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THE LASER LIGHTNING ROD PROJECT

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BACKGROUND

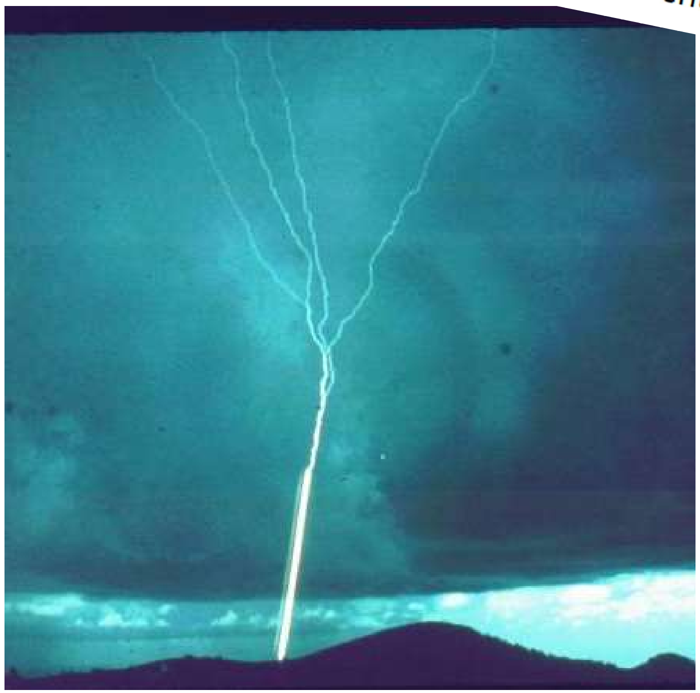

Faits divers 23/06/2023 09:30

En Haute-Savoie, un homme foudroyé sur un parking après avoir ouvert son parapluie

Un homme est mort jeudi après-midi foudroyé à Gaillard, en Haute-Savoie, lors des violents orages qui se sont abattus dans la journée sur le département.

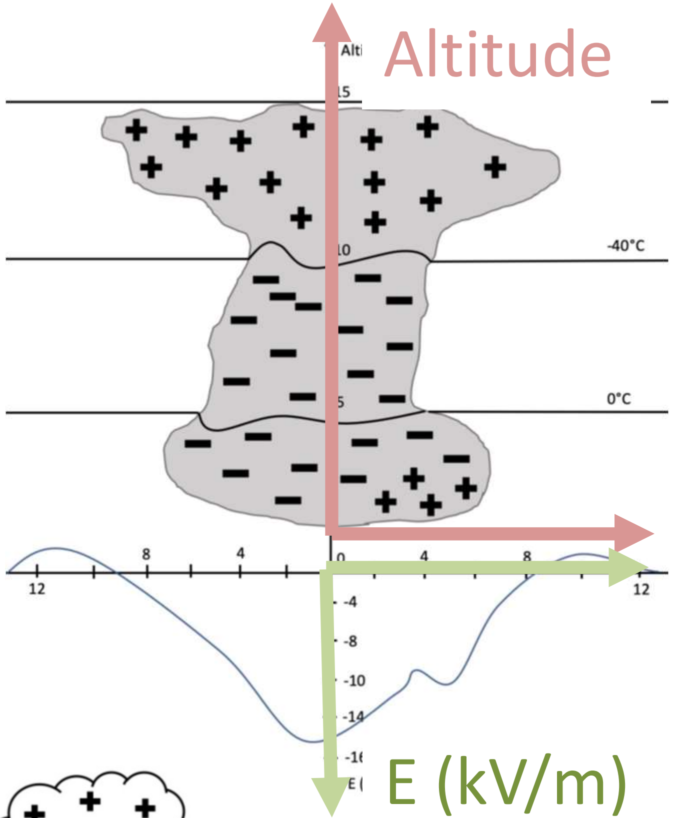
- Between 40 and 120 lightning flashes per second
- Causing every year more than **4000 fatalities** and damages amounting to **billions of dollars**

- Protection: Lightning rod invented by Benjamin Franklin in the 18th century
- Initiation demonstrated with rockets (Newman *et al.* 1965)

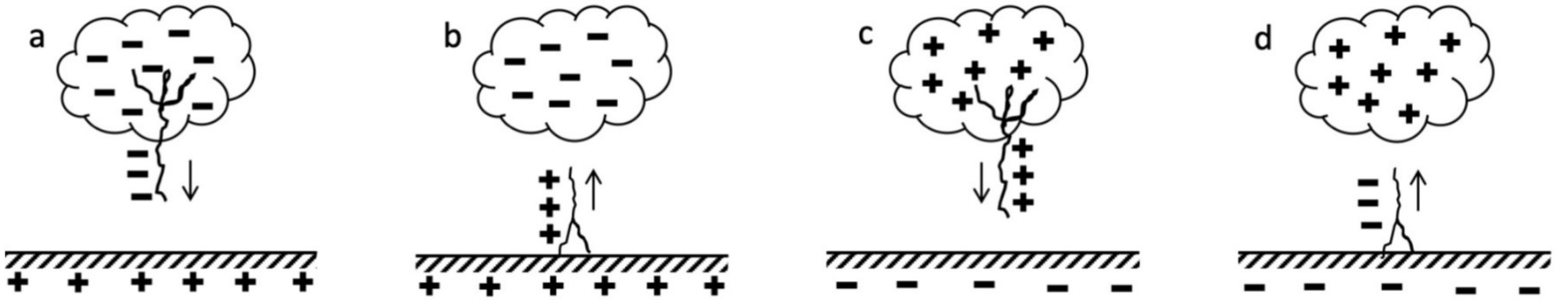


Lightning triggered by a rocket trailing a conducting wire (USA)

BACKGROUND



- Stratification distribution of the electrical charges of a cumulonimbus
- Apparent electric field between the ground and the bottom of the cloud



