LOFT
External Final Presentation of the CDF Study

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European Space Agency

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CDF Study Objectives

1. To design a mission that will satisfy all scientific and mission requirements while maintaining compatible with the M-class mission boundaries
    a. overall mission scenario: launch, ground segment, operations, etc.
    b. design the complete S/C with related subsystems and interfaces with payload
    c. identify technology developments and propose development plan
    d. perform cost, risk, and AIV analysis

2. To update the mission reference documents: SRD, MRD & PDD

ESA M-class boundary conditions

1. European led mission
2. Launch between 2020 and 2022
3. Cost at Completion for ESA < 470 MEUR
4. Instruments provided by Member States
5. Compatibility with a medium class launcher (Soyuz ST)
6. High technology level readiness (i.e. no significant technology development possible):
    a. TRL ≥ 5 at the end of Phase A/B1, i.e. mid 2014
    b. Low development risk in phase B2/C/D

Study logic

1. Study has focused on checking the feasibility of a launch with **Vega**
    a. Proposal (based on Vega scenario) used as starting point
    b. System and sub-system trade-offs solved for a launch with Vega
    c. Mission and spacecraft design proposed
        - Detailed S/C configuration model
        - Structural, thermal, mechanisms, and AOCS simulations performed
        - Payload design assessed
        - System budgets (mass, power, Delta-V, propellant, link, etc.)
    d. Assessment of sensitivity of the mission compatibility with a launch with Vega as a function of the LAD area

2. Adaptations of the proposed design for a launch with **Soyuz** have been assessed
    a. Design trade-offs were not re-opened
    b. No detailed spacecraft design proposed for a launch with Soyuz

Main Requirements & Design Drivers

1. **Orbit (altitude <= 600 km, inclination <= 5.24 deg)**
2. **Mission duration (nominal operations phase shall last 4 years)**
    a. Driven by probability to observe rare events, net observing time could be achieved in less mission duration
    b. Impacts mainly cost (mission operations) & propellant (constraints minimum orbit altitude)
3. **Accessible sky (50% for LAD continued observations)**
    a. Impacts thermal & power design (**+/-30 deg** solar incidence angle on LAD)
    b. Short (TBD) observations are possible outside the accessible sky fraction (while in eclipse and may be also outside eclipse)
4. **Observation plan (inertial pointing to any star in accessible sky from few ks to up to 1 week)**
    a. Drives AOCS design, determines AMR, observing efficiency
5. **LAD area (the LAD effective area shall be greater than 10 m^2 at 8 keV)**
    a. Geometric area PDD value used for this study
    b. Drives S/C configuration, especially for a launch with Vega
6. **LAD and WFM operating and non-operating temperature requirements**
    a. Coupled with orbit selection (i.e. radiation) for determining spectral resolution
    b. Current max T values assume minimum solar activity (worst case for radiation)
    c. Non-operating temperature important for LAD pre-deployment phase (hottest) and safe mode definition (coldest)
7. **Data download (6.7 Gbit per orbit) and timeliness (max delay of 3 hours for WFM)**
    a. Drives choice of band/modulation and ground stations

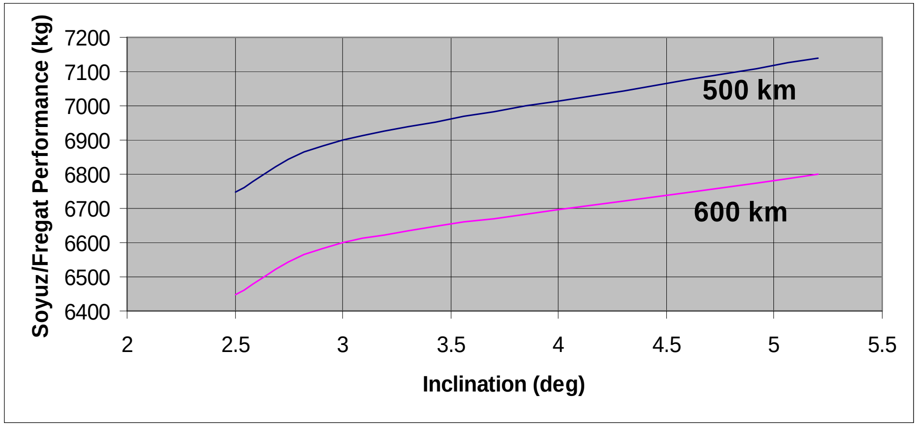
Mission Analysis

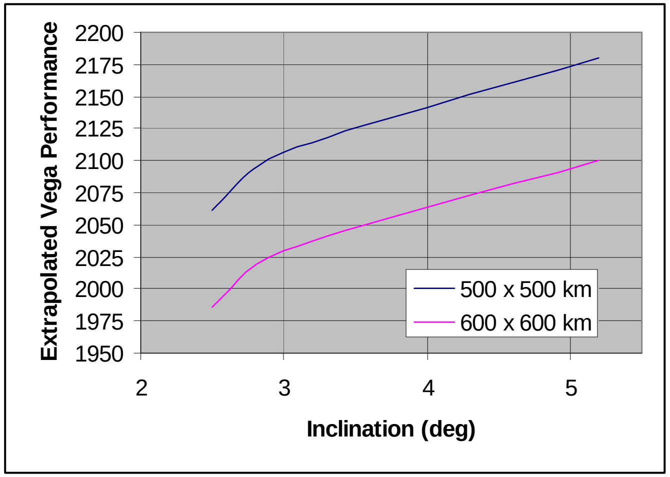
Launcher performance

1. **Soyuz** performance from Kourou calculated with an ascent trajectory optimization SW
   a. 6800 kg to 600 km, 5.2 deg

2. **Vega** performance from User Manual
   a. Scaling of the performance loss for lower inclinations based on Soyuz results
   b. 2100 kg to 600 km, 5.2 deg

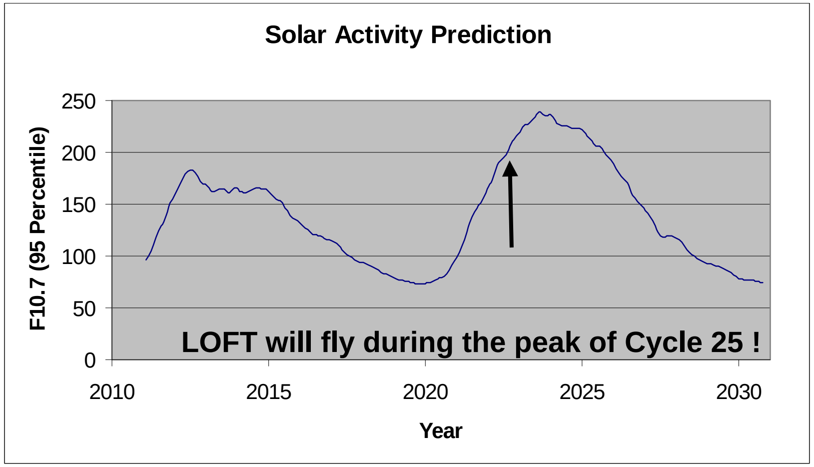
3. 5% launcher performance margin assumed for both Vega and Soyuz





Orbital decay & orbit maintenance

1. The orbital decay depends on
   a. the atmospheric density which depends on solar activity
   b. the S/C area to mass ratio (assumed AMR = 0.012 m^2/kg)
2. Orbit maintenance
   a. Orbit raise manoeuvre when S/C has reached lower altitude limit
   b. Total Delta-V increases as the altitude decrease



Source: http://sail.msfc.nasa.gov/current_solar_report/CurF10.txt

Altitude bandwidth (km)	# manoeuvres (in 5 years)	Total ΔV (m/s) (in 5 years)
540 : **550**	22	143
530 : **550**	11	145
565 : **575**	16	104
555 : **575**	9	113
590 : **600**	12	74
580 : **600**	7	82

Controlled re-entry

1. Space debris mitigation requirement OR-07:
    a. *"In case the total casualty risk is larger than 10^{-4}, uncontrolled re-entry is not allowed. Instead, a controlled re-entry must be performed such that the impact foot-print can be ensured over an ocean area, with sufficient clearance of landmasses and traffic routes."*

2. Casualty risk for BeppoSax (comparable in size and orbit) was estimated as 1/5200
   ⇒ LOFT casualty risk (if no special design) probably also exceeds threshold of 1/10000
    a. Detailed analysis and/or dedicated design actions could reduce the casualty risk and remove the need for controlled re-entry

3. Impact at system level (mass / accommodation / cost) of controlled re-entry capability
    a. 1 de-orbit burn required at 500 km to bring pericentre to 0 km (70 km upper limit)
    b. Delta V: ~ 145 m/s (excl margins)
    c. Additional propellant mass: ~ **150 kg**
    d. Additional propulsion S/S equipment: one 400 N thruster, two additional tanks
    e. Cost impact ~ 1 – 3 M€

Launch with Vega

European Space Agency

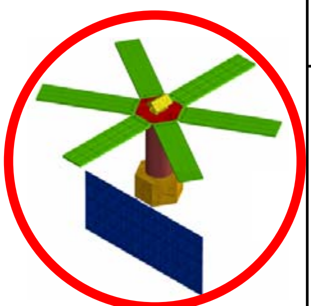
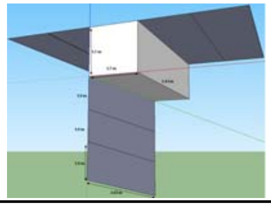
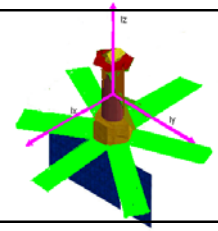
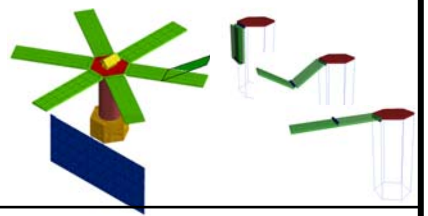
Orbit trade-offs for a Vega launch

Altitude			
Lower Orbit (550 km)		Higher Orbit (600 km)	
(+)	(-)	(+)	(-)
Lower radiation Higher launcher performance	**-Higher Decay Rate: higher Delta V for orbit maintenance**	-Lower Decay Rate: lower Delta V for orbit maintenance	–Higher radiation –Lower launcher performance
Inclination			
Lower Inclination (2.5 deg)		Higher Inclination (5.24 deg)	
(+)	(-)	(+)	(-)
Lower radiation	**Lower launcher performance**	Higher launcher performance	Higher radiation

1. Orbital altitude trade-off: the increase in wet mass by reducing the altitude is higher than the increase in launcher performance
2. Due to negative mass margins for Vega, a 600 km, 5.2 deg orbit is selected

Configuration trade-offs

1. LAD configuration (stowed & deployed) drives S/C configuration and size
   a. LAD is composed by rigid panels requiring a total area of 20 m^2 orthogonal to a common direction
2. Several potential configurations qualitatively traded off wrt LOFT proposal configuration ("*petals up*") for a launch with Vega

