P7-11

Measurement of gas composition ratio of H-He mixed plasmas in Divertor Simulator MAP-II

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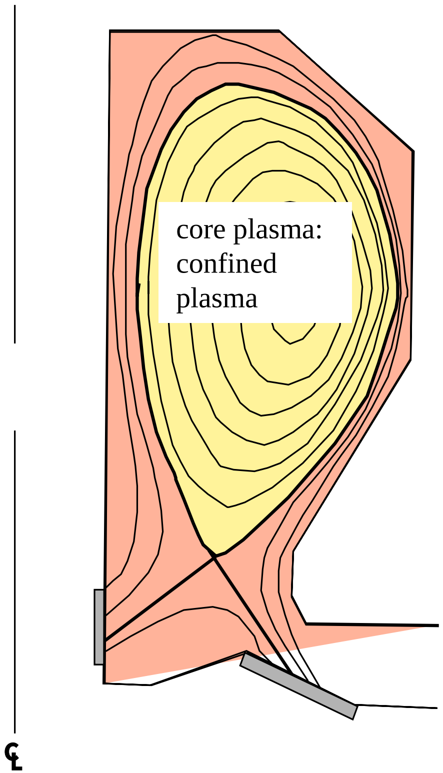
Background

- In divertor region of fusion reactor, plasmas are mixed with puffed molecular hydrogen, dissociated atomic hydrogen and atomic helium through fusion reaction are mixed.



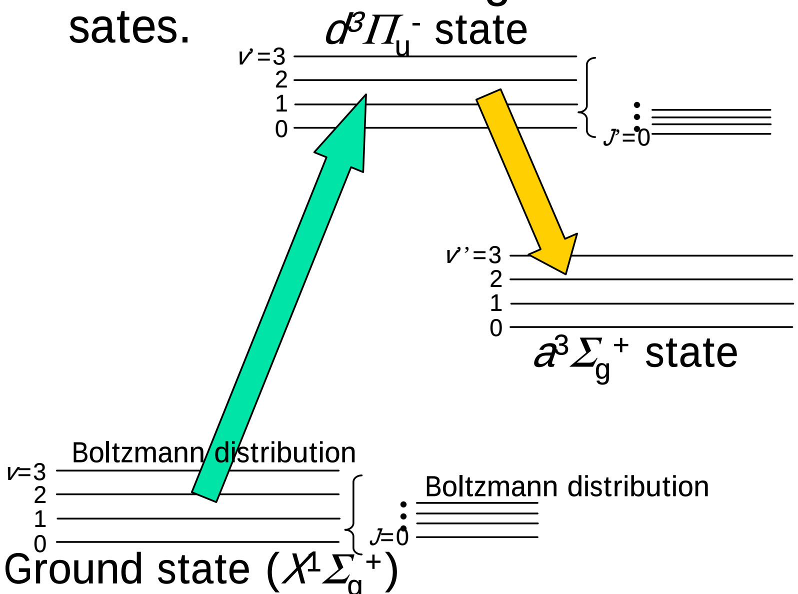
In order to evaluate these atomic/molecular processed, measurement of its gas composition ratio is acquired.

- We propose the method to measure the gas composition ratio by using the ratio of hydrogen Balmer series, Fulcher-α band and helium balmer series.

*S. Kado, Y. Iida, *et al.*, J. Plasma and Fusion Res., **81**, 810 (2005).

Fulcher-α band

- For the ro-vibrational structure of the ground state we assume Bolzmann distribution and calculate the emissions of each band with its parameter as rotational and vibrational temperatures.
- For the plasma we assumed a coronal model that is electron impact excitation from the ground state and spontaneous emission from the excited sates.



●Rate equation of coronal model

$$n_e \sum_{vJ} N_{XvJ} R^{dv'J'}_{XvJ} - N_{dv'J'} \sum_{v''J''} A^{dv'J'}_{av''J''} = 0$$

