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***On-ground tests of the NISP infrared spectrometer instrument
for Euclid***

Cyril Jomni

Anne Ealet

William Gillard

Éric Prieto

et al.



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On-ground tests of the NISP infrared spectrometer instrument for Euclid

C. Jomni¹, A. Ealet¹, W. Gillard¹, E. Prieto², and Frank Grupp³

¹Centre de Physique des Particules de Marseille, Marseille, FRANCE

²Laboratoire d'Astrophysique de Marseille, Marseille, FRANCE

³Max-Planck-Institut für extraterrestrische Physik Giessenbachstr, Garching, GERMANY

Abstract

Euclid is an ESA mission dedicated to understand the acceleration of the expansion of the Universe. The mission will measure hundred of millions of galaxies in spectrophotometry and photometry in the near infrared thanks to a spectro-photometer called NISP. This instrument will be assembled and tested in Marseille. To prepare the on-ground test plan and develop the test procedure, we have used simulated PSF images, based on a Zemax optical design of the instrument. We have developed the analysis tools that will be further used to build the procedure verification. We present here the method and analysis results to adjust the focus of the instrument. We will in particular show that because of the sampling of the PSF, a dithering strategy should be adapted and will constraint the development of the test plan.

Keywords: Euclid, NISP, sensors, focalization, PSFs, calibration, FWHM

I.- INTRODUCTION

Euclid is a scientific mission of the European Space Agency (ESA). With a planned launch in 2020, this project was selected in 2011 as part of "Cosmic Vision" program and aims to determine the origin of the accelerating expansion of the Universe and of defining the nature of dark energy. To this end, a 3D mapping of hundreds of millions of galaxies must be established. Euclid will carry out an imaging and spectroscopic wide survey of the entire extragalactic sky (15000 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 years mission lifetime. The payload consists of a 1.2 m diameter 3-mirror telescope with two channels: a VISible imaging channel (VIS) and a Near Infrared Spectrometer and Photometer channel (NISP). Both instruments observe si-

multaneously the same Field of View (FoV) on the sky and the system design is optimized for a sky survey in a step-and-stare tiling mode.

In this paper, after a short description of the NISP instrument, we will explain how the simulated PSFs are constructed. We will describe the tool to provide a library of simulated PSFs. We will then present a method to determine the best focus of the instrument from the simulated PSFs database. This procedure will be implemented during the ground test plan of the instrument.

II.- NISP OVERVIEW (NEAR IR SPECTROMETER PHOTOMETER)

1. Description of the instrument

The NISP Instrument is the near-infrared Spectrometer and Photometer operating in the 0.9

– 2.0 micron range. 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 telescope light is in the wavelength range from 920 nm to 2000 nm (Y, J, H bands).

In the spectrometer mode the light of the observed target is dispersed by means of gratings covering the wavelength range of 1250 – 2000 nm. In order to provide a flat resolution over the specified wavelength range, four gratings are mounted in a wheel. These four gratings yield three dispersion directions tilted against each other by 90° in order to reduce confusion from overlapping. The spatial resolution is required to be 0.3 arcsec per pixel. The Field of View of the instrument is 0.55 deg² having a rectangular shape of 1.25 * 0.722 deg².

The instrument focal plane will support 16 H2RG sensors, of 2kx2k pixels of 18 μm each. The temperature of the instrument is around 140K, except for detectors, cooled to ~95 K or below. A warm electronics has been design for commanding the NISP and the detectors and will be located in the service module, at a temperature around 20°C.

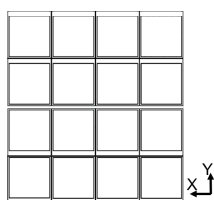


Figure 1: Focal plane of the NISP

2. Optical model

The optical design shown on Figure 2, is composed of :

- A corrective lens (Dichroic) with a spherical-aspherical meniscus lens (called CoLA) and indicated as CL);
- One of the filter of the wheel;
- One of the gratings;
- Three spherical-aspherical meniscus lens (L1, L2, L3) called CALA;

- The focal plane with its 16 detectors H2RG: pixel's size is 18 μm*18 μm, being oriented along the Z axis as represented on the figure 2;

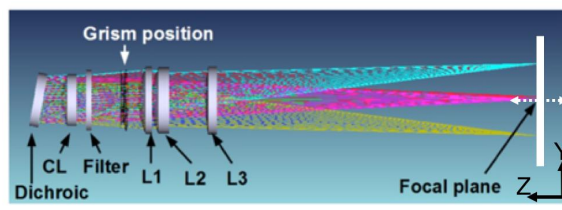


Figure 2: Optical design of the NISP

The figure 1 highlight the orientation of the X and Y axis, the Z-axis being oriented in the direction of beams.

