Facets of alpha particle physics anticipated in D-^{3}He plasmas in preparation for deuterium-tritium at the Joint European Torus

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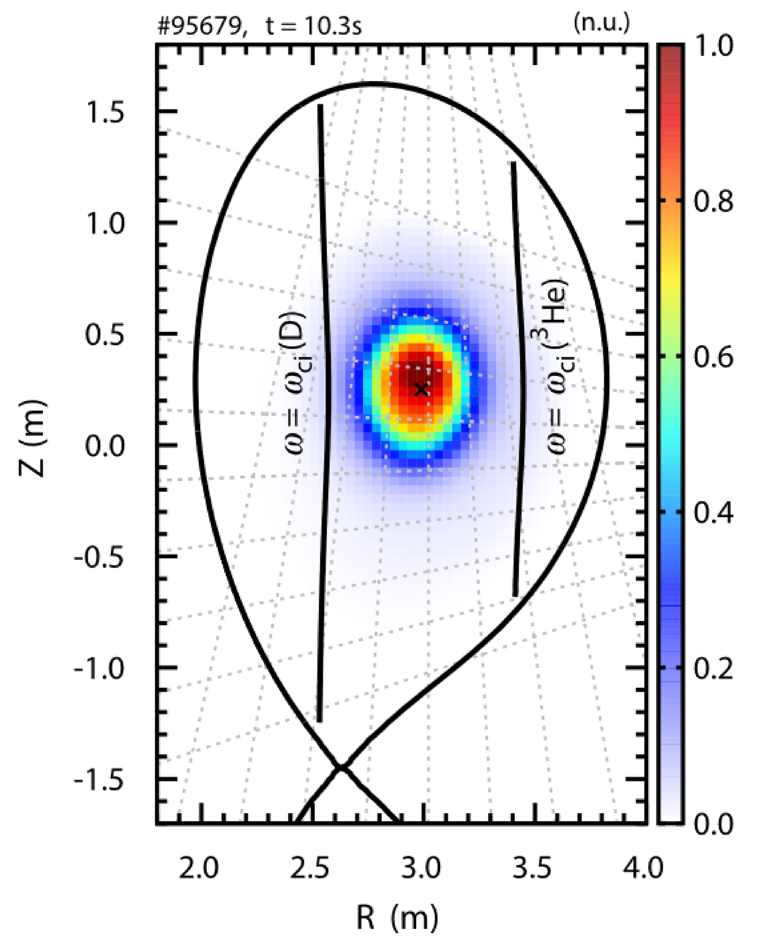
INTRODUCTION

Experiments aimed at the **generation of alpha particles in D-^{3}He** plasmas with radio-frequency (RF) heating [1] were conducted at JET. The experiments had two aims

1) Maximization of **alpha particle production** via the d+^{3}He→ α+ p reaction
2) Observation and studies of alpha particles and fast ions with the **upgraded suite of fast ion diagnostics at JET**

Besides these main goals, the experiments showed peculiar plasma regimes which allowed studying **novel aspects of fast ion physics** and their **interplay with transport and confinement** at JET.

