ID: EX/P6-27

Assessment of W density in LHD core plasmas using visible forbidden lines of highly charged W ions

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ABSTRACT

- ✓ Total tungsten (W) density in core plasmas of LHD is assessed with the measurement of visible magnetic-dipole (M1) lines emitted from W^{26+} and W^{27+} in the ground states.
- ✓ Hollow radial profile of W density in LHD core plasmas with a line-averaged n_e ~ 4×10^{19} m^{-3} and central T_e ~ 1 keV is found.
- ✓ Rapid decrease of W density in the whole core region is observed during reheat mode with elevated electron temperatures.

BACKGROUND

- ✓ W transport and its density control are key issues for ITER with W divertor, because it is well known that W has a strong radiation cooling power.
- ✓ Quantitative understanding required for predicting effects of MHD mode activity, turbulent transport, and neoclassical transport are still limited.
- ✓ Direct measurements of W cooling factors have a large uncertainty as independent measurements of total W density in plasmas are inaccurate.
- ✓ Until now, only a few direct measurements of W ion density with spectroscopic diagnostics of emission lines in the extreme-ultraviolet (EUV) range.

CHALLENGES / METHODS / IMPLEMENTATION

W pellet injection experiment at LHD

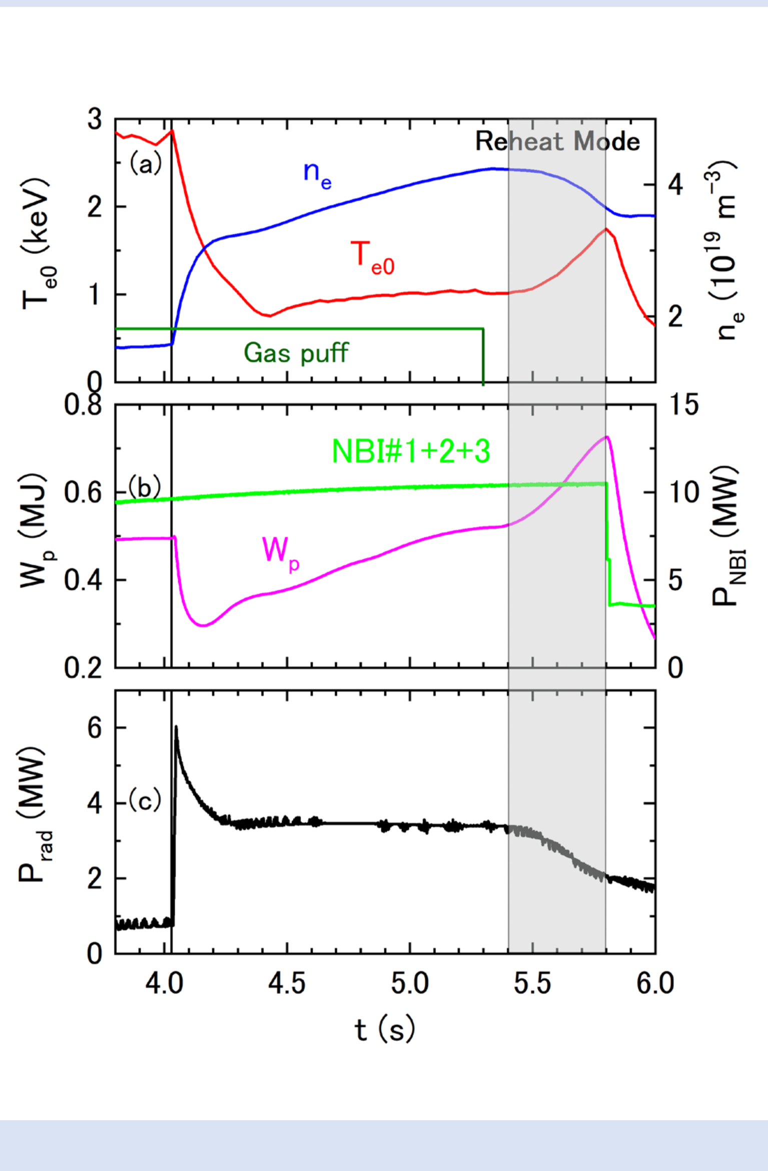
- ✓ Pellet consists of polyethylene tube containing a tungsten wire (0.6 mm long and 0.15 mm diameter, 6.8×10^{17} W/pellet) .
- ✓ Time-resolved (38 ms exposure at every 100 ms) emission spectra at 44 LOS along the vertical direction of a horizontally elongated poloidal cross section measured using a Czerny-Turner visible-UV spectrometer (grating 1200 gr/mm, slit width 50 µm).

