XEUS Payload Accommodation Study
Executive Summary

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1. THE XEUS MISSION

XEUS (X-ray Evolving Universe Spectroscopy) is one of the missions under consideration by ESA for its Cosmic Vision programme of advanced space exploration concepts set for launch in the 2015-2025 timeframe. Following-on from ESA successes in space observatories like XMM-Newton, XEUS relies on a number of innovative technologies to explore the universe at X-Ray wavelengths (e.g., micropore optics, formation flying control and detector and cooling technologies). Although the launch of XEUS is still some years away, the technology developments needed to meet the exacting science requirements mean that an early start is required to ensure that these technologies can be fully tested and qualified beforehand. At the same time this will enable XEUS to take full advantage of additional performance that these technologies can offer and deliver exciting new science. The XEUS Instrument Accommodation study was specifically focussed on assessing the spacecraft resource and technology development implications of carrying a suite of instruments on XEUS is thus the first step towards the successful implementation of XEUS.

Europe has a long heritage in space-borne X-Ray instrumentation dating back more than 40 years and culminating with the launch of the XMM-Newton in 1999. XMM has provided unique insights into the physics of black holes, the nature of exotic matter and observation of gamma-ray bursts, however, these advances have led to a new set of questions in X-ray astronomy. The XEUS mission was thus conceived to answer these new questions and specifically three key science objectives:

- Evolution of Large Scale Structure and Nucleosynthesis
- Coeval Growth of Galaxies and Supermassive Black Holes
- Matter Under Extreme Conditions

The XEUS mission is designed to look much deeper into the past than XMM and so to observe much fainter objects. The current required sensitivity limit for XEUS is $4x10^{-18}$ erg/cm^2/sec (3 orders of magnitude fainter than XMM). This is equivalent to a few photons/day with a collecting area of 10m^2, which implies a large effective collecting area is needed to achieve sufficient S/N for the observed objects. In addition, since X-Rays can be efficiently reflected only at very shallow angles of incidence to maximize efficiency it is also necessary to have a long focal length (35m baseline for XEUS). This means that the telescope optics has to be housed on a separate spacecraft (MSC) from the detecting instruments (DSC), imposing in turn challenging Formation Flying (FF), requirements and baffle performance requirements. Since XEUS will observe so deep, it will also see a very large number of sources. To avoid source confusion, XEUS needs to have a high angular resolution: at least 5 arcsec Half Energy Width, with a goal of 2 arcsec.

Due to the long focal length and separated mirror and detectors, XEUS has to rely on accurate formation flying technology to maintain the correct optical alignment. This in turn relies on metrology, actuation and control to achieve its performance. The optical metrology system is also a potential source of stray light for the instruments. Thus instrument performance cannot be separated from the performance and interface to the whole system.

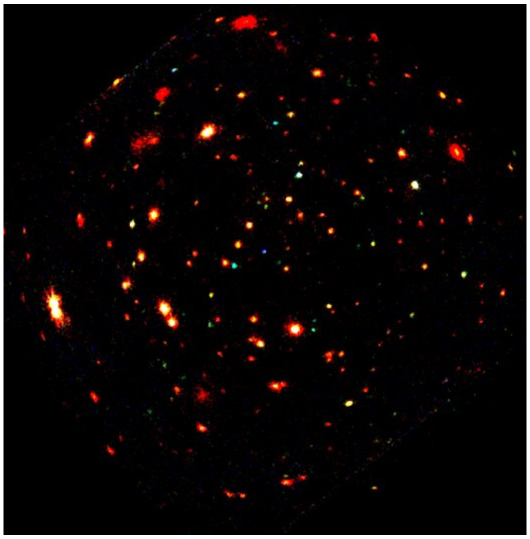


Figure 1-1 Deep field image from XMM-Newton

Thanks to new technology developments XEUS will be able to go much deeper

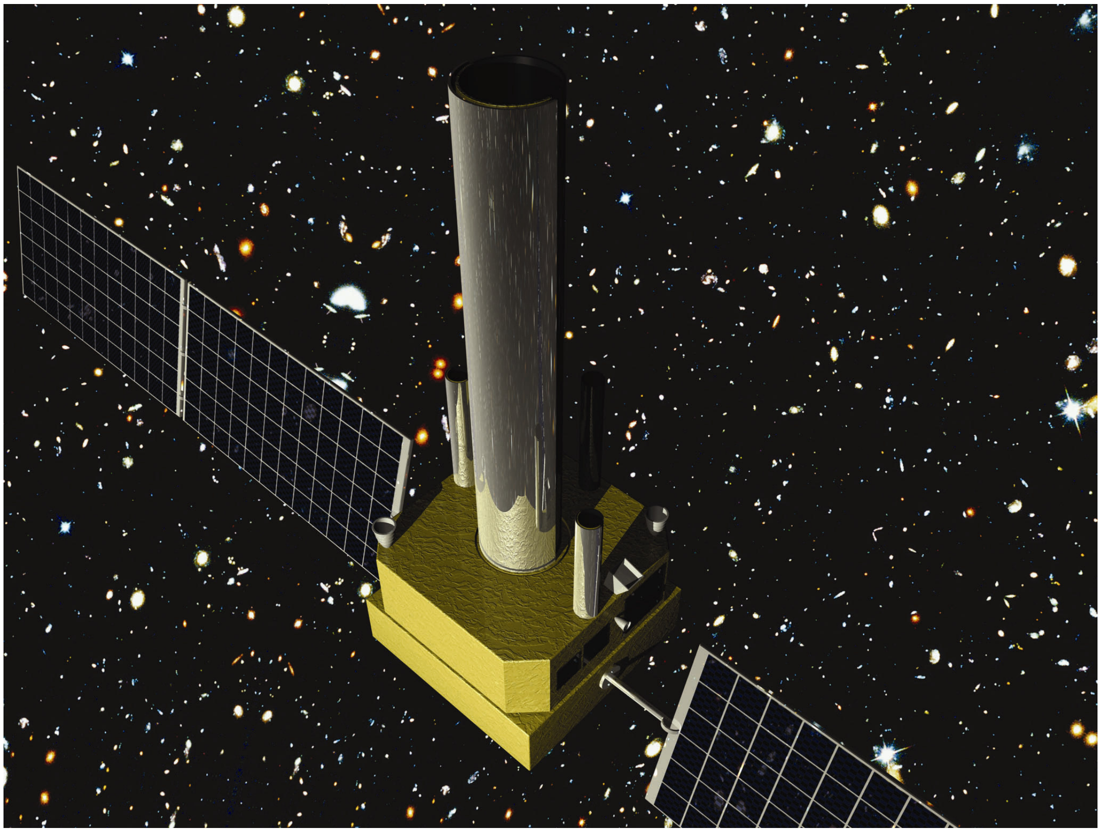


Figure 1-2: Rendition of DSC spacecraft

2. THE XEUS INSTRUMENTS

To meet the science requirements the XEUS mission must have high angular resolution due to its ability to see deep fields with multiple objects. In addition the mission is designed to extract high-resolution spectral information from the observed sources, so that specific elemental lines can be resolved from IGM and black holes accretion disks. XEUS requires a resolving power (E/dE) of the order of 1000 in the spectral region of 1-6 keV and of around 40 for the wide field and at high energies. This imposes stringent requirements on the detector technology, material and operating temperature. XEUS will look at large-scale structures, including clusters of galaxies and other extended objects, which places a demand on the field of view (FOV) of the instruments. XEUS requires at least a 7 arcmin FOV for the wide field imager and a 45x45 arcsec from the narrow field imager. This is particularly challenging for the narrow field, where extending the detector area is extremely difficult.

The science objectives drive the selection of the instrument suite for the XEUS mission. Each of the science objectives has different requirements in terms of energy range, angular resolution, field of view, spectral resolution, etc. The core payload necessary to meet the science objectives comprises:

- A Wide Field Imager (WFI)
- A Narrow Field Imager (NFI)

Presently, two different Narrow Field Imager designs are available (identified as NFI1 and NFI2). Both designs were analysed in the context of the XEUS Instrument Accommodation study. To take full advantage of the potential for new science with XEUS, however, a number of ancillary instruments has also been identified. These include:

- The second Narrow Field Imager (NFI)
- An X-Ray polarimeter (XPOL),
- A Hard X-Ray Camera (HXC) to extend the energy range of the wide field imager
- A High Time Resolution Spectrometer (HTRS) for fast time-resolved measurements.

The XEUS mission would not be conceivable without the recent advances in detector technology, particularly for the high energy resolution narrow-field imagers, but also in the field of active pixel sensors for the wide field imager. The two alternative technologies for the NFI instrument, Superconducting Tunnelling Junction (STJ) with Distributed Read Out Imaging Detectors (DROID) and Transition Edge Sensors (TES), both present demanding challenges for the payload definition in terms of operating temperatures (50-300 mK), control of magnetic fields, electrical read-out and data handling.