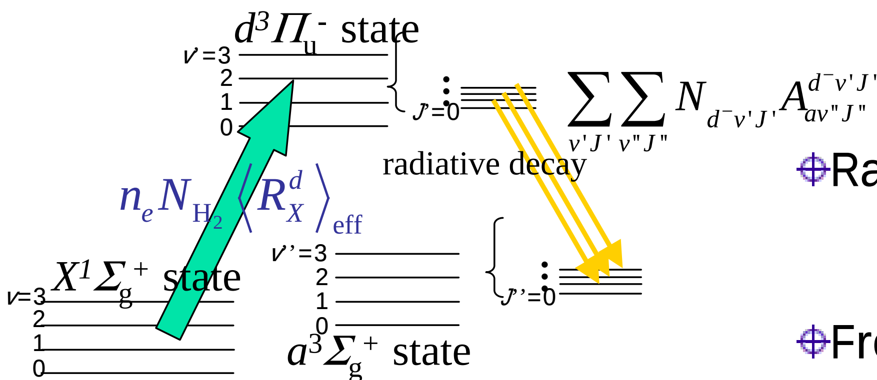
$$I^{dv'J'}_{av''J''} = \frac{hc}{\lambda^{Uv'J'}_{Lv''J''}} A^{dv'J'}_{av''J''} N_{dv'J'}$$

$$= \frac{hc}{\lambda^{dv'J'}_{av''J''}} \frac{A^{dv'J'}_{av''J''}}{\sum_{v''J''} A^{dv'J'}_{av''J''}} n_e \sum_{vJ} R^{dv'J'}_{XvJ} N_{XvJ}$$

$$I^{dv'J'}_{av''J''} = \frac{hc}{\lambda^{dv'J'}_{av''J''}} \frac{A^{dv'J'}_{av''J''}}{\sum_{v'J'} A^{dv'J'}_{av''J''}} n_e \sum_{vJ} R^{dv'J'}_{XvJ} C_v g^J_{as} (2J+1) \exp\left[-\frac{\Delta F_X(J,v)}{kT^X_{rot}} - \frac{\Delta G_X(v)}{kT^X_{vib}} \right]$$

Fulcher-α band emission

- Molecular hydrogen density



⊕Rate equation

$$n_e N_{H_2} \langle R_X^d \rangle_{eff} = \sum_{v'J'}\sum_{v''J''} N_{d-v'J'} A_{av''J''}^{d-v'J'}$$

⊕From Fulcher-α the ro-vibronic structure of *d* state, $N_{d\text{-}v'J'}$, can be obtained.

Observed Fulcher-α band

$$\varepsilon_{av''J''}^{d-v'J'} = \frac{N_{d-v'J'} A_{av''J''}^{d-v'J'}}{\sum_{v'J'}\sum_{v''J''} N_{d-v'J'} A_{av''J''}^{d-v'J'}} n_e N_{H_2} \langle R_X^d \rangle_{eff}$$

Total loss from *d* state

- Effective reaction rate from *X* to *d*

$$\langle R_X^d \rangle_{eff} \equiv \frac{\sum_{v'J'}\sum_{vJ} N_{XvJ} R_{XvJ}^{d-v'J'}}{\sum_{v'J'}\sum_{vJ} N_{XvJ}}$$

✓In order to reduce the effect errors, we used the summation of 12 observed lines.

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Hydrogen and Helium Balmer emission

- Hydrogen Balmer emission

Population coefficient ← Hydrogen CR model*

$$\frac{\varepsilon_{\mathrm{H}(2\leftarrow p)}}{\varepsilon_{\mathrm{Ful}}^{\mathrm{total}}}=\frac{n_e\left[N_{\mathrm{H}}R_1^{\mathrm{H}_2}(p,n_e,T_e)+N_{\mathrm{H}_2}R_2^{\mathrm{H}_2}(p,n_e,T_e)\right]A_{2\leftarrow p}}{n_e N_{\mathrm{H}_2}\left\langle R_X^d\right\rangle_{\mathrm{eff}}}=\frac{R_1A_{2\leftarrow p}}{\left\langle R_X^d\right\rangle_{\mathrm{eff}}}\left(\frac{N_{\mathrm{H}}}{N_{\mathrm{H}_2}}+\frac{R_2^{\mathrm{H}_2}}{R_1^{\mathrm{H}_2}}\right).$$