a) Downward negative lightning

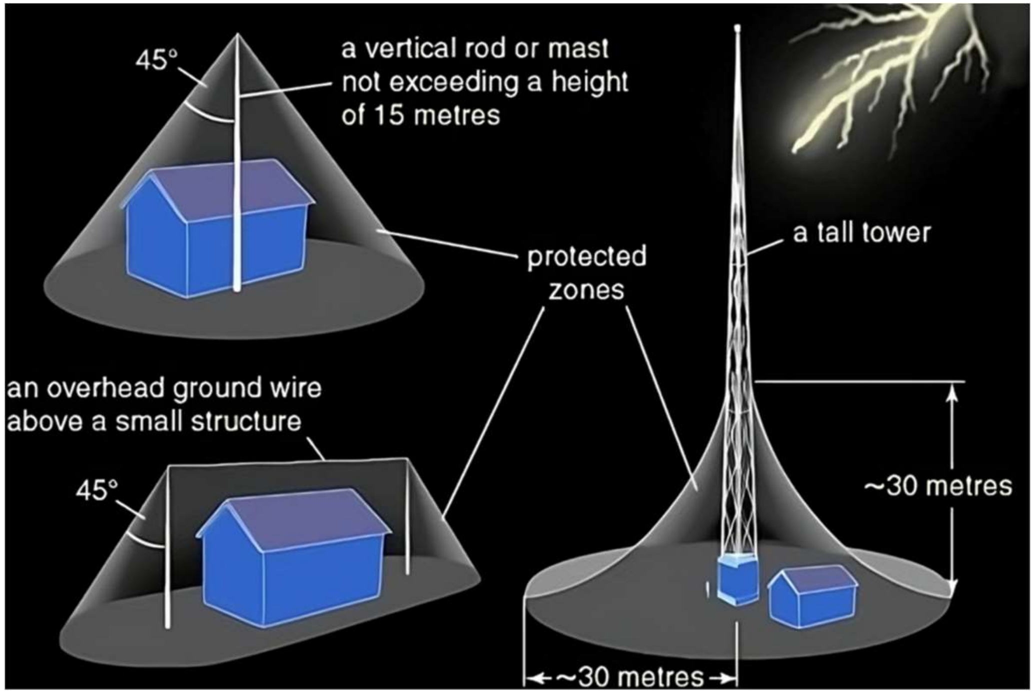
b) Upward negative lightning

c) Downward positive

d) Upward positive

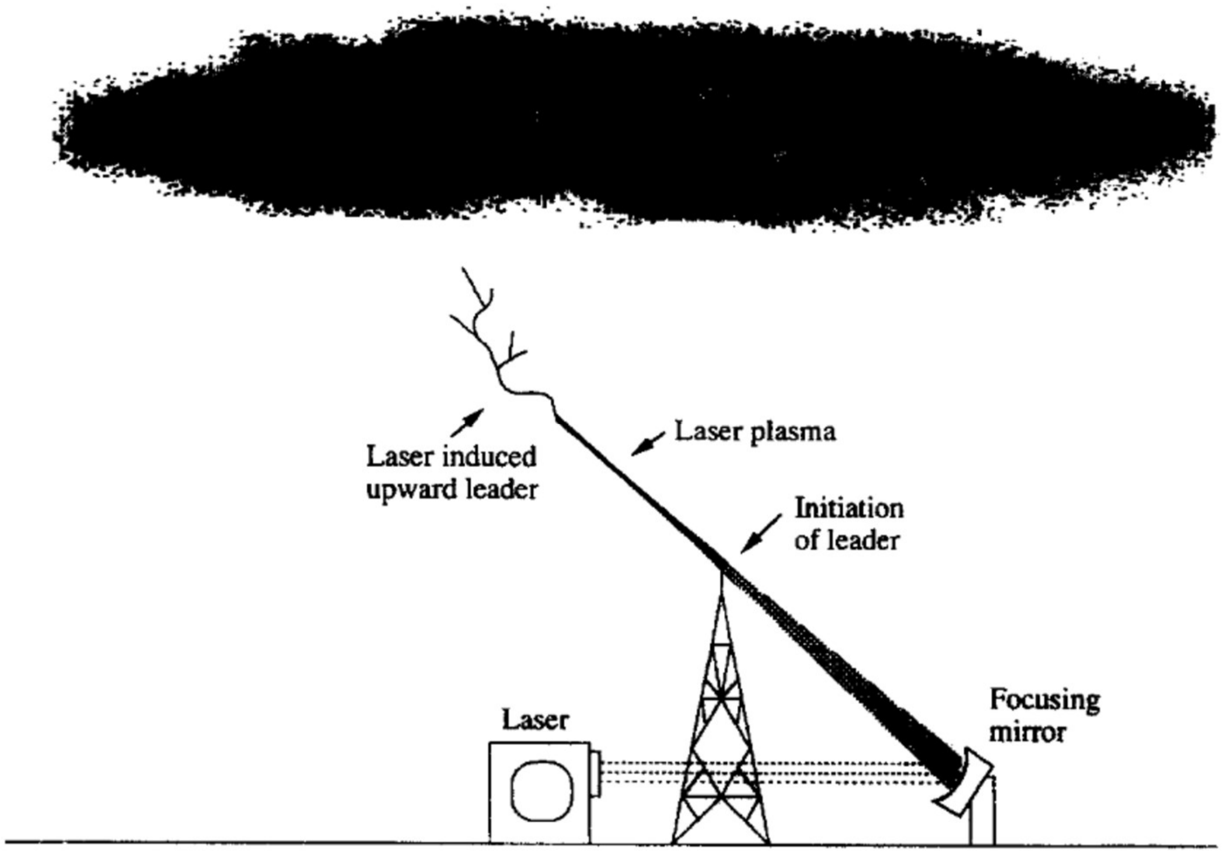
LIGHTNING PROTECTIONS

- Typical lightning rod protection area **approximately equal to the height of the rod above the ground**. Taller structures, the protective range extends only around 30m from the base. Reliable for small installation such but fails for large sensitive installations.



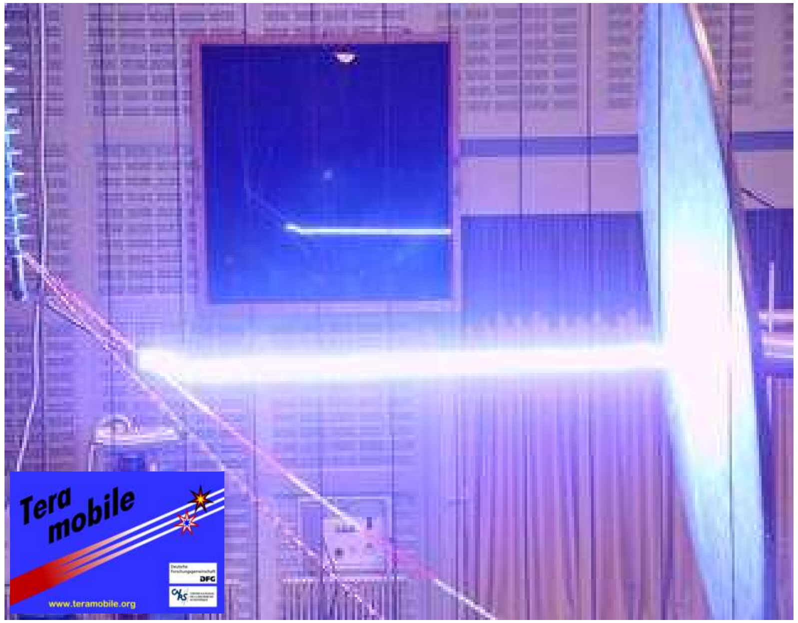
LIGHTNING PROTECTIONS

- First demonstration in the 90’s in Japan
- Idea emerged in the 70’s in Japan



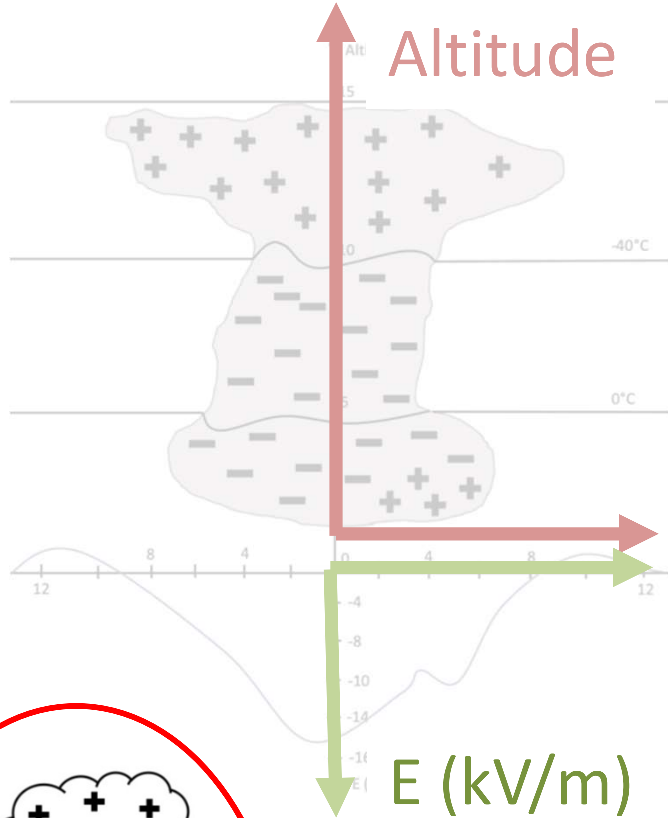
GUIDING DISCHARGES WITH LASER FILAMENTATION

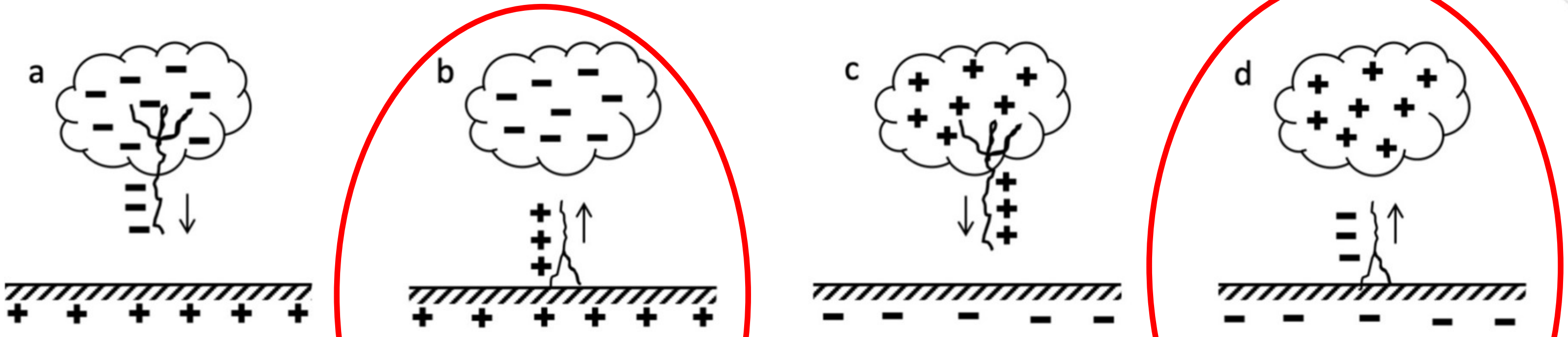
- Demonstration of guiding with fs UV laser (J.-C. Diels 1994)
- Meter scale discharges with TW lasers (IR, UV, Bessel beam, dual pulse)
  - INRS, Teramobile, Fujii et al., Ionin et al, Schwartz et al., Polynkin et al.
- 2004: First campaign of lightning triggering with fs laser filament by the Teramobile group -> Observe corona initiation with TW filament in the clouds



