The Euclid Mission

René Laureijs

The Dark Side of the Universe – ISSS, l'Aquila

Some history, 10 years ago…..

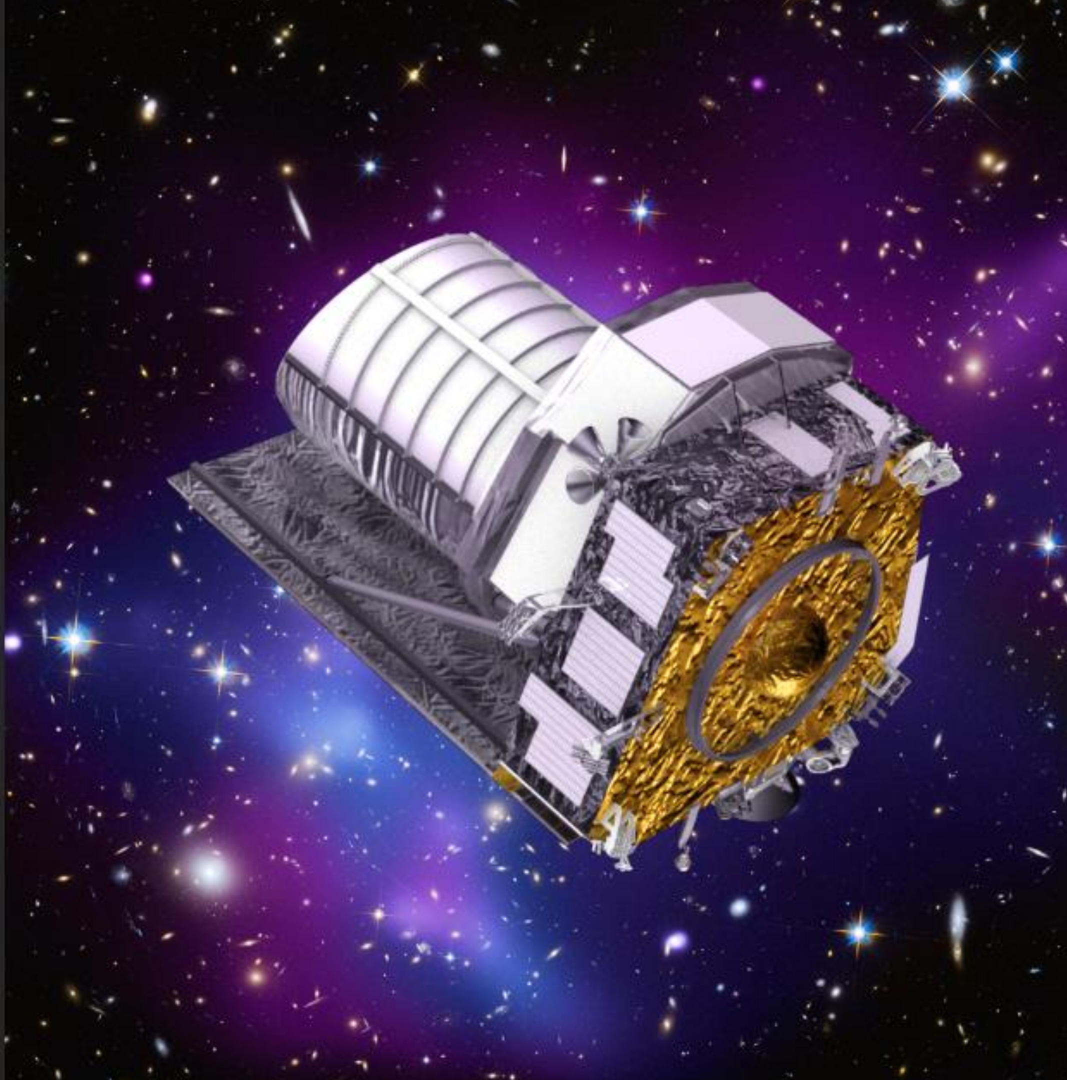
Subject: Name for the merged concept
From: "Refregier, Alexandre" <refregier@cea.fr>
Date: 05/03/2008 12:31 PM
To: Malcolm Longair <msl1000@cam.ac.uk>, Rene Laureijs <rlaureij@rssd.esa.int>
CC: John Peacock <jap@roe.ac.uk>, Simon Lilly <simon.lilly@phys.ethz.ch>, Peter Schneider <peter@astro.uni-bonn.de>

Dear Malcolm and Rene,

Within the DUNE team, we have been thinking about suggestions for the name of the merged DUNE/SPACE mission concept.
Our preferred name is:
EUCLID: a mission to map the geometry of the dark universe.
If needed it can be interepreted as the acronym "EUropean Cosmology aLl-sky Investigator of the Dark universe".

We have also alternatives that we are still discussing, but this is our favorite. What do you think?

Cheers,
Alexandre

Outline

Lecture: Euclid Mission I

- Space Science, ESA, and Programmatics
- Mission concept and trade-offs

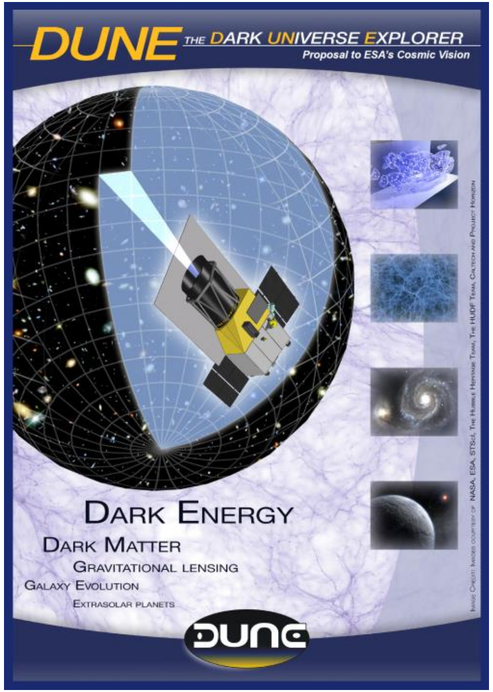
Lecture: Euclid Mission II

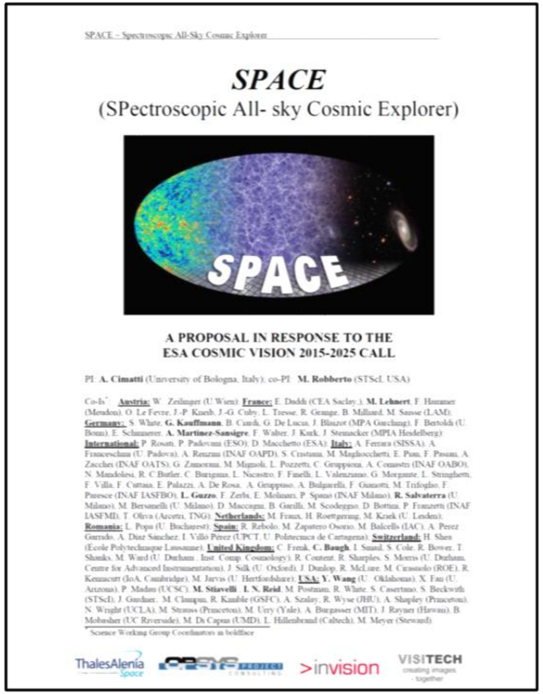
- Requirements Engineering
- Design Solutions
- Mission Overview

Euclid

SPACE SCIENCE, ESA AND PROGRAMMATICS

Why a space experiment in the first place?





SPACE – Spectroscopic All-Sky Cosmic Explorer

SPACE

(SPectroscopic All- sky Cosmic Explorer)

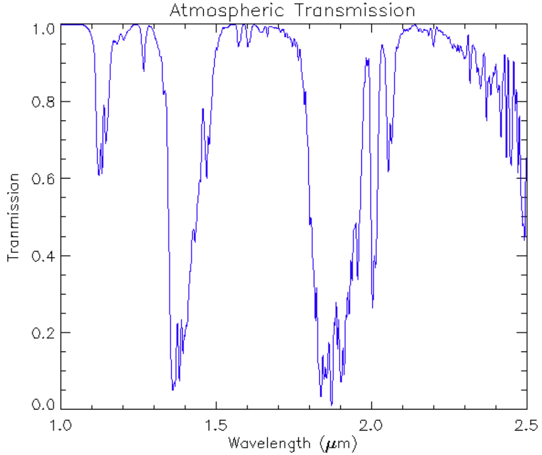
A PROPOSAL IN RESPONSE TO THE ESA COSMIC VISION 2015-2025 CALL

PI: A. Cimatti (University of Bologna, Italy); co-PI: M. Robberto (STScI, USA)

Morphometry: Compact and stable PSF in the optical λ > 0.5 micron

Infrared photometry and spectroscopy: wavelength range 1 < λ < 2 micron

Survey: observing several 10000 deg2, homogeneous observations



Both proposals were submitted simultaneously in 2007 for ESAs call for missions

Space Science

Why you scientists should be interested:

- Highly abstract – imaginative work
- Working in groups and teams – high level of organisation complexity
    - Social skills matters!
- Requiring technical knowledge – instrumentation and mission
- Data Analysis – statistics and complex software systems

What has Space Science to offer?

- Great Science! Excitement…?!
- Large international network – politics…
- Bridging science and technology
- (Appealing to the public.)

What is ESA (not)?

ESA is not CERN!

- CERN does one thing in one place, with the Nobel prize as ultimate reward

ESA is not (a European) NASA!

- NASA benefits from a massive (single) US military programme
- (…therefore) NASA has a single and complete domestic market it can use
  - …e.g WFIRST telescope is a donation from the National Reconnaissance Office
- NASA directly supports the efforts by scientists

→ **Space Science is the only mandatory programme for ESA**

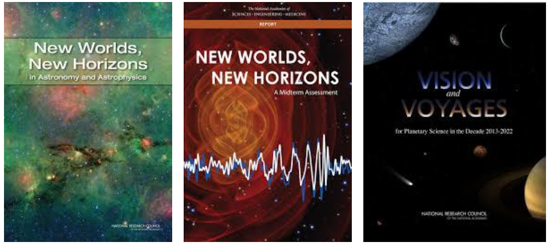
ESA is a reflection of the political will to accomplish a European effort

A strong believe in the European industrial capacity and in the strength of the scientists, engineers, project managers, and administration.

Read: *Fifty years of European Coorporation in space* by John Krige (2014)

Space Science: Agency Programmes

Budgets are available, but the individual projects are expensive. Need to probe the communities and define a process to (fairly) satisfy all parties

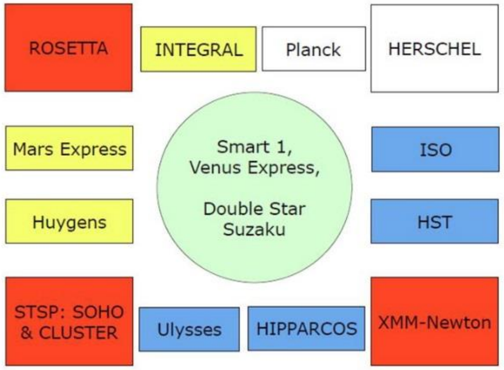


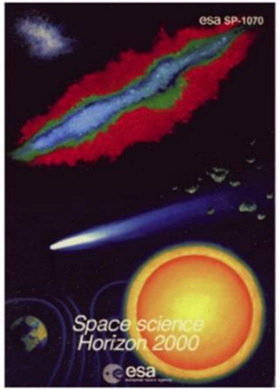
NASA:

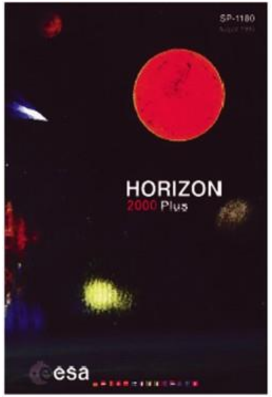
- Decadal survey for astrophysics
- Visions and Voyages for planetary science in the decade 2013-2022

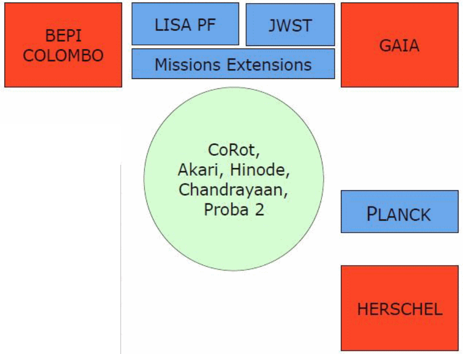
ESA:

- Horizon 2000 (1986-2005), Horizon 2000+ (Roger Bonnet, D/SCI 1983-2001)
- Cosmic Vision 2015-2025 (David Southwood, D/SCI 2001-2011)



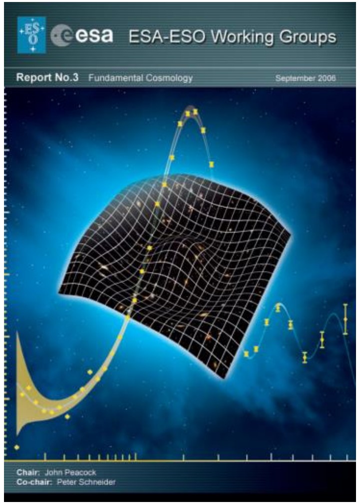






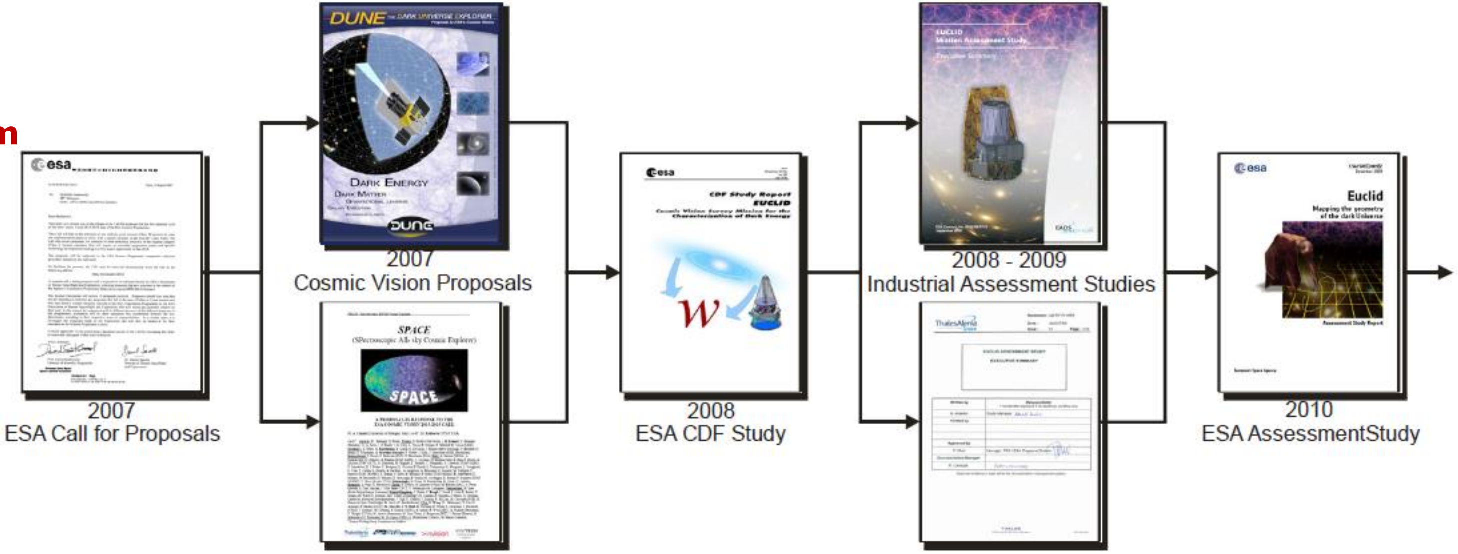
Programmatics related to Euclid

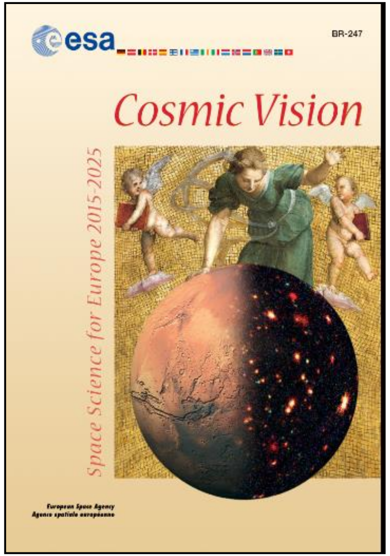
- Call for Ideas / Science Themes (2004)
- Overall programmatic envelope: Cosmic Vision 2015-2025 (2005)
- Call for Missions (2007) → more than 50 proposals
- Proposal Selection for M-class missions for entering Assessment Phase (2007)
  - *Cross Scale, Plato, SPICA, Solar Orbiter, Marco Polo, Dune+Space = Euclid*
- Selection for Definition Phase (2009):
  - *Solar Orbiter, Euclid, Plato*
- Mission Selection (4 October 2011, same day as Nobel price for Dark Energy was announced to S. Perlmutter, B. Schmidt, A. Riess)
- Mission Adoption (2012):
  - *Start of the Euclid Project*
    - Launch in Q2 2020
    - ESA budget 606 Meuro (2012 e.c.)