- Helium Balmer emission

Population coefficient ← Helium CR model**

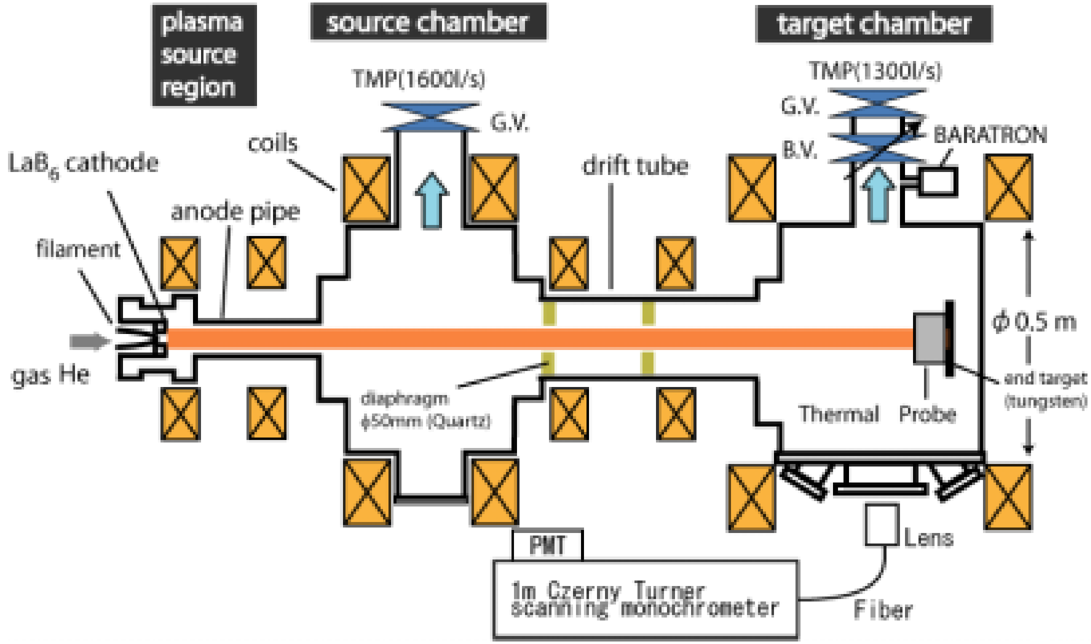
$$\frac{\varepsilon_{\mathrm{He}}(2^{2s+1}L\leftarrow p)}{\varepsilon_{\mathrm{Ful}}^{\mathrm{total}}}=\frac{n_eN_{\mathrm{He}}R_1^{\mathrm{He}}(p,n_e,T_e)A_{2^{2s+1}L\leftarrow p}}{n_eN_{\mathrm{H}_2}\left\langle R_X^d\right\rangle_{\mathrm{eff}}}=\frac{R_1^{\mathrm{He}}A_{2^{2s+1}L\leftarrow p}}{\left\langle R_X^d\right\rangle_{\mathrm{eff}}}\frac{N_{\mathrm{He}}}{N_{\mathrm{H}_2}}.$$

→Gas composition ratio, $N_{\mathrm{H2}}:N_{\mathrm{H}}:N_{\mathrm{He}}$,can be obtained

*T. Fujimoto, K. Sawada and K. Takahara, J. Appl. Phys., 66, 2315 (1989).
**T. Fujimoto, Quant. Spectrosc. Radial. Transfer., 21 (1979) 439

Experimental device

Divertor simulator MAP(material and plasma)**-II**



✓Condition

➤DC arc discharge, H_2 & He plasma

□@target chm.

