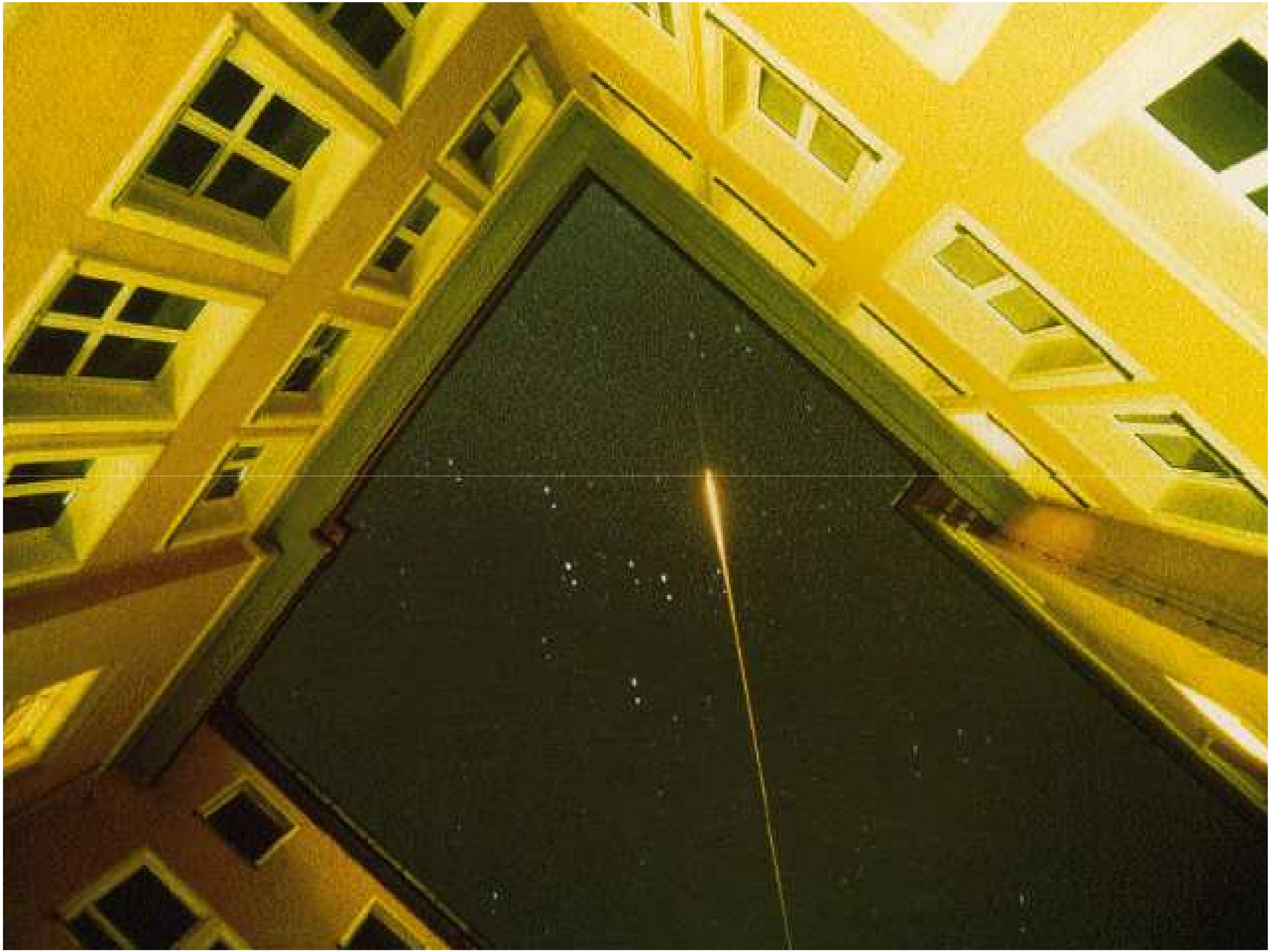


Fundamentals and Applications of Plasma Filaments

L. Wöste
Fachbereich Physik der Freien Universität
woeste@physik.fu-berlin.de

Coworkers
K. Stelmaszczyk
P. Rohwetter

Cooperation partners
J.-P. Wolf
J. Kasparian

W. Nakaema, M. Rodriguez, H. Wille, R. Bourayou, H. Zuoquiang, T. Fujii,
R. Sauerbrey, A. Mysyrowicz, W. Kalkner, G. Méchain, Y. Petit, S. Henin,
J. Yu, E. Salmon, G. Méjean, Y.-B. André, L. Klingbeil, K. Rethmeier

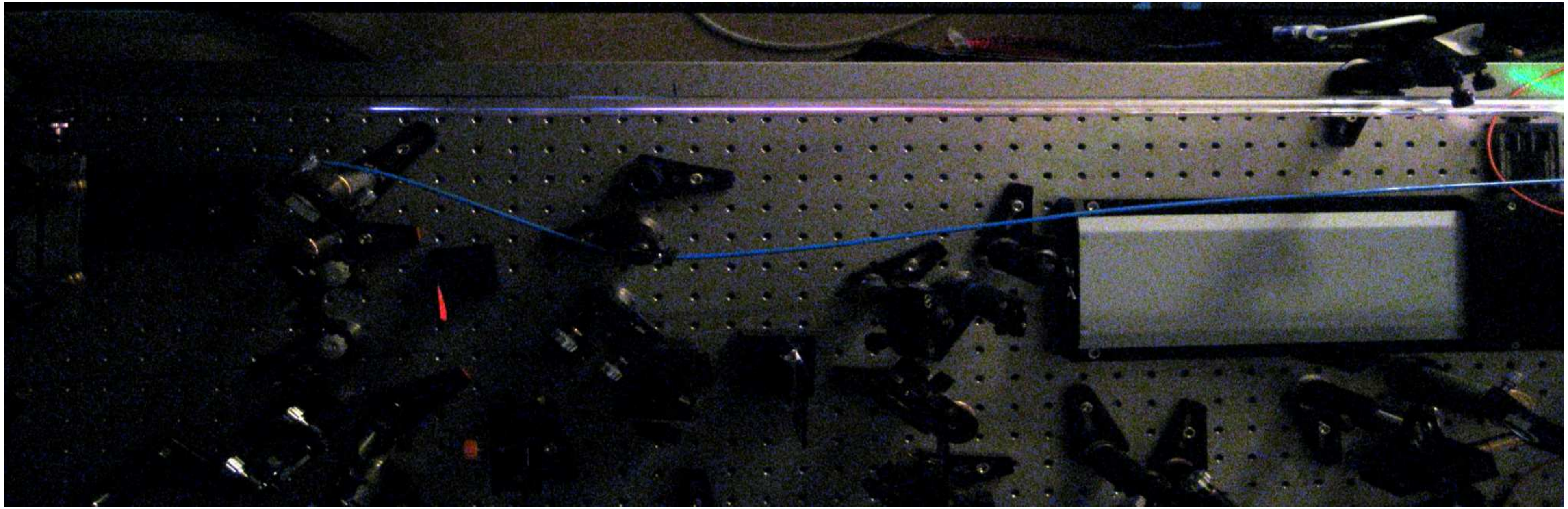
TheTeramobile Project was financed by CNRS, DFG and SNF

Fundamentals and Applications of Plasma Filaments

<u>Contents</u>

- Formation of white light filaments
- Properties and applications
- Remote sensing of solid targets
- Single and multiple filaments
- White light analysis of the atmosphere
- Filament-induced water condensation
- Filament-based discharge control
- Perspectives of lightning protection

Let' s propagate a millijoule femtosecond laser pulse in air or gas!



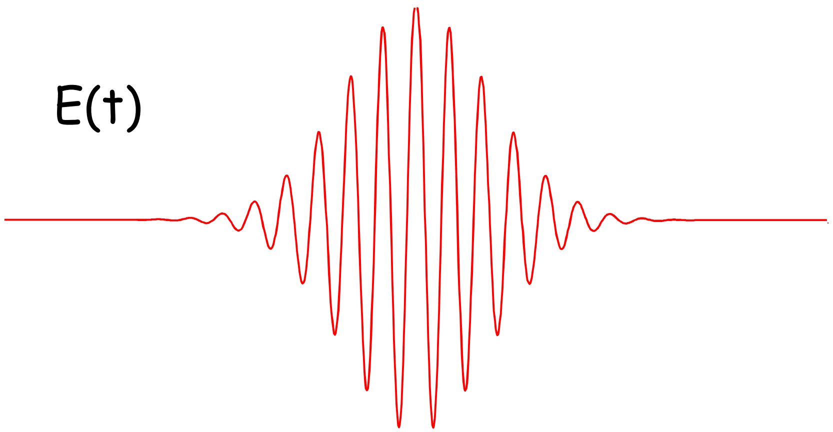
An amazing, white-light emitting filament emerges!

First time observed in the lab by:

A.Braun, G.Korn, G.Mourou et al. Opt. Lett., 20(1995),73

How is the white light formed ?

E(t)



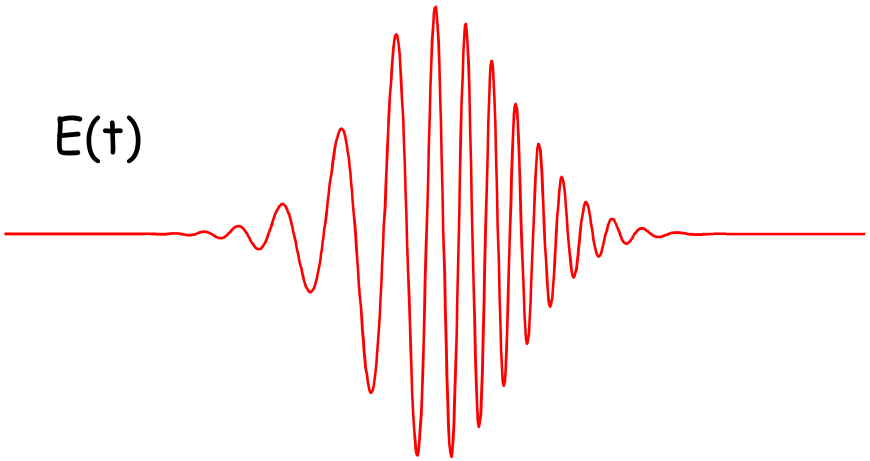
Kerr:

$$n = n_0 + n_2 I(x,t)$$

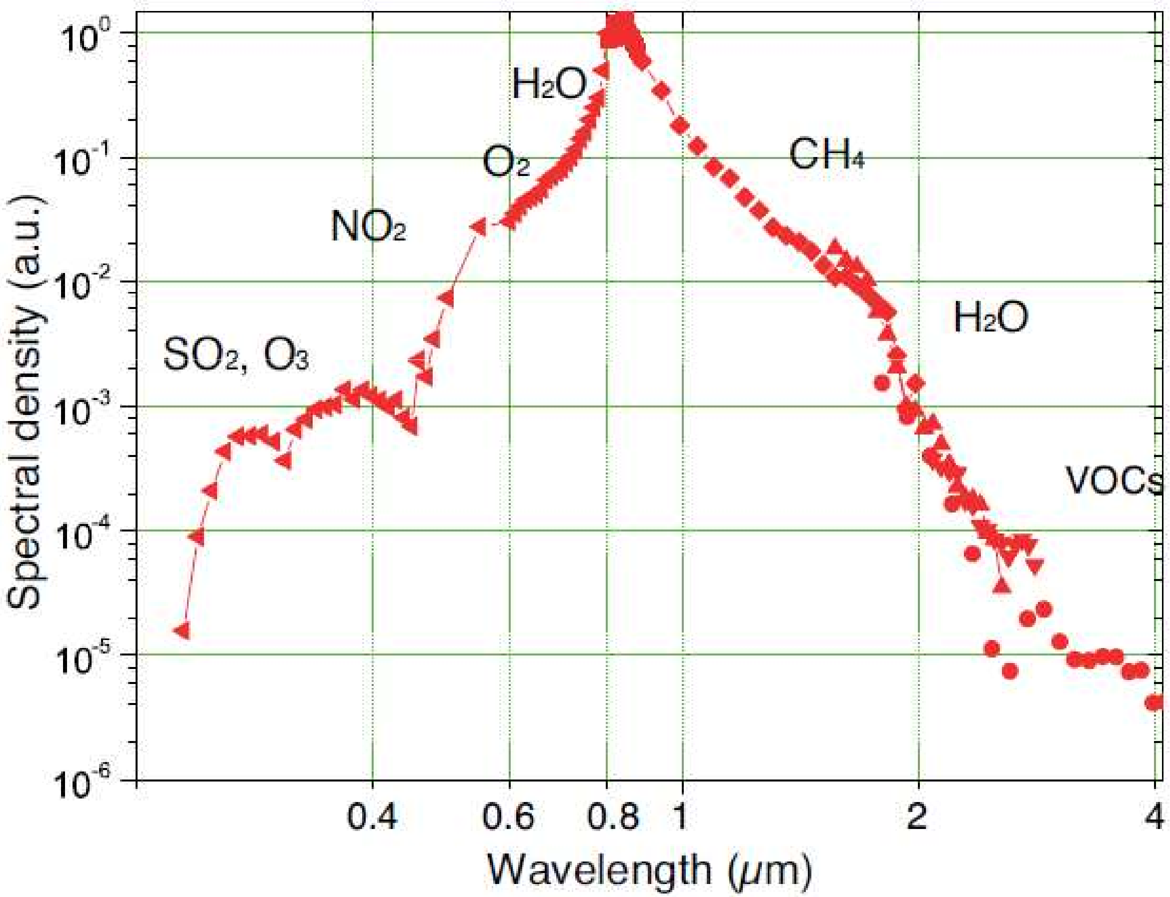
Self-Phase Modulation

$$\omega(t) = \omega_0 - \frac{n_2 \omega_0}{c} z \frac{dI(t)}{dt}$$

E(t)



White-Light Continuum



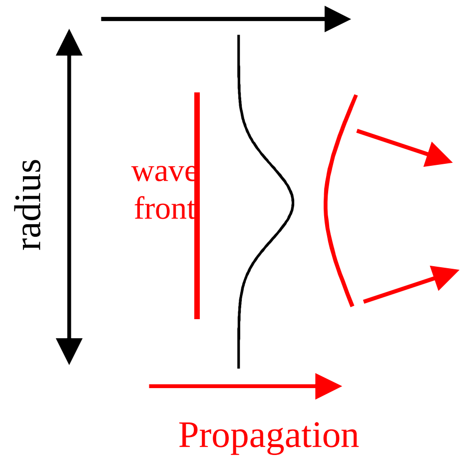
J.Kasparian et al., Opt. Lett. ***25****, 1397 (2000)*

What is the filament formation mechanism?

Kerr Lens

$$n = n_0 + n_2 I(r)$$

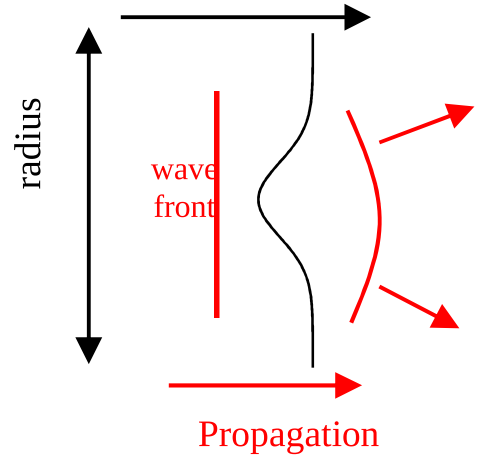
$n_2 = 3\ 10^{-19}\ \mathrm{cm^2/W}$ in air

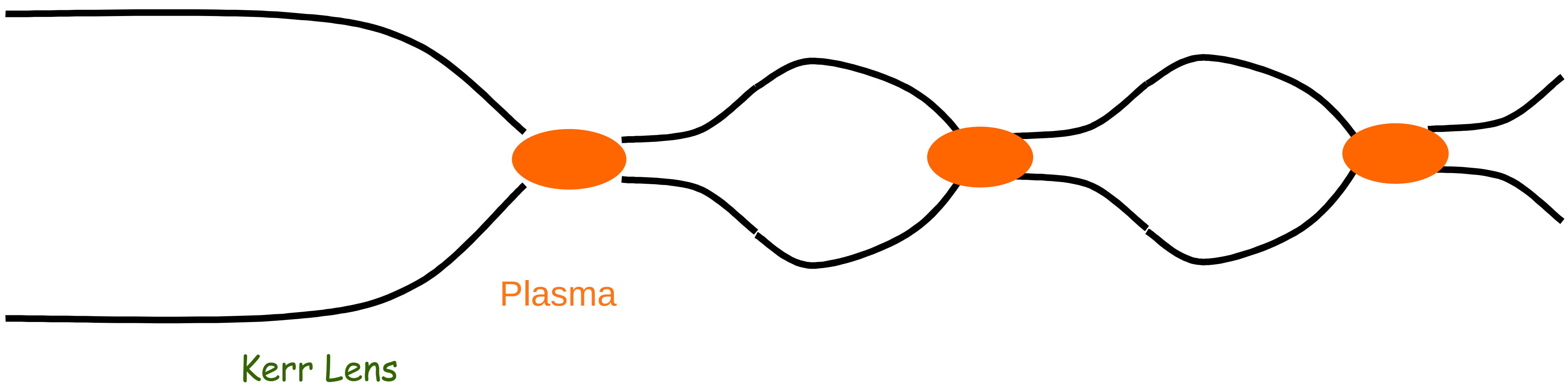


Plasma Lens

$$\Delta n = -\frac{\rho(I)}{\rho_c}$$

$\rho_c = 2\ 10^{21}\mathrm{cm^{-3}}$ in air





Theoretical calculation

Properties

Φ = 100 µm

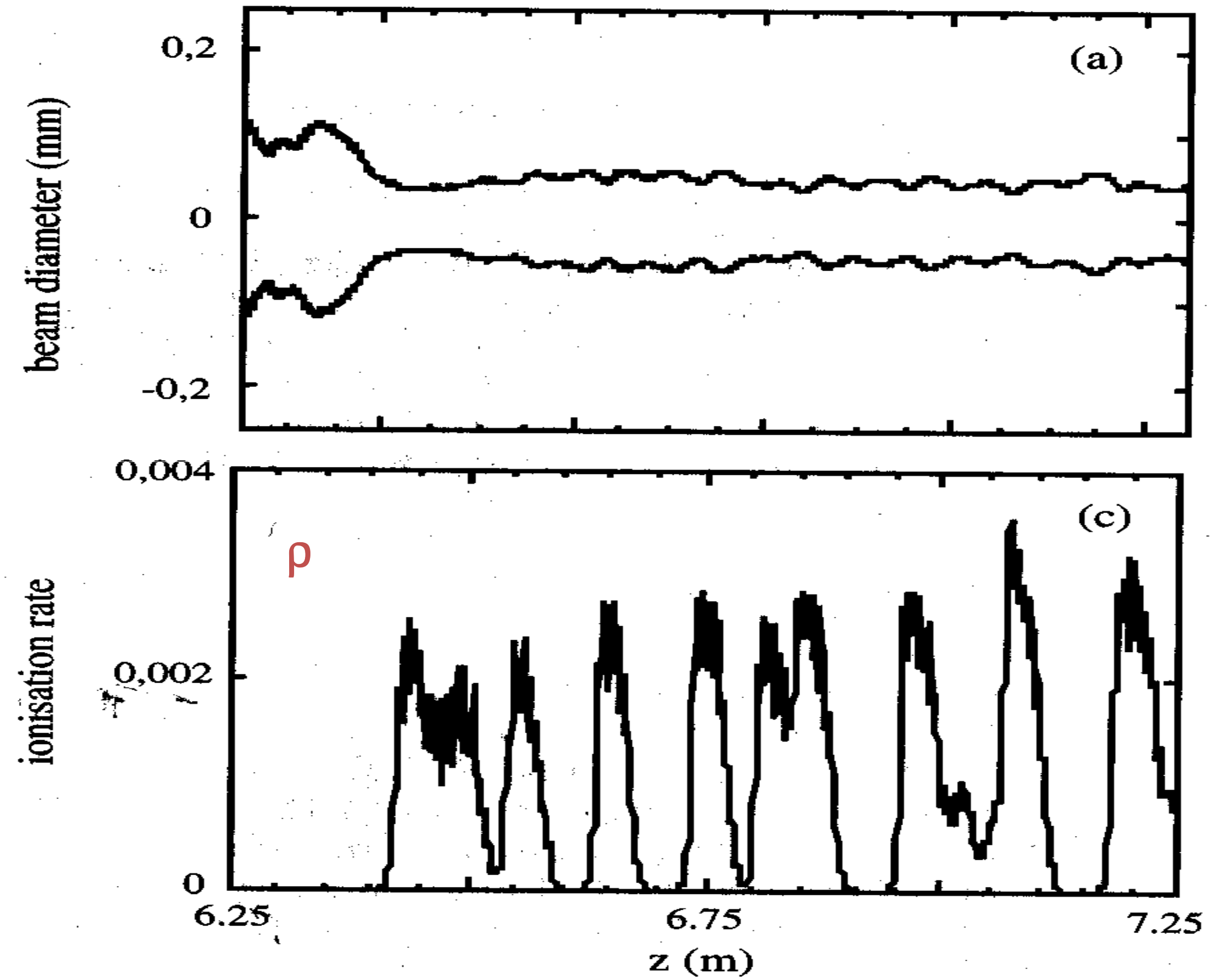
L > 300 m

Δn <> 10^{-5}

E = 1-5 mJ

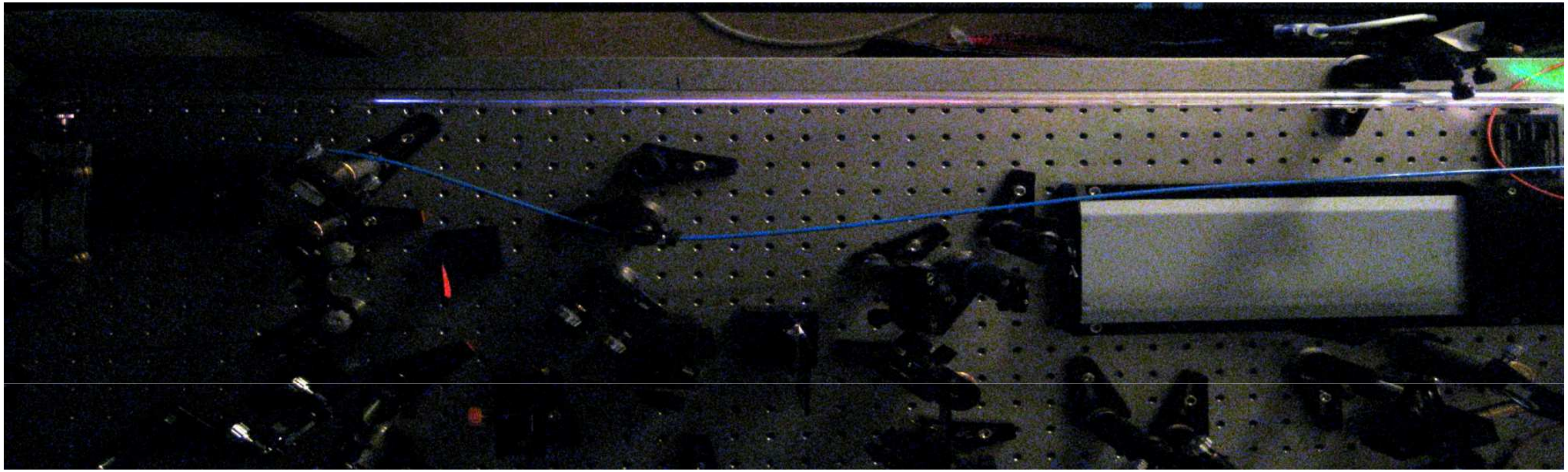
I = 10^{14} W/cm^2

ρ = 10^{15} cm^{-3}



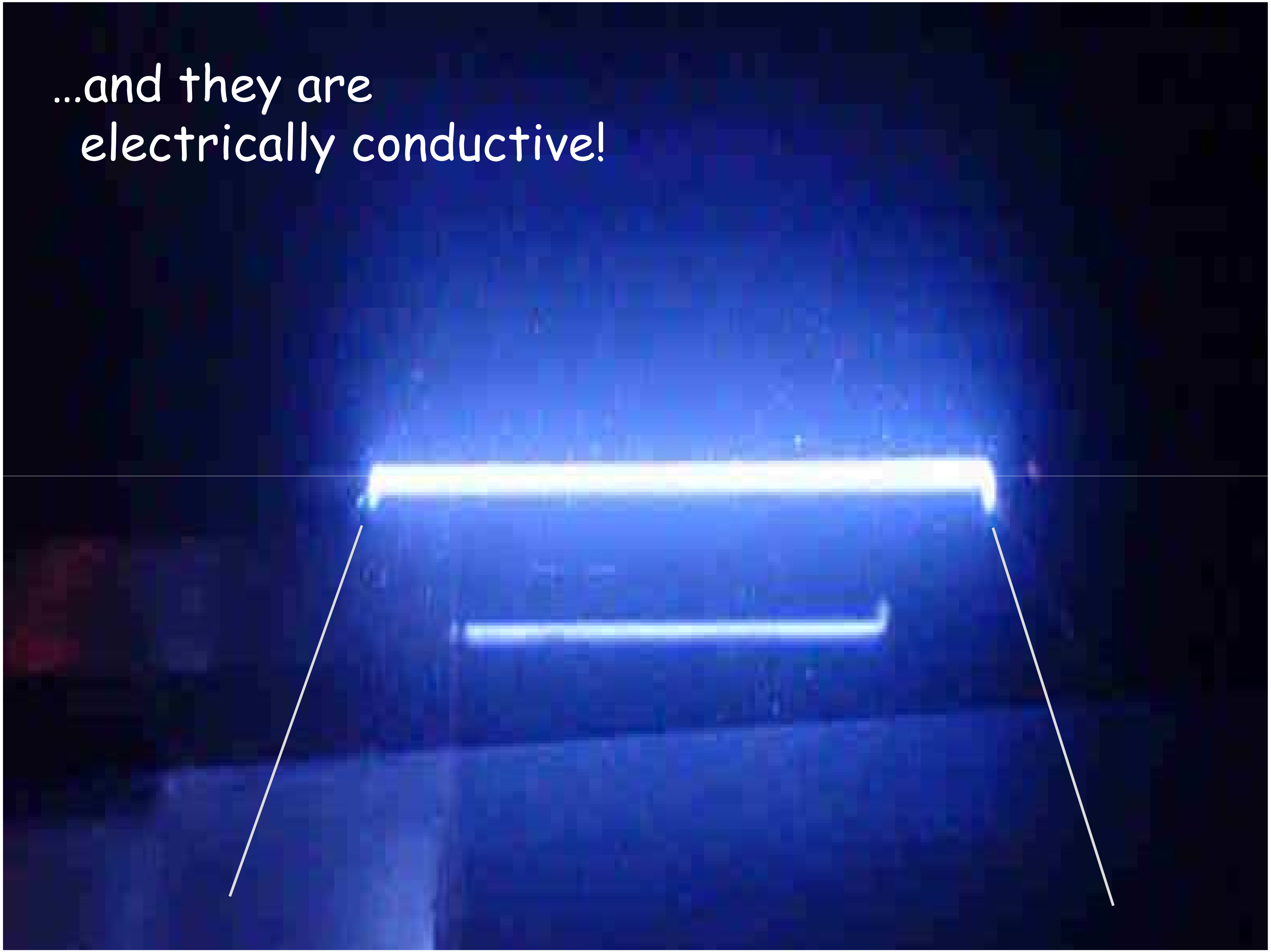
…Δn larger than thermal turbuleces -> almost no influence on propagation !