Collisional-Radiative (CR) model for PEC of M1 line

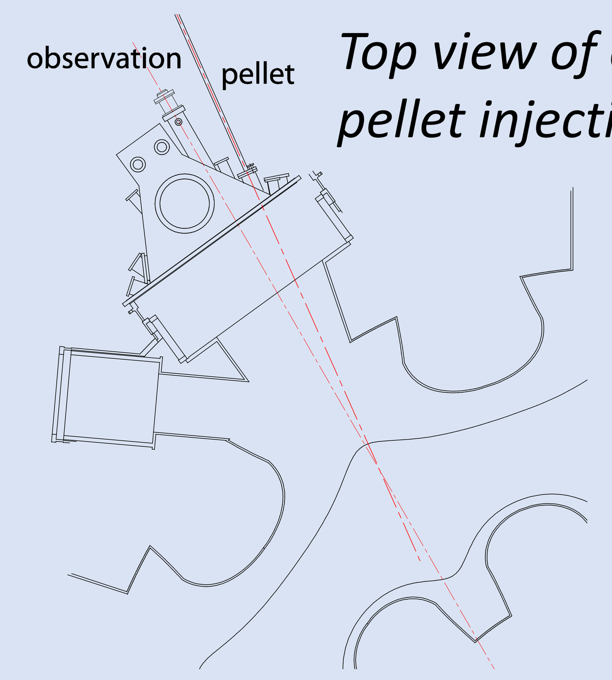
- ✓ CR model for fractional populations of excited levels $n_i^{(q)}$ of W^{q+} ions:

$$\left[\sum_{j\neq i}\left(n_e C_{ji}^{e} + n_p C_{ji}^{p}\right) + n_e S_i^{q\to q+1} + \sum_{j<i} A_{ji}\right] n_i^{(q)} = \sum_{j\neq i}\left(n_e C_{ij}^{e} + n_p C_{ij}^{p}\right) n_j^{(q)} + \sum_{j>i} A_{ij} n_j^{(q)}$$

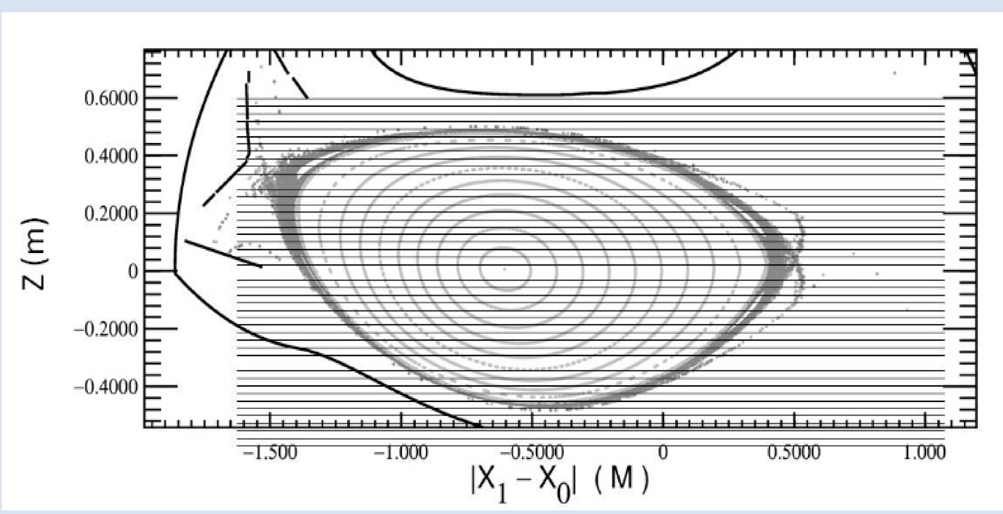
where n_e and n_p electron and proton densities, C_{ij}^{e} and C_{ij}^{p} (de-)excitation rate coefficients, $S_i^{q\to q+1}$ ionization rate coefficients, A_{ij} transition rates.



