## **TFAWS Active Thermal Paper Session**



# Design of the thermal control system for the ULTRASAT camera



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Presented By Juan María Haces Crespo (DESY)

Thermal & Fluids Analysis Workshop TFAWS 2022 September 6<sup>th</sup>-9<sup>th</sup>, 2022 Virtual Conference





Israel Aerospace Industries

ElOp, Elbit Systems

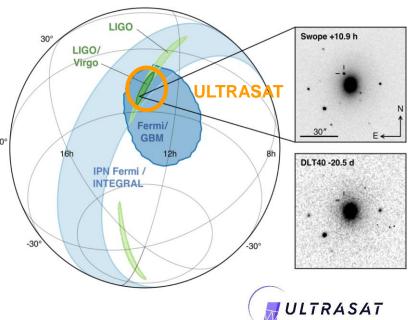


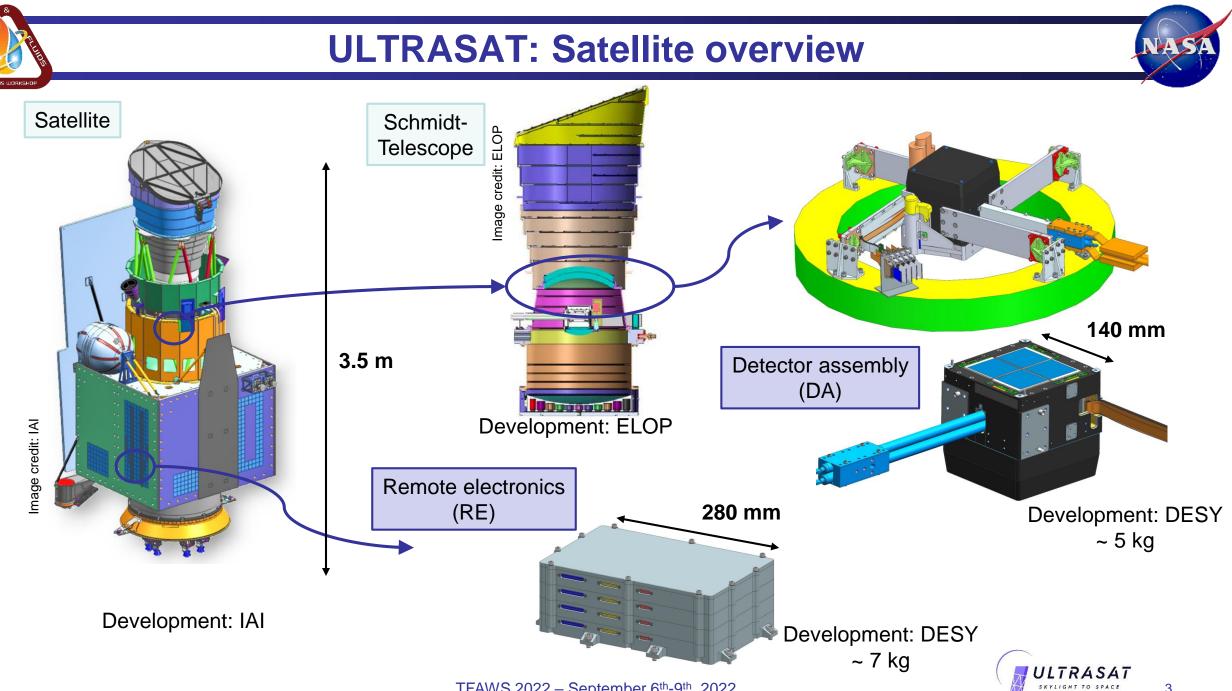
#### Astronomical satellite mission

- "Early warning system" for Earth-based observation of astronomical events by wide-angle telescope, permanent communication and < 15 min for reorientation.</li>
- Led by the Weizmann Institute of Science and the Israeli Space Agency
  - Satellite build by
  - Telescope build by
  - Camera build by
  - 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.

