# Impact of Ion Temperature on Detached Plasma in GAMMA 10/PDX Divertor Simulation Plasma

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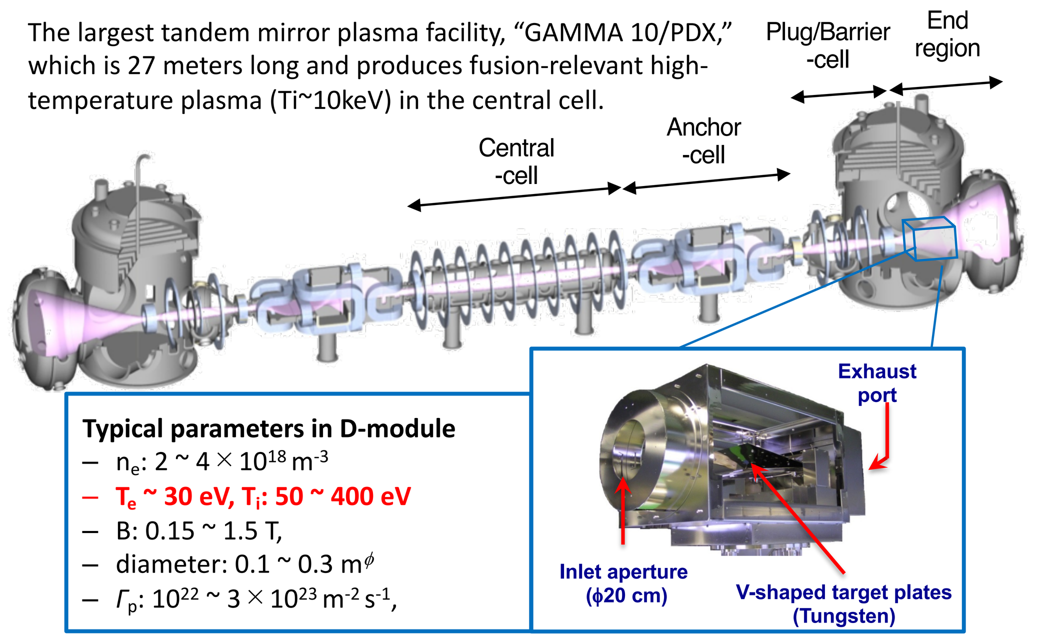
## OVERVIEW

- Plasma-gas interactions involving high-temperature ions and electrons are critical for managing heat and particle flux to the plasma-facing components of magnetic fusion devices, including ITER and a DEMO reactor. Specifically, **the effect of ion temperature ($T_i$) on the formation of detached plasma remains unclear**.
- Variations resulting from $T_i$ changes are believed to involve a change in the population of excited hydrogen atoms and a change in the excited state of the hydrogen molecule.
- Using the high-$T_i$ feature of the largest tandem mirror device, GAMMA 10/PDX, we have investigated how $T_i$ affects the processes of detached plasma formation by adjusting RF heating power.
- In the detached plasma formation experiment that results in hydrogen molecular activated recombination (MAR) [1-3], we compared the differences in detached plasma in three different diamagnetisms (DM) of the central cell, ranging from 0.1 to 0.5 x $10^{-4}$ Wb.

