

Thermal design issues for FIRI

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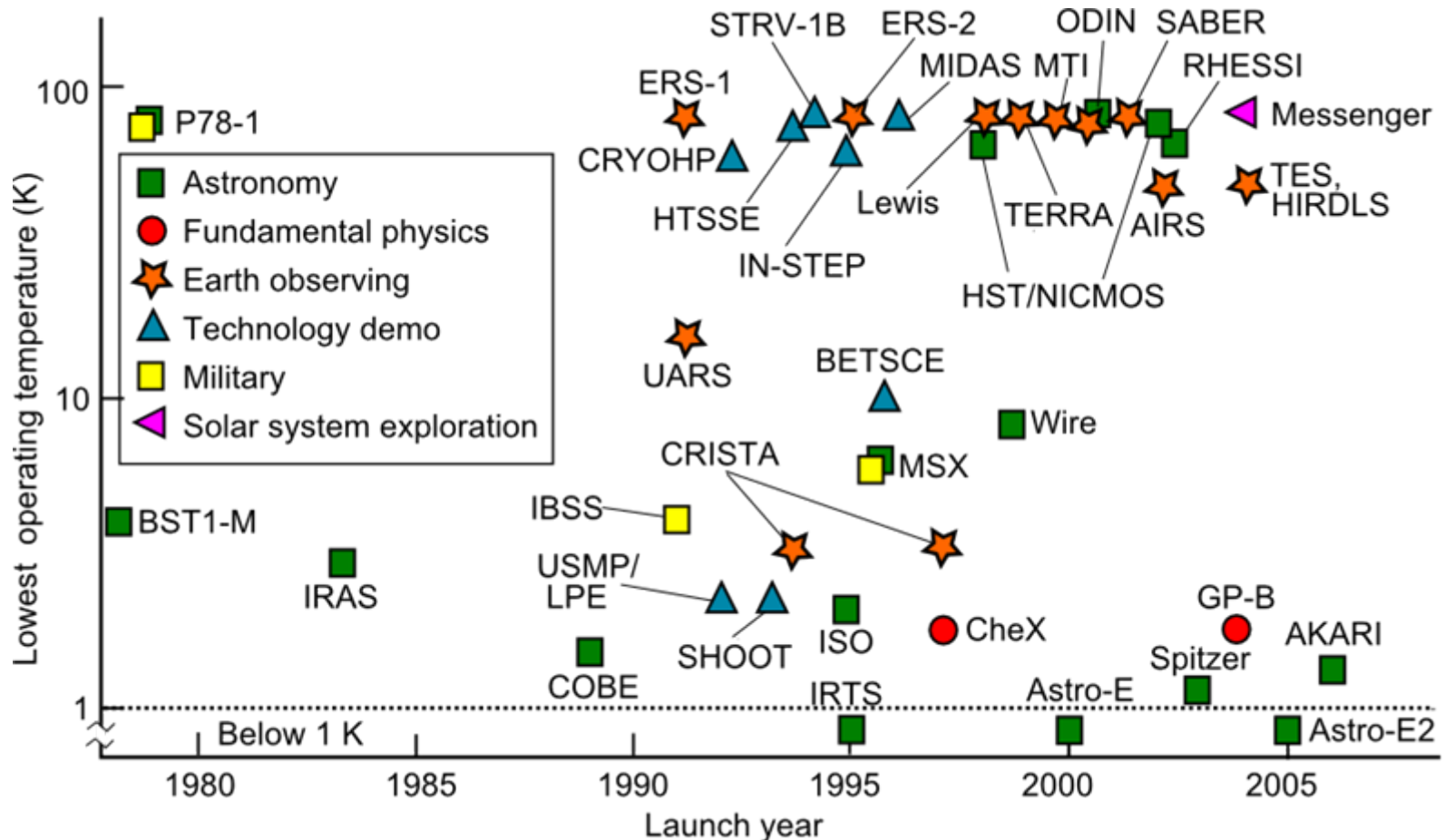


