Experience from Astro-H

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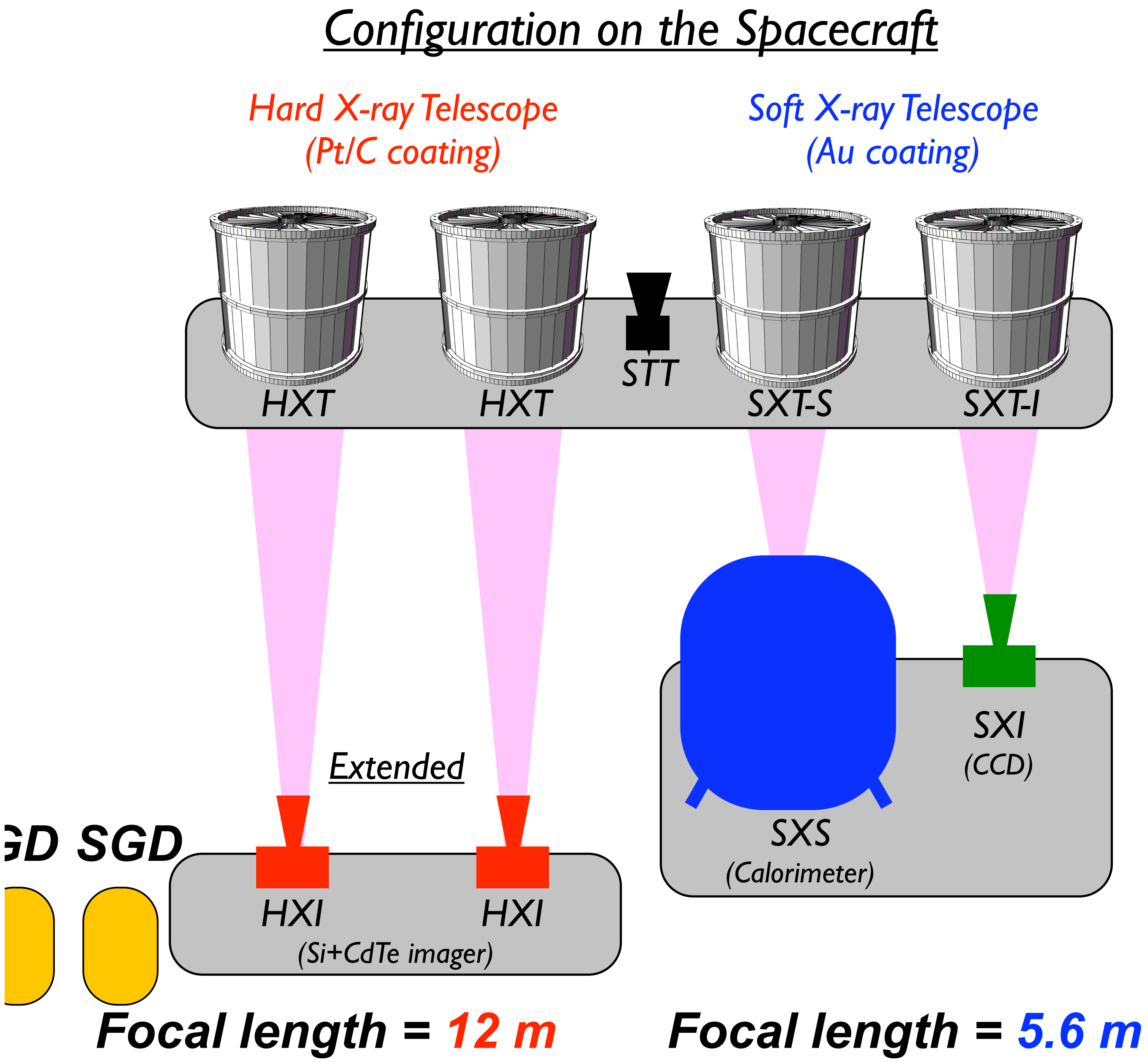
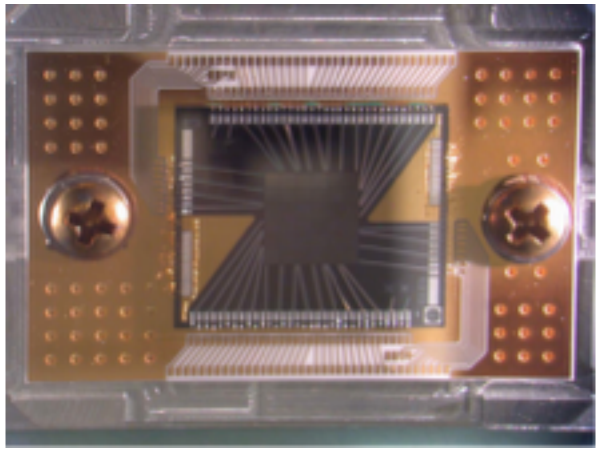
Astro-H mission

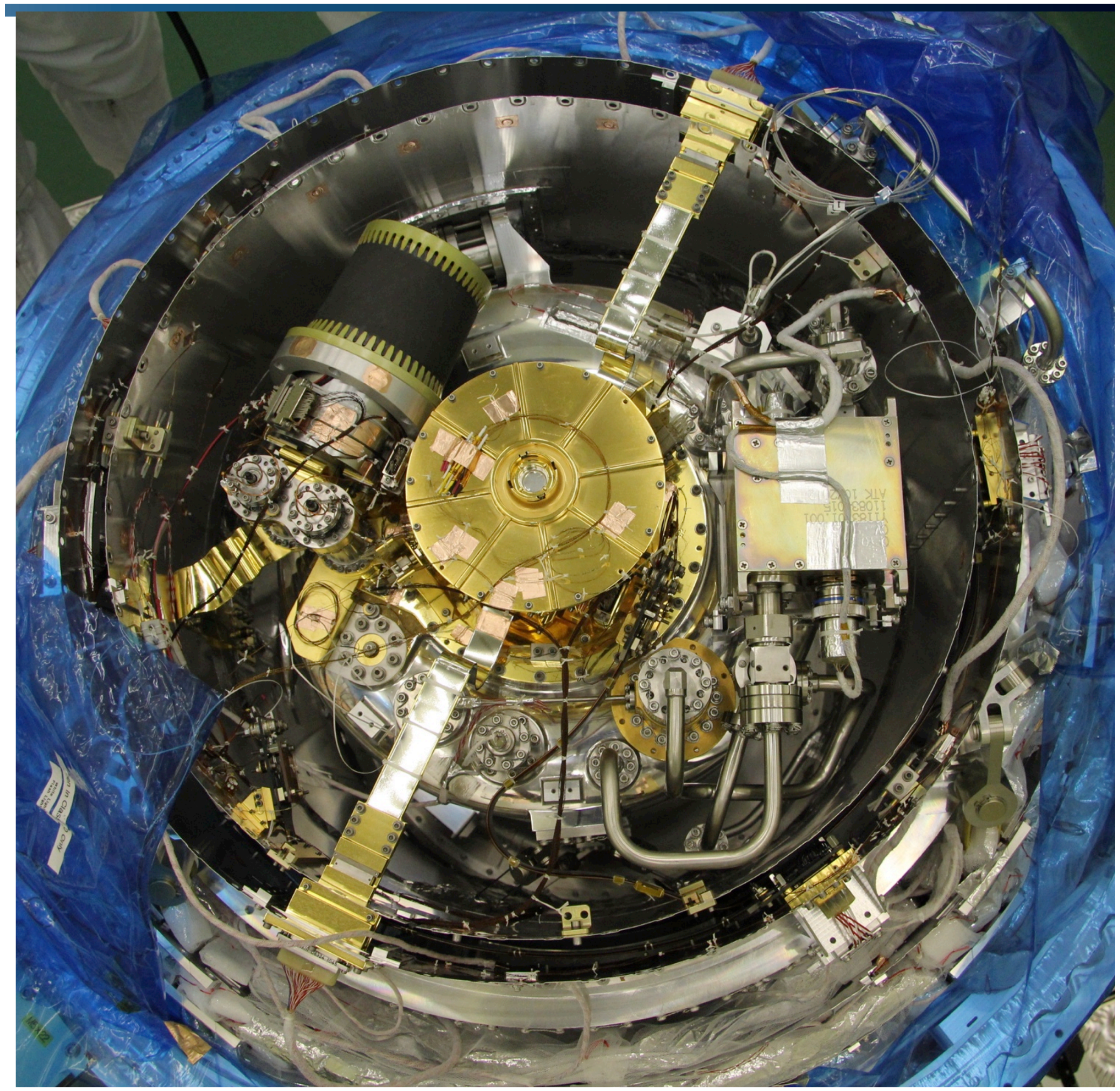


Astro-H is an international X-ray observatory which will be launched on 2016 Feb 12th by HII-A rocket. There are 4 instrument, and SXS (Soft X-ray Spectrometer) is a X-ray microcalorimeter operated at 50 mK.

