

**2nd Symposium
On
Plasma Physics and Radiation Technology**



**Nederlandse Natuurkundige Vereniging (NNV)
April 1-2, 2026 – Hotel & Conferentiecentrum Zonheuvvel**

Welcome to the 1st NNV Plasma Rolduc Symposium

About 2nd NNV Plasma Physics Symposium Zonheuvél

The 2nd “Plasma Zonheuvél” conference, short for “NNV Plasma Physics Symposium Zonheuvél”, is part of the renewed conference series that revives and unites the two former 2-day annual plasma physics meetings in The Netherlands: the series in Lunteren (NNV Section meeting) and the one in Rolduc (WELT-PP).

The Lunteren series brought together all plasma physics groups in The Netherlands, including fusion research. The Rolduc series focused on low-temperature plasma physics, while also involving nearby groups from Germany and Belgium. After the disruption caused by the Covid pandemic, the series successfully restarted in Rolduc.

With the 2nd edition, we continue this broader tradition, changing venue from Rolduc to conference center Zonheuvél, once again covering the wide spectrum of plasma physics research carried out in groups across The Netherlands, Belgium, and Germany (and beyond).

The conference is organized by the section Sectie Plasma- en Gasontladingsfysica ([NNV-PG](#)) of the Netherlands’ Physical Society ([NNV](#)).

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Scientific Program

Day 1: Wednesday April 1st, 2026

10:30 – 11:15		Registration & coffee
		Location: Conference hall A/B
11:15 – 11:20		Oscar Versolato Opening of the conference
Session chair:		Jan Trieschmann
11:20 – 12:00	M1	Dongshuai Li Blue Corona Discharges at the Top of Thunderclouds
12:00 – 12:15	O1	Yurui Li Effects of Hydrometeors on Lightning Optical Emissions
12:15 – 12:30	O2	Thije Tjebbes Hop, Skip, and Jump: Ultrafast vibrational dynamics enable double electron capture in slow Sn³⁺-H₂ collisions
12:30 – 12:45	O3	Felix Kohlmeier Full reconstruction of the energy partitioning in 2-μm-wavelength-laser-driven plasma sources of extreme ultraviolet light
12:45 – 13:00	O4	Mikheil Kharbedia Plasma-driven deformation of water droplets after laser impact
13:00 – 14:00		Lunch break / Location: public space
14:00 – 15:30		Poster session A / Location: Conference hall A/B
Session chair:		Sander Nijdam
15:30 – 16:10	M2	Jan Trieschmann Data-driven and physics-informed machine learning surrogates for low-temperature plasmas
16:10 – 16:25	O5	Stijn Helsloot Mapping species in the afterglow of oxygen plasma using Rotational Raman
16:25 – 16:40	O6	Jianan Wang Electric field measurements on filamentary DBDs by E-FISH
16:40 – 17:00		Coffee Break/ Location: Conference hall A/B
17:00 – 17:15	O7	Rik Peelen Charging behaviour of single and clustered microparticles in spatiotemporal afterglow plasmas
17:15 – 17:30	O8	Mark Cornelissen Multi-spectral coherence imaging spectroscopy to visualize the plasma flows in fusion devices
17:30 – 17:45	O9	Calum Ryan Igniting a Spark - Towards Improving Plasma Science Communication
18:30 – 20:00		Dinner - Paviljoen Restaurant
20:00 – 00:00		After dinner drinks - Paviljoen Bar

Scientific Program

Day 2: Thursday April 2nd, 2026

Session chair:		Ivo Classen
07:00 – 09:00		Breakfast
		<i>Location: Conference hall A/B</i>
09:00 – 09:40	M3	Peter de Vries The ITER project, its goals, status, plans and physics
09:40 – 09:55	O10	Lex Kuijpers Probing Soot in Dry Reforming of Methane Microwave plasmas using Optical Emission Spectroscopy
09:55 – 10:10	O11	Christine Vantomme Shining Light on Plasma Catalysis: Transparent DBD Reactors for CO₂ Conversion
10:10 – 10:45		<i>Coffee break / Location: Conference hall A/B</i>
10:45 – 11:00	O12	Martijn Ruijzendaal Plasma size as a control parameter for chemical conversion
11:00 – 11:15	O13	Rubén Marnef Heat recovery for NH₃ plasma cracking, a modeling-based approach
11:15 – 11:30	O14	Richard Engeln Unravelling EUV-Induced Plasma Chemistry
11:30 – 13:00		<i>Poster session B /Location: Conference hall A/B</i>
13:00 – 14:00		<i>Lunch break + Board meeting</i>
Session chair:		Annemie Bogaerts
14:00 – 14:40	M4	Carmen Guerra Garcia Beyond zero-dimensional chemical kinetics: Seeking agreement between numerical models and experiments
14:40 – 14:55	O15	Bowie Brewster A refined model for laser absorption in plasmas involving the Langdon effect
14:55 – 15:10	O16	Lukas Vogelhuber Electronegativity effects on plasma dynamics in He/O₂ RF microplasma jets at atmospheric pressure
15:10 – 15:25	O17	Yuting Gao Numerical Determination of Partial Discharge Inception Voltage in Gas-Filled Defects
15:25 – 15:40	O18	Duarte Gonçalves Unsteady flow dynamics in a microwave plasma reactor
15:40		<i>Closing: Poster & Oral Prize Ceremony</i>

M1: Blue Corona Discharges at the Top of Thunderclouds

Dongshuai Li

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Eindhoven University of Technology, Eindhoven

Apart from normal lightning, what happens above thunderstorm tops? Convection modifies charge and particle distributions in the cloud-top region and generates small-scale (hundreds of meters to a few kilometers), transient electrical discharges that last from hundreds of microseconds to tens of milliseconds. Most of these discharges are dominated by streamer coronas with little or no hot leader activity. They are characterized by optical emissions strongly dominated by the blue spectrum, with absent or weak red emissions. In this talk, we present an overview of recent findings related to blue corona discharges observed from space and explain how these blue flashes help us to understand lightning initiation and propagation, convection formation and thunderstorm effects in the upper troposphere

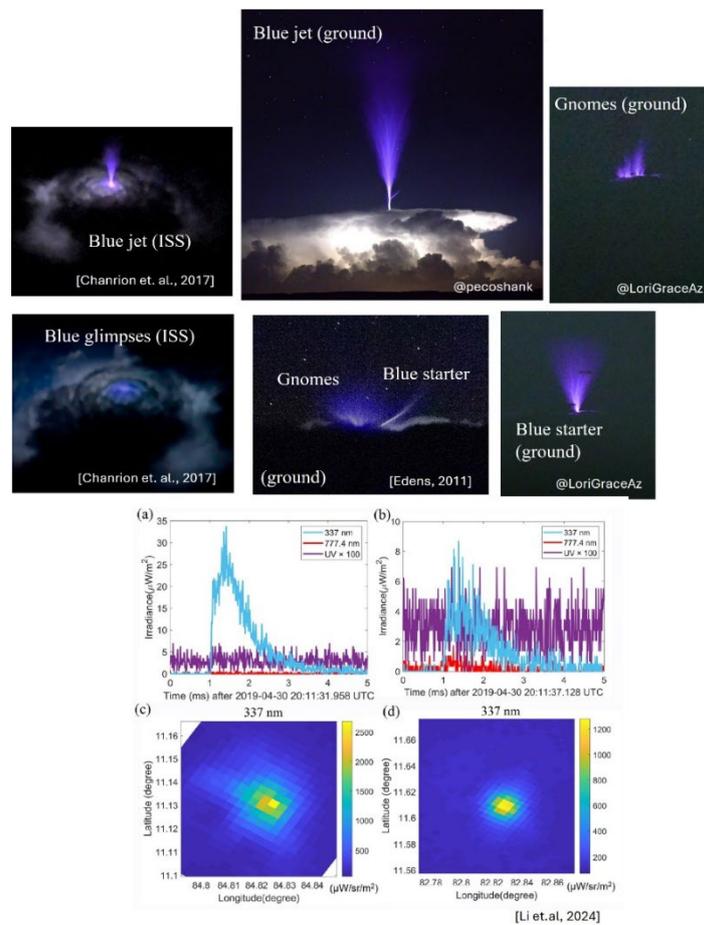


Fig. Blue corona discharges (top) and their optical signals measured from ASIM on ISS (bottom)

M2: Data-driven and physics-informed machine learning surrogates for low-temperature plasmas

I. Chaerony Siffa,^{1,2} T. Gergs,¹ R. Lamprecht,¹ S. Yarragolla,¹ D. Loffhagen,² H. Kohlstedt,¹ M.M. Becker,² and **J. Trieschmann**¹

¹*Kiel University, Kiel, Germany*

²*Leibniz Institute for Plasma Science and Technology, Greifswald, Germany*

As part of the general developments in artificial intelligence, the paradigm of scientific machine learning (SciML) has established also in plasma science and engineering in the past decade [1,2]. Data-driven ML approaches guided by physics may be delineated from (or blended with) data-free physics-informed ML, embedding partial differential equations into the loss function to be minimized. This contribution focuses on a modular modeling and simulation approach that aims to integrate ML surrogates as submodels into low-temperature plasma (LTP) simulations. Specifically, a variety of surrogate models is discussed in this presentation, ranging from bridging the time scales in plasma-surface interaction based on Monte Carlo and reactive molecular dynamics simulation data [3,4], over a transformer-based artificial neural network solution to Poisson's equation [5] as well as a physics-informed neural network (PINN) solution of the spatially resolved electron Boltzmann equation. This is complemented by a data-driven analysis of plasma processing of resistive switching devices at the wafer level. The presentation concludes with an outlook on future directions.

[1] R. Anirudh et al., IEEE Trans. Plasma Sci. 51, 1750 (2023)

[2] J. Trieschmann et al., JM3 22, 041504 (2023)

[3] T. Gergs et al., J. Vac. Sci. Technol. B 40, 012802 (2022)

[4] T. Gergs et al., J. Phys. D: Appl. Phys. 56, 194001 (2023)

[5] I. Chaerony Siffa et al. Mach. Learn.: Sci. Technol. 5, 025031 (2024)

M3: The ITER project, its goals, status, plans and physics

Peter de Vries

ITER Organization, Route de Vinon sur Verdon, 13067 St Paul Lez Durance, France.

ITER is an international collaboration involving China, the European Union, India, Japan, Korea, Russia, and the United States. These members are working jointly to design, construct, and prepare for the operation of the ITER experimental device. ITER is a tokamak designed to confine plasmas at temperatures high enough that the power produced by the fusion of deuterium-tritium in the plasma significantly exceeds the external heating power. Besides this main target, however, the project's mission is also to assess various technological aspects that are essential for the development of a power plant based on fusion energy.

The facility is currently under construction in southern France. As a first-of-a-kind experimental device, ITER faces a wide range of scientific and technical challenges. This presentation will describe the latest progress in construction. It will explain the reasons behind some recent updates to the design and introduce the revised approach for the technical and scientific exploitation of the device.

The last part of the presentation will highlight several key ITER physics topics, illustrating that, despite the project's strong focus on large-scale engineering, fundamental plasma physics continues to play a central role in shaping both its design and the operational strategy of the machine.

M4: Beyond zero-dimensional chemical kinetics: Seeking agreement between numerical models and experiments

Carmen Guerra-Garcia,

Massachusetts Institute of Technology

Repetitively Pulsed Nanosecond Discharges (NRPD) are widely used to generate non-thermal plasmas for chemical applications. Numerous studies have investigated the underlying chemical kinetics using zero-dimensional (0D) numerical simulations, often validated against experiments in nearly uniform plasma environments such as low-pressure, highly diluted mixtures, dielectric barrier discharges, or fast ionization waves. Even in these kinetics-focused configurations, modeling multiple nanosecond pulses remains challenging due to the extreme disparity in timescales between intra-pulse chemistry (sub-nanosecond) and inter-pulse or cumulative chemistry (milliseconds and longer).

In engineering-relevant systems, such as plasma reactors for CO₂ conversion or plasma-assisted combustion, the 0D approximation often breaks down, even for academic setups. Spatial non-uniformities arise from plug-flow reactor geometries or from the filamentary nature of microdischarges at near-ambient pressures in dielectric barrier discharges. The resulting increase in dimensionality significantly complicates modeling efforts, not only because of the expanded computational requirements but also due to the assumptions required to retain detailed plasma chemistry.

Model development in such contexts requires careful consideration of the model's objective: whether to explain physical mechanisms or predict engineering performance, as this determines the model outputs that must be resolved with confidence. In addition, knowledge of the available inputs, often limited to electrical diagnostics, and the measurable quantities available for validation, along with their associated uncertainties, is needed to make robust choices.

In this talk, we examine these modeling challenges through two experimental platforms developed in the Aerospace Plasma Group at MIT. The first is a mesoscale combustor for studies of plasma-assisted combustion, where quantities of interest span from detailed evaluation of the species generated by the plasma that directly influence combustion (e.g., O-atom measurements via TALIF) to engineering performance indicators such as laminar flame speed, with electrical measurements serving as primary inputs. The second example is a dielectric barrier discharge reactor driven by nanosecond pulses for CO₂ conversion to CO and O₂ at low pressure (~5 Torr), targeting Mars In-Situ Resource Utilization (ISRU). Here, variables of interest range from species identification (often measured through optical emission spectroscopy) to engineering metrics such as conversion, energy efficiency, and specific energy consumption.