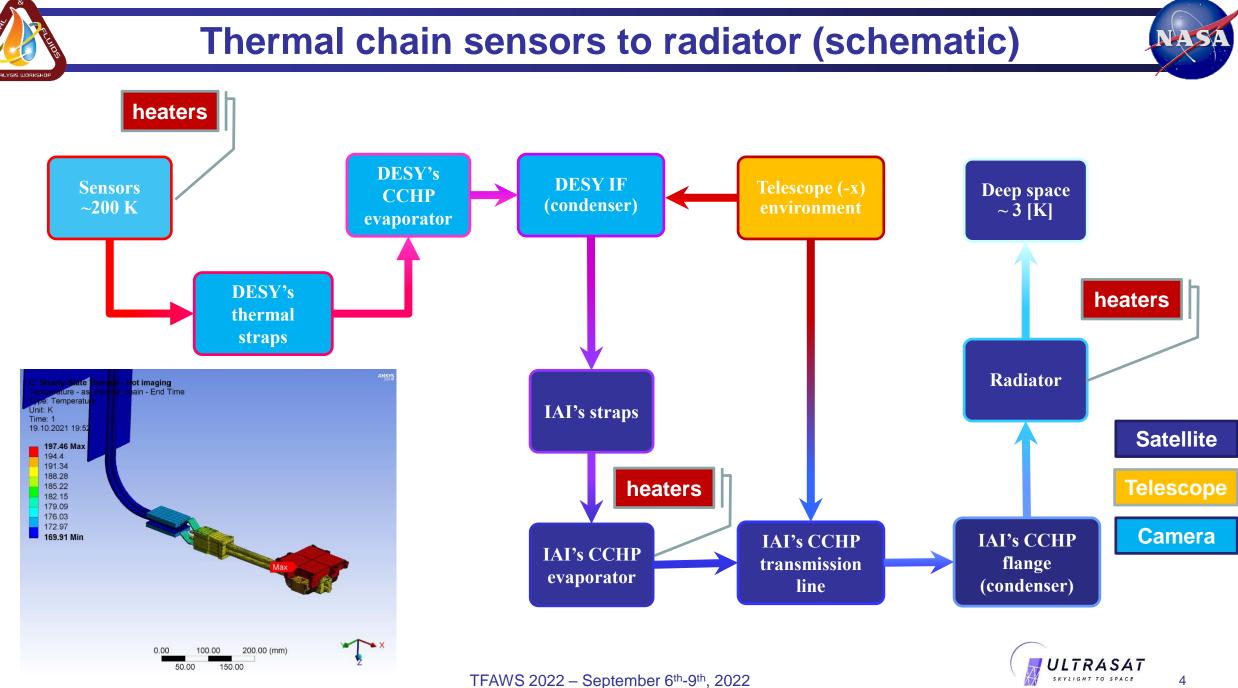
DESY







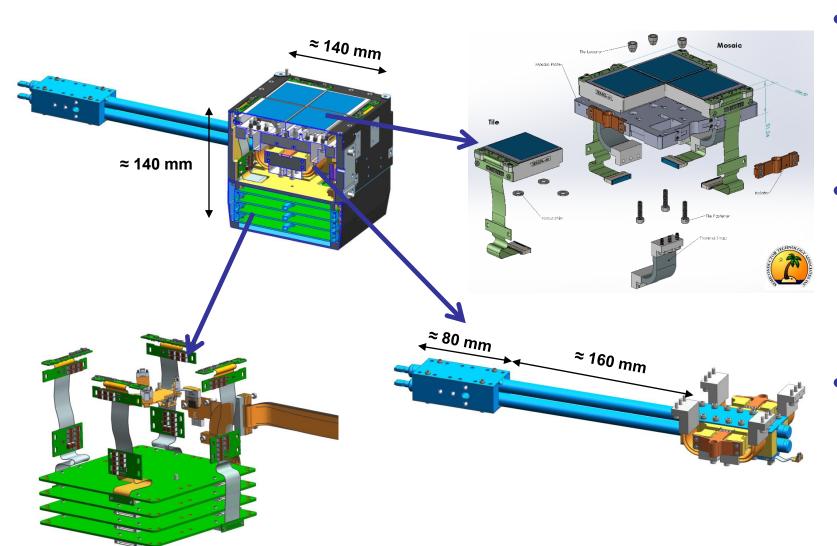
TFAWS 2022 – September 6th-9th, 2022





## **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.

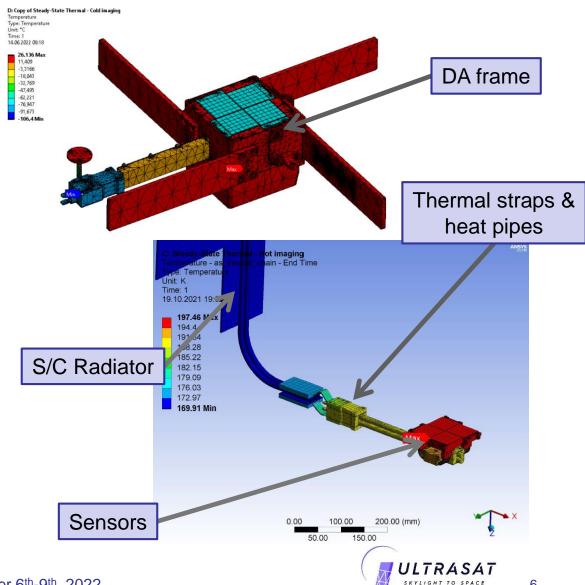




# **Thermal design**



- Thermal requirements
  - T<sub>sensor</sub> = 200 ± 5 K, ΔT ≤ 1 K in 300 s
  - Optical requirement  $\rightarrow$  T<sub>DA,frame</sub> ~ T<sub>telescope</sub>
    - $T_{telescope} = 295 \pm 3 \text{ K}$  ('environment')
  - 338 K < Tsensor < 348 K for decontamination
- How to decouple the sensor thermally?
  - ULTEM flexures  $\rightarrow$  low heat flow
  - DA inner surfaces  $\rightarrow$  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**