Rodriguez, OL 27, 772 (2002)

BACKGROUND





a) Downward negative lightning

b) Upward negative lightning

c) Downward positive

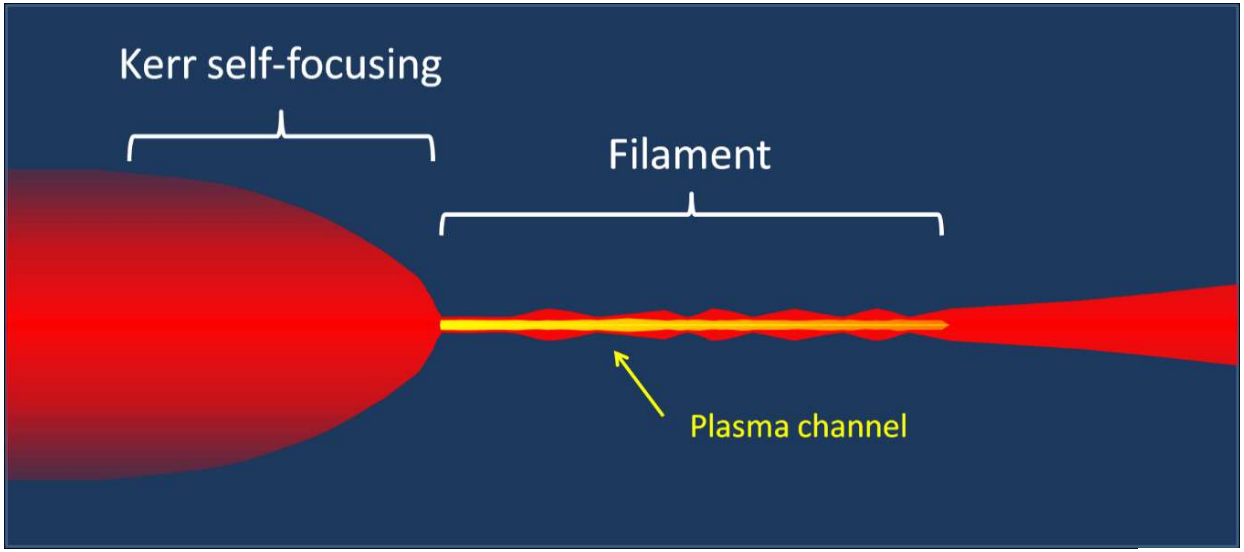
d) Upward positive

LLR GOAL

- Demonstrate the guiding of lightning flash over long distance with laser filamentation
- Stimulate the number of lightning flashes in the presence of laser filaments

- Final application:
  – Study of lightning
  – Lightning protection for airports, launchpads or large infrastructures

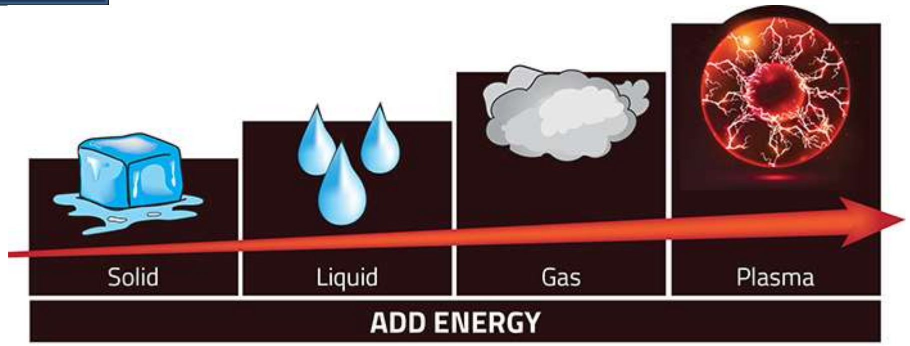
WHAT IS A LASER FILAMENT ?

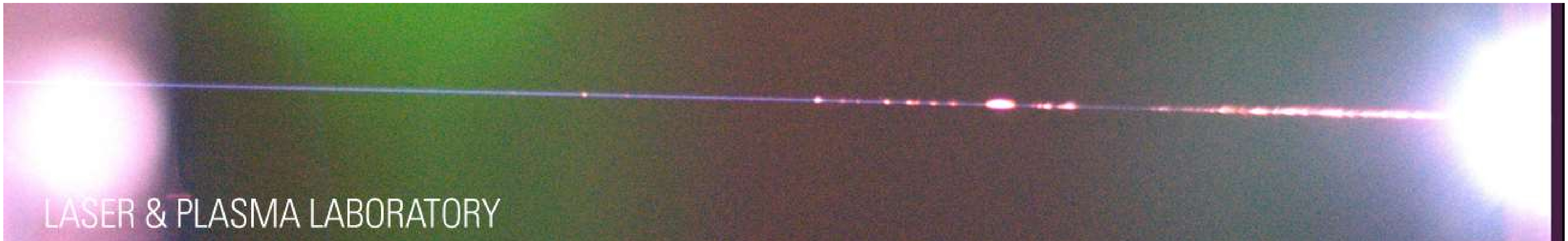


"In nonlinear optics, filament propagation is propagation of a beam of light through a medium without diffraction."

NSLE

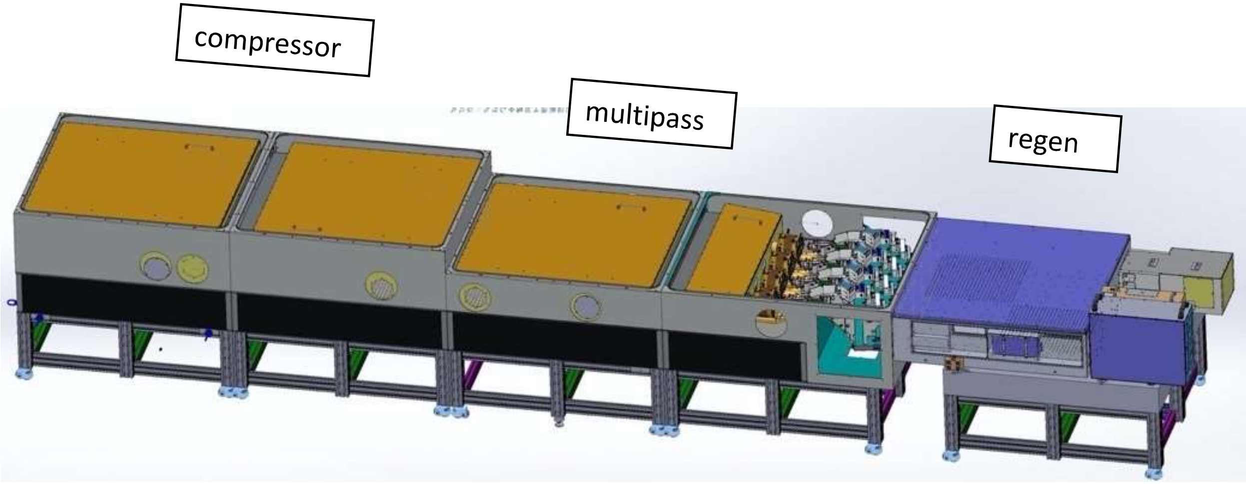
$$\frac{\partial}{\partial z}\varepsilon = \frac{i}{2k_0}\Delta_\perp \varepsilon - \mathrm{i}\frac{k''}{2}\frac{\partial^2}{\partial t^2}\varepsilon + \mathrm{i}\frac{k_0}{n_0}n_2|\varepsilon|^2\varepsilon - \mathrm{i}\frac{k_0}{2n_0^2\rho_c}\rho\varepsilon - \frac{\sigma}{2}\rho\varepsilon - \frac{\beta^{(K)}}{2}|\varepsilon|^{2K-2}\varepsilon$$





wavelength : **1030 nm**
pulse energy : **500 mJ**
pulse duration : **1 ps**
repetition rate : **1 kHz**

