# Spectroscopic Characterization of the Plasma in the Near-Field of RF Antennas in Tore Supra*

C.C. Klepper[1], R.C. Isler[1], L. Colas[2], M. Goniche[2], D. Guilhem[2], J. Hillairet[2], P.M. Ryan[1], Ph. Lotte[2], G. Colledani[2], Y. Marandet[3], A. Ekedahl[2], J.P. Gunn[2], V. Petrzilka[4], V. Martin[2], T.M. Biewer[1], D.L. Hillis[1], J.H. Harris[1], and B. Saoutic[2]

*[1]Oak Ridge National Laboratory, Oak Ridge, TN 37831-6169, USA; [2]CEA, IRFM, F-13108 Saint Paul-Lez-Durance, FRANCE; [3] PIIM, CNRS/Université de Provence, Centre de Saint Jérôme, Marseille F-13397, France; [4]Assoc. Euratom-IPP.CR, Za Slovankou 3, P.O. Box 17, 182 21 Praha 8, Czech Republic*

## Introduction

Plasma-surface interactions near and around high-power RF antennas have been receiving increasing attention as such processes, including erosion and the arc-induced damage due to the formation of strong dc sheath potentials, limit the attainment of high-power, long-pulse operation. A better understanding of these near-field interactions is also important for improved antenna design. The 3-d nature of these interactions makes realistic modeling difficult. Nevertheless, recent developments include models that predict both RF and DC electric fields around realistic RF antennas, in particular for ICRH antennas [1]. Also, in recent years, dc (sheath) potentials have been deduced from direct measurements of impurity generation [2] or by means of electrical probes magnetically connected to antenna structures [3]. Here the feasibility of a direct, non-intrusive measurement of both dc and rf electric fields from the external electric field Stark effect on the profiles of Balmer-series deuterium spectral lines is explored. The study is being carried out in Tore Supra, where 3 ICRH antennas and 2 LH launchers are designed for long-pulse operation with up to 4MW possible from each of these RF components. An optical periscope was installed in port 4A of this tokamak to gain tangential optical access to either the "Q5" ICRH antenna in port 5B or the "C3" LH launcher in port 6A. The periscope is not actively cooled and thus inserted only half way through the ~1m deep port that traverses the cryostat in the superconducting tokamak. A single spot on either RF structure can be sampled at one time and the location of the view spot can be changed by rotation of a flat, polished stainless-steel, first mirror. An optical fiber conducts the collected light to a

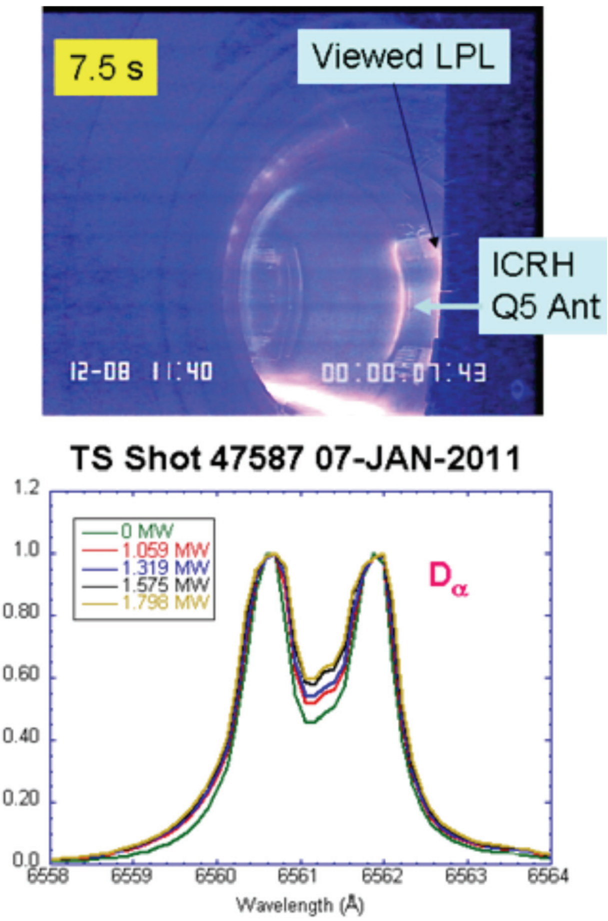


**Figure 1. Tangential camera image and Dα Spectra (all normalized to 1) from ICRH Ant. Q5 at 57 MHz and at 5 power levels.**

high-resolution optical spectrometer. The diagnostic is called DIAS, originally for "Dedicated ICRH Antenna Spectrometer". Just below the vacuum end of the DIAS periscope is a CCD survey camera, which is water-cooled and at the end of a (non-cooled) re-entrant tube. Thus, the images from this (visible region, non-filtered) CCD are from about the same perspective as the DIAS periscope and, for this reason, they are included in this paper together with early spectra acquired in this study. The CCD images show glowing light in the vicinity of the objects observed by DIAS, and give an idea of the spatial localization of the measurement along the DIAS line of sight. Early attempts to model these spectra with a computational tool that includes combined Stark and Zeeman effects in the actual magnetic field and viewing chord geometry are also presented. Both static and dynamic fields are included.

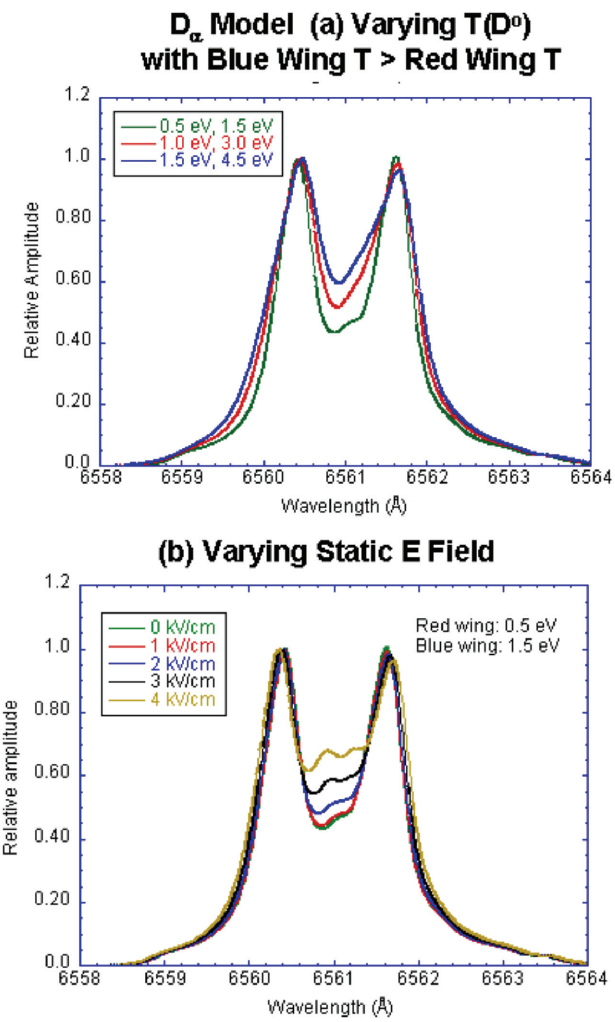


**Figure 2. Two sets of modeled Dα spectral profile to simulated the measured spectra of Fig. 1. In the top graph, only the species temperatures are varied; no external dc or rf electric field are included. In the bottom graph, the temperatures are fixed and only a static electric field is applied and varied.**

## Measured and Modeled Spectral Profiles.

In Fig. 1, $D_\alpha$ spectra are shown for a shot in which the power of ICRH antenna Q5 was stepped up from 0 to ~1.8 MW. The tangential camera image is from the 1.8 MW plateau. The DIAS periscope view was centered on the nearest lateral protection limiter (LPL) with a circular footprint of about 10 cm in diameter and at the midplane. Even though the midplane of this LPL is obscured from the tangential CCD by the edge of the Q4A port, it was just within the limits of the range for the DIAS optics. The intent here was to try to avoid any effect from the RF fields, by missing the mouth of the antenna, and to determine if the effect of a sheath electric field could be detected in the spectra. The theory predicts the formation of a "oscillating sheath" potential at the leading edge of the antenna, as a result of the presence of a toroidal component of the RF field; and the subsequent enhancement of the dc sheath potential in the dense plasma fueled by recycling at the LPL.

