XIPE

Introduction

IFP
ESTEC, 23-09-2015

Prepared by the CDF* Team

(*) ESTEC Concurrent Design Facility

Background

- XIPE has been recommended by SSAC on June 3rd 2015 as candidate missions for the Cosmic Vision 2015-2025 M4 slot, out of 27 proposals received
- The other candidates are ARIEL and THOR already studied in CDF
- X-ray Imaging Polarimetry Explorer:
  - Wolter-I Nickel mirror shells (a la XMM-Newton)
  - Gas Pixel Detector
- The nominal mission duration is 3 years from a launch date in 2025-2026, with a possible extension of +2 years.
- Cost at completion shall stay within 450 Meuro (2014 economic conditions) all included except payload
- Instrument(s) provided by Member States
- Development risk shall be low: TRL6 by 2018 required for all mission elements
- Launcher is VEGA (or VEGA-C, if available)
- Proposal consortium led by INAP-IAPS, Italy (PI: Paolo Soffitta)

Study objectives (1/2)

The CDF study served the following purposes:

- consolidate the science and mission requirements definition
- prepare a preliminary design of the S/C supported by dedicated analysis specifically the Service Module and the Telescope (stating from the proposal)
- Propose a definition of the concept of operations including: mission profile, spacecraft and science operations timeline
- identify any critical technologies, potentially requiring TDAs
- perform a programmatic analysis (cost, risk and schedule)
- propose P/L accommodation

Study objectives (2/2)

Emphasis was given to the following analyses/trade-offs:

- Mission profile: operational orbit and de-orbit strategy trade-offs
- Feasibility of the proposed observation plan (operational availability)
- Spacecraft and instrument configuration trade-off (focal length accommodation at launcher fairing, detail the I/F mechanical/electrical)
- Thermal stability and sunshield requirements (Eclipse/Earth occultation).
- Pointing requirements
- Angular resolution assessment
- Data and link budget assessment
- Radiation environment analysis (SAA)
- End of life re-entry strategies: uncontrolled and controlled options

Study timeline

Wednesday	**26/08/2015**	**9:30-13:30 CET**	**Kick-Off**	
Friday	28/08/2015	9:30-13:30 CET	Session 2	
Wednesday	02/09/2015	9:30-13:30 CET	Session 3	Telecon SST #1
Friday	04/09/2015	9:30-13:30 CET	Session 4	
Wednesday	09/09/2015	9:30-13:30 CET	Session 5	Telecon SST #2
Friday	11/09/2015	9:30-13:30 CET	Session 6	
Wednesday	16/09/2015	9:30-13:30 CET	Session 7	Telecon SST #3
Wednesday	**23/09/2015**	**9:30-16:30 CET**	**IFP**	

XIPE

<Payload IFP>

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Requirements

ID	Statement	Comments
R-PL-0020	**Mirror Assembly Angular resolution** The mirror assembly design shall allow imaging of X-ray sources at 3 keV with an angular resolution better than TBD arcsec HEW on-axis	TBD value assumed to be 30 arc sec
G-PL-0010	**Mirror Assembly Angular resolution goal** The mirror assembly design should allow imaging of X-ray sources at 3 keV with an angular resolution better than TBD arcsec HEW on-axis	TBD value assumed to be 20 arc sec
R-PL-0030	**Detector Spectral resolution** FWHM Spectral resolution shall be <20% at 5.9 keV for point-like sources	
R-PL-0040	**Mirror Assembly Field of View** The mirror assembly design shall allow an useful Instrument Field of View ≥ 10X10 arcmin^2 at 3 keV energy and with vignetting factor> 20%	
R-PL-0050	**Detector Time resolution** Instrument time resolution shall be better than 8 μs.	Science requirement
R-PL-0060	**Detector dead time** Instrument dead time shall be < 300 μs	Science requirement
R-PL-0070	**Mirror mutual alignment** The mutual alignment between each of Mirror Module optical axes shall be better than TBD arcmin (95% probability)	Apportionment of Science requirement
R-PL-0080	**Effective area** The payload design shall allow a total effective area as follows: 1100 cm^2 at 3 KeV on axis 450 cm^2 at 7 KeV on axis Assuming a detector efficiency >10%	Science requirement
R-PL-0090	**South Atlantic Anomaly (SAA) passage** During the SSA the Control electronics of the instrument shall command entering into specific mode with reduced functionalities and performance.	Science requirement

Design drivers

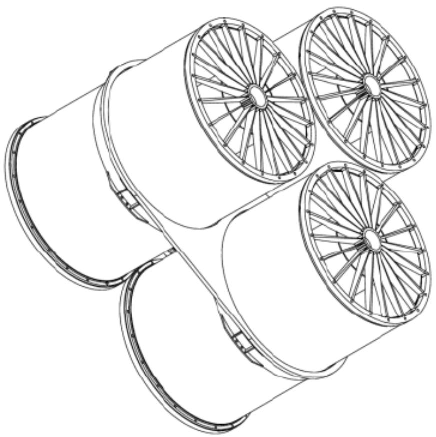
- *In terms of Scientific performance the main drivers are:*
  - *Detection of polarization at X-ray wavelengths: usage of GPD*
  - *Imaging of X-rays with sufficient effective area (also at high energies) and proper angular resolution with mass constraints: a set of three Wolter I X-ray telescopes based on electroformed Nickel replication technology*

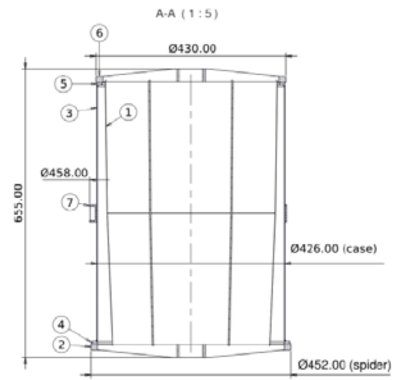
Assumptions and trade-offs

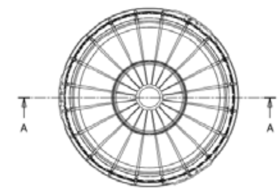
- *Not applicable for instruments/telescope*
- *Instruments are provided*
- *Mirrors under ESA responsibility. Current assumptions/optical design: focal length= 3.5 m (wish to move to 4 m), 27 shells (wish to move to 30 shells), length 600 mm. Further iterations on optical design to be done during phase A*

Baseline design

- Set of three detectors (incl. BEE) with one CE fed by three Wolter I X-ray telescopes.



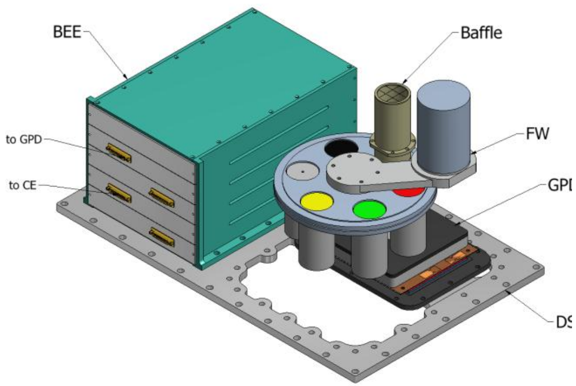


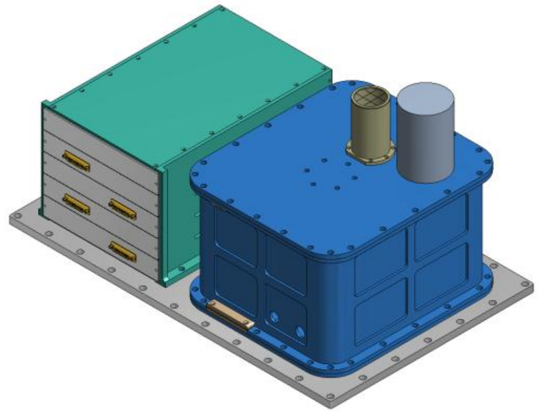


Parts List			
ITEM	PART NUMBER	MASS	MATERIAL
1	shells	31.684 kg	Generic
2	spider1	4.500 kg	Steel
3	case2	6.580 kg	Steel
4	flangia_est2	0.783 kg	Steel
5	flangia_est2b	0.657 kg	Steel
6	spider2	4.417 kg	Steel
7	flangia_med2	1.804 kg	Steel
Tot.		50.4 kg	

Geometrical profile	Wolter I
Focal length	3.5 m
Mirror length	60 cm
Max/min shell diam.	380-180 mm
# of spiders	2
# of spokes per spider	20
Spiders & case material	Steel
# of shells per module	27
Wall material	Electroformed NiCo
Wall thickness	0.33-0.20 mm
Coating	Ir (30 nm)+C (10 nm) bilayer
Weight (without margins)	50.4 kg
Power (without margins)	<16 W

Baseline design

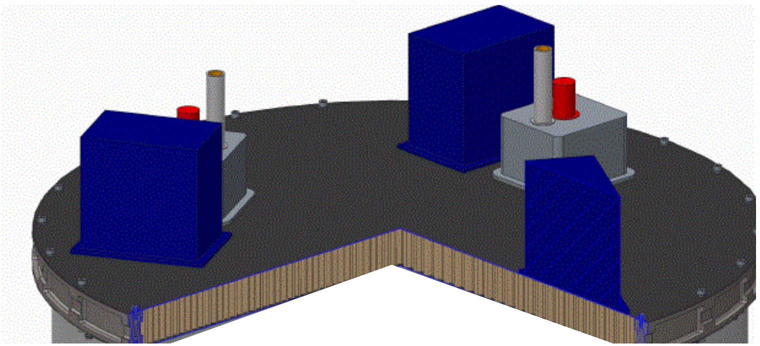




Left: no cover, right: with cover.

Note BEE and detector need to be close, but not necessarily arranged as above

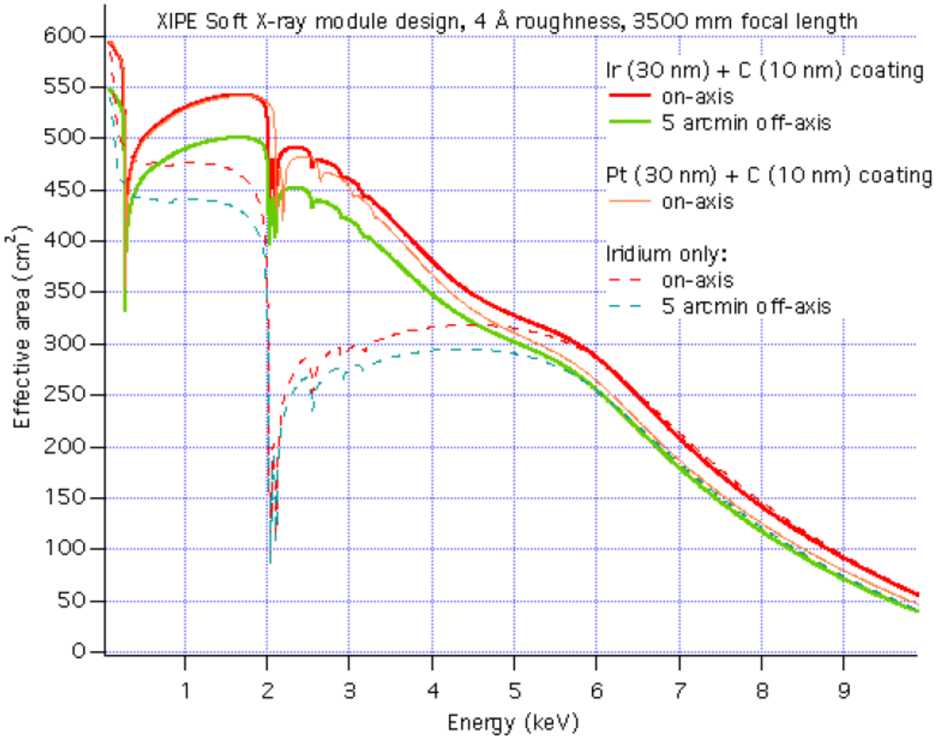
Starting point from proposal



Detectors are arranged in a 120° symmetry supported by an instrument platform.

CE currently envisaged “far away” on SVM.

Analyses



Effective area per Mirror Module

Equipment summary

Mass

	mass (kg)	mass margin (%)	mass incl. margin (kg)
Instrument	**32.90**	**23.37**	**40.59**
CE (Control Electronics)	**6.50**	**20.00**	**7.80**
FPA (Focal Plane Assembly)	**26.40**	**24.20**	**32.79**
DetSet (Detector Set)	5.80	26.38	7.33
BEE (Back End Electronics)	1.70	30.00	2.21
DSMI (Detector Set Mounting Interface)	0.60	30.00	0.78
FW_Baff (Filter Wheel and Detector Baffle)	1.50	20.00	1.80
GPD (Gas Pixel Detector)	2.00	27.00	2.54
DetSet2 (Detector Set2)	5.80	26.38	7.33
BEE (Back End Electronics)	1.70	30.00	2.21
DSMI (Detector Set Mounting Interface)	0.60	30.00	0.78
FW_Baff (Filter Wheel and Detector Baffle)	1.50	20.00	1.80
GPD (Gas Pixel Detector)	2.00	27.00	2.54
DetSet3 (Detector Set3)	5.80	26.38	7.33
BEE (Back End Electronics)	1.70	30.00	2.21
DSMI (Detector Set Mounting Interface)	0.60	30.00	0.78
FW_Baff (Filter Wheel and Detector Baffle)	1.50	20.00	1.80
GPD (Gas Pixel Detector)	2.00	27.00	2.54
ISS (Instrument Support Structure)	9.00	20.00	10.80

	mass (kg)	mass margin (%)	mass incl. margin (kg)
MAM (Mirror Assembly Module)	**164.10**	**20.00**	**196.92**
MA (Mirror Assembly)	**151.20**	**20.00**	**181.44**
MM1 (Mirror Module)	50.40	20.00	60.48
MM2 (Mirror Module 2)	50.40	20.00	60.48
MM3 (Mirror Module 3)	50.40	20.00	60.48
MBaf (Mirror Baffle)	**4.30**	**20.00**	**5.16**
MBaf2 (Mirror Baffle 2)	**4.30**	**20.00**	**5.16**
MBaf3 (Mirror Baffle 3)	**4.30**	**20.00**	**5.16**

In OCDT: CE includes harness (6.5 kg). Other harness at system level

Power

Power (W)	P_on	P_stby
FPM (Focal Plane Module)	**60.20**	**0.00**
CE (Control Electronics)	**26.00**	**0.00**
FPA (Focal Plane Assembly)	**34.20**	**0.00**
DetSet (Detector Set)	11.40	0.00
BEE (Back End Electronics)	4.70	0.00
FW_Baff (Filter Wheel and Detector Baffle)	5.00	0.00
GPD (Gas Pixel Detector)	1.70	0.00
DetSet2 (Detector Set2)	11.40	0.00
BEE (Back End Electronics)	4.70	0.00
FW_Baff (Filter Wheel and Detector Baffle)	5.00	0.00
GPD (Gas Pixel Detector)	1.70	0.00
DetSet3 (Detector Set3)	11.40	0.00
BEE (Back End Electronics)	4.70	0.00
FW_Baff (Filter Wheel and Detector Baffle)	5.00	0.00
GPD (Gas Pixel Detector)	1.70	0.00

This is the installed power, duty cycle is assumed for the mean power calculation (info in the power budget)

Payload: description

- XIPE payload consists of two main elements:
  - X-ray Mirrors (ESA responsibility)
  - Detectors set (provided)

During the CDF study (and Phase A) the X-ray mirrors are also considered payload, although they will be under ESA responsibility.

X-ray mirrors: set of three Wolter I X-ray telescopes, focal length 3.5m, 27 shells, outer radius 0.38 m, length 600mm, 50.4 kg (each, without margin)

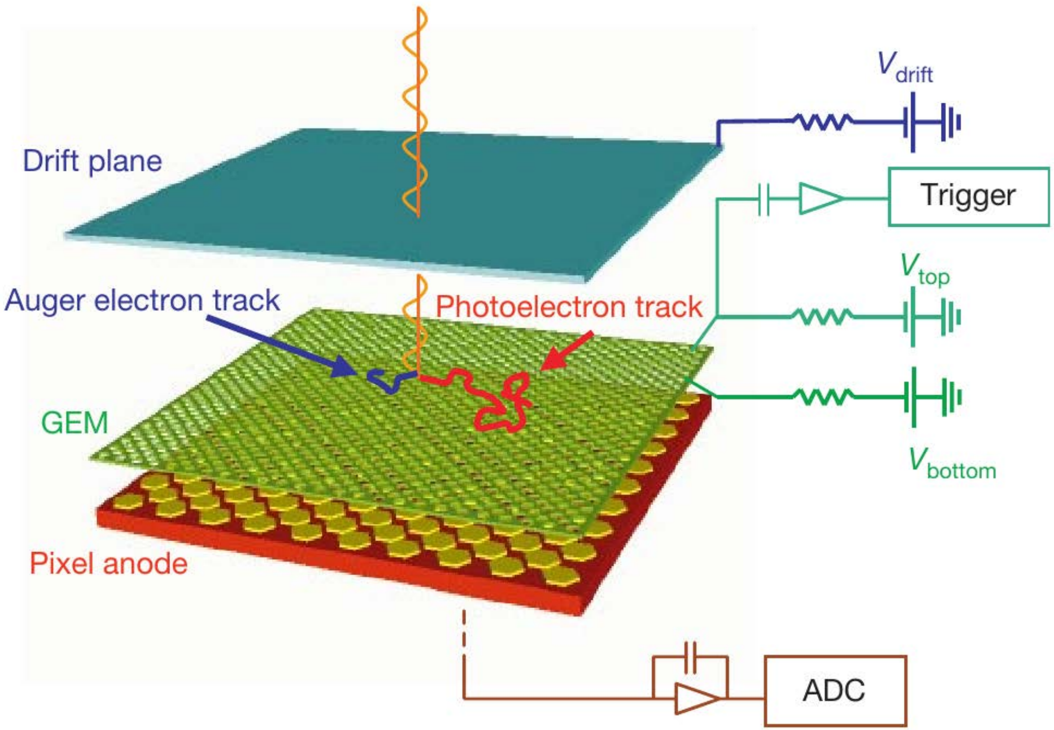
Detector set: set of three identical GPD detectors including associated electronics, aimed at measuring polarization at X-ray wavelengths. Includes Support Structure.

Detector: Filter Wheel (FW)

- Each detector set contains one mechanism: a Filter Wheel with 7 positions:

1. open slot for standard observations;
2. slot with a Be absorber to reduce the flux of exceptionally bright sources (rate >500 c/s on each DS);
3. slot with a diaphragm to observe faint sources close to a bright source;
4. slot with a 55Fe unpolarized calibration source (Calibration);
5. slot with a Cu/Cd-109 (TBC) unpolarized fluorescence source (Calibration);
6. slot with a polarized X-ray source (Calibration);
7. closed slot for the launch and the study of the internal background and safety.

Principle of operation

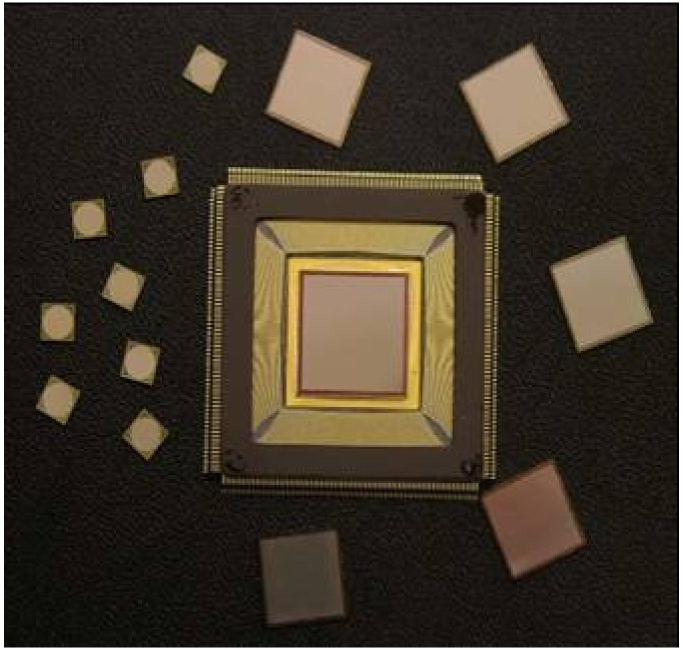


Photoelectron track which is formed depends on polarization direction of photons.

Reconstruction of (distribution of) main axis of photoelectron tracks allows to determine polarization direction.

CMOS array with 105600 pixels, 50 µm

ASIC detector



ASIC (center) with 105,600 pixels is shown bonded to its ceramic package (304pins).

Thermal stability mirror

- Mirror thermal stability is very important since (absence of) deformations determine optical quality.
- Spatial gradients: less than 1K in longitudinal direction (along axis), less than 1K in azimuthal direction
- Time stability: less than 10K/hour (on any point on the MA), operational and non-operational
- Survival temperature mirror: -10°C to 50°C (changed).

Note: operation also during eclipse.

Thermal stability detector

Operating temperature: 278-293K, stability 1 K

Aim is to operate near 293 K.

Result of CDF study (see thermal presentation) is operation near 293 K, with good stability.

Alignment

- Detectors and Mirrors need to be aligned precisely: thermoelastic effects to be considered! Including temporal properties (HEW budget).
- Telescope optical axis mutual alignment: < 3 arc min
- Telescope optical axis alignment to boresight: < 2 arc min (to be broken down into SC-detector, and SC-Mirror alignment. SC-detector 0.5 arc min (TBC))
- Focal plane distance error < 1 mm (Mirror to detector). Currently assume 0.5 mm for both SC-detector and SC-mirror.

Telemetry

Bright source (Crab Nebula, flux=1950x10^{-11} erg/cm^2 s)	903 kbit/s for 20 ks
Typical source (Her X-1, flux=90x10^{-11} erg/cm^2 s)	42 kbit/s for 200 ks
Faint source (Sgr B2, flux=0.3 x10^{-11} erg/cm^2 s)	0.1 kbit/s for 1 Ms
Housekeeping	<4 kbit/s

For each photon							For each fired pixel	TOT
Time	Energy	ROI vertex coord.		ROI XY length		TOT	Energy or coord. (+1 bit marker)	
18	8	9	9	6	6	**58**	13	**903**

903 bit per photon, assuming 50 fired pixels and 15 transitions

For a ToO a max brigthness of 4 crabs was assumed ~ 4 Mbit/s

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Mission Analysis

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Trade-off SSO vs near-equatorial

- *Trade-off on mission scenario:*

	SSO
Ground station coverage	- - *
Eclipses	++
ΔV budget	-
Range of orbital altitude	-
Collision avoidance	-
Radiation	-

- *SSO scores worse than the low inclination LEO except for eclipse duration*
- *As the SC design shall cope with payload operating during eclipses low inclination LEO has been selected*

Orbit characteristics

Altitude (km)	550	625
Inclination (°)	6.0	6.0
RAAN	free	free
Orbital period (min)	95.65	97.2
Maximum eclipse duration (min)	36	

Station (latitude)	Average contact time (min)	Total contact time per day (min)	Station passages per day
Malindi (-3°)	10.1	143.0	14
Kourou (5.25°)	9.8	137.6	14

(for 550 km and 5° minimum elevation)

Orbital lifetime

- using the value of **200 kg / m²** and starting **at 500 km** lifetime of:
- \- 6.79 ys when using the 95% worst/best prediction
- \- 7.84 ys when using the Monte Carlo method (this method, among the three considered more accurate, is the one with the highest values of the solar flux)
- using the value of **250 kg / m²** and starting **at 500 km** lifetime of:
- \- 7.49 ys when using the 95% worst/best prediction
- \- 8.39 ys when using the Monte Carlo method (this method, among the three considered more accurate, is the one with the highest values of the solar flux)

Even if the altitude of the orbit is 500 km, the estimated mission lifetime is still within the requirement

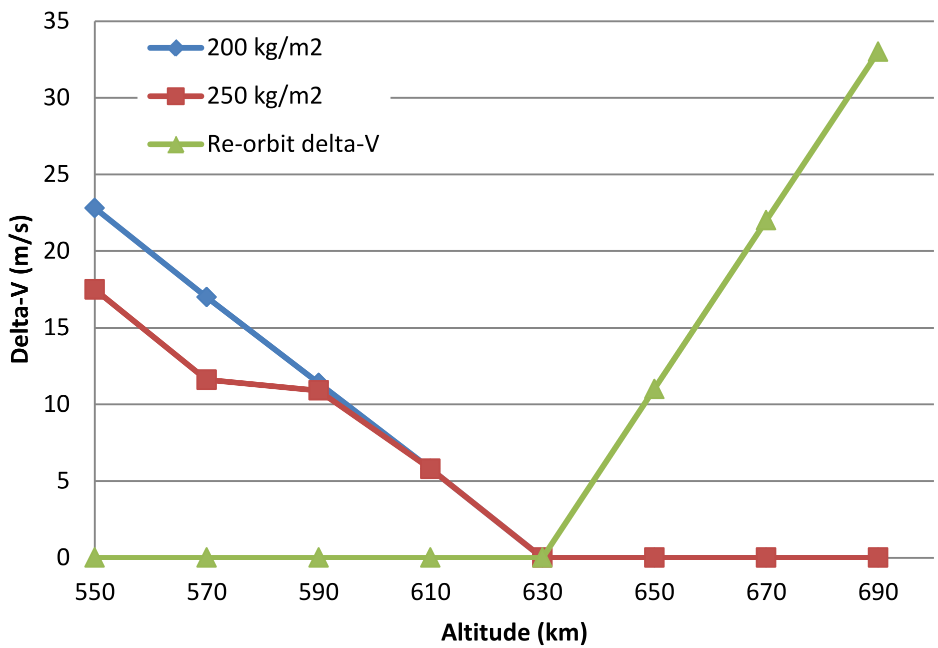
Orbital lifetime after EOL

- In gravity gradient configuration m/A is **130 kg/m²**
- Running **DRAMA** with ECCS solar activity assumptions (that gives the worst result):

  at **630 km** lifetime = 25 years

Even if the altitude of the orbit is 630 km, the SC will de-orbit by itselft within 25 years

ΔV for Re-orbit and Orbit Altitude Maintenance



- The orbit maintenance deltaV can be set to zero if it is not required to keep the altitude during the operational lifetime

- Assuming an altitude corridor of 10 km, e.g. from 540-550 km
- Even though the optimum altitude to minimise the deltaV is 625 km, the baseline altitude chosen was 550 km driven by radiation considerations
- With a 25 m/s deltaV allocation the SC can cope with altitudes from 535 km to 680 km and some uncertainties in the ballistic coefficient

De-orbit strategy

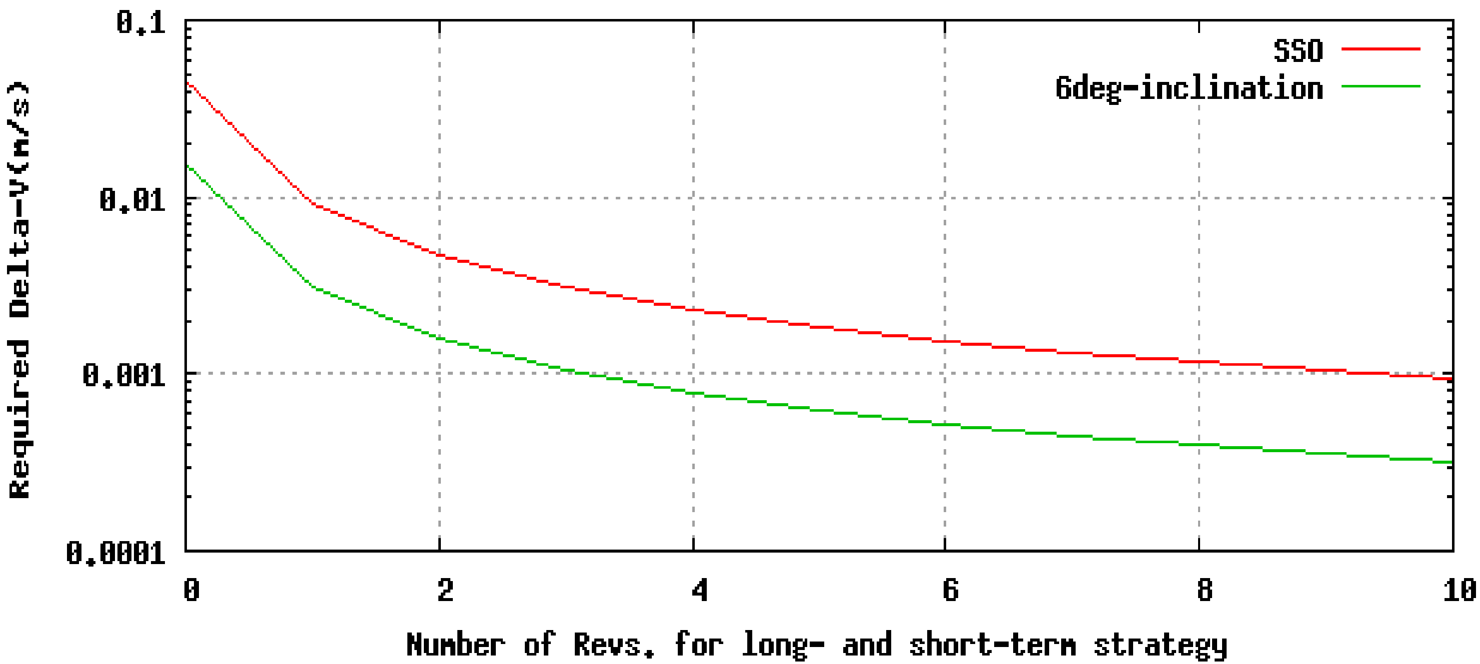
- For a 1000 kg spacecraft mass, at least 30 N thrust is required for a targeted de-orbit. 3 or 4 burns are possible (thrust direction is kept inertially fixed during each burn):

	Initial Orbit (km x km)	Final Orbit (km x km)	Delta-V (m/s)	Duration (min)
1	625x625	478x626	44.5	24.4
2	478x626	331x627	45.6	24.5
3	331x627	185x628	46.5	24.5
4	185x628	40x629	47.4	24.4
Total			184	

Thrust [N]	20	30	40	60	80
DV 1 [m/s]	125.8	66.8	59.8	56	54.5
DV 2 [m/s]	102.8	69.2	61.2	57.6	56.7
DV 3 [m/s]	148.3	70.8	63	59.6	58.8
TOT DV [m/s]	376.9	206.8	184	173.2	170

- The spacecraft would drop into the Pacific typically along an area of 1300 km

Annual ΔV for collision avoidance manoeuvres



an accepted collision probability level of 10^{-4} is assumed

Manoeuvre ΔV budget

• **Launcher dispersion correction**	0 m/s	(no needed)O
• **Orbit maintenance / de-orbit**	25 m/s	(including margin)
• **Collision avoidance manoeuvres**	2 m/s	(100 %)
• **3 De-orbit burns (for controlled entry option, if needed)**	184 m/s	(10m/s margin)

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Systems

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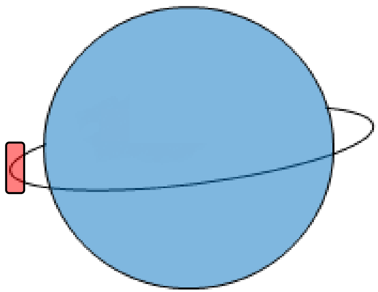
Mission Scenario

- Launch date in late 2025 or early 2026
- Launcher shall be VEGA with PLA 1194 VG adapter
- Orbit shall be circular LEO at an nominal altitude of 550 km and cope with altitude range between 535 and 640 km
- Nominal inclination of 5.6º
- Actual altitude and inclination may depend on the launcher dispersion
- End of Life will be an uncontrolled (baseline) or controlled descent into Earth’s atmosphere



Requirements Breakdown

- XIPE MRD Issue 0.0

Mission Lifetime	
R-MIS-020	**Launch date** The mission and system design shall allow launch in late **2025**.
R-MIS-120	**Mission nominal timeline** The mission design shall guarantee a nominal in-orbit lifetime of 3 years from launcher separation to disposal.
R-MIS-130	**Lifetime for consumables** For Spacecraft consumables sizing, an in-orbit lifetime extension of 2 years beyond the nominal lifetime shall be considered
R-MIS-180	**Storage** The design shall allow Spacecraft storage in a controlled environment for up to 2 years (TBC)
Orbit	
R-MIS-090	**Nominal operational orbit** The mission and system design shall assume a nominal operational orbit as follows: • Circular • Altitude between 550 and 600 km • Inclination: 5.4 deg

