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Diagnostics based on Helium Neutral Beams in ITER

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1. INTRODUCTION

Reducing the activation of the vessel and its components during the early phase of ITER operation is important. One scheme of minimising the activation is to use helium as the heating neutral beam species. This gives rise to a concern about how effective diagnostic spectroscopy will be with such beams. The diagnostic use of deuterium heating beams is well established yielding, for example, ion temperature profiles, plasma rotation, magnetic fields, impurity concentration, Z_{eff} and beam penetration measurements. The experience with helium beams is more limited and there are greater uncertainties in the fundamental atomic data. A helium neutral beam has certain potential advantages: a reduced beam halo, no fractional energy compo-nents, greater penetration than deuterium beams and possibly more efficient charge exchange donation in certain energy regions. At JET a series of experiments have been undertaken with helium beams to address these issues. A number of these plasmas have very high concentrations of He, up to 100%, which is also of relevance for future ITER operations. Beam emission and charge exchange spectra were detectable and useful. It is shown that the diagnostic capability is high matching that of deuterium but with some marked differences.

2. JET EXPERIMENTS AND IMPLICATIONS FOR ITER

The JET experiments have used both a He-doped deuterium beam and a full helium beam. The doped D_2/He system was developed[1] to make fast He beams routinely available by using the heating beam as a parasitic He source. The beam emission is viewed by a twelve chord spectrometer whose lines of sight are almost parallel to the beam at their intersections, located between the boundary and the plasma centre. By sweeping the plasma, a much higher spatial resolution is achieved together with an in situ relative calibration between lines of sight. A high clearance L-mode plasma was selected for all experiments to give ELM free plasmas. The plasma was swept by ±6cm with a ramp rate of ~ 5cm/s. The volume varied by ~ 2% and the line averaged density was constant to within 5%.

2.1. PHENOMENOLOGY

The two electron nature of helium produces a rich spectral phenomenology from both HeI and HeII emission, from both beam and plasma. This has no equivalent in a deuterium beam but initial studies show it to have special diagnostic potential. Note that at the JET beam energies there is a negligible motional (linear) Stark effect on then $n = 3$ He levels. Although this simplifies the spectral analysis, there is no direct MSE diagnostic. The immediate analysis focuses on beam emission (BME) and impurity charge exchange (CXS) which are the equivalents of these for deuterium beams and on the role of metastables.

2.2. BEAM EMISSION

Monoenergetic, essentially Stark unperturbed beam emission from helium is much simpler than that from of deuterium. The Doppler beam emission spectra is well separated from the 'cold' edge HeI emission at most radii, and is not contaminated by impurities. Figure 1 shows the principal characteristics of the singlet and triplet emission. Weak collisonal coupling between the two metastables of helium, $1s^2\,{}^1S$ and $1s2s\,{}^3S$, means that there are effectively two beams in the plasma attenuating with different decay lengths. The true excited populations have formation and relaxation lengths of ~ 3cm and can be treated as quasistatic relative to the unrelaxed beam. The singlet beam is observed to penetrate to the centre of the plasma while the triplet side stops at ~ 30cm along the beam. Initial modelling of the triplet [2,3] indicates a larger Z_{eff} than measured by bremsstrahlung (without allowance for 'hollow' profiles). The edge triplet BME reflects the decay of an initial metastable entry fraction in the beam rather than a collisonally regenerated population in the plasma. This fraction can be estimated directly from the edge singlet BME as seen in Fig. 2. Full collisional-radiative BME coefficients have been calculated. Ratios are plotted in the figure to cancel any uncertainities in the viewed volume.

When scaled to ITER conditions the triplet BME can be used to measure the rapidly varying ne edge profile and ITB shear region. These clear triplet and singlet BME signals can be used to diagnose beam deposition, plasma density and Z_{eff} more clearly than the deuterium BME. The precision of the deduction is limited by the quality of the ion impact excitation cross sections for higher Z impurities ($Z \geq 3$).

2.3. CHARGE EXCHANGE

Core impurity measurements rely on modelling the re-distribution and cascade emission following state selective single charge transfer from the beams into high $n\ell$ states of plasma impurities. In comparison with the D beams it is notable that the CXS emission is stronger towards the edge, where the He metastable is an efficient donor, and weaker at the core where the tightly bound ground state is the donor. The HeII $n = 4 - 3$ charge exchange emission at 468.5nm is present, as previously recorded[4]. The spectral analysis is complicated since it requires modelling of the helium plume, which is appreciable. It is nonetheless tractable and is a favourable method of measuring core helium concentrations. Neon was actively introduced (up to 4% concentration) to investigate the CXS diagnostic capability of higher Z impurities with He beams launched into He plasmas. Figure 3 shows that one of the significant effects of a helium plasma is to completely suppress carbon in the confined plasma, as seen by the absence of the CVI CXS emission (the suppression is also confirmed by VUV spectroscopy). The NeX (11 - 10) CXS signal is evident and comparable to that in D beam observations. Results from the different viewing lines show that, again, the most effective CXS is in the edge region where the triplet is the primary donor. In the practical diagnostic procedure with D beams, the CVI CXS emission is used to determine T_i and the weaker NeX signal yields the concentration. Its absence in the He beam/He plasma case means that the HeII CXS signal must provide the ion temperature. Hence the methodology will be different but CXS with He beams is a feasible diagnostic. For a primarily D plasma CVI CXS driven by the He beam is expected to be useful. Confirmation in the experiment was not possible since dilution of the helium plasma by introducing CD_4 was prohibited.

