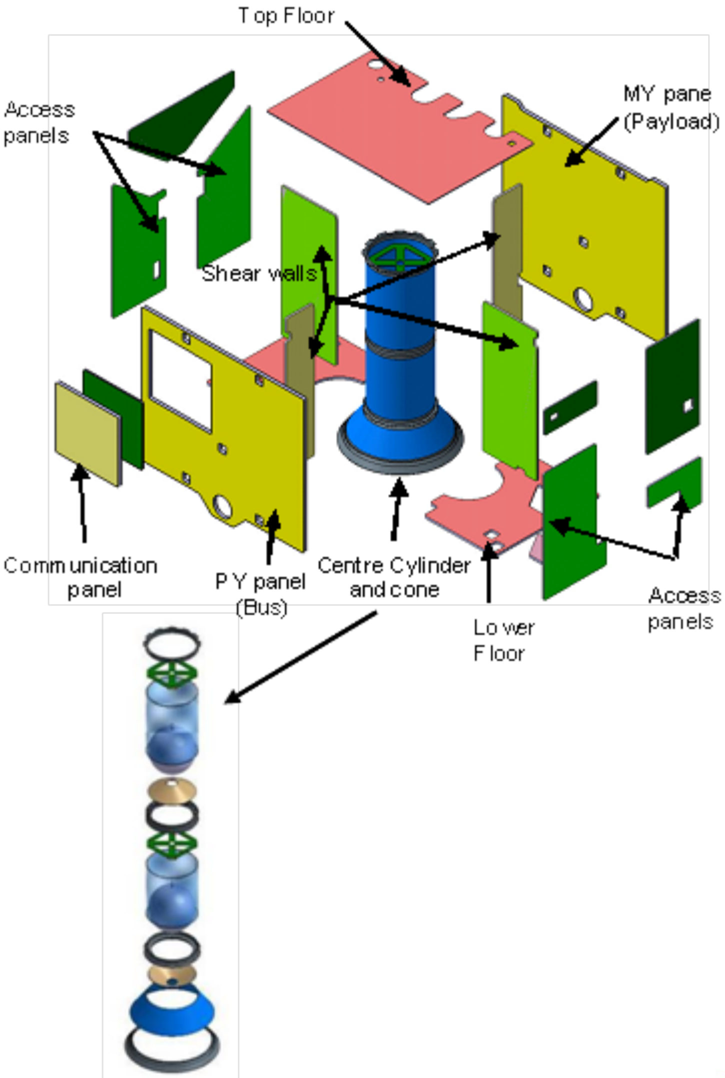
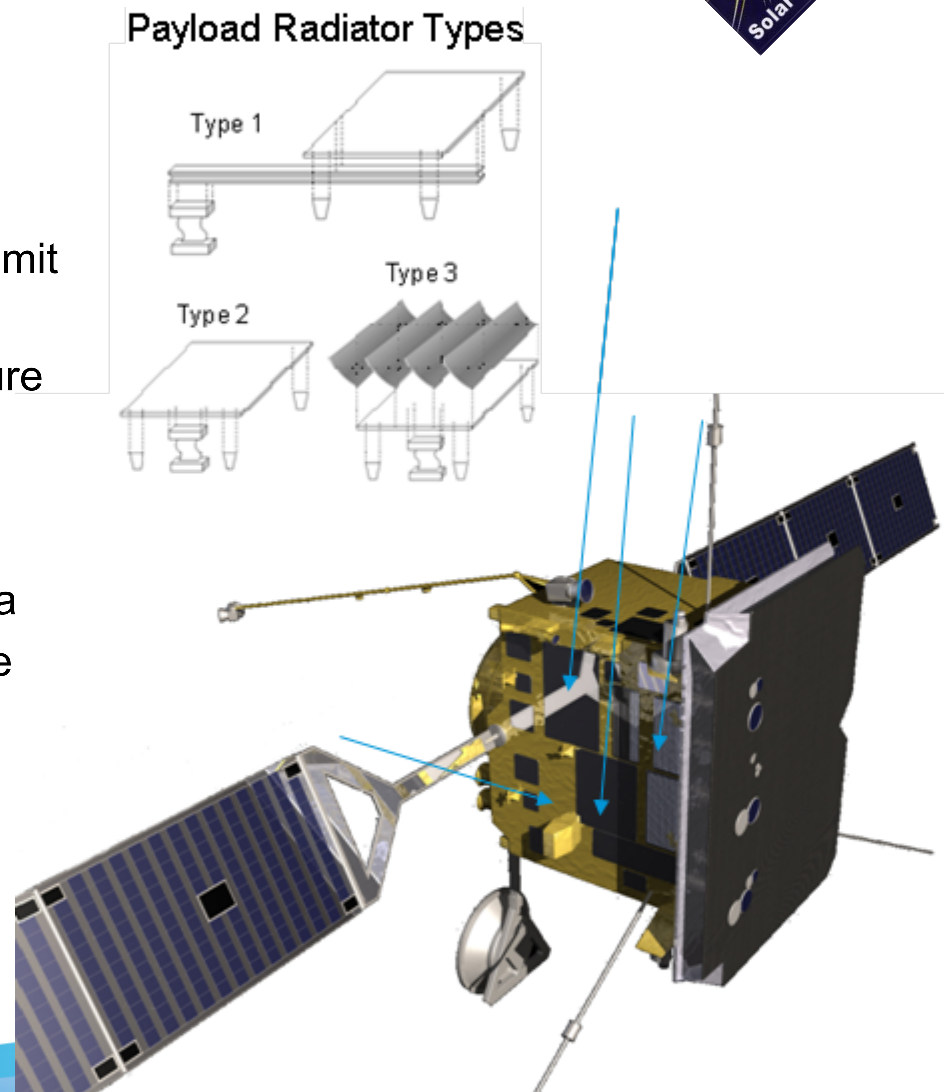
Structure



- Main dimensions :
  - 2.20m (w) x 1.50m (d) x 1.80m (h)
- Mass budget 288 kg
- Material and technologies :
  - Central CFRP cylinder with support for propellant tanks
  - Outer panels and shear walls: sandwich with metallic skins
  - Some embedded heat pipes
  - Contaminant free (bake-out req'd)
  - Minimised thermo-elastic distortion
- Interfaces with :
  - about 100 equipment units
  - 9 flexible appendages
  - 1194mm launch interface ring

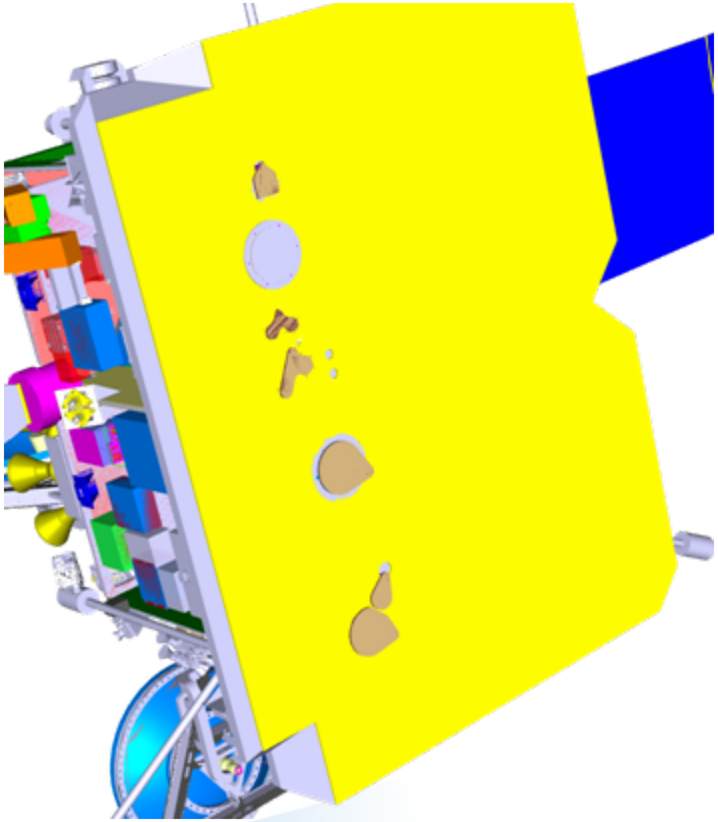
Thermal Implementation

- Design, procurement and breadboard testing of Payload radiator assemblies:
  - Includes radiating panels, flexible blades, heat straps, heat pipes, reflecting fins to limit heat from external loads (eg solar array)
  - Thermal and mechanical isolation to ensure spacecraft thermoelastic performance
- Design and procurement of Platform MLI
  - High IR exposure from High Gain Antenna
  - Coverage of platform panels and equipme
  - Electrically conductive (surface charge control)
- Procurement of heaters, thermistors and low conductivity washers



