**SPICA-VIS**

**General Requirements**

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**CHANGE RECORD**

|  |  |  |  |
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# Scope

This document describes the general requirements of the SPICA-VIS instrument.

As a short summary, the SPICA-VIS system is located in four main places :

1. The modules needed to operate SPICA-VIS but not part of the instrument. These modules located on CHARA tables are for example: STS-VIS, LDC-VIS... The three other groups are part of the instrument itself:
2. the modules located on the CHARA visible table: Periscope and ADCs,
3. the modules located before the optical fibers on the injection table,
4. the modules located after the optical fibers on the spectrograph table

# Introduction

SPICA can be fed either by the 6 CHARA beams or by the 6 STS visible beams.

## 2.1 CHARA beams

* The 6 CHARA beams are sent to SPICA with the main VIS dichroics. They have a diameter of 3/4'' and are separated by 3''. The position of the pupil plane is defined in the CHARA document 'CHARA-Distances-wAO.pdf' and in the excel sheet CHARA\_PupilPositions-SPICA.xlsx.

## 2.2 STS beams

* SPICA could also be fed by the STS, through 6 STS-VIS dichroics. These last ones are removable to authorize the switch between the sky and the STS.
* The STS-VIS system is described in document SPICA\_VIS\_008 (mechanical design).
* *1 ON/OFF mechanism + control of the sources*

## 2.3 Functional analysis

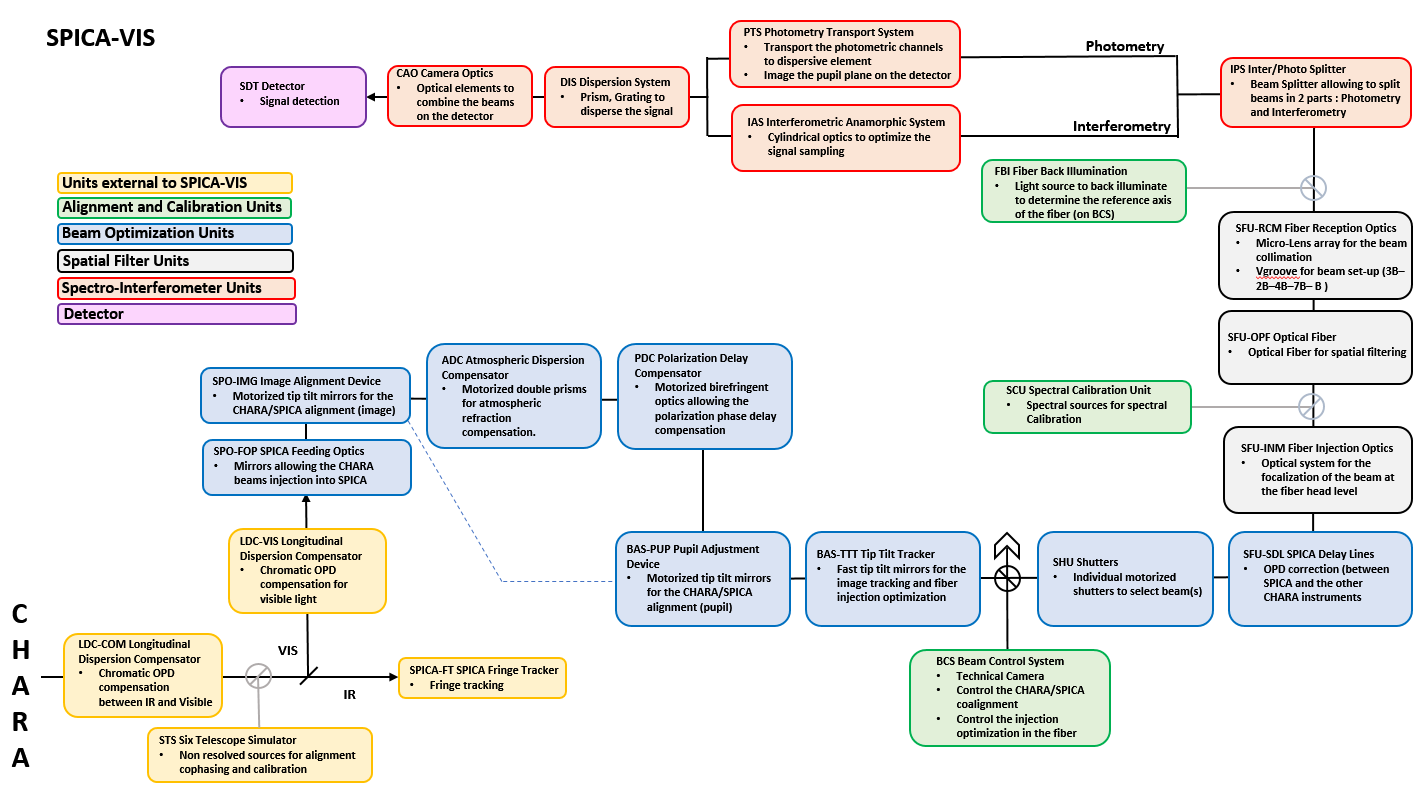
The guiding principle of the SPICA-VIS modules between the CHARA beam and the injection in the single mode fibers is to adapt the wavefront in all its dimensions to the needs of the interferometric recombination. It means that we have to perform the following functions:

* Co-alignement of the pupil plane (XYZ) and of the image plane (Tip/tilt)
* Active stabilization of the image plane for the fiber injection
* Longitudinal dispersion compensation (LDC-COM within CHARA, LDC-VIS in addition for Visible instruments)
* Lateral dispersion compensation
* Fiber birefringence compensation
* Optical path equalization for the internal cophasing and the cophasing with the Fringe Tracker
* Injection in single mode fiber

The functional analysis of the SPICA-VIS spectrograph leads to the following functions:

* Back illumination for the determination of the reference positions
* Spatial filtering
* Output pupil configuration
* Extraction of the photometric channels
* Anamorphosis of the interferometric beam
* Dispersion
* Detection
* Spectral calibration

The general functional diagram of SPICA is presented in Figure 1.

*Figure 1: functional diagram of SPICA, from the entrance beams of CHARA (bottom left) to the science detector (upper left corner).*

## 2.4 Spectral domain

The SPICA-VIS requirements are defined for the spectral band 650-850nm. However the total band that should be acceptable on the detector is as large as 600-900nm, even with partially degraded performance.

# Presentation of the functions up to the injection

## 3.1 Co-alignement and active control

### 3.1.1 SPICA Feeding Optics: SFO

* The implementation of SPICA is based on a 6-beam periscope installed at the entrance of the CHARA visible table. For each beam the mirrors are called **FOP** (Feeding Optics, M1) and **IMG** (Image adjustment, M2). The periscope permits to go over the current optics of the CHARA Visible Table. As for the VEGA periscope, the 6 bottom mirrors **FOP** are automatically removed altogether when CHARA needs to use the reference source. Each mirror **FOP** is mounted on a mechanism allowing, for each mirror individually, a repeatable position when in place for SPICA. The requirement for this motion and repeatable positioning should ensure that the pupil is not translated more than 1mm, so 5% of its diameter and that its deviation is smaller than 10’’ (lab).
* The 6 **IMG** mirrors are used to adjust the low-frequency drift of the alignment with the correction of the tip/tilt of the beams with two slow motions (IMG1X, IMG1Y, IMG2X…). The resolution of these motions should permit to correct at a level of 10% of the stroke of the **TTT** mirrors (see 3.1.2), which corresponds to ~10’’ (lab). The center of rotation of these motions should be in the center of the surface of the mirror to avoid any introduction of optical path difference.
* The new periscope is described in document *SPICA\_VIS\_008* (mechanical design).
* *6x2 motions (IMG1X, IMG1Y, IMG2X…)*
* *1 ON/OFF mechanism*