TRUMPF

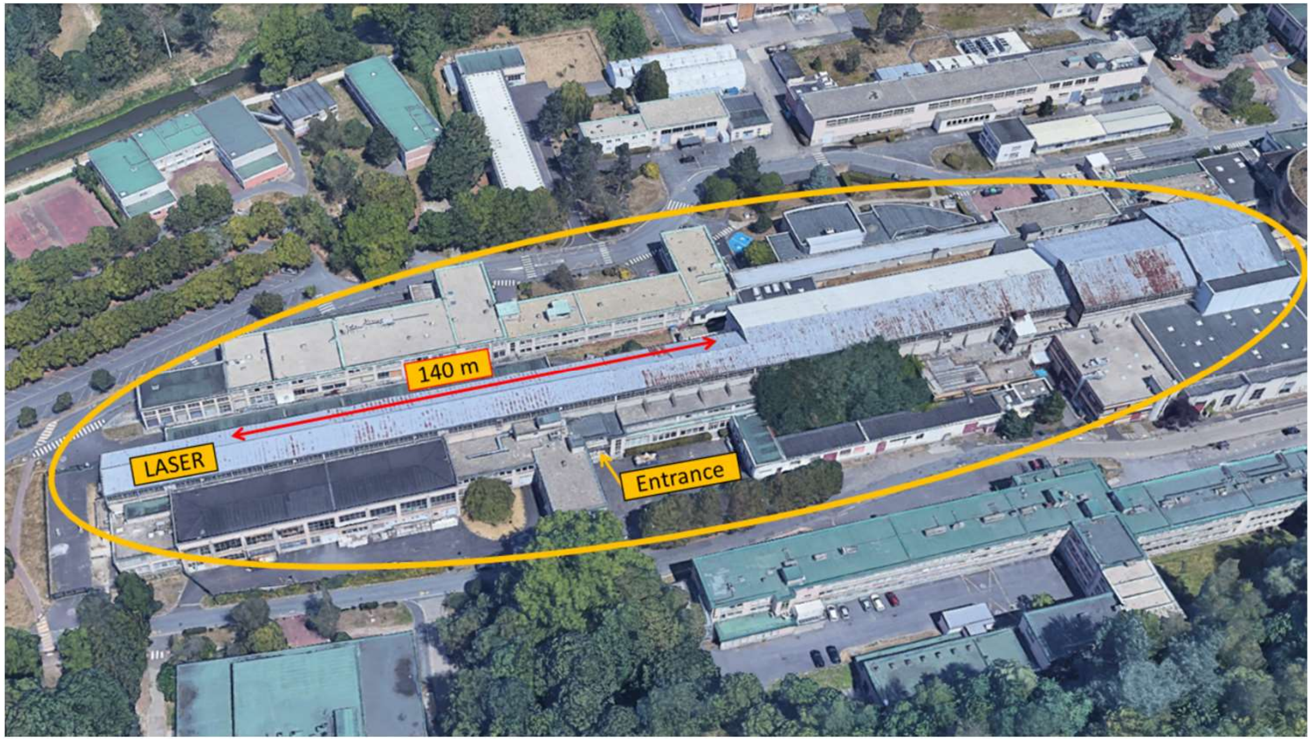


LLR laser inside the tent

Final laser system delivered in January 2020

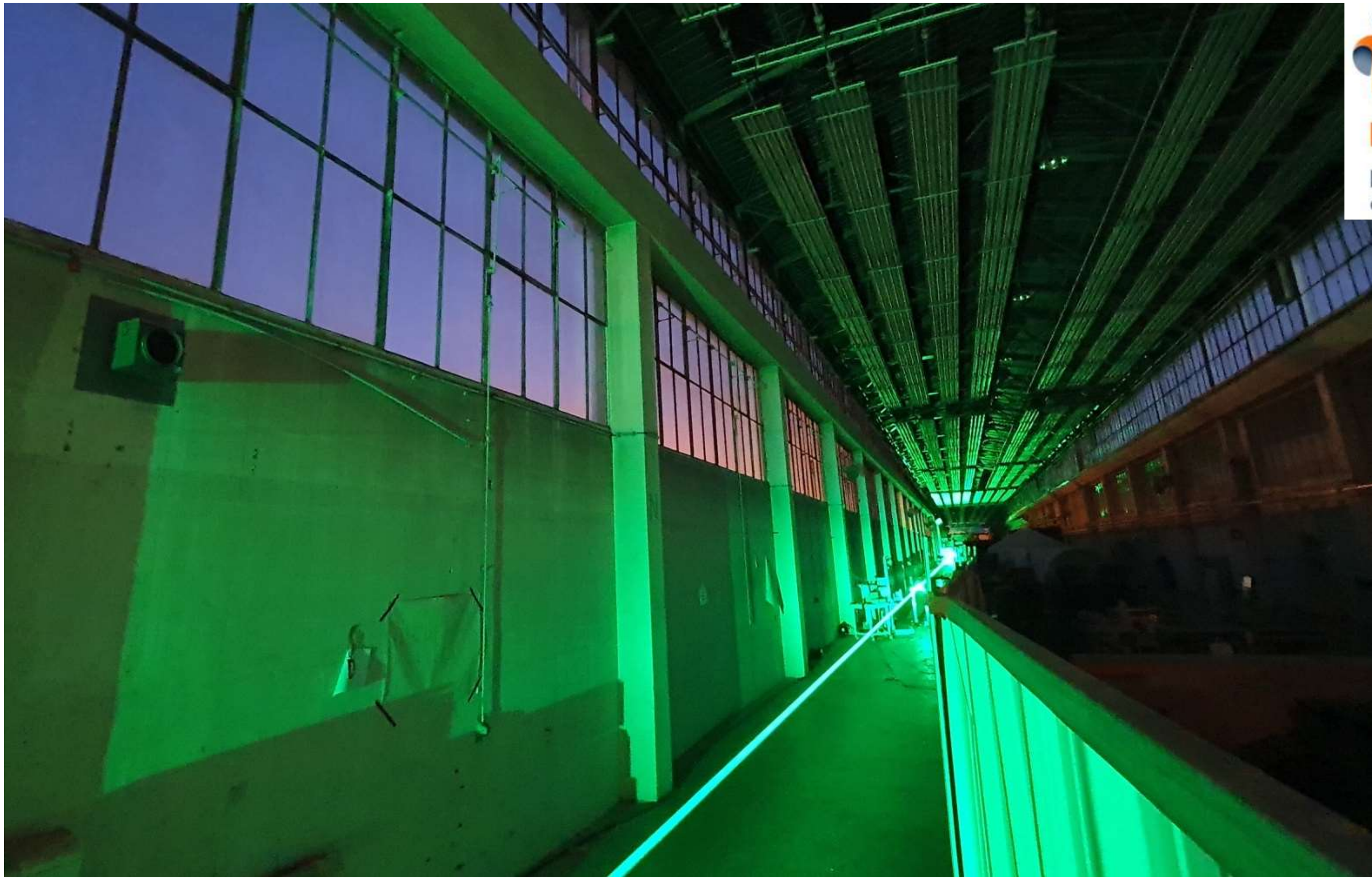
CHARACTERIZATION OF LONG RANGE FILAMENTATION

- **October 2020 March 2021**
  - **Long distance propagation** (>150 m)
- Testing the laser
- Characterize filament up to 110 m
- Preparation of the final experiment



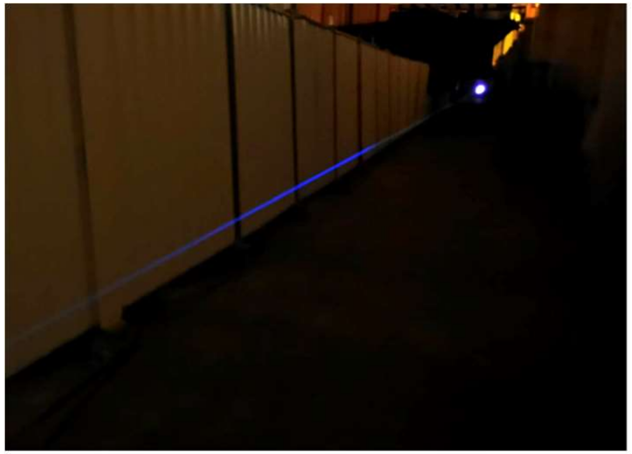
Former linear accelerator of Orsay LAL (IJCLab)

