Comparison of Measured and Computed Plasma Densities at Laser Supported Detonation Waves

Session number: C-2

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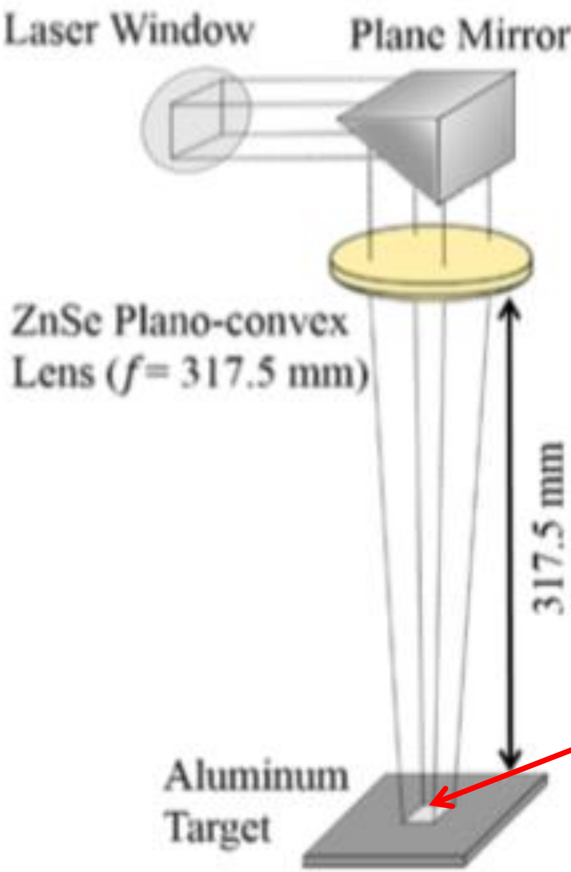
Background

Laser Supported Detonation Wave

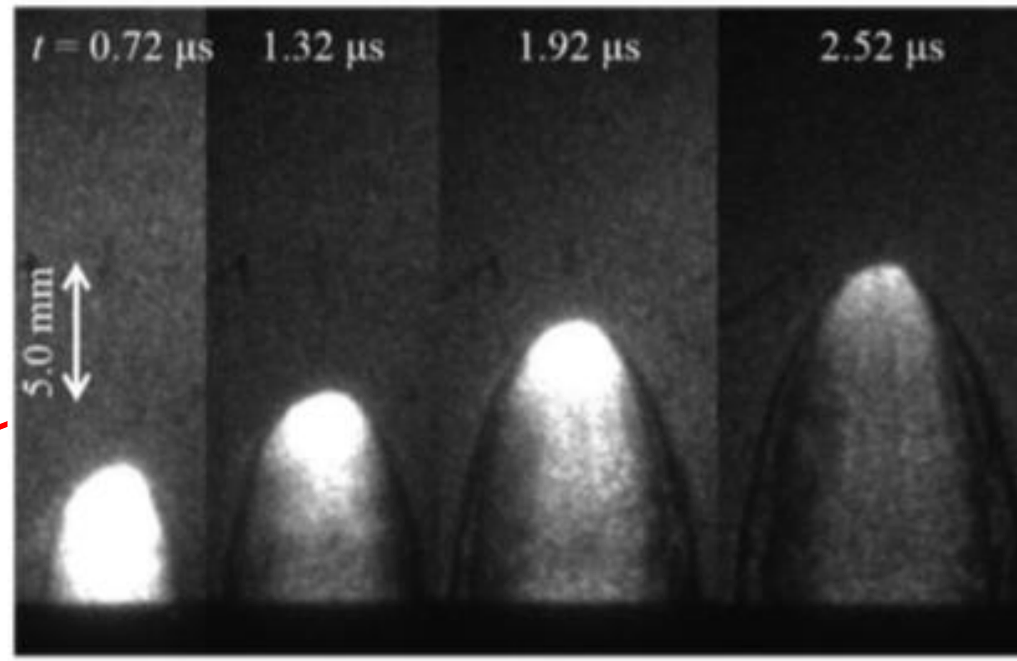
LSD occurs when a laser is focused to a high intensity



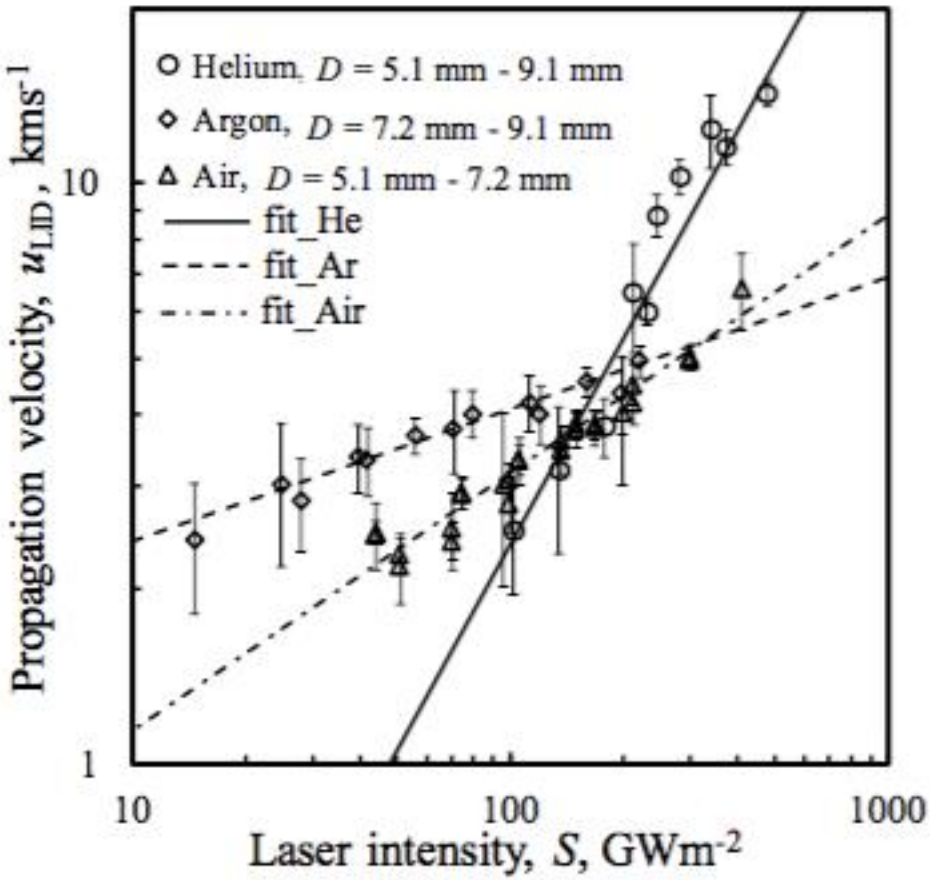
Laser Supported Combustion (LSC)

