Euclid Near InfraRed Spectrograph (ENIS) Focal Plane

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Introduction

The ENIS spectrograph is part of the instrument package on board of the European space mission Euclid devoted to map the dark universe with different probing methods. ENIS is proposed for launch in 2017; it will operate in the near-IR spectral region (0.8-2 μm) and will provide in 4-5 years an accurate and extremely large survey of cosmological redshifts.
The ENIS focal-plane, based on a combination of state of the art detectors, will be fed by a 'slitless' or, possibly, a DMD based spectrograph allowing coverage and analysis of a high number of targets per cycle. A description of the on-going focal-plane study is here presented.

The EUCLID Mission

Euclid is a medium class mission (See Ref. 1) part of the Cosmic Vision 2015-2025 program. It will investigate the distance-redshift relationship and the evolution of cosmic structures by measuring shapes and redshifts of galaxies and clusters of galaxies by means of two main cosmological probes:

- Weak lensing: will probe the distribution of dark matter measuring with extremely high precision subtle shape-distortions for an extremely high number of distant galaxies. Measures will be made by means of a visible imager and a NIR photometer.

- BAO: The baryonic acoustic oscillations method will analyze the spatial scale of baryonic matter distribution at different redshifts by means of a NIR widefield spectrograph. It will allow to determine the characteristic scale length of structures and the universe expansion history H(z).

The Euclid payload is based on a 1.2m primary mirror telescope feeding a 3 scientific instruments package:

- VIS: a Visible Imager, dedicated to the weak lensing measurements. Its main characteristics are a Field of View of 0.5 deg^2, covering the R+I+Z (0.55-0.92μm) broad band, a scale of 0.10 ''/pixel and 0.23'' PSF FWHM.
- NIP: a Near Infrared Photometer dedicated to the estimation of photometric redshifts of distant galaxies. Its main characteristics are a Field of View of 0.5 deg^2, covering Y,J,H bands (1.0-1.7μm) and a scale of 0.3 ''/pixel.

- NIS: a BAO dedicated Near Infrared Spectrometer whose main characteristics are described in the following sections.

The telescope will be placed in L2 orbit and its foreseen lifetime will be about 4-5 years with a foreseen survey coverage of about 20000 deg^2. In addition to the primary science objectives in fundamental cosmology, these surveys will provide unique legacies for galaxy evolution, the search for distant objects, strong lensing, galactic structure and the search for extra-solar planets.

The ENIS Instrument

In both instrument designs, I.E. 'slitless' and 'DMD' models, the telescope beam is collected at an intermediate instrument position by a flat pick-off mirror (See Fig. 1, 2), to feed the instrument.
The main difference between the two concepts is determined by the fixed geometry of the available DMD devices (TI XVGA). In the 'slitless' case all the required FOV is obtained by a single spectrograph based on a folded, reflective collimator followed by a f/6.8 dioptric camera.

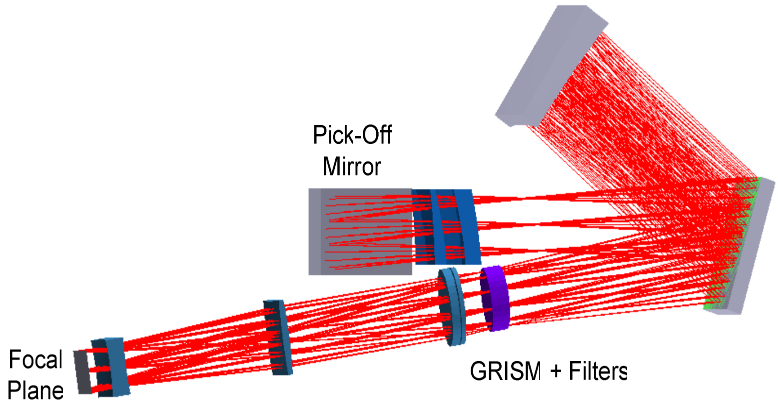

Fig. 1 – The optical design for the 'slitless' spectrograph model made by Duhram and Milano Institutes. After passing through a couple of corrector lenses (blue), the beam is directed to the collimating parabola by a flat folder. The same folder, after collimation, projects the beam to the removable disperser. Light is then refocused onto the NIR focal plane array by a four transmissive elements f/6.8 camera.

