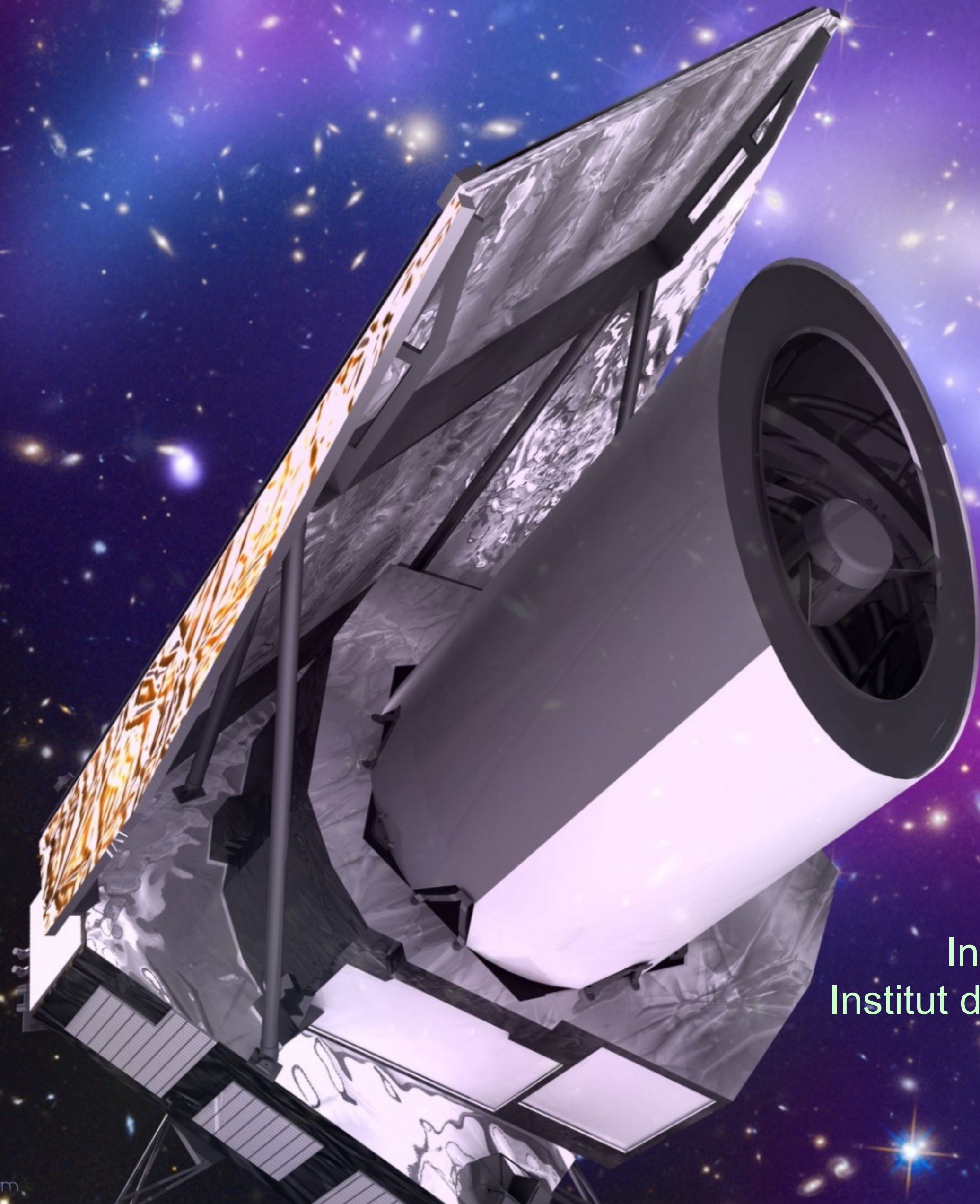
Euclid: ESA Cosmology Mission

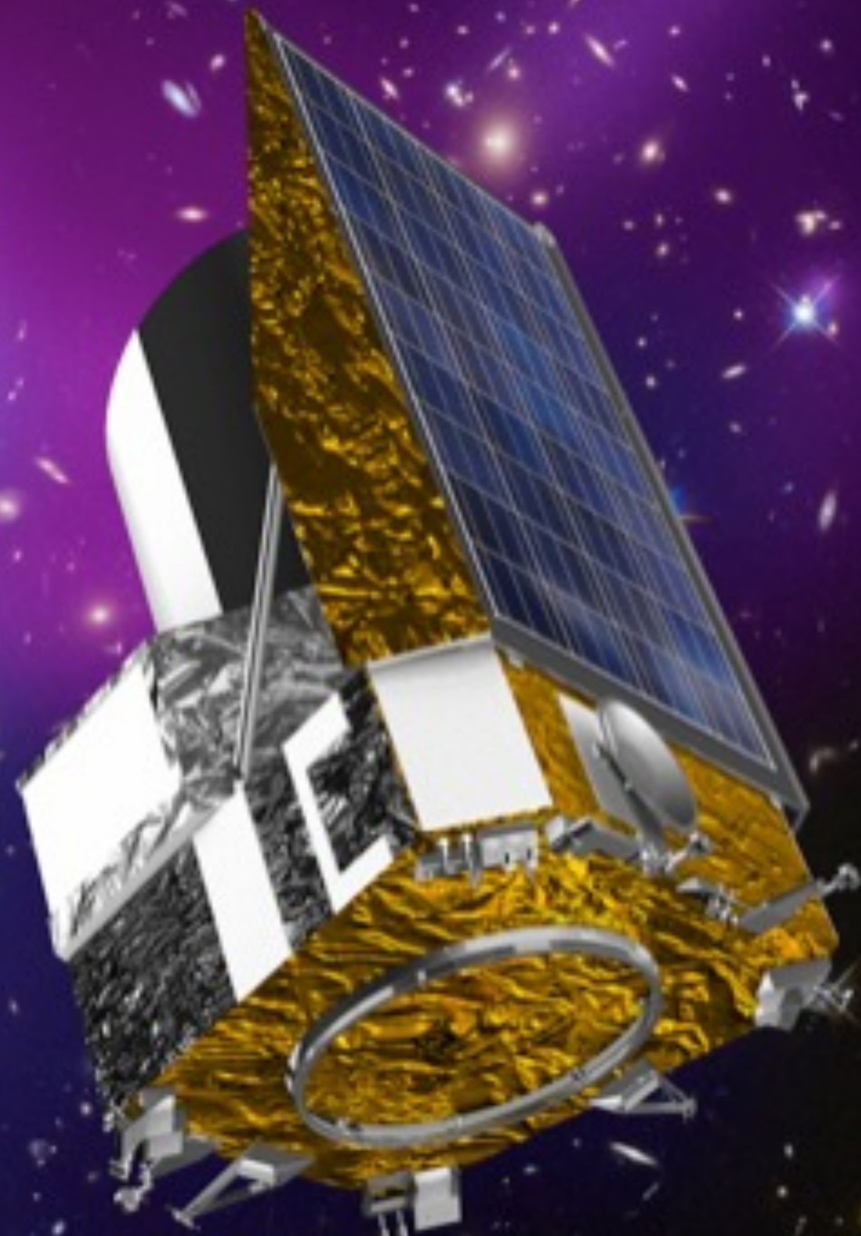


F.J. Castander
on behalf of the Euclid Consortium
www.euclid-ec.org

Institut de Ciències de l'Espai (ICE-CSIC)
Institut d'Estudis Espacials de Catalunya (IEEC)

Euclid

- Cosmology mission to study the accelerated expansion of the universe aka dark energy
- Selected by ESA on October 4th 2011
- Adopted June 19th 2012
- M class mission
- M2 launch slot
- launch Q3 2023



Euclid:
Overview and current status

Euclid Science Objectives

Issue	Euclid's Targets
What is Dark Energy	**Measure the Dark Energy equation of state parameters** w_p and w_a to a precision of 2% and 10%, respectively, using both expansion history and structure growth.
Test Gravity	**Distinguish General Relativity from modified-gravity theories**, by measuring the galaxy clustering growth factor exponent γ with a precision of 2%.
The nature of dark matter	**Test the Cold Dark Matter paradigm** for structure formation, and measure the sum of the neutrino masses to a precision better than 0.04eV when combined with Planck.
The seeds of cosmic structure	**Improve by a factor of 20 the determination of the initial condition parameters** compared to Planck alone. n (spectral index), σ_8 (power spectrum amplitude), f_{NL} (non-gaussianity)

Euclid Top Level Science Requirements

Sector	Euclid Targets
Dark Energy	• Measure the cosmic expansion history to better than 10% in redshift bins $0.9 < z < 1.8$ • Look for deviations from $w = -1$, indicating a dynamical Dark energy. • Euclid *alone* to give $FoM_{DE} \geq 400$ (1-sigma errors on w_p, & w_a of 0.02 and 0.1 respectively)
Test Gravity	• Measure the growth index, γ, with a precision better than 0.02 • Measure the growth rate to better than 0.05 in redshift bins between $0.5 < z < 2$. • Separately constrain the two relativistic potentials. ψ and ϕ • Test the cosmological principle
Dark Matter	• Detect Dark matter halos on a mass scale between 10^8 and $>10^{15}$ M_{Sun} • Measure the Dark matter mass profiles on cluster and galactic scales • Measure the sum of neutrino masses, the number of neutrino species and the neutrino hierarchy with an accuracy of a few hundredths of an eV
Initial Conditions	• Measure the matter power spectrum on a large range of scales in order to extract values for the parameters σ_8 and n to a 1-sigma accuracy of 0.01. • For extended models, improve constraints on n and α wrt to Planck alone by a factor 2. • Measure a non-Gaussianity parameter : f_{NL} for local-type models with an error < +/-2.

- DE equation of state: $P/\rho = w$, and $w(a) = w_p + w_a(a_p - a)$
- Growth rate of structure formation: $f \sim \Omega^{\gamma}$;
- FoM=$1/(\Delta w_a \times \Delta w_p) > 400 \rightarrow$ ~1% precision on w's.

Euclid consortium

Euclid Euclid Consortium Institutions

EUCLID CONSORTIUM

TTK RWTH AACHEN UNIVERSITY · Aalto University School of Science · AARHUS UNIVERSITY · SUOMEN AKATEMIA FINLANDS AKADEMI ACADEMY OF FINLAND · Argelander-Institut für Astronomie · AIM · asi agenzia spaziale italiana · SSDC

Aix-Marseille université · Astronomický ústav AV ČR · belspo · BERKELEY CENTER for COSMOLOGICAL PHYSICS · ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA · CAAUL · Caltech · CSA ASC

CAR · CARDIFF UNIVERSITY PRIFYSGOL CAERDYDD · Carnegie Mellon University · Centro de Astrofísica da Universidade do Porto · CCIN2P3 · CDTI Centro para el Desarrollo Tecnológico Industrial · cea · IP2I · IPhT SACLAY · CEFCA · CENTRA · CAB · CERN · CFH

FACULTY OF MATHEMATICS AND PHYSICS Charles University · Ciemat · cnes · CPPM · CPT · CRAL · CSIC · CSL · DAL

UNIVERSITY OF CAMBRIDGE Department of Applied Mathematics and Theoretical Physics · Dark Cosmology Centre · DLR · DTU Technical University of Denmark · Durham University · ENS · PSL · EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

esa · ESO · ETH zürich Institute for Theoretical Physics · FINCA · Fyzikální ústav Akademie věd ČR, v. v. i. · NASA Goddard · GRAPPA · ICRAR · IAA · ia instituto de astrofísica e ciências do espaço

IAC · IAP · IAS · IEEC · ICE · Imperial College London · INAF · IASF · INAF Arcetri · Osservatorio Astronomico di Brera

INAF Osservatorio Astronomico di Bologna Istituto Nazionale di Astrofisica · INAF ISTITUTO NAZIONALE DI ASTROFISICA OSSERVATORIO ASTRONOMICO DI CAPODIMONTE · INAF- Osservatorio Astrofisico di Catania · INAF - Osservatorio Astronomico di Padova

OAR INAF Osservatorio Astronomico di Roma · INAF · INAF - ISTITUTO DI RADIOASTRONOMIA · INFN · INFN

INFN Padova · INFN Sezione di Roma · INFN · INFN Istituto Nazionale di Fisica Nucleare Sezione di Torino · INAF - IASF BOLOGNA · ICE · ICG Portsmouth · Institute for Astronomy

Institute for Astronomy University of Hawaii · institut für astronomie · IFAE · IFCA Instituto de Física de Cantabria · cnrs IN2P3 · NRC CNRC Canada · ia · cnrs INSU · ioa · ipac

ICCUB · IPAG · IPNL · irap · Irfu cea · ISS · ISDC · ISTI · LMU USM · IST TÉCNICO LISBOA · JOHNS HOPKINS UNIVERSITY · Liverpool JMU

JPL Jet Propulsion Laboratory California Institute of Technology · THE KAVLI FOUNDATION · KING'S College LONDON · LAB · LAL LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE · LAM · Physics Lancaster University · BERKELEY LAB · LPNHE PARIS

LPSC Grenoble · AIP Leibniz-Institut für Astrophysik Potsdam · Universiteit Leiden · L2S · l'Observatoire de Paris · LUTH · Ludwig-Maximilians-Universität München · Maynooth University 1997–2017 · Ciemat · MAX-PLANCK-GESELLSCHAFT

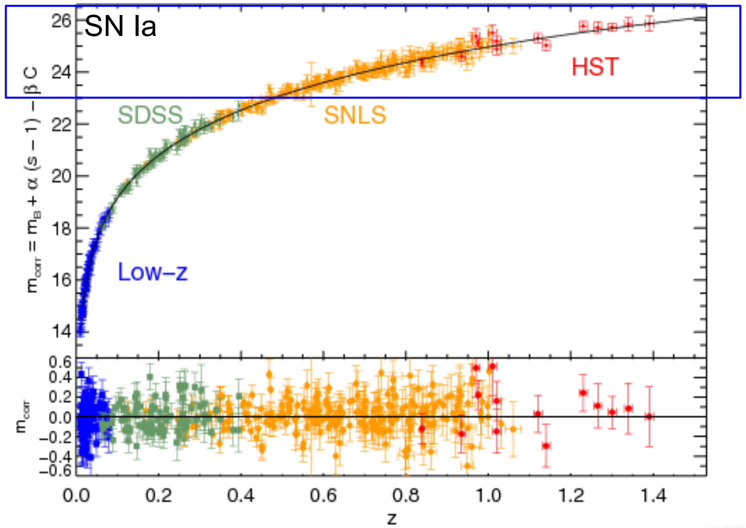
Max-Planck-Institut für Astrophysik · MPE · McGill · McMaster University · UCL MULLARD SPACE SCIENCE LABORATORY · NASA · NOAO · NAOJ · NORDITA · NOVA

Euclid

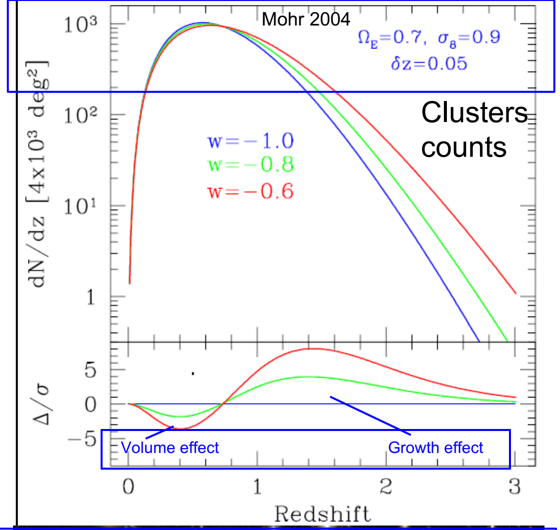
Euclid Consortium Institutions

EUCLID CONSORTIUM

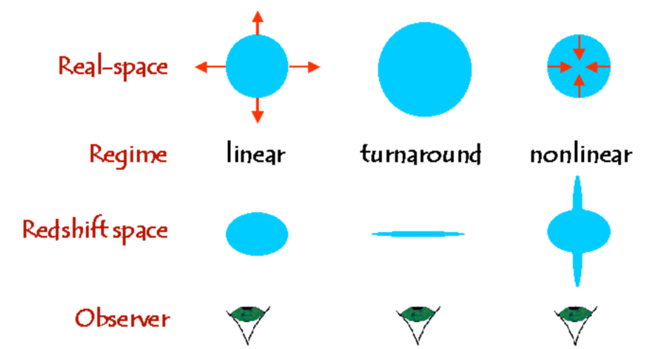
Norsk Romsenter – Norwegian Space Centre
NWO
Observatoire de la Côte d'Azur
Observatoire de Paris
Observatoire astronomique de Strasbourg
OmegaCEN
The Ohio State University
Perimeter Institute
PIC
Princeton University
Queen's University Belfast
Radboud Universiteit
RMC CMR
Saint Mary's University
Smithsonian
SISSA
Scuola Normale Superiore
SLAC National Accelerator Laboratory
Sorbonne Universités
Space Science Center
SRON Netherlands Institute for Space Research
Stanford University
UK Astronomy Technology Centre
Stockholm University
sc | nat
Technische Universität München
Tsinghua University Department of Physics
UK Space Agency
University of Applied Sciences and Arts Northwestern Switzerland
DSFC
UAM
Universidade de Aveiro
University of Bath
University of Birmingham
Universität Bonn
UBC
Berkeley
UC Irvine
Universidad Politécnica de Cartagena
The University of Chicago
fcfm
UCL
UC Davis
UC Riverside
University of Cambridge
Università degli Studi di Catania
Universidad Complutense Madrid
University of Cyprus Department of Physics
Università degli Studi di Ferrara
Università degli Studi Firenze
UF Florida
Université de Genève
Ghent University
University of Groningen
University of Helsinki
Zentrum für Astronomie
Universität Hamburg
University of Hawai'i
Universität Heidelberg
UiO Institute of Theoretical Astrophysics University of Oslo
University of Bristol
Jyväskylän Yliopisto University of Jyväskylä
AGO
University of Louisville
UCL Université catholique de Louvain
L-Università ta' Malta
Manchester 1824 The University of Manchester
UMass Amherst
The University of Melbourne
Università degli Studi di Milano
University of Minnesota
UMKC
Universidad Nacional Autónoma de México
Université de Namur
The University of Nottingham
University of Oxford
Universidad del País Vasco
Università degli Studi di Padova
Penn
University of Portsmouth
UPMC
Dipartimento di Matematica Università degli Studi di Roma "Tor Vergata"
Roma Tre
Sapienza Università di Roma
Universidad de Salamanca Departamento de Física Fundamental
Università del Salento
Università degli Studi di Salerno
The University of Sheffield
Université Nice Sophia Antipolis
University of Southampton
University of St Andrews
University of Surrey
University of Sussex
The University of Texas at Austin
University of Toronto
Università degli Studi di Trento
Università degli Studi di Trieste
Turun yliopisto University of Turku
Universitat de València
University of Victoria
University of Waterloo
Universität Zürich
Utrecht University
VUB
Yale University
York University



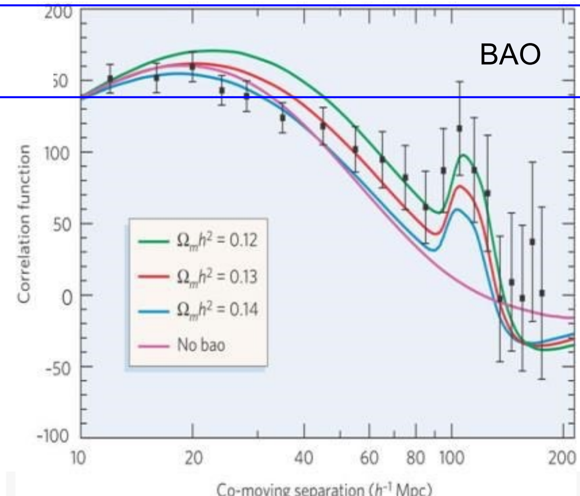
Probes of Dark Energy



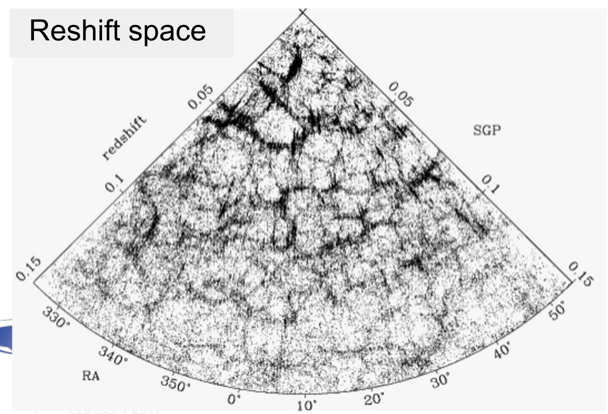
Redshift Space Distortions

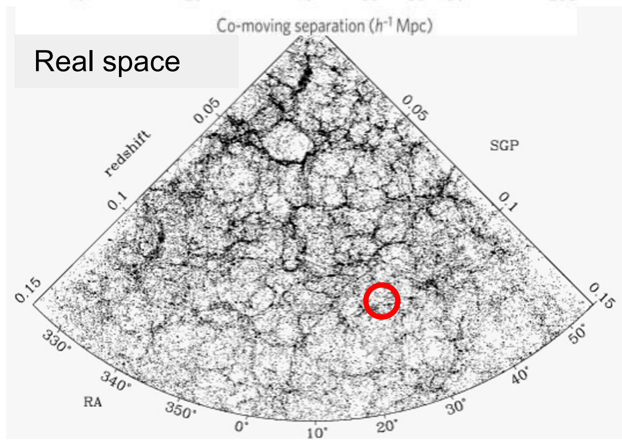


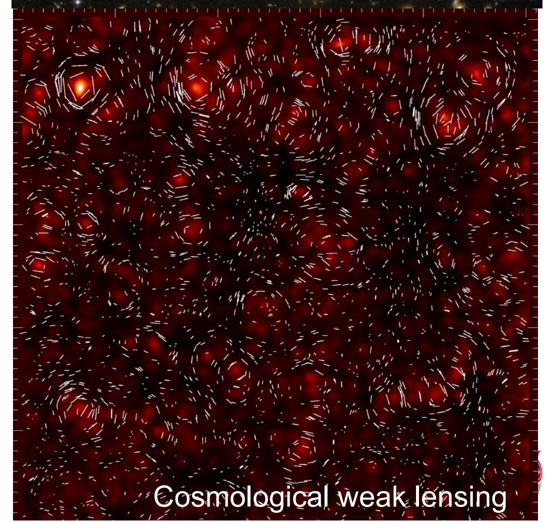
BAO



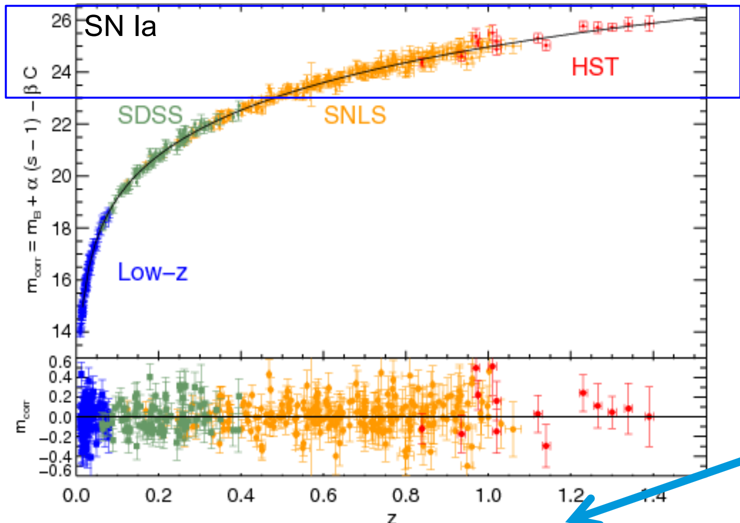
Strong/WeakCluster lensing

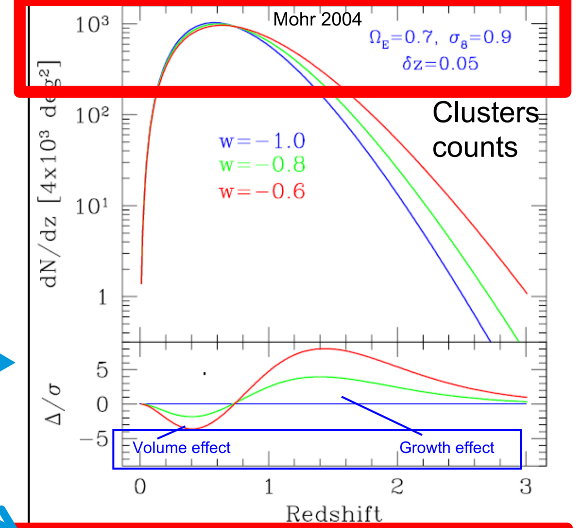






Euclid probes of Dark Energy





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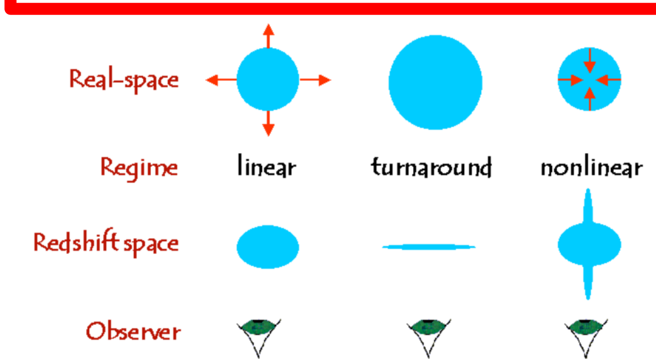
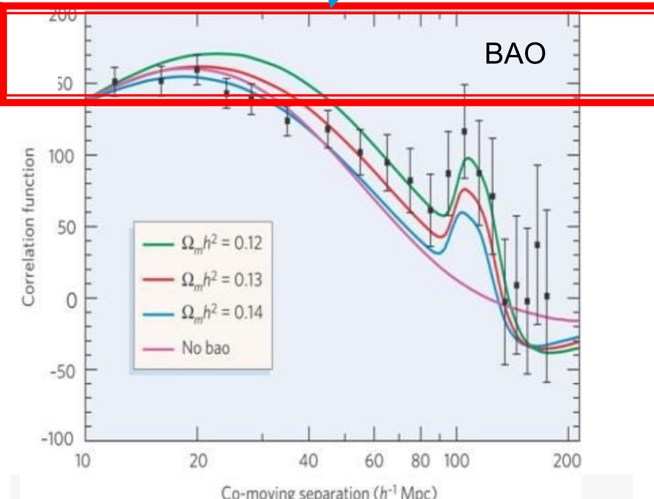