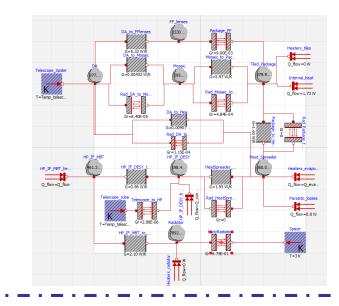
#### Simplified thermal model

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

Ho	rne Insert PageLayout For	nulas Data Review	View Help 🖓 Tr	ell me what you want									
Α	8	c	D	E	F	G	н	1	1	K	L	M	N
	Nominal												
	Elements			Cold Body	Thermal conductivity		Cross section			Thermal conductance			
	Heat along glue	glue	sensor die	sensor tile	1,30 W/m-K		2396 mm <sup>2</sup>	4		311,52 W/K			
	Heat along sensor tile	sensor tile	glue	thermal strap	110,00 W/m-K		3115 mm <sup>2</sup>	4	12460 mm <sup>2</sup>	84,40 W/K			
	Heat along mosaic plate Heat along mosaic plate interface	mosaic plate mosaic plate interface	mosaic plate interface DA frame*		110,00 W/m-K		1392 mm <sup>3</sup> 18 mm <sup>2</sup>	4	5568 mm <sup>2</sup> 144 mm <sup>2</sup>	10,56 W/K		2x4 vanes	
	Heat along mosaic plate interface Heat along DA middle plate	mosaic plate interface DA middle plate	DA frame*	mosaic plate	0,24 W/m-K 8,11 W/m-K		18 mm* 19321 mm <sup>2</sup>	8	144 mm* 19321 mm <sup>2</sup>	0,0029 W/K	0,27 W	2x4 vanes	
	Heat along DA frame*	DA frame*	spider	DA spacer DA middle plate	8,11 W/m-K 8,11 W/m-K		19321 mm <sup>2</sup> 695 mm <sup>2</sup>		2780 mm <sup>2</sup>	0.28 W/K	0,15 W		
	Heat along DA frame Heat along Stravlight Cover	Stravlight Cover	DA frame*	FF lenses	8,11 W/m-K		176 mm <sup>2</sup>	4		0,28 W/K			
	Heat along Strayinght Cover Heat along SBB	Strayight Cover	DA spacer	DA middle plate	10,50 W/m-k		1/6 mm <sup>2</sup>	4	57600 mm <sup>2</sup>	0,38 W/K 9.00 W/K	4,82 W	z-axis	
	Heat along \$88	588	DA spacer	DA middle plate	0,25 W/m-k		24400 mm <sup>2</sup>	-	384 mm <sup>2</sup>	9,00 W/K	0.00 W		
	Heat along DA spacer	DAspacer	SBB	cover 588	167.00 W/m-K		3375 mm <sup>2</sup>		3375 mm <sup>2</sup>	46.97 W/K		Arans or years	•
	Heat along cover SBB	cover SBB	cover SBB	DA spacer	167,00 W/m-K		378 mm <sup>2</sup>		1512 mm <sup>2</sup>	4,01 W/K	0,40 W		
	Heat along 588 to spider interface			DA side walls	0.00 W/m K		2-mm2	4	9-mm <sup>2</sup>	0.00-W/K			
	Heat along Harness: sensor cables			SRR	0.00 W/m-K		3 mm <sup>2</sup>	4	10 mm <sup>2</sup>	0.00 W/K	0.00 W	See wiring & F	larness
	Heat along thermal strap	thermal strap	sensor tile	IF straps to HP y-a	2000.00 W/m-K	65.00 mm	100 mm <sup>2</sup>	4	400 mm <sup>2</sup>	12.31 W/K	51.69 W		
	Heat along IF straps to HP y-axis	IF straps to HP y-axis	thermal strap	IF straps to HP x-a	199,10 W/m-K	29,15 mm	389 mm <sup>2</sup>	2	777 mm <sup>2</sup>	5.31 W/K	10.61 W		
	Heat along IF straps to HP x-axis	IF straps to HP x-axis	IF straps to HP y-axis	HP	199,10 W/m-K	45,00 mm	288 mm²		576 mm <sup>2</sup>	2.55 W/K	10,19 W		
	Heat along HP mount lower part	HP-mount-lower-part	DA side walls	HP mount x axis	8,11 W/m K	62,50 mm	190 mm <sup>2</sup>	5	380 mm <sup>2</sup>	0,05 W/K	AN/A		
	Heat along Interface HP to DA	Interface HP to DA	DA frame*	IF straps to HP y-a	0,24 W/m-K	10,00 mm	42 mm <sup>2</sup>	6	252 mm <sup>2</sup>	0,0060 W/K	0,60 W	3x2 vanes	
	Heat along HP evaporator	HP evaporator	Cross_IF y-axis	HP	199,10 W/m-K								
	Heat along HP condenser	HP condenser	HP	LAL IF	199,10 W/m-K	80,00 mm							
	Heat along HP	HP											
	Extreme Case 1							_					
	Elements	Body	Hot body	Cold Body	Thermal conductivity		Cross section			Thermal conductance			
	Heat along thermal strap	thermal strap	sensor tile	IF straps to HP y-a	2200,00 W/m-K	65,00 mm	100 mm²	4	400 mm <sup>2</sup>	13,54 W/K	56,86 W	For TAI PGS	
	Extreme Case 2												
	Extreme Case 2							_			_		
		Body	Hot body	Cold Body	Thermal conductivity		Cross section	Qty	Total Cross section 400 mm <sup>2</sup>	Thermal conductance			
	Heat along thermal strap	thermal strap	sensor tile	IF straps to HP y-a	1600,00 W/m-K	65,00 mm	100 mm <sup>2</sup>	4	400 mm*	9,85 W/K	41,35 W	For graphene	

