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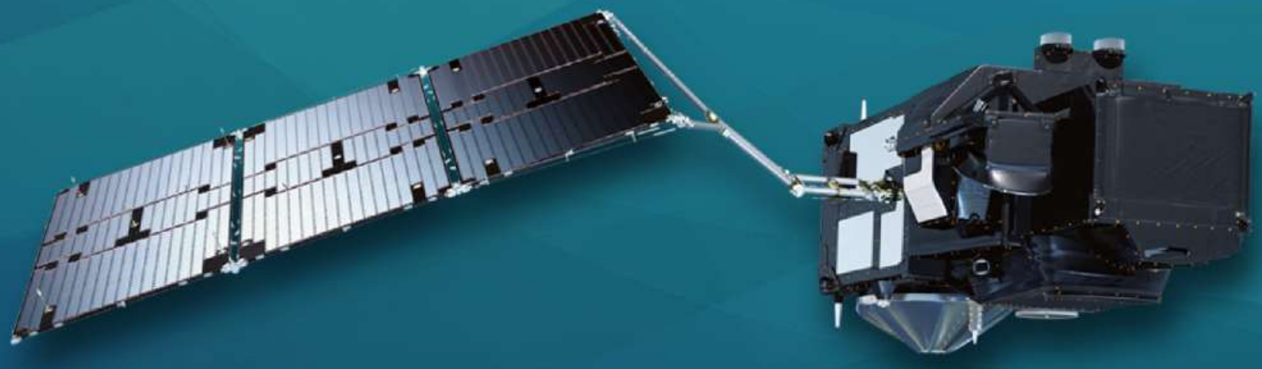

9th Sentinel-3 Validation Team meeting 2026

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ASTeRN: A validation radiometer for fiducial measurements of SST, LST and IST

Tim Nightingale[1], *Werenfrid Wimmer*[2], *Arrow Lee*[1], *Dave Smith*[1], *Michelle Williams*[1], *Darren Ghent*[3] *and Ruth Wilson*[4]

1 STFC RAL Space
2 University of Southampton
3 University of Leicester
4 Space ConneXions Ltd

UKRI Science and Technology Facilities Council RAL Space

University of Southampton

University of Leicester

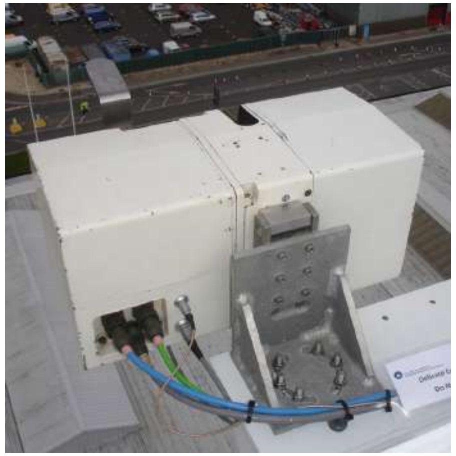
NPL National Physical Laboratory

Space ConneXions

Background (ESA case study)

- The current UK in-situ radiometer designs (ISAR, SISTeR) are now 25+ years old
  - Issues with obsolescence, flexibility, maintenance
  - Lessons learned
- User consultation (2020) and case study (2022) for a next-generation in-situ validation radiometer as a part of the ESA FRM4SST program. Drivers identified included:
  - Cost
  - Accuracy (particularly for validation)
  - Flexibility (other missions, including LST, IST, in-situ science)
- These drivers led to an outline design highlighting:
  - Simplicity
  - Traceability
  - Multispectral measurements
- Proposed design was an evolution of existing designs:
  - Same basic measurement approach
  - Draws on lessons learned
  - New emphasis on maintainability

ISAR (University of Southampton)



SISTeR (RAL Space)

Background (DSIT/UKSA proposal)

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- During the UK's (brief) exit from Copernicus, the UK Government solicited proposals for space-related projects from the UK space community
- ASTeRN (the Advanced Surface Temperature Radiometer Network), led by Dave Smith at RAL Space, was one of the successful proposals
  - Significant funding from DSIT, later managed by UKSA
  - Strict deadline for completion
- The ASTeRN consortium was based on the UK members of the FRM4SST consortium:
  - **RAL Space** (consortium lead, opto-electronics and calibration subsystems)
  - **University of Southampton** (mechanical and electronic design)
  - **University of Leicester** (LST specification, demonstration deployment)
  - **Space ConneXions Ltd** (project management support)
  - **National Physical Laboratory** (laboratory demonstration against a traceable reference black body)
- The ASTeRN proposal included:
  - Specification
  - Optical, mechanical and electronic design
  - Construction of three prototype instruments
  - Laboratory testing and demonstration deployments

Key requirements

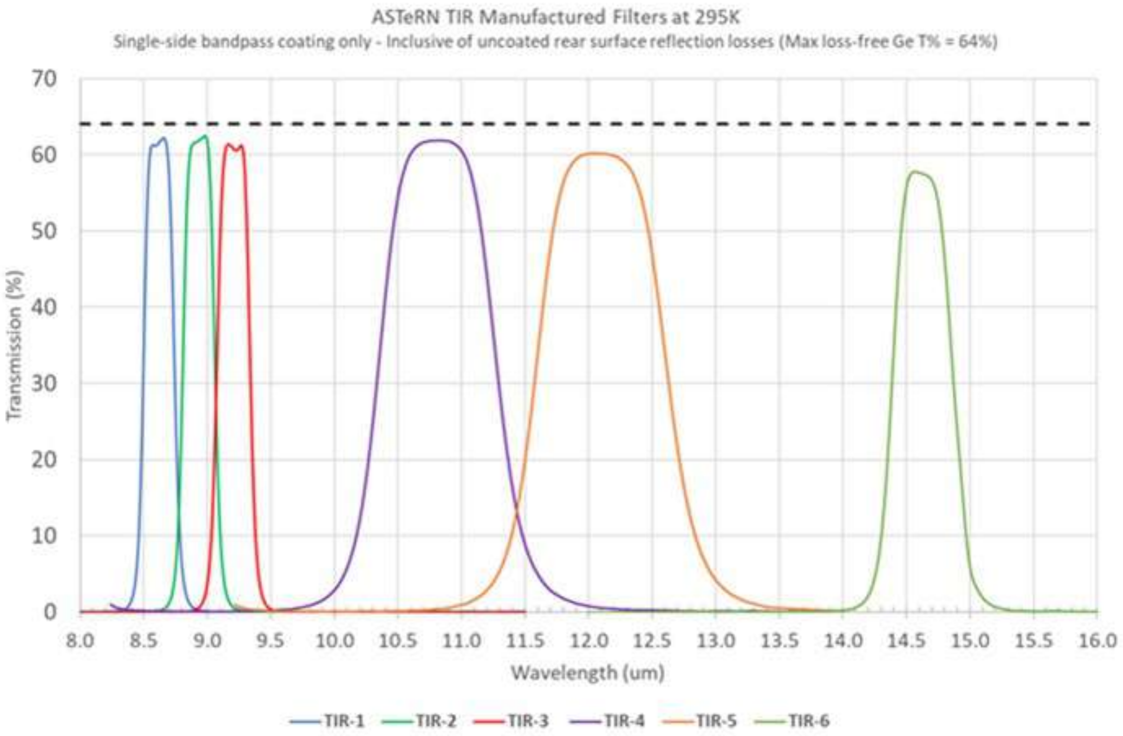
- All instrument scientific products shall be traceable to SI units
- The instrument shall be capable of measuring radiances / brightness temperatures suitable for the calculation of:
  - **SST** for all combinations of sea and atmospheric temperatures
  - **LST** for most (T) / all (G) combinations of land and atmospheric temperatures
  - **IST** for a limited range of ice and atmospheric temperatures
- Assumes:
  - SST in the range −2 °C to 35 °C
  - LST −30 °C to 50 °C.
- NEΔT 50 mK (T) / 25 mK (G) in the split window bands
- BT systematic uncertainty (1σ) of 70 mK (T) / 40 mK (G) near to ambient temperature
- Skin SST measurements with a systematic uncertainty (1σ) of 100 mK (T) / 50 mK (G).