STUDY OF FILAMENT PRODUCED AT LONG DISTANCE : FIRST TEST AT LAL

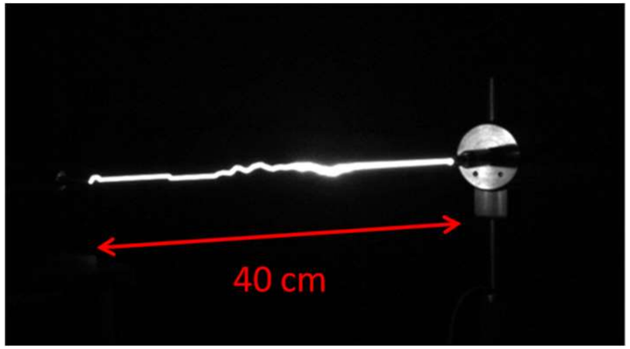


OUTDOOR FILAMENT CHARACTERIZATION

- Evidence of filamentation at long distance (> 110 m)
- Guiding of discharges
- Generation of strong SHG and THG



Plasma filament at 55 m



Guided discharge

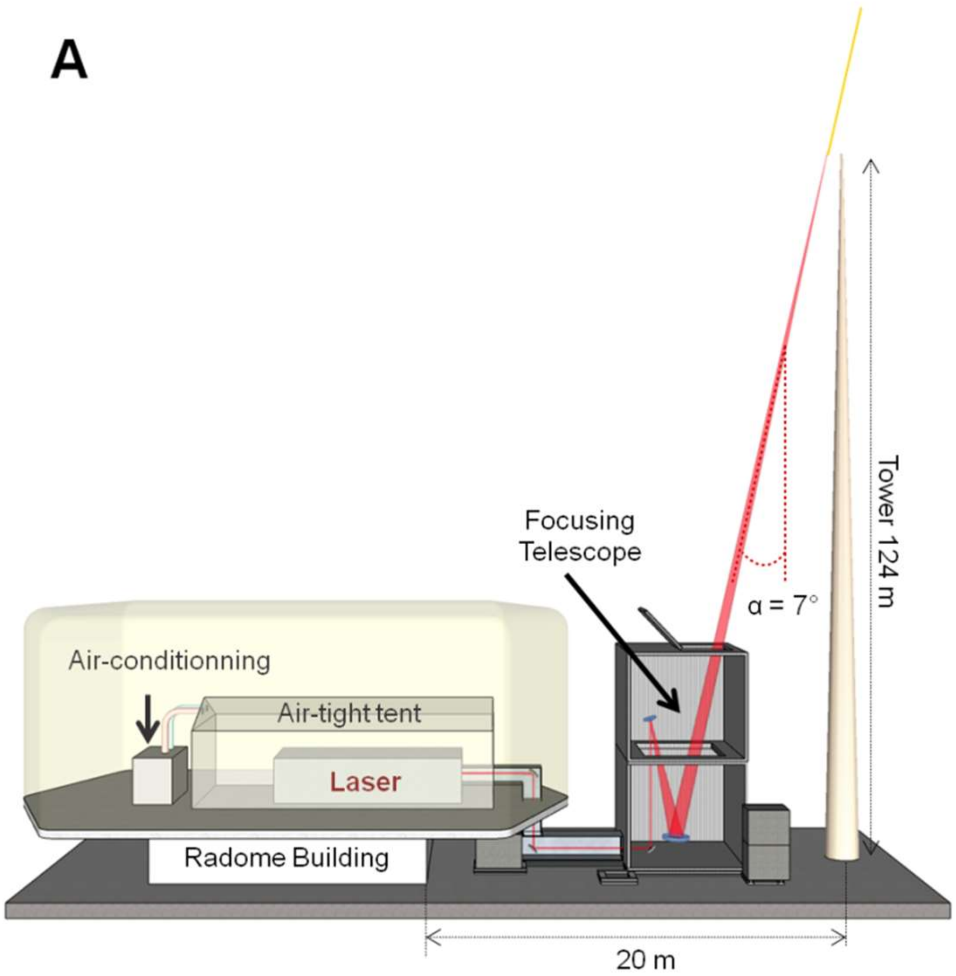
Input 500W @ 1030nm	Power @ 1ps	Efficiency @ 1ps
SHG	~ 300 W	~60%
THG	~ 100 W	~ 20%

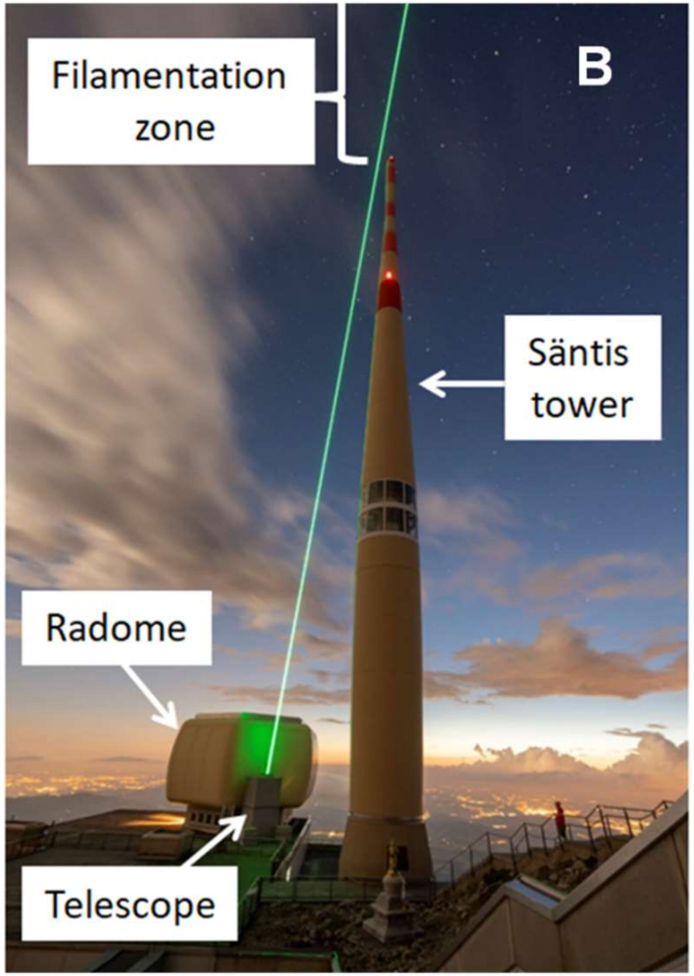
SUMMER 2021: LIGHTNING CAMPAIGN

Meteorological station of Mount Säntis (Switzerland)

- Altitude 2 500 m
- Fully instrumented for the detection of lightning
- 100 lightning strikes every year
- 97% of events are upward lightning leaders

