

Journées du GDR EMILI, Saint-Etienne, 27-30 octobre 2025

Plasmas produits par filamentation laser dans l'air : dernières avancées et nouveaux challenges

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Plan de la présentation

- 1. Filamentation laser dans l'air**

- 2. Le filament comme source de rayonnements**
Contrôle spatiotemporel des filaments

- 3. Filaments de plasma pour le contrôle de la foudre**



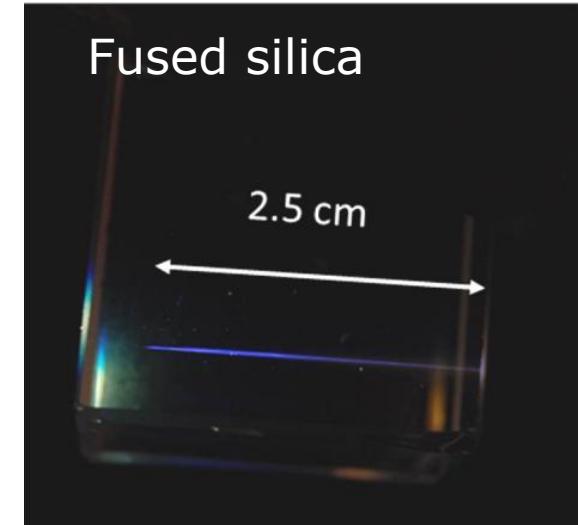
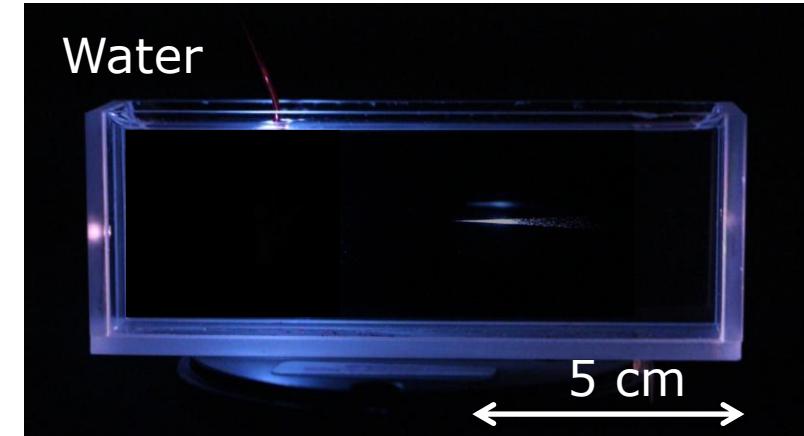
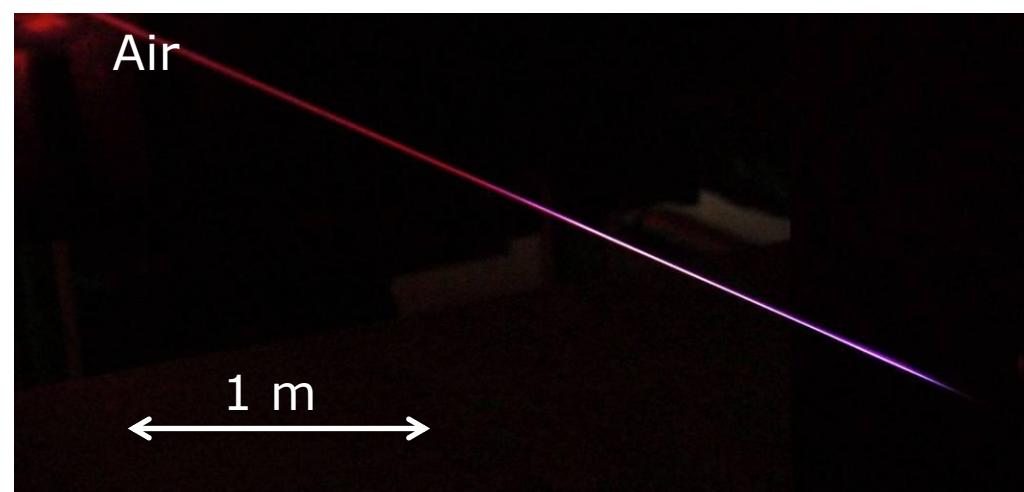
Filamentation laser femtoseconde



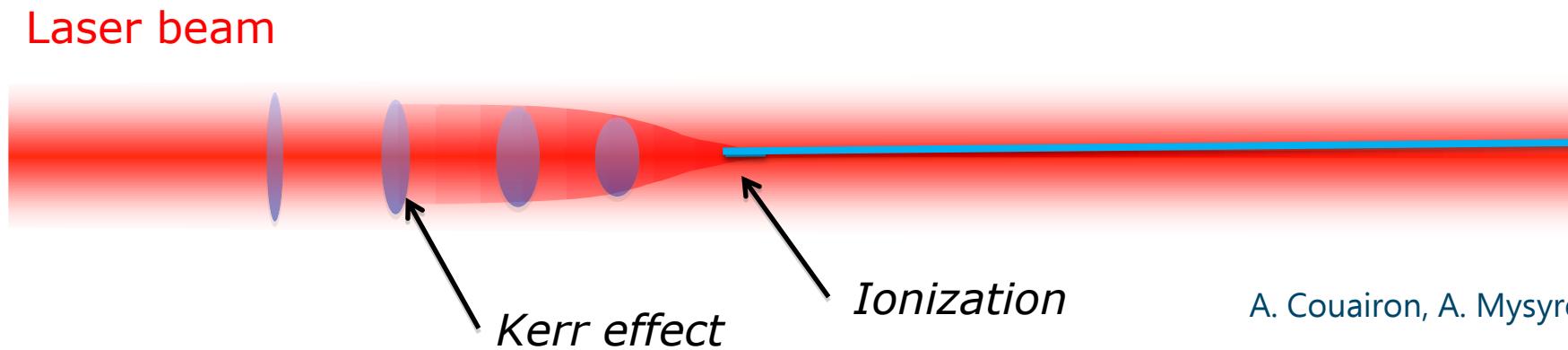
A. Braun, G. Korn, X. Liu, D. Du, J. Squier, and G. Mourou, "Self-channeling of high-peak-power femtosecond laser pulses in air," Opt. Lett. **20**, 73-75 (1995)

CUOS 1995

Un phénomène universel dans les milieux transparents



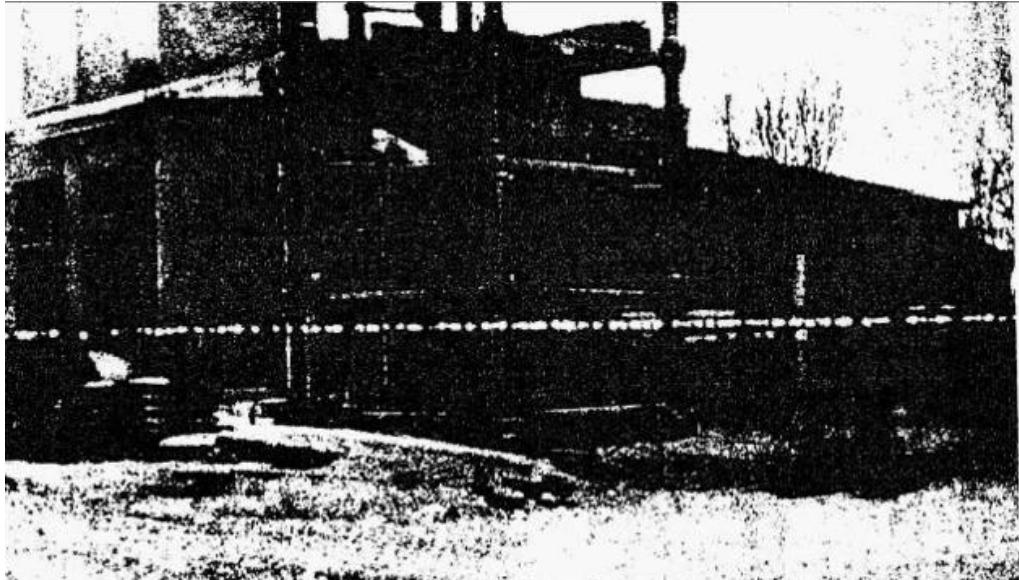
Filament fs : canal de lumière intense ($I > 10^{13} \text{ W/cm}^2$) formé par autofocalisation Kerr