↕

Laser Supported Detonation (LSD)



LSD velocity depends on gas species



Ar and He for simplicity

From Theory of Detonation
$U_s \propto S^{1/3}$
No dependence of gas

From experiments $U_s \propto S^a$
a = 0.4 (@Air)
a = 0.22(@Ar)
a = 1.18(@He)

Must be elucidated by simulation

1. Shimano, T., Ofosu, J. A., Matsui, K., Komurasaki, K., and Koizumi, H.: "Laser-induced discharge propagation velocity in helium and argon gases" *Trans. Japan Soc. Aero. Space Sci.*, **60**, 6 (2017), pp. 371-378.

Objective

Numerical model that determines LSD wave velocity is yet to be found

Not completely determined by Fluid dynamics

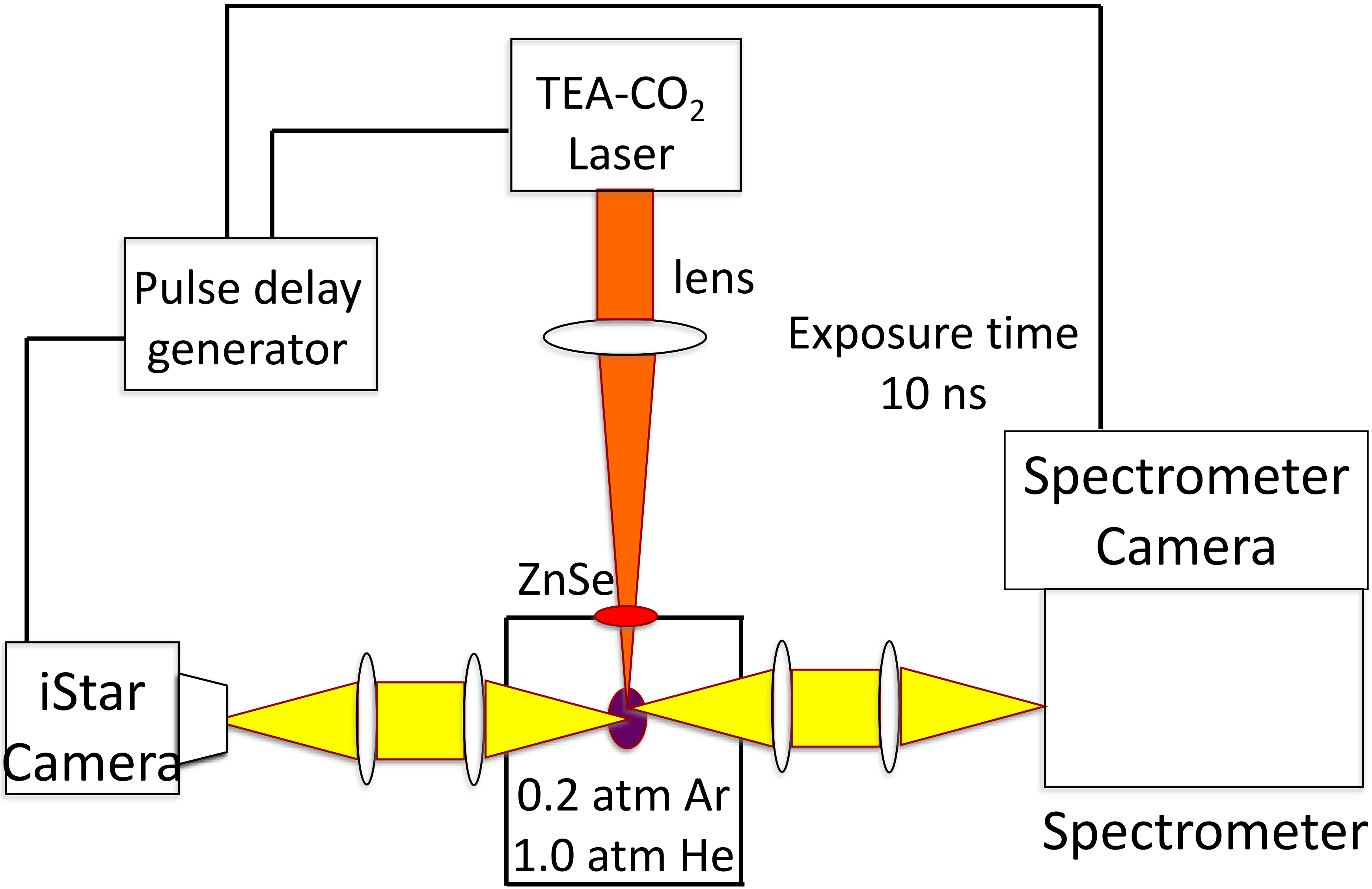
Actual velocity is determined by Discharge Physics ?