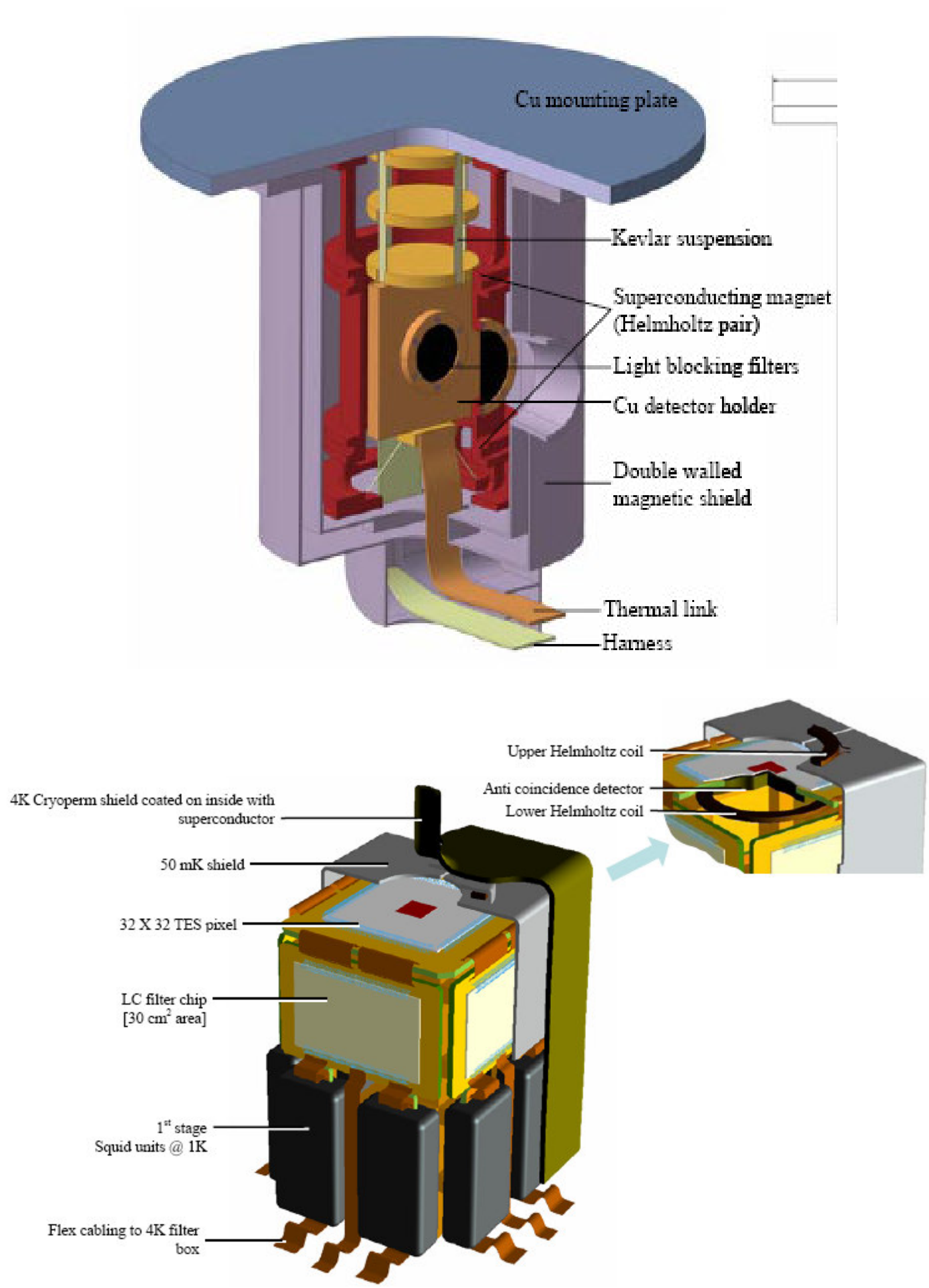


Figure 2-1: The Narrow Field Instruments (NFI1 & NFI2) focal plane units

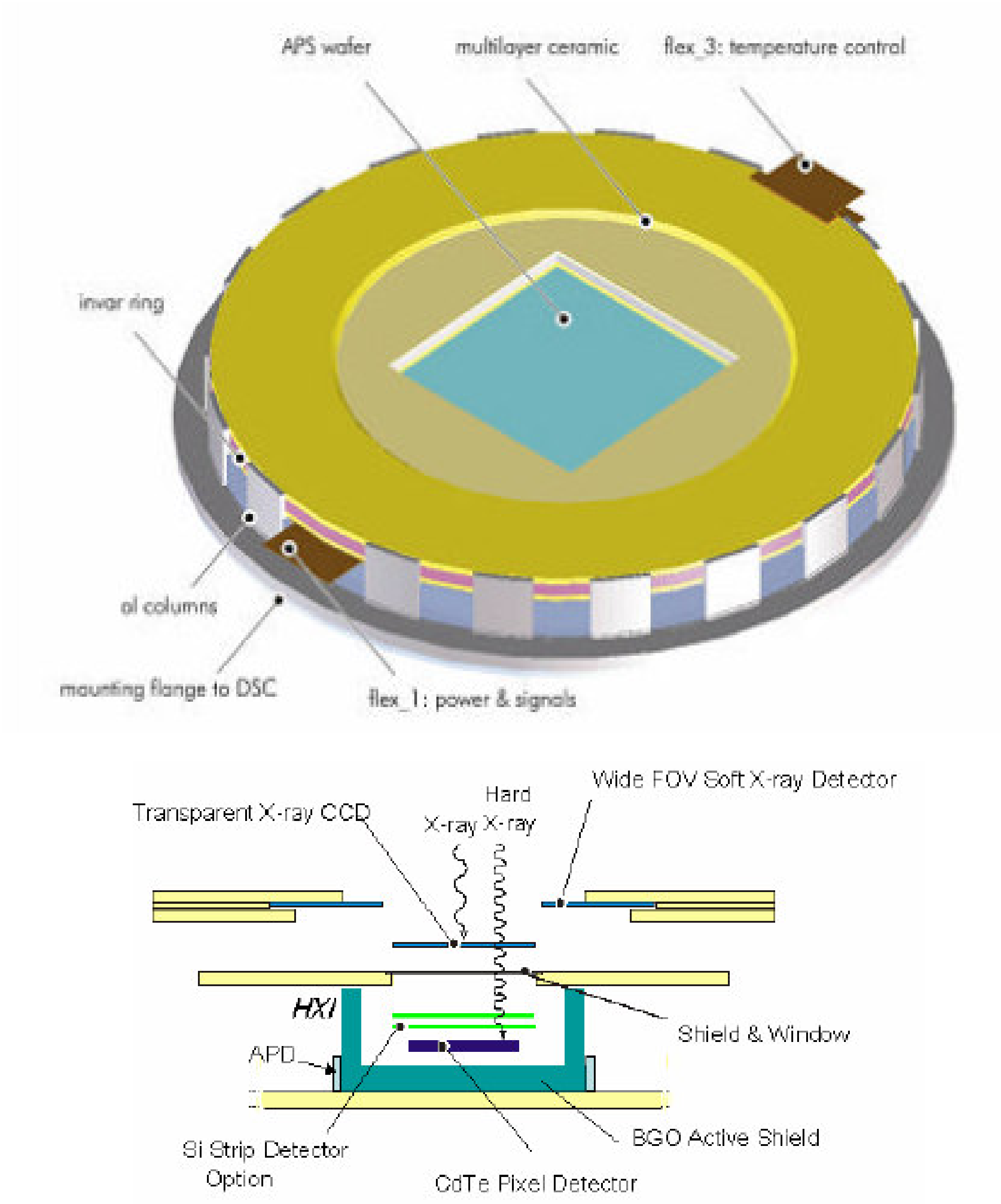


Figure 2-2: WFI and HXC instruments

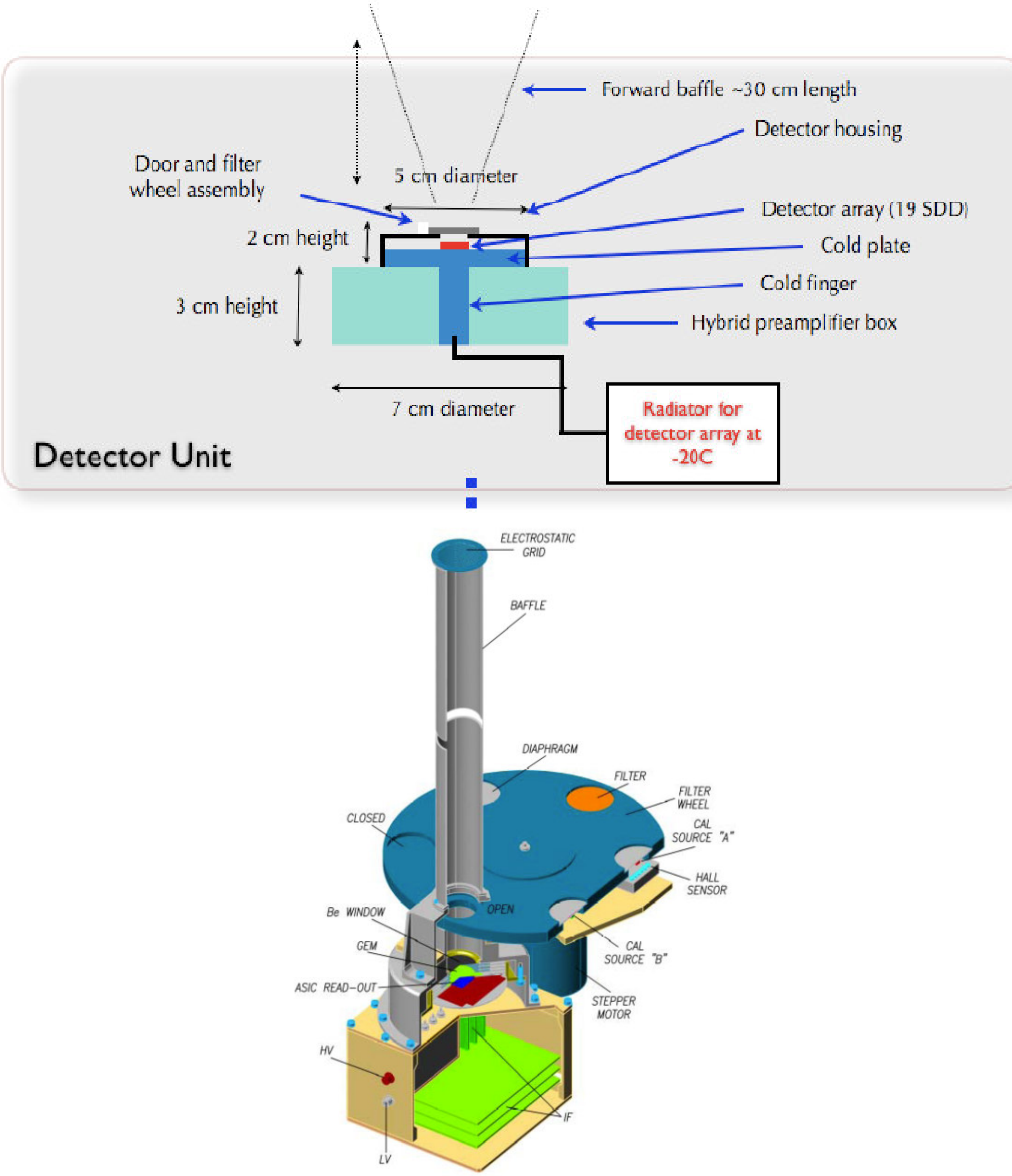


Figure 2-3: HTRS and XPOL Instruments

3. INSTRUMENT ACCOMMODATION

The accommodation of the core and ancillary instruments in an integrated payload was one of the main objectives of the study. To produce an efficient design, the critical requirements and design drivers from each instrument had to be assessed thoroughly and integrated in the design. From this perspective, the critical design drivers for each instrument can be summarised as follows:

- WFI:
    - Accommodation of an 8.0m long baffle to control stray light
    - Cooling of the detector to 210K
    - Shielding the detector from energetic particles & X-ray background
    - Control of detector contamination from outgassed chemicals
- NFI1 & NFI2:
    - Cooling the detector to 300 mK (NFI1) or 50 mK (NFI2)
    - Shielding the detector from energetic particles & X-ray background
    - Accurate control of stray magnetic fields that may affect detector performance
- HXC:
    - Integration of instrument with WFI to share wide-field baffle
- HTRS & XPOL:
    - Accommodation as stand-alone instruments in a payload module

The requirements of the core instruments and in particular the accommodation of the WFI baffle and of the cryogenic cooling for the NFI instruments were found to be the strongest drivers for the design. The size of the WFI baffle drives the location of the instrument to a central position within the payload module, this enables the use of the WFI baffle as the payload module central structure and ensures that the field of view of the other instruments is not obscured. The WFI instrument is cooled passively through a radiator placed close to the detector at the bottom of the PLM. The cryogenic system for the NFIs also has important consequences for the instrument accommodation and was specifically designed to facilitate integration of the NFI instruments in the PLM. After an extensive trade-off process an active cooling system was chosen for both NFIs.

The WFI instrument is mounted on a panel at the bottom of the main baffle, this panel is located close to the bottom of the SVM to minimise the baffle height protruding from the spacecraft. The baffle acts as a central cylinder for both the PLM and SVM. The WFI electronics are located on an external PLM panel.

