2-6 Juillet 2018, Toulouse, France

Compte-rendu sur la conférence :

HTPP 15 : High-Tech Plasma Processes

Ph. Teulet
Laboratoire Plasma et Conversion d'Energie (Laplace)
www.laplace.univ-tlse.fr

Pour l'**Association Arc Electrique**

HTPP 15 : High-Tech Plasma Processes

Conférence co-organisée par
- **l'Université de Limoges (IRCER)**
- **l'Université de Toulouse (Laplace)**

Local Organizing Committee

Université de Limoges :

- **Armelle Vardelle (Co-Chair)**
- **Christophe Chazelas**
- **Vincent Rat**

Université de Toulouse :

- **Marie-Ange Albouy** (Pôle congrès UPS Toulouse III)
- **Yann Cressault**
- **Pierre Fort**
- **Benoit Lantin**
- **Mathieu Masquère**
- **Manitra Razafinimanana**
- **Marc Ternisien**
- **Philippe Teulet (Co-Chair)**
- **Flavien Valensi**

International Scientific Committee (16 membres)

Jochen Schein (Université de Munich, Germany), Head of ISC
Dirk Urlhand (INP Greifswald, Germany)
Antony Murphy (CSIRO, Australia)
Mikhail Benilov (Universidade da Madeira, Portugal)
Javad Mostaghimi (University of Toronto, Canada)
Matteo Gherardi (Università di Bologna, Italy)
Anatoly Veklich (Taras Shevcheko University, Ukrain)
Yasunori Tanaka (Kanasawa University, Japan)
Jean-Luc Meunier (McGill University, Canada)
Jean-Marc Bauchire (Université d'Orléans, France)
Juan Pablo Trelles (Lowell University, USA)
Gervais Soucy (University of Sherbrooke, Canada)
Claudia Riccardi (University of Milan-Bicocca, Italy)
Arnaud Bultel (University of Rouen, France)
Françoise Massines (University of Perpignan, France)
Georg Mauer (Forschungszentrum Jülich GmbH, Germany)

Toulouse Cité Européenne de la Science 2018

ESOF 2018 TOULOUSE
9-14 JULY 2018
SHARING SCIENCE: TOWARDS NEW HORIZONS

Toulouse a accueilli en **juillet 2018** la **8e édition d'ESOF - EuroScience Open Forum,** la plus grande rencontre interdisciplinaire sur la science et l'innovation en Europe.

HTPP15 a obtenu le label « ESOF 2018 ».

HTPP15 a été reconnue comme évènement satellite ESOF 2018 (ESOF satellite event).

SATELLITE EVENT
TOULOUSE
EUROPEAN CITY OF SCIENCE
ESOF 2018

Laplace · Université Toulouse III Paul Sabatier · Université de Limoges · cnrs · AAE · IRT Saint Exupéry · Labex Σ LIM · INP Toulouse · irCer

Programme scientifique

10 Sessions

Chaque session : 1 conf. « Plenary » (45min) et 1 conf. Topical (30min) + conf. Orales (20min) + 1 session posters

From Fundamental…

1) Special session (ITER)
Plenary: **Tim LUCE** (ITER Project)
Topical: **Gwenaël FUBIANI** (University of Toulouse)

2) Plasma sources and discharges (plasma generation)
Plenary: **Jochen SCHEIN** (University of Munich)
Topical: **Luc STAFFORD** (University of Montréal)

3) Advances and challenges in plasma diagnostics
Plenary: **Stéphane MAZOUFFRE** (University of Orléans)
Topical: **Arnaud BULTEL** (University of Rouen)

4) Advances and challenges in plasma modelling and simulation
Plenary: **Juan Pablo TRELLES** (Lowell University)
Topical: **He Ping LI** (Tsinghua University)

5) Plasma-material interactions: liquid/solid
Plenary: **Mikhail BENILOV** (University of Madeira)
Topical: **Khaled HASSOUNI** (Paris 13 University)

To applications

6) Material and Surface processing
Plenary: **Dirk UHRLANDT** (INP Greifswald)
Topical: **Christian MOREAU** (Concordia University)

7) Powders and additive manufacturing
Plenary: **Filomeno MARTINA** (Cranfield University)
Topical: **Romain VERT** (TEKNA)

8) Aeronautics and aerospace applications
Plenary: **Roland CAUSSE** (AIRBUS)
Topical: **Franck FLOURENS** (AIRBUS)

9) Energy and transport applications
Plenary: **Christophe LAUX** (Ecole Centrale Paris)
Topical: **Alexander BARTH** (Oerlikon-Metco)

10) Environmental applications
Plenary: **Izak Jacobus VAN DER WALT** (NECSA)
Topical: **Laurent FULCHERI** (Mines ParisTech)

Quelques chiffres

Nombre total de participants : 115

Pour comparaison :

HTPP14 (2016) Munich : ≈ 80

HTPP13 (2014) Toulouse : 140

Présentations orales : 39

Posters : 59

Indicateur de dimension internationale

Pays représentés - Présentation orales : 12

Royaume-Uni (2), France (14), Canada (4), Japon (3), Allemagne (3), Russie (5), Portugal (2), Suisse (2), USA (1), Chine (1), Italie (1), Afrique du Sud (1).

Pays représentés – Participants : 19

Royaume-Uni, France, Canada, Japon, Allemagne, Russie, Portugal, Suisse, USA, Chine, Italie, Afrique du Sud, Liban, Corée du Sud, Tunisie, Ukraine, République Tchèque, Algérie.

Laplace · Université Toulouse III Paul Sabatier · Université de Limoges · CNRS · AAE · IRT Saint Exupéry · LABEX ΣLIM · INP Toulouse · IRCER Institut de recherche sur les céramiques

Lien avec l'industrie

Industriels représentés

AIRBUS (4)
TEKNA (1)
OERLIKON-METCO (1)

Instituts, EPIC

IRT Antoine de Saint-Exupéry (3)
ONERA (1)
CEA (1)
NECSA (1)

1 stand IRT Antoine de Saint-Exupéry

Indicateurs jeunes chercheurs

Nombre de participants Jeunes Chercheurs (Masters + Doctorants + Post-Docs) : 45

Nombre de participants Doctorants : 29

Nombre de participants Masters + Doctorants : 33

2 prix posters décernés à des jeunes chercheurs

- Youssef Abdo (Mines-Paris-Tech, Nice)
- Aurélien Favre (CORIA, Rouen)

Plasmas thermiques vs Plasmas hors équilibre

Présentations orales :

- 16 oraux plasmas HE
- 22 oraux plasmas thermiques
- 1 oral plasma chaud (ITER – plasma de fusion)

Posters :

- 21 posters plasmas HE
- 38 posters plasmas thermiques

Séparation entre plasma thermique et plasma hors équilibre pas vraiment pertinente

Bilan pour chaque sessions – Principaux travaux présentés

1) Special session (ITER)
2) Plasma sources and discharges (plasma generation)
3) Advances and challenges in plasma diagnostics
4) Advances and challenges in plasma modelling and simulation
5) Plasma-material interactions: liquid/solid
6) Material and Surface processing
7) Powders and additive manufacturing
8) Aeronautics and aerospace applications
9) Energy and transport applications
10) Environmental applications

1) Special Session ITER

Session courte et ciblée : 2 presentations

- Plenary Lecture (45 minutes): **Tim LUCE** (CEA Cadarache, ITER's Chief Scientist)
Overview of the ITER Research Plan and the Challenges Ahead

- Topical Lecture (30 minutes): **Gwenaël FUBIANI**, Jean-Pierre Boeuf, Laurent Garrigues (Laplace, University of Toulouse)
Modelling of the Negative Ion Source and Accelerator of the ITER Neutral Beam Injector

Session en partie destinée à donner de l'information sur l'advancement du projet ITER et sur les challenges à relever dans le cadre de ce projet.

1) Special Session ITER : Tim LUCE, ITER Project

1) Special Session ITER : Tim LUCE, ITER Project

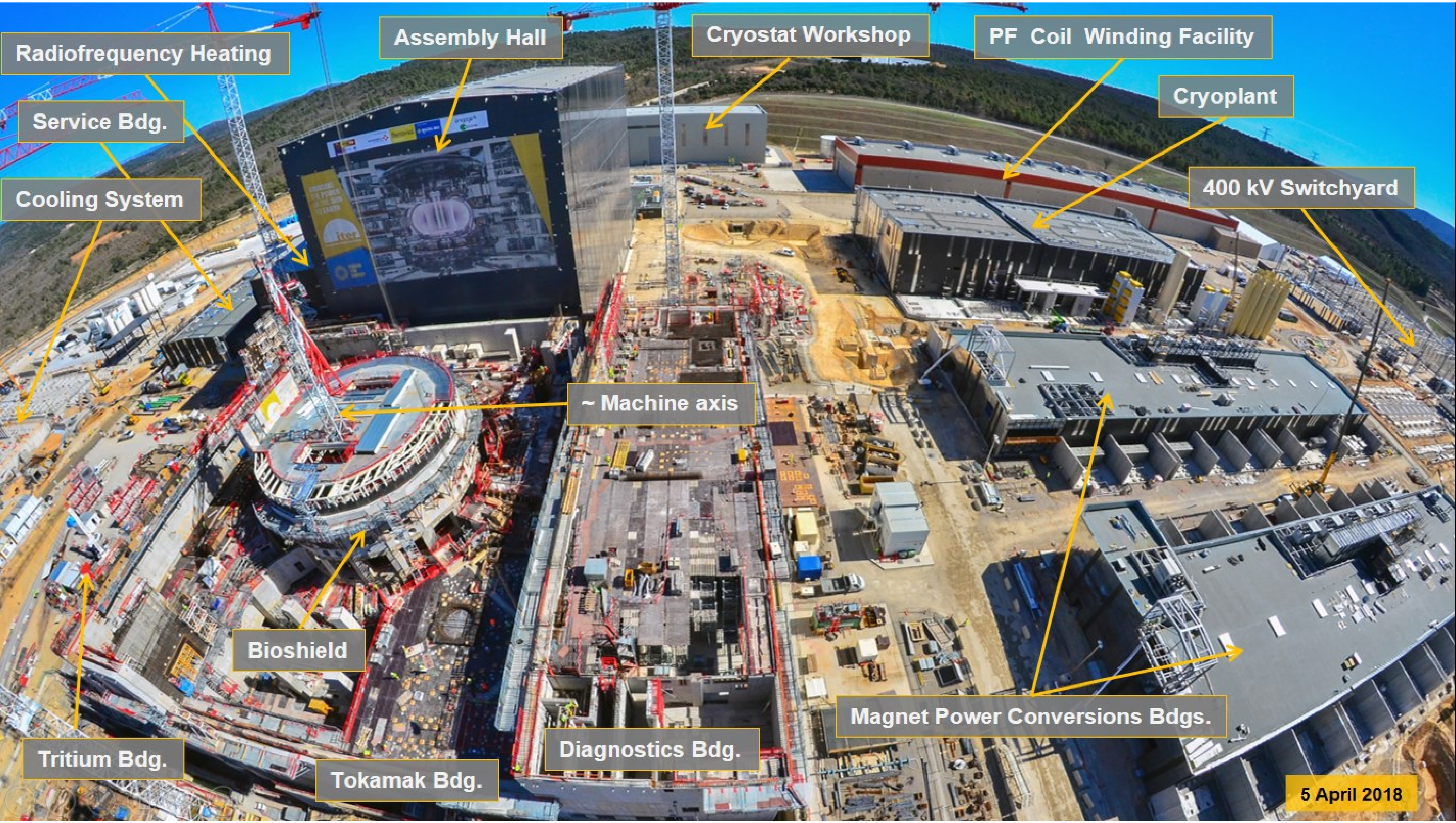
What Is the Mission of ITER?

"To demonstrate the scientific and technological feasibility of fusion energy for peaceful purposes"

– **How can we claim we have done this?**

- Achieve fusion power of 500 MW with P_{fus}/P_{in} ($\equiv$ Q) $\geq$ 10 for 300-500 s (i.e., stationary conditions)
- Aim at demonstrating steady-state operation with Q $\geq$ 5
- Capable of advanced operational modes and a wide operating parameter space
- Achieve the minimum cost device that meets **all** the stated requirements

1) Special Session ITER : Tim LUCE, ITER Project

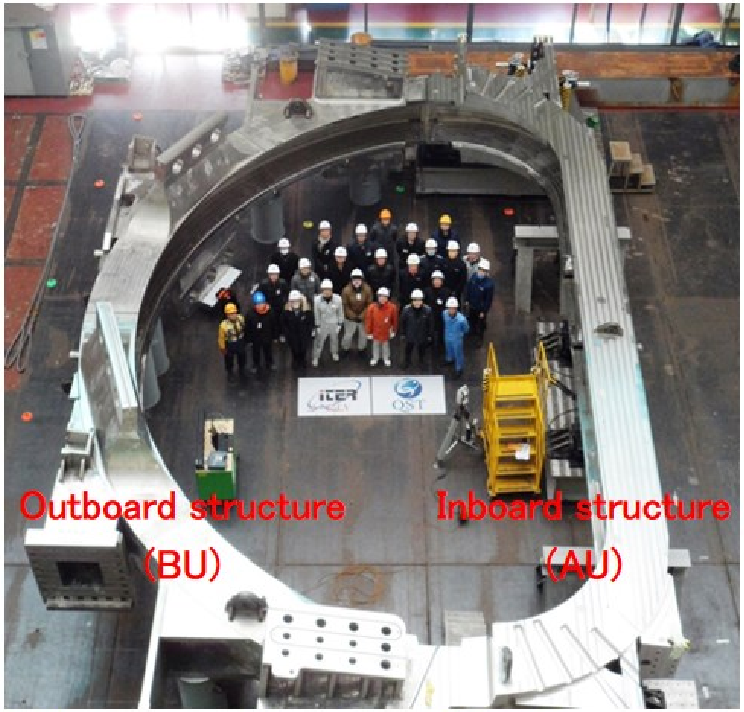


1) Special Session ITER : Tim LUCE, ITER Project

Tokamak Building

The bioshield (left) is now finalized. Openings in the bioshield wall (right) are for the cryostat bellows that will connect the machine to the ports for access for the heating and diagnostics systems. Under a protective “lid” work progresses on the tokamak’s “crown”.

Toroidal Field Coils

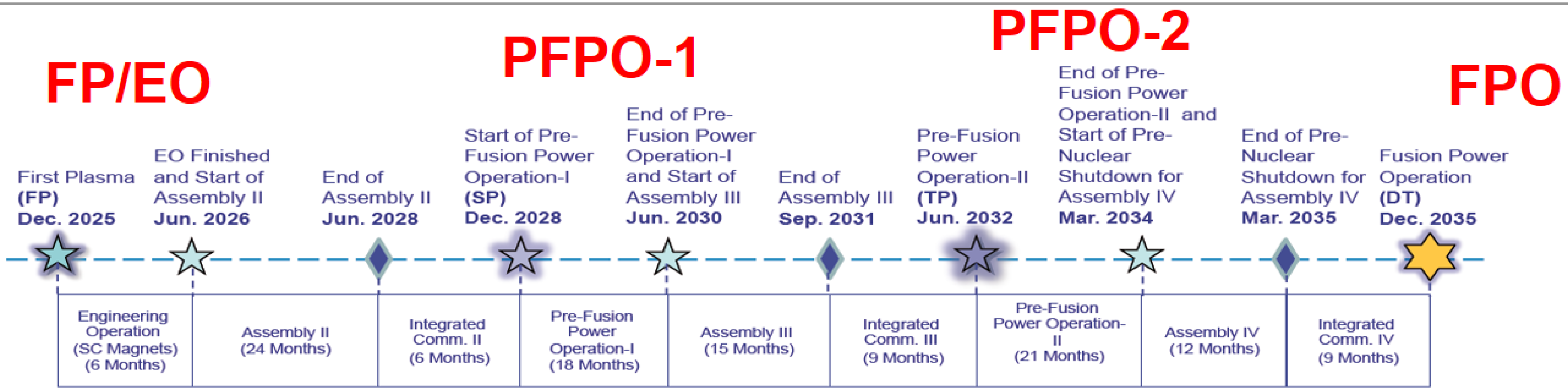


Fitting test of the 1st TF Coil Inboard and Outboard structures at Hyundai Heavy Industries

The first Toroidal Field coil winding pack has been completed at Mitsubishi Futami plant.
Similar operations are ongoing at Keihin Product Operations of Toshiba Corp.

1) Special Session ITER : Tim LUCE, ITER Project

A “Staged Approach” to Full Operating Capacity



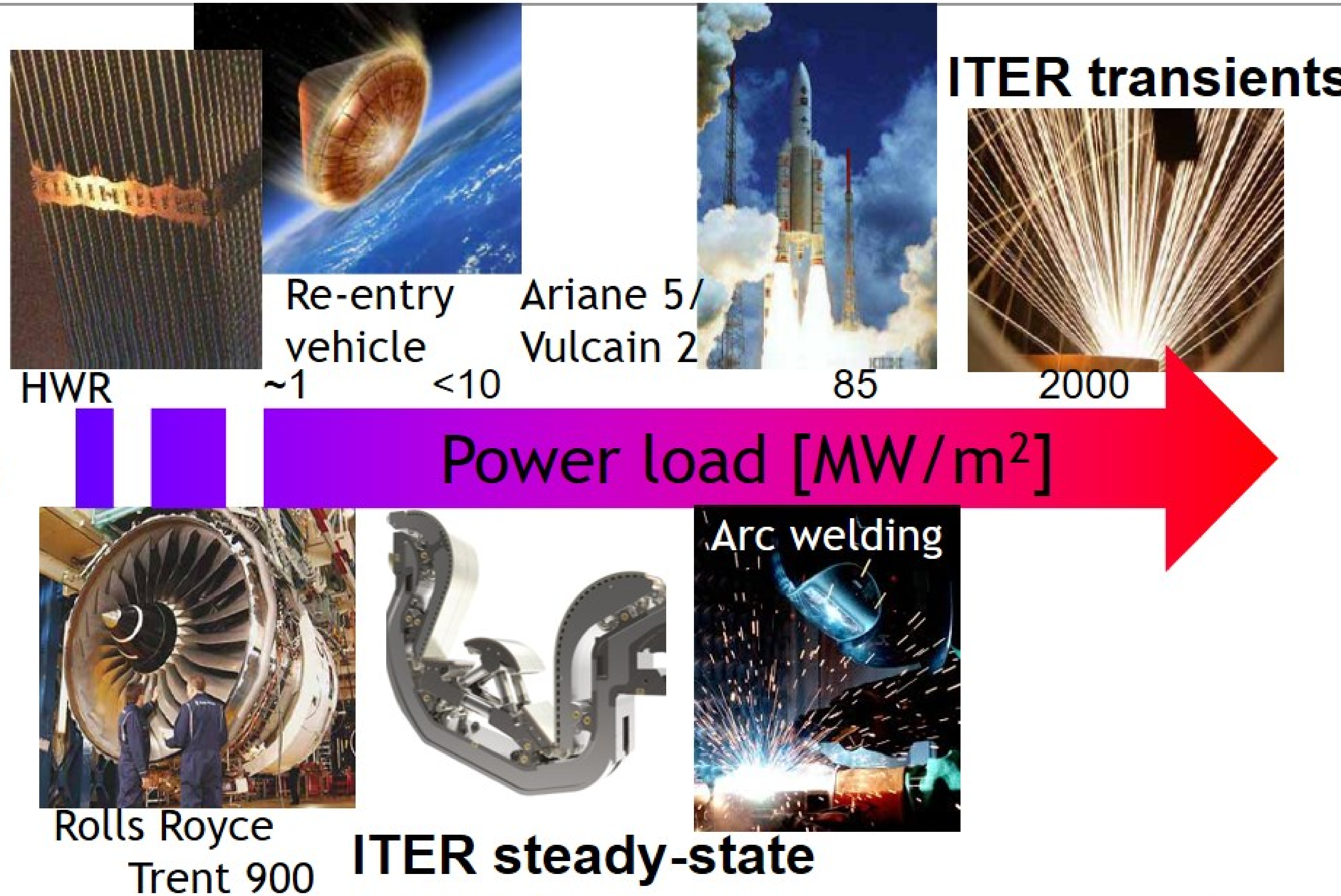
- Extensive interactions among the ITER Organization and Domestic Agencies to finalize revised baseline schedule (2015-6)
  - Schedule estimates through First Plasma (2025) up to DT operation (2035) consistent with Members’ budget and technical constraints
- Required a new ITER Research Plan (completed in 2017)

1) Special Session ITER : Tim LUCE, ITER Project

Challenge #3: Handling Heat and Particle Flux

The challenge is not small!

