Appendix L

Thermal model and analysis of the BELA transmitter Stavroudis baffle in Mercury orbit

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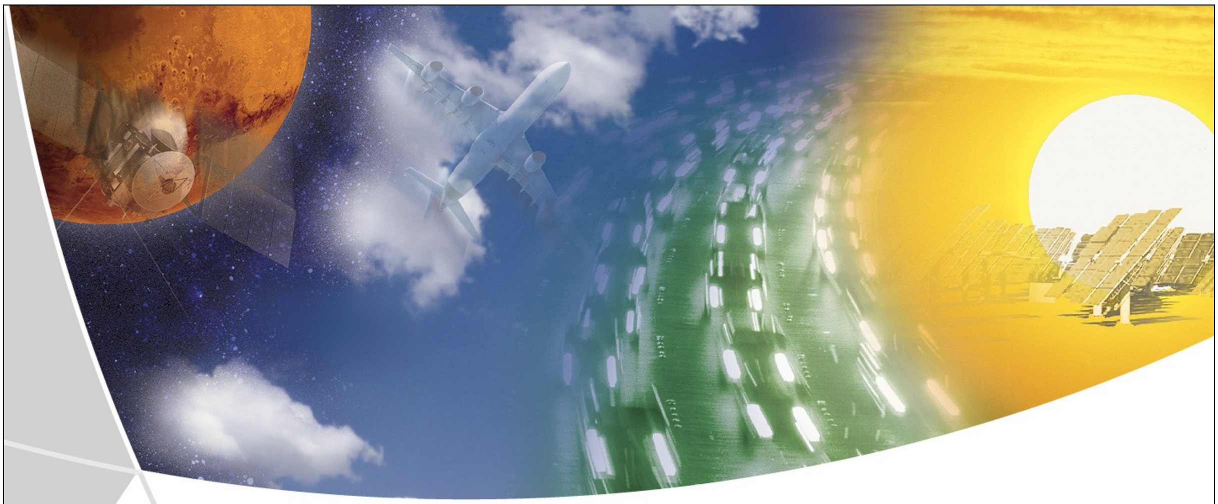
Abstract

In the frame of the ESA BepiColombo mission to the planet Mercury the German Aerospace Center (DLR), in cooperation with the University of Bern, is designing the first European laser altimeter for planetary exploration (BELA).
While orbiting Mercury the solar flux reaches 14 kW and strikes on the instrument at angles of $\geq$ 38 deg from the instrument line of sight. The planet surface reaches 700 K while the view factor with the instrument aperture is high due to the low orbit altitude.
Under these conditions a major challenge is the design of the instrument baffles, which shall avoid direct sunlight to reach the optics, minimize the heat load to the instrument and the S/C cavity and reduce stray light.
We describe the thermal model of the transmitter baffle, focusing on advanced features like the approximation of ellipsoids and hyperboloids in the geometrical mathematical model, its optimization with respect to computational time and baffle efficiency, the dynamic implementation of wavelength dependant thermo- optical properties for the calculation of both absorbed planetary fluxes – as function of Mercury surface temperature – and radiative conductances (GR).
The worst cases selection in the scenario of the whole Mercury orbit about the sun is also presented followed by a detailed overview of the analysis results.



Thermal model and analysis of the BELA transmitter Stavroudis baffle in Mercury orbit

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The BepiColombo mission

BepiColombo is the first European mission to explore the planet Mercury, carried out jointly by ESA and JAXA