An optical model (Figure 2) has been developed based on Zemax (<http://www.zemax.com>), a modeling and analysis software of optical systems. Zemax works by ray tracing, modeling the propagation of rays through an optical system. It can model the effect of the optical elements such as lenses (spherical, aspherical), reflectors, or other dispersive optical elements. In particular, it allows to generate simulated PSF images of the instrument in different points onto the focal plane for all wavelengths accounting for all the configurations of the instrument. Figure 3 shows an example of one PSF in center of the focal plane at 1 μm. The PSF is very regular (not far to look like a 2D Gaussian).

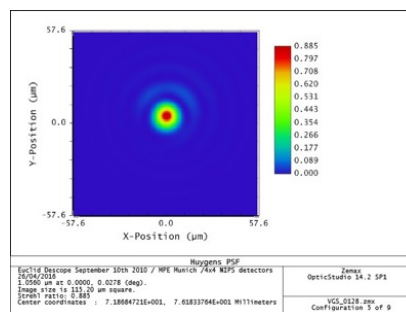


Figure 3: Example of PSF observed with Zemax

The PSF images generated by Zemax are perfect, without noise and over sampled (128*128 subpixels with a size of 0.9 μm*0.9 μm).

To reproduce NISP realistic PSF as measured on the detector, we should introduce realistic noises (Poisson noise, detector noise etc..) and we should pixelize them with the H2RG pixel size of $18\mu\text{m}$. We expect then a PSF to be imaged on $\sim 6 \times 6$ pixels. The signal has been defined to reach a signal to noise of 560s on the PSF determination.

After pixelisation (with 1 pixel = $18\mu\text{m}$) and addition of a Poisson noise on each images, the PSFs look like the ones on Figure 4. We see that the PSF is strongly under sampled and it will be difficult to determine precisely its position and size because of a sub sampling effect.

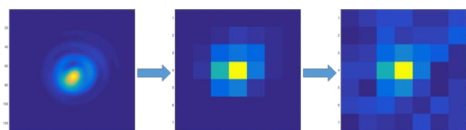


Figure 4: Process of pixelisation and addition of noise

We have then developed a tool, entirely automatized, to build a full database of PSF images, from the Zemax design. We have first simulate the PSFs for wavelengths from $0.9\mu\text{m}$ to $1.9\mu\text{m}$, for different Zemax tolerancing.

Figure 5 below summarizes the procedure used to determine the database. This database will be used to simulate PSF images in different configurations, in particular to prepare the on ground test analysis and define the test procedure.

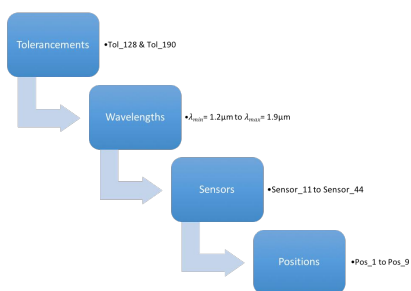


Figure 5: Procedure of the generation of the database of the PSFs

III.- DETERMINATION OF THE FOCUS OF THE NISP

1. Description of the method

During the ground test campaign, a full analysis framework will be developed to verify the functionalities of the instrument and test its performance. Flexible analysis tools based on MATLAB libraries are under development to fulfill the test procedure needs.

One of the first test that should be done is to determine the focus of the instrument. This means to reconstruct the object plane of the instrument, which should be placed where the telescope simulator¹ is focusing ($\sim 3\text{m}$). The telescope simulator rotate around the center of the entrance pupil of the NISP (see Dichroic in Figure 1).

The instrument should be aligned at the good focus compared to the telescope with a precision of $150\mu\text{m}$. The budget for focus measurement is allocated to be less than $20\mu\text{m}$.

