Appendix E

Development of methodologies for Brightness Temperature evaluation for the MetOp-SG MWI radiometer

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Abstract

The MicroWave Instrument (MWI) is a conical scanning radiometer, which shall be embarked on MetOp Second Generation satellite. MWI will provide precipitation monitoring as well as sea ice extent information. It is now entering the detailed design phase.
Conical scanning radiometers are characterized by a continuous instrument calibration, with the sensors passing, at every rotation, below two calibration sources: a cold sky reflector providing 3K reference, and an On Board Calibration Target (OBCT) which provides an Hot temperature reference.
The high performance required to the instrument implies that the OBCT temperature is known with high accuracy, and that the gradients along its surface are suppressed. However, gradients are intrinsic to the structure of the OBCT, and driven by the day-night induced temperature cycles of its environment. Gradients can therefore only be minimized through a very extensive use of active control on the OBCT thermal environment.
The development of a Brightness Temperature computation method, i.e. the computation of the temperature sensed by the radiometer in the RadioFrequency (RF) band, was therefore a necessary step for the instrument thermal control optimization. It allowed to assign the limited instrument resources in the most efficient way, and to justify the design solutions.
In this presentation the details of the Brightness Temperature (BT) computation are provided. The OBCT temperature maps are generated by Thermica 4.6.1 using its fast-spin feature and are then post-processed with MatLab, filtering them with the Feed Horns Patterns. This results in the BT profiles along the orbit, with their associated errors. The method is then extended to the *High Frequency* analysis in order to assess the influence of each position of the rotation cycle on the BT. Results are shown, demonstrating that a passive thermal control is suitable to meet the strict performance requirements.

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3-4 November 2015,
ESTEC

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SPACE SYSTEMS

Development of methodologies for Brightness Temperature evaluation for MetOp-SG MWI radiometer

Presentation Content

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- MetOp & MWI instrument introduction
- Conical scanning concept and Instrument calibration
- OBCT: features and temperature knowledge
- Standard thermal analysis: gradients requirements and Modelling detail effect
- Brightness temperature approach: concept an implementation

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MWI instrument introduction

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METOP Second Generation overview

- MetOp-Second Generation: follow-on system to the 1st gen. series of MetOp (**Met**eorological **Op**erational) satellites, which currently provide operational meteorological observations from polar orbit.
- To provide operational observations and measurements from polar orbit for numerical weather prediction and climate monitoring in the early 2020's to mid-2040's timeframe.
- To provide services to atmospheric chemistry, operational oceanography and hydrology.
- With respect to First Generation:
  - To ensure continuity
  - to improve the accuracy / resolution of the measurements;
  - to add new measurements / missions.

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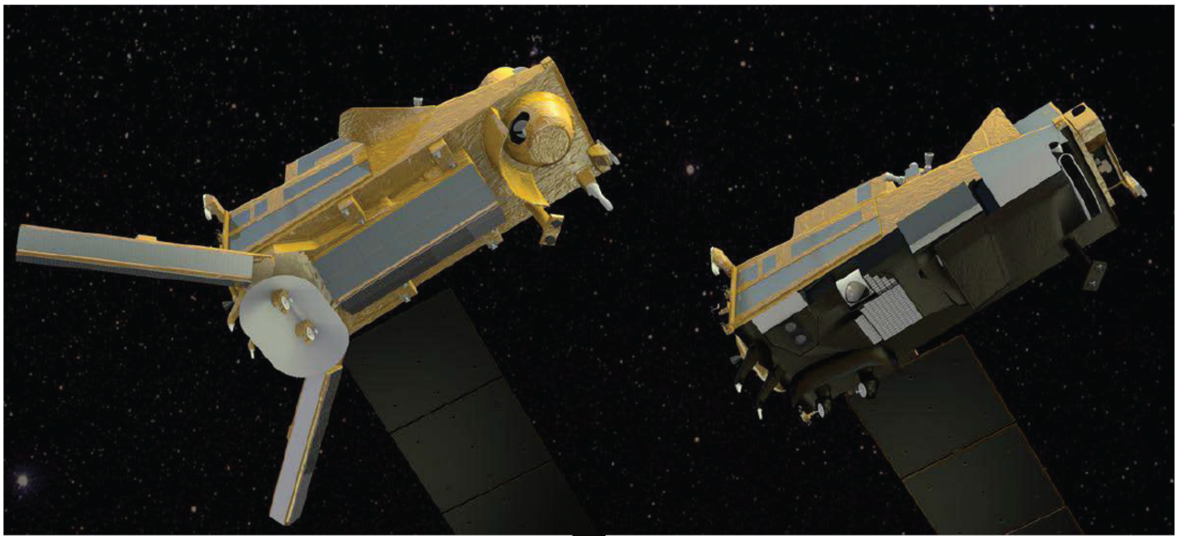

