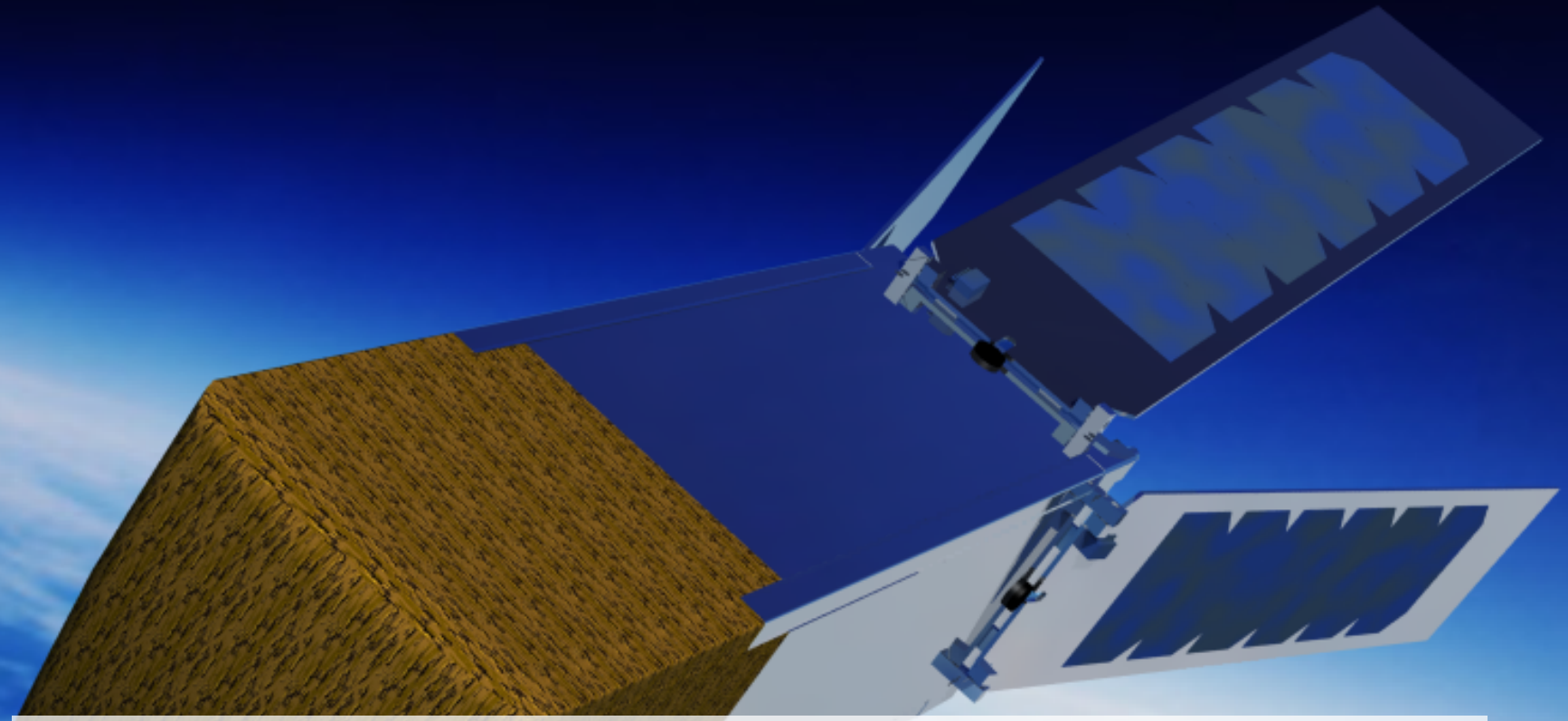

Radiative and Ablative Studies for In-flight Validation on Reentry Platforms

IPPW 12

- Cologne, June 2015 -

G. Bailet[1]

A. Bourgoing[2], T. Magin[3] and Ch. Laux[1]

Other members of the QARMAN team[3] :

V. Van der Haegen, I. Sakraker, T. Scholz and E. Ümit

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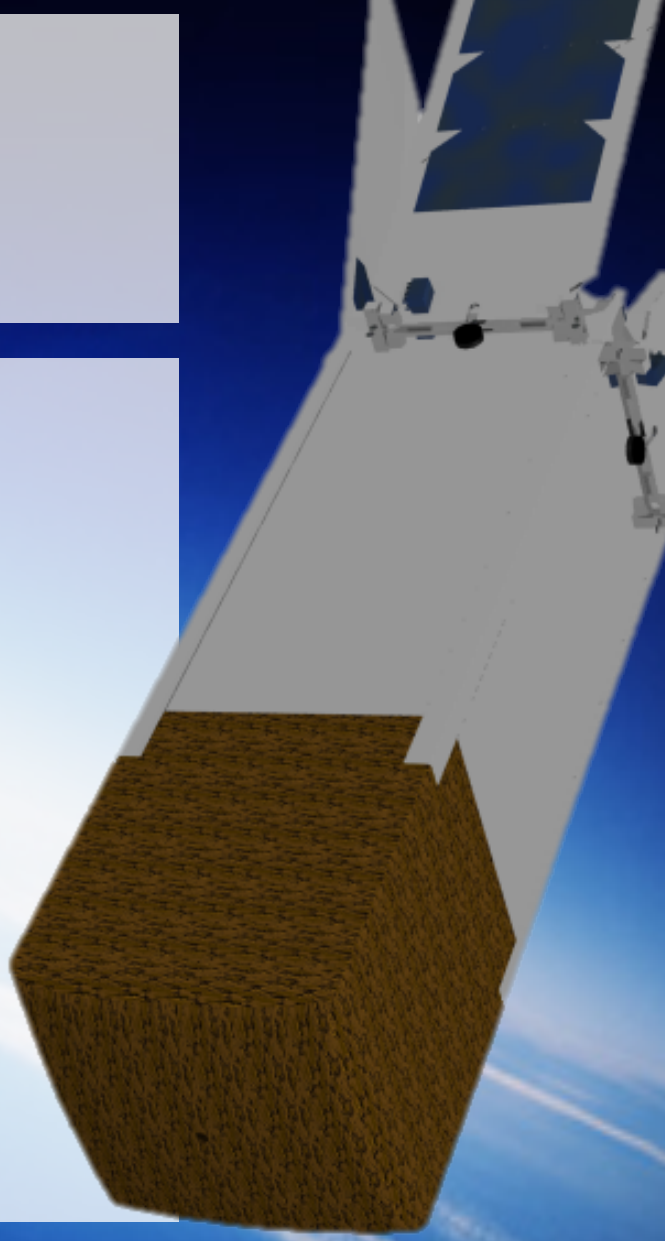
[2]Airbus Space and Defence, Les Murreaux, France

[3]Von Karman Institute, Rhodes-Saint-Genèse, Belgium

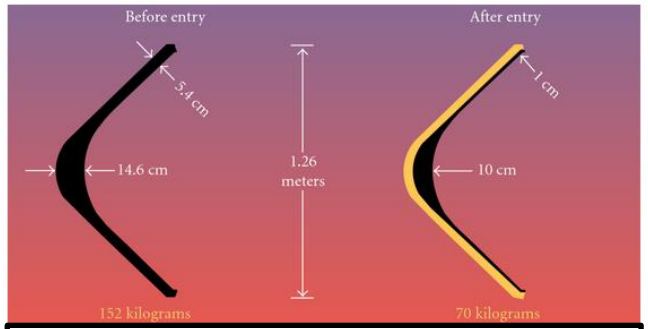
Content

- Context
- QARMAN Platform
- Radiative Environment
- Spectrometer Payload
- Future Prospectives
- Conclusion



Introduction

-Problematic-

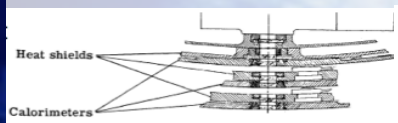


Galileo Probe
Reentered Jovian Atmosphere on December 7th 1995

Ablation/Radiation coupling:

- High Uncertainties (≥20%)
- Effect of ablation product radiation not well understood
- Recession rate measurement should be encouraged
- Intrusive measurement technics (FIRE II: Stacked TPS)

Result: High margins on TPS sizing



Cauchon, D. L., Radiative Heating Results from the FIRE II Flight Experiment at a Re-entry Velocity of 11.4 Kilometers per Second, TM X-1402, NASA, 1967.

Data Period	Altitude / km	Velocity / km/s
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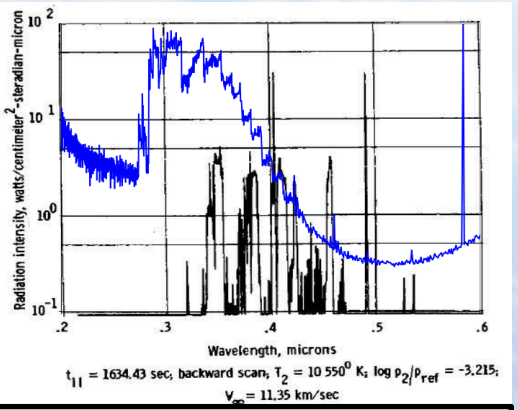
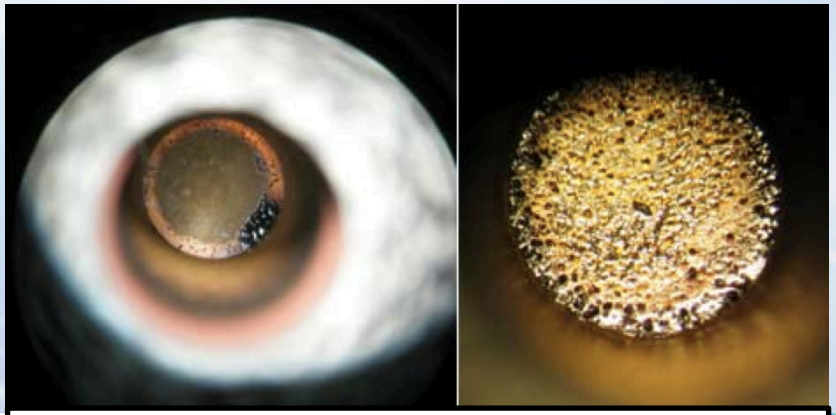
3	41.80 – 40.75	8.20 – 7.74



Spectral Comparison for a Fire II test case

(Left: Context; Blue: Simulation and Black: Experiment)



Preci, et Al., **Development of a Combined Sensor System for Atmospheric Entry Missions**, 7th European Symposium on Aerothermodynamics for Space Vehicles

Introduction

-What to do?-

Design criteria for a new instrument:

- The instrument should have a small mass/form factor and minimal impact on the platform design enabling **cross platform flexibility**

- Able to measure radiative flux and TPS recession rate a the same location and for the **full duration** of the reentry to correlate Radiation/Ablation coupling

  (resistant to optical path pollution by ablation products)

→ Necessity of in-flight qualification ASAP in order to be considered suitable for the coming mission proposals

QARMAN Platform

-Is QARMAN Platform Relevant?-

Mission	Year	Entry speed [km.s^{-1}]	Altitude range [km]	Spectral range [nm]	Spectral resolution [nm]	Focus
FIRE I	1964	11.5	70-89	300-600	4	Coupled ablation/ radiation
FIRE II	1965	11.5	40-83	300-600	4	Coupled ablation/ radiation
BSUV I	1990	3.5	38-70	200-400	1	UV diagnostic
BSUV II (UVDE)	1991	5.1	62-110	200-400	1	UV diagnostic
Ground observations (Stardust, ATV 1 and Hayabusa)	2006 2008 2010	>12 7.8 >12	?	300-2000	0.1-20	Global observation
EXPERT	2013?	5	?	200-850	1.5	Build a database
→ QARMAN	2015	7.6-7.8	50-120	200-1100	0.8-1.5	

