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ABSTRACT

The Euclid mission objective is to map the geometry of the dark Universe by investigating the distance-redshift relationship and the evolution of cosmic structures. The NISP (Near Infrared Spectro-Photometer) is one of the two Euclid instruments operating in the near-IR spectral region (0.9-2µm). The instrument is composed of:

- a cold (140K) optomechanical subsystem constituted by a SiC structure, an optical assembly, a filter wheel mechanism, a grism wheel mechanism, a calibration unit and a thermal control
- a detection subsystem based on a mosaic of 16 Teledyne HAWAII2RG 2.4µm. The detection subsystem is mounted on the optomechanical subsystem structure
- a warm electronic subsystem (280K) composed of a data processing / detector control unit and of an instrument control unit.

This presentation will describe the architecture of the instrument, the expected performance and the technological key challenges. This paper is presented on behalf of the Euclid Consortium.

Keywords: Euclid, Spectroscopy, Photometry, Infrared, Instrument, Dark Energy, Dark Matter, Baryon Acoustic Oscillation

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1. INTRODUCTION

Euclid is a wide-field space mission concept dedicated to the high-precision study of dark energy and dark matter. Euclid will carry out an imaging and spectroscopic wide survey of the entire extra-galactic sky (15000 deg2) along with a deep survey covering 10-100 deg2. To achieve these science objectives the current Euclid reference design consists of a wide field telescope to be placed in L2 orbit by a Soyuz launch with a 6 year mission lifetime. The payload consists of a 1.2m diameter 3-mirror telescope with two channels: a Visible imaging channel (VIS) and a Near Infrared Spectrometer and Photometer channel (NISP). Both instruments observe simultaneously the same Field of View on the sky and system design is optimized for a sky survey in a step-and-stare tiling mode. The mission details can be found in [1].

The NISP Instrument is the near-infrared Spectrometer and Photometer operating in the 0.9-2.0 micron range at a temperature lower than 140K, except for detectors, cooled to ~100 K. The warm electronics will be located in the service module, at a temperature higher than 240 K.

The NISP instrument has two main observing modes: the photometric mode, for the acquisition of images with broad band filters, and the spectroscopic mode, for the acquisition of slitless dispersed images on the detectors.

In the photometer mode the NISP instrument images the telescope light in the wavelength range from 920nm to 2000nm (Y, J, H bands). The spatial resolution is required to be 0.3arcsec per pixel. The FoV of the instrument is 0.55deg2 having a rectangular shape of 0.763deg × 0.722deg.

In the spectrometer mode the light of the observed target is dispersed by means of grisms in wavelength range of 0.92 − 2µm. In order to provide a flat resolution over the specified wavelength range two sets of two grisms each are applied in a wheel. These four grisms open two dispersion directions tilted against each other by 90° in order to reduce confusion in the spectra taken (due to slit less philosophy). The field and waveband definition used in the individual configurations for spectroscopy and photometry are:

- Three photometric bands:
  1. Y Band: 920 − 1146nm
  2. J Band: 1146 − 1372nm
  3. H Band: 1372 – 2000nm
- Four Slitless spectroscopic bands:
  1. Blue 0° disp. : 1100 − 1457nm
  2. Blue 90° disp. : 1100 − 1457nm
  3. Red 0° disp. : 1445 − 2000nm
  4. Red 90° disp. : 1445 − 2000nm

The spectral resolution shall be higher than 250 for a 1 arcsec homogenous illumination object size. For such object, the flux limit in spectroscopy shall be lower than $3x10^{-16}$ $erg.cm^{-2}.s^{-1}$ at 1.6µm wavelength. As all slit less spectrograph, the real resolution is varying with the object size. Smaller the size is, higher the resolution is.

The image quality of the instrument in flight shall deliver a 50% radius encircled energy better than 0.3” and a 80% one better than 0.7”. There is a variation due to diffraction with wavelength. A discussion on image quality is presented in paper 8442-30 of the same conference.

