ATSR'S IN-FLIGHT BLACKBODY CALIBRATION SYSTEM

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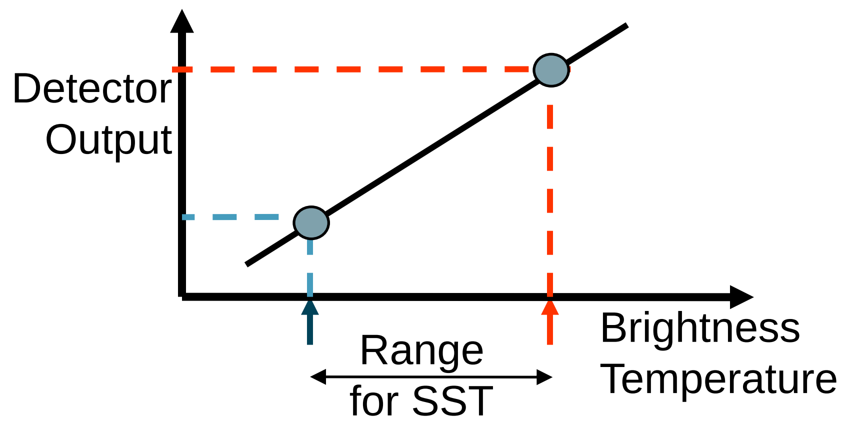
WHAT WAS REQUIRED?

- A continuous in-flight calibration
  - because of offset & gain drifts in the infrared telescope / detectors
- A two-point calibration
  - By using two simulated ‘blackbody’ sources at either end of the range of observed SSTs
  - At a uniform temperature, a perfect blackbody (emissivity = 1) gives a maximum, known radiation output
- Full-beam calibration within the scan
  - By locating the blackbodies between the two viewports
- Calibration to 0.1 K (0.1 C)
  - maximum allowable error
  - about 5 times better than previous missions



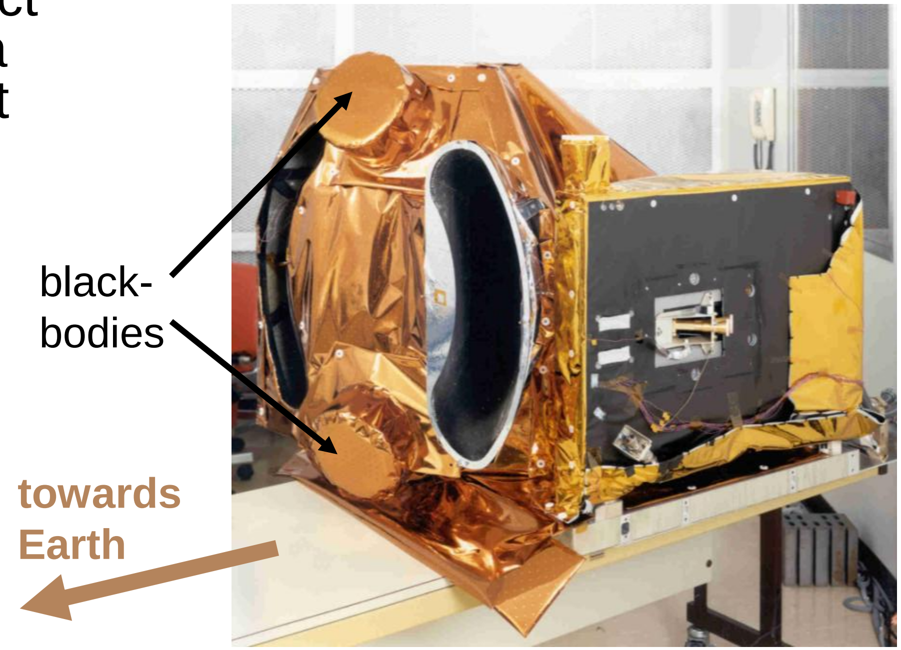


Photo from RAL

WHAT COULD CONTRIBUTE TO THE CALIBRATION ERROR?