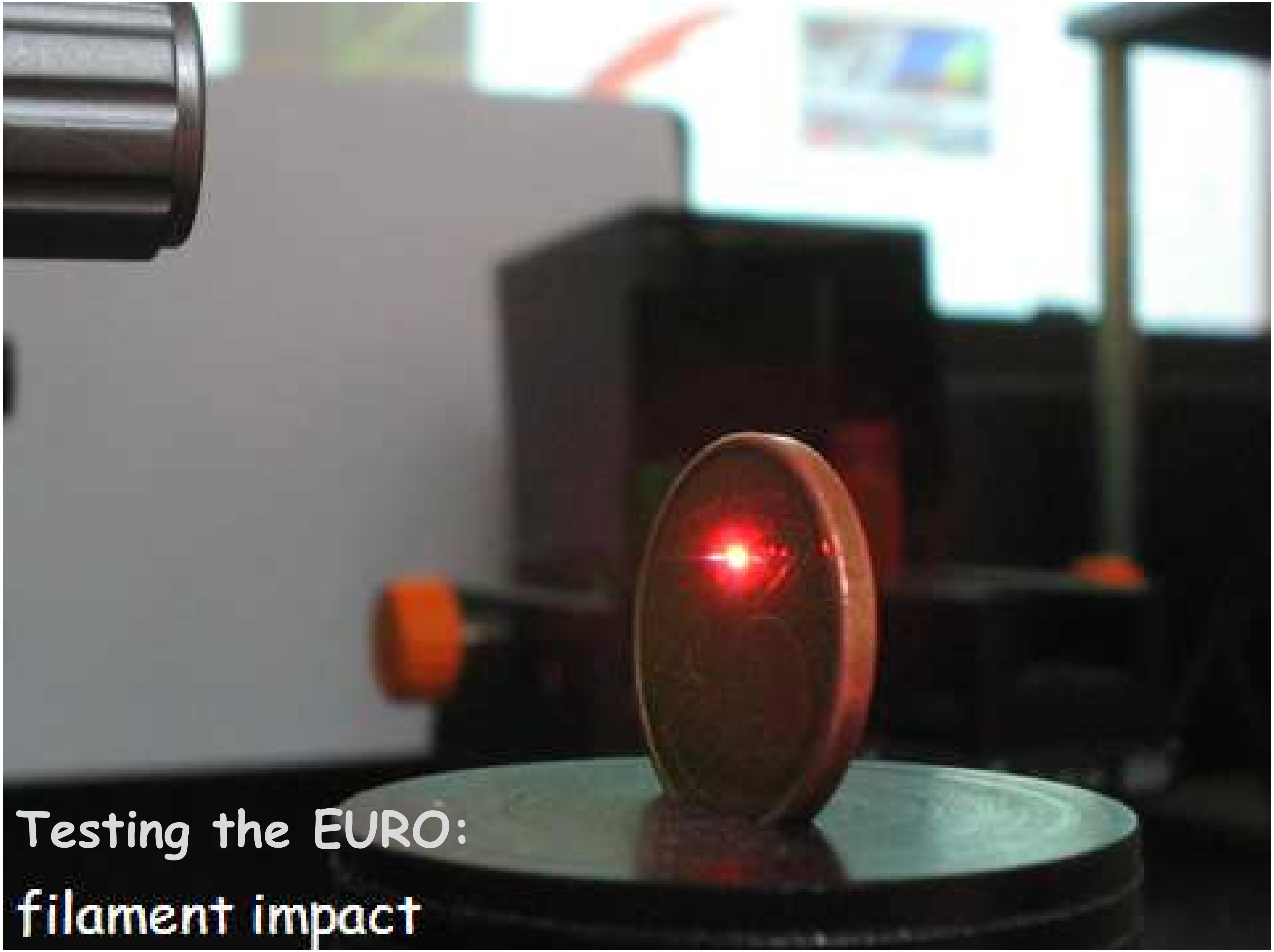
Properties of these filaments



When pumping @ 800nm
with 4mJ pulses of 60fs:

d = 100 μm
L ~ 100 m,
I = 10^{14} W/cm^2,
ρ = 10^{15} cm^{-3}


…and they are
electrically conductive!


Testing the EURO:
filament impact

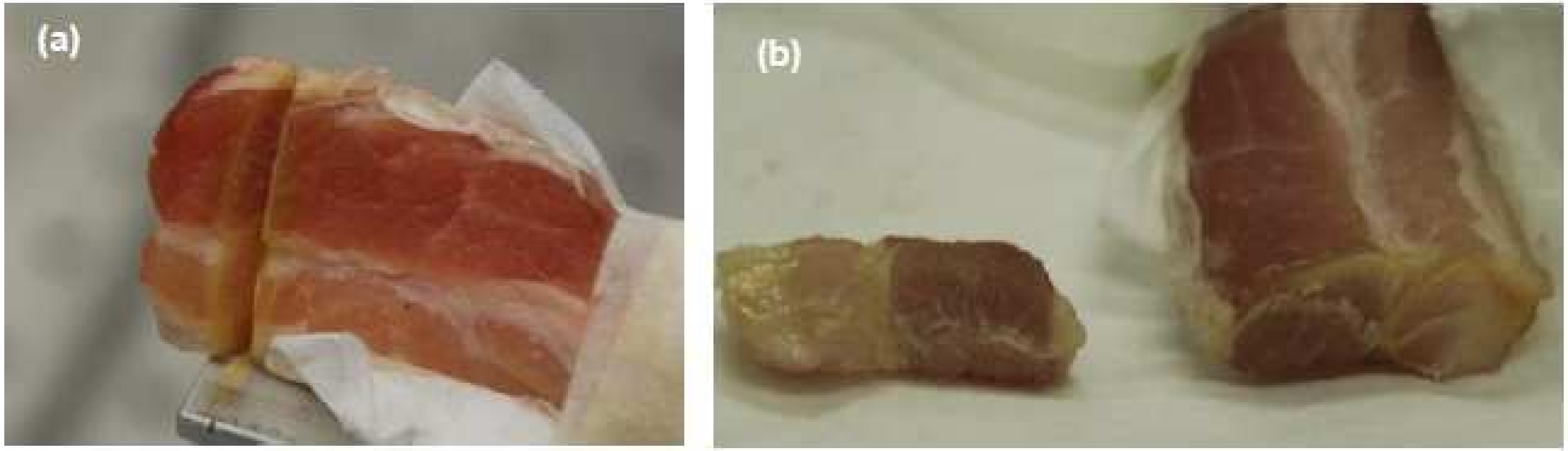
An emerging industrial application:*

Filament cut @ 6m distance

* Patent No.:US 8,097,830 B2

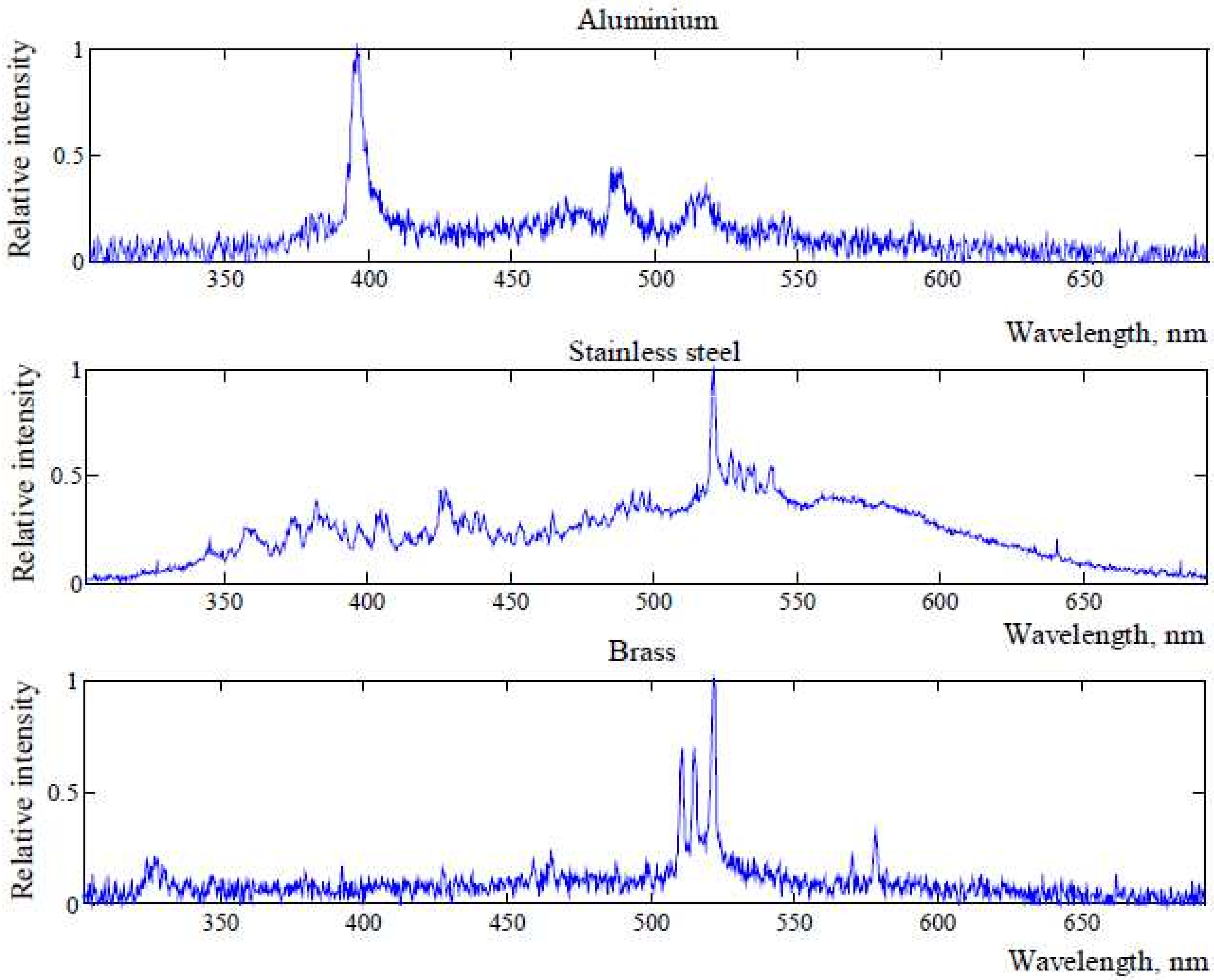
Filament Cut

An emerging medical application:

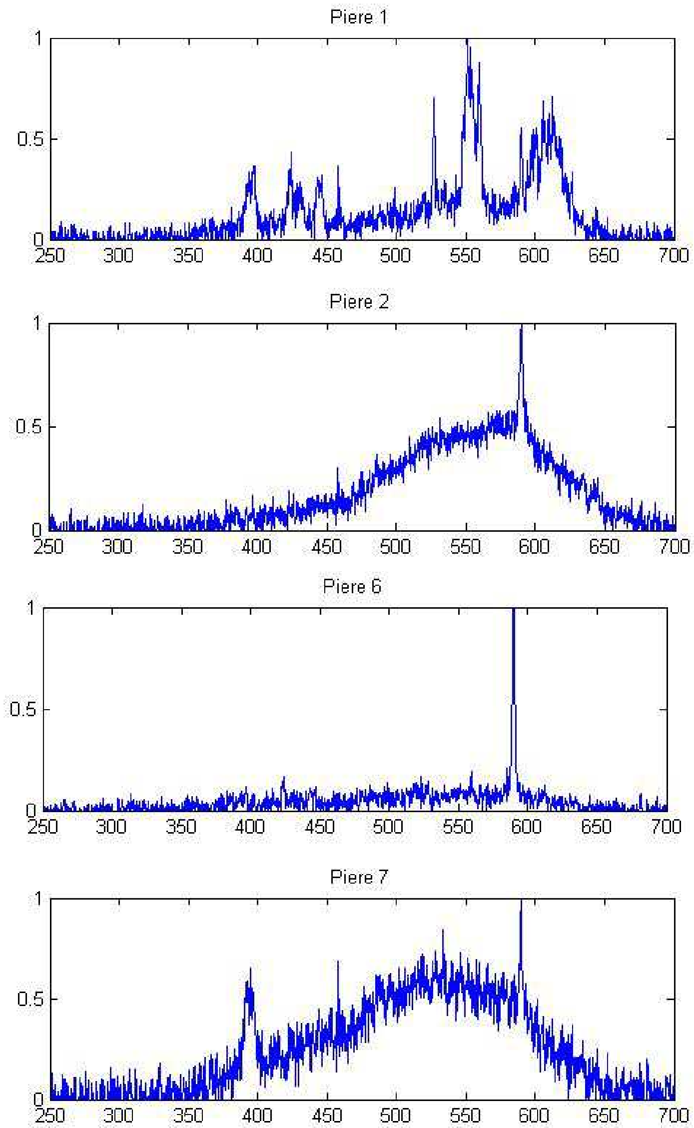


Bone and Filament cut @ 2m distance

Filament- induced breakdown spectroscopy (FIBS) on different metals



FIBS on different Minerals

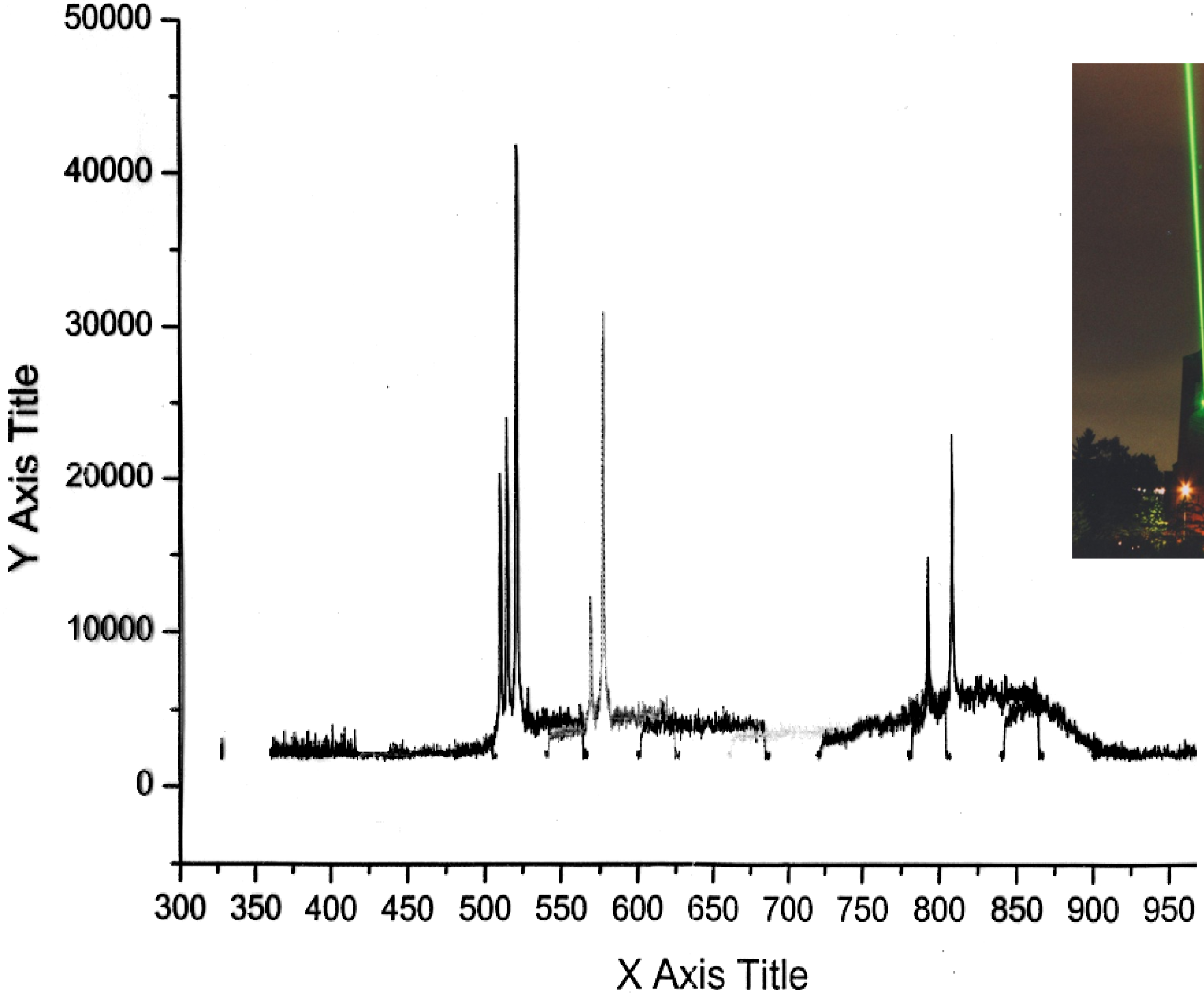


Future Objects

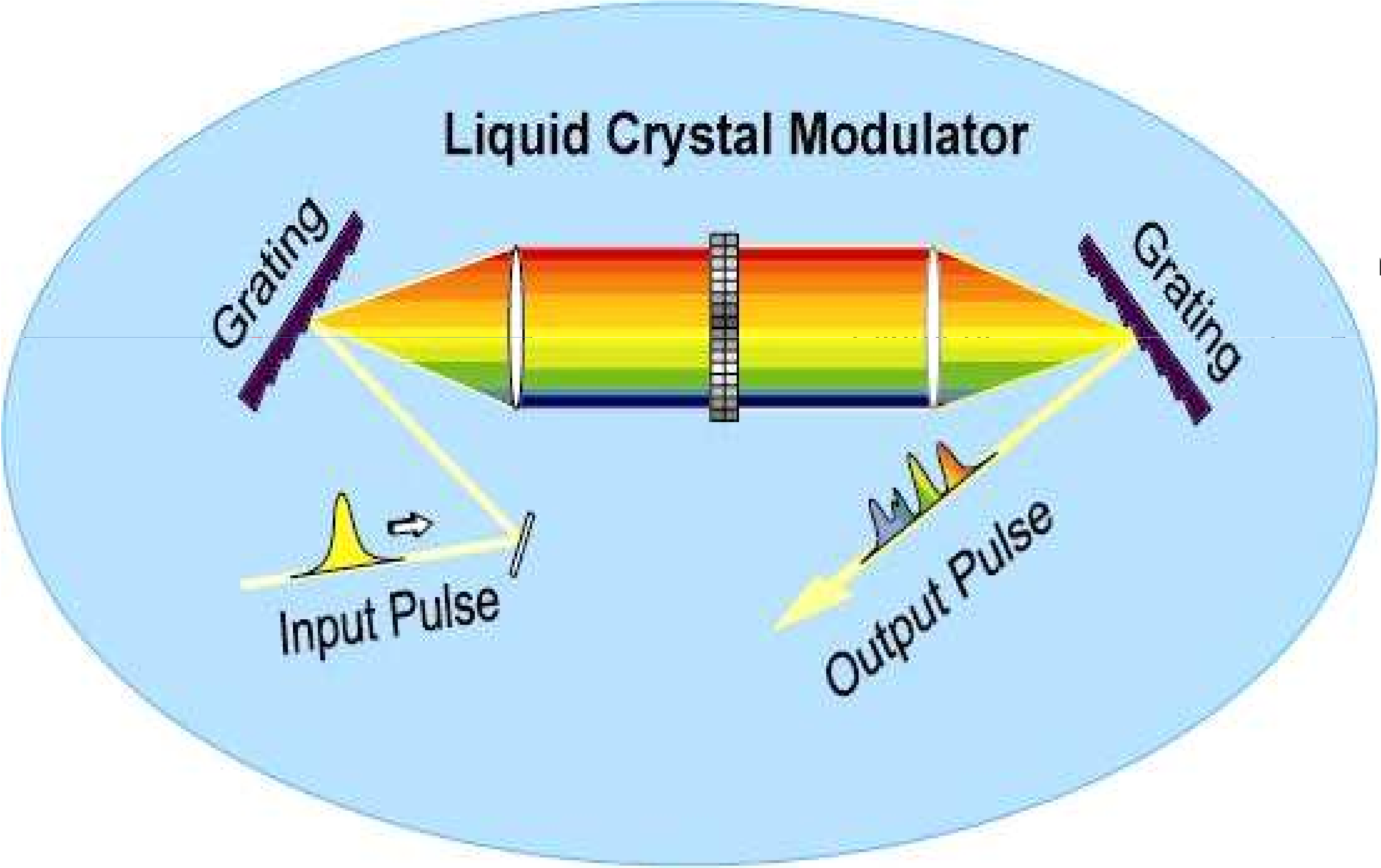
- mineral analysis
- industrial deposits
- radioactive fallouts
- ground humidity
- plant stress detection

But how far can we go?

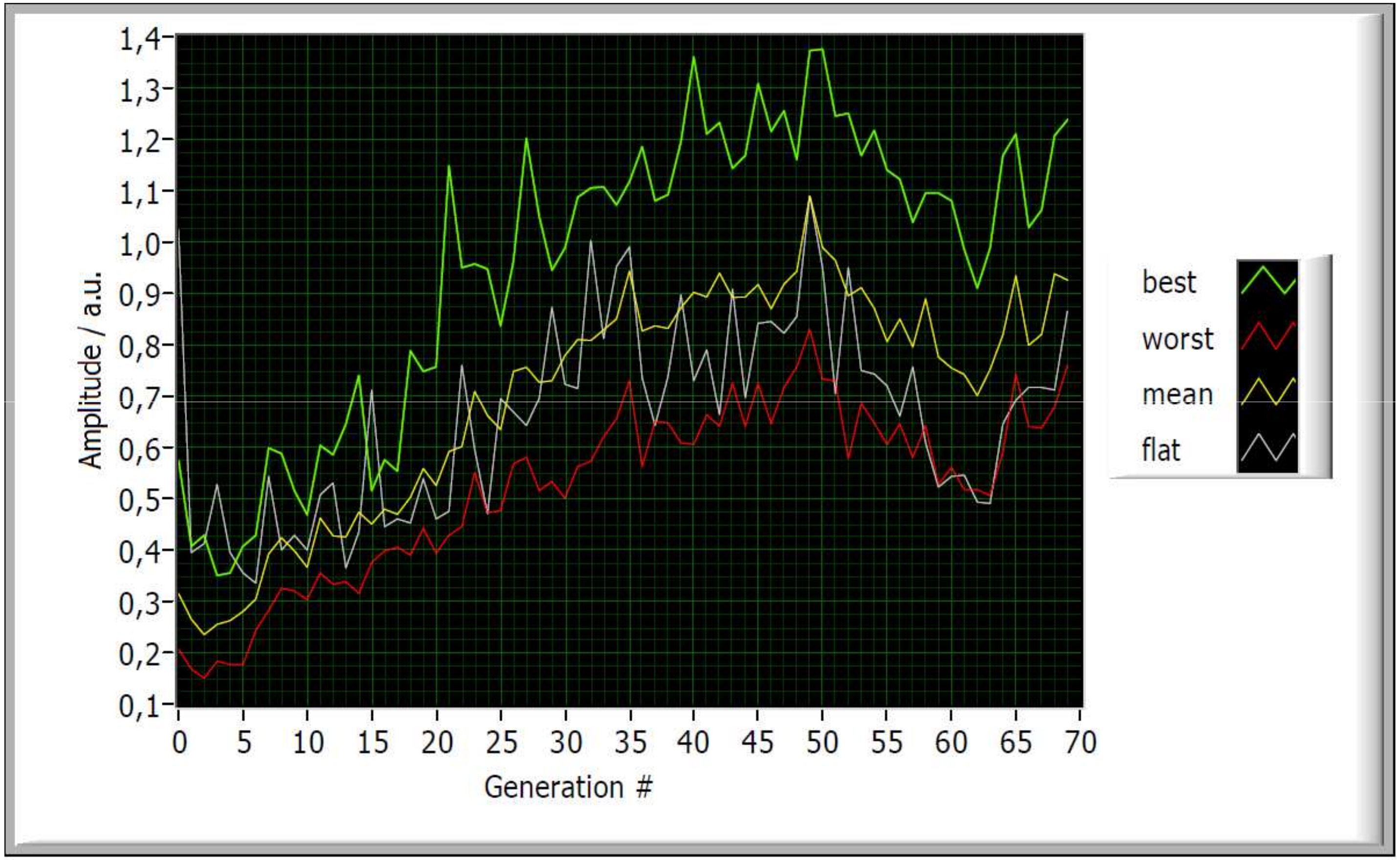
Plasma-lines of copper observed at 100 meters distance



Optimizing the supercontinuum for remote FIBS
(filament induced breakdown spectroscopy)