Conversely the DMD based design requires the split of the input light beam to feed four identical spectrograph units. Each Digital Micromirror Device is illuminated at an f/3 intermediate focal plane created by a TMA (Three Mirror Anastigmatic) system with an incident angle of 24 deg defined by the DMD geometry. A second TMA system produces a final image on four identical cameras. Appropriate selection of DMD positions and disperser insertion allows full field image or selected objects spectra registration.

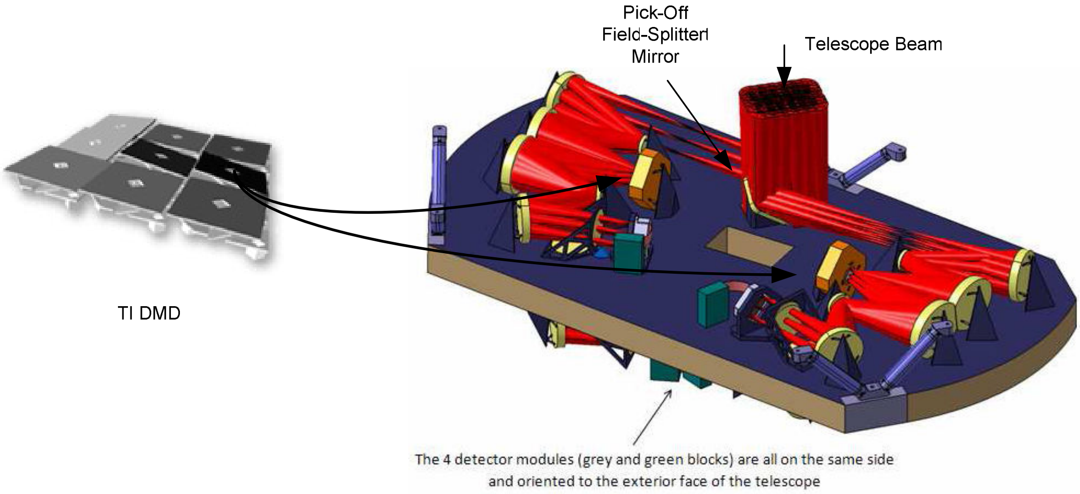

Fig. 2 – The 'DMD' based ENIS spectrograph designed by LAM Marseille. A field of about 0.4ºx0.9º in the sky is covered by four identical DMD spectrographs distributed on the two sides of a common platform. Detector heads and control electronics are placed on the same platform lateral side in a way to facilitate the mount of a cooling radiator system.

The Focal-Plane

Focal planes will use the forthcoming generation of 2048x2048 H2RG made by Teledyne Imaging Sensors (TIS, See Ref. 2, 5). They are hybrid detectors with a deposited MeCdTe sensitive layer, a Si readout multiplexer and SiC mechanical basement. The two focal-plane versions are illustrated in Fig. 3, where the DMD version is representative of a single focal-plane from four identical.

