Caesiated H^- source operation with helium

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outline

- Introduction
- Experimental Background
- Experimental Setup
- Increase of co-extracted electron current.
- Increase of Cs neutral.
- Processes through diffusion of parent particles to beam extraction.
- Summary

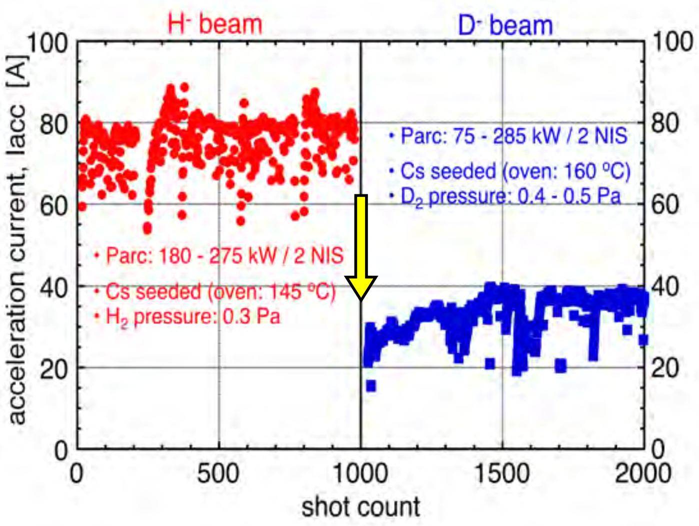
Introduction

- By replacing the operation gas from H_2 to D_2,
  a. Decrease of negative ion current.
  b. Increase of co-extracted electron current.
  c. Increase of caesium (Cs) consumption.

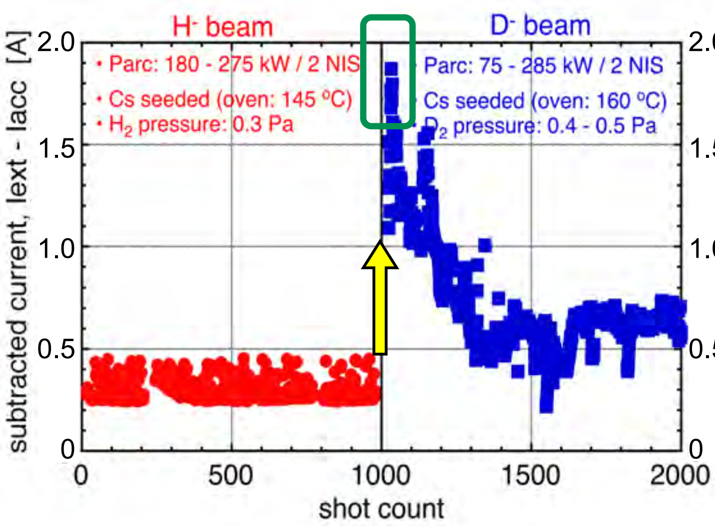
Similar phenomena have been observed at JAEA and IPP.

Not favorable to improve the performances of negative-NBI ion sources

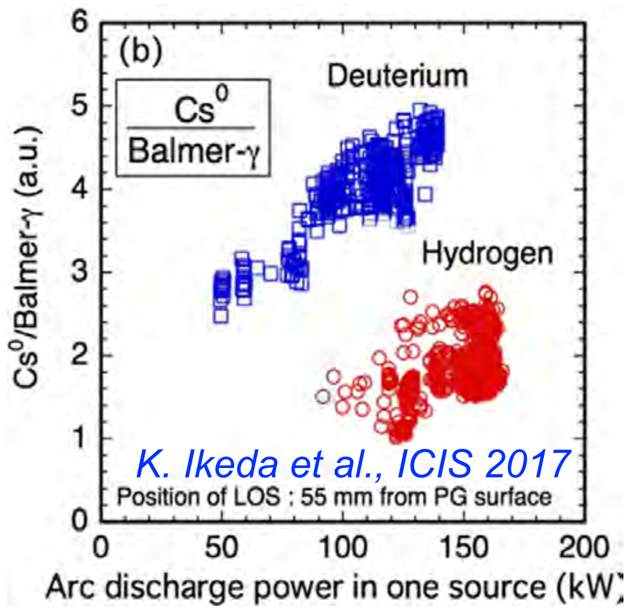
→ Important Issue to resolved for the acceleration of D^- ions



a. Decrease of negative ion current



b. Increase of co-extracted electron current



c. Increase of Cs evaporation

Background

Question

- What is the main cause of this degradation of “Cs effect”?
- Why Cs signal increases in the D_2 discharge?

↓

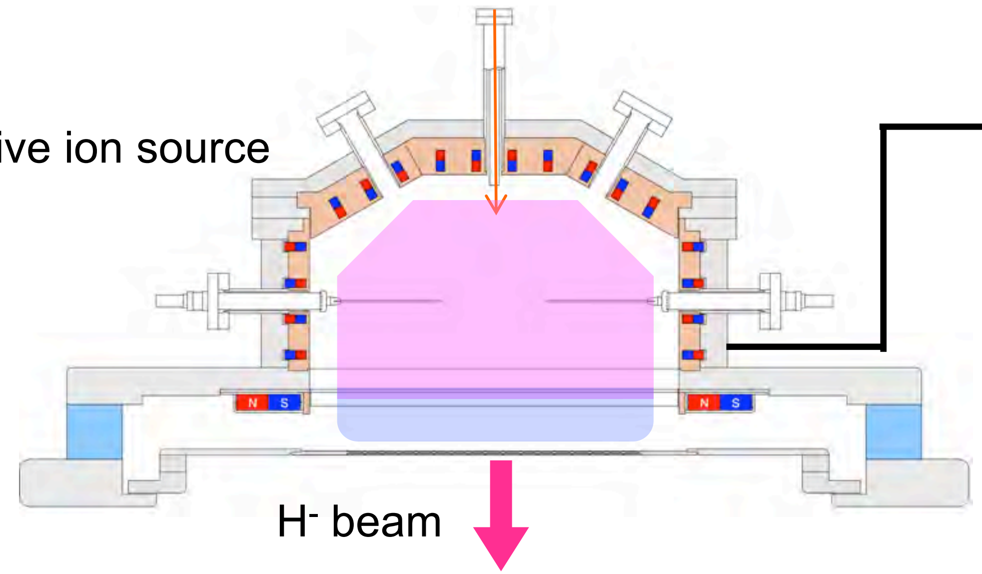
NBI test-stand in NIFS

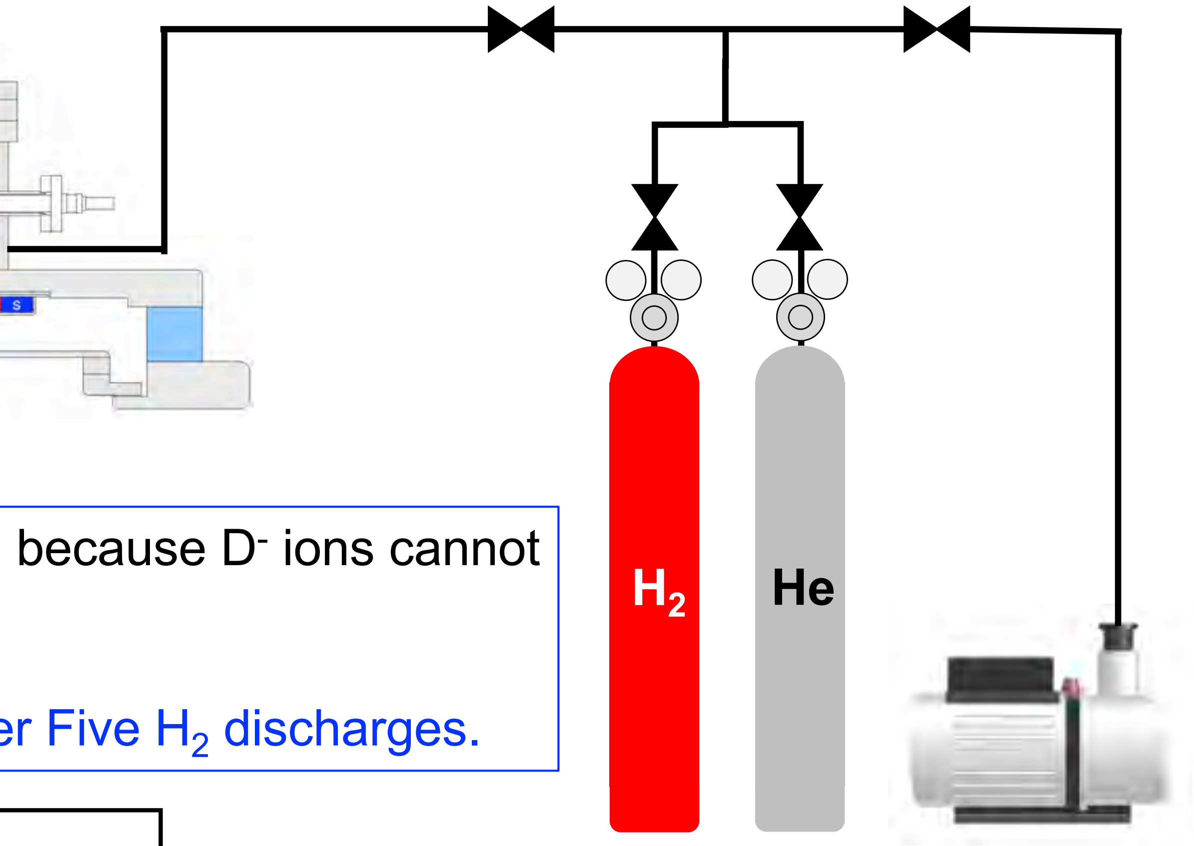
- Merit: several diagnostics comparing to NBI for Large Helical Device.
- Demerit: D_2 discharge was not allowed at the test-stand until last week.