- Launch mass = **3.93** tons
- Mean power consumption in operation = **2.5** kW
- Data rate = day / night / peak
  15 / 15 / 19 Mbps

- Launch mass = 4,22 tons
- Mean power consumption in operation = **3.2** kW
- Data rate = day / night / peak
  64 / **25** / **85** Mbps

- Launcher: Soyuz in Kourou / Falcon 9 / Ariane 5 / **Ariane 6**
- Orbit: MetOp Sun Synchronous Orbit **835 km mean altitude**, 9h30 Local Time at Descending Node
- Controlled re-entry into the South Pacific Ocean Uninhabited Area

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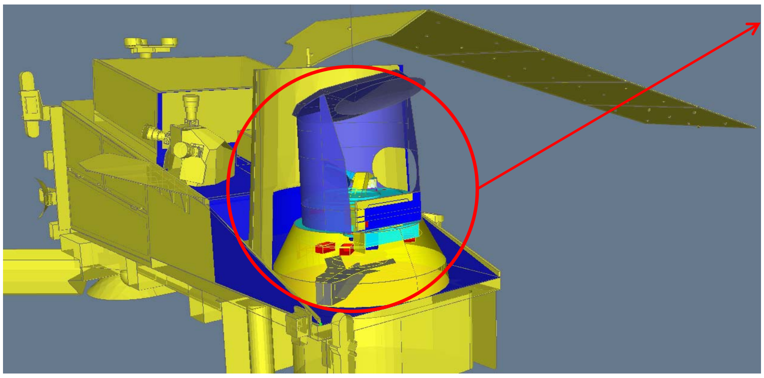
MWI instrument overview



MicroWave Imager:

- Conical scanning radiometer
- Cloud and precipitation, snow and sea-ice, profiles of water vapor and temperatures
- Collects MW radiation from Earth and atmosphere
- Frequency range of 18.7GHz to 183.3GHz
- Constant speed rotation at 45rpm

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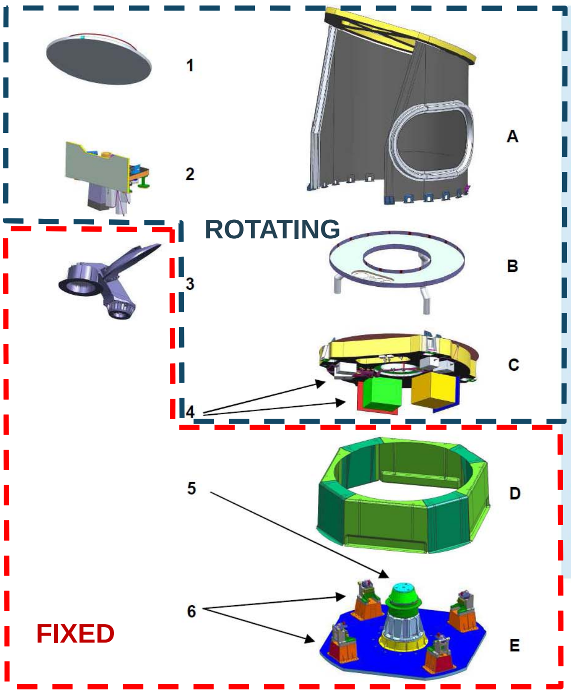
MWI instrument introduction



A	Tube Structure (Rotating Part)	
B	Racetrack (Rotating Part)	
C	Rotating Deck (Rotating Part)	
D	Thermal Skirt (Fixed Part)	
E	Baseplate (Fixed Part)	
1	Main Reflector (Rotating Part)	
2	Front End Sub-Assembly (Rotating Part)	
3	Calibration Assembly (Fixed Part)	
4	Low Frequency Equipment, FEE and CDPU (Rotating Part)	
5	Scan Mechanism (Joint between Rotating and Fixed Part)	
6	Launch Locking Devices (Fixed Part)	