### 3.1.2 Beam Adjustment System: BAS

* To compensate the low-frequency lateral translations of the beams (pupil alignment) the 6 **PUP** (Pupil Adjustement Device, M3) mirrors are used to allow the slow corrections (PUP1X, PUP1Y, PUP2X…). This system makes use of a lens called **FOC** (Focalization optics, L1) to form the image plane at its correct location on the **PUP** mirror and the pupil plane on the fast tip/tilt mirror **TTT** (Tip Tilt Tracker, M4). The beams are collimated after **TTT** by a lens called **COL** (Collimators, L2) identical to the **FOC** lens. The motions of the **PUP** mirrors should guaranty a centering of the pupil at a level of 5% of its diameter, needed for having of loss of injection in the fibers less than 1% (see SPICA-VIS injection table concept V03.pdf, pages 8 and 9). The center of rotation of these motions should be in the center of the surface of the mirror to avoid any introduction of optical path difference.
* Each beam is equipped with a fast tip/tilt mirror **TTT** provided by the PI company, models S-330.2SH with the amplifier E-616.SS0. The resolution of 20nanoradian and the stroke of 0.5mrad are compatible with a frequency of 200Hz needed for the fast correction.
* *6x2 motions (PUP1X, PUP1Y, PUP2X…)*
* *6 fast motions (TTT)*

### 3.1.4 Beam Control Feeding Optics: BFO

* On each beam, a beamsplitter called **BSP** send 20% (see SPICA-VIS injection table concept V03.pdf, page 10) of the flux to the image and pupil control system, on a fast EMCCD IXON 897 detector for the image plane (through a series of small prism to deviate the beams) and the control of the servo loops of the **TTT** fast tip/tilt mirrors. A movable optics should permit to switch from the 6 image planes to the 6 pupil planes during the alignment phase.

### 3.1.5 Beam Control System: BCS

* To feed the Image and Pupil camera with the retro light from the spectrograph, 6 corner cubes called **RFL** (Reflectors) are installed.
* The optical system of the BFO is composed of a 6 individual mirrors called **FOM** (Folding mirrors, M5)permitting to orient each beam on its specific location on the detector, a large mirror called BCC (Beam Control Camera, M6) forming the images on the detector called **BCD** (Beam Control Detector). A movable optics called **PIS** (Pupil Image Selector) permit to image the pupil planes instead of the image planes.
* The repeatability of the **PIS** optics should guaranty the reproducibility of the pupil position at the level of 1 pixel.
* *1 translation with two active positions (PIS)*
* *1 EMCCD IXON 897 (BCD)*

## 3.2 Longitudinal dispersion compensation: LDC

* According to *SPICA-VIS-LDC document (Issue 6, 9 Apr 2020)*, two different LDC systems are installed on each CHARA beam, one (LDC-COM) is installed at the actual location of the CHARA LDC (common beam before the beam sampler) and one (LDC-VIS) is installed after the main VIS dichroics and after the STS-VIS dichroics.
* When operating with the STS, the light will go through the LDC-VIS that will be all set at the same minimal thickness.
* According to the current design of the CHARA LDC, the LDC-COM will be removable.
* The design of all prisms is described in document *LDC\_Requirements20200430.docx*. The mechanical setup of the LDC-VIS is described in in document *SPICA\_VIS\_008* (mechanical design).
* The document SPICA-VIS-LDC describes the command laws to be applied on the LDC-COM and LDC-VIS, depending on the set of instruments that are considered.
* This module will be totally under the control of CHARA but their command laws integrate the correction of the residual of the chromatic delay between SPICA-VIS and SPICA-FT, that has to be applied on the SPICA-VIS internal delay lines (**SDL**, see Section 3.5)
* *6 translations (LDC-VIS)*

## 3.3 Atmospheric Dispersion Compensator: ADC

* Because of the low spectral resolution mode that are considered and the wide visible band, it is necessary to correct the atmospheric dispersion compensation in SPICA. The so-called ADC are made of two prisms, **ADC1F** (ADC Beam 1 First prism) and **ADC1S** (ADC Beam 1 Second prism, that could rotate with respect to each other.
* To take correctly into account the field rotation of the alt-az mount of the telescopes, both prisms will have to be rotated at the same time in addition to the differential motion.
* According to the document *RefractionSPICA.pdf*, it is not necessary to correct the refraction faster than every 10mn. And this is the same for the field rotation.
* These motions are done in open loop configuration with predicted laws easily computable as a function of time and position of the star. An IDL simulation program has been written.
* The custom rotation stages are described in document *SPICA\_VIS\_008* (mechanical design).
* *12 rotations, with a precision of 0.5° (ADC1F, ADC1S, ADC2F…)*