To develop the procedure, we propose to use the previous simulated PSF images, as representative of the ground test ones, at several positions.

The PSF images at the center position and at different focus are shown on Figure 6. We can observe the effects of focus / defocus of the instrument by the variation of the size of the PSF on the image:

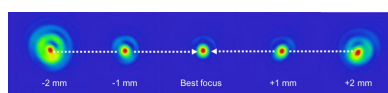


Figure 6: PSFs for different focus (-2 mm; -1 mm; BF; + 1 mm; + 2 mm)

We observe that there is one image with a smaller PSF that corresponds to the best focus at $z = 0.0\text{ mm}$, best focus determined by Zemax. This verification is facilitated thanks to a very good sampling in Zemax. In the instrument, the pixels will be 20x coarser.

¹"How to test NISP instrument for EUCLID mission in laboratory", A. Costille, SPIE, June 2016

We need an estimator of the width of the PSF. To do so, there is different way. We can use:

- 50% encircled energy (EE50)
Starting from the over sampled PSF of Zemax, we calculate circle around the PSF center and search for the one that contains 50% of the total energy of the image. The radius of the circle give us the EE50 radius.
- Full Width at Half Maximum (FWHM)
We consider the PSF as a gaussian and the full width at half maximum as estimator.

To simulate the procedure, we start by simulating PSF images for 5 positions of the focal plane (center + 4 corners). For each of these positions, a focus pad is recovered: the focus is varied from -2 mm to +2mm over the best focus (process of focus/defocus) as explain in the previous section.

The position of $z = 0.0$ mm is defined as the best focus of the nominal optical design. The focus position is varied from $z = -2.0$ mm to $z = +2.0$ mm around the Zemax focus by step of 0.2 mm (to be optimized with the result of the present simulation) with Zemax. For each of the PSF we will compute the EE50 and FWHM and search for the smallest one.

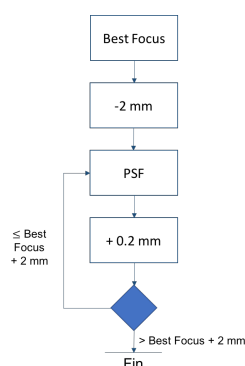


Figure 7: Process of focus/defocus

In the next section, we just consider for the study the center of the focal plane and we simulate the PSFs at $1 \mu\text{m}$.

2. Computation of the reference PSF at focus

To estimate the reference position, we will compute the EE50 and the FWHM at $z = 0$. We project on X and Y axis and fit a gaussian:

$$G(x_i) = \frac{1}{2\pi\sigma_x} e^{-\frac{(x_i - \mu_x)^2}{2\sigma_x^2}} \quad (1)$$

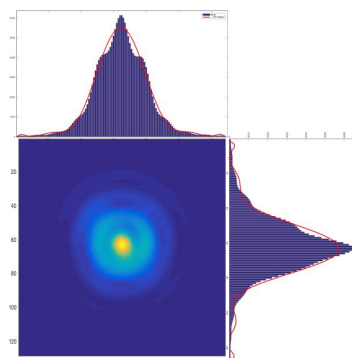


Figure 8: Example of fit of 2D Gaussian without pixelisation and no noise, without dithering

The results of the fit of the projection give us the FWHM according the X-axis and the Y-axis:

$$FWHM_{PSF} = 12.53 \mu\text{m}$$

For the radius of the EE50, we find

$$EE50 = 5.80 \mu\text{m}$$

We recover well the knowledged relation which validate the computation:

$$FWHM = \frac{2 * EE50}{1.17} \quad (2)$$

3. Determination of the best focus position

To find the focus, we use a minimization of the previous estimators FWHM or EE50 by changing the z position: first we use the over sampled PSF at different positions of the focus and fit the minimum of the position. We should find the $z = 0$ from Zemax.

