Aerosol Formation and Hydrogen Co-Deposition by Colliding Ablation Plasma Plumes

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Princeton Plasma Physics Lab.

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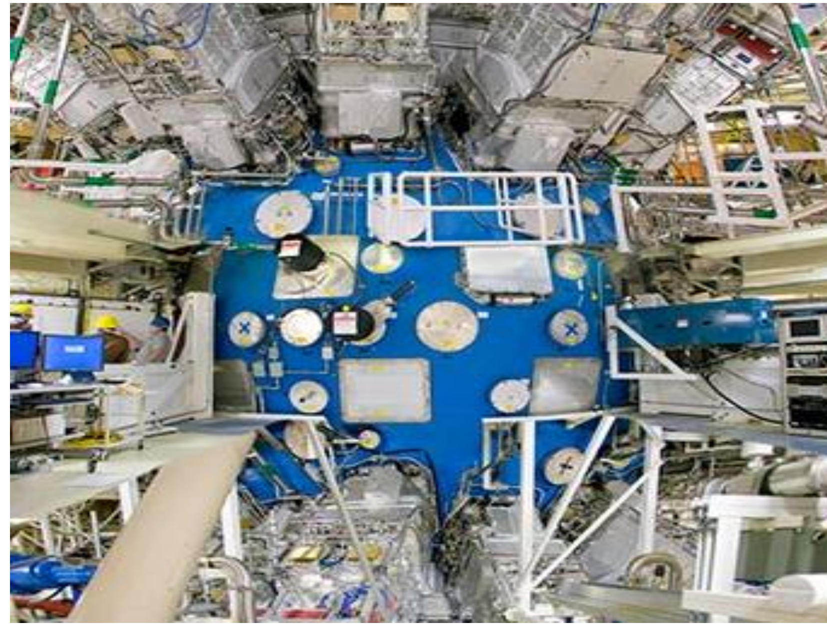
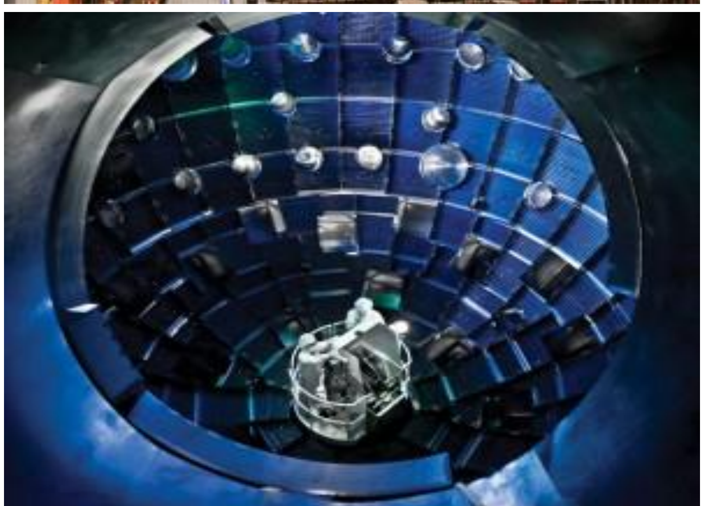
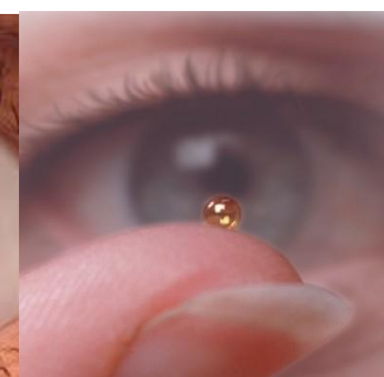
National Ignition Facility (NIF)

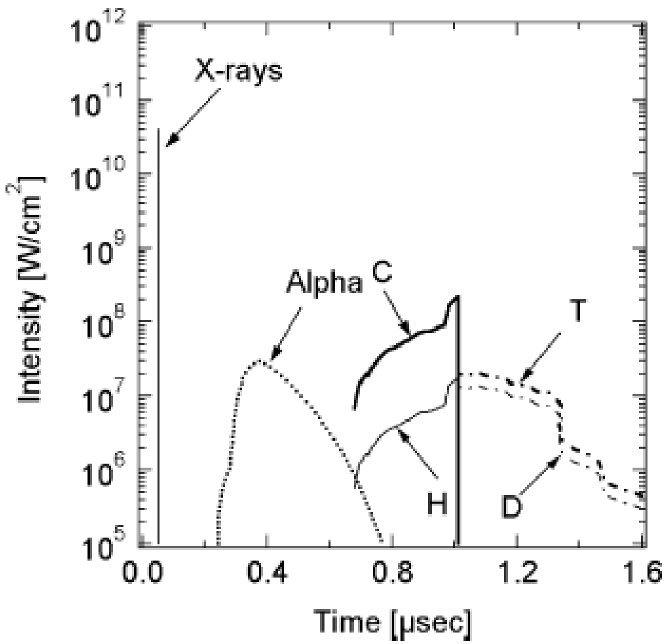






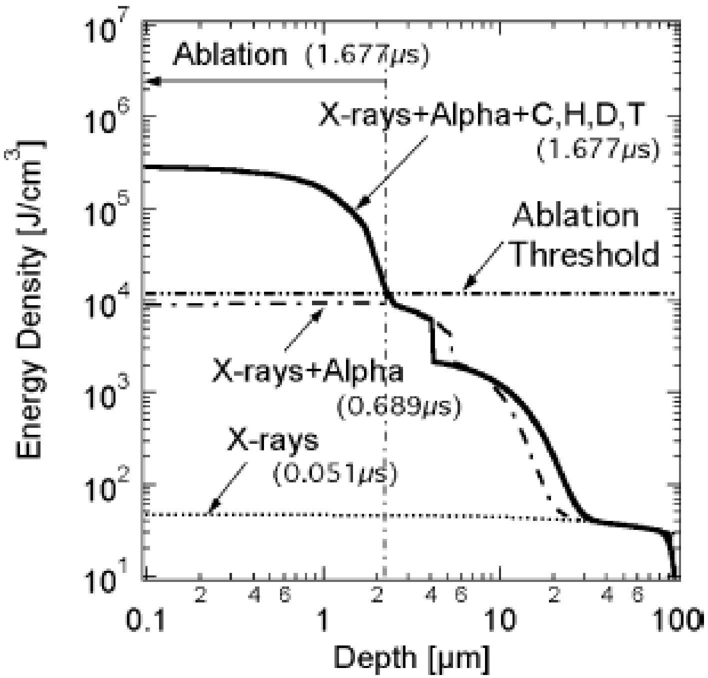
Implosion debris generation dynamics

Time evolution



Irradiation intensity of the X-rays, alpha particle, carbon, a hydrogen, heavy hydrogen, and tritium ions in the first wall surface in conditions with a nuclear fusion output 400MJ and a chamber radius of 4 m.

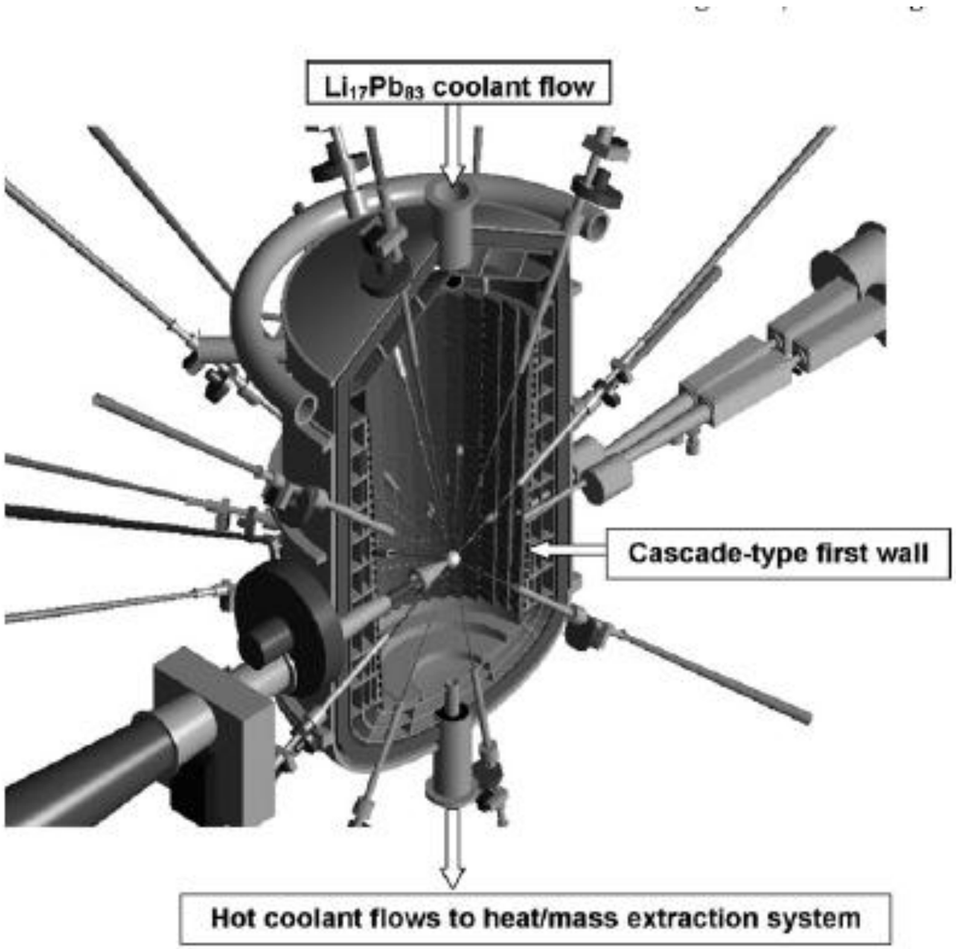
Penetration depth

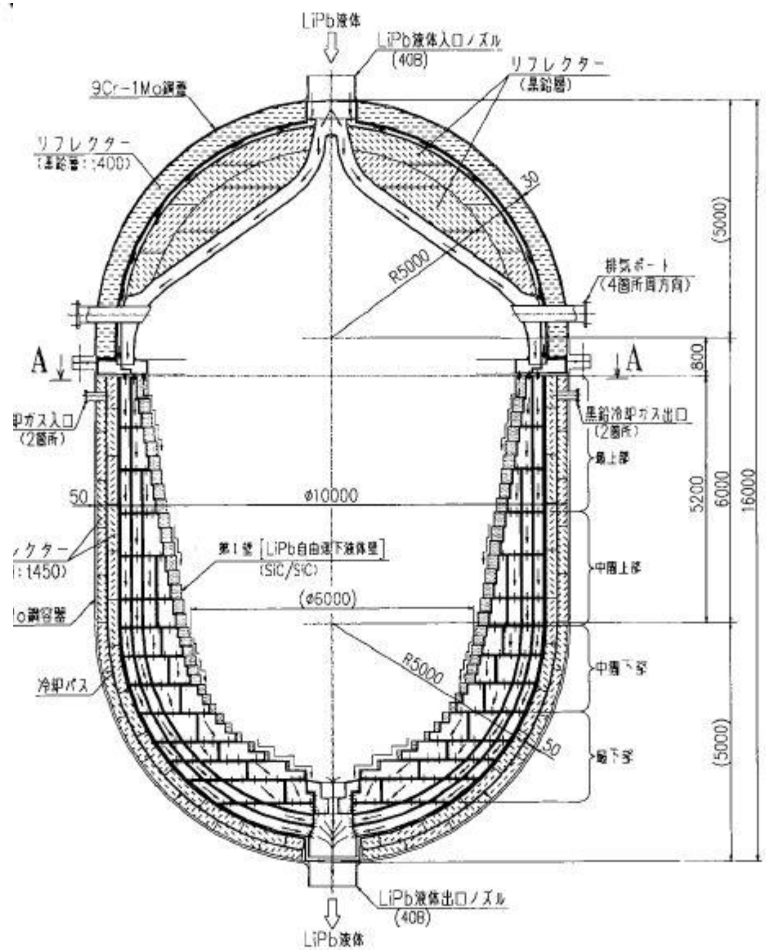


The calculation result of energy deposited on the first wall by the X-rays and charged particles.

After Yamamoto et al. in JSFP (2006)

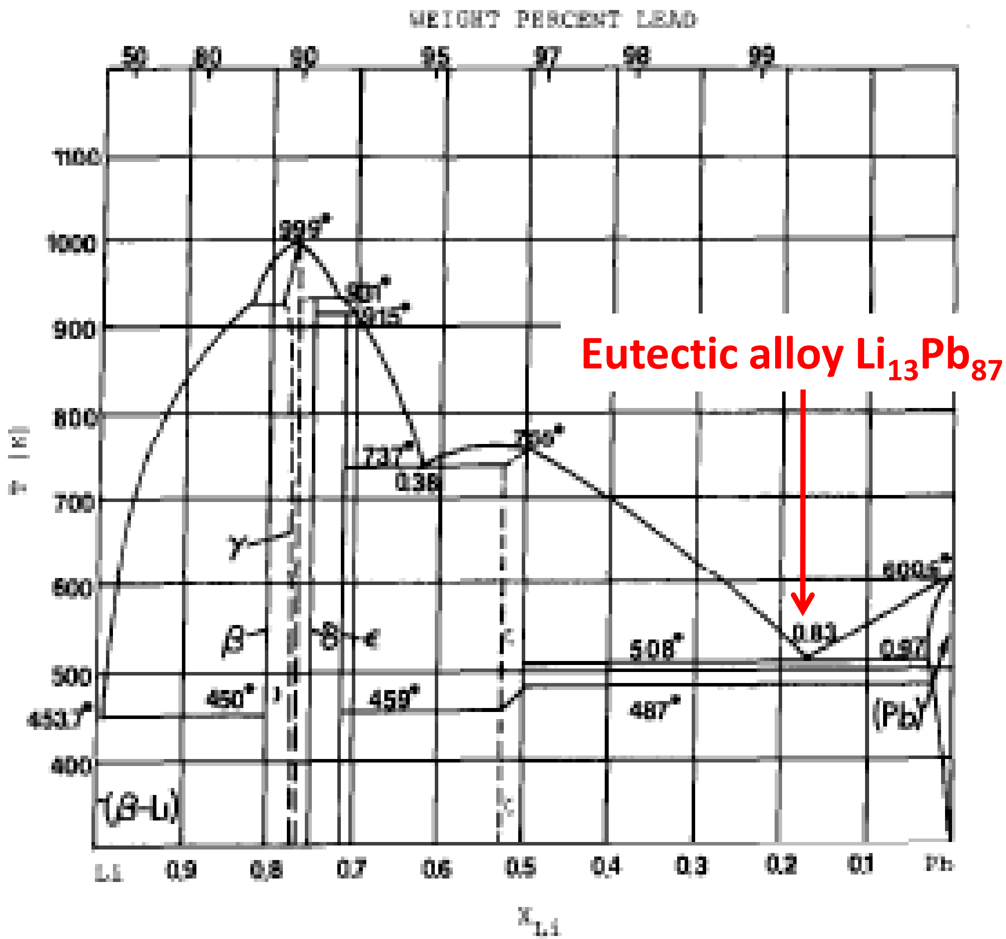
KOYO-FAST reactor with a liquid metal 1st wall





After T. Kunugi et al. in FED 83(2008)1888.

