New black body technologies for EO instruments

Tim Nightingale

Traceability

''*Those responsible for studies of Earth resources, the environment, human well-being and related issues [must] ensure that measurements made within their programs are in terms of well-characterized SI units so that they are reliable in the long term, are comparable world-wide and are linked to other areas of science and technology through the world's measurement system established and maintained under the Convention du Metre*''.

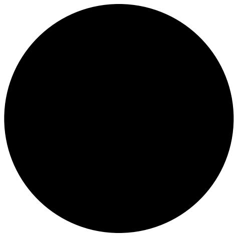
GCOS, 20th Conference Generale des Poids et Mesures. Paris, 1995

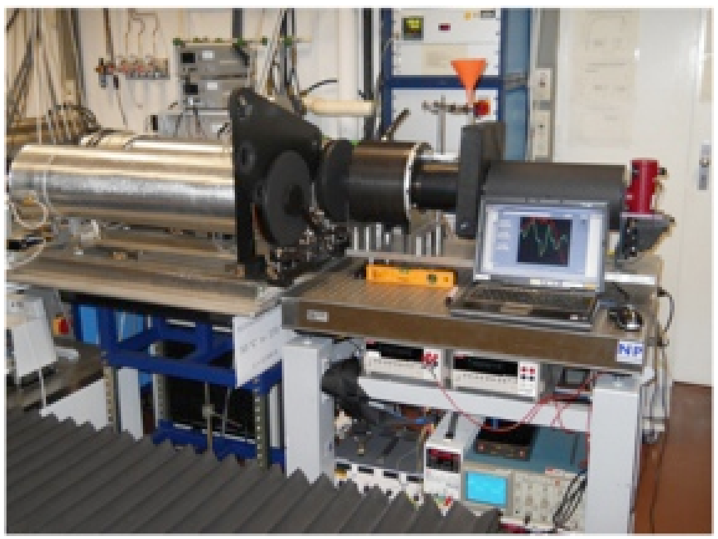
Why are black bodies important?

RAL Space

- Black bodies are radiance sources
- Black bodies are the fundamental calibration reference for all infrared (and many microwave) satellite radiometers
  - Directly relevant to EO measurements of sea, land and ice surface temperature, atmospheric temperature, atmospheric constituents, cloud and aerosol properties, earth radiation budget, …
  - Especially important for climate-related studies
  - Quality of reference signal is directly reflected in quality of scientific products

What are black bodies?





- Black bodies are a practical implementation of Planck's law
  - Radiance uncertainty dependent on knowledge of black body temperature(s) and emissivity
- Can be very simple
  - Just a metal disc painted black
  - Small and light
  - Poor radiometric performance
- Can be complex
  - Cavity with carefully designed geometry
  - Specialist surface coatings
  - Well controlled temperature
  - Sometimes massive and bulky
  - High radiometric performance
- Satellite instrument builders want aspects of both!

Where are we now?

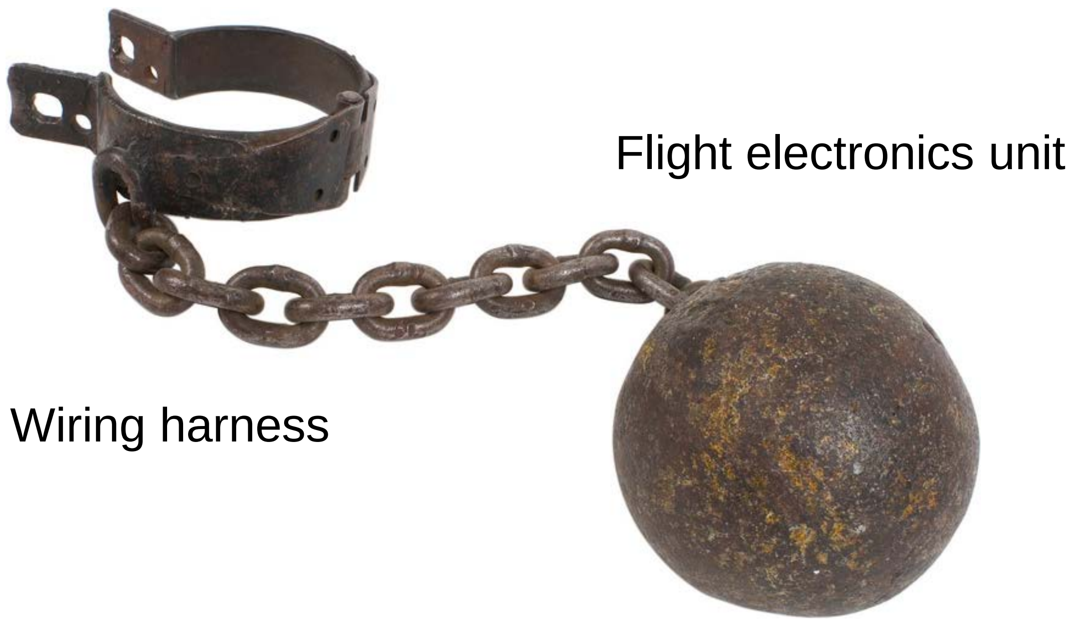
- Emissivity
- Thermometry
- Flight electronics

