EUCLID
Mission Assessment Study

Observing the Dark Universe with EUCLID

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ESTEC, Noordwijk

All the space you need

EADS astrium

Outline

- Introduction
- Driving requirements
- Major system trades
- Mission reference design
    - Instruments
    - Payload
    - Spacecraft
- System performance
- Programmatics
- Conclusions

Introduction

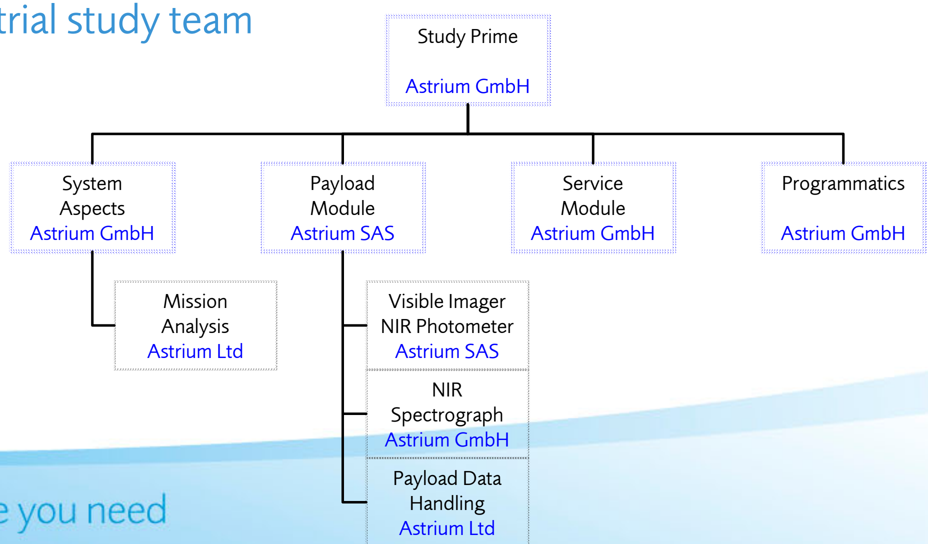
EUCLID Mission Assessment Study

- Industrial part of the Assessment Phase (2008 – 2009)
- Phase 0: mission definition, system concepts

Study objectives

- Define mission at system level
- Demonstrate technical feasibility
- Demonstrate programmatic feasibility
- Analysis of entire space segment

Industrial study team



Top-Level Requirements

Science Requirements

- Wide Extragalactic Survey
  - |b| ≥ 30 deg
  - 20.000 deg²
- Deep Survey
  - 40 deg²
  - close to galactic poles
- Instruments
  - Visible imager (VIS)
  - NIR Photometer (NIP)
  - NIR Spectrograph (NIS)
- FoV Dithering
  - 2 spatial directions (>45 deg)
  - 95% pixels within 3 frames
- VIS PSF Size & Stability
  - 0.18 as < FWHM < 0.23 as
  - 83.6% within 3xFWHM
  - ellipticity variation < 0.02% rms
  - FWHM variation < 0.1% rms

System Requirements

- SEL2 Orbit
  - large amplitude orbit
  - direct transfer
- Soyuz ST 2-1B Launcher
  - Kourou
- 5 Years Mission Lifetime
  - 4.5 years for science
- Sky Observation
  - Observation strategy
  - Observation mode
- Data Volume
  - 850 Gbit/day
  - K-band communication
  - Cebreros ground statation
- Pointing Stability
  - RPE < 25 mas rms (600s)
  - APE < 10 as (field step)
  - APE < 25 mas rms (dither step)
  - knowledge < 100 mas

Programmatic Requirements

- M-Class Mission
  - 450 M€ CaC
- TRL>5 in 2011
  - European technology preferred
- Number of Detectors
  - max. 36 CCDs
  - max. 26 NIR detector arrays
- Instruments
  - Developed by consortia
  - Procured by national agencies
- Launch in 2017-2018

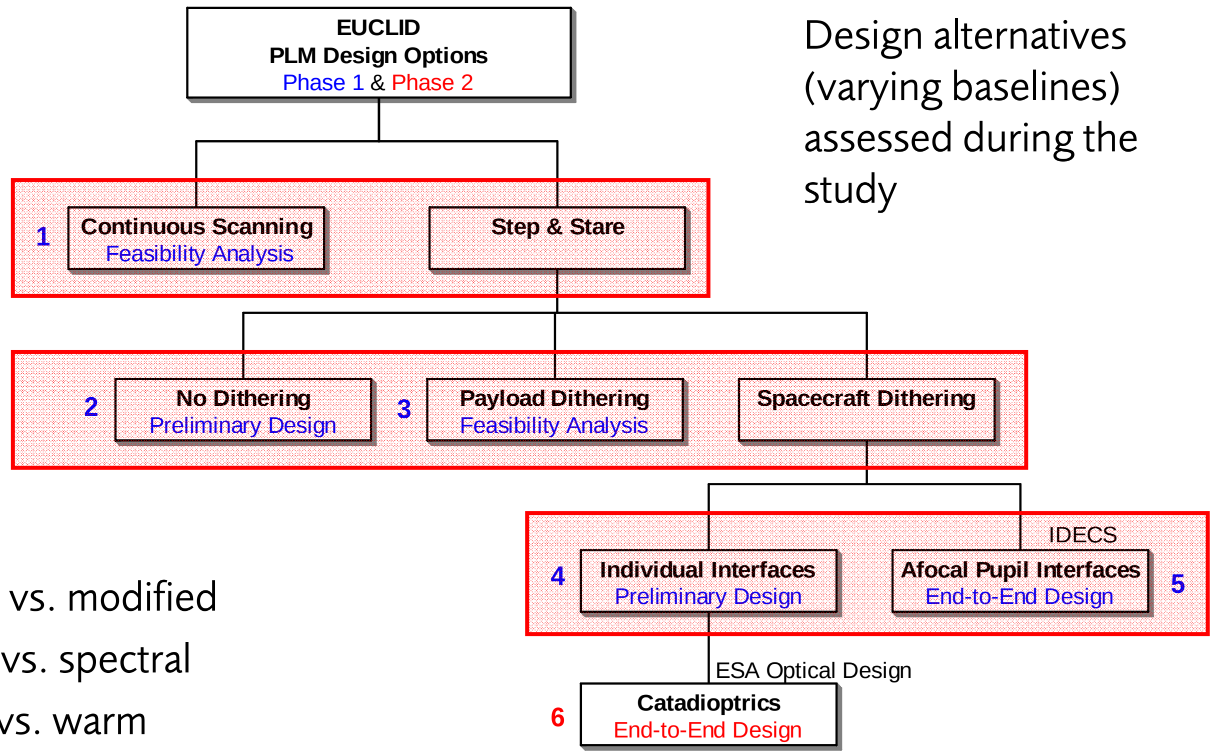
Requirements driving the system design

Driving Requirements

Requirement		Major system impact
Instruments	VIS, NIP, NIS	Payload interfaces → AIT
Mission lifetime	4.5 years	Observation strategy → Thermal design AOCS design → Duty cycle
Ellipticity stability	$\sigma_e < 0.02\%$ rms over 3 days	Thermal stability (~30 mK) → Thermal design → Observation strategy
Pointing stability	APE < 25 mas rms (dither steps)	AOCS design → Payload star tracker Thermal design
Data volume	850 Gbit/day	Communication system → On-board compression → Data rate
PSF size (VIS)	0.18"≤FWHM ≤0.23" 83.6% within 3×FWHM	Increase PSF → AOCS, mechanism, optics

