Design of the thermal control system for the ULTRASAT camera

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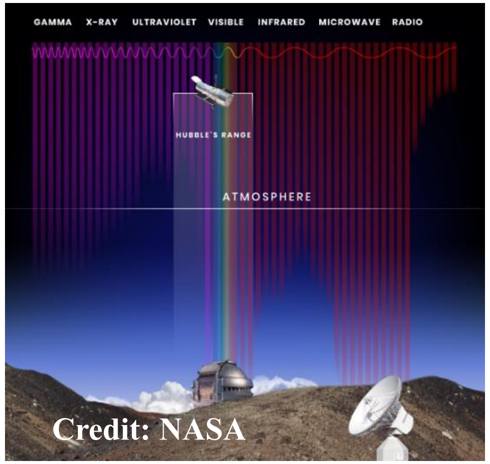
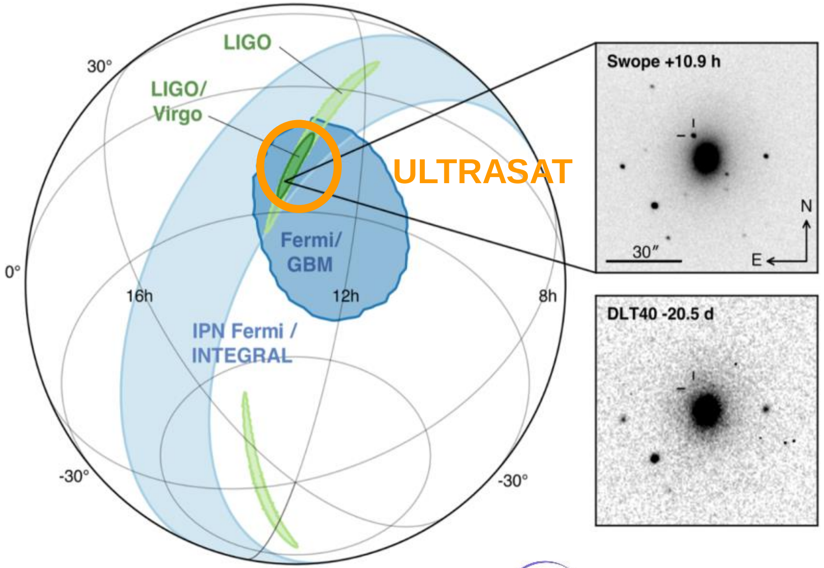
ULTRASAT: Mission overview

- Astronomical satellite mission
  - "Early warning system" for Earth-based observation of astronomical events by wide-angle telescope, permanent communication and < 15 min for reorientation.
  - Led by the Weizmann Institute of Science and the Israeli Space Agency
    - Satellite build by Israel Aerospace Industries
    - Telescope build by ElOp, Elbit Systems
    - Camera build by DESY
  - CDR was conducted in Q2 2022
  - Launch to GTO is scheduled for 2025
  - Launch mass is 1,000 kg
  - Scientific goals are the detection of mergers of binary stars with neutron stars (kilonovae), origin of the heaviest elements, expansion rate of the universe, supernova explosions.





ULTRASAT: Satellite overview

Satellite

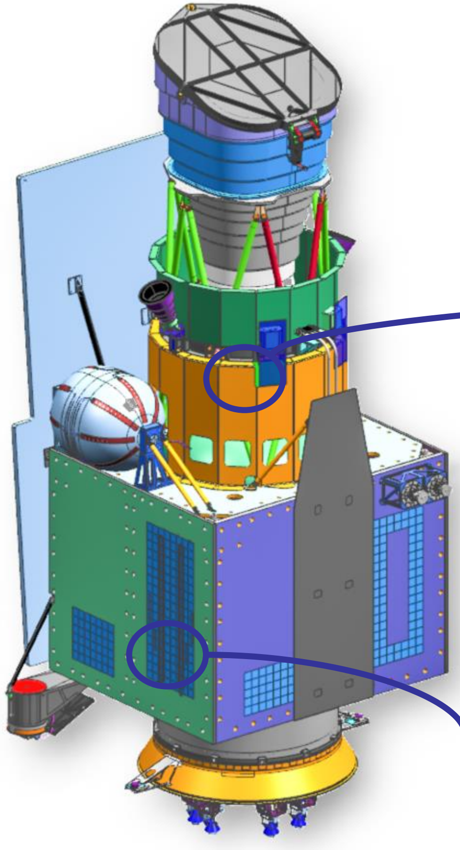


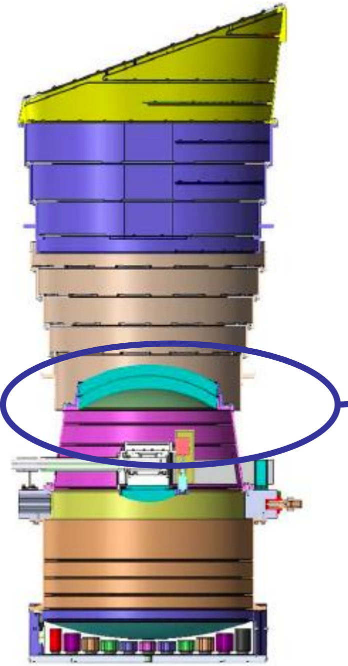
Image credit: IAI

Development: IAI

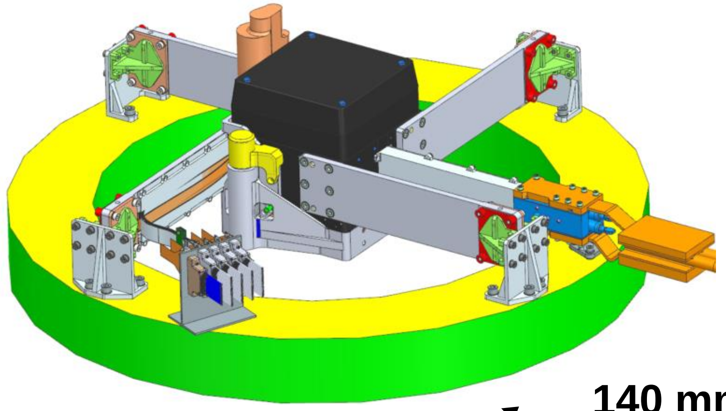
3.5 m

Schmidt-Telescope

Image credit: ELOP

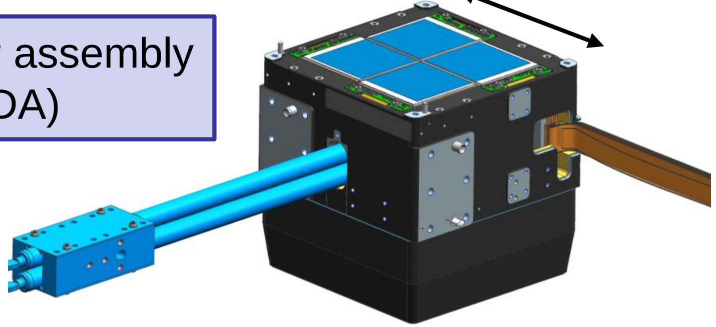


Development: ELOP



140 mm

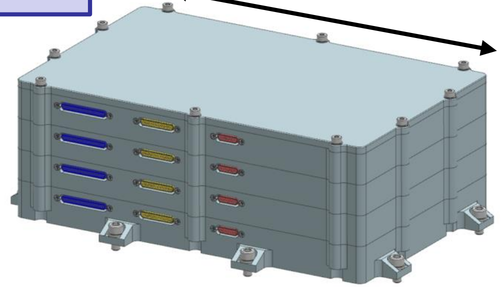
Detector assembly (DA)