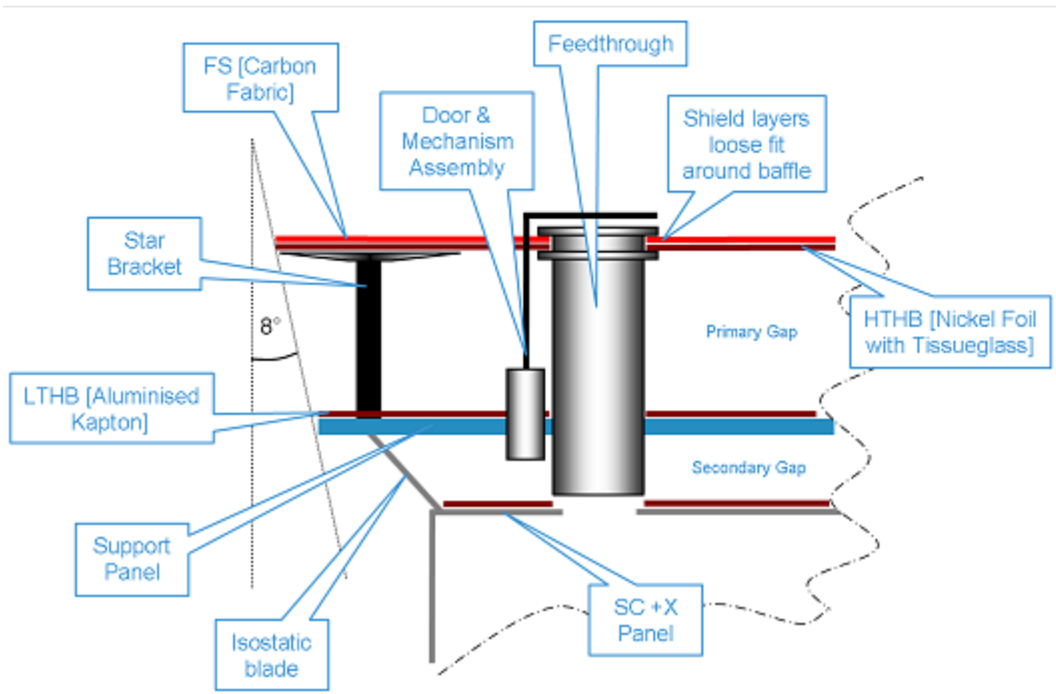
Heatshield

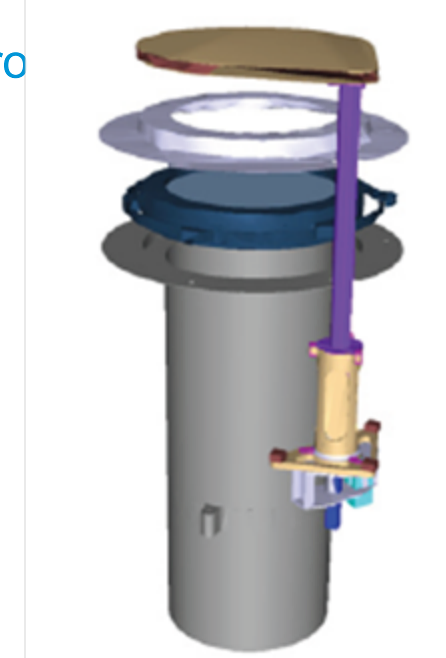
- Protects the spacecraft from the Sun
  - Slightly oversized beyond spacecraft body to ensure spacecraft in shadow
  - Limits the radiated heat flux to the spacecraft to +/-30W
- Induce minimal thermo-elastic distortion into the spacecraft structure
- Control the surface charge
- Responsibility of TAS-I



Feedthroughs, Doors and Mechanisms

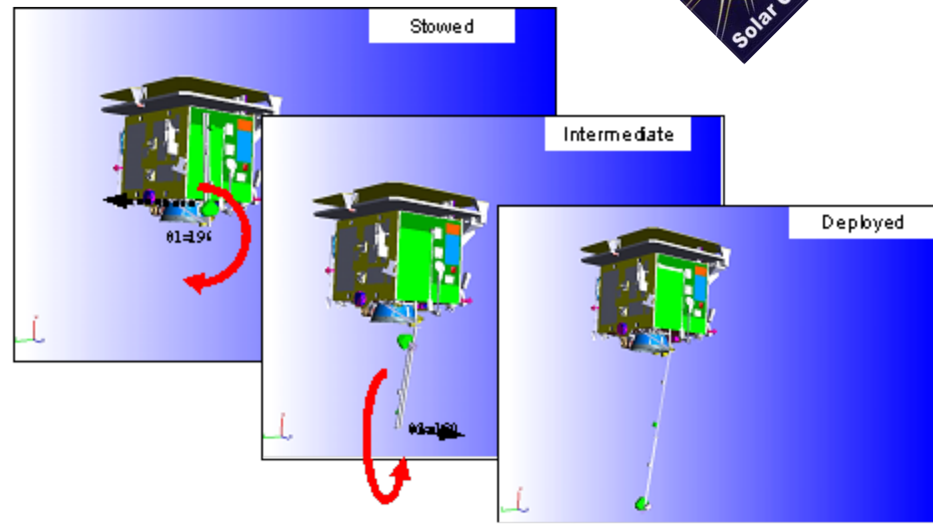
- 8 feedthroughs for PL instruments, 7 with doors
- Edge and corner feedthroughs for Sun Sensors and SoloHI
- Minimise straylight, high cleanliness, surface charge contro
- Materials/manufacturability development necessary

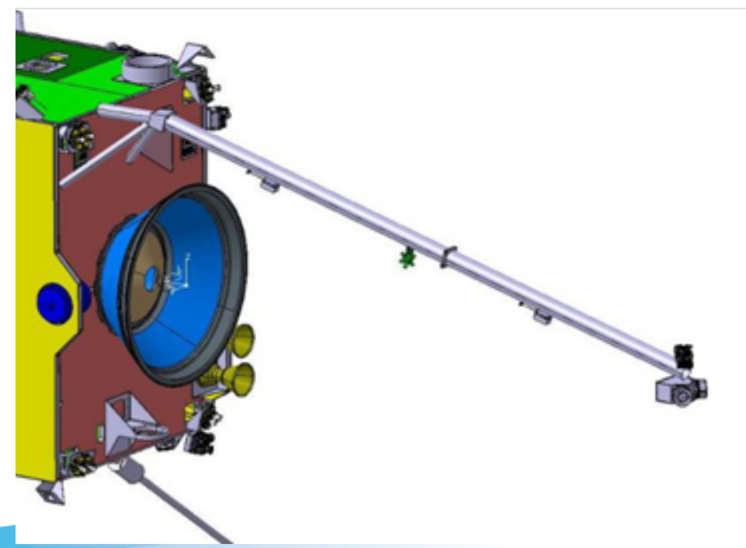




Instrument Boom

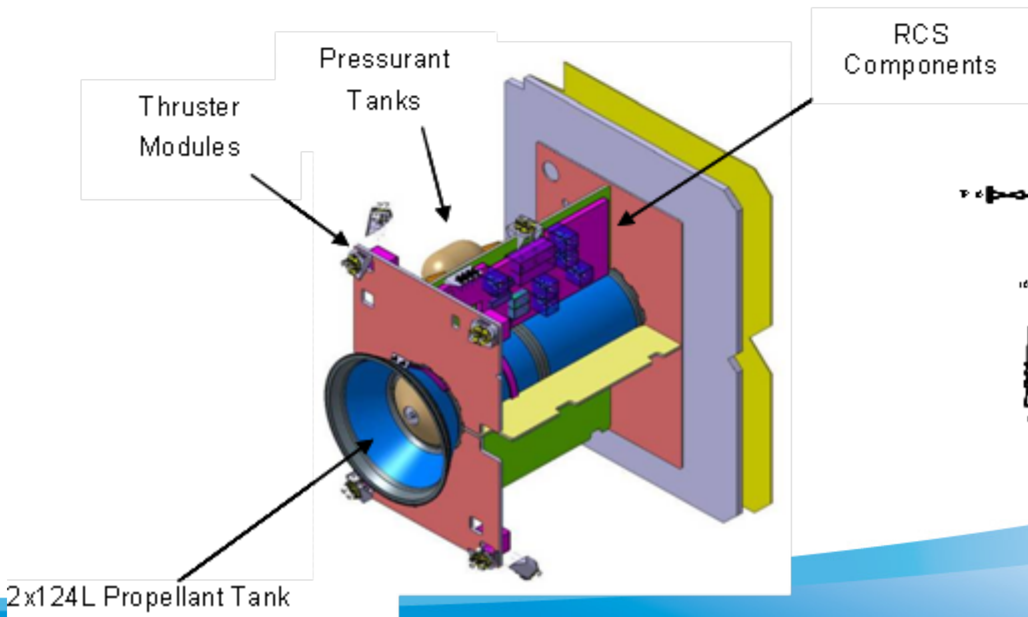
- 4m deployed / 2m stowed
- 2 segments, 2 hinges with switches
- Interface to 5 sensors (incl harnesses)
- Pointing accuracy better than 0.15°
- Low shock HDRM to S/C
- Contaminant free (bake-out required)
- Magnetically “clean”
- Always in the shadow of the Heatshield below 0.8 AU