Phase diagram of the Li-PB system

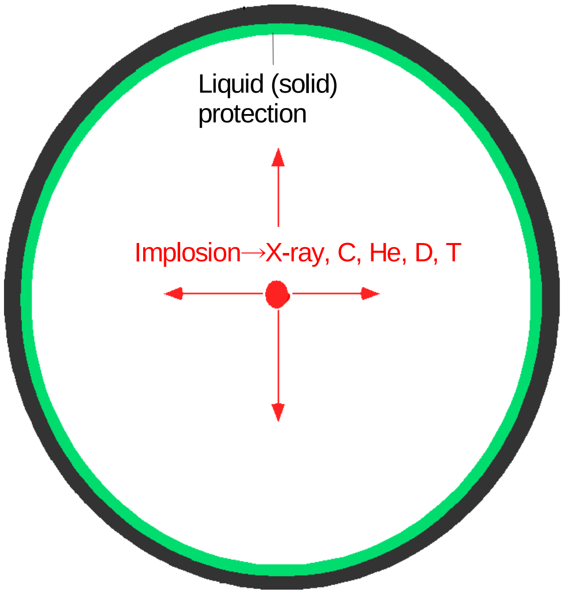


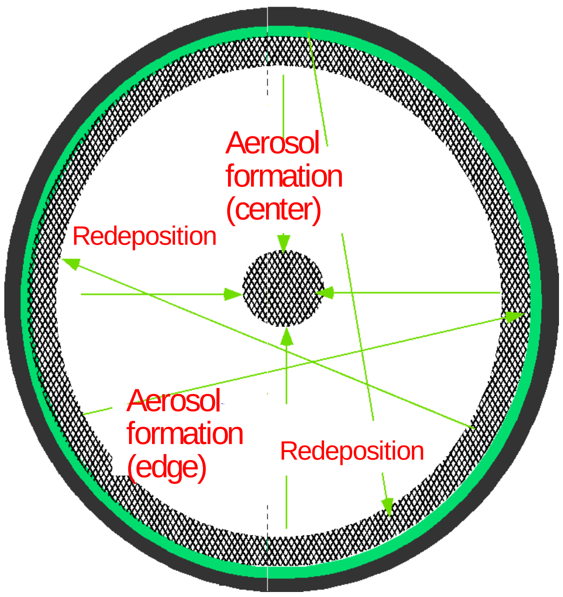
After Grube and Klaiber (1938).

Motivations

- <u>The chamber clearing issue</u> In a high-repetition IFE reactor, along with implosions, the interior of target chambers will be exposed repeatedly to short-pulse X-ray, DT and He ash particles and pellet debris . Wall materials will be eroded by ablation, leading to the formation of aerosol particles that can scatter subsequent laser beams, i.e. limiting the repetition rate.

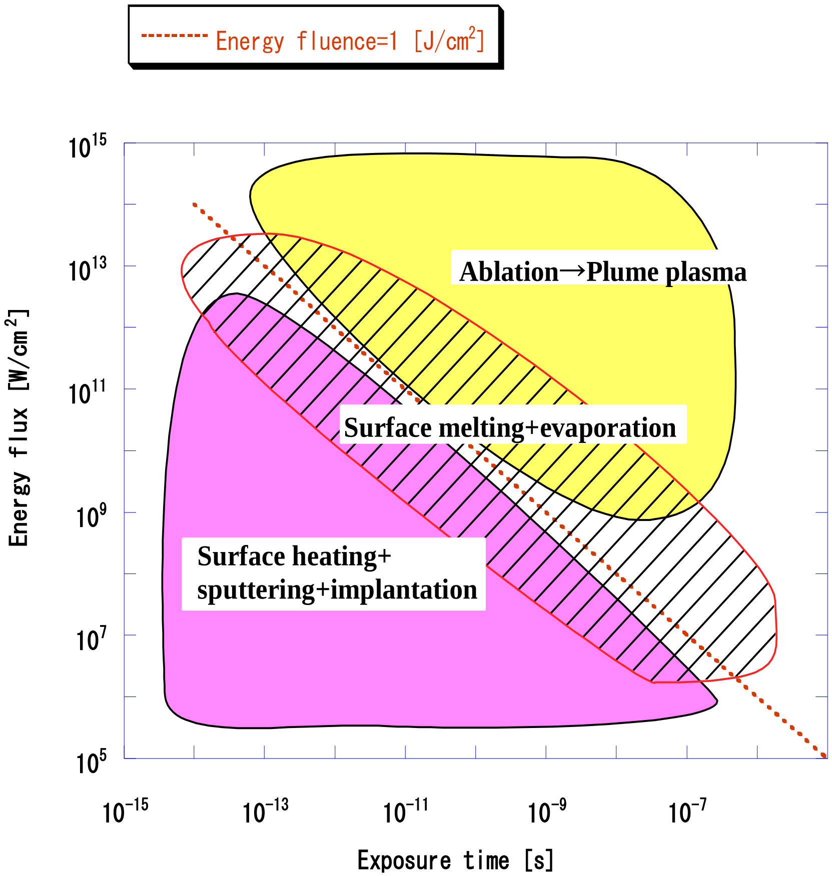
- <u>The radiation safety issue</u> If ablated materials are re-deposited elsewhere on the wall, which extends the wall lifetime, tritium may be co-deposited.



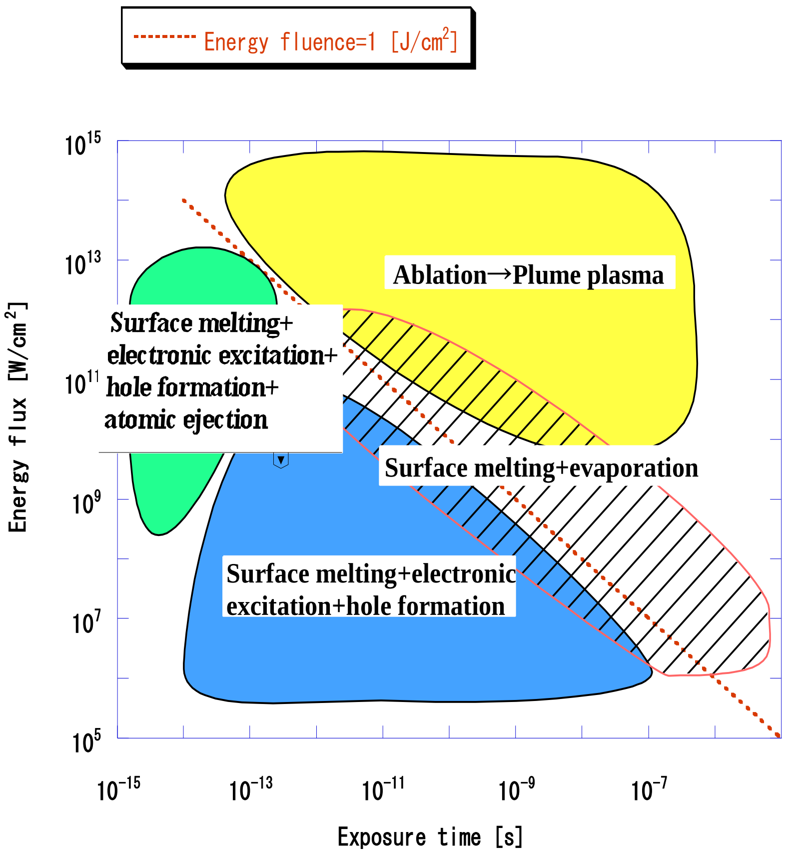


Ion, laser beam-matter interactions

Ion beam-matter



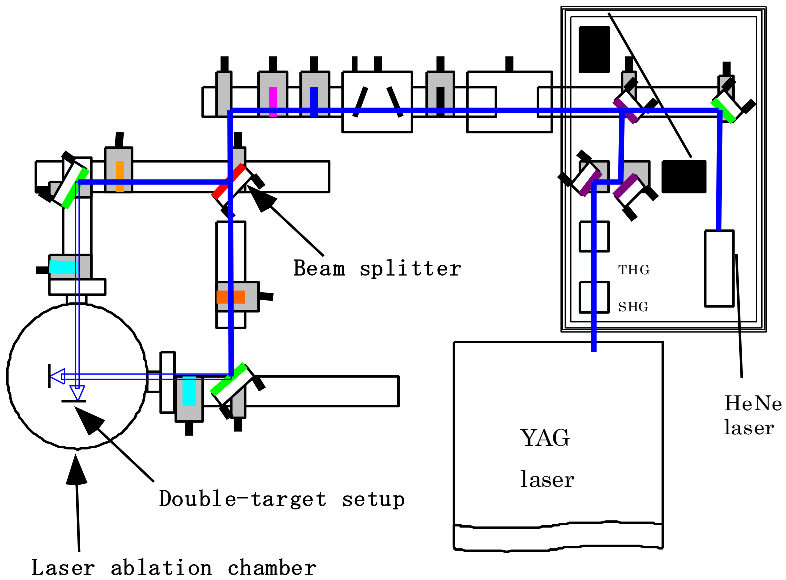
Laser beam-matter

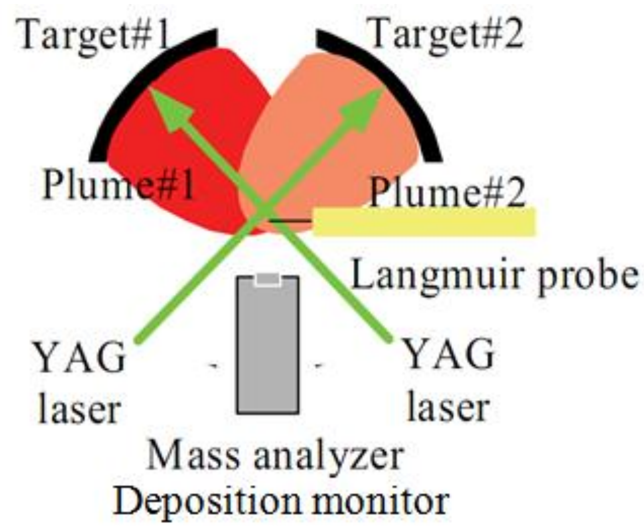


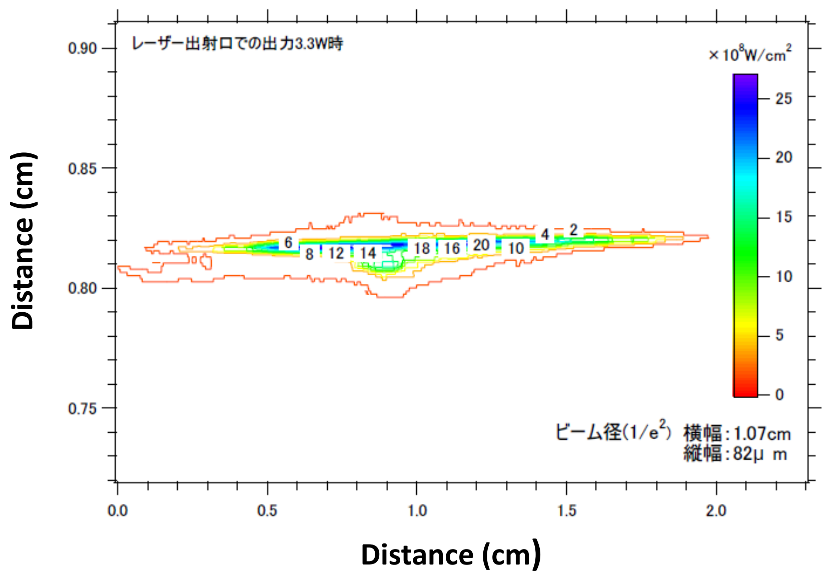
Laboratory Experiments on Aerosol Formation by Colliding Ablation Plumes (LEAF-CAP)

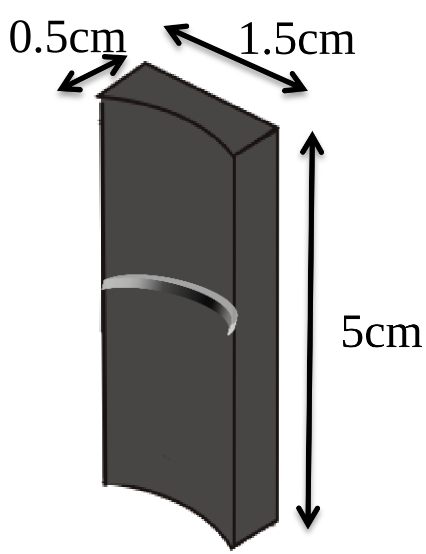
- A YAG laser beam (1064nm, 6ns, 10Hz) is first converted into the 3rd harmonic (355nm).
- The 3ω beam is split into two beams and line-focused to irradiate two arc-shaped targets at power densities up to ~30J/cm^2/pulse.
- Two targets generate ablation plumes, which will collide with each other in the center-of-arc region.
- Used as the target material are Cu, Al, W, C, Pb and Li. All ablation experiments are conducted in vacuum $\leq 10^{-5}$Torr, except that hydrogen co-deposition experiment is done at 10Pa.