In Fig. 2, two sets of computer profiles are shown that attempt to model the observed profiles. The top set was generated without including an external electric field. Only the temperature of the emitting deuterium neutrals ($D^o$) was varied. In fact, in each case, a different T($D^o$) is taken for the blueshifted and the red-shifted sides of the spectrum. Such asymmetries in the Doppler broadening of emission lines of atoms and ions in a plasma facing component have been studied [4]. The other set of modeled profiles keeps the temperatures fixed and varies the static electric field. The full (static) Stark + Zeeman problem is solved for each profile and the static E was assumed to be perpendicular to the surface of the LPL as would be expected for a sheath field. Precise angles were then determined between the confinement magnetic field (including the ripple), the assumed electric field direction and the design direction of the viewing chord, and these we used in the model.

In Fig. 3, $D_\alpha$ profiles with and without LH injection are shown from a discharge using only the C3 LH launcher. The DIAS optical footprint on the C3 was ~15cm in diameter and set about half on the

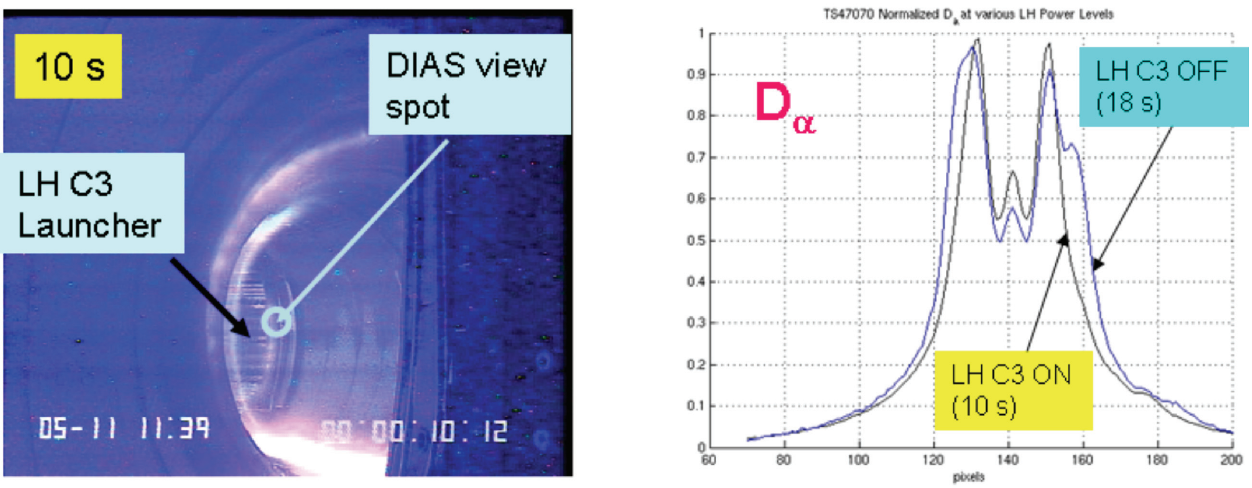


**Figure 3. Tangential camera image and Dα Spectra (both normalized to 1) from the 3.7 Ghz LH Launcher C3 at 0 and 2.62 MW. Since the experiments of Fig. 1, additional thermal protection tiles at the edge of port Q4B obscure the ICRH antenna Q5 from both DIAS and the tangential camera.**

LPL and half on the grill (composed mostly of metal ends of the waveguides). Although the camera image implies that the DIAS view is not crossing the inner boundary emission region, the "LH-off" spectral profile appears, even "to the eye" as having contributions from both a high and a low magnetic field region (from the spacing of the dominant σ components of the Zeeman effect features of the profile).

Fig. 4 shows fitting of modeled profiles to both LH on and off profiles for the same shot as in Fig. 3. A ~40% "inner wall contribution" is determined in the LH off profile fit. In the "LH on" case, only high frequency (HF) fields are assumed. Present models predict $E_{perp}{}^{RF}$~$E_{//}{}^{RF}$ near the grill mouth! with strength of ~1 kV/cm for 1 MW of LH injection. Indeed for the shown ~2.6MW case, the best fit of the data is found by using ~3 kV/cm , albeit with a direction at ~90° with respect to the magnetic field..