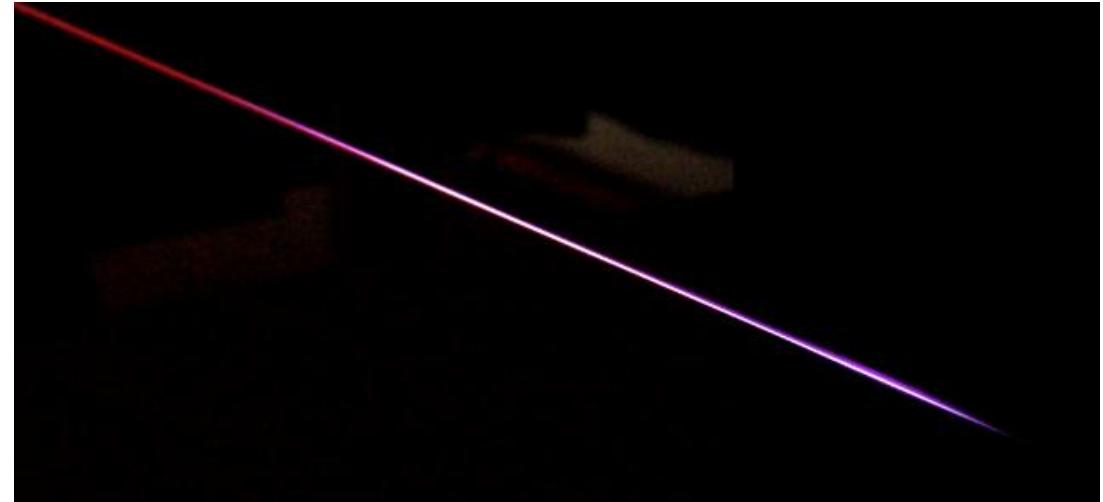
A. Couairon, A. Mysyrowicz, Phys. Rep. **441**, 47 (2007)

Colonnes de plasma générées dans l'air par laser

Des lasers à impulsions longues à la filamentation laser



160 J, 30 ns CO₂ laser (Parfenov et al. 1976)



10 mJ, 50 fs TiSa laser (LOA)



ns
10-100 J/m
Impact ionization



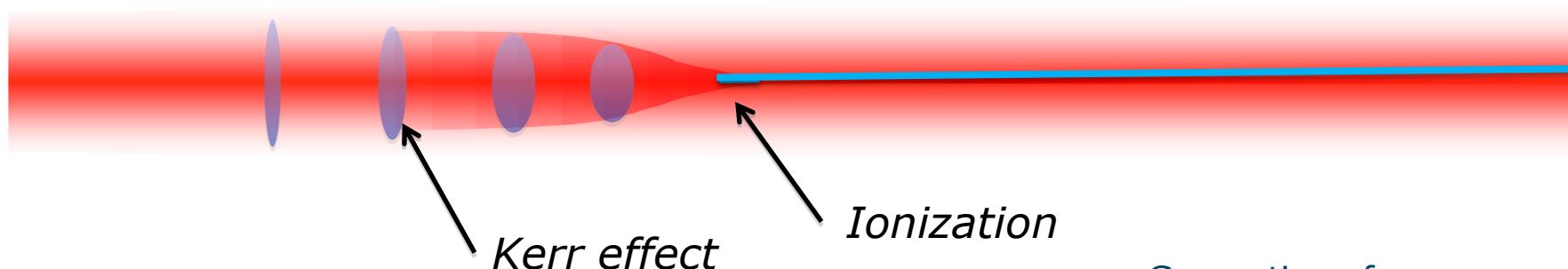
fs
10-100 mJ/m
Multiphoton ionization

→ Les laser femtoseconde permettent de former des canaux de plasma beaucoup plus longs avec moins d'énergie laser

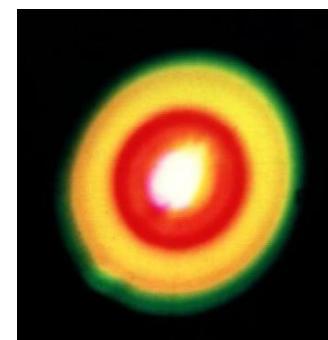
Le filament en 3 étapes

1. **Light channel (fs):** intense light channel formed by Kerr self focusing ($I > 10^{13} \text{ W/cm}^2$)

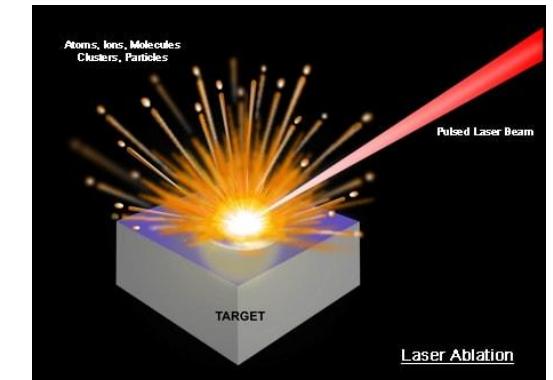
Colimated beam



Generation of
continuum and
conical emission



Laser induced breakdown
spectroscopy (LIBS)



Le filament en 3 étapes

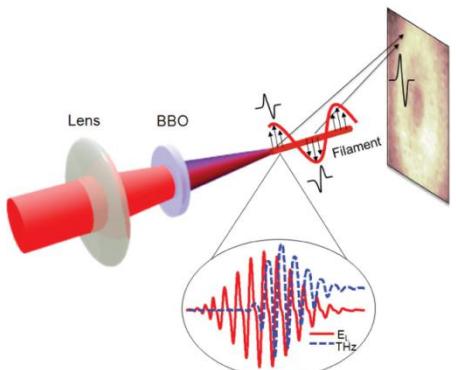
1. Light channel (fs)

2. Plasma channel (ps-ns)

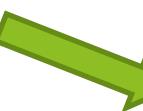
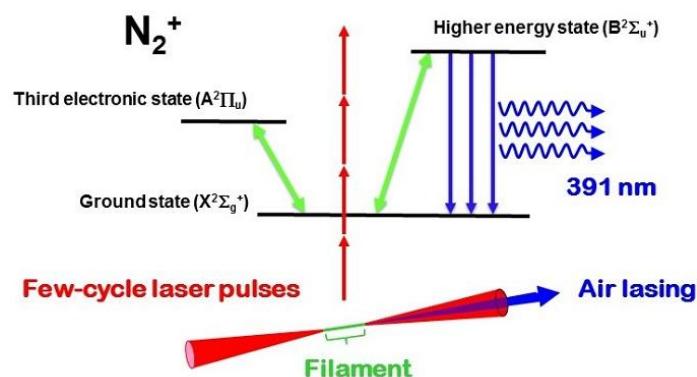
- formed in the wake of the pulse
- Short lifetime -> short length