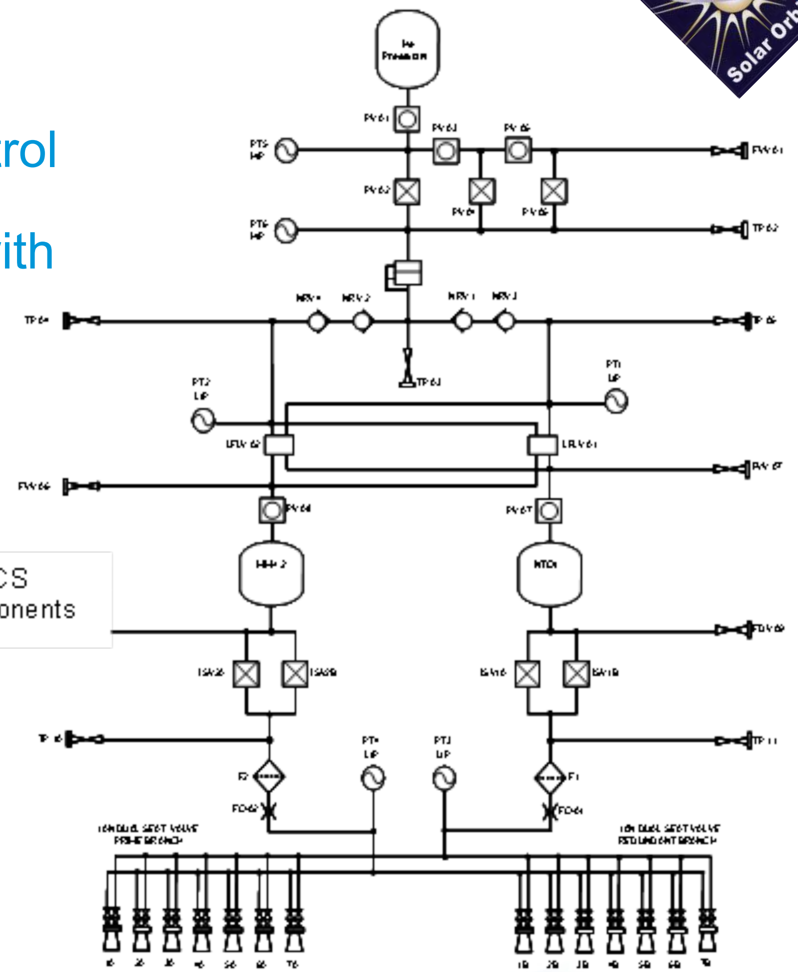




Propulsion Subsystem

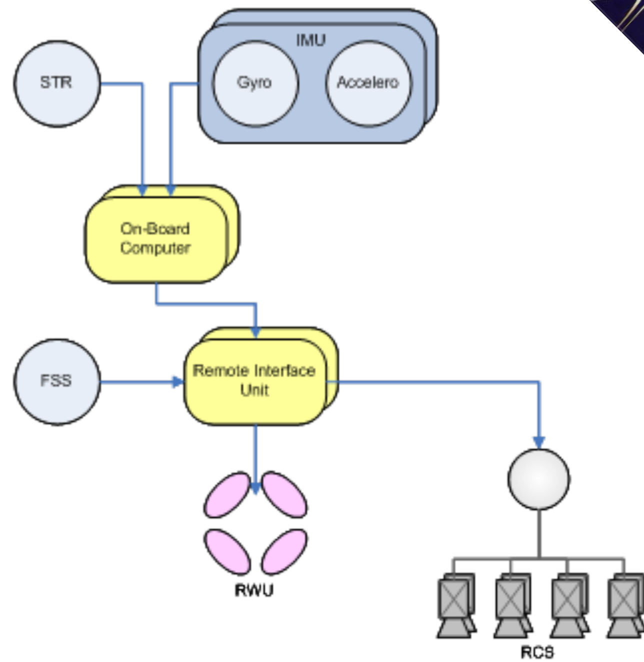
- ΔV for gravity assist and torques for attitude control and wheel speed control
- Bi-propellant (MON3/MMH) system with one-shot re-pressurisation (He)
- Two propellant tanks (2 x 124 litre)
- 18 dual valve thrusters (10 N)

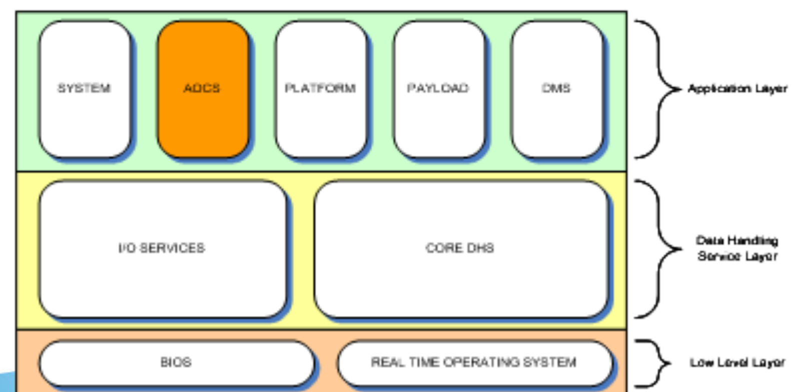




Attitude and Orbit Control

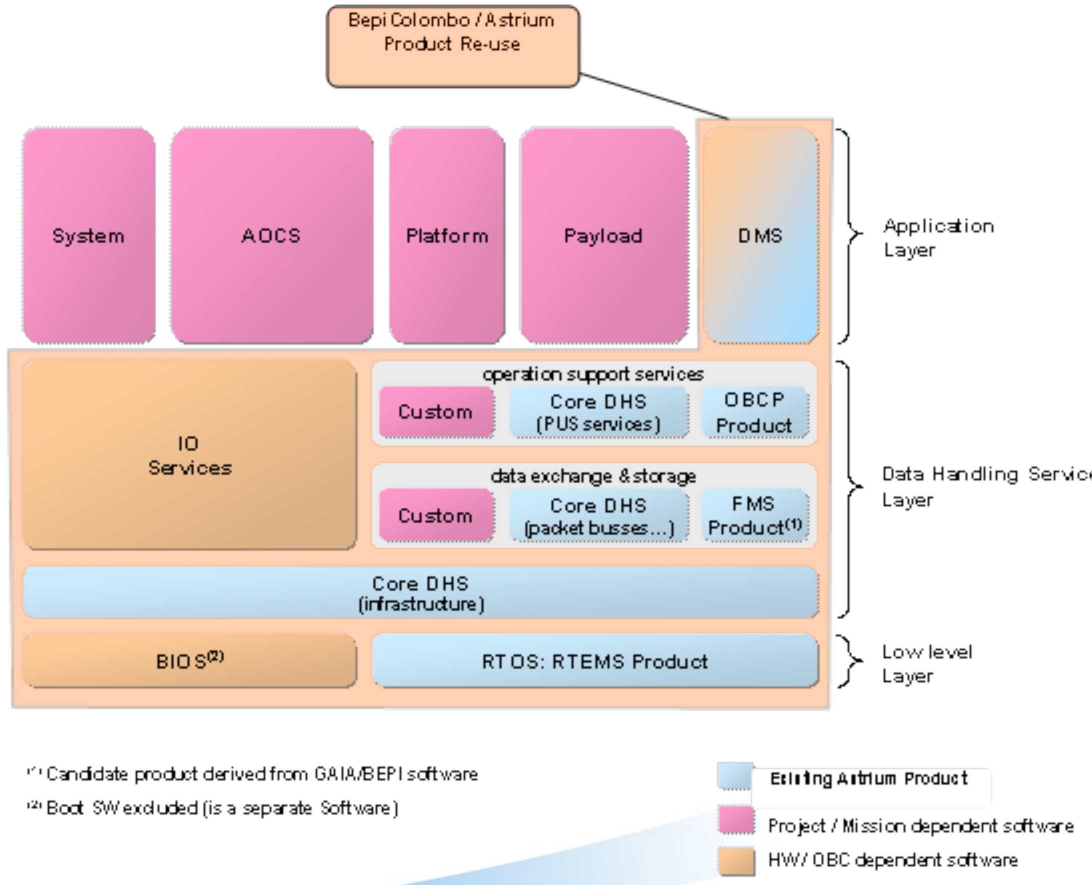
- Main design drivers
  - Precise pointing (RPE 1 arcsec in 10 s)
  - Sun pointing constraints
  - Complex thruster configuration
  - Highly autonomous
  - Complex FDIR
- Sensors and actuators
  - Star Tracker (x 2)
  - Inertial Measurement Unit (x 2)
  - Fine Sun Sensor (x 2)
  - Reaction Wheels (set of 4)
  - Thrusters (part of Propulsion subsystem)
- AOCS subsystem tasks include
  - AOCS hardware procurement
  - Completion of algorithm design
  - Detailed design and coding of AOCS SW
  - Development of simulation framework
  - Verification and validation of AOCS
  - Support to prime for integration, test and maintenance of flight SW