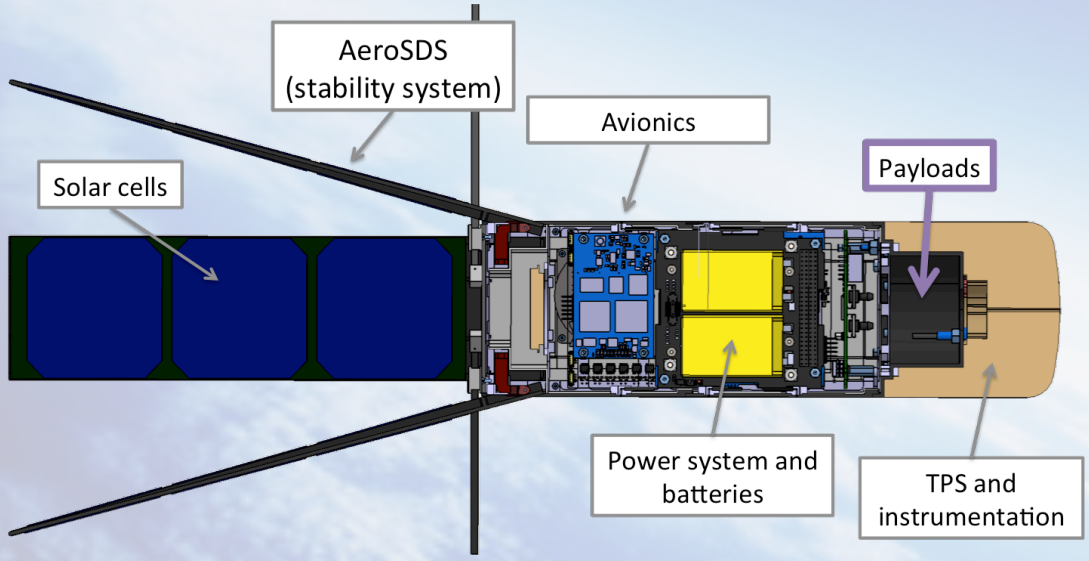
QARMAN Platform

-Mission Scenario-

QARMAN Platform

-System Design-

Collaborators: V. Van der Haegen, I. Sakraker, T. Scholz and Ertan Ümit



Volume 34x10x10 cm^3
Mass 5 kg
Flight 2016

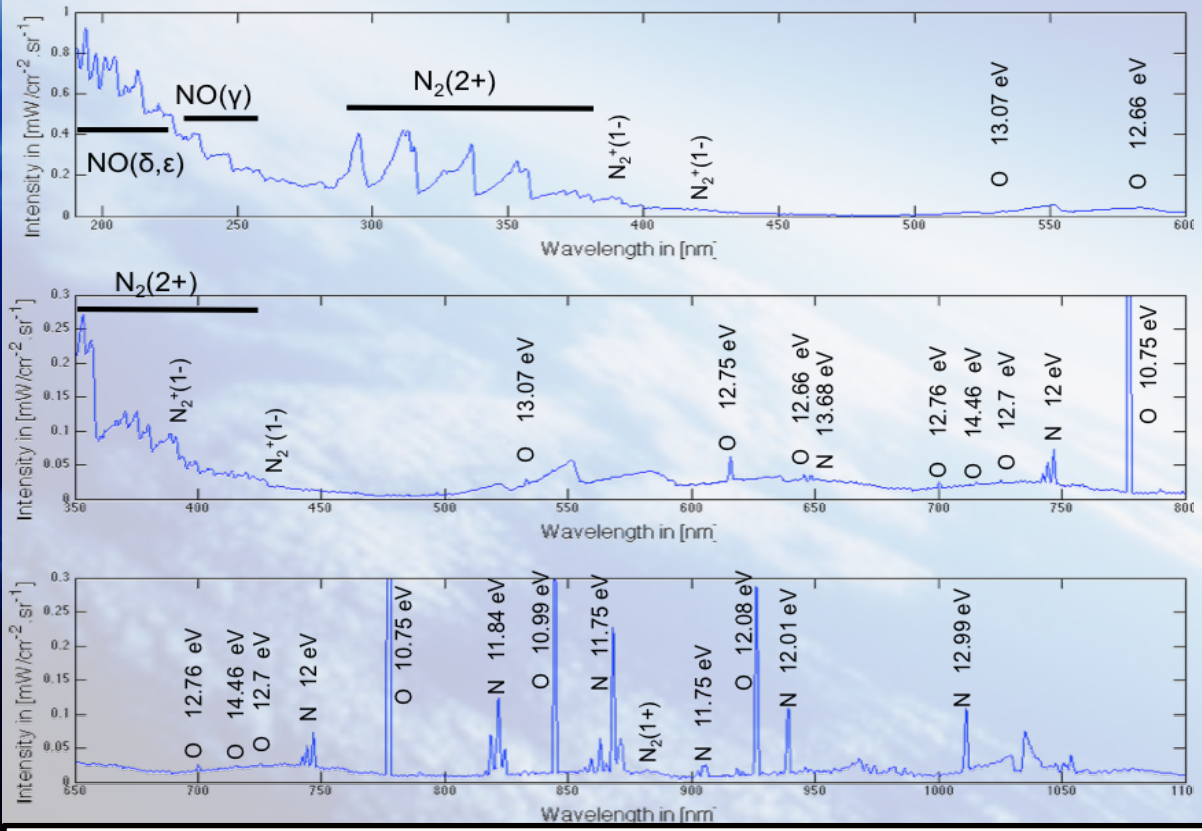
Payload	Objective	Sensor
XPL01	TPS Efficiency	Temperature
XPL02	TPS & Environment, FADS	Pressure
XPL03	Stability, FADS	Pressure
XPL04	Laminar to Turbulent Transition, FADS	Pressure
XPL05	Off-Stagnation Temperature, FADS(?)	Temperature
XPL06	Aerothermodynamic Environment and Radiation	Spectrometer

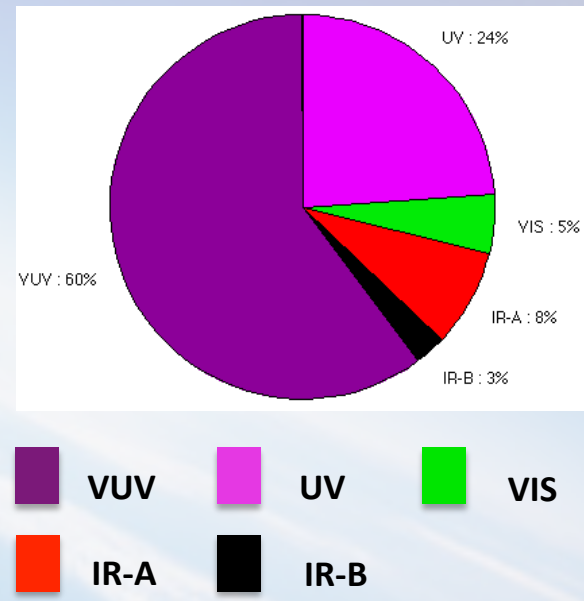
Radiative Environment

-Prediction of the Line-of-Sight's Radiation-

SPECAIR

Identification for remarkable transitions (For each Emission Spectrometer available)



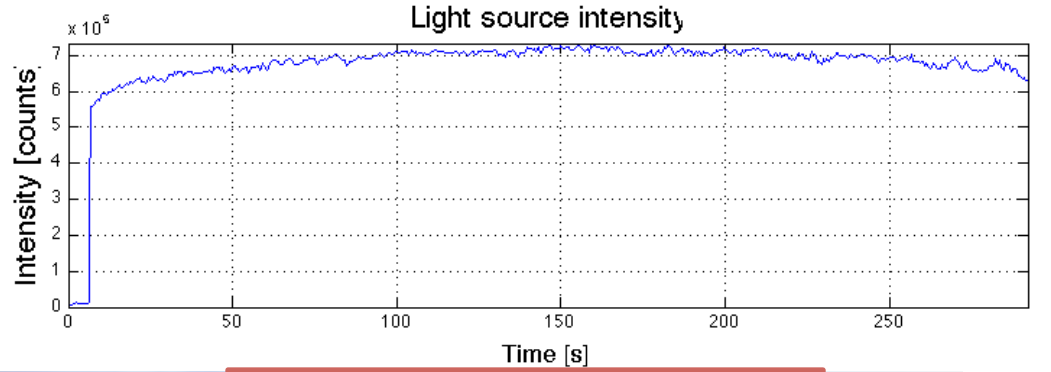


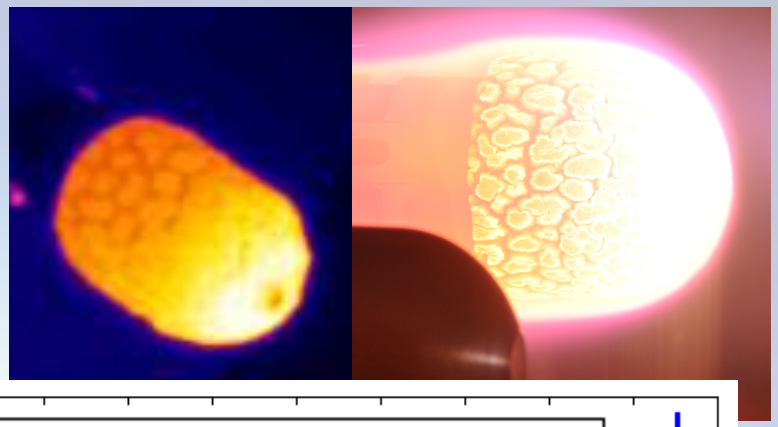
Maximal heating conditions

Altitude = 61.251 km; Velocity = 6421.4 m/s; Free Stream Pressure = 19.7184 Pa; Free Stream Temperature = 239.3856 K

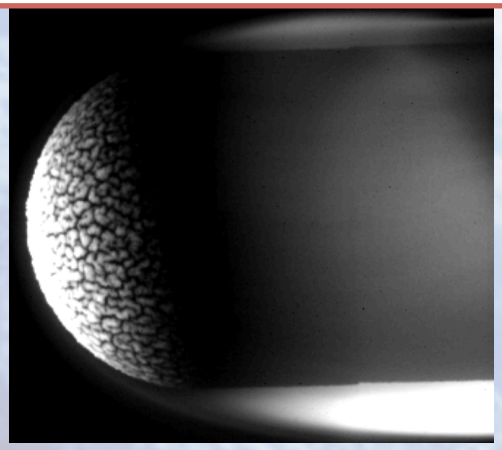
Spectrometer Payload

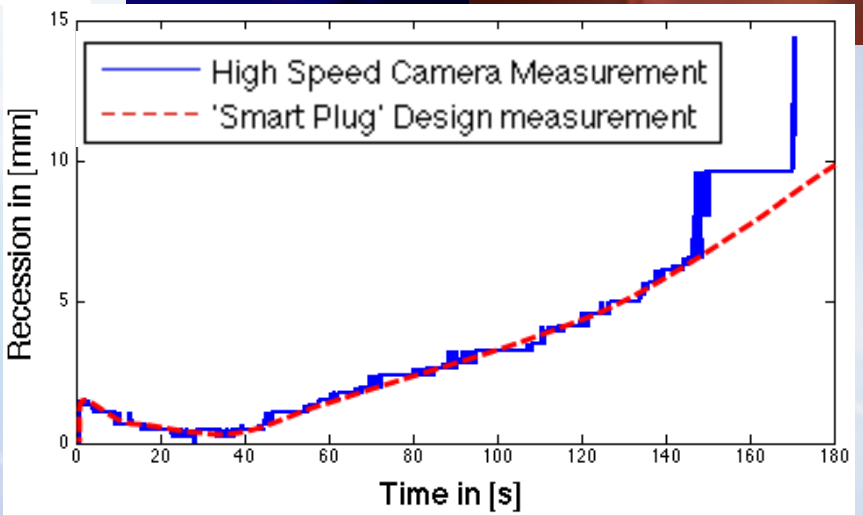
-Performances-





No effect of ablation contamination





Smooth measurement of recession and swelling

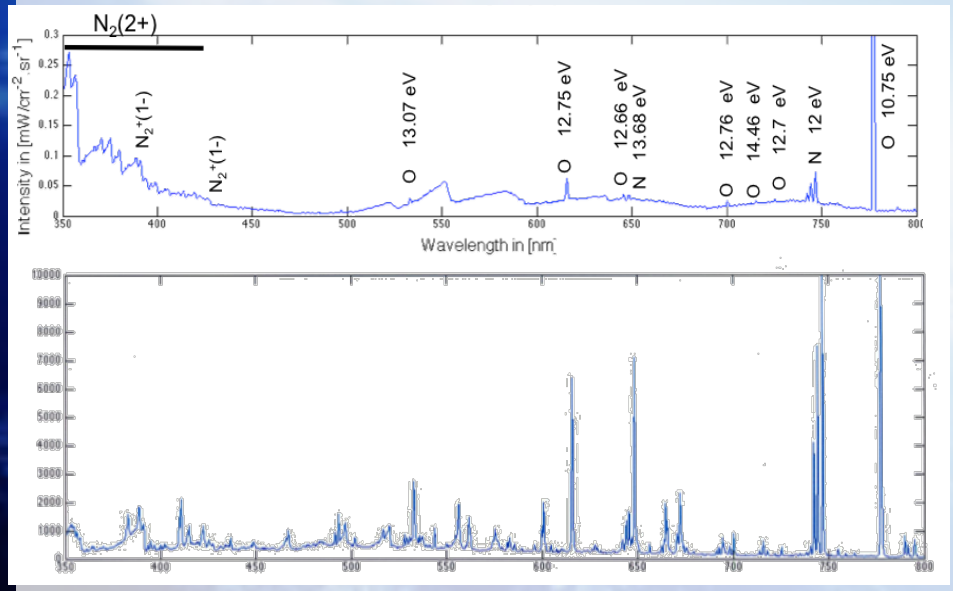
<u>Test conditions</u>:

HeatFlux: 1.2 MW/m2; HeatLoad: 368 MJ/m^2; Pressure: 100 mbar; Quartz tube inner diameter: 30 cm

Radiative Environment

-Prediction of the Line-of-Sight's Radiation-

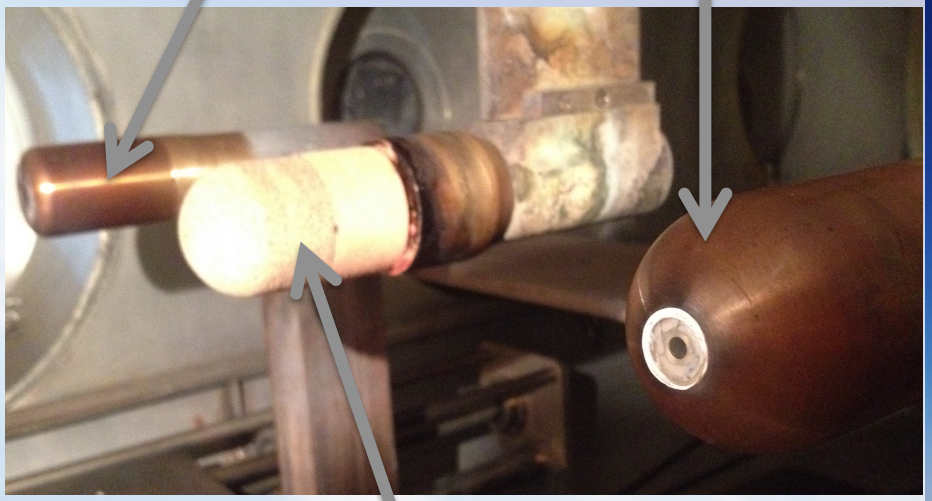
How to understand ablation of a TPS when it is not properly characterized