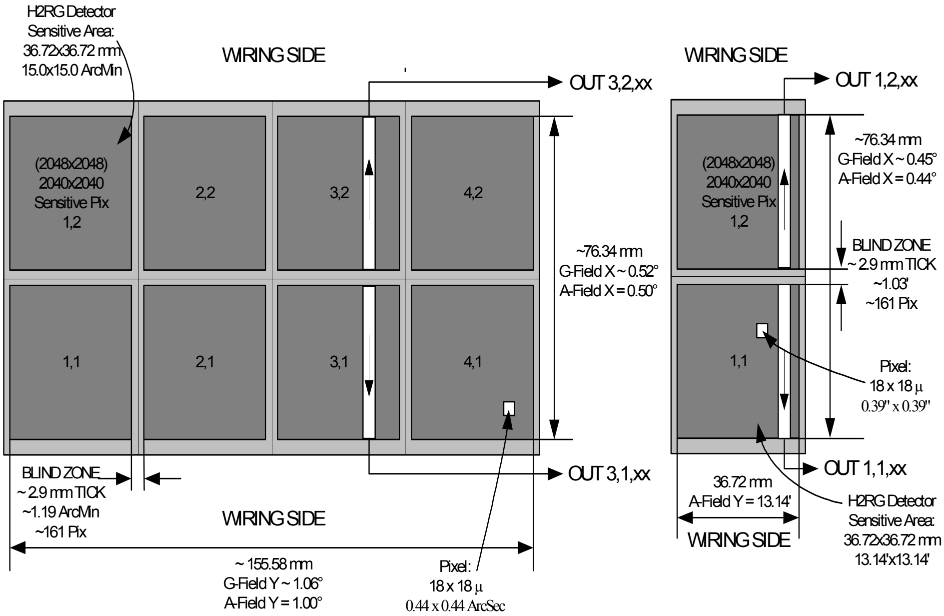

Fig. 3 – Focal plane coverage with H2RG detectors: left, the single 'Slitless' detector head. Right, one from four 'DMD' detector heads. In both cases 8 H2RG detectors are required in order to populate focal planes.

Both systems realize a total coverage on sky of about half square degree, slightly more resolved in the DMD case (0.39"/pixel against 0.44"/pixel), making use of 8 detectors. Spectral dispersion direction will be placed along the H2RG strips of columns individuated by single outputs (32 in the present case); readout wires will be extracted from the upper and lower mosaic sides (See Fig. 4).

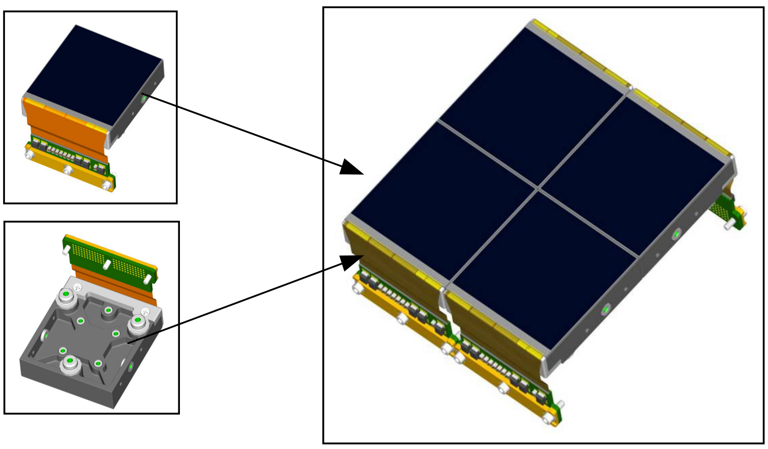

Fig. 4 – A pictorial example (from TIS) showing the building process for an H2RG mosaic focal-plane. Blind strips can have a thickness of 2.9 mm equivalent to about 160 pixels. Single H2RG are provided with three fixation points directly inserted on the SiC

basement and allowing tilt and piston adjustment with respect to a main reference SiC basement providing cooling and mechanical support.

The Detector Heads

Physical model for the two detector heads are shown in Fig. 5 and 6, in both cases the following main parts can be distinguished:

- A SiC reference baseplate providing: a reference frame for single detectors alignment, a temperature stabilized cooling frame and a reference for the overall focal plane alignment
- An aluminum cover carrying the frontal optical window
- A second SiC plate allowing heat extraction from the internal focal-plane and mechanical mount at the optical bench
- A separated frame mounting the readout electronics