↓

- **Helium** is alternately applied for D_2 to observe
    1. Mass effect to ion source plasma
    2. Mass effect to Cs evaporation

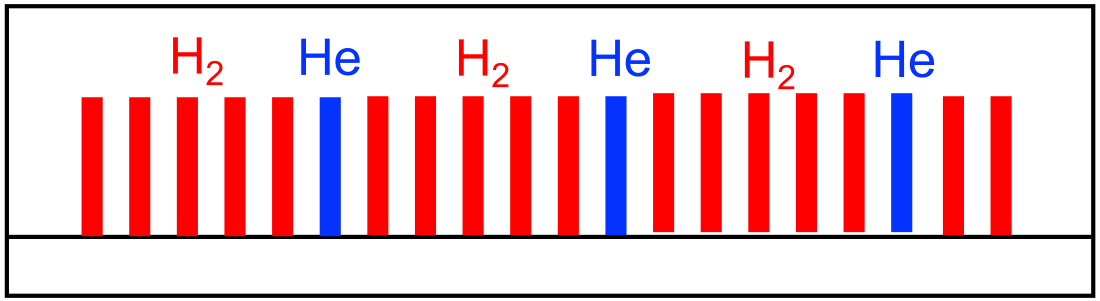
experimental setup





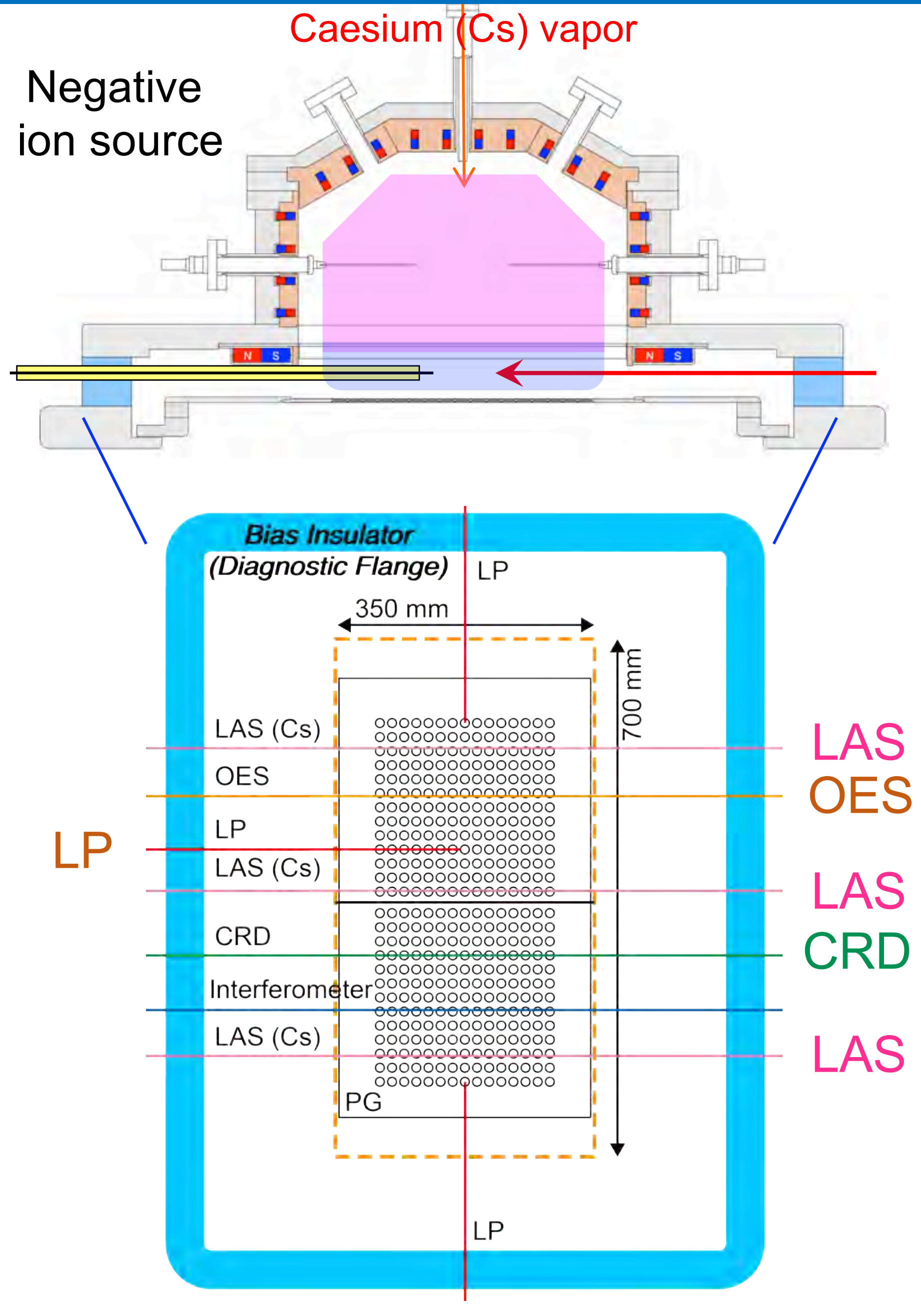
Helium is applied as the alternative for D_2, because D^- ions cannot be accelerated at NIFS NBI test-stand.

Discharge: Repeat One He discharge after Five H_2 discharges.



After continuous helium discharges damage filament surface and discharge resistance increases shot by shot.

Diagnostics



Diagnostics :

<u>Langmuir probe (LP)</u>

Plasma parameters.

<u>Optical Emission Spectroscopy (OES)</u>

Balmer α, He and Cs lines.

<u>Cavity Ring-Down (CRD)</u>

Density of H^- ions.

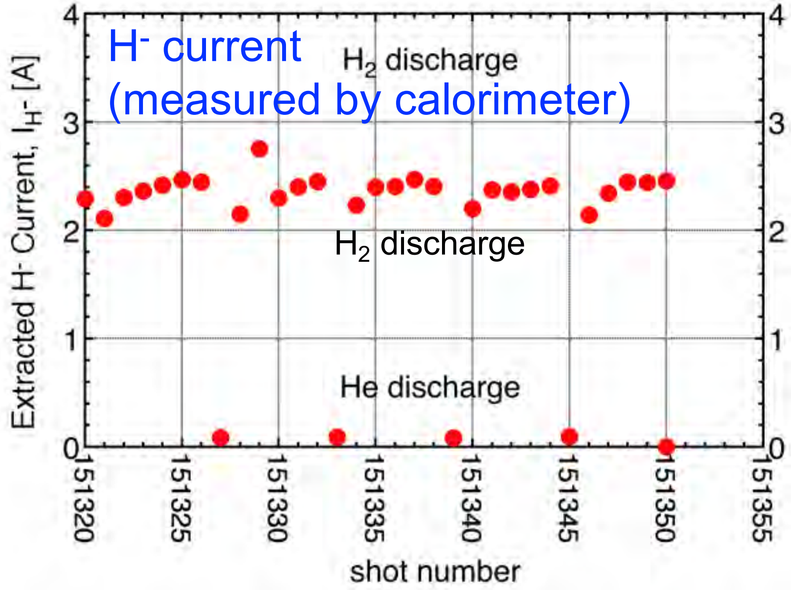
<u>Cs Laser Absorption Spectroscopy (Cs LAS)</u>

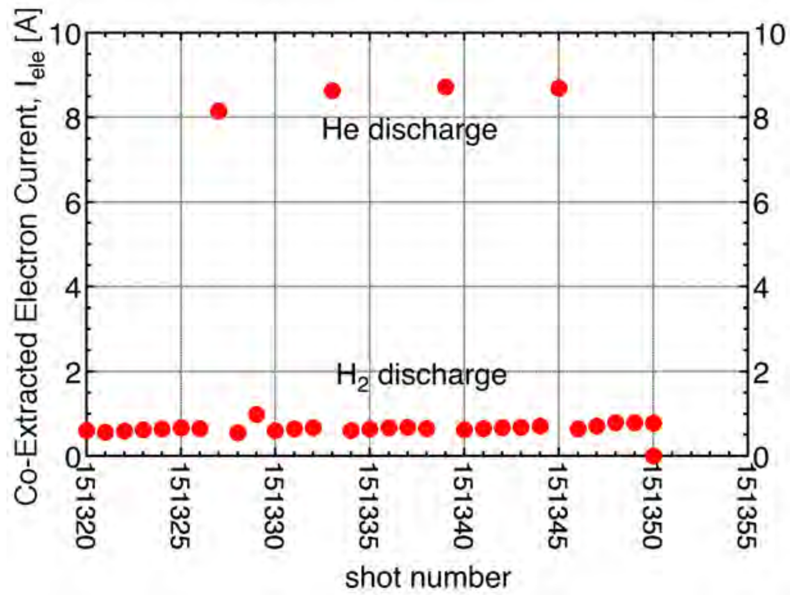
Density of neutral Cs atom.