Takahashi+ 2010, Mitsuda+2010 @SPIE

SXS

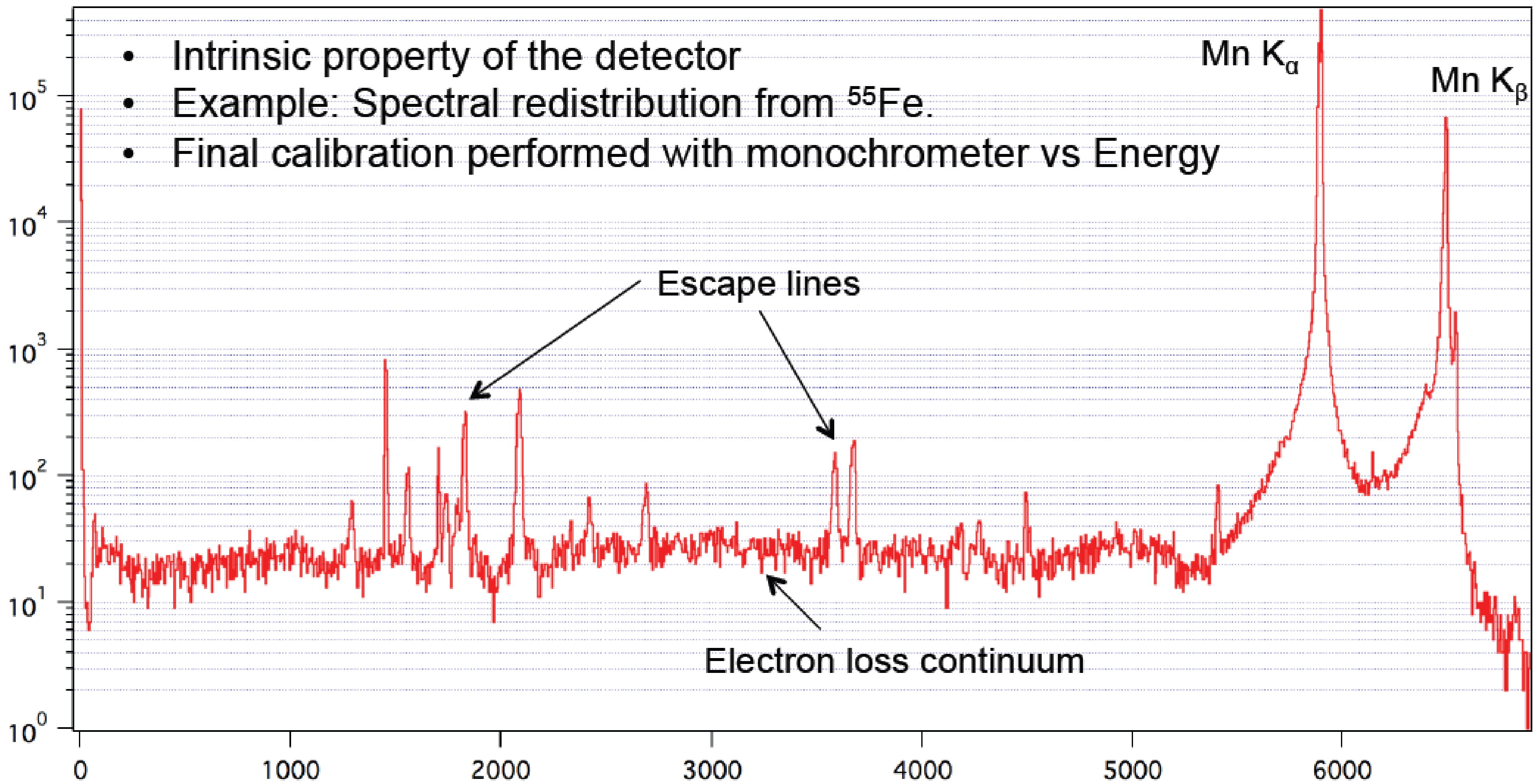




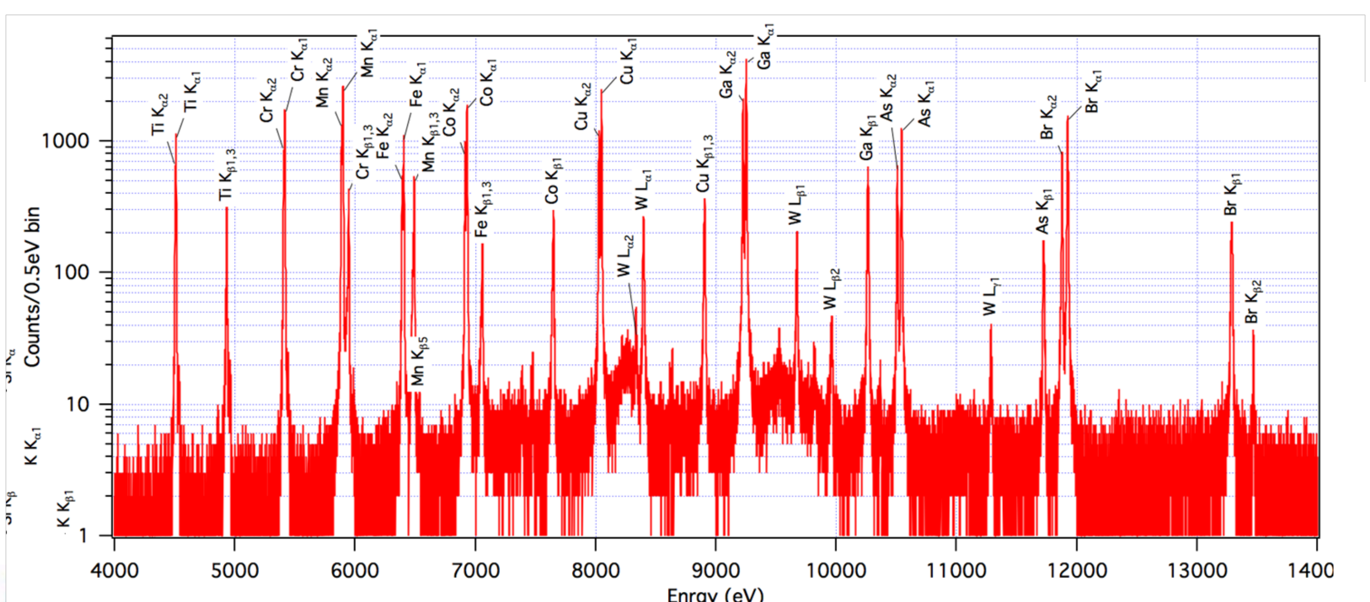
The sensor is a Si microcalorimeter array of 32 pixel, 3x3 mm^2.

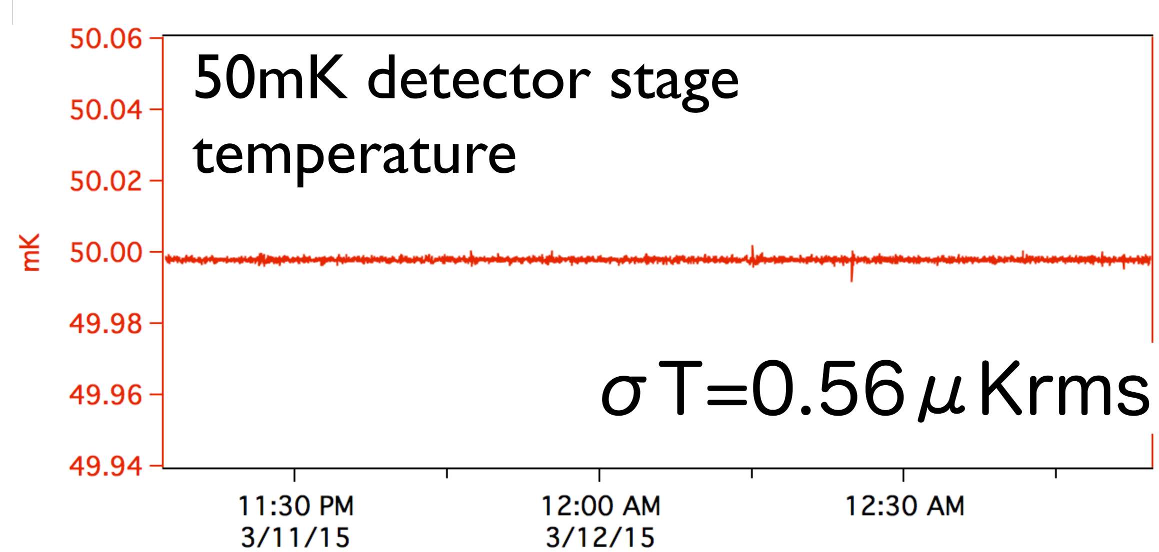
SXS sensor +ADR are fabricated at GSFC, and installed in the dewar in Japan.