Research examples presented received support from the National Science Foundation (NSF), Award Number 2339518, the US Department of Energy (DOE), Award No. DE-SC0025358, the MIT-Portugal program, Exxon Mobil, and used resources of the Low Temperature Plasma Research Facility at Sandia National Laboratories, which is a collaborative research facility supported by the U.S. Department of Energy, Office of Science, Office of Fusion Energy Sciences.

O1: Effects of Hydrometeors on Lightning Optical Emissions

Y. Li^{1,2}, D. Li^{1,3}, A. Luque⁴, Y. Zhang², O. Chanrion³, E. Bruning⁵, T. Neubert³, F. J. Gordillo-Vázquez⁴, M. Marisaldi⁶, Z. Li², W. Wang², X. Wu²

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⁵TTU

⁶UiB

Can optical observations of lightning be used to determine the distribution of hydrometeors in clouds? In this study, we use ASIM, LMA, and weather radar data with CloudScat.jl and a WRF model to answer this question.

ASIM measures from the space station the 777.4nm red band (oxygen line) of leaders and the 337nm blue band (N₂ second positive system) of streamers, using photometers sampling at 100kHz and cameras recording at 12 frames per second with ~400m spatial resolution. The LMA network detects 3D lightning channel dynamics at 80 μs and tens of meters resolution.

We model light transmission in clouds with CloudScat.jl. The hydrometeor distribution that gives the best fit to the ASIM observations and is consistent with radar and the WRF model is determined through iteration.

Our results show the potential of optical spectral observations of lightning from space for estimating cloud-top microphysics, which are important for understanding thunderstorm convection dynamics.

O2: Hop, Skip, and Jump: Ultrafast vibrational dynamics enable double electron capture in slow Sn^{3+} - H_2 collisions

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¹*University of Groningen, Groningen*

²*ARCNL, Amsterdam*

³*UAM, Madrid*

We present our joint experimental and theoretical study of low-energy collisions between Sn^{3+} and H_2 , a collision system of relevance to Sn containing plasma environments, as e.g. in divertors of fusion reactors and EUV sources powering nanolithography machines. At energies below 50 eV/u, double electron capture (DEC) cross sections are sizable ($\sim 10^{-15} \text{ cm}^2$) despite a strong ($\sim 6 \text{ eV}$) expected endothermicity for instantaneous double ionization of H_2 .

We proposed [1] that a delicate interplay between the ultrafast molecular dynamics and sequential DEC enables these reactions. Measurements of the kinetic energy release (KER) spectra of the protons emitted in the Coulomb explosion following DEC will prove the correctness of this model. Our measured KER spectra yield low-energy protons which are in good agreement with fully quantal calculations, showing that after the first electron capture the H_2^+ wavepacket evolves at comparable timescales to laser pump-probe experiments.

[1] L. Oltra *et al.*, Phys. Rev. Lett. 134 (2025)

O3: Full reconstruction of the energy partitioning in 2- μ m-wavelength-laser-driven plasma sources of extreme ultraviolet light

Felix Kohlmeier^{1,2}, Dion Engels^{1,2}, Yahia Mostafa^{1,2}, Edcel Salumbides¹, Bas Slotema^{1,2}, Ronnie Hoekstra^{1,3}, John Sheil^{1,2}, Wim Ubachs^{1,2} and Oscar Versolato^{1,2}

¹*ARCNL, Amsterdam*

²*VU, Amsterdam*

³*RUG, Groningen*

State-of-the-art nanolithography uses extreme ultraviolet (EUV) radiation at 13.5 nm emitted from tin laser-produced plasma (LPP), driven by a 10.6 μ m-wavelength CO₂-gas laser, to create the smallest features on semiconductor devices. Advances in solid-state laser technologies have led to the alternative concept of a 2 μ m-wavelength-driven LPP as a promising candidate for a more efficient and more powerful EUV source. At this drive laser wavelength a high conversion efficiency of laser energy into EUV radiation of 4% has been demonstrated, but a full picture of the plasma has not been shown to date.

In this study we characterize the partitioning of all emissions of a 2 μ m laser driven plasma to have a full picture of the energy sinks. We use our custom-built high energy 2 μ m laser system, developed at ARCNL, to heat a tin sheet into an EUV emitting plasma, and measure the emissions with an extensive setup of diagnostics. Combining EUV emissions, the radiative emission spectrum, and ion emissions we can for the first time reconstruct 100% of the incoming laser energy. With ~70%, most of the energy goes into photons, the largest part of which is emitted in the 5-80 nm wavelength range. Plasma ions contribute ~30% of the energy, and, contrary to available theory and numerical simulations, we find that this fraction decreases as a function of the laser intensity. This is a key insight in finding pathways to optimize plasma for industrial application. Our results offer insight into the energy partitioning of EUV-emitting plasmas for research and industrial nanolithography alike, and provide a benchmark for plasma light source development.

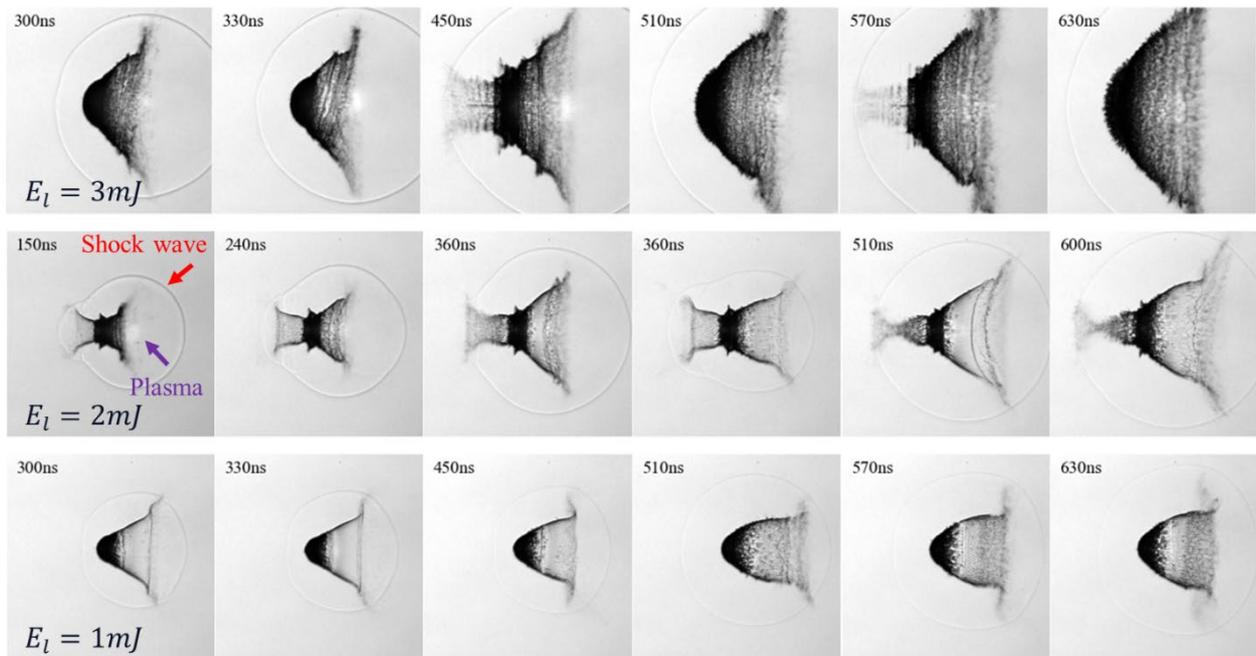
O4: Plasma-driven deformation of water droplets after laser impact

M. Kharbedia,¹ M. Brugge,¹ S. Belois,¹ S.S. Ade,¹ and O.O. Versolato^{1,2}

¹ARCNL, Science Park 106, 1098 XG Amsterdam

²LaserLab, Vrije Universiteit Amsterdam, De Boelelaan 1100, 1081 HZ Amsterdam

Nanosecond laser irradiation of micrometer-sized water droplets generates hot plasma, triggering intense cavitation and bubble expansion. The resulting shock wave strongly deforms the droplet [1]. Depending on laser intensity and focal position within the droplet, distinct deformation regimes are observed, including smooth liquid film formation, shock-driven supersonic jetting, and complete atomization of the liquid shell. Understanding plasma-droplet interactions under such extreme conditions is relevant to the development of extreme ultraviolet light sources for industrial nanolithography.



Deformation phases over time (left to right) as a function of laser energy (top to bottom): liquid film ($E_l = 1mJ$), symmetric breakup ($E_l = 2mJ$) and full atomization ($E_l = 3mJ$)

[1] A. Vogel et al., J. Acoust. Soc. Am. 100, 148-165 (1996)

O5: Mapping species in the afterglow of oxygen plasma using Rotational Raman

S, Helsloot

Mechanistic understanding of trace methane destruction with an oxygen plasma requires the detection of the activated and present species. Raman scattering is a non-invasive and accurate method to measure local temperatures and concentrations of O radicals as well as O₂ and N₂ molecules. To reliably fit the measured spectra in a wide temperature range (300-4000K), a robust fitting method was developed. Extension of this method with NO_x is foreseen.

The downstream region of an atmospheric, 20 SLM oxygen plasma was characterized with rotational Raman, both with and without injecting synthetic barn-air downstream (2400 ppm of methane in air). With the 2D species density and temperature maps, downstream cooling and mixing effects are investigated, which are important for the verification of computational models used for reactor design. Our data also sheds light on oxygen radical transport, and its relation to the gas temperature. Optimization of the O radical transport could improve the efficiency of trace methane destruction.

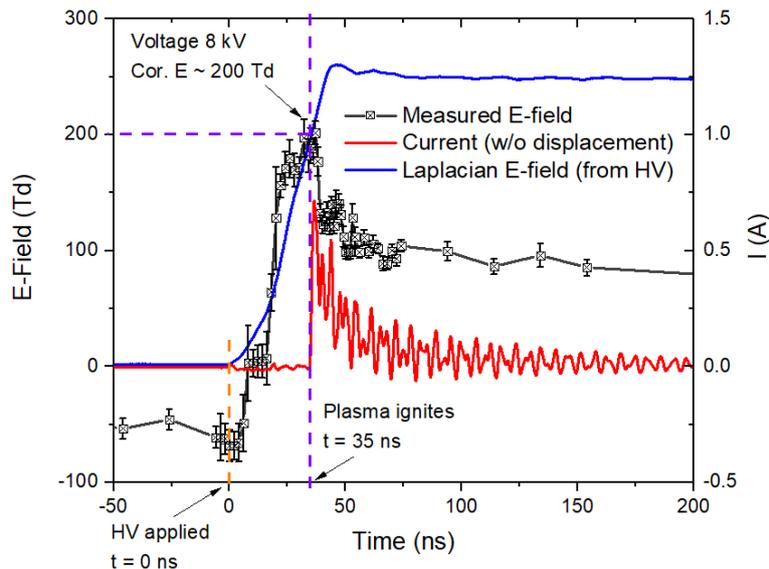
O6: Electric field measurements on filamentary DBDs by E-FISH

J. Wang,¹ H. Höft,² M. Becker,² and S. Nijdam¹

¹Eindhoven University of Technology, Eindhoven

²Leibniz Institute for Plasma Science and Technology (INP), Greifswald, Germany

We report electric-field measurements in filamentary dielectric barrier discharges (DBDs) with a 1 mm gap at atmospheric pressure [1], using electric-field-induced second harmonic generation (E-FISH) [2]. The electric field was measured to be approximately -50 Td prior to the onset of the high-voltage pulse and increased to about 200 Td at the peak of the discharge current. Notably, the measured electric field rises more rapidly than the Laplacian electric field estimated from the applied voltage, indicating strong local field enhancement during the discharge development due to space charge effects.



[1] H Höft et al. 2022 *J. Phys. D: Appl. Phys.* **55** 424003.

[2] Y Guo et al. 2025 *Physical Review Research* **7.1**:013051.

O7: Charging behaviour of single and clustered microparticles in spatiotemporal afterglow plasmas

R. Peelen,¹ P. Blom,² and J. Beckers¹

¹*Eindhoven University of Technology, Eindhoven*

²*VDL Enabling Technologies Group, Eindhoven*

As semiconductor devices become progressively smaller, the need for extremely clean fabrication conditions grows more critical. To remove unwanted particles from low-pressure, high-purity processing systems, a new method known as the “plasma seal” is proposed. This approach relies on plasma to electrically charge contaminant particles so they can be steered away using an externally applied electric field. However, since the plasma also electrostatically screens the particles from the electric field, deflection can only take place either outside the active plasma region, immediately after the plasma is switched off or during the spatiotemporal afterglow, which combines aspects of both regimes.

Recent studies have focused on understanding particle charging mechanisms in the spatiotemporal afterglow. However, the influence of particle clustering remains insufficiently explored. This contribution investigates the effect of cluster size on particle charging behaviour. Optical emission spectroscopy is applied to correlate particle charge with relevant plasma parameters. The results provide experimental validation of established theoretical models describing particle charging processes.

