EUROfusion

M18-48 report:
Impact of energetic He ions on the dynamics of L-mode and H-mode mixed plasmas

Y. Kazakov, J. Garcia, V. Kiptily, M. Nocente,
E. Delabie, M. Dreval, E. Solano, H. Weisen and M18-48 Team

JET TF Meeting, 07 April 2020

https://users.euro-fusion.org/tfwiki/index.php/M18-48:_Impact_of_energetic_He_ions_on_the_dynamics_of_L-mode_and_H-mode_mixed_plasmas

JET

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

Experiment deliverables

	SL	EIC	DC	SC
Early shift (18/03/2020)	M. Maslov, Ph. Jacquet	S. Hotchin	Z. Stancar	Y. Kazakov
Late shift (18/03/2020)	F. Nave, M. Lennholm	B. Graham	E. Solano	J. Garcia

M18-48:

TFL J. Garcia, E. de la Luna

RSL M. Maslov

SC Y. Kazakov

D1: Determine the impact of MeV-range He ions on plasma transport under ITER-relevant conditions of dominant electron heating

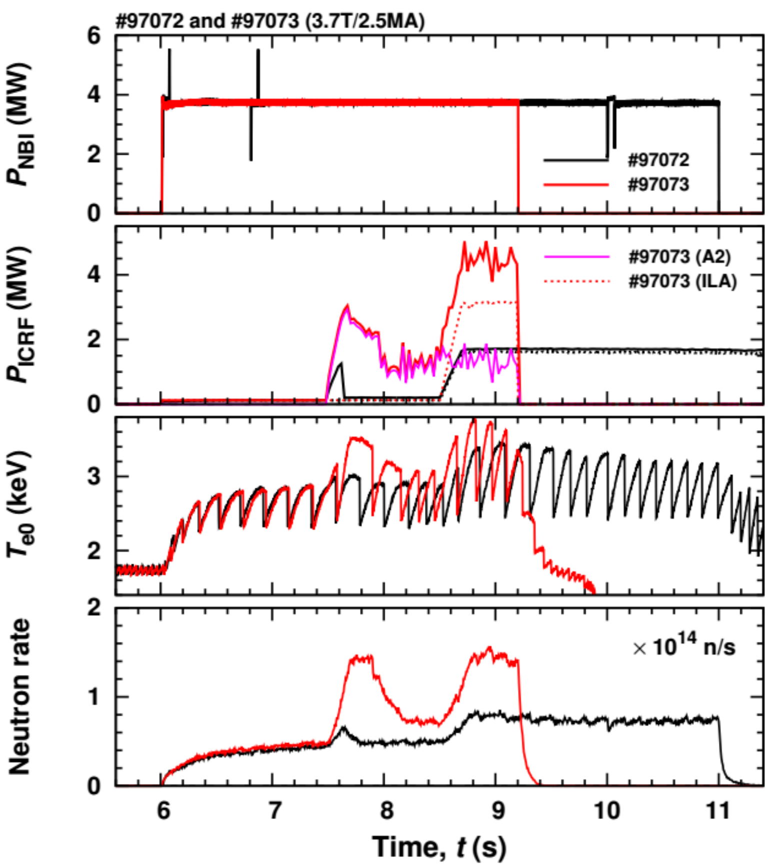
D2: Compare the 3-ion D-(^{3}He)-H ICRH scheme absorption, heating and fast-ion generation in on-axis conditions wrt off-axis as expected in ITER

D3: Evaluate electron heating from the post-sawteeth T_{e0} recovery rate in plasmas with MeV-range He ions in view of DT

D4: Determine the 3-ion D-(^{3}He)-H ICRH scheme coupling, absorption and impact on energy confinement in H-mode plasmas

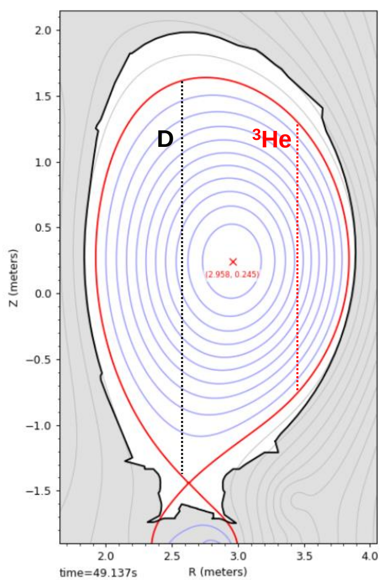
+ M18-11 references for C40 with TIM-equivalent GIMs (3.7T/2.5MA, no ^{3}He puff)
[on 18/03/2020, we didn't know that M18-11 was de-selected from the C40 list]

C40 references: 3.7T/2.5MA, no ^{3}He puff



- #97072: H/(H+D) ≈ 0.90-0.95, NBI, @46.0-51.0s, 3.7MW, ICRF, 1.7MW (ILA), **A2 antennas tripped**
- Gas fueling with T-equivalent GIMs ✓
- Generation of energetic D ions not as efficient as in #91256 (2.5MW with A2 ICRF antennas), why (?) ✗

→ A2 vs. ILA antenna spectrum ($k_{||}$)
→ Competitive off-axis ICRF absorption by residual ^{3}He (?)

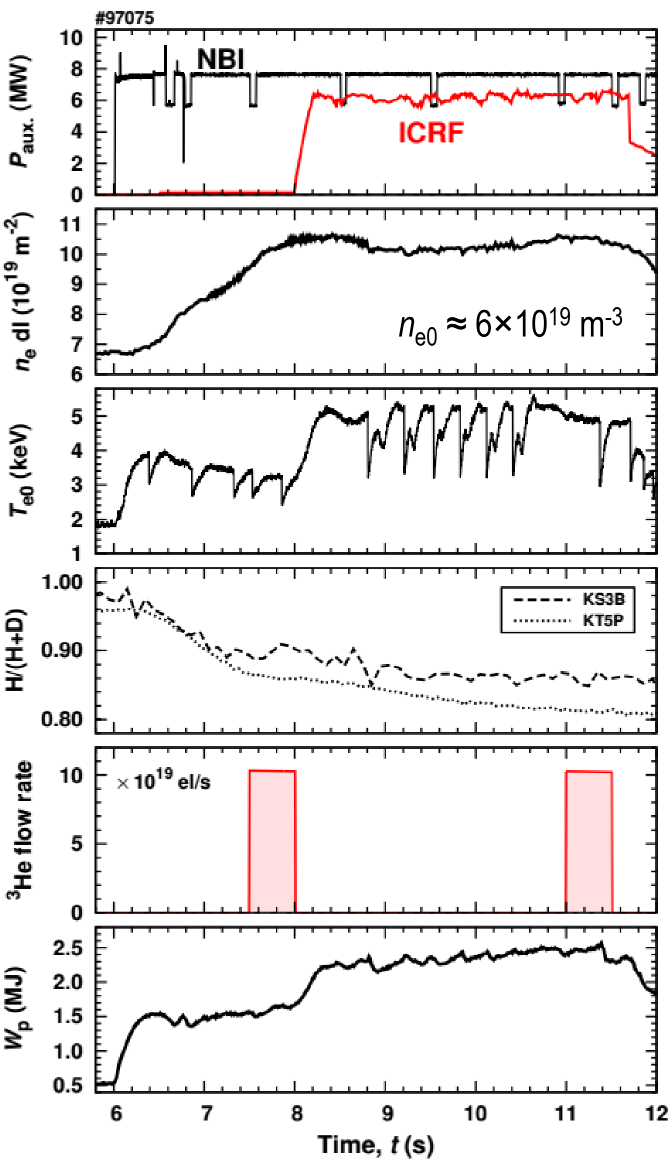


Changed ^{3}He fueling strategy on the fly:

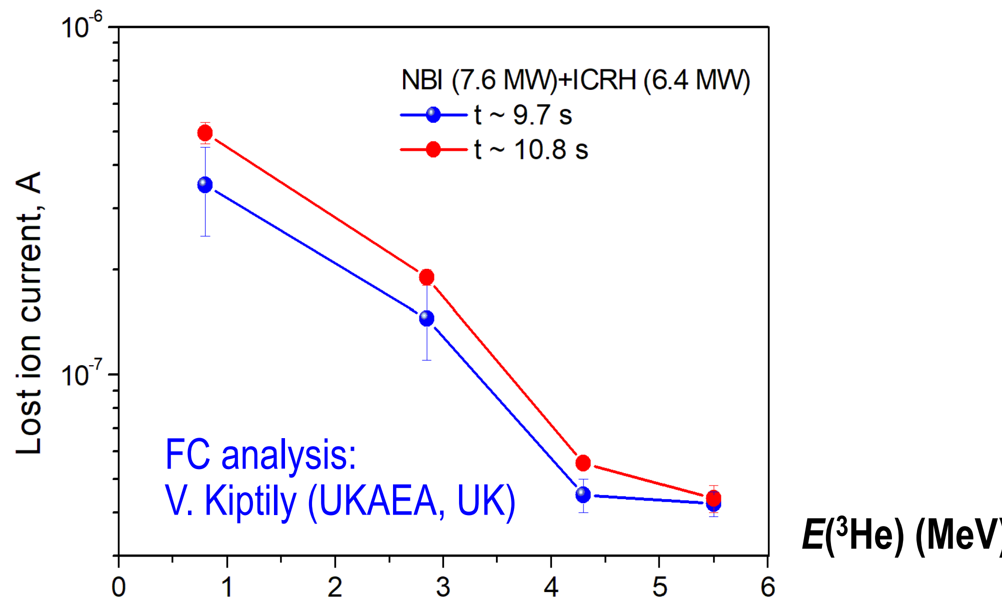
^{3}He RTC (offset level unknown)
→ ^{3}He feedforward fueling

#97073: hotspot stop at @49.2s

(D1) Generation of MeV-range ^{3}He ions with on-axis 3-ion ICRF scheme

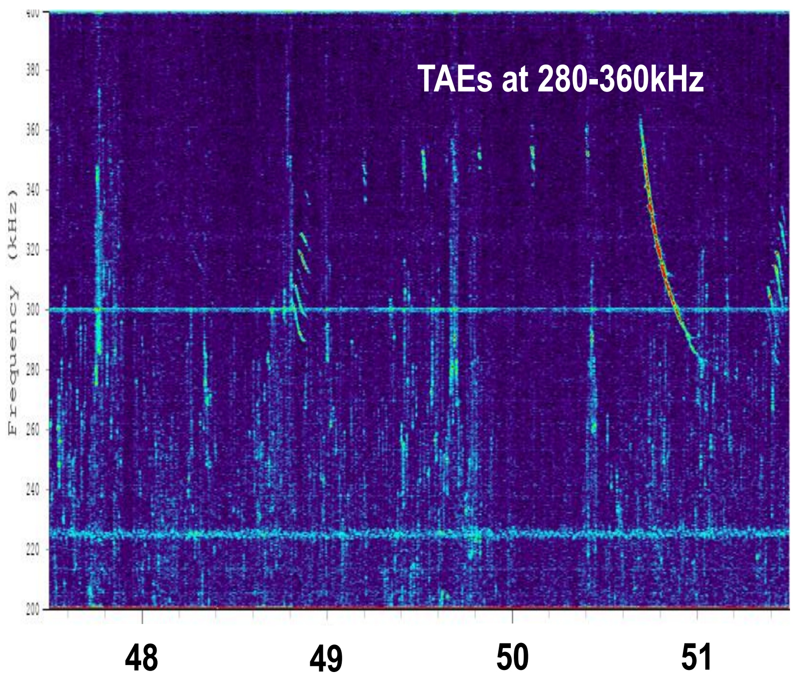


- #97075: first ^{3}He pulse (10:50)
- Feedforward ^{3}He fueling (@47.5-48.0s; @51.0-51.5s)
- **Energetic ^{3}He ions generated with ICRF**
  - → gamma-ray measurements
  - → AE modes (next slide)
  - → Faraday cup data
  - → long-period sawteeth (@50.4-51.4s)