Energy resolution E/ΔE>1000

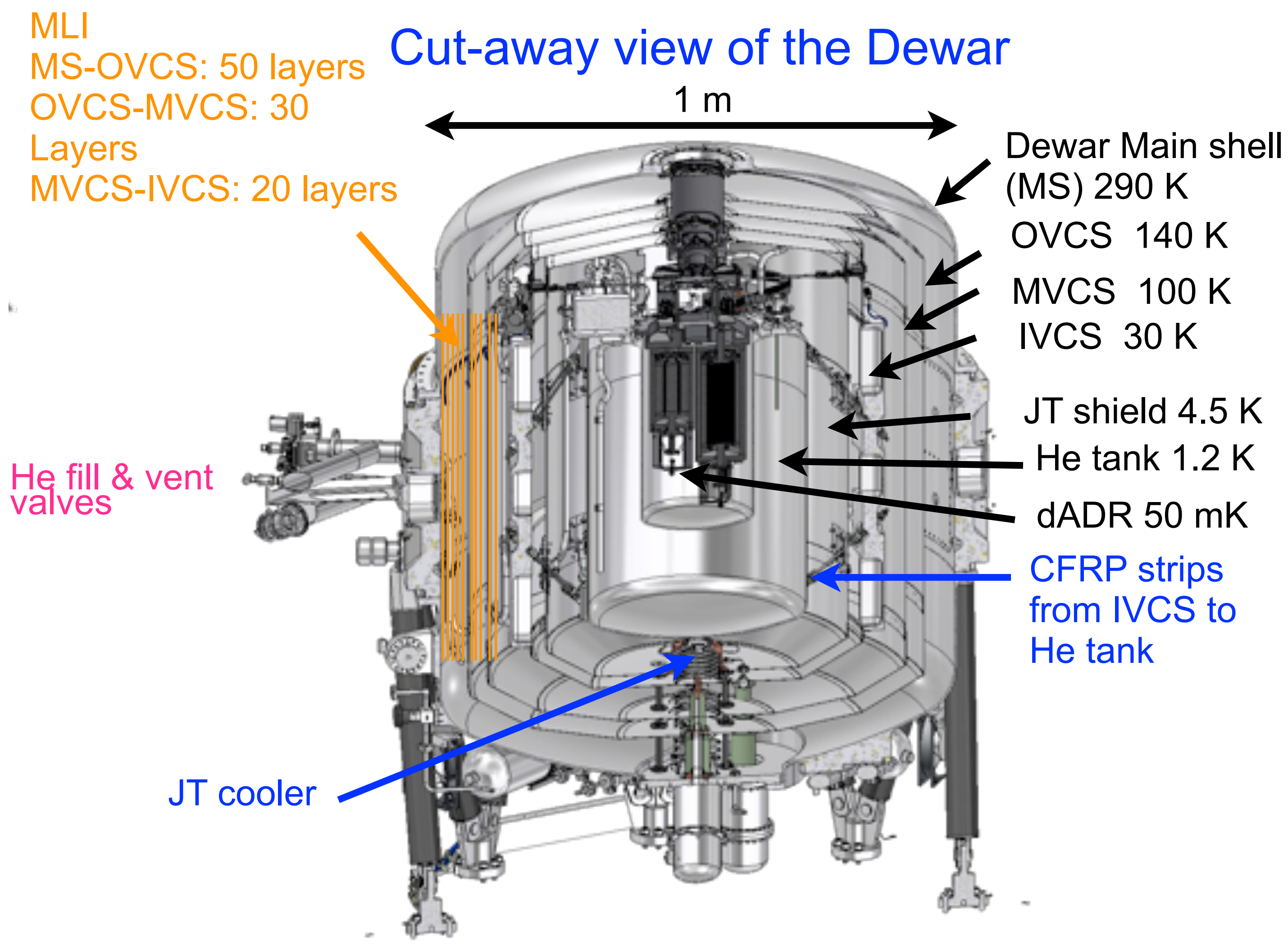


ΔE< 5eV
at 5.9 keV Mn Kα

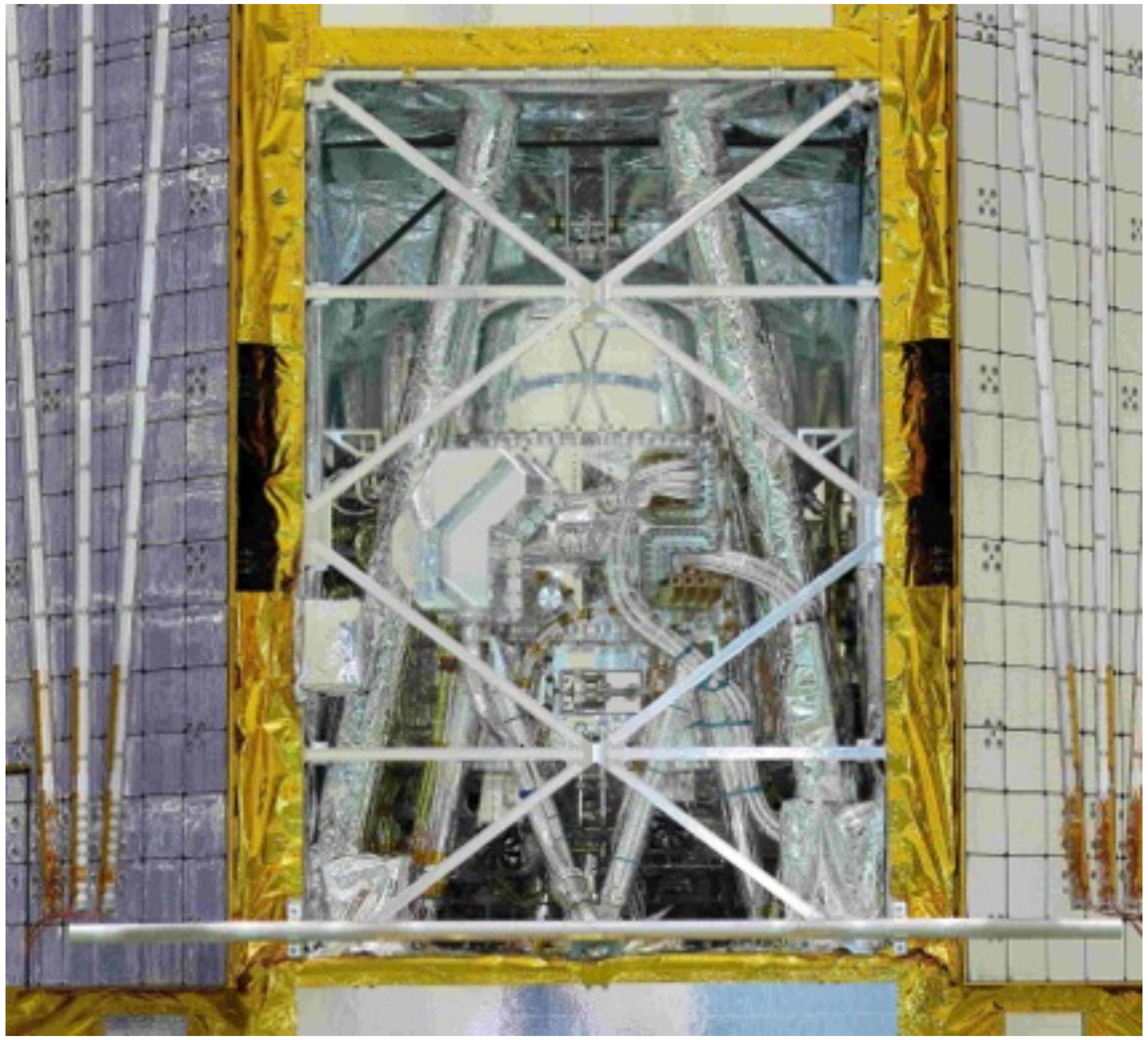




SXS dewar

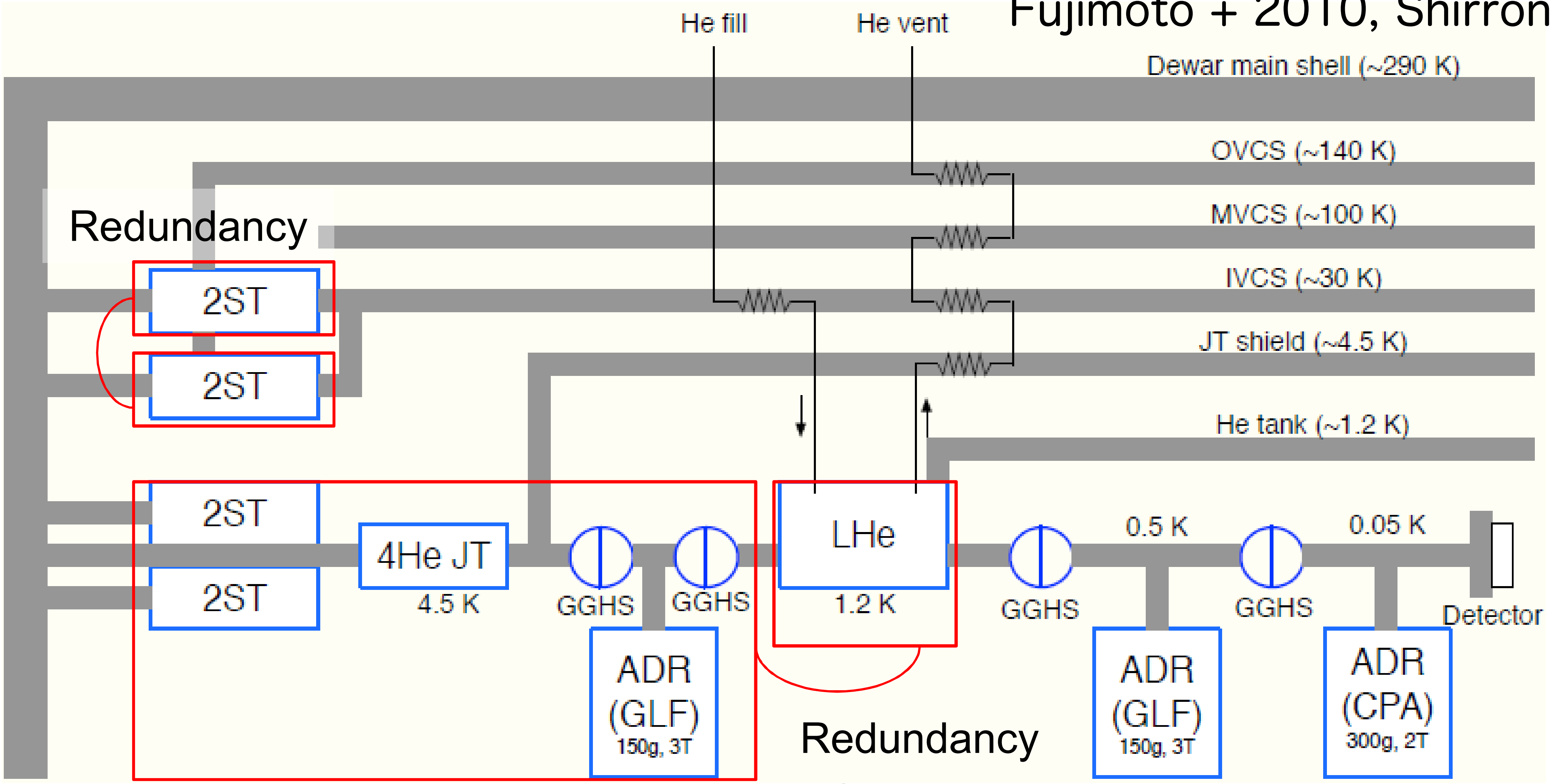


MLI
MS-OVCS: 50 layers
OVCS-MVCS: 30 Layers
MVCS-IVCS: 20 layers
Cut-away view of the Dewar
1 m
Dewar Main shell (MS) 290 K
OVCS 140 K
MVCS 100 K
IVCS 30 K
JT shield 4.5 K
He tank 1.2 K
dADR 50 mK
CFRP strips from IVCS to He tank
He fill & vent valves
JT cooler



SXS Cryogenic system

