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

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Alpha particles are the key players of a burning plasma as they provide the self-heating required for the sustainment of the fusion burn. At the same time, however, there is only little experimental knowledge on their properties, mostly because of the limited availability of deuterium-tritium (DT) plasmas. Among the challenges that the scientific program of the Joint European Torus (JET) is preparing to face is thus the unambiguous observation of alpha particle physics effects. This encompasses the excitation of alpha-driven Toroidal Alfvén Eigenmodes (TAE) [Ref. 1], as well as the documentation of the general impact of the alpha particles on a number of plasma properties such as, for instance, their expected positive impact on transport through the stabilization of turbulence.

This ambitious scientific goal requires the development of a dedicated scenario at JET, where the production of alpha particles is maximised at limited input power. Of special benefit would here be the capability to produce a steady state supra-thermal deuterium and/or tritium distribution function, as this can in principle maximize the DT reactivity, which is not achieved in a solely thermal plasma. Among the tools that can realize this scenario in DT is an application of the novel '3 ion'scheme [Ref. 2], which is based on ion-cyclotron resonance heating (ICRH) in a mixed species plasma and has recently been applied at JET in D-^{3}He. In this contribution we present the findings of this experiment, which led to the generation of a significant amount of alpha particle through the ^{3}He(d, p)α reaction. We also demonstrate that these plasmas anticipate many of the peculiarities that are commonly associated to alpha particles, without the technical complications of a DT environment, and are thus worth studying per se.

In the set of D-^{3}He JET experiments we have conducted, deuterium ions from the neutral beam injection (NBI) system were accelerated by ICRH. The concentration of ^{3}He ions ~20-25% was chosen to locate the ion-ion hybrid (IIH) layer in the plasma core, where the wave polarization is particularly favourable for ICRH absorption by D-NBI ions through their Doppler shifted fundamental resonance. This leads to the acceleration of D ions up to the MeV range, which is unambiguously demonstrated by a large variety of diagnostics data. Among these are a factor ≈ 10 enhancement of the DD neutron rate, the observation of high energy tails in the neutron spectrometers and neutral particle analyzers, the production of gamma-rays from nuclear reactions driven by the energetic deuterons, and many others. A peculiarity of the scenario is the capability to change the plasma reactivity by modifying the NBI/ICRH heating mix at fixed input powers up to about 15 MW. In all these plasmas, ^{3}He acts as an element for ICRH acceleration of D ions and as the target of the ^{3}He(d, p)α fusion reaction, and we can produce alphas at the level of 10^{16} particle/s and with a mean energy around 4 MeV, with a spectral width that depends on the average energy of the fast deuterium. Of particular relevance is here the unique capability that JET has to determine the image of the fusion born alpha particle source, which is made possible by a tomographic inversion of the 16.4 MeV gamma-ray emission from d+^{3}He fusion reactions using data from the recently enhanced gamma-ray cameras [Ref. 3] (figure 1).

As MeV range ions are produced, the plasma responds in a peculiar way. Despite a dominant electron heating predominantly constrained in the very core region where the IIH layer occurs, we observe $T_i \approx T_e$ throughout the plasma and we achieve core temperatures of about 8 keV at moderately high electron densities of $\approx 6 \cdot 10^{19}$ m^{-3}. This suggests an important contribution of MeV range fast ions in the mitigation of turbulence in a scenario with dominant electron heating that, in many respects, mocks up some of the heating conditions expected by alpha particles in DT [Ref. 4].

Another common observation is the presence of a large variety of fast ion driven MHD and, in particular, of Reversed Shear Alfvén Eigenmodes (RSAE), that persist also in the main heating phase, suggesting that a non-monotonic q-profile is unexpectedly achieved.

Furthermore, we have developed a "slowing down"scenario, whereby the NBI source is switched off while ICRH persists (figure 2), as a way to study the decay of the energetic deuteron and fusion born alpha populations. In the "after glow"phase of this discharge there is a spatial change of the alpha particle source (figure 1), which is accompanied by long lived elliptic Alfvén eigenmodes (EAE). Numerical simulations of the drive and damping of these modes are being carried out to establish the contribution of the fusion born alphas to the drive of the observed EAEs, with application to the possibility of developing a new scenario for the destabilization of α-driven AEs studies in DT in NBI/ICRH plasmas at moderate input power levels.

We finally discuss the implications of these results for JET DT and ITER, in particular with respect to the facets of alpha particle physics that these plasmas anticipate, what can be learnt from them and their readiness level in view of DT.