## 3.4 Polarization Delay Compensator: PDC

* To correct the differential birefringence of the optical fibres, 1 fixed and 5 rotatable plates are installed. These systems are called **PDC**. Their definition follows the work that have been done for the FRIEND experiment (Martinod et al., A&A 2018, 618, Martinod PhD thesis).
* The definition of the SPICA LDC plates will be done after the characterization of the fibers that will equip the selected V-groove. A measurement of the birefringence will permit to estimate the differential delay to correct and thus the thickness of the plates.
* The custom rotation stages are described in document SPICA\_VIS\_008 (mechanical design).
* *5 rotations with a precision of 0.1° (PDC1, PDC2…)*

## 3.5 Shutters: SHU

* Each beam is equipped with a motorized shutter.
* *6 shutters with two active positions*

## 3.6 Spatial Filter Unit: SFU

* Each beam is focalized on the single mode fiber thanks to the combination of two lenses in the **INM** module (Injection Module, lens L3 and L4). The injection module should guaranty to reach at least 90% of the theoretical injection level, computed as 70% in the case of the CHARA beams.
* Each injection module is mounted on a translation stage for the internal optical delay line **SDL** (SPICA Delay Line). Considering the lowest spectral resolution and the specification of having a loss of visibility because of residual OPD less than 1%, it comes that the requirement on the correction of residual OPD should be lower than 7µm.
* Each beam is equipped with an optical fiber (**OPF**). These fibers should be equalized in dispersion at the level of 0.2mm (see document *SpecCombinerV2.pdf*) required for minimizing the loss in visibility to 1% in the case of the lowest spectral resolution (R=140, =5nm).
* The 6 fibers are assembled in the reception module **RCM** made of a V-groove (**VGR**) and a micro-lens array (**MLA**) that will be glued.
* The arrangement with the V-groove and the MLA should guaranty that the minimal output baselines is larger than 2 times the diameter of the effective beam after the MLA.
* The optical and mechanical design of the injection module is described in document *SPICA\_VIS\_008* (mechanical design).
* *6 translations*
* *6 fibers mounted on a V-groove + MLA*

## 3.7 Fiber Back Illumination: FBI

* The fibers **OPF** in the V-groove **VGR** can be back-illuminated to control the internal alignment in combination with the BFO and the BCS. To simplify the device and if compatible with the flux on the BCD detector, all fibers will be illuminated simultaneously.
* *Fiber back illumination device*

## 3.8 Spectral Calibration Unit: SCU

* Additional fibers are mounted on the V-groove VGR to perform the spectral calibrations. The sources will be selected with the requirement of having at least three identified lines for the smallest spectral band (highest spectral resolution).
* *Sources, fibers*

# Presentation of the functions from the injection to the detection

## 4.1 Entrance plane: the V-Groove with the fibers: VGR

* The entrance plane of the spectrograph is defined by the V-Groove **VGR** assembling the 6 main single mode fibers (PM630-HP) in a non-redundant linear configuration.
* The V-Groove should provide the following spacings: 3B – 2B – 4B – 7B – B giving the following set of spatial frequencies: 1,2, 3, 4, 5, 6, 7, 8, 9, 11, 12, 13, 14, 16, 17 B/. The minimal separation between two beams (closest baseline B) is 500µm.
* Additional fibers are installed to illuminate the spectrograph with spectral calibration lamps.

## 4.2: the microlens array: MLA

* At the exit of the V-groove a micro lens array (**MLA**) is installed, with a pitch of 250µm to collimate the different beams and to define a pupil stop by the diameter of the microlens.
* The size of the output pupil must be shaped to avoid crosstalk between fringe peaks. This is more critical for the peaks corresponding to the highest frequencies. To minimize this effect the ratio between the minimal beam separation and the pupil size B/D must be greater than (2R+1)/(R-16) where R is the spectral resolution. With R=140 (cf section 4.7) and B=500µm (cf section 4.1) the pupil size B must be smaller than 220µm.

## 4.3 Field Limitation

* To avoid the contamination of the photometric fluxes by the interferometric channels, a field stop has been considered with a mask in an intermediate image plane.
* The conclusion of the numerical study has demonstrated (reference document Cyril to be included) that the photometric channel closer to the interferometric channel will receive a contamination not larger than 0.5% of the flux of the photometric channel.
* The conclusion is that we will not install a field limitation in SPICA-VIS.