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MWI instrument introduction

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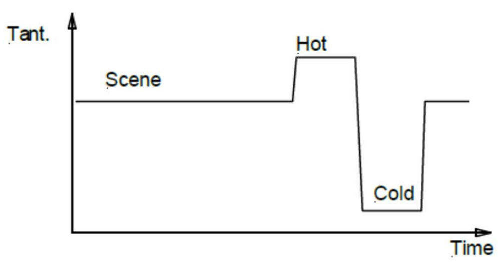
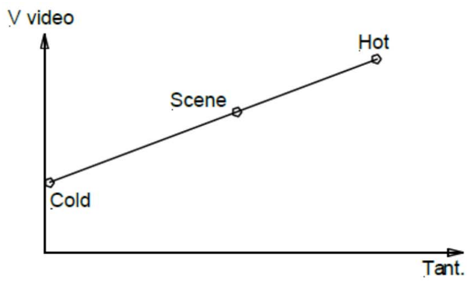
Instrument Calibration

- Calibration principle based on linearity of receiver chain.
- Linear interpolation used to calculate the scene brightness temperature from 2 known reference temperatures
  - Cold Sky Target, i.e. calibration reflector @ 3K
  - On Board Calibration Target (OBCT): hot RF source at known temperature
- The antenna rotation (45 RPM) creates observation cycles
- Necessity of accurate knowledge of OBCT temperature





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OBCT

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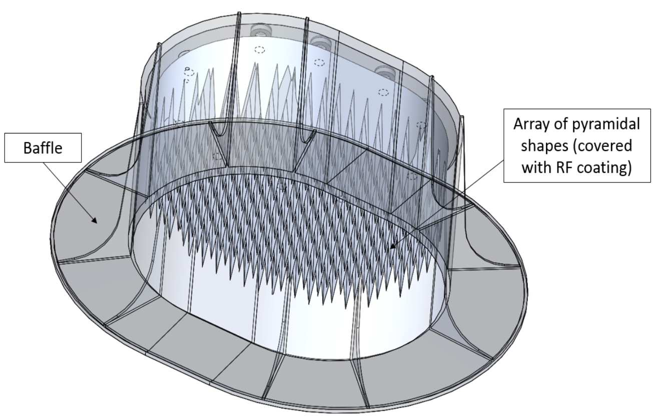
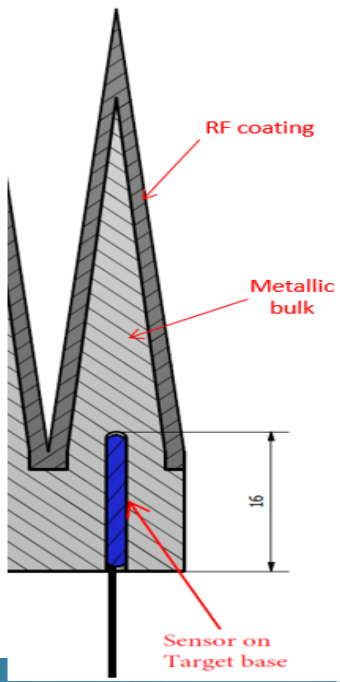
OBCT structure





- Regular pyramidal pattern to have a RF perfect absorber (-40dB return loss)
- ECCOSORB RF coating
- Baffling system for protection from environment

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OBCT requirements

- First Issue:
  - Derived from initial system level error apportionment
  - Attempt to translate the temperature knowledge accuracy into gradients & stability requirements

OBCT specific requirements (operational cases)		
Quantity	**Required value**	**Notes/remarks**
OP temperature variation over one orbit	< 5°C	
OP temperature variation over lifetime	n.a.	
Surface temperature variation over one orbit	< 0.1°C/s	
Nominal gradient across the surface	< 0.35 °C	
Gradient variation across the surface over one orbit	< 0.25°C	
Gradient variation across the surface over one rotation	< 0.1°C/s	
Surface temperature knowledge	0.15°C	applicable to measurement chain overall accuracy, and considering gradient uncertainty from thermal model

