Laser driven oxygen ion acceleration from heated Ti tape targets

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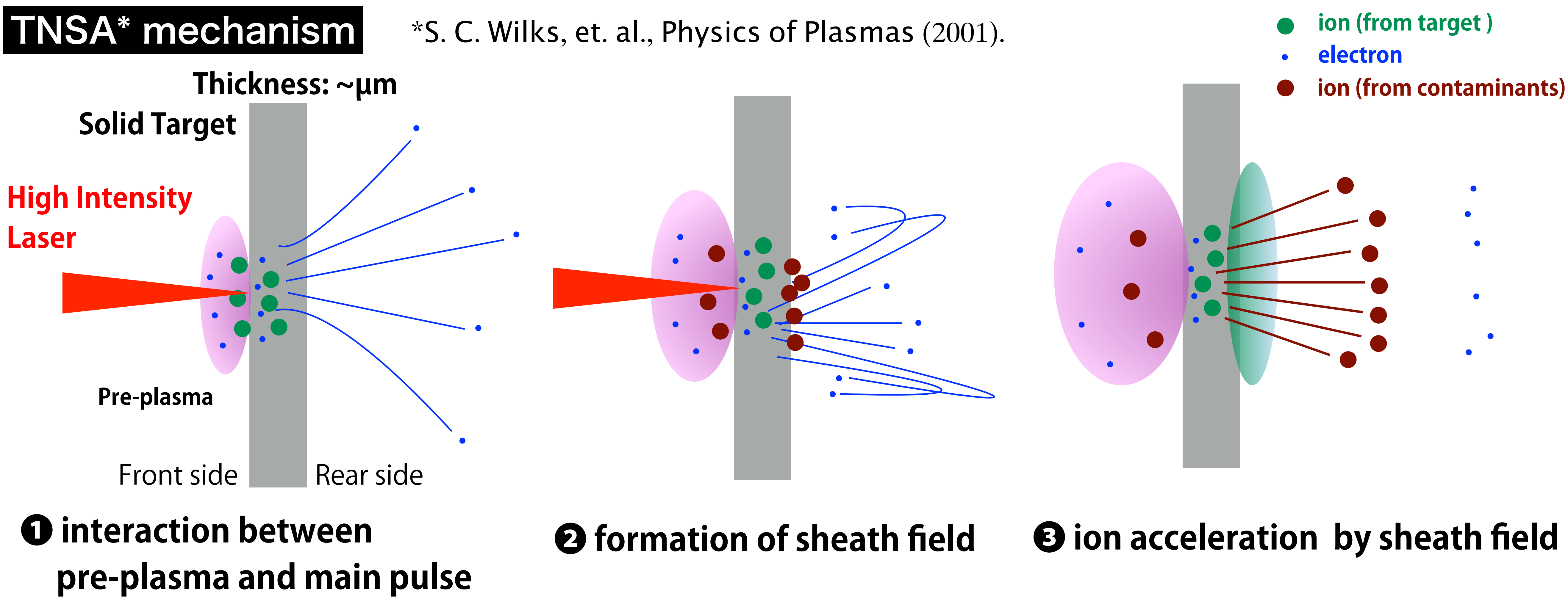
Contamination layers on target surface degrade the acceleration performance



Contamination layers mainly consist of hydrocarbon. Especially proton (charge to mass ratio:1) prior to other ions could be accelerated which results in decrease of acceleration efficiency of heavy ions from target.

