Charge Exchange Spectroscopy Results of JET Neutral Helium Beam Heating Experiments

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Introduction

Helium beam fuelling experiments provide an ideal test bed for the investigation of slowing-down low energy alpha particles (< 145 keV) and their velocity distribution functions as well as their radial distribution. Considerable progress has been achieved in the modelling of the expected charge exchange spectra observed parallel and perpendicular to the magnetic field and the development of suitable spectral analysis procedures /1/. The first full analysis of radial profiles of temperature and slowing-down and thermalised alpha particle densities has however revealed several puzzling results, such as anisotropic ion temperatures and phase differences in the sawtooth oscillation of fast and thermal particles which require intense future modelling efforts.

Results

The fast particle component in the observed charge exchange spectra ($He^0 + He^{2+} \rightarrow He^{2+} + He^{+,*}$, n=4→n=3, at λ=4685Å) is found to be in excellent agreement with predictions which are based on anisotropic velocity distribution functions obtained from the analytical solution of the neutral injection Fokker Planck equation /1,2/. Independent numerical calculations solving the Fokker Planck equation /3/ have confirmed that numerical and analytical solution agree in a first approximation (cf. Fig.1). The complete velocity distribution function covering the energy range up to the neutral beam injection energy may therefore be represented as the sum of an anisotropic slowing-down function and a Maxwellian thermal distribution function. This implies that analytical expressions may be used for the calculation of the expected charge exchange spectra cf. /1/ and usable plasma parameters such as ion temperature, thermal ion density and fast particle density can be extracted from a non-linear least square parameter fit to the observed spectra.

The effects of collision energy dependent charge transfer cross-sections on the intensity and shape of the observed spectrum is taken into account. Similar to the thermal case, where the observed spectrum maintains its Gaussian character, the predicted slowing-down spectrum is essentially unaffected in its spectral form but is modified in its amplitude and peak position (Fig.2). The spectral fit involves therefore only the determination of an amplitude factor (i.e. fast particle density) and the actual shape is calculated on the basis of known geometry factors (pitch angle etc.), electron temperature data and neutral beam injection energy.

Radially and temporally resolved measurements of fast and thermal helium ion density profiles have shown that the injection process is characterised by a change-over from a distinctly non-

Maxwellian alpha particle velocity distribution function to a dominantly Maxwellian distribution function (Fig.3). A novel result, which is confirmed by a range of pulses with different target densities and helium beam powers, is that in the first few hundred milliseconds following the start of injection the ion temperature $T_{i,\parallel}$ deduced from an observation parallel to the toroidal magnetic field is distinctively lower than the ion temperature $T_{i,\perp}$ deduced from a spectrum observed perpendicular to the magnetic field. The values of central electron temperature based on ECE measurements appear to follow a value in between $T_{i,\perp}$ and $T_{i,\parallel}$ (Fig.4).

The ion temperature anisotropy observed in the initial helium beam fuelling phase is contradicting a classical ion-ion isotropisation time of the order 30 to 40 msec. The slowing-down time is of the order 0.3 to 0.6 sec (Fig.5). A further interesting experimental result is the phase difference between thermal and non-thermal particle densities which was reported already for a single central channel in a previous paper /2/. The present results (Fig.6) show clearly the sawtooth propagation over the radius. It is important to note that the fast particle density sawtooth activity is in phase with ion and electron temperature, but out of phase with the thermalised alpha particle density.

The fast ion density profile (Fig.6) which is rather peaked at the start of neutral beam injection is broadened subsequently but increases only slightly in its amplitude for the case of an approximately constant source rate and target density. Fig.7 shows the ratio of fast to thermal population for three different radii (r/a=0.14, r/a=0.26 and r/a=0.51 respectively).

