DYNAMIC EVOLUTION OF PELLET FUELING FROM ABLATION CLOUD TO REHEAT MODE IN HELIOTRON J

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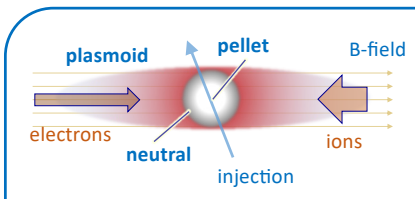
ABSTRACT

- Impact of small hydrogen **pellet injection** on plasma fueling and confinement dynamics in **Heliotron J** are investigated.
- A comprehensive diagnostic suite—including two-dimensional high-speed Stark broadening spectroscopy, event-triggered Thomson scattering, EUV spectroscopy, and AXUV detectors—was employed to characterize the ablation, homogenization, and plasma profile reconstruction (including the "reheat") phases.

Diagnostic Strategy from Ablation to Profile Recontraction



brightness, size, trajectory, penetration depth
n_e, T_e , etc.

Required diagnostics

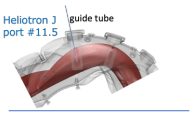
1) Ablation (~ 0.4 ms) ← Fast visible camera (trajectory,) H_α array (brightness, penetration depth) H_β Stark broadening (brightness, n_e) Balmer line ratio (Te(LTE))

2) Homogenization: (~ during/just after ablation) ← Event-triggered Thomson Scatt.

3)Plasma Profile Reconstruction (10 ~ 20 ms) ← Thomson Scatt. EUV spec. AXUV detector array Diamagnetic Energy etc.

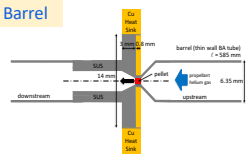
Pellet Injection in Heliotron J

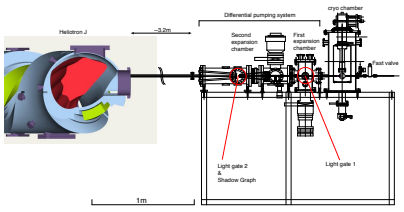
R= 1.2 m, a = 0.15 m,
B = 1.2 T
T_e < 3 keV,
T_i < 0.4 keV



N_{pellet}/N_{bulk} ~ 10

Tapered Barrel



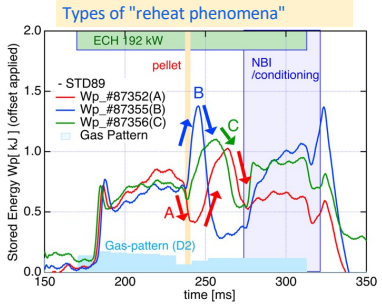


G. Motojima et al., Review of Scientific Instruments, 87, 103503 (2016).

Shadow Graph and light gate measurements show that the intact pellets have speeds of 260±30 m/s and a typical size of 1.1-1.2 mm.

Note: Recent optimal size for the injection experiment is 0.6 – 0.8 mm.

Types of "reheat phenomena"

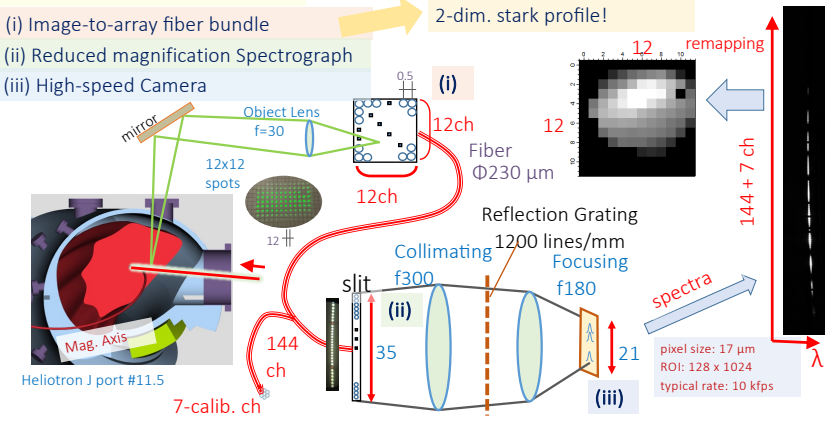


Diagnostic Suite for the Pellet Fueling Phase 1) ~ 3)

