Plasmas magnétisés

CNRS GDR Groupement de recherche EMILI Étude des milieux ionisés Plasmas froids créés par décharge et laser

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Plateforme SPEKTRE
(Sheaths, Plasma Edge Kinetic Turbulence Radiofrequency Experiment)

Abstract

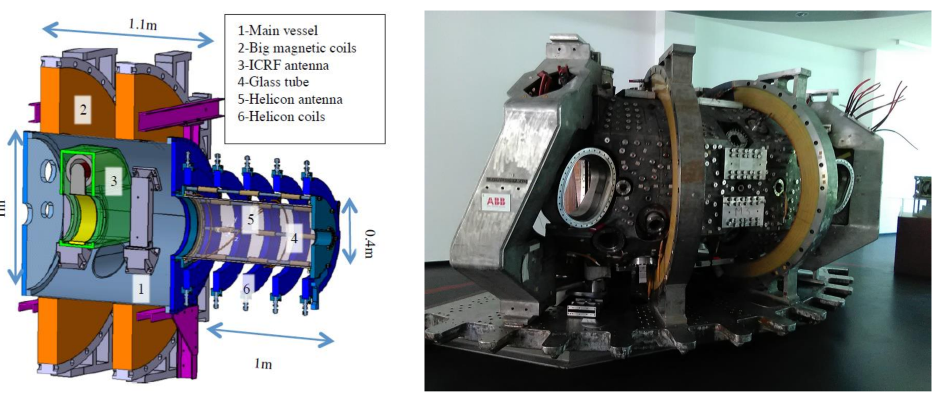
SPEKTRE (Sheaths, Plasma Edge & Kinetic Turbulence Radio-Frequency Experiment) is a research platform under construction in Nancy, dedicated to magnetized plasmas.
It is based on a collaboration agreement with the Max-Planck Institute for Plasma Physics in Garching, Germany, which donates 13 large copper coils from the previous Wendelstein 7 stellarator [1] as well as pieces of equipments, and can be seen as a major upgrade of former ISHTAR device [2].

2 modes of operation will be possible:

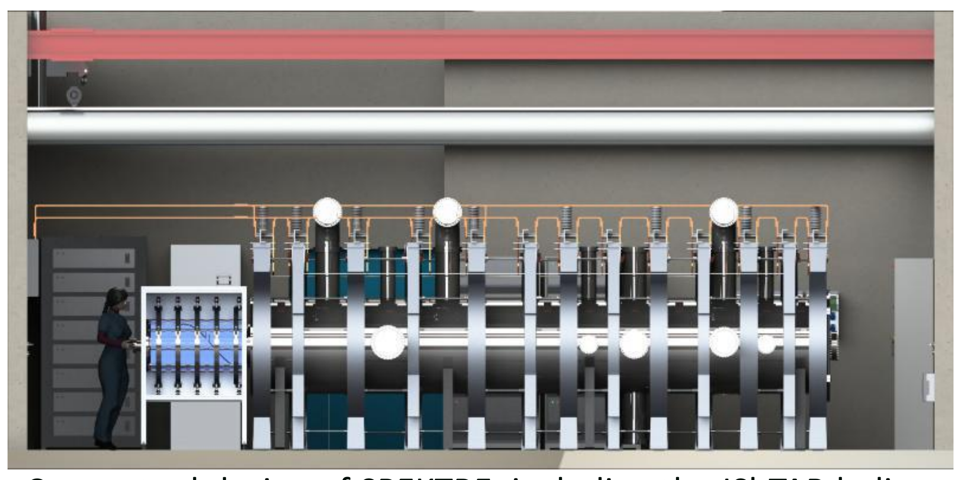
- **Pulsed operation with a magnetic field up to 0.5 Tesla** for 2 seconds, for research in thermonuclear fusion by magnetic confinement,
- **Stationary operation, with a field up to 0.1 Tesla**, to study low-temperature plasma instabilities and surface treatment processes in a homogeneous magnetic field.