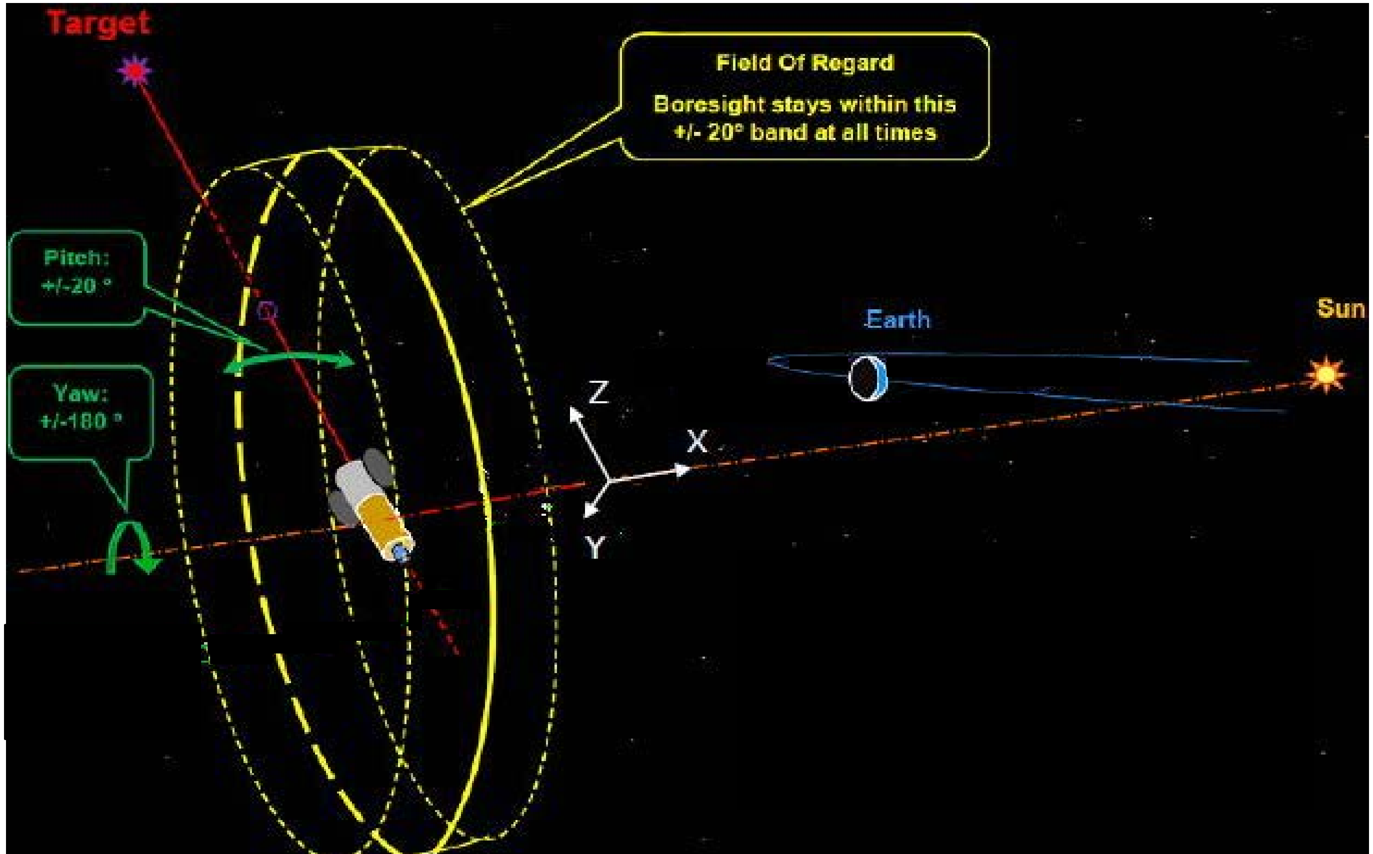
Requirements Breakdown

Launch segment	
R-MIS-050	**Nominal Launch Vehicle** The mission and system design shall allow launch with VEGA vehicle whose main characteristics and interfaces shall be taken from AD9.
R-MIS-060	**Launch Vehicle performance** The mission and system design shall assume as a reference a VEGA mass capability of 2000 kg (TBC) into a 600 km altitude circular orbit with 6 deg inclination
R-MIS-070	**Back-up Launch Vehicle** The mission and system design shall be compatible with Soyuz ST-B, Fregat MT launched from Kourou as back-up Launch Vehicle. Relevant performance and interfaces shall be taken from AD12
Operations and Ground Segment	
R-OPGS-010	**Ground Station(s)** The mission and system design shall be compatible with the use of a single X-band Ground Station for science data downlink during the operational phase
R-OPGS-020	**Ground Control outage** During the operational phase, the mission and system design shall allow nominal operations without Ground contact for up to 3 days (TBC)
R-MI-210	**Data availability** Raw observation data shall be made available to the SOC within 7 days from measurement

Requirements Breakdown

Mission Performance requirements	
R-MIS-230	**Science performance** The mission and system design shall allow fulfilment of the Science requirements level 1 defined in SciRD.
R-MIS-240	**Target Sources** The mission and system design shall ensure at least fulfilment of the reference observation plan specified in SciRD within the mission nominal lifetime.
R-MIS-250	**Field of Regard** The mission and system design shall allow Field of Regard of 1/3 of the celestial sphere at any given time with no forbidden directions over one year
R-MIS-260	**Observation efficiency** The observation efficiency shall be such to allow 150 pointings to sources per year each with an average time of 100ks
R-MIS-270	**Pointing durations** The mission design shall allow pointings to target sources with duration variable from 5 ks to 2 Ms
R-MIS-280	**Targets of Opportunity - time** The mission and system design shall be such that the time from a triggered request at SOC to acquiring a Target of Opportunity in the detector.is less than 12 hours d within the constraints of and during normal working hours
R-MIS-290	**Targets of Opportunity - number** The mission and system design shall provide the capabilities for a minimum number of Targets of Opportunity of 6 per year and shall assume a maximum number of Targets of Opportunity of 18 per year

Field of Regard



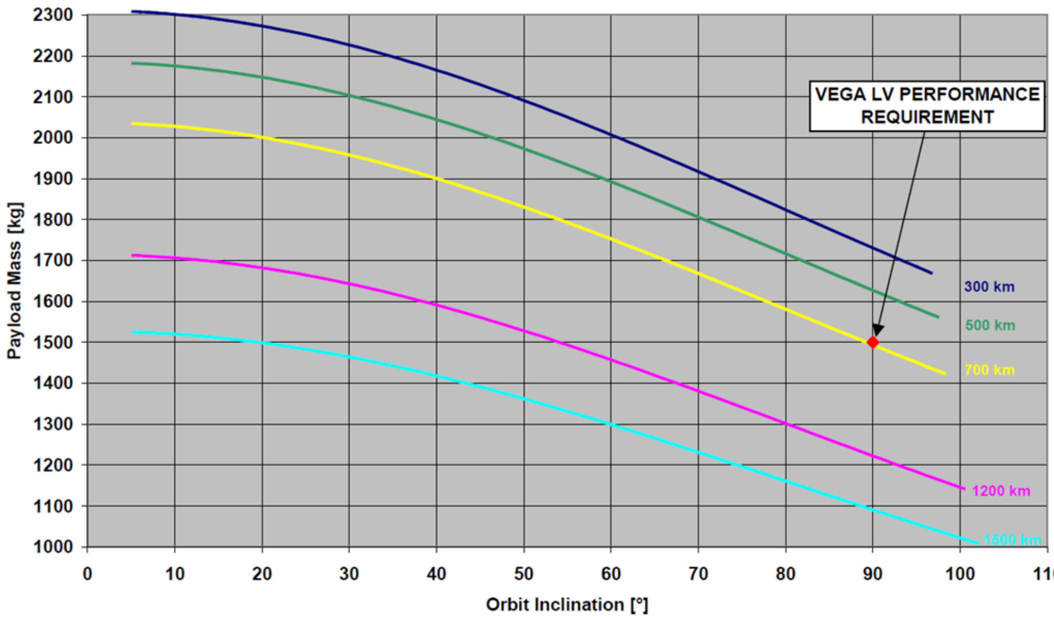
$Pitch \mp sin^{-1}(\text{FoR})$

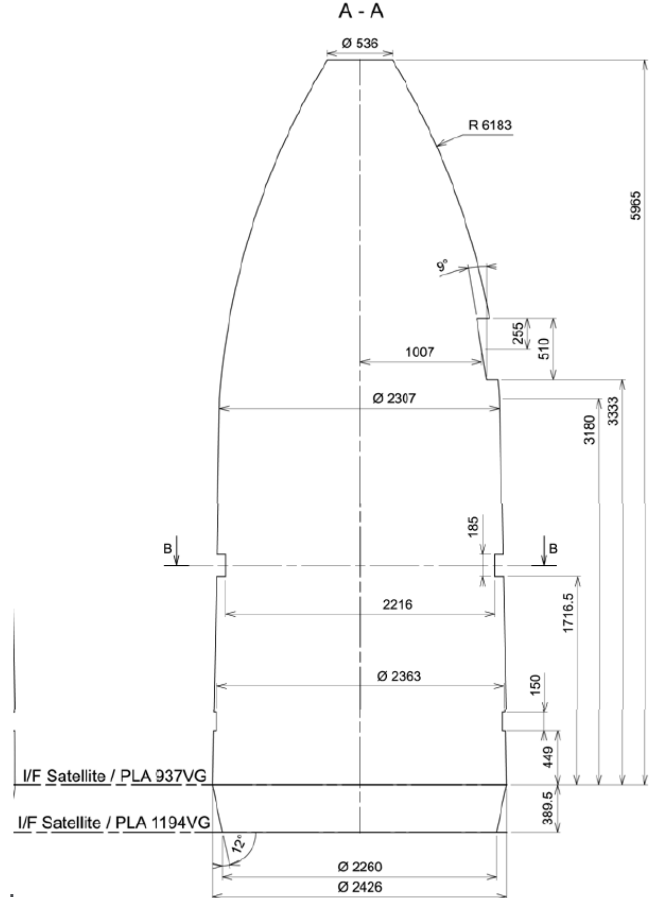
$Pitch \mp sin^{-1}\ (1/3)$

$Pitch\ \mp 19.47\ \text{deg}$

VEGA

	VEGA	Soyuz
Launch to LEO	~2200 kg	4850 kg





- Issue 3.0 of Vega User Manual, M4 Call Technical Annex
- Launcher performance at equatorial orbit not yet confirmed by Arianespace

Concept of Operations

- Science Operation Centre shall be ESAC
- Mission Operation Centre shall be ESOC
- Malindi shall be the Communications Ground Station

Assumptions

- Vega C has equal or better performance than Vega
- No launcher correction manoeuvres
- 5.6º inclination circular orbit at 550 km of altitude
  - ~96 min/orbit of which ~34 min/eclipse
- Instrument “on” all the time (including Eclipse, SAA and downlink)
- No communication downlink while slewing
- No additional vignetting effects from the S/C
- No need for x-ray straylight baffling provided by the S/C
- MOC takes up to a total of 270 min to respond to a ToO alert (GSO)
- SOC takes up to a total of 87 min to respond to a ToO alert (on working hours)
- Margin philosophy according to SRE specification
- The harness mass is considered 5% of total dry mass

Baseline design

Subsystem	Options	
Comms/GS	X-band system 4 kbps uplink, 6 Mbps downlink using Malindi. Backup Kourou	
Propulsion	Monopropellant, blow-down system, 8 (+8 redundant) x 1 N thrusters	Monopropellant, blow-down system, 8 (+8 redundant) x 1 N thrusters, 4 (+4 redundant) 20 N thrusters
AOGNC	4 x star trackers, 2 x medium-accuracy gyros, 4 x reaction wheels (>8Nm) 2 x sun sensors, 2 x coarse gyros 2 x magnetometers, 2 x GPS receivers & antennas	
Instruments	3 x Wolter I X-ray telescopes, focal length 3.5 m, 27 shells, outer radius 0.38 m, length 600mm, 50,4 kg each without margin 3 x GPD detectors and associated electronics	

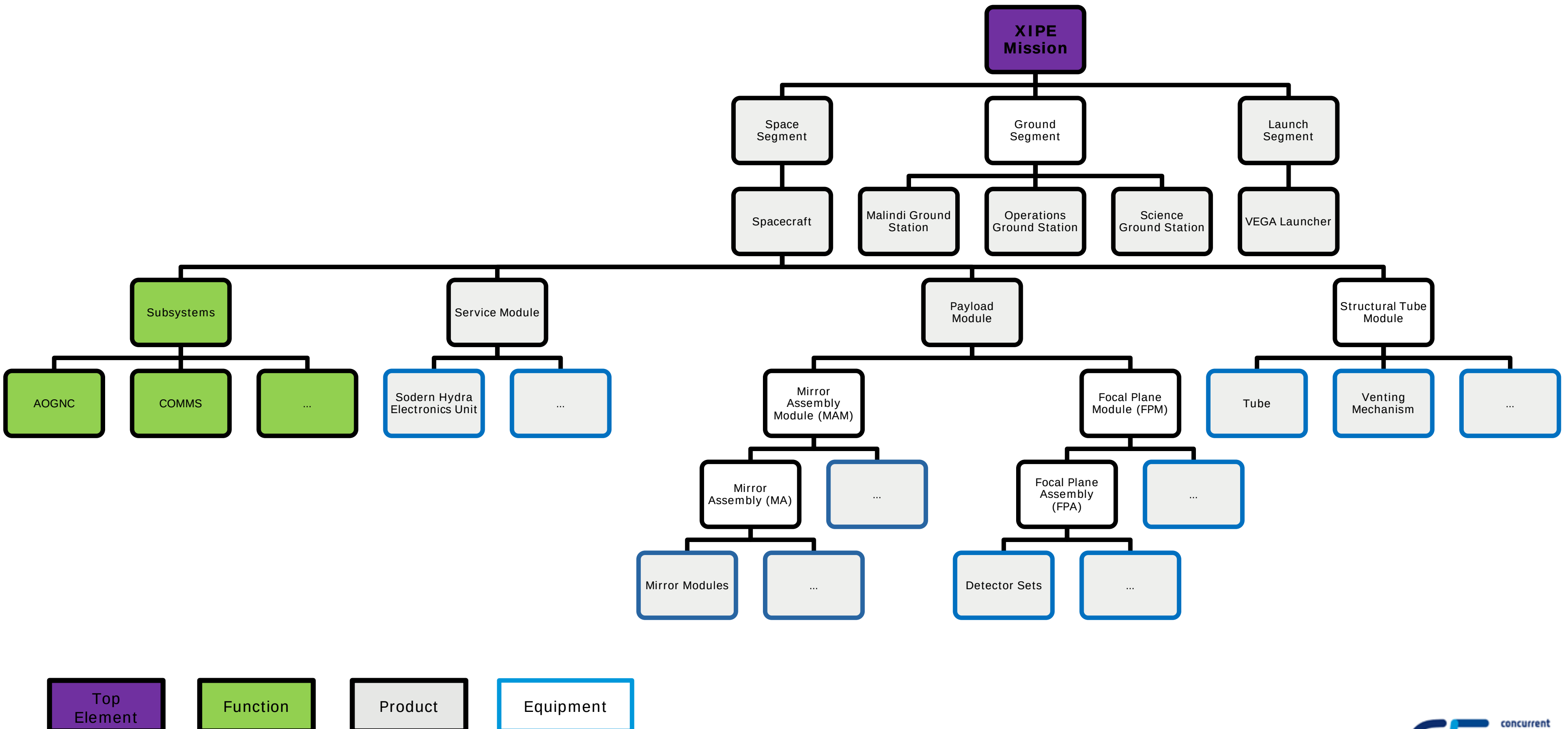
Baseline design

Subsystem	Options
Radiation	3 NGRM, 3 x 1.4 kg, 68 × 132 × 150 mm each
Thermal	Heater based thermal control for FPM, Structural Tube and MAM
Power	Solar Array: 5.8m2, 22.3 kg Battery: 2 x [10.4 kg, 180 x 190 x 370 mm] PCDU: 25 kg, 390 x 350 x 230 mm
DHS	OBC: OSCAR Solid State Mass Memory (SSMM) 240 Gbits (including margin) RTU: 2 x 7 kg

Baseline design

Subsystem	Options
Mechanisms	Deployable Sun Shield H:150 mm W:900mm 1 fixed and 1 H:650mm W:900mm deployable sandwich panels, three mirror cover mechanisms and venting mechanism
Mission Analysis	Direct Injection, circular orbit 5.6 deg inclination. Baseline at 550 km altitude but compatible with altitudes from 535 to 680 km.

Mission Breakdown



System Modes

System Modes

- Umbiliical to Sun acquisiition
  - SC in Launch Configuration, Initial Sun acquisition
- Observation Low Declination
  - SC in a configuration where observations are being done, all services from platform running including thermal and comms, S/C attitude close to equatorial
- Manoeuvre
  - SC manoeuvring for orbit maintenance, collision avoidance or disposal manoeuvres
- Slow Slew
  - SC slewing using Reaction Wheels (to repoint for a new observation)
- Safe
  - SC in Safe Mode. Begins with sun acquisition mode. Shut-down of on non essential systems, only essential functions such as survival thermal management, safe mode AOCS, and HK-TM/TC comms are active.
- Observation High Declination
  - SC in a configuration where observations are being done, all services from platform running including thermal and comms, S/C attitude close to polar

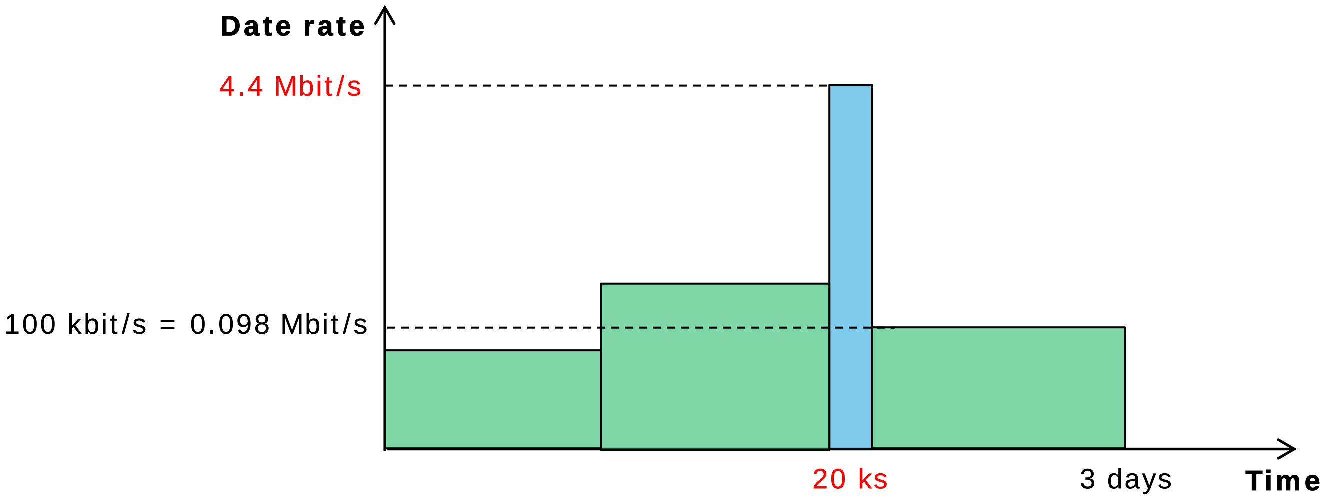
Power budget

	Man	ObsHiDec	ObsLowDec	Safe	SSlew	UMB_SUN
PLM (Payload Module)	207.35	207.35	166.35	100.00	207.35	40.55
FPM (Focal Plane Module)	66.35	66.35	58.35	10.00	66.35	10.00
MAM (Mirror Assembly Module)	141.00	141.00	108.00	90.00	141.00	30.55
SVM (Service Module)	292.88	292.11	292.11	375.53	392.91	232.62
ST (Structural Tube Module)	41.00	41.00	38.00	41.00	41.00	1.00
Grand Total	541.23	540.46	496.46	516.53	641.26	274.17
Total with (30% margin)	703.60	702.59	645.39	671.49	833.63	356.42

- **Power subsystem sized for the "Observation for High declination sources"** system mode (ObsHiDec) -> cold thermal case. Eclipse assumed for roughly 1/3 of the orbit
- **Slewing mode** (SSlew) **was not considered to be the driving case** because of its relatively short duration (only up to 40 min in the worst case scenario of 180 deg slew, average of 20 min)
- Safe mode (Safe) assumed to be in an attitude perpendicular to the S/C-Sun line. MAM heating power calculated to maintain non-operation temperature, instruments in stand-by.
- The "Umbilical to Sun acquisition" system mode (UMB_SUN) includes LEOP and does not assume any illumination. Potential problem of safe mode at this stage was taken into account.

Data budget

- The on board memory was sized to take into account **3 days of ground control outage** (R-OPGS-0020). For a worst case scenario we assumed that, during this period, the S/C continues performing normal science operations and acquires a very bright ToO (with a brightness of 4 crab ~ 4.4 Mbit/s) for a total of 20 ks + 4 kbit/s for H/K.



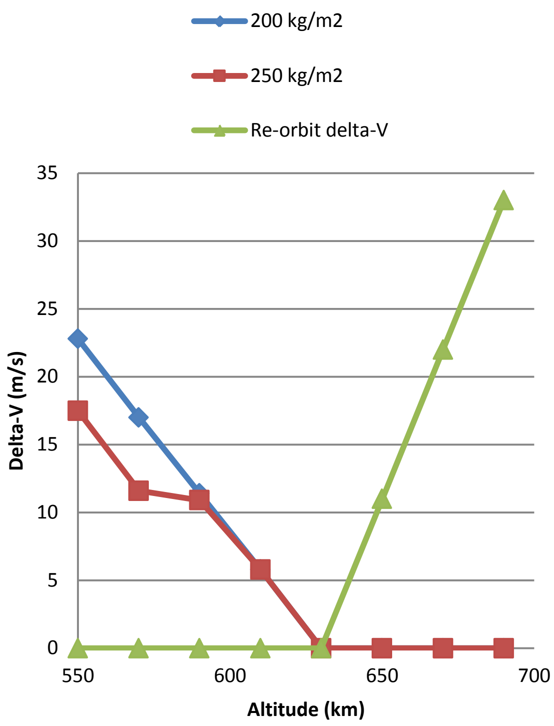
- Total mass memory required (Gbit) = 4.4*20e3/1e3+(3*24*3600-20e3)*100/1e6 + 4*3*24*3600/1e6

  = 114 Gbit

- Assumed **228 Gbit with 100% margin**

Δv budget: Uncontrolled reentry

Purpose	Δv [m/s]	Remark
orbit acquisition	0	
AOCS	1.68 kg/year	100 % margin included
Collision avoidance	2	
Orbit Maintenance/de-orbit	25	Margin taken for drag and ballistic coefficient
Total	**27 + AOCS**	



Δv budget: Controlled reentry option

Purpose	Δv [m/s]	Remark
orbit acquisition	0	
AOCS	1.68 kg/year	100 % margin included
Collision avoidance	2	
Controlled reentry from 625 km	184	3 burn strategy, 60 N thrust (decided by the propulsion subsystem): 174 m/s + 10 m/s (margin)
Total	**186 + AOCS**	

Baseline Mass budget Uncontrolled Reentry

	Switch	Mass (kg)
AOGNC	Product	**68.89**
COM	Product	**19.17**
CPROP	Product	**18.03**
DH	Product	**32.92**
EMC	Not used	**0.00**
INS	Product	**237.51**
MEC	Product	**29.89**
PWR	Product	**77.41**
SYE	Not used	**0.00**
TC	Product	**29.12**
STR	Product	**292.39**
	Total (kg)	**805.33**

Harness	5.00%
Harness mass	28.39kg
System Margin	20.00%
System Margin Mass	161.0658369kg
Total Dry Mass	994.79kg
Propellant Mass	20.87kg
Propellant Margin	2.00%
Total Wet Mass	**1016.07**kg
Launcher Adapter	78.00kg
Wet Mass + Adapter	1094.07kg

Mass budget Controlled Reentry

	Switch	Mass (kg)
AOGNC	Product	**68.89**
COM	Product	**19.17**
CPROP	Product	**33.80**
DH	Product	**32.92**
EMC	Not used	**0.00**
INS	Product	**237.51**
MEC	Product	**29.89**
PWR	Product	**77.41**
SYE	Not used	**0.00**
TC	Product	**29.12**
STR	Product	**292.39**
Total (kg)		**821.10**

Harness	5.00%
Harness mass	29.18kg
System Margin	20.00%
System Margin Mass	164.2200369kg
Total Dry Mass	1014.50kg
Propellant Mass	98.20kg
Propellant Margin	2.00%
Total Wet Mass	**1114.66kg**
Launcher Adapter	78.00kg
Wet Mass + Adapter	1192.66kg

HEW budget (1/2)

- The angular resolution requirement is expressed in terms of **Half Energy Width** of the PSF
- HEW is defined as the angular diameter containing 50% of the photons corresponding to a point source. **R-PL-0020=30 arcsec, G-PL-0010=20 arcsec**
- **Preliminary allocation:**

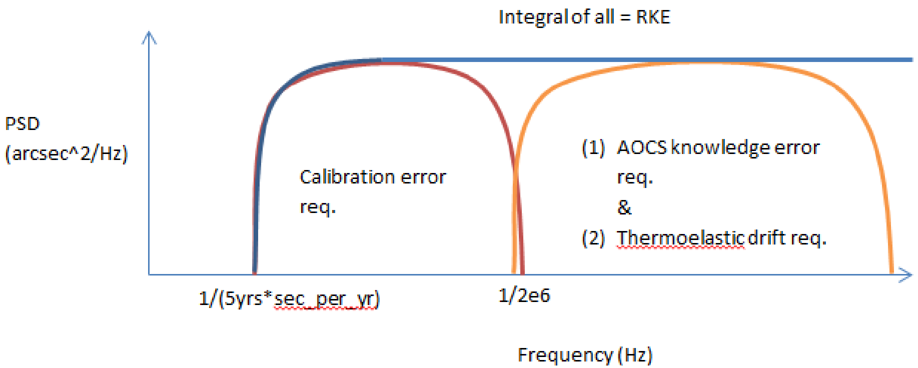
HEW budget on-axis for each telescope @3 keV			
	Contribution	**Value (arcsec)**	**Comment**
Payload	MM internal effects	20	From proposal. Mainly due to manufacturability. Half energy width on-axis measured at 3 keV.
	GPD internal effects	9	Effect of the GPD thickness. Due to inclined penetration of photons. Half energy width on-axis measured at 3 keV.
	Total payload contribution	**21.9**	
RPE of focal length	Focussing effects (longitudinal changes in the Telescope tube)	3	Estimated with thermoelastic model, assumed 10 degC longitudinal gradient . Half energy width on-axis measured at 3 keV < 3 arcsec, over a period of 5 years.
	Total RKE internal	**3.00**	

- **Internal payload contributions** have been measured with an **end to end test** (MM+GPD)
- **Inclined penetration effects** are assumed for a **on-axis** (effect of the detector thickness)
- The effects **of longitudinal changes of the structural tube** translates into a defocusing effect of the PSF (estimated with an optical model at 3 arcsec).

HEW budget (2/2)

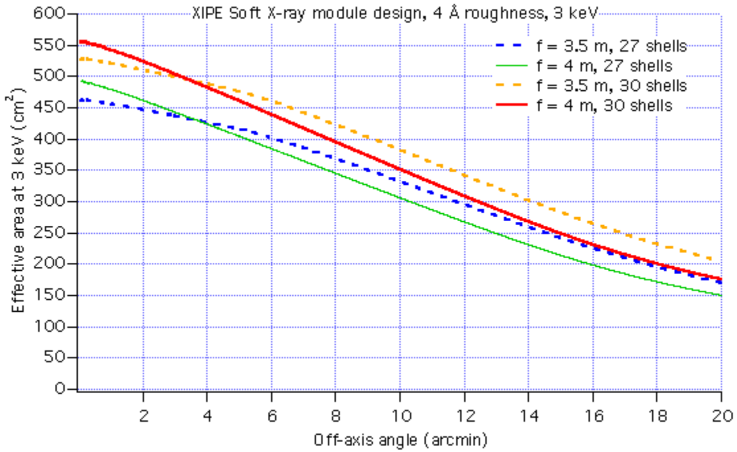
RKE of each telescope LoS	Thermoelastic deformation introduced by the structural tube (tilt)	2	Estimated with thermoelastic model, assumed 10 degC gradient on the cross section of the structural tube.
	Thermoelastic deformation introduced by the mirror module support structure (tilt)	2	Assumption. Thermoelastic model needs to be performed at later design stages.
	Thermoelastic deformation between the star tracker LoS and the star tracker mounting plane normal vector	5.875	<5 arcsec over 2 Ms, 95% of the time (2 sigma). Allocation only.
	Thermoelastic RKE LoS	**9.875**	
	AOCS RKE LoS	5.875	Knowledge of the actual LoS <5 arcsec over 2 Ms, 95% of time (2 sigma).
	Calibration KDE LoS	2.35	<3 arcsec difference between 2 Ms means over 5 years, with aid of calibration/centroid data, for 99.7% of calibrations (3 sigma). Based on an ensemble statistical interpretation.
	Total RKE LoS	**11.7**	
	Total	**25.1**	

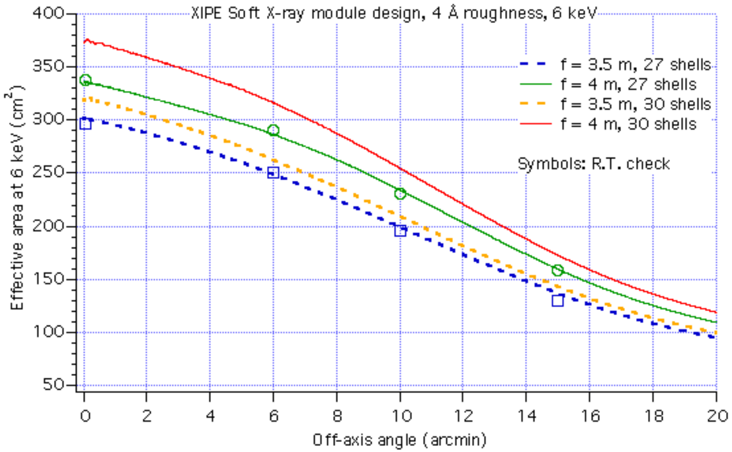
- **Total = 25.1 arcsec < 30 arcsec**
- **Correlated errors are added linearly** and **uncorrelated errors are summed in RSS**
- The thermoelastic effects are correlated and therefore added linearly
- Decreasing the calibration frequency, poses stricter requirements on the AOCS RKE and thermoelastic behaviour of the SC



Focal length considerations

- The **current design** based itself on a configuration **with 3.5 m focal length with 27 shells**
- The accommodation on the launcher shows that it is possible to achieve the 4 m focal length
- The increase to the higher number of shells (30 shells) could not be confirmed during the study





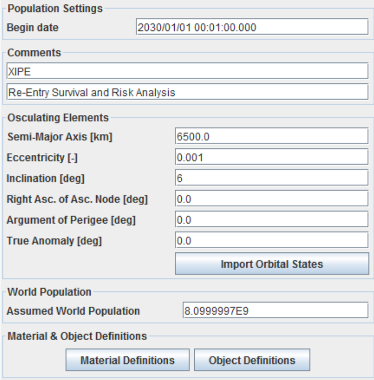
- The **additional vignetting** introduced by the higher focal length poses questions on its scientific advantages vs. the 3.5 m (particularly for the science cases requiring lower energies).

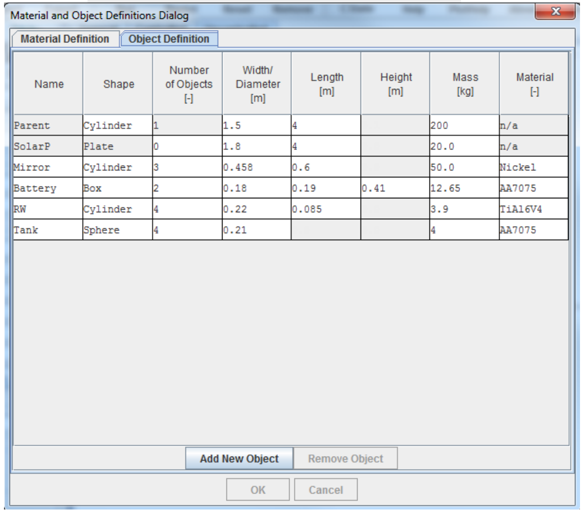
DRAMA analysis

- World population assumed 8.1 billion at 2030 (SARA analysis)
- Modelled orbit and main equipment
  - MMs
  - Solar Panels
  - Batteries
  - RWs
  - Tanks
- No interaction between different equipment
- Mirror Modules have been modeled with an average density rather than as individual shells => conservative
- Results show that the total casualty probability (for combined casualty cross sections) over one orbit has the following distribution

Min	Avg	Max
5.63e-5	6.99e-5	7.33e-5

- Since < 1e-4, the preliminary results **do not point towards the need of controlled re-entry**.