Comparison between **Simulation (up) and Test results (down)**

Heat flux probe

Cooled Probe With Radiation Measurement



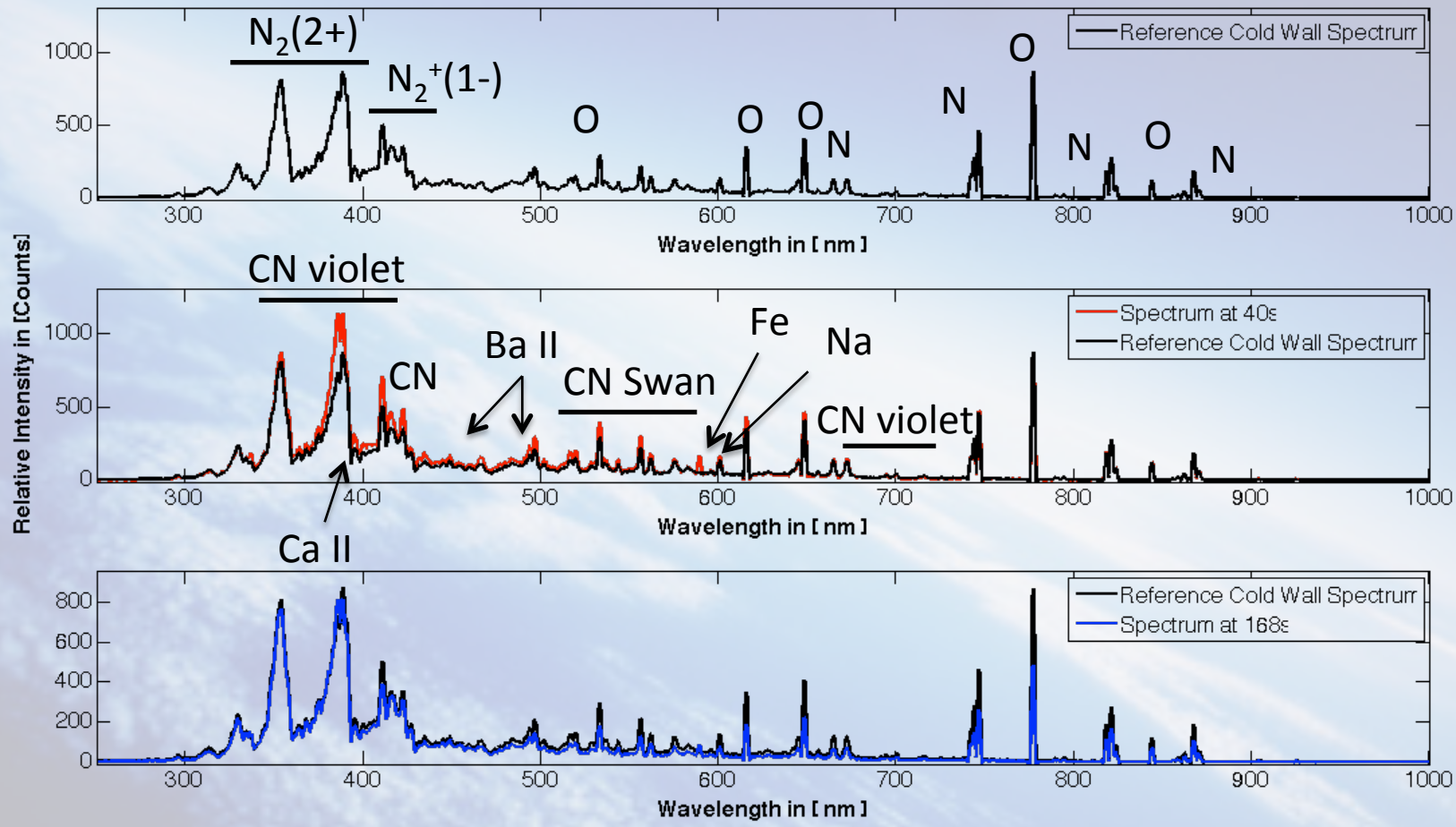
Test Sample With Radiation Measurement

Discrepancies: Ablation products
Coil Area (High temperatures plasma generator)

Radiative Environment

-Contribution of the Absorption/Emission-

TPS tested: Cork P50 (Amorim)



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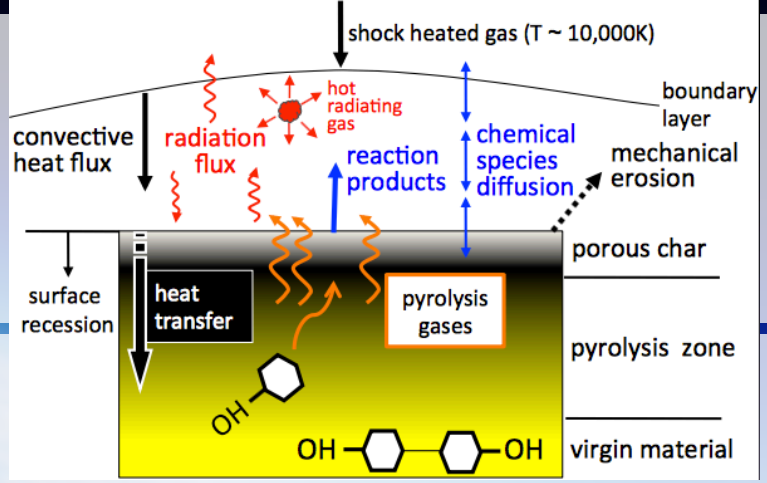
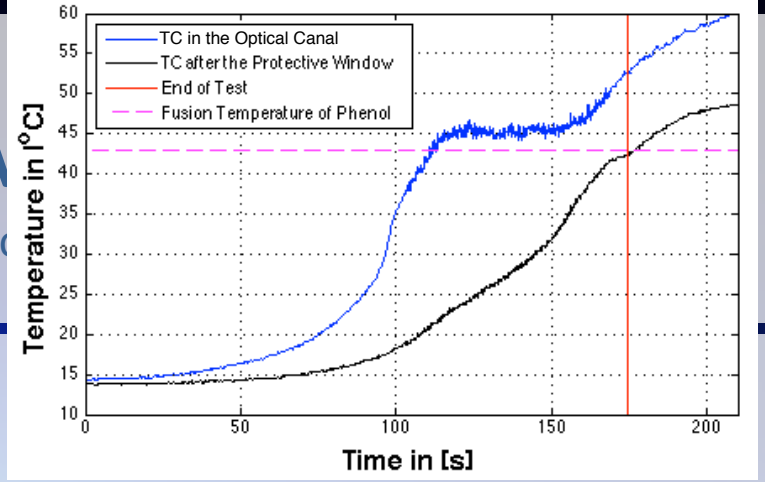
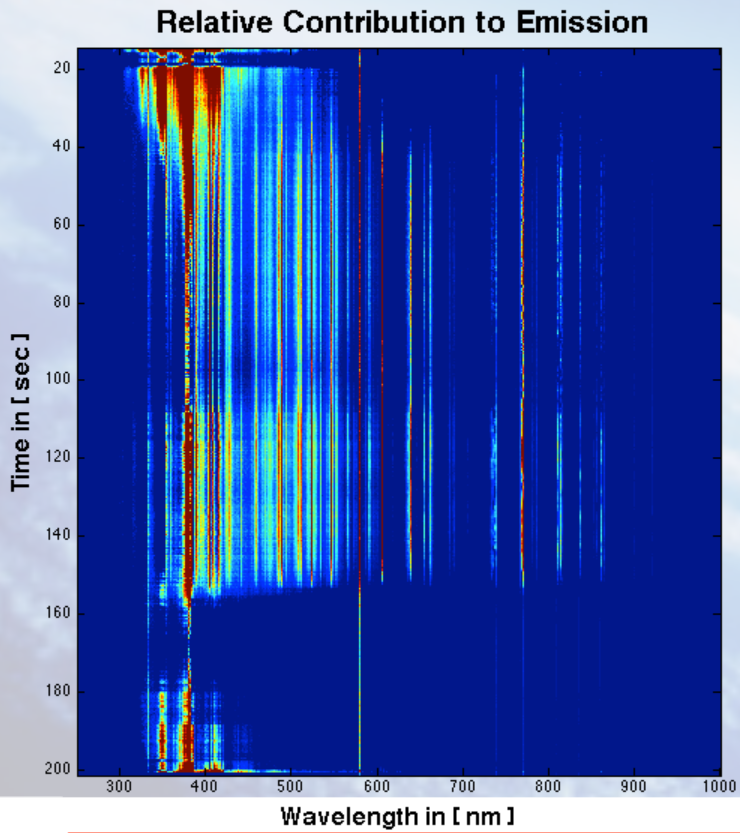
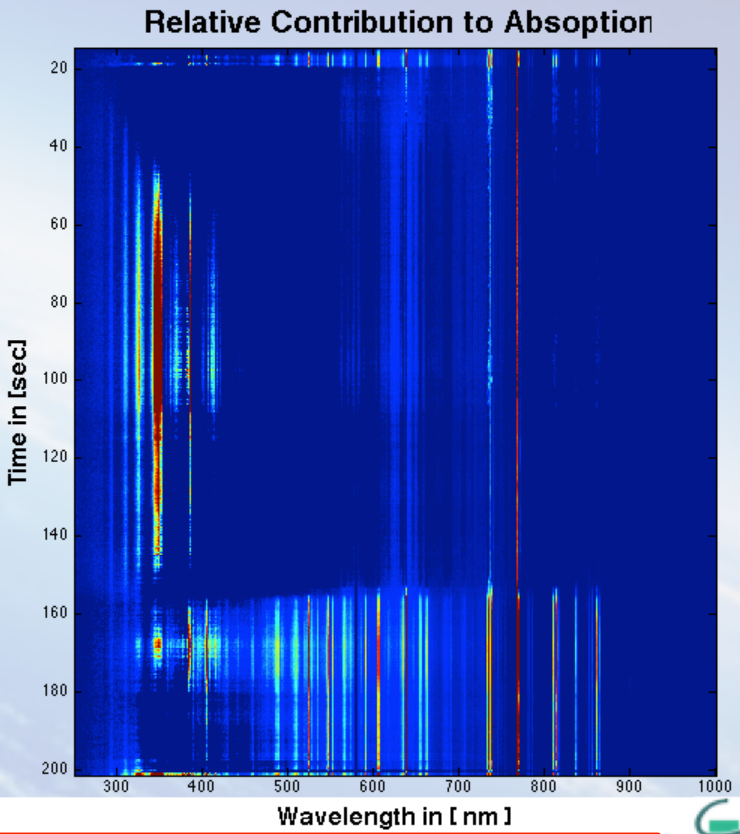




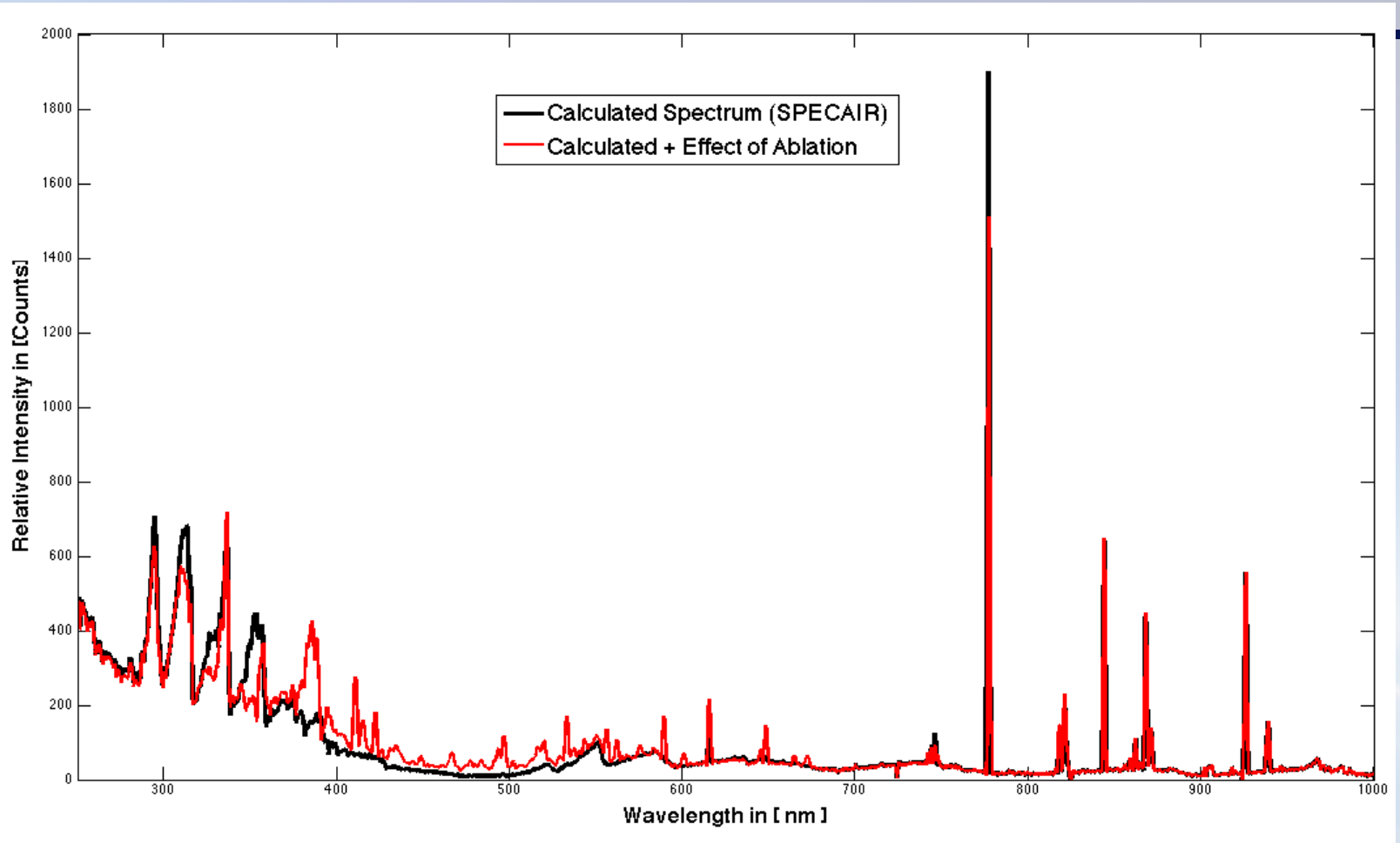




- **Emission from Ablation in the boundary layer**
- **Absorption from the low temperature pyrolysis gas inside the optical canal**

Radiative Environment

-Contribution of the Absorption/Emission-



Extrapolation of the effect of ablation on the stagnation line measurement
Trajectory point: Altitude = 61.251 km; Velocity = 6421.4 m/s

