Study of suprathermal ions flows measured by passive doppler spectroscopy

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INTRODUCTION. The observation of suprathermal protons in ECRH TJ-II plasmas [1] capable of contributing to the heating of the thermal component has been used to support theories based on parametric decay mode conversion in ECRH plasmas with much lower threshold than expected [2]. Former experiments performed in TJ-II [3] have also studied how this suprathermal component could be detected in other ions apart from protons and how the values and behavior of their temperatures were compared with the thermal one.

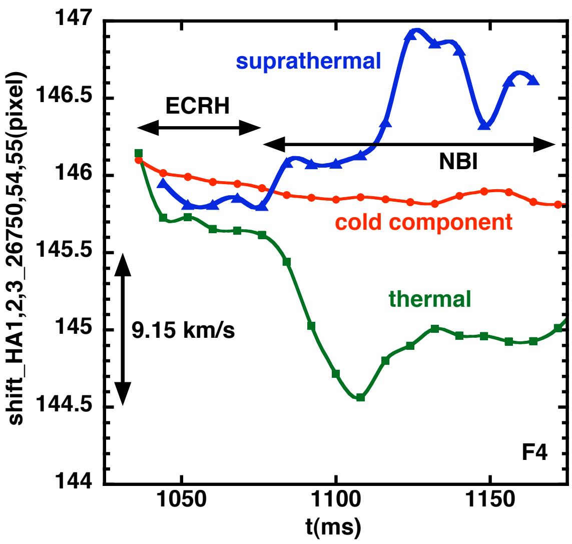
The goal of the present work is to investigate under which conditions the flow of the suprathermal component with respect to the thermal component can be measured with reasonable accuracy. This can shed some light about its generation mechanisms and on the plasma rotation physics, as the hot suprathermal ion population is expected to be less affected than the thermal population by standard collisional drag and viscosity.

EXPERIMENTAL. The methods used were based on passive spectroscopy with spatial and time resolution. The systems used were upgraded versions of those used formerly [1] and [4]. Plasma conditions were chosen where the line emission of interested was strong enough to be broken into two components: the thermal and the suprathermal one.

The spectral line shapes of intrinsic impurity ions and H_α emission have been recorded in TJ-II plasmas by means of high spectral resolution spectrometers viewing the plasma perpendicular to the main magnetic field by means of fiber guides. One of them has single-shot-spatial resolution capabilities with 9 equal-spaced channels, while the other one monitors the impurity emission lines along a fixed chord collinear to any of the other nine channels. The results of the first system are used to put in an absolute scale the temporal behavior of the relative ion flow monitored by the second system. We have not used the absolute calibration method developed for the single chord system [5], because of its limited time resolution. Also, since extra detector pixels are needed in order to record the calibration lines in the same image as the plasma line making the data analysis more time consuming. The experimental system and data analysis methods are described in some detail in [5] and [6].

In these measurements, we have not tried to achieve maximum time resolution but are looking for a compromise, choosing integration times compatible with an acceptable statistics and capturing the substantial evolution of the discharge. In addition, we ignore the rapid events at the very beginning or at the very end of the discharge. Typical integration times used are between 10 and 20 ms; some data have been recorded with shorter times mainly to explore the limit of the method.

RESULTS AND DISCUSSION. Suprathermal velocities obtained for protons, carbon (C^{4+}) and helium (He^{+}), and averaged along specific chords have been studied under different ECRH and NBI heating conditions. We will present here a sample of these results to illustrate the different rotation behavior of the suprathermal component with respect to the thermal one, in particular for the case of the protons. In Fig. 1, we present the relative shift of the three gaussian components in which the H_{α} emission line has been measured with modest (8 ms) time resolution along a chord located 3.75 mm below the magnetic axis. The results shown in this figure represent the average of a set of three similar discharges in order to smooth out any variability from discharge to discharge and any intrinsic low frequency fluctuation. The plasma (Conf: 100_42_64) was created by two gyrotrons each one with a power of 250 kW, tuned off-axis (ρ=0.33) and adding 530 kW NBI parallel to the toroidal field. One can see the smooth time behavior of the cold component, in contrast to the other two which exhibit opposite trends in their shift with time and a clear change when passing from the ECRH to the NBI phase: downward shift corresponds to red shift.