EXPERIMENTAL SETUP



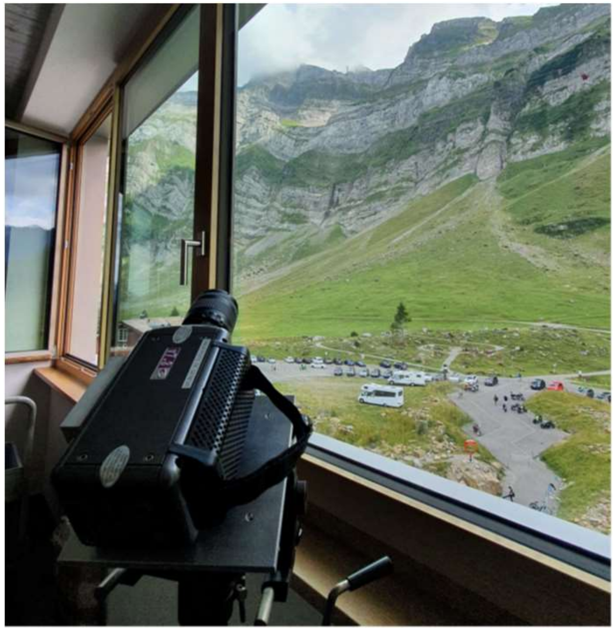


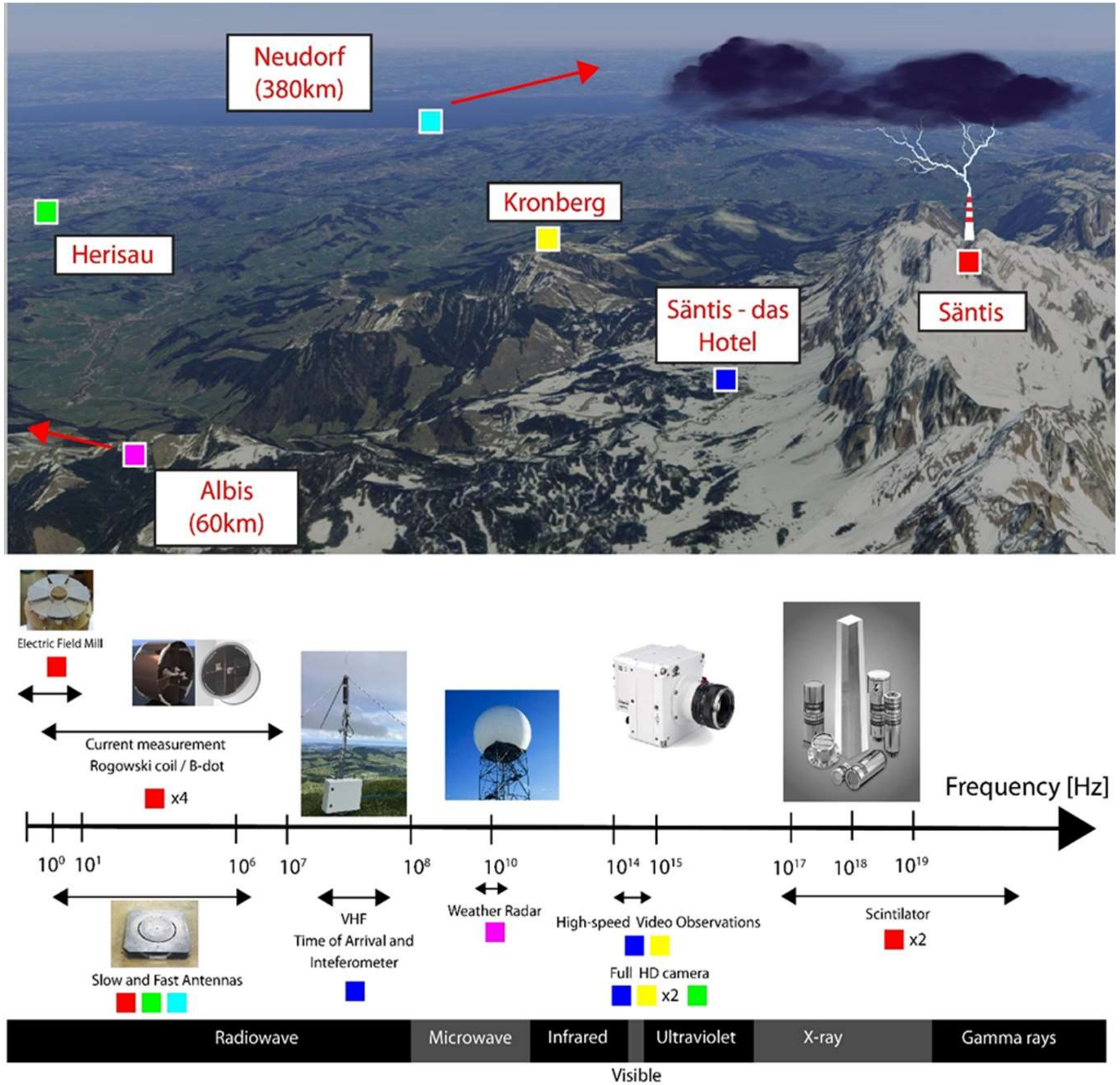
REAL CONDITIONS

DIAGNOSTICS: THE SÄNTIS LIGHTNING RESEARCH FACILITY

EPFL / HES-SO

Installation of different measuring equipments to characterize lightning





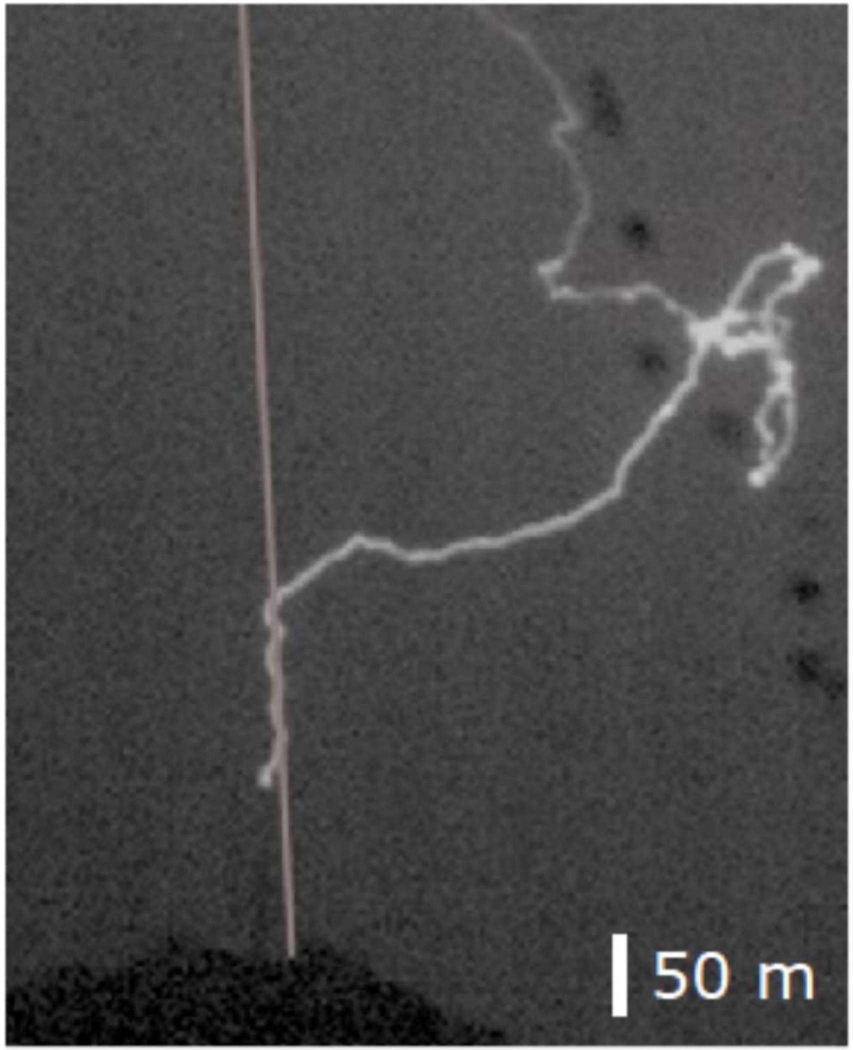
SELECTED DATA

Events	Date	UTC Time	Laser	Current	Flash polarity	HSC	INT	X-RAY	E (20m)	E (15km)
L1	24.7.2021	16:06:07	ON	YES	POS	NO	YES	YES	YES	YES
L2	24.7.2021	16:24:03	ON	YES	POS	YES	NO	YES	YES	YES
L3	30.7.2021	18:00:10	ON	YES	POS	NO	YES	YES	YES	YES
L4	30.7.2021	18:02:40	ON	YES	POS	NO	YES	NO	NO	YES
N01	30.7.2021	15:17:09	OFF	YES	NEG	NO	YES	YES	YES	YES
N02	30.7.2021	15:22:29	OFF	YES	NEG	NO	YES	NO	NO	NO
N03	30.7.2021	15:30:51	OFF	YES	NEG	NO	YES	YES	YES	NO
N04	30.7.2021	15:35:41	OFF	YES	NEG	NO	YES	YES	YES	YES
N05	30.7.2021	15:38:10	OFF	YES	NEG	YES	YES	YES	YES	YES
N06	30.7.2021	18:04:53	OFF	YES	POS	NO	YES	YES	YES	YES
N07	16.8.2021	02:00:27	OFF	YES	NEG	NO	YES	NO	NO	NO
N08	16.8.2021	02:34:10	OFF	YES	NEG	YES	YES	YES	YES	YES
N09	16.8.2021	05:53:24	OFF	YES	NEG	NO	YES	YES	YES	YES
N10	16.8.2021	10:16:32	OFF	YES	NEG	NO	YES	NO	NO	NO
N11	16.8.2021	15:06:45	OFF	YES	NEG	NO	YES	YES	YES	NO
N12	16.8.2021	15:08:34	OFF	YES	NEG	NO	YES	YES	YES	NO

