New Diagnostics Developments on IShTAR

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The diagnostics developed for the IShTAR (Ion Cyclotron Sheath Test ARrangement) facility are oriented towards measurements of plasma parameters and electric fields in the vicinity of a Radio Frequency (RF) antenna in order to provide input for sheath modelling codes [1, 2, 3]. The plasmas are created by a helicon antenna operated at a frequency of 11.76 MHz and with a power up to 3kW (the maximum power coupled to the plasma is around 2.7 kW).

Plasma characterisation and optimisation

A schematic view of IShTAR is presented in [1]. Improvements have been made for more complete density measurements in the helicon source and the main vessel. An additional array of RF compensated probes has been installed to allow for a better characterisation of the plasma parameters. In this way an optimised performance regime was found. By adjusting the magnetic topology the plasmas density can be increased by a factor 3 to 5, which is beneficial to the sheath studies. It is believed to be linked to the helicon wave propagation, but further investigation is needed to confirm the results. A current scan in helium plasmas is shown in figure 1. The current in the big magnetic field coils around the main chamber is varied between 200 and 800 A. The current in the small coils around the helicon source is kept constant at a level of 300 A. The corresponding magnetic field topology for the 200 A and 800 A cases are presented resp. in the figures 1 (b) and (c). It can be seen that for stronger magnetic fields the maximum densities are higher, but the radial profiles are more peaked. The RF antenna location is at radius $r = -20$ cm. The most homogenous and broad profile in this example is obtained for a coil current of ±650 A. In order to benchmark the electron density measurements from the Langmuir probes an interferometer has been designed. The schematic picture and hardware are shown in figures 2 (a) and (b). The probing frequency of 47 GHz, associated to an intermediate frequency of 144 MHz, is suitable for the typical plasma densities of IShTAR. The first results indicate a peak electron density in the helicon source of the order of $2 \cdot 10^{17}$ m^{-3} (figure 2(c)). The order of magnitude is in agreement with the results found by the Langmuir probes. Systematic scans for different plasma parameters and input power levels of the helicon antenna are planned.