Key requirements

- Self-calibrating thermal infrared (TIR) radiometer containing two black bodies
- Black bodies to be placed at the end of the optical chain
- One black body to be operated at the instrument ambient temperature and one black body at an elevated temperature
- Capable of views to an external scene in a range extending at least 180° from local nadir to zenith.
- Low power consumption
- Autonomous operation
- Mass and dimensions suitable for handling by single person

Spectral bands

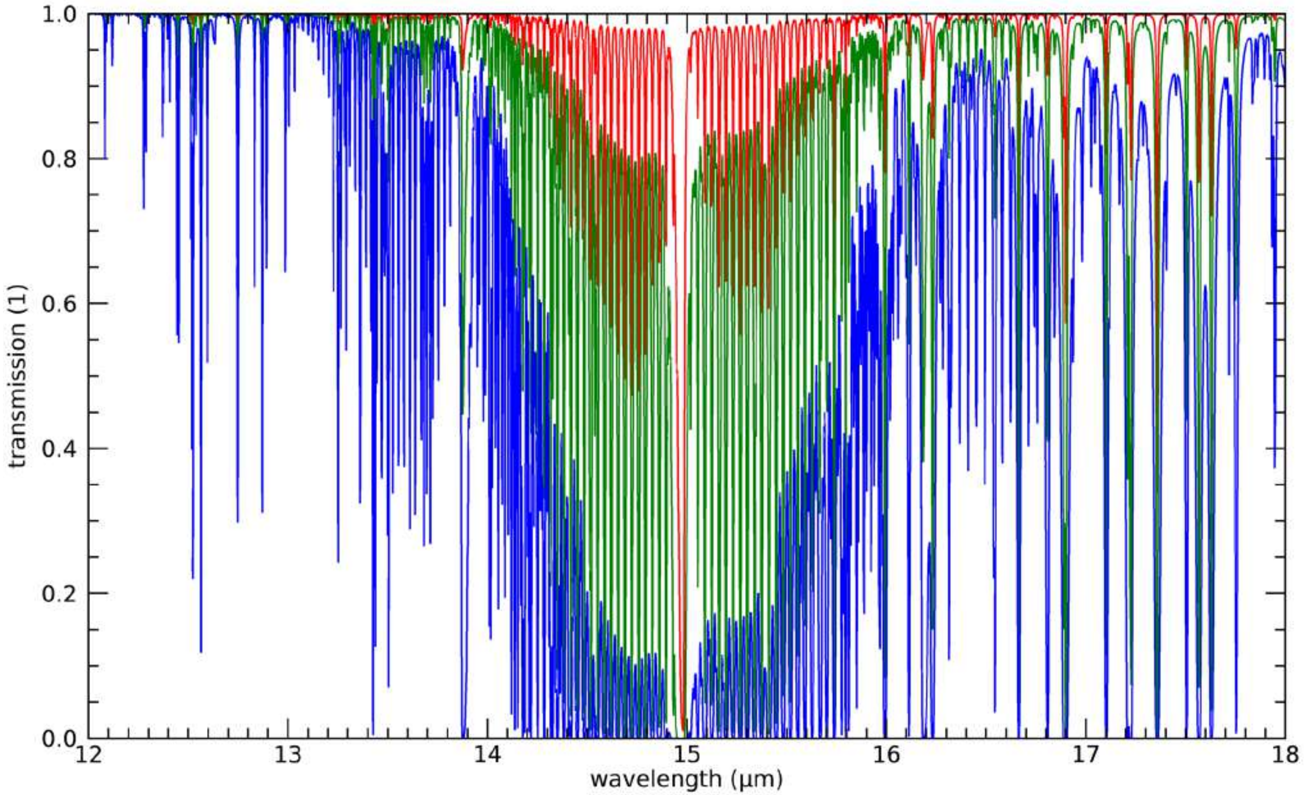
Band centre	Bandwidth	Application	Source
8.6 µm	0.24 µm	LST, Emissivity	LSTM
8.9 µm	0.24 µm	LST, Emissivity	LSTM
9.2 µm	0.24 µm	LST, Emissivity	LSTM
10.8 µm	0.9 µm	SST, LST	SLSTR
12 µm	1.0 µm	SST, LST	SLSTR
14.6 µm	0.5 µm	Air Temperature	-



- Six bands in initial instrument design:
  - 10.85 µm and 12 µm: split window (SST, LST, IST)
  - 8.6 µm, 8.9 µm and 9.2 µm: surface characterisation (LST)
  - 14.6 µm: CO_2 band (air temperature)
- Filters designed and built by the Infrared Multilayer Laboratory (IML) at Oxford University
  - Low sensitivity to substrate temperature
  - All filters characterised at ambient temperature in representative (f/5) beam

