Neo-Narval Calibration Unit

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Summary: This document specifies characteristics of Neo-Narval calibration unit. After studying the specifications of Neo-Narval, it appears that the existing calibration unit of Narval cannot be modified to fill all requirements, other calibrations units are studied, SOPHIE lacks a dual output, hence the simplest viable option is probably to adapt SPIRou/SPIP calibration unit to Neo-Narval.

Keywords: Neo-Narval, calibration unit

DOCUMENT CHANGE RECORD

Issue	Revision	Date	Modified pages	Reason for change / Observations
V1		June 2016		

Acknowledgements

Neo-Narval is made possible by support from CNRS/INSU, a CPER grant, University of Toulouse, UPS, OMP, and TBL.

Table of Contents

1. GENERAL ASPECTS
    - 1.1. Scope of the document
    - 1.2. Introduction
    - 1.3. Description of the calibration needs
        - 1.3.1 Spectropolarimetry
        - 1.3.2 velocimetry
    - 1.4 Technical constraints on Neo-Narval calibration unit

2. Existing Calibration Units
    - 2.1 Narval
        - 2.1.1 Technical description
        - 2.1.2 Narval CU physical location
    - 2.2. SOPHIE
        - 2.2.2 Technical description
        - 2.2.2 SOPHIE CU physical location
    - 2.3. SPIRou
        - 2.3.2 Technical description

3. Neo-Narval CALIBRATION UNIT
    - 3.1. Neo-Narval CU conceptual design
    - 3.4. Neo-Narval CU possible designs
        - 3.3.1 Upgrade of Narval CU
        - 3.3.2 Copy SPIRou CU
        - 3.3.3 Location of Neo-Narval CU

Appendix 1: Narval CU components

1. GENERAL ASPECTS

1.1. Scope of the document

This document specifies the technical requirements and characteristics of Neo-Narval Calibration unit, and its optimal physical location (telescope, dome, close to spectrograph?).

1.2. Introduction

The science requirements of Neo-Narval are given in the Science case document. They boil down to achieving the same sensitivity than Narval in the measurements of Stokes parameters in absorption lines of stellar spectra, and to reach a velocimetry accuracy better than 3m/s on the long term.
The science requirement on Narval (spectropolarimetry only) is currently achieved by the Narval calibration unit described section 2. Section 2 also details existing UC (SOPHIE calibration unit, SPIRou). Section 3 proposes technical solutions for Neo-Narval calibration unit.

1.3. Description of the calibration needs

1.3.1 Spectropolarimetry

Technical specifications have not evolved from Narval to Neo-Narval. The reader is referred to Narval/Espadons online documentation and to the history of calibration maintenance on TBL www pages (and appendix 1).
In short, spectropolarimetry requires three levels of calibrations, (i) a CCD characterisation done with a bias image measuring the amplification off-set, a dark current quantification, a pixel-to-pixel sensitivity quantification (traditionally done with a flat illuminated image). (ii) A geometric calibration done by a series of flats (or Fabry-Perot) diffusing light across all orders as flat as the echelle-grating blazing function allows and a Fabry-Perot cavity used to fit the slit position. (iii) A wavelength calibration done with hollow cathode lamps providing many lines in all orders.
The broad wavelength range of Narval (370-1000 nm) makes the choice of halogen lamps and hollow cathode lamps tricky. Finding halogen and hollow cathode sets following the specs is not trivial and required to use 2 halogen lamps and 2 hollow cathode lamps for intensity and color balance. Another option is to use a solar spectrum for wavelength calibration. Of course, Neo-Narval has the same wavelength range than Narval so the current situation (Th Lamps and Halogens) works, hence the constraints from spectropolarimetry is to provide at least the current Narval calibration specifications.
A notable improvement of Narval in the red part of the spectrum will come from the new detector/camera, and progress made in the last 10 years in calibrators will tend to simplify the CU. It is expected that only one lamp for wavelength calib and one lamp for flats will be needed. Actually, a minimal solution can use only a Fabry-Perot file and solar spectrum as a complete calibration set (A. Lopez-Ariste, priv. com.).

The current wavelength solution given by the reduction software Libre-Esprit, gives an absolute Mean rms accuracy in radial velocity of ca. 200 m/s, averaged over all orders. The measured stability (cf document on detector choice) over a day/night with regard to temperature and pressure is much better (a few m/s) but not needed for spectropolarimetry.

1.3.2 velocimetry

Velocimetry is much more demanding in terms of wavelength definition and stability. The stability requirements of Δrv < 3m/s, requires us to monitor any shift during the night to 1m/s. This means that :

1. an absolute wavelength solution can be found to Δrv~1m/s with some wavelength calibrator (Hollow cathode lamp) from one night to another. Given the number of Thorium reference lines (>3000), such precision ought to be feasible, and has been demonstrated by previous tests with Espadons and Narval
2. Any wavelength shift should be monitored to 1m/s during any night (and following day). That requires a constant calibrator to be fed in parallel to the science channel. This requires an additional stable reference, such as a stable Hollow cathode lamps or a stabilized Fabry-Perot cavity providing a continuous reference on the detector at the same time as science data is taken.

Geneva Team (priv. comm. F. Pepe), based on their CORALIE experience, suggests that night-to-night rv shifts < 3m/s can be corrected. Larger shifts might induce additional error in radial velocity.

1.4 Technical constraints on Neo-Narval calibration unit

The technical capabilities identified to reach the science specs can be summarized as follows, in order to give us a maximum redundancy:

- each calibration lamp (Thorium, Fabry-Perot, Halogen) must be injectable simultaneously or independently in each fibre. Either going through the polarimeter or fed directly to the spectrograph (calibration fibre only). cf Figure 3.1:

    - Namely, the Fabry Perot lamp must be injectable simultaneously in fibres 1,2 and 3, but also only in 3 (the calibration fibre) in parallel to science data. It must be the same lamp. A fibre must come from the Fabry-Perot box or calibration box to the polarimeter environment in order to be injected in fibres 1 & 2, while a 3rd fibre must take the same light and inject it directly in the scrambler and image slicer (fibre 3).

    - The same injection options must be possible for the absolute wavelength calibrator (Hollow Cathode Lamp Thorium+gaz), and Halogen lamps for flats. It must be ascertained that each time it’s exactly the same lamp which is injected, we cannot make simultaneous use of two different lamps.

- The Fabry Perot lamp and absolute wavelength calibrators must have an adjustable neutral density wheel, and the density must be adapted automatically as a function of the total exposure time, in order to guarantee the same exposure level (⅔ of full well?) independently of the exposure time.

- Not directly concerning the calibration unit, but important enough to be mentioned here is the fact to register continuously the flux rate via some counter and to register it, from beginning till the end of the true exposure. This enables us to derive the barycenter of the exposure. Once the barycenter is determined, the continuous flux count rate curve does not need to be kept, but it could be.

In short, all the following output permutation should be feasible (cf Fig 3.1):

Template	CU output towards Polarimeter	CU output towards spectrograph
#1	Stabilised Fabry-Perot	Stabilised Fabry-Perot
#2	Absolute calibrator (Sun, Th, ...)	Absolute calibrator (Sun, Th, ...)
#3	Flat	Flat
#4	Stabilised Fabry-Perot	Absolute calibrator (Sun, Th, ...)
#5	Absolute calibrator (Sun, Th, ...)	Stabilised Fabry-Perot
#6	Star/Sky	Stabilised Fabry-Perot
#7	Star/Sky	Absolute calibrator (Sun, Th, ...)

2. Existing Calibration Units

This section describes existing calibration units and analyses their capabilities with regard to the technical constraints (cf previous section).