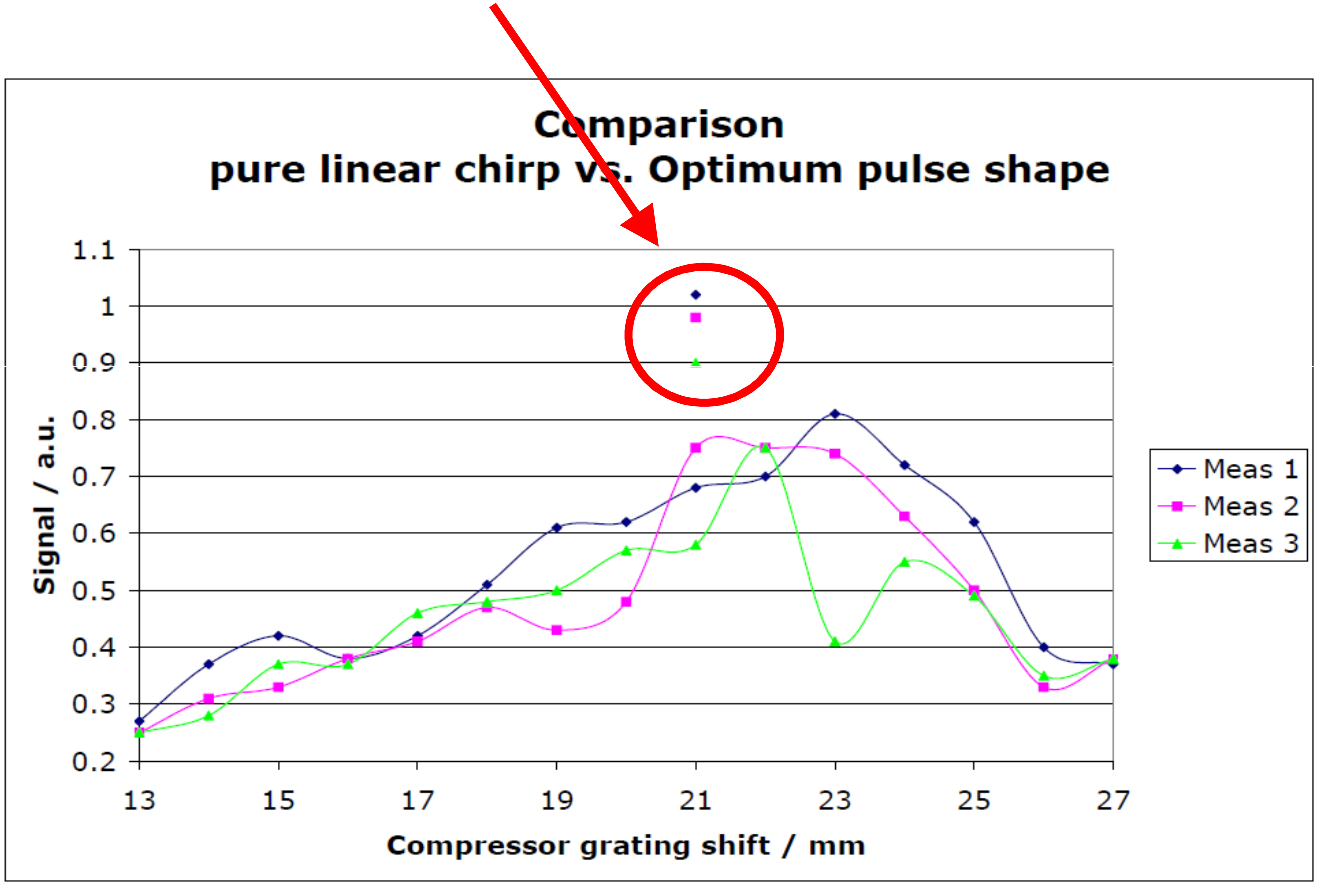
First preliminary results



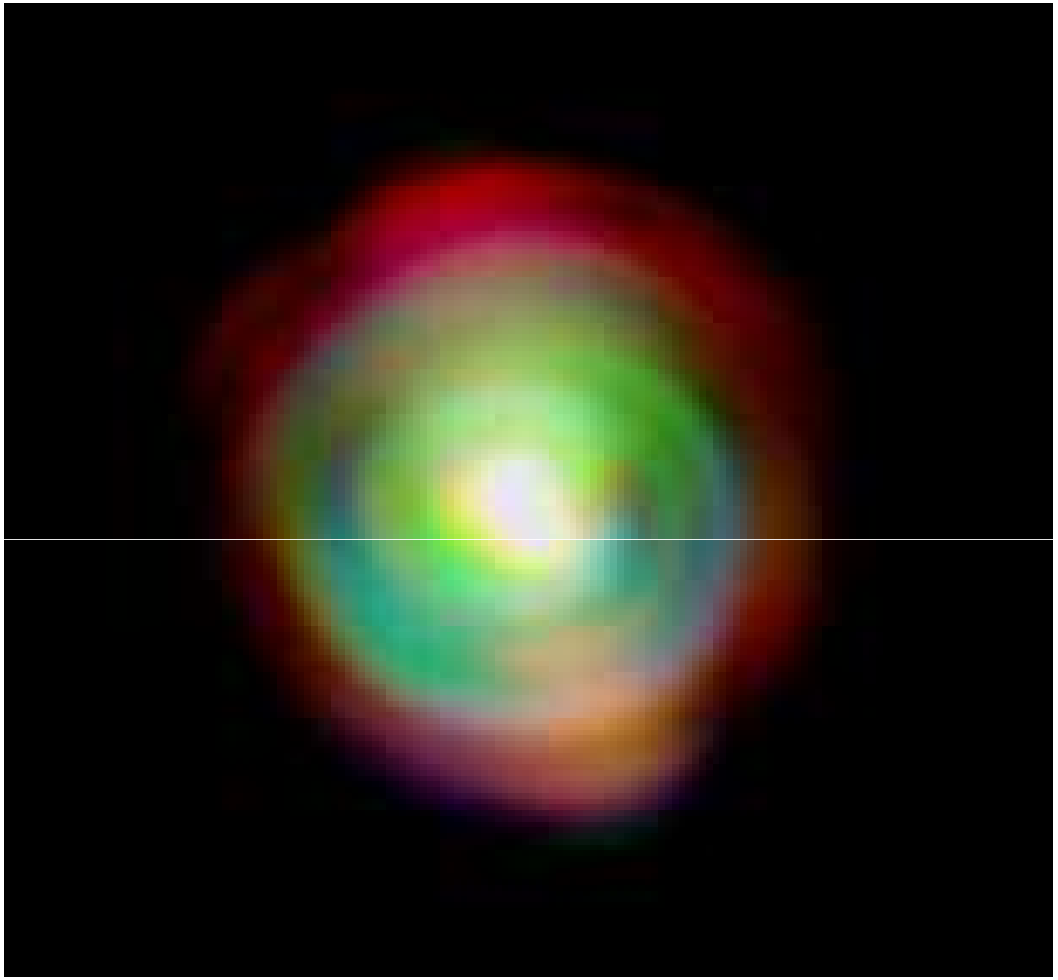
Evolution graph

Observations suggest:

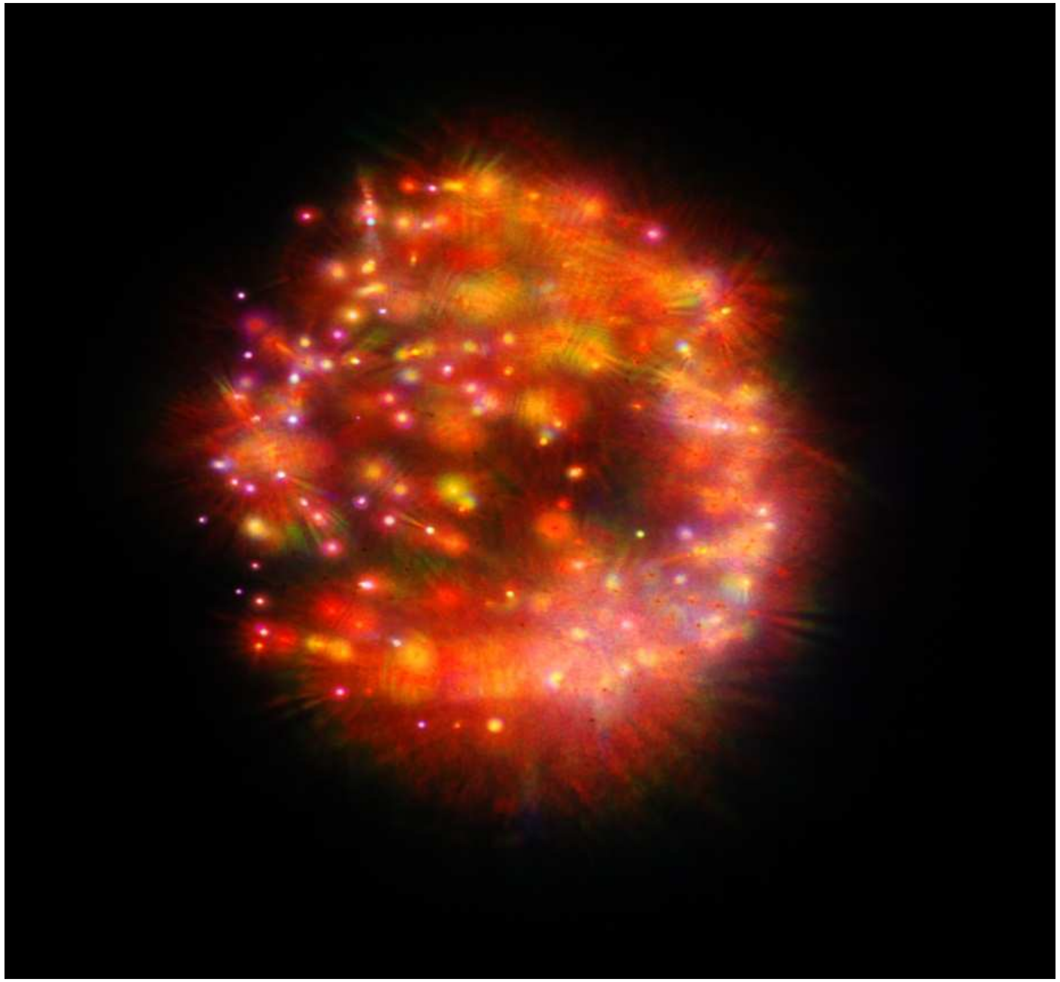
„Optimal pulse shape“ increases Supercontinuum intensity by up to ~20% compared to the optimum linear chirp.



… and now let us work at higher energies !



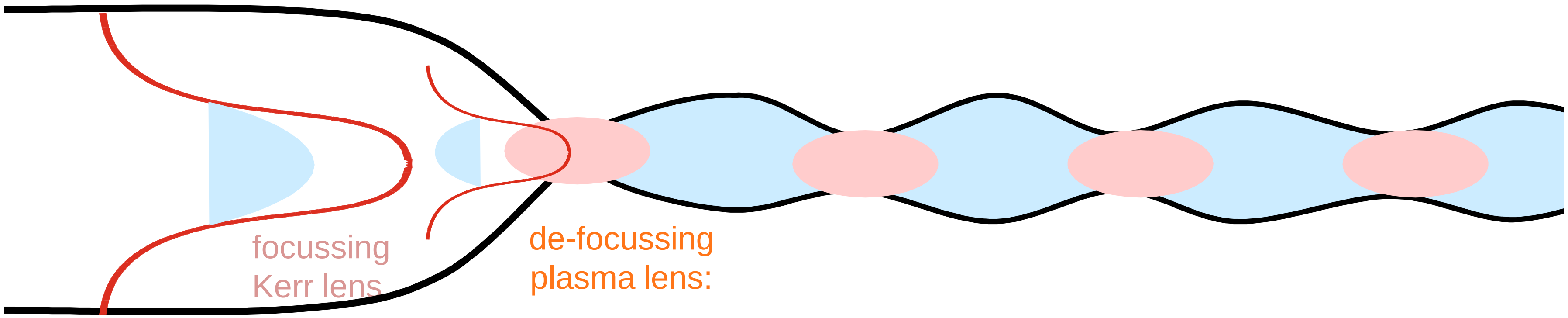
Mono-filamentation(<5 mJ)



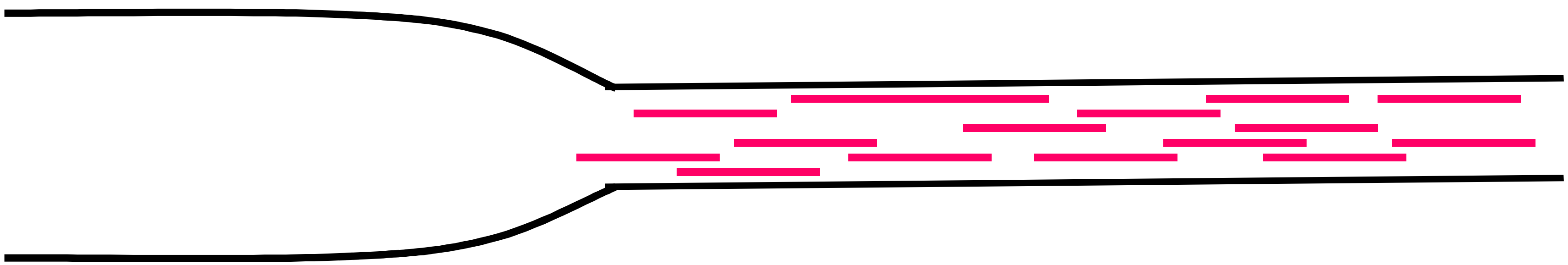
Multi-filamentation(>5 mJ)

Autoguided propagation

and multiple filamentation

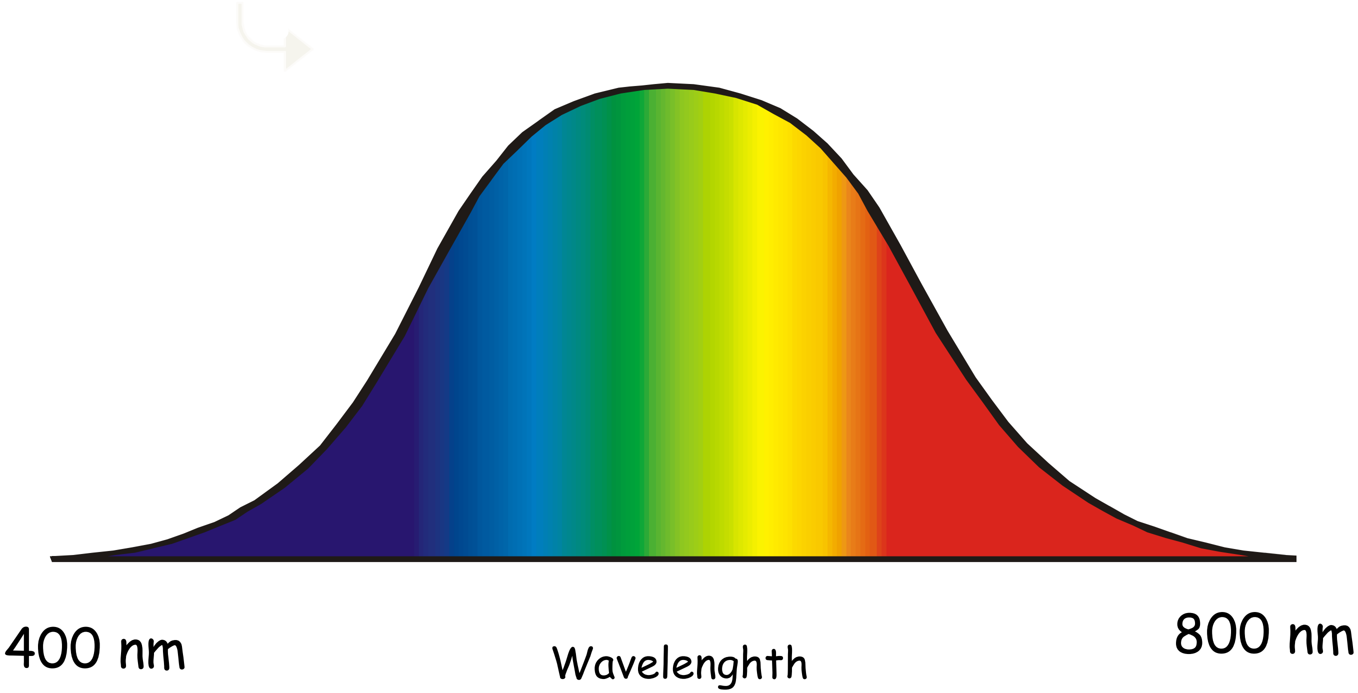


At higher energies (>5 mJ): multiple filamentation



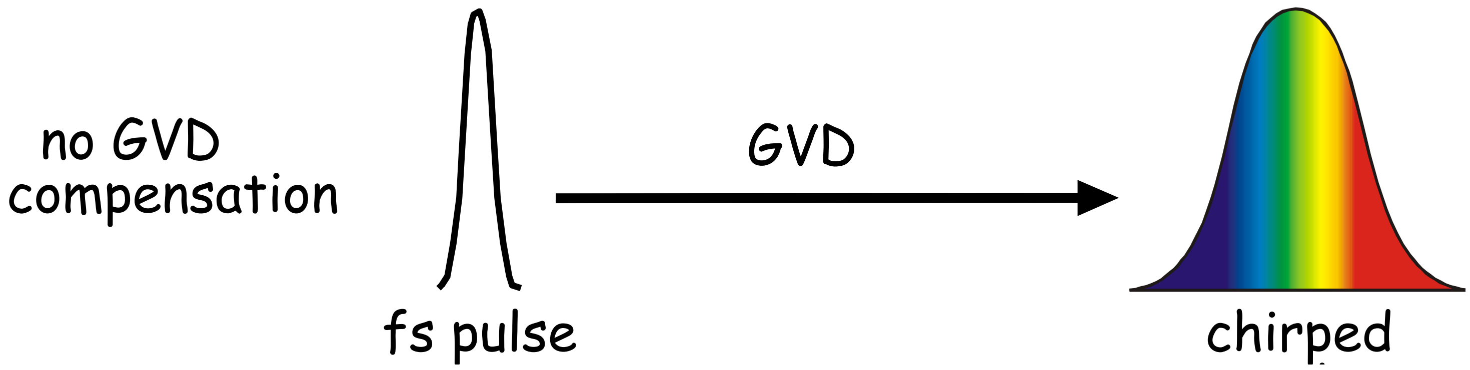
And now lets produce extended filament bundles to study the atmosphere

Specs of our pump laser: 240mJ @ 60fs = 4 Terawatt

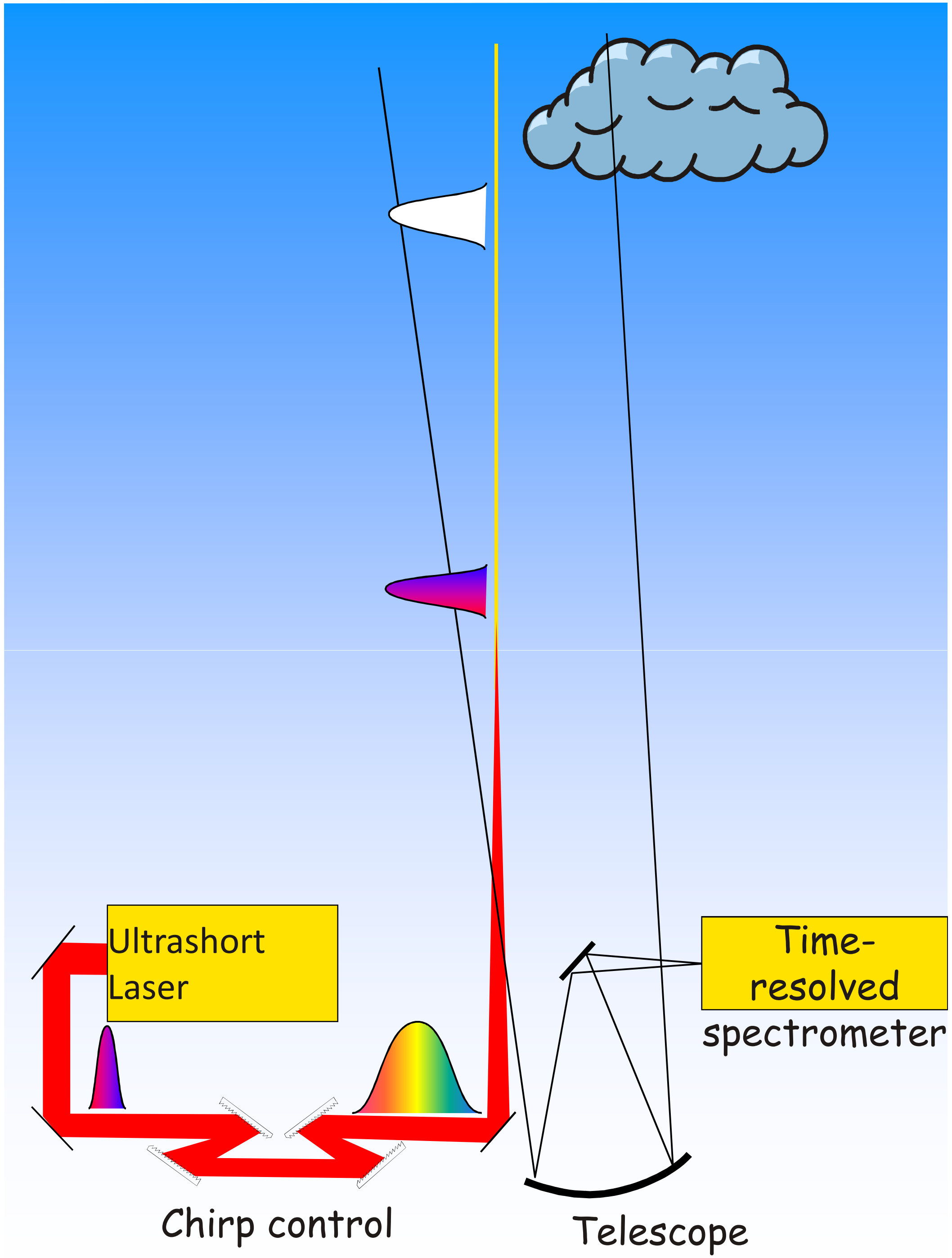


Careful: Since the spectral bandwidth of our filaments is rather broad, this has to be considered, when propagating over long distances !

Group-Velocity Dispersion



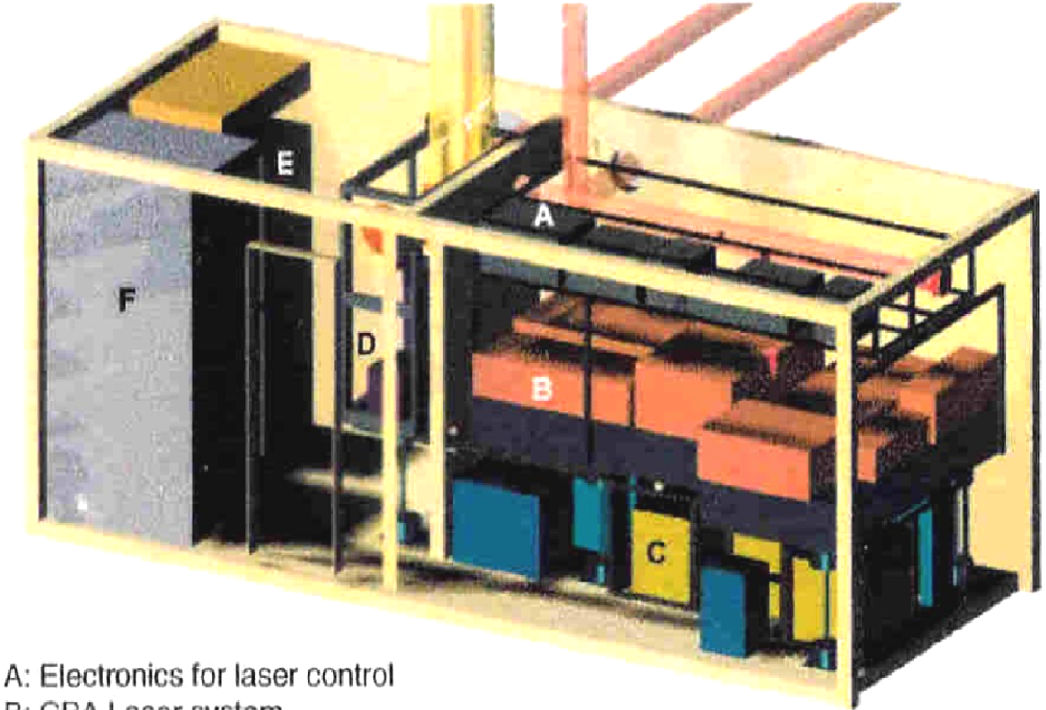
Principle of the fs - Lidar



The **result:**

extended bundles of
FILAMENTS !

