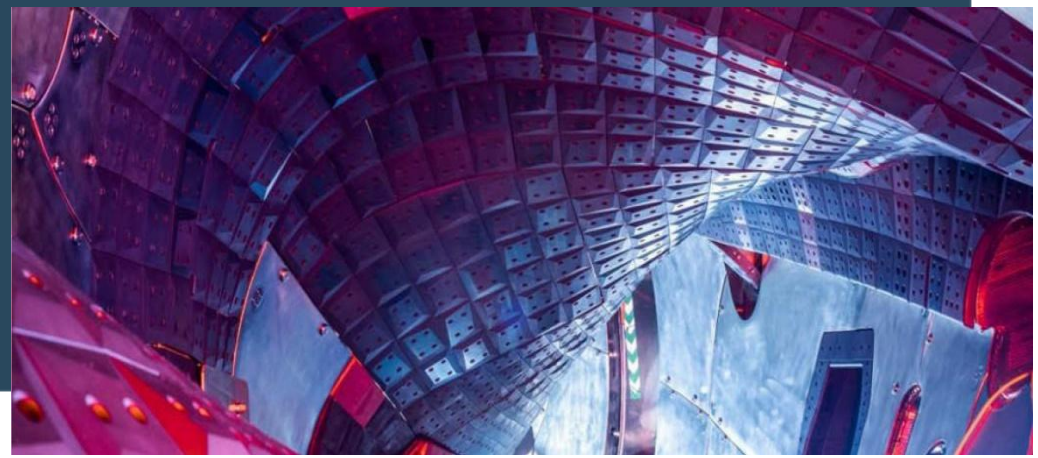
MAX-PLANCK-INSTITUT
FÜR PLASMAPHYSIK

Machine report: W7-X Core Transport after OP2.3

Wendelstein 7-X

D. Carralero, on behalf of the W7-X team



EUROfusion

This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

Outline

- Core physics highlights
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- Low fie
  - *A re*
- High pe
  - *Full*
  - *High performance regimes*

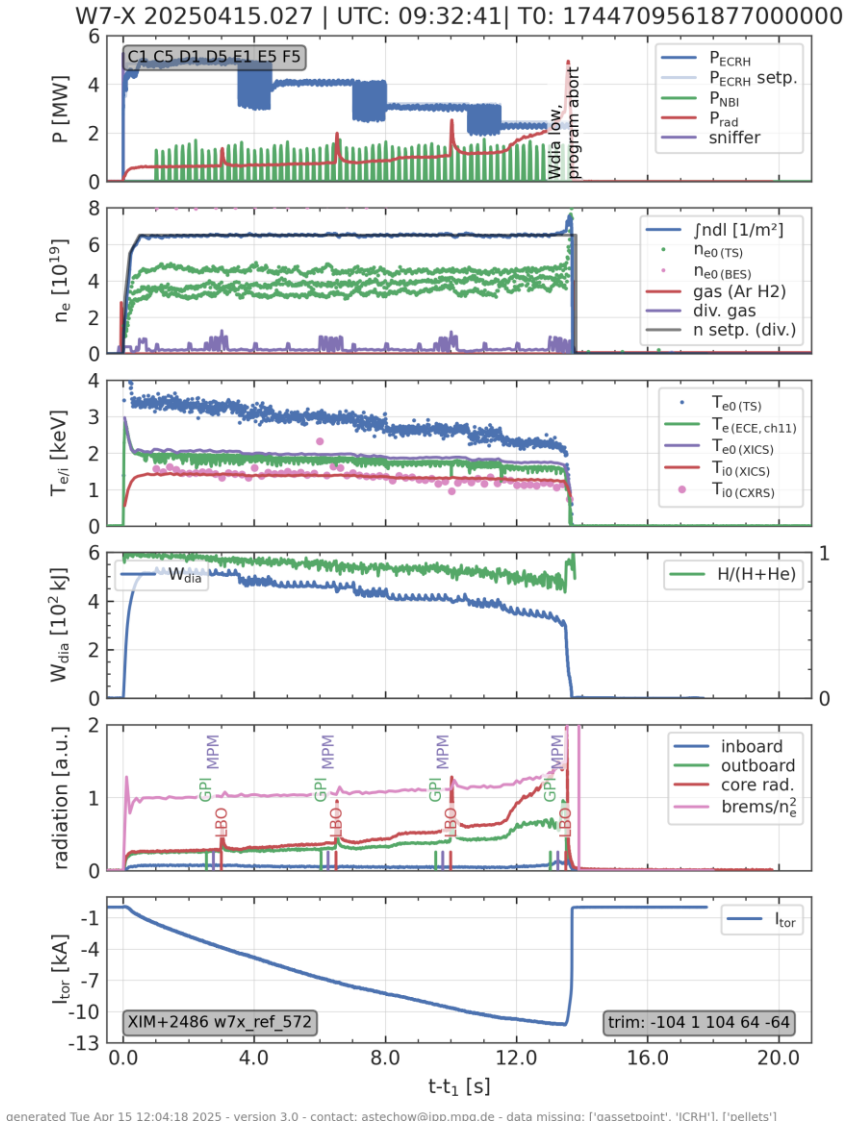
Important disclaimer:

The OP2.3 campaign ended just two weeks ago:

- All presented results are still preliminary and intended as an update for CWGM purposes.
- Please, do not distribute outside this meeting.

Magnetic configuration space has been systematically explored

- 15 “Umbrella” sessions have been carried out over a large fraction of the operational space of W7-X.
- These sessions are a refinement of OP2.1 power step downs and covered achievable power and densities under most frequent configurations.
- These programs have also been used as reference in new scenarios outside of umbrella sessions (low field, shear scan, etc.).
- While sometimes resulting in complex programs, this approach achieves a high efficiency in the use of W7-X machine time (in terms of proposals covered per shot).



