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Control of heat and particle fluxes in tokamak double null magnetic configuration: experimental and modeling studies on WEST and extrapolations for fusion power plants

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Short summary :
Among the challenges on the road map to fusion power plants, the control of power exhaust is one of the most critical. Many of the concepts developed for future fusion power plants are based on a so-called "Double Null" (DN) magnetic configuration, characterized by two symmetrical upper and lower x-points, where the magnetic field in the poloidal plane is zero. Compared to the ITER "Lower Single Null" (SN) configuration, which has only one x-point and a low divertor, the theoretical advantage of the DN configuration is to double the area available for the evacuation of the convected energy towards the divertor. This thesis project focuses on experimental and numerical studies of power extraction in the DN magnetic configuration. Dedicated experiments will be performed on the WEST tokamak which offers the possibility to study the full range of magnetic equilibria, ranging from the lