Opto-acoustic measurements for plasma diagnostics

Performed at SPARC_LAB

A. Biagioni

On behalf of SPARC_LAB collaboration

Outline

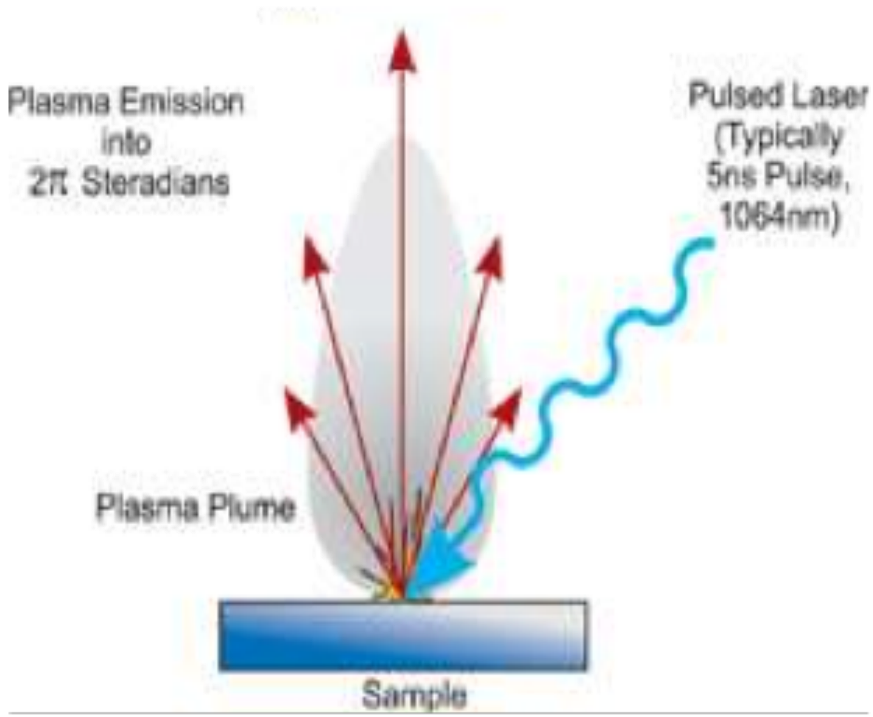
- Motivation
- Plasma generated by a solid target
- Theoretical background on opto-acoustic diagnostics
- The experimental set-up
- Preliminary results
- Perspectives: gas-filled capillary plasma source
- Conclusions

Plasma generation by a solid target

The laser beam hits the sample's surface and ionizes some molecules

Free electrons are accelerated by the laser field and then collide with the neighboring molecules in air, creating a plasma plume

A shock wave, related to the number of generated electrons, appears during the avalanche mechanism of the ionization



For irradiances beyond 10^9 W/cm^2 we can have a plasma expansion mechanism

During the plasma wave generation we have to take into account:

- thermal energy (thermoelastic expansion)
- optical energy (plasma spark) ⇨ **Stark broadening**
- acoustic phenomenon that consists of a broadband acoustic wave due to the supersonic expansion of the shock wave ⇨ **Acoustic technique for plasma**

Plasma generation by a solid target

J. Liu, B. Clough, and X.-C. Zhang, ‘**Enhancement of photoacoustic emission through terahertz-field-driven electron motions**’, PHYSICAL REVIEW E **82**, 066602 (2010)

$$\left(\nabla^2-\frac{1}{c_s^2}\frac{\partial^2}{\partial t^2}\right)\boxed{p(r,t)}=-\frac{\beta}{C_p}\frac{\partial \boxed{H(r,t)}}{\partial t}$$

is the ***heating function***, defined as the rate of the heat transfer from electrons into molecular translational energy

acoustic pressure (deviation from Atmospheric)

$$H(r,t)=n_e E_T \boxed{h(r,t)}=n_e\frac{1}{2}m_e v_e^2 h(r,t)$$

is determined by the nature of the energy transfer process and is a complex function of gas density, laser intensity etc.

$$p(r,t)=n_e \boxed{E_T} f(r,t)\propto n_e\frac{1}{2}m_e v_e^2 \boxed{f(r,t)}$$

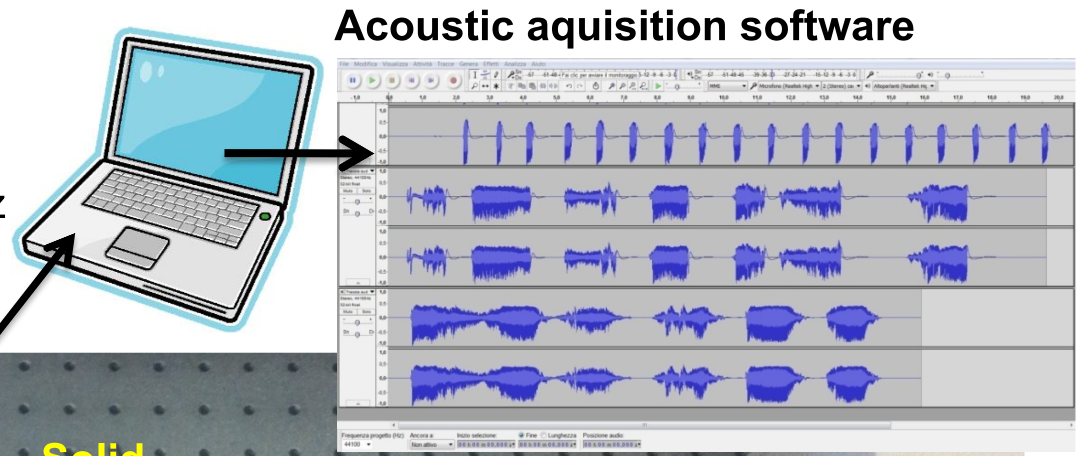
can be obtained using the Green’s function solution of the wave’s equation