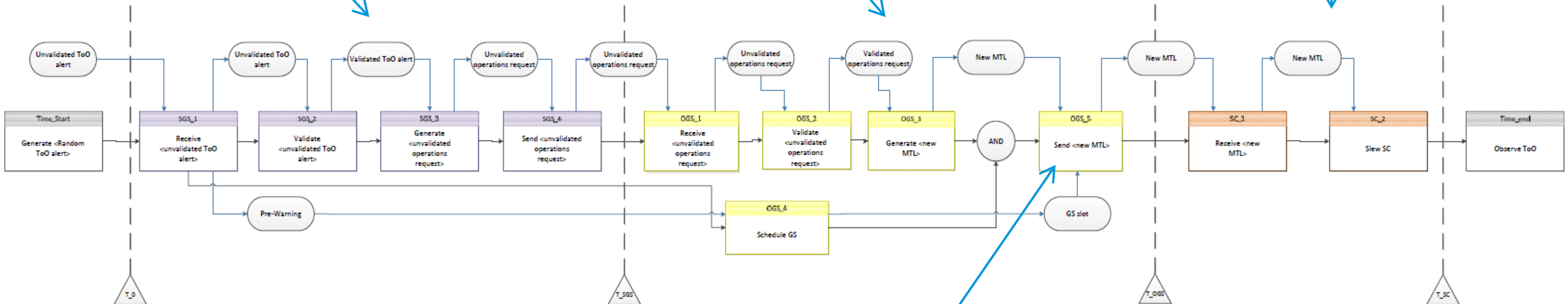


ToO: Diagram

SGS validates Science request and sends an Operations request

OGS validates Operations requests, generates a new MTL and sends it

S/C receives new MTL and slews to acquire target



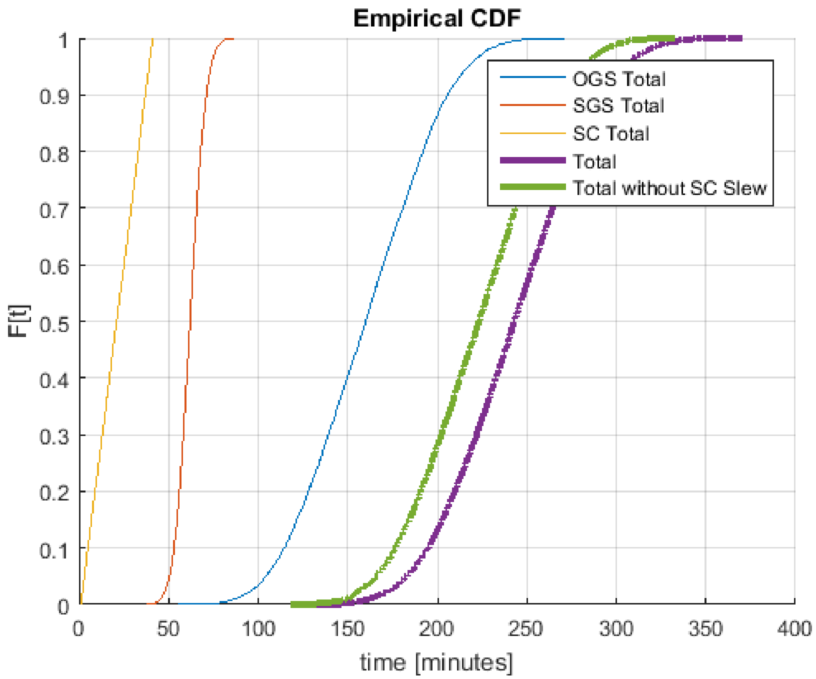
- Except for OGS_5 and SC_2, each event is modelled by a normal distribution function.

Satellite must be visible from Ground station

ToO: Assumptions

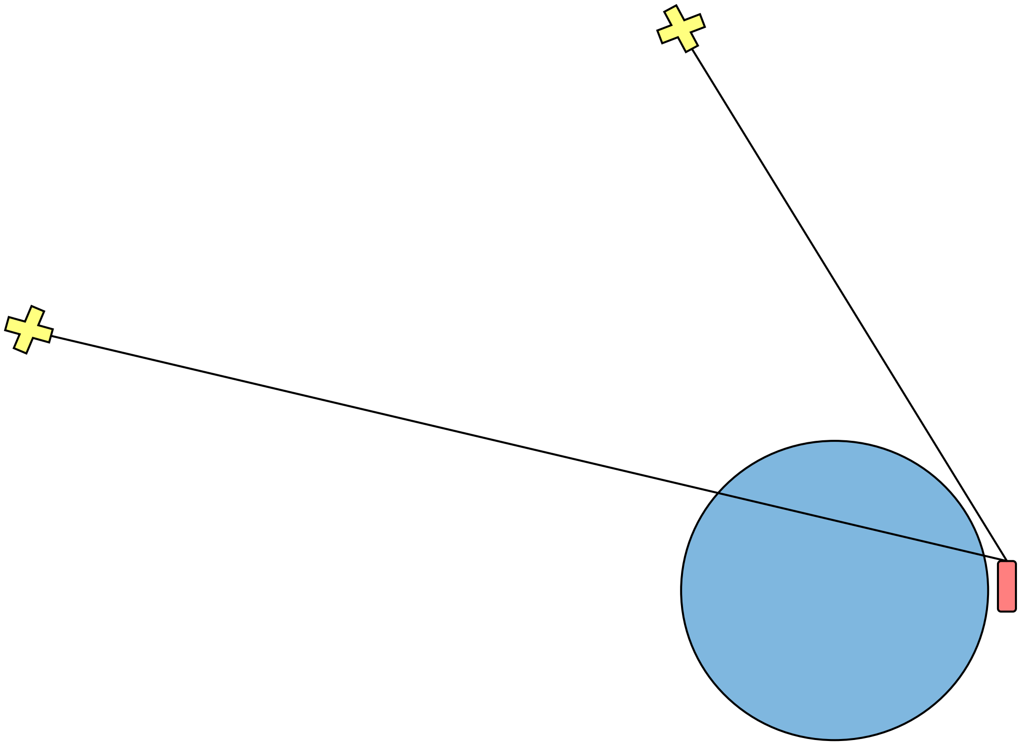
- Assumptions
  - One Ground Station at Malindi
    - Longitude 40.194511º, Latitude -2.995556º, Height -12.75 m
  - 6º inclination circular orbit at 600 km of altitude
    - ~96 min/orbit of which ~34 min/eclipse
  - 180º slew is the worst case scenario. This should be done in 40 minutes, yielding a velocity of 4.5º/min
  - In average the MOC should take a total of 2.5 hours (GSO)
  - SOC keeps the same values of similar studies
  - **ToO should not drive MOC concept**

ToO: Results



- Worst case scenario:
  - SGS: 87 min
  - OGS: 270 min
  - SC: 41 min
  - Total: 370 min
- Within mission requirements (< 12 hours [720 min])

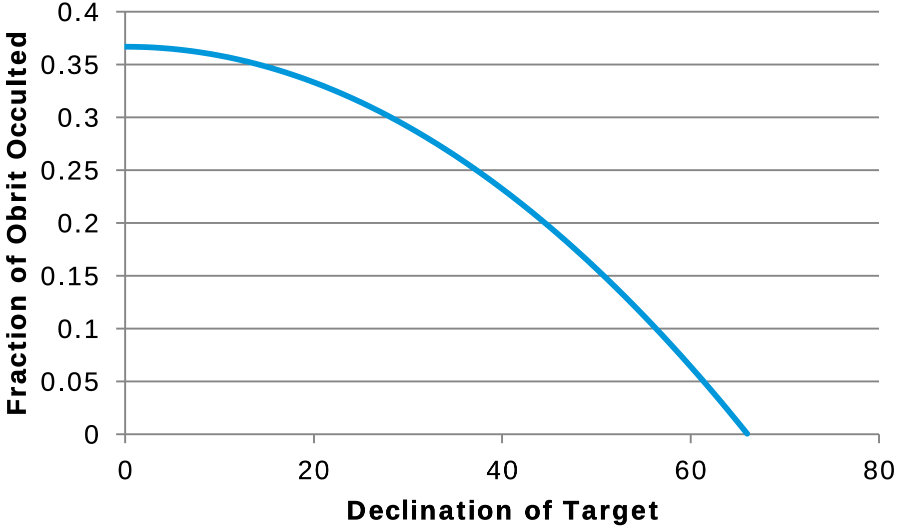
Obscuration for targets at low declinations

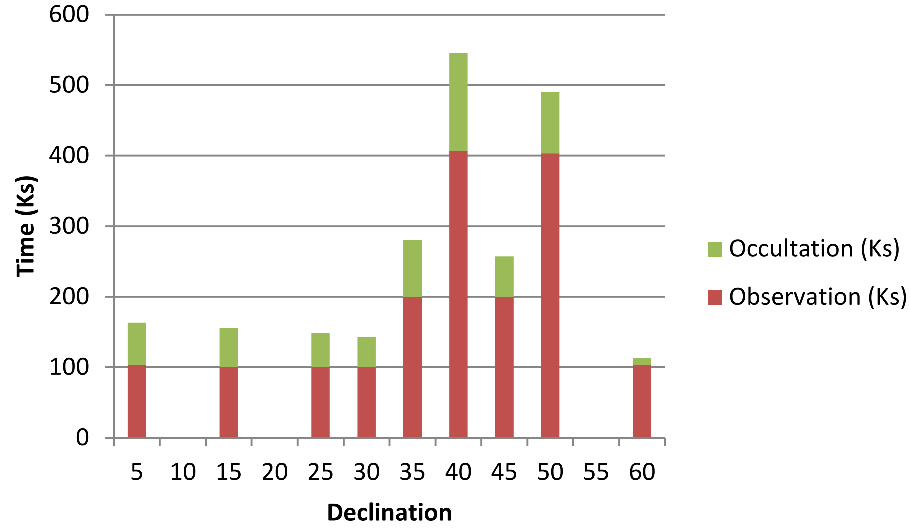


- Part of the orbit will be obscured if the target source's declination is low, increasing the time spent for each observation and lowering overall efficiency

Sources of Observation Inefficiencies

- Occultation of Target by Earth
  - Small sample of only 17 scientific targets were used
  - Assumed 100 Ks of required observation time for each target
  - Assumed 600 Km altitude, equatorial (0º) orbit





Sources of Observation Inefficiencies

- Slewing
  - Assumed XMM slew distribution
  - Slew speed of 4.5º/min
- South Atlantic Anomaly
  - Assumed 5% of each orbit

- Calibration
  - 300 s every 2 Ms of net time
- Safe mode
  - 8 days/year -> 691.2 Ks/year
- Monitoring of sources
  - 14 Sources to be monitored for 300 s every 2 weeks, plus slewing to the median angle (50º) each time
- Manoeuvres (if needed)
  - 100 min in total mission (5 years)
- Occultation due to star tracker optical head TBD (not included)

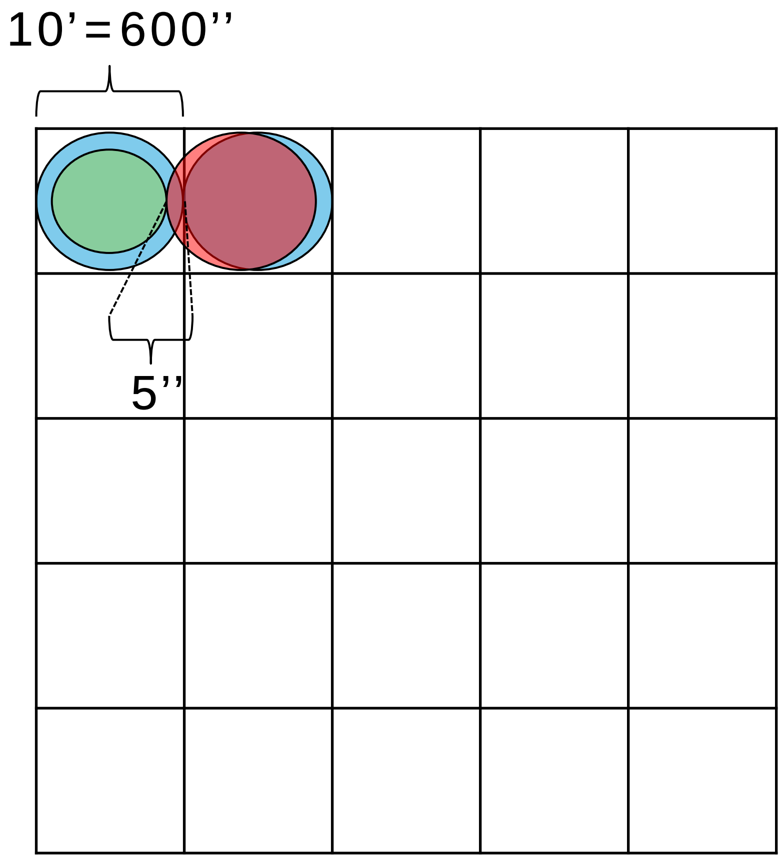
Sources of Observation Inefficiencies

- Extended observations
  - Worst case scenario of 10'':
    - 5'' from PDE
    - 5'' from overlap

$$\left(\frac{600 \times 5}{600 - 5 - 5}\right)^2 > 5^2$$

$$25.85 > 25$$

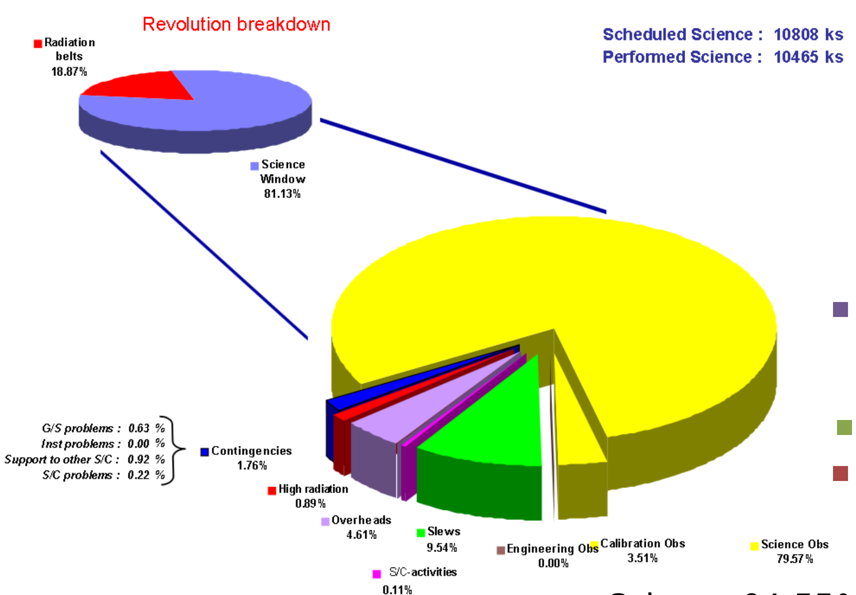
  - Each observation must take an additional 3.4% duration to compensate for error



Efficiency: XMM-Newton vs XIPE estimations

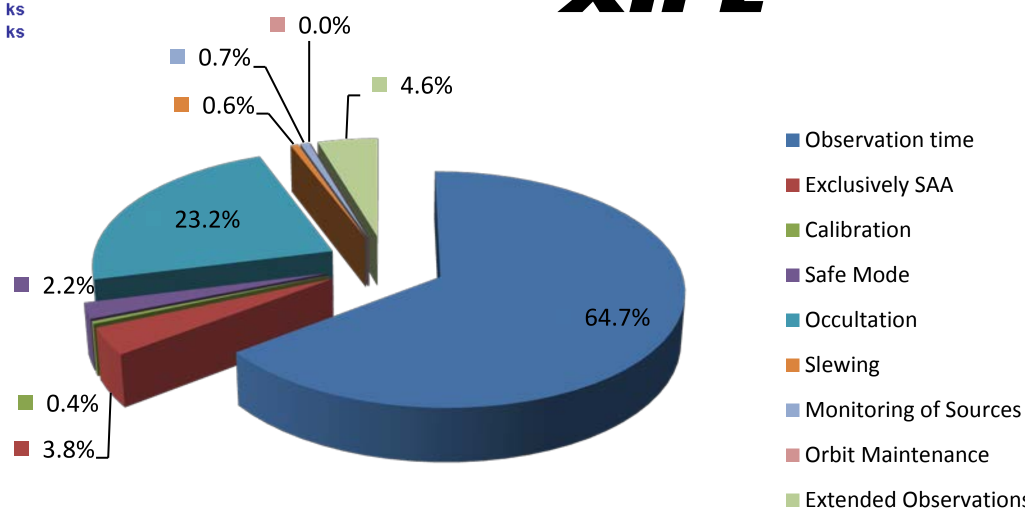
XMM

PN efficiency breakdown over the last 6 months (revs 2759 to 2848)



Science 64.55% of total time

XIPE



About 20 Ms of Science per year

- XMM has an average observation of 30 Ks, hence the slew discrepancy

XIPE

Attitude & Orbit Guidance, Navigation & Control (AOGNC)

Session 8
ESTEC, 23-09-2015

Prepared by the CDF* Team

(*) ESTEC Concurrent Design Facility

Requirements

ID	Statement	Comments
R-SC-0070	Over a period of 2 Ms, the spacecraft design shall ensure a Relative Knowledge Error (RKE) during an observation of each telescope's LoS pointing and any source across the entire field of view less than 10 arcsec TBC at 95 % confidence, using the temporal statistical interpretation.	Allocation from HEW Budget. Preliminary Subsystem Allocation: -5 arcsec AOCS (STR) -8 arcsec STR to Telescope LoS offset
R-SC-0060	During observation, the spacecraft design shall ensure an Absolute Knowledge Error (AKE) of each telescope's pointing in all axes less than 5 arcmin at 95% confidence, using the temporal statistical interpretation.	Allocation of a science requirement to measure polarization angle w.r.t. celestrial frame better than 15 arcmin.
R-SC-0050	During observation, the spacecraft design shall ensure an Absolute Performance Error (APE) of each telescope's LoS pointing is less than 3 arcmin at 95% confidence, using the temporal statistical interpretation	Direct conversion of a maximum vignetting requirement to meet science needs

Design drivers

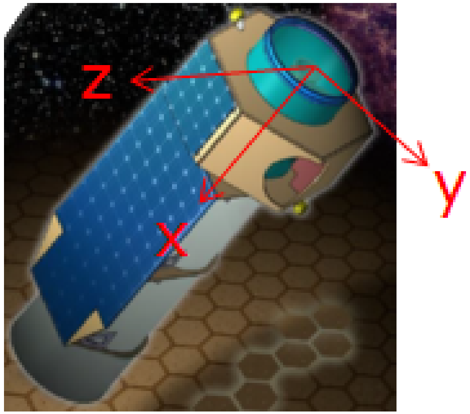
- *In terms of AOCS the main design drivers for this mission are:*
  - *Meet stringent pointing RKE requirement during observations*
  - *Minimize impacts to science availability from Earth-Sun occultation of star trackers*
  - *Permit attitude estimation throughout the entire orbit*
  - *Support orbit maneuvers*
  - *Provide an attitude safe mode*

Assumptions (general)

- *Assumptions:*
  - *Mass: 1000 kg*
  - *C.g.: [1.6, 0.1, 0.1] m*
  - *Inertia about c.g.:* $\begin{bmatrix} 460 & 40 & 40 \\ 40 & 3080 & -5 \\ 40 & -5 & 3080 \end{bmatrix}$ $kg.m^2$
  - *Spacecraft max. cross-sectional area:* $10\ m^2$
  - *Magnetic Residual Dipole:* $10\ Am^2$

    (based on mass formula)

Assumed AOGNC coordinate frame



Assumptions and trade-offs (safe mode)

- *Assumed safe attitude requires solar panels pointed to sun within 20deg (similar to field of regard constraints) from initial spin rate of 2 deg/s (Vega + 100% margin), ~6 days of safe modes per year (for 5 years)*
- *Sensors selected:*
  - *2 x Sun sensors with 180deg FoV*
  - *2 x Coarse gyros to hold attitude during eclipse and damp rate about sun-direction*

Eclipse navigation:	Earth Sensor & Magnetometer	Coarse Gyro	Medium-accuracy Gyro
Accuracy	-- (given available hardware)	-	++
Simplicity	-	+	+
Cost	-	=	-- (However, could re-use in normal mode)

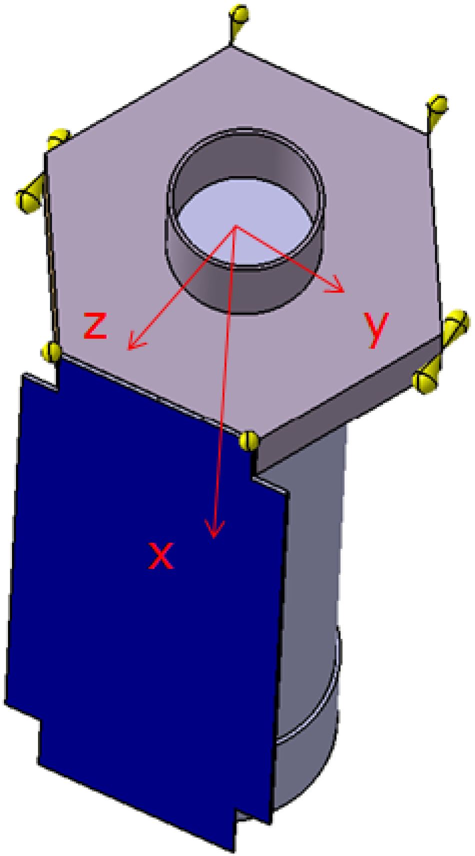
Assumptions and trade-offs (safe mode)

- *Actuators selected:*
  - *1N Thrusters, with 3-axis attitude control*

Actuators:	**Magnetorquers**	**Thrusters**	**Thrusters & Magnetorquers**
Accuracy	--	+	+
Simplicity	+	-	--
Mass	-- 29 kg (3 x 480 Am^2)	+ 8.4 kg fuel (incl. margin) 2.5 kg extra thrusters (8 x 1 N)	++ some fuel savings

Thruster configuration

- *Selected thruster configuration allows decoupled (dedicated thrusters per axis) torque control about all 3 axes and force in +X axis.*
- *Y/Z torques induce parasitic forces which will modify orbit, but will be in mostly random directions and constitute < 2kg of fuel. Therefore, net orbit change expected to be negligible.*
- *For thruster size, we only need 0.015 N for a 1 hour de-tumble from launcher*
  - *Selected 1 N thrusters de-tumble in 1 min*
  - *Sizing case is burn time for orbit manoeuvres (see Propulsion presentation)*



Assumptions and trade-offs (normal mode)

- *Inertial pointing attitude*
  - *Primary objective: telescope LoS to target*
  - *Secondary objective: solar panels to sun*
- *Sensors selected:*
  - *4 x Star trackers (to handle Earth/Sun occlusions in wide range of attitudes)*
  - *Baseline but not mandatory: 2 x Medium-accuracy gyros to navigate STR occultation (& improve RKE as bonus)*

STR occultation navigation:	**Earth Sensor & Magnetometer**	**Medium-accuracy Gyro**	**More star trackers (probably 1-2 extra to handle failure case)**
Accuracy	-- (given available hardware)	++ (RKE bonus)	+
Simplicity	-	= (possibility to also use in safe mode)	-

Assumptions and trade-offs (normal mode)

- *Actuators selected:*
  - *4 x Reaction wheels (> 8 Nms)*
  - *3 x Magnetorquers (> 100 Am^2, for momentum management)*

Momentum management device:	Thrusters	Magnetorquers
Mass	-- 25 kg fuel Larger wheels needed (> 150 Nms!)	+ 11.5 kg
Operations / science impact	- (almost daily mom. dump operations)	++

Assumptions and trade-offs (normal mode)

- *Auxiliary AOCS Sensors:*
  - *2 x GNSS receivers, LNA's and antennas*
    - *Necessary to meet science UTC time tagging requirements of 4 us*
    - *Current GPS receivers are UTC-accurate to better than 1us*
    - *Also provide a navigation function which may alleviate ground-based ranging burden*
  - *2 x Magnetometers*
    - *Necessary to align radiation monitors with magnetic field.*
    - *Positioned externally to focal plane assembly structure to be as far as possible from magnetorquers. Remains to be studied whether the magnetorquers would still need to switch off periodically for magnetometer measurements.*

Assumptions and trade-offs (orbit control mode)

- *In-plane burn:*
  - *align X-axis with orbit velocity at local midday +/-20deg phase) or any time during eclipse (if sufficient power)*
- *Out-of-plane burn:*
  - *align X-axis with +/- cross-track anytime of orbit.*
- *Sensors:*
  - *same as normal mode.*
- *Actuators:*
  - *Pitch/yaw (Y/Z) with off-pulsing of +X-direction thrusters (canted to avoid plume impingement on mirrors)*
  - *Roll (X) with on-pulsing of dedicated roll thrusters*
    - *Alternative is roll control with reaction wheels, but roll thrusters available anyway – driven by safe mode – and very little fuel penalty due to low roll disturbances.*

Assumptions and trade-offs (orbit control mode)

- *Uncontrolled Re-entry Design (as per previous slide)*
  - *Standard 1N thrusters recommended due to low mass.*
  - *Mission availability loss due to having to split up large orbit maintenance or de-orbit burns is acceptable (< 40 orbits spread over the mission).*

- *Controlled Re-entry Design*
  - *Large 20 N thrusters perform delta-V.*
  - *If 3 or 4 x 20 N thrusters active then they can perform off-pulsing for attitude control, hence dedicated attitude control thrusters not required.*
  - *1.5 N (EOL!) attitude control thrust required if 2 x 20 N thrusters active*

Baseline design

- 4 x Star trackers (normal & orbit control modes)
- 2 x Medium-accuracy gyro (normal & orbit control modes)
- 4 x Reaction wheels (> 8 Nms, normal mode)
- 3 x Magnetorquers (> 100 Am^2, normal mode)

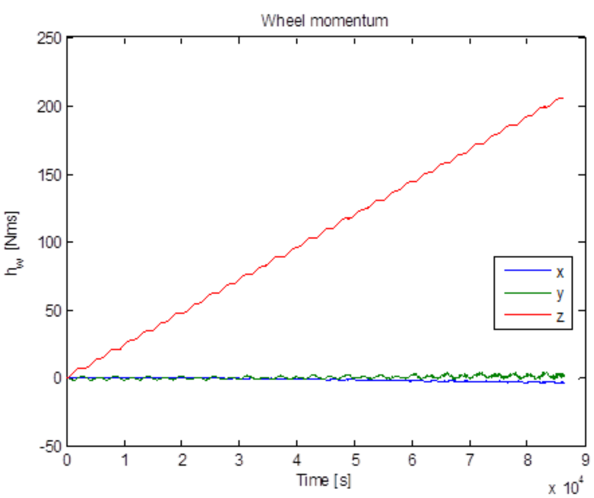
- 2 x Sun sensors (safe mode)
- 2 x Coarse gyros (safe mode)

- 2 x Magnetometers (for aligning radiation detectors with mag. field in normal mode)
- 2 x GPS receivers & antennas (for accurate science time tagging)

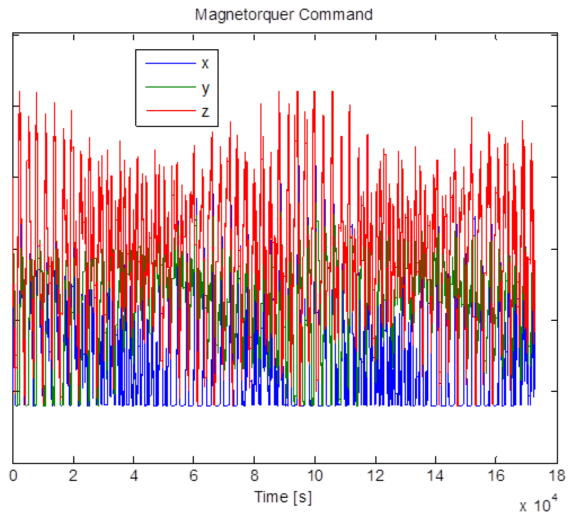
- No technology development required

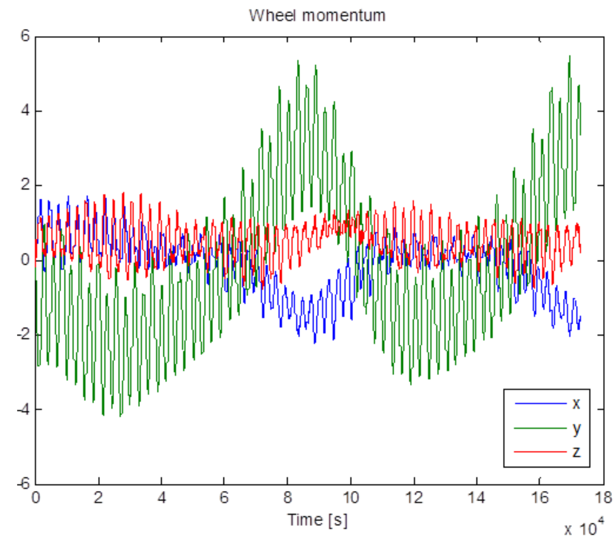
Analyses (Momentum accumulation)

- Thruster-based momentum dumping (intermittent)
- Worst case momentum accumulation per day



- Magnetorquer-based momentum dumping (continuous)
- Magnetorquer command and worst case momentum history





Analyses (Slew)

- 180 deg slew duration = 40 min
  - with 4 Nms slew allocation
- Settle time = 30 secs
  - driven by attitude controller
- Design compatible with science availability requirement

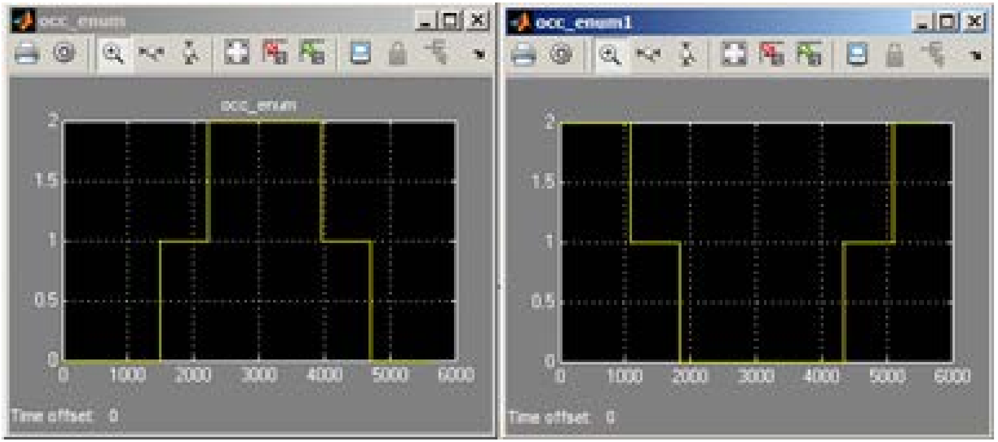
Analyses (Star tracker occultations)

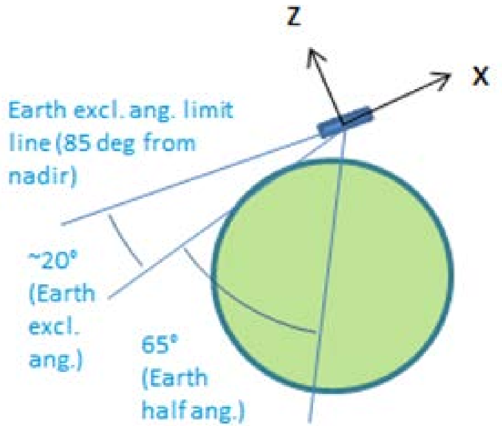
- Star trackers have 20 deg Earth exclusion angle (unlike telescope)
- Whenever Star trackers point within 85° of nadir they cannot be relied upon for science (note: if limb in eclipse then >65° from nadir is ok [same as telescope] – but this is neglected in the performed analysis).
- We also have to consider failure of 1 star tracker
- Performed simulations to check duration per orbit that telescope can see target but all remaining star trackers (after 1 STR failure) are occulted by Earth.