Launch is scheduled for August 2013; orbit insertion in late summer 2019

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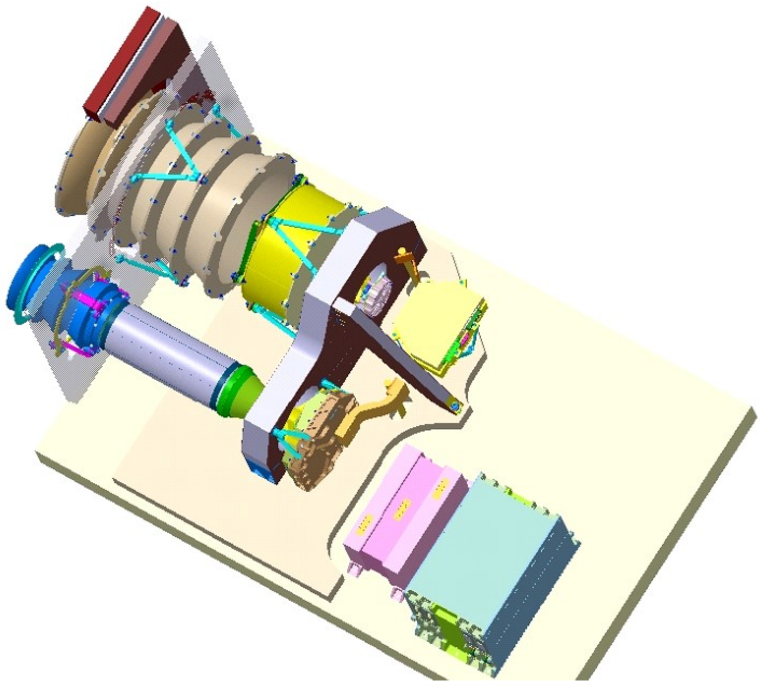
BELA Stavroudis Baffle in Mercury orbit

The BepiColombo Laser Altimeter (BELA)



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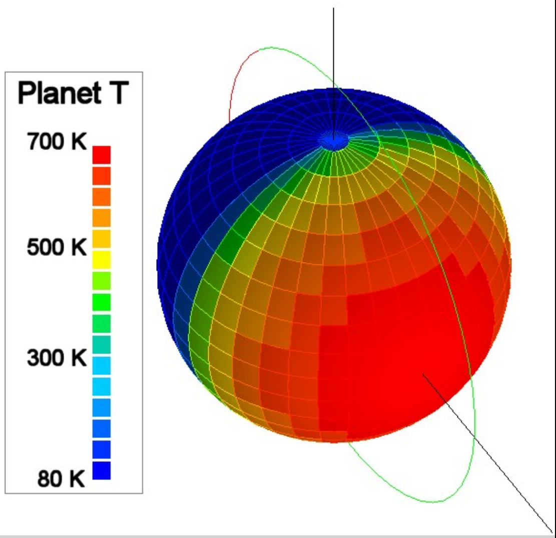
The Mercury environment

0.38 AU → thermal harsh environment:

- Solar flux up to 14 kW
- Planet surface 80 K < T < 700 K
  - → very high IR planetary fluxes
  - → substantial ΔT along the orbit

Charged particles, solar wind and high VUV radiation:

- ε, α ageing



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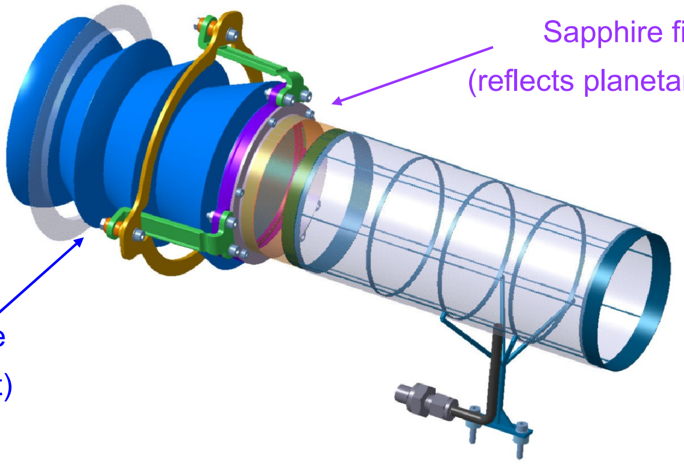
Transmitter baffle

Requirements:

- Avoid direct sun light on the optics
- Minimize the environmental heat load to both instrument and s/c
- Reduce the stray light



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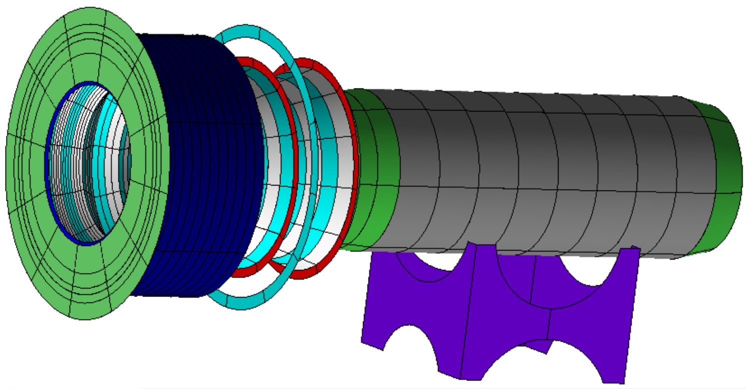
Thermal model