● radial profile

● P:3.3mTorr, I_{dis}: 45A, V_{dis}: 86V

● Source gas: H_2: 50sccm, He: 50sccm

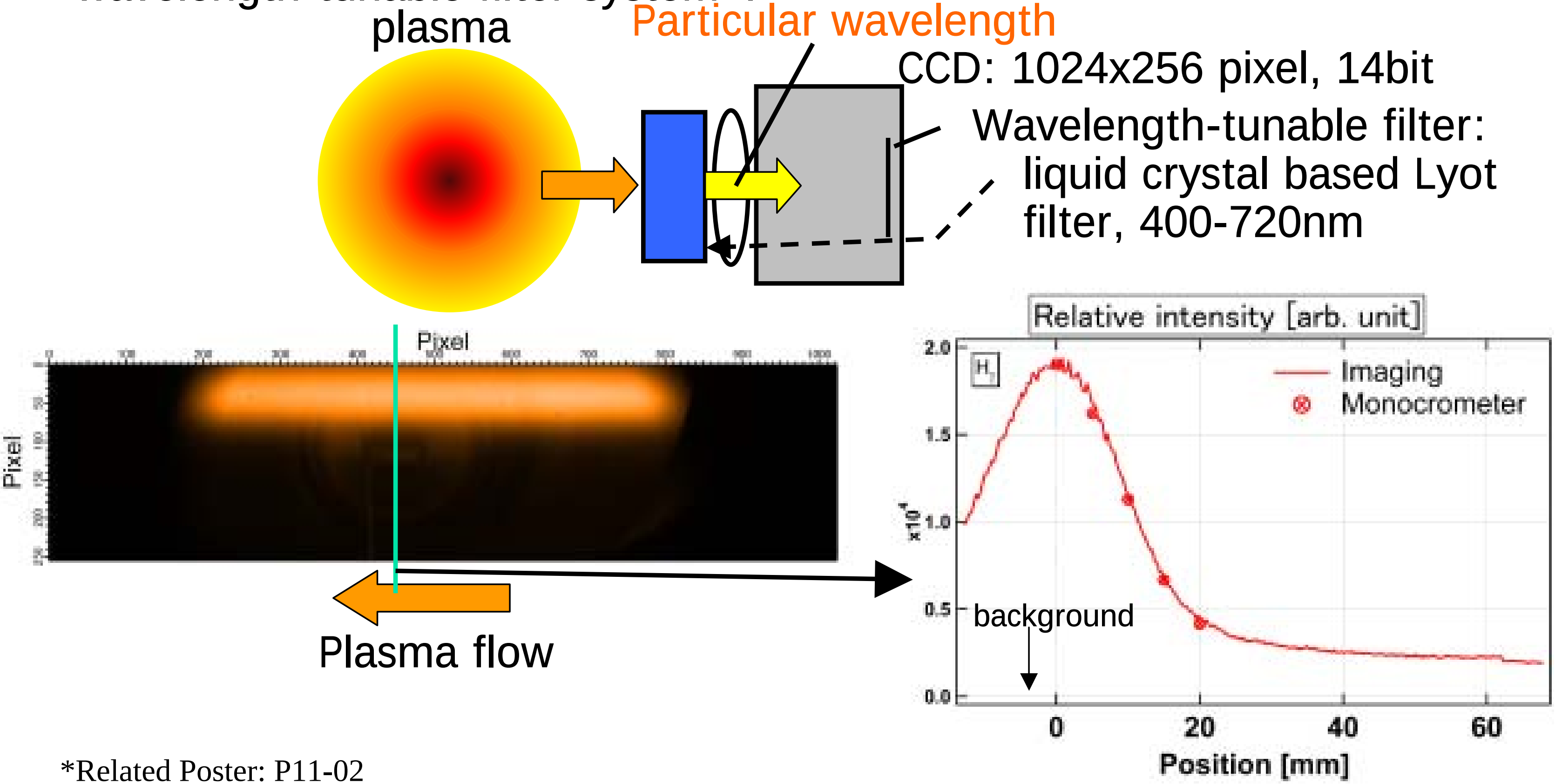
● T_e and n_e measurement: electrical probe

Abel inversion

- Observed emissions are line integrated along the viewing chord

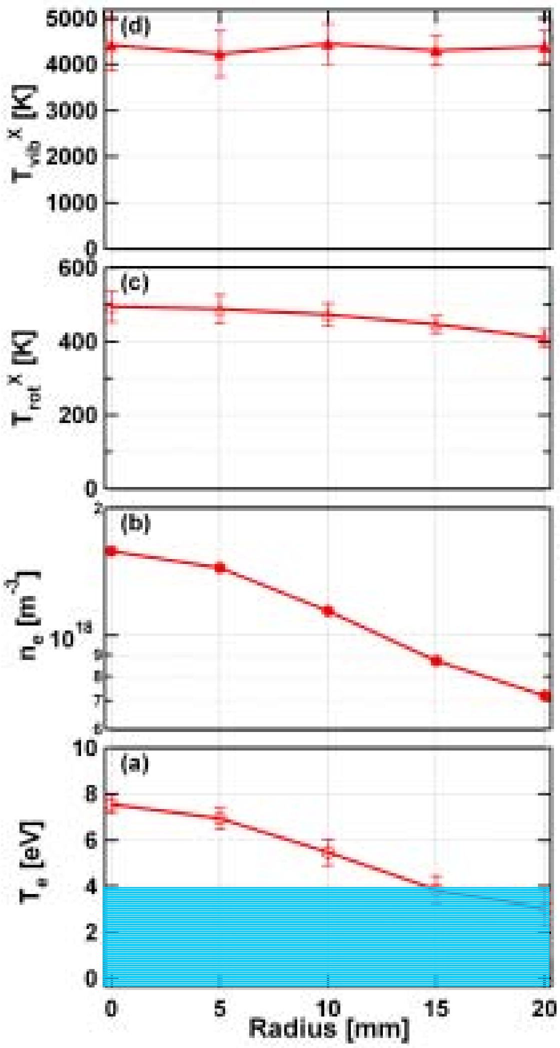
→ Abel inversion is needed to obtain the local emission at each point.