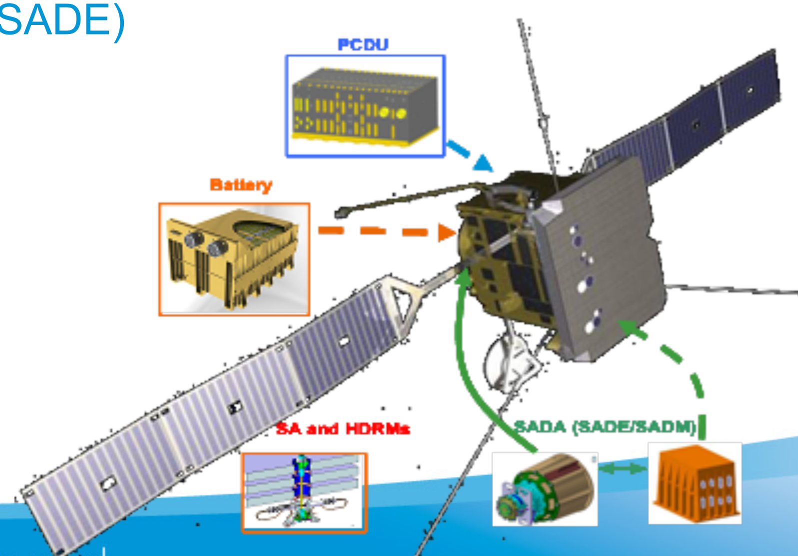
Central Software (CSW)

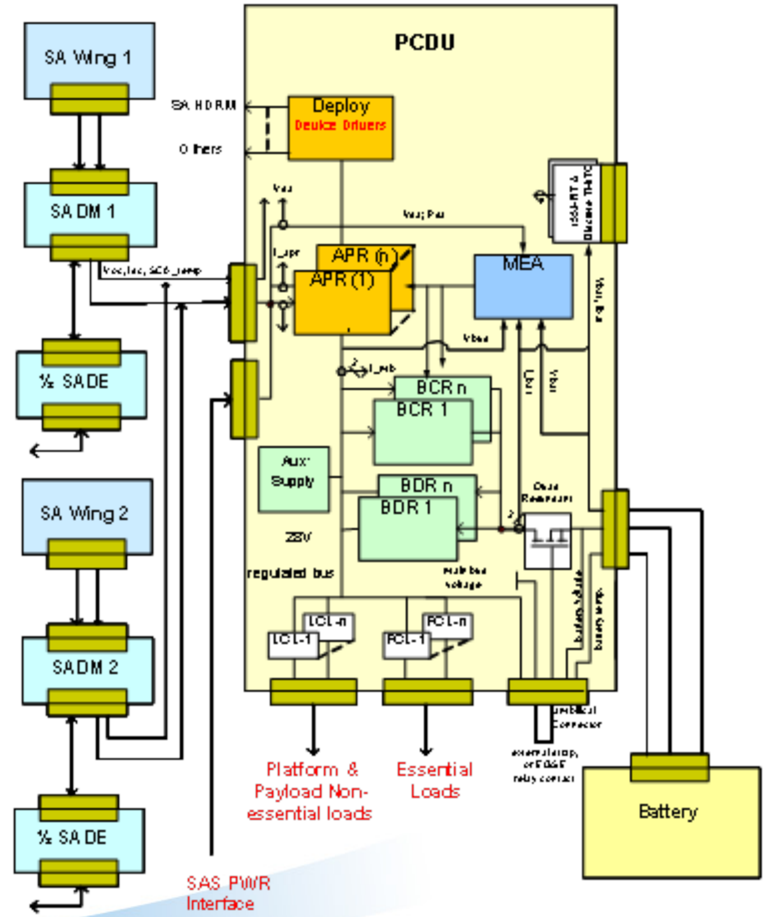
- The spacecraft on-board software includes the CSW residing in the OBC
- It is anticipated that the data handling service layer is re-used from other programmes
- Application layer to be coded against Requirement Specs
- Verified software integrated by Prime in the overall CSW



Electrical Power

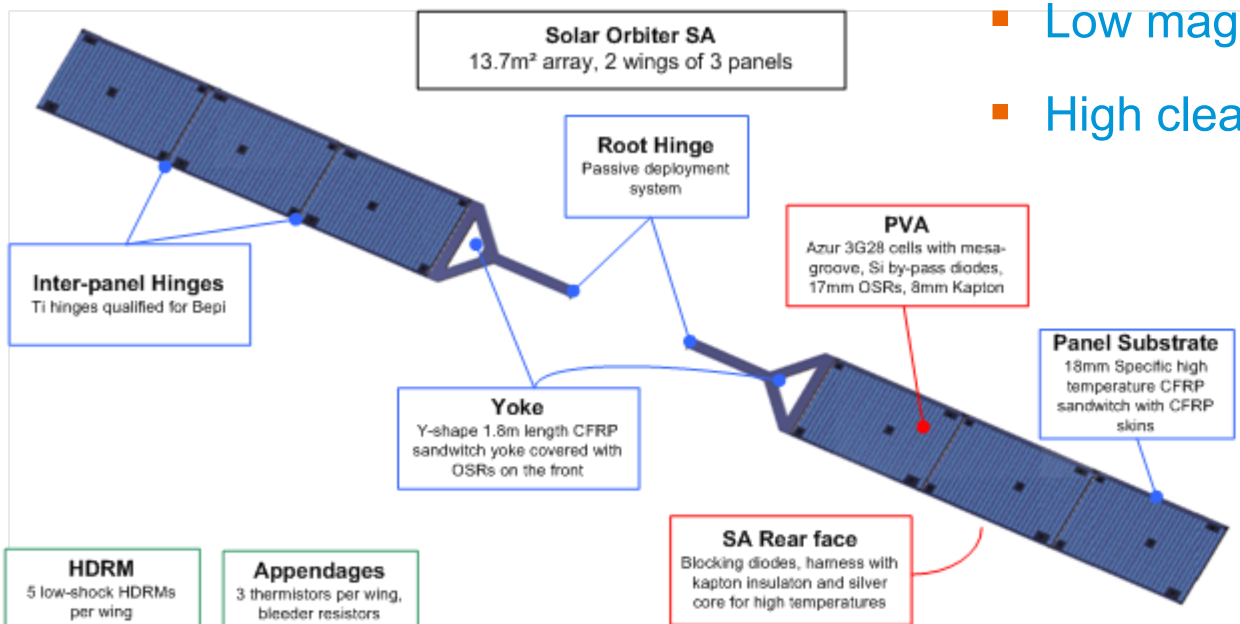
- Fully regulated and protected power bus
- S/C power requirement is 28V, 1500W (in Sun)
- PCDU input voltage range 32V to 136V
- Battery 2000Whr (25V) Li-ion for LEOP and Gravity Assist
- Includes Solar Array Drive Mechanisms (SADM) and Solar Array Drive Electronics (SADE)
- MIL-1553 control and TM/TC interfaces (PCDU and SADE)





Solar Array

- Re-uses BepiColombo MPO technology
- 2 wings, 3 single-sided panels
- Each panel 1.2m x 1.91m
- Array provides ~945W at 1.5AU
- Survives harsh environment with peak solar flux of 17.5 kW/m^2
- Low magnetic footprint
- High cleanliness