Conceptual Design

- Based on the heritage of former Wendelstein 7 stellarator and IShTAR device from IPP Garching.
- 1 helicon plasma source (3 kW -11.76 MHz) to initiate plasma, combined with substantial RF heating provided by ICRF Antenna (100 kW – 13.56 MHz).
- Large main chamber (590 cm in length, 90 cm in diameter), equipped with numerous flanges in the perspective of various diagnostics and auxilliary equipments.
- Versatile device: 2 sets of power supplies for the coils, possibility of using the chamber as a housing for a smaller secondary chamber dedicated tp reactive plasma experiments…



Scheme of the IShTAR device (left) and Photography of one sector of former Wendelstein 7 stellarator (right).



Conceptual design of SPEKTRE, including the IShTAR helicon source on the left and 13 coils from Wendelstein 7.

High-B field research program

SPEKTRE is designed to investigate fundamental issues relevant to the edge of fusion devices, but in a linear configuration:

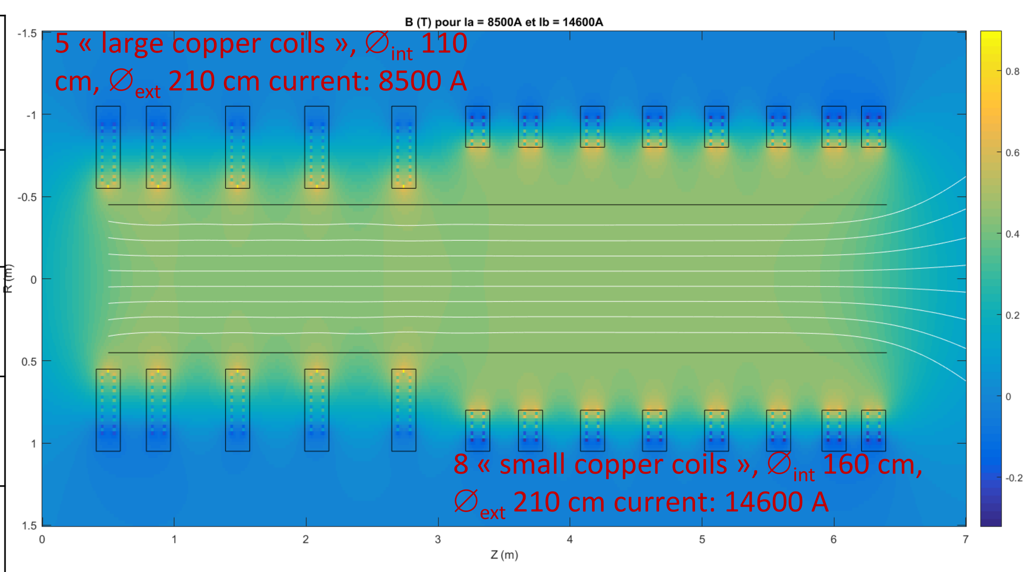
- Generation and heating of a plasma by Ion Cyclotron Resonance Heating, including magnetized RF sheath effects;
- Developped turbulence & turbulent transport in magnetized plasma;
- Plasma/surface Interactions in magnetized plasma (incl. Sheaths & arcs);
- Instrumental & diagnostics developments.

RF heating & RF sheath effects, impurity transport & turbulence and unipolar arcing will be investigated in the frame of a joined research agreement between the University of Lorraine and IPP Garching. Other fundamental issued will be carried out in the frame of the French Federation for Magnetized Fusion (FR-FCM) and other european partners in the frame of EUROfusion calls for proposals.

SPEKTRE will also be used for applied research in fusion and for testing key fusion technologies, such as thick flowing metal walls in the frame of a partnership with Renaissance Fusion [3].

Main working scenario is based on the use of 2 banks of supercapacitors (11.2 MJ each), required to generate homogeneous 440 mT magnetic field in 2 s flattop pulses, with hydrogen plasma, resulting in the following plasma parameters:

n_e	$10^{16} – 10^{19}$ m^{-3}	Ionization rate	10 %
T_e	1-10 eV	υ_{ee}	5.10^4 – 4.10^7 s^{-1}
T_i	1 eV – 10 eV	υ_{en}	4.10^3 – 4.10^6 s^{-1}
P	1 Pa	υ_{in}	2.10^2 – 3.10^5 s^{-1}
λ_D	$4.10^{-6} – 1.10^{-4}$ m	υ_{ii}	4.10^2 – 4.10^5 s^{-1}



Magnetic field stream lines @ 440 mT. B is homogeneous at 96% in a cylindrical volume of length 506 cm and 56 cm diameter.