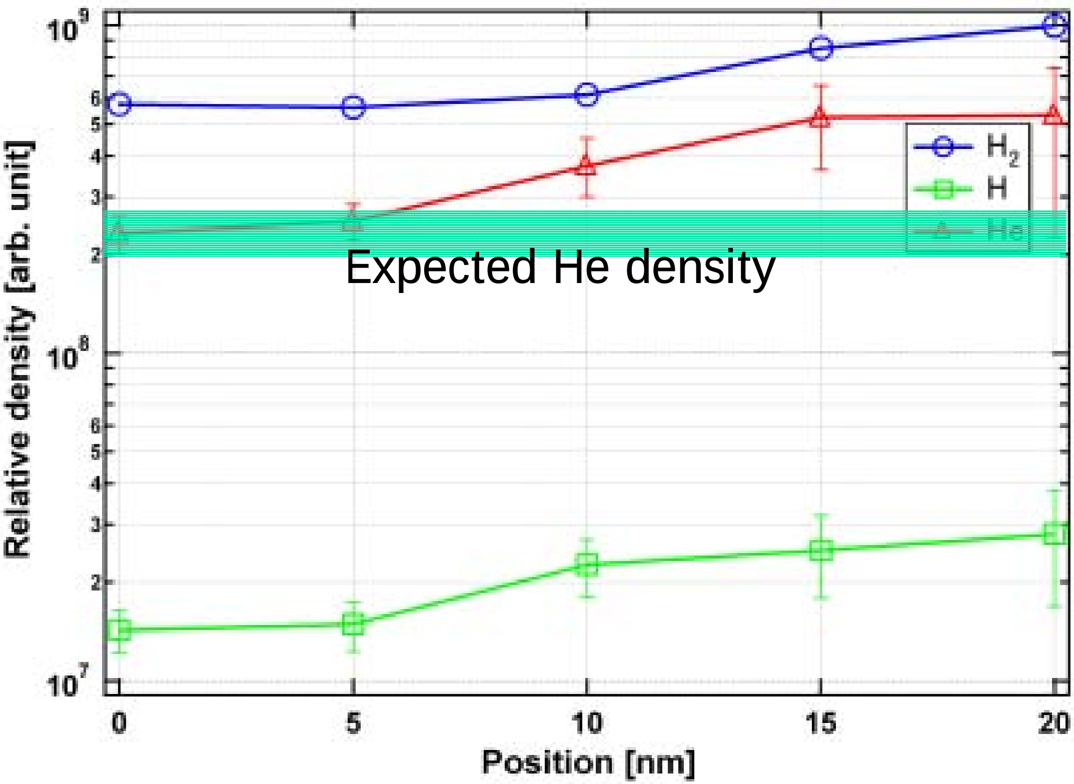
we measure the emission profile of each line by means of a CCD and wavelength-tunable filter system*.



*Related Poster: P11-02

Density profile





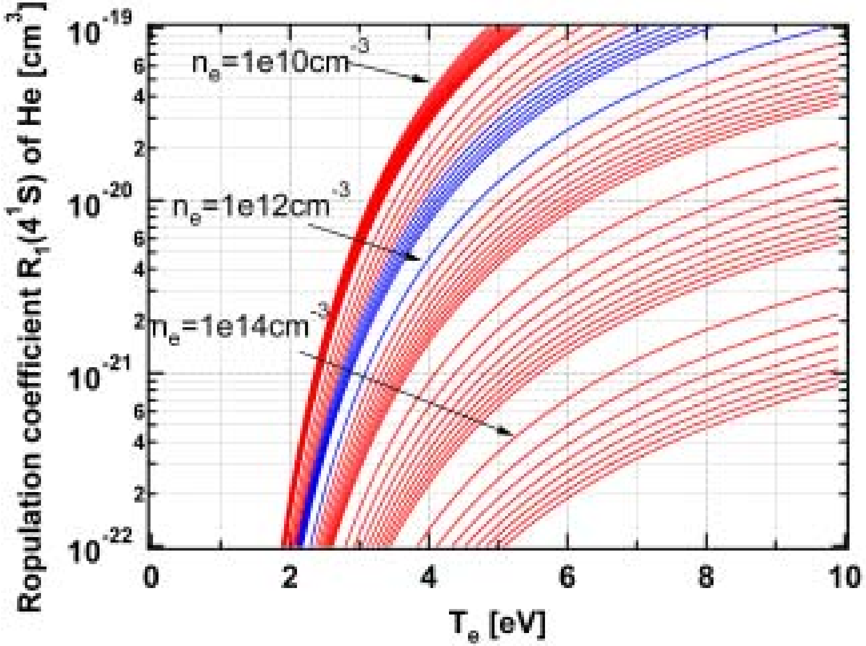
- Because the degree of ionization is assumed to be less than 10%, the density profile of He should be flat.

