ARIEL

Introduction

Internal Final Presentation
ESTEC, 8th July 2015

Prepared by the CDF* Team

(*) ESTEC Concurrent Design Facility

Agenda

Agenda ARIEL - Kick-off		Time	Duration
Introduction	Jakob	09:30	00:15
System	Friederike / Andrew	09:45	00:30
Mission Analysis	Michael	10:15	00:15
Payload design (instruments, telescope and detectors)	Paul	10:30	00:20
AOCS	Fabrice	10:50	00:15
Break		11:05	00:15
Propulsion	Andreas	11:20	00:15
Data Handling	Carlos	11:35	00:15
Communications	Andrea / Raffaello	11:50	00:15
Mechanisms	Claudia	12:05	00:15
Lunch break		12:20	01:00
Power	Hadrien	13:20	00:15
Thermal	Felix / Thierry	13:35	00:20
Structure	Alexander	13:55	00:15
Configuration	Sandra	14:10	00:15
Prgrammatics	Massimo	14:25	00:15
GS & Operations	Kate	14:40	00:15
Cost	Giorgio	14:55	00:15
Risk	Dietmar	15:10	00:15
System update	Friederike	15:25	00:10
Conclusions / Discussion	Jakob / all	15:35	00:20
End		15:55	

Study Team

Position	Team Member
Study Manager	Ludovic Puig
Study Responsible	Peter Falkner
Telescope Design Responsible	Isabel Escudero Sanz
Detectors	Pierre-Elie Crouzet
Payload Manager	Astrid Heske
Team Leader	Jakob Huesing
Systems	Friederike Beyer
Systems Support	Andrew Wolahan
AOCS	Fabrice Boquet
Communications	Andrea Modenini
Communications Support	Raffaello Lorenzo Mancini
Configuration	Sandra Mangunsong
Configuration Support	Nicola Clemencin
Structures	Alexander Ihle
Cost	Giorgio Cifani
Data Handling	Carlos Urbina Ortega
Ground Segment and Operations	Kate Symonds
Mechanisms	Claudia Allegranza
Mechanisms Support	Paolo Zaltron
Power	Hadrien Carbonnier
Programmatics / AIV	Massimo Braghin
Propulsion	Andreas Gernoth
Risk	Dietmar Wegner
Technical Author	Andrew Pickering
Thermal	Felix Beck
Thermal support	Daniel Winter
Cryogenics	Thierry Tirolien

Position	Consultants
OCDT	Hans-Peter de Koning
Optics	Dominic Doyle
Mission Analysis	Michael Khan
Ground Segment & Operations	Kate Symonds

ARIEL Background

- 6 session CDF study
- Requested by SRE-FM after M4 candidate selection (beside THOR and XIPE)
- Based on M3 candidate mission EChO
- PLM under payload consortium responsibility

Areas of focus

- Possibility to launch with a dedicated or dual launch in Ariane 6 or Soyuz from Kourou, as opposed to a Vega launch with the LPF propulsion module
- Thermal analysis to confirm the passive cooling capability, coupled with a structural analysis for the sizing of the SVM/PLM struts interface
- Confirmation of whether the AOCS requirements can be met with reaction wheels as the only actuators
- Possibility to re-use an existing small/medium size platform for the S/C SVM
- Overall payload / scientific performance optimisation, including noise and photometric stability budgets, observation efficiency budget, effective area, throughput and QE of the optics/ detector chain etc.

Schedule

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	
June	1	2	3	4	5	6	7	
	8	9	10	11	12	13	14	
	15 K/O	16	17	18 Session 2	19	20	21	
	22	23 Session 3	24	25 Session 4	26	27	28	
	29	30	1	2 Session 5	3	4	5	July
	6	7	8 IFP	9	10 IFP in TN	11	12	
	13	14	15 Report input due 1	16	17	18	19	
	20	21	22	23	24	25	26	
	27	28	29	30	31			

- Six morning sessions (9:30 – 13:30) and IFP (all day)
- Consortium participation in (nearly) all sessions
- Report due after one week on July 15th

Study products

- Internal Final Presentation handout
- Final Report * (Inputs due July 15th, 2015)
- Cost Report

* CDF standard Rules & Guidelines to be followed:
  - Use the report template prepared by Andy Pickering and available on the server (W:\ARIEL_Study\ARIELReport\Project Final Report Inputs)
  - Report shall be structured as reflected in the templates
  - Write the report directly online, i.e. work on the server
  - Delivery of the report inputs via email is NOT accepted

ARIEL

Systems

Session 6 – IFP
ESTEC, 8th July 2015

Prepared by the CDF* Team

(*) ESTEC Concurrent Design Facility

Content

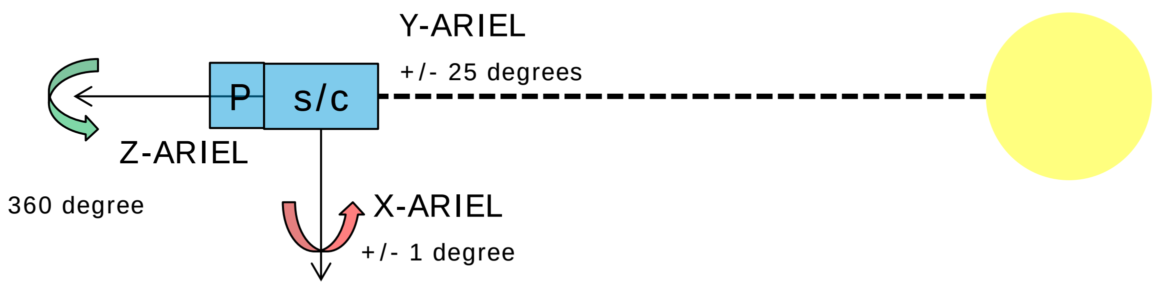
- Mission and System Requirements
- Design drivers
- Baseline description
- System Level Trade-offs
  - Orbit insertion and Launcher Selection & Overview
- Subsystem Level Trade-offs
- Mission Phases
- System Modes
- Budgets
  - Power Duty Cycle
  - Delta-v Budget
  - Mass Budget
  - Observation Efficiency Budget

Mission and System Requirements

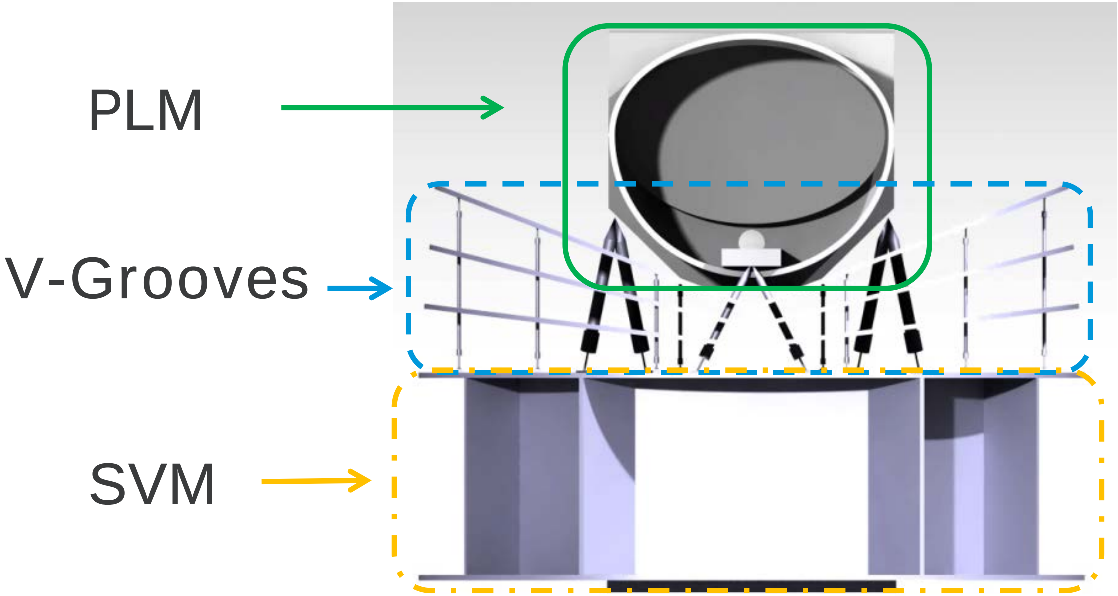
- Launcher: The satellite shall be compatible with a launch with Ariane 62. Three back-up options considered: Shared Ariane 64/62 or Soyuz dedicated.
- Launch Date: The ARIEL mission shall be compatible with a launch in 2026.
- Operational orbit: The science operations orbit shall be an **eclipse-free** (Earth and Moon) orbit around the **Sun-Earth L2** point, with an amplitude of TBC.
- Observation Efficiency: The overall observation efficiency shall be >85%.
- Reliability: The overall reliability of the mission until EOL of the nominal lifetime shall be ≥ 85%.
- Cost: The ESA CaC for the ARIEL mission shall be ≤ 450 MEur (2014 e.c.)
- Equipment TRL: All equipment shall be TRL 6 (new ISO scale) by the end of the definition phase (Phase A/B1).
- Operations: The mission shall be compatible with 4 years nominal operational lifetime with an extended science operations phase of 2 years.

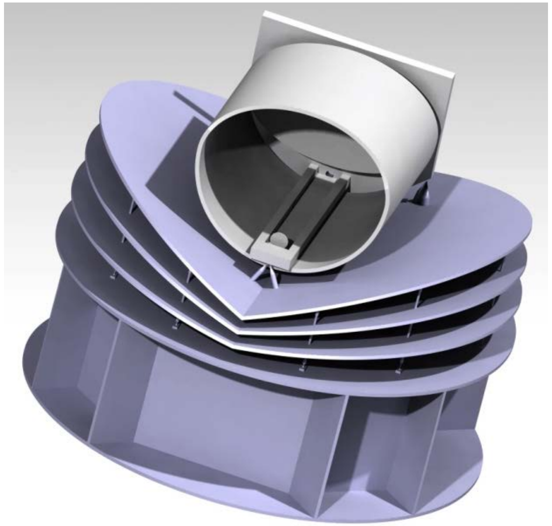
Design Drivers

- The **mass** including all margins should be <1000kg.
- With the exception of the LEOP, the spacecraft should be **eclipse free**.
- GS & Ops: MOC at ESOC, SOC at ESAC, European ground stations
- Payload: Cooling, 11.5 Gbit/day
- Assumption: Upper stage to provide the burn required for the high thrust manoeuvre to L2.
- In order to avoid sunlight the following observation constraints are considered:



Baseline Description Spacecraft





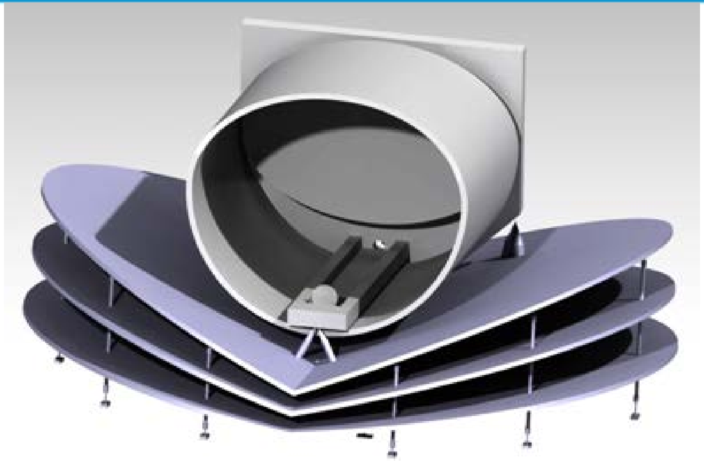
Baseline Description PLM

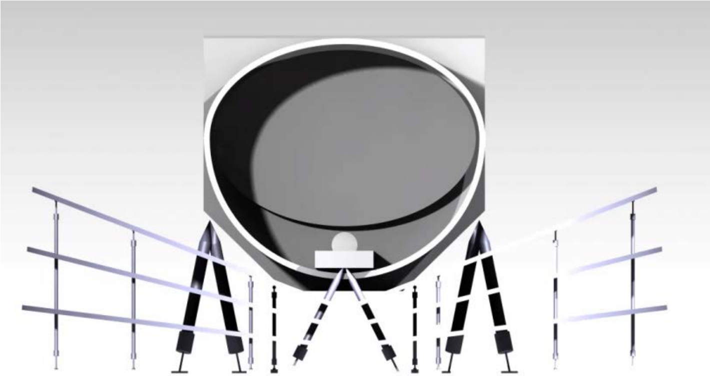
Payload Characteristics:

- Data Rate 11.5 Gbits/day
- Mass: 189kg
- Power: ≈65W during operations

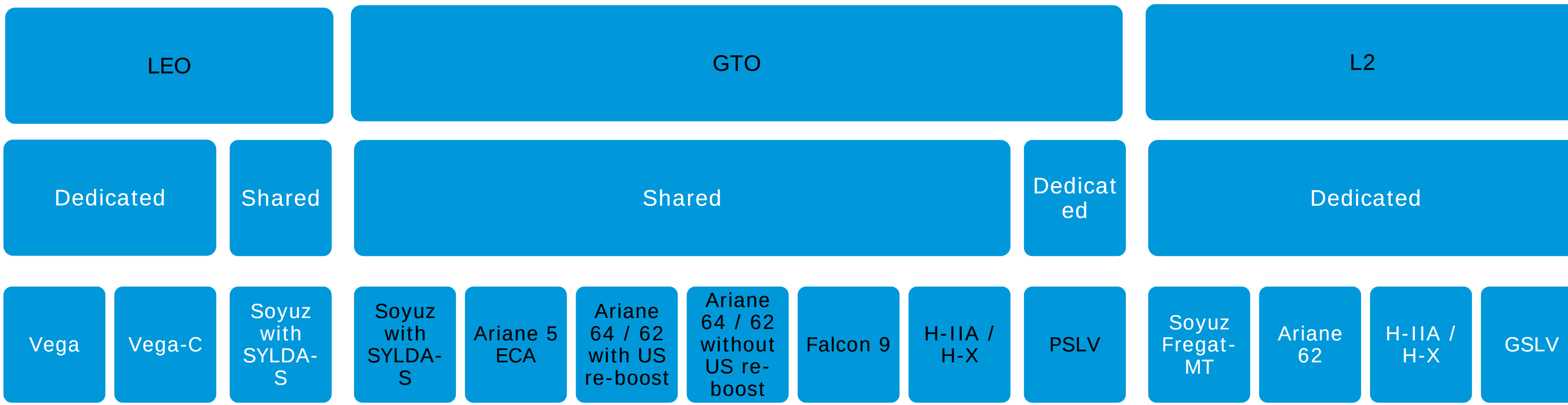
Component Description:

- Afocal 3-mirror off-axis **telescope** with elliptical M1: ~1.1 m x 0.7 m
  - Operating temperature: <70 K
- **NIR Spectrometer** operating between 1.95 µm and 7.8 µm
  - Operating temperatures: detectors: ≤42 K, optics: ≤50 K, FEE: ≤55 K
- **VIS-NIR Photometer / Fine-Guidance System** (FGS)
  - Operating temperatures: detectors and optics: ≤50 K, FEE: ≤55 K





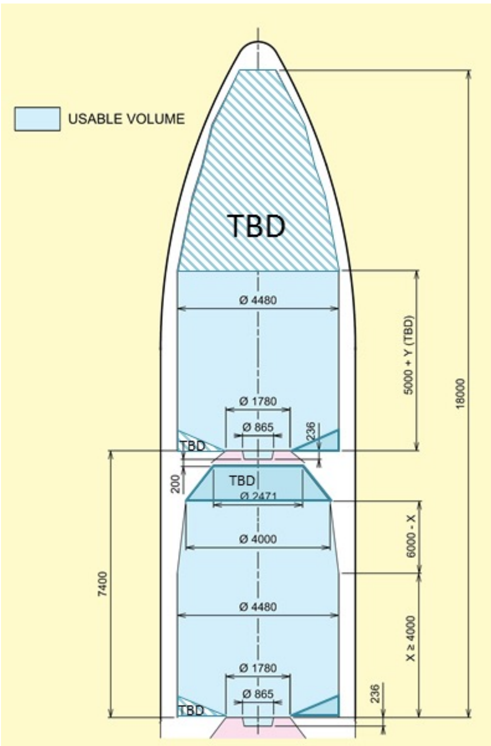
System Level Trade-off - Launcher Selection



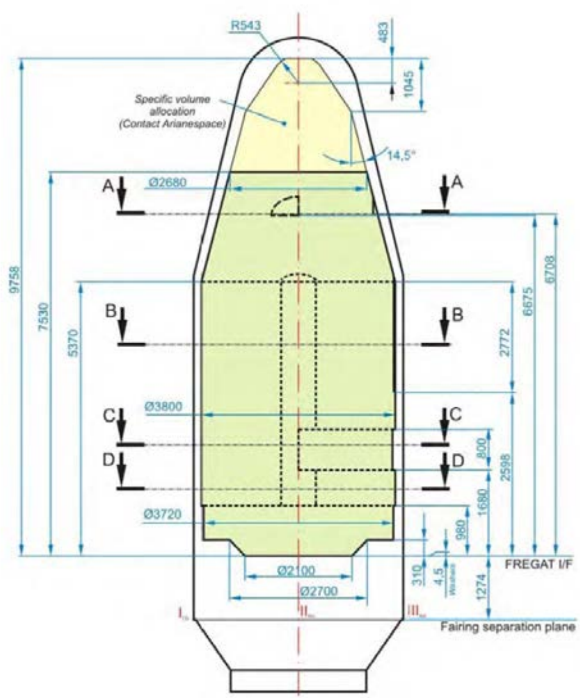
Trade-off criteria: Launch cost, Availability, SVM propellant mass, Available mass and volume, ITAR restrictions, European launcher, Radiation belt crossing, Sun Illumination during Transfer, Heritage

ARIEL baseline: Dedicated launch to L2 with Ariane 62 from Kourou
ARIEL backup 1: Shared launch to GTO with Ariane 64 or 62 from Kourou
ARIEL backup 2: Dedicated launch to L2 with Soyuz Fregat-MT from Kourou

Launcher constraints



Ariane 6
dual launch adapter



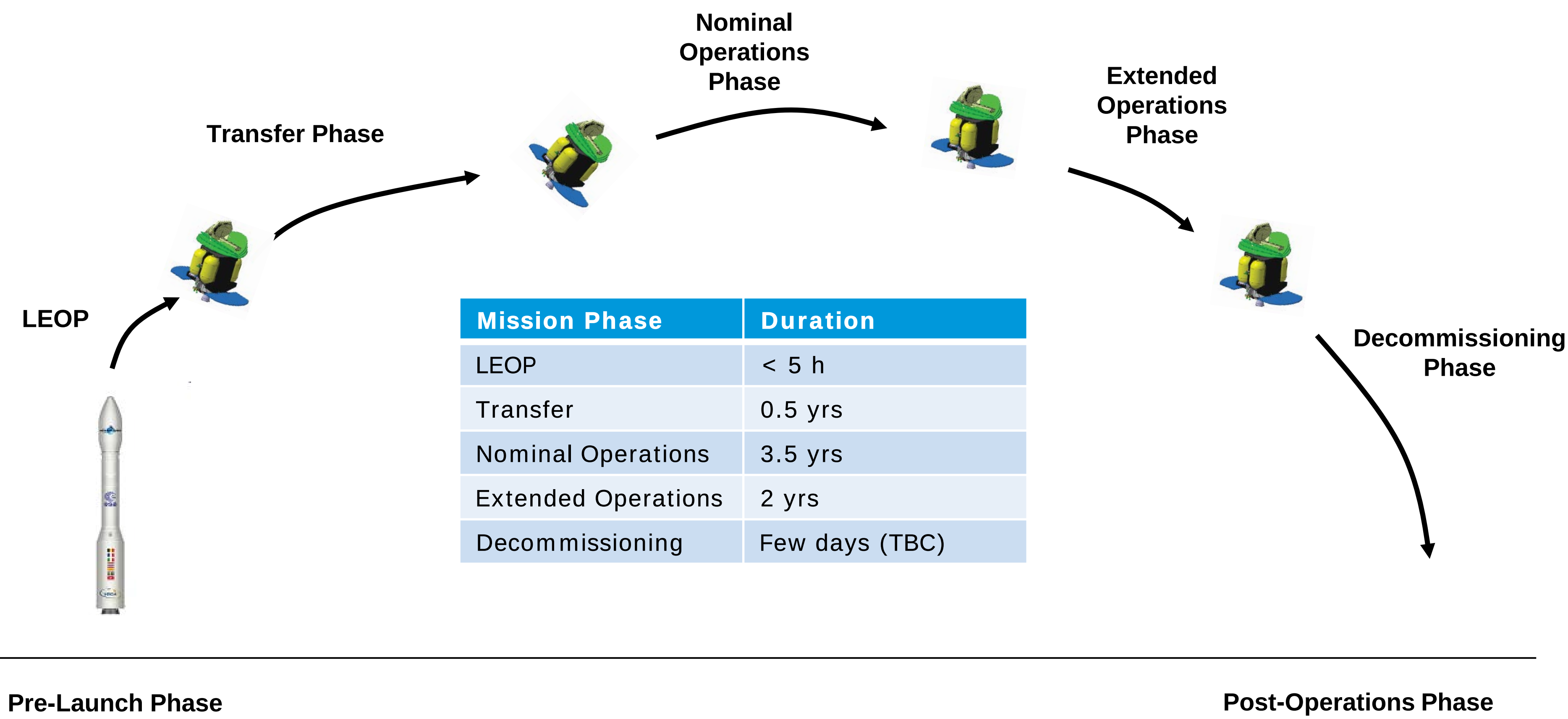
Soyuz ST

- Among the selected launcher options, Soyuz is most constraining w.r.t. available volume and mass
- Net performance to GTO:
  - Soyuz: 3.25 t
  - Ariane 62: 5 t
  - Araene 64: 9.5 t
- ARIEL spacecraft designed to be compliant to worst case

Sub-System Level Trade-Offs

AOGNC	Reaction Wheels vs. Cold Gas Thrusters	Thruster Configuration
DHS	Separated Vs. Integrated RTU	Separated Vs. Integrated Mass Memory
Structures	Structural Baffle Vs. Metering Structure Vs. Truss Structure	
Propulsion	Hydrazine Vs. Green Propellant	1N vs. 20 N thrusters
Power	Regulated Vs. Unregulated	Maximum Power Point Tracking Vs. Sequential Shunt Switching Regulator
TCS	Payload Cooling: Active Vs. Passive Vs. Mixed Cooling	Detector Harness Routing
Communications	Medium Gain Antenna Vs. High Gain Antenna	
Mechanisms	M2 refocusing mechanism: Gaia M2M vs. Euclid M2M vs. JWST vs. EChO-SPICA	Optional tip tilt mechanism

Mission Phases & Durations



Mission Phase	Duration
LEOP	< 5 h
Transfer	0.5 yrs
Nominal Operations	3.5 yrs
Extended Operations	2 yrs
Decommissioning	Few days (TBC)

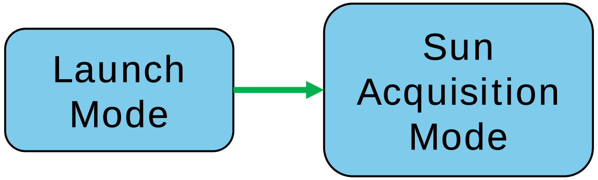
System Modes

Launch Mode

Launch Mode (LM)

- From launch until launch vehicle separation
- S/C in launch configuration
- All equipment and instruments are OFF, except for RTU and receiver
- S/C powered by battery
- Duration: 90 min

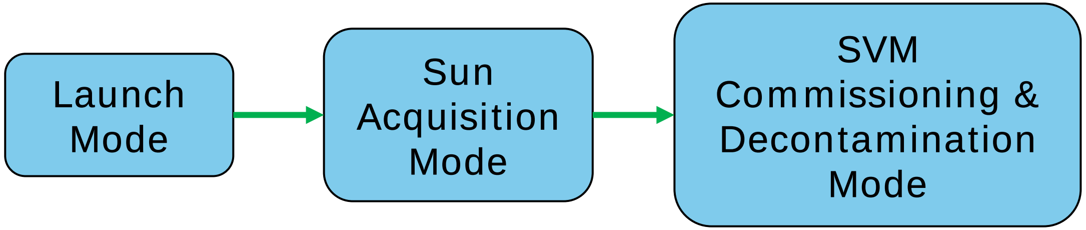
System Modes



Sun Acquisition Mode (SAM)

- Coarse gyro and sun sensor are ON
- Sun acquisition is achieved with small thrusters
- Comms and DHS equipment is ON
- Duration: <3.5 h

System Modes



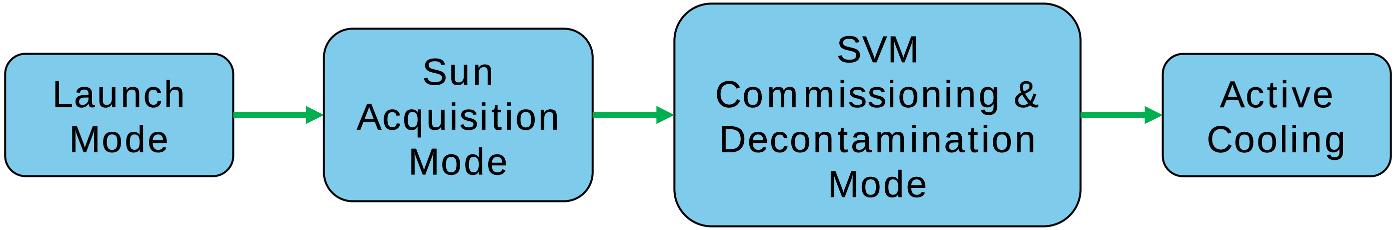
Service Module Commissioning and Decontamination Mode (SCDM)

- Each SVM subsystem is turned On sequentially for P/F check-out
- Passive cooling and decontamination of optics until 150 K are reached
- Communication with Earth: 8 h out of 24 h, while Rx is always ON
- Thrusting possible
- Slews possible
- Duration: 3 months

Service Module Commissioning and Decontamination Peak Power Mode (SCDMP)

- Peak power draw during SCDM
- Duration: 8 h
- Comms ON, DHS ON, thrusters are being heated
- RWs ON, STR ON, fine gyro ON
- Decontamination heater is ON
- Instruments and active coolers still OFF

System Modes



Active Cooling Mode (ACM)

- SVM completely ON
- Actively cooling but instruments still OFF
- Communication and thrusting (station keeping or RW off-loading) possible
- Attitude kept w.r.t. stars, i.e. STR, RWs and fine gyro ON

System Modes

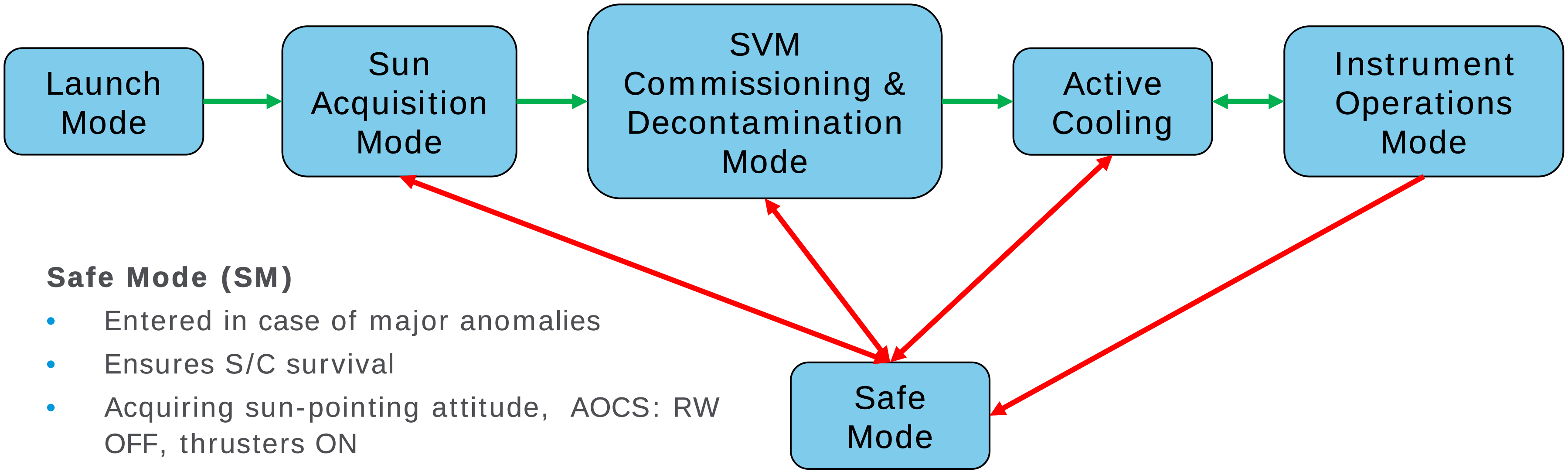
Instrument Operations Mode (IOM)