- The error budget of 0.1 K was divided equally between three design areas:
  - < 33 mK error due to the emissivity being less than 1
    - Emissivity design – Ian Mason
      - Valuable initial input from SIRA & the Met Office
      - Emissivity measurement support from Gareth Davies
  - < 33 mK error due to residual temperature non-uniformities
    - Stuctural & thermal design – Peter Sheather
      - Main technical support – Peter Kendon
  - < 33 mK error due to the temperature measurement accuracy
    - Electronic design – Jim Bowles
      - Main technical support – Jason Tandy

HOW TO ACHIEVE THIS?

- Typical laboratory solution (e.g. NPL)
  - High emissivity:
    - Very long small-aperture black cavity
  - Temperature uniformity & control
    - Heavy copper construction & liquid circulation
  - Accurate temperature readout
    - Large unsupported platinum resistance thermometer
    - Regularly calibrated against a standard

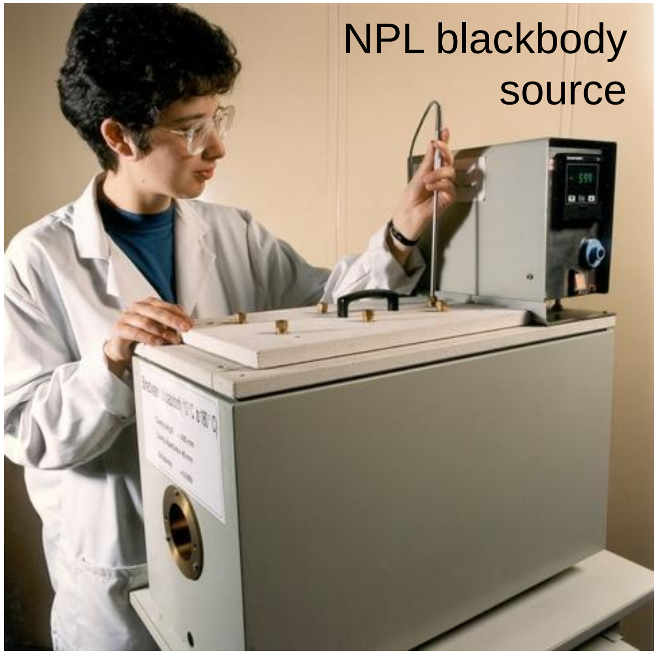


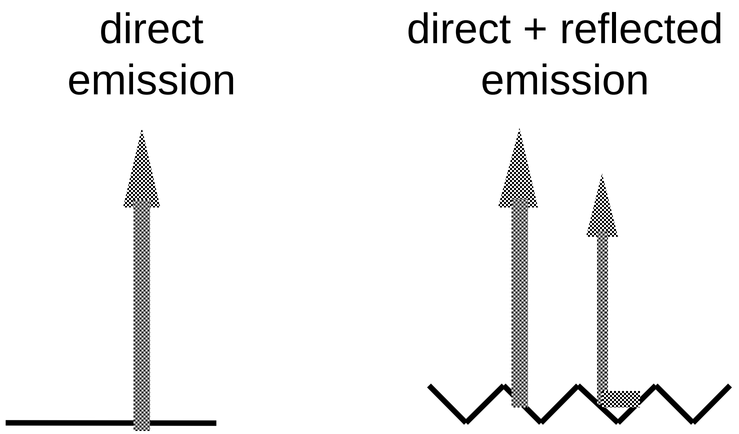
Photo from NPL

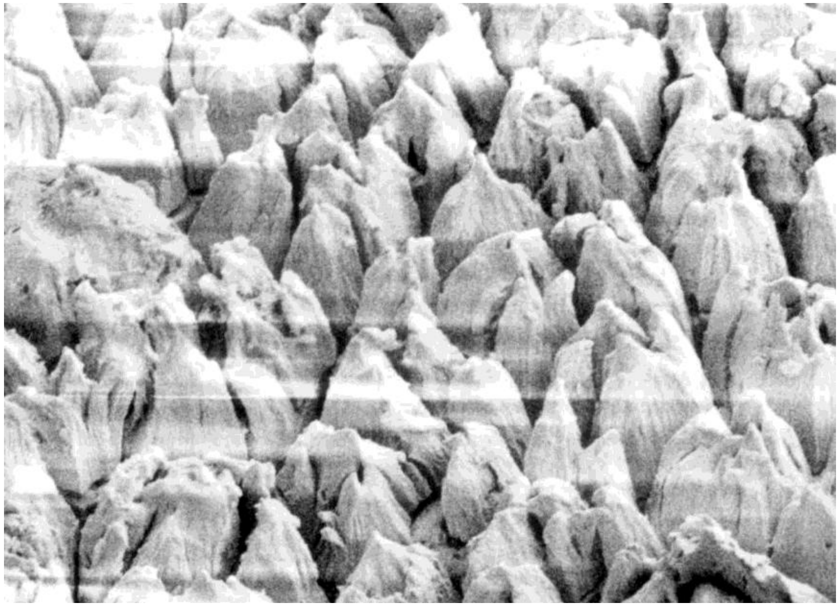
- Space solution (ATSR)
  - Constraints:
    - Relatively large aperture (140 mm)
