EUCLID Near-Infrared Spectro-Photometer Instrument & Science

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The Euclid Mission

Euclid is an ESA mission designed to understand the nature of the Dark Energy responsible for the accelerated expansion of the Universe and constrain the nature of Dark Matter. Euclid will map the geometry of the dark Universe by investigating the distance-redshift relationship and the evolution of cosmic structures. The Euclid 1.2 m Korsch telescope will observe 15000 deg^2 of the sky 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) and the near-infrared spectrometer and photometer (NISP). VIS provides high quality images to carry out the weak lensing galaxy shear measurements. NISP performs imaging photometry to provide Near InfraRed photometric measurements for photometric redshifts, and also carries out slitless spectroscopy to obtain spectroscopic redshifts.
The Euclid spacecraft will be launched from the Guiana Space Centre, Kourou, on board a Soyuz rocket. The survey will last 6 years. At least one ground station is available to receive the science data from the spacecraft at a rate of at most 850 Gbit over a daily pass time of 4 hours.

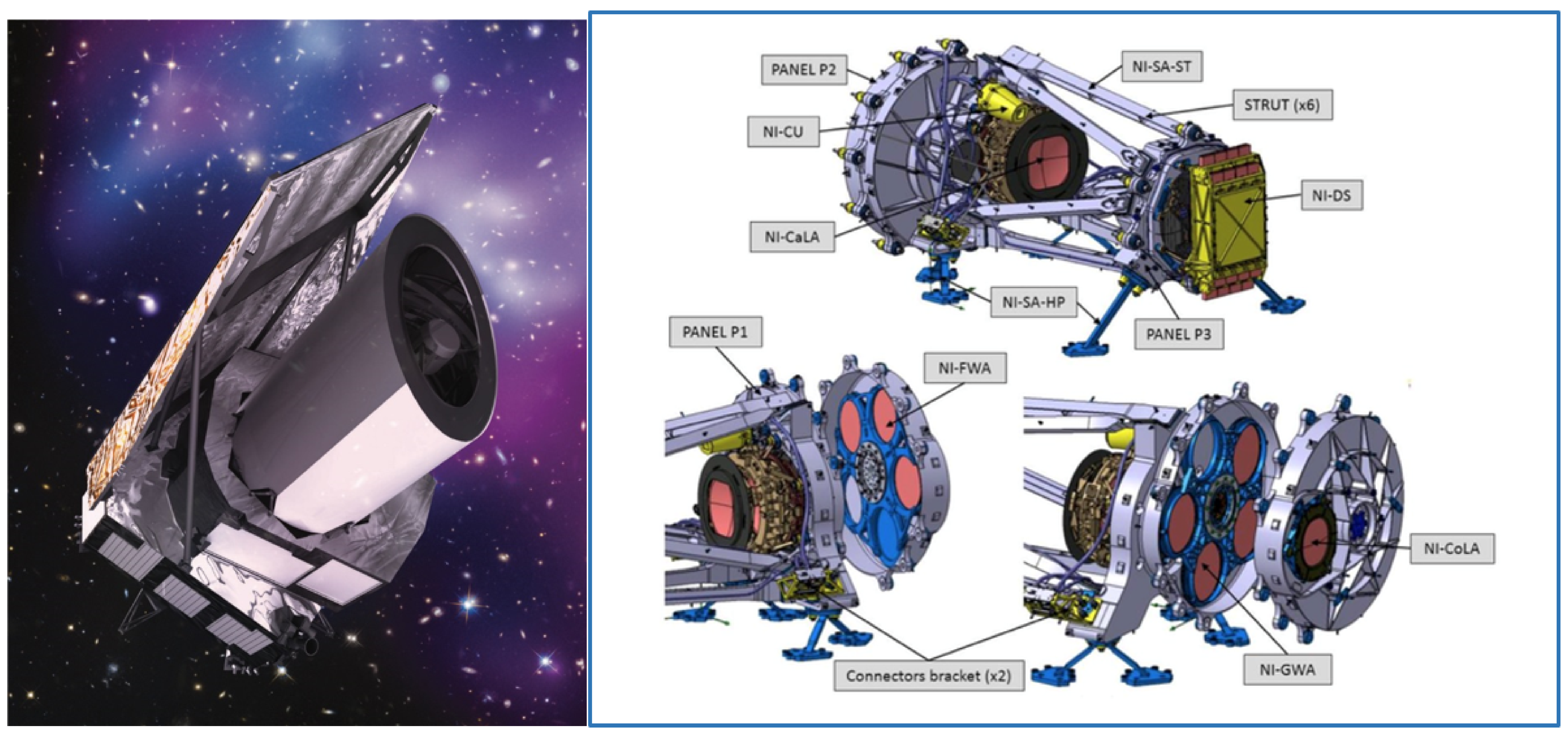

Figure 1: Euclid satellite's artist impression (left) & the NISP instrument (right) with its subsystems.