- Includes the instrument performance verification at the beginning of the mission
- After IPV: instruments ON, cryocooler ON
- Comms possible for 4h out of 48 h
- Thrusting possible
- Slews possible, AOCS with STR, RWs and fine gyro
- I/F heater for 50% ON
- Duration: 3 months IPV + 5.5 yrs nominal ops

Instrument Operations with Communications Mode (IOCM)

- IOM with Comms
- Duration: 4 h
- Thrusters being heated but not thrusting
- RWs ON
- I/F heater ON

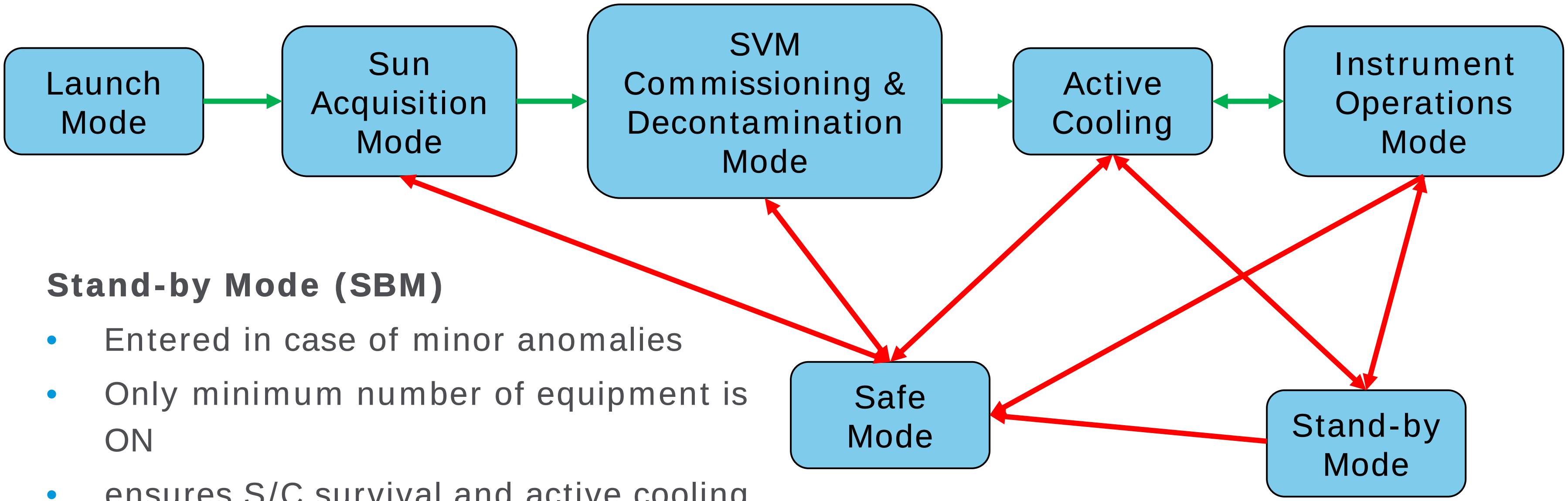
System Modes



Safe Mode (SM)

- Entered in case of major anomalies
- Ensures S/C survival
- Acquiring sun-pointing attitude, AOCS: RW OFF, thrusters ON
- Only minimum number of units ON (thermal management, AOCS, minimum comms), non-essential eqt is off,
- Communication possible
- Duration: 3 events à 2 days/year + recovery

System Modes



Stand-by Mode (SBM)

- Entered in case of minor anomalies
- Only minimum number of equipment is ON
- ensures S/C survival and active cooling
- Communication with Earth possible, AOCS: RW ON, thrusters OFF.
- Duration: same as for Safe Mode

Delta-V Budget

	ARIEL Delta-v Budget	Baseline: Dedicated launch to L2 - Ariane 62	Back-up 1: Shared launch to GTO - Ariane 64/62	Back-up 2: Dedicated launch to L2 - Soyuz	Unit	Comment
TCM#1	**Launch dispersion correction manoeuvre (stochastic)**	45	80	31.2	m/s	A62 to L2: Herschel CReMA (Ariane 5 ECA), spherical thrust capability Shared A64/62 to GTO: Assuming entirely pre-programmed upper stage burn (800 m/s) and no time or manoeuvre size correction based on orbit determination after the first insertion into GTO [MK] Soyuz to L2: EChO CReMA
	Perigee velocity correction manoeuvre (deterministic)	26	13.5		m/s	GTO: EChO: 13.5 m/s [ADS & TAS budget reports]
TCM#2	**Correction of TCM#1 (stochastic)**	3	3	2	m/s	
TCM#3	**Correction of TCM#2 (stochastic)**	2	2	0.1	m/s	
	Margin on stochasitic delta-v	0	0	0	%	Margin philosophy for science assessment studies, SRE-PA/2011.097/ iss. 2 rev. 0
	Margin on deterministic delta-v	5	5	5	%	
	Nominal lifetime	4	4	4	yrs	
	Extended lifetime	2	2	2	yrs	
	Orbit maintenance per year	8.5	8.5	8.5	m/s/yr	EChO CReMA: 8.5 m/s per year for biased trajectory
	Orbit maintenance	51	51	51	m/s	
	Margin on orbit maintenance delta-v	5	5	5	%	SRE-PA/2011.097/ iss. 2 rev. 0 due to EChO reference
	Disposal	15	15	15	m/s	
	RW offloading and safe mode recovery				m/s	25 kg AOCS propellant (6 kg for RW off-loading + 18 kg for safe mode recovery + 1 kg first sun acquisition) safe mode recovery: 0.5 kg x 2 days x 3 times per year x 6 years
	Margin on AOCS delta-v	100	100	100	%	SRE-PA/2011.097/ iss. 2 rev. 0
	Total without margin	**142.0**	**164.5**	**99.3**	**m/s**	
	Total incl. margin on MA delta-v	**145.9**	**167.7**	**101.9**	**m/s**	

Mass Budget SVM
- status: post IFP and power update (28.7.2015)

Row Labels	Mass (kg)	Mass margin (%)	Mass incl. margin (kg)
INS	**17.50**	**20**	**21.00**
fgs_wu (FGS Warm Unit)	7.00	20	8.40
icu (Instrument Warm Unit)	10.50	20	12.60
MEC	**4.00**	**20**	**4.80**
ADPM_EB (Antenna Deployment and Pointing Mechanism with Electronics Box)	4.00	20	4.80
STR	**176.93**	**0**	**176.93**
BOT (Bottom_Plate)	24.83	0	24.83
CONE (Central_Cone)	18.13	0	18.13
LIR (Launcher_Interface_Ring)	33.48	0	33.48
MISCS (Brackets_Misc_SVM)	23.91	0	23.91
OSTR (Octogonal_Structure)	29.82	0	29.82
SHPA (Shear_Pannels)	21.84	0	21.84
TOP (Top_Plate)	19.60	0	19.60
TSTR (Tank_Support_Structure)	5.32	0	5.32
TC	**39.50**	**19**	**47.03**
CryoCooler (Cryo Cooler)	10.00	20	12.00
CDE (Cryo Drive Electronics)	2.00	20	2.40
SVM_TCS_MISC (SVM TCS MISC)	25.00	20	30.00
IF_HTR (Interface Heater)	1.25	5	1.31
SURV_HTR (Survival Heater)	1.25	5	1.31
AOGNC	**57.35**	**6**	**60.53**
AAD (Attitude Anomaly Detector)	0.20	5	0.21
RW_RDR68_3_1 (RW Rockwell Collins RDR 68-3 1)	8.90	5	9.35
RW_RDR68_3_2 (RW Rockwell Collins RDR 68-3 2)	8.90	5	9.35
RW_RDR68_3_3 (RW Rockwell Collins RDR 68-3 3)	8.90	5	9.35
RW_RDR68_3_4 (RW Rockwell Collins RDR 68-3 4)	8.90	5	9.35
GYRO_Airbus_Astrix_200 (GYRO Airbus Astrix 200)	9.50	5	9.98
GYRO_Sireus_1 (GYRO Selex Galileo Sireus 1)	0.80	5	0.84
GYRO_Sireus_2 (GYRO Selex Galileo Sireus 2)	0.80	5	0.84
STR_HydraEU_1 (STR Sodern Hydra Electronics Unit 1)	1.85	5	1.94
STR_HydraEU_2 (STR Sodern Hydra Electronics Unit 2)	1.85	5	1.94
STR_HydraOH_1 (STR Sodern Hydra Optical Head 1)	1.25	10	1.38
STR_HydraOH_2 (STR Sodern Hydra Optical Head 2)	1.25	10	1.38
STR_HydraOH_3 (STR Sodern Hydra Optical Head 3)	1.25	10	1.38
SUN_BradTNO_FSS_1 (SUN Bradford TNO Fine Sun Sensor 1)	1.50	9	1.64
SUN_BradTNO_FSS_2 (SUN Bradford TNO Fine Sun Sensor 2)	1.50	9	1.64
PWR	**26.20**	**13**	**29.50**
Bat (Battery_general)	4.40	10	4.84
PCDU (Power Conditioning & Distribution Unit)	15.00	10	16.50
SA (SolarArray)	6.80	20	8.16
COM	**19.58**	**10**	**21.55**
MGA (Medium Gain Antenna)	0.68	5	0.71
RFDU_Rover (Radio Frequency Distribution Unit (Rover))	5.00	20	6.00
LGA_LHCP (Low Gain Antenna (LHCP))	0.95	5	1.00
LGA_RHCP (Low Gain Antenna (RHCP))	0.95	5	1.00
EPC_Nominal (Electronic Power Conditioning (Nominal))	1.40	10	1.54
EPC_Redundant (Electronic Power Conditioning (Redundant))	1.40	10	1.54
TWT_Nominal (Traveling Wave Tube (Nominal))	1.00	10	1.10
TWT_Redundant (Traveling Wave Tube (Redundant))	1.00	10	1.10
XPND_Nominal (Transponder Nominal)	3.60	5	3.78
XPND_Redundant (Transponder Redundant)	3.60	5	3.78

Row Labels	Mass (kg)	Mass margin (%)	Mass incl. margin (kg)
CPROP	**33.27**	**7**	**35.68**
Feed_Lines_ARIEL (Feed_Lines_ARIEL)	5.00	20	6.00
Fill_Drain_Valve_Pressurant_ARIEL (Fill_Drain_Valve_Pressurant_ARIEL)	0.05	5	0.05
Pressure_transducer_ARIEL_1 (Pressure_transducer_ARIEL)	0.22	5	0.23
Pressure_transducer_ARIEL_2 (Pressure_transducer_ARIEL)	0.22	5	0.23
Pressure_transducer_ARIEL_3 (Pressure_transducer_ARIEL)	0.22	5	0.23
Latch_Valve_ARIEL_1 (Latch_Valve_ARIEL)	0.55	5	0.58
Latch_Valve_ARIEL_2 (Latch_Valve_ARIEL)	0.55	5	0.58
Latch_Valve_ARIEL_3 (Latch_Valve_ARIEL)	0.55	5	0.58
Latch_Valve_ARIEL_4 (Latch_Valve_ARIEL)	0.55	5	0.58
Small_thruster_ARIEL_01 (Small_thruster_ARIEL)	0.29	5	0.30
Small_thruster_ARIEL_02 (Small_thruster_ARIEL)	0.29	5	0.30
Small_thruster_ARIEL_03 (Small_thruster_ARIEL)	0.29	5	0.30
Small_thruster_ARIEL_04 (Small_thruster_ARIEL)	0.29	5	0.30
Small_thruster_ARIEL_05 (Small_thruster_ARIEL)	0.29	5	0.30
Small_thruster_ARIEL_06 (Small_thruster_ARIEL)	0.29	5	0.30
Small_thruster_ARIEL_07 (Small_thruster_ARIEL)	0.29	5	0.30
Small_thruster_ARIEL_08 (Small_thruster_ARIEL)	0.29	5	0.30
Small_thruster_ARIEL_09 (Small_thruster_ARIEL)	0.29	5	0.30
Small_thruster_ARIEL_10 (Small_thruster_ARIEL)	0.29	5	0.30
Small_thruster_ARIEL_11 (Small_thruster_ARIEL)	0.29	5	0.30
Small_thruster_ARIEL_12 (Small_thruster_ARIEL)	0.29	5	0.30
Small_thruster_ARIEL_13 (Small_thruster_ARIEL)	0.29	5	0.30
Small_thruster_ARIEL_14 (Small_thruster_ARIEL)	0.29	5	0.30
Small_thruster_ARIEL_15 (Small_thruster_ARIEL)	0.29	5	0.30
Small_thruster_ARIEL_16 (Small_thruster_ARIEL)	0.29	5	0.30
Passivation_System_ARIEL_1 (Passivation_System_ARIEL)	0.55	5	0.58
Passivation_System_ARIEL_2 (Passivation_System_ARIEL)	0.55	5	0.58
Propellant_Tank_ARIEL (Propellant_Tank_ARIEL)	15.50	5	16.28
Large_Thruster_ARIEL_1 (Large_Thruster_ARIEL)	0.39	5	0.41
Large_Thruster_ARIEL_2 (Large_Thruster_ARIEL)	0.39	5	0.41
Pressure_transducer_ARIEL_4 (Pressure_transducer_ARIEL)	0.22	5	0.23
Pressure_transducer_ARIEL_5 (Pressure_transducer_ARIEL)	0.22	5	0.23
Pressure_transducer_ARIEL_6 (Pressure_transducer_ARIEL)	0.22	5	0.23
Fill_Drain_Valve_Propellant_ARIEL_1 (Fill_Drain_Valve_Propellant_ARIEL)	0.05	5	0.05
Fill_Drain_Valve_Propellant_ARIEL_2 (Fill_Drain_Valve_Propellant_ARIEL)	0.05	5	0.05
Fill_Drain_Valve_Propellant_ARIEL_3 (Fill_Drain_Valve_Propellant_ARIEL)	0.05	5	0.05
Fill_Drain_Valve_Propellant_ARIEL_4 (Fill_Drain_Valve_Propellant_ARIEL)	0.05	5	0.05
Fill_Drain_Valve_Propellant_ARIEL_5 (Fill_Drain_Valve_Propellant_ARIEL)	0.05	5	0.05
Propellant_Filter_ARIEL (Propellant_Filter_ARIEL)	0.11	5	0.12
Large_Thruster_ARIEL_3 (Large_Thruster_ARIEL)	0.39	5	0.41
Large_Thruster_ARIEL_4 (Large_Thruster_ARIEL)	0.39	5	0.41
Large_Thruster_ARIEL_5 (Large_Thruster_ARIEL)	0.39	5	0.41
Large_Thruster_ARIEL_6 (Large_Thruster_ARIEL)	0.39	5	0.41
Large_Thruster_ARIEL_7 (Large_Thruster_ARIEL)	0.39	5	0.41
Large_Thruster_ARIEL_8 (Large_Thruster_ARIEL)	0.39	5	0.41
DH	**18.00**	**20**	**21.60**
OBC (On-Board Computer with Mass Memory)	6.00	20	7.20
uRTU (Remote Terminal Unit)	12.00	20	14.40

Mass Budget PLM
- status: post IFP and power update (28.7.2015)

Row Labels	Mass (kg)	Mass margin (%)	Mass incl. margin (kg)
INS	**47.80**	**20**	**57.36**
com_opt (Common Optics and Cal unit)	2.00	20	2.40
fgs (FGS Phot unit)	4.00	20	4.80
spectro (Spectrometer Optics Unit)	6.00	20	7.20
tel_sic (Telescope SiC)	29.50	20	35.40
cry_har (Cryo Harness)	6.30	20	7.56
MEC	**8.00**	**20**	**9.60**
M2M (M2 Pointing Mechanism)	8.00	20	9.60
STR	**175.85**	**0**	**175.85**
BAF (Baffle)	20.11	0	20.11
BIP (Telescope_Support_Bipods)	5.14	0	5.14
IHO (Instruments_Housing)	3.74	0	3.74
MET (Metering_Structure)	9.45	0	9.45
MISCP (Brackets_Misc_PLM)	29.31	0	29.31
TOB (Telescope_Optical_Bench)	32.29	0	32.29
VGRO (V-Grooves)	72.22	0	72.22
VINT (V-Grooves_Struts_Interfaces)	2.86	0	2.86
VSTR (V-Grooves_Support_Struts)	0.73	0	0.73
TC	**14.50**	**17.41**	**17.03**
DeconHeater (Decon HTR)	2.50	5	2.63
PLM_TCS_MISC (PLM TCS MISC)	12.00	20	14.40

Mass Budget S/C level
- status: post IFP and power update (28.7.2015)

Mass Budget SVM	Switch	Mass (kg)
INS	Product	21.00
MEC	Product	4.80
STR	Product	176.93
TC	Product	47.03
AOGNC	Product	60.53
PWR	Product	29.50
COM	Product	21.55
CPROP	Product	35.68
DH	Product	21.60
Harness	5%	20.93
Total Dry SVM		**439.54**

Mass Budget PLM	Switch	Mass (kg)
INS	Product	57.36
MEC	Product	9.60
STR	Product	175.85
TC	Product	17.03
Harness	5%	12.99
Total Dry PLM		**272.83**

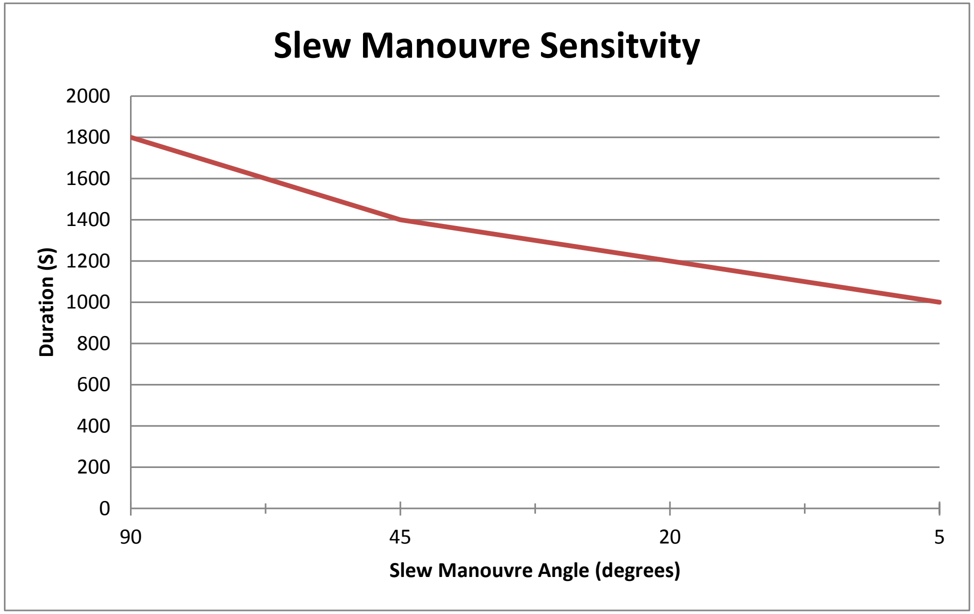
Mass Budget S/C		Mass (kg)
Total Dry SVM		439.54
Total Dry PLM		272.83
System Margin	20%	142.47
Total Dry Mass S/C		854.84
Propellant Mass		140.01
Propellant Margin	2%	2.80
Total Wet Mass S/C		**997.66**
Launcher Adapter		115.00
Total Launch Mass		**1112.66**

Observation Budget

esa

Action	Duration	hours/year	Potential for Reduction
One year in hours		8766	
Safe Mode	3 per year at 2 days each	144	
Reaction Wheel off loading	negligble	0	
Orbit Maintenance (slew(FGS)-thrust(s.t.) manouvre/stabilisation - slew (FGS))	4 hours per manouvre, 1 manouvre per month	48	●
Instrument callibration	N/A	0	
Reaction Wheel Torque Spikes	(1.3%) of operational time (excl. safe modes)	112.086	●
Time available for observations		8461.914	
Fraction of a year for observations and science target acquisition (%)		**0.965310746**	
Observation time	3.7 hours per observation		
Time for slew manouvre for target acquisition	20 minutes		●
Total time per observation	4.03 per target		
Number of observations	time available / total time per observation	2099.730521	
Observation time	average observation time * number of observations	7769.002928	
Observation Efficiency (%)		**0.886265449**	

Observation Budget - Slew Manoeuvre Sensitivity



Duration includes:

- Slew manouvre
- Damping
- Kalman Filtering

Angle (deg	Duration (s)
90	1800
45	1400
20	1200
5	1000

ARIEL

Mission Analysis

Internal Final Presentation
ESTEC, 8th July 2015

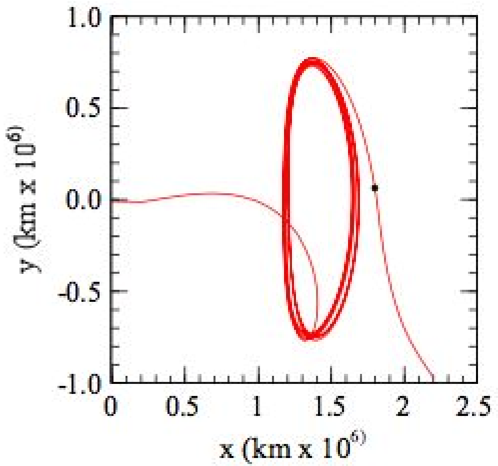
Prepared by the CDF* Team

(*) ESTEC Concurrent Design Facility

Requirements and Assumptions

- Operational Orbit about the Sun-Earth Libration Point 2 (SEL2)
  - Eclipse-free
- Launch scenarios
  - Baseline: Direct launch with Ariane 6.2
  - Backup 1: Shared Launch with Ariane 6.2 or 6.4 into GTO, injection to L1
  - Backup 2: Direct Launch with Soyuz-Fregat

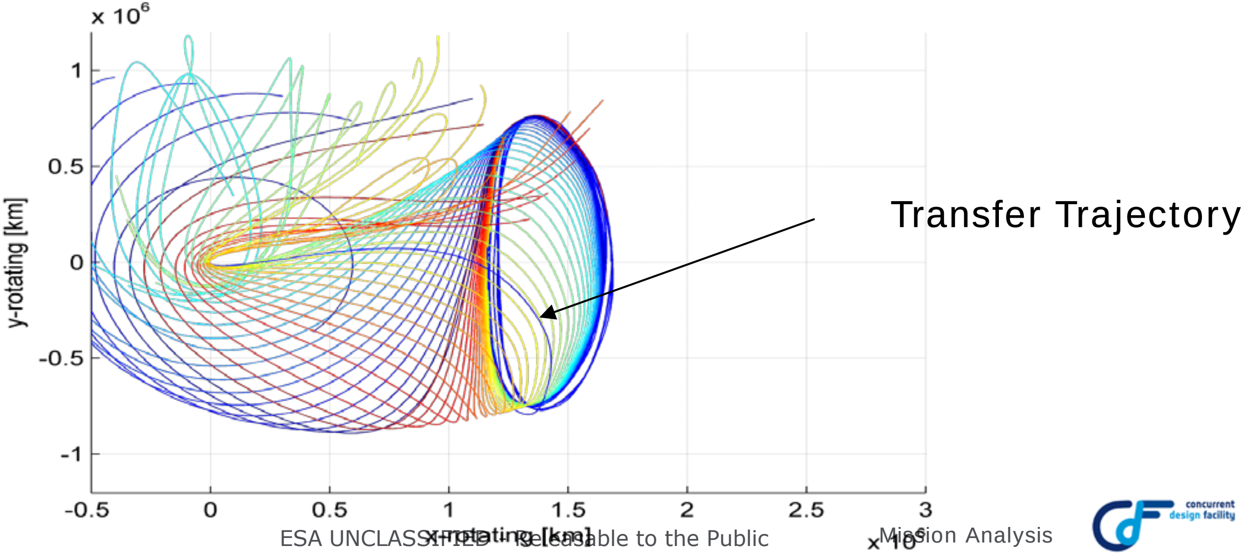
Target Operational Orbit



- Large quasi-Halo orbit (like Herschel)
  - Permanently eclipse free
  - Sun-spacecraft-Earth angle can be up to almost 30 deg
- Position variations
  - in x-direction (in Sun-Earth line): 1.1 – 1.7 E6 km
  - in y direction (in ecliptic plane): +/- 800,000 km
  - In z-direction (normal to ecliptic): +/- 400,000 km
- Maximum Sun-Spacecraft-Earth angle: 30 deg
- Station keeping budget:
  - Depends on uncertainties: Low noise, accurate thrusters, absence of unplanned pointings, high predictability → annual s.k. budget down to ca. 2-3 m/s/year
  - Hemispherical thrust requires biased trajectory, stationkeeping delta- rises by factor of 2.

