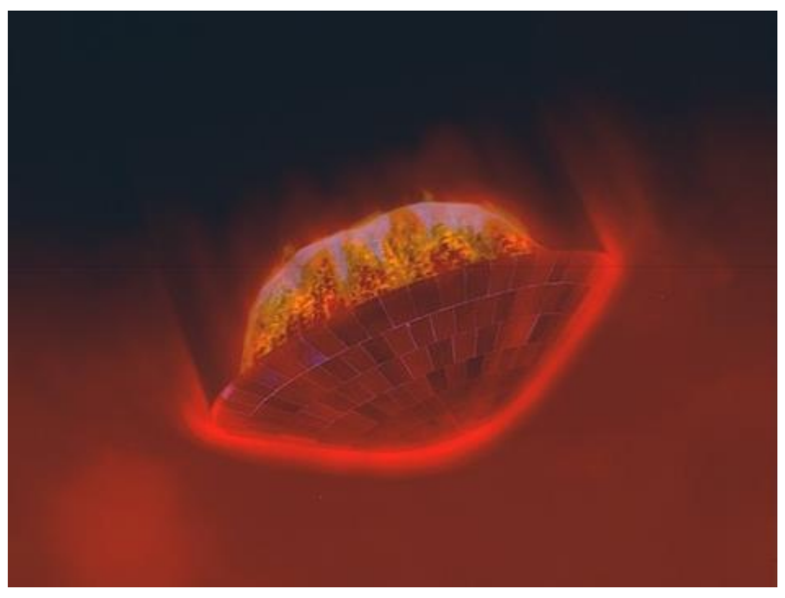
Uncertainty Quantification of Aerothermal Flow Simulation Through Low-Density Ablative Thermal Protection Materials

Joffrey Coheur

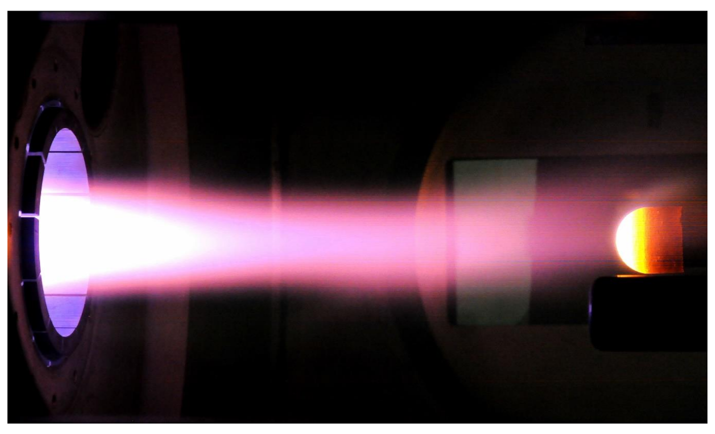
Supervisors: Thierry Magin (VKI), Maarten Arnst (ULg), Philippe Chatelain (UCL)

Introduction

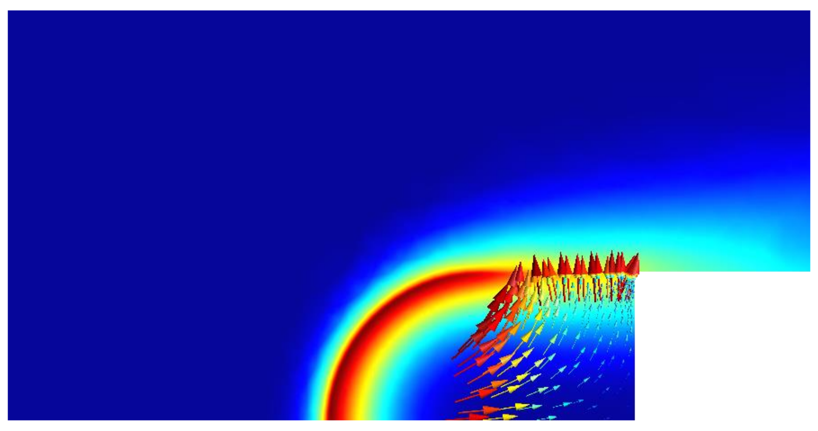


Huygens Probe entry into Titan's atmosphere
Source: ESA.