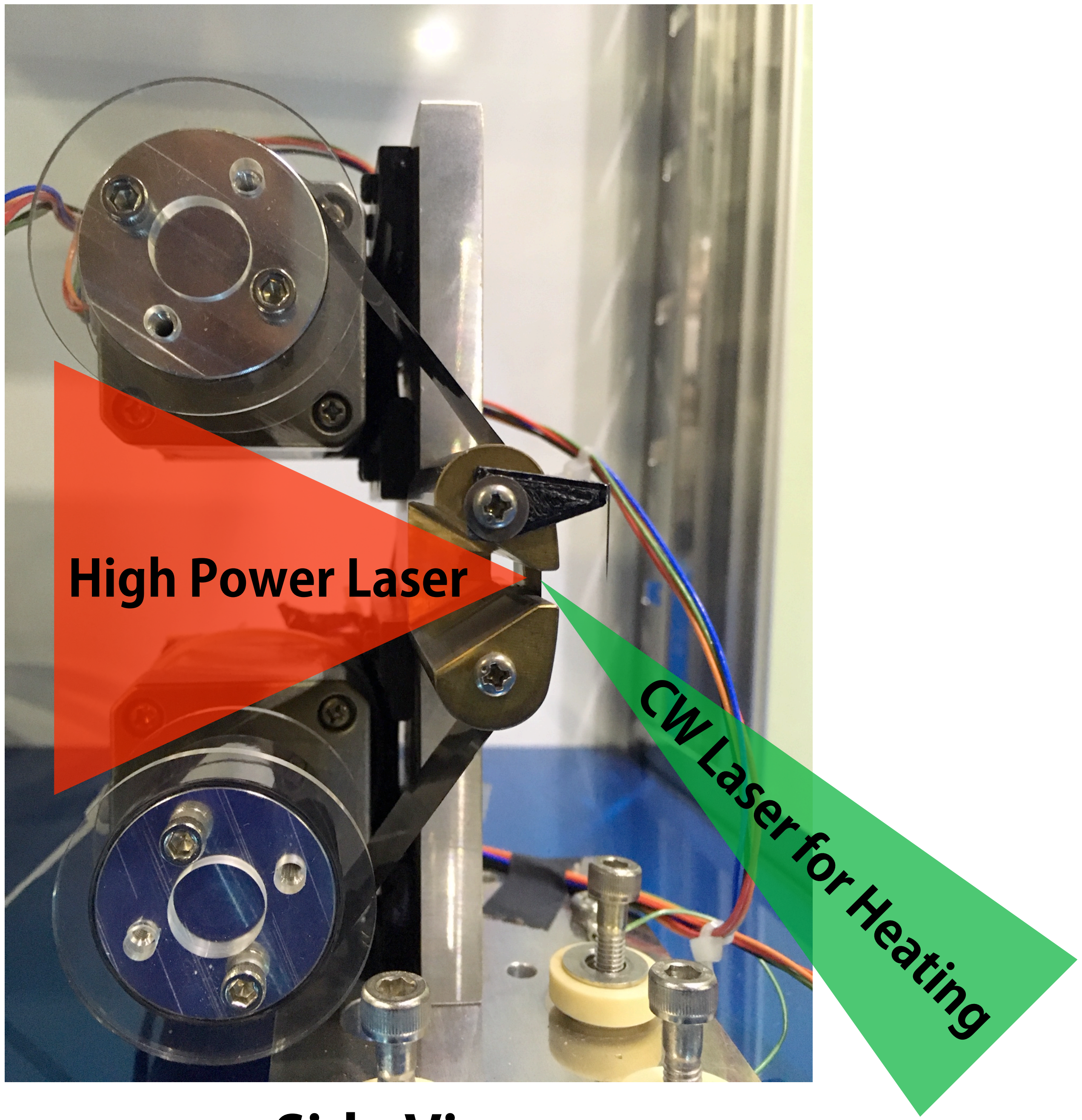
Solution

in-situ formation of contamination-free target

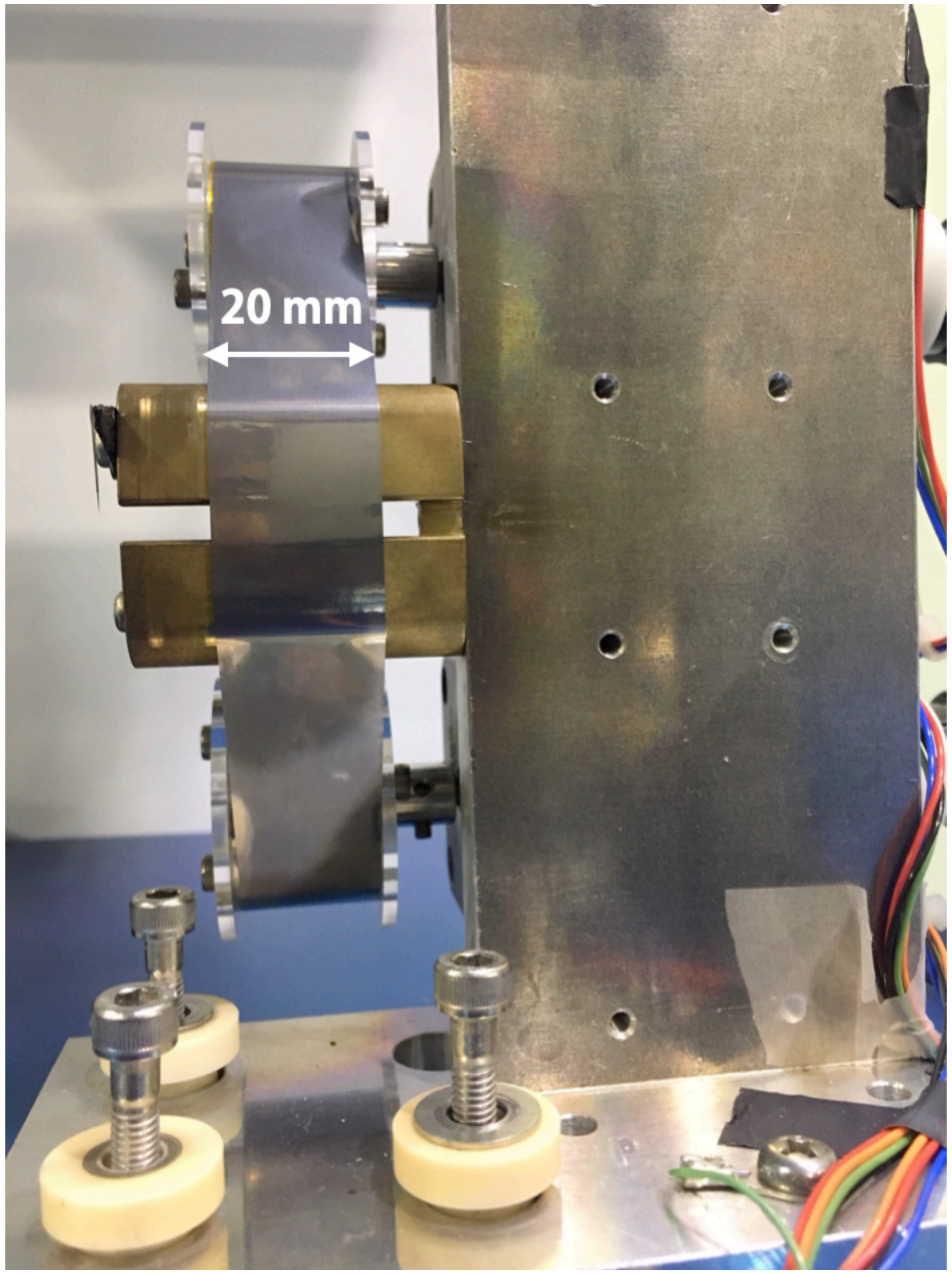
→ **We propose a method as surface cleaning and modification using a CW laser which heats a tape film target with micrometer scale thickness.**

Micrometer thick scale tape film target

After high intensity laser shot (-10^{21} W/cm^2) on target, ~ cm holes on the targets with micrometer thickness were observed. Therefore, a few cm distance is required for each shot.
The tape target holder with stepper motors can supply a fresh target continuously with long term operation and that matches to the CW laser heating to remove contaminants.



Side View



Rear View

How much is a CW laser power required for heating?

A heat transfer 1-D simulation to estimate heating temperature and heating time.

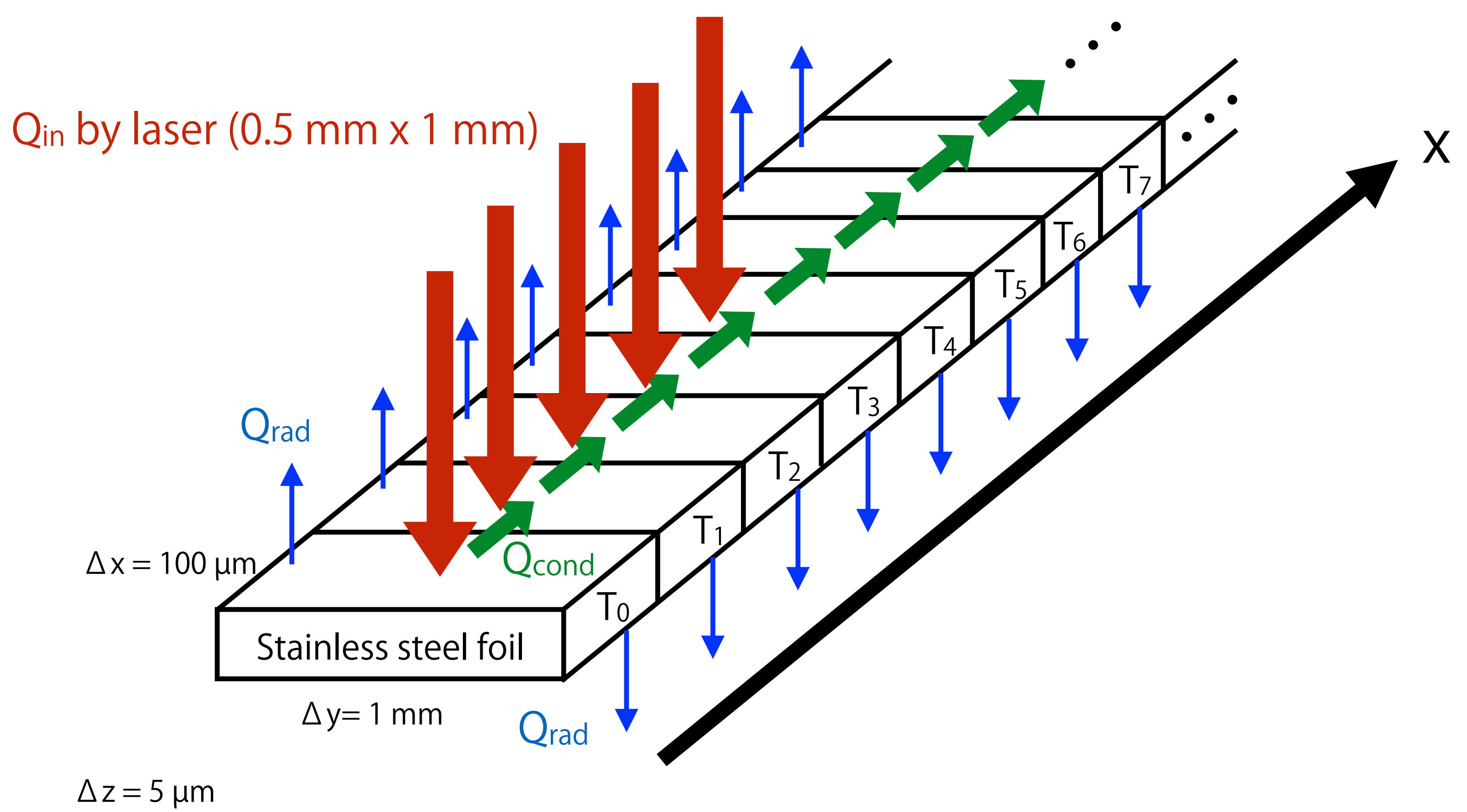
Q_{in}: Laser power (laser spot size ~ 0.5 mm x 1mm square, absorption rate: ~ 0.5)