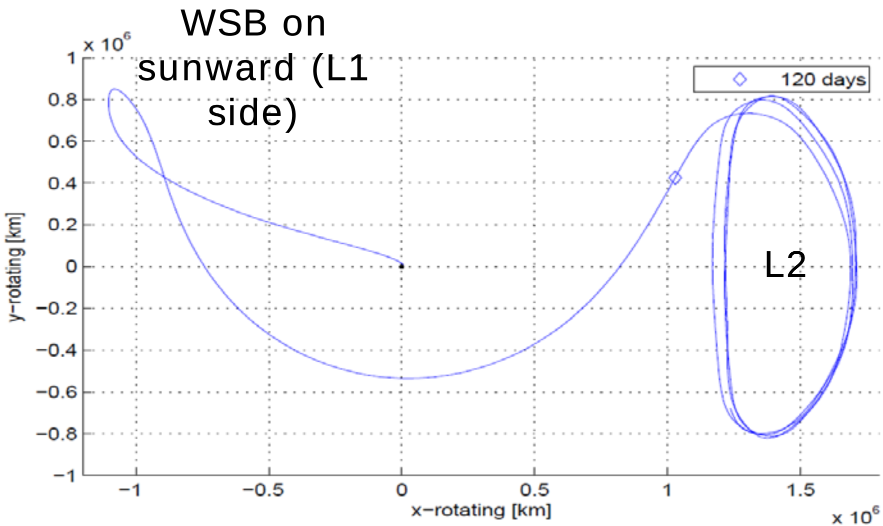
Transfer to Operational orbit

- Large Amplitude Libration Point Orbit
  - Sun-Earth-Libration Point 2 located about 1.5 Mio km from Earth away from the Sun
  - Stable manifold intersects with Earth
  - Free transfer – no insertion manoeuvre required



GTO shared launch

- Launches into GTO are highly standardized and usually around midnight, pointing the line of apses towards L1
- Added 800 m/s manoeuvre at 1st perigee will be required
  - To be performed by upper stage
  - Feasibility is TBD:
    - Soyuz: Fregat battery lifetime? TBD
    - Ariane 62: Cryogenic boil-off? TBD
- Added TCMs might be required
- All year launch window is TBD



Launcher performance issues

- Ariane 6.2:
  - Dedicated launch: at least 50% more than Soyuz-Fregat
- Ariane 6.2 or 6.4 shared launch into GTO:
  - Pending confirmation that second upper stage manoevre 11 hours after liftoff is feasible, data on cryogenic boil-off must be provided to assess payload mass
- Soyuz-Fregat:
  - Direct launch no constraints on SAA during ascent:
  - Launch via intermediate LEO as for PLATO: 2178 kg performance incl. adapter

ARIEL Payload Design:
CDF Study Final Presentations

Paul Eccleston

STFC – RAL Space

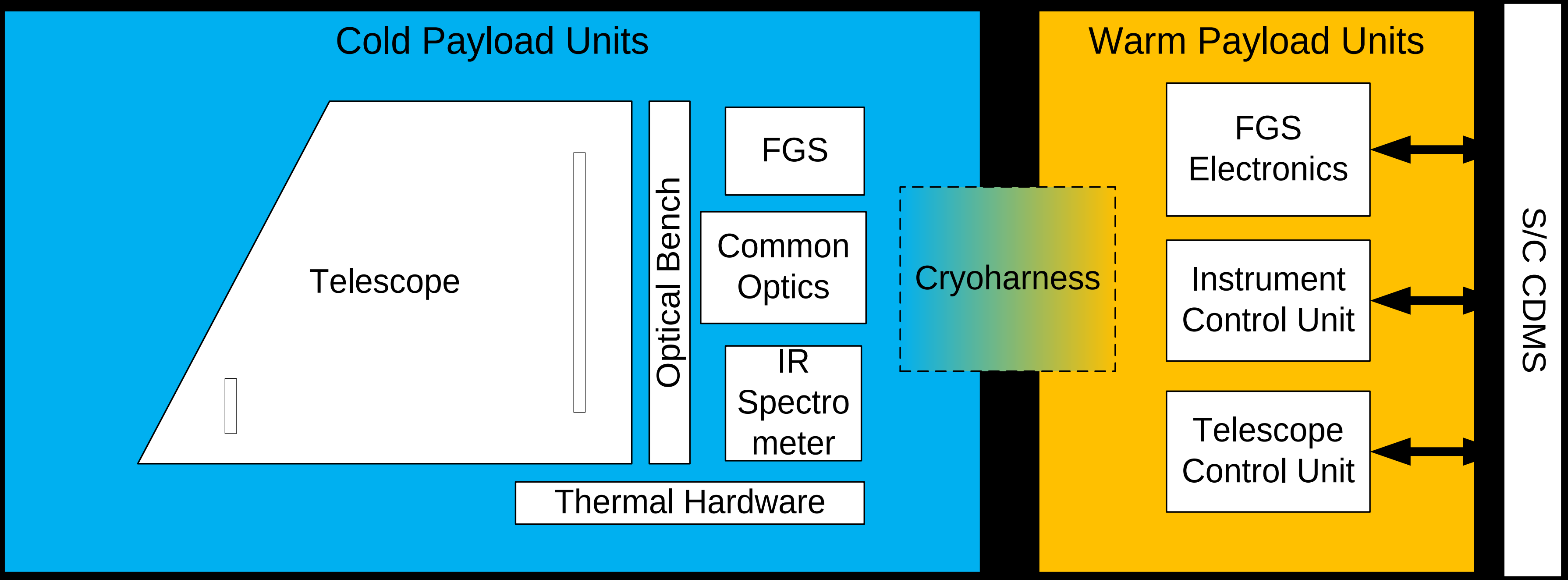
Introduction

- Overview of ARIEL payload design architecture and budgets
- Based largely on design proposed initially with updates as output from the work which has been happening in parrellel to the CDF
- Outline of the major resource budgets for the payload module from the consortium calculations
  - Intended to allow consistency checking with budgets generated by CDF experts

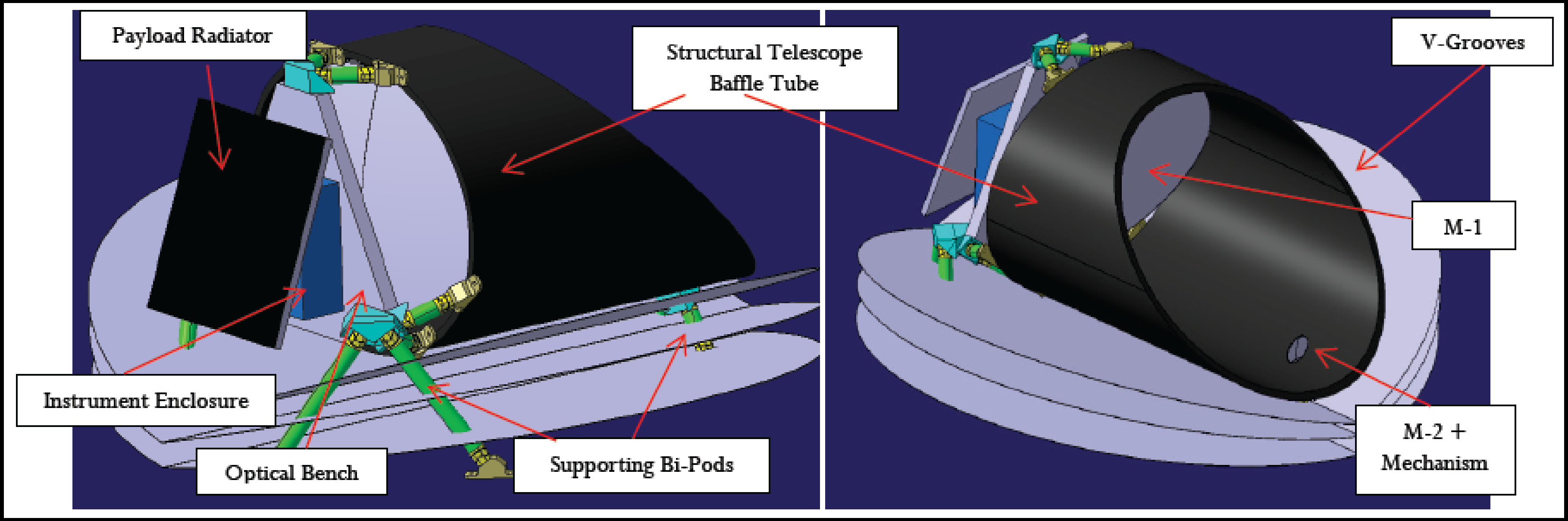
Payload Module Functions

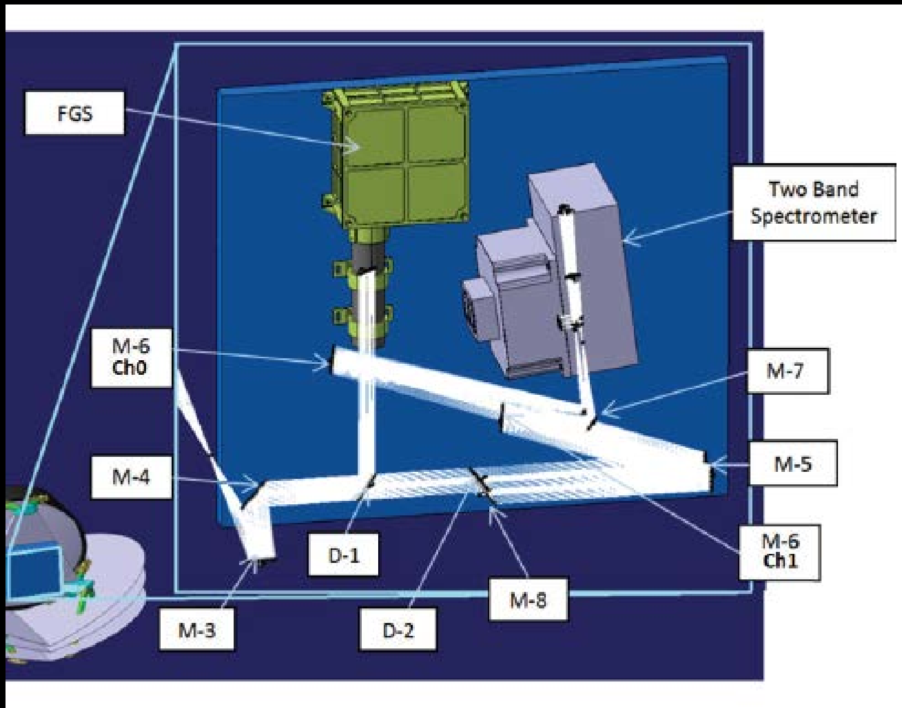
- Telescope (~1 meter class), passively cooled to <80K, diffraction limit at ~3 μm
- Single spectrometer module with dual optical chains providing R ~ 300 coverage from 1.95 – 7.8 microns (TBC) on single detector
- FGS system (redundant) which doubles as a NIR photometer for stellar variability monitoring
- Common optical bench and structure to support both the instrument boxes and the telescope primary mirror
- Thermal isolation from SVM via V-grooves and GFRP / CFRP struts and isolating cryo-harnesses.

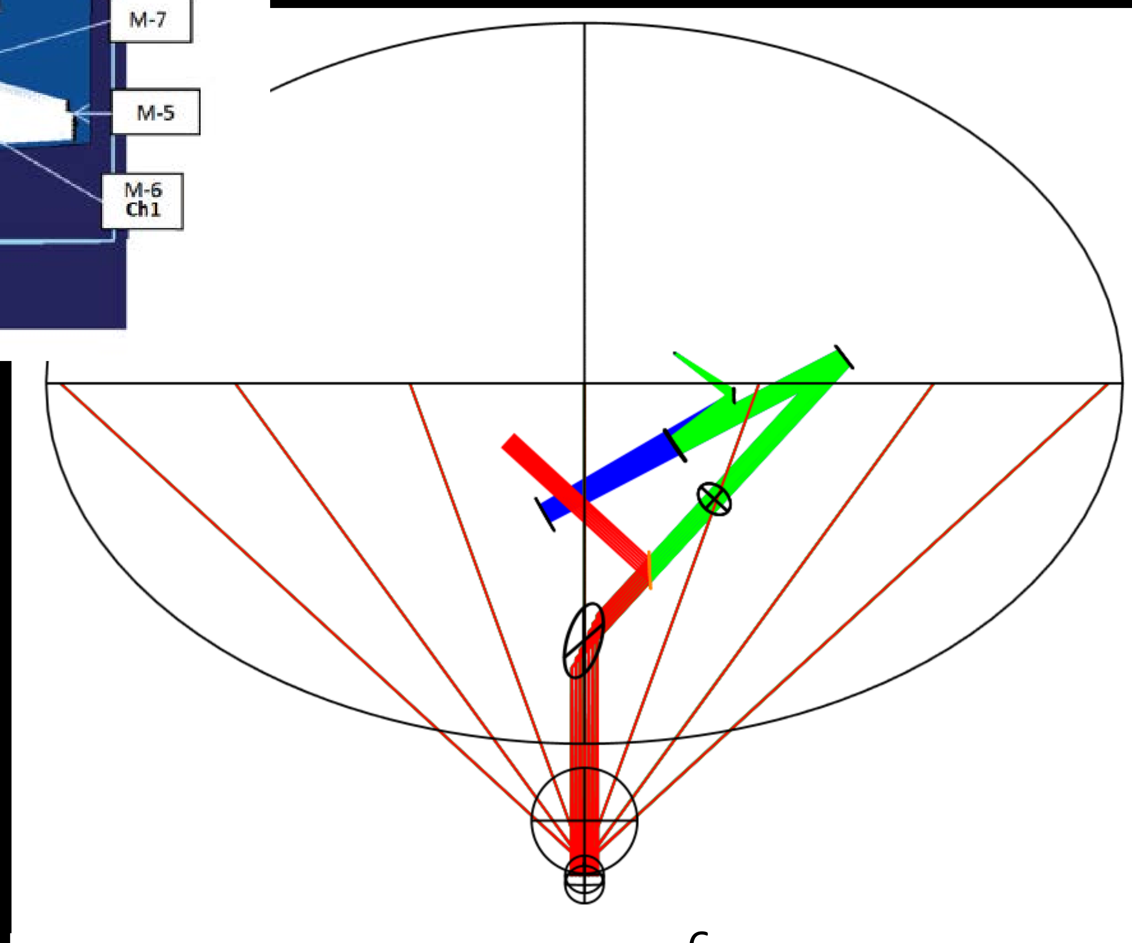
Architecture



Overview of Payload Module




FGS
Two Band Spectrometer
M-6 Ch0
M-7
M-5
M-4
D-1
M-6 Ch1
M-8
M-3
D-2

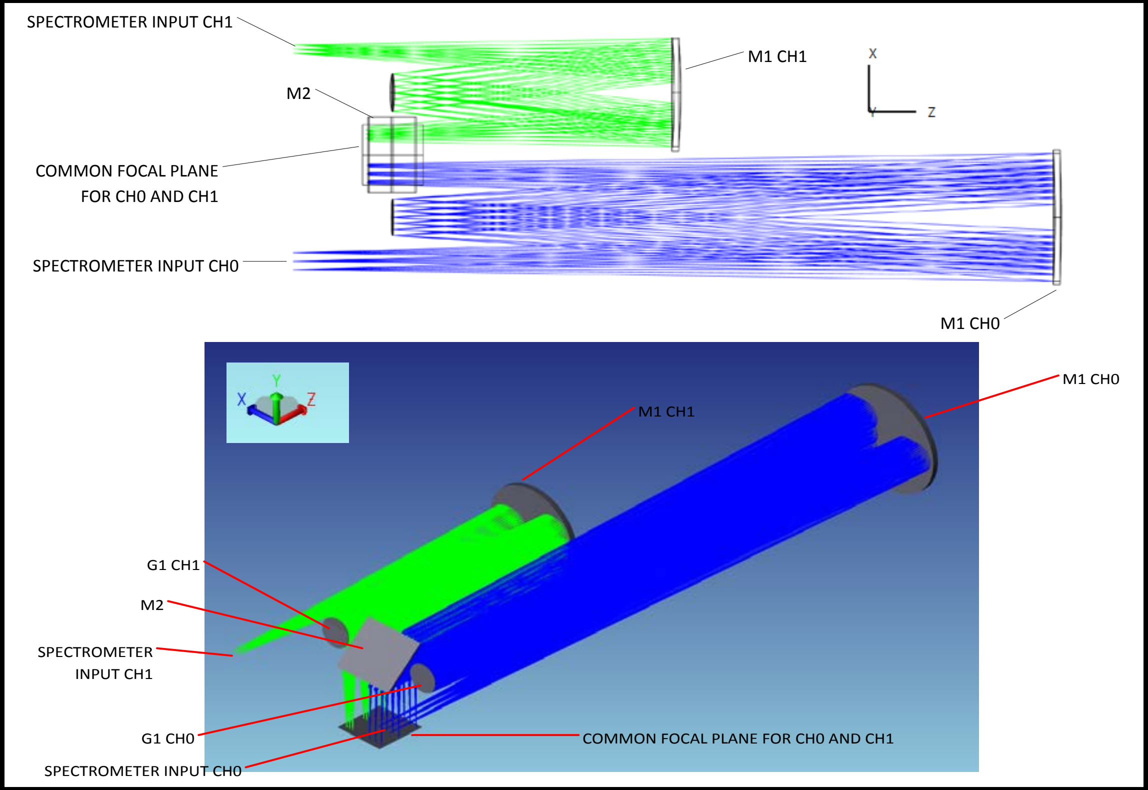


Telescope Parameters

Parameter	Ch0 (1.95-3.9m)	Ch1(3.9-7.8um)
Telescope f/number	f/13.4 (for 0.9 diameter circular aperture)	
Entrance pupil diameter	Elliptical, 1.1 m x 0.7 m (equivalent to 0.9 m circular)	
Plate scale at prime focus	58 um / arc sec	
Collimated beam diameter after M3	Elliptical, 22.2 mm x 14.5 mm	
f/no at spectrometer input	20.5	10.3
Space envelope (optics only)	1400 mm (z) x 950 mm (y) x 1200 mm (x)	

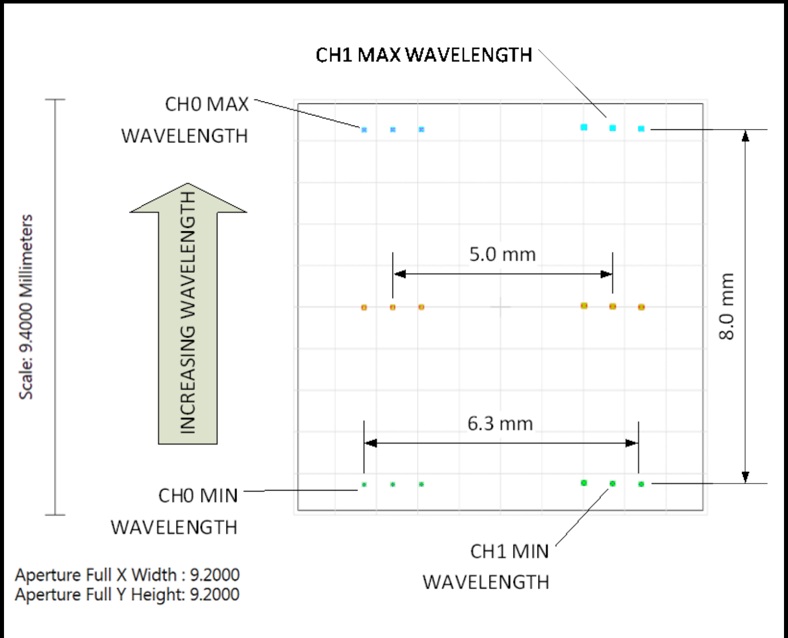
Spectrometer Instrument

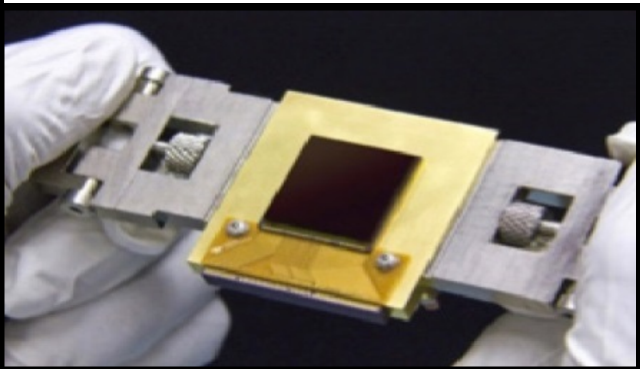
- Dual Offner spectrometers with common focal plane and grating ruling density
- Details in proposal



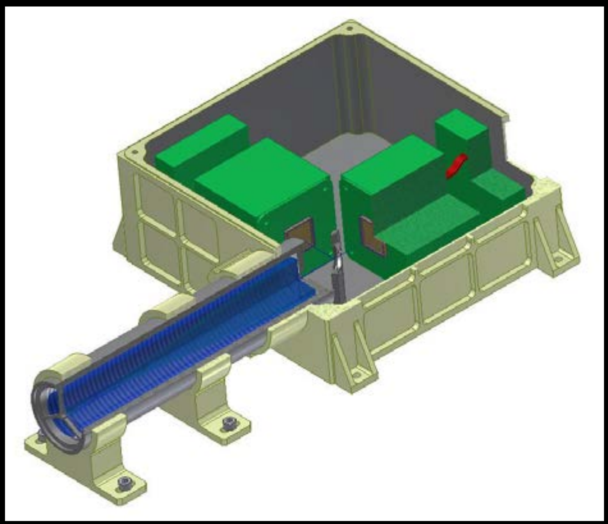
Spectrometer Detector

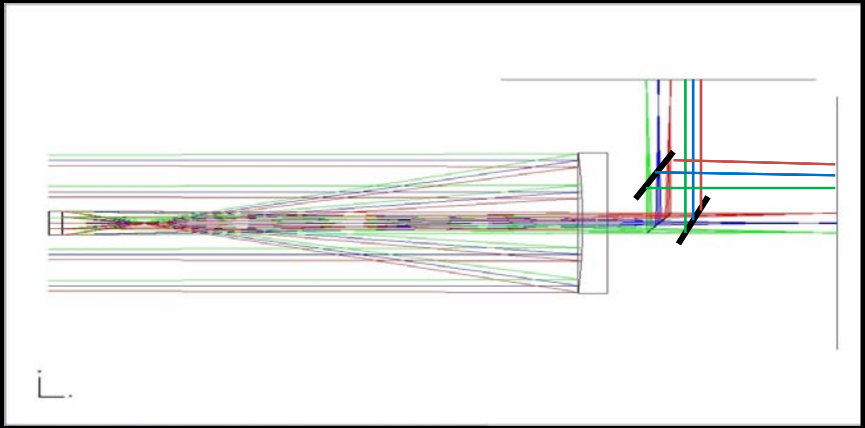
- Baselined NEOCam MCT detector for proposal
- Know that work is on-going in Europe on MCT devices out to ≥ 8 µm
  - On-going contacts with CEA/LETI on their progress
- Work is continuing within consortium both on developing concepts to allow detectors to run warmer or to allow use of European existing detectors – will continue through phase A study.





Fine Guidance System / NIRPhot





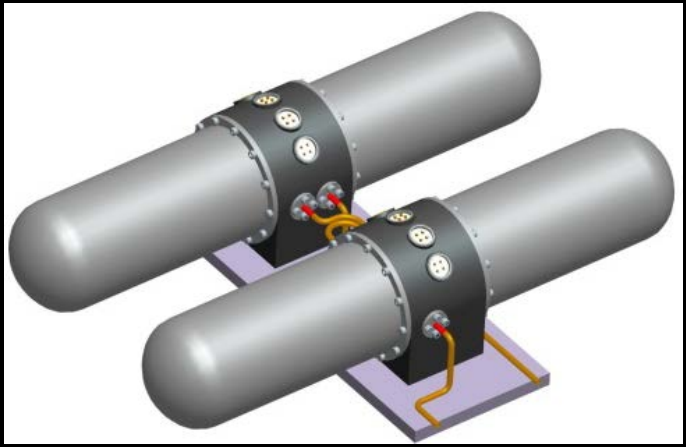
- Baseline is now a 4 channel FGS / Photometer behind Gregorian telescope
  - Provides full redundancy in guidance function
  - Offset detectors in focus in opposite directions and allow to use as Shack-Hartmann WFS in early commissioning?
  - Provides four channels of NIR photometer to assist in decorrelating spectrometer signals
- Exact optical design implementation still to be iterated and agreed in consortium

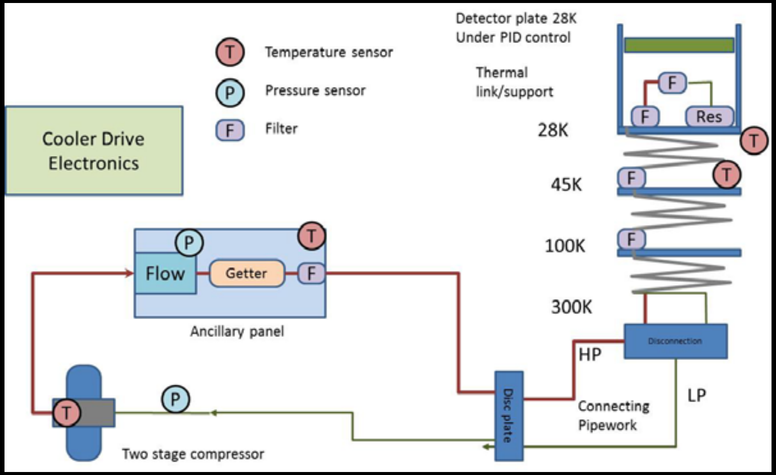
FGS / NIRPhot Detectors

- Design baseline is European detector for this channel, on-going developments at numerous manufacturers
- Data shows acceptable performance from existing detectors in terms of dark current & noise, key factor now getting sufficient sensitivity at shortest wavelength end.
  - Under consideration if the coverage down to 0.55 microns is really necessary
- Back-up option of higher TRL (9) detectors from US

Coolers

- Assuming that Coolers are required to ensure sufficiently cold temperature for the spectrometer detectors then baseline is implementation of Neon JT cooler.
- Believe that thermal requirements can be satisfied by a (probably dual-stage) tactical cooler compressor (developed by RAL / Hymatic) converted to run as a JT.
  - Study kicked off to consider the expected performance in this case.
- Backup would be the larger Neon JT cooler system as baselined for EChO.
- This can provide ~200 mW cooling at ~30 K
  - Input power required: 95 W
  - System mass: ~11.5 kg
  - These numbers (worst-case) are assumed for the budgets below





Payload Mass Budget

Item		CBE Mass - Baseline (kg)	Nominal Mass - Baseline (kg)
Cold Instrument Assembly		**37.2**	**44.64**
	Spectrometer Optics Unit	6	7.2
	FGS / NIR-Phot Optics Unit	4	4.8
	Common Optics & Cal Module	2	2.4
	Radiators	10.2	12.2
	Payload Optical Bench	15	18.0
	JT Cooler Cold Head	1.5	1.8
Telescope Assembly		**84.3**	**100.8**
	M1 Mirror	27.8	33.4
	M1 Mirror ISMs	1.8	2.2
	M2 Mirror	1.5	1.8
	M2 Refocus Mechanism	3.8	4.2
	M3 Mirror	0.2	0.2
	M3 Support structure	1.5	1.8
	Baffle & Structure	47.7	57.2
Payload Cryo-harnesses		**6.5**	**7.8**
Thermal Shield Assembly		**30**	**36.0**
	Top floor MLI & connections	3	3.6
	V-Groove Assy & PLM Struts	27	32.4
Payload Warm Units		**17.5**	**21.0**
	Instrument Control Unit (inc TCU)	10.5	12.6
	FGS Electronics	7	8.4
	Cooler Compressors & Plumbing	8.1	9.7

Payload Power Budget

Item	Basic Power (W)	Nominal Power (W)
Instrument Control Unit	37.5	45.0
FGS Control Unit	16.5	19.8
Cooler Electronics & Compressors	80.0	95.0

- Note that contamination control heater lines not included in baseline operational power budget.
- All dissipation within PLM would be drawn by one of the warm payload units in the SVM.

Payload Data Rate Budget

	Pixels Spect.	Pixels Spat.	Chan Total	Bits per sample	Prim. Rate (Hz)	Int. time per ramp (sec)	No. Bits / ramp	Total Bits / sec	GBits Per day
Science Channels									
FGS photometer mode (x4)	32	32	1024	16	1/3			21485	1.76
FGS AOCS mode	16	1	16	21	10			3360	0.27
AIRS-1	512	16	8192	16	10	3	21	57344	4.61
AIRS-2	512	16	8192	16	10	3	21	57344	4.61
		Total	16400		Total Sci (bits/sec)			139893	
					Total sci/day (Gbits)				11.26
Houskeeping Channels									
Instrument									
Temps			16	16	2			512	
Electronics etc			32	12	2			768	
M2 actuators			8	16	0.5			64	
Heaters			8	16	0.5			64	
Temps			32	16	2			1024	
					Total HK bits/sec)			2432.00	0.20
Grand total									11.46

ARIEL

<AOCS>

IFP
ESTEC, 8th July 2015

Prepared by the CDF* Team

(*) ESTEC Concurrent Design Facility

AOCS : Agenda

- Requirements
- Architecture
- Environment
- Simulator
- Performances
- Conclusion

AOCS : Requirements

- AOCS functionalities:
  - 3-axes stabilized
  - Rate damping and sun acquisition at launcher separation
  - Sun acquisition in case of major failure
  - Orbit correction maneuvers (during transfer and on L2)
  - Large slew capability between 2 observations: up to 90deg in about 1800sec
  - Coarse pointing capability at least in case of minor failure, OCM, slews
  - Fine pointing using FGS during observations
- Pointing Requirements (3σ)
  - APE Coarse = 15”
  - APE Fine = 1” (with the FGS)
  - RPE from 1s to 90s = 100mas
  - RPE < 1s = 150mas
  - PDE 90s separated by 10 hours = 100mas

AOCS : Architecture / Actuators trade-off

	RW	Cold Gas	Comment
Noise	1	3	
Micro-vibrations	2	3	RW microvib can be reduced using passive isolator for HF and by limiting the rate range to limit impact of H1
Slew	3	1	
Mass	3	1	36kg vs 200kg
Cost	3	1	
Power	2	3	90W for the wheels but for a limited amount of time (at the beginning / end of slews and off-loading)
Life time	3	1	
Parasitic DV	3	2	RW off-loading : no impact on DV thanks to a balanced thruster configuration
Devel status	3	2	
Total	23	17	

⇒ Selection of wheels in baseline

⇒ Assessment of their impact on performances = major AOCS driver of this CDF study

AOCS : Architecture / Wheels

- Wheel micro-vibration impacts are due to coincidence between wheel harmonics with structure modes
- In order to reduce the impact of wheels micro-vibrations it is proposed to:
  - Use dampers under the wheels
    => filters the high rank harmonics
  - Use high capacity wheels, and frequent off-loading (every typ. 10h)
    => limits the wheel rate range
  - Use wheel rates such that harmonics H1 / H0.6 be out of structure or damper mode
  - Choose damper Q-factor to optimize the global performance : high-frequency filtering vs amplification of H1 and H0.6
  - Possible alternatives : use 8 small wheels instead of 4 big wheels in order to additionally limit the unbalance
  - Additional solution : use of a tip-tilt mirror

AOCS : Architecture / Modes

- SAM : Sun Acquisition Mode
  - At separation
  - After a major failure
- CPM : Coarse Pointing Mode, in any other situation :
  - Slews
  - Wheel off-loading
  - After a minor failure
- OCM : Orbit Control Mode
  - For trajectory correction maneuvers
  - Wheel off-loading
- FPM : Fine Pointing Mode
  - During Instrument Observation with FGS

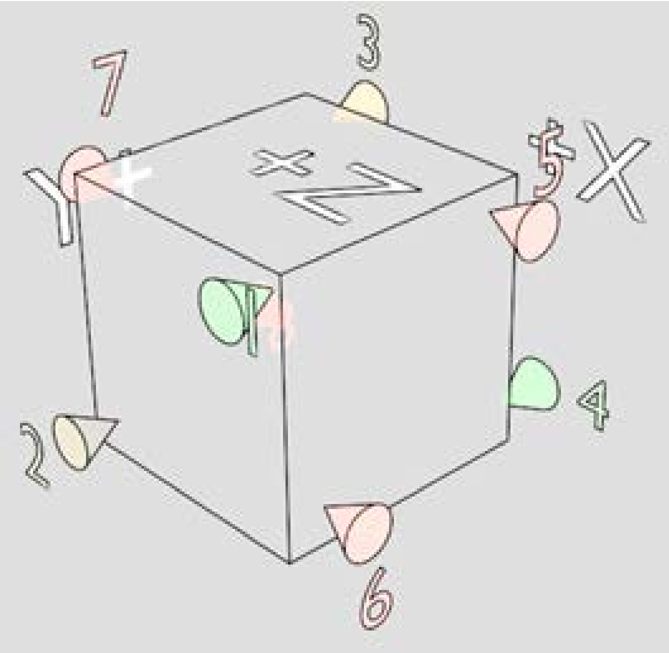
AOCS : Architecture / Modes

- Attitude Anomaly Detector (AAD) is only used for payload protection
- 1 Coarse Gyro is used for payload protection
- Wheel off-loading are performed:
  - after long-duration observations (above 5h) => thrusters are used in Open Loop in CPM
  - During TCMs => Wheels are used in open loop in OCM