- **The thermal protection system (TPS)** is essential to shield spacecraft and their payload from the severe aerothermal conditions associated with atmospheric entry [1]
- Ablative TPS design process



Wind tunnel experiments [2]



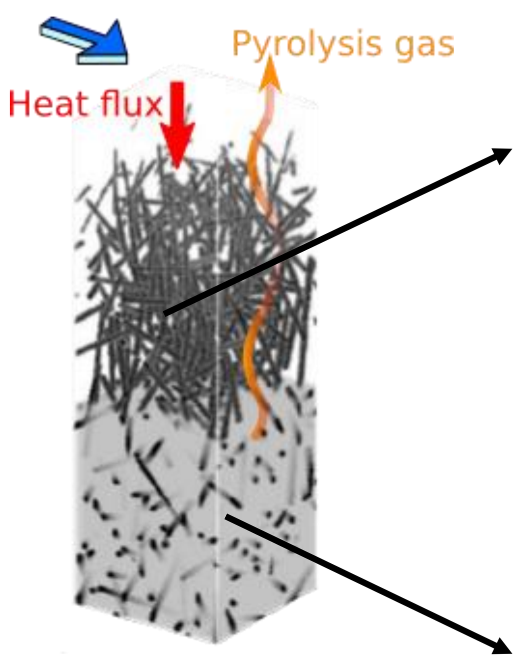
Numerical simulations [3]

- Uncertainties coming from **experiments** and **physical models** are affecting **simulations** with **unknown impact on predictions!**
- **Objective:** develop a rigorous **uncertainty quantification** approach for **ablative** TPS **characterization** and **design**

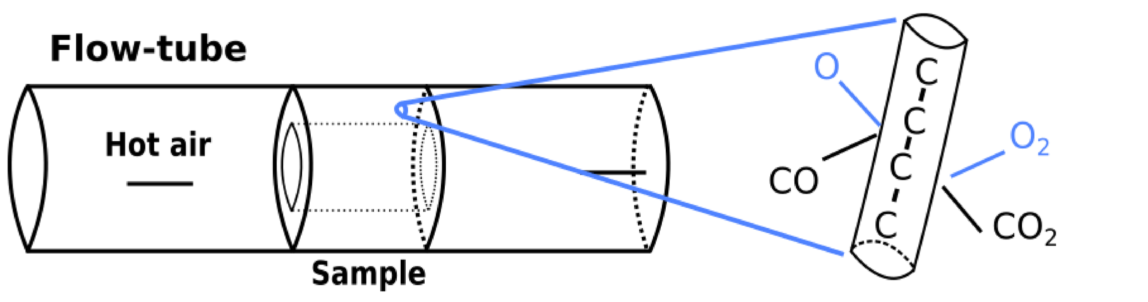
Methodology

1. Which uncertainties? ➡ Reassess physico-chemical models

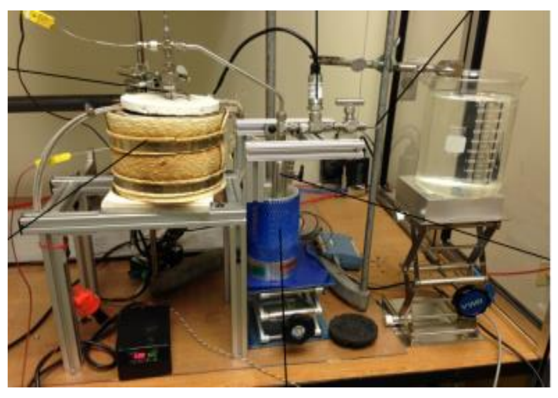
- **New** experiments on pyrolysis and oxidation of phenolic-impregnated carbon **ablation**

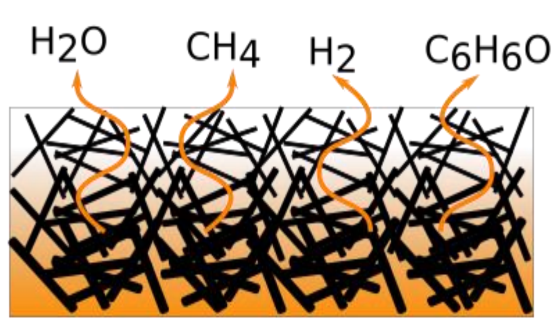


- **Carbon Fiber oxidation [4]**



- **Phenolic resin pyrolysis [5]**

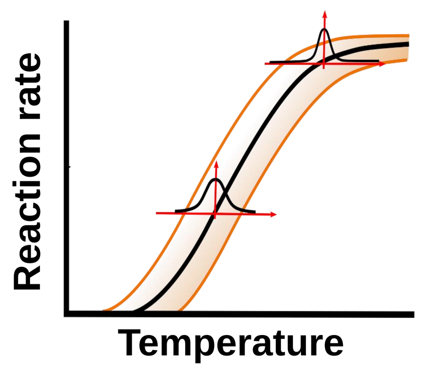




- Apply **stochastic inference methods** to those **new experimental** results for quantifying uncertainties on **physico-chemical models**