Euclid: Assessment Phase

ESA provide
→ **Study Team**
→ **Science Study Team**





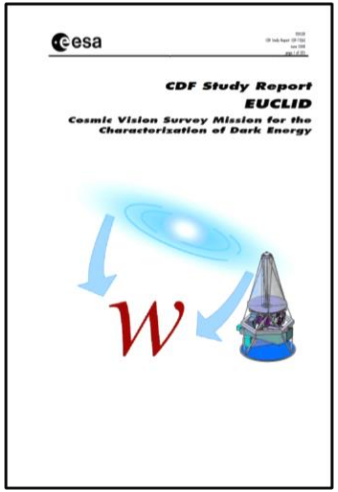
Euclid was a candidate M-class mission for the Cosmic Vision 2015-2025 Plan.

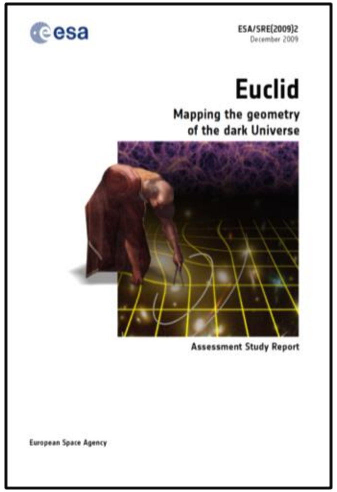
It is a merge of two independent proposals Dune and Space. During the Assessment Phase, the instrument payload was studied by two scientific consortia.

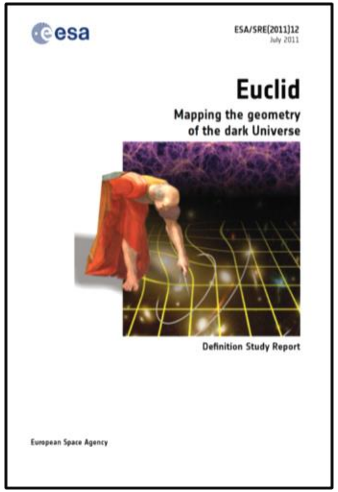
In February 2010, Euclid was selected by the ESA Science Programme Committee to enter the next phase, the **Definition Phase**

Study Phase = Assessment + Definition

- **Pre-Assessment**
  - Concurrent Design Facility – after merger of two proposals
- **Assessment Phase**
  - Two independent industrial studies (9 months)
  - Science study team: further discussion of the science requirements → **"Yellow book"** (arXiv1110.3193L)
- **Definition Phase**
  - Two independent industrial studies (1 year)
  - Studies on the payload component
  - Science Study team: further discussion on the science requirements → **"Red Book"** (arXiv0912.0914L)







Science Management

- *ESA science advisory structure*
  - Solar System and Astronomy working groups (SSWG, AWG)
  - Space Science Advisory Committee (SSAC)
  - Science Programme Committee (SPC)
- *Science Management Plan*: provides instructions how the scientific return is managed – endorsed by the advisory structure. *It is the commitment of ESA to the member states.*
  - Composition and Responsibilities of parties (ESA, other agencies, Community, Science Team)
  - Overall Scientific Organisation
  - Timescales and data governance
  - Monitored by **Euclid Science Team** (Chair Project Scientist)
- *Multi Lateral Agreement*: gives the description of the commitment of each country / funding agency to the project signed by the participating countries
  - Monitored by **Euclid Steering Committee** (Chair: Project Manager)
- *Bi-Lateral agreement* with NASA
  - Joint Project Implementation Plan

Euclid Consortium

The Euclid Consortium will, as agreed in the MLA and SMP, provide:

- The VIS instrument
- The NISP instrument
- The Science Ground Segment
    - algorithms and related production pipeline software
    - infrastructure and data processing centres
    - data products
- Scientific requirements

Euclid

CONCEPT AND TRADE-OFFS

"IT WAS A LOT EASIER TO KEEP AN EYE ON THINGS BEFORE THE BIG BANG. EVERYTHING WAS ALL IN ONE PLACE THEN."

Spacecraft Engineering/Project development

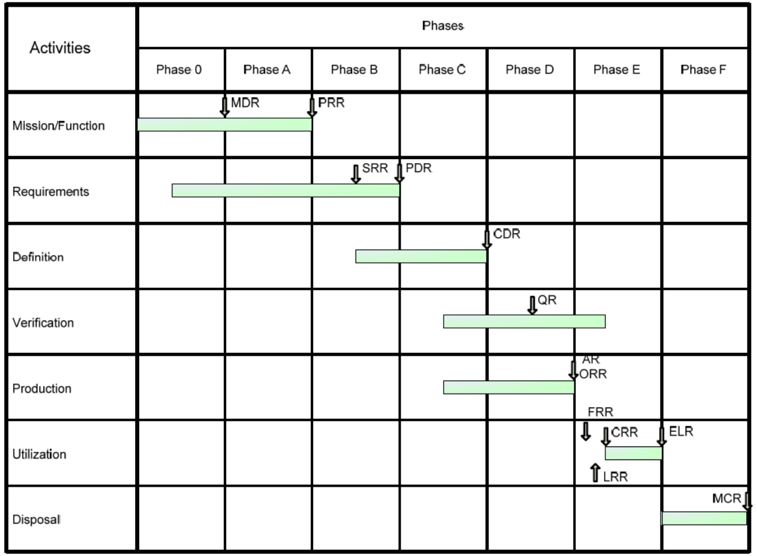
General Approach – involve following steps

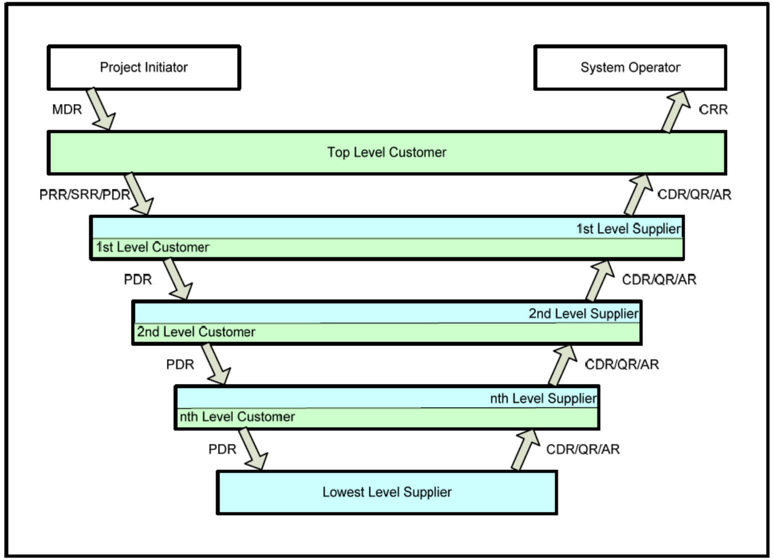
- Concept / assumptions -- involve boundary conditions
- Development Plan / Implementation Plan / Operation Plan
- Requirements and interfaces
- Design Solutions
- Implementation
- Testing
- Operation and maintenance

Spacecraft Engineering/Project Development

ECSS – European Cooperation for Space Standardisation

- ECSS is a cooperative effort of the European Space Agency, national space agencies and European industry associations for the purpose of developing and maintaining common standards.
- Requirements in this Standard are defined in terms of ***what shall be accomplished***, rather than in terms of how to organize and perform the necessary work.



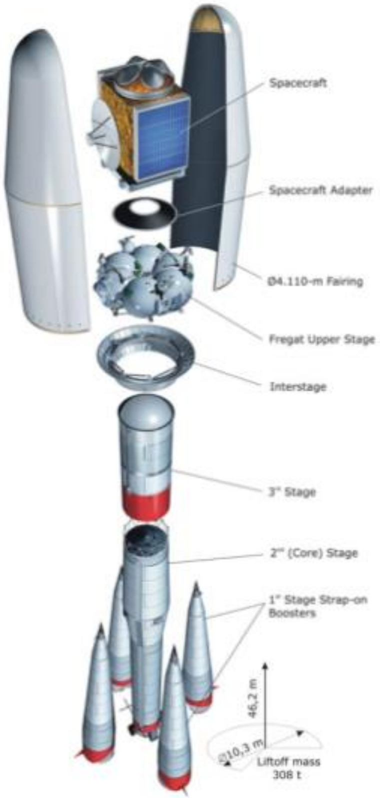


Boundary Conditions for Euclid

Should be a benefit for (European) Science and European space industry, according to equal return

- **M-class mission:**
  - Launch slots in 2017 and 2018
  - ESA costs should be less than 450 ME
  - Technology Readiness Level TRL > 5 at end of definition phase for satellite and payload components and subsystems
- **Foreign partners can be considered for a more expensive solution:**
  - Depending on the "stakeholders" / communities
  - To enable non-European technologies
- **European Launch → Soyuz 2-1B was then the only option:**
  - Mass limited by launch capacity of Soyuz

- Further important constraints from:
  - Available industrial companies with sufficient proven expertise in Europe (e.g. Mersen Boostec for SiC)



Trade offs: orbit selection

Assuming a Launch with Soyuz 2-1b from French Guyana

	Small Lissajous around SEL2	Free insertion libration around SEL2	HEO (low perigee)	HEO (high perigee)	GEO
Δv (deterministic)	200 m/s Long transfer time (depending on Lissajous amplitude, 1-3 months)	**0 m/s** Science ops can start typically 30d after launch	75m/s Short transfer	400 m/s Short transfer	1478 m/s Short transfer (1 day)
Heritage	Planck, GAIA	Herschel, LPF	Integral (10000/152000/51.6)	No heritage	Hipparcos (failed to reach)
Soyuz capacity	2146 kg	2146 kg	2360 kg	2270 kg	1300 kg for direct injection 2730 kg from GTO, with SC propulsion module (apogee engine)
Mass after injection	2013 kg	2146 kg	2304 kg	2010 kg	1300 kg for direct injection 1723 kg from GTO
Sky viewing	Earth and Moon never seen by the telescope	Earth and Moon never seen by the telescope	Some occultation by Earth +Moon	Some occultation by Earth +Moon	Some occultation by Earth +Moon
Eclipses	No eclipse for 6 years, moon eclipses possible	None	Seasonal Earth-Sun daily eclipses Moon-Sun eclipses : marginal occurrence	Seasonal Earth-Sun daily eclipses Moon-Sun eclipses : marginal occurrence	Seasonal Earth-Sun daily eclipses Moon-Sun eclipses : marginal occurrence

$\Delta v = v_e \ln(m_o/m_1)$ – rocket equation – note: LHC/ATLAS is 7000 tonnes!

Stability and orbit control

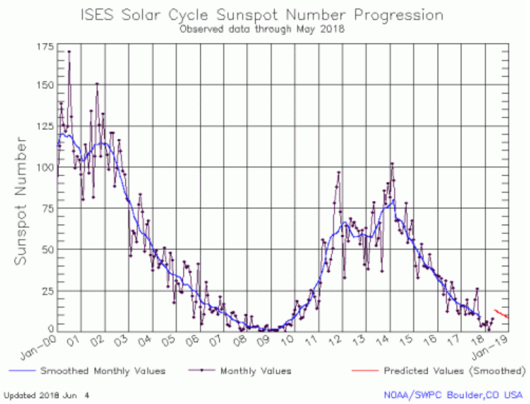
- AOCS = attitude and orbit control system → to maintain orbit stability

	SEL2 orbits	GEO	HEO
FDIR aspects			
Failure detection	Easy and robust	Medium	Worst case
Failure correction	Easy	Medium	Highest cost
Disturbances			
Gravity gradient	None	Residual, but changing with time and orientation	Sizing at perigee for the 3-day orbit
Earth magnetic field	None	Very small, but changing unevenly	Variable over the orbit for low perigee case, high perigee case similar to GEO
Effect of Moon	None	Negligible (TBC)	Negligible (TBC)
Thermal perturbations (impacting AOCS)	None	Small but not static	Variable over the orbit for low perigee case, high perigee case similar to GEO

Orbit details

- The launch will be on a Soyuz 2-1b from French Guiana

- The trajectory is a direct ascent trajectory without a drift phase
  - The direct ascent provides the maximum performance
  - All orbital parameters are free except the apogee altitude

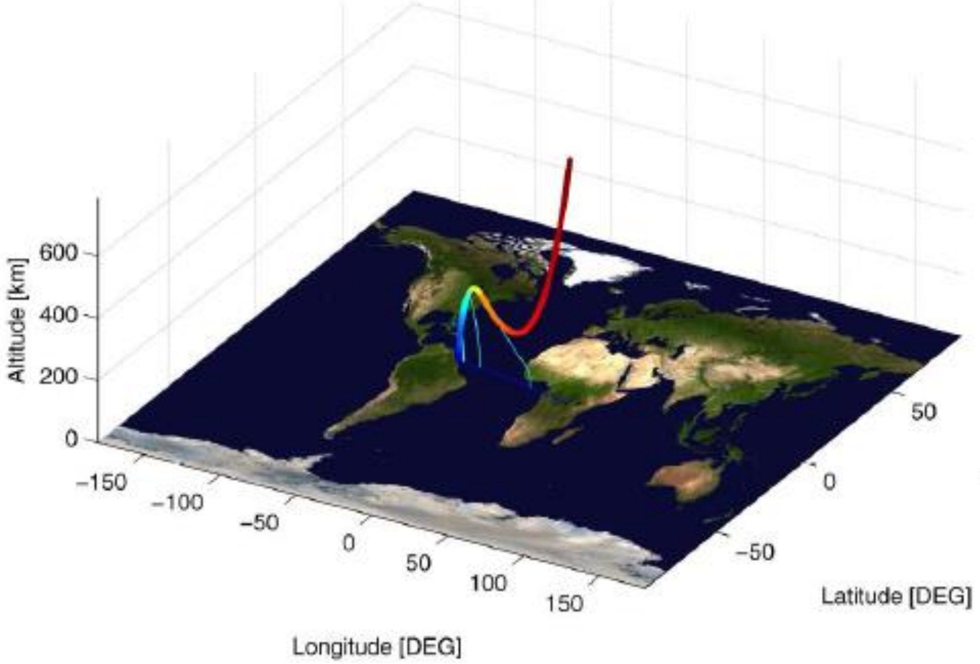


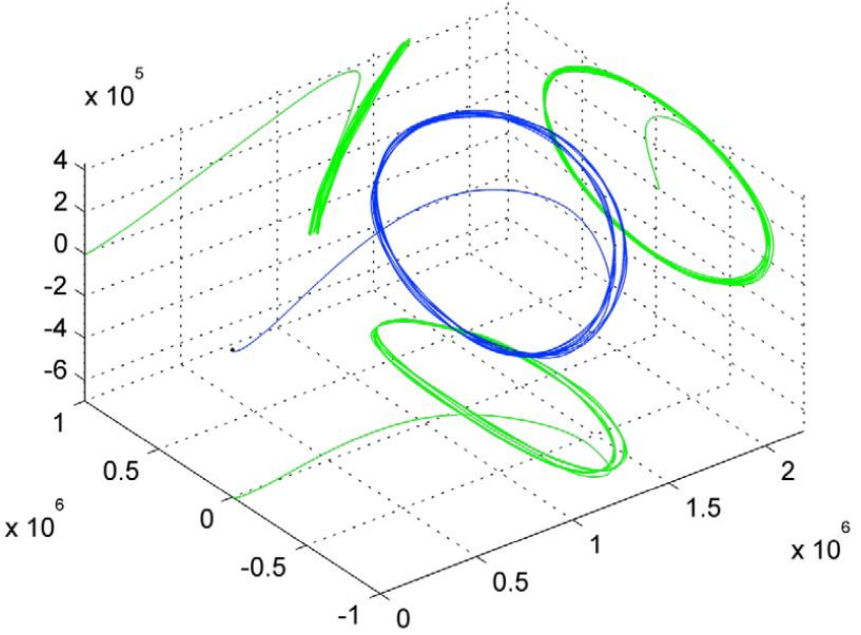
- The daily launch window is constrained by
  - Size of the science orbit defined by the Sun-S/C-Earth angle
  - Illumination constraints
  - Maximum deviation of the required perigee velocity from the launcher flight program
  - Eclipses during transfer and operational orbit