BAO



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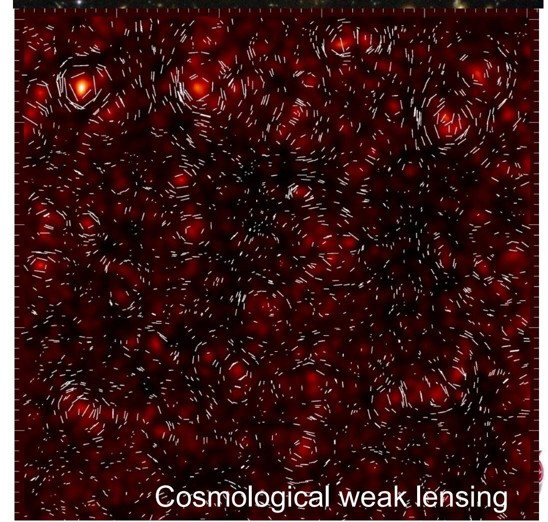
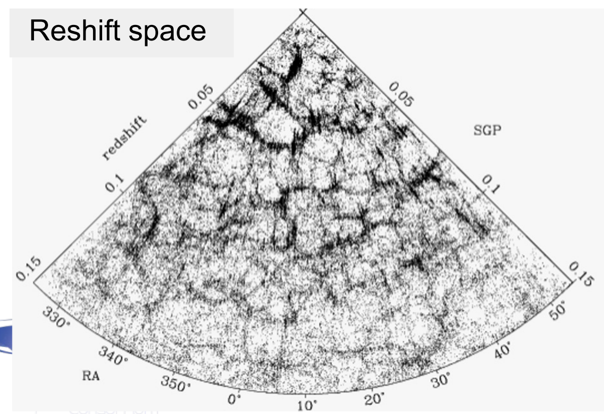
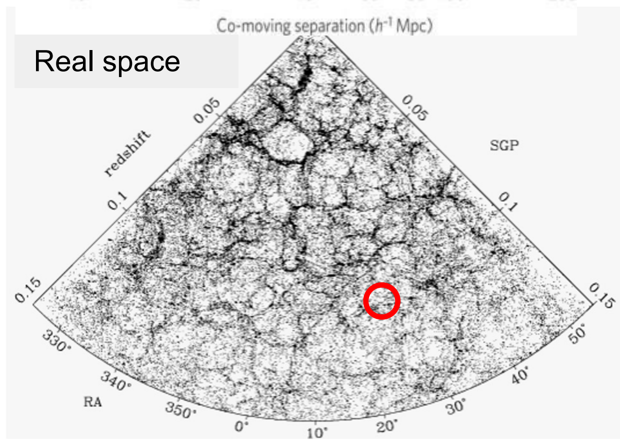
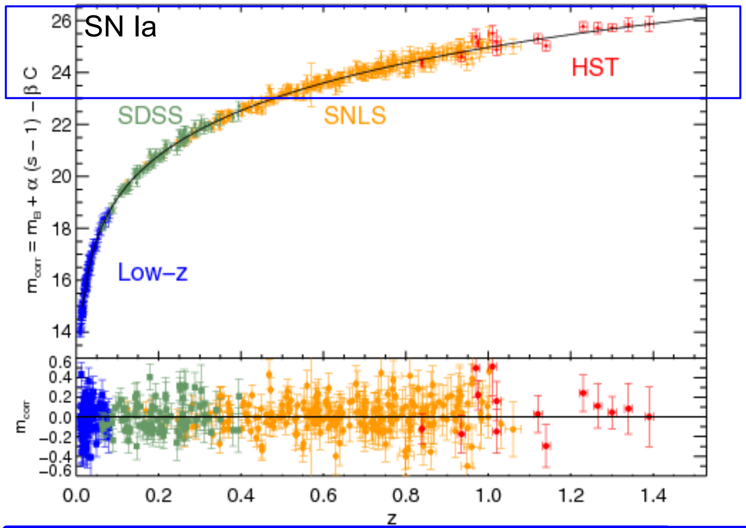
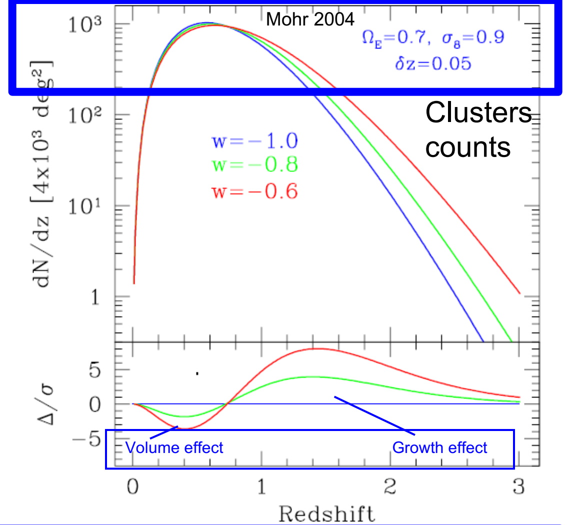


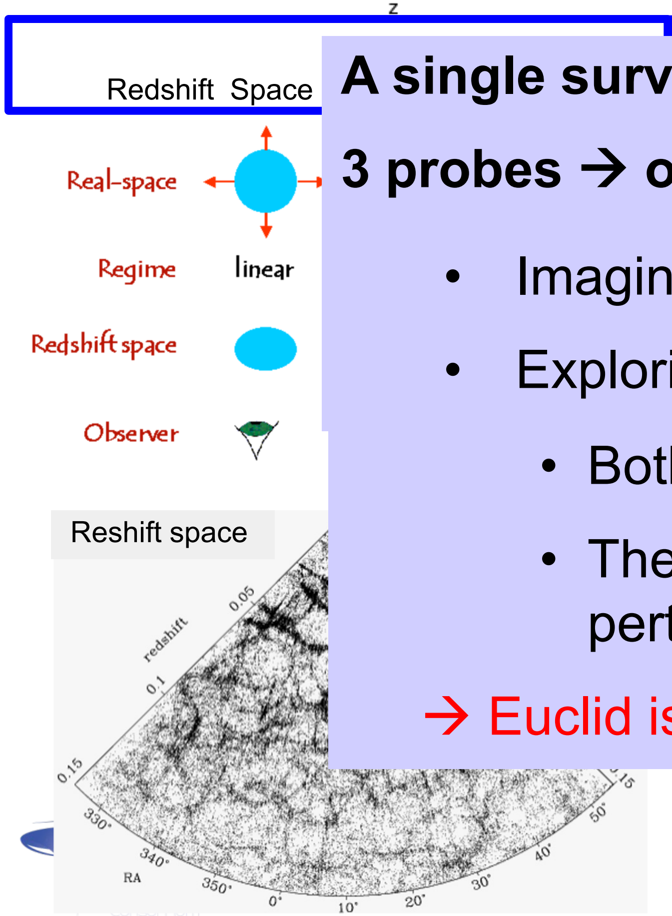


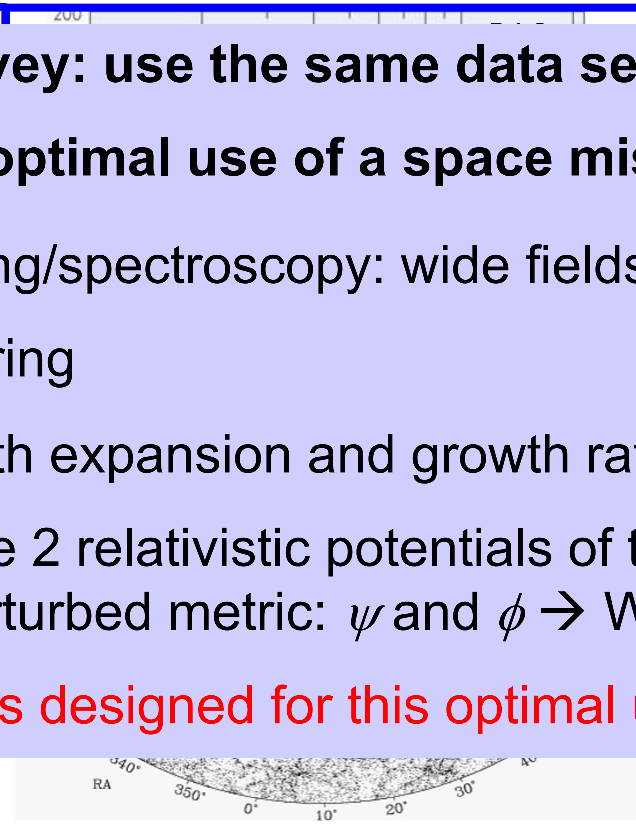


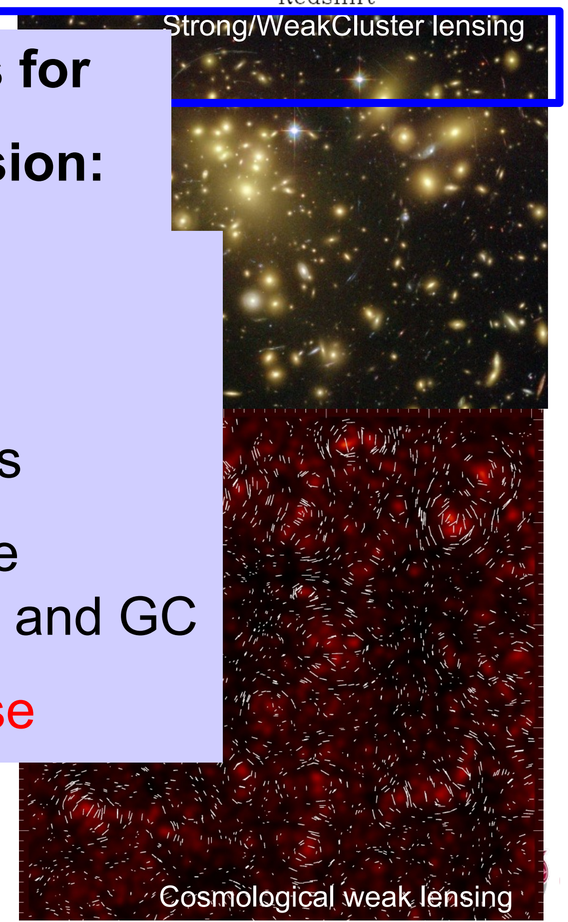
Euclid probes of Dark Energy











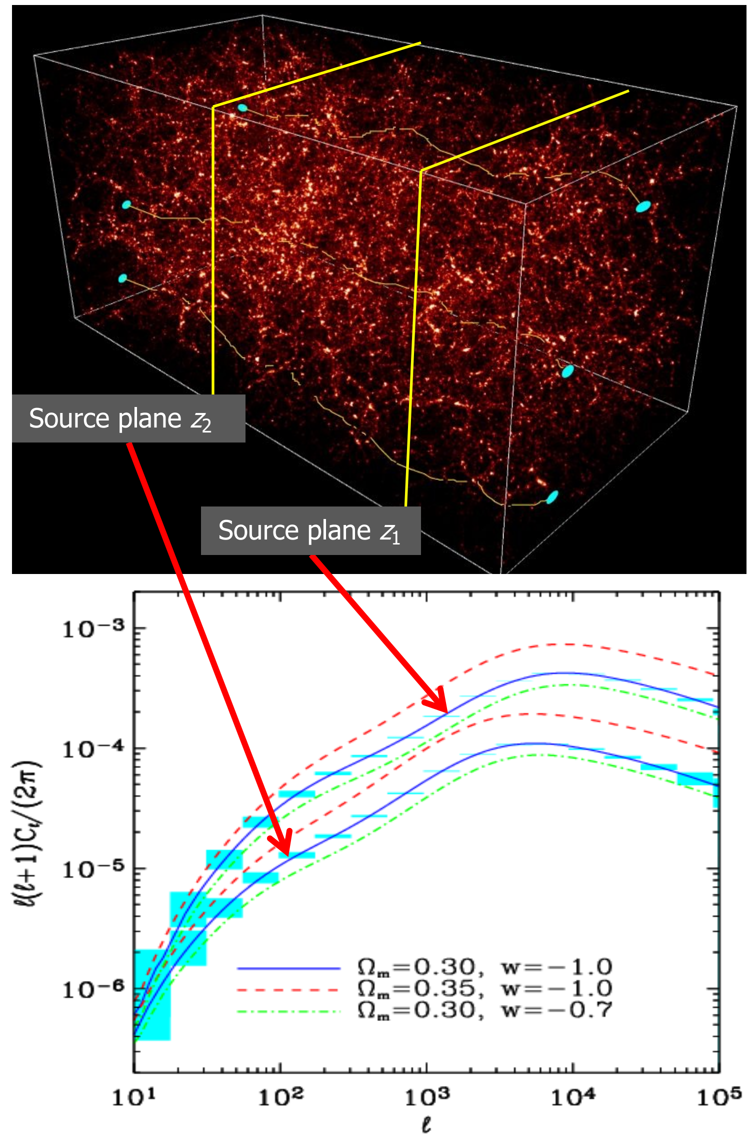
A single survey: use the same data sets for 3 probes → optimal use of a space mission:

- Imaging/spectroscopy: wide fields
- Exploring
  - Both expansion and growth rates
  - The 2 relativistic potentials of the perturbed metric: ψ and ϕ → WL and GC

→ Euclid is designed for this optimal use

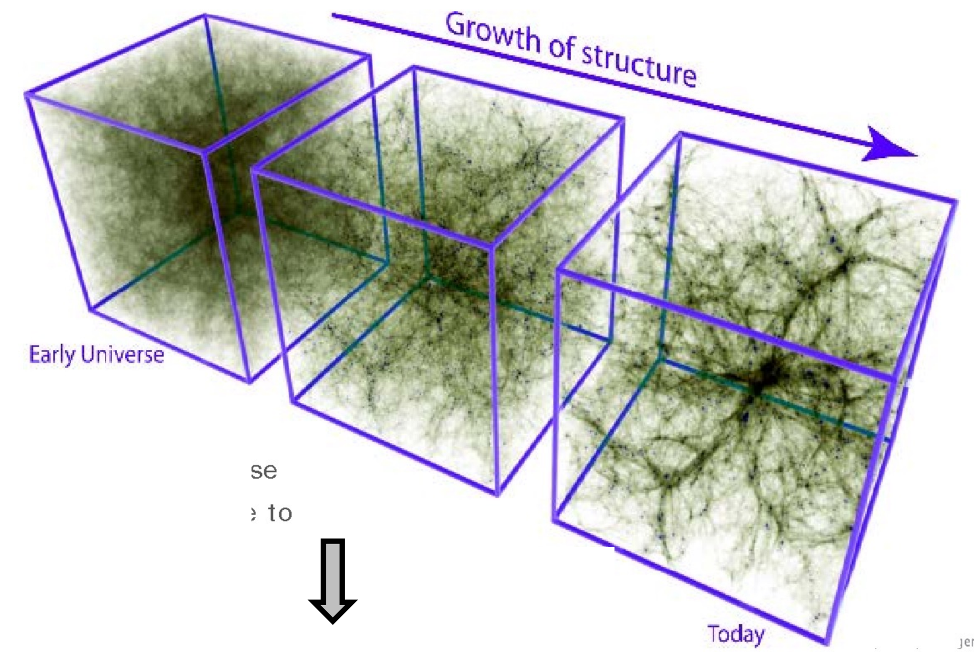
WL probe: Cosmic shear over 0<z<2 :

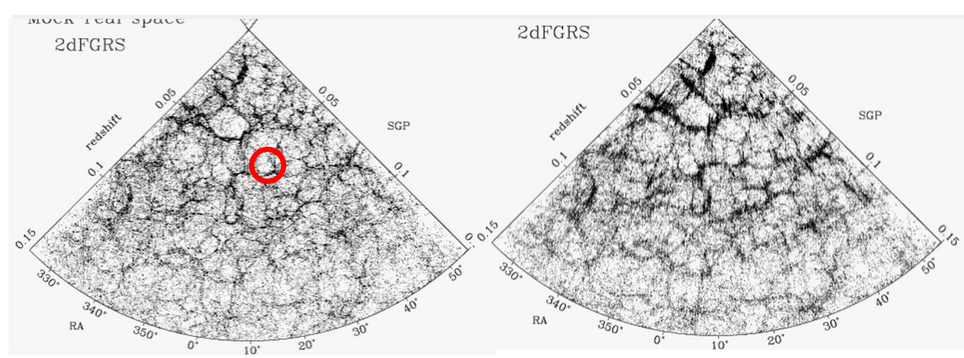
1.5 billion galaxies shapes, shear and phot-z (u,g,r,i,z, Y,J,H) with 0.05 (1+z) accuracy over 15,000 deg^2



GC: BAO, RSD probes: 3-D positions of galaxies over 0.9<z<1.8 :

35 million spectroscopic redshifts with 0.001 (1+z) accuracy over 15,000 deg^2



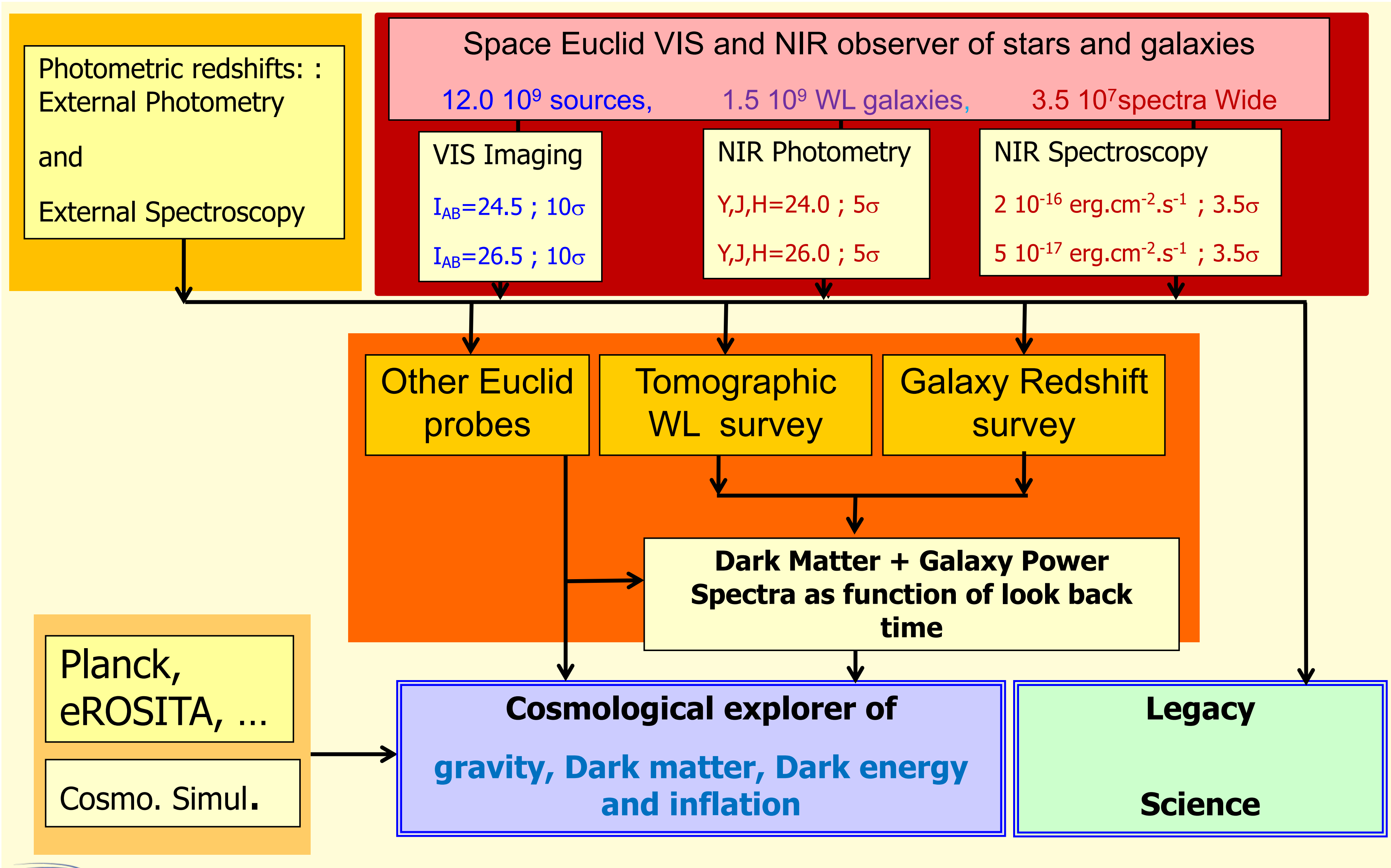


Euclid Wide+Deep Surveys

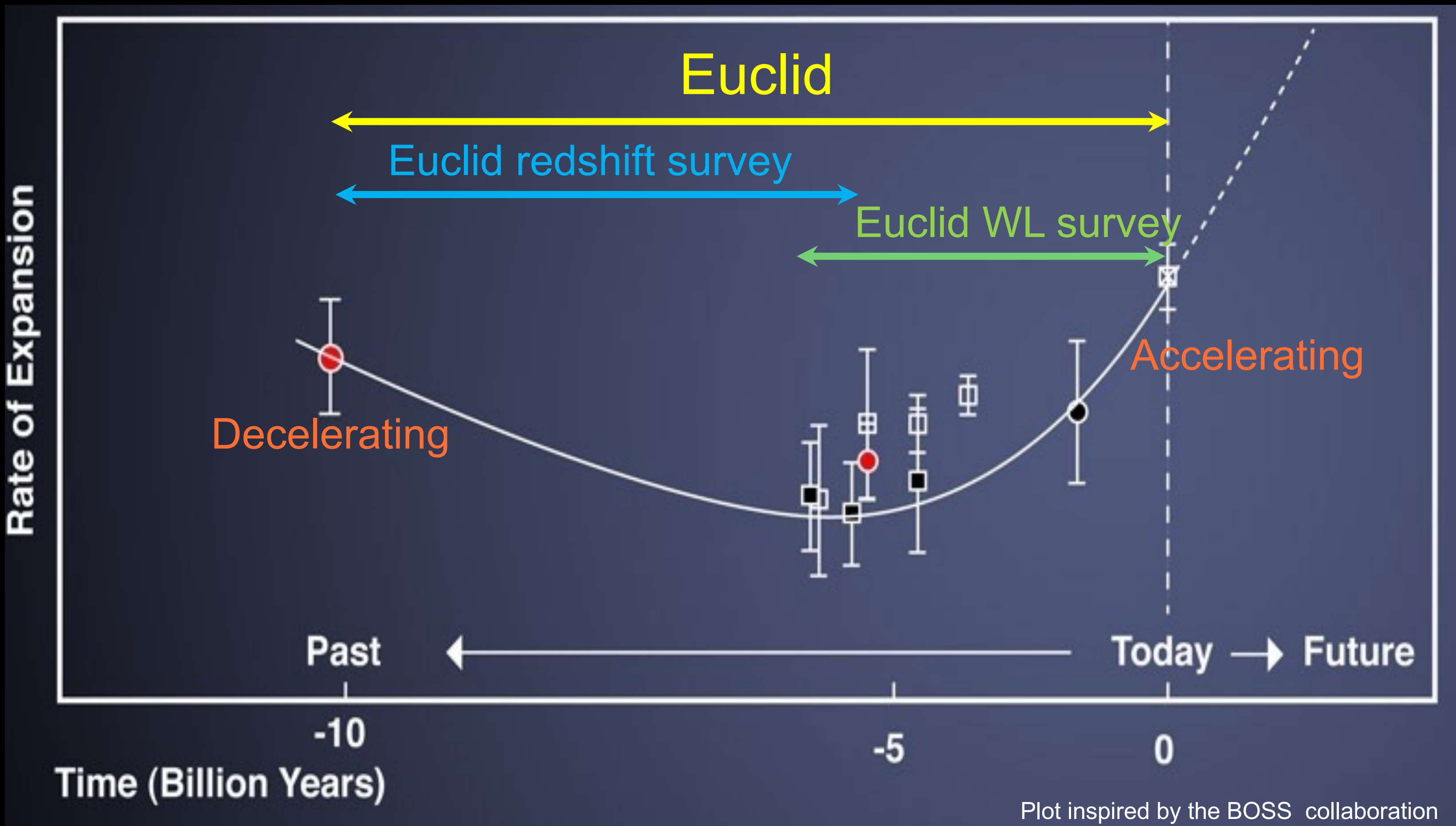
- **Euclid Wide:**
  - 15000 deg^2 : avoid the galactic and ecliptic planes
  - 12 billion sources (3-σ)
  - 1.5 billion galaxies (30 gal/$arcmin^2$) with
    - Very accurate morphometric information (WL)
    - Visible photometry: (u), g, r, i, z , (R+I+Z) AB=24.5, 10.0 σ +
    - NIR photom: Y, J, H AB = 24.0, 5.0σ
    - Photo-z with 0.05(1+z) accuracy
  - 35 million spectroscopic redshifts of emission line galaxies with
    - R: 260
    - 0.001 z accuracy
    - Hα galaxies within 0.9 < z < 1.85
    - Flux line: 2 . 10^{-16} $erg.cm^{-2}.s^{-1}$; 3.5σ

