

Experimental team encompasses wide range of competences

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Scenario preparation for the observation of alpha-driven instabilities and transport of alpha particles in JET DT plasmas

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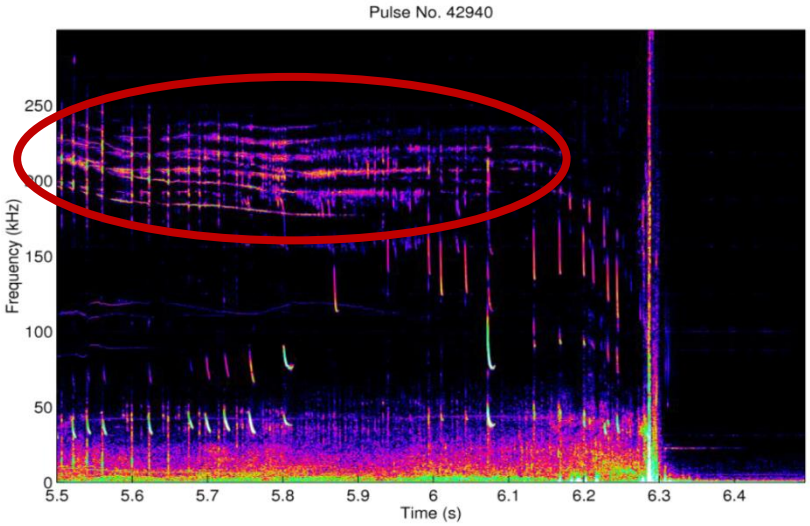
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**See the author list of 'Overview of JET results for optimising ITER operation' by J. Mailloux et al to be published in Nuclear Fusion Special issue: Overview and Summary Papers from the 28th Fusion Energy Conference (Nice, France, 10-15 May 2021)*

JET is the only ongoing fusion device in which alpha effects can be studied experimentally

- TAEs (Toroidal Alfvén Eigenmodes) are instabilities excited by energetic ion radial pressure gradient, experience moderate damping by thermal plasma species
- α-driven TAEs may induce energetic ion transport / losses in burning plasmas (e.g. in ITER)
- TAEs observed in all plasmas with elevated q-profile ($q_0 > 1.5$) in JET DT plasmas (DTE1)
- Caveat: ICRH-accelerated ions always present, provided large TAE drive, dominating α-drive



- No conclusions regarding α-driven TAEs could be drawn from JET DTE1 data [Sharapov NF 1999], unlike from successful TFTR experiments [Budny NF 1992, Spong NF 1995, Nazikian PRL 1997]

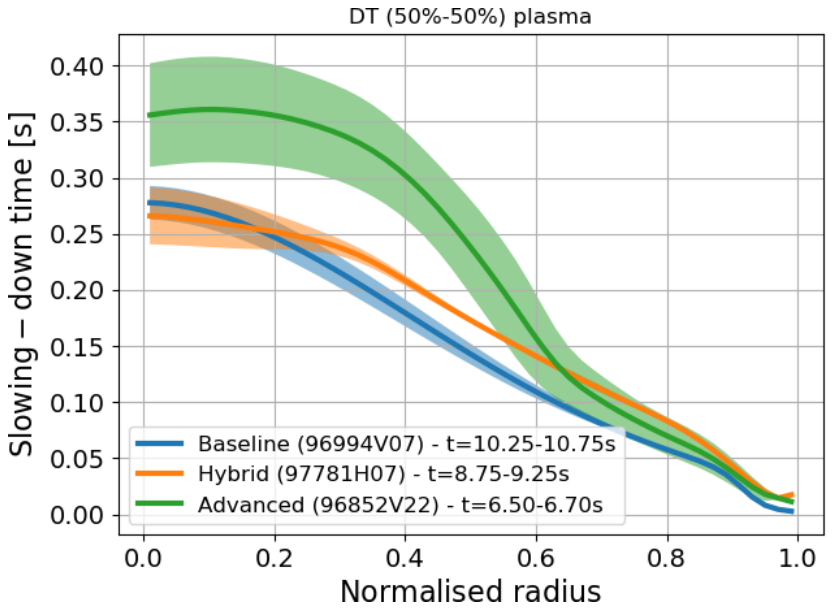
Dedicated advanced scenario under development for the study of alpha-driven instabilities in JET