Development: DESY
~ 5 kg

Remote electronics (RE)

280 mm



Development: DESY
~ 7 kg

Thermal chain sensors to radiator (schematic)

heaters

Sensors ~200 K

DESY's thermal straps

DESY's CCHP evaporator

DESY IF (condenser)

Telescope (-x) environment

Deep space ~ 3 [K]

heaters

Radiator

IAI's straps

heaters

IAI's CCHP evaporator

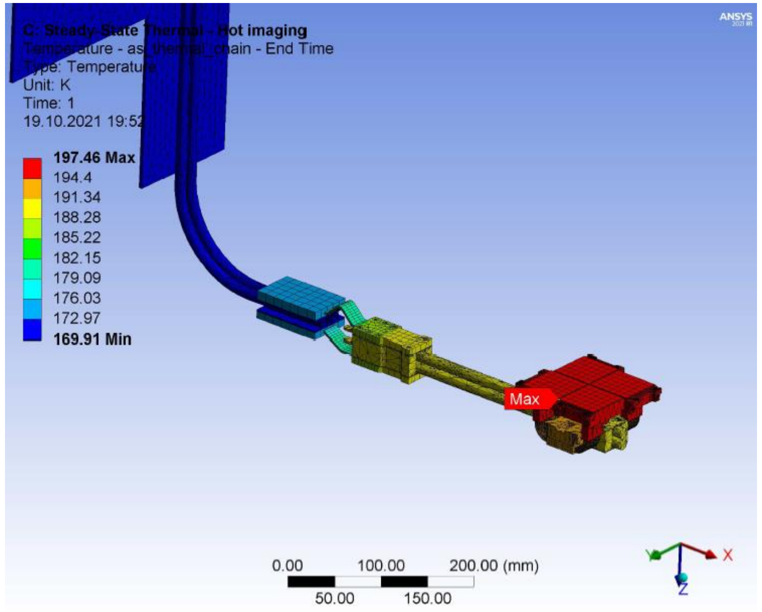
IAI's CCHP transmission line

IAI's CCHP flange (condenser)