    - Low mass, low power, small size, launch vibration survival, vacuum operation
    - Several years of operation after the final thermometer calibration
  - A radically different design was required
    - 2 blackbodies + electronics: 4.7 kg & 6 W

Photo from ABSL

EMISSIVITY DESIGN – 1

- The emissivity requirement was 0.999
  - To achieve a maximum error of 33 mK
- Flat surface with high emissivity black paint?
  - Maximum emissivity is ~ 0.96
- Grooved surface?
  - On a macroscopic scale, practical difficulties
  - On a microscopic scale, a surface treatment of aluminium by Martin Marietta achieves an emissivity of ~ 0.99



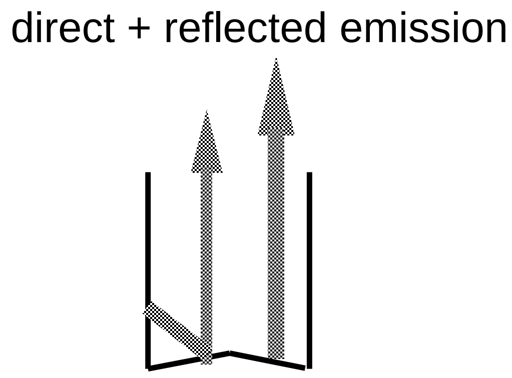


EMISSIVITY DESIGN – 2

- Final design: open ended cylinder
  - Interior treated with Martin Marietta black
  - Relatively small height to diameter ratio

- 140 mm diameter aperture
  - to cover the 110-mm beam with a reasonable integration time for good signal-to-noise

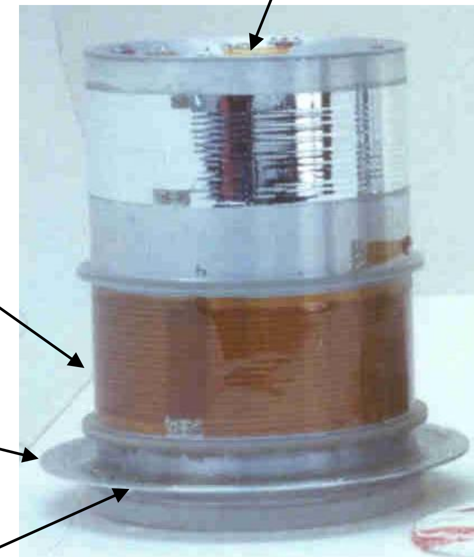
- Emissivity ≈ 0.999
  - Meets the design goal
  - Confirmed by measurement in an in-house facility, designed by Jeremy Allington-Smith

