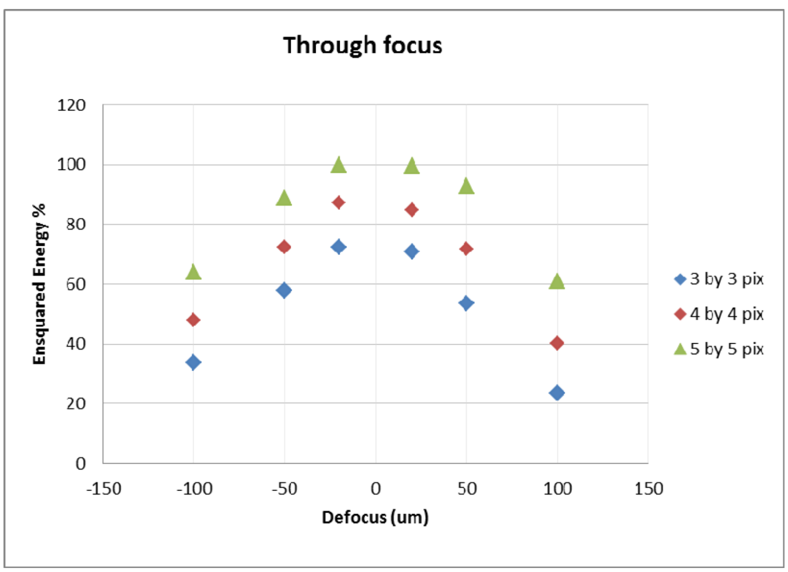

Figure 6 Through focus with different size of EE measurement area

The detector field and wavelength sampling was also studied, the Figure 7 shows the difference between the focal plane location in the nominal design and the best focus position for each wavelength / field.

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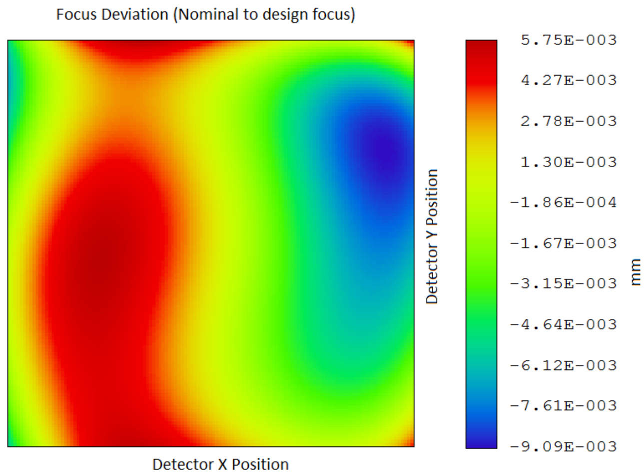

Figure 7 Difference between best focus position for each point and Detector position in Zemax

Even in the nominal design, the focal plane is not exactly at the best focus for each field and wavelength. Furthermore, the flatness of the detector is about 15 microns so it cannot be at the best focus everywhere. For these reasons, we need to have a sufficient sampling on the detector to find a position that minimizes the focus deviation for a maximum of fields/wavelengths.

The Figure 8 shows the through-focus curves for 9 by 9 points on the detector. As shown, the best focus obtained (maximum of the curve) depends on the field/wavelength position. The maximal error to the best focus position is about 10 microns, the mean is 3.8 microns.