## 4.4 Interferometric photometric splitter: IPS

* A 90/10 beam splitter called **BSL** permits to separate the interferometric channels and the photometric channels.
* The 90/10 ratio has been calculated so that the superposition of 6 anamorphosed beams in the interferometric channel (90%) will give the same maximum intensity than one single photometric (10%) channel.
* In the photometric channel, the **BSL** is followed by a Photometric Folding Mirror (**PFM**)

## 4.5 Photometric transfer system: PTS

* This module composed of three lenses (**FLS**, **SLS**, **TLS** for First, Second and Third Lens) permits the correct sampling of the dispersed pupil planes in the photometric channels.

## 4.6 Interferometric Anamorphic System: IAS

* From section 4.8, the fringe sampling of the largest baseline (17B) is 3 pixels per fringe at =650µm. As a result, the sampling of the closest one (B) is 51 pixels per fringe. Considering the necessary ratio between D and B (<220/500) given in section 4.2, /D is sampled by more than 116 pixels.
* To limit the size of the signal in the spectral direction, the sampling of the spectral channel defined by /D must be 2 pixels. As consequence, an anamorphic system with a differential magnification ratio greater than 58 is necessary to optimize the signal in the spectral and the spatial directions.
* This system is composed of the **FCL** (First Cylindrical Lens) and of the **SCL** (Second Cylindrical Lens).

## 4.7 Dispersion system: DIS

* Three modes of dispersion are considered
  + LR: R=140 with a mirror **LDM** and two prisms **LFP**, **LSP**.
  + MR: R=3000 with a grating **MDG**
  + HR: R=10000 with a grating **HDG**
* An interchangeable system of the three dispersers is necessary.
* An additional rotation is necessary for the MR and HR modes for adjusting the central wavelength on the detector.
* *1 multi-position system*
* *1 rotation*

## 4.8 Camera optics: CAO

* To combine the beams and form the image of the interferometric channel on the detector, a camera lens called **CAO** is necessary and it should allow a sampling of at least 3 pixels per fringes at =650nm for the closest fringes.

## 4.9 Detector: SDT

* We consider the use of the ANDOR EMCCD IXON 888 (1024x1024) as the main SPICA-VIS detector.
* When working in coherence mode, the detector should permit to reach a maximum DIT of 20ms with a frame rate of not less than 40fps.