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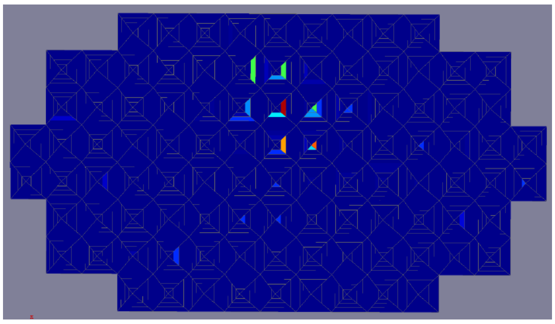
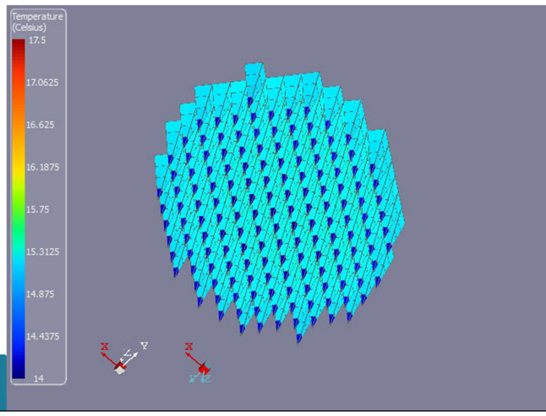
OBCT Standard Thermal Analysis

OBCT environment

- Sun Intrusion: avoid direct and reflected Solar Fluxes on Pyramids (local hot spots)
  - Solutions: “Racetrack” baffling system
- Orbital oscillation of environment
  - Variable sink temperatures
  - Massive base is stable
  - Lighter peaks have wider oscillation
- Result: typical gradient along pyramids, in top-bottom direction





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Stadard Thermal Analysis

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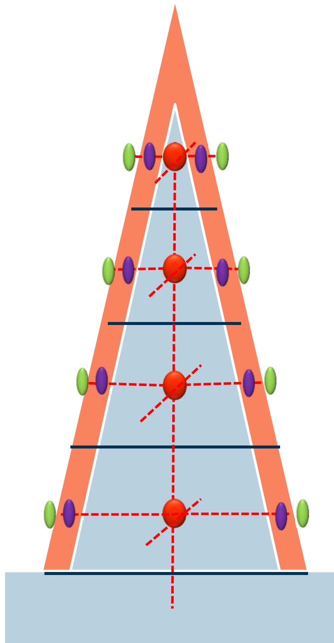
Model detail level and gradients

- Step 0: Initial Phase A model: 4 pyramid layers,
  - 1 node for bulk
  - 1 node for epoxy layer, with mass
- Step 1: Final Phase A model:
  - 1 node for bulk
  - 1 node with Cp for epoxy core
  - 1 node, massless, for epoxy surface
- Step 2: Phase B1 model:
  - 1 node for bulk
  - 4 nodes for each side, with Cp for epoxy core
  - 4 nodes for each side, massless, for epoxy surface
- Gradient estimation: ~0.15-0.3K (COMPLIANT)
- OBCT: for final OBCT ~4000 nodes



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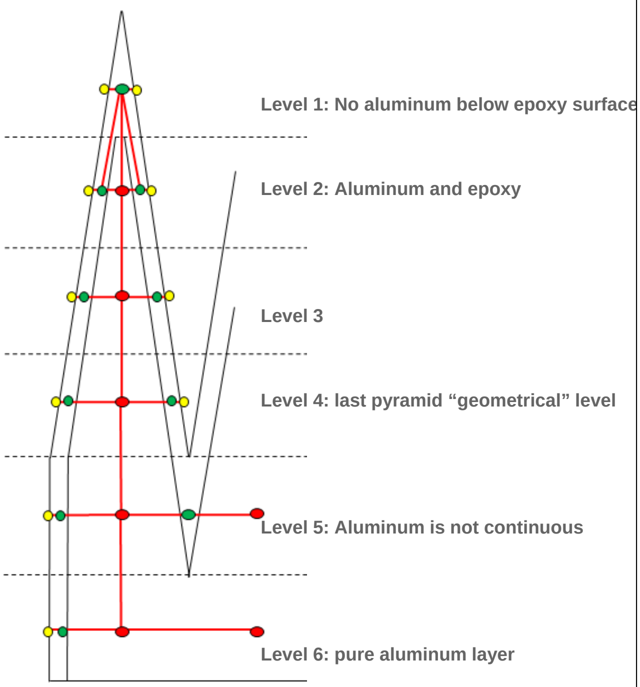
- Step 3: Phase B2 model:
  - Tip area with NO aluminum core
  - Base area with discontinuity (epoxy)