THz generation



Air lasing



FLEET

Electron density = 10^{15} - 10^{16} e⁻/cm³, T_e = 1 eV
 Diameter = 100 μm-1 mm



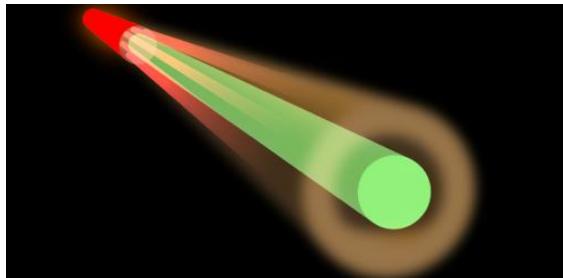
Le filament en 3 étapes

1. *Light channel (fs)*
2. *Plasma channel (nanosecond)*
3. **Hot gas channel (μs -ms)**
 - Ionization energy is converted into thermal energy

Cloud clearing



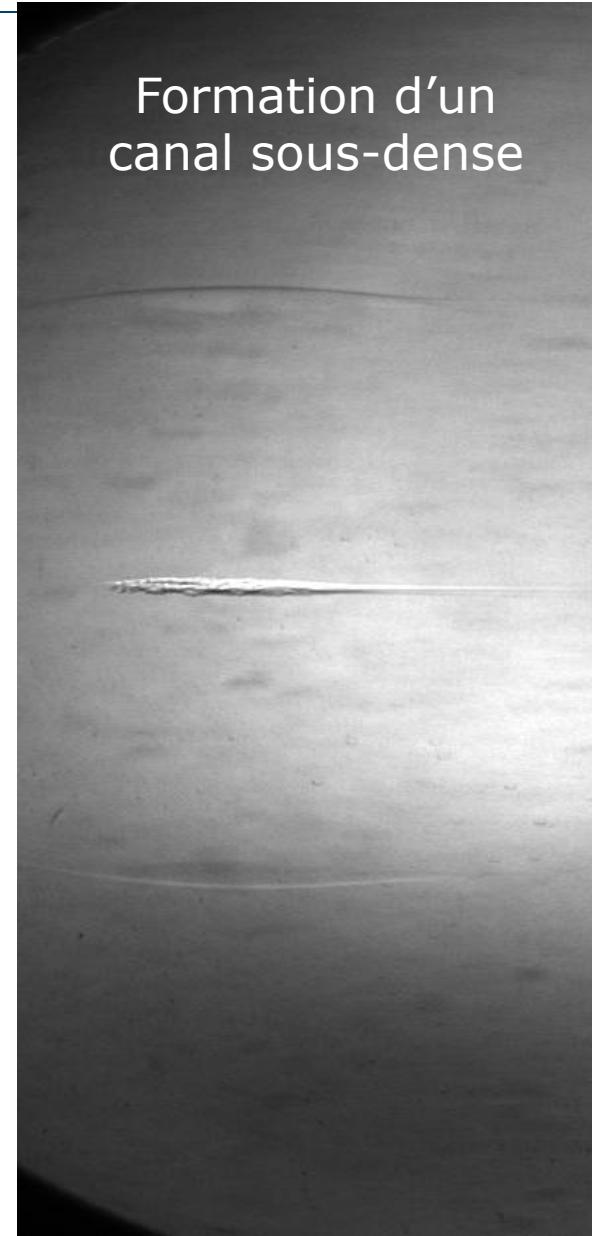
Optical air waveguide



Guiding of discharges

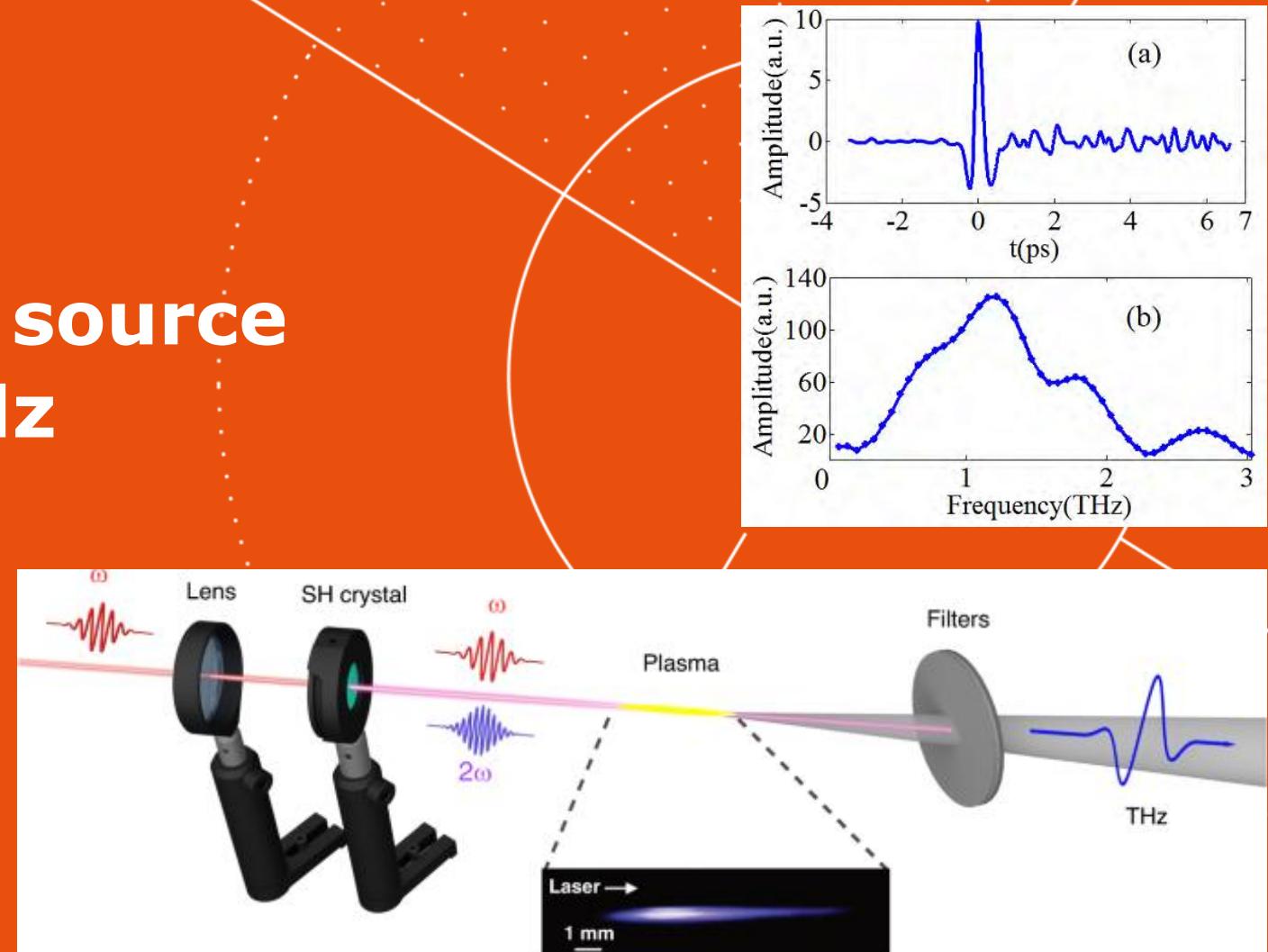


Formation d'un canal sous-dense