2.1 Narval

Reference documents: ESP-CB-FRD_2.pdf: Espadons CU, Narval_elec_vol1: Narval electronics vol1

2.1.1 Technical description

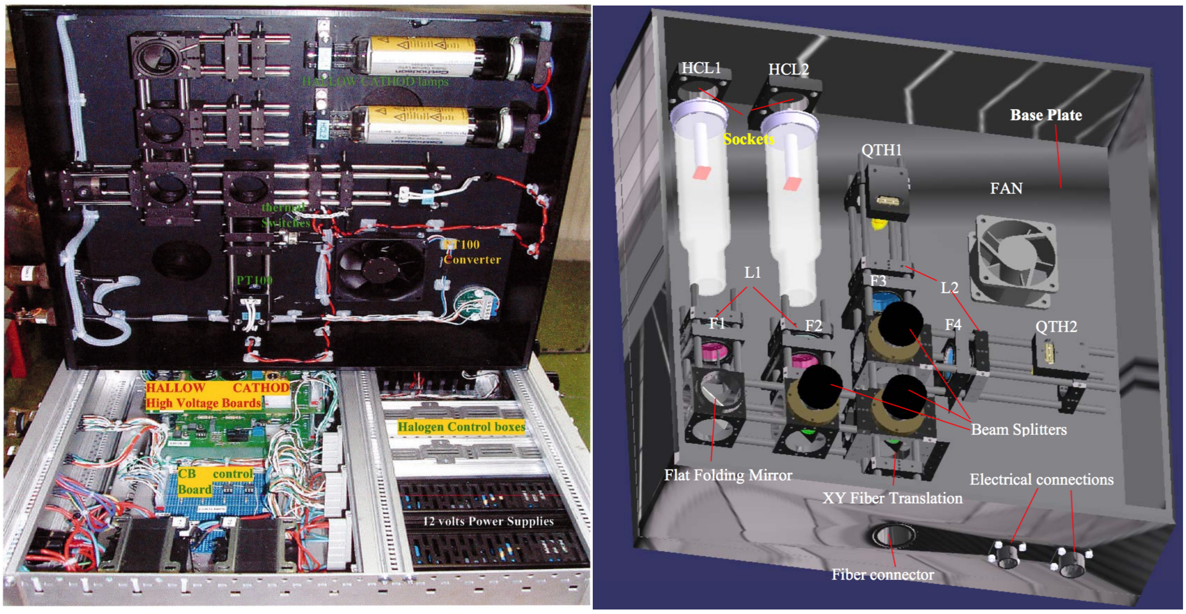

Fig 2.1: photo of Narval CU (left) and mechanical drawing (right), (credits L Parès)

Narval CU was designed to have no moving parts and multiple lamps lighting the pupil. It has two Hollow Cathode Lamps (originally a “blue” Th-Ar and a “red” Th-Ne) for wavelength calib and two halogen lamps (again, one “blue”, one “red”) for flats. There is an additional Fabry-Perot cavity in the polarimeter, fed by the Halogen lamps, for order and slit definitions. All lamps are directed through a series of 45° (flat-folding) mirror and beam-splitters to a single output (800µm fiber) and fed to the polarimeter after the Atmospheric Dispersion Corrector, and before the guiding-mirror entrance pupil.

The Lamps type have evolved a bit since 2007. Current Hollow cathode lamps come from Australian Photron Corp. TBL tech team will be testing simple Th (no filling rare gaz) lamps in order to quantify their reliability. Halogen lamps are still coming from the original provider, they are simple tungsten halogens (Hereus QTH lamps, Mazda Xenon car light).

A better solution adopted by current instruments (SOPHIE, Fabry-Perot modules) are Laser Driven Light Sources providing stable flat emission accross the UV-NIR spectrum.

2.1.2 Narval CU physical location

Narval calibration unit is currently attached to TBL tube. The calibration box and the polarimeter electronics are attached on each side of Narval Polarimeter with a robust iron welded frame. This was done for injection purpose, the 800µm fiber is short and cannot flex easily, hence a non-moving CU with regard to the pupil was favored.

