

The Euclid Near Infrared Spectro-Photometer (NISP) instrument and science

N Mauri^{1,2}, S Dusini³, F Fornari^{1,2}, D Di Ferdinando², F Giacomini⁴,
F Laudisio^{3,5}, L Patrizii², C Sirignano^{3,5}, G Sirri², L Stanco³,
M Tenti⁴ and L Valenziano^{6,2} on behalf of the Euclid Consortium

¹ Department of Physics and Astronomy, University of Bologna, V.le Bert Pichat 6/2, 40127 Bologna, Italy

² INFN-Bologna, V.le Bert Pichat 6/2, 40127 Bologna, Italy

³ INFN-Padova, V. Marzolo 8, 35131 Padova, Italy

⁴ INFN-CNAF, V.le Bert Pichat 6/2, 40127 Bologna, Italy

⁵ Department of Physics and Astronomy, University of Padova, V. Marzolo 8, 35131 Padova, Italy

⁶ INFN-IASF Bologna, V. Gobetti 101, 40129 Bologna, Italy

E-mail: nicoletta.mauri@bo.infn.it

Abstract. Euclid is an ESA mission designed to understand why the expansion of the Universe is accelerating and what is the nature of the dark energy responsible for this acceleration. By measuring two cosmological probes simultaneously, the Weak Gravitational Lensing and the Galaxy Clustering (BAO and Redshift-Space distortions), Euclid will constrain dark energy, general relativity, dark matter and the initial conditions of the Universe with unprecedented accuracy. Euclid will be equipped with a 1.2 m diameter SiC mirror telescope feeding 2 instruments: the visible imager and the Near-Infrared Spectro-Photometer. Here the Euclid's observation probes and main aims are recalled, and the NISP instrument and expected performances are presented.

1. Introduction

The Euclid mission will map the geometry of the dark Universe by investigating the distance-redshift relationship and the evolution of cosmic structures. It will measure shapes and redshifts of galaxies and clusters of galaxies out to redshifts ~ 2 , or equivalently to a look-back time of 10 billion years. In this way, Euclid will cover the entire period over which dark energy played a significant role in accelerating the expansion of the Universe. A 1.2 m Korsch telescope will observe 15000 deg² of the darkest sky, free of contamination by light from our Galaxy and our Solar System, from the Sun-Earth L2 Lagrangian point. The telescope directs the light to two instruments via a dichroic filter in the exit pupil: the visual imager (VIS, 550-900 nm) and the near-infrared spectrometer and photometer (NISP, 920-2000 nm, shown in Fig. 1). Both instruments observe simultaneously a large field of view (0.53 deg²). The system design is optimized for a sky survey in a step-and-stare tiling mode. The Euclid spacecraft will be launched in 2021 from the Guiana Space Centre in Kourou on board a Soyuz rocket and the survey will last more than 6 years. The science data from the spacecraft will be received on ground at a rate of 850 Gbit/day over a daily pass time of 4 hours.



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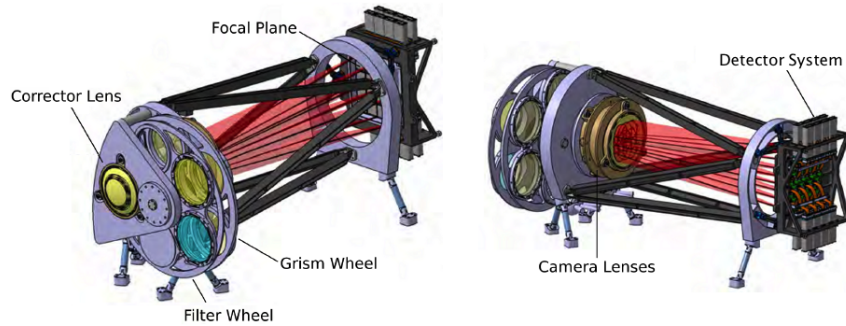


Figure 1. The NISP instrument with its subsystems [1].