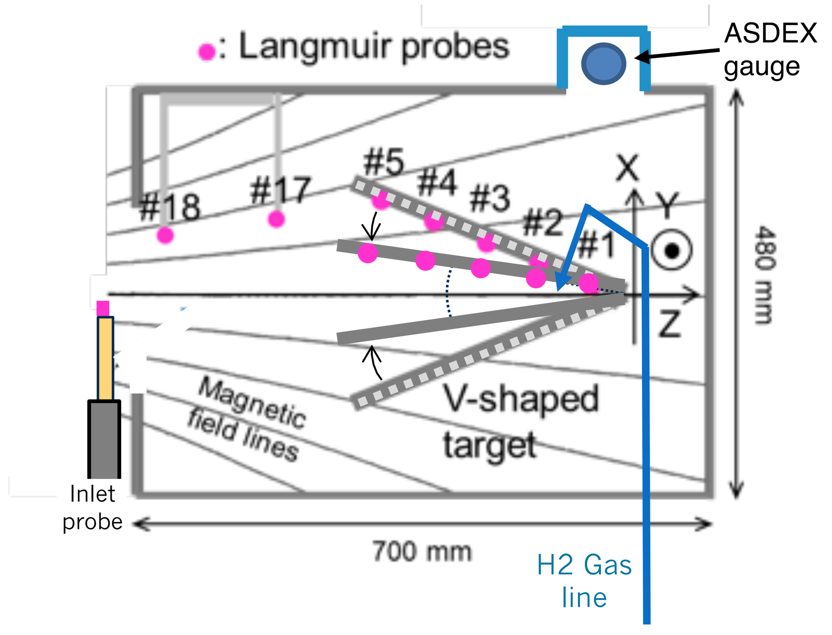


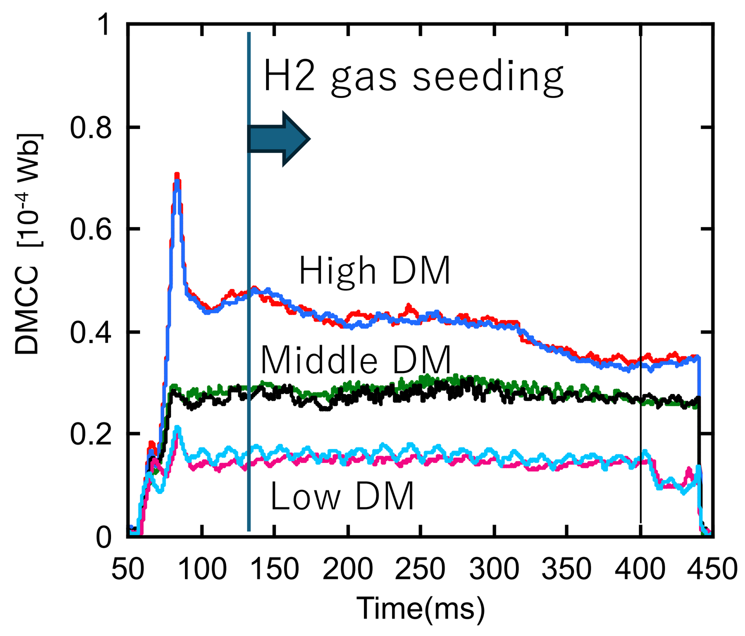

- The spatiotemporal distribution of the Balmer Hα and Hβ emission intensity ratios, observed with a high-speed camera, along with measurements from the electrostatic probe array on the target plate, indicates that **the MAR recombination region shifts downstream at higher DM, corresponding to high-$T_i$ plasmas**.

## SETUP of the Divertor simulation experiment

### GAMMA 10/PDX tandem mirror & D-module

- We observed plasma detachment caused by gas seeding in the Divertor Simulation Experimental Module (D-module), which is installed in the end region of GAMMA 10/PDX.
- The $T_i$ of entering the D-module can be changed by adjusting the diamagnetisms (DM) of upstream plasmas, which can be altered by ICRF heating applied at the central cell.
- The V-shaped target plate, equipped with a Langmuir probe array #1-5, received end-loss plasma in an open magnetic field.
- The aperture angle of the target plate was set at 15 to avoid the influence of gas seeding on the upstream region.