Air temperature band

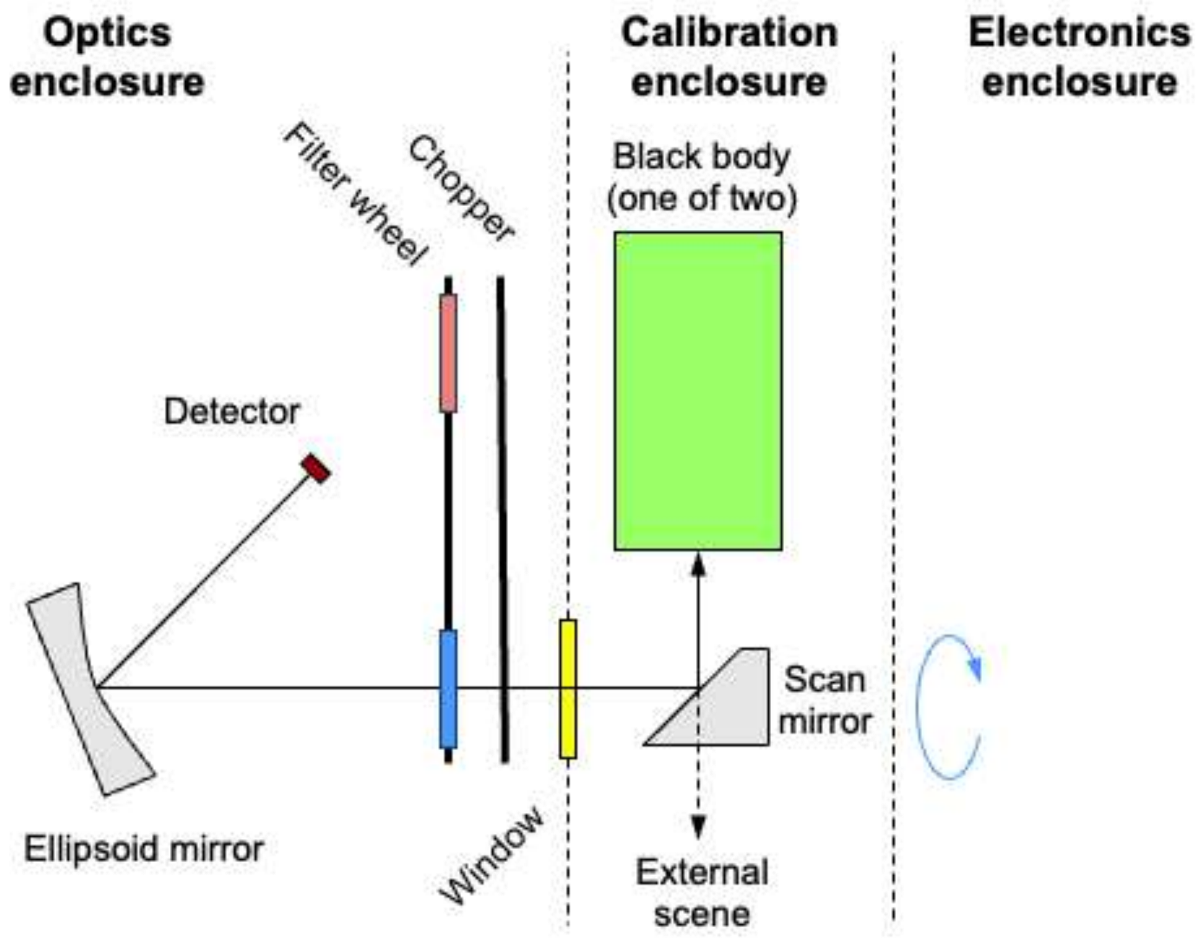
- Not much precedent for air temperature measurement with an in-situ filter radiometer
- Performed study to determine preferred filter parameters
- Selected a 0.5 μm FWHM filter centered at 14.6 μm in shortwave wing of CO_2 band
  - CO_2 well mixed so not sensitive to environmental conditions
  - 50% absorption at 14 m
  - Less than 10% sensitivity either to path below 1 m or beyond 100 m
  - Not too sensitive to filter build tolerances
  - Better throughput and lower demand on window spectral transmission range than at longwave side of band



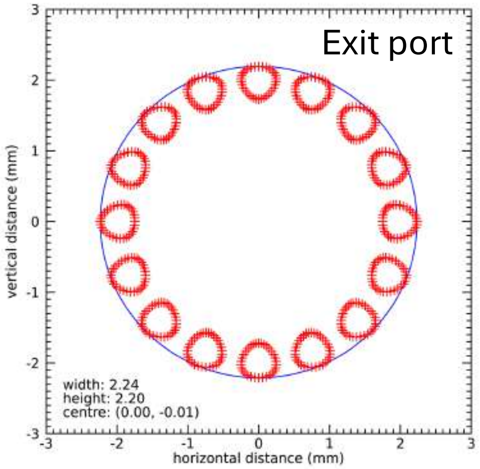
Atmospheric transmission at ground level along 1 m (red), 10 m (green) and 100 m (blue) paths between 12 μm and 18 μm. (US standard atmosphere, adjusted to 415 ppm CO_2 and 80% RH)

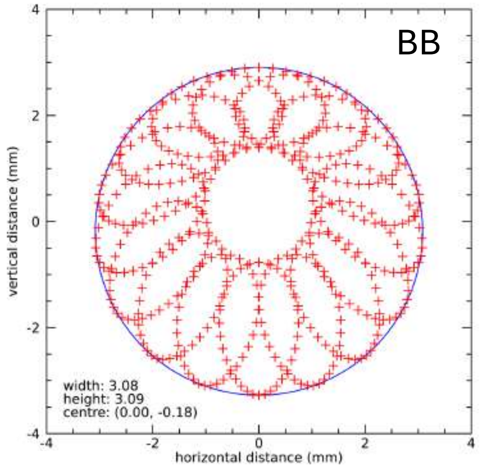
Instrument schematic

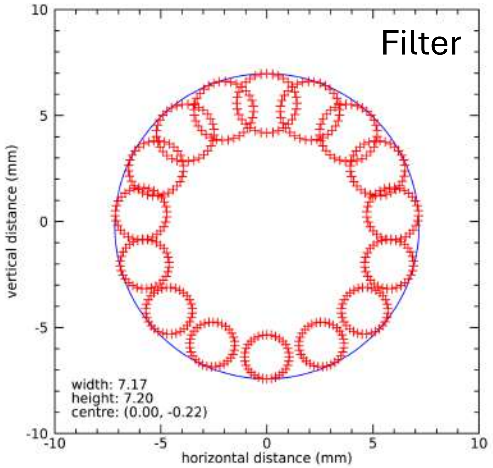
- Chopped, self-calibrating filter radiometer
- Split into three compartments.
  - Optics and electronics compartments are watertight
- DLATGS detector
- Single powered optic (ellipsoid mirror)
- Detector is field stop; mirror is aperture stop
- Detector re-imaged at exit port
  - Small exit aperture for environmental protection
  - Small aperture, high emissivity black bodies
  - Divergent beam (6° half-angle)
- Chopper moved as far forward in system as possible
  - Detector only "sees" chopped signal
- Black bodies at end of optical chain
- Integrated weather door (planned)