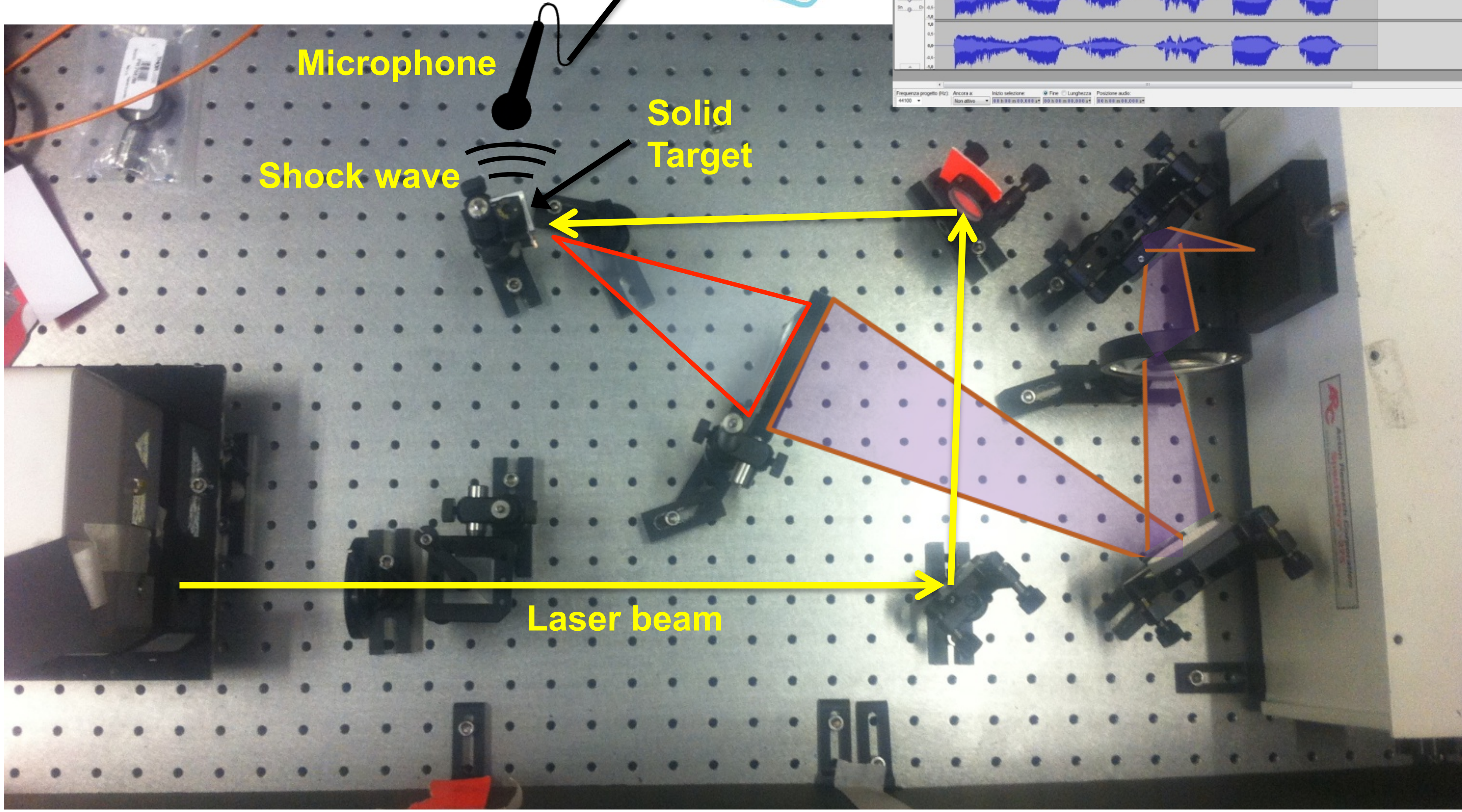
E_T is the ***total energy*** transferred from each electron to neighboring air molecules