Distance from Plasma Grid

Cs LAS:	19.5 mm
OES line-of sight:	19.5 mm
Langmuir probe:	19.5 mm
Cavity Ring-Down:	17.5 mm

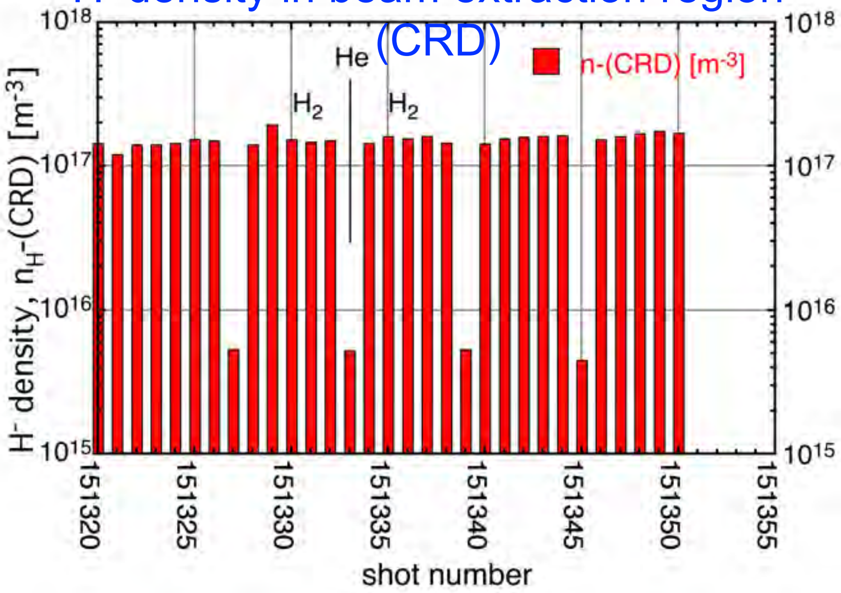
H^- Density and Extracted H^- Current





Co-extracted electron current

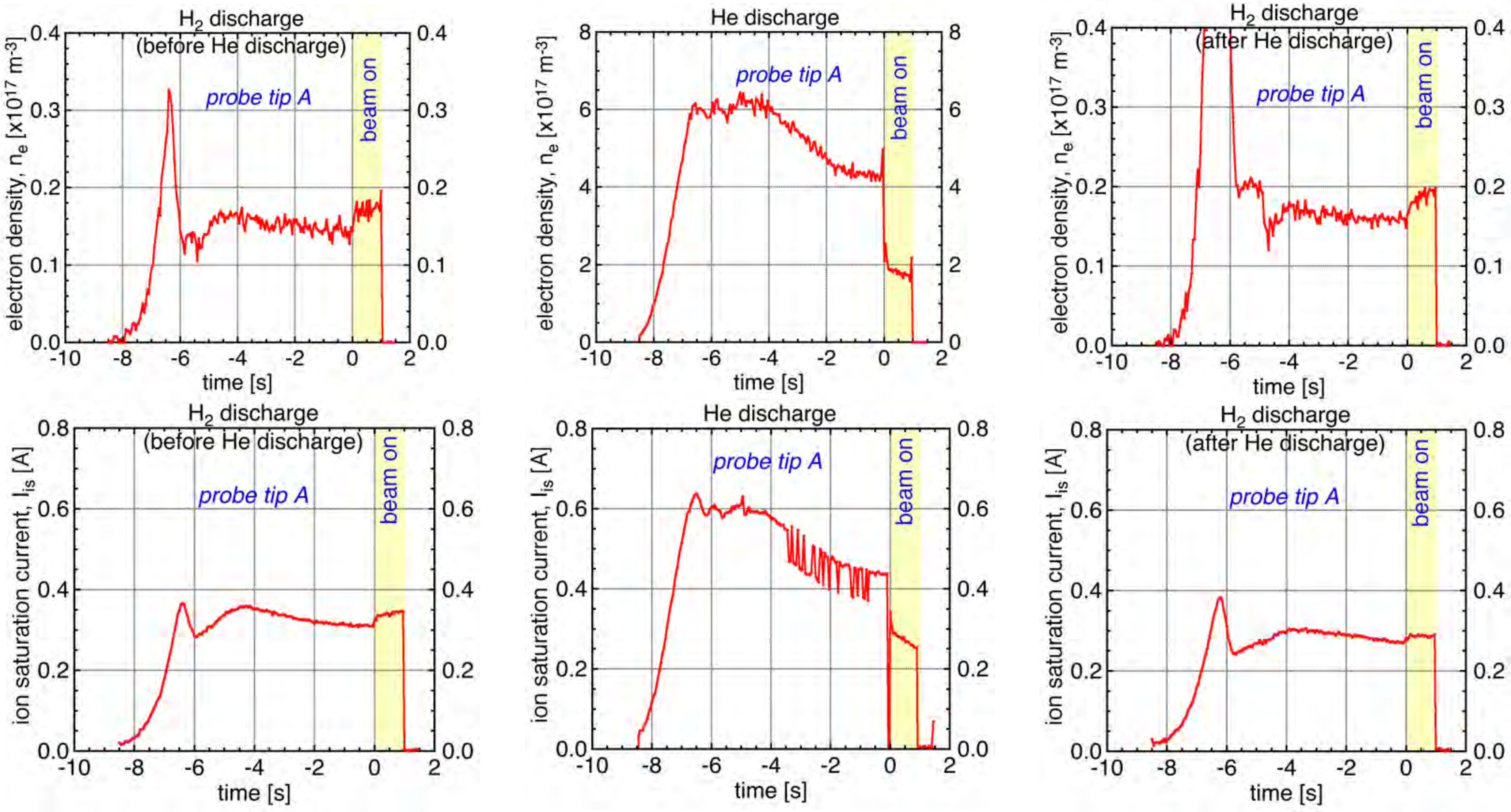
H- density in beam extraction region (CRD)



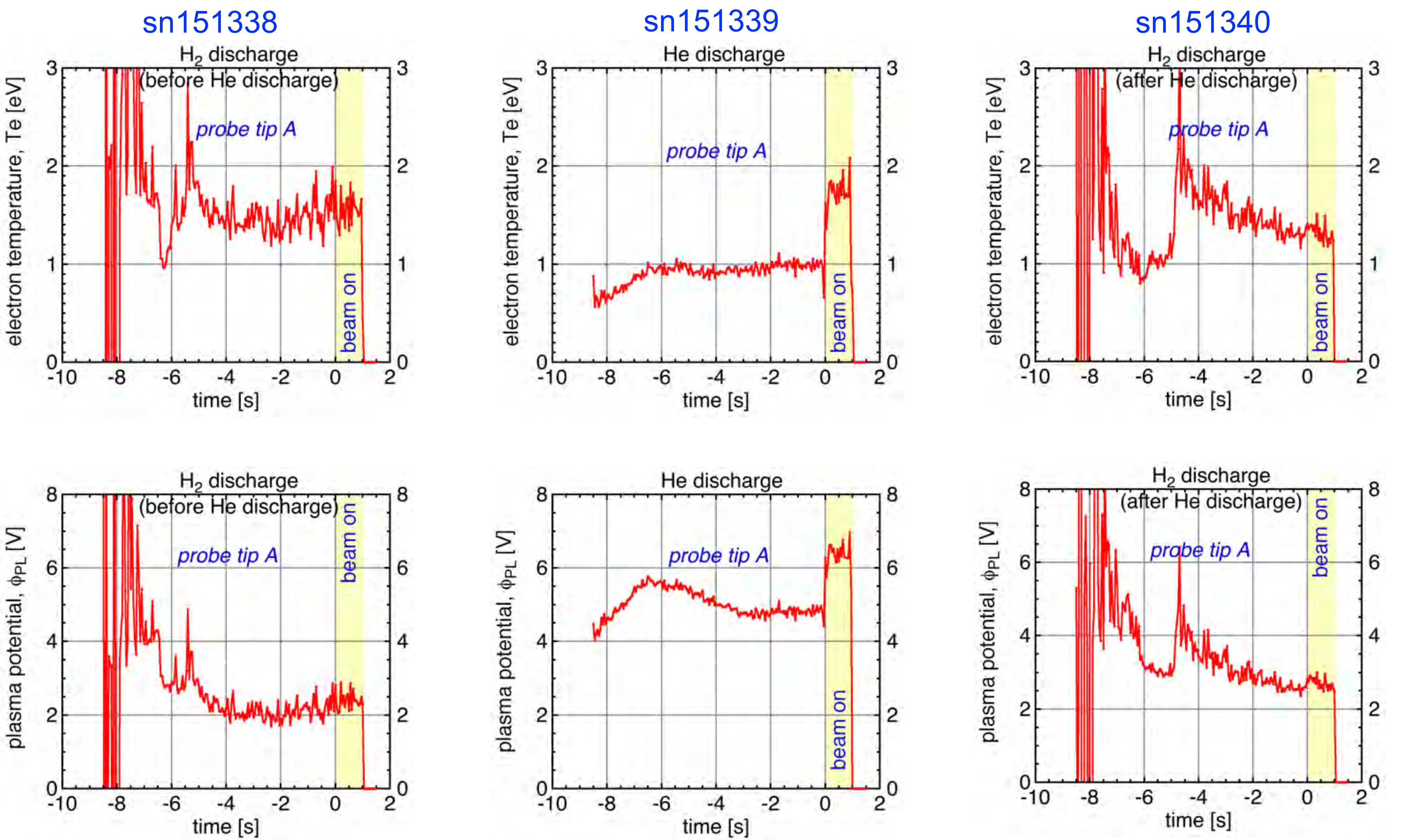
- In helium discharge, H atoms adsorbs on the chamber walls were removed during pre-arc discharge.
- Co-extracted electron current becomes one order higher in helium discharge.
- H^- current measured with calorimeter array shows recovery character after helium discharge.