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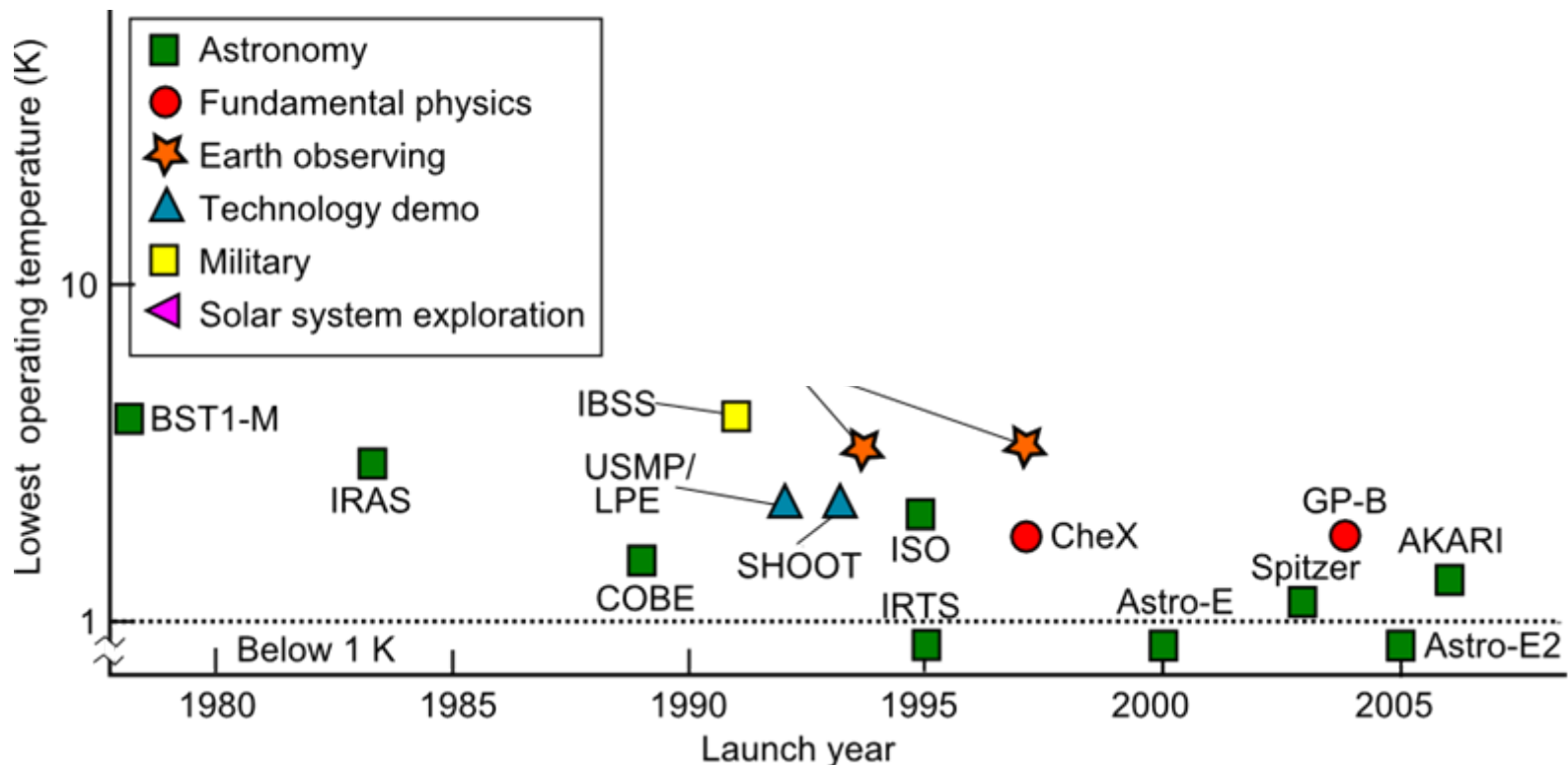


Scottish Universities Physics Alliance

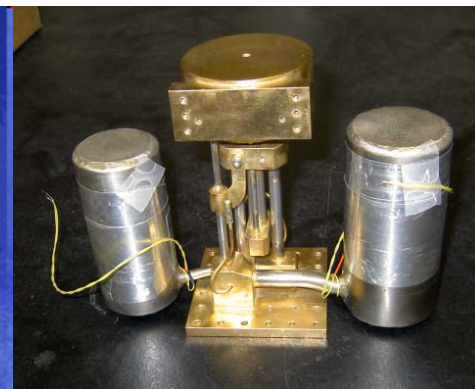
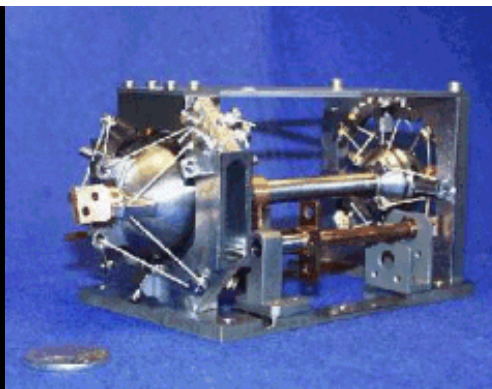
- Fair amount of experience with cryogenics in space > 1 K