Sensor	ARAD	SAM	OCM	CPM	FPM
AAD	x				
CGYR	x	x			
SS		x			
STR			x	x	
FGYR			x	x	x
FGS					x
Actuator					
RCS		x	x	x (O.L.)	
RW			x (O.L.)	x	x

AOCS : Architecture / Thruster configuration

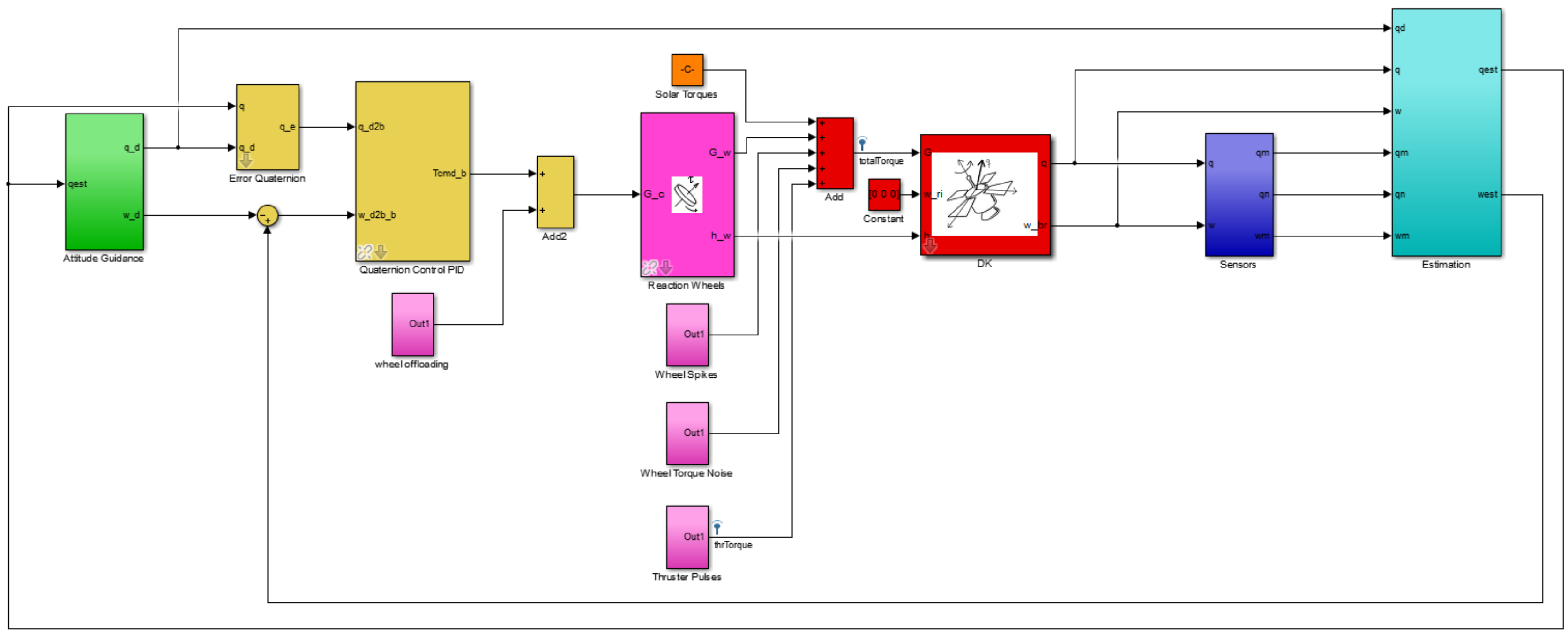
- Fully balanced configuration (i.e. generates pure torques around X, Y and Z axis)
  => No parasitic force
- Hypothesis:
  - Lever arm (2x) 1.5m
  - Isp = 210s
  - Force = 1N
  - MIB in [0.01, 0.04] Ns
  - Efficiency = 0.75
- Additional pure force thrusters for TCMs : e.g. 20N on –Z face towards +Z and 2x10N on +X/-X faces towards –Z and +X/-X



AOCS : Main disturbances

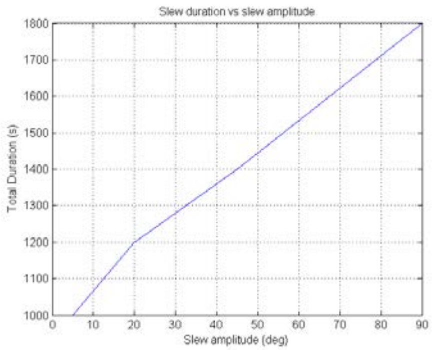
- Main external disturbances torques in L2 are due to Sun Pressure
  - Surface about 10m2
  - Distance between center of pressure and COM = 1m
  - Maximum induced torques = 60microNm
- Main internal disturbances torques are due to the wheels
  - Micro-vibrations : 4x68Nms wheels, 5g.cm / 20g.cm2 unbalance each
  - Torque noise : 0.1 mNm up to 1Hz
  - Torque spikes : 15 mNm during 2sec (+15 / 1sec, -15 / next second)

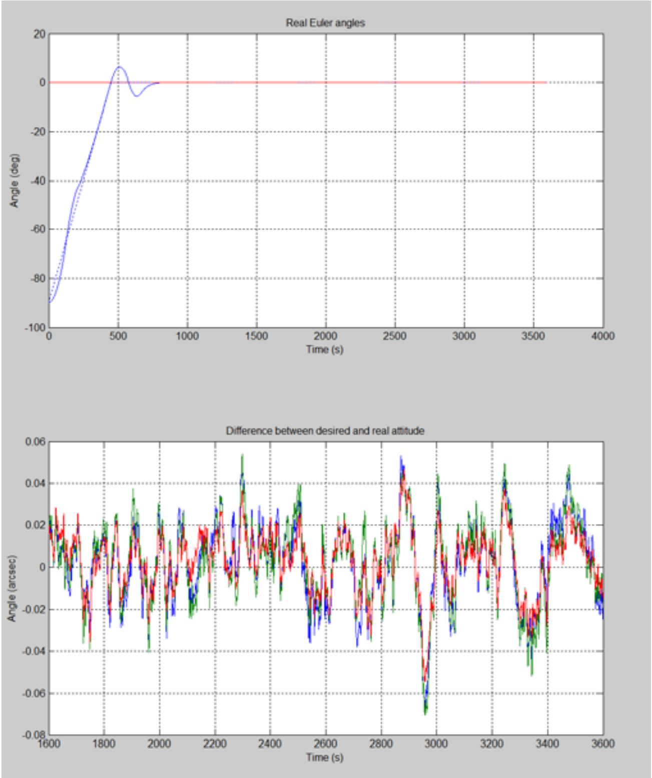
AOCS : Simulator



AOCS : Performances / slew

- Wheel off-loading is performed at the beginning of the slew to save time
- Slew duration includes:
  - the slew itself
  - the slew damping
  - the convergence of attitude for the next observation

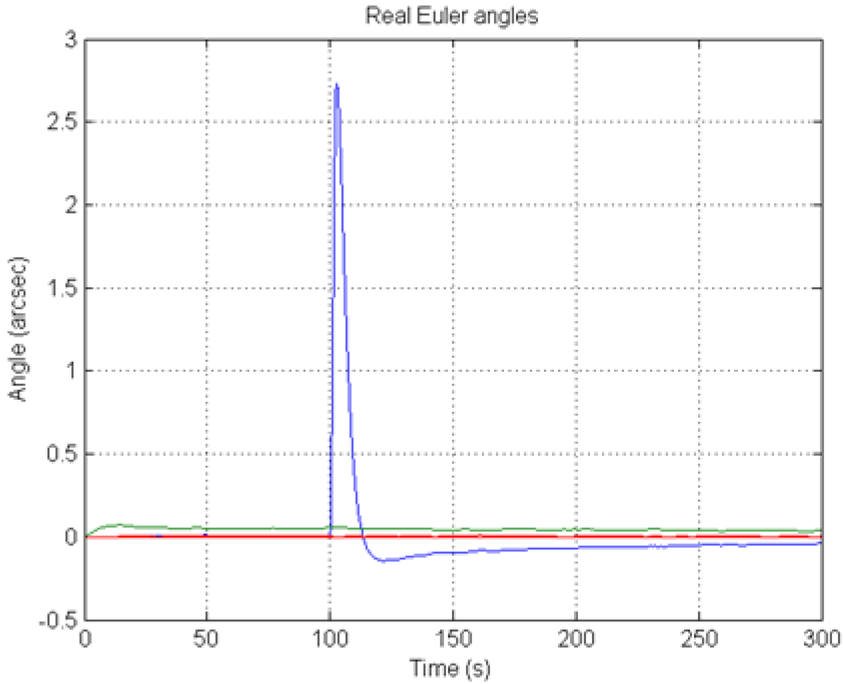




Example of a 90deg slew

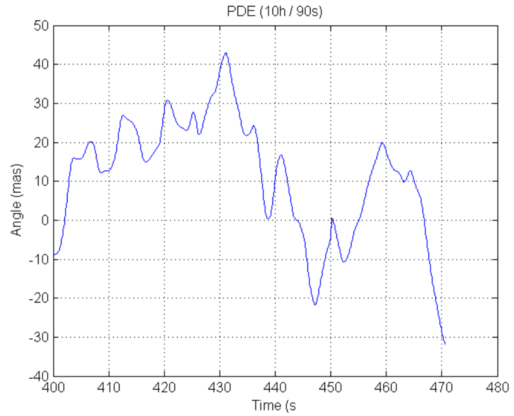
AOCS : Performances / Impact of torque spikes

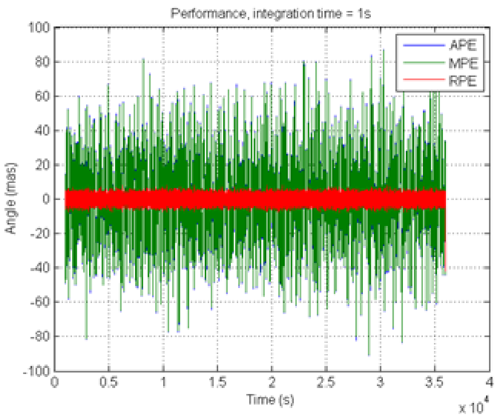
- Impact on APE = 3 arcsec during 1sec, followed by convergence back to 0 below 100 mas in less than 20sec

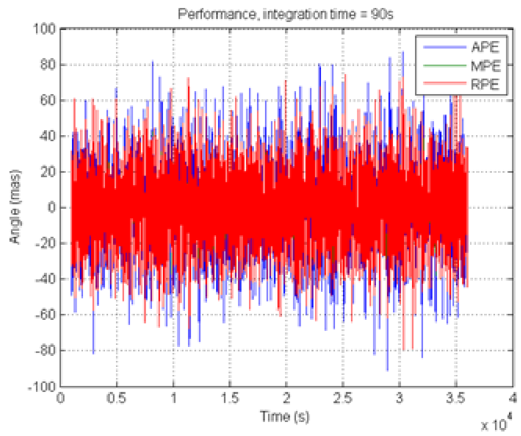


AOCS : Performances / Impact of torque noise

- Impact on APE is below 100mas
- Impact on RPE 1s = 5 mas at 99.73%
- Impact on RPE 90s = 60mas at 99.73%
- Impact on PDE 90s / 10h = 40 mas at 99.73%







AOCS : Performances / Impact of micro-vibrations

- Wheels
  - Rate variation is limited to 200 rpm (Sun pressure torque 60microN, off-loading every 10h)
  - Isolator under the wheels Q factor = 8, frequency = 10Hz
  - Linear summation of the 4 wheels impacts
  - => Total impact on RPE (<1s) < 80mas
- Cryo-cooler
  - Force = 0.25Nm, lever arm = 2m
  - Frequency = 50Hz
  - No resonances with structure even for higher rank harmonics
  - => Impact on RPE (<1s) < 2mas
- To limit further the RPE (<1s), a solution might be the use of a tip-tilt mirror, or the use of 8 smaller wheels instead of 4 big wheels

AOCS : Pointing performances / synthesis

Index	Req (3σ)	Comment
APE Coarse	15”	Star Tracker bias and misalignment (3’) => requires Star Tracker calibration with FGS image or centroid (ground processing)
APE Fine	1”	OK (100mas) except during wheel torque spikes (up to 3”) Impact of thermo-elastic not included
RPE 90s	100mas	OK (60mas), wheel torque noise
RPE 1s	100mas	OK (5mas), wheel torque noise
RPE (<1s)	150mas	OK (82mas), mainly wheel micro-vibrations
PDE (90s / 10h)	100mas	OK (40mas), impact of thermo-elastic not included

AOCS : Conclusions

- Wheel-based AOCS is compatible with pointing requirements
- Further improvement of the RPE (<1s), and mitigation of wheel torque spikes impact could be achieved thanks to the use of a tip-tilt mirror mechanism together with a large bandwidth sensor and controller, and/or the use of 8 smaller wheels instead of 4 big wheels.

ARIEL

Chemical Propulsion

Session 6 – IFP
ESTEC, 08th July 2015

Prepared by the CDF* Team

(*) ESTEC Concurrent Design Facility

Chemical propulsion- Input

- Dry mass of the system including system margin – taken 08.07.2015
- Monopropulsion system due to diaphragm tanks
- Different Δv-manoeuvres due to the different options– one propulsion system
- 20N thruster for main manoeuvres, 1N thruster for AOCS sufficient
- 8 thruster for AOCS and 4 main thruster for manoeuvres (+/-z), redundancy taken into account
- No adapter added to the overall wet mass

Chemical Propulsion – Requirements

- Three barriers for the system
- Passivation at end of life (active system assumed)
- Pressurant and corresponding influence has to be minimal (nitrogen assumed)
- 3 safe modes per year for six year lifetime, leading to a steady state on for the cat bed heater

Additional investigations

- Microvibrations due to the propellant in the tank
  - Diaphragm assumed to be stiff enough to damp this behavior, therefore no issue
  - One tank is therefore equal to the behavior of four tanks
  - Diaphragm tank to neglect sloshing effects
- If possible no moving parts with high impact
  - No pyrovalves used, only latch valves for the mission
  - Each branch separately to reduce risk of leakage or abnormal thruster behavior
  - Integrated test ports due to testing on ground
- Passivation at end of life is done
  - Propellant through the thruster
  - Latch valve for the pressurant (EUCLID assume that the pressure within the tank at EOL is not an issue (will be between 5.5 and vacuum)

Input AOCS

- Masses for safe modes and first pointing
- Each year divided into science phase and AOCS manoeuvres

Year	Nominal sun acquisition mass needed	Days for sun acquisition	Nominal sun modes per year	Safe mode mass needed	Days for safe mode	Safe modes per year	Mass needed per year	AOCS mass needed additionally	Additional manoeuvers	Sum per year	Margin	Total per year
1	0.5	2	0	0.5	2	3	3	1	1	4	100%	8
2	0.5	2	0	0.5	2	3	3	1	0	4	100%	8
3	0.5	2	0	0.5	2	3	3	1	0	4	100%	8
4	0.5	2	0	0.5	2	3	3	1	0	4	100%	8
5	0.5	2	0	0.5	2	3	3	1	0	4	100%	8
6	0.5	2	0	0.5	2	3	3	1	0	4	100%	8
Total	0		0	18		18	18	6	1	24		48

Manoeuvres

- Input for each manoeuvre individually – example most demanding case
- No angle introduced for the firings of the 20N thruster, propellant mass assumed to be in flight direction without angle

Input	Manoeuvre	velocity increment [m/s]	propellant mass [kg]
delta v	Launch dispersion correction manoeuvre (stochastic)	84.00	
delta v	Perigee velocity correction manoeuvre (deterministic)	14.18	
delta v	Correction of TCM#1 (stochastic)	3.15	
delta v	Correction of TCM#2 (stochastic)	2.10	
propellant mass	First pointing		2.00
delta v	Science Phase	8.93	
propellant mass	AOCS		8.00
delta v	Science Phase	8.93	
propellant mass	AOCS		8.00
delta v	Science Phase	8.93	
propellant mass	AOCS		8.00
delta v	Science Phase	8.93	
propellant mass	AOCS		8.00
delta v	Science Phase	8.93	
propellant mass	AOCS		8.00
delta v	Science Phase	8.93	
propellant mass	AOCS		8.00
delta v	Disposal	15.00	

Options for the different systems

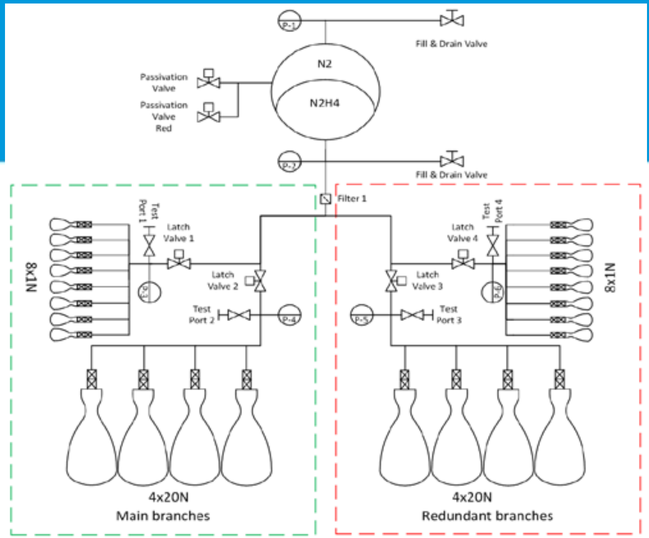
- Two different options for the propellant
  - Hydrazine
  - LMP-103S
- Hydrazine thruster from Airbus (TRL 9)
- LMP-103S from ECAPS
  - 1N thruster flown on PRISMA (TRL 9)
  - 20N thruster in development (TRL 4-5), ISO TRL 6 achievable with funding at 2018

Propellant masses and delta-v's

- Baseline (Hydrazine – most demanding delta-v case (back-up 1))

Manoveure	mass begin [kg]	mass end [kg]	velocity increment [m/s]	Thruster	propellant mass [kg]	Calc. Tank size fuel [l]	tank pressure [bar]	Firing time [s]
Launch dispersion correction manoeuvre (stochastic)	1081.16	1037.06	84.00	CHT-20N	44.10	40.42	24.00	6751.97
Perigee velocity correction manoeuvre (deterministic)	1037.06	1029.63	14.18	CHT-20N	7.43	6.81	11.56	1210.75
Correction of TCM#1 (stochastic)	1029.63	1027.98	3.15	CHT-20N	1.65	1.51	10.63	272.05
Correction of TCM#2 (stochastic)	1027.98	1026.88	2.10	CHT-20N	1.10	1.01	10.44	182.80
First pointing	1026.88	1024.88	3.99	CHT-1N	2.00	1.98	10.32	7463.56
Science Phase	1024.88	1020.37	8.93	CHT-1N	4.52	4.43	10.11	17638.68
AOCS	1020.37	1012.37	15.98	CHT-1N	8.00	7.92	9.66	32249.01
Science Phase	1012.37	1007.88	8.93	CHT-1N	4.49	4.41	8.96	19293.41
AOCS	1007.88	999.88	16.06	CHT-1N	8.00	7.92	8.60	35317.65
Science Phase	999.88	995.41	8.93	CHT-1N	4.47	4.39	8.04	20846.57
AOCS	995.41	987.41	16.17	CHT-1N	8.00	7.92	7.76	38294.81
Science Phase	987.41	982.98	8.93	CHT-1N	4.43	4.36	7.30	22302.36
AOCS	982.98	974.98	16.29	CHT-1N	8.00	7.92	7.06	41183.30
Science Phase	974.98	970.59	8.93	CHT-1N	4.39	4.32	6.68	23664.95
AOCS	970.59	962.59	16.43	CHT-1N	8.00	7.92	6.49	43986.14
Science Phase	962.59	958.23	8.93	CHT-1N	4.35	4.28	6.16	24938.44
AOCS	958.23	950.23	16.59	CHT-1N	8.00	7.92	6.00	46706.41
Disposal	950.23	943.34	15.00	CHT-20N	6.89	6.79	5.72	1893.09
Summation	943.34		273.49		137.82	132.24	5.50	

Equipment



- Equipment for Hydrazine – baseline
- All systems equal, all tank sizes equal
- Except thruster, all TRL 9
- # of 20N thruster

Number	Description	Type	Amount	Mass per unit	Margin	Mass incl. margin
1	Pipes	Titanium	1	5.00	20%	6.00
2	Latch valve	LPLV 3554258 - Galileo heritage	4	0.55	5%	2.31
3	Propellant Filter	430-PF2	1	0.11	5%	0.12
4	Passivation valve	Assumed as latch valves - passivation thruster are missing	2	0.55	5%	1.16
5	Pressure transducer	SAPT-250 Pressure transducer	6	0.22	5%	1.36
6	Propellant Fill & Drain Valve	VC03-xxx	5	0.05	5%	0.26
7	Pressurant Fill and drain valve	VC03-xxx	1	0.05	5%	0.05
8	Propellant Tank	PTD-177s	1	15.50	5%	16.28
9	Pressurant	Nitrogen	1	1.23	2%	1.26
10	Thruster 1 (22N)	CHT-20N	8	0.39	5%	3.28
11	Thruster 2	CHT01N	16	0.29	5%	4.87
12	Propellant	Hydrazine	1	137.82	2%	140.58
Total	Chemical propulsion system		1	172.34	9%	177.53

Power

- Power calculated for given time

Number	Description	Type	Amount	Power	time	Power over all	Standby power
1	Pipes	Titanium	1	0	0	0	0
2	Latch valve	LPLV 3554258 - Galileo heritage	4	30	0.1	6	0
3	Propellant Filter	430-PF2	1	0	0	0	0
4	Passivation valve	Assumed as latch valves - passivation thruster are missing	2	30	0.1	6	0
5	Pressure transducer	SAPT-250 Pressure transducer	6	0.2	1	0.8	0.2
6	Propellant Fill & Drain Valve	VC03-xxx	5	0	0	0	0
7	Pressurant Fill and drain valve	VC03-xxx	1	0	0	0	0
8	Propellant Tank	PTD-177s	1	0	0	0	0
9	Pressurant	Nitrogen	1	0	0	0	0
10	Thruster 1 (22N)	CHT-20N	8	24.2	1	48.4	0
11	Thruster 2	CHT01N	16	15.9	1	127.2	6.5
12	Propellant	Hydrazine	1	0	0	0	0
Total	Chemical propulsion system	0	1			188.4	0

- Standby power due to cat-bed heater
- Thruster configuration is currently under an update

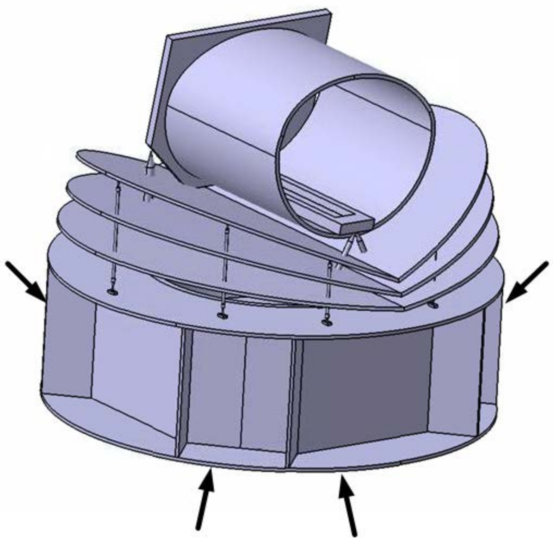
Comparison

- Comparison regarding dry mass, wet mass and overall residuals possible to store within the tank (currently 144l max)

Description Delta v option	22N & 1N (ECAPS) Back-up 1 delta-v	22N & 1N (ECAPS) Baseline delta-v	22N & 1N (ECAPS) Back-up 2 delta-v	20N & 1N (Hydrazine) Back-up 1 delta-v	20N & 1N (Hydrazine) Baseline delta-v	20N & 1N (Hydrazine) Back-up 2 delta-v
Propellant + Pressurant	131.99	120.70	99.99	137.49	125.01	102.50
Dry mass system	36.99	36.99	36.99	34.04	34.04	34.04
Overall mass Propulsion system	168.98	157.69	136.98	171.53	159.05	136.54
Delta v	280.30	258.27	215.96	273.49	251.58	209.56
Tank size [l]	177.00	177.00	177.00	177.00	177.00	177.00
AOCS delta v	104.04	105.38	107.83	97.53	99.04	101.75
Stationkeeping	53.55	53.55	53.55	53.55	53.55	53.55
Orbital manoeuvres	122.71	99.34	54.58	122.41	98.99	54.26
Dry mass Spacecraft	944.96	944.96	944.96	941.42	941.42	941.42
Wet mass Spacecraft	1076.95	1065.66	1044.95	1078.91	1066.42	1043.92
Pressure EOL	10.08	11.31	13.58	6.07	7.76	10.80

Current open points

- Configuration of the 20N thrusters/10N thruster not existing
  - No +/-z thruster possible in redundant configuratiion
  - Impact on the payload shall be as minimal as possible (30 or 45° of angle)
  - Two thruster at the bottom to deliver pure forces (through CoG) → Impact of CoG shift
  - Impact of angle and # of thruster is not currently within the model
  - Full redundancy need 8 thruster (Astrium and TAS have only used 1N thruster full redundant)



Preliminary results: (best performance, difference will increase due to angle)

8x20N thruster: 943.38kg dry / 1081.05 kg wet / 35.68kg system (228-210s Isp)

24x1N thruster: 942.37kg dry / 1081.85kg wet / 34.84kg system

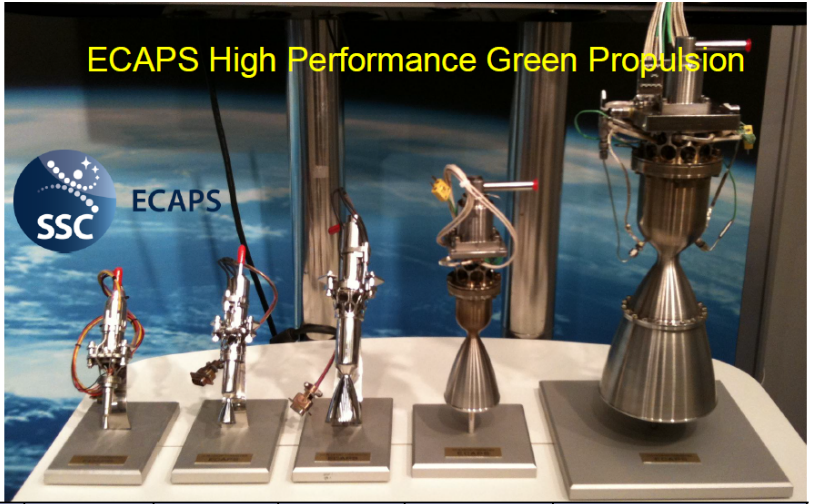
Also available: 4N thruster for this reason

Conclusion

- Green propulsion shows great benefits in terms of wet mass and corresponding pressure levels within the tanks
- Disadvantages of the current propellant is in this mission no issue since the thruster have to be heated (only 10 cold starts possible, 18 needed)
- Overall wet mass is currently slightly above 1to

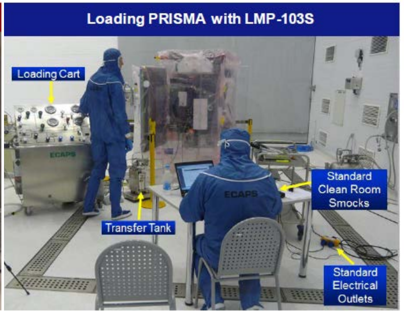
ECAPS LMP-103S thruster

- Planned to be used on Skybox as propulsion system
- Advantages:
  - Higher Isp, higher density
  - Green (No-Scape suits needed)
- Disadvantages:
  - No cold starts possible



Thrust	0.5 N	1 N	5 N	22 N	50 N	220 N
Propellant	LMP-103S	LMP-103S	LMP-103S	LMP-103S	LMP-103S	LMP-103
Isp (Ns/kg)	2210* (~ 225 sec)	2310* (~ 235 sec)	2450* (~ 250 sec)	2500* (~ 255 sec)	2515** (~ 255 sec)	2800** (~ 255 - 285 sec)
Density Impulse (Ns/L)	2730	2860	2900	3030	3120	3580
Status	TRL 5	TRL 9 *flight proven*	TRL 5	TRL 5	TRL 3	TRL 4/5

* Delivered steady-state vacuum specific impulse at MEOP and ε = 150:1
** Predicted steady-state vacuum specific impulse at MEOP and ε = 150:1



Dinardi-26th AIAA/USU small satellite conference2012

ARIEL

Data Handling

IFP
ESTEC, 8th July 2015

Prepared by C. Urbina Ortega

Requirements and Design Drivers

- Single OBC for AOCS and spacecraft control. Payload with dedicated electronics
- CPU, TM, TC, Reconfig., OBT, HPC, HK acq. I/Fs (100s), AOCS sensors & actuators, Propulsion system IF, DC/DC
- Memory:
  - WC science data is 4 days storage: 11.5 Gbit/day * 4 days = 46 Gbit
  - WC S/C+HK data is 6 days storage: 1.5 Gbit/day* 6 days = 9 Gbit
  - TOTAL with 50% margin: **82.5 Gbit**
- Temperature sensor acquisition: <70 units, 3 thermistors/unit, 50% margin
  - Approximately 300 thermistors.