2. Euclid science objectives

Euclid is designed to accurately measure the expansion history of the Universe and the growth of cosmic structures using a large area optical and NIR imaging survey and a massive spectroscopic NIR survey, with a precision that will allow us to distinguish time-evolving dark energy models from a cosmological constant, and to test the theory of gravity on cosmological scales. It will determine the dark energy equation of state $w(a) = w_0 + w_a(1 - a)$ with a Figure of Merit $FoM = 1/\Delta w_0 \Delta w_a > 400$, it will study dark matter properties and provide new insights into the initial conditions of the Universe constraining primordial non-Gaussianity. Two cosmological probes will be used:

- (i) Galaxy Clustering (GC): by measuring spectroscopic redshifts the 3D distribution of galaxies can be mapped and quantified in terms of its power spectrum within several redshift bins. Baryon Acoustic Oscillations (BAO), seen as a preferred co-moving separation of galaxies related to the sound horizon, provide a standard ruler to probe the expansion history of the Universe and thus $w(z)$; redshift-space distortions provide a measurement of the growth rate $f(z)$.
- (ii) Weak Lensing (WL): by measuring the correlation between the photometric deformation of the shape of galaxies, the distribution of ordinary and dark matter can be reconstructed, while the measurement of the photometric redshift of shape-distorted galaxies allows to trace back the information on their evolution.

In Table 1 the scientific specifications for weak lensing and galaxy clustering observations are summarized.

Galaxy Clustering			Weak Lensing		
Spectroscopic redshift accuracy	$\sigma_z < 0.001(1+z)$	$0.7 < z < 1.8$ with 1700 galaxies/deg ²	Photometric redshift accuracy	$\sigma_z < 0.05(1+z)$	$0 < z < 1.2$ with 30 galaxies/arcmin ²

Table 1. Scientific specifications on redshift accuracy for weak lensing and galaxy clustering observations in Euclid [1].

Euclid will also allow determining the total neutrino mass with high accuracy. The neutrino mass reflects on the process of cosmic structure formation since lighter neutrinos have more chances to travel longer distances, hence slightly weakening structure formation in the early Universe. A more or less intense suppression effect can be observed by Euclid in the matter power spectrum over a wide range of scales and in particular at small scales. The Euclid sensitivity to the sum of neutrino masses ($\Delta m_\nu \lesssim 0.05$ eV) will provide crucial information on the absolute scale, not accessible even to future laboratory experiments, and could allow the two mass hierarchies to be distinguished.

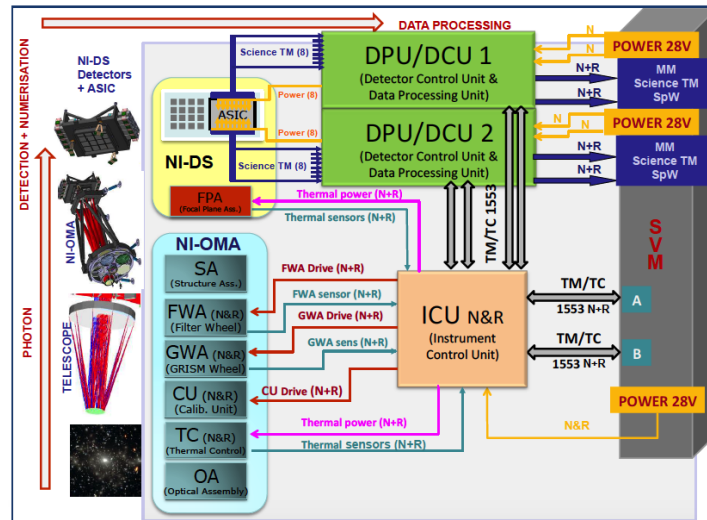


Figure 2. Overview of NISP functional architecture.