Plasma Density in H_2 and He Discharges

sn151338 sn151339 sn151340



Electron Temperature and Plasma Potential



Plasma Density in H_2 and He Discharges

Electron density:

- One order higher in the helium discharge.
- H^- ions suppress the increase of electron density in H_2 discharge.

Ion saturation current:

- The currents are almost the same in H2 and helium discharges.
- The He^+ density is about twice larger than that of H_2.

Electron temperature:

- During beam extraction, no difference in H_2 and helium discharge.

Plasma potential is 2-3 times higher in the case of helium discharge.

Spectra in H_2 Discharge

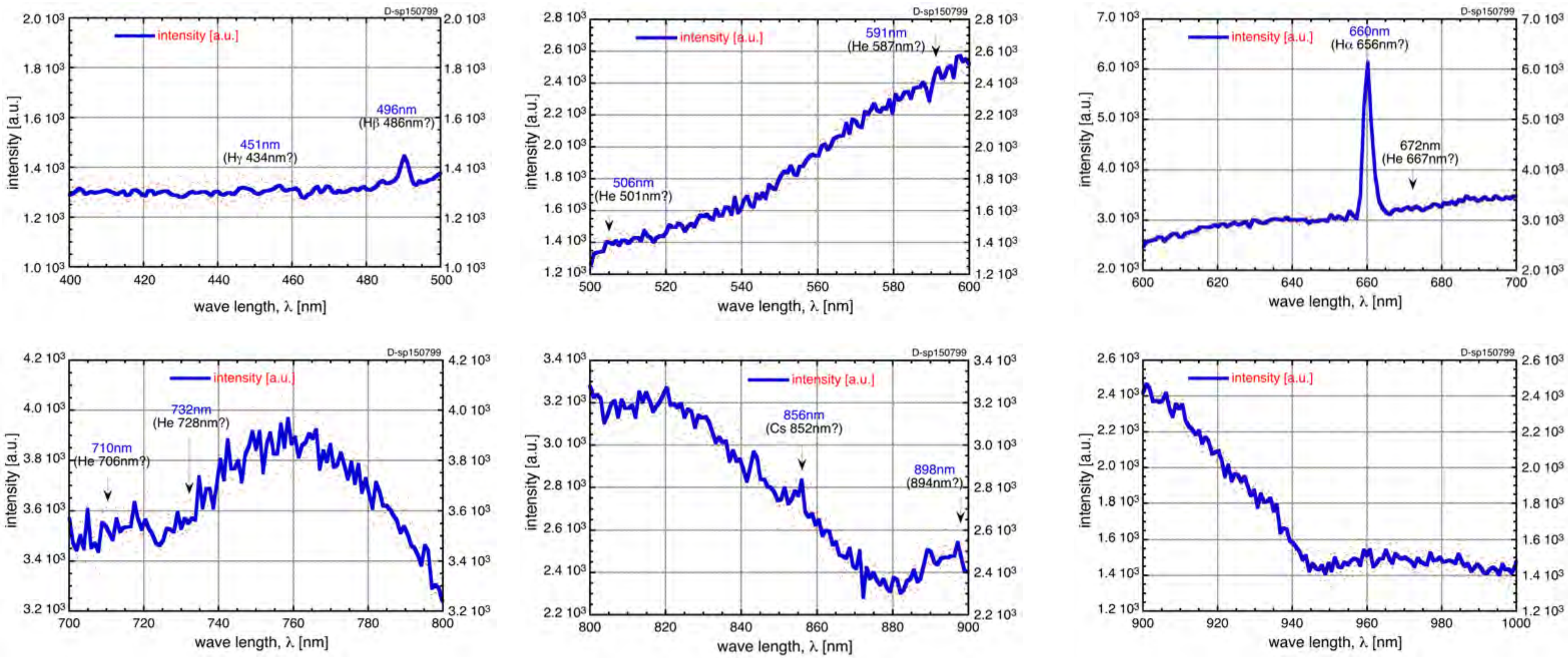
> Hα 656.28nm : 3S → 2S
> Hβ 486.13nm : 4S → 2S
> Hγ 434.05nm : 5S → 2S
? Hδ 410.17nm : 6S → 2S

? He 587nm : $3^3D \rightarrow 2^3P$
> He 706nm : $3^3S \rightarrow 2^3P$
? He 501nm : $3^1P \rightarrow 2^1S$
? He 728nm : $3^1S \rightarrow 2^1P$
? He 667nm : $3^1D \rightarrow 2^1P$

> Cs 852nm
? Cs 522nm
? Cs 460nm

? O 777nm

Sn150799 (H_2 discharge)



Spectra in He Discharge

> Hα 656.28nm : 3S → 2S
> Hβ 486.13nm : 4S → 2S
> Hγ 434.05nm : 5S → 2S
? Hδ 410.17nm : 6S → 2S

> He 587nm : $3^3D \rightarrow 2^3P$
> He 706nm : $3^3S \rightarrow 2^3P$
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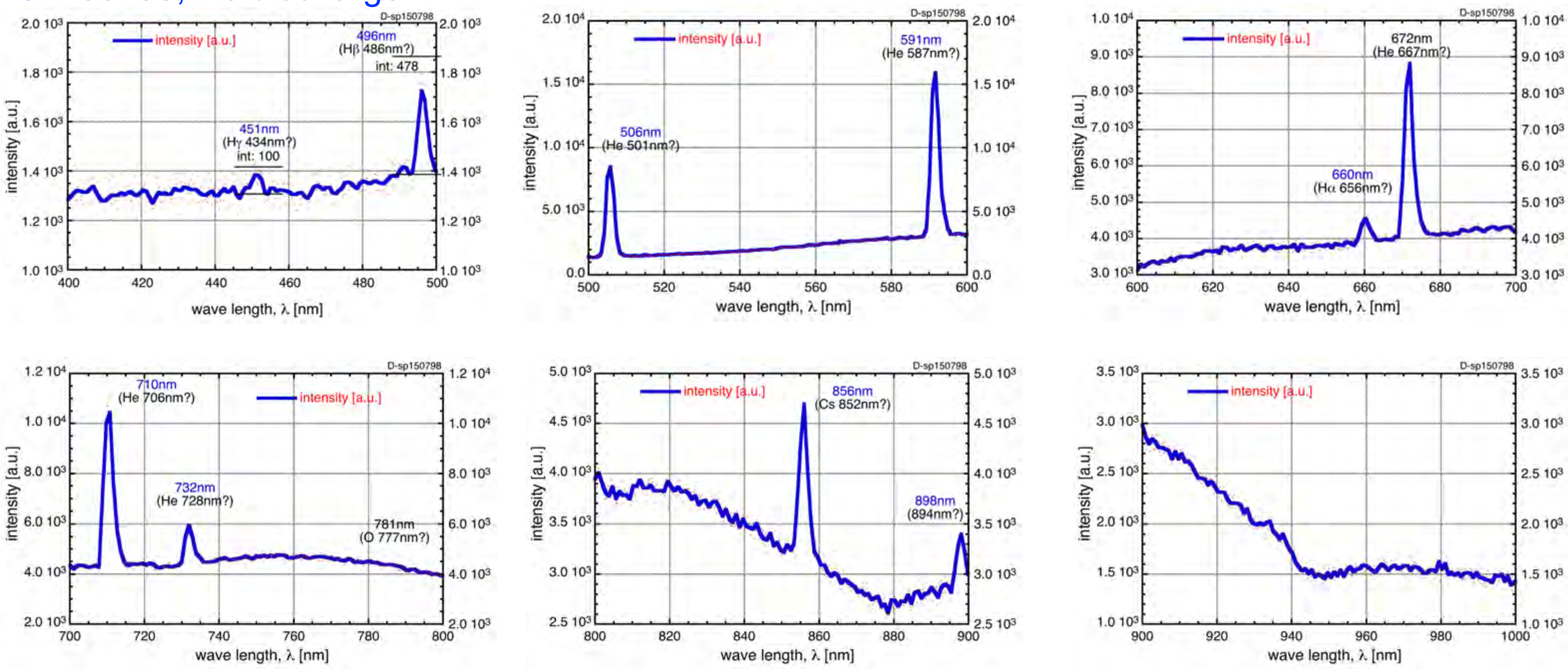
> He 728nm : $3^1S \rightarrow 2^1P$
> He 667nm : $3^1D \rightarrow 2^1P$