- α-driven TAE growth / damping rate is given by

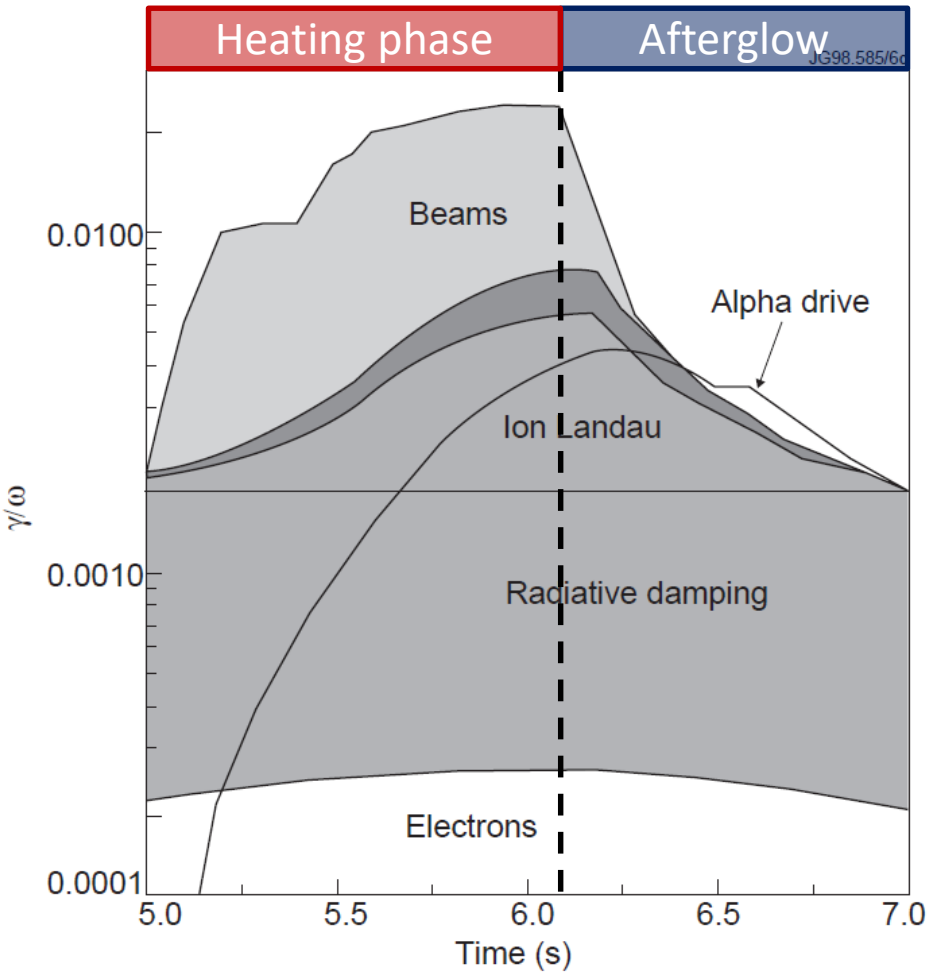
$$\gamma \equiv \gamma_\alpha - \gamma_d = -Cq^2\beta_\alpha\left(1 - \frac{\omega_\alpha^\star}{\omega}\right)F(v_\alpha/v_A) - \gamma_d$$

- Key parameters to maximise TAE drive (γ_α):
  - High α-pressure + large pressure gradient
    - Large P_{add}, T_i (increase fusion yield), T_e (increase slowing-down time)
      → Low n_e, low I_p (still large enough for alpha confinement)
  - Elevated q-profile

- Optimal conditions for TAE excitation not naturally fulfilled by parameters of baseline or hybrid steady-state scenarios in JET DT plasmas
  [Garcia, EX1-989] [Mailloux, OV1-1080]
  → dedicated development of an advanced scenario for JET-ILW