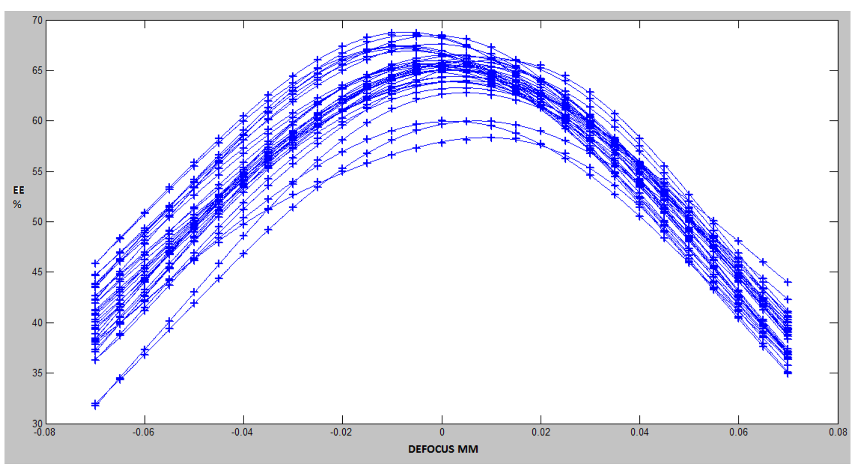

Figure 8 Through focus curves for 9 by 9 points on the detector

When we decrease the number of points, the determination of the best focal plane remains the same until 4 by 4 points. With only 3 by 3 points the definition of the best focal plane becomes less precise. So the good range for the detector sampling is between 4 by 4 and 7 by 7 points. It means that we need, at least, 4 different wavelengths for each camera and 4 different fibers.

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3.4 Illumination source

The aim of this AIT tool is two-fold: first, facilitate the performance tests and perform the optical alignment.

This illumination source will used to validate by test the wavebands, the image quality and stability and the image centering and size. The waveband test consists in verifying that one entire column of each detector is illuminated when white light is used and verifying the relative position of two different wavelengths on each detector. For the image quality by the measure the spot size for several points in the field/spectra on each detector for which one need for a uniform illumination of the pupil and emission lines with narrow spectral width (unresolved emission line). For the image centering and size, one measure the distance between two centroid spots coming from two different fibers and wavelengths (known) to deduce the field /wavelengths positions and dimension on each detector. For the image stability, one measure the displacement of the centroid spots on each detector over time with a sub-pixel resolution, so one need for a good spectral stability of the source to avoid wavelength drift. For ghosts and scattered light, one measures the signal on the detector when one fiber is illuminated, so one need for a good power stability.

The main specifications for the illumination source are described on the Figure 9 below.

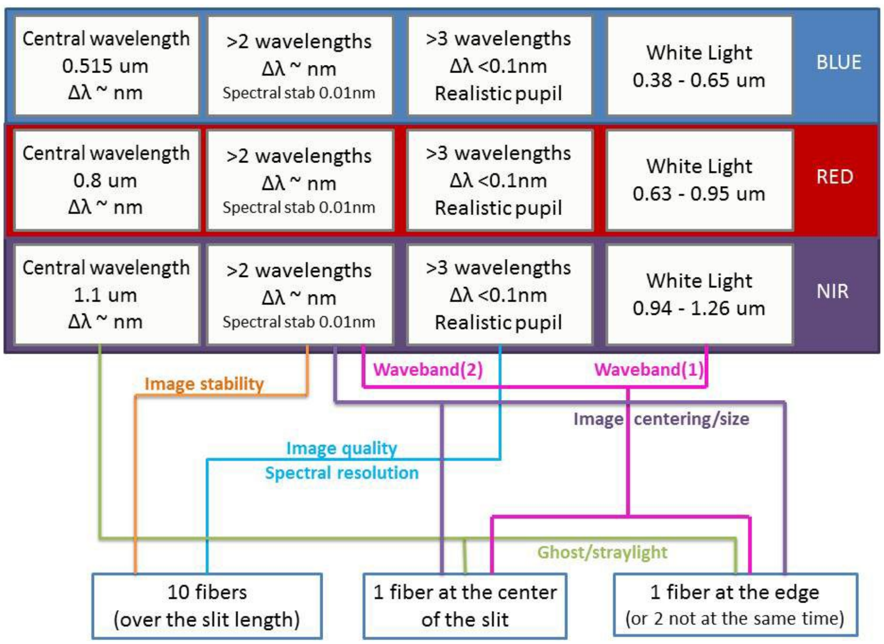

Figure 9 illumination source main specifications

The Fiber slit of PFS has two connectors, so the illumination source will be connected to the slit using these two connectors and will be linked to the source by fibers plugged on an integrating sphere on which every sources will be attached.

4. CONCLUSION

The CU AIT Station is fully designed and all manufacturing drawings are finished. The manufacturing of the first part has already started. The illumination source design is almost final. The main specifications of software during the AIT phase are under finalization. PFS AIT activities on the instrument at LAM will start at the end of this year

5. ACKNOWLEDGEMENT

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