The consequences of failing to protect in-vessel components are big—components are actively cooled (water) and replacement time is months



2) Plasma sources and discharges (plasma generation)

Présentations orales :

• **Plenary Lecture**: Jochen SCHEIN, Stefan Kirner, Guenter Forster, Michal Szulc, Karsten Hartz-Behrend (University of Munich): Phenomena during wire arc spray applications

• **Topical Lecture**: Luc STAFFORD (Universty of Montréal): Analysis of the electron population in non-equilibrium plasmas sustained by low-frequency, RF, and microwave electric fields

1) Experimental and Numerical Approaches on 2D Rapid Surface Oxidation of Si/SiC Substrate by Exposure of Loop-type of Induction Thermal Plasmas, *Yasunori Tanaka et al*

2) Characterization of a Helicon Plasma System for Deposition of Thin Film Coatings and for Surface Modification, *German Cota et al.*

3) High-Speed Visualization of Temperature Field in Diode-Rectified Multiphase AC Arc with Bipolar Electrode, *Manabu Tanaka et al.*

4) Model of the cathode region of plasma photoelectric converter of concentrated solar radiation, *Nikolay Gorbunov, and Gilles Flamant*

5) Simulation of pre-breakdown discharges in air in a wide range of conditions, *Mikhail Benilov et al.*

6) Treatment of graphene films in the early and late afterglows of N2 plasmas: comparison of the defect generation and N-incorporation dynamics, *Germain Robert Bigras, Luc Stafford et al.*

7) Densities of active species in R/N2 and R/N2-x%H2 (R = Ar or He) microwave early afterglows, *André Ricard*

8) Effect of an external magnetic field on a DC plasma spray torch with a cascaded anode, *Rodion Zhukovskii, Christophe Chazelas, Armelle Vardelle, Vincent Rat*

9) Parameters of the atmospheric pressure CW microwave discharge sustained by focused gyrotron radiation, *Sergey Sintsov, Alexander Vodopyanov, Mikhail Viktorov, Dmitry Mansfeld*

Session Posters :

1-1 - Development of distributed ferromagnetic enhanced inductively coupled plasma source for plasma processing, *Gennadiy Sukhinin, Mikhail Isupov, Ivan Yudin, Alexander Fedoseev*

1-2 - Microwave Plasma Reactor for Atmospheric-Pressure Carbon Dioxide Decomposition, *Sina Mohsenian, Juan Trelles*

1-3 - Influence of current modulation on arc instabilities in dc plasma spray torch, *Fabrice Mavier, Fadi Zoubian, Vincent Rat*

1-4 - Contribution to the study of the electric arc displacement, *Mohamed BOUKHLIFA, Romaric Landfried, Thierry Leblanc, Philippe Testé*

1-5 - Experimental Study on insulation properties of C4F7N/N2 mixture substituting SF6 in insulation, *tian shuangshaung, Cressault Yann, Zhang Xiaoxing, Xiao Song, Li Yi, Zhang Ji, Chen Qi*

1-6 - Development and characterization of a 3D-printed compact atmospheric plasma reactor, *Fadi Zoubian, Hervé Rabat, Olivier Aubry, Nicolas Dumuis, Sebastien Dozias, Dunpin Hong*

1-7 - Electric arc conductivity in a three-phase AC plasma torch operating on a mixture of air and methane, *Viktor Popov, Sergey Popov, Alexander Surov, Dmitry Subbotin, Eugeny Serba, Nikita Obraztsov*

1-8 - Temporal analysis of DC- and Microwave-driven plasma micro-discharges, *Antoine SIMON, Th. Callegari, Romain PASCAUD, Laurent LIARD, Olivier PASCAL*

1-9 - Study of emitted radiations in High Intensity Discharge (HID) Lamps, *Antoine SAHAB, Mohamad Hamady, Georges Zissis, Yann Cressault*

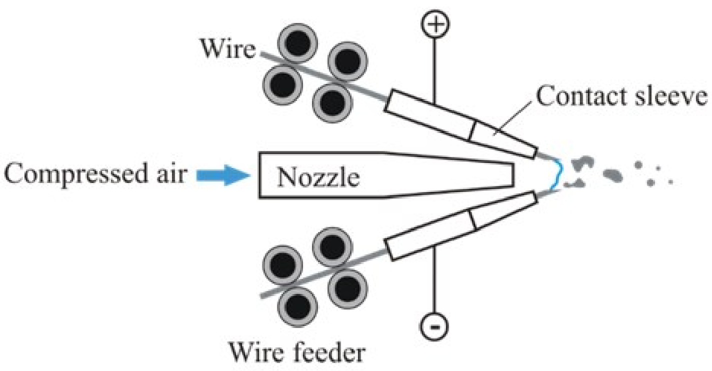
2) Plasma sources and discharges (plasma generation) : Jochen Schein

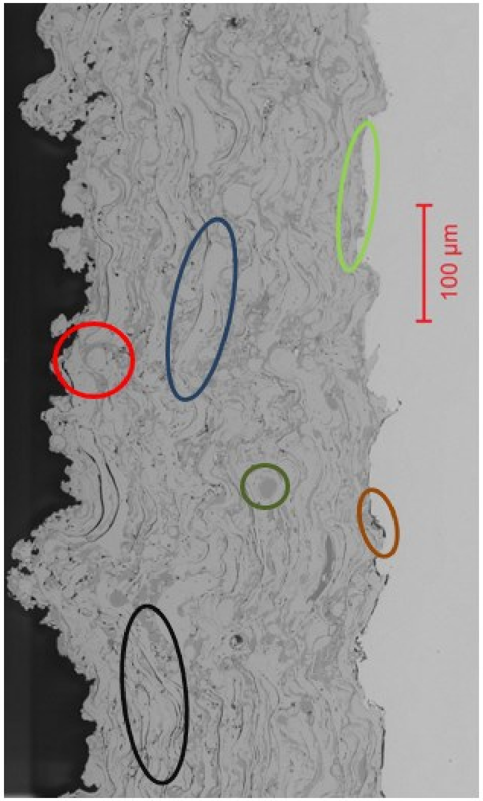
LPT
Lab. for Plasma Technology

Phenomena during wire arc spray applications

Jochen Schein, Stefan Kirner, Guenter Forster, Michal Szulc,
Karsten Hartz-Behrend

What is WAS?





unmolten particle

wire material

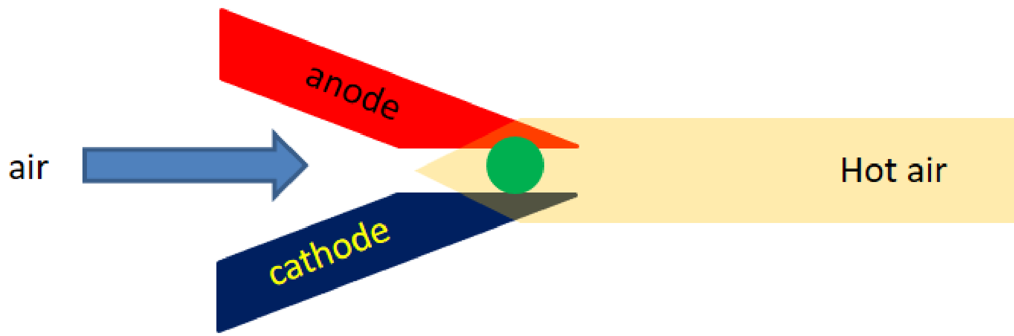
fully oxidized particle

porosity

lamellae structure „Oxidstrings“

connection to substrate

Oxides, oxides!



Influence de l’oxydation des particules ?

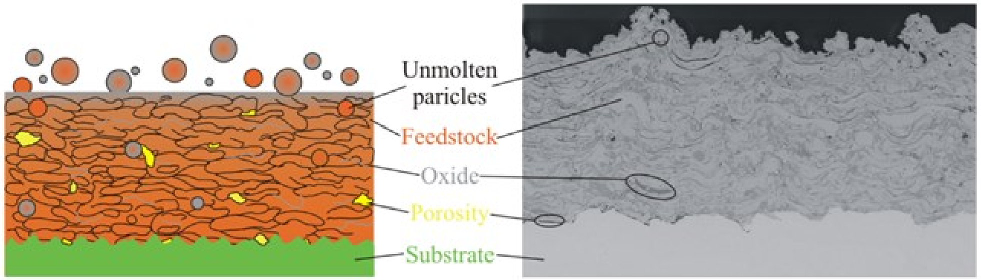
Développement d’un outils de diagnostic de l’état d’oxydation des particules en vol

- Main gas for WAS is compressed air
- Oxidation of particles takes place
- Nobody has a tool to detect that

2) Plasma sources and discharges (plasma generation) : Jochen Schein

So far oxides can be detected in the coating only

En général, la présence d’oxydes n’est mesurée que dans le dépôt



	Trend	Particle oxidation	Reason
Particle temperature	↗	↗	Arrhenius law
Particle size	↗	↘	Lower surface area to volume ratio
Particle velocity	↗	↘	Reduced dwell time

2) Plasma sources and discharges (plasma generation) : Jochen Schein

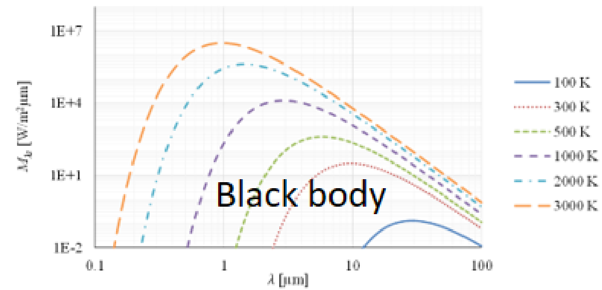
Approach

Goal: to detect the oxidation of particles during flight

- Two color pyrometry delivers information about temperature independent of emissivity
- Oxidation changes emissivity
- Changes in emissivity in connection w/ temperature/particle size/velocity allow to determine oxidation

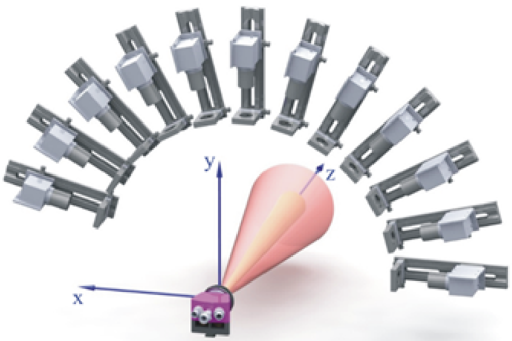
Material/phase	Emissivity	Wavelength	Temperature
Iron/liquid	0.394	807 nm	1600 K to 1950 K
Iron/liquid	0.38, 0.37	800 nm, 900 nm	1808 K
S235/liquid	0.087	650 nm to 850 nm	>2100 K
FeO/liquid	~0.7	500 nm to 700 nm	>2100 K

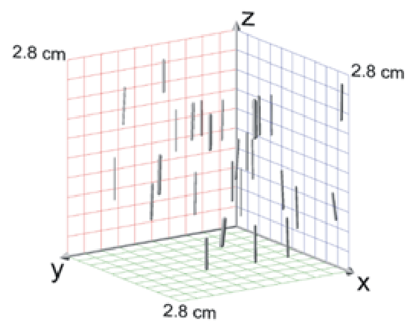
$$M_\lambda(\lambda, T) = \varepsilon(\lambda, T) \cdot \frac{C_1}{\lambda^5} \cdot \frac{1}{\exp\left(\frac{C_2}{\lambda T}\right) - 1}$$

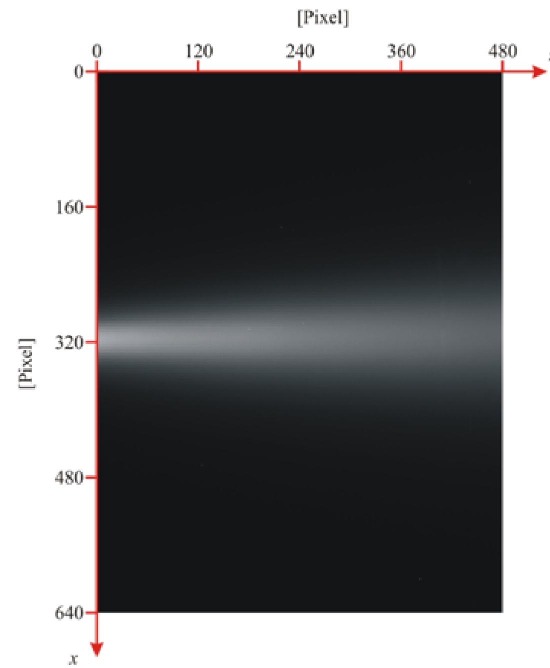


Evaluer l’oxydation des particules par pyrométrie

Tomography of particle beam







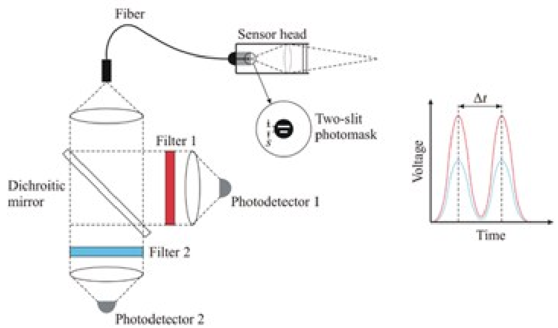
Tomography delivers integrated images
To quantify we need to know how much particle surface area we see and for that we need more info

Mise en œuvre d’une tomographie pour réaliser ce travail

2) Plasma sources and discharges (plasma generation) : Jochen Schein

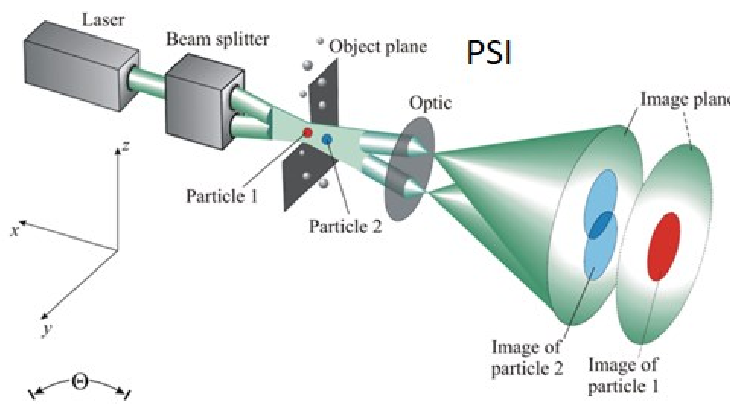
Supporting tools

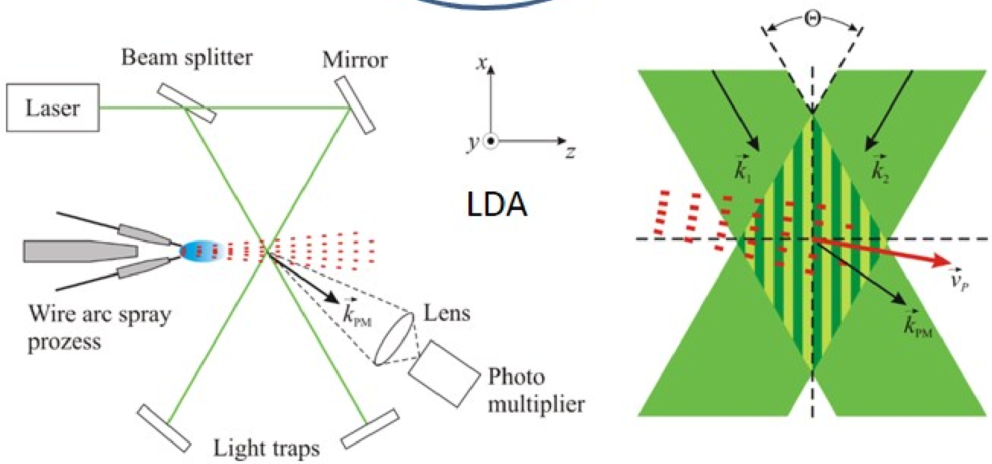
DPV



Particle rate
Particle size
Particle velocity

PSI

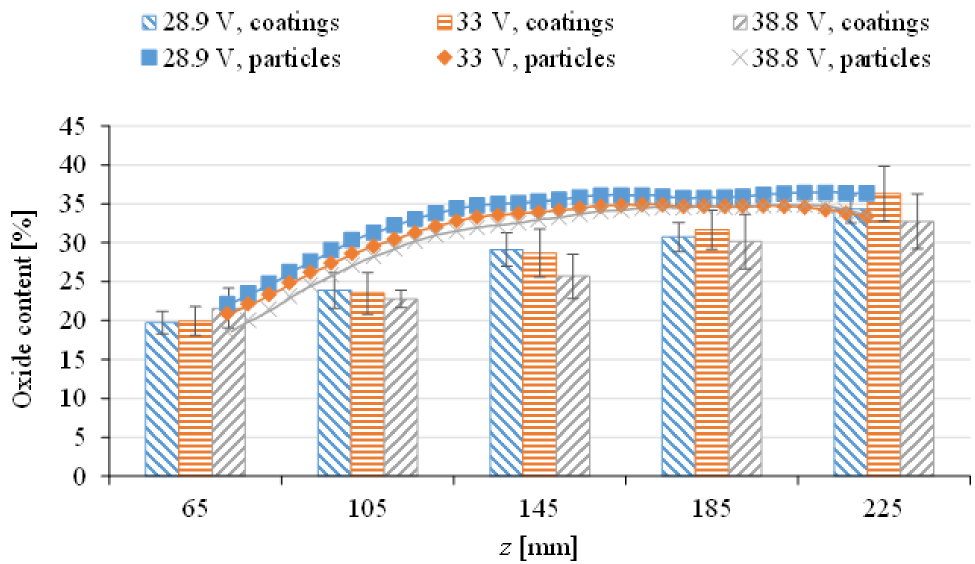




Diagnostics particules nécessaires

2) Plasma sources and discharges (plasma generation) : Jochen Schein

Result: Comparison between in flight measurement & coating



CA

Technique efficiente pour caractériser l'oxydation des particules en vol

2) Plasma sources and discharges (plasma generation) : Manubu Tanaka

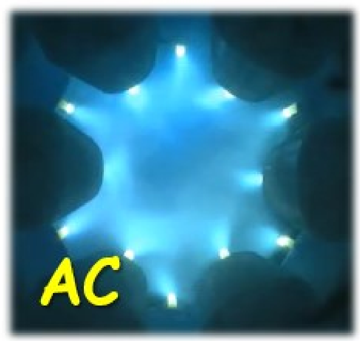
16:15-16:35

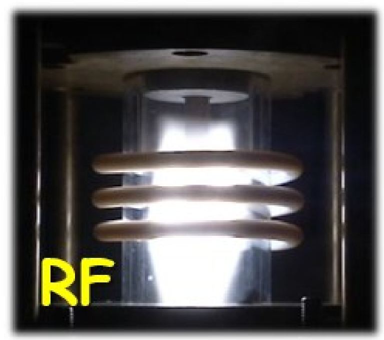
3 July 2018

15th High-Tech Plasma Processes, HTPP15

Plasma sources and discharges

High-Speed Visualization of Temperature Field in Diode-Rectified Multiphase AC Arc with Bipolar Electrode





M. Tanaka, T. Watanabe

Dept. Chemical Engineering, Kyushu University

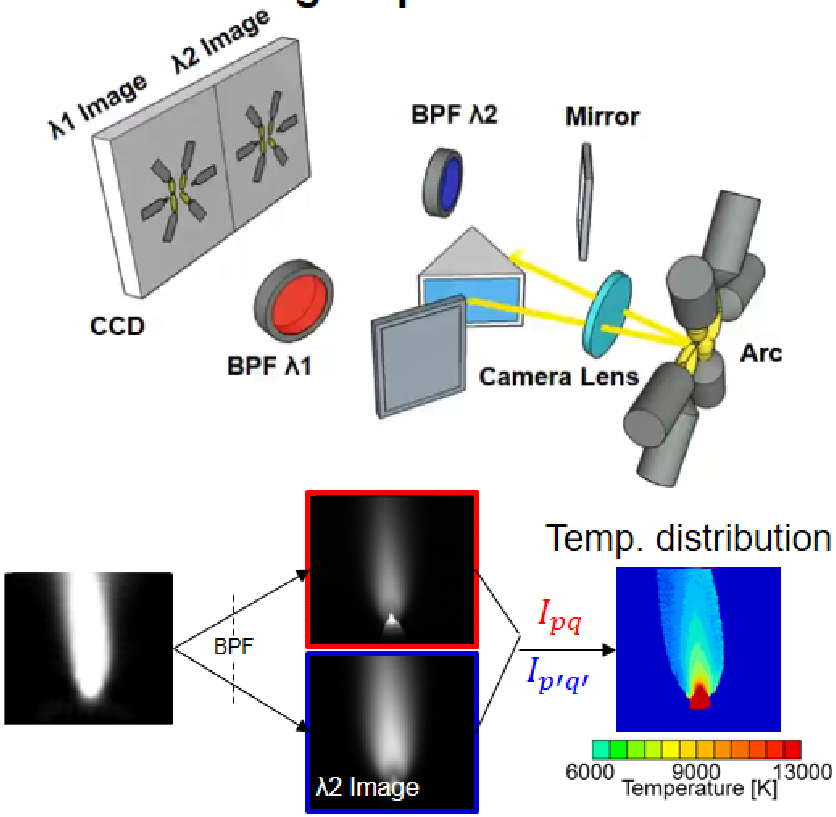
T. Matsuura

Tasoarc Co.