0 = cold sky

1 = Earth in exclusion zone

2 = Earth in FOV





Analyses (Star tracker occultations)

- A range of configurations were examined
  - 2 vs 3 vs 4 star trackers
  - Offset from telescope LoS <43 deg. Beyond this the star tracker would be constrained to the XY-plane to avoid Sun occultation. Such configurations could be investigated in Phase A.
- Need at least 3 star trackers to constrain availability loss to <10% in no-failure case
- Need at least 4 star trackers to constrain availability loss to <10% in failure case

- Final configuration selection
  - ***Recommendation:*** 4 star trackers canted 43 deg from –X, equal azimuthal spacing, mounted as close as possible to one another on a thermally stable structure.
  - ***Compromise:***
    - Lack of space to mount 4 trackers on mirror assembly or associated support structure led to location of trackers on detector plane.
    - Solar panel obscures view along +Z axis, thus final solution was two trackers canted 43 deg from –X (in XY plane) and two trackers canted 43 deg from +X (in XY plane).
    - If we located trackers on opposite ends of telescope it may help estimate 1st thermal bending mode of telescope, but often you may have just 1 or 2 star trackers in tracking mode at a time (due to Earth occultation) thus information could be limited.

Analyses (Star tracker occultations)

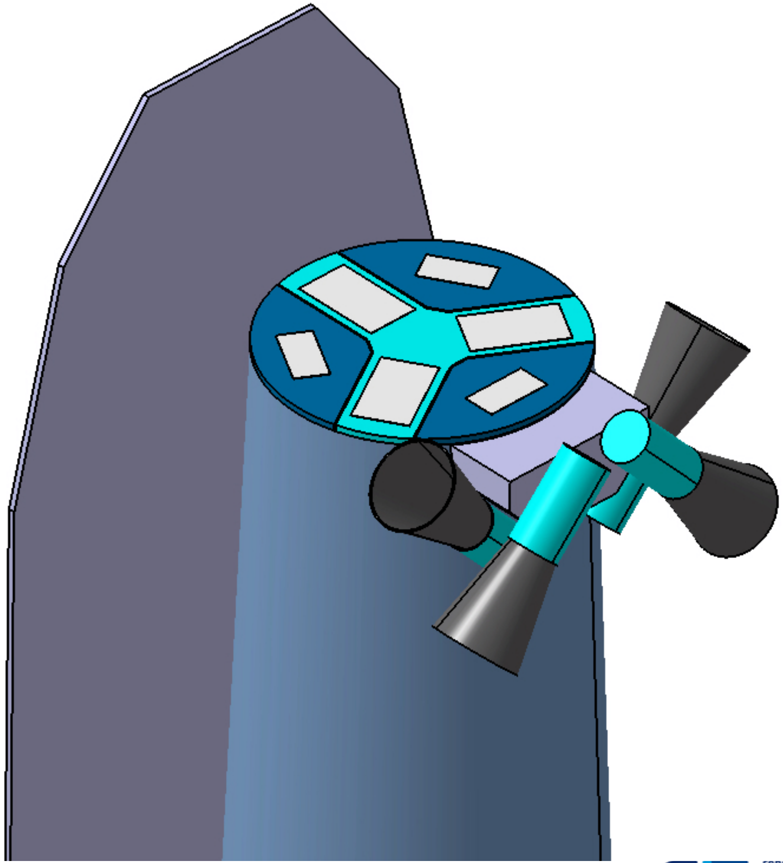
				Target Angle from Celestial North (or South)		
			0°	30°	60°	90°
Cant angle°	Star trackers	Failures	Additional science availability loss			
0	2	0 or 1	77%	27%	17%	15%
20	2	0	14%	26%	16%	15%
20	3	0	0%	11%	7%	7%
43	3	0	0%	0%	0%	0%
20	4	0	0%	9%	4%	4%
43	4	0	0%	0%	0%	0%
43	4 (two near +X, two near -X)	0	6%	4%	4%	6%
20	2	1	59%	32%	17%	15%
20	3	1	70%	26%	16%	15%
43	3	1	60%	26%	16%	15%
20	4	1	14%	17%	10%	9%
43	4	1	6%	10%	8%	8%
43	4 (two near +X, two near -X)	1	7%	18%	9%	6%

Recommended → (43, 4, 0)

Compromise → (43, 4 (two near +X, two near -X), 0)

Analyses (Star tracker occultations)

- Proposed star tracker configuration
- Because of limited time to iterate on the configuration aspects and the need for 4 optical heads, the STR has been moved up to the FPM
- This accommodation might need to be revisited during the later design phases



Analyses (Pointing Budget)

- RKE (2Ms) LoS 2-sigma = 4 arcsec + thermal
  (requirement 10 arcsec)
- AKE roll (worst-case axis) 2-sigma
  = 20 arcsec + thermal + calib. error
  (requirement 5 arcmin)
- APE LoS 2-sigma = 10 arcsec + thermal + calib. error
  (requirement 3 arcmin)
- PDE (over mosaic) LoS 2-sigma = thermal
  (no requirement, but probably < 8 arcsec since thermal RKE sub-allocation is 8 arcsec TBC. Hence negligible impact on 2Ms mosaic assembly duration)

	XIPE - 1 STR only		
	Roll (x)	Pitch (y)	Yaw (z)
Star tracker cyclic error	0.2	0.5	0.5
Gyro misalignment	5.7	0.5	
Gyro scale factor error	1.9	0.2	
Diurnal pointing estimation error	**6**	**0.7**	**0.5**
Star tracker NEA	1.4	0.8	0.4
Random pointing estimation error	**1.4**	**0.8**	**0.4**
RxWheel torque noise	1.4	0.2	0.2
Pointing estimation jitter	**1.4**	**0.2**	**0.2**
RKE (1-sigma) over 80ks	**8.8**	**1.7**	**1.1**

Equipment summary

	mass (kg)	mass margin (%)	mass incl. margin (kg)	P_on (W)	P_stby (W)
⊞ GNSS (Nominal GNSS Receiver)	4.00	5.00	4.20	8.00	0.00
⊞ GYRO Medium (Nominal GYRO Medium-accuracy)	4.20	5.00	4.41	12.00	0.00
⊞ GYRO Coarse (Nominal GYRO Coarse)	0.80	10.00	0.88	5.50	0.00
⊞ MAG (Nominal MAG)	0.30	5.00	0.32	1.00	0.00
⊞ MTQ 1 (MTQ 110)	3.80	5.00	3.99	2.90	0.00
⊞ MTQ 2 (MTQ 110)	3.80	5.00	3.99	2.90	0.00
⊞ MTQ 3 (MTQ 110)	3.80	5.00	3.99	2.90	0.00
⊞ Red_GNSS (Redundant GNSS Receiver)	4.00	5.00	4.20	8.00	0.00
⊞ Red_GYRO Medium (Redundant GYRO Medium-accuracy)	4.20	5.00	4.41	12.00	0.00
⊞ Red_GYRO Coarse (Redundant GYRO Coarse)	0.80	10.00	0.88	5.50	0.00
⊞ Red_MAG (Redundant MAG)	0.30	5.00	0.32	1.00	0.00
⊞ Red_STR EU (Redundant STR Electronics Unit)	1.85	5.00	1.94	11.00	0.00
⊞ RW_1 (Nominal RW 12Nms)	4.85	5.00	5.09	90.00	0.00
⊞ RW_2 (Nominal RW 12Nms)	4.85	5.00	5.09	90.00	0.00
⊞ RW_3 (Nominal RW 12Nms)	4.85	5.00	5.09	90.00	0.00
⊞ RW_4 (Nominal RW 12Nms)	4.85	5.00	5.09	90.00	0.00
⊞ STR_EU (Nominal STR Electronics Unit)	1.85	5.00	1.94	11.00	0.00
⊞ STR_OH_1 (STR Optical Head)	3.00	5.00	3.15	7.50	0.00
⊞ STR_OH_2 (STR Optical Head)	3.00	5.00	3.15	7.50	0.00
⊞ STR_OH_3 (STR Optical Head)	3.00	5.00	3.15	7.50	0.00
⊞ STR_OH_4 (STR Optical Head)	3.00	5.00	3.15	7.50	0.00
⊞ SUN_CSS_1 (SUN Coarse Sun Sensor)	0.22	5.00	0.23	0.00	0.00
⊞ SUN_CSS_2 (SUN Coarse Sun Sensor)	0.22	5.00	0.23	0.00	0.00
Grand Total	65.53	5.12	68.89	473.70	0.00

XIPE

THERMAL

Session 8
ESTEC, 23-09-2015

Prepared by the CDF* Team

(*) ESTEC Concurrent Design Facility

Requirements

- Main thermal requirements

ID	Statement	Comments
TH_01	Mirrors shall operate at 20°C (±2°C) during imaging	
TH_02	Radial gradient inside Mirror Module shall be less than ±1°C during imaging	
TH_03	Longitudinal gradient inside Mirror Module shall be less than ±1°C during imaging	
TH_04	Detectors shall operate at 20°C (±1°C) during imaging, with a time stability better than 1°C peak to peak	

TCS Design drivers

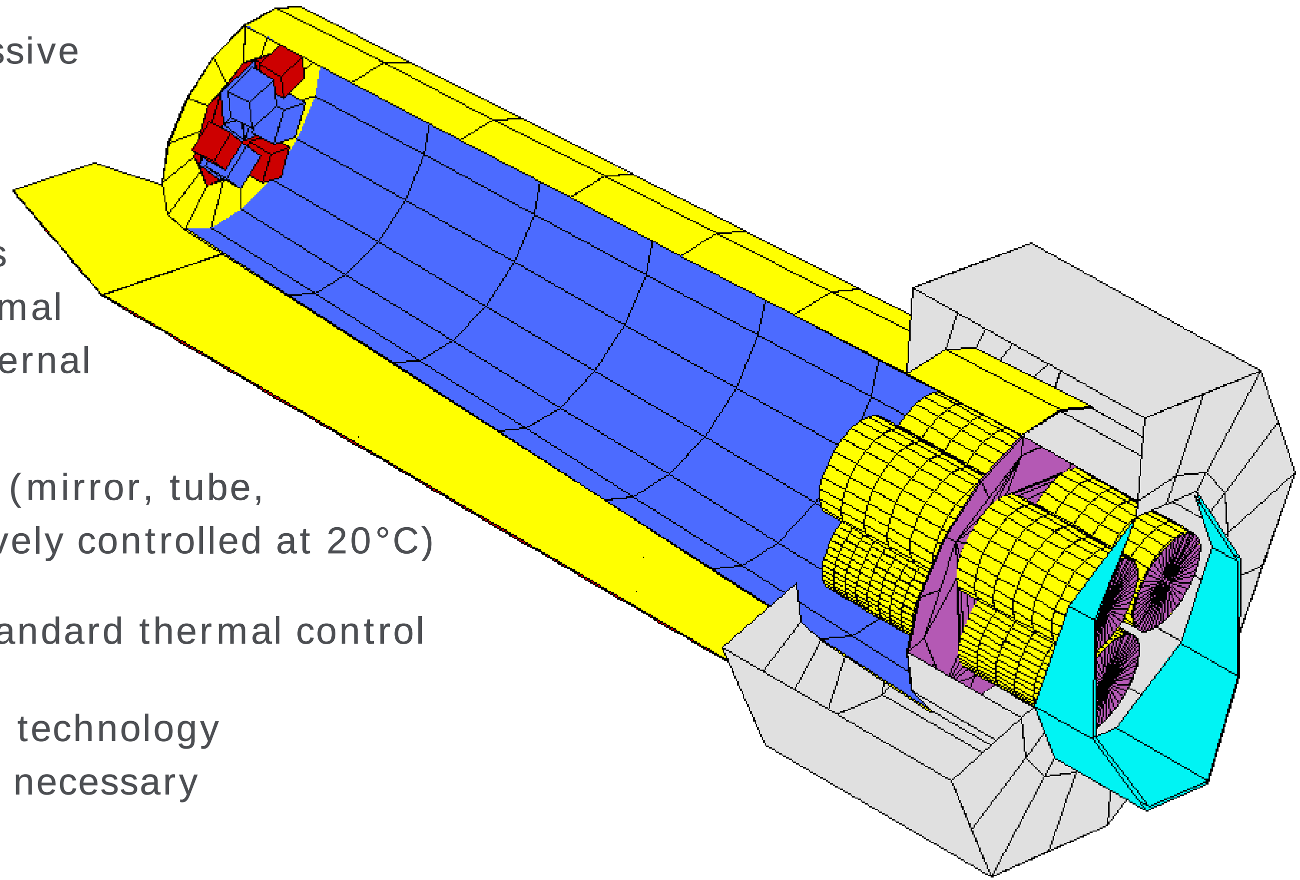
- Variable thermal environment :
  - Equatorial Low Earth orbit (Sun, albedo and Earth IR fluxes continuously vary)
  - very large range of attitudes (elevation: ±180°, azimuth ± 20°)

- Warm (20°C) and stable temperature required for detectors and tube

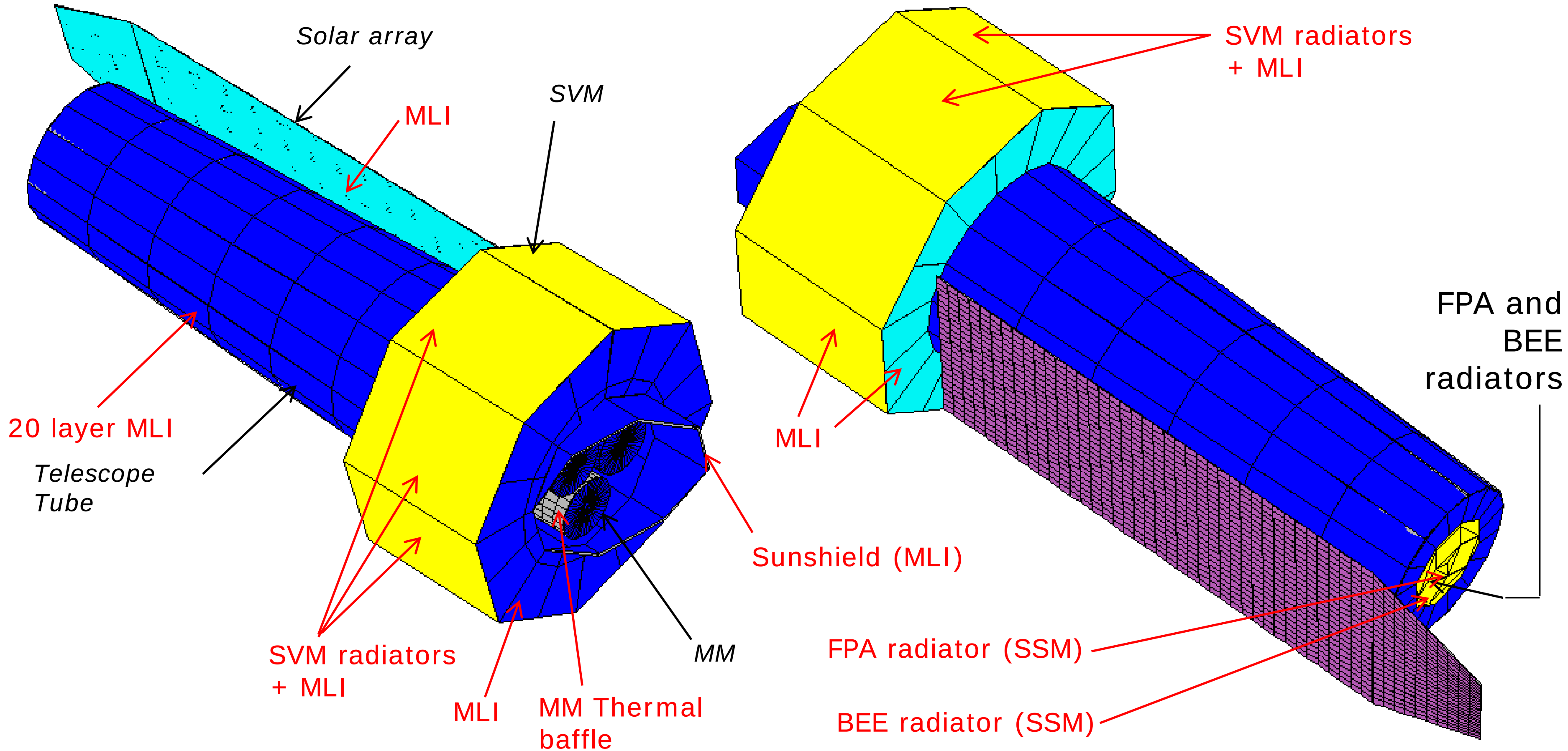
- Warm (20°C) and stable temperature required for the 3 x 27 mirrors with no possibility to use direct (conductive) heating but only radiative heating (from outside of the optical path)

TCS Baseline design

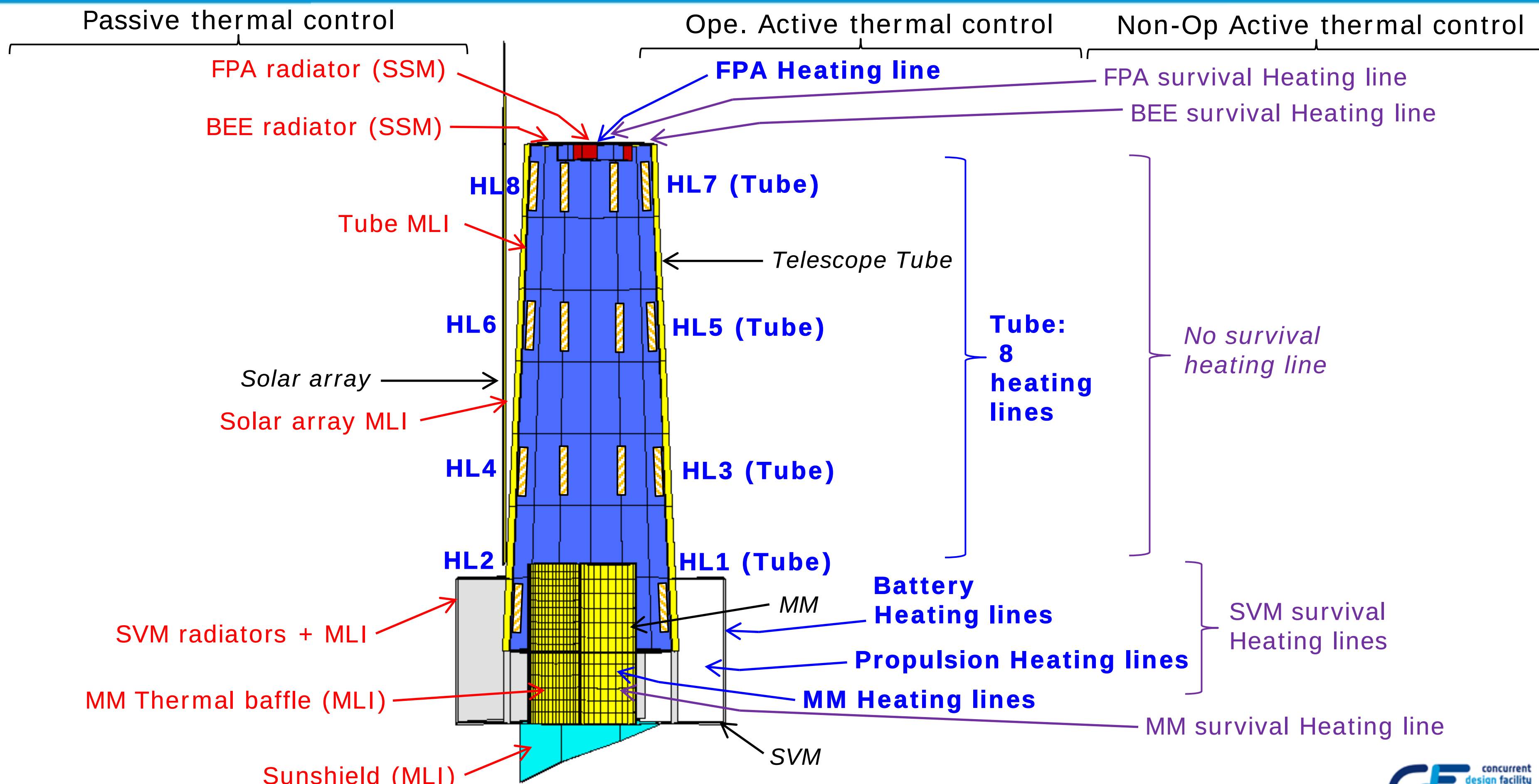
- Combination of passive and active thermal control
- Main effort consists in maximizing thermal insulation from external environment
- The whole payload (mirror, tube, detectors) are actively controlled at 20°C)
- SVM has a quite standard thermal control
- No specific thermal technology development seem necessary



TCS Design: passive thermal control

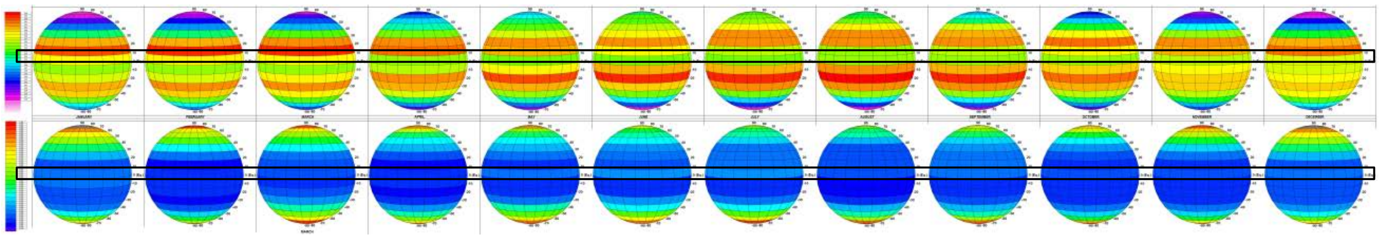


TCS Design: active thermal control



TCS Design: mission and environment analysis

- Orbital thermal environment analysis

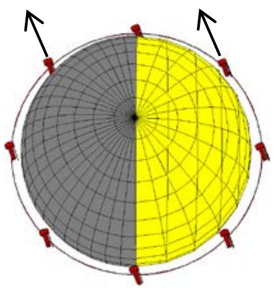


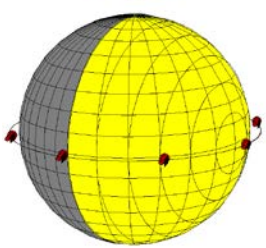
Min Earth temp: 254 K
Max Earth temp: 265 K

Min albedo: 0.2
Max albedo: 0.3

Sun flux in Winter: 1410 W/ m² / Summer: 1310 W/m²

- Identification of worst cold case and worst hot case





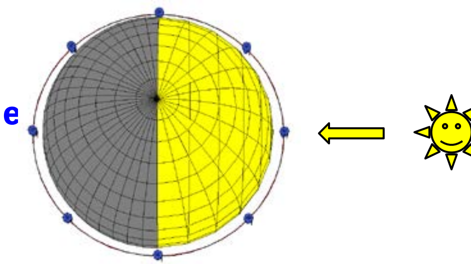
Worst hot case attitude:
- **Elevation: 0°**
- **Azimuth: 110°**

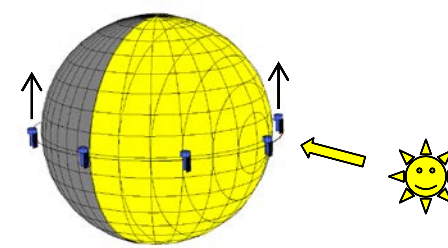
⇨ FPA is Sun illuminated during day part of the orbit, and then in the shadow (eclipse)

⇨ MM face the Earth (max albedo) during part of the orbit, and then face cold Space

Worst cold case attitude
- **Elevation: 90°**
- **Azimuth: 0°**

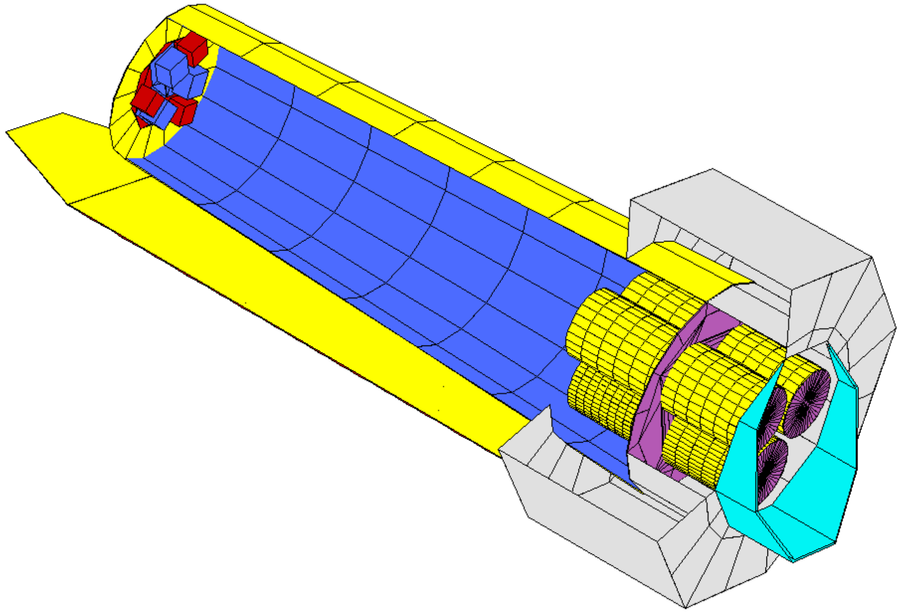
⇨ FPA and MM have a very stable environment with no direct Sun illumination and reduced FoV with the Earth





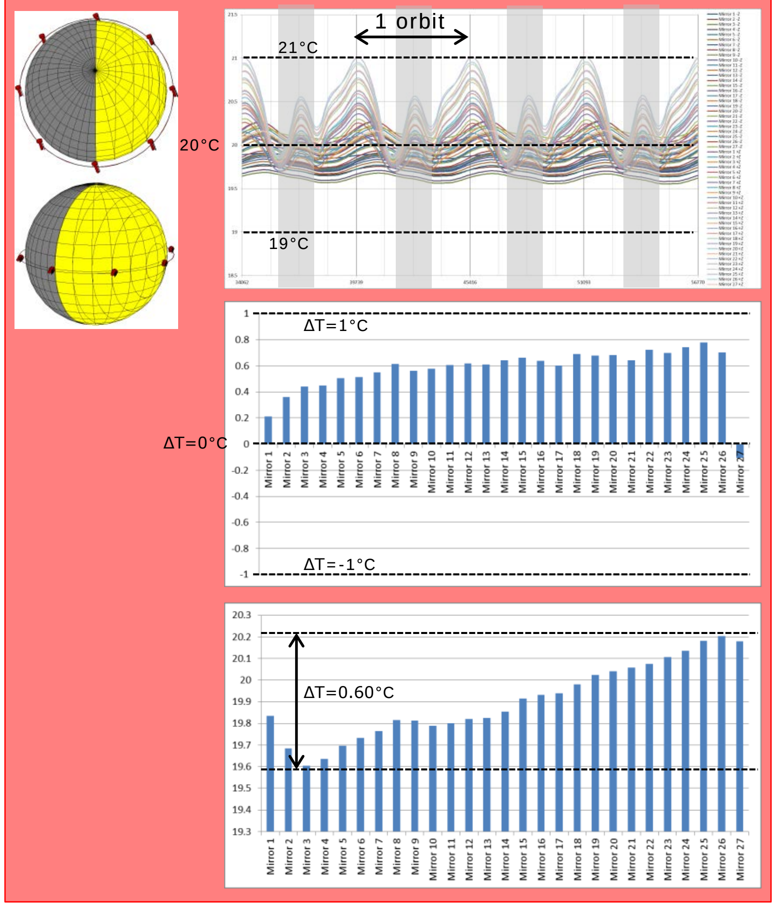
Thermal Analyses (baseline)

- Operational Hot case is used to size radiator area + check payload stability
- Operational Cold case is used to size operational heating power
- In-orbit Survival Cold case is used to size non-operational heating power
- LEOP Cold case is simulated to provide early need of heating power



Mirrors thermal performance (1/2)

HOT CASE (0° elevation, 110 azimuth)

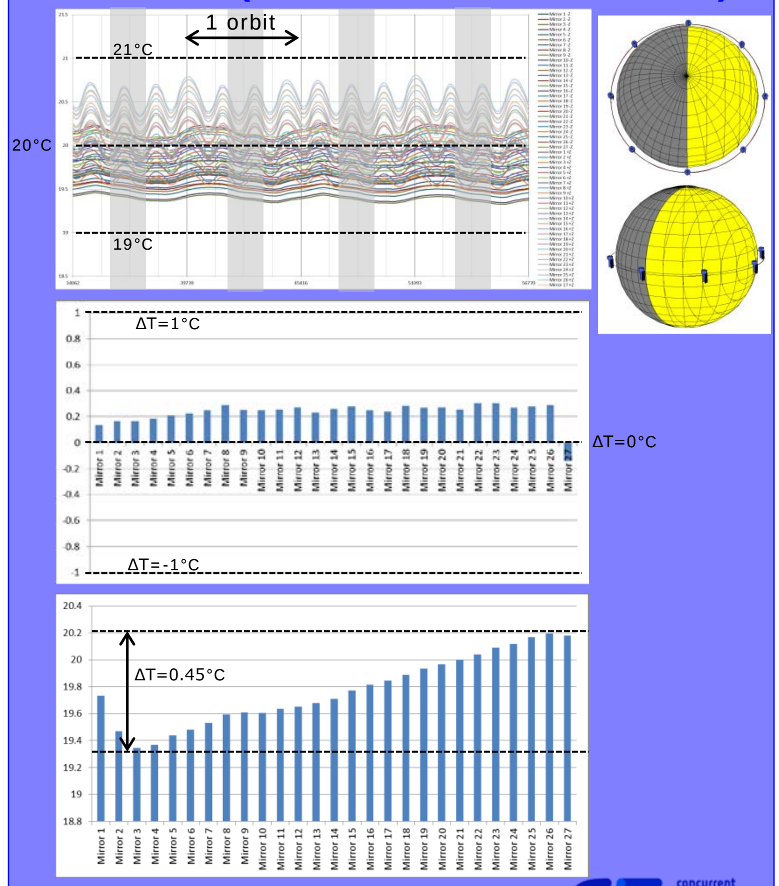


All mirrors remain in the range [19-21°C]

Longitudinal gradient better than ±1°C

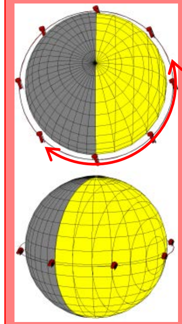
Radial gradient better than ±1°C

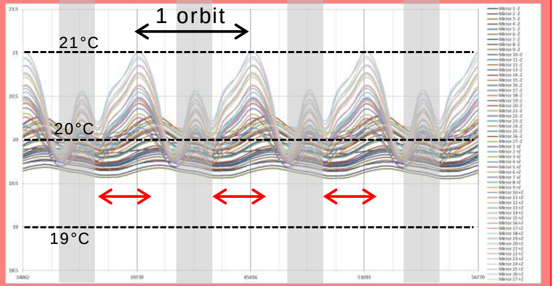
COLD CASE (90° elevation, 0° azimuth)

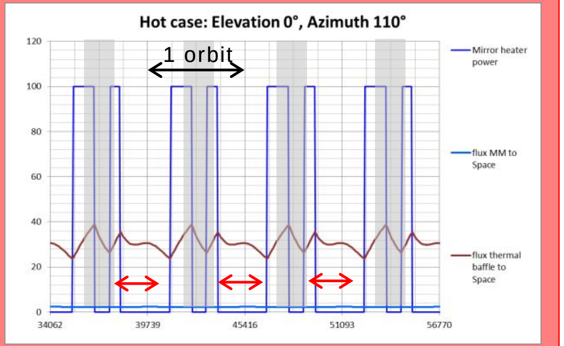


Mirrors thermal performance (2/2)

HOT CASE (0° elevation, 110 azimuth)







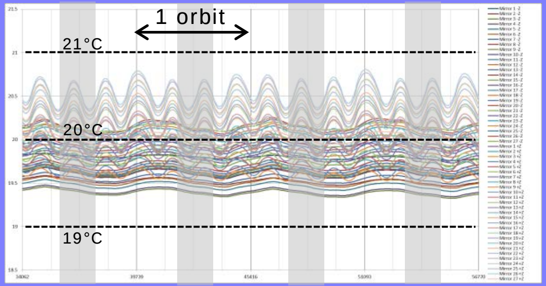
All mirrors remain in the range [19-21°C] (*with not much margin in hot case*)

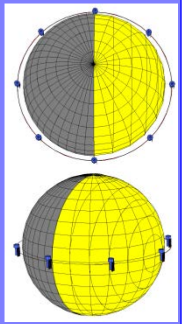
Average heating power per MM :

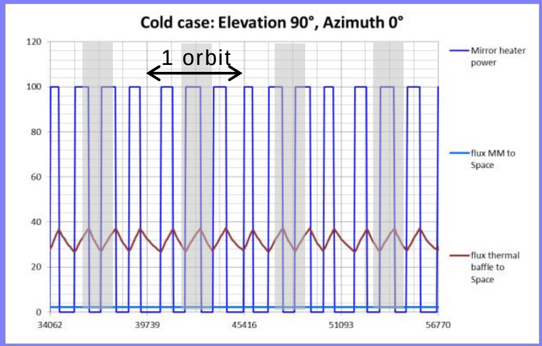
34 W (hot case)
46 W (cold case)