Euclid cosmology

Euclid's primary goal is to provide constraints on theories about the accelerated expansion of the Universe. It will use two cosmological probes:

1. *galaxy clustering*, measuring spectroscopic redshifts to reconstruct 3D distribution of galaxies: at a specific redshift, the *Baryon Acoustic Oscillation* model predicts the presence of overdensities in the distribution of galaxies at a relative distance related to the sound horizon of the perturbations generated in the primordial baryon-photon plasma at the *recombination* epoch ($z \simeq 1100$), so that a comparison between these typical distances at different redshifts is a *standard ruler* to measure the expansion of the Universe.
2. *weak lensing*, measuring the photometric redshift of galaxies and the correlation between the deformations of their shape in order to trace back the information on the distribution of Dark Matter.

Euclid will combine galaxy clustering and weak lensing to measure the Dark Energy parameters and the total neutrino mass with unprecedented 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.

NISP Instrument

The NISP operates in the range $900 \div 2000$ nm:

- Field of view = 0.5 deg^2
- Mass = 155 kg
- Maximum power consumption = 178 W
- Telemetry = 290 Gbit/day
- Cold part size = $1\,\mathrm{m} \times 0.6\,\mathrm{m} \times 0.5\,\mathrm{m}$ (+ 3 electronic 50 lt boxes) [4].

The NISP instrument 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.

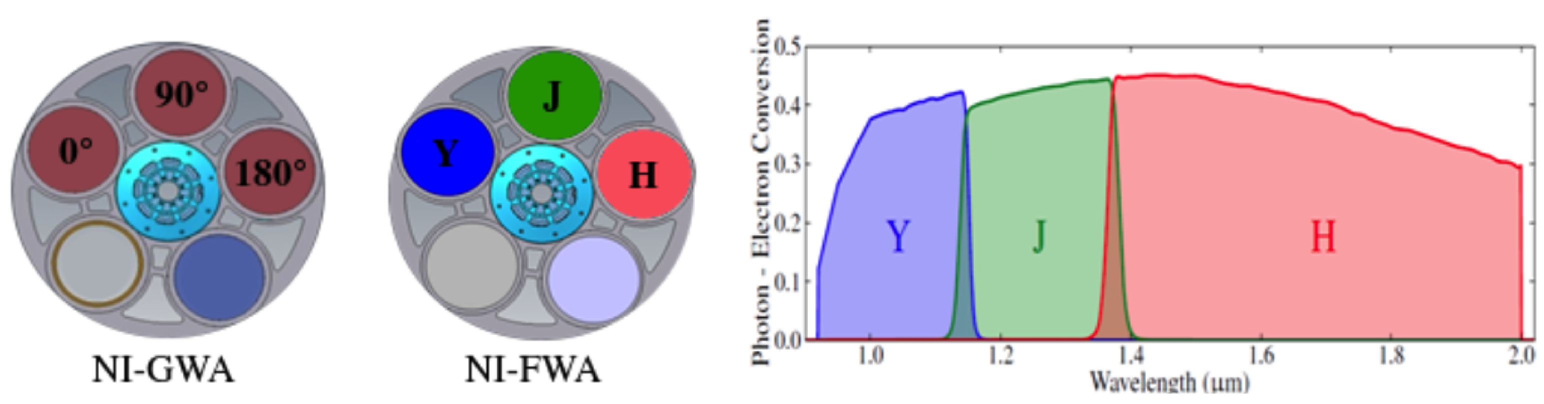

Figure 2: Grisms and Filters Wheel Assembly (GWA and FWA) and their 5 positions (left) with profiles of the Near InfraRed filters of NISP (right).

- a **focal plane**, equipped with a 4×4 array of HgCdTe 2048×2048 pixel detectors; the *Sensor Chip System* of the detectors (by Teledyne Imaging Systems) is made of [1] [2]:
  1. a *Sensor Chip Assembly* (SCA)
  2. a *readout ASIC* (SIDECAR)
  3. *Cryogenic Flexi Cable* (CFC) links
  4. a *Telemetry & Telecommand router* based on SpaceWire Link technology
  5. a *thermal controlling system* (detector operating temperature is 95 K)
- a **calibration unit**, providing near-uniform illumination in 5 wavelength channels of the detector plane, ensuring a stable flat sensor calibration source.
- a **warm electronics** system, composed of 2 units:
  1. two *Data Processing Units* (DPU), each allowing synchronous acquisition of 8/16 detectors, on-board data compression, pre-processing and transfer to spacecraft (S/C) mass memory. Each DPU is interfaced with a *Detector Control Unit* (DCU) managing the Sensor Chip System.
  2. the *Instrument Control Unit* (ICU) in cold redundancy, exchanges Telemetry and Telecommand data with the Data Processing Unit using an intra-instrument interface and providing control electronics for filter wheels and calibration unit. It is also responsible for temperature sensors monitoring/heaters powering.