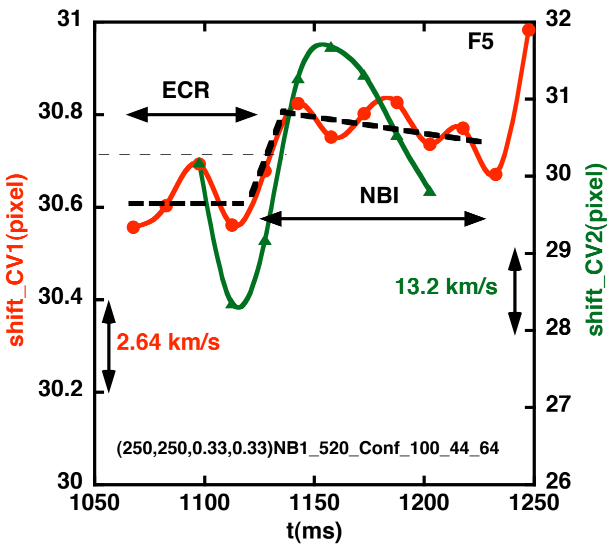


Fig. 1. Relative flow of the three "proton" components and for a chord 3.75 cm below the magnetic axis.

Fig. 2. Relative shifts of thermal and suprathermal populations (C^{4+}) notice the different vertical scales.

In Fig. 2, we compare the time evolution of line shifts for the thermal and suprathermal components of the C^{4+} (2271 Å) line. Notice the different scale of suprathermals, corresponding to the right vertical axis: the rotation change from ECR to NBI phase is approximately a factor 5 higher for the suprathermal component. One can observe that the time behavior of both ion populations in Fig. 2 is similar; it contrasts with the behavior of the suprathermal component for the same ion, displayed in Fig. 3 for close although slightly different discharges. The rise exhibited when NBI is turned on is more rapid for one of the displayed discharges (#27079). For the other one (#27081) we plot together raw and smoothed data.

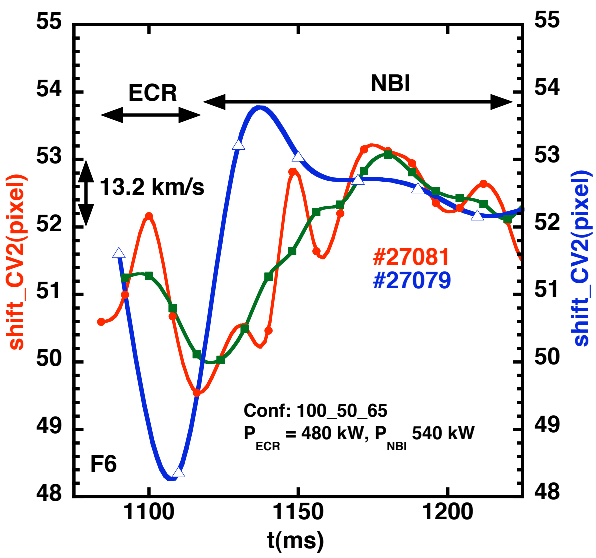


Fig. 3. Evolution of the relative shift of suprathermal population of C^{4+} (ρ = 1.25 mm) for two close shots.

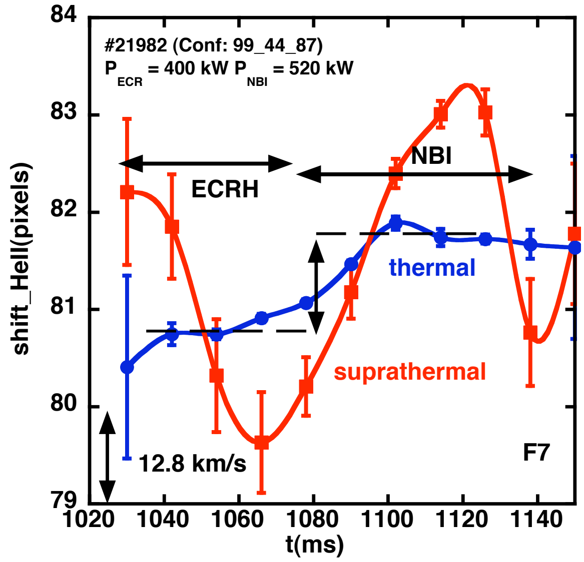


Fig. 4. Shifts evolution for the case of He^+ in a discharge started with ECR and continued with NBI.