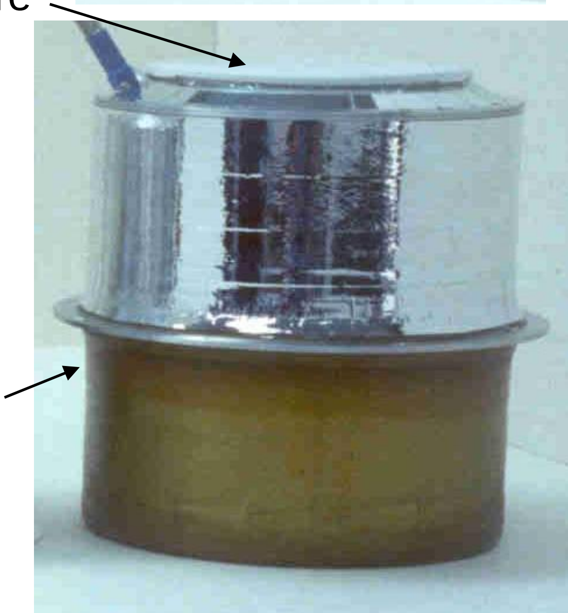


THERMAL / STRUCTURAL DESIGN – 1

- Requirements
  - Maximum spatial temperature gradient:
    - a few 10s of mK over the cylinder base
  - Maximum rate of temperature change
    - A few 10s of mK per minute
  - One blackbody needs heating (to ≈ 30°C), one acquires instrument temperature (≈ -10 C)

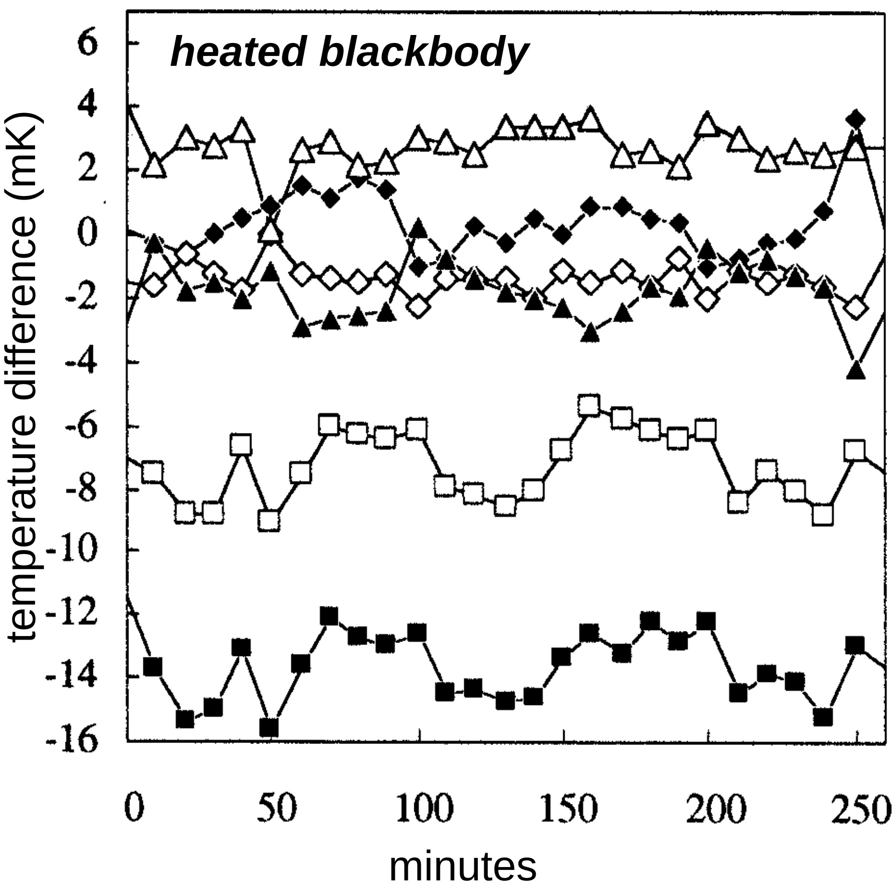
- Design philosophy was to minimise thermal disturbances, especially to the viewed cylinder base
  - Cylinder made of aluminium for low mass & high thermal diffusivity
  - Heater on cylinder wall with no temperature control
  - Attachment at the aperture end only
  - Thermal isolation by low conductivity fibreglass mount and thermal blankets