To minimize the estimators, we follow this procedure:

- Determination of the estimator according to the position z
- Fit the data
- Determination of the z at the minimum position

We apply the different steps for the EE50:

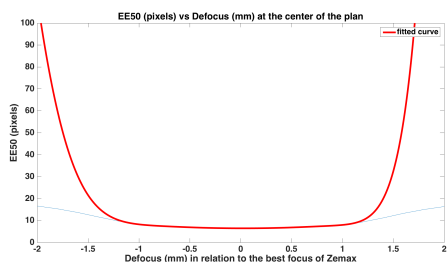


Figure 9: EE50 variation in function of z , from a 2D Gaussian fit, over sampled PSF

We find:

$$z_{min_{EE50}} = 22.6 \mu\text{m}$$

For FWHM, we obtain the Figure 10:

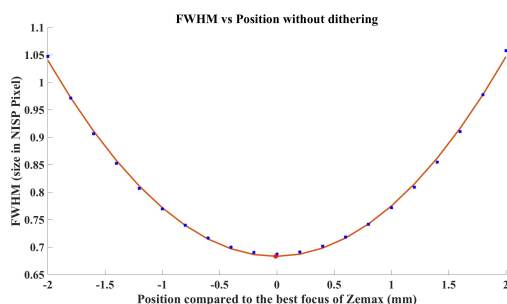


Figure 10: FWHM variation in function of z , from a 2D Gaussian fit, over sampled PSF

We find the focus at $z_{min_{FWHM}} = 1.3 \mu\text{m}$.

We observe that the EE50 minimum is too large and give a large incertitude in the z minimum determination. We have a better result with the FWHM as expected. Anyway, we don't find $z = 0$: it is probably due to the approximation in the method as PSF is not a perfect gaussian.

Anyway, we will take it as the reference for the next section with the real PSF.

4. Application for realistic PSF

We will apply the method on pixelised PSF with noise.

a) Application for pixelised PSF with noise

In this part, we pixelize the PSF image and add a detector noise and a white noise representative of the photon noise as seen on Figure 4.

For each PSF we then introduce the realistic properties of the detector. We consider 1 electron/second/pixel with long exposure of 560 seconds.

We have an image as shown on Figure 11

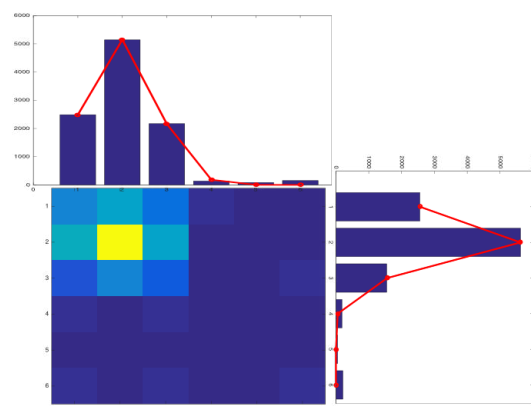


Figure 11: Example of fit of 2D Gaussian with pixelisation and noise

After X and Y-axis projection we extract the FWHM and by doing 100 realisations, we compute also the error and find:

$$FWHM(z = 0) = 11.2824 \pm 5.49 \mu\text{m}$$

The value is closed to the perfect case, but the error is larger due to the noise and to the pixelisation.

We then have produced with this FWHM, 100 focus-defocus realisations as shown in Figure 12.

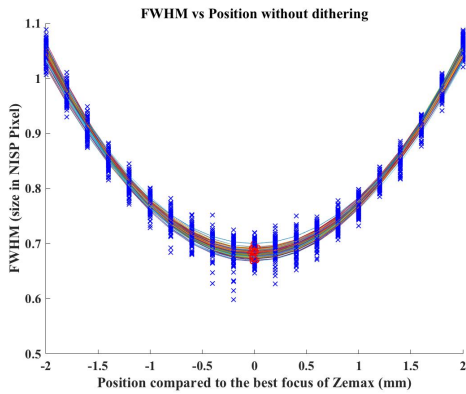


Figure 12: Variation of the FWHM according to the position z of the focus with pixelisation and noise, without dithering (100 iterations)

We find the minimum, representative of the position of the focus:

$$z_{min} = -9.6 \pm 16.1 \mu\text{m}$$

Compared to the focus determined with an over sampled PSF, we have now an error of $16.1 \mu\text{m}$ approximately. The margin is very short compared to the budget of $20 \mu\text{m}$. So we propose to improve the method by adding dithering to reduce the error on the focus evaluation.

b) Improving of the focus measurement by using dithering

To improve the FWHM value, we use dithering which means that we move the FWHM around the center of the PSF with an offset of $\frac{1}{10}$ of a pixel and compute a mean FWHM by position. Then we reapply the minimization procedure in function of z . We dither with 4 (2×2), 9 (3×3), 25 (5×5) positions.