Thermometry

Thermometer calibrations

- The launch environment is very unfriendly for mechanically fragile devices such as platinum resistance thermometers (PRTs). Possibility for one-time calibration shifts
- Thermometer calibrations can drift with time. The further you are from the last calibration, the less you can trust the reported temperatures
- Planned mission lengths are now seven years or longer
- *Like all measuring devices, thermometers need periodic recalibrations to maintain **traceabilty**.*

Flight electronics



- Current black bodies need a separate flight electronics unit
  - Significant impact on instrument mass and volume budgets
  - Bulky wiring harness carrying heater supplies, analogue signals from each thermometer (and there can be a large number), possibly analogue power too
  - EM pickup can be a problem

Flight electronics

- Most current electronics use "old school" analogue-to-digital converters
  - Power hungry
  - Low resolution
  - So-so linearity
  - Preferred states
  - Best-performing devices subject to ITAR
- Can't make true ratiometric measurements of thermometer resistances
  - Restricted measurement range leads to dependence on (unverifiable) stability of analogue thermometer conditioning electronics

What can we improve?

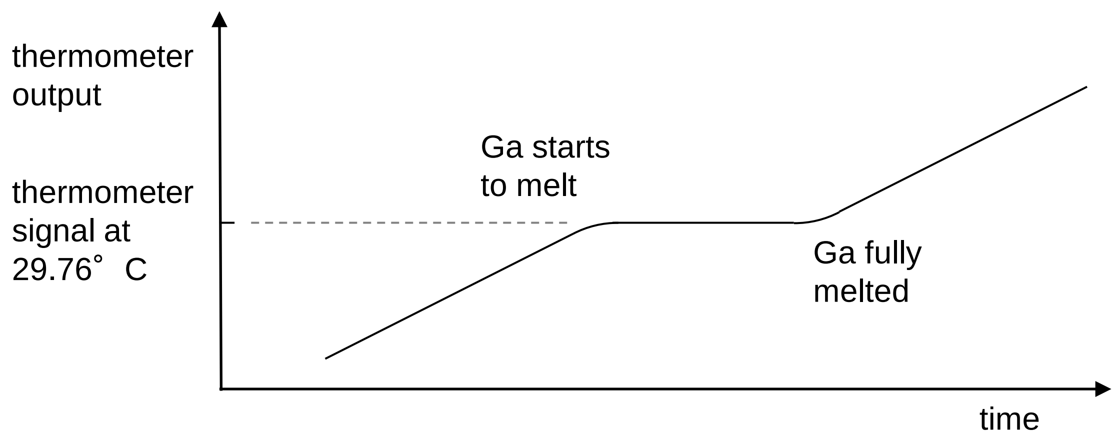
- Emissivity
- Thermometry
- Flight electronics