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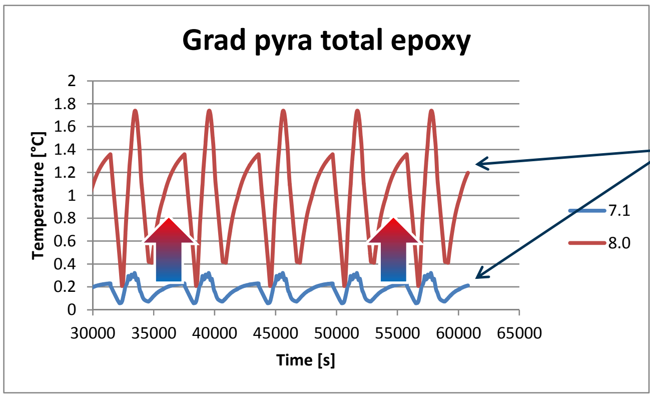
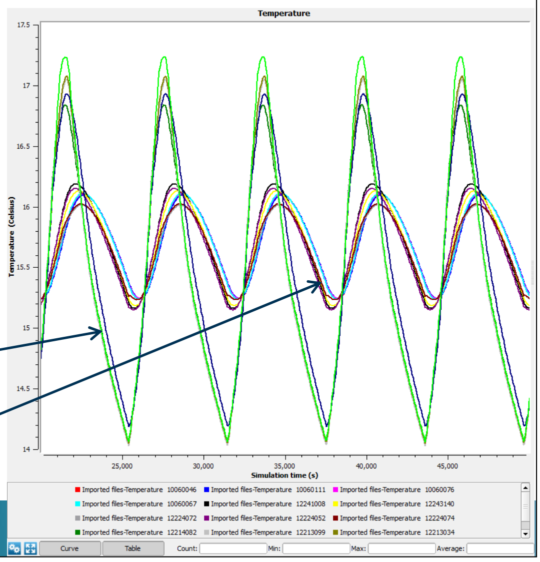


- Gradient over OBCT surface,
  - from step 2 (blue)
  - to step 3 (red):

effect of model detail



- Temperature orbital oscillations:
  - Level 1 (tips)
  - Levels 2 to 6 (all other nodes)

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- The tips, once modelled in a more realistic way, amplify the already known «tip-bottom» gradient by about one order of magnitude.
- Gradients have a very regular pattern (no local hot spots), all tips are typically at the same temperature with a dispersion of ~0.5K
- Requirements are far from being respected in the current configuration
- Corrective actions to reduce (but not realistically a by factor 10) the gradients are:
  - […] (long list of unfeasible options for other system constraints)
  - Racetrack **active heater control** to damp its oscillations
    - ROM estimation: ~200W heater (150% of entire instrument budget)
- Alternative: coupled RF&Thermal analysis
  - temperature maps post-processing to verify brightness temperature, the *real* quantity of interest
  - To investigate the effect of the «Shape» of the gradient pattern, not only its max value

OBCT brightness temperature,
detected by each feed horn,
in any operational condition,
shall not deviate from the PRT temperatures
by more than ±0.25K

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NEW ANALYTICAL APPROACHES

- At the core of the approach there is the consideration that each feed horn is actually «filtering» the pyramids temperature, combining them in a unique «Brightness Temperature» (BT) reading.
- This is achieved through a kind of weighted average of the physical temperatures
- The real meaningful information, important to assess the performance of the instrument, is not really the gradient along the surface, but the difference between the PRT temperature and the BT acquired by the horns
- In this sense, NOT ALL THE GRADIENTS are equivalent; a periodic gradient is much less harmful than a uniform gradient, because the horn is a low-pass filter.

High level Logic flow:

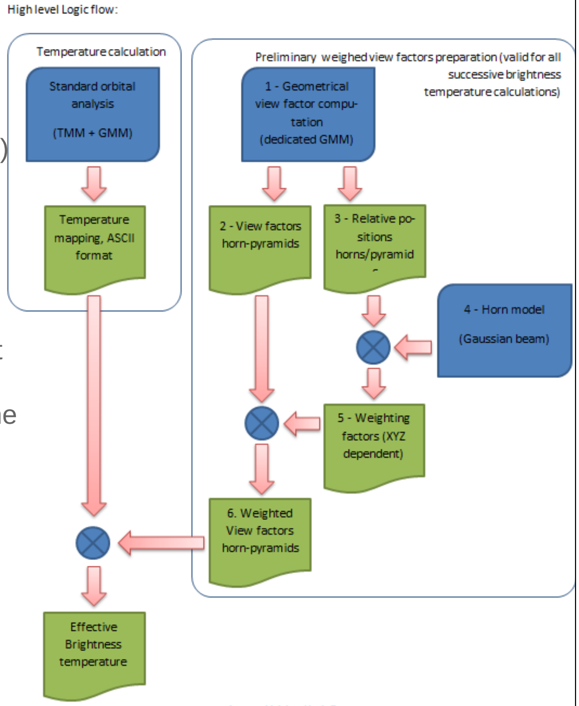
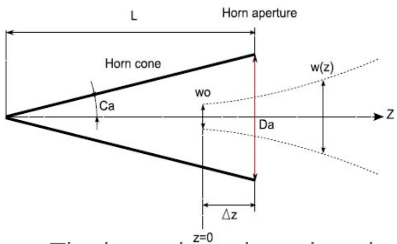