Objective

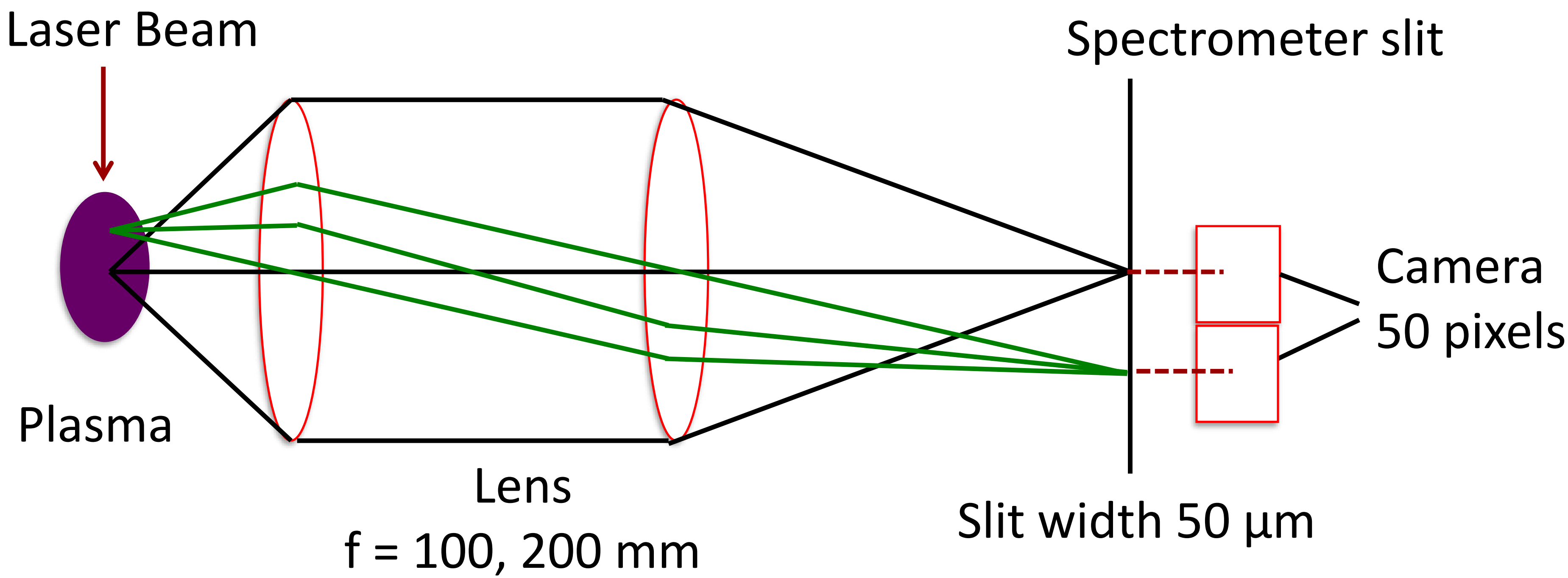
Measure n_e distribution of plasma and find out how to improve the current numerical model