The Teramobile:
A mobile fs -TW Laser and LIDAR System

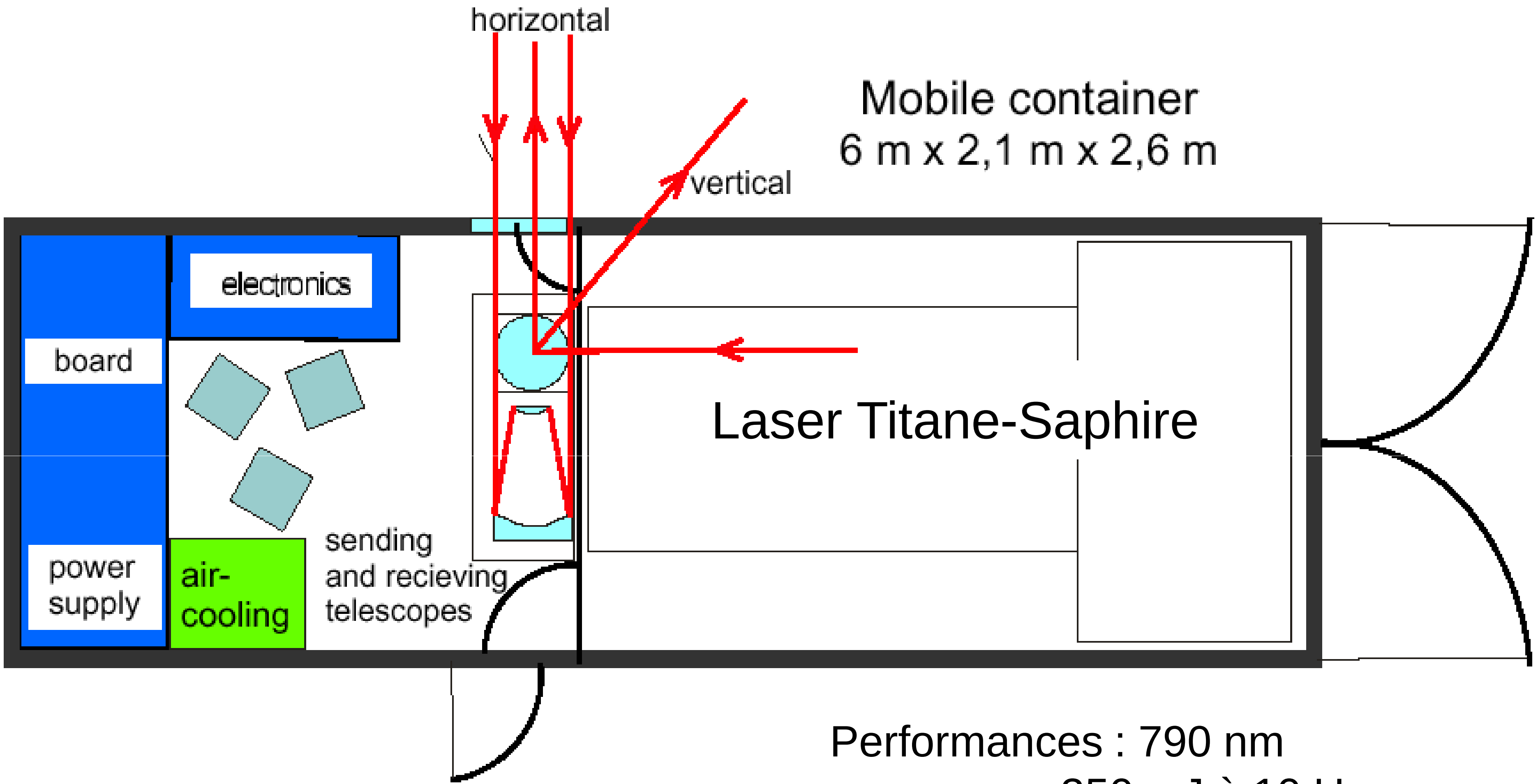


A: Electronics for laser control
B: CPA Laser system
C: Power units (stored in a closed clima box)
D: Detection box (telescope, spectrometer, detectors,...)
E: Computer and electronics
F: Power supply and air conditioning

Nominal laser specifications:

shortest pulse 70 fs, energy 350 mJ → 5 TW, rep. 10 Hz

TeraMobile

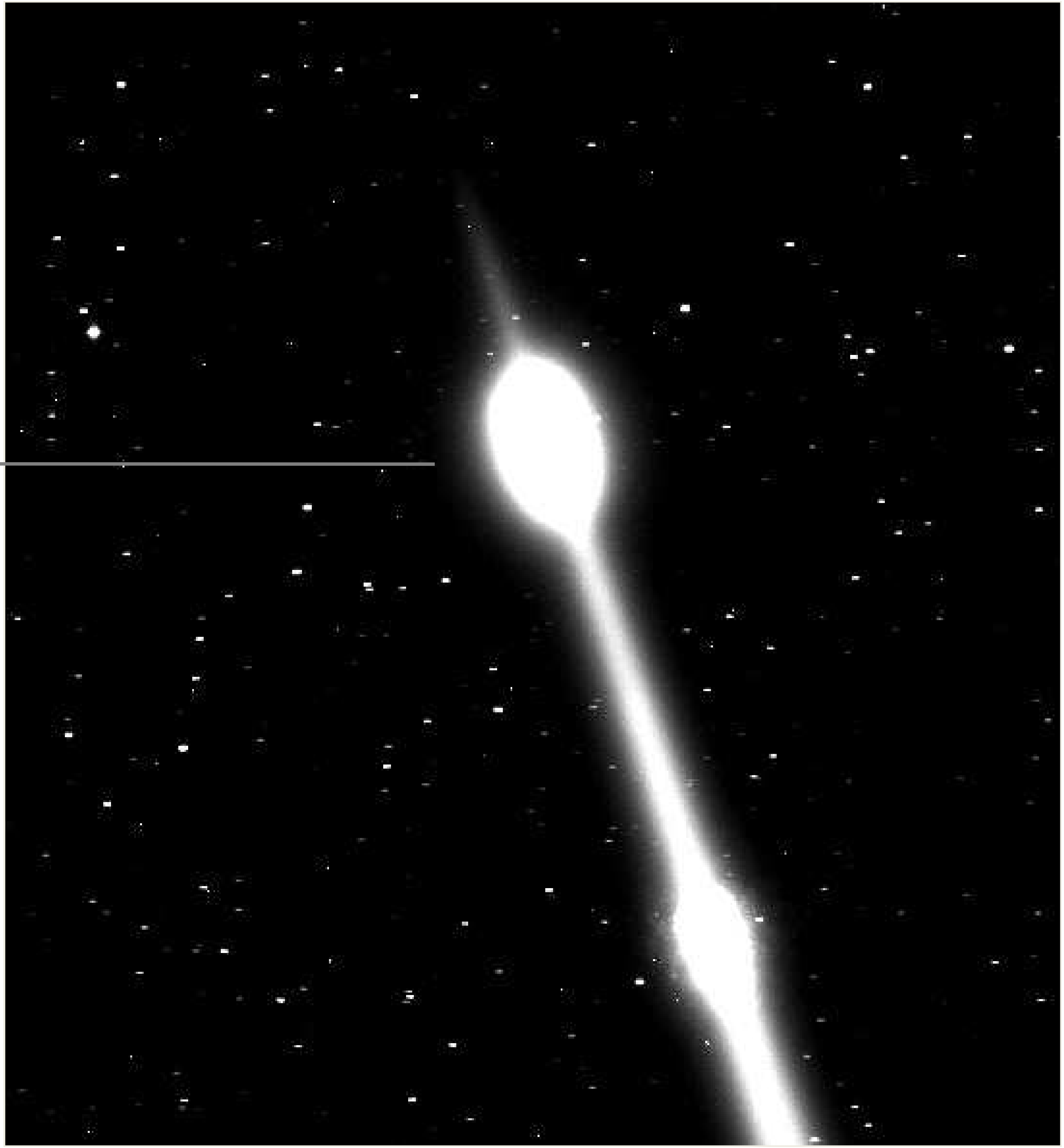


Performances : 790 nm
350 mJ à 10 Hz
60 fs
5 TW

H. Wille *et al.*, Eur. Phys. J. - A.P., **20**, 183 (2002)
J. Kasparian *et al.*, Science **301**, 61 (2003)

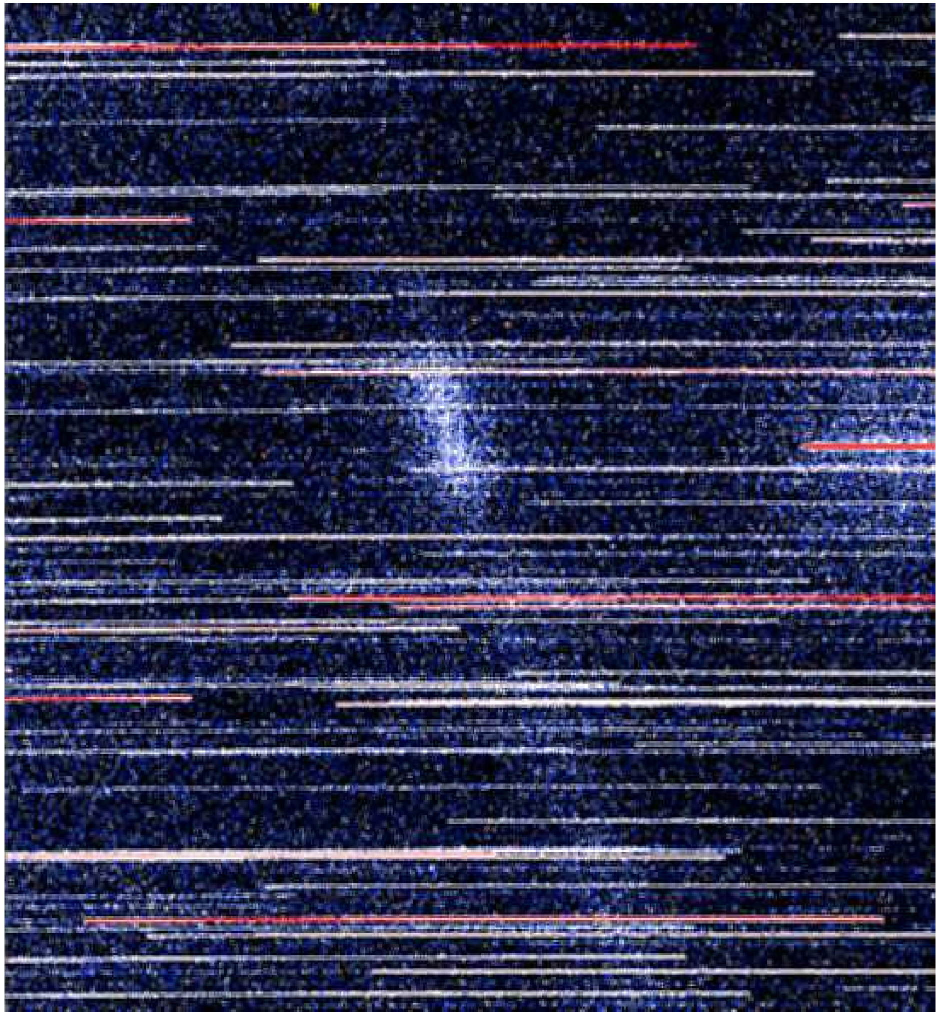
Tautenburg Observatorium

White Light
until
18 km

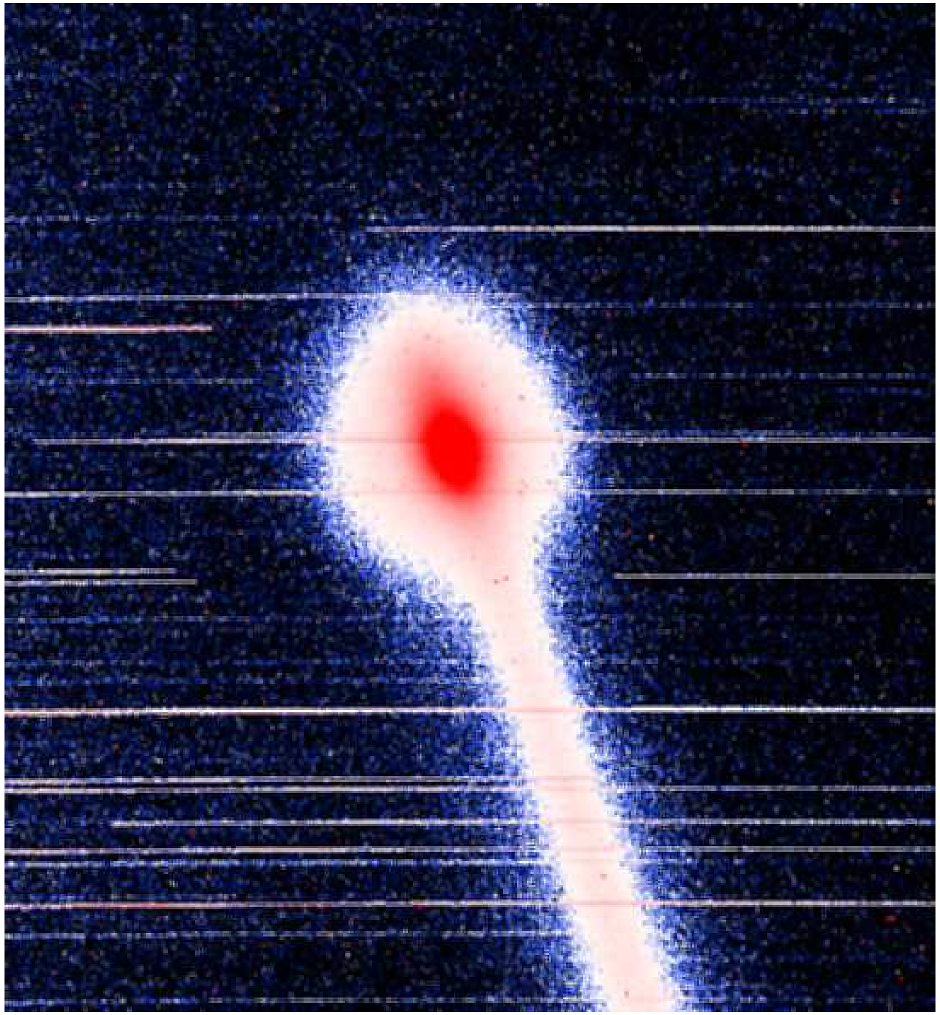


Control of the white-light generation

Positive chirp (600 fs)

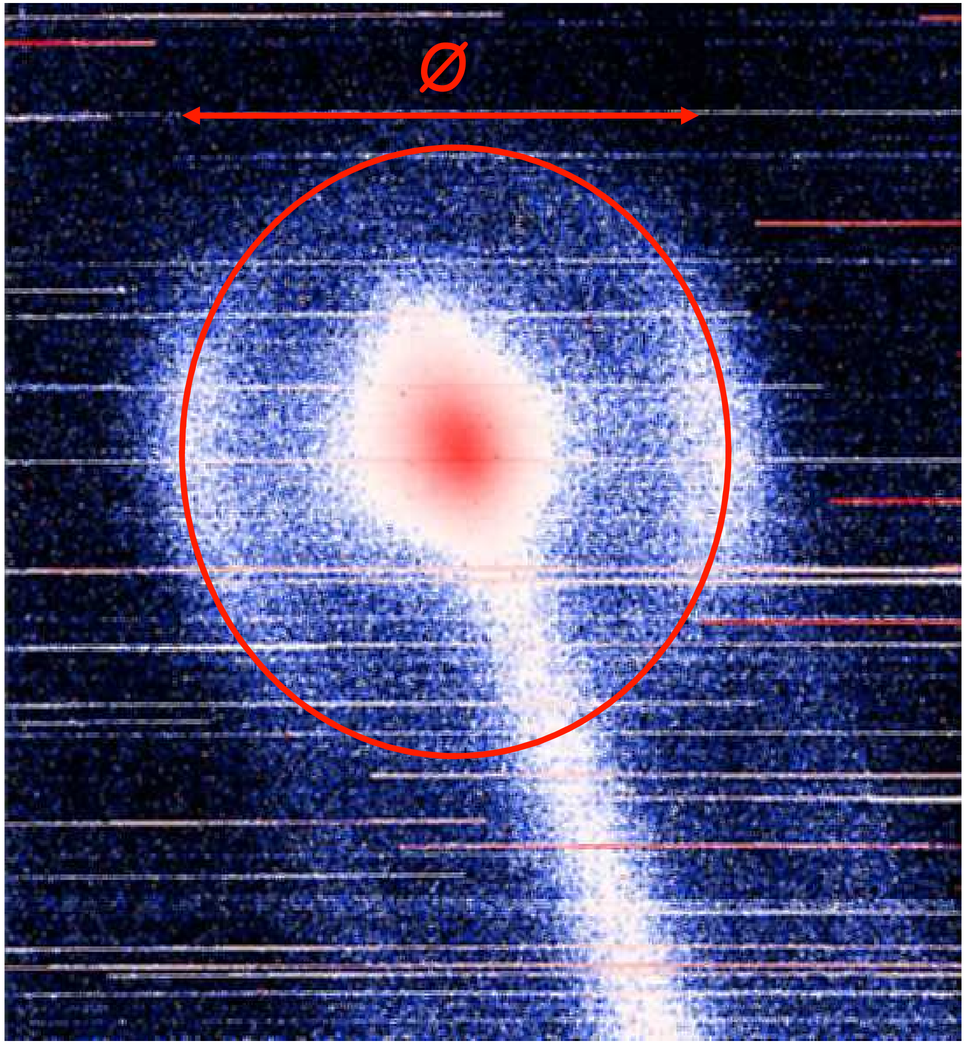


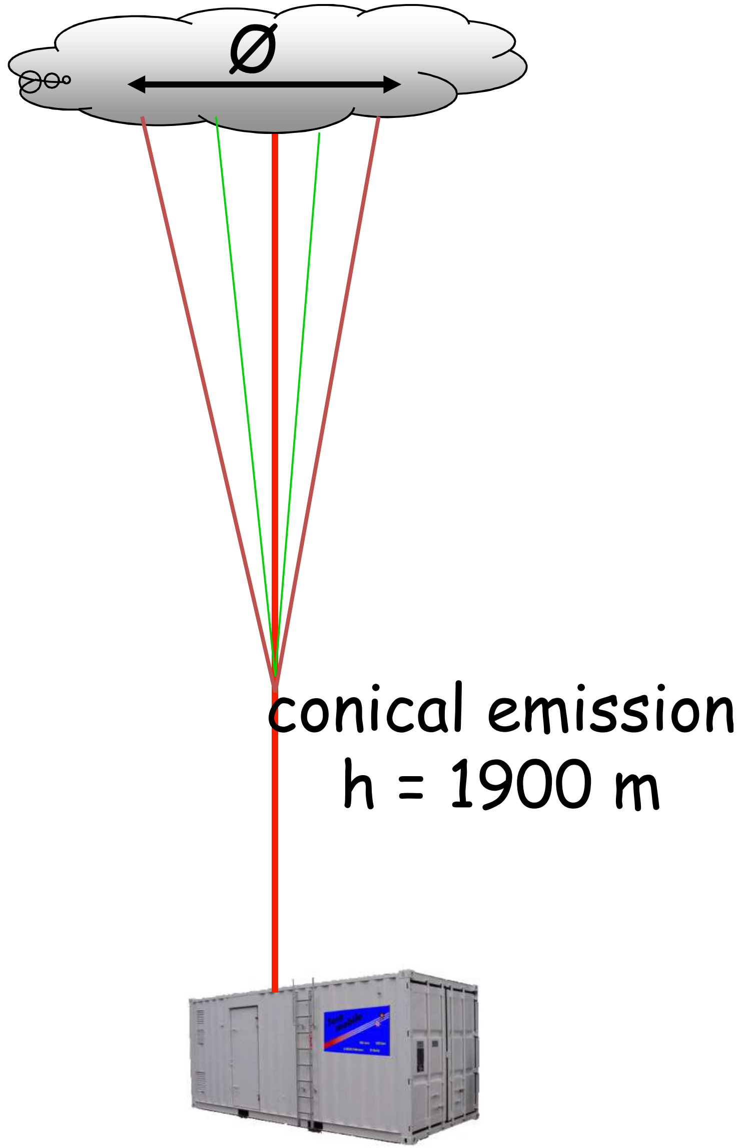
GVD precompensation (-600 fs)



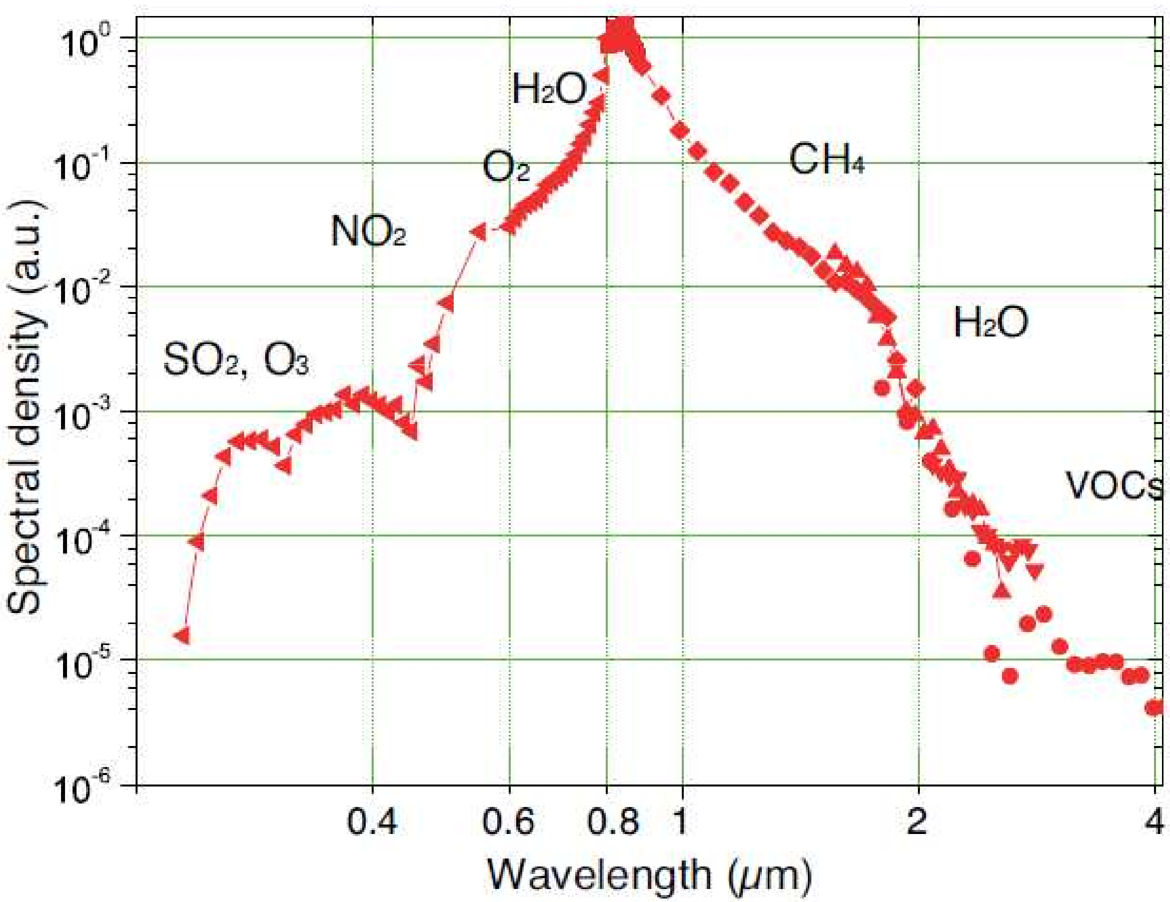
Conical emission

Slight pre-compensation of GVD (-150 fs)