Petals up	Book	Petals down	Sub-panels
 **Selected**			
	Discarded due to: 1. More complex deployment (need for synchronization) 2. Thermal issues: less radiator surface, lower panel view factor to space, higher heat exchange with SA	Discarded due to: 1. Difficult accommodation of LAD and SA mechanisms in SVM 2. Power: potential shadowing of SA by LAD panels 3. Thermal issues: higher heat exchange with SA	Discarded due to: 1. No radial space to accommodate 2 folded sub-panels in the Vega fairing 2. More complex deployment ((need for synchronization)

Solar Arrays trade-off: Fixed vs. Rotating

Fixed	Rotating
Pointing restricted at any time by power reasons	Pointing not restricted at any time by power reasons
SA surface (mass) sized for the maximum allowed off-pointing angle (30 deg) *SAA = 20 deg → SA 16.1 m2;* ***72.45*** *kg* *SAA = 30 deg → SA 17.1 m2; 76.95 kg*	SA surface (mass) can be reduced (factor cos 30 deg) as SA are always ⊥ to Sun *SAA = 0 deg → SA 15.1 m2;* ***67.95*** *kg*
No rotating mechanism	Rotating mechanism needed (added complexity and mass ~ 9 kg per SADM)

Rotating brings no mass saving and increased complexity

System Overview (1/2)

MISSION PARAMETERS	
Launcher	VEGA (from Kourou)
Launch Date	2020 -**2022** Nor seasonal no daily constraints
Lifetime:	**4 years** (+1 year extended lifetime)
Ground Segment and Ops	Kourou all pass. + Malindi 4 pass./day
Launch Mass	Dry Mass: 1995.62 kg (incl. margins) Wet Mass: 2117.97 kg Launch Mass (incl. adapter): 2177.97 kg
Delta V (excl. De-orbit)	89.14 m/s (wo margins)
Dimensions	Stowed: 1.7 x 1.7 x 3.7 m
AMR	0.0136 m2 / kg (worst case) 0.0073 m2 / kg (best case)
Orbit	Circular, 600 km, i = 5.24 deg
Observable Sky	360° around X ±30° around Y (50% Accessible Sky)

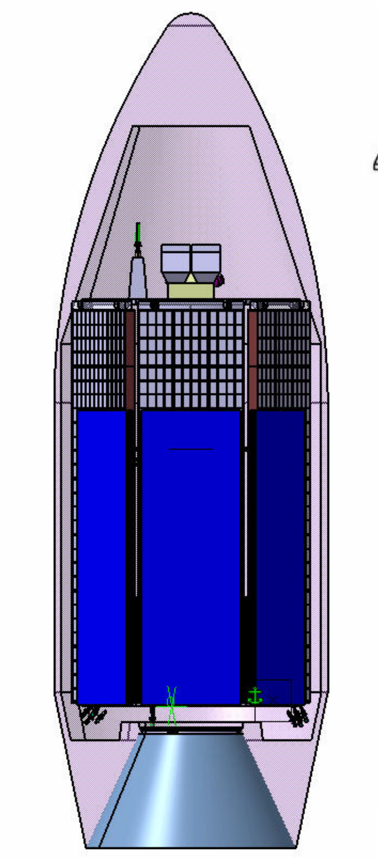
SUBSYSTEMS	
Payload (1)	Large Area Detector (20 m2 geometric) 6 Panels (3.6x0.9 m) deployed from Central Tower
Payload (2)	Wide Field Monitor (Fov: 90 x 180 deg)
Structure	Structural Tower, Intermediate Shear Panel, Intermediate Support Panels Optical Bench, SVM structure
Power	Power Consumption in Ops: ~ 2 kW 16.2 m2 Solar Panels (7 wings) 155 strings 29 cells, EOL Pwr: 4218W Battery: ABSL18650HC (2 modules)
Mechanisms	1 S/A Deployment 8 SA HDRM 6 LAD Hinge 6 LAD Damper 6 Cable Wrap Assembly 36 LAD HDRM + 36 Connectors

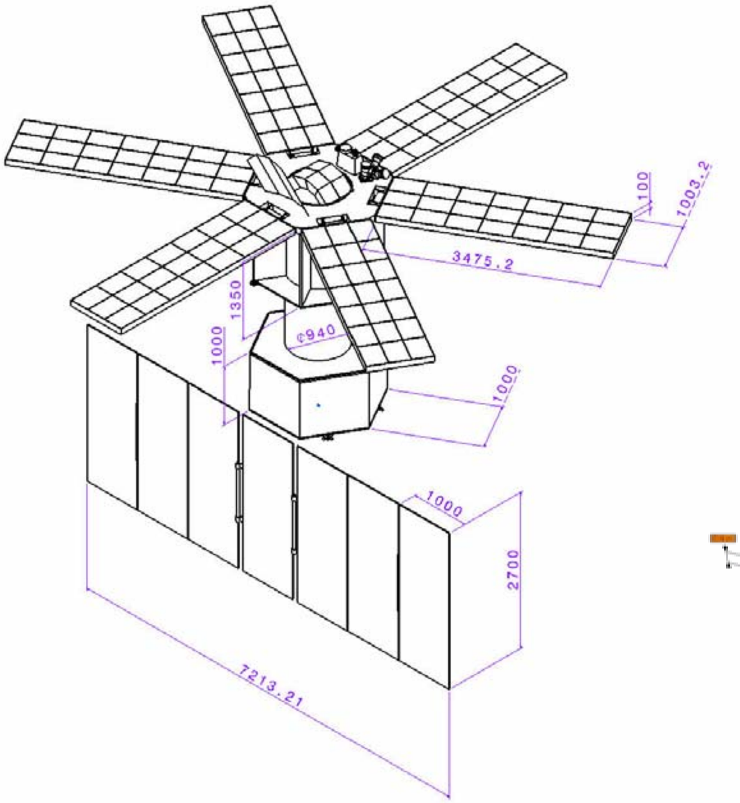
System Overview (2/2)

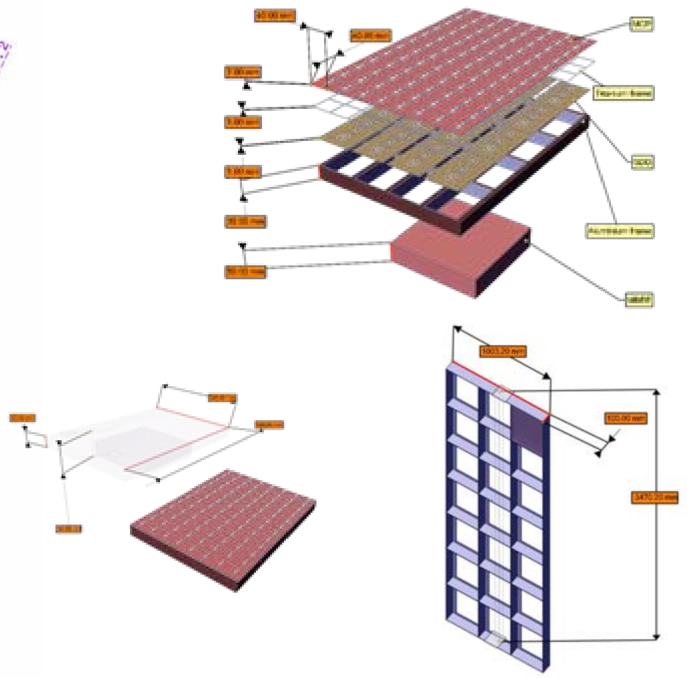
SUBSYSTEMS	
AOCS	4 Star Tracker 4 Reaction Wheel (Teldix RSI-12) 3 Magnetorquer 2 Coarse Gyro 8 Cosine Sun Sensor 2 GPS + 2 Antenna
DHS	OBC LAD DHU & PSU WFM DHU & PSU
COMMS	2 X-band Transmitter 2 X-band Receiver 2 SSPA (6W) 1 RFDU 3 LGA
Propulsion	Conventional Monopropellant Hydrazine 1 Propellant Tank 12 x 1 N thruster 1 x 20N thruster

SUBSYSTEMS	
Thermal	MLI Blankets HPs White Paintings

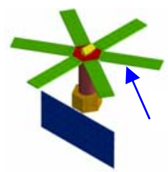
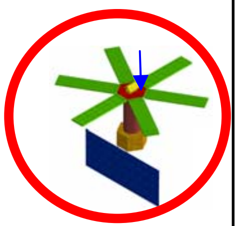
Configuration





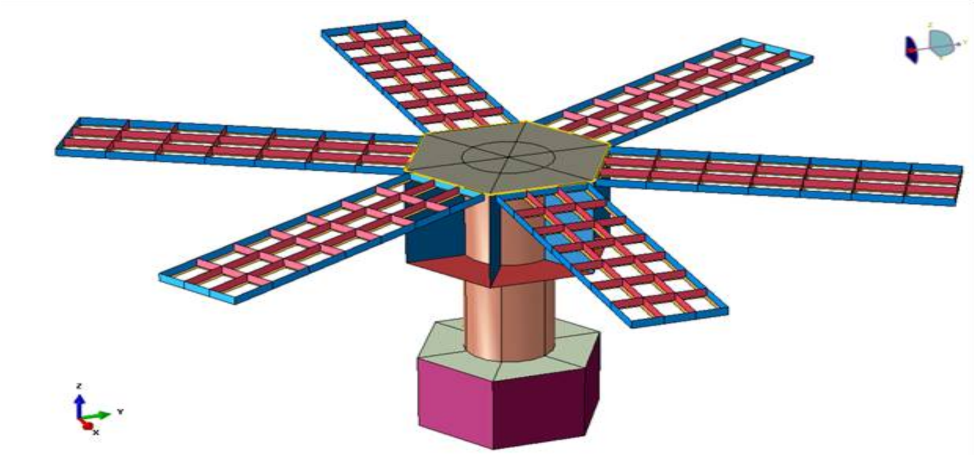


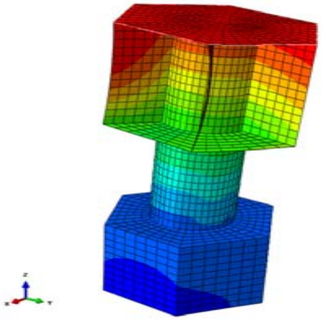
PBEE Location trade-off: Panel vs. Optical Bench

	Testing	Thermal	Harness	Configuration
	(+) Potential Easier Testing	(-) High T gradient in the panel due to High Pwr dissipation (~51.6W)	(+) Less harness through the LAD hinge	(-)  Challenging to find a location suitable for stowed and deployed configuration
	(-) Potential Complex Testing	(+) Uniform T can be assured over the LAD surface With PBEE on the OB, HPs could bring heat towards the tower for dissipation	(-) More harness through the LAD hinge	(+) PBEE shall be placed on the bottom side of the Optical Bench

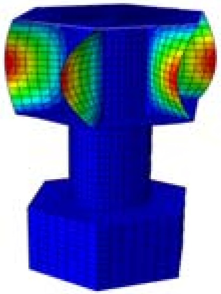
S/C structure

1. The structural tower provides the stiffness for the first lateral frequency
2. The intermediate panel is used to support hard points
3. The top shear panels provide bending stiffness to the optical bench
4. The service module has been dimensioned to support the equipment and S/S that do not require to be near the payload