Experimental Setup

Overview of experimental setup



Spectroscopy optics

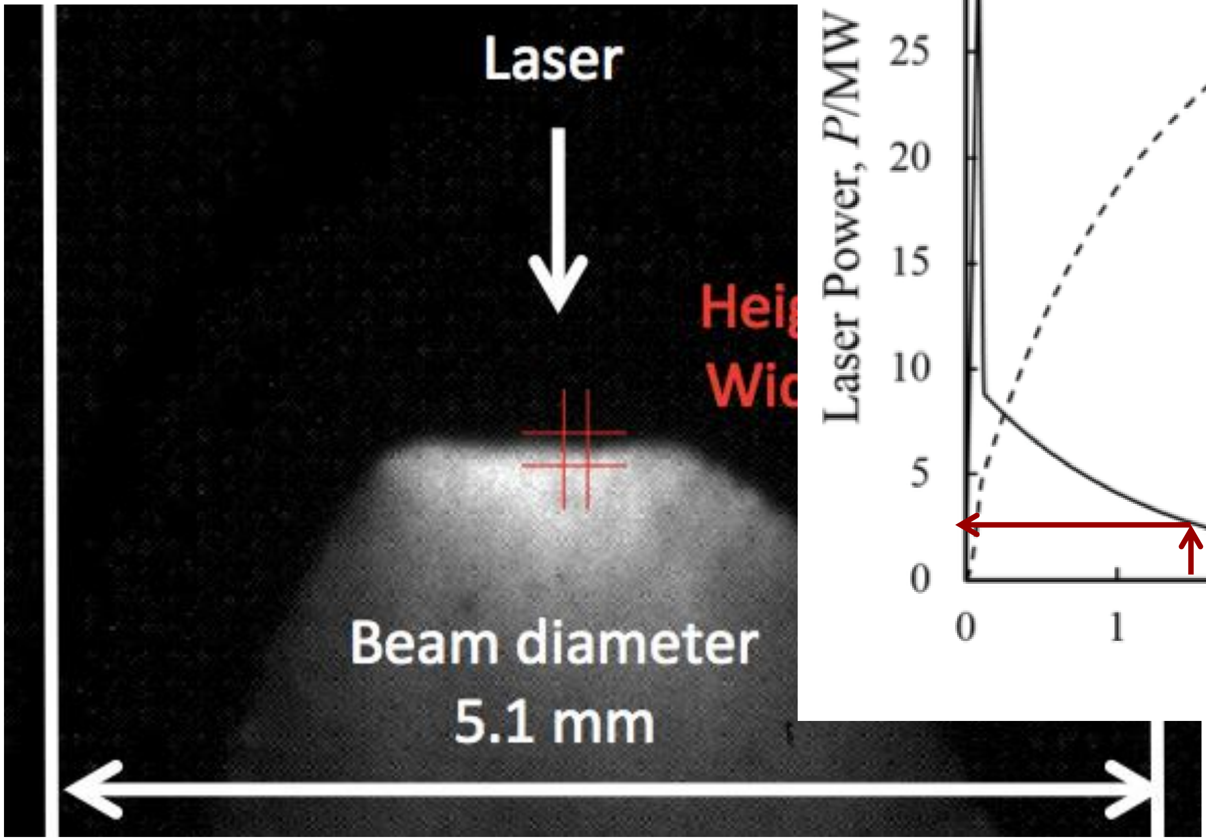


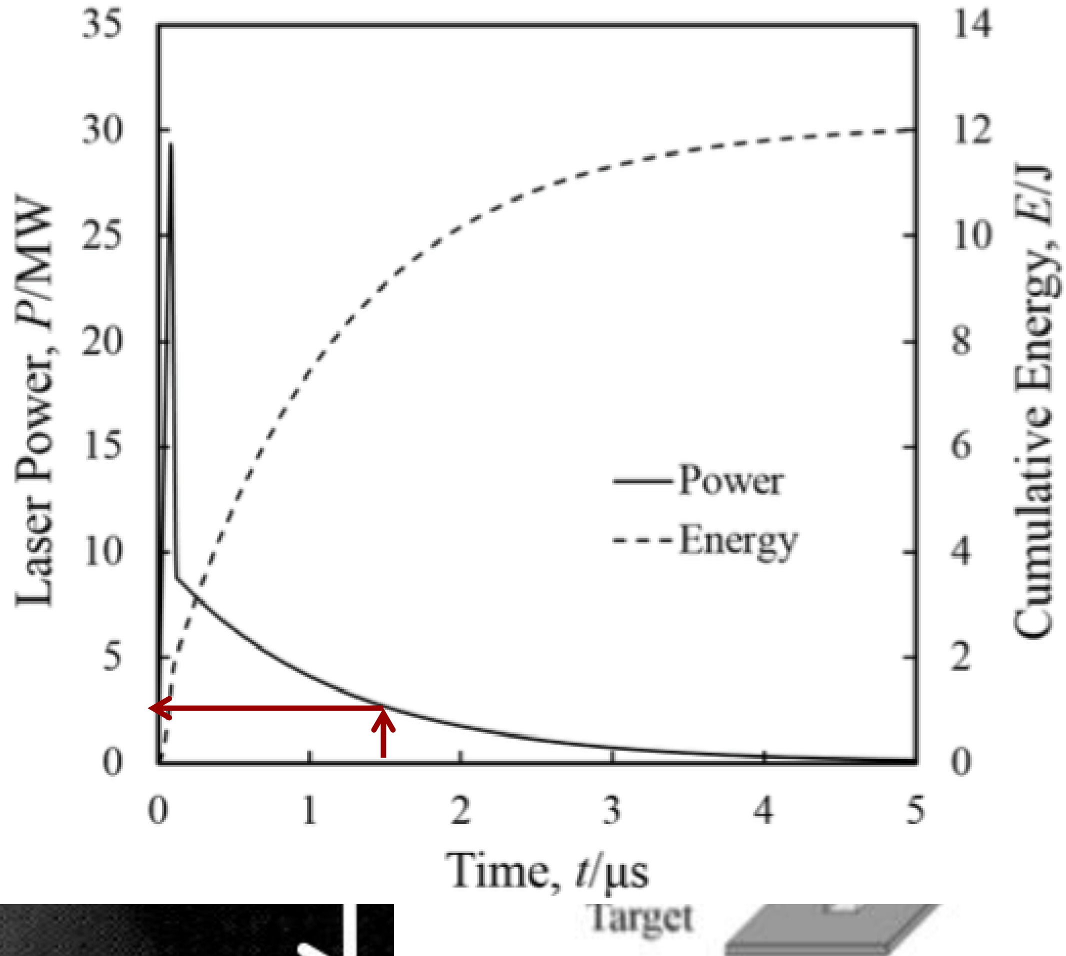
Data of 50 pixels (0.13 mm) was averaged