> Cs 852nm
? Cs 522nm
? Cs 460nm

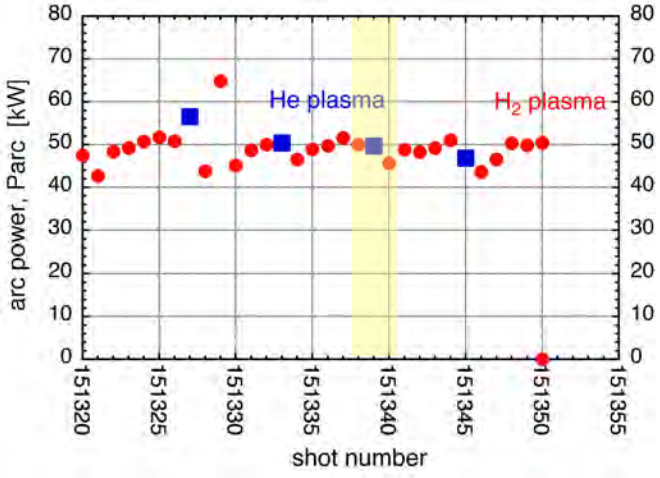
? O 777nm

Sn150798, He discharge

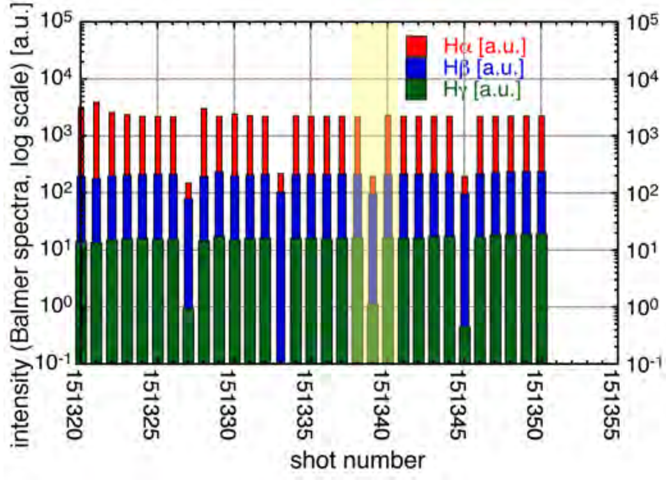


Shot Trends of OES Spectra

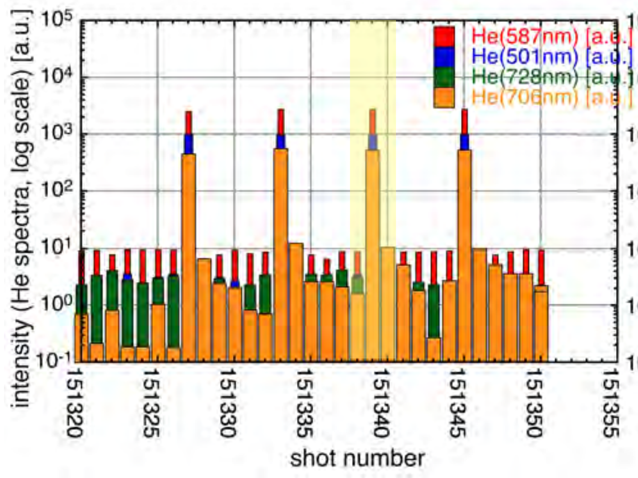
Arc power



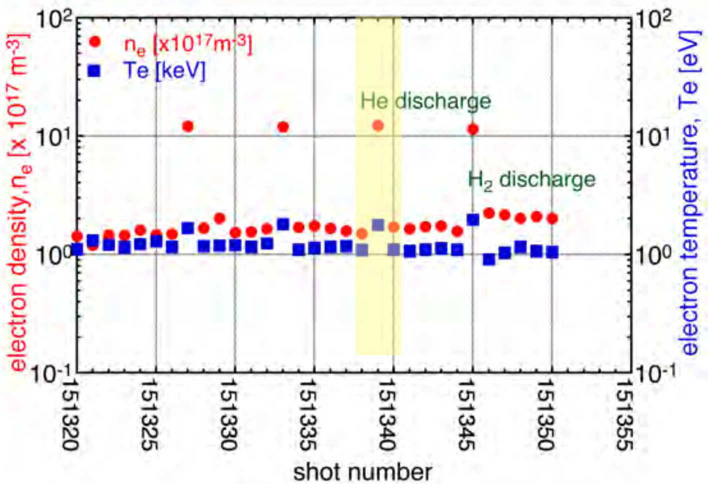
Balmer lines (OES)



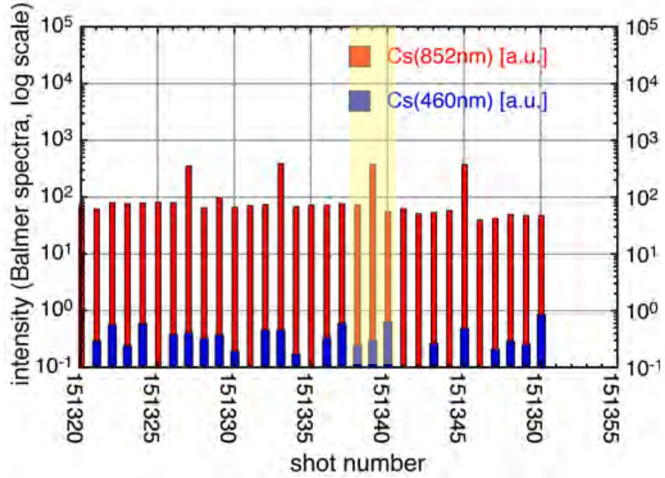
He lines (OES)



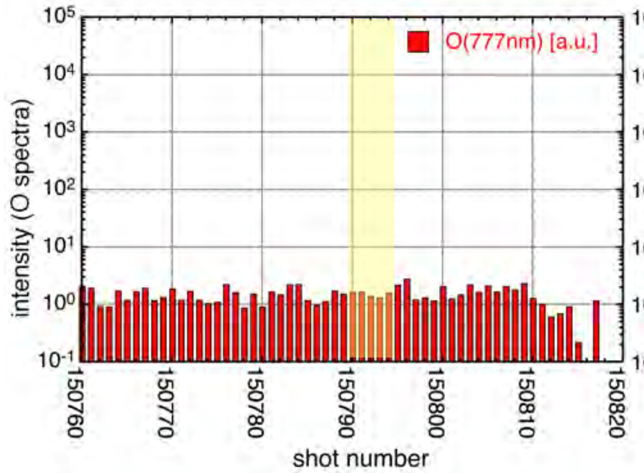
T_e and n_e (Langmuir probe)



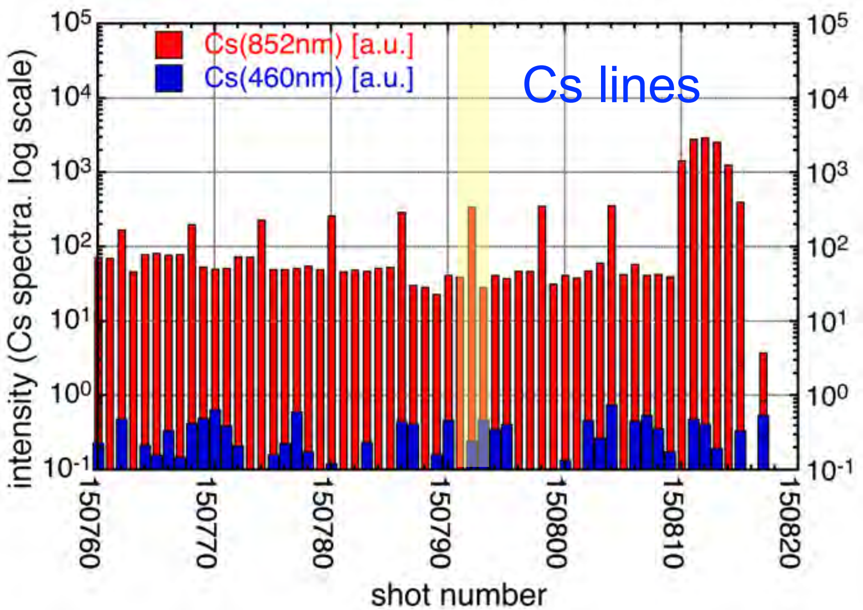
Cs(852nm), Cs(460nm) (OES)



O(777nm) (OES)

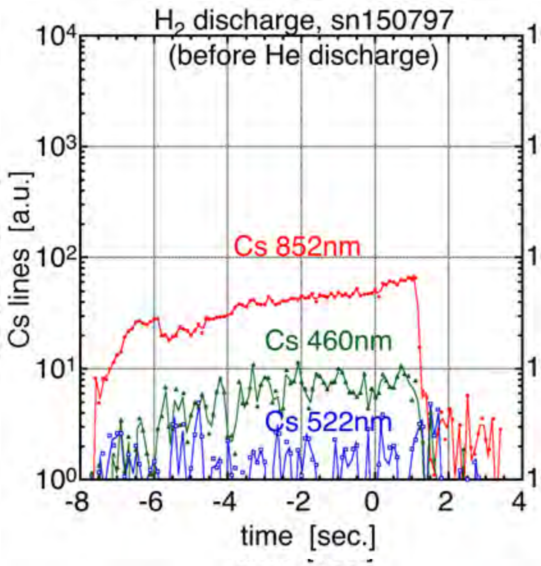


Comparison of Cs Lines Height in H_2 and He Discharges

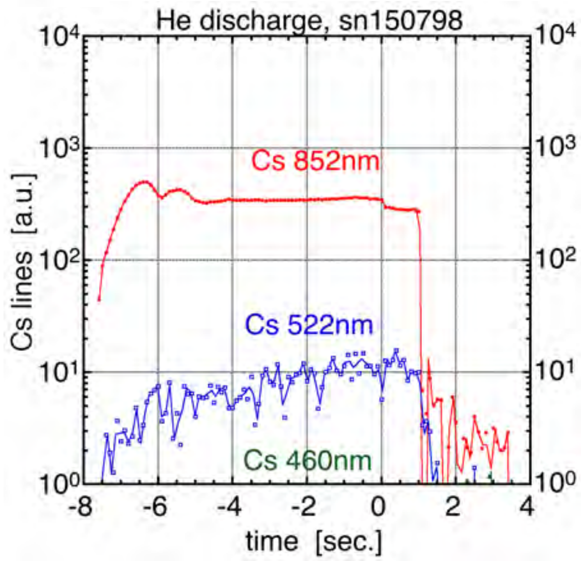


- Cs 852nm intensity in helium discharge increases about 5 – 8 times higher than that in H_2 discharge.