Major System Trades

- Observation mode
- Dithering
- Instrument interfaces



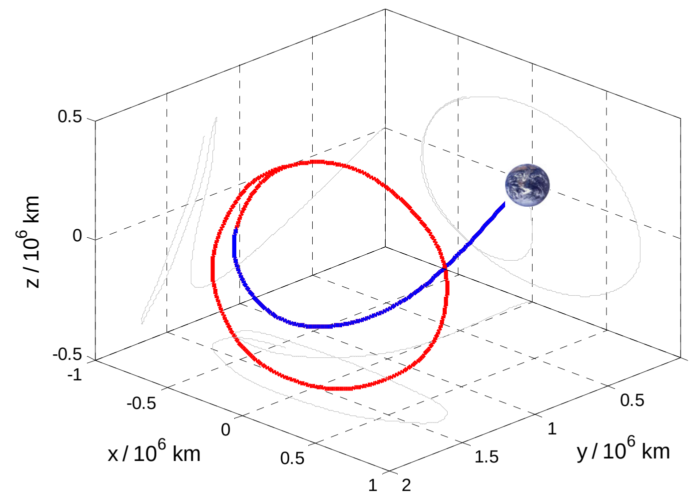
Design alternatives (varying baselines) assessed during the study

- Observation strategy: basic vs. modified
- VIS/NIP separation: spatial vs. spectral
- Payload temperature: cold vs. warm
- Spectroscopy: multi-object vs. slitless

Orbit & Transfer

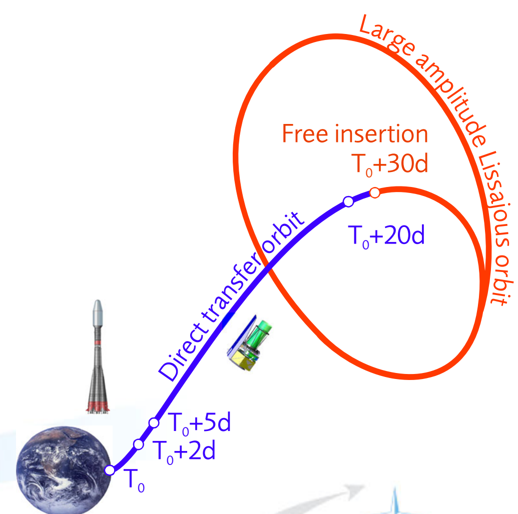
Operational orbit

- SEL2 (0.01 AU=1.5×10^6 km from Earth)
- Free-insertion large-amplitude orbit
- No eclipses
- SSE angle ≤ 30 deg
- Daily visibility ≥ 4 h/day
- Orbit maintenance: every 30 days, guarantees non-escape orbits
- ΔV ~ 20 m/s for station keeping (every month)



Launch & transfer scenario

- Soyuz ST 2-1B from Kourou
- Direct injection into transfer orbit
- 3 correction manoeuvres: ΔV ~ 34 m/s
- Transfer time: 30 days
- Transfer orbit inclination: 5.3 deg
- Total mass capacity: 2160 kg
- Fairing dynamic envelope: ∅ 3.2 m



Sky Observation

- Step & stare observation mode

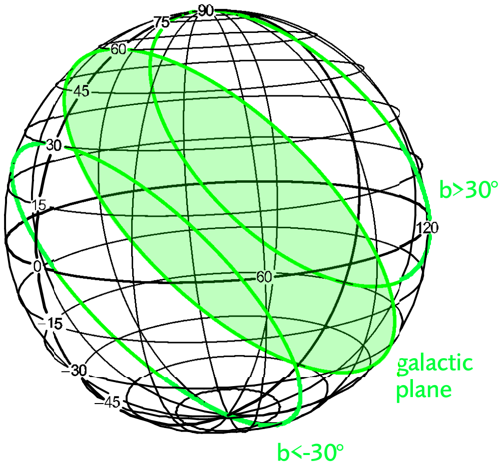
Nominal mode

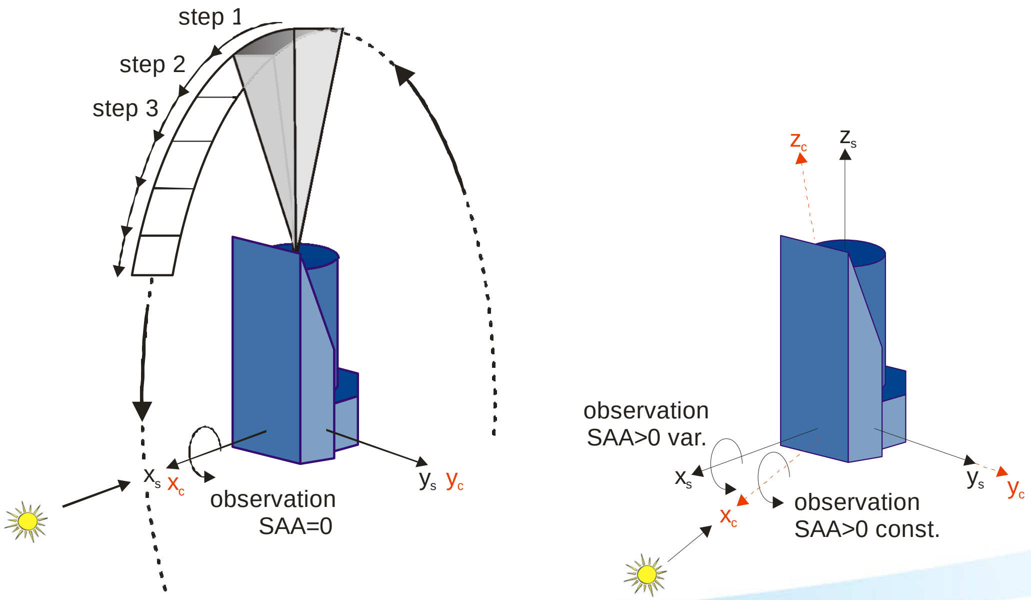
- Sunshield always ⊥ to Sun direction (SAA = 0)

Equinox mode

- Spacecraft tilted away from Sun during Equinoxes
- Observation along small circles
- Observation along great circles

wide survey: 20.000 deg^2

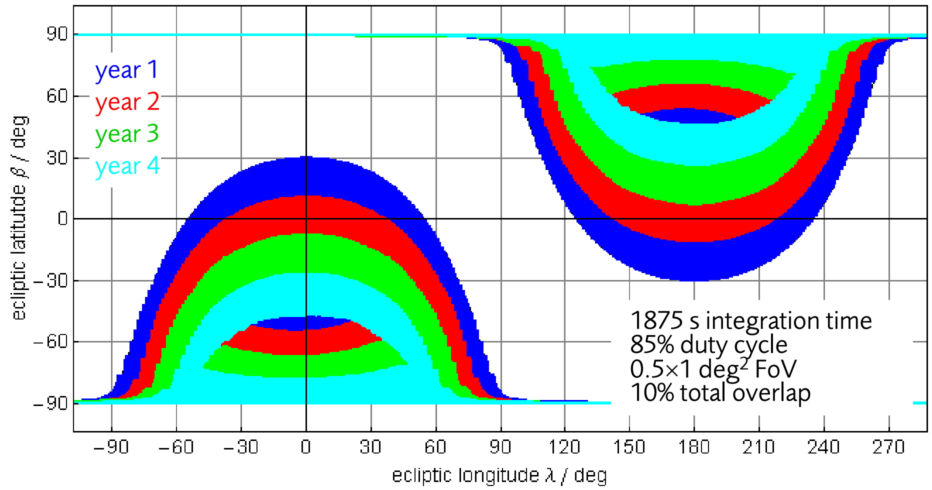




Sky Observation

Sky observation simulation

- Nominal mode (44740 fields)
- Equinox mode (5141 fields)
- Deep survey (90 fields, 29 revisits)
- SAA determined by missing area