Exposure time 10 ns was short enough
Plasma travels 0.06 mm

CO_2 Laser focusing optics

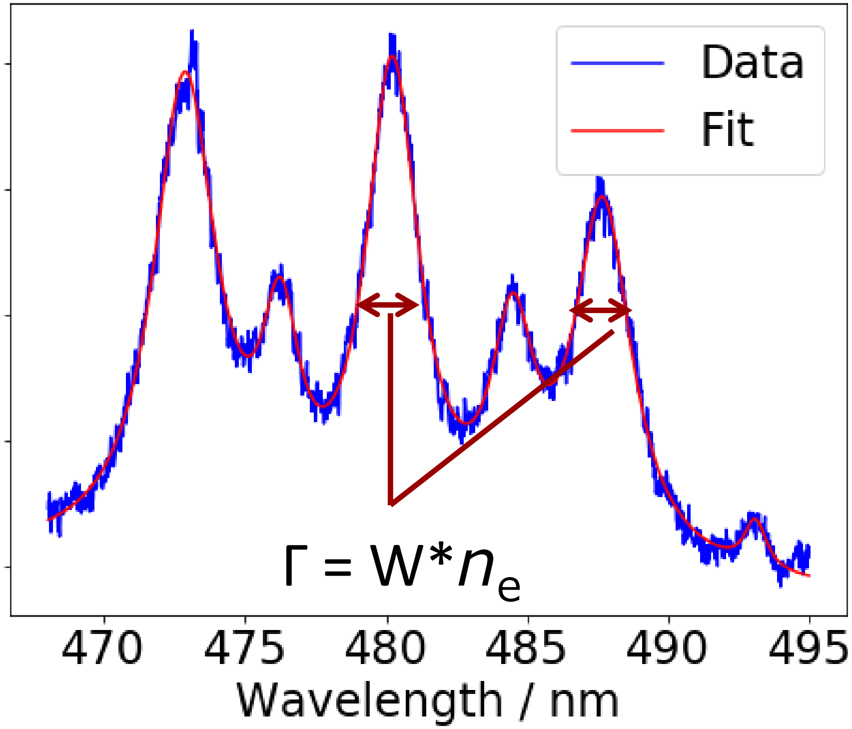
Wave length 10 μm
1 shot 12 J

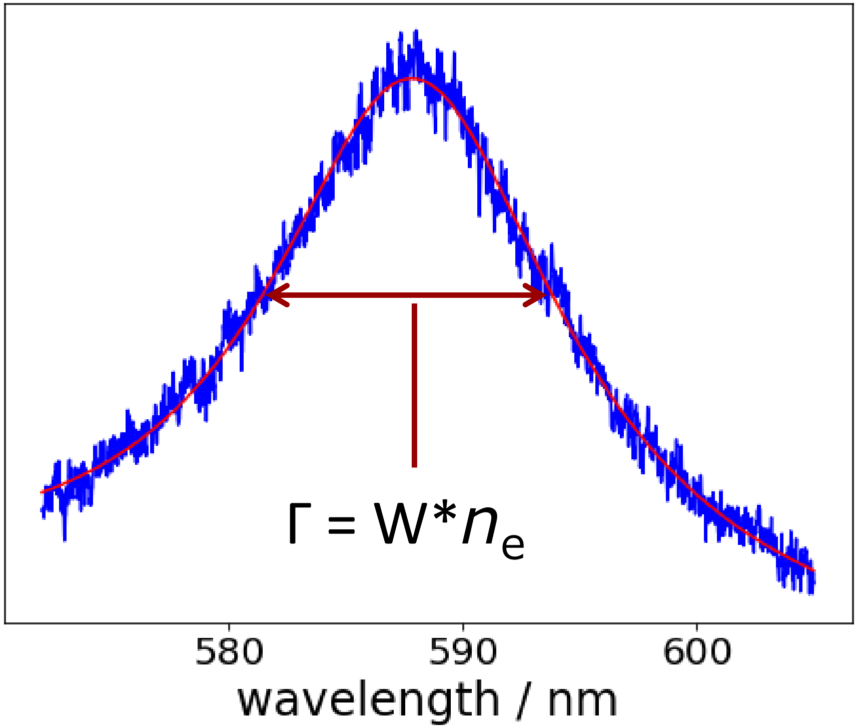




Stark broadening analysis for n_e

Stark braodening $\Gamma = W*n_e$



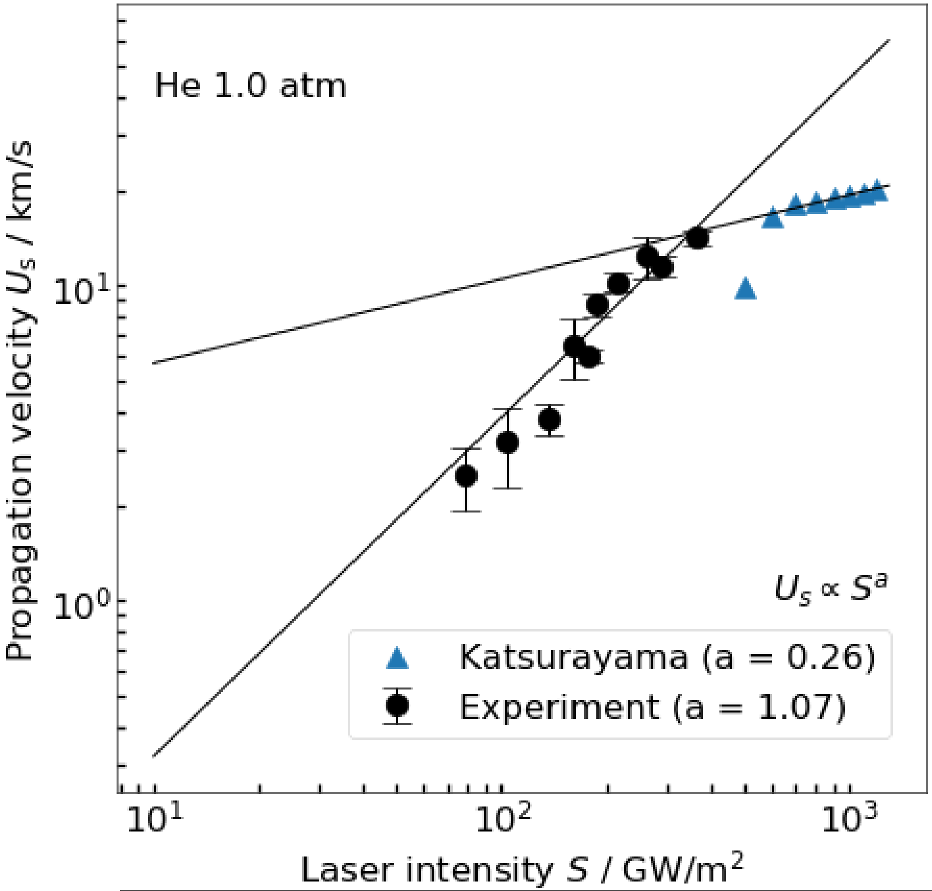


0.2 atm Ar in which ArII spectral lines were visible

Spectral lines were visible in He even at 1.0 atm

Results and Discussion

LSD velocity in 1.0 atm He