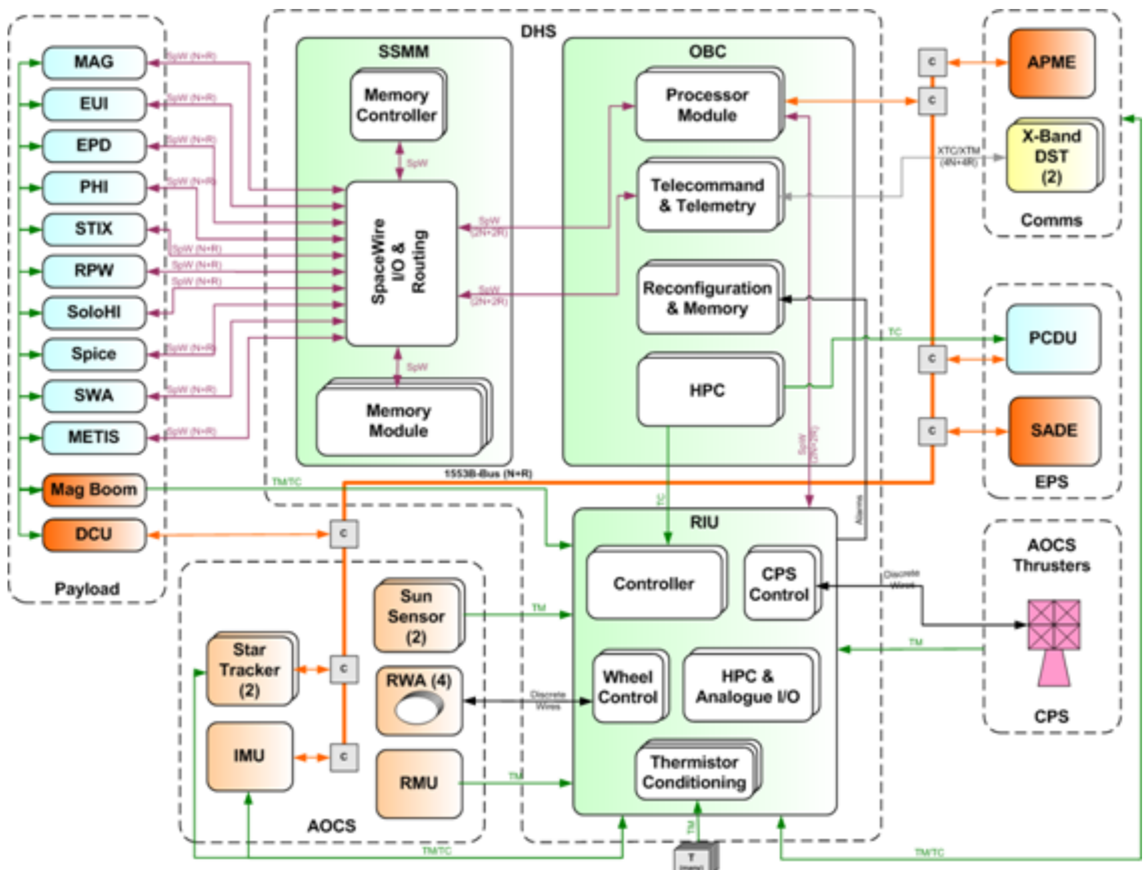


Harness

- Conventional design and manufacture (approx 80kg)
  - Power harness (energy sources double insulated)
  - Signal harness
  - Pyro and deployment device harness
  - SpaceWire and Mil-1553 harness
  - Safe/Arm plugs
  - Excludes intra-Instrument harness
  - Low magnetic footprint and high cleanliness
- Subsystem tasks include:
  - Design, build and test from design rules, equipment Interface Control Documents and Spacecraft configuration.
  - Integrate and test on the Spacecraft.

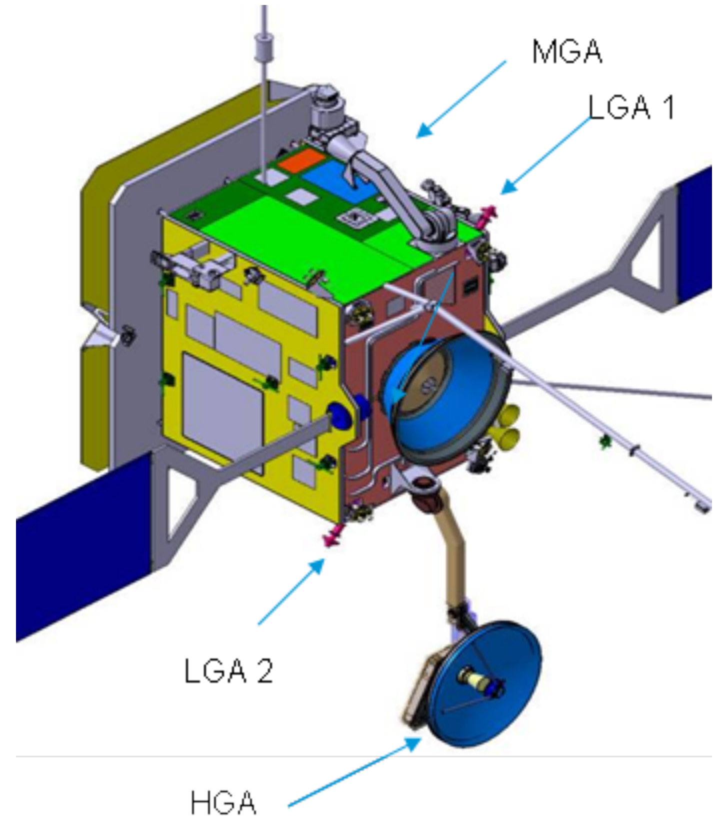
Data Handling

- OBC is main computer for command, monitoring, AOCS and FDIR. Based on ERC-32 processor. Includes reconfiguration, TC/TM processing, …etc.
- SSMM provides house-keeping and science data storage. Approx 512 Gbits EoL. Acts as SpW router between OBC & Instruments
- RIU includes interfaces to heaters, thermistors and bespoke control interfaces to thrusters, pressure transducer, Sun Sensor, Reaction Wheels (tbc), etc



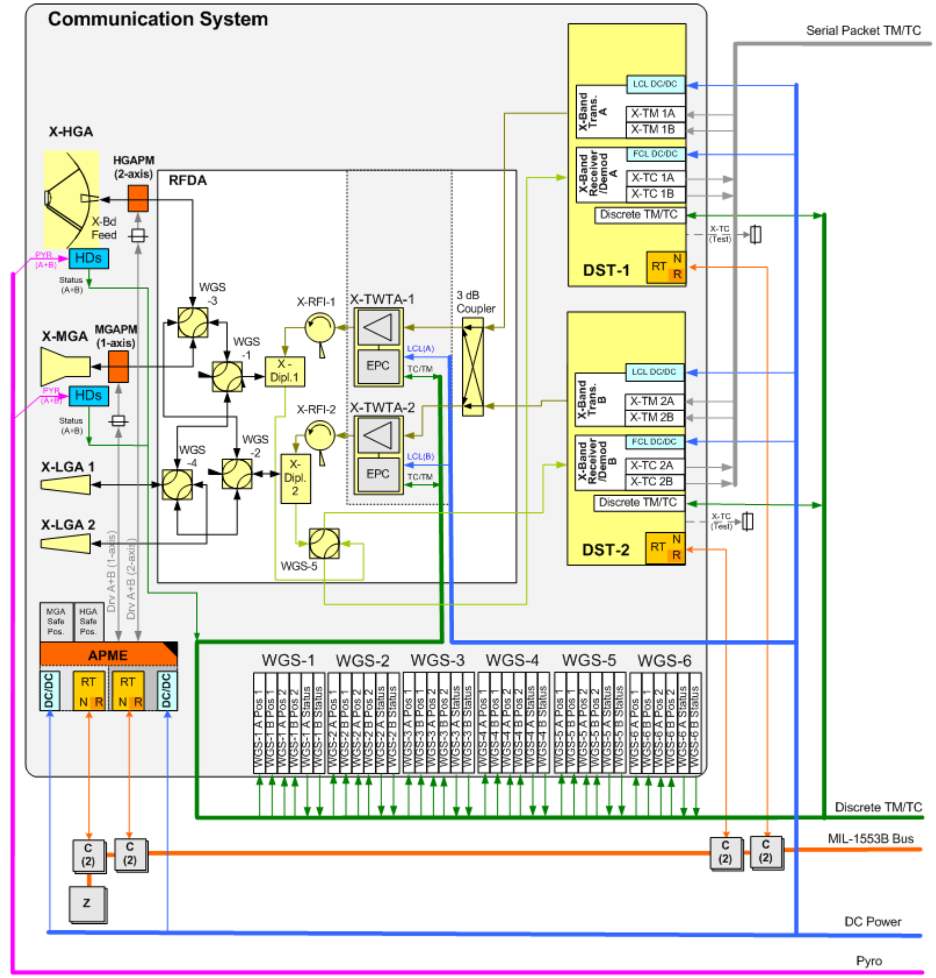
Antennas

- Two-way X-Band communication
- Low Gain Antennas (LGA1 and LGA2)
  - Low data rate during LEOP, near Earth, and as backup
  - Near 4π steradian coverage
- High Gain Antenna (HGA) for high data-rate during nominal and extended mission phases
  - 1.1m dish, dual axis pointing mechanisms, gain 34dBi to 36dBi
- Medium Gain Antenna (MGA) for medium data rate up-down communications in backup situations and during Safe Mode operation
  - 0.19m horn, single axis pointing, gain 20dBi to 22dBi
- Antenna Pointing Mechanism Electronics (APME)