Baseline design updated: OBCwMMB + RTU

- Going for a separate mass memory is definitely more power consumption, heavier and more expensive, with no major advantages compared to the autonomous MMB selected

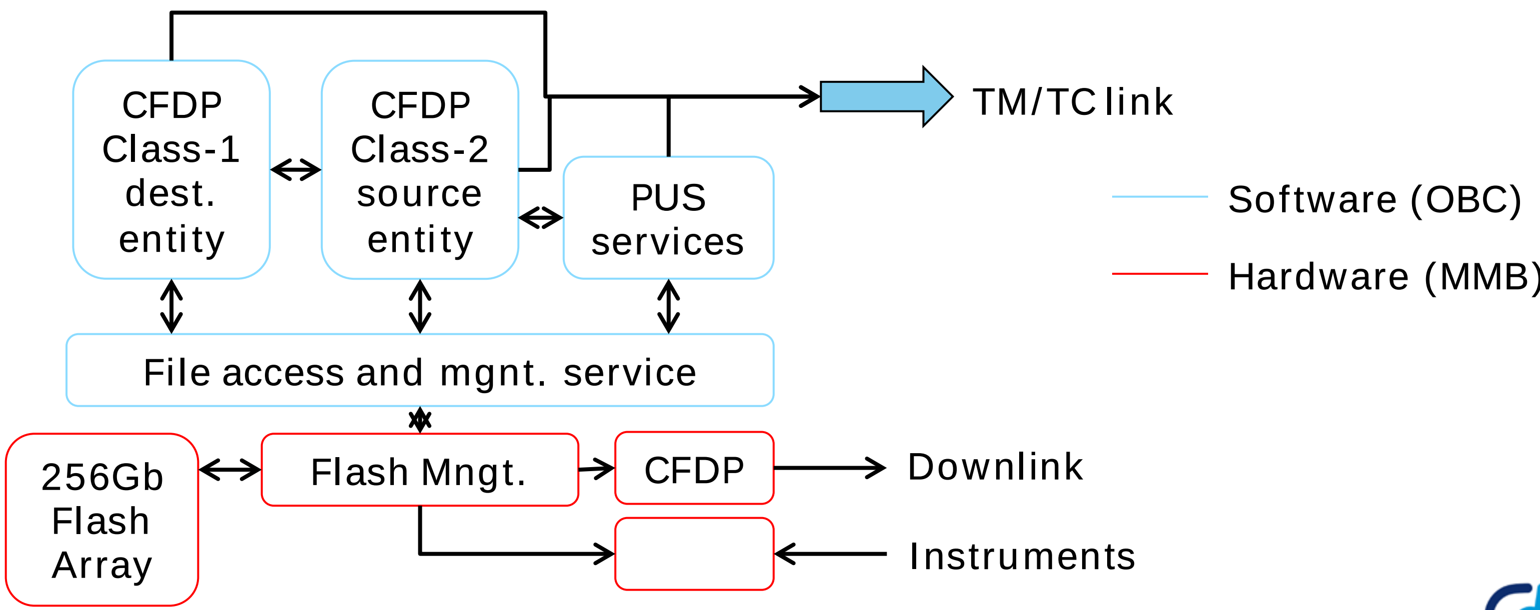
- OBCwMMB: 6kg, 12W, 22x20x18cm
- RTU: 12kg, 20W, 30x25x20cm

- All functions are Fully Redundant
- 50 MIPS CPU with NV and RAM memory, SGM
- 256 Gbits MM with SpW network
- Prop.: Latch Valves, 4-8 thrusters, heaters, separation status acq.
- HK: 300 therm., 16 BL, 30 analog, 4 UARTs, 12 LLC, 2 SPI, etc.

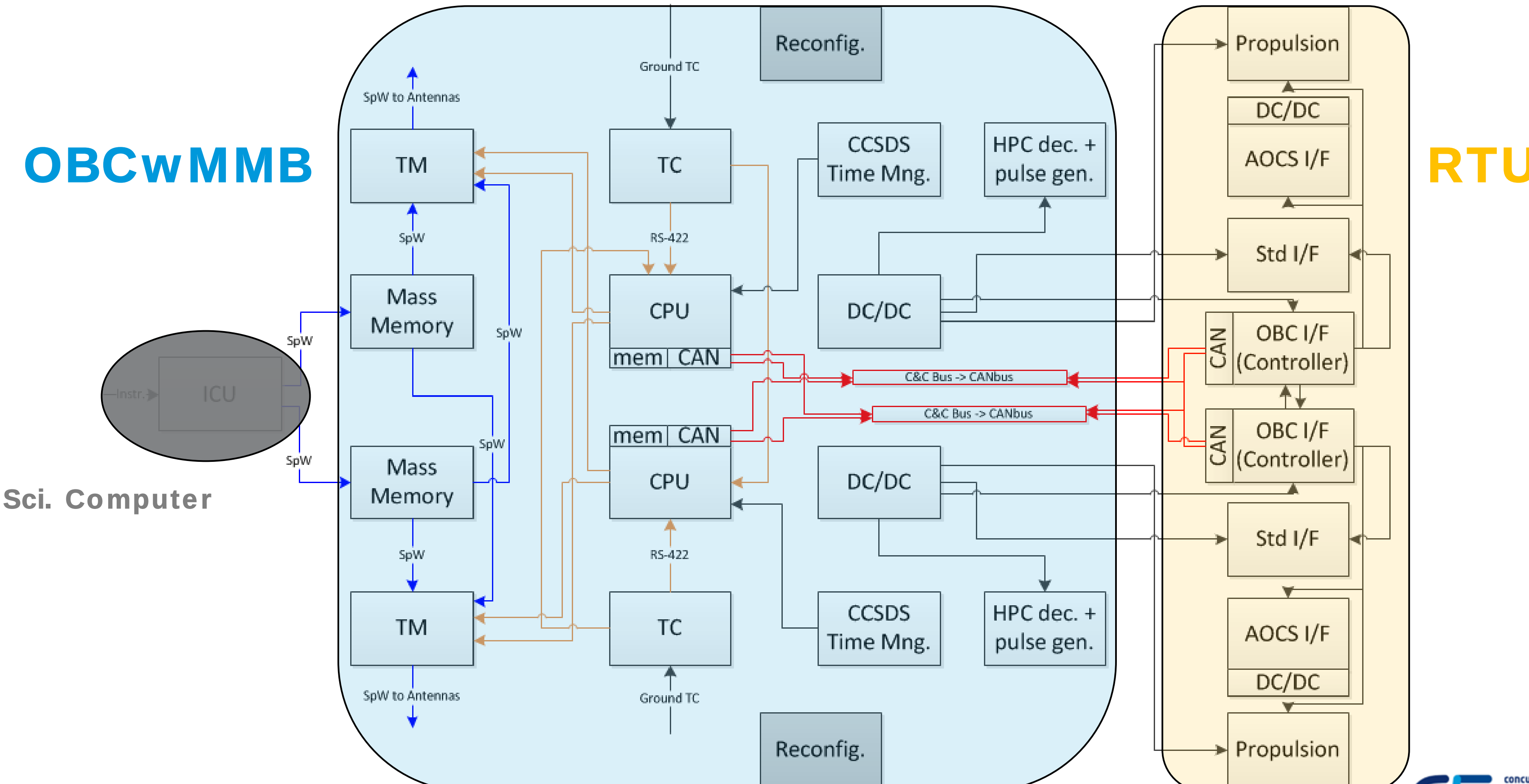
- AOCS: Sun sensor, x4 pulse & speed & voltages for reaction wheels, etc.
- CCSDS Time Mngt., Reconfig module, TMTC
- Software with CDFP and RT-OS
- CAN as C&C bus, SpW ntw. Science data, SPI internal
- DC/DC + 10-40 HPC

Memory Management System

- CFDP:
  - Class-1 for uplink
  - Class-2 for downlink
  - HW&SW implementation
- Separate file access and management system
- SpaceWire concentrator



Detail Design



ARIEL

Communications

Session 8 – IFP
ESTEC, 8th July 2015

Prepared by the CDF* Team

(*) ESTEC Concurrent Design Facility

Requirements and Design Drivers

The S/C shall orbit around L2 with the nominal distance to Earth 1,770,000 km.

Hot redundancy shall be provided for telecommand (uplink) and cold redundancy for telemetry (downlink)

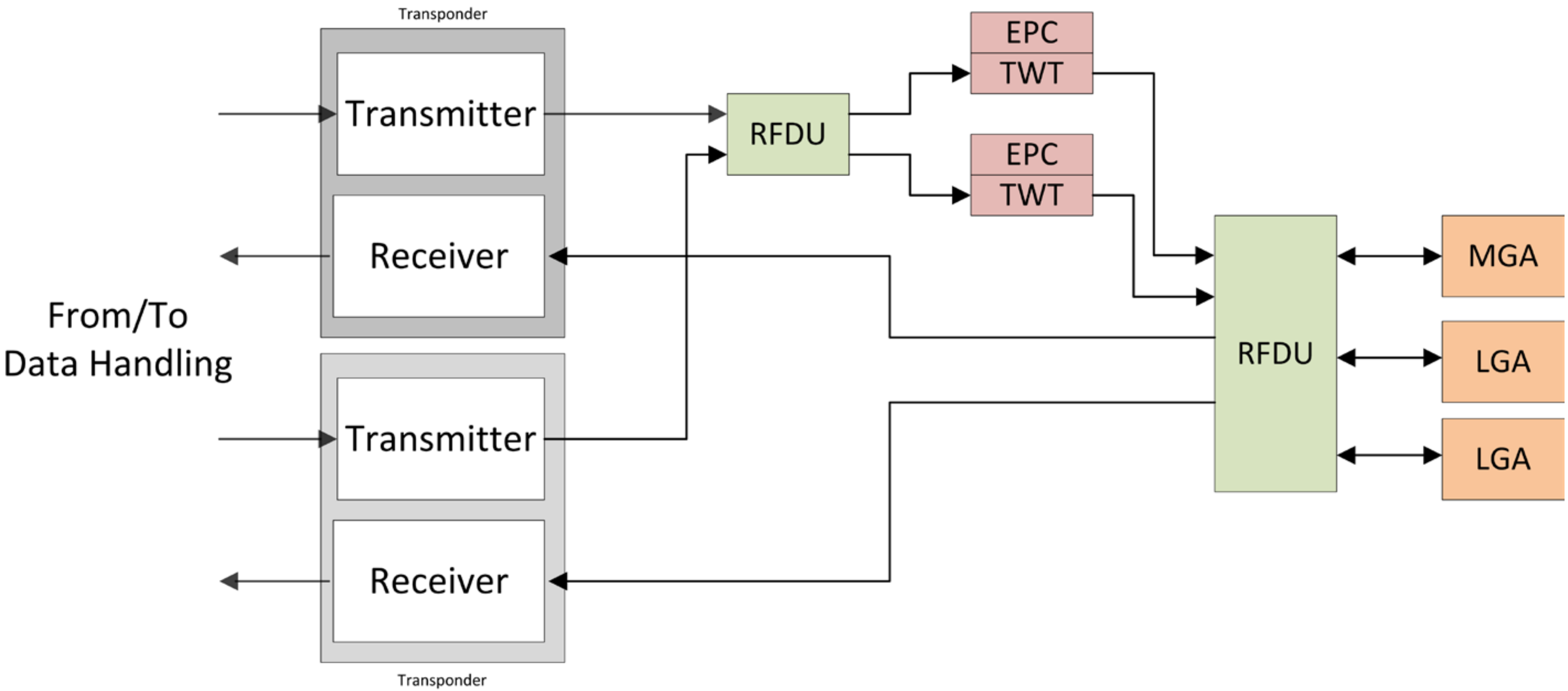
The TT&C subsystem shall allow ranging

Assumptions

Communication link

- Total Data Volume for TM is ~14 Gb/day
  - 11.5 G/b day for Science (ARIEL report)
  - 1.5 G/b day for HK (input from DHS)
  - 1 G/b day (8% overhead on Science and HK)
- Ground passes 4h every 2 days (baseline)
- New Norcia 35 m G/S
- Ranging 30 min for each pass (input from Ground op.)
- The transponder switch from a suppressed carrier modulation (for high data rate TM) to a residual carrier modulation (for ranging) when needed
- **TM downlink data rate 2.15 Mbps**

Baseline Design



Link Budget - 1

MGA + APM		
PARAMETER	VAL.	Notes
RANGE [km]	1770000.0	*From Mission Analysis*
FREQUENCY [MHz]	8475	
MAX BIT RATE [kbps]	2228.57	
MAX BIT RATE [dBHz]	**63.48**	
TX POWER [W]	22.00	
TX POWER [dBW]	13.42	
TX ANTENNA GAIN [dB]	17.96	*from Planck presentation (Alenia)*
TX LOSSES [dB]	2.50	*Estimation RFDU*
TX EIRP [dBW]	**28.88**	*Calculated*
PATH LOSSES [dB]	**235.96**	*Calculated*
ATMOSPHERE LOSS [dB]	1.00	*From ECHO Astrium report*
RX G/T [dBK]	50.10	*New Norcia 35m*
DEMOD. LOSS [dB]	2.00	*EChO Astrium report + 0.5*
INSERTION. LOSS [dB]	1.00	*APM*
REQIRED Eb/No [dB]	1.10	*Turbo 1/2*
MINIMUM MARGIN [dB]	**3.04**	

Power	Value
Transmitter power consumption [W]	15
Receiver power consumption [W]	10
PA efficiency	0.5605
total [W]	74.25066905

Link Budget - 2

MGA + APM		
PARAMETER	VAL.	Notes
RANGE [km]	1770000.0	*From Mission Analysis*
FREQUENCY [MHz]	8475	
MAX BIT RATE [kbps]	5000.00	
MAX BIT RATE [dBHz]	**66.99**	
TX POWER [W]	50.00	
TX POWER [dBW]	16.99	
TX ANTENNA GAIN [dB]	17.96	*from Planck presentation (Alenia)*
TX LOSSES [dB]	2.50	*Estimation RFDU*
TX EIRP [dBW]	**32.45**	*Calculated*
PATH LOSSES [dB]	**235.96**	*Calculated*
ATMOSPHERE LOSS [dB]	1.00	*From ECHO Astrium report*
RX G/T [dBK]	50.10	*New Norcia 35m*
DEMOD. LOSS [dB]	2.00	*EChO Astrium report + 0.5*
INSERTION. LOSS [dB]	1.00	*APM*
REQIRED Eb/No [dB]	1.10	*Turbo 1/2*
MINIMUM MARGIN [dB]	3.09	

Power	Value
Transmitter power consumption [W]	15
Receiver power consumption [W]	10
PA efficiency	0.5605
total [W]	124.206066

With 50W extra of peak power consumption (+67%), the data rate can be increase to 5 Mbps (+125%), maximum value in X-Band for the signal considered.

Equipment

	mass (kg)	mass margin (%)	mass incl. margin (kg)
⊞ LGA_LHCP (Low Gain Antenna (LHCP))	0.95	5.00	1.00
⊞ LGA_RHCP (Low Gain Antenna (RHCP))	0.95	5.00	1.00
⊞ MGA (Medium Gain Antenna)	0.68	5.00	0.71
⊞ RFDU_Rover (Radio Frequency Distribution Unit (Rover))	5.00	20.00	6.00
⊞ EPC_Nominal (Electronic Power Conditioning (Nominal))	1.40	10.00	1.54
⊞ EPC_Redundant (Electronic Power Conditioning (Redundant))	1.40	10.00	1.54
⊞ TWT_Nominal (Traveling Wave Tube (Nominal))	1.00	10.00	1.10
⊞ TWT_Redundant (Traveling Wave Tube (Redundant))	1.00	10.00	1.10
⊞ XPND_Nominal (Transponder Nominal)	3.60	5.00	3.78
⊞ XPND_Redundant (Transponder Redundant)	3.60	5.00	3.78
Grand Total	19.58	10.06	21.55

Power (W)		
	P_on	P_stby
⊞ LGA_LHCP (Low Gain Antenna (LHCP))	0.00	0.00
⊞ LGA_RHCP (Low Gain Antenna (RHCP))	0.00	0.00
⊞ MGA (Medium Gain Antenna)	0.00	0.00
⊞ RFDU_Rover (Radio Frequency Distribution Unit (Rover))	0.00	0.00
⊞ EPC_Nominal (Electronic Power Conditioning (Nominal))	1.79	0.00
⊞ EPC_Redundant (Electronic Power Conditioning (Redundant))	1.79	0.00
⊞ TWT_Nominal (Traveling Wave Tube (Nominal))	34.08	0.00
⊞ TWT_Redundant (Traveling Wave Tube (Redundant))	34.08	0.00
⊞ XPND_Nominal (Transponder Nominal)	25.00	10.00
⊞ XPND_Redundant (Transponder Redundant)	25.00	10.00
Grand Total	121.76	20.00

Options

- Using an High Gain Antenna the required RF transmitted power decreases to ~3W
  - The peak power consumption can be decreased to ~50W (30% saving in power). Alternatively we can keep same power consumption and increase the bitrate to 5 Mbps
  - The mass by ~5Kg (use of transponder internal SSPA instead of TWTA)
  - More accurate pointing is required
    - Larger antenna
    - Bigger antenna pointing mechanism (?)

ARIEL

Mechanisms

Session 8 – IFP
ESTEC, 8th of July 2015

Prepared by the CDF* Team

(*) ESTEC Concurrent Design Facility

Contents

Service Module:

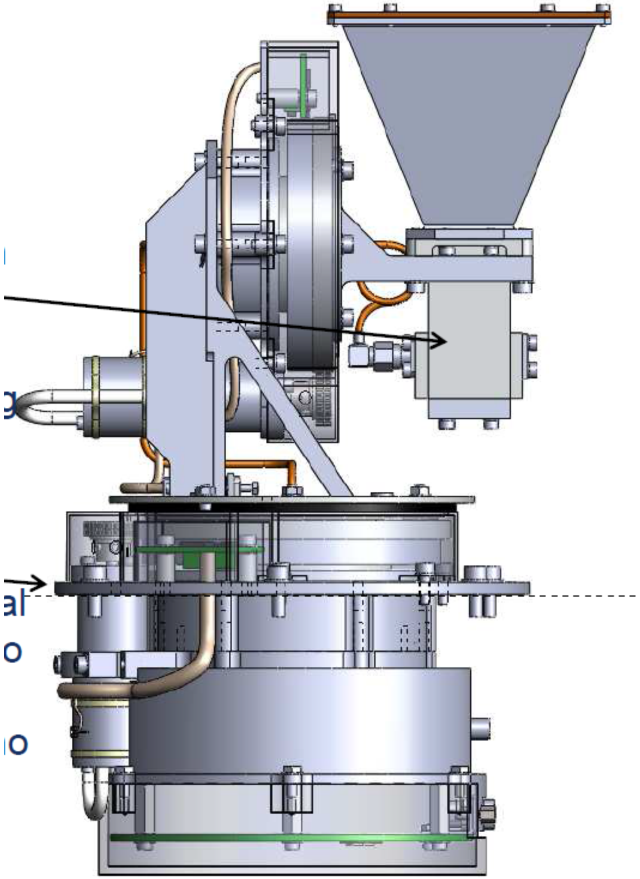
- Antenna Pointing Mechanism and HDRM;

Payload Module:

- M2 refocusing Mechanism;
- Optional: tip – tilt mechanism for M3 (TBC) repointing

Antenna Pointing Mechanism

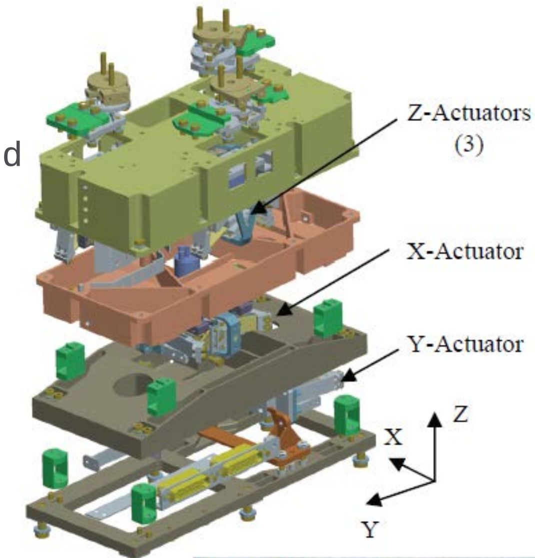
- Medium Gain Antenna 2DoF Pointing;
- accuracy of 0.25 deg and resolution of 0.025deg
- Motors: 2x stepper motors;
- Power consumption, peak <5 W;
- Mass: 4 kg (excluding Antenna and HDRM);
- Operation: every 48 hours, a repointing shall be done lasting typically 1 minute

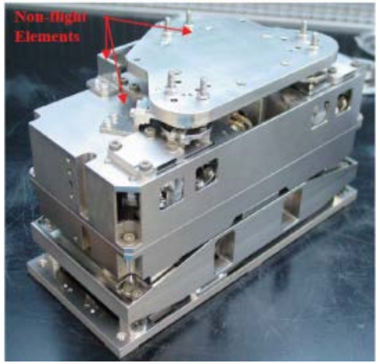


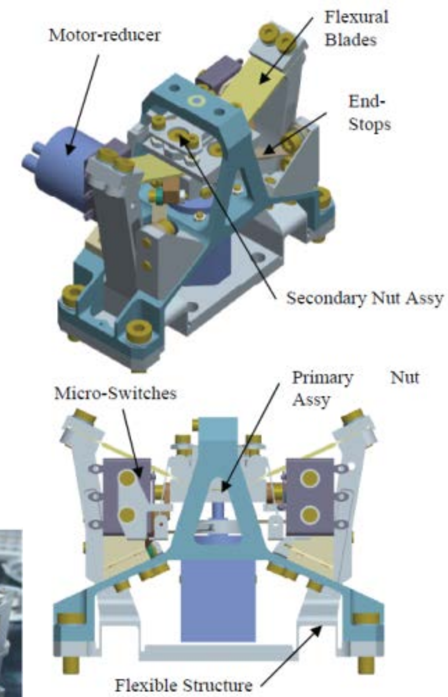
M2 Mechanism for Refocusing, Tip / Tilt and Decentering

Gaia M2MM

- Layout: 2 stages, X-Y stage plus Tripod stage;
- Linear actuator based on:
  - Stepper Motor;
  - Planetary Gearbox;
  - Plain Screw-nut;
  - Flex joint with structural reduction;







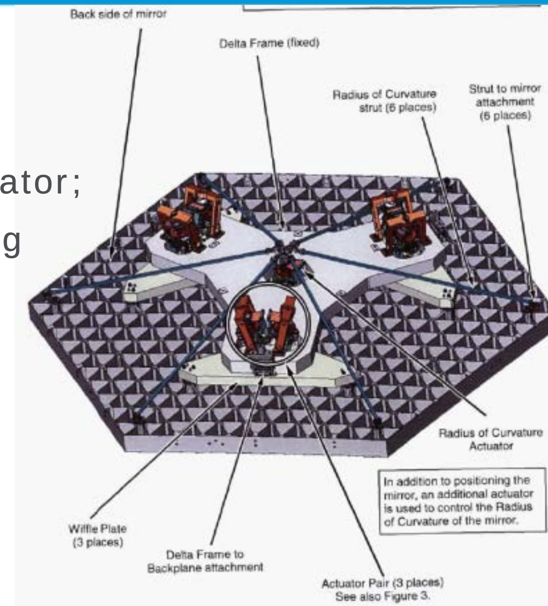
Euclid M2M

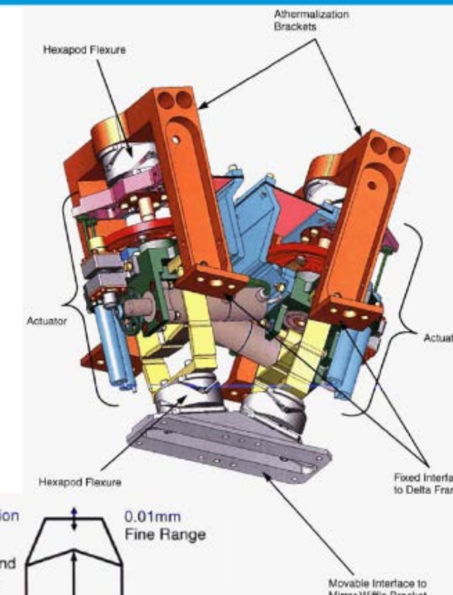
Design similar to Gaia case, but translational stages not present (tripod kinematic: piston + tip/tilt DoF);

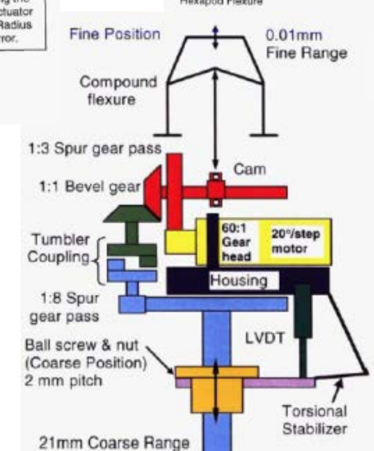
M2 Mechanism for Refocusing, Tip / Tilt and Decentering

JWST

- Layout: Hexapod + curvature actuator;
- Integrated fine + coarse positioning stages for each actuator;
- Embedded coarse position sensor;
- Linear actuator based on:
  - Stepper Motor;
  - Planetary Gearbox;
  - Ball-screw for coarse motion;
  - Eccentric bearing/cam for fine motion and rotation to translation conversion;
  - Flex joint with structural reduction;







M2 Mechanism for Refocusing, Tip / Tilt and Decentering

R&D activity going-on (Spica/Echo Cryogenic IR Telescope application):

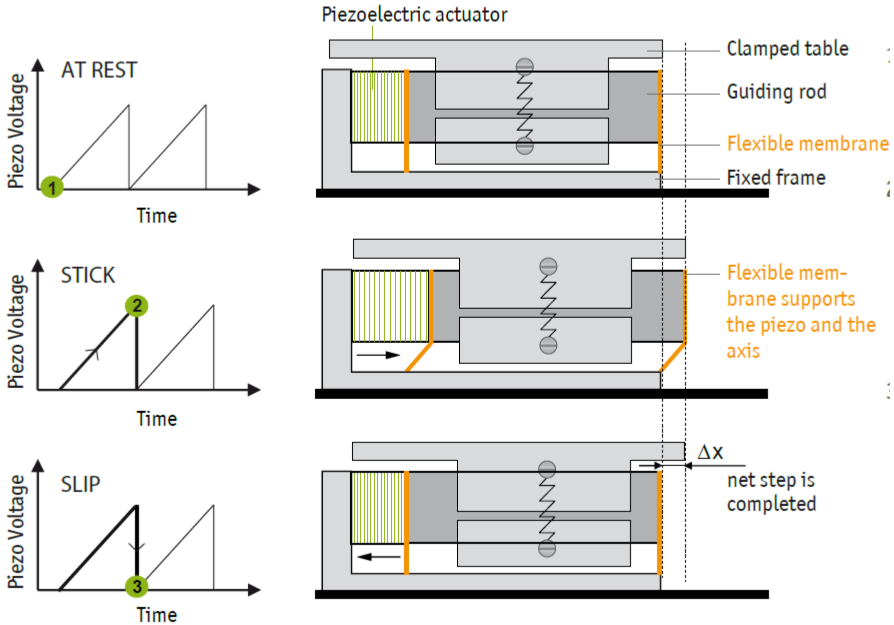
- Layout: Hexapod;
- Fully in Invar alloy, thermo-elastic distortion minimization for Cryogenic environment;
- Innovative flexure-joint design, avoidance of the screw-nut element;
- Actuated by stepper motor;
- Fully open loop motion control (no displacement sensor);