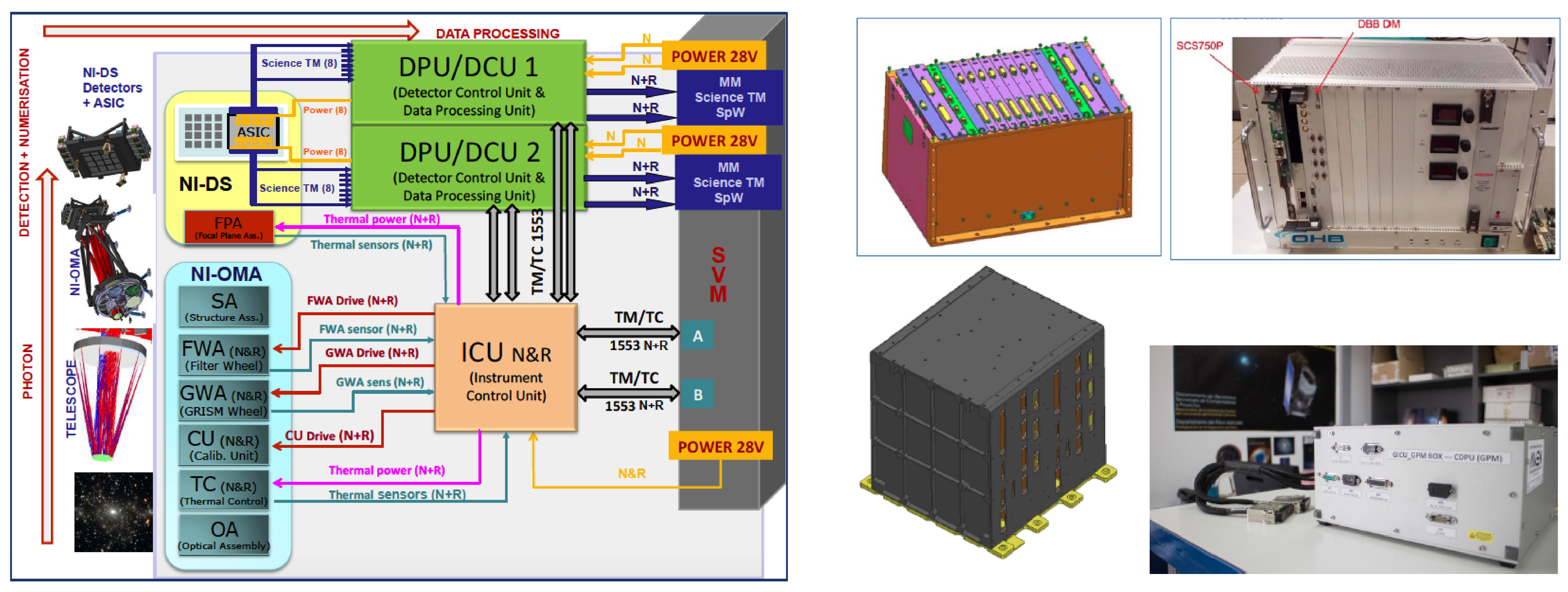

Figure 3: Schematic overview of NISP architecture (left) & Data Processing Units (top right) and Instrument Control Unit (bottom right) mechanical design and demonstration models [4].

NISP performances

For NISP spectroscopic observation, the minimum flux for the detection is 2×10^{-16} erg/(s $\cdot$ cm^2) $\sim 3.5\sigma$ SNR. In addition, photometric detection limit in NIR wavelength bands Y, J and H for 5σ SNR point sources is of 24 AB magnitude. The number of expected observed galaxies is: 2.5×10^7 for spectroscopic & 1.5×10^9 for photometric sample.

Galaxy Clustering		
Spectroscopic redshift accuracy	$\sigma_z < 0.001(1+z)$	$0.9 < z < 1.8$ with 1700 galaxies/deg^2

Weak Lensing		
Photometric redshift accuracy	$\sigma_z < 0.05(1+z)$	$0 < z < 1.2$ with 30 galaxies/arcmin

Table 1: Scientific specifications for weak lensing and galaxy clustering observations for the Euclid mission [3].