- **Euclid Deep:**
  - 1x20 deg^2 North Ecliptic pole (EDF-N) + 1x20 deg^2 South Ecliptic pole (EDF-S1 + 1x10 deg^2 at CDFS (EDF-S2)
  - 10 million sources (3-σ)
  - 1.5 million galaxies with
    - Very accurate morphometric information (WL)
    - Visible photometry: (u), g, r, i, z , (R+I+Z) AB=26.5, 10.0 σ +
    - NIR photom: Y, J, H AB = 26.0, 5.0σ
    - Photo-z with 0.05(1+z) accuracy
  - 150 000 spectroscopic redshifts of emission line galaxies with
    - R: 260
    - 0.001 z accuracy
    - Hα galaxies within 0.7 < z < 1.85
    - Flux line: 5 . 10^{-17} $erg.cm^{-2}.s^{-1}$; 3.5σ

Euclid Survey Machine: 15,000 deg^2 + 50 deg^2

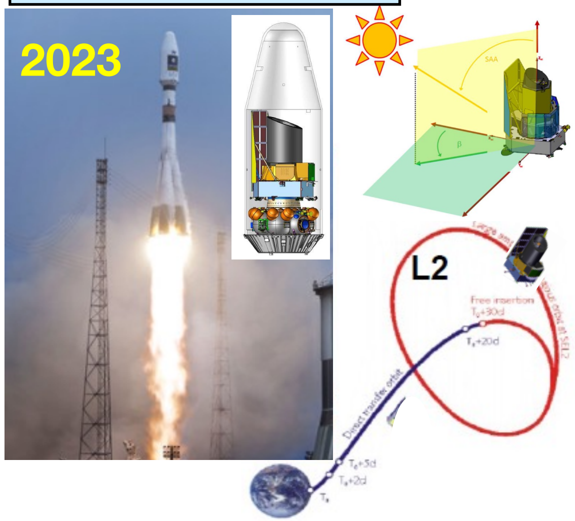


Euclid: exploring the DM-dominated / DE-dominated transition period

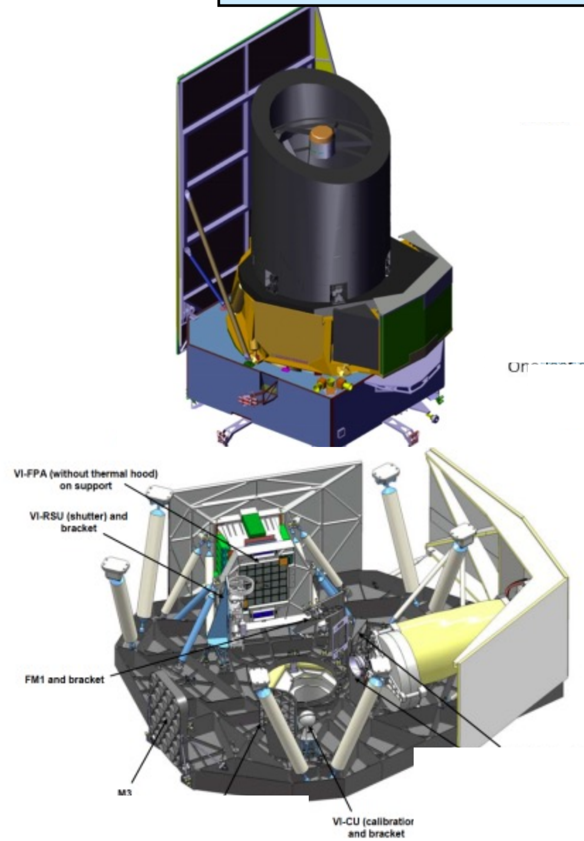


The Euclid mission

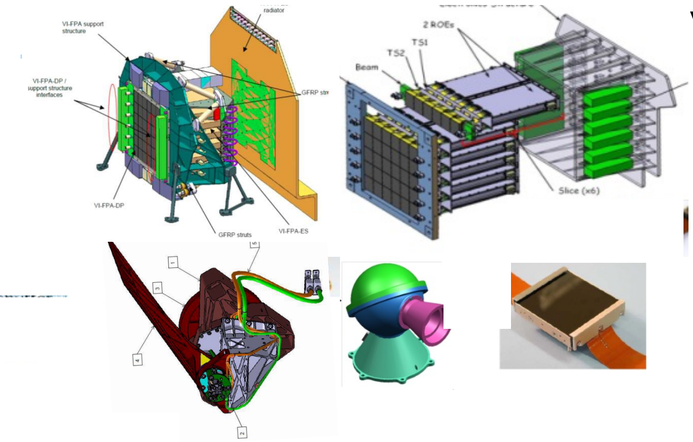
Launch and transfer to L2



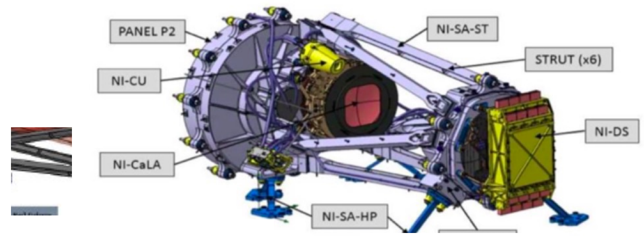
Satellite, Telescope …. and… Instruments



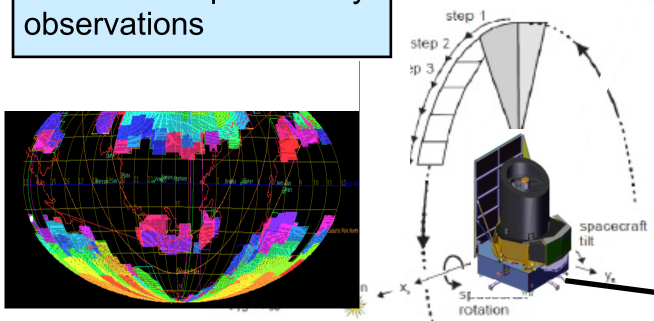
VIS



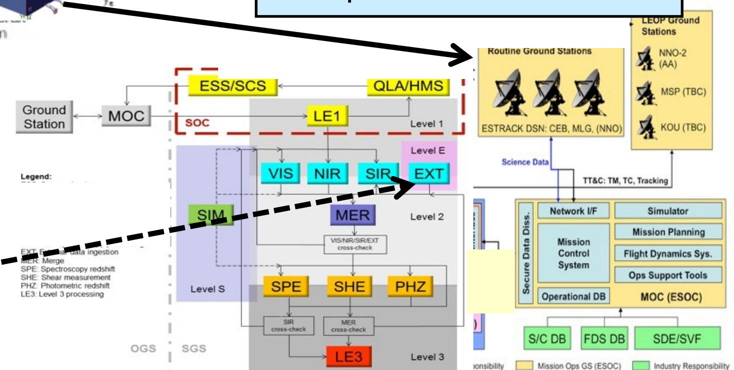
NISP



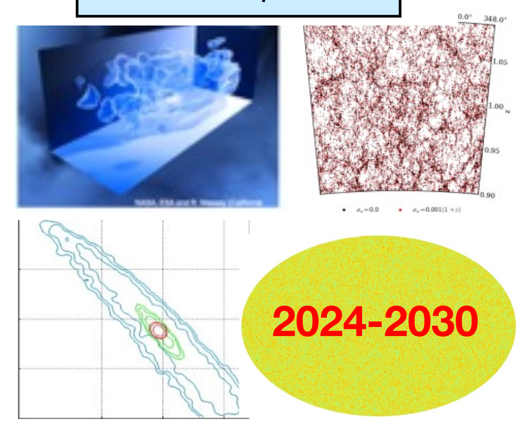
Euclid & complementary observations



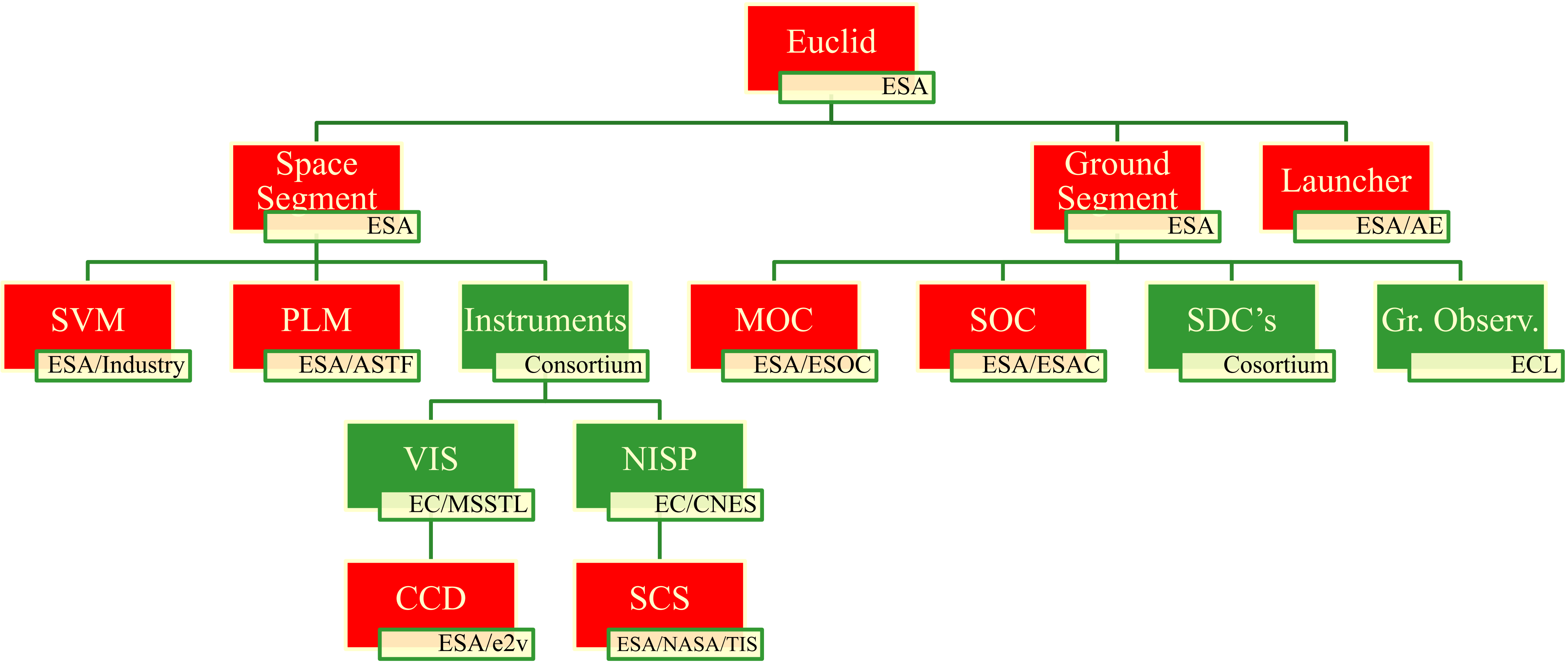
Data production and archive



Scientific exploitation

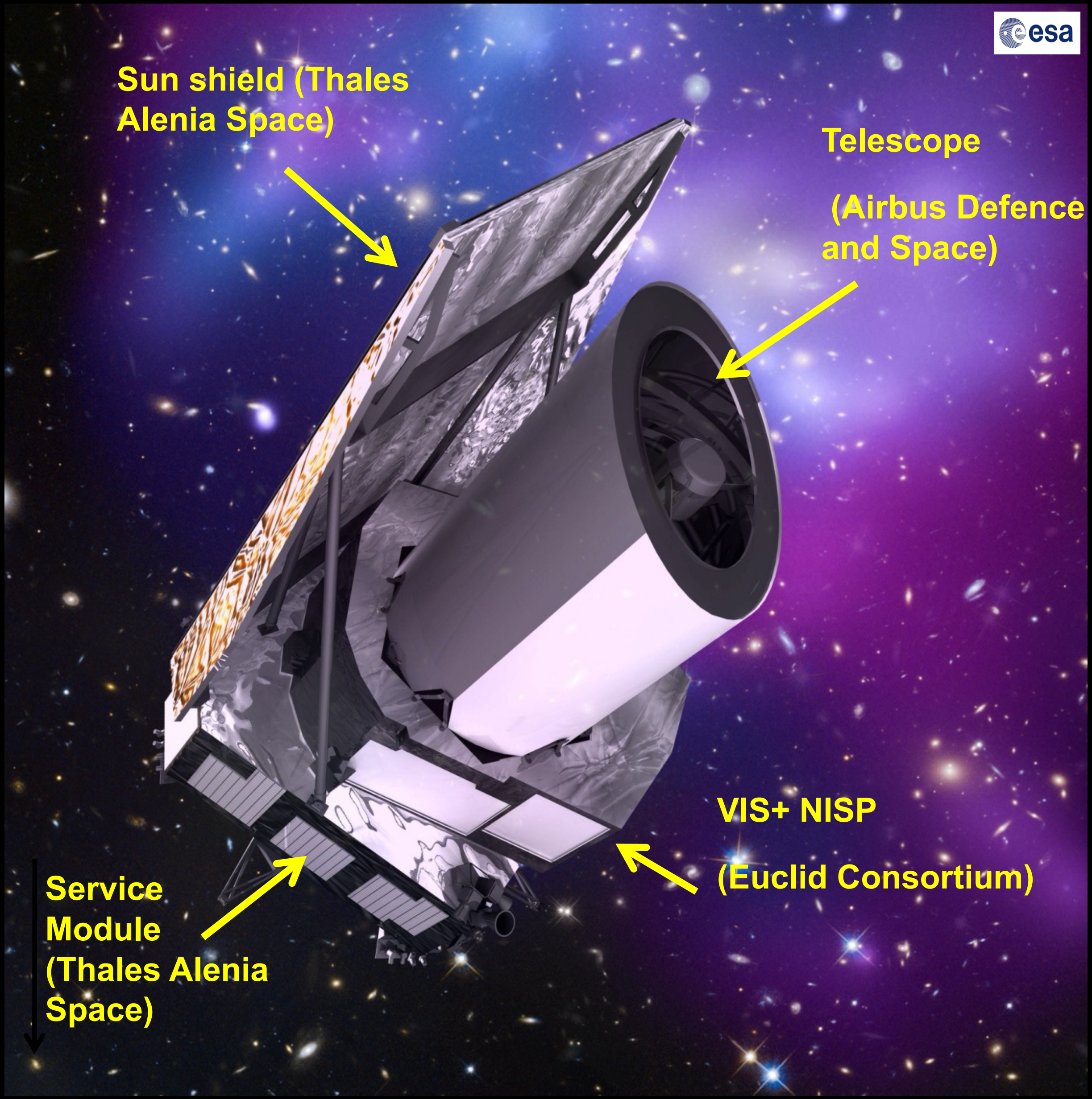


ESA product tree

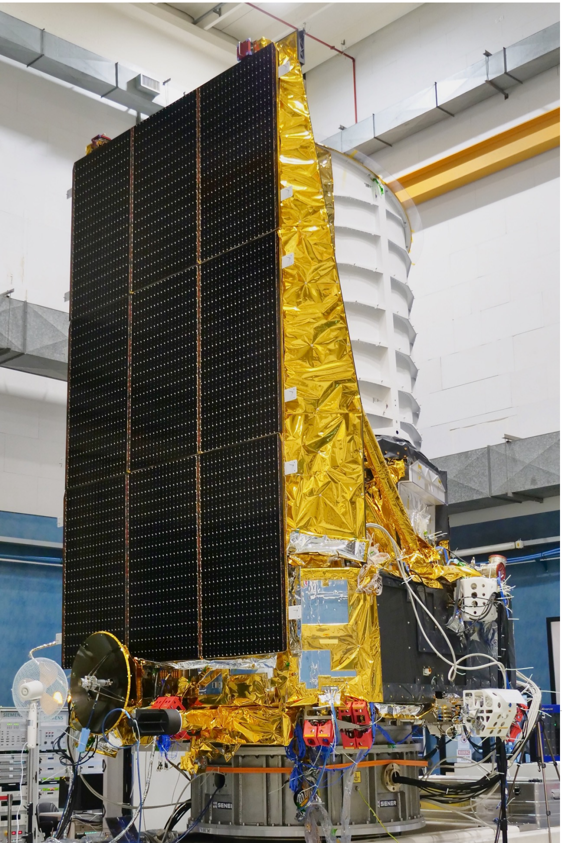


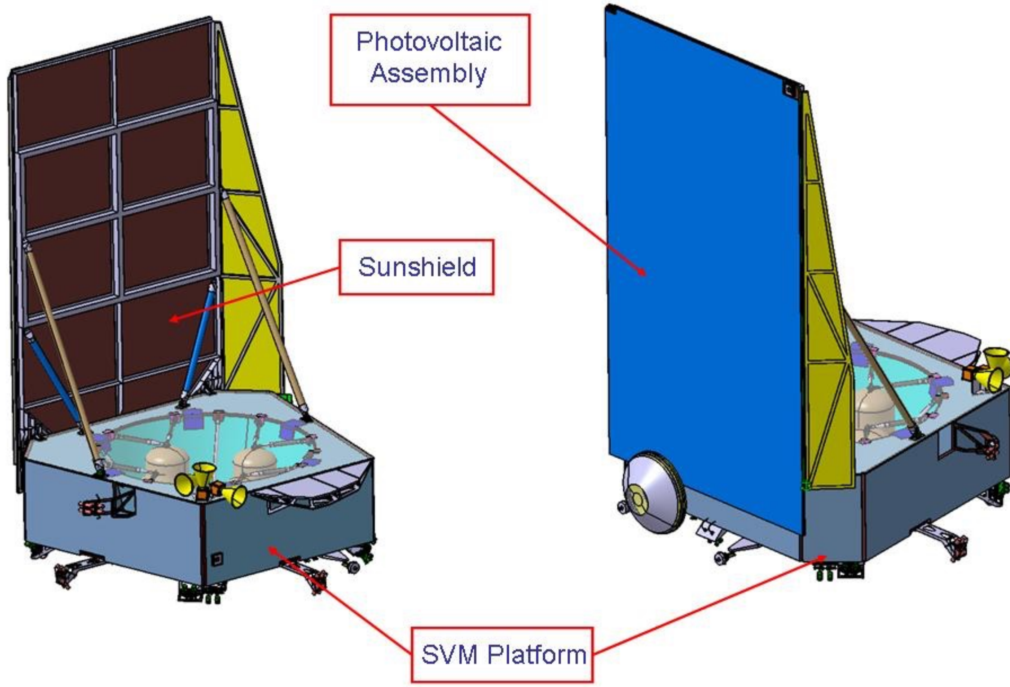
ESA Euclid mission:

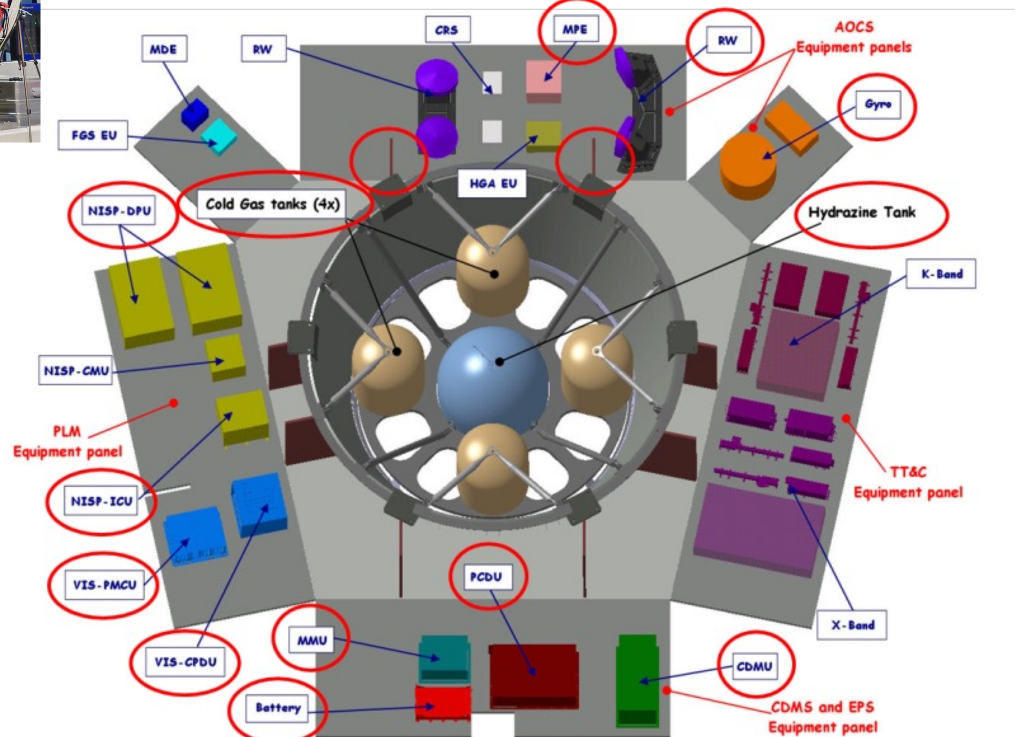
- \- Total mass satellite :
- 2 200 kg
- \- Dimensions:
- 4,5 m x 3 m
- \- Launch: Q3 2023 by a SpaceX/Falcon9 rocket from Cape Canaveral
- Euclid placed in L2
- \- Survey: 6 years