$Q_{cond} = -\lambda\, \Delta T_x / \Delta x$ (Heat flux by thermal conduction)

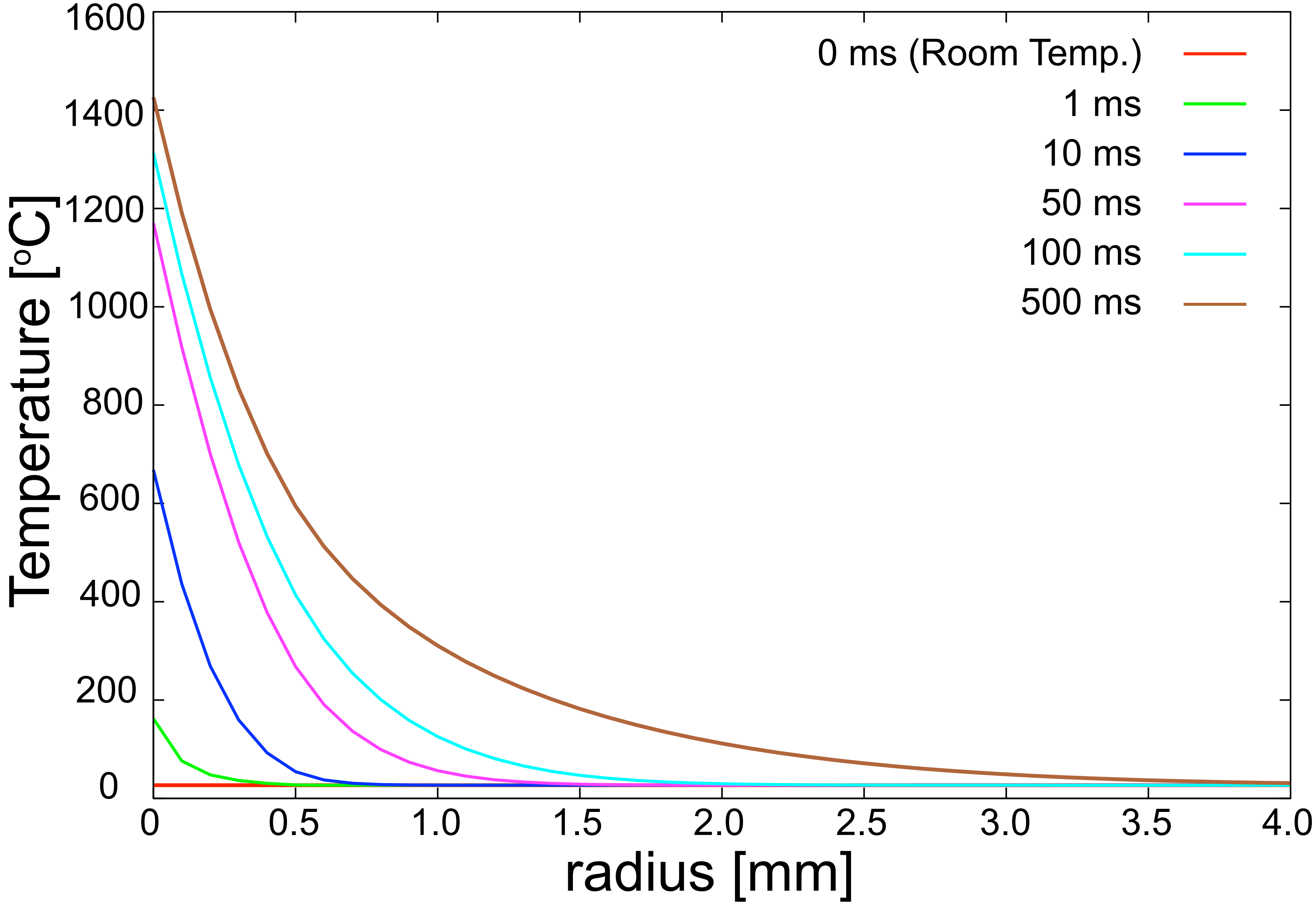
$Q_{rad} = \sigma T^4$ (Black body Radiation)

Heat transfer equation @Vacuum (we ignore thermal convection)

$$\Delta x \Delta y \Delta z\, \rho c\, \Delta T / \Delta t = \Delta Q_{cond} \Delta y \Delta z - 2 {*} Q_{rad} \Delta x \Delta y + Q_{in}$$