2) Plasma sources and discharges (plasma generation) : Manubu Tanaka

Principle of Temp. Measurement

Data Acquisition with High-Speed Camera

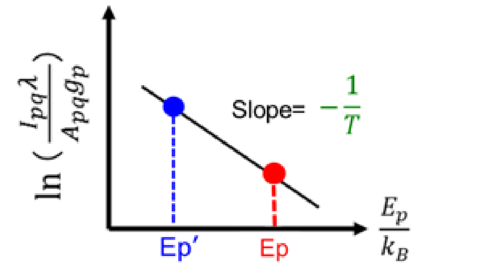


Data Analysis

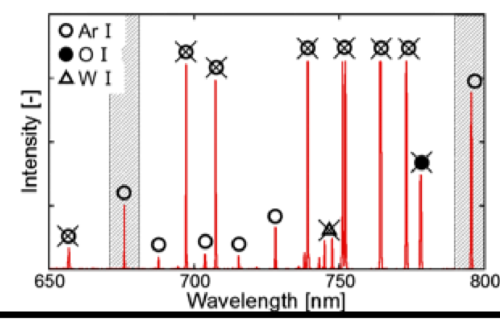
Line spectrum emission intensity

$$I_{pq} = \frac{A_{pq} g_p}{\lambda} \cdot \frac{hcN(T)}{4\pi Z(T)} \exp\left(-\frac{E_p}{k_B T}\right)$$

$$\ln\left(\frac{I_{pq}\lambda_{pq}}{A_{pq} g_p}\right) = -\frac{1}{T} \cdot \left(\frac{E_p}{k_B}\right) + \ln\left(\frac{hcN(T)}{4\pi Z(T)}\right)$$



675 nm
794 nm

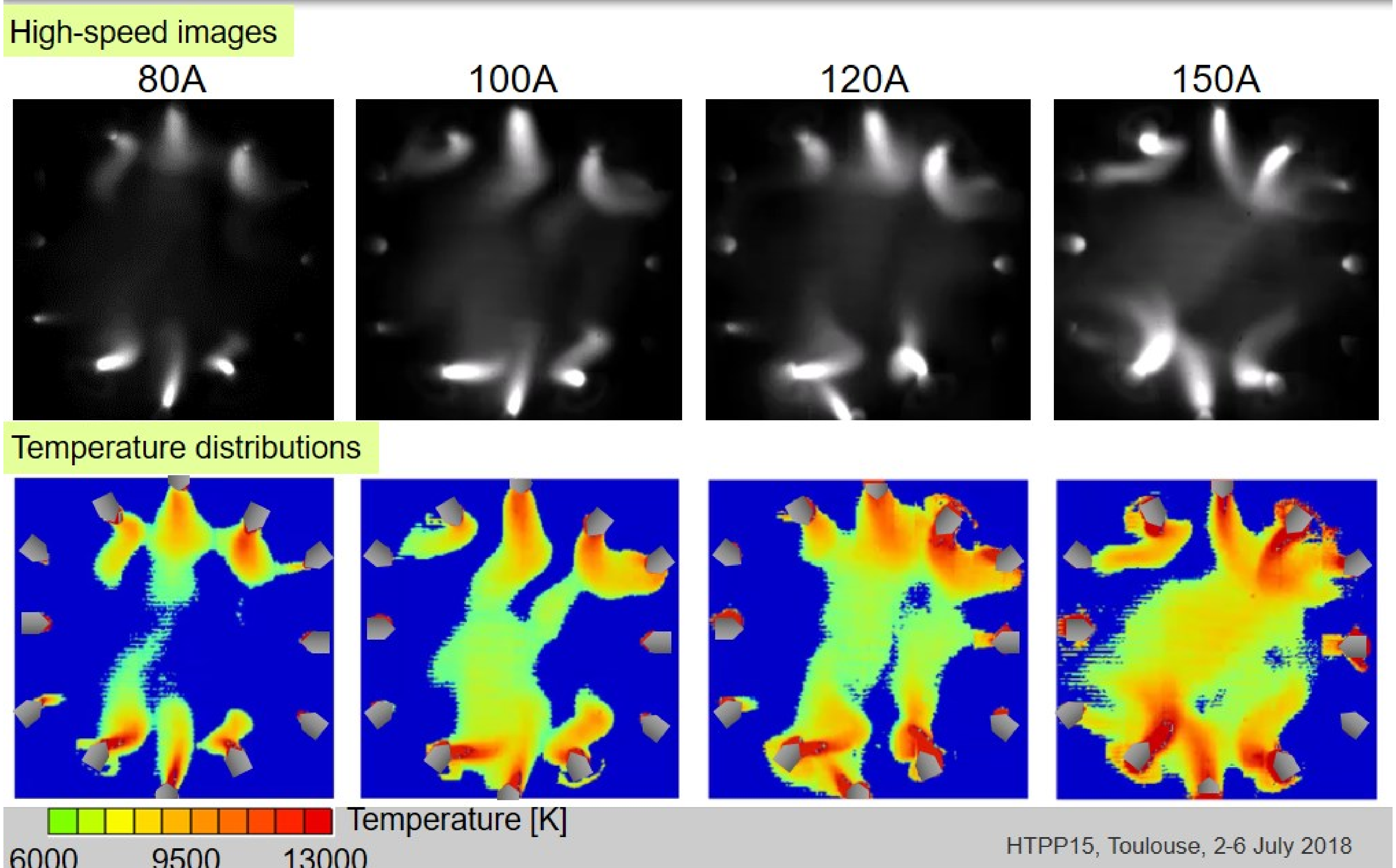


2) Plasma sources and discharges (plasma generation) : Manubu Tanaka

Visualization of Temp. Field

-Effect of Arc Current-

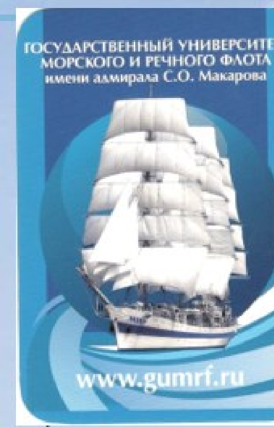
7



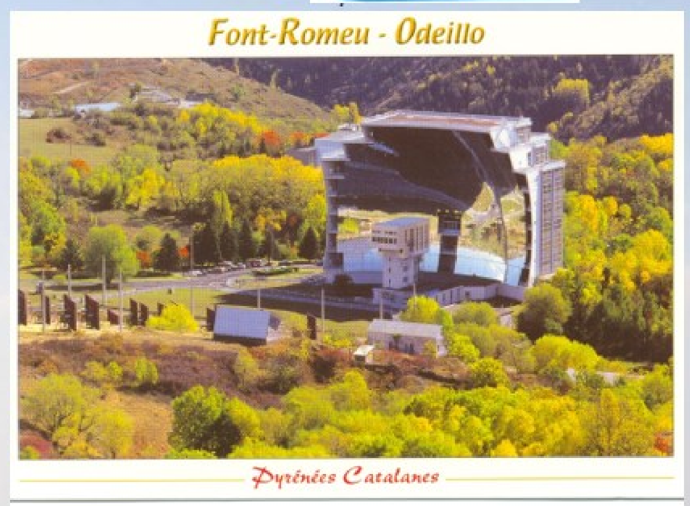
HTPP15, Toulouse, 2-6 July 2018

2) Plasma sources and discharges (plasma generation) : Gorbunov - Flamant

Model of the cathode region of plasma photoelectric converter of concentrated solar radiation.



- Nikolay Gorbunov
  - **Admiral Makarov State University of Maritime and Inland Shipping , Russia**



- Gilles Flamant
  - **Processes, Materials and Solar Energy laboratory (PROMES), France**

3) Advances and challenges in plasma diagnostics

Présentations orales :

- **Plenary Lecture**: Stéphane MAZOUFFRE (University of Orléans): Laser-aided diagnostics applied to ion thrusters

- **Topical Lecture**: Arnaud BULTEL, Aurélien Favre, Vincent Morel, Gilles Godard (University of Rouen): Characterization of laser-induced plasmas

1) Understanding chemical kinetics of CH4 and C2H2 dissociation by optical emission spectroscopy during graphene nano-flakes production in an inductively coupled plasma reactor, *Antaryami Mohanta, Briac Lanfant, Marc Leparoux*

Session Posters :

2-1 - Effect of plasma torch operating parameters on plasma jet velocity at torch nozzle exit, *Jérôme Betoulle, Simon Goutier, Michel Vardelle*

2-2 - Investigations of Stark Profiles of Argon Lines using Laser-Induced Plasma, Thomson Scattering and Optical Emission Spectroscopy, *Mamadou Sankhe, Tomek Pieta, Stéphane Pellerin, Krzysztof Dzierzega, Maxime Wartel*

2-3 - Experimental characterization of double pulse laser-induced plasmas, *AURELIEN FAVRE, Vincent Morel, Gilles Godard, Arnaud Bultel*

2-4 - Experimental characterization of a surface-wave sustained Argon-N2-H2 mixture plasma column at atmospheric pressure, *Jong Hern MUN, Mathieu Masquère, Philippe TEULET, Yann Cressault*

2-5 - Impact of the substrate on the discharge characteristics in an atmospheric-pressure helium plasma jet: Optical diagnostics, *Julien Cosimi, Frédéric Marchal, Nofel Merbahi, Mohammed Yousfi*

2-6 - Synthesis of N-B substituted single wall carbon nanotubes by electric arc: plasma diagnostic, *Soumaya Ben Nasr, Gourari Djamel Eddine, Valensi Flavien, Yann Cressault, Lotfi Beji, Riadh Hannachi, Manitra Razafinimanana, Sébastien JOULIE, Marc MONTHIOUX*

2-7 - Measurement of the gas temperature of neutrals in reactive plasmas by moderate-resolution OES, *Andrey Miakonkikh, Konstantin Rudenko*

3) Advances and challenges in plasma diagnostics : A. Bultel

High-Tech Plasma Processes 15
HTPP 15
2 - 6 July 2018,
Université Toulouse III -France

Characterization of laser-induced plasmas

Arnaud Bultel, Aurélien Favre, Vincent Morel, Gilles Godard

CORIA, UMR CNRS 6614, Normandie Université, 76801 Saint-Etienne du Rouvray cedex, France

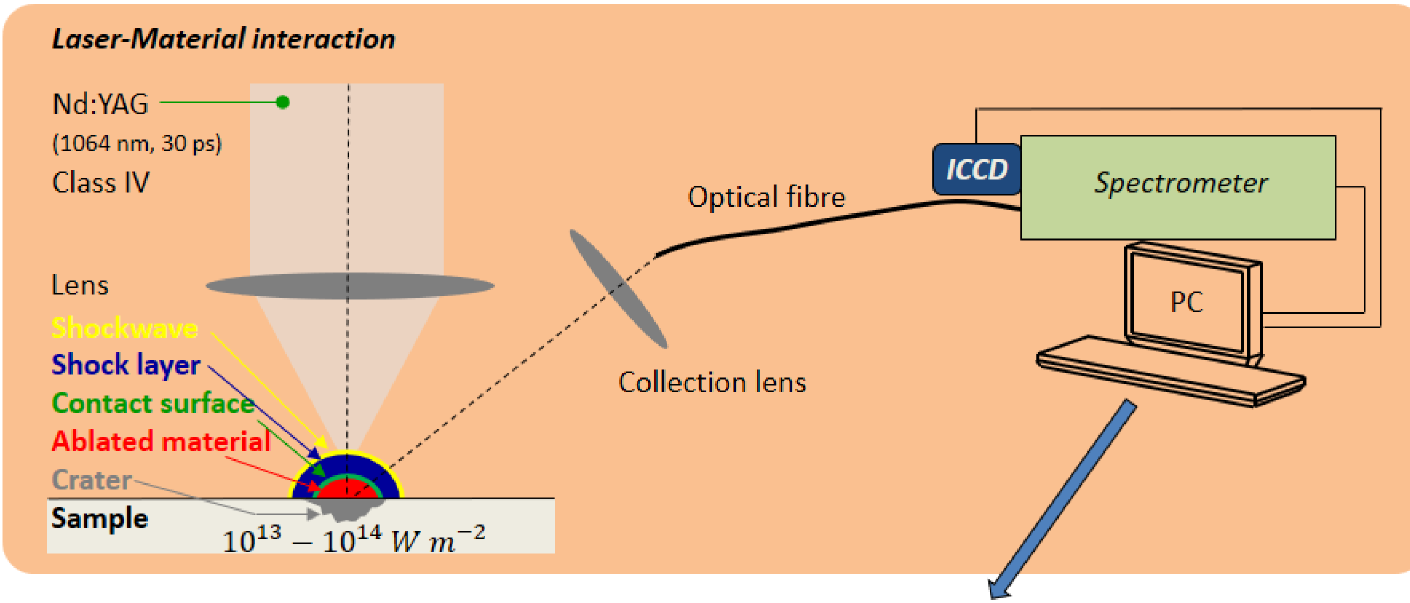
arnaud.bultel@coria.fr

Horizon 2020

TRANSAT
TRANSversal Actions for Tritium

3) Advances and challenges in plasma diagnostics : A. Bultel

Composition analysis by Laser-Induced Breakdown Spectroscopy – LIBS



Melting

Vaporization – explosion phase

Ionization (MPI & IB)

Plasma ($10^{10} Pa$, $10\ 000\ K$)

Shockwave

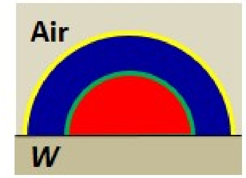
Spectroscopic analysis

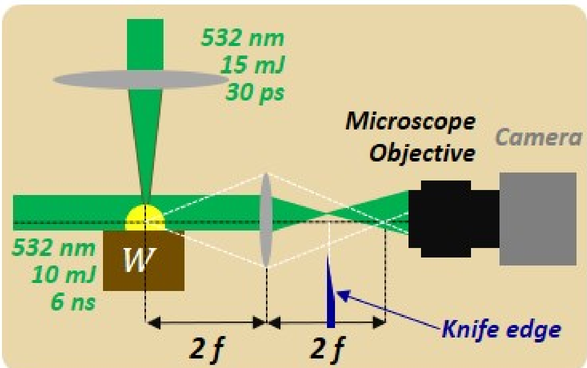
- $0 < t < 100\ ns$ strong continuum
- $t < 500\ ns$ strong departure from equilibrium
- $t > 500\ ns$ low non equilibrium (atom. and molec. Rad.)

$\Rightarrow$ Exploitation of **Saha-Boltzmann** plots

3) Advances and challenges in plasma diagnostics : A. Bultel

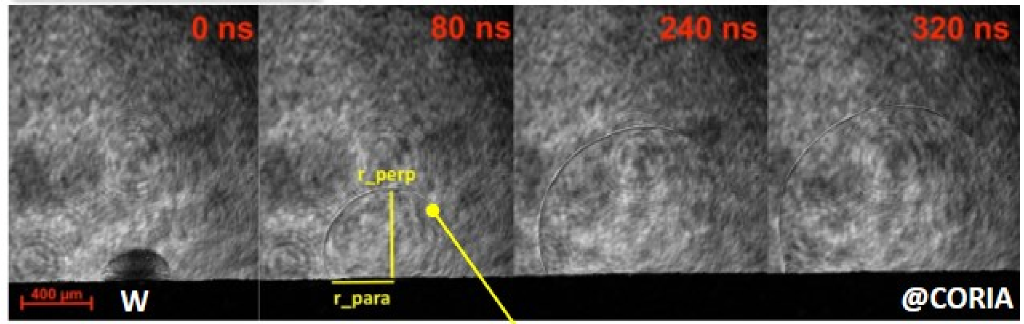
Fluid dynamics / structure





Laser shadowgraphy

Sensitive to $\frac{\partial^2 n}{\partial z^2}$

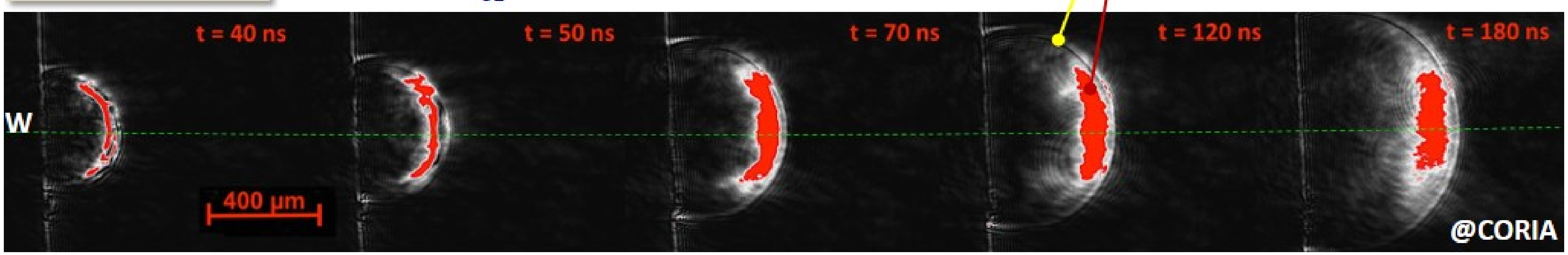


Shockwave

Contact surface

Schlieren Imagery

Sensitive to $\frac{\partial n}{\partial z}$



Very rapid evolution over the first 200 ns then slower evolution…

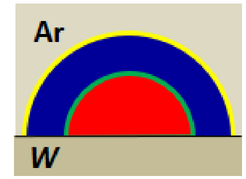
The contact surface remains close to the shock front

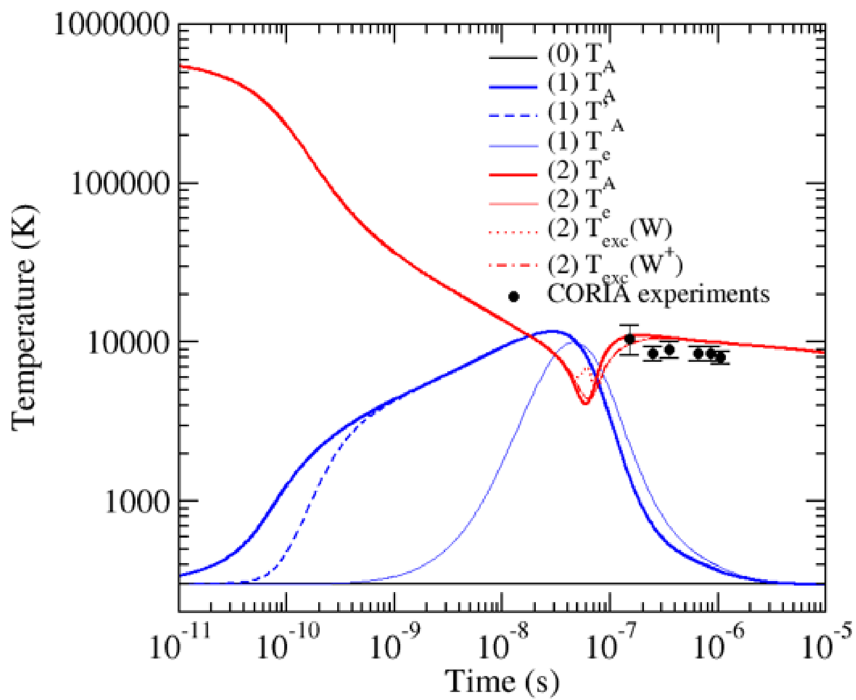
3) Advances and challenges in plasma diagnostics : A. Bultel