Spectrometer Payload

-Selected emission spectrometer for the QARMAN's platform-

STS-Ocean Optics

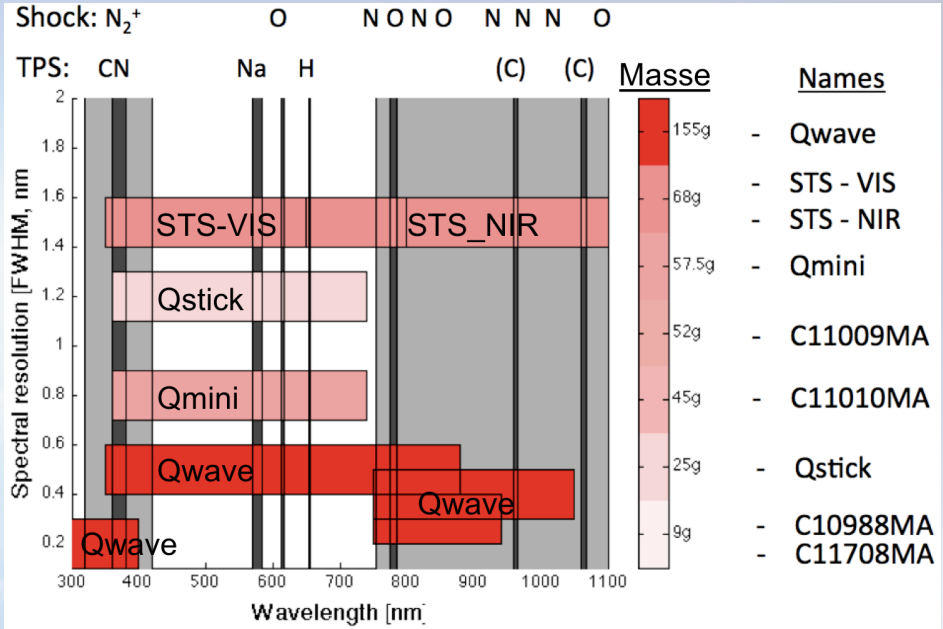
Dimensions: **40x42x24 cm³**

Weight: **68 g**

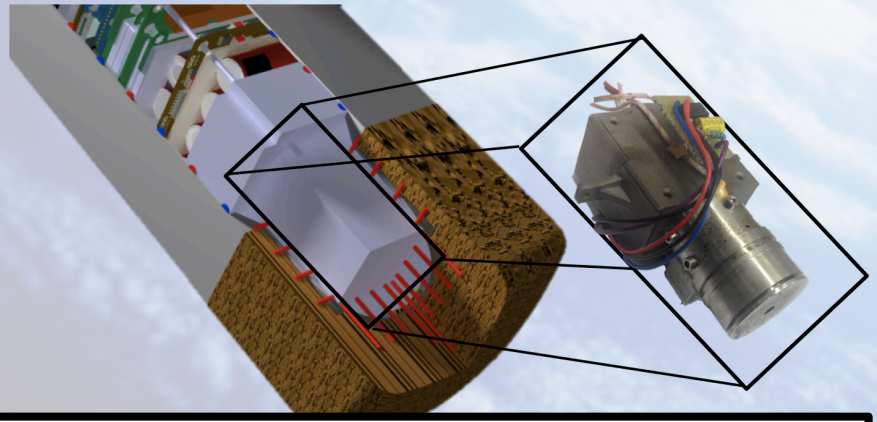
Wavelength range:

~450 nm over [190 1100]

Spectral resolution: **~1 nm**



Overview of possible emission spectrometers for QARMAN



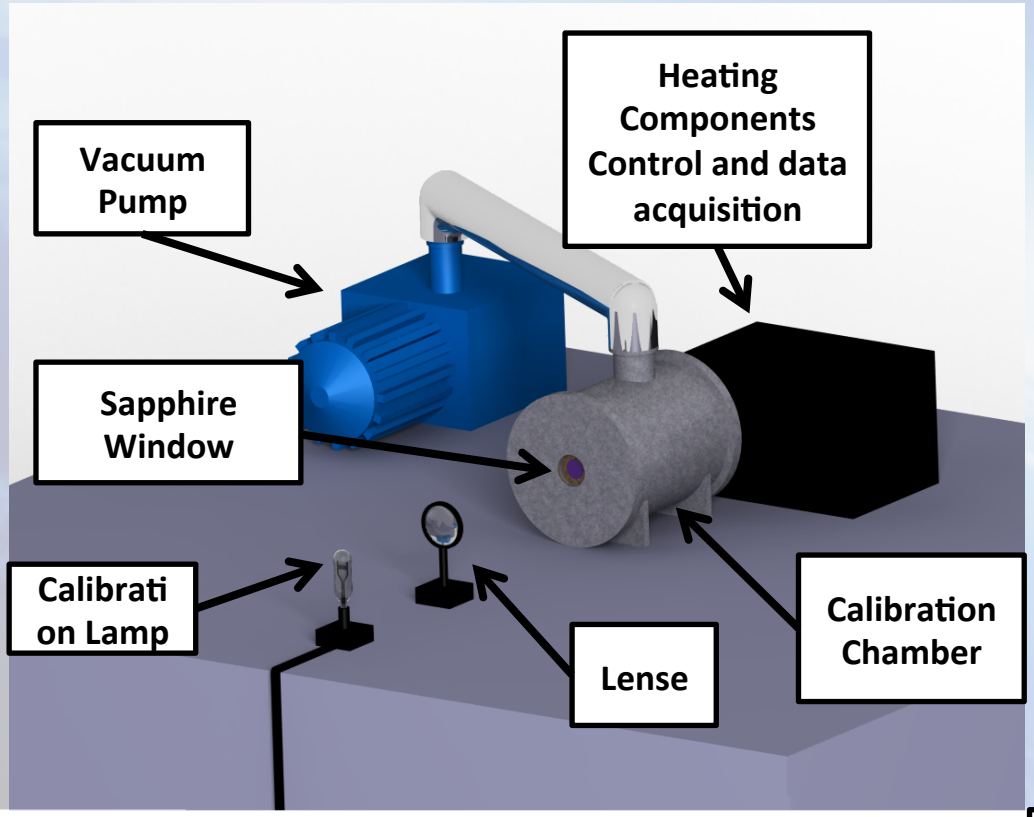
Integrated view of the Imbedded Nano-size Emission Spectrometer within the QARMAN's platform

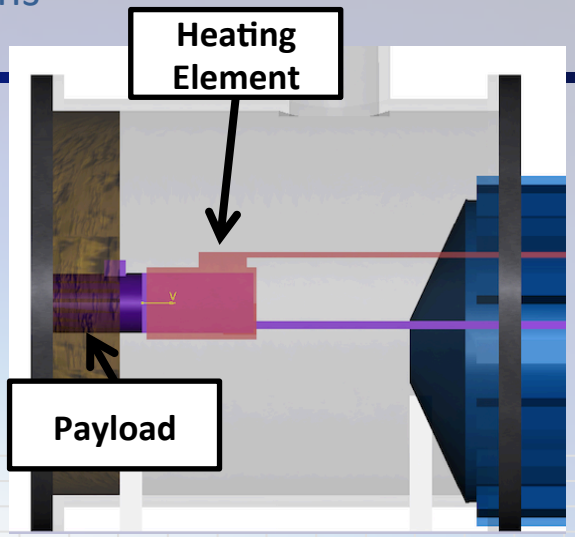
Spectrometer Payload

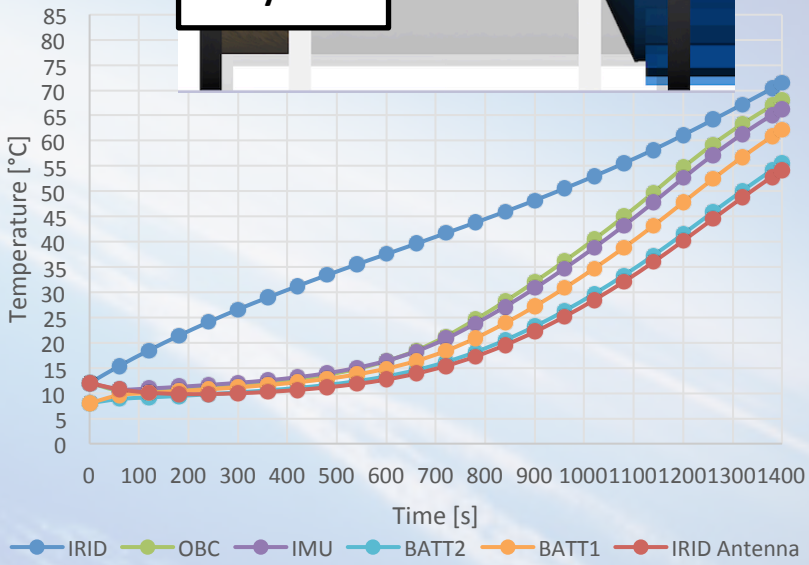
- Calibration for Reentry Constrains -

Characterize Spectral Shift

Design of a dedicated calibration Chamber







Temperature profiles during the mission

Future Prospectives

Ongoing

- Qualification Test for TRL 7 (**See Isil Sakraker's Poster**)
- Thermal Vacuum Calibration (Spectral shift in wavelength and intensity)

Planned

- Validation of the ablation impact on radiation with Preform TPS material
- Qualification with different TPS materials and at high heat flux (Asterm at 10 MW/m^2)
- Qualification for other atmospheres (Mars, Venus, Titan, Gas & Ice giants?)

Conclusion

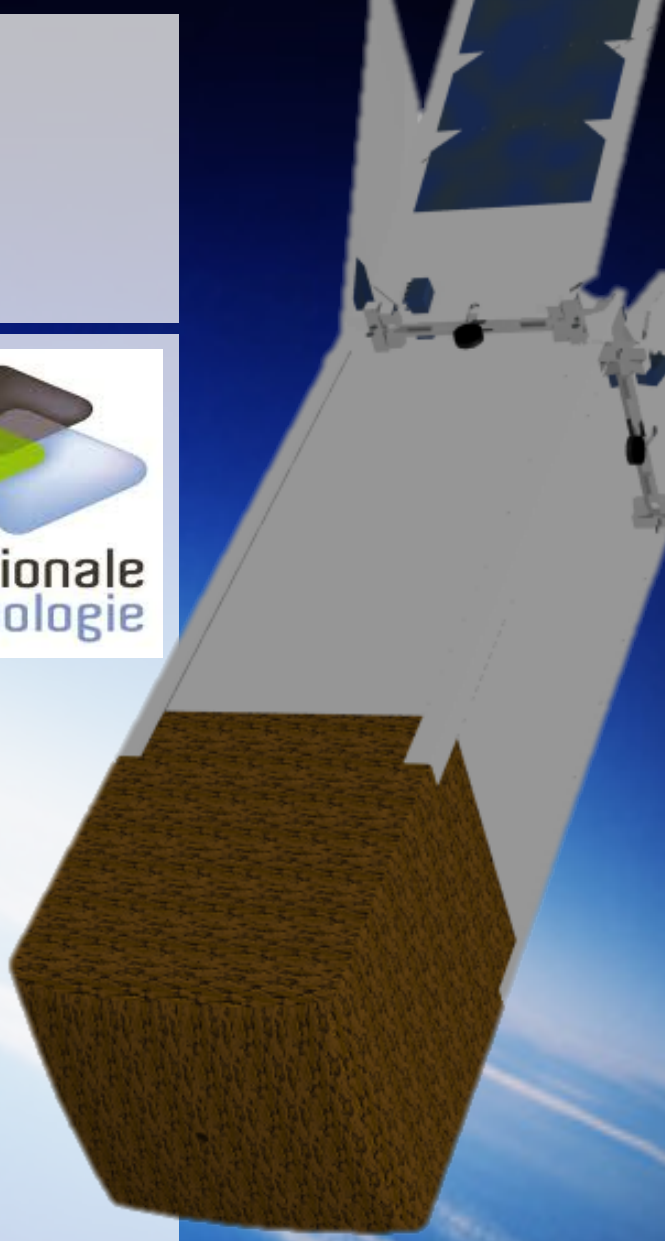
- **Efficient payload** able to measure recession rate and radiative flux in a small mass/form factor
- Equipped with photometers, **3 to 5 instruments** will enable data gathering for **validating radiation/ablation coupling** with only **few hundred grams** of payload mass with minimal bulkiness
- Will be Space Qualified (**TRL 9**) by 2016
- Will be qualified (**TRL 7**) for other atmospheres (Mars, Titan, Gas giants?)

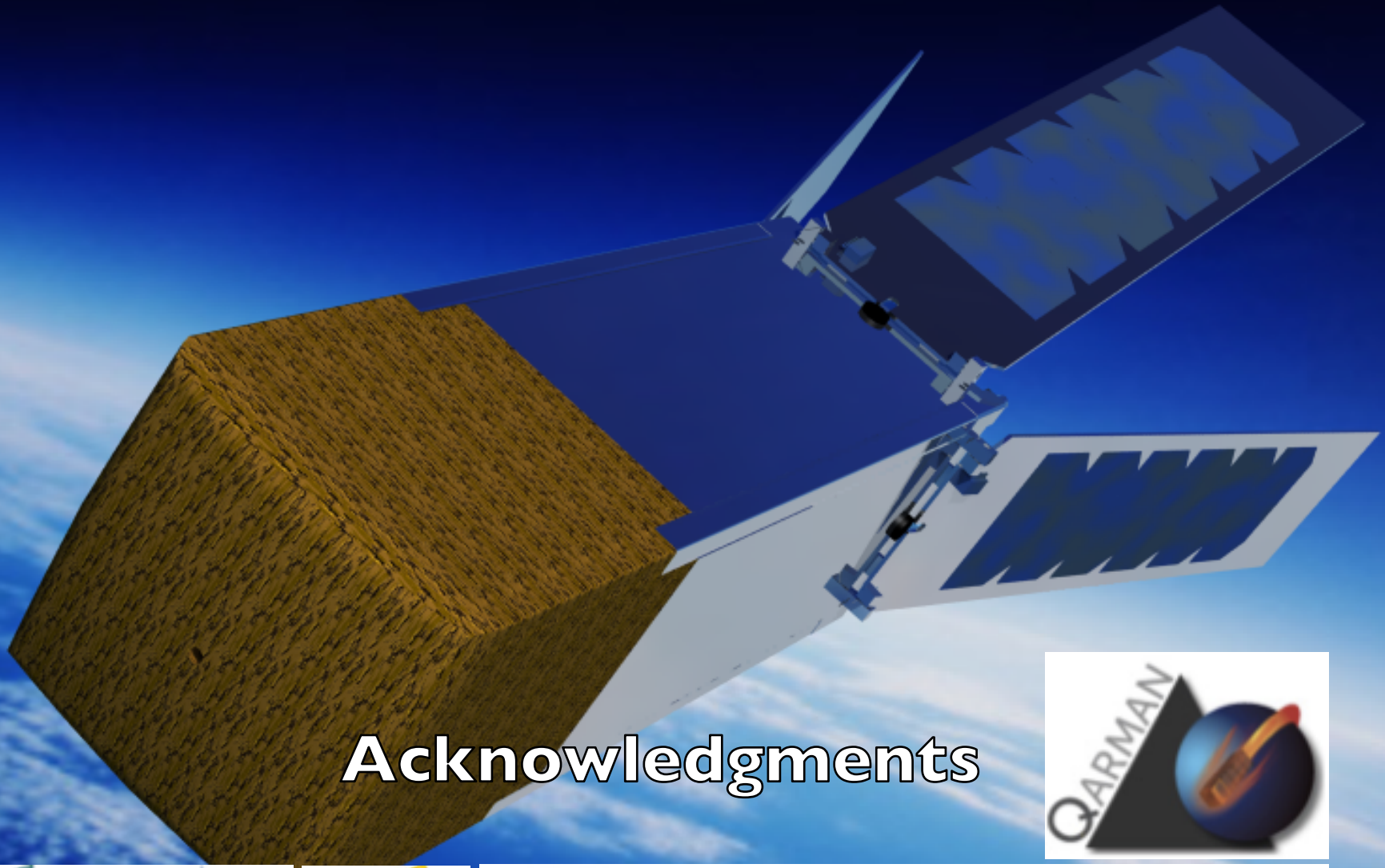
Acknowledgements

The research leading to these results has received funding and support from AIRBUS DS through the ANRT's CIFRE program