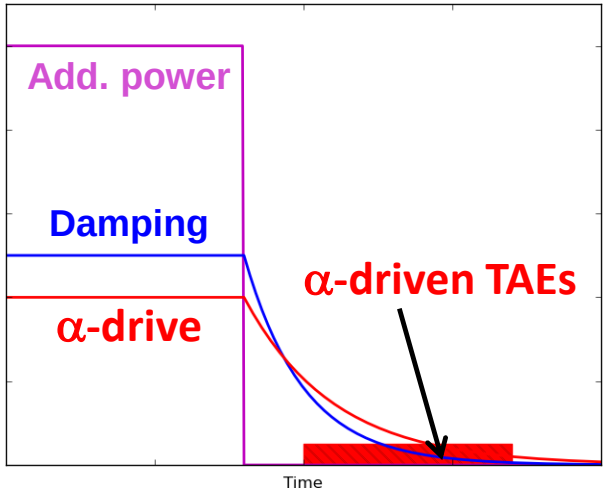


Observation of alpha-driven TAEs in JET requires afterglow phase in the pulse



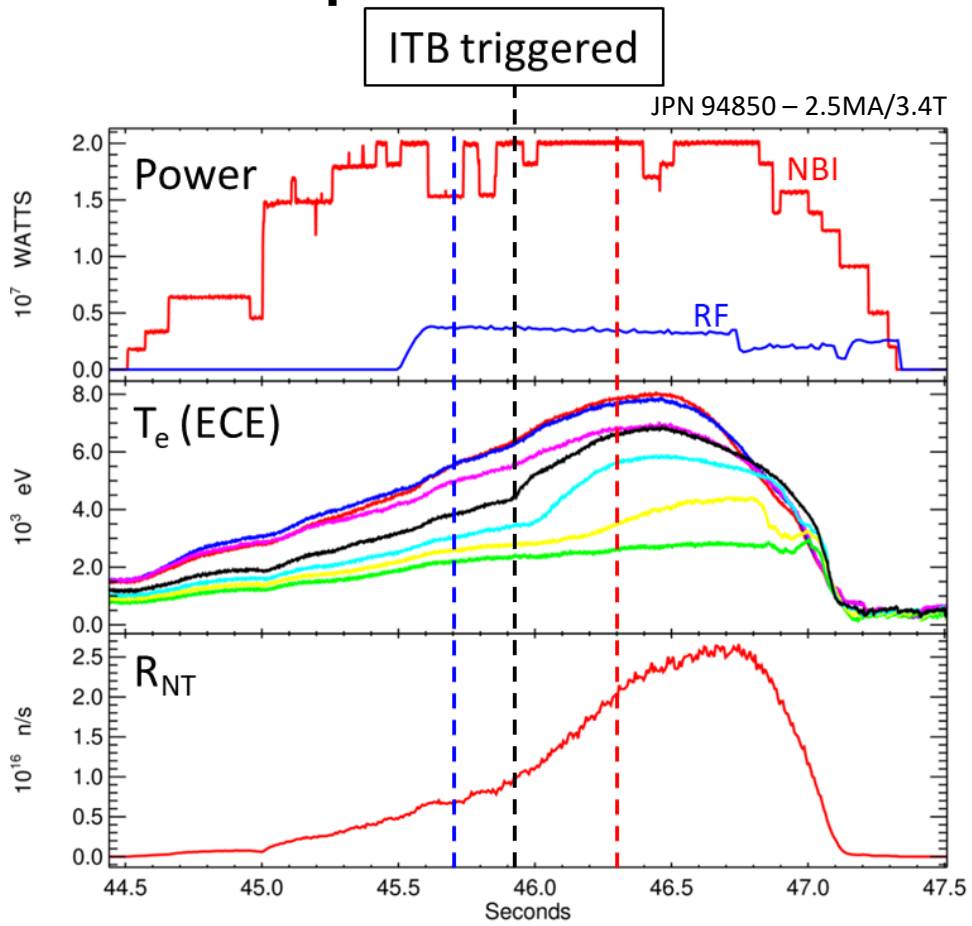
JET DT pulse 41723 – CASTOR-K, MISHKA [Sharapov NF 1999]

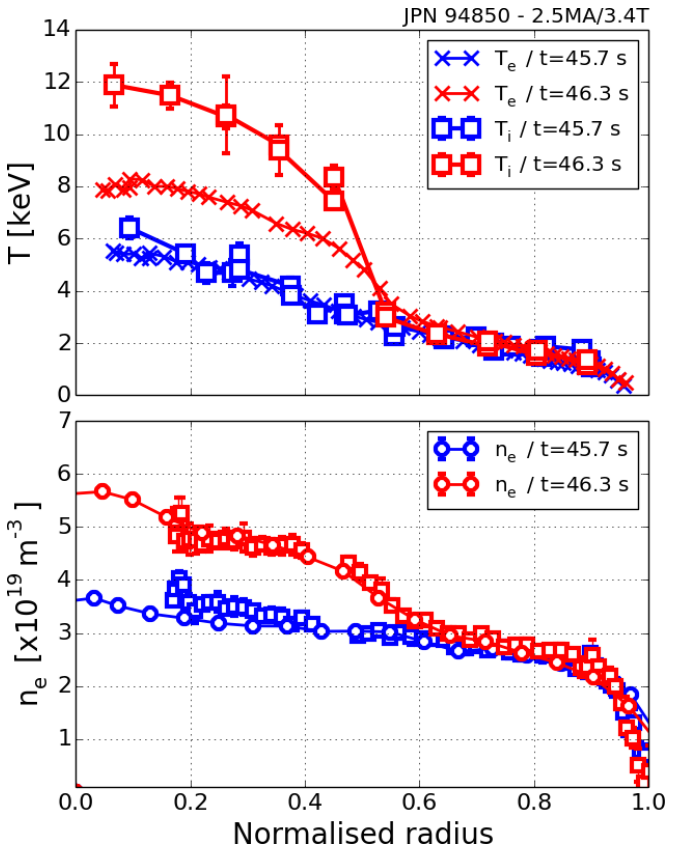
- TAEs very stable during main heating phase
  - Beam + th. damping ~1-2%
  - Alpha drive ~0.1-0.2%
- α-driven TAEs may be observed only during afterglow phase