- 924 thermal nodes (360 for the baffle)
- 7329 radiative active faces (4512 for the baffle)

- Complex 3D optical surfaces in the GMM
- Temperature dependant thermo-optical properties



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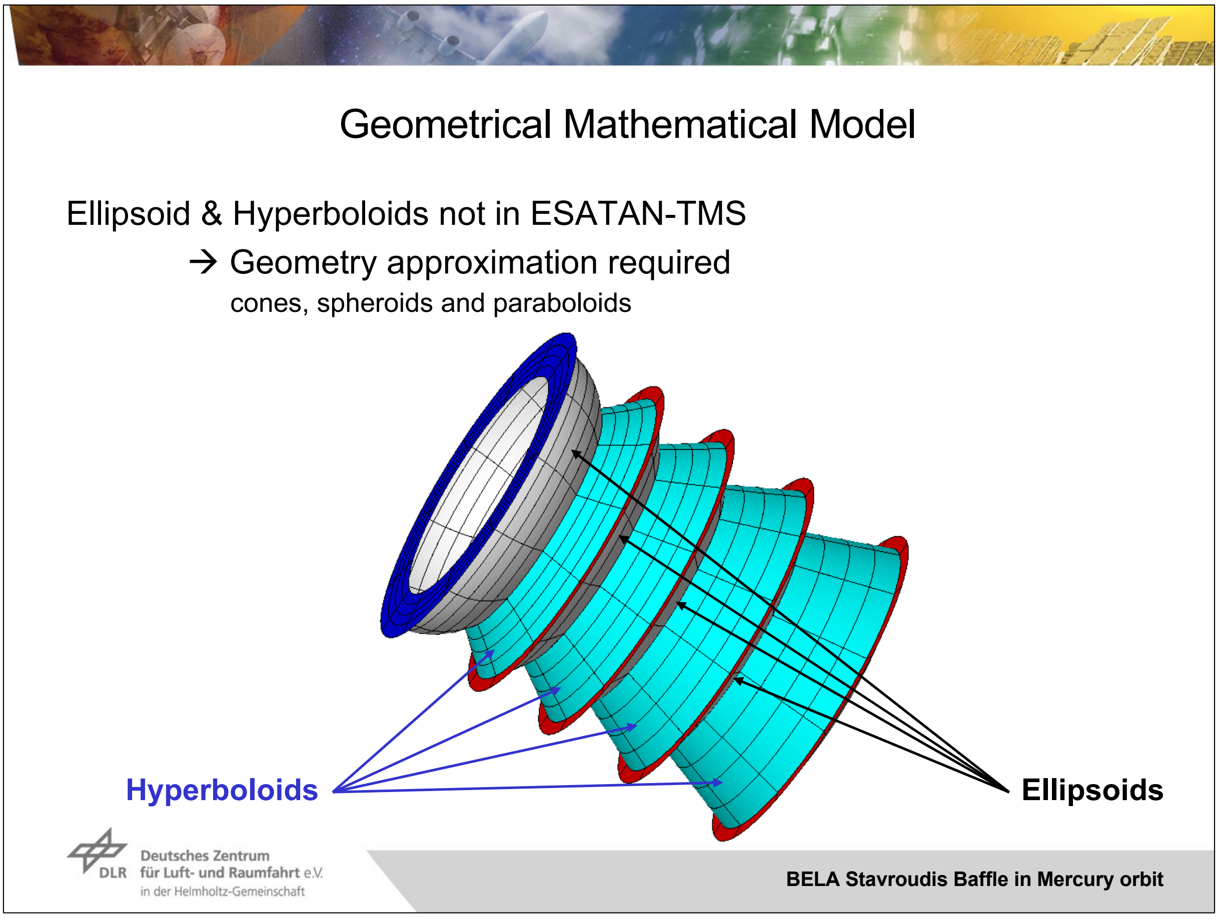
BELA Stavroudis Baffle in Mercury orbit