→In the outer region the density rises.

→The Te and ne errors can affect the density distribution.

Population coefficient of He

Population coefficient of 4^1S state of He



- For Te<4eV, the value of population coefficient greatly changes.

→An error of 0.1eV can result in 30% error of density if Te<3eV and 60% error if Te<2eV

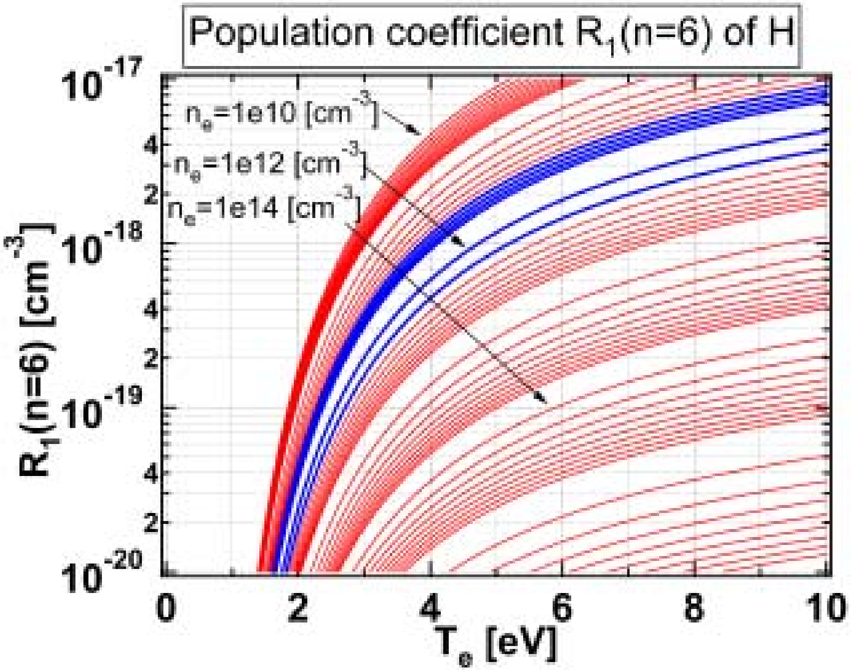
→This implies a big error in the evaluation of density for r>15.

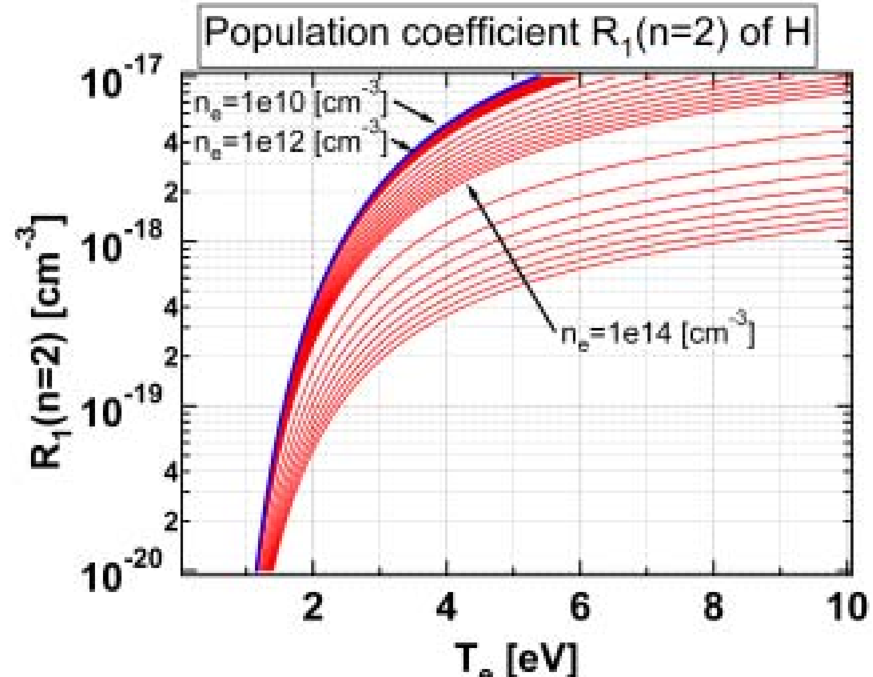
→Precise measurement of Te is need in order to obtain the density profile.