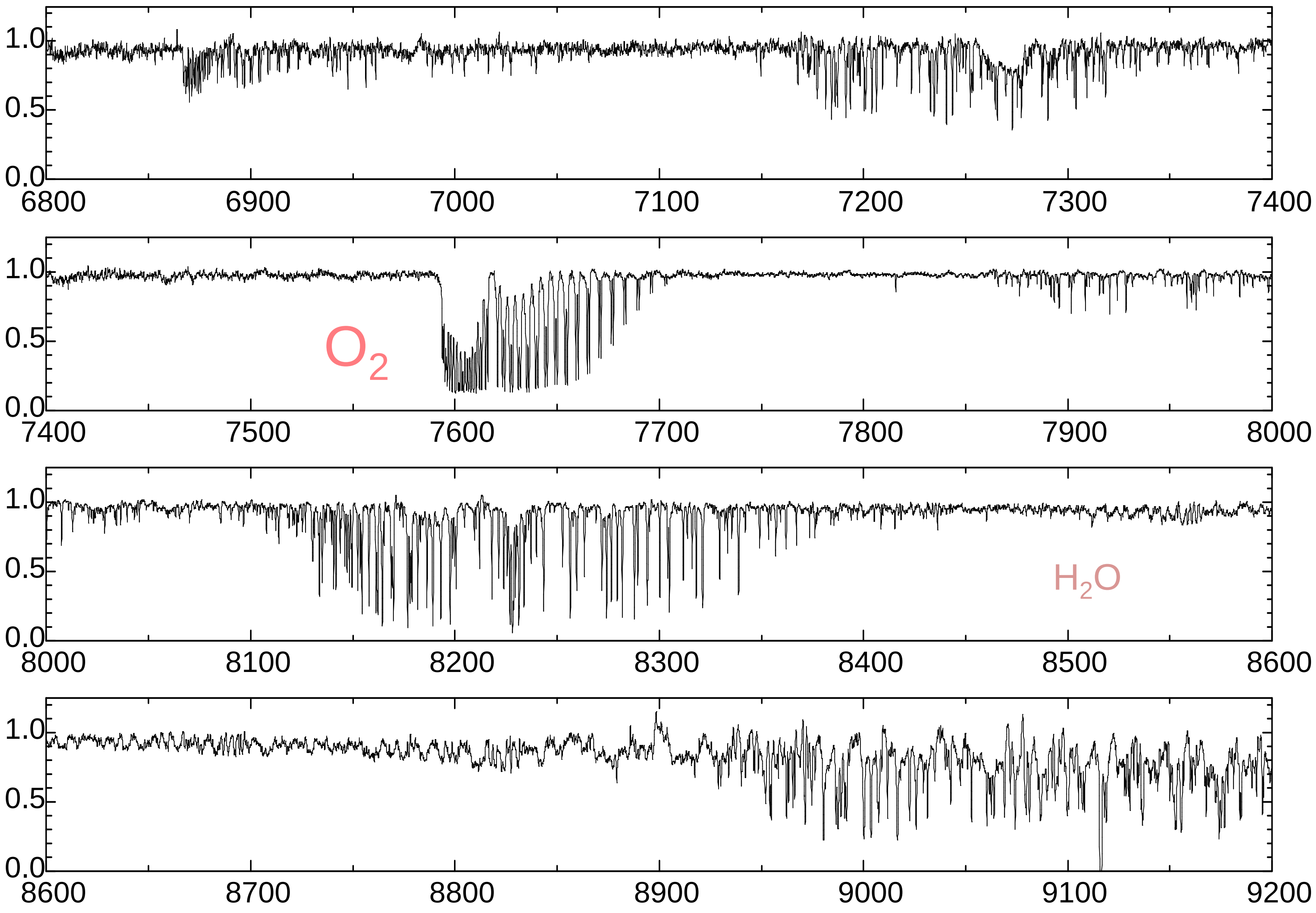


White-Light Continuum

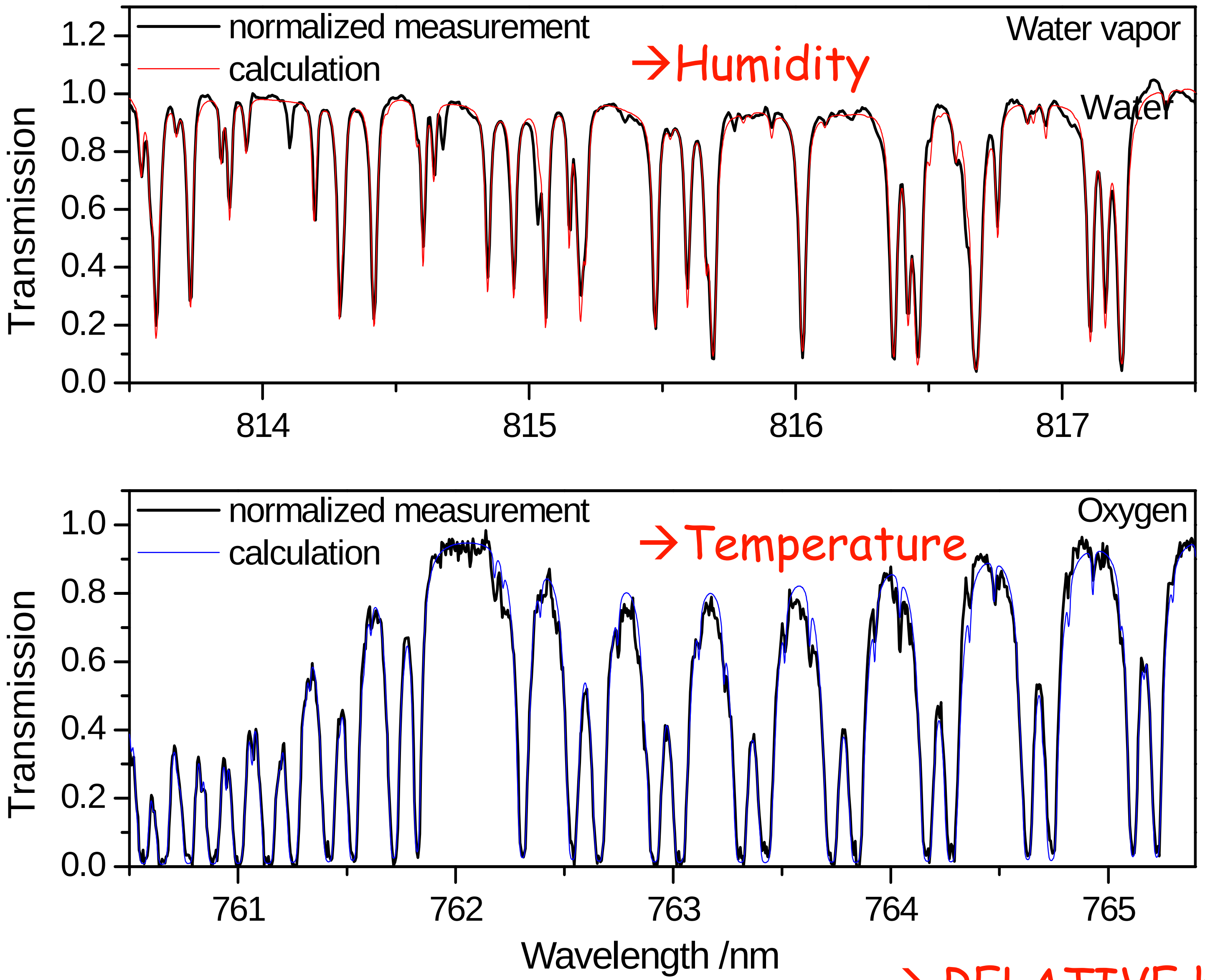


J.Kasparian et al., Opt. Lett. ***25****, 1397 (2000)*

White-light atmospheric absorption spectrum from 4 km altitude

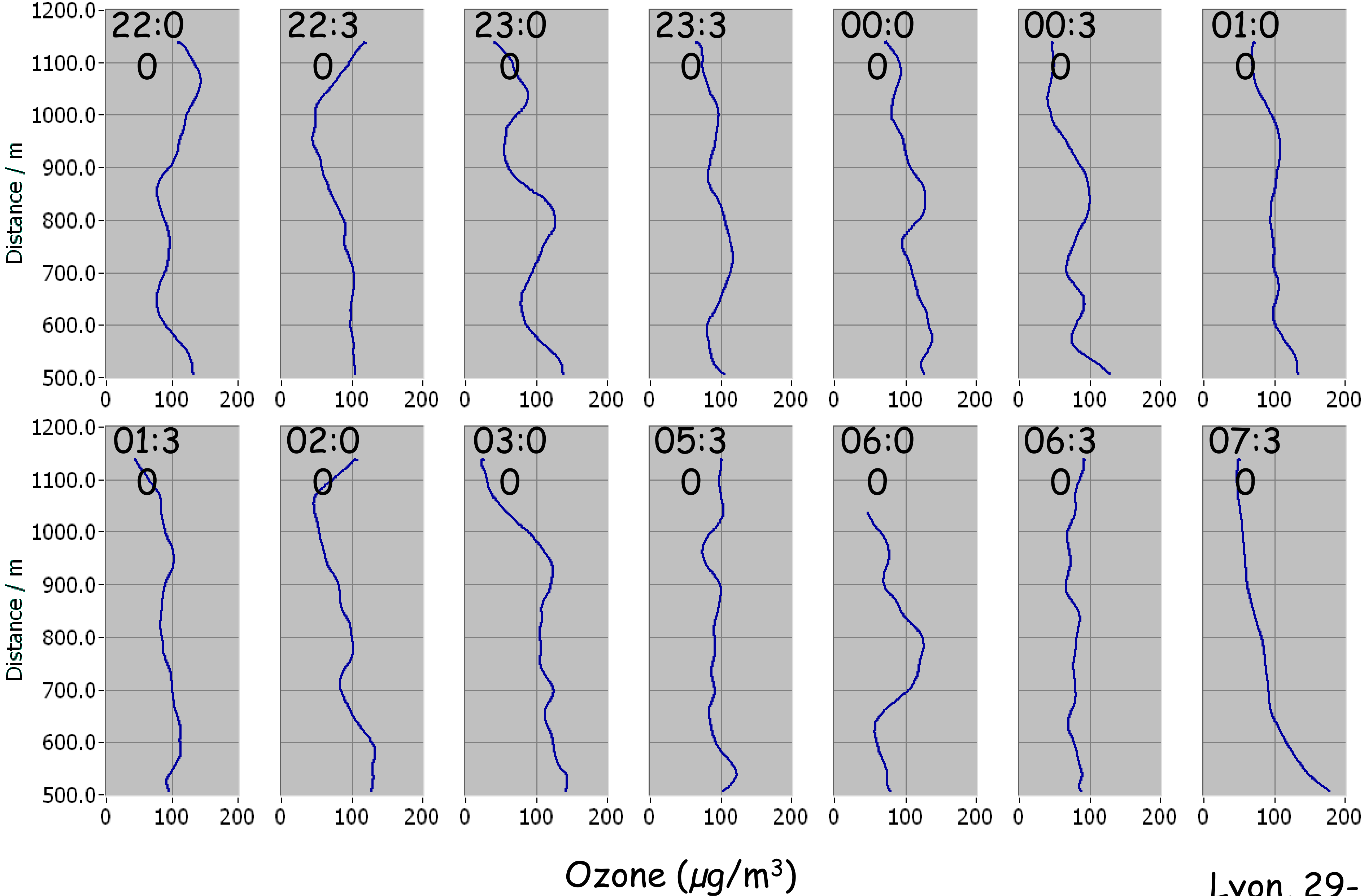


Simultaneous oxygen and water vapor measurement

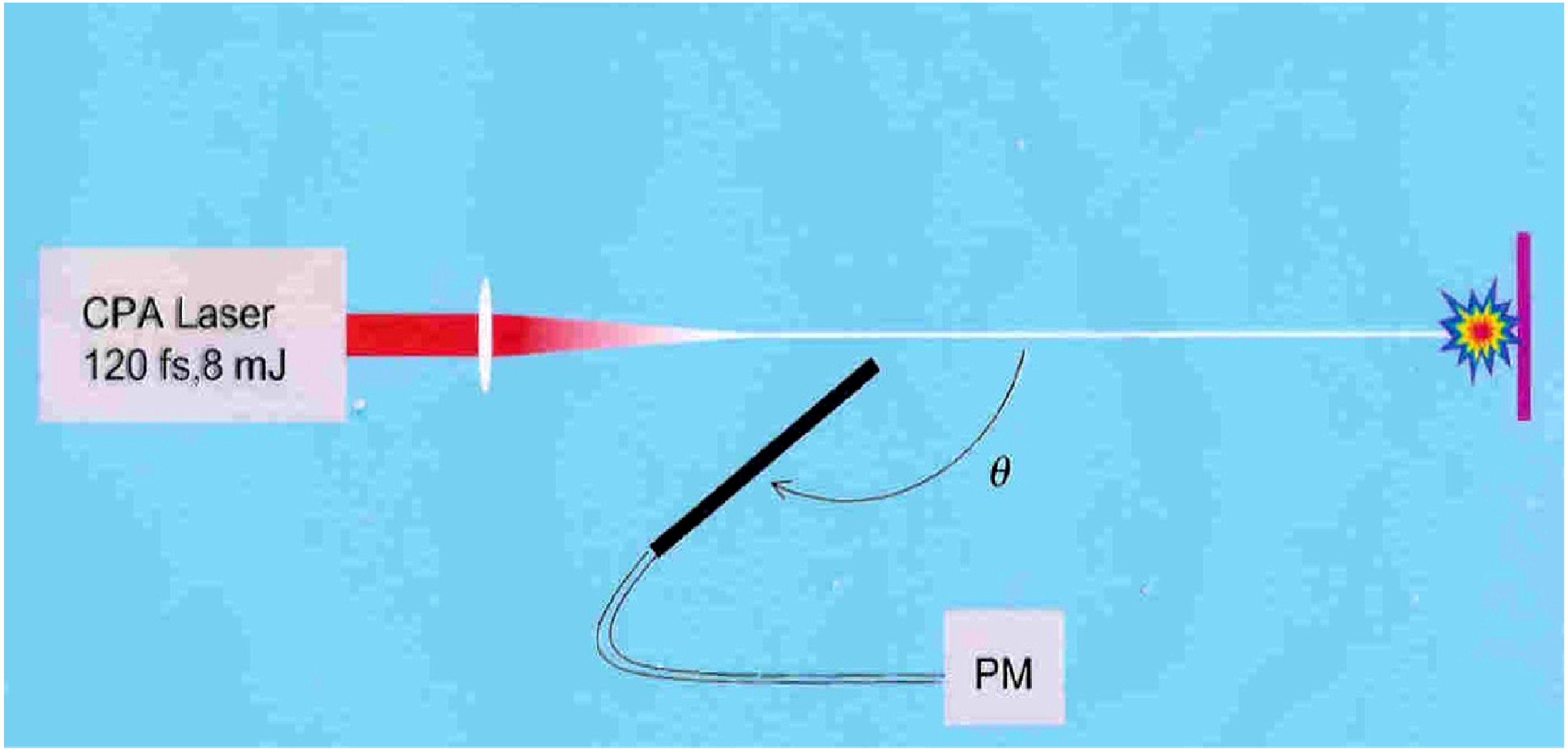


→ RELATIVE humidity

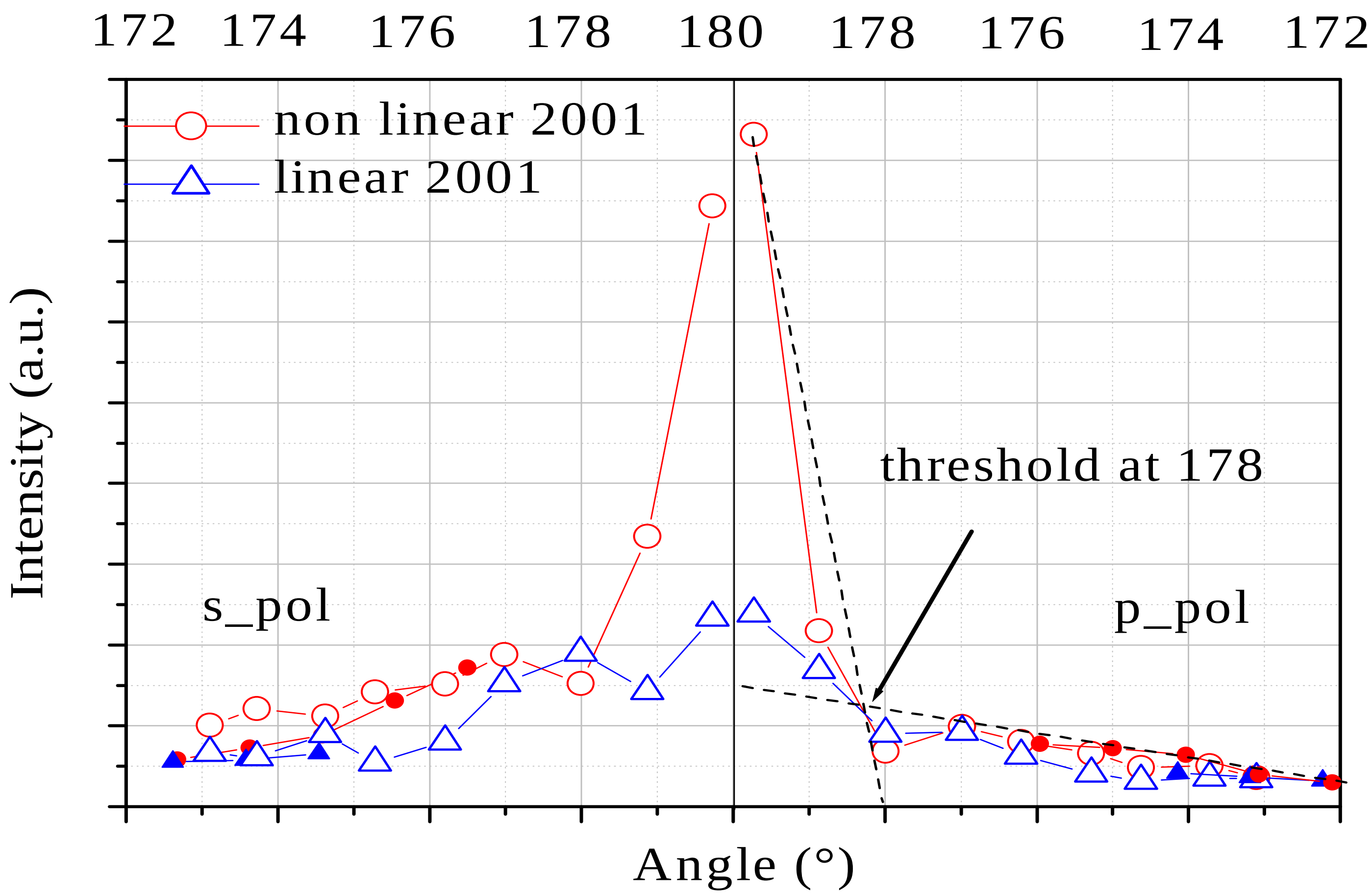
Time evolution of the Ozone profile



Angular distribution measurement of the white-light emitted from a filament

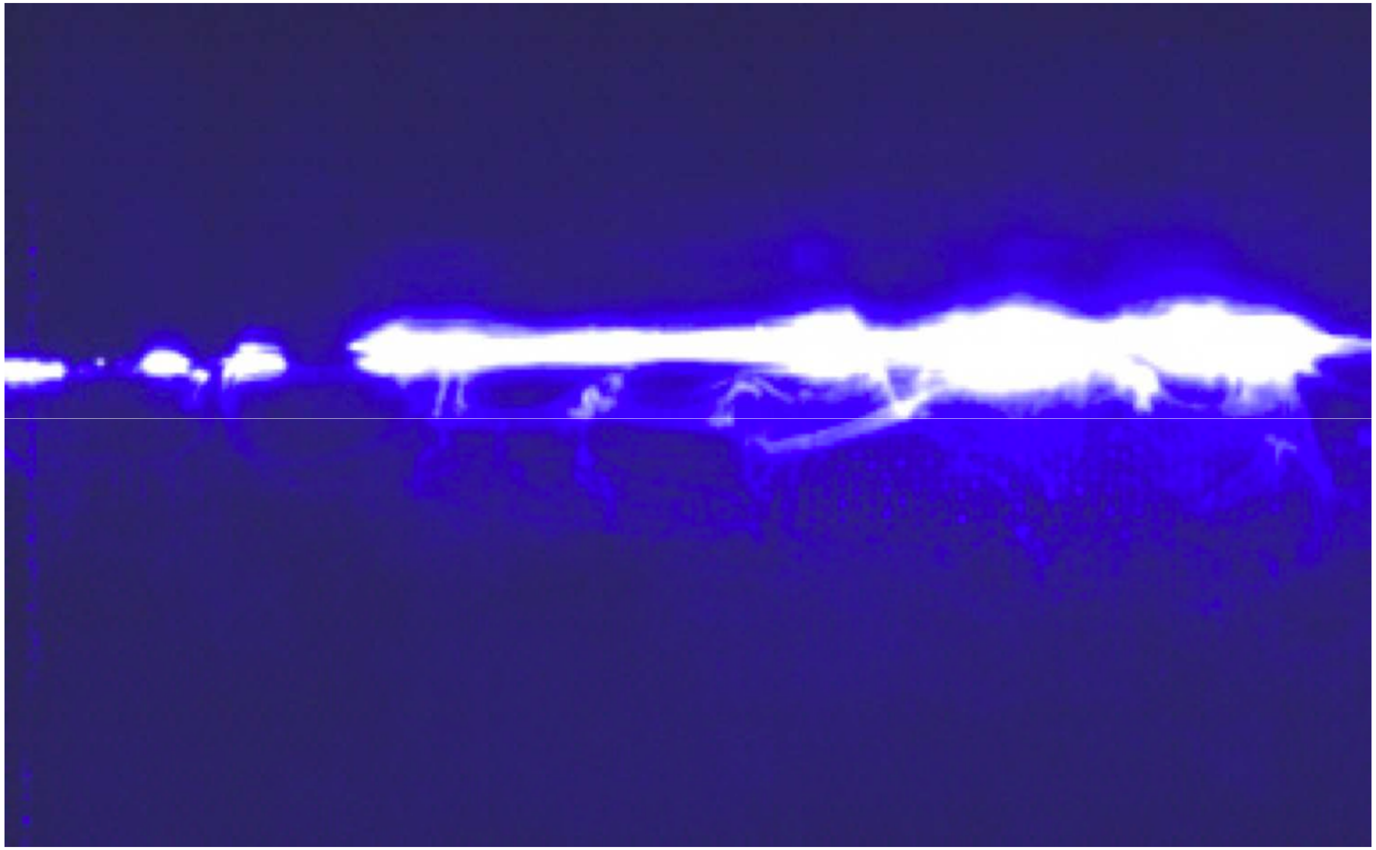


Backward enhancement of the white light emission



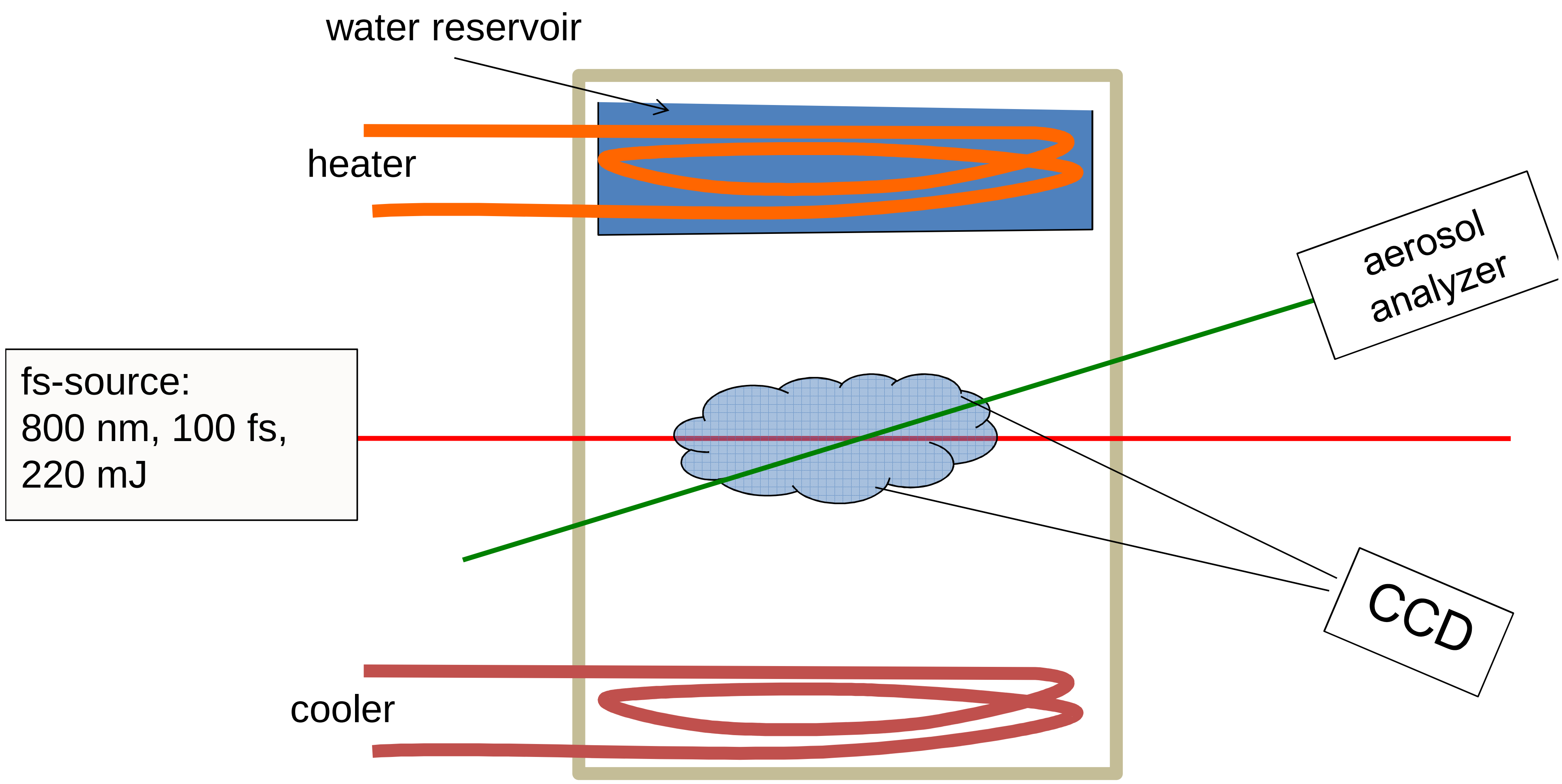
J.Yu et al, Opt. Lett. **26(8)**, 533-535 (2001)

