Material property needs for cryogenic instruments

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SUPA
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What are cryogenic material property needs in different fields?

Cryogenic systems vary from one person to huge instruments

A biased view based on what I've worked on

- Mainly care about thermal properties

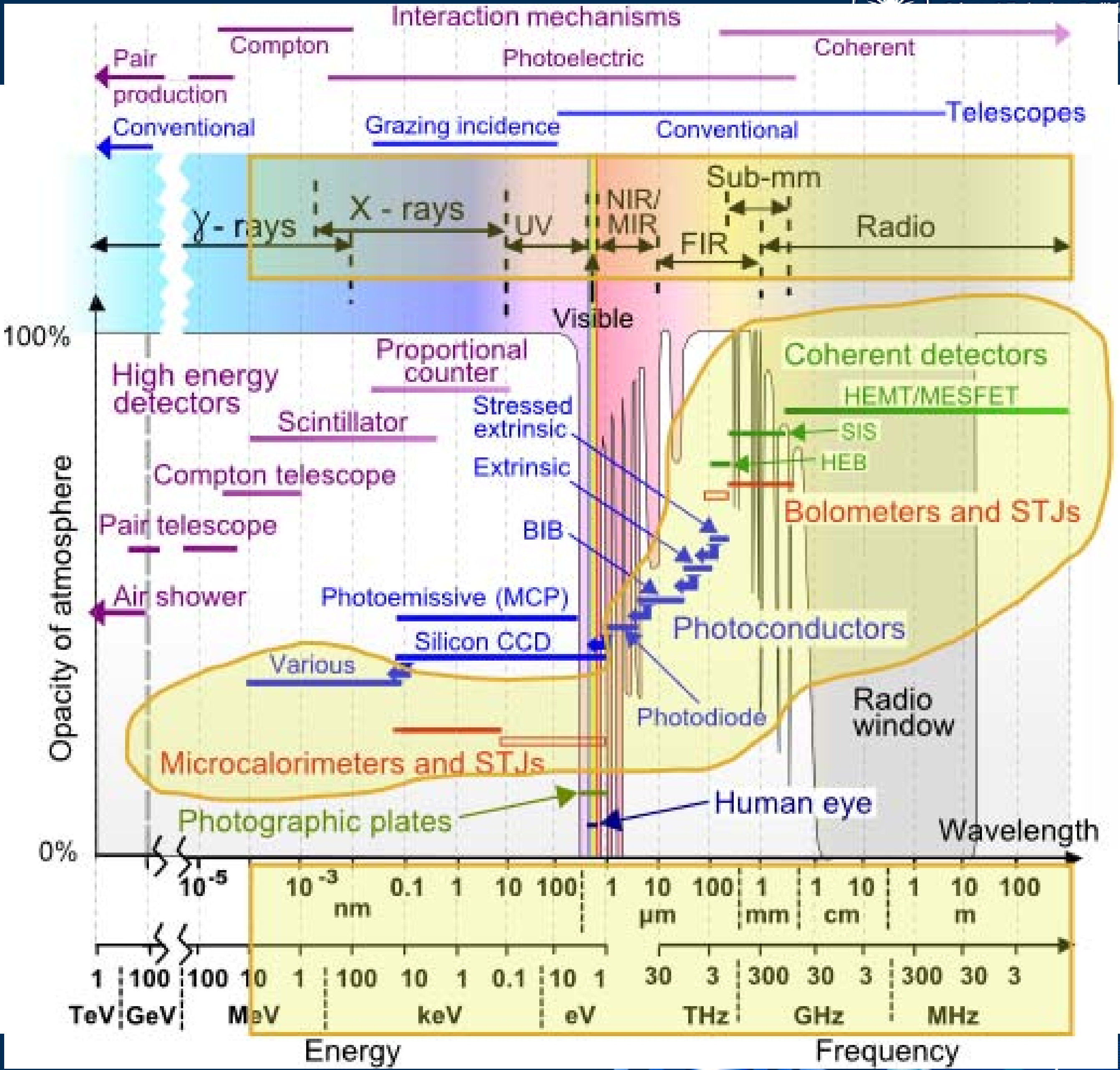
Different areas have different needs, but there's a lot in common

Helium physics

- Tried-and-tested techniques for cryostat construction are sufficient (though improvements might be good)
- Little need for new measurements, especially above 4 K

Astronomical instruments > 1 K

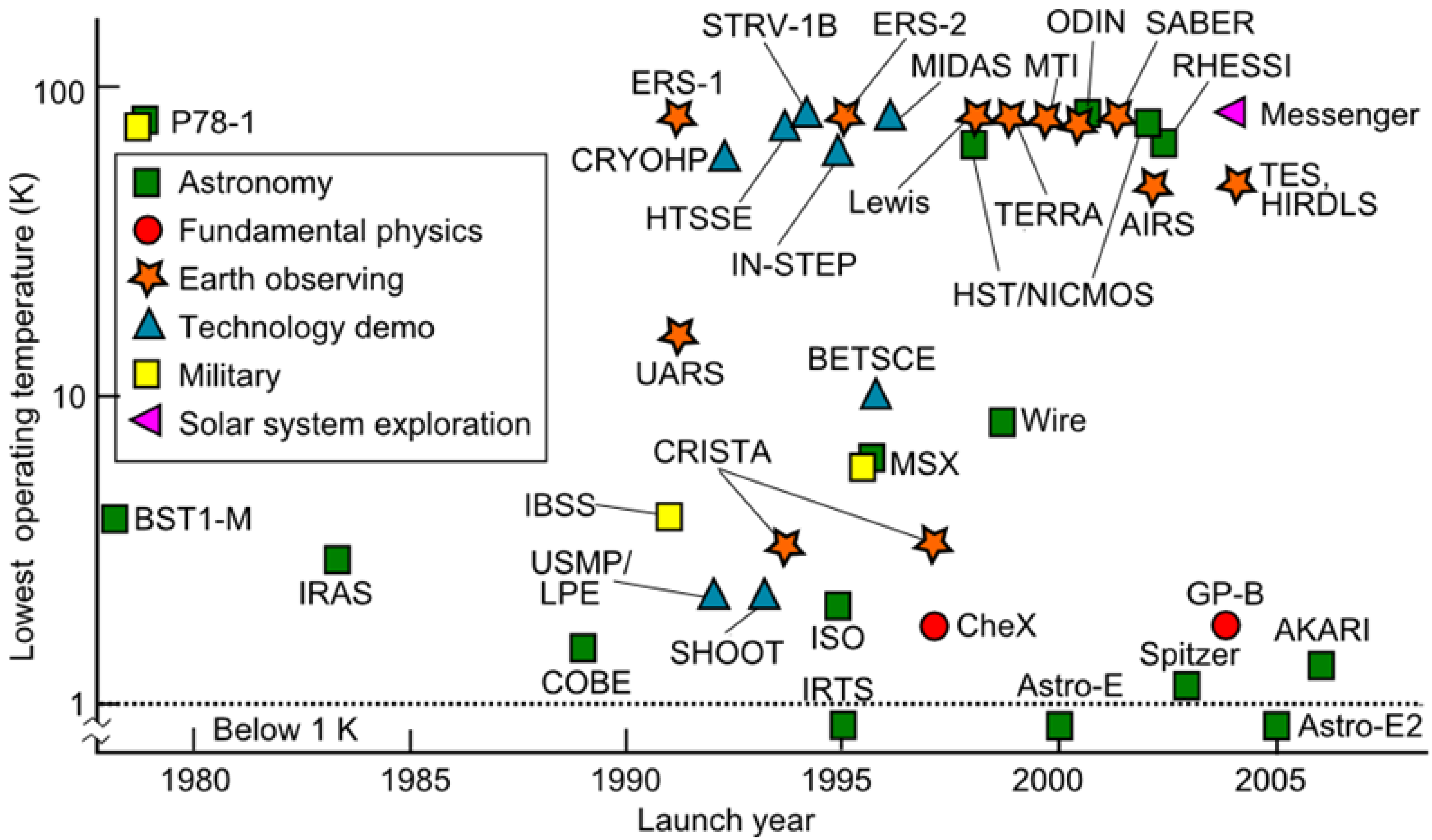
- Have tried-and-tested techniques
  - But instruments getting bigger and more complex; need new solutions
  - Wider range of known materials could give cheaper/faster/more efficient design, reduce over-engineering
  - Margins often small
    - Lot-to-lot variations and errors in measurements can be a problem



