# WP TE priorities for the He campaigns

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**On behalf of the WP TE TFL team**

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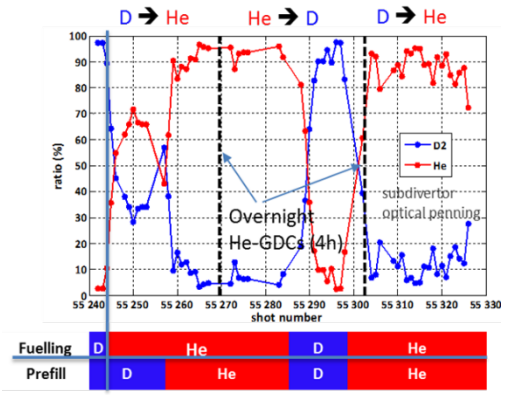
# Overview of past He campaigns: AUG, TCV, JET, and WEST

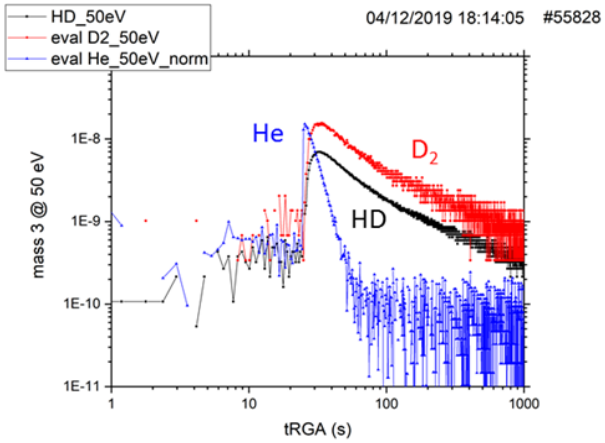
- He campaigns carried out in 2015 and 2019 on AUG, in 2015-2016 on TCV, and in 2019 (4 weeks, 17 EUROfusion sessions) on WEST
- Focus points of the campaigns
  - ✓ **AUG 2015**: ITER baseline, ELM mitigation, detachment, plasma-wall interactions (W fuzz and changeover)
  - ✓ **AUG 2019**: plasma-wall interactions (W fuzz), detachment, pedestal studies, W transport, I-mode
  - ✓ **TCV 2015-2016**: plasma-wall interactions (ECRH conditioning), SOL power widths and power loads, filamentary transport
  - ✓ **WEST 2019**: changeover between He and D in a full W device, W sources in He and interactions between He and W plasma facing components
  - ✓ **JET ILW 2020**: He pulses during diagnostics calibration and LH transitions but not a full He campaign
- **Not too many results available from the analyses**
  - ✓ Exceptions are plasma-wall interaction topics (e.g., W fuzz, changeover studies, wall conditioning) with several conference contributions and journal articles
  - ✓ For the rest, mainly Task Force Meeting talks exist

# Highlights from AUG, TCV, and WEST

- **Wall conditioning** in He (ECWC, ICWC) and changeover from D to He or He to D
  - ✓ Remaining D (respectively He) ratio quickly falls below 10% during a changeover
  - ✓ WEST: He released much faster (~50 s vs. ~700 s) than D
  - ✓ AUG: He-ICWC can be applied to result in clean plasmas with a He content of >80%
  - ✓ TCV: An optimized combination of vertical and radial magnetic fields determined for efficient ECWC and to sustain standard ohmic $D_2$ plasma




*He and D concentrations as a function of shot number for a series of D to He and He to D changeover phases*