(*100 W installed*)

COLD CASE (90° elevation, 0° azimuth)

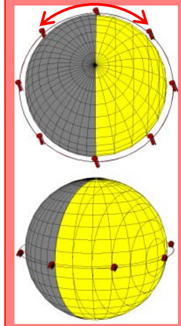


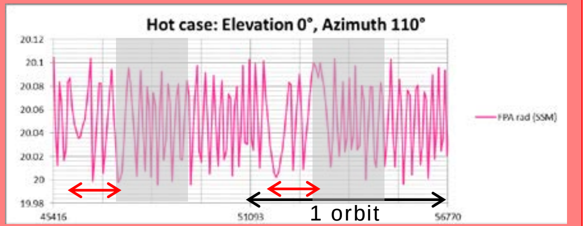


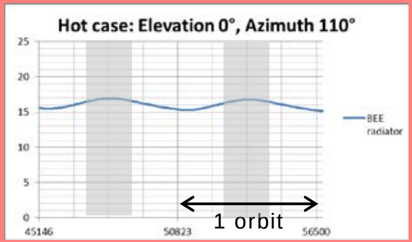


FPA / BEE thermal performance

HOT CASE (0° elevation, 110 azimuth)







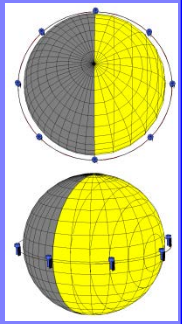
FPA remains in the range [19, 20°C]

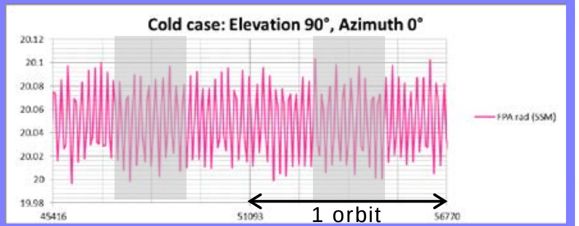
FPA average heating power:

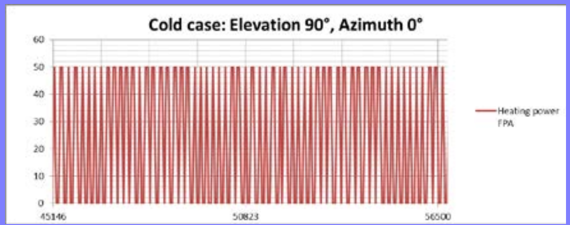
22 W (hot case)
25 W (cold case)

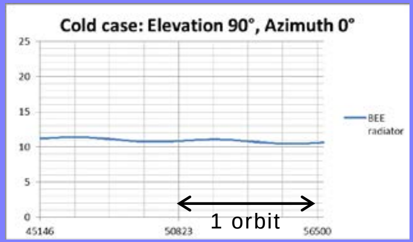
BEE passively maintained in its temperature range when operating

COLD CASE (90° elevation, 0° azimuth)



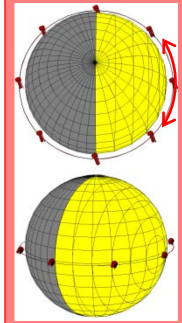


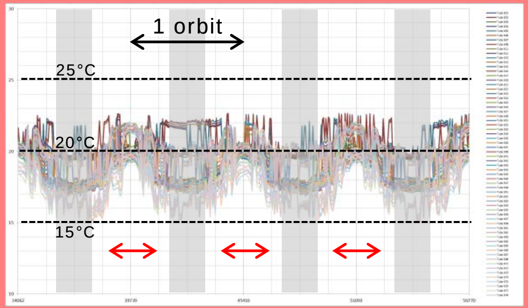


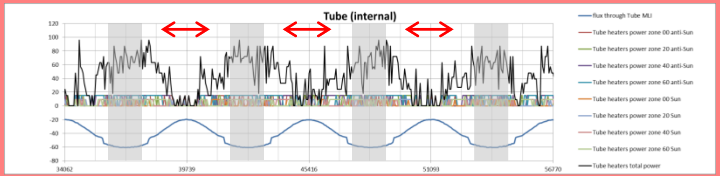


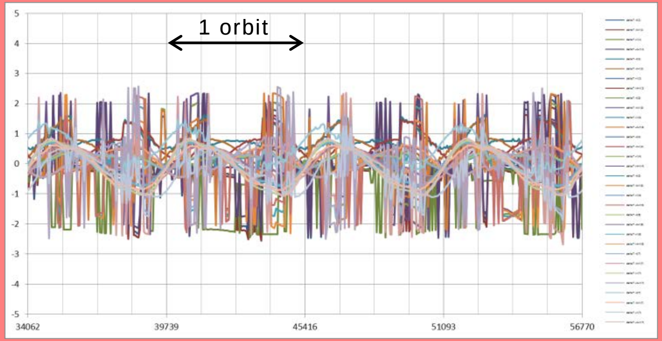
Telescope Tube thermal performance

HOT CASE (0° elevation, 110 azimuth)

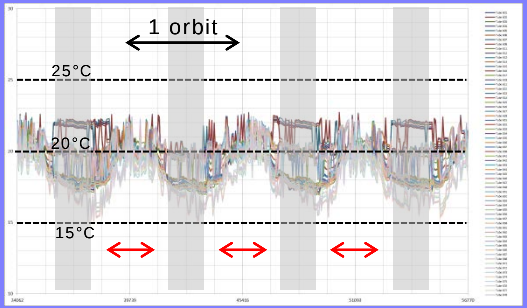


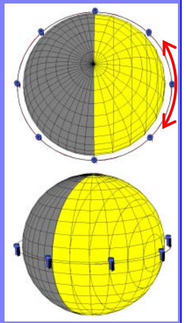


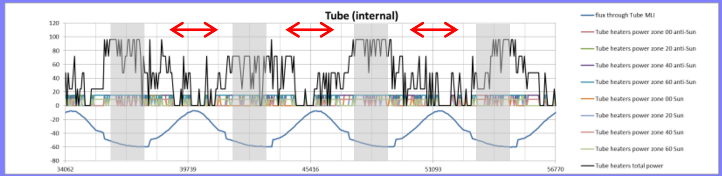


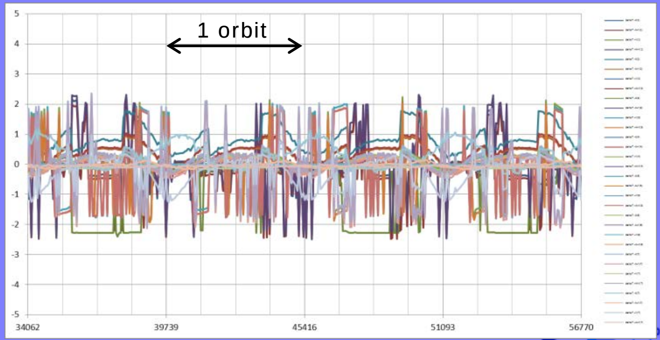


COLD CASE (90° elevation, 0° azimuth)









Tube remains in the range [15, 25°C]

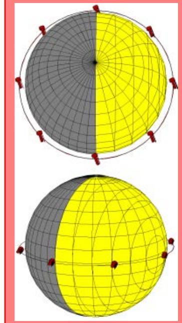
Tube average heating power:

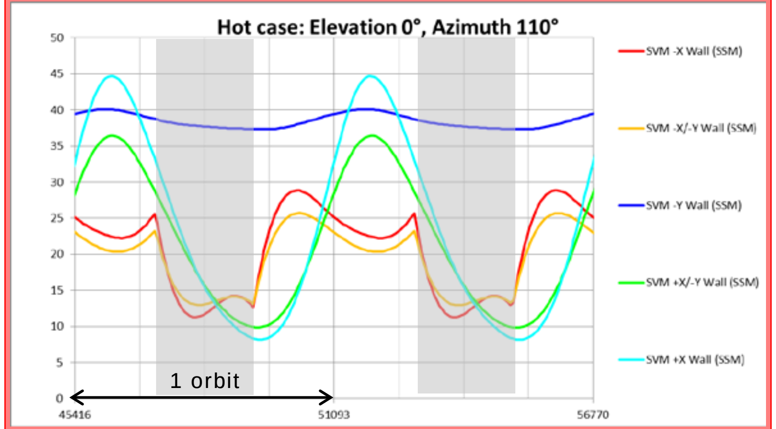
40 W (hot case)
47 W (cold case)

Transversal gradients remain always below ±3°C

SVM thermal performance

HOT CASE (0° elevation, 110 azimuth)

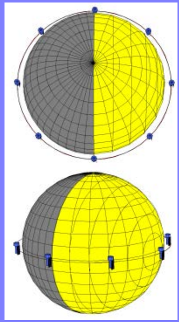


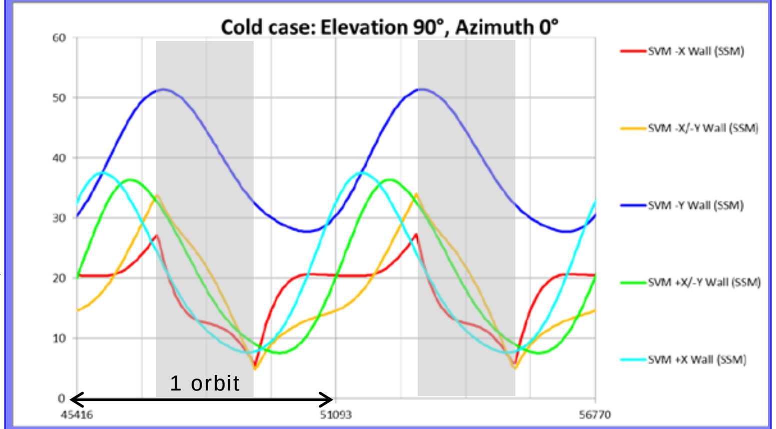


The following heat rejection capacity is demonstrated (with only structure heat capacity -*conservative hypothesis*):

-X (Sun): 100 W
-X+Y (Sun):130 W
-X-Y (Sun): 130 W
+Y (South): 270 W
-Y (North): 270 W
+X-Y (anti-Sun): 200 W
+X+Y (anti-Sun): 200 W
+X (anti-Sun): 200 W

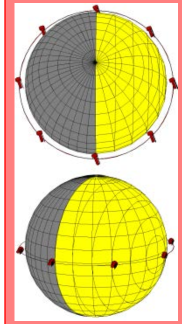
COLD CASE (90° elevation, 0° azimuth)

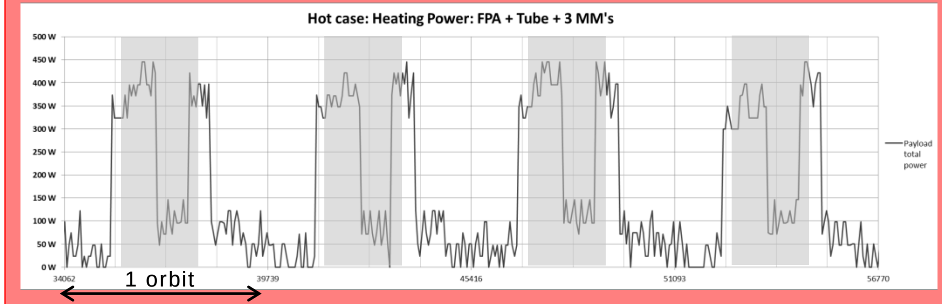




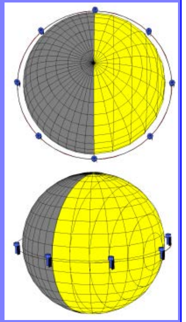
Overview of heating power in operational mode

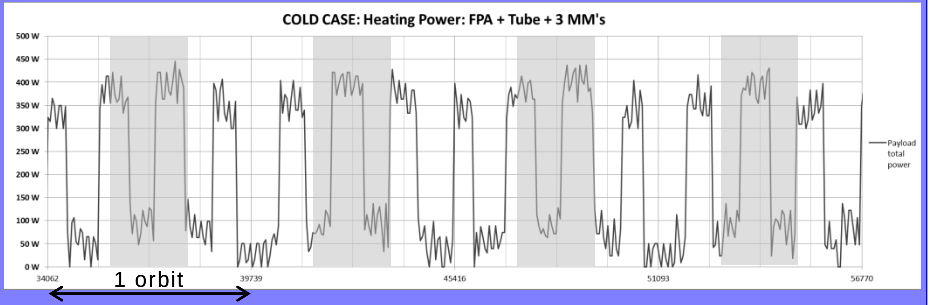
HOT CASE (0° elevation, 110 azimuth)





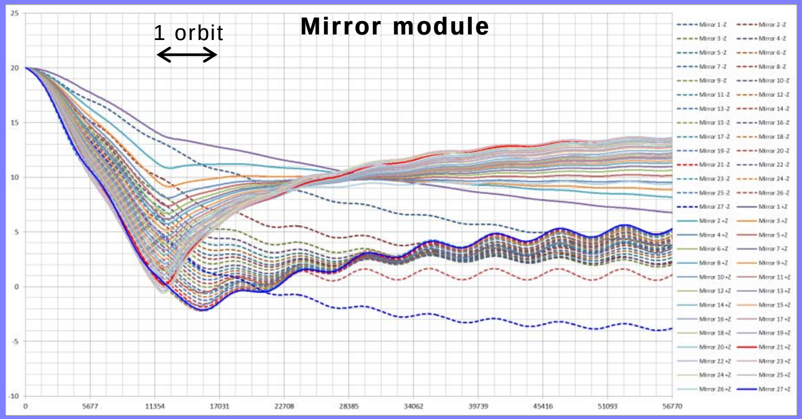
COLD CASE (90° elevation, 0° azimuth)





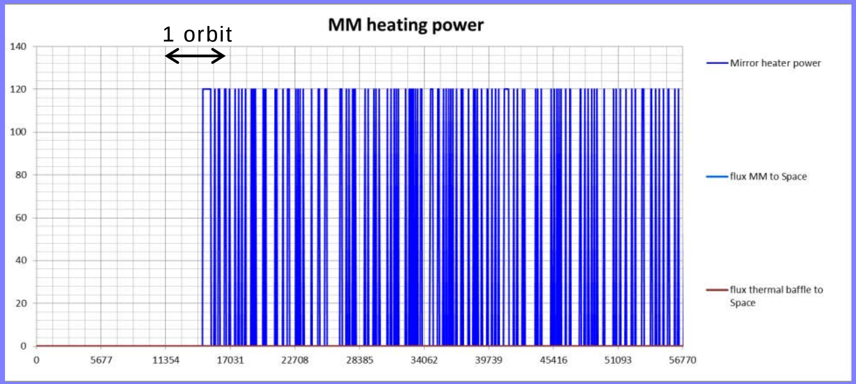
Survival mode: MM thermal performance

SURVIVAL MODE - COLD CASE (90° elevation, 0° azimuth)



1 Survival Heating Line per MM

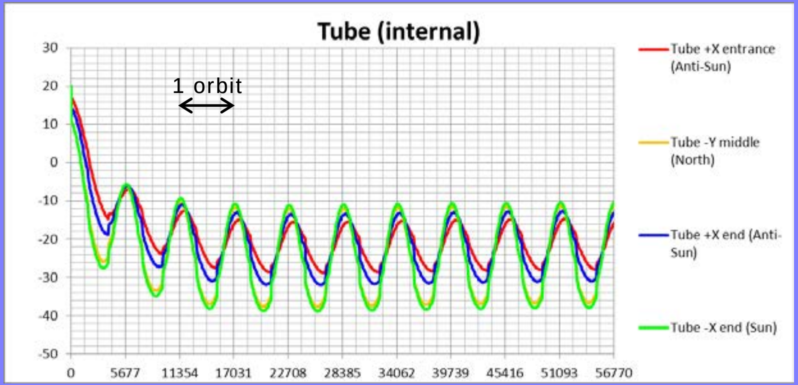
- Tmin > -5°C targeted
- 120 W installed per MM.



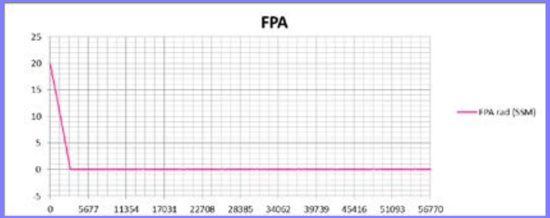
Once stabilized, about 25 W average is used per MM.

Survival mode: thermal performance

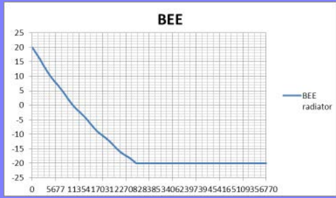
SURVIVAL MODE - COLD CASE (90° elevation, 0° azimuth)



Tube:
No heating line,
Calculated Tmin: -40°C



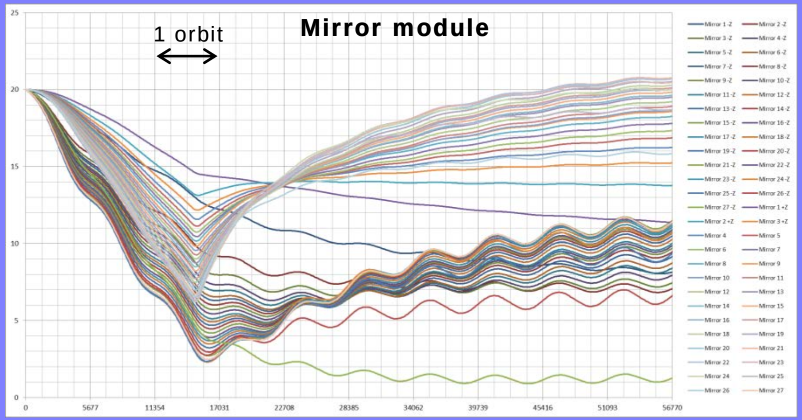
FPA:
1 heating line,
Tmin: 0°C
Once stabilized: 29 W consumed



3 BEE:
1 heating line,
Tmin: -20°C
Once stabilized: 11 W consumed

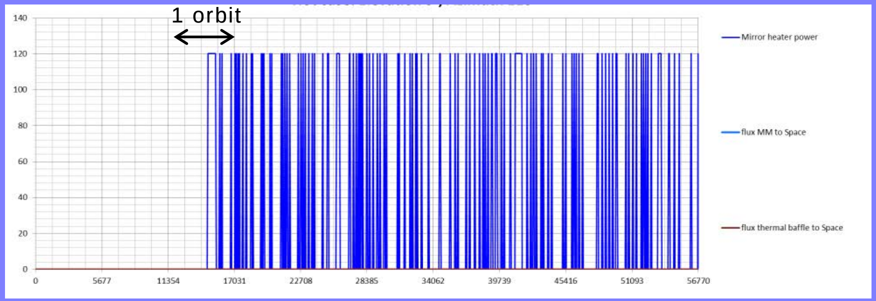
LEOP mode: MM thermal performance

SURVIVAL MODE - COLD CASE (90° elevation, 0° azimuth)



1 Survival Heating Line per MM

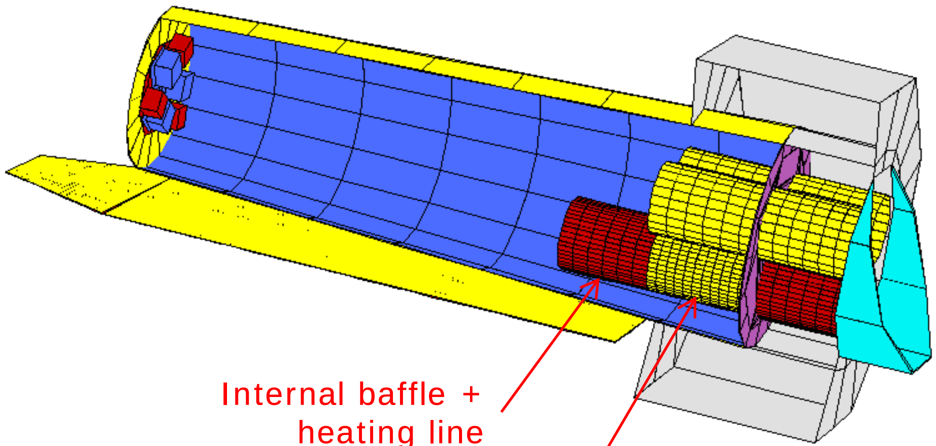
- Tmin > -5°C targeted
- 120 W installed per MM.



Once stabilized, about 20 W average is used per MM.

Option: Passive thermal control for the structural tube

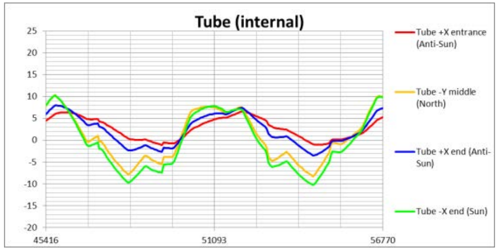
- Alternative thermal control: no heating power on the tube



⇨ If no measure taken, MM will see a cold and instable thermal environment (black tube) and would not meet their temperature / stability and gradient thermal requirements

⇨ Additional thermal hardware + heating lines are needed to compensate

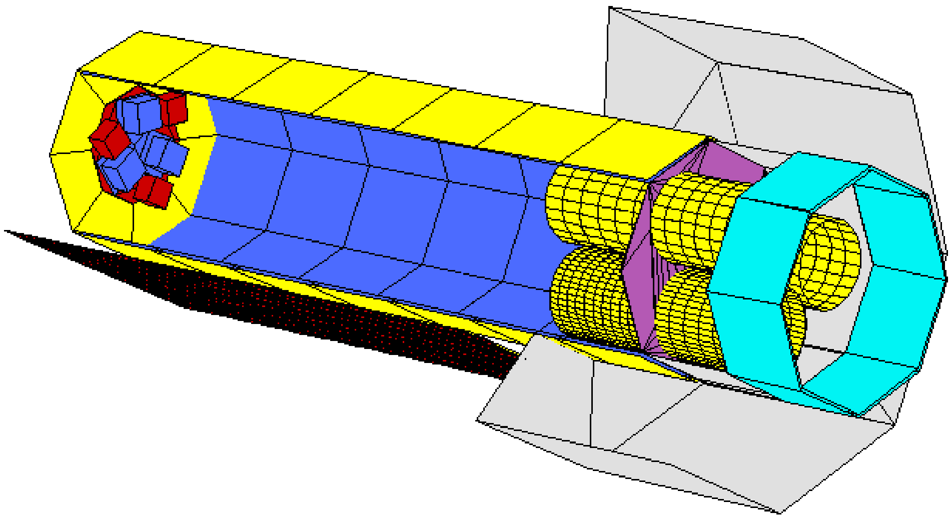
⇨ Tube temperature gets uncontrolled, colder and instable.



⇨ Thermal performances (temperature, gradients, stability) meet requirements with a little bit less heating power but with more mass and complexity.

Option without sunshield

- Alternative thermal control: MM mounted deeper inside the SVM with no Sunshield. Sun never illuminates the thermal baffles but can be reflected inside the SVM inner cylinder (assumed black).



⇨ Thermal performances (temperature, gradients, stability) seems to meet requirements. ➲ potentially interesting alternative but requires a reduction in the focal length of about 0.5 m which will have to compensated by shifting the FPM up in the fairing

Equipment summary

	mass (kg)	mass margin (%)	mass incl. margin (kg)
FPM (Focal Plane Module)	8.20	19.63	9.81
FPA (Focal Plane Assembly)	8.20	19.63	9.81
Htr_FPA (Heater_FPA)	0.20	5.00	0.21
Rd_FPA (Radiator_FPA)	8.00	20.00	9.60
Htr_Prop (Heater_Propulsion)	0.50	5.00	0.53
Htr_SM (Heater_ServMod)	0.50	5.00	0.53
Htr_tube (Heater_Tube)	0.80	5.00	0.84
MAM (Mirror Assembly Module)	1.94	3.87	2.02
MA (Mirror Assembly)	0.14	0.00	0.14
MLI_MM (MLI_MM)	0.14	0.00	0.14
MBaf (Mirror Baffle)	0.60	4.17	0.63
Htr_MM (Heater_MM)	0.50	5.00	0.53
MLI_Bfl (MLI_Baffles)	0.10	0.00	0.10
MBaf2 (Mirror Baffle 2)	0.60	4.17	0.63
Htr_MM (Heater_MM)	0.50	5.00	0.53
MLI_Bfl (MLI_Baffles)	0.10	0.00	0.10
MBaf3 (Mirror Baffle 3)	0.60	4.17	0.63
Htr_MM (Heater_MM)	0.50	5.00	0.53
MLI_Bfl (MLI_Baffles)	0.10	0.00	0.10
MLI_SvM (MLI_ServiceModule)	3.50	0.00	3.50
MLI_Tube (MLI_Tube)	8.30	0.00	8.30
SA (SolarArray)	2.40	0.00	2.40
MLI_SA (MLI_SolarArray)	2.40	0.00	2.40
Dblr_SVM (ThermalDoubler_SVM)	1.00	0.00	1.00
Rd_SVM (Radiator_SVM)	0.20	0.00	0.20
Grand Total	27.34	6.49	29.12

Power (W)	P_on	P_stby
FPM (Focal Plane Module)	50.00	0.00
FPA (Focal Plane Assembly)	50.00	0.00
Htr_FPA (Heater_FPA)	50.00	0.00
Htr_Prop (Heater_Propulsion)	37.00	0.00
Htr_SM (Heater_ServMod)	90.00	0.00
Htr_tube (Heater_Tube)	100.00	0.00
MAM (Mirror Assembly Module)	300.00	0.00
MBaf (Mirror Baffle)	100.00	0.00
Htr_MM (Heater_MM)	100.00	0.00
MBaf2 (Mirror Baffle 2)	100.00	0.00
Htr_MM (Heater_MM)	100.00	0.00
MBaf3 (Mirror Baffle 3)	100.00	0.00
Htr_MM (Heater_MM)	100.00	0.00