- No ICRH before afterglow period in DT plasmas
- ICRH used in D plasmas to develop scenario & probe TAE stability

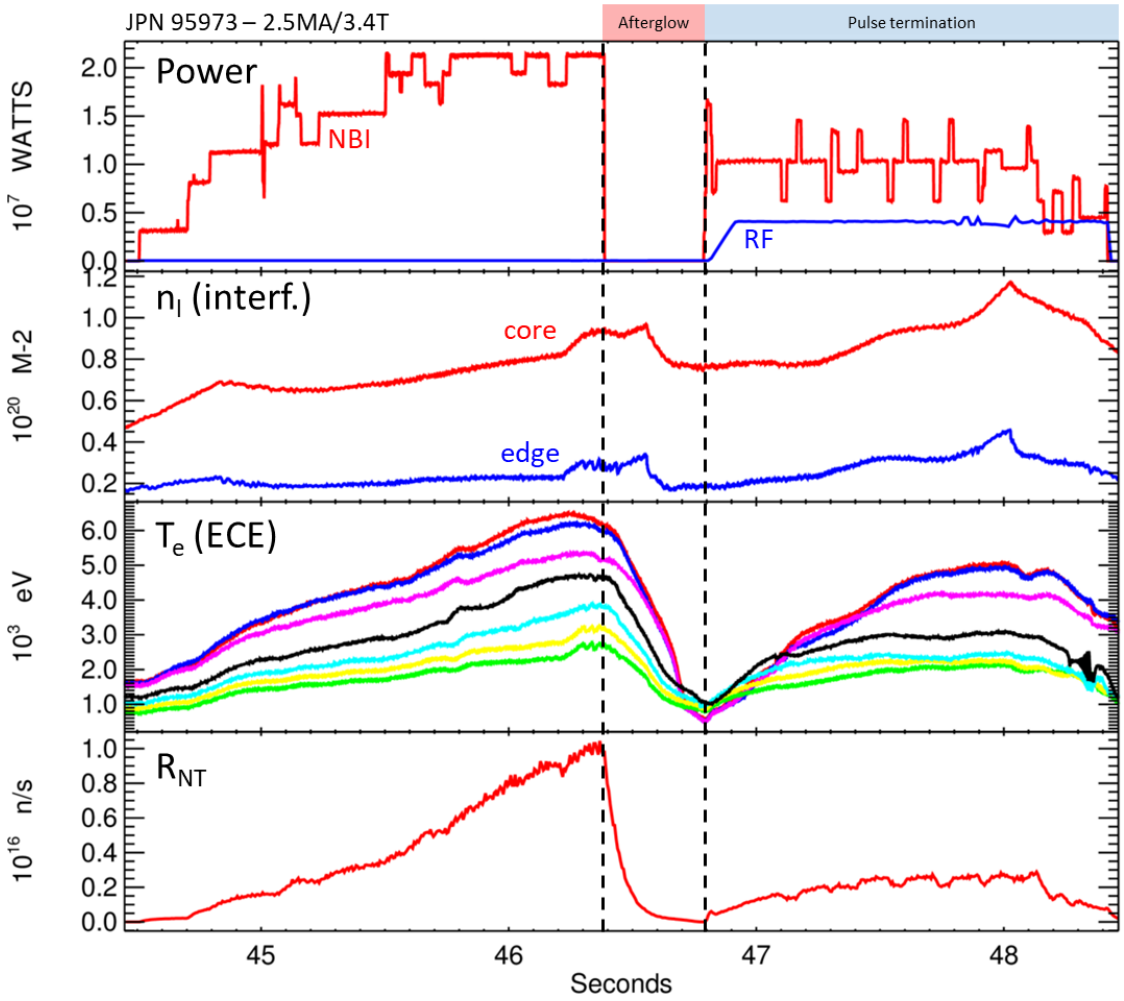
ICRH used to reveal and tune ITBs at relatively moderate levels of NBI power