Euclid satellite elements



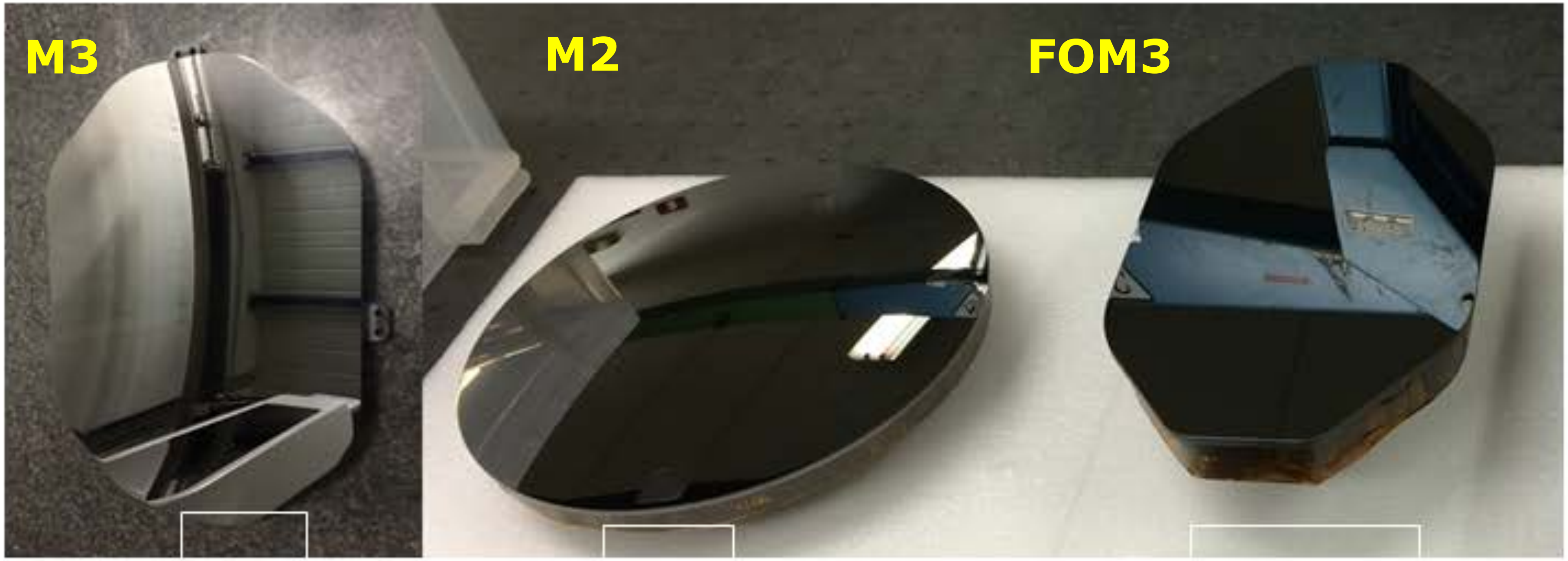


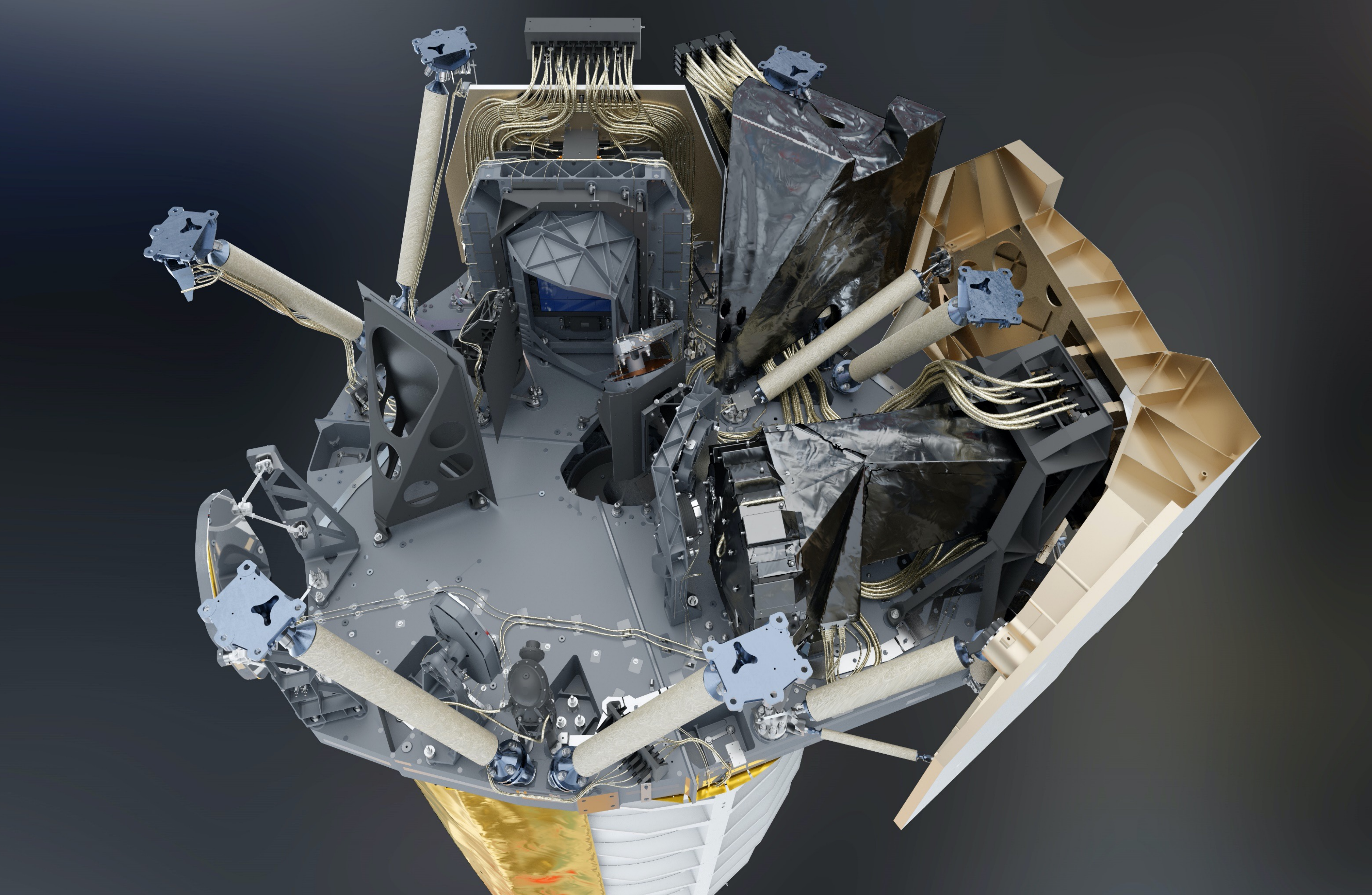


S/C QR done 2021

PLM SVM mating done 2022

Euclid Spacecraft Flight Hardware






ERAL FRAME
BASSY COG
euclid

PLM, scientific instruments

From Thales Alenia Italy, Airbus DS, ESA Project office, Euclid Consortium

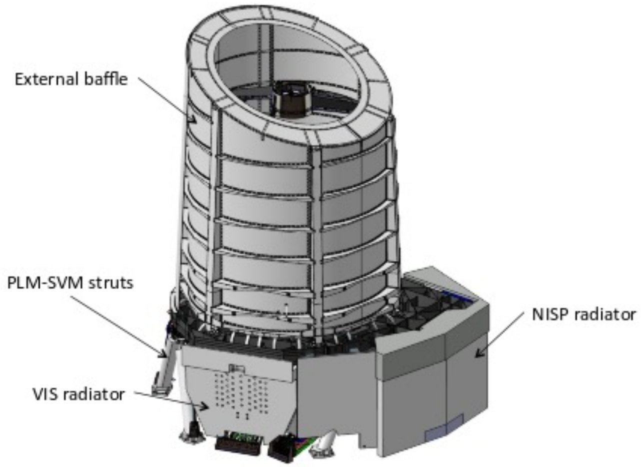
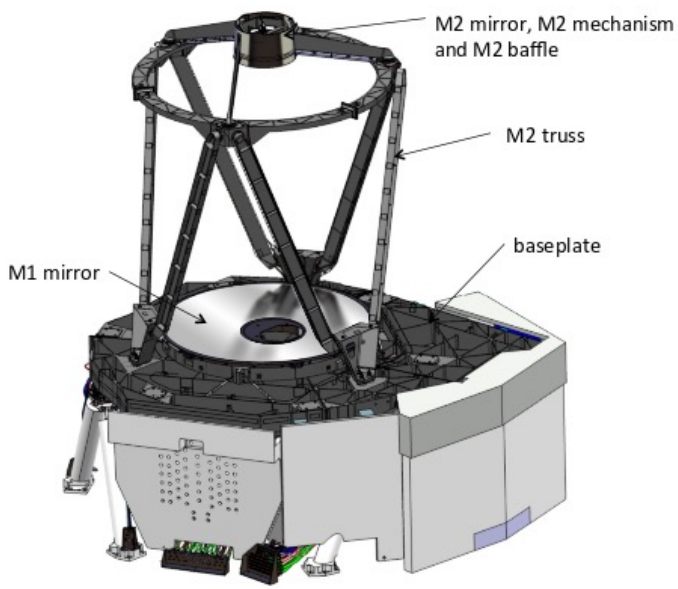
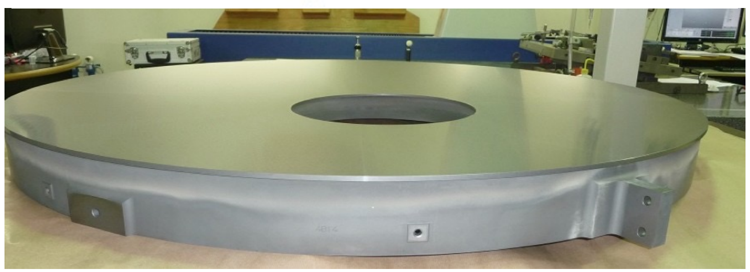
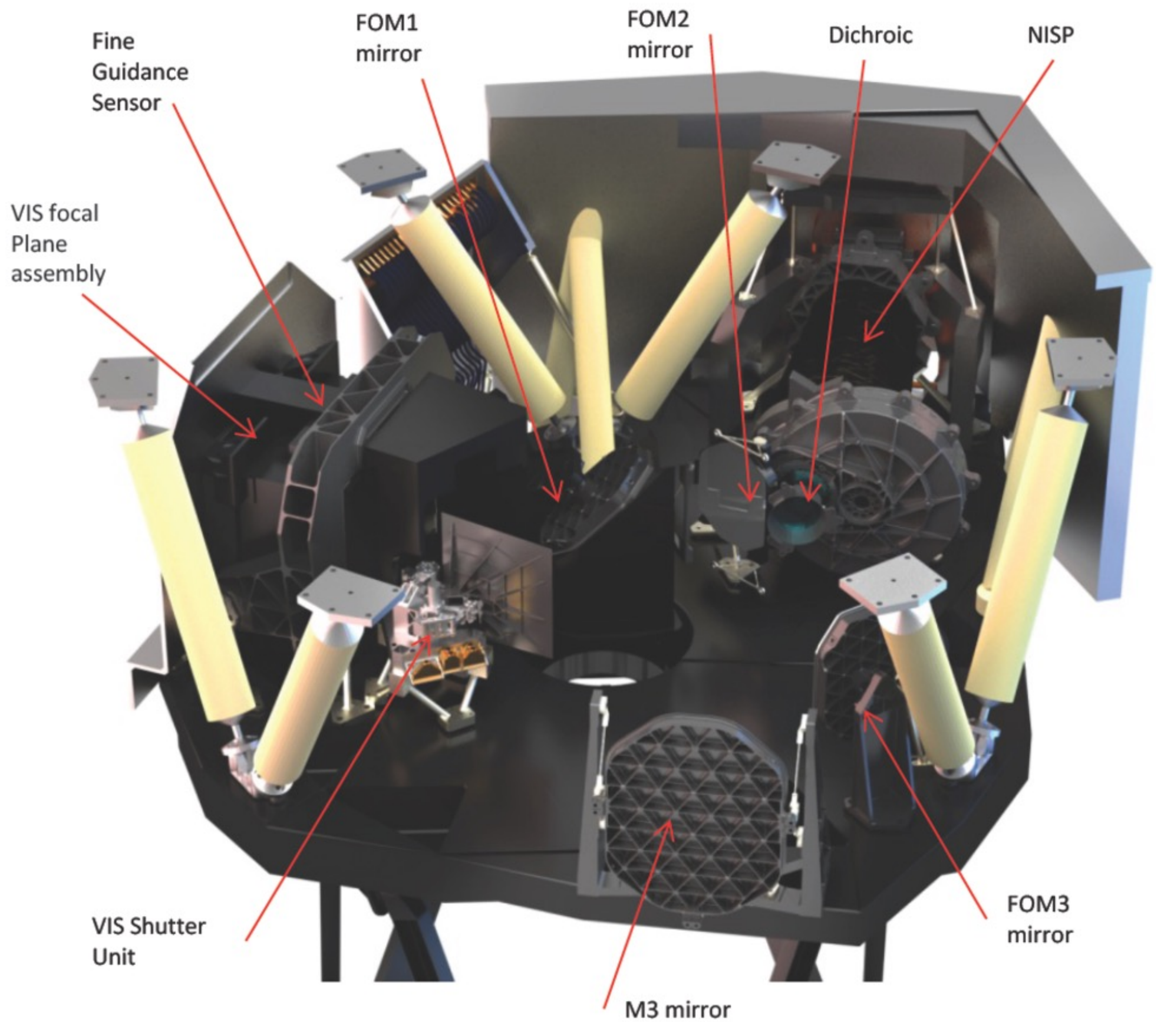


Figure 3-7 External front view of the PLM





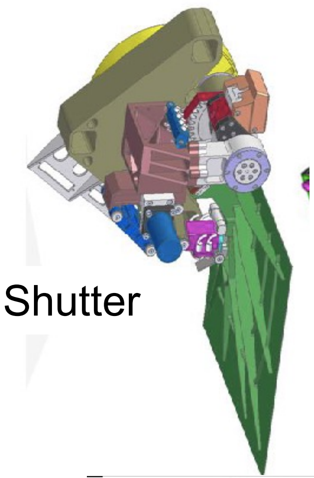


PLM FM e2e tests : May-June 2021

Courtesy: S. Pottinger, M. Cropper and the VIS team

VIS

VIS delivered Mar 2021



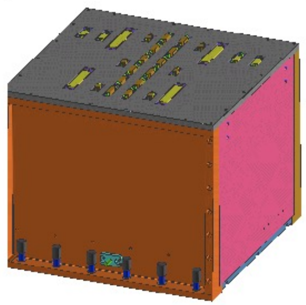
Shutter

Calibration Unit

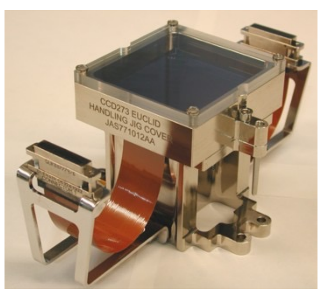
Cropper et al 2016:SPIE

Spectral Band	550 – 900 nm
System Point Spread Function size	≤0.18 arcsec full width half maximum at 800 nm
System PSF ellipticity	≤15% using a quadrupole definition
Field of View	>0.5 deg^2
CCD pixel sampling	0.1 arcsec
Detector cosmetics including cosmic rays	≤3% of bad pixels per exposure
Linearity post calibration	≤0.01%
Distortion post calibration	≤0.005% on a scale of 4 arcmin
Sensitivity	$m_{AB} \geq 24.5$ at 10σ in 3 exposures for galaxy size 0.3 arcsec
Straylight	≤20% of the Zodiacal light background at Ecliptic Poles
Shear systematic bias allocation	additive $\sigma_{sys} \leq 2 \times 10^{-4}$; multiplicative $\leq 2 \times 10^{-3}$

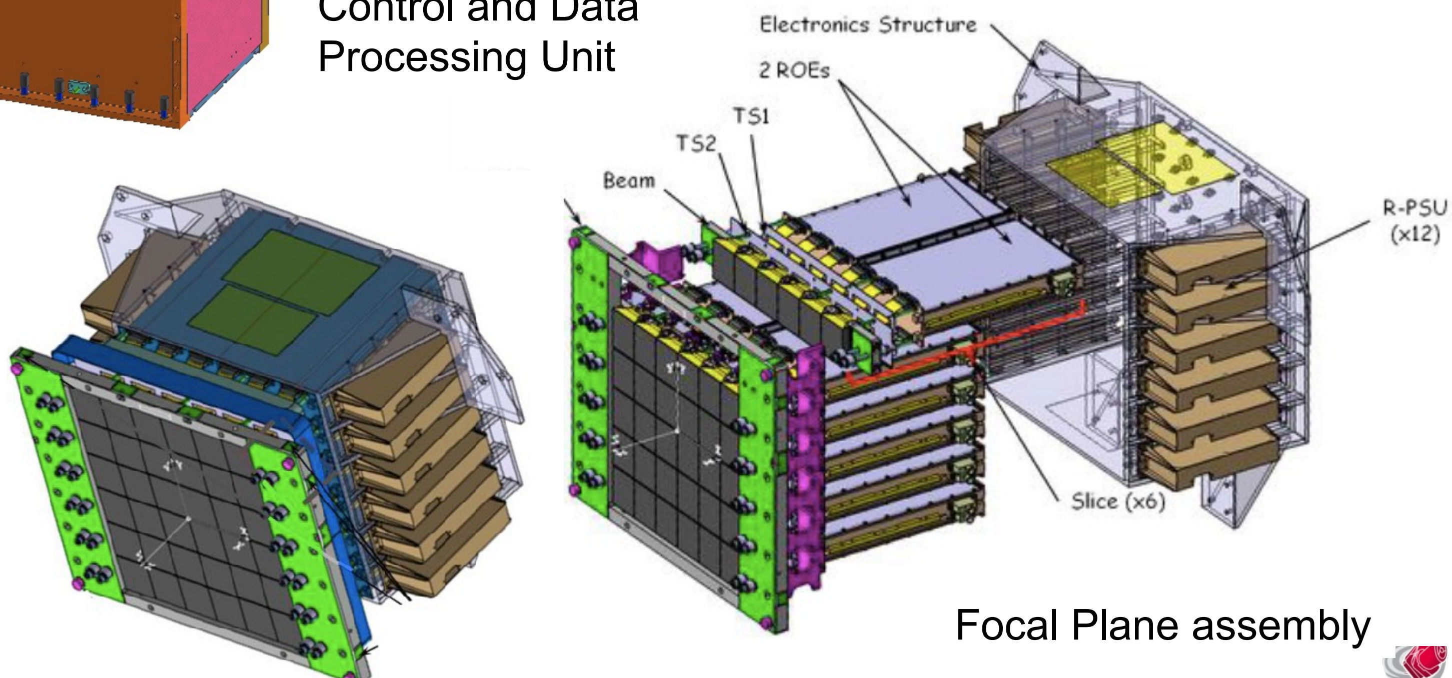
Power and Mechanism Control Unit



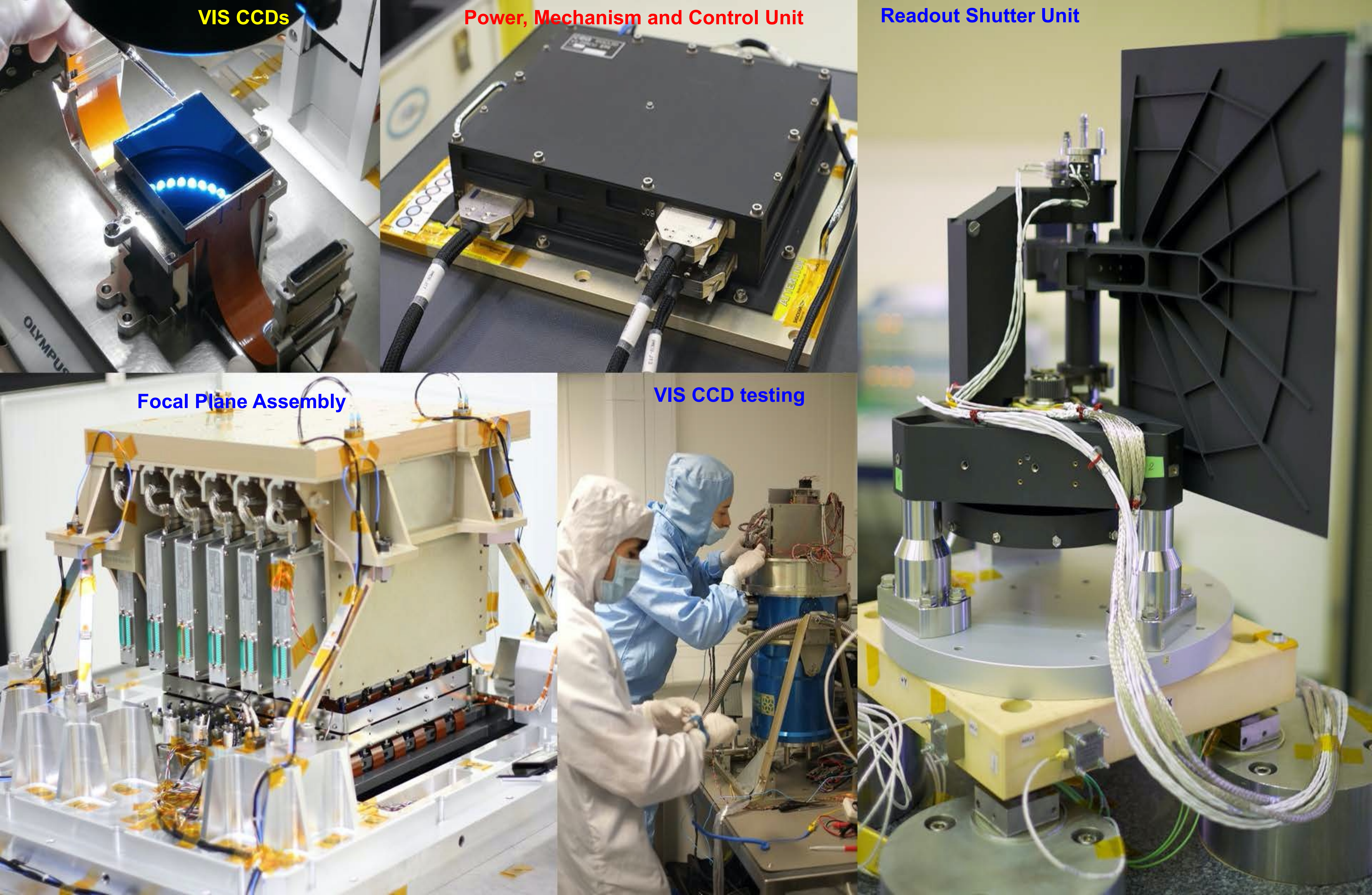
Control and Data Processing Unit

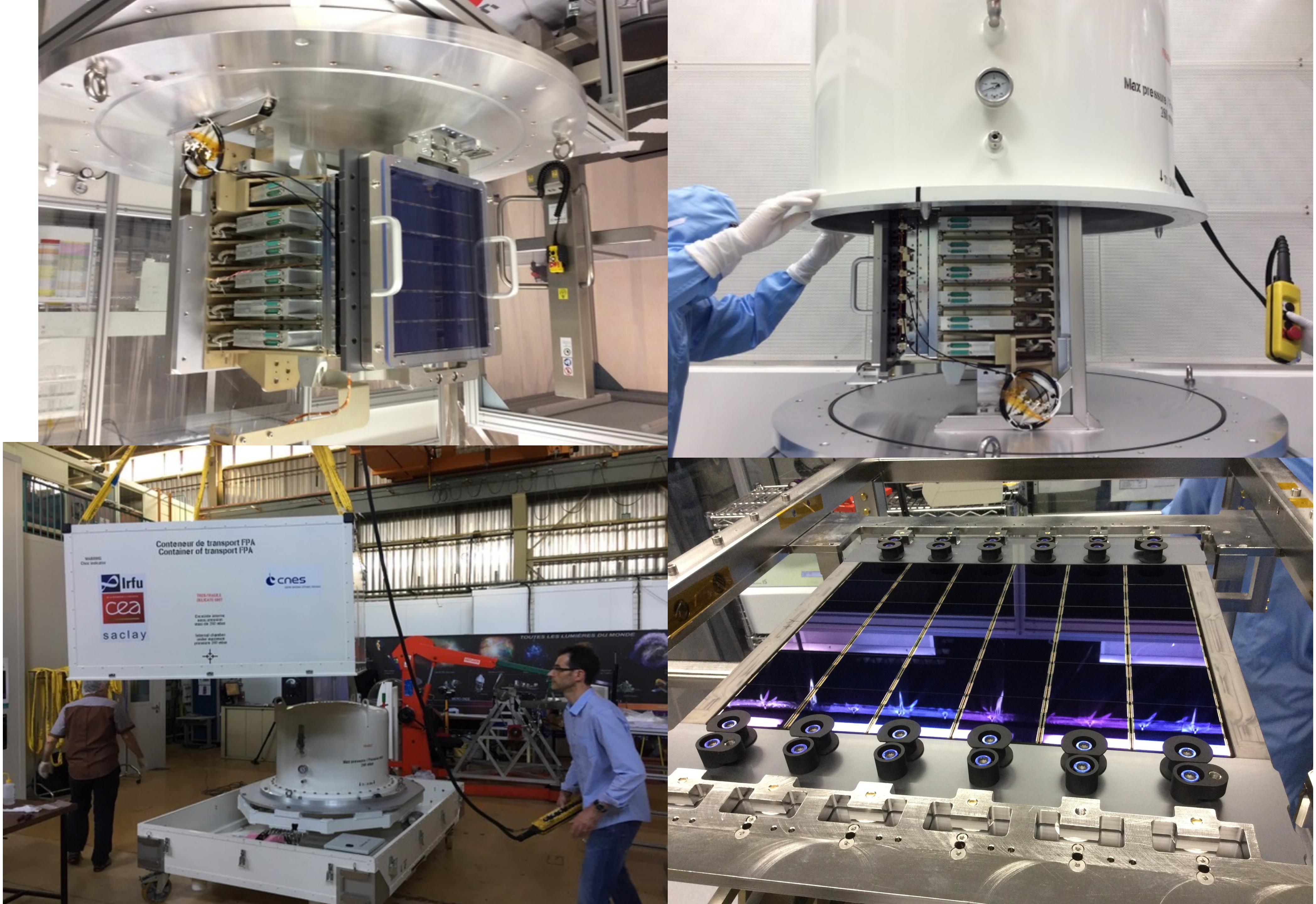


CCD



Focal Plane assembly

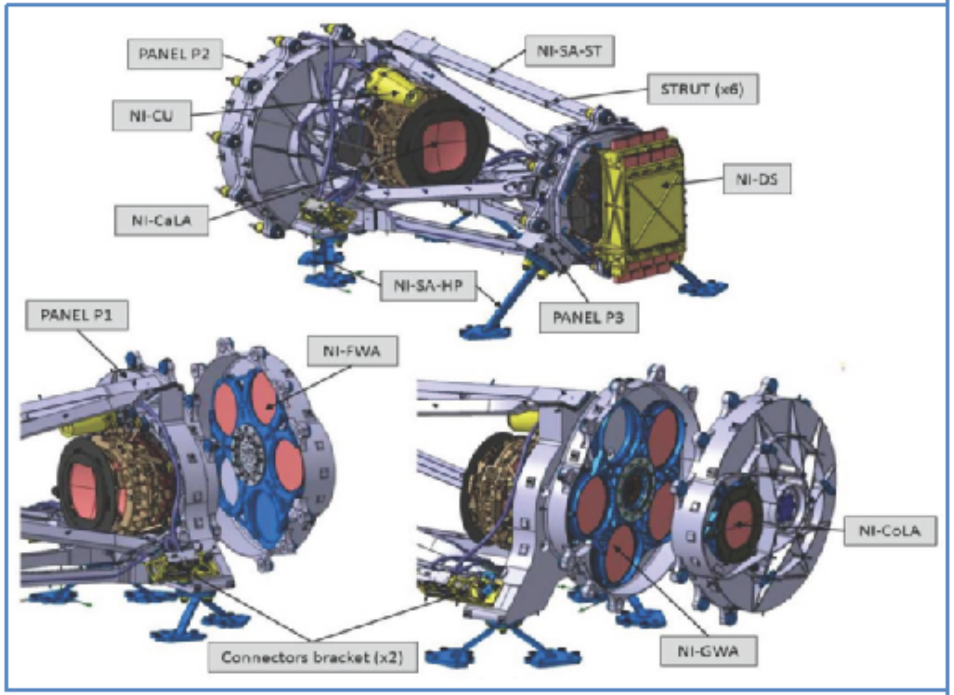

VIS CCDs
Power, Mechanism and Control Unit
Readout Shutter Unit
Focal Plane Assembly
VIS CCD testing