O8: Multi-spectral coherence imaging spectroscopy to visualize the plasma flows in fusion devices

M.J.H. Cornelissen^{1,2,3}, A. Perek², R.A.D. Ducker², I.G.J. Classen³, B.P. Duval², C.G. Theiler², R.J.E. Jaspers¹, the TCV Team^a

¹ Eindhoven University of Technology, Eindhoven, The Netherlands

² Ecole Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland

³ Dutch Institute for Fundamental Energy Research (DIFFER), Eindhoven, The Netherlands

^a See B.P. Duval et al 2024 (<https://doi.org/10.1088/1741-4326/ad8361>) for the TCV team

Plasma flows play a fundamental role in various aspects of the power exhaust in fusion devices, including the impurity transport, detachment processes, and asymmetries in the diverted heat flux [1]. However, a comprehensive understanding of the plasma flows remains a key challenge in evaluating and optimizing power exhaust strategies [2]. A multi-spectral coherence imaging spectroscopy (CIS) system has been developed to simultaneously acquire the plasma flows of several impurities, as well as an achromatic CIS system. CIS is a camera-based interferometer technique that obtains 2D integrated plasma velocity profiles from the Doppler shift of emission lines. Its spatial resolution and velocity accuracy (± 0.2 km/s) were improved and verified against high-resolution spectroscopy. Measurements on linear plasma devices and the TCV tokamak enable the characterization of the flows in the plasma exhaust, giving insights into the suitability of detachment strategies and alternative configurations for future fusion reactors.

[1] P.C. Stangeby et al., Nuclear Fusion (2020),60(10):106005

[2] Y. Wang et al., Nuclear Fusion (2024),64(5):056040

O9: Igniting a Spark - Towards Improving Plasma Science Communication

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²*École Polytechnique Fédérale de Lausanne, Lausanne, Switzerland*

³*University of Amsterdam, Amsterdam, The Netherlands*

A 2021 study on Dutch traditional media found “plasma physics” to be the lowest represented topic amongst news articles discussing physics, at only 0.4%^[1]. In contrast, “astronomy and astrophysics” (a topic overlapping with plasma physics) had over 100 times more representation with 44.4%. These numbers reflect the general public's lack of awareness of (technological) plasmas. In a small informal survey conducted by the authors (n=15) asking “Waaraan denkt u als u plasma hoort?”, only one respondent's answer was somewhat related to ionised matter, associating plasma with science fiction energy.

To improve the conversation between science and society regarding plasma technology^[2,3], the authors seek to improve communicating plasma by promoting dialogue between researchers, industry and communicators, learning from astrophysicists, and producing interactive shows and exhibitions for the public.

[1] Kristensen, S.W. *et al.* J.Sci.Com. 20(07)(2021)A02.

[2] Maryikan, D. *et al.* J.Info.Sci. (2023) 01655515231191177

[3] Gupta, N. *et al.* Public Understanding Sci. 21.7(2012):782-795.

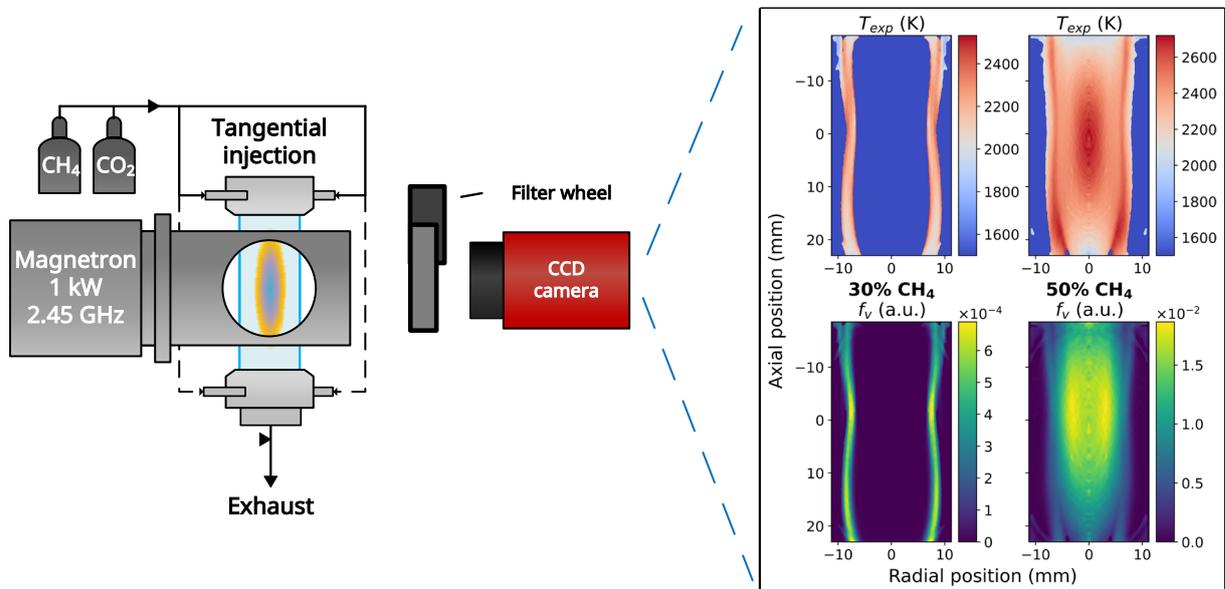
O10: Probing Soot in Dry Reforming of Methane Microwave plasmas using Optical Emission Spectroscopy

L. Kuijpers,¹ Q. Shen,¹ C.F.A.M. van Deursen,¹ W.A. Bongers,¹ and
M.C.M. van de Sanden^{1,2}

¹*DIFFER, Eindhoven*

²*Eindhoven University of Technology, Eindhoven*

Microwave plasma have shown promising results for the dry reforming of methane (DRM) to produce synthesis gas [1]. For methane rich DRM discharges the production of soot remains a challenge, as it deposits on reactor walls and downstream. In this work the temperature and volume fraction of soot are probed using an optical emission technique called Spectral Soot Emission [2].



A CCD camera with six bandpass filters (700 to 900 nm) is applied to measure the temperature (top) and volume fraction (bottom) of soot in microwave DRM plasmas operated at 150 mbar, 17 slm and 1000 W.

[1] A. Bogaerts, Nat. Chem. Eng. 2, 336-340 (2025)

[2] R. R. Snelling, 2002, *AIAA Journal* Vol. 40 No. 9 1789–1795.

O11: Shining Light on Plasma Catalysis: Transparent DBD Reactors for CO₂ Conversion

C. Vantomme,^{1,2,3} S. Verbruggen^{1,2}, A. Bogaerts³

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²*NANOLight Center of Excellence, University of Antwerp, Belgium*

³*Plasma Lab for Applications in Sustainability and Medicine – Antwerp (PLASMANT) and PLASMA Center of Excellence, University of Antwerp, Belgium*

Carbon Capture and Utilization (CCU) is a key strategy to mitigate excessive atmospheric carbon dioxide (CO₂) levels, by capturing and converting CO₂ into value-added products. Among emerging CCU technologies, plasma catalysis is particularly promising. It employs a reactive chemical cocktail -generated by plasma, driven by electrical energy - in combination with a catalyst to enhance process selectivity and exploit synergistic plasma–catalyst interactions.[1] Despite its potential, significant challenges remain, notably the development of catalyst materials optimized for plasma environments and plasma reactor designs that ensure improved plasma–catalyst contact.[2] In this study, we investigate the integration of plasma with a semiconductor catalyst (photocatalyst) and an external UV light source, to perform plasma-photocatalysis (Fig. 1). A novel, custom-made transparent dielectric barrier discharge (DBD) reactor was designed as a starting point. Multiple reactor configurations were systematically compared. Three electrode materials were investigated: stainless-steel mesh, indium-doped tin oxide (ITO)-coated quartz, and fluorine-doped tin oxide (FTO)-coated glass (Fig. 2). In addition, a double DBD (DDBD) configuration was explored by introducing a borosilicate plate into the discharge gap. All reactor configurations were benchmarked for pure plasma CO₂ splitting in terms of CO₂ conversion, plasma power, energy efficiency, UV-light transparency, and electrode lifetime. The detailed experimental setup and key results will be presented.

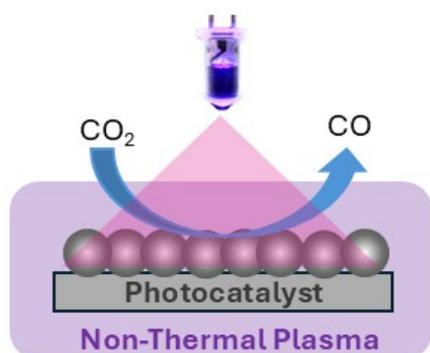


Fig 1. Concept of plasma-photocatalysis

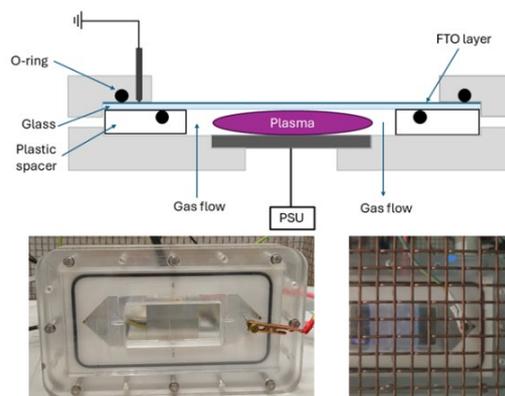


Fig 2. Schematic (up) and pictures (below) of the reactor configuration plasma off (left) plasma on (right)

[1] Snoeckx, R.; Bogaerts, A. *Chem. Soc. Reviews* **2017**, *46*, 5805–5863

[2] Van Turnhout, J.; Rouwenhorst, K.; Lefferts, L.; Bogaerts, A. *EES Catalysis* **2025**, *3*, 669-

O12: Plasma size as a control parameter for chemical conversion

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The chemical industry is seeking ways to move towards circular and carbon-neutral processes. Plasma is a promising way to drive endothermic chemical reactions due to their high power density and steep temperature gradients. However, these parameters arise from mass- and heat transport phenomena that are difficult to measure and control.

Here we show that the dilution of the plasma with a noble gas is an effective tool to tune power density and peak temperature. In the case of an H₂ plasma, serving as a source of H-radicals for CH₄ coupling, dilution with argon increased the power density by a factor of 10 and the peak gas temperature by 1000 K. This improved the reactor-integrated H-radical production by an estimated 30 times, leading to a boost from 2% to 20% conversion of the CH₄ mixed downstream of the plasma.

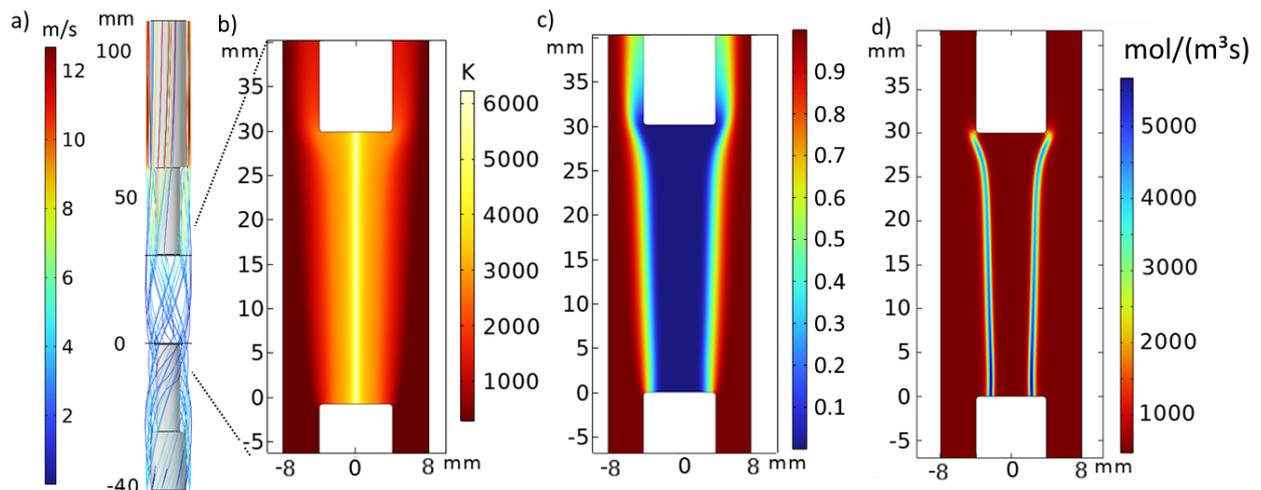
These findings highlight the importance of tuning plasma size – a parameter normally fixed by pressure, which also determines reaction rates and transport timescales. Exploring ways to independently expand or contract the plasma can increase the parameter space and provide better control over reactor performance and product distribution.

O13: Heat recovery for NH₃ plasma cracking, a modeling-based approach.