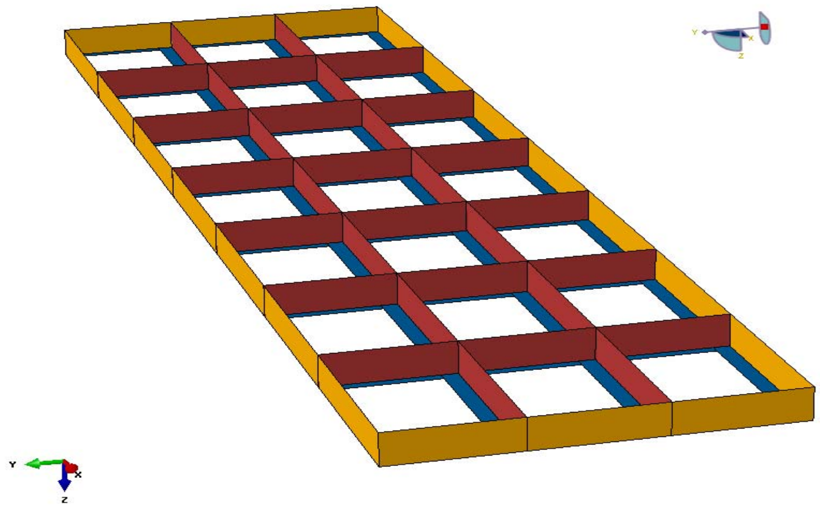
1st Lateral Normal Mode
f=16 Hz

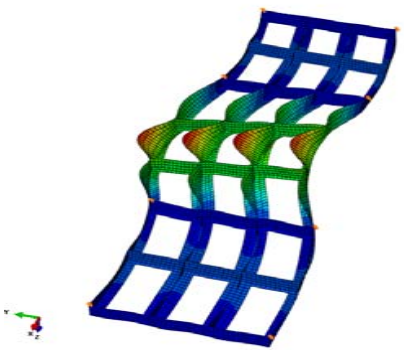


1st Long. Normal Mode
f=35 Hz

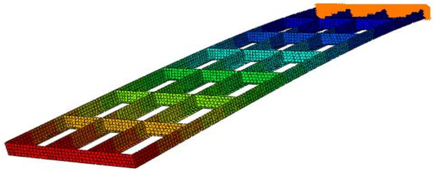
LAD panel structure

1. Requirements
   a. Sufficient stiffness
      - High frequency at launch and operation
      - Low stress in the payload
   b. Large view factor
      - Thermal control
   c. Optimized mass





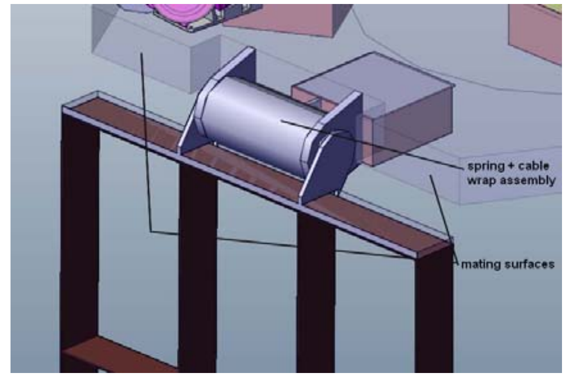
Launch Configuration
f_1 = 48.12Hz

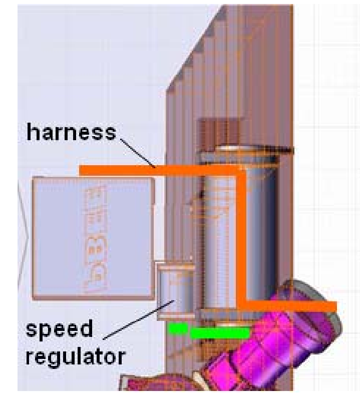


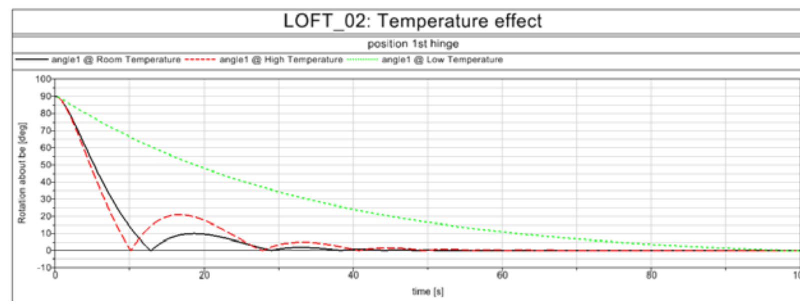
Deployed Configuration
f_1 = 3.05Hz

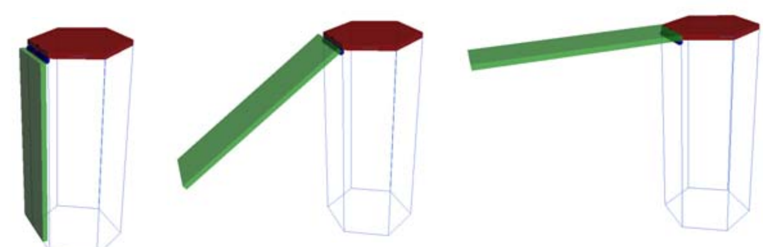
LAD deployment & HDRM mechanisms

1. TRL level for the LAD panel deployment mechanism is 5-6
2. Design based on:
    a. Spring aided solution
        - Higher torque budget than for SMOS
        - Pre-loaded hinges (in plane accuracy remains challenging for such large LAD panels)
    b. Fluid damper as speed regulator
        - requires heaters to minimize temperature range for deployment
    c. Large cable wrap assembly for harness through hinge
    d. WFM magnetic susceptibility requirements still to be checked
3. 6 HDRM per LAD panel

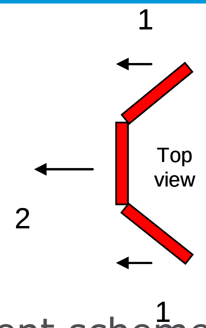


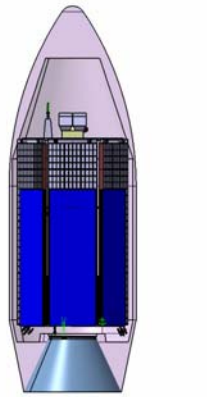




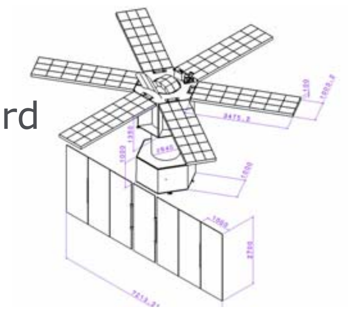


SA deployment & HDRM mechanisms

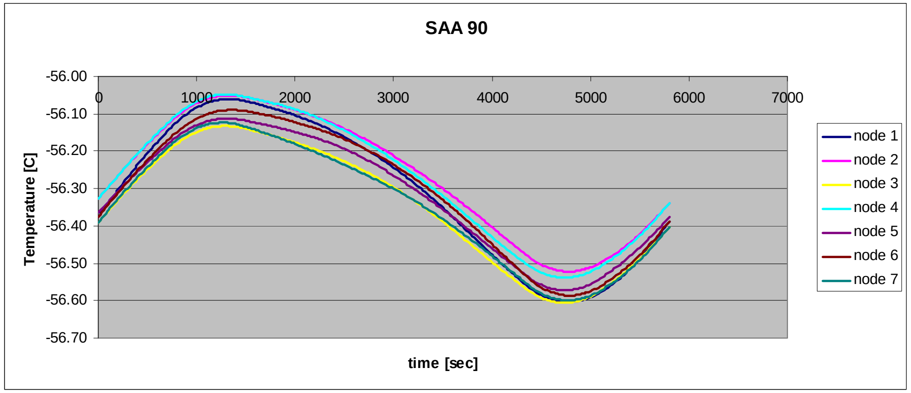


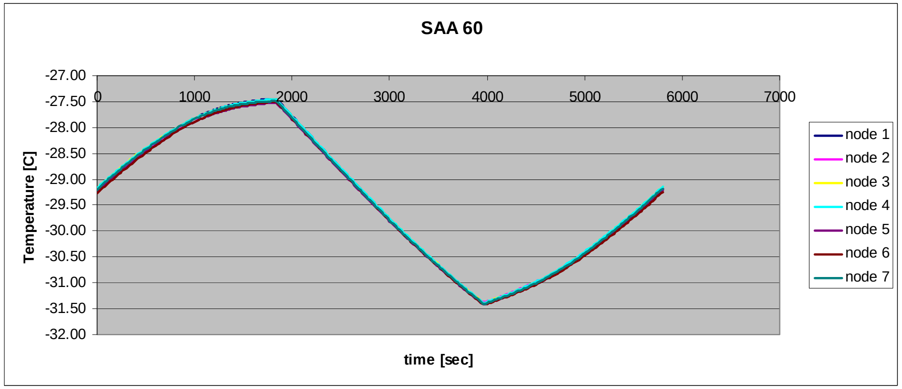


1. Major challenges:
   a. solar array (SA) stowed on top the petals
   b. find some hard points for the solar array
   c. design a HDRM compatible with a sequential deployment scheme of the SA and then LAD panels
2. Proposed design
   a. SA stowed on 3 panels
      – One central sub-SA and 3 sub-SA on each of the 2 side panels
      – HDRM: 3 + 3 hard point on the 2 side sub panels + 2 for the central sub-SA
   b. Deployment: 1) side sub-SA, 2) main SA
3. Complex interface between LAD, SA and S/C (especially for common hard points between LAD and SA)
   a. Same company should be responsible of panel structure and deployment tower

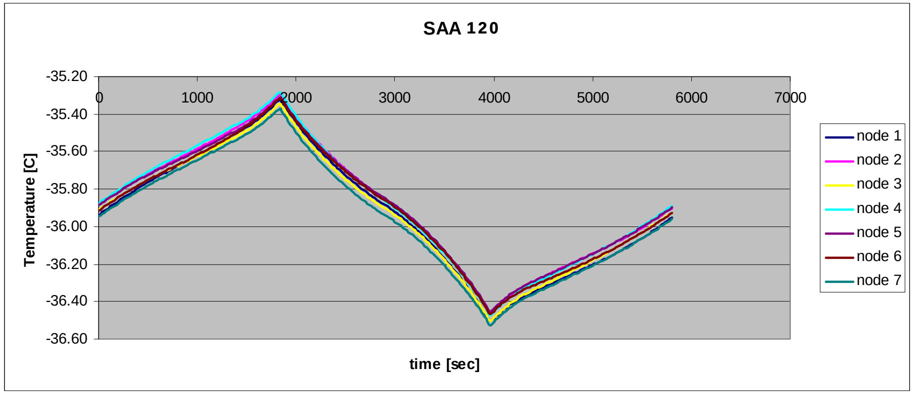


LAD thermal analysis (1)