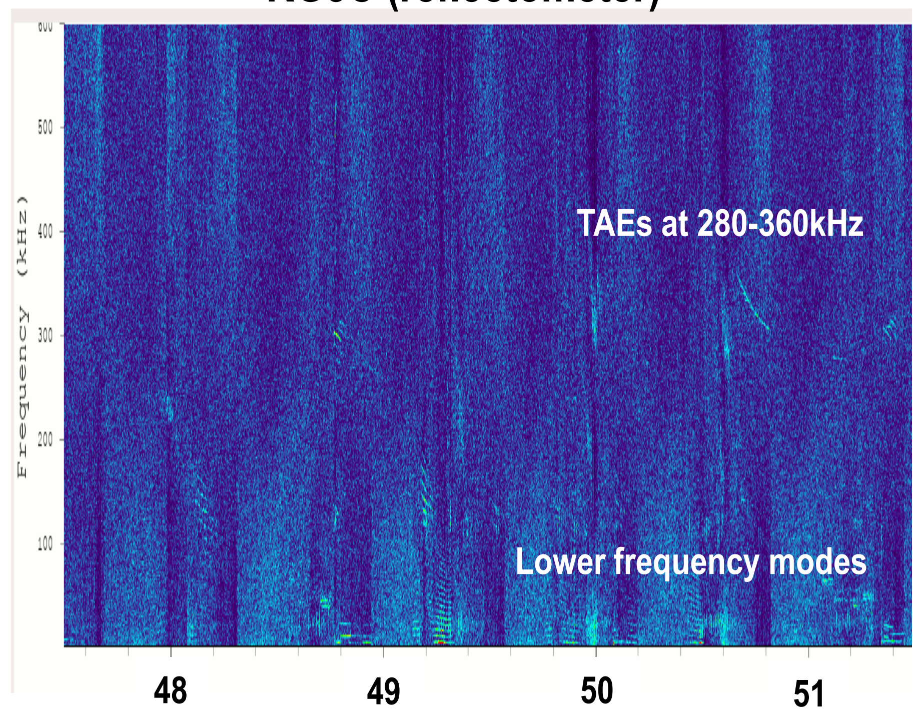


AE modes observed in #97075

Core interferometer

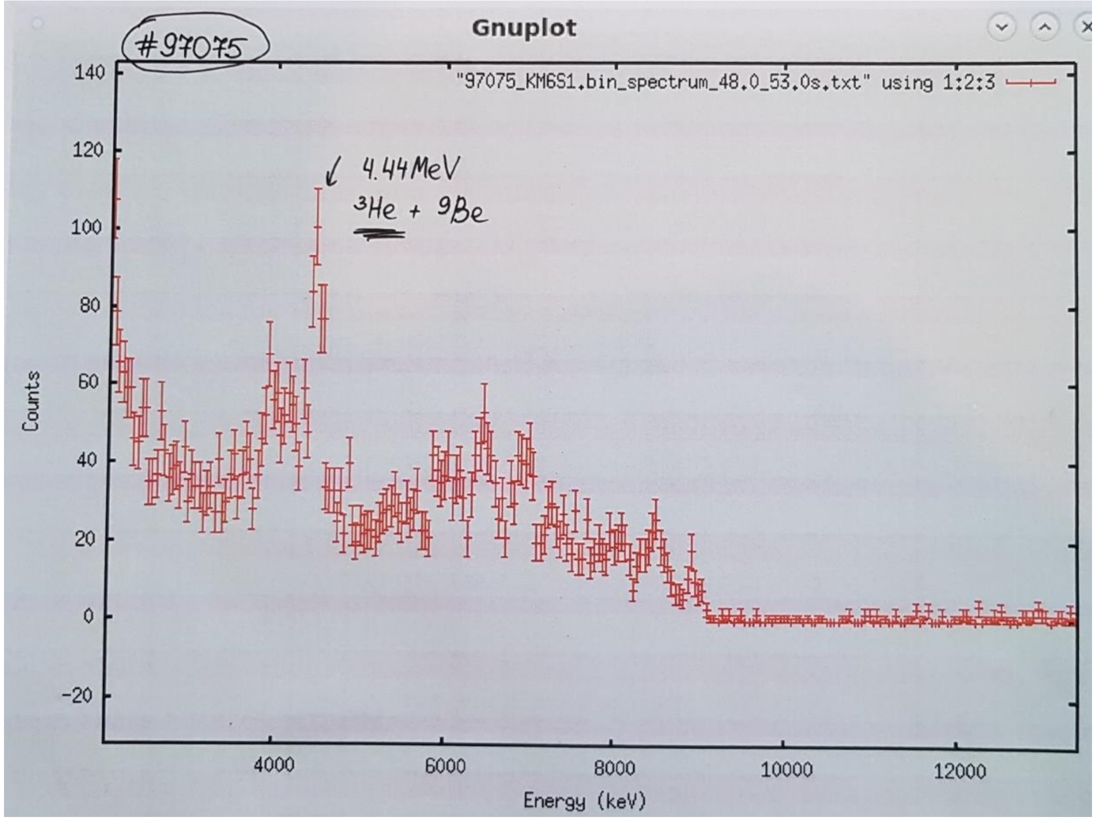


KG8C (reflectometer)



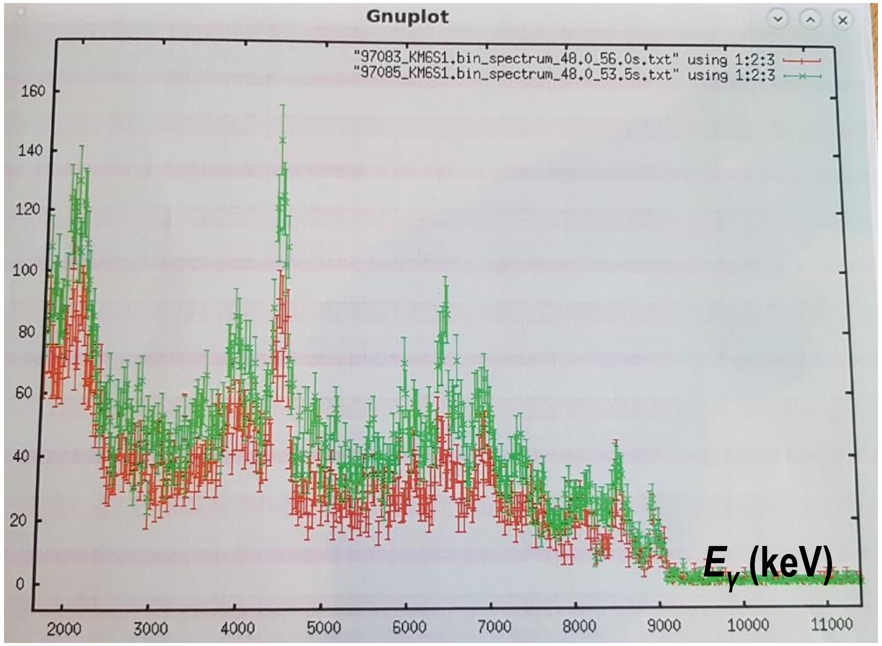
Core interferometer and KG8C analysis: M. Dreval (KIPT, Ukraine)

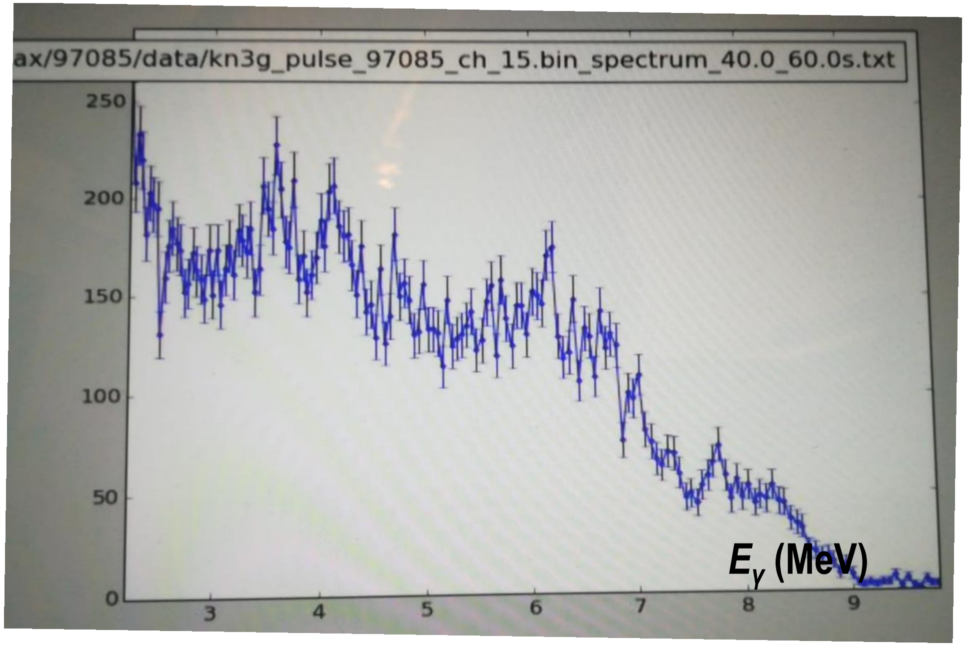
Presence of MeV-range ^{3}He ions in #97075: gamma-ray measurements