Operational orbit

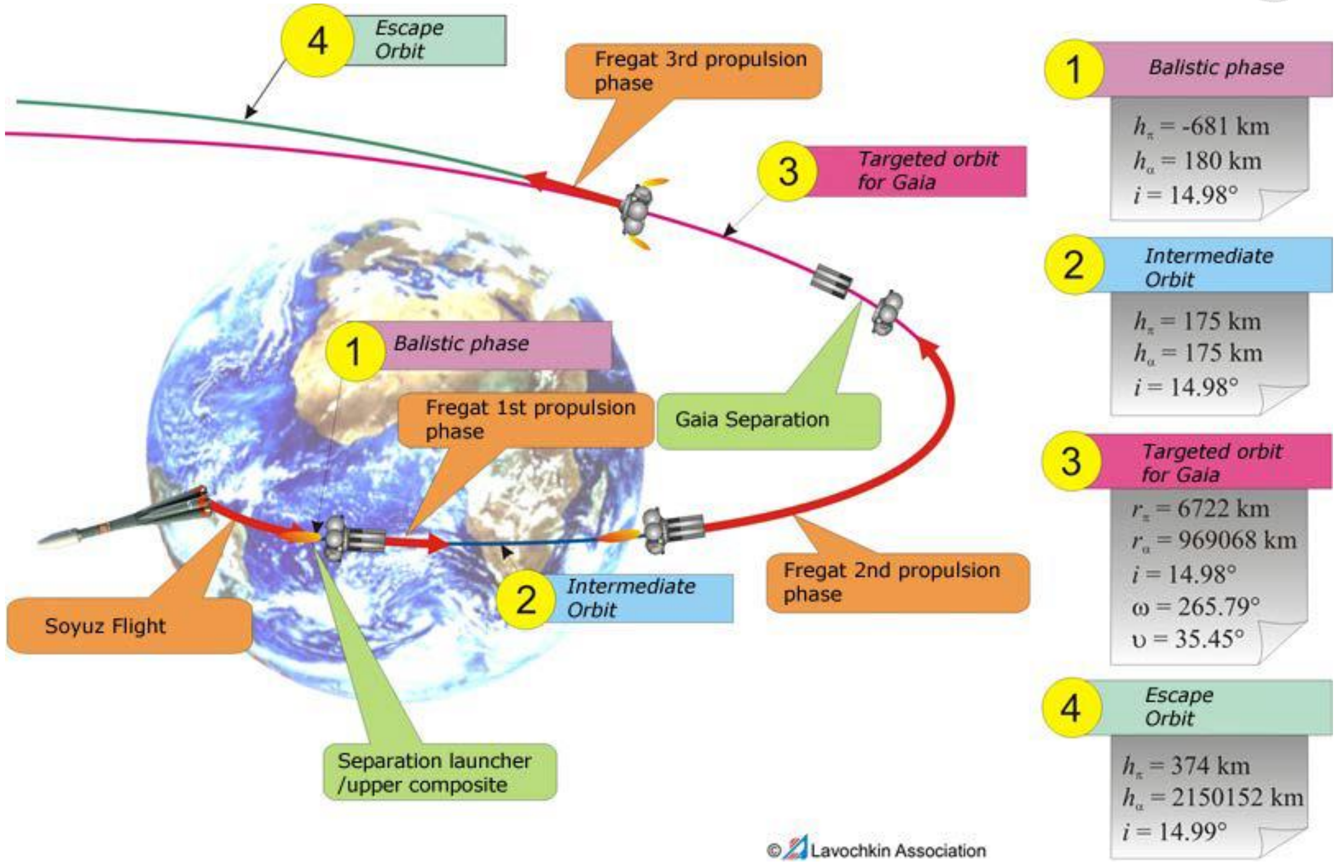
Large amplitude orbit around the SEL2 point:

- ➢ High thermal stability
- ➢ Communication distance is limited
- ➢ Unobstructed observations in one hemisphere

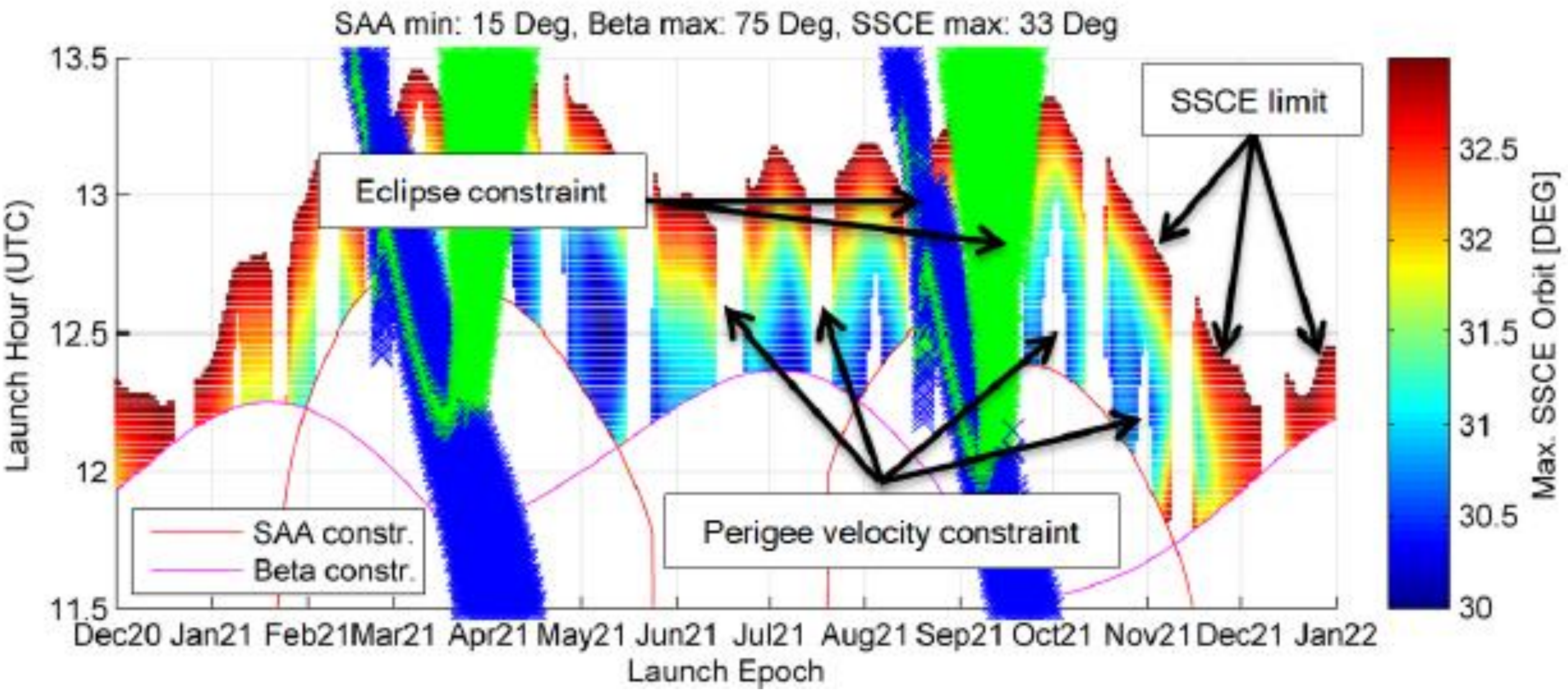




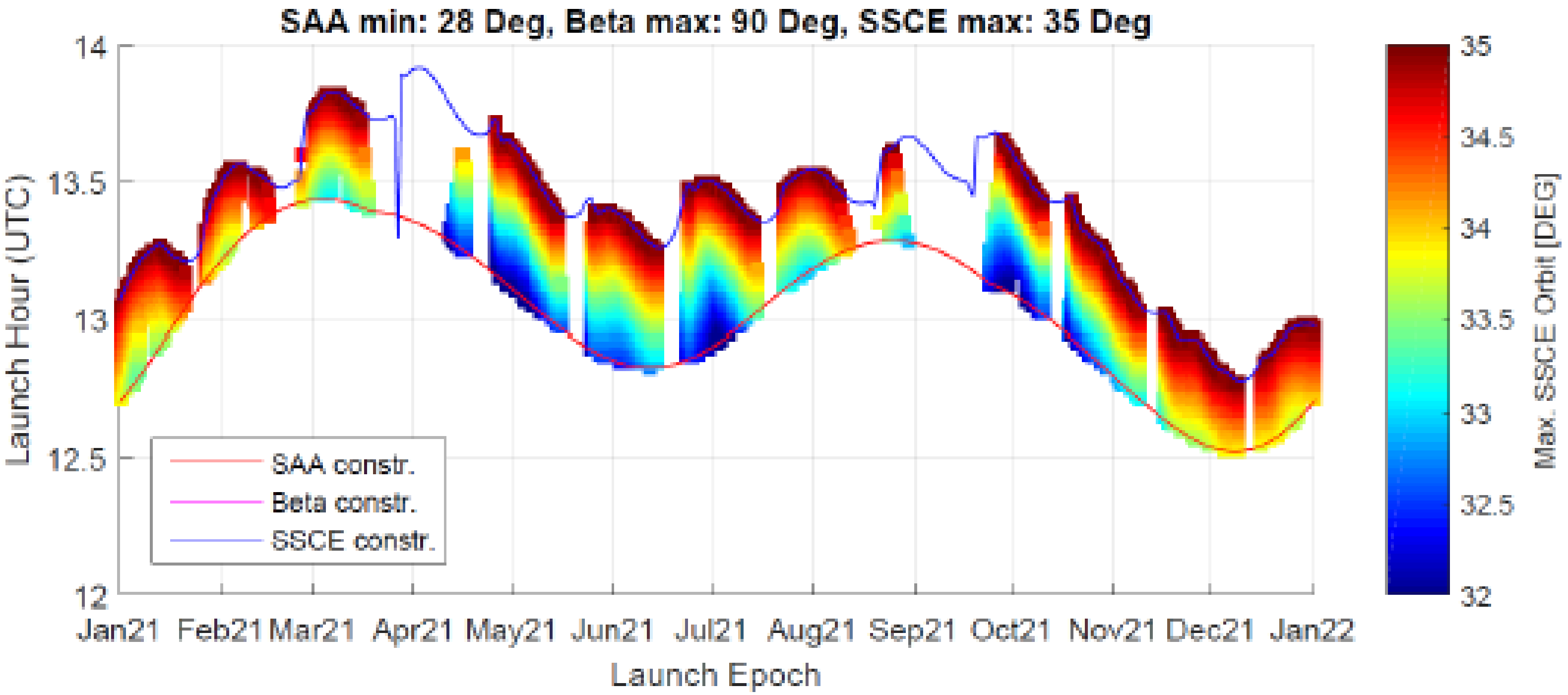
Typical SEL2 launch sequence (Gaia)



Launch opportunities



Present launch date: end 2021- end 2022

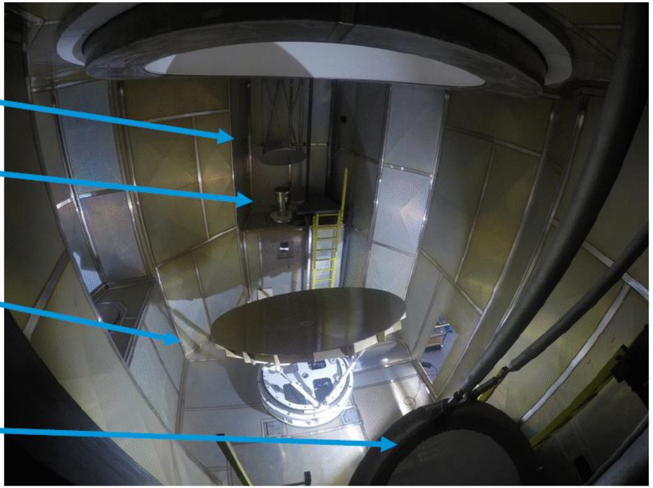


Trade Offs: telemetry

- X-band (for housekeeping)
- K-band with 850 Gb/4hours (~60 Mbps) for science data → new for ESA, need new hardware

Band	Frequency	Bandwidth	Comments
S-band	2200-2290 MHz	6 MHz/mission	Max symbol rate 6 Msps Band quite congested, complex frequency coordination
X-band	8450-8500 MHz	10 MHz/mission	Max symbol rate 10 Msps Using GMSK and standard coding, max data rate of 5-8 Mbps 10 Mbps easier with dual polarisation Use from GEO quite restricted
X-band EES	8025-8400 MHz	375 MHz	Enabling high data rates > 100 Mbps But strictly reserved for Earth Exploration missions
K-band	25.5-27 GHz	1.5 GHz	No bandwidth restrictions but efficient use encouraged For L2 missions requiring > 5 Mbps "Hardware limit" at 100 Mbps (200 MHz clock-frequency)
Ka-band	31.8-32.3 GHz	500 MHz	Strictly reserved for Deep Space missions
Ka-band	37-38 GHz	1 GHz	Manned planetary exploration Shared with fixed satellite services (telecom)

Cebreros upgrade for K-band



- Mirror M9
- X/K-band feed (new)
- Movable M5
- Dichroic mirror M7 (legacy)
- X-band feed (legacy) behind M7

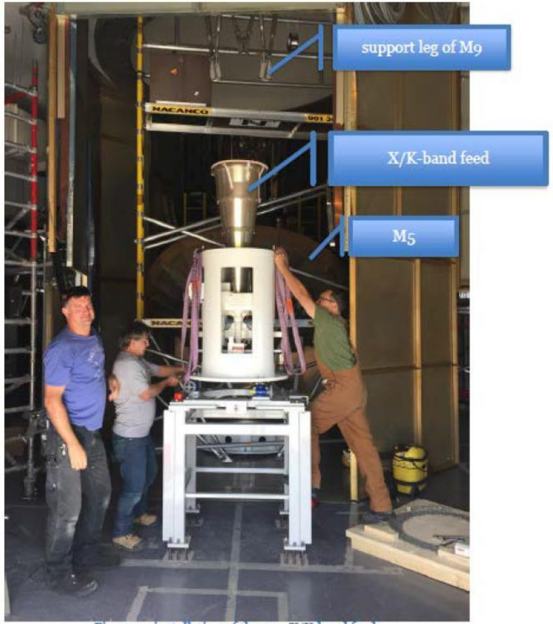


Figure 2 - installation of the new X/K-band feed.

Trade-offs: Aperture, Mass and costs

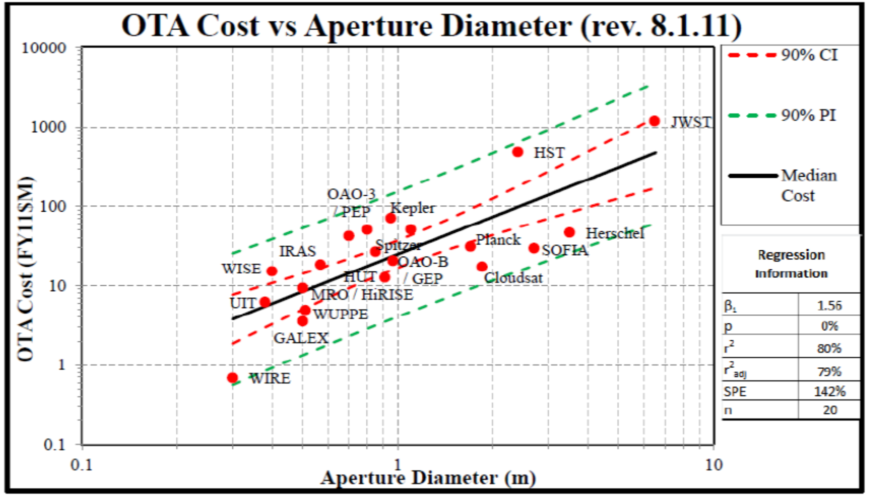
OTA = optical telescope assembly

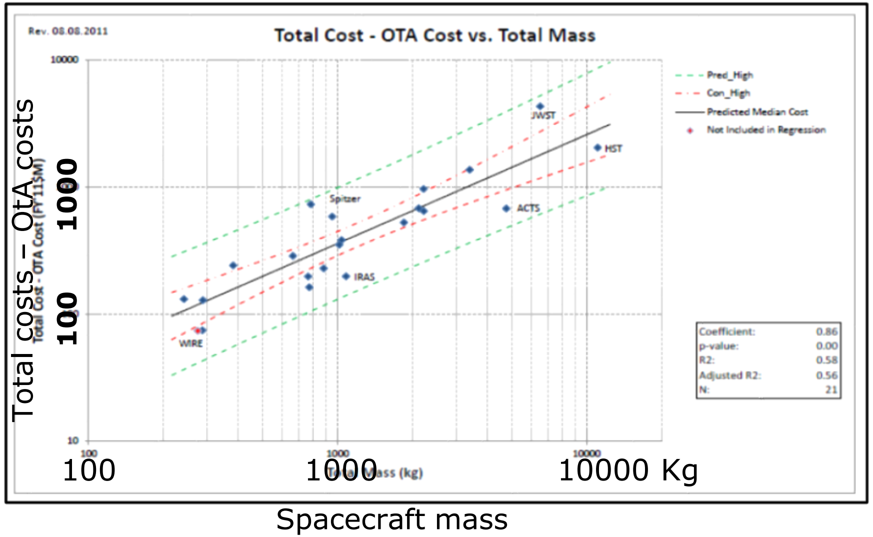
→ **OTA Cost ~ $D^{1.7}\lambda^{-0.3}T^{-0.25}$**

Where, D=diameter, λ= diffraction limited wavelength, T= temperature of OTA

→ (**Total costs –OTA costs**) ~ **$Mass^{0.9}$**

Stahl, H.P., et al (2012, NASA publication)





Trade-off: Telescope Size

Telescope size was fixed at 1.2 m at an early stage

- Monolitic SiC design – max diameter of 1.2 m possible
- Zerodur design – no max diameter, but constrained by mass and minimum temperature
- The science requirements did not impose larger size telescope
    - Effective area = 1.00 m^2 (identical to that of Fermi satellite)

Euclid Science Concept

- Determine the dark energy equation of state, pressure over density, as a function of cosmic scale *a*:
  w(a) = P/ρ, a = 1/(1+z)
  - $w(a) = w_p + w_a(a_p - a)$
  - w_p is a measure of the *acceleration* of the Universe's expansion, and w_a is a measure of the *variation* of the acceleration.