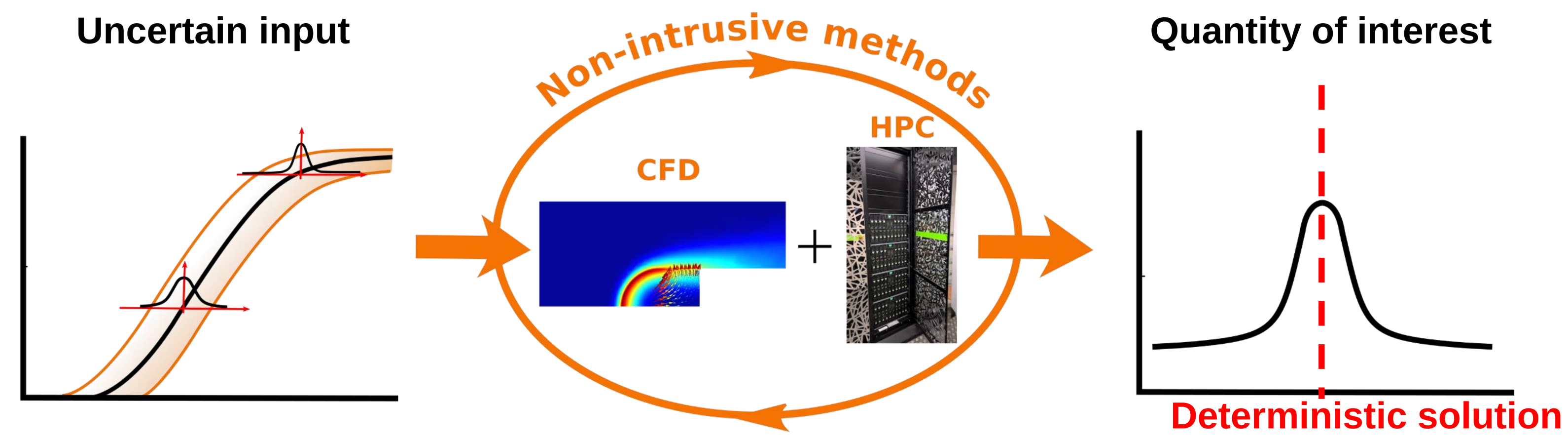
E.g. pyrolysis gas production model:

$$\mathrm{Gas}^i_{\mathrm{prod}} = -A_i\, e^{-\frac{E_a^i}{RT}} \left(\frac{\rho - \rho_{char}}{\rho_{virgin}}\right)$$

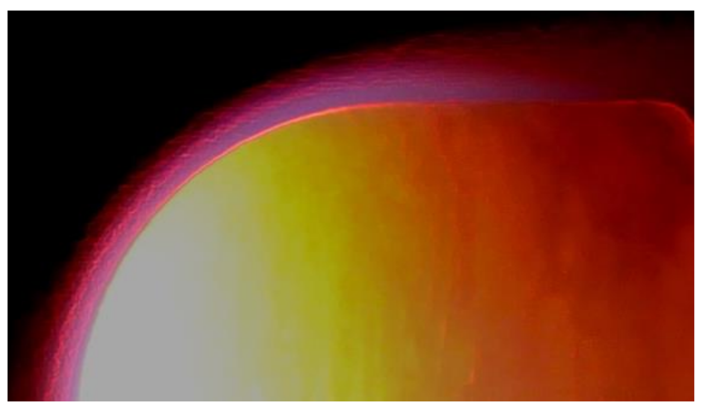


2. How? ➡ Aerothermal flow simulations

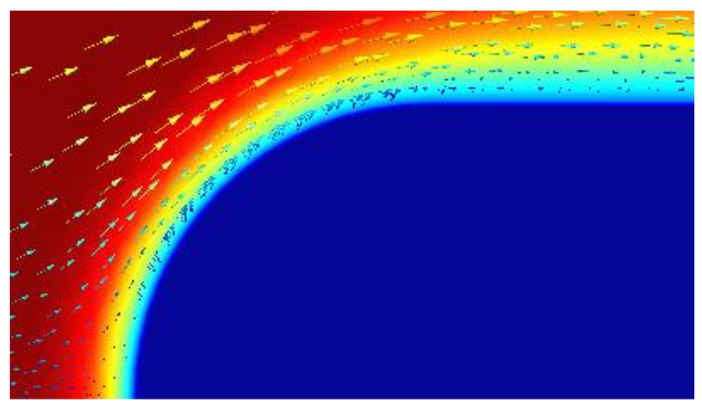
- Develop **non-intrusive** uncertainty quantification **methods** around numerical codes for the study of ablation phenomena. Perform uncertainty propagation through the model



- Numerical simulations of **VKI Plasmatron experiments** on ablative thermal protection materials and quantification of uncertain margins