Highlights of the umbrella program

- A large database of equivalent discharges has been created, providing a standardized reference for inter-configuration studies.
- Thanks to the standardized approach, the impact of configuration parameters can be separately evaluated.

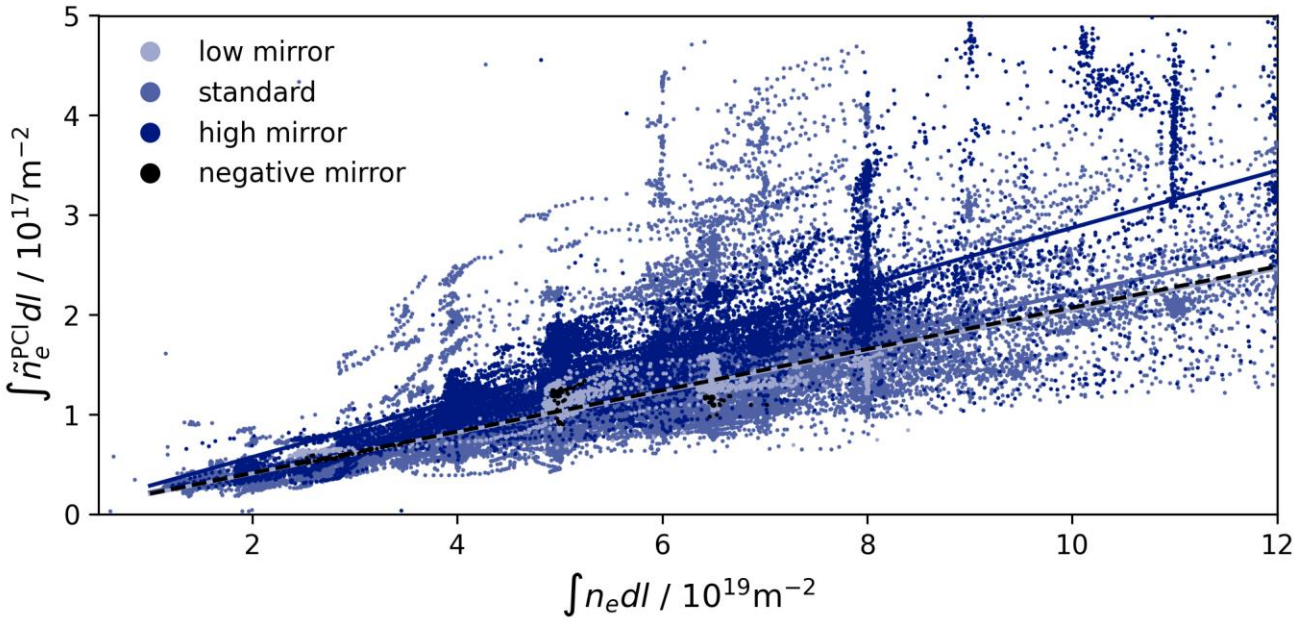
Some preliminary results:

- PCI data indicates that, contrary to expectations, no major enhancement of turbulence appears with low or negative mirror.
- A dedicated scan indicates ITG stabilization with magnetic shear (see K. Aleinikova talk on June 4th)