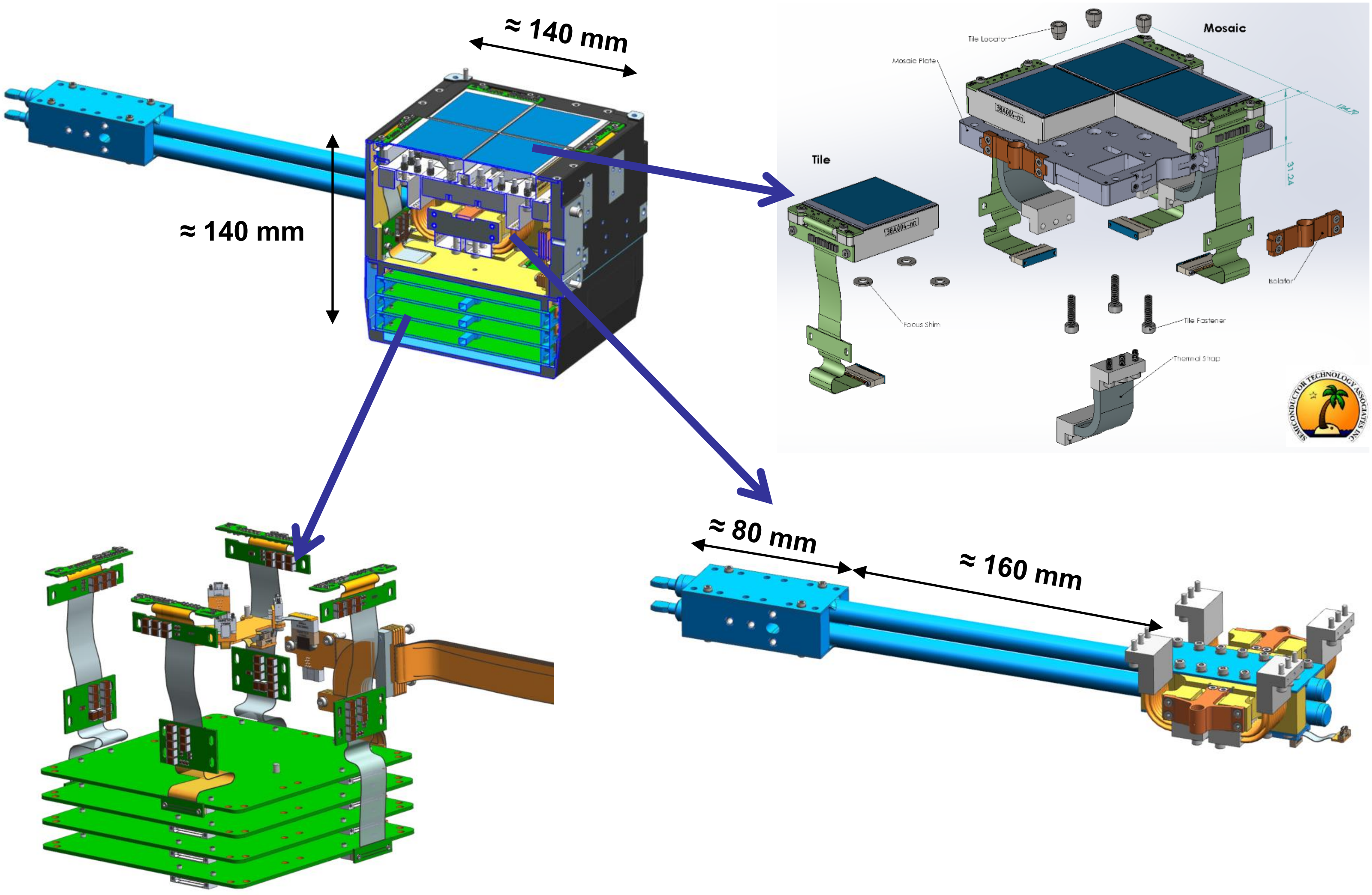
Satellite

Telescope

Camera



ULTRASAT camera: Detector assembly



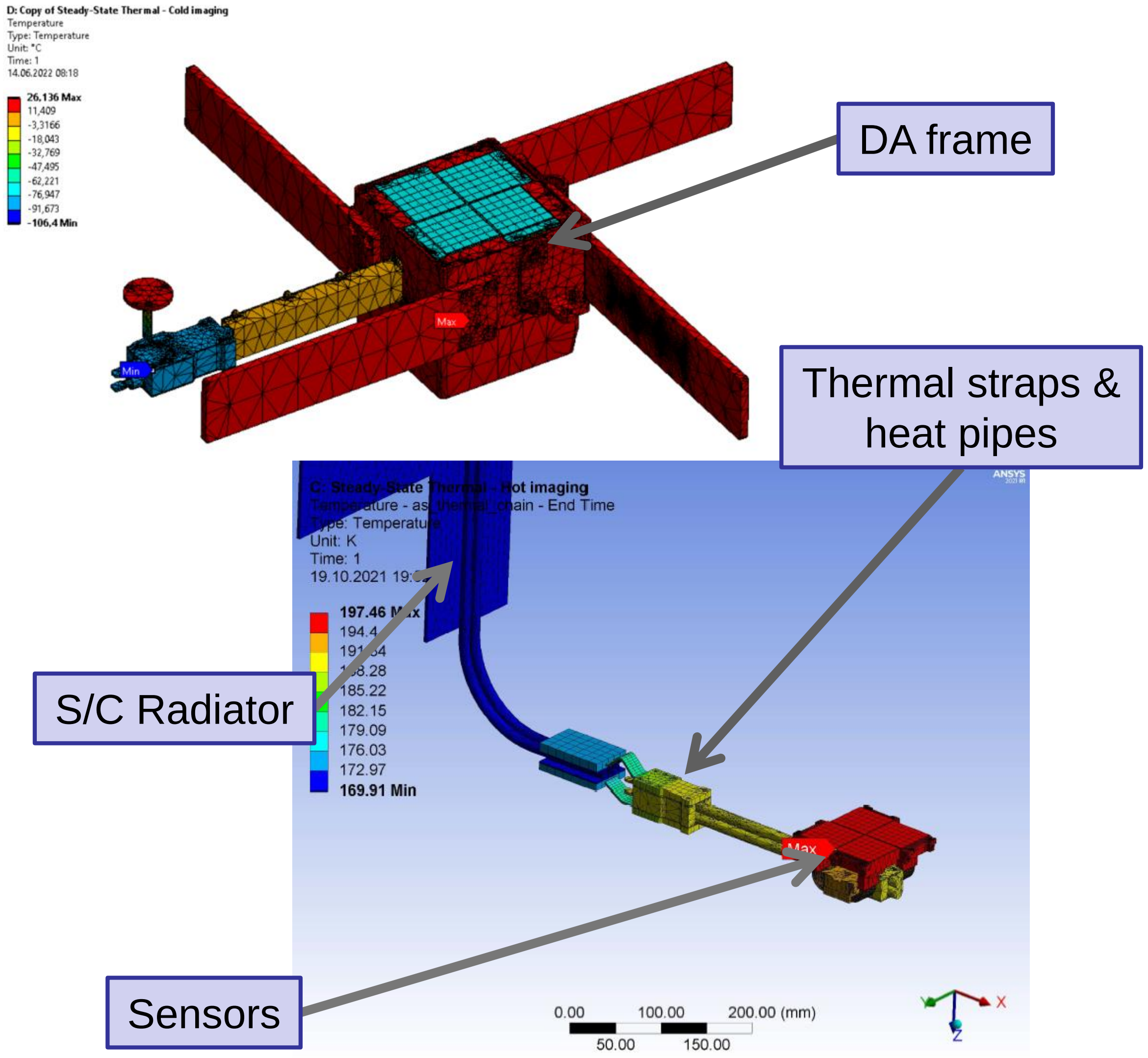
- Optomechanical
  - Mosaic assembly of 4 sensors
  - Bonding & packaging by STA.
  - High requirements on flatness & alignment.
- Thermal
  - Cooling of the sensors by thermal straps & heat pipes.
  - Thermal isolation of the sensors from the rest of the structure
- Electronics
  - 4 independent sensor units (sensor + flex-rigid PCB + PCB)
  - Cable for readout electronics.

Thermal design

- Thermal requirements
  - T_{sensor} = 200 ± 5 K, ΔT ≤ 1 K in 300 s
  - Optical requirement → $T_{DA,frame} \sim T_{telescope}$
    - $T_{telescope}$ = 295 ± 3 K (‘environment’)
  - 338 K < Tsensor < 348 K for decontamination

- How to decouple the sensor thermally?
  - ULTEM flexures → low heat flow
  - DA inner surfaces → low emissivity
- How to cool the sensor to 200 K?
  - By thermal straps and heat pipes, removing heat directly to the radiator of the spacecraft

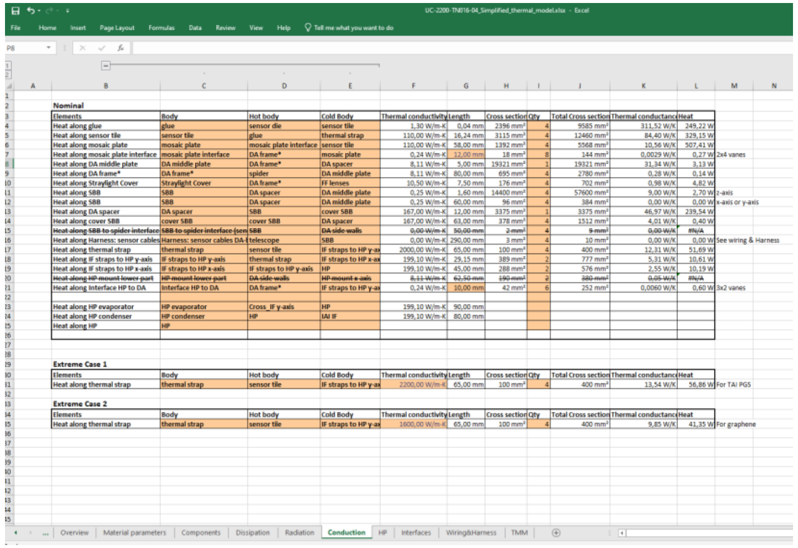
- How to stabilise temperature? Active control
  - 3 x 2 W voltage regulated heaters per tile
  - 60 W on satellite HP evaporator
  - 200 W available on radiator



Thermal modelling

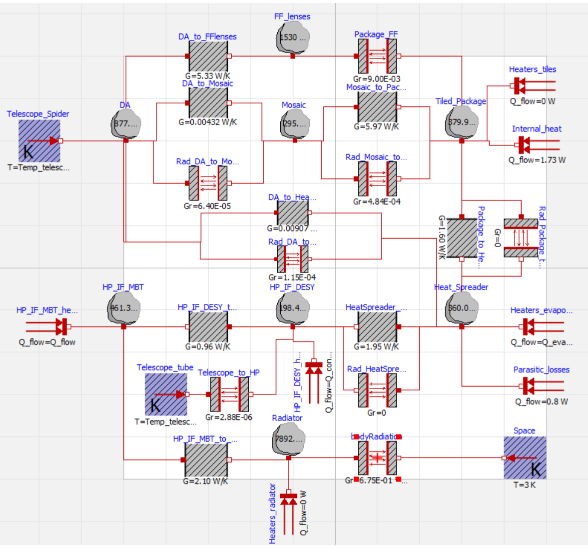
Simplified thermal model

- Excel
- Steady-state
- Preliminary sizing of components
- Check for plausibility
- Database min/max values
- Exchange with IAI/ELOP



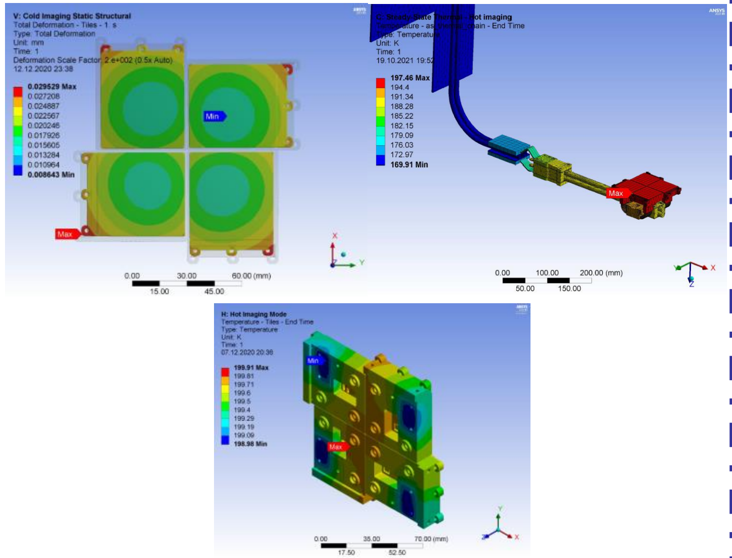
E2E model

- TMM in OpenModelica
- Steady-state & transient
- Best/worst case scenario
- Radiator dimensioning
- Heater dimensioning
- Sensitivity studies
- Exchange with IAI/ELOP