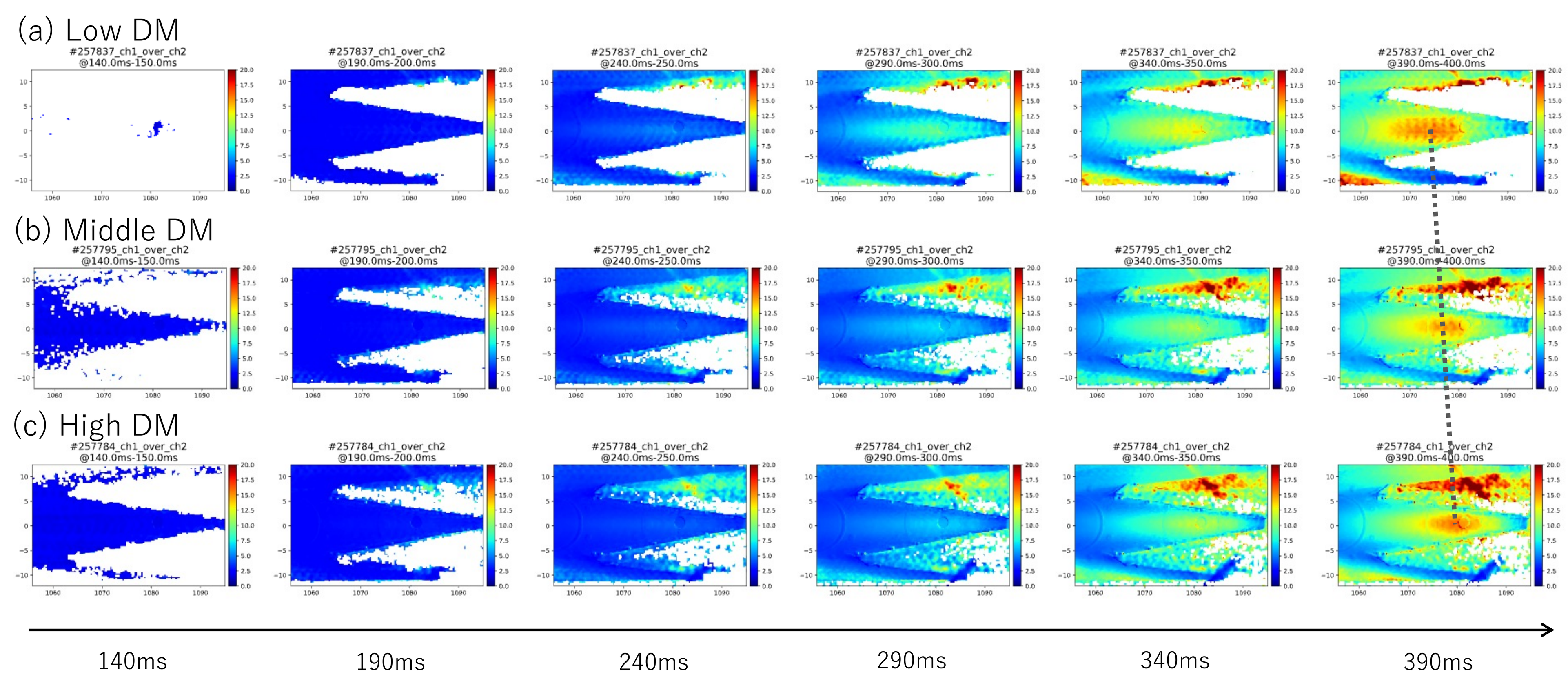



- $H_2$ gas was injected through the gas line between probes #1 and #2 on the upper target plate 130 ms after the trigger. The $P_n$ in the D-module increases to about 1 Pa.
- In this study, a high-speed camera with 4-branch optics [3], known as the "Arbaa prism [4]," was utilized to observe emissions during detached plasma operations. This system enables the simultaneous capture of the spatial distribution of Hα and Hβ. This ratio serves as a reliable indicator of **MAR** under our experimental conditions [2].