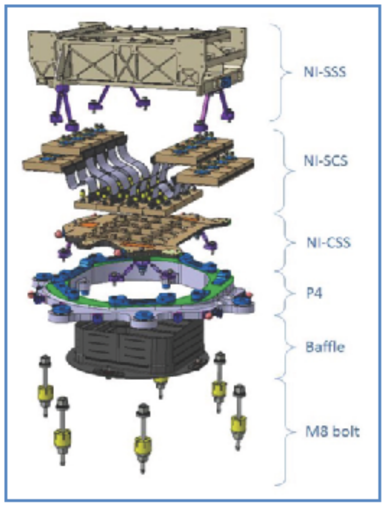

Conteneur de transport FPA
Container of transport FPA
Irfu
cea
saclay
cnes

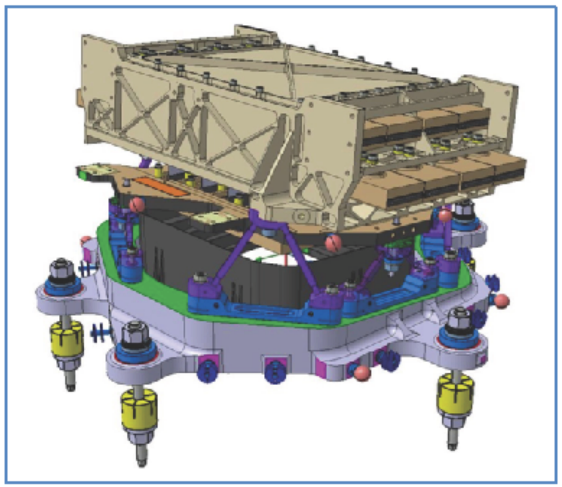
NISP

NISP delivered April 2021

Courtesy: T. Maciaszek and the NISP team



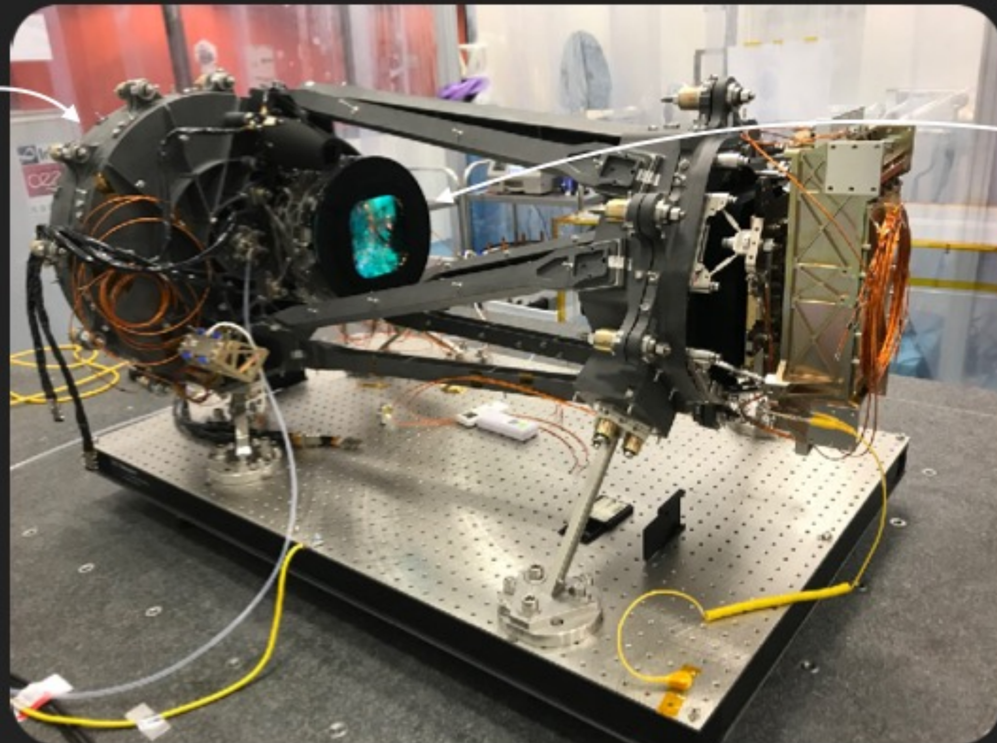




- FoV: 0.55 deg^2
- Mass : 159 kg
- Telemetry: < 290 Gbt/day
- Size: 1m x 0.5 m x 0.5 m
- 16 2kx2K H2GR detectors
- 0.3 arcsec pixel on sky
- Limiting mag, wide survey AB : 24 (5 σ)
- **3 Filters**:
- Y (950-1192nm)
- J (1192, 1544nm)
- H (1544, 2000nm)
- **4 grisms**:
- 1B (920 – 1300) , 1 orientation 0°
- 3R (1250 – 1850), 3 orientations 0° , 270° , 180°

Overview of the NISP instrument

CoLA (Corrector lens Assembly)



CaLA (Camera lens Assembly)

GWA (Grism Wheel Assembly)

Slitless Spectrometer:

RGS	0°, 180°, 270°	1250-1850 nm
BGS	0°	920-1250 nm

Photometer:

FW-Y	950 - 1192 nm
FW-J	1192 - 1544 nm
FW-H	1544 - 2000 nm

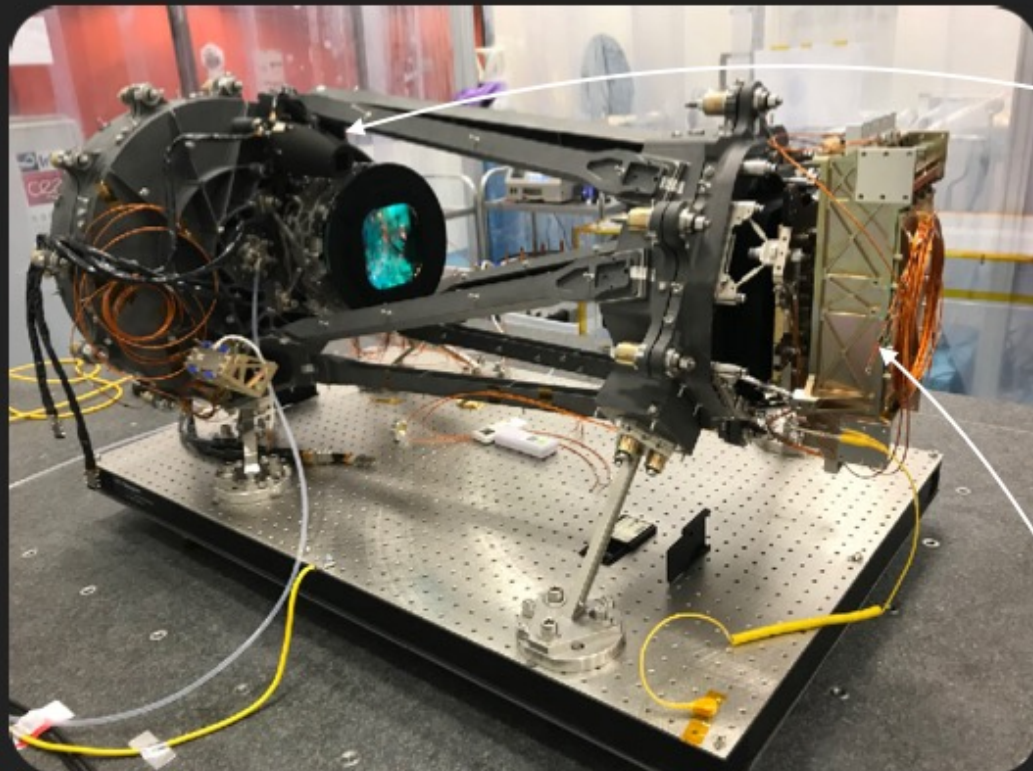
FWA (Filter Wheel Assembly)

Overview of the NISP instrument

Warm electronic

ICU : Instrument Control Unit

DPU : in-flight Data Processing Unit



NI-CU (NISP Calibration Unit)

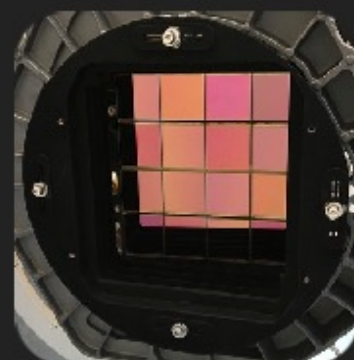
Calibration unit:

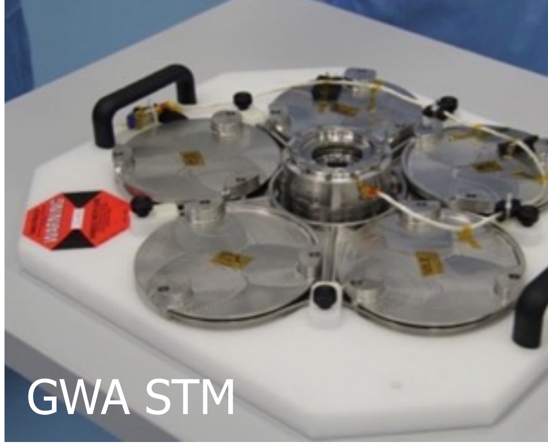
2×5 infrared LEDs (nominal+redundant) for detector flat field and detector calibration

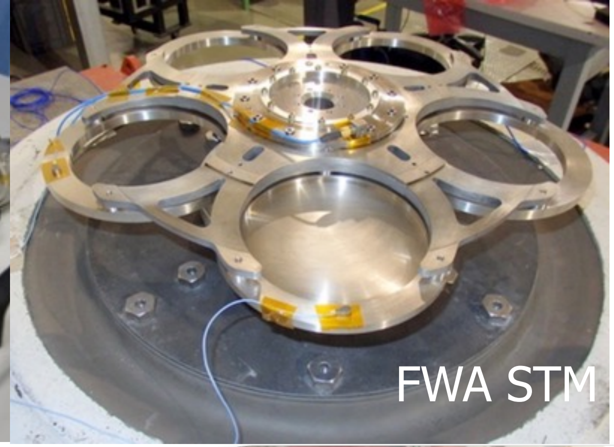
Focal Plane Array:

16 HgCDTe infrared sensor of 2048×2048 pixels

FoV	0.55 deg^2
Pixel scale	0.3″

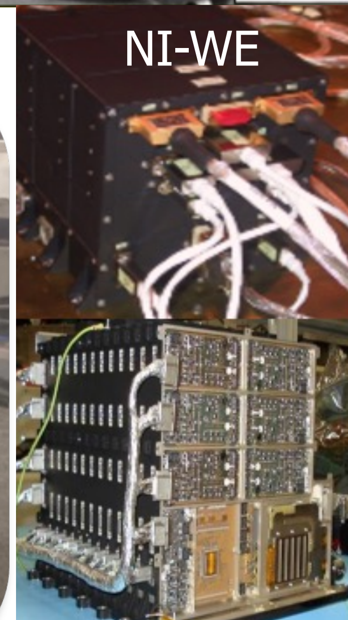


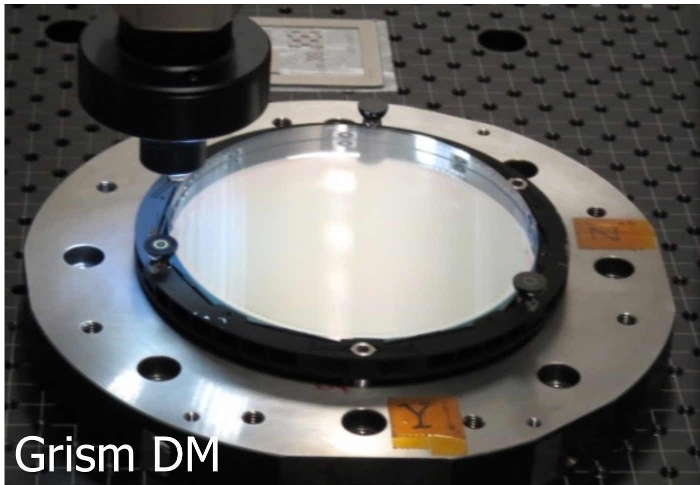


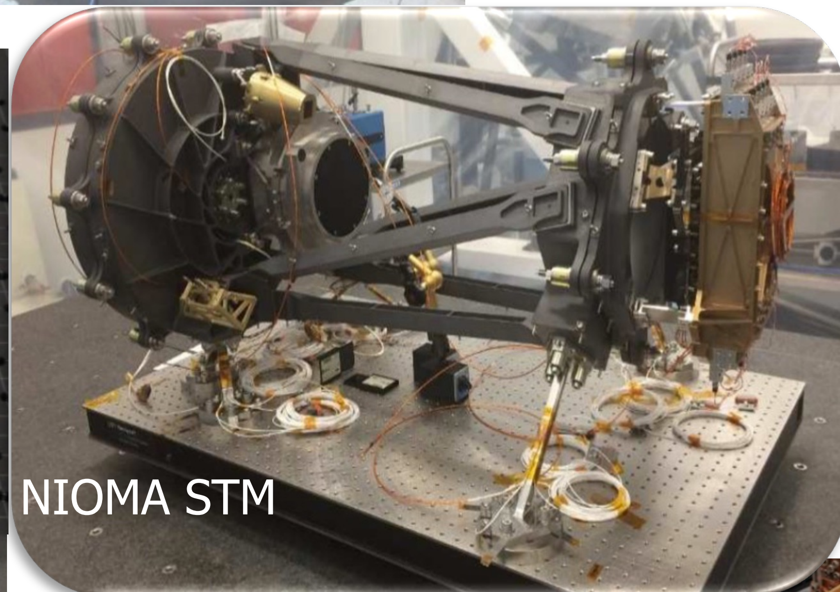


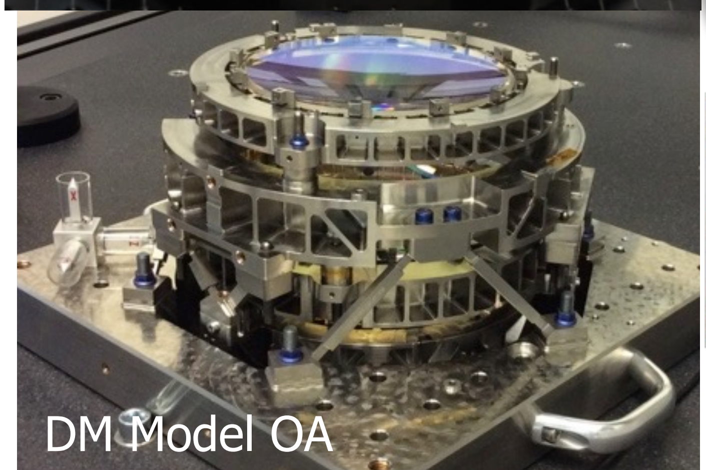
NISP

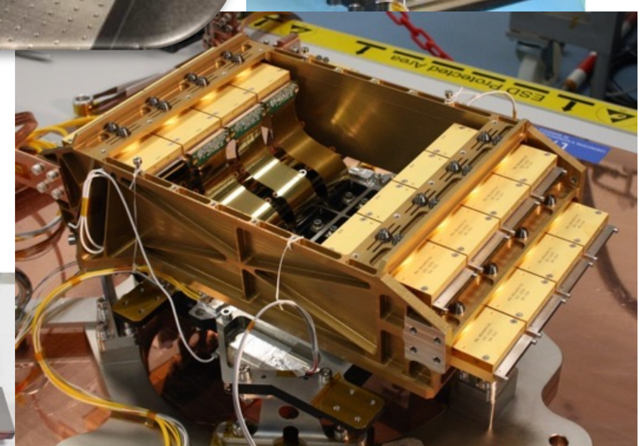
Courtesy::
Euclid
Consortium
NISP team







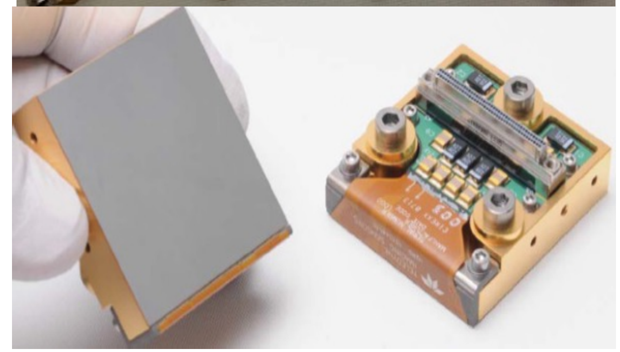


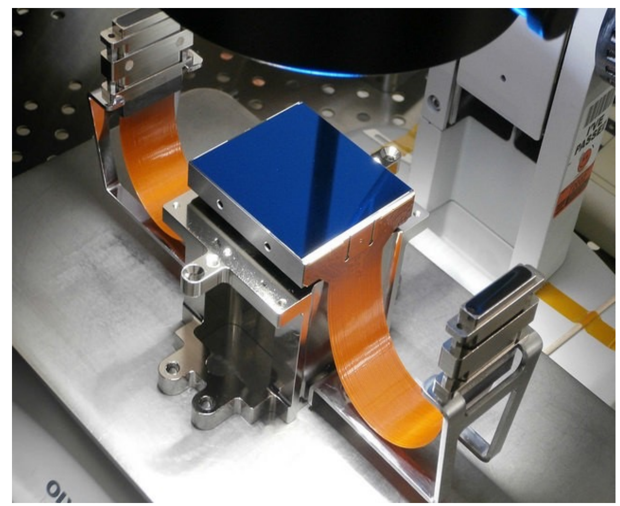


NIR detectors and VIS CCD's

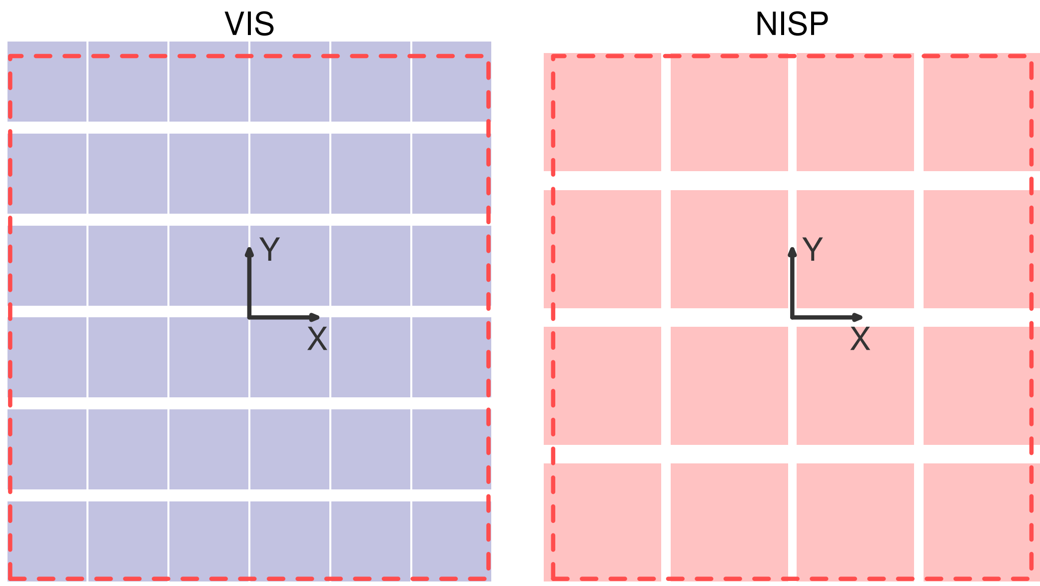
- NIR HgCdTe detectors (Teledyne), 2040X2040 pixels, 18x18 μm, 2.3 μm cut-off, FW=130,000 e-:
- QE ≥ 90% 1 μm to 2.2 μm
- Spectroscopic noise ≤ 7 e- over 560 s
- Photometric noise ≤ 5 e- over 60 s
- Dark current ≤ 0.005 e-/s/px
- Linearity ≤ 0.7% between 6 ke- and 60 ke-

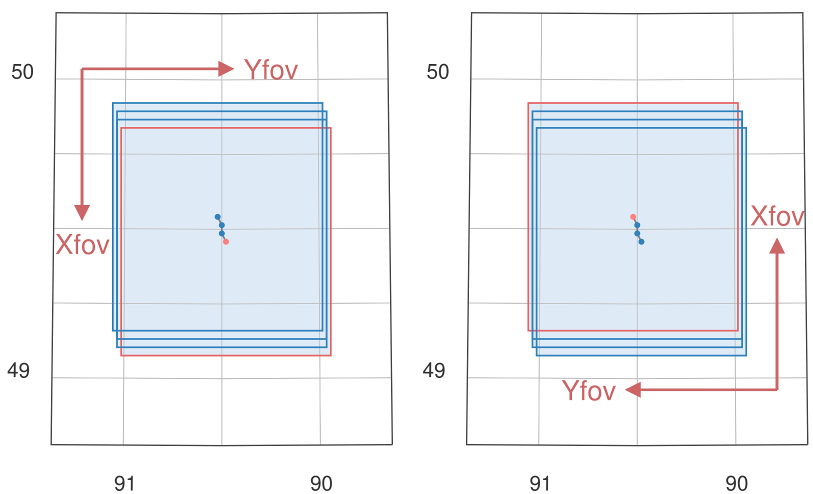
- CCD (e2v), 4096 x 4132 pixels, 12x12 μm FWC=175,000e-
- 4 read-out nodes (in corners)
- SiC package extremely tight flatness
- QE ≥ 70% 500nm to 850nm (95% at 650nm)
- PRNU much better than 2% at all spatial scales
- Noise better than required 3.6 e- at 70 kpix/s

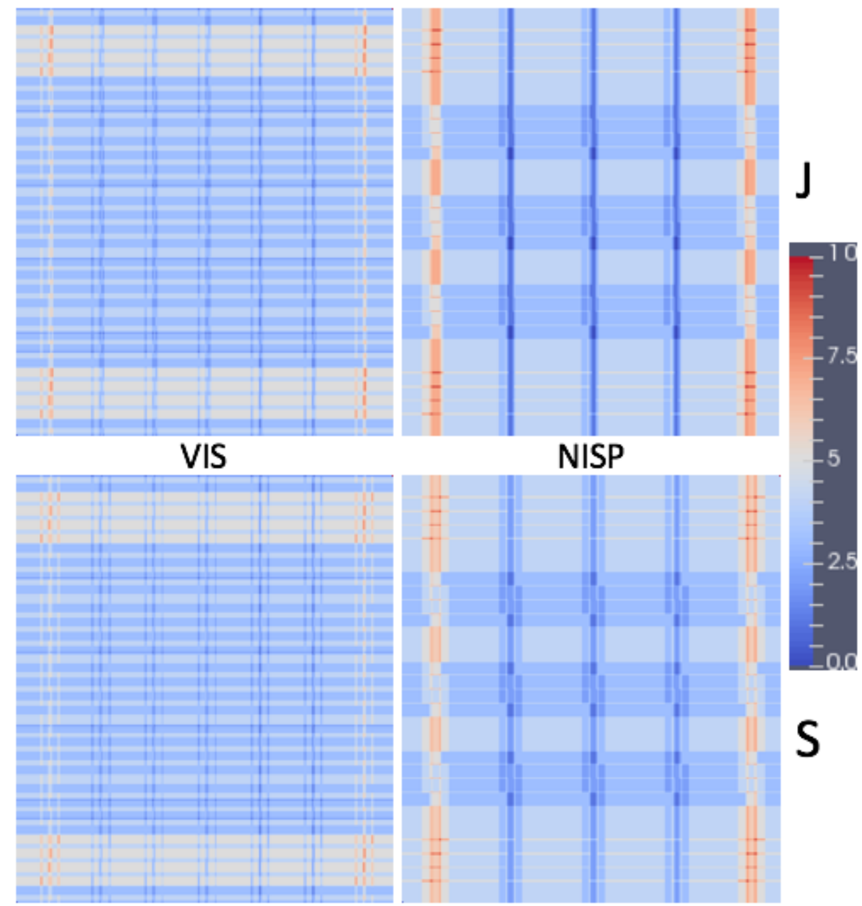




NIR and VIS focal planes & dithers



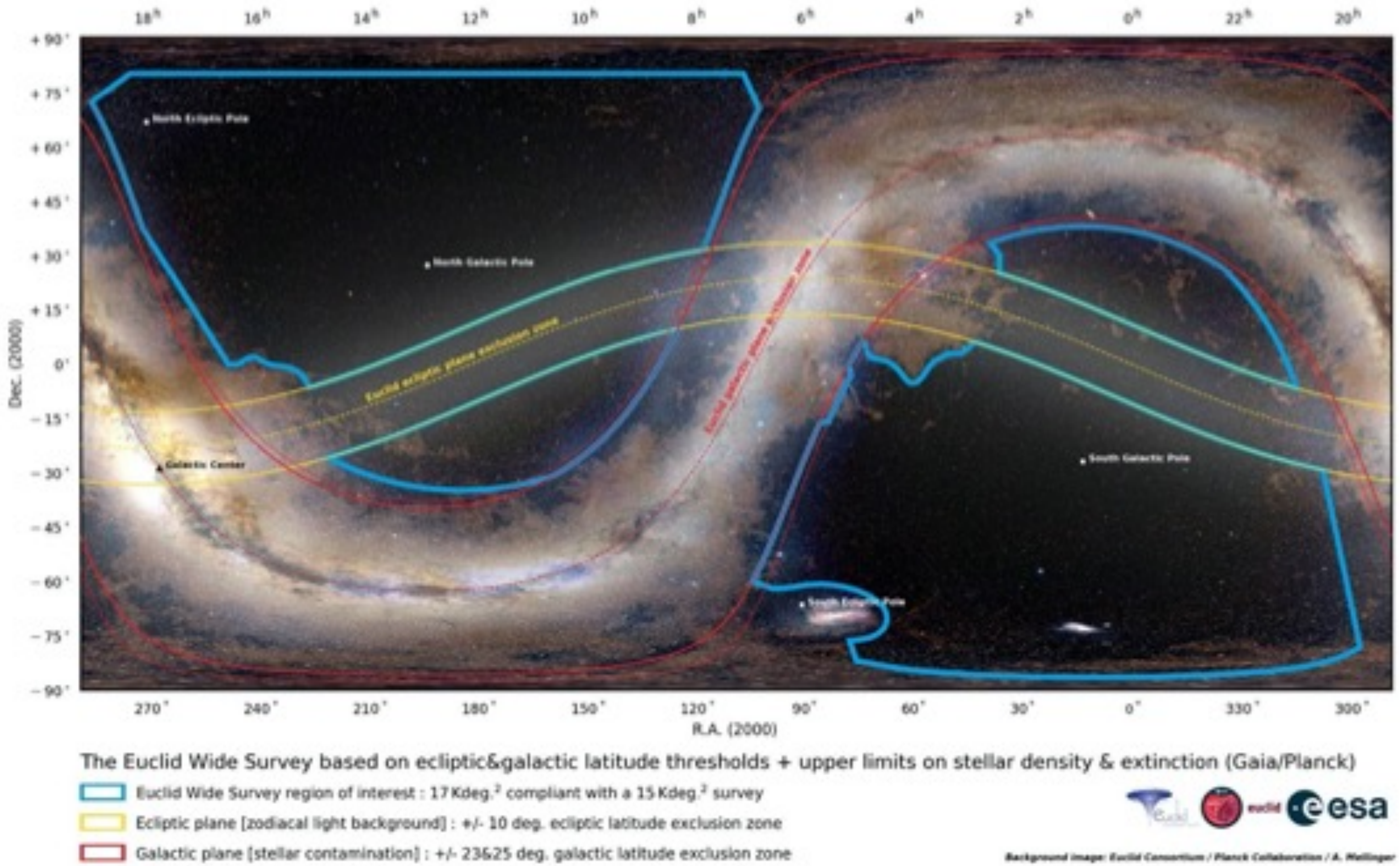




Euclid Survey: Wide and Deep

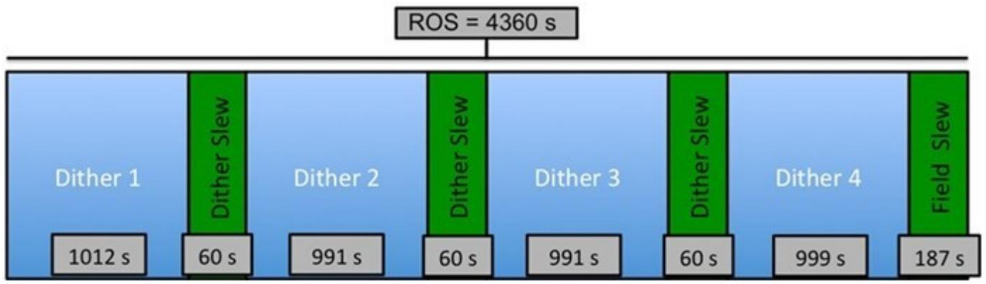
- |b|>30º
- Minimise SAA variations;
- Minimise zodiacal light → high ecliptic latitude;
- Low galactic extinction;
- Specific pointed calibration;
- Wide survey: one visit / field
- Deep survey: many visits