R. Quiroz Marnef, S. Maerivoet, I. Tsonev and A. Bogaerts

PLASMANT, UAntwerpen, Groenenborgerlaan 171, 2020 Antwerp, Belgium

We are developing a novel plasma reactor for NH₃ cracking. The design is guided by our previously published 2D axisymmetric fully coupled model [1]. Earlier results showed that reactor performance can be significantly improved by incorporating heat recovery into the design. Our modeling framework provides a versatile toolbox to design multiple reactor concepts in silico, allowing selection of the best candidates for experimental validation. This work presents our progress toward a new generation of NH₃ plasma cracking reactors. Preliminary results show a strong reduction in energy cost, from 200 kJ/mol (in our basic pin-to-pin arc plasma reactor) to 85 kJ/mol in an ideally insulated reactor.



Calculated gas velocity profile (a), temperature profile (b), NH₃ mass fraction (c), and rate of NH₃ destruction (d)

[1] Quiroz Marnef, R.; Maerivoet, S.; Tsonev, I.; Reniers, F.; Bogaerts, A. Chem. Eng. J. 2025, 508, 161180.

O14: Unravelling EUV-Induced Plasma Chemistry

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³*University of Trento, Trento, Italy*

Understanding the complex plasma chemistry initiated by extreme-ultraviolet (EUV) radiation is essential for optimizing the performance and lifetime of ASML's latest lithography scanners, which operate using 13.5 nm EUV light generated from tin plasmas. When EUV photons propagate through the few-Pascal hydrogen background gas inside the scanner, a low-density but highly reactive EUV-induced plasma is formed. The resulting ions, radicals, and photons strongly influence the processes occurring on critical scanner surfaces.

To unravel this plasma chemistry, a combined experimental and modelling approach is pursued. A predictive three-dimensional (3D) particle-in-cell (PIC) model is being developed to simulate plasma composition, electron properties, and species fluxes, while diagnostics are being designed to validate the model under EUV-exposed conditions. During the presentation, an overview of the diagnostics will be provided, and preliminary results will demonstrate the potential of these diagnostics for revealing the fundamental plasma mechanisms that govern EUV-induced plasma chemistry.

O15: A refined model for laser absorption in plasmas involving the Langdon effect

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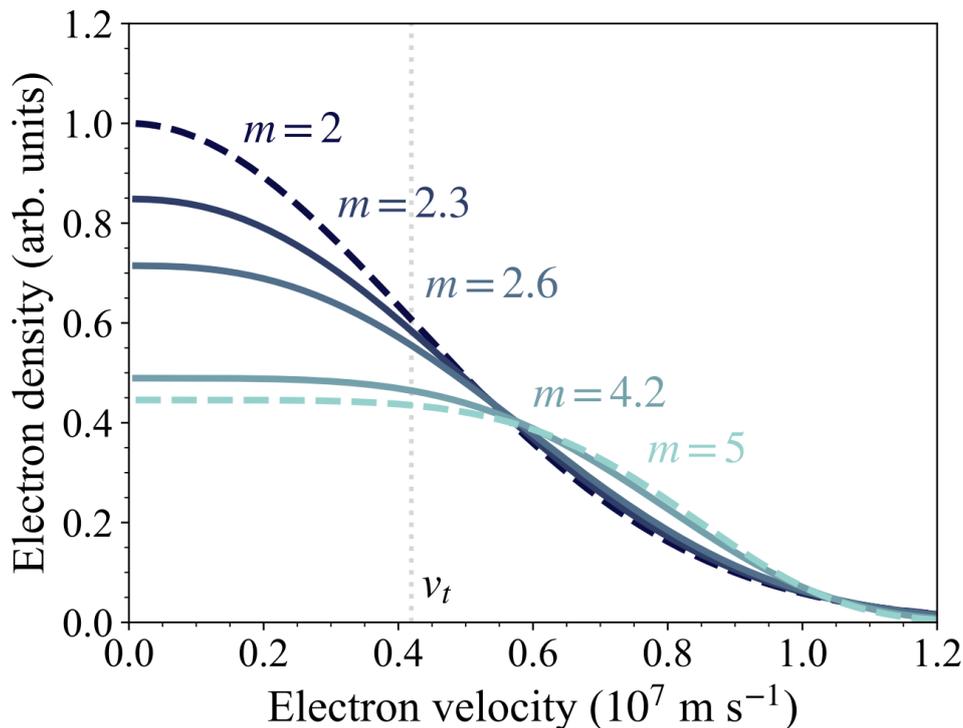
¹ARCNL, Amsterdam

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Abstract

Laser absorption via inverse bremsstrahlung is commonly modeled using a thermal Coulomb logarithm and a Maxwellian electron velocity distribution. Under strong laser heating, however, the electron velocity distribution deforms into a super-Gaussian shape, which reduces the laser absorptivity. This deformation is known as the Langdon effect (see Fig. 1).

We present an integral expression for the absorptivity that retains the full velocity dependence by consistently accounting for both super-Gaussian distributions and the velocity-dependent Coulomb logarithm. The integral can be written in a simple form: the standard thermal Coulomb logarithm plus an m -dependent correction term (with $m = 2$ corresponding to a Maxwellian and $m > 2$ to super-Gaussians). The resulting formula is straightforward to implement in radiation-hydrodynamics codes.



Scaled super-Gaussian electron distributions $f_m(v)/f_2(0)$ for selected values of m

O16: Electronegativity effects on plasma dynamics in He/O₂ RF microplasma jets at atmospheric pressure

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R.P. Brinkmann,¹ and T. Mussenbrock²

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³*Institute for Solid State Physics and Optics, Wigner Research Centre for Physics, Budapest*

This work investigates the transitions between ohmic mode and Penning-Gamma mode in a capacitively coupled radio frequency micro atmospheric pressure plasma jets operated in He/O₂ mixtures by comparing phase-resolved optical emission spectroscopy measurements of helium excitation with numerical simulations. The simulations employ a hybrid model that treats electrons kinetically via particle-in-cell/Monte Carlo collision simulation, while ions and neutrals are modeled based on fluid dynamics. These results reveal that an increasing electronegativity causes inhomogeneities in the bulk electric field, consequently modulating the electron impact excitation dynamics. A good agreement was found between experiments and simulations.

O17: Numerical Determination of Partial Discharge Inception Voltage in Gas-Filled Defects

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Electrical devices such as coils are designed for compact size, high voltage, and high operating frequency due to economic demands. These requirements can lead to an increased occurrence of partial discharges (PDs), which tend to start and propagate within local insulation defects. PDs represent a major degradation and failure mechanism in these devices. We aim to quickly identify PD inception regions through simulation to support design optimization and to better understand the factors influencing PD initiation. We present a Monte Carlo-based stochastic model for simulating discharge inception in gases. The model estimates the discharge inception probability as a function of the initial electron position. Avalanches are assumed to propagate along field lines and may generate secondary avalanches through photon and ion feedback. Compared to traditional K-factor-based criteria, the model accounts for photoionization as well as surface ion and photon emission, with adjustable surface emission rates for different materials and applicability to various gases. Compared to particle-in-cell simulations, the model offers a significant computational speed advantage.

O18: Unsteady flow dynamics in a microwave plasma reactor

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²*Delft University of Technology, Delft*

Microwave reactors are a promising tool to study hypothesis on the electrification of the chemical industry through plasma chemistry. Plasma produces reactive species which can be useful in different applications, e.g. nitrogen activation to nitrogen containing molecules is important for the production of fertilizers and fine chemicals.

In this work we analyze 3D simulations of an N₂-O₂ MW reactor performed in PeleLMeX [1,2]. In particular we focus on finding structure to the unsteady flow dynamics. We use dynamic mode decomposition [3] to analyze important oscillating modes related to vortex precession and quench gas injection, and how they relate to gas mixing. We also analyze the steady flow to find important regions in the reactor, hinting to where reactive species are produced and their transport to the outlet.

[1] Esclapez et al. (2023). JOSS, 8(90), 5450

[2] Henry de Frahan et al. (2024) SIAM PP, 13

[3] Poletti et al. (2024). JOSS, 9(102), 6753

PA1: Bottled Lightning: Experimental study of electric fields near ellipsoidal, hydrometeor-like particles

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The inception of lightning remains an inadequately understood concept. Previous research has shown that field enhancement due to elongated ellipsoidal crystals of ice, i.e. hydrometeors, combined with thunderstorm electric field variations and initial seed electrons, can lead to discharges at far lower values than the classical breakdown field [1].

We present the results from experiments on electric field measurements near such an ellipsoidal particle and its behavior during the initial moments of a discharge using Electric Field Induced Second Harmonic Generation (E-FISH) in compressed air at 150 mbar pressure using a 200 ns duration 20kV maximum pulsed-voltage supply and with varying particle aspect ratios. E-FISH measures transient fields in gases via the third-order nonlinear susceptibility, $\chi^{(3)}$, in a non-intrusive way, which results in less interference with the electric field [2].

[1] Anna Dubinova *et al* Phys. Rev. Lett., 115:015002, Jun 2015.

[2] T L Chng *et al* 2019 *Plasma Sources Scim. Technol.* **28** 045004, 10.1088/1361-6595/ab0b22.

PA2: Gaunt Factors and Collisional-Excitation Cross-Sections: Toward Accurate NLTE Modeling of High-Z Plasmas

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⁸Theoretisch-Physikalisches Institut, Friedrich-Schiller-Universität Jena, 07743 Jena, Germany

Accurate modeling of hot plasmas under non-local thermodynamic equilibrium (NLTE) conditions is essential for interpreting spectra, determine charge-state distributions, and compute material properties such as opacities and emissivities [1]. These calculations rely on reliable atomic rates, and recent studies [2] have shown that uncertainties of 30-50% in excitation cross-sections can substantially modify the predicted radiation output and electron-temperature evolution of high-Z plasmas, whereas variations in recombination and other processes tend to have a smaller impact. Such sensitivity highlights the importance of physically accurate excitation data, even though achieving it often requires computationally intensive methods. These issues are equally relevant for laser-driven Sn plasmas used as the primary extreme-ultraviolet (EUV) light sources in semiconductor manufacturing [3]. Recent work [4] on open-N-shell tin ions (Sn^{11+} - Sn^{14+}) has shown that their complex population distributions can often be described by a single “effective temperature”. A simplified two-level model captures this behavior remarkably well and reveals that the effective temperature depends directly on the Gaunt factor \bar{g} [5]. The Gaunt factor introduces quantum mechanical corrections to classical cross-sections. Accurate determination of the Gaunt factor is crucial for estimating the correct effective temperature and therefore population densities of atomic levels. Several formulations exist in the literature for calculating the Gaunt factor [6,7], with some providing analytical expressions while others offer tabulated or fitted values based on the specific transitions and energy ranges involved. In this work, the Flexible Atomic Code (FAC) [8] has been employed to compute the electron-impact excitation cross-sections. To assess the accuracy and applicability of various Gaunt factor formulations, the computed cross-sections from FAC are compared with those obtained via analytical cross-section formulas incorporating Gaunt factors. Finally, the analysis is extended to Nd, Er, and Au ions.

References

- [1] H.A. Scott and S.B. Hansen 2010 *High Energy Density Phys.* **6** 39-47.
- [2] W. A. Farmer *et al.* 2025 *Phys. Plasmas* **32** 072709.
- [3] O. O. Versolato 2019 *Plasma Sources Sci. Technol.* **28** 083001.
- [4] J. Sheil *et al.* 2021 *J. Phys. B: At. Mol. Opt. Phys.* **54** 035002.
- [5] S.B. Hansen *et al.* 2005 *J. Quant. Spectrosc. Radiat. Transfer* **99** 272-282.
- [6] R. Mewe 1972 *Astron. & Astrophys.* **20** 215-221.
- [7] S. M. Younger and W. L. Wiese 1979 *J. Quant. Spectrosc. Radiat. Transfer* **22** 161-170.
- [8] M. F. Gu 2008 *Can. J. Phys.* **86** 675.

PA3: From N atoms to NO_x: kinetic constraints on O₂ quenching of N₂ plasmas

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Reactive nitrogen produced in N₂ plasmas can, in principle, be mixed with cold O₂ to simultaneously quench the gas and form NO_x at high yield. The outcome depends on whether N atoms survive transport and whether NO formation outcompetes NO loss during quenching, but it is unclear which combinations of quench temperature, N-radical availability, and O₂ dosing enable high NO_x fractions.

We use 0D kinetic modelling to track an idealized mixing event where an N₂ stream containing a tunable fraction of N atoms mixes with O₂ at a prescribed downstream temperature. We scan three control variables mapping to distinct operating regimes: quench-region temperature, initial N content in the N₂ stream (poor to good N transfer), and O₂:N₂ flow ratio.

The system requires (i) a cool quench region (strong gains when $T_g \lesssim 1500$ K), (ii) an N-rich feed (sharp rise for $\geq 50\%$ N atoms), and (iii) O₂ in excess of N₂ ($O_2:N_2 > 1$) to reach $\geq 10\%$ NO_x.

PA4: Surface effects during plasma-activated nitrogen splitting for catalytic ammonia formation

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Plasma-assisted catalysis (PAC) enables the activation of stable molecules, e.g. N₂ or CO₂, by generating reactive species that interact with a catalyst, thereby lowering dissociation barriers and creating new reaction pathways. For ammonia synthesis, PAC is particularly attractive as it can operate under milder conditions than the conventional Haber-Bosch process, potentially improving efficiency while reducing energy input. However, plasma fundamentally alters the reaction environment, which limits the applicability of concepts from thermal catalysis. Therefore, in-situ studies of surface properties and adsorbate evolution are needed to understand the surface chemistry in plasma.