ALPHA PARTICLE GENERATION WITH THE 'THREE-ION' RF SCHEME AT JET

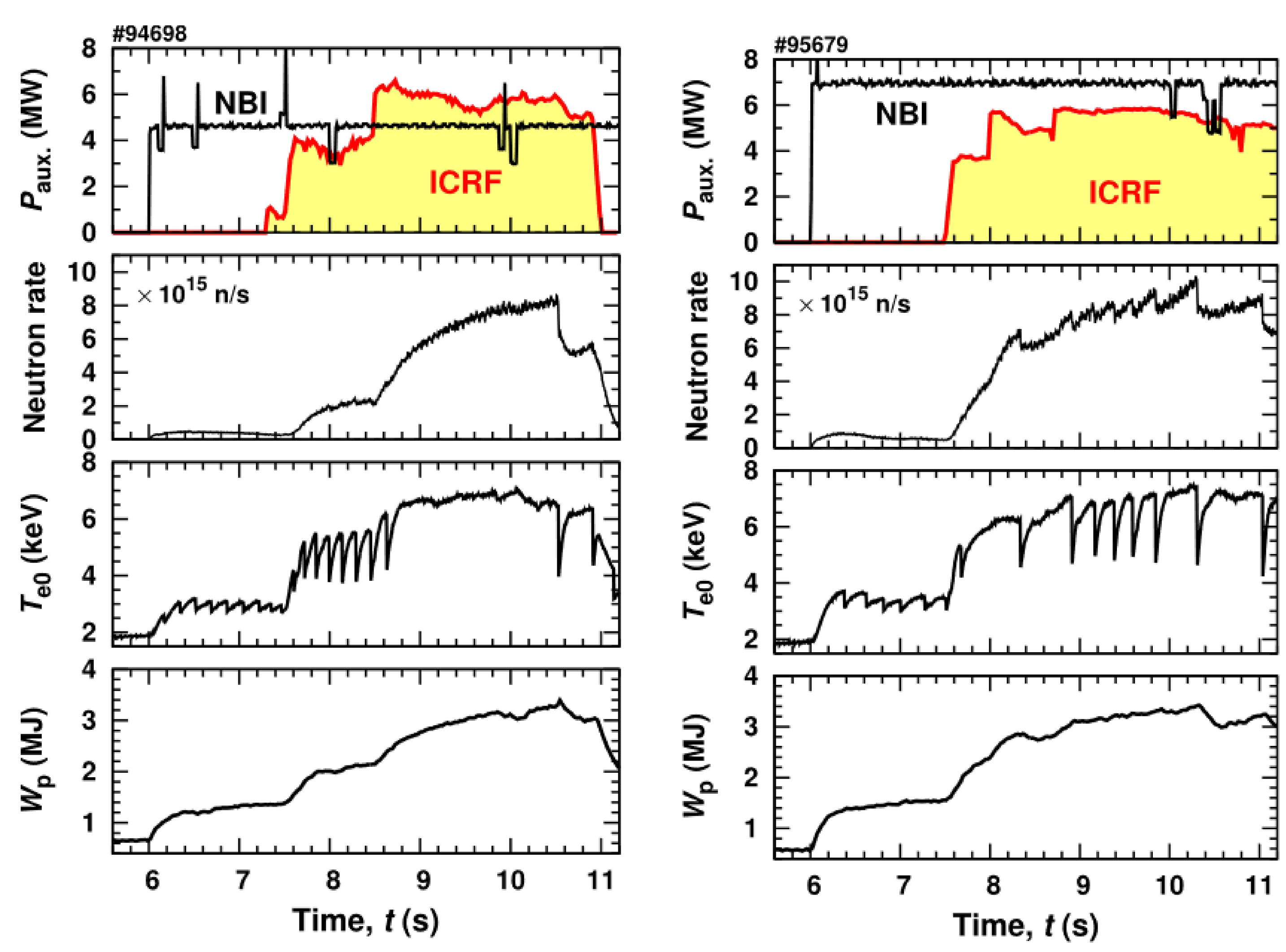


- 50:25 % D-^{3}He plasmas
- The 'three ion' RF scheme [2] is used to accelerate **D-NBI ions** in the core **from 100 keV to the MeV range**
- **D+^{3}He fusion** occurs due to reactions between **MeV range deuterons and thermal ^{3}He**, which acts as the target.

The poloidal cross-section of the JET tokamak with off-axis location of the ion cyclotron resonance for thermal D and ^{3}He ions for 3-ion ICRF fast-ion experiments in D−^{3}He plasmas(3.7 T/2.5 MA, ne_0≈6×10^{19}m−3, f=32.2–33.0 MHz, dipole phasing, E_{NBI}≈100 keV). The coloured image is a tomographic reconstruction of the neutron emissivity for discharge #95679. The dashed lines are the lines of sight of the JET neutron camera.