Scaramella et al 2022



Region of interest

The Euclid survey Reference Observation Sequence (ROS)



Unique ROS over the whole wide survey → the depth will vary for VIS and NISP across the RoI

Median depths driven by the Euclid core science

The mission was proposed in 2011 based on a median performance across the RoI out of 3 exposures only (over the 4 dithers) = ~90% of the survey coverage:

- VIS : 24.5 AB at SNR=10 for extended sources (field galaxies ~1" size)
- NISP (Y/J/H) : 24.0 AB at SNR=5 for point sources
- The performance from 4 exposures (~50% survey area) adds 0.15 magnitude

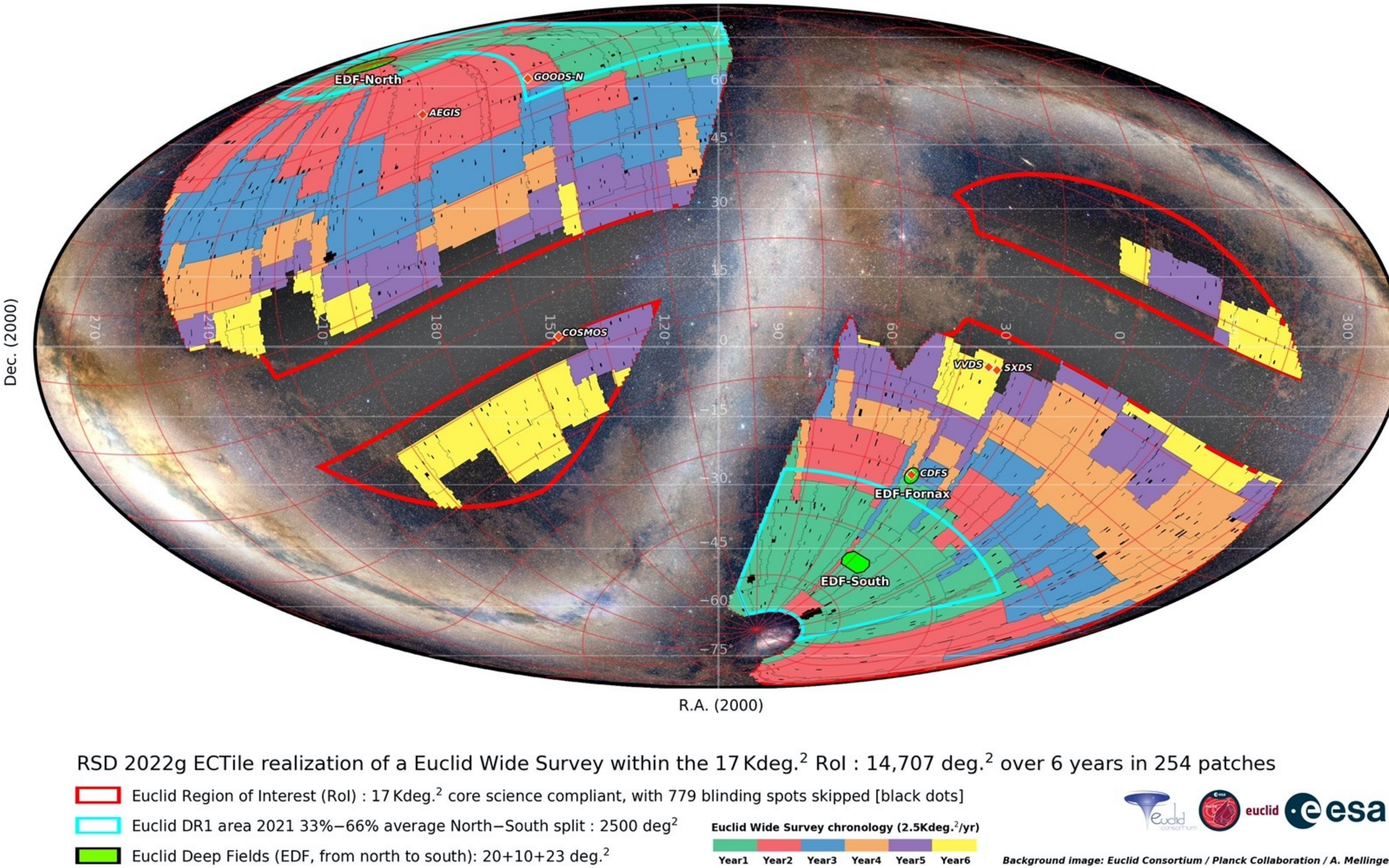
Euclid was built to achieve this performance near the worst part of the RoI (margin = minimum depths reached), and the actual median (2021, still assuming some remaining margins through the depth metric) is expected to be, out of 3 exposures:

- VIS : 24.5 AB at SNR=16 for extended sources (field galaxies ~1" size)
- NISP (Y/J/H) : 24.0 AB at SNR=7.2 for point sources

This translates in depths for the initial SNR requirements to:

- VIS : 25.0 AB at SNR=10 for extended sources (field galaxies ~1" size)
- VIS : 26.2 AB at SNR=5 for point sources (PSF fitting photometry)
- NISP (Y/J/H) : 24.4 AB at SNR=5 for point sources
- The performance from 4 exposures (50% survey area) adds 0.15 magnitude

Euclid Wide and Deep Surveys



Euclid deep and auxiliary fields characteristics

Field	R.A.	Dec	Area [deg^2]	Δm	Completion (semester)	EWS Footprint
Self-Cal	270.000	+66.50	4	2.80	12	in
CDFS	53.117	-27.81	0.5	2.27	2	in
EDF-N	269.737	+66.02	20	2.00	6	in
EDF-F	52.938	-28.10	10	2.00	12	in
EDF-S	61.240	-48.42	23	2.00	12	in
COSMOS-Wide	150.119	+02.21	2	1.75	4	out
SXDS	34.500	-05.00	2	1.75	8	in
VVDS-Deep	36.500	-04.50	0.5	1.75	9	in
CANDELS/AEGIS	214.827	+52.82	1	1.50	1	in
CANDELS/GOODS-N	189.250	+62.25	0.5	1.50	9	in
~~CPC-N (outer annulus)~~	~~269.737~~	~~+66.02~~	~~10~~	~~1.25~~	~~2~~	~~in~~

Delta(m) gives the extra depth versus the Wide survey at that location which can be derived from the previous maps

Euclid complementary data

- Spectroscopy:
    - 45 nights at Keck telescope: spectroscopy on Euclid Wide fields north
    - 25 nights at VLT VMOS/KMOS: spectroscopy on Euclid Wide fields south
    - programmes at GTC & LBT: further supporting spectroscopic data
- Complementary space data on Euclid Deep Fields:
    - 5300 hrs of Spitzer satellite, period 13, priority 1 on 2 Euclid Deep field (20 deg2)
- Complementary visible photometry on Euclid Wide:
    - DES survey data
    - 271 nights at CFHT *u*-, *r*- band data on Euclid Wide North
    - 110 nights at JST/T250 *g*- band data on Euclid Wide North
    - WHIGS: g band data on Subaru/HSC
    - WHISHES: z band data on Subaru/HSC
    - *i*-band and *z*-band on Euclid Wide North with Pan-STARRS PS1/2
    - Rubin-LSST ugrizY data on Euclid Wide South

Euclid Data Releases and expected ground depths

Photo-z proxy depth metric (for all): point source in 2 arcseconds diameter aperture, 10σ

Euclid (median over the RoI, as-built): VIS=25.0, Y=J=H=23.5

DES in Euclid DR1/2/3: *g=24.7, r=24.4, i=23.8, z=23.1 (~1600, ~3000, ~4500 sq. deg)*

UNIONS in Euclid DR1: *u=23.6, g=24.5, r=24.1, i=23.6, z=23.4 (~900 sq. deg)*

UNIONS in Euclid DR2: *u=23.6, g=24.5, r=24.1, i=23.7, z=23.4 (~3000 sq. deg)*

UNIONS in Euclid DR3: *u=23.6, g=24.5, r=24.1, i=23.8, z=23.4 (~5000 sq. deg)*

Rubin LSST* Y1 in Euclid DR2: *u=23.7, g=24.9, r=25.0, i=24.3, z=23.6 (~3000 sq. deg)*

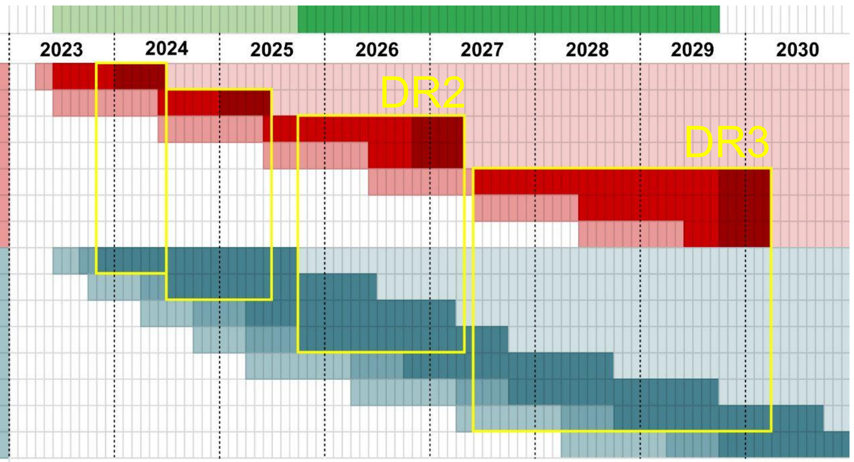
Rubin LSST* Y1 to Y4 in Euclid DR3: *u=24.4, g=25.6, r=25.7, i=25.0, z=24.3 (~7000 to ~9000 sq. deg)*

*Rubin-LSST DDP main releases depth with point source PSF performance scaled to the 2" diam. metric

Euclid and the Rubin LSST Derived Data Products

Rubin-Euclid Coordination Timeline

Survey	Data Release	
Euclid	Q1	Misc. sky areas (EDF, etc), total 50 sq deg
Euclid	DR1	Euclid Y1 (2500 sq deg, << 1000 sq deg overlap)
Euclid	Q2	Euclid Y2
Euclid	DR2	Euclid Y3 (7500 sq deg, ~3000 sq deg overlap)
Euclid	Q3	Euclid Y4
Euclid	Q4 (TBC)	Euclid Y5
Euclid	DR3	Euclid Y6 (15000 sq deg, ~7000 sq deg overlap)
LSST	DP1	LSST ComCam
LSST	DP2	LSST SV (~1000 sq deg, 180 visits / Y2 depth)
LSST	DR1	LSST First 6 Months
LSST	DR2	LSST Y1 (90 visits)
LSST	DR3	LSST Y2 (180 visits)
LSST	DR4	LSST Y3 (270 visits)
LSST	DR5	LSST Y4 (360 visits)
LSST	DR6	LSST Y5 (450 visits)



Assumptions:

February 2023	Euclid mission launch date
April 2024	LSST survey start

Surveys color keys:

- Observing
- Processing
- Proprietary Access
- Public Access

Notes:

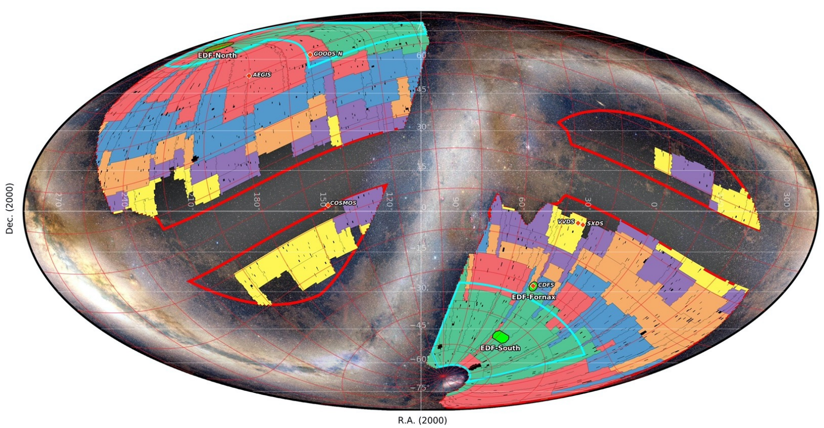
(a) LSST data release dates may move by +/3 months as the operations team adapts to circumstances.

(b) Euclid plan additional quick releases containing specific featured data products made with the Y2 ("Q2") , Y4 ("Q3") and Y5 ("Q4", TBC) data. The data from these years will be available to the Euclid Consortium to use while they are being processed, there just won't be an internal release of a full data release dataset.

(c) The overlap between Euclid Y1 and LSST SV is potentially quite small, because Rubin commissioning observations are needed at a wide range of latitude (and the best calibration pre-cursor data tends to be closer to equatorial). The SIT-Com team's field selection is not yet determined.

(d) DDP transient science can start in 2023 with limited sky overlap (green bar).

(e) LSST Y1 leads to matched survey depths for photo-z estimation: the production of related DDPs (photometric catalogs) spans 4 years (top darker green bar, 2025 to 2029) based on LSST Y1 to Y4 yearly data releases progressively matched to the Euclid survey increasing overlap.



RSD 2022g ECTile realization of a Euclid Wide Survey within the 17 Kdeg.^{2} RoI : 14,707 deg.^{2} over 6 years in 254 patches

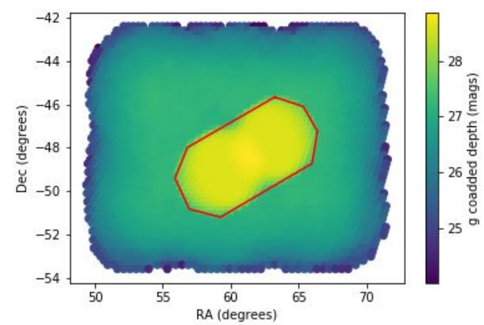
- Euclid Region of Interest (RoI) : 17 Kdeg.^{2} core science compliant, with 779 blinding spots skipped [black dots]
- Euclid DR1 area 2021 33%−66% average North−South split : 2500 deg^2
- Euclid Deep Fields (EDF, from north to south): 20+10+23 deg.^{2}

Euclid Wide Survey chronology (2.5Kdeg.^{2}/yr): Year1 Year2 Year3 Year4 Year5 Year6

Background image: Euclid Consortium / Planck Collaboration / A. Mellinger

Rubin-Euclid DDPs is the only existing path to an early access to the LSST dataset with at least a one-year lead time on our public releases. This conditions the Euclid DRs as follows:

- DR2 will rely on LSST Year 1 at best
- DR3 will rely on LSST Year 4 at best



Uniform depth on EDF-South with an optimal Rubin dithering

Ground Segment

SGS Implementation Review passed Mar 2021

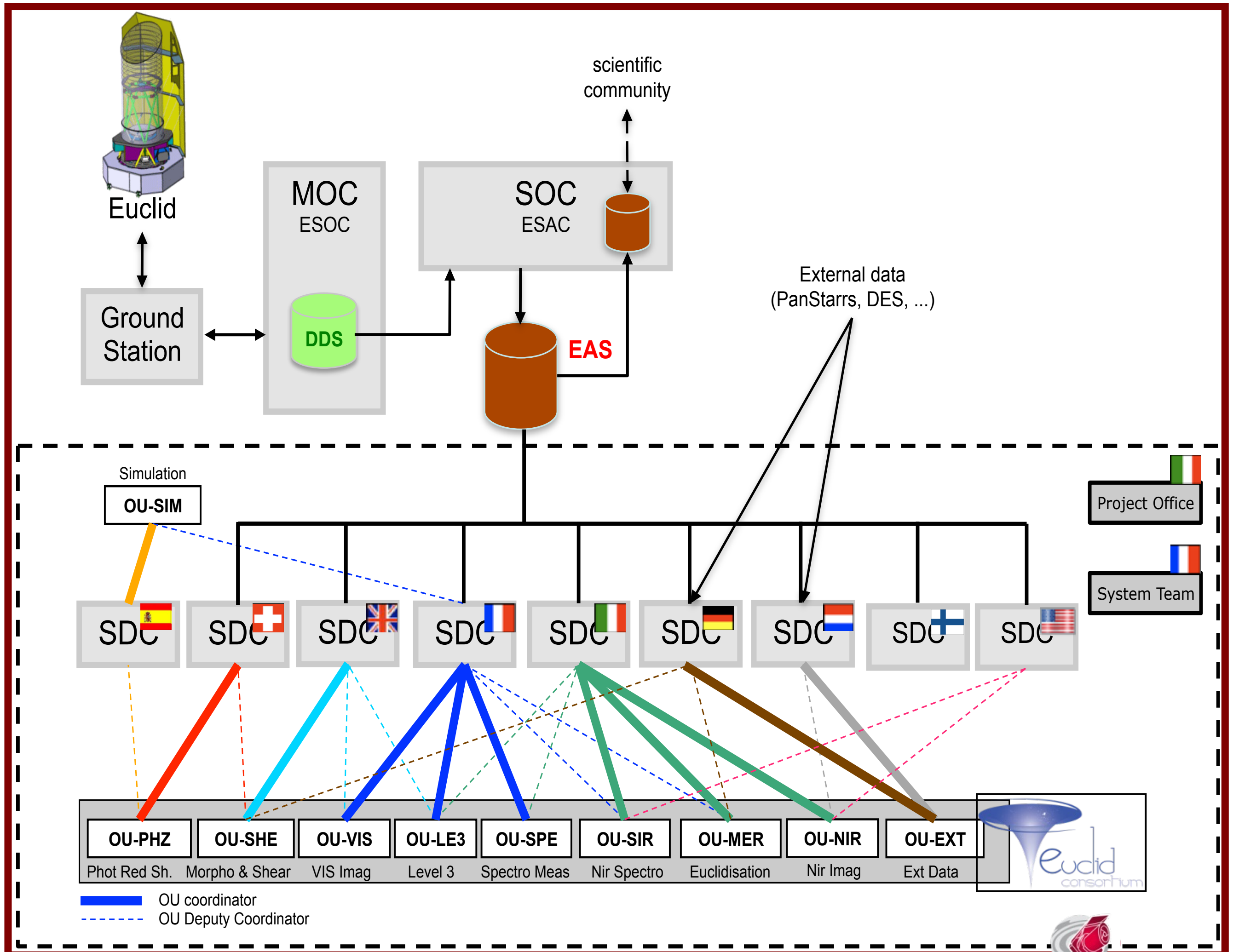
SGS Readiness Review ongoing

Complex organisation:

- 10 Organisation Units
- 9 Science Data Centers

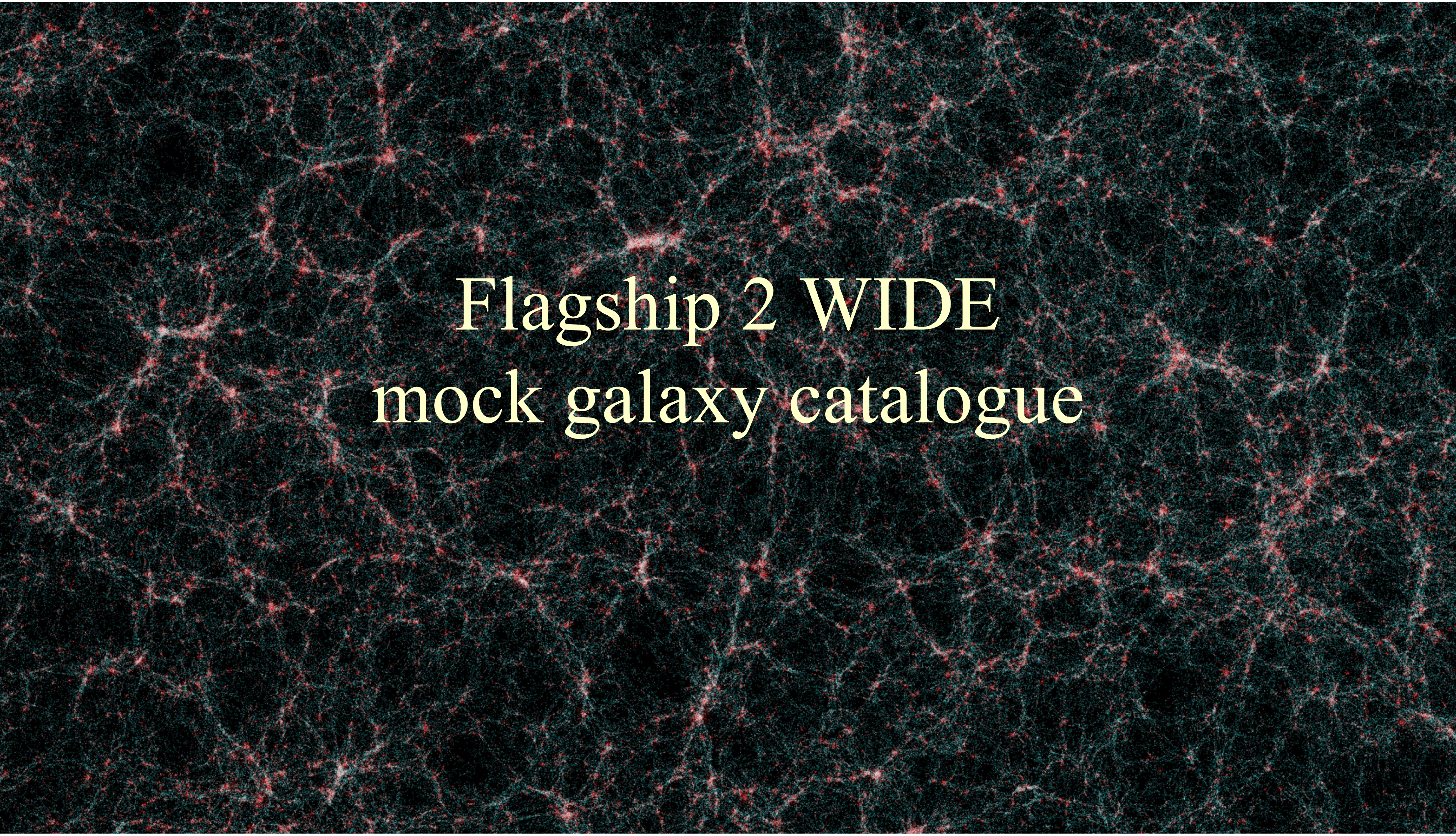
Data: huge volumes, heterogeneous data sets

- VIS+NIR imaging, morphometry, photometry , spectroscopy, astrometry, transients
- data ground + space
- ~100 Pbytes
- 1^{+} million images
- > 10^{10} sources (>3-σ)