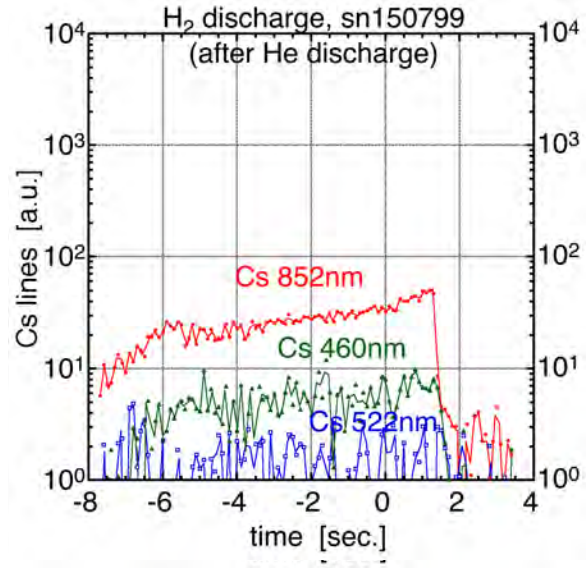
- electron temperature
  - H_2 discharge: about 1.0 eV
  - He discharge: about 2.0 eV



sn150797



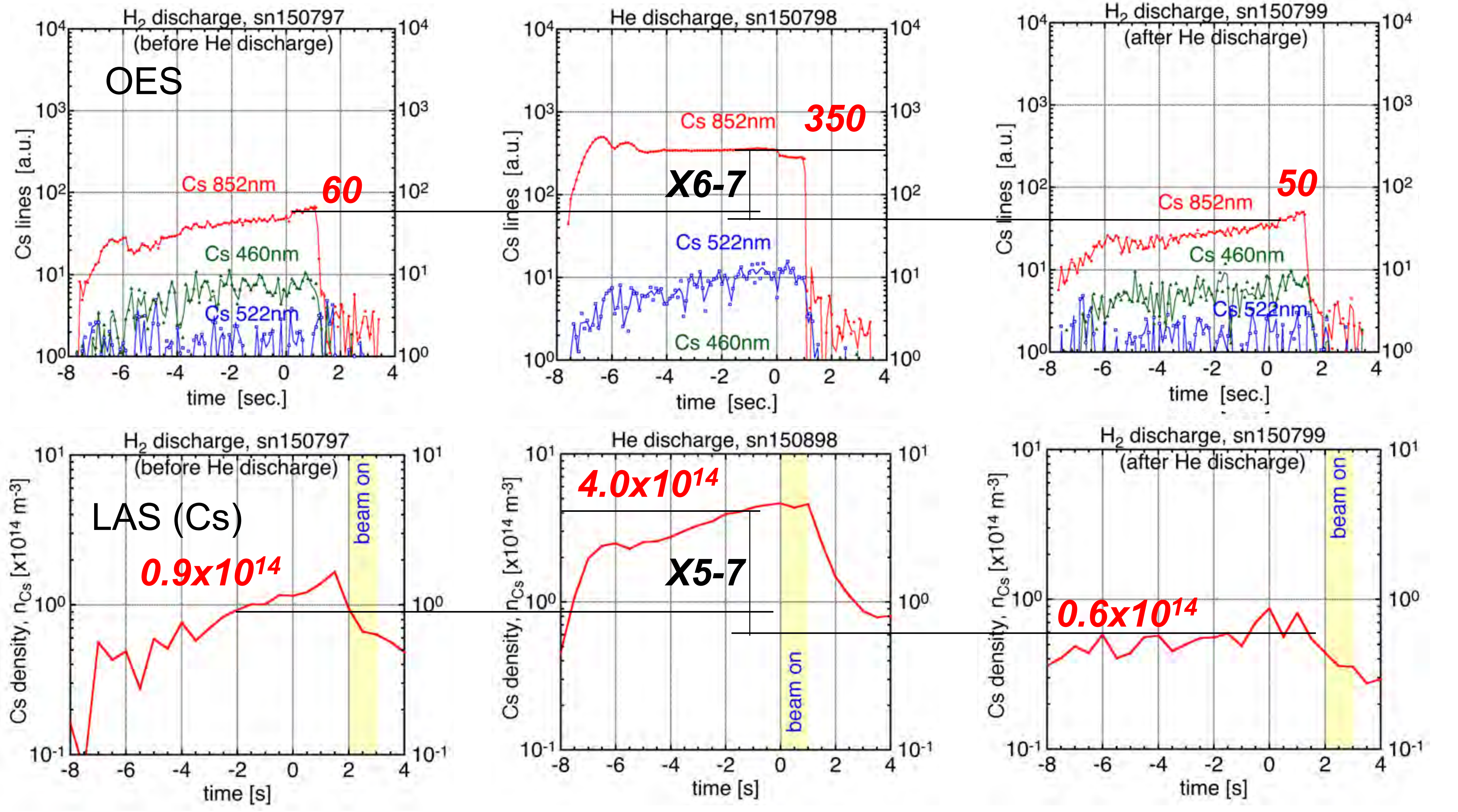
sn150798



sn150799

Cs: Comparison of OES Signal and LAS

sn150797 (H_2 discharge) | sn150798 (He discharge) | sn150799 (H_2 discharge)

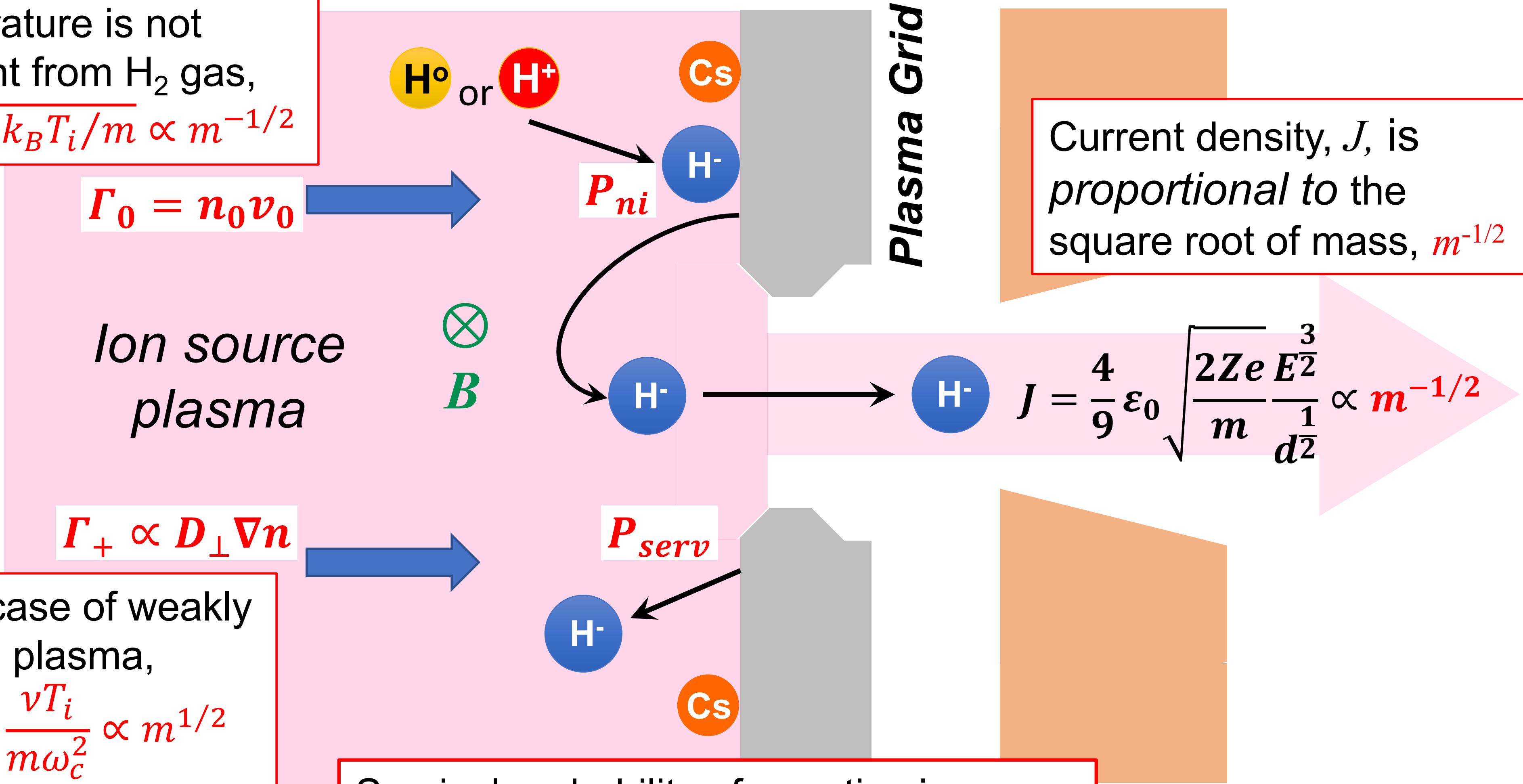


Mass Dependence through Diffusion to Beam Extraction 1

Assuming D_2 gas temperature is not different from H_2 gas,
$v_o \sim \sqrt{3k_B T_i/m} \propto m^{-1/2}$