2. ARCHITECTURE

2.1 Functional Architecture

The NISP functional architecture is given on Figure 2-1

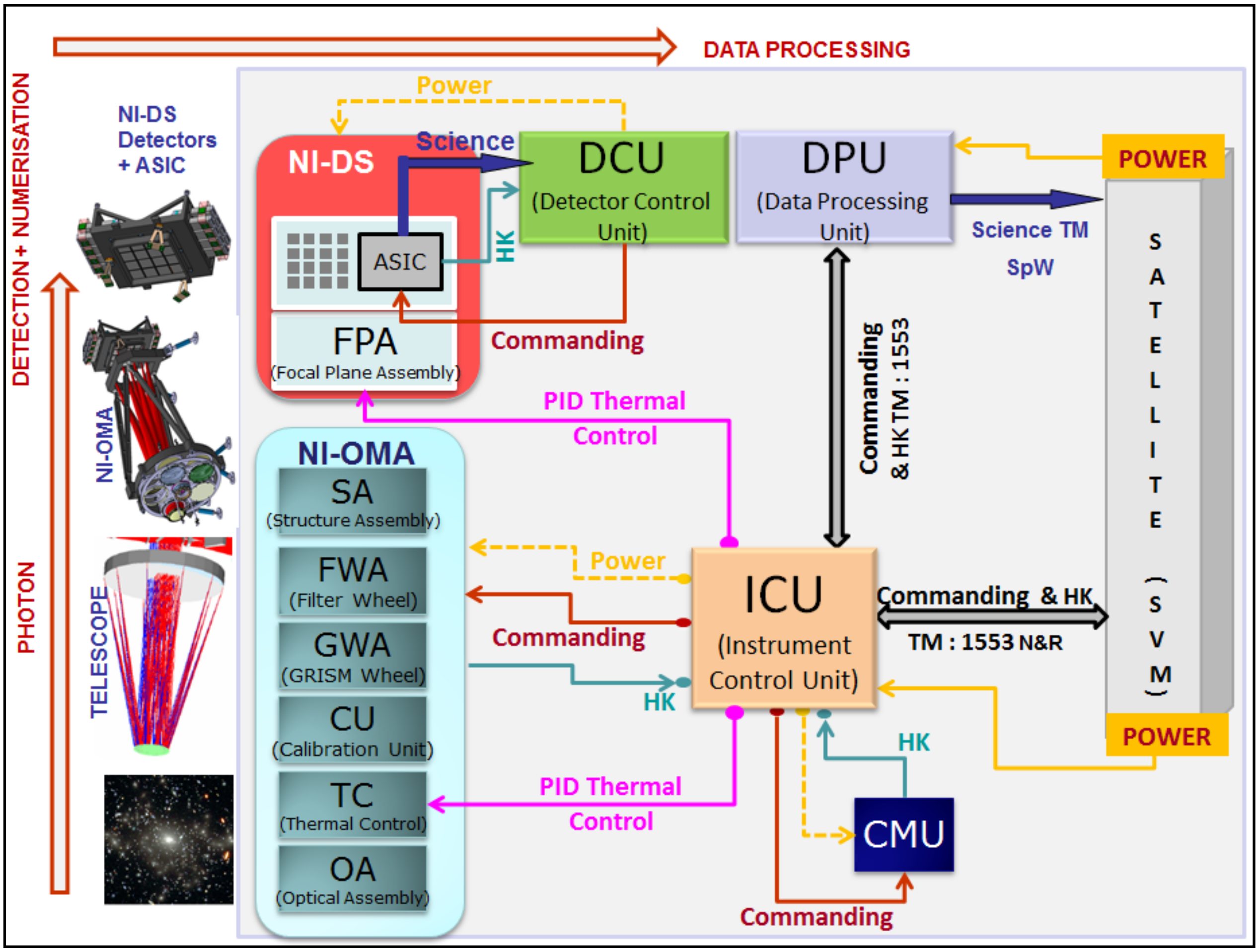

Figure 2-1: NISP functional architecture

2.2 Product Tree

The NISP instrument consists of 3 main Assembly:

- The NI-OMA (Opto-Mechanical Assembly), composed of the Mechanical Support Structure (NI-SA) and its thermal control (NI-TC), the Optical elements (NI-OA), the Filter Wheel Assembly (NI-FWA), the Grism Wheel Assembly (NI-GWA), the Calibration Unit (NI-CU) and a Compensation Mechanism Unit (NI-CMU).
- The Focal Plane Array (NI-FPA) and the Sensor Chip System (NI-SCS) compose the Detector System Assembly (NI-DS).
- The Warm Electronics Assembly (NI-WE), composed by the Instrument Data Processing Unit (NI-DPU), the Instrument Control Unit (NI-ICU) and the detection Control Unit (NI-DCU).

The NI-OMA structure supports the Optical elements, the calibration unit, the Filter and Grism Wheel Units and the detection system. It provides thermo-mechanical interface towards the Euclid SVM.

The NI-DS comprises the 16 H2RG detectors and associated 16 ASICS (Sidecars), passively cooled at operating temperature (<100K for the detectors; 140K for the ASICS). Thermal stabilization is provided by a dedicated PID system, controlled by the NI-ICU.

The Warm Electronics assembly is composed by:

- The NI-ICU (Instrument Control Unit) which sends commands to the FPA Control Unit, it acquires Instrument HK data and transfer to the S/C Mass Memory, it can upload on-board SW into the NI-DPU. It also includes the
- The NI-DPU (Data Processing Unit), which performs data acquisition and deglitching, compression and transfer scientific data to the S/C Mass Memory; the Instrument Control Unit receives telemetry commands from the S/C, drives the NI-FWA, the NI-GWA
- The NI-DCU, which controls the Sensor Chip System and represents the data interface towards the NI-DPU.

The NI-DPU and the NI-DCU functions are regrouped in a single mechanical box for controlling 8 detectors. There are two NI-DPU/NI-DCU.

The NISP hardware tree is summarized in the following Figure 2-2.