Fujimoto + 2010, Shirron + 2010

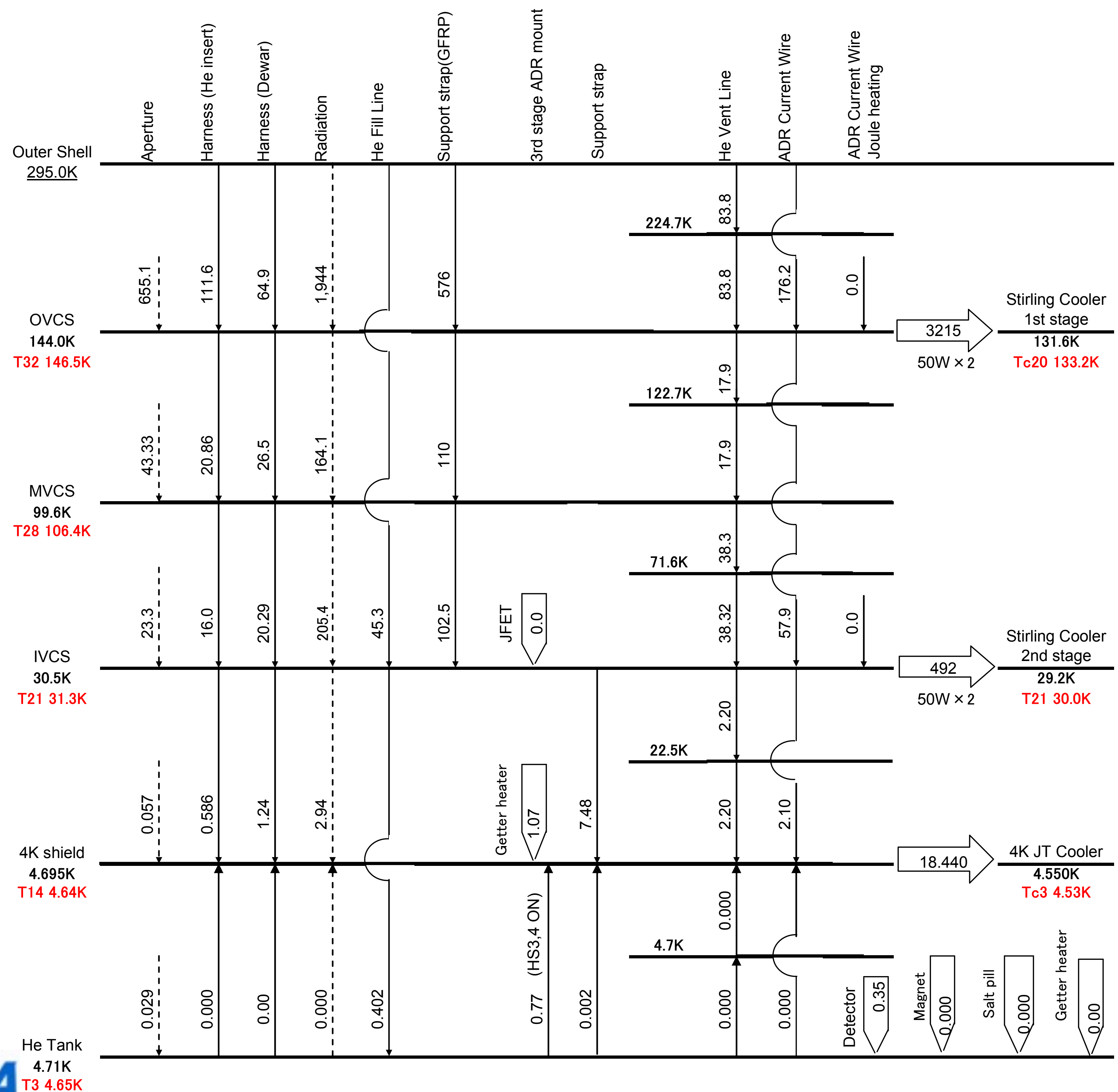


30 L of LHe will survive more than 3 years.

3rd ADR is redundant for LHe, or cryogen-free operation is feasible.

2x 2-stage Stirling coolers(2ST) + 4He Joule-Thomson coolers (JT) with 2x2ST pre-coolers are installed.

Performances of cooler



Load from detector: 0.36mW

This condition is kept by ~ 300W power input to mechanical coolers.

2STs are connected at OVCS (150K) and IVCS (30K)

