# Euclid's Near Infrared Spectro-Photometer (NISP) Instrument performances and capabilities

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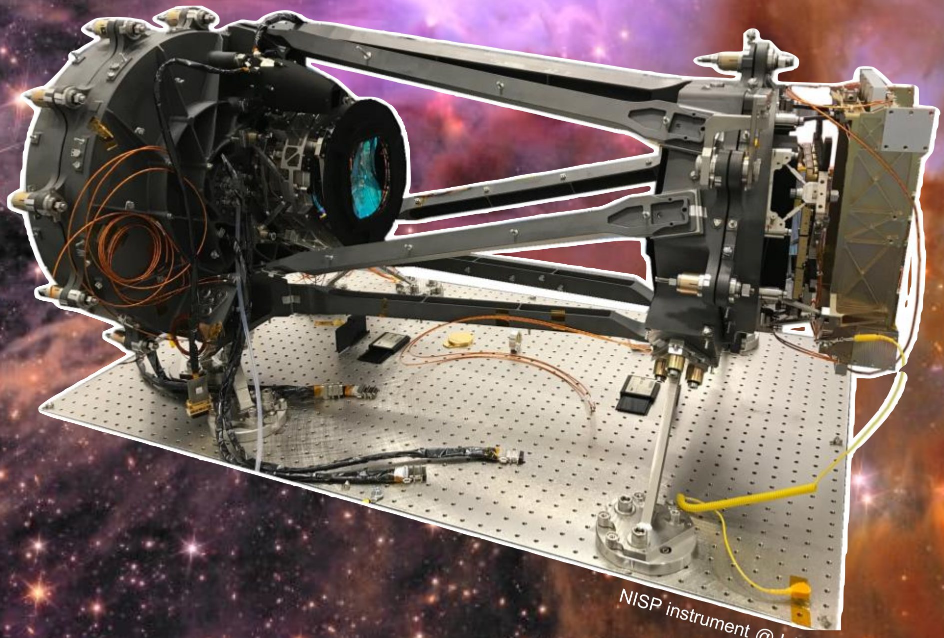
Messier78 – Euclid ERO



NISP instrument @ LAM

Seventeenth Marcel Grossmann Meeting
July 2024

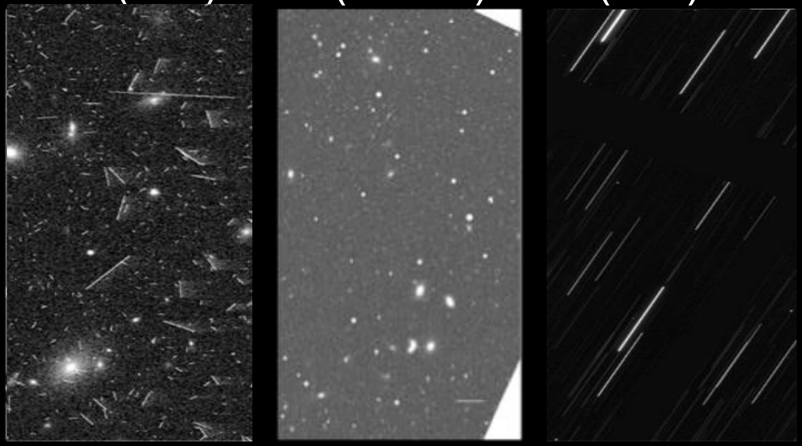
# Euclid observation technique

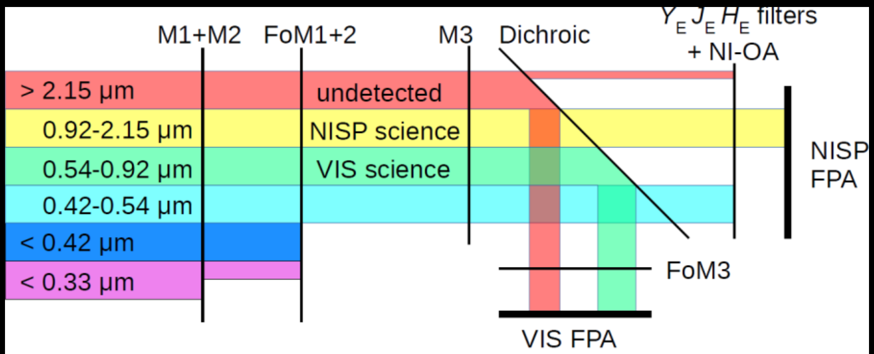
- Building a sequence of > 40 000 observations over the sky in 6 years
- 1.5 billion Galaxy shapes (Weak Lensing), 25 million Galaxy spectra (redshift $\sigma_z$=0.001)
- Field of View = 0.54 deg$^2$

## A panchromatic view

Dither

VIS (565 s) | NISP (112 x 3 s) | NISP grism (574 s)