  This gives us the dark energy Figure of Merit: $FoM = 1/(\Delta w_p \Delta w_a)$

  Aim: *FoM* > 400

- Determine the growth rate of structure formation $f \sim \Omega^{\gamma}$

  Aim: $\Delta\gamma < 0.02$

- General Relativity with a cosmological constant and cold dark matter (ΛCDM model) **predicts**:
  - **$w_a = 0$, $w_p = -1$, $\gamma = 0.55$**

  ...but this would be in contradiction with the standard model of particle physics. Euclid has sufficient precision to test any deviations in this triplet!

Euclid Design Concept

Optimize the mission for two complementary dark energy probes: galaxy clustering and weak lensing;
Minimum survey area of 15,000 deg^2 (36% of the total sky)
→ **6 year nominal mission**

Weak Lensing: → VIS imager + NIR imaging-photometer

- Shapes and shear of galaxies with a density of >30 galaxies/$arcmin^2$
- Minimum Systematics $\sigma^2_{sys} < 10^{-7}$
  - Very high image quality, high stability
- Redshift range 0<z<~2, accuracy dz/(z+1) < 0.05

Galaxy clustering → NIR slitless spectrometer

- H_alpha Redshifts for >1700 galaxies/deg^2
- Redshift range 0.9< z <1.8, accuracy dz/(z+1) < 0.001
- Same area as for WL→ line Flux limit < $2\ 10^{-16}$ erg $cm^{-2}s^{-1}$.

Euclid Design Concept → *challenges*

Optimize the mission for two complementary dark energy probes: galaxy clustering and weak lensing;

Minimum survey area of 15,000 deg^2 (36% of the total sky)

→ 6 year nominal mission → *exposure times, survey area, and viewing constraints are very tightly connected*

Weak Lensing: → VIS imager + NIR imaging-photometer

- Shapes and shear of galaxies with a density of >30 galaxies/arcmin^2 → ***limited by backgrounds & straylight***
- Minimum Systematics $\sigma^2_{sys} < 10^{-7}$
  - Very high image quality, high stability
- Redshift range 0<z<~2, accuracy dz/(z+1) < 0.05 → ***need ground based g,r,i,z photometry***

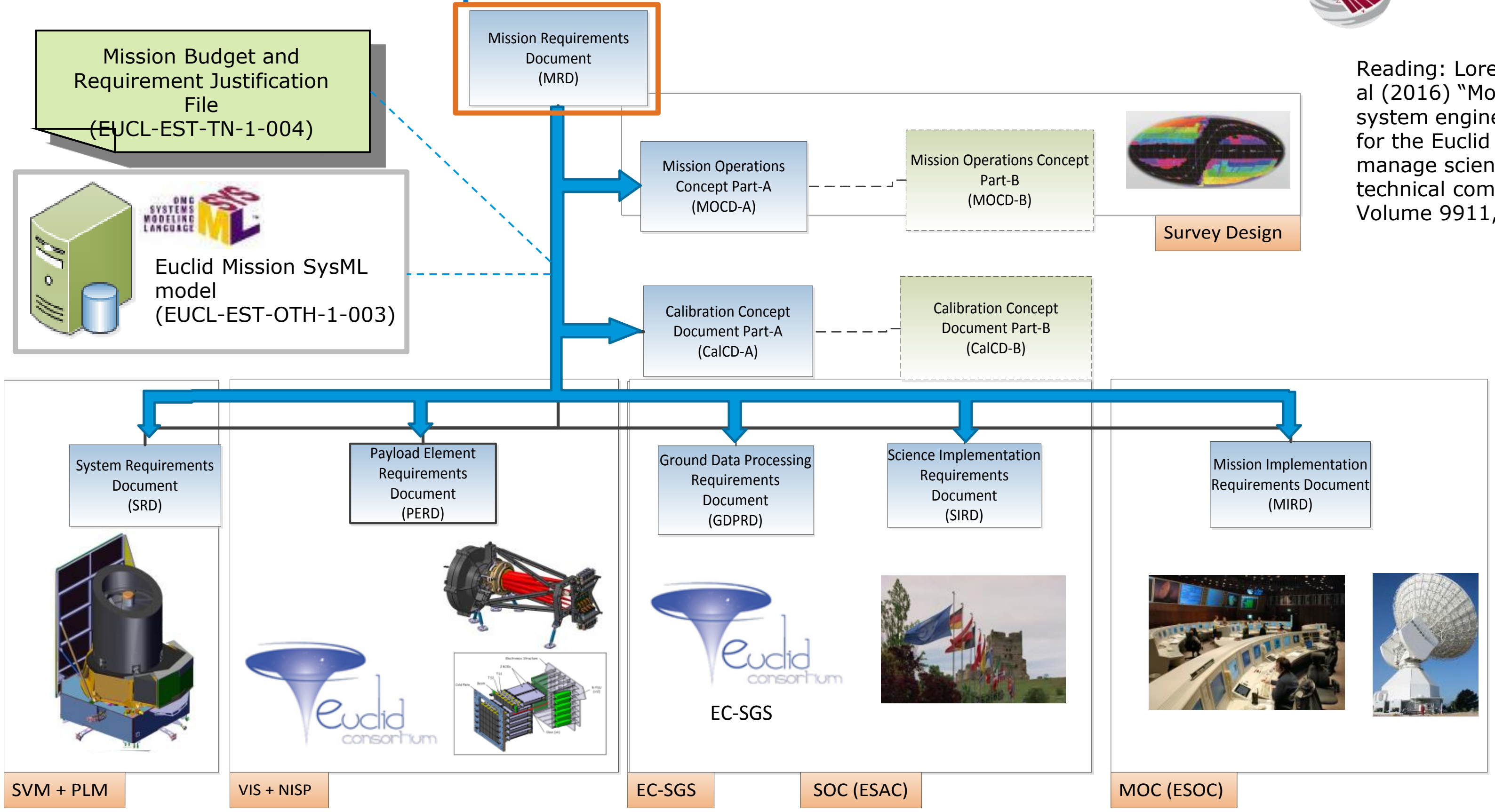
Galaxy clustering → NIR slitless spectrometer

- Redshifts for >1700 galaxies/deg^2 → ***purity & completeness limited by background level and source confusion***
- Redshift range 0.9< z <1.8, accuracy dz/(z+1) < 0.001
- Same area as WL→ line Flux limit < 2 10^{-16} erg cm^{-2}s^{-1} → ***VIS and NISP-S exposure times are identical***

Euclid

REQUIREMENTS ENGINEERING

Euclid Mission: Requirements flow down



Reading: Lorenzo Alvarez, et al (2016) "Model-based system engineering approach for the Euclid mission to manage scientific and technical complexity" SPIE, Volume 9911, id. 99110C

Requirements engineering

MRD top-level functional requirements

Functions
- Perform Wide Survey: 15,000 deg2
- Perform Deep Survey: 40 deg2
- Visible imaging
- Near-Infrared Slitless Spectroscopy
- Near-Infrared Photometry
- Provide mission data products in a Euclid Legacy Archive (ELA)

Architecture
- Space Segment
  - Single Telescope
  - VIS Instrument provided by EC
  - NISP Instrument provided by EC
- Ground segment
  - MOC at ESOC
  - SOC at ESAC
  - EC-SGS
  - GSN with X & K-band capability
- Launch Segment
  - Soyuz Launcher

Mission
- Science Lifetime 6 years
- L2 orbit

Agency Constraints
- ECSS Standards
- Decommissioning
- Passivation

Requirements engineering

MRD Main Weak-Lensing Science requirements

Galaxy Shape Measurement

Galaxy sample selection

- **Survey size**
  - 15,000 deg^2
  - 85% survey efficiency
- **Average Galaxy density 30 deg^2**
  - Sensitivity: mAB = 24.5 (10σ)
  - Straylight <20% Zodiacal
- **Median redshit Z>0.8**
  - VIS spectral range 550-900mn

Measurement Bias Control

- **VIS PSF Shape**
  - FWHM < 0.18”
  - $\varepsilon_i < 0.15$
  - $\left(\frac{R_{PSF}}{R_{ref}}\right)^2 < 4$
- **VIS PSF knowledge**
  - $\frac{\sigma(R_{PSF})^2}{\langle R^2 \rangle} < 10^{-3}$
  - $\sigma(\varepsilon_i) < 2\times10^{-4}$
- **Distortion**
  - Residual < 0.003%
- **CTI effects**
  - $\sigma(\varepsilon_{NC})$ < 1.1x10-4
- **Shear Model bias**
  - Additive $\sigma[c]$ < 5x10-4
  - Multiplicative $\sigma[\mu] < 2\times10^{-3}$

Photometric red-shift determination

- **Photo-z precision and uncertainty**
  - $\sigma(z)/(1+z) < 0.05$
  - $\sigma(\langle z \rangle)/(1+z) < 0.002$
  - $f_{cat} < 10\%$
- **Image quality**
  - Encircled Energy
  - Pixel scale: 0.3”/pix
- **Sensitivity**
  - m_{AB} = 24 (5σ) in all bands
- **Calibration**
  - Relative Photometric error post-calibration <1.5%
- **Number of photo-z bins**
  - NISP-P wavelength range
  - 3 Euclid NIR bands
  - External g,r,i,z data under EC responsibility

Requirements engineering

MRD Main Weak-Lensing Science requirements

Galaxy Shape Measurement

Galaxy sample selection

- Survey size
  - 15,000 deg^2
  - 85% survey efficiency
- Average Galaxy density 30 deg^2
  - Sensitivity: mAB = 24.5 (10σ)
  - ~~Straylight <20% Zodiacal~~
- Median redshit Z>0.8
  - VIS spectral range 550-900mn

Measurement Bias Control

- VIS PSF Shape
  - FWHM < 0.18″
  - $\varepsilon_i < 0.15$
  - $\left(\frac{R_{PSF}}{R_{ref}}\right)^2 < 4$
- VIS PSF knowledge
  - $\frac{\sigma(R_{PSF})^2}{\langle R^2 \rangle} < 10^{-3}$
  - $\sigma(\varepsilon_i) < 2\times10^{-4}$
- Distortion
  - Residual < 0.003%
- CTI effects
  - $\sigma(\varepsilon_{NC}) < 1.1\times10^{-4}$
- Shear Model bias
  - Additive $\sigma[c] < 5\times10^{-4}$
  - Multiplicative $\sigma[\mu] < 2\times10^{-3}$
- Calibration
  - Relative Photometric error post-calibration <1.0%

Photometric red-shift determination

- Photo-z precision and uncertainty
  - σ(z)/(1+z) < 0.05
  - σ(<z>)/(1+z) <0.002
  - $f_{cat} < 10\%$
- Image quality
  - Encircled Energy
  - Pixel scale: 0.3″/pix
- Sensitivity
  - m_{AB} = 24 (5σ) in all bands
- Calibration
  - Relative Photometric error post-calibration <1.5%
- Number of photo-z bins
  - NISP-P wavelength range
  - 3 Euclid NIR bands
  - External g,r,i,z data under EC responsibility

Requirements engineering

MRD Main Galaxy Clustering Science requirements

Galaxy sample selection

- Survey size
  - 15,000 deg^2
  - 85% survey efficiency
- Average Number of galaxies
  3500 gal/deg^2
  - Flux limit Hα-line: $3x10^{-16}$ erg cm^{-2} s^{-1} @ 1600nm
  - Flux limit other wavelenghts: $3.6x10^{-16}$ erg cm^{-2} s^{-1}
- Galaxy redshift distribution
  - Completeness > 45%
- Median redshit
  0.7<Z<2.05
  - NISP-P spectral range 1100-2000nm

Spectroscopic red-shift determination

- Redshift (z) precision, uncertainty and systematic offset
  (see SciRD)
  - Wavelength error
  - NISP-S Imaging of the NISP-P field with sensitivity
    m_{AB} = 24 (5σ)
  - Spectral resolution > 250
- Redshift catastrophic error fraction
  f_{cat} < 0.2%
  And
  f_{cat} knowledge better than 1%
  - Z measurement purity > 80%
  - Subsample >140,000 galaxies with purity > 99%
  - External data under EC responsibility

Requirements engineering

MRD Main Galaxy Clustering Science requirements

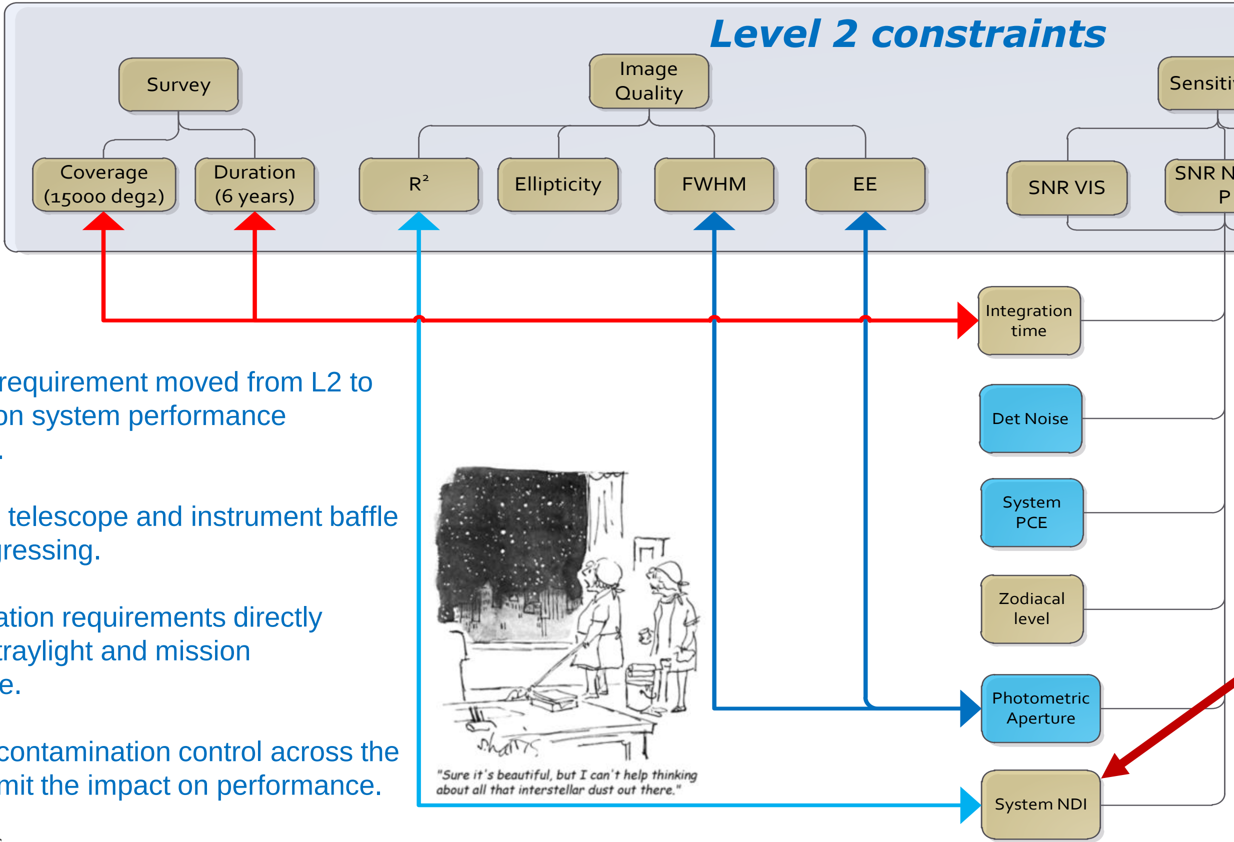
Galaxy sample selection

- **Survey size**
  - 15,000 deg^2
  - 85% survey efficiency
- **Mean surface density** of galaxies: **1700 gal/deg^2**
  - Flux limit Hα-line: **$2x10^{-16}$** erg cm^{-2} s^{-1} @ 1600nm
  - Flux limit other wavelenghts: **$2.4x10^{-16}$** erg cm^{-2} s^{-1}
- **Galaxy redshift distribution**
  - Completeness > 45%
- **Median redshit 0.9<Z<1.8**
  - NISP-P spectral range **1250-1850** nm

Spectroscopic red-shift determination

- **Redshift (z) precision, uncertainty and systematic offset** (see SciRD)
  - Wavelength error
  - NISP-S Imaging of the NISP-P field with sensitivity m_{AB} = 24 (5σ)
  - Spectral resolution > **380**
- **Redshift catastrophic error fraction** f_{cat} < 0.2% And f_{cat} knowledge better than 1%
  - Z measurement purity > 80%
  - Subsample >**120,000** galaxies with purity > 99%
  - External data under EC responsibility

Straylight requirements changed to level 3



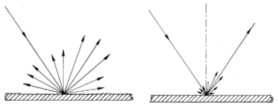
- Straylight requirement moved from L2 to L3: impact on system performance understood.