EXPERIMENTAL RESULTS

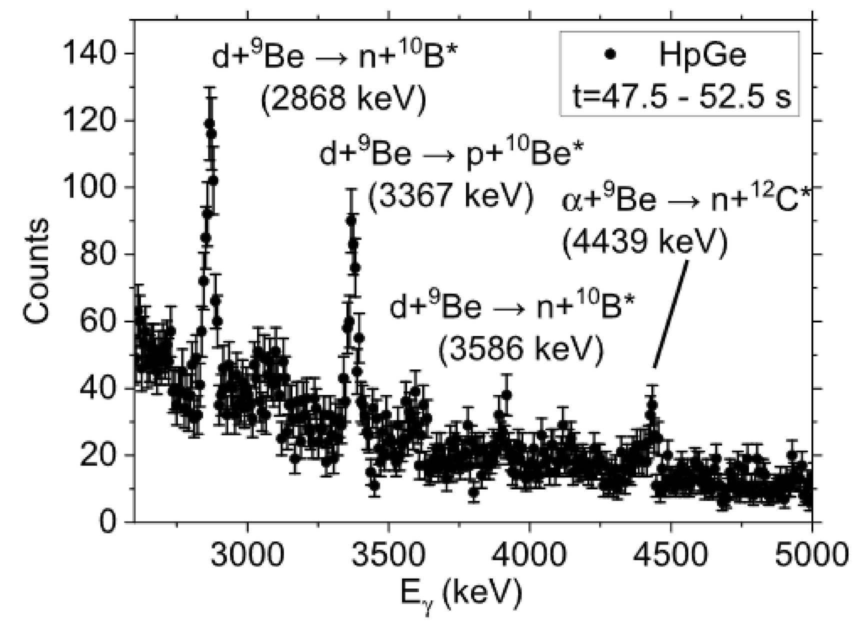
- Two-fold increase of the plasma energy suggests **RF power is efficiently absorbed** by the plasma in the core.
- **Ten-fold increase of the d+d neutron rate**, accompanied with the stabilization of the sawtooth period, indicates the production of MeV range deuterons.
- Depending on the plasma conditions, the (stabilized) **sawtooth period can range from 100 ms to > 1 s**.



Overview of two JET-ILW pulses in mixed D−^{3}He plasmas, where the 3-ion D−(D_{NBI})−^{3}He scenario was applied (3.7 T/2.5MA, n_{e0}≈6×10^{19}m^{-3},n_{3He}/n_e≈20%–25%): (a) #94698 and (b) #95679. The panels from top to bottom show the NBI and ICRF power, neutron rate, the central electron temperature and the plasma stored energy.

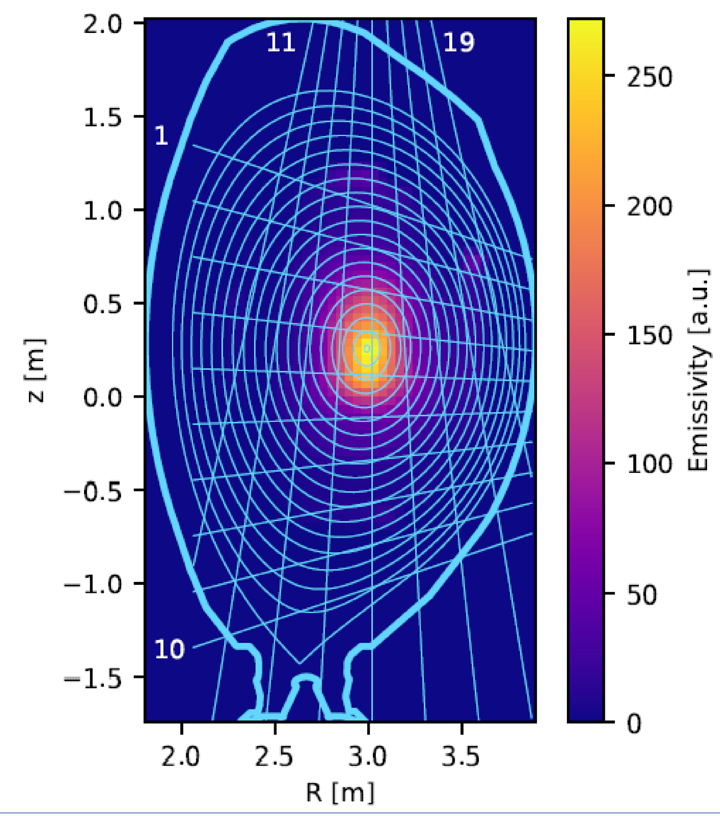
OBSERVATION OF CO-PASSING DEUTERONS IN THE MeV RANGE AND ALPHA PARTICLES WITH GAMMA-RAY SPECTROSCOPY