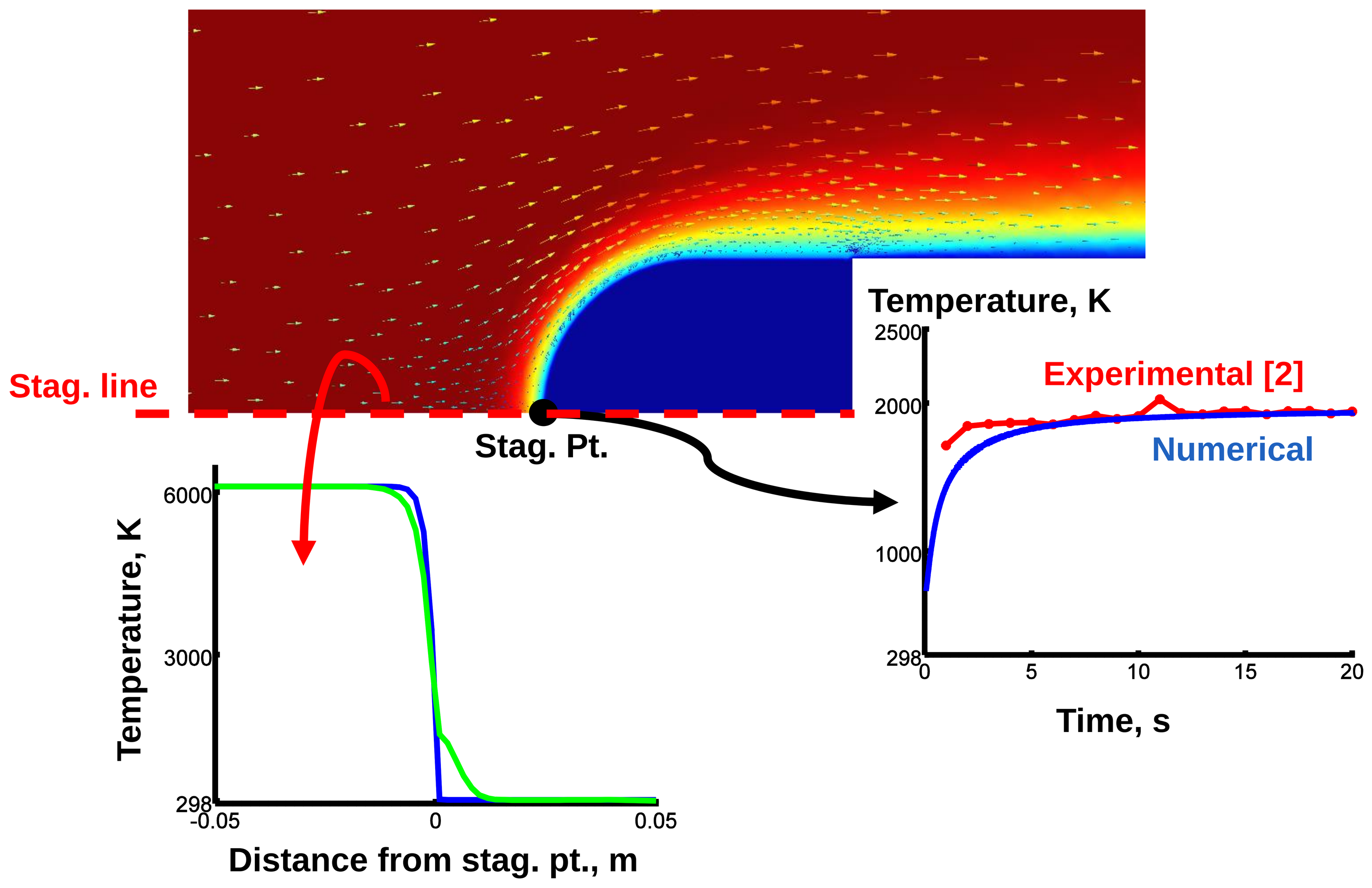
VKI Plasmatron exp. [2]



Plasmatron simulation

Preliminary results

- **Argo** multiphysics and multidimensional CFD tool developed at Cenaero, based on a discontinuous Galerkin method



➡ **Deterministic simulations!**

- **Ongoing work:** review of stochastic inference methods (Bayesian, optimization problem with uncertainties) with application to **physico-chemical models**

Acknowledgments

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References

[1] G. Duffa. *Ablative Thermal Protection Systems Modeling*. AIAA Education Series, 2013.
[2] B. Helber. *Material Response Characterization of Low-Density Ablators in Atmospheric Entry Plasmas*. PhD Thesis, VUB & VKI, 2016.
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[4] F. Panerai *et al.* Flow-tube Oxidation Experiments of the Carbon Preform of a Phenolic-Impregnated Carbon Ablator. Journal of Thermophysics and Heat Transfer, 28(2):181-190, 2014.
[5] H.-W. Wong *et al*. Quantitative Determination of Species Production from Phenol-Formaldehyde Resin Pyrolysis. Polymer Degradation and Stability, 112:122-131, 2015.