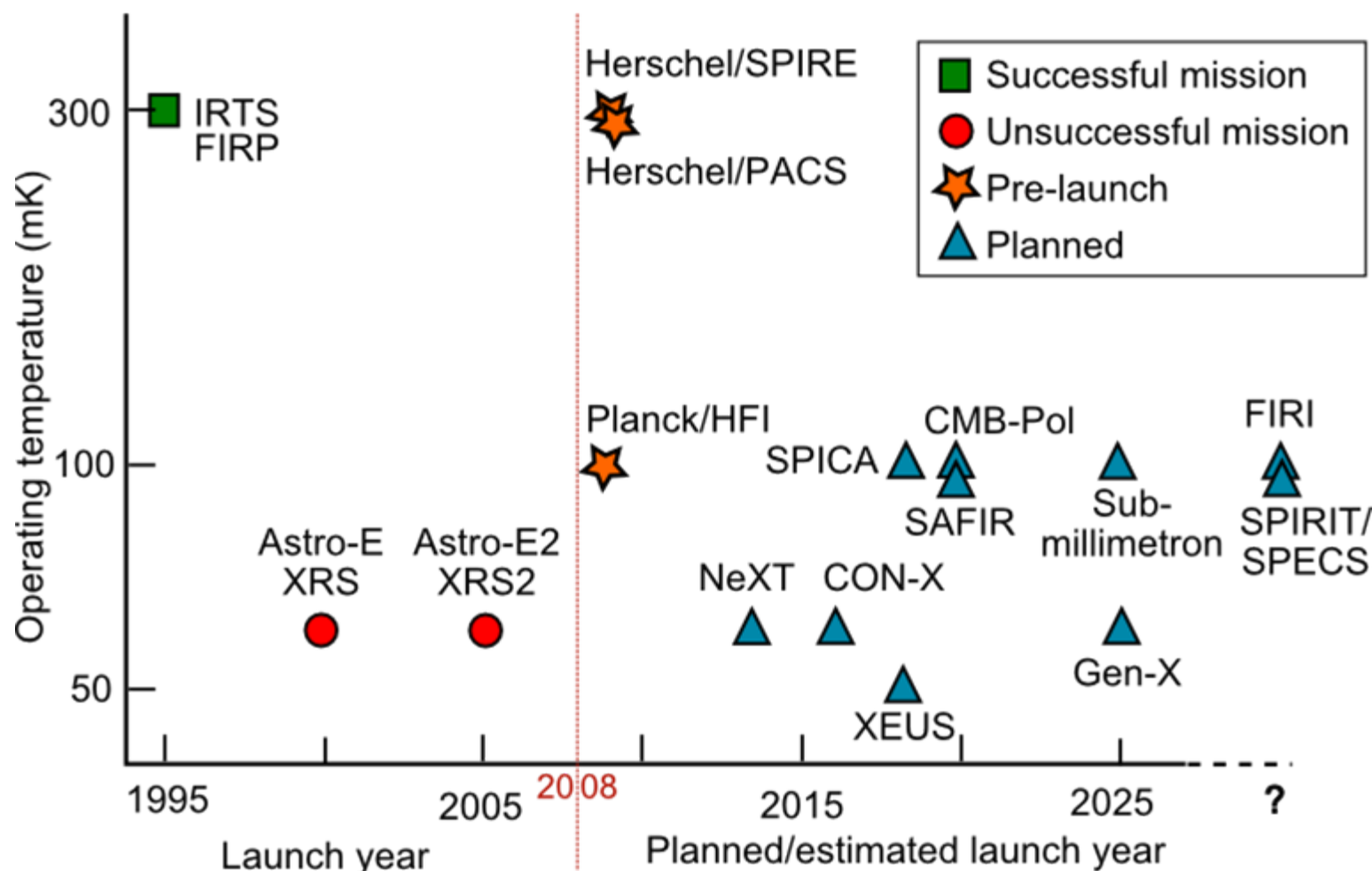
- But experience around 4 K more limited
- Mass, power and thermal budgets likely to be tighter than existing instruments



- Building good sub-Kelvin (< 1 K) instruments is hard
- Building good instruments for space is hard
- Doing both at once is very hard!



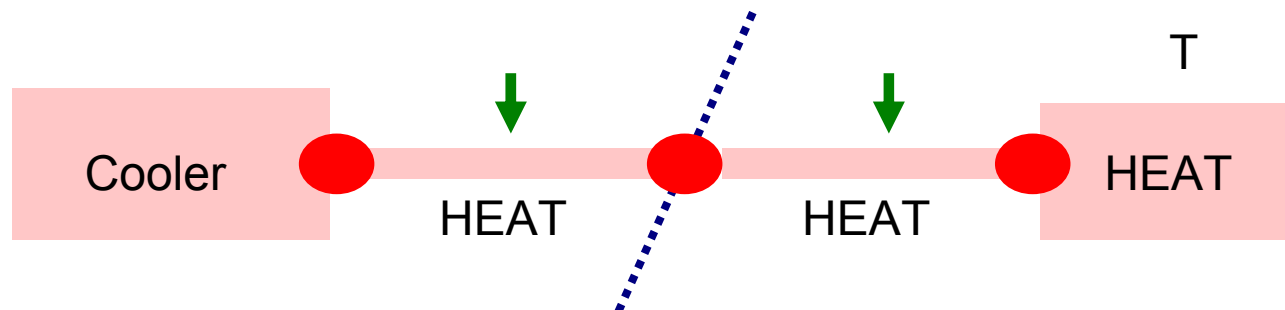
- Current and planned missions



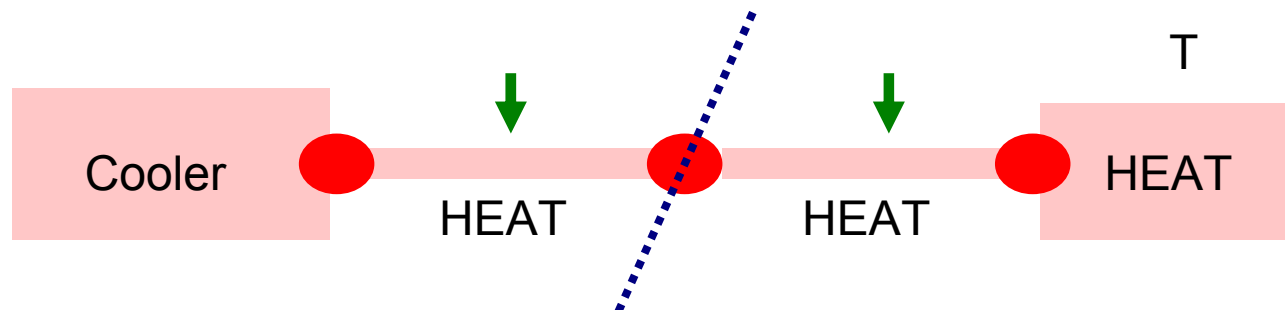
- Effective thermal design is fundamental to a successful mission
 - It doesn't matter how good your detectors are if you can't get them cold enough to work!
 - Details matter as well as overall design
- Cooling
 - Work now ongoing on sub-K designs for SPICA and IXO
 - Mechanical coolers + ADR and/or sorption fridge
 - But will still have to adapt to particular requirements