Figure 1: high level logic flow

NEW ANALYTICAL APPROACHES

- A Gaussian horn beam is considered, according to ADS-Tolouse inputs (responsible of Radiofrequency Assembly)
  - Different for each of the 7 horns;
  - Function of r, z
- The beam is the weighting factor for the physical temperatures

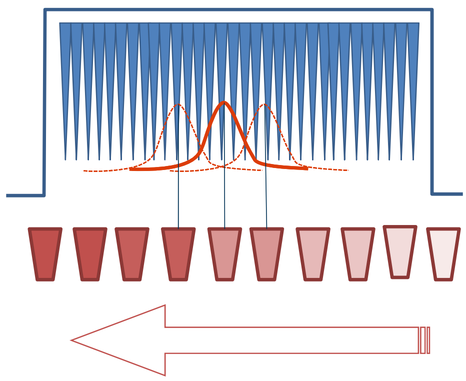


$$E(r) = Eo\exp\left(\frac{r^2}{w(z)^2}\right)$$

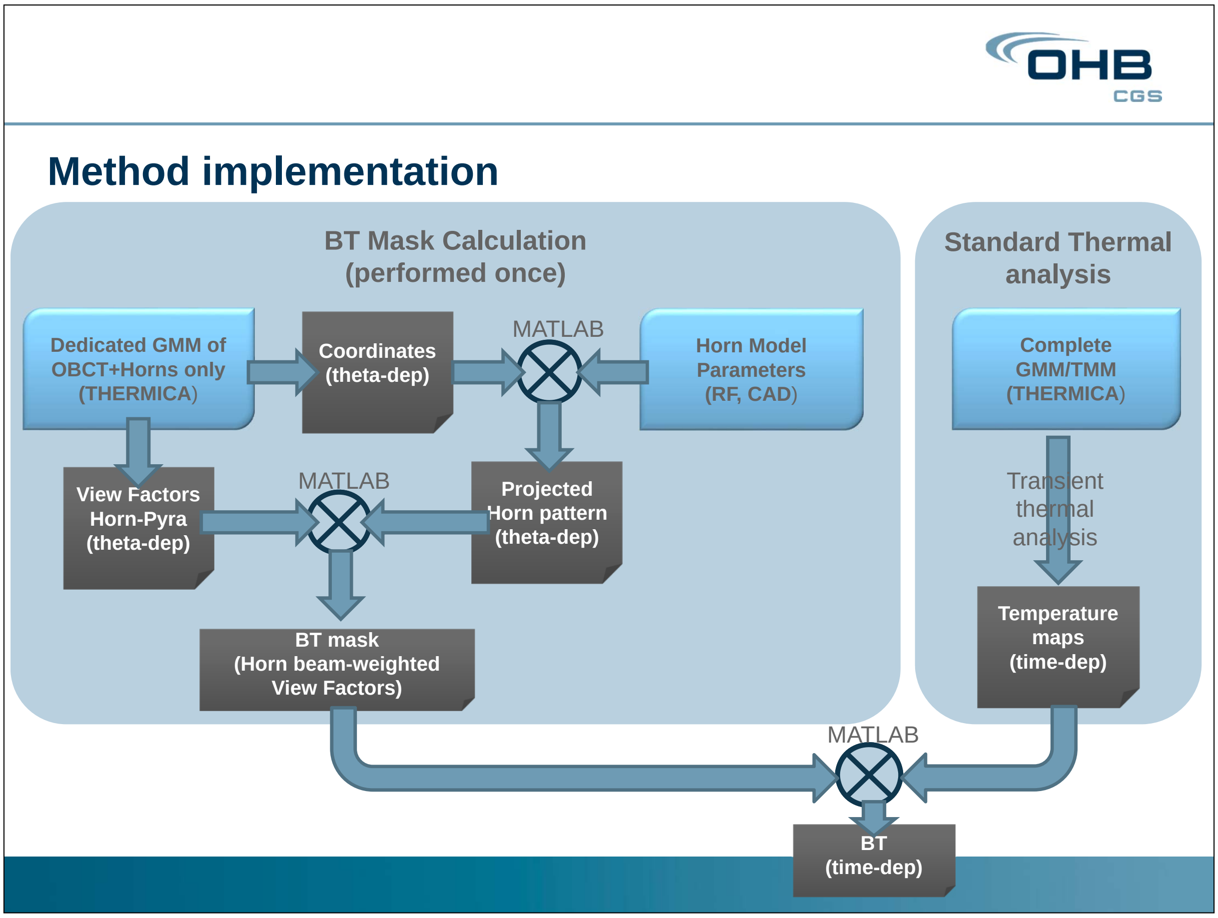
$$w(z) = wo\sqrt{1+\left(\frac{z}{zr}\right)^2} \quad \text{With}$$