Comparison of Mirror Positioning Mechanisms for Cryogenic IR-Telescopes

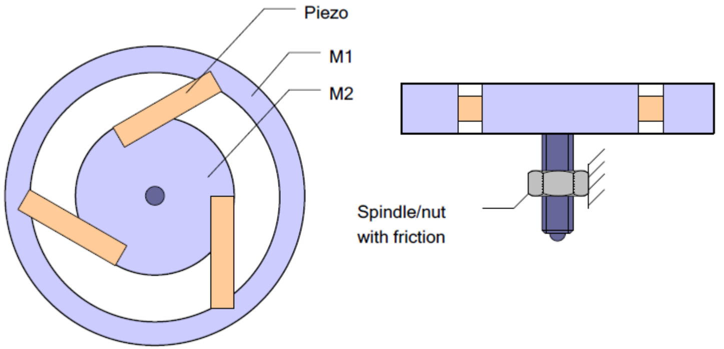
		Gaia	JWST	Echo-Spica
Actuators layout		serial + parallel tripod	parallel hexapod	parallel hexapod
Number of DoF		5	7	6
Position measurement		No	Coarse	No
Minimum operative temperature	K	100	20	5
Resolution, translations	um	0.07	0.01	0.1
Range, translations	um	550	20000	1000
Resolution, rotations	urad	1.8	-	2.5
Range, rotations	urad	2000	-	4000
Mass of the mirror	kg	1.8	5	5.4
Launch-locking provisions		No	In lat. Direc.	No
Mass of the mechanism	kg	4.8	4.2	8
Deployable		No	Yes	No

M2 Mechanism for Refocusing, Tip / Tilt and Decentering: actuator

An example of interesting alternative actuator: Friction-Inetia-Piezoelectric



From *AttoCube Systems AG*



From *Janssen Precision Engineering BV*

Advantages wrt Stepper Motors

- No need of dry-lubricated gearboxes (decrease of mechanism complexity and cost);
- Finer resolution;

Disadvantages wrt Stepper Motors

- Lower repeatability, need for displacement sensors (no need if optical feedback available);
- Applicability to space environment to be demonstrated, especially for vibrations and life (friction element). ESA

Optional: tip tilt mechanism

- TDA run to fulfill EChO study needs
- Less stringent requirement might be foreseen here wrt:
  - minimum operating temperature
  - Accuracy and resolution
  - Stability vs. time
  - Drift
- Higher operating frequency (well below the resonance of the mechanism)
- Possibly a follow on on this development could be initiated to tune the performances of the Cryo Tip Tilt Steering Mechanism (Cedrat Technology)

ARIEL

Power

Session 6 – IFP
ESTEC, 8th of July 2015

Prepared by the CDF* Team

(*) ESTEC Concurrent Design Facility

Main Mission Constraints

- Eclipse free mission, in L2
- Max solar aspect angle of +/- 25° on one axis, and +/- 5° on the other
    - Resulting WC SAA = 25.5°
- Relatively soft radiation environment (as per PLATO radiation analysis)
- 6 years max mission duration
- Bus voltage should be stable during observation phases, to guarantee constant thermal dissipation inside payload units (thermal stability)

Power Budget

- Average consumption, max value for SCDM

					LM	SCDM	SBM	IOM	SAM	ACM	SCDMP	IOCM	SM
28/07/15		LCLs	Pon (W)	Pstby (W)	Pavg	Pavg	Pavg	Pavg	Pavg	Pavg	Pavg	Pavg	Pavg
AOGNC	1	12	326 W	84 W	0 W	113 W	110 W	113 W	6 W	110 W	110 W	110 W	6 W
COMMS	1	8	64 W	10 W	10 W	28 W	15 W	15 W	64 W	15 W	64 W	64 W	15 W
CPROP	1	6	502 W	53 W	1 W	53 W	53 W	53 W	91 W	53 W	53 W	53 W	57 W
DHS	1	4	32 W	23 W	20 W	32 W	32 W	32 W	32 W	32 W	32 W	32 W	32 W
MEC	1	4	6 W	0 W	0 W	0 W	0 W	0 W	0 W	0 W	0 W	0 W	0 W
TCS	1	4	820 W	0 W	50 W	277 W	275 W	206 W	50 W	275 W	236 W	154 W	236 W
POW	1	0	20 W	20 W	20 W	20 W	20 W	20 W	20 W	20 W	20 W	20 W	20 W
INS	1	4	65 W	0 W	0 W	0 W	0 W	65 W	0 W	0 W	0 W	65 W	0 W
Sub Total		42	1835 W	190 W	102 W	523 W	506 W	504 W	263 W	506 W	516 W	499 W	365 W
System Margin	30 %	13	551 W	57 W	30 W	157 W	152 W	151 W	79 W	152 W	155 W	150 W	110 W
Harness + Distrib Losses	3 %		54 W	5 W	2 W	15 W	15 W	15 W	7 W	15 W	15 W	14 W	10 W
Total		55	2440 W	252 W	135 W	696 W	672 W	670 W	350 W	672 W	685 W	663 W	485 W

- 523 W during SCDM, 696 W with margins
  - System 30 %, distribution and harness 3 %
  - Solar array sized for that power

concurrent design facility

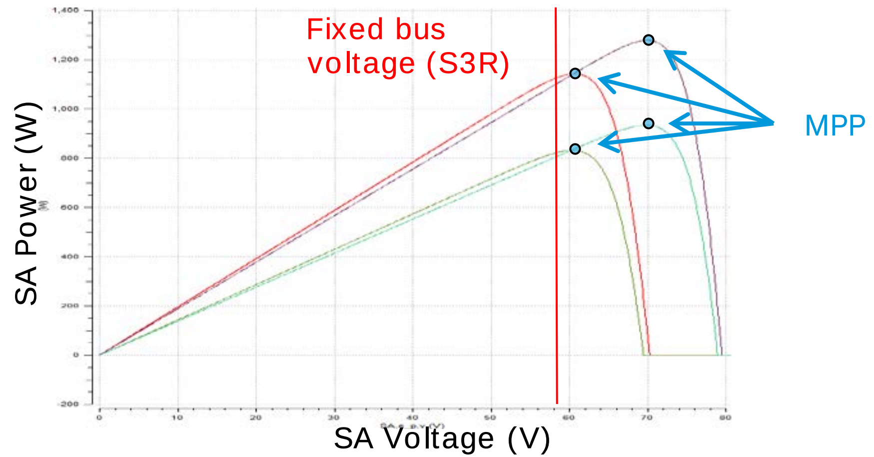
Trade off 1 : MPPT vs S3R

- MPPT : Maximum Power Point Tracking
  - Tracks and extracts the maximum possible power out of the array
  - 95 % efficiency, 5 % dissipation
  - More complex, heavier

- S3R : Sequential Switching Shunt Regulator
  - Based on direct energy transfer
  - Works at a fixed panel operating voltage, not necessarily at MPP
  - 97 % efficiency, 3 % dissipation
  - Less complex and lighter.

Trade off 1 : MPPT vs S3R

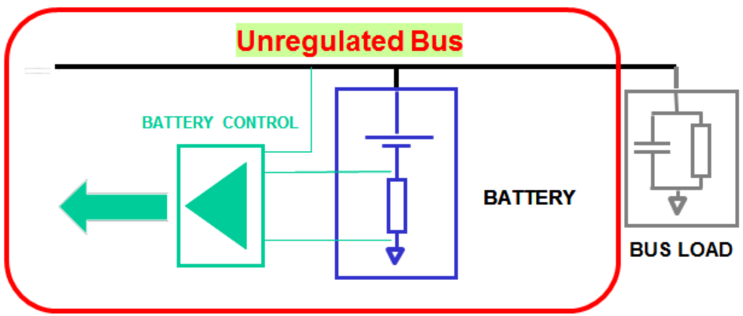
- SA Electrical Parameters vary with environmental conditions
  - SA temperature, illumination & SAA, radiations…



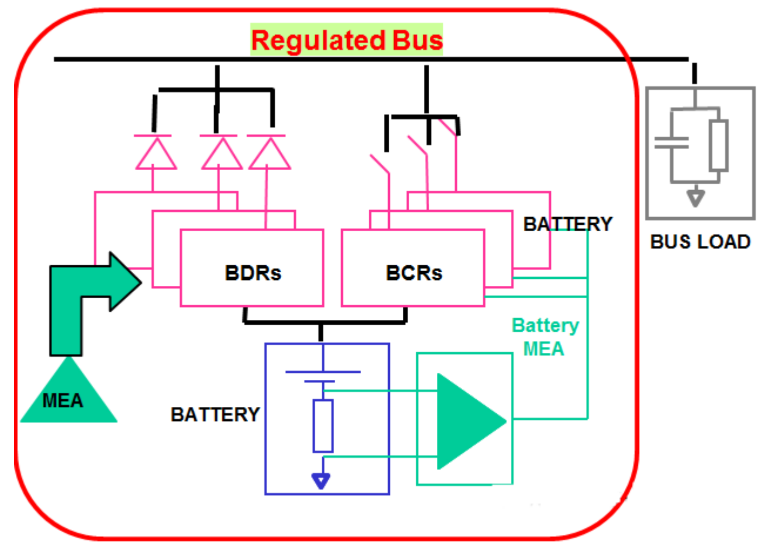
  - For ARIEL, MPPT is chosen to decrease SA area

Trade off 2 : Unregulated vs Regulated

- “Unregulated” and “Regulated” refers to bus architecture



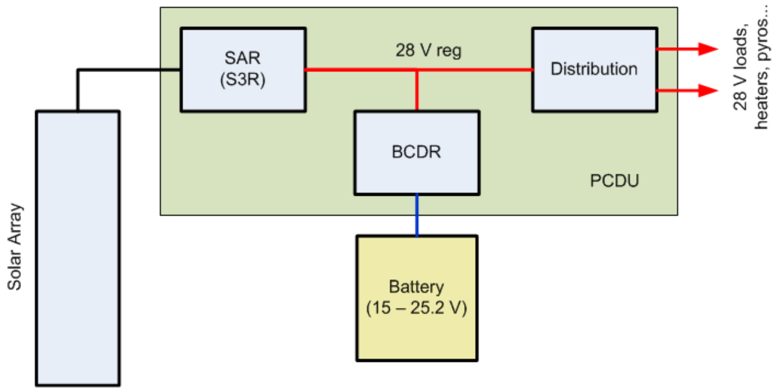
- Both topologies capable of providing regulated voltage if the right conditions are met



- Unregulated bus topology is adequate if Psa > Psat during observation phase, ie Array is sized for worst case peak power during obs phase. Peak power is for at least 5 seconds (assumed)

Trade off 2 : Unregulated vs Regulated

- Insufficient data at this point to conclude
  - Both solutions "work", winner in terms of size unclear at this point
  - Low impact on mass/dimensions of EPS
  - MPPT will have to be considered if main criteria is minimum SA size (because of space constraints on sunshield)
- For this study, regulated option chosen
  - Uncertainty on worst case consumption during observation phase
  - Bus kept in regulation even during battery discharge



SA Sizing

- Radiation dose considered is 5E14 MeV on Voc, 2.5E14 MeV on Isc (> PLATO levels)
- Additional degradation parameters:

Current Degradation		
Cell Mismatch	0.99	*random*
Calibration	0.97	*random*
Cover Glass	0.99	*direct*
Pointing error (°)	0	*direct (°)*
UV degradation	0.985	*direct*
Micrometeorites	0.99	*direct*
Random	0.99	*random*
Miscellaneous	1	*direct*
Total Loss Factor	0.934	-
Voltage Degradation		
Random	1	*random*
Miscellaneous	1	*direct*
Harness Vdrop (V)	1.5	*direct (V)*
Blocking Diode Vdrop (V)	0.8	*direct (V)*

SA Sizing

- 4.25 m2 Array seems sufficient (6.8 kg, 8.2 kg with margin)
- 24s44p configuration, 3G30 Cells from Azur Space

Insolation and SAA		
Reference Solar flux	1367	*W/m2*
Sun to S/C distance	**1.028187**	*A.U.*
Solar Flux @ distance	1293.1	*W/m2*
SAA	**25.5**	°
Cosine	0.903	-
Solar flux received	1167.1	*W/m2*

Parameter	Value
Manufacturer	Azur Space (GER)
Cells	3G30
Cells in series	24
Strings in parallel	44
EoL power (1.028 AU)	711 W (@ SA I/F, 98°C, 1 string failure, 25.5°SAA)
Mass (PVA only, no margin)	6.8 kg
Total Panel Area	4.25 m2

- Body mounted cells -> no radiation cooling possible from the back -> cells run hot

- Area available for solar cells ~ 4.7 m2 -> 10 % growth margin available

Battery Sizing

- Battery sized for Launch Mode (101 W, 134 W with margins)

- 1h30 assumed for LM
  - 283 Wh BoL needed, assuming 80 % DoD max, 5 % capacity loss and 6 % BDR loss
  - Li-Ion technology
    - 18650HC (ABSL), VES16 (SAFT) or MPS176065 (SAFT)
    - About 4.4 kg single battery module could be sufficient

PCDU Sizing

- PCDU Sized for regulated bus, S3R
  - 64 x 1.5 A LCL
  - 16 x 5 A LCL
  - 16 x pyro lines
  - 1000 W S3R capability
  - 450 W BCDR
  - Mass = 11.5 kg (manufacturer = Terma)

- Great spread in PCDU mass depending on manufacturer
  - 15 kg budgeted for in ARIEL
  - 16.5 kg including 10 % margin

Sizing summary

- Solar Array
  - Single plane, body mounted
  - 4.5 m2, 24s44p, 8.2 kg with margin
- Battery
  - 8S10P 18650HC or similar, ~ 500 Wh
  - 4.4 kg, 5.8 kg with margin
  - 220 x 180 x 110 mm
- PCDU
  - S3R, regulated bus
  - 16.5 kg
  - Dim = 190 x 270 x 230 mm

ARIEL

Session 6 - Thermal

IFP
ESTEC, 8th July 2015

Prepared by the CDF* Team

(*) ESTEC Concurrent Design Facility

Outline

- Requirements
- Design Drivers
- SVM Thermal Design
- PLM Thermal Design
- Analysis results
- Mass budget
- Cryocooling options
- Conclusion

Requirements

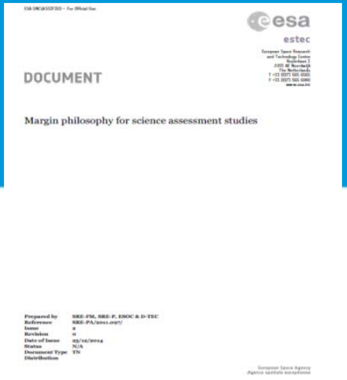
- PLM
  - Telescope **< 77K**
  - Optical bench **< 55K**
  - Detectors
    - FGS **15mW < 55K**
    - Spectro **15mW @ 40K**
  - FEEs (FGS and Spectro)
    - FGS **65mW < 55K**
    - Spectro **20mW < 55K**
- Dissipations are based on the proposal and already include margins

Requirements

- SVM
  - Maintain all the units in their acceptable temperature range
  - The thermal I/F with the PLM shall be:
    - **As stable as possible**
    - **As cold as possible**

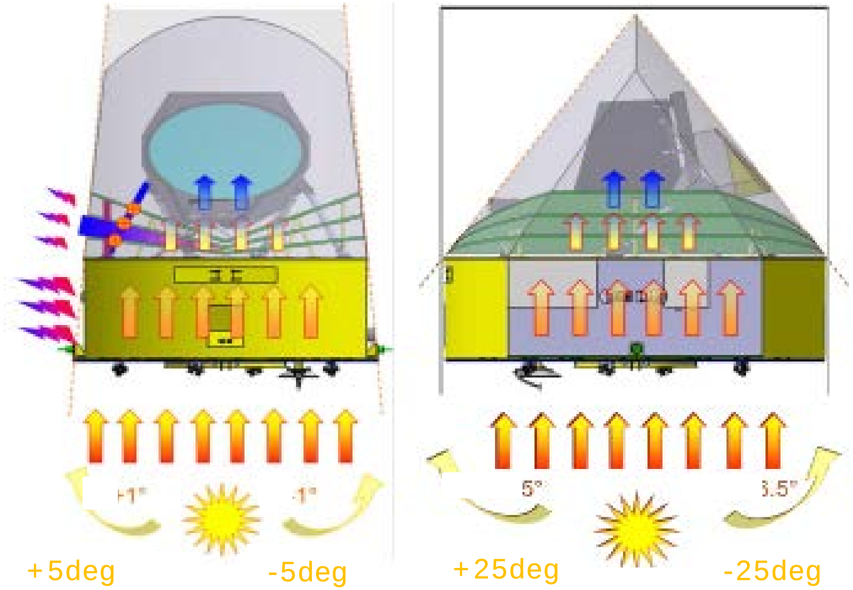
→ The SVM will be in charge of contributing to the stringent thermal stability of the PLM module → 'oversized' radiators + compensation heaters to maintain **SVM@10°C +/-TBD°C**

Design Drivers



- Orbit and Attitude
  - L2
  - +/- 25deg in one axis
  - +/- 5deg in others

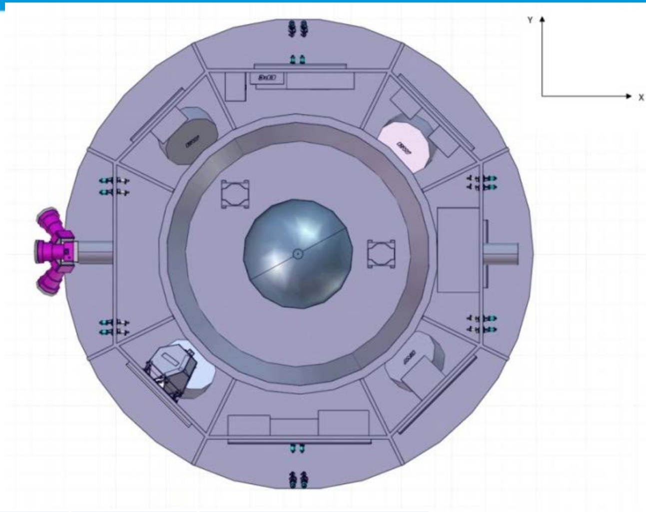
- Margin Philosophy
  - V-Grooves
    - 5K (uncertainties) + 5K (Margins)
    - Shall be testable (including uncertainties + Margins) on ground with a T_{sink}@30K
  - Active Coolers:
    - Uncertainties calculated considering:
      - Margins on dissipation *(→ already accounted for in the proposal)*
      - +/-100% conductivity of the Harness
      - +/- 100% Conductance of GFRP
    - 50% system margin on heat load + uncertainties
    - 20% margin on total capacity of the cooler



SVM Thermal Design

- Standard equipment, e.g. PCDU, Battery, OBDH,...
  - No special thermal requirements

- Standard design, mainly passively based
  - Accommodation driven by the volume and dissipation:
    - Most dissipative units (COMS, CRYO) put on the sides with a solar incident angle <5º (+/-Y)
    - Others were accommodated preferably in the corner enclosures.



Enclosure	Units	Radiator T° (°C)	Radiator Coating	Solar absorptivity	Epsilon	Sink Temp (K)	Dissipation (W)	Radiator Area (m2)	Effect of the Sun (W)
+X	RTU	10	SSM/OSR	0.15	0.8	211	20	0.136	12.16
+X-Y	RW, OBC	10	SSM/OSR	0.15	0.8	193	33	0.193	12.21
-Y	Cooler, ICU, FGS WE	10	White Paint	0.25	0.92	156	120	0.510	15.72
-X-Y	RW, Gyro	10	SSM/OSR	0.15	0.8	193	45	0.262	16.64
-X		N/A	MLI	0.4	0.7	N/A	N/A	N/A	N/A
-X+Y	RW, Batt	10	SSM/OSR	0.15	0.8	193	26	0.151	9.61
+Y	Comms	10	White Paint	0.25	0.92	156	64	0.273	8.42
+X+Y	RW, STR EU	10	SSM/OSR	0.15	0.8	193	32	0.186	11.83

SVM Thermal Design

- 2 Types of Active Thermal Control:
  - Compensation (Interface) Heating → ensures in operation a stable I/F to the PLM
  - Survival Heating → ensures in all the modes that the temperature inside the SVM is maintained above -20ºC.

- Compensation Heating sized to counteract two phenomena:
  - Variation of Sun Incidence on the radiators: ~100W.
  - Variation of Dissipation in the different modes.

- Survival Heating is sized in order to guarantee at least ~310W inside the SVM in all modes to maintain the units above -20ºC

Safe Mode	Total Radiator Area	Tsink	SVM T° (°C)	Necessary Power	Dissip	Heating Power
	1.71	3	-20	308.94	72.48	236.46

SVM Thermal Design

- Active Thermal Control Power Consumption:

		Pav I/F Heating (W)	Pav Survival Heating (W)	Duty Cycle I/F Heating (with On Power = **290W**, Off = 0)	Duty Cycle SURV Heating (with On Power = **315W**, Off = 0)
Safe Mode	SM	0.00	236.46	0.00	0.75
Launch Mode	LM	0.00	50.00	0.00	0.16
SVM Commissioning & Decontamination Mode	SCDM	0.00	115.55	0.00	0.37
Stand-by Mode	SBM	220.00	0.00	0.76	0.00
Instrument Operations Mode	IOM	149.73	0	0.52	0.00
Sun Acquisition Mode	SAM	0.00	50.00	0.00	0.16
Active Cooling Mode	ACM	220.00	0	0.76	0.00
SVM Commissioning & Decontamination Peak Power	SCDMP	0.00	76.09	0.00	0.24
Instrument Operations Comms Mode	IOCM	100.00	0	0.34	0.00

SVM – PLM I/Fs

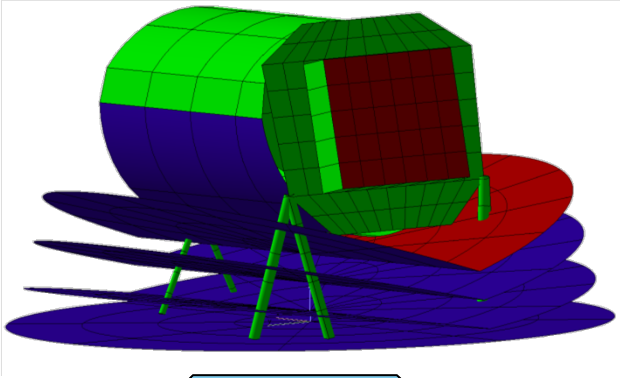
- Cryocooler and CDE embarked in the SVM
  - Heat generated by cryocooler to be radiated at SVM level
  - FPAs cooled thanks to a Joule-Thomson loop (stainless steel piping needs to be routed from the SVM to the PLM)
  - Micro vibrations on PLM minimized

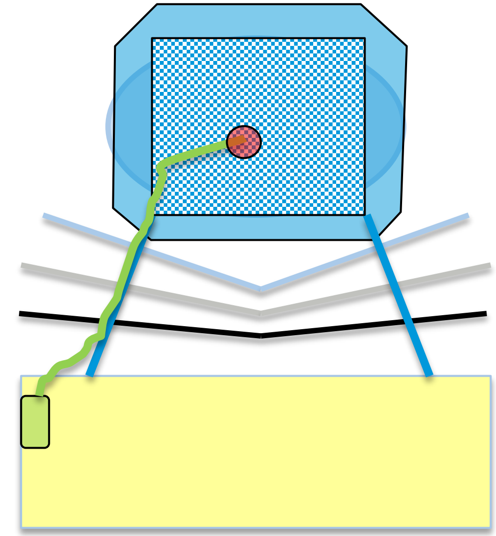
- SVM top platform
  - PLM sunshield
    → no sunlight to PLM
  - Temperature stabilized @ 10°C by active heating
    → PLM temperature variation minimized
    → PLM temperature gradients minimized

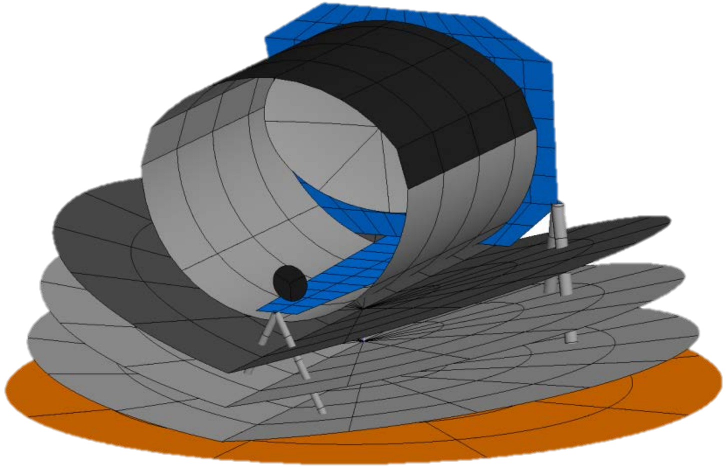
PLM – Thermal Design

- 3 Temperature Levels (70K, 55K and 40K) obtained thanks to the following stages:
  - 3 V-Grooves to cool down to ~70K and pre-cool the IOB.
  - 1 Open Honeycomb radiator on the OB ($0.45 m^2$) + Top part of the Baffle to cool down to 55K (Straps connect box to Radiator).
  - 2x1 (redundant) Neon Joule-Thomson Cooler to provide the 40K Stage.

- Relies heavily on (simplified) Planck Heritage.



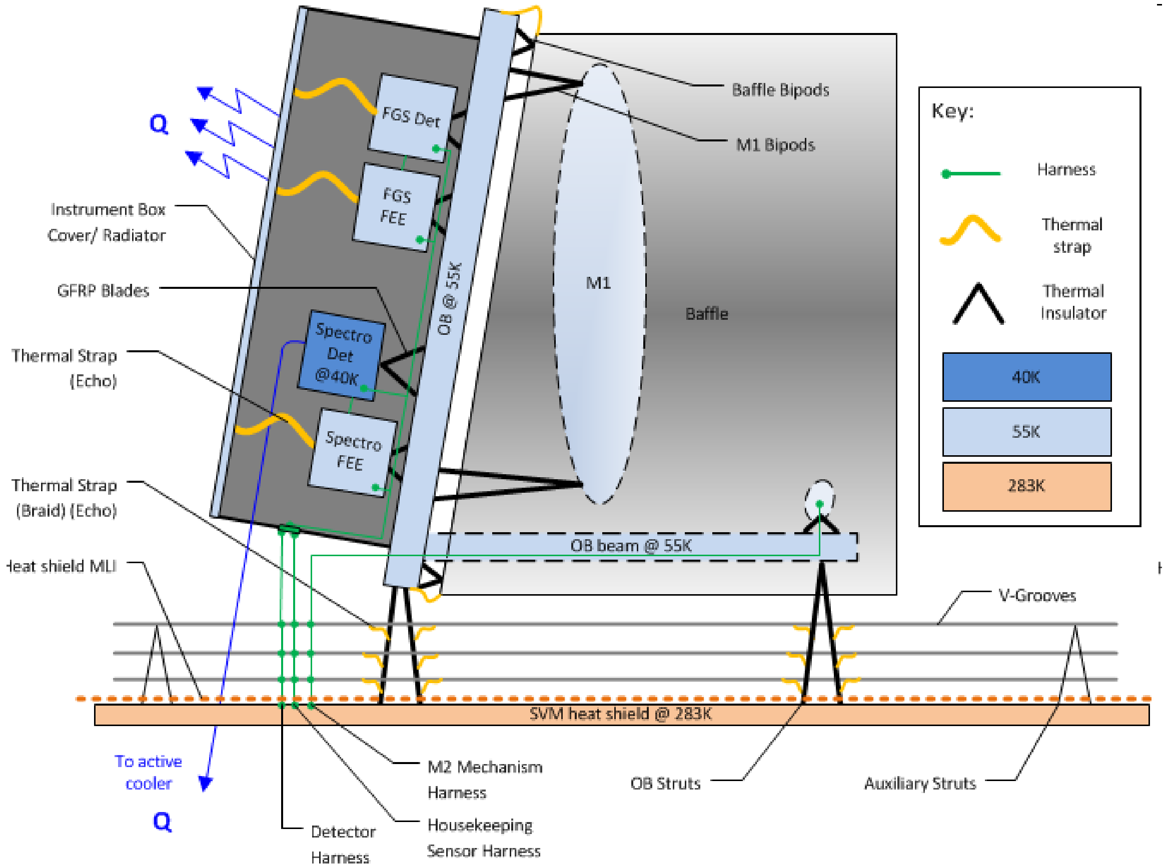




PLM – Thermal Design

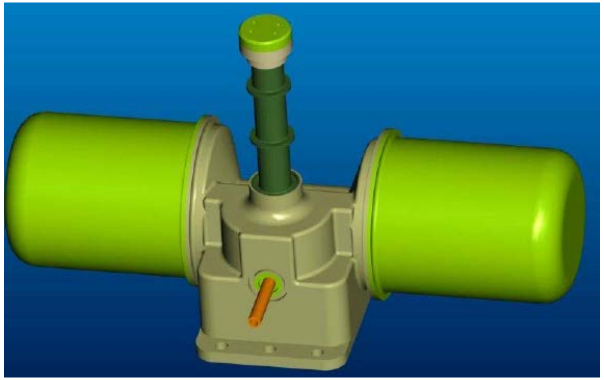
Thermal design drivers:

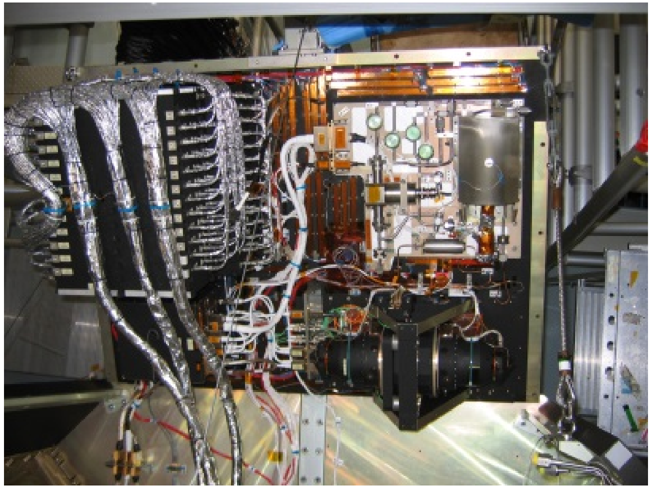
- Minimize parasitic HFs from SVM!
  -> Conductivity of struts as low as possible
- Use VGs as intermediate cooling stages for struts & harness
  -> highly conductive thermal straps between struts/harness and VGs
- Minimize spatial thermal gradient between M2 and OB
  -> adjust struts geometries to balance parasitic homogeneously



PLM – Cooler

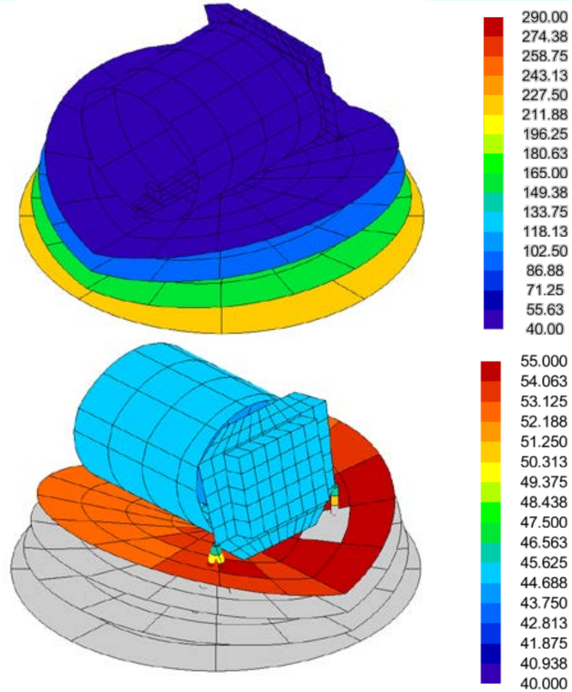
- Cooler Based on:
  - Small Scale Cooler development for the Compressor Technology (~0.5kg)
  - The ancillary equipment of the 2K JT Cooler development.