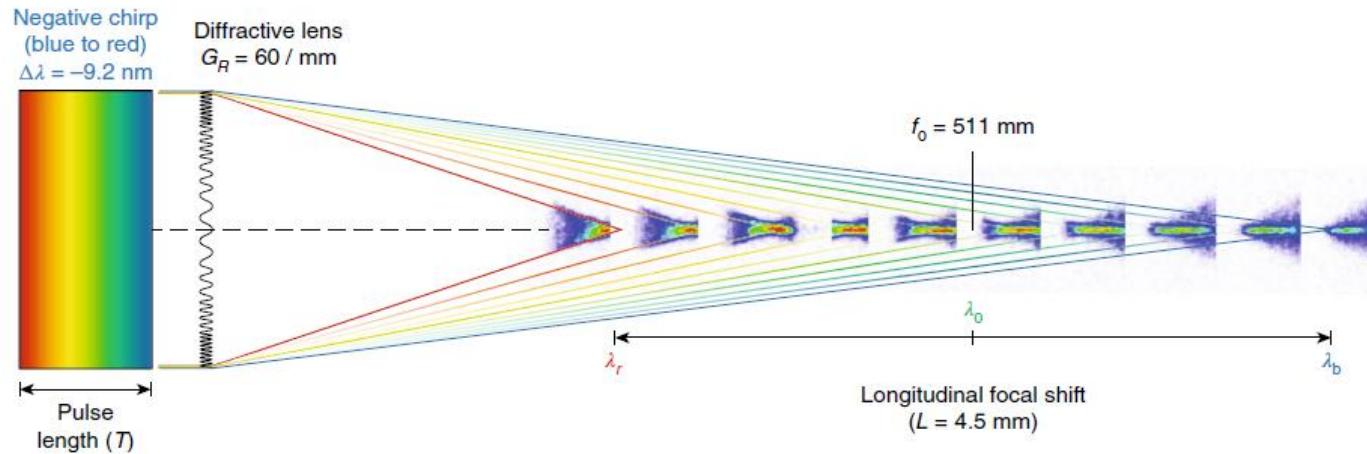


Le filament comme source de rayonnement THz

Emission conique vers l'avant liée à la forme de la source plasma

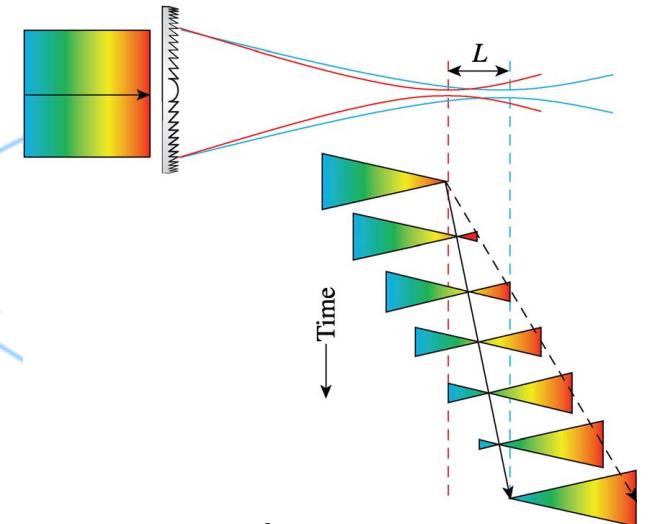


Technique du flying focus

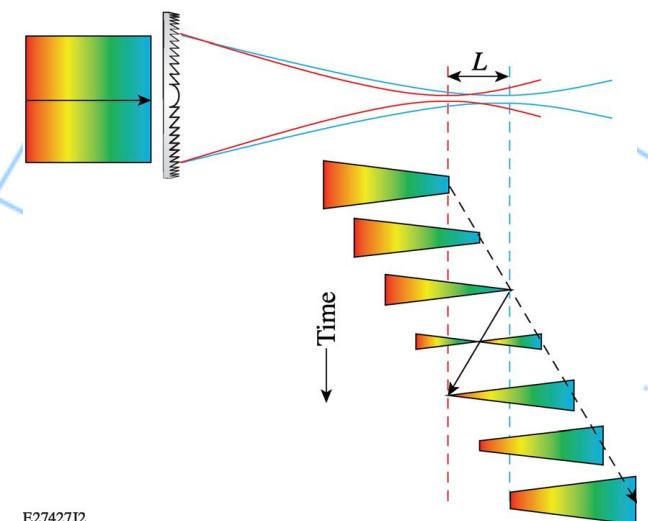


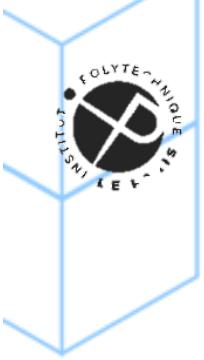
- ❖ The **different wavelengths** are focused at **different positions** by the diffractive lens.
- ❖ By changing **the chirp of the pulse** one can control the sign of the velocity of the ionization front