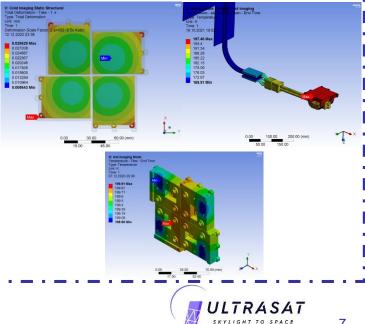
#### E2E model

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



#### FE model

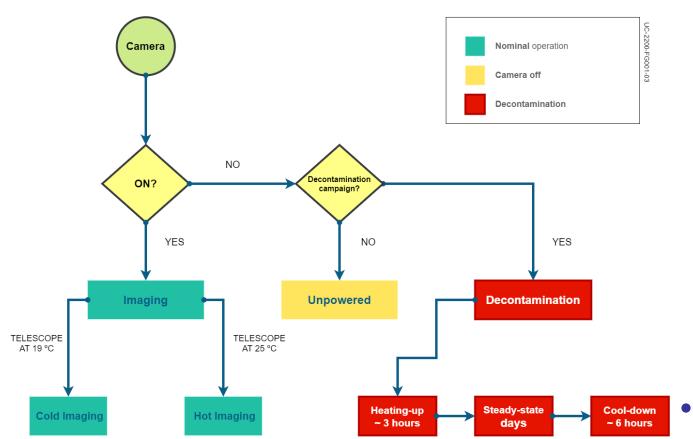
- ANSYS
- Local temperature effects
- Coupling thermal mechanical
- Exchange with IAI/ELOP





## **Thermal cases**





# • Thermal analysis

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





## **Imaging case example**

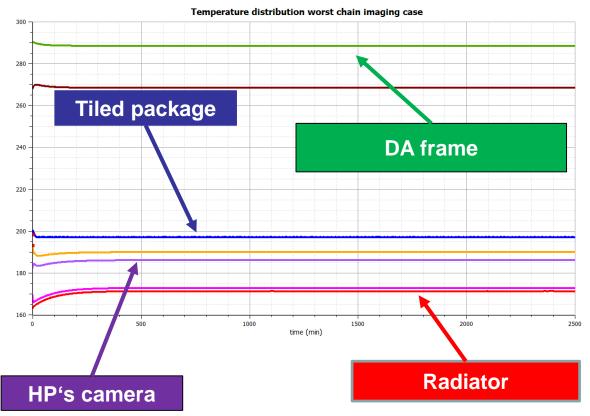


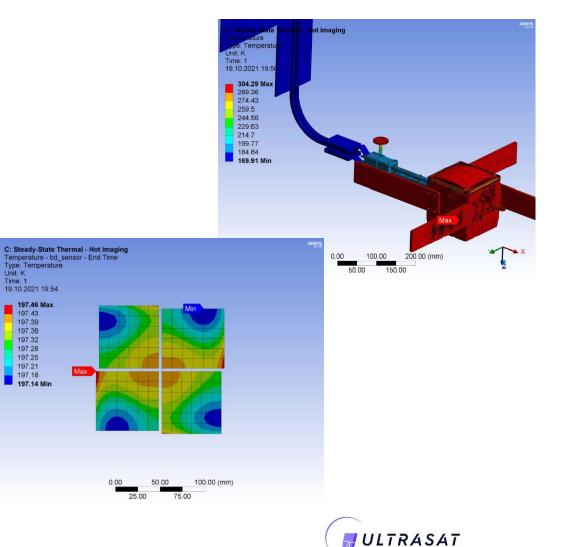
## **FEM Steady-state**

#### Images of 300 s - 280 s integration

#### - 20 s read-out

Radiator.T (K) — Tiled\_Package.T (K) — DA.T (K) — Sensor\_HP\_DESY\_adiabatic.y — Sensor\_HP\_MBT\_adiabatic.y — Heat\_Spreader.T (K) — Filter.T (K)





SKYLIGHT TO SPACE



# 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
  - Camera off -
  - Decontamination (heating-up)
  - Decontamination (steady-state) -

1.3 to 7.4 W

- 5 W (camera) and 12 W (satellite)
- 16 W (camera) plus 60 W (satellite)
- 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.