The LEAF-CAP experimental setup



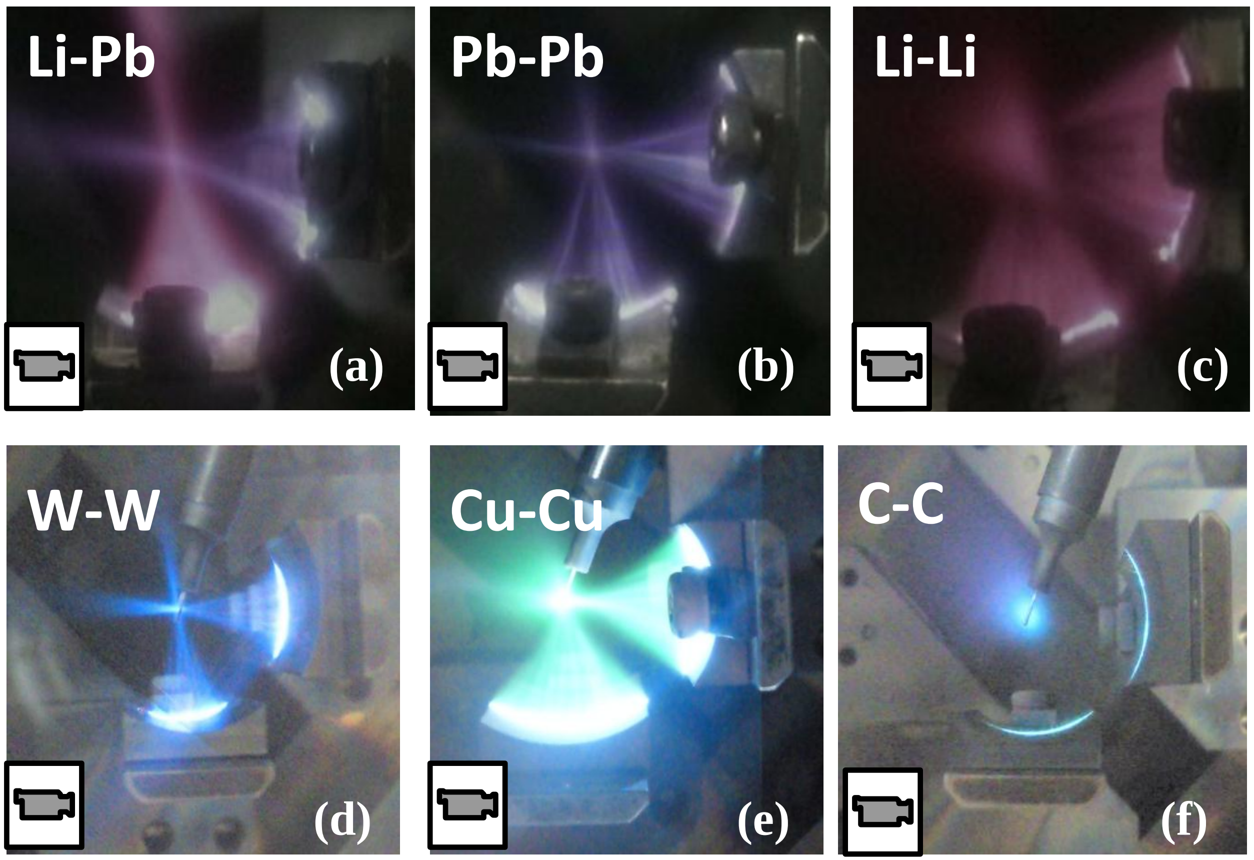






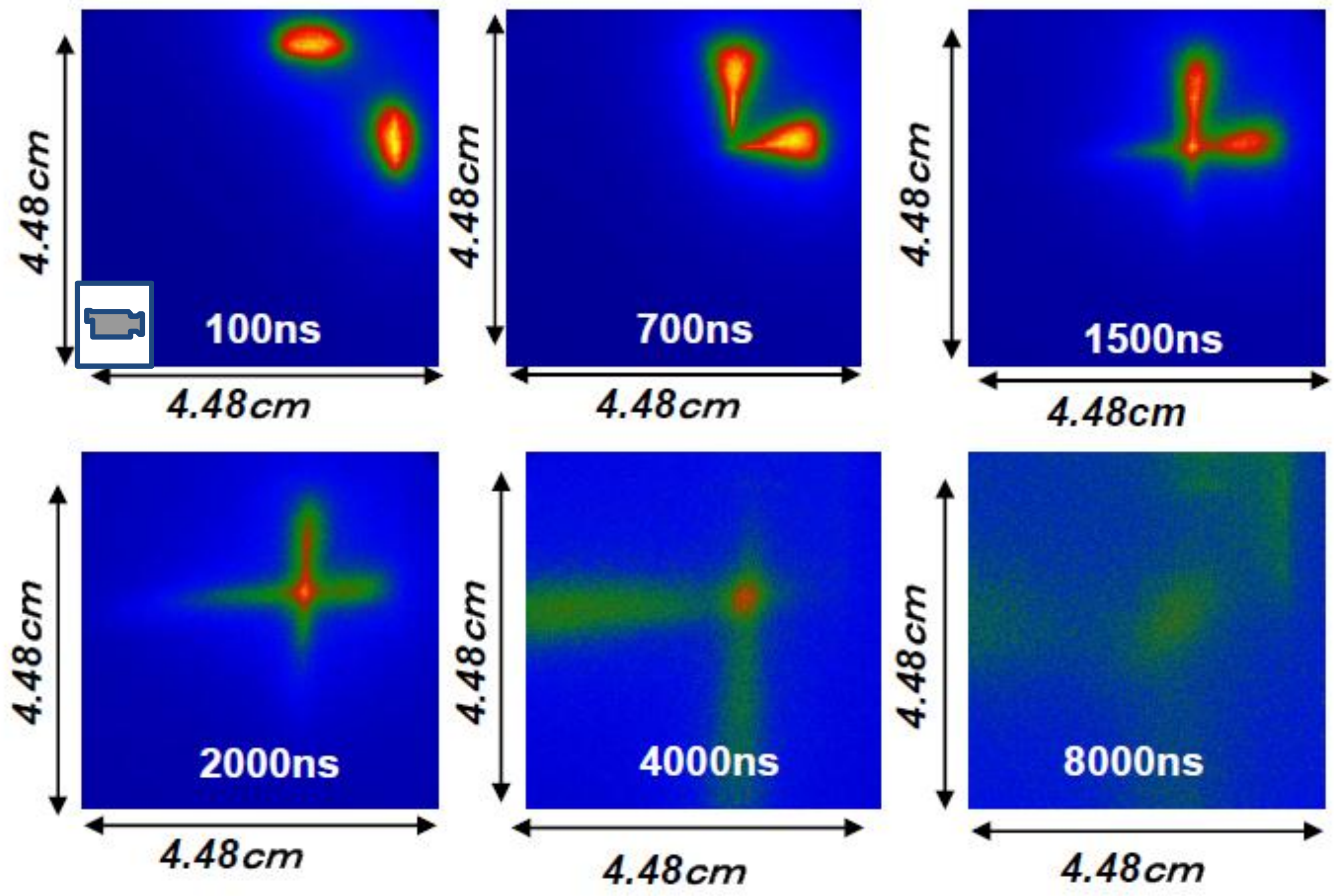
CCD images of colliding ablation plumes

(3~5J/cm^2/pulse)



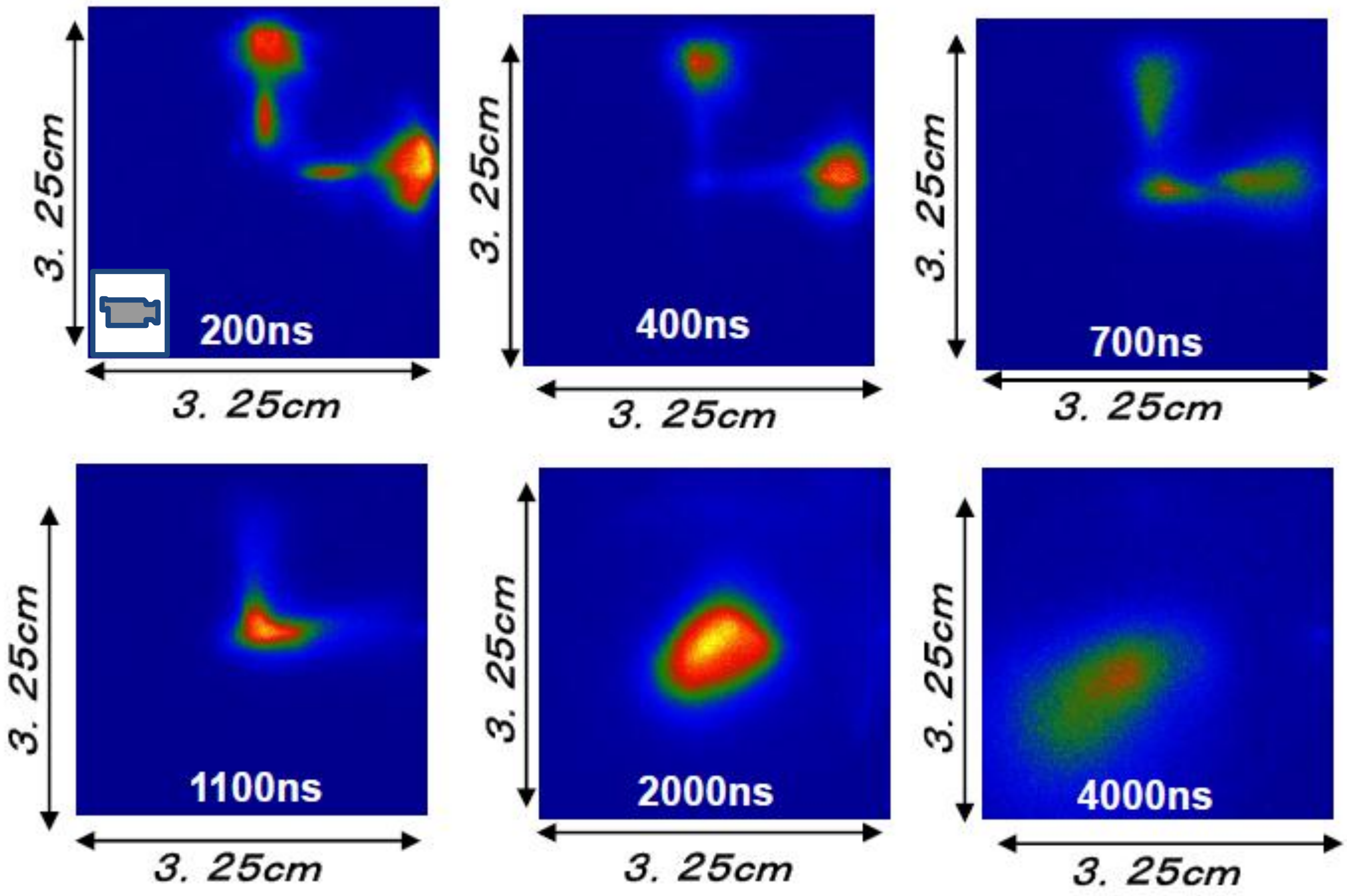
ICCD images of colliding Cu-Cu plumes

(4.3J/cm^2/pulse, Δt=5ns)