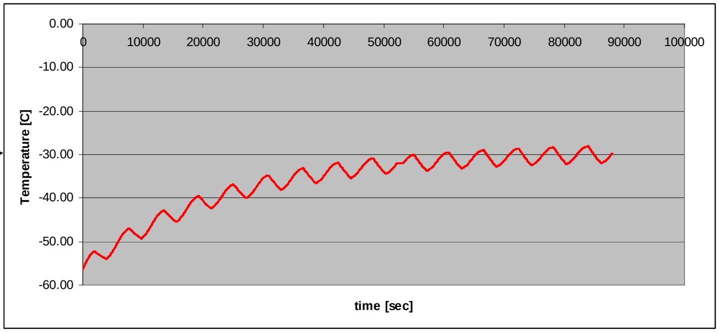
1. 3 cases analyzed: SAA = 90, 60 and 120 deg
2. At equilibrium:
   a. For SAA **90** the SDD temperature is < -30 °C but goes below its min OP temperature of **-50 °C** (-56.7 °C)
   b. For SAA **60**, temperatures stay within the range [**-27.5:-31.5**] °C (cycles around -30 °C)
   c. For SAA **120** the temperatures stay within the range [**-34.2:-36.6**] °C
3. For the 3 attitudes
   a. temperature gradient over detector plane < 5 °C
   b. the temperature variation over 1 orbit < 5 °C



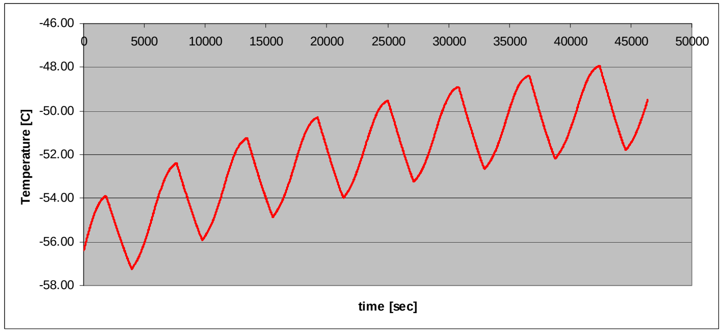
LAD thermal analysis (2)

Transient analyses:

1. 14 orbits are needed to reach SDD temperature stabilization when passing from the SAA 90 deg to the SAA 60 deg attitude (impulsive manoeuvre considered)



2. If the instrument is switched off (safe mode) when in SAA 90 deg attitude (coldest)
   a. the min NOP temperature is violated in 1 orbit
   b. however if the satellite is put in the SAA 60 deg (hottest) the temperature is kept within its temperature range
   c. alternatively, heaters (2 per detector) could be analyzed and included in the design
      - Small mass impact (~ 2 g each
      - Negligible impact on power – as long as heaters are used when the LAD is off
      - Complex integration (they would have to be placed in the LAD Al frame)



WFM thermal analysis

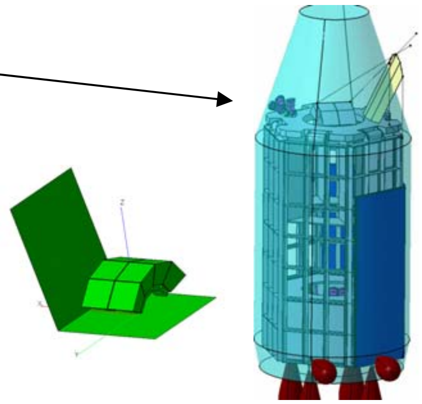
SAA = 60 deg

	Camera 1 Temperatures [C]			
Max	-3.210	-3.210	-3.210	-3.210
Min	-3.230	-3.230	-3.230	-3.230
	Camera 2 Temperatures [C]			
Max	-3.268	-3.268	-3.268	-3.268
Min	-3.280	-3.280	-3.280	-3.280
	Camera 3 Temperatures [C]			
Max	-0.468	-0.468	-0.468	-0.468
Min	-0.490	-0.490	-0.490	-0.490
	Camera 4 Temperatures [C]			
Max	-0.826	-0.826	-0.826	-0.826
Min	-0.840	-0.840	-0.840	-0.840
	Camera 5 Temperatures [C]			
Max	-3.6170	-3.6170	-3.6170	-3.6170
Min	-3.6410	-3.6410	-3.6410	-3.6410
	Camera 6 Temperatures [C]			
Max	-8.2210	-8.2210	-8.2210	-8.2210
Min	-8.2420	-8.2420	-8.2420	-8.2420
	Camera 7 Temperatures [C]			
Max	6.160	6.160	6.160	6.160
Min	6.150	6.150	6.150	6.150
	Camera 8 Temperatures [C]			
Max	-0.173	-0.173	-0.173	-0.173
Min	-0.180	-0.180	-0.180	-0.180

With Supp. Structure = -1.71deg

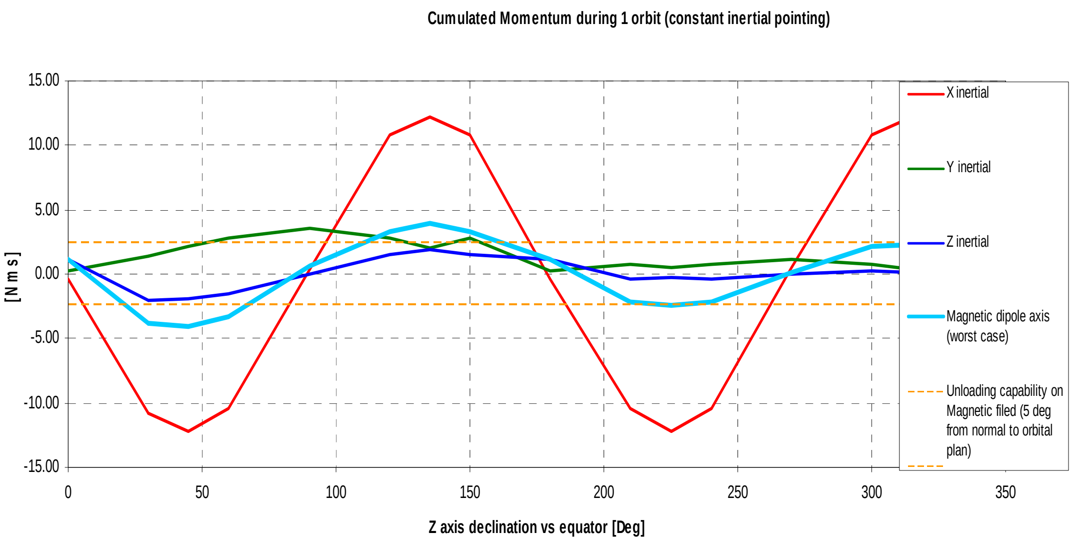
1. Attitudes SAA 90, 120 deg meet all requirements
2. Attitude SAA 60 deg is critical as the requirement of keeping the SDD below -15 °C is not respected
   a. With a sunshield, the operative temperature of the SDDs stays below -15 °C for the 3 SAA, but…
   b. a sunshield cannot be baselined because it does not fit in Vega
   c. Other design options may exist for solving this (white paintings, radiator areas, potential lower orbit, etc.)
   d. Further analysis is required

	Camera 1 Temperatures [C]			
Max	-17.132	-17.132	-17.132	-17.132
Min	-17.142	-17.142	-17.142	-17.142
	Camera 2 Temperatures [C]			
Max	-17.070	-17.070	-17.070	-17.070
Min	-17.079	-17.079	-17.079	-17.079
	Camera 3 Temperatures [C]			
Max	-17.12	-17.12	-17.12	-17.12
Min	-17.125	-17.125	-17.125	-17.125
	Camera 4 Temperatures [C]			
Max	-17.066	-17.066	-17.066	-17.066
Min	-17.071	-17.071	-17.071	-17.071
	Camera 5 Temperatures [C]			
Max	-17.149	-17.149	-17.149	-17.149
Min	-17.153	-17.153	-17.153	-17.153
	Camera 6 Temperatures [C]			
Max	-17.120	-17.120	-17.120	-17.120
Min	-17.128	-17.128	-17.128	-17.128
	Camera 7 Temperatures [C]			
Max	-17.06	-17.06	-17.06	-17.06
Min	-17.069	-17.069	-17.069	-17.069
	Camera 8 Temperatures [C]			
Max	-17.050	-17.050	-17.050	-17.050
Min	-17.061	-17.061	-17.061	-17.061



AOCS (1)

1. RW off-loading
   a. Magnetic torquers (MTQ) cannot generate torque parallel to the Earth's magnetic field vector
   b. For an almost equatorial orbit, the efficiency of MTQ for dumping the excess momentum along the Earth magnetic dipole axis is low
   c. In case continuous inertial pointing, MTQ may not be sufficient to compensate all the average disturbance torque
      – Residual disturbance torque shall be stored in RW and eventually unloaded with RCS thrusters.
   d. Worst-case occurrence is difficult to estimate and would require a detailed statistical analysis
      – 10 kg of propellant preliminarily allocated for this



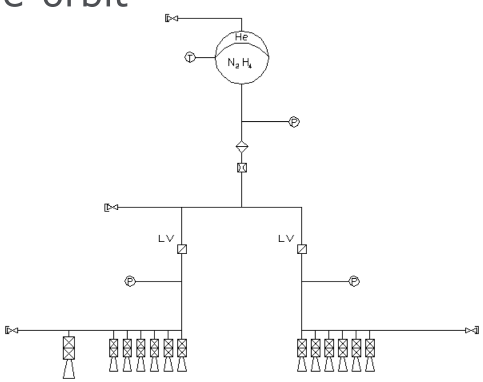
Unloading around Magnetic axis		Observation plan: Average disturbance momentum over 1 orbit	Inertial pointing: Worst case disturbance momentum over 1 orbit
		0. 83 Nms	4.05 Nms
MTQ Unloading capability over 1 orbit (M. field 5 deg)	2.42 Nms	OK	NOK
MTQ Unloading capability over 1 orbit (M. field 10 deg)	4.79 Nms	OK	OK
MTQ Unloading capability over 1 orbit (M. field 15 deg)	7.01 Nms	OK	OK

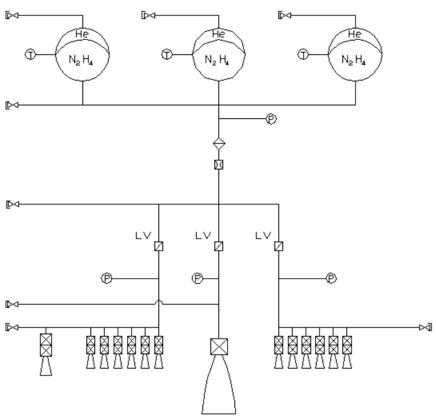
AOCS (2)

1. Pointing accuracy
   a. Star trackers (STR) performances guarantee required APE and AKE even with one single active optical head (OH)
   b. But even with 4 OH (especially if one fails) it is not possible to avoid potential geometries with the Earth blinding all STR OH for part of the orbit
      - the Earth subtends an angle of ~132 deg when viewed from the LOFT orbit
      - during that period, AKE will increase but potentially could be kept within the requirement with other sensors: MTM, gyros, Sun sensors
   c. Open issue requiring further analysis: STR accommodation and attitude reconstruction when STR are all blocked
2. Agility:
   a. 4 large RW provide agility on max inertia axis: > 6 deg/min
3. Safe mode:
   a. THR are preferred instead of MTQ due to low orbit inclination
   b. ~5 Kg of propellant for safe mode