The APS detector temperature is maintained at 198K with a $0.28m^2$ SSM radiator located on the outside of the panel, a small sunshield is included to ensure that the radiator is not illuminated during observations.

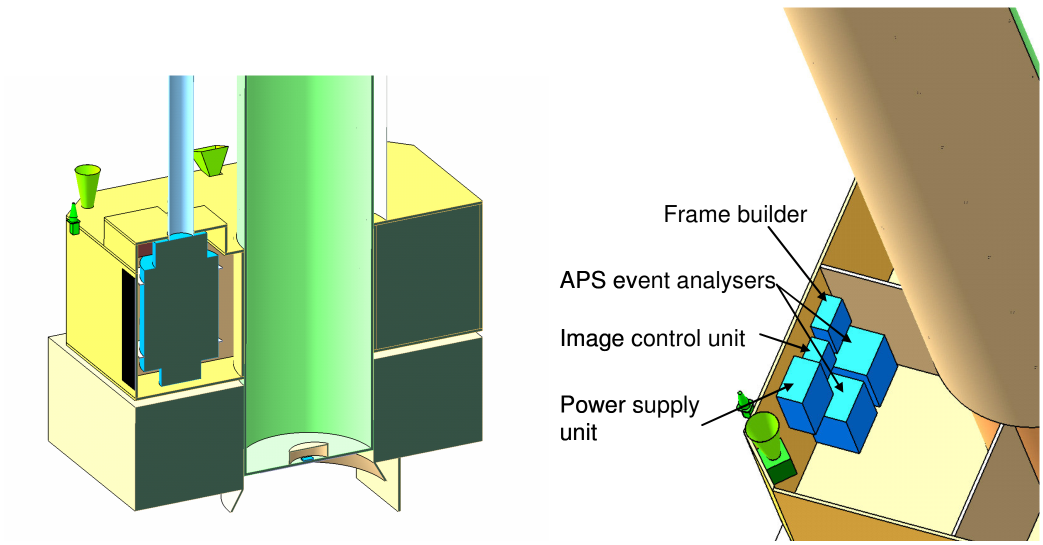


Figure 3-1: WFI instrument and electronics accommodation

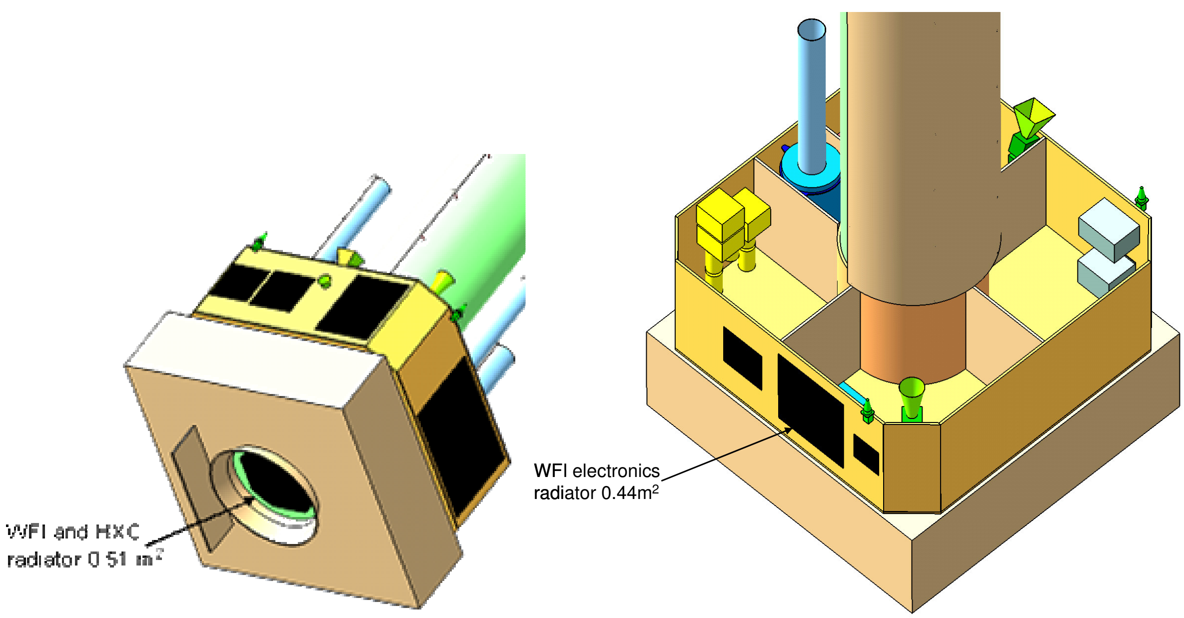


Figure 3-2: WFI radiator sizes, note $0.28m^2$ required for WFI only $0.51m^2$ required for integrated WFI + HXC

The NFI1 cryostat is mounted using 3 point support to the outer panel and the shear walls. The instrument electronics, cooler electronics and compressors are mounted to the outer panel. The 1.18m^2 NFI electronics and compressor radiator- is mounted on the outer surface of this panel.

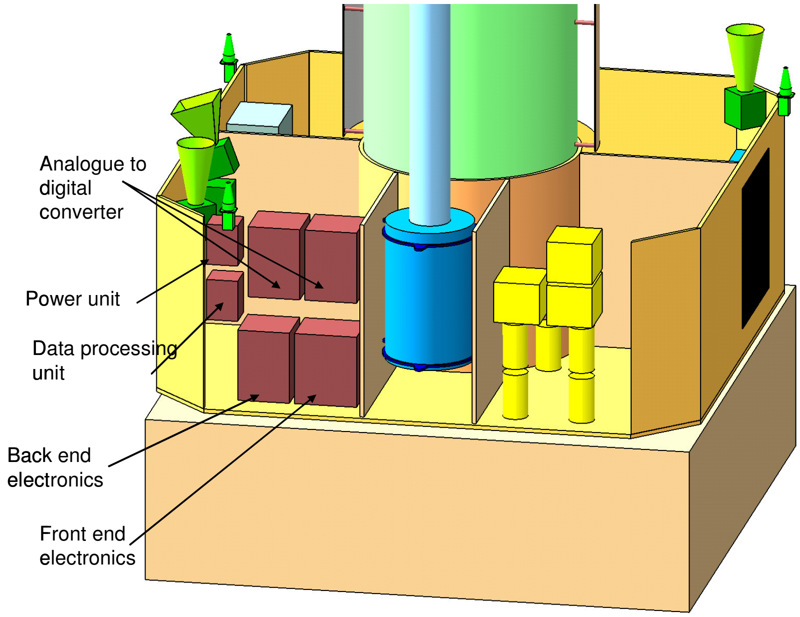


Figure 3-3: NFI1 instrument and electronics accommodation

The NFI2 cryostat is mounted using 4 point support to the outer panel and the shear walls. The instrument electronics, cooler electronics and compressors are mounted to the outer panel with the exception of the SQUID electronics box which is mounted close to the cryostat to minimise harness length. The 1.26m^2 NFI electronics and compressor radiator is mounted on the outer surface of the instrument panel.

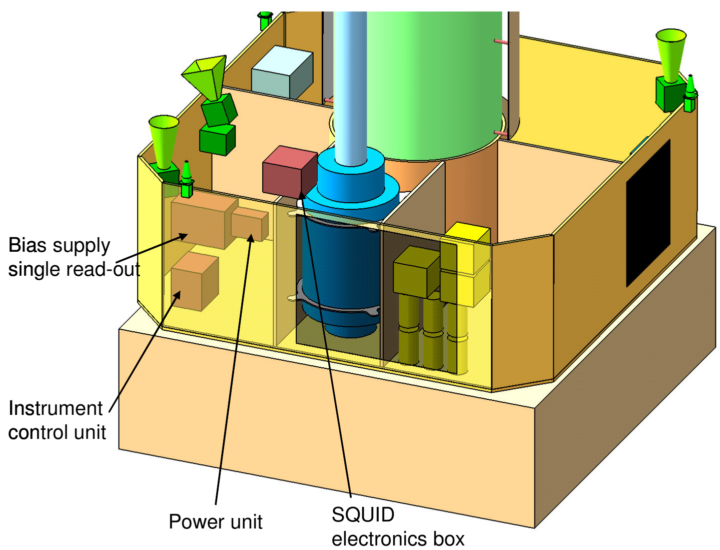


Figure 3-4: NFI2 instrument and electronics accommodation

The HTRS and XPOL units are mounted to outer panels of the PLM.

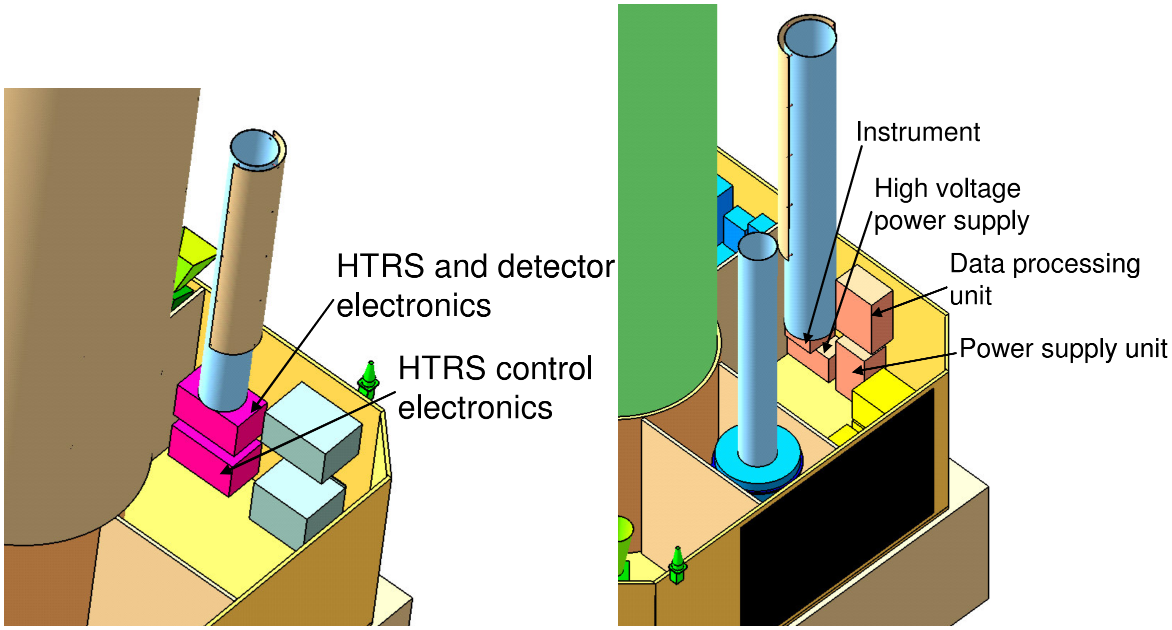


Figure 3-5: HTRS (left) and XPOL (right) interfaces

The HXC detector is mounted in a shared instrument housing with the WFI at the base of the WFI baffle. The detectors share the 0.51m^2 SSM radiator on the outer surface of the WFI base panel and an additional aluminium cylinder is used to support the APS detector and transport heat to the cold finger. The HXC electronics share an outer PLM panel with the WFI electronics.

