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Characteristics of Tungsten Impurity Sources and Transport in KSTAR Plasmas

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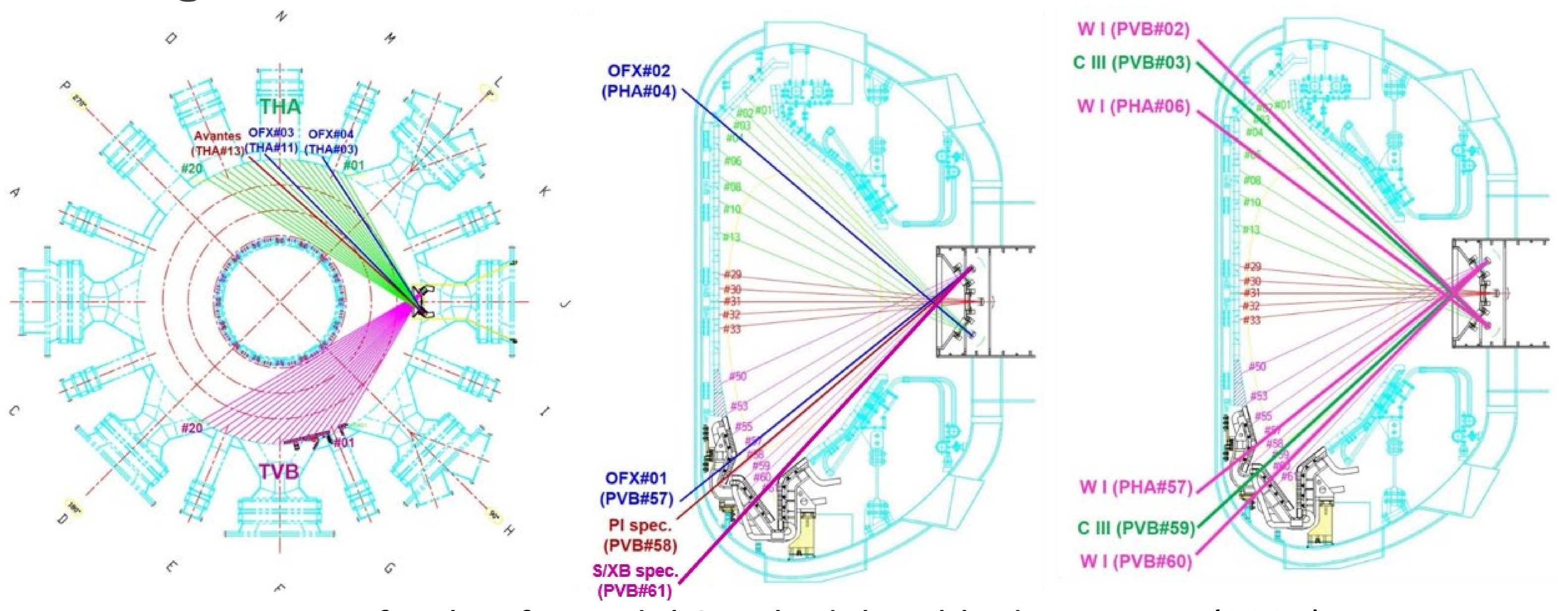
Abstract

- Tungsten (W), the divertor material for ITER, can strongly degrade plasma performance through radiative loss in plasmas. To study physics issues in tungsten sources and transport, KSTAR was upgraded with tungsten monoblock divertor cassettes in 2023.
- KSTAR diagnostics were also upgraded for W measurement, and dedicated W transport experiment in KSTAR were conducted.
- The core plasma radiation and effective charge level is increased by the tungsten impurity transported from the divertor. The core plasma radiation shows asymmetric pattern with tungsten divertor.
- Plasma configuration and plasma-target distance affect W source generation significantly. RMP-induced ELM mitigation further suppressed tungsten generation at the divertor and reduced their core accumulation. Detailed transport analysis is also planned to clarify the underlying mechanisms.
- These findings demonstrate that plasma shaping and RMP application provide control strategies for tungsten impurities in KSTAR plasmas.