Mission duration determined by

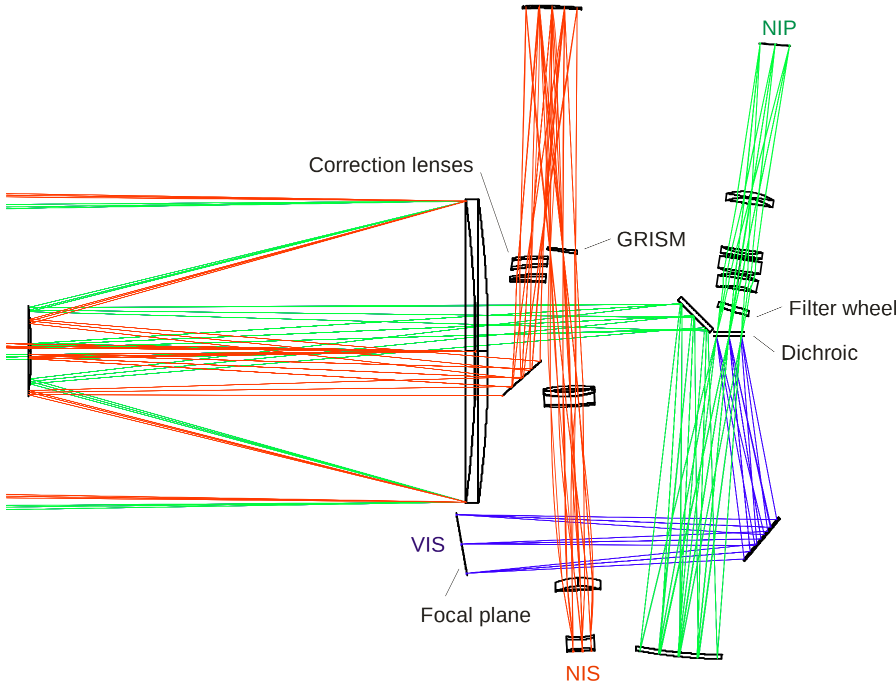
- Integration time
- Duty cycle
- FoV

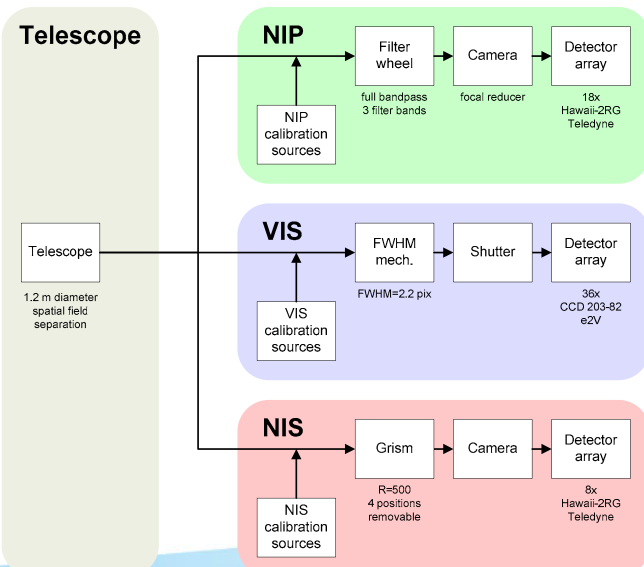
Total time per field [s]	FoV [deg^2]	Maximum SAA [deg]		
		4 years	5 years	
2200	0.5×1	42.5	14.5	CDF
2734	0.478×1.031	–	41.5	
2734	0.535×1.085	48.5	25.0	

Instrument Definition

Payload module

- Telescope and payload bench
- VIS instrument
- NIP instrument
- NIS instrument





- wavelength bands:
  - Y: 920 – 1146 nm
  - J: 1146 – 1372 nm
  - H_p: 1372 – 2000 nm
- number of pixels = 2048x2048
- pixel size = 18 µm

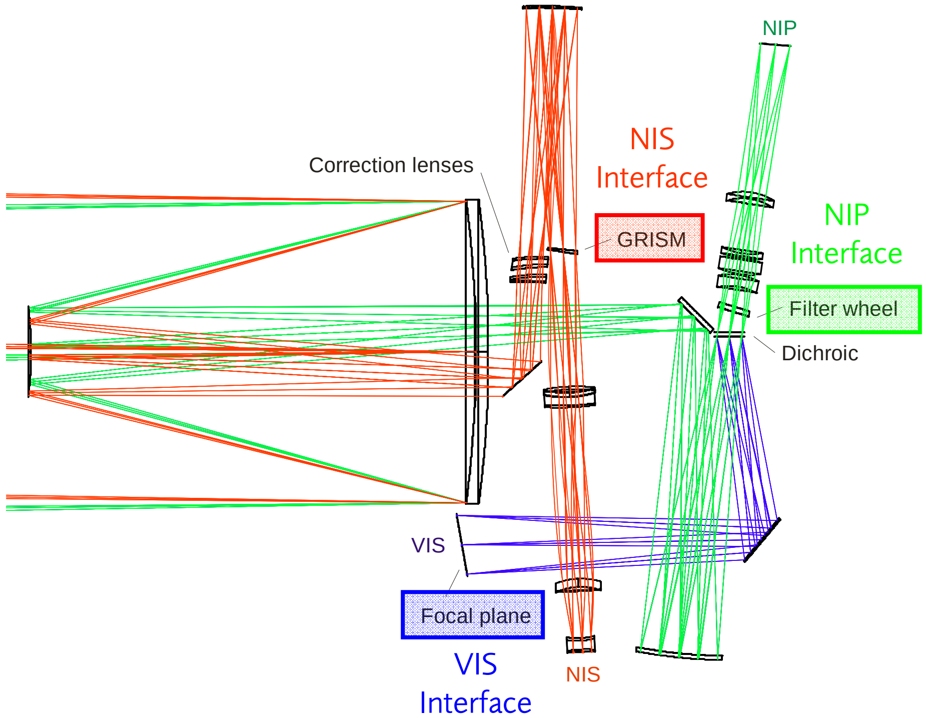
- wavelength band:
  - R+I+Z: 550 – 920 nm
- number of pixels = 4096x4096
- pixel size = 12 µm

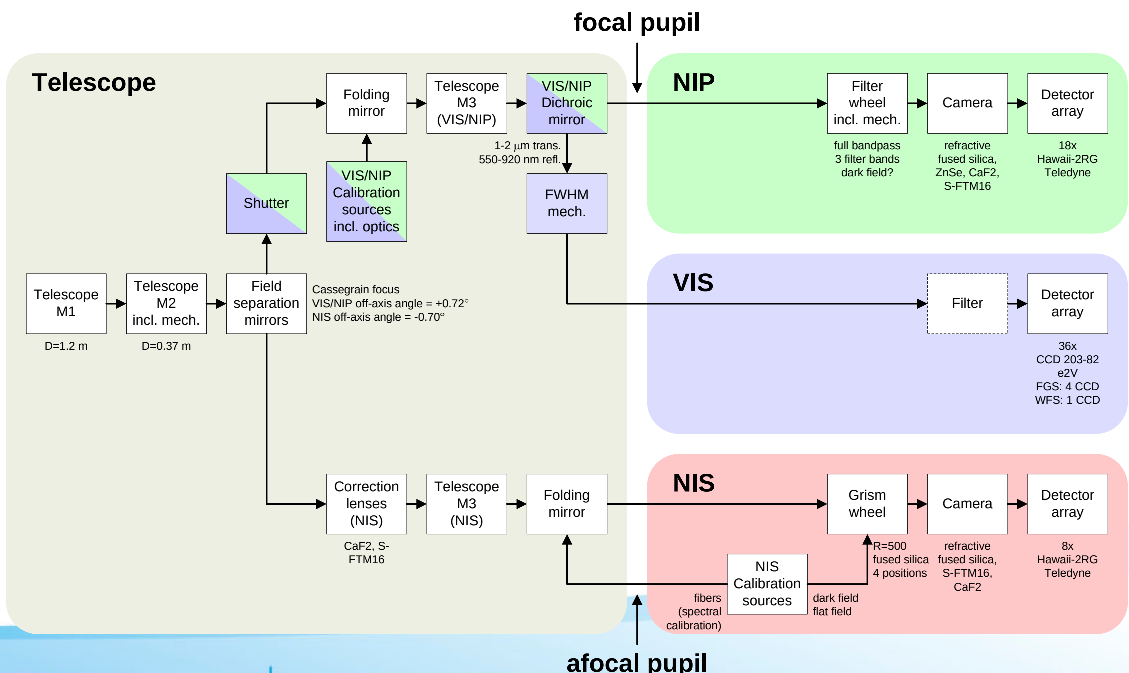
- wavelength band:
  - 1000 – 2000 nm
- number of pixels = 2048x2048
- pixel size = 18 µm