We show as an example the case of a dither with 9 positions on Figure 13.

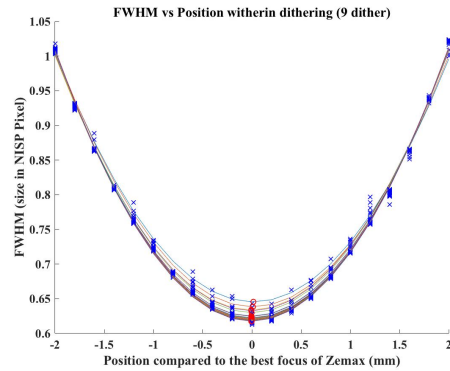


Figure 13: Example of Gaussian RMS dithered versus focus (9 dithers)

We can observe the distribution and determine the error position :

We find now:

$$z_{min} = -0.4 \pm 0.52 \mu\text{m}$$

Compared to the z_{min} of the over sampled PSF, we have an error of $\sim 1 \mu\text{m}$ compared to the reference's focus. That's better than the last $16.1 \mu\text{m}$.

The final evaluation in function of the dithering is shown on figure 14:

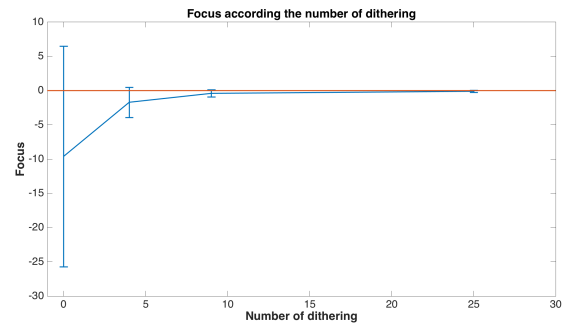


Figure 14: Evolution of the focus according the number of dither

We see that with ~ 10 dither, we recover well the focus with a small error.

We have significantly improved the position error inside the requirement of $20 \mu\text{m}$ and this demonstrate that the dithering is needed and will help to recover the minimum position with a good accuracy.

We propose to have at least 25 dither (5*5) to ensure a good precision.

IV.- CONCLUSION

In this paper we have developed a method to recover the focus of the NISP instrument of the Euclid mission during the ground test campaign. We have done this study using Zemax simulated PSFs in the center of the focal plane.

This study has highlight that it would be very difficult to determine the position of the focus with the evaluation of the EE50 and it is better to consider the FWHM.

Since the PSF of NISP is strongly under sampled, this study has highlight also that the PSF is too noisy to recover the focus position with enough accuracy. We have shown that using dithering in the ground campaign will allow to recover the best focus of the instrument in the required accuracy. In fact, without this step, the noise of the FWHM dominates the determination of the best focus position. We propose then to implement 25 dither (5*5) to ensure precision better than 1 μm .

REFERENCES

[1] Definition Study Report, ESA/SRE (2011)12 (2011)

[2] Prieto, E., "NISP Technical Description", EUCL-LAM-OTH-7-001 (2014).

[3] Niclas, M., "EUCLID NISP NI-DS SCA mosaic configuration", EUCL-CPP-DRW-7-031 (2015).

[4] Snyder, L., "A Programmers Guide to ZPL", Department of Computer Science and Engineering, University of Washington, Seattle WA 98195 (1999).

[5] Zemax, "Optical Design Program, User's Manual" Radiant ZEMAX LLC, Chapter 25 Zemax Programming Language (2011).

[6] Hohendorff, J. M., "An Introduction to Markov Chain Monte Carlo", University of Toronto (2005)

[7] Hanson, K. M., "Tutorial on Markov Chain Monte Carlo", 29th International Workshop on Bayesian Inference and Maximum Entropy Methods in Science and Technology (2000)

[8] "How to test NISP instrument for EUCLID mission in laboratory", A. Costille, SPIE, June 2016