- Will have to transfer heat from detectors to coolers, and from coolers to higher temperature stages
- It's not likely to be straightforward
 - SPIRE, PACS and HFI have complex cryogenic systems
 - SCUBA-2 is maybe more representative
 - Very complex cryogenic system
 - Meets specs, but only at the expense of a lot of hard work on design and plenty of overengineering
- Cryogenic system HAS to work
 - Almost certainly won't be able to entirely use existing measurements and methods
 - Some R&D almost certainly required (as with SPIRE, HFI, SCUBA-2)

- Problems with splitting cryogenic systems into separate subsystems
 - Example: far end has maximum tolerable T
 - Must divide into contribution from each subsystem
 - Each subsystem needs power budget. Cooler temperature depends on power
 - BUT we have to set these budgets *before* detailed design, yet we don't know appropriate values at this point
 - We've now turned a simple system with one requirement (T) into something much more complex

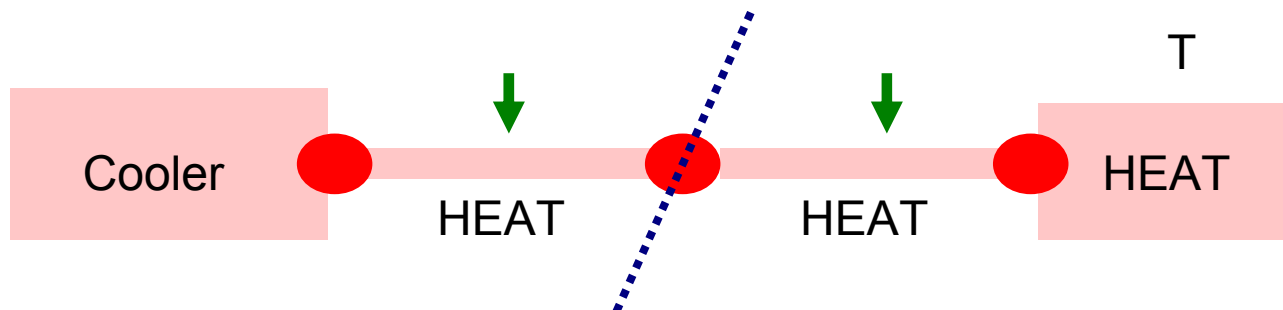


- Probably can't avoid splitting into subsystems. But can:
 - Define carefully, basing not entirely on mechanical considerations
 - Have strong oversight of overall thermal design
 - Integral part of overall systems design
 - Be ready to adjust requirements where necessary



From a mechanical point of view, a bolted joint in a strap is an obvious interface

- But from a thermal point of view this is a subsystem, which should be designed and tested in one piece
- (And whose thermal budget does the temperature drop across the interface come out of?)

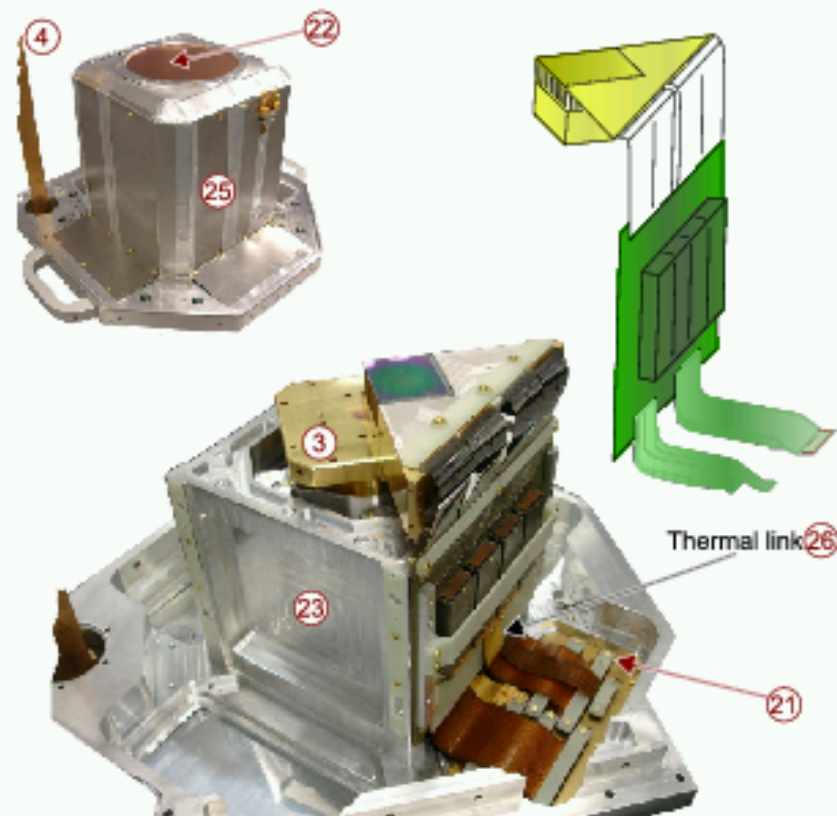
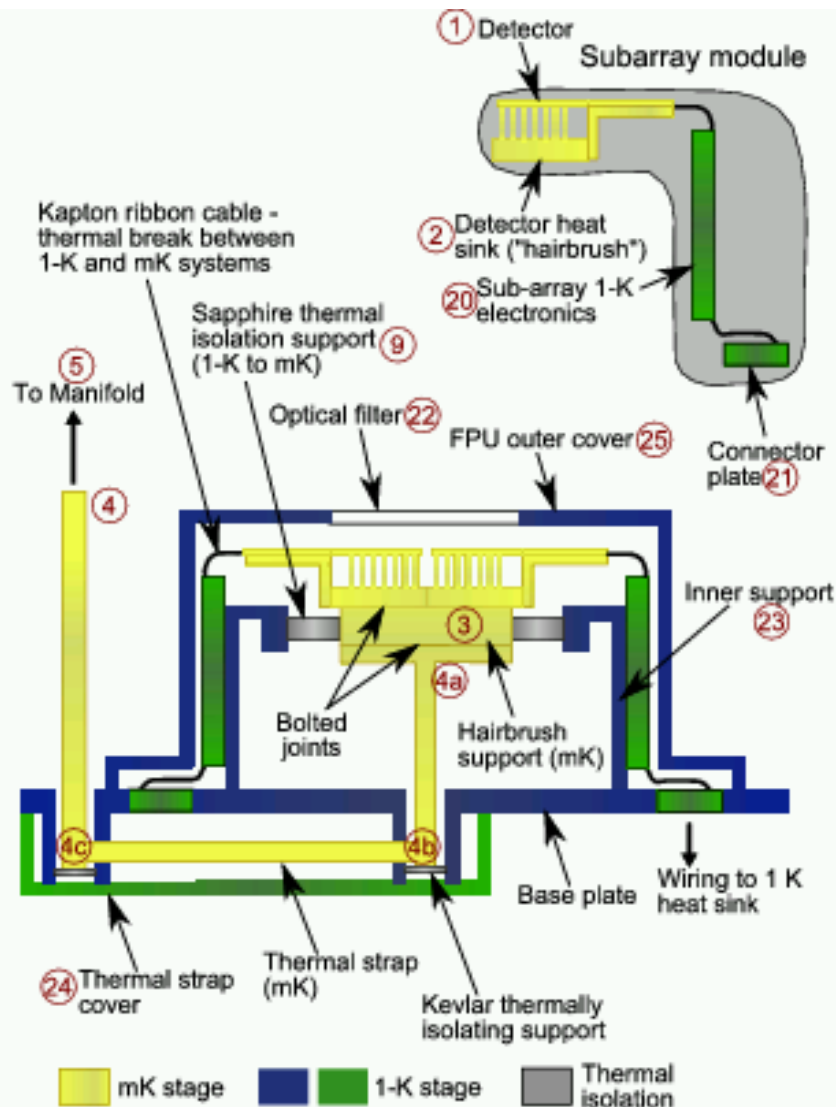


