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► **To cite this version:**

F. Brochard, D Genève, V Bobkov, E Faudot, S Heuraux, et al.. SPEKTRE, a linear radiofrequency device for investigating edge plasma physics. 49th EPS Conference on Plasma Physics, Jul 2023, Bordeaux, France. . hal-04171521

**HAL Id: hal-04171521**

**<https://hal.science/hal-04171521>**

Submitted on 26 Jul 2023

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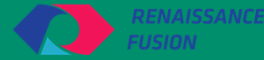
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# SPEKTRE, a linear radiofrequency device for investigating edge plasma physics



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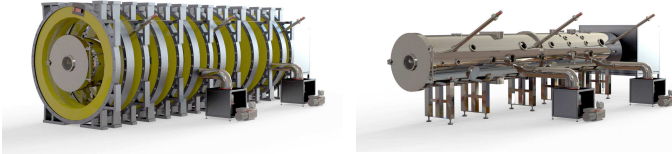
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SPEKTRE (Sheaths, Plasma Edge & Kinetic Turbulence Radiofrequency Experiment) is a research platform in plasma physics and nuclear fusion, currently under construction in the Institut Jean Lamour (Nancy). SPEKTRE is the result of a cooperation within a research agreement between the University of Lorraine and the IPP Garching. It will produce a plasma 40 cm in diameter and 6 m long, under a maximum magnetic field of 0.5 Tesla generated by 13 large flat coils of the former W7-AS stellarator. The first plasma is scheduled for late 2023, and will be followed by a gradual ramp-up to enable research in the following areas:

- Physics of RF sheaths and ICRF heating;
- Instabilities in magnetized plasmas, turbulent transport of impurities;
- Targeted studies on plasma-wall interactions, including liquid metal wall;
- Beyond the scope of fusions plasmas, surface treatments by magnetized plasmas.

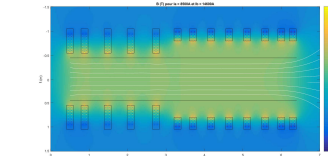
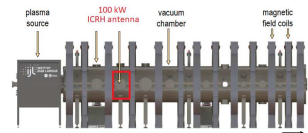
## Conceptual Design

SPEKTRE was originally designed to be a step beyond the ISHTAR device [1]. The final design integrates the ISHTAR's helicon source chamber and 13 planar coils from former W7-AS stellarator, in the frame of a research agreement between MPG-IPP and the University of Lorraine.

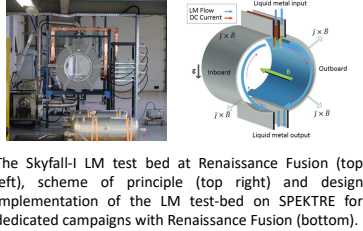


CAD views of the assembled device with and without the coils, respectively.

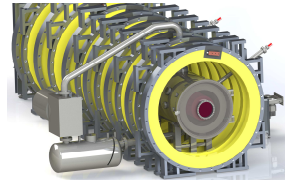
- Main vacuum vessel 5.97 m long,  $\phi$  0.9 m
- Plasma diameter 0.4 m
- 42 ports available for diagnostics



Side view (top) and B-field configuration in the main chamber @ 0.5 T (bottom)



The Skyfall-I LM test bed at Renaissance Fusion (top left), scheme of principle (top right) and design implementation of the LM test-bed on SPEKTRE for dedicated campaigns with Renaissance Fusion (bottom).



## Current status and next steps

### Current status:

- Coils and supporting structures are in place.
- Main vacuum vessel is being manufactured and will be installed in September 2023.
- Helicon plasma source is being adapted to the new vacuum vessel, new RF generator arriving this fall.

### Next steps:

- First plasma in Dec. 2023 (no B field in the main coils)
- Coils connected to cooling and power supplies by summer 2024, first experiments with homogeneous 0.1 T by sept. 2024.
- Installation of banks of capacitors for 0.5 T operation and ICRF generator and antenna expected by mid-2026.