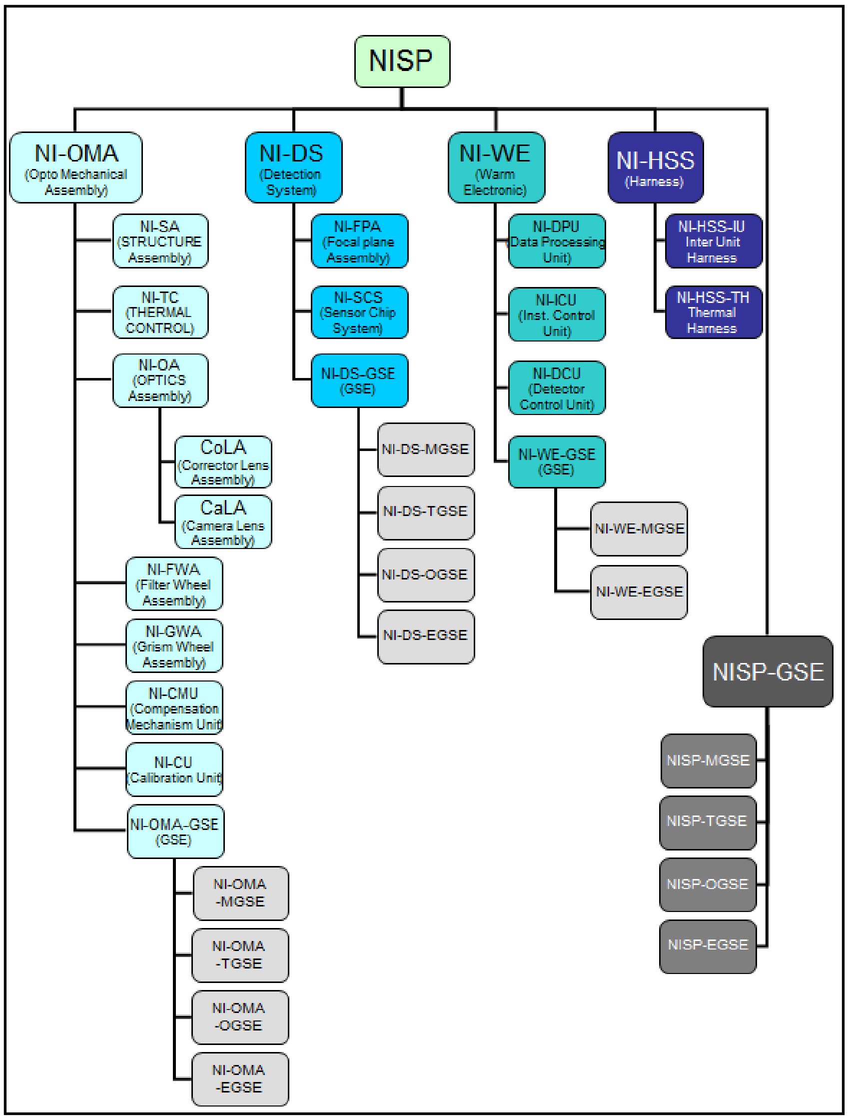

Figure 2-2: NISP Hardware Tree

3. OBSERVING SEQUENCE

The instrument has a specific observing sequence that will be repeated all along the mission lifetime. As the mission is a survey, no modification is anticipated (see Figure 3-1).

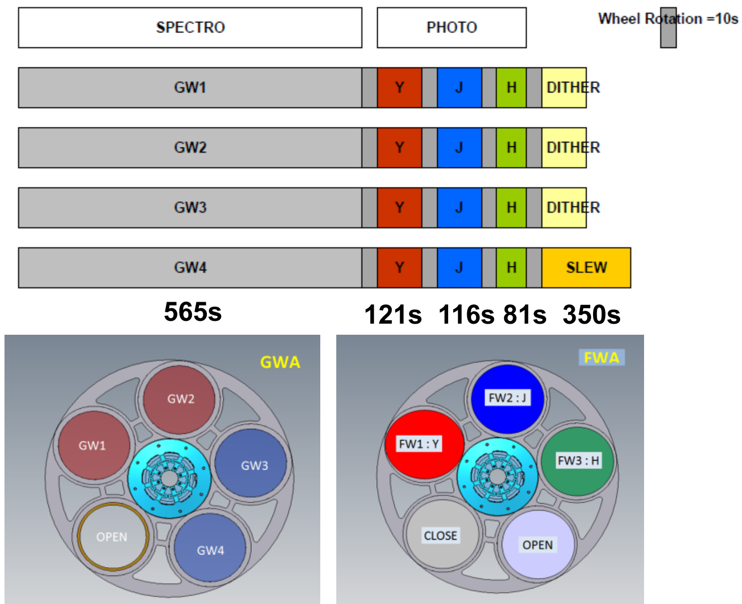

Figure 3-1: NISP Observing sequence

The survey is decomposed in fields. To avoid confusion and increased spatial resolution each field is observed thanks to 4-dithered frames for each band. For noise optimization, the spectroscopy needs a longer exposure time then only one grism will be observed at each dither. The spectrum confusion is minimized thanks to the 90° rotation of the dispersion between to same spectral band.
Each individual frame will be: 565 sec for spectroscopy observation, respectively 121,116 and 81 sec for the Y, J, H photometric bands. The wheels activate between each observation to set the instrument in the proper configuration. Due to the specificity of the H2RG detector, no shutter is needed to stop the integration. The shutter is included only for dark calibration purpose (close position of the filter wheel). The observing sequence rational can be found in [2]