- What did we get right with SCUBA-2?
- SCUBA-2 was designed by people with the right experience (Cardiff and ATC)
- Experience from outside astronomy on review boards
- Sub-systems were (mostly) tested before finalising design
- Large safety margins were used where required
- Detailed thermal model to compare with tests
- Thermal design hand-in-hand with overall system design
- A LOT of time was spent on the thermal design!

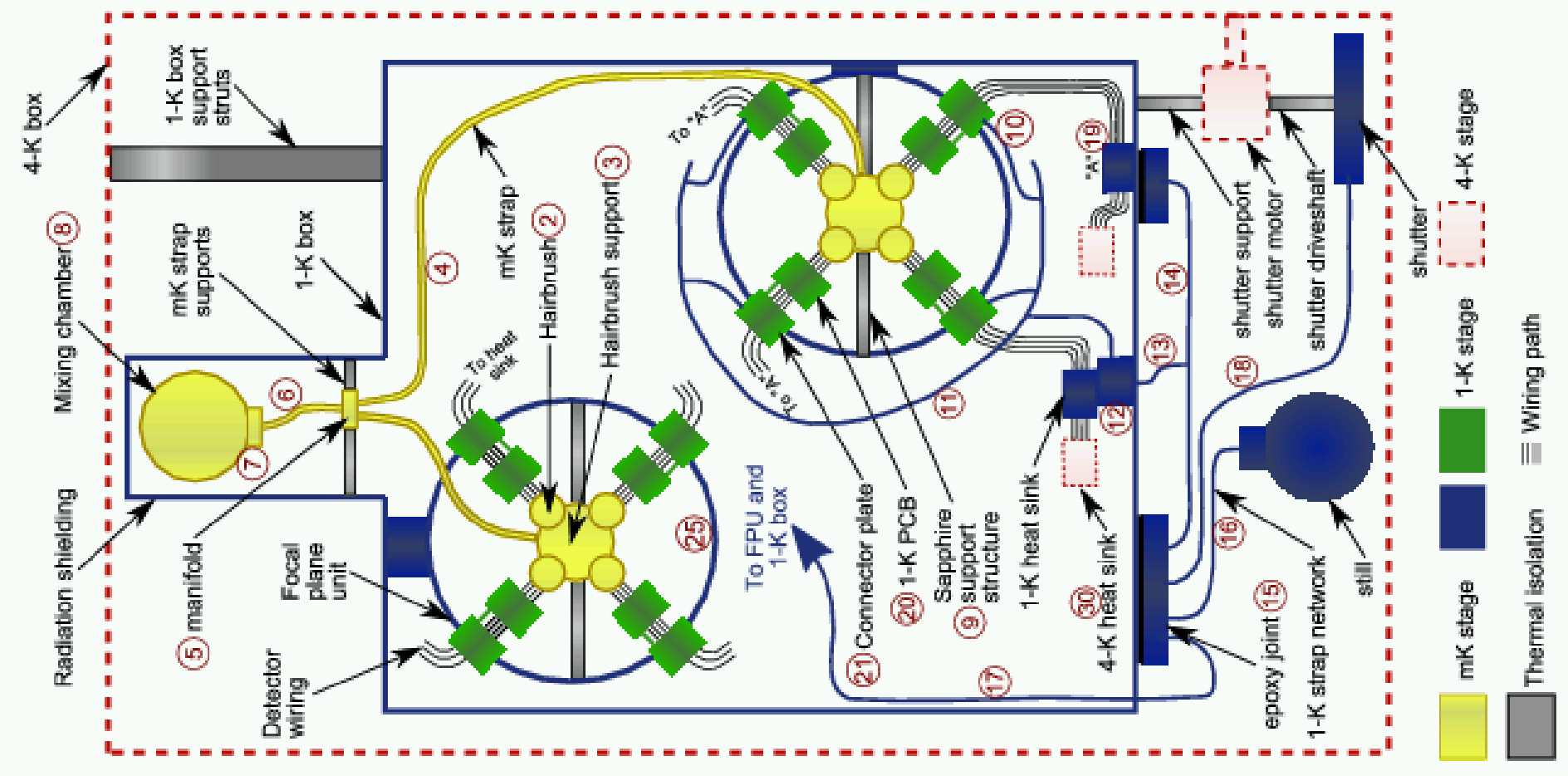
