SPEKTRE,
a linear radiofrequency device for investigating edge plasma physics

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SPEKTRE (Sheaths, Plasma Edge & Kinetic Turbulence Radiofrequency Experiment) is a research platform in plasma physics and nuclear fusion, currently under construction in Nancy, France. SPEKTRE is the result of a cooperation within a research agreement between the University of Lorraine and the IPP Garching, and it can be seen as a step beyond the IShTAR device [1], of which it integrates several components such as the helicon source chamber, together with 13 large flat coils of the former W7-AS stellarator. These components are already installed and they will be connected to a new vacuum chamber currently under construction, to produce a 6 meters long and 40 cm in diameter plasma column, as shown in Fig. 1.

A first technical plasma is planned in December 2023, before connecting the main coils to the water-cooling system and to a first set of power supplies in Sept. 2024. This will enable to operate the device at low but stationary 0.1 T magnetic field, mostly homogeneous in the plasma volume (0.75 m^3). In this configuration, the plasma will have cold ions, electron temperature in the eV range, and rather low plasma density (10^{16} – 10^{18} m^3 in hydrogen depending on the RF coupling). This will enable to conduct fundamental investigations on plasma instabilities in large, low-magnetized plasma columns [2], as well as to work on the improvement of surface treatments for applications to large surfaces in some industrial processes. SPEKTRE is also designed to experiment in separate measurement campaigns a loop of flowing liquid metal (LM) in the perspective of future LM walls, as part of a partnership with Renaissance Fusion. In order to conduct these studies, SPEKTRE will be equipped with a complete set of diagnostics (IR and fast visible imaging, probe arrays, OES, mass spectrometer…), taking advantage of the 42 ports available for that purpose on the vacuum vessel. SPEKTRE will also be used for education and training of students at the Master level.

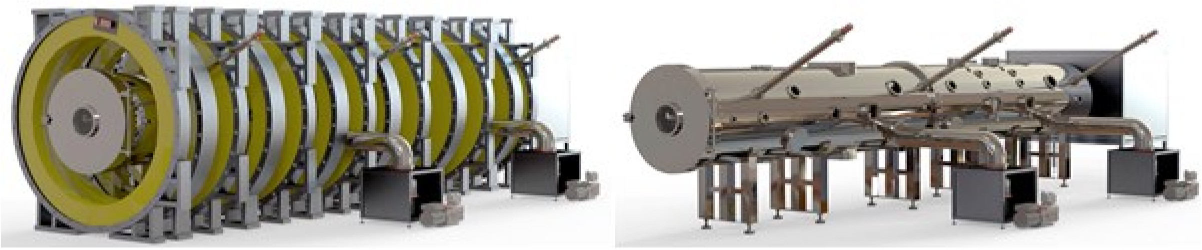

Figure 1: CAD views of the assembled SPEKTRE device (left), and without the coils (right)

In the course of years 2025 and 2026, two banks of supercapacitors will be installed in order to be able to operate SPEKTRE at a B-field up to 0.5 T (in pulse mode, with 2s flattop). This upgrade will come together with the installation of an ICRF system composed of 1 or 2 antennas connected to a maximum RF power of 100 kW operating at 13.56 MHz. By operating the device with hydrogen at a B field of 0.44 T, we expect to reach plasma density up to 2.10^{19} m^{-3}, with electrons and ions temperature distributions peaked around 10 eV. This will enable to conduct a wide range of investigations related to fusion edge plasma, with a main focus on the physics of RF sheaths and Ion Cyclotron Range of Frequency Heating (ICRH).