Experimental Setup

Visible Diagnostics



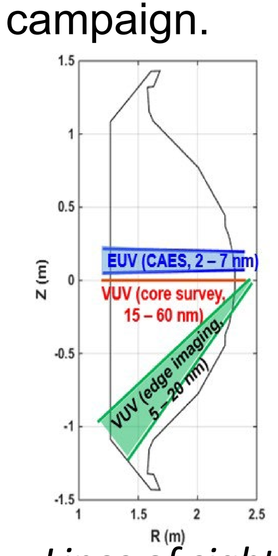
Lines of sight of toroidal & Poloidal visible diagnostics (2024)

- H_α monitor : hydrogen/deuterium line intensity at plasma edge [3]
- Visible Bremsstrahlung (VB) : bremsstrahlung radiation profile → Z_{eff} profile [4]
- **Impurity Filterscope** : some channels were modified for impurity monitoring
  - ➢ **W I line filter (400.9 nm)** was used to estimate W source from divertor.
- Visible Survey Spectroscopy (VSS) : impurity line wavelength, width, intensities
  - ➢ Avantes 1ch, OceanFX 4ch: operational in 2024
- **S/XB spectrometer** 1ch : erosion rate of W divertor target [5]
- All visible diagnostic channels have been calibrated for 2023 - 2024 campaign.

VUV & EUV spectrometers

Diagnostics	Observed impurity species	Time res.	Target wavelength
Core VUV survey #1 (PI BI-CCD)	He, C, Ne, Fe, and **W**	40.8 ms	29.0 – 51.0 nm
Core VUV survey #2 (Andor CCD with MCP) [2]	Kr and **W**	30.6 ms	12 – 32 nm
Divertor VUV imaging spectrometer	W (?)		
Compact Advanced EUV Spectrometer (CAES) [4]	B, C, N, O, Ar, and **W**	102.37 ms	1.8 – 8.3 nm