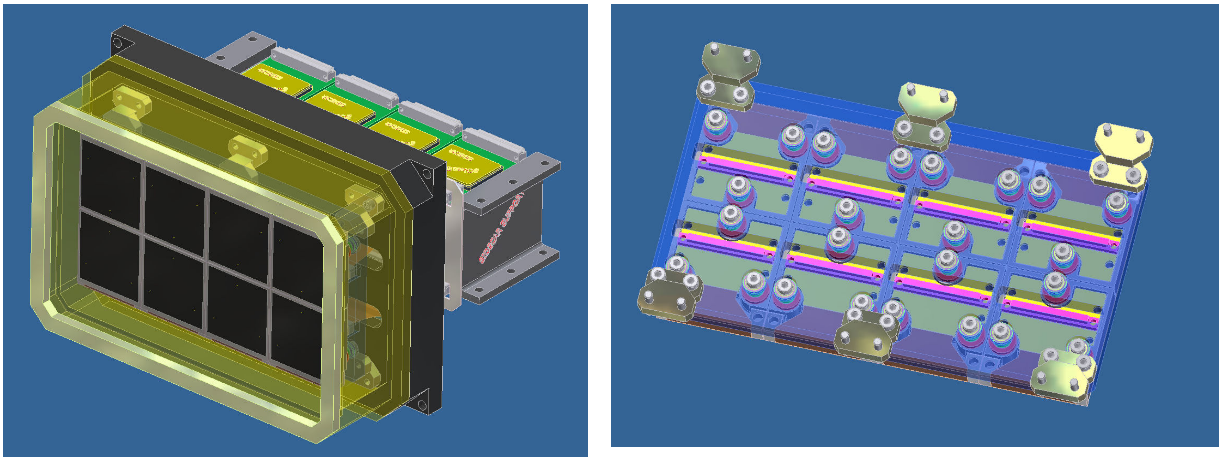

Fig. 5 - The 'slitless' detector housing (left side). The rear cage provides support and mount on the spectrograph optical bench for eight SIDECAR-ASIC boards, one per detector, providing full focal-plane electrical control. H2RG detectors are directly mounted to an intermediate synterized SiC frame (right side) allowing individual detectors position adjustement and acting as temperature stabilized reference. Electrical wires (flexy-circuit straps, max. length 7 Cm) are directly inserted on each detector back-side trough eight rectangular windows made on the SiC frame and a couple of connectors.

Readout electronics is located on an external cage electrically interconnected through eight flexy-circuit straps to eight companion SIDECAR ASICs (See Ref. 2, 3) providing signal conversion and all variable and fixed control signals required by a 32 outputs H2RG device. This solution allows to keep different temperatures between detectors and readout electronics.

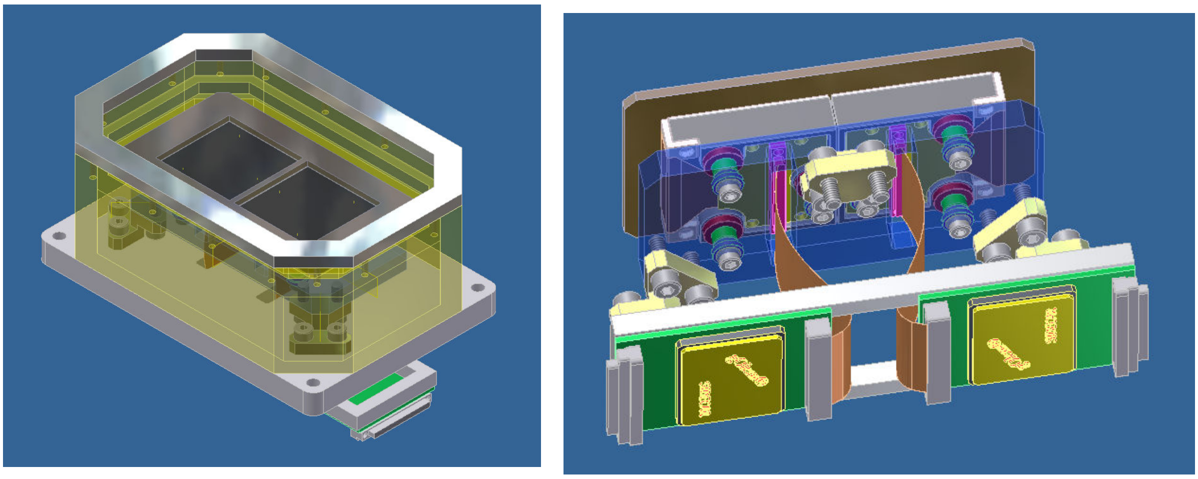

Fig. 6 – The two detectors head. ASICS are in this case directly mounted on the rear side of the head to minimize the overall volume.