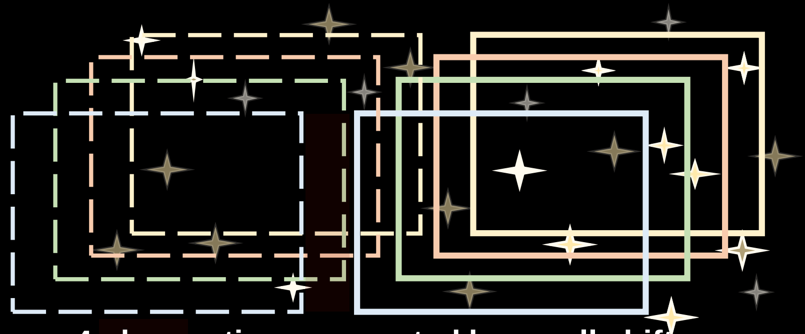





Chromatic selection function of the Euclid optical elements

M.Schimer et al. 202

## Dithering technique

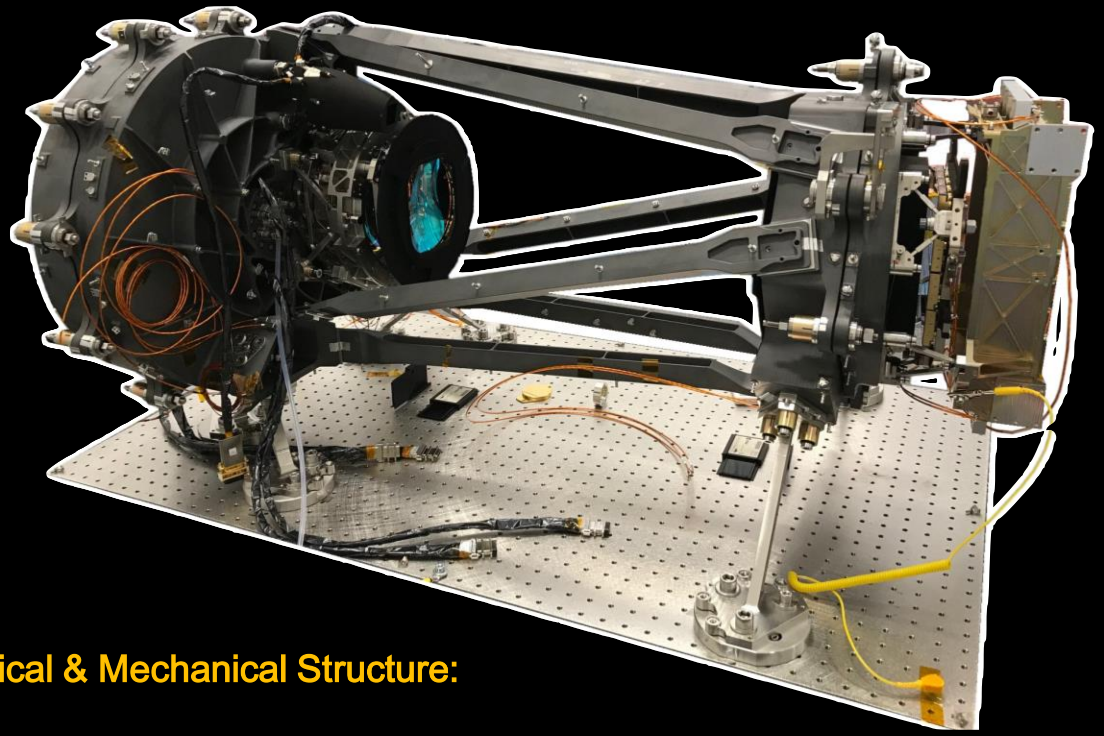


4 observations separated by small shifts

- Single Euclid Observation is composed by
  1 visible and 1 Spectroscopic simultaneously followed by 3 Photometric.
- 4 x observation sequence are done for each field
- total length = 1h 15'
- budget = ~ 20 observations / day

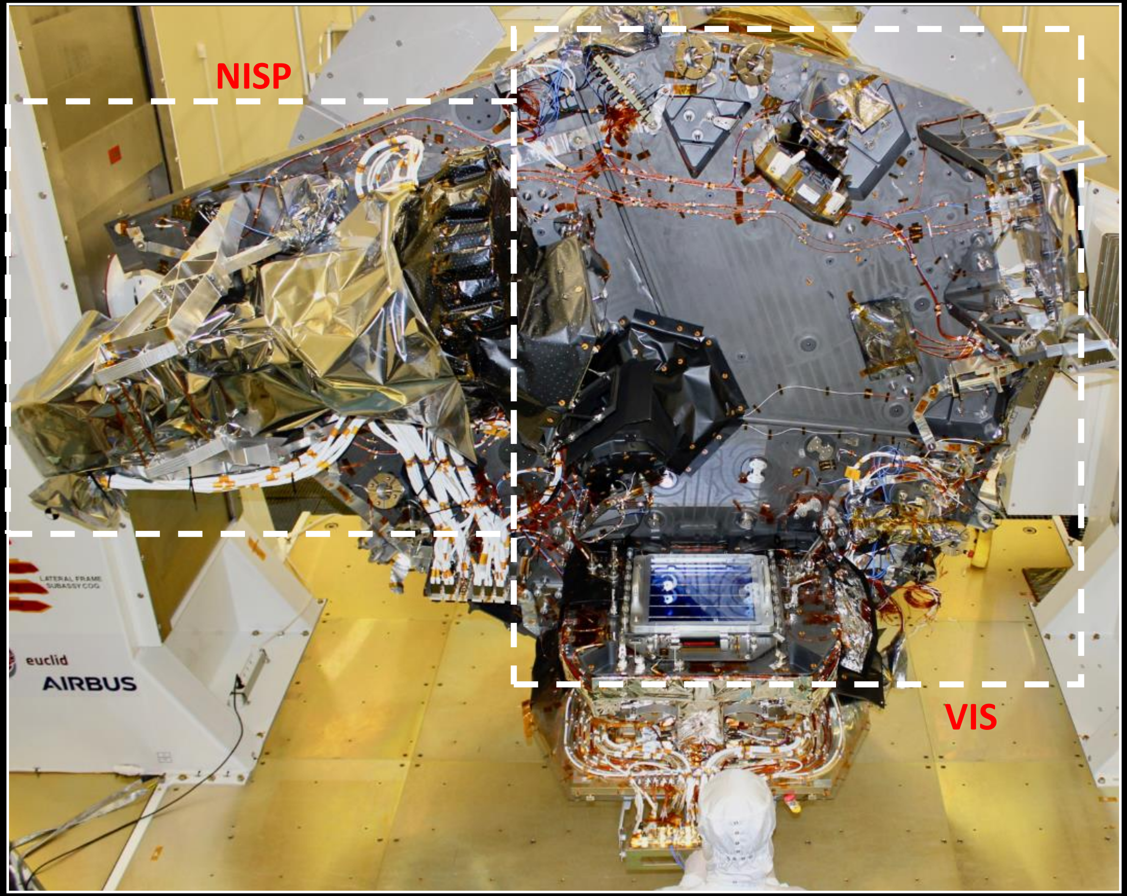
# Euclid's Near Infrared Spectro-Photometer (NISP)

NISP is made by two instruments
(Spectrometer and Photometer)
with a spectral range 0.9-2 μm
and was designed to measure a 3D map of the Universe



NI-Optical & Mechanical Structure:

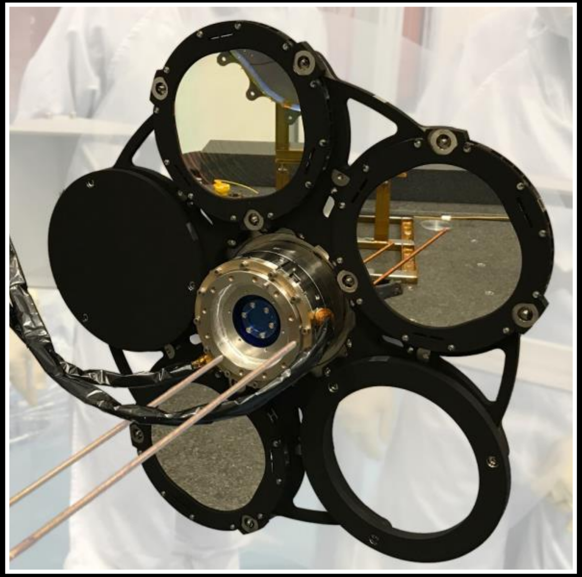
- SiC mechanical structure (to ensure optical alignment) operating at 135 K
- Optical system composed by Correction lenses (entrance pupil) to correct the waveform, and the Camera lenses to collimate light to the focal plane