- Multiple gamma-ray lines associated with fast ^{3}He ions
- Gamma-ray measurements: M. Nocente (Milano Univ., Italy), V. Kiptily (UKAEA, UK)

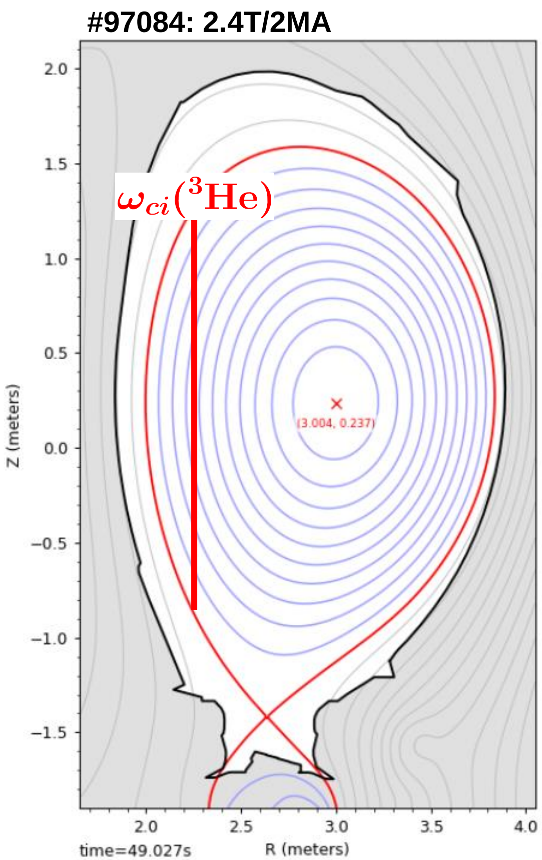
Presence of MeV-range ^{3}He ions: gamma-ray measurements

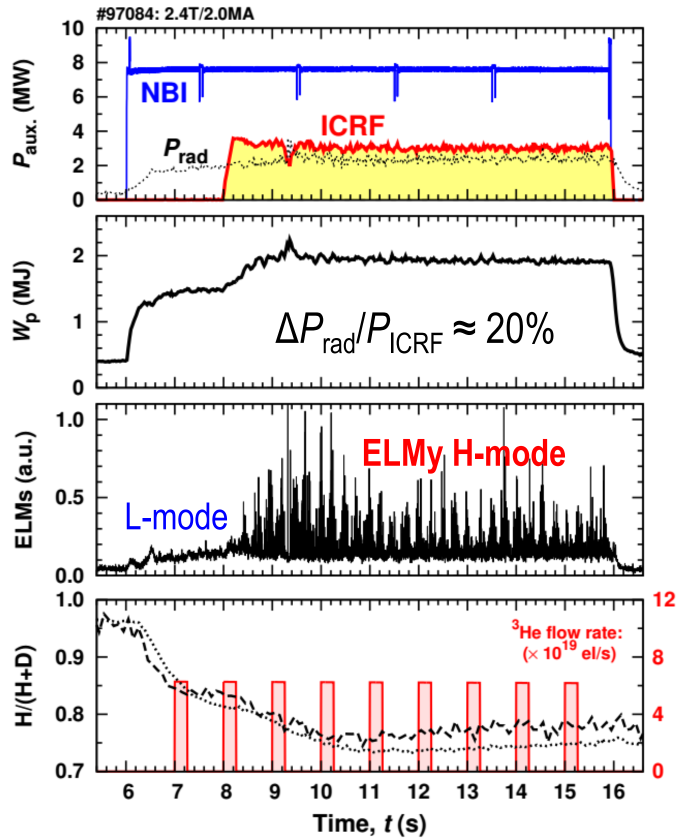




- Multiple gamma-ray lines associated with fast ^{3}He ions
- Good quality gamma-ray measurements: M. Nocente, D. Rigamonti (Milano Univ., Italy)
- #97085 (^{3}He < 0.1%): gamma peaks seen in the KN3G camera

(D2) ITER-relevant H-mode access with off-axis 3-ion ICRF scheme





JET #97084: mix H-D ≈ 75%:25%

Equivalent ITER mix (PFPO-II): Hydrogen + ≈12-13% ^{4}He

Feedforward ^{3}He fueling for ICRF → $n(^3\text{He})/n_e \approx 0.1\%$

^{3}He ICRF resonance (2.4T/33MHz): far off-axis, $(r/a)_{HFS} \approx 0.8$

Equivalent location as for ITER at B_0 = 2.9-3.0T (40MHz)

L-mode with 8MW NBI →

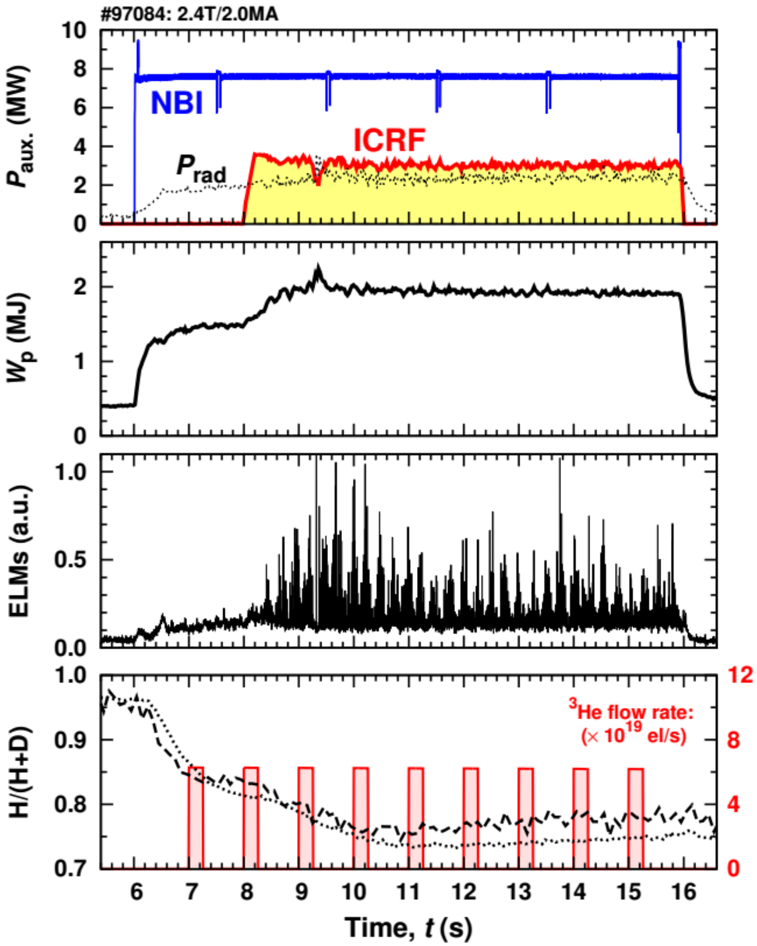
ELMy H-mode with 8MW NBI + 3MW 3-ion ICRF scheme