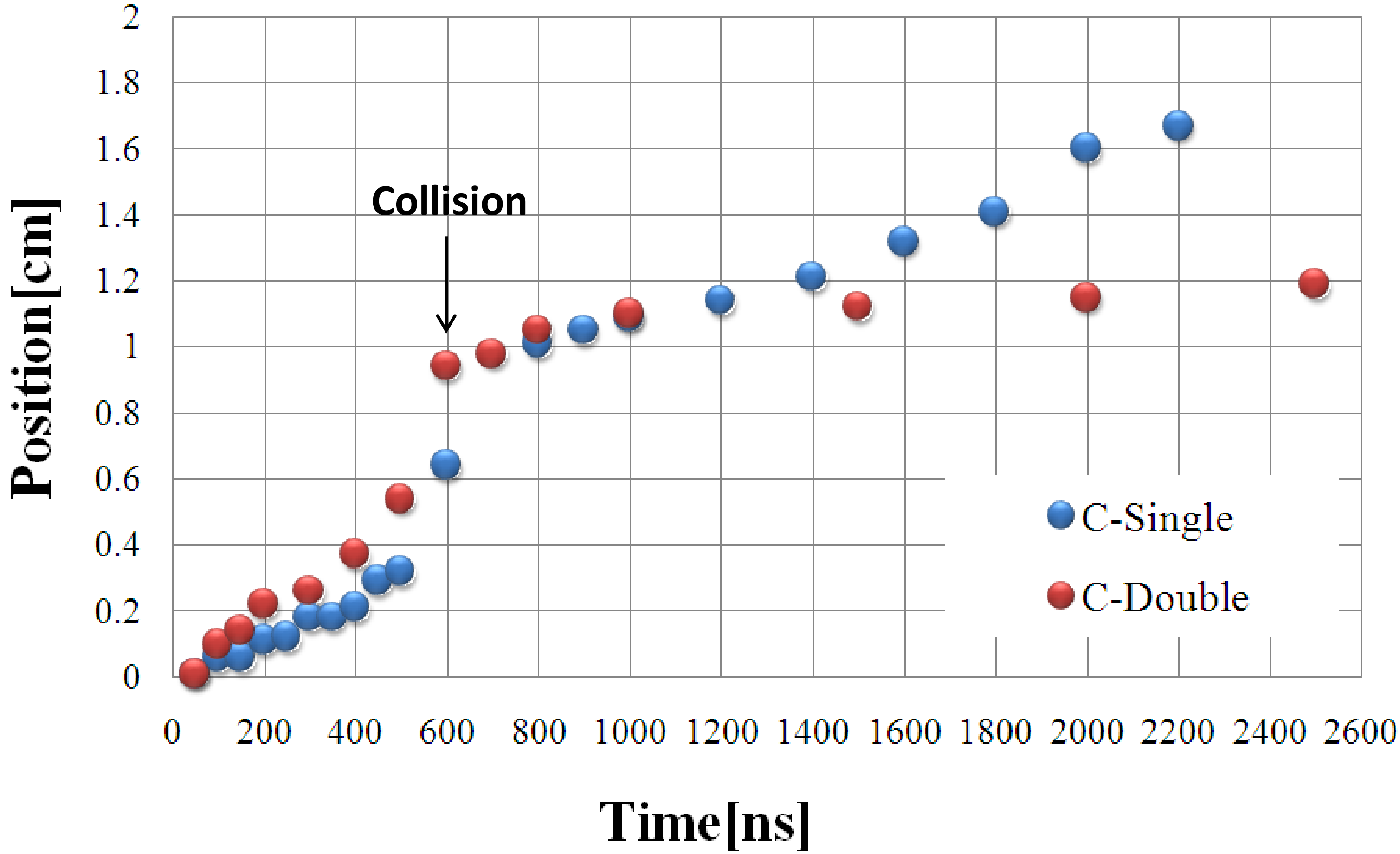


ICCD camera images of colliding C-C plumes

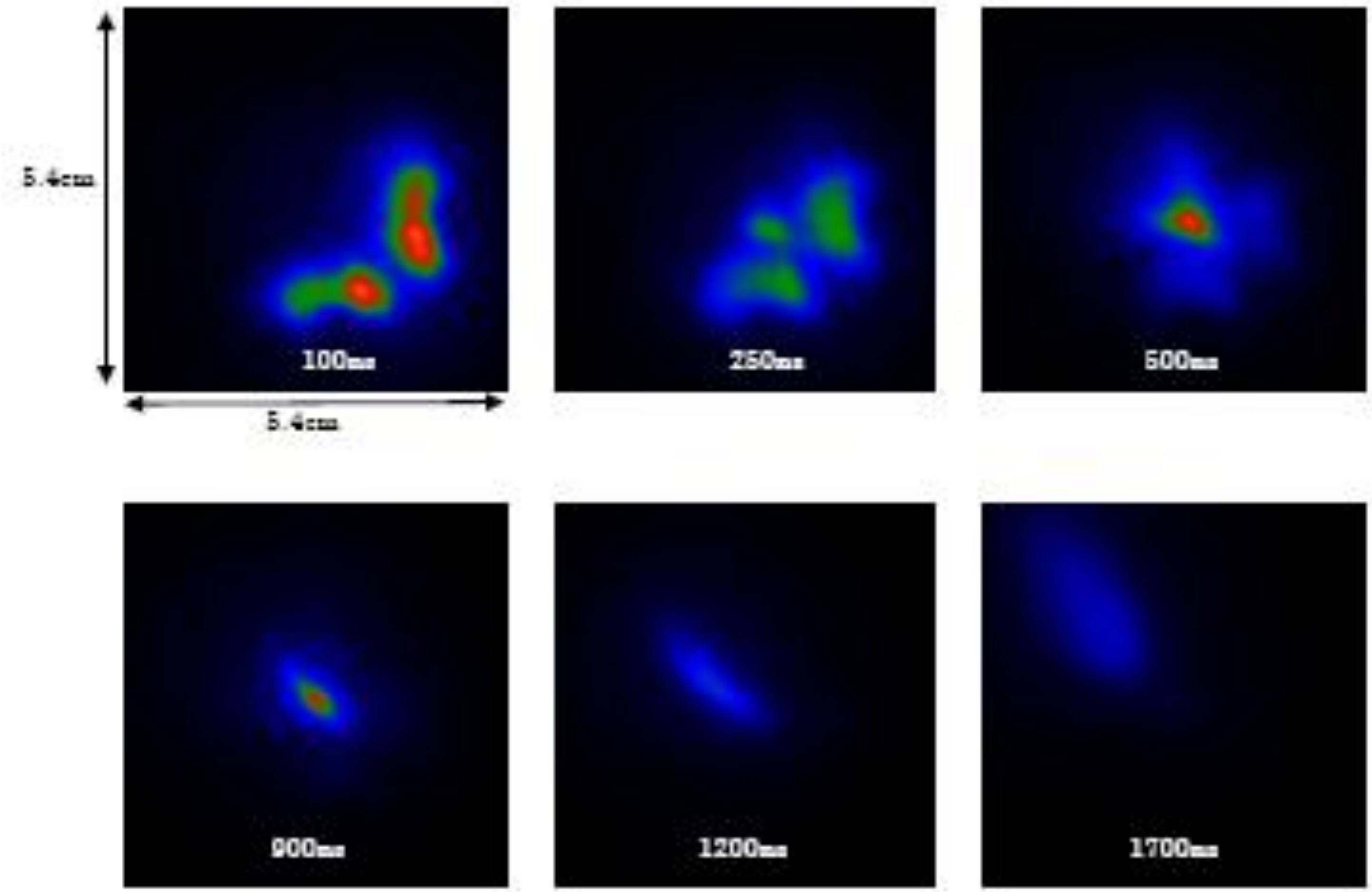
(29J/cm²/pulse)



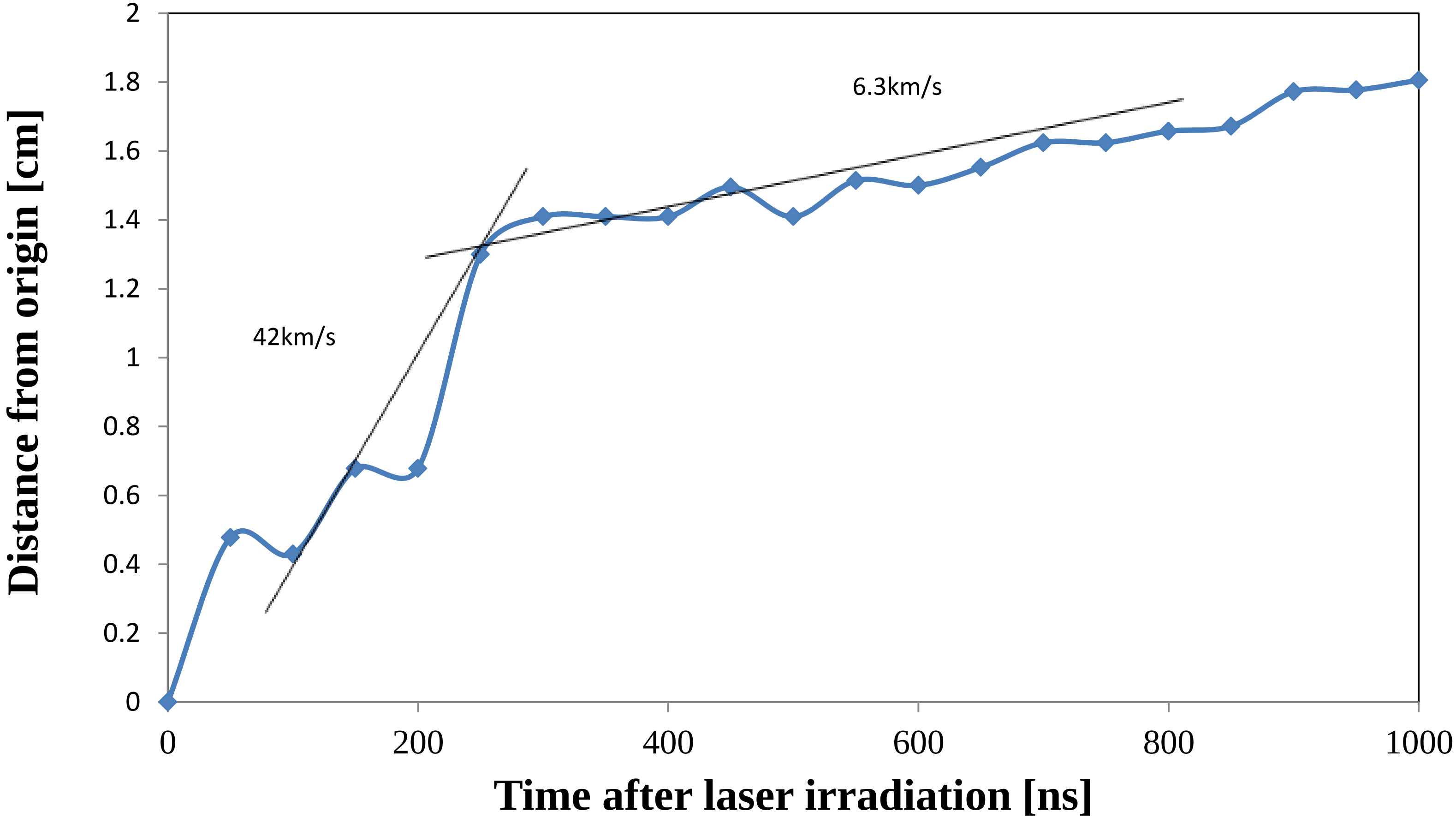
Distance-from-origin for C-plumes



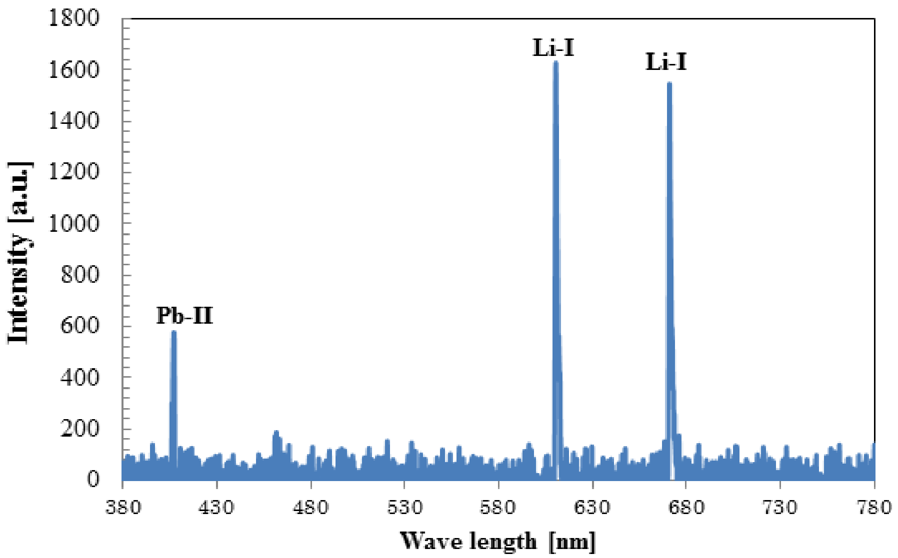
ICCD camera images of colliding Li-Li plumes