Communications

- Single X-band downlink and uplink
- 150kbps main data downlink rate
- Turn-around and differential one-way ranging
- Two Deep Space Transponders (DST) based on BepiColombo design
- Two 70W X-band TWTA
- RF distribution assembly containing the passive hardware
- To be integrated and tested on Communications Panel

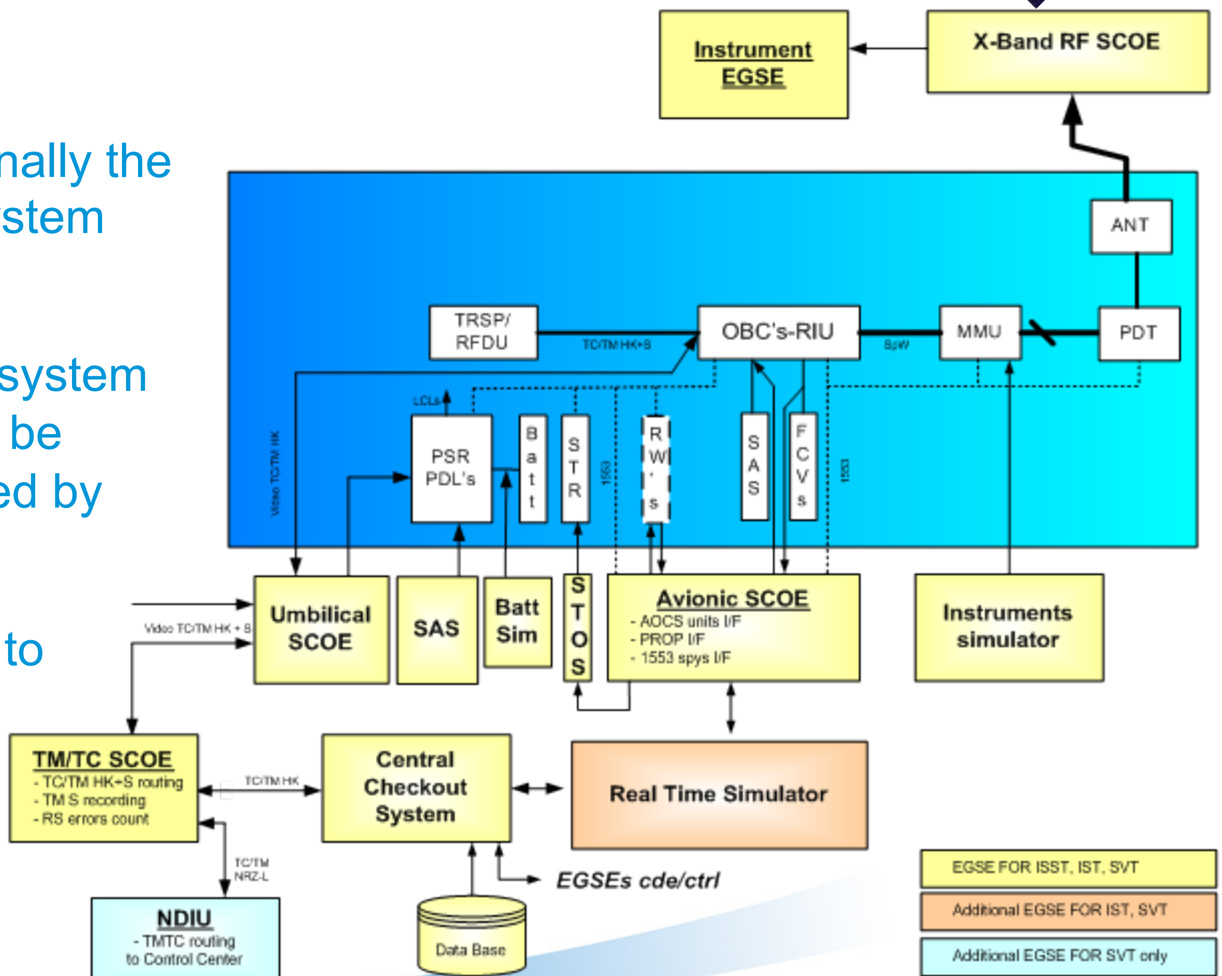


Mechanical Ground Support Equipment

- Astrium will carry out spacecraft AIT activities in Stevenage.
  - Some GSE will be re-used from other programmes and the remainder will be procured specifically for Solar Orbiter
- The mechanical ground support equipment (MGSE) needed to support spacecraft AIT includes:
  - Spacecraft Container
  - Multi-Purpose Trolley
  - Vertical Trolley
  - Spacecraft Lifting Device
  - MGSE Lifting Brackets
  - Panel Handling Frame/Trolley/Lifting Device/Transport Container
  - Clampbands
  - Adaptors
  - Unit Mass Dummies

Electrical Ground Support Equipment

- Subsystem EGSE is nominally the responsibility of the Subsystem supplier
- Astrium is responsible for system level EGSE but EGSE will be designed and manufactured by external Companies
- 2 EGSE sets are required to support system level tests



UK EXPORT CONTROL RATING: 9E001/9A004

Rated By: P. D'Arrigo

Solar Orbiter AOCS

All the space you need

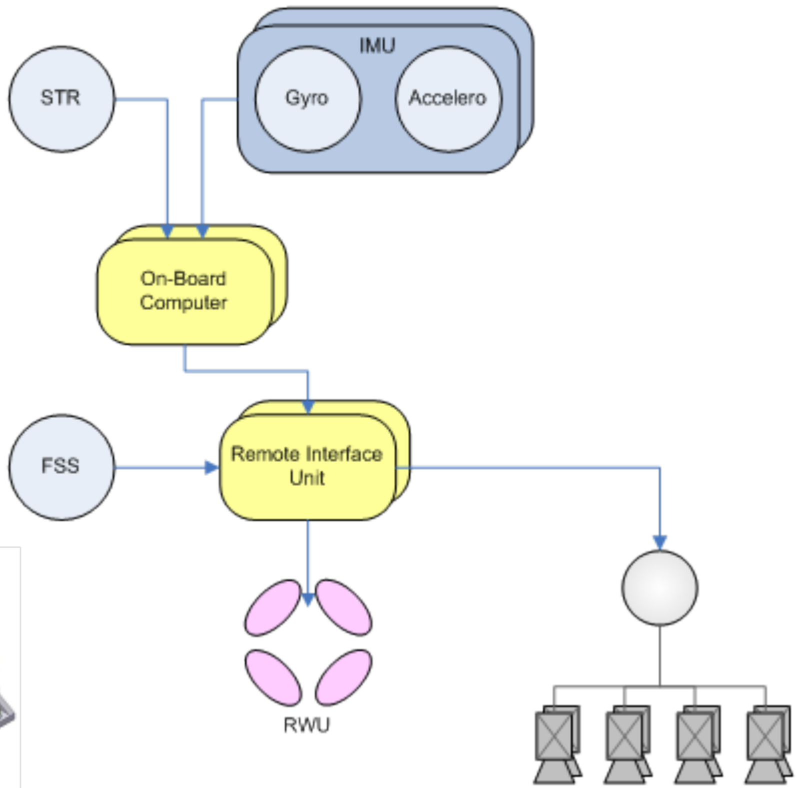
ASTRIUM
AN EADS COMPANY

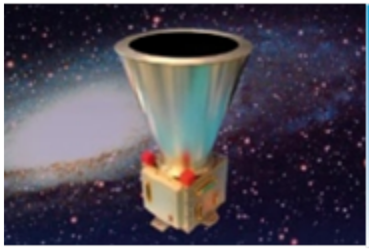
Key Points

- The AOCS provides all the functionalities required to control the spacecraft attitude and rates, and perform orbit correction manoeuvres
- Drivers include:
  - Pointing performance requirements (RPE 1 arcsec in 10 s)
  - Sun pointing constraints (max off-pointing of 6.5º in 20 s)
- Pure-torque thruster control
  - Force-free to avoid orbit disturbance
- Multiple delta-V thrust directions (+X, -X, -Y)
  - Complex thruster configuration
- Highly autonomous subsystem which requires minimal ground support
  - E.g. long-duration conjunctions
- Complex FDIR
  - Earth strobing in Safe and Survival Modes.
  - Autonomous transition from thrusters to wheel-based Safe Mode (if wheels available after autonomous check).
  - Autonomous transition to inertial pointing if star tracker available.