XIPE

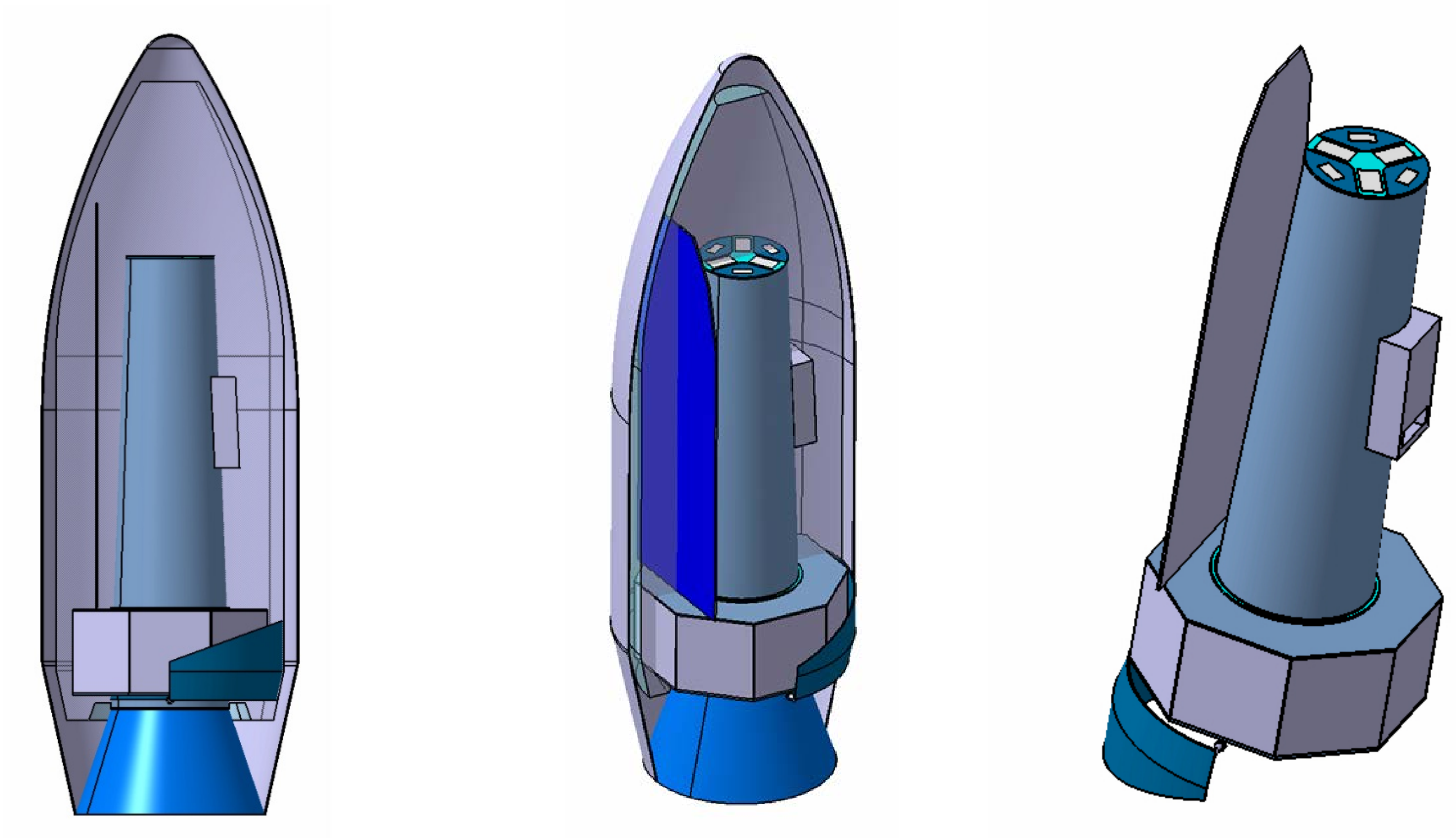
Structures

Session 8
ESTEC, 23-09-2015

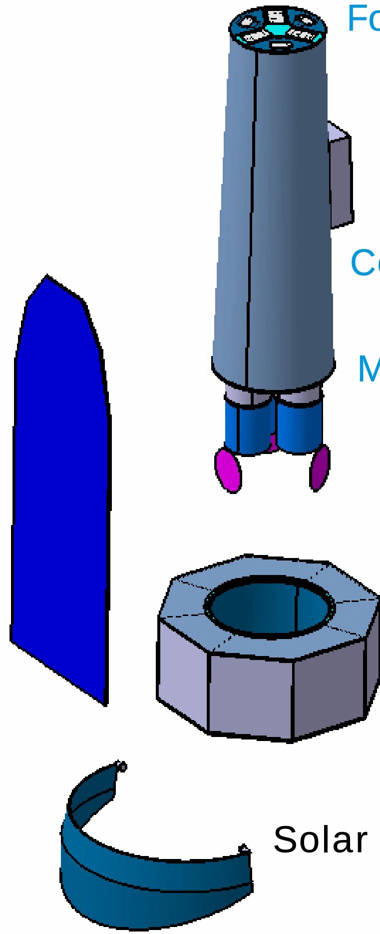
Prepared by the CDF* Team

(*) ESTEC Concurrent Design Facility

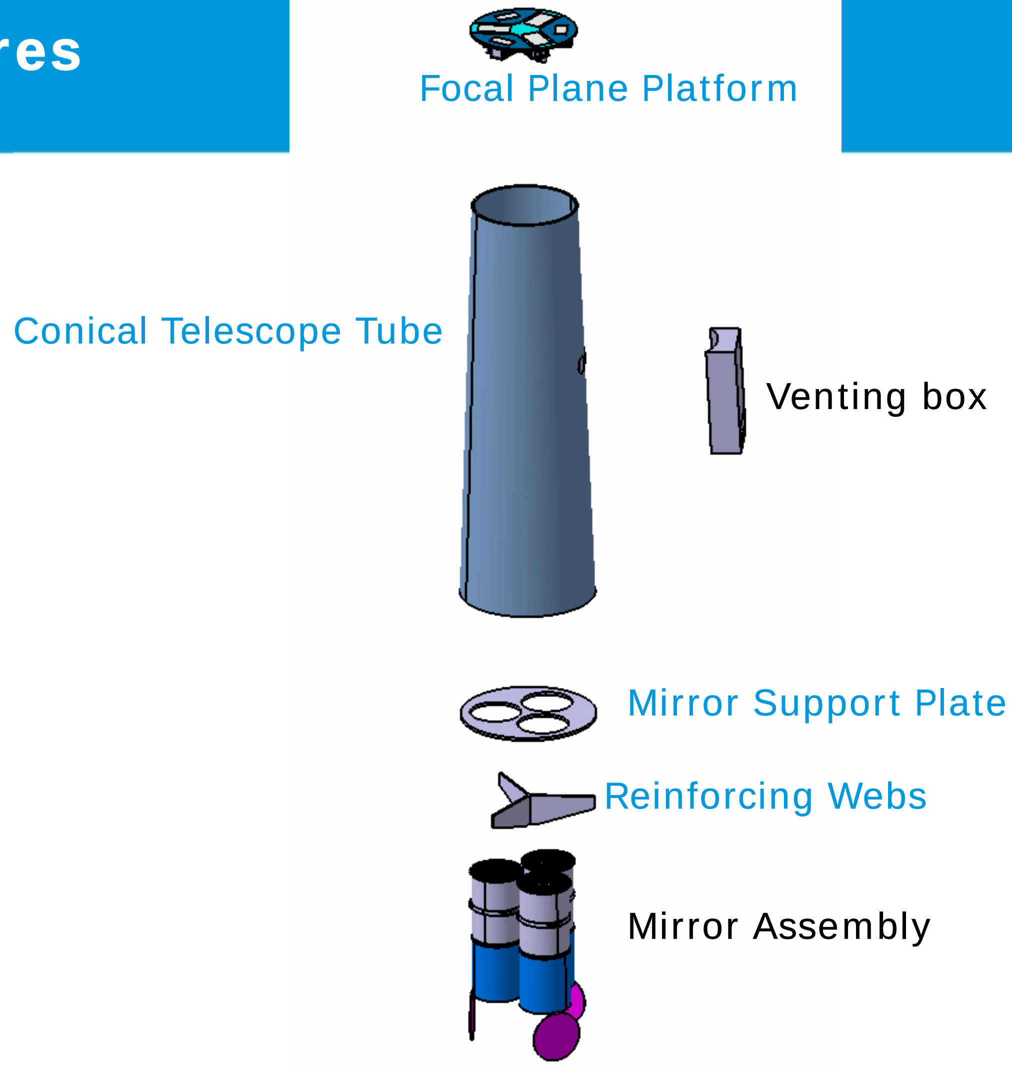
Telescope configuration



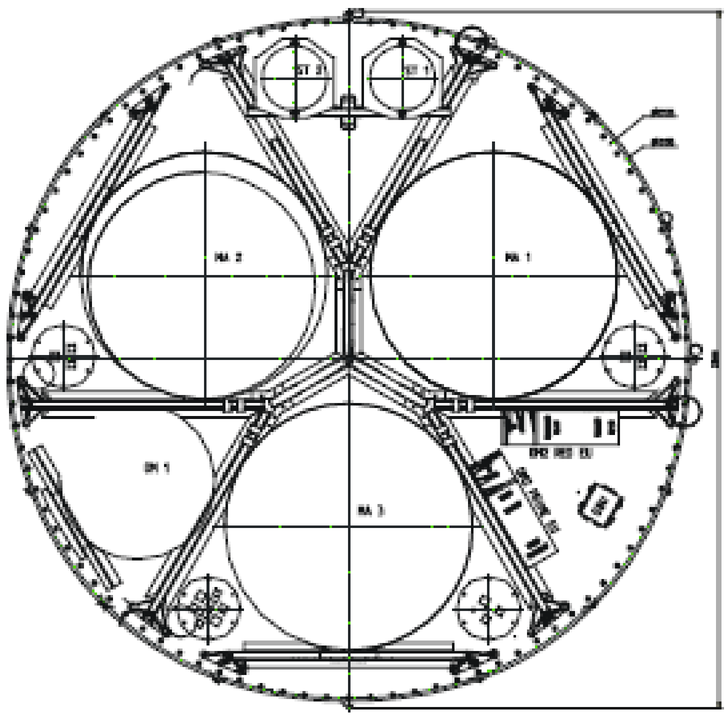
Structures

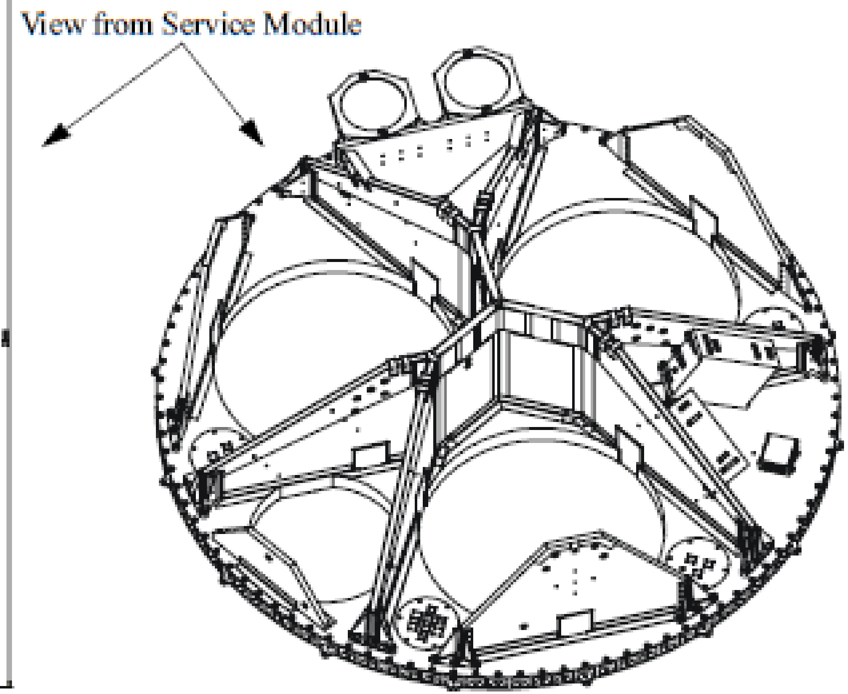

Focal Plane Platform
Conical Telescope Tube
Mirror Support Plate
Solar Panel
Service Module
Solar Shield

Structures

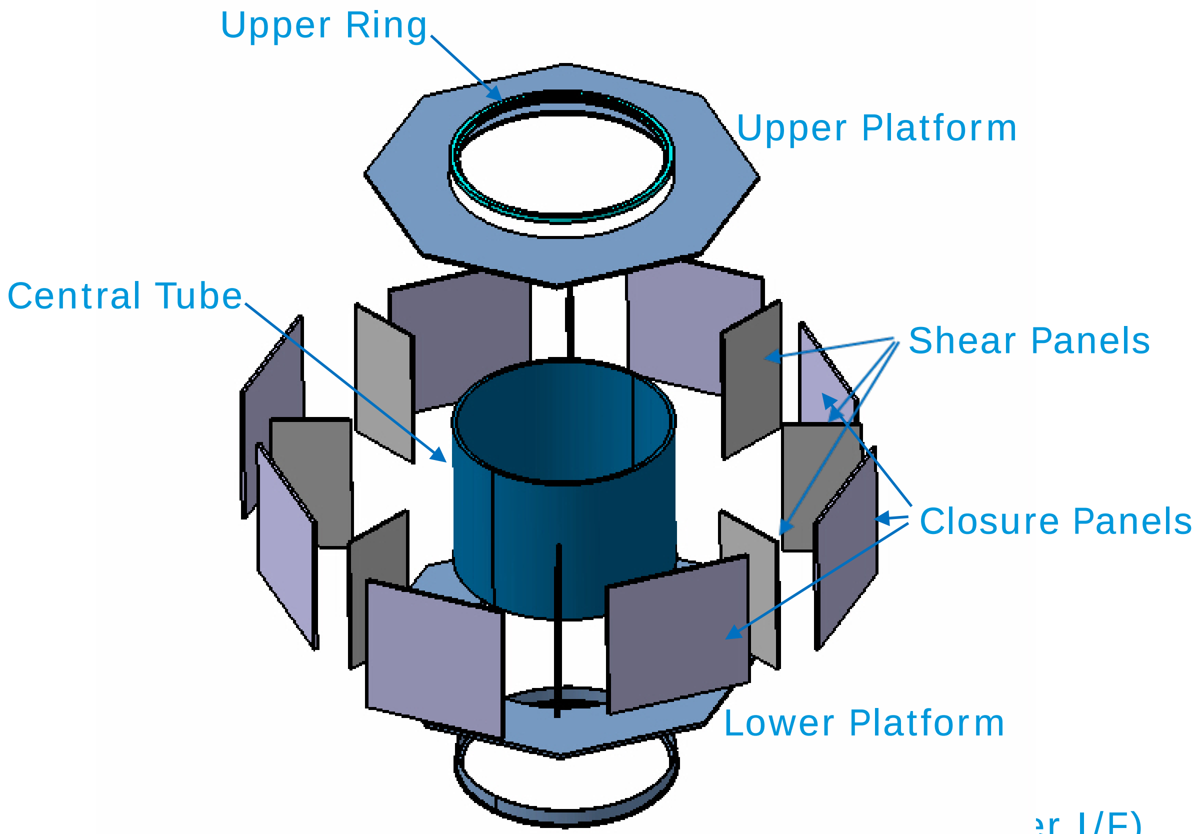

Focal Plane Platform
Conical Telescope Tube
Venting box
Mirror Support Plate
Reinforcing Webs
Mirror Assembly

Mirror Module Mounting Structure (from XMM)





Service Module Structures



ɘr I/F)

Secondary Structures

- Tanks Support Structure (x2)
- Sunshield Support Structure
- Thruster Bracket (x16)
- Umbilical Connector Bracket (x2)
- Solar Panel Support Structure
- StarTracker Support Structure

SIMPLIFIED THERMOELASTC ANALYSIS of the STRUCTURAL TUBE

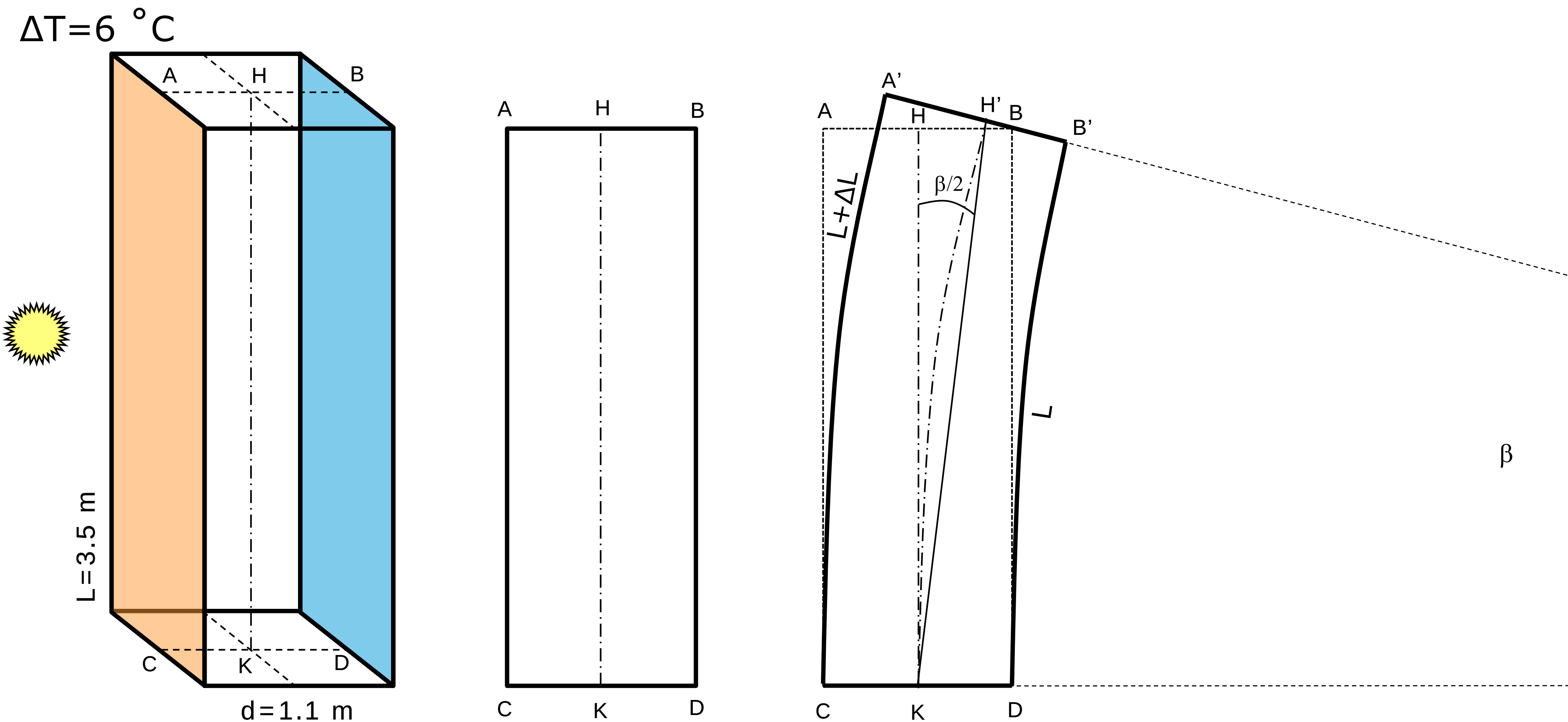
Main assumptions:

- Simple geometry made of bars jointed with perfect no-friction hinges -> stress-free
- Steady state
- Max thermal gradient on the cross section: $\Delta T = 6^\circ C$ (margin 100% wrt to thermal analysis)
- Temperature range over time during orbit: [15, 25 °C] ($\Delta T = 10^\circ C$)
- Isotropic material properties (E, CTE)

Requirement:

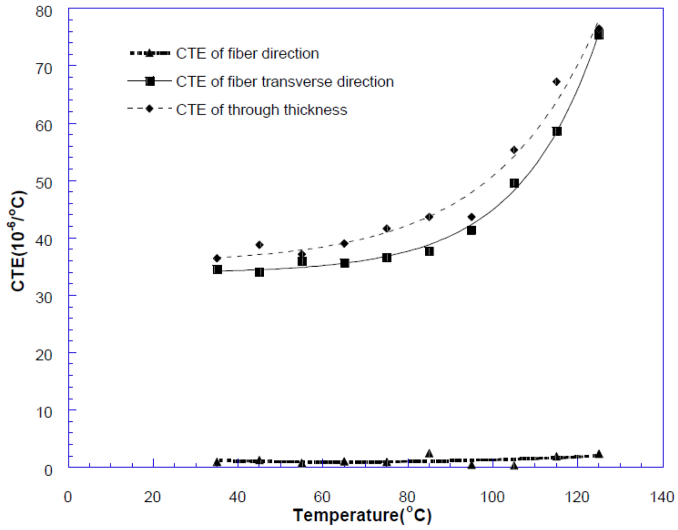
- Max deviation of the LoS due to thermal effect < 2 arcsec (from HEW budget CDF allocation)

SIMPLIFIED THERMOELASTC ANALYSIS: The model



SIMPLIFIED THERMOELASTC ANALYSIS: Input data

Material	Linear coefficient α at 20 °C (10^{-6} K^{-1})
Aluminium	23.1
Brass	19
Steel	11.0 ~ 13.0
Carbon steel	10.8
Stainless steel	10.1 ~ 17.3
Diamond	1
Glass	8.5
Glass, borosilicate	3.3
Zerodur	≈0.02
Invar	1.2
Iron	11.8
Kapton	20
Magnesium	26
Mercury	61
Nickel	13
PP	150
PVC	52
Titanium	8.6
Tungsten	4.5
CFRP	– 0.8
Fiberglass laminate	9.9, 11.9



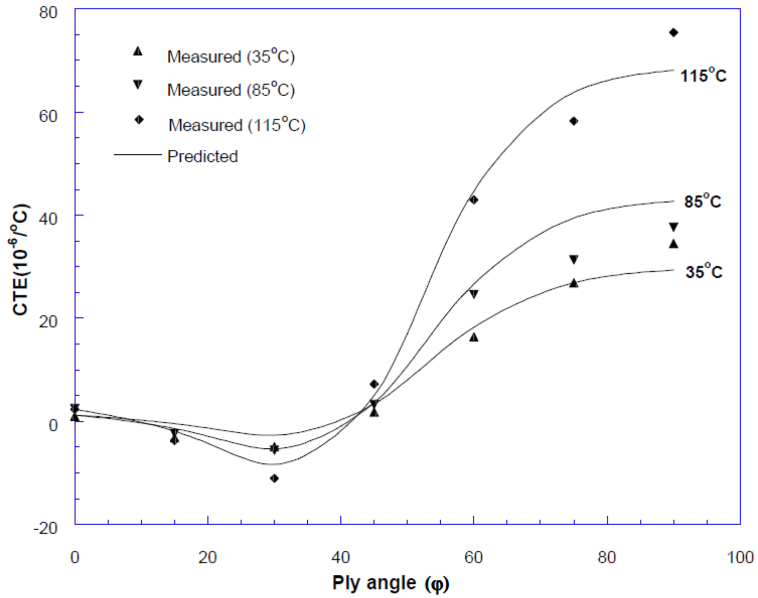
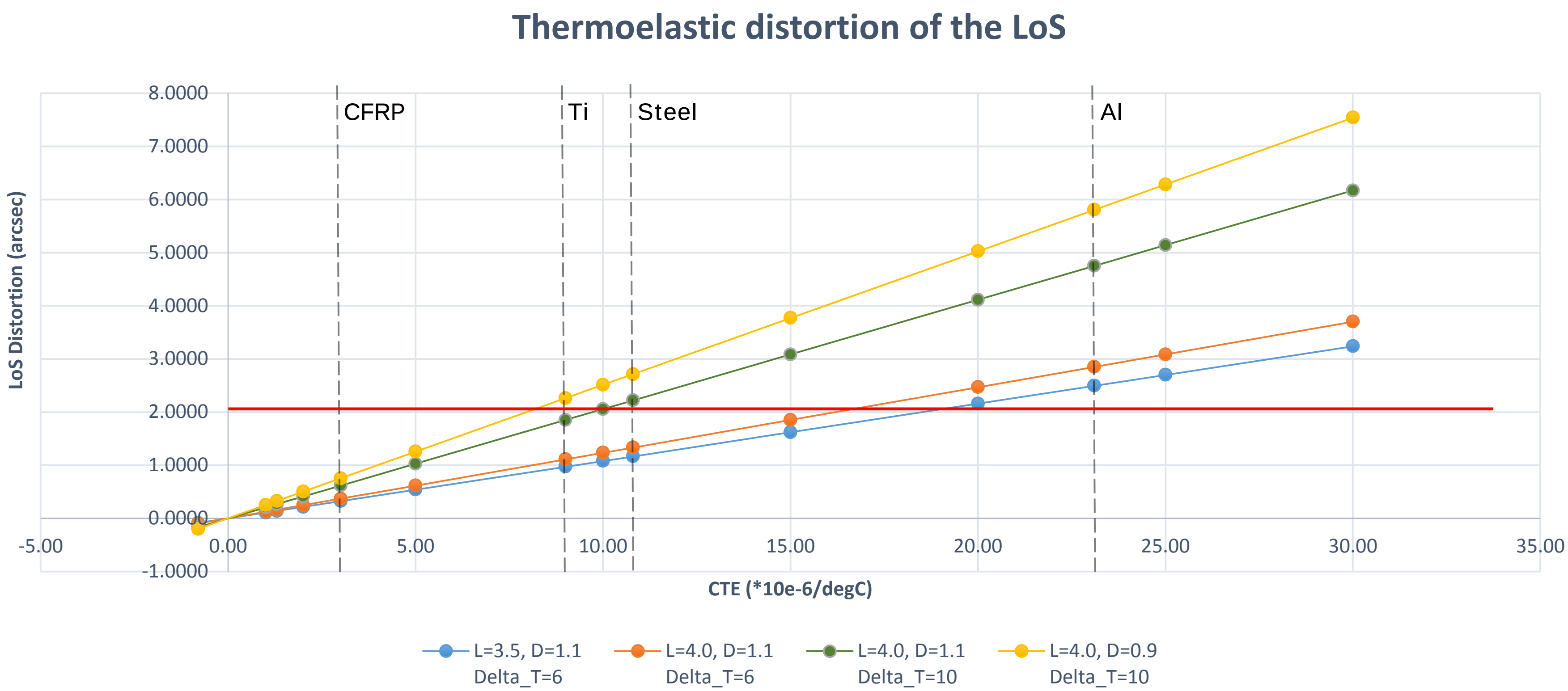


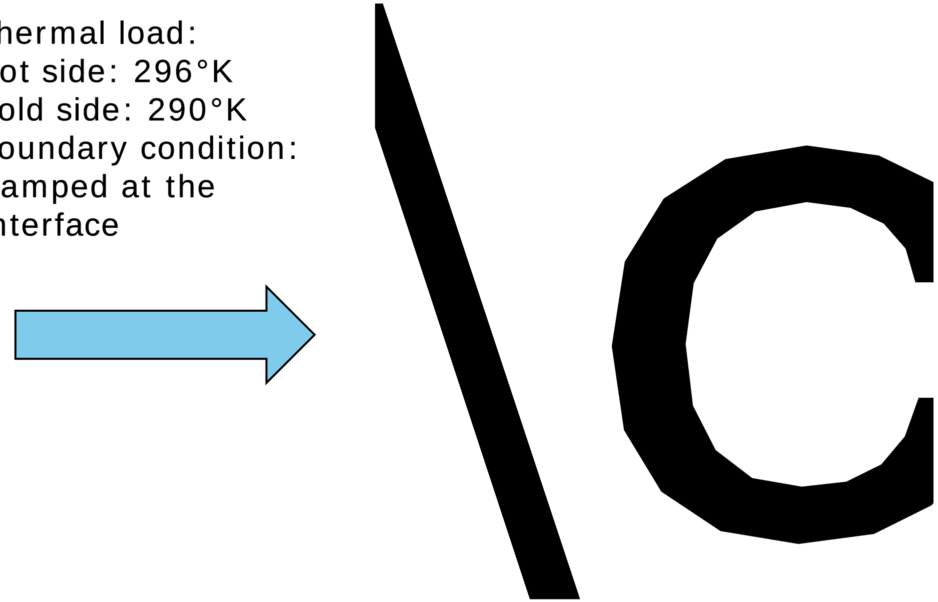
Fig. 5 : Measured and Predicted CTEs of $[\pm\varphi]_{2S}$ Laminate

SIMPLIFIED THERMOELASTC ANALYSIS: Results



Thermal distortion based on FEM

Thermal load:
Hot side: 296°K
Cold side: 290°K
Boundary condition:
clamped at the
Interface

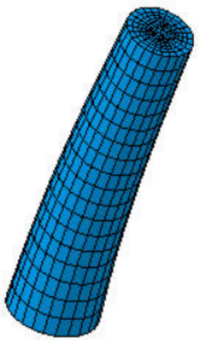


- Results confirm the simplified analysis

Modal analysis

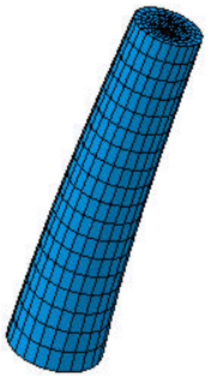
1st Lateral 1

Occurrence 1 - Frequency 45.5282Hz



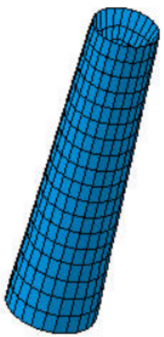
2nd Lateral 2

Occurrence 2 - Frequency 45.5328Hz



1st Axial

Occurrence 18 - Frequency 189.828Hz



- Compliance with launcher requirements

Structural Tube: conclusions and design recommendations

- Preliminary thermal analysis has been performed
- Worst case results are in line with the requirement (<2 arcsec), if the CTE is below ~15*10e-6/deg (for a cylinder D=1.1, L=4.0, $\Delta T=6^{\circ}C$)
- The order of magnitude of the thermal distortions measured on XMM is consistent with the model
- Preliminary modal analysis confirms compliance with launcher requirements (VEGA)

Design recommendations:

- Specific tailoring of CFRP laminate in order to minimize the global longitudinal CTE (optimization of ply angle and/or possible combination of different fibers in the same laminate)
- Choice of High Modulus Carbon Fibers, with low CTE
- CFRP cylindrical (or conical) shell, balanced laminate +/-45, seems a promising solution
- Filament winding manufacturing technology recommended for cost effectiveness
- Slightly conical shape is beneficial for FW manufacturing, as mandrel extraction is facilitated
- Constant winding angle is possible also with slightly conical shape
- I/F flanges (Al) can be bonded and bolted to the CFRP FW shell
- Simple FEM analysis showed fulfillment of VEGA stiffness requirements for CFRP t=3 mm

Equipment Summary

	mass (kg)	mass margin (%)	mass incl. margin (kg)
PLM (Payload Module)	15.41	15.13	17.75
FPM (Focal Plane Module)	3.76	0.00	3.76
MAM (Mirror Assembly Module)	11.66	20.00	13.99
ST (Structural Tube Module)	54.98	20.00	65.97
Tube (Telescope Tube)	54.98	20.00	65.97
SVM (Service Module)	173.90	20.00	208.68
IF_SVM_PLM (Service Module to Payload Module Interface)	10.00	20.00	12.00
IF_SVM_VEGA (Service Module to VEGA Adaptor Interface)	10.00	20.00	12.00
SVM_bottom (Service Module Bottom Panel)	6.97	20.00	8.37
SVM_CC (Service Module Central Cylinder)	14.45	20.00	17.34
SVM_top (Service Module Top Panel)	1.20	20.00	1.44
SVM_shear_1 (Service Module Shear Panel)	1.20	20.00	1.44
SVM_shear_2 (Service Module Shear Panel)	1.20	20.00	1.44
SVM_shear_3 (Service Module Shear Panel)	1.20	20.00	1.44
SVM_shear_4 (Service Module Shear Panel)	1.20	20.00	1.44
SVM_shear_5 (Service Module Shear Panel)	1.20	20.00	1.44
SVM_shear_6 (Service Module Shear Panel)	1.20	20.00	1.44
SVM_shear_7 (Service Module Shear Panel)	1.20	20.00	1.44
SVM_shear_8 (Service Module Shear Panel)	1.20	20.00	1.44
IF_SVM_MM (Service Module to Mirror Module Interface)	6.78	20.00	8.14
Misc (Miscellaneous Structure for XIPE)	22.99	20.00	27.59
Solar_Panel_SS (Solar Panel Support Structure)	30.00	20.00	36.00
Star_Tracker_SS (Star Tracker Support Structure)	5.00	20.00	6.00
Sunshield_SS (Sunshield Support Structure)	2.00	20.00	2.40
SVM_outer_1 (Service Module Outer Panel)	2.24	20.00	2.69
SVM_outer_2 (Service Module Outer Panel)	2.24	20.00	2.69
SVM_outer_3 (Service Module Outer Panel)	2.24	20.00	2.69
SVM_outer_4 (Service Module Outer Panel)	2.24	20.00	2.69
SVM_outer_5 (Service Module Outer Panel)	2.24	20.00	2.69
SVM_outer_6 (Service Module Outer Panel)	2.24	20.00	2.69
SVM_outer_7 (Service Module Outer Panel)	2.24	20.00	2.69
SVM_outer_8 (Service Module Outer Panel)	2.24	20.00	2.69
Tank_SS_1 (Tank Support Structure)	4.00	20.00	4.80
Tank_SS_2 (Tank Support Structure)	4.00	20.00	4.80
Thruster_SS_01 (Thruster Support Structure)	1.50	20.00	1.80
Thruster_SS_02 (Thruster Support Structure)	1.50	20.00	1.80
Thruster_SS_03 (Thruster Support Structure)	1.50	20.00	1.80
Thruster_SS_04 (Thruster Support Structure)	1.50	20.00	1.80
Thruster_SS_05 (Thruster Support Structure)	1.50	20.00	1.80
Thruster_SS_06 (Thruster Support Structure)	1.50	20.00	1.80
Thruster_SS_07 (Thruster Support Structure)	1.50	20.00	1.80
Thruster_SS_08 (Thruster Support Structure)	1.50	20.00	1.80
Thruster_SS_09 (Thruster Support Structure)	1.50	20.00	1.80
Thruster_SS_10 (Thruster Support Structure)	1.50	20.00	1.80
Thruster_SS_11 (Thruster Support Structure)	1.50	20.00	1.80
Thruster_SS_12 (Thruster Support Structure)	1.50	20.00	1.80
Thruster_SS_13 (Thruster Support Structure)	1.50	20.00	1.80
Thruster_SS_14 (Thruster Support Structure)	1.50	20.00	1.80
Thruster_SS_15 (Thruster Support Structure)	1.50	20.00	1.80
Thruster_SS_16 (Thruster Support Structure)	1.50	20.00	1.80
Umb_Con_SS_1 (Umbilical Connection Support Structure)	2.50	20.00	3.00
Umb_Con_SS_2 (Umbilical Connection Support Structure)	2.50	20.00	3.00
Grand Total	244.29	19.69	292.39

	mass (kg)	mass margin (%)	mass incl. margin (kg)
PLM (Payload Module)	15.41	15.13	17.75
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SVM_CC (Service Module Central Cylinder)	14.45	20.00	17.34
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SVM_shear_1 (Service Module Shear Panel)	1.20	20.00	1.44
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SVM_outer_4 (Service Module Outer Panel)	2.24	20.00	2.69
SVM_outer_5 (Service Module Outer Panel)	2.24	20.00	2.69
SVM_outer_6 (Service Module Outer Panel)	2.24	20.00	2.69
SVM_outer_7 (Service Module Outer Panel)	2.24	20.00	2.69
SVM_outer_8 (Service Module Outer Panel)	2.24	20.00	2.69
Tank_SS_1 (Tank Support Structure)	4.00	20.00	4.80
Tank_SS_2 (Tank Support Structure)	4.00	20.00	4.80
Thruster_SS_01 (Thruster Support Structure)	1.50	20.00	1.80
Thruster_SS_02 (Thruster Support Structure)	1.50	20.00	1.80
Thruster_SS_03 (Thruster Support Structure)	1.50	20.00	1.80
Thruster_SS_04 (Thruster Support Structure)	1.50	20.00	1.80
Thruster_SS_05 (Thruster Support Structure)	1.50	20.00	1.80
Thruster_SS_06 (Thruster Support Structure)	1.50	20.00	1.80
Thruster_SS_07 (Thruster Support Structure)	1.50	20.00	1.80
Thruster_SS_08 (Thruster Support Structure)	1.50	20.00	1.80
Thruster_SS_09 (Thruster Support Structure)	1.50	20.00	1.80
Thruster_SS_10 (Thruster Support Structure)	1.50	20.00	1.80
Thruster_SS_11 (Thruster Support Structure)	1.50	20.00	1.80
Thruster_SS_12 (Thruster Support Structure)	1.50	20.00	1.80
Thruster_SS_13 (Thruster Support Structure)	1.50	20.00	1.80
Thruster_SS_14 (Thruster Support Structure)	1.50	20.00	1.80
Thruster_SS_15 (Thruster Support Structure)	1.50	20.00	1.80
Thruster_SS_16 (Thruster Support Structure)	1.50	20.00	1.80
Umb_Con_SS_1 (Umbilical Connection Support Structure)	2.50	20.00	3.00
Umb_Con_SS_2 (Umbilical Connection Support Structure)	2.50	20.00	3.00
Grand Total	244.29	19.69	292.39

XIPE

<Chemical Propulsion>

Session 8
ESTEC, 23-09-2015

Prepared by the CDF* Team

(*) ESTEC Concurrent Design Facility

Requirements

ID	Requirement	Results/Impacts
CPROP-1	The XIPE mission will last 3 year with an extension of 2 years. Delta –v for deorbiting/maintenance given as maximum value, incl. collision avoidance	Propellant mass
CPROP-2	No preheating during launch	Cold-start capable (at least 10 times)
CPROP-3	Controlled/uncontrolled reentry	Different thruster configuration, different propellant mass
CPROP-4	Thruster needed only during safe modes	Thruster and propellant mass
CPROP-5	No balanced thruster configuration needed	Thruster configuration
CPROP-6	Reason of symmetry – 2 tanks required	2 tanks, not volume optimized
CPROP-7	No plume impingement on telescopes and sunshield	Canting of thruster needed during lifetime, thruster for controlled reentry not canted

Design drivers

- Delta-v and AOCS mass
- Number of thruster for the controlled reentry and number of burns
- Plume impingement and corresponding configuration of the thruster on the lower panel
- Tank size for the controlled reentry(volume available within two compartments is 160l)

Assumptions and trade-offs

- *Assumptions*
  - → Δv-budget:
    - Collision avoidance: 0.4 m/s (margin already included) per year
    - Uncontrolled De-Orbiting/Maintenance: 25 m/s (margin already included) – calculated at end of life (worst case)
    - Altitude control: 1.68 kg (incl. margin) per year
  - Monopropulsion system
  - Nitrogen as pressurant gas
  - Diaphragm tanks
  - No time constraint for firing during each manoeuvre
  - Controlled reentry:
    - Delta-v values given by ESOC in relation to thrust