For 1) : Development of fast imaging spectroscopy

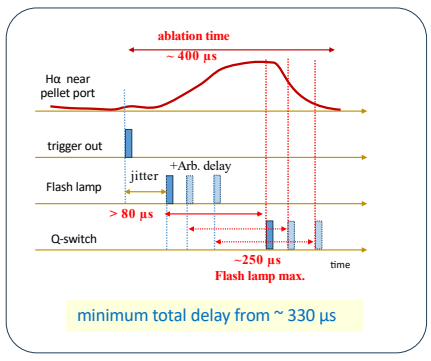
- 2D, Δλ, fast
- (i) Image-to-array fiber bundle
- (ii) Reduced magnification Spectrograph
- (iii) High-speed Camera

enabled fast observation of 2-dim. stark profile!



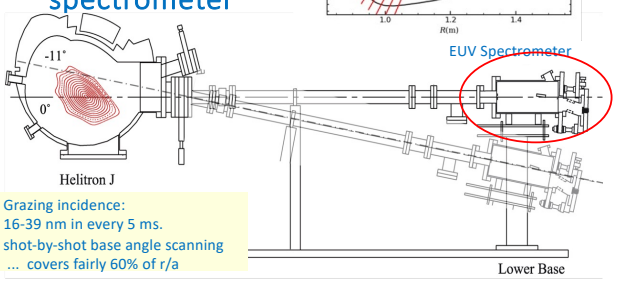
Note: near-term upgrade : 12x12 -> 16 x 17 channels

For 2) Event-triggered Thomson Scattering

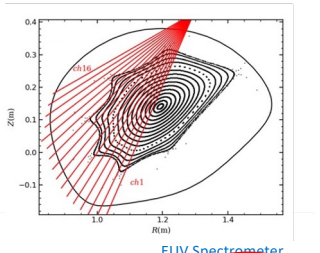


minimum total delay from ~ 330 μs

for 3) EUV spectrometer

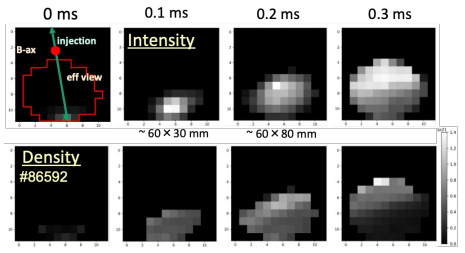


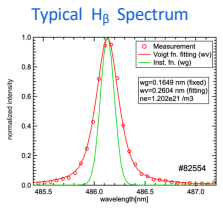
For 3) AXUV detector



Results

1) Ablation (~ 0.4 ms)