Here, we present our first in-situ XPS data of Ru surfaces during N₂ plasma exposure, as well as in mixed N₂/H₂ plasmas. To correlate surface processes and plasma properties, we further monitor gas-phase products using mass spectrometry. Results reveal distinct differences of the surface chemistry in different types of plasma. Our findings highlight the need for a combined approach to identify the role that plasma and catalytic surfaces play – and thus to understand the interactions driving plasma-assisted catalysis.

PA5: Probing the active state of Cu(111) for plasma-catalytic CO₂ hydrogenation

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Plasma catalysis combines the concept of heterogeneous catalysis with the activation of reactants by a plasma discharge. The activation of strong molecular bonds is expected to change the kinetics of challenging reactions such as the hydrogenation of CO₂ to methanol. This reaction proceeds in a mixed H₂/CO₂ plasma, which consists of a multitude of species, including radicals, atoms, and ions with energy stored in various states and degrees of freedom. The state of surfaces interacting with this complex mixture is poorly understood, even for well-defined single-crystalline model catalysts. Here, we use *in situ* X-ray photoelectron spectroscopy (XPS) and residual gas analysis to disentangle reaction pathways and the evolution of a Cu(111) model catalyst surface during exposure to radicals generated in plasma. Optical emission spectroscopy (OES) is used to characterize plasma and to assess the species hitting the surface during the exposure. XPS reveals the formation of adsorbed oxygen, followed by Cu(I) and finally Cu(II) oxides. Carbon is fully absent during the reaction with neutral activated CO₂ species. Upon reduction by plasma-activated hydrogen, hydroxides are formed. Depending on the operating conditions, we thus expect the active surface of a Cu plasma catalyst to be either Cu hydroxide or Cu metal.

PA6: Chemistry Catalog (ChemCat): An open data platform for reproducible plasma chemistry simulations

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²*Plasma Matters, Eindhoven*

Plasma chemistry studies are notoriously hard to reproduce. The main reason is the lack of open data platforms to share full plasma chemistry (mechanism) data in the low-temperature plasma (LTP) community. This work introduces ChemCat, a new data platform that extends the recent work on LXCat 3 [1,2] to encompass full plasma chemistry datasets [3].

ChemCat defines a flexible and extensible JSON schema for representing plasma chemistries, including species and process definitions, references, and a variety of LTP data types such as cross sections, rate coefficients, and transport coefficients.

Additionally, we present a suite of tools built around ChemCat, including a fast, browser-based 0D plasma modeling tool. This tool enables users to reproduce 0D plasma chemistry simulations with a single click. Conference attendees will be able to reproduce a plasma simulation study on their (mobile) devices using ChemCat and this modeling tool.

All software that is produced as part of this project will be open-sourced on GitHub under the banner of the LXCat-project organization [4].

[1] demo.lxcat.net

[2] Carbone, E. et al. (2021). *Atoms*, 9(1), 16. 10.3390/atoms9010016

[3] www.chemcat.net

[4] <https://github.com/LXCat-project>

PA7: Experimental and Numerical Characterization of the μ APPJ in Argon

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²*Wigner Research Centre for Physics, Hungary*

Non-thermal plasma conversion of CO₂ has attracted considerable attention due to its operation at atmospheric pressure and low gas temperatures. The development of such concepts requires combined experimental and numerical investigations to resolve the underlying plasma-chemical processes.

In this work, the micro atmospheric pressure plasma jet (μ APPJ) is characterized in pure argon as a preparatory step toward future CO₂ conversion studies. An energy-efficient dissociation pathway of CO₂ is vibrational ladder climbing (≈ 5.5 eV). In this context, argon offers economic advantages and favorable electron kinetics. Due to the Ramsauer minimum around 0.2 eV, the electron–neutral collision cross section exhibits a minimum, potentially increasing the population of low-energy electrons.

A combined experimental and numerical study compares phase-resolved optical emission spectroscopy (PROES) measurements with fluid simulations. The spatio-temporal excitation dynamics are analyzed to validate the model and determine stable operating conditions in pure argon. The results provide a validated reference for future CO₂ admixture studies.

PA8: Deconvolution of extreme-ultraviolet Imaging Spectrometry

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²*University of Twente, Twente*

We present a diagnostic method for resolving the spatial and spectral emission characteristics of extreme-ultraviolet light from laser-produced tin plasmas, used in nanolithography. A broadband EUV imaging spectrometer, combining a transmission grating with a dispersion-matched tapered Fresnel zone plate, is used to investigate plasma emission. In this work a tin plasma is imaged onto a back-illuminated CCD with 1.9× magnification and ~15 μm resolution.

To fully interpret the measured images, we model the system's wavelength-dependent point spread function (PSF) using Rayleigh–Sommerfeld propagation, capturing the significant contributions from non-focused light transmitted through the tapered ZP optics. Forward convolution of simulated PSFs with test objects reproduces experimental lineouts, including higher-order diffraction components. We then apply Richardson–Lucy deconvolution to recover intrinsic plasma structures, yielding FWHM values in close agreement with known source dimensions. The combined modeling and reconstruction efforts provides an approach for EUV producing plasma diagnostics relevant to nanolithography source development.

PA9: Sustainable plasma production of hydrogen cyanide and acetylene in nitrogen plasma

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This work explores a direct plasma synthesis route for hydrogen cyanide (HCN) and acetylene (C₂H₂) from a nitrogen plasma, with methane addition. Efficient plasma synthesis of HCN and C₂H₂ requires precise control of reaction selectivity by balancing competing pathways. Literature suggests nitrogen radicals preferentially promote HCN formation, whereas CH₃ radicals from methane favor C₂ products such as acetylene. Thus, product selectivity is governed by the relative availability of N and CH₃ radicals and can be steered by preferential nitrogen activation. We use a purpose-built reactor, utilizing a microwave nitrogen plasma as a high enthalpy nitrogen radical source with downstream quenching with methane. We focus on optimizing energy efficiency whilst maximizing HCN and C₂H₂ selectivity from the plasma. We present an initial assessment of reactor performance based on equilibrium thermodynamics, zero-dimensional (0D) chemical kinetic modelling, and preliminary experimental results for HCN and C₂H₂ production.

1. DOI: 10.1002/aic.18261

2. DOI: 10.1126/sciadv.adl4246

3. DOI: 10.1021/acs.iecr.0c02140

PA10: FEM-based numerical simulation of low-temperature plasmas

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The finite element method (FEM) is used to discretize the physical equations that govern the behavior of low-temperature plasmas under the local mean energy approximation. The key physical equations include the Poisson equation for electrostatics, advection-diffusion-reaction equations for the active species, and an equation for the electron energy [1]. A diagram is presented to illustrate the interplay between these components. Several challenges that arise from the strong coupling of these physical equations under typical plasma conditions are highlighted. It is shown how these challenges may be addressed in a way that is natural to FEM.

The FEM code is currently being integrated in the plasma modeling toolkit PLASIMO [2] as an alternative to the existing finite volume method. Preliminary results are shown, and plans for future extension and improvements are discussed.

[1] Mihailova, D. B. (2010). PhD thesis TU/e. doi: 10.6100/IR672762 (2010)

[2] J. van Dijk et al, J. Phys. D: Appl. Phys. 42 194012 (2009)

PA11: Pulsed DC Arcs for Thermal Plasma Synthesis

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In view of optimizing thermal plasma synthesis of H₂, C₂H₂, NO_x etc., we investigate the applicability of pulsed DC arcs. An in-house built reactor comprises a tungsten cathode-nozzle allowing fast ignition and shielding from non-compatible oxygen and methane. The anode transfer is achieved by nozzle-decoupling. Effects of geometry variations (rounded/pointed cathodes, nozzle and anode diameters) are investigated. The heat transfer to each of the electrodes is measured separately by caloric measurements of cooling water. Vortex injectors are applied in the cathode and anode sections.

The poster shows first data obtained under continuous and 200 kHz pulsed conditions. In continuous mode, low-frequency 100-1000 Hz Helmholtz oscillations appear. In pulsed mode, anode transferred arcs are obtained in pure nitrogen. Voltage and current amplitudes were 1000-1600V and 20-40A.

Erosion rates generally depend on arc current, root dynamics and heat transfer, not on voltage. Electrode life time is one of the key performance factors for industrial applied arc reactors. We investigate how high voltage/current ratio of the arcs may be used to suppress electrode erosion

PA12: Raman scattering in plasma on methane and its products

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Non-oxidative methane conversion to acetylene and ethylene faces a fundamental challenge: high temperatures activate C-H bonds, but also drive over-conversion to carbon. Microwave plasmas enable rapid activation with fast quenching (1-10 ms), kinetically trapping C₂ products before degradation. In this project, methane plasma dynamics are characterized using Raman scattering to map how plasma parameters influence product distribution. Currently Raman scattering is done on hydrogen molecules. Since pure methane plasma contains insufficient hydrogen molecules, extra hydrogen must be mixed into the feed gas, altering plasma chemistry. By switching to scattering on methane and its mayor products (acetylene and ethylene) directly, no hydrogen mixing is needed. Moreover, direct measurement of CH₄, C₂H₂, and C₂H₄ spatial distributions provides insight into where species are produced and destroyed. By exploiting the polarized nature of Raman scattering, unpolarized background emission is filtered out. This work presents initial spectra measured in the plasma.

PA13: ICP torch modeling - comparison between boundary techniques for a finite solenoid

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Radio-frequency inductively coupled plasma torches at atmospheric pressure are key tools in high-purity manufacturing like quartz glass processing for producing optical fibers. Reliable ICP modeling is essential for estimating operating conditions and plasma composition. A Finite Element Method (FEM)-based, local thermal equilibrium plasma model is therefore being developed in PLASIMO [1] using C++ library MFEM [2]. A Finite Volume Method (FVM) implementation existed previously.

With magnetic fields extending far beyond the plasma, suitable boundary methods are required to truncate the simulation domain. Various techniques are compared: FEM- and FVM- implementations of a boundary relaxation approach for determining Dirichlet values, extending the computational domain using homogeneous Dirichlet conditions or approximating exterior fields via a Kelvin transform. The finite solenoid with uniform surface current density distributed over an infinitesimally thin, finite-length cylindrical shell is employed as an analytical benchmark.

[1] J. van Dijk et al., J. Phys. D: Appl. Phys. 42 194012 (2009)

[2] R. Anderson et al., Comput. Math. Appl. 81 42–74 (2021)

PA14: Modal analysis of plasma-flow interaction structures in a swirling microwave plasma reactor

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Swirling flows are inherently characterized by vortical structures that transition to unsteady behavior as inertial force increase, leading to coherent oscillations, vortex precession and flow asymmetries [1-2]. This study investigates whether observed plasma eccentricity originates from coherent vortical modes and identifies the dominant structures governing plasma-flow interaction.

Time-resolved imaging at 5000 fps was performed for neat CH₄ and CH₄/H₂ mixtures at two axial heat-source locations. Dynamic Mode Decomposition (DMD) was applied to extract coherent spatio-temporal modes, and results were compared with Fast Fourier Transform analysis. DMD eigen value spectra revealed dominant oscillatory modes and spatial structures directly captured the eccentric plasma displacement, while modal growth rates quantifies the influence of heat-source location on stability.

Understanding these plasma-flow modes provides the foundation for quantifying soot-flowfield interactions, which will be investigated in future work using time-resolved high-speed optical emission spectroscopy.

[1] J.J. Cassidy et al., J. Fluid Mech. 41, 727-736 (1970)

[2] A.Y. Gelfgat et al., J. Fluid Mech. 311, 1-36 (1996)

PA15: Plasma chemistry model of the COST plasma jet, for a plasma-microfluidic device

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The composition and concentration of plasma-generated reactive species delivered to cancer tissue influence treatment response, yet control of this delivery and understanding of the underlying formation mechanisms remain challenging. Therefore, we propose a plasma–microfluidic approach to study the effects of tailored reactive species on cancer models, with emphasis on plasma–liquid interactions, as cancer cells and tissues are typically covered by a liquid layer. Microfluidics enables control of the cellular microenvironment through flow rates and reaction conditions [1], allowing modelling of coupled plasma–liquid interactions and reactive species transport. The microfluidic device is compatible with the COST-jet for interlaboratory comparability [2,3]. Building on this concept, we present a zero-dimensional plasma chemistry model of the COST jet to identify dominant species and key reaction pathways.

1. Whitesides GM, Nature 442:368–373. (2006)
2. Bissonnette-Dulude J et al, Plasma Sources Sci Technol 32:055003. (2023)
3. Bissonnette-Dulude J et al, Plasma Sources Sci Technol 33:015001. (2024)

PA16: Investigating X-ray Emission from Lightning Discharges in the Bottled Lightning experiment

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The emission of high-energy radiation, including X-rays, from lightning discharges has been established for several decades. This phenomenon is not limited to natural lightning; meter-scale laboratory discharges exhibit similar behavior (see e.g. [1]). In all such discharges, electrons are accelerated to relativistic energies (becoming so-called *runaway electrons*), after which they create X-rays by bremsstrahlung. Although the overall picture of runaway-electron production is well established, key aspects remain poorly understood. Current models invoke ‘thermal’ runaway, whereby low-energy electrons are driven into the runaway regime by intense local electric fields.