Positive chirp →

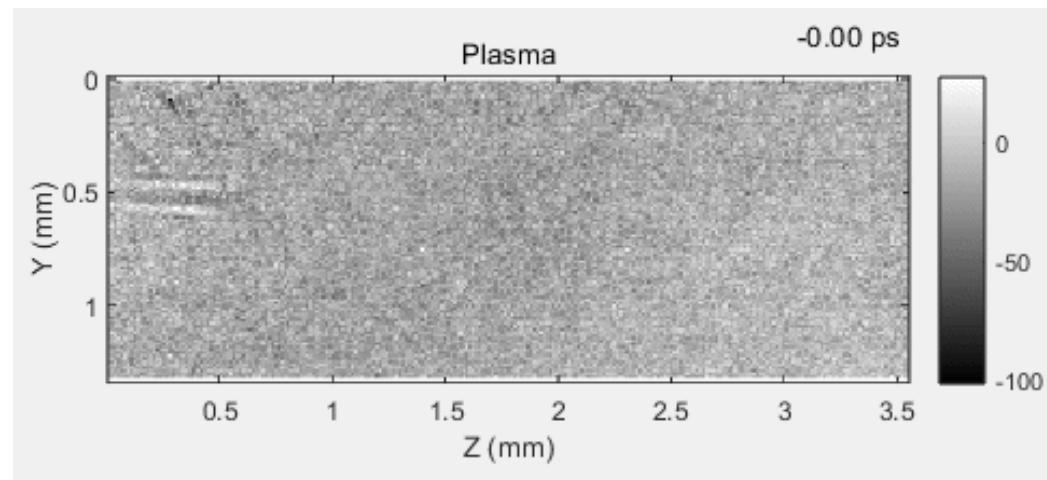


negative chirp ←

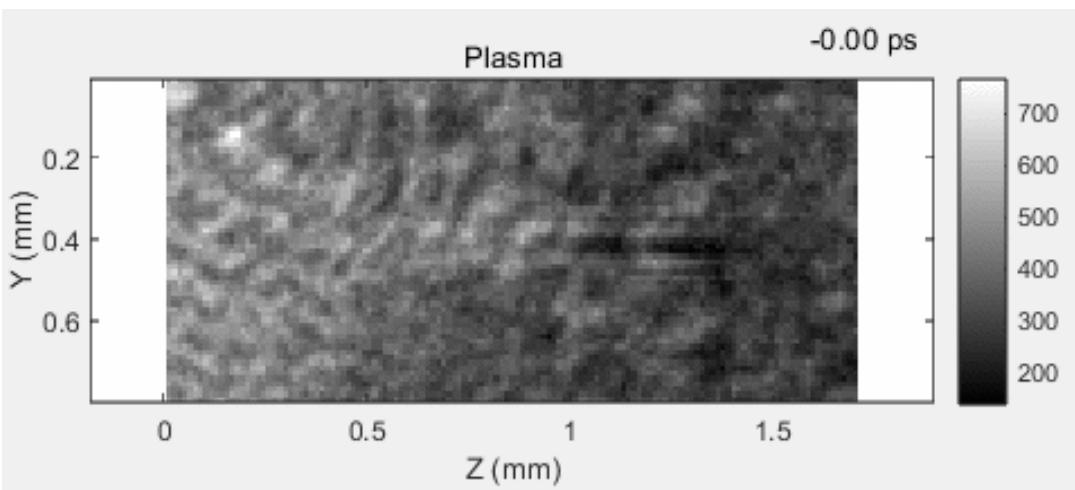




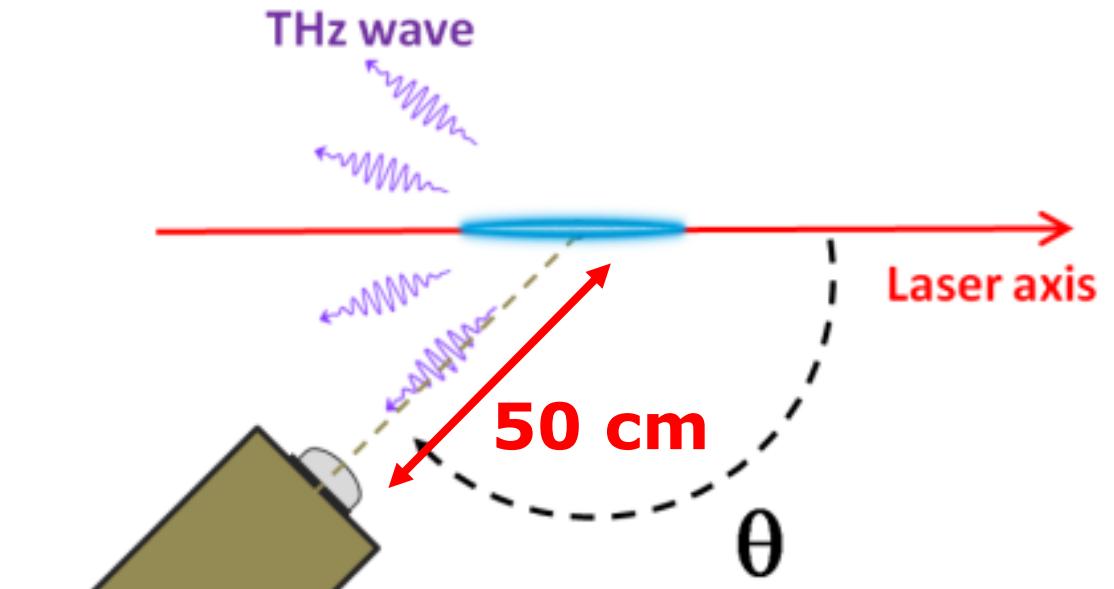
Vitesse du front d'ionisation



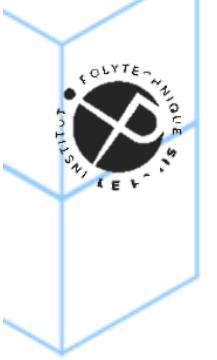
Laser direction



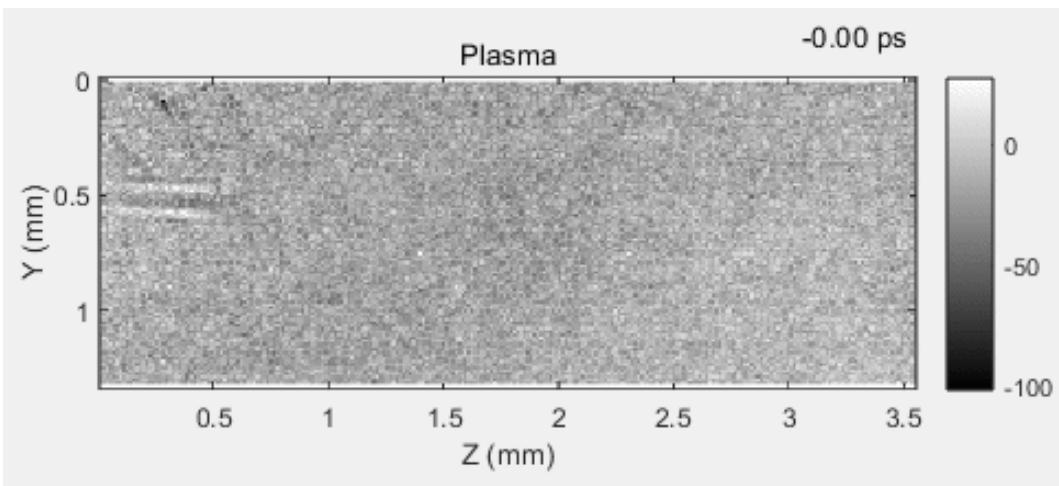
Set-up for THz measurement



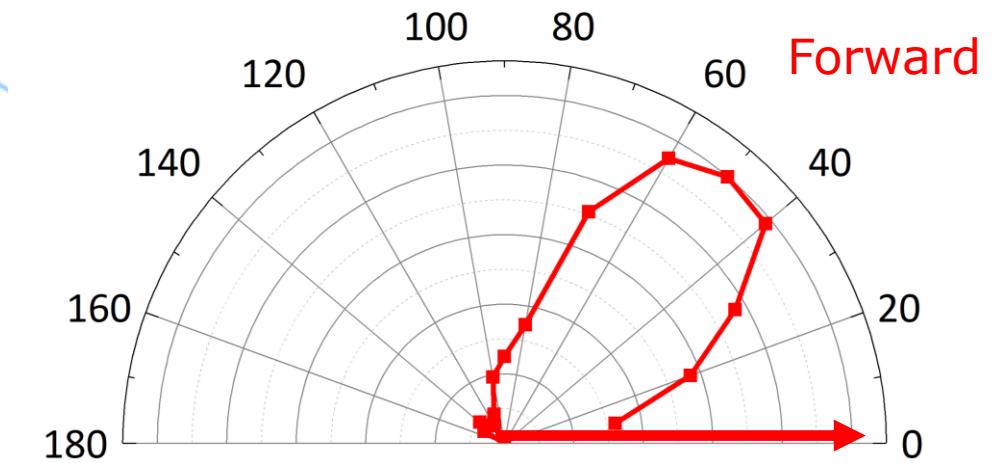
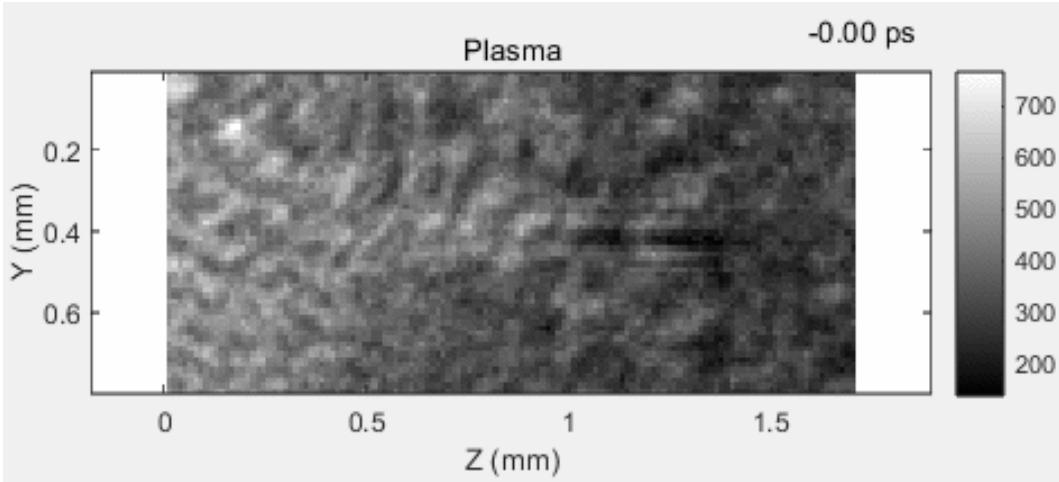
THz detector
at 0.1 THz