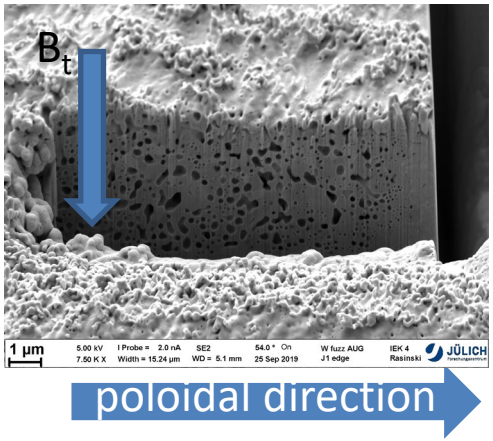


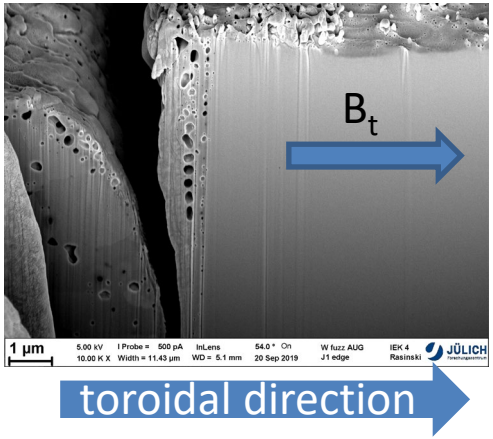

*Post pulse outgassing for He and D*

**R. Bisson et al., NME 2021**

# Highlights from AUG, TCV, and WEST

- **Erosion and W fuzz studies** in Helium
  - ✓ Sample surfaces tend to become covered with thick co-deposited layers → extra W sources in the main chamber?
  - ✓ AUG: In the absence of ICRH and boronizations, clear signs of fuzz growth and destruction observed at different distances from the strike point; **NB!** The role of Mo to be checked
  - ✓ WEST: Significant He trapping during the discharges but conditions only marginally favorable for fuzz formation
  - ✓ WEST: W source in He is a factor of two lower than in D and clear inner/outer divertor asymmetry observed



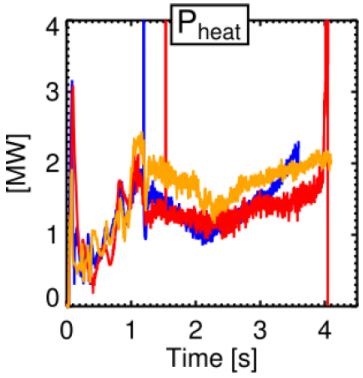



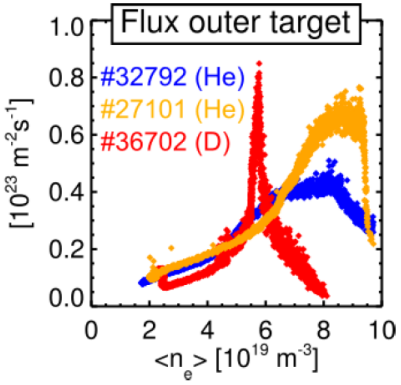

**S. Brezinsek et al., ITPA DiVSOL 28.06.2021**

# Highlights from AUG, TCV, and WEST

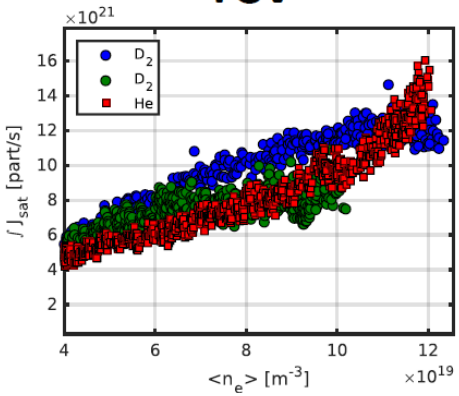
- **Detachment** in He plasmas
  - ✓ High detachment threshold observed on AUG compared to D → role of molecules!?
  - ✓ No roll-over seen on TCV and low radiated fraction may indicate less C impurities!?