X-ray emission is generally thought to occur prior to the final breakdown of the spark gap, during the streamer-dominated phase of discharge evolution. Earlier theoretical and numerical studies have offered plausible explanations linking the strong electric fields associated with streamers (and leaders) to the generation of X-rays. These involve for example the collision of two streamers of opposite polarity [2] and streamers encountering a neutral plasma patch [3].

Laboratory discharges provide a unique platform for high-precision studies of lightning-like phenomena, as they allow simultaneous measurements of energy spectra and the temporal and spatial properties of the emitted radiation. We employ X-ray detectors with high energy, spatial, and temporal resolution to test the colliding-streamer hypotheses in the Bottled Lightning set-up. This recently commissioned facility is designed for laboratory investigations of the fundamental physics of lightning and consists of a large ($> 6 \text{ m}^3$) discharge vessel in which long streamer discharges of up to 1 m can be generated under varying gas compositions and pressures, with full optical access to the discharge region. A fast voltage rise is used to ensure that the relevant processes occur at the maximum applied voltage. Here, we will show preliminary measurements using the LaBr₃(Ce⁺) X-ray detectors.

[1] P. O. Kochkin, ‘Understanding lightning: experiments on meter long discharges and their x-rays’, Technische Universiteit Eindhoven, 2014. doi: 10.6100/IR783261.

[2] V. Cooray, L. Arevalo, M. Rahman, J. Dwyer, and H. Rassoul, ‘On the possible origin of X-rays in long laboratory sparks’, *J. Atmospheric Sol.-Terr. Phys.*, vol. 71, no. 17–18, pp. 1890–1898, Dec. 2009, doi: 10.1016/j.jastp.2009.07.010.

[3] K. M. A. Ihaddadene, J. R. Dwyer, N. Liu, S. Celestin, and F. Shi, ‘Modeling of a New Electron Acceleration Mechanism Ahead of Streamers’, *J. Geophys. Res. Space Phys.*, vol. 124, no. 8, pp. 7301–7319, Aug. 2019, doi: 10.1029/2018JA026084.

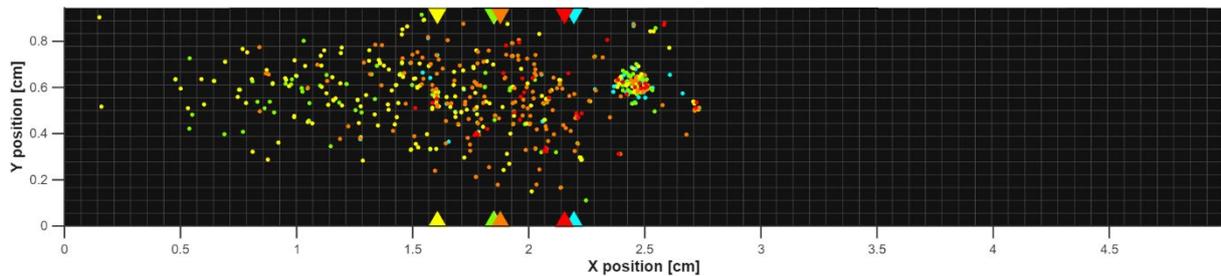
PA17: Deflection based investigation of charging of microparticles in a plasma and spatial afterglow

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In this work we present measurements of the deflection of microparticles that have fallen through a volumetric dielectric barrier discharge to gain charge. The deflection is caused by a separate set of electrodes which apply an electric field at the end of the falling trajectory of the microparticles. The microparticles are captured on a microscope plate, which allows for precise determination of their final location to find their deflection when compared to a reference measurement. These measurements have been performed for multiple electric field strengths and show positive charging for all values.



A depiction of a measurement of the final location of the microparticles. Different colors represent different cluster sizes. The triangles indicate the average value.

PA18: Measuring methane conversion using ultrabroadband optical frequency comb spectroscopy

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Methane is a major feedstock for ammonia, methanol, and ethylene. Plasma-based conversion of methane is a promising sustainable alternative to current conversion methods. However, optimizing the efficiency is still a challenge, requiring in-depth knowledge about kinetics and reaction pathways. We use optical frequency comb (OFC) absorption spectroscopy to obtain in-situ insights into the plasma processes during conversion.

OFCs based on intrapulse difference-frequency generation (IDFG) have been able to push into the mid-IR, simultaneously achieving an ultrabroad spectrum (2-11.5 μm). Making simultaneous measurements of a high number of rovibrational absorption lines from different compounds possible enabling monitoring of concentrations and rovibrational temperatures of many molecules.

Using fiber-based supercontinuum sources, we have previously investigated methane plasmas in the functional group region [1]. The capabilities of the IDFG-based OFC have been demonstrated by measurements of various compounds [2]. Here, we have applied this light source to investigate the conversion of methane in a glow discharge and show how conversion into ethane and acetylene depends on the input power.

[1] R. Krebbers et al., Appl. Phys. B, 131(1), 2025

[2] R. Krebbers et al., Opt. Express, 32(8), 2024

PA19: Optimization of methane conversion to higher hydrocarbons in a high-power microwave plasma reactor

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The electrification of the chemical industry is creating new opportunities for utilization of methane (CH_4), traditionally treated as low-value byproduct, by converting it into higher-value base chemicals, such as ethylene. Plasma-assisted processes offer a good, electrified route for methane valorization. For large-scale industrial implementation, arc reactors would likely be considered, as similar systems have been operated in the past [1]. However, a plasma reactor allows better control over temperature, residence time and power.

Maximizing the proportion of ethylene in the exhaust is a key performance target. A laboratory-scale plasma experiment is operational to study methane conversion. The experiment features a 2.45 GHz microwave with adjustable power between 1 and 10 kW. For the analysis of product formation, FTIR and GC will be employed to quantify key species. The expected outcome of this project is to provide insight into reaction mechanisms that govern ethylene formation in plasma reactors.

[1] J.R. Fincke et al., Plasma Chem. Plasma Process. 22, 105–136 (2002)

PA20: Temperature Dependence of E-FISH in Plasmas with High Temperature Gradients

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The electric field dictates the dynamics of electrons and ions within a plasma and is therefore essential for understanding plasma chemistry. [1] A non-intrusive technique for measuring the electric field in plasma is electric-field induced second harmonic (E-FISH) generation. [2] Previous studies using the E-FISH technique have largely focused on non-thermal plasmas, where temperature variations are relatively limited, while its applicability to thermal plasmas remains largely unexplored. [3]

This research aims to address this gap by investigating the performance of E-FISH in thermal plasmas, specifically by examining the temperature dependence of the E-FISH signal under strong temperature gradient conditions through both theoretical analysis and experimental validation. The theoretical analysis will focus on the temperature dependent components in the ‘calibration constant’ that relates the E-FISH signal to the electric field strength. The experimental campaign involves a temperature-controlled gas cell, as shown in figure 1, to measure the relation between the temperature and the E-FISH signal for various gases.

By clarifying whether and how the E-FISH signal varies with temperature, the study will contribute to the fundamental understanding of the E-FISH diagnostic and show its applicability to plasmas with significant temperature gradients.

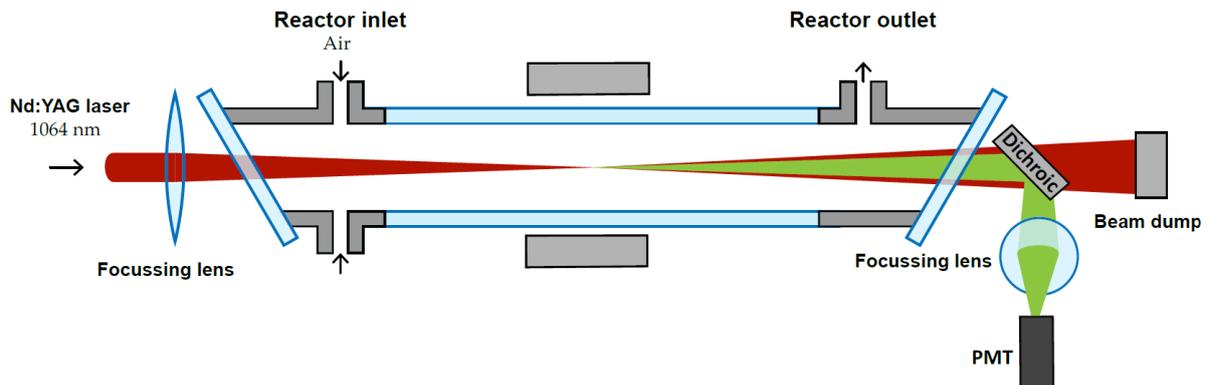


Figure 1: E-FISH setup containing a temperature-controlled gas cell and two parallel plate electrodes to apply a known electric field over the cell. PMT: photo-multiplier tube.

[1] Bogaerts A, Neyts E, Gijbels R, and van der Mullen J. Gas discharge plasmas and their applications. *Spectrochimica Acta Part B: Atomic Spectroscopy* 2002; 57:609–58. doi: [https://doi.org/10.1016/S0584-8547\(01\)00406-2](https://doi.org/10.1016/S0584-8547(01)00406-2)

[2] Goldberg BM, Hoder T, and Brandenburg R. Electric field determination in transient plasmas: in situ & non-invasive methods. *Plasma Sources Science and Technology* 2022; 31:21. doi:10.1088/1361-6595/ac6e03

[3] Limburg AAA. Optical diagnostics for electric field measurements in all states of matter: solids, liquids, gases and plasmas. Phd Thesis 1, Eindhoven University of Technology, Applied Physics and Science Education, 2025

PB1: The stopping of laser-produced Sn^{1+} ions by a hydrogen buffer gas

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We studied the stopping of energetic keV Sn^{1+} ions by a hydrogen buffer gas. For this collision system, that is of direct relevance to model EUV sources, the existing limited amount of work does not yet present a complete and consistent picture [1,2]. In an extensive experimental and modeling effort we obtained new data. A good agreement is found between stopping data extracted from flight-time shifts of Sn ions flying through H_2 at different pressures, and our semi-classical collision model incorporating DFT interaction potentials. Sn ions, photons and electrons originating from the main plasma ionize a considerable fraction of the hydrogen gas. Consequently, hydrogen ions have become of interest. For this purpose a flexible collision model is developed to compute tin ion stopping in collisions with various hydrogen (H , H_2 , H_3) ions.

[1] Abramenko et al., Appl. Phys. Lett. 112, 164102 (2018)

[2] Bartlett et al., Phys. Scr. 99, 065411 (2024)

PB2: Impact of Electromagnetic Field Coupling and Polarization in Microwave Plasmas

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A correct description of the power deposition in plasma systems is essential for accurately calculating the evolution of the gas temperature and composition, yet traditional approaches often rely on experimental emission profiles, which inaccurately predict power deposition. To overcome this, a computational framework for coupling fluid models with a microwave propagation model is developed in order to self-consistently calculate the absorbed power density profile.

The microwave propagation model solves a modified Helmholtz equation in the frequency domain. This approach eliminates the computational complexity of full Maxwell's equations system while retaining wave propagation and interaction with the electrons.

This framework is extended from a 2D slice on the core of the plasma to the axial dimension, allowing for the investigation of the coupling between electric field components and the resulting plasma-induced mode generation. The impact of these effects on the absorbed power density profile is analyzed and shown to explain plasma elongation along the polarization direction, variations that are tested by simulating different waveguide configurations.

PB3: Chemical kinetics of CH₄ plasma pyrolysis: Mechanism reproduction and assessment

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Plasma-assisted methane pyrolysis is an effective method for CO₂-free methane valorization and hydrogen production. The chemical kinetics involved is complex, making 3D computational fluid dynamics (CFD) simulations memory intensive. This highlights the need to develop a 0D chemical kinetic model for mechanism reduction. The initial step in creating a reduced model is to select an established mechanism. This study involves selecting a chemical kinetics mechanism and reproducing the results for validation. Methane mechanisms from two literature sources by Fincke et al. [1, 2] are analyzed. The reproduced models demonstrate the qualitative behavior of methane conversion kinetics. The outcome gained from this analysis will be used to conduct sensitivity studies and develop a simplified mechanism for future integration with 3D CFD modeling.

[1] J. R. Fincke et al., *Plasma Chemistry and Plasma Processing*, 22(1), 105-136 (2002)

[2] J. R. Fincke et al., *Ind. Eng. Chem. Res.*, 41(6), 1425-1435 (2002)

[3] D. G. Goodwin et al., <https://www.cantera.org>, Version 3.2.0 (2025)

PB4 Photon-induced electron-detachment from negatively charged glass and ceramic substrates

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Photon-stimulated emission of bulk electrons has been widely studied, but the detachment of excess surface electrons remains less explored, particularly for non-conducting materials. This process is governed by the surface electron affinity, which is generally lower than the work function.