Temperature – Expansion

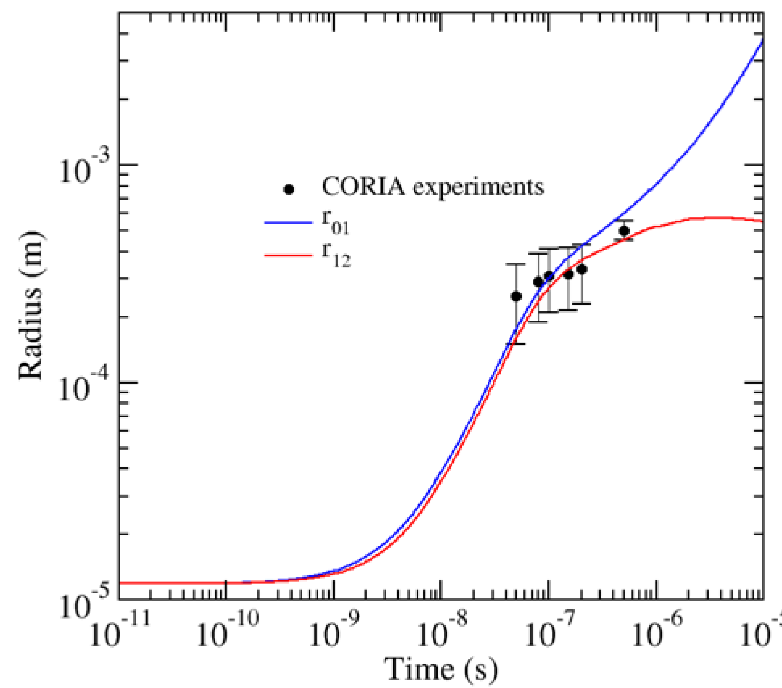
Laser-Induced Absorption Spectroscopy

W (Ar, p_{atm}) 30 ps 532 nm 10 J cm^{-2}





Calculated temperature slightly higher…

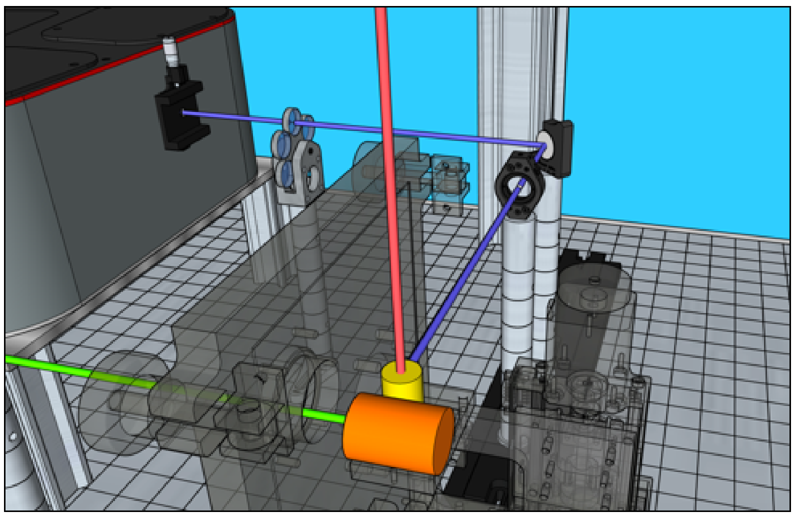


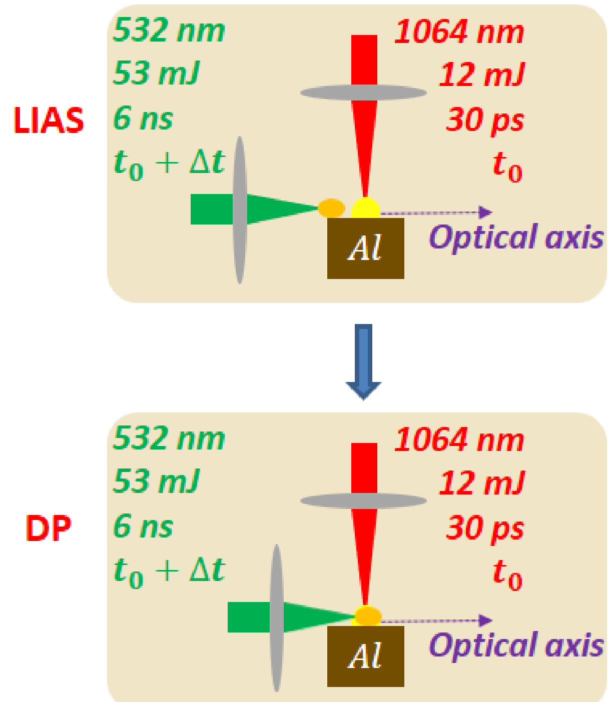
Satisfactory agreement for the radii…

Laser-Induced Absorption Spectroscopy LIAS

↓

DP – Double Pulse Configuration





Double pulse laser - Efficient absorption of the second pulse by the plasma

Inverse Bremsstrahlung !!!

4) Advances and challenges in plasma modeling

Présentations orales :

- **Plenary Lecture**: Juan Pablo TRELLES (Lowell University): Advances and Challenges in Modeling and Simulation of Thermal Plasma Flows

- **Topical Lecture**: He Ping LI, Heng Guo, Wen Zhou, Jian Chen, Jing Li, Zeng-Yao Li (Tsinghua University): Challenges in modelling of non-equilibrium transport processes in high-pressure thermal plasmas

1) A Hybrid Finite-Element-Finite-Volume Mixed Method for Thermal Arc Simulations, *Youssef Abda, Laurent Fulcheri, Vandad Rohani*

Session Posters :

3-1 - An electric arc upon opening contacts of a low-voltage switch model, *Jessica Almurr, David Rochette, William Bussière*

3-2 - 3D simulation of a point to plane air corona discharge, *Olivier Eichwald, Olivier Ducasse, Joseph Marie PLEWA*

3-3 - Nonequilibrium effects in the arc in crossflow, *Vyasaraj Bhigamudre, Juan Trelles*

3-4 - Modelling of the plasma parameters of an arc discharge with sputtered metal-graphite anode, *Alexander Fedoseev, Nikon Demin, Salavat Sakhapov, Alexey Zaikovskii, Dmitriy Smovzh*

3-5 - Energy and momentum transport in thermal arcs: a simple method for modelling, *YOUSSEF ABDO, Laurent Fulcheri, Vandad Rohani*

3-6 - Calculation of electron-impact excitation and ionisation cross sections and reaction rate coefficients for C, N and O atoms, *ALI HLELI, Philippe TEULET, Yann Cressault, Riahi Riadh, Ghalila Hassen*

3-7 - H2020 NanoDome project: a comprehensive multiscale approach to the modelling of nanoparticle synthesis in gas phase, *Francesco Strappaveccia, Francesco Galleni, Emanuele Ghedini*

3-8 - A novel approach for the estimation of nanoparticle evaporation through the Method of Moments, *Francesco Galleni, Francesco Strappaveccia, Emanuele Ghedini*

3-9 - Numerical Simulation of Triple DC Plasma Torch System, *LEE YONG HEE, Kim Tae-Hee, Choi Sooseok*

3-10 - Numerical optimization of Mean Absorption Coefficient in Air using Planck Modified Mean Function, *narjisse kabbaj, Yann Cressault, Philippe TEULET, Frank Reichert*

3-11 - Numerical Analysis of SF6 Decomposition Process in a Cement Kiln Reactor Combined with Thermal Plasma, *Juyoung Ko, Sooseok Choi, Tae-Hee Kim*

3-12 - A robust method to compute the 2T reactive thermal conductivity of SF6 plasma, *Gabriel Vanhulle, Yann Cressault, Ph Teulet*

3-13 - A Multi-Stage approach for DBD modelling, *Andrea Cristofolini, Arturo Popoli*

3-14 - Theoretical study of molecular spectra in nitrogen, *Abdel Majid Kassir, Yann Cressault, Mathieu Masquère, Philippe TEULET*

4) Advances and challenges in plasma modelling : Juan Trelles

University of Massachusetts
UMASS Lowell

R·Eng | Lab
Re-Engineered Energy Laboratory
University of Massachusetts Lowell

Advances and Challenges in Modeling and Simulation of Thermal Plasma Flows

Juan Pablo Trelles

Department of Mechanical Engineering *and* Energy Engineering Graduate Program

University of Massachusetts Lowell

15th International High Tech Plasma Processes Conference (HTPP15)
July 2 to 6, 2018
Toulouse, France

4) Advances and challenges in plasma modelling : Juan Trelles

Outline

1. Motivation
2. Thermal Plasma Flow Models
3. Computational Modeling & Simulation

(Background)

4. Advances & Challenges: Fidelity
   - Multi-phase / material interactions
   - Chemical nonequilibrium
   - Thermodynamic nonequilibrium
   - Radiative transport

(Multi-physics)

5. Advances & Challenges: Accuracy
   - Complex geometries
   - Pattern formation
   - Stability
   - Turbulence

(Multi-scale)

6. Bridging the Fidelity-Accuracy Gap

Closing Remarks

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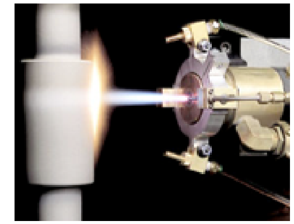
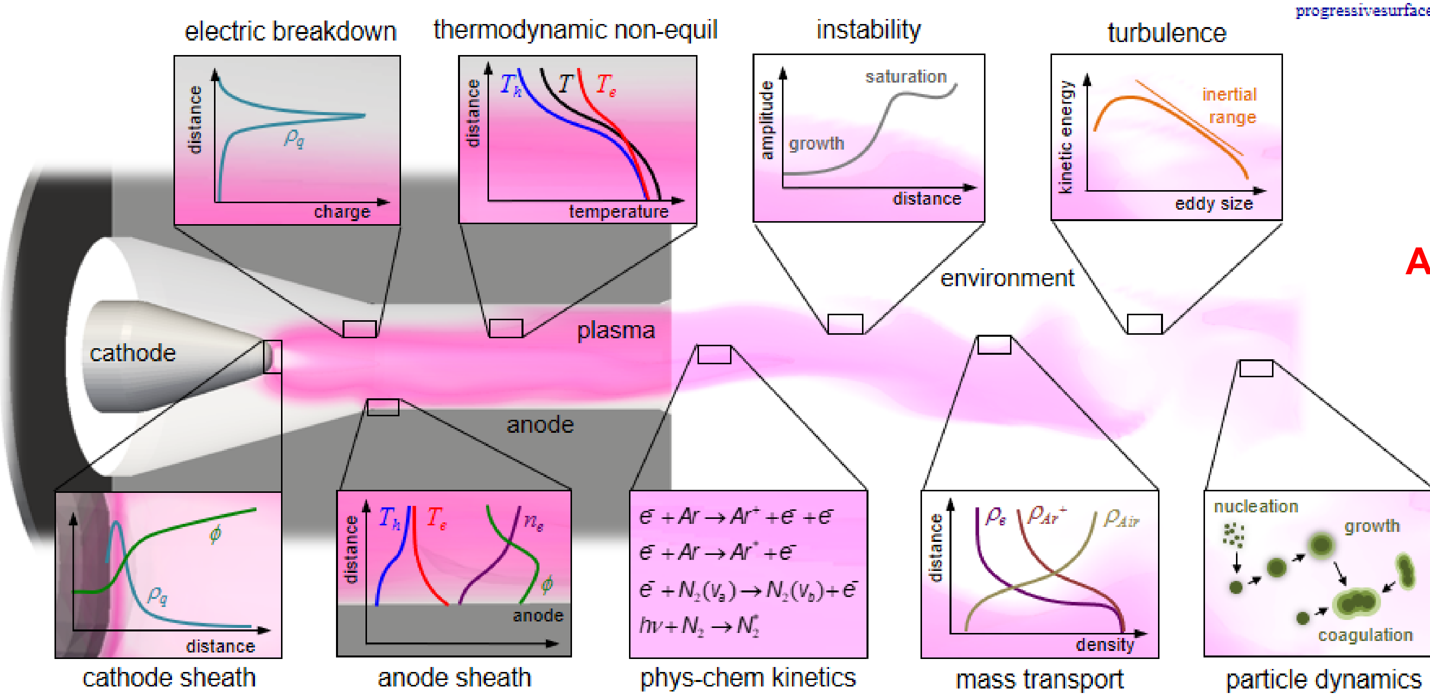
4) Advances and challenges in plasma modelling : Juan Trelles

Representative Application: Arc Torches

- **Applications:** spraying, synthesis, gasification, metallurgy, …
- **Relatively simple design:** pin-nozzle electrodes, DC power, …
- **Phenomena:** microscopic (kinetic) and macroscopic (dissipative)



progressivesurface.com



De nombreux challenges – Approche multi-physique

➢ Enormous challenge for computational modeling & simulation!

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[1] Chazelas *et al*, J Therm Spray Tech (2017) 26:3–11, [2] Chazelas *et al*, Plasma Chem Plasma Process (2017) 37:627–651

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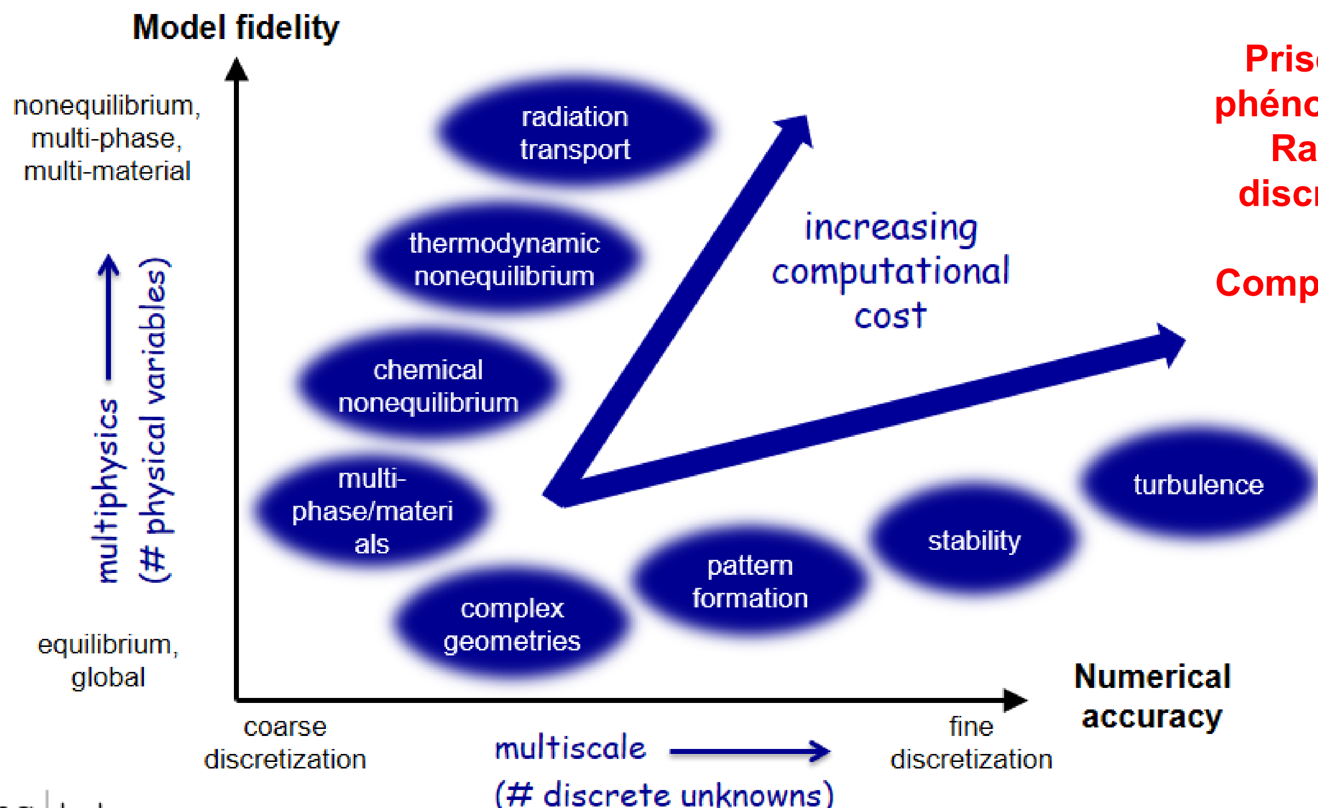
4) Advances and challenges in plasma modelling : Juan Trelles

Modeling & Simulation Advances and Challenges

Categorized in terms of:

- **Model fidelity:** degree of underlying phenomena captured by the model
- **Numerical accuracy:** precision of the numerical solution of the model



Prise en compte des phénomènes physiques
Raffinement de la discrétisation / multi-échelles
Compromis avec temps de calcul

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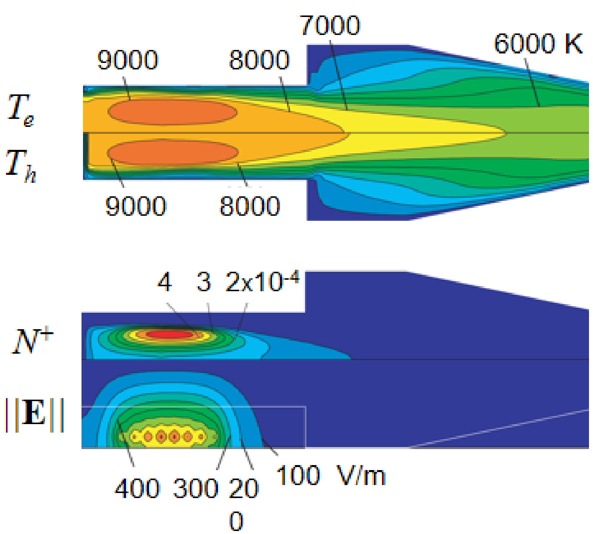
4) Advances and challenges in plasma modelling : Juan Trelles

Chemical & Thermodynamic Nonequilibrium

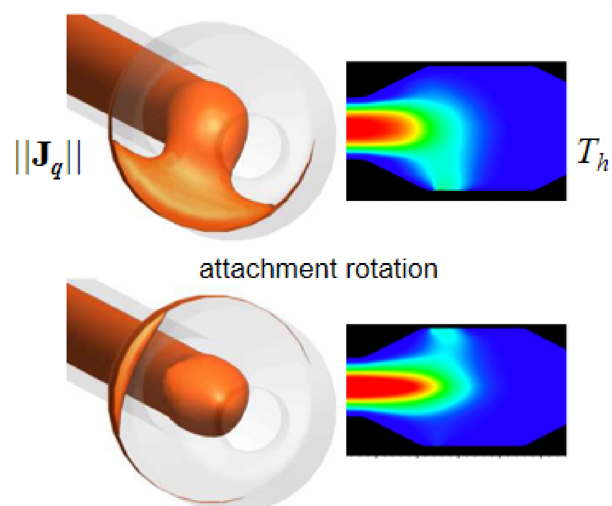
- **Chemical nonequilibrium:** chemical/particle synthesis, materials modification, …
  - Huge fidelity challenge, i.e. large # species/reactions
- **Thermodynamic nonequilibrium:** plasma-gas/electrode interactions, heat transfer, …
  - Just 1 more eqn. … yet, large increase in comput. cost (convergence, properties)
- **Advances:** e.g.