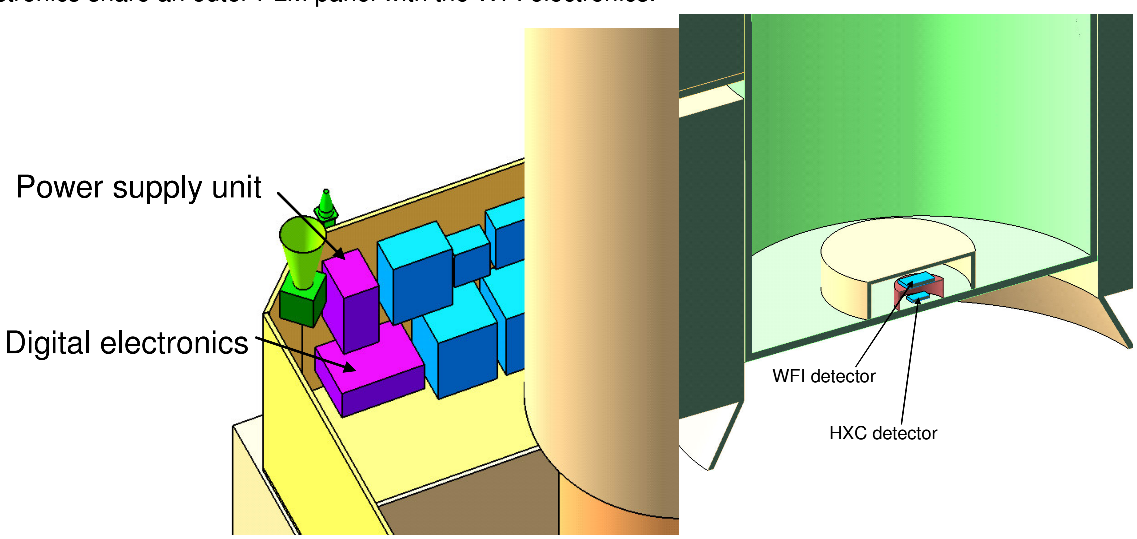


Figure 3-6: HXC interfaces

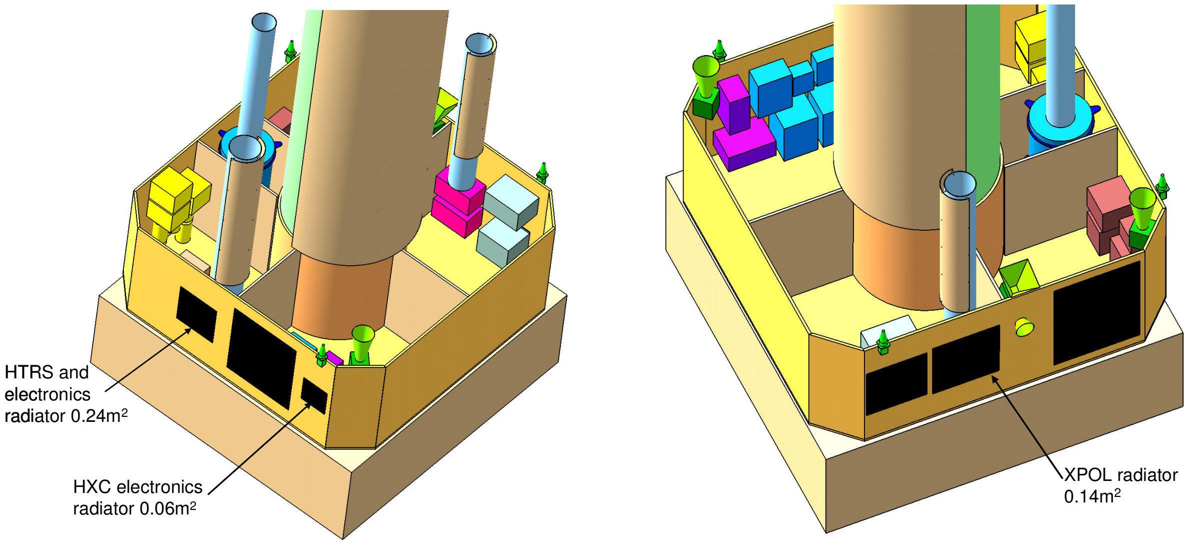


Figure 3-7: Ancillary instrument radiators

The payload module will require computer resources to command the instruments and manage the mass memory. It is anticipated that the SVM computer will have a high processor loading providing accurate formation control and therefore a separate payload module computer is proposed. A separate computer will allow the full functionality of the payload module to be tested independently of the service module and simplify the interface between the SVM and the PLM. The instruments in the XEUS mission will use a shared SpaceWire network to transport the data packets from the instruments to the mass memory.

A 28V power bus is provided to the PLM units from the SVM PCDU, the voltage conversion for each of the instruments is carried out locally.

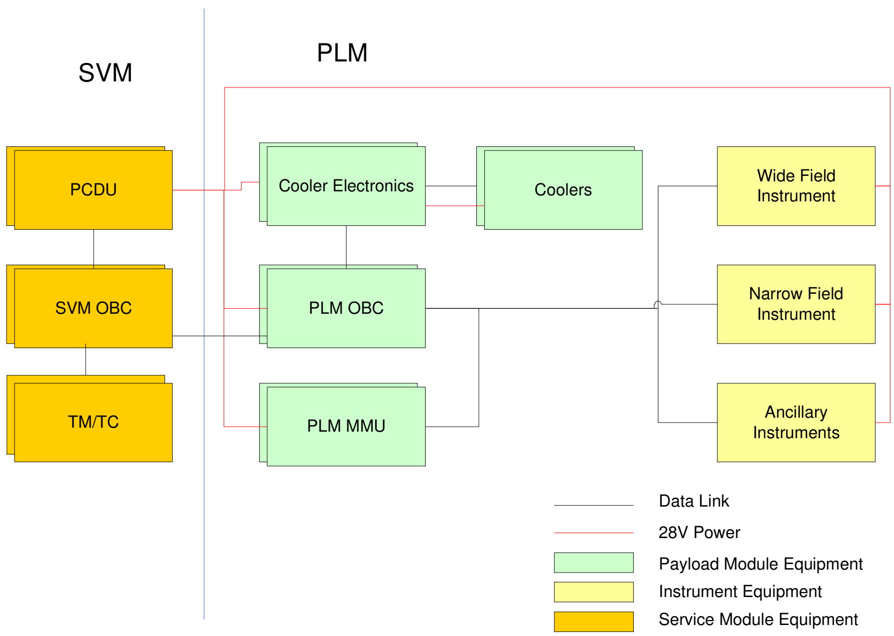


Figure 3-8: Payload module functional architecture

4. BAFFLE DESIGN

The design of the instrument baffles and in particular of the 8.0m WFI baffle was a major task of the study. The baffle needs to block unwanted visible/UV stray light that might hit the detector, while at the same time act as a shield against X-rays from outside the field of view of the instrument and against energetic particles (mostly protons and electrons) which could also perturb the detection of the X-Ray signals. Finally the baffle needs to be structurally sound, surviving launch and delivering a stable performance in the operational environment while also housing a magnetic deflector system to divert energetic particles coming from the same direction as the X-Rays from the astronomical objects under observation.

The solution adopted consists of a carbon-fibre outer baffle cylinder with an inner thin layer of gold to protect against secondary fluorescence of the carbon baffle. The baffle also contains three vanes to block stray light and is assembled from 4 segments to ease integration. The carbon fibre cylindrical structure means that the baffle can be structurally sound while also relatively light. The design of the baffles for the other instruments follows similar principles.

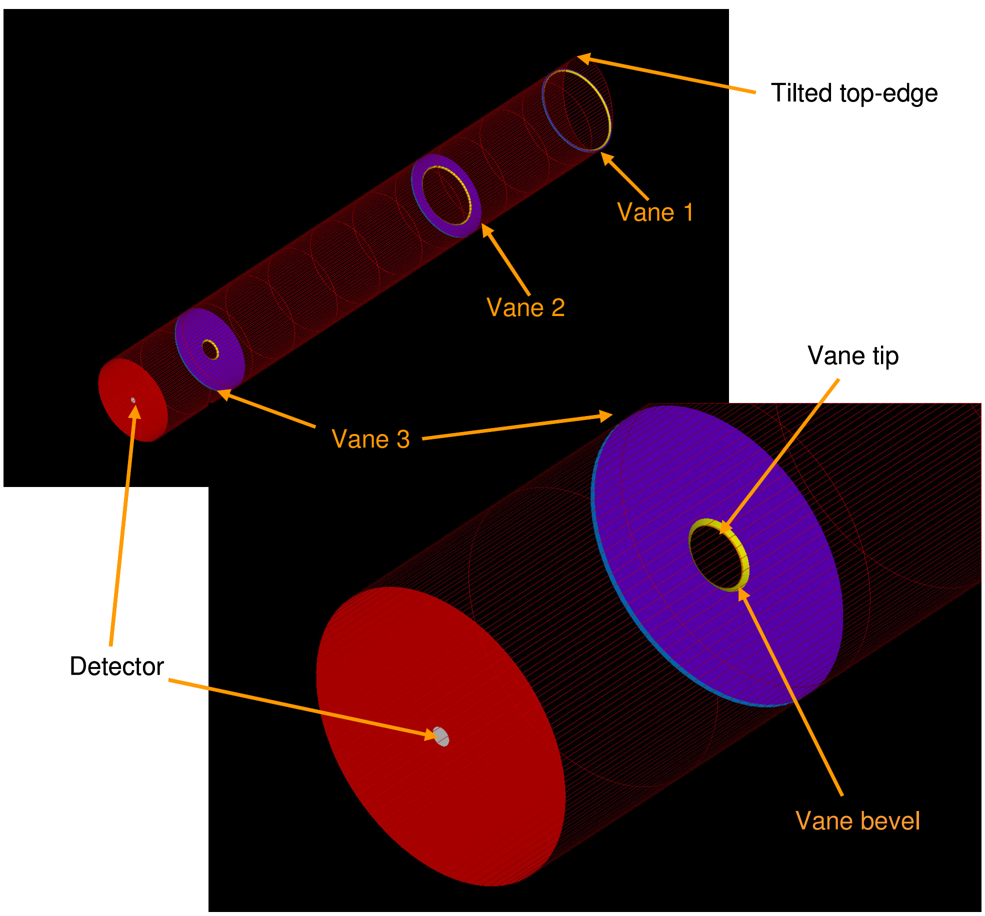


Figure 4-1: Design of the WFI baffle

5. NFI1 & NFI2 COOLER SYSTEM

The cryogenic sub-systems for the Narrow Field Instrument (NFI) detectors is a critical aspect of the XEUS payload accommodation because of the extremely low temperatures at which the detectors operate. Moreover, a 5 year mission lifetime (with a goal of 10 years) imposes severe constraints on the cooling technologies that can be used. Because of these constraints a considerable part of this study has been devoted to examining all possible solutions identified for the XEUS cryogenic chain. The goals were to develop a credible preliminary design which can be achieved based on known or only moderately extrapolated performances, and a technology plan which maximizes heritage whilst minimizing cost. The work at Astrium was performed in collaboration with our partners for this project: The Mullard Space Science Laboratory (MSSL, University College London), The Rutherford Appleton Laboratory (RAL, CCLRC), and Commissariat à l'Energie Atomique Service Des Basses Temperatures (CEA-SBT). We acknowledge their importance assistance, and are grateful for it.