Photon-induced electron detachment (PIED) experiments on glass and ceramics provide valuable insights into charging dynamics, secondary electron emission, and photoemission. Preliminary results presented here demonstrate PIED in a nitrogen atmosphere using an LED. These processes are critical for understanding plasma–wall interactions, including capacitively coupled discharges, dusty plasmas, and electrostatic probe diagnostics. Additionally, the findings have significant applications in plasma material processing, plasma propulsion, and gas breakdown [1].

[1] Y. Ussenov, M. N. Shneider, S. Yatom, and Y. Raitses, “Laser-stimulated photodetachment of electrons from the negatively charged dielectric substrates,” *Applied Physics Letters*, vol. 125, no. 25, p. 254102, Dec. 2024, doi: [10.1063/5.0237392](https://doi.org/10.1063/5.0237392).

PB5: Numerical Investigation of Streamer Branching in Air under Varying Altitude, Voltage and Polarity Conditions

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Streamer discharge propagation exhibits pronounced branching characteristics in nonuniform electric fields, a common phenomenon in lightning, long sparks, and short gap discharges [1]. The branching process is generally attributed to stochastic photoionization, which is possible influenced by environmental conditions such as altitude, ultraviolet radiation, and humidity [2]. Previous quantitative studies on streamer branching under 233 mbar in a 10 cm air gap show good consistency with the experimental results [3]. To investigate how altitude, applied voltage, and polarity affect streamer branching and development, we performed numerical simulations of both positive and negative streamers under different voltage polarities and air pressures using the Afivo library [4]. The results reveal clear trends in streamer branching number, propagation velocity, and channel radius within the same computational domain. These simulations cover partly physical conditions that are difficult to reproduce experimentally and provide valuable insights into streamer discharge behavior under diverse environmental and operational conditions.

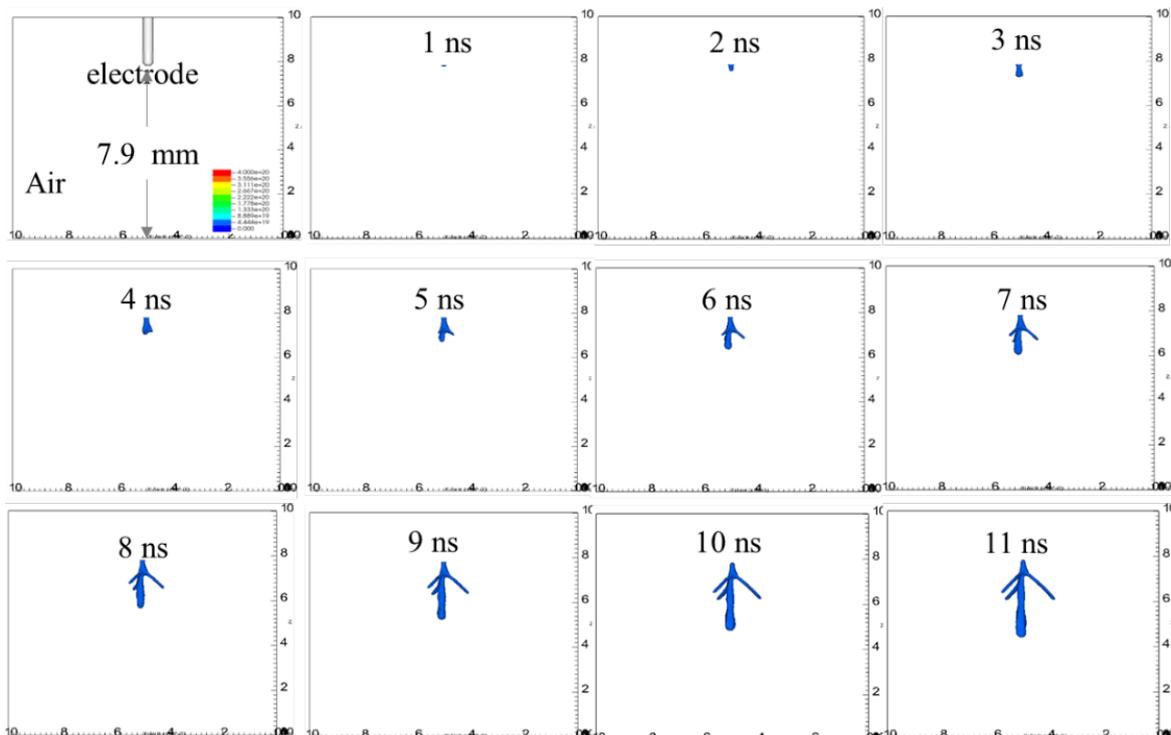


Fig.1 Streamer branching process under positive 12 kV and ground pressure

- [1] U. Ebert, S. Nijdam, C. Li, et al., *J. Geophys. Res. Space Phys.* 115, A7 (2010).
- [2] S. Nijdam, J. Teunissen, and U. Ebert, *Plasma Sources Sci. Technol.* 29, 103001 (2020).
- [3] Z. Wang, S. Dijkstra, Y. Guo, et al., *Plasma Sources Sci. Technol.* 32, 085007 (2023).
- [4] J. Teunissen and U. Ebert, *Comput. Phys. Commun.* 233, 156 (2018).

PB6: Laser absorption in the mid-IR for absolute density measurements of nitrogen containing molecules in low pressure-low temperature plasmas

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Most molecular absorption features lie within the mid-infrared region of the spectrum. As such, lasers that emit in the mid-IR can interrogate this fingerprint region to both identify present molecules and determine their concentration.

Utilizing this spectroscopic technique, we study nitrogen-containing plasmas at low-temperature, low-pressure conditions. Our investigation focuses on two systems: (i) microwave-induced nitrogen-oxygen (N₂-O₂) plasma, where the objective is to measure nitric oxide (NO) density; (ii) ECR-induced nitrogen-hydrogen (N₂-H₂) plasma, relevant due to its presence in ASML's lithography machines, with ammonia (NH₃) as the species of interest.

In case (i), we use a quantum cascade laser (QCL) centered near 1976 cm⁻¹ to scan across two R-branch transitions of NO in its ground electronic state [1], stimulated at the temperatures reached in a microwave plasma. To do so, the QCL is fixed in temperature and modulated in current with a frequency of 100 kHz, allowing fast measurements and reaching a scan depth of 1.5 cm⁻¹ with high spectral resolution.

Measurements along both longitudinal and axial directions are carried out in the reactor, allowing for the retrieval of radially resolved information and providing insight into fundamental plasma processes. Accurate determination of NO density is essential for validating model-predicted mechanisms [2] and for quantifying the local energy cost associated with NO production from N₂-O₂ mixtures.

For the N₂-H₂ plasma (case (ii)), we employ a broadband frequency comb spanning 3–11 μm, a spectral range in which ammonia exhibits strong absorption features. After interacting with the sample, the light is analyzed using a Fourier transform spectrometer in combination with a balanced detection scheme [3], allowing for high-resolution measurements with a high signal-to-noise ratio [4]. Specifically, our goal is to quantify ammonia at the plasma-surface interface and to obtain a spatially resolved concentration profile. This data is necessary to pinpoint and verify the main surface and/or volume mechanisms responsible for NH₃ formation.

[1] Gilvey J. et al., "Quantum-cascade-laser-absorption- spectroscopy diagnostic for temperature, pressure, and NO X 2 Π 1/2 at 500 kHz in shock-heated air at elevated pressures." *Appl. Opt.* 62, A12-A24 (2023)

[2] Altin M., "Plasma modelling for sustainable nitrogen fixation: transport and excitation kinetics" (PhD thesis). Maastricht University (2025)

[3] Abbas, M. A., et al. "Fourier transform spectrometer based on high-repetition-rate mid-infrared supercontinuum sources for trace gas detection." *Optics Express* 29.14 (2021): 22315-22330.

[4] Picqué, N., Hänsch, T.W. "Frequency comb spectroscopy". *Nature Photon* 13, 146–157 (2019)

PB7: Atomic oxygen generation by means of an RF discharge: effect of amplitude modulation on plasma emission, gas temperature, and cleaning performance

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Atmospheric-pressure plasma jets (APPJs) enable materials processing directly in ambient air, allowing reactive oxygen and nitrogen species (RONS) to be generated and transported efficiently to target surfaces without the need for vacuum infrastructure. This makes APPJs especially attractive for treating delicate, sensitive materials where minimal thermal and mechanical stress are essential. Building on this capability, our team has recently explored plasma-based approaches for cultural heritage conservation, focusing on the cleaning of diverse samples and historical artifacts[1].

Within the context of this study, a parametric investigation of O density is conducted by varying the duty cycle (d.c %) and amplitude of an AM modulated RF discharge. Actinometry and laser fluorescence spectroscopy are used to extract O densities near the nozzle and in the region where the treated target is located. A temperature probe measures the gas and sample/target temperature. Profilometry is employed to measure the etching depth of plasma treated polystyrene samples. Finally, the removal rate of the contaminants is measured with a quartz crystal microbalance.

[1] Shumikhin, K., Poupouzas, M., Song, Y., Duce, C., Pizzimenti, S., Manariti, A., Markevicius, T., van den Berg, K. J., Sobota, A., Nikiforov, A., Morent, R., & Bonaduce, I. (2025). Investigating the Effects of Atomic Oxygen Cold Plasma Surface Cleaning on the Oil Paint. *Advanced Materials Interfaces*, 12(22). <https://doi.org/10.1002/admi.202500220>.

PB8: Investigation on the Physics of a Supersonic EUV Induced Hydrogen Plasma Jet

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An EUV lithography device consists of two stages, EUV generation and EUV exposure, connected by a small orifice known as the intermediate focus (IF). Due to the pressure difference between these stages, a supersonic hydrogen jet emerges from the IF. High-intensity EUV radiation ionizes H₂, creating a supersonic hydrogen plasma jet. This project aims to characterize the behavior and underlying physics of such a jet. A dedicated experimental setup is currently under development. Two cylindrical chambers (30 cm × 60 cm) at high and low pressure are connected by an interchangeable orifice with a 2.5 mm radius. Hydrogen is injected on the high-pressure side, while a 3000 L/s turbopump and pendulum valve regulate the low-pressure conditions. For a 200–5 Pa pressure drop, the flow is expected to reach ~1.8 SLM at Mach 1.4. A 2.45 GHz microwave source (SAIREM Hi-Wave) generates the plasma upstream of the orifice, producing electron densities around 10¹⁷ m⁻³. Optical emission spectroscopy will be the first diagnostic employed.

PB9: Influence of streamer polarity on volatile organic compound conversion in a surface dielectric barrier discharge

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Abstract

A surface dielectric barrier discharge (SDBD) is investigated for the conversion of volatile organic compounds (VOCs) in O₂/N₂ gas mixtures at atmospheric pressure. The system is operated using a pulsed power supply providing a square voltage waveform with amplitudes up to 5 kV, a pulse duration of 5 μs, and variable repetition frequencies up to 20 kHz. The influence of positive or negative streamer discharges on VOC conversion is examined over a range of gas flow rates and pulse repetition frequencies. The results provide insight into the influence of streamer polarity under identical operating conditions on plasma assisted VOC removal, potentially caused by modifications in gas-phase chemistry and varying strengths of underlying physical mechanisms.

Acknowledgements

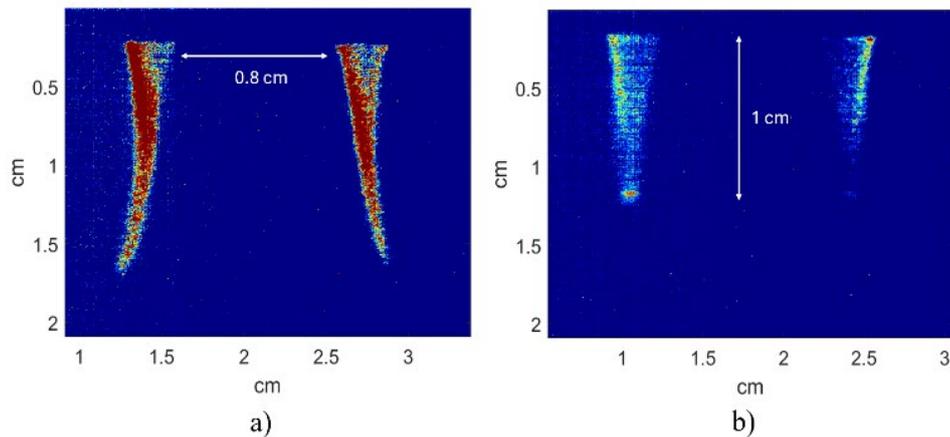
This work was supported by the DFG via Collaborative Research Center SFB 1316 (327886311), Project A7.

PB10: Electric field measurement in multi jet system using stark spectroscopy

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An often overlooked condition caused by overexposure to UV light is actinic keratosis. Utilizing cold atmospheric plasma jets, especially multi-jet systems, are currently being studied for such conditions. However, multi-jet systems face complexities such as inter-jet interactions, as shown in figure. One of the key plasma diagnostics affected by these interactions is the electric field of the plasma jet, which plays an important role in plasma dynamics and plasma chemistry. It can be measured using Stark spectroscopy, a diagnostic method with low complexity, and thus can help in understanding whether the electric field influences the transport of reactive species through membranes due to electroporation [1].