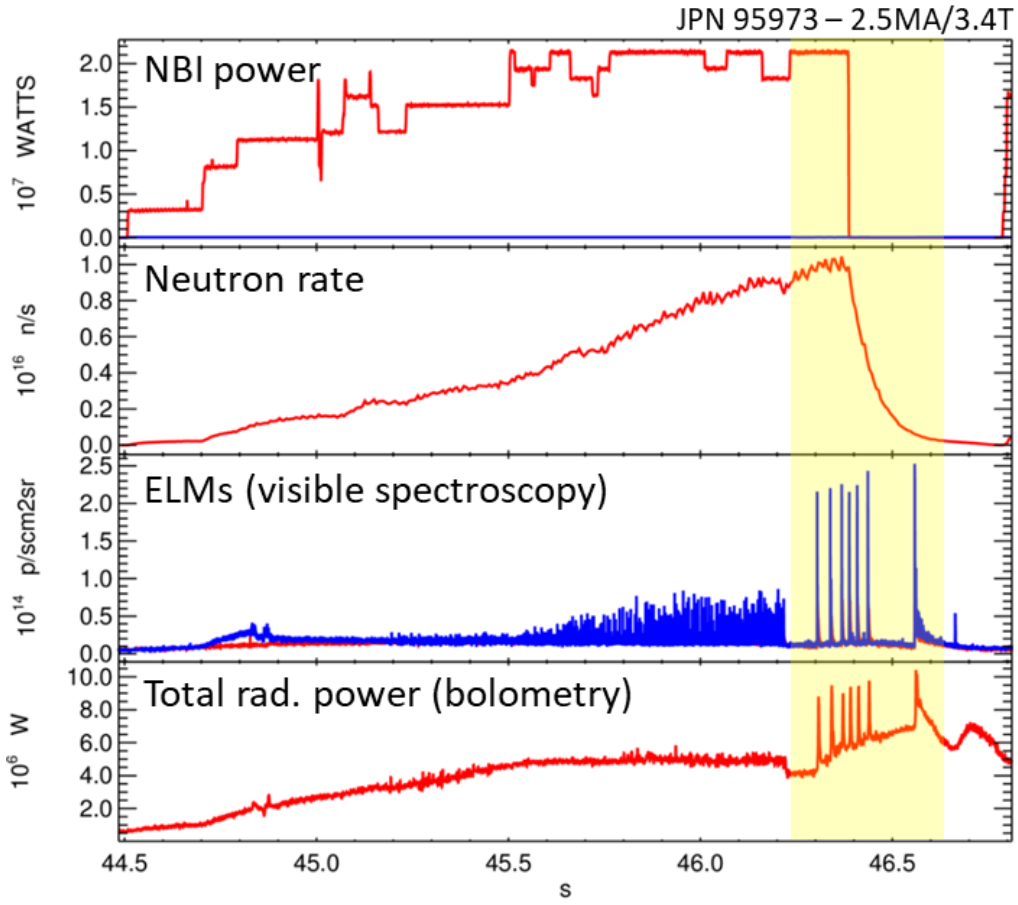
- Pulse 94850: ITB triggered with NBI+ICRH - R_{NT}=2.6x10^{16}/s with P_{tot}=(20+3.8)MW
- No sign of shear reversal in most pulses. ITB triggered upon q=2 surface entering plasma
- Scenario development and ITB tuning done with ~20MW NBI power + ~4MW ICRH, then applied to NBI-only pulses at higher NBI power levels (> 24MW)