Interaction mechanisms
Pair production
Compton
Photoelectric
Coherent
Conventional
Grazing incidence
Conventional
Telescopes
γ - rays
X - rays
UV
NIR/ MIR
Sub-mm
FIR
Radio
Visible
100%
0%
Opacity of atmosphere
High energy detectors
Proportional counter
Scintillator
Compton telescope
Pair telescope
Air shower
Stressed extrinsic
Extrinsic
BIB
Photoemissive (MCP)
Silicon CCD
Various
Microcalorimeters and STJs
Photographic plates
Coherent detectors
HEMT/MESFET
SIS
HEB
Bolometers and STJs
Photoconductors
Photodiode
Radio window
Human eye
Wavelength
10⁻⁵ 10⁻³ nm 0.1 1 10 100 1 10 µm 100 1 mm 1 10 cm 1 10 m 100
1 TeV 100 GeV 100 MeV 10 1 100 keV 10 1 0.1 10 eV 1 30 THz 3 300 GHz 30 3 300 MHz 30 3
Energy
Frequency

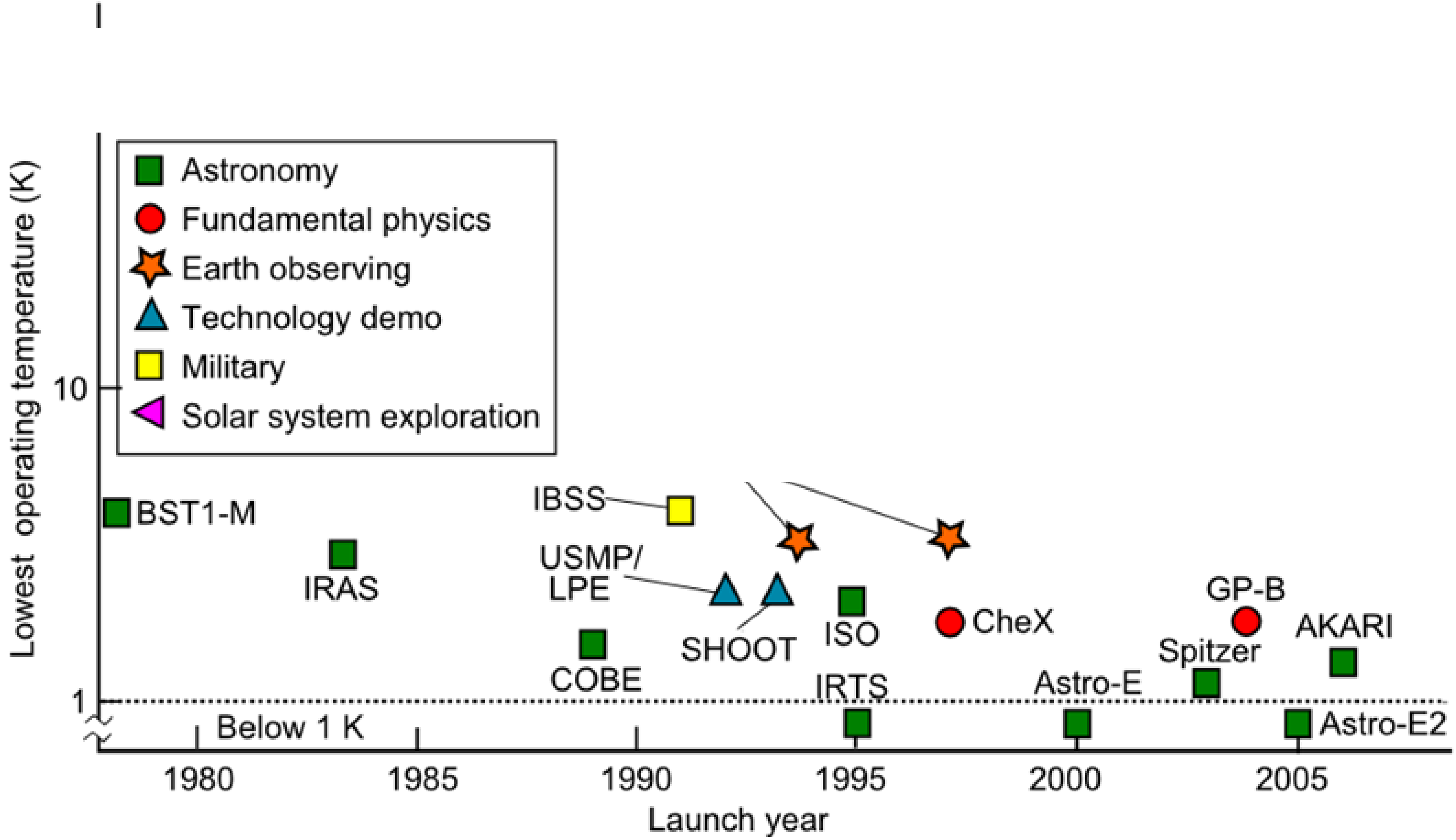
Background

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



Background

- But experience < ~4 K more limited

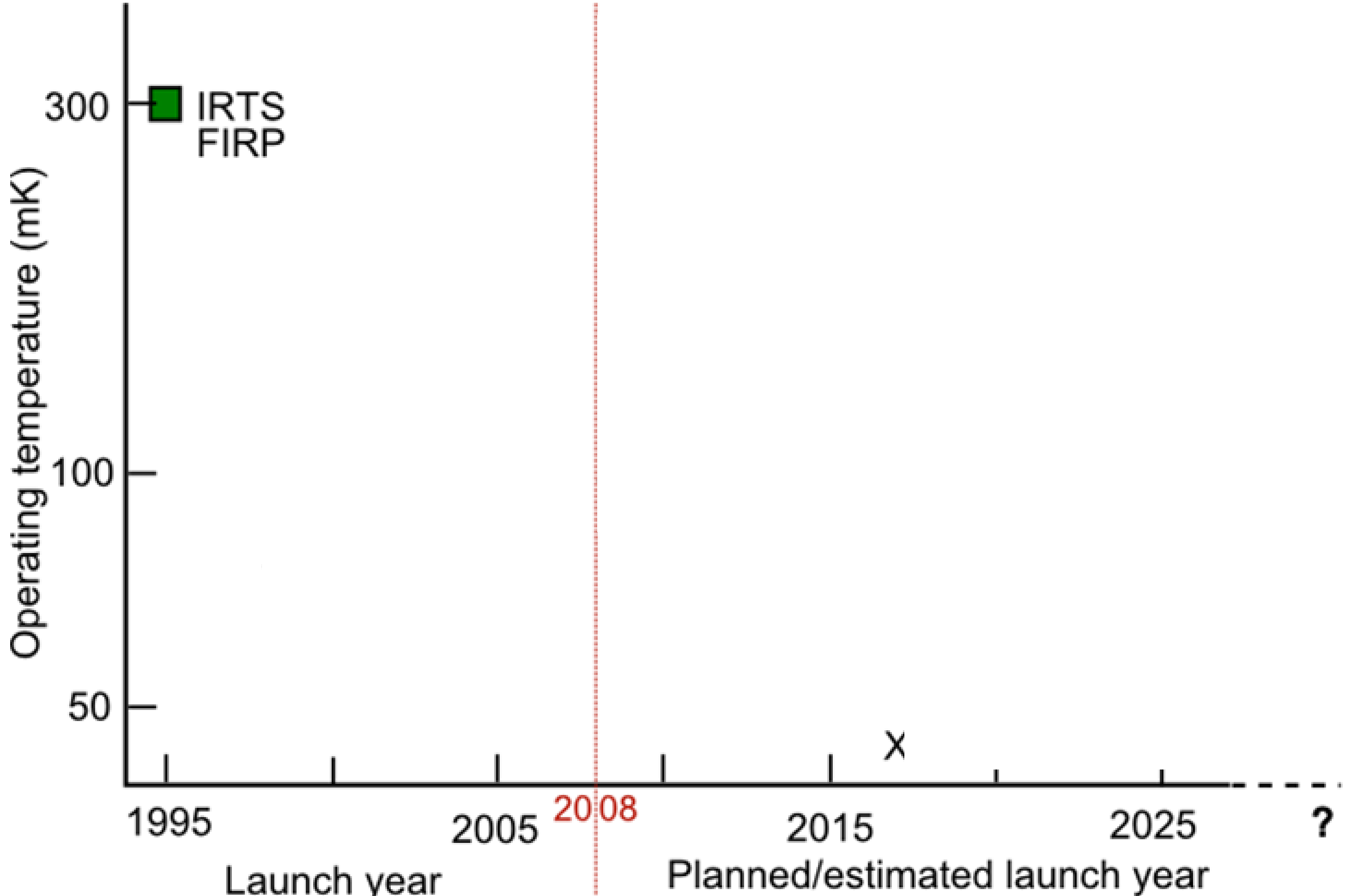


Astronomical instruments < 1 K

- Similar to > 1 K, but less experience, smaller margins, tougher requirements
- Even greater need to understand materials currently used better, and to find better materials than the ones we currently use