	EIM	DBM	FTM	XIM	AIM	KJM
ECRH	x	x	x	x	x	x
ECRH+NBI	x	x	x	x	x	x

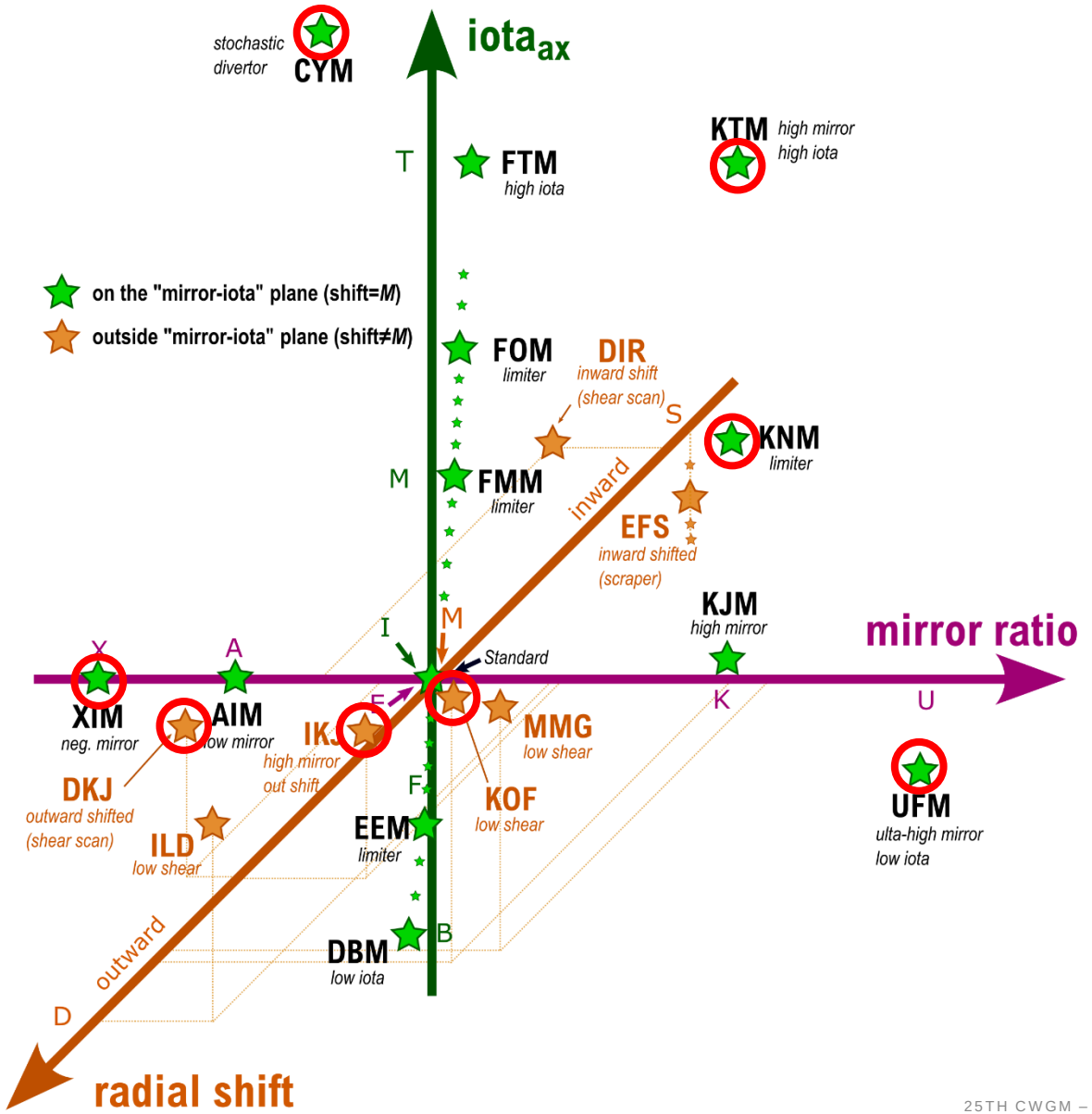
OP2.2
OP2.3

Courtesy of J.P. Bähner



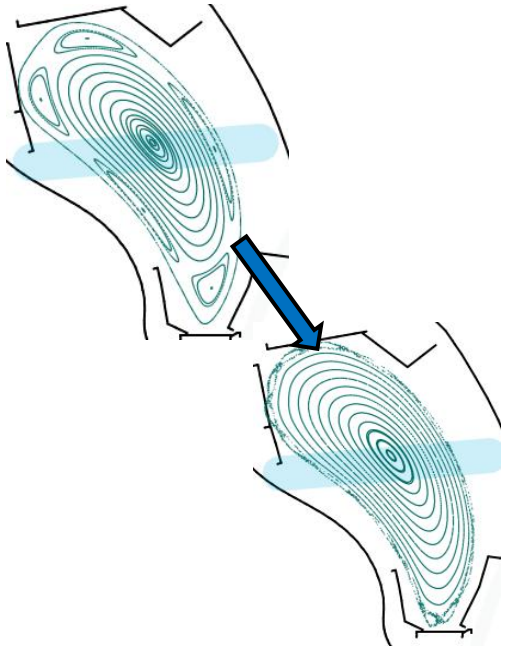
New magnetic configurations

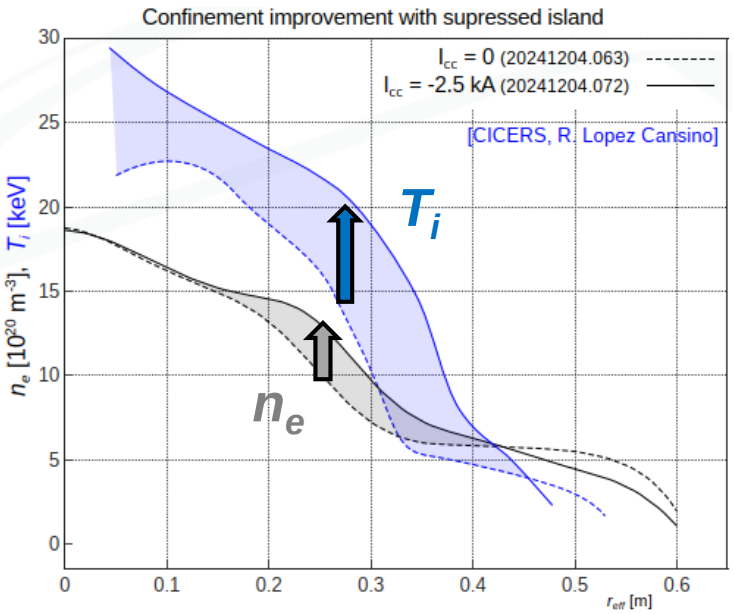
configuration ran for the first time in 2024/2025