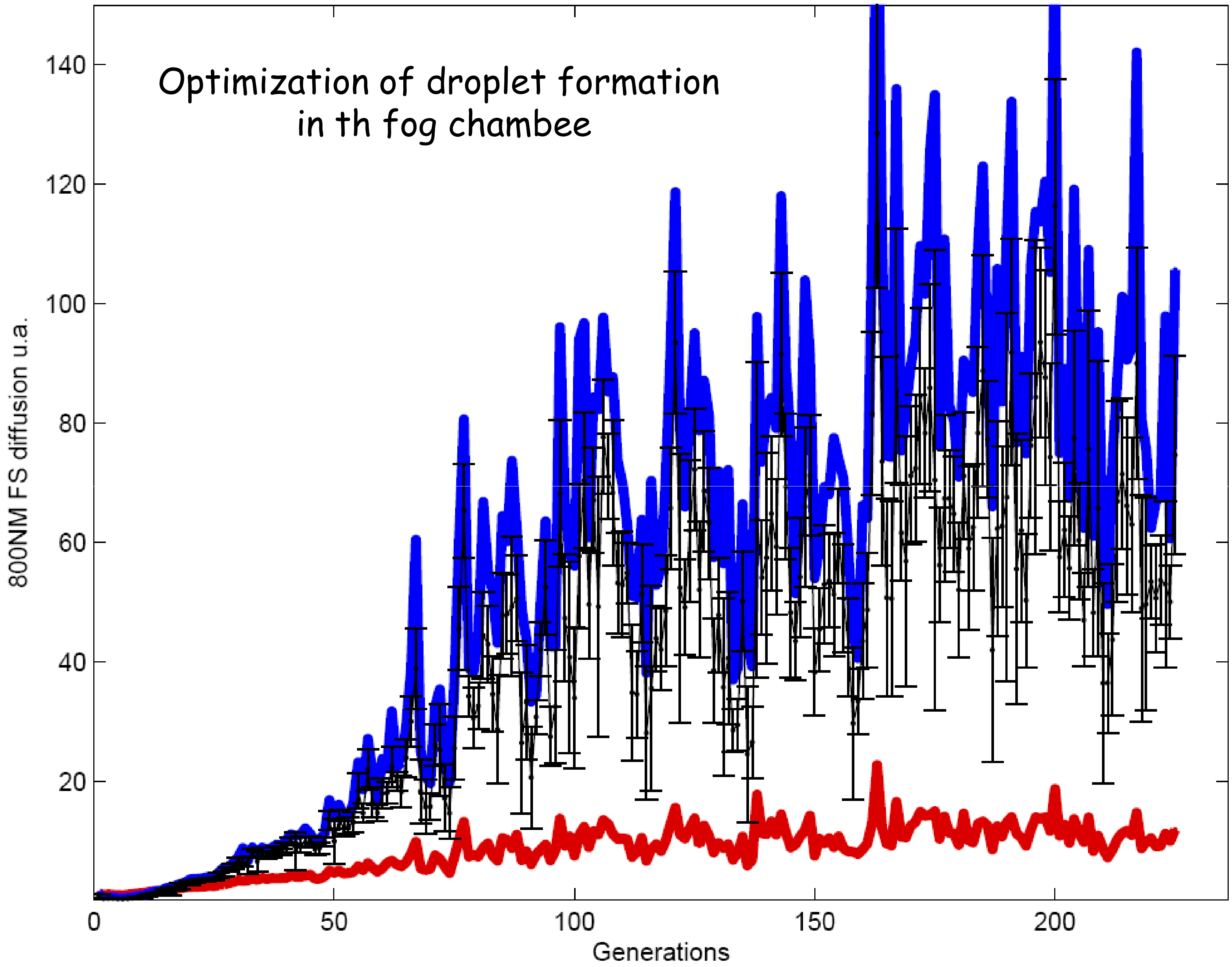
Filament-induced Condensation



P. Rohwetter *et al.*, *Nature Photonics,* DOI 10.1038/NPHOTON.2010.115

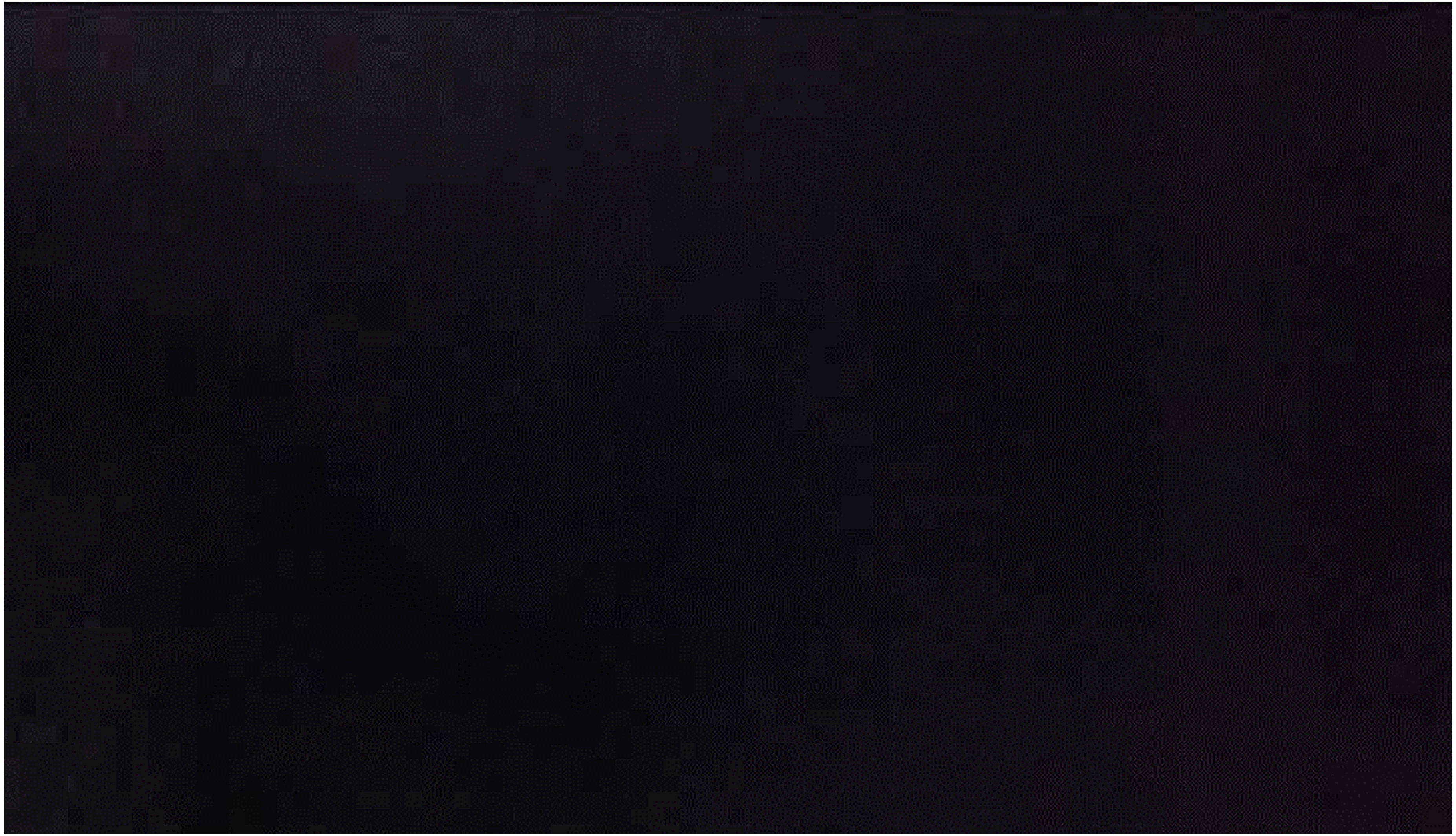
Diffusion cloud chamber



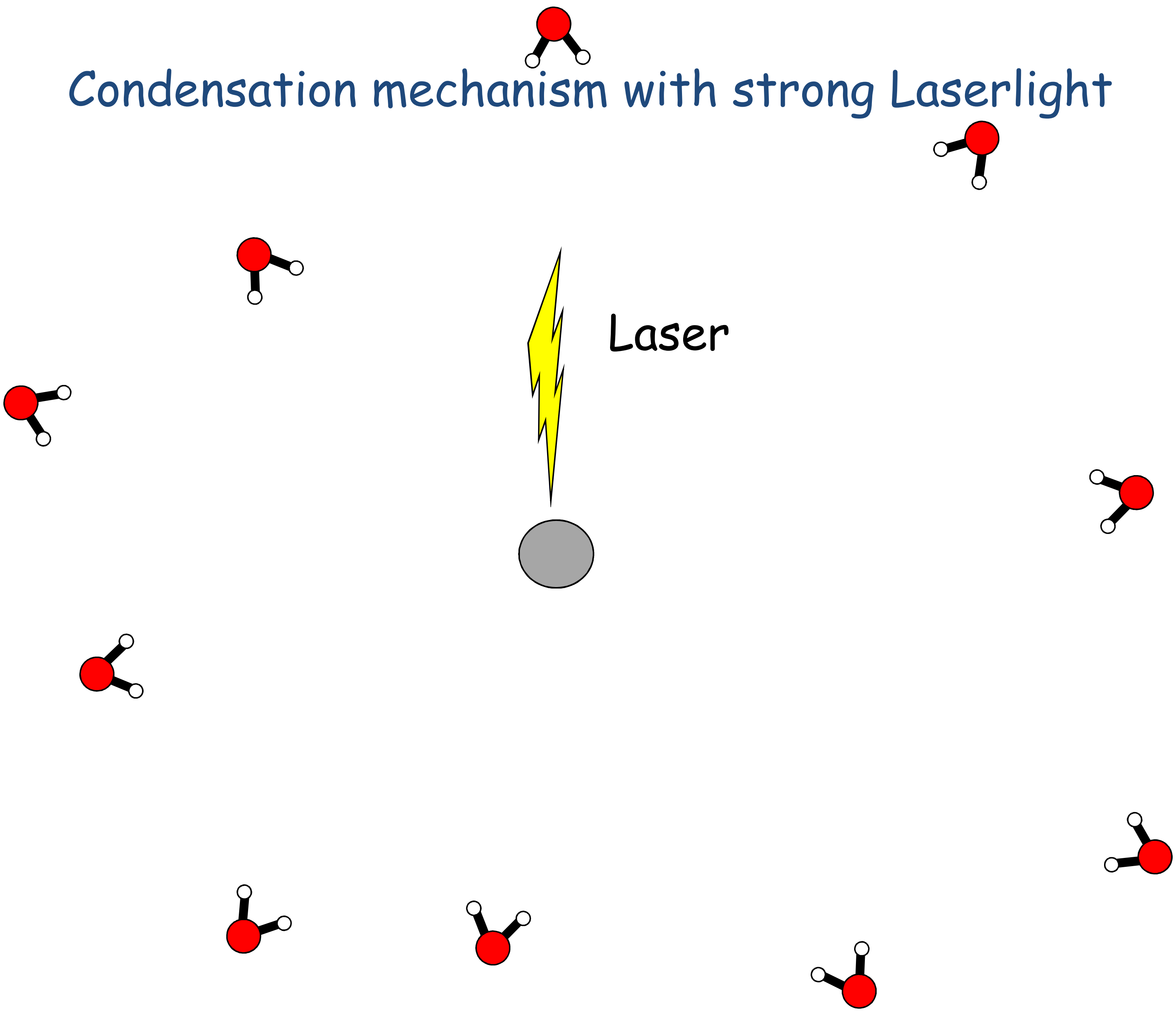


Optimization of droplet formation
in th fog chambee
800NM FS diffusion u.a.
Generations
0
50
100
150
200
20
40
60
80
100
120
140

Laser-produced Condensation

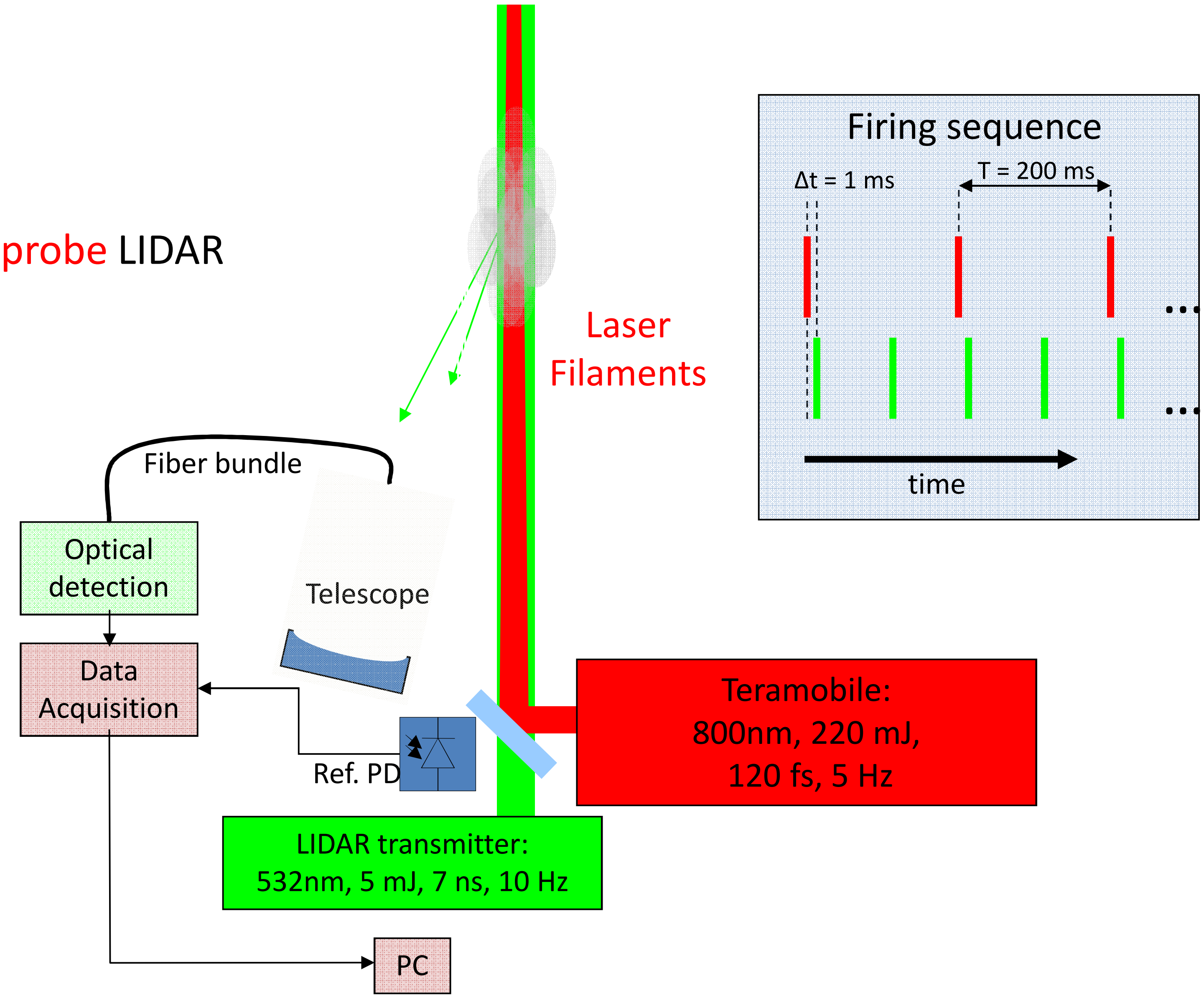


Condensation mechanism with strong Laserlight

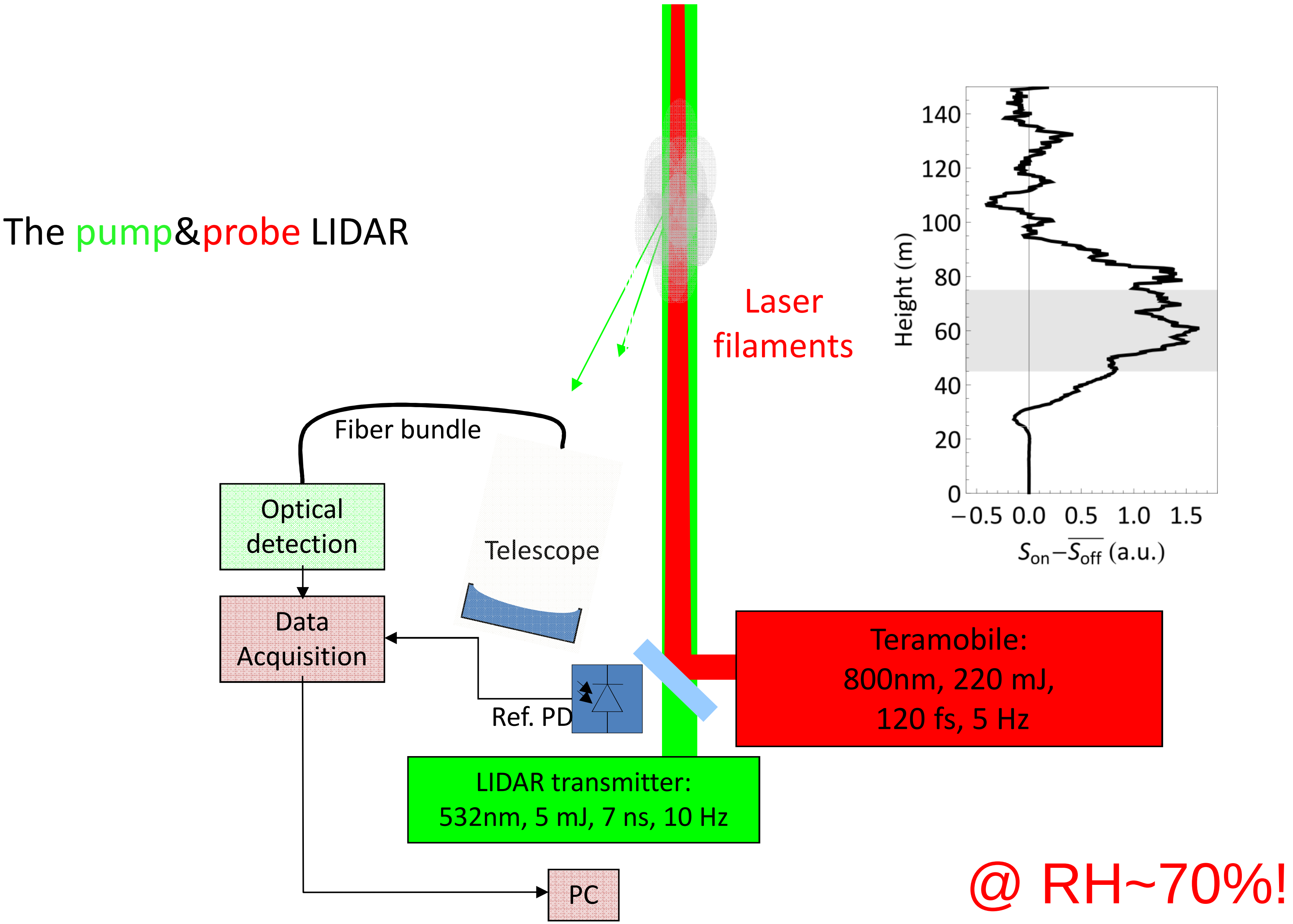


Test in the real atmosphere:

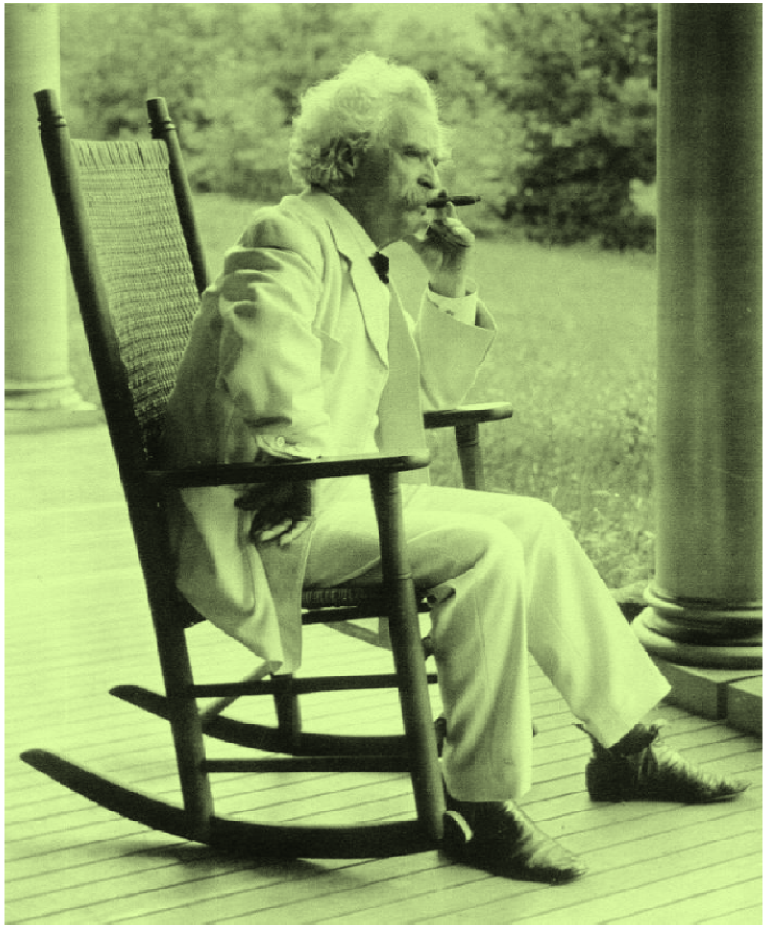
The pump&probe LIDAR



Appearance of filament-formed droplets



Let´s get back to him!



Mark Twain (1835-1910):

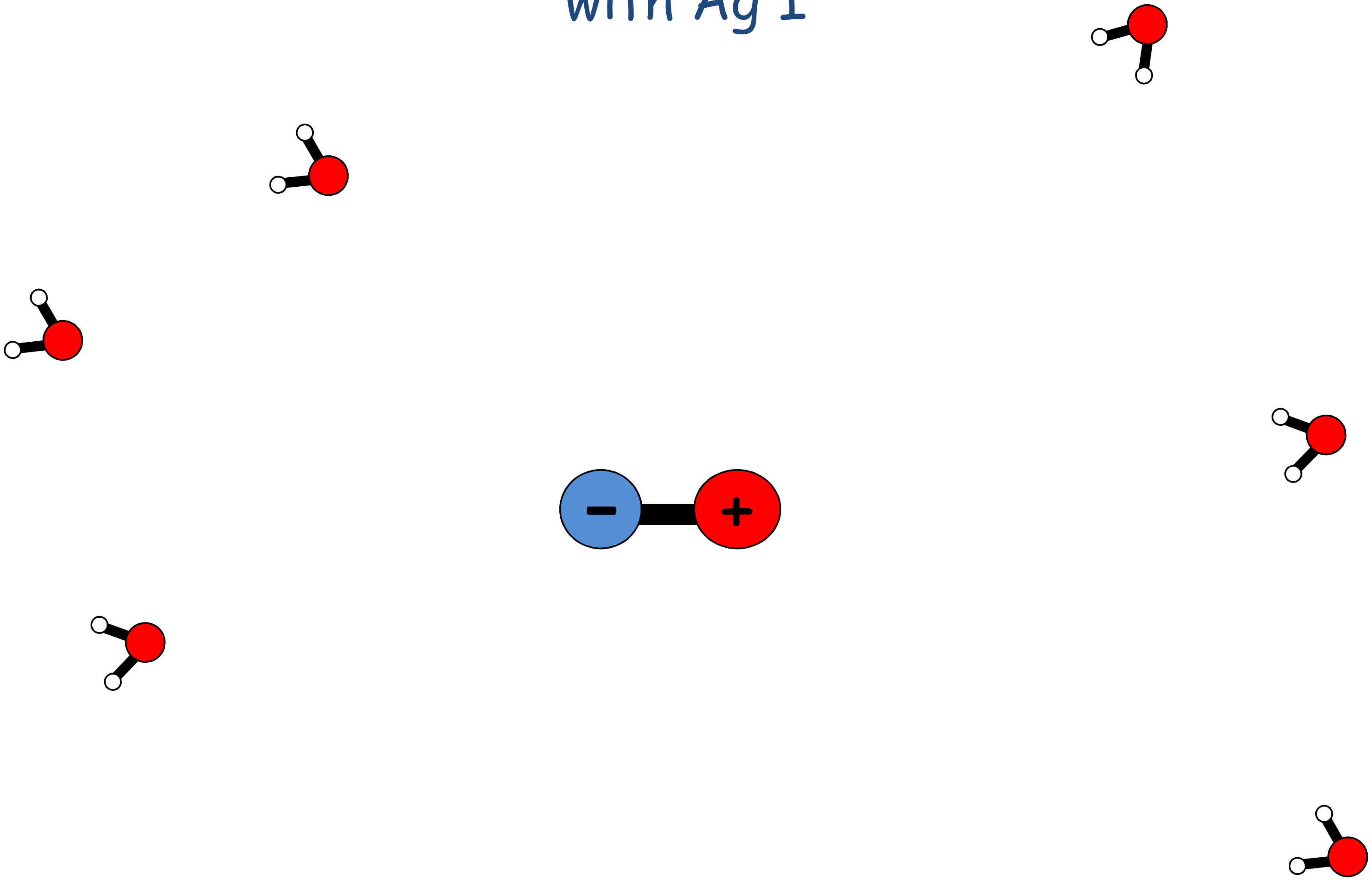
« Everyone talks about the weather, but no one tries to do something about it! »

After the hail storm !

….what can be done?

Hail flyers

Condensation mechanism with $Ag^{+}I^{-}$



Do we want to contaminate our atmosphere wit expensive AgI ?

Weather control

Chinese bureau for weather control

北京市人工影响天气办公室

- 37 000 employe
- 7000 r ases
- 2 produced (claim)
- 1/8 increase of rain (claim)

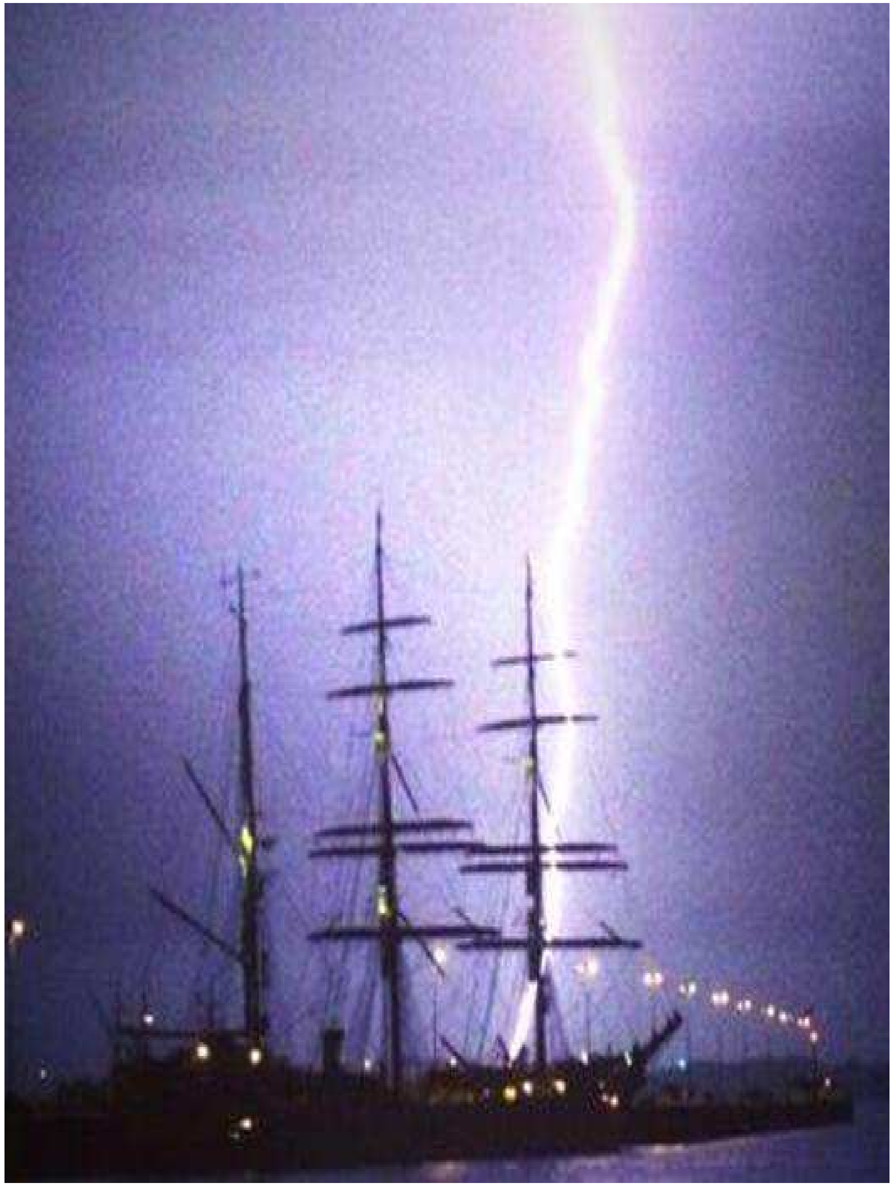
It will be better to replace AgI by light !