Un exemple de challenge identifié : la prise en compte du déséquilibre

Inductively-coupled torch [1]



Arc heater [2]



R·Eng Lab

[1] Tanaka Y 2004 J. Phys. D: Appl. Phys. 37 1190–1205
[2] Sahai A, Mansour N N, Lopez B, Panesi M 2017 Plasma Sources Sci. Technol. 26 055012

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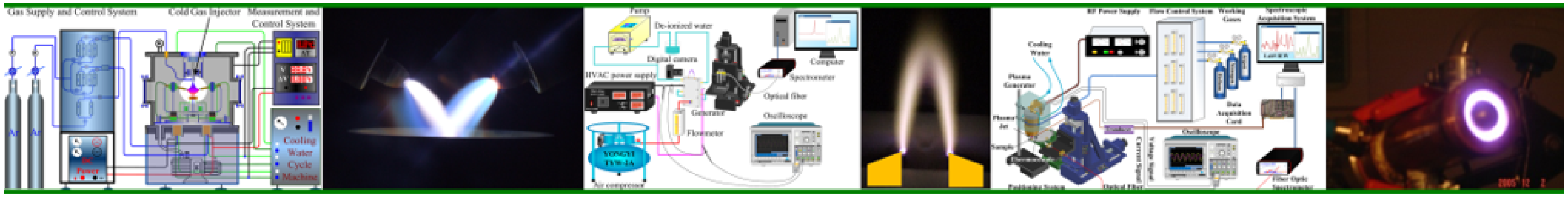
4) Advances and challenges in plasma modelling : He Ping Li



Challenges in modelling of non-equilibrium transport processes in high-pressure thermal plasmas

He-Ping Li[1], Heng Guo[1], Wen Zhou[2], Jian Chen[1], Jing Li[1], Zeng-Yao Li[2]

[1] Department of Engineering Physics, Tsinghua University, Beijing 100084, P. R. China

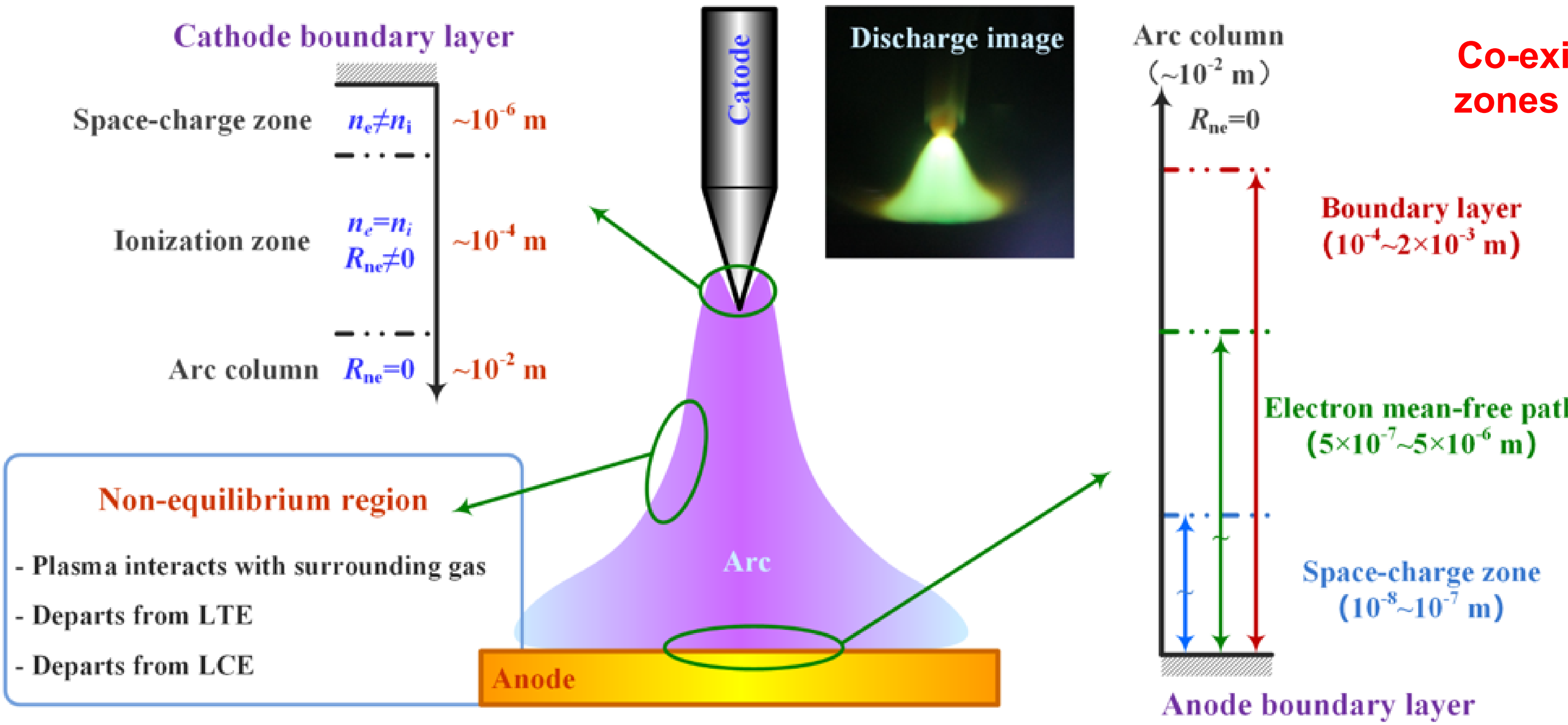
[2] Key Laboratory of ThermoFluid Science and Engineering, Ministry of Education, School of Energy and Power Engineering, Xi'an Jiaotong University, Xi'an 710049, People's Republic of China

July 4, 2018 @ HTPP 2018, Toulouse, France

4) Advances and challenges in plasma modelling : He Ping Li

Fundamentals – Non-equilibrium characteristics of plasmas

Co-existence de zones ETL et HE

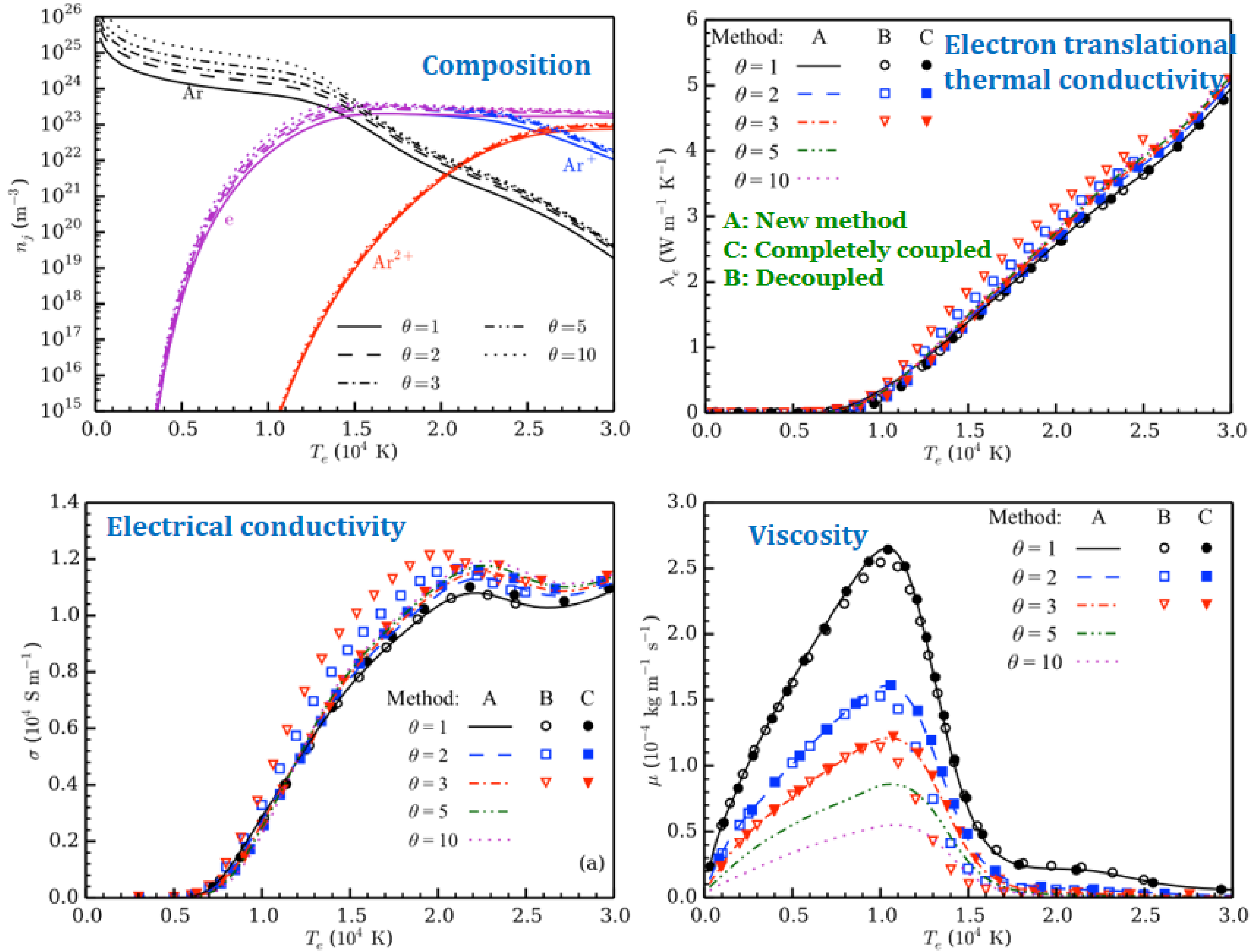


- Co-existence of equilibrium (LTE, LCE, CN) and non-equilibrium (Non-LTE, Non-LCE, Non-CN) regions in one arc plasma system;
- Existence of a large spatial variation of the temperature ratio, $\theta(=T_e/T_h)$.

LTE: Local thermodynamic equilibrium; LCE: Local chemical equilibrium; CN: Charge neutrality

4) Advances and challenges in plasma modelling : He Ping Li

Transport coefficients (4)



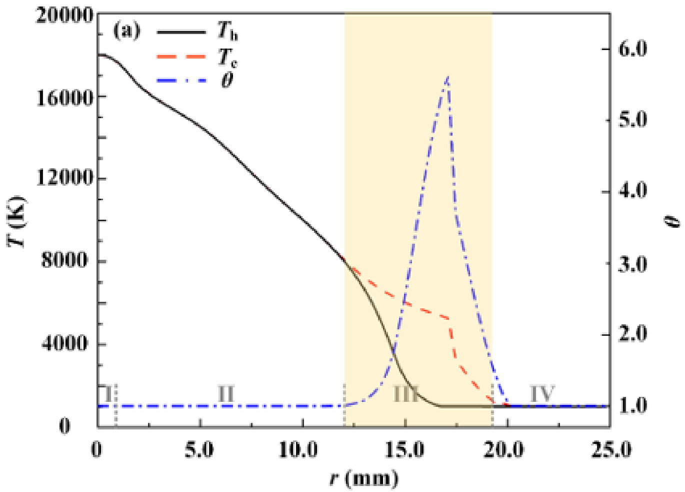
Etude des coefficients de transport 2T

X.-N. Zhang, et al., Plasma Sources Sci. Technol., 2015, 24: 035011

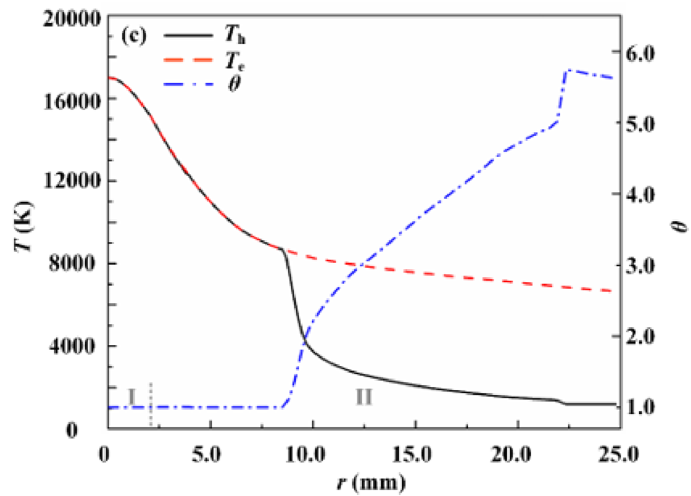
4) Advances and challenges in plasma modelling : He Ping Li

Non-equilibrium modelling – Transition region (2)

Complete non-equilibrium model with $\vec{\nabla} \ln \theta$

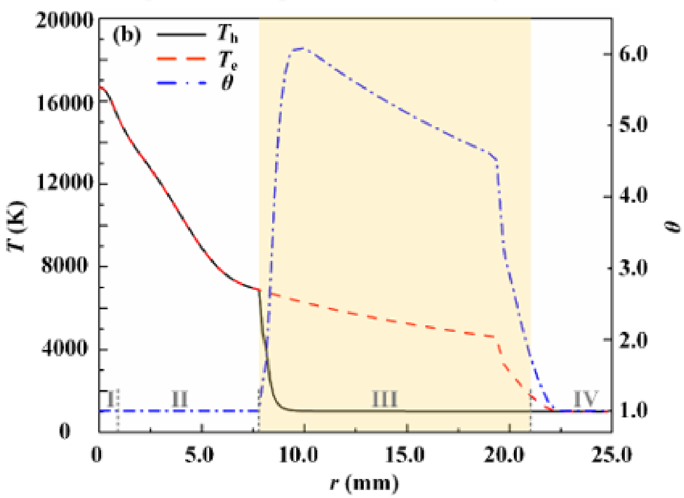


2T-LCE Model



Différences notables entre HE complet et 2T + équilibre chimique Influence du ∇ln θ

Complete non-equilibrium model w/o $\vec{\nabla} \ln \theta$



- The Non-LCE process determines dominantly this non-equilibrium transition region.
- The energy transfer processes related to the term involving $\vec{\nabla} \ln \theta$ enhance the energy exchanges between the sub-systems of electrons and heavy particles.

H. Guo, et al., Sci. Rep., 2018, 8: 4783

5) Plasma-material interactions: liquid/solid

Présentations orales :

• **Plenary Lecture**: Mikhail BENILOV (University of Madeira): Recent advances in the modelling of plasma-electrode interaction and electrode erosion in high- to low-pressure to vacuum arcs

• **Topical Lecture**: Khaled HASSOUNI, Karim Ouaras, Catalina Quiros-Lara, Armelle Michau, Guillaume Lombardi, Michael Redolfi, Jonathan Mougenot, Swaminathan Prasanna, Thierry Chauveau, Ovidiu Brinza (Paris 13 University): Dust particle formation and bulk material alteration through the interactions between non equilibrium hydrogen/argon plasmas and carbon and metal samples

1) Study of GMAW regime transition in Ar-CO2/O2 shielding gases, *Quentin Castillon, Nadia PELLERIN, Stéphane PELLERIN, François Faubert, Maxime Wartel, Jean-Pierre Planckaert, Francis BRIAND*

Session Posters :

4-1 - Interaction between electric arc and Ag-SnO2 electrodes, *Aurélien Fouque*

4-2 - Chemical analysis of Plasma Activated Water using Gliding Arc Discharge at atmospheric pressure: influence of the water content on the activation process, *Maxime Wartel, William Desdions, François Faubert, Nadia PELLERIN, Stéphane PELLERIN, Catherine Stride*

4-3 - Setting for defined fume particle generation and observation using a TIG welding torch, *Stefan Eichler, Erwan Siewert, Jochen Schein*

4-4 - Study of underwater pulsed electric discharge plasma for synthesis of metal colloidal solutions, *Tetiana Tmenova, Yann Cressault, Valensi Flavien, Anatoly Veklich, Viatcheslav Boretskij, Konstantin Lopatko*

5) Plasma-material interactions: liquid/solid – M. Benilov

Recent advances in the modelling of plasma-electrode interaction and electrode erosion in high- to low-pressure to vacuum arcs

Mikhail Benilov

Departamento de Física, FCEE, Universidade da Madeira, Portugal

Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, Portugal

The 15th High-Tech Plasma Processes Conference (HTPP 15)

Toulouse, July 5, 2018

Conclusions

Comparaison de différentes approches

Plasma-cathode interaction in arcs in ambient gas: Four self-consistent modelling approaches

Approach	Approxima-tions	Boundary conditions at the arc-solid interfaces describe	Transport and kinetic coefficients	Numerical realization
Unified	$n_e \neq n_i$ $n_e \neq n_{Saha}$ $T_e \neq T_h$	Contact with the solid	$F(n_e,n_i,n_a,T_e,T_h)$ Ar, Xe, Hg	Difficult, 1D and 2D low-current arcs
NonLTE-sheath	$n_e = n_i$ $n_e \neq n_{Saha}$ $T_e \neq T_h$	Sheath ($n_e \neq n_i$)	$F(n_e,n_a,T_e,T_h)$ Ar, Xe, Hg	Difficult
2T-ionization layer-sheath	$n_e = n_i$ $n_e = n_{Saha}$ $T_e \neq T_h$	Sheath ($n_e \neq n_i$), Ionization layer ($n_e \neq n_{Saha}$)	$F(p,T_e,T_h)$	Moderately difficult
LTE-near-electrode layers	$n_e = n_i$ $n_e = n_{Saha}$ $T_e = T_h$	Sheath ($n_e \neq n_i$), Ionization layer ($n_e \neq n_{Saha}$), Layer of thermal non-equilibrium ($T_e \neq T_h$)	$F(p,T)$	Straight-forward

Conclusions

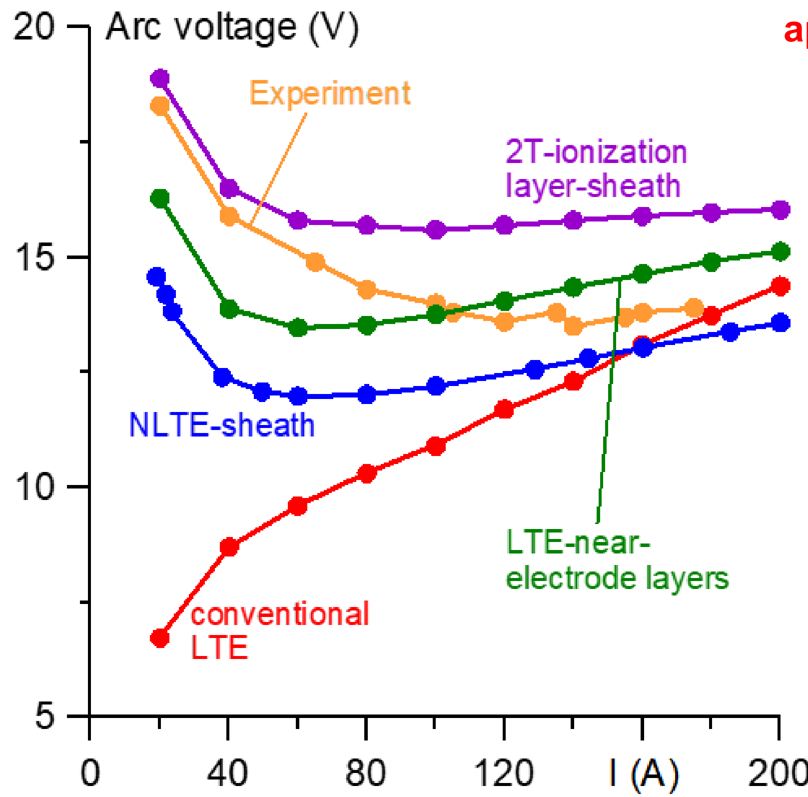
Plasma-cathode interaction in arcs in ambient gas: Comparison of different approaches

Comparaison de différentes approches

- The near-cathode sheath contributes about two thirds of the arc voltage.

Voltage over a 1cm-long free-burning arc in 1bar Ar. Rod W cathode with a hemispherical tip, *R* = 1mm, *h* = 12 mm.

- 2T-ionization layer – sheath: M. S. Benilov, L. G. Benilova, H.-P. Li, and G.-Q. Wu 2012.
- NLTE-sheath: M. Baeva, M. S. Benilov, N. A. Almeida, and D. Uhrlandt 2016.
- LTE-near-electrode layers: M. Lisnyak, M. D. Cunha, J.-M. Bauchire, and M. S. Benilov 2017.
- Experiment: N. K. Mitrofanov and S. M. Shkolnik 2007.