References:

/1/ M von Hellermann et al., JET-P(92)95, Pl.Phys. Contr.Fus.1993
/2/ W.G.F. Core, JET-P(93)19
/3/ B.Wolle, L.Eriksson, JET-P(92)30, Pl.Phys.Contr.Fus.1993

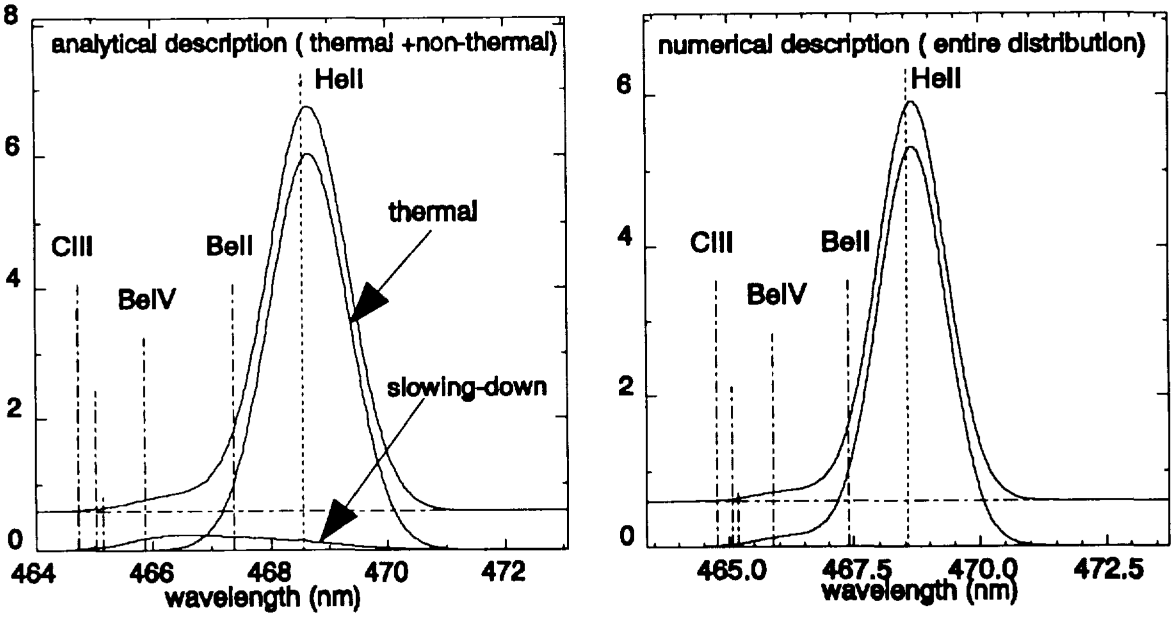

Fig.1

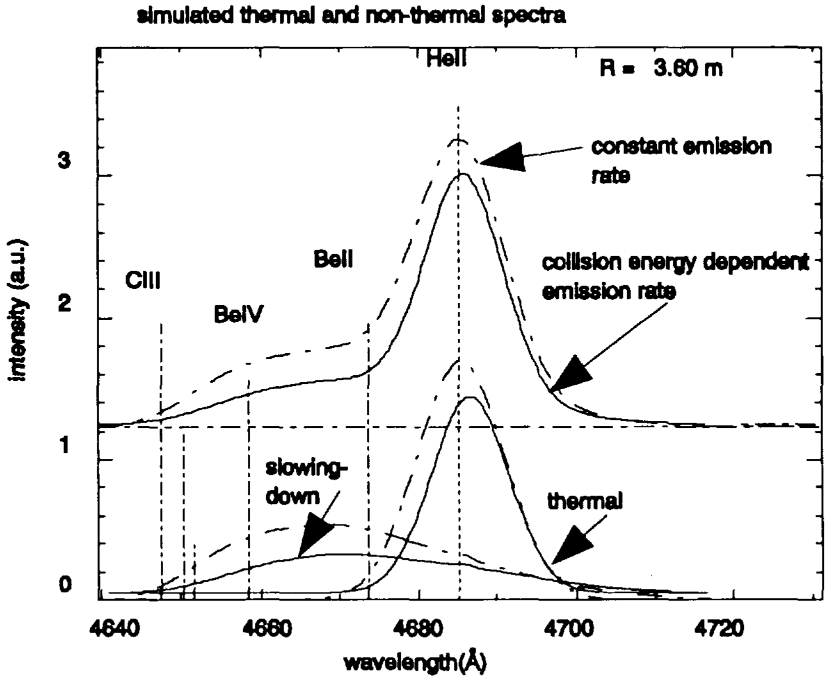
simulated thermal and non-thermal spectra
HeII
R = 3.60 m
constant emission rate
collision energy dependent emission rate
CIII
BeIV
BeII
slowing-down
thermal
intensity (a.u.)
0
1
2
3
4640
4660
4680
4700
4720
wavelength(Å)