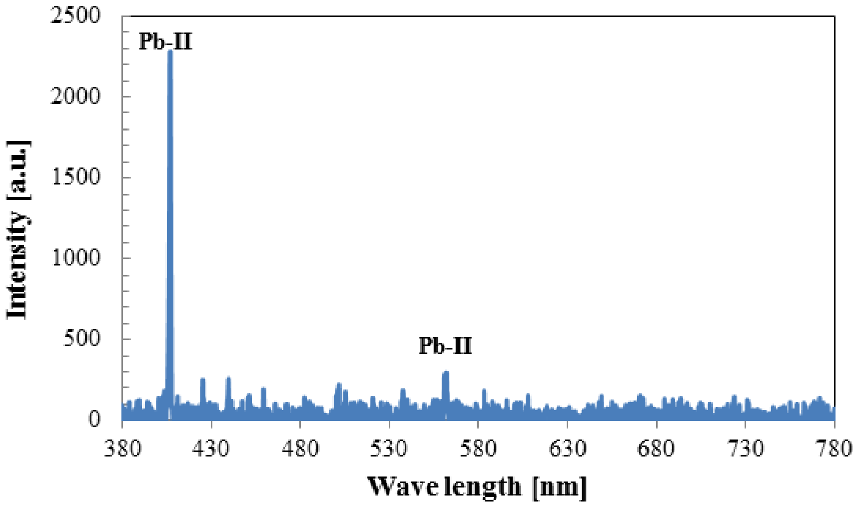


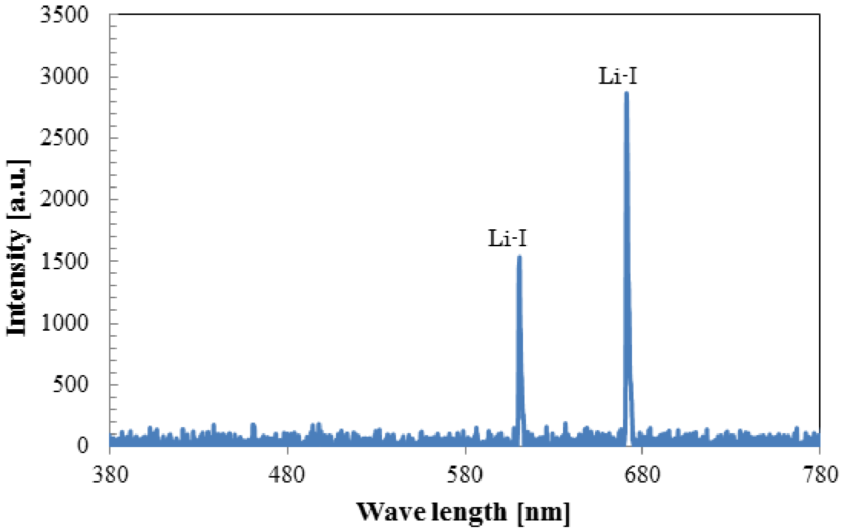
Distance-from-origin for Li-plumes



Visible spectroscopy of colliding ablation plumes

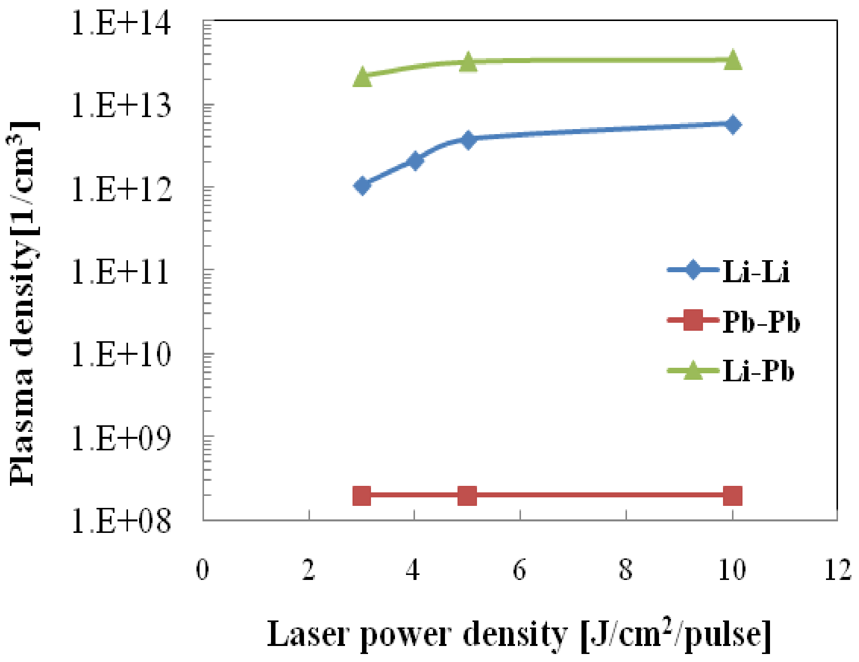




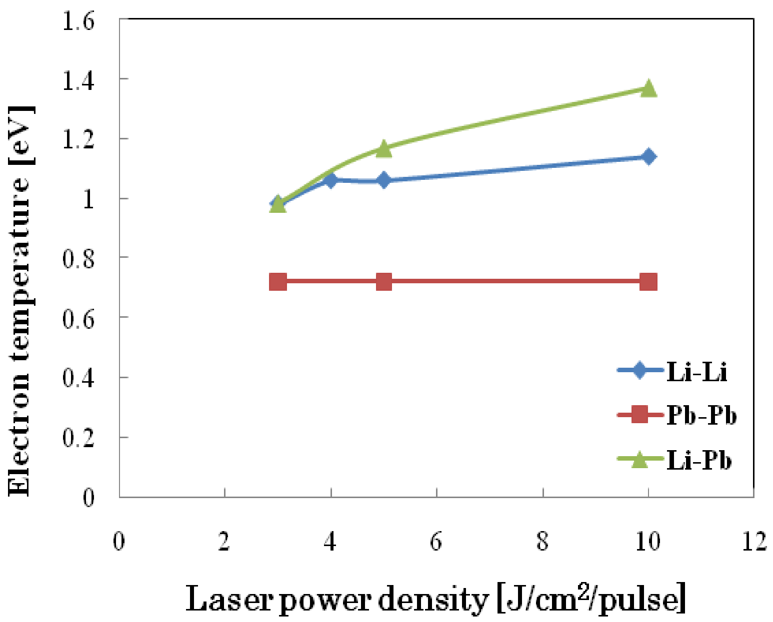


Plasma parameters of colliding ablation plumes

Plasma density (1/cc)

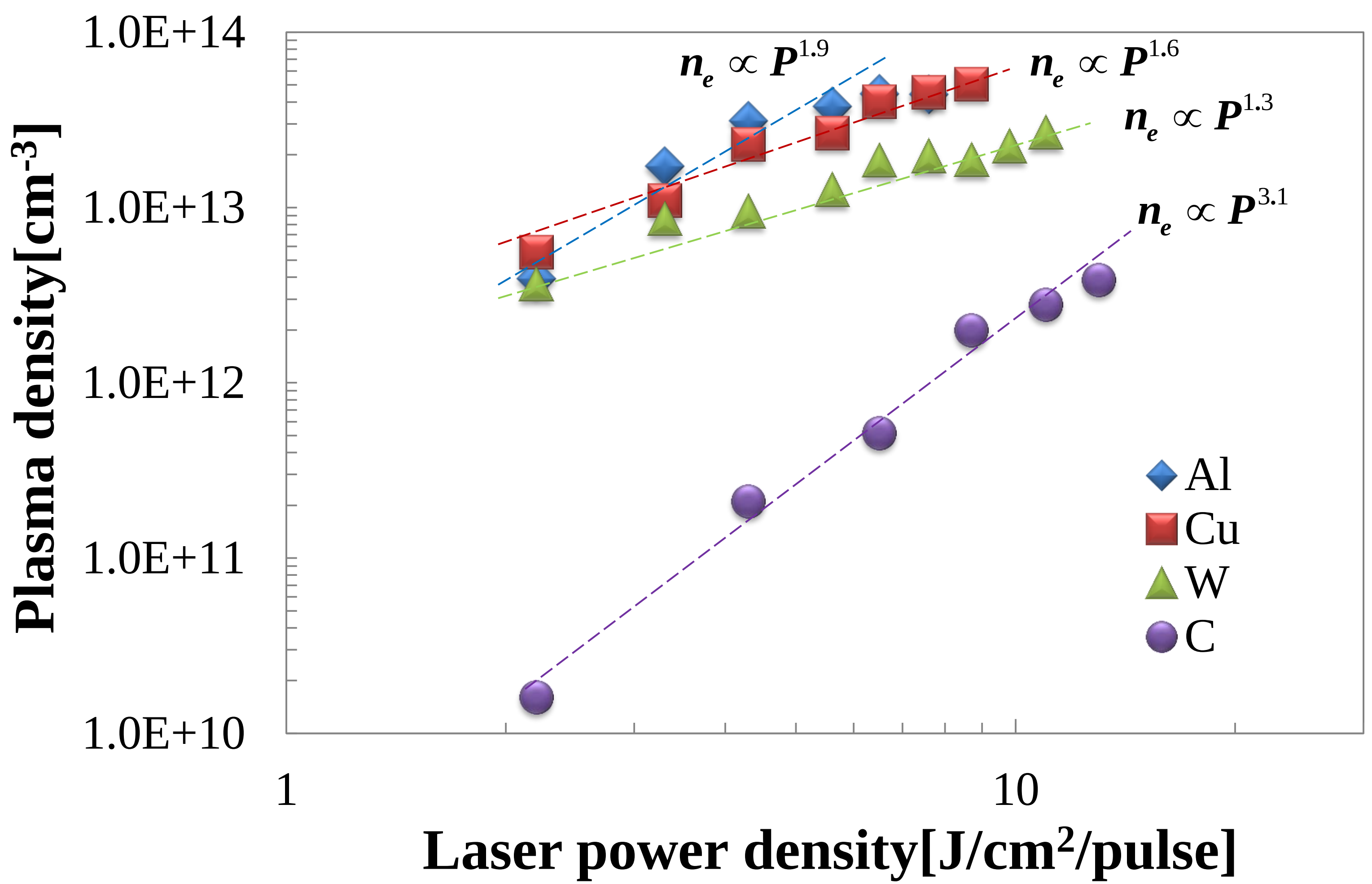


Electron temperature (eV)



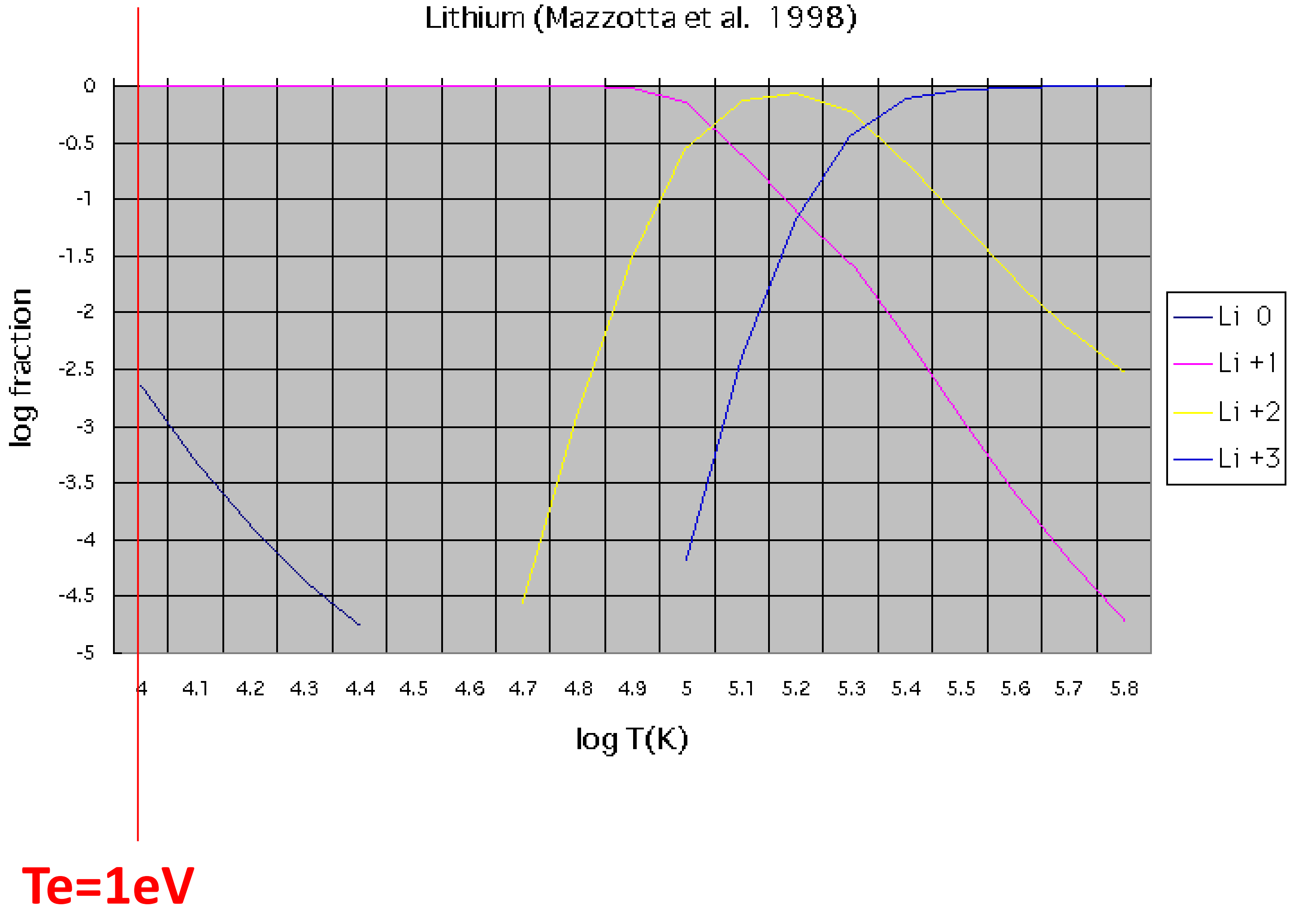
Plasma density vs. laser power density

（Power-laws indicative of the multi-photon processes）



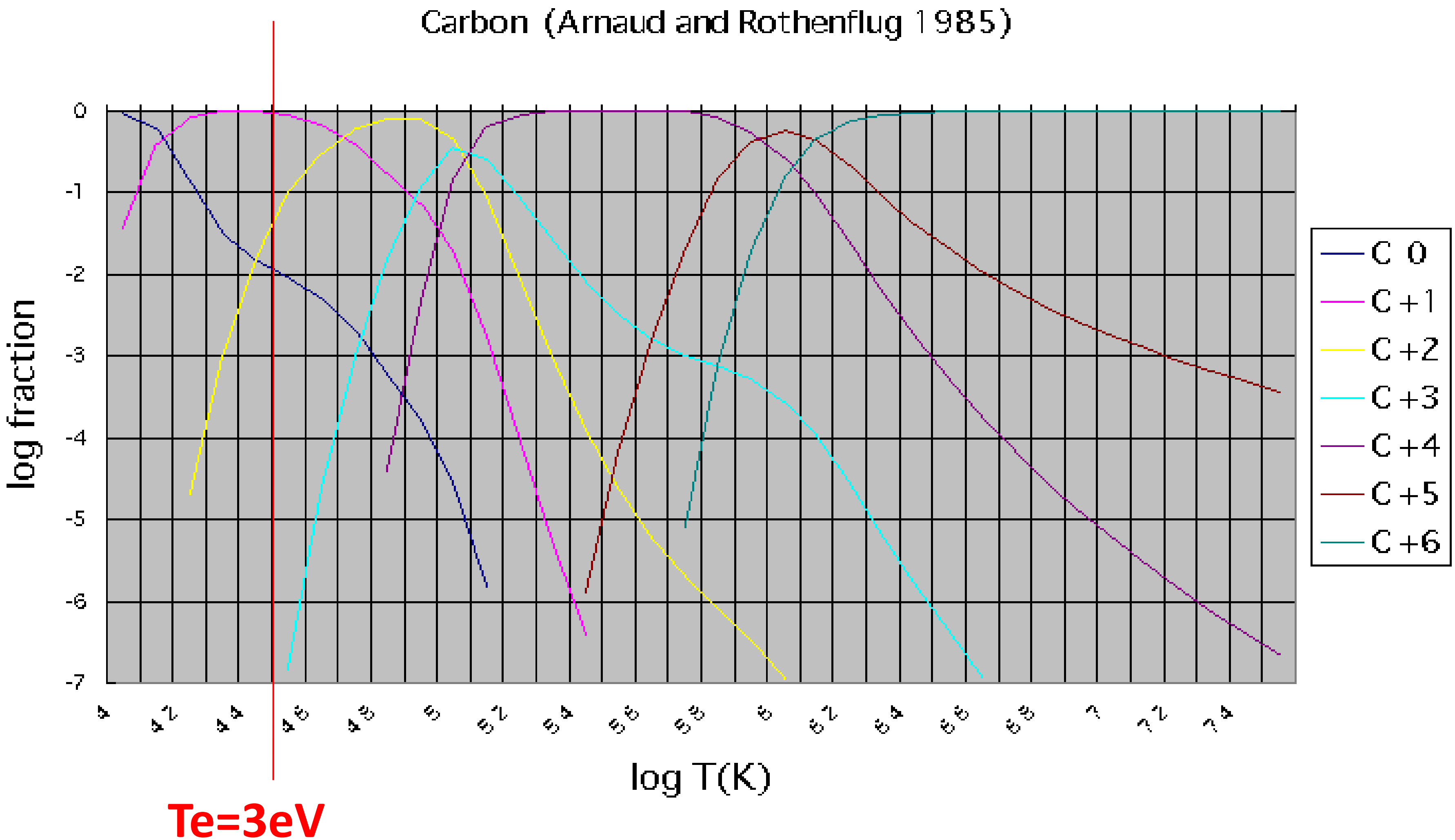
Ionic fractions in lithium plasma

(NIFS A&M database)