CONCLUSIONS

Experiments at JET confirm that the combined beam emission and charge exchange analysis can provide a significant diagnostic for ITER plasmas. Using helium beams and H_e plasmas to minimise vessel activation does not imply a major impairment to diagnostic capability but reduction techniques must be altered. The most marked difference from D beams is the clear BME signals. Over the extent of the H_e triplet, BME measurements yield edge parameters and conventional CXS analysis gives ion temperatures and concentrations. Deeper into the plasma the combination of BME and CXS signals can be used to deduce a collisionality profile. Continuing work will address the limitations in the precision of interpretation due to the present ion impact excitation data and improvements will be incorporated into the Atomic Data and Analysis Structure (ADAS)[5]. This provides modelling of effective stopping and emission data for helium beams at all energies for ITER.

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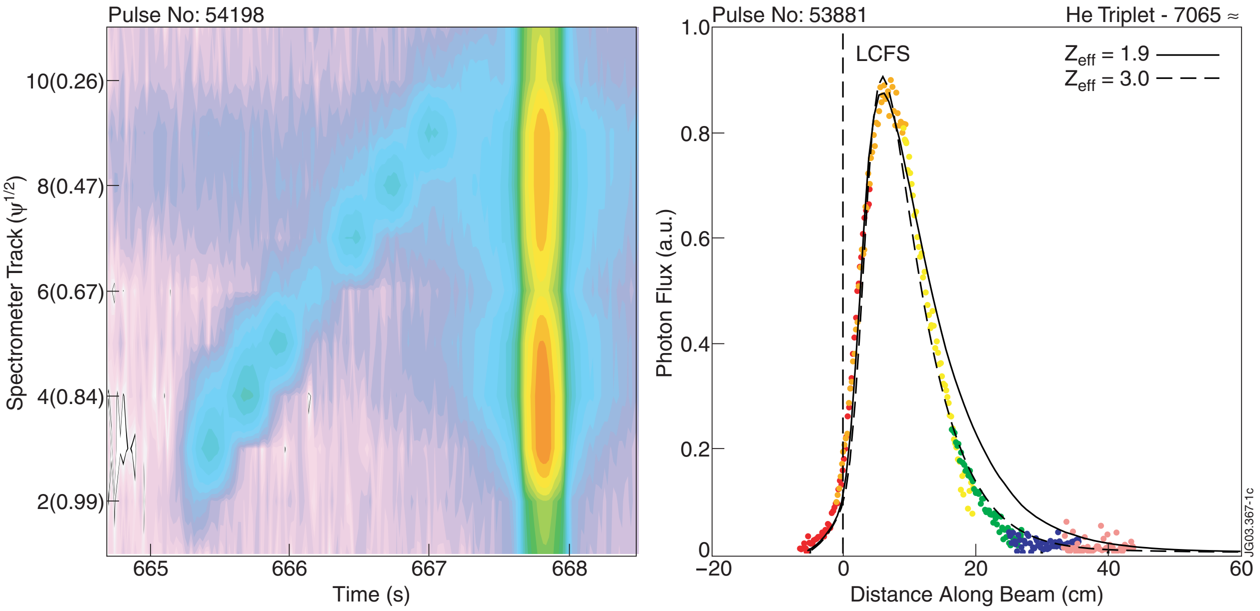

Figure 1: Beam emission characteristics of HeI: (left) the singlet, 667.8nm is present across the plasma radius and is well separated from the edge emission by the Doppler shift. The triplet, 706.5nm (right), is not measurable beyond 300mm along the beam. Note that line averaged Z_{eff} measured from the bremsstrahlung is 1.9.