Fig.2

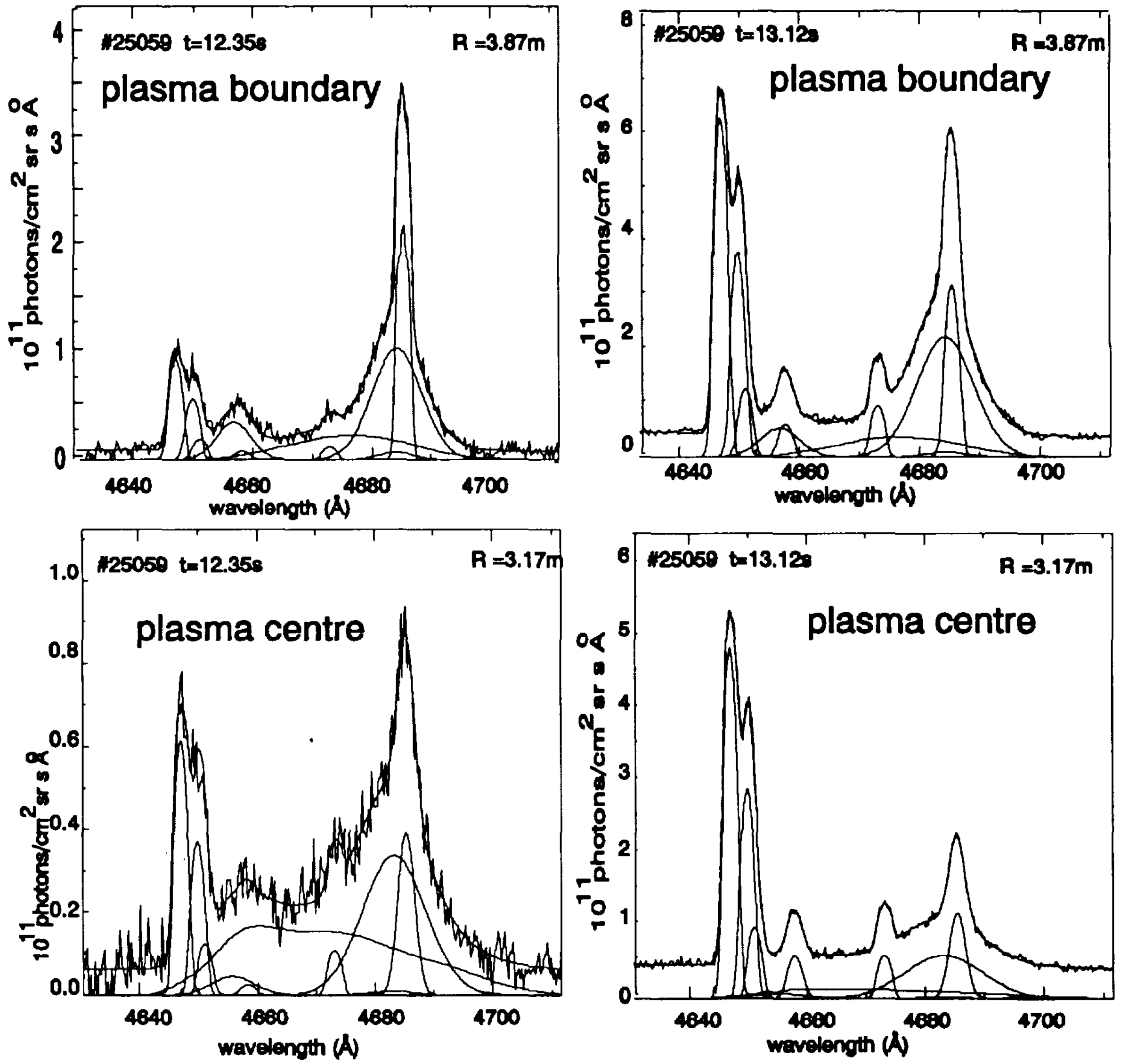
#25059 t=12.35s
R =3.87m
plasma boundary
#25059 t=13.12s
R =3.87m
plasma boundary
#25059 t=12.35s
R =3.17m
plasma centre
#25059 t=13.12s
R =3.17m
plasma centre
10^11 photons/cm^2 sr s Å
wavelength (Å)
4640
4660
4680
4700
0
1
2
3
4
6
8
0.0
0.2
0.4
0.6
0.8
1.0
5