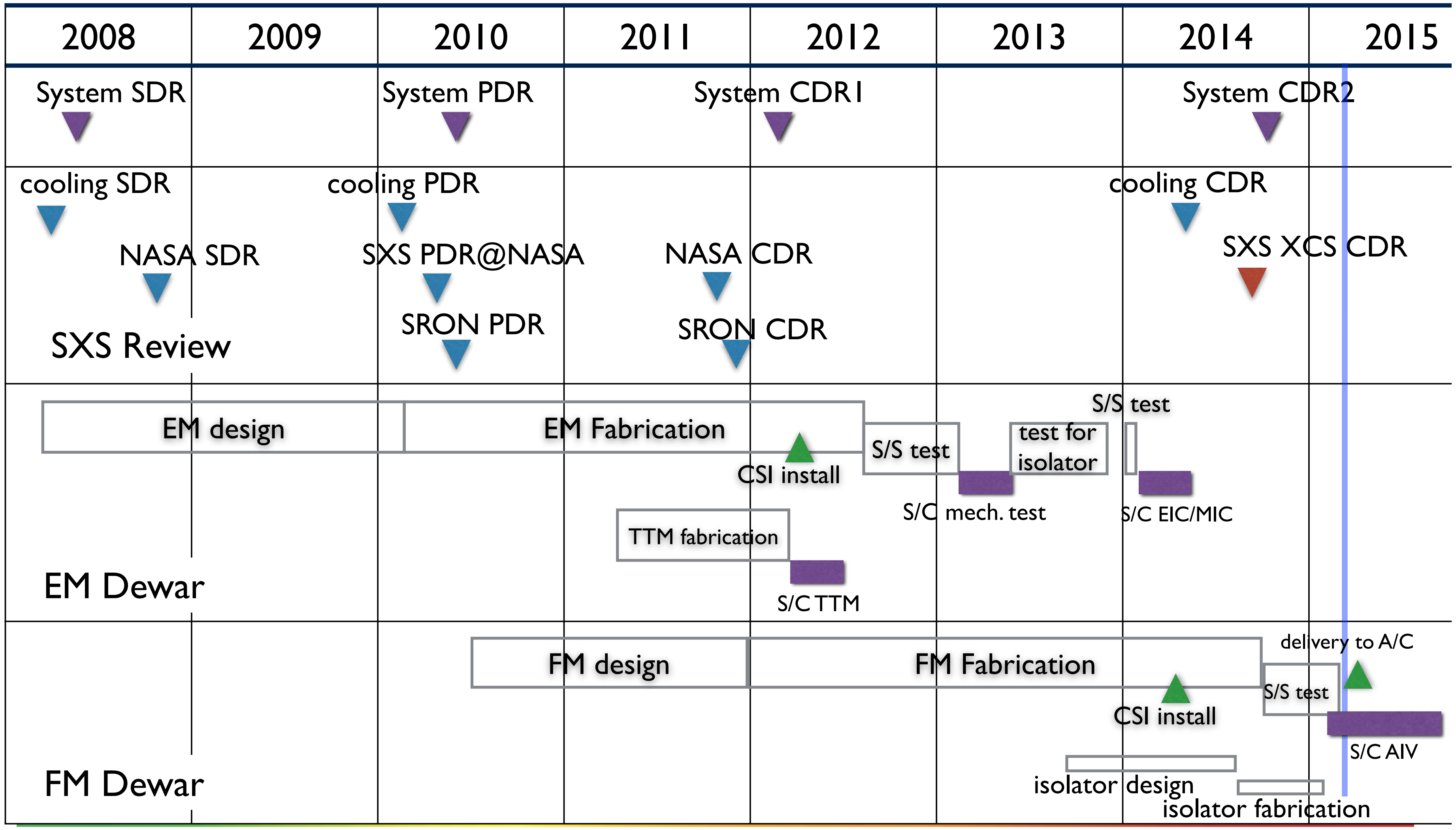
4K JT cooling power 18 mW @ 4.5 K

Heat load to the He tank 1.23 mW

Development History

!! It is not a good example. Please have a schedule margin !!

- We have started the dewar design ~ 2005. There were several design changes.
- We made 3 cryostat for Astro-H, TTM, EM and FM
- TTM :Mock up for TTM heat simulator
- EM : should be identical with FM, practices of assembly
- There were leaks in HS, and could not test the ADR cooling in FM-like sequences.



Lesson : Definition of Requirements

We define 32 requirements for dewar system.

XCS-1.1 The SXS-XCS cooling chain shall use the superfluid He as a primary cryogen. The He lifetime shall be longer than the requirement for minimum success criteria (see below for a value), even with a failure in a cryocooler.

XCS-1.2 SXS-XCS shall be capable of continuing scientific observations even without the superfluid He, if no failure occurs to cryocoolers.

- Requirements shall be identified by their origin
  - Top level requirements from mission success criteria (life, detector performance, effective area etc.)
  - Requirements from observatory science
  - Practical requirements for ground test and launch operation
  - Boundary condition from S/C and other subsystem
- Requirements shall be clarified which can be evaluated.
  - Verification method of each requirements should be defined.
- Do not confuse the requirements and results of design.

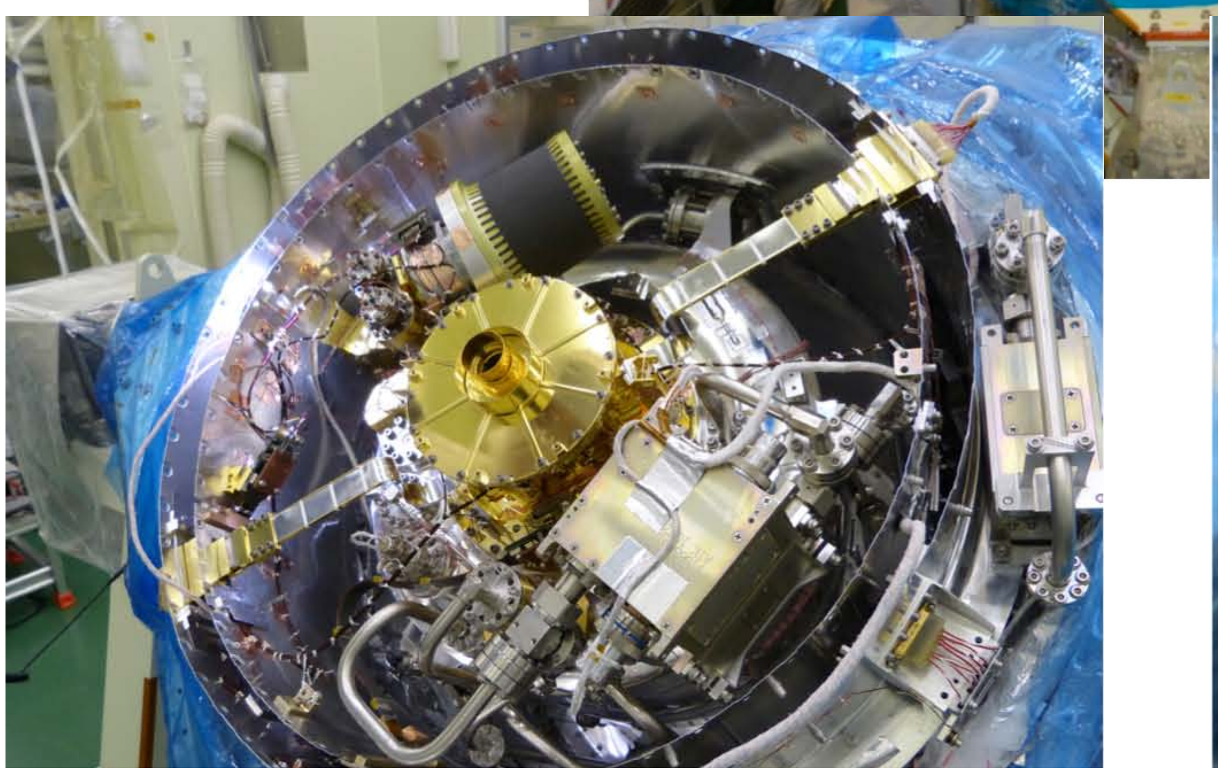
Lesson : Design with margin and redundancy

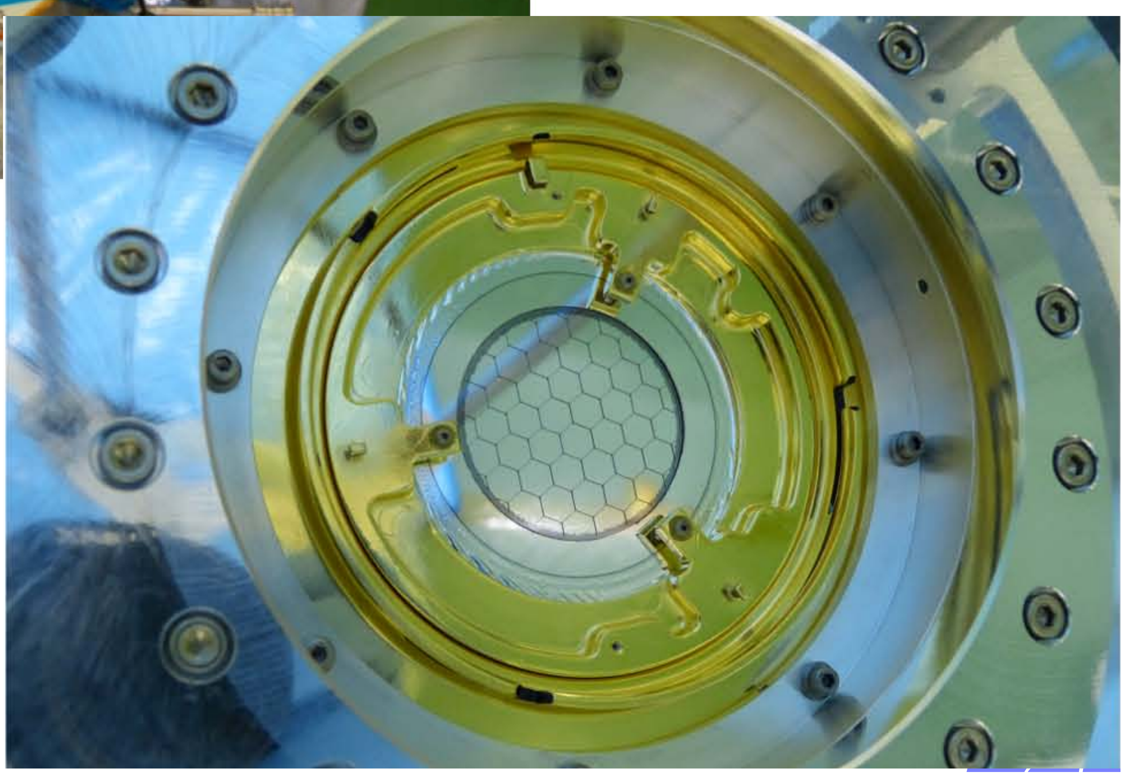
- Physical parameters at low temperature are not always well-defined to trust. (extrapolation from 4K, small sample ..) Be careful to set margins, and it shall be evaluated constantly.
- “Redundant” system sounds robust and nice. But it causes extra heat-load, extra complexity of the system, extra test resources. Consider cons & pros of redundant system, and identify risks.
    - In case of Astro-H, He tank and JT are redundant, but complicated.
    - Simple examples: un-operated 2ST will be just a heat-path, JT circulation without JT effect will heat up He tank.