As a result of a thorough assessment of the cryogenic technologies the following options were identified for NFI1:

1. 300mK 3He evaporation sorption cooler + 1.6K superfluid helium dewar + ~50K radiator
2. 300mK 3He evaporation sorption cooler + 2.5K mechanical J-T cooler + 10-20K Stirling/PTC
3. 300mK 3He evaporation sorption cooler + 2.5K mechanical J-T cooler + 10-20K J-T sorption cooler + 50K radiator
4. 300mK 3He evaporation sorption cooler + 2.5K J-T helium sorption cooler + 20K J-T hydrogen sorption cooler + 50K radiator
5. 300mK 3He evaporation sorption cooler + 2.5K J-T helium sorption cooler + 20K J-T hydrogen sorption cooler + 50K Stirling/PTC
6. 300mK 3He evaporation sorption cooler + 2.5K J-T helium sorption cooler + 20K Stirling/PTC + 50K Stirling/PTC
7. 300mK ADR + 1.6K superfluid helium dewar + ~50K Radiator
8. 300mK ADR (rejecting heat at 10-20K) + 10-20K Stirling/PTC
9. 300mK ADR (rejecting heat at 2-6K) + 2.5/4K mechanical J-T cooler + 10-20K Stirling/PTC
10. 300mK ADR (rejecting heat at 2-6K) + 2.5/4K mechanical J-T cooler + 10-20K J-T sorption cooler + 50K radiator
11. 300mK ADR (rejecting heat at 2-6K) + 2.5/5K J-T helium sorption cooler + 20K J-T hydrogen sorption cooler + 50K radiator
12. 300mK ADR (rejecting heat at 2-6K) + 2.5/5K J-T helium sorption cooler + 20K J-T hydrogen sorption cooler + 50K Stirling/PTC
13. 300mK ADR (rejecting heat at 2-6K) + 2.5/5K J-T helium sorption cooler + 20K Stirling/PTC + 50K Stirling/PTC
14. 300mK 3He evaporation sorption cooler + 2.5/5K J-T helium sorption cooler + 20K solid neon dewar + ~50K radiator
15. 300mK 3He evaporation sorption cooler + 2.5/5K mechanical J-T cooler + 20K solid neon dewar + ~50K radiator
16. 300mK ADR (rejecting heat to ~7K) + solid hydrogen dewar + ~50K Radiator
17. 300mK ADR (rejecting heat to 10-20K) + solid neon dewar + ~50K Radiator
18. 300mK 3He evaporation sorption cooler + 1.6K mechanical J-T cooler + 10-20K Stirling/PTC
19. 300mK ^{3}He evaporation sorption cooler + non-structural superfluid helium dewar at 1.7 K + ~50 K radiator

A similar exercise for NFI2 yielded the following possible combinations of coolers:

1. 50mK ADR (0.3K magnets) + 300mK 3He evaporation sorption cooler + superfluid helium dewar (1.6K) + ~50K radiator (dewar shell)
2. 50mK ADR (0.3K magnets) + 300mK 3He evaporation sorption cooler + 2.5K 3He Mech. J-T + 16K Stirling/PTC

3. 50mK ADR (0.3K magnets) + 300mK 3He evaporation sorption cooler + 2.5K 3He Mech. J-T + 14.5K H2 J-T sorption cooler + 50K radiator + 80K radiator
4. 50mK ADR (0.3K magnets) + 300mK 3He evaporation sorption cooler + 2.5K 3He J-T sorption cooler + 14.5K H2 J-T sorption cooler + 50K radiator + 80K radiator
5. 50mK ADR (0.3K magnets) + 300mK 3He evaporation sorption cooler + 2.5K 3He J-T sorption cooler + 14.5K H2 J-T sorption cooler + 50/80K Stirling/PTC
6. 50mK ADR (0.3K magnets) + 300mK 3He evaporation sorption cooler + 2.5K 3He J-T sorption cooler + 14.5K Stirling/PTC + 50K Stirling/PTC
7. 50mK ADR (rejecting heat to 10-20K) + 10K Stirling/PTC
8. 50mK ADR (rejecting heat to 4.5K) + 4.5K 4He mech. J-T + 18K Stirling/PTC
9. 50mK ADR (rejecting heat to 1.6K) + 434 litre superfluid helium dewar + ~50K radiator (dewar shell)
10. 50mK ADR (rejecting heat to 4.5K) + 4He J-T sorption cooler (4.5K) + 14.5K H2 J-T sorption cooler + 50K radiator + 80K radiator
11. 50mK ADR (rejecting heat to 4.5K) + 4He J-T sorption cooler (4.5K) + 14.5K H2 J-T sorption cooler + 50/80K Stirling/PTC
12. 50mK ADR (rejecting heat to 4.5K) + 4He J-T sorption cooler (4.5K) + 14.5K Stirling/PTC + 50K Stirling/PTC
13. 50mK ADR (rejecting heat to 4.5K) + 4He J-T sorption cooler (4.5K) + 17K Solid Neon Dewar + ~50K radiator (dewar shell) + 50K radiator
14. 50mK ADR (~7K magnets) + Solid hydrogen dewar (7K) + ~50K radiator (dewar shell)
15. 50mK ADR (10-20K magnets) + Solid neon dewar (17K) + ~50K radiator (dewar shell)
16. 50mK ADR (rejecting heat to 4.5K) + 4.5K 4He mech. J-T + 14.5K H2 J-T sorption cooler + 50K radiator + 80K radiator
17. 50mK ADR (rejecting heat to 1.6K) + superfluid helium dewar (1.6K) + 50K radiator (dewar shell) + Intermediate shields (separated dewar)

The following technologies were judged to be too immature, without enough information to base a sound decision on:

- NIS coolers – immature and development problems.
- Helium Dilution refrigerators – open cycle cooler (like Planck), too massive for 5 years operation. Closed cycle cooler technology not proven.
- <10K Turbo Brayton coolers – immature.
- <6K PTCs – No flight heritage or activities in Europe. Low frequency pulse tubes (e.g. CryoMech), not suitable for space applications.
- The CEA <2-4K ^{4}He evaporation cooler – does not seem to offer a significant advantage – a 5K J-T (or other cooler), stage is still required and it is considered that it is easier to adapt 5K coolers to operate at ~2.5K rather an introduce another stage.

The following technologies were not selected as they were not deemed feasible:

- Pomeranchuk cooling – Moving parts, no development, and low cooling power.
- Nuclear refrigeration – This technique is only efficient <10mK.
- Superfluid Stirling cooler – Immature and having complex moving parts <4K.
- Optical cooler – Unproven and only useful at 80K.
- Direct ^{3}He evaporation –Requires large vacuum pump due to exhaust pressure drop.

An exhaustive set of trade-offs were carried out for the selected options (including a very detailed modelling and design of various superfluid helium dewar based options). The following options were identified for NFI1 (these masses and powers include electronics, radiators, cryostat mass, and a TRL based margin, the figures are also for a fully redundant system – except for radiators and dewars):

Opt.	Description	Stages
2	300mK 3He evaporation sorption cooler + 2.5K 3He Mech. J-T + 16K Stirling/PTC x 2	3
3	300mK 3He evaporation sorption cooler + 2.5K 3He Mech. J-T + 14.5K H2 J-T sorption cooler + 50K radiator (0.2 sq. m) + 80K radiator (6.6 sq. m)	5
8	300mK ADR (10-20K magnets) + 10K Stirling/PTC	2
9	300mK ADR (4K magnets) + 4.5K 4He Mech. J-T + 18K Stirling/PTC + 80K Stirling Cooler	4
16	300mK ADR (~7K magnets) + Solid hydrogen dewar (7K) + 52.8K radiator (dewar shell)	3
19	300mK 3He evaporation sorption cooler + 667 litre 'side-by-side' superfluid helium dewar + 40.0K radiator (dewar shell) + Intermediate shields	4

The following options were identified for NFI2 (these masses and powers include electronics, radiators, cryostat mass, and a TRL based margin, for a fully redundant system – the figures are also for a fully redundant system – except for radiators and dewars):

Opt.	Description	Stages
1	50mK ADR (rej. heat to 300mK) + 300mK 3He evaporation sorption cooler + 622 litre superfluid helium dewar (1.6K) + 55.0K radiator (dewar shell)	4
2	50mK ADR (rej. heat to 300mK) + 300mK 3He evaporation sorption cooler + 2.5K 3He Mech. J-T + 16K Stirling/PTC	4
3	50mK ADR (rej. heat to 300mK) + 300mK 3He evaporation sorption cooler + 2.5K 3He Mech. J-T + 14.5K H2 J-T sorption cooler + 50K radiator (0.1 sq. m) + 80K radiator (5.0 sq. m)	6
7	50mK ADR (rejecting heat to 10-20K) + 10K Stirling/PTC	2
8	50mK ADR (rejecting heat to 4.5K) + 4.5K 4He mech. J-T + 18K Stirling/PTC + 80K Stirling Cooler	4
9	50mK ADR (rejecting heat to 1.6K) + 628 litre superfluid helium dewar + 40.0K radiator (dewar shell)	3
14	50mK ADR (~7K magnets) + Solid hydrogen dewar (7K) + 55.0K radiator (dewar shell)	3

An important technology which was not carried forward at this stage was the helium J-T sorption cooler under development at the University of Twente for Darwin. This is because this would require a very large radiator area at 50 K (>15 sq. m). This would be extremely difficult to accommodate onto the XEUS spacecraft due to the large WFI baffle, which would be much warmer than this temperature – although any alternations in the WFI baffle requirements may affect this trade-off in the future. Also there are no low-vibration requirements for XEUS, as for Darwin. However the hydrogen sorption cooler proposed for Darwin, which does not require such a large radiator, would be interesting for XEUS and was carried forward for further study.

A careful trade-off of the above options was performed on the basis of programmatic aspects, including technical developments required. No specific limitation was set on the mass and power budgets since it is recognized that these may change later in the programme. Each system was scored on a number of aspects with weighting functions applied, agreed by ESA. Simply comparing the trade-off scores showed that for NFI1 option 2 (sorption cooler + 2.5 K J-T + Stirling/PTC), should be the primary and option 9 (300 mK ADR + 4.5 K J-T + Stirling/PTC), should be the back-up. For NFI2 the scores showed that option 8 (ADR + 4.5 K J-T + Stirling/PTC), should be the primary and option 2 (ADR + 300 mK sorption cooler + 2.5 K J-T + Stirling/PTC), should be the back-up.

Trade-offs for redundancy options at the T0 stage (ADR and sorption coolers), were also carried out and it was shown that there was no advantage to having any T0 cooler redundancy in a redundant cryostat. The best option would be to have two non-redundant cryostats instead (e.g. one primary NFI1 and one back-up). Particularly because the heat loads from a redundant T0 stage would be much greater than a single T0 cooler, and therefore considerable complexity would be added to the pre-cooling system.