$$zr = \pi\frac{wo^2}{\lambda} \quad and \quad wo = 0.29\,Da$$

$$\Delta z = \frac{L}{1+\left(\frac{\lambda L}{\pi wo^2}\right)^2}$$



- The beam is projected on the pyramids, at several different instrument rotation angles, weighting it to its view factor to the horn
- Per each rotation angle, each pyramid surface element is weighted in a different way
- Per each angle (and per each horn) the BT is calculated
- The BT is compared to the PRT temperatures
- The difference is the error contribution to the BT evaluation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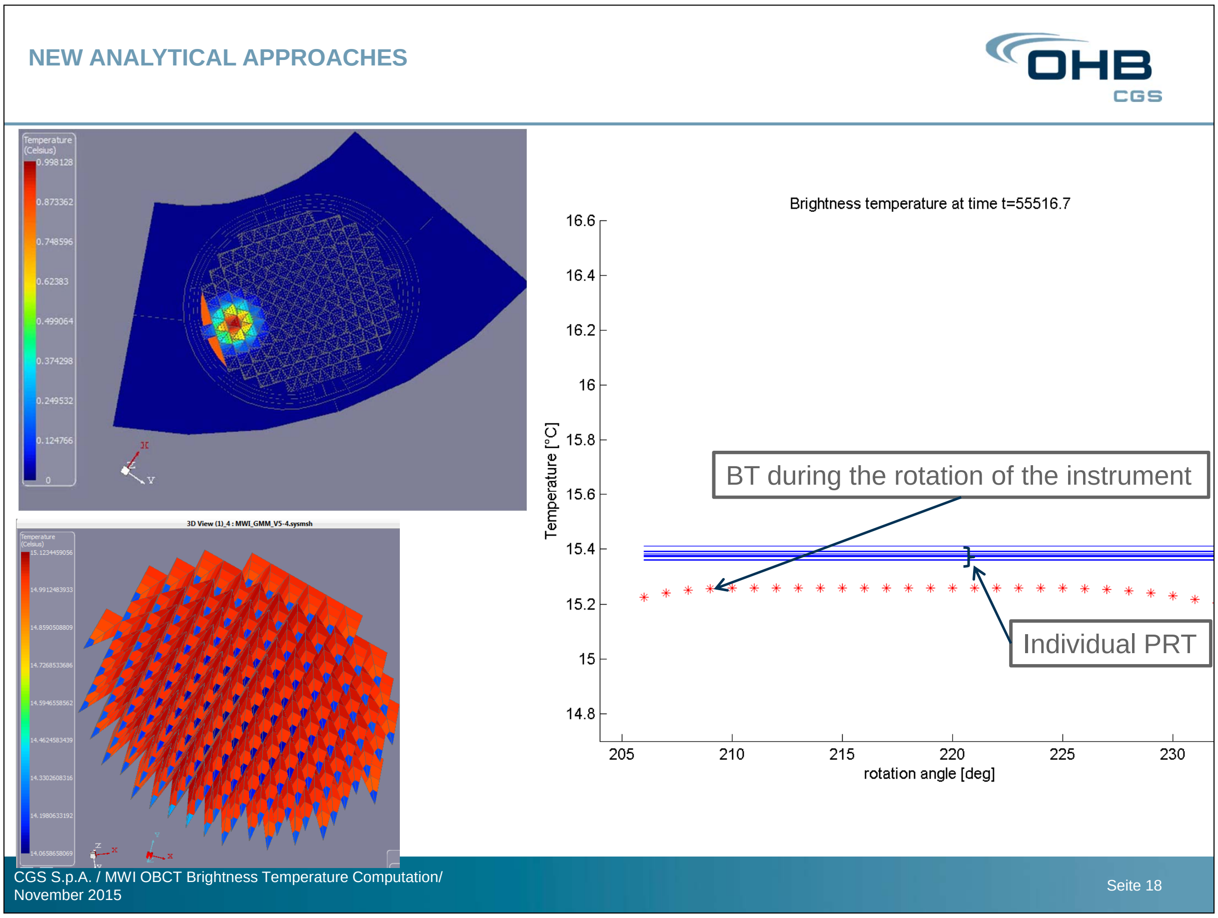
Method implementation
BT Mask Calculation
(performed once)
Standard Thermal analysis
Dedicated GMM of OBCT+Horns only (THERMICA)
Coordinates (theta-dep)
MATLAB
Horn Model Parameters (RF, CAD)
Complete GMM/TMM (THERMICA)
View Factors Horn-Pyra (theta-dep)
MATLAB
Projected Horn pattern (theta-dep)
Transient thermal analysis
BT mask (Horn beam-weighted View Factors)
Temperature maps (time-dep)
MATLAB
BT (time-dep)