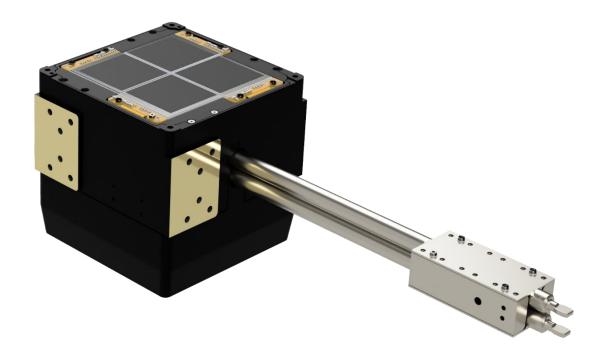
- We would like to acknowledge the help and support of the ULTRASAT camera advisory board, composed of Andrei Cacovean, Maria Fürmetz, Norbert Kappelmann, Olivier Limousin, Harald Michaelis, Achim Peters, Chris Tenzer, Simone del Togno, Nick Waltham and Jörn Wilms.
- We would also like to express our gratitude to the Institute of Planetary Research of the DLR for their advice.





# Thank you for your attention! Questions?













# **ULTRASAT camera status**



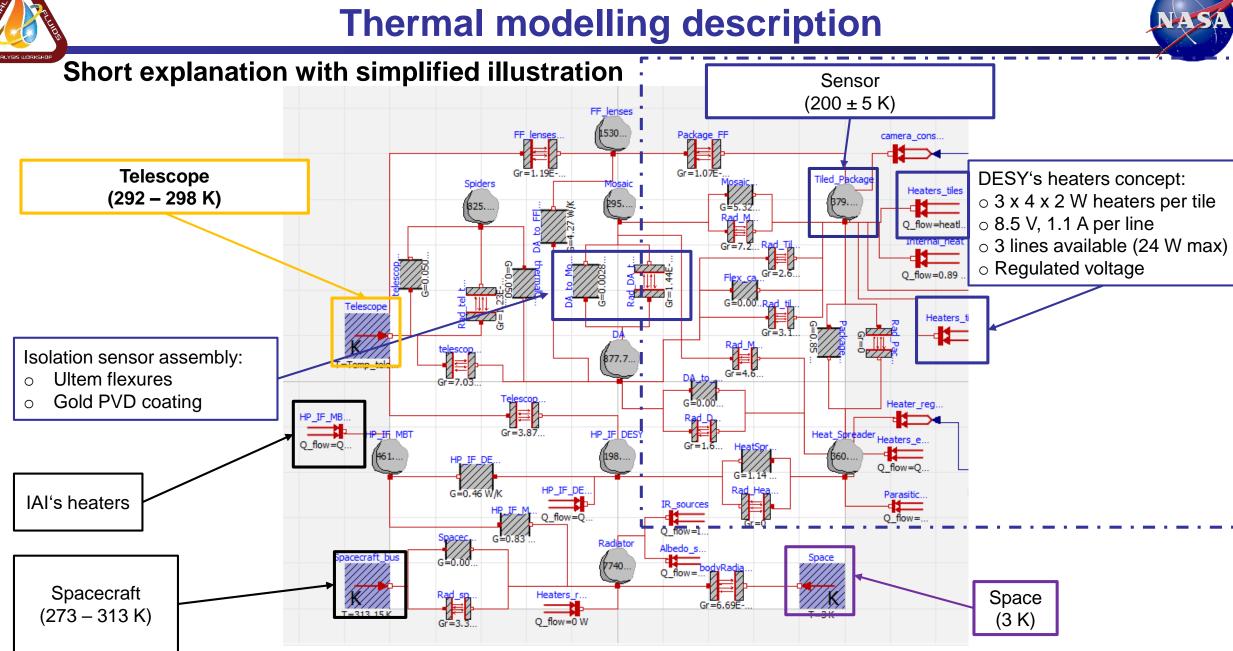
- 09/2019: Projekt entry DESY
- 03/2020: System Design Review
- **12/2020:** Preliminary Design Review
- **10/2021:** Critical Design Review
- Q3 2022: Clean room & vacuum chamber operative
- 09/2022: 1st sensor units in Zeuthen
- Q4 2022: Production & tests Prototype
- **Q3 2023:** Delivery of engineering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