With the trade-offs completed the cooler sub-system (CSS), design was carried out on the basis of examining the following cases:

- NFI1 only – redundant case.
- NFI 1 only – non-redundant case.
- NFI2 only – redundant case.
- NFI2 only – non-redundant case.
- NFI1 and NFI2 – both fully redundant or non-redundant.

An analysis was carried out to show that the optimum solution if both NF1 and NFI2 were carried would be for each NFI to be non-redundant. This minimizes mass and leads to a reasonable system reliability (if each NFI can serve as a back-up to the other).

The proposed baseline option for a redundant NFI1 is:

- T0: 1 x 300 mK helium-3 evaporation sorption cooler with interfaces to 2.5 K and 15 K.
- T1: 2 x 2.5 K Joule-Thompson cooler with mechanical/Stirling-type compressors
- T2: 3 x “10 K” two-stage Stirling cycle cooler
- Integrated cryostat with hybrid composite tube/Kevlar/s-glass suspension system.

For NFI2 the redundant baseline is:

- T0: 1 x 50 mK dADR with interface at 4-4.5 K.
- T1: 2 x 4 K Joule-Thompson cooler with mechanical/Stirling-type compressors.
- T2/4: 2 x “10 K” two-stage Stirling cycle coolers.
- T3: 2 x 50-80K single stage Stirling coolers.
- Integrated cryostat with hybrid composite tube/Kevlar/s-glass suspension system.

The following resource requirements have been identified:

Case	Mass, exc. margin [kg]	Mass margin [kg]	Mass, inc. margin [kg]	Max power, exc. margin [W]	Max power margin [W]	Max power, inc. margin [W]	Sleep power, inc. margin [W]
NFI1 redundant	189	51	240	679	301	980	131
NFI1 non-redundant	125	53	178	652	281	933	82
NFI2 redundant	245	62	307	559	165	724	115
NFI2 non-redundant	183	60	243	531	159	690	81

A number of improvements have been identified to reduce the number of coolers required, which would make the systems simpler and less massive, as well as leading to an increase in reliability. We have not baselined them at present, but further investigation is required during the next phase of XEUS studies.

The functional block diagrams for NFI1 and NFI2, as proposed, are shown in the figures below:

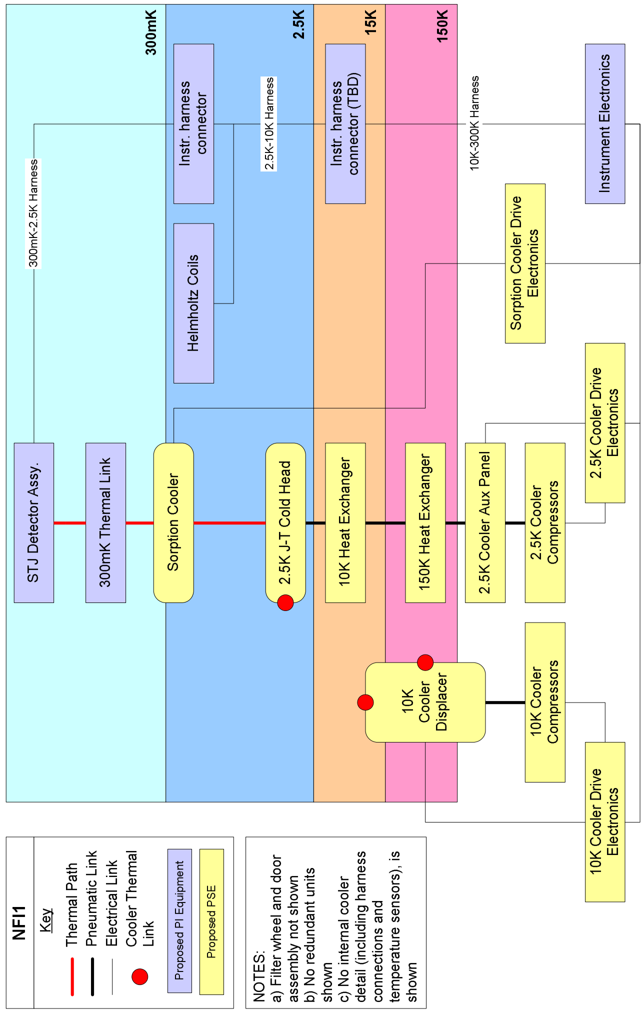


Figure 5-1. Functional architecture of proposed NFI1 solution

We anticipate cooler electronics will be subordinate to the instrument electronics, which provide overall control; no additional 'cooler system' controller is required, although this may be subject to further trade-off.

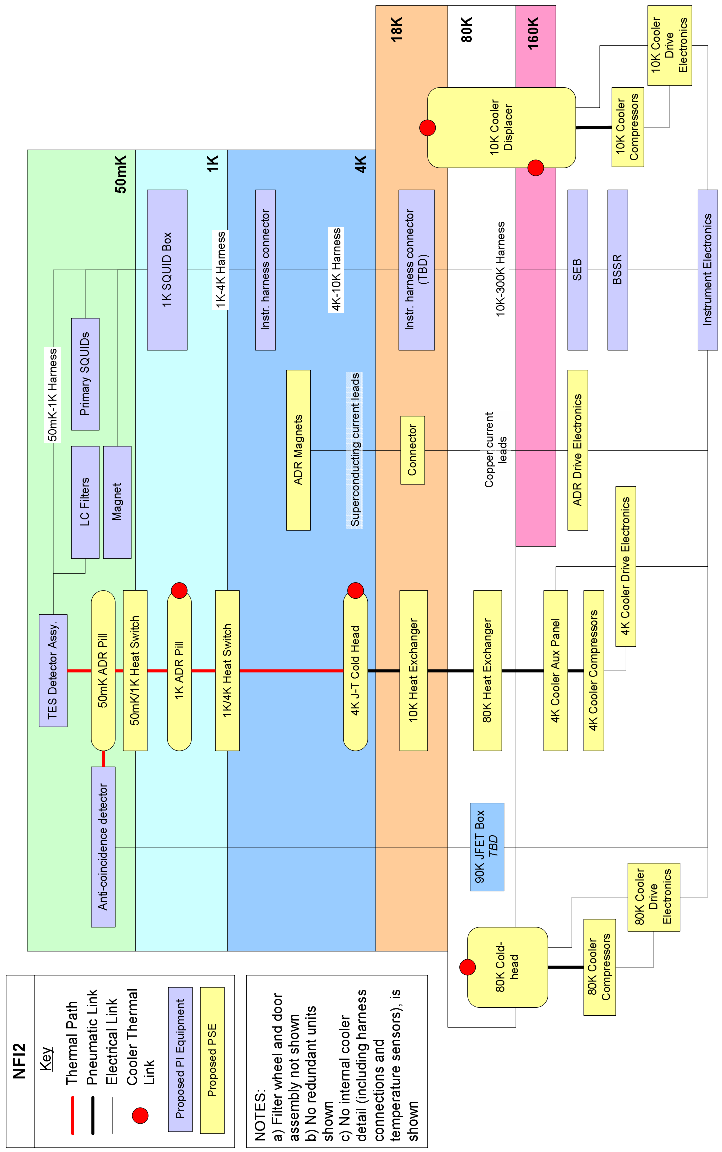


Figure 5-2. Functional architecture of proposed NFI2 solution

We anticipate cooler electronics will be subordinate to the instrument electronics, which provide overall control; no additional 'cooler system' controller is required, although this may be subject to further trade-off.

In both cases, the coldest stage ("T0") coolers operate from a Joule-Thomson (J-T) cooler, which is in turn cooled through Stirling cycle coolers from a room temperature outer shell. This arrangement facilitates integration as the instrument can be tested with its own cooler separate from the rest of the payload module. Additionally all PLM level testing can be carried out in a conventional manner near ambient temperatures. A further advantage of this configuration is the possibility of effectively unlimited life by the elimination of fluid cryogens and the use of well proven long-life compressor technology. This minimizes the impact of extending the mission life to 10 years or more.