Low-B field research program

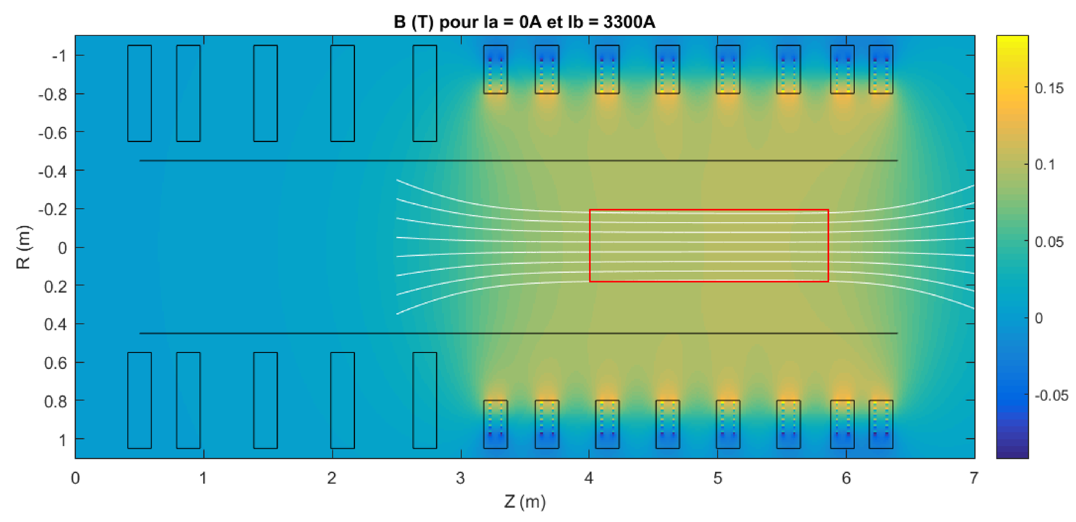
By powering the coils with DC power supplies instead of supercacitors, SPEKTRE can be operated in stationnary mode but at lower B field values (50 mT). B-field restrictions are due to the available power, 250 kW, and to the coil cooling capability, 180 KW.

Considering non-reactive plasmas, experiments can take place in the main vacuum vessel for fundamental studies of:

- Plasma instabilities;
- Sheaths and other physical processes at play in plasma/surface interactions;
- Instrumental & diagnostic development;

Reactive plasma experiments could take place in a secondary chamber placed in one half of the main vacuum vessel. Stationnary B-field up to 100 mT could be achieved, homogeneous in a large volume.

Alternate configuration for stationnary B field @ 100 mT, homogeneous at 96% in a volume of length 173 cm and 40 cm diameter, delimited in red, which could host a secondary chamber dedicated to reactive magnetized plasma experiments.



Diagnostics for both low- and high- B fields operations include:

- Standard, fast and ultrafast visible imaging (up to 2 Mfps)
- IR camera (80 fps, range from ambient temperature to 2500 K)
- Optical Emission & Mass spectrometers
- Interferometer
- Mirnov & B-dots probes
- Langmuir & emissive probes, 3D motorized probe manipulator
- 128 channels data acquisition system (up to 10 MHz)
- Discussions with IST Lisbon for designing reflectometer

Status of the project

- April 2021: new concrete slab to support the 40 tons of SPEKTRE
- September 21: coils installed at their final position
- December 21: design of the main vacuum chamber to be finalized before call for trend
- Fall 22: assembly of the helicon source chamber & main chamber, surrounded by the coils
- December 22: first plasma (low-B)
- Fall 23: installation of supercapacitors and ICRF antenna, first plasma at 0.5 Tesla

Picture showing the 13 coper coils after their installation in SPEKTRE experimental room.

References

[1] H. Renner et al., *Initial operation of the Wendelstein 7AS advanced stellarator,* Plasma Physics and Controlled Fusion. **31** (10): 1579–1596 (1989).
[2] I. Shesterikov et al., *IShTAR: a test facility to study the interaction between RF wave and edge plasmas*, Rev. Scientific Instrum. 90, 083506 (2019).
[3] Renaissance Fusion is a Fusion startup based in Grenoble, designing a stellarator fusion power plant: https://stellarator.energy/