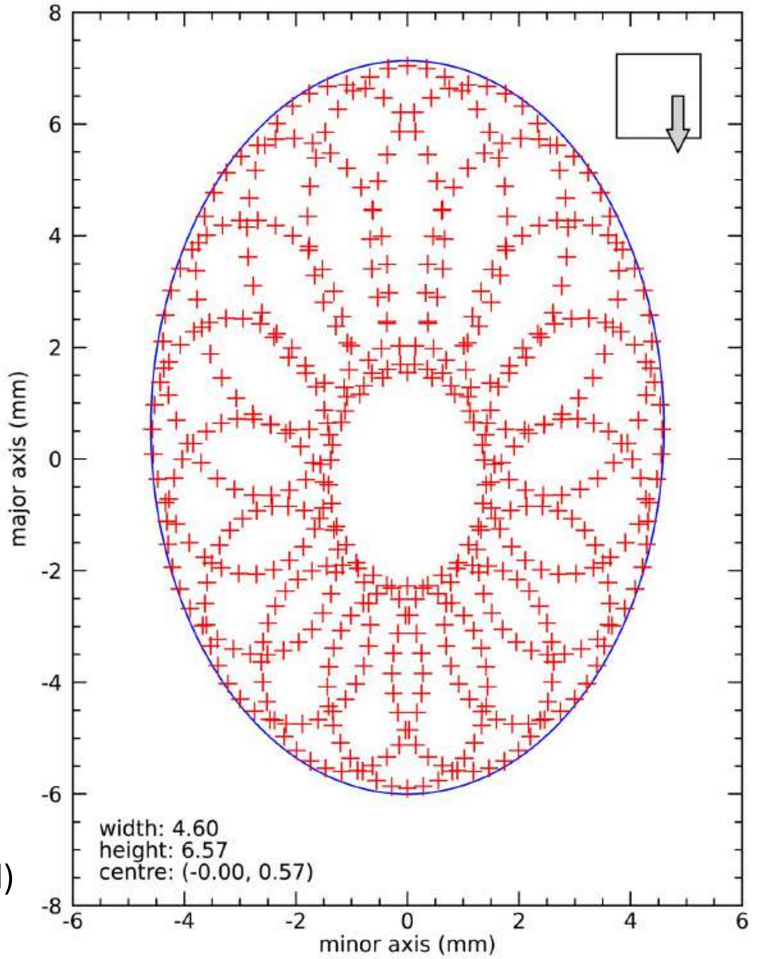
Ray tracing



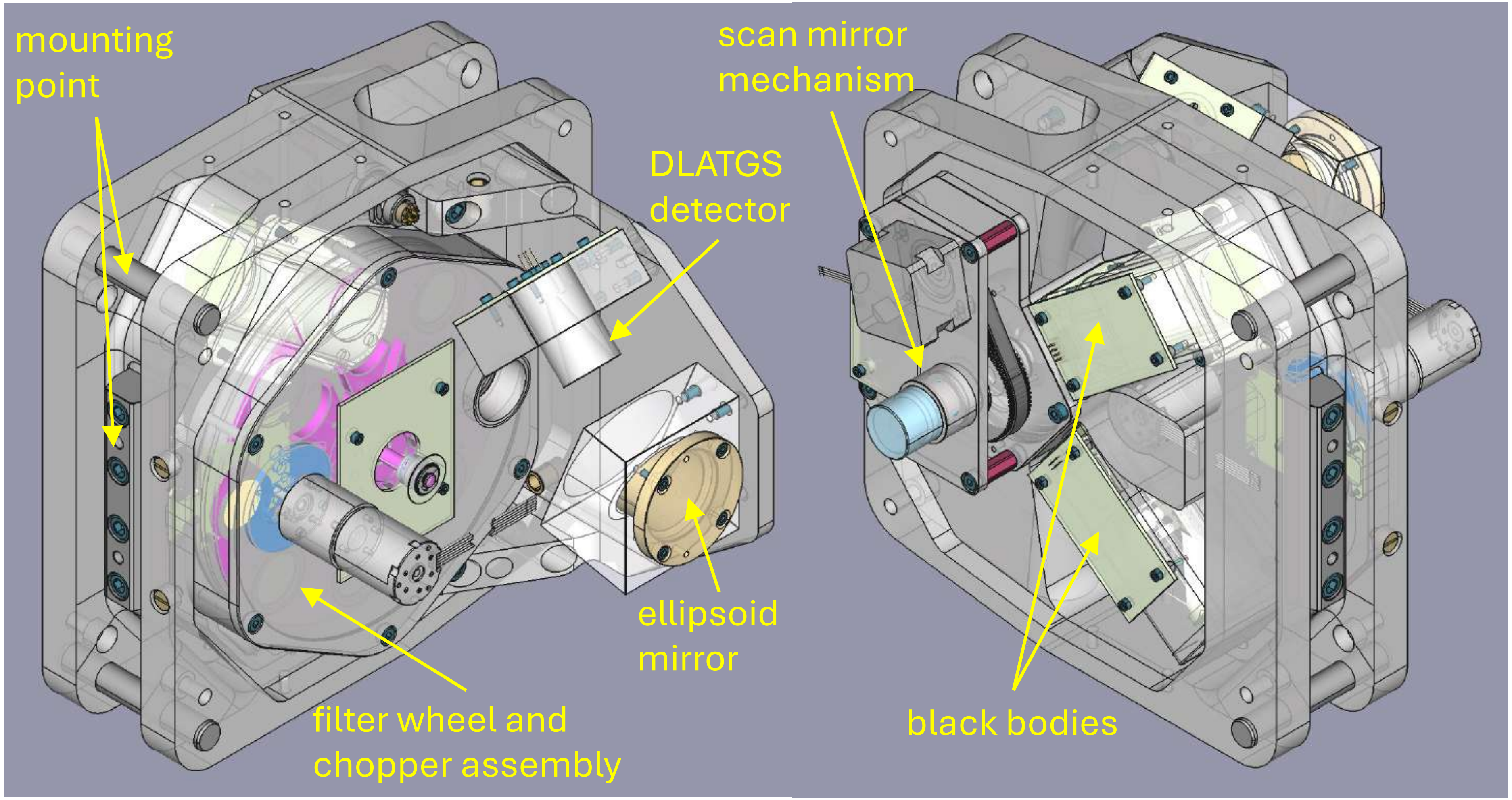




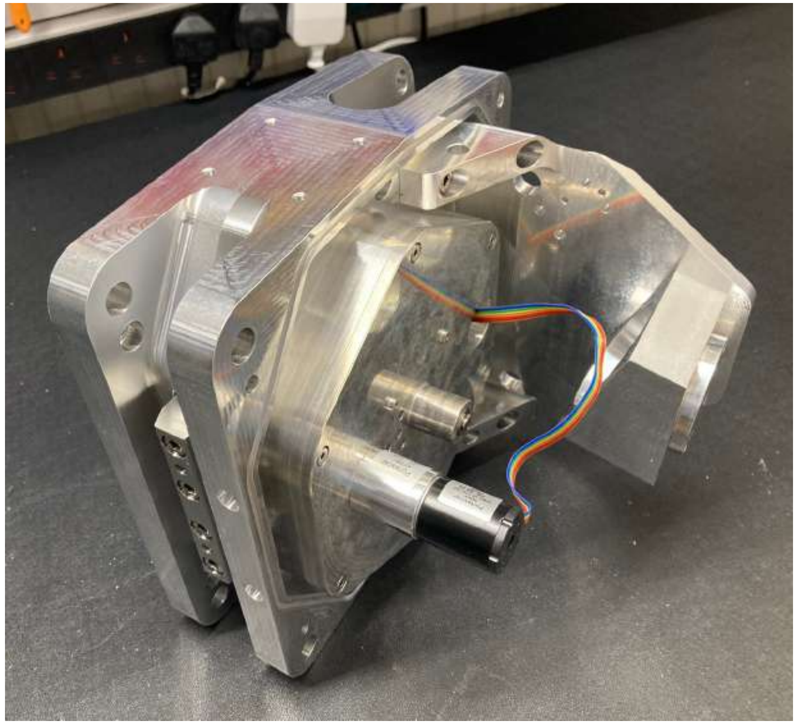
Scan mirror
(untilted, de-rotated)