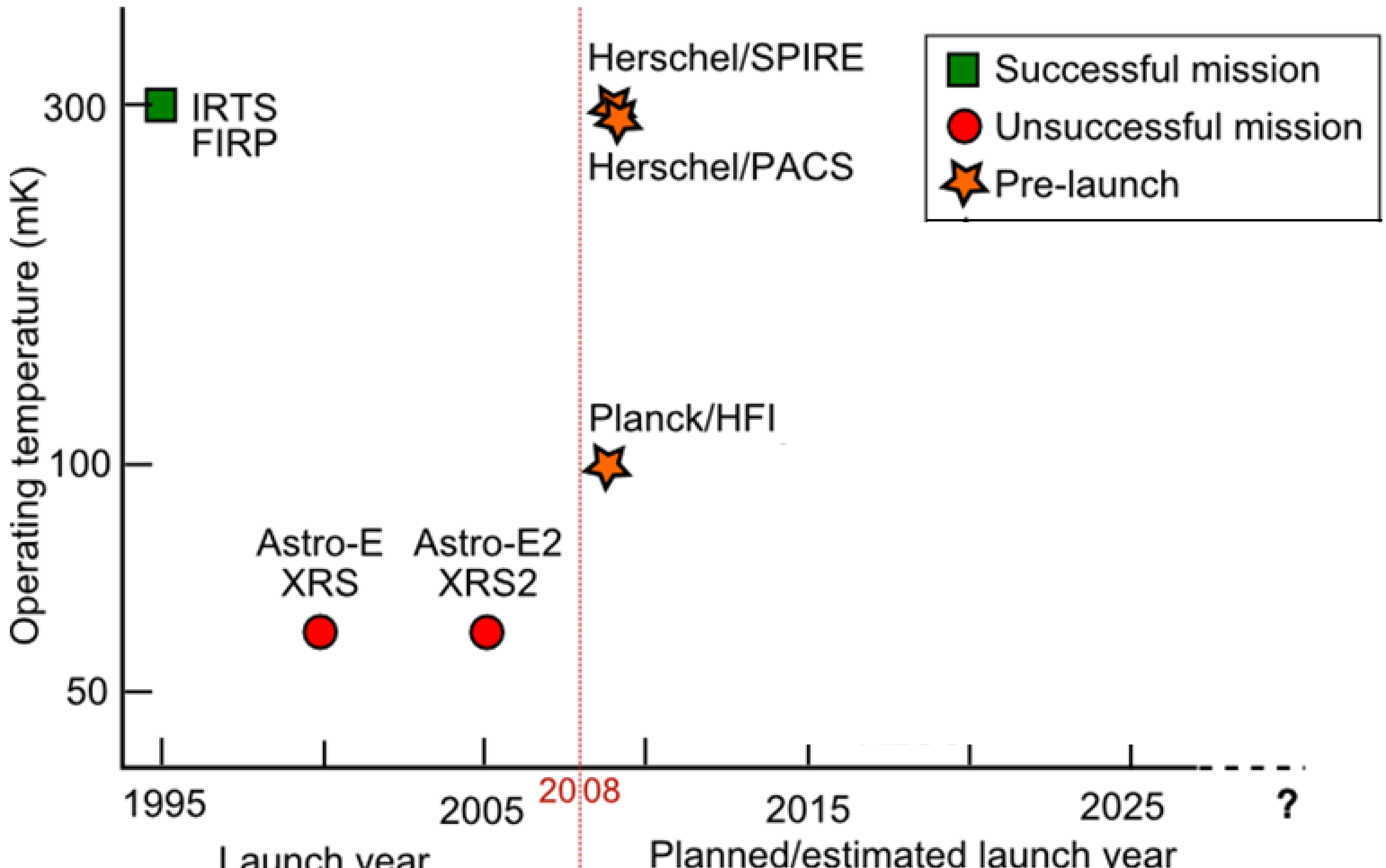
Background

- Current experience in space is somewhat limited



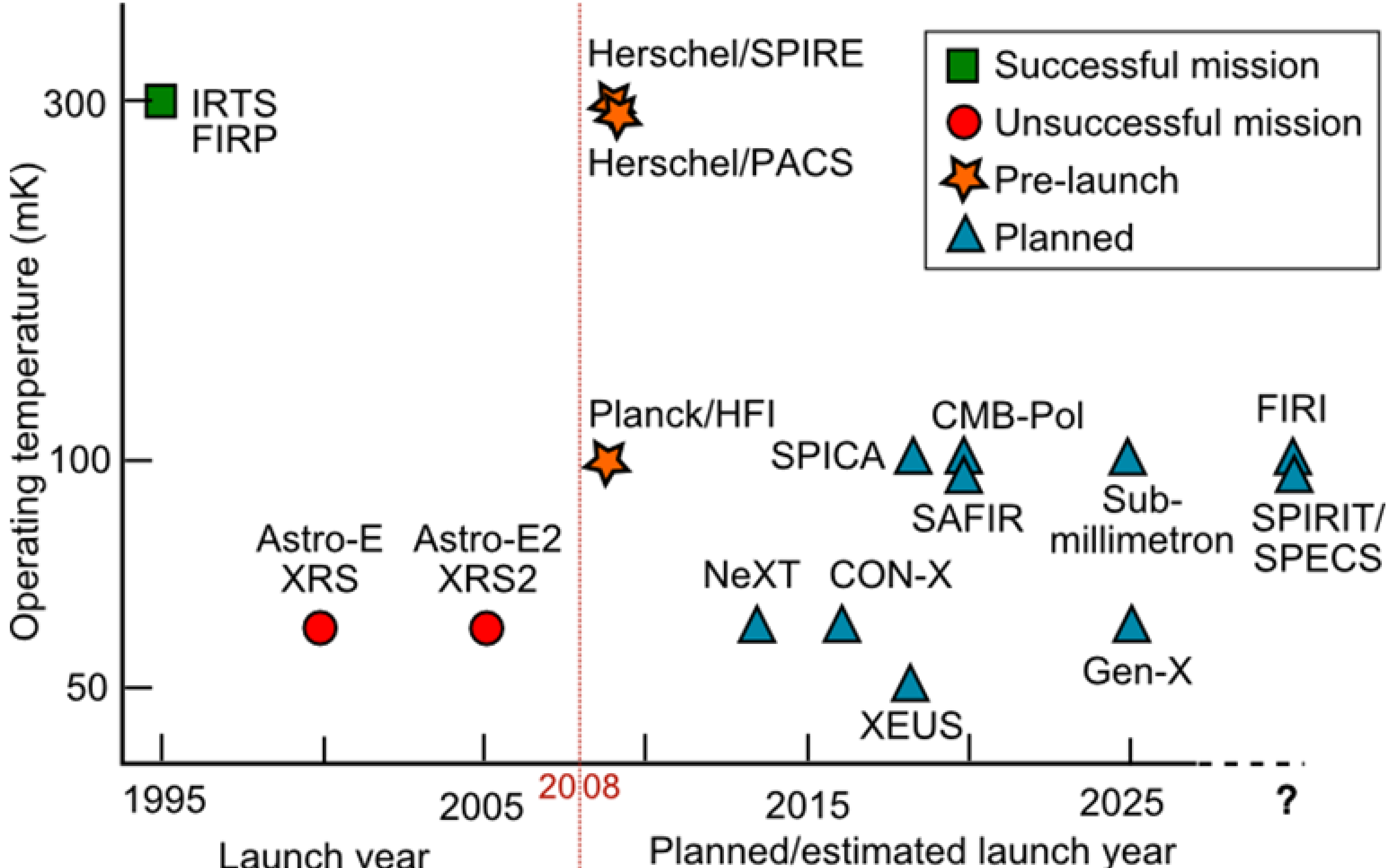
Background

- Current missions



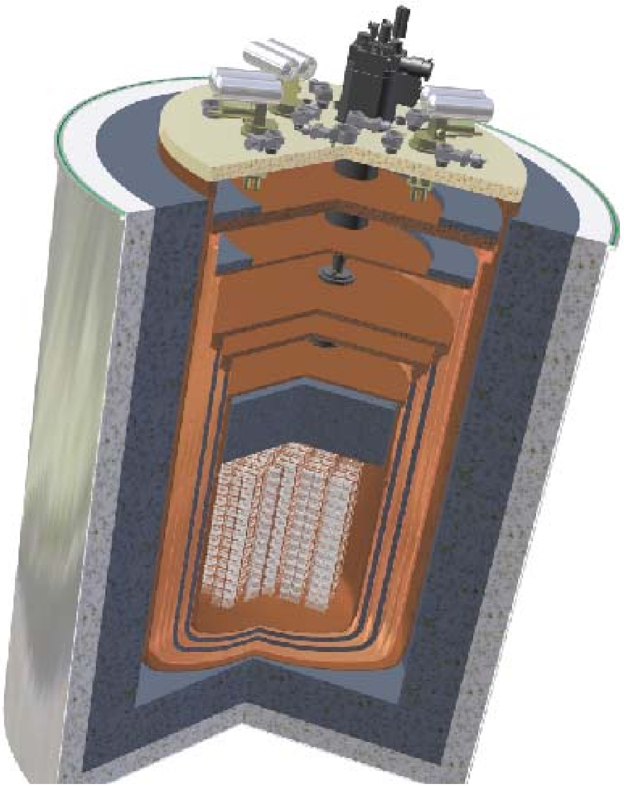
Background

- + planned missions



Fundamental physics

- E.g. dark matter detection, double beta decay
- Temperature vary from 'mildly' cryogenic to ULT (e.g. 10 mK)
- Even more demanding than astronomy (lower temperatures, large masses)
- Materials have to be radiopure



Gravitational wave detection

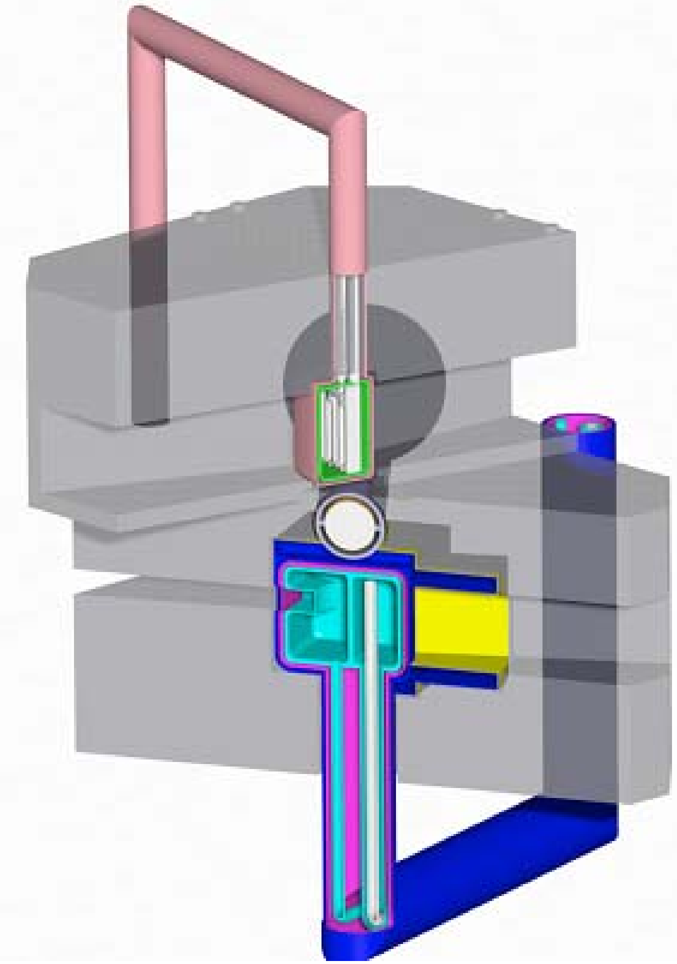
- Resonant mass detectors; cool huge masses to 4 K or even mK (largely becoming obsolete)
- Laser interferometers
  - Currently RT, considering lower temperatures
  - Work now on measuring Q factor of bulk materials and optical coatings
  - How do you extract heat from laser on mirror suspended on thin fibre?