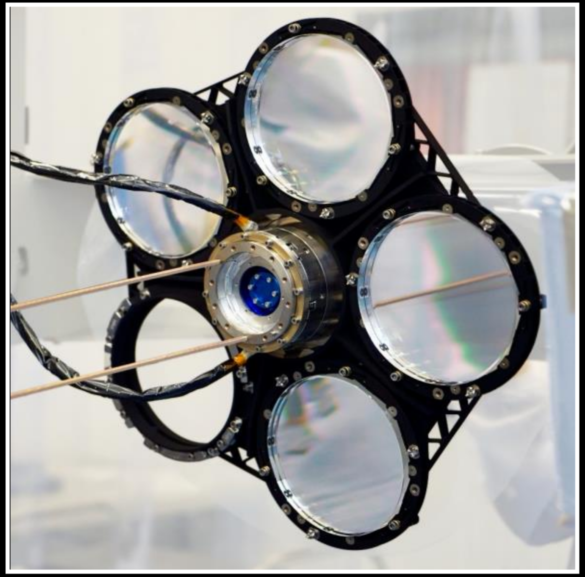

NISP and VIS integrated on the flight PLM baseplate

https://www.esa.int/Science_Exploration/Space_Science/Euclid/Euclid_s_instr

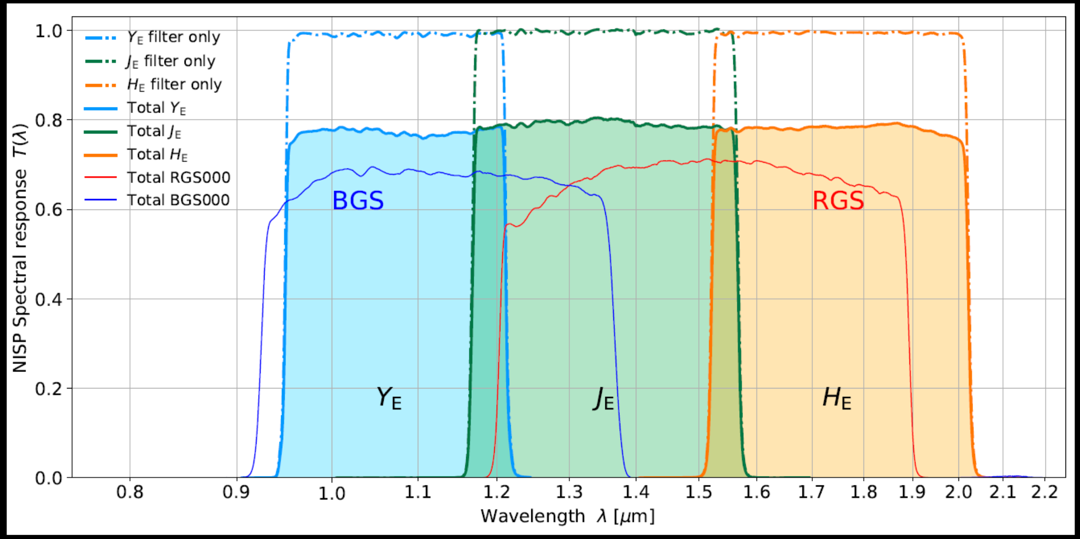
# Euclid's Near Infrared Spectro-Photometer (NISP)



Filter Wheel



Grism Wheel




Euclid passbands

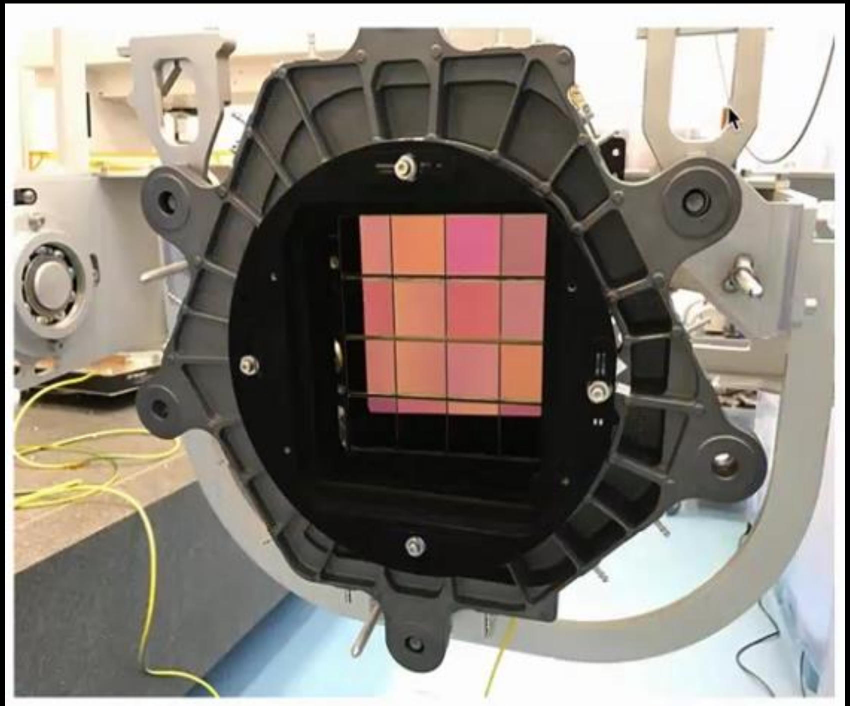
M.Schimer et al. 2022

NI-Filter (FWA) and Grism Wheel Assembly (GWA):

- Photometry using 3 filter passbands – to measure photometric redshifts distances for billions of Galaxies with dz/(1+z) = 5%
  FWA: 3 filters, 1 open position, 1 close position:
  Y (0.92-1.15µm ± 0.2 nm),
  J (1.15-1.37µm ± 0.3 nm),
  H (1.37-2.0µm ± 0.4 nm)

- Slit-less Spectroscopy using grisms – to measure spectrometric redshifts of 50 million Galaxies with dz/(1+z) = 0.1%
  GWA: 4 Grisms, 1 open position:
  1 Blue grism (926-1366 nm) single orientation $0^0$ ($H_\alpha$: 0.41 < z < 1.08, $O_{III}$: 0.86 < z < 1.74);
  3 Red grisms (1206-1892 nm) with orientations $0^0$, $180^0$, $270^0$ ($H_\alpha$: 0.48 < z < 1.88, $O_{III}$: 1.45 < z < 2.79)

# NISP Focal Plane Array (FPA)



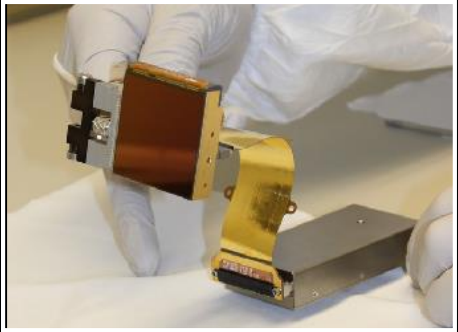
NI-FPA © Euclid consortium

## Detector System ~ 95 K

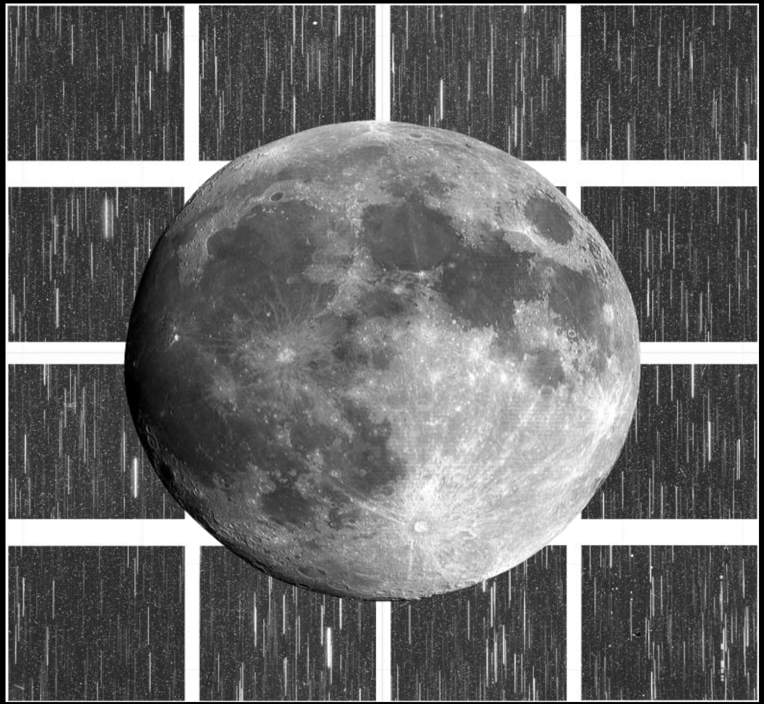
- 16 Teledyne's HAWAII-2RG (HgCdTe) hybrid CMOS, each with 2048x2048 pxs, 2.3µm cut-off
- resolution: 0.3 arcsec/px
- 18 µm pixel pitch
- FoV = 0.55 $deg^2$