LSD propagation velocity laser intensities in He 1.0 atm

Numerical simulations were in LSC regions @ under 500 GW/m^2

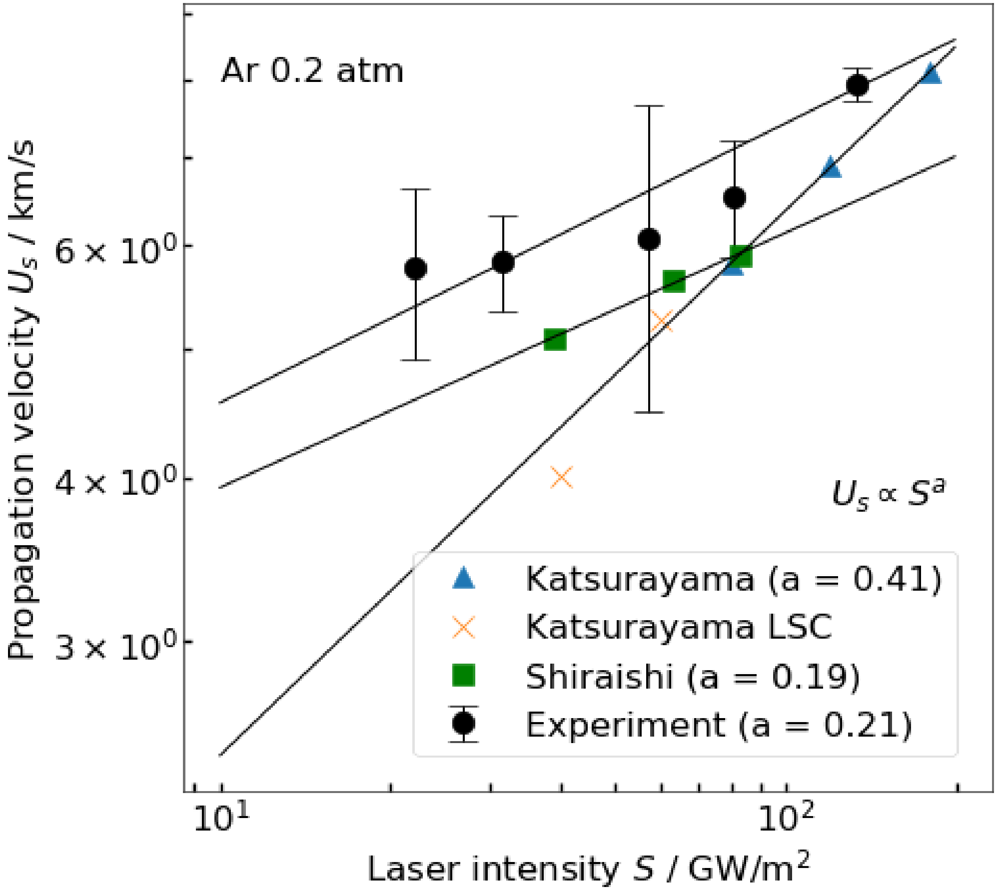
All previous experiments were in the LSC region

New model for LSC

Experiment in higher Laser Intensity

1. Shimano, T., Ofosu, J. A., Matsui, K., Komurasaki, K., and Koizumi, H.: "Laser-induced discharge propagation velocity in helium and argon gases" *Trans. Japan Soc. Aero. Space Sci.*, **60**, 6 (2017), pp. 371-378.