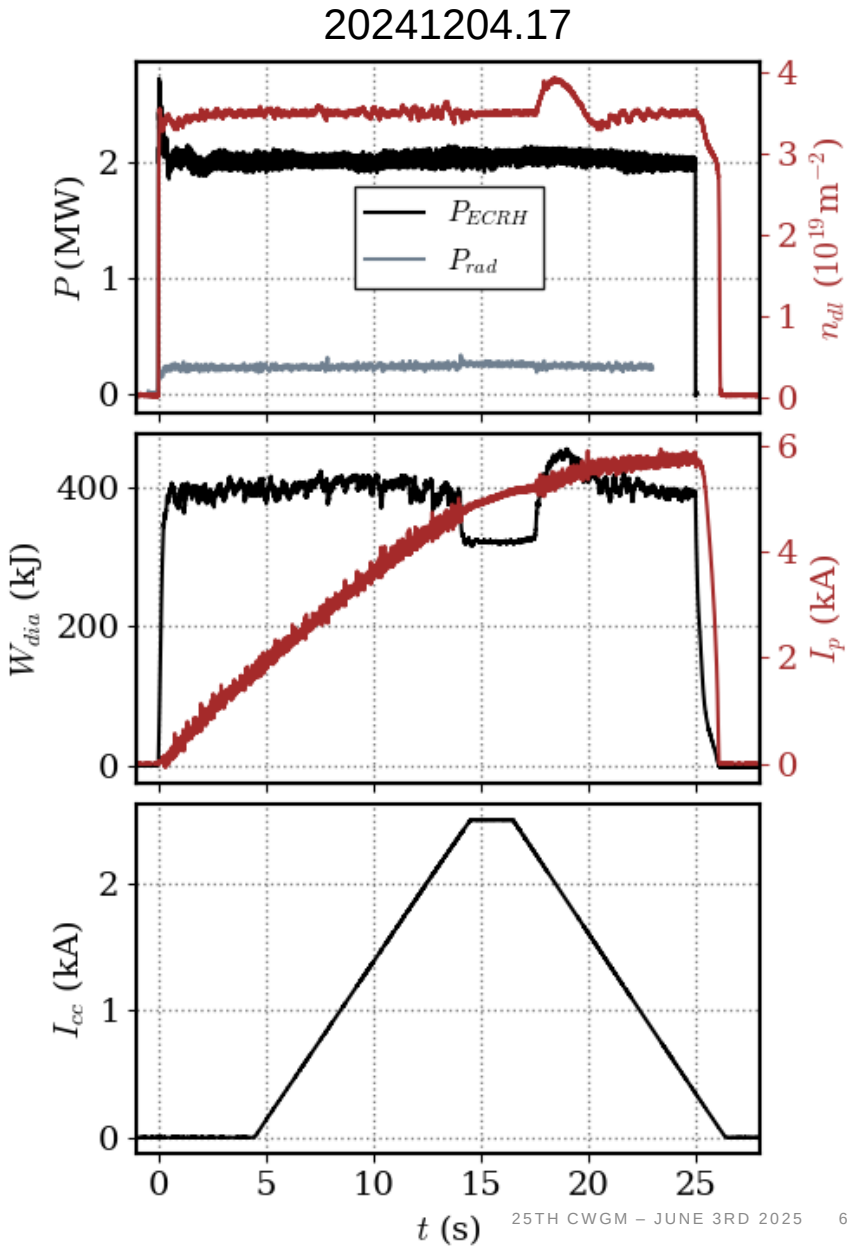


Confinement control via manipulation of internal islands

- Configurations with large islands just inside the LCFS feature improved energy confinement and intermittent crashes (known since 2018, superficially looks like H mode + ELMs but still under discussion)
- **Transition between both confinement modes is now possible using island control coils**







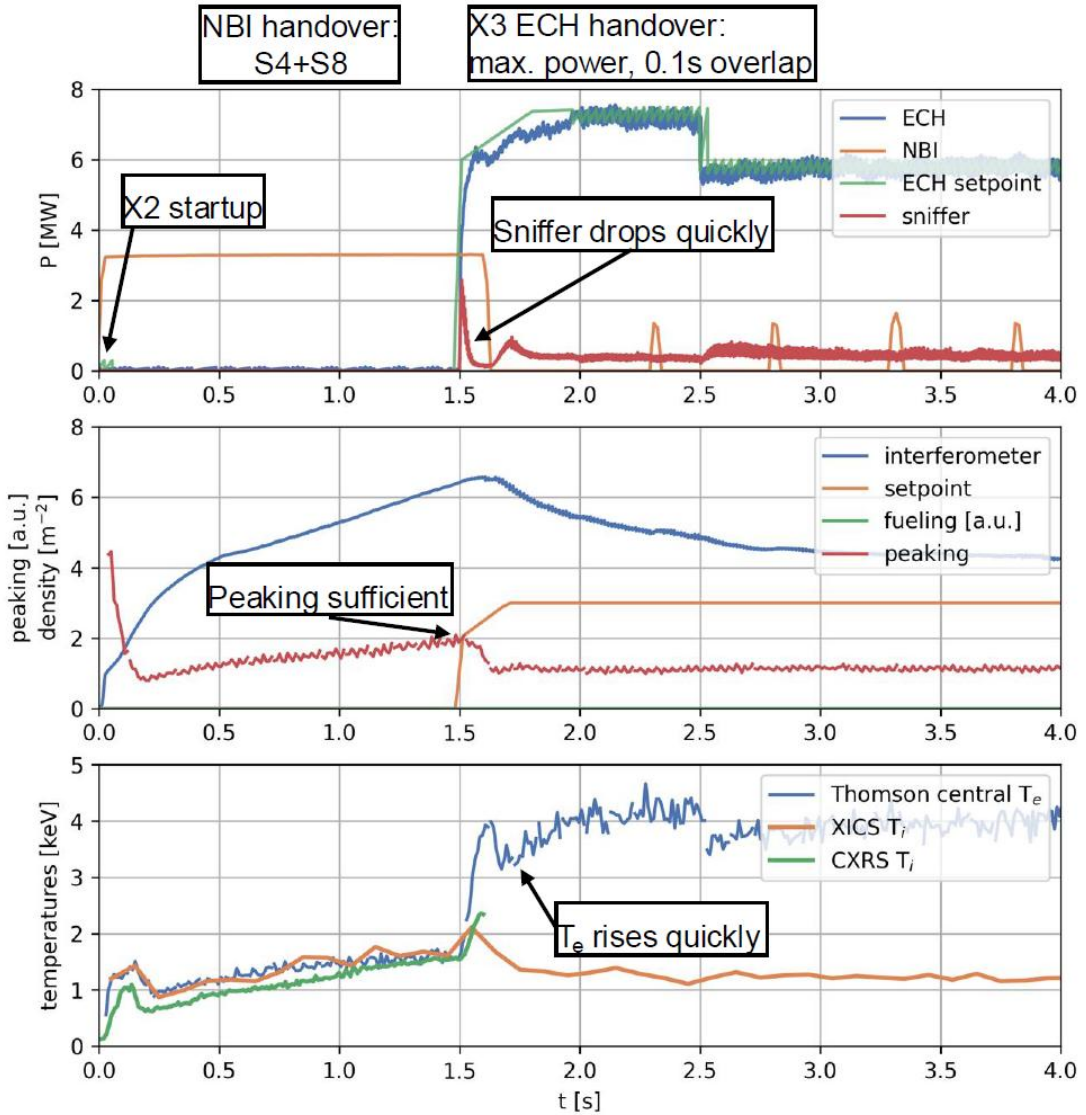
Outline

- Core physics highlights
  - *Magnetic configuration characterization*
  - *Confinement control by internal islands*
- Low field operation
  - *A reliable plasma startup scenario*
- High performance operation
  - *Full heating power operation*
  - *High performance regimes*