## Read-out electronics ~135K

- Teledyne's SIDECAR ASIC

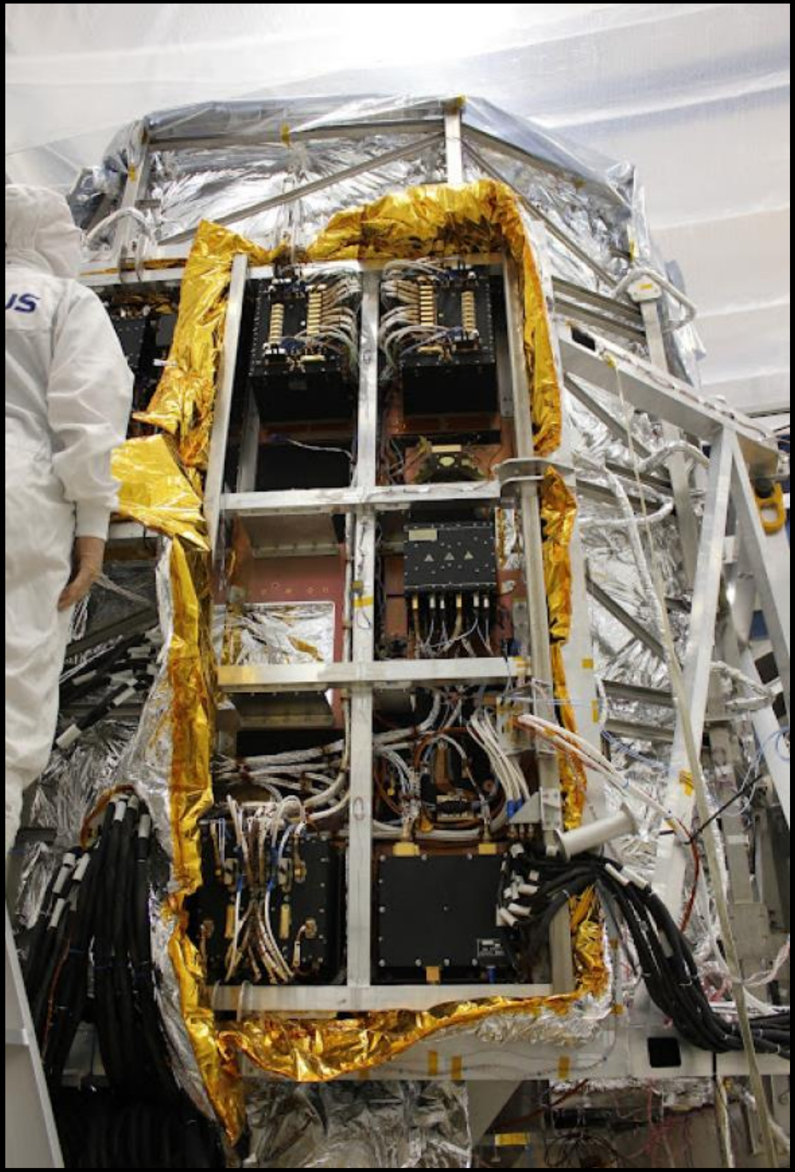


H2RG – flex cable – SIDECAR ASIC



NI-FoV comparison

# NISP Warm Electronics (WE) ~293 K




NI-WE mounted on the SVM panel Y. Top: 2 DPUs, Middle: ICU

NI-WE is composed of 2 identical Data Processing Units (DPU) and 1 Instrument Control Units (ICU)

- DPU:
  - Manages the NI-FPA raw data acquisition through 16 Detector Control Units, with a synchronization < 10 ns
  - Performs the on-board data pre-processing, compression, and transmission to the Spacecraft mass memory unit

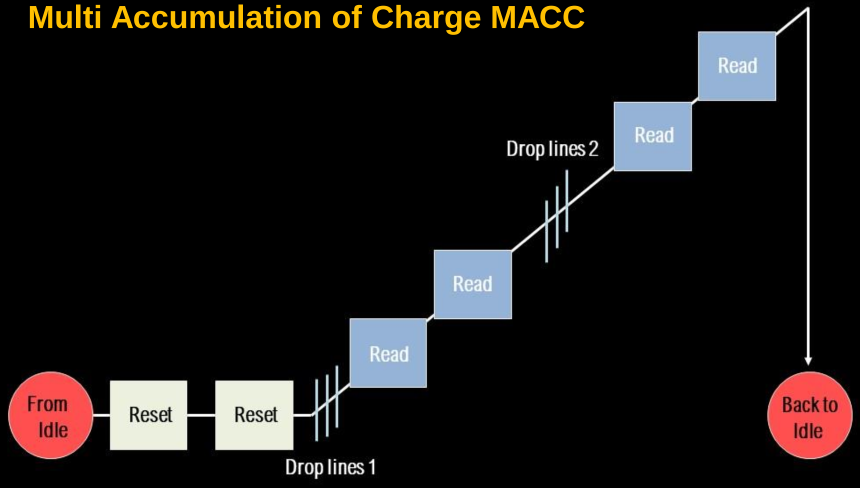
- ICU:
  - Manages the communication with the Platform
  - Handles the operations of both DPUs
  - Operates the Filter and Grism Wheels Assamblies and Calibration Unit

The NI-WE orchestrates NISP operations including Failure Detection and recovery procedures.

Data Budgets: - telecomands rate 1Hz (512 bit)
- telemetry transmission 40 Hz (~18Kbit)
- downlink of ~290 Gbit/day

