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


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Experimental team encompasses wide range of competences

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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
- $\alpha$-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 $\alpha$-drive
- No conclusions regarding $\alpha$-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

• $\alpha$-driven TAE growth / damping rate is given by

$$\gamma = \gamma_\alpha - \gamma_d = -C q^2 \beta_\alpha \left( 1 - \frac{\omega^*_\alpha}{\omega} \right) F\left(\frac{v_\alpha}{v_A}\right) - \gamma_d$$

• Key parameters to maximise TAE drive ($\gamma_\alpha$):
  • High $\alpha$-pressure + large pressure gradient
    • Large $P_{\text{add}}$, $T_i$ (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]
  → dedicated development of an advanced scenario for JET-ILW [Mailloux, OV1-1080]
Observation of alpha-driven TAEs in JET requires afterglow phase in the pulse

- TAEs very stable during main heating phase
  - Beam + th. damping \( \sim 1-2\% \)
  - Alpha drive \( \sim 0.1-0.2\% \)
- \( \alpha \)-driven TAEs may be observed only during afterglow phase

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

- 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 - $R_{NT}=2.6 \times 10^{16}/s$ with $P_{tot}=(20+3.8)\text{MW}$
- 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 (> $8 \times 10^{15}$/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 ($R_{NT}=2.55 \times 10^{16}/s$)
- 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 development

- **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