Plasma parameter in W pellet injection experiment



Top view of observation and pellet injection ports at LHD



Horizontally elongated poloidal cross section and 44 LOS viewing from the right-hand side

OUTCOME

Observation of visible M1 lines from W^{26+} and W^{27+} in LHD core plasma

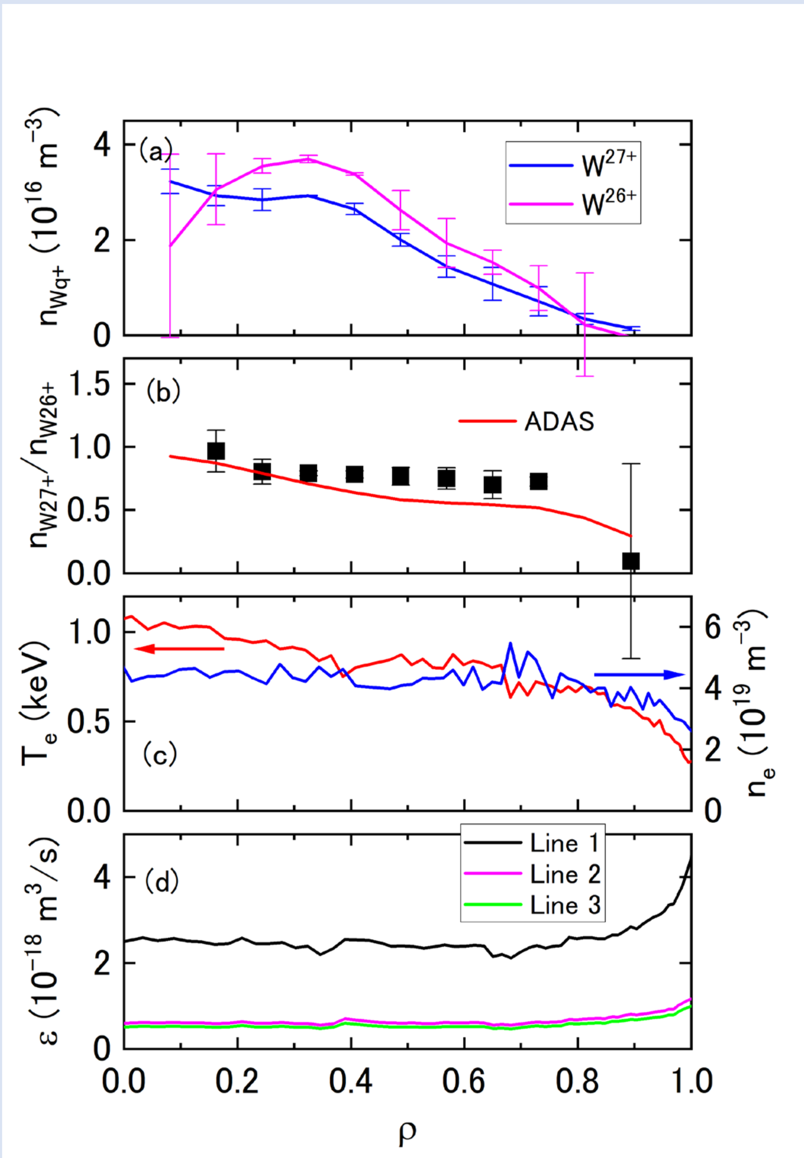
- ✓ Line 1: $4f\ ^2F_{7/2} \to\ ^2F_{5/2}$ of W^{27+} at 337.73 nm
- ✓ Line 2 and 3: $4f^2\ ^3F_4 \to\ ^1G_4$ and $^3F_4 \to\ ^3F_3$ of W^{26+} at 335.73 and 333.70 nm

Radial profiles of W^{26+} and W^{27+} densities

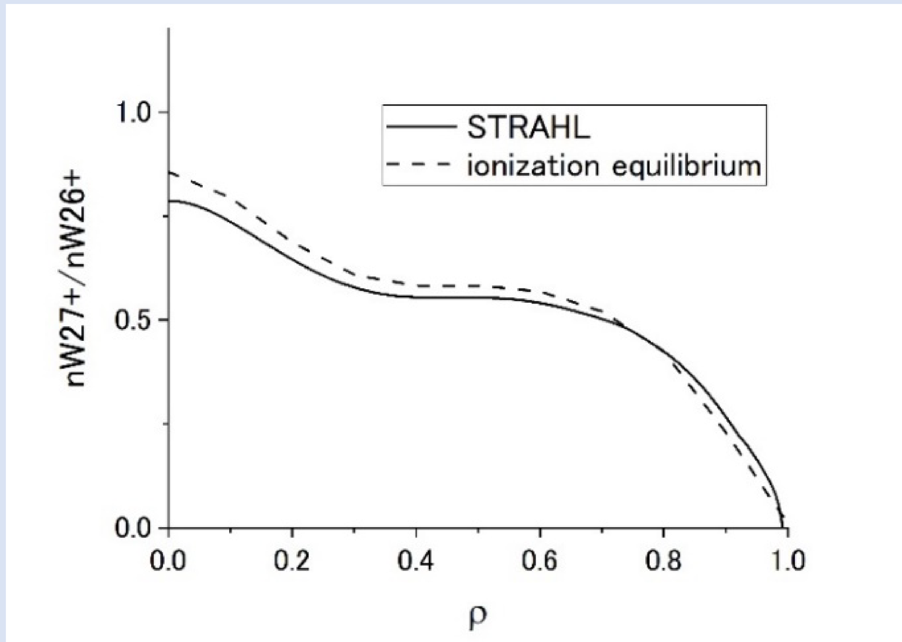
- ✓ Density ratios of W^{27+} to W^{26+} approximately agree with transport-free ionization equilibrium model. This result is validated by tungsten radial transport simulation using STRAHL code.