- Detectors, telescope and instrument baffle design progressing.

- Contamination requirements directly related to straylight and mission performance.

- Focus on contamination control across the system to limit the impact on performance.

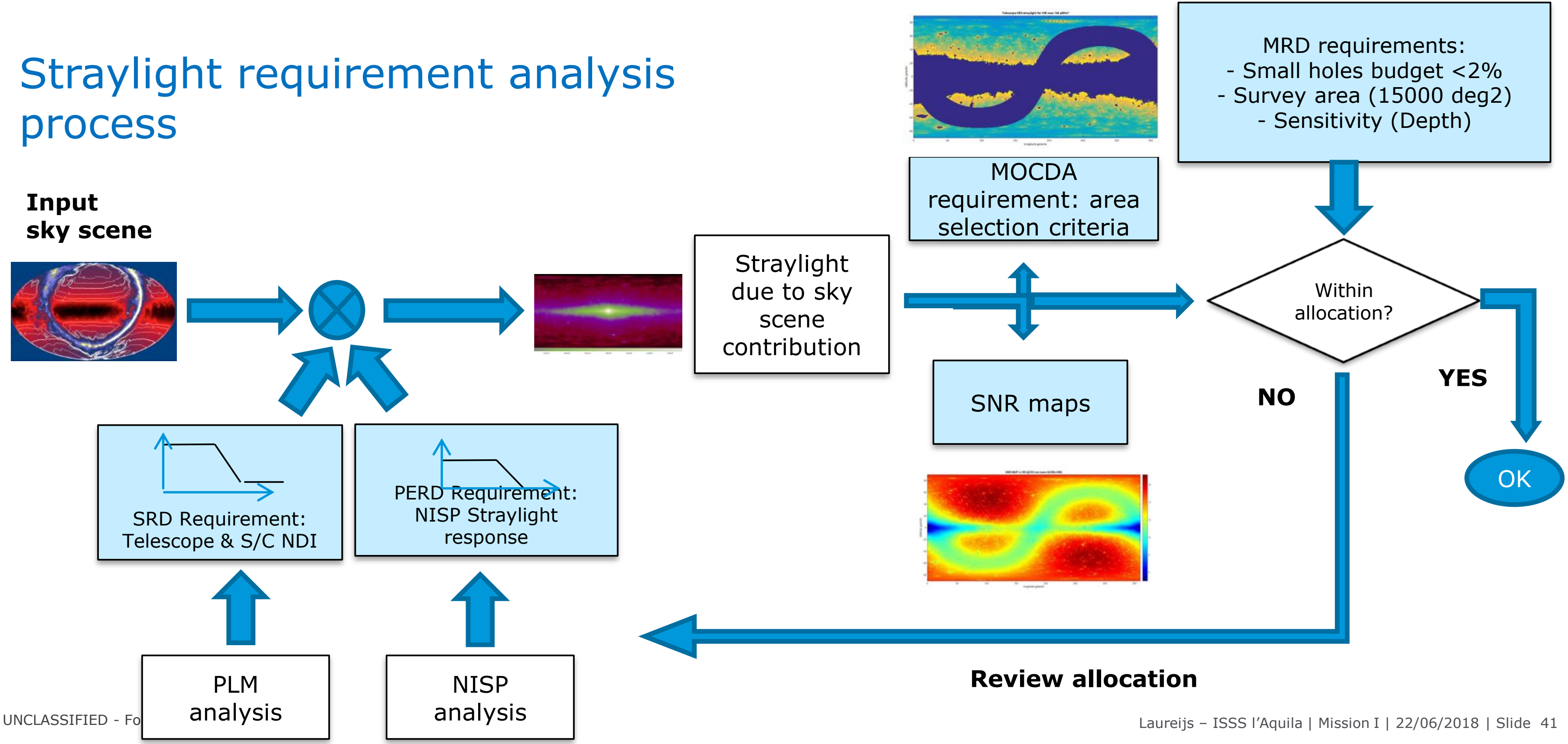
"Sure it's beautiful, but I can't help thinking about all that interstellar dust out there."



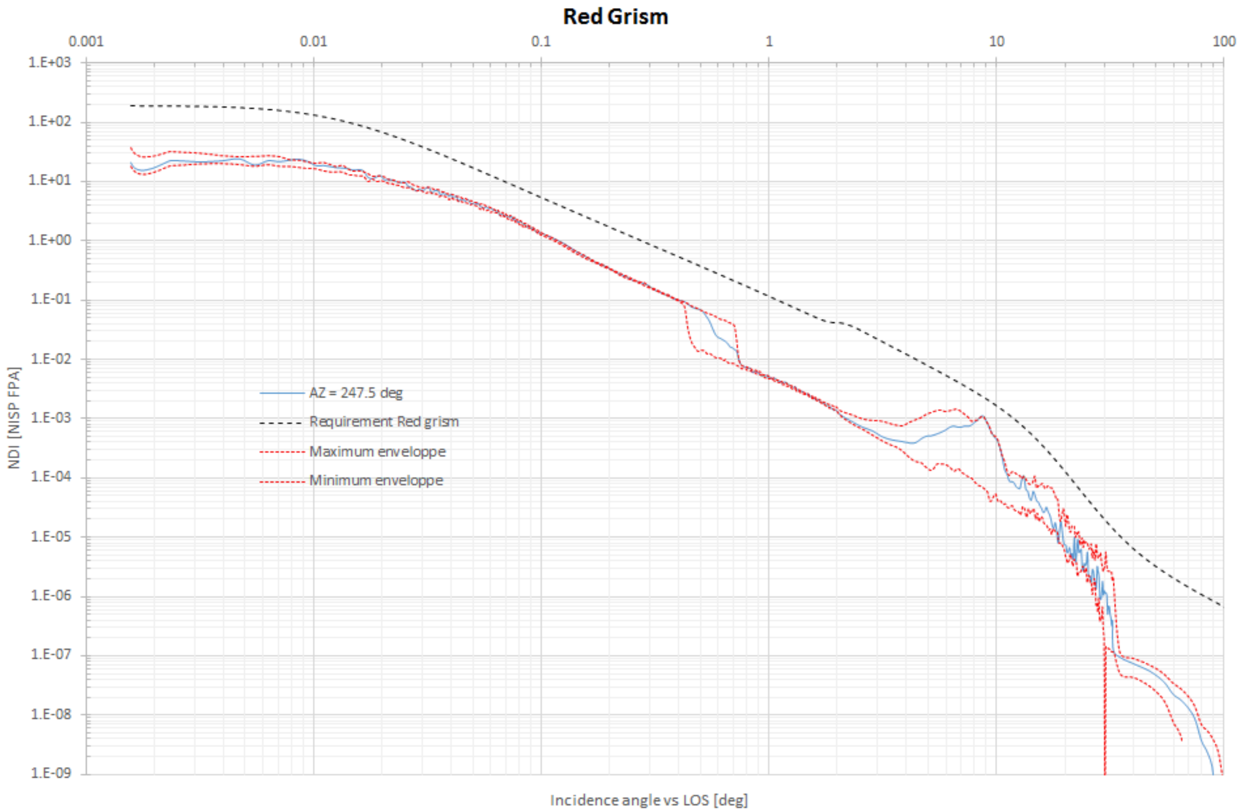
Controlled by Baffle design and Contamination levels

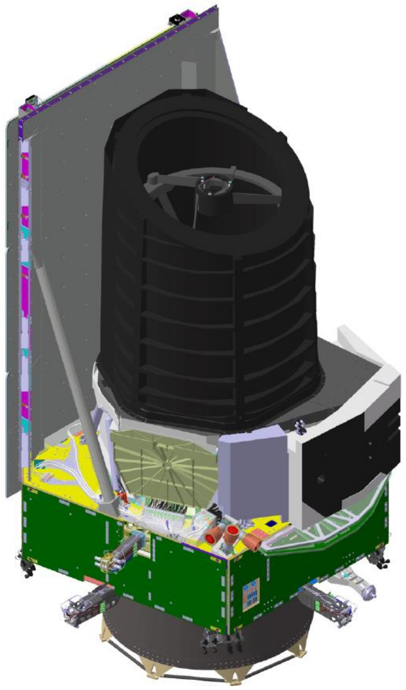
Straylight requirement change

Straylight requirement analysis process



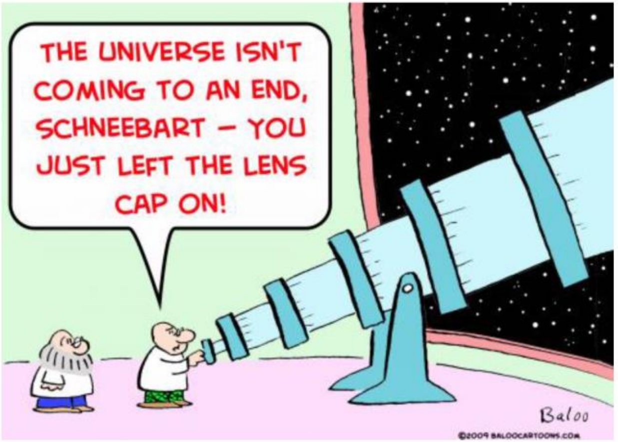
Latest NDI curve for the red grism channel





Euclid

DESIGN SOLUTIONS

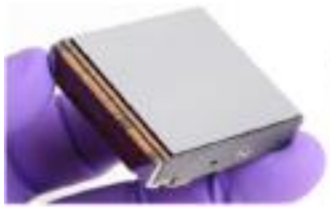


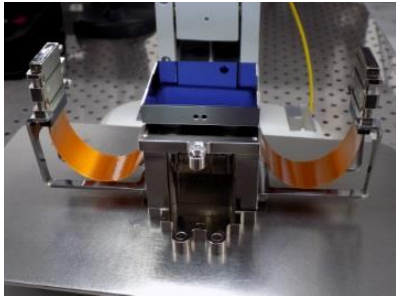
“Novel” System solutions (1)

- **SiC Homothetic design** for he payload: same coefficient of thermal expansion
  - All mirrors, baseplate, truss, brackets are made of SiC
- **Large FoV telescope** (0.8x0.7 deg), with large dichroic → Korsch TMA (**flat FPA**)
- **Stable pointing**: sophistic Attitude and Orbit Control System
  - Reaction wheels stop rotating during a science exposure
  - Optical gyroscope for stability at short time intervals
  - Fine Guidance Sensor using the telescope, with *absolute pointing* capabilities (to calibrate the startracker)
  - Cold pressurised gas for actuation during exposure
  - “compensating mechanism unit” to counter the NISP filterwheel torque

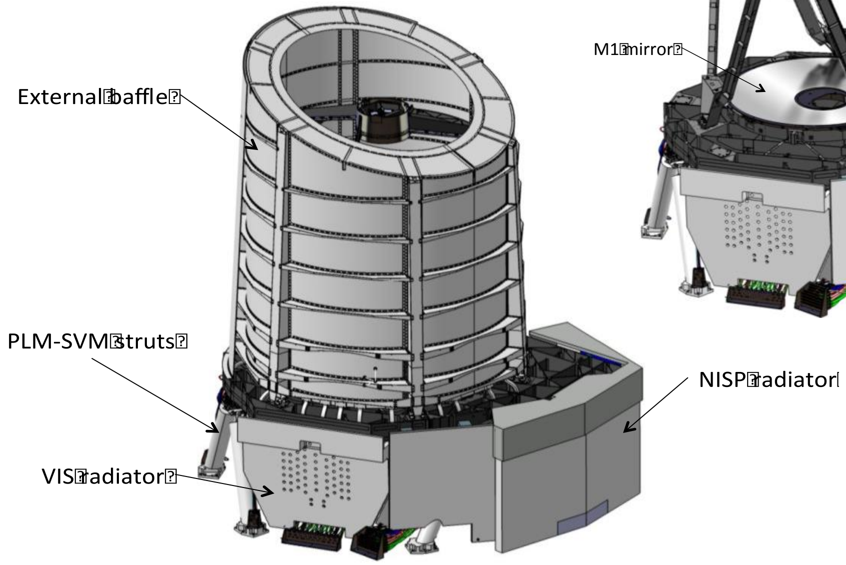
“Novel” System solutions (1)

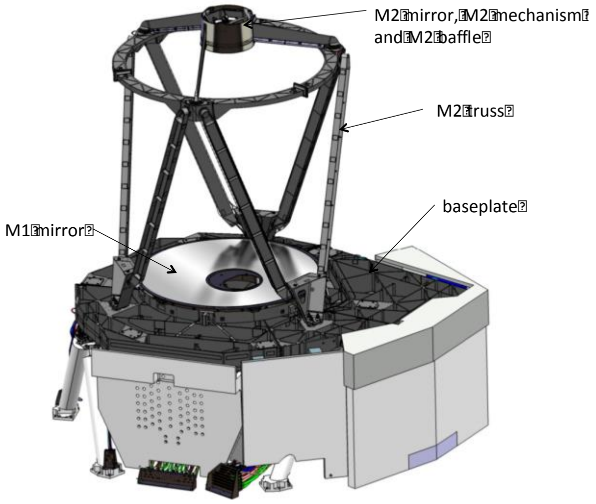
- **K-band operations** → 850 Gb/day (assuming 4 hours of station time)
  - New file transfer protocol between spacecraft and Earth (CFDP)
  - Use of flash memory
- **Customised Sensors**
  - Infrared: H2RG (HgCdTe) sensors with 2.3 micron cutoff (Teledyne + NASA)
  - Optical: CCDs e2v model 273 – better equipped against radiation, low CTI