$$n_e \propto p(r,t)$$

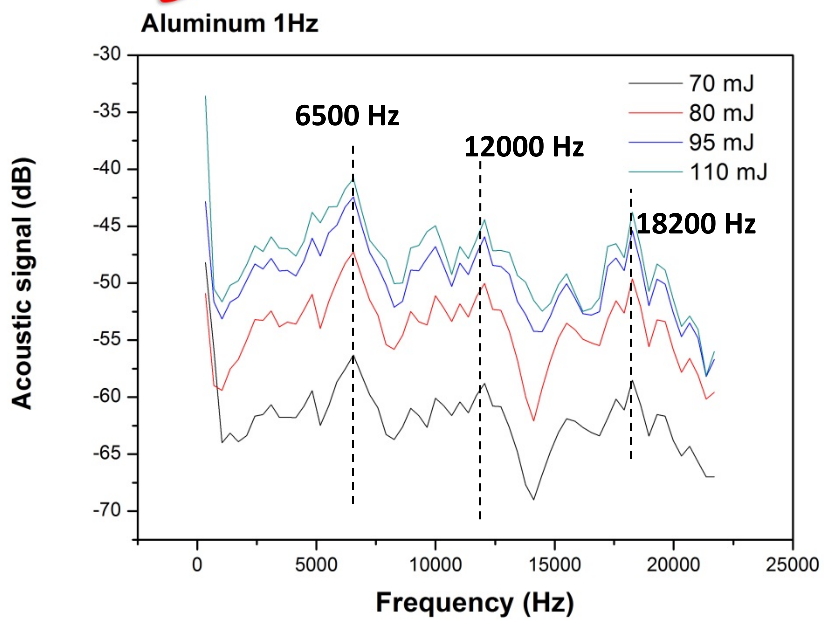
Nd:Yag laser
10 ns pulse
110 mJ
1064 nm

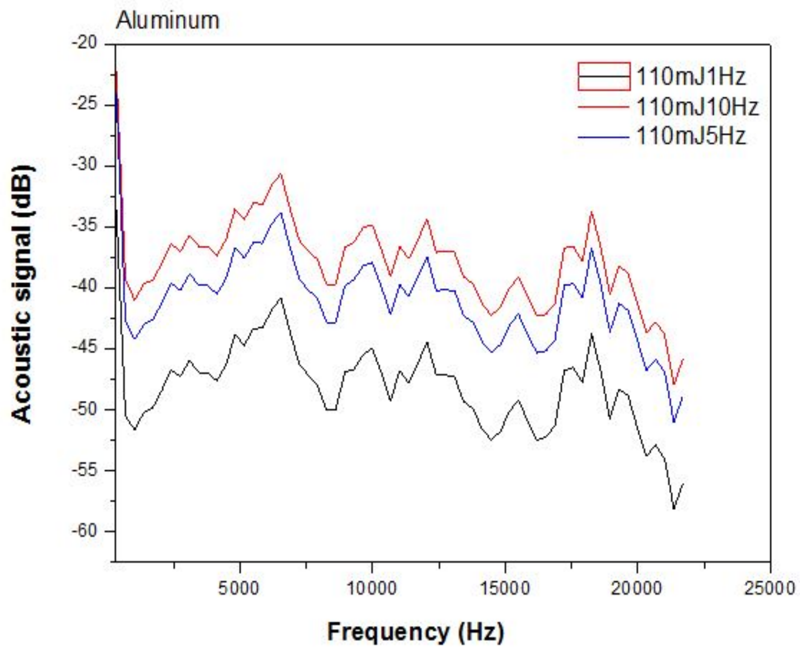
Microphone
Dynamic range: -60 dB
Bandwidth: 20-20000 Hz