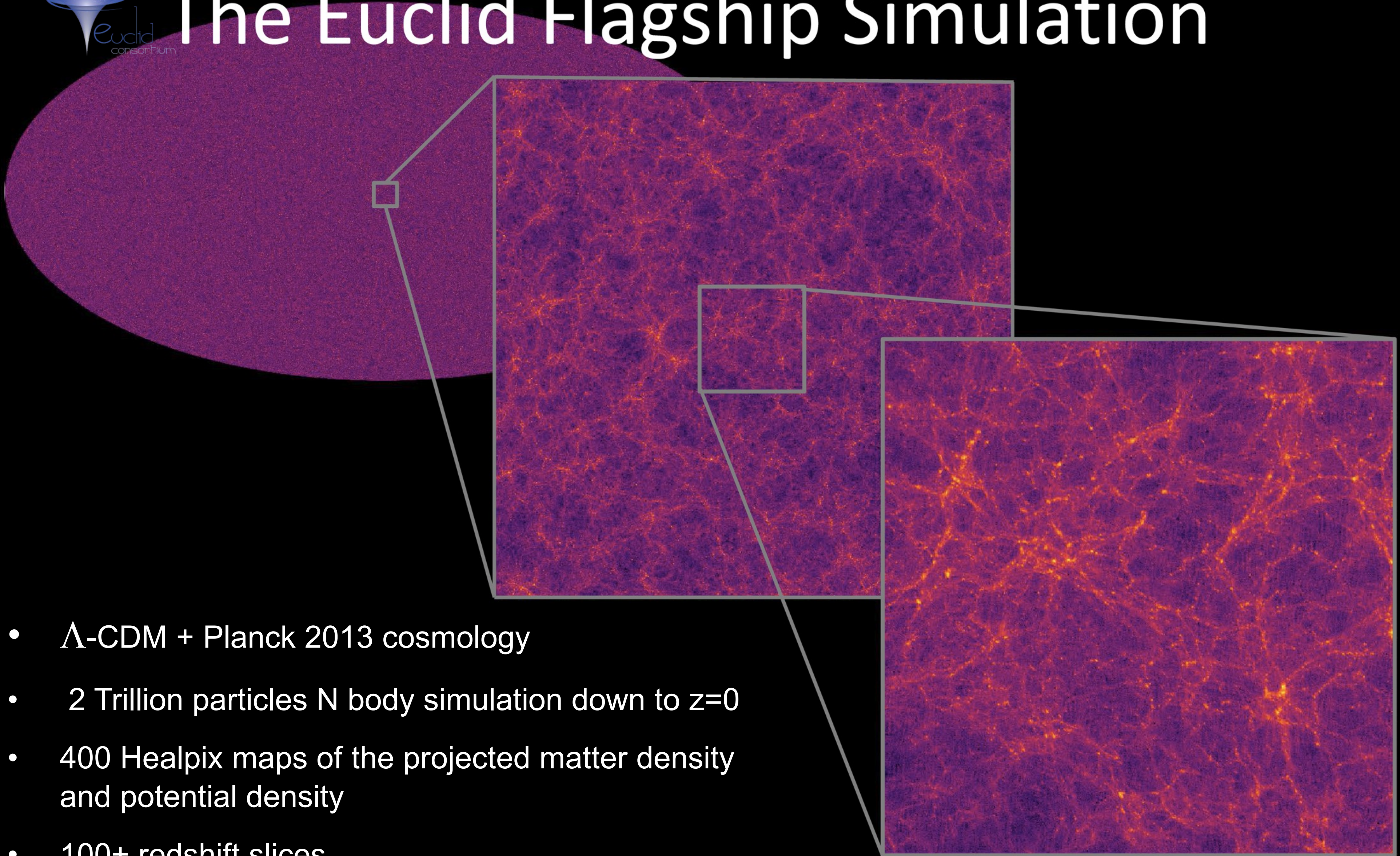


Euclid Flagship Simulation:

a tool for Euclid E2E performances


Flagship 2 WIDE
mock galaxy catalogue

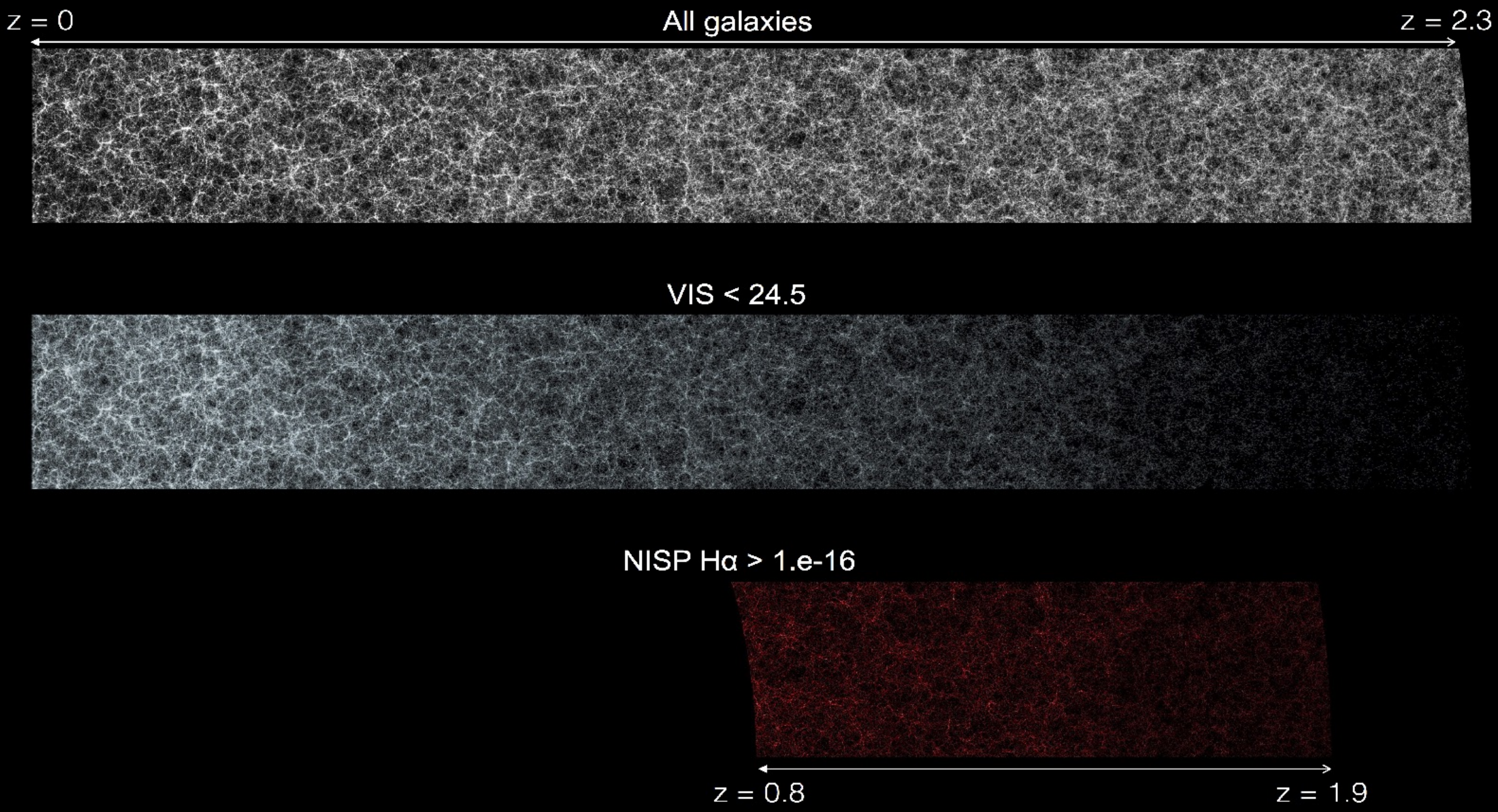
The Euclid Flagship Simulation



From D. Potter, J. Stadel, R. Teyssier

- Λ-CDM + Planck 2013 cosmology
- 2 Trillion particles N body simulation down to z=0
- 400 Healpix maps of the projected matter density and potential density
- 100+ redshift slices
- Consistent mocks for WL and GC

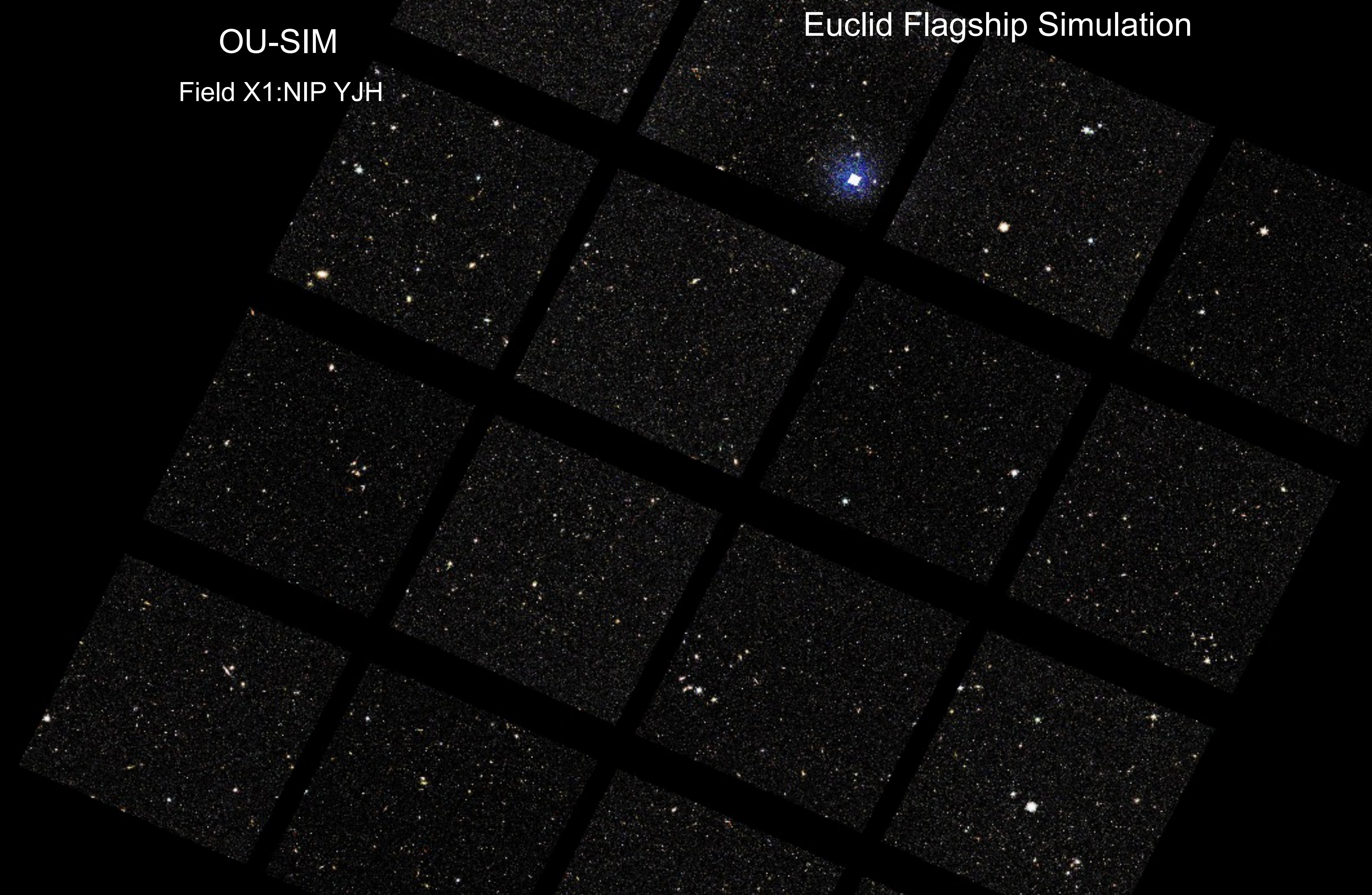
Euclid Flagship Simulation: mock galaxy catalog



OU-SIM

Field X1:NIP YJH

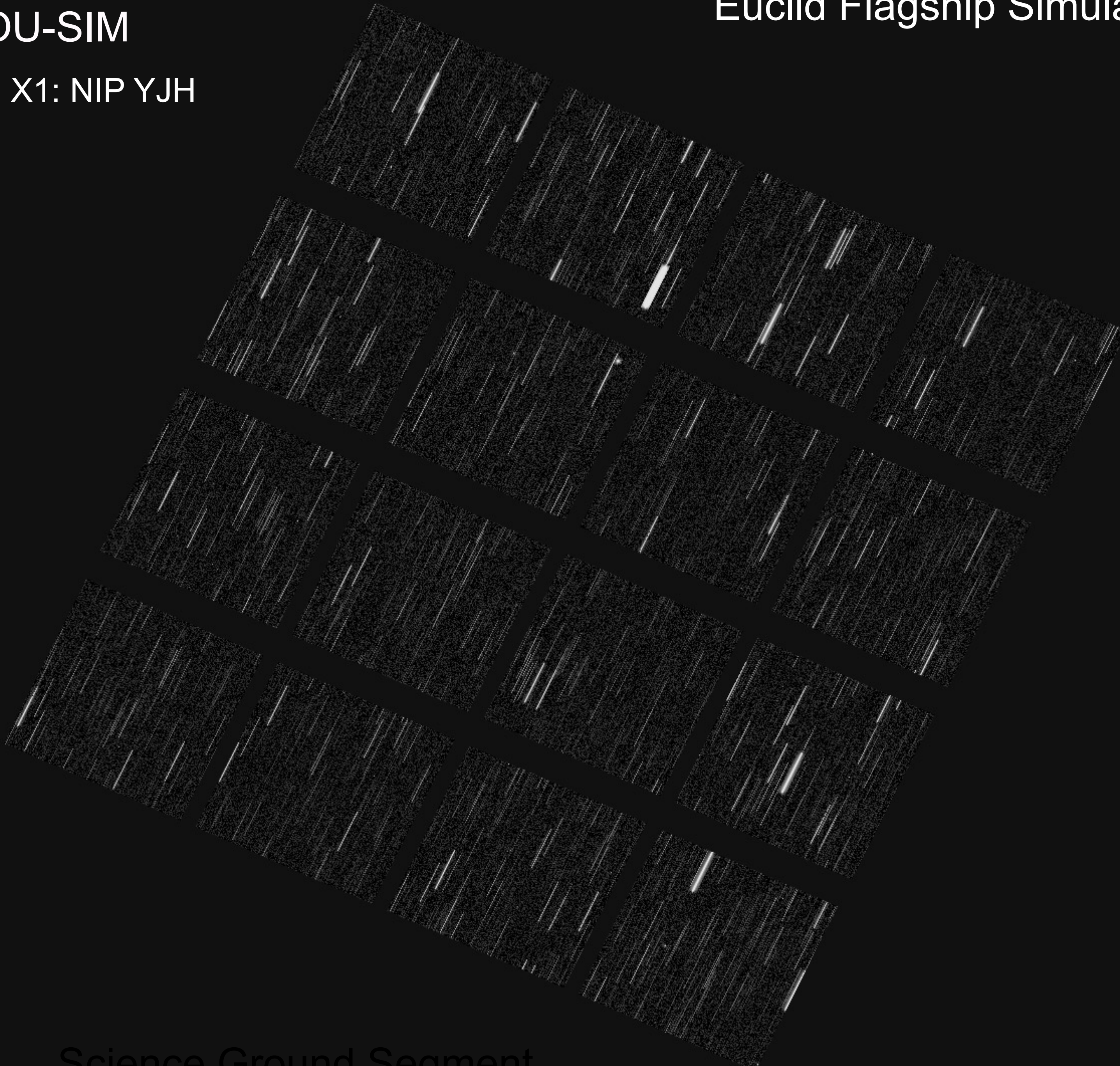
Euclid Flagship Simulation


OU-SIM
Field X1:NIP YJH
Euclid Flagship Simulation

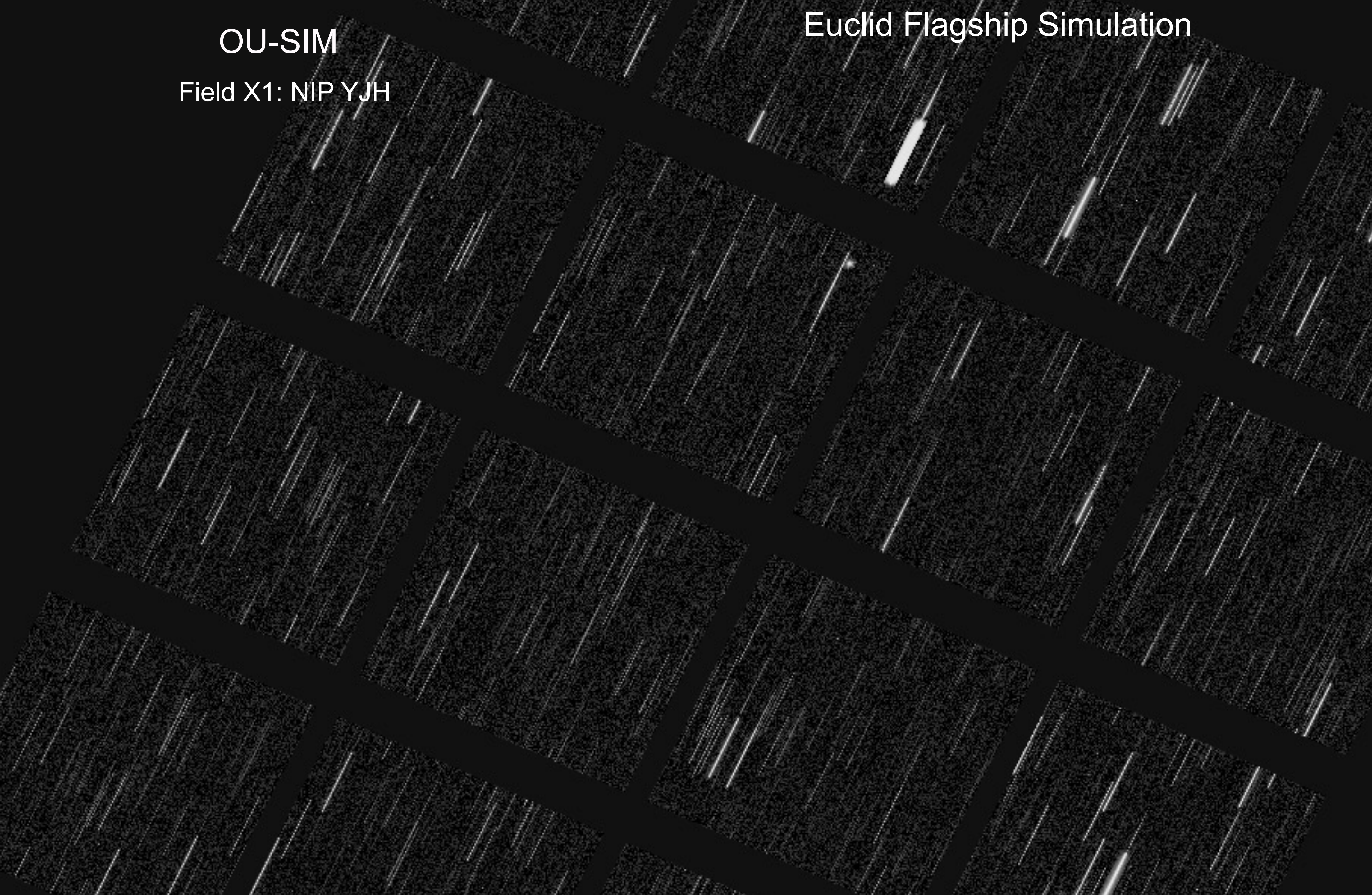
OU-SIM

Euclid Flagship Simulation

Field X1: NIP YJH

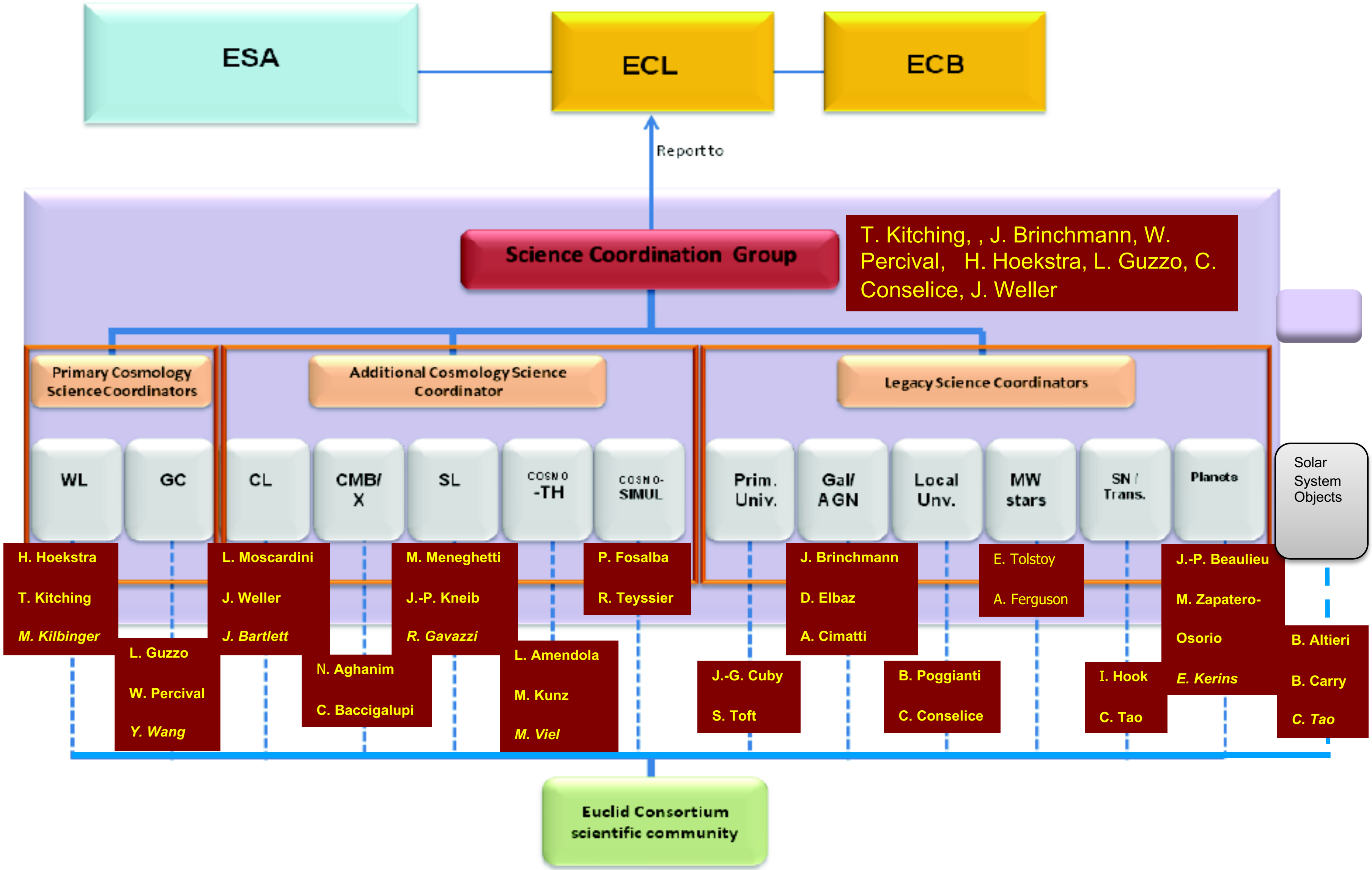


Science Ground Segment


OU-SIM
Field X1: NIP YJH
Euclid Flagship Simulation

Performances and forecasts

EC Science Working Groups



Performance Status on Oct 2018

Technical Performance Measure		Requirement	CBE Current
Image Quality			
VIS Channel	FWHM (@ 800nm)	180 mas	160 mas
	ellipticity	15.0%	9.4%
	R2 (@ 800 nm)	0.0576	0.0551
	ellipticity stability σ(εi)	2.00E-04	1.90E-04
	R2 stability σ(R2)/<R2>	1.00E-03	1.00E-04
	Plate scale	0.10 "	0.100 "
NISP Channel	rEE50 (@1486nm)	400 mas	225 mas
	rEE80 (@1486nm)	700 mas	584 mas
	Plate scale	0.30 "	0.299 "
Sensitivity			
VIS SNR (for mAB = 24.5 sources)		10	16.99
NISP-S SNR (@ 1.6um for 2xe-16 erg cm-2		3.5	4.81
NISP- P SNR (for mAB = 24 sources)	Y-band	5	5.89
	J-band	5	6.69
	H-band	5	5.34
NISP-S Performance			
Purity		80%	72%
Completeness		45%	52%
Survey			
Wide Survey Coverage		15,000 deg2	15,000
Survey length [years]		5.5	5.4

From ESA PO

Mission CDR passed in Oct 2018

Euclid performances meet the scientific and survey requirements

- Image quality of the system fully in line with needs.
- Ellipticity, R^2 stability and Non-convolutive errors performance dictated mainly by ground processing
- *Purity* not compliant with current data processing methods but expected to be recovered with Euclid specific algorithms (not yet installed at this stage).