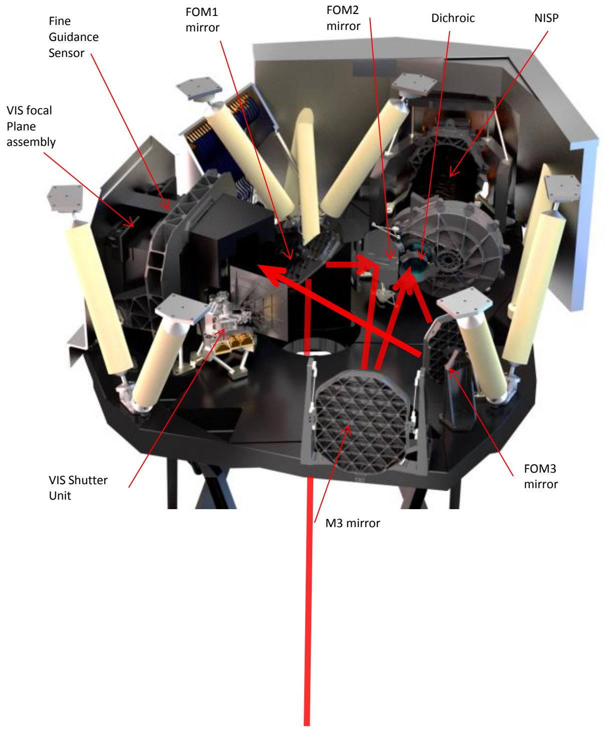


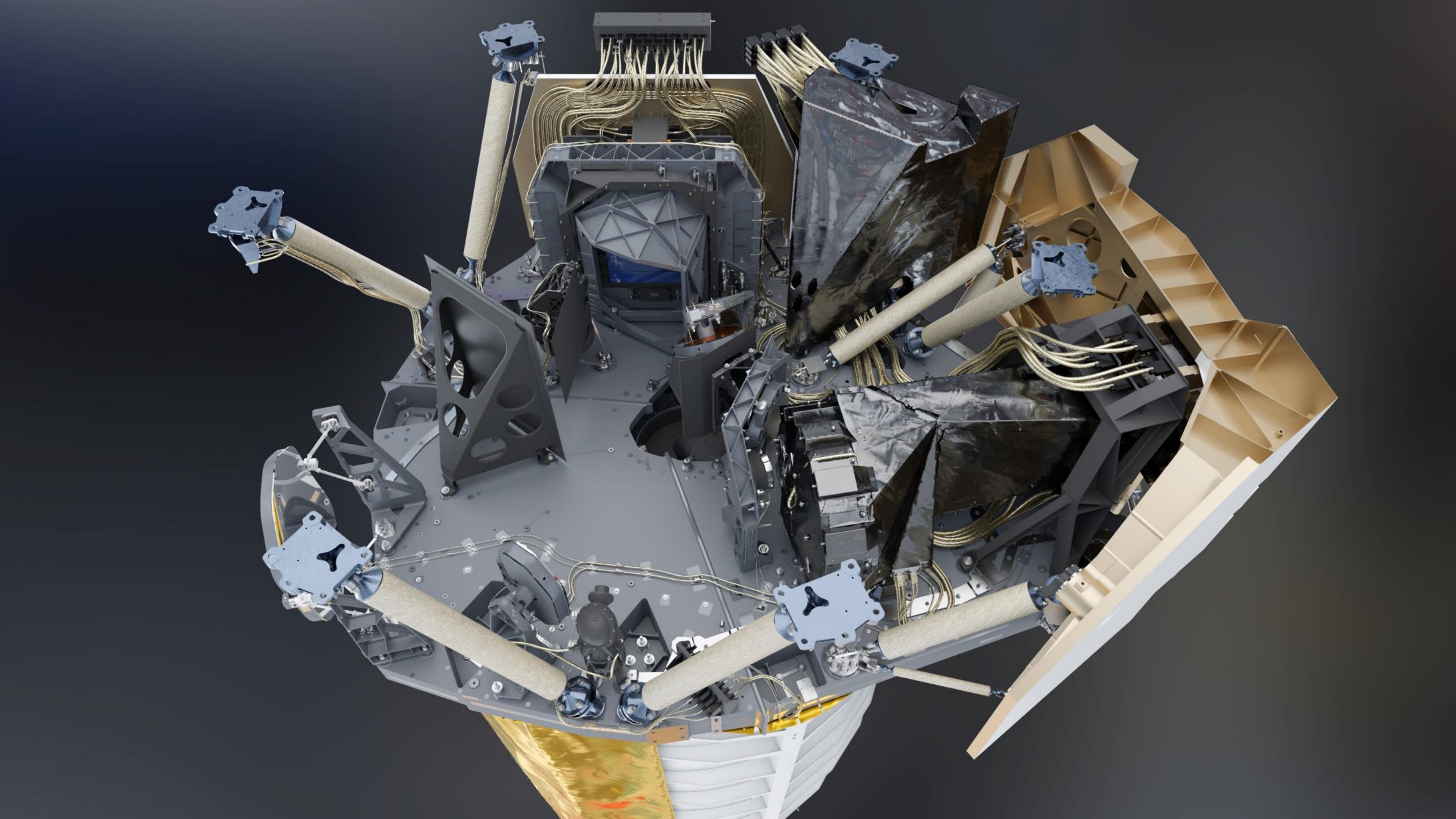



Mission Implementation (1): Payload Module

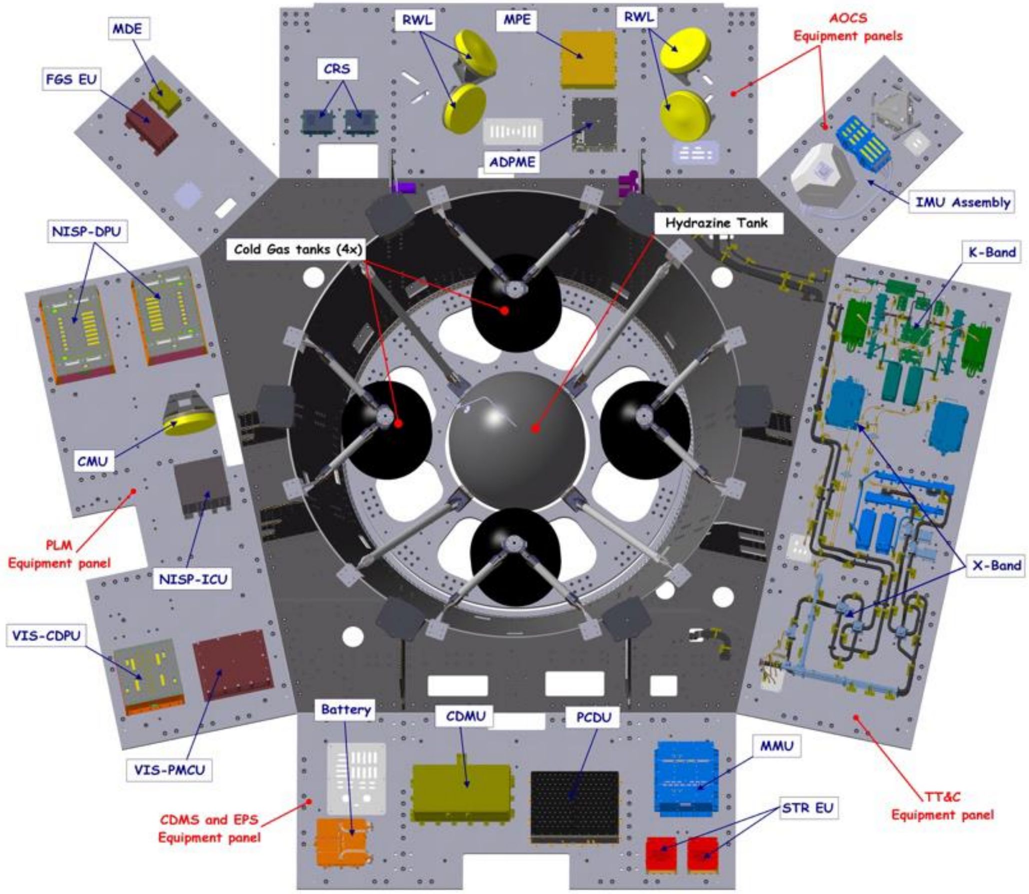


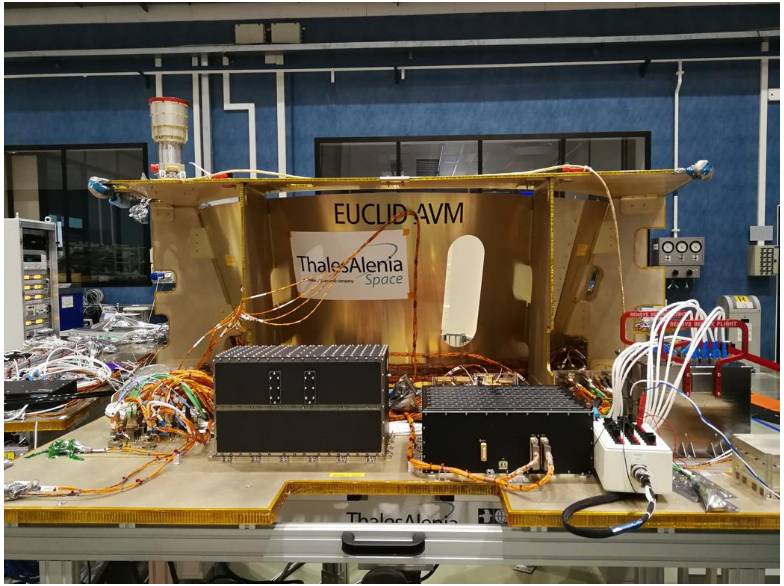




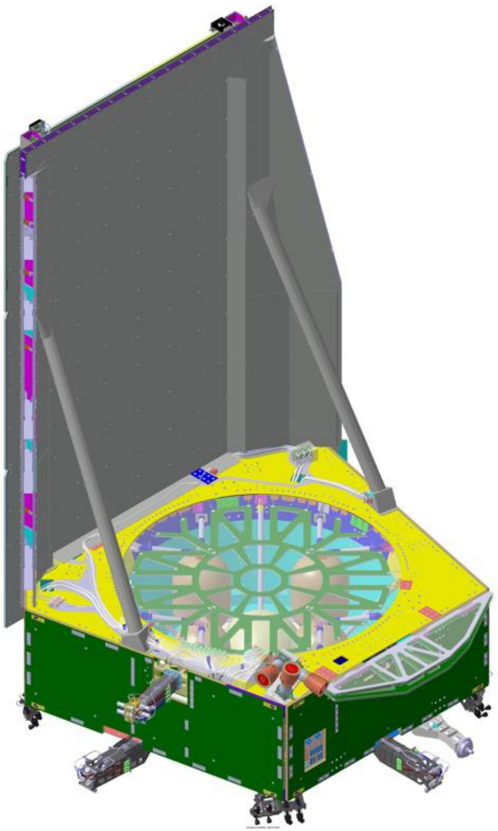


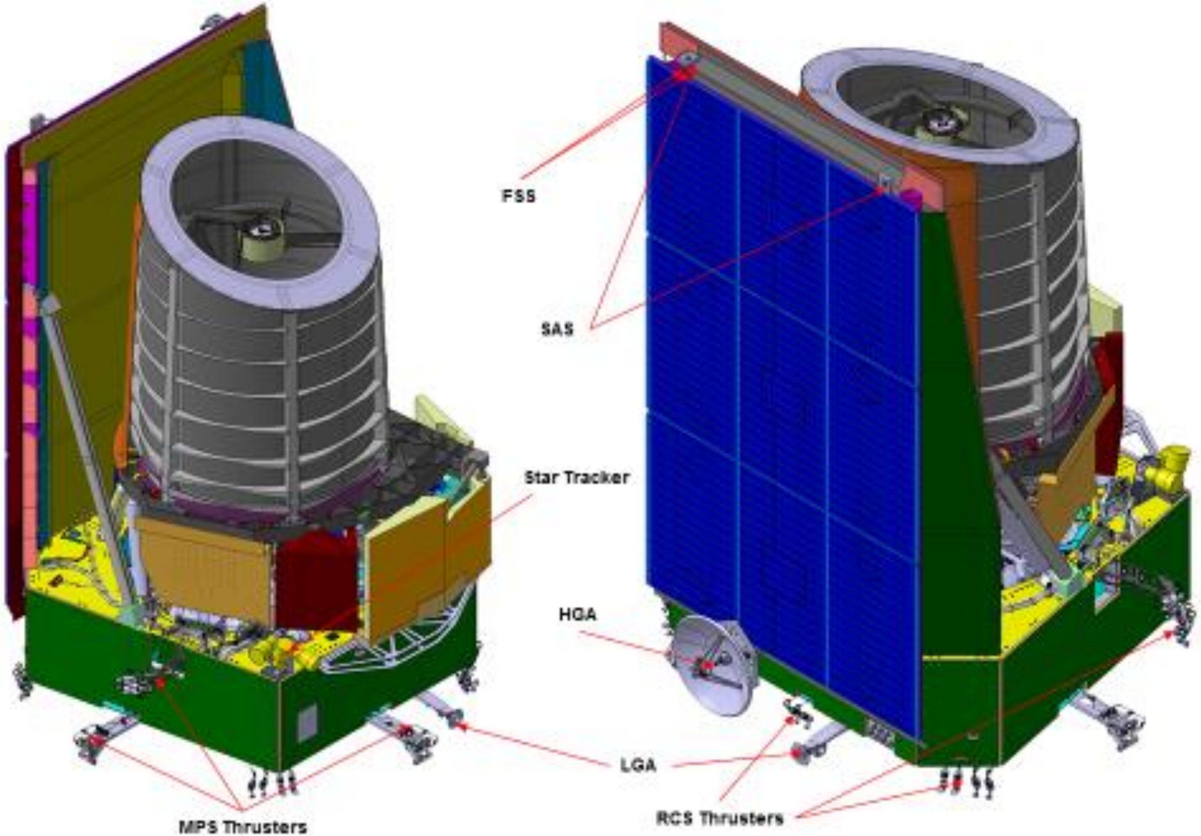
Mission Implementation (2): Service Module



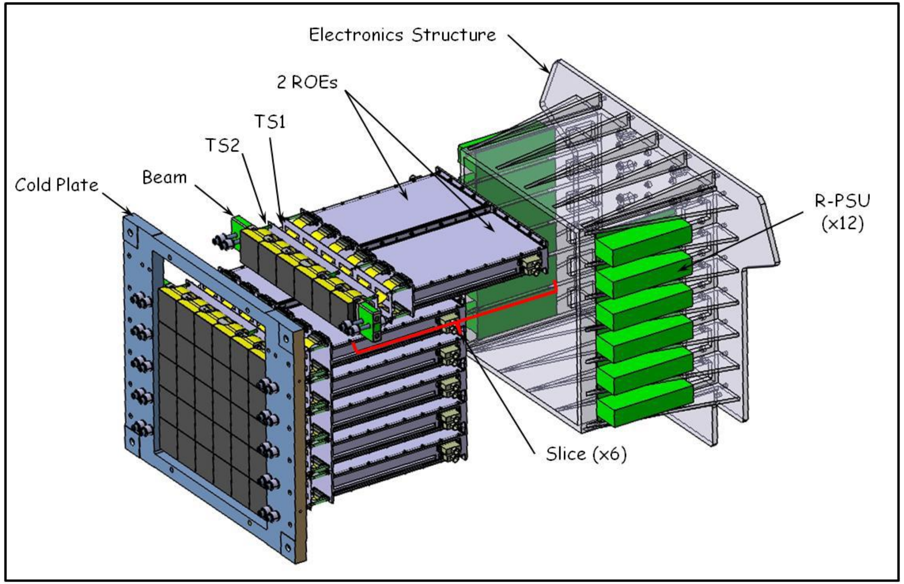


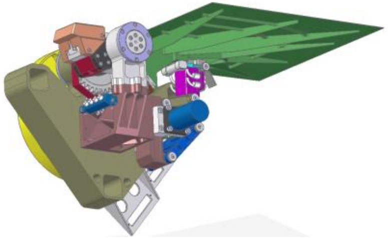
Mating of the SVM and PLM

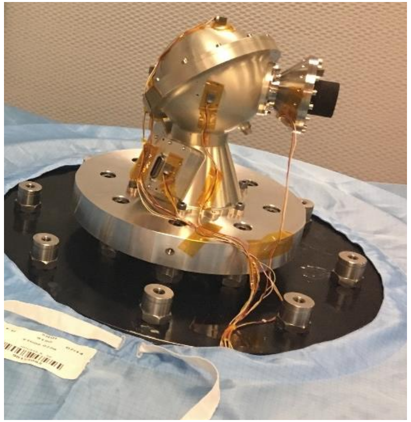




Instruments - VIS



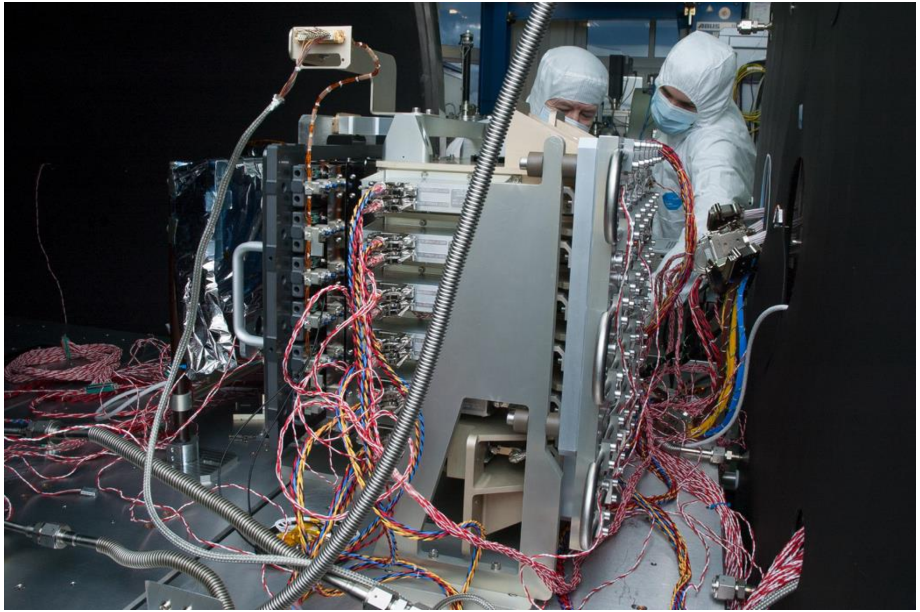


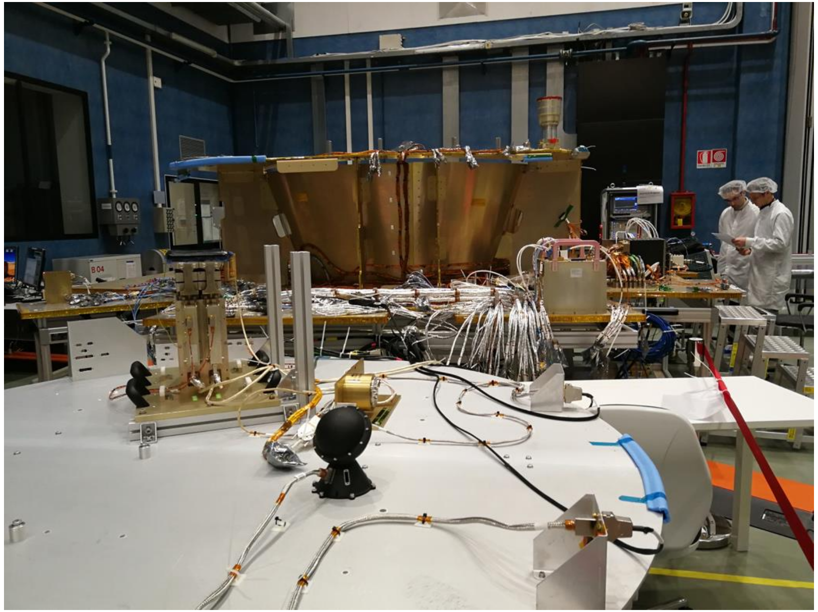


- Focal plane assembly, with read-out electronics, and power support units
- Shutter or door
- Calibration unit
- One wide band 0.55-0.90 micron