The frontal window presents on the two configurations provides, besides the obvious detectors protection functions, also spectral pass-band functions. In fact, at the present state of development, it is assumed to make use of the most technically consolidated H2RG device I.E. the one providing a 2.5 µ cut-off and to cover in the two alternative configurations the following spectral regions :

- Slitless Mode: 1.0 – 2.0µm   (Goal 0.8 - 2.0µm)
- DMD Mode: 1.3 – 1.7µm (Goal 0.9 – 1.7µm)

In this framework, the input window will provide appropriate wavelength stops in order to avoid collection of spurious signal at the focal plane.

Detector System Radiometry

Radiometry is dominated by the presence of the high galactic latitude Zodiacal background and by the instrument mode (slitless or DMD). In the active instrument window (0.8 – 2.0 µm) Zodiacal light (See Ref. 4) is dominated by dust-scattered sunlight and the selection of a slit instrument produces a decrease in background of about three orders compared to the slitless case. This is well evidenced in the next Figure 7.

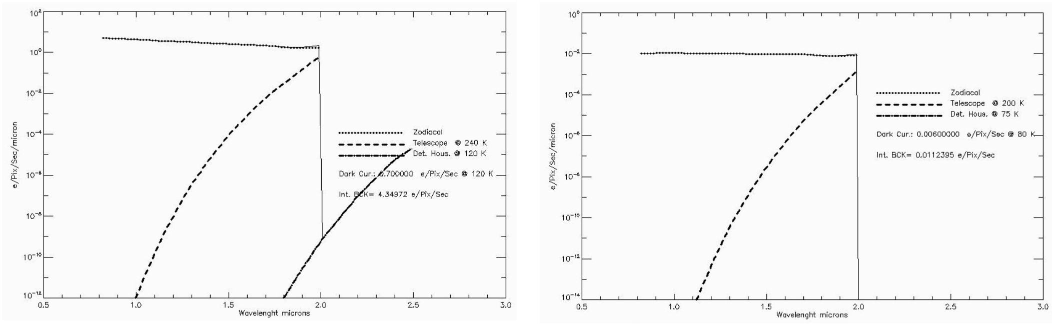

Fig. 7 – Left panel: ‘slitless’ case background with assumed temperatures of 240 K° at primary and 120 K° at detector head. Right panel: DMD case background with assumed temperatures of 200 K° at primary and 75 K° at detector head.

The DMD mode drives the choice of temperatures concerning the thermal background and detector dark current. A set of operational temperatures as derived from modeling is given in Tab. 1.

System:	Nominal Temperature :	Long Term Stability :
H2RG Detector	80 K°	< 10 m K° (500 Sec)
H2RG Housing	75 K°	< 2 K° (annual)
SIDECARs	75 or 150 K°	< 2 K° “
SPW Adapters	150 K°	< 2 K° “
Spectrograph	150 K°	< 2 K° “
Optical Bench	150 K°	< 2 K° “
Telescope M1	< 200 K°	TBD

Tab. 1 – DMD mode temperature requirements for the ENIS instrument.

Also the acceptable readout noise (RON) is strongly dependent on the selected instrument, the present specification for the DMD mode is of an RMS equivalent RON of about 5 e^- at the nominal exposure time of 500 Sec.

ENIS focal plane readout

The readout strategy for ENIS has been designed keeping in mind some crucial requirements: to keep low the resulting equivalent noise after the ENIS average exposure, to allow discarding of spurious charge induced by cosmic ray (CR) hits and to achieve and maintain the highest focal-plane thermal stability. All these requirements produced a readout strategy as shown in Fig. 9 with the detectors being continuously read at around the maximum speed achievable by ASICs and data distribution and handling system (in our case FT= 2.6 Sec per frame). This readout mode peculiar of non destructive readout detectors is often called ‘multi-accumulation’ (See Ref. 7). As illustrated in Figure, a given exposure is an FT multiple where groups of processed readouts are interleaved by discarded readouts. Each group is then averaged to optimize the overall noise and the final exposure result is obtained by a linear fit of the obtained values.