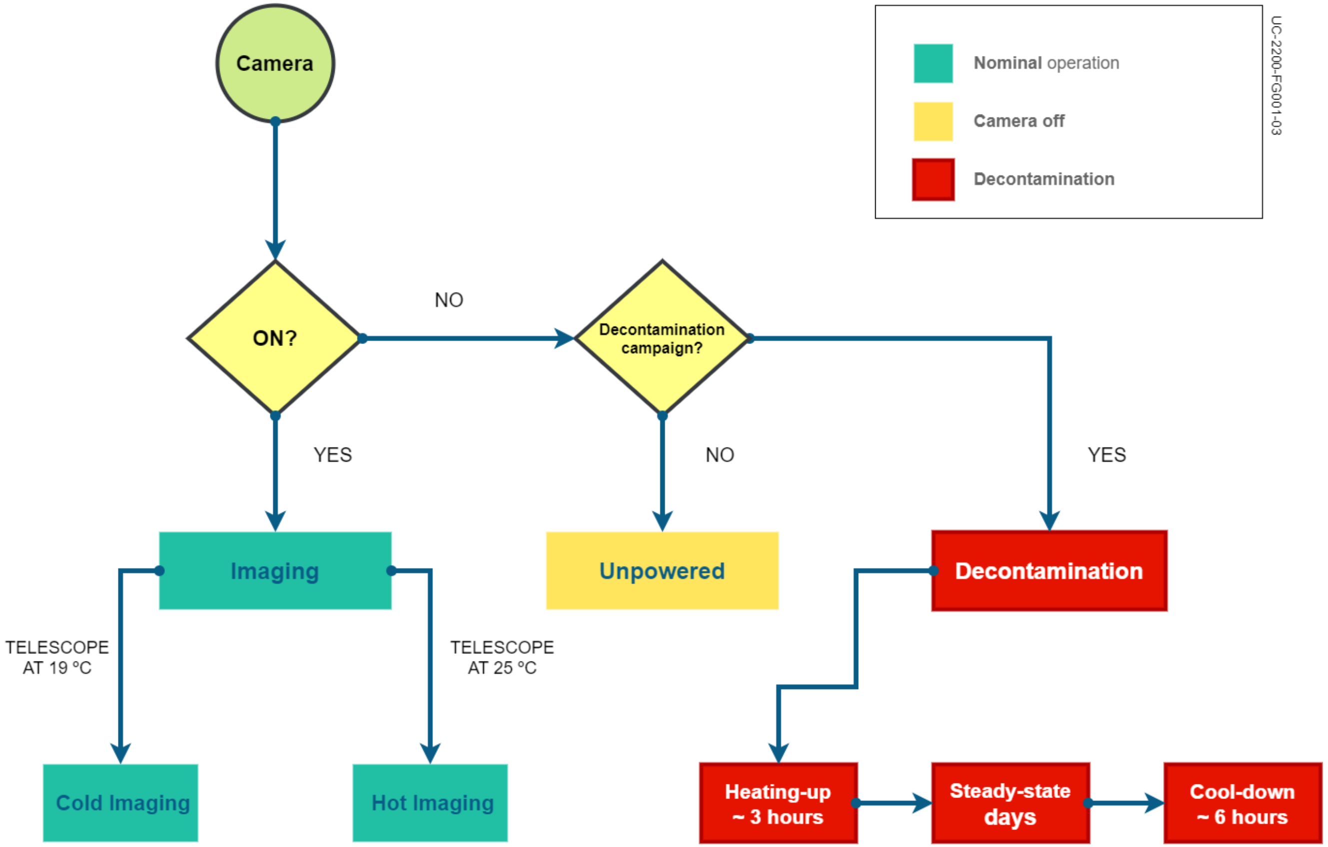


FE model

- ANSYS
- Local temperature effects
- Coupling thermal – mechanical
- Exchange with IAI/ELOP



Thermal cases



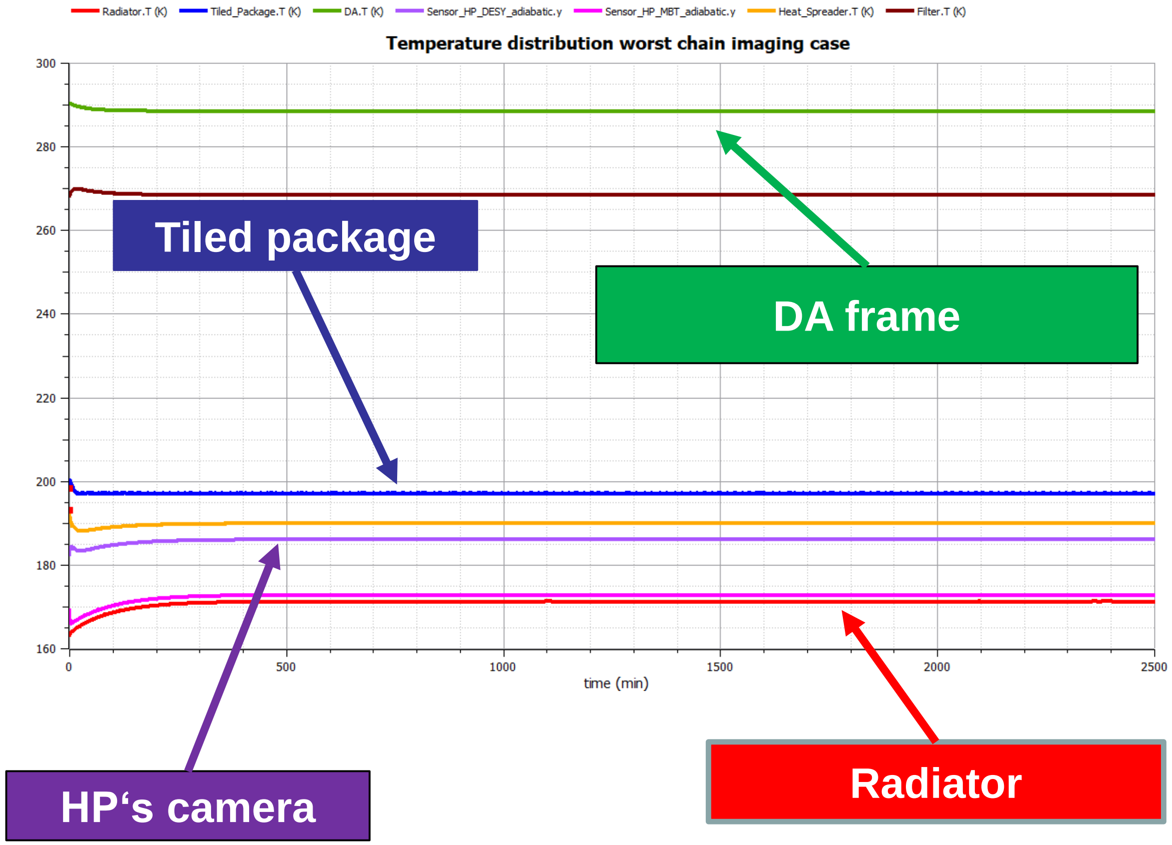
- Thermal analysis
  - Thermal steady-state
    - ANSYS
      - All cases studied
  - Thermal transient
    - OpenModelica
      - All cases studied
    - ANSYS
      - $\Delta T \leq 1$ K in 300 s
      - Reduced Imaging mode studied
- Requirements fulfilled? ✓