Time-dependent thermal heat transport simulation

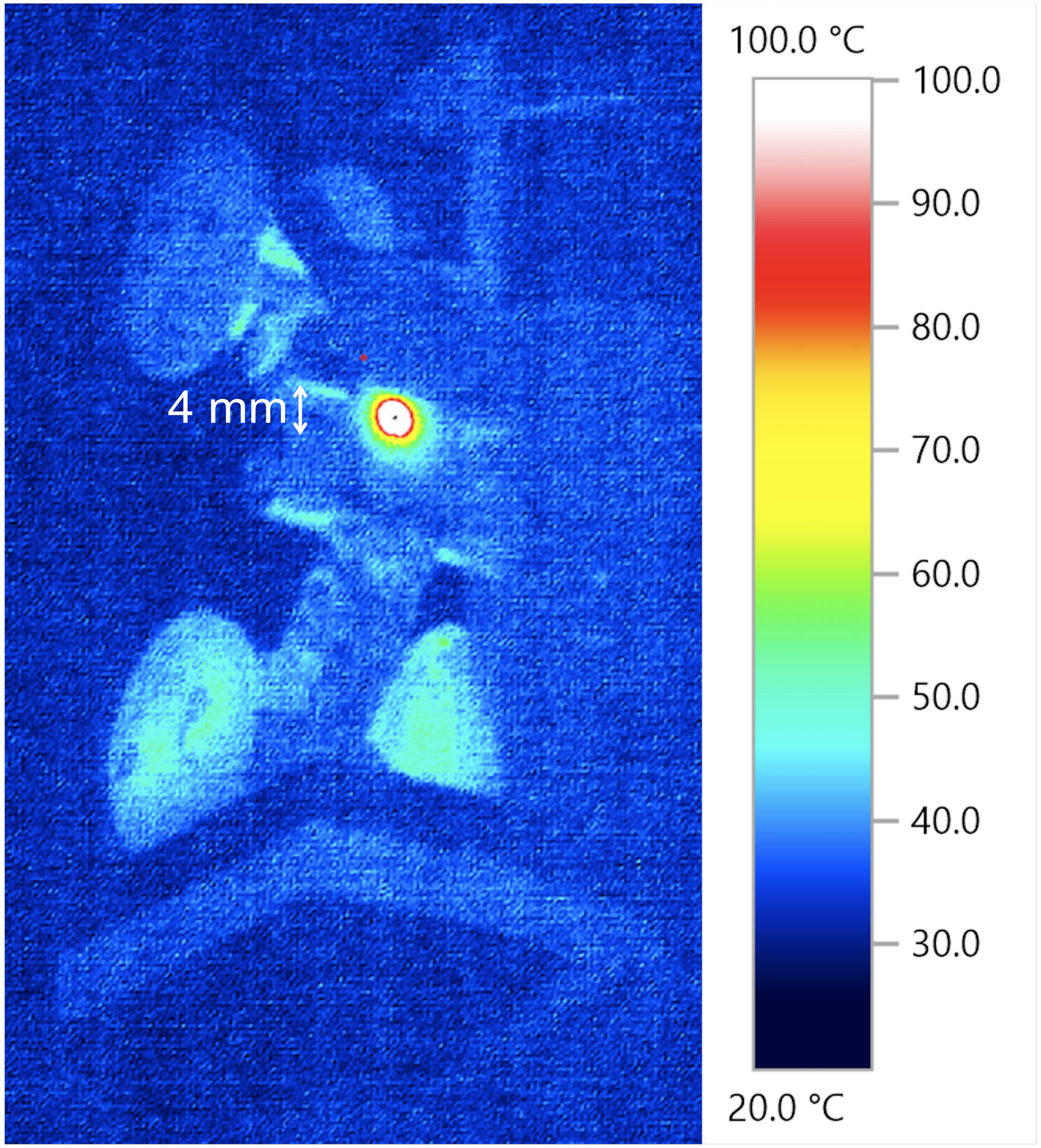


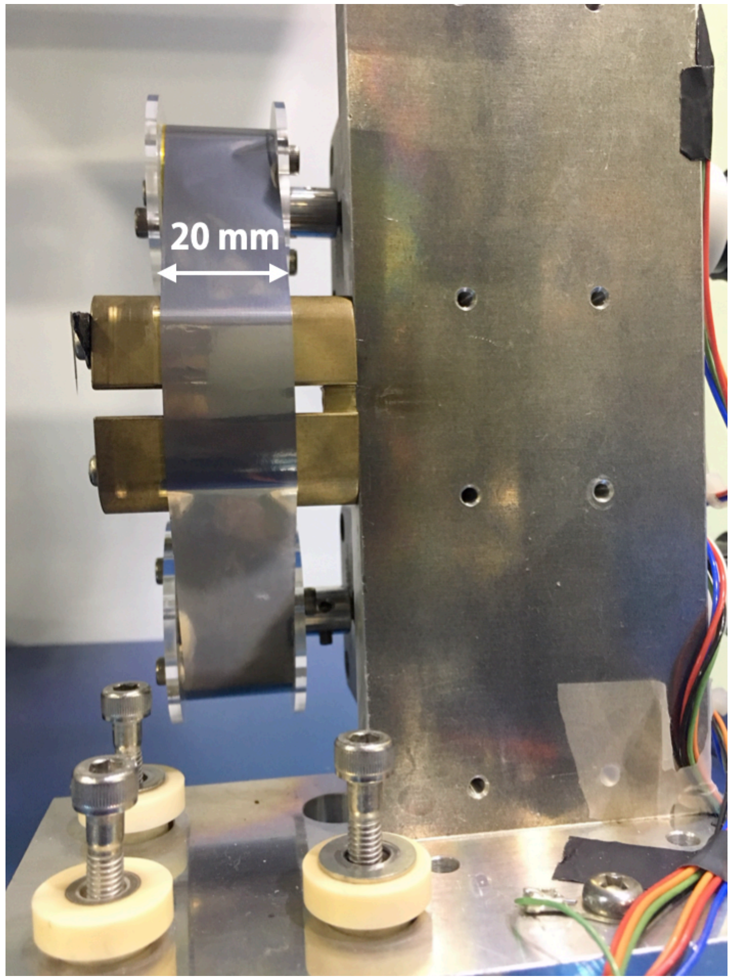
Simulation condition

- Laser size (D4 σ) : 1 mm
- Laser Power: 1 W
- Absorption of the laser to Ti: 50%
- Target Materials: Ti
- Target thickness: 5 μm

To confirm the measurement, we performed a time-dependent thermal heat transport simulation in polar coordinates with radial symmetric, including thermal conductivity and radiation.
The simulations indicated a localized region several mm in size with a temperature beyond 100 ℃ as well as a smaller region with a temperature beyond 1000 ℃, showing good agreement with the IR thermography measurement.