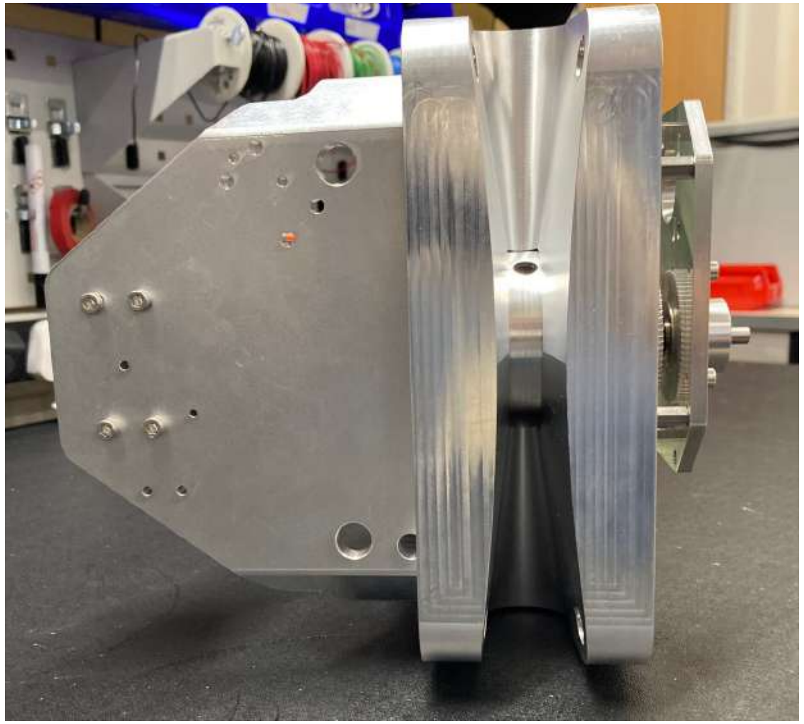


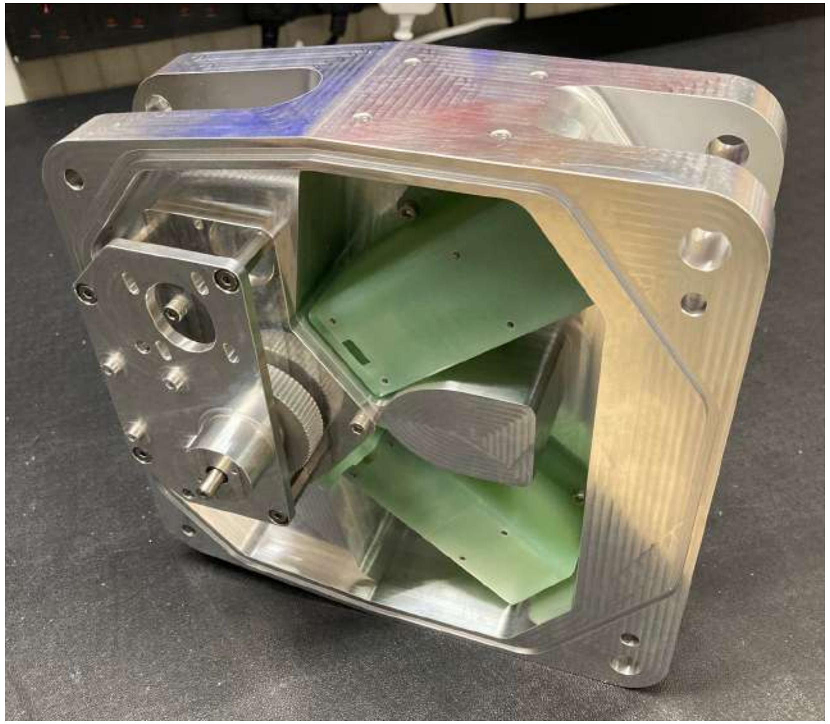
Instrument overview



Trial assembly

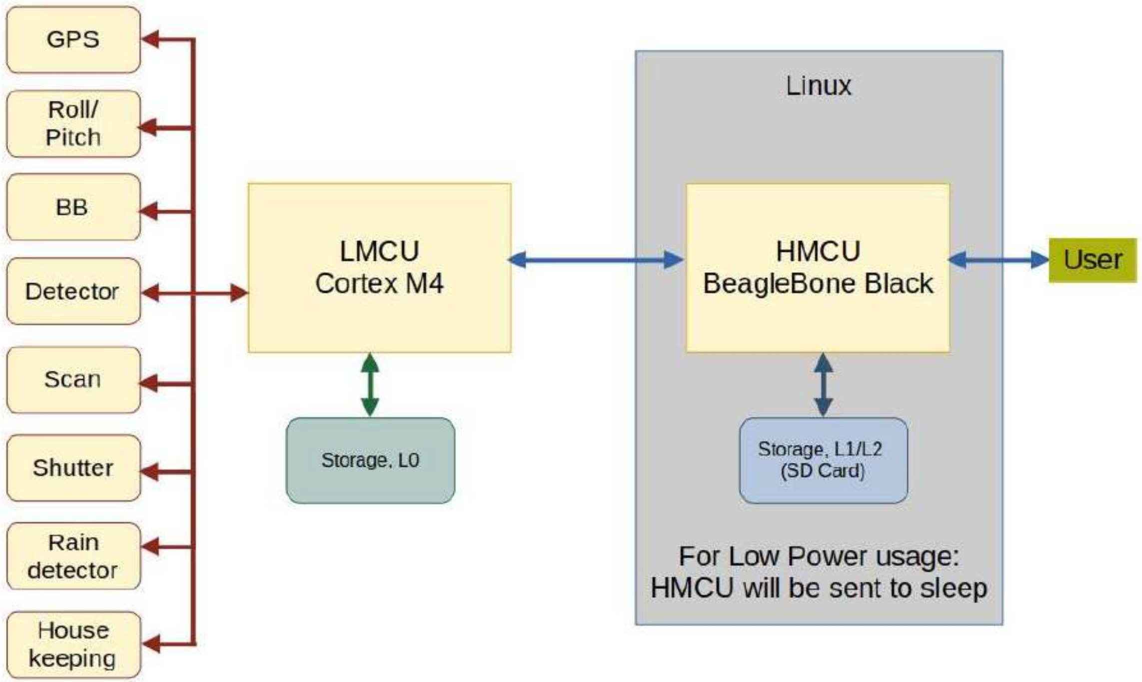






Electronic architecture

- A low level “scheduler” MCU manages the instrument subsystems
  - coordinates measurement sequence
  - demands mechanism positions
  - requests and stores raw data
  - responds to instrument safety events (rain, power failure...)
- A high level “supervisor” PC manages the user interface



Subsystem philosophy

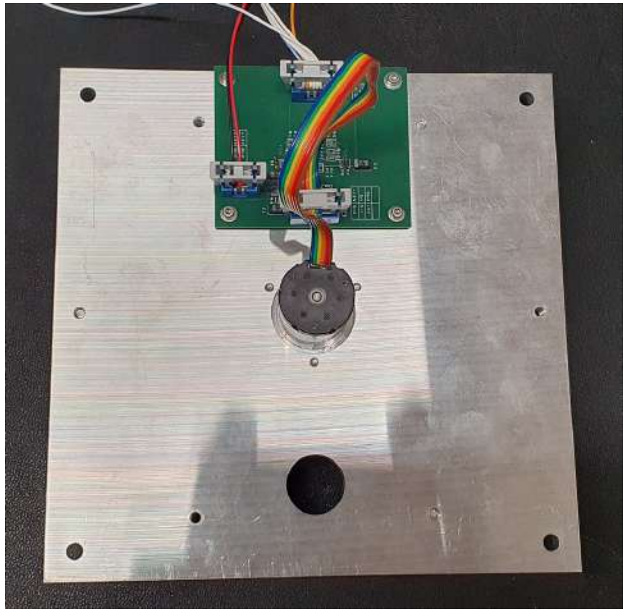
- Subsystems are “plug-and-play”
- All subsystems have an identical electrical interface
  - power (9 V “dirty”, 6 V “clean”)