Reliable Low Field operation scenario has been established

During OP2.3 a breakthrough was achieved in low field operation: reliable plasma startup scheme was developed.

- Detuned 101 GHz gyrotron achieves breakdown.
- 2 NBI sources rise density, T_e for 1.5-2 s, giving rise to density peaking
- Sufficient ECRH X3 heating (up to 7 MW) is introduced to bring up T_e, stabilize plasma.
- After ~2 s, “proposal phase can begin”



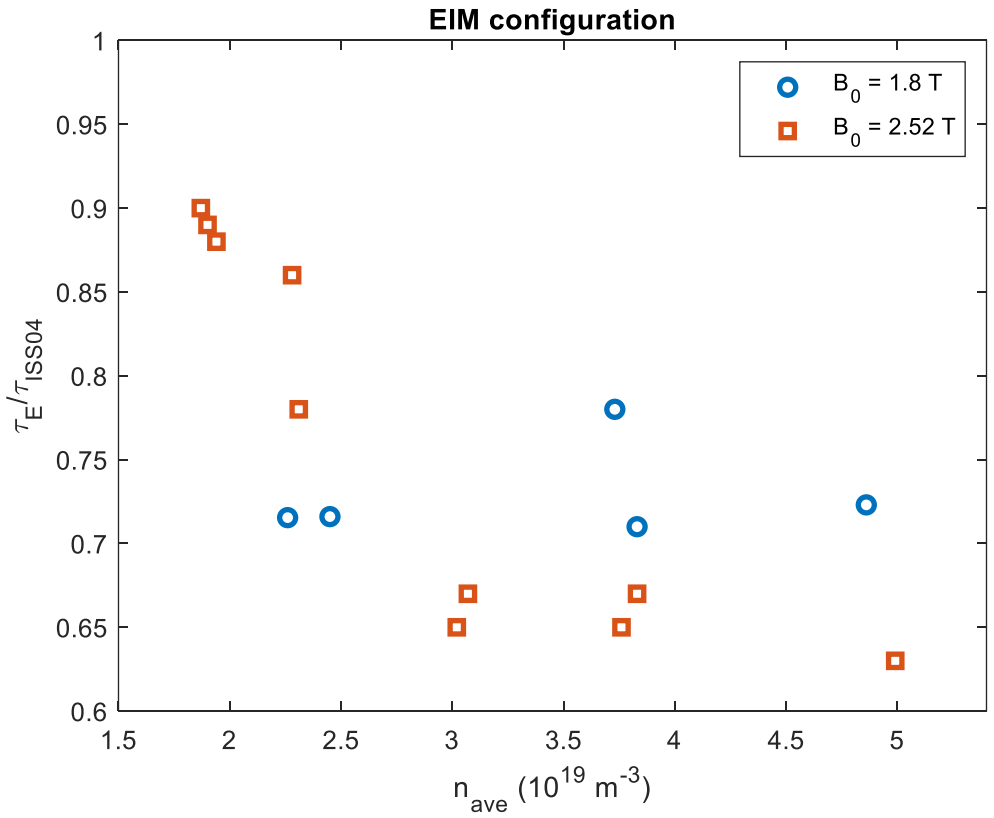
A. von Stechow, OP2.3 SOII-20 Session Report

Reliable Low Field operation scenario has been established

On a first look, performance scaling with magnetic field seems to follow ISS scaling expectations.