High energy physics

- Need magnets to operate at higher fields and higher radiation environments
- Detectors run at slightly low temperatures (considering -40 C), but still problems with lack of knowledge of properties

Neutron sources

- Cryogenically cooled moderators (methane at 20 K)
- Problems extracting heat from methane



Industry

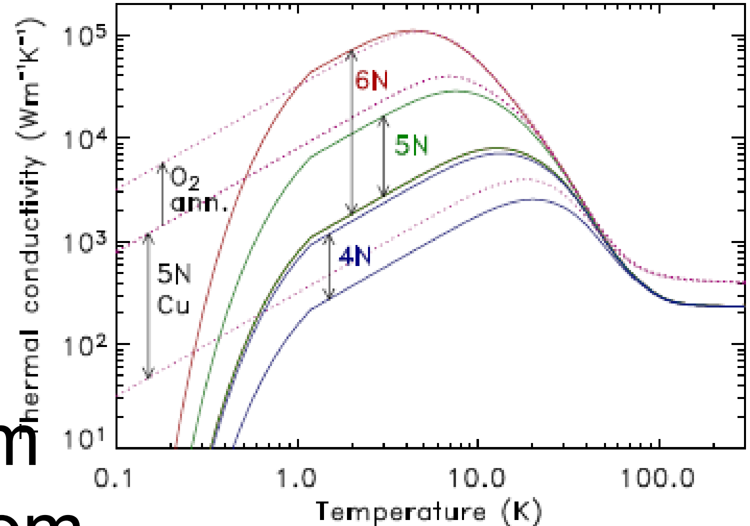
- Large cryogenic magnets are mainstream
- They suffer from lack of knowledge of material properties too
  - Have less ready access to journals than us
- Considerable interest in high T_c magnets

What do we know well?

- Heat capacity and thermal contraction well known for most metals and crystalline dielectrics
- Simple behaviour; not significantly affected by impurities (e.g. by alloying)
- Contraction can be predicted well from room temperature values

What do we know well?