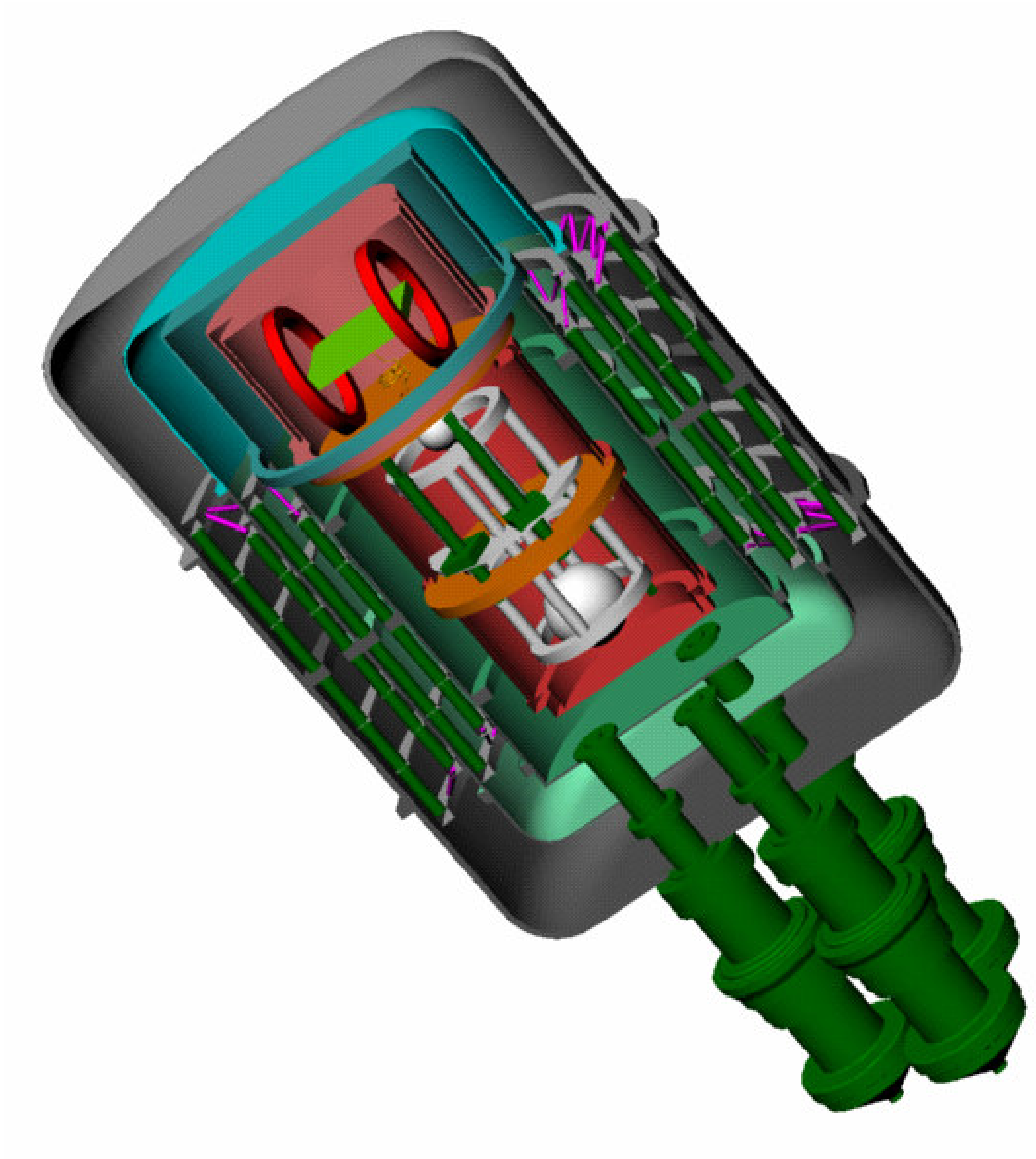


Figure 5-3: 300mK NFI1 Cryostat design

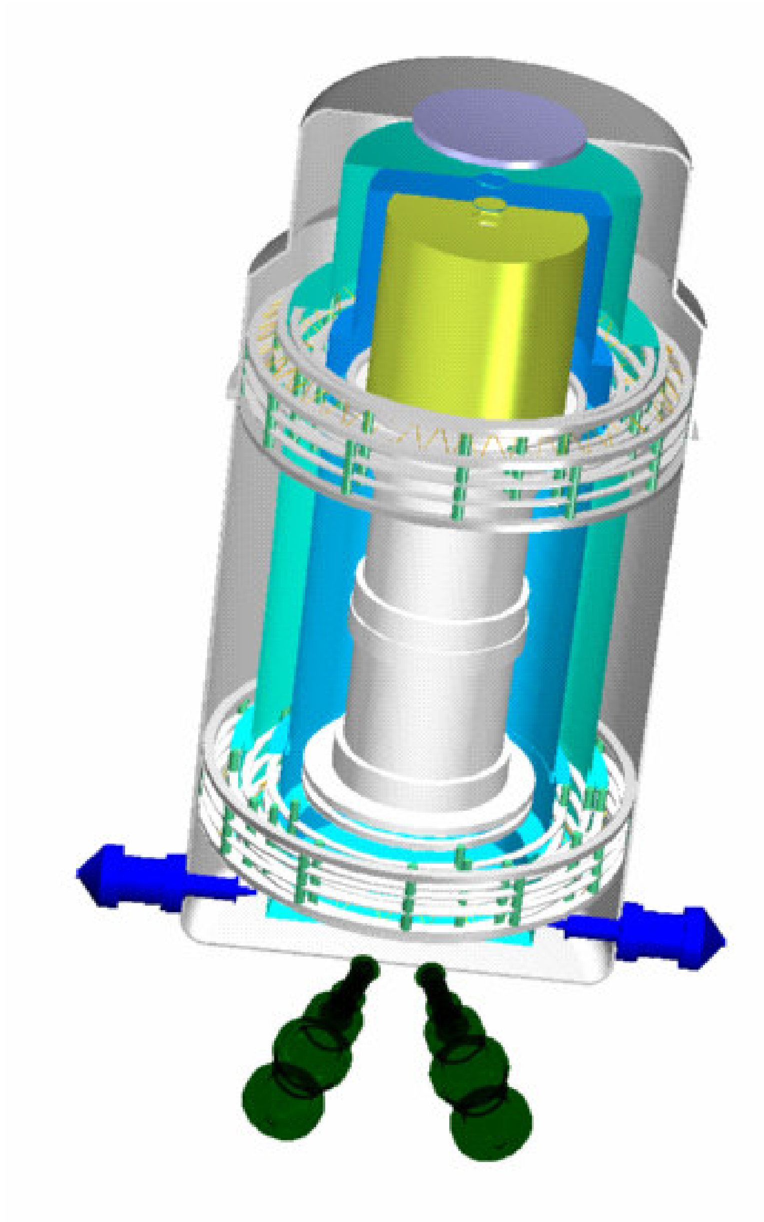
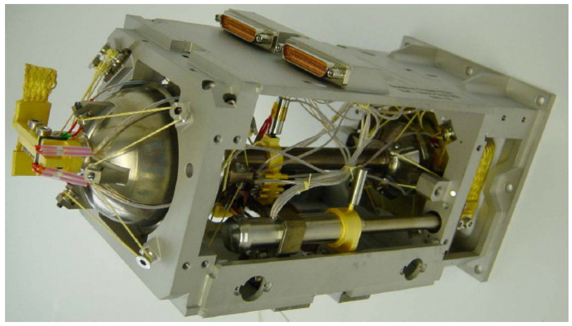


Figure 5-4: 50mK NFI2 Cryostat design



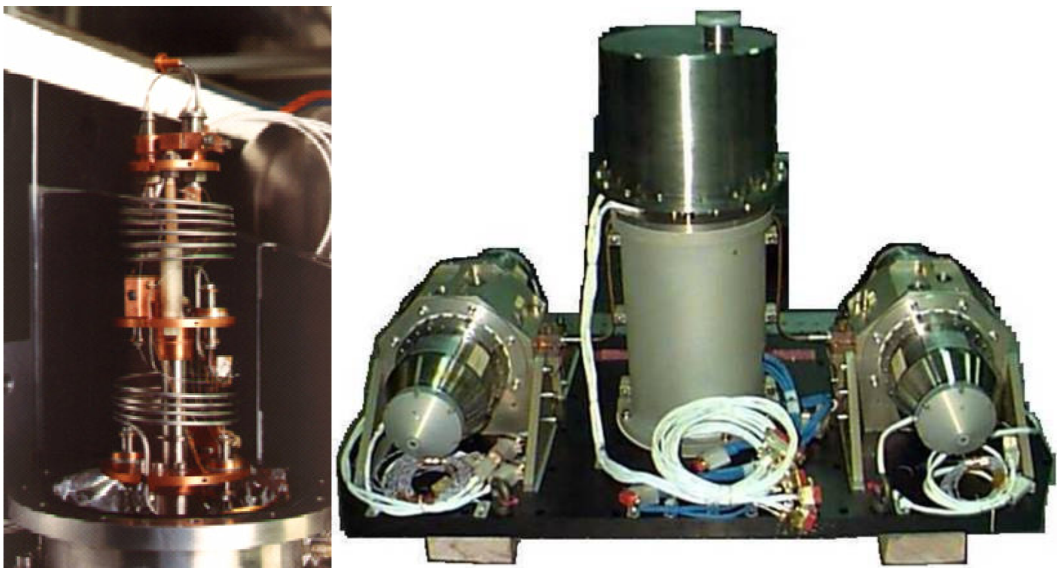


Figure 5-5: Cooling technologies for NFI1: 300mK Helium-3 Sorption Cooler (HSC) from Herschel (courtesy CEA-SBT), Joule-Thompson Cooler (J-T), similar to that used for Planck (courtesy RAL), & Stirling cycle coolers

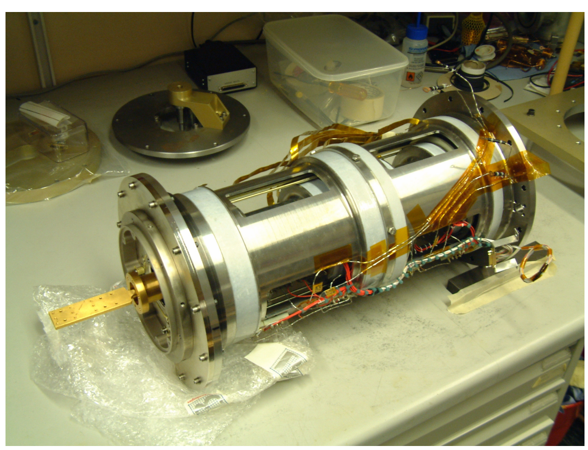


Figure 5-6: The 50 mK Adiabatic Demagnetization Refrigerator (ADR) cooler for NFI2 (courtesy MSSL)

5.1 Cooler Technology developments

The cryogenics systems for NFI1 and NFI2 have been designed to be credible and achievable in the time-frame required for XEUS, using extensions of well proven and known technologies with maximum use of existing flight heritage to minimize cost and risk. The following Technology Development Activities (TDAs), are foreseen for the proposed baseline:

- ***Common items***
  - Suspension – breadboarding and characterization
  - Thermometers (should be generic activities) – investigation of primary calibration sources <1K
  - 10K Cooler – Development (using Maxi compressor), interfaces to JT and HSC, qualification *(this activity has already started and is due to complete at the end of 2008)*
  - Harnesses – instrument level but strong interaction required between cryo-team and instrument team
    - 10K Cooler Low Vibration Drive Electronics (LVDE) – development based on existing LVDEs
- ***NFI1***
  - 300mK HSC – development based on Herschel cooler, demonstration of interfaces, and qualification
  - 2.5K J-T Cooler – design based on Maxi compressor (valves required), integration study with other coolers, qualification
  - NFI1 CSS – detailed design activity and demonstration of EM system to characterize interfaces, system performance, and recycling strategies
  - 2.5K Cooler Electronics – based on Planck electronics
  - HSC Electronics
- ***NFI2***
  - dADR – improvement of existing dADR, development of magnetoresistive heat switches and MgB2 current leads, demonstration of integration with JT and Stirling cooler
  - 4K J-T Cooler – design trade-off as part of NFI2 CSS design between Planck cooler and improved 2.5K cooler (operating at 4K)
    - If the 2.5K cooler is chosen then the 2.5K J-T cooler activity would become a common item, relabelled as 'Improved J-T cooler operating at 2.5K or 4K'.
  - NFI2 CSS – detailed design activity and demonstration of EM system to characterize interfaces, system performance, and recycling strategies
  - ADR Electronics

Clearly there a large number of TDAs, although the approach could be simplified with careful planning and further design work.

Once developed and qualified these active cooling systems would open the door to new cryogenic space missions with long mission duration and enabling the use of extremely low temperature detectors and other equipment.

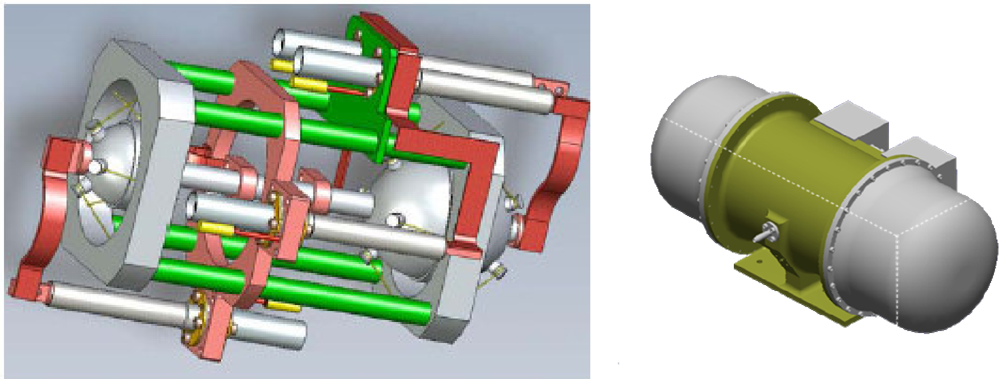


Figure 5-7: 300mK HSC proposed by CEA for NFI1 (courtesy CEA-SBT), and breadboard Maxi compressor (courtesy RAL)