Afterglow successfully triggered by bespoke real-time control scheme



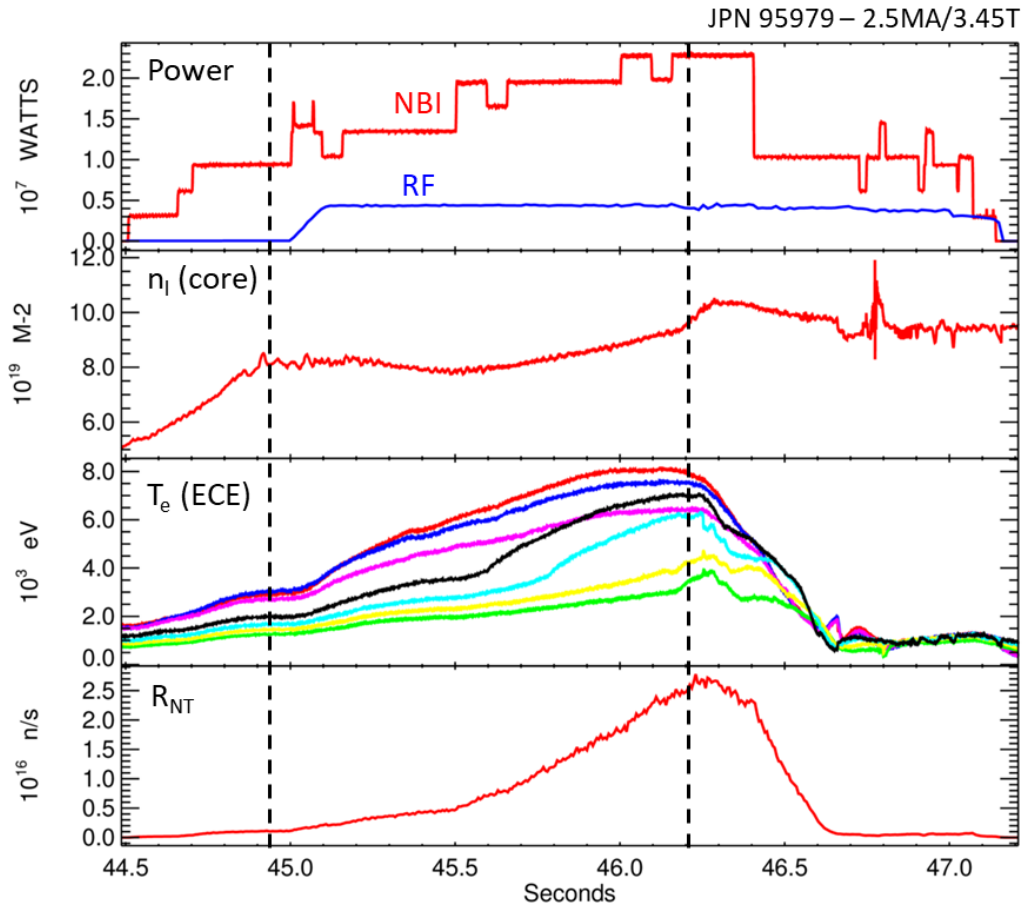
- Pulse 95973 set up to trigger afterglow when
  - Neutron rate large enough (> 8×10^{15}/s)
  - dR_{NT}/dt low (< $1 \times 10^{13}/s^2$)
- First successful demonstration, although just above threshold (limited NBI power)
- RF power applied to ensure safe pulse termination (requirement for DTE2)
- Neutron rate threshold can be used as dud detector (requirement for DTE2)

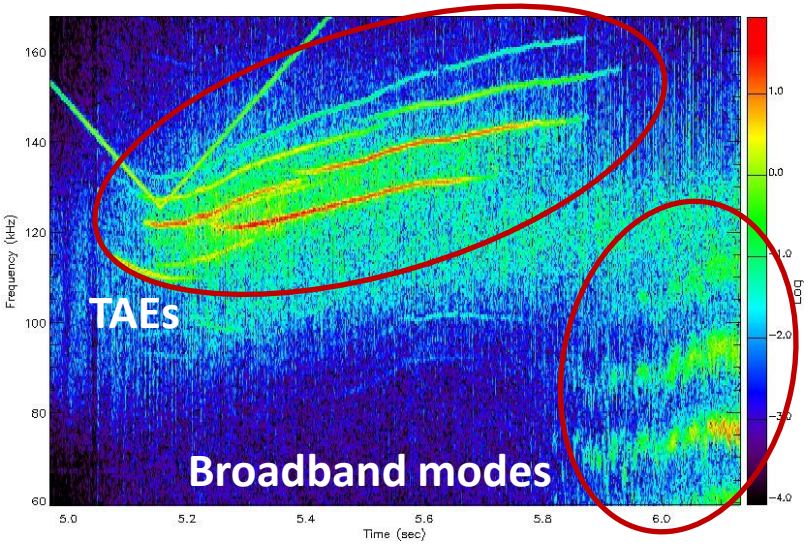
ELM control achieved in advanced scenario



- Pulse 95973: ELM-free/type-I ELMs period before peak performance
- In this example, radiation peaking induces power ramp-down just following afterglow
- ITB beneficial for performance → ELM control needed
- ELM pacing by D pellets (~1.4mm, ~30Hz-45Hz) effective
- Last sessions much less affected by ELM issues compared to previous sessions, despite larger NBI power
- H pellets successfully tested → usable during T campaign (although H minority concentration increase can make ICRH use difficult)