4. NISP OPTO-MECHANICAL ASSEMBLY

This assembly has the function to filter, disperse and image the science telescope field of view. The Figure 4-1 shows 4 views of the NI-OMA. The NI-SA-ST (the structure) will be made in Silicon Carbide. The choice of the material is the result of a long trade-off with carbon fiber and aluminum. The main driver was the very tight constraint of dimension stability of the system from AIV to end of mission. The system doesn't include any refocus mechanism independent to the VIS channel. Thus the stability of the co-focus of the two channels is a driver. Managing the CFRP water desorption or the aluminum thermal stability were the major concerns to be solved by choosing the SiC very stable material.

In front of the instrument, we have a circular box. The first lens (CoLA[2]) is attached on the front side of this box (see bottom-left image). The filter wheel (NI-FWA) and the grism wheel (NI-GWA[3]) are mount in the box (see top-right image). The 4 grisms are innovative very low dispersing element of 19ln/mm with aberration correction thanks to variation of the lines density[4]. The imaging optics NI-CaLA is attached on the second side of the box. This optical component is made of 3 lenses.
A hexapod made of the 6 SiC bar link the box to the rear panel. This panel permits to interface with the NI-DS (Detector System).
Finally the system is mount on the telescope thanks to 2 bipods and 2 monopods (NI-SA-BI) in blue in the figure.
This system is set at a temperature below 140K with stability better than 0.3K for all the mission operation[5].
A calibration unit (not represented in the figure) shall permit to illuminate the focal plane directly. This unit permits to calibrate the pixel-to-pixel flat field, the persistence, and the non-linearity of the detectors.
Including the NI-DS the system, the instrument sits in a box of 1x0.6x0.5m for a mass of 75.3kg.

The main challenges for the development of this system are:

- The very large cryogenic optics: The diameters of these lenses are in the range of 140-170mm with fragile materials as CaF2. It is the very first time that such lenses will fly in cryogenic environment. An intensive qualification work has been conduct to achieve TRL5 by end of the phase B1. (see [2])
- The Grism technology: Due to the low-resolution need, the gratings need to have very low lines density with a very shallow angle. None of the traditional technics could be competitive for a 140mm granting diameter. A new method using photolithography technics has been developed and qualified. (see [4])
- The very large and massive wheels: Due to the optics dimensions, the wheels shall be very large. Their diameter goes up to 475mm for a weight of 10kg. These characteristics lead to a very challenging concept of cryo-mechanism. To avoid too large perturbation during activation at spacecraft level a compensating mechanism unit is been studied. (see [3])
- The stiff and very stable structure: We need to have a very stable structure from ground alignment to end of life. The SiC has been selected for this. This choice imposes high level of management, system, product assurance expertise in the project.

[2] See 8442-30 of the same conference
[3] See 8442-34 of the same conference
[4] See 8442-31 of the same conference
[5] see 8442-112 on the same conference