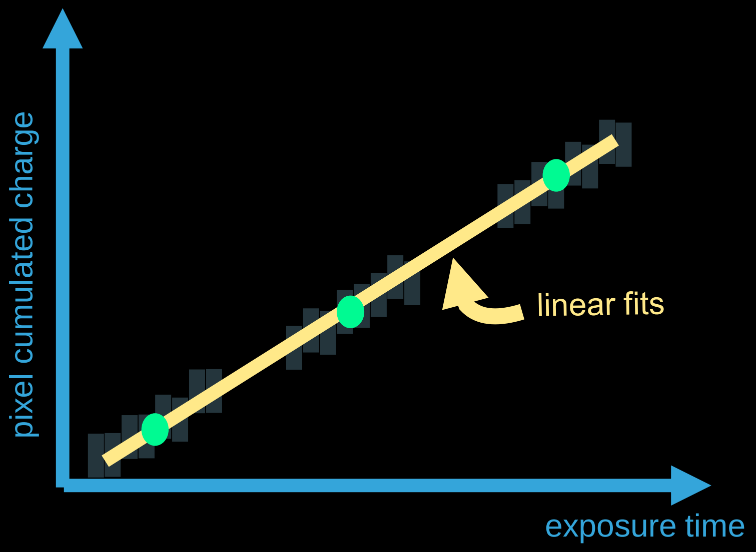
# DPU-ASW on-board data processing

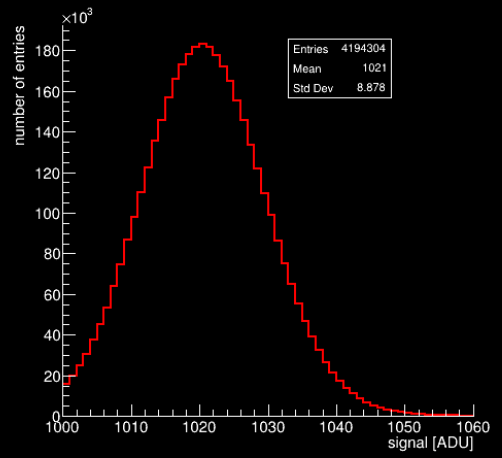
Multi Accumulation of Charge MACC



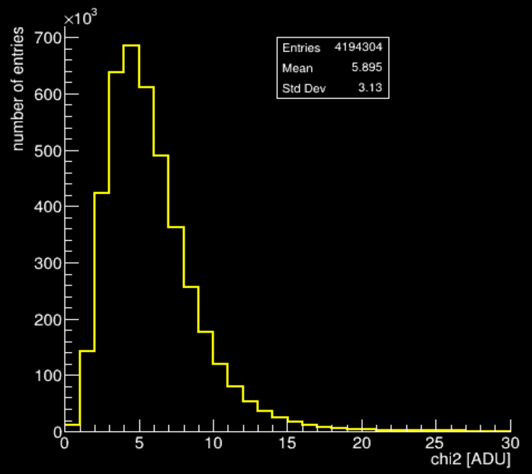

- Evaluate mean charge per group
- least square linear fit on charge derivative / px
- extract slope as NISP flus estimator, reduces correlation noise between consecutive frames
- evaluation of the $\chi^2$ as quality factor / px this allows to detect bad pixels, Cosmic Rays, transients, and test linearity of charge collection

Bogna Kubik et al 2016 PASP 128 104504




Signal Frame




$\chi^2$Frame

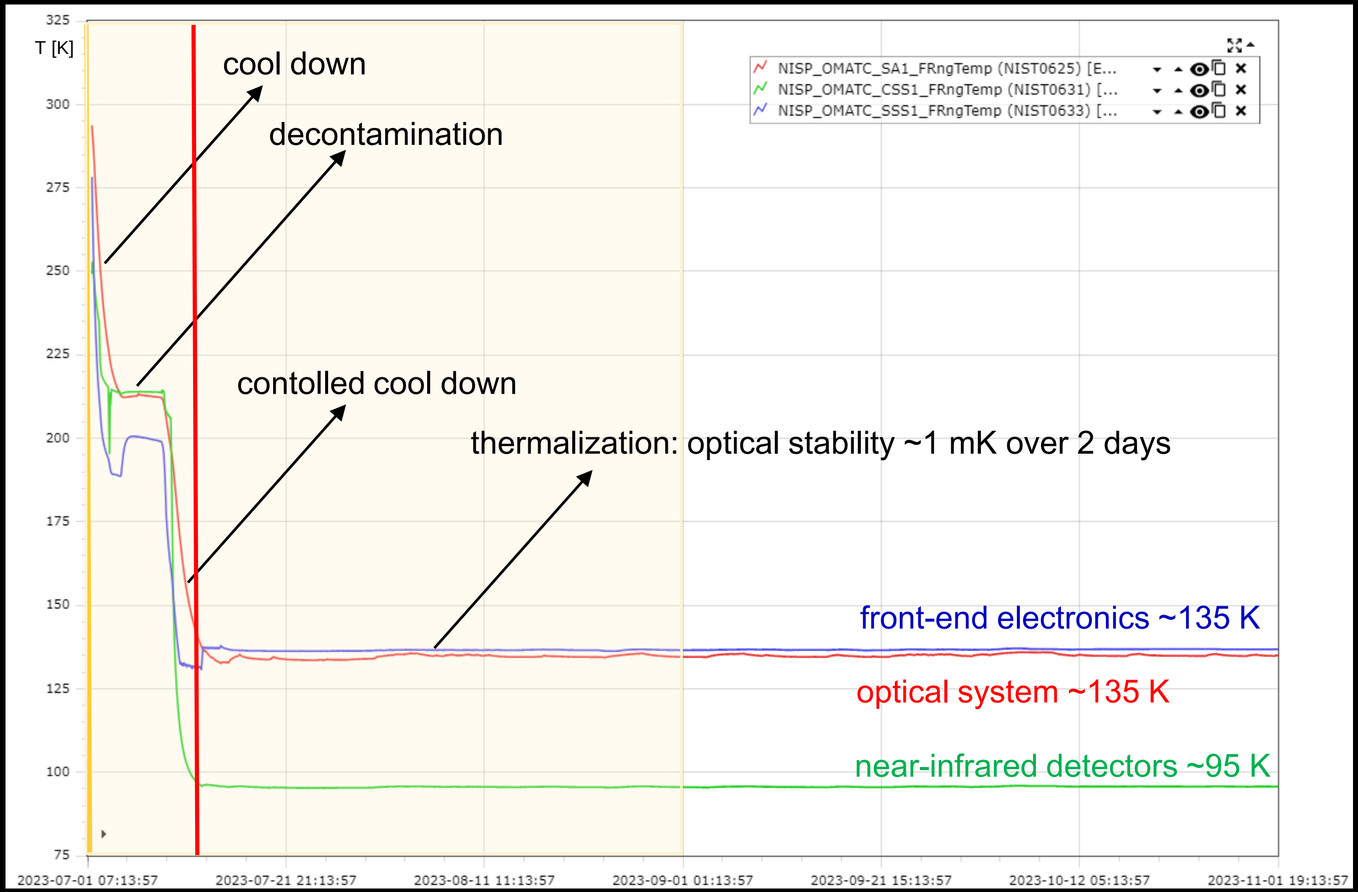


Proc. of SPIE Vol. 9904 99045R-1

# NISP in-flight activities

SpaceX Falcon 9

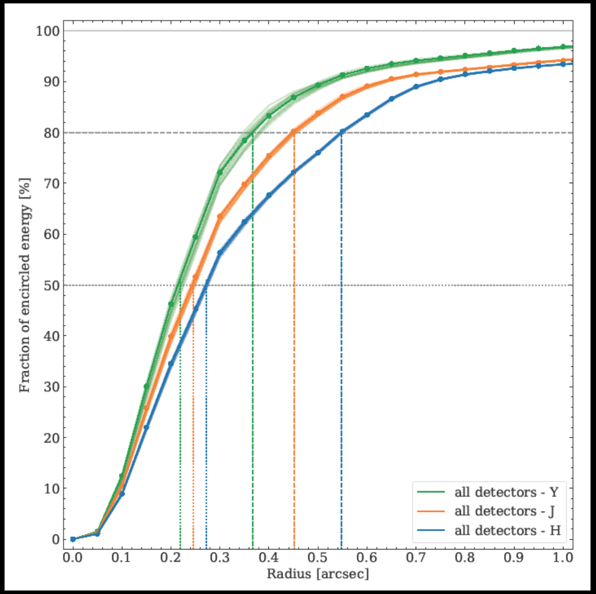
- Launch date July 1, 2023, Cave Canaveral, Florida, USA – NASA space port
- NI-ICU was powered-on on July 2, 2023 to monitor the temperatures
- NI-FPA powered on July 14, 2023
- 30 days transit to L2 – full commissioning took place (up to end of August)
- followed by the performance verification (calibrations up to November 2023):
  - 12 dedicated observation sequences
  - 34 calibration products
- Nominal survey since February 15, 2024