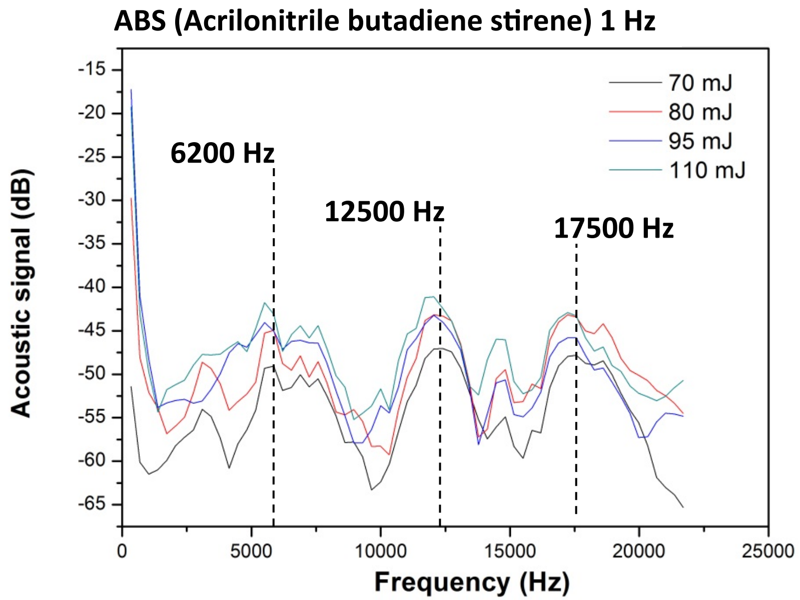


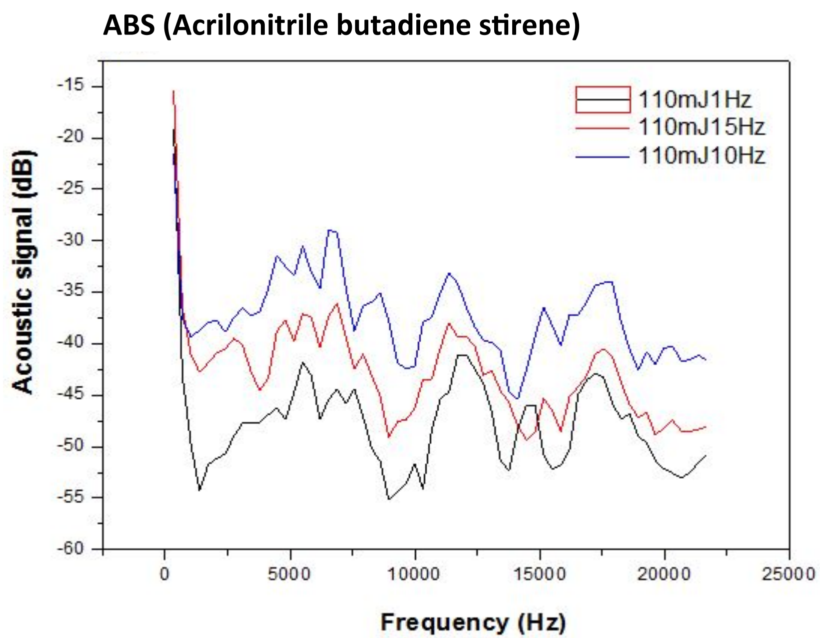


Preliminary results



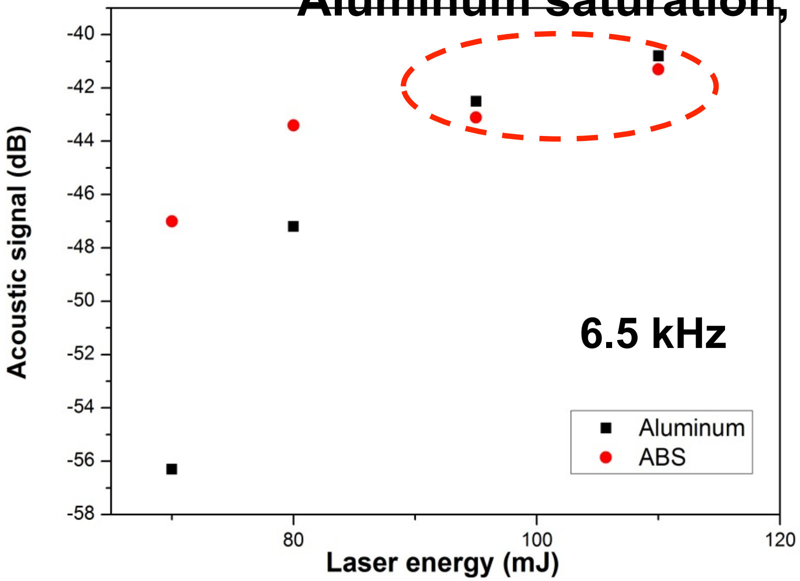


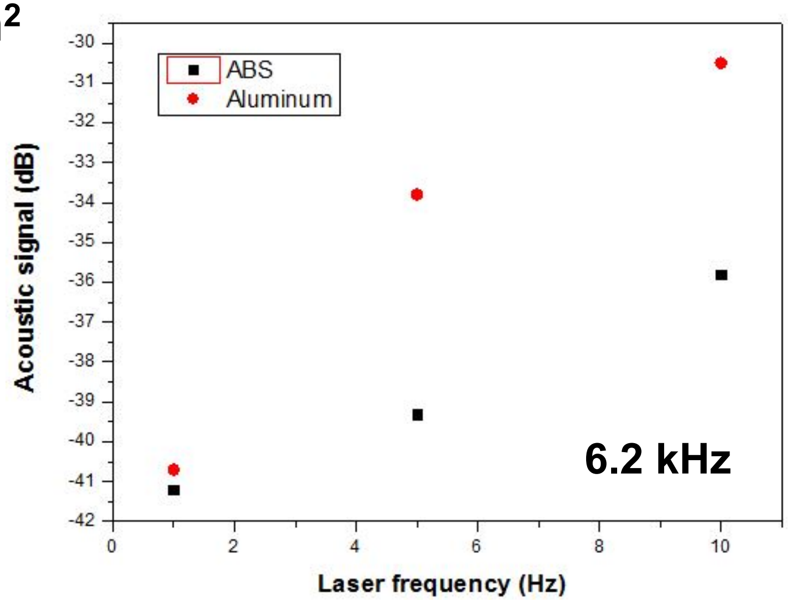




Preliminary results: comparison with data from literature

Aluminum saturation, 10^9 W/cm^2





Al saturation, 1 GW/cm^2

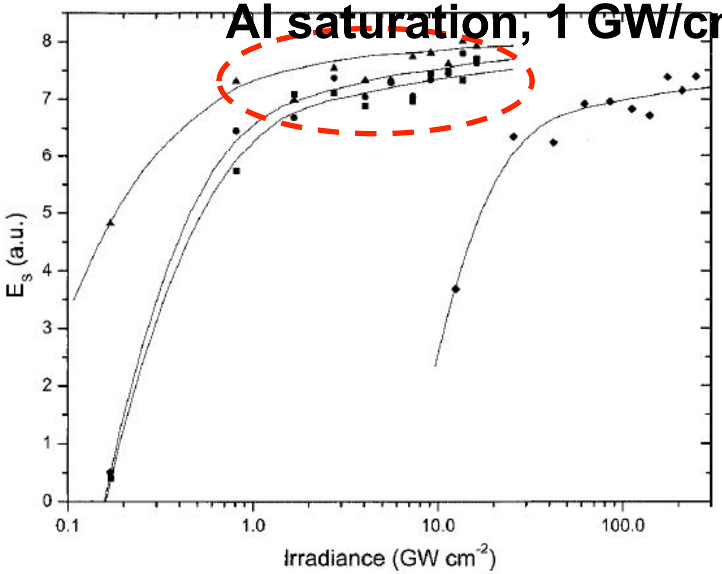