HW architecture - 1

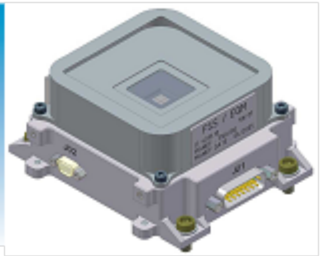
- The subsystem consists of a dedicated set of sensors:
  - Star Tracker
  - Inertial Measurement Unit
  - Fine Sun Sensor
- And a dedicated set of actuators:
  - Reaction Wheels
  - Thrusters





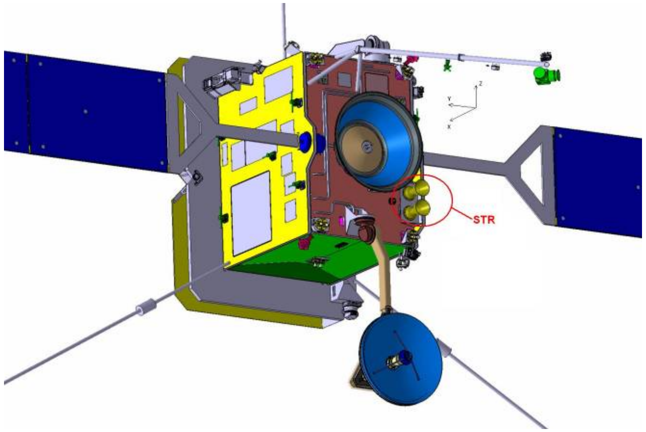
Star Tracker: tolerant to SEU, flares, etc.

IMU: gyro and accelerometer, high accuracy, low drift

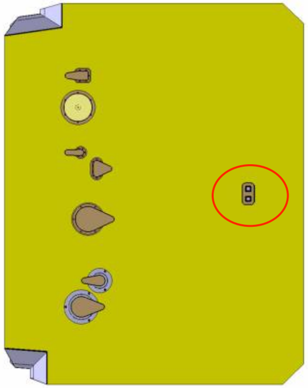


FSS: tolerant to close sun proximity

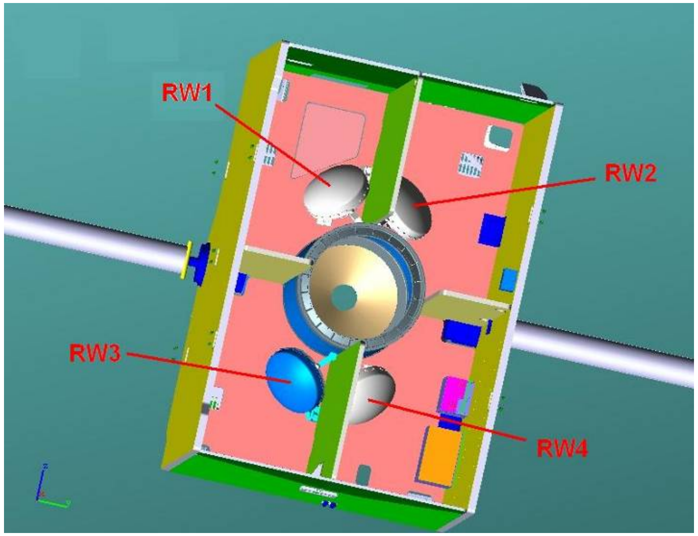
HW architecture - 2



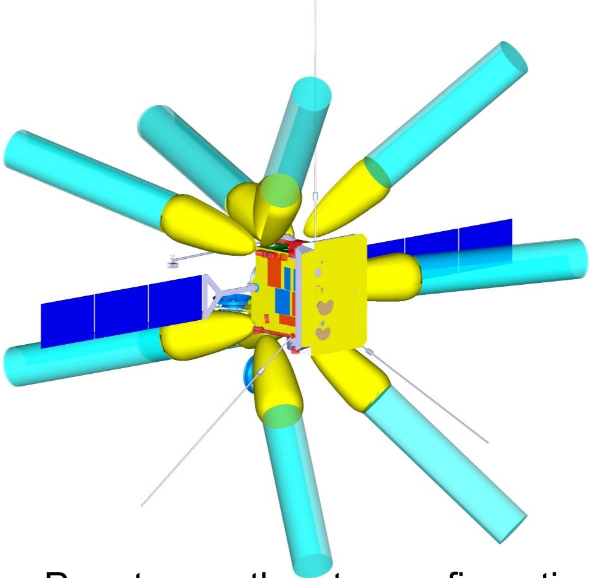
Star trackers face away from sun



Sun sensors on front face



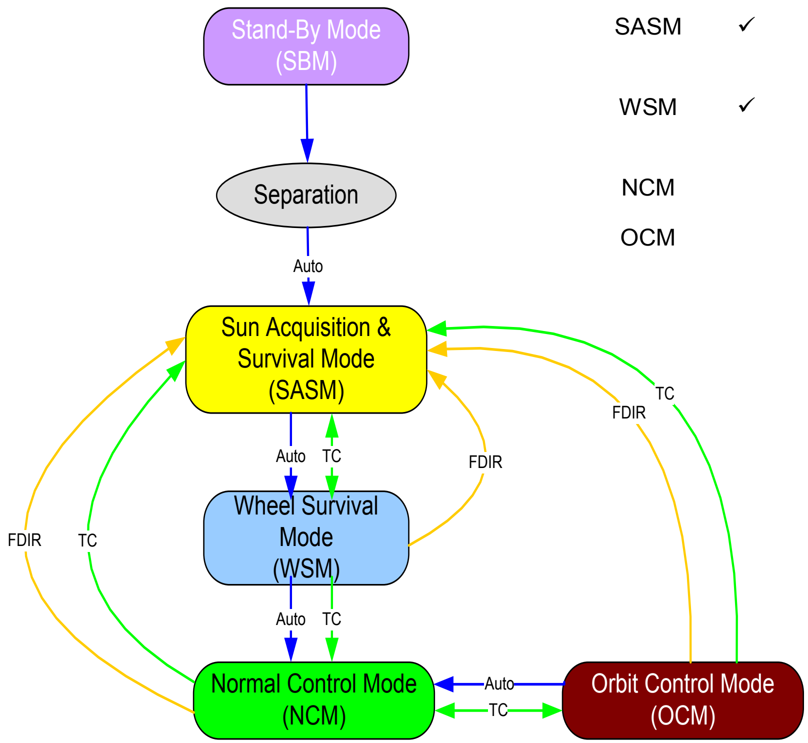
4 reaction wheels



Pure torque thruster configuration

Mode architecture - 1

AOCS Mode	Sensors				Actuators		Notes
	FSS	IMU	STR	ACC	RWU	RCS	
SBM						✓	RCS for priming – no control.
SASM	✓	✓			✓*	✓	Control suspended during SA deployment. RWU in open-loop (speed control)
WSM	✓	✓	✓*		✓	✓*	RCS used for wheel offloading in open-loop. STR used for attitude reconstruction.
NCM		✓	✓		✓	✓*	RCS used for wheel offloading in open-loop.
OCM		✓	✓	✓	✓*	✓	RWU in open-loop (speed control)

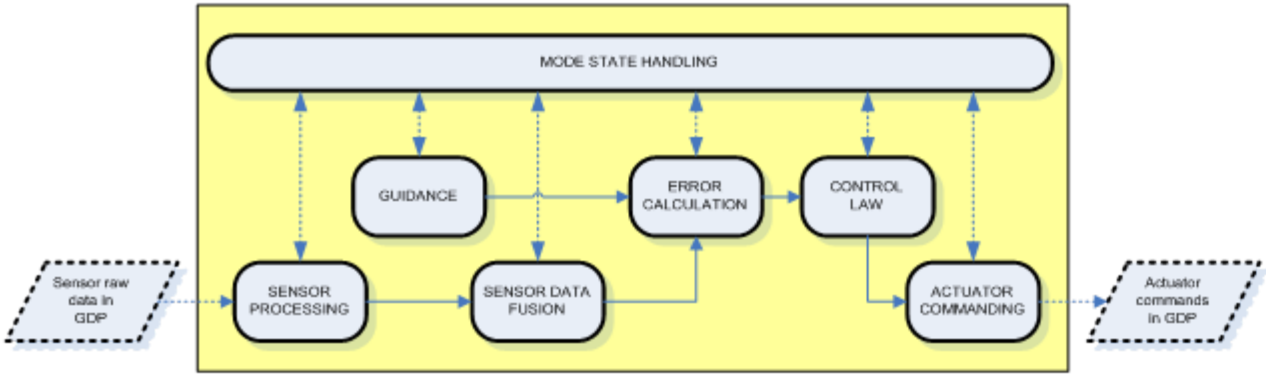


System Modes	AOCS Modes				
	SBM	SASM	WSM	NCM	OCM
Off					
Pre-Launch and Launch	✓				
Acquisition		✓			
Nominal				✓	✓
Safe				✓	
Survival		✓	✓		