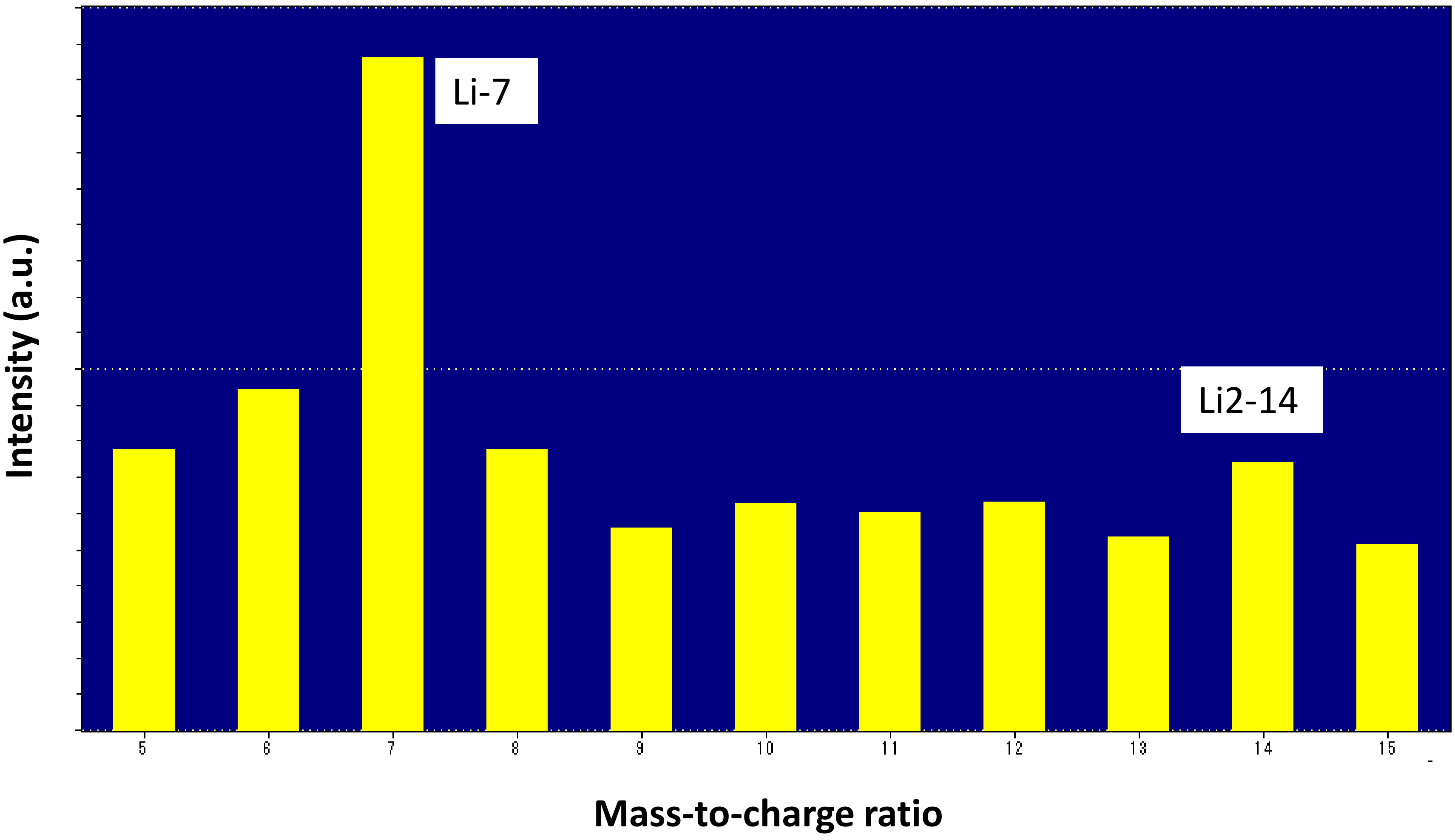


Ionic fractions in carbon plasma

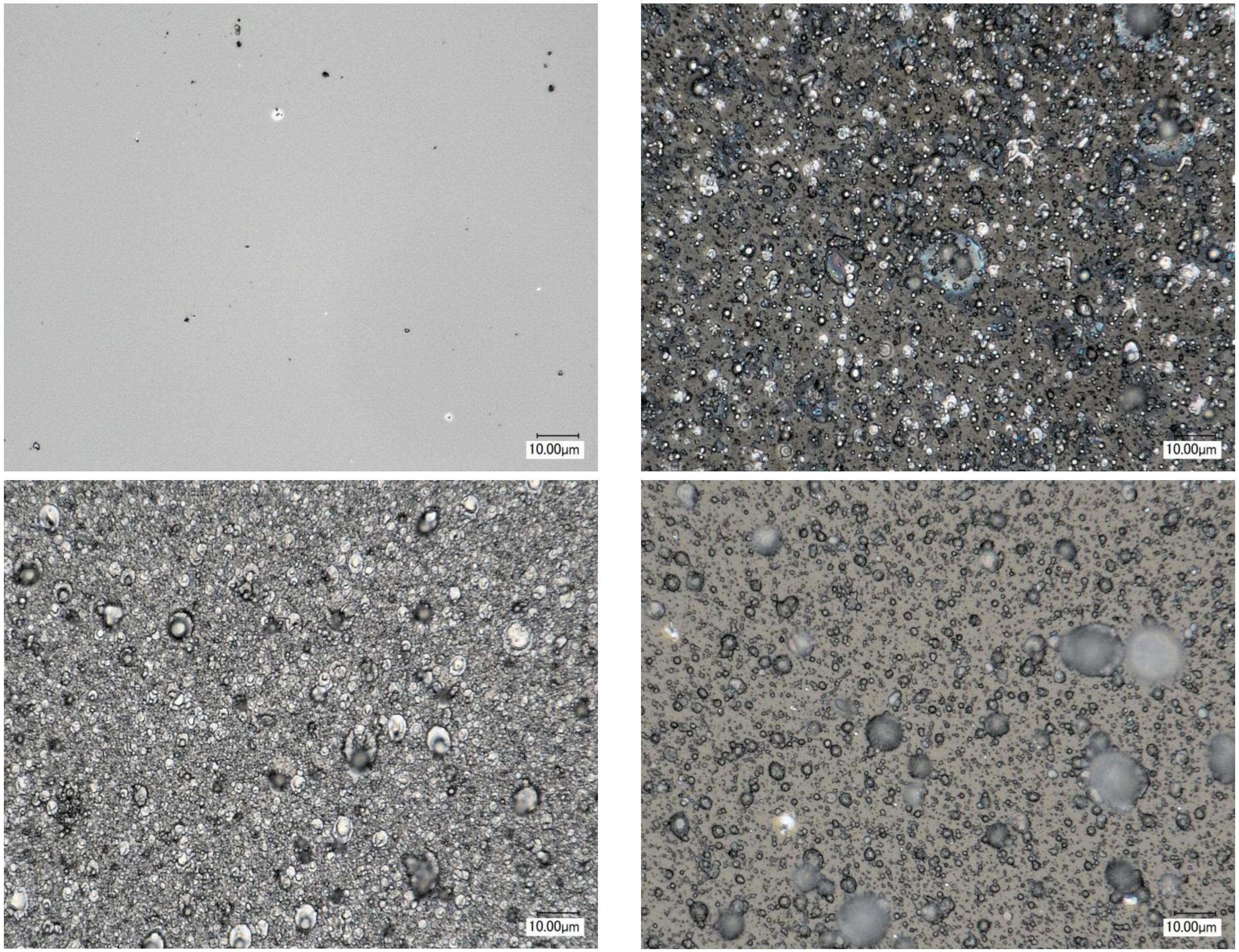
(NIFS A&M database)



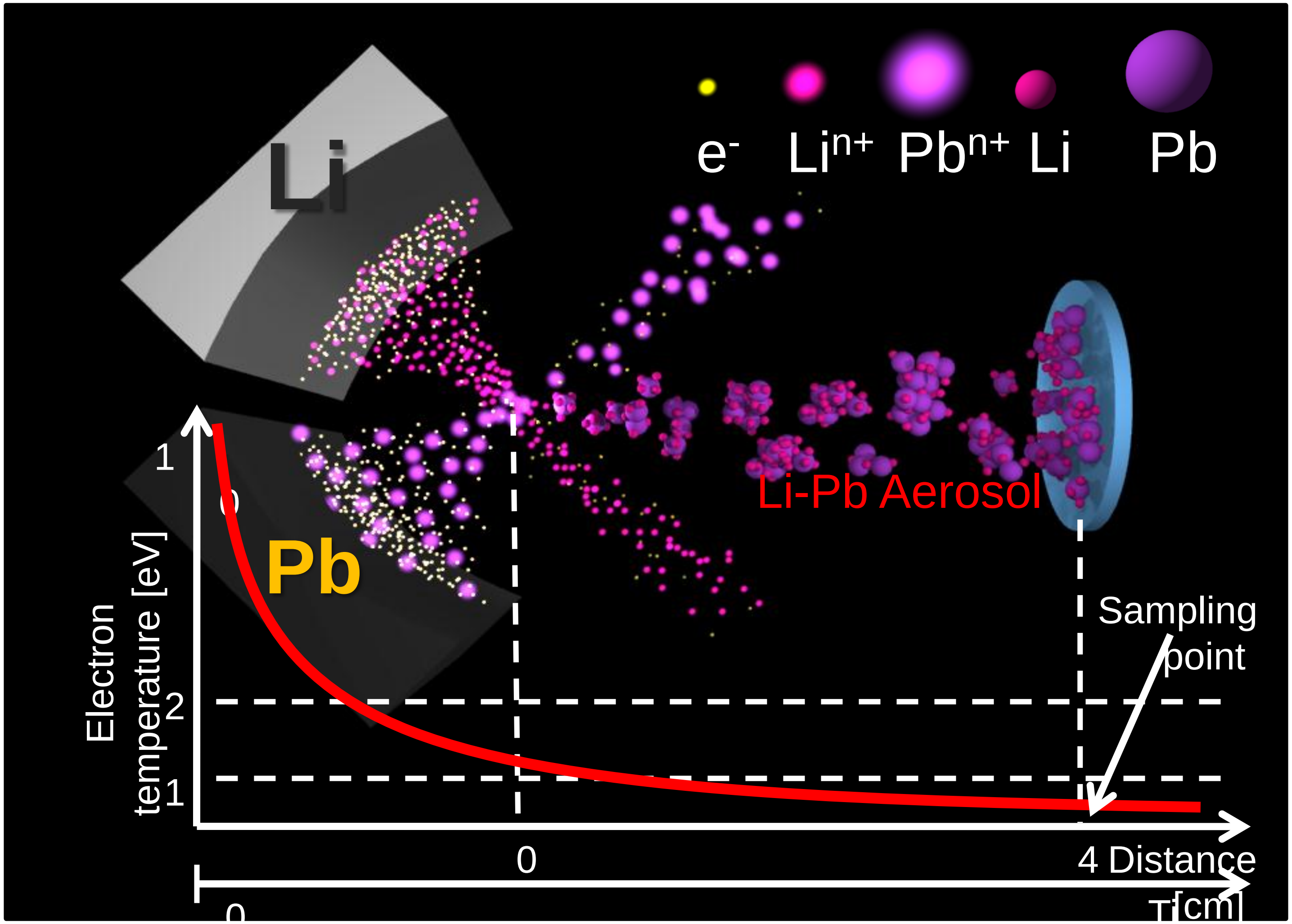
Ion mass spectrometry of Li plumes



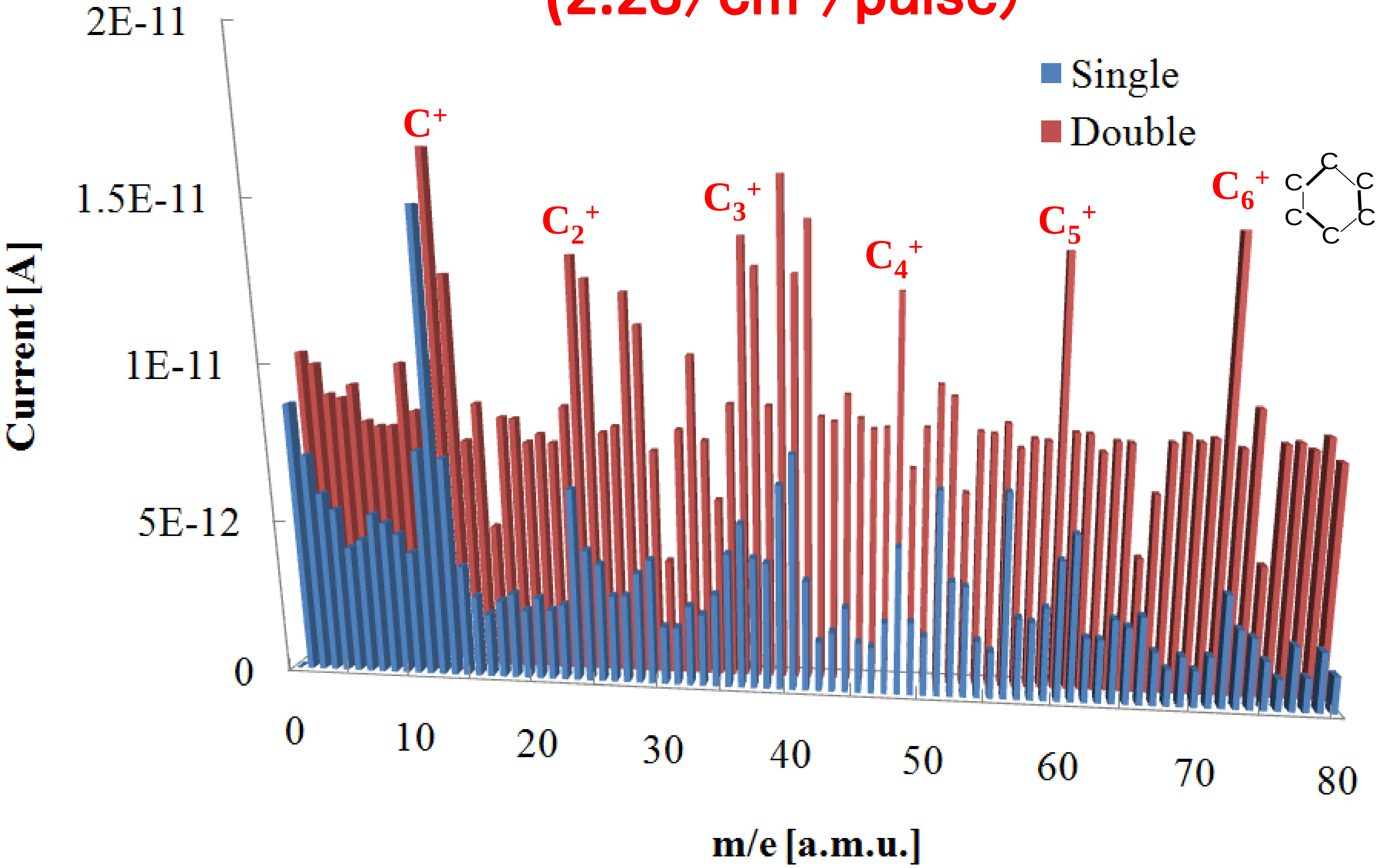
Aerosol formation by colliding ablation plumes