Instruments - VIS

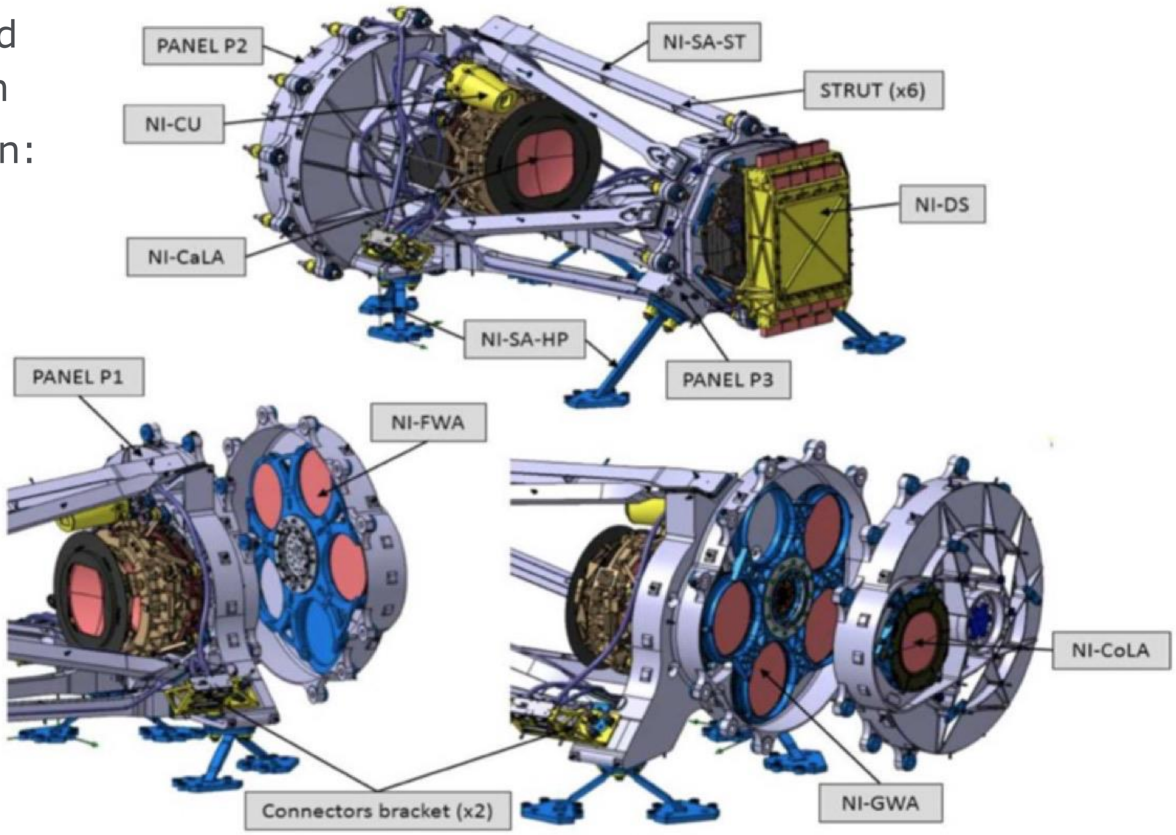
- STM FPA and the AVM parts





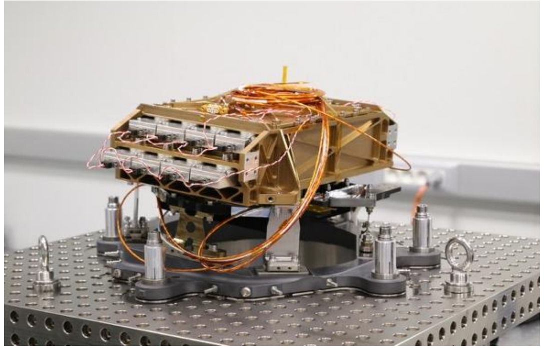
Instruments - NISP

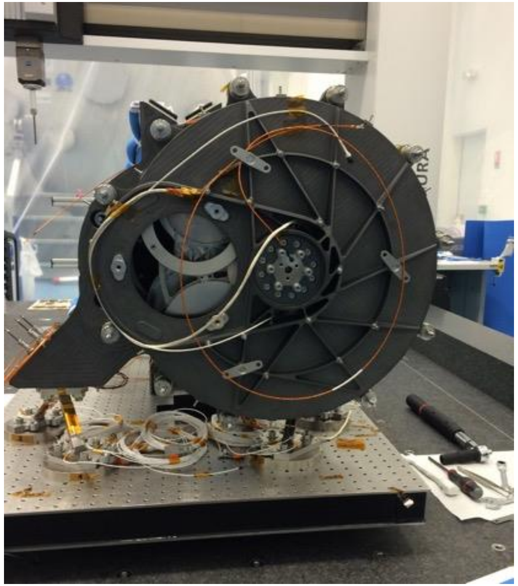
- ❑ Three Red grism with 0°; 90° and 180° dispersion: 1250 – 1850nm
- ❑ One Blue grism with 0° dispersion: 920 – 1300nm
- ✓ Y Band: 950 – 1192nm
- ✓ J Band: 1192 – 1544nm
- ✓ H Band: 1544 – 2000nm



Instruments: NISP STM parts

- STM = structural thermal model





System Performances

Pointing	Attitude range	87° < SAA < 121°, -8° < a <8°	
		Requirement	*Performance*
	Absolute Pointing Error (APE) 99.7% CL	7.5 arcsec,	6.25 arcsec on X, and Y
	Relative Pointing Error (RPE) 99.7% CL	75 mas / 700 s	70.5 on X , 47.3 on Y
Survey	No. of fields, dithers, large slews	60,000 fields, 4 dithers per field (≤100"), 16 large slews per month	
	Max accumulated maintenance time	2 months in 6 years	
	Field overlap	< 1% (99.7% CL)	
VIS Image quality		*Requirement*	*Performance*
	PSF FWHM (800 nm, 700 s)	< 0.155 arcsec	<0.141 arcsec
	PSF ellipticity (800nm, 700 s)	< 14%	<10.4%
	PSF R^2 (800nm, 700 s)	< 0.055 arcsec^2	<0.054 arcsec^2
	Ellipticity, R^2 variation (800nm, 11000 s)	< 2%	<0.4%
NISP Image quality	Maximum Encircled Energy (EE) radius	*50% / 80%*	*50% / 80%*
	@ 1033nm	19.2 nm / 43 nm	16.5 nm / 41.4 nm
	@ 2000nm	31.5 nm / 77 nm	27.1 nm / 75.6 nm

These are the performances derived by the prime contractor (TAS), for S-CDR

Survey Design

- The Euclid Collaboration is responsible for the survey plan according to
  - Scientific requirements for the **wide survey** and **deep survey**
  - Operational constraints
  - Calibration requirements (to remove instrumental effects)

- Wide Survey:15,000 deg2, in 6 year nominal mission
- Deep Survey: 40 deg2, 2 mag deeper than the wide survey
  - Ecliptic poles (2 fields)
  - Fornax field (1 field)

Euclid Survey Development

Euclid will survey 15,000 deg^2 in 6 years nominal mission

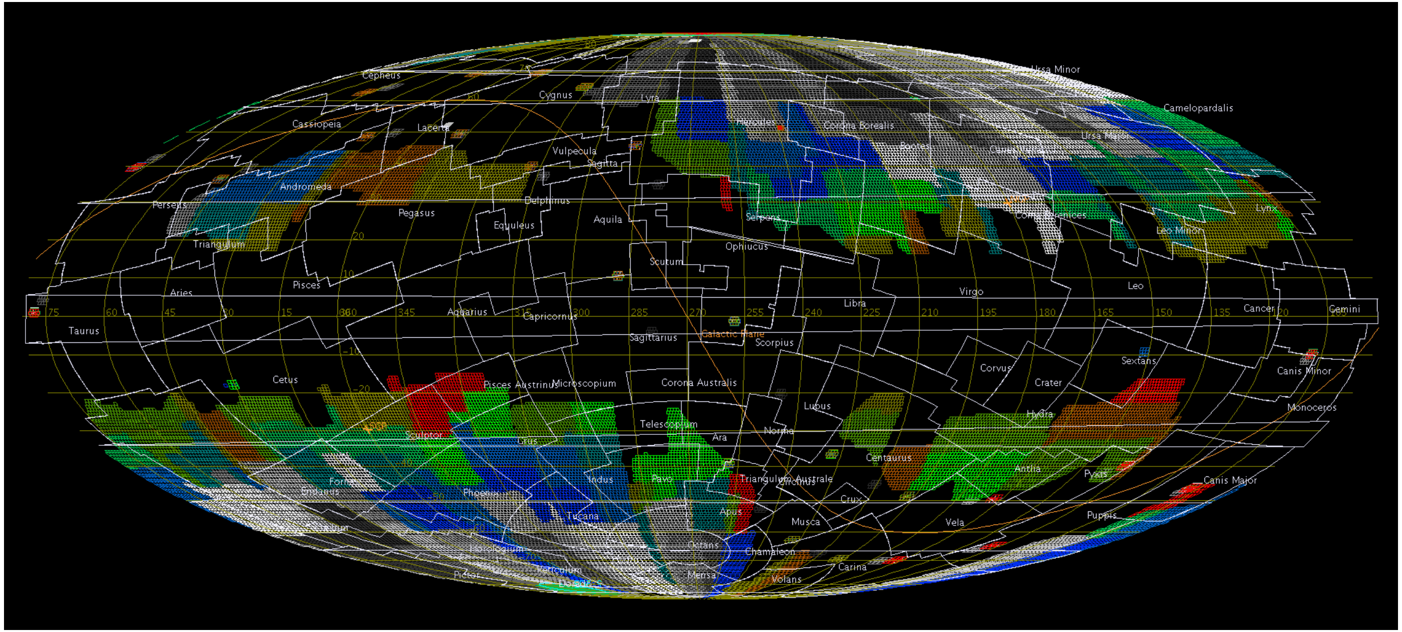
The survey plan has to take the following issues into account:

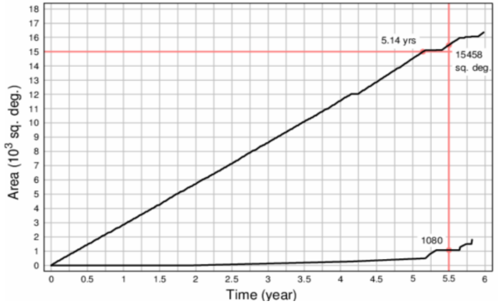
- S/N depends on sky background and source density (for spectroscopy)
- Required calibrations and the deep field observations
- Each Field consists of 4 dithered exposures, and the overlap between fields is at most 2%, no re-visit
- Spacecraft slewing overheads and viewing constraints
- Viewing angles are also constrained by the thermal stability of the payload, to minimise biases in the PSF
- Exclusion of the galactic plane, the ecliptic plane, and regions with high galactic extinction.

This is a non-trivial exercise and is closely coupled with the performances of the scientific instruments, telescope and satellite (straylight, pointing stability, and thermal stability).

The survey pointing plan is developed by the Euclid Consortium and delivered to the SOC for scheduling and maintenance.

Reference Survey (for M-PDR)





Mollweide projection in ecliptic coordinates, different colours give different years of the mission. Each field is indicated by a small rectangular box. The curved line is the galactic plane. Overlayed are the constellations.

This is the survey plan developed by the EC survey group, scheduling algorithm by J. Dinis (Univ. Lisbon).

It shows the feasibility to build a survey satisfying given constraints – this was done for the Mission preliminary design review.

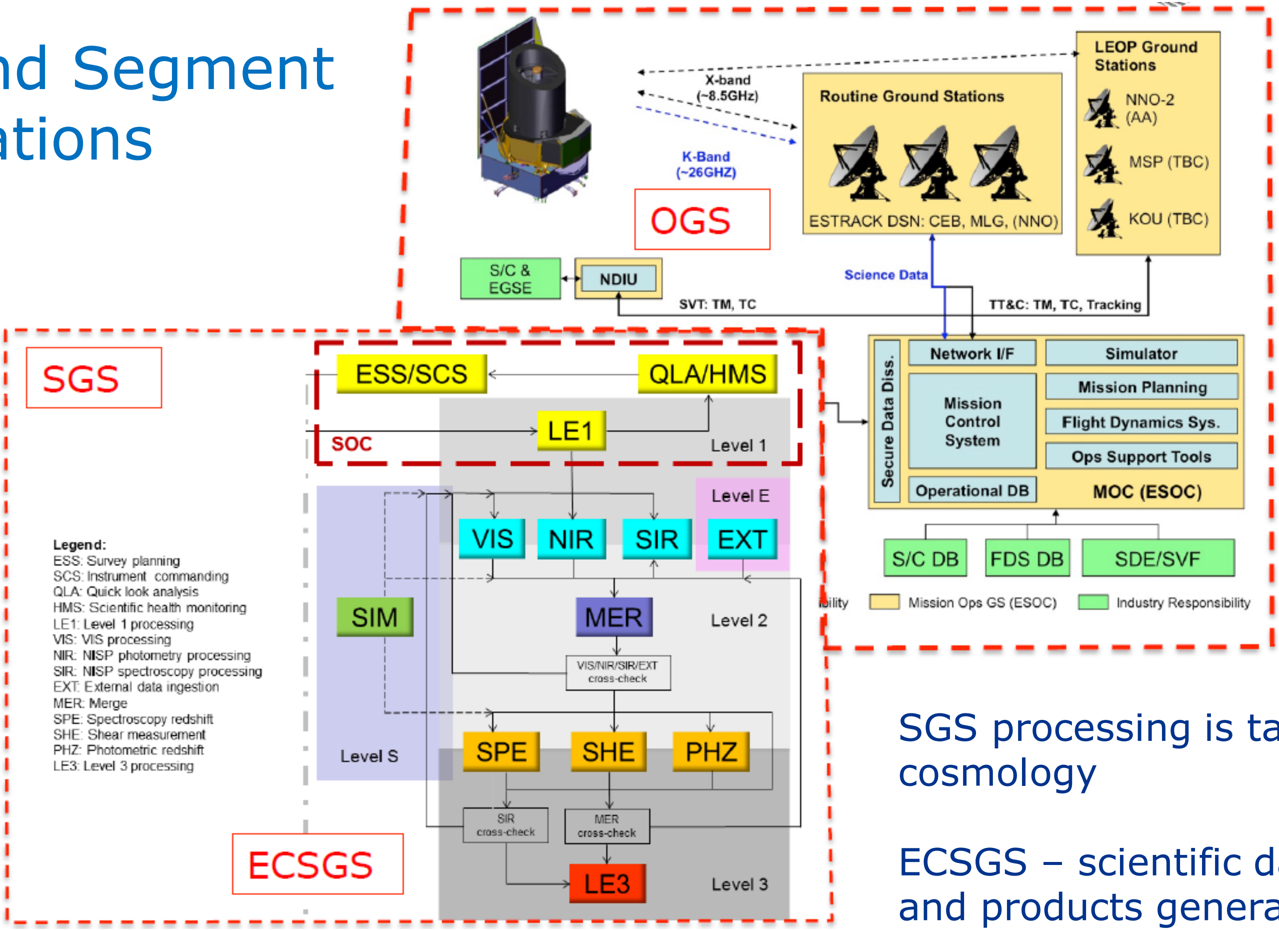
Ground Segment

Consists of three major elements

- **Operational Ground Segment (OGS):** Mission operations centre (MOC) for the satellite in orbit
  - Satellite Operations (uplink/downlink telemetry, commanding)
  - Orbit maintenance
  - Management of ground stations for Euclid
  - First line of housekeeping monitoring to check systems health
- **Science Operations Centre (SOC)**: scientific operations and science data handling
  - Survey Execution: delivery of the pointing plan to MOC
  - First level of data processing
  - Science data (quality) monitoring
  - Data distribution via the Euclid Archive System
- **Euclid Consortium science ground Segment (EC-SGS):** data processing and product generation
  - Scientific data processing
  - Provision and development of the processing pipelines

SOC and EC-SGS should conserve the knowledge of the mission and the products to ensure correct interpretation of the data.