Thermal design



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Thermal design



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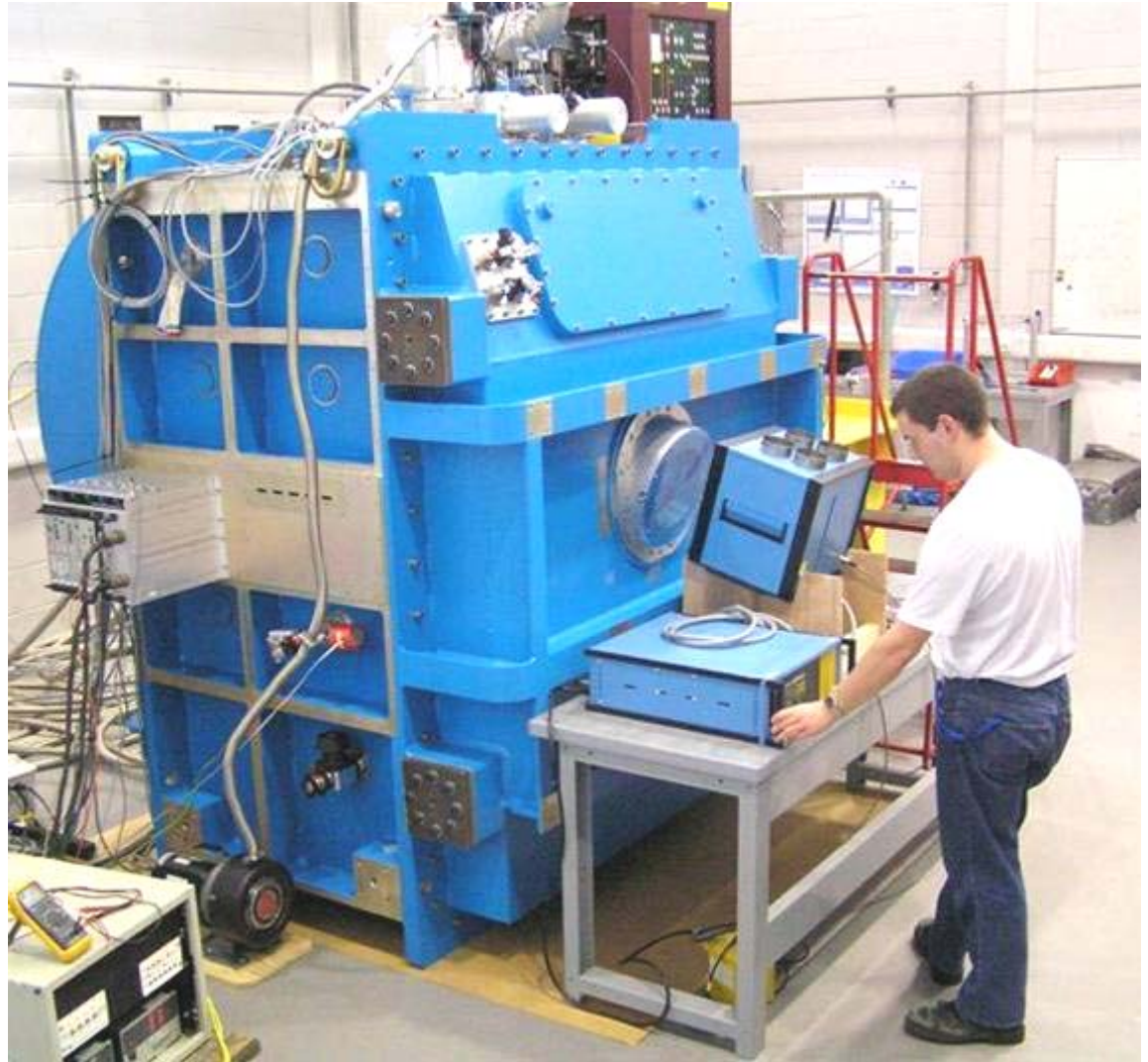
Thermal design



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In the **first** test, the instrument cooled down below the required temperature, and more quickly than required!

BUT: with hindsight, some things could have been better...



What did we do wrong?