Radial profile of total W density

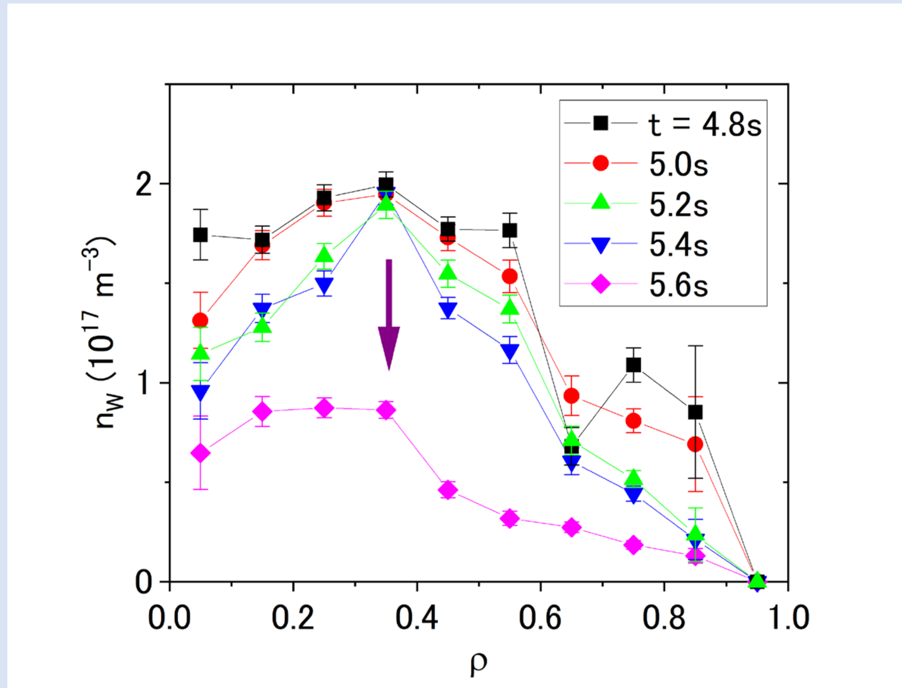
- ✓ Hollow radial profile of W density in LHD core plasmas with a line-averaged n_e ~ 4×10^{19} m^{-3} and central T_e ~ 1 keV.
- ✓ Rapid decrease of W density in the whole core region during reheat mode with elevated electron temperatures.
- ✓ Total W density obtained with the present PECs of the M1 lines is assessed to be overestimated (at least factor of 3).



Radial profiles of (a) W^{26+} and W^{27+} densities at t = 5.0 s, (b) ion abundance ratio, (c) electron temperature and electron density, and (d) PECs for Line 1 of W^{27+} and for Lines 2 and 3 of W^{26+}.



Validation of transport-free density ratio of W^{27+} to W^{26+}.



Radial profiles of total W density from t = 4.8 s at 0.2 s interval.

CONCLUSION

- ✓ Visible W M1 lines are useful for assessment of W density and quantitative understanding of W transport in core plasma.
- ✓ For precise assessment, accurate PEC calculations of the M1 lines are crucial. Further improvement of CR models for W spectra is necessary.
- ✓ Usage of W visible M1 lines at ITER has a potential advantage because mirrors and optical fibers are available to avoid direct neutron irradiation on detectors.

ACKNOWLEDGEMENTS

JSPS KAKENHI 18H01201, NIFS20KLPF075, NIFS21KLPF083, and the NINS program of Promoting Research by Networking among Institutions (grant No. 01411702)