ICCD imaging of multi jet system a) without target b) with Metal (grounded) at 1 cm from nozzle

[1] X. Hu.; et al. Results in Physics. **51**, 106621(2023)

PB11: Ion energy distributions from a 2-um laser-driven plasma

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The ion emission from a 2-um laser-driven plasma is studied for different laser parameters. For this study, retarding field analyzers were used in time-of-flight mode to measure charge-energy distributions at different angles with respect to the laser axis. To get information about the amount of ions, the power-law scaling as presented by *Sheil et al.* [1] was used, providing a per-shot alternative to the method used by *Poirier et al.* [2].

[1] Sheil, J., Poirier, L., Lassise, A. C., Hemminga, D. J., Schouwenaars, S., Braaksma, N., ... & Versolato, O. O. (2024). Power-Law Scaling Relating the Average Charge State and Kinetic Energy in Expanding Laser-Driven Plasmas. *Physical review letters*, 133(12), 125101.

[2] Poirier, L., Lassise, A., Mostafa, Y., Behnke, L., Braaksma, N., Assink, L., ... & Versolato, O. O. (2022). Energy-and charge-state-resolved spectrometry of tin laser-produced plasma using a retarding field energy analyzer. *Applied Physics B: Lasers and Optics*, 128(7), 135.

PB12: Dynamics and charge transfer of a bouncing spherical particle in a high-voltage air gap

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In high-voltage applications, small particles and dust can accumulate charge from a conducting surface at high potential. In extreme conditions this leads to particle lift-off and transfer of charge to the oppositely charged electrode. What follows is either a particle-induced breakdown or a continuously repeating cycle of the particle bouncing between the electrodes. To date, the theoretical framework for this bouncing motion does not adequately cover the limit case of a particle being closely confined between the electrodes. In our research, we record the dynamics and charge transfer of 1 mm particles exposed to high electric fields within a millimeter sized air gap and we will point out where the theories break down.

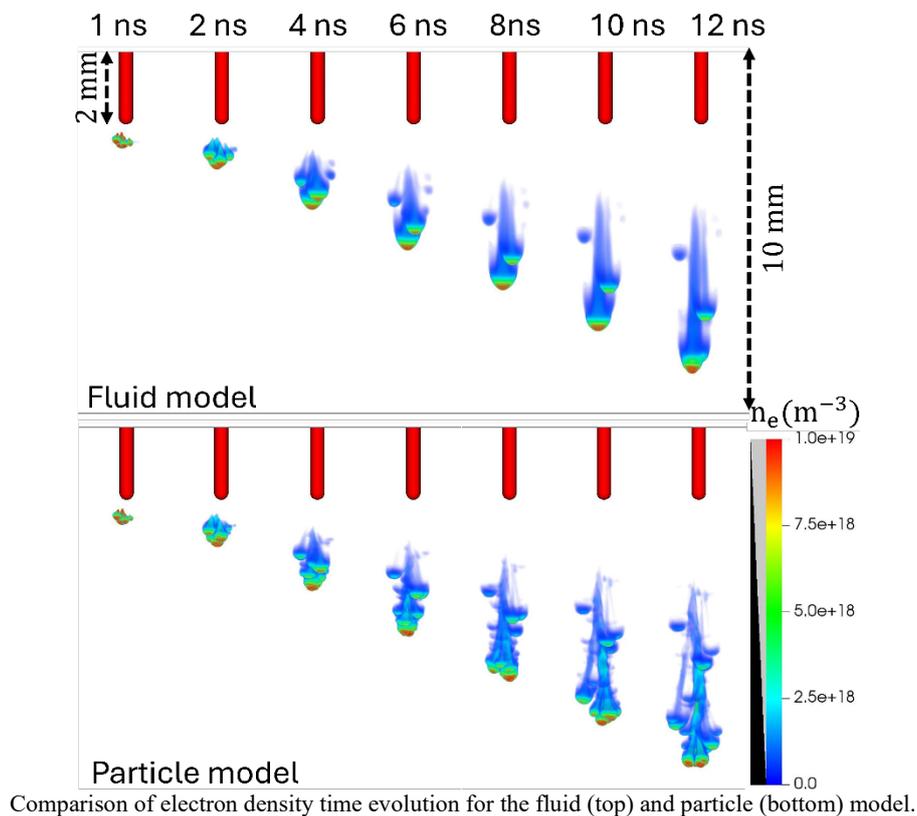
PB13: Models for negative streamers in eco-friendly insulation gas

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Our focus is on streamer discharges, which are non-stationary and transient phenomena that often precede other types of discharges. In mixtures of CO₂ and C₄F₇N, which is an eco-friendly insulation gas, the sources of free electrons are not well understood. Therefore, we focus on negative streamers.

We focused on comparing and verifying 3D fluid models with a 3D particle model for negative streamers in CO₂:C₄F₇N mixtures. The comparison showed that fluid models are capable of modelling the negative CO₂:C₄F₇N streamers. The main difference is that fluid models branch less. Verifying fluid models in these gases is the first step toward reduced large-scale models.



PB14: Bottled Lightning: Experimental investigation of laser-triggered electrodeless streamers

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Despite significant progress in understanding leader formation and stepping, the plasma-physical mechanisms governing these processes remain poorly understood. While the role of streamer discharges in negative leader stepping is established, recent observations of positive leader stepping reveal distinct behavior. The differing physical properties of streamers and leaders, together with their complex transition regions, make experimental study challenging under the scaling constraints linking lightning and laboratory discharges.

To address these challenges, we developed a large experimental setup designed for fundamental studies of laboratory-scale lightning discharges. In this contribution, we will present the first steps towards laser-triggered electrode-less streamer discharge inception to investigate streamer-to-leader transition without the effects of the metal electrodes. A focused pulsed laser generates localized ionization in the interelectrode gap, allowing double-headed streamer formation. In addition to these laser-induced discharges, comparative measurements of positive and negative streamers under identical conditions will be presented, forming the basis for future upscaling and advanced diagnostic studies toward fully electrode-less discharge inception in large geometries.

PB15: Reduced modeling of streamer discharges

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Lab discharges and lightning phenomena often contain many streamer channels, making simulations with conventional models computationally too expensive. On this poster we present recent work of our group on the development of reduced models. Two different approaches are considered:

1. A reduced model [1] in which discharge channels are described as growing conducting cylinders, and the electric field is solved self-consistently. A simple growth model for streamers is fitted against a simulation dataset in air. We show that large 3D streamer trees can be simulated.
2. A 1D ODE model [2] for streamers, under the assumption that their velocity is approximately constant. We demonstrate that the model can be used for both positive and negative polarities in different gases.

We provide a brief outlook on how these approaches could be used to better understand lightning leaders and the streamer-to-leader transition.

[1] J. Teunissen and A. Malagón-Romero, *Computer Physics Communications* <https://doi.org/10.1016/j.cpc.2025.109733> (2025)

[2] D. Bouwman, J. Teunissen, U. Ebert, *Plasma Sources Sci. Technol.* <https://doi.org/10.1088/1361-6595/adaf53> (2025)

PB16: EUV induced hydrogen plasmas: energy and mass reconstruction using an advanced RFA-design in combination with ToF techniques

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Extreme ultraviolet (EUV) induced hydrogen plasmas are of particular interest because of their presence in EUV nanolithography machines. Experimental data on energy and composition of the plasma is required to model the interaction with materials in the machine. Accurate measurements of the plasma composition (H^+ , H_2^+ and H_3^+) are difficult to perform due to plasma electrons, secondary electrons and high energy photons interacting with the ion detector. In this work, an advanced retarding field analyser (RFA) to perform dual energy and time of flight (ToF) measurements is proposed to measure the plasma composition. By measuring ToF spectra at various RFA settings, we demonstrate that energy and mass separation can be achieved. The validity of this approach is supported by ToF simulations reconstructing the initial plasma composition. Additionally, for the case without a plasma start for ToF, a hybrid detector is presented which utilises a magnetic field for mass separation.

PB17: Simulation of methane microwave plasma pulsed experiments with 0D chemical kinetics

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Pulsed microwave plasma experiments were conducted in a methane and hydrogen mixture at low pressure (20 mbar). Measurements of the temperature at the core were made with time-resolved in-situ H₂ Raman spectroscopy. Gas chromatography was used to measure the gas composition at the outlet of the reactor, obtaining yields and selectivity. A zero-dimensional reactor model with thermal kinetics was employed to reproduce selected experimental conditions, using measured power deposition profiles. Simulated and experimentally obtained temperature profiles are a reasonable match, which reinforces the initial assumption that the role of electrons in these conditions is negligible. Furthermore, constant pressure simulations overpredict experimental temperature evolutions, which suggests that pressure increases in the plasma core during the plasma pulse. If true, this would indicate the presence of acoustic waves in the pulsed plasma. Experimental and simulated selectivities are also compared and analyzed although a direct comparison cannot be made between selectivities in the plasma core and at the outlet.

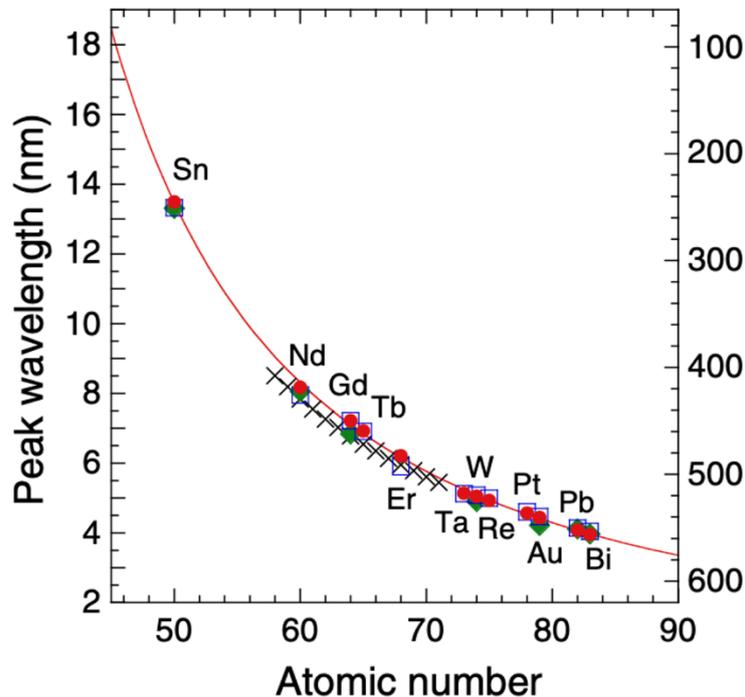
PB18: Cross-section measurements of low energy Au³⁺ collisions with H₂

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For EUV sources operating at photon wavelengths below 13.5nm, heavy atoms with open 4d or 4f shells are considered as atomic sources. Possible candidates are shown in the figure. Moving towards high-Z ions is required to generate photons of shorter wavelengths. This implies higher charge states of the emitting ions, and an increase in potential energy, as compared to the Sn ion plasma used for 13.5-nm EUV sources. We focus on the interaction of heavy ions with molecules, in a regime where potential energy dominates over kinetic energy. Here we present first results on low energy Au³⁺ - H₂ collisions.



Peak emission wavelengths of $4d^{10}4f^n-4d^94f^{n+1}$ and $4p^64d^n-4p^54d^{n+1}+4d^{n-1}4f$ transition arrays for high Z elements. Ohashi et al 2014 Appl. Phys. Lett. 104 234107

PB19: The Hop-Skip-Jump mechanism: investigating femtosecond dynamics in ion collisions with H₂

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We show first center-of-mass measurements of proton kinetic energy release (KER) spectra of double electron capture (DEC) by slow, (<100 eV/u) multiply charged Sn ions colliding on H₂. The measured KER spectra deviate strongly from typical Franck-Condon values, proving that DEC in these collisions happens rather through a delicate interplay between the ultrafast vibrational dynamics and the slow-moving ion. This does not only affect the KER, but even drives DEC by Sn³⁺ at low energies, a reaction that would otherwise be endoergic by ~6 eV [1].

We support the measurements by quantum wavepacket propagation calculations, which are in good agreement with the measured values.

[1] L. Oltra *et al.*, Phys. Rev. Lett. 134 (2025)

PB20: Influence of hydrogen addition on carbon growth & morphology in microwave plasma driven pyrolysis of methane

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Plasma pyrolysis of methane offers a promising route for producing valuable hydrocarbons such as acetylene and ethylene, with solid carbon typically formed as a byproduct. Hydrogen is widely recognized as a key species in microwave plasma methane pyrolysis, however, its precise role in the underlying reaction mechanisms remains unclear. In this study, we examine the effect of hydrogen addition on temperature, methane conversion, product composition, hydrogen balance, and carbon morphology. By varying hydrogen content to the main flow, the H/C ratio was tuned to evaluate the influence of flow rate, pressure, and input power. H₂ rotational temperature was measured by Raman spectroscopy, while carbon deposits collected from two reactor locations were analyzed by SEM and Raman, and quantified using GC and profilometry. Results show that hydrogen enhances methane conversion, suppresses solid carbon formation, and promotes structural ordering of deposited carbon, providing insight into controlling carbon formation and improving selectivity toward gaseous hydrocarbons.