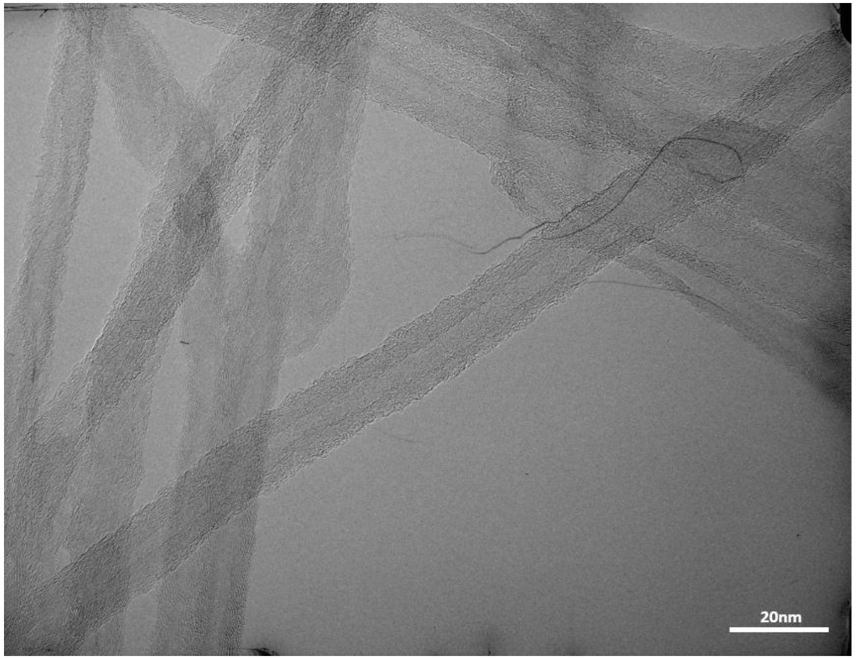
Aerosol formation model for metals

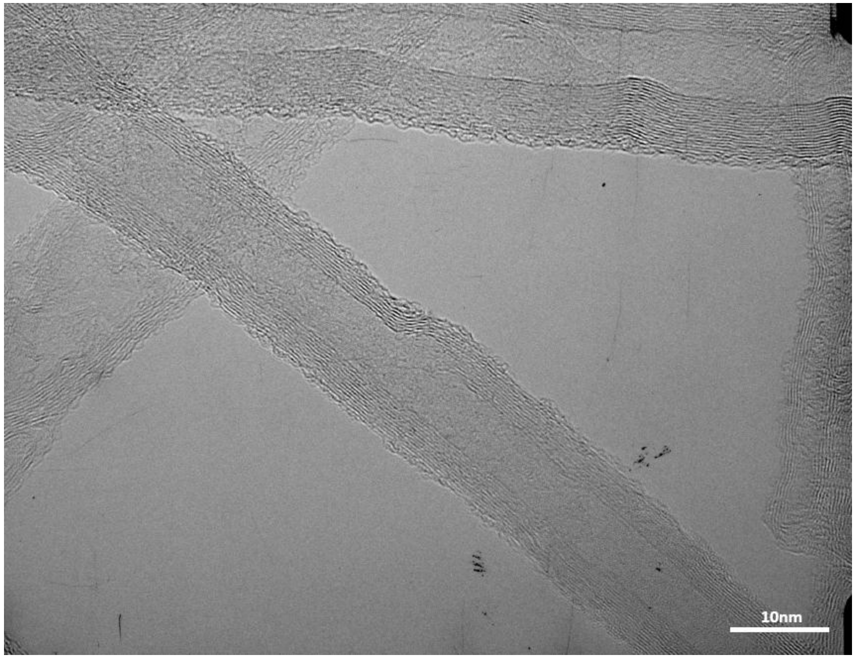


C_n^+ formation in colliding C plumes (2.2J/cm^2/pulse)

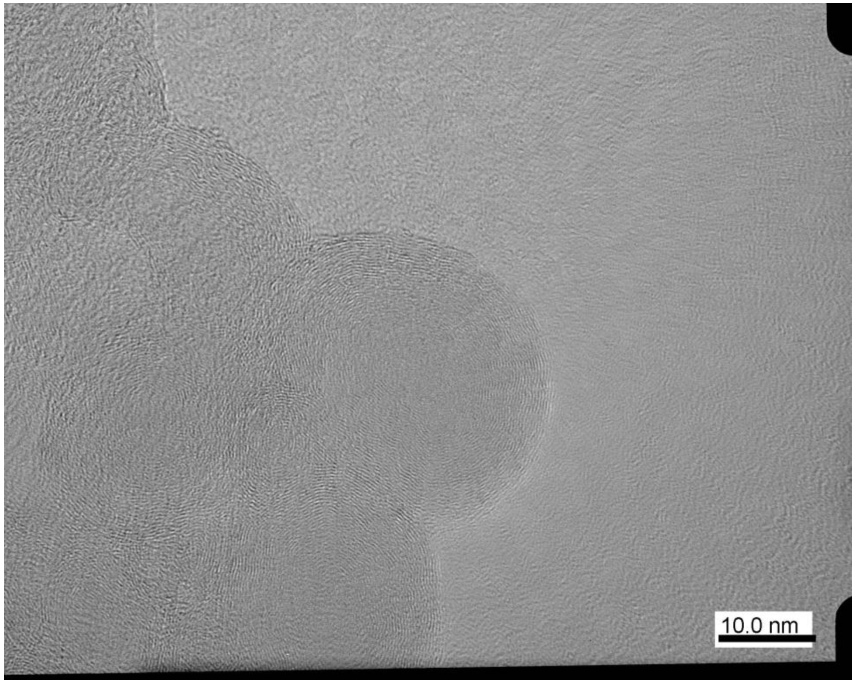


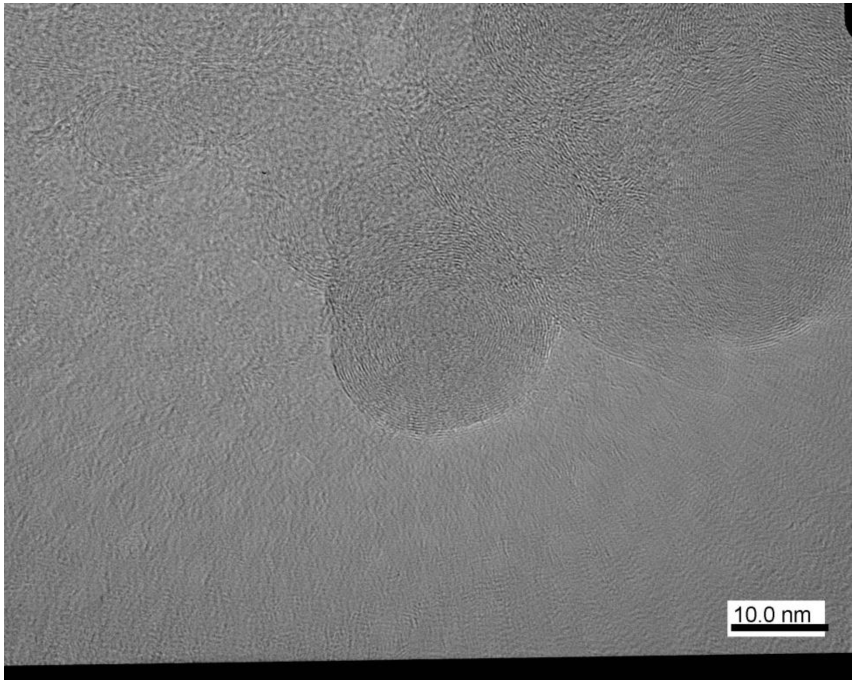
Carbon nano-tubes from LEAF-CAP exps. at 2.2J/cm^2/pulse for 3hrs



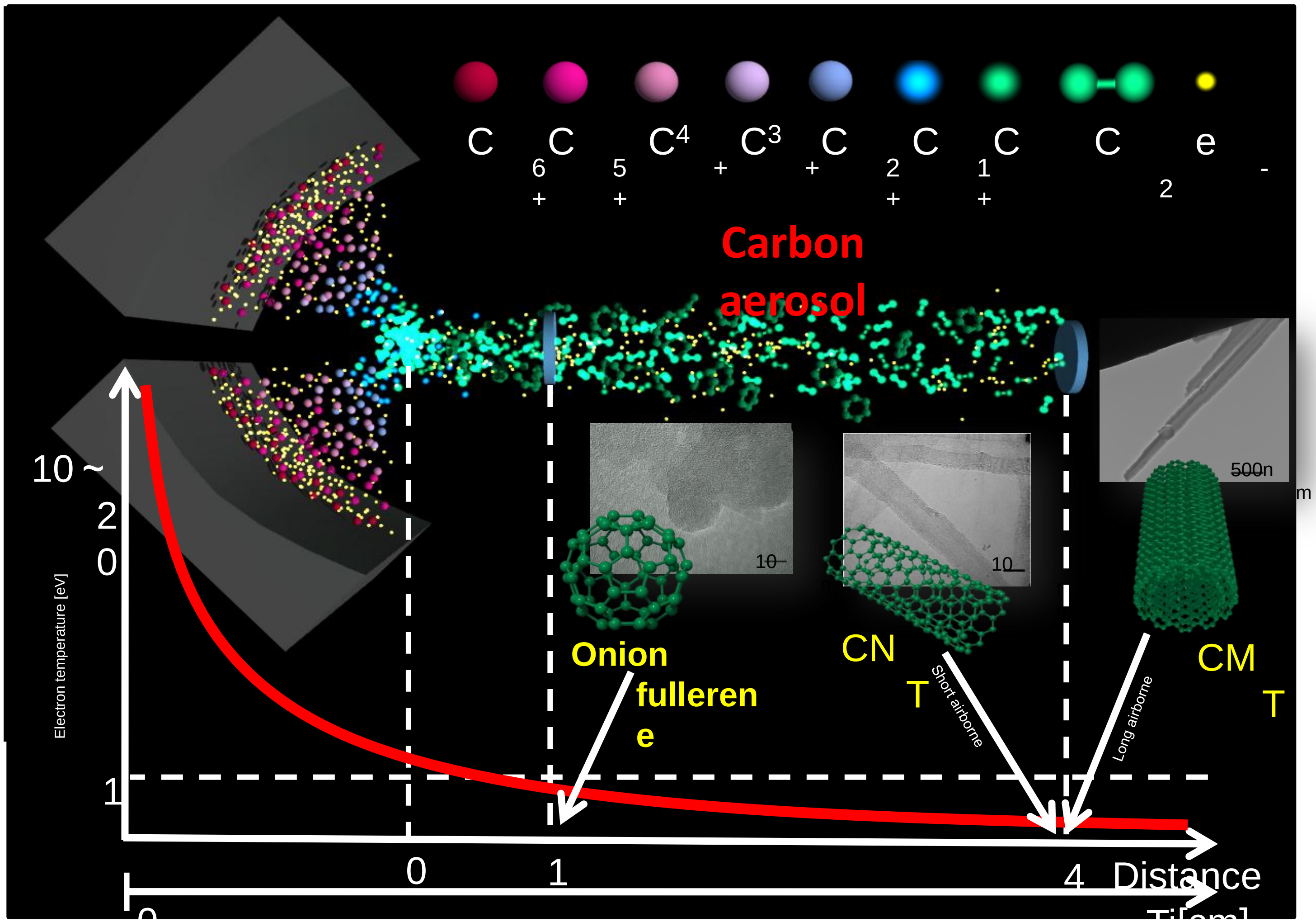


Fullerene "onion" from LEAF-CAP exps. (at 5J/cm^2/pulse for 1hr)