Fig. 8. E_s parameter calculated from the acoustic emission of plasmas for Cu (■), Al (●), Pb (▲), and air (◆) along the irradiance range shown in Figs. 5–7.

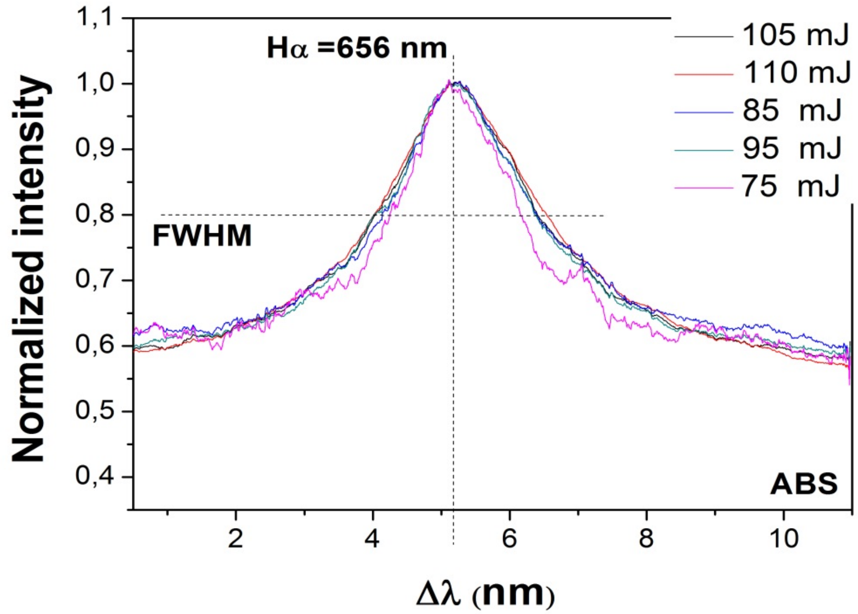
S. Palanco et al.
'Spectral analysis of the acoustic emission of Laser-produced plasma'

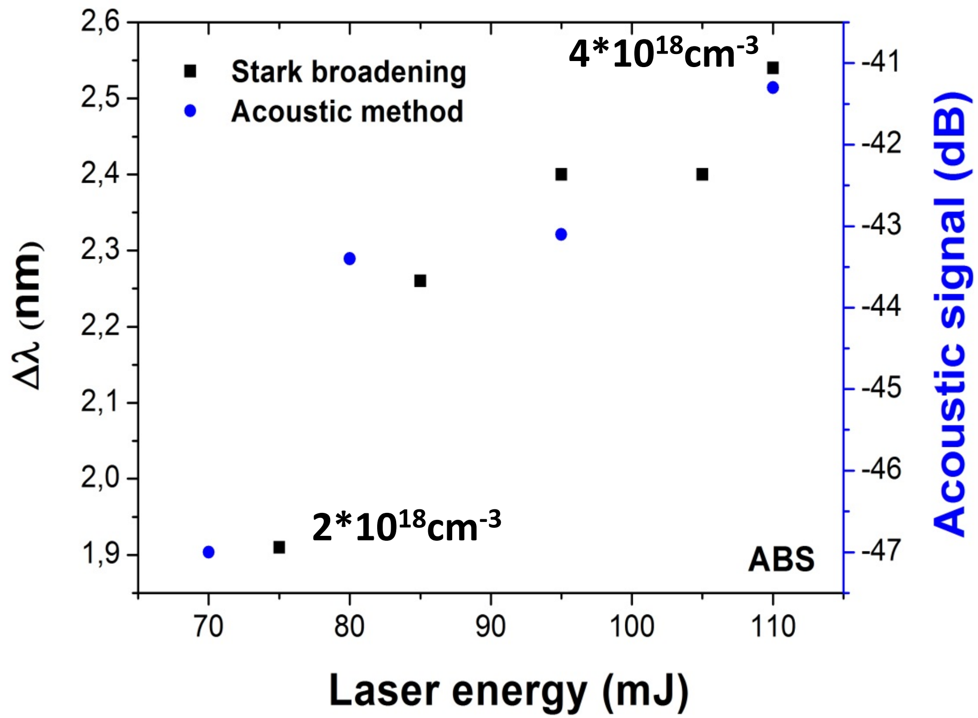
J. Diaci and J. Mozina
'*A Study of Blast Waveforms Detected Simultaneously by a Microphone and a Laser Probe During Laser Ablation*'