# **FE model description**



#### • CAD models included:

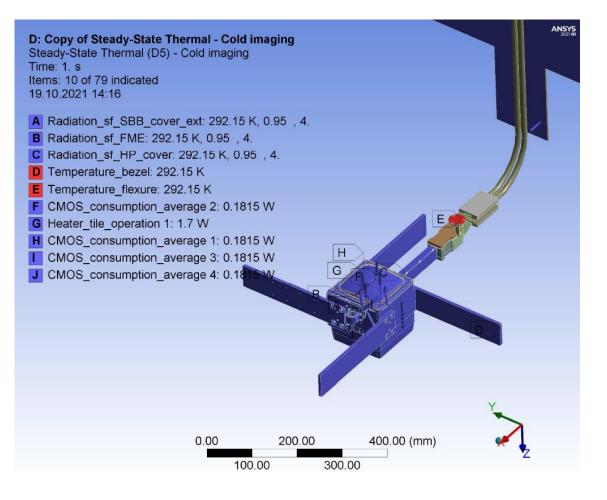
- IAI: Thermal chain until radiator
- ELOP: optical parts
- Telescope/bezel between

292 - 298 K

Radiator

-	Equivalent area	0.39 m²
-	Emissivity	0.88-0.90
-	Absorptivity	0.25-0.40

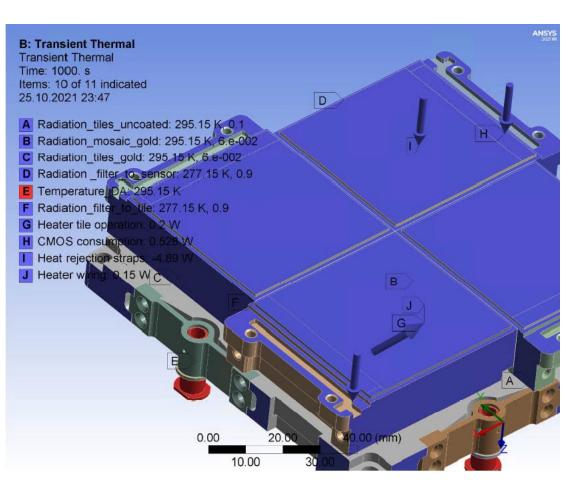
- Thermal model
  - Thermal conductances calculated
  - 8 enclosures or cavities created
- Equivalent modelling generated for
  - Thermal straps
  - Heat pipes
  - Radiator







- Requirements
  - $T_{sensor} = 200 \pm 5 \text{ K}$
  - $\Delta T_{sensor} \le 1 \text{ K in 300 s}$
  - 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