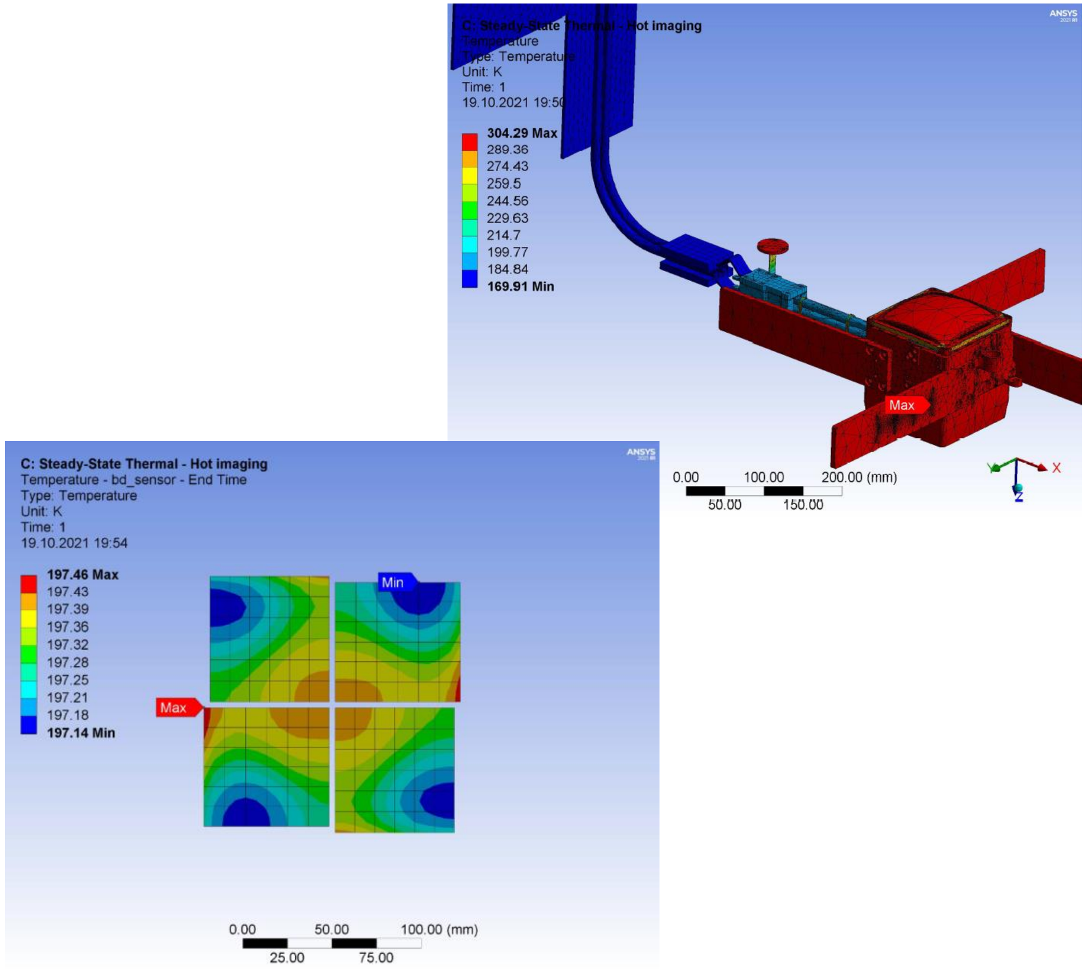
FEM Steady-state

Images of 300 s

- 280 s integration

- 20 s read-out





Summary

- ULTRASAT camera thermal design and analysis was performed for all operational modes with best and worst case performance of the thermal chain.
- Required temperature stability was achieved with active thermal control. Thermal control average power consumptions are:
  - Imaging 1.3 to 7.4 W
  - Camera off 5 W (camera) and 12 W (satellite)
  - Decontamination (heating-up) 16 W (camera) plus 60 W (satellite)
  - Decontamination (steady-state) 13.5 W (camera) plus 25 W (satellite)
- Sensor surface can be maintained within 1 K during 300 s.
- A development model of the camera is currently build up to test & verify the performance of the thermal control system.

Acknowledgement

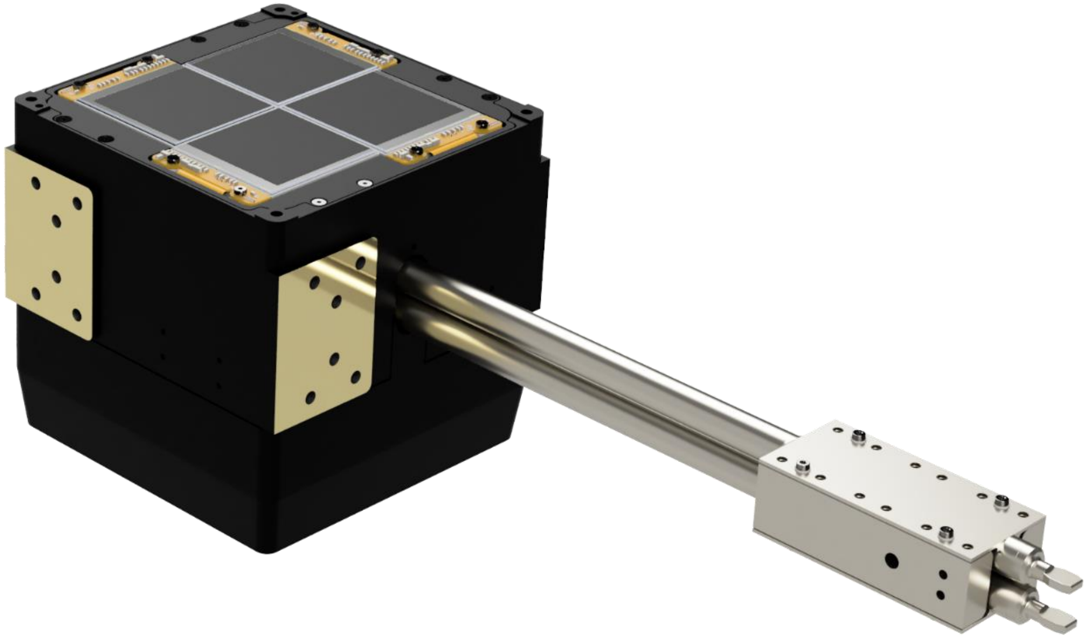
- We would like to acknowledge the help and support of the ULTRASAT camera advisory board, composed of Andrei Cacovean, Maria Fürmetz, Norbert Kappelmann, Olivier Limousin, Harald Michaelis, Achim Peters, Chris Tenzer, Simone del Togno, Nick Waltham and Jörn Wilms.

- We would also like to express our gratitude to the Institute of Planetary Research of the DLR for their advice.

Thank you for your attention! Questions?