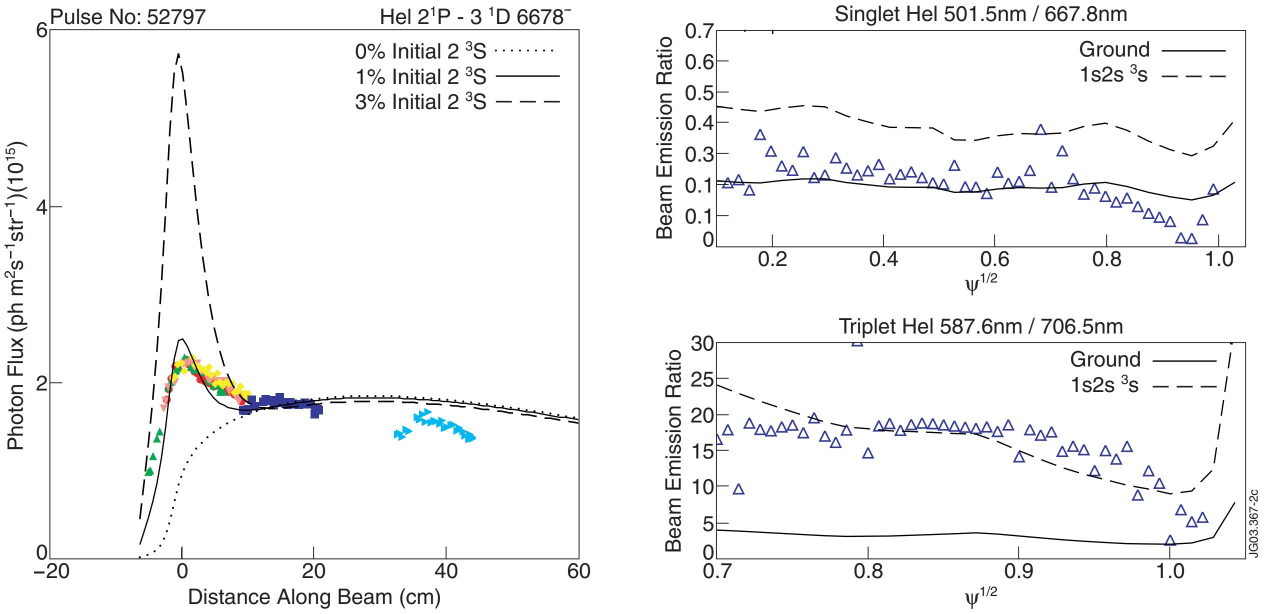

Figure 2: Composition of H_e beams: (left) modelled[2,3] 667.8nm emission at three initial metastable fractions. (right) measured ratios (triangles) of singlet and triplet beam emission showing their principal driving source and inter alia validation of the BME calculations. Note that the $\psi^{1/2}$ scales are different reflecting the region of valid data across the plasma.

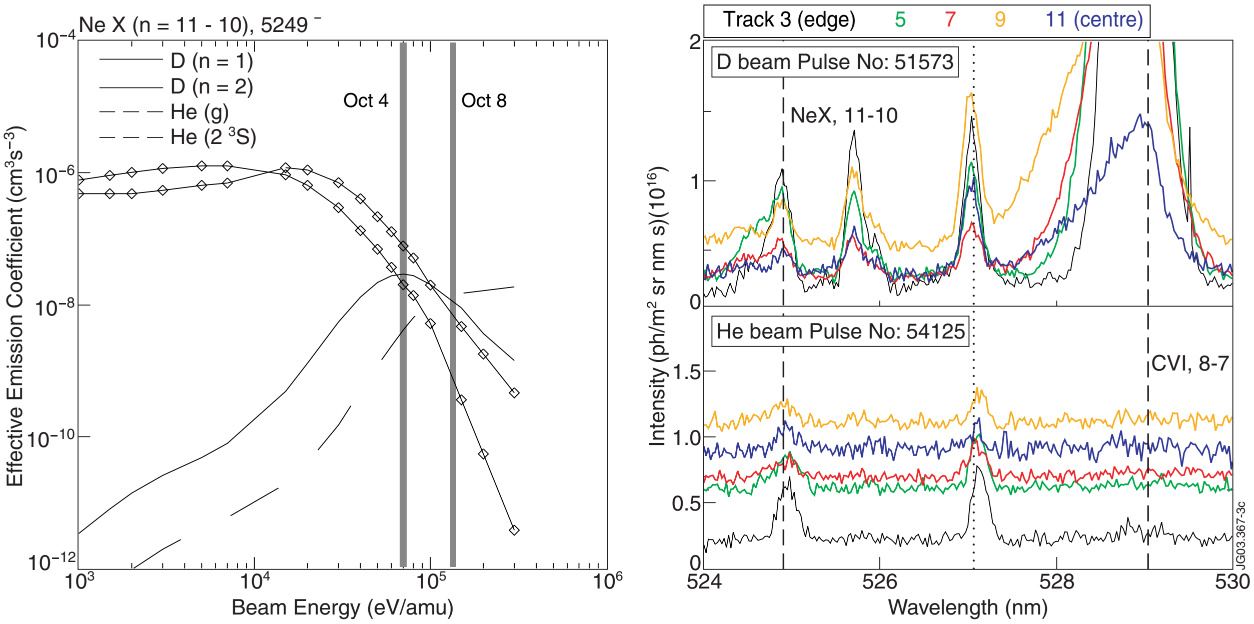

Figure 3: Charge exchange emission: (left) metastable beam donor influence on the effective emission coefficients from fully ionised Ne X — the coefficient is given relative to the donor population. (right) Progression of NeX 524.8nm (n = 11 - 10) CXS emission across the plasma in a deuterium and helium plasma.