5 µm thick Ti was heated up to 1000 ℃ during CW laser irradiation





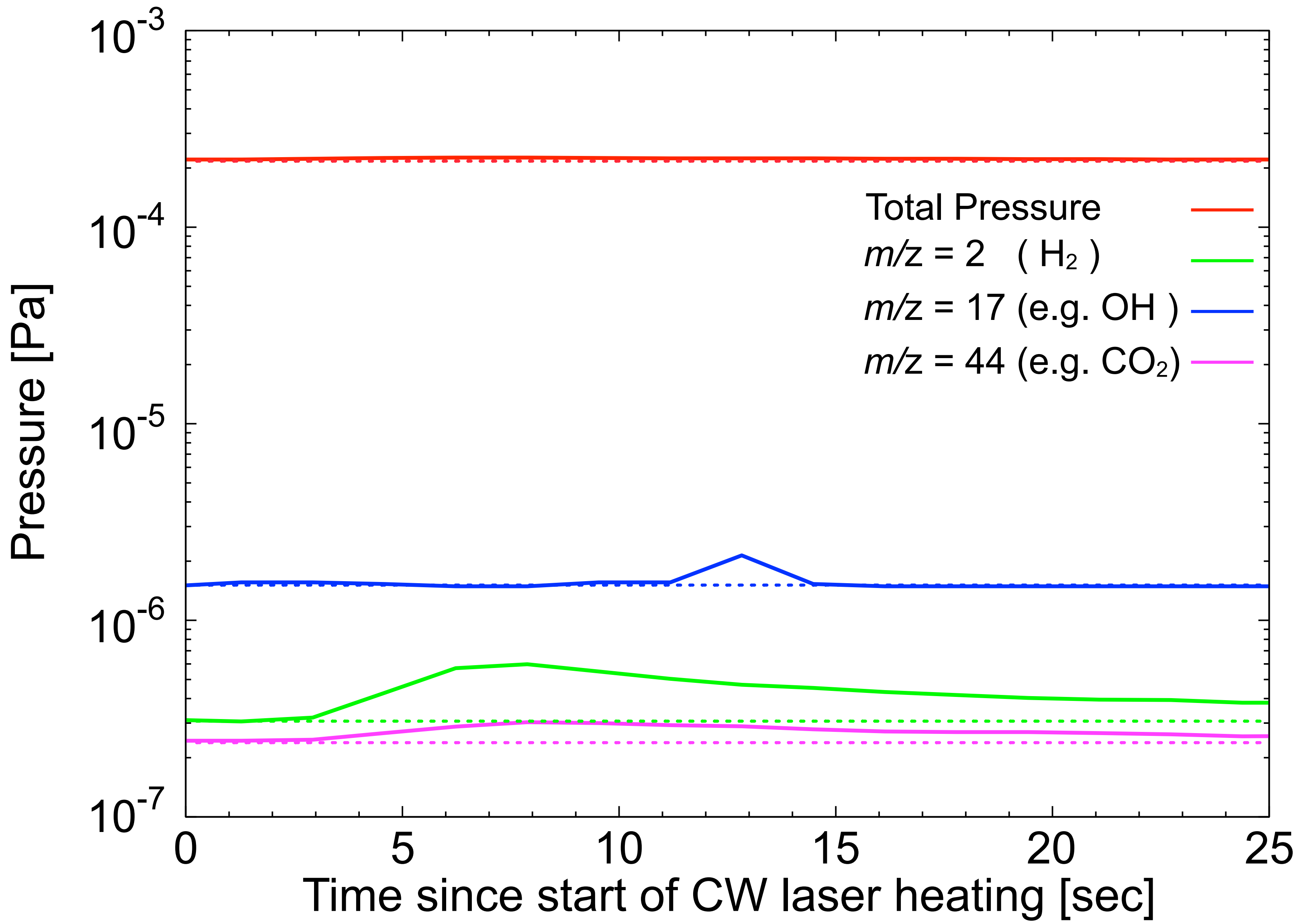
Ti Tape Target Holder

IR thermography shows CW laser heats Ti foil up to ~ 1000 ℃ in the black point at the center of the white region.
(The melting points of Ti: ~ 1670 ℃, TiO_2: ~ 1840 ℃)

Heating condition

- CW Laser wavelength: 532 nm
- CW Laser spot on target: Φ ~ 1 mm
- CW Laser Power: 1 W
- Target Material: Ti (Emissivity: 0.5)
- Target thickness: 5 µm

Quadrupole mass spectrometer measurement



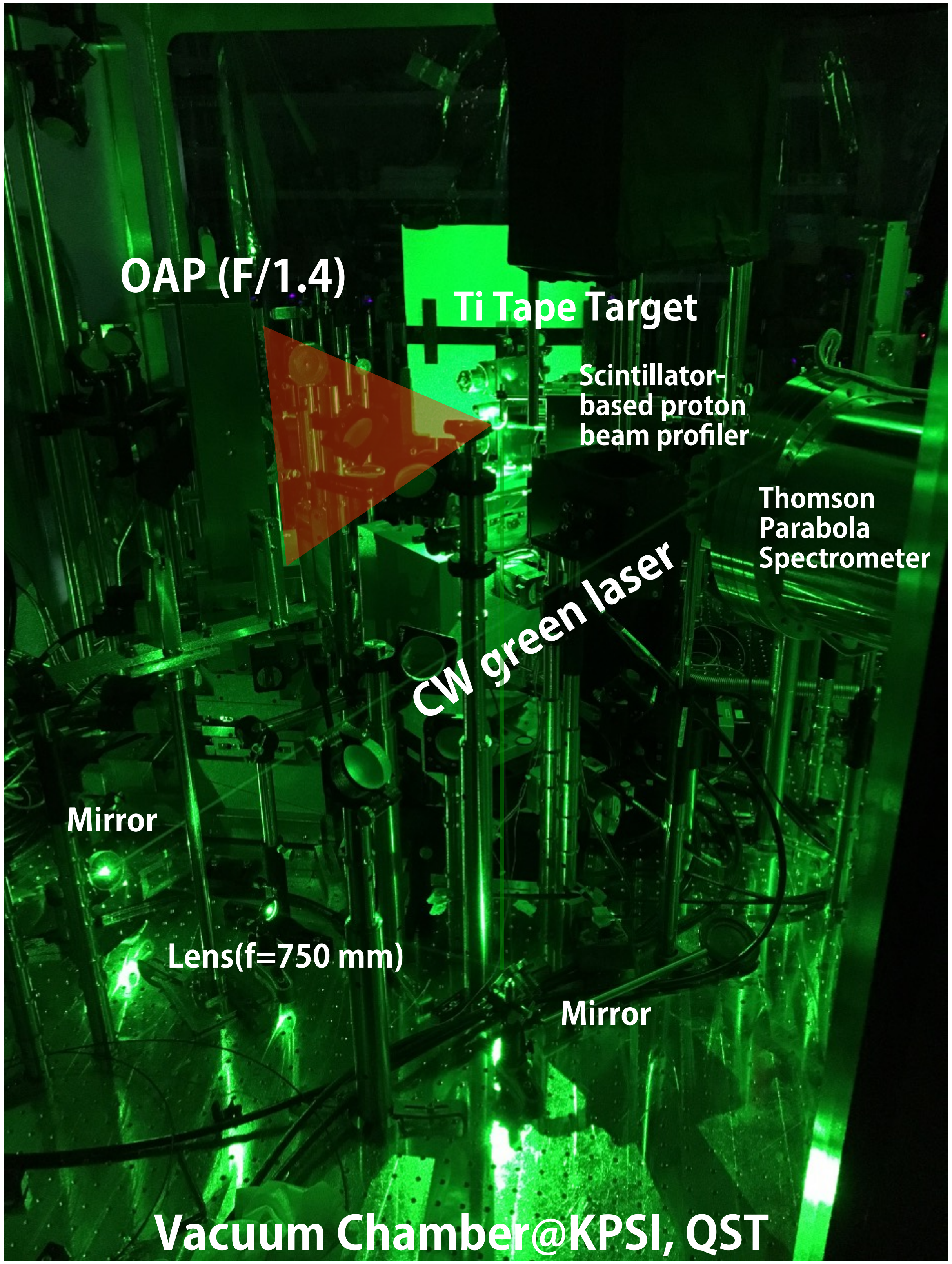
Heating condition for QMS

- CW Laser wavelength: 532 nm
- CW Laser spot on target: Φ ~ 1 mm
- CW Laser Power: 0.3 W
- Target thickness: 5 μm

In order to confirm the desorption of the contaminants from the Ti tape by the CW laser heating, heating, we also used a quadrupole mass spectrometer (QMS) as a residual gas analyzer. Emissions of hydrogen, hydrogen, hydroxide and carbon dioxide were observed after the CW laser heating began, providing supporting evidence that the technique can be used to desorb contaminants from the Ti tape.