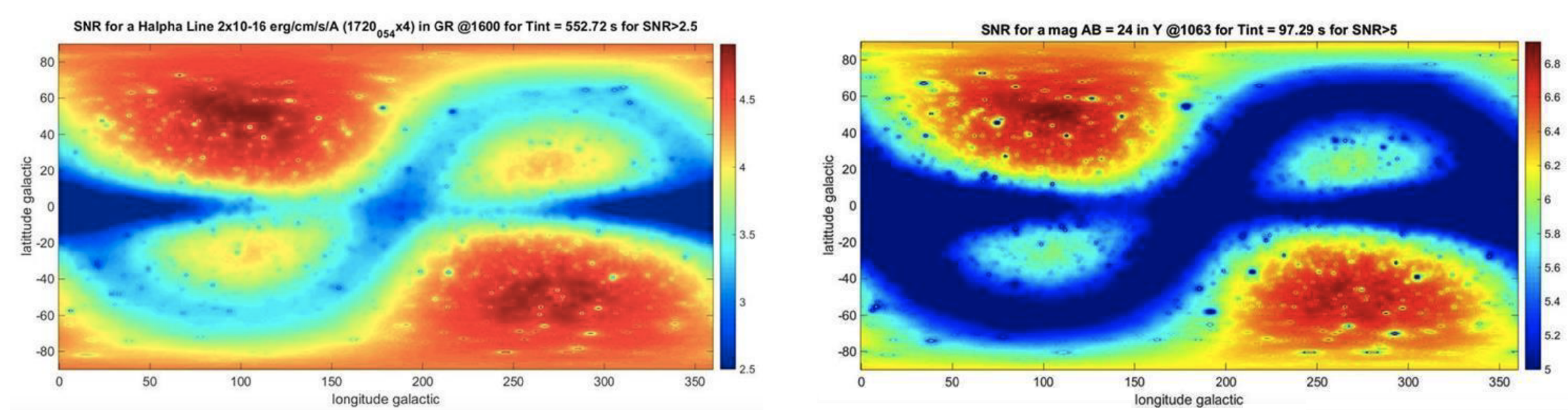

Figure 4: Left: SNR map (galactic coordinate) Current Best Estimate of the System in NISP red grism channel (SNR after 4 exposures on line of flux of 2×10^{-16} erg/(s $\cdot$ cm^2) at 1720 nm in 4×4 aperture). Right: SNR map CBE of the System in NISP Y photo band channel (SNR after 3 exposures out of 4 on $m_{AB} = 24$ object in 3×3 aperture) [4].

Conclusions

Euclid will be able to improve the accuracy on cosmological parameter measurements:

	Modified Gravity	Dark Matter	Initial Conditions	Dark Energy		
Parameter	γ	m_ν/eV	f_{NL}	w_p	w_a	FoM
Euclid Primary	0.010	0.027	5.5	0.015	0.150	430
Euclid All	0.009	0.020	2.0	0.013	0.048	1540
Euclid+Planck	0.007	0.019	2.0	0.007	0.035	4020
Current	0.200	0.580	100	0.100	1.500	~10
Improvement Factor	**30**	**30**	**50**	**>10**	**>50**	**>300**

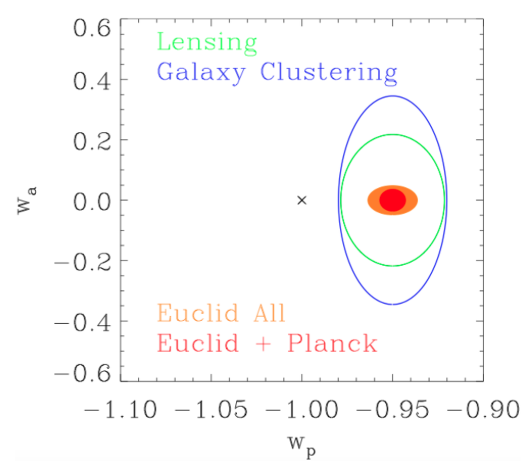

Figure 5: Accuracy for cosmological parameters (left) & error on w_a, w_p parameters (right) expected for Euclid [3].

- γ = General Relativity modification index (GR predicts $\gamma \approx 0.56$)
- m_ν = sum of neutrino masses (if $m_\nu \leq 0.1$ eV, the accuracy on the sum of neutrino masses will allow to discriminate between normal and inverted mass hierarchy)
- f_{NL} = non-Gaussianity correction in primordial density fluctuations
- w_a & w_p = parameters characterizing Dark Energy equation of state $p = w(a)\rho c^2 \rightarrow w(a) = w_p + w_a(a_p - a)$, expected values are $w_p \simeq -0.95$ & $w_a \simeq 0$

References

[1] R. Barbier. NI-SCS characterization requirements. 2016.

[2] J. W. Beletic et al. Teledyne Imaging Sensors: infrared imaging technologies for astronomy and civil space. *SPIE Proc. 7021*, 2008.

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[4] T. Maciaszek et al. Euclid NISP instrument concept and first test results obtained for different breadboards models at the end of phase C. *SPIE Proc. 9904*, 2016.