The overall goal of research on ICRH in SPEKTRE will be to help improving RF coupling to the plasma while minimizing heat flux and impurity release [3]. For that purpose, a first ICRF antenna with active limiters is currently being designed, and other concepts could also be tested. The RF sheaths and coupling between the RF and plasma will be investigated through a combination of diagnostics, including triple probe arrays magnetically connected to the antenna, emissive probes, VUV spectroscopy, IR and fast visible cameras. The possibility of measuring the plasma potential by Stark spectroscopy is also being investigated [4]. The experiments will be closely accompanied by modeling of RF sheaths and their effects around the antenna with the RAPLICASOL, Petra-M [5] and TORIC codes. An effort will be made on improving the interpretation of RFA and probe diagnostics in RF plasmas, and the arcing in presence of RF will be studied experimentally and with PIC codes.

Another field of research in SPEKTRE will be the investigation of turbulent transport and impurity transport. Due to ICRF, Ion Temperature Gradient (ITG) instabilities are expected to occur in SPEKTRE, together with standard instabilities ordinary observed in plasma column, such as flute modes. Experimentally, the studies on impurity transport will involve deliberately injected impurities at various locations and their observation with optical diagnostics (fast visible cameras, Optical Emission Spectroscopy and Absorption

Spectroscopy over a whole diameter of plasma), completed with post-mortem collection and analysis of samples and with measurements of the plasma parameters with probe arrays. The experimental observations will be confronted to numerical simulations carried out with a modified version of the GYSELA code, which is currently being adapted to SPEKTRE geometry. The propagation of waves in the μ-wave range in turbulent plasma will also be investigated.

Dedicated Plasma-Wall Interactions (PWI) studies will also be run in SPEKTRE to investigate the triggering and sustaining of unipolar arcs and the resulting release of impurities and droplets. Dedicated campaigns with the Renaissance Fusion LM test-bed will be carried out in order to investigate several critical issues related to the possible use of a flowing LM wall in the context of fusion edge plasma: mainly the plasma survivability with strong impurity emission (experiments will be cross-compared to PIC and GYSELA simulations), but also the efficient active control of the LM flow as well as the evaporation of Li and/or LiH from a liquid solution of the two.

In the end, SPEKTRE is designed for flexibility, which should enable it to be used both for fundamental plasma studies and for more targeted applications, in both nuclear fusion and plasma surface treatment (separate campaigns with stationary plasmas up to 0.1 Tesla will still be possible after the machine upgrade planned in 2026). The diagnostic possibilities are numerous, as are the possibilities of developing new diagnostics or technological bricks, which could be tested in SPEKTRE at lower cost and risk, before possible installation in larger instruments. In order to facilitate exchanges with present and future partners, and to guarantee improved data usability, the complete data produced will be standardized according to the IMAS format and available to external collaborators. Last but not least, SPEKTRE should be an excellent tool for training engineers and researchers, in a context where manpower is sometimes in short supply.

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References

[1] I. Shesterikov, K. Krombe, A. Kostic et al., IShTAR: a test facility to study the interaction between RF wave and edge plasmas, Rev. Scientific Instrum. 90, 083506 (2019).

[2] M.J. Pueschel, G. Rossi, D. Told et al., A basic plasma test for gyrokynetics: GDC turbulence in LAPD, Plasma Phys. Control. Fusion 59, 024006 (2017). G. Rossi, Electromagnetic turbulence and transport in increased beta LAPD plasmas, UCLA Electronic Theses and Disseration, 2021.

[3] G. Urbanczyk, Main challenges of heating plasma with waves at the Ion Cyclotron Resonance Frequency (ICRF), in « Advances in Fusion Energy Research – Theory, models, algorithms and Application », IntechOpen, London.10.5772/intechopen.105394. ISBN: 978-1-80356-279-7 (2022)

[4] A. Kostic, K. Crombé, R. Dux et al., Polarization Stark spectroscopy for spatially resolved measurements of electric fields in the sheaths of ICRF antenna, Review of Scientific Instruments 90, 123101 (2019)

[5] W. Tierens, R. Otin, G. Urbanczyk, Progress on 3D calculations of the DC sheath potential near ICRF antennas, 24th Int. Conf. on Plasma Surface Interactions (PSI 24th).