Fig.3

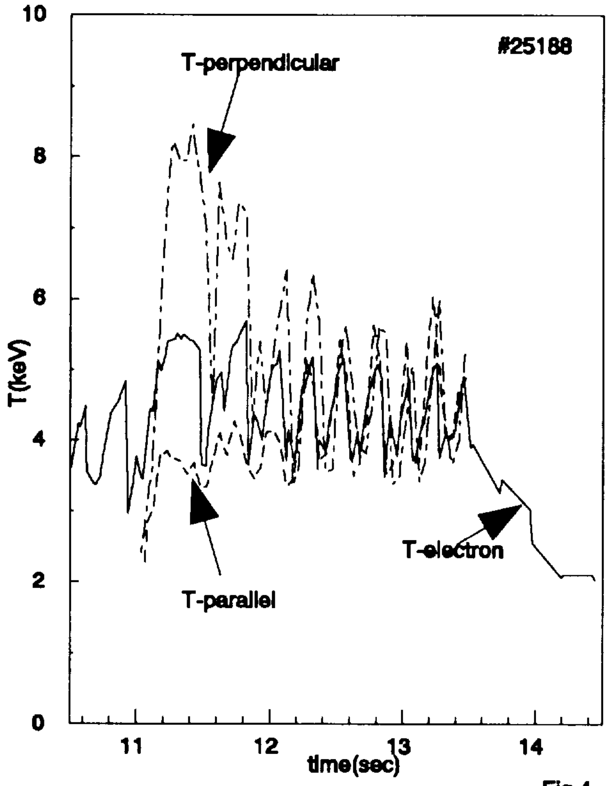

Fig.4

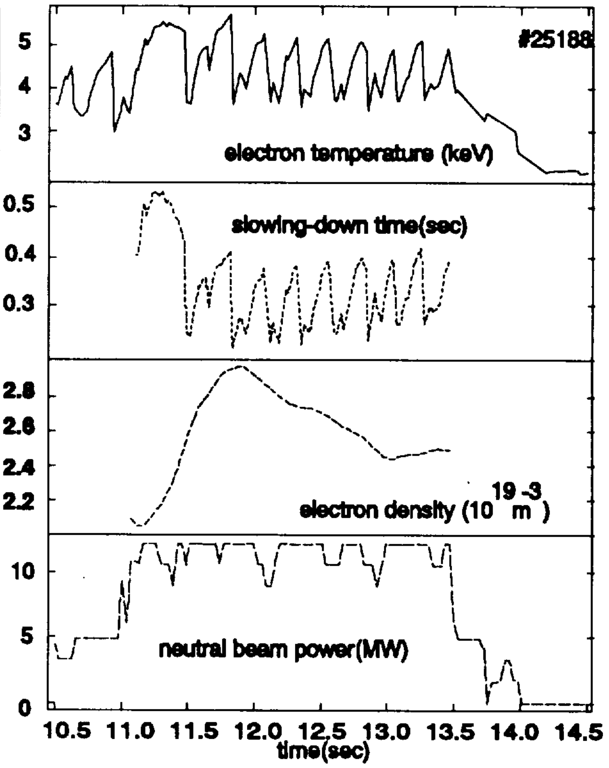