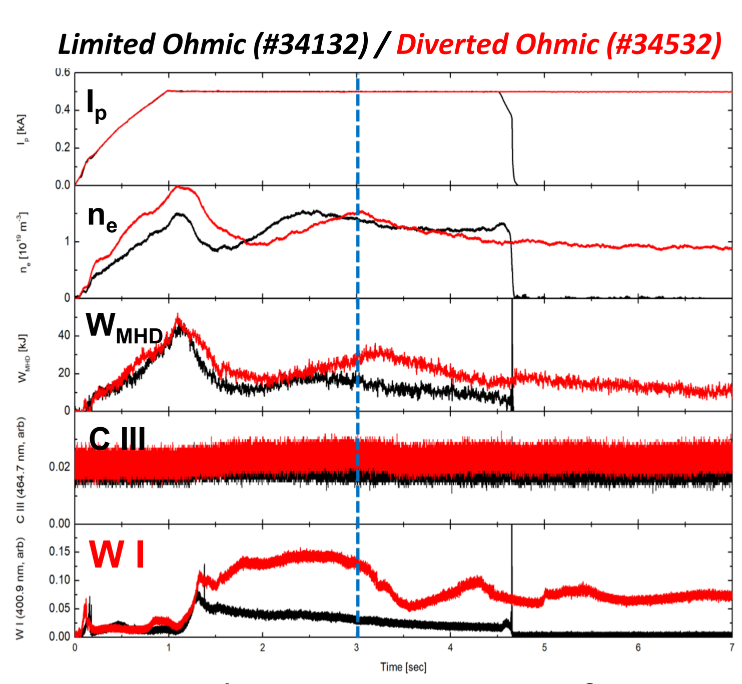
KSTAR VUV & EUV diagnostics



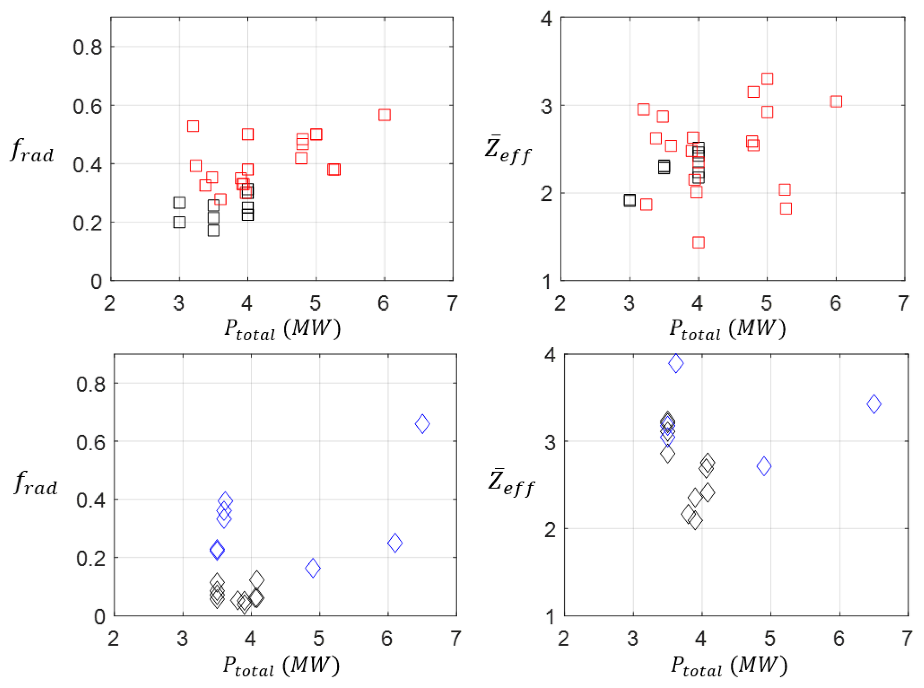
Lines of sight

- Routine updates of **VUV** and **EUV** spectral data to the MDSplus database began with the 2024 KSTAR campaign [6].
- Routine operation of **CAES**, for W spectroscopy, also began with the 2024 KSTAR campaign [7].
- Divertor VUV imaging spectrometer is under maintenance (mirror box issue).

Radiation and Zeff with Tungsten Source



Plasma parameters of Limited / Diverted Ohmic discharges



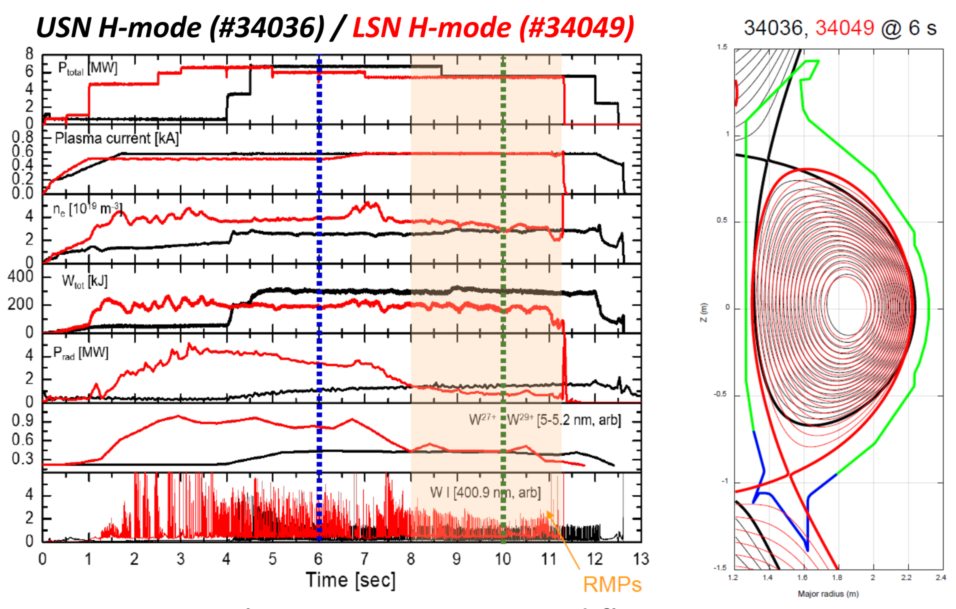
f_{rad} and $\bar{Z}_{eff}$ before / after W divertor