  - serial data interface (I2C)
  - simple handshaking (interrupt, reset)
- All detailed subsystem control and signal processing is managed locally
  - Simplifies mods, upgrades and replacements
- Where possible, relevant calibration information is embedded in the subsystem, not held in the scheduler or supervisor.
  - Calibration information follows the subsystem

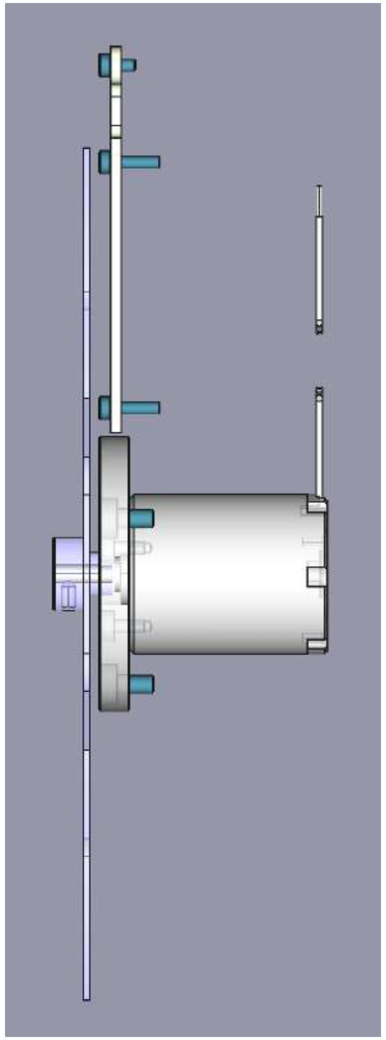
Subsystems: scan mirror

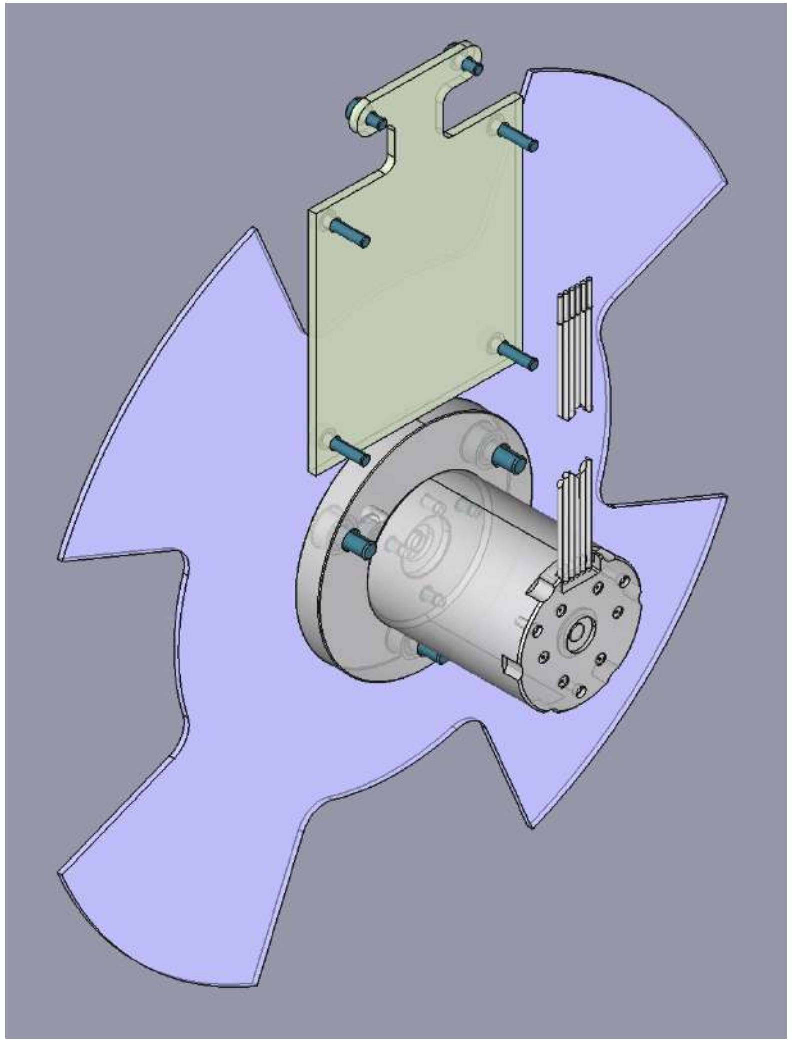
- Two concentric baffles rotate with scan mirror
- Easy access to the scan mirror for maintenance
- Belt driven 4:1 ratio from stepper motor
- 16-bit encoder for position feedback