2.2. SOPHIE

2.2.2 Technical description

SOPHIE calibration unit uses a very different concept then Narval. It uses a rack of calibration lamps feeding a moving fibre mounted on a chariot.
The output fiber is then fed to the T193 bonnette. In the bonnette a moving mirror allows users to select the science pupil, the calibration pupil, or both (HR, LR, slit vs circle) at the same time. Among the rack incoming fibers are allowed, for instance a FP fiber can be injected in SOPHIE calibration unit and re-injected to the output fiber.

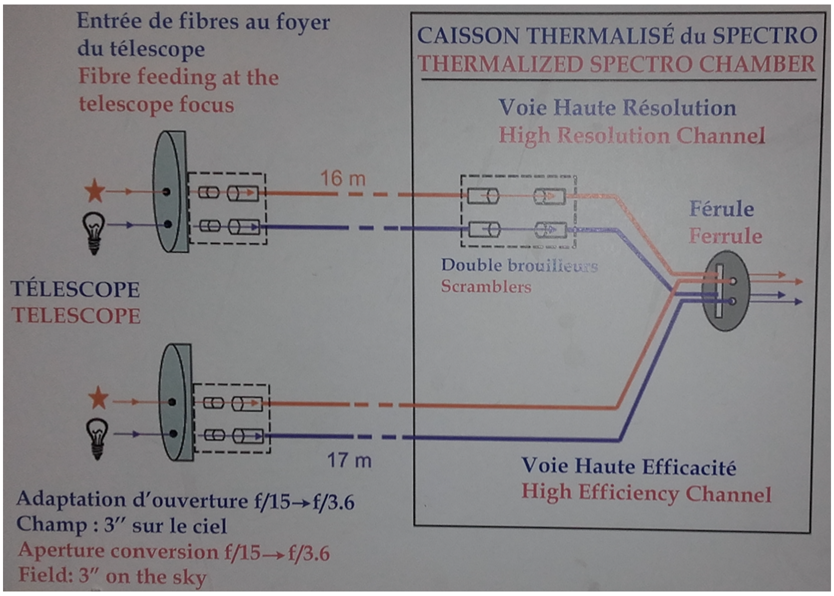

Fig 2.2: SOPHIE CU (photo credit R Cabanac)