## Discussion, Conclusions and Upcoming Work

The results of this preliminary study indicate $D_\alpha$ profiles along may be insufficient for unique characterization of electric fields (RF or DC) near antenna structures. Simultaneous acquisition of $D_\beta$ profiles is expected to improve this measurement and this capability has been partially implemented. In the case of the ICRH LPL study, one could argue that the electric field is a more likely explanation of the observed profile changes. Langmuir probe measurements of similar discharges and ICRH power levels suggest that local Te changed from ~15 to 19 eV as $P_{ICRH}$ stepped from 1 to 1.8 MW. But a cursory look at the literature would suggest that, for this low range of Te, the energies of the $D^o$ molecular dissociation products actually change in inverse proportion to Te [5]. Nevertheless, it is clear that the detailed features in the middle of the modeled profiles not fully match those of the measured profiles and further study is needed.

In the LH case, the mostly radial direction of the HF electric field deduced from the $D_\alpha$ profiles may be a result of the emission coming from significantly further in to the plasma from the grill and also dominated by the LPL region. The HF $E_r$ component is expected to grow very strongly with distance from the grill. An alternative explanation is that the collected light was primarily from luminous region of the C3 LPL primarily excited by electrons beams, known to form by Landau damping in the fringing electric field patterns at the grill. Resulting dc sheath fields of few kV/cm have been estimated to form in such luminous regions [6]. In either case, better localization would greatly improve this measurement.

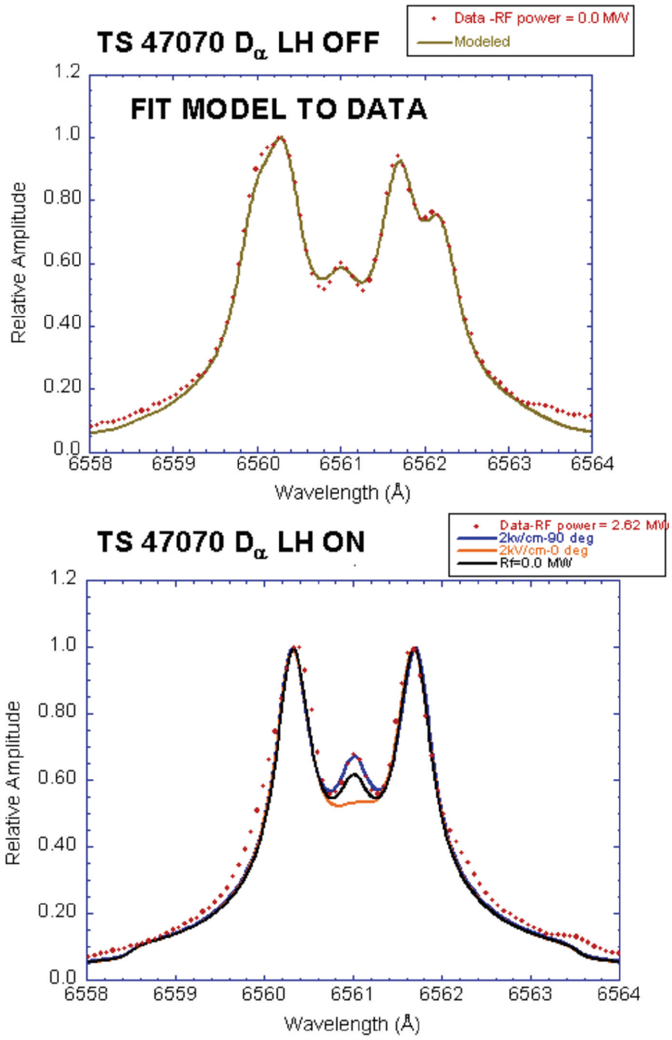


**Figure 4. Dα spectral profile models fitted to the experimental spectra of Fig. 3 for LH OFF (top graph) and LH ON (bottom graph).**

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