Instrument Interfaces

Interfaces

- Driven by procurement approach and AIT requirements
- VIS interface: focal plane
- NIP interface: filter wheel
- NIS interface: GRISM





NIP

- wavelength bands:
  Y: 920 – 1146 nm
  J: 1146 – 1372 nm
  H_p: 1372 – 2000 nm
- FoV = 0.59°x1.08° = 0.64 deg^2
- plate scale = 0.3"/pix
- $F_{\#}$ = 10.3
- f = 12.376 m
- number of pixels = 2048x2048
- pixel size = 18 μm

VIS

- wavelength band:
  R+I+Z: 550 – 920 nm
- FoV = 0.52°x1.07° = 0.56 deg^2
- plate scale = 0.1"/pix
- $F_{\#}$ = 20.6
- f = 24.752 m
- number of pixels = 4096x4096
- pixel size = 12 μm

NIS

- wavelength band:
  1000 – 2000 nm
- FoV = 0.59°x1.07° = 0.63 deg^2
- plate scale = 0.45"/pix
- $F_{\#}$ = 6.9
- f = 8.251 m
- number of pixels = 2048x2048
- pixel size = 18 μm

Payload Design –Principles

Interfaces

- Independent instruments: fully qualified before integration
- Clear optical interfaces: validated during telescope alignment, telescope simulator for each instrument
- Simple electrical interfaces: interface module for each instrument

Configuration

- Minimum payload volume: minimizes mass, high stiffness and stability
- Payload radiators: view to cold space, minimum view factor between each other

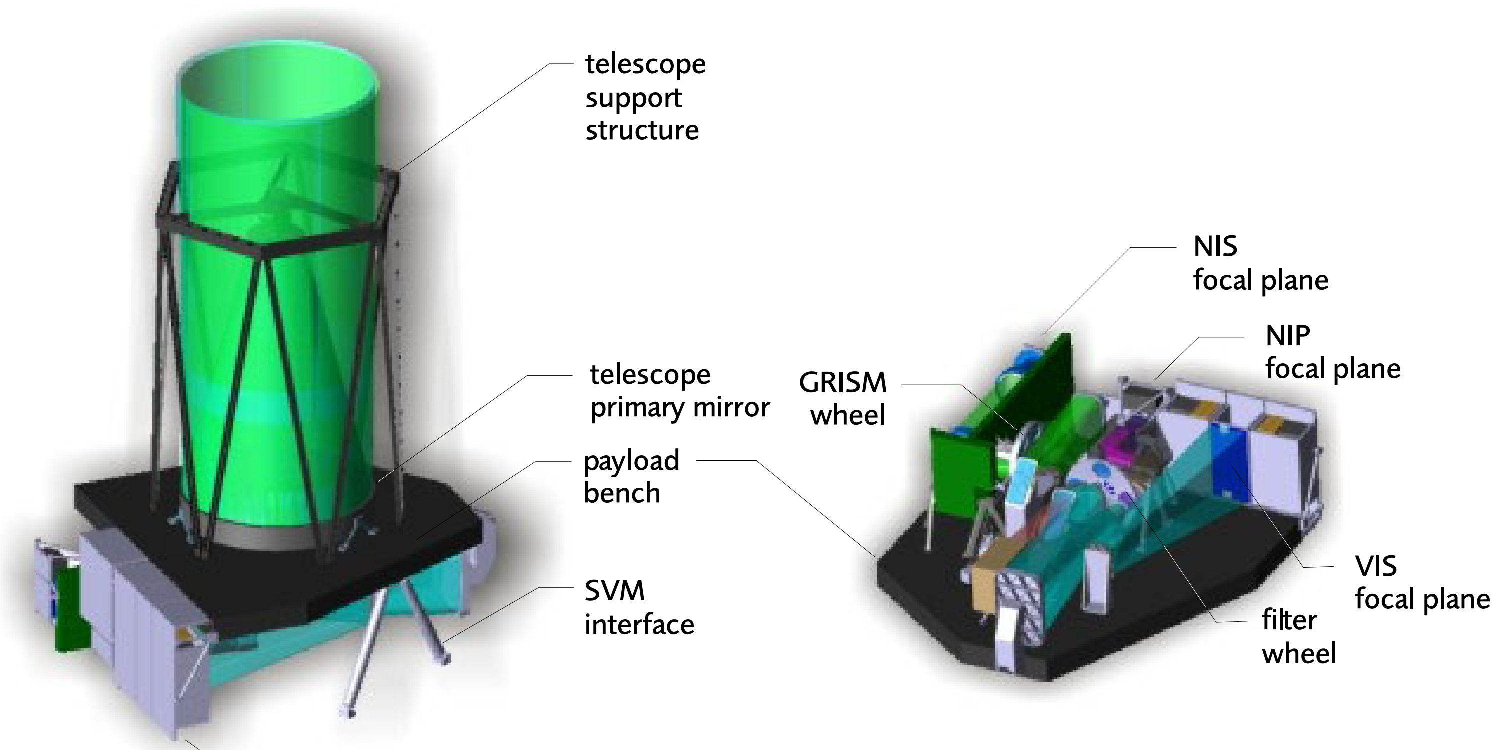
Material

- Homothetic design analog to GAIA payload:
  Silicon Carbide (SiC) in particular for telescope and payload structure
- Optimum in terms of mass, stiffness, thermal stability
- Compatible with other materials for instruments (especially for NIR instruments)

Thermal

- Low payload temperature (150K) allows higher thermal stability
- Passive cooling

Payload Module – Overall Design



- overall mass: 783 kg (incl. 20% margin)
- overall dimensions: 2640 mm × 2420 mm width, 3300 mm height
- each instrument on separate bench (3 bipods as interface)

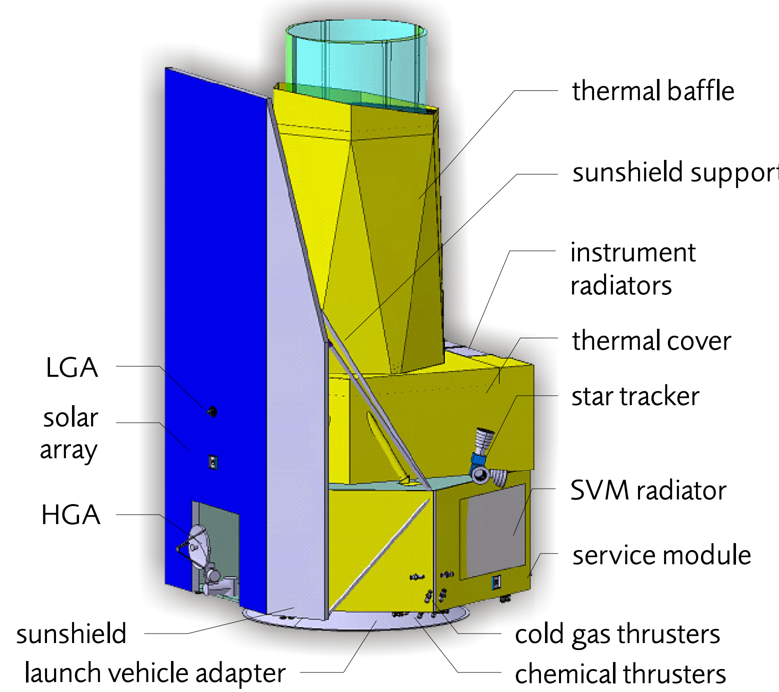
Spacecraft Design

Configuration

- Payload atop service module (SVM)
- Sunshield directly interfaces the SVM
- Thermal cover for payload