- Decoupled thermal and mechanical design too much during detailed design
 - Elegant thermal design was corrupted piece by piece to meet mechanical requirements
- Didn't have time to test all sub-components
 - Had to overengineer

Material properties

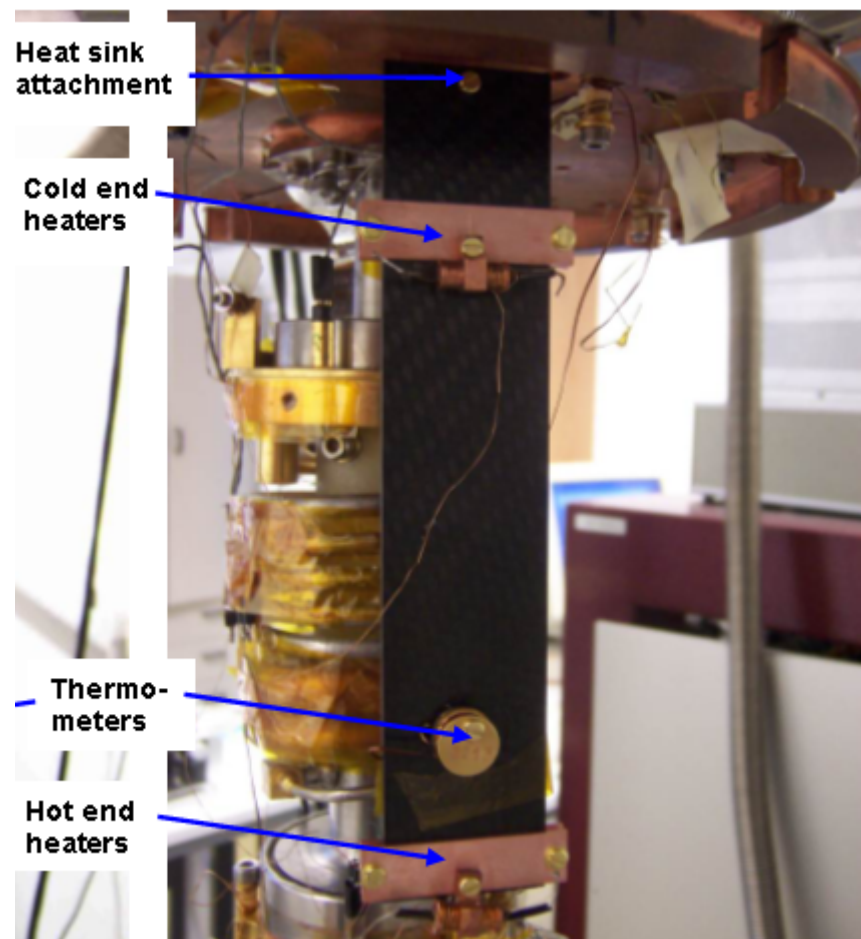


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The 1-K box is supported from the 4-K shield with CFRP
Properties are somewhat variable depending on the exact composition, and possibly from lot to lot

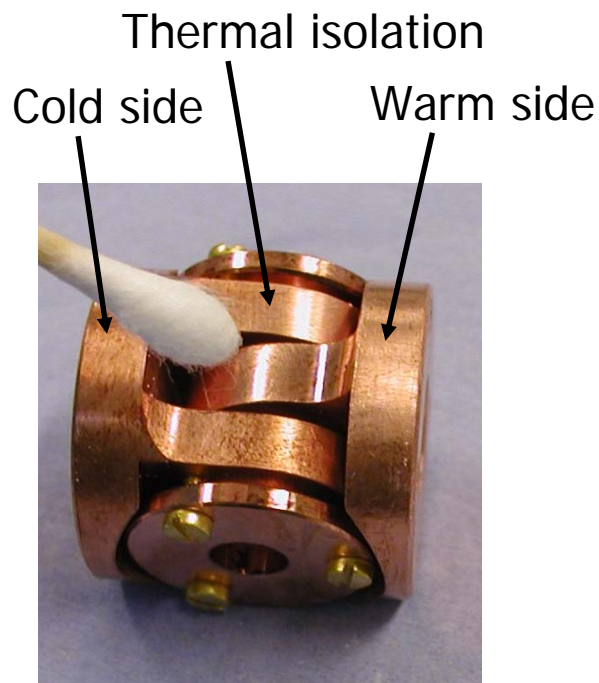
We therefore measured the conductivity of samples from the material used

Measured in Cardiff
SCUBA-2 array
characterisation testbed!