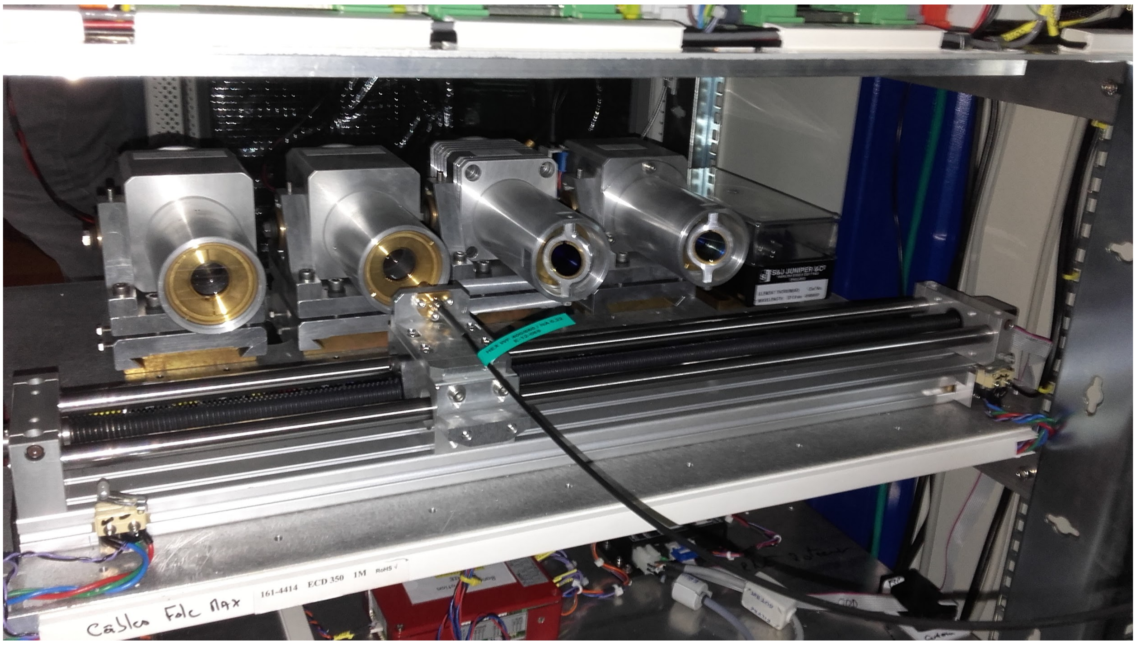

Fig 2.3: photo of SOPHIE CU chariot with output fiber (Photo credits R Cabanac).

The advantage of the SOPHIE CU is flexibility and simplicity of injection, but the single fiber output implies we need to re-build Narval polarimeter adding a 3rd channel for calibration all the way from the guiding mirror to the spectrograph. This is not a viable option for Neo-Narval, we do not plan to redesign the polarimeter further than a possible upgrade of the optical encoders of the rhomb drawers.

2.2.2 SOPHIE CU physical location

SOPHIE CU was originally attached to the telescope in the dome, but it made any maintenance very cumbersome and the large temperature amplitude were suspected to have an impact on calibrators stability. The current upgraded version of SOPHIE CU is located close to SOPHIE in a thermally controlled room. Finally the stable temperature does not seem to play a major role in calibration stability, most of the error vanished through a careful optical reshuffling of near and far fields scramblers, and polygonal output fibers. The calibration injection is still done at the same location than before in the bonnette.

2.3. SPIRou

2.3.2 Technical description

Although SPIRou is an infrared spectrograph, the calibration unit is worth presenting here because TBL will house a copy of SPIRou (SPIP), and it does make a lot of sense to recycle as many components as possible between Neo-Narval and SPIP. The concept of SPIRou CU is very similar to the SOPHIE CU one (fig 2.3), but it has two chariots on top of each other each equipped with a folding mirror pointing to a different output fiber. In addition to refinements in the way lamps and aligned and handled compared to SOPHIE CU, SPIRou CU houses a cold pupil (mandatory for K IR Band but not for Neo-Narval).

2.2.2 SPIRou CU physical location

The SPIRou CU is a built in a rack that can be located anywhere, easy access and stable environnement is of the essence.