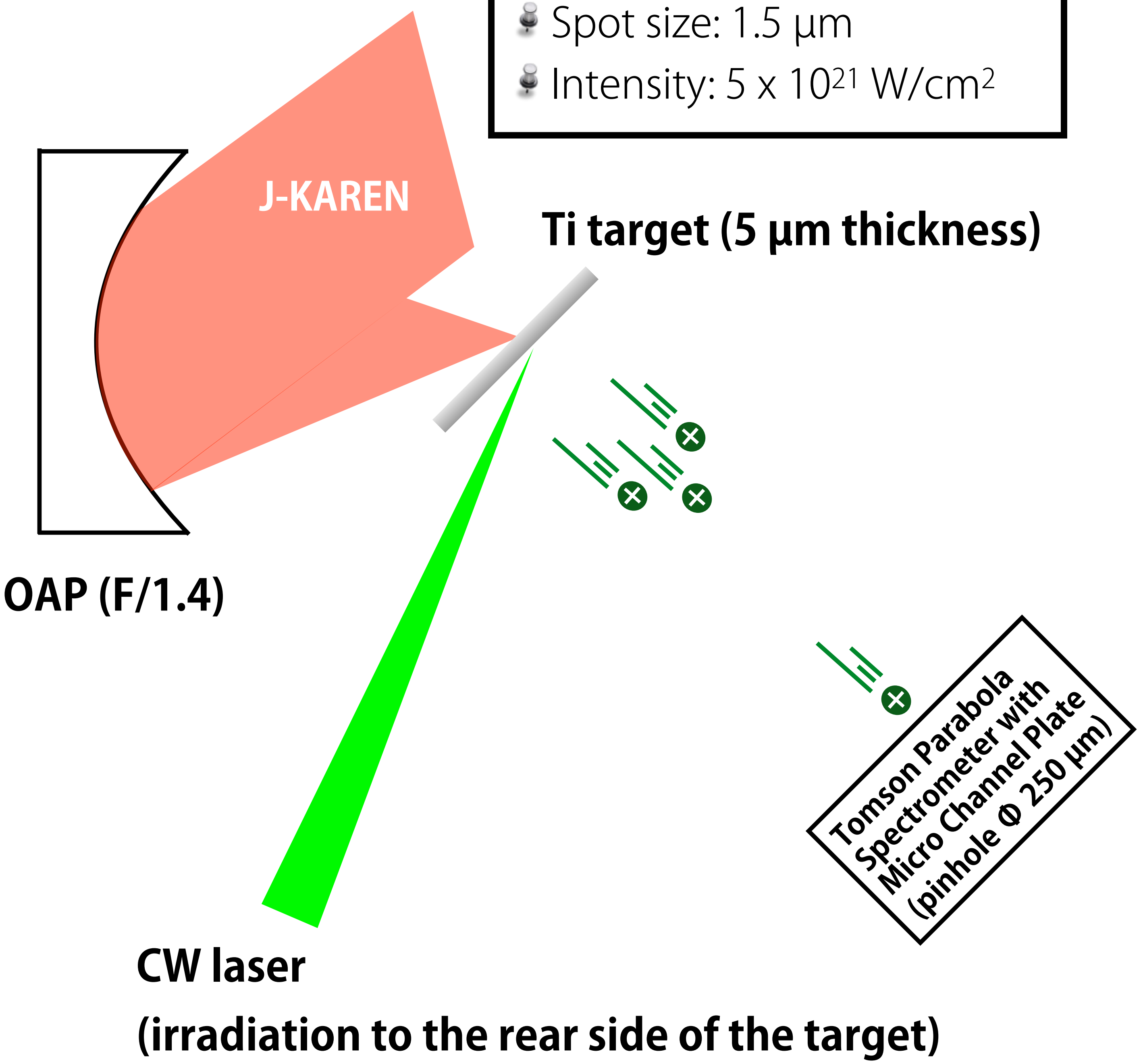
Ion-acceleration demonstration setup using a 5 μm Ti tape

*H. Kiriyama, et. al., Optics Letters (2018).