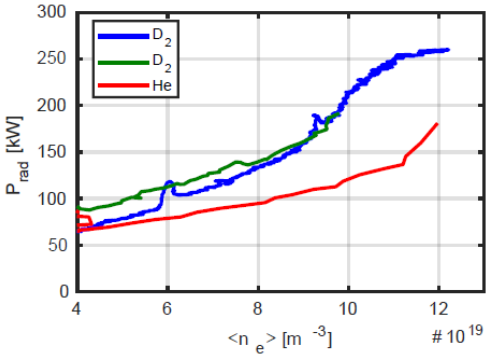
**AUG**




**TCV**




**S. Henderson et al., MST1 TFM 09.11.2020**

- **ELM characteristics and mitigation**
  - ✓ Substantial effort made to create a target plasma with sufficiently large ELMs and then try to mitigate them using RMPs (AUG): H NBI, small He puff rate & Ar frosting
  - ✓ A moderate mitigating effect (factor 3 energy loss) found at $q_{95}$~3.7, no significant moderation at $q_{95}$~4.2, and no ELM suppression
  - ✓ Outlook: With moderate shaping one could try to fully suppress ELMs at $q_{95}$~3.7

# Highlights from JET

- **NB!** The He mini campaigns very limited in scope and volume – and no He beams used
- **L-H transition power thresholds**
  - ✓ Density minimum for the L-H power threshold significantly higher (>50%) in He than in D in JET-ILW → different from AUG results!?
  - ✓ Indicated little benefit in terms of H-mode access to operate in He!?
- **W erosion in JET-ILW** in He plasmas
  - ✓ Erosion during ELMs dominates the total W source in D and He plasmas
  - ✓ Intra-ELM sputtering in He plasmas prevails by a factor of 4 over inter-ELM sputtering
  - ✓ In He plasmas, Be erosion on the first wall enhanced
  - ✓ Large in/out asymmetry of the intra-ELM W sources in He plasmas (see also WEST results)

# New He campaigns under WPTE

- Due to the interesting past results but still limited database, He campaigns are foreseen in 2022
  - ✓ AUG: the **last two weeks of July**
  - ✓ JET: a 3-month period, **tentatively from July to September + selected C42 experiments** (clean-up campaign after DT and TT where He plasmas foreseen)
- Main goals of the He campaigns:
  - ✓ Provide **feedback to ITER** for planning the PFPO operational phase
    - Develop scenarios for He plasmas with low D and H contents
    - Explore H-mode operations and ELM control in He
    - Assess detachment characteristics in He compared to H or D plasmas
    - Characterize key plasma-wall interaction phenomena in He
  - ✓ Perform **experiments in multiple devices** for better understanding of the underlying physics
- Campaigns in WPTE devices have the following **high-level scientific objectives**
  - ✓ Access H-mode in He
  - ✓ Mitigate risks related to transients (e.g., disruptions) and suppress ELMs
  - ✓ Understand tranport phenomena and impurity behaviour in He
  - ✓ Operate with a radiative divertor and control heat loads in He
  - ✓ Select proper operational domain to ensure sufficient divertor and limiter lifetime

# Set-up for the campaigns

- The TFLs have assessed the needs for He campaigns on AUG and JET based on the **outcomes of two dedicated Task Force meetings** (19 and 26 July, 2021)
  - ✓ Headlines with priorities (Priority 1, 2, 3) identified for guiding the community
- Next step will be transferring the list on the following slides into a **Call for Proposals to be launched in December**
- **Boundary conditions**
  - ✓ Limitations to the NBI operation
    - Only H beams foreseen on AUG
    - Power limited to ~14 MW on JET with He NBI
    - Still under discussion if He beams will be used on JET and if yes for how long
  - ✓ Low density operations challenging due to pumping capabilities
    - However, Ar frosting can be applied at least on JET
  - ✓ $T_i$ measurements a known issue → can be addressed by injection of impurities on AUG
  - ✓ Plasma-wall interaction studies with the divertor manipulator block an entire day on AUG
  - ✓ Tile removal next to impossible after the He campaign on JET
  - ✓ Clean-up in the end of operations required (incl. beam boxes), especially on JET