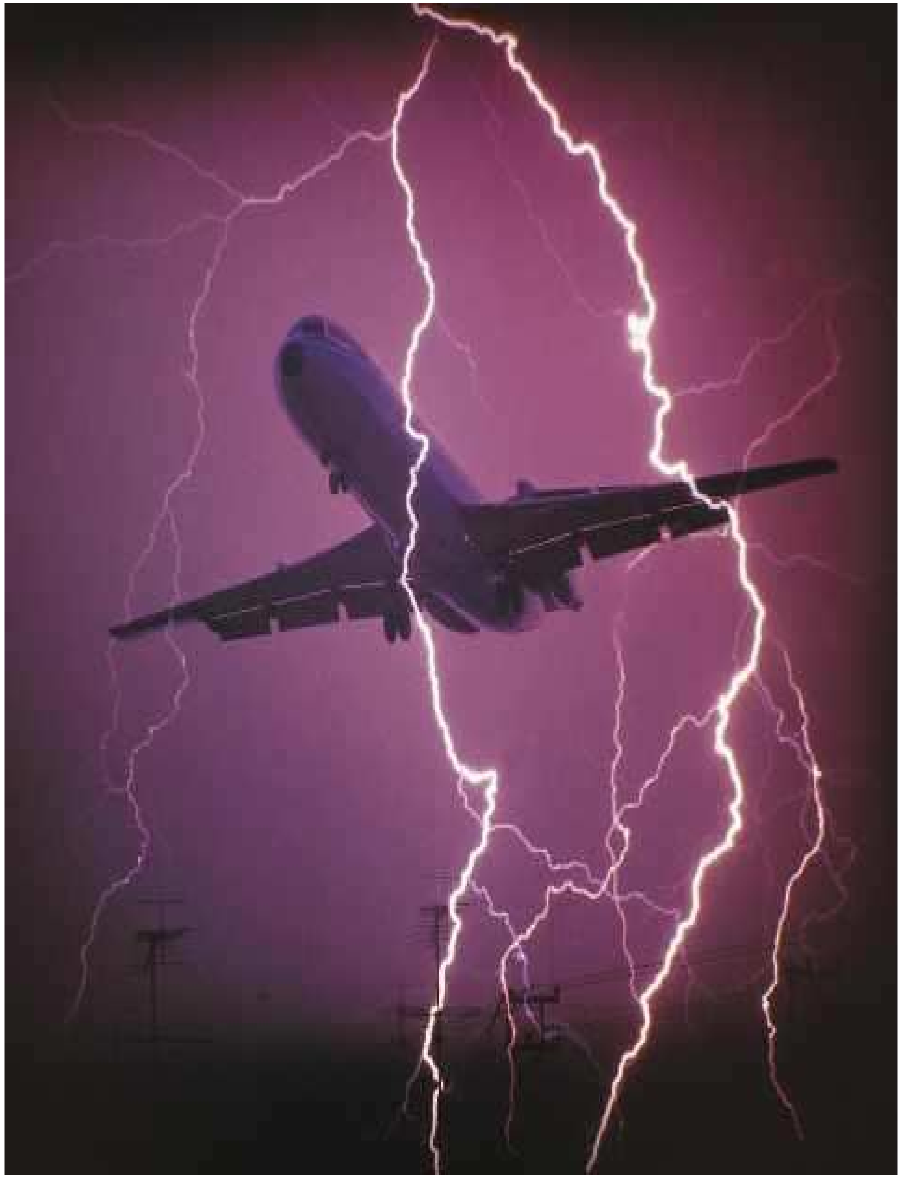
China Photos/Getty Images News/Getty Images

Staff members from Beijing's Xiangshan Weather Modification Practice Base stand next to a two-pipe cannon used for rain reduction and cloud dispersion.

How about lightnings?

Who is threatened by lightnings?

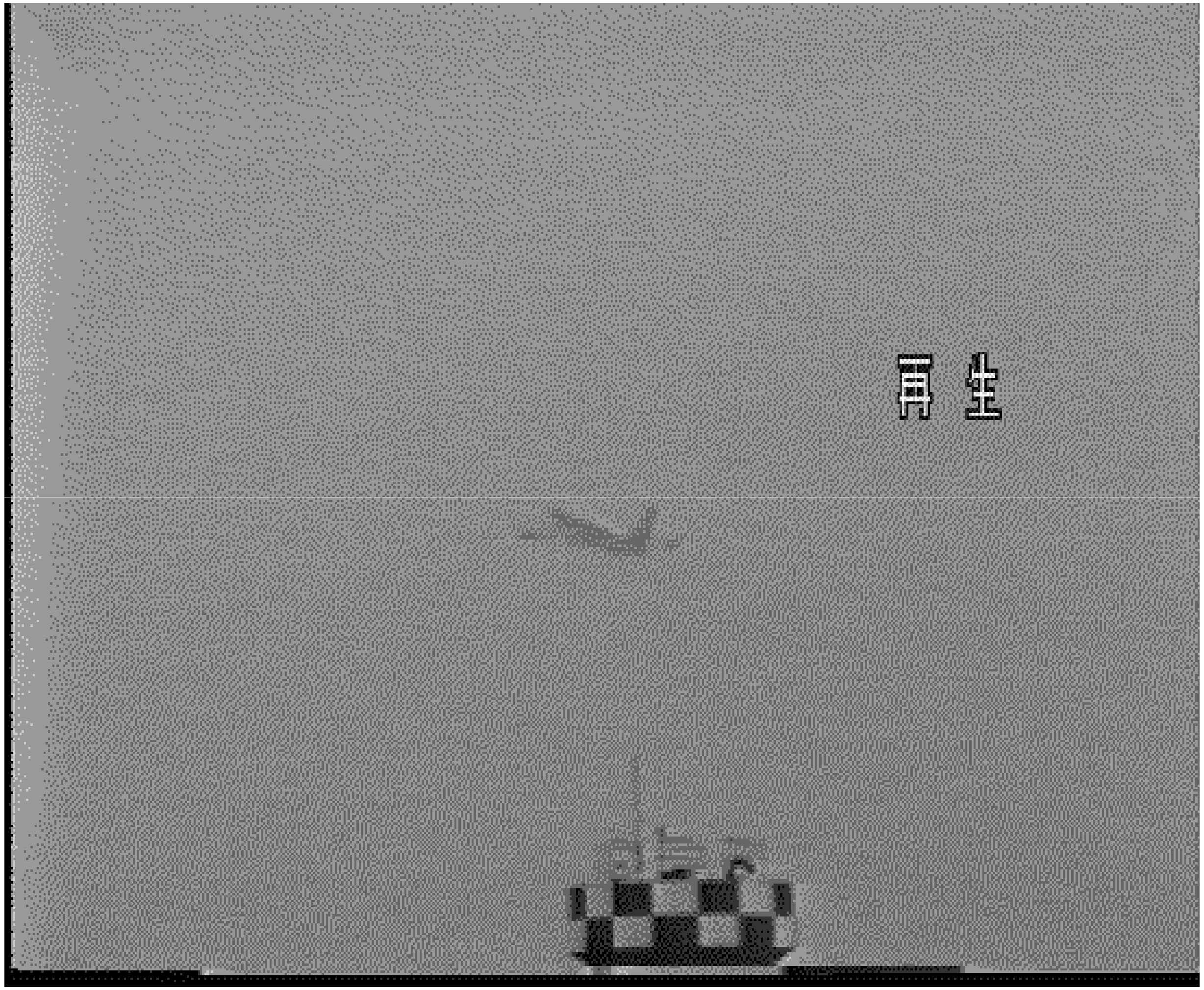




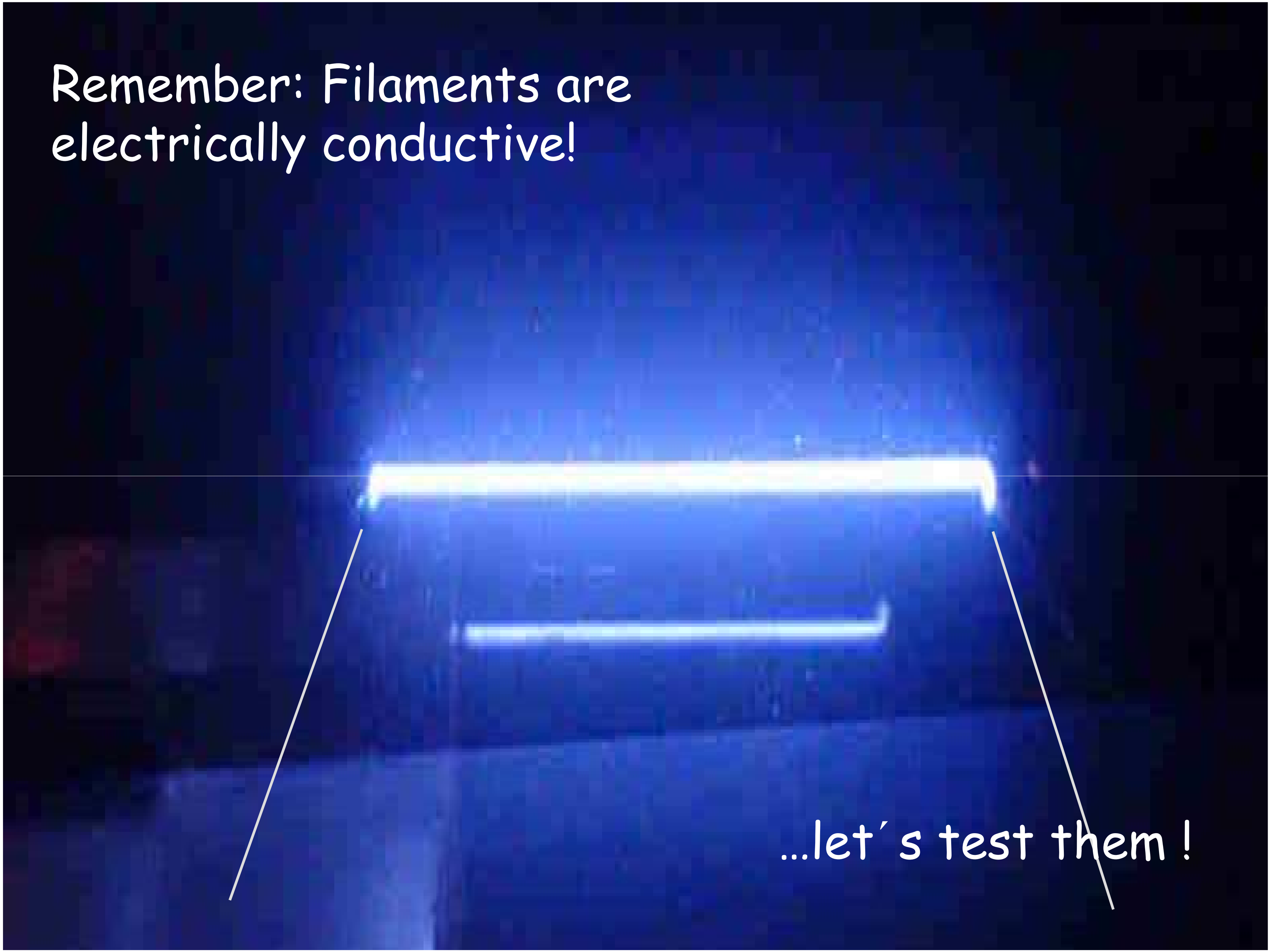
And what can be done?

...he had the first idea!

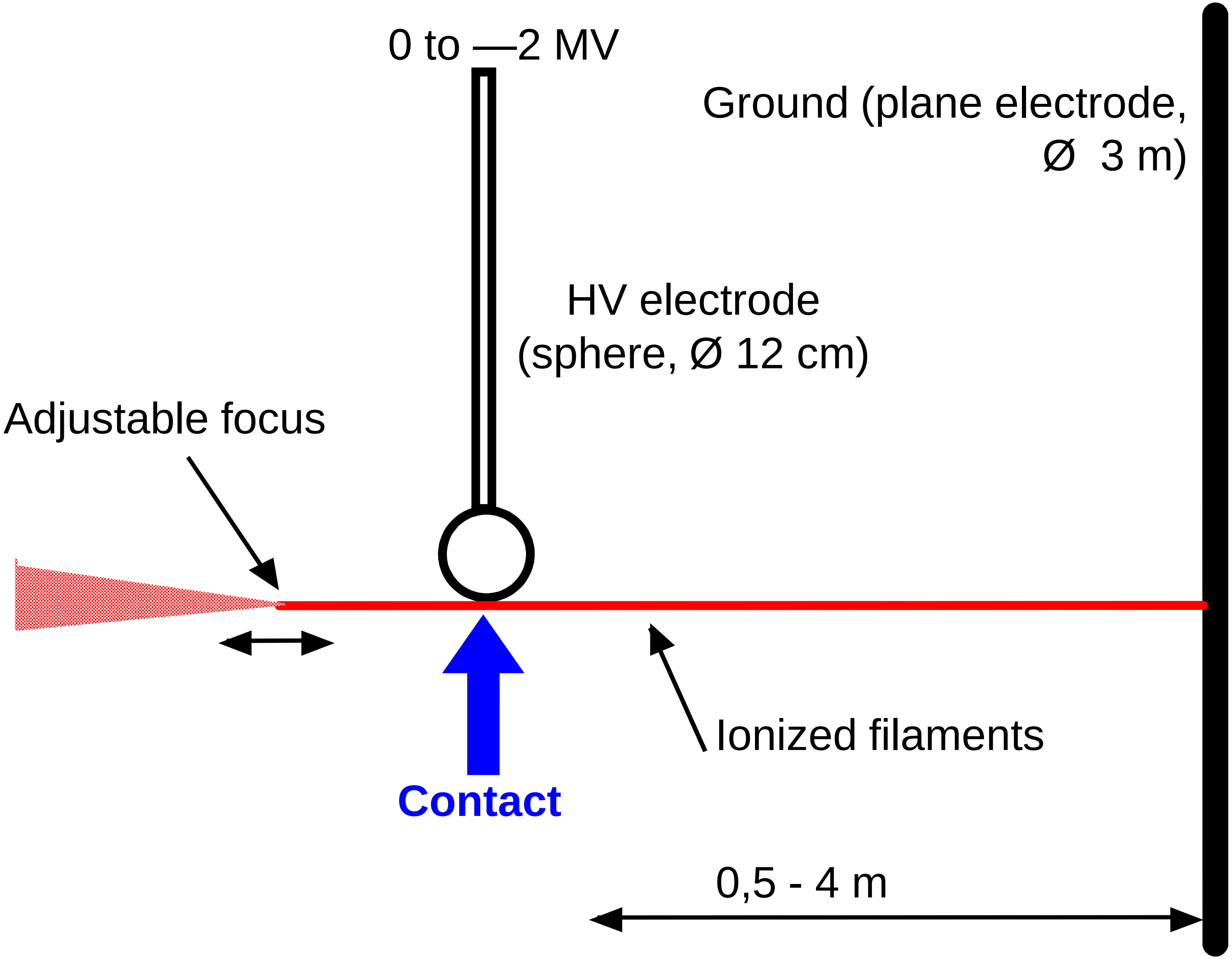

A more modern solution :
No good approach for protecting airplanes
rockets



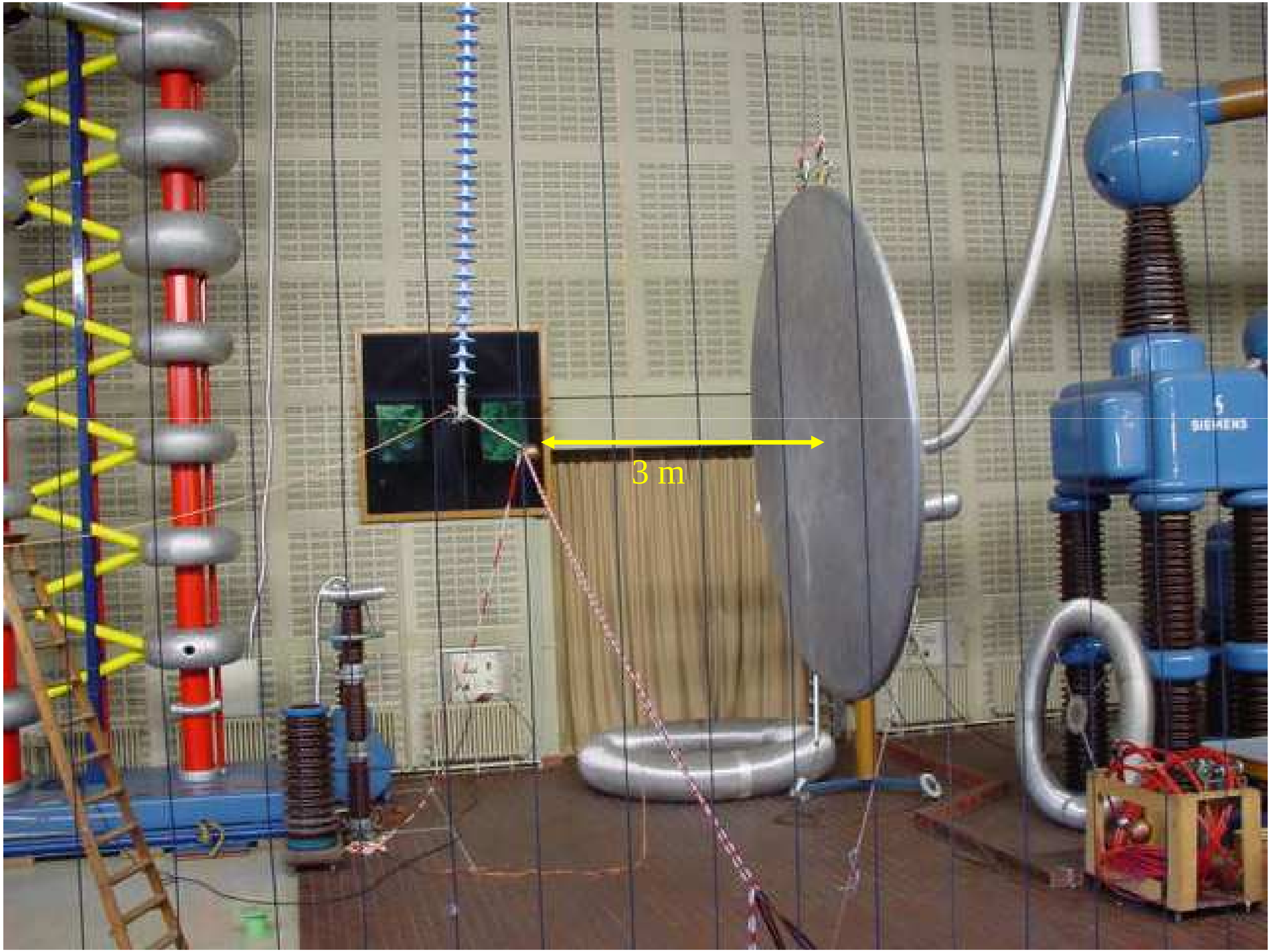
We want to prevent this!


Remember: Filaments are electrically conductive!
...let´s test them !