Special thanks to Alexis Bourgoing, Franck Delattre, Jean-Marc Bouilly and Coumar Oudea

Thanks to the QARMAN Team members for their help and support





Acknowledgments

QARMAN

CENTRALE

von KARMAN INSTITUTE FOR FLUID DYNAMICS

EM2C

cnrs

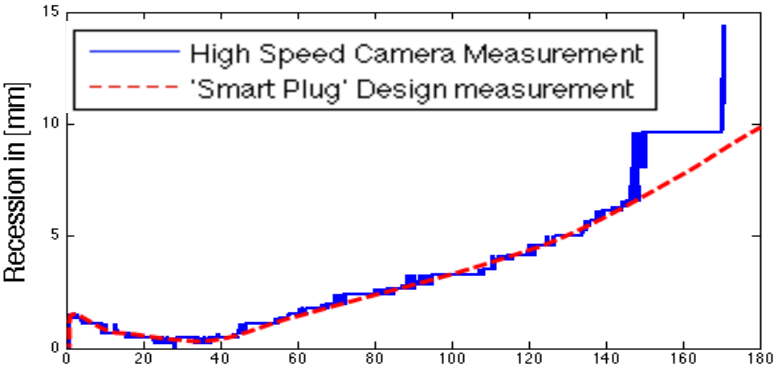
Cifre Conventions

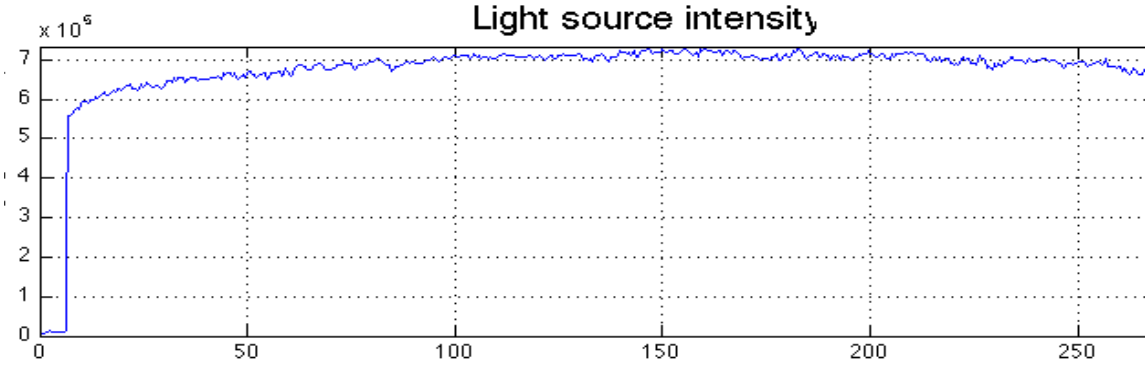
anrt association nationale recherche technologie

AIRBUS DEFENCE & SPACE

Thank you
for your attention

-gilles.bailet@ecp.fr-





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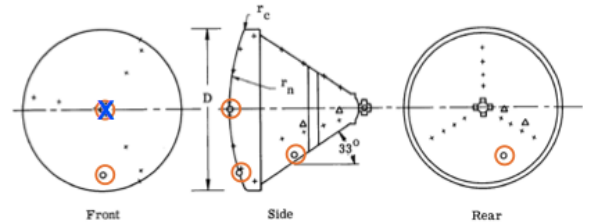
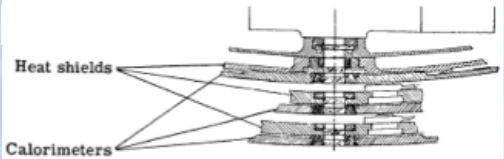


Fire II architecture



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Mission conclusions:

High Uncertainties on:

-Radiative heat flux (≈20%)

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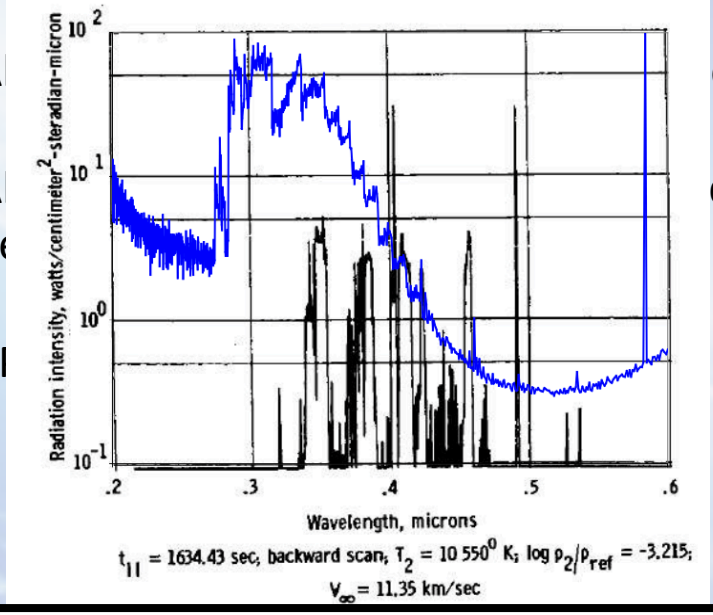
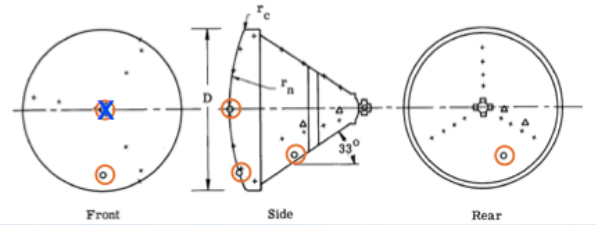


Spectral Comparison for a Fire II test case

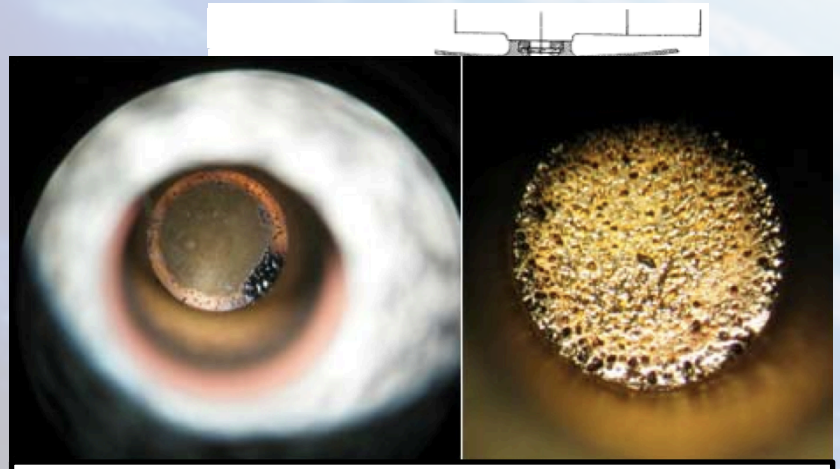
(Blue: Simulation and Black: Experiment)

Introduction

-Problematic-



Fire II architecture



Preci, et Al., **Development of a Combined Sensor System for Atmospheric Entry Missions**, 7th European Symposium on Aerothermodynamics for Space Vehicles

Mission conclusions:

High Uncertainties on:

-Radiative heat flux (≈20%)

→ -Ablation product impacts on heat fluxes

-Ablation rate (intrusive methods or indirect measurement with velocity gradient)

-TPS sizing (≥20% margin)

Introduction

-Problematic-

Mission conclusions:

Fire II architecture

High Uncertainties on:

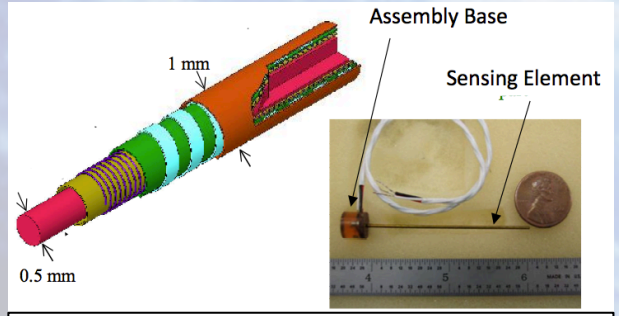
-Radiative heat flux (≈20%)

-Ablation product impacts on heat fluxes

ARAD probe (Galileo, MSL)

-Ablation rate (intrusive methods or indirect measurement with velocity gradient)

-TPS sizing (≥20% margin)

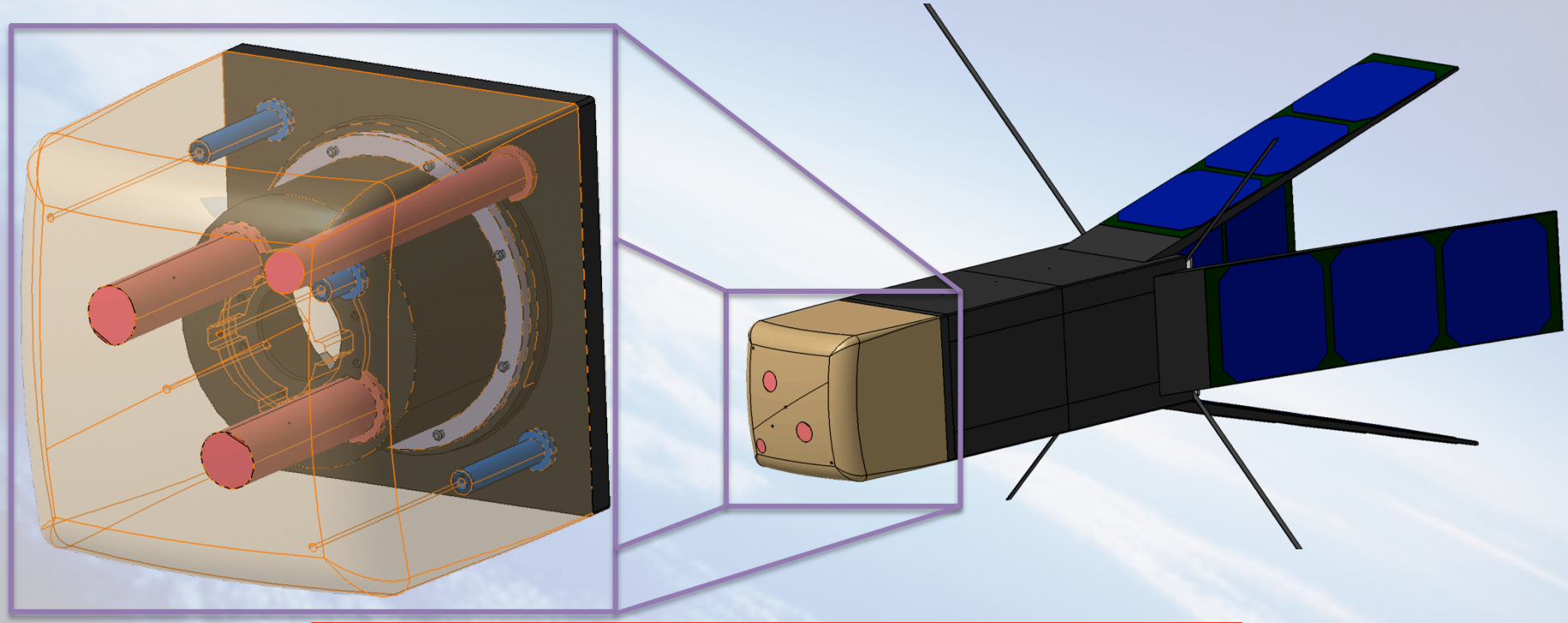


D. M. Empey, et al., **NASA Application of TPS Instrumentation in Ground and Flight, IPPW 9**

Both systems impose strong design constrains on the mission and are considered as highly intrusive technics only suitable for a certain range of applications

QARMAN Platform

-Want to know more?-



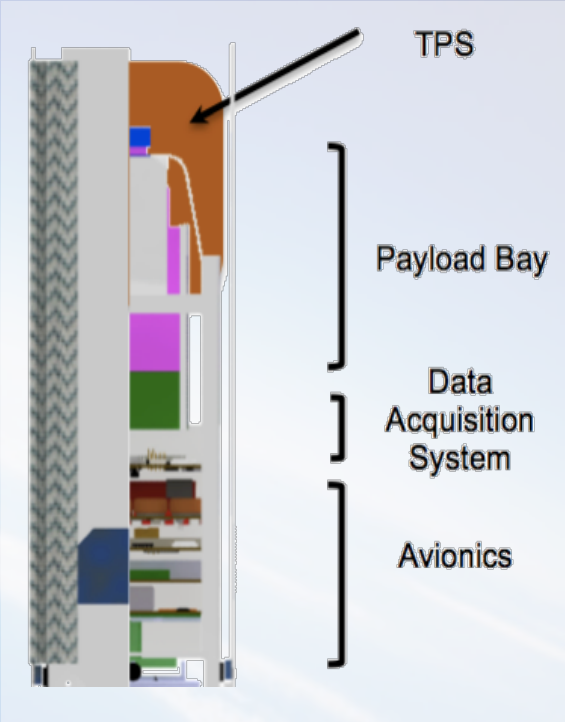
Thermal plugs and Pressure ports

QARMAN Platform

-Preliminary design-

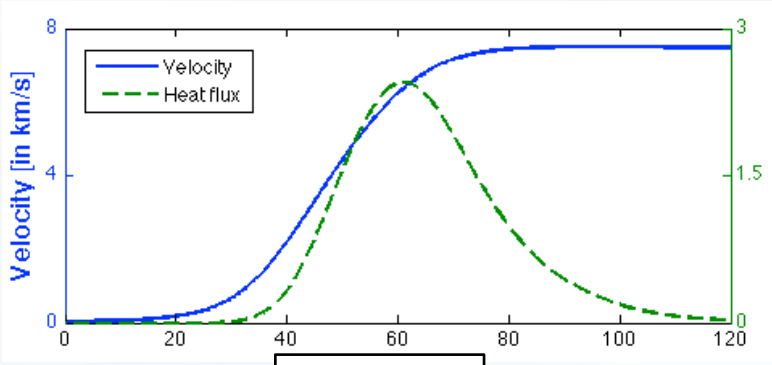
Reference: QARMAN proposal for QB50 call