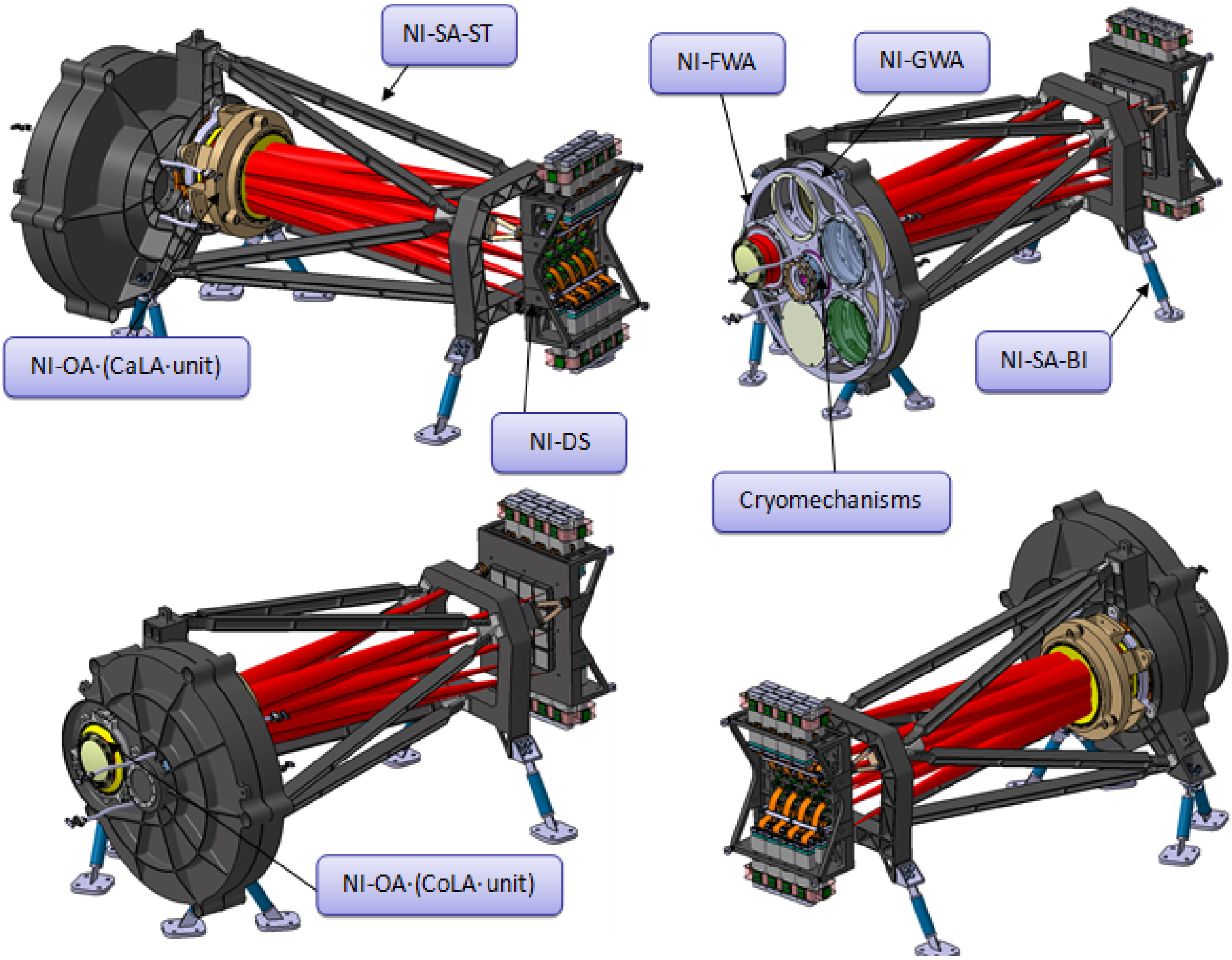

Figure 4-1: 4 views of the NI-OMA with the NI-DS mounted on it.

5. THE NISP DETECTOR SYSTEM

This assembly has the function to acquire the image by sampling the image in a matrix of 8160x8160 pixels of 18µm (0.3" on the sky) and provides a light data processing to deliver digitalized data to the NI-WE.
This assembly is composed by the following main components: one Cold Support Structure (NI-CSS), 16 Sensor Chip System (NI-SCS), one baffle to hide the reflective part of the detectors, the bipods to interface with the NI-OMA.

From the photon to digitalized data, each detection chain is independent. Each one count a 2kx2k HgCdTe 2.5µm cut-off detector, a 10cm long flexible cable, and one readout electronic based on the ASIC circuit. All these will be Teledyn furniture. The consortium is in charge to design the mosaic, integrate and qualify it.
The operating temperature of the mosaic is below 100K while each individual readout electronic will be stabilized below 140K. The instrument in front of the detector shall be below 140K, then the

thermal emission up to 2.5µm permit to insure a very low thermal noise. This choice of architecture permit to optimize the thermal load of the system on to the satellite radiator and insure the reach all specification in term of noise.