Geometrical Mathematical Model
Ellipsoid & Hyperboloids not in ESATAN-TMS
→ Geometry approximation required
cones, spheroids and paraboloids
Hyperboloids
Ellipsoids
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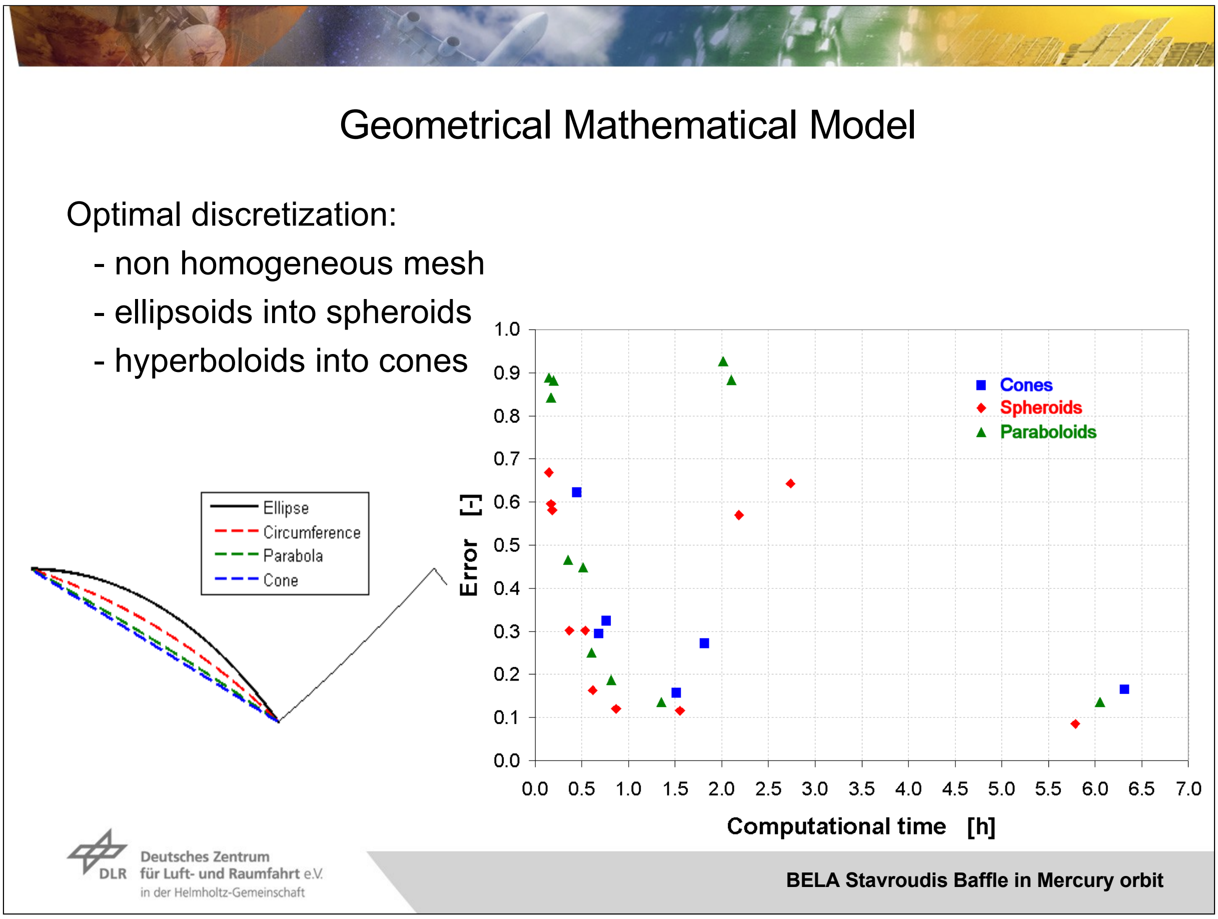
Geometrical Mathematical Model
Optimal discretization:
- non homogeneous mesh
- ellipsoids into spheroids
- hyperboloids into cones
Ellipse
Circumference
Parabola
Cone
Error [-]
Computational time [h]
Cones
Spheroids
Paraboloids
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0
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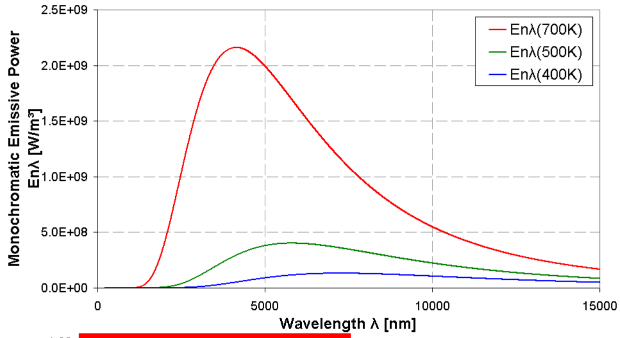
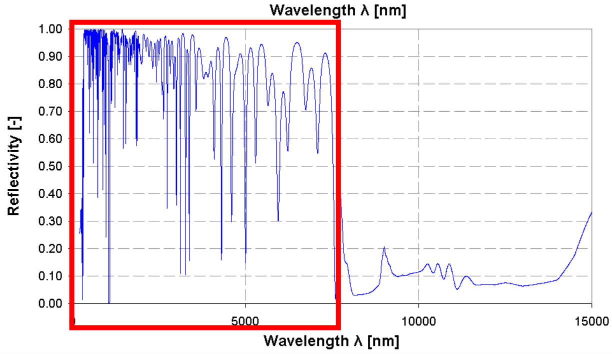
Temperature dependant thermo-optical properties