Propulsion

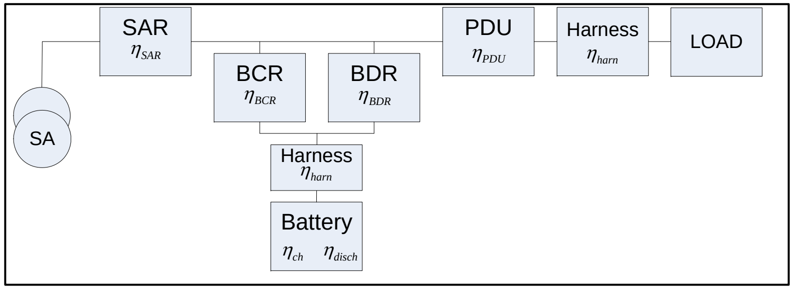
1. Two options considered (with and without controlled de-orbit)
2. Taking dry mass, ΔV and heritage into account, the following propulsion system was chosen:
   a. Monopropellant (Hydrazine)
   b. Isp = 220 s (low level assumed due to blow down operations)
   c. Thrusters
      – 6 + 6 (redundant) 1N for attitude control
      – 1 20N for orbit maintenance
      – 1 400N for controlled de-orbit
   d. Existing diaphragm tanks

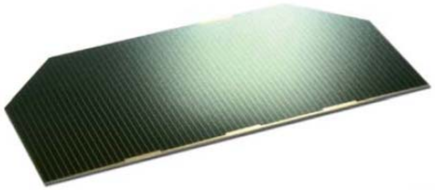




Power S/S

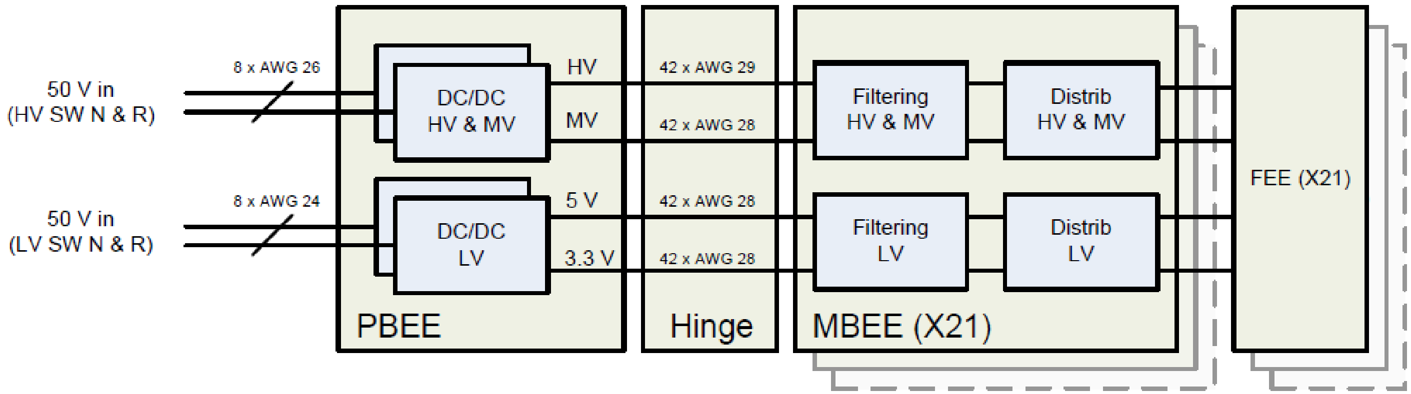
1. Proposed bus architecture is MPPT - 50 V regulated
2. Sizing case is nominal and eclipse modes
    a. Power budget values of 1932 and 1943 W
3. SA: 16.2 m^2 array needed assuming 85 % packing factor
    a. Triple junction solar cells
    b. EoL Power of 4218 W
4. Battery
    a. 15 charge/discharge cycles per day, 28 k cycles in 5 years
    b. Two modules



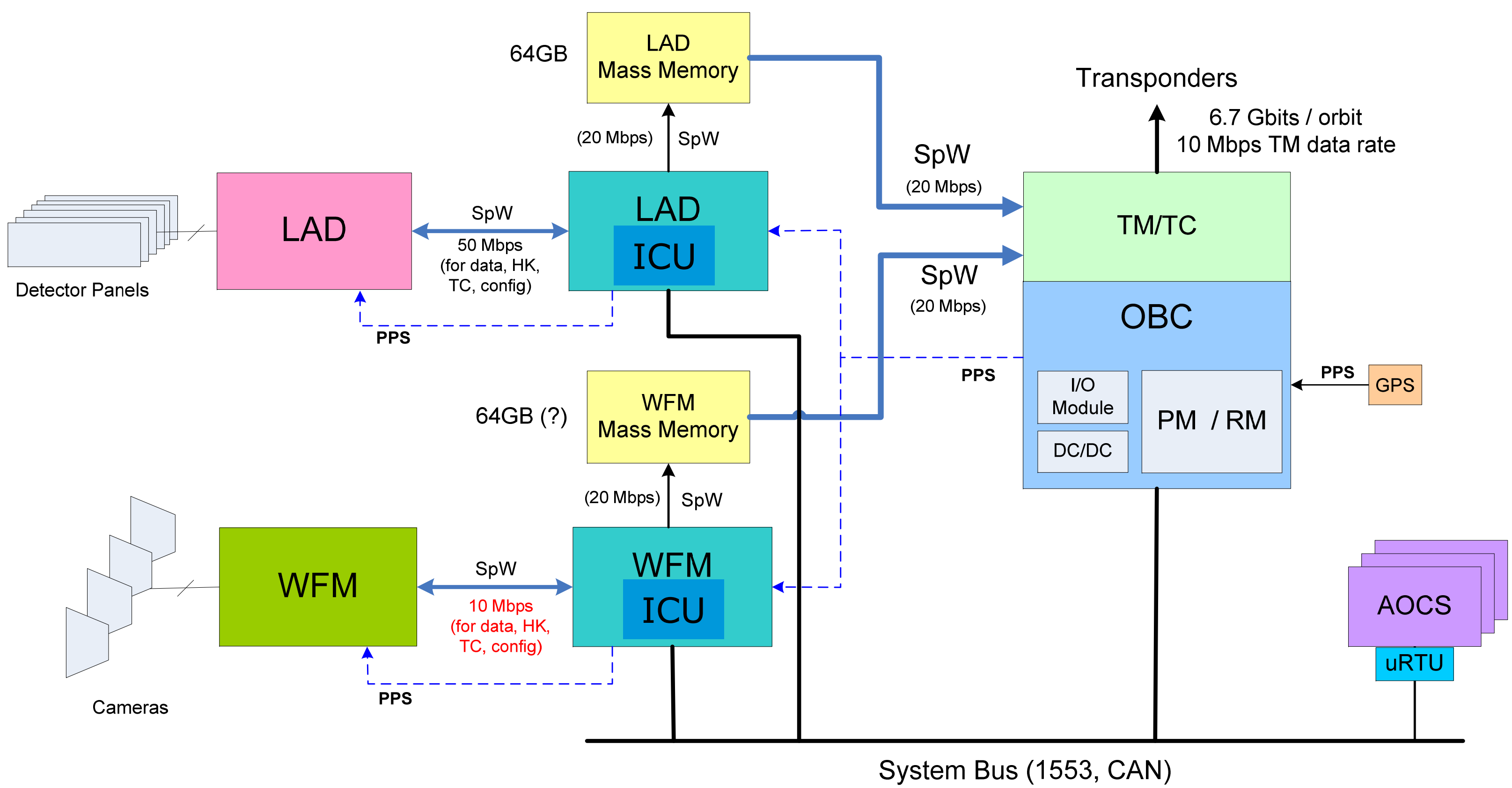


LAD power distribution trade-off

1. Centralised power conversion (in PBEE) vs Distributed (in MBEE)
    a. Centralised: Higher Conversion Efficiency
        – Cold Redundant HV/MV and LV converters, Individual Filtering in MBEE
        – Distribution (Switches) may be placed in MBEE (individual module switching) or in PBEE (one switch for X modules - flexibility)
2. Impact on Mechanisms has been assessed
    a. Number of wires from PBEE to LAD panel can be accommodated



Data handling S/S



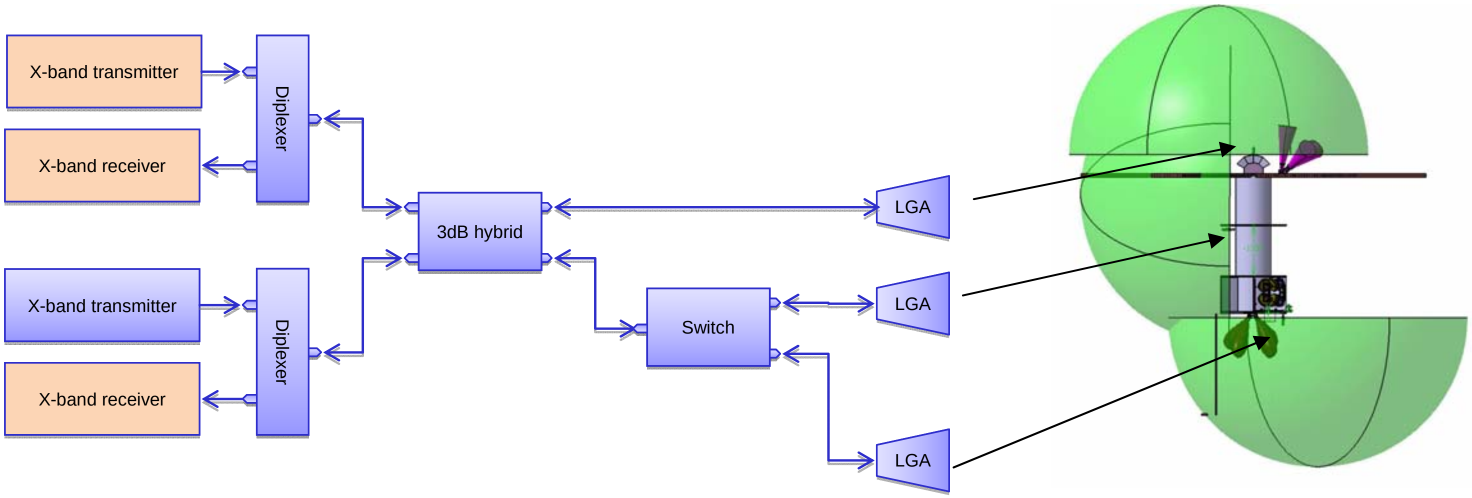
Communications trade-offs

Frequency Band for Downlink			
S-band		X-band	
(+)	(-)	(+)	(-)
1. Very mature S-band transponder market 2. Larger choice of existing ground stations	1. **Uncertain future avail. (regulations)** 2. Congested 3. Lower data rates 4. Spread-F	1. Higher data rates	1. High rain attenuation, but workable 2. Relatively mature X-band transponder market
Ka-band has been discarded as very unsuitable for humid tropical regions			
Modulation			
GMSK or OQPSK		8PSK	
(+)	(-)	(+)	(-)
1. Maturity	1. Lower data rates (10 Mb/s)	1. Higher data rates (13 Mb/s)	1. **Not in the standards** 2. Higher power required

Use of high order modulation (8PSK and above) is under discussion with regulators