Subsystem	Mass [g],	Mass [%]	Volume [10cm],	Volume [%]
Heat Shield				
Front surface	360	20	0.63	25
Side-Panels	217	20	n/a	0
Functional Unit				
Structure (2U)	468	20	n/a	
OBC	161	10	0.17	10
EPS + Batteries	248	10	0.33	25
Solar Panels	336	5	n/a	
Communication	263	10	0.46	10
Payloads				
Acquisition PCB	240	20	0.25	25
Sensors	469	20	0.25	25
AeroSDS	300	20	0.5	25
Total	**3062**		**2.59**	

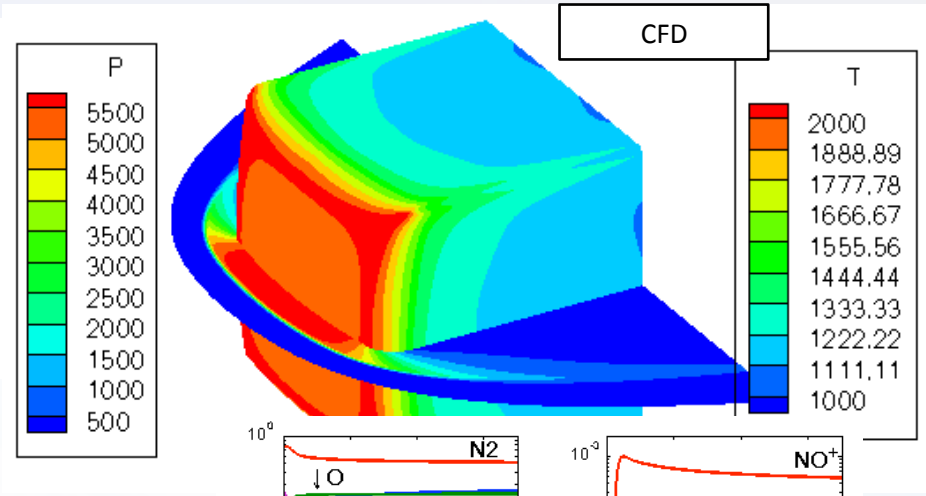


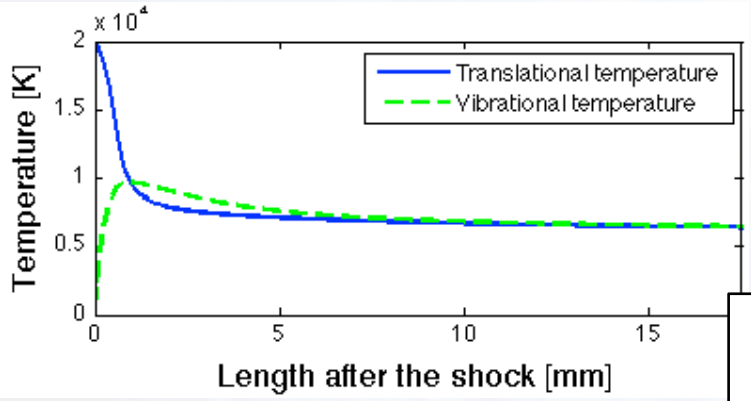
Radiative Environment

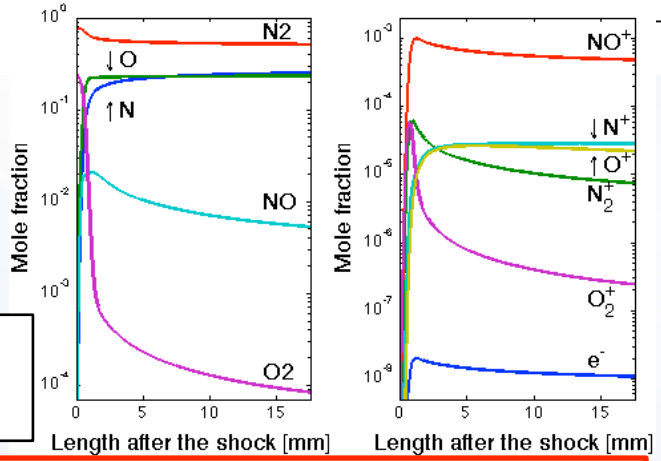
-Prediction of the Line-of-Sight's Radiation-



Trajectory





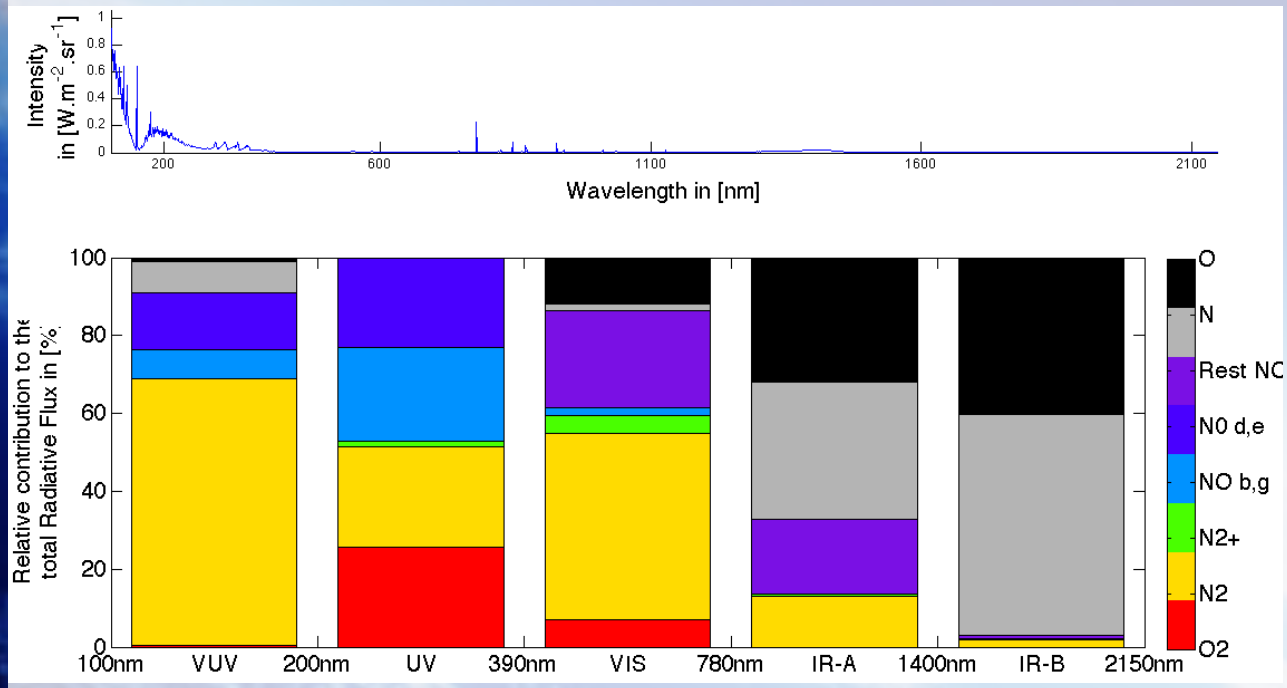


Thermal and Chemical properties of the stagnation line

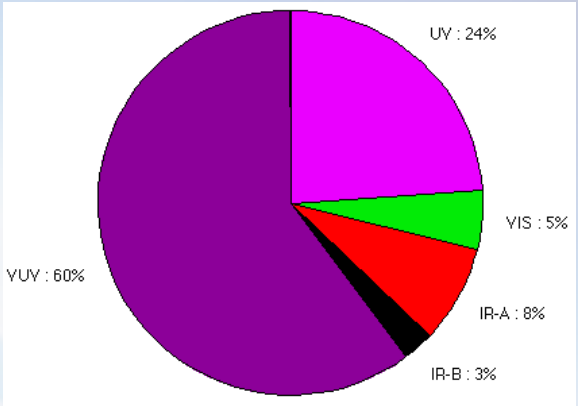
Steps leading to the calculus of Line-of-sight's radiations at a given altitude

Radiative Environment

-Prediction of the Line-of-Sight's Radiation-



Prediction at 60 km

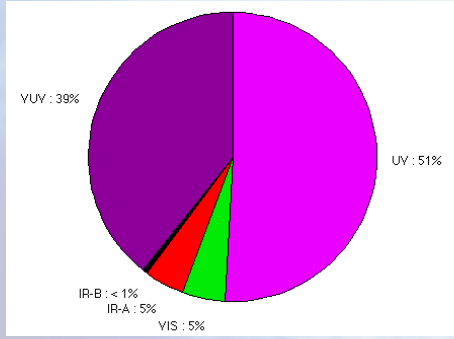


N, O, N^+ and O^+, N_2, O_2, NO, the molecular band systems, N_2 1st Pos, N_2 2nd Pos, N_2 Birge-Hopfield, O_2 Schumann-Runge, NO β, NO γ, NO δ, NO ε, N_2^+ 1st Neg and N_2^+

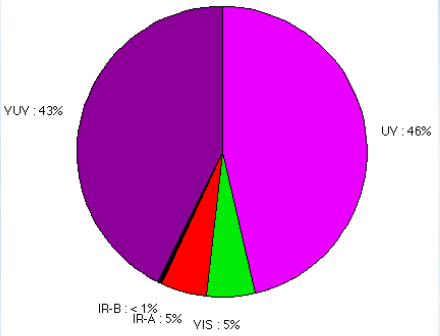
Radiative Environment

-Prediction of the Line-of-Sight's Radiation-

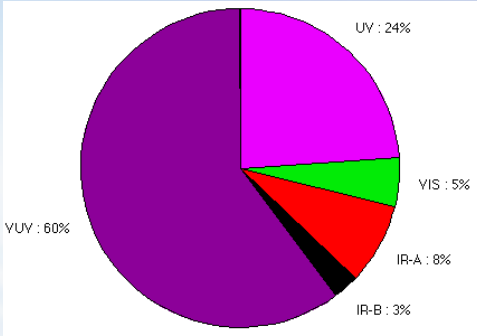
Prediction at 50 km



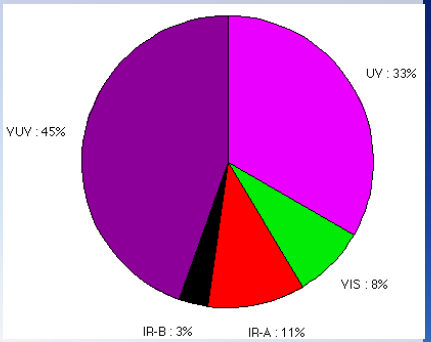
Prediction at 55 km



Prediction at 60 km



Prediction at 65 km



VUV **UV** **VIS** **IR-A** **IR-B**

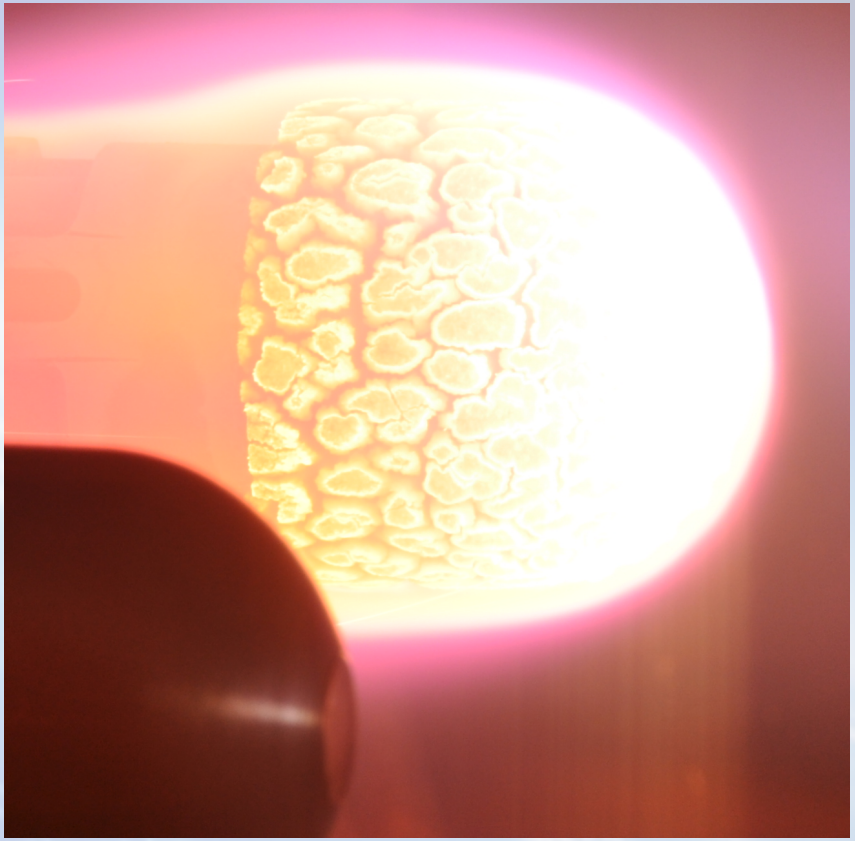
N, O, N^+ and O^+, N_2, O_2, NO, the molecular band systems, N_2 1st Pos, N_2 2nd Pos, N_2 Birge-Hopfield, O_2 Schumann-Runge, NO β, NO γ, NO δ, NO ε, N_2^+ 1st Neg and N_2^+