Mercury T = [80-700] K
→ different emission spectra



Filter properties strongly λ-dependant

→ Th-opt properties to be updated as function of planet temperature



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Temperature dependant thermo-optical properties

On each orbit position the filter spectrum is weighted on the planet spectrum

Grey-body assumption → the emission spectrum is function of the temperature

Flux through aperture:

$$QE = \varepsilon \cdot \sigma \cdot F \cdot T_{EQ}^4$$

Unknowns

F can be calculated analytically or numerically
QE is calculated by ESATAN-TMS
$T_{EQ}(t)$ → ρ(t), ε(t), τ(t)

Implementation of T-dependant GRs requires high computational resources!

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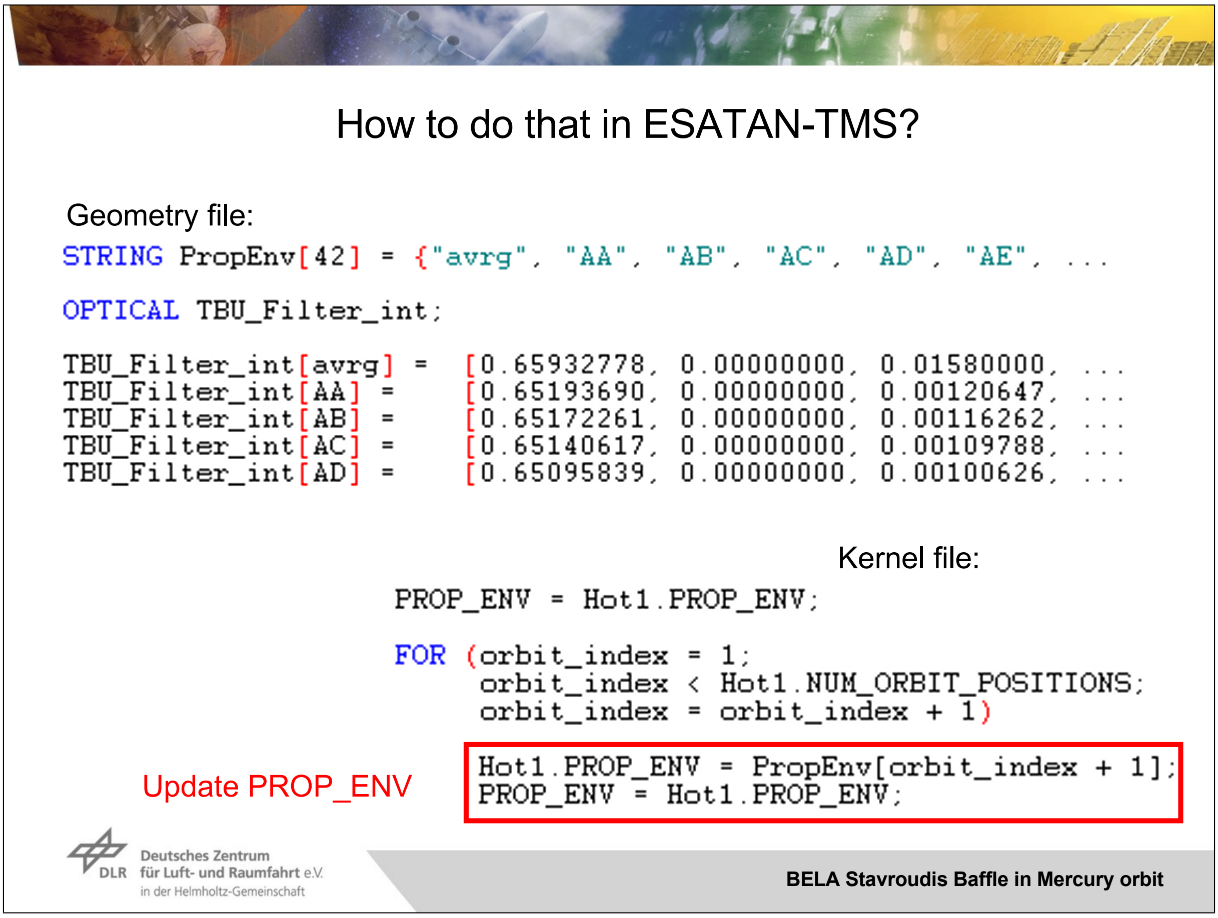
How to do that in ESATAN-TMS?
Geometry file:
STRING PropEnv[42] = {"avrg", "AA", "AB", "AC", "AD", "AE", ...
OPTICAL TBU_Filter_int;
TBU_Filter_int[avrg] = [0.65932778, 0.00000000, 0.01580000, ...
TBU_Filter_int[AA] = [0.65193690, 0.00000000, 0.00120647, ...
TBU_Filter_int[AB] = [0.65172261, 0.00000000, 0.00116262, ...
TBU_Filter_int[AC] = [0.65140617, 0.00000000, 0.00109788, ...
TBU_Filter_int[AD] = [0.65095839, 0.00000000, 0.00100626, ...
Kernel file:
PROP_ENV = Hot1.PROP_ENV;