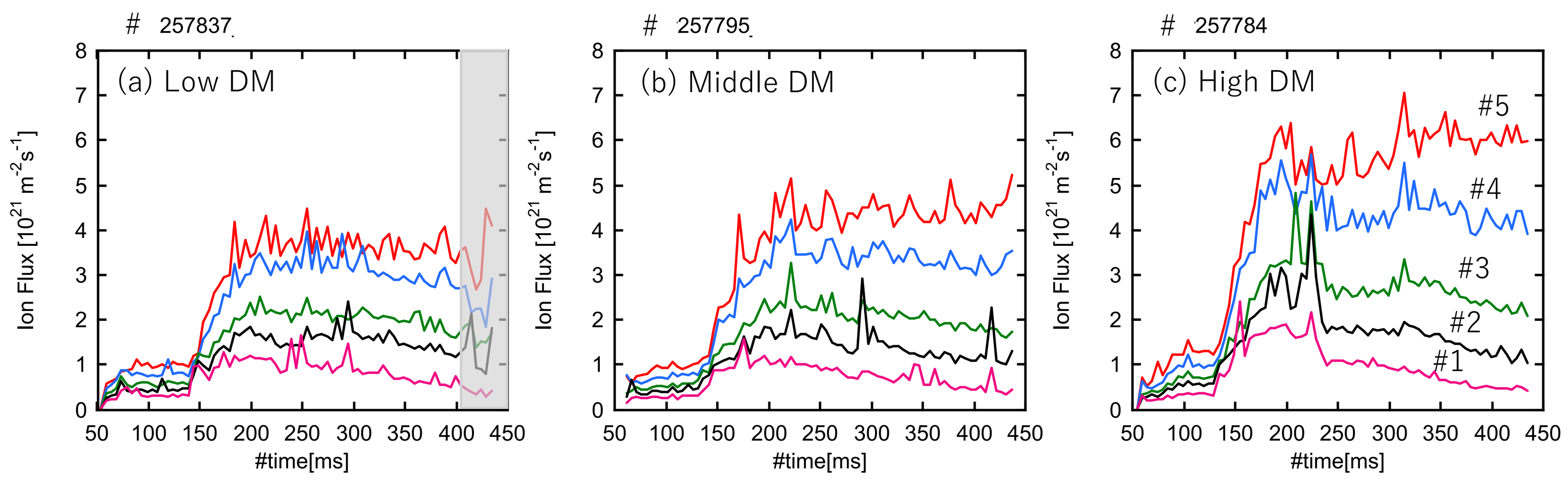
## EXPERIMENTAL RESULTS & DISCUSSION

### 1. Spatiotemporal change in Hα / Hβ in the case of (a) Low DM, (b) Middle DM, and (c) High DM.




- The lower DM indicates that the recombination region is upstream and larger, while **the higher DM corresponding to high-$T_i$ shows that the MAR region is pushed downstream.**

### 2. Time variation of ion flux measured by the electrostatic probe array on the target plate during gas injection




- The ion flux to the target plate probe indicates that it increases with gas injection upstream and then remains nearly constant, while the ion flux is reduced for the probe located downstream of the MAR region.

- The electron temperature across all DMs was 20-25 eV before gas injection.
- After gas was injected, the electron temperature decreased over time (as gas pressure increased) and dropped to about 5 eV at 350-400 ms.

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- In the high DM scenario, the increase in flux due to gas injection is significant, but the flux at downstream probe #1 decreases to a level similar to that in the low DM scenario. This is likely caused by greater momentum loss between upstream and downstream compared to the low DM case.
- The rates of reduction in flux and electron density are similar, and there is little variation in electron temperature between the probes. Therefore, recombination likely contributes to this loss of momentum. The MAR region is narrower in the higher DM scenario, but the MAR amount might be larger.
- A sharp increase in flux is observed from 150 to 250 ms immediately after gas injection. The changes are more pronounced at higher DM levels. Since such rapid changes are not seen further upstream in the divertor simulation region, this phenomenon might be unique to the interaction between high DM (high $T_i$) plasma and hydrogen gas, warranting detailed analysis.
- These results may be explained by $H^+$ related reactions in MAR, where either the MN reaction ($H^+ + H^+ \rightarrow H^+ + H^*$) in DA-MAR becomes less likely to occur, or the initial reaction in IC-MAR, $H_2(v) + H^+ \rightarrow H_2^+ + H$, becomes more probable.

**Hydrogen MAR reaction chains**

| Label | | Reaction |
|---|---|---|
| DA-MAR | DA | $H_2(v) + e \rightarrow H^- + H$ |
| --> Hα | MN | $H^- + H^+ \rightarrow H + H^*$ (n=2, 3) |
| IC-MAR | IC, CX | $H_2(v) + H^+ \rightarrow H_2^+ + H$ |
| Hα, Hβ | DR | $H_2^+ + e \rightarrow H + H^*$ (n ≥2) |
| MIC-MAR | MIC | $H_2(v) + H_2^+ \rightarrow H_3^+(v) + H$ |
| | DR | $H_3^+(v) + e \rightarrow 3H$ , $H_2(v) + H^*$ |

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