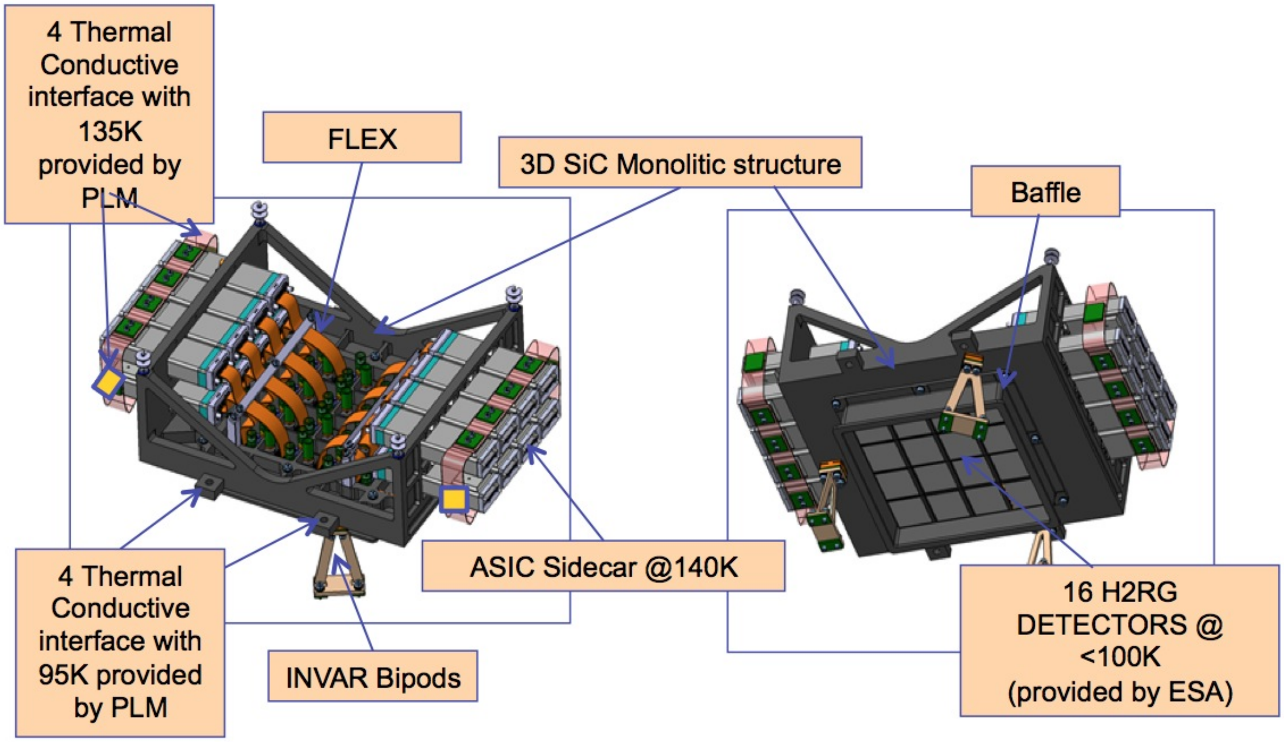

Figure 5-2: The NISP Detector System (NI-DS)

The main challenges of this sub-system are:

- Integrate a mosaic of 16 detectors with a 0.3mm range gap between each pedestal
- Provide a good thermal architecture to insure temperature stability and good thermal decoupling between electronic and detector. A SiC structure shall provide the stability and thermal insulator the decoupling
- Crosstalk minimization: Extensive demonstration work will be done early in the project

An long work of detector characterization will be conduct early in the project at individual detector chain to obtain precise characteristics for noise, linearity, QE, crosstalk and persistence.

6. THE NISP WARM ELECTRONIC

The electronic is composed by (see Figure 6-1):

- Two Data Processing Units each one is including:
  - Detector Control Units that provide clock and power to the readout electronic. In addition, these units will preprocess the data using FPGA boards.
  - Central Processor Unit that finalize the on board data processing, format the data and send them on to the SpaceWire bus to the central spacecraft memory.

- One Instrument Control Unit in charge of:
  - Thermal control servo loop (thermal sensor and heaters will be placed in the cold instrument part to actively control the instrument)
  - Housekeeping
  - General power supply
  - Command signal to the cryomechanism, calibration source lamps