PLM analysis results – test case

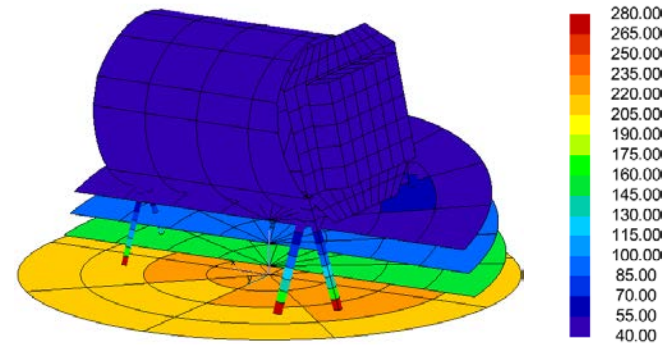
	Group	Power [mW] QI	Power [mW] QR	Prediction (calc +/- 10K) cold	Temperature [K] min	Temperature [K] Ave	Temperature [K] MAX	hot	Spacial gradient Ave - [mK]	Spacial gradient Ave + [mK]	Spacial gradient total [mK]
SVM	Conductive sink (SMV sunshield)					283					
	Sunshiled - Rear MLI	0		204	214	220	224	234	-5756	+4043	+9799
PLM	Aux struts	0		51	61	107	169	179			
	OB struts	0		36	46	108	274	284			
	VG 1	0		139	149	155	162	172	-5982	+7273	+13255
	VG 2	0		83	93	94	95	105	-835	+901	+1736
	VG 3	320		42	52	53	56	66	-1164	+2599	+3762
	Optical bench	0		35	45	45	45	55	-82	+56	+138
	Optical bench, beam	0		35	45	45	46	56	-79	+154	+233
	Inst_Box, int	0		35	45	45	45	55	-5	+6	+12
	Inst_Box, ext	0		35	45	45	45	55	-5	+6	+12
	FGS, Det	15		35		45		55			
	FGS, FEE	65		35		45		55			
	Spectro, Det	15	-26			40					
	Spectro, FEE	20		35		45		55			
	M1	0		34	44	44	44	54	-0	+0	+1
	M2	0		36	46	46	46	56	-0	+0	+1
	Baffle	0		35	45	45	45	55	-144	+183	+327
	Radiative Sink					30					
	Total dissipation QI [mW]					435					
	Total HTR Power QR [mW]					-26					

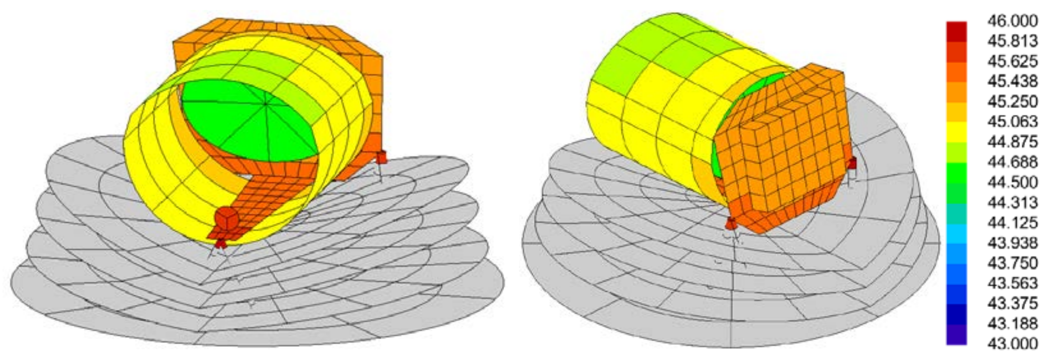


- Passive cooling on the FEEs & FPA Det is sufficient
- Active detector cooling requ. ~26mW cooling power (calculated)

Parasitic heat fluxes - test case

	Group	Power [mW] QI	Power [mW] QR	calculated Temperature [K] min	calculated Temperature [K] Ave	calculated Temperature [K] MAX	Parasitic heat fluxes [mW] GL
VG1	Total VG1	*0*		**149**	*155*	**162**	5815
	- OB struts			**160**	*165*	**168**	5625
	- Aux Struts			**152**	*160*	**169**	157
	- Harness			**162**	*162*	**162**	33
VG2	Total VG2	*0*		**93**	*94*	**95**	570
	- OB struts			**94**	*95*	**95**	425
	- Aux Struts			**97**	*99*	**101**	128
	- Harness			**95**	*95*	**95**	17
VG3	Total VG3	*320*		**52**	*53*	**56**	751
	- OB struts			**53**	*54*	**56**	524
	- Aux Struts			**61**	*62*	**63**	207
	- Harness			**54**	*54*	**54**	21
OB	OB			**45**	*45*	**46**	51
	- OB struts 1				**46**		49
	- OB struts 2				**46**		100
	- OB struts 3				**46**		115
	- harness			**45**	*45*	**45**	5
	- baffle			**45**	*45*	**45**	-218
FGS Det		*15*			**45**		-15
	- mounting				**45**		0
	- harness				**45**		0
	- thermal strap				**45**		-15
FGS FEE		*65*			**45**		-65
	- mounting				**45**		-9
	- harness from OB				**45**		0
	- harness to Det				**40**		0
	- thermal strap				**45**		-56
Spectro Det		*15*	*-26*		**40**		9
	- 3 GFRP bades				**45**		4
	- harness				**45**		5
Spectro FEE		*20*			**45**		-20
	- mounting				**45**		-5
	- harness from OB				**45**		0
	- harness to Det				**40**		-5
	- thermal strap				**45**		-9





PLM analysis results – orbit case

	Group	Power [mW] QI	Power [mW] QR	Prediction (calc +/- 10K) cold	Temperature [K] min	Temperature [K] Ave	Temperature [K] MAX	Prediction (calc +/- 10K) hot	Spacial gradient Ave - [mK]	Spacial gradient Ave + [mK]	Spacial gradient total [mK]
SVM	Conductive sink (SMV sunshield)					**283**					
SVM	Sunshiled - Rear MLI	*0*		204	**214**	*220*	**224**	234	*-5757*	*+4044*	*+9801*
PLM	Aux struts	*0*		50	**60**	*106*	**169**	179			
PLM	OB struts	*0*		34	**44**	*107*	**274**	284			
PLM	VG 1	*0*		139	**149**	*155*	**162**	172	*-5983*	*+7273*	*+13255*
PLM	VG 2	*0*		83	**93**	*94*	**95**	105	*-829*	*+887*	*+1715*
PLM	VG 3	*320*		41	**51**	*52*	**55**	65	*-1177*	*+2613*	*+3789*
PLM	Optical bench	*0*		33	**43**	*43*	**43**	53	*-91*	*+62*	*+152*
PLM	Optical bench, beam	*0*		33	**43**	*44*	**44**	54	*-90*	*+176*	*+266*
PLM	Inst_Box, int	*0*		33	**43**	*43*	**43**	53	*-6*	*+6*	*+12*
PLM	Inst_Box, ext	*0*		33	**43**	*43*	**43**	53	*-6*	*+6*	*+12*
PLM	FGS, Det	*15*		33		**43**		53			
PLM	FGS, FEE	*65*		33		**43**		53			
PLM	Spectro, Det	*15*	*-22*			**40**					
PLM	Spectro, FEE	*20*		33		**43**		53			
PLM	M1	*0*		32	**42**	*42*	**42**	52	*-0*	*+1*	*+1*
PLM	M2	*0*		34	**44**	*44*	**44**	54	*-0*	*+0*	*+1*
PLM	Baffle	*0*		33	**43**	*43*	**43**	53	*-156*	*+201*	*+357*
	Radiative Sink					**8**					
	Total dissipation QI [mW]					**435**					
	Total HTR Power QR [mW]					**-22**					

concurrent design facility

Parasitic heat fluxes – orbit case

	Group	Power [mW] QI	Power [mW] QR	calculated Temperature [K] min	calculated Temperature [K] Ave	calculated Temperature [K] MAX	Parasitic heat fluxes [mW] GL
VG1	Total VG1	*0*		**149**	*155*	**162**	5812
	- OB struts			**160**	*165*	**168**	5623
	- Aux Struts			**152**	*160*	**169**	156
	- Harness			**162**	*162*	**162**	33
VG2	Total VG2	*0*		**93**	*94*	**95**	558
	- OB struts			**94**	*94*	**95**	416
	- Aux Struts			**97**	*99*	**101**	126
	- Harness			**95**	*95*	**95**	16
VG3	Total VG3	*320*		**51**	*52*	**55**	757
	- OB struts			**52**	*53*	**55**	526
	- Aux Struts			**60**	*61*	**62**	210
	- Harness			**53**	*53*	**53**	21
OB	OB			**43**	*43*	**44**	56
	- OB struts 1				**44**		52
	- OB struts 2				**44**		107
	- OB struts 3				**44**		122
	- harness			**43**	*43*	**43**	5
	- baffle			**43**	*43*	**43**	-231
FGS Det		*15*			**43**		-15
	- mounting				**43**		0
	- harness				**43**		0
	- thermal strap				**43**		-15
FGS FEE		*65*			**43**		-65
	- mounting				**43**		-9
	- harness from OB				**43**		0
	- harness to Det				**40**		0
	- thermal strap				**43**		-56
Spectro Det		*15*	*-22*		**40**		6
	- 3 GFRP bades				**43**		3
	- harness				**43**		3
Spectro FEE		*20*			**43**		-20
	- mounting				**43**		-6
	- harness from OB				**43**		0
	- harness to Det				**40**		-3
	- thermal strap				**43**		-11

Sizing of the Active Cooler

- Heat Loads at 40K
  - Dissipation: 15mW
  - Parasitics from the Blade: ~6mW
  - Parasitics from the Harness: ~6mW.
  - → 27mW without uncertainties and margins.
  - → ~35mW considering uncertainties (+100% for blades, and +100% for harness)
  - → 53mW considering uncertainties and margin

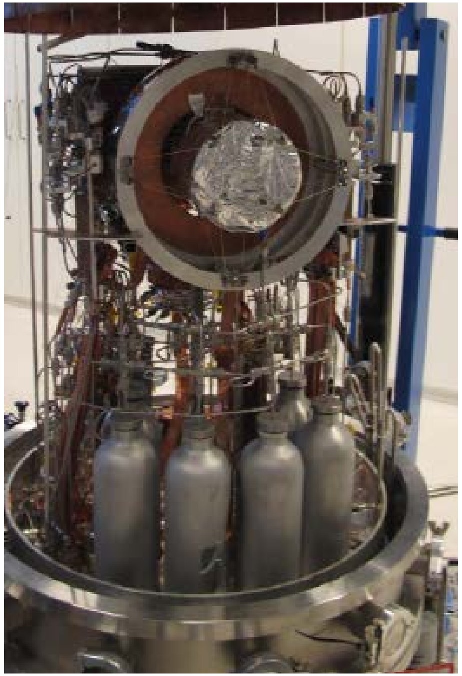
- At first approach shall be feasible with a Small Scale Cooler compressor (<40W of consumption). 2 coolers are considered in the model for redundancy/margin and 320mW intercepted at 65-70K

Mass Budget

Assembly Level	ITEM		Mass (kg or kg/m²)	Quantity (items or m²)	Subtotal (kg)	Maturity Marging (%)	Subtotal (kg)
PLM	VGs coating	VDA SLI, 5 sides [kg/m²]	0.040	24.000	0.96	20%	1.15
		Open Honeycomb, upper side [kg/m²]	0.680	4.916	3.34	20%	4.01
	VGs, thermal straps		0.100	18.000	1.80	20%	2.16
	Baffle Coating	VDA SLI, lower part [kg/m²]	0.040	2.311	0.09	20%	0.11
		Open Honeycomb, upper part [kg/m²]	0.680	1.763	1.20	20%	1.44
	Optical bench coating	Black Paint	0.400	1.185	0.47	20%	0.57
	FEEs cooling	thermal straps	0.100	2.000	0.20	20%	0.24
	FPAs mounting	GFRP waschers/bades	0.022	6.000	0.13	20%	0.16
	Electrical Heaters, incl. harness	(Decon, Stabilization, ...)	2.500	1.000	2.50	20%	3.00
	PLM total		-	-	**10.70**	-	**12.84**
SVM	Sunshield	MLI 500 g/m2	0.500	6.16	3.08	20%	3.69
	Electrical Heaters, incl. harness	(SunShield stabilization, unit, survival, ...)	2.500	1.000	2.50	20%	3.00
	SVM MLI	MLI 500 g/m2	0.500	15.049	7.52	20%	9.03
	Radiator OSR		0.700	2.750	1.93	20%	2.31
	Thermal painting	all units	0.400	10.000	4.00	20%	4.80
	Thruster Insulation		0.500	3.000	1.50	20%	1.80
	Tanks Insulation (MLI/Standoffs)		0.500	1.701	0.85	20%	1.02
	Radaitor heat Pipes		0.500	6.40	3.20	20%	3.84
	Cryo Cooler	Cooler	6.000	1.00	6.00	20%	7.20
		CDE	2.000	1.00	2.00	20%	2.40
	SVM total		-	-	**32.58**	-	**39.09**
	PLM & SVM total		-	-	**53.98**	-	**64.77**

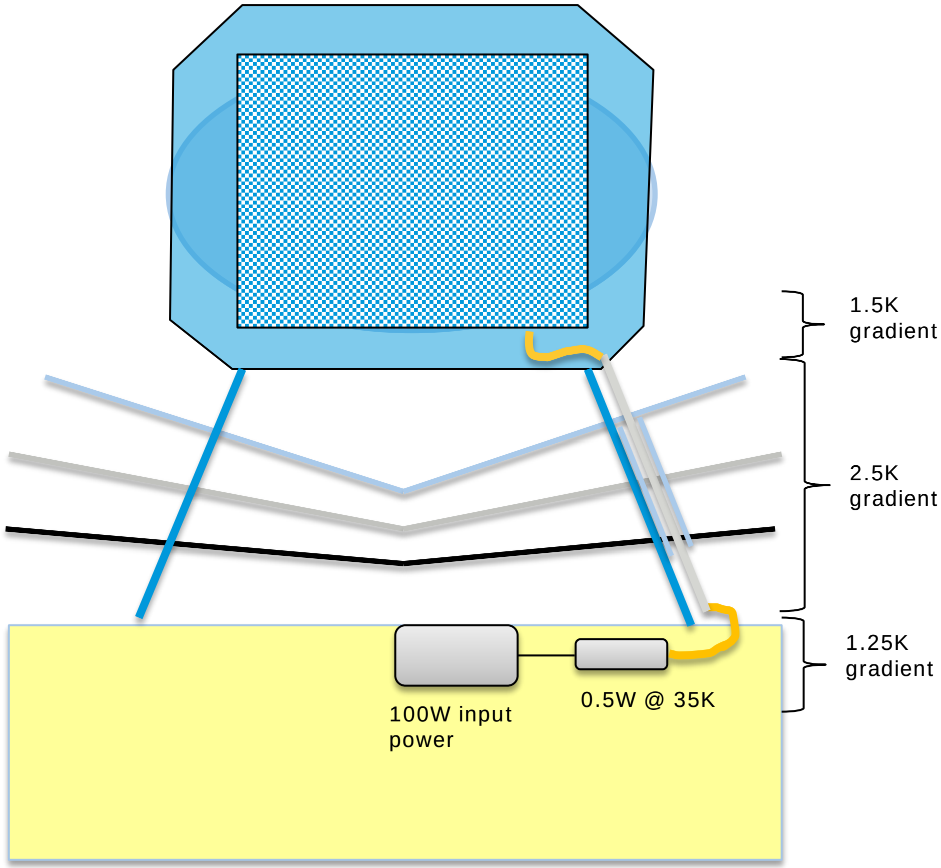
Cryocooling Options

- Cryocooling option:
  - Sorption Cooler Neon JT instead of Mechanical Cooler
    - ☺ Vibration Free
    - ☹ Sorptions Cells to be installed on the V-Grooves (~3 kg)
    - ☹ Heat Loads Peaks of ~4W @ 180K (and maybe smaller peaks at lower temperature) to be analyzed



Cryocooling Options

- Cryocooling option:
  - 2 Stage Pulse Tube in the SVM + Flexible Thermal Link + 1m Pure Aluminum Rod + Flexible Thermal Link:
    - ☺ 80% derived from the MTG cooler (only the PT configuration changes)
    - ☺ Thermodynamically optimized
    - ☺ 'Easily' reaches cooling power beyond 400mW (if the heat loads grow – or we want to get rid of the radiator)
    - ☹ Needs a Heat Transportation solution
      - Gas Loop using the He of the Cooler (solution being studied by ALAT, TRL3, impact on the performance)
      - Solid Conduction
    - ☹ Constraint on the orientation (Horizontal cold finger)
    - ☹ Redundancy concept impact the budget.
    - ☹ Microvibrations transmitted to the FPA



Conclusion

- Feasibility of current thermal design is shown
  - End to End analysis of PLM
  - Parasitic heat loads from SVM via OB struts driving the thermal PLM design
  - Trimming capabilities available on PLM increasing the heat radiation to deep space of the
    - baffle and
    - optical bench
  - Sizing for test case incl. 30K sink temperature

- Cryocooling system is judged as feasible
  - Multiple Cooling options identified.
  - Baseline accommodates a redundant cooler

ARIEL

Structures

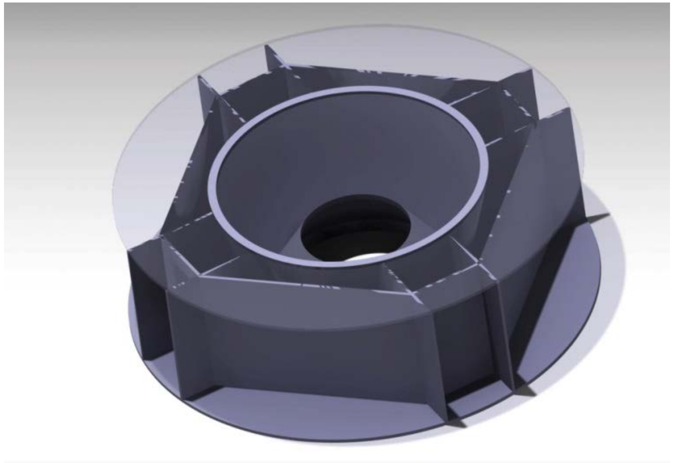
Session 8 – IFP
ESTEC, 8th of July 2015

Prepared by the CDF* Team

(*) ESTEC Concurrent Design Facility

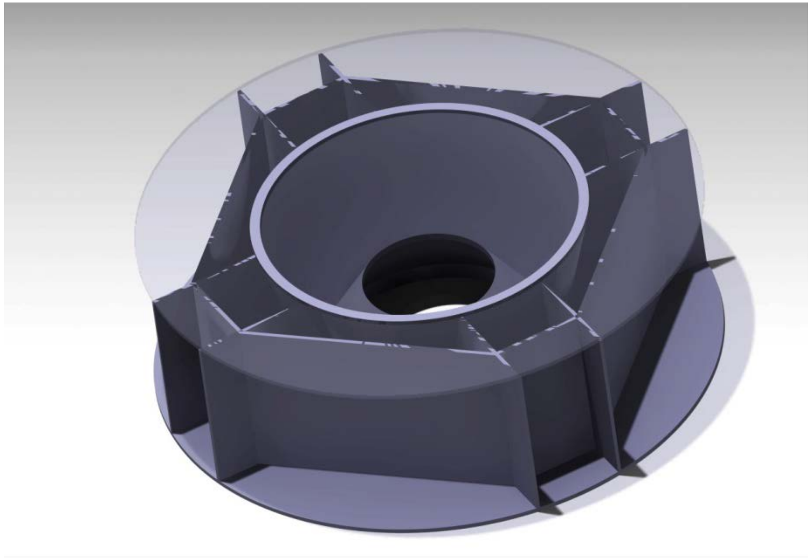
SVM – Structural Layout

- CFRP/Al-honeycomb sandwich
  - 2 x 1.2 mm CFRP faceskin (1620 kg/m^3)
  - 20 mm 3/16–5056–.0007 (32 kg/m^3)
  - 2 x 0.2 kg/m^2 adhesive layers
  - Total areal density of sandwich 4.928 kg/m^2
  - Based on CAD surface area
- Al launch adapter I/F ring (not including clampband)



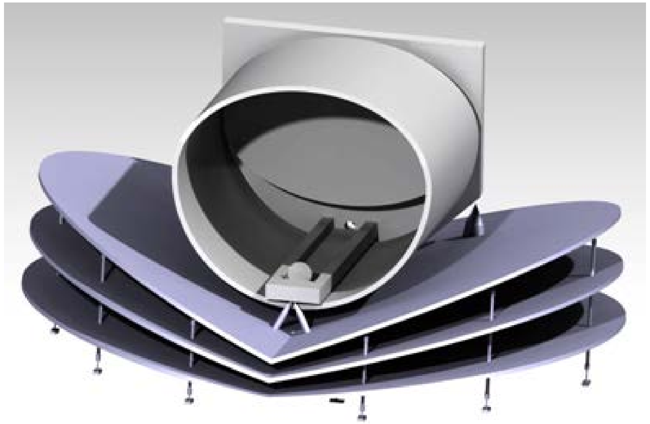
SVM - Massbudget

Component	*Mass (kg)*
Octogonal Structure	26.84774
Bottom Plate	24.82726
Top Plate	19.60358
Shear Pannels	23.02362
Tank Support structure	7.189952
Central cone	18.12518
Bolts, brackets, misc (20% of above)	23.92347
Launcher Interface Ring	33.47755
Total SVM Mass w/o margin	**177.0184**



PLM – Structural Layout

- TOB & metering structure: SiC (27 kg/m^2, c.f. Planck mirror)
- Baffle: CFRP-skin/Al-honeycomb sandwich (as of SVM)
- 2 x Bipods (M1 side): GFRP, d=50 mm, t=4 mm, E=49 GPa (isotropic)
- 1 x Bipod (M2 side): GFRP, d=30 mm, t=3 mm, E=49 GPa (isotropic)
- 8x V-groove support struts: GFRP, d=15 mm, t=1.5 mm, E=49 GPa (isotropic)
- Bipod & support struts endfittings: Aluminium
- 3 x V-grooves: Al-skin/Al-honeycomb sandwich:
    - 0.3 mm Al faceskins, E=72 GPa
    - 20 mm 3/16–5056–.0007 (32 kg/m^3)
    - 0.2 kg/m^2 adhesive layers
- 42 x V-groove I/Fs: Aluminium, \`Z\`shaped
- Instrument housing: Al-skin/Al-honeycomb sandwich



PLM – Frequency Requirement

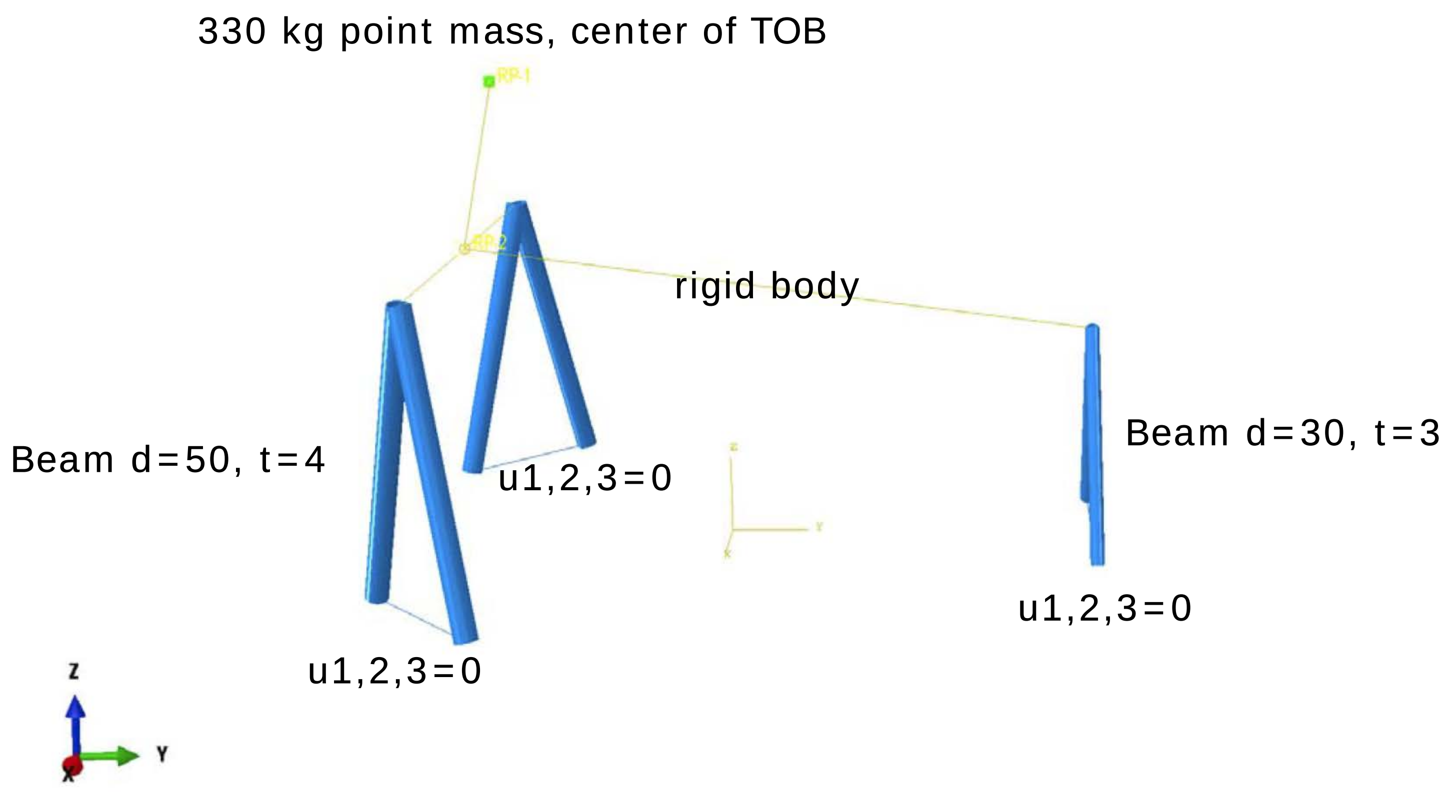
Soyuz frequency requirement:

- **Lateral frequencies**
  - The fundamental (primary) frequency in the lateral axis of a spacecraft cantilevered at the interface must be as follows with an off-the-shelf adapter:
    - ≥ 15 Hz
- **Longitudinal frequencies:**
  - The fundamental (primary) frequency in the longitudinal axis of a spacecraft cantilevered at the interface must be as follows with an off-the-shelf adapter:
    - ≥ 35 Hz

ARIEL PLM freq. req.	SOYUZ	Factor $\sqrt{2}$ **
Lateral	15	21.2
Longitudinal	35	49.5

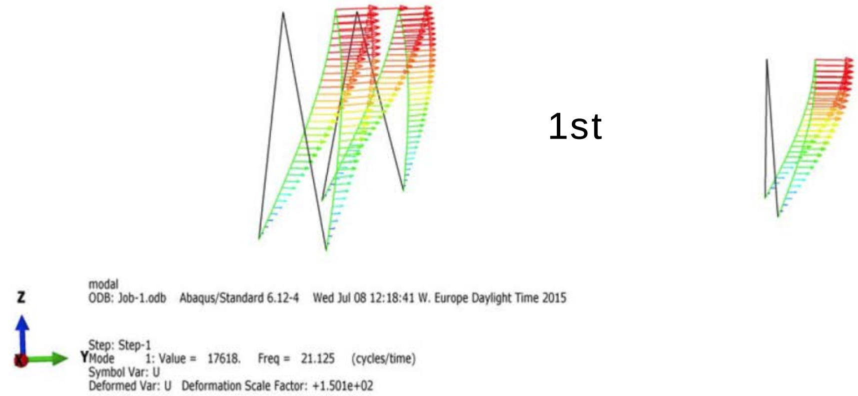
** the PLM stiffness requirements have been derived from the spacecraft stiffness requirement by using a frequency separation factor of $\sqrt{2}$.