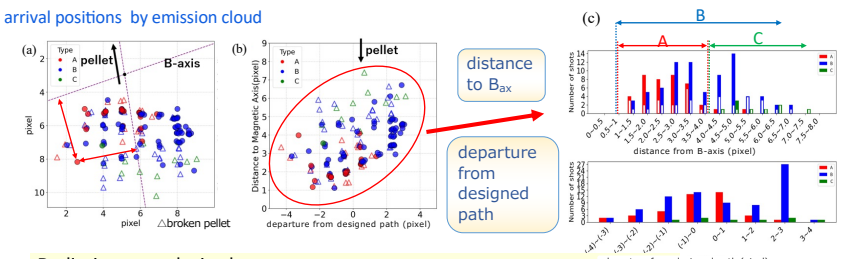




$$w_v = \frac{w_l}{2} + \sqrt{\frac{w_l^2}{4} + w_g^2}$$

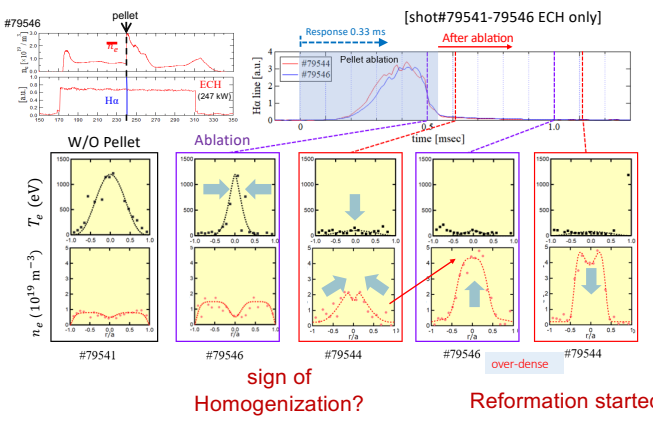
- Gaussian = inst. (fix)
- Voigt = measurement
- Lorentzian = > to determine n_e

arrival positions by emission cloud



Preliminary analysis shows:
NBI seems to depart the ablation cloud from the injection path.

2) Homogenization: (~ during/just after ablation)



sign of Homogenization?

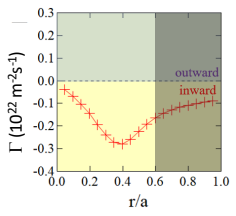
Reformation started

$$\Gamma_e(r) = -\frac{1}{r}\int_0^r \left(\frac{dn_e}{dt} - S_n\right) x dx$$

flux

0 assumed
. may broken in edge

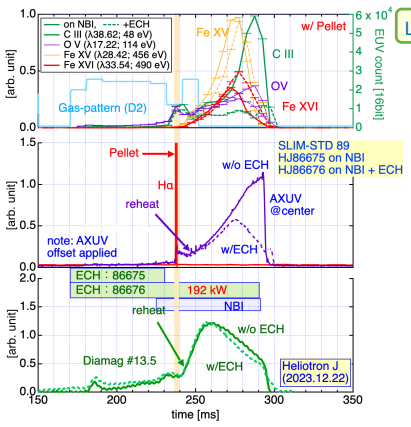
0.6 -1.0 msec after ablation started



peaking by inward flux

Matsutani+, EPS P4.043(2023).

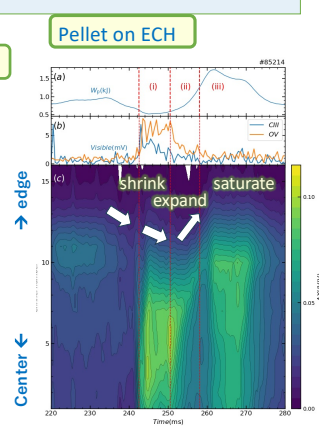
3) Plasma Profile Reconstruction (10 ~ 20 ms)



Line integral EUV in the central chord

- O V ↘, C III ↗ just after the injection is indicative of cold pulse.
- Then, radiators *tend to* shift from lower to higher charge state ions, ex. C III ↘, O V ↗ Fe XV, XVI ↗
- cooling occurs at the 2nd half of the reheat, Fe XV, XVI ↘
- ECH *seems to* act both as pumping out the highly-charged ions O V ↘ and heating of C III ↘
- Detailed mechanisms are still open question.

Pellet on ECH



K. Ogihara *et al.*, Scientific Reports, **15**, 16503 (2025).

CONCLUSION (^_-)-☆

- A diagnostics suite covering ablation, homogenization, and profile reconstruction was proposed and implemented for pellet-injected plasmas (pellet diameters 0.6–1.2 mm) in Heliotron J.
- The plasmoid (density cloud) was visualized, revealing elongation along magnetic field lines.
- We succeeded in capturing the intensity, density, and trajectory of the ablation cloud, providing a nearly complete view of the ablation process.
- The penetration path and arrival position (bright core of the neutral cloud) were identified.
- An event-triggered Thomson scattering system captured snapshots of n_e and T_e during the homogenization process.
- The temporal evolution of total radiation (AXUV) and impurity emissions (EUV) was analyzed to elucidate profile reconstruction dynamics, including the “reheat” phenomenon.

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