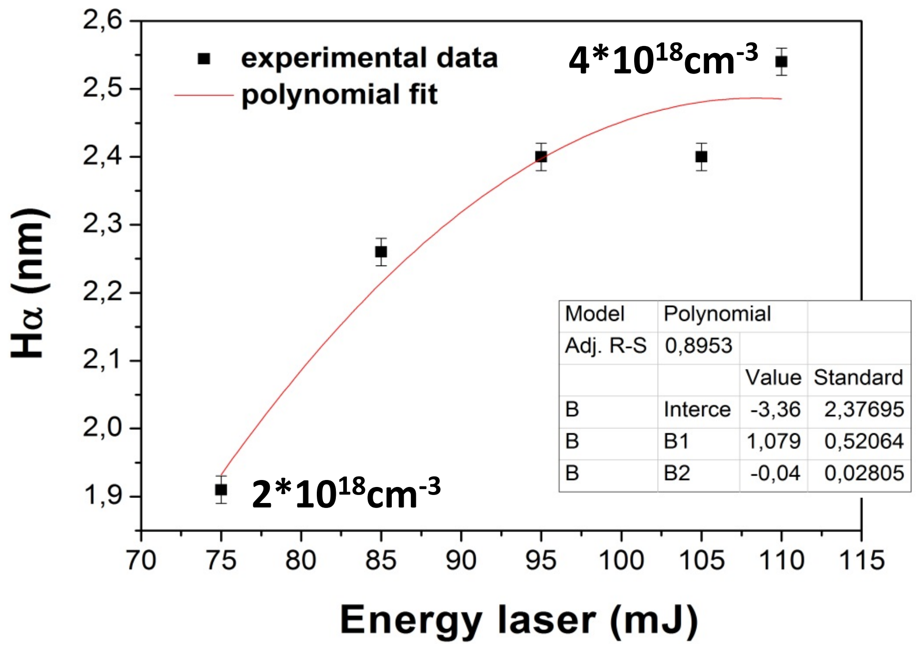
S. Conesa et al.
'Acoustic and optical emission during laser-induced plasma formation'

D. F. Farson and K. R. Kim
'Generation of optical and acoustic emissions in laser weld plumes'

Preliminary results: comparison with Stark broadening







Model	Polynomial		
Adj. R-S	0,8953		
		Value	Standard
B	Interce	-3,36	2,37695
B	B1	1,079	0,52064
B	B2	-0,04	0,02805

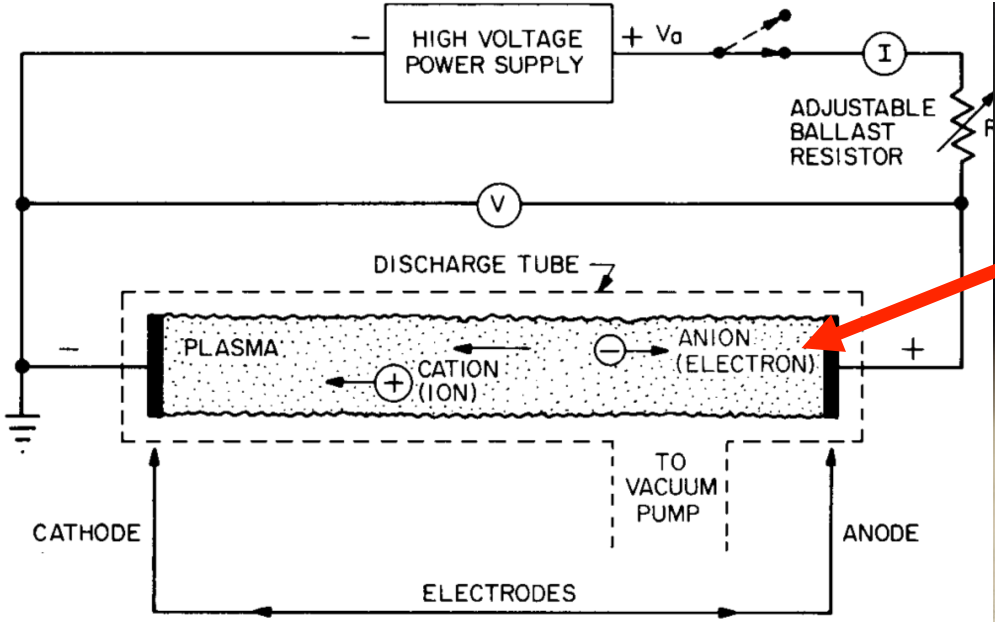
Both curves have a similar behaviour: there is a saturation when the laser energy reaches the values around 100/110 mJ