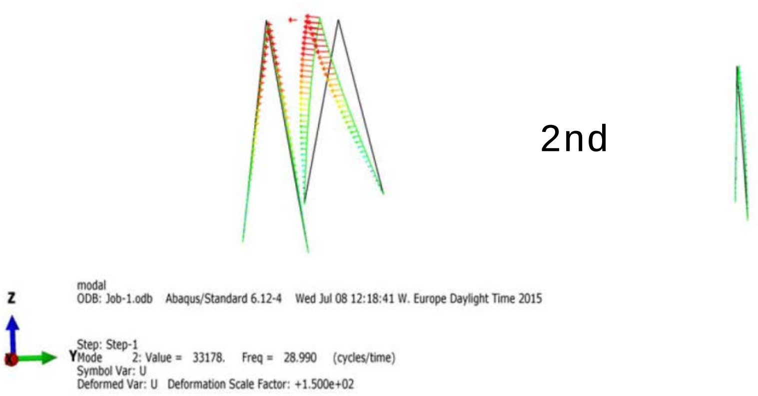
PLM – Bipods analysis

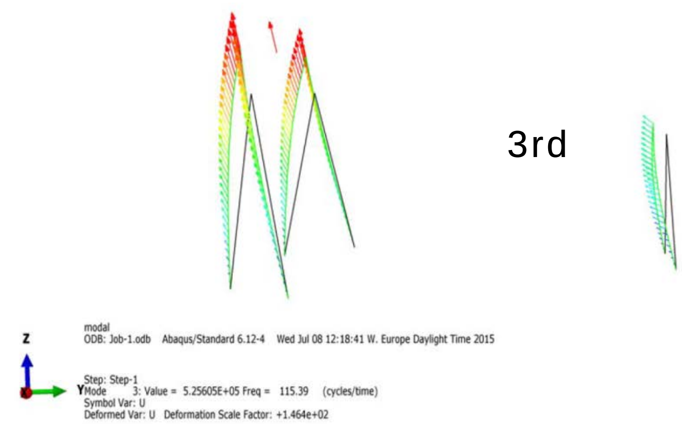


PLM – Bipods analysis

- 21.12 Hz (1st, lateral)
- 28.99 Hz (2nd, lateral)
- 115.39 Hz (3rd, longitudinal)

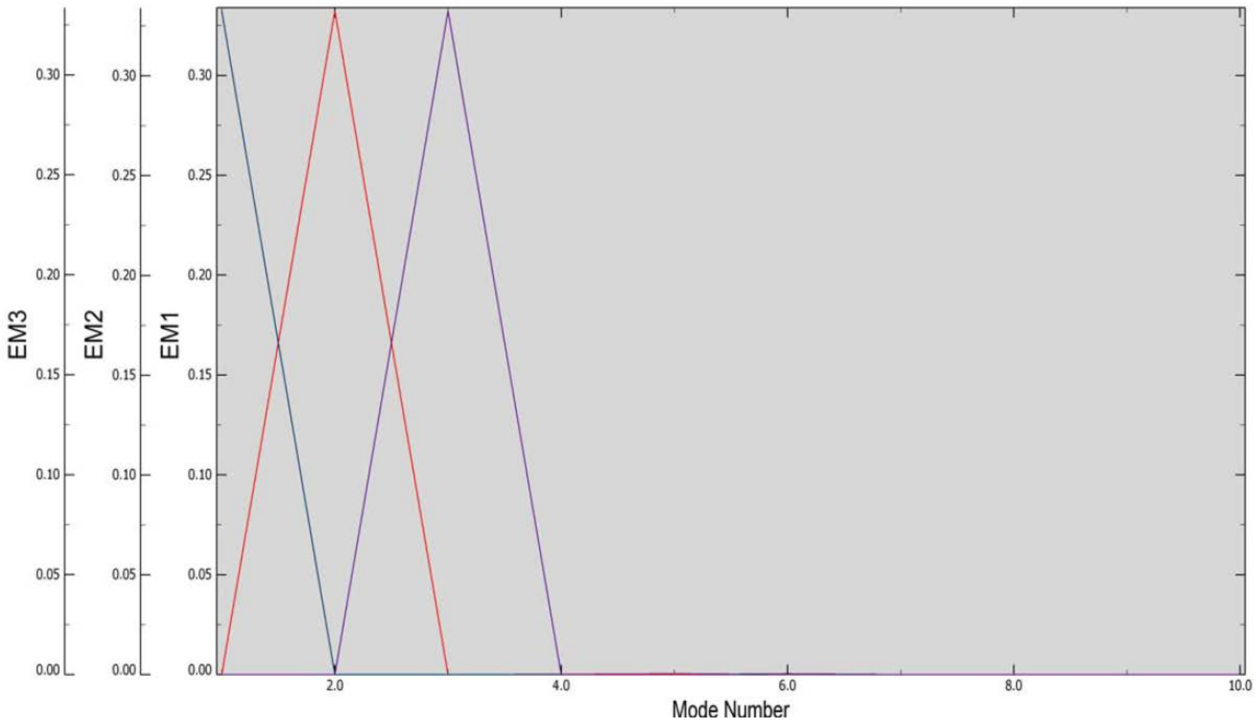




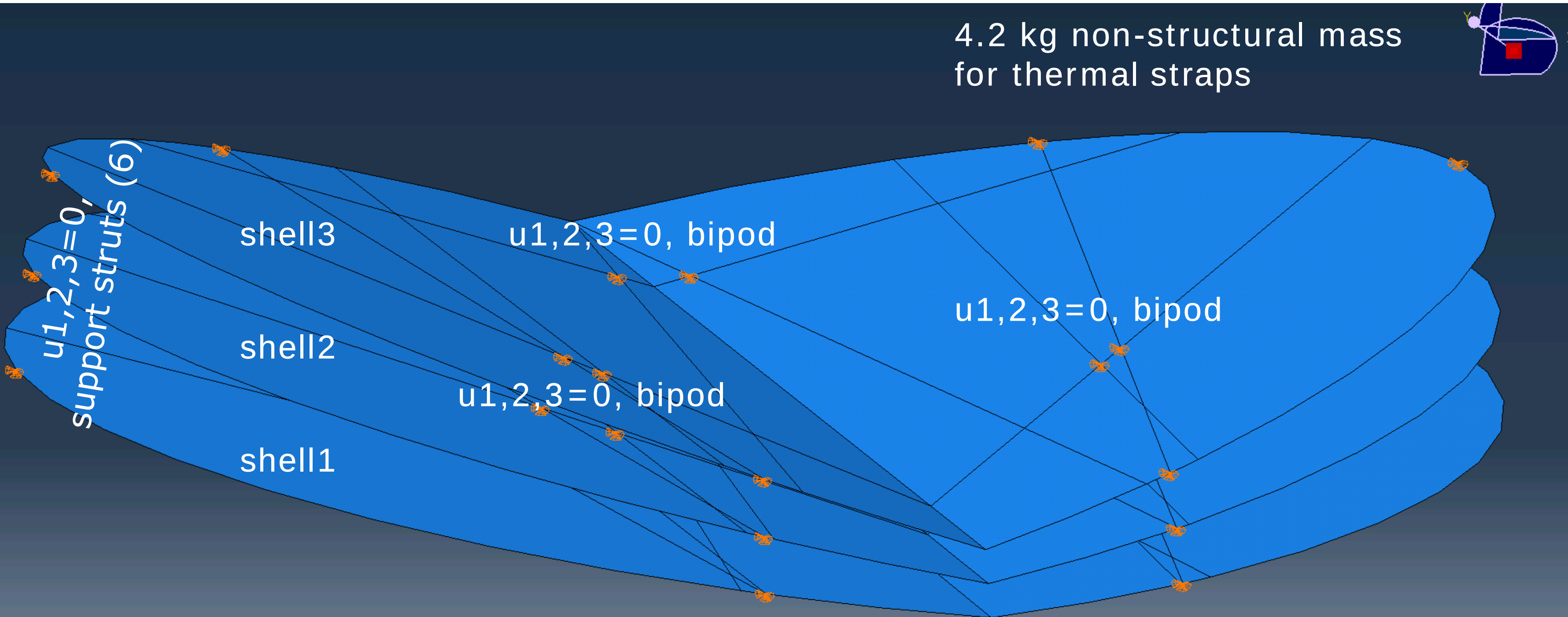


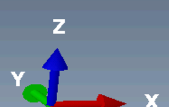
PLM – Bipods analysis

- 21.12 Hz (1st, lateral), 28.99 Hz (2nd, lateral), 115.39 Hz (3rd, longitudinal)



PLM – V-grooves analysis

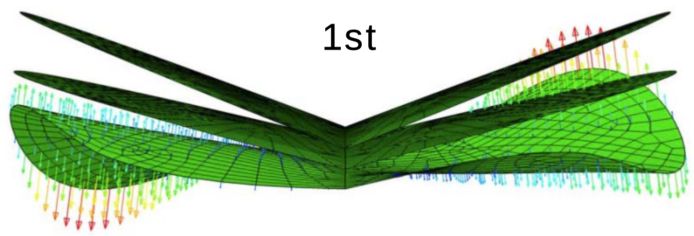


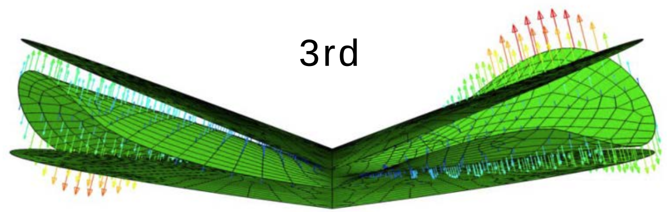


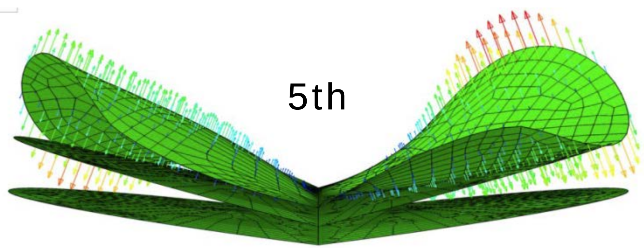
shell1 - [VDA, Al skin, adhesive, Al core, adhesive, Al skin, VDA]
shell2 - [VDA, Al skin, adhesive, Al core, adhesive, Al skin, VDA]
shell3 - [VDA, Al skin, adhesive, Al core, adhesive, Al skin, *adhesive, open Al honeycomb*]
(Note: VDA is 40g/m², incl. in thermal HW budget)

PLM – V-grooves analysis

- 38.7402 Hz, 39.3313 Hz, 41.1879 Hz, 42.9865 Hz, 46.6692 Hz,
- **-> 8 support struts considered**

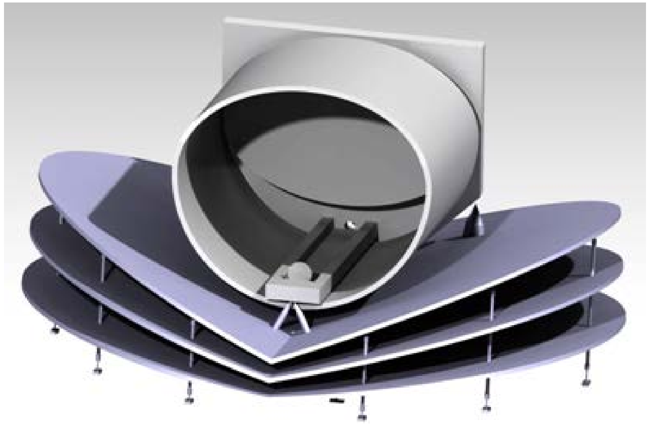






PLM – Massbudget

Component	*Mass (kg)*
Baffle	20,11422
TOB	32,292
Metering Structure	9,45
Instrument Housing	3,735584
Bipods	5,141954
V-groove support struts	0,731183
V-grooves	72,21547
V-grooves I/Fs (42)	2,864219
Brackets, misc (20% of above)	29,30893
Total PLM Mass w/o margin	**175,8536**



ARIEL

Programmatic - AIV

Session 1 – Kick-off
ESTEC, 15th June 2015

Prepared by the CDF* Team

(*) ESTEC Concurrent Design Facility

Programmatic assumptions

- Phase A Kick-off March 2016
- SPC Selection M4 Mission June 2017
- Phase B1 Kick-off July 2017 – Completion September 2018
- SPC process and go-ahead M4 Mission November 2018
- Implementation Phase Kick-off 2019
- Launch 2026
- TRL status = or > 6 at Phase B2 Kick-off, all technologies
- Reference made to EChO study.
- Planck spacecraft design heritage

Programmatic approach

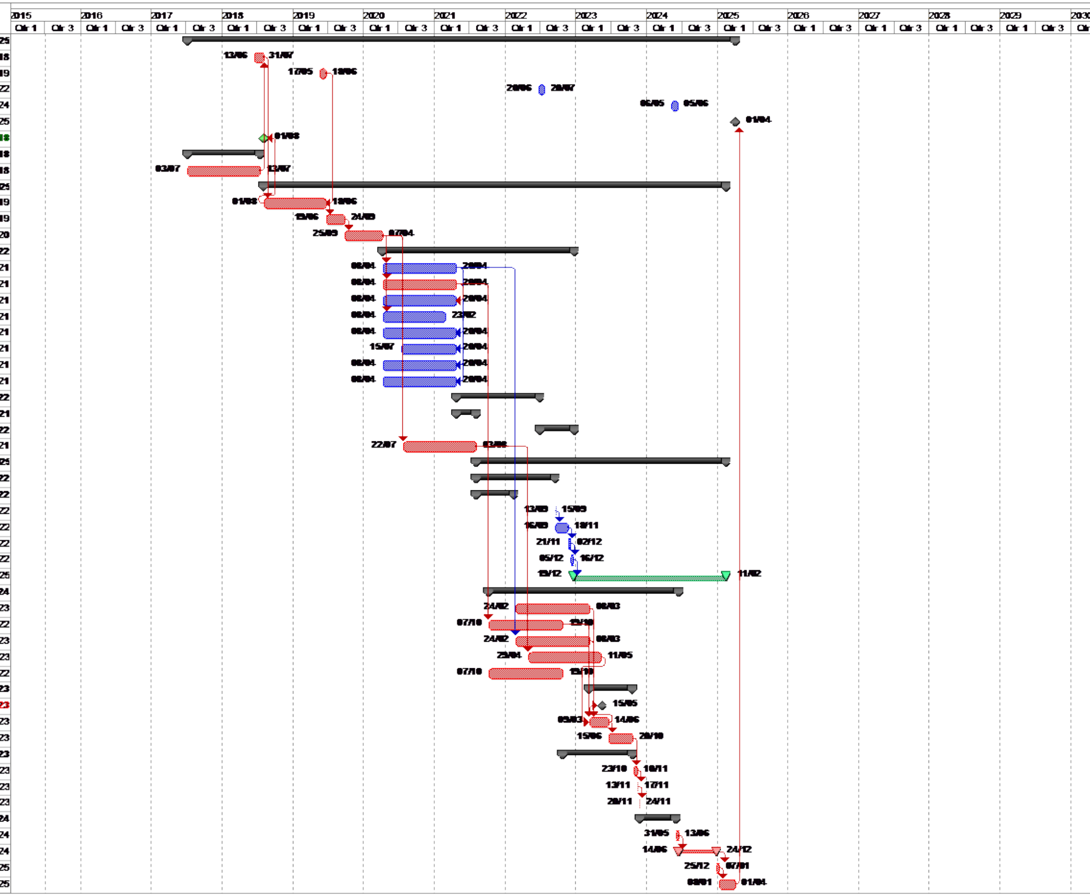
- The Spacecraft is designed with two well identified modules, the Service Module SVM, and the payload Module PLM.
- The Prime Contractor will take care of the design of the SVM and of the S/C level
- The PLM, including its instruments, will be procured and entirely tested by a PLM Contractor
  - The performances of the PLM will be demonstrated (qualified) by the PLM Contractor
  - Cryogenic test at PLM level will be performed to qualify the PLM design with a Cryogenic Qualification Model (CQM). After PLM level testing, the PLM CQM will be mated to the SVM STM for S/C level STM testing.
  - The PLM will be integrated and acceptance tested by the PLM Consortium (may or may not include a PLM cryo-performance test)

Model Philosophy

- The Prime Contractor will be responsible for the qualification of the ARIEL S/C and may make use of the following spacecraft models:
  - Structural and thermal model (STM) for mechanical and thermal qualification and in support of mathematical models correlation
  - Avionics Model (AVM) for S/C level functional test
  - Protoflight Model (PFM) for S/C level functional and environmental acceptance, and for qualification completion where needed
- The PLM Contractor will be responsible for the qualification of the PLM cryogenic chain, procuring and making use of the following models:
  - Cryogenic Qualification Model (CQM), where the PLM capability to provide the required cryogenic performances will be verified by test in a thermal vacuum chamber. This test module may also support a partial verification of the scientific performances.
- The PLM Contractor will also provide the PLM EM units for the system AVM, integrate and acceptance test the PLM PFM, and will deliver it to the Prime.

Schedule

ID		Task Name	Duration	Start	Finish
2		**ARIEL**	**2022 days**	**Mon 03/07/17**	**Tue 01/04/25**
3		SRR	35 days	Wed 13/06/18	Tue 31/07/18
4		PDR	23 days	Fri 17/05/19	Tue 18/06/19
5		CDR	23 days	Mon 20/06/22	Wed 20/07/22
6		FAR	23 days	Mon 06/05/24	Wed 05/06/24
7		Launch	0 days	Tue 01/04/25	Tue 01/04/25
8		**Impl. Phase start**	**0 days**	**Wed 01/08/18**	**Wed 01/08/18**
9		**Definition Phase**	**270 days**	**Mon 03/07/17**	**Fri 13/07/18**
10		Phase B1	270 days	Mon 03/07/17	Fri 13/07/18
11		**Implementation Phase**	**1705 days**	**Wed 01/08/18**	**Tue 11/02/25**
12		Phase B2	230 days	Wed 01/08/18	Tue 18/06/19
13		C/D Kick off	70 days	Wed 19/06/19	Tue 24/09/19
14		Detailed Design	140 days	Wed 25/09/19	Tue 07/04/20
15		**STM / CQM**	**706 days**	**Wed 08/04/20**	**Wed 21/12/22**
16		STM SVM Structure mfg/test	270 days	Wed 08/04/20	Tue 20/04/21
17		STM PLM Structure mfg/test	270 days	Wed 08/04/20	Tue 20/04/21
18		CQM SVM units procurement	270 days	Wed 08/04/20	Tue 20/04/21
19		STM RCS comp / lines mfg AIT	230 days	Wed 08/04/20	Tue 23/02/21
20		STM Sunshield mfg/test	270 days	Wed 08/04/20	Tue 20/04/21
21		STM unit dummies mfg	200 days	Wed 15/07/20	Tue 20/04/21
22		STM TCS items procurement	270 days	Wed 08/04/20	Tue 20/04/21
23		STM dummy harness pipelines proc	270 days	Wed 08/04/20	Tue 20/04/21
24		**CQM PLM AIT**	**311 days**	**Wed 21/04/21**	**Wed 29/06/22**
37		**SVM AIT**	**75 days**	**Wed 21/04/21**	**Tue 03/08/21**
41		**STM Tests**	**125 days**	**Thu 30/06/22**	**Wed 21/12/22**
46		EM/FuMo units mfg/test	270 days	Wed 22/07/20	Tue 03/08/21
47		**AVM**	**520 days**	**Wed 04/08/21**	**Tue 11/02/25**
48		**AVM SVM AIT**	**289 days**	**Wed 04/08/21**	**Mon 12/09/22**
56		**AVM PLM AIT**	**139 days**	**Wed 04/08/21**	**Mon 14/02/22**
61		AVM SVM / PLM connection/check	3 days	Tue 13/09/22	Thu 15/09/22
62		AVM final IST	46 days	Fri 16/09/22	Fri 18/11/22
63		AVM EMC CE CS	10 days	Mon 21/11/22	Fri 02/12/22
64		AVM SVT0	10 days	Mon 05/12/22	Fri 16/12/22
65		**AVM Support tasks**	562 days	Mon 19/12/22	Tue 11/02/25
66		**PFM**	**701 days**	**Thu 07/10/21**	**Thu 13/06/24**
67		PFM RCS mfg / acceptance	270 days	Thu 24/02/22	Wed 08/03/23
68		PFM PLM Structure mfg	270 days	Thu 07/10/21	Wed 19/10/22
69		PFM SVM Structure mfg	270 days	Thu 24/02/22	Wed 08/03/23
70		PFM SVM units manufacturing	270 days	Fri 29/04/22	Thu 11/05/23
71		PFM PLM avionics mfg	270 days	Thu 07/10/21	Wed 19/10/22
72		**PFM SVM AIT**	**162 days**	**Thu 09/03/23**	**Fri 20/10/23**
73		**PFM SVM side Instrument units need date**	**0 days**	**Mon 15/05/23**	**Mon 15/05/23**
74		PFM SVM Integration	70 days	Thu 09/03/23	Wed 14/06/23
75		PFM SVM Functional tests	92 days	Thu 15/06/23	Fri 20/10/23
76		**PFM PLM AIT**	**262 days**	**Thu 20/10/22**	**Fri 20/10/23**
81		PFM PLM / SVM mating and checks	15 days	Mon 23/10/23	Fri 10/11/23
82		PFM PLM / SVM unmating	5 days	Mon 13/11/23	Fri 17/11/23
83		PFM PLM / SVM transportation	5 days	Mon 20/11/23	Fri 24/11/23
84		**PFM S/C testing**	**134 days**	**Mon 27/11/23**	**Thu 30/05/24**
92		Packing	10 days	Fri 31/05/24	Thu 13/06/24
93		ESA Contingency	138 days	Fri 14/06/24	Tue 24/12/24
94		Transportation to Launch Site	10 days	Wed 25/12/24	Tue 07/01/25
95		Launch campaign	60 days	Wed 08/01/25	Tue 01/04/25



Programmatic Summary

- Prime Contractor responsible for the Spacecraft procurement, qualification and acceptance, with STM, AVM and PFM models
- The PLM Contractor responsible for the procurement, qualification and acceptance of the full Payload Module including Instruments, with CQM and PFM module, and PLM AVM pre-test before delivery to the Prime Contractor
- Feasible schedule with a **phase B start on July 2017**, a C/D phase lasting 5 years including 6 months of ESA contingency.
- A (about) 6 months time spent for ITT processes at C/D kick-off is accounted for.
- A further margin of 1 year exists to cope with usual schedule obstacles as late funding release, Instrument availability delays, extended procurement and testing of avionic units etc.
- Launch in **2026** feasible with margin

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GS & OPS

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Data Rates and Ranging

Data Rates:

- Science Data rate 11.5Gb per day
- Payload and Platform Housekeeping TM at 1.5 Gbit per day.
- Total daily data volume of 13 Gbit + 1 Gb protocol overheads

~28 Gbits data to be downlinked during each nominal planned ground station coverage during routine phase.

Required downlink data rate of at least 2.22 Mbps for the 3.5 hours data downlink/pass.

Ranging:

Ranging data taken for 15 minutes at the start and 15 minutes at the end of each pass during the 4 hour passes planned every 2 days would provide sufficient ranging and tracking data spread for orbit determination needs.

Note: Use of GMSK modulation and simultaneous pn Ranging will be implemented in the TTC processors (new IFMS in ground stations) from end 2017 resulting in the ability to dump at higher data rates and range in parallel. This capability will extend the time available during a pass to utilise the high data rate telemetry links.

Ground Stations

For LEOP, transfer, commissioning and routine operations;

X-Band communication based ground station capability provided by one of 35m antennas:

- Malargüe,
- New Norcia (NNO-1) or
- Cebreros

Additional 15m ground station coverage support during the LEOP phase including the

- Kourou and
- Maspalomas (TBC) stations.

Ground Station and Autonomy aspects

During **Transfer phase and Commissioning**, daily (8hr) passes to be baselined for operations and tracking support.

During **Routine phase**, 4 hour pass every 2 days.

- S/C design must be robust to lost/failed ground station passes.
  - S/C to operate nominally without loss of stored science or HK for 4 days
  - S/C to survive without ground contact for 6 days in all mission phases.
  - S/C design must ensure sufficient autonomy to allow for full autonomous operations for at least 4 days.
- Use of APM allows to achieve communication links in parallel to observations and during slews.
  - APM impact on observation stability. Not Applicable. APM operates during slews and not observations.

Payload operations and planning

Cryogenics:

- The use of Cryogenic option provides operational constraints and overheads the details of which are not established at this point of the study.

Observation operations

- Single payload and all detectors are operated in parallel.
- On board mission timeline to achieve required slews to observation targets and execution of platform and payload activities.
- Average observation duration of 3.7 hours.
- SOC (ESAC) to provide observation planning to MOC for inclusion in the mission planning process.
- Combined platform and payload schedules uplinked from MOC (ESOC).
- No Target of opportunity observations requirements.
- Planning cycle based on long, medium and short (weekly) planning periods.

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Conclusion

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ESTEC, 8th July 2015

Prepared by the CDF* Team

(*) ESTEC Concurrent Design Facility

System options

- Propellant increase → Green propellant (vs. Hydrazine)
- Temperatures too high → Carbon bi-pods and Gaia like mechanism
- Temperatures still too high → Use detectors at higher temperatures (→ European detectors?)
- Microvibrations → Tip/tilt mirror / smaller and more RWs
- Avoid single supplier → Aluminium vs. SiC
- Scheduling → no STM
- SA size reduction → MPPT instead of S3R

Further study areas

- Further design optimisation iteration (Bi-pod design and # of auxiliary struts, cooler sizing, white paint vs OSR, power architecture, structure optimisation, propulsion optimisation)
- Detailed sub-system design
- Detector selection
- Interface between FGS and OBC and AOCS
- Data-rate peaks allocation
- Definition of commissioning phase (incl. communication allocation)
- Thermal architecture vs. detector working point
- Telescope material substitution impact
- Backup-launcher definition (availability of Soyuz, late re-ignition capability of A6 US, Falcon 9)

Further study areas (cont.)

- Thermal analysis on sun illumination on payload during ascent
- Programmatic responsibilities
- Kinematic mounting of instruments (Al on SiC)
- Electronics radiation shielding
- Power bus trade-off (regulated vs. unregulated)