3. The NISP instrument

The scientific objectives described above will be accomplished through two instruments, VIS and NISP, that will be operated simultaneously sharing a large common field of view. Here we present the NISP instrument, which performs imaging photometry to provide NIR photometric measurements for photometric redshifts, and also carries out slitless spectroscopy to obtain spectroscopic redshifts. In the photometer mode the instrument images the telescope light in the 920-2000 nm wavelength range, with a spatial resolution of 0.3 arcsec per pixel. In the spectrometer mode the light of the observed target is dispersed by grisms covering the wavelength range of 1.1-2 μm . The NISP, with a mass of 155 kg, has an allocated volume of $1 \times 0.5 \times 0.6 \text{ m}^3$ and will produce 240 GBit of data per day. The NISP functional architecture is shown in Fig. 2. It comprises:

- two filter wheels, one hosting the optical filters required for photometric observation (in Y, J and H bands) and the grisms allowing slitless spectroscopic observations.
- the focal plane, equipped with a 4×4 array of HgCdTe 2048×2048 pixel detectors and the Sensor Chip System [2]. The operating temperature of the detectors is lower than 100 K while each individual readout electronic (ASIC for digitization) operates at around 140 K in order to ensure low thermal noise.
- the calibration unit, providing uniform illumination (flat-field) of the detector plane at 5 wavelengths, ensuring a stable flat sensor calibration source.
- the warm electronics system, composed of 2 units:
 - two Data Processing Units (DPU), each allowing synchronous acquisition of 8 detectors, pre-processing, on-board data compression [3] and transfer to the spacecraft mass memory. Each DPU contains 8 Detector Control Unit boards, each connected to a Sensor Chip System.
 - the Instrument Control Unit (ICU), arranged in cold redundancy, exchanges telemetry and telecommands with the spacecraft electronics and with the DPU and includes control electronics for filter wheels and calibration unit. It is also responsible for temperature sensors monitoring/heaters powering and it is interfaced with the spacecraft via a MIL-STD-1553 bus. The interface with the DPU is also based on a 1553



Figure 3. The NISP observing sequence.

bus. The ICU Application software (ASW) is devoted to manage the satellite/platform interface, the ICU/DPU interface and all the functionalities related to instrument commanding. The ICU uses a space qualified version of RTEMS real-time operating system [4].

The warm electronics is located in the service module of the spacecraft at ambient temperature. A more detailed description can be found in [5].

4. NISP operation and performance

The NISP observing sequence consists of an exposure of 565 s for spectroscopy observation and of three exposures of 121, 116 and 81 s for the Y, J, H photometric bands, respectively (Fig. 3). The wheels activate between each observation to set the instrument in the proper configuration. This sequence is repeated four times, then a slew is performed in order to change the field of view. For the spectroscopic observation, the minimum flux for the detection is $2 \times 10^{-16} \text{ erg} \cdot \text{s}^{-1} \cdot \text{cm}^{-2}$, corresponding to $\sim 3.5\sigma$ SNR. In addition, photometric detection limit in NIR wavelengths for 5σ SNR point sources is of 24 AB magnitude [5]. The number of expected observed galaxies is 2.5×10^7 and 1.5×10^9 for the spectroscopic and the photometric sample, respectively.

5. Conclusions

Explaining the origin of cosmic acceleration is one of the most compelling problems in cosmology and fundamental physics. The Euclid mission, combining WL and GC, will allow investigating the nature of dark energy and testing general relativity with unprecedented accuracy. We are now in a crucial phase of integration and tests of the two instruments, VIS and NISP. Regarding the NISP, different models have been developed, namely: the Structure and Thermal Model (STM) to validate the design of the optical assembly and the detector system. This model has been already successfully tested. The NISP Engineering Model (EM) will be built to fully qualify the instrument functional behaviour. Then a NISP Avionic Model consisting in a subset of the NISP EM equipped with DPU and ICU qualification models will be realized. Finally, the NISP Flight Model will be delivered to ESA.

Acknowledgments

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