Mode architecture - 2

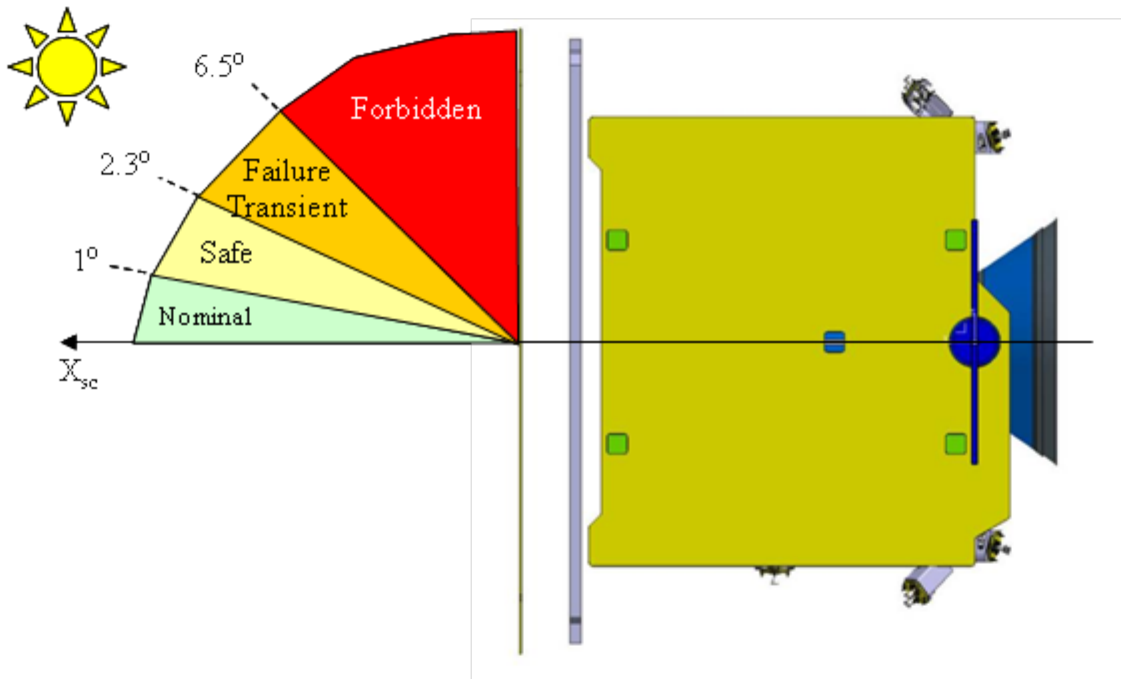
AOCS Mode	Description
Sun Acquisition and Survival Mode (SASM)	- Initial sun acquisition and lowest level system survival mode following FDIR fail-safe alarms. - Nominal sun acquisition with FSS and IMU, thrusters for actuation. - Control is suspended during solar array deployment and rotation. - Rotation about the sunline (Earth strobing) controlled by on-board flags and TC.
Wheel Survival Mode (WSM)	- Sun pointing on wheels in preparation for transition to NCM and second level of system survival mode. - Sun pointing based on 2-axis control about sunline with FSS and rate control on third axis. - Rotation about the sunline (Earth strobing) controlled by on-board flags and TC. - Autonomous wheel momentum management is performed using thrusters.
Normal Control Mode (NCM)	- Main mode to support the mission science operations. Provides high accuracy pointing. - This mode is also employed in the system Safe Mode when IMU, STR and RWU are deemed usable. - Guidance is semi-autonomous based on ground up-linked attitude guidance profiles. - Autonomous or commandable wheel momentum management is performed using thrusters.
Orbit Control Mode (OCM)	- Used to perform trajectory correction manoeuvres (TCM) of any type. - Employs same sensors as NCM, thrusters provide three axis control torque. - Reaction wheels are kept at constant speed. - The ΔV amplitude can be controlled by either the pulse count method or using accelerometers.

Functional architecture



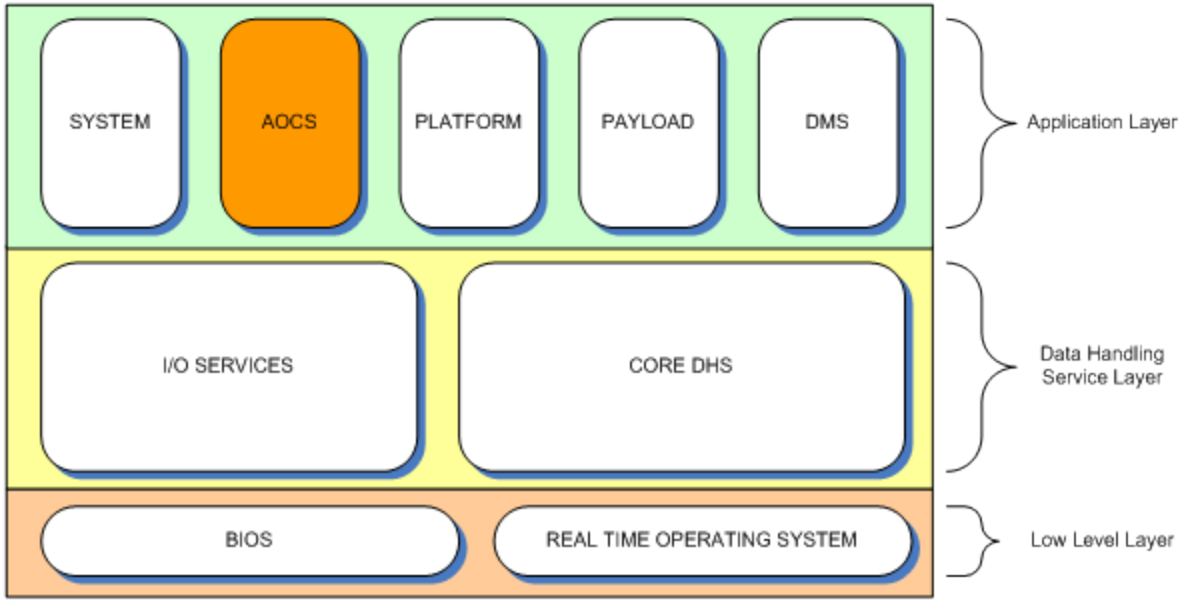
- Sensor processing: processing of raw sensor data to global datapool (acquisition the DHS).
- Sensor Data Fusion: attitude and rate fusion.
- Guidance: generation of attitude and rate demands, based on direct measurements or ground defined attitude profiles.
- Error calculation: rate and angle error calculation, based on the difference between the attitude/rate demands and the attitude/rate estimates/measurements.
- Control Law: 3 single axis PID controllers with saturation limiters, plus flexure filters.
- Actuator Commanding: On modulated PWM (Pulse Width Modulator) thruster commanding or wheel torque generation.
- Mode State Handling: controls state transitions and switching logics.

FDIR



Region	Depointing	Exposure	Notes
Nominal	Θ ≤ 1º	Continuous	This region covers all operational attitudes up to Sun limb pointing.
Safe	1º < Θ ≤ 2.3º	Continuous	This region covers off-pointing up to the FDIR attitude monitor threshold and steady state attitude in Survival.
Failure transient	2.3º < Θ ≤ 6.5º	Transient < TBD sec	This region covers transient off-pointing during attitude recovery in Survival.
Forbidden	Θ > 6.5º	Never	This region cannot be protected by the heat shield.

Software architecture



Data Interface

- Global datapool (GDP): central memory area where parameters, flags, raw and processed data, are stored and accessible to all the application layer functions and the DHS.
- Safe Guard Memory (SGM-RAM): memory area which retains its content when rebooting or reconfiguring the OBC between prime and redundant process modules (PM). Guidance: generation of attitude and rate demands, Sun pointing with/without rates on X axis.
- Ground TC: the AOCS can be controlled by ground TC whose application ID (APID) is the one assigned to the AOCS.

AOCS Subsystem Activities

- AOCS Detailed Design includes:
  - Completion of the detailed design, development and definition of the AOCS algorithms
  - Development of a simulation framework to tune, test, verify and validate the AOCS
  - Verification and validation of the AOCS

- AOCS Software Implementation includes:
  - Generation of the Specifications for the AOCS flight software
  - Production of the software detailed design
  - AOCS SW components
  - Development, unit test and integrated test of the AOCS flight code
  - Verification and validation of the AOCS SW
  - Support to Prime for integration, testing and maintenance
  - Contributions to the preparation of AOCS aspects of SW budgets
  - Close collaboration with Prime throughout to ensure overall system consistency

- AOCS Unit Procurement