NI-temperature profile during early flight phases

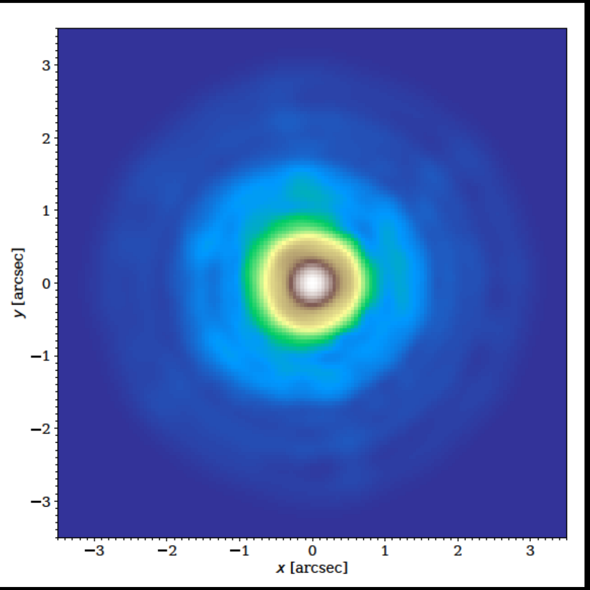
# NISP Photometric performances

## Cumulative EE of point sources




Modelled encircled energy (EE) of the NISP PSF in the 3 photometry channels from data acquired during the PV phase.

## NI-Photometric PSF




NI-P example PSF in the $H_E$ passband.

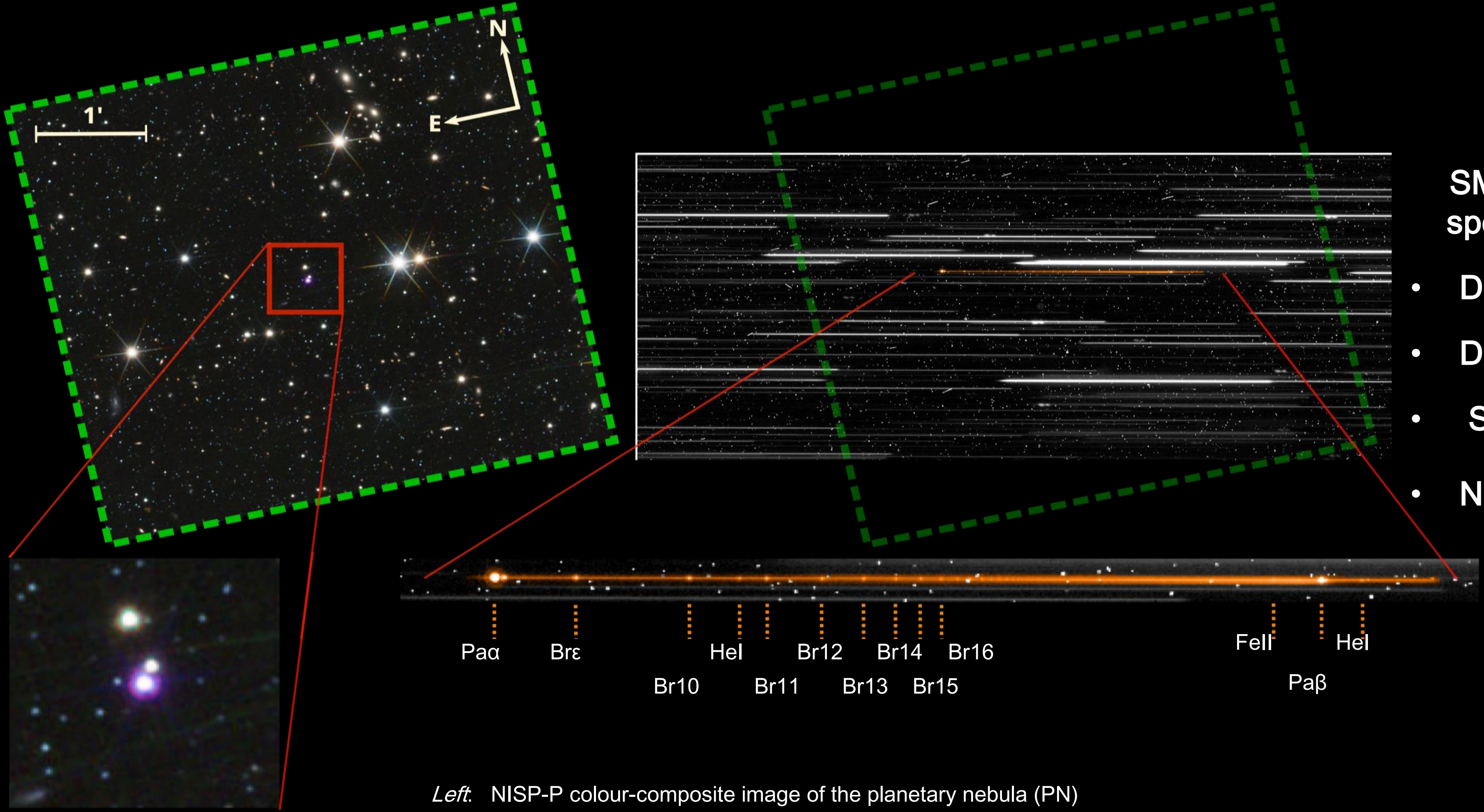
- PSF encircled energy compliant with requirement

| Filter | EE50 (50%) | EE80 (80%) | FWHM | Lim. Sens. |
|---|---|---|---|---|
| $Y_E$ | 0"22 | 0"37 | 0"35 | 24.6 |
| $J_E$ | 0"24 | 0"45 | 0"34 | 24.6 |
| $H_E$ | 0"27 | 0"55 | 0"35 | 24.5 |

- Small trefoil stemming from the Euclid primary mirror

K. Jahnke et al., Euclid. III. The NISP Instrument, arxiv.org/2405.13493

# NISP Spectroscopic performances




SMC-SMP-20 NISP inflight spectroscopic calibrator:

- Diameter[1] : 0.4" → unresolved
- Dispersion law : ≃1.37 nm/px
- Spectroscopic PSF : ≃ 20 Å FWHM
- NISP $\mathcal{R}=\frac{\Delta\lambda}{\lambda}$ 450 < for 0.5" source diameter
  → Scientific requirement : $\mathcal{R}$ > 380