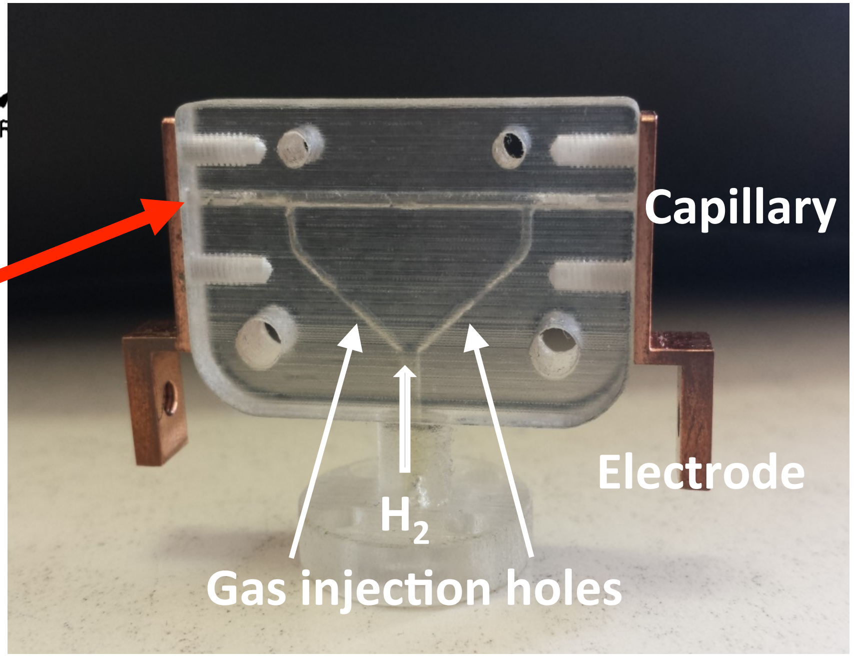
Correlation between acoustic and optical measurements can be taken into account

The Stark broadening technique can be used to calibrate the acoustic one

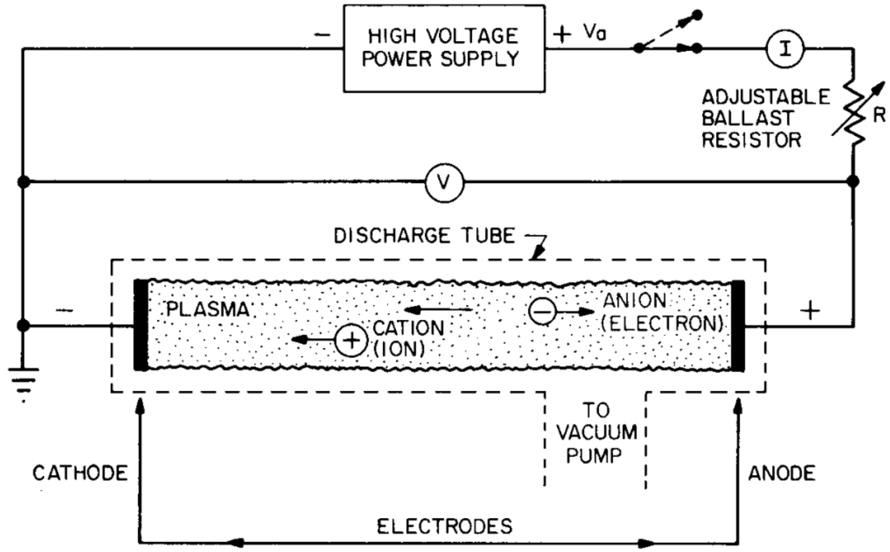
Acoustic technique for plasma capillary

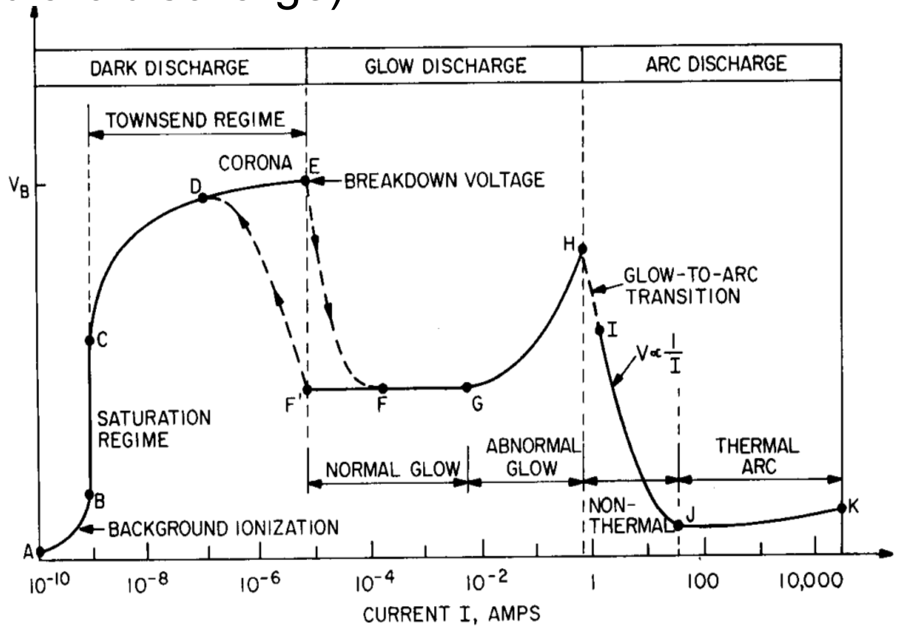
At the SPARC_LAB test facility we are going to use a gas-filled capillary plasma source for which we will employ an electrical discharge to generate the plasma





The Plasma generation inside a gas-filled capillary will be a bit different from the Laser-Induced Plasma in air (Dark, Glow and arc discharge)