Assumptions and trade-offs

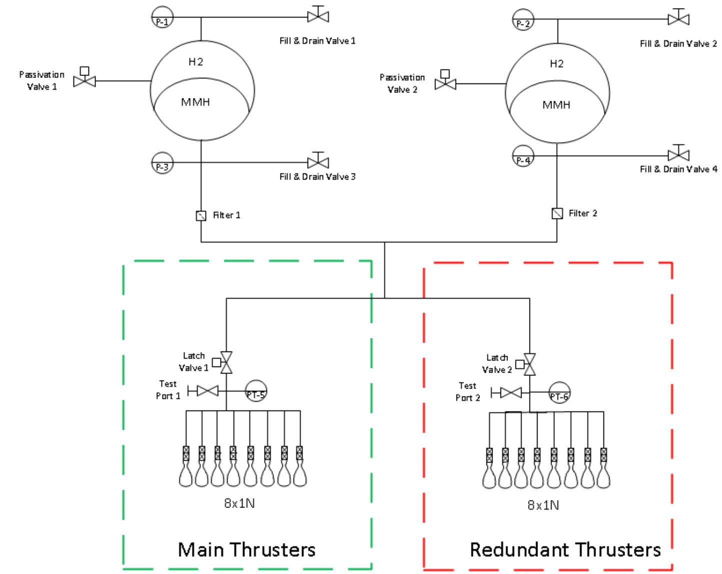
- *Controlled reentry*
  - Trade-off was performed w.r.t. tank size, number of thruster and number of burns
  - Result is that 4 thruster (+4 redundant) are needed, 3 burns sufficient

Baseline design - uncontrolled

- 2 Options of Baseline:
  - Uncontrolled
  - Controlled De-Orbiting

Mono-Propellant (Hydrazine)

- Uncontrolled De-Orbiting:
  - 2 tanks due to symmetry reason
  - 8 (+8 Redundant) 1N-Thrusters
  - Thrusters in blow down modus
  - Thrusters for Safe Mode & De-Orbiting
  - 5° canting angle



Baseline design - uncontrolled

AOCS mass: 8.4kg in total (1.68kg per year)

Deorbiting manoeuvre at the end of life: Worst case, propellant mass smaller for manoeuvre at BOL due to high Isp of the thruster

0.4m/s for collision avoidance per year

Manoeuvre	mass begin [kg]	mass end [kg]	velocity increment [m/s]	propellant mass [kg]	tank pressure [bar]
Collision avoidance	943.63	943.46	0.40	0.17	27.30
altitude control	943.46	941.78	3.88	1.68	27.07
Collision avoidance	941.78	941.61	0.40	0.17	25.03
altitude control	941.61	939.93	3.89	1.68	24.84
Collision avoidance	939.93	939.75	0.40	0.17	23.11
altitude control	939.75	938.07	3.90	1.68	22.95
Collision avoidance	938.07	937.90	0.40	0.17	21.47
altitude control	937.90	936.22	3.87	1.68	21.33
Collision avoidance	936.22	936.05	0.40	0.17	20.04
altitude control	936.05	934.37	3.85	1.68	19.92
Uncontrolled deorbiting	934.37	923.29	25.00	11.08	18.79
Summation	923.29	0.00	46.39	20.34	13.69

Baseline design – uncontrolled

Same assumptions as before, only dry mass increase up to 995 kg including system margin

1.74kg above 1to launch mass, tank pressure still within nominal region

Manoeuvre	mass begin [kg]	mass end [kg]	velocity increment [m/s]	propellant mass [kg]	tank pressure [bar]
Collision avoidance	1001.74	1001.55	0.40	0.18	27.30
altitude control	1001.55	999.87	3.66	1.68	27.05
Collision avoidance	999.87	999.69	0.40	0.18	24.94
altitude control	999.69	998.01	3.66	1.68	24.73
Collision avoidance	998.01	997.83	0.40	0.18	22.96
altitude control	997.83	996.15	3.67	1.68	22.78
Collision avoidance	996.15	995.96	0.40	0.18	21.26
altitude control	995.96	994.28	3.64	1.68	21.11
Collision avoidance	994.28	994.10	0.40	0.19	19.80
altitude control	994.10	992.42	3.62	1.68	19.67
Uncontrolled deorbiting	992.42	980.62	25.00	11.80	18.53
Summation	980.62	0.00	45.25	21.12	13.18

Analyses

- Uncontrolled De-Orbiting: (old masses used-for information)
  - Comparison of Δv_deorbiting-ranges

Δv_deorbiting [m/s]	**28.88**	**30**	**35**	**40**	**45**	**50**
Tank name	ATK-80342	ATK-80342	ATK-80481		ATK-80389	
Number of tanks	2	2	2	2	2	2
Geom. tank volume [l]	15.08	15.08	20.2	20.2	30.56	30.56
Propell. Volume [l]	14.45	14.45	19.19	19.19	22.53	22.53
Tank size Ø [mm]	327	327	338.58	338.58	390.6	390.6
Tank mass [kg]	2.72	2.72	1.81	1.81	3.72	3.72
Wall thickness [mm]	0.533	0.533	0.457	0.457	0.483	0.483
Tank pres. at BOL [bar]	24.82	24.82	18.96	18.96	17.58	17.58
Tank pres. at EOL [bar]	6.65	6.13	7.21	5.98	9.0	8.27
Total propell. mass [kg]	**22.3**	**22.93**	**25.29**	**27.94**	**30.13**	**32.71**

  - p_EOL=**5.5 bar** for thruster operation

Analyses

- Uncontrolled De-Orbiting: Baseline
  - Comparison of Δv_deorbiting ranges with same tank (ATK-80481)

Δv_deorbiting [m/s]	28.88	30	35	40
Geom. tank volume [l]	20.2			
Propell. volume [l]	19.19			
Tank size Ø [mm]	338.58			
Tank mass [kg]	1.81			
Tank pres. at BOL [bar]	18.96			
Tank pres. at EOL [bar]	8.68	8.41	7.21	5.98
Total propell. mass [kg]	**22.12**	**22.69**	**25.29**	**27.94**

→ Optimized tank covers large Δv_deorbiting range at lowest tank mass results in decrease of total propellant mass

Equipment summary - uncontrolled

- Power within the system
- 2% margin for propellant and pressurant

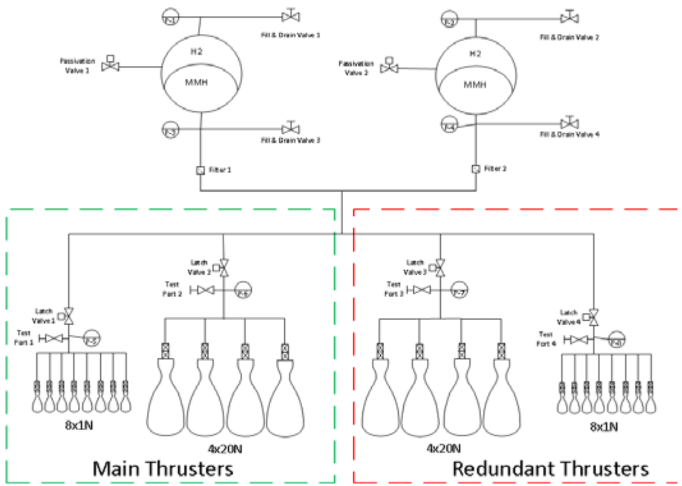
Number	Description	Type	Amount	Mass per unit [kg]	Margin	Mass incl. margin [kg]
1	Pipes	Pipes	1	5.00	20%	6.00
2	Fill & drain valve	AST-FFVV	4	0.07	5%	0.29
3	Pressure trandsducer	SAPT	6	0.22	5%	1.36
4	Latch valves	LPLV 3554258	2	0.55	5%	1.16
5	Test ports	AST-FFVV	2	0.07	5%	0.15
6	1N thruster	CHT-1N	16	0.29	5%	4.87
7	Propellant Filter	430-PF2	2	0.11	5%	0.23
8	Passivation Valves	vgl. bar mit Test Ports	2	0.07	5%	0.15
9	Tank	DS216	2	1.81	5%	3.80
Total	Chemical propulsion system			8.19		18.01
10	Propellant	Hydrazine	1	20.34	2%	20.75
11	Pressurant	Nitrogen	1	0.64	2%	0.65

Baseline design - controlled

- 2 Options of Baseline:
  - Uncontrolled
  - Controlled De-Orbiting

  } Mono-Propellant (Hydrazine)

- Controlled De-Orbiting:
  - 2 tanks due to symmetry reason
  - 8 (+8 Redundant) 1N-Thrusters
  - Thrusters in blow down modus
  - Thrusters for Safe Mode & De-Orbiting
  - 5° canting angle
  - In addition: 4 (+4 redundant) 20N-Thruster
    Canting angle 0° from Airbus (as example)
  - Additional equipment needed



Baseline design - controlled

AOCS mass: 8.4kg in total (1.68kg per year)

Calculation for delta-v and using 5% margin, three burns, four thruster

0.4m/s for collision avoidance per year

Manoeuvre	mass begin [kg]	mass end [kg]	velocity increment [m/s]	propellant mass [kg]	tank pressure [bar]
Collision avoidance	1025.97	1025.76	0.44	0.21	24.00
altitude control	1025.76	1024.08	3.57	1.68	23.91
Collision avoidance	1024.08	1023.87	0.44	0.21	23.22
altitude control	1023.87	1022.19	3.58	1.68	23.14
Collision avoidance	1022.19	1021.99	0.44	0.21	22.49
altitude control	1021.99	1020.31	3.58	1.68	22.42
Collision avoidance	1020.31	1020.10	0.44	0.21	21.81
altitude control	1020.10	1018.42	3.58	1.68	21.74
Collision avoidance	1018.42	1018.21	0.44	0.21	21.17
altitude control	1018.21	1016.53	3.57	1.68	21.10
Controlled deorbiting Firing #1	1016.53	990.33	56.71	26.20	20.56
Controlled deorbiting Firing #2	990.33	962.11	61.56	28.22	14.70
Controlled deorbiting Firing #3	962.11	932.83	64.99	29.28	11.25
Summation	932.83	0.00	203.34	93.13	9.05

Baseline design – controlled

Same assumptions as before

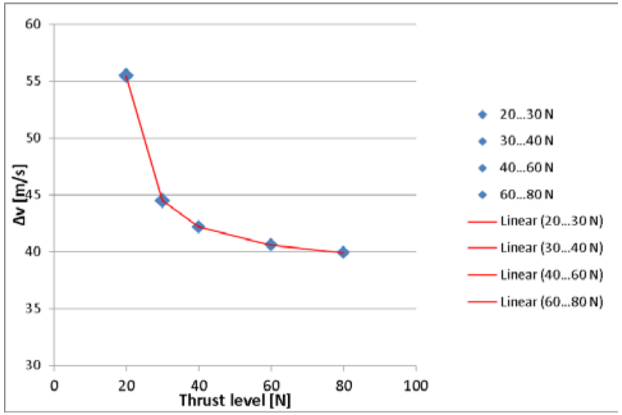
Wet mass is about 1.1to (slightly above)

Delta-v's for the controlled deorbiting are slightly higher (~0.6%) due to the lower thrust at EOL

Manoeuvre	mass begin [kg]	mass end [kg]	velocity increment [m/s]	propellant mass [kg]	tank pressure [bar]
Collision avoidance	1100.69	1100.47	0.44	0.22	24.00
altitude control	1100.47	1098.79	3.33	1.68	23.89
Collision avoidance	1098.79	1098.57	0.44	0.22	23.11
altitude control	1098.57	1096.89	3.33	1.68	23.01
Collision avoidance	1096.89	1096.67	0.44	0.22	22.28
altitude control	1096.67	1094.99	3.34	1.68	22.18
Collision avoidance	1094.99	1094.76	0.44	0.22	21.50
altitude control	1094.76	1093.08	3.33	1.68	21.42
Collision avoidance	1093.08	1092.86	0.44	0.22	20.78
altitude control	1092.86	1091.18	3.32	1.68	20.70
Controlled deorbiting Firing #1	1091.18	1062.84	56.93	28.34	20.11
Controlled deorbiting Firing #2	1062.84	1032.15	62.05	30.69	13.56
Controlled deorbiting Firing #3	1032.15	1000.34	65.47	31.81	10.02
Summation	1000.34	0.00	203.29	100.35	7.89

Analysis

- *Controlled/uncontrolled reentry*
  - Optimization using linear approaches to calculate delta-v w.r.t. thrust/number of thruster, all manoeuvres then +5% margin



→ delta-v in accordance with thrust at end of manoeuvre

3 burns

T [N]	20	30	40	80
DV 1 [m/s]	125.8	66.8	59.8	54.5
DV 2 [m/s]	102.8	69.2	61.2	56.7
DV 3 [m/s]	148.3	70.8	63	58.8
TOT DV [m/s]	**376.9**	**206.8**	**184**	**170**

4 burns

T [N]	20	30	40	60	80
DV 1 [m/s]	55.5	44.5	42.2	40.6	39.9
DV 2 [m/s]	56.6	45.6	43.4	42	42.1
DV 3 [m/s]	58.3	46.5	44.2	43.1	43.2
DV 4 [m/s]	59.5	47.4	45.3	44.3	43.1
TOT DV [m/s]	**229.9**	**184**	**175.1**	**170**	**168.3**

Analysis

- Different thruster with different number of burns

# of burns	Option	Dry mass w propulsion system [kg]	Propellant mass [kg]	Wet mass [kg]	Tank volume [l]
3	Hydrazine, 1N & 2x20N	946.47	94.64	1045.87	238
	Hydrazine, 1N & 3x20N	932.56	94.06	1029.08	182
	Hydrazine, 1N & 4x20N	**932.83**	93.13	1027.50	148
4	Hydrazine, 1N & 2x20N	931.62	95.07	1029.13	182
	Hydrazine, 1N & 3x20N	932.56	91.02	1026.12	182
	Hydrazine, 1N & 4x20N	932.83	91.11	1025.54	148

- Delta in wet mass between four and three burns is calculated to be 1.96kg. It is assumed that this mass is consumed by the residuals implied due to the additional firing

Equipment summary

- Power consumption within the system
- 2% margin for propellant and pressurant

Number	Description	Type	Amount	Mass per unit [kg]	Margin	Mass incl. margin [kg]
1	Pipes	Pipes	1	5.00	20%	6.00
2	Fill & drain valve	AST-FFVV	4	0.07	5%	0.29
3	Pressure trandsducer	SAPT	8	0.22	5%	1.81
4	Latch valves	LPLV 3554258	4	0.55	5%	2.31
5	Test ports	AST-FFVV	4	0.07	5%	0.29
6	1N thruster	CHT-1N	16	0.29	5%	4.87
7	Propellant Filter	430-PF2	2	0.11	5%	0.23
8	Passivation Valves	vgl. bar mit Test Ports	2	0.07	5%	0.15
9	20N Thruster	CHT-20N	8	0.37	5%	3.11
10	Tank	PEPT-420	4	3.50	5%	14.70
Total	Chemical propulsion system			10.25		33.77
11	Propellant Filter	Hydrazine	1	93.13	2%	95.00
12	Pressurant	Nitrogen	1	1.54	2%	1.57

- Tank system with four tanks leading to a mass estimation and the corresponding volume (148l), but
  - Corresponding tanks have to be developed or different configuration has to be investigated

XIPE

Power

Session 8
ESTEC, 23-09-2015

Prepared by the CDF* Team

(*) ESTEC Concurrent Design Facility

Requirements

- Main requirements that need to be taken into account in the analysis related to the power system:

ID	Statement	Comments
R-MI-0090	**Nominal operational orbit** The mission and system design shall assume a nominal operational orbit as follows: • Circular ~~• Altitude between 550-600 km~~ • Inclination: 5.6 deg Revised to 550 km nominal.	Gives a period of 96 min, with an eclipse of ~34-36 min.
R-MI-0120	**Mission nominal lifetime** The mission design shall guarantee a nominal in-orbit lifetime of 3 years from launcher separation to disposal	Lifetime extension of 2 additional years is also considered.
R-MI-0250	**Field of Regard** The mission and system design shall allow Field of Regard of 1/3 of the celestial sphere at any given time with no forbidden directions over one year	Leads to a S/C slew range of ± 20° from the median attitude (axis normal to sun direction)
R-SC-0030	**Payload operations** The spacecraft design shall allow operations of the Payload described in [AD2] during the full orbit.	Operation continuous through the eclipse/sun cycle.
R-MI-0220	**Minimum TRL level** The mission and system design shall be based uniquely on technologies which are projected to achieve at least Technology Readiness Level of 6 according to the definition of [AD6] by the time of the Mission Adoption.	Note: Mission Adoption is expected to take place at the end of 2018

Design drivers

- LEO in low inclination orbit = more than 1/3 of orbit is in eclipse, at all times of the year.
- Full operation of the platform and payload is required for the full orbit
- Heating power demand is large, and may be higher in eclipse than in sunlight.
- Spacecraft attitude with respect to the sun will be quite constant, except ± 20° slew rotation around the (y) axis perpendicular to both the S/C axis and the S/C-sun direction. Payload has no requirements on S/C roll (around x axis), so this is a DoF that can be dedicated to sun-pointing.
  - Geometry conclusion: a single flat solar array can remain sun-pointed within 20° at all times.

Design drivers – Power demand budget

- This table shows the average power, per mode, per equipment.
  - The table is displayed at OCDT model "level 5" – in some cases the power is attributable to equipment at a lower hierarchy level.
- SSlew is the highest power mode, but:
  - Slew maneuvers will be performed infrequently (less than once per orbit)
  - Slew maneuvers will last a *maximum* of 40 minutes (in the worst case of 180 degrees).
- Power system sizing is therefore performed on the basis of ObsHiDec mode, with 40 min of SSlew per 5 orbits approx.

	ObsLowDec	Man	SSlew	Safe	ObsHiDec	UMB_SUN
FPM (Focal Plane Module)	58.4	66.4	66.4	10.0	66.4	10.0
MAM (Mirror Assembly Module)	108.0	141.0	141.0	90.0	141.0	30.6
Htr_tube (Heater_Tube)	38.0	41.0	41.0	41.0	41.0	0.0
Venting_Mech (Venting Mechanism)	0.0	0.0	0.0	0.0	0.0	1.0
Htr_Prop (Heater_Propulsion)	3.7	3.7	3.7	37.0	3.7	37.0
Htr_SM (Heater_ServMod)	9.0	9.0	9.0	90.0	9.0	9.0
Lat_Val_1 (Equipment XIPE_Latch Valves)	0.3	0.3	0.3	0.3	0.3	0.3
Lat_Val_2 (Equipment XIPE_Latch Valves)	0.3	0.3	0.3	0.3	0.3	0.3
OBC_XIPE (OBC OSCAR for xipe)	15.0	15.0	15.0	15.0	15.0	15.0
RIU_XIPE (RIU for XIPE)	20.0	20.0	20.0	20.0	20.0	0.0
SSMM_XIPE (Solid State Mass Memory for xipe)	15.0	15.0	15.0	15.0	15.0	15.0
X_Band_EPC (X Band Electronic Power Conditioning)	0.1	0.1	0.1	0.1	0.1	0.1
X_Band_TWT (X Band Traveling Wave Tube)	1.8	1.8	1.8	1.8	1.8	1.8
STR_HydraOH_1 (STR Sodern Hydra Optical Head)	7.5	7.5	7.5	7.5	7.5	0.0
STR_HydraOH_2 (STR Sodern Hydra Optical Head)	7.5	7.5	7.5	7.5	7.5	0.0
X_XPND (X band Transponder)	10.8	10.8	10.8	10.8	10.8	10.8
X_XPND_RED (X band Transponder Redundant)	10.8	10.8	10.8	10.8	10.8	10.8
Press_Transduc_1 (Equipment XIPE_Pressure Transducer)	0.2	0.2	0.2	0.2	0.2	0.2
Press_Transduc_2 (Equipment XIPE_Pressure Transducer)	0.2	0.2	0.2	0.2	0.2	0.2
Press_Transduc_3 (Equipment XIPE_Pressure Transducer)	0.2	0.2	0.2	0.2	0.2	0.2
Press_Transduc_4 (Equipment XIPE_Pressure Transducer)	0.2	0.2	0.2	0.2	0.2	0.2
Press_Transduc_5 (Equipment XIPE_Pressure Transducer)	0.2	0.2	0.2	0.2	0.2	0.2
Press_Transduc_6 (Equipment XIPE_Pressure Transducer)	0.2	0.2	0.2	0.2	0.2	0.2
RADMON_1 (Radiation Monitor)	2.3	2.3	2.3	2.3	2.3	0.0
RADMON_2 (Radiation Monitor)	2.3	2.3	2.3	2.3	2.3	0.0
RADMON_3 (Radiation Monitor)	2.3	2.3	2.3	2.3	2.3	0.0
Red_Thr_1N1_1 (Redundant CHT-1N Thruster)	6.4	6.5	6.4	6.4	6.4	6.4
Red_Thr_1N1_2 (Redundant CHT-1N Thruster)	6.4	6.5	6.4	6.4	6.4	6.4
Red_Thr_1N1_3 (Redundant CHT-1N Thruster)	6.4	6.5	6.4	6.4	6.4	6.4
Red_Thr_1N1_4 (Redundant CHT-1N Thruster)	6.4	6.5	6.4	6.4	6.4	6.4
Red_Thr_1N1_5 (Redundant CHT-1N Thruster)	6.4	6.5	6.4	6.4	6.4	6.4
Red_Thr_1N1_6 (Redundant CHT-1N Thruster)	6.4	6.5	6.4	6.4	6.4	6.4
Red_Thr_1N1_7 (Redundant CHT-1N Thruster)	6.4	6.5	6.4	6.4	6.4	6.4
Red_Thr_1N1_8 (Redundant CHT-1N Thruster)	6.4	6.5	6.4	6.4	6.4	6.4
RW_RSI12_1 (Nominal RW Rockwell Collins RSI 12)	19.8	19.8	45.0	19.8	19.8	19.8
RW_RSI12_2 (Nominal RW Rockwell Collins RSI 12)	19.8	19.8	45.0	19.8	19.8	19.8
RW_RSI12_3 (Nominal RW Rockwell Collins RSI 12)	19.8	19.8	45.0	19.8	19.8	19.8
STR_HydraOH_3 (STR Sodern Hydra Optical Head)	7.5	7.5	7.5	7.5	7.5	0.0
GYRO_Astrix_1090 (Nominal GYRO Airbus Astrix 1090)	12.0	12.0	12.0	0.0	12.0	0.0
GYRO_Sireus (Nominal GYRO Selex Galileo Sireus)	0.0	0.0	0.0	5.5	0.0	0.6
RW_RSI12_4 (Nominal RW Rockwell Collins RSI 12)	19.8	19.8	45.0	19.8	19.8	19.8
STR_HydraEU (Nominal STR Sodern Hydra Electronics Unit)	11.0	11.0	11.0	0.0	11.0	0.0
STR_HydraOH_4 (STR Sodern Hydra Optical Head)	7.5	7.5	7.5	7.5	7.5	0.0
MTQ_MT110_2_1 (MTQ Zarm MT110-2)	1.5	1.5	1.5	0.0	1.5	0.0
MTQ_MT110_2_2 (MTQ Zarm MT110-2)	1.5	1.5	1.5	0.0	1.5	0.0
MTQ_MT110_2_3 (MTQ Zarm MT110-2)	1.5	1.5	1.5	0.0	1.5	0.0
MAG_FGM_A_75 (Nominal MAG Zarm FGM-A-75)	1.0	1.0	1.0	0.0	1.0	0.0
GNSS_Airbus_Mosaic (Nominal GNSS Airbus Mosaic Receiver)	8.0	8.0	8.0	0.0	8.0	0.0
Grand Total	**496**	**541**	**641**	**516**	**540**	**274**
Including 30% margin	**645**	**703**	**833**	**671**	**702**	**356**

Assumptions and trade-offs

- Much of the total electrical energy makes the round-trip through the battery.
- Heating power forms a significant part of the total, and heaters can directly use unregulated voltage.
  - Unregulated battery bus is efficient to avoid BCR & BDR losses.
  - A regulated bus is also realistic, but not optimum, and does simplify interfaces to payload equipment.
- Power level looks appropriate for 28V.
- An MPPT solar array regulator makes best use of the extra energy available from the cold solar array on every eclipse exit.

Baseline design

- Single, flat, body mounted solar array
  - Triple junction cells with 30% nominal efficiency are assumed.
  - Thermally isolated on the back side to prevent radiating heat to the spacecraft platform and payload.

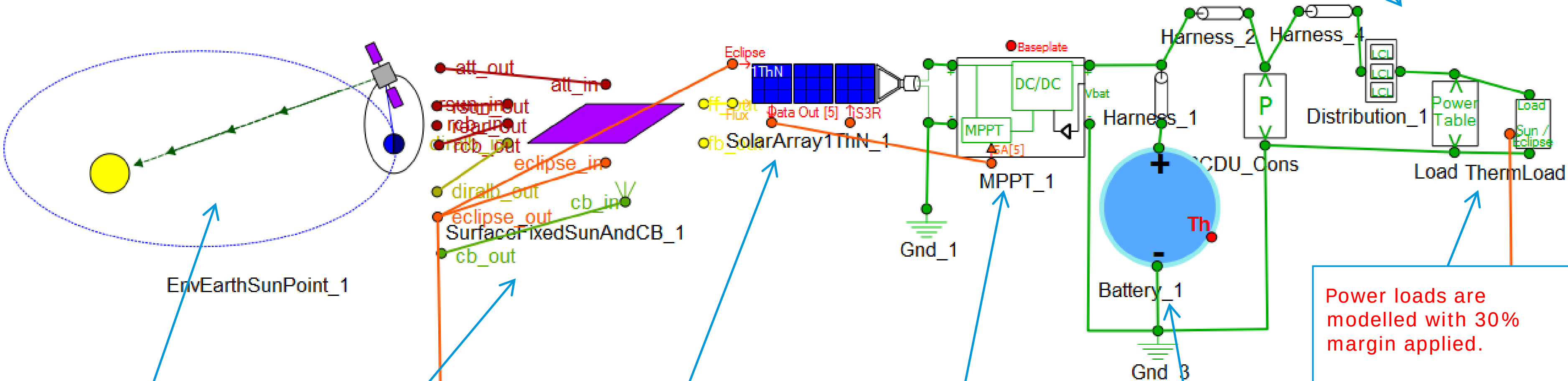
- MPPT solar regulation feeding a 28 V (nominal) unregulated battery bus.

- Li-ion secondary battery
  - 8 cells in series
  - Likely split into 2 or (even more) modules for practicality / configuration.

Analyses

- Power system was simulated and sized using the ESA "PEPS" modelling tool:

Losses from harness and distribution are modelled with dedicated elements.



550 km, 5.4°, June 21st

Model element to account for attitude / geometry. Set 20° off-pointed from sun

22 cells per string, 70 strings, 1 string assumed failed. Degradation appropriate for 5 years in LEO. Thermal model is integrated. 5.8 m²

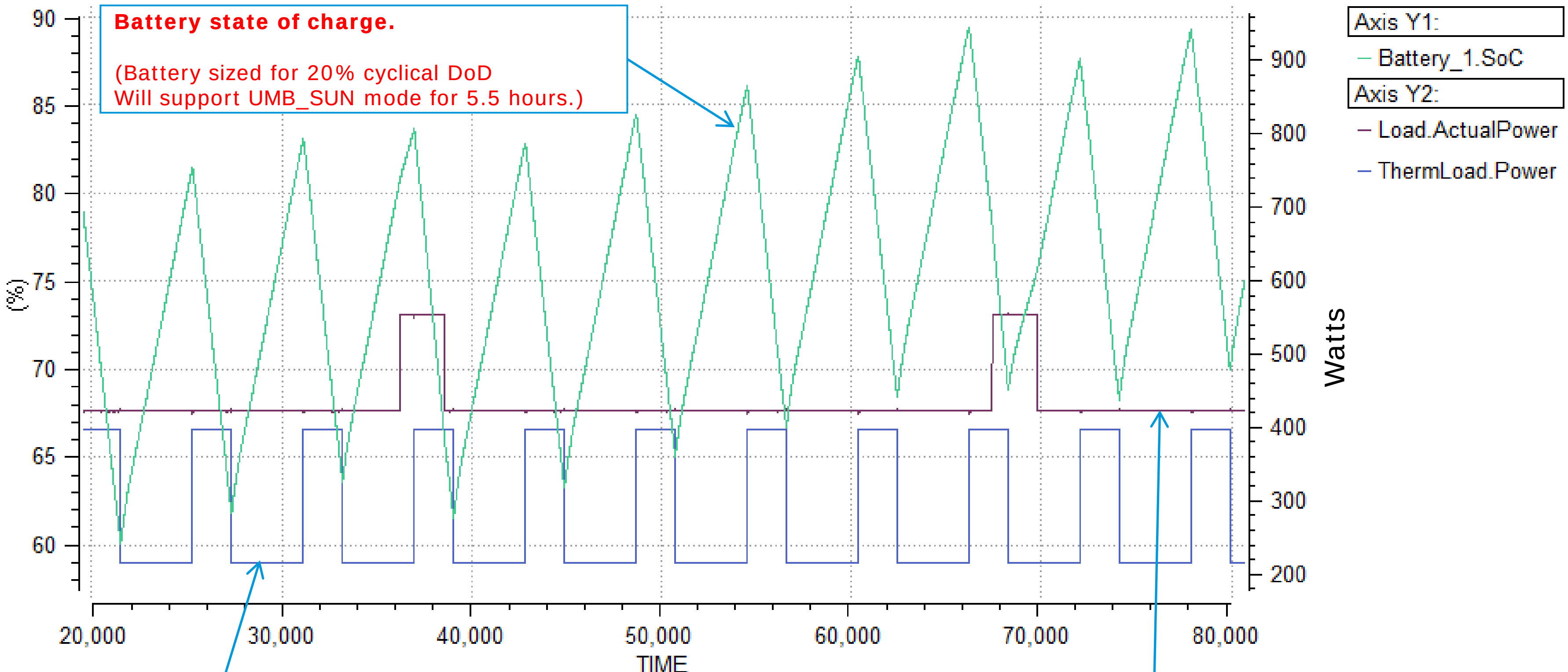
Buck MPPT regulation, modelled with load and ΔV-dependent efficiency.

Li-Ion, 8s, 81Ah battery (total for all modules). 16000 cycles in 3 yrs, 27000 cycles in 5 yrs

Power loads are modelled with 30% margin applied.

Increased heating demand in eclipse, and periodic application of SSlew mode are accounted for.