Thermometry

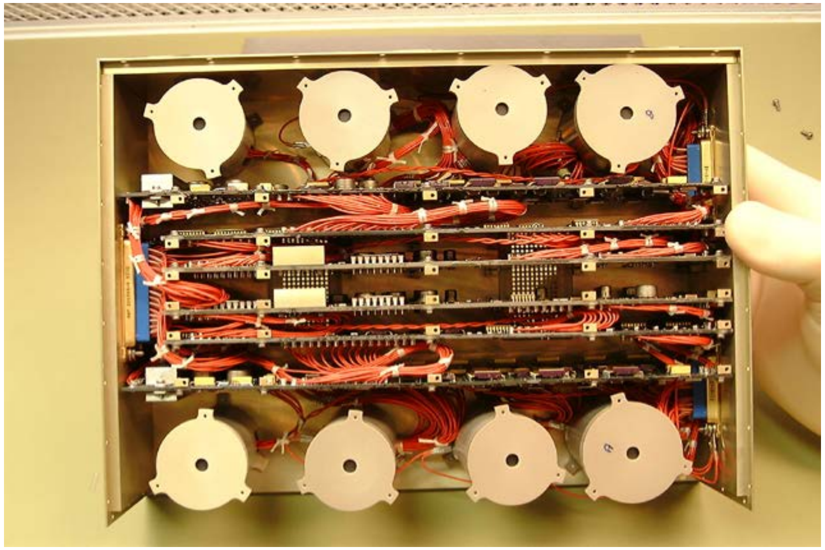
- International Temperature Scale of 1990 (ITS-90) defined by phase change cells
  - Hg, H_2O (triple point) and Ga (melting point) all close to ambient temperature
- Phase change cells embedded in a black body give us a "flying calibration laboratory"
  - Ties thermometer calibrations to fundamental material properties *which do not change with time*
- Obvious problems with format of conventional cells (H_2O pictured)
  - Too big
  - Thermometer has to be removed from black body for calibration

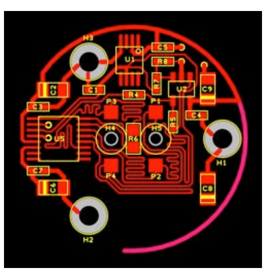
Thermometry

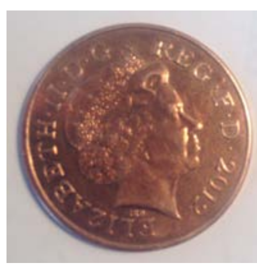
- Plan to make miniature glass ampoule phase change cells
  - Cells will be embedded in the black body between the thermometers
- Normally, the black body is not operated at the phase change temperatures
  - Behaves like a conventional black body
- Periodically, the black body temperature is ramped slowly up through the phase change temperatures
  - As each cell changes phase, it absorbs heat but does not change temperature
  - Small corresponding “plateaus” in response of the thermometers



Flight electronics







- Plan to:
  - Embed some or all electronics on black body structure
  - Condition and digitise temperature sensors in situ
- Advantages:
  - All-digital communication with sensors – much reduced EM susceptibility
  - Digital heater control too
  - Digital communications can be consolidated on the black body structure so only a small wiring loom is required (power + serial I/O)
  - External electronics infrastructure reduced or eliminated

Flight electronics

- Thermometer conditioning uses ΣΔ ADC
  - Very low power consumption (mW)
  - Very high linearity
  - Very high resolution
- Fully ratiometric measurement of thermometer impedance
  - All measurements referred to a standard resistor
  - Offset (e.g. thermocouple potentials) and gain (e.g. current source) uncertainties differenced and ratioed out
  - Circuit capable of mK measurement accuracies (not including thermometer accuracies)
  - Low parts count
  - Low overall power dissipation
- Challenges
  - No flight-qualified ΣΔ ADCs yet. Three possible solutions:
    - Wait
    - Qualify one ourselves
    - Build one in a qualified mixed signal ASIC

Summary: Why you should care about black bodies

- Black body performance determines the accuracy and repeatability of all infrared (and many microwave) radiometric measurements
- Quantitative scientific interpretations of radiometric measurements, and of quantities derived from them, require *traceability*
- Extended measurement time series, notably those associated with climate studies, require extreme stability and also consistency between different platforms
- Mass, volume and power are all expensive on a satellite. Any reductions you can make increase your chances of building a viable instrument