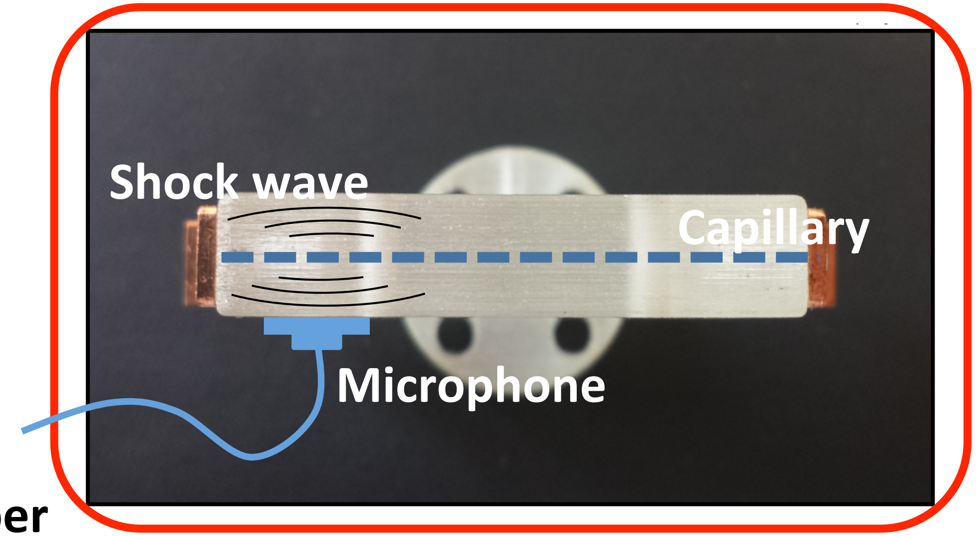




A shock wave propagation also occurs during the gas discharge

The shock wave is related to the electron density produced inside the capillary

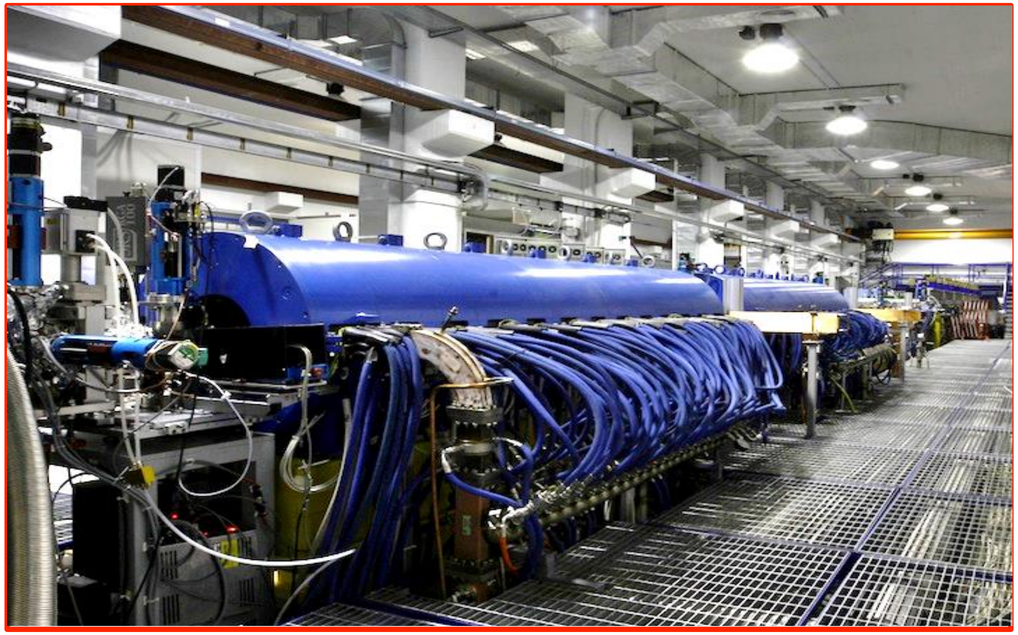
$$n_e \propto p(r,t)$$



Vacuum chamber

- About the Laser-Induced Plasma in Gases, there is a close relationship among the amplitude of the acoustic signal, the ablated mass/plasma generation, and the optical emission
- The Stark broadening technique could be used to calibrate the acoustic signal (shock wave) in order to determine the starting parameters of the plasma (The shock wave is only generated during the gas discharge)
- The acoustic method described for a Laser-Induced Plasma in Gases can be extend to a gas-filled capillary plasma source, since also in the latter a shock wave will be generated during the gas ionization
- The acoustic techniques are reliable and simple to make: we need a microphone attached on the wall of the capillary

Acknowledgments



M. P. Anania, M. Bellaveglia, E. Chiadroni, D. Di Giovenale, G. Di Pirro, M. Ferrario, R. Pompili, V. Shpakov, C. Vaccarezza, F. Villa (Laboratori Nazionali di Frascati, INFN)

A. Cianchi (Dipartimento di Fisica, Università di Roma Tor Vergata)

F. Filippi, A. Mostacci (Dipartimento di Scienze di Base e Applicate per l'Ingegneria, Sapienza Università di Roma)

A. Zigler (Hebrew University of Jerusalem, Jerusalem)

Thank you for your attention