- The dependence is the same for R_1 for other levels.

**T. Fujimoto, Quant. Spectrosc. Radial. Transfer., 21 (1979) 439

Population coefficient of H





- As in the case of helium, the population coefficient changes greatly around Te<3eV.
- For n=2 level, the change of R1 is relatively slow. (especially the effect of ne error is much smaller than that of n=6 state)

→If we can use Lyman a line, the effect of Te and ne errors can be reduced.

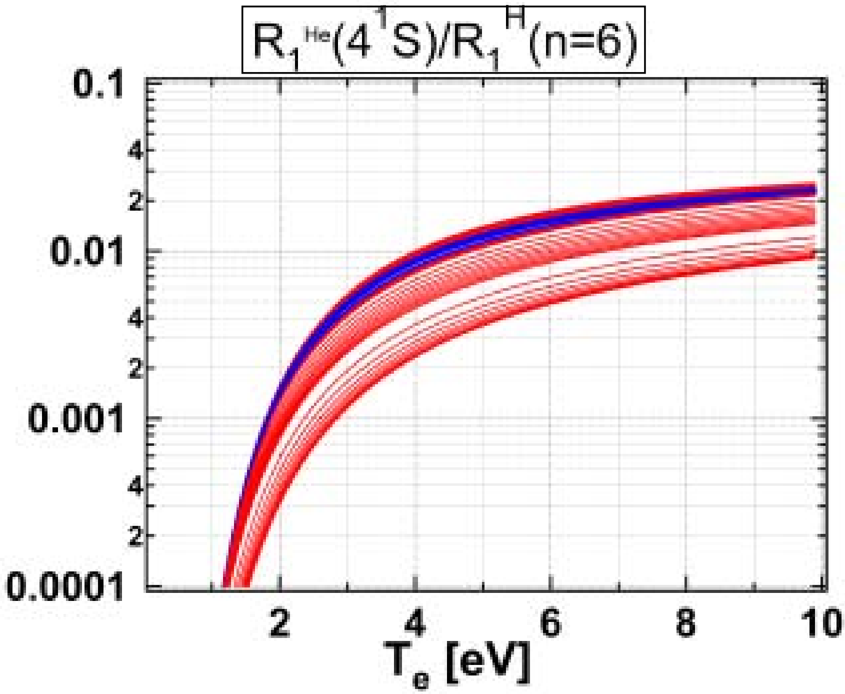
*T. Fujimoto, K. Sawada and K. Takahara, J. Appl. Phys., 66, 2315 (1989).

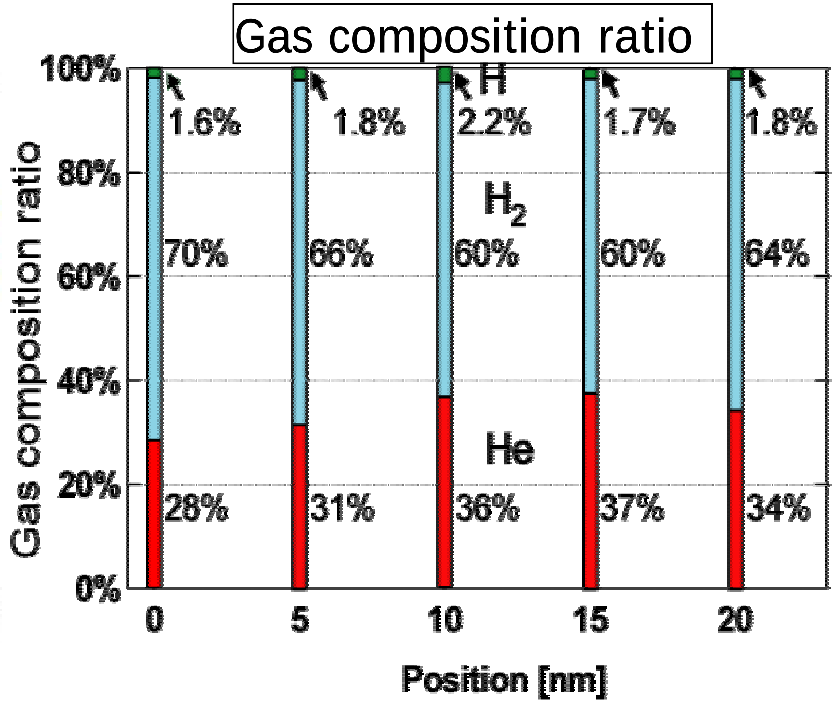
Gas composition ratio

- The region where R_1 of He and H largely change is close.