# 5 Product Tree

**In color: remote controlled modules (in red: actuators, in blue: sources, in green: detectors)**

|  |  |  |
| --- | --- | --- |
| **LEVEL 1** | **LEVEL 2** | **LEVEL 3** |
| SFO (SPICA Feeding Optics) | FOP (Feeding Optics) |  |
| IMG (Image Adjustment) | IMG1X (IMG Tip Beam 1) |
| IMG2X (IMG Tip Beam 2) |
| IMG3X (IMG Tip Beam 3) |
| IMG4X (IMG Tip Beam 4) |
| IMG5X (IMG Tip Beam 5) |
| IMG6X (IMG Tip Beam 6) |
| IMG1Y (IMG Tilt Beam 1) |
| IMG2Y (IMG Tilt Beam 2) |
| IMG3Y (IMG Tilt Beam 3) |
| IMG4Y (IMG Tilt Beam 4) |
| IMG5Y (IMG Tilt Beam 5) |
| IMG6Y (IMG Tilt Beam 6) |
| ADC (Atmospheric Dispersion Compensator) | ADC1F (ADC First Prism Beam 1) |  |
| ADC2F (ADC First Prism Beam 2) |  |
| ADC3F (ADC First Prism Beam 3) |  |
| ADC4F (ADC First Prism Beam 4) |  |
| ADC5F (ADC First Prism Beam 5) |  |
| ADC6F (ADC First Prism Beam 6) |  |
| ADC1S (ADC Second Prism Beam 1) |  |
| ADC2S (ADC Second Prism Beam 2) |  |
| ADC3S (ADC Second Prism Beam 3) |  |
| ADC4S (ADC Second Prism Beam 4) |  |
| ADC5S (ADC Second Prism Beam 5) |  |
| ADC6S (ADC Second Prism Beam 6) |  |
| PDC (Polarization Delay Compensator) | PDC1 (PDC Beam 1) |  |
| PDC2 (PDC Beam 2) |  |
| PDC3 (PDC Beam 3) |  |
| PDC4 (PDC Beam 4) |  |
| PDC5 (PDC Beam 5) |  |
| PDC6 (PDC Beam 6) |  |
| BAS (Beam Adjustment System) | FOC (Focalization Optics) |  |
| PUP (Pupil Adjustment Device) | PUP1X (PUP X direction Beam 1) |
| PUP2X (PUP X direction Beam 2) |
| PUP3X (PUP X direction Beam 3) |
| PUP4X (PUP X direction Beam 4) |
| PUP5X (PUP X direction Beam 5) |
| PUP6X (PUP X direction Beam 6) |
| PUP1Y (PUP X direction Beam 1) |
| PUP2Y (PUP X direction Beam 2) |
| PUP3Y (PUP X direction Beam 3) |
| PUP4Y (PUP X direction Beam 4) |
| PUP5Y (PUP X direction Beam 5) |
| PUP6Y (PUP X direction Beam 6) |
| TTT (Tip Tilt Tracker) | TTT1X (TTT Tip Beam 1) |
| TTT2X (TTT Tip Beam 2) |
| TTT3X (TTT Tip Beam 3) |
| TTT4X (TTT Tip Beam 4) |
| TTT5X (TTT Tip Beam 5) |
| TTT6X (TTT Tip Beam 6) |
| TTT1Y (TTT Tilt Beam 1) |
| TTT2Y (TTT Tilt Beam 2) |
| TTT3Y (TTT Tilt Beam 3) |
| TTT4Y (TTT Tilt Beam 4) |
| TTT5Y (TTT Tilt Beam 5) |
| TTT6Y (TTT Tilt Beam 6) |
| COL (Collimators) |  |
| BFO (Beam Control Feeding Optics) | BSP (Beam Splitters) |  |
| RFL (Reflectors) |  |
| BCS (Beam Control System) | FOM (Folding Mirrors) |  |
| BCC (Beam Control Camera) |  |
| PIS (Pupil Image Selector) |  |
| BCD (Beam Control Detector) |  |
| SHU (Shutter) | SHU1 (Shutter 1) |  |
| SHU2 (Shutter 2) |  |
| SHU3 (Shutter 3) |  |
| SHU4 (Shutter 4) |  |
| SHU5 (Shutter 5) |  |
| SHU6 (Shutter 6) |  |
| SCU (Spectral Calibration Unit) | NES (Neon Source) |  |
| ARS (Mercury Argon Source) |  |
| SFU (Spatial Filter Unit) | INM (Injection Module) | INO (Injection Optics) |
| IFH (Input Fiber Heads) |
| SDL (SPICA Delay Lines) | DL1 (Beam 1) |
| DL2 (Beam 2) |
| DL3 (Beam 3) |
| DL4 (Beam 4) |
| DL5 (Beam 5) |
| DL6 (Beam 6) |
| OPF (Optical Fiber) |  |
| RCM (Reception Module) | VGR (V Groove) |
| MLA (Micro Lens Array) |
| FBI (Fiber Back Illumination) | WHS (White Source) |  |
| FFS (FBI Feeding System) |  |
| IPS (Inter./Photo. Splitter) | BSL (Beam Splitter) |  |
| PFM (Photo. Folding Mirror) |  |
| IAS (Inter. Anamorphic System) | FCL (First cylindrical Lens) |  |
| SCL (Second Cylindrical Lens) |  |
| PTS (Photo. Transfer System) | FLS (First Lens) |  |
| SLS (Second Lens) |  |
| TLS (Third Lens) |  |
| DIS (Dispersion System) | LDU (Low Dispersion Unit) | LDM (Low dispersion Mirror) |
| LFP (Low dispersion First Prism) |
| LSP (Low dispersion Second Prism) |
| MDG (Medium Disp. Grating) |  |
| HDG (High Dispersion Grating) |  |
| CAO (Camera Optics) |  |  |
| SDT (SPICA Detector) |  |  |