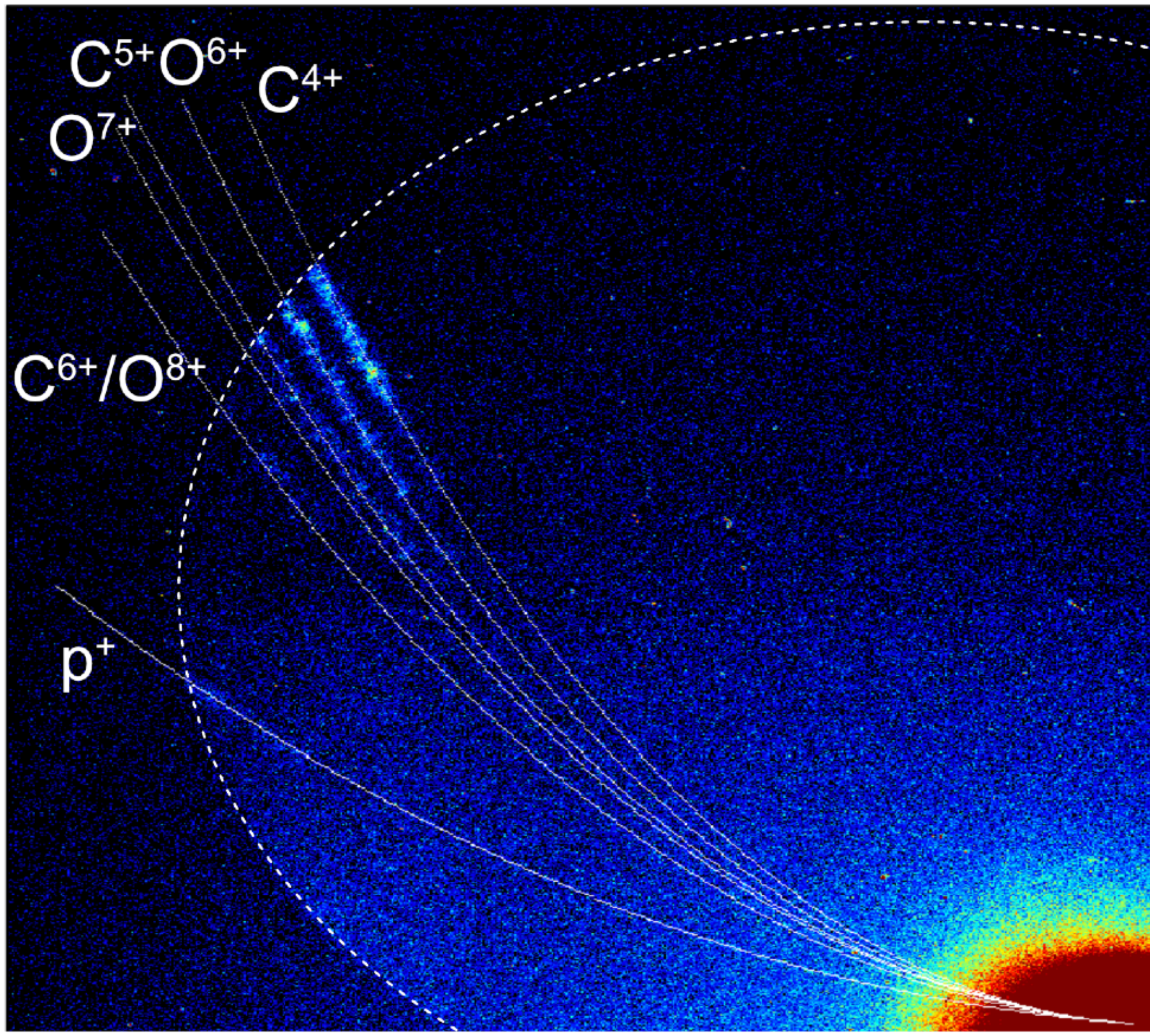


J-KAREN-P* Parameters

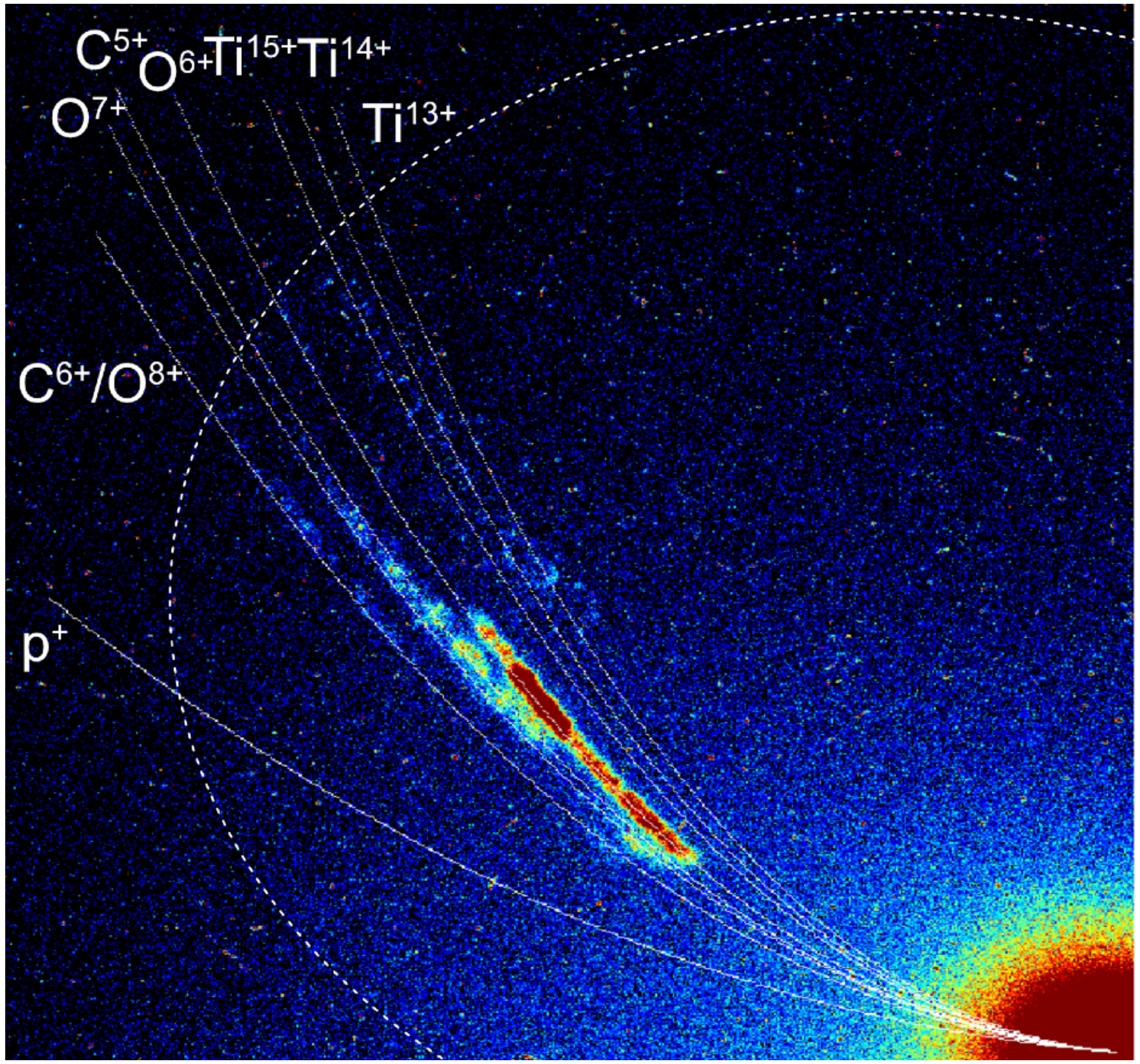
- Pulse Length: 40 fs (FWHM)
- Energy: 10 J
- Spot size: 1.5 μm
- Intensity: 5 x 10^{21} W/cm^2



Thomson Parabola (TP) Spectrometer Results (1)