FOR (orbit_index = 1;
orbit_index < Hot1.NUM_ORBIT_POSITIONS;
orbit_index = orbit_index + 1)
Hot1.PROP_ENV = PropEnv[orbit_index + 1];
PROP_ENV = Hot1.PROP_ENV;
Update PROP_ENV
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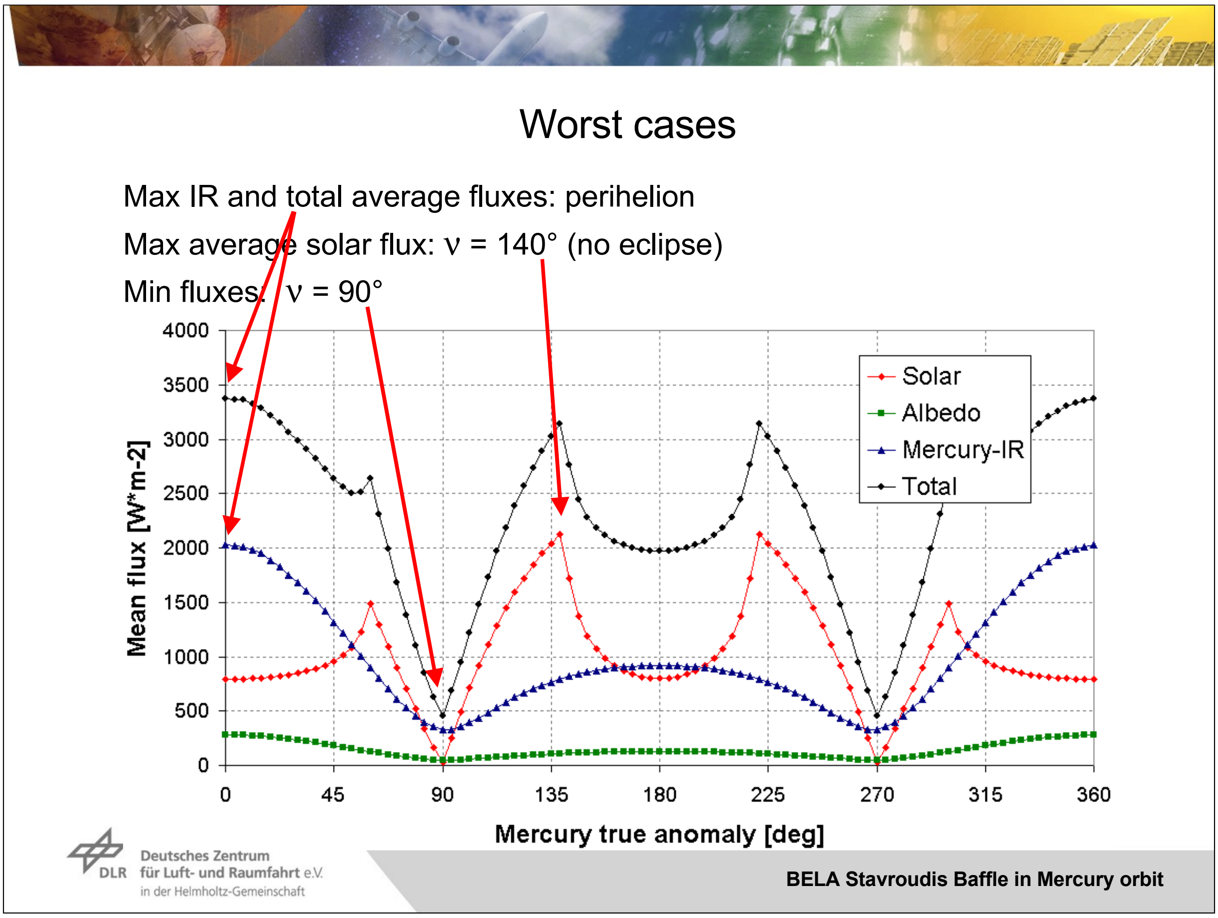
Worst cases
Max IR and total average fluxes: perihelion
Max average solar flux: ν = 140° (no eclipse)
Min fluxes: ν = 90°
4000
3500
3000
2500
2000
1500
1000
500
0
Mean flux [W*m-2]
0
45
90
135
180
225
270
315
360
Mercury true anomaly [deg]
Solar
Albedo
Mercury-IR
Total
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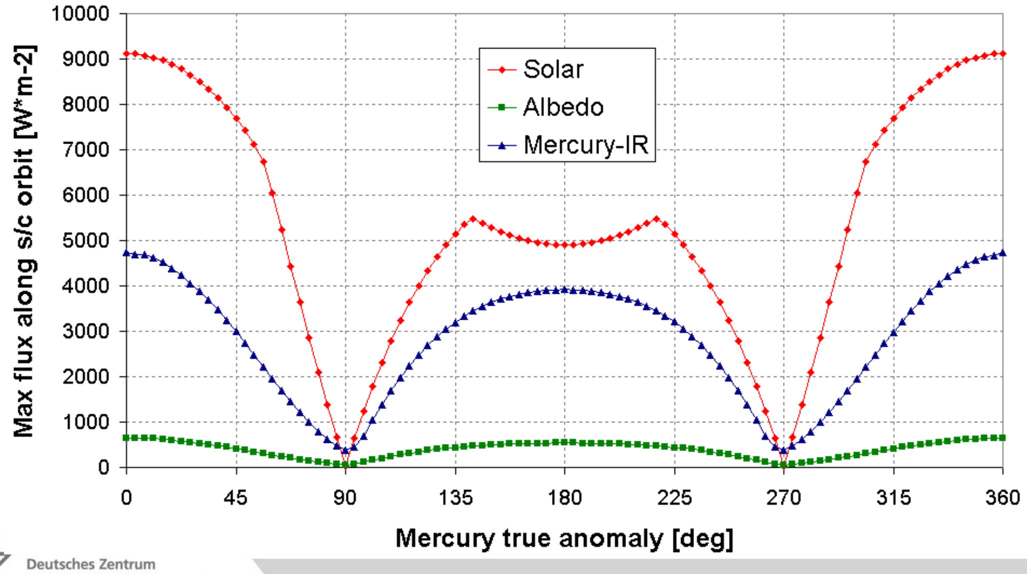
Worst cases