- Thermal (and electrical) conductivity of pure metals highly variable depending on purity
- But for copper and aluminium can predict kappa up to RT from simple electrical measurement at 4 K
- For other materials can predict low temperature conductivity from electrical measurement



Predictions

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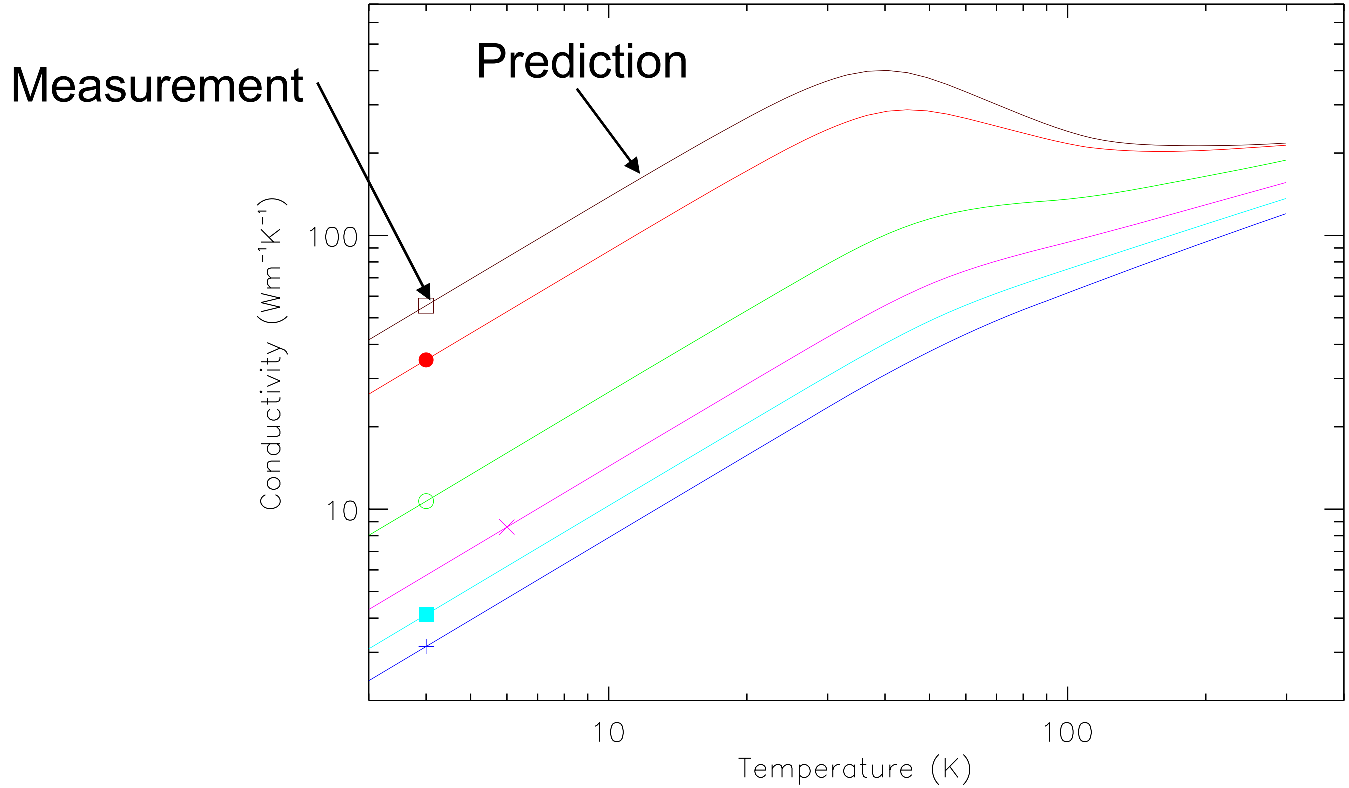
- Method to predict aluminum alloy conductivity from a measurement at a single temperature
- Work carried out for instruments under development



OPTICON

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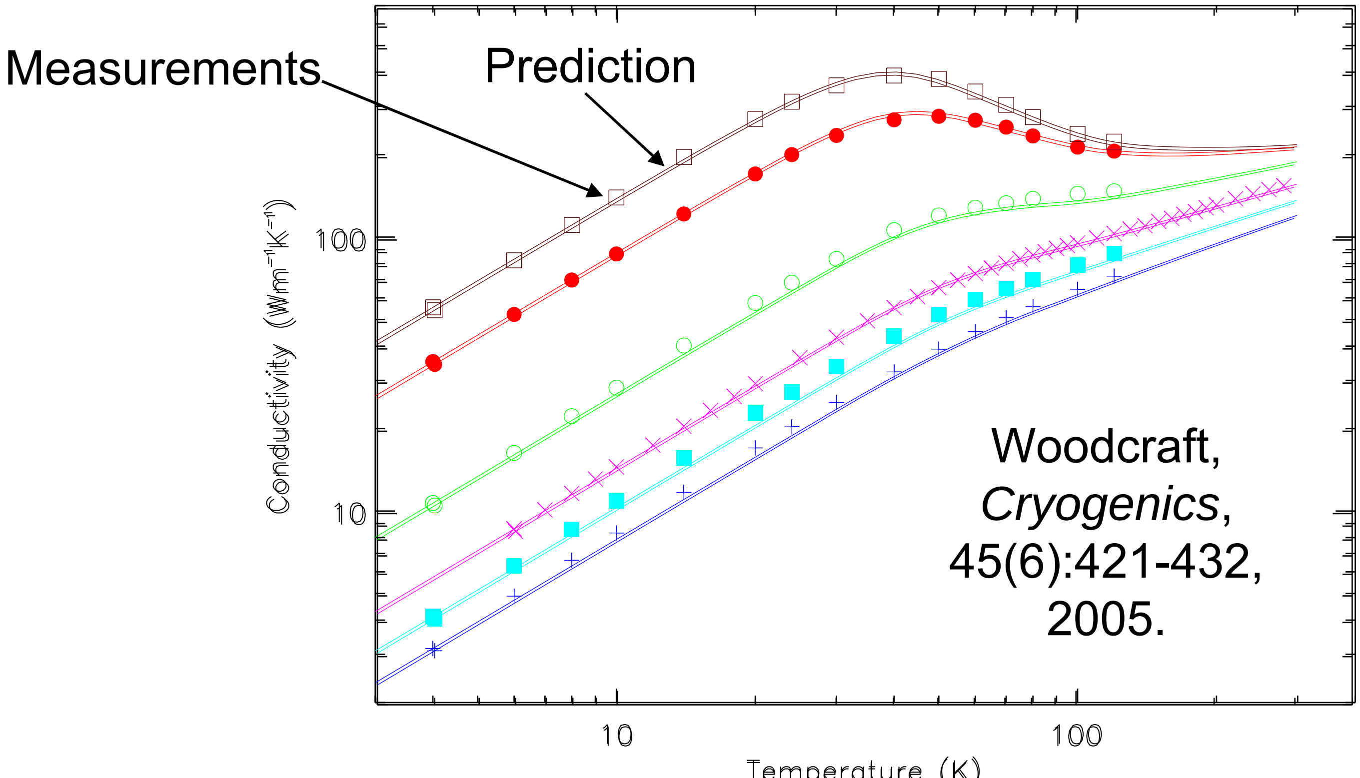


- Can we do this for other alloys?

What do we know well?