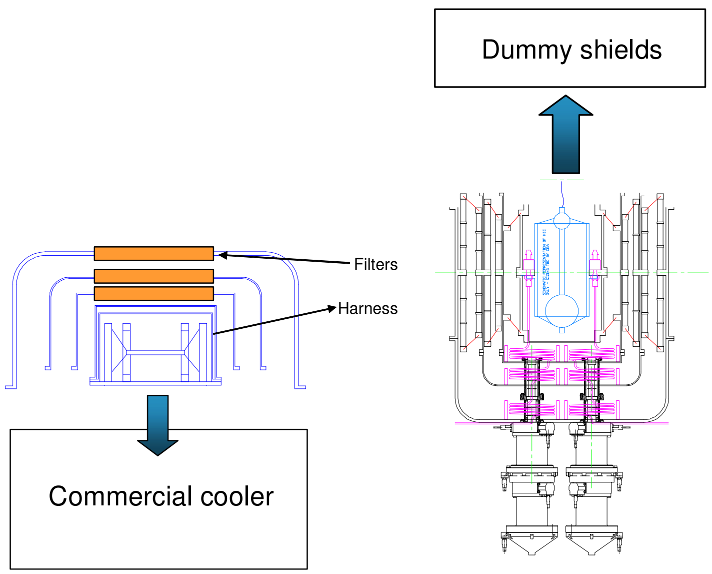


Figure 5-8: Ease of test and integration is a key aspect of the selected cooler design

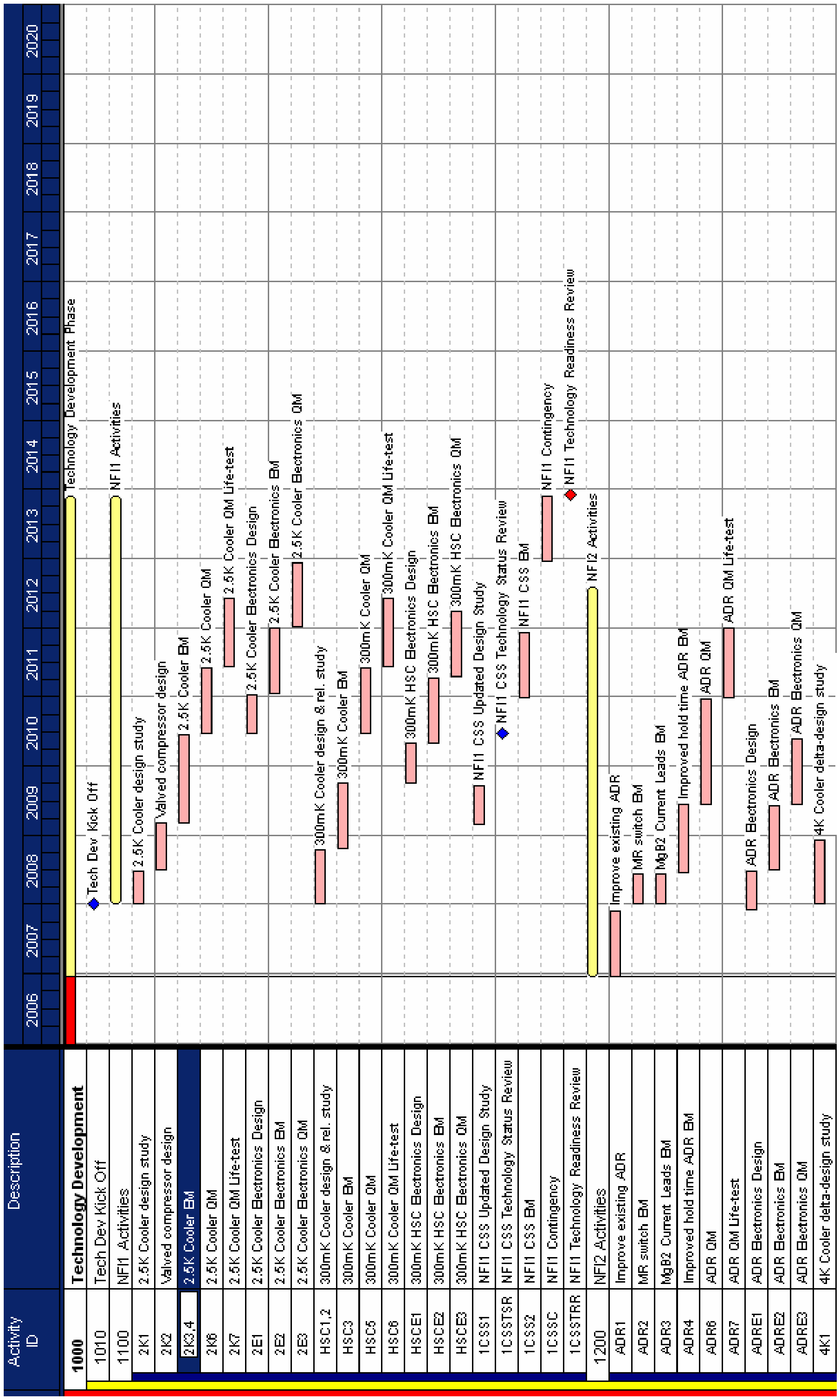


Figure 5-9 Proposed TDA schedule – part A.

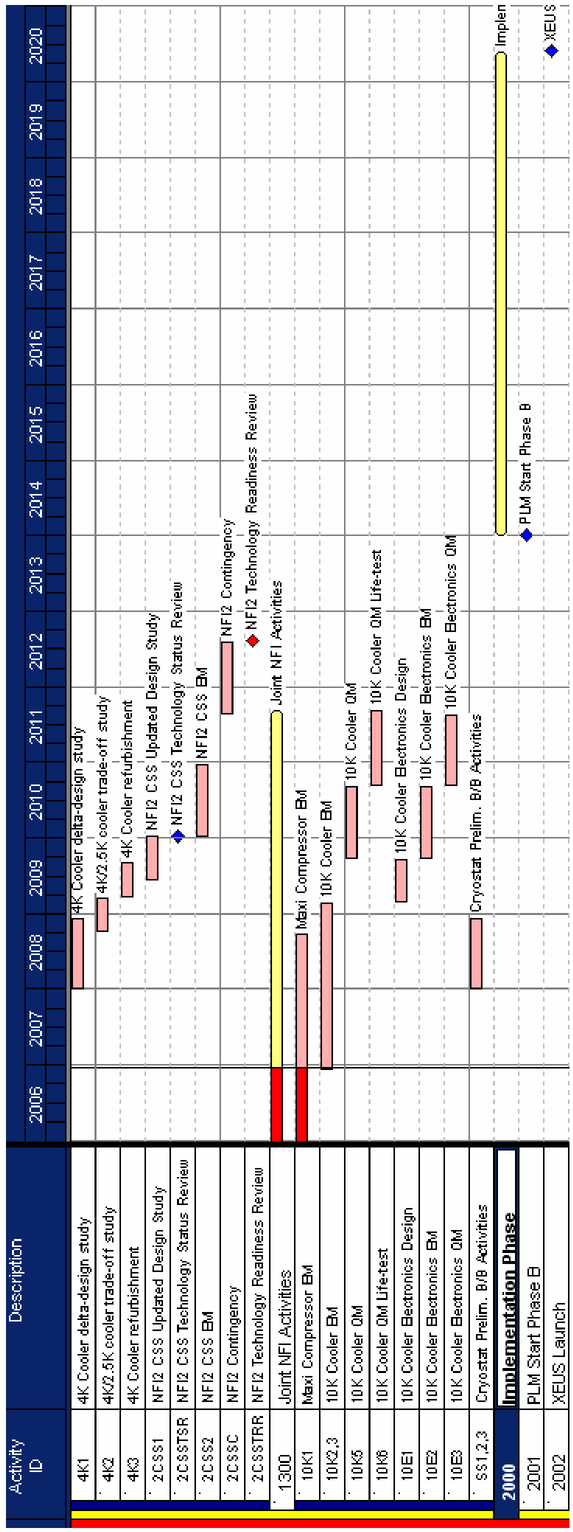


Figure 5-10 Proposed TDA schedule – part B.

6. RESOURCE REQUIREMENTS

The resources required for the accommodation of each of the candidate instruments have been assessed and the total impact on the detector spacecraft and the launch composite has been assessed. The table below shows the preliminary mass budget calculated for a number of different instrument options. It should be noted that no service module design activity was included in this study and therefore the mass presented is a rough estimate.

Option	WFI + NFI1	WFI + NFI2	WFI + NFI1 + Ancillaries	WFI + NFI2 + Ancillaries	WFI + NFI1 + NFI2	WFI + NFI1 + NFI2 + Ancillaries
PLM	776.59	821.16	934.54	979.23	1010.06	1156.13
SVM	548.21	548.21	548.21	548.21	548.21	548.21
MSC I/F Adaptor	30	30	30	30	30	30
20% System Margin	270.96	279.87	302.55	311.49	317.65	346.87
propellant	130	132	143	143	154	167
DSC	**1755.76**	**1811.24**	**1958.3**	**2011.93**	**2059.93**	**2248.21**

Table 6-1: Preliminary DSC mass budgets for different PLM configurations.

The target mass for the DSC including system margin is 2000kg, in the cases where the ancillary instruments are included there is limited margin or the target mass is exceeded.

The highest payload module power demand of 1424W is required in the case where the ancillary instruments are included and results in a solar array area of ~7m^2.This power is an early estimate as the standby powers for the instruments are not yet available.

Instrument	Nominal Rate	Peak Rate	Data Volume for 24 Hours Observation
WFI	13 kbits/s	300 kbits/s	26 Gbits
NFI	36 kbits/s	1.1 Mbits/s	100 Gbits
HTRS	500 kbits/s	150 Mbits/s	16 Gbits
HXC	40 kbits/s	10 Mbits/s	3.5 Gbits
XPOL	300 kbits/s	7.5 Mbits/s	26 Gbits

Table 6-2: Instrument data budgets

Assuming the average data rates for the core instruments and a downlink period of 3 hours a downlink rate of 142kbits/s is required. If the ancillary instruments are included the downlink rate increases to ~300kbits/s. A 200Gbit mass memory is required based on the instrument peak rates and assuming a missed link opportunity.

7. CONCLUSIONS

The critical issues with respect to payload accommodation can be divided into the individual instruments.

For the WFI one of the critical issues is the baffle design:

- The size and mass of the baffle is critical together with possible distortions.
- Stray-light issues are critical.
- Implementation of a thin gold coating on then inside of the baffle on top of the CFRP structure.
- General design and manufacture of the baffle and practicality of manufacturing and integrating a segmented baffle with vanes and different layers.
- Contamination is critical especially due to the size of the baffle.

For the narrow field instruments, the cryogenics and the interface between the instrument and the cryogenic chain are the most critical. For the cryogenics, the main critical issues are the heat loads, interfaces and reliability. The cryostat suspension system is also critical.

For the HXC, the main critical issue is the integration of the instrument together with the WFI and the baffle design to ensure sufficient x-ray attenuation. The thermal design is critical and the WFI can only be cooled from the sides inducing thermal gradients.

Both the XPOL and HTRS are stand alone instruments and do not provide any additional accommodation issues.

Astrium are grateful for the work of their partners for the cryogenic systems design: The Mullard Space Science Laboratory (MSSL, University College London), The Rutherford Appleton Laboratory (RAL, CCLRC), and Commissariat à l'Energie Atomique Service Des Basses Temperatures (CEA-SBT).

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