Subsystems: chopper

- Four-bladed chopper
- Spins at 1,500 RPM
- 100 Hz chopping frequency
- Optos on PCB sense blade position and close servo loop



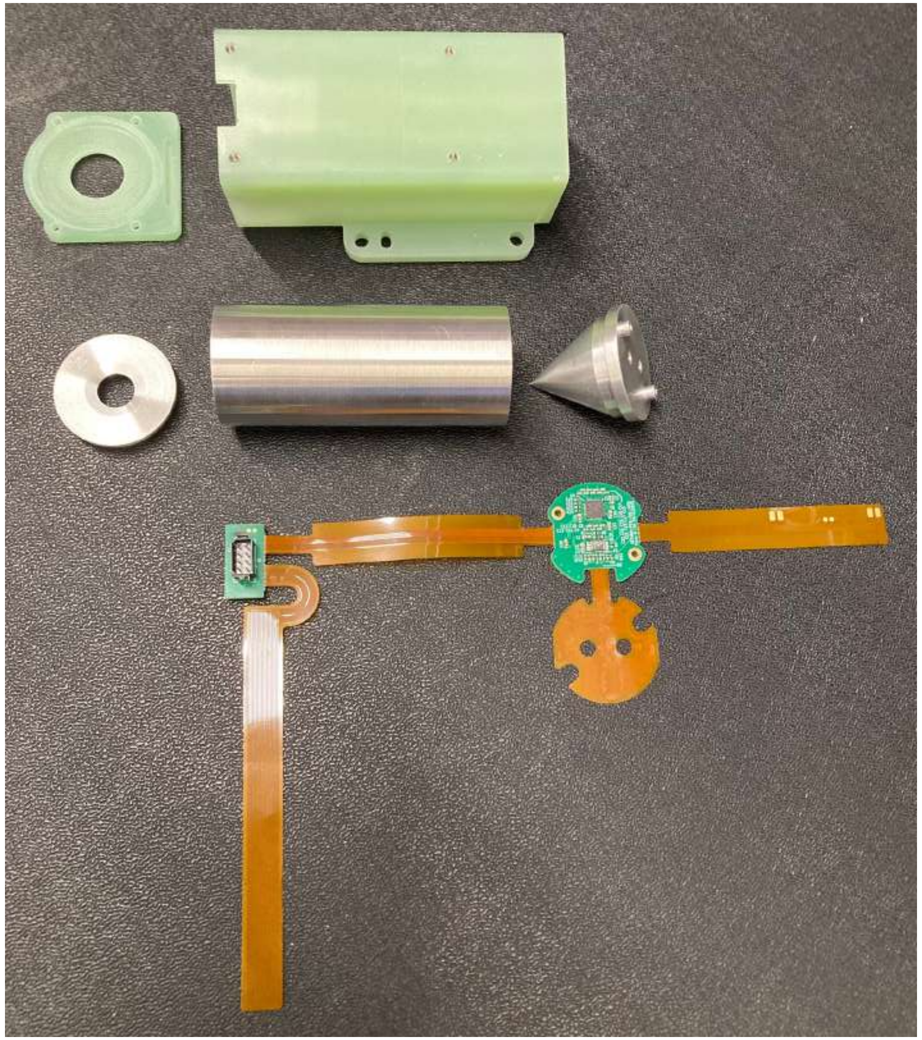




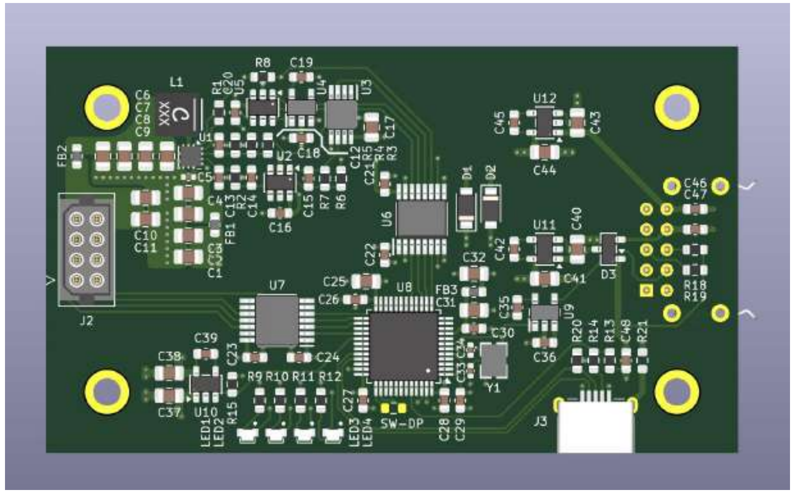
Subsystems: Filter wheel

- Accommodates up to 8 filters which can be interchanged as required
- Geneva mechanism to rotate wheel to move and lock filter into required position.