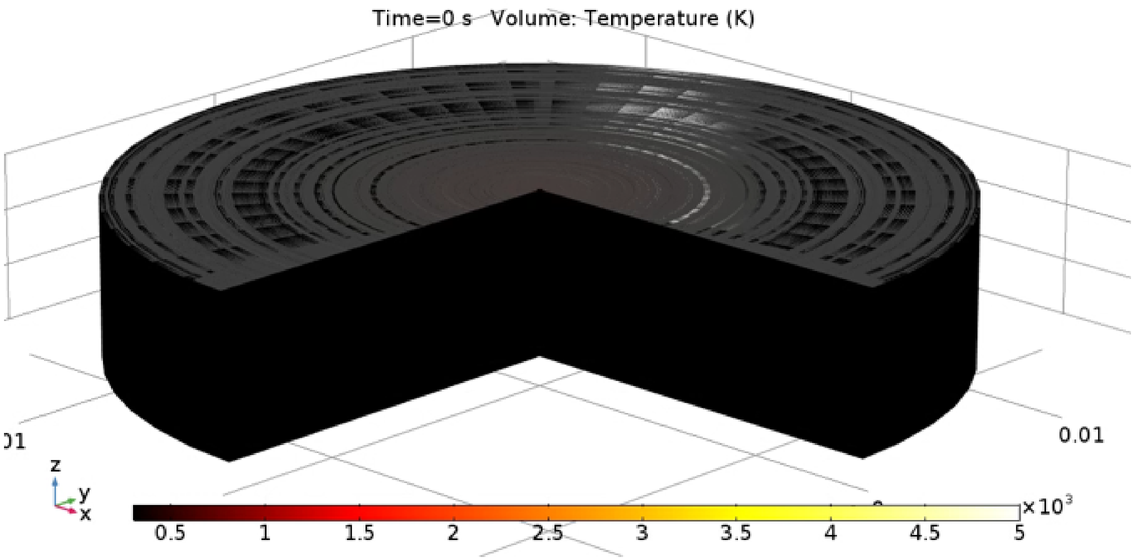
Conclusions

Plasma-cathode interaction in arcs in ambient gas

- The physics has been clarified quite some years ago.
- **There is no new physics in recent publications; the goal is to devise a numerical method suited for industrial applications.**
- The results given by the four different approaches are generally close to each other (comparison: M. S. Benilov, N. A. Almeida, M. Baeva, M. D. Cunha, L. G. Benilova, and D. Uhrlandt 2016; M. Lisnyak, M. D. Cunha, J.-M. Bauchire, and M. S. Benilov 2017) and to the experiment.
- **The LTE-near-electrode layers approach is by far the simplest one:**
  - One-parameter lookup tables for transport coefficients;
  - No kinetic coefficients;
  - Simple for numerical realization: a standard LTE code with appropriate boundary conditions at the plasma-cathode interface;
  - The possibility to use ready-to-use specialized software such as Plasimo or Equilibrium DC Discharge (sub)module of the Plasma module of COMSOL.
- **The LTE-near-electrode layers approach has the potential of being best suited for industrial simulations of high-current arcs.** Hopefully, it will be completed soon…

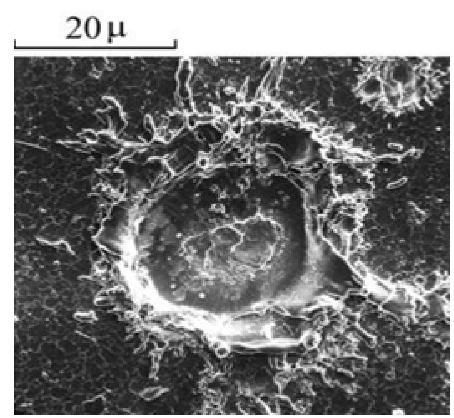
Cathode erosion

- **Modeling assumes axial symmetry =>** formation of axially-symmetric jet and detachment of a ring:



Modèle d'érosion à la cathode

- The assumption of axial symmetry is reasonable as far as the formation of craters is concerned. On the other hand, a ring jet does not develop => **One or a few 3D jets will be formed.**

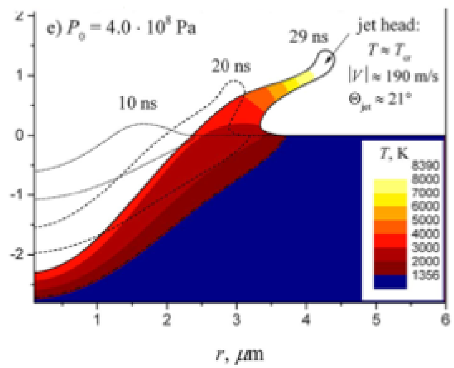


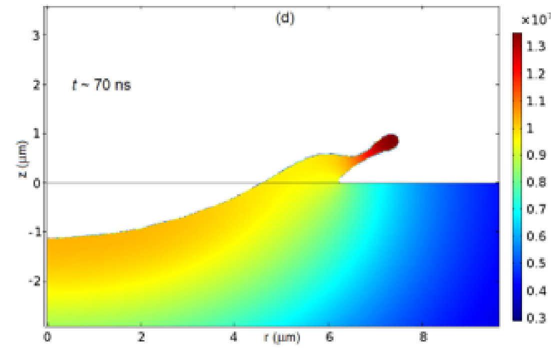
The crater on a cathode spot. From Shkolnik 2016.

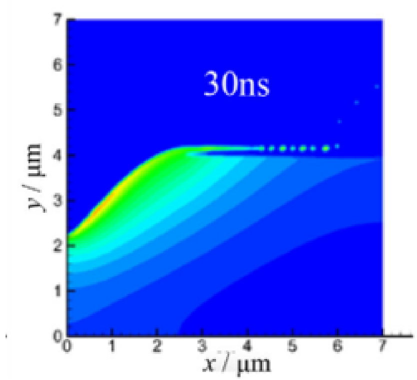
Comparison of results given by different models

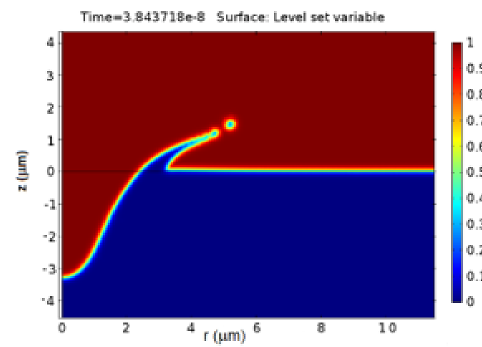
Modèle d'érosion à la cathode Exemples de résultats

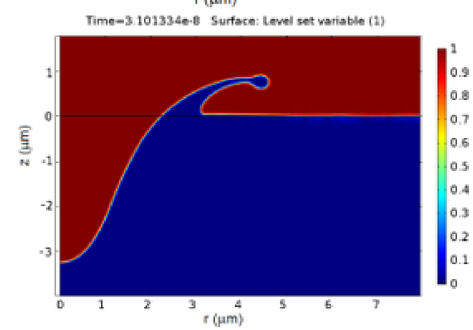
- The different results obtained in the modeling of other groups and this work are owed to the **neglect of the interaction of the plasma produced in the spot with the cathode surface**, in particular the neglect of **electron emission cooling** and the **plasma pressure due to ions produced from the metal vapor**.











- **Poor mesh resolution** during the simulation can be **misleading** with regard to droplet ejection!

Univ. Madeira ipfn FCT

6) Powders and additive manufacturing

Présentations orales :

• **Plenary Lecture**: Filomeno MARTINA**,** Philippe Bridgeman, Gianrocco Marinelli, Jialuo Ding, Supriyo Ganguly, Stewart Williams (Cranfield University): Use of plasma-arc source in large-scale additive-manufacturing, also for the deposition of materials of interest in plasma-confinement applications for fusion

• **Topical Lecture**: Romain VERT and Alexandre Vassa (TEKNA): Spherical powders manufacturing by Induction Plasma technology

1) Two-dimensional estimation of number density distribution of precursor molecules during TiO2 nanopowder synthesis using induction thermal plasmas, *Naoto Kodama, Yasunori Tanaka, Kazuki Onda, Kotaro Shimizu, Yoshihiko Uesugi, Tatsuo Ishijima, Sueyasu Sueyasu, Shu Watanabe, Keitaro Nakamura*

Session Posters :

5-1 - Trial Synthesis of Silicon Nanoparticles using a Newly Developed Tandem Type of Modulated Induction Thermal Plasma with Lower Coil Current Modulation, *Kazuki Onda, Naoto Kodama, Yosuke Ishisaka, Kotaro Shimizu, Yasunori Tanaka, Uesugi Yoshihiko, Tatsuo Ishijima, Shiori Sueyasu, Shu Watanabe, Keitaro Nakamura*

5-2 - Aluminum oxynitride nanopowders synthesis in a reactor with a confined plasma jet, *Aleksey Astashov, Andrey Samokhin, Nikolay Alekseev, Mikhail Sinayskiy, Inessa Pahilo-Daryal*

5-3 - Atmospheric pressure plasma modification of powder dispersions using RF jet and RF slit nozzle, *Barbora Pijáková, Jozef Ráheľ*

5-4 - In-liquid synthesis of CuO nanoparticles by bipolar pulsed microplasma, *Dong-Wook Kim, Dong-Wha Park*

5-5 - Synthesis of Metal Boride Nanoparticles in Triple Thermal Plasma Jet System, *Minseok Kim, Jeong-Hwan Oh, Tae-Hee Kim, Yong Hee Lee, Seung-Hyun Hong, Sooseok Choi*

5-6 - Synthesis of Tungsten Carbide Nanoparticles using Triple Thermal Plasma Jet System, *Jeong-Hwan Oh, Minseok Kim, Young Hee Lee, Seung-Hyun Hong, Tae-Hee Kim, Sooseok Choi*

5-7 - Reproduction of cosmic dust by non-equilibrium condensation in triple thermal plasma jet system, *Tae-Hee Kim, Jeong-Hwan Oh, Minseok Kim, Yong Hee Lee, Akira Tsuchiyama, Junya Matsuno, Aki Takigawa, Sooseok Choi*

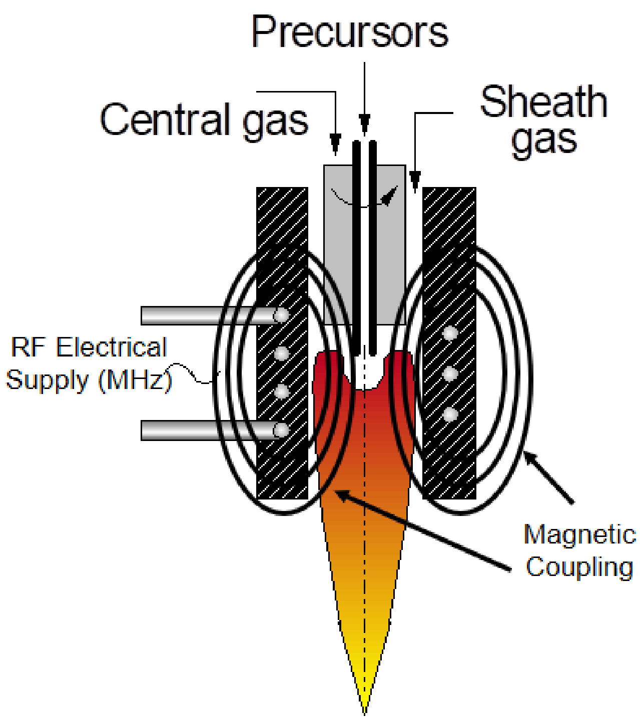
6) Powders and additive manufacturing : Romain Vert

6) Powders and additive manufacturing : Romain Vert

TEKNA

Induction Plasma Principle

Characteristics of Tekna's Core Technology



- **No electrodes** (no consumable; continuous process; no contamination);
- **High purity** environment;
- **Axial injection** of feed stock in the highest temperature zone of the plasma (homogeneous precursor treatment or reaction);
- Rather **long in-flight time** in the hot gas stream (up to ~500 ms depending on reactor design);
- **Large volume plasma** (up to ~100mm in dia., hundreds of mm long);
- Discharge sustainable in **various atmospheres** ensures high purity environment and enables controlled chemical reactions if needed;
- Rather **high yields** (5-60 kg/h depending on material & plasma power).

Présentation des technologies TEKNA

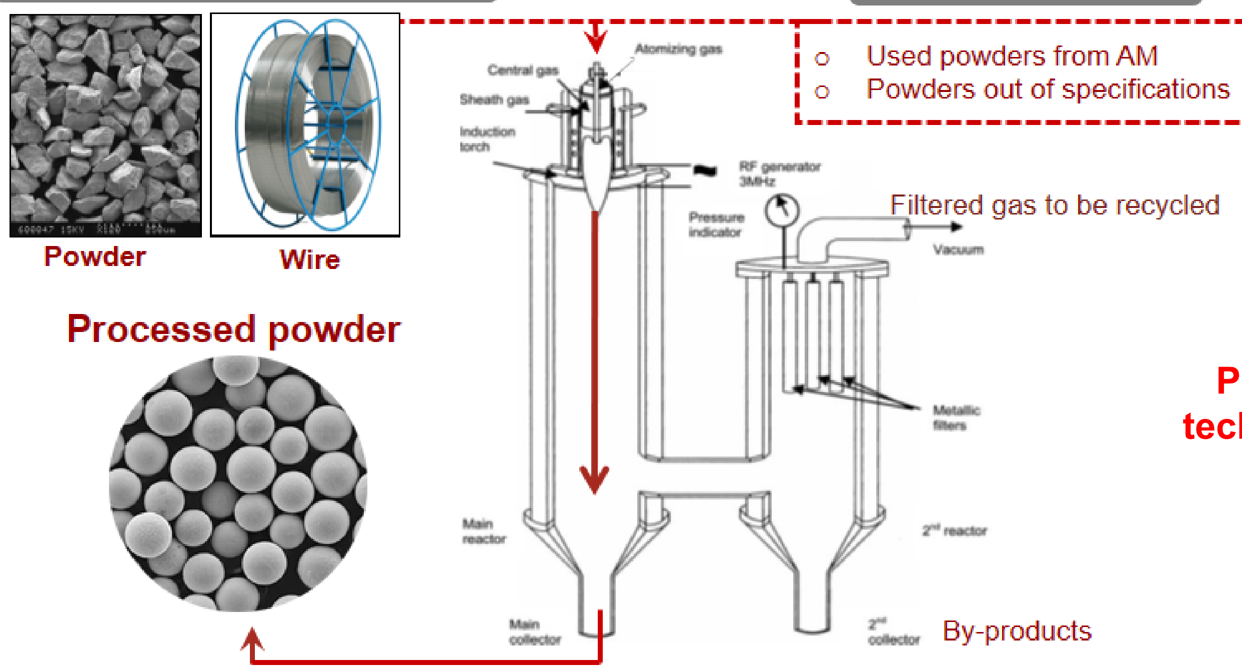
6) Powders and additive manufacturing : Romain Vert

Spherical Powders

Powder Production and Reconditioning by Induction Plasma

Spherical powder production

Powder reconditioning



Présentation des technologies TEKNA

7) Material and Surface processing

Présentations orales :

• **Plenary Lecture**: Dirk UHRLANDT (INP Greifswald): Arc-electrode interaction in thermal plasma applications

• **Topical Lecture**: Christian MOREAU (Concordia University): Suspension Plasma Spraying

1) Supersonic Plasma Deposition of Zinc Oxide Nanostructured Thin Films, *Elisa Dell'Orto, Silvia Freti, Claudia Riccardi*

2) Anisotropic plasma etching of Silicon in gas chopping process by alternating steps of oxidation and etching, *Andrey Miakonkikh, Sergey Averkin, Konstantin Rudenko*

Session Posters :

6-1 - Determination of residual stress by X-ray diffraction in a weld cordon, *Driss Dergham*

6-2 - Tribological investigations of YSZ-CuAg composite coating, *Yan WANG, Yongli ZHAO, Geoffrey DARUT, Thierry POIRIER, Jorge STELLA, Hanlin LIAO, Marie-Pierre PLANCHE*

6-3 - Reactive magnetron sputter deposition of titanium oxynitride TiNxOy coatings: influence of substrate bias voltage on the structure, composition, and properties, *nadia saoula, Farroudja Lamdani, Larbi Bait, noureddine madaoui, Hanane Mechri, Mourad azibi, samira sali, Abdelkader Hammouche*

6-4 - Decomposition of ceramic inks by an arc plasma jet operating in a pulsed mode and coating deposition, *Fabrice Mavier, Fadi Zoubian, Pascal André, Marguerite BIENIA, Martine Lejeune, Vincent Rat*

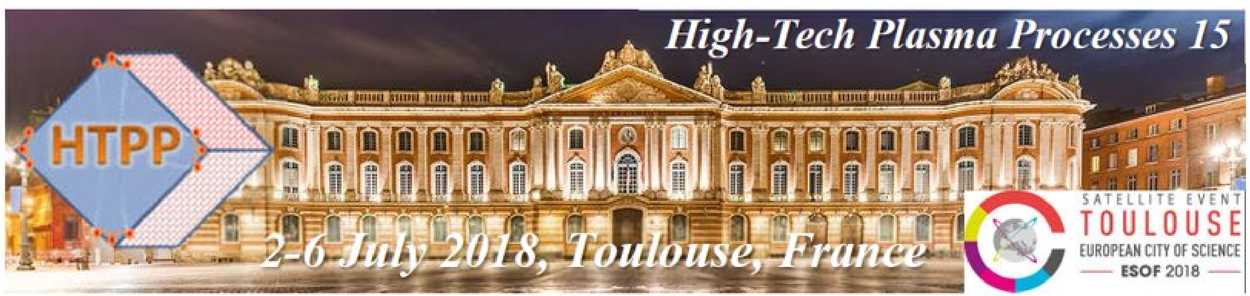
6-5 - In situ measurement of Silicon surface oxidation in low temperature oxygen plasma, *Andrey Miakonkikh, Iosif Clemente, Konstantin Rudenko, Sergey Averkin*

7) Material and Surface processing : Dirk Uhrlandt

Arc electrode interaction in thermal plasma applications

Dirk Uhrlandt, Guokai Zhang, Gregor Gött, Margarita Baeva, Sergey Gortschakow

Leibniz Institute for Plasma Science and Technology (INP Greifswald)



Leibniz Association

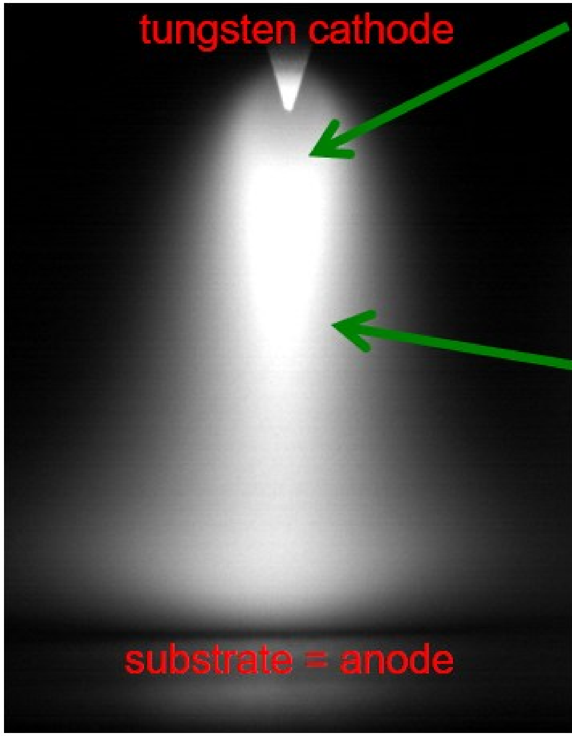
FROM IDEA TO PROTOTYPE

7) Material and Surface processing : Dirk Uhrlandt

1. Theoretical background of arc-electrode interaction

Example: TIG arc

Application Soudage



arc attachment regions:
up to 70 % of the energy transfer in the non-equilibrium plasma sheath,

arc column:
close to thermal, chemical, ionisation equilibrium,

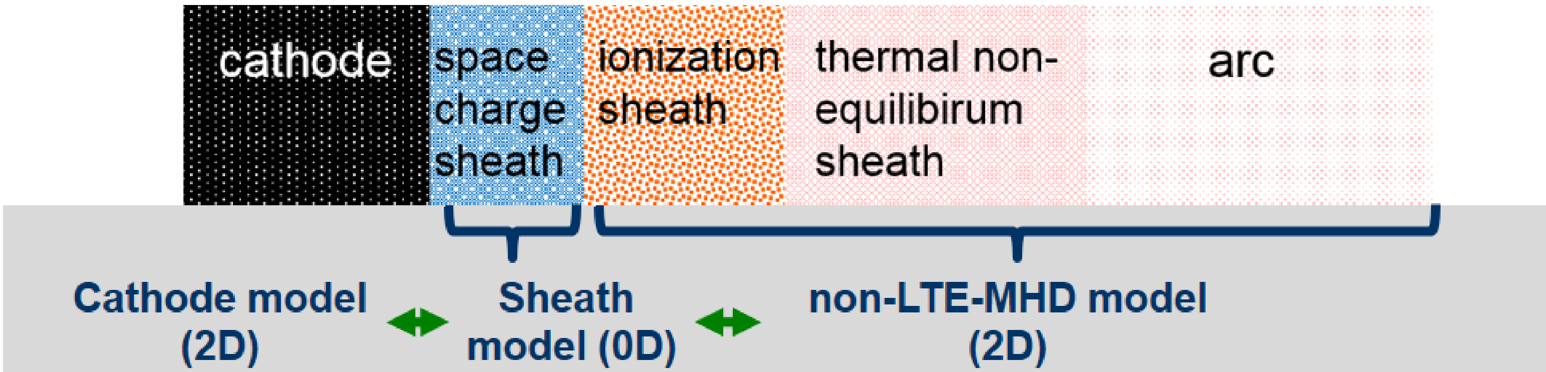
7) Material and Surface processing : Dirk Uhrlandt

INP FROM IDEA TO PROTOTYPE

2. TIG arc – inside from a non-equilibrium model

Model approach

Modèle 2T – interaction arc-cathode



- Consistent two-way coupling with the current and energy balances of electrodes
- Arc attachment results self-consistently from current continuity
- Metal vapour included

- Thermal non-equilibrium
- Chemical non-equilibrium
- Strict treatment of drift and diffusion fluxes by Stefan-Maxwell equations
- Generalized Ohm`s law

Baeva M, Benilov M S, Almeida N A and Uhrlandt D, Novel non-equilibrium modelling of a DC electric arc in argon, *J. Phys. D.: Appl. Phys.* 49 (2016) 245205