- Thermal and electrical properties known with varying degrees of reliability for many other materials
- But information not all in one place
  - Often hard to track down
  - Lot to lot variation generally unknown
  - Sometimes just wrong

What don't we know?

- Thermal conductivity of many materials
  - Particularly polymers
    - Complex behaviour
    - Huge sample variation
    - New materials never measured
      - Might be some really useful materials there
  - Also ceramics & composites; SiC, C/SiC

What don't we know?

- Thermal conductance across interfaces, especially bolted contacts
- A big problem across scientific instruments and industry
- Very poorly understood
- Often neglected
- Properties of bulk materials well understood by comparison!

What don't we know?

- Lot-lot variation
  - Very little information
  - "Well known material" often means somebody measured it once in 1967
  - Hard enough to get people to do first measurement on a material
    - Second measurement not likely
    - Measuring many samples…forget it!

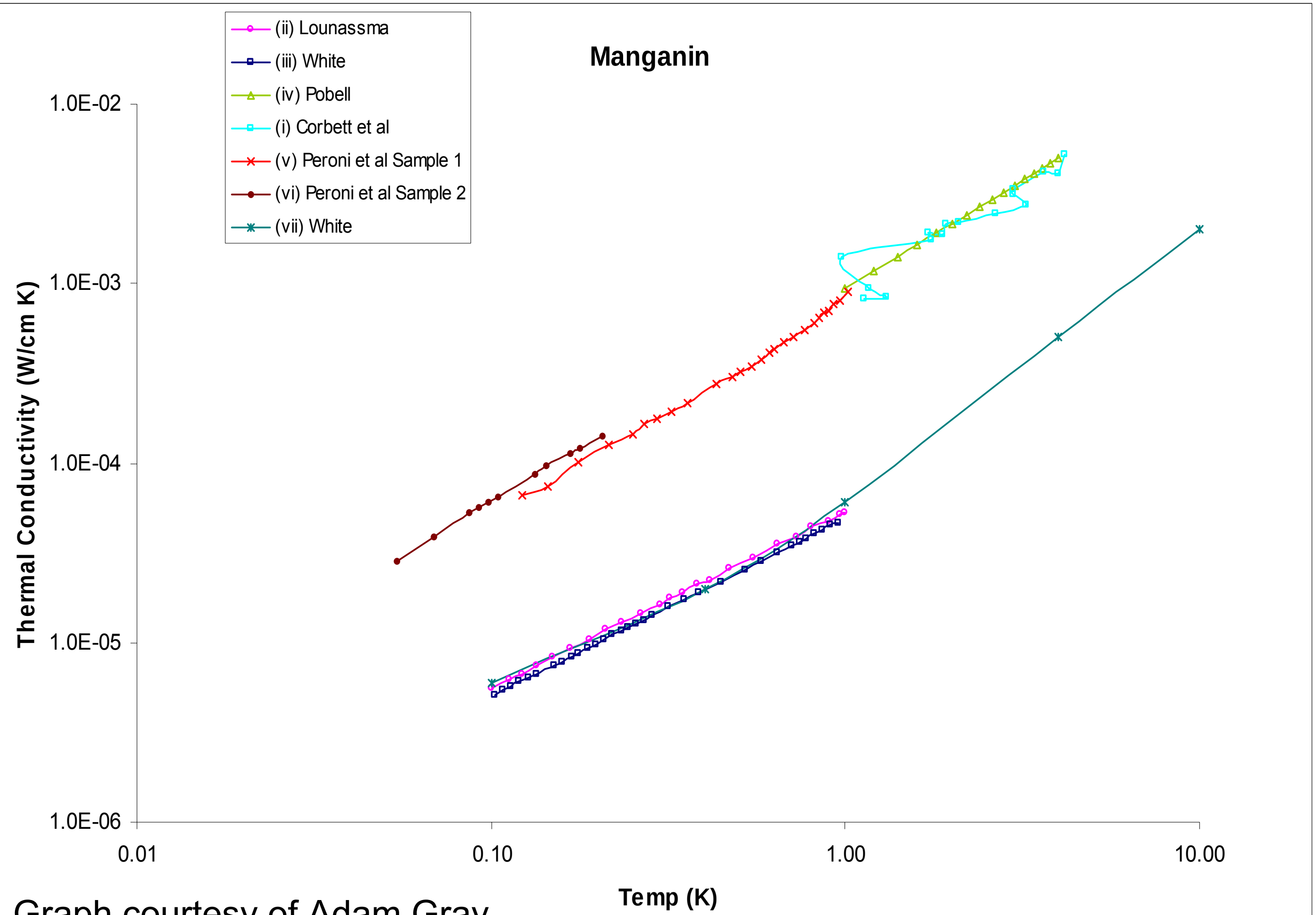
What are we doing at the ATC?

- Testbed for thermal and electrical conductivity measurements
  - Other properties possible later
- Supporting existing work at ATC, Edinburgh and Glasgow university
- Doing more speculative measurements

What are we doing at the ATC?

- Consolidating information in the literature
- Collecting papers
  - Searching is hard (what does “low temperature mean”?)
  - Zerodur papers in earlier talk were new to me!
- Effort: some from PhD student, + undergrad projects

Example of consolidation: errors in textbooks!