- □ LN H-mode with Tungsten divertor (2023)
- □ LN H-mode with Graphite divertor (2022)
- ◇ UN L-mode with Tungsten divertor (2023)
- ◇ UN L-mode with Graphite divertor (2022)

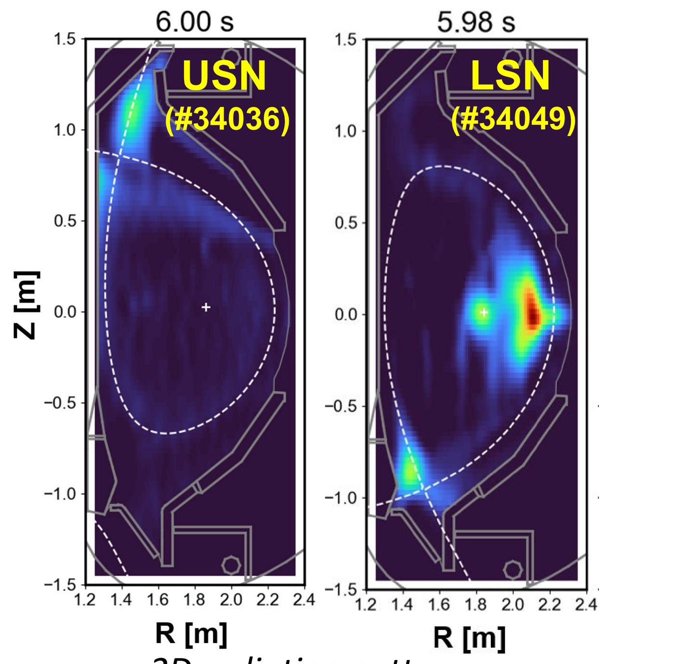
- Visible filterscope channel show that tungsten source is generated after the tungsten divertor installation.
- Radiation fraction (f_{rad}) and line-averaged effective charge ($\bar{Z}_{eff}$) were typically elevated with tungsten source from lower divertor in KSTAR.

Plasma Shape Effect on W Source & Transport

W source measurements



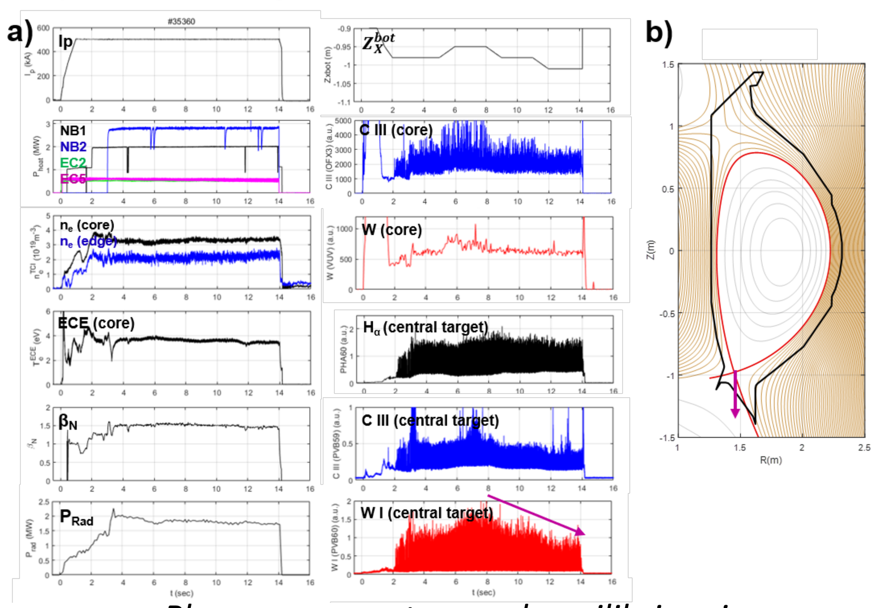
Plasma parameters and flux geometry With USN & LSN H-mode plasmas