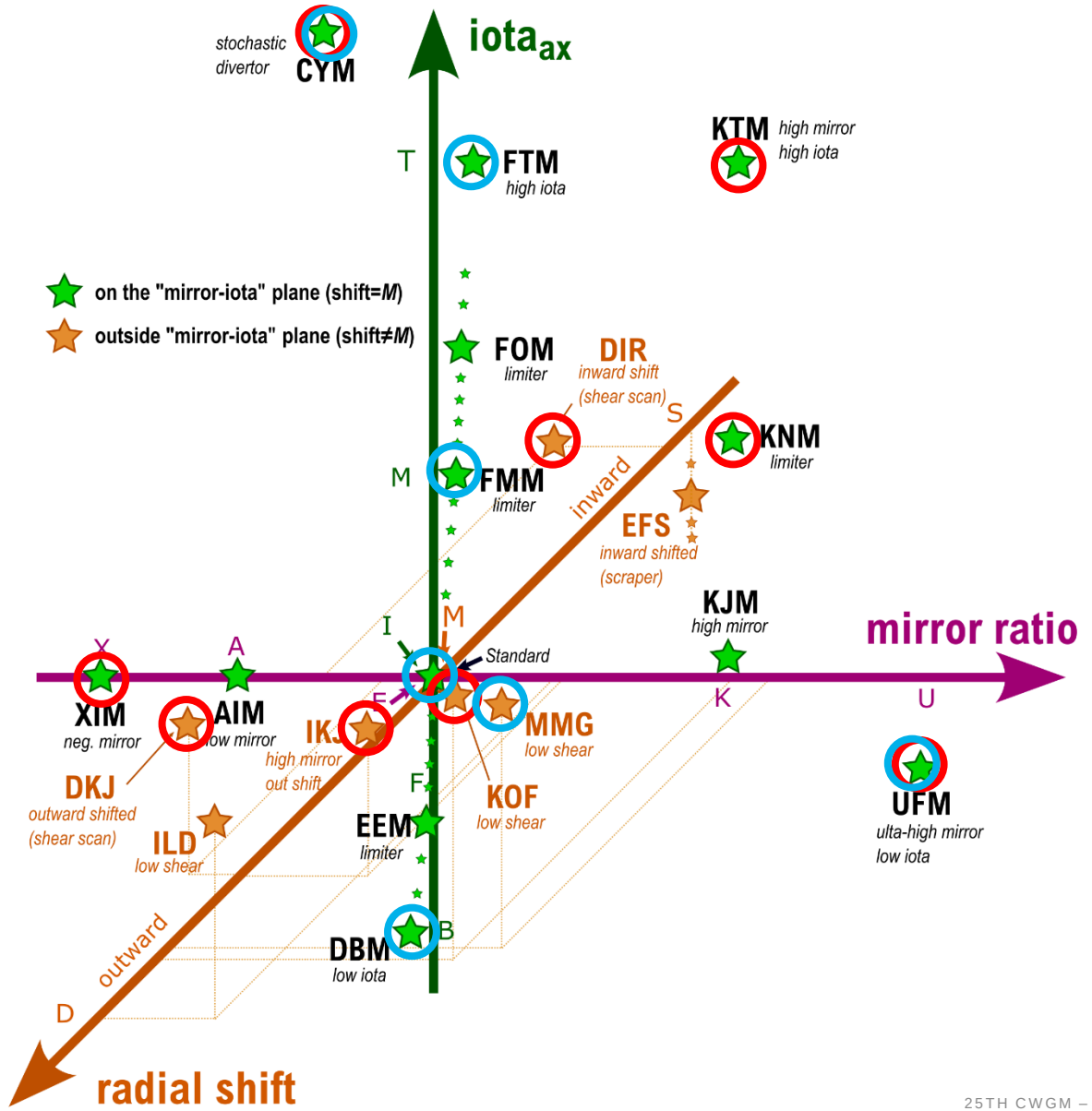
- Comparing stable X3 heating phases in low field with equivalent umbrella steps (same P_{ECRH}, $n_{e,line}$) in EIM yield qualititatively similar f_{ren}
- Preliminary analysis suggests that the density degradation effect (Fuchert NF 2022) would be weaker in low field.

Succesful operation in EIM allowed exploration of a number of additional configurations (FTM, DBM, FMM), some of which are not accesible in full field (CYM, UFM).



New magnetic configurations (low field)

- configuration ran for the first time in 2024/2025
- configuration ran in low field



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Heating Scenarios: Safe Operation of Heating Systems

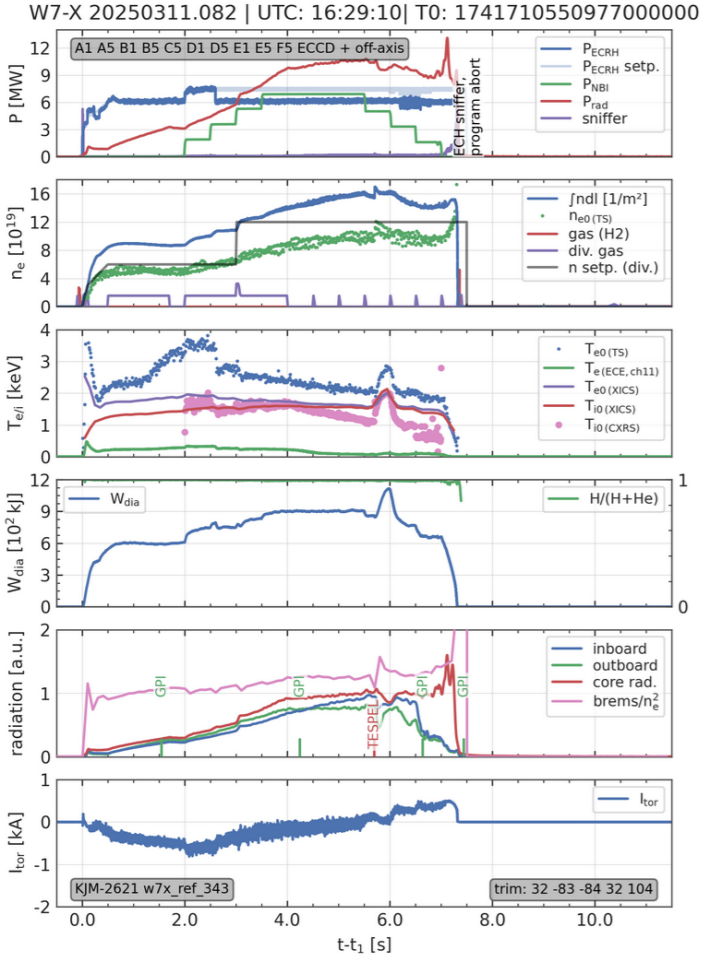
Safe operation of all heating systems at their maximum operation values has been demonstrated

- P_{ECRH} = 8.5 MW
- P_{NBI} = 7.1 MW
- $P_{TOT} = P_{ECRH} + P_{NBI}$ = 13 MW
- P_{ICRH} = 0.8 MW

No damage on the machine. Some operational limitations identified:

- Divertor/baffle heat loads for P_{TOT} > 8 MW
- W_{dia} < 1.5 MJ limit
- O2 sniffer interlock in HP scenarios at normal field