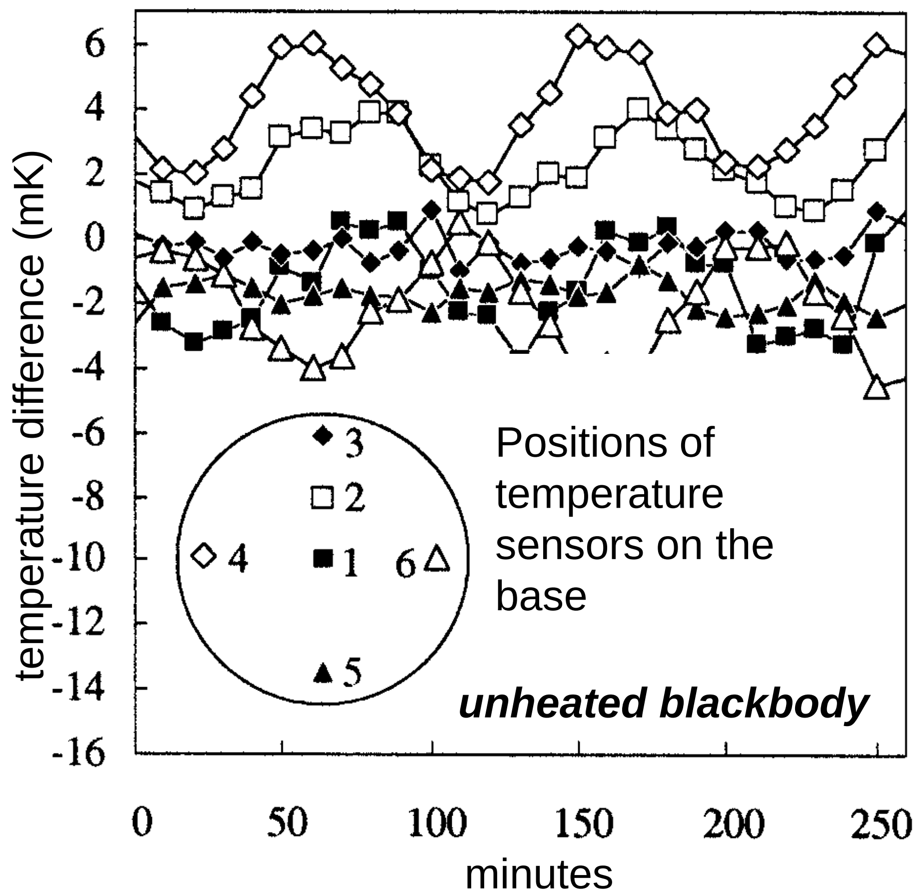




THERMAL / STRUCTURAL DESIGN – 2

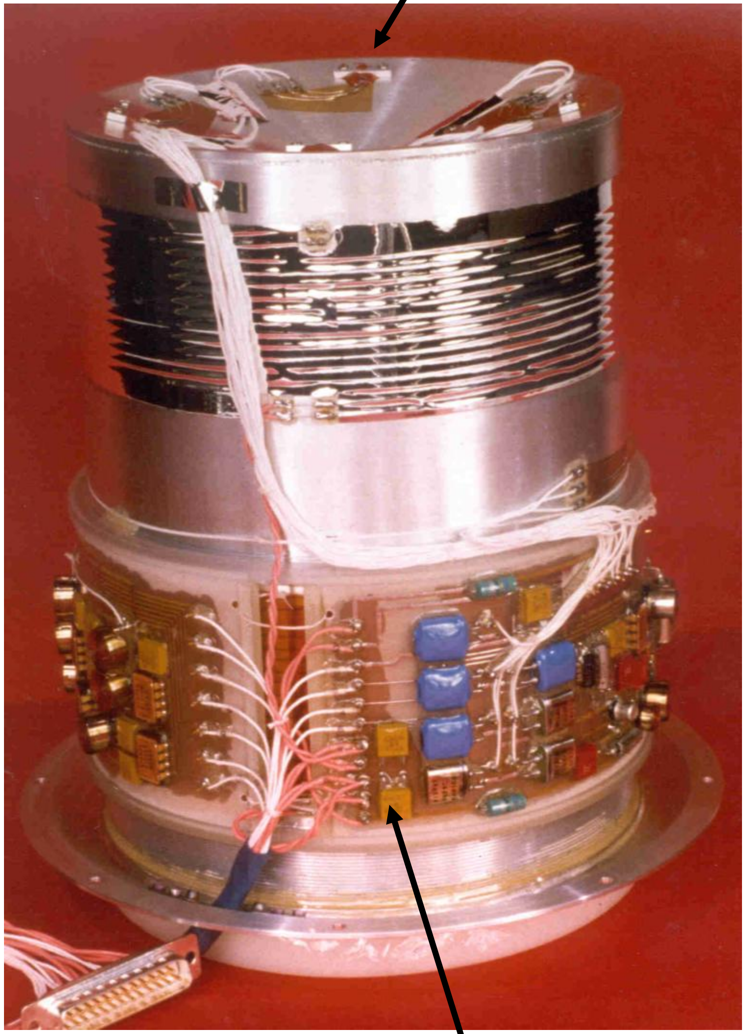
- In-flight performance was better than the design goal
  - Spatial variations of < 20 mK (heated blackbody)
  - Temporal variations of < 4 mK round the ~100-minute orbit