ULTRASAT

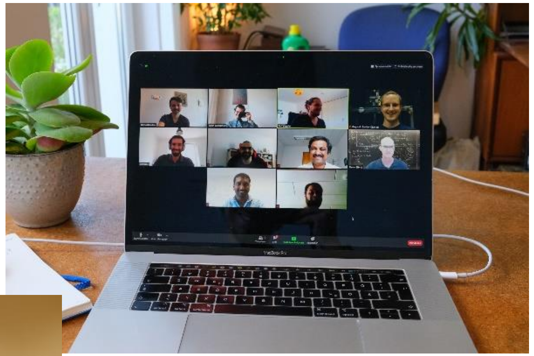
SKYLIGHT TO SPACE

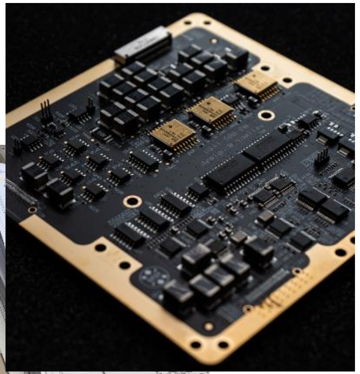


Back-up

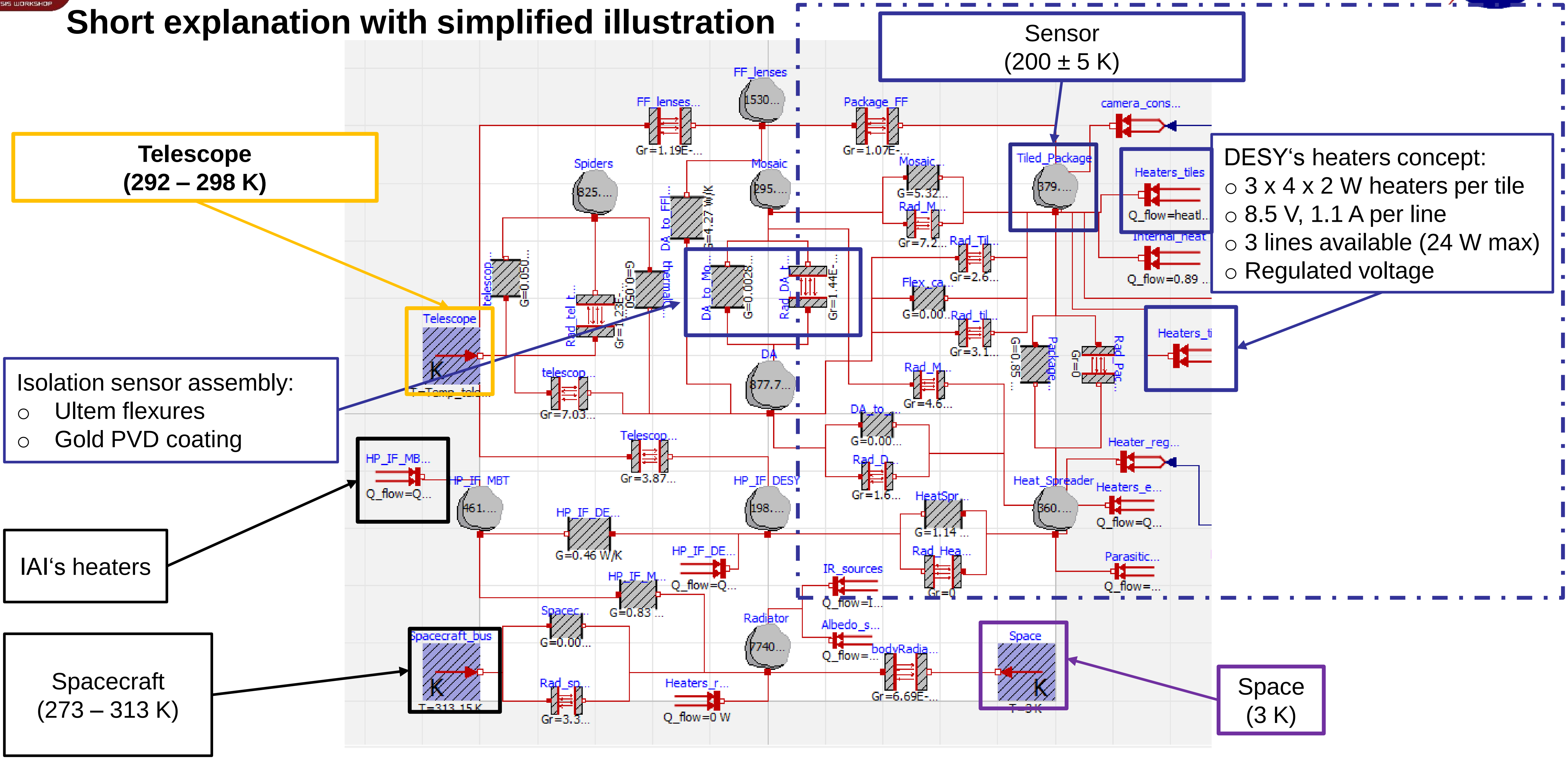
ULTRASAT camera status

- **09/2019**: Projekt entry DESY
- **03/2020:** System Design Review
- **12/2020:** Preliminary Design Review
- **10/2021:** Critical Design Review
- **Q3 2022:** Clean room & vacuum chamber operative
- **09/2022**: 1st sensor units in Zeuthen
- **Q4 2022**: Production & tests Prototype
- **Q3 2023:** Delivery of engineering model to partners
- **Q4 2023:** Delivery Flight model
- **Q2/Q3 2025:** Satellite launch
- **2025 - ?:** Scientific mission work / Data Analysis (3-6 years)