Lesson: Development

- Space cryogenic system is still under development phases.
- Tight collaboration between manufacturer and project (engineer and scientists) is useful and essential.
    - Ex. CO_2 contamination in operating gas will reduce the mission life. CO_2 was measured to be ~ ppb level with API-MS. Careful calibration is required to prove the effect.

Integration



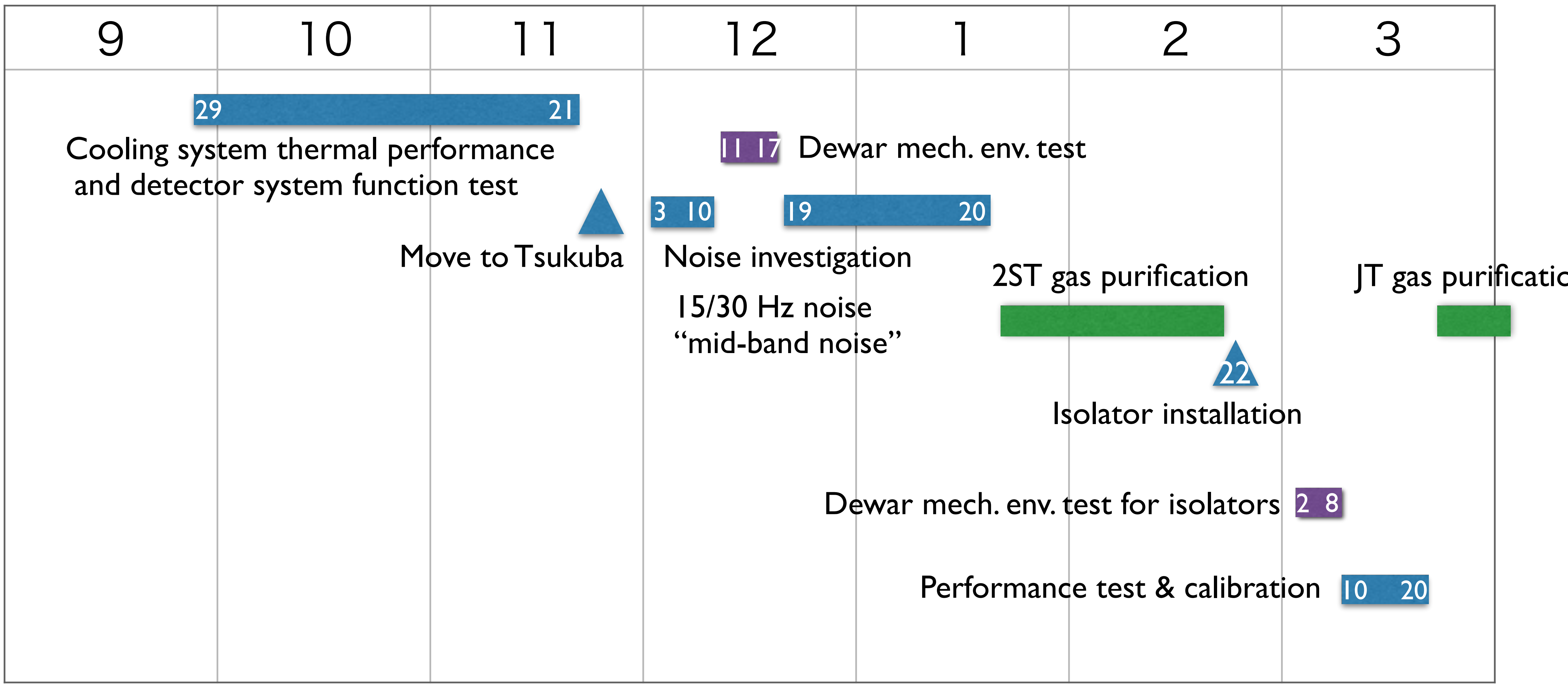


Lesson :Fabrication and Integration

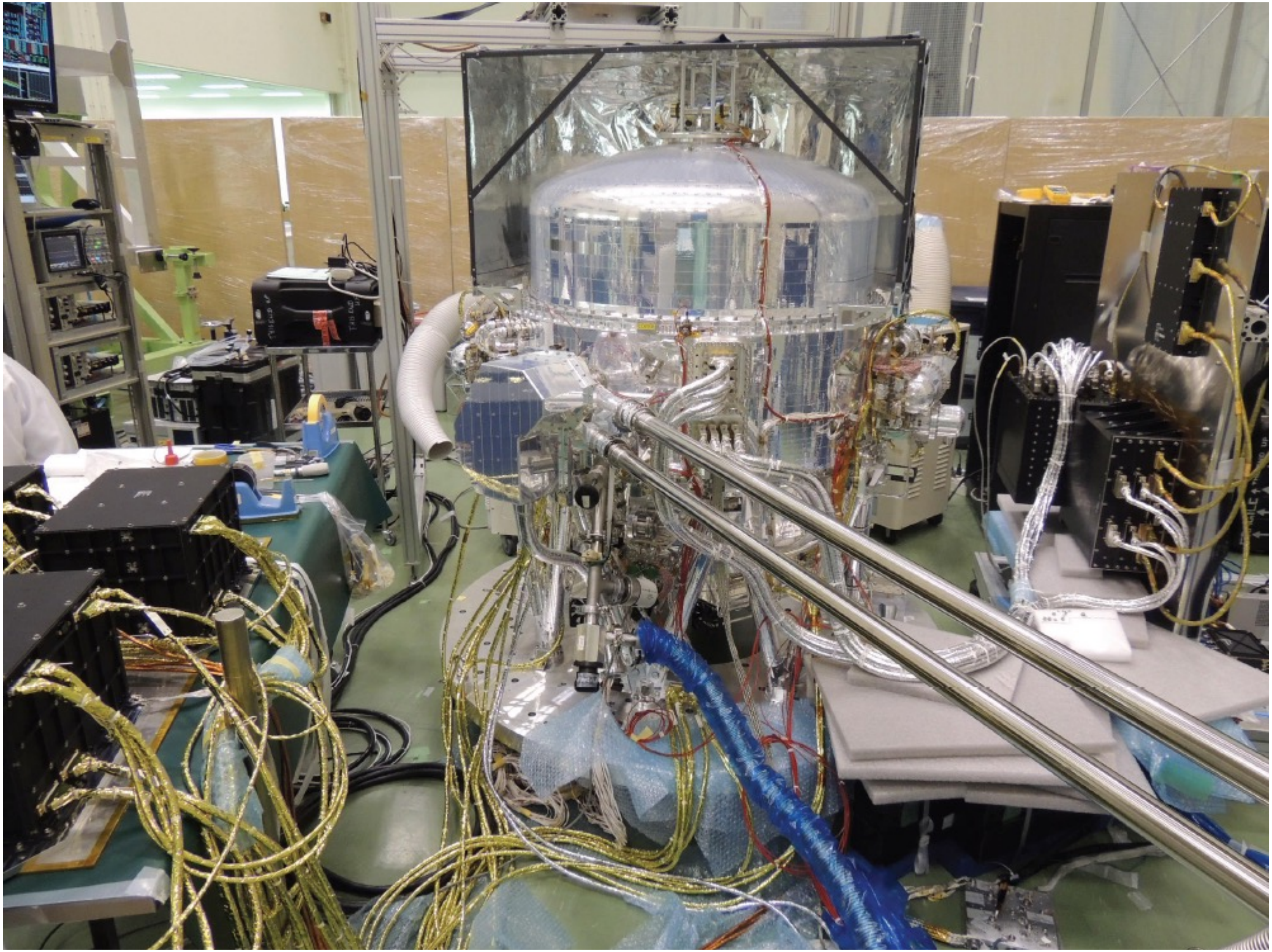
- Clarify the I/F between several manufacturer (GSFC, SRON, JAXA, SHI, MHI, NEC). Mechanical coolers and CSI are modularized, i.e. simple I/F plate. Small parts, like connectors, bolts and non-flight items are often neglected.
- The I/F can not be identified only by CAD.
  - we transfer I/F plate beforehand
- Integration needs time, and human resources.
  - MLI installation, need stitching by hand ~ 4 weeks
  - Gas purification ~ 2 weeks
- Shipping and custom clearance needs time, costs and lots of paper works.