Spectrometer Payload

-Performences-

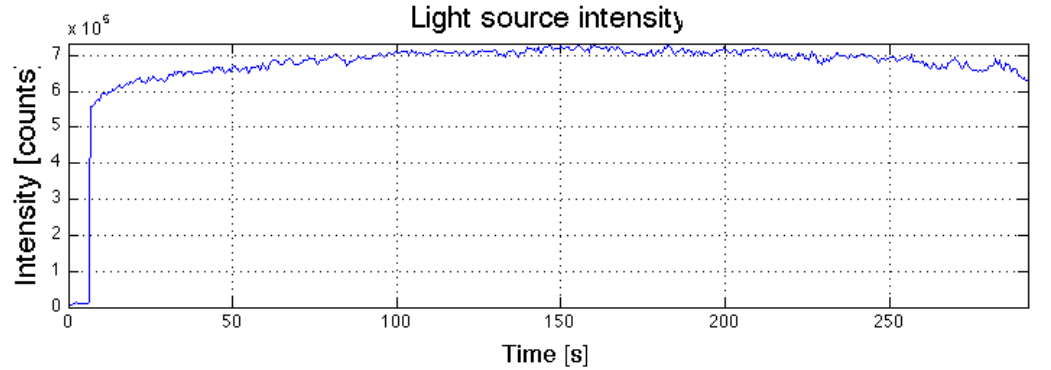
Test conditions:

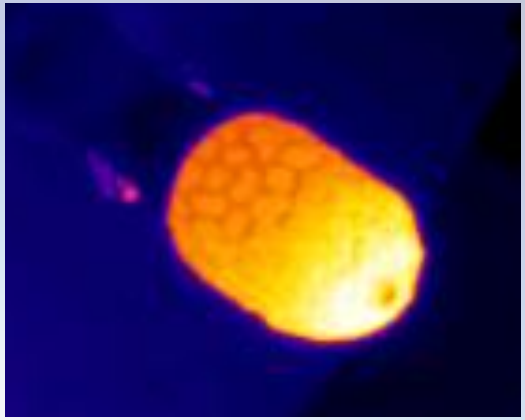
HeatFlux:	1.2 MW/m^2
HeatLoad:	368 MJ/m^2 (~5 minutes)
Pressure:	100 mbar
Quartz tube inner diameter:	300 mm



Spectrometer Payload

-Performences-





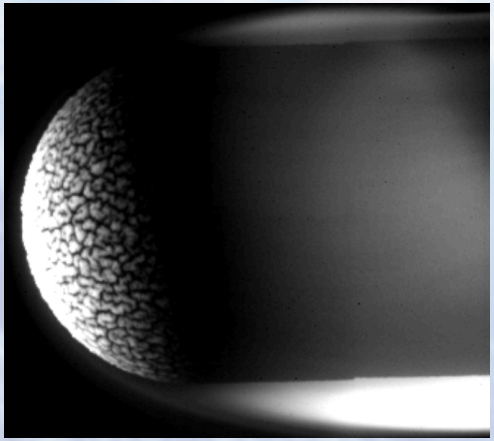
Test conditions:

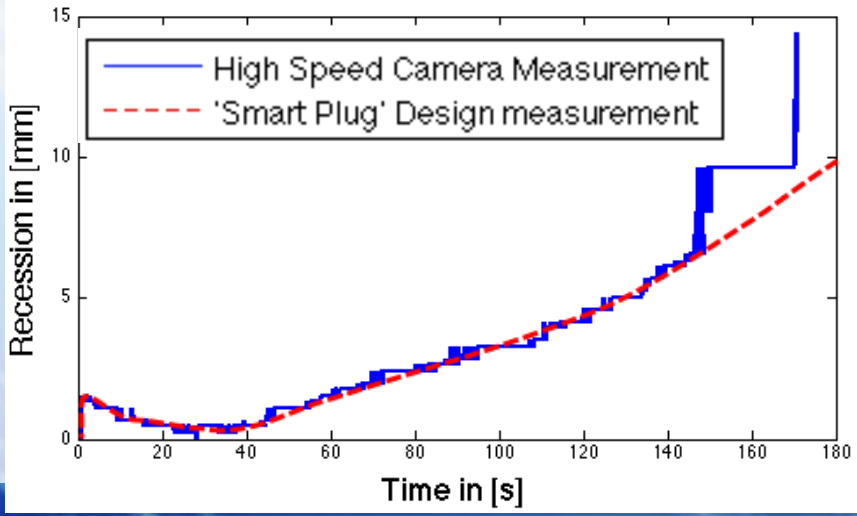
HeatFlux: 1.2 MW/m^2

HeatLoad: 368 MJ/m^2

Pressure: 100 mbar

Quartz tube
inner diameter: 30 cm





Radiative Environment

-Prediction of the Line-of-Sight's Radiation-

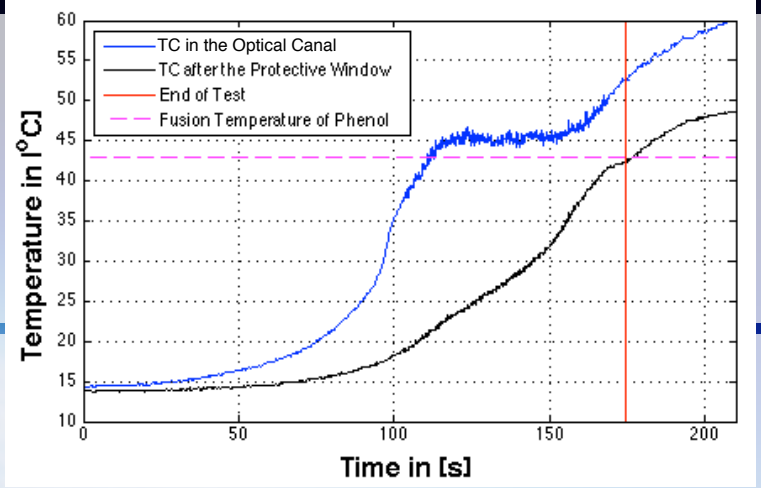
Discrepancies:

-Ablation products

-Coil Area (High temperatures) ← Addressed by the Cooled Optical Path

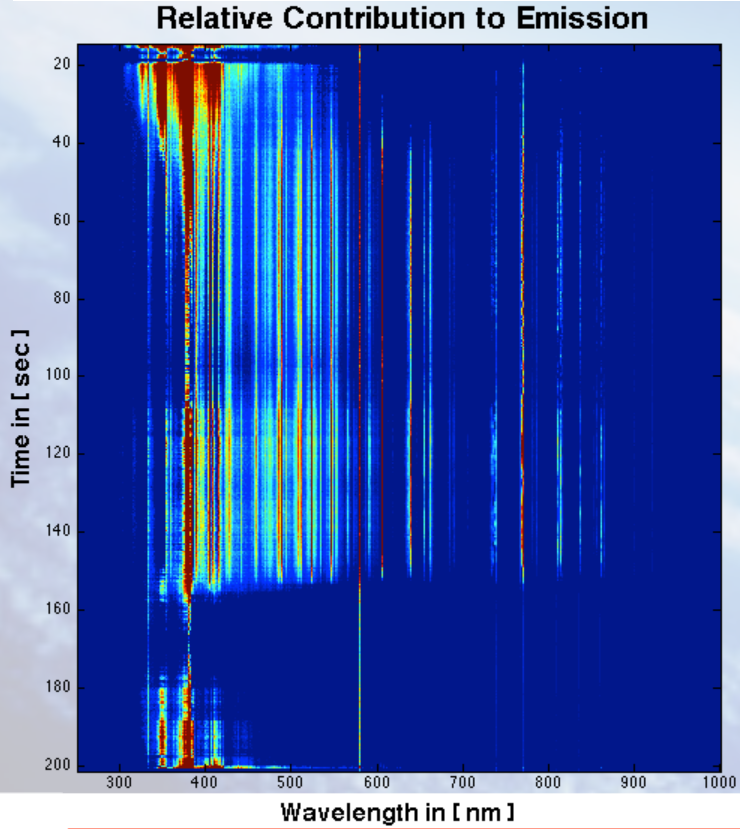
nvi

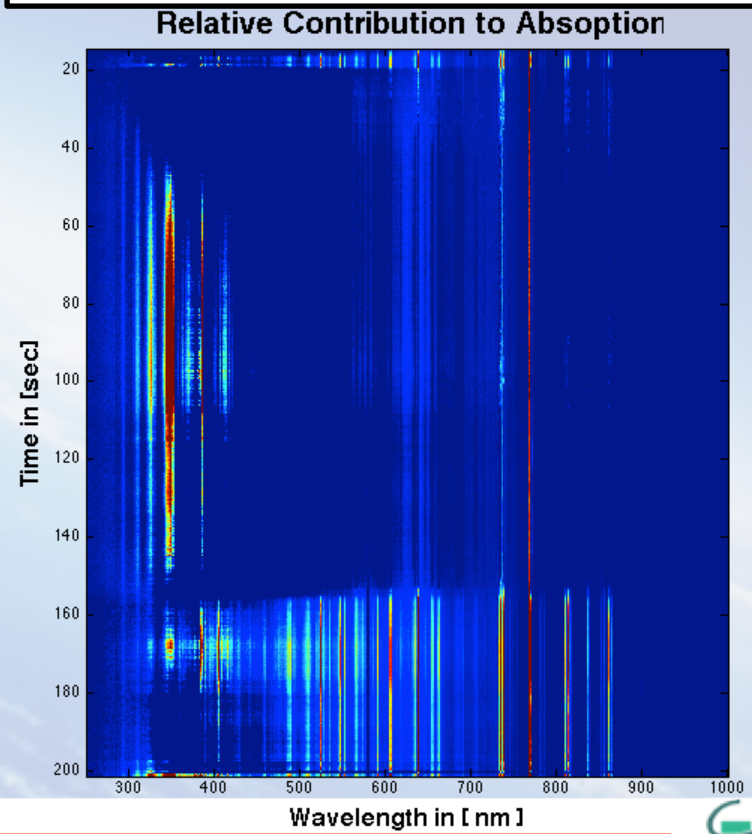
Absor



Temperature, °C	Total moles observed, percent								
	CO_2	CO	C_6H_6	C_7H_8	$C_6H_5{\cdot}OH$	$(CH_3)_2C_6H_3{\cdot}OH$	CH_4	H_2O	H_2
100								1.47	
150								.75	
200								.48	
250								.57	
300								1.28	
350								3.44	
400					0.46	0.13	0.05	3.44	
450		0.21			.81	.25	.15	5.42	0.76
500	0.09	.44	0.02	0.08	2.72	.75	.75	3.35	1.47
550	.11	.87	.06	.13	1.62	.38	1.29	2.44	2.18
600	.32	1.30	.06	.05	.79	.14	2.61	.40	3.65
650	.51	1.19	.03	.04	.44	.10	2.35	.26	5.17
700	.26	.77		.01	.21	.05	1.32	.13	5.88
750	.17	.54			.09		.83		6.64
800	.11	.26					.40		7.35
850		.20					.20		5.88
900							.08		4.50
950									3.65
1000									2.94

George F. Sykes, NASA TN D-3810
Decomposition Characteristics of a Char-forming Phenolic Polymer Used For Ablative Composites

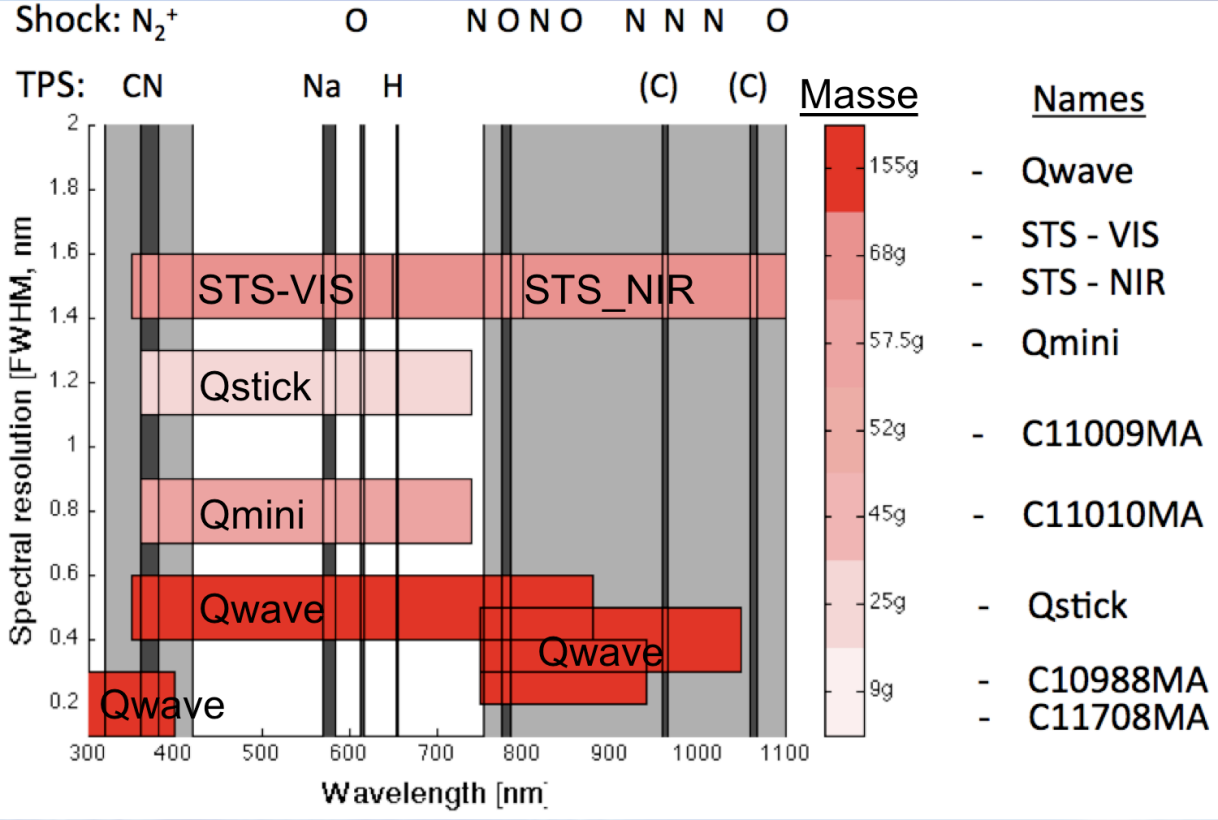




- **Emission from Ablation in the boundary layer**
- **Absorption from the low temperature pyrolysis gas inside the optical canal**