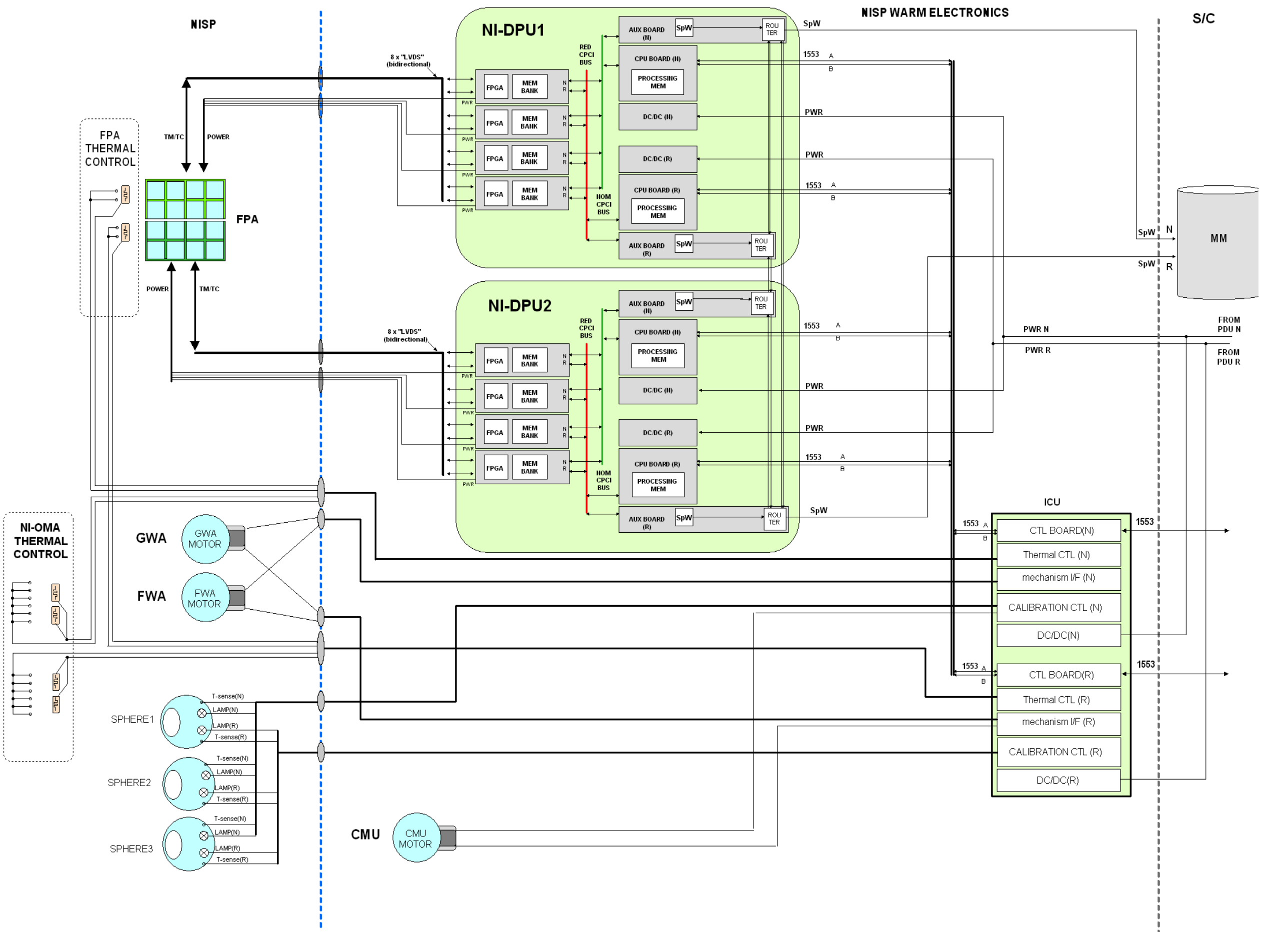

Figure 6-1: NISP Warm Electronic schematic view

The warm electronic will be placed in the service module of the spacecraft at ambient temperature. A harness under Prime contractor responsibility provides the link with the NI-OMA and NI-DS. This cable will carry LVDS signal for scientific data, housekeeping signals, control command and power supply for equipment.

The main challenge of the warm electronics is to process the amount of data delivered by the detector during the integration of the coming frame. The onboard data processing is complexified by the fact that the amount of downlink accepted to ground is very limited. Only final frames can be send to ground, but as describe later, HgCdTe detectors deliver lots of intermediate frames to be processed to build the science one which achieve final science performances.

The complete description of the warm electronic can be found in [6]

7. ONBOARD DATA PROCESSING

As previously stated, the instrument needs a powerful onboard data processing to minimize the amount of data transferred to ground. Two main readout schemes for the detectors will be used: The fowler for photometry and the Multi Accumulation for the spectroscopy.

The Folwer mode consist in read a bunch of 16 frames (in our case) at the start of the exposure and read 16 others at the end. By subtracting the mean of each bunch, we obtain a very low noise frame. The requirement for the photometric frame is to obtain a better noise that 7.7 e/sec/pix including all detector noise contributors.

The Multi Accumulation mode is a continuous read of the detector during the integration. The Figure 7-1 shows the scheme. All along the integration ramp, the detector pixels are non-destructively read at a 1.32sec cadence. Package of some read are averaged (in red in the figure) and the rest are discarded. The averaged packages will be fit to measure the slope and then the signal. Such a readout permit to find cosmic hit and correct by measuring the slope before and after the hit. A better description of the onboard data processing can be found in [6,7]