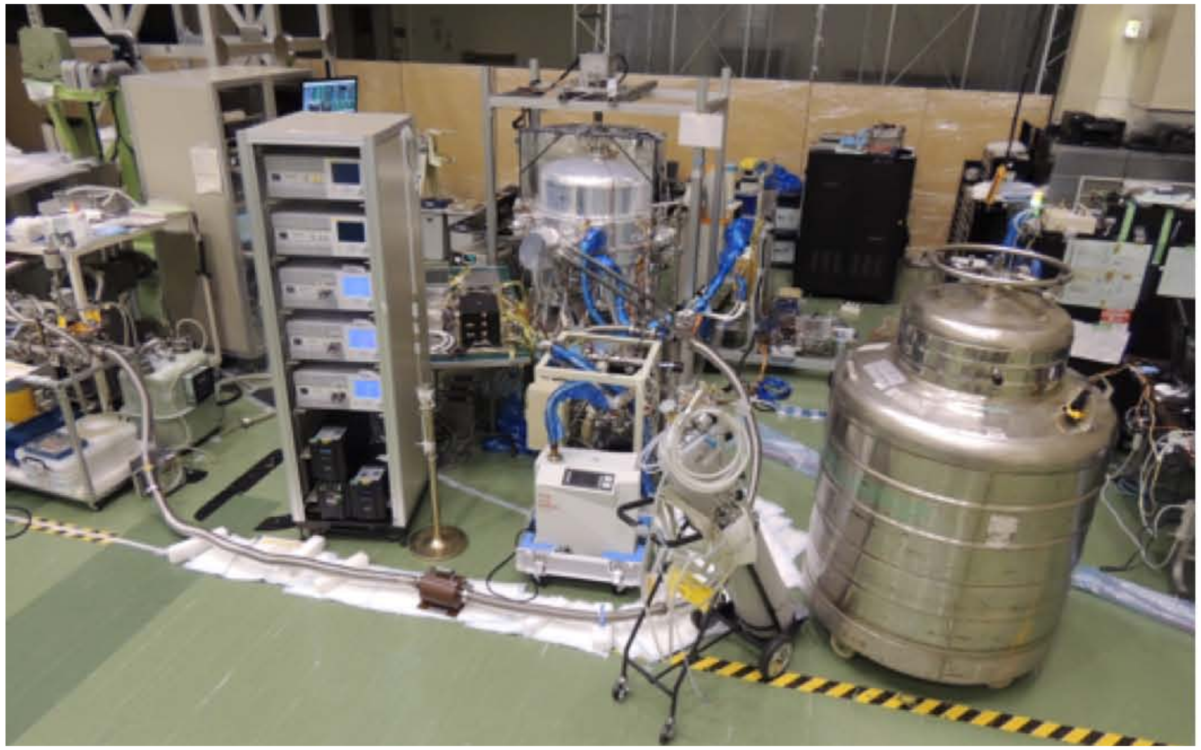
subsystem level test in 2014-2015 winter

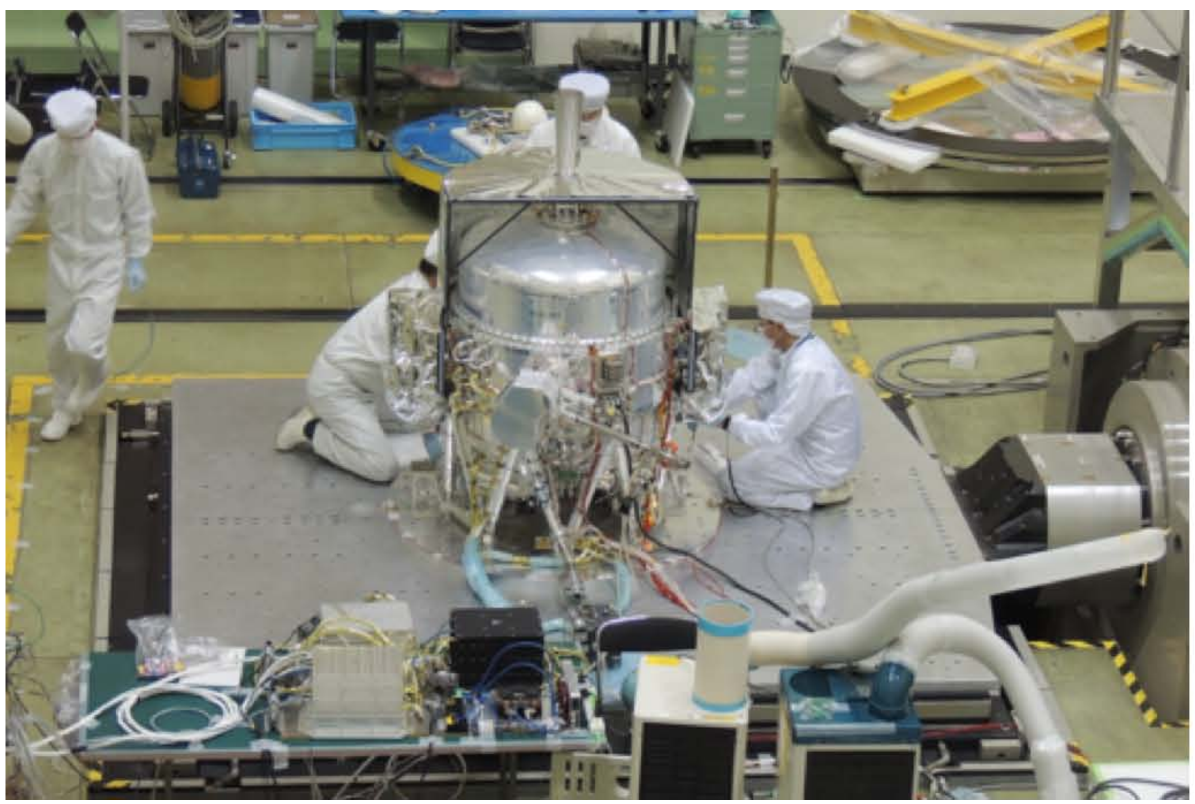
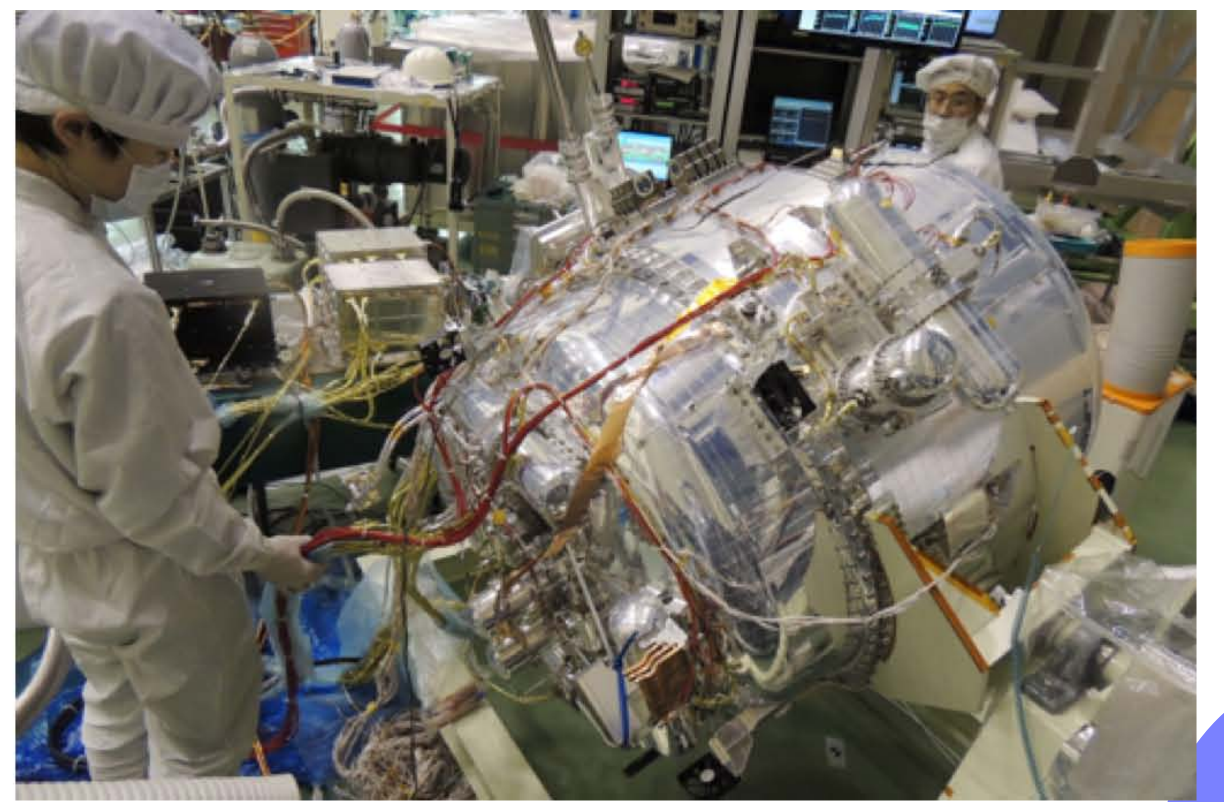
SXS subsystem level



SXS dewar at subsystem test





Lesson: Verification

- Define the verification matrix carefully, for each development phase.
  - End-to-end tests and test-as-you-fly style are preferable, but some of them are impossible. Combination of analysis/design shall be considered carefully.
- Test for cryogenic system needs time
  - He fill for the SXS dewar : 4 days.
  - Cryogen-free cooling of SXS dewar: 40 days.
  - During the tests, test personnels shall be assigned.