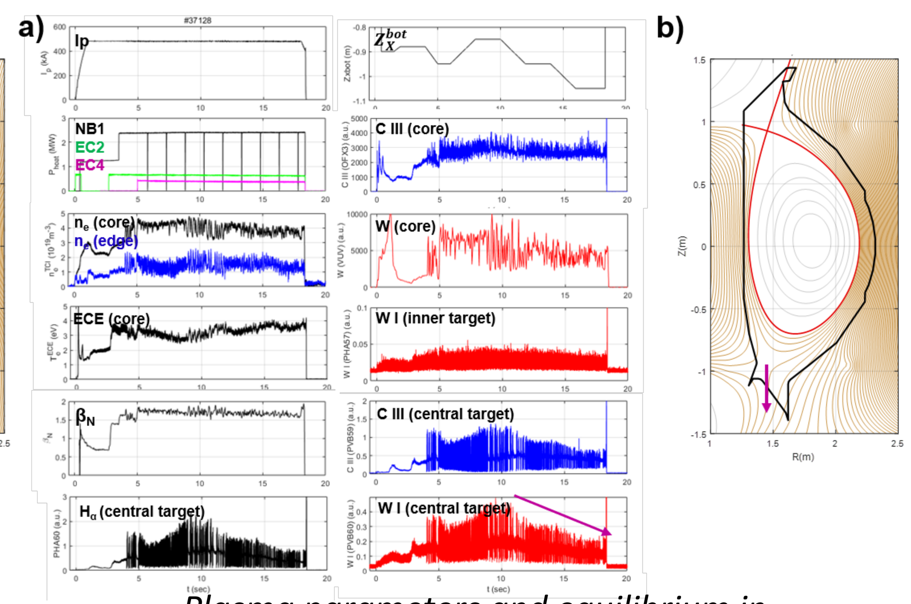
2D radiation patterns with USN & LSN configurations

- Visible filterscope (W I) showed tungsten source generated from lower divertor
- CAES showed that core W concentration (W 27+ or W29+) in LSN is much higher than that in USN → resulting in increased plasma radiation (bolometer image)
- Core W radiation pattern: off-axis due to centrifugal effects

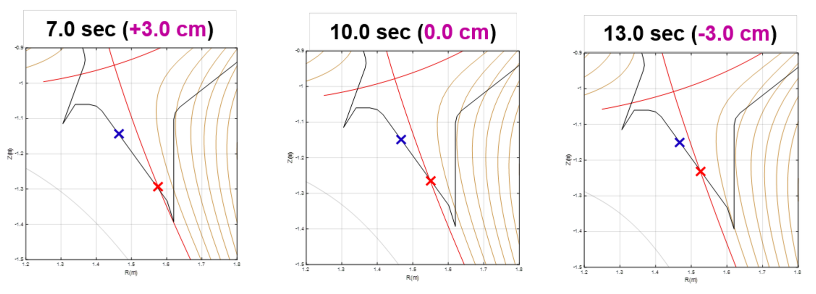
X-point height scan (2024)



Plasma parameters and equilibrium in lower X-point height scan in LSN (#35360)