A typical result of a similar analysis performed on the He^+ (4686 Å) emission line is depicted in Fig. 4. As before, we have chosen a case where the different behavior of thermal and suprathermal ions is clearly seen. For He^+, the rotation change from ECR to NBI phase is approximately a factor 2.5 higher for the suprathermal component. Finally, we depict in Fig. 5 (a) and (b), the time behavior of He^+ and "protons" in purely ECRH discharges performed with He as the filling gas.

We have shown with different examples of spectral line shape analysis that the hotter part of the ion distribution may rotate differently than thermal ions. Although we are aware of some of the limitations of passive spectroscopy: the difficulties of observation and analysis in a complicated geometry such as the TJ-II flexible heliac and the limitations of the observational geometry used to disentangle the separate effects of perpendicular and parallel flows with a purely poloidal view. Nevertheless, this work indicates that it is not justified to ignore some of the terms usually neglected when analyzing rotation data [7] In addition, future work in this direction may provide additional insights on the sometimes mysterious

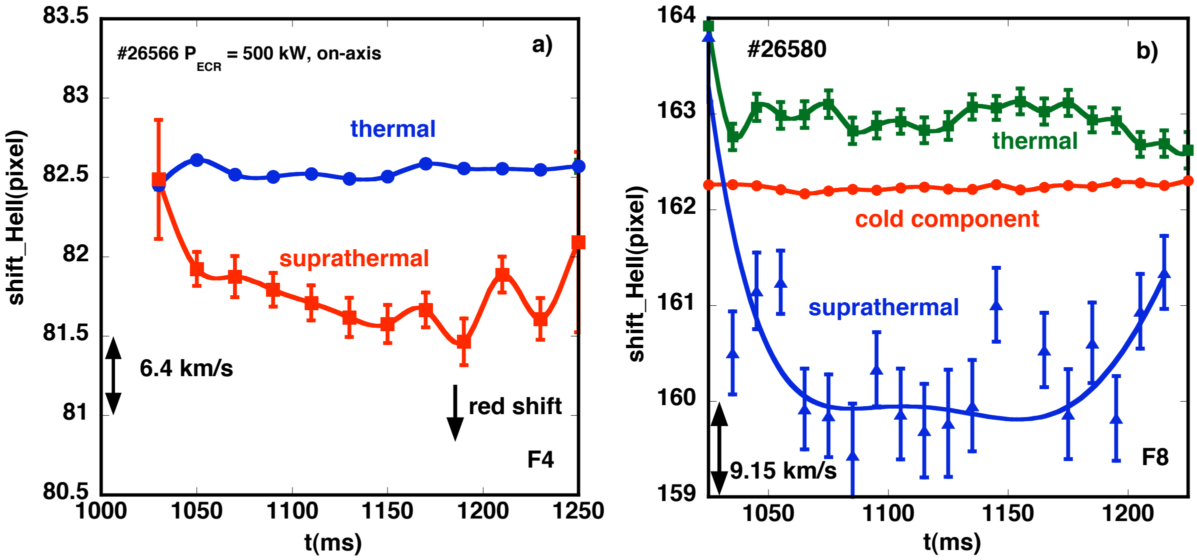


Fig. 5. We highlight in these plots the behavior of He and "protons" flows in He discharges, in both cases, and for upper and lower chords with respect to the magnetic axis (only shown one of each chord per ion), the shift of suprathermal protons is clearly displaced towards the red.

behavior of rotation in TJ-II. Although these types of studies cannot be done in a routine way due to signal limitations in many cases, several approaches can be followed to perform them in selected discharges: choose discharges with higher contamination, average several discharges performed in similar conditions, and use longer integration times as long as be possible without smoothing out the relevant physics.

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