- Good plasma heating with far off-axis 3-ion ICRF scheme confirmed (earlier observed on AUG)
- **Stable ELMy H-mode in majority hydrogen plasma achieved**

Future developments in H/^{4}He plasmas on JET (2020):

- Proof-of-principle demonstration of the heating scheme in non-active plasmas (M18-11, SC: Y. Kazakov)
- L-H transition optimization using the 3-ion ICRF scheme (M18-13, SC: E. Solano)

(D2) ITER-relevant H-mode access with off-axis 3-ion ICRF scheme



- #97084: feedforward ^{3}He fueling

  6.3e19 el/s (25% duty cycle) → ^{3}He ~ 0.1% (KT5A)

- C39 plasma mix: H + ^{4}He (~10-15%) + ^{3}He (< 1%)

  He measurement ≈ $n(^4\mathrm{He})/n_e$ (RTC scheme)

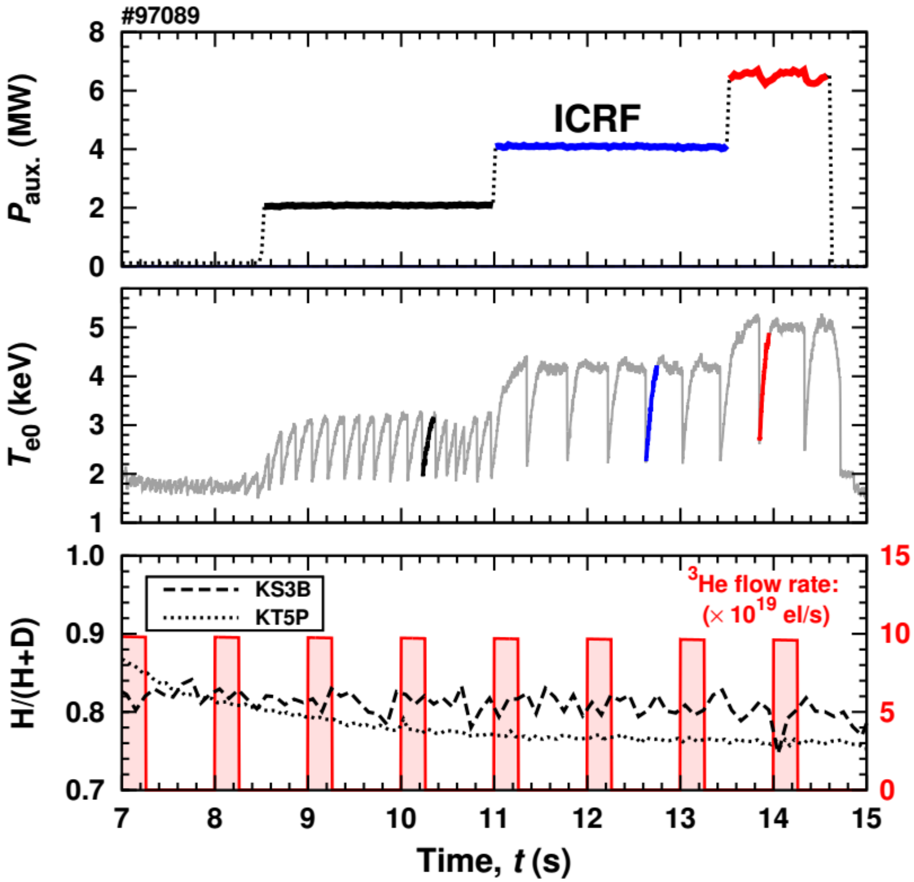
  ^{3}He feedforward fueling: which level is optimal (?)

- **Request for extra time in C38B extension (H-D mix)**:

  → calibration for $n(^3\mathrm{He})/n_e$ vs. feedforward ^{3}He fueling

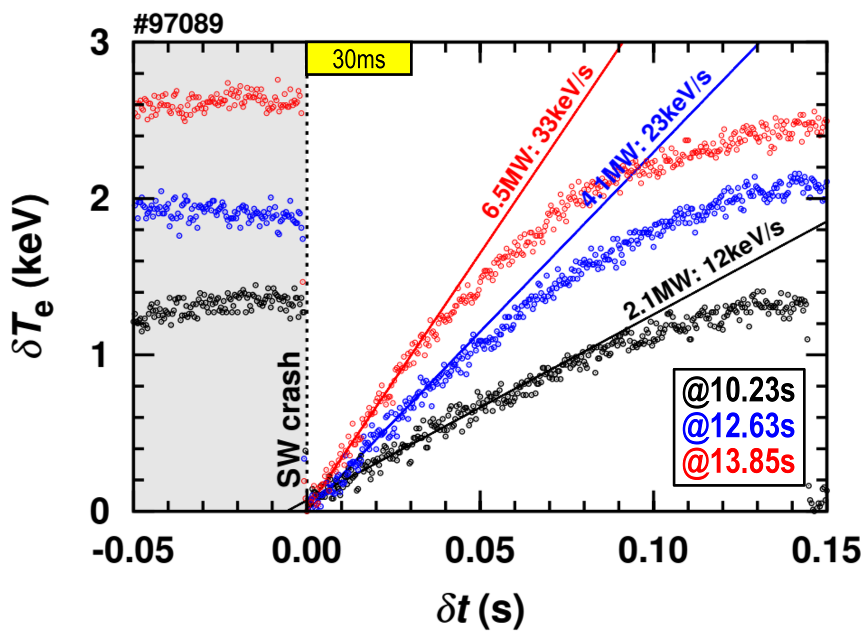
  → good quality KK3 data (n/a in #97084)