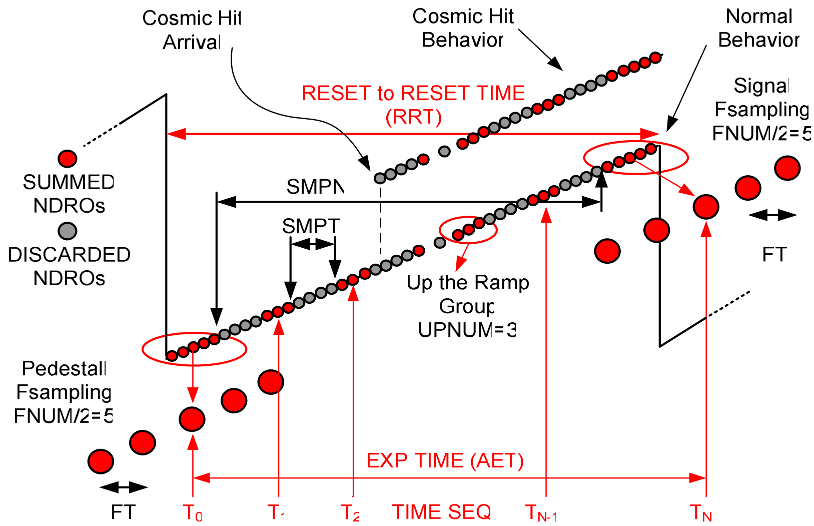

Fig. 9 – Focal-plane sampling in 'multiaccumulation' mode illustrated for a single H2RG cell. Different readout strategies (Fowler, Up the Ramp) can be obtained discarding intermediate reads. FT is the frame to frame readout, 2.6 Sec in the ENIS case.

A Monte Carlo simulator has been written to verify the multi-accumulation process. Simulations made for the ENIS case have shown good match with analytical RON estimates derived in Ref. 7. As an example starting from single CDS (Correlated Double Sampling) RON figures of about 15 e^- RMS (even better values can be found for nowadays H2RG detectors) one can reach the ENIS-DMD specific (5 e^- RMS in 500 Sec exposure) with 15 readout groups each one made by two consecutive readouts.

This strategy allows to follow each pixel behaviour along the whole charge ramp, so evidencing the arrival of a cosmic hit in any position of the time sequence and to correct the resulting flux during the linear fit procedure (See Fig. 9 and Ref. 8). Tests made on the same ENIS simulator have shown that a number of 15-20 readout groups along the 500 Sec sequence are good to achieve a good correction for an expected cosmic rays flux about 5-30 events/sec/cm^2 compatible with L2 operation.

Data readout and processing strategy has a strong impact on the on-board computational resources and maximum telemetry allocable rate. In practice the present telemetry budget allows only to download a single FP frame (67.1Mbytes) as representative of a typical ENIS exposure that forces to directly process all multi-accumulation partial frames directly on the on board data handling computer. Preliminary simulations based on the precedent assumptions have shown the possibility to deglitch and construct the final result image directly working on the multi-accumulation data stream in a way to limit both the final required telemetry rate and the amount of storage memory needed on-board.

Focal Plane Thermal

Thermal requirements for the ENIS focal plane in the DMD configuration are reported in Tab. 1. Detectors temperature stability is quite stringent because of direct impact on the final achievable RON figure (See Ref. 6).

This level of control can be obtained, as currently under verification in other experiments working in L2 (Plank mission), with a combination of passive and active regulation systems.