LSD velocity in 0.2 atm Ar



LSD propagation velocity
laser intensities in Ar 0.2 atm

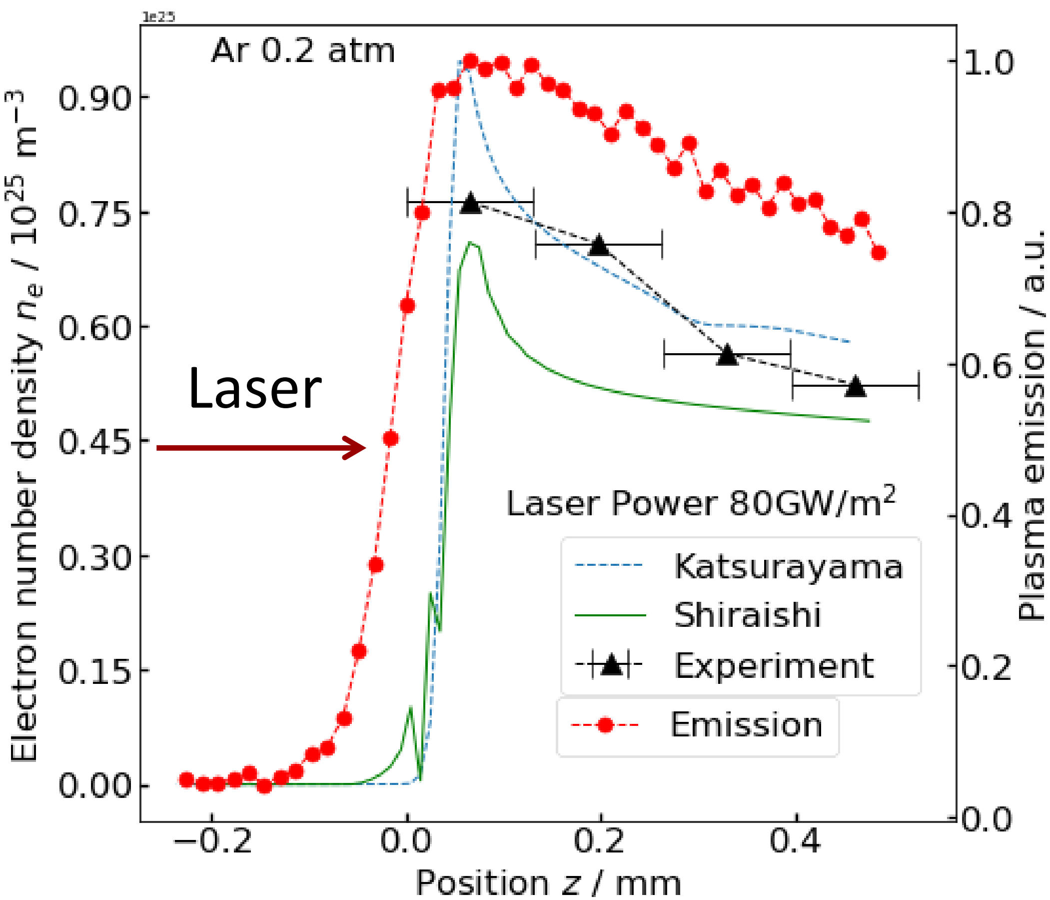
$U_{s,exp} > U_{s,num}$
In every case

Must think of effect that increases U_s

Measurement of n_e may help finding reason for disagreement

2) K. Matsui, *et al*, "The effect of gas species on propagation velocity of laser-induced discharge in laser propulsion," *Trans*. JSASS (2017)

Spatial distribution of n_e (Ar)



Emission and n_e distribution from experiment and simulations

Densities within the wave front have not been deduced yet

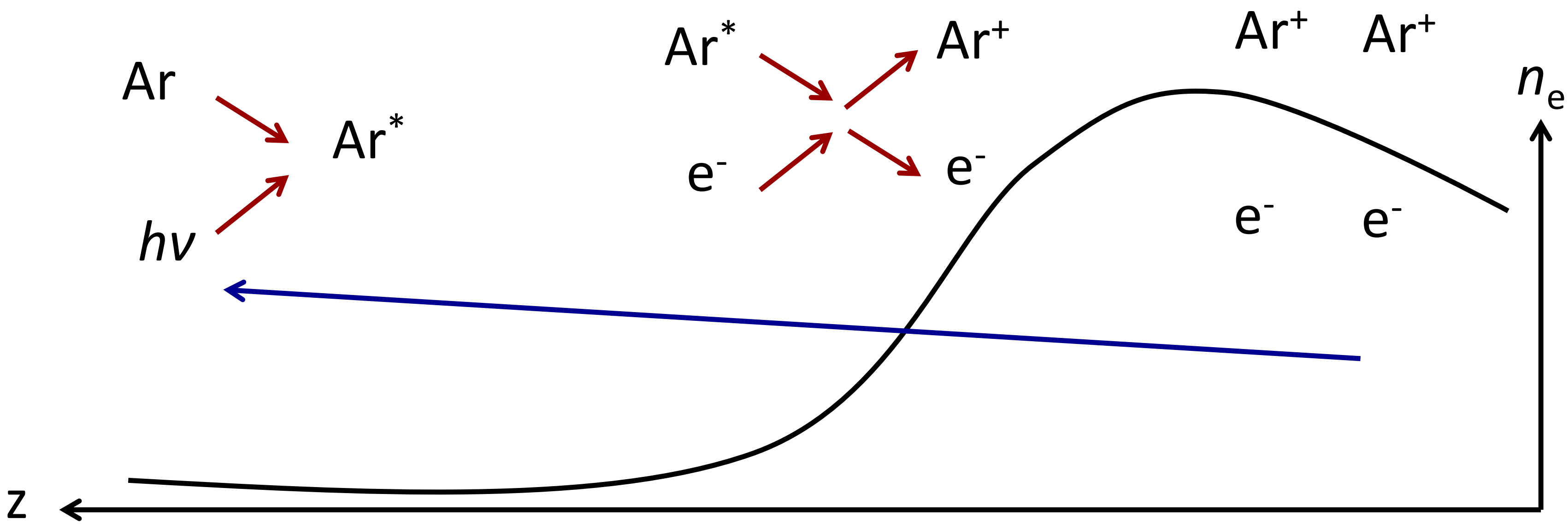
Distribution of emission suggested slower increase of n_e

Model of ionization in front of shock may be important (Cumulative ionization)

Cumulative ionization

Numerical models in millimeter-wave discharge consider cumulative ionization
Ex)Ionization of neutral particles excited by photons

Velocity increased in the millimeter-wave discharge



3. Nakamura, Y., *et.al.:* "Role of Photon-Carrying Excited-Neutral-Particles on Ionization Front Propagated in Millimeter Wave with Under Critical Intensity", *IAPS Meeting, P-18, 2019.*

Conclusion

- Measured U_s was higher than computed U_s in all conditions
- Previous measurements of U_s in helium were conducted in the LSC region
- Distribution of n_e within the wave front is yet to be measured
- Ionization process from the precursor to the shock wave should be reconsidered
- Consideration of cumulative ionization from excited particles may increase U_s as in millimeter-wave discharge