Communications S/S architecture

1. Transmitters: cold redundancy
2. Receivers: hot redundancy
3. Omni-directionality: though 3dB hybrid connected to LGAs
4. Nominal antennas: nadir and zenith
5. RF switch: select between the nadir and lateral antenna when the nadir antenna is masked by the SA



Ground stations trade-off

Data Volume Capacity LOFT Ground Stations [Gbit/day]								
Band	Kourou		Kourou + 4 x Malindi		Kourou + 7 x Malindi		Kourou + Malindi	
	GMSK/ QPSK	8PSK	GMSK/ QPSK	Kourou 8PSK Malindi QPSK	GMSK/ QPSK	Kourou 8PSK Malindi QPSK	GMSK/ QPSK	Kourou 8PSK Malindi QPSK
X-Band	78	106	100	128	117	144	155	182

1. Kourou timeliness (> 99% reliability annual average) Ok for WFM data sent at centre of pass
2. Available data volume requirement: 14 passes with 6.7 Gbit => 93.5 Gbit/day
3. Baseline
    a. 14 (i.e. all) Kourou passes
    b. 4 Malindi passes for baseline (includes margin for flexibility)
    c. Malindi used to increase data downlink volume and to increase flexibility for usage conflicts and timeliness

Pass Operations Concept

1. 2 + 2 pre-planned manned TT&C passes per day
2. +2 TT&C passes only used for ToOs (Targets of Opportunity)
    a. (and potentially for critical emergencies)
3. TT&C passes Kourou only
4. Science downlink passes automated (including data dissemination to SOC via MOC)
5. Operated within Science Observatory Family of Missions
6. Flight Dynamics for LEOP, orbit maintenance, slew commands, and on call for ToO commanding

Operational Strategy

Event	Description	Duration
Launch		
LEOP	15 hours autonomy Initial Attitude Tip-off rate damping (thrusters) Attitude Determination Sun Acquisition Inertial Pointing Acquisition (Sun in the XZ plane of the S/C with SAA~68 deg) SA Deployment	~ 1 day
LAD Deployment (by pairs)	1st pair	1 orbit (90 min)
	Confirmation of Success	
	2nd pair	1 orbit (90 min)
	Confirmation of Success	
	3rd pair	1 orbit (90 min)
Commissioning and Nominal Ops		

Delta V & Propellant Budget (no controlled re-entry)

Delta V Budget					Propellant Budget	
Manoeuvre	**# Manoeuvres**	**Delta V per year**	**Total Delta V Incl De-orbit (5 years) No Margins**	**Total Delta V Incl De-orbit (5 years) Incl Margins**	**Propellant Mass Incl De-orbit No Residuals**	**Propellant Mass Incl De-Orbit with Residuals**
	#	*m/s*	*m/s*	*m/s*	*kg*	*kg*
Launcher Dispersion	1		8.14	8.547	8.02	8.18
Orbit Maintenance	12	14.8	74.00	82.88	79.17	80.75
Collision Avoidance	2	1	5.00	5.6	5.25	5.36
De-orbit	0		0.00	0	0.00	0.00
Gravity loss de-orbit			0.00	0	0.00	0.00
AOCS Losses			3.70	3.89	3.64	3.72
TOTAL			**90.84**	**100.912**	**96.80**	**98.73**

AOCS Manoeuvre					Propellant Mass	
					Wo Margin	Incl Margin
				Kg/year	*kg*	*kg*
Initial Rate Dumping					**0**	**0**
RW Unloading	assuming worst case occurring for < 10% lifetime			2	**10**	**18**
Safe Mode	for 5 years lifetime			1	**5**	**9**
Margins are applied 100% to 4 years + 0% 1 year (extended lifetime)						
					15	27

MISSION PARAMETERS		
Orbit Altitude	**600.00**	**km**
Orbit Inclination	**5.24**	**deg**
Isp	**220.00**	**s**
OM Delta V Margin	**15.00**	**%**
CA Delta V Margin	**15.00**	**%**
Other Delta V Margin	**5.00**	**%**
Residuals Margin	**2.00**	**%**

Mass Budget for a launch with Vega (no controlled re-entry)

LOFT						
	Without Margin		Margin		Total	% of Total
Dry mass contributions			%	kg	kg	
Structure	**441.24**	**kg**	**20.00**	88.25	**529.48**	31.42
Thermal Control	**29.45**	**kg**	**10.00**	2.94	**32.39**	1.92
Mechanisms	**42.15**	**kg**	**10.00**	4.21	**46.36**	2.75
Communications	**15.10**	**kg**	**9.37**	1.42	**16.52**	0.98
Data Handling	**14.00**	**kg**	**10.00**	1.40	**15.40**	0.91
AOCS	**74.21**	**kg**	**5.11**	3.79	**78.00**	4.63
Propulsion	**26.20**	**kg**	**7.00**	1.83	**28.03**	1.66
Power	**136.90**	**kg**	**13.73**	18.80	**155.70**	9.24
Harness	**52.97**	**kg**	**20.00**	10.59	**63.56**	3.77
Instruments	**600.64**	**kg**	**19.82**	119.03	**719.67**	42.71
Total Dry(excl.adapter)	**1432.86**				**1685.13**	**kg**
System margin (excl.adapter)			**20.00**	**%**	**337.03**	**kg**
Total Dry with margin (excl.adapter)					**2022.15**	**kg**

	Wo Residuals	*With Residuals*
TOTAL PROPELLANT MASS kg	**111.80**	**125.73**
TOTAL WET MASS (excl. Adapter) kg		**2147.88**
Adapter Mass kg		**60.00**
LAUNCH MASS (incl ADAPTER) kg		**2207.88**

Launcher Capability	Orbit Altitude	Orbit Inclination	
kg	*km*	*deg*	
1995.00	*600.00*	*5.24*	**VEGA**
ABOVE MASS TARGET BY:		-212.88	kg

Risk drivers

Environmental Factors

a. **Radiation environment (soft protons, SAA)**
b. **High expected micrometeoroid / orbital debris penetration in LAD**
c. Temperature gradients
d. High solar activity cycle (solar maximum peaks in 2025)
e. EMI/EMC (WFM)

Reliability Issues

a. **High accuracy deployment mechanism for LAD panels**
b. **Solar array deployment mechanism**

New Technology

LAD & WFM

a. ASIC (TRL 3)
b. Silicon Drift Detector (TRL 4)
c. Collimator (TRL 4)

Design Challenges

a. Complex payload (integration, test and calibration) with large detector procurement
   - Detector MAIT in schedule critical path
   - Limited availability of X-ray calibration facilities
b. **Payload contribution to S/C mass**
c. **Configuration and mass/volume constraints (Vega)**
d. Large amount of payload data to be processed & downlinked

Major Mission Events

a. LEOP (including Solar Array and LAD deployment)
b. De-orbit

Cost

1. Assumptions
   a. Cost estimates include LAD panel structure, deployment mechanisms and thermal control
   b. 4 years of nominal operations

2. Cost drivers
   a. Launch
      – The launch with a Soyuz represents a cost increase wrt Vega`
   b. Operations
      – MOC and especially SOC represent a large part of the total LOFT mission cost
   c. The S/C cost is driven by the power and structure S/S

3. Cost estimation
   a. For the 2 potential launchers, LOFT is presently expected to be compatible with the Cosmic Vision M-class budget limit of 470 M€, also taking into account cost evolutions during the development.

Model philosophy & Test Matrix

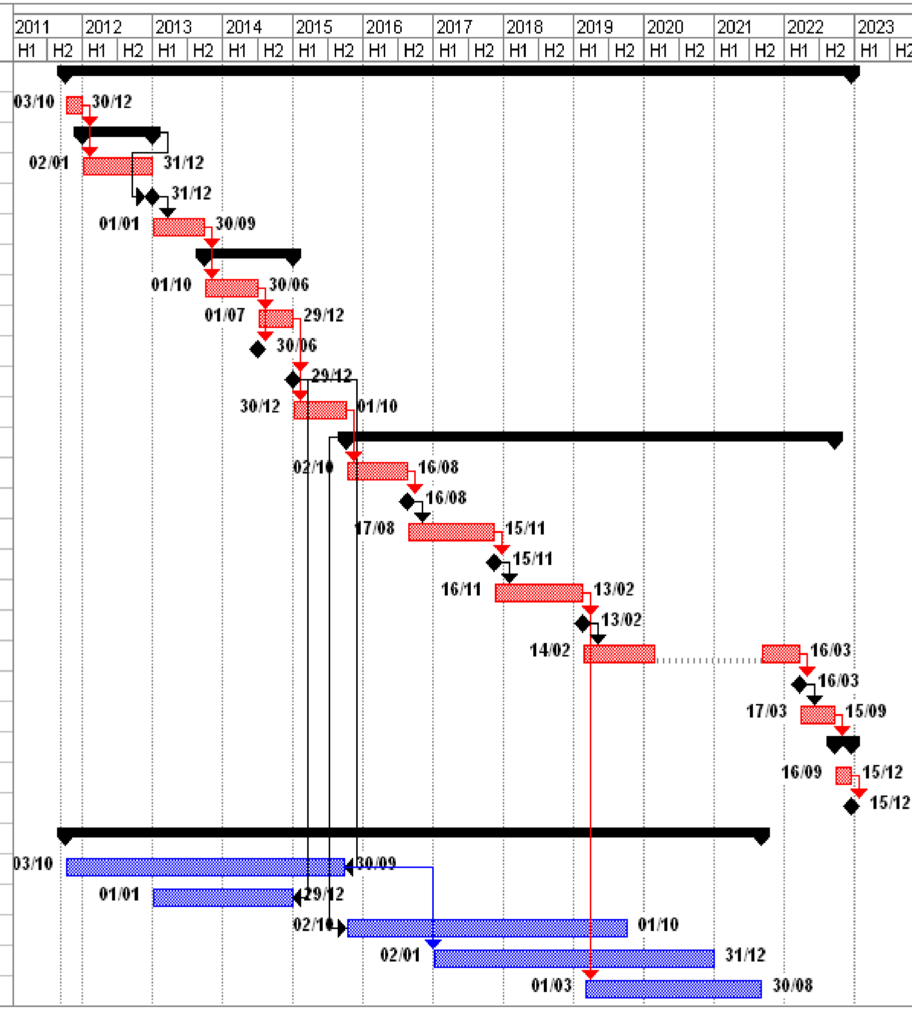
1. An STM, ATB, PFM approach is proposed
   a. STM can be refurbished after the qualification campaign and be re-used as PFM.
   b. ATB shall be used for electrical and functional tests and for SW verification and validation.
2. All equipment shall be fully qualified at equipment or subsystem level.
3. LAD panels and mechanisms shall be under the responsibility of the prime contractor
   a. After the qualification campaign the pre-integrated (harness & thermal control) panels shall be delivered to the payload manufacturer for SDD module integration
4. Payload verification shall be performed as far as possible at detector, module & panel level
   a. EGSE with simulators could be made available by the prime contractor

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

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

Schedule (1)