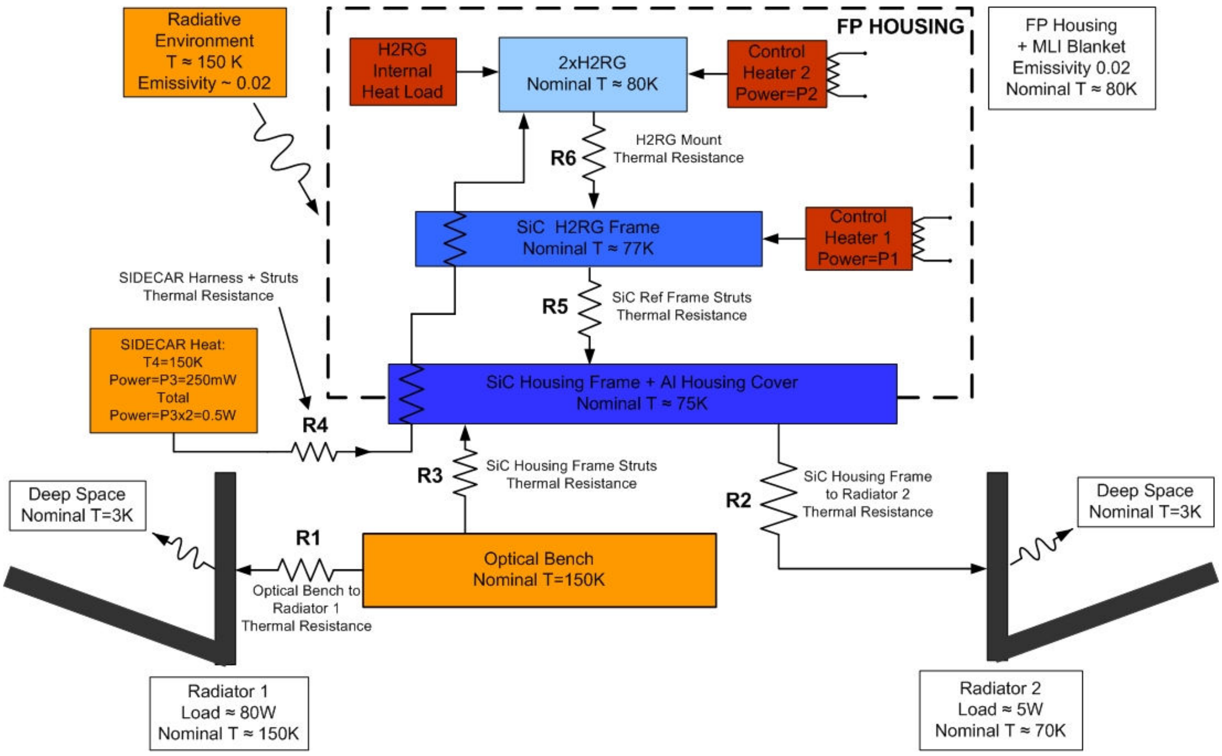

Fig. 10 – Thermal view of a 2x detectors DMD mode focal plane. Two radiators looking at the 3 Kº space are foreseen in order to separately cool the instrument optical bench (See Fig. 2) and the 4x focal plane. They will be dimensioned to stay at averages temperatures respectively of 150 and 70 Kº.

The passive component exploits thermal masses and resistances of the control stages while the active regulation is made by a double stage as shown in Fig.10: a first actively stabilized reference is created at level of the SiC reference frame where detectors are mounted (77Kº) while a second active stabilization is obtained directly, and separately, on each H2RG device (80 Kº) making use of the temperature measurement and compensation provided on the detector SiC basements.

Conclusions

A feasibility study for the construction of a focal-plane detector head for the EUCLID near infrared spectrograph has been made and delivered. Two possibilities, both based on the forthcoming space-oriented version of the 2Kx2K H2RG sensor have been studied. The first one based on a 2x4 detectors mosaic is to be employed on a 'slitless' spectrograph while the second, based on 4 heads whit a 2x1 detectors mosaic, are compatible with a four, DMD based, spectrograph system. Main addressed issues have been: focal-plane radiometry, readout mode, deglitching and processing, thermo-mechanics.

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