3. Neo-Narval CALIBRATION UNIT

3.1. Neo-Narval CU conceptual design

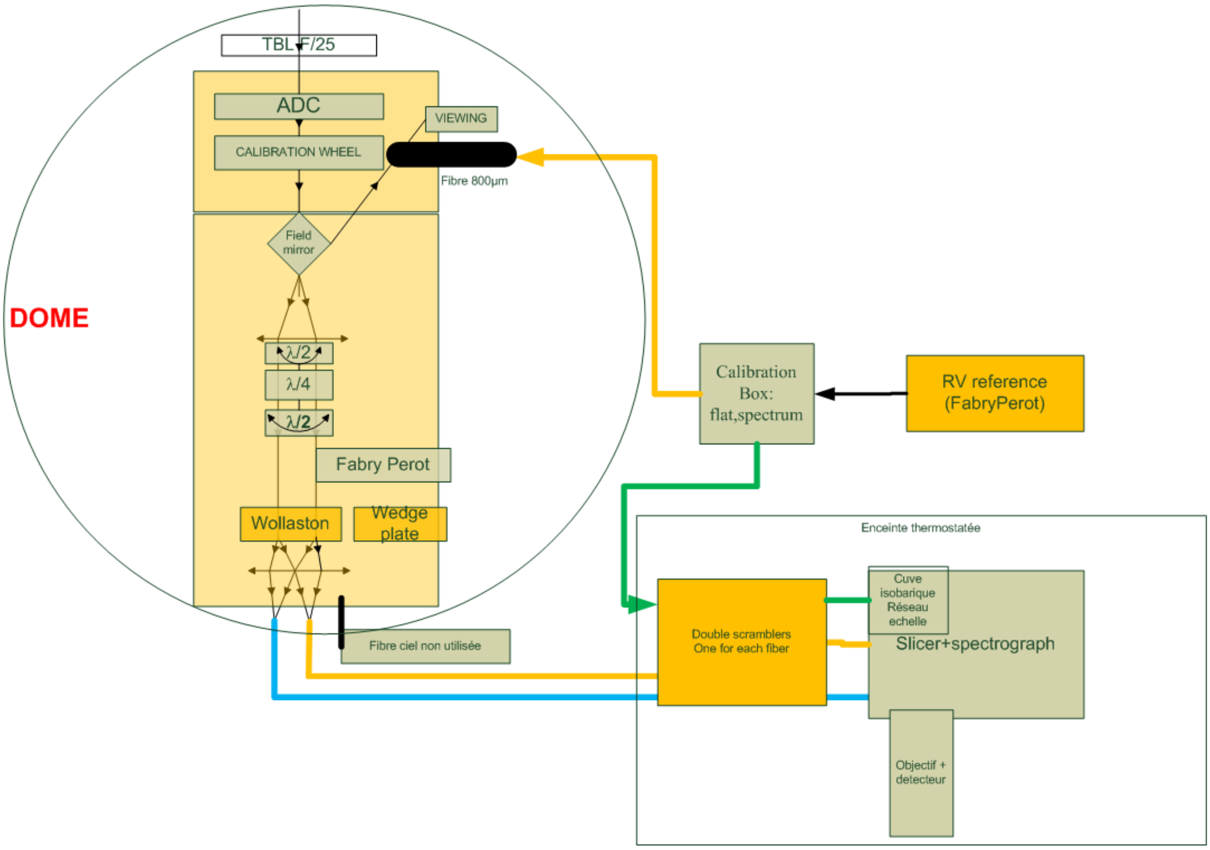

Fig 3.1: shows Neo-Narval functional design for the calibration box, with a simultaneous feed to the polarimeter and the spectrograph (Credits: Laurent Parès, IRAP)

3.4. Neo-Narval CU possible designs

3.3.1 Upgrade of Narval CU

One solution is to keep the “no-moving-part” concept of Narval CU, but upgrade it to provide a dual output, one output would be fed to the polarimeter and the other to the spectrograph. Figure 3.2 shows the design for 4 lamps (or inputs).
At this time, each input is transmitted at 25% of its nominal intensity because of the number of reflexions.

An example of the lamps could be:
L1: Laser Driven Light Sources (flat), L2: Fabry-Perot fiber, L3: Thorium, L4: Sunlight fiber.