Fig.5

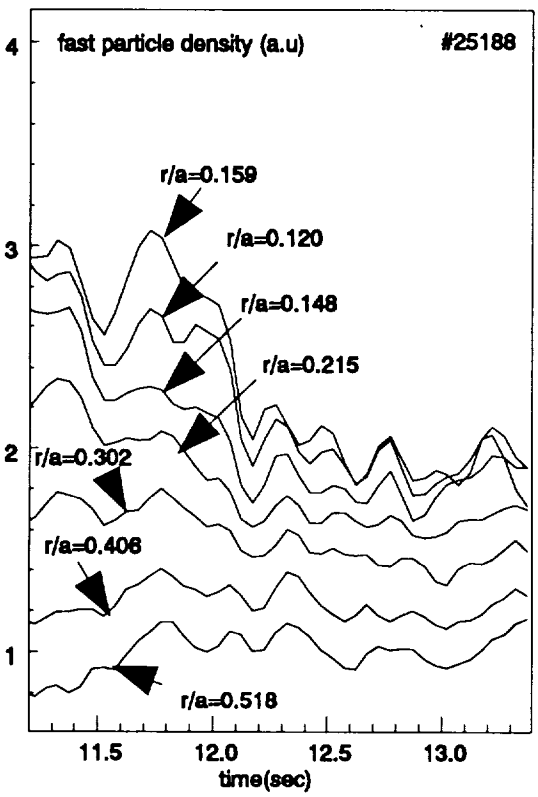

Fig.6

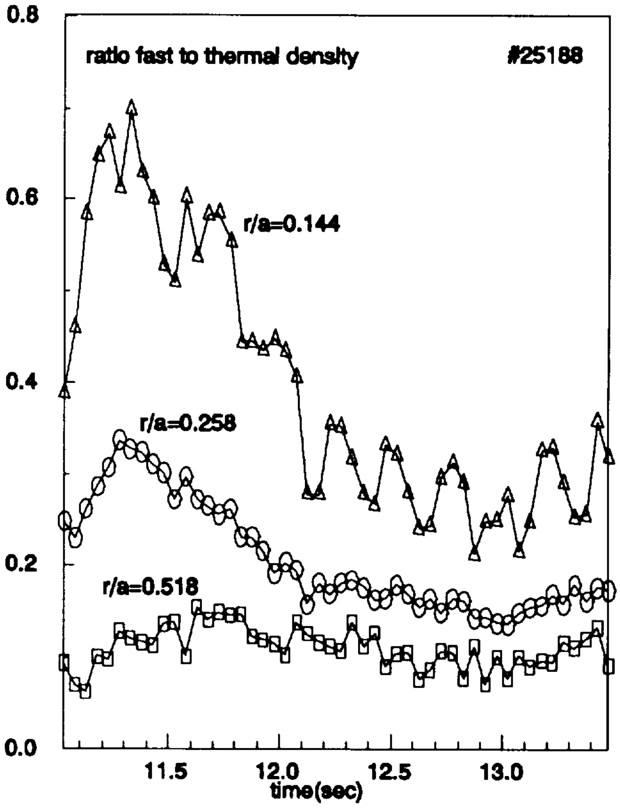

Fig.7