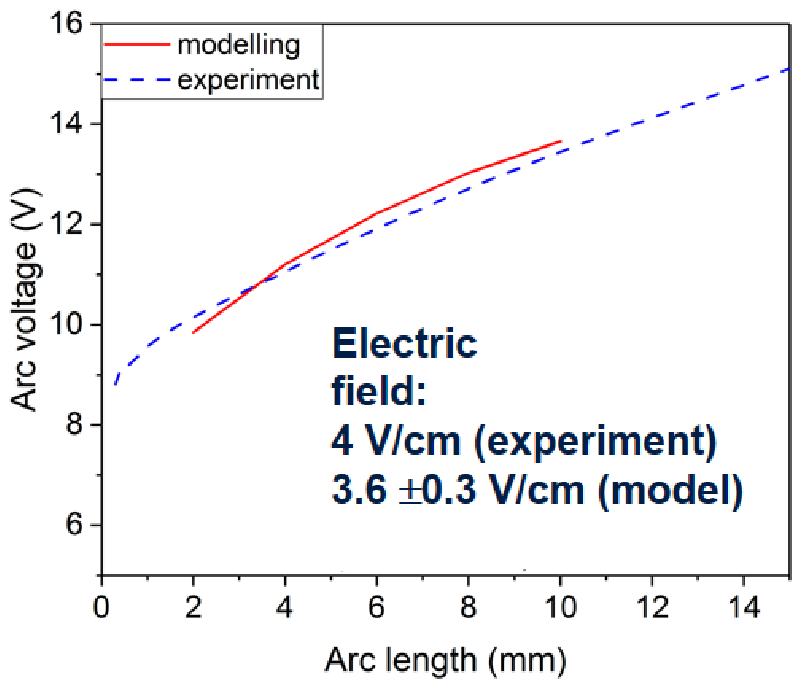
7) Material and Surface processing : Dirk Uhrlandt

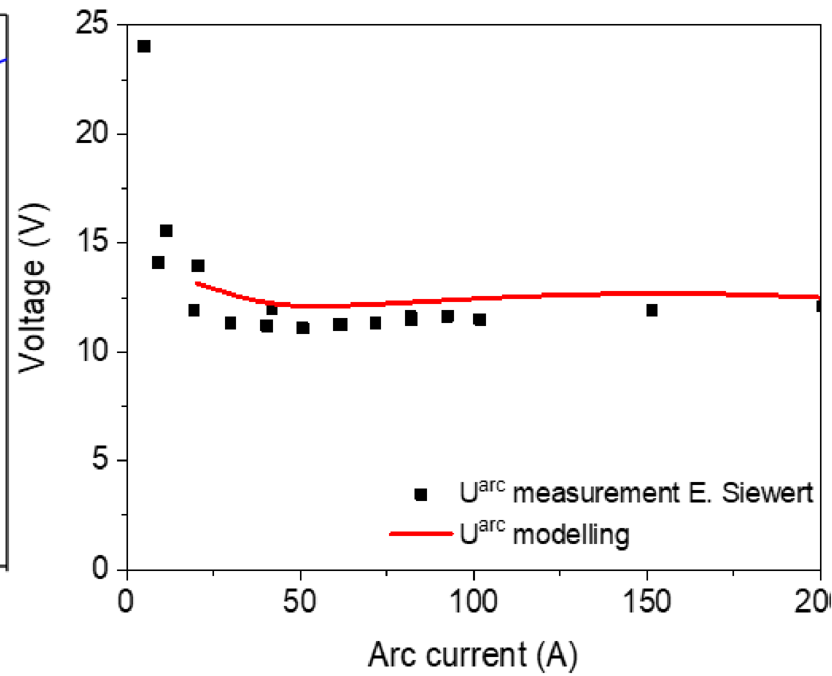
Modèle 2T – interaction arc-cathode

INP

2. TIG arc – inside from a non-equilibrium model

Model results – comparison with measurements





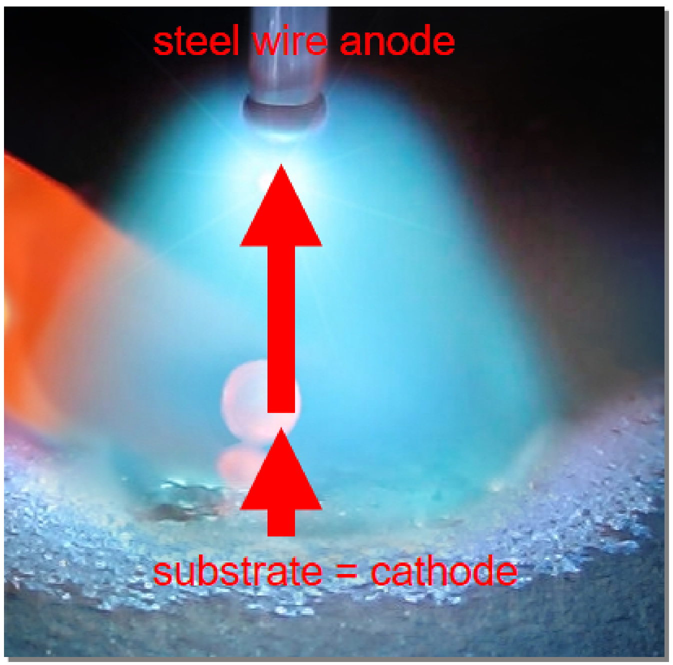
example: 60° electrode ∅ 4 mm,
15 slpm Ar, 100 A

7) Material and Surface processing : Dirk Uhrlandt

GMAW : modèles existants à améliorer

3. GMAW – limitations of existing models

Gas Metal Arc Welding



Differences to the TIG arc:

- polarity – flat cathode
- non-refractory cathode
- higher amount and impact of metal vapour

Energy transport:

- from cathode sheath to column ?
- in the column against the gas flow to the anode ?

7) Material and Surface processing : Dirk Uhrlandt

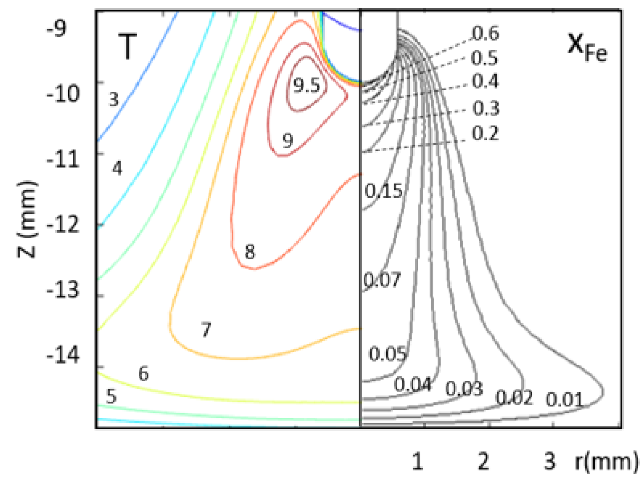
GMAW : modèles existants à améliorer

3. GMAW – limitations of existing models

Non-LTE MHD simulation of GMAW – requirements:

- non-LTE plasma model including metal vapour (Fe)

Baeva M, Uhrlandt D, Murphy A B, A collisional-radiative model of iron vapour in a thermal arc plasma, *J. Phys. D: Appl. Phys.* 50 (2017) 22LZ02



- description of sufficient electron emission at a non-refractory cathode
  - ➢ spot model similar to vacuum arcs ? (needs 3D)

Suspension Plasma Spraying

Christian Moreau

Concordia University
Canada Research Chair in Thermal Spray and Surface Engineering

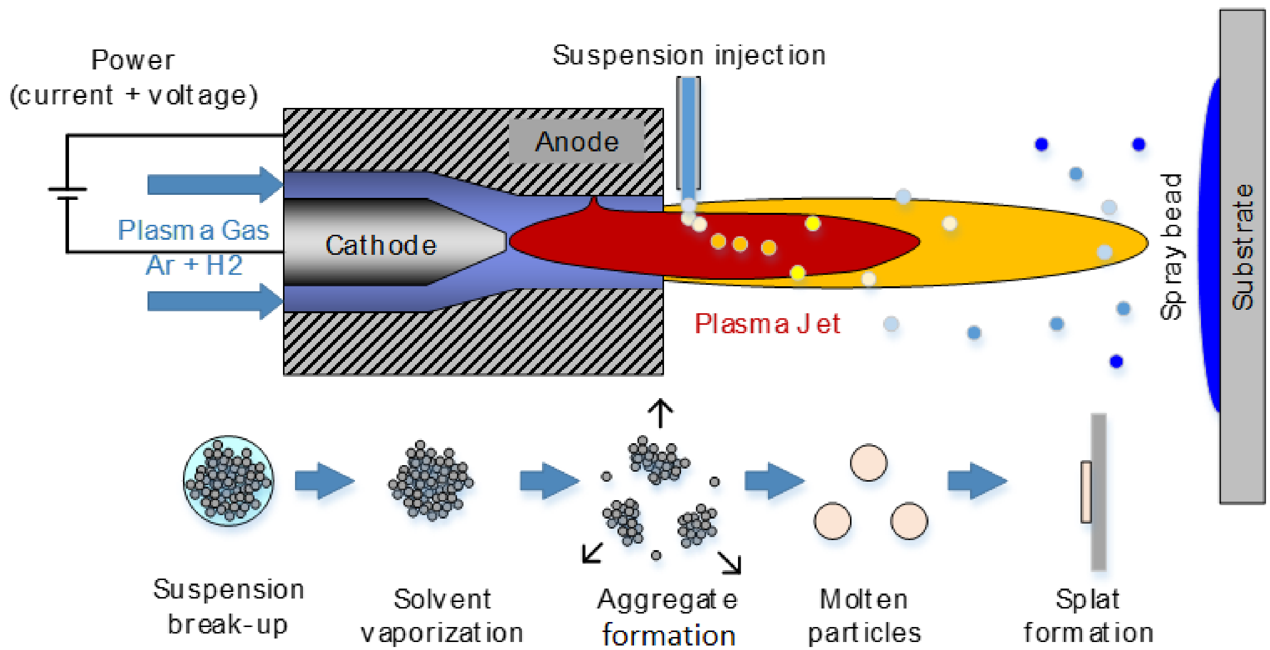
High Tech-Plasma Processes 15
Toulouse, France, July 206, 2018

UNIVERSITÉ Concordia UNIVERSITY

THERMAL SPRAY & MULTIPHASE FLOW LABORATORY

7) Material and Surface processing : Christian Moreau

Suspension Plasma Spray



THERMAL SPRAY & MULTIPHASE FLOW LABORATORY

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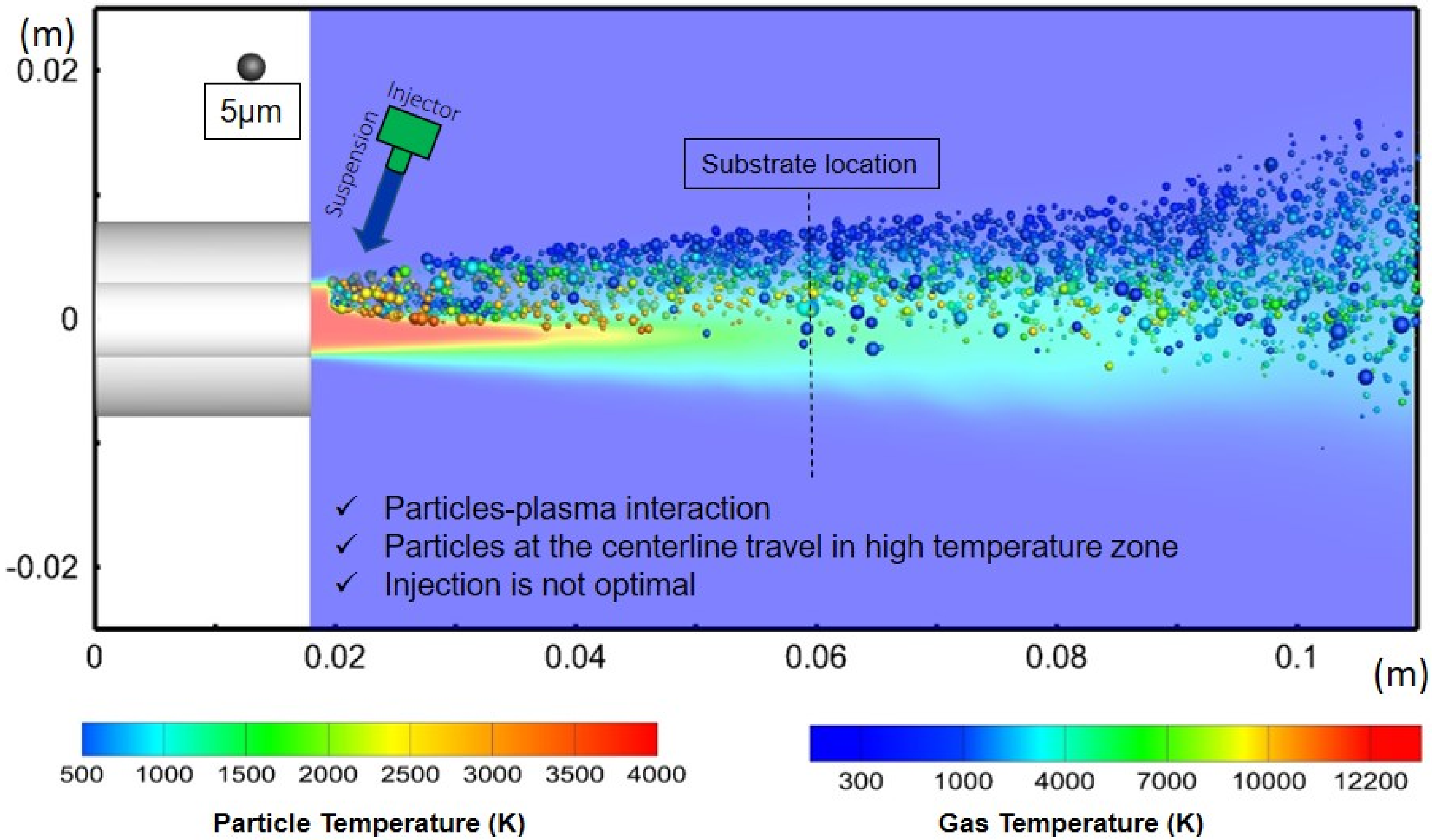
7) Material and Surface processing : Christian Moreau

Modélisation du jet de plasma et de l'interaction plasma / particules

Particle Injection into Free Jet



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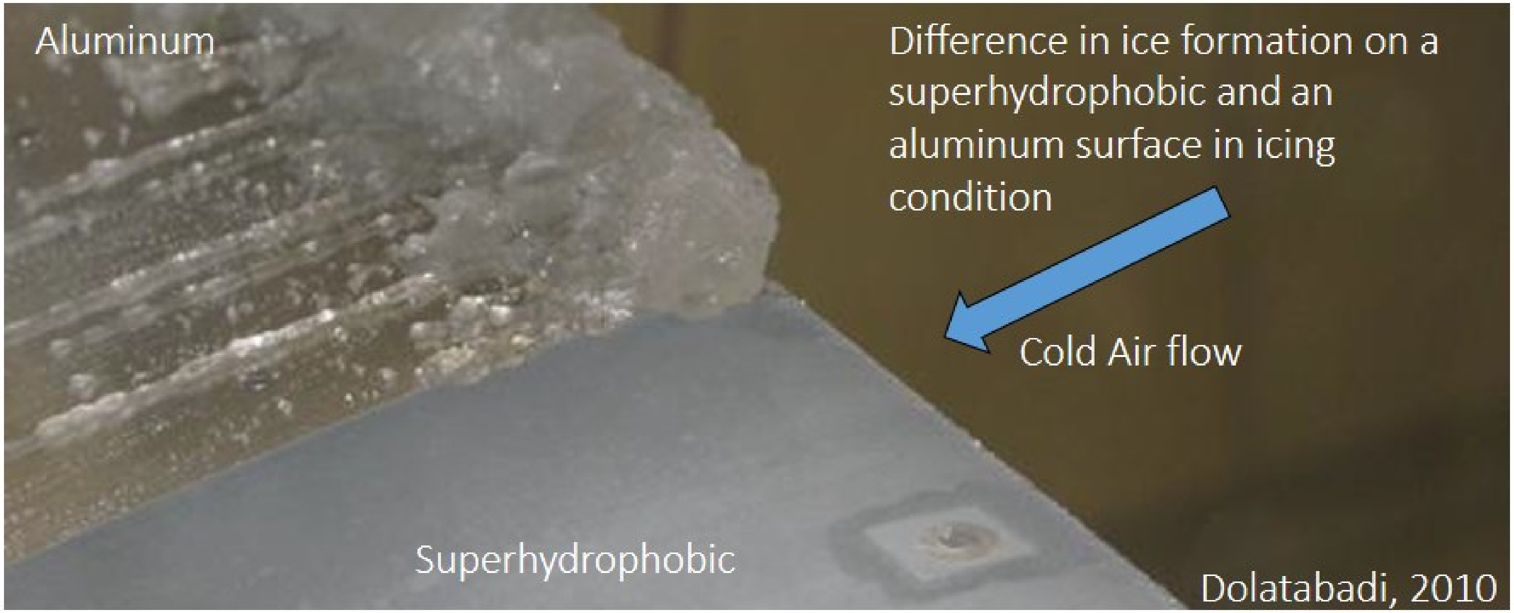
THERMAL SPRAY & MULTIPHASE FLOW LABORATORY

7) Material and Surface processing : Christian Moreau

Exemple d'application : effet antigivrage sur voilure d'aéronef

Anti-icing Superhydrophobic Coatings

- Water drops bounce back before freezing
- Heated de-icing is facilitated



Université Concordia University

THERMAL SPRAY & MULTIPHASE FLOW LABORATORY

8) Energy and transport applications

Présentations orales :

• **Plenary Lecture**: Christophe LAUX (Ecole Centrale Paris): Control and Stabilization of Flames with Plasma Assistance

• **Topical Lecture**: Alexander BARTH, Malko Gindrat, Richard Schmid (Oerlikon Metco AG, Wohlen): Vapor Phase deposition using a plasma spray process

1) Plasma spraying at very low pressure (VLPPS): Model development and experimental validation beyond continuum conditions, *Georg Mauer, Dmitrii Ivchenko, Gilles Mariaux, Armelle Vardelle, Simon Goutier, Tatiana Itina, Cong Zhao, Robert Vassen*

Session Posters :

7-1 - Study on reaction rates for 2T SF6 plasma: application to chemical kinetics of a decaying arc in high voltage circuit breakers, *Xavier BAUMANN, Philippe TEULET, Yann Cressault, Arnaud Bultel*

8) Energy and transport applications : Christophe Laux

Control and Stabilization of Flames with Plasma Assistance

CentraleSupélec

Christophe Laux
Laboratoire EM2C / CNRS
CentraleSupelec

Work supported by:
INCA, ANR FAMAC,
ANR PLASMAFLAME, ANR PASTEC, LASIPS SF3P,
LASIPS PLASMA-STAB
Chaire d'Excellence on Optical Diagnostics

15th International High Tech Plasma Processes Conference
Toulouse, July 2-6, 2018

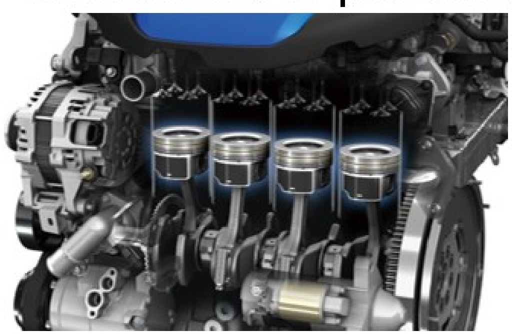
8) Energy and transport applications : Christophe Laux

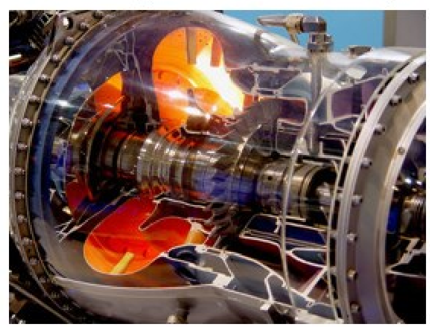
CentraleSupélec

Potential benefits of plasma-assisted combustion

- Ignition and stabilization of lean or diluted flames
- High altitude relight
- Control of transient regimes
- Control of thermo-acoustic instabilities
- Greater fuel flexibility
- More compact combustors
- Improvement of combustion efficiency
- Reduction of pollutant emissions (NOx, Soot)