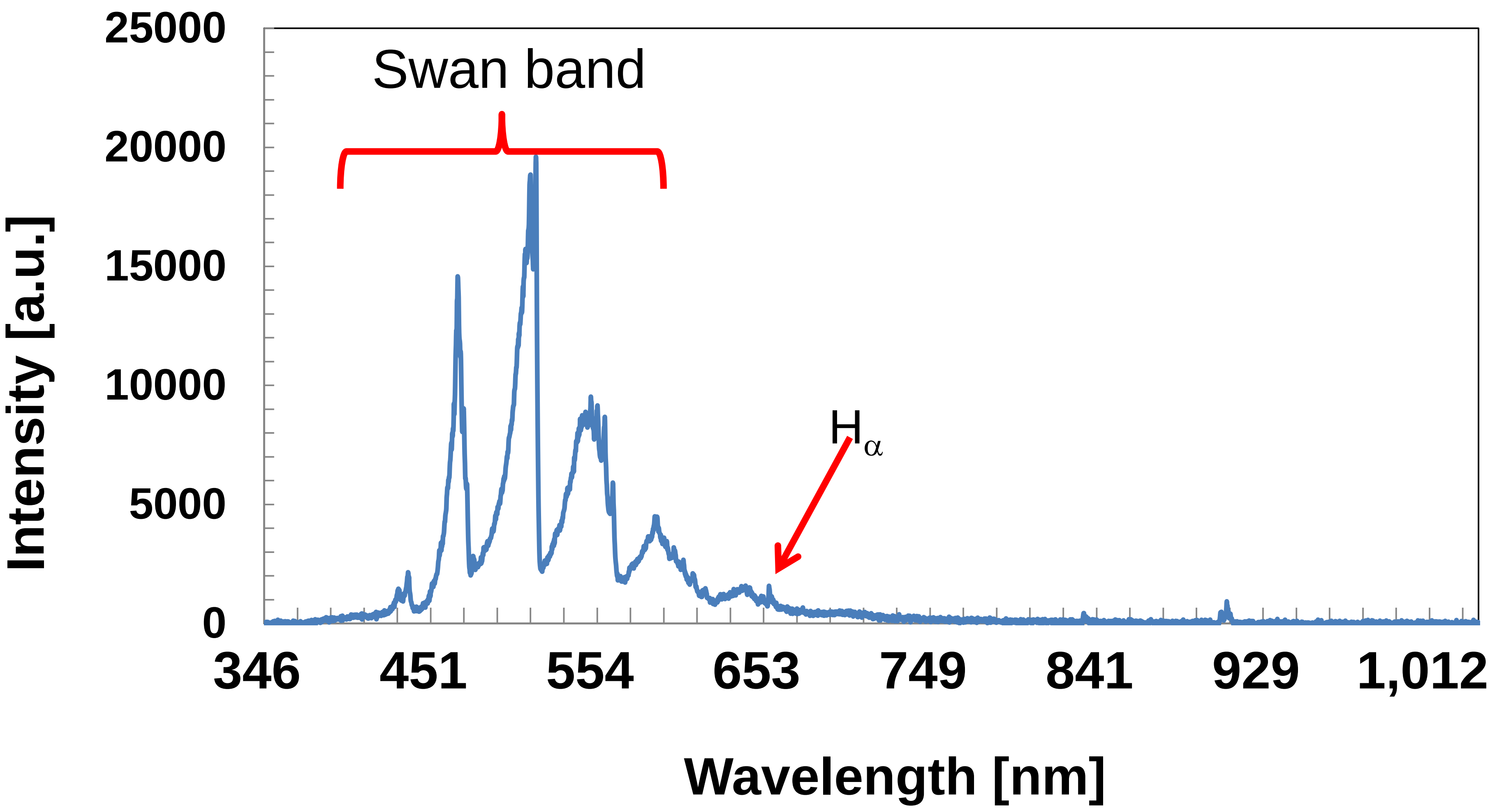


Aerosol formation model for carbon

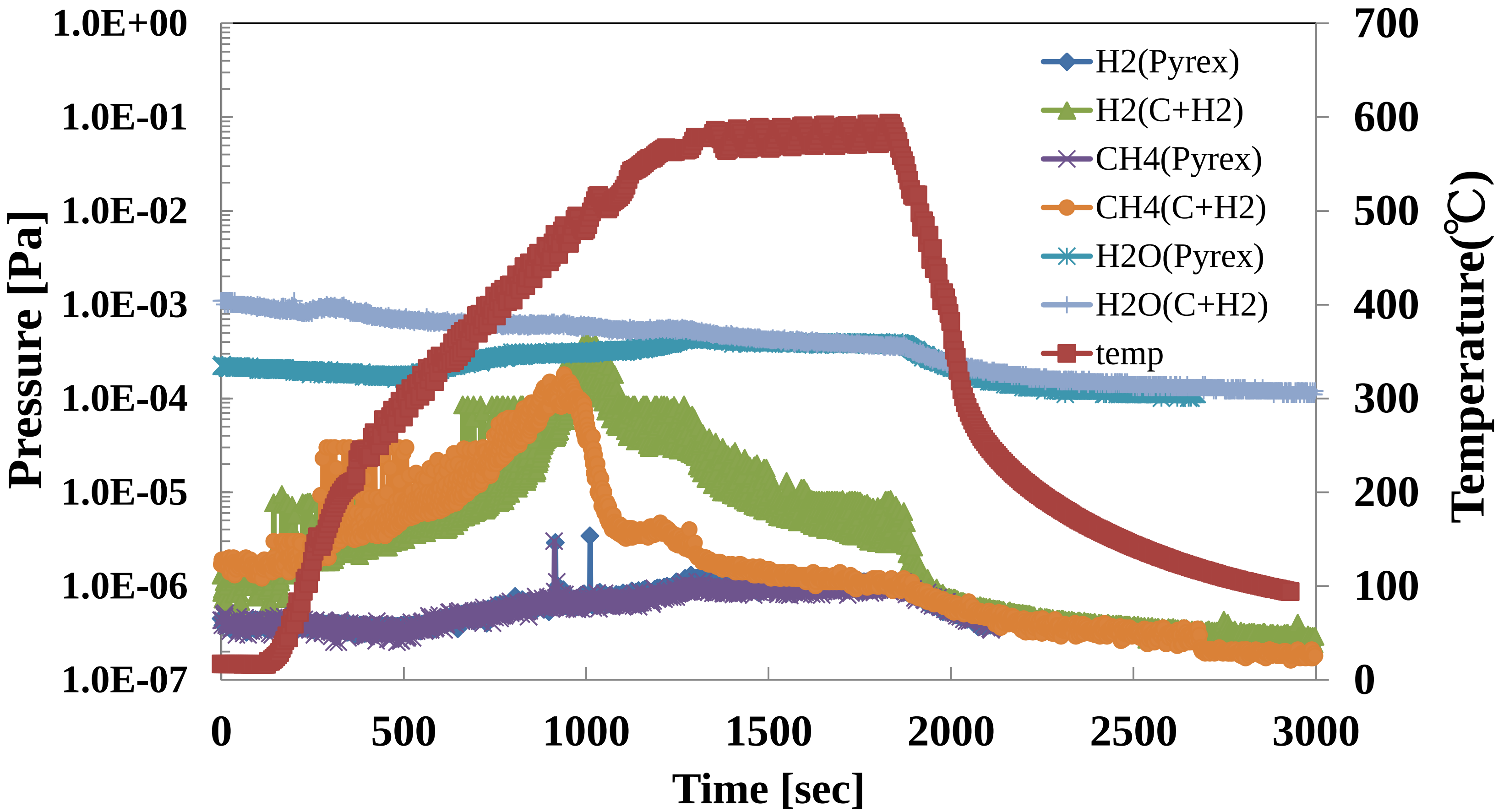


Colliding carbon plumes in hydrogen

(at 10J/cm²/pulse and 10Pa of H_2)

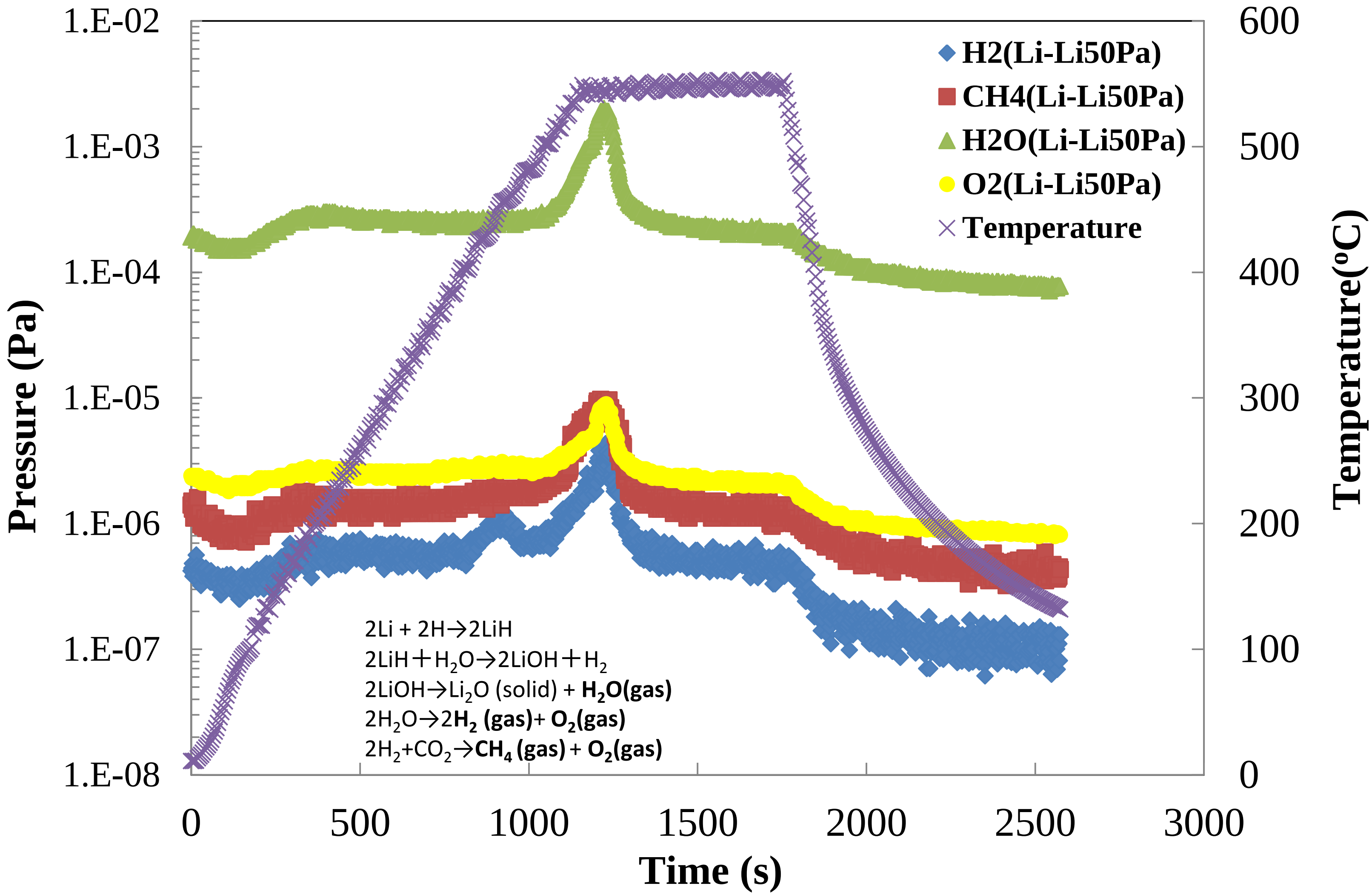


TDS: Hydrogen retention in C-deposits

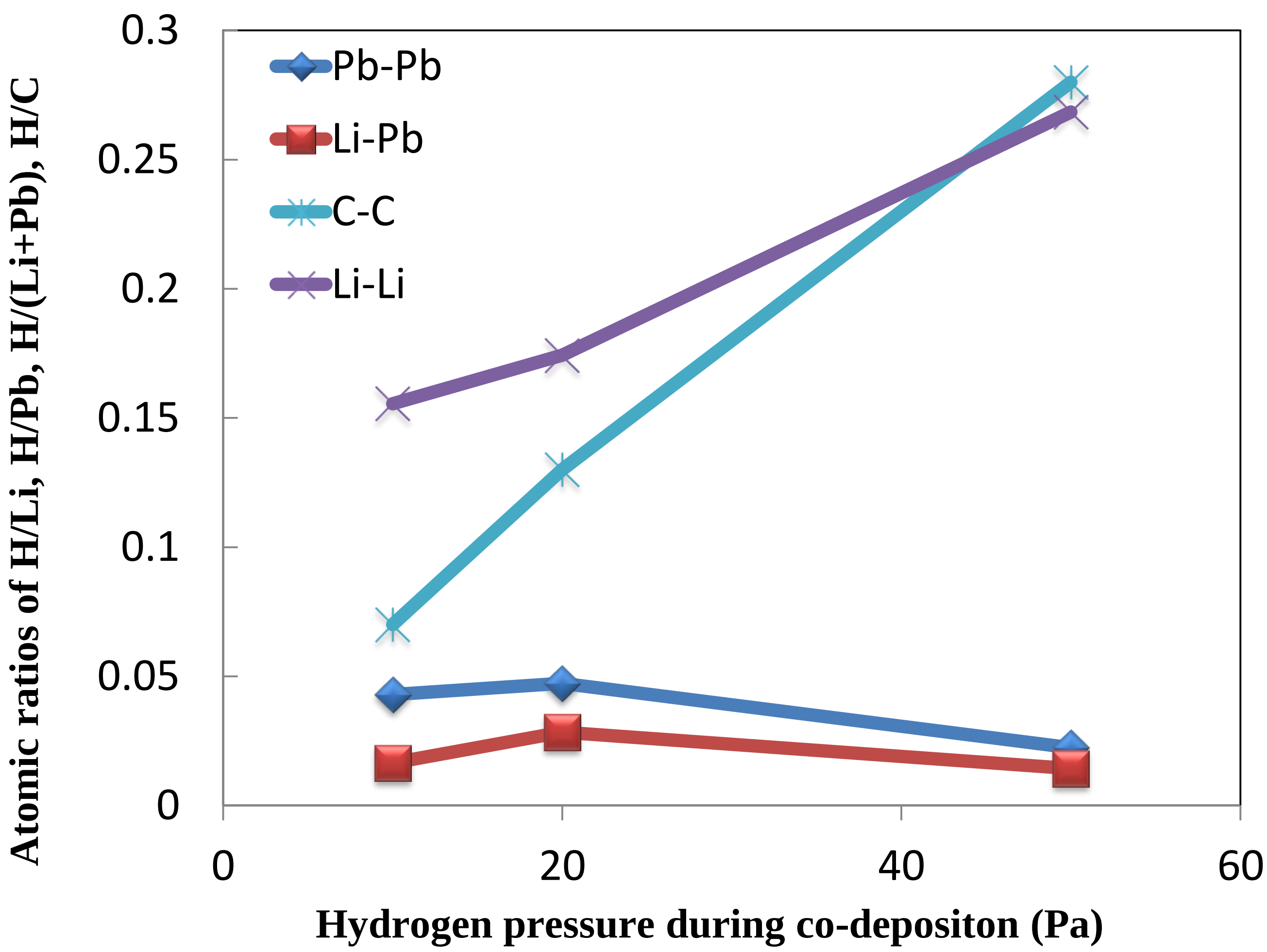


The H/C ratio is of the order of 0.1

Thermal desorption spectra from Li-H co-deposits



Hydrogen co-deposition in Li and Pb



Summary and future plans

- First-of-a-kind experiments on the aerosol formation by colliding ablation plasma plumes have been conducted using a laboratory laser-beam setup: LEAF-CAP.

- Colliding ablation plumes of Li and Pb have demonstrated to form aerosol in the form of droplet, the diameter of which ranges from 100nm to 10μm. As opposed to that, colliding carbon plumes have shown the formation of CNTs and CMTs.

- Ablated Li-deposits have been found to retain hydrogen as much as (H/Li)~0.3, which can be extended to a 10Hz power reactor with $1kJ/m^2$/pulse with such that $50kg\text{-}T/m^2$/day ! (･_･;) over a room temperature 1^{st} wall.

Laser ablation yields of Li and Pb