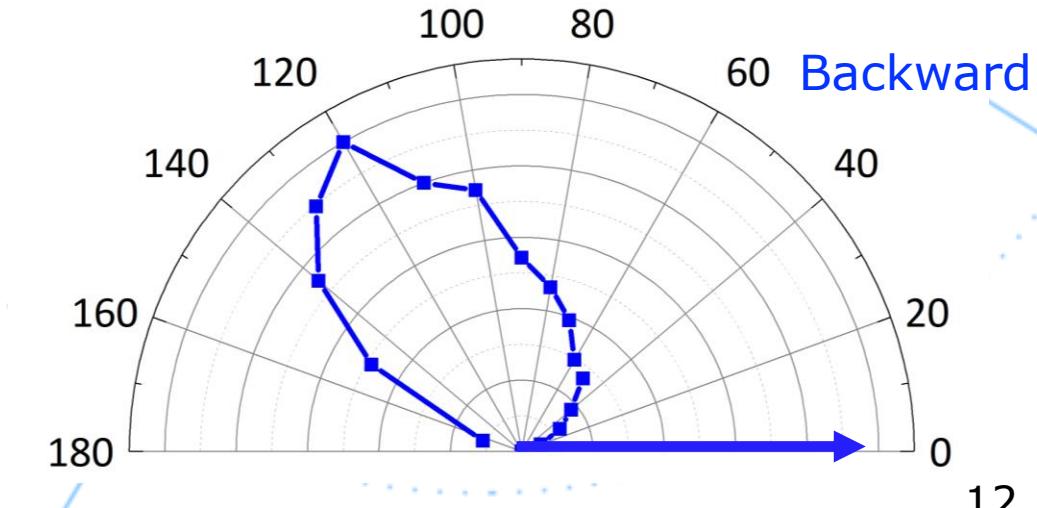
THz angular emission



Laser direction

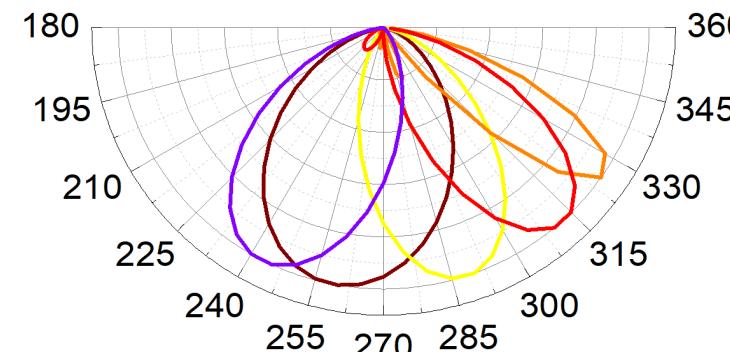
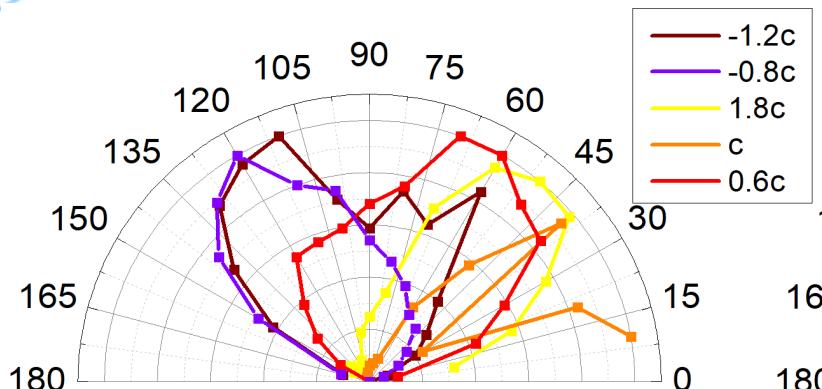


0 is the laser direction.



Conclusion et perspectives

Mesure



Théorie

- Le flying focus permet de contrôler la direction d'émission du rayonnement THz d'un filament
- Avec une vitesse super lumineuse on retrouve des propriétés similaires à un **rayonnement Cherenkov**

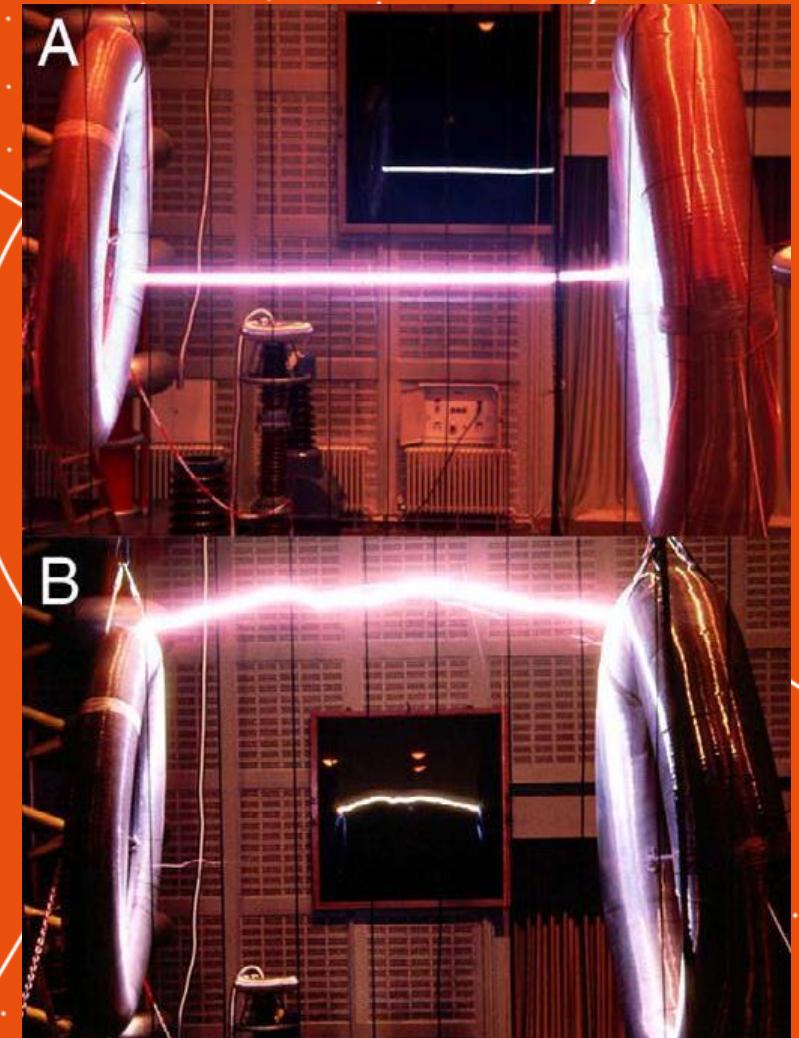
Perspectives

- Augmenter le rayonnement THz avec une impulsion à 2 couleurs (800 + 400 nm)
- Utiliser le flying focus pour contrôler le lasing UV