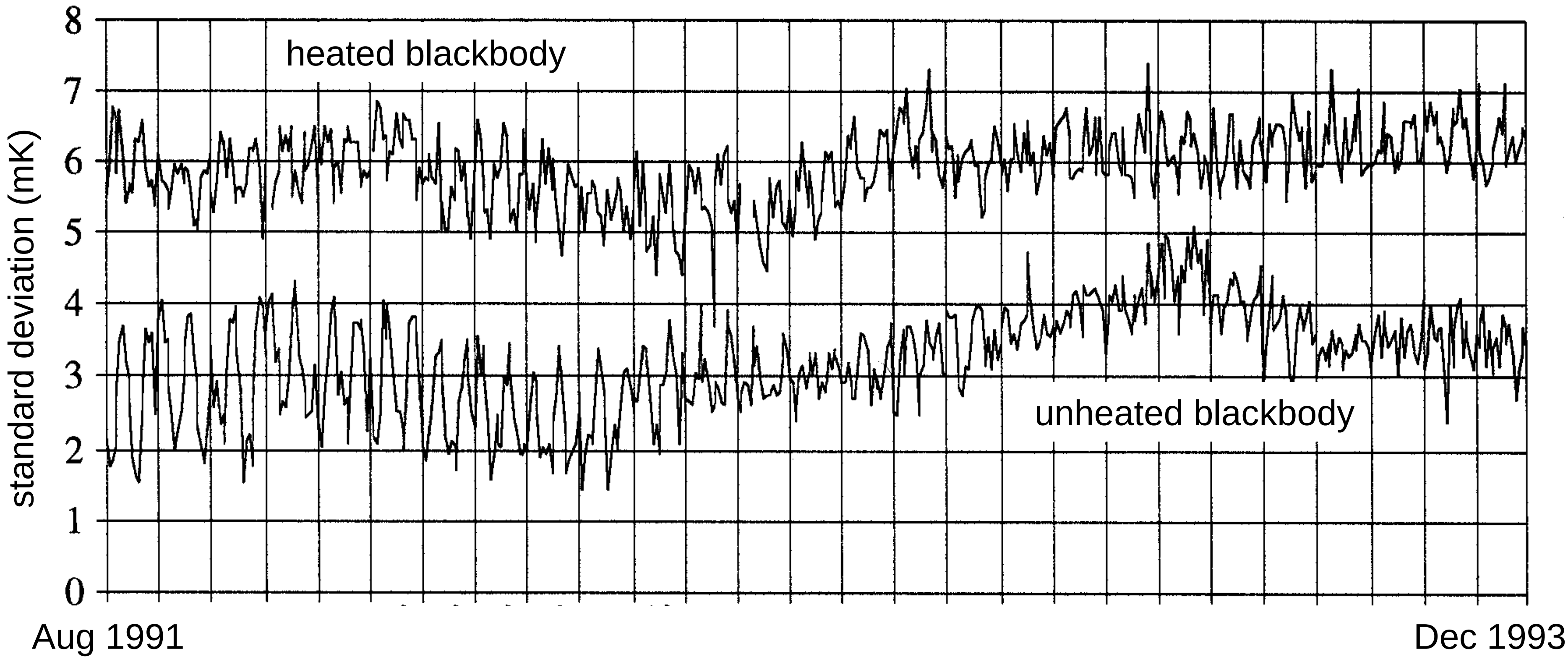
TEMPERATURE MEASUREMENT DESIGN – 1

- Requirements
  - Measurement error of <33 mK, several years after the final thermometer calibration
- Design
  - Miniature encapsulated platinum resistance thermometers, read out by resistance bridges
  - Cylindrical front end electronics card inside blackbody mount for thermal stability
  - Components chosen for ultra low drift & temperature coefficient
- Calibration
  - End-to-end calibration against transfer standard thermometers
  - These were periodically calibrated against NPL standards
  - Overall calibration accuracy was 15 mK (3σ)



TEMPERATURE MEASUREMENT DESIGN – 2

- In-flight performance was better than the design goal
  - Plot shows that the relative variations between the thermometer readings were very small & constant over a 2.5 year period
  - This suggests that absolute offsets were also very small
    - Confirmed with a long term laboratory experiment in similar conditions



TECHNOLOGY TRANSFER

- After ATSR-2 the ATSR blackbody technology was successfully transferred to industry (AEA Technology, now ABSL)
  - Construction of AATSR blackbodies
  - Design & build of other space blackbodies for:
    - MIPAS on Envisat (2002)
    - GERB on MSG-1 (2002)
    - SEVIRI on MSG-1 (2002)
    - IASI on MetOp-A (2006)
    - SLSTR on Sentinel-3 (2012)