Sunshield

- Canted design for high stiffness and optimum shading
- 8.9 m^2 solar arrays, mounted onto the sunshield
- Size of 4670 mm in height and 2990 mm in width



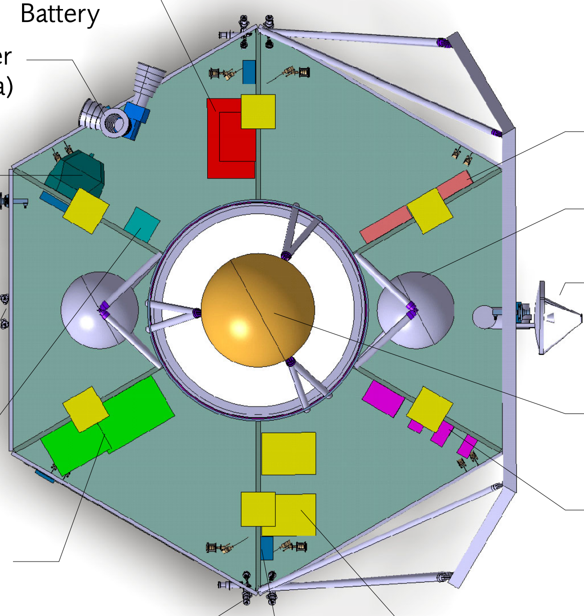
Service Module Design

Configuration

- Size driven by tank accommodation
- Units mounted on shear walls
- Size of 3100 mm in diameter and 1100 mm in height

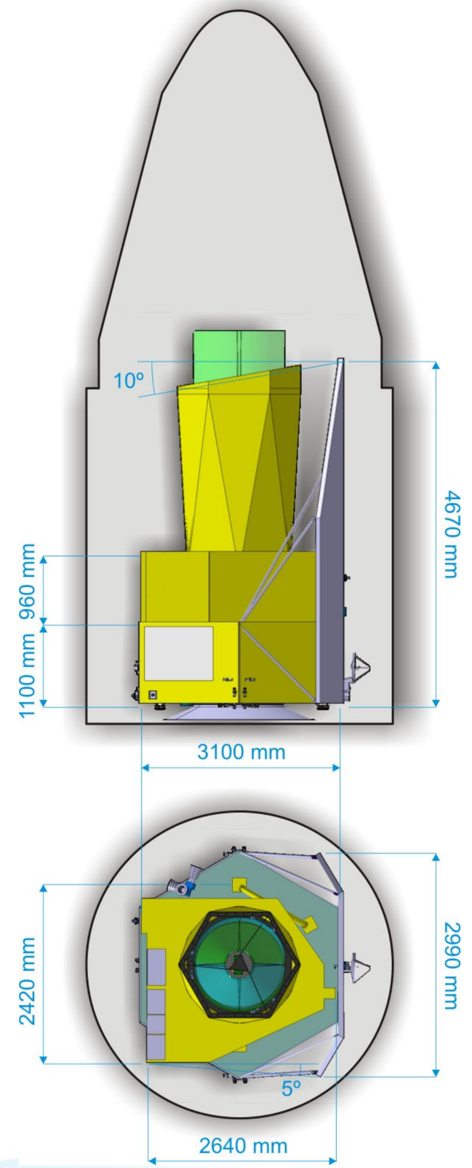
SVM structure

- Hexagonal shape, Al honeycomb with CFRP facets
- Central cone (1194mm) interfaces the launch adapter



Spacecraft Design

(subsystem margin included)	Mass incl. margin [kg]
Service Module	676
Telescope, bench, common elements	510
VIS Instrument	75
NIP Instrument	81
NIS Instrument	117
Payload Module	783
Nominal dry mass	1458
Nominal dry mass incl. 20% margin	1750
CPS propellant	65
MPS propellant	62
Launch vehicle adapter	110
Launch mass	1987
Launch vehicle capacity	2160
Launch margin	+8%

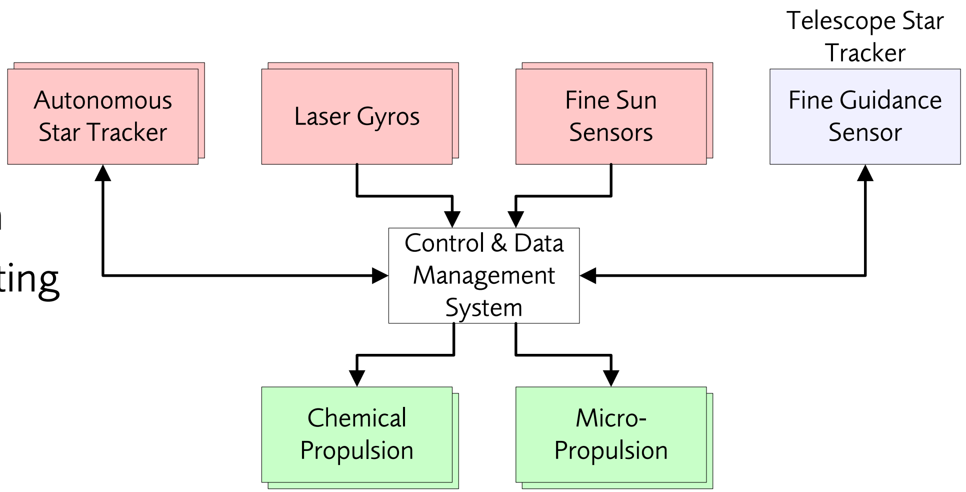


System Performance – AOCS

Requirements

- RPE < 25 mas RMS over 375 s
- APE < 10 as RMS for field steps
- APE < 25 mas RMS for dither steps

AOCS configuration



- Star tracker: FGS lock
- IMU (laser gyro): attitude propagation
- Fine guidance sensor (FGS): fine pointing
  - telescope star tracker
  - located within VIS instrument
  - half frame transfer CCDs
- Fine sun sensor: safe mode
- Chemical propulsion: orbit maintenance and attitude control
- Cold gas micro-propulsion: field steps and dither steps
  - 0.5 mN thrusters developed for GAIA
  - Higher thrust δ-development feasible