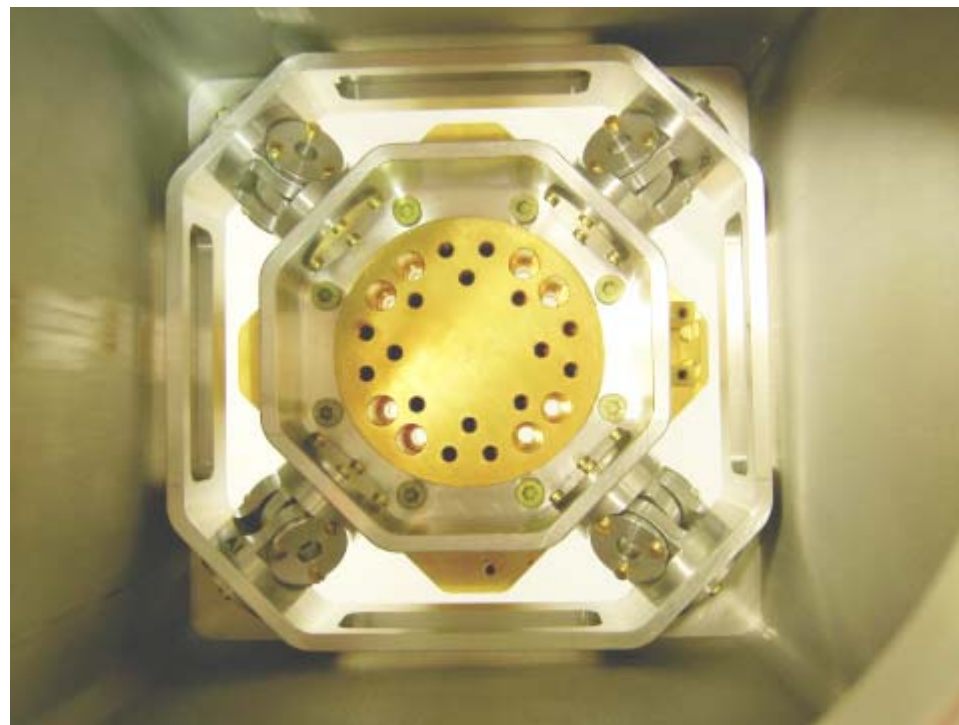


- Limited design by concentrating on materials which have already been measured
- Stopped tests as soon as we had a good enough solution for SCUBA-2
 - With further testing could have developed more generic solutions and more understanding of principles
- These are near universal problems

Test joint:



Finished isolation support



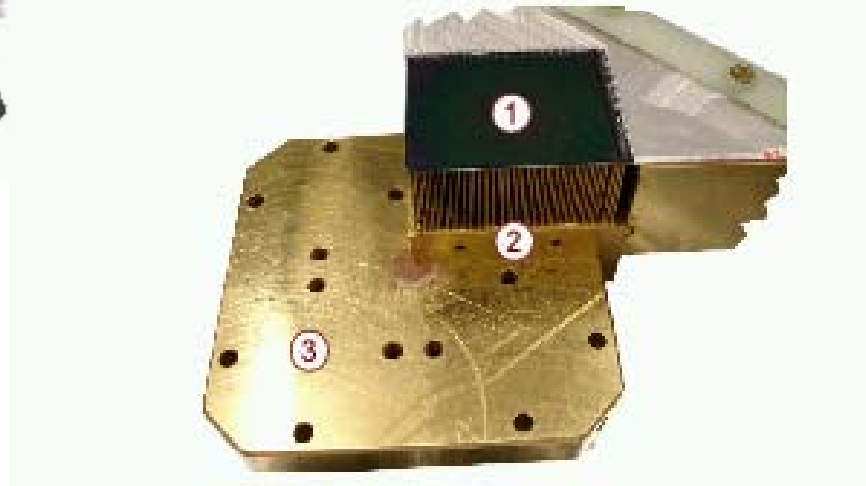
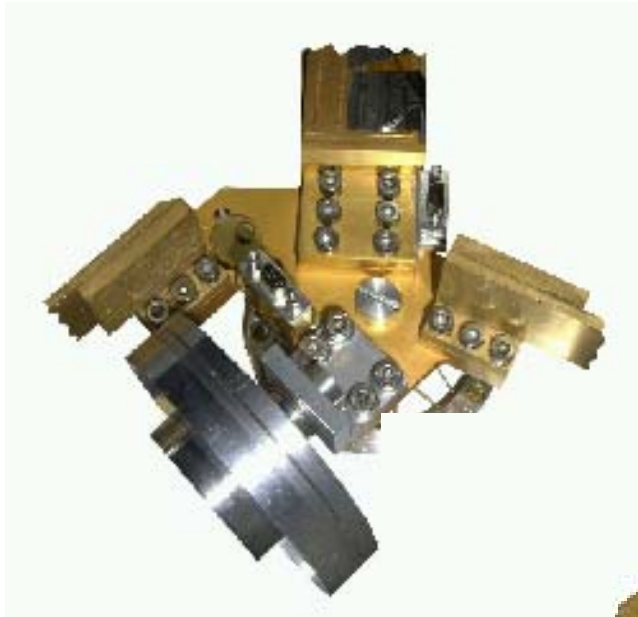
2.5 μW heat leak from 1 K to 100 mK
Now copied for use in Clover

Work stopped when
requirements met

Other components



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All “just” good enough

What have we learned?



- Good thermal design is hard!
 - Necessary data is often lacking
 - Data in literature may be wrong or inappropriate
 - Example: G10 is an electrical specification not a material!
 - There are no comprehensive reference works

Probably the biggest problem of all



- This is a problem in many areas of cryogenics
 - Space missions e.g. FIRI
 - Ground based instruments e.g. ELT
 - High energy physics e.g. LHC Quench
 - Gravitational wave detection
 - Industry e.g. superconducting MRI magnets

What have we learned?



- What can we do?
 - Material property work must be decoupled from instrument design programmes!
 - Start to build robust reference works
 - Some undergrad project effort at U of E
 - Measurement programme on new and poorly understood materials (most materials we use!)
 - Develop new techniques without pressure of instrument programme
 - Work underway at ATC (one PhD student)
 - Funding application in to STFC to expand
 - Need more than this though
 - Joint European effort required (LTnet)



- Work **now** on material properties and components will give us the information we need to do the thermal design for FIRI (and other missions) and get it right
- Thermal design for FIRI should be treated as fundamental to the overall design, with attention paid to lessons learned from previous instruments in space *and* on the ground.