Ground Segment Operations



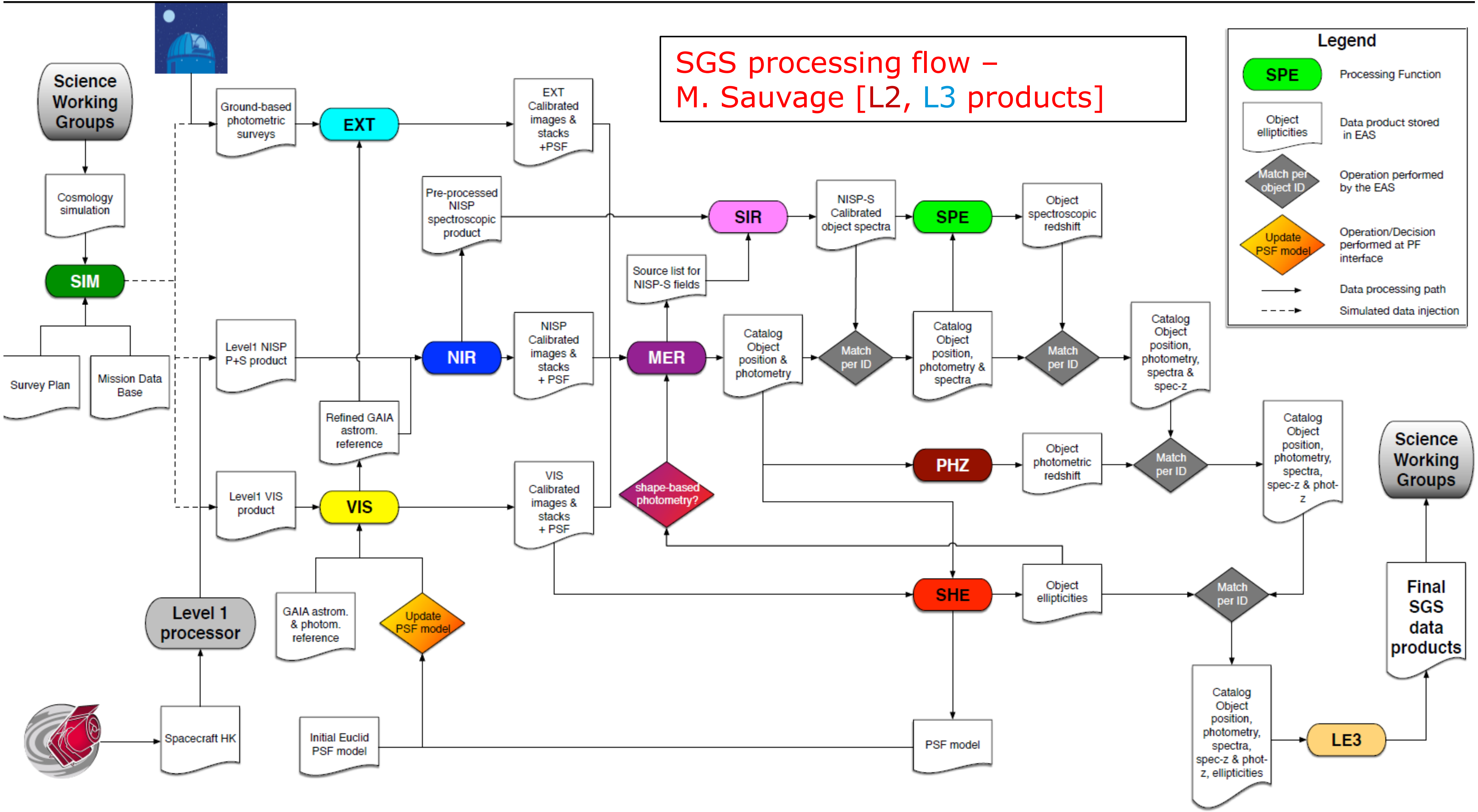
Operations Ground Segment

Science Ground Segment

SGS processing is tailored for cosmology

ECSGS – scientific data processing and products generation are provided by the Euclid Consortium

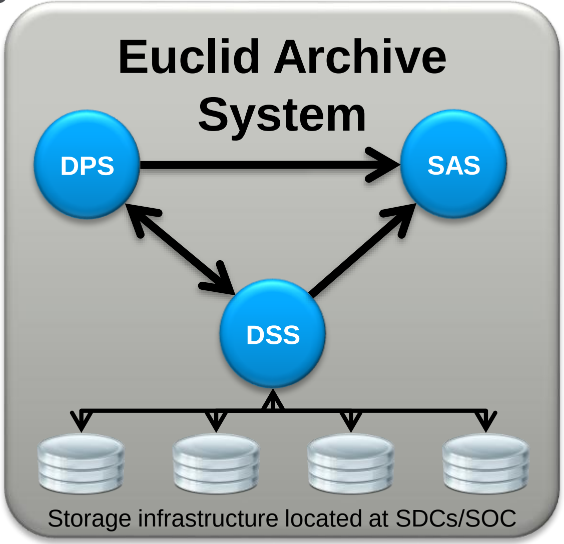
SGS processing flow – M. Sauvage [L2, L3 products]



SGS design and development

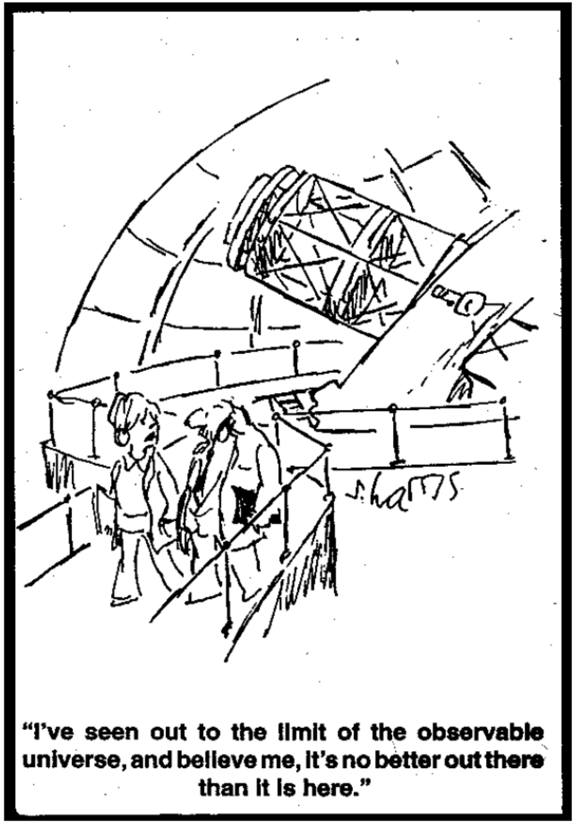
a few more words…:

- Micro-pipelines → "code to data" instead "data to code"
- Agile development → science challenges and IT challenges
- Archive is an important central component:
  - Consists of 3 components: DPS, SAS, and DDS
  - Functions for (giant) tables
  - Common Data Model



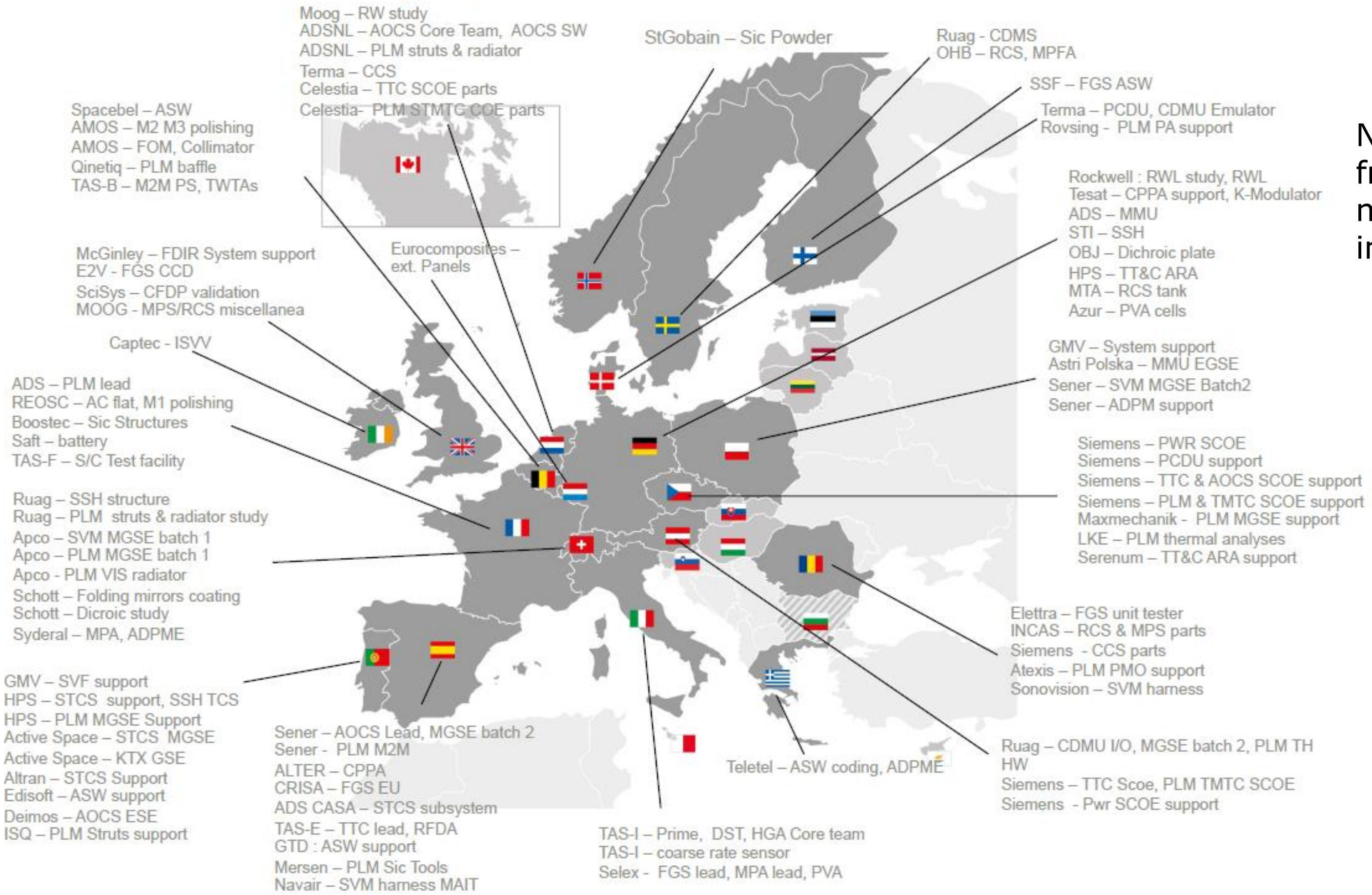
Euclid

MISSION OUTLOOK



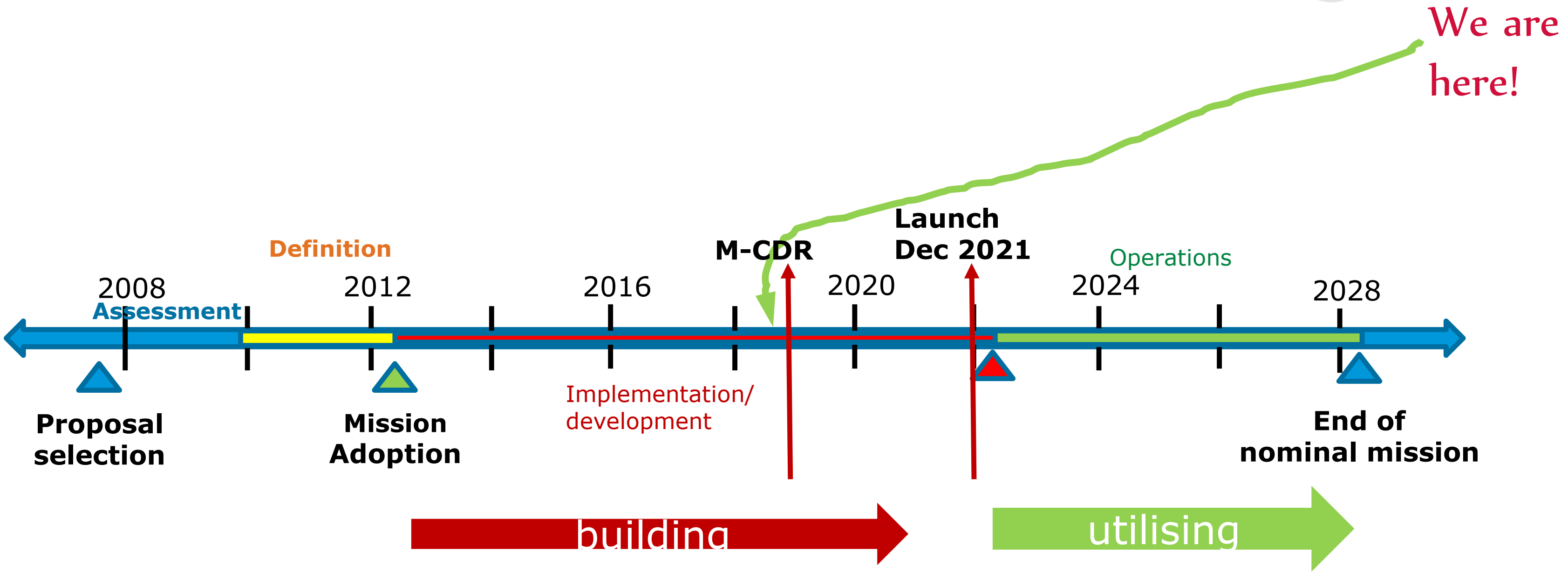
"I've seen out to the limit of the observable universe, and believe me, it's no better out there than it is here."

Industrial Geographical Distribution



Not only scientists benefit from the mission. It is also meant to boost the space industries in Europe.

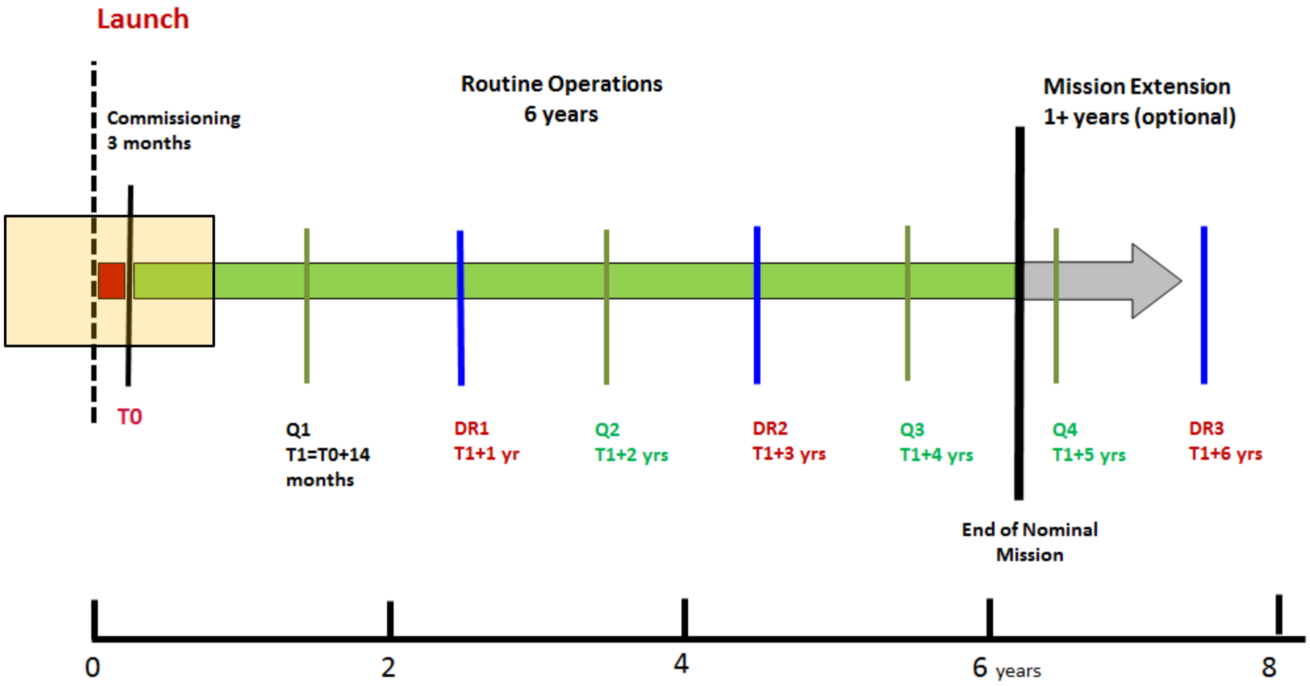
Project Development: timeline



ESA: Project + Industry
EC: instruments
ESA+EC: ground segment and operations development (MOC, SOC, ECSGS)

ESA: Mission Manager, MOC, SOC, Euclid Product Archive
EC: Instrument Operations Teams, ECSGS

Data release plan: preparing the scientific return



Note: the mission duration is limited by the availability of cold gas