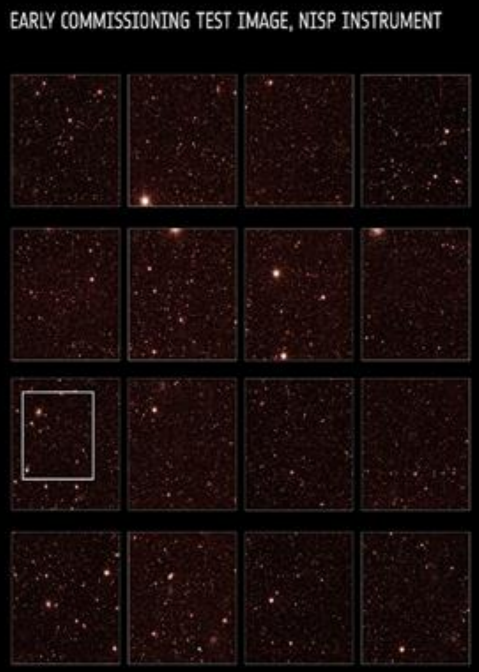
*Left*: NISP-P colour-composite image of the planetary nebula (PN) SMC-SMP-20 from wavelength calibration.
*Right*: Raw NISP-S 2d-spectrogram of the same area -photometry field is sketched with a green box.
*Bottom*: extracted 1d-spectrum

K. Jahnke et al., Euclid. III. The NISP Instrument, arxiv.org/2405.13493



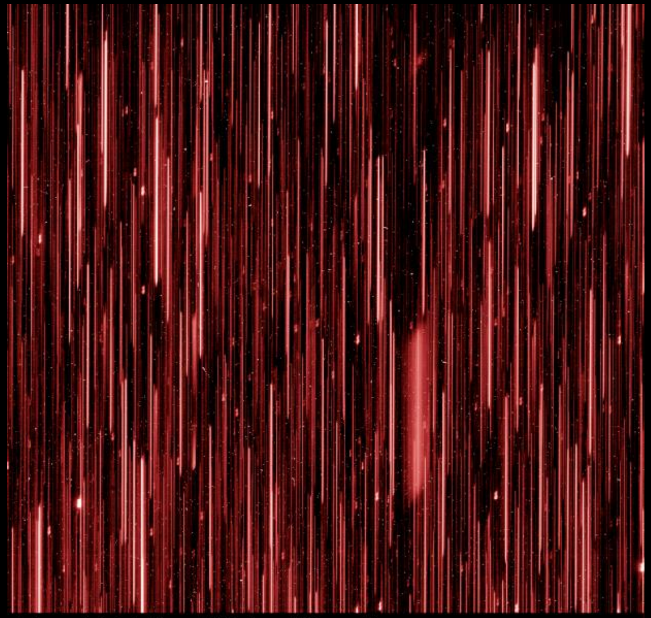
Slide courtesy of W. Gillard

# Euclid first data release – first (public) light





Early commissioning test image, NISP instrument


Early commissioning test image, NISP instrument (grism mode)

First commissioning (after telescope focusing) full raw images
July 2023 release – 87 seconds exposure.
No post-processing was applied, nor cosmic rays rejection, nor any Euclid's processing pipeline was applied.

*Left*: Full NISP FPA image
*Center*: Photometric image detail; spiral galaxy 2MASX J05571041−6750268
*Right*: Spectrocopic image of the same field

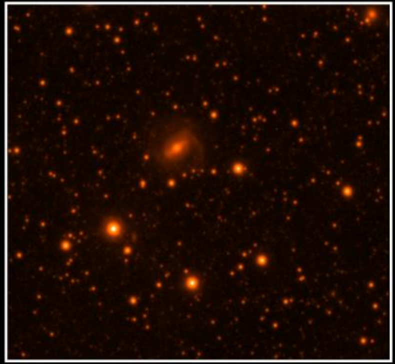
## NISP instrument is outperforming

- High optical image quality, with photometric PSF better than requirement
- Photometric noise < 8 $e^-$
- Spectroscopic resolving power better than requirement
- Spectrometric noise < 6.5 $e^-$

https://www.esa.int/Science_Exploration/Space_Science/Euclid
https://www.youtube.com/watch?v=7zdIdAVNyUE&t=6s

# Euclid's performances and comparison with other telescopes

- Euclid (NISP) vs. JWST (NIRCam):
  - field-of-view highly increased



VISTA VMC J-band

Euclid NISP Test Image

- Euclid (NISP) vs. Visible and IR Survey Telescope for Astronomy ground based telescope:
  - resolution highly improved

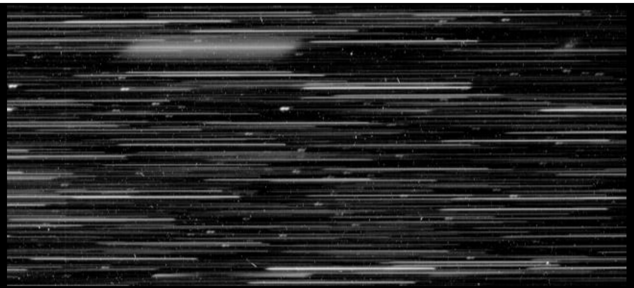
Euclid – ERO: Perseus Cluster - 240x10$^6$ light years away

- Outstanding image quality with an incomparable resolution power.
  In this image are shown 1200 galaxies of the cluster plus more than 100 000 galaxies in the background



https://www.esa.int/Science_Exploration/Space_Science/Euclid/Euclid_s_first_images_the_dazzling_edge_of_darkness
https://www.esa.int/Science_Exploration/Space_Science/Euclid/Euclid_s_view_of_the_Perseus_cluster_of_galaxies

# NISP challenges



*ESA/Euclid/Euclid Consortium/NASA, [CC BY-SA 3.0 IGO]*

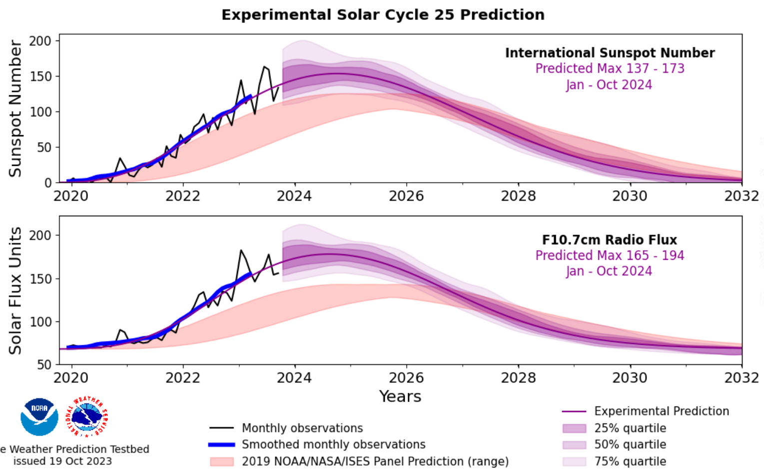
## Challenges to be fully addressed:

- Spectroscopic extraction & decontamination
  - observation strategy provides 4 dispersion directions to allow decontamination;
    >1700 redshift measurements every 1ºx 1º