SPEKTRE in June 2023, before the installation of the main vacuum vessel

## 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, P.W. Terry, F. Jenko and T.A. Carter, A basic plasma test for gyrokinetics: 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 Dissertations, 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).

## Operational Phase I (2023 - 2025)

### Technical capabilities

- B-field: max 0.1 T, stationary.
- RF power: 6 kW @ 13.56 MHz (only helicon source).
- Cold ions,  $T_e$  in the eV range and low plasma density expected ( $10^{16} - 10^{18} \text{ m}^{-3}$  with H), derived from 0<sup>th</sup> order model. H plasmas dominated by longitudinal losses, He plasmas dominated by radial losses.

### Program

- Development, testing and installation of diagnostics and main auxiliary systems.
- Fundamental investigations on plasma instabilities in large, low-magnetized plasma columns [2].
- First experiments with LM SkyFall test-bed (Renaissance Fusion).
- Education & training.

## Operational Phase II (from 2026/2027)

### Technical capabilities

- B-field: max 0.5 T (pulse, 2s flat-top) and still 0.1T stationary in dedicated campaigns.
- RF power: 20 kW @ 27.2 MHz (helicon source) and up to 100 kW ICRF @ 13.56 MHz.
- Standard scenario:  $B = 0.44 \text{ T}$ , 120 kW RF.

	H	He
$n_e \text{ (m}^{-3}\text{)}$	$3.4 \cdot 10^{16}$ (a) $2.7 \cdot 10^{19}$ (b)	$6.5 \cdot 10^{16}$ (a) $3.5 \cdot 10^{19}$ (b)
$T_e \text{ (eV)}$	$\sim 10$ (1-100)	$\sim 10$ (1-100)
$T_i \text{ (eV)}$	6.5 - 26	6 - 10

Expected plasma parameters at  $B = 0.5 \text{ T}$  with (a) 20 kW RF,  $T_e = 100 \text{ eV}$ ; (b) 120 kW RF,  $T_e = 1 \text{ eV}$

### Research Program

- RF sheath and ICRF:
  - Exp. & modelling of RF sheaths & their effects around antennas (Petra-M + TORIC)
  - Interpretation of RFA and Probe diagnostics in RF plasmas
  - RF active compensation based on the excitation of slow waves
  - Arcing in presence of RF field
  - Improving RF coupling while minimizing heat flux and impurity release [3]
- Turbulent transport and impurity transport
  - Experimental characterization of impurity transport and comparison with modelling with GYSELA «  $R_{\infty}$  » version
  - Propagation of waves in the  $\mu$ -wave range in turbulent plasma
- Dedicated PWI investigations
  - Thresholds for triggering and sustaining unipolar arcs in magnetized plasma (exp. and PIC simulations)
  - Impurity and droplets release by arcs
  - Physics and control of flowing liquid metal walls, link to the release and transport of metal impurities (experiments, PIC and GYSELA simulations)
- Fundamentals of magnetized plasmas
- Diagnostics and software development, including AI and real-time control
- Surface treatments by low-temperature magnetized plasmas (0.1 T): improving uniformity for large samples
- Education & training

## Conclusion and perspectives

SPEKTRE is a new magnetized plasma research facility about to start operation. After a first operational phase during which the machine will be progressively upgraded, SPEKTRE will acquire some fairly unique features (a large-volume, well-magnetized plasma column with 100 kW of ICRF heating) combined with many diagnostic possibilities, that will make it an accessible instrument for the study of phenomena of broad interest in magnetized plasmas.

The SPEKTRE team is widely open to collaborations

Acknowledgement: This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them. This work was also supported by the french national research agency (Agence Nationale de la Recherche) under project SHEAR ANR-19-CE30-0033-01, as well as by the Métropole du Grand Nancy.

49<sup>th</sup> EPS Conference on Plasma Physics  
03-07 July 2023