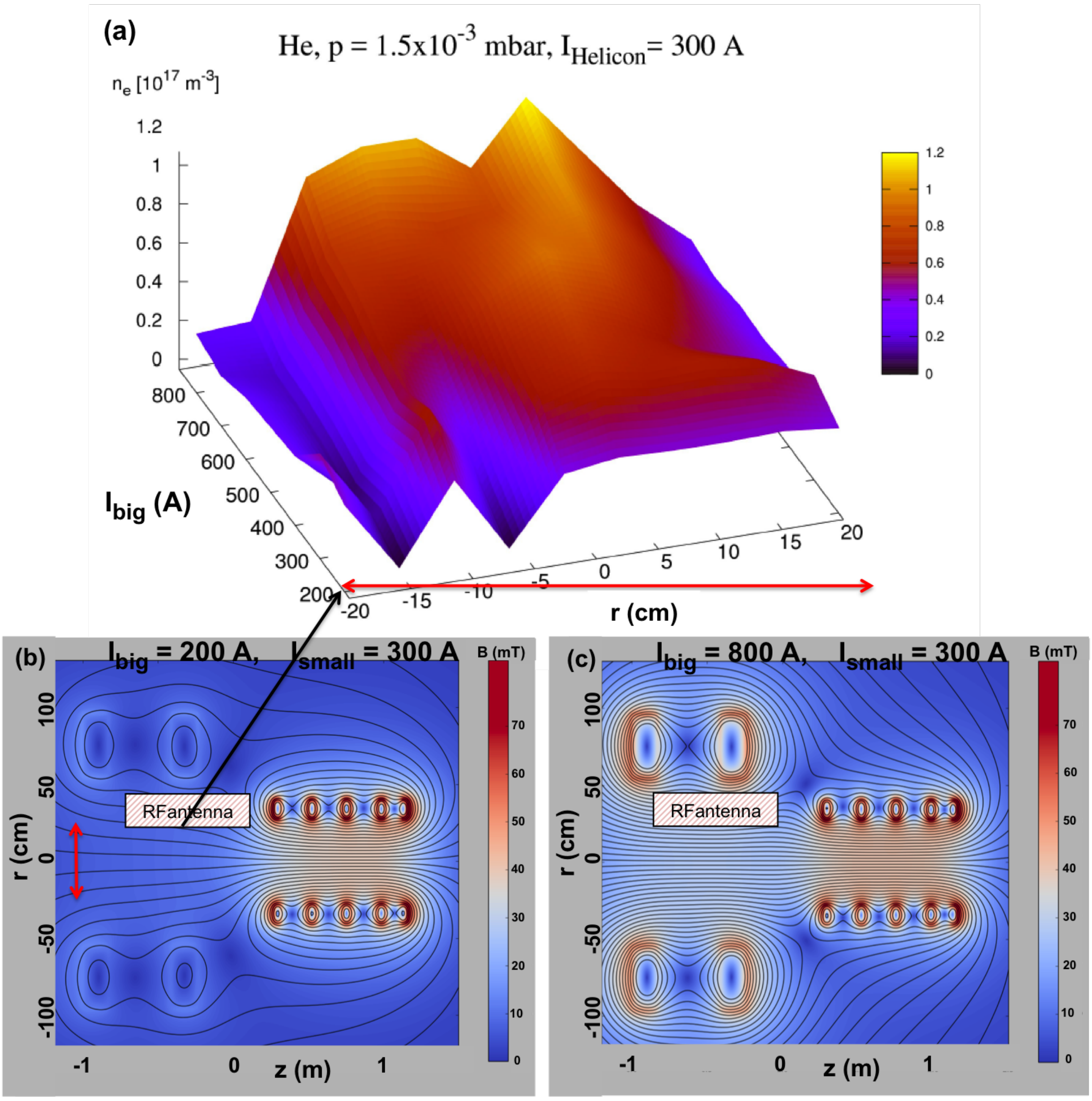

Figure 1: *(a) Density profiles of helium plasmas for a current scan in the big coils between 200 and 800A. The current in the small coils was kept constant at 300A.(b) Corresponding magnetic field topology for 200 A and (c) for 800 A in the big coils.*

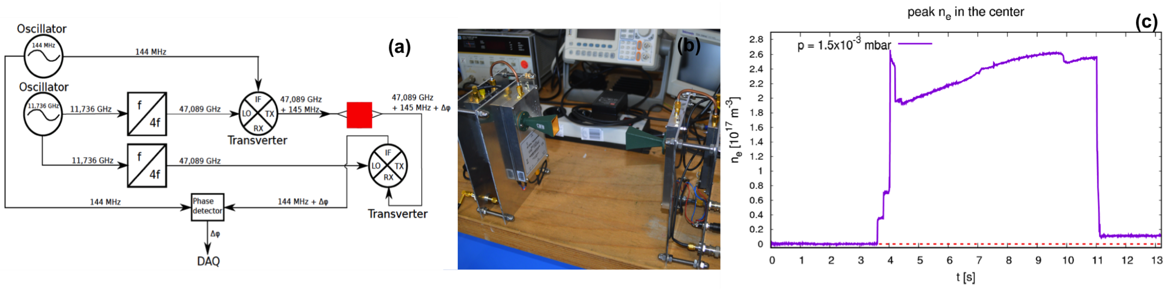

Figure 2: *(a) Schematic of the interferometer diagnostic, (b) sender and receiver horns, (c) measured peak density in the centre of the helicon plasma (assuming a parabolic profile).*

Electric field measurements

Two approaches are followed to measure the electric (E-) fields in the plasma caused by the RF antenna sheaths. (i) Passive optical emission spectroscopy monitors Stark effects on spectral lines with a high-resolution spectrometer [4, 5], provided that the local electric fields are strong enough to overcome the broadening of the lines. (ii) Doppler-free saturation spectroscopy is more powerful: a laser beam depletes the ground state, eliminates the line broadening effects and makes the effect of smaller electric fields more visible. However, the more complicated set-up, with a careful alignment of laser beams, makes the measurements much more challenging.

(i) Successful measurements have been obtained from the shift of helium spectral lines under the influence of an electric field [4, 5]. The best balance between spectral line intensity and sensitivity to the E-field was seen for the transition at 447.1 nm (4^3D-2^3P) of He I. The experimental data was collected from two view-locations. One was installed on a DC biased electrode in the helicon plasma source. The other one was placed on the side of the ICRF antenna in the main vacuum chamber. A more pronounced shift of the spectral line is detected with increasing electric fields, in correspondence with modelling predictions [6, 7] , for a field strength up to $E = 3.4 \pm 0.3$ kV cm^{-1}. With the passive spectroscopy system the measurements of electric fields are limited by the spectral resolution of the spectrometer. It was found that for the He I lines a spectral line shift for fields above ±2 kV/cm is detectable. Furthermore, the interpretation of the spectroscopic data is not straightforward, since the passive measurements are line-integrated, while the electric field is localised.

(ii) In order to bypass these two issues a set-up for Doppler-Free Saturation (laser) Spectroscopy is being prepared in parallel [7, 8]. This will allow for local measurements and will be more sensitive, such that also smaller E-field strengths can be detected. The laser absorption has been tested in a glow discharge plasma [9] and is presently being installed at IShTAR [10]. In figure 3 the set-up is shown. The laser beam is split into a pump beam, which will deplete the ground state, and two probe beams for the measurement. The laser light is guided to the flanges in the IShTAR room by lenses and mirrors. The measurement location at the feeding point of the antenna is shown in figure 3(c). It is the same location of the passive system, in order to make a direct comparison between the sensitivity of the two systems.