→The errors on T_e and n_e can directly affect on the density profile.
However, the effect of T_e and n_e errors on the gas composition ratio at the same position can be small because the effect of error may cancel each other.

- The effect of error is still big in the region of T_e<2.
- The obtained gas composition ratio is assumed to be within the error of several tens percent.





Summary

- We proposed a method to measure the gas composition ratio of H-He mixed plasma, and applied it to the divertor simulator MAP-II.
- The population coefficient of H and He can be largely affected by the errors on T_e and n_e.

→An error of ΔTe=0.1eV can result in 60% error on density if Te<2eV.

→A precise measurement of T_e and n_e is needed in order to measure the density profile.

- In case of gas composition ratio, the effect of errors on T_e and n_e can be reduced because they are canceled out each other.

→If Te>3, an error of ΔTe=0.1eV result in less than 10% error of gas composition ratio.

→If the density profile of a particular species can be obtained with another method like LIF, the density profile of the others can be obtained from the gas composition ratio.

Principle -effective reaction rate-

- The effective reaction rate considering the ro-vibrational structure is used.

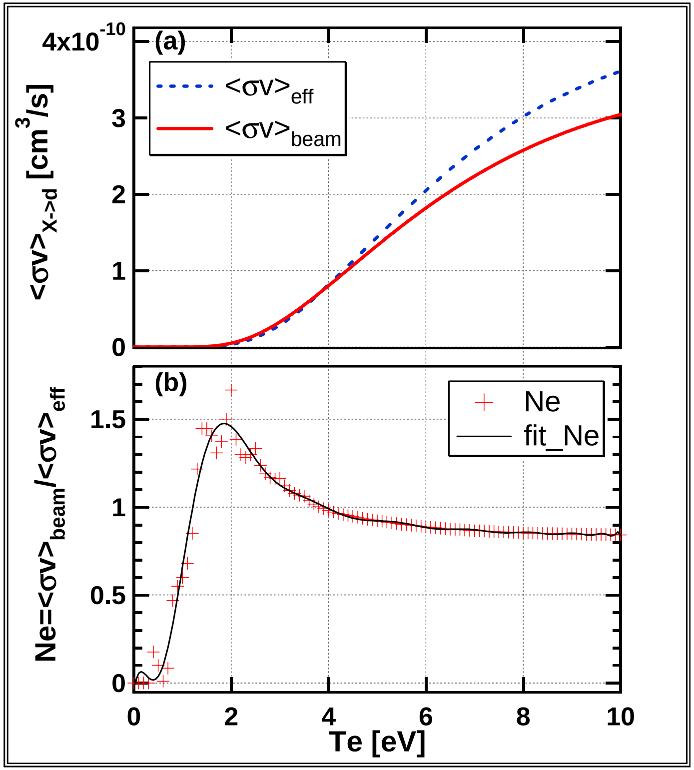
$$\left\langle R_X^d \right\rangle_{\mathrm{eff}} = \frac{\sum_{v'J'} \sum_{vJ} N_{XvJ} R_{XvJ}^{dv'J'}}{\sum_{vJ} N_{XvJ}}$$

●There is no data of reaction rate of molecular hydrogen, by using Gryzinski's semi- classical model we calculate the cross section and then obtained the reaction rate.

$$Q_{\mathrm{Gry}} = N_e \int f(\Delta E)\, d\Delta E$$

shape factor

Gryzinski's Ne factor: absolute value



●It is know that the reaction rate of Gryzinski agree with the experimental one if N_e=1.

●In order to obtained the reaction rate more precisely, we normalized the effective reaction rate calculated under the condition of beam experiment(T_{vib}=0, T_{rot}=room temp.) to the experimental reaction rate** .

→If we normalize around 10eV, N_e is 0.85. But around low temperature region it does not agree. So we obtained N_e as a function of T_e.

*M. Gryzinski, Phys. Rev., **138**, A305 (1965).
G. R. Möhlmann and F. J. De Heer, Chem. Phys. Lett., **43, 240 (1976).