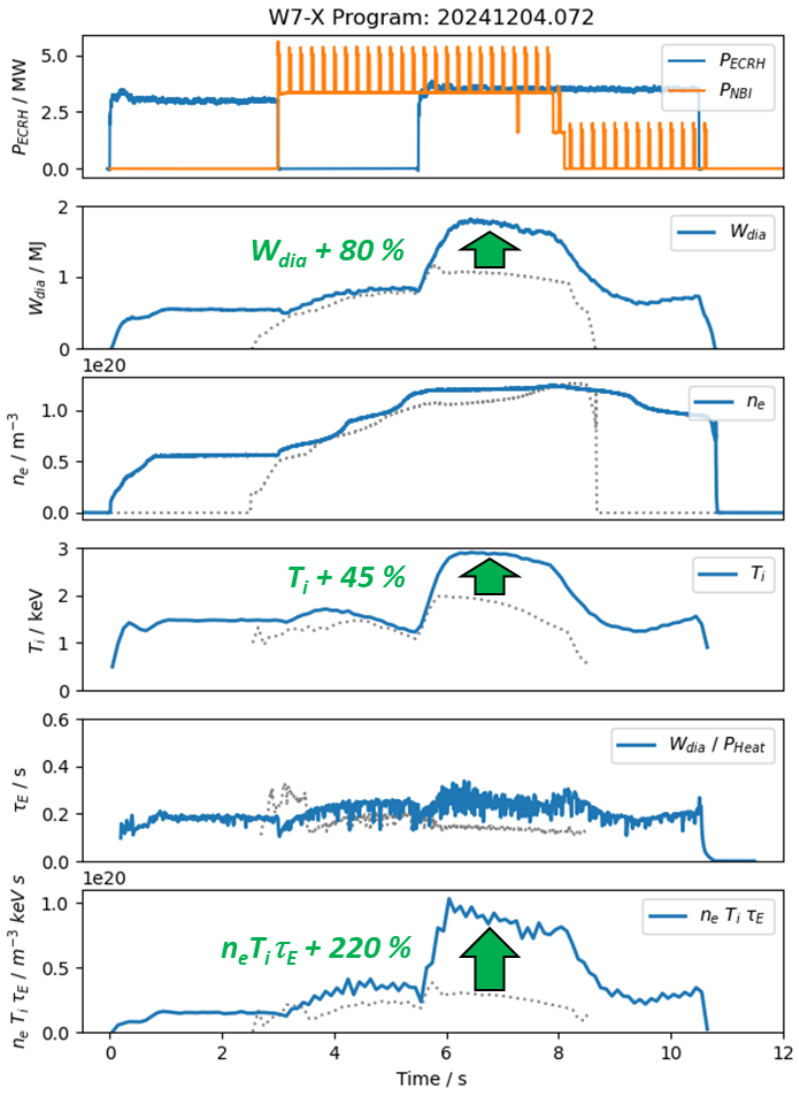
Core accumulation of low Z impurities has been observed during HP scenarios.



High performance regimes

Two main improved HP scenarios in OP2.3:

- O2 reintroduction scenario
  - Pure NBI is used to achieve n_e peaking
  - n_e peaking sustained by NBI+adjusted ECRH

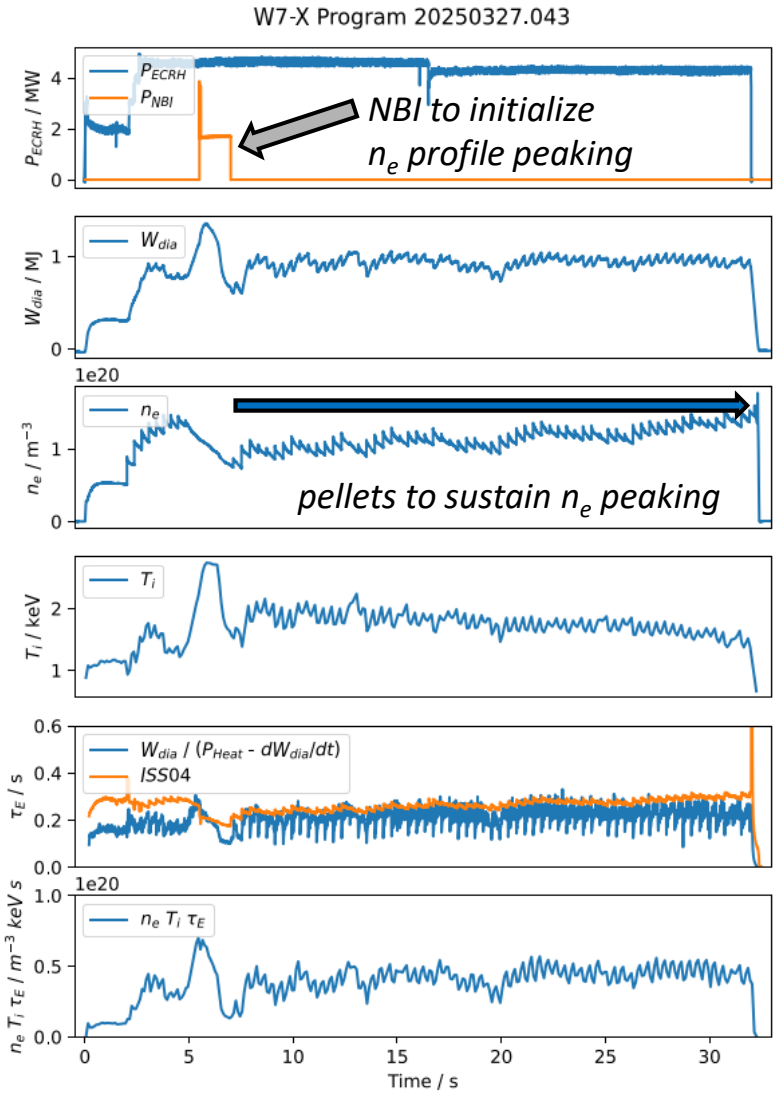


- W_{dia}^{max} = 1.85 MJ
- n_e = 1.5x10^{20} m^{-3}
- T_i^{max} = 2.9 keV
- τ_E ~ 260 ms
- f_{ren} = 1.3
- $n_e T_i \tau_E$ = 0.9 x10^{20} m^{-3} keV s