Graph courtesy of Adam Gray

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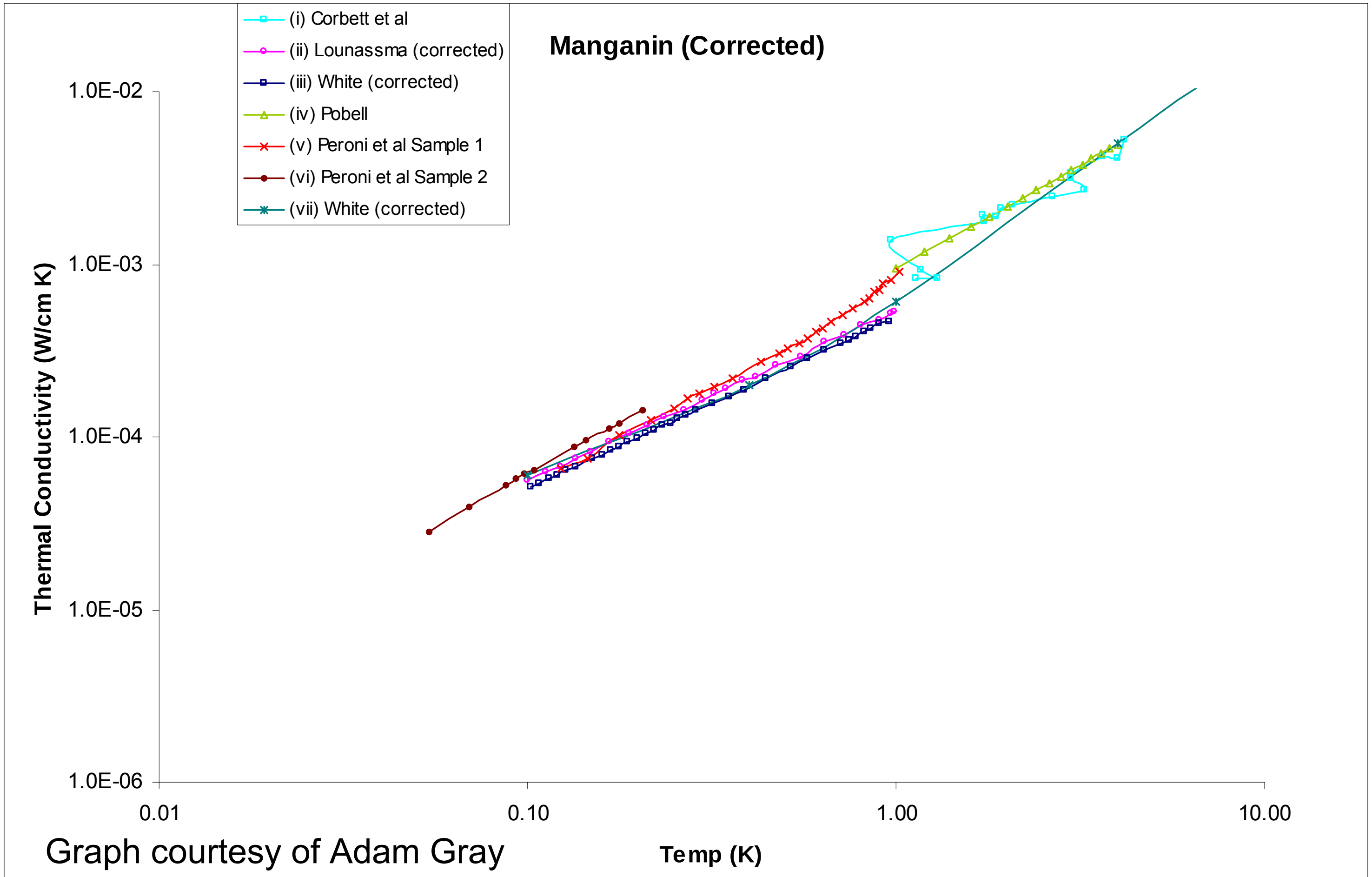
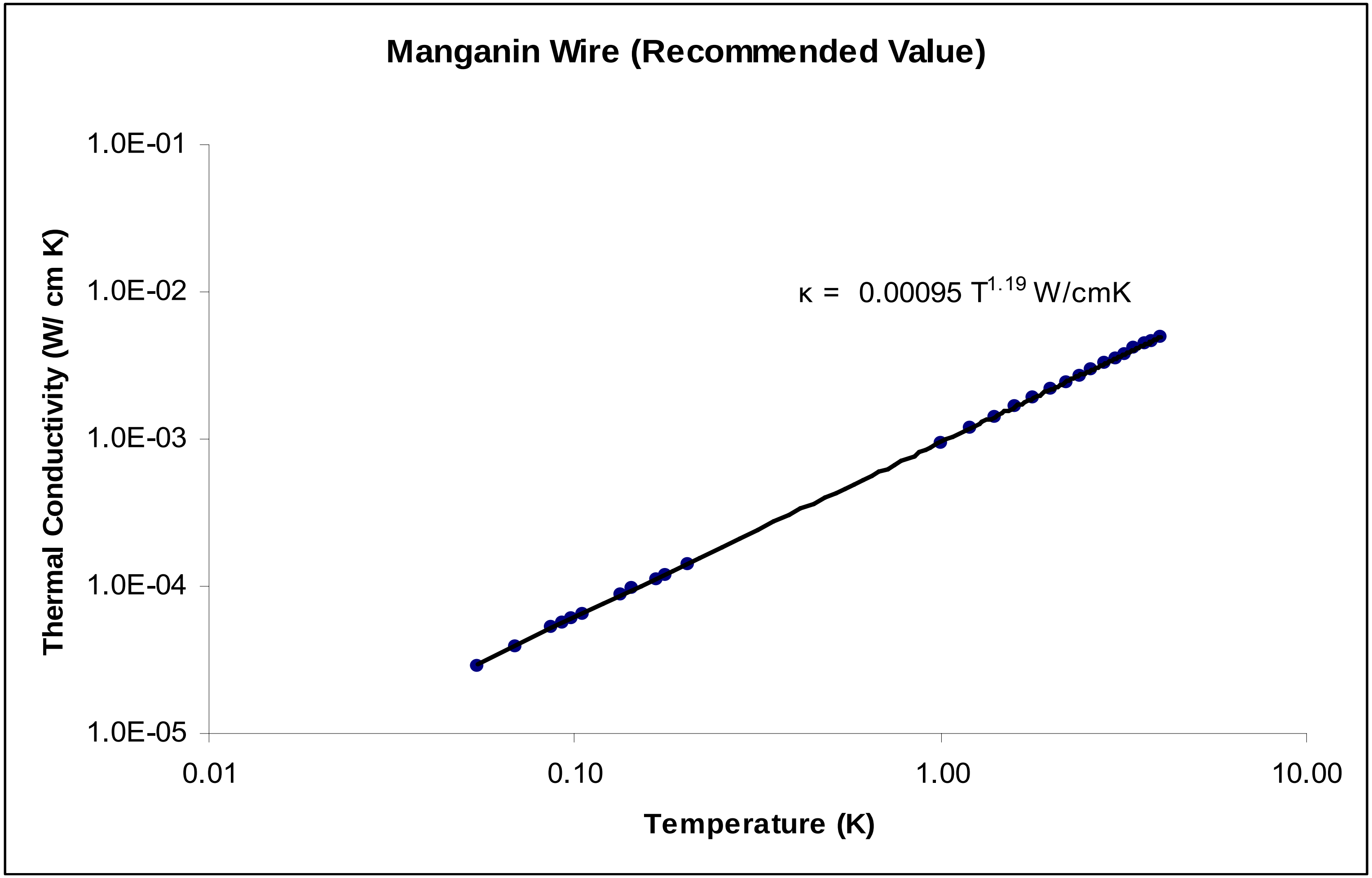


Graph courtesy of Adam Gray



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