ID	Task Name
1	**LOFT**
2	ITT - 3 month
3	**Assessment phase - 12 month**
4	Industrial Phase 0 (parallel competitive, 2 primes) -12 month
5	MDR (Mission Definition Review)
6	Preparation of competitive definition phase - 9 month
7	**Definition phase (completion of Phase A, B1) - 15 month**
8	Phase A (Feasibility) - 9 month
9	Phase B1 (Requirements consolidation) - 6 month
10	PRR (Preliminary Requirements Review)
11	SRR (System Requirements Review)
12	Follow-up time - 9 month
13	**Implementation phase (Phase B2/C/D) - 61.5 month**
14	Phase B2 (preliminary design) - 10.5 month
15	PDR (Preliminary Design Review)
16	Phase C (Detailed definition) - 15 month
17	CDR (Critical Design Review)
18	STM and ATB pocurement and qualification - 15 month
19	QR (Qualification Review)
20	STM refurbishment, PFM integration and acceptance - 17 month split
21	AR (Acceptance Review)
22	Contingency - 6 month
23	**Phase E1 - 3 month**
24	Launch preparation
25	LRR (Launch Readiness Review after ORR & FRR)
26	**Payload Development & MAIT**
27	Technology development from TRL 3-4 to TRL 5-6 - 4 years
28	Technology development from TRL 4-5 to TRL 5-6 - 2 years
29	Technology development from TRL 5-6 to TRL 8-9 - 4 years
30	Payload detectors, modules & electronics production - 4 years
31	Payload moduls integration into panels - 2.5 years



Schedule (2)

1. **Driving for the overall schedule is the payload MAIT**
2. Major challenges
   a. Achievement of TRL 5 by mid 2014 for all payload elements appears as challenging and requires special effort
      – Typically this would be achieved only in the 3rd quarter 2015
   b. ASICs - completion of the design (two types) and the production of all ASICs (>28000)
   c. Serial production of all detectors, their assembly to modules and their verification and calibration in the given timeframe
3. Other critical issues
   a. the electronics development
   b. the design and verification of the panels and their deployment
4. The integration of the modules into the panels and the panel verification shall be done in a staggered way
   a. If the delivery of the panels after QR would be too late, then an extra panel could be procured and be delivered in advance

5. Nevertheless a launch by end 2022 appears to be feasible

Launch with Soyuz

Delta-design for Soyuz

1. Additional mass (increased performance) and volume (larger fairing) with respect to Vega could be used for:

   a. Reducing cost
      - No major cost drivers identified at S/C level; no major gain expected from Soyuz
      - But savings enabled by a reduced development risk (cost risk, see below).

   b. **Reducing risk**
      - Use mass margins to solve issues at lower cost
      - Unusual SA stowed accommodation (on top of LAD detectors) and deployment is considered risky
      - Better antenna and thrusters accommodation, reducing plume impingement issues
        - Re-opening of configuration trade
      - Environment (MMOD, radiation) can damage the LAD detectors
        - Increased redundancy would reduce risk (e.g. power distribution to LAD modules)

   c. **Increasing performance**
      - Orbit more favourable for radiation
        - Re-opening of orbit trade
      - Change to Soyuz not to be used for escalation of requirements

Alternative configurations for Soyuz (1)

1. Objectives:
   a. Independent deployment of SA & LAD
   b. SA not obstructing the launcher interface panel
2. Benefits
   a. If the stowed LAD panels do not cover the SVM, standard SA wings could be used (heritage, symmetry)

RadarSat-2, 13.2 m2

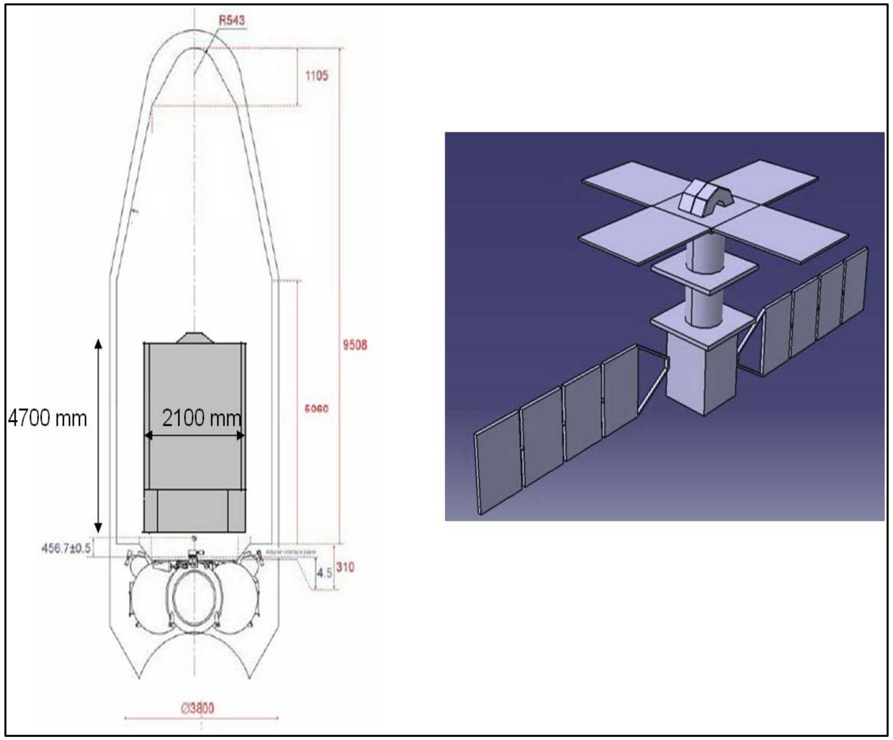
Cosmo SKYMED, 18 m2

Sentinel-1, 25 m2

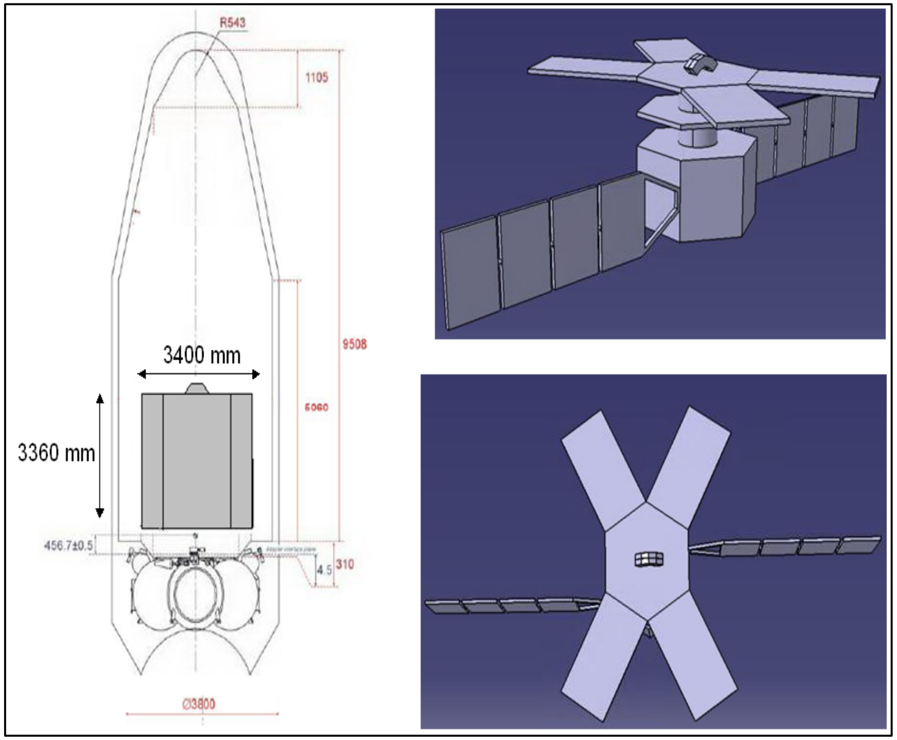
1. Alternative arrangements of the LAD panels have been investigated (# of panels, # of rows and columns of modules)
   a. Even number of panels enhance a more balanced deployment

# Panels	# Rows	# Columns	Dim [m x m]	Modules
6	7	3	3.6 x 1.0	126
5	6	4	3.0 x 1.3	120
5	5	5	2.5 x 1.6	125
5	4	6	2.0 x 2.0	120
4	6	5	3.0 x 1.6	120
4	5	6	2.5 x 2.0	120

Alternative configurations for Soyuz (2)



- 4 panels: 5 x 6 modules (2 x 2.6 m)
- Square service module (1.34 x 1.34 x 1.7)
- 2 wings of 4 panels (1.24 x 1.64 m), attached to SVM with 2 yokes (1.24 m width)



- 4 panels: 6 x 5 modules (1.6 x 3 m)
- Hexagonal service module
- 2 wings of 4 panels (1.24 x 1.64 m), attached to SVM with 2 yokes (1.24 m width)

Orbit trade-off for Soyuz

1. Impact of reducing orbit altitude and/or inclination for Soyuz only qualitative assessed; a detailed analysis is required

   a. Orbit maintenance
      – More frequent orbit altitude control manoeuvres, but impact on observing efficiency is low

   b. AOCS
      – Lower altitude $\Rightarrow$ higher attitude disturbances (gravity gradient, atmospheric torque), but also higher control authority for magnetorquers
      – Lower inclination $\Rightarrow$ lower maximum angle between orbital plane and magnetic field $\Rightarrow$ potentially less efficient magnetorquers

   c. Impact on power (duration of eclipses), comms (duration of ground station passes, lower distance), thermal (eclipses, increased albedo & Earth IR) are expected to be minor

Mass Budget for a launch with Soyuz (including controlled re-entry)

esa

LOFT

	Without Margin	Margin		Total	% of Total
Dry mass contributions		%	kg	kg	
Structure	**441.24 kg**	**20.00**	88.25	**529.48**	31.02
Thermal Control	**29.45 kg**	**10.00**	2.94	**32.39**	1.90
Mechanisms	**42.15 kg**	**10.00**	4.21	**46.36**	2.72
Communications	**15.10 kg**	**9.37**	1.42	**16.52**	0.97
Data Handling	**14.00 kg**	**10.00**	1.40	**15.40**	0.90
AOCS	**74.21 kg**	**5.11**	3.79	**78.00**	4.57
Propulsion	**46.80 kg**	**6.50**	3.04	**49.84**	2.92
Power	**136.90 kg**	**13.73**	18.80	**155.70**	9.12
Harness	**52.97 kg**	**20.00**	10.59	**63.56**	3.72
Instruments	**600.64 kg**	**19.82**	119.03	**719.67**	42.16
Total Dry(excl.adapter)	**1453.46**			**1706.93**	**kg**
System margin (excl.adapter)		**20.00**	**%**	**341.39**	**kg**
Total Dry with margin (excl.adapter)				**2048.32**	**kg**

	Wo Residuals	*With Residuals*
TOTAL PROPELLANT MASS kg	**192.07**	**207.61**
TOTAL WET MASS (excl. Adapter) kg		**2255.93**
Adapter Mass kg		**40.00**
LAUNCH MASS (incl ADAPTER) kg		**2295.93**

Launcher Capability	Orbit Altitude	Orbit Inclination
kg	*km*	*deg*
6460.00	*550.00*	*2.50*