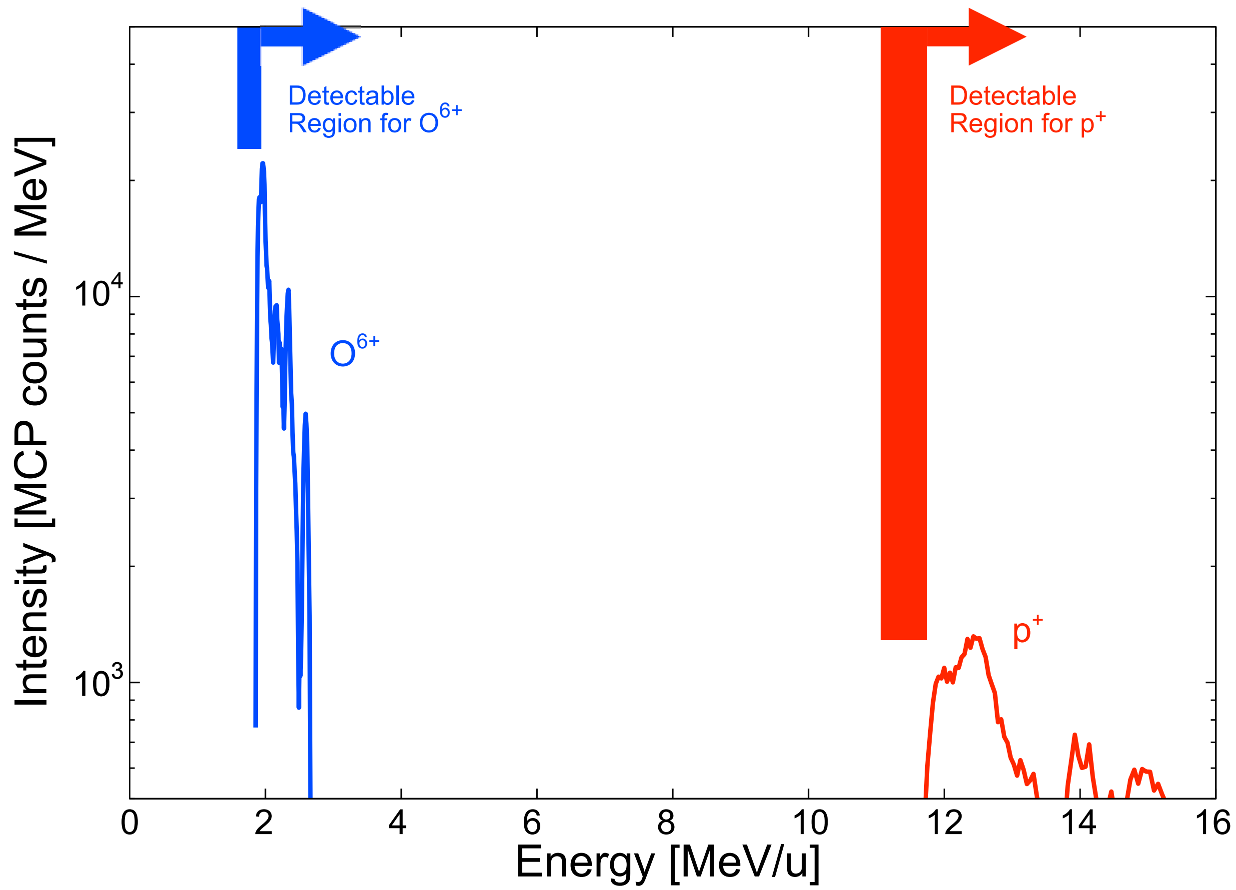
without the CW laser heating



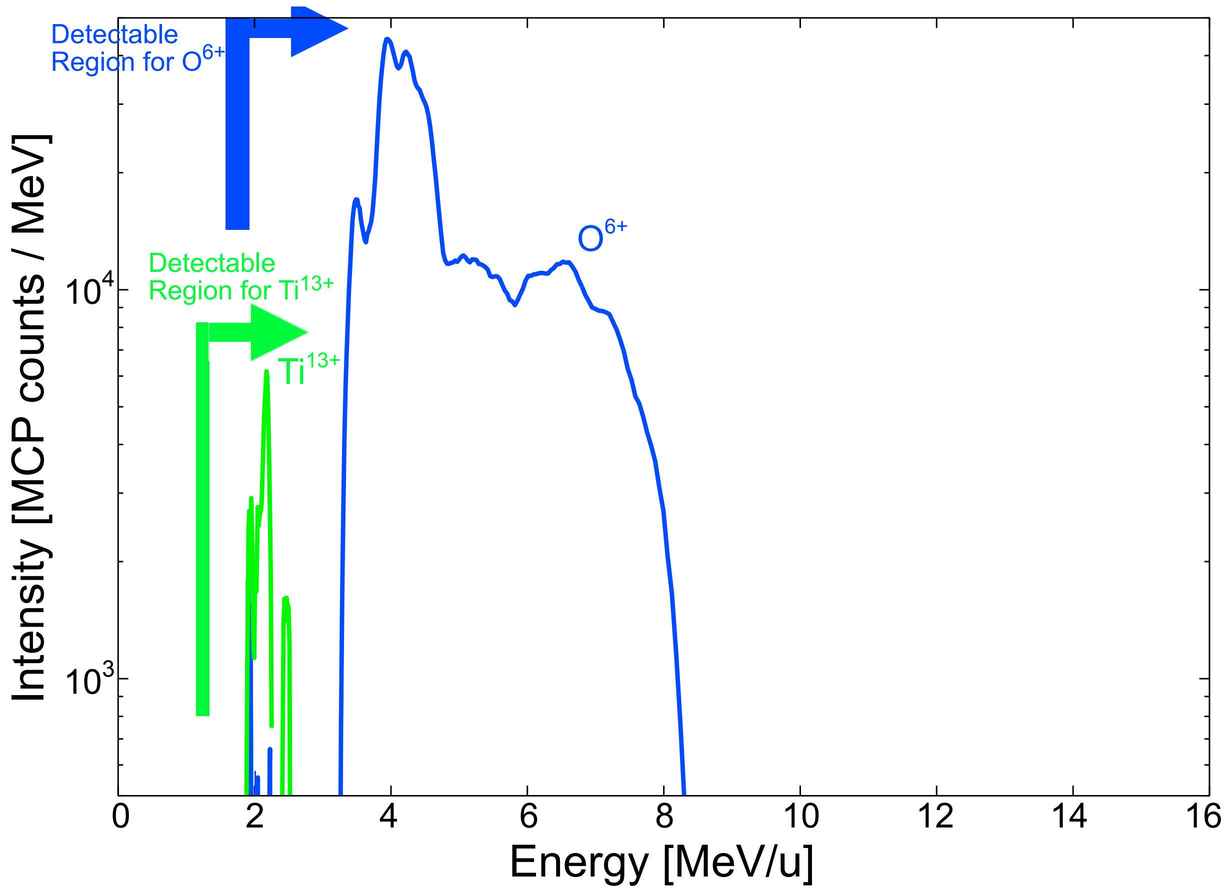
with the CW laser heating

C^{4+}, O^{6+}, C^{5+}, O^{7+}, C^{6+}/O^{8+} and proton were observed without the CW laser heating. On the other hand, O^{6+}, C^{5+}, O^{7+} and C^{6+}/O^{8+} were observed, but no proton signal was visible above the background level with the heating. Signal consistent with Ti ions is also observed with the CW laser heating.

Thomson Parabola (TP) Spectrometer Results (2)



without the CW laser heating



with the CW laser heating

In the case without the heating, the proton beam has a typical thermal-like thermal-like spectrum from the minimum detector cut-off of 11.5 ± 0.3 MeV to a maximum cut-off of 15.2 ± 0.4 MeV. A just-detectable oxygen beam is observed up to a maximum energy of 2.6 ± 0.1 MeV/u.

On the other hand, the O^{6+} ions appear from 3.3 ± 0.1 MeV/u to 8.3 ± 0.5 MeV/u. The CW laser heating therefore not only increased the flux and energy of the O^{6+} ions, but also generated ions in a relatively narrow energy band ($\Delta E \sim 5$ MeV/u).

Summary*

*Kotaro Kondo et. al., Crystals (2020).

- The target surface treatment by a CW laser is proposed for laser-driven heavy ion acceleration. That has potential to supply contamination-free targets with long term operation.
- Laser-driven ion acceleration using a 5 μm Ti with CW laser heating was demonstrated for oxygen ion source.
- A Thomson parabola spectrometer provided evidence that oxygen ions were preferentially accelerated compared to the case without the CW laser heating.
- The experimental results indicate stable thin oxide layers on the surface of the Titanium foil can be accelerated when we apply the CW laser heating.