Euclid forecast: Primary Program

Ref: Euclid RB arXiv:1110.3193	Modified Gravity	Dark Matter	Initial Conditions	Dark Energy		
Parameter	γ	m_ν /eV	f_{NL}	w_p	w_a	FoM $= 1/(\Delta w_0 \times \Delta w_a)$
Euclid primary (WL+GC)	0.010	0.027	5.5	0.015	0.150	430
EuclidAll (clusters,ISW)	**0.009**	**0.020**	**2.0**	**0.013**	**0.048**	**1540**
Euclid+Planck	0.007	0.019	2.0	0.007	0.035	**6000 →**
Current (2009)	0.200	0.580	100	0.100	1.500	~10
Improvement Factor	**30**	**30**	**50**	**>10**	**>40**	**>400**

Laureijs et al 2011

DE equation of state: $P/\rho = w$, and $w(a) = w_p + w_a(a_p - a)$

From Euclid data alone, get FoM=$1/(\Delta w_a \times \Delta w_p)$ > 400→ ~1% precision on w's.

Growth rate of structure formation: $f \sim \Omega^{\gamma}$; .

Notice neutrino constraints -> minimal mass possible ~ 0.05 eV

Euclid forecast: Primary Program

SPV02

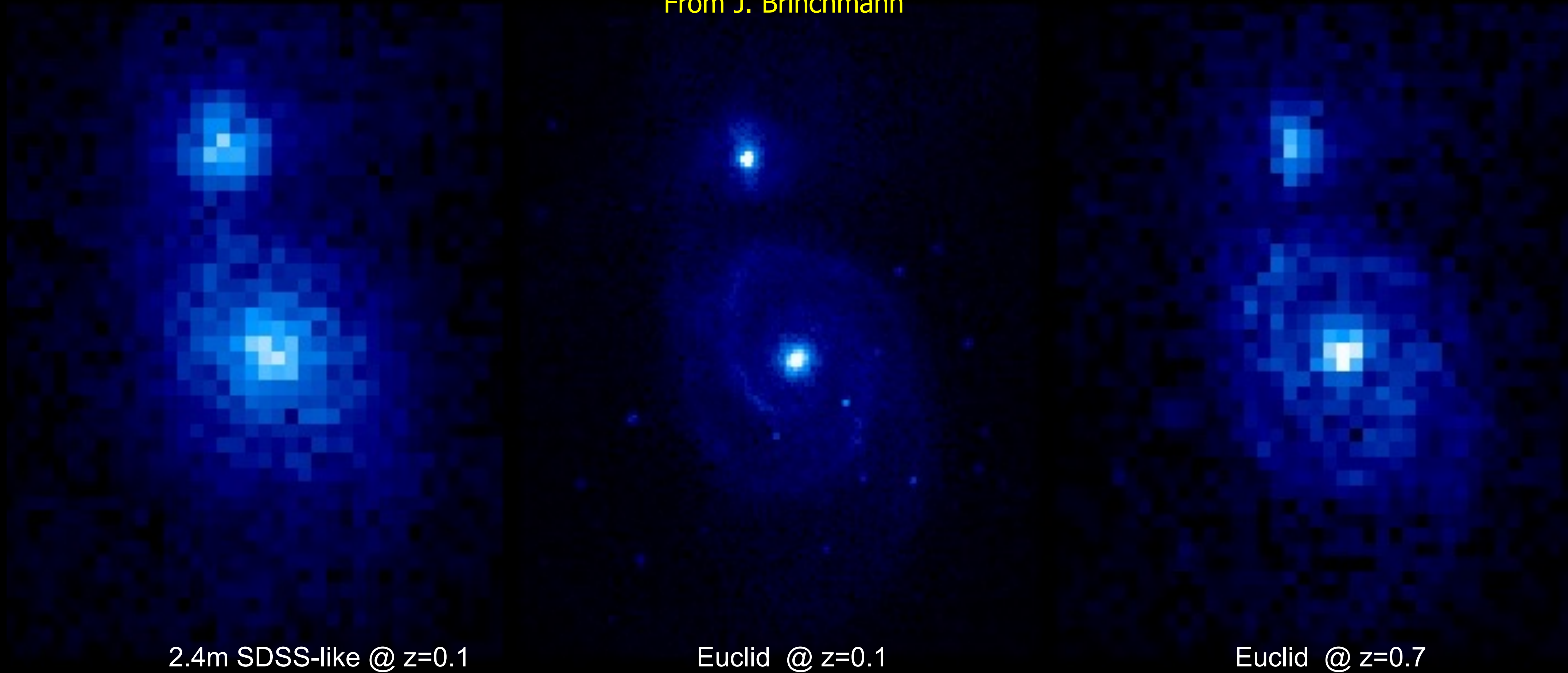
Table 20.1.: Figure of Merit for non flat GR and MG cosmological models. We set $\ell_{max} = 5000$ for WL forecasts, and take two values of ℓ_{max} for GCp and XC. First (second) half of the table refers to GCs forecast with $k_{max} = 0.30h\text{Mpc}^{-1}$ leaving the nuisance parameters $(\sigma_p, \sigma_\text{v})$ free (fixing them).

data	GR		MG	
	$\ell_{max} = 3000$	$\ell_{max} = 5000$	$\ell_{max} = 3000$	$\ell_{max} = 5000$
GCs	24.70	24.70	16.13	16.13
WL + GCp + XC	127.3	219.0	94.45	163.6
WL + GCp + XC + GCs	227.2	347.0	211.66	317.8
GCs	32.55	32.55	21.07	21.07
WL + GCp + XC	127.3	219.0	94.45	163.6
WL + GCp + XC + GCs	261.6	399.7	256.22	384.7

Euclid Legacy Science

VIS: Simulation of M51

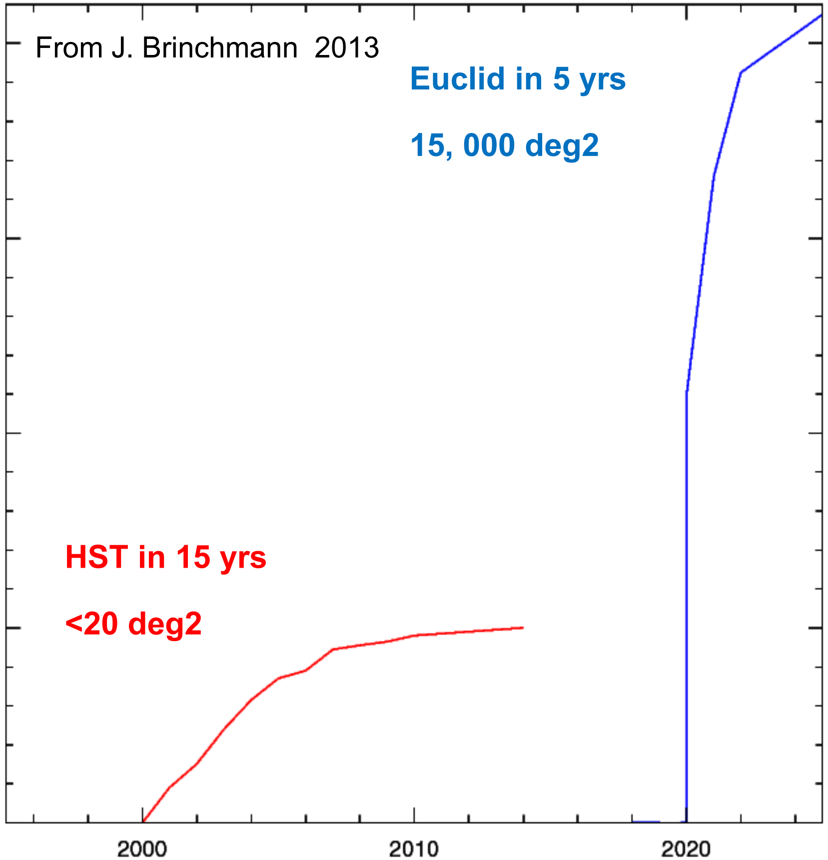
From J. Brinchmann



- Euclid will get the resolution of SDSS but at z=1 instead of z=0.05.
- Euclid will be 3 magnitudes deeper → Euclid Legacy = Super-Sloan Survey

Euclid and the next generation wide field VIS/NIR surveys

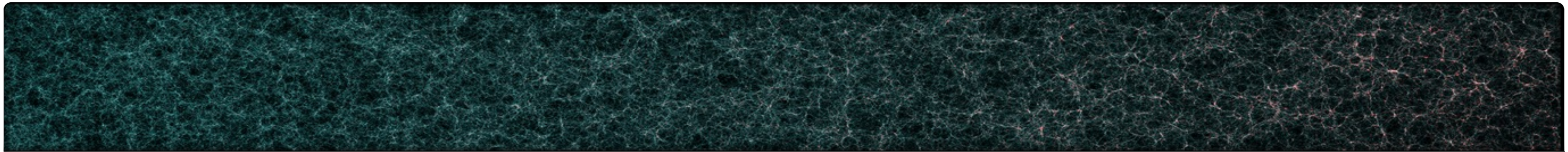
Objects	Euclid	Before Euclid
Galaxies at 1 < z < 3 with precise mass measurement	~2x10^8	~5x10^6
Massive galaxies (1< z< 3)	Few hundreds	Few tens
Hα Emitters with metal abundance measurements at z~2-3	~ 4 10^7 ?	~10^4 ?
Galaxies in clusters of galaxies at z > 1	~1.8x10^4	~10^3 ?
Active Galactic Nuclei galaxies (0.7 < z< 2)	~10^4	<10^3
Dwarf galaxies	~10^5	
T_{eff} ~400K Y dwarfs	~few 10^2	<10
Lensing galaxies with arcs and rings	~150,000	~10-1000
Quasars at z > 8	~30	None



- Spectroscopic targets for JWST, E-ELT, TMT, Subaru, VLT, 4MOST, MSE,
- Synergy with Rubin-LSST, eROSITA, Subaru/HSC, Roman, Planck, SKA

Schedule

Development – Planning/Progress Overview



2012
- Mission Adoption June
- PLM ITT July
- PLM Contract Dec
- Prime ITT Dec

2013
- VIS SRR May-Jun
- SGS PRR May-Jul
- NISP SRR Jun-Jul
- Prime Contract Jul
- MOC CRR Nov
- PLM SRR Nov
- Mission SRR KO Nov

2014
- Mission SRR Board Feb
- VIS PDR Apr
- PLM PDR May
- NISP PDR May
- Calibration Review Sep

2015
- SFS SRR KO Jan
- SCS CDR Mar
- S/C PDR May-Jul
- M-PDR Sep-Oct

2016
- SGS TK1 Jun
- GSRqR Jul
- NISP CDR Sep-Nov

2017
- VIS CDR KO Jan
- SPV KO Jan
- PLM CDR Jun-Jul
- GSDR KO Nov

2018
- GSDR Board Jan
- VIS CDR C/O Feb
- AVM full ready Jun
- S/C CDR Mar-May
- M-CDR Oct-Nov

2019
- S/C STM ready Apr
- S/C STM test Apr-Nov
- SGS TK2 Oct

2020
- VIS FM delivery Mar
- NISP delivery Apr-May
- S/C TMQR KO Mar
- VIS QAR KO Sep
- SCOMTR KO Sep
- NISP QAR KO Oct

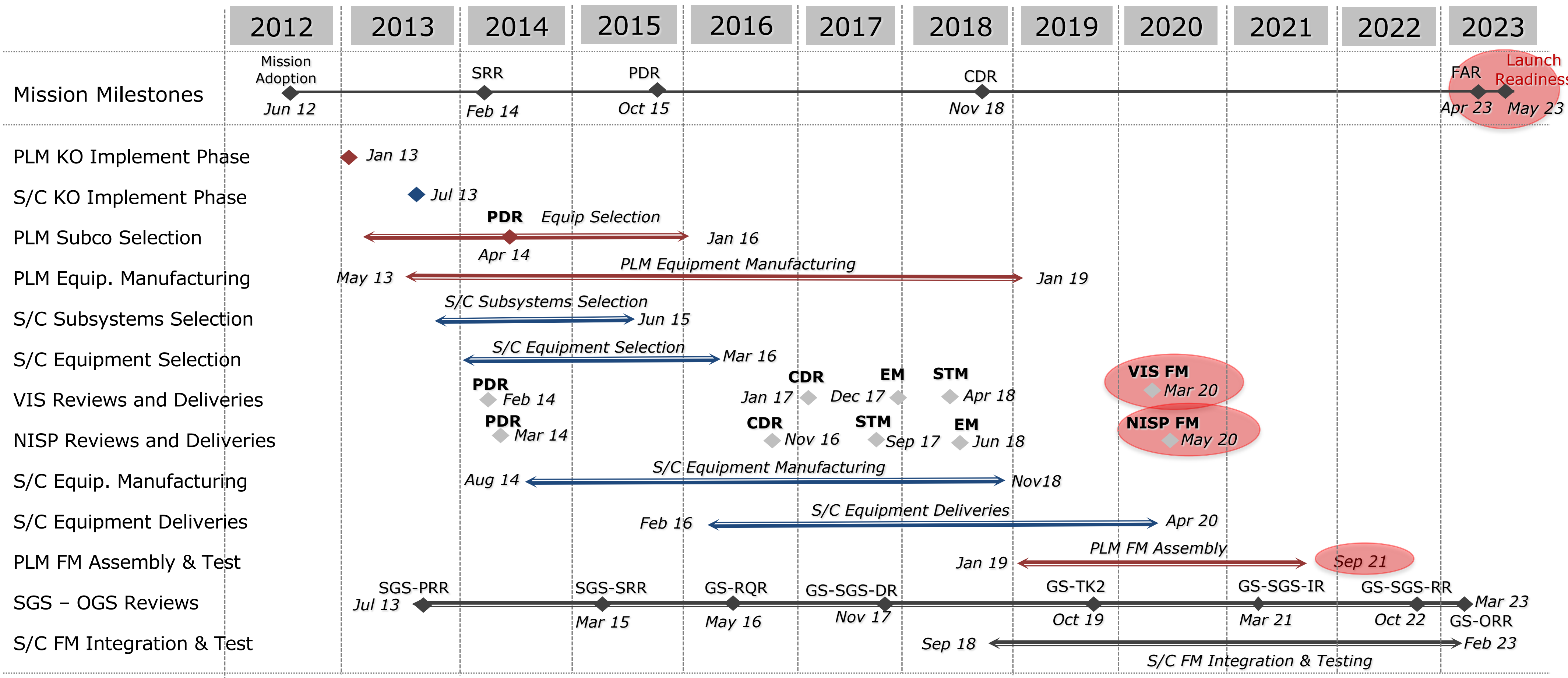
2021
- GSIR Mar
- PLM FM e2e test Apr-Jul
- PLM FM delivery Oct
- SVM/PLM EI int. end Nov
- Spacecraft QR KO Dec

2022
- QR Board Mar
- SVM/PLM FM mating Mar
- S/C FM Env Test start Jul
- TBTV Test Oct-Nov
- GSRR Oct-Dec
- Mech Tests Nov-Dec

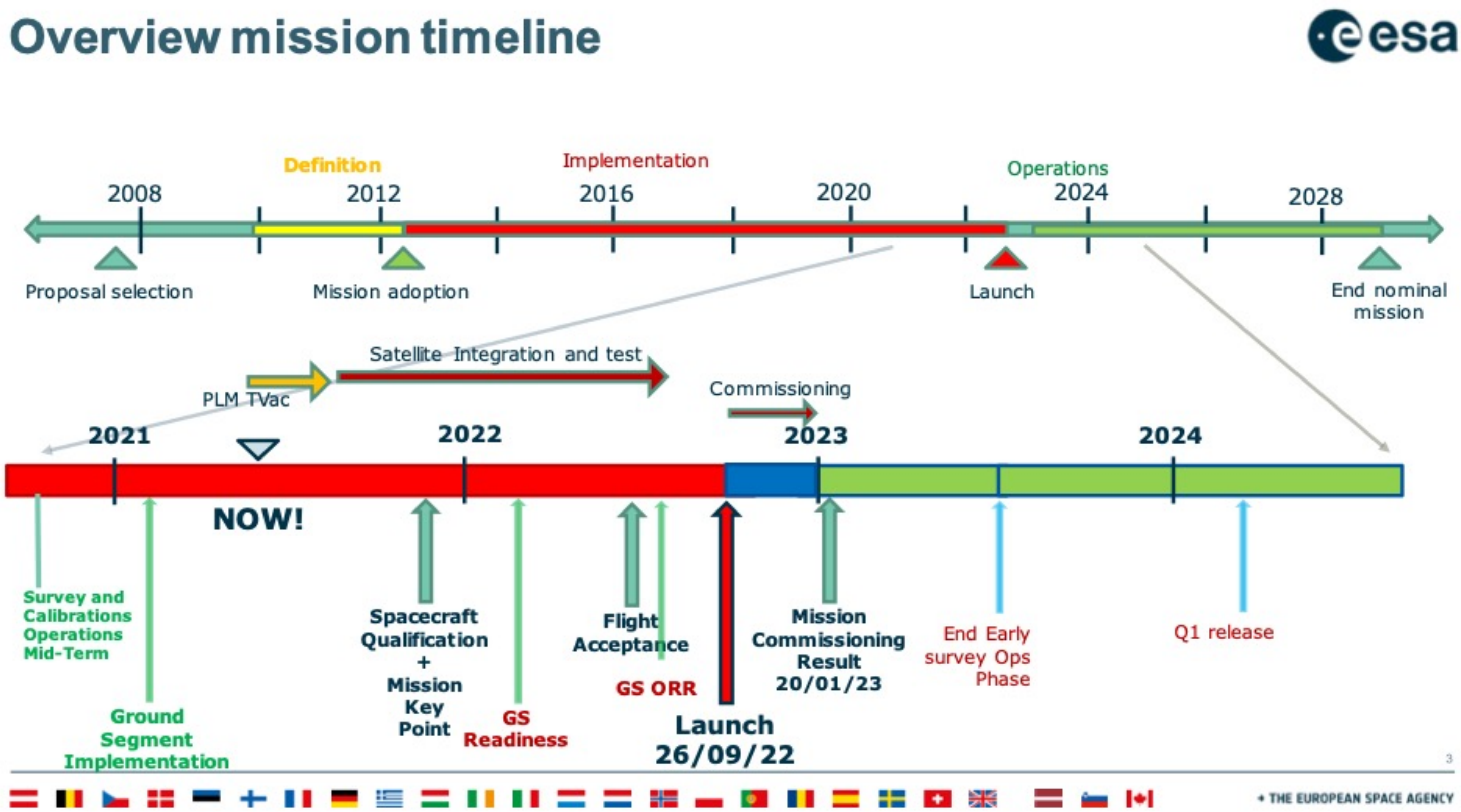
2023
- Test finished Feb
- FAR Feb-Apr
- Transport to LS or storage Apr
- S/C Ready to Launch Jun
- Launch with F9 Jul-Sep
- MCRR Oct/Dec

Euclid Schedule

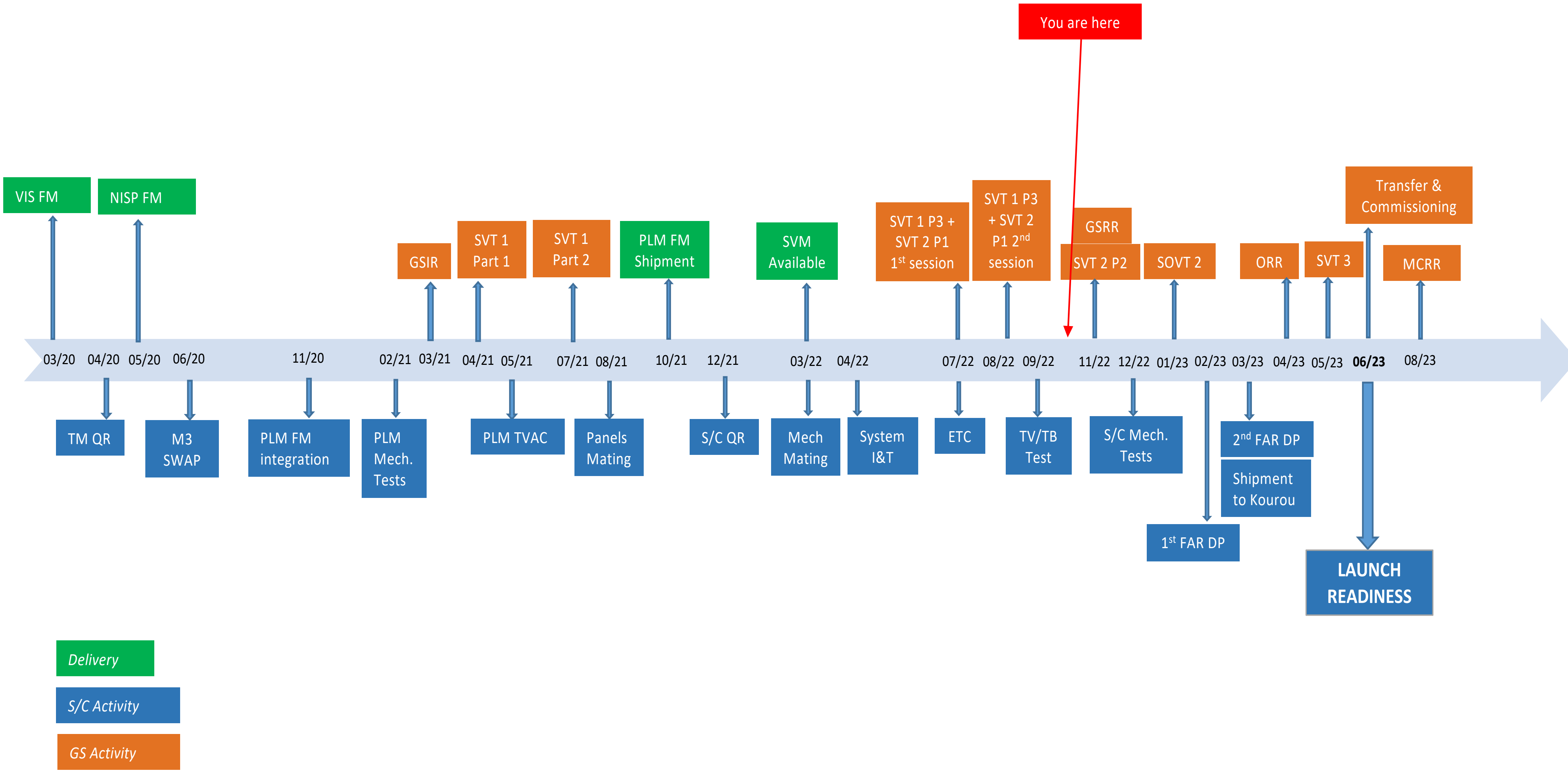
Euclid Schedule: Oslo 2022



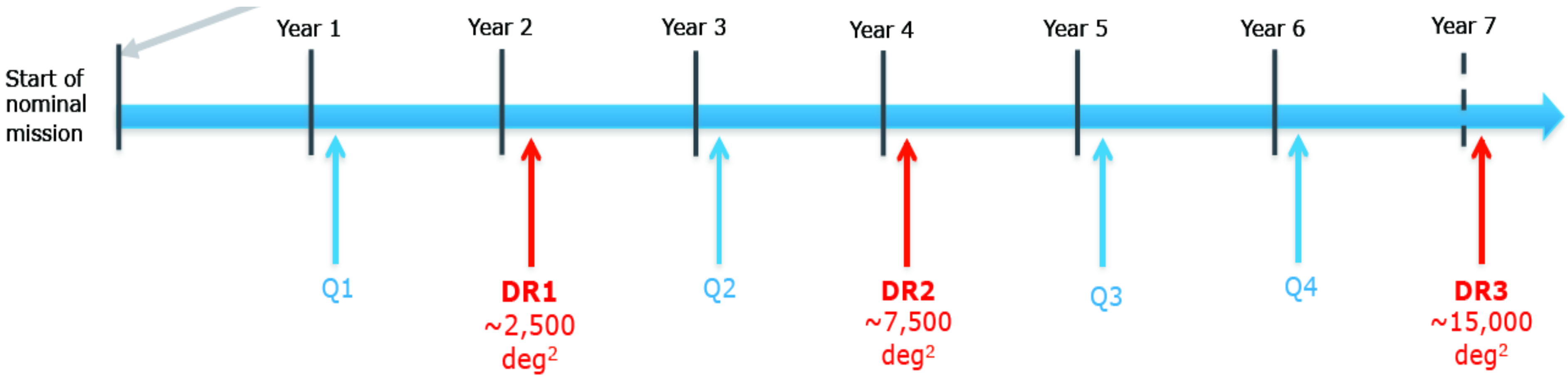
Mission Timeline



Mission Timeline



Data Releases



Science with Euclid will start in 2024 with Q1 and in 2025 with DR1

Summary

- Euclid cosmology mission to study the structure of the Universe and the nature of dark energy:
  - Uses 3 cosmological probes, and their cross-correlations
  - Perfect complementarity with Planck: probes and data, cosmic time
  - Explore the Dark universe: DE, DM (neutrinos), MG, inflation, biasing, baryons
  - Explore the transition DM-to-DE-dominated universe period
  - Get the percent precision on w and the growth factor γ
  - Synergy with New Gen wide field surveys: LSST, Roman, e-ROSITA, SKA
- Euclid =12 billion sources, 35 million redshifts, 1.5 billion shapes/photo-z of galaxies;
  - A huge dataset of images and spectra for the community to study for years;
  - A reservoir of spectroscopic targets for JWST, E-ELT, TMT, ALMA, VLT, MSE, 4MOST, MOONS,
  - A set of astronomical catalogues useful until 2040+
- Big challenges: data processing (100-300 Petabytes), cosmological simulations
- Launch 2023, start 2023: **2500 deg^2 public in 2025**, 7500 deg^2 in 2027, final 2029

Euclid Consortium Meeting in Helsinki 2019

Thanks