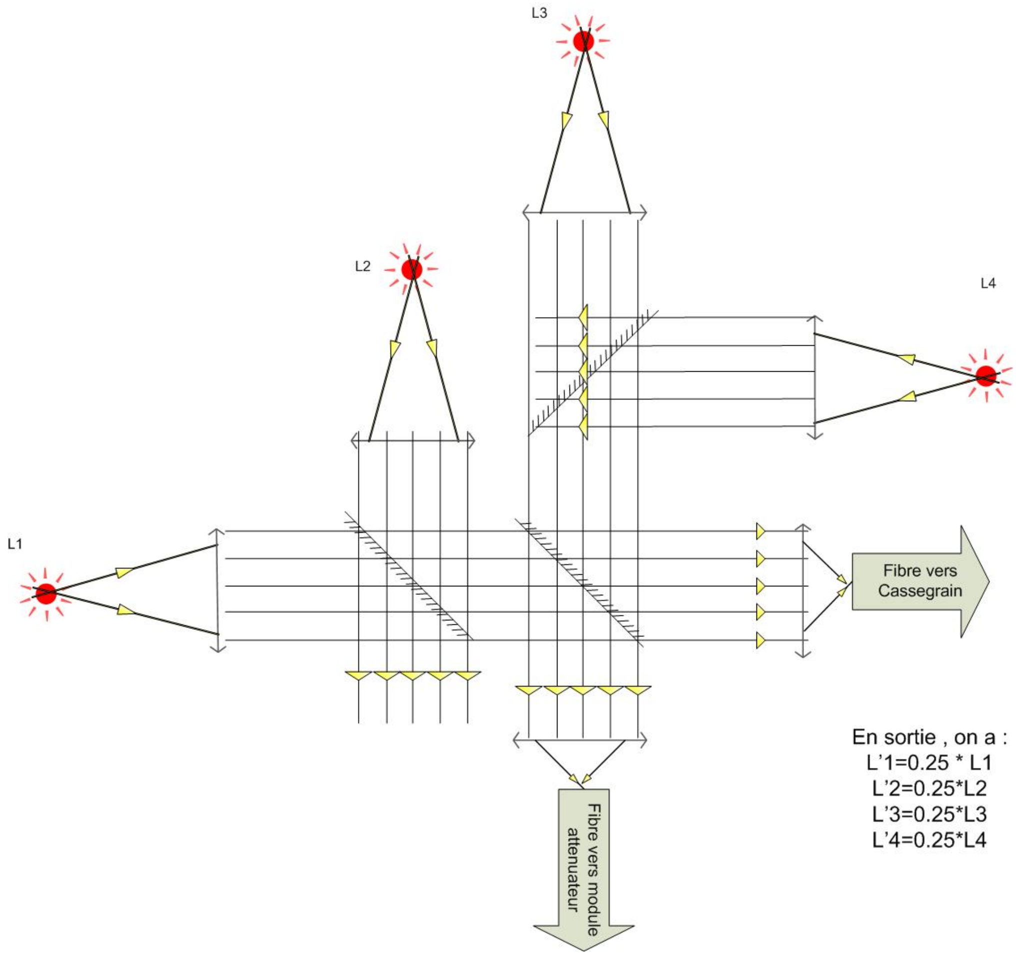

Fig 3.2: Neo-Narval no-moving part concept. This concept allows us to feed both the polarimeter and the spectrographe with both lamps. (Credits: Laurent Parès, IRAP)

3.3.2 Copy SPIRou CU

Another option would be to copy the mandatory features of SPIRou for Neo-narval with lamps L1: Laser Driven Light Sources (flat), L2: Fabry-Perot fiber, L3: Thorium, L4: Sunlight fiber.

3.3.3 Location of Neo-Narval CU

One of the Neo-Narval lamp will actually be a fiber feed from a stabilised Fabry-Perot. This makes a Narval-type calibration CU i.e. attached to the bonnette close to the polarimeter difficult unless the FP is in the dome. This also assumes that a moving FP fiber will deliver a stable signal to the calibration CU. On the other hand, the location of the CU will necessarily be either close to the polarimeter of close to the spectrograph, and one of the Calibration fiber output will necessarily be as long as the existing science fiber bundle. As the is no strong incitive for either location. The choice of the optimal location will boil down to technical feasibility and cost. This analysis will be done in the coming months.

Appendix 1: Narval CU components

Lamps:
Hollow cathode: Thorium, Thorium-Argon: Photron Corp.
Halogen: Qartz-Tungstene-Halogen Lamp: HERAEUS Corp., Mazda: 50w; code:09117; 12v; GY.6.35; 091175, OSRAM: H7 silverstar; 64210SVS; 55w; PX26d

Mechanical and Optical components described in ESP-CB-FRD_2.pdf

Control schematics