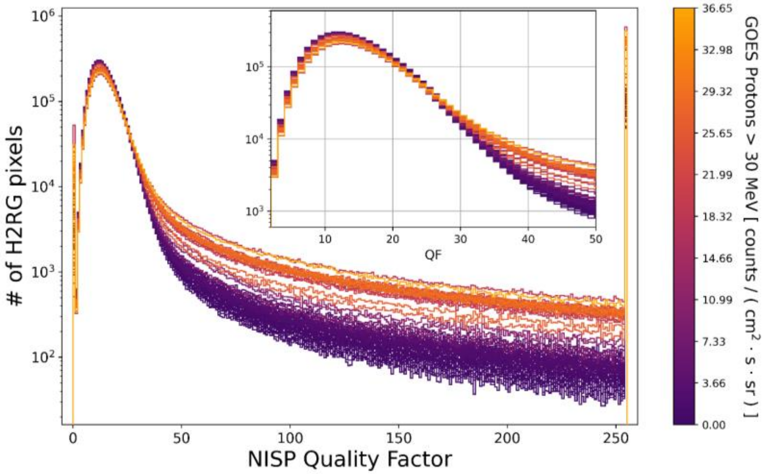
- Detector persistence
  - persistence level as expected from ground measurements but challenges data processing

## Example of 'unexpected' challenges fully addressed:

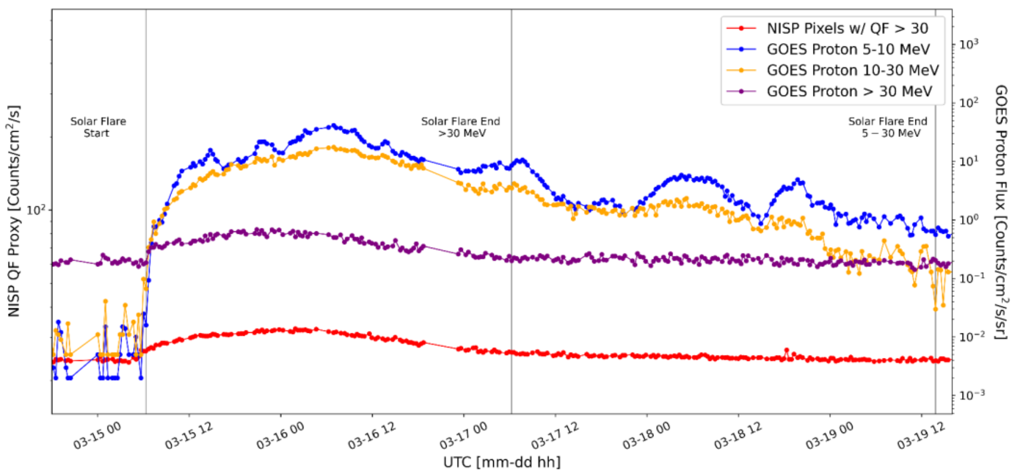
- Extremely intense Solar activity (intense proton flux from CMEs) [F. Cogato et al., SPIE 2024]




Expected intense Solar activity for the mission lifetime




NISP $\chi^2$ proxy to identify CR in NISP data




$\chi^2$proxy strongly correlated with proton flux with E > 30 MeV

# ERO: NISP only sources and the search for luminous z=6-8 galaxies

J.R.Weaver et al. arXiv:2405.13505

This paper shows Euclid ability to identify rare NISP-only objects $Y_E$, $J_E$, and $H_E$ bands (i.e., not detected in VIS/$I_E$), such as luminous high-redshift galaxies and extremely red sources.

## Dataset

Using the observations, and photometric catalogue of galaxy clusters Abell 2390 and Abell 2764; and adopting standard ΛCDM cosmology ($H_0$ = 70 km $s^{-1}$ $Mpc^{-1}$, $\Omega_m$ = 0.3 and $\Omega_\Lambda$ = 0.7)

Euclid magnifying power of their deep gravitational potentials helps to resolve galaxies immediately behind the cluster, the large 0.75 $deg^2$ area of each field enables an order-of-magnitude increase in the number of detectable z ≳ 6 UV

Abell 2390 galaxy cluster

Abell 2764 galaxy cluster

s ; R
showing their photometry, best fit template and binomial, cutouts, and light
surveys. Upper limits for $I_E$ are shown by the leftmost grey bar with an arrow, while selection limits for NISP bands $Y_E$, $J_E$, and $H_E$ are shown as grey bars.

## Results

The 168 sources selected in this work represent the most robust NISP-only objects. It is neither a complete sample nor a pure one, but is intended to showcase the potential of Euclid and its ability to select promising high-redshift galaxies, among other interesting NISP-only sources.

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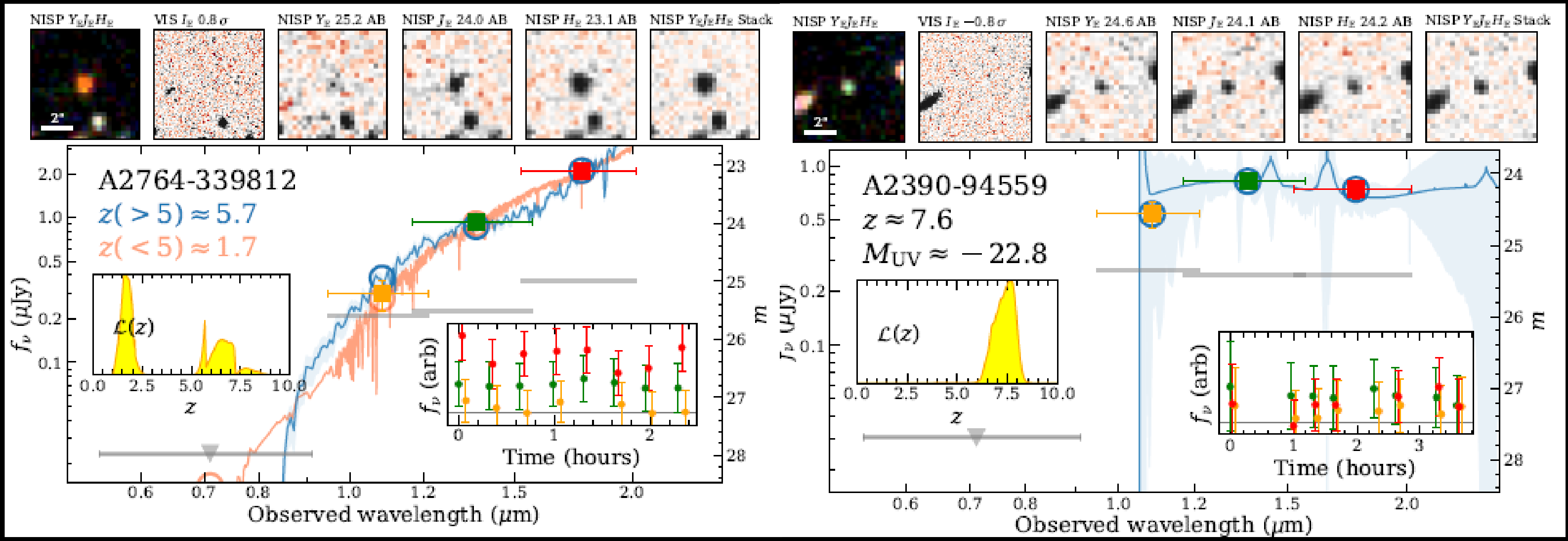


*Left*: extremely Red sources ; *Right*: Lyman-break galaxy candidate showing their photometry, best fit template and binomial, cutouts, and light curves. Upper limits for $I_E$ are shown by the leftmost grey bar with an arrow, while selection limits for NISP bands $Y_E$, $J_E$, and $H_E$ are shown as grey bars.

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