Analyses



Thermal system power requirement:

398 W in eclipse
216 W in sun

Other (non-thermal) loads:

422 W in ObsHiDec
533 W in SSlew

Equipment summary

- Power system equipment summary:
  - PCDU mass is estimated using previous comparable spacecraft power systems.
  - Solar array mass includes PVA, panel, wiring, but NOT rear side MLI.
  - Battery is split into two equal modules.

	mass (kg)	mass margin (%)	mass incl. margin (kg)
⊞ PCDU (Power Conditioning & Distribution Unit)	25.00	20.00	30.00
⊞ SA (SolarArray)	22.30	10.00	24.53
⊞ Bat1 (Battery_general1)	10.40	10.00	11.44
⊞ Bat2 (Battery_general2)	10.40	10.00	11.44
Grand Total	68.10	13.67	77.41

XIPE

Communications

Session 8
ESTEC, 23-09-2015

Prepared by the CDF* Team

(*) ESTEC Concurrent Design Facility

Requirements

ID	Statement	Comments
COM-010	The COMM s/s shall be able to perform TT&C operations regardless of the S/C attitude, throughout all the mission phases	
COM-020	The COMM s/s shall allow the transmission of all the scientific and housekeeping telemetry data to Earth	
COM-030	Active (hot) redundancy shall be provided for telecommand (uplink) and passive (cold) redundancy for telemetry (downlink)	
COM-040	The link budget margins shall be as defined in ECSS-E-50-05C Rev.2	
COM-050	The COMM s/s must be compatible with the ground station site in Malindi	

Design drivers

- The main design drivers are:

Downlink data rate. Consequences on

- frequencies for uplink/downlink
- Ground segment

Cost. Consequences on

- Communication equipment on the service module
- Ground segment utilization

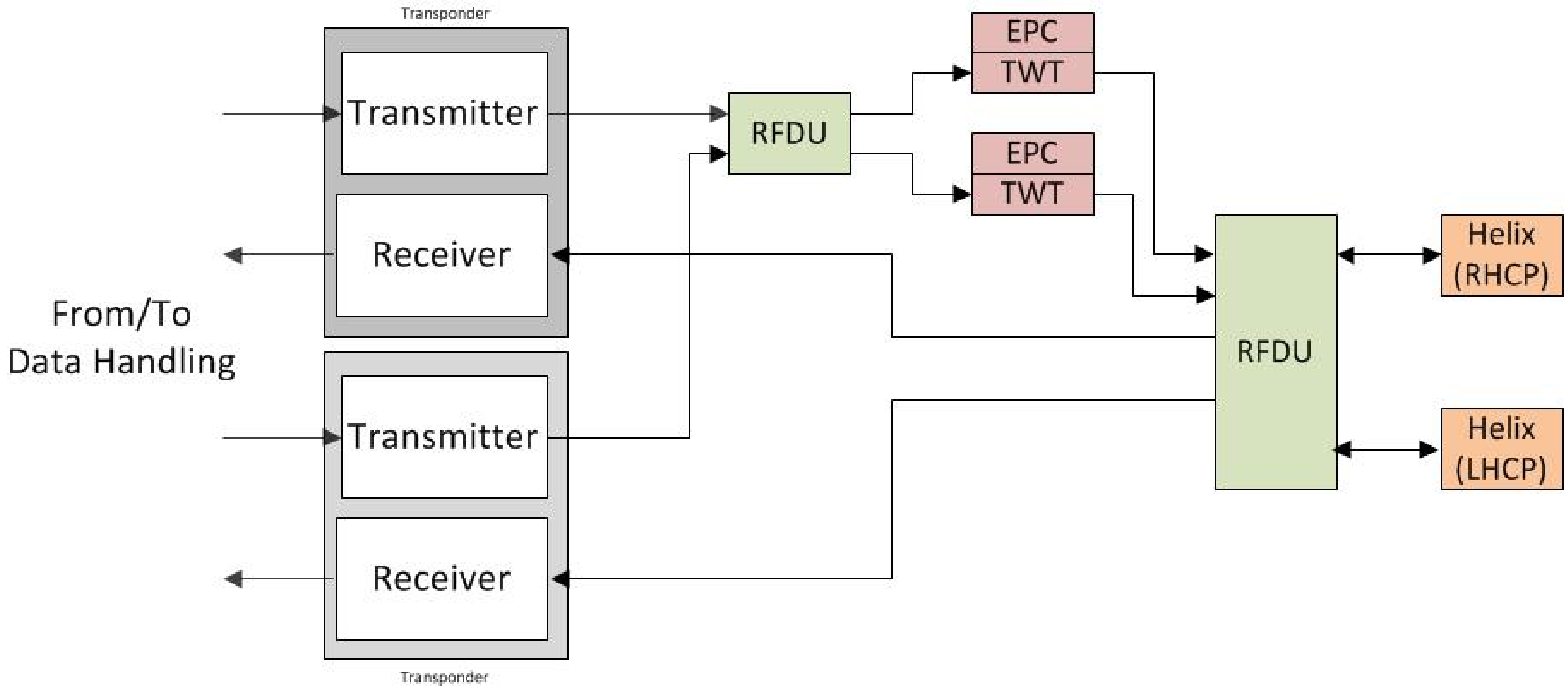
Assumptions and trade-offs

- Assumptions:
  - *The COMM s/s shall be able to download 120 Gbit in less than 3 days*
  - *There are on average 14 G/s passes/day each ~10 minutes.*
- Trade-off on mission scenario:
  - Frequency selection: S-Band (up/down), X-Band (up/down), S (up) and X (down)

	Complexity	G/S use	Cost	TRL	Data rate	Power
S-Band	+	-	+	+	-	++
X-Band	+	+	-/--	-/+	+	+/-
S- and X-Band	-	+	-	-	+	-

- *X-Band (up/down) was selected*

Baseline design



Baseline Design

High data rate mode (HDR mode, for nominal mode)

- NRZ/PSK/PM, 4 kbps, in uplink (compatible with Malindi 2m)
- GMSK, 6 Mbps, in downlink (compatible with Malindi 10m)
- Tracking is not possible

Tracking/Low-data rate mode (LDR mode, safe mode and LEOP)

- NRZ/PSK/PM in uplink (compatible with Malindi 2m)
- SPL/PSK/PM in downlink (compatible with Malindi 2m)
- Tracking is possible

Analyses

- Required data rate:
  - 120 Gbit over 3 days (40 Gbit/day) (Crab nebula)
  - Malindi: 14 passes/day of 10.1 minutes
  - 20% of capacity loss due to protocol overhead, tracking, G/S availability
  - → 6 Mbps for downlink
  - HDR mode is the sizing case for the required power (LDR will have high margin)

PARAMETER	VALUE	Notes
REQ. BIT RATE [kbps]	6000.00	
REQ. BIT RATE [dBHz]	67.78	
ALTITUDE [km]	625.0	
ELEVATION ANGLE [deg]	5.0	
RANGE [km]	2389.0	
FREQUENCY [MHz]	8450	
PATH LOSSES [dB]	178.54	Calculated
ATMOSPHERE LOSS [dB]	5.00	99% Availability Malindi
RX G/T [dBK]	31.80	Malindi 10m
DEMOD. LOSS [dB]	2.00	Estimation
MOD. LOSS [dB]	0.00	
REQIRED Eb/No [dB]	6.60	Reed Solomon FER 1e-5
MINIMUM MARGIN [dB]	3.00	Standard ESA
REQ. EIRP [dBW]	**2.52**	**Calculated**
TX ANTENNA GAIN [dB]	-4.00	
TX LOSSES [dB]	4.00	Preliminary Estimated Value
REQ. TX POWER [W]	**11.28**	

Equipment	Watt	Notes
X-Band Transmitter	15.00	
X-Band Receiver	10.00	
RF Power	11.28	
TWT eff	0.60	
EPC eff	0.95	
TWT ON	18.81	
EPC ON	0.99	
Peak	54.80	

Equipment summary

- 2 X-Band transponders
- 2 TWTA (EPC+TWT)
- 2 X-Band helix antenna
- Radio frequency distribution unit (RFDU)

Mass budget: ~16 kg (with margin)

	mass (kg)	mass margin (%)	mass incl. margin (kg)
SC (Spacecraft)	**15.10**	**7.09**	**16.17**
SVM (Service Module)	**15.10**	**7.09**	**16.17**
X_Band_EPC (X Band Electronic Power Conditioning)	1.40	5.00	1.47
X_Band_EPC_Red (X Band Electronic Power Conditioning Redudant)	1.40	5.00	1.47
X_Band_TWT (X Band Traveling Wave Tube)	1.00	0.00	1.00
X_Band_TWT_Red (X Band Traveling Wave Tube Redundant)	1.00	0.00	1.00
X_XPND (X band Transponder)	3.50	5.00	3.68
X_XPND_RED (X band Transponder Redundant)	3.50	5.00	3.68
X_LGA_LHCP (X band Low Gain Antenna LHCP)	0.40	10.00	0.44
X_LGA_RHCP (X band Low Gain Antenna RHCP)	0.40	10.00	0.44
X_RFDU (X band Radio Frequency Distribution Unit)	2.50	20.00	3.00
Grand Total	15.10	7.09	16.17

Equipment summary

Power budget: Peak power 54.8W (1 MOD, 2 Rx_DED, 1 TWT, 1 EPC are ON)

Power (W)	P_on	P_stby
⊞ X_Band_EPC (X Band Electronic Power Conditioning)	0.99	0.00
⊞ X_Band_EPC_Red (X Band Electronic Power Conditioning Redudant)	0.99	0.00
⊞ X_Band_TWT (X Band Traveling Wave Tube)	18.81	0.00
⊞ X_Band_TWT_Red (X Band Traveling Wave Tube Redundant)	18.81	0.00
⊟ X_XPND (X band Transponder)	25.00	0.00
⊞ MOD (Modulator)	15.00	0.00
⊞ Rx_DED (Receiver (dedicated))	10.00	0.00
⊟ X_XPND_RED (X band Transponder Redundant)	25.00	0.00
⊞ MOD (Modulator)	15.00	0.00
⊞ Rx_DED (Receiver (dedicated))	10.00	0.00
Grand Total	89.59	0.00

XIPE

Data Handling Sub-System

Session 8
ESTEC, 23-09-2015

Prepared by the CDF* Team

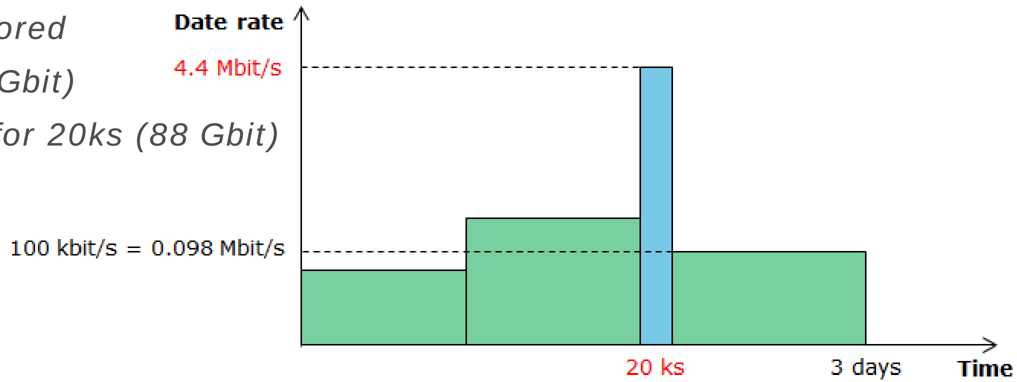
(*) ESTEC Concurrent Design Facility

Design drivers

- Provide sufficient data storage to prevent data loss through outage
- Provide adequate data handling resources
  - OBC
    - TMTC to and from Ground Control Stations
    - Autonomous FDIR capabilities
    - Protected data storage
    - On-board Timings
  - SSMM
    - Provide around 228 Gbit of data capacity (science and HK data up to 3 days)
    - Interface over a redundant SpaceWire link (designed for high data rates)
  - RIU
    - Provide discrete TMTC interfaces to all the on-board subsystems to acquire HK telemetry
- Provide reliable equipment to work in LEO

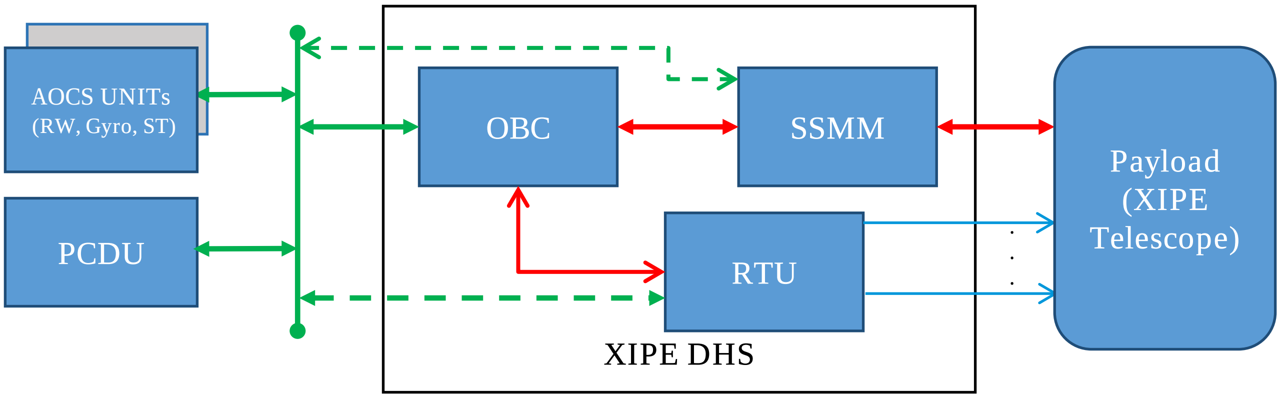
Assumptions and trade-offs

- *Main assumptions for Target of Opportunity:*
  - *3 days of observation to be stored*
  - *Typical TM is 100kbps (23.92 Gbit)*
  - *Special science case (4 crab) for 20ks (88 Gbit)*
  - *Total 113.92 Gbit*
  - *With 100 % margin:*
  - *228 Gbit*



- *Trade-off on mission scenario:*
  - *The CHEOPS mission was studied to find reusable systems to provide more with reliable and dependable parts (ESSS-Q-ST-30)*
  - *An OBC of the same class of the CHEOPS mission was selected*

Baseline design



Platform Bus: MIL-1553B (as heritage from many ESA missions)

Payload interface: SpaceWire (to cope with the data rates from the science instruments)

Equipment summary

	mass (kg)	mass margin (%)	mass incl. margin (kg)
OBC_XIPE	5.20	5.00	5.46
RIU_XIPE	7.00	10.00	7.70
SSMM_XIPE	3.00	10.00	3.30
RED_OBC_XIPE	5.20	5.00	5.46
RED_RIU_XIPE	7.00	10.00	7.70
RED_SSMM_XIPE	3.00	10.00	3.30
Grand Total	30.40	8.29	32.92

Power (W)		
	P_on	P_stby
OBC_XIPE	15.00	10.00
RIU_XIPE	20.00	15.00
SSMM_XIPE	15.00	10.00
RED_OBC_XIPE	15.00	10.00
RED_RIU_XIPE	20.00	15.00
RED_SSMM_XIPE	15.00	10.00

XIPE

<Mechanisms IFP>

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Design drivers

- *In terms of Mechanisms the main design drivers for this mission are:*
  - *Minimise the number of mechanisms*
  - *Ensure proper functional role*
  - *Ensure proper stiffness when stowed or deployed*
  - *Ensure redundancy of mechanisms active elements (springs, motors …)*
  - *Ensure motorization margins*
  - *Minimize mass*

Assumptions and trade-offs

- *Assumptions:*
  - *The analysis for the sun shield assumed only panels (fixed: 900 mm width; 150 mm height; deployable: 900 mm width; 325 mm height)*
  - *Aluminum core and CFRP face sheet sandwich panels only have been considered*
  - *XMM heritage is considered for the mirrors covers*
  - *XMM heritage is considered for brackets and connectors*
  - *XMM heritage is considered for the venting mechanism (with the difference that for XIPE the venting mechanism is not supposed to protect the detectors while the main goal of the venting mechanism for XMM was to protect the detectors => smaller mechanism for XIPE)*

Assumptions and trade-offs

- *Trade-off sunshield fixed | deployable:*

	Fixed sunshield H:800 mm W:900 mm 1 sandwich panel CFRP face sheet (0.2 mm thick) and aluminium core (10 mm total thickness)	**Deployable sunshield H:150 mm W:900 mm 1 fixed and 1 H:650 mm W:900 mm deployable sandwich panels**
Natural frequency > 15 Hz	30 Hz without MLI ++	200 Hz without MLI ++
Mass	4 Kg including brackets, bolts and connectors (MLI not included) +	8 Kg including brackets, bolts, connectors and mechanisms (deployment hinges with AMPEP bearings and springs, release nuts (non explosive) with kick-off springs and brackets) -
Configuration	Out of the allowable area for VEGA => needs agreement with the launcher authority - - -	Stays inside the allowable area for VEGA ++
Light protection	Compliant with mirror covers opening out-of-plane +	Compliant with mirror covers opening out-of-plane +
Reliability	No mechanisms +	Presence of mechanisms but redundant deployment springs and redundant initiators/ electrical lines for the release nuts -

- *Deployable selected because a fixed sunshield could not be accommodated (to be reviewed in future design phases)*

Assumptions and trade-offs

Trade-off sunshield deployable XMM like | deployable by motorised hinges

	Deployable sunshield H:150 mm W:900 mm 1 fixed and 2 H:325 mm W:900 mm deployable sandwich panels (OPTION1)	**Deployable sunshield H:800 mm W:900 mm 1 sandwich panel CFRP face sheet (0.2 mm thick) and aluminium core (10 mm total thickness) (OPTION2)**
Natural frequency > 15 Hz	Around 153 Hz without MLI ++	Around 30 Hz without MLI +
Mass	Around 12 Kg because of additional HDRMs and additional deployment springs ++	Around 14 Kg because of additional electrical motors and reinforced HDRMs brackets Electrical motors are needed to provide a controlled deployment with limited perturbations on the spacecraft +
Configuration	After careful analysis, more than 2 deployable parts are needed to reach the needed deployed location from the stowed location. Therefore, the spacecraft configuration is not compliant with this solution - - -	Possible but care should be taken with interferences during the deployment due to the large deployment angle (180 deg) +
Light protection	Compliant with mirror covers opening out-of-plane ++	Compliant with mirror covers opening out-of-plane It will need shielding (labyrinth seal for example) at the foot +
Reliability	Presence of mechanisms but redundant deployment springs and redundant initiators/ electrical lines for the release nuts -	Additional electronics are needed to drive the electrical motors Latching mechanisms needed to keep the sunshield in place after deployment Perturbation torque on the spacecraft - -

Assumptions and trade-offs

Trade-off mirrors covers:

	Cover opening out-of-plane Sandwich CFRP face sheet 0.2 mm aluminium core 4.6 mm Deployment springs, one hold down and release mechanism (non-explosive), end-stop defines aperture angle	Cover opening in-plane with deployment springs and one hold down and release mechanism (non-explosive)	Iris shutter CFRP 12 CFRP leaves of 1 mm thickness
Natural frequency > 50 Hz	Compliant ++ (f=319 Hz)	Compliant ++ (f=319 Hz)	Compliance achieved but less performant + (f=66.1 Hz)
Mass	Mass is about 3.3 Kg +	Mass is about 3.3 Kg +	Mass is about 3.3 Kg +
Configuration	Simple configuration with enough allowable space despite an increase in sunshield height ++	Incompatible with the allowable space - -	Might be compatible with the allowable space but needs to be investigated further because of the volume needed for the leaves storage after deployment +
Cleanliness	Very good ++	Very good ++	The cleanliness is not guaranteed because of a needed clearance between the leaves -
Reliability	Simple design with one hold down and release mechanism with redundant initiators and redundant lines +	Not so simple because there are sliding surfaces -	Complex design with risk of jamming in case of fretting during launch - -

Baseline design

- **Deployable sunshield**
  - Sandwich structure 10 mm thickness (9.6 mm aluminum core and 0.2 mm x2 face sheet)
  - Latching mechanisms: springs latches
  - Electrical actuators (heritage from GAIA/Sentinel 2 actuators including stepper motor with redundant motor coils, harmonic drive size 20 with reduction ratio 160, Ball bearings, grease for harmonic drive and ball bearing lubrication, anti-creep barriers to prevent grease migration, labyrinth seal to prevent grease contamination)

Heritage from GAIA/Sentinel2

Baseline design

- **Deployable sunshield**
  - 2 Non-Explosive Actuators to have a low release shock (alternative from European source exists)
  - Each actuator has redundant initiators (fusible wire)
  - Brackets, cables , bolts and connectors
  - The sunshield components are already qualified but the assembly is to be developed

NEA actuator for 35 kN preload

Baseline design

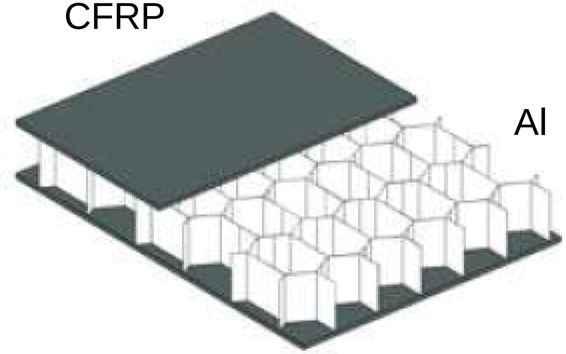
- **Mirror cover mechanism**
  - Sandwich disk 5 mm thickness (4.6 mm aluminum core and 0.2 mm CFRP face sheet)
  - Redundant spiral drive springs in stainless steel: springs are used to deploy and to latch as well
  - Redundant AMPEP type journal bearings
  - 1 Non-explosive actuator
  - Brackets, cables , bolts and connectors
  - Modification of the XMM mechanism

Baseline design

- **Venting mechanism**
  - Modification of the XMM mechanism (scaled down version)
  - 2 paraffin actuators (for redundancy) which provides linear motion
  - 2 integral mechanisms which translate the linear motion into rotation
  - Redundant spiral drive springs in stainless steel
  - Redundant AMPEP type journal bearings
  - Brackets, cables , bolts and connectors
  - The spiral springs are used to close the door and the paraffin actuators are used to open the door (counteracting the springs) => no need for a hold down and release mechanism

Analyses

- Eigen frequency calculation of stowed sun shield:



$$f := \frac{\lambda 2}{2 \cdot \pi \cdot a^2} \cdot \left[\frac{E \cdot t^3}{12 \cdot \rho \cdot t \cdot \left(1 - \nu^2\right)} \right]^{\frac{1}{2}}$$

$$f = 30.68$$

Analyses

- Motorization margins for the sun shield during deployment:
- Assuming M 4 Kg, the sun shield mass, which has to move (being deployed) and a service module diameter D of 1.88 m, if the actuator gearbox (harmonic drive) ratio N is 160, the dynamic torque Tm at actuator's motor level is calculated

$$I := M \cdot \left(\frac{D}{2}\right)^2 \qquad Im := \frac{I}{N^2} \qquad Tm := Im \cdot acc$$

considering that in 1 motor step, the full deployment speed is reached (stepping frequency of 135 Hz => 2.356 rad/sec at motor level), the acceleration is 320 rad/sec2

Tm is 0.044 Nm

- The resistive torque in cold (measured at -70 deg C) (due to ball bearings, ...) is 0.035 Nm

- Required motor torque (ECSS factored):2x(1.25x0.044+1.5x0.035)=0.216Nm

- Stepper motor delivers a torque of 0.242 Nm => OK compliant

Analyses

- Disturbance torque on spacecraft:
- \- Considering Tm (dynamic torque at motor level), the dynamic torque at spacecraft level (neglecting friction losses) is TmxN=7 Nm which is < typical disturbance torques during deployment (for example the Northrop Grumman Large Deployable Reflector delivers disturbance torques of about 300 Nm during deployment) => OK compliant
- Deployment time:
- \- Considering the deployment speed wm at motor level (2.356 rad/sec), knowing the gearbox ratio (160), the deployment speed is:

$$w := \frac{wm}{N}$$

- This gives a sun shield deployment speed of 0.844 deg/sec and a deployment time (180 deg deployment angle) of 214 sec.

Analyses

- Natural frequency of the deployed mirror covers:
- - Considering a hinge stiffness K of 5000 Nm/rad, a cover mass m of 0.3 Kg with a diameter d of 0.3 m, assuming the center of gravity of the cover at its center,

$$I := m \cdot hcog^2 \qquad f := \frac{1}{2 \cdot \pi} \cdot \sqrt{\frac{K}{I}}$$

- The deployed cover frequency is 137 Hz => OK compliant

Equipment summary

	mass (kg)	mass margin (%)	mass incl. margin (kg)
⊟ MAM (Mirror Assembly Module)	23.90	15.86	27.69
⊞ Mirror_Cover (Mirror Cover)	3.30	10.00	3.63
⊞ Mirror_Cover2 (Mirror Cover 2)	3.30	10.00	3.63
⊞ Mirror_Cover3 (Mirror Cover 3)	3.30	10.00	3.63
⊞ Sun_Shield (Deployable Sun Shield)	14.00	20.00	16.80
⊞ Venting_Mech (Venting Mechanism)	2.00	10.00	2.20
Grand Total	25.90	15.41	29.89

Power (W)	P_on	P_stby
⊟ MAM (Mirror Assembly Module)	55.00	0.00
⊞ Mirror_Cover (Mirror Cover)	5.00	0.00
⊞ Mirror_Cover2 (Mirror Cover 2)	5.00	0.00
⊞ Mirror_Cover3 (Mirror Cover 3)	5.00	0.00
⊞ Sun_Shield (Deployable Sun Shield)	40.00	0.00
⊞ Venting_Mech (Venting Mechanism)	10.00	0.00
Grand Total	65.00	0.00

XIPE

GS&Ops

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Prepared by the CDF* Team

(*) ESTEC Concurrent Design Facility

Requirements

- Mission lifetime is 3+2 years
- Equatorial orbit
- Science data shall be available at the SOC within 7 days TBC of the measurement
- ToO acquisition shall be within 12 working hours of the initial request received at the SOC
  - 6 – 18 ToO per year
- Single pass per orbit (X-band downlink) for science data dumps

Requirements

ID	Statement	Comments
R-MI-0120	Mission nominal lifetime The mission design shall guarantee a nominal in-orbit lifetime of 3 years from launcher separation to disposal	
R-MI-0130	Lifetime for consumables For Spacecraft consumables sizing, an in-orbit lifetime extension of 2 years beyond the nominal lifetime shall be considered	
R-MI-0210	Data availability Raw observation data ***with auxiliary FD products*** shall be made available to the SOC within ***7*** days from measurement	Updates TBC
R-MI-0280	Targets of Opportunity - time The mission and system design shall be such that the time from a triggered request at SOC to acquiring a Target of Opportunity in the detector is less than 11 hours within the constraints of R-MI-0250 and during normal working hours	During normal working hours means excluding weekends
R-MI-0290	Targets of Opportunity - number The mission and system design shall provide the capabilities for a minimum number of Targets of Opportunity of 6 per year and shall assume a maximum number of Targets of Opportunity of 18 per year	
R-OPGS-0010	Ground Station(s) The mission and system design shall be compatible with the use of a single X-band Ground Station ***per orbit*** for science data downlink during the operational phase	
R-OPGS-0020	Ground Control outage During the operational phase, the mission and system design shall allow nominal operations without Ground contact for up to 3 days	

Design drivers

- The Malindi Ground Station suitability assessed:
  - MAL-2 is an S/SXL-band 10m antenna
  - MAL-X is a new 2m X/X-band antenna being commissioned for LPF
- MAL-2 is used to command launch vehicles and support mission LEOPs
  - No plan to change this (assume that the station will still be available in 2026)
  - Assume these uses will take priority over routine operations
- X-band will be susceptible to the rainy seasons
  - Expect high rate of transmission corruptions so require CFDP to manage the end-end data completeness
  - High priority data (if any) shall be transmitted during the middle of each pass (best link margin)
  - Assume 10% of the link capacity is reserved for protocol overhead and retransmissions

Assumptions and trade-offs

- Mission Timeline including the Routine Science Observations Plan can be uplinked for multiple days in advance, e.g. 7 days
- No on-board resource issues when switching from Routine Observations to ToOs
- No data completeness requirement: observations can be repeated
- Definition of “Normal Working Hours” is 9am – 5pm, Mon – Fri, excluding public holidays
- Direct launch into operational orbit
  - Sunshield needs to deploy before thrusters can be used to detumble following launcher separation (nominally a step in the automated Separation Sequence)
  - No other critical appendage deployments
- Future status/developments at Malindi uncertain (e.g. MAL-2 X-band uplink)

Baseline design

- Standard “EO mission”-type operations
  - Roughly only 10mins visibility every 100mins
  - Repetitive ground station requirement
  - Contribution to the SPACON-pool
  - FCT engineer on-call for anomalies
  - FD engineer on-call for Collision Avoidance
- MAL-2 data dump pass taken every orbit except for when it will be a TT&C pass
  - Downlink timetagged to start/end at 10deg elevation
  - HKTM also dumped every pass
  - Science data tagged with (uncalibrated) position and pointing data routed directly to the SOC

Baseline design

- MAL-X TT&C pass twice per day, morning and evening
  - Once per day as an option
  - MTL topped-up to 7 days in to the future
- Reliable commanding still possible every pass (using BD-mode and CFDP)
  - ToO commanding
  - Interrupting data dumps if MAL-2 is offline and uploading new dump planning
- Interruptions to routine pass plan to be expected due to Launches/LEOPs
  - Kourou and/or KSAT-Singapore as default backup

XIPE

Programmatics & AIV

Session 8
ESTEC, 23-09-2015

Prepared by the CDF* Team

(*) ESTEC Concurrent Design Facility

Requirements and design drivers

- The nominal mission duration is 3 years from a launch date in 2025-2026, with a possible extension of +2 years.
- Instrument(s) provided by Member States
- Development risk shall be low: TRL6 by 2018 required for all mission elements
- Launcher is VEGA (or VEGA-C, if available)

Assumptions & trade-offs

- Phase A/B1 starting in March 2016
- M4 selection June 2017
- Mission adoption November 2018
- Instrument verification with the Panter X-ray facility close to Munich

Options

- The options considered are for controlled or uncontrolled re-entry.
- The difference is for the controlled re-entry a larger propulsion system is required
- For AIV this means limited additional integration and verification effort which is neglected in the proposed schedule.

Technology requirements

- No critical technology has been identified which could possibly impact on the system model philosophy or the overall schedule.

Integration and verification approach

- A typical hybrid model philosophy is proposed to be followed with structural and thermal qualification with an STM, electrical and functional (software) verification with an EFM and completion of the qualification and acceptance with a PFM.
- It is mandatory that all equipment is qualified and, where possible, acceptance tested before integration on the s/c.
- Cleanliness requires particular attention
- The payload, mirrors and instrument, shall be verified at the Panter X-ray facility in Munich for which a duration of 6-9 month, possibly 12 month is anticipated
- This might be done within the PFM environmental test campaign (tbd)
- Schedule risk: Panter facility will be also used for Athena test campaign, i.e. facility will be blocked for about a year at least but the blockage might extend up to 3 years

Model philosophy

- At system level:
  - Structural Thermal Model (STM)
  - Electrical Functional Model (EFM, also called AVM)
  - Protoflight Model (PFM)
  - RF Suitcase

- At equipment level
  - Depending on equipment heritage
  - For new developments
    - EM (for Avionics testing issues), QM (also ESD verification) and FM
  - For recurrent equipment
    - EM and FM

Test matrix

Test Description	STM	EFM	PFM
Mech. Interface	R, T		R, T
Mass Property	A, T		A, T
Electr. Performance		T	T
Functional Test		T	T
Propulsion Test		T	T
Deployment Test	A, T		A, T
Telecom. Link		T	A, T
Alignment	A, T		T
Strength / Load	A, T		T
Shock / Seperation	T		T (tbd)
Sine Vibration	A, T		T
Modal Survey (base excitation)	A		
Acoustic	T		T
Outgassing			I (T)
Thermal Balance	T		A, T
Thermal Vacuum			T
Micro Vibration			
Grounding / Bonding		T	R, T
Radiation Testing		T	A
EMC Conductive Interf.		T	T
EMC Radiative Interf.			T
DC Magnetic Testing			
RF Testing			T

Abbreviations: I: Inspection, A: Analysis, R: Review, T: Test

Schedule (example)

ID		Task Mode	Task Name	Duration	Start	Finish	Predecessors
1			**XIPE Schedule**	**2187 days**	**Tue 01/03/16**	**Wed 17/07/24**	
2			Kick-off	0 days	Tue 01/03/16	Tue 01/03/16	
3			PRR	40 days	Wed 04/01/17	Tue 28/02/17	10FF
4			SRR	40 days	Thu 04/01/18	Wed 28/02/18	11FF
5			PDR	50 days	Fri 23/08/19	Thu 31/10/19	13FF
6			CDR	60 days	Fri 30/10/20	Thu 21/01/21	14SS+260 days
7			QR	44 days	Thu 01/07/21	Tue 31/08/21	17
8			AR	41 days	Fri 06/10/23	Fri 01/12/23	25FF
9			Launch	0 days	Wed 17/07/24	Wed 17/07/24	27
10			Phase A (12 month)	261 days	Tue 01/03/16	Tue 28/02/17	2
11			Phase B1 (12 month)	261 days	Wed 01/03/17	Wed 28/02/18	10
12			Intermediate phase (8 month)	175 days	Thu 01/03/18	Wed 31/10/18	11
13			Phase B2 (12 month)	261 days	Thu 01/11/18	Thu 31/10/19	12
14			**Phase C/D**	**1066 days**	**Fri 01/11/19**	**Fri 01/12/23**	**13**
15			Detailed Design	261 days	Fri 01/11/19	Fri 30/10/20	
16			STM procurement	261 days	Fri 01/05/20	Fri 30/04/21	15SS+130 days
17			STM environmental test campaign	43 days	Mon 03/05/21	Wed 30/06/21	16
18			AVM procurement	130 days	Mon 03/08/20	Fri 29/01/21	15SS+196 days
19			AVM integration	175 days	Mon 01/02/21	Fri 01/10/21	18
20			AVM testing	346 days	Mon 04/10/21	Mon 30/01/23	19
21			PFM procurement	261 days	Thu 31/12/20	Thu 30/12/21	16SS+174 days
22			PFM integration	175 days	Fri 31/12/21	Thu 01/09/22	21
23			PFM environmental test campain part 1	41 days	Fri 02/09/22	Fri 28/10/22	22
24			PFM test campaign at Panter facility (9 month)	195 days	Mon 31/10/22	Fri 28/07/23	23
25			Completion of acceptance testing (3 month) in	90 days	Mon 31/07/23	Fri 01/12/23	24
26			Contingency (6 month)	130 days	Mon 04/12/23	Fri 31/05/24	14
27			Launch campaign (1.5 month)	33 days	Mon 03/06/24	Wed 17/07/24	26