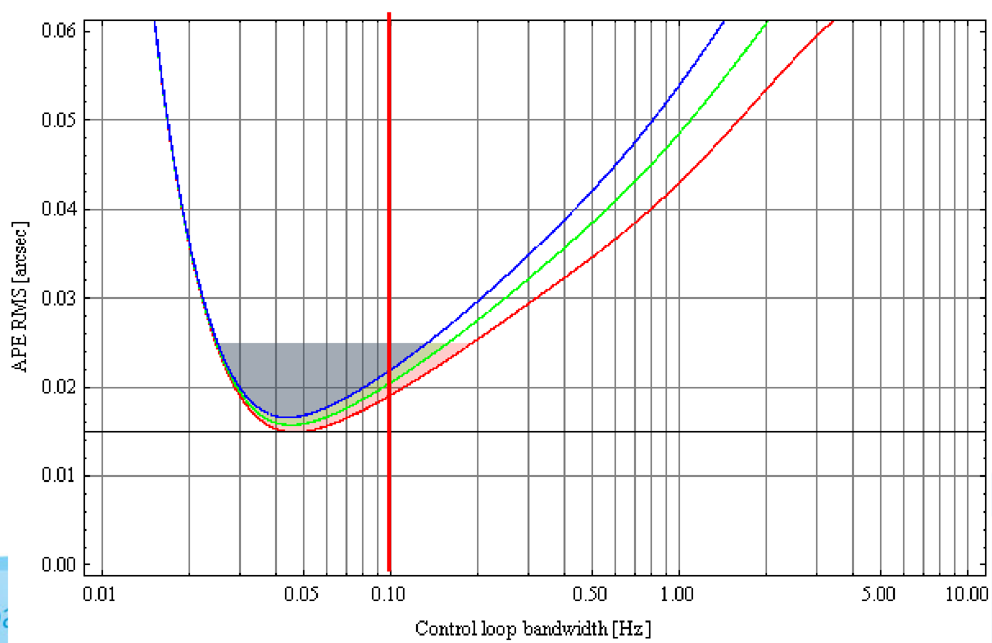
System Performance – AOCS

Fine Guidance Sensor integrated into VIS focal plane

- Bandwidth: 0.5 Hz – 1 Hz
- Performance: sensor noise not performance-limiting

Control loop design for science mode AOCS

- Bandwidth: ~0.1 Hz … set by low thrust of cold gas system
- Relies on sensor fusion of FGS and IMU
- IMU (Astrix-200, 10 Hz bandwidth) propagates attitude to achieve higher attitude rate
- Pointing requirement (APE < 25 mas) can be safely fulfilled



FGS at 0.5 Hz noise:
50 mas RMS
70 mas RMS
60 mas RMS

System Performance – Radiometry

Integration times per frame

- VIS: 568 s
- NIP: 466 s
  (2 intermediate read-outs)
- NIS: 531 s

Dither manoeuvre

- 43 s slew time
- 14 s settling time

Step manoeuvre

- 217 s slew time
- 10 s settling time

Total

- Frame: 641 s
- Field: 2734 s
- Duty cycle per field: 83%

Instr.	SNR Requ.	Band	FWHM [arcsec]	Integration time per frame [s]	
VIS	10	R+I+Z 550–920 nm	0.40	568	568
NIP	5	Y 920–1146 nm	0.29	160	
		J 1146–1372 nm	0.30	209	
		Hp 1372–2000 nm	0.30	97	466
VIS	5	1000 nm	0.99	531	
		2000 nm	1.00	446	531

Integration times longer than estimated by ESA due to different assumptions for instrument transmission

System Performance – Mission Duty Cycle

	Scientific mission time	4.5	yr	
	FoV	0,492812	deg^2	0.478×1.031 deg^2
	Integration time per frame	568	s	
Manoeuvres/Operations	Shutter closing and opening	0	s	during SC manoeuvre
	Detector readout	0	s	during SC manoeuvre
	SC dither slew	43	s	70 arcsec dither step
	SC dither settling	14	s	0.5 Hz FGS readout
	SC step slew	217	s	0.5 deg step
	SC step settling	10	s	0.5 Hz FGS readout
	Antenna repointing	0	s	during SC manoeuvre
	Orbit maintenance	43200	s	12 h per month, CDF
	Equinox mode slew manoeuvre	168	s	90° bang-bang, 10 N
	SC north-south flip manoeuvre	236	s	180° bang-bang, 10 N
	Deep survey slew manoeuvre	168	s	90° bang-bang, 10 N
	Thermal stabilisation	432000	s	120 h for 45° slew worst case
Calibration	Dark field exposure	600	s	daily
	Flat field exposure	600	s	daily
	Known field exposure	600	s	monthly
	Total number of fields	46505	s	including overlaps
	Total observation time	105659873	s	wide survey
	Total non-observation time	31572041	s	Sum of above contributions
	Duty cycle over mission	**77,0**	**%**	

System Performance – Ellipticity

Requirement

- Ellipticity variation over FoV $\leq$ 20%

Analysis

- Statistical analysis (Monte-Carlo)
- Margin, e.g. for CCD trapping effects

Ellipticity Contributor	Ellipticity [%]
Optical distortion	2.0
Wavefront error (60 nm RMS)	7.6
Inhomogeneous detector MTF	5.0
Line of sight stability	0.0
Effect of FWHM increase mechanism	5.0
Total (RSS)	10.6

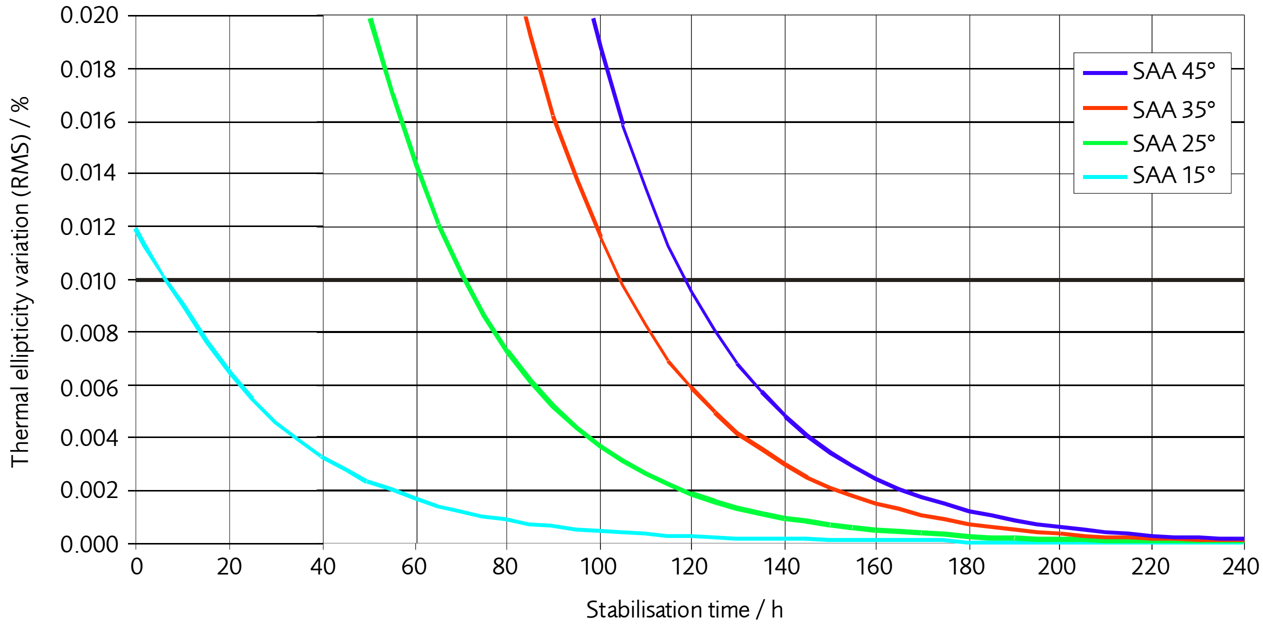
System Performance – Ellipticity Stability

Requirement

- Ellipticity stability over 3 days ≤ 0.02%

Thermal analysis

- Thermal model of spacecraft
- M1-M2 stability drives the ellipticity stability
- Thermal stability of ~30 mK required
- Most critical are changes in the thermal environment
  → sudden change of SAA in Equinox mode