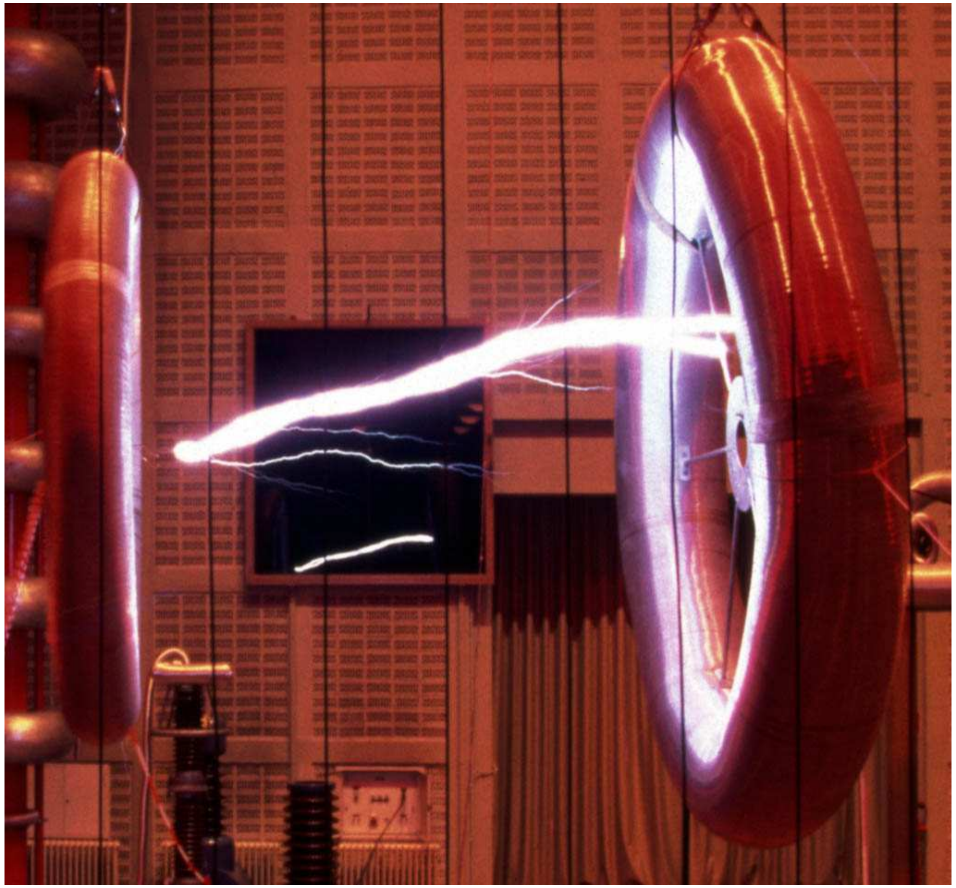
Laser guiding setup



Laser-control of high-voltage discharges

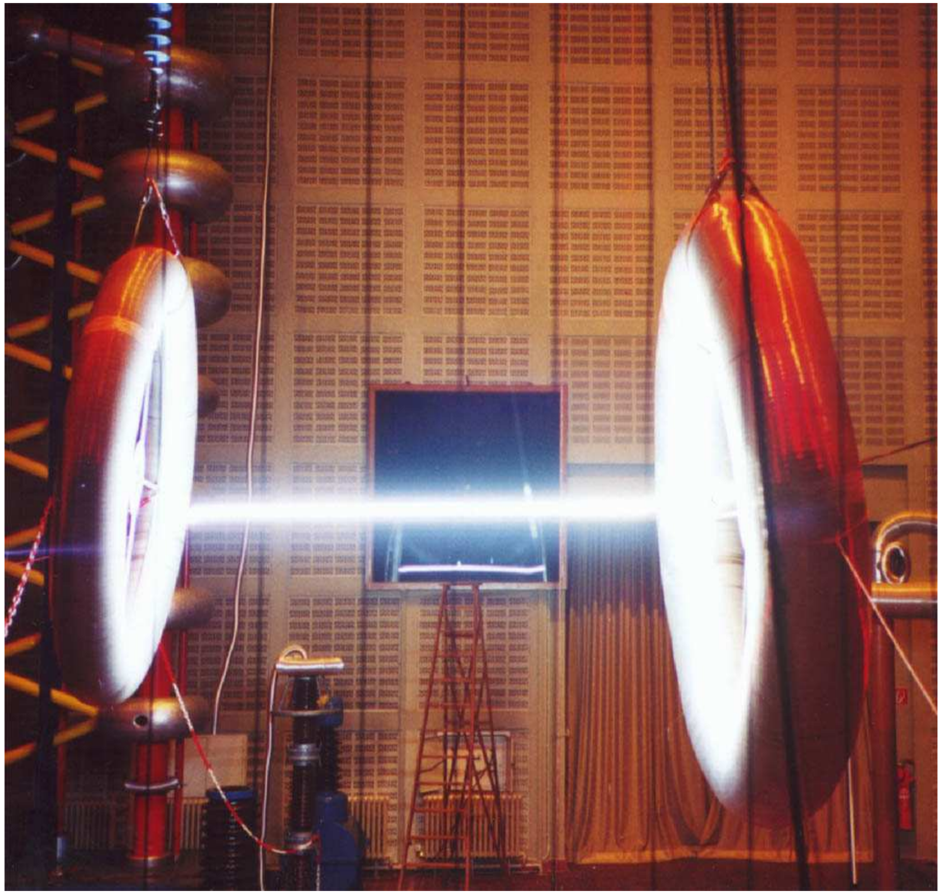


1 MVolt



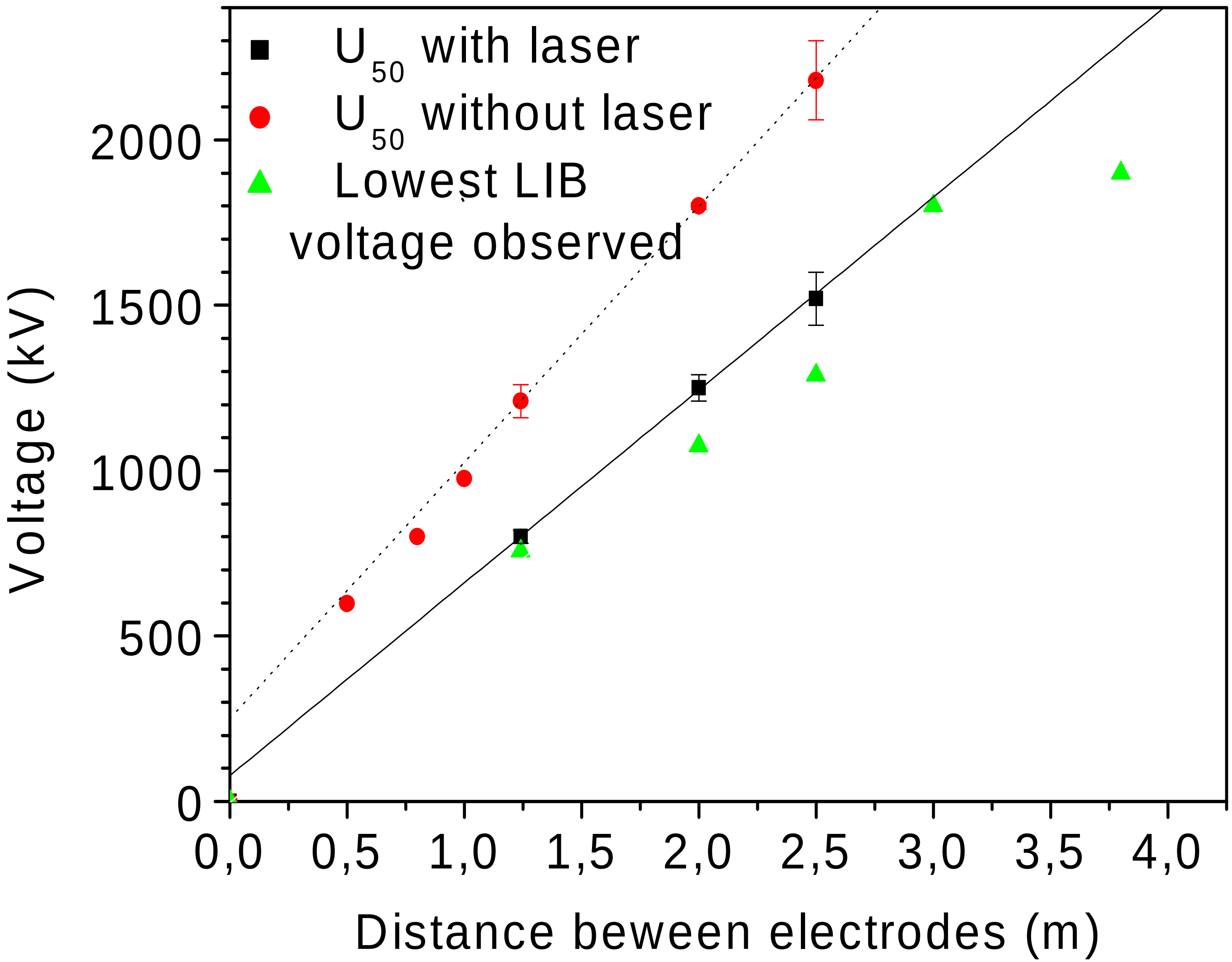
without filament

0.7 MVolt



with filament

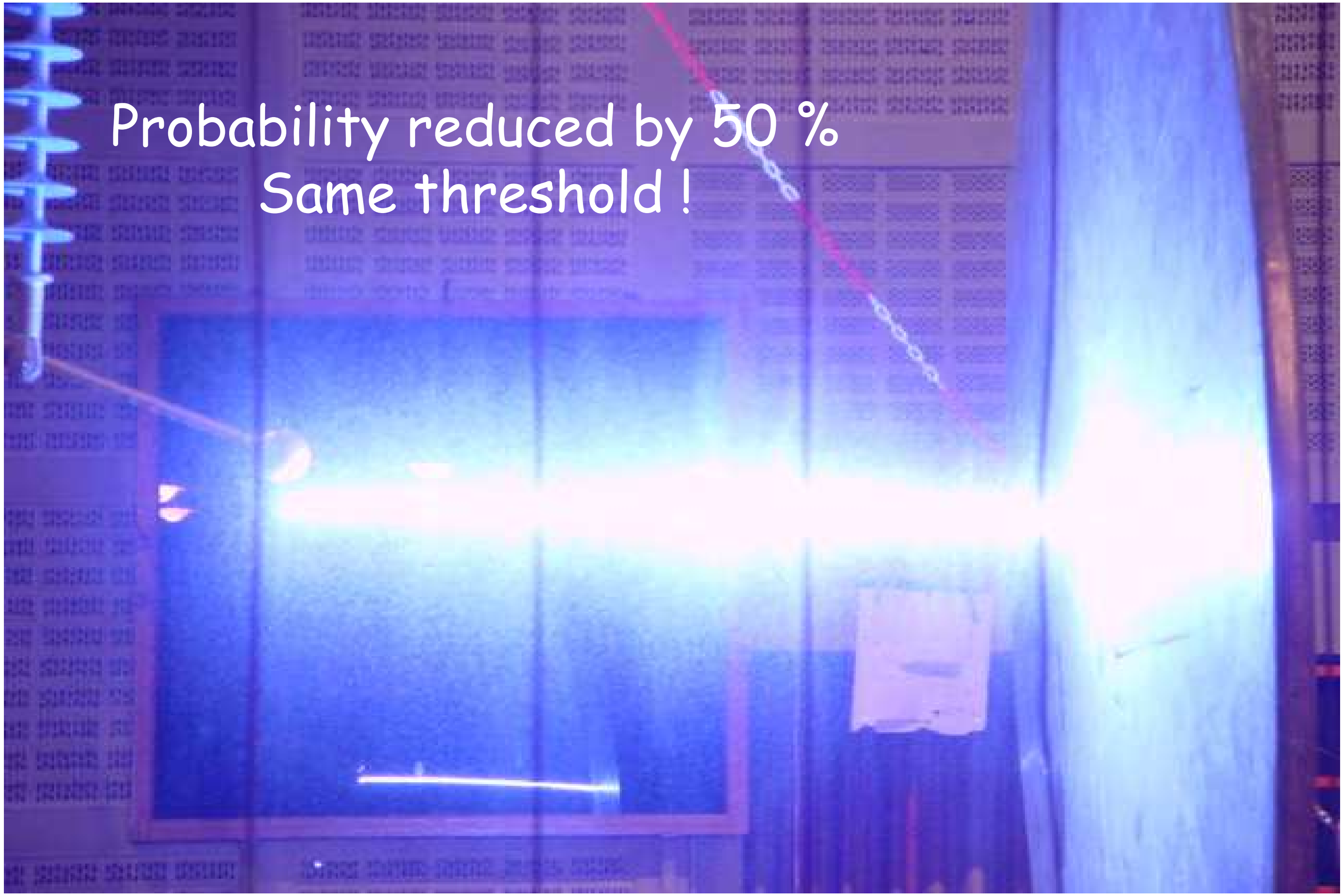
Discharge triggering



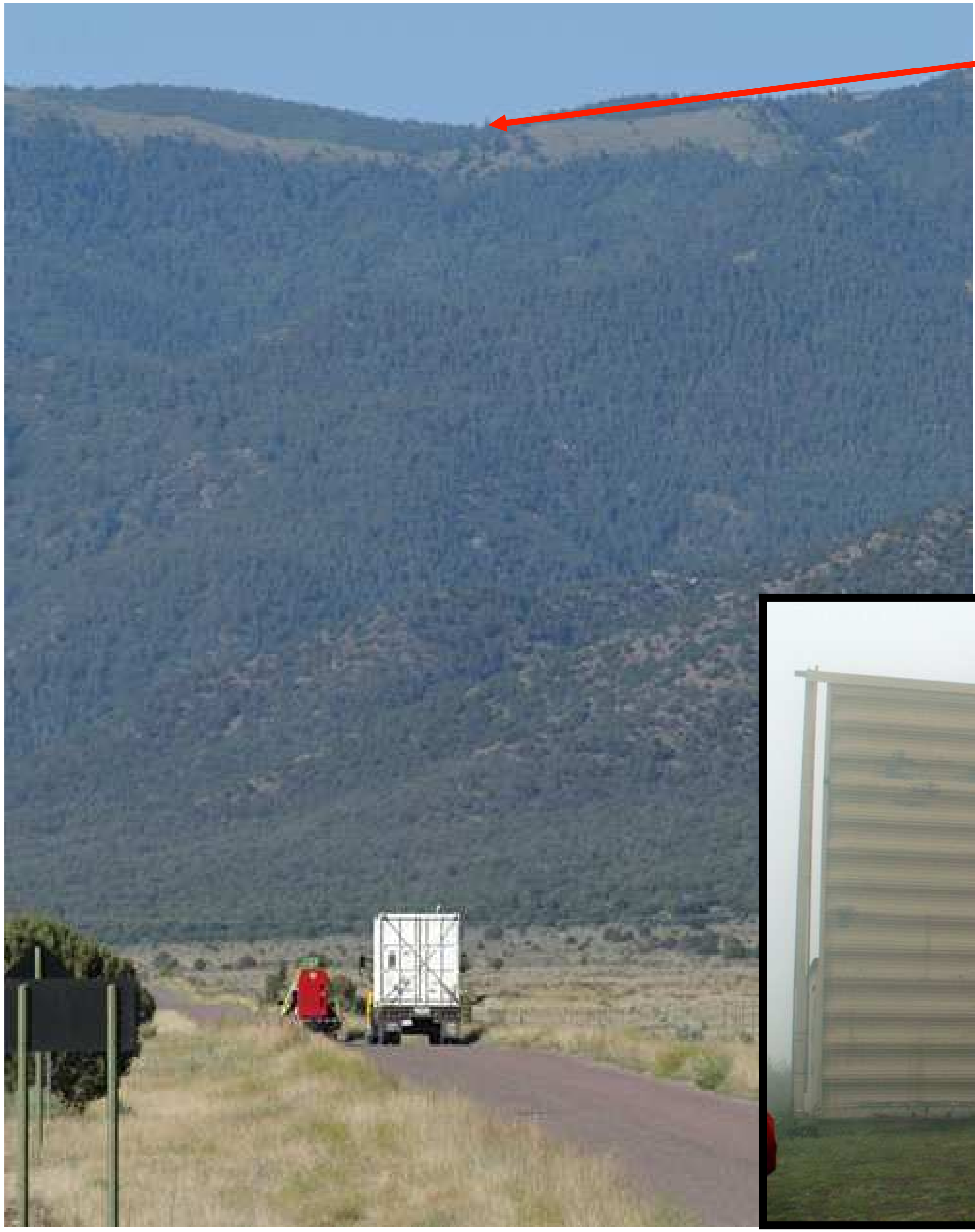
M. Rodriguez *et al.*, Opt. Lett. **27**, 772 (2002)

Wetting the Discharge Gap

Filament-induced Discharge in Rain



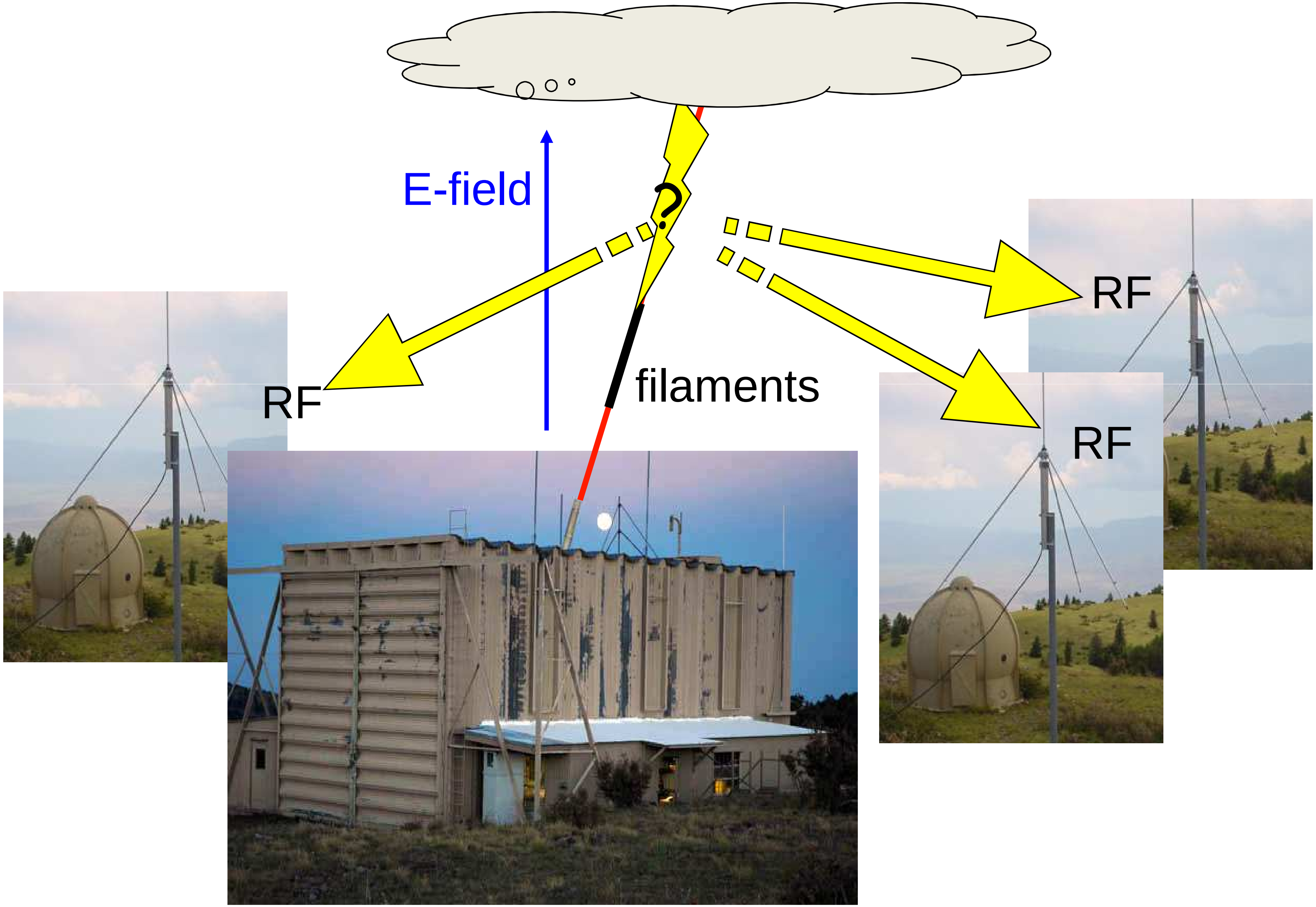
Field campaign



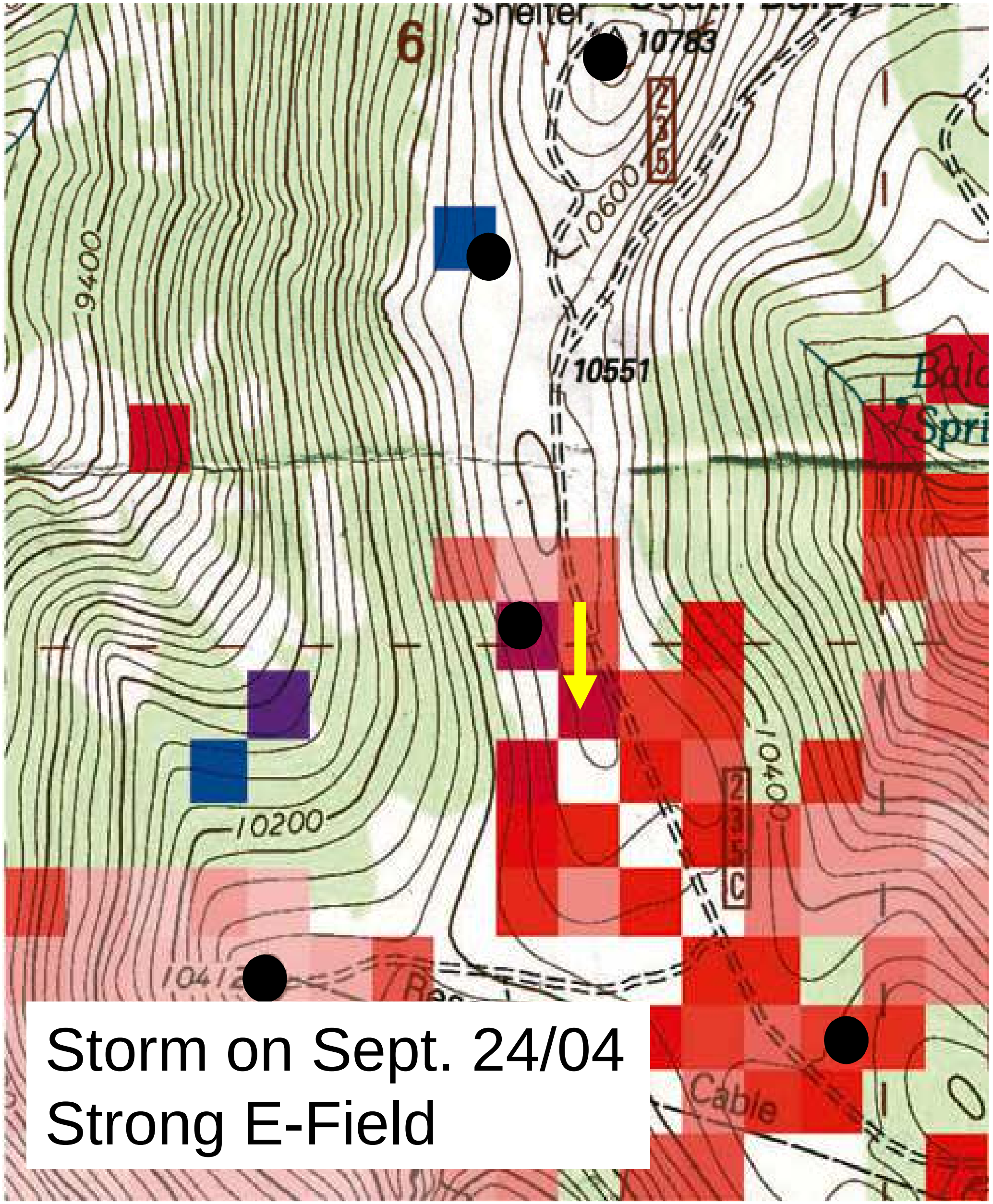
Langmuir laboratory,
New Mexico Tech
Altitude 3200 m

Metallic hall:
Faraday cage for Teramobile

Experimental Setup



Lightning Strikes

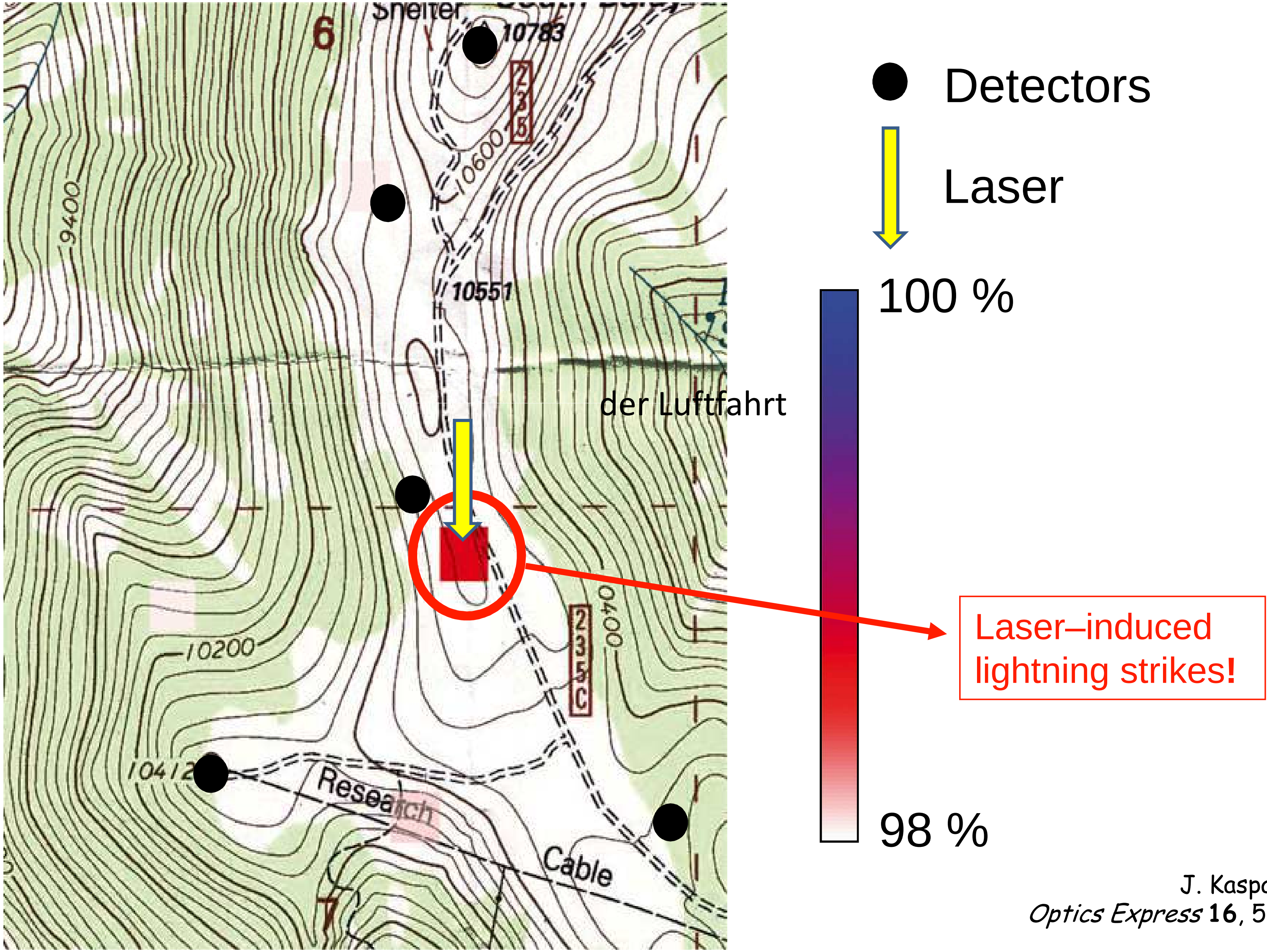


● RF detectors(LMA)

Laser and filament

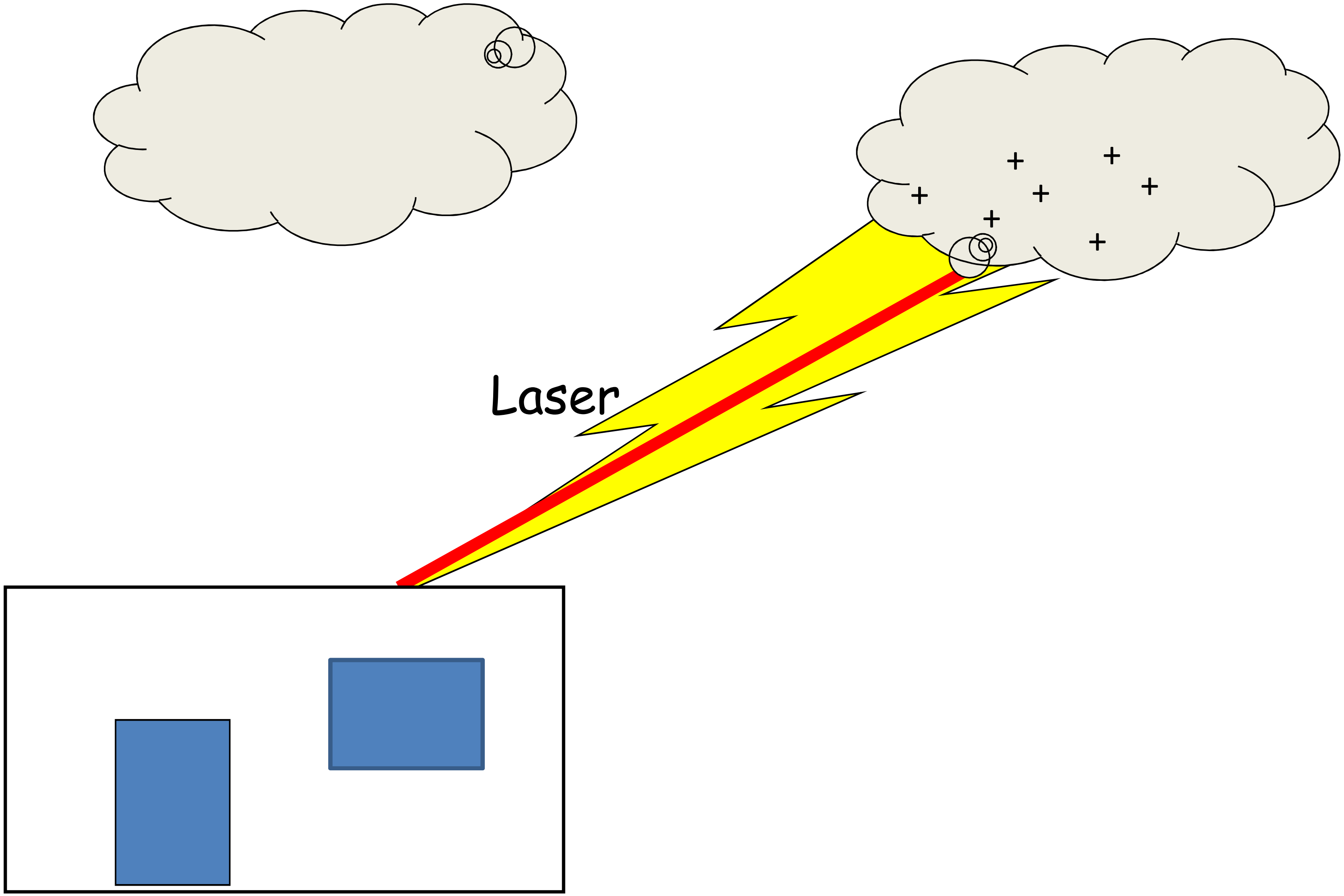
Let us look for pulse-synchronized strikes!

Laser-controlled lightning strikes



J. Kasparian *et al.*,
Optics Express **16**, 5757 (2008)

The future of lightning control



Thank You !

To the Team

MatthieuLalanne FalkoSchwaneberg AlbrechtLindinger OliverGause JörgWichmann
HaoZuoquiang LW GeorgAchazi FabianWeise
MonikaPawlowska FranzHagemann PhilipRohwetter TorstenSiebert
AndreaMerli WaltherNakaema CristinaKaposta BrigitteOdeh ThomasGelot KamilStelmaszczyk

And to our cooperation Partners:

Jean-PierreWolf JeromeKasparian