High performance regimes

Two main improved HP scenarios in OP2.3:

- O2 reintroduction scenario
  - Pure NBI is used to achieve n_e peaking
  - n_e peaking sustained by NBI+adjusted ECRH
- Pellet injection
  - n_e peaking is achieved by NBI phase+pellets
  - Scenario sustained by continuous pellet fueling



➢ W_{dia} = 1.0 MJ

➢ n_e = 1.2x10^{20} m^{-3}

➢ T_i^{max} = 1.9 keV

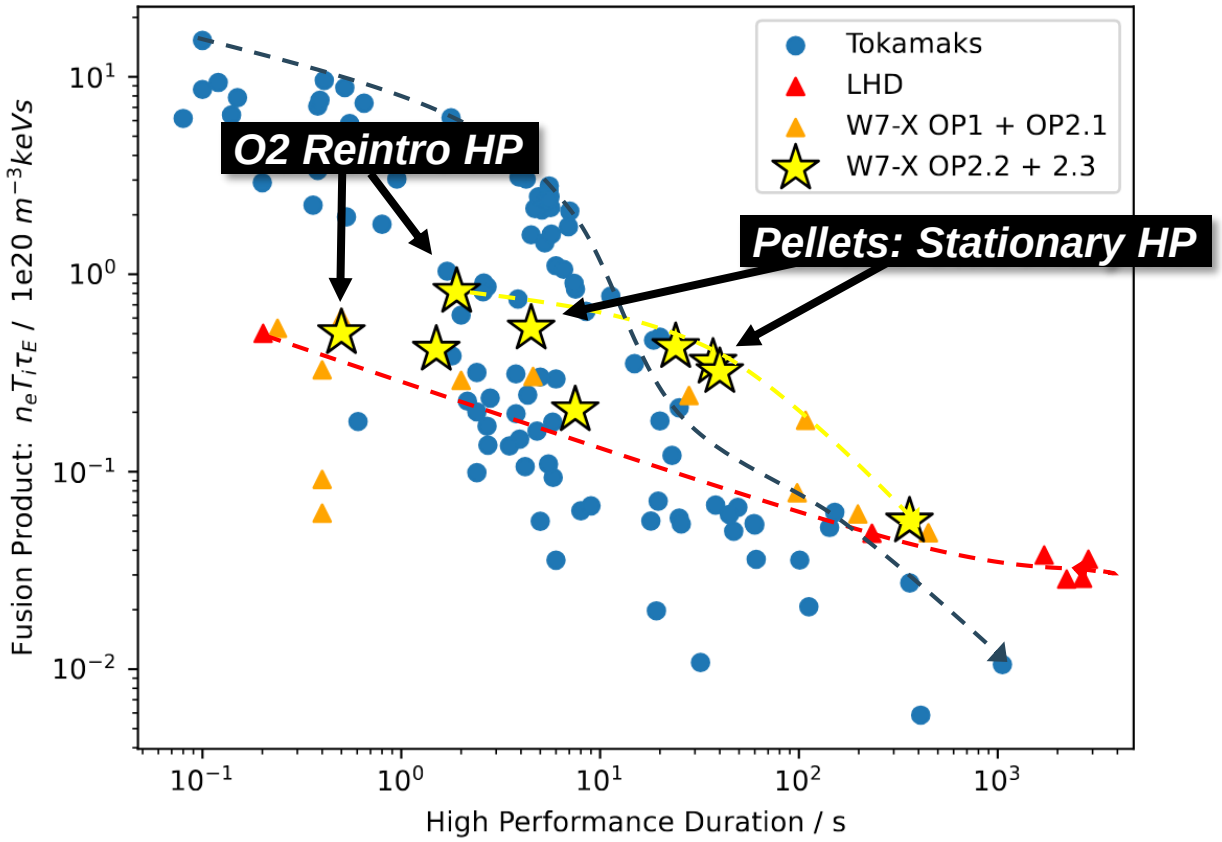
➢ τ_E = 200 ms, f_{ren} ~ 1

➢ $n_e T_i \tau_E$ = 0.45 x10^{20} m^{-3}keVs

High performance regimes

Two main improved HP scenarios in OP2.3:

- O2 reintroduction scenario
  - Pure NBI is used to achieve n_e peaking
  - n_e peaking sustained by NBI+adjusted ECRH
- Pellet injection
  - n_e peaking is achieved by NBI phase+pellets
  - Scenario sustained by continuous pellet fueling
- Several operational records achieved:
  - Triple product + HP duration
  - Tokamak “envelope” breached
  - $T_{i,core}$ (> 3 keV)
  - Discharge energy (1.78 GJ)



Summary

- A substantial expansion of the magnetic configuration operational space has been achieved
  - *Large database for turbulence & transport*
- Internal island modification has been applied as a method to control confinement
- Reliable low field operation has been established
  - *Gateway to high beta scenarios, extreme magnetic configurations (UFM, CYM)*
- High performance scenarios have been substantially improved
  - *Full heating power has been safely deployed*
  - *Records in triple product, core temperature, discharge energy.*
  - *Surpassed tokamak "envelope" in $n_e T_i \tau_E$ vs duration diagram*

Thanks for your attention!