Negative-ionization probability, P_{ni}, has no difference

Current density, J, is *proportional to* the square root of mass, $m^{-1/2}$



In the case of weakly ionized plasma,
$D_\perp = \frac{\nu T_i}{m\omega_c^2} \propto m^{1/2}$

Survival probability of negative ions, P_{serv}, is a function of escaping velocity.
$P_{serv} = 1 - exp(-4\pi\Delta_0 e^{-\gamma v t}/h\gamma v)$

Mass Dependence through Diffusion to Beam Extraction 2

	diffusion	Negative Ionization probability	Survival probability	H^- extraction
atom	$\propto m^{-1/2}$	*Independent of H and D*	$1 - exp(-4\pi\Delta_0 e^{-\gamma v t}/h\gamma \boldsymbol{v})$	$\propto m^{-1/2}$
proton	$\propto m^{1/2}$	*Independent of H and D*	$1 - exp(-4\pi\Delta_0 e^{-\gamma v t}/h\gamma \boldsymbol{v})$	$\propto m^{-1/2}$

Mass dependence through the processes above are;

	Total mass dependence
atom	$[1 - \ exp(-4\pi\Delta_0 e^{-\gamma v t}/h\gamma \boldsymbol{v})] \times \boldsymbol{m^{-1}}$
proton	$[1 - \ exp(-4\pi\Delta_0 e^{-\gamma v t}/h\gamma \boldsymbol{v})] \times \boldsymbol{m^{0}}$

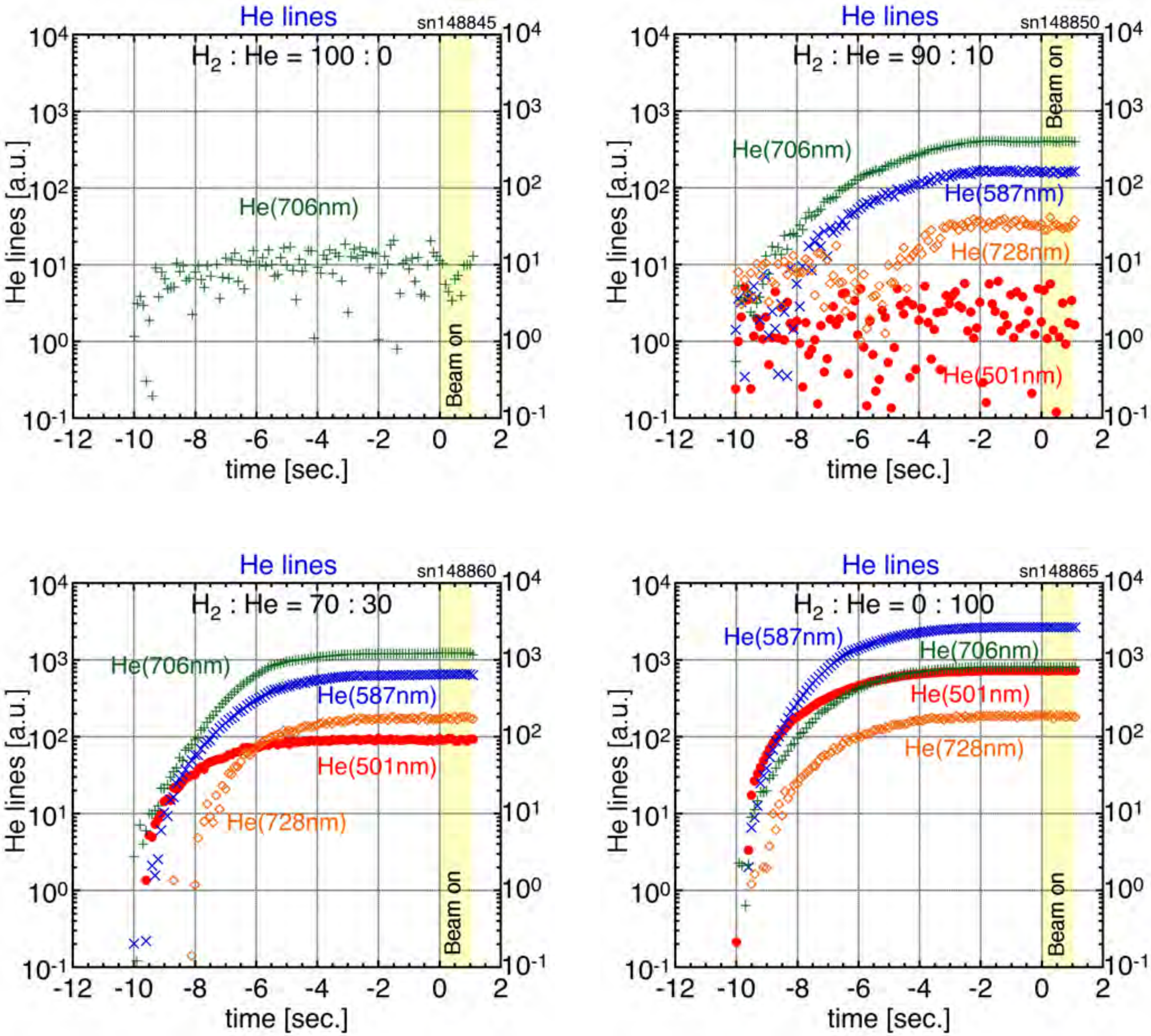
Survival probabilities of H^- and D^- in low energy range such as less than 5 eV are unknown.

Summary

- To simulate the D_2 discharge, helium plasma is compared to H_2 plasma using OES, Langmuir probe, CRD, Cs-LAS measurement.
- In helium discharge, plasma density becomes higher than that in H_2 discharge.
- Increase of the plasma density is observed in NIFS recently (to be presented by H. Nakano).
- Evaporation of Cs is enhanced in helium discharge and the enhanced rate to H_2 discharge is ~6.
- Negative ionization probability is the same in H^- and D^- formation.
- Survival probability is a function of escaping velocity of negative ions, and escaping velocity of D^- is considered slower than that of H^-.

APENDIX

He 587nm and 706nm Lines in He and H_2 Mixture Gas



<u>pure He discharge:</u>

Intensity of He has an order of 587nm, 706nm, 501nm, 728nm

<u>Discharge with H_2 and He:</u>

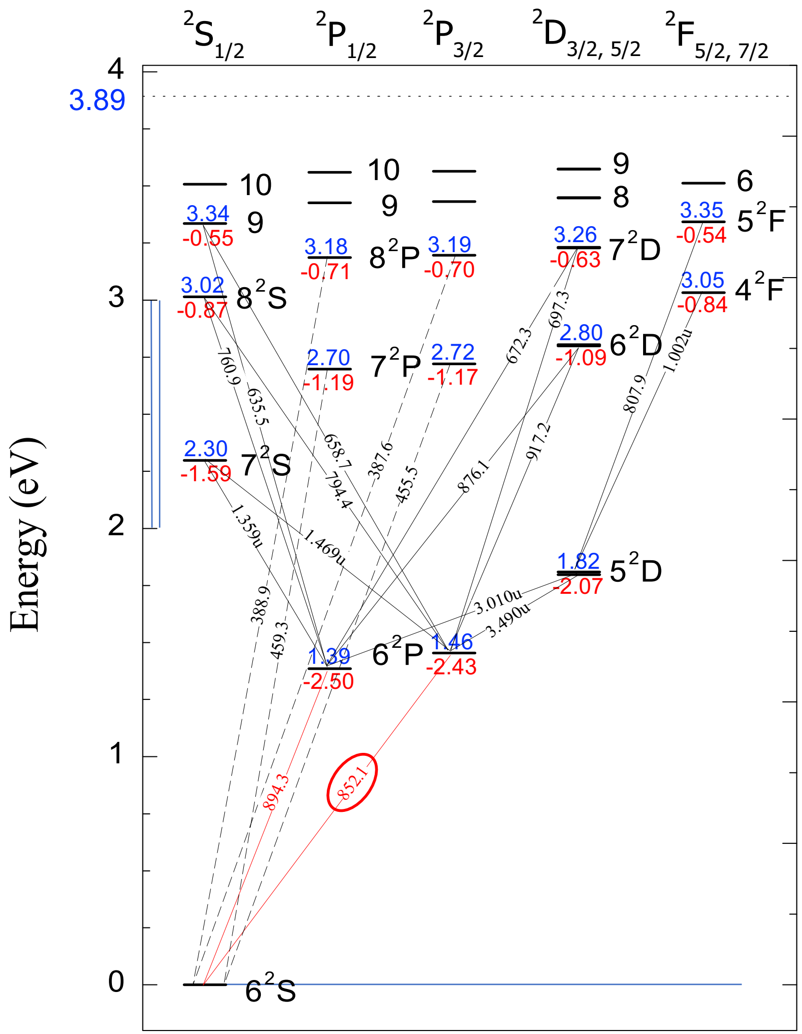
Mixture gas discharge flips the order;