Conclusions

An interferometer and more probes have been added to the IShTAR suite of diagnostics for an improved characterisation of the plasma operation. A sensitivity of the electron density to the magnetic topology has been observed, possibly related to the helicon wave propagation. Successful E-field measurements by Passive Optical Emission Spectroscopy were achieved at

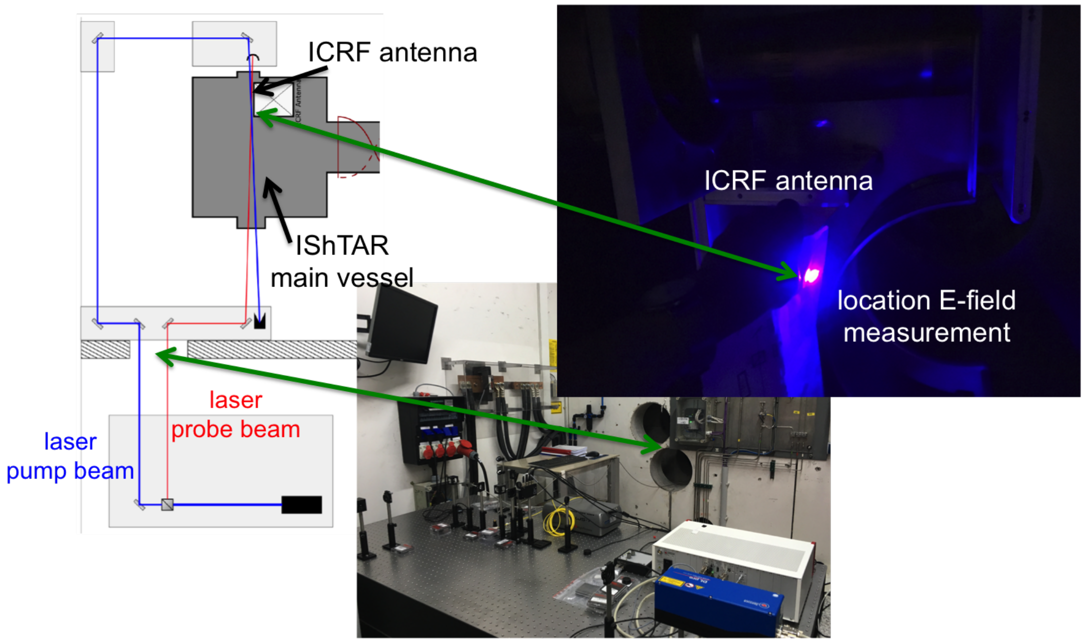

Figure 3: *Set-up of the Doppler-free saturation spectroscopy system on IShTAR.*

two viewing locations: a DC biased electrode and the ICRF antenna. The installation of an active Doppler-Free Saturation Spectroscopy diagnostic has started. Future plans include a further optimisation of the plasmas, the installation of a linear to linear fibre bundle instead of a single fibre for the spatial evolution of the E-field intensity inside the sheath, and improvements to the signal to noise ratio by installing a local gas-puff for helium at the antenna view-point.

References

[1] K. Crombé et al., “IShTAR: a helicon plasma source to characterize the interactions between ICRF and plasma”, 26th IAEA Fusion Energy Conference, EX P6-48, 2016, Kyoto, Japan.

[2] L. Lu et al., Plasma Phys. Control. Fusion, Vol. 60, No. 3, 035003 (2018).

[3] K. Crombé and D. Van Eester, J. Plasma Phys. (2016), vol. 82, 905820203.

[4] A. Kostic et al., “Feasibility study of Passive Optical Emission Spectroscopy for the electric field measurements in IShTAR”, EPJ Web of Conferences 157, 03025 (2017).

[5] A. Kostic et al., “Development of a spectroscopic diagnostic tool for electric field measurements in IShTAR”, Rev. Scientific Instruments (accepted for publication).

[6] E. H. Martin, “Electric field measurements of the capacitively coupled magnetized RF sheath utilizing passive optical emission spectroscopy”, PhD Thesis (2014), North Carolina State University.

[7] E. H. Martin, A. Zafar, et al., Review of Scientific Instruments 87, 11E402 (2016).

[8] C.Wieman and T. Hansch, Phys. Rev. Lett. 17, 1170 (1976).

[9] K. Crombé et al., “Helium operation of IShTAR in preparation of E-field measurements”, 44th EPS Conference on Plasma Physics, 2017, Belfast, Northern Ireland, UK, ECA Vol. 41F, P5-144.

[10] T. Verstrynge, “Spectroscopic diagnostics of IShTAR plasma”, Master Thesis (2018), Ghent University, Belgium.

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