FAST CAM IMAGES OVERLAYED WITH BEAM PICS

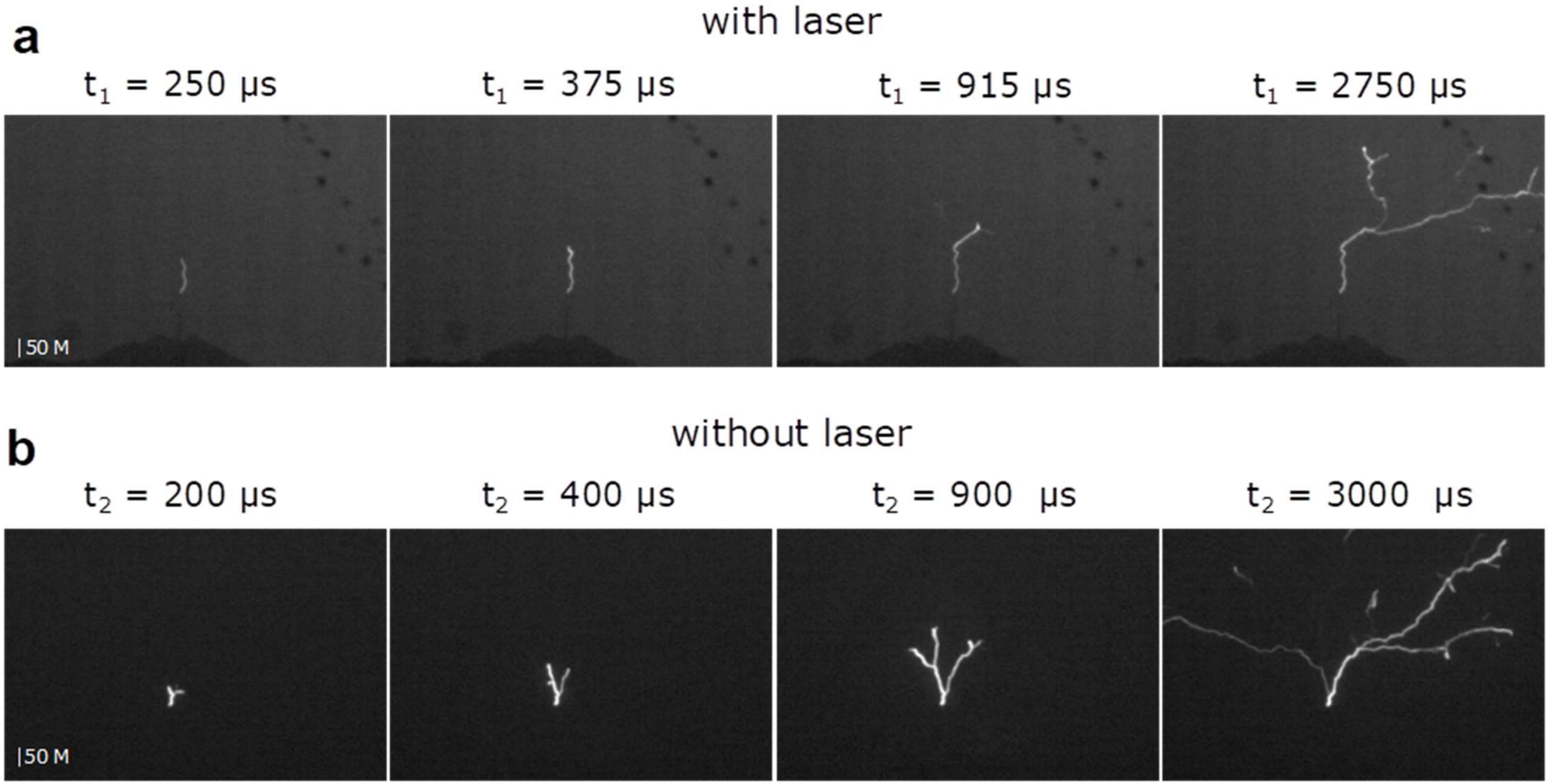
a

b

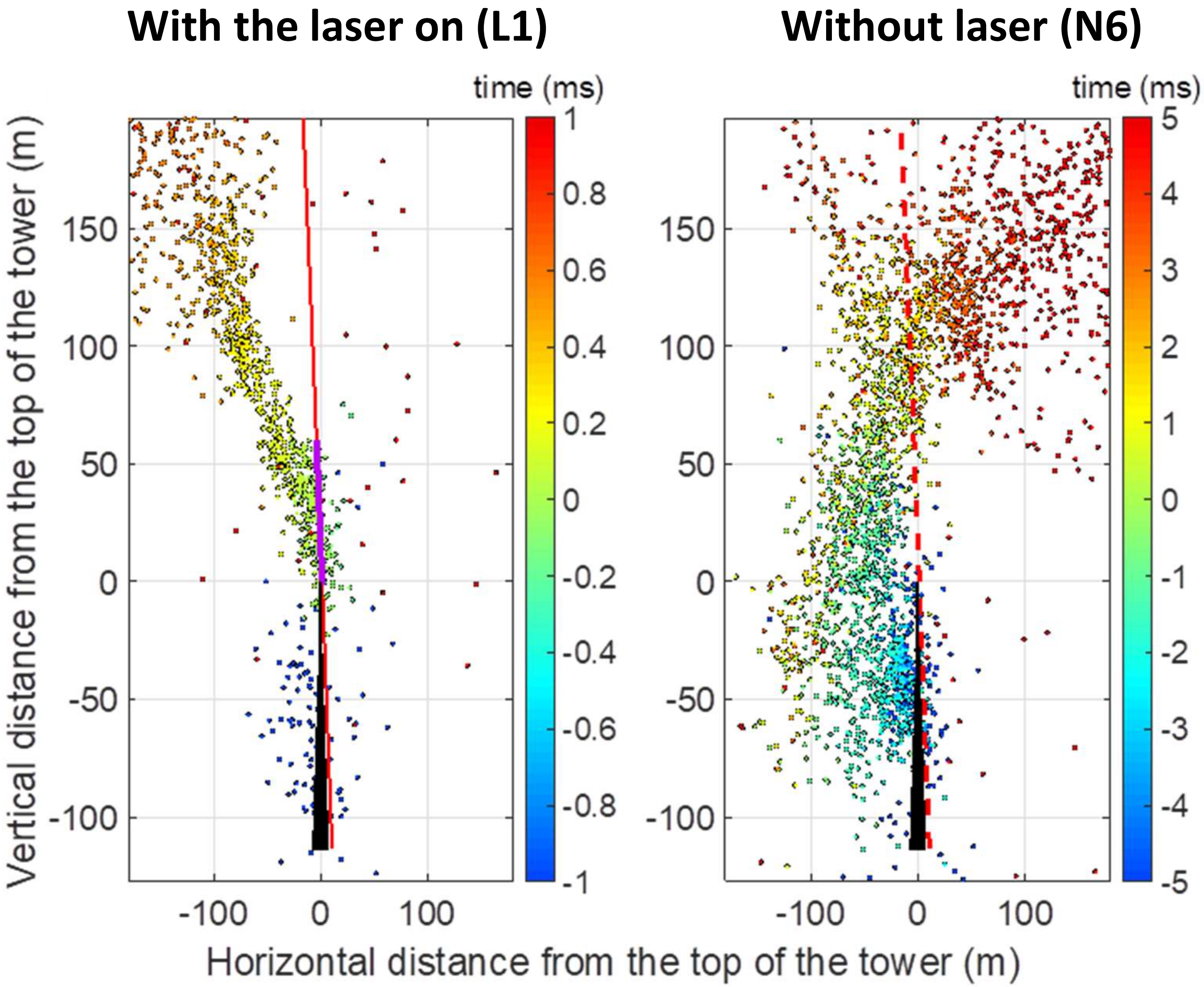


The lightning follows the laser path over 60 m

HIGH SPEED IMAGES OF UPWARD LEADERS



Measurement with the VHF Interferometer imaging system (Langmuir Laboratory)



Average distance between the VHF emitting sources and the laser beam:

Laser ON: 20.6 m

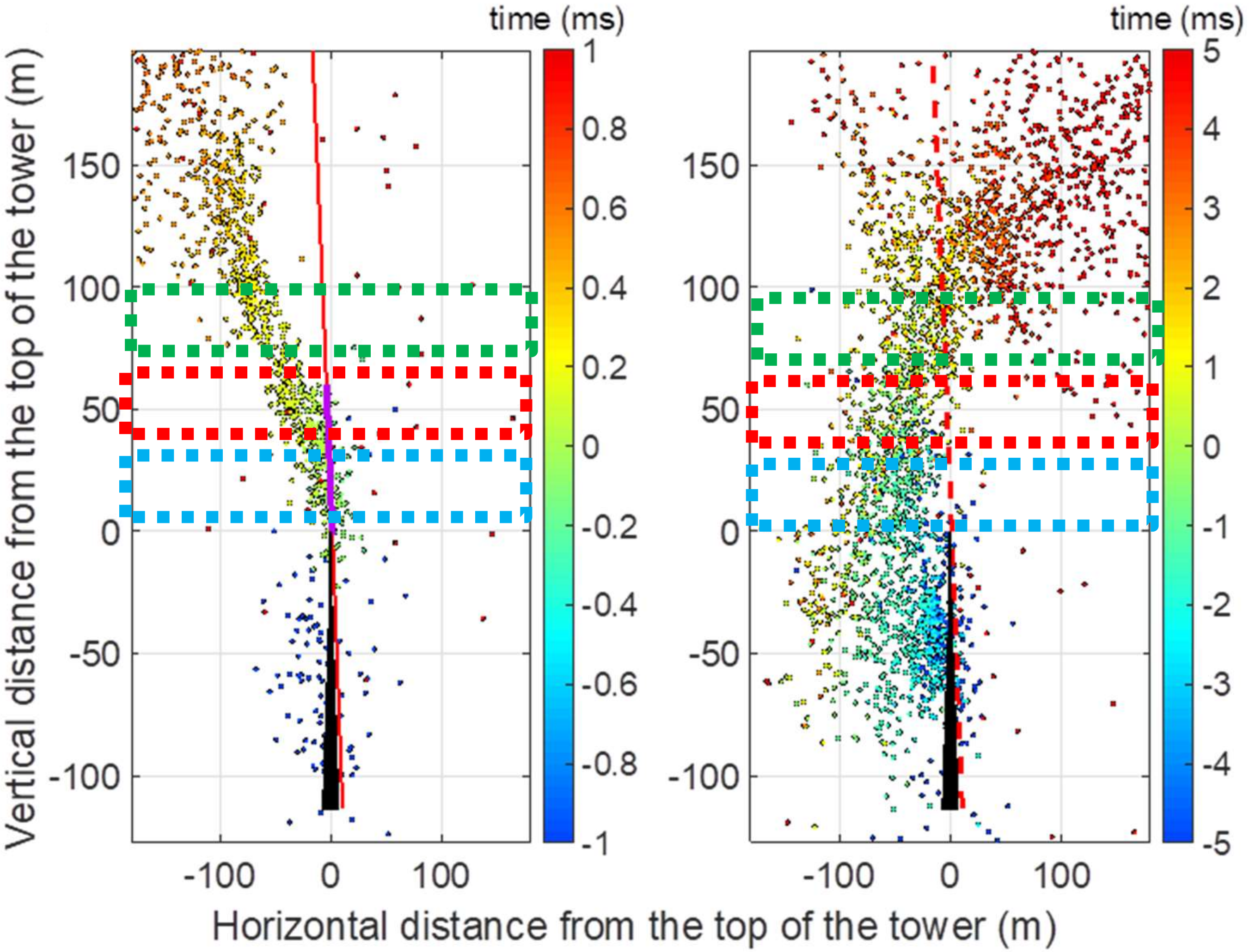
Laser OFF: 28 m

Stanley, M. A. et al.
AGU Fall Meeting,
December 1-17 2020

Laser Lightning Rod

MEASUREMENT WITH THE VHF INTERFEROMETER IMAGING SYSTEM (LANGMUIR LABORATORY)

With the laser on (L1) **Without laser (N6)**



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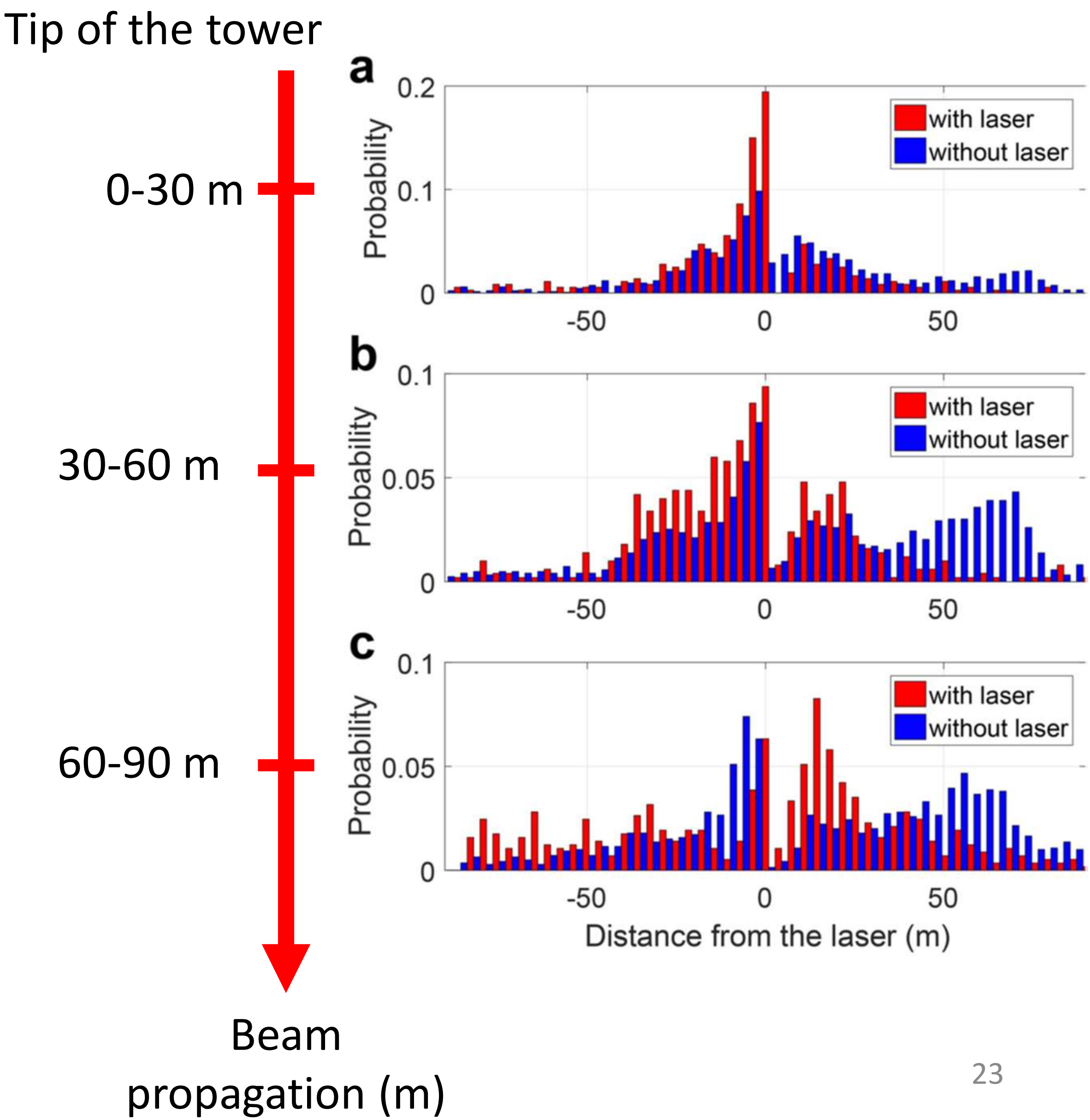
Laser Lightning Rod

VHF SOURCE DISTANCE TO LASER FILAMENTS

- 0–60 m range above tower, the standard deviation of **the distance of the sources to the laser is reduced by 45% when the laser is on**.
- Above 60 m, this reduction due to the laser filament is much weaker, as expected since the length of the filament is estimated to be 50–60 m.



CONCLUSIONS

- We study the effect of filaments formed by a TW laser working at kHz repetition rate on the initiation and propagation of upward lightning flashes above the Säntis tower
- We observe evidence of **laser guided lightning flashes over 50 m**
  - One event recorded by 2 separate cameras and 3 events recorded by VHF interferometer
- The fact that **all laser events were of positive polarity** can be explained by the stronger effect of filaments on the inception of positive lightning flash
- These preliminary results should be confirmed by additional campaigns to obtain more statistics and test new configurations

Laser Lightning Rod

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A. Houard, *et al.,*“Laser Guided Lightning”, https://doi.org/10.48550/arXiv.2207.03769