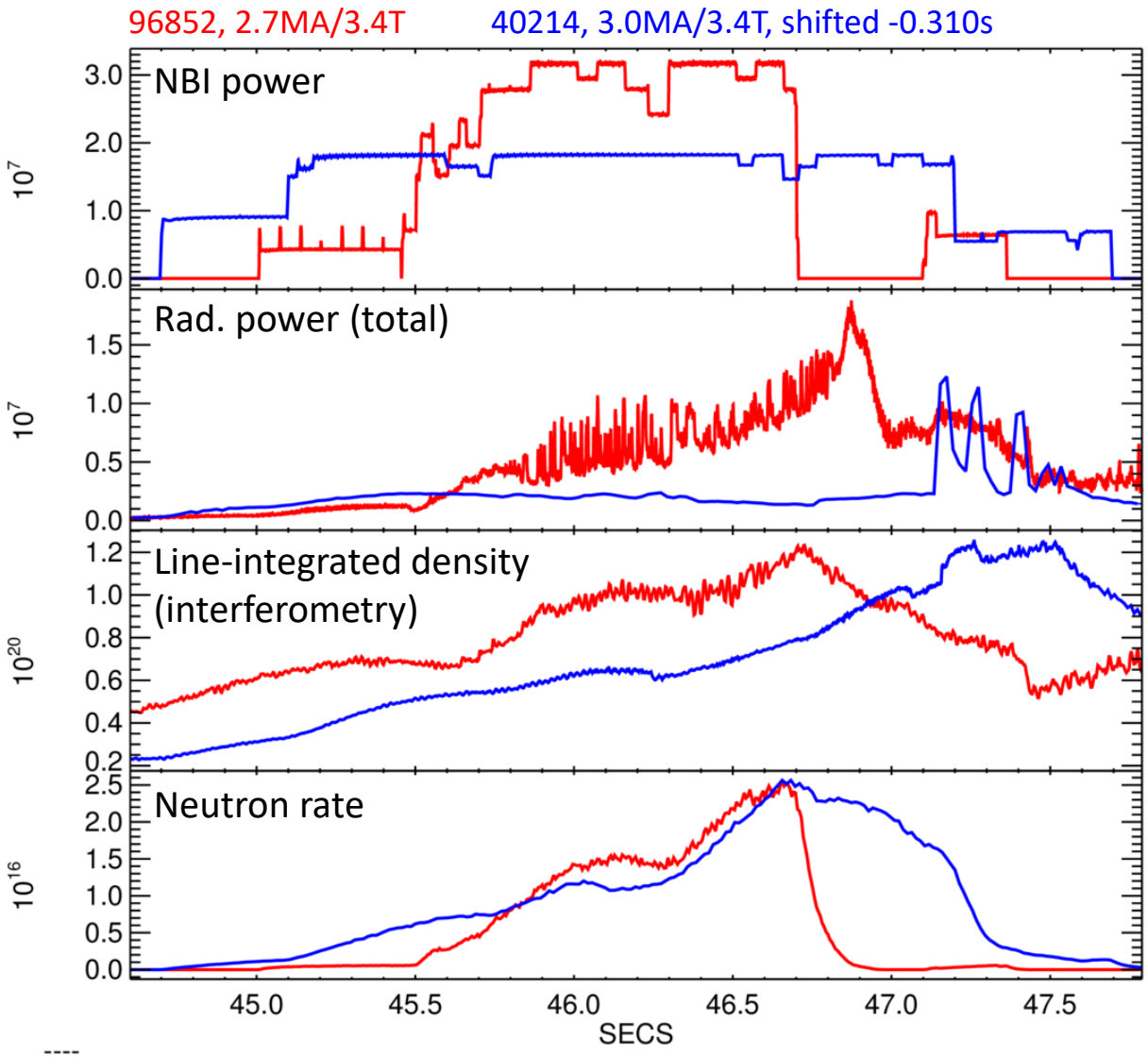
Core TAEs observed during RF-powered ITBs