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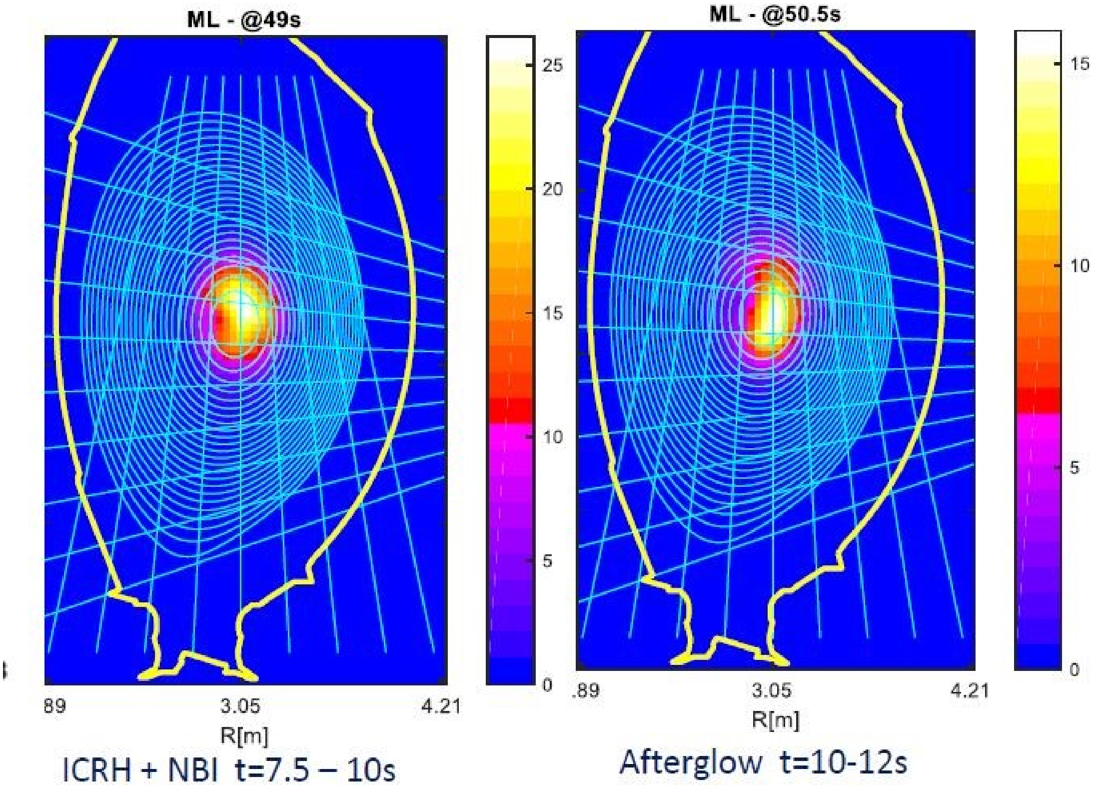

ICRH + NBI t=7.5 – 10s

Afterglow t=10-12s

Figure 1: Image of the alpha particle source before (7.5-10 s) and during (10-12s) the after-glow phase

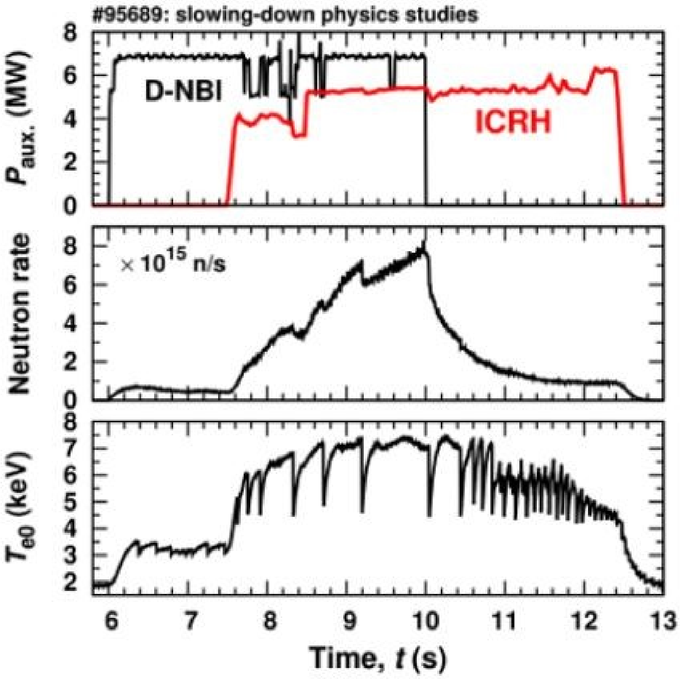

Figure 2: Time traces of the NBI/ICRH auxiliary power, neutron rate and core electron temperature Te0 for JET discharge #95689 (afterglow scenario)

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