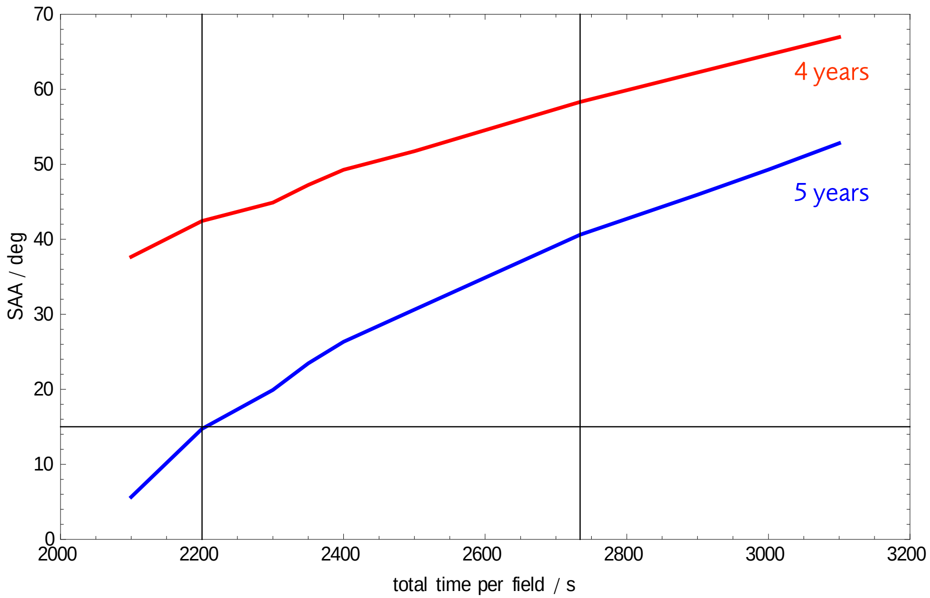


- Worst case: SAA=45° ⇒ ~120 h settling time
- Optimum case: SAA<15 ° ⇒ negligible settling time

System Performance – Observation Strategy

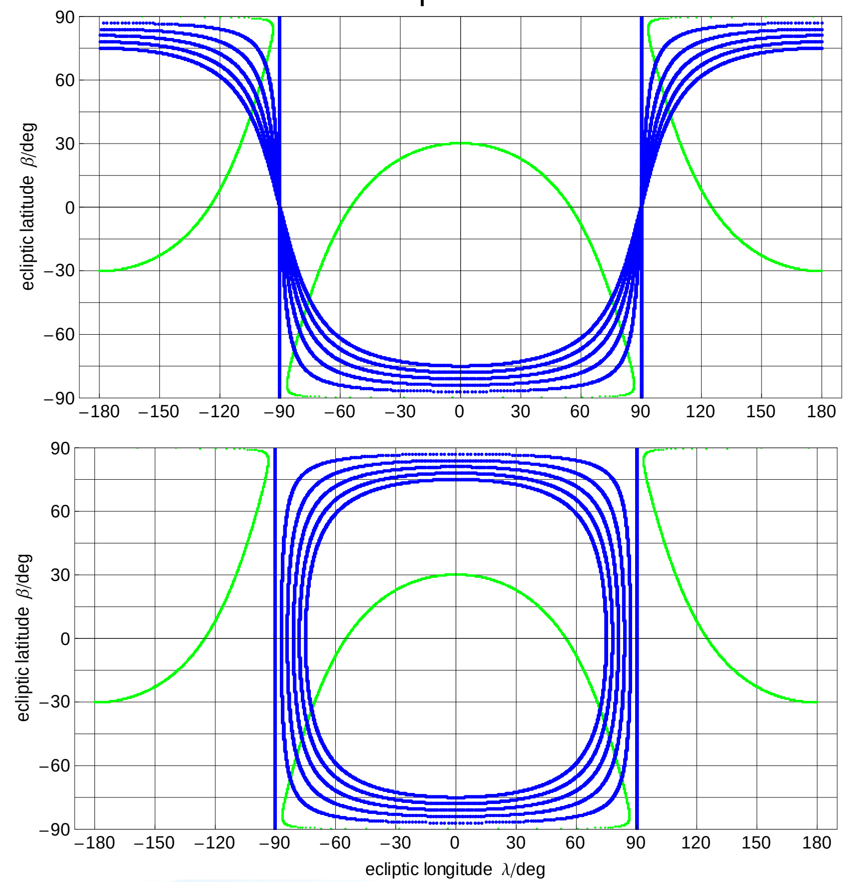
Avoid influence of thermal transients

- Negligible settling times for SAA < 15 °
  ⇒ total time per field < 2200 sec



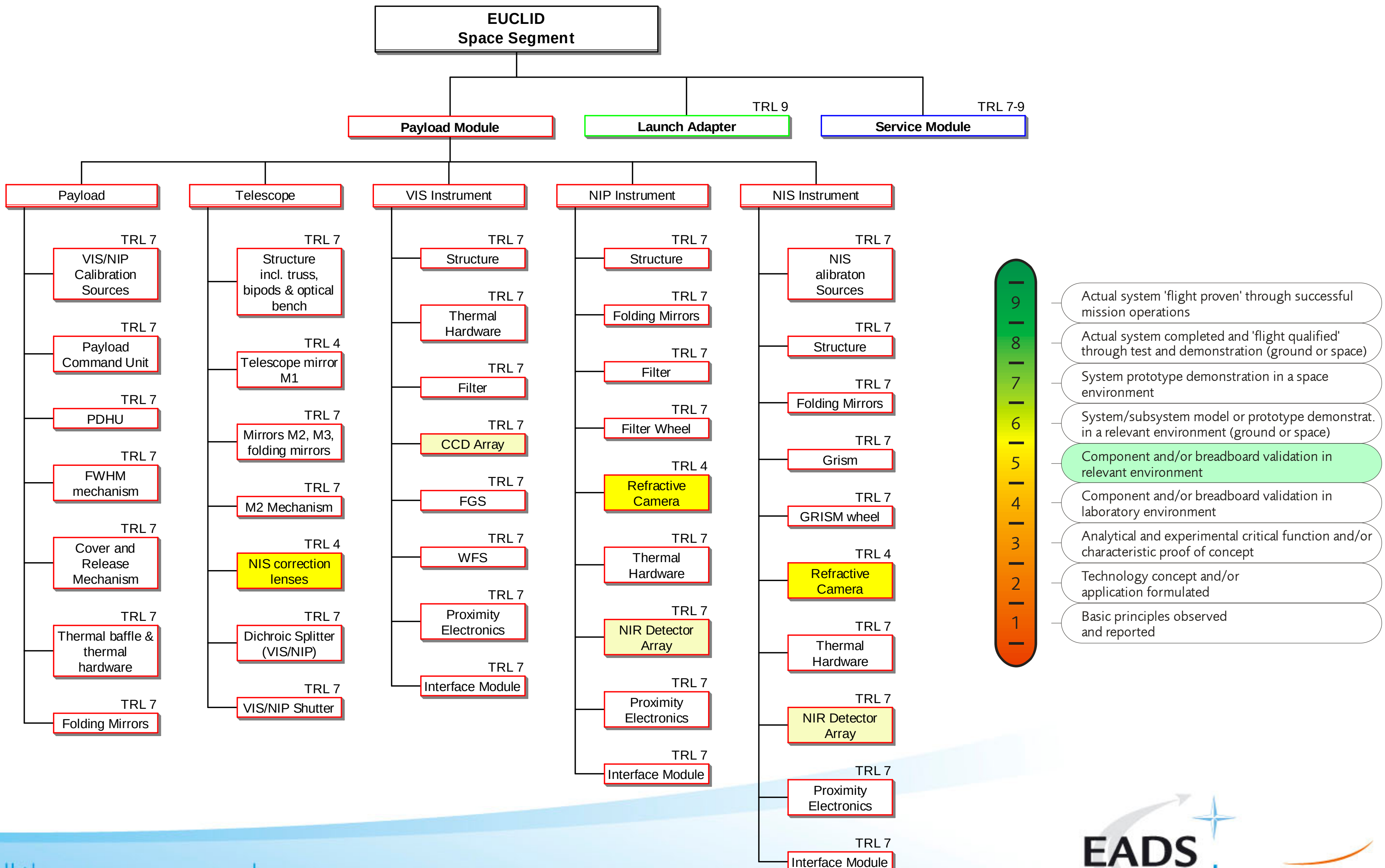
- Increasing mission time to 5 years
- Increase FoV or modify SNR requirement

Instantaneously accessible sky area at Equinoxes



SAA = 0° … 15°

Programmatics – Technology Readiness



Programmatics – Major Risks & Critical Issues

Assembly, integration and testing (AIT)