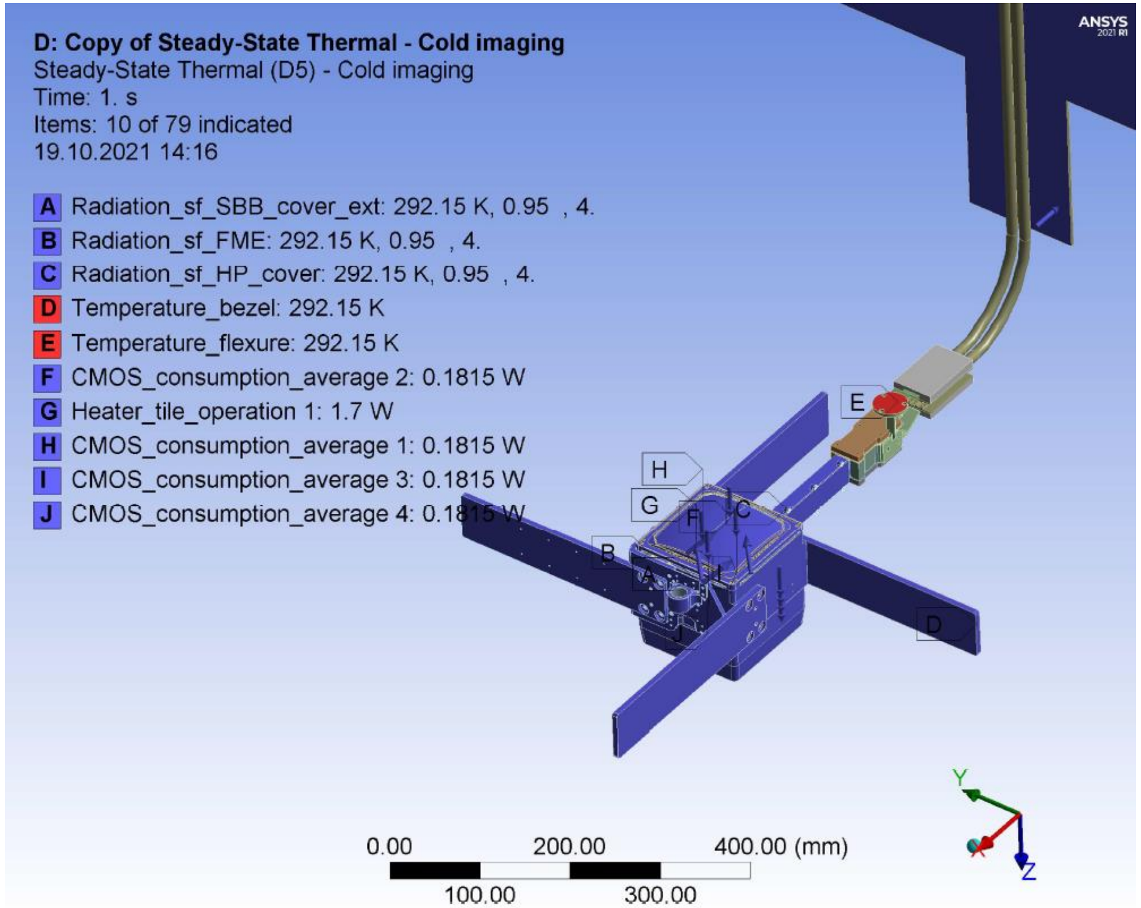


Short explanation with simplified illustration



FE model description

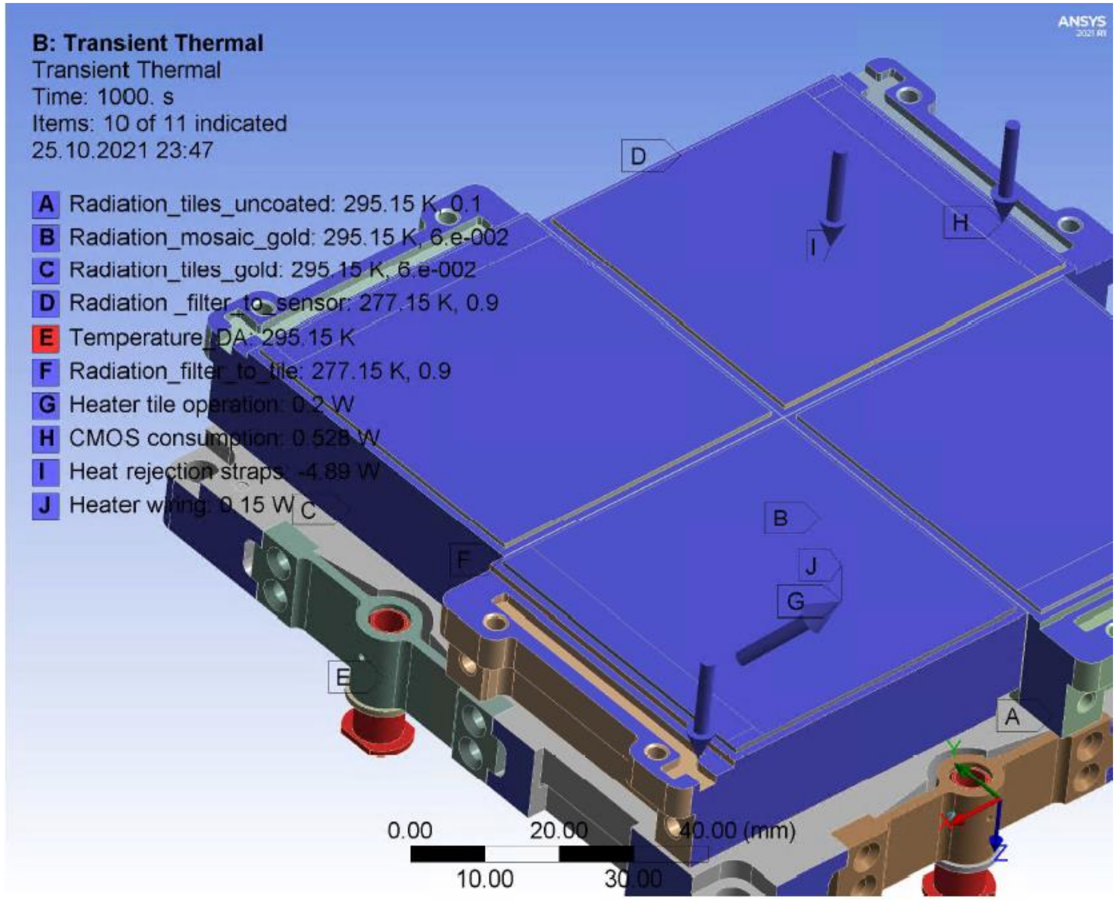
- CAD models included:
  - IAI: Thermal chain until radiator
  - ELOP: optical parts
- Telescope/bezel between 292 - 298 K
- Radiator
  - Equivalent area 0.39 m²
  - Emissivity 0.88-0.90
  - Absorptivity 0.25-0.40
- Thermal model
  - Thermal conductances calculated
  - 8 enclosures or cavities created
- Equivalent modelling generated for
  - Thermal straps
  - Heat pipes
  - Radiator



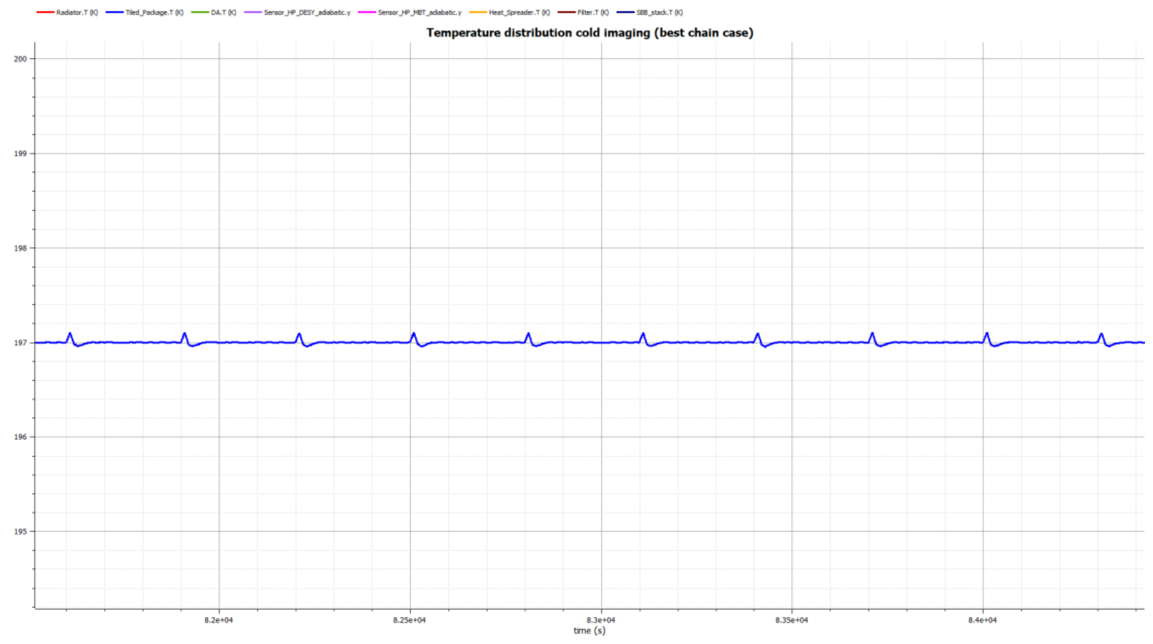
Mosaic assembly transient analysis

- Requirements
  - $T_{sensor} = 200 \pm 5$ K
  - $\Delta T_{sensor} \leq 1$ K in 300 s
  - Images of 300-600s
  - Max read-out 20 s