Spectrometer Payload

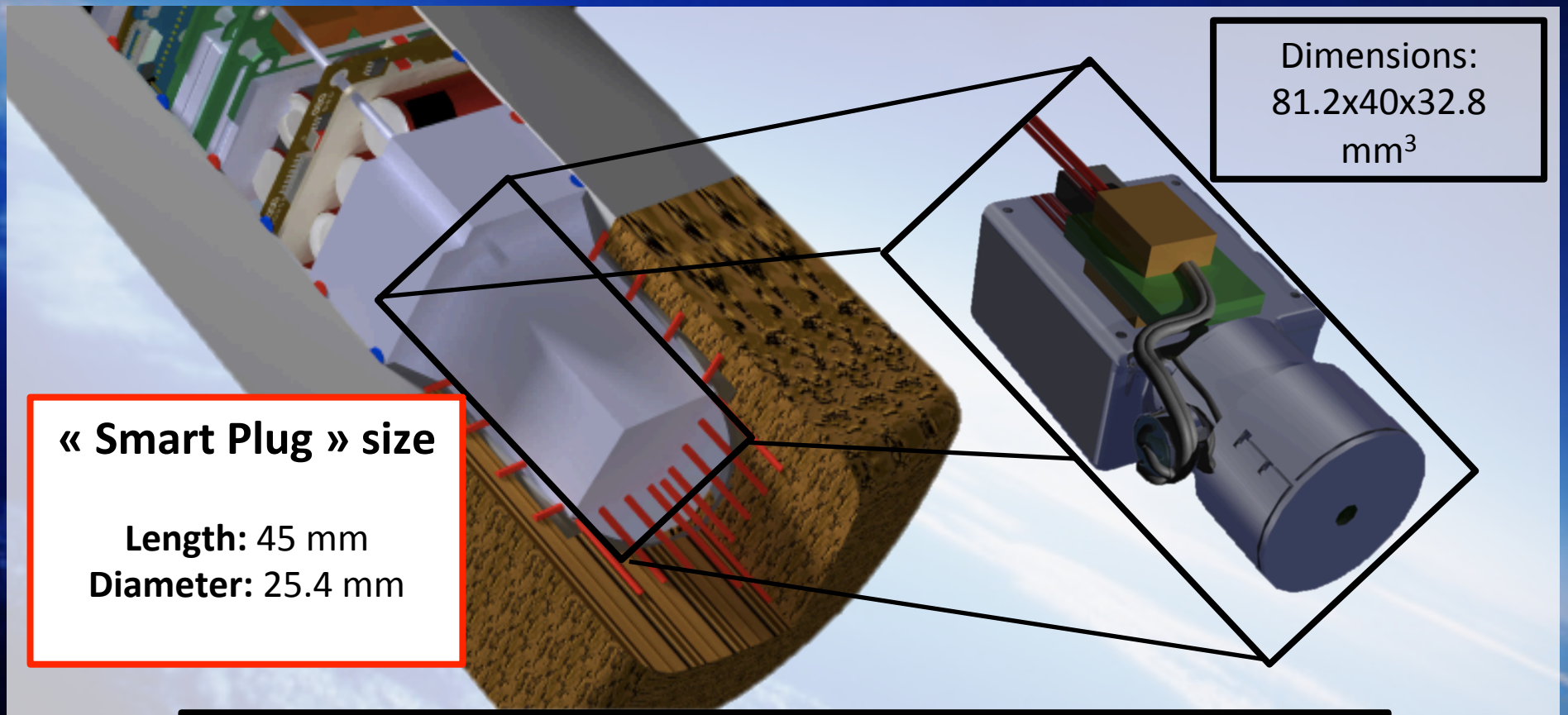
-Hardware Selection-



Overview of possible emission spectrometers for QARMAN

Spectrometer Payload

-Solution-



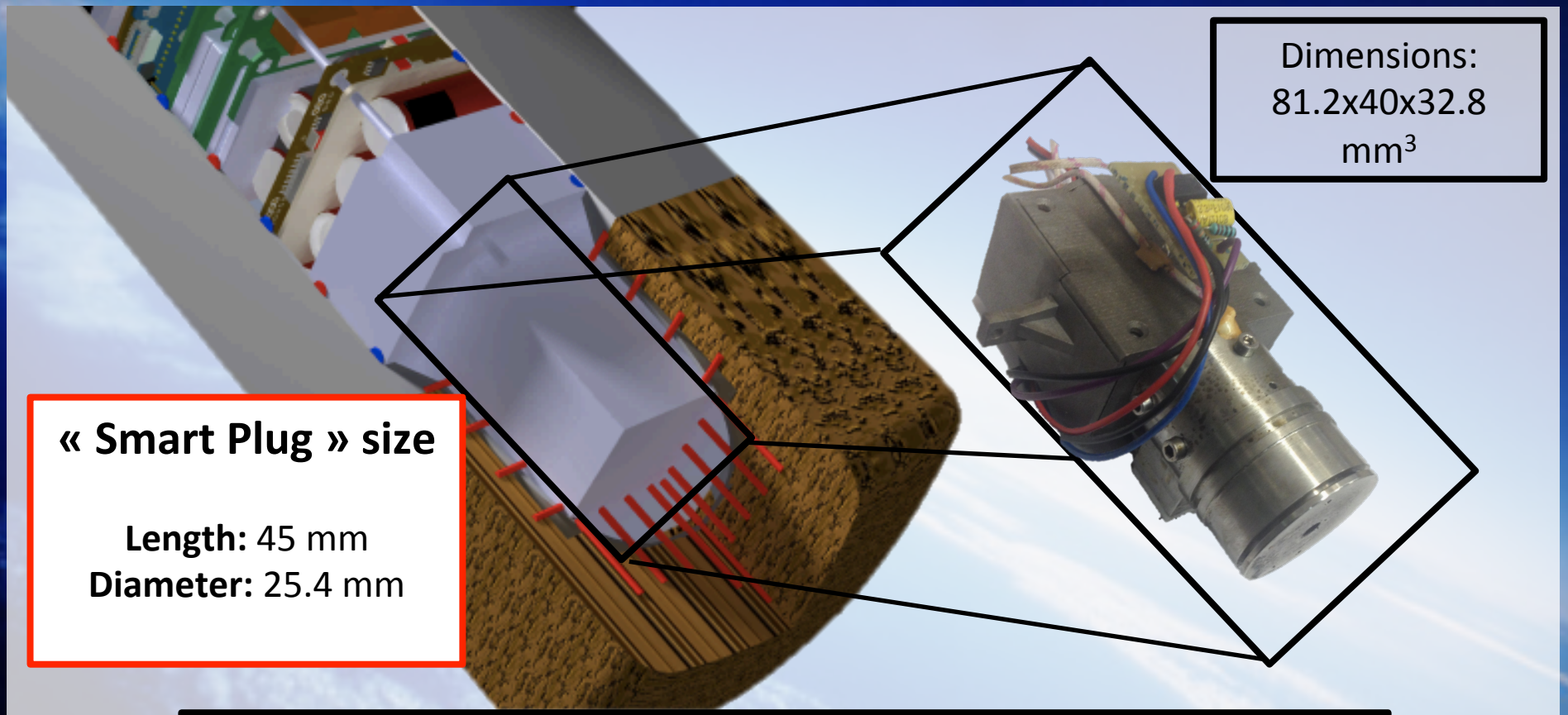
« Smart Plug » size

Length: 45 mm
Diameter: 25.4 mm

Integrated view of the Imbedded Nano-size Emission Spectrometer within the QARMAN's platform

Spectrometer Payload

-Solution-



« Smart Plug » size

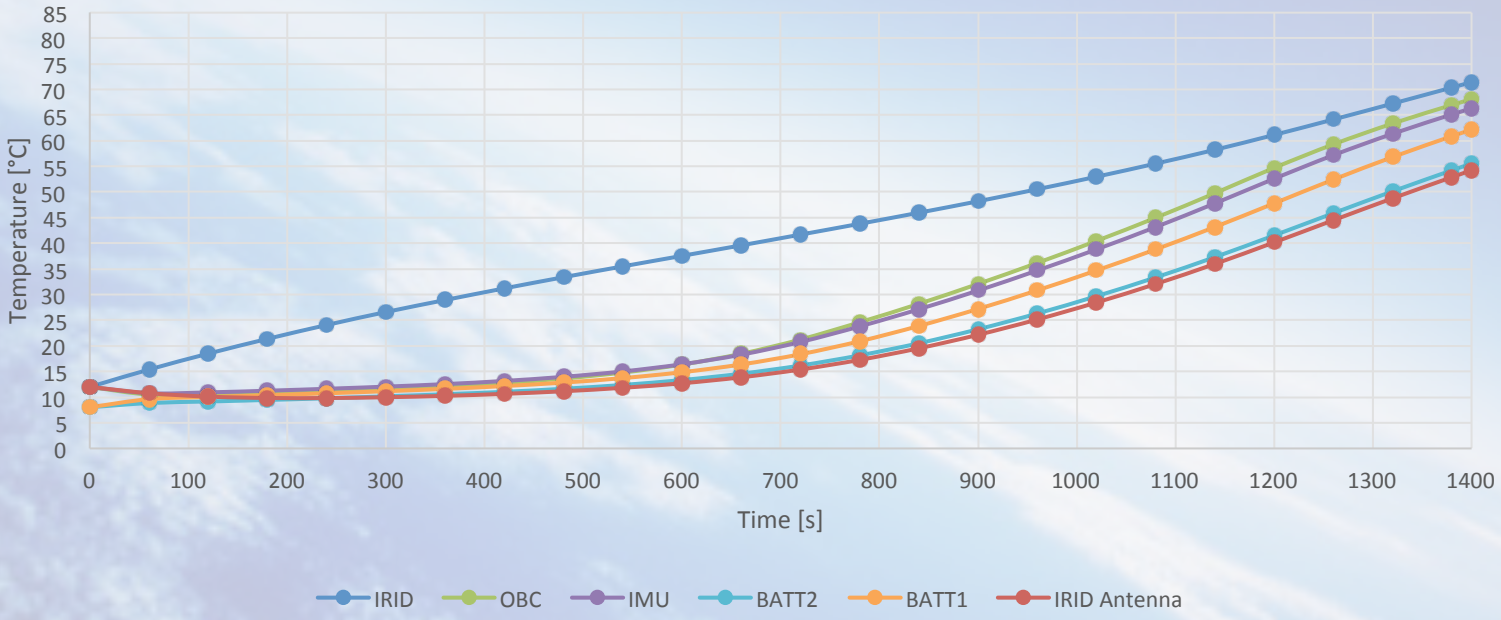
Length: 45 mm
Diameter: 25.4 mm

Integrated view of the Imbedded Nano-size Emission Spectrometer within the QARMAN's platform

Spectrometer Payload

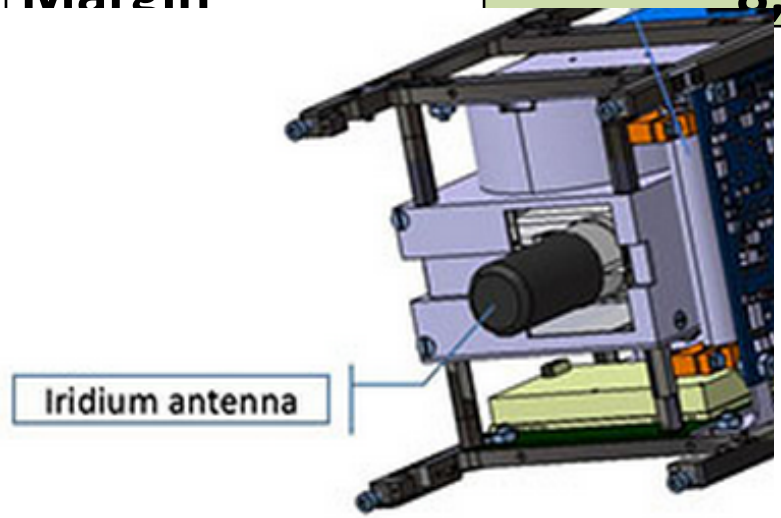
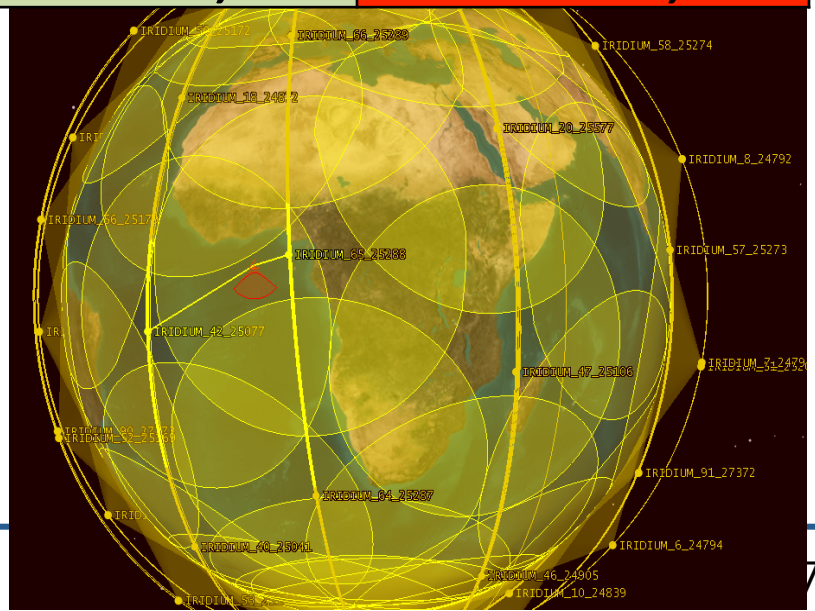
- Calibration for Reentry Constrains -

Temperature profile of the main subsystem of QARMAN during reentry



Temperature effect on CCD sensor of the Payload:

- Shift of the Spectrum on the wavelength range
- Intensity response varying with temperature

Communication System

	Transmission duration (Land on sea)	Transmission duration (Land on 474m)	Transmission duration (Land on 3027,4m)
Available data transmission (bits)	**508800**	**492000**	**420000**
Required data transmission (bits)	**467972**	**467972**	**467972**
Difference	40828	24028	-47972
Margin	**8,72%**	**5,13%**	**-10,25%**