Thank you for your kind attention

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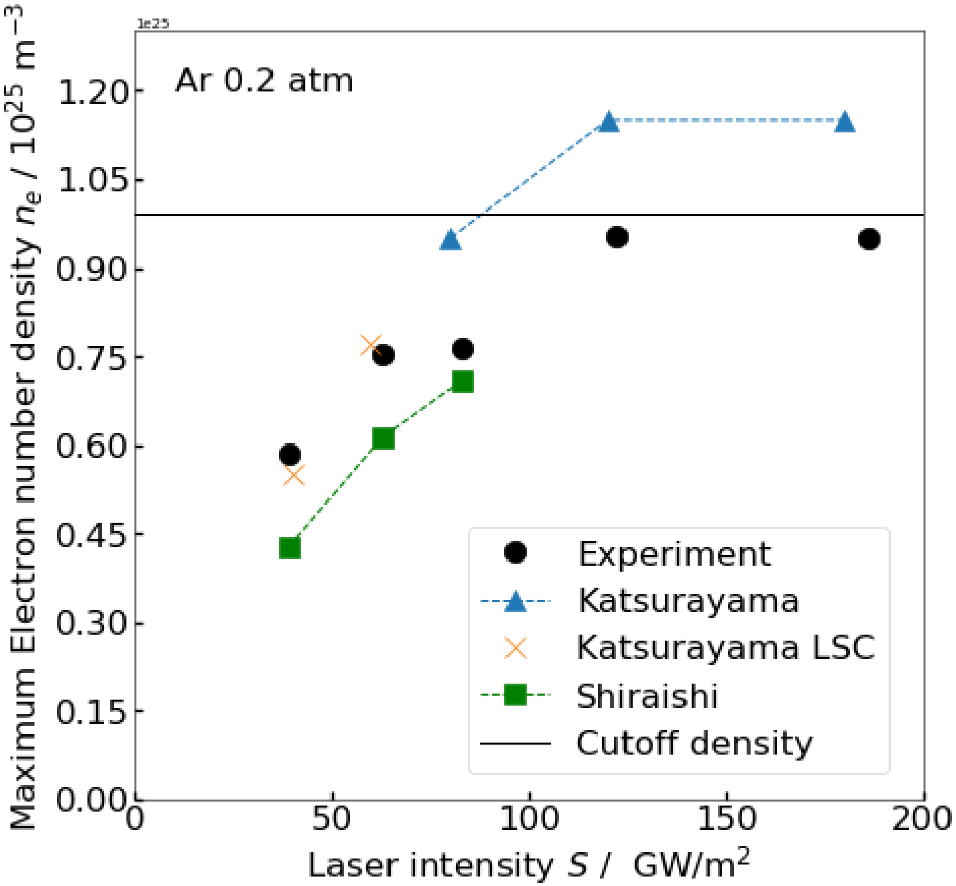
Maximum n_e in 0.2 atm Ar



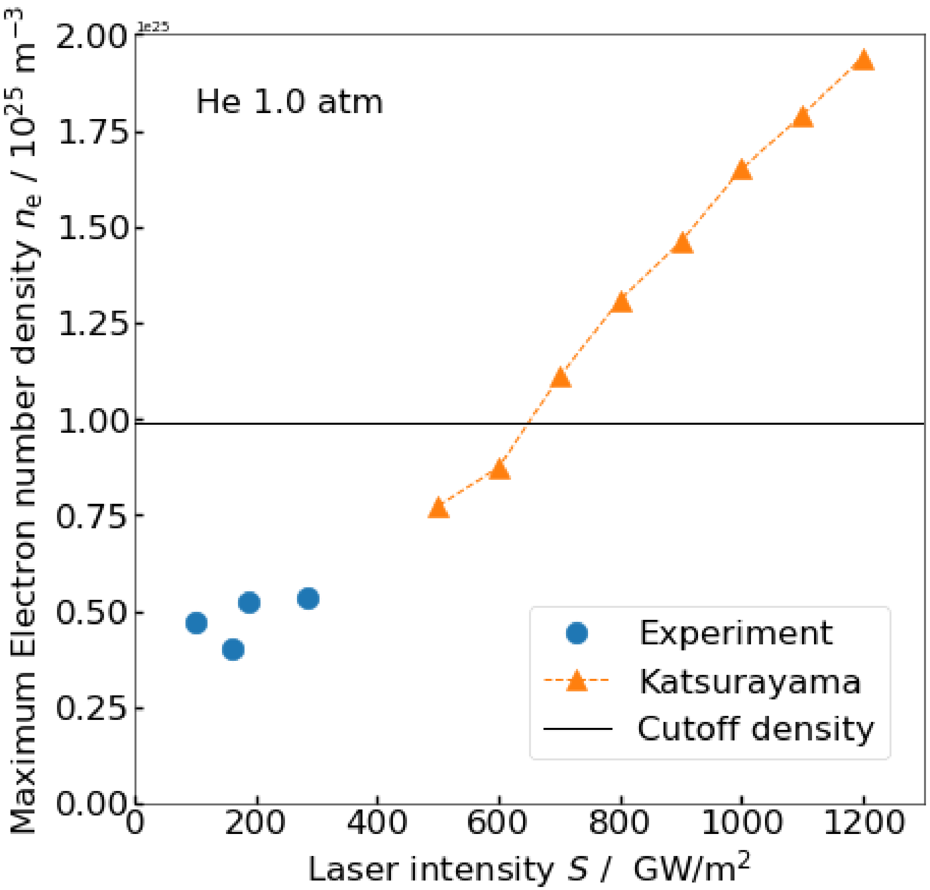
Maximum n_e at several laser intensities in Ar 0.2 atm

Peak number of n_e had similar trend and had quantitative agreement in some cases

LSD velocity differed even when peak number of n_e was the same

LSD velocity is not determined only by peak

Maximum n_e in 1.0 atm He



Maximum n_e at several laser intensities in He 1.0 atm

Peak number of n_e did not change much (compared to Ar)

Slope of velocity $U \propto S^a$
a = 0.22(@Ar)
a = 1.18(@He)

Increase in laser power is used to increase velocity (and not n_e)