Avantages de la combustion assistée par plasma





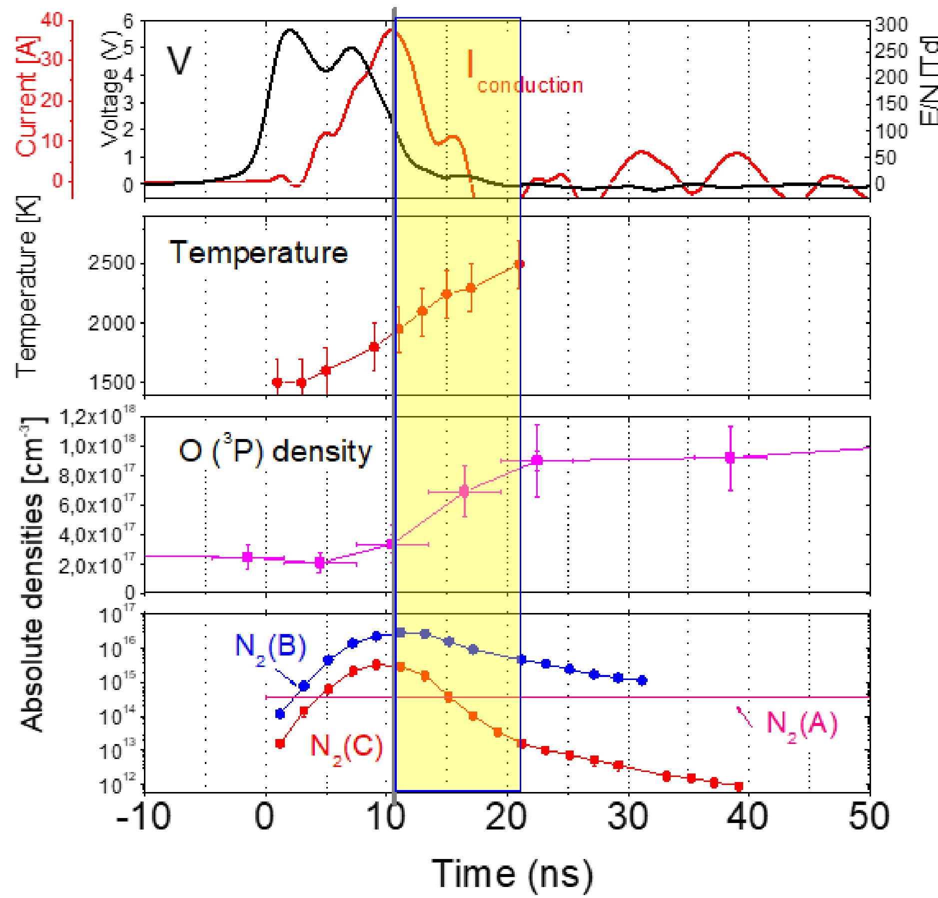
8) Energy and transport applications : Christophe Laux

CentraleSupélec

Synchronized measurements of V, I, temperature, densities

Ultrafast heating: 900 K in 20 ns

50% dissociation of O_2



Electric energy: 670±20 μJ/pulse

$\eta_{heating}$ =21±5%

$\eta_{diss.}$ = 35±5%

Nanosecond Repetitively Pulsed (NRP) discharges

Short, high voltage pulses: 10 ns, 5-30 kV

high repetition frequency (10-100 kHz)

Rusterholtz et al., J. Phys D., 2013

$N_2^* + O_2 \rightarrow N_2 + O + O + \Delta T$

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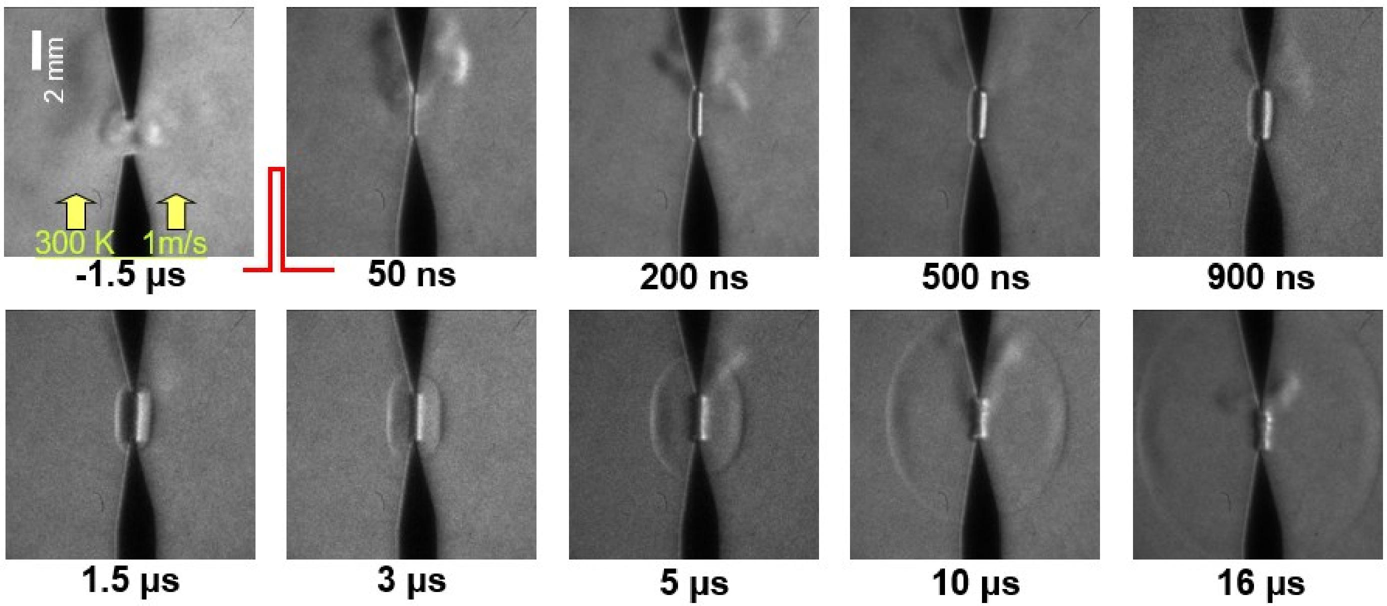
cnrs

Hydrodynamics (fast Schlieren imaging)



D.A. Xu et al., Appl. Phys. Lett. ***99****, 121502, 2011*

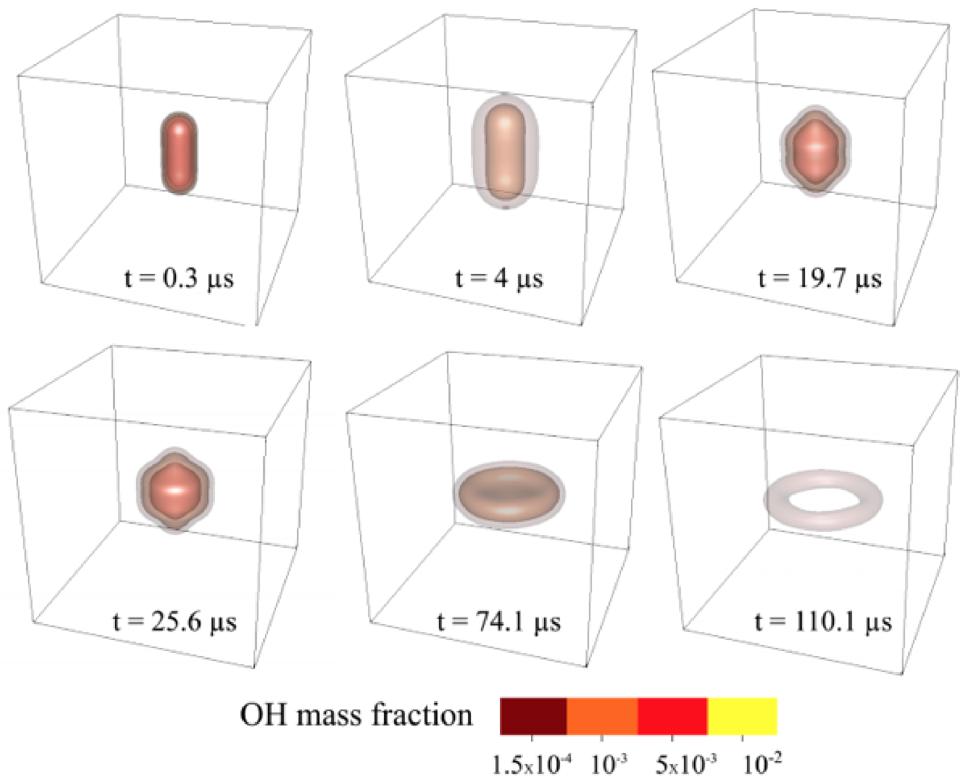
1 kHz
1 mJ/pulse

- Shock wave
- Hot channel

8) Energy and transport applications : Christophe Laux

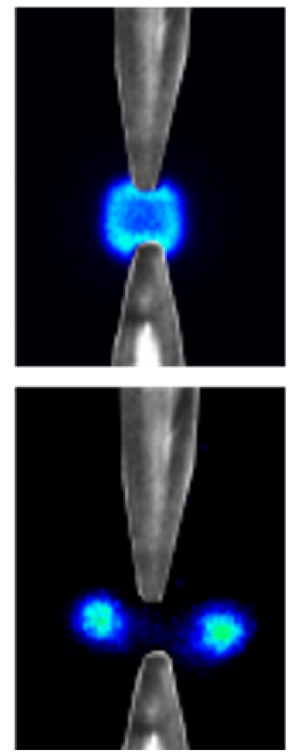
Discharge column evolves into torus of active species

3D-Direct Numerical Simulations



Castela et al, Proc.Combustion Symposium, 36(3), 4095-4103 (2017)

OH PLIF experiments



5 µs

100 µs

Minesi et al, 2017

9) Aeronautics and aerospace applications

Présentations orales :

- **Plenary Lecture**: Roland CAUSSE and David ROUSSET (AIRBUS): HVDC Networks and the Aircraft Electrical Installation

- **Topical Lecture**: Frank FLOURENS (AIRBUS): Lightning: a constraining environment for aviation

1) Experimental investigation of the repeatability of direct damage induced by lightning strikes on metallic panels, *Christine ESPINOSA, Iman Alhossen, Anis Hor, Estelle Pierré, Stéphane Vilcocq, Rémy Chieragatti, Thomas Montel, Oscar Gnangnon*

2) Novel Distributed Air-Breathing Plasma Jet Propulsion Concept for All-Electric High-Altitude Flying Wings, *Berkant Goeksel*

Session Posters :

8-1 - Experimental arc root sweeping simulation and motion tracking for aeronautics applications, *clement zaepffel, Rafael Sousa Martins*

8-2 - Study of electric arc extinction in aeronautical environment, *Loïc HERMETTE, Guillaume Belijar, Gaëtan Chanaud, Emeric Boliga, Yann Cressault, Philippe TEULET*

8-3 - Introduction of Molecular Dynamics (MD) as a tool for the investigation of gridded ion thrusters, *Karsten Hartz-Behrend, Jochen Schein*

8-4 - Determination of faults arc energy ignited between aeronautic cables, *Thomas Vazquez, Philippe TEULET, Flavien Valensi, Aurore RISACHER, Loïc HERMETTE, Vincent Casanovas*

8-5 - Cold Atmospheric Pressure Plasma applied for Aeronautical Polyurethane surface activation: preliminaries characterizations, *Audrey SANCHOT, Vivien MURAT, Nicolas NAUDE, Bertrand RIVES, Laurent GUERRE-CHALEY, Thomas DELSOL*

8-6 - Lightning arc interaction with complex structure, *Audrey BIGAND, Jean-Marc Bauchire, Christine Espinosa, Hervé Rabat*

8-7 - Lightning strike protection explosion and overpressure profile, *Audrey BIGAND, Christine Espinosa, Jean-Marc Bauchire, Hervé Rabat*

8-8 - LDA Electric Wind Velocity Measurements Behind Single Dielectric Barrier, Multi Dielectric Barrier and Sliding Discharge Plasma Actuators, *Berkant Goeksel*

9) Aeronautics and aerospace applications : Roland Caussé / David Rousset

HVDC Neworks and the Aircraft Electrical Installation

HTPP 2018 High-Tech Plasma Processes – Toulouse

David Rousset Electrical Systems Research
Roland Caussé Electrical Installation Directives
6th July 2018 - Toulouse

AIRBUS

9) Aeronautics and aerospace applications : Roland Caussé / David Rousset

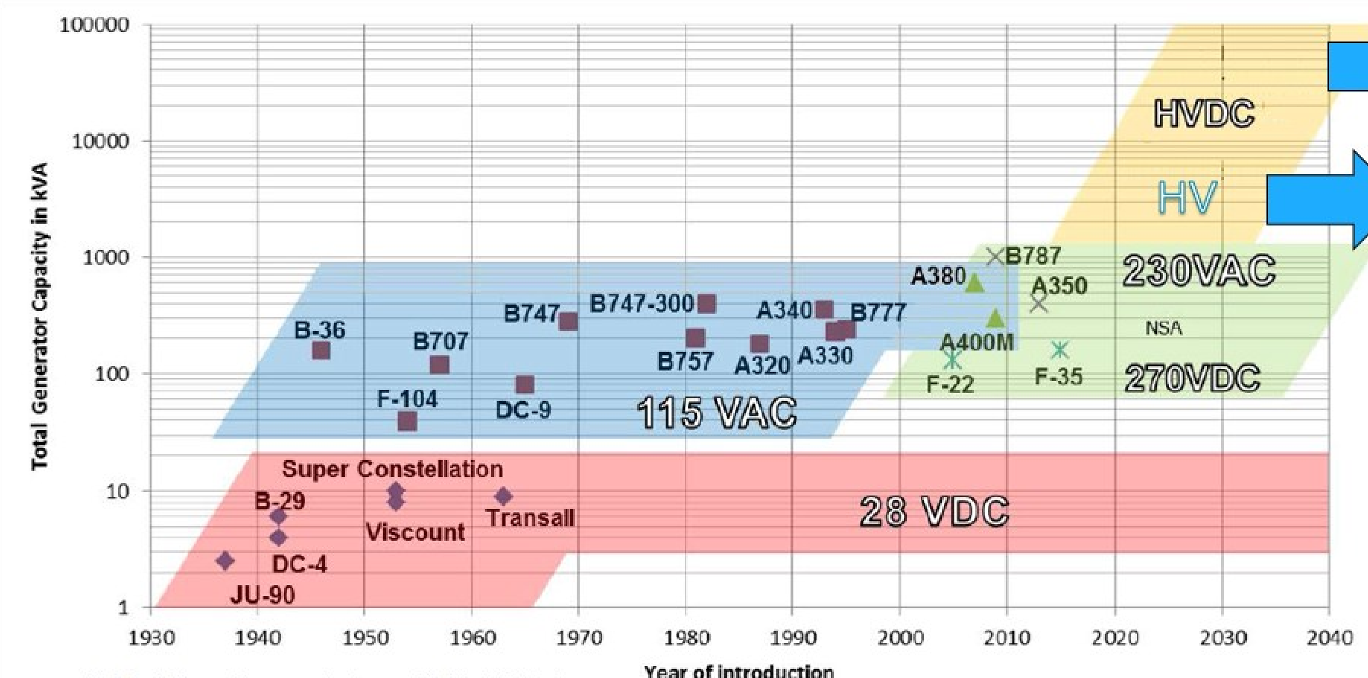
Pourquoi un avion plus électrique

Why More Electric Aircraft
2 – Innovation challenges

Two mains objectives : From More Electrical Aircraft to all Electrical Aircraft

	Equipment	Aircraft	Airline
Cost Reduction	Standard use No specific manufacturing	Easy integration More modularity	Less maintenance Less fuel burn
Added value	Key technologies	New functions	More services

Impact : power rationalisation + innovation → MEA



All electric aircraft:
- Electric propulsion solutions

More electric aircraft:
- Simplification of on-board
- Management of non propulsive energy

MEA → voltage increase

AIRBUS

Today Arc Fault Mitigation on EWIS (Electrical Wiring Interconnection System)

AMC 25.1709 System safety; EWIS (Acceptable Mean of Compliance)

«Any single failure condition, such as an arc fault, should be assumed to occur regardless of probability»

Current Aircraft Voltage networks:

- 28V DC low voltage for loads lower that 150W
-115V or 230V AC for loads higher than 150W

Arc Prevention
Installation Rules (Passive protection)

Arc Occurrence
Damage containment

Arc cut-off
Protection Device (Active Protection)

Cas des réseaux embarqués actuels
Risque Arc « accepté »

AIRBUS

9) Aeronautics and aerospace applications : Roland Caussé / David Rousset

EWIS & High Voltages Networks

Propulsive HVDC Networks > 1kVdc

Power Arcing Risk not acceptable for the A/C environment

« Predictive mean » of EWIS damage based on active and passive protections

HVDC or HVAC

Distribution Network

Fast trip Protection Device

Serial Arc protection : to be investigated

Current networks

- 28Vdc
- 115 / 230 Vac

I^2t Protection Device

Futurs réseaux embarqués – Arcs de défaut inacceptables

AIRBUS

9) Aeronautics and aerospace applications : Franck Flourens

9) Aeronautics and aerospace applications : Franck Flourens

Anticipation des risques futurs
Effort de modélisation à poursuivre

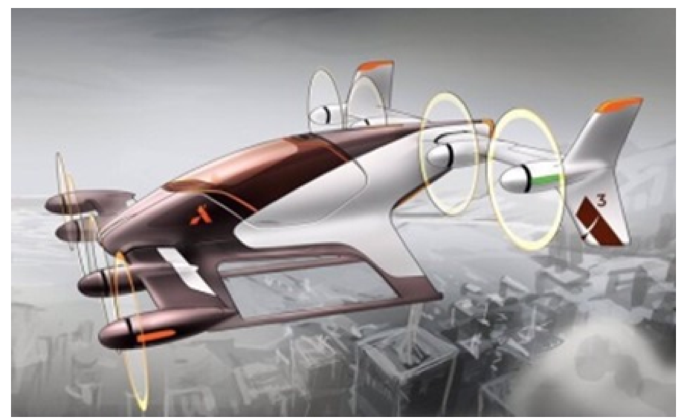
Conclusion

A350: Design strongly influenced by lightning strike protection
→ 1st time on the critical path

Need to pursue effort to develop models to support design and certification

NEED TO ANTICIPATE:

- → New mode of transportation?
- → Threat evolution?
- → Real time weather conditions?
- → New propulsion means (H_2)?



10) Environment applications

Présentations orales :

• **Plenary Lecture**: Jaco VAN DER WALT (NECSA): Musical Chairs with Waste-to-Energy Technologies

• **Topical Lecture**: Laurent FULCHERI (Mines ParisTech): Direct decarbonization of methane by thermal plasma for the co-production of hydrogen and carbon nanostructures

1) Co-gasification of lignite and used car tires by H2O/air thermal plasma, *Viktor Popov, Dmitry Subbotin, Alexander Surov, Sergey Popov, Evgeny Serba*

Session Posters :

•**9-1** - Effects of discharge voltage and current on PFCs treatment process in an elongated arc reactor, *K-T Kim, D. H. Cho, D. R. Lee, S. K. Jo, D. H. Lee, Y-H Song*

•**9-2** - Matrix Impact On Bacterial Biofilms Response and Resistance To Cold Plasma Treatments, *Frédéric Marchal, Maritxu Labadie, Elisabeth GIRBAL-NEUHAUSER, Catherine Fontagné-Faucher, Nofel Merbahi, Claire-Emmanuelle Marcato-Romain*

•**9-3** - Reduction in size and quantity of by-product particles using a low-pressure plasma reactor in SiO2 thin film deposition, *Jae-Ok Lee, Jin-Young Lee, Seok Jun Suh, Dae Woong Kim, Woo Seok Kang, Min Hur*

•**9-4** - Degradation of phenol aqueous solution using submerged arc plasma, *Eun Seo Jo, Dong-Wook Kim, Dong-Wha Park*

10) Environment applications : Jaco van der Valt

10) Environment applications : Jaco van der Valt

Waste to Energy Technologies

necsa
We're in your world
South African Nuclear Energy Corporation SOC Limited

- Waste to Energy technologies include:
  - Incineration
  - Conventional gasification
  - Plasma gasification
  - Pyrolysis
- Typical commercial size for these systems are presented below

Compétition (jeu des chaises musicales) entre les différentes technologies

WtE Technology	Typical size (tpd)	Energy product
Incineration	7.2, 10, 72, 181, 1500 *	Electricity by steam
Conventional gasification	90 – 10 000	Diesel, jet fuel, electricity, heat
Plasma arc gasification	0.1 - 500	H_2, electricity, synfuel, heat, ...
Pyrolysis	0.7, 7, 12, 19, 36**	Methane, pyrolysis oil, tar

** http://www.biogreen-energy.com/industrial-pyrolysis-capacities/

* Integrated Pollution Prevention and Control, Reference Document on the Best Available Techniques for Waste Incineration, August 2006

HTPP16 en 2020 ?

Collègues au Québec sollicités
Luc Stafford (UdeM) et/ou Gervais Soucy (UdeS)
Cela constituerait une rupture ($1^{ère}$ HTPP hors Europe)