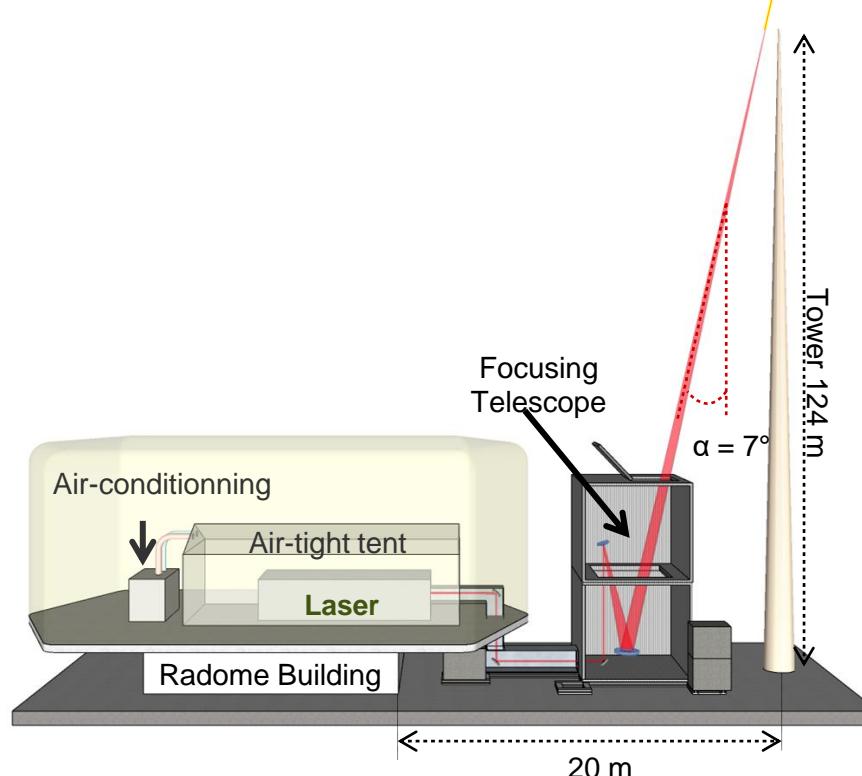
Le filament laser pour contrôler les décharges

Le filament créé un chemin préférentiel pour une décharge
- effet retardé lié au chauffage

Teramobile group



Le projet Laser Lightning Rod (FET-OPEN)



Laser Yb:YAG
1 J, 1 ps,
1 kHz

Station météo du Mont Säntis (Switzerland)

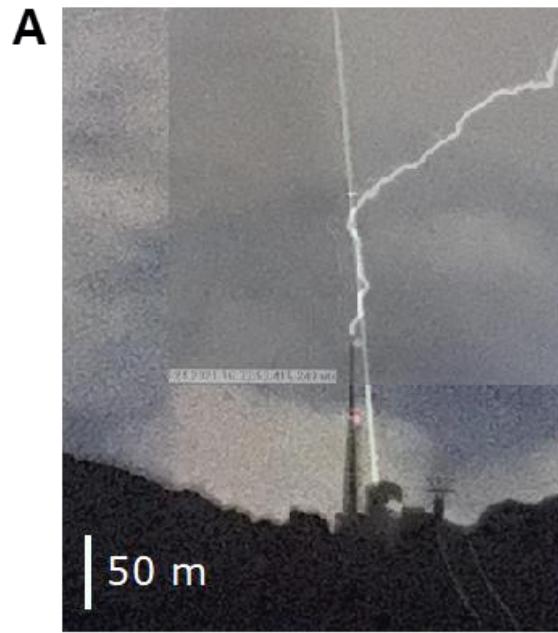
- Altitude 2 500 m
- Instrumentée pour la détection de la foudre
- 100 impacts de foudre par an
- 97% des événements sont des leaders ascendants



Laser guided lightning and the Laser lightning Rod

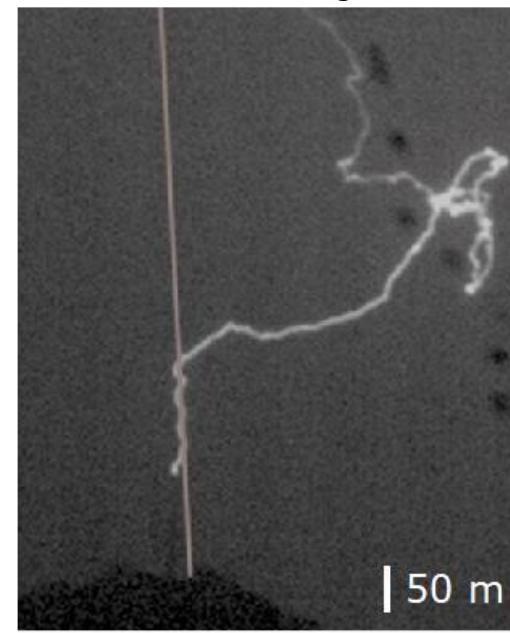
Mesure par **interférométrie VHF** de la propagation des traceurs de foudre avec et sans laser (Langmuir Laboratory, Mexico Tech University)

Image depuis Schwaegalp



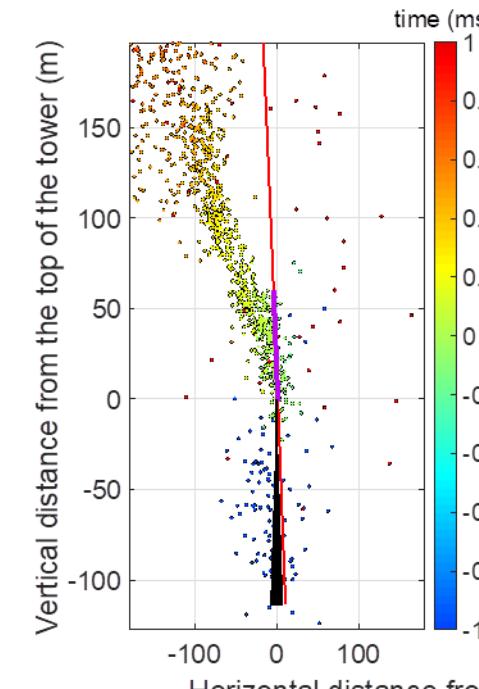
B

Image depuis le mont Kronberg

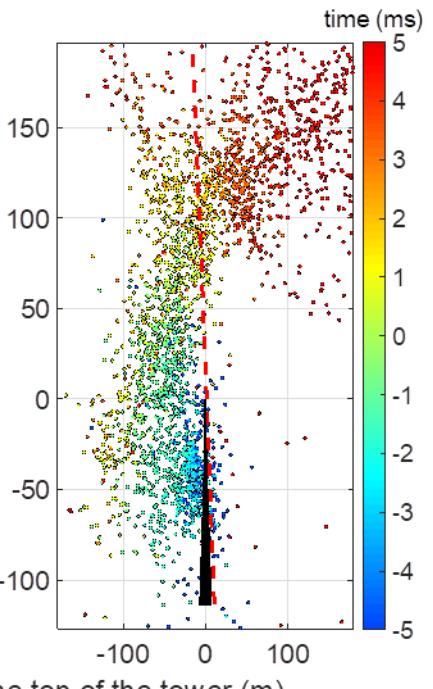


Evénement du 24 Juillet 2021

With the laser on (L1)