(D3) Post-sawtooth T_{e0} recovery rate: demonstrate alpha heating in DTE2



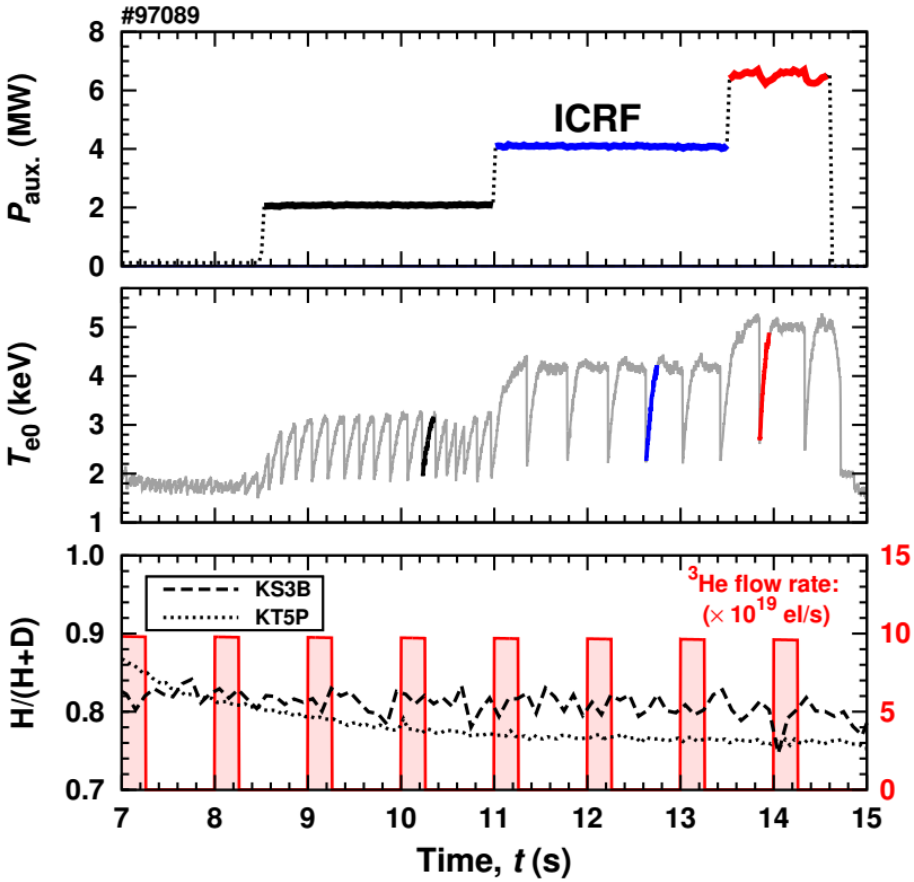
Post-sawtooth T_{e0} recovery rate vs. P_{ICRF}

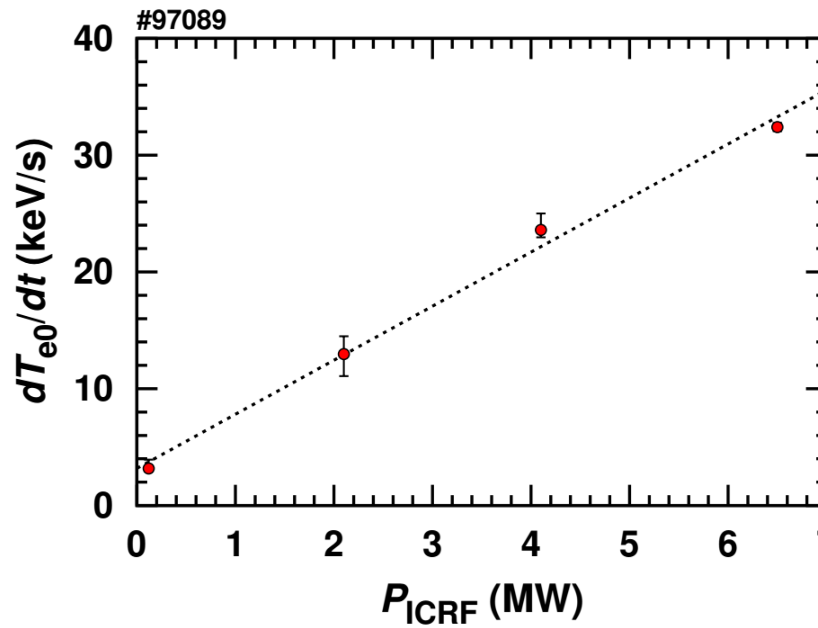
P_{ICRF}	0.12MW	**2.1 MW**	**4.1 MW**	**6.5 MW**
dT_{e0}/dt	3.5keV/s	**12 keV/s**	**23 keV/s**	**33 keV/s**



- #97089, three ICRF power steps (dipole phasing): P_{ICRF} = 2.1MW → 4.1MW → 6.5MW
  $n(^3He)/n_e$ < 0.1% (KT5A; E. Delabie)
- T_{e0} recovery rate scales with ICRF power (fast-ion electron heating)
  → promising way to demonstrate **alpha particle heating** in the dedicated DTE2 scenario [H. Weisen]

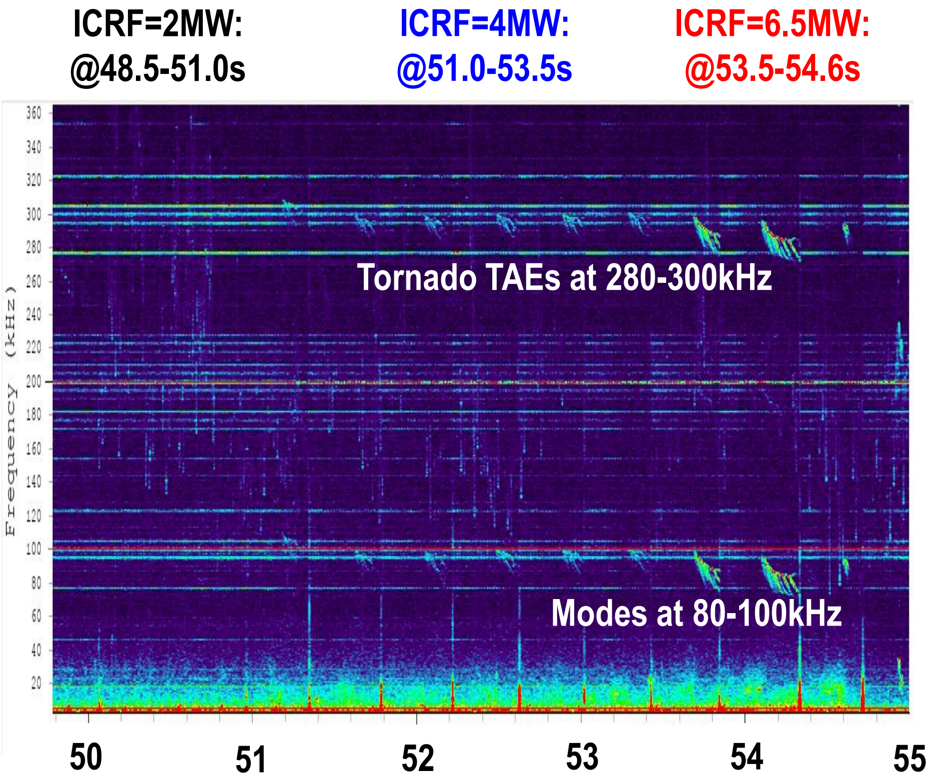
(D3) Post-sawtooth T_{e0} recovery rate: demonstrate alpha heating in DTE2