System level test in 2015

- System I /F test
- Integration
- Post-integration detailed function test
- Thermal-vac test (3 weeks)
- Acoustic sine-vibration, and shock test (5 weeks)
- Pre-shipment detailed function test

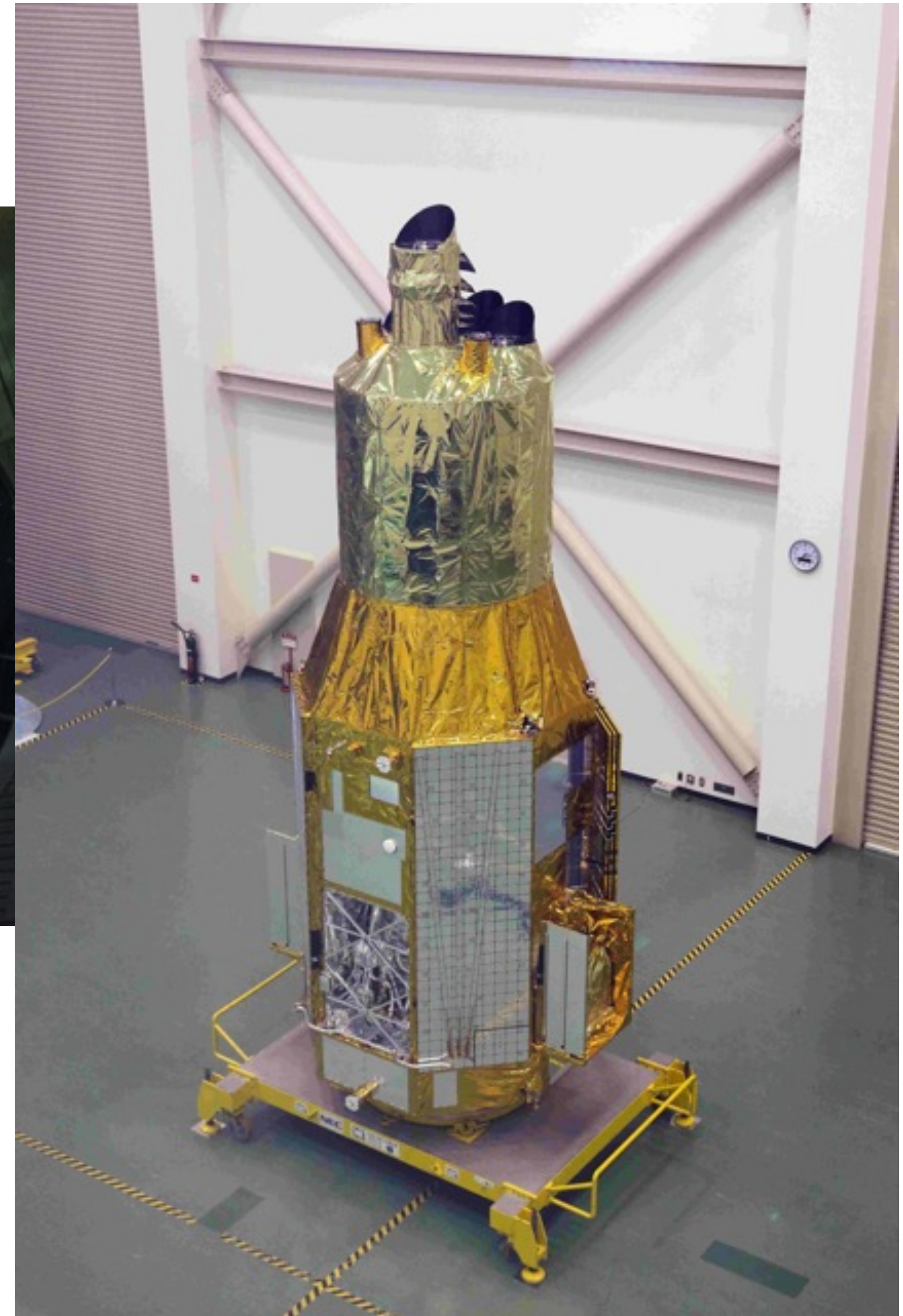
Tukuba by Nov

Tanegashima from Dec

- Post-shipment detailed function test
- Final cool down and check
- He Top-off and Launch operation

An example timeline based on S/C EIC test

	Night time									Day time											Night time			
Test item	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
SXS-DIST, SXS-SWR-A/B										A			Lunch					MD MIC						
SXS-FWE, FWM										A			Lunch											
SCD, PCD, JTD (1)										A			Lunch											
SCD, PCD, JTD (2)										A			Lunch											
PSP-A/B										A			Lunch											
SXS-PSU, XBOX, ADRC										A			Lunch											
He transfer										A Setup			Lunch	Setup				Y Setup						
Cooling (1)										A Setup			Lunch	Cryo-cooling (MD), He transfer										
Cooling (2)	Cryo-cooling (MD)									A Cryo-cooling (MD)			Lunch	Cryo-cooling (MD)										
Cooling (3)	Cryo-cooling (MD)									A Cryo-cooling (MD)			Lunch	Cryo-cooling (MD)										
SXS (0) by MD	Cryo-cooling (MD)									A SXS func test via MD						ADR S1, S2	Tuning IV crv	ΔE (norm)	ΔE (CC max)	Cryo-cooling (MD)				
SXS (1)	Cryo-cooling (MD)										A MD/SA	Bus ON	SXS ON	CC (JT circ)	[CC (JT drive)]		ADR S1, S2	Tuning SXS func test (requiring SMU, FWE, etc)			CC (SA)			
SXS (2)	Cryo-cooling (SA)									A AOCS ON	ΔE (MTQ)		Lunch	ΔE (MTQ)		ΔE (RW)	ΔE (BCCU)		AT (CC), ΔE (CC off)	Y SA/MD CC (MD)				
Func-D (1)	Cryo-cooling (MD)									A MD/SA Bus ON		SXS ON	CC (JT circ)		CC (JT drive) & others		ADR S1, S2	Tuning SXS func test (requiring SMU, FWE, etc)			CC (SA)			
~~Func-D (2)~~	~~Cryo-cooling (SA)~~									~~A~~			~~Lunch~~							~~[ADR S1, S2]~~	~~CC (SA)~~			
Func-D (3)	Cryo-cooling (SA)									A [ADR S3]			Lunch	[ADR S1-3]					Y SA/MD CC (MD) & evacuation					
Evacuation (1)	CC (MD) & evacuation									A CC (MD) & evacuation			Lunch	CC (MD) & evacuation					Y CC (MD) & evacuation					
Evacuation (2)	CC (MD) & evacuation									A CC (MD) & evacuation			Lunch	CC (MD) & evacuation					Y CC (MD) & evacuation					
SXS (3)	Cryo-cooling (MD)										A MD/SA	Bus ON	SXS ON	CC (JT circ)	[CC (JT drive)]		ADR S1, S2	Tuning IV crv	ΔE (norm)	ΔE (CC max)	CC (SA)			
SXS (4)	Cryo-cooling (SA)									A AOCS ON	ΔE (MTQ)		Lunch	ΔE (MTQ)		ΔE (RW)	ΔE (BCCU)		AT (CC), ΔE (CC off)	Y SA/MD CC (MD)				
Disassemble	CC (TM) & warm-up									A Disassemble			Lunch											



Lesson:Operation and test plan

- Every possible operation modes shall be tested on ground. No one dare to use un-tested commands in orbit.
  - Test schedule shall be planned with all possible (nominal/emergency/initial) cases.
- At S/C level, the boundary conditions are set for launch operation, and in-orbit operation. The system and instrument team should understand both requirements. Careful negotiation is needed.

Summary: Experience from Astro-H

We will know a lot of lessons from in orbit operation, which will come soon.

Cooling power and resources are limited,
but scientists' ambitions are not limited.
Thus, the system shall be delicately balanced.