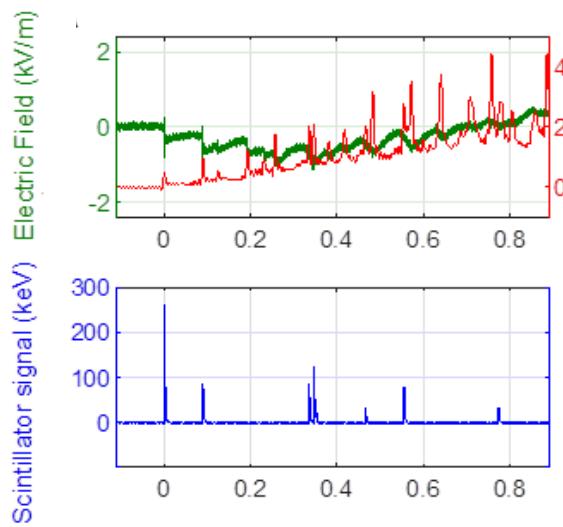


Without laser (N6)

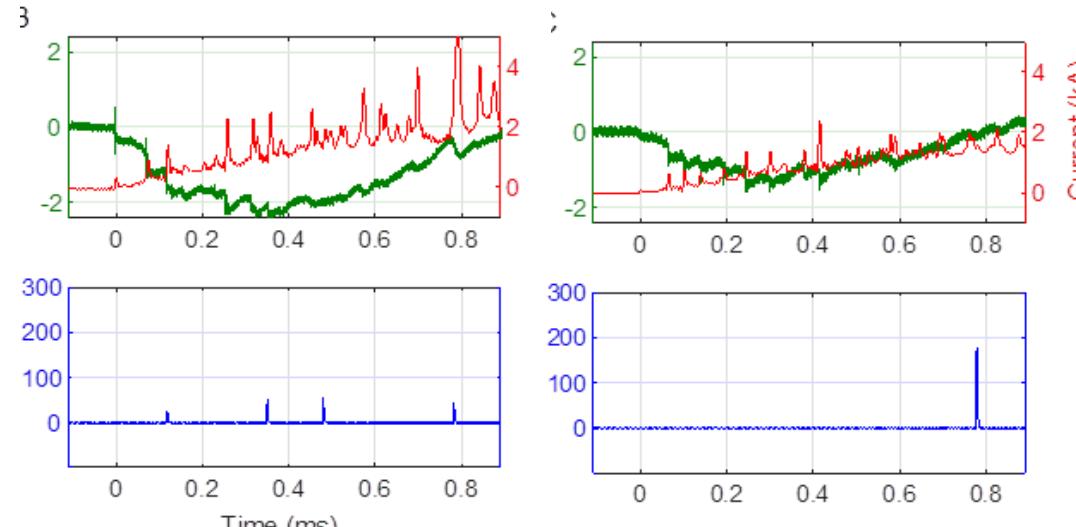


Emission de rayons X par les éclairs

Avec le filament laser



Sans laser



- Nombre moyen de bursts de rayons X détecté par événement :
 - Laser OFF: 1 par événement
 - Laser ON: **4.3** par événement
- Quel est l'effet du guidage sur l'émission de rayons X ?

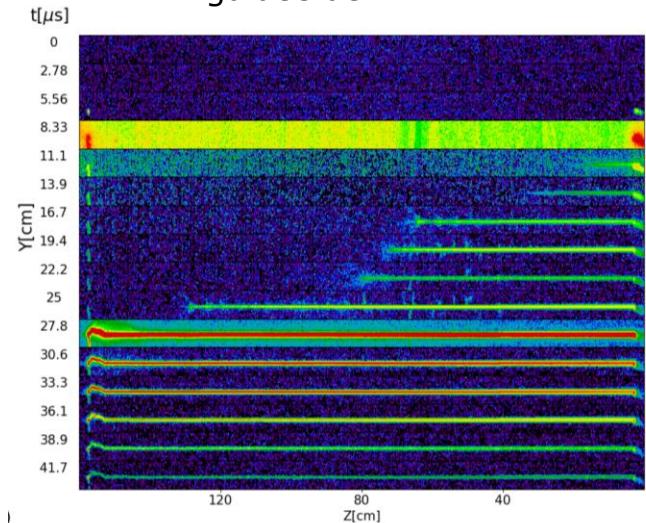
Prochaines étapes

→ Comprendre l'**interaction filament-décharge et le guidage de streamers : effet du plasma ?**

→ **Simulations**

→ **Tests en laboratoire**

Development d'une décharge guidée de 1 m



Comment déclencher la foudre avec un filament ?

→ Générer une colonne de plasma de **longue durée de vie capable d'initier des leaders**

→ Chauffage externe (laser ns, μondes, multipulses..)



Lightning triggered by a rocket trailing a conducting wire (USA)

Le groupe F-ILM au LOA

Permanents

Aurélien HOUARD
Thomas CLARK
Magali Lozano
Fatima Alahyane

Postdoc et doctorants

Quentin Gutierrez
Nicolas Cantonnet-Paloque
Léa Bernardot

Emérites

André Mysyrowicz
Yves-Bernard André
Leonid Arantchouk



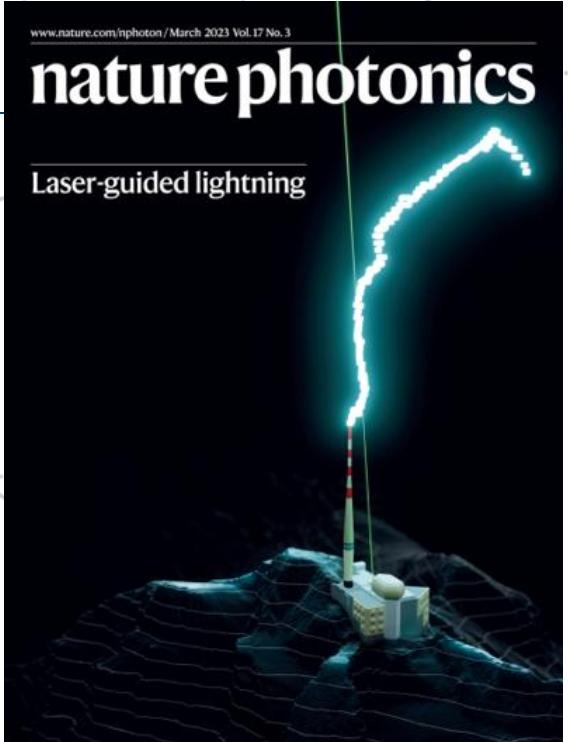
The Filamentation group at LOA (June 2024)



Thomas CLARK
Ing. Recherche X



Quentin GUTIERREZ
Postdoctorant



ONERA
THE FRENCH AEROSPACE LAB





10th International Conference on Laser filamentation COFIL 2026

20-23 July 2026

Laboratoire d'Optique Appliquée,
Institut Polytechnique of Paris
Palaiseau (FRANCE)



Chairs:
André MYSYROWICZ
Aurélien HOUARD

Website available soon

Merci de votre attention