NEW ANALYTICAL APPROACHES
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Brightness temperature at time t=55516.7
Temperature [°C]
rotation angle [deg]
BT during the rotation of the instrument
Individual PRT
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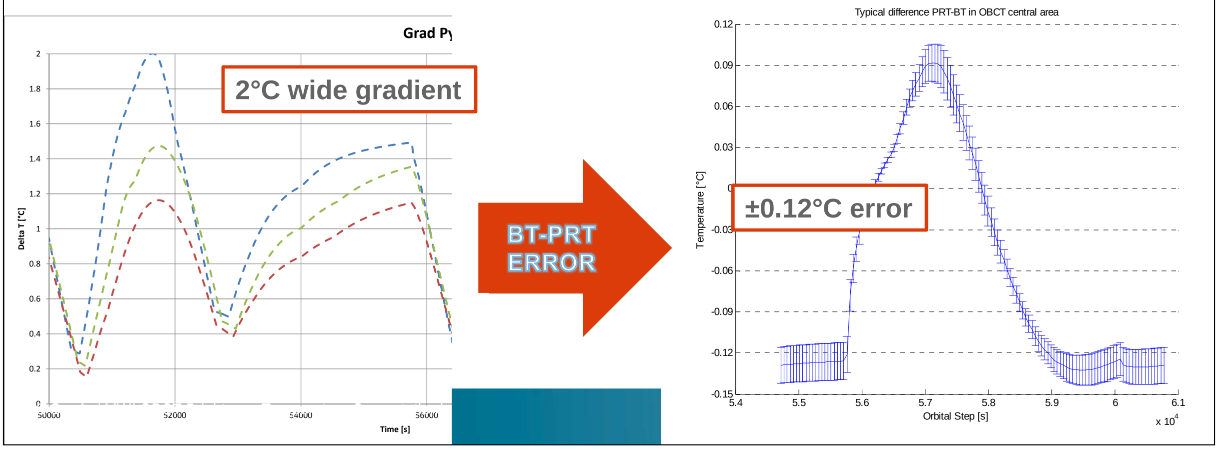
NEW ANALYTICAL APPROACHES

- The BT evaluation is performed at each orbital position of standard thermal analysis.
- A profile of the ERROR PRT--BT is available in function of orbital time
- The profile is typically presented as the profile of the Average ERROR value + standard deviation band.
  - Average error over the central area of the feed horn path below the OBCT (typically, 5° wide)
  - Standard deviation is the deviation of the error computed all over this 5° wide window (typically, with a step of 1°)



Conclusions

- Generic Temperature Gradient requirements results are often dependent on Model Detail
- In case of MWI OBCT, gradient requirement could no longer be met, unless a big amount of resources are assigned to thermal control
- A re-discussion of requirements was needed (should be a general good practice)
- A joint RF-thermal analysis was carried, developing routines to compute the Brightness Temperature profiles along the orbit and comparing to the PRT readings
- Analysis allowed to demonstrate that the proposed design was compatible with performance targets
- Method allowed to refine thermal control system and to correctly assign the instrument resources

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