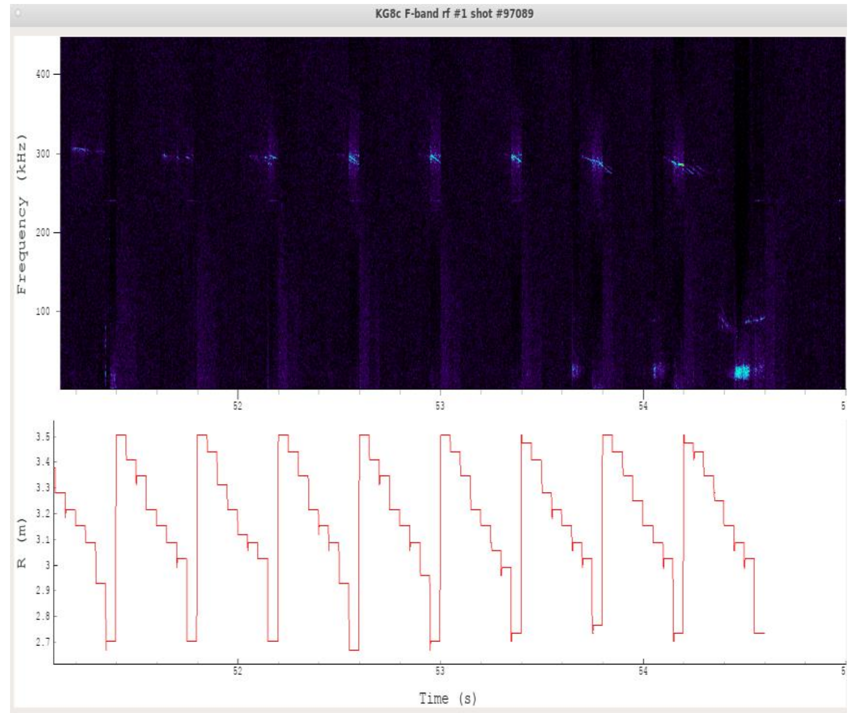




- #97089, three ICRF power steps (dipole phasing): P_{ICRF} = 2.1MW → 4.1MW → 6.5MW
  $n(^3He)/n_e$ < 0.1% (KT5A; E. Delabie)
- T_{e0} recovery rate scales with ICRF power (fast-ion electron heating)
  → promising way to demonstrate **alpha particle heating** in the dedicated DTE2 scenario [H. Weisen]

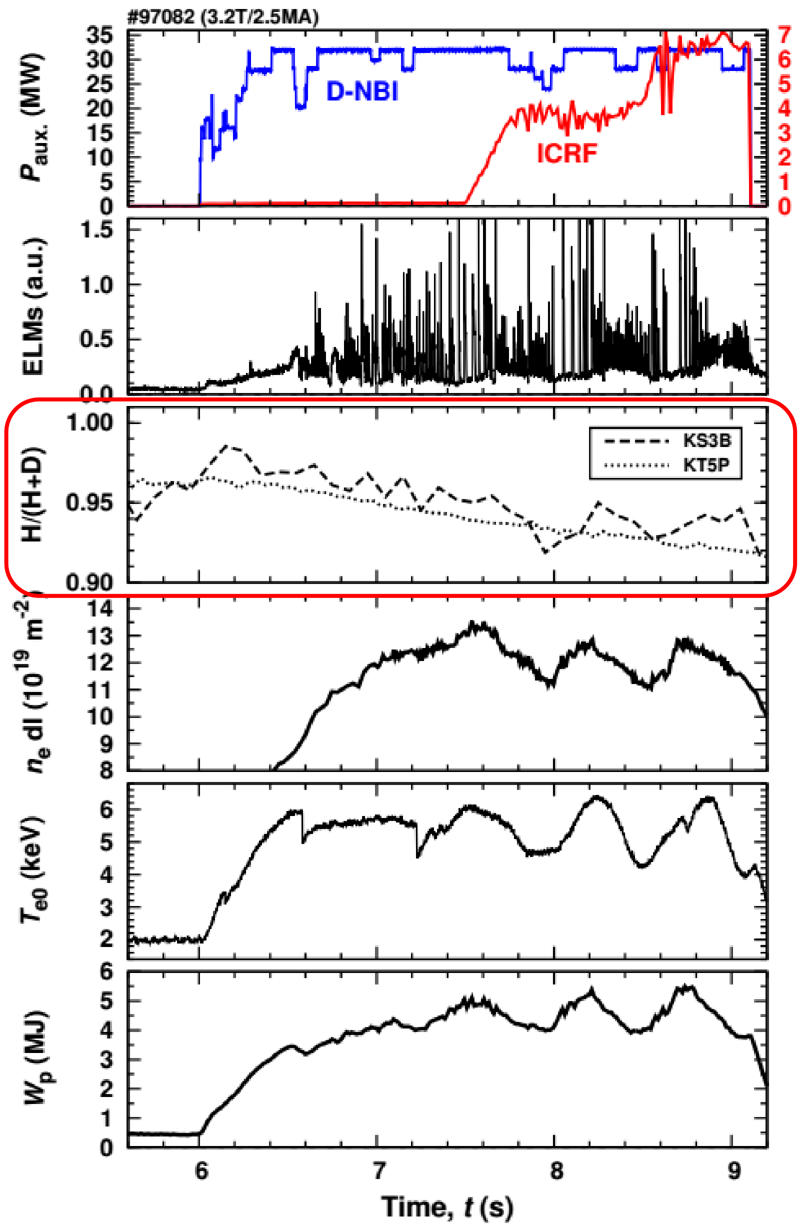
AE modes observed in #97089





- Core interferometer and KG8C analysis (preliminary): M. Dreval (KIPT, Ukraine)
- Frequency range of TAEs consistent with earlier observations at JET
  [Y. Kazakov et al., *Nature Physics* (2017); V.G. Kiptily et al., *Nucl. Fusion* (2020)]

(D4) H-mode studies



First test in #97082:

- Excellent NBI=32MW and RF=6.7MW, $P_{aux.}$ ≈ 39MW
- $n(^3He)/n_e$ ≈ 0.1-0.3% (KT5A, E. Delabie) (continuous puff, 1.1e20 el/s)
- Fueling: H gas (no D) + 32MW D-NBI

  expected: H/(H+D) ≈ 0.80-0.85

  measured: H/(H+D) ≈ 0.94

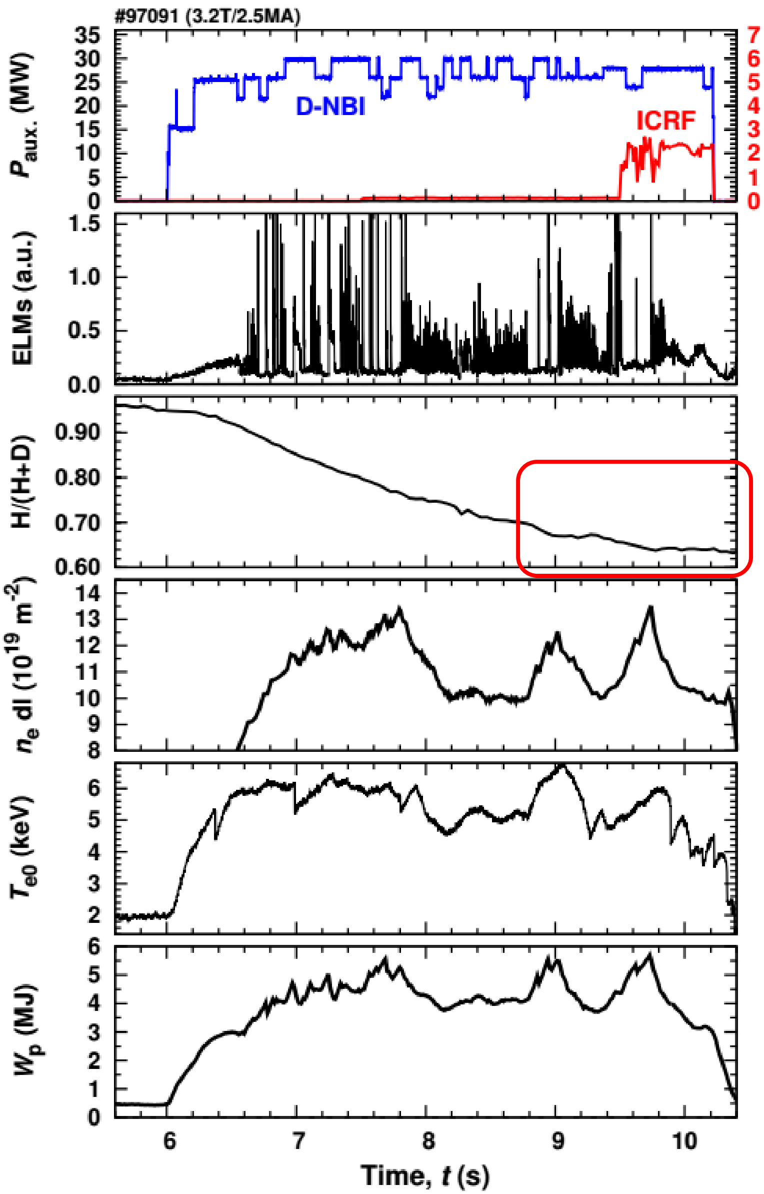
→ Almost pure H plasma, not good H/(H+D) for the 3-ion ICRF scheme ✗

→ Good news for M18-10 (D-NBI in T-rich plasma, T/(T+D) ≈ 0.90-0.95 ?) ✓

→ Interesting pulse for H-mode and ELM-analysis: **H-mode in H plasma at high B_t** ✓

- In preparation for #97082, we lost #97081 (no NBI)

(D4) H-mode studies



<u>#97091 (last pulse of M18-48):</u>

- No ^{3}He fueling (cleaning pulse)
- H/(H+D) < 0.70:
  not good for the 3-ion ICRF scheme with ^{3}He (poor single-pass ICRF absorption) ✗

M18-48 summary

Main achievements:

- #97072-97074: M18-11 references for C40 with TIM-equivalent GIMs (3.7T/2.5MA, NBI = 4MW, no ^{3}He puff)
- L-mode plasmas with core fast-ion (^{3}He) electron heating
  → good-quality gamma-ray measurements
  → post-sawtooth T_{e0} recovery rate as an indicator for fast-ion electron heating (e.g., #97089); promising way to demonstrate alpha particle heating [H. Weisen]
  → KT5A measurements for ^{3}He (~0.1%) [E. Delabie et al.]
  → KG8C in DBS mode: to be analyzed
- #97084: first demonstration of the ITER-relevant off-axis 3-ion ICRF scheme to access ELMy H-mode in H majority plasmas at JET
- Good experimental results obtained despite difficult conditions …:
  special thanks to our control-room team and those colleagues who contributed remotely
- Very good RF power: up to 6-7MW at 33MHz
- #97082: 32MW of D-NBI power + 6.5MW of ICRF, but unexpectedly very high H/(H+D) ≈ 0.94 (!)
  → not good for the 3-ion ICRF scheme

M18-48 difficulties and unconducted studies

- Changed ^{3}He fueling strategy on the fly:
  ^{3}He RTC (offset level unknown) → ^{3}He feedforward fueling
- Don't use the KT5B ppf for $n(^3\text{He})/n_e$ for this session [E. Delabie]:
  the helium density on KT5B tends to get swamped in background lines (neon and molecular)
- Very low ^{3}He concentrations, $n(^3\text{He})/n_e < 0.1\%$
  [KT5A analysis, E. Delabie & E. Solano – many thanks!]:
  - → Didn't take risk to increase ^{3}He puff rate w/o $n(^3\text{He})/n_e$ measurements in the control room (minimizing the risks for the follow-up sessions)
  - → **^{3}He concentrations in most of M18-48 pulses likely below optimal values for plasma heating** (~0.2-0.3% as in B15-12 and H16-12)
  - → Studies at higher ^{3}He concentrations (0.2-1.5%) not conducted
- +pi/2 vs. –pi/2 ICRF antenna phasing comparison not conducted
- Limiter hotspot problems (next time should use GIM6 with H rather than Ne and an increased ROG)
- H-mode studies: problems with getting a proper isotopic ratio, H/(H+D) and $n(^3\text{He})/n_e \approx 0.2\text{-}0.3\%$:
  H/(H+D) ≈ 0.94 in #97082 (with 32MW of D-NBI); H/(H+D) < 0.7 in #97091
- #97084, ITER-relevant off-axis ^{3}He heating: wrong settings for KK3
  (B_0-change was not communicated to DC)

M18-48: bid for contingency in C38B extension

Bid for contingency in C38B extension: 1-1.5 sessions

- ITER-relevant off-axis heating (2.4T):
  optimization of $n(^3\text{He})/n_e$ and ^{3}He feedforward fueling calibration
  (^{3}He KT5A vs. puff rate; important for the prep. of M18-11 and M18-13 studies in C39; $n(^3\text{He})/n_e$ measurements will likely not be available in H/^{4}He plasmas in C39)

  3-4 good pulses

- Repeat on-axis ^{3}He heating (3.2T) at higher
  $n(^3\text{He})/n_e$ = 0.2-0.3%, 0.5% and 1%
  (more optimal for plasma heating and AE physics)

  3-4 good pulses

- If Alfvén cascades (reversed shear AEs) observed,
  +pi/2 vs. –pi/2 phasing comparison

  2 good pulses

- Repeat H-mode studies with a better control
  of H/(H+D) and $n(^3\text{He})/n_e$

  3 good pulses