# Priority 1 headlines

| Priority 1 - Headline | WP TE comments | IRP category (ITER) | Devices |
|---|---|---|---|
| Clarifying the LH power threshold and development of ELMy H-mode scenario in He | • AUG-JET comparison high on the agenda<br>• Investigations in wave-heated plasmas to maximize ITER relevance<br>• Would include impact of seeding on He confinement (AUG mainly) | Cat 1 | AUG<br>JET |
| Characterization of ELMs and their control with 3D fields in He | • Essential to test the efficiency of RMPs in the presence of ELMs<br>• Can be combined with W sputtering investigations via piggy back | Cat 1 | AUG |
| Understanding detachment threshold and SOL transport in He | • Present database very scarce<br>• Includes studies related to broadening of the heat-flux profiles on the targets | Cat 2 | AUG<br>JET |
| Plasma-wall interaction studies in He | • Formation of W fuzz and modification of PFC surfaces, incl. recrystallization<br>• Main-chamber vs. divertor erosion, comparison between He and D<br>• Sputtering during and in-between ELMs<br>• Retention with available diagnostics | Cat 1 & Cat 2 | AUG<br>JET* |

Addressing successfully (most of) the Headlines above requires **achieving a robust ELMy H-mode scenario in He**

* No sample removal possible

# Priority 1 headlines

| Priority 1 - Headline | AUG relative share* | JET relative share** | JET relative share - requiring He beams |
|---|---|---|---|
| Clarifying the LH power threshold and development of ELMy H-mode scenario in He | 25%/8 shots | 30%/min 15 sessions | Min 15 sessions |
| Characterization of ELMs and their control with 3D fields in He | 19%/6 shots | N/A | N/A |
| Understanding detachment threshold and SOL transport in He | 19%/6 shots | 10%/min 5 sessions | Min 3 sessions*** |
| Plasma-wall interaction studies in He | 25%/8 shots | 30%/min 20 sessions | Min 15 sessions |

* Assuming 40 shots over the course of 2 weeks and 20% contingency (of the absolute share)

** Assuming 10 sessions/week, on average 7 good pulses/session, and ~100 sessions for the campaign

*** Exact number can only de determined following the Call for Proposals

- Approximately 2/3 of the JET experiments under the headlines would require He beams and 1/3 would greatly benefit from He beams
- Minimum reasonable program at JET would correspond to ~2 month-long He campaign to meet the high-level objectives (~60 sessions + contingency)

# Priority 2 and 3 headlines

| Priority 2 - Headline | WP TE comments | IRP category | Device |
|---|---|---|---|
| Determining fuelling efficiency in He | • Would require extensive modelling and mining of old data<br>• Need to be combined with interpretative SOL modelling | Cat 2 | AUG<br>JET |
| Main-ion and impurity transport in He | • Can be largely done piggy back or during dedicated phases of the discharges | Cat 2 | AUG<br>JET |

| Priority 3 - Headline | WP TE comments | IRP category | Device |
|---|---|---|---|
| Fast-ion studies in He | • Largely piggy back studies by using FILD and FIDA during other discharges<br>• Scope of JET program TBD following the Call for Proposals | Cat 3 | AUG<br>JET |
| Changeover from D to He and He to D | • Extensive database already collected in the past on AUG and WEST → this exercise would consume a large number of plasma time<br>• Main issue is to ensure the presence of the key diagnostics team on-site<br>• On JET, would contribute to machine clean-up | Cat 3 | (AUG)*<br>JET |

* Only piggy back

# Priority 2 and 3 headlines

| Priority 2 - Headline | AUG relative share* | JET relative share** | JET relative share - requiring He beams |
|---|---|---|---|
| Determining fuelling efficiency in He | 6%/2 shots | 5%/min 4 sessions | Min 2 sessions*** |
| Main-ion and impurity transport in He | 6%/ 2 shots | 5%/min 4 sessions | Min 0 sessions |
| **Priority 3 - Headline** | **AUG relative share*** | **JET relative share** | **JET relative share - requiring He beams** |
| Fast-ion studies in He | 0% | 5%/min 4 sessions | Min 2 sessions*** |
| Changeover from D to He and He to D | 0% | 5%/min 4 sessions | Min 2 sessions |
| **Others** | **AUG relative share*** | **JET relative share** | **JET relative share - requiring He beams** |
| Outstanding ideas | From contingency | 10%/min 4 sessions | Min 2 sessions*** |

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