706nm ↔ 587nm,

728nm ↔ 501nm

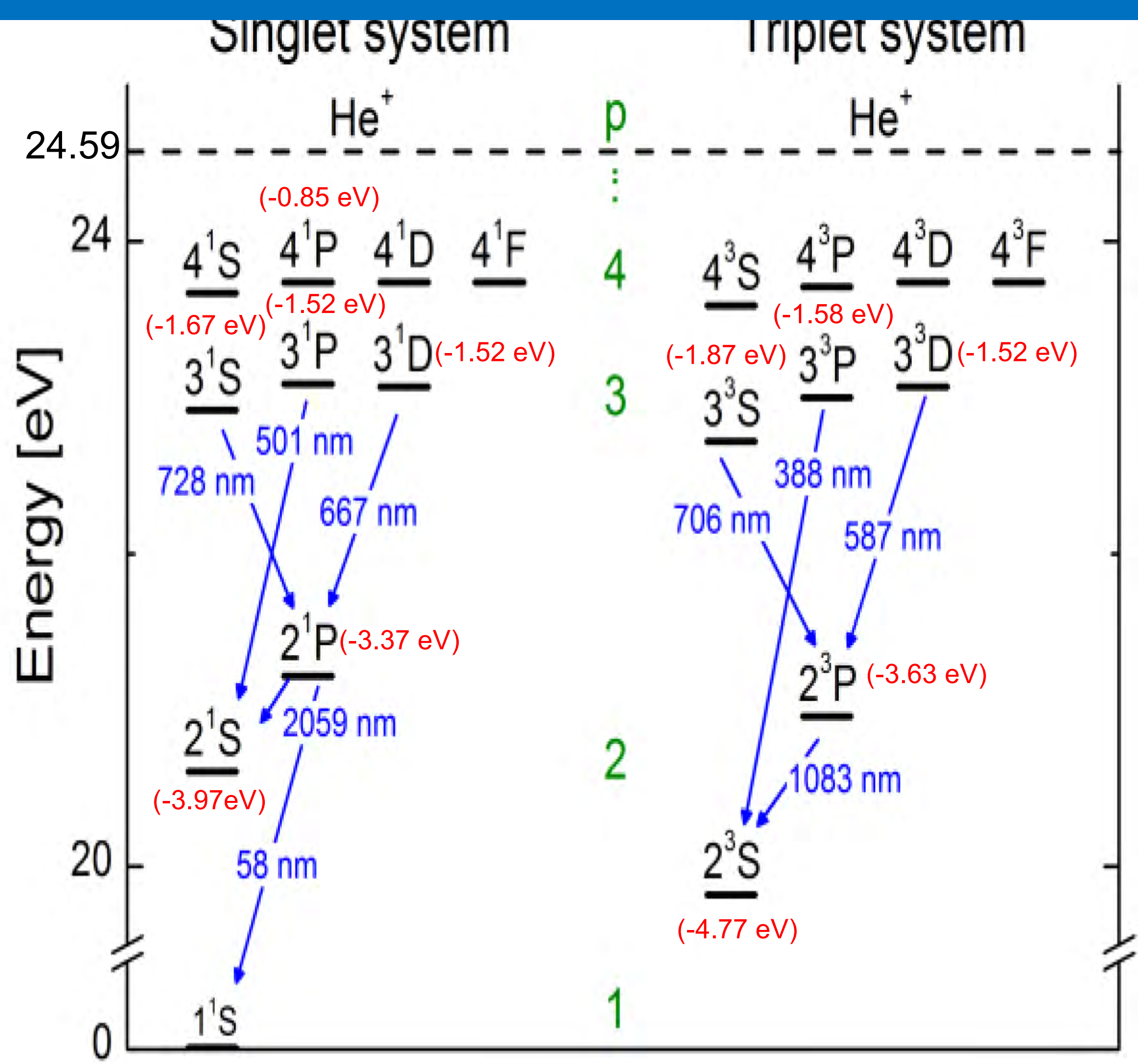
In the case of <u>mutual neutralization of He^+ and H^-</u>, intensities of 706nm and 728nm should decrease.

→ **the other processes.**



Cesium

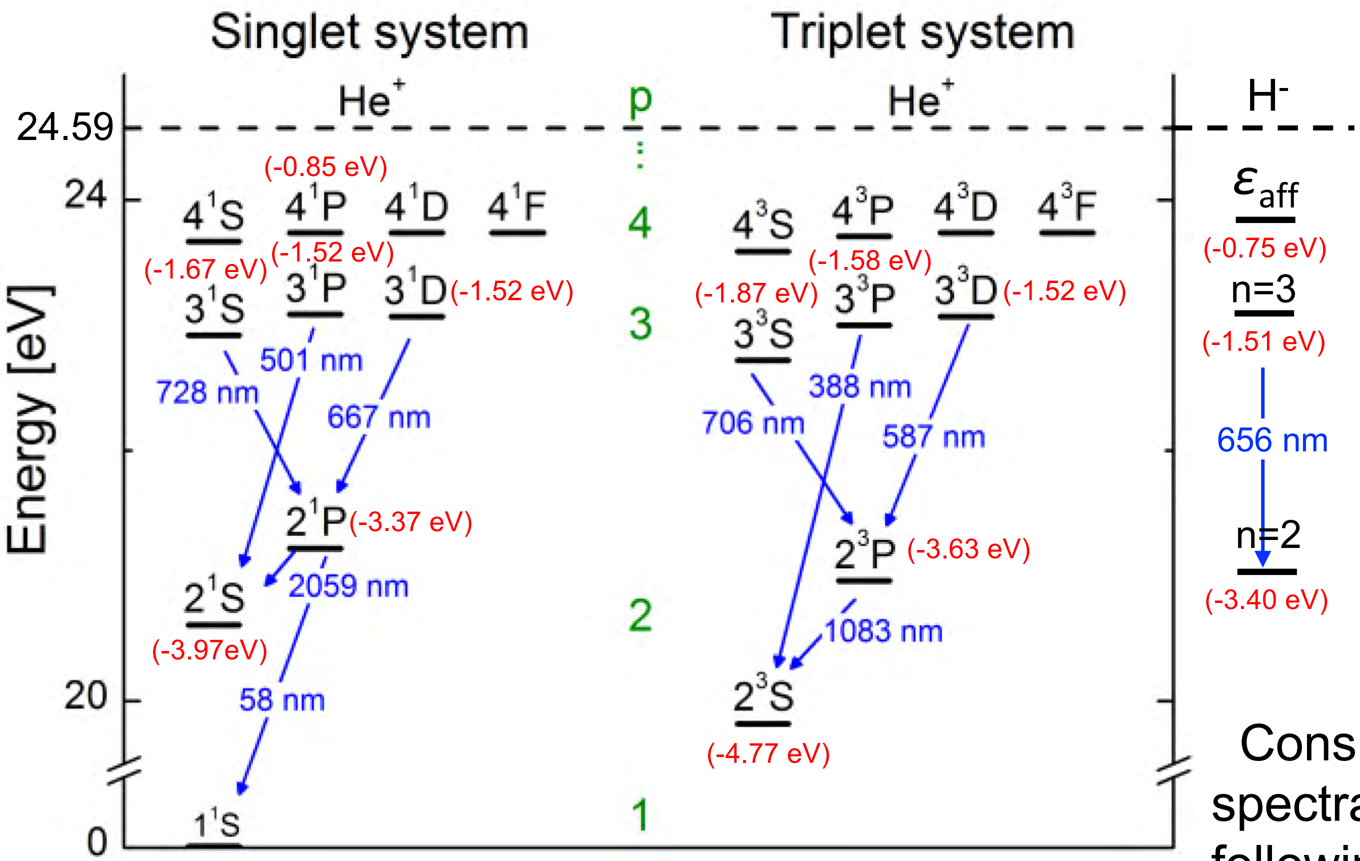
Hydrogen



Z : 55 Ioniz. Pot. : 3.893 eV

ground state : $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^{10}\ 4s^2\ 4p^6\ 4d^{10}\ 5s^2\ 5p^6\ 6s$

Transition from H(n=3) to He^+



2^1S: 20.62 eV
2^1P: 21.22 eV
3^1S: 22.92 eV
3^1P: 23.07 eV
3^1D: 23.07 eV
4^1P: 23.74 eV

2^3S: 19.82 eV
2^3P: 20.96 eV
3^3S: 22.72 eV
3^3P: 23.01 eV
3^3D: 23.07 eV

from 1^1S state

[***He discharge***]

He 587nm: $3^3D \rightarrow 2^3P$
He 706nm: $3^3S \rightarrow 2^3P$
He 501nm: $3^1P \rightarrow 2^1S$
He 728nm: $3^1S \rightarrow 2^1P$

[***He + H_2 discharge***]

He 706nm: $3^3S \rightarrow 2^3P$
He 587nm: $3^3D \rightarrow 2^3P$
He 728nm: $3^1S \rightarrow 2^1P$
He 501nm: $3^1P \rightarrow 2^1S$

Considering the non-decrease He spectra and transition probability, following processes are possible;

$He^+ + H(n=3) \rightarrow He(3^3S) + H^+$
$He(3^3S) \rightarrow He(2^3P) + h\nu(706nm)$

$He^+ + H(n=3) \rightarrow He(3^1S) + H^+$
$He(3^1S) \rightarrow He(2^1P) + h\nu(728nm)$