Subsystems: Black body

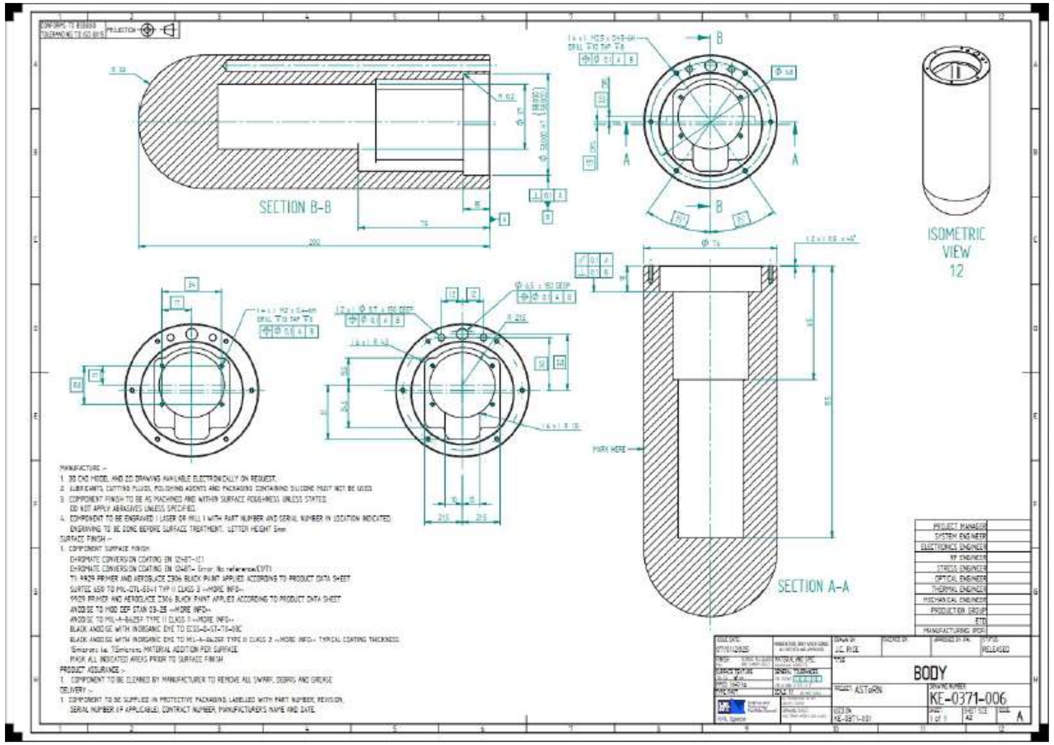


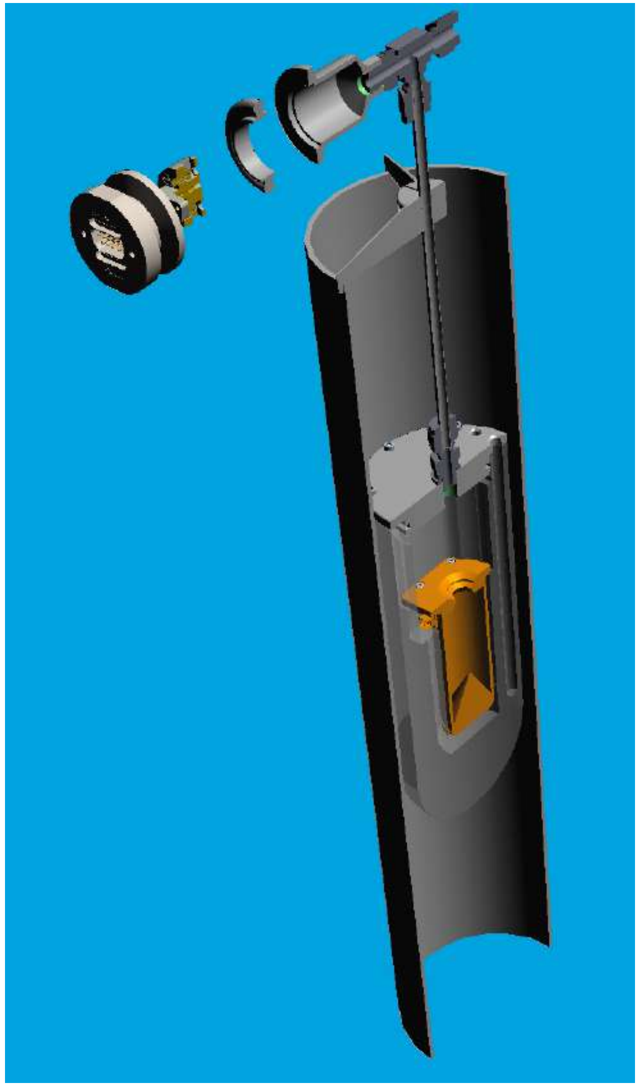
- Small aperture and re-entrant cone (painted black)
- Two thermistors in base, two on wall
- All-in-one flex / rigid PCB
  - Thermistor excitation circuit mounted on base
  - Flexible thermal breaks and heater bonded to body
  - Connector and calibration EEPROM
- Second external PCB manages thermistor excitation, heater power, serial interface



Black body calibration “torpedo”

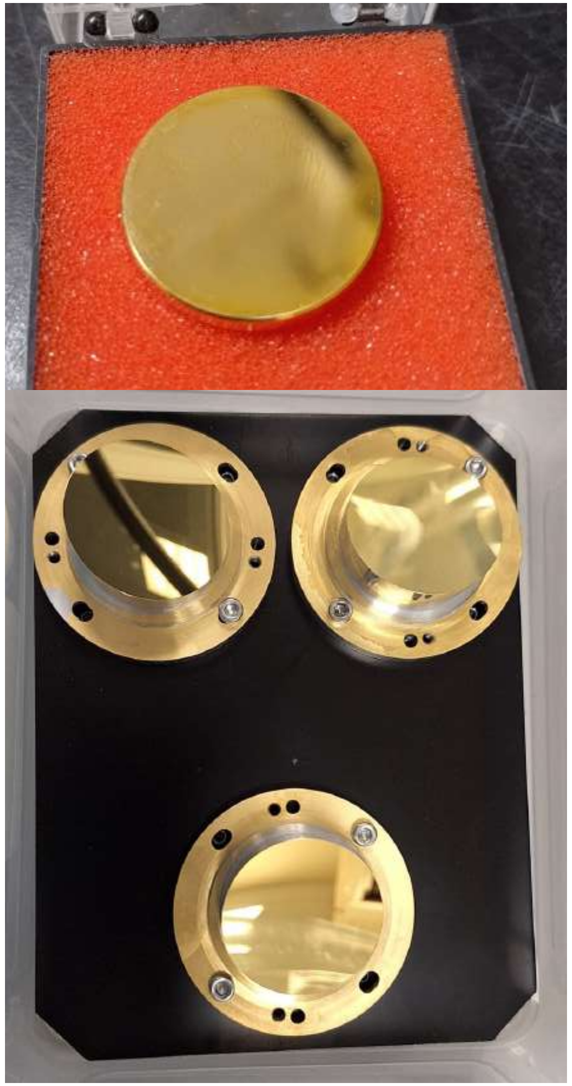
- Black body internals installed complete inside torpedo
- Torpedo evacuated and back-filled with helium
- Calibrated against an SPRT in a calibration bath





Optics

- **Scan Mirror**
  - Identical to ISAR scan mirror, hard gold on copper
  - Manufactured by ULO Optics
- **Ellipsoid Mirror**
  - Diamond turned aluminium
  - Gold sputtered coating with nickel adhesion layer
- **Window**
  - zinc selenide substrate
  - wideband AR coating on dry side
  - hard carbon coating on wet side
- **Filters**
  - germanium substrate
  - dichroic coatings for in-band response and out-of-band blocking



Where we are

- Centre section structure complete
- All mechanisms (except weather door) complete and functioning
- All major procurements (filters, mirrors, windows, detectors) complete
- First issue power supply electronics complete
- Optical alignment tools complete
- Scheduler breadboarded
- Designs in place for remaining structure

What’s left

- Weather door
- Detector electronics
- Final design and fabrication of remaining structure
- Painting and anodising
- Mechanical assembly and wiring
- Optical alignment
- First release code for subsystems, scheduler, supervisor, data processor
- Black body thermometer calibration
- Functional test
- Validation of instrument calibration (six bands)
- Demonstration deployments
- Documentation (procedures and handbook)