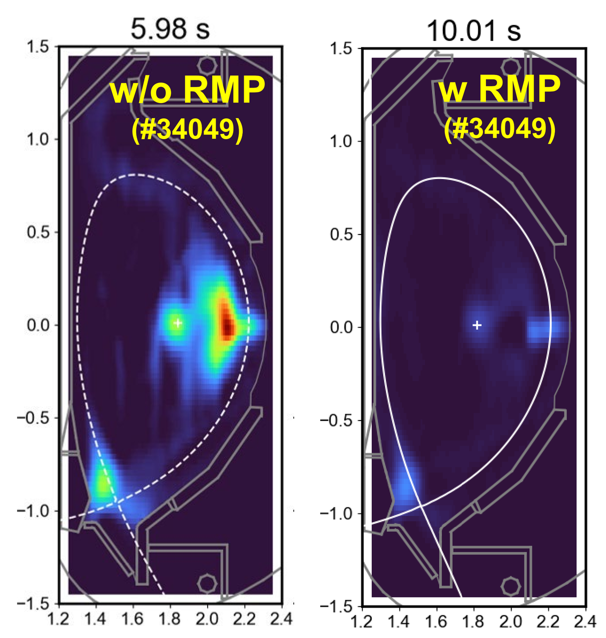
Plasma parameters and equilibrium in lower X-point height scan in USN (#37128)



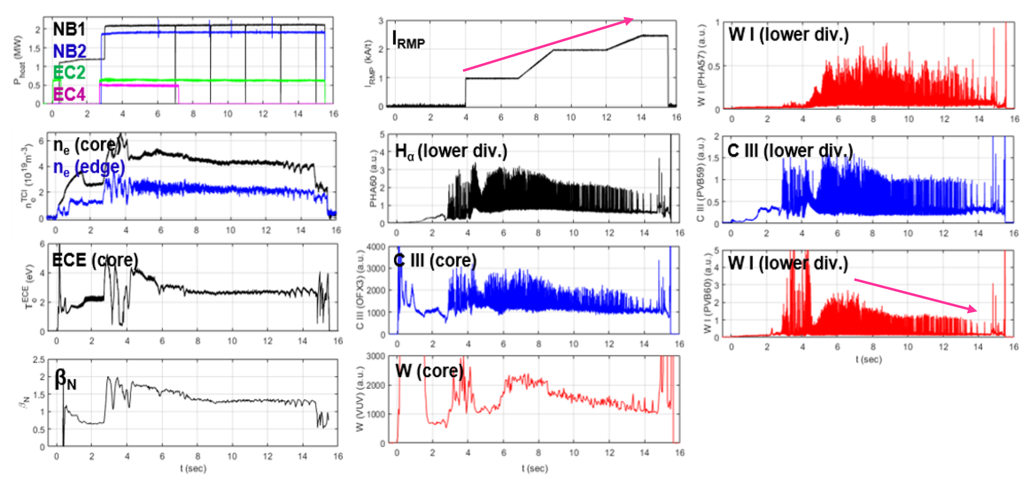
Flux geometry in LSN with X-point displacement
X : W I filterscope channel
X : outer strike point

- Lower X-point height scanned by ±3 cm in LSN / USN configurations
- Significant W source reduction with downward X-point shift observed in both LSN / USN plasmas.
- Slight reduction in core W emission also observed.
- Mechanism of W source reduction not fully understood → requires transport modeling

RMP Effect on W Source & Transport



2D radiation patterns before & during RMP (#34049)



Plasma parameters of RMP experiment (#36872, 2024 campaign)

- ELM mitigation by n=1 RMP
  - → Reduction of W source by sputtering
- Bolometer images showed that plasma radiation by W impurity reduced
- VSS and filterscope showed that W I and C III intensities reduced in both lower divertor and plasma core.

Summary & Future Works

- Visible and VUV diagnostics in KSTAR were upgraded for W transport study.
- After tungsten divertor installation in KSTAR, radiation fraction (f_{rad}) and effective charge (Z_{eff}) elevated significantly.
- Tungsten source strongly depends on plasma configuration, plasma–target distance and ELM activity.
- RMPs effectively mitigate ELMs and suppress W impurity generation.
- Future work
  - ➢ Quantitative W influx via S/XB method
  - ➢ Follow-up experiments with L-mode plasma and more W filterscope channels
  - ➢ Transport modeling with SOLEDGE3X-ERO [10]

Acknowledgements / References

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