SOYUZ

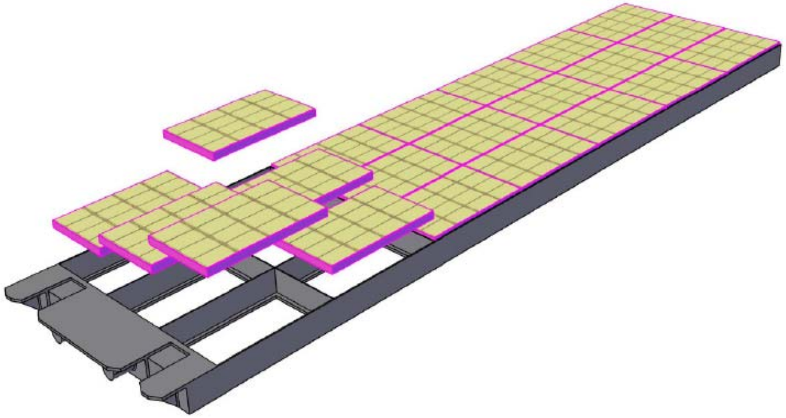
Below Mass Target by: 4164.07 kg

Payload aspects

Division of LAD hardware between PIs and Prime

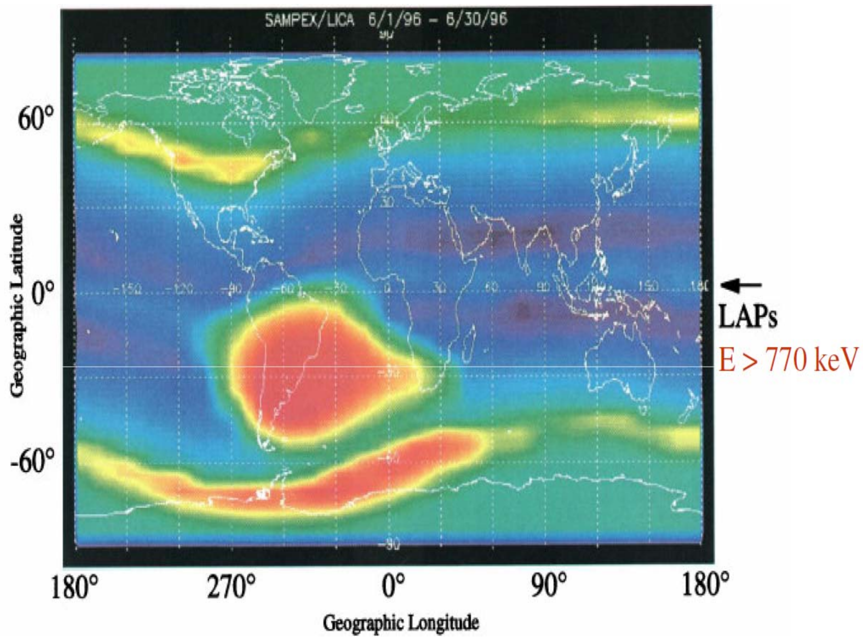
Based on a detailed programmatic analysis and assessment, recommendation of the CDF is that:

- The Prime contractor will provide the structure of the LAD panels complete with integrated hinges, harness, heaters etc. These items are very much part of the satellite system design.
- The instrument team (LAD PI) will provide the detector modules with mechanical interfaces to the panels and electrical interfaces to the LAD harness.
- The instrument team (LAD PI) will also provide all LAD electronics units as far as the LAD PDHU regardless of where these units are finally located.
- The LAD panel structures should be delivered from the Prime to the LAD PI so that integration, alignment and calibration of the LAD can be conducted by the PI at panel level.



Radiation damage to SDDs: Soft protons

1. Both the LAD and WFM have “open” solid angles through which even very low energy (soft) protons will be able to reach the SDDs.
2. We need to assess the fluence of soft (but possibly highly damaging) protons that will reach the SDDs (very soft protons are not included in AP8 (SPENVIS) models).



1. Band of directional (perpendicular to B) soft protons measured at all longitudes close to the equator.
2. Dispersion of fluxes in measurements
3. Short lived, storm enhanced

- The susceptibility of the LOFT SDDs to proton displacement damage needs to be measured at the earliest opportunity

Assessing micro-meteoroid damage

1. As a rule of thumb, particles will penetrate layers 3 to 5 times the particle diameter and will make a crater also about 3 to 5 times the particle diameter
2. The ECSS standards give particle flux tables as a function of diameter
3. Using this information, the consortium will make a first assessment of the damage expected during a 4 year mission

Must consider:

- ➢ stray light due to holes in optical filter
- ➢ Damage mechanism in glass MCPs
- ➢ Damage mechanism in SDDs themselves

Conclusions

Launch with Vega (1)

1. Current mission is **not compatible** with a launch with Vega

2. Mass margin at launch is **-210 kg** (for the option with no controlled re-entry)

3. Heavier S/C wrt proposal mainly due to:

   a. Increased payload mass
      – Includes Pb layer for LAD radiation shielding
      – Lower mass for LAD and WFM DHU

   b. Increased propellant mass
      – High solar activity expected, high cross area, safe mode
      – Increased propulsion S/S mass

   c. Increased mass of mechanisms and tower

Launch with Vega (2)

1. Additional issues

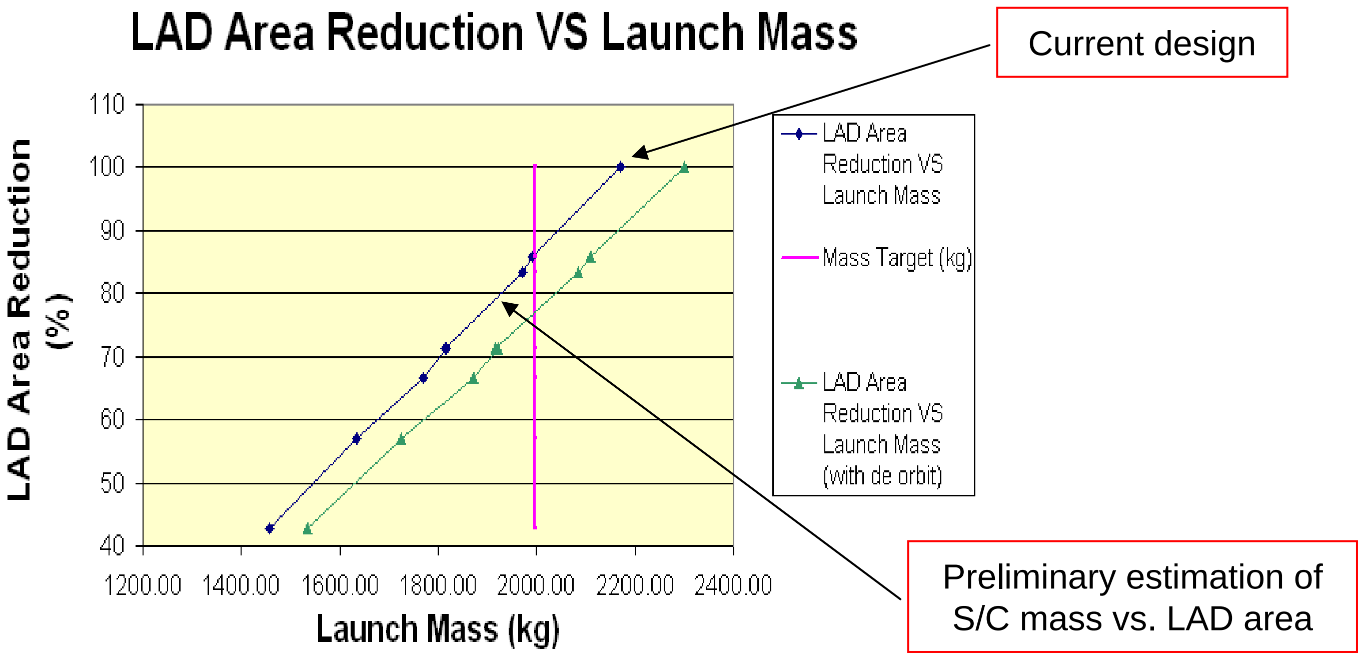
    a. Accommodation of
        - RCT thrusters (plume impingement on solar array)
        - LGA (need of a third LGA and a switch)
        - WFM thermal shield (if needed)
        - STR

    b. SA stowed on top of LAD panels
    c. No possibility of controlled re-entry

2. When considering all elements and natural study evolution, the VEGA launch scenario is not considered as realistic with the present model payload

Launch with Vega (3)

1. S/C optimization (e.g. configuration, structures, AOCS propellant, etc.) could reduce S/C mass…
2. but to fit in Vega possibly we will require a reduction in payload mass.
3. The most direct way to achieve that would be to reduce the LAD area.



Launch with Soyuz

1. A launch with Soyuz increases the mission cost, but it is expected to remain within the CaC target.

2. Additional mass (increased performance) and volume (larger fairing) would allow for
   a. Reduced development risk
   b. More robust design solution
      – Independent LAD and SA deployment
      – More optimal accommodation of equipment (thrusters, antennas, radiator)
   c. Potential use of standard platform and components (SA)
   d. Orbit less exposed to radiation (lower inclination and/or altitude) $\Rightarrow$ increased spectral resolution
   e. Being compliant with the required controlled de-orbit
   f. Less sensitivity of design to P/L mass and volume growth

3. System trade-offs and design would need to be reconsidered from for a launch with Soyuz (no proper design possible during the CDF study)

Conclusions

1. A technically feasible mission and S/C design satisfying all mission requirements has been identified for a launch with Soyuz

2. A VEGA launch scenario is not considered as realistic with the nominal model payload. A cut of ~ 20% on the P/L mass would be required

3. With respect to M-class boundary conditions, LOFT (with a Soyuz launch):
   a. It is compatible with the CaC target (first iteration)
   b. It has low risk development (high TRL, most COTS) for the spacecraft
   c. Achieving TRL 5 by mid 2014 for all P/L elements appears to be challenging and requires special effort
   d. schedule is rather tight for payload procurement & AIT

4. The industrial assessment study is expected to revisit these conclusions (final LV selection expected by the end of phase 1)

Open issues

1. AOCS
   a. detailed analysis of wheel off-loading considering observation plan
      – frequency and propellant of RCS manoeuvres for wheel off-loading when magnetorquers are not enough
   b. detailed analysis of star tracker optimal accommodation and estimation of AKE when all optical heads are blinded by Earth

2. Detailed thermal analysis for both LAD and WFM
   a. WFM thermal shield (see non compliant temperature)
   b. LAD Heaters

3. Comms and ground segment
   a. Confirm Malindi status
   b. 8 PSK waiver for LOFT

4. **Launch with Soyuz**
   a. **Re-opening of configuration trade-off**
   b. **Re-opening of orbit trade-off**

Actions for Study Science Team

1. Consolidate science requirements:
    a. Flow-down from science objectives to science requirements
    b. LOFT observation plan
        - Statistics are needed of pointing, duration, slew manoeuvres, slew angle, ToO, observations during eclipse, calibration
    c. Pointing and alignment requirements (e.g. flat-top response of collimators)
    d. Temperature requirements for LAD and WFM

2. Assess environmental damage to instruments
    a. Radiation (soft protons)
    b. Micrometeoroids & space debris

3. Consolidate design of instruments
    a. WFM design
    b. LAD module design and interface to LAD panel
    c. Power distribution architecture, including location and functions of PBEE, MBEE, DHU (LAD), and BEE and DHU (WFM)
    d. Data handling architecture

This study is based on the CDF Integrated Design Model (IDM), which is copyright.