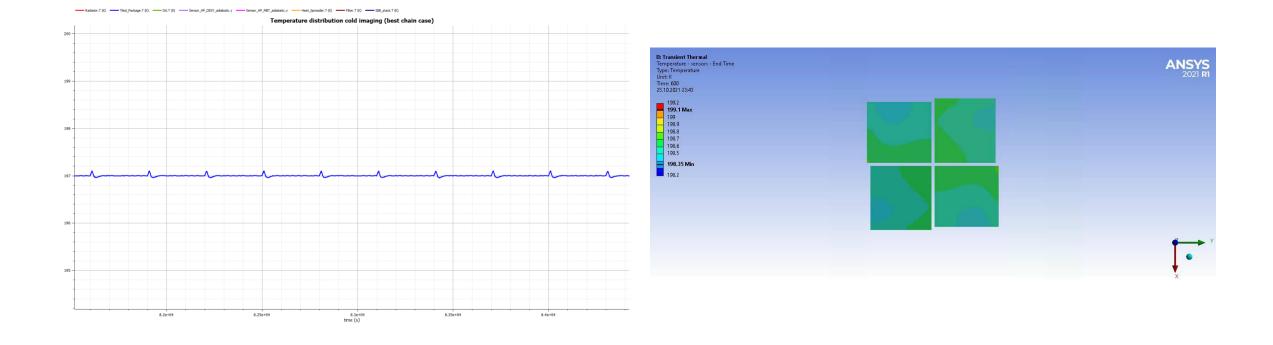






## Modelica transient analysis

## **FEM transient analysis**









• Target temperature: 348.15 K

#### • Heating-up

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

# 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		

#### • Heaters

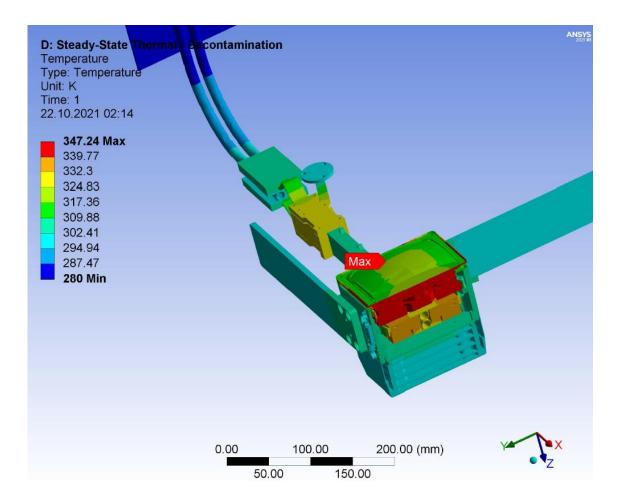
- o DESY
- $\circ$  Filter
- o HP IAI evaporator
- $\circ$  Radiator

16 W (24 W in total) 24 W (ELOP) 60 W (IAI) 200 W (IAI)





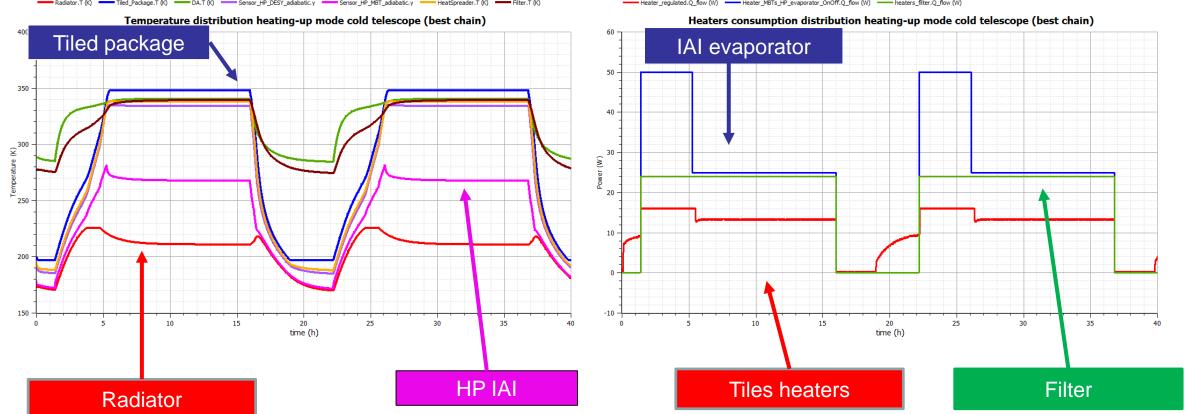
- Will be performed several times
  - 1<sup>st</sup> time, beginning of mission
  - $T_{\text{sensor, decontamination}} = 75^{\circ} C$
  - $T_{\text{Telescope}} = 19 25 \, ^{\circ}\text{C}$
- How to heat-up the sensor?
  - Sensor to be heated-up first (filter follows)
  - Tile heaters ~ 16 W (24 W)
  - IAI's HP evaporator ~ 50 W
  - IAI's HP to achieve dry-out when possible
- How to maintain the sensor heated at 75°C?
  - **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**





r Radiator. T (K) 🛛 Tiled\_Package. T (K) 🚽 DA. T (K) Sensor\_HP\_DESY\_adiabatic. y 🥌 Sensor\_HP\_MBT\_adiabatic. y HeatSpreader. T (K) Filter.T (K)