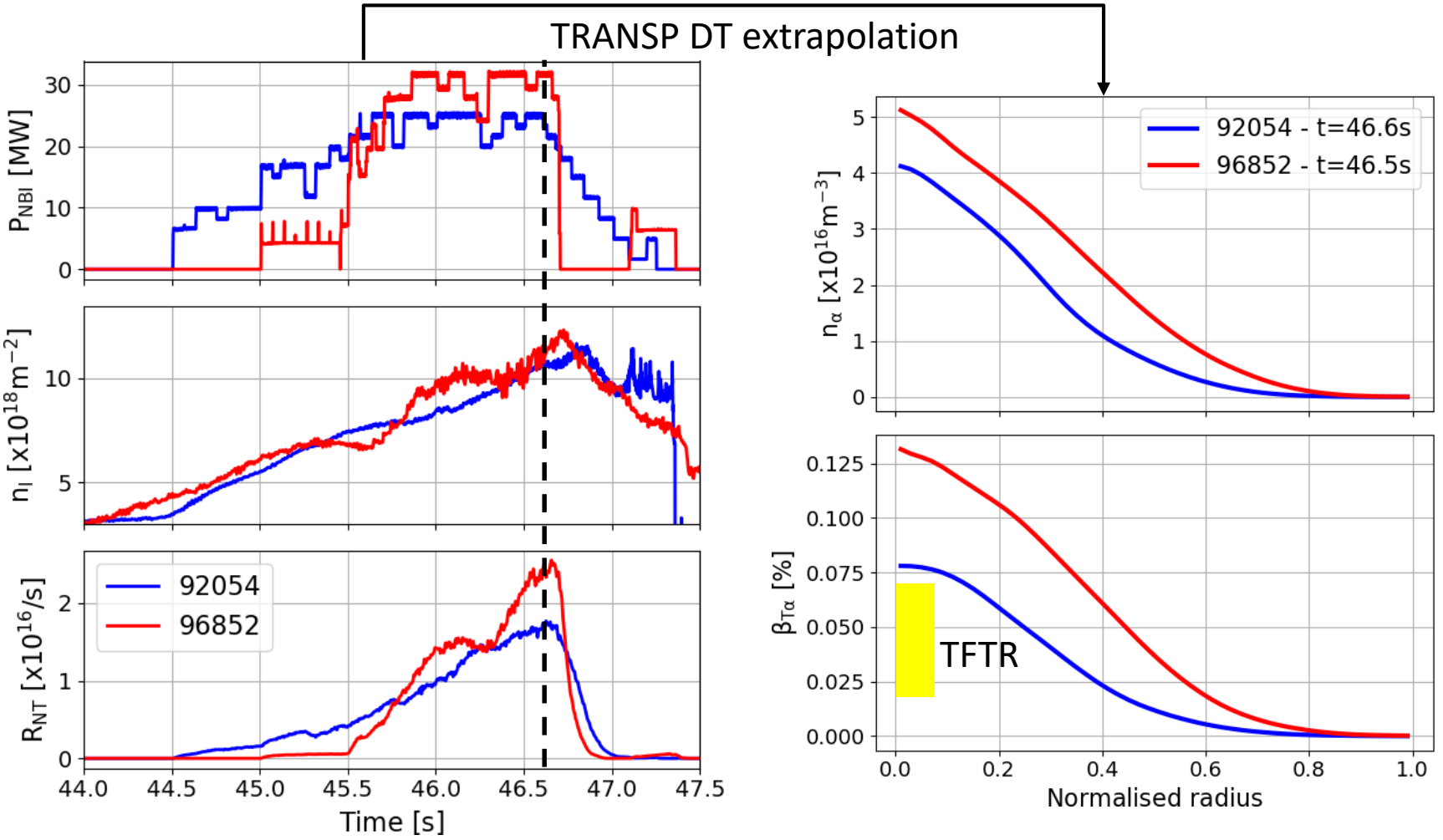
- Core TAEs n=3-7 seen during D(H) ICRH at 51MHz, damped by thermal/NBI ions as P_{NBI} increases
- Broadband modes 60-120kHz often seen in ITB pulses after TAEs disappear under study [Fil 2021]
- Alfvén cascades observed only during pulse termination (shear reversal)

Record pulse, performance comparable to reference C-wall pulse for alpha studies



- Pulse 96852: highest neutron rate obtained to date in JET-ILW with NBI only (R_{NT}=2.55x10^{16}/s)
- Good ITB obtained with NBI starting at 45.0s (differs from previous sessions)
- Performance similar to reference JET C-wall pulse for alpha studies
- Afterglow automatically triggered on R_{NT} rollover
- No ELM-free/type I ELM period seen (pacing pellets used)

Extrapolation to DT confirms significant progress in scenario developement



- Pulse 92054: former best NBI-only pulse for the study of alpha-driven instabilities [Dumont NF 2018]
- TRANSP DT simulation of 96852 very similar to CRONOS DT simulation of 92054 with extrapolated NBI power (31MW) [Garcia NF 2019]

Summary & prospects

- Main deliverable of development phase in D achieved: NBI-only pulses with good fusion performance in the presence of Internal Transport Barriers
- Core-localised TAEs in pulses with ICRH
- Pulses ready to be run in T and DT, include
  - ELM pacing by pellets
  - Real-time control-triggered afterglow
  - Gas injection with T-compatible modules
- Impossible to achieve 100% reproducibility in this scenario - included in strategy for DTE2 by allowing small changes in NBI switch-on time
- Data analysis ongoing, including fast ion transport/losses, MHD…
- Modelling effort ongoing
  - TRANSP modelling of best pulses, using refined equilibrium - extrapolations to DT
  - MHD stability analyses to evaluate damping mechanisms remaining during afterglow phase, and compare to alpha drive
- Experimental effort to couple TAE antenna power in these plasmas → probe stable modes [Tinguely, EX/P3-889]
- JET/TFTR comparisons included in DTE2 experimental plans