- Clear interfaces required between instruments and payload module
- Final performance can only be verified at payload/spacecraft level (ellipticity)
- Instruments have to be fully qualified before integration into payload module

Radiation persistent CCDs

- Radiation effects cause charge traps → noise on PSF shape (FWHM, ellipticity)

Cryogenic dioptric (lens) systems

- Optical performance verification required in ambient and cryogenic conditions
- Lens mounts compatible with the environment

Cryogenic mechanisms

- Filter wheel, grism wheel, FWHM mechanism, M2 mechanism, shutter
- ~190.000 operations over mission lifetime for wheels
- Positioning accuracy, repeatability

IR detector availability

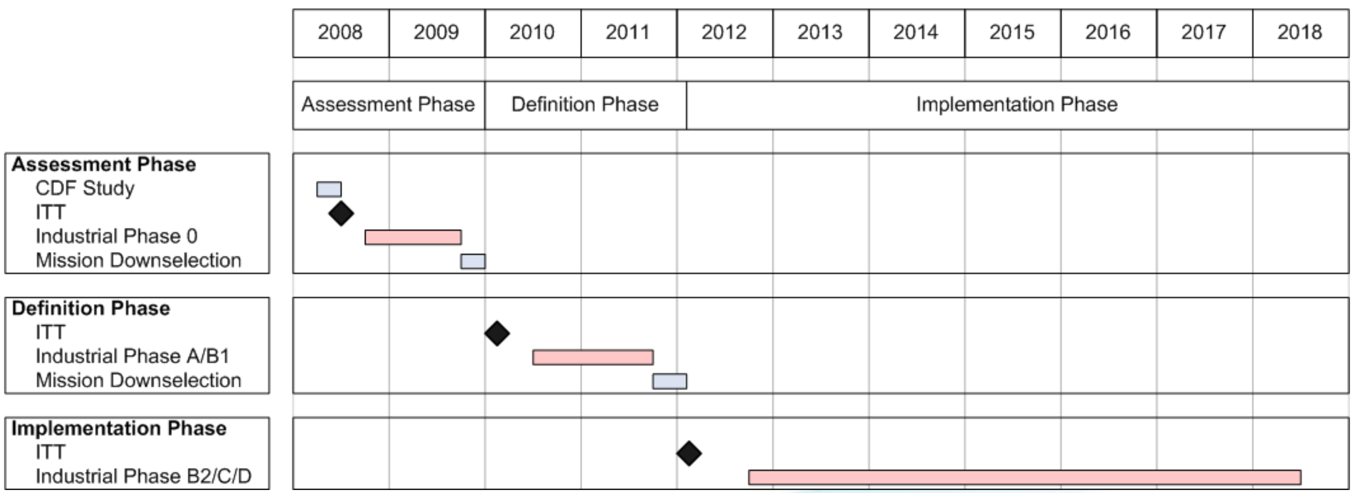
- Hawaii 2RG and Sidecar (Teledyne)
- ITAR restricted, no European alternative today

Programmatics – Schedule

- Schedule with launch in 2018 is demanding: spacecraft delivery not before end of 2017

Long-lead items

- Telescope
  - Mirror polishing is driving the schedule
  - Development schedule critical but compatible with M-class schedule
- Focal plane and proximity electronics
  - Detectors, proximity electronics, interface module
  - Instrument activities to be started as early as possible



Summary & Conclusions

Summary

- Mission has been basically defined
- Major system concepts have been established
- Potential risks have been identified

Conclusion: EUCLID is feasible

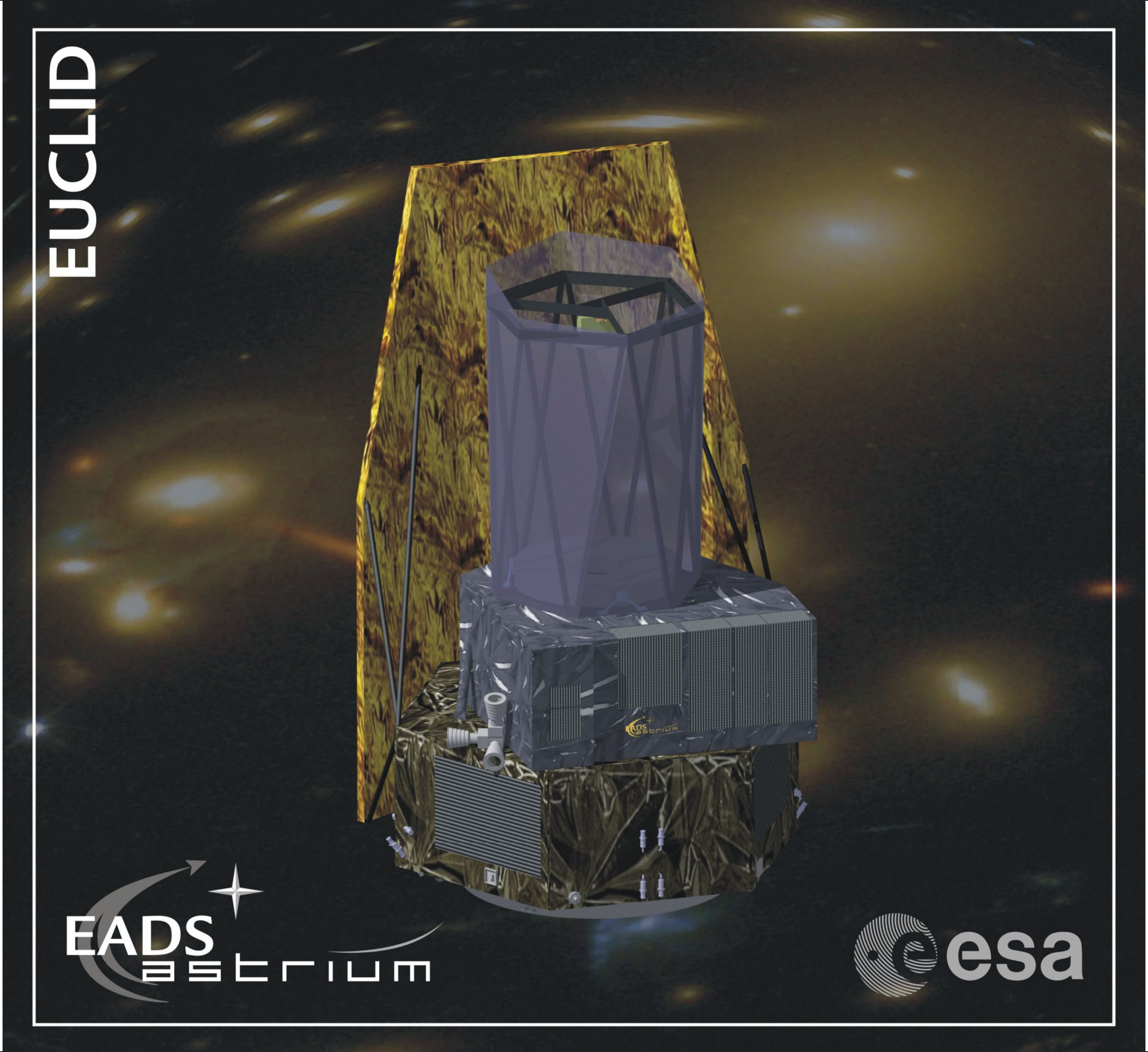
- Preliminary concepts for mission, spacecraft, payload and instruments derived
- Key mission requirements can be fulfilled
- Risks are manageable
- No show stoppers have been identified

Conclusion: EUCLID is compatible with the Cosmic Vision M-class constraints

- Technology Readiness
- Planning
- Costing

Conclusion: reconsideration of some requirements reasonable to simplify mission

- Mission lifetime versus SNR definitions & FoV
- APE definition as AOCS driver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