- **Gamma-ray spectroscopy** measurements with improved instruments provide **direct evidence** of the production of **co-passing MeV range deuterons** and **fusion born alpha particles** by the d+^{9}Be and α+^{9}Be nuclear reactions.
- **Alpha particle generation** is also proven by measurements of **16.4 MeV gamma-rays** from the d+^{3}He fusion reaction.
- The **gamma-ray camera** determines an **experimental image of the alpha particle source** after tomographic inversion of the 16.4 MeV gamma-ray emission.



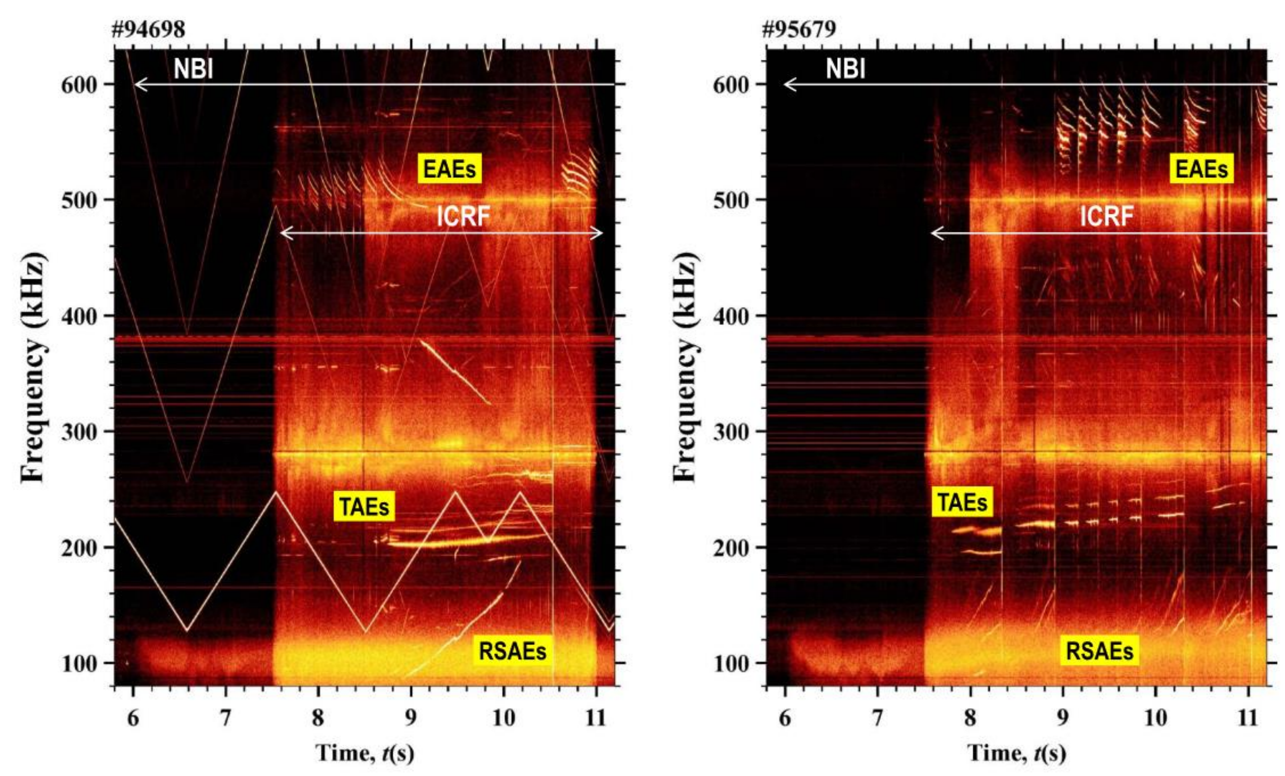
Gamma-ray spectra measured in JET pulse #95679. Data obtained with the high-purity Germanium detector with a vertical line-of-sight passing through the plasma core. The most prominent gamma-ray lines are labelled by the reaction they come from.