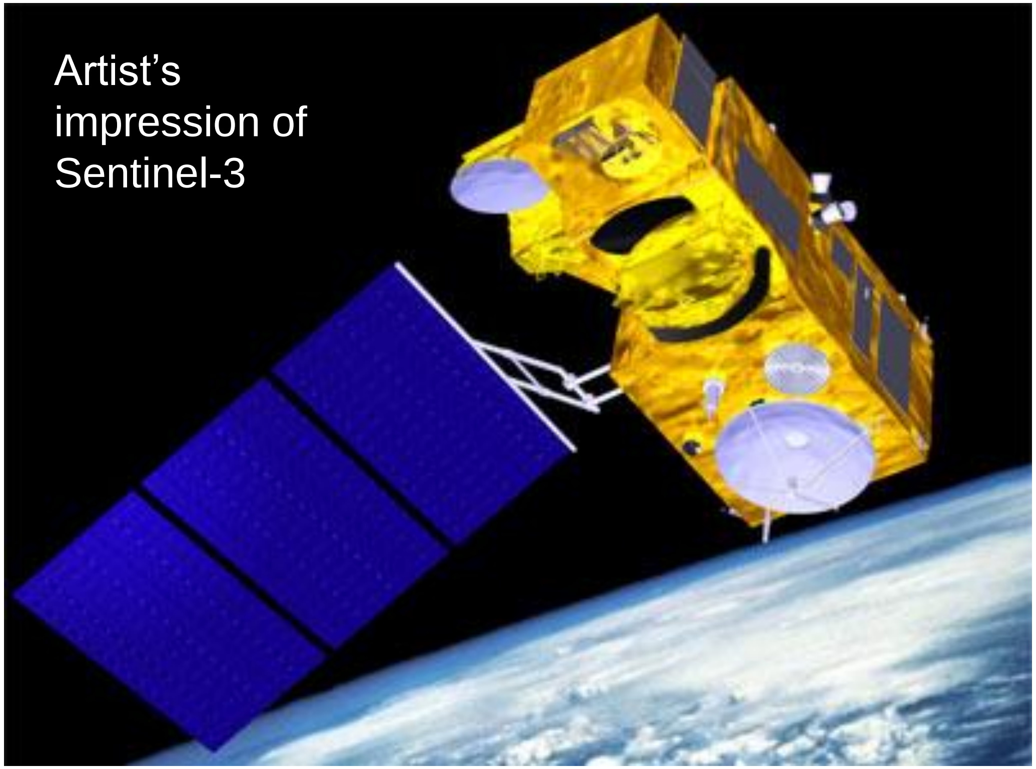


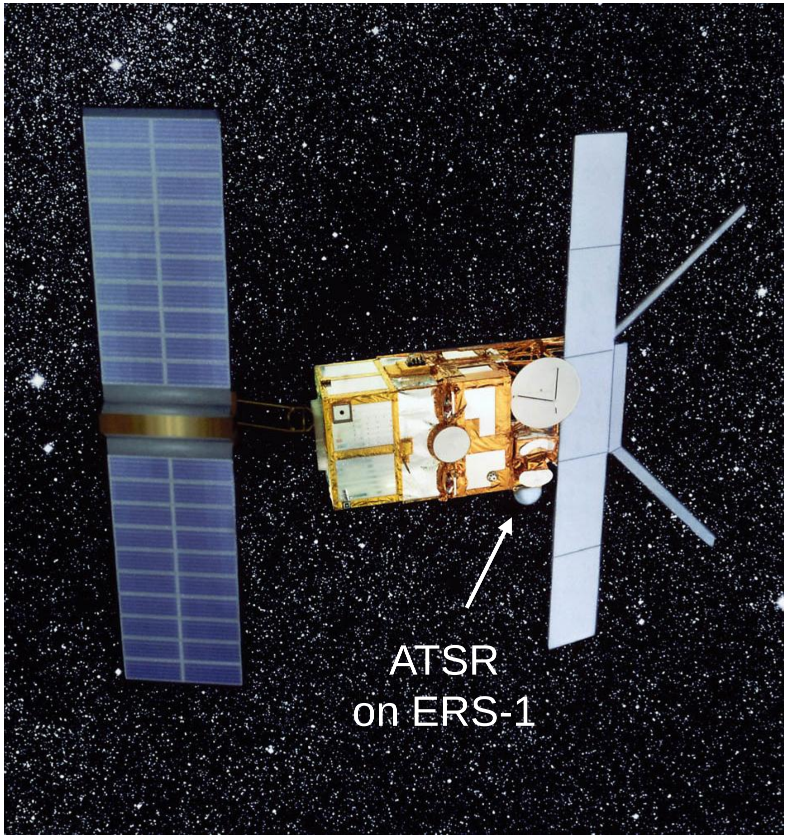
image from ESA

CONCLUSION

- The ATSR blackbodies provided the most accurate in-flight calibration of any spaceborne infrared radiometer to date
  - Maximum calibration error of < 0.1 C

- This was achieved by the creative application of space engineering techniques to the whole design:
  - Emissivity
  - Temperature uniformity
  - Temperature measurement

- Following transfer of the technology to industry, similar blackbodies are being used on other major Earth observation missions



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