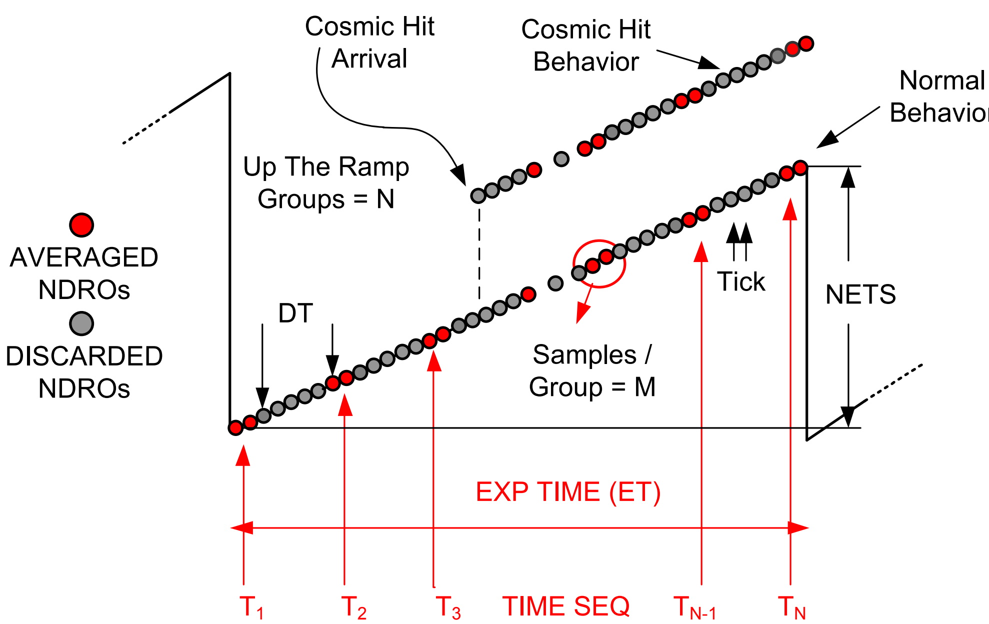

Figure 7-1: Scheme of the Multi Accumulation readout mode

[6] see 8442-110 on the same conference
[7] see 8442-109 on the same conference

8. NISP ORGANISATION

The European ESA consortium specificity is to force to have very large collaboration. Despite of the increase of management complexity, the diversity of talents permit to increased the value of the overall consortium. The Figure 8-1 shows the organization of the NISP. Main contributor countries are: France, Italy, Germany and Spain. While Denmark, Norway are providing parts or GSEs.

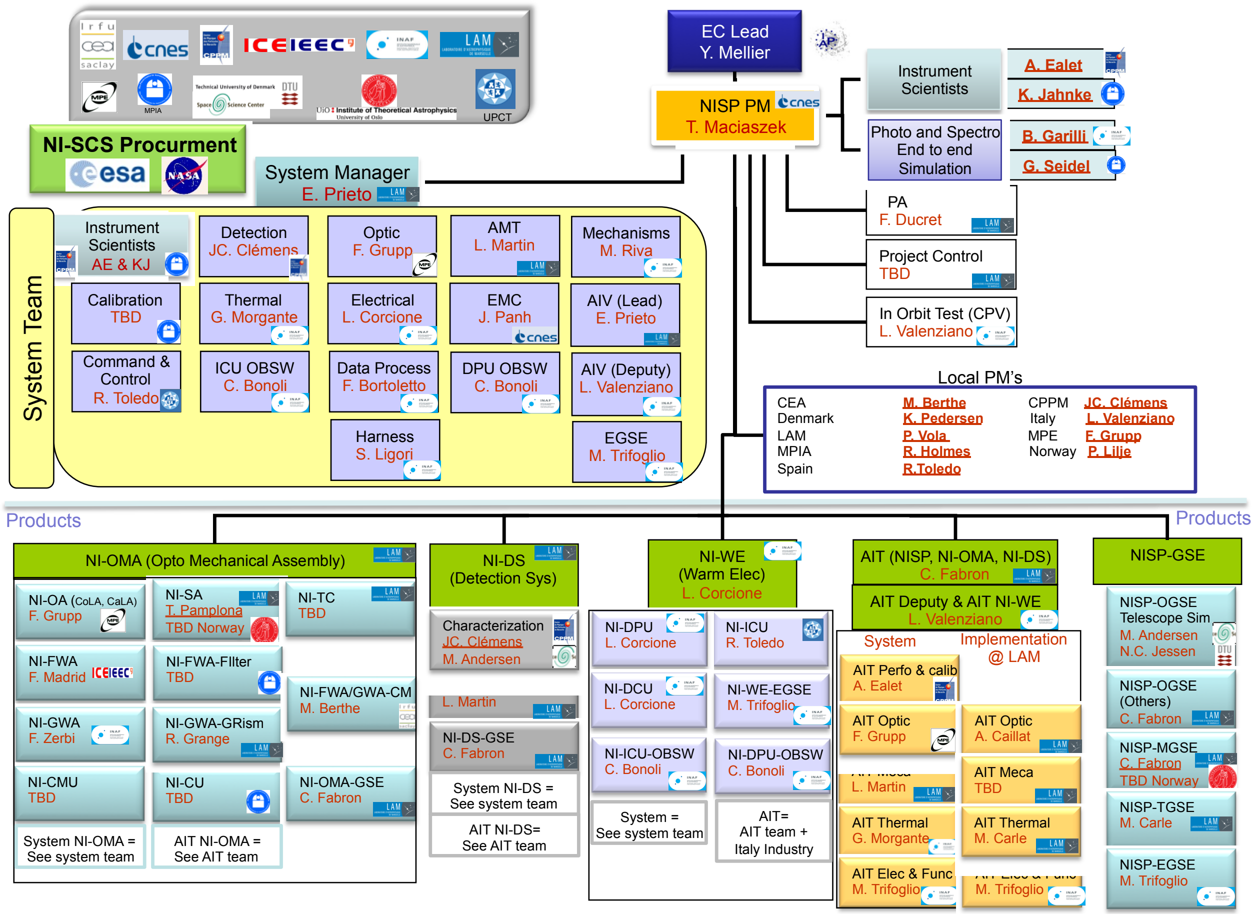

Figure 8-1: NISP Instrument organization

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