Peak of solar and IR fluxes: perihelion



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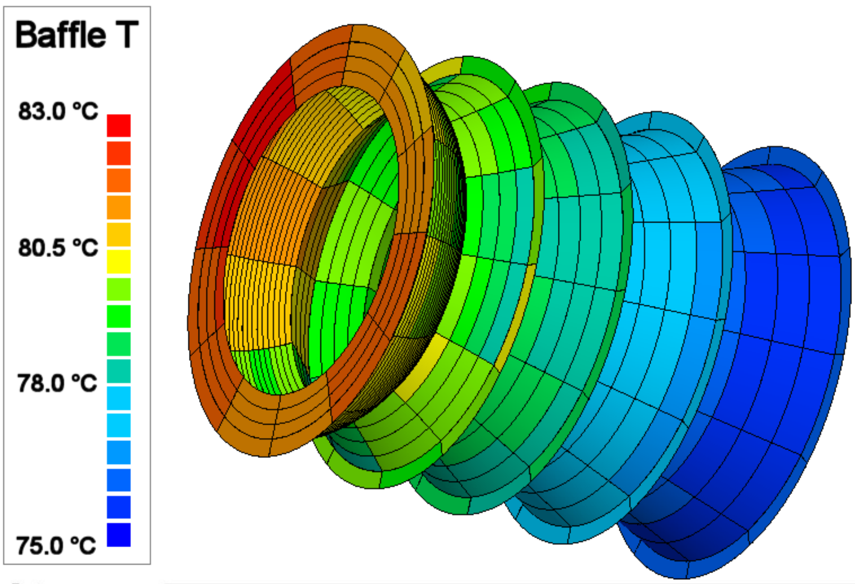
Analysis results: Steady state

Mercury at perihelion, BOL



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BELA Stavroudis Baffle in Mercury orbit

Analysis results: Steady state

Absorbed and rejected fluxes

At the aperture	85.2 W	
Instrument (sink)	0.06 W	0.07 %
S/C (sink)	5.22 W	6.12 %
Rejected	79.9 W	93.81 %
TOT	85.2 W	100.00 %

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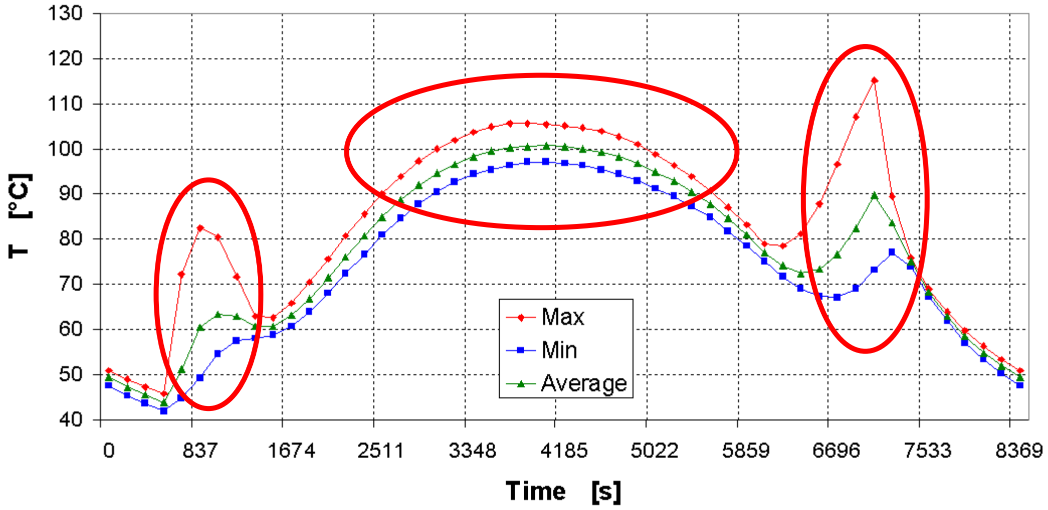
Analysis results: Transient



TMax = 115 °C

TMin = 42 °C

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