Alpha particle source from the d+^{3}He fusion reaction as determined by tomographic inversion of 16.4 MeV gamma-ray measurements using the JET gamma-ray camera.



RICH SPECTRUM OF ALFVEN EIGENMODES

- A rich spectrum of **Alfvén Eigenmodes** (AE) has been observed in the RF+NBI phase, including **Toroidal** (T), **Elliptical** (E) and **Reversed Shear** (RS) instabilities.
- RSAEs imply **q-profile reversal**, which may be linked to the generation of **MeV range co-passing deuterons**. RSAEs are more easily observed when the sawtooth period is > 1 s.
- Mode number analysis show instabilities with **n = 1,2,3 but also n=-2,-1,0**. The latter may be associated **to alpha particle drive [3].**



A rich variety of fast-on driven Alfven eigenmodes is observed in D−^{3}He plasmas using the 3-ion D−(D_{NBI})−^{3}He scenario:(left) #94698 and (right) #95679.

TURBULENCE STABILIZATION BY THE FAST IONS

- Careful T_i measurements with charge exchange reveal **T_e≈T_i** despite the dominant electron heating from the MeV range fast ions. A **≈50% improvement of the H_{98}** confinement factor is observed with respect to similar plasmas w/o MeV range ions.
- Gyrokinetic simulations reveal **the key role of fast ions in suppressing turbulence** through coupling between low (drift wave) and high (TAE-range) frequency instabilities [4]

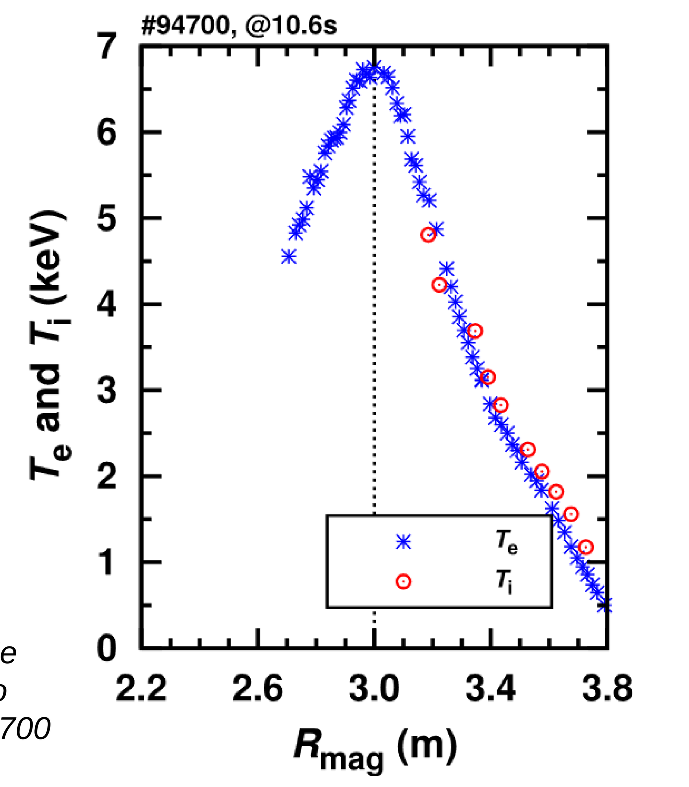


Illustration of the electron and ion temperature profiles in JET experiments in D−^{3}He plasmas, in which the 3-ion D−(D_{NBI})−^{3}He ICRF scenario accelerated D-NBI ions to MeV range energies. The example shows T_e and T_i profiles measured in pulse #94700 at t=10.6 s (P_{ICRF}≈6.0 MW, P_{NBI}≈6.3 MW, n_{e0}≈6×10^{19} m^{-3}).

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