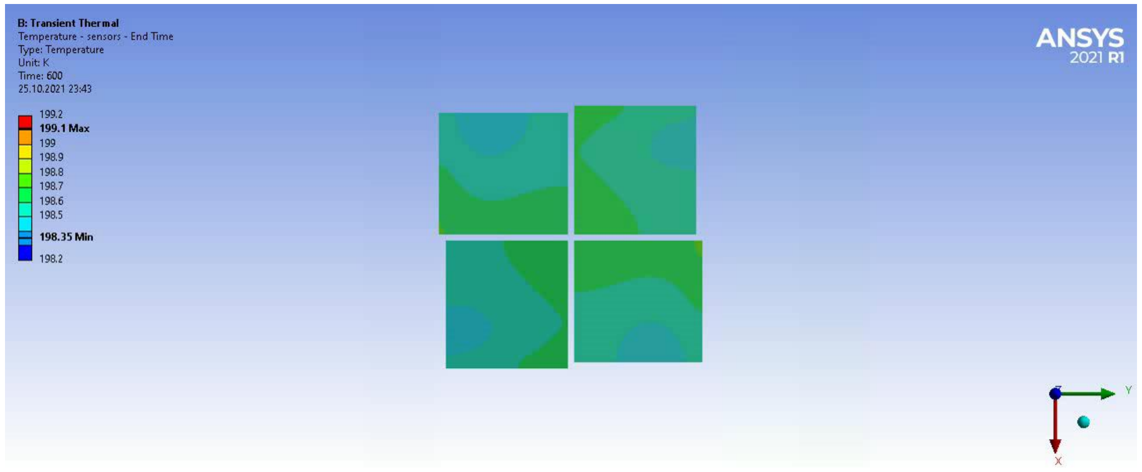
- Considerations
  - Min load on system → Effect of read-out increased
  - Sensor's hottest area: ADC's
  - Sensor's coldest area: I/F to straps on tiles
  - Image of 300 s considered (280 s / 20 s read-out)
    1. Temperature distribution before read-out
    2. Temperature distribution after read-out



Modelica transient analysis



FEM transient analysis



Thermal case: decontamination

- Target temperature: 348.15 K

- Heating-up
  - Telescope temp (operating) 292-298 K
  - Space temperature 3 K
  - Best chain (if dry-out not relevant)
  - Radiator emissivity $\varepsilon_{rad} = 0.9$
  - Radiator dimensions $A = 0.39\ m^2$
  - Sensor emissivity $\varepsilon_{sens} = 0.5 - 0.9$

- Heaters
  - DESY 16 W (24 W in total)
  - Filter 24 W (ELOP)
  - HP IAI evaporator 60 W (IAI)
  - Radiator 200 W (IAI)

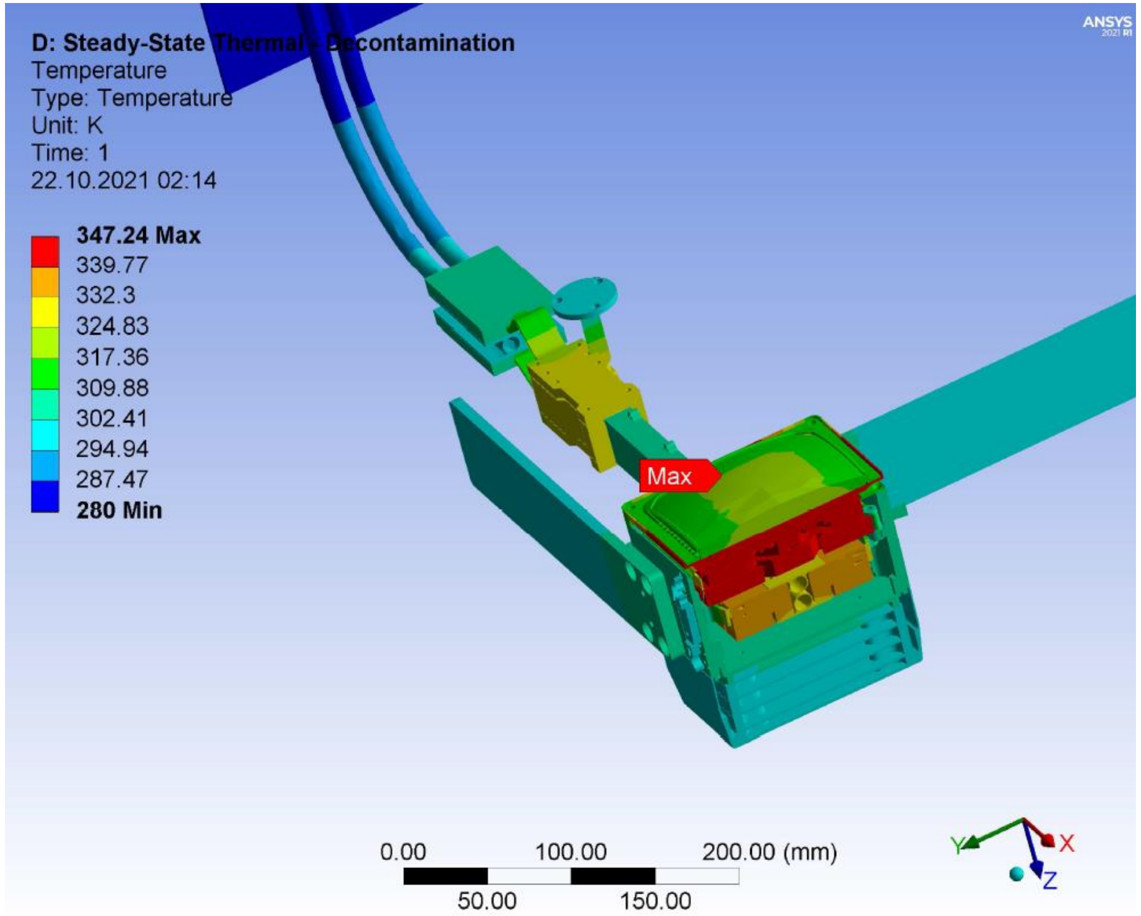
Outgassing mode

- Selected temperature regime:

Surface	Temperature
Detector	75°C
Detector housing	13°C
FF lenses	65°C
Corrector lenses	3°C, 16°C
Mirror, Mirror tube	19°C
Bezel	18°C
Baffle	-56°C, -10°C

Thermal case: decontamination

- Will be performed several times
  - 1^{st} time, beginning of mission
  - $T_{sensor, decontamination}$ = 75° C
  - $T_{Telescope}$ = 19 – 25 ºC
- How to heat-up the sensor?
  - Sensor to be heated-up first (filter follows)
  - Tile heaters ~ 16 W (24 W)
  - IAI's HP evaporator ~ 50 W
  - IAI's HP to achieve dry-out when possible
- How to maintain the sensor heated at 75ºC?
  - **Dry-out** in IAI's HP < 5 W steady-state
  - **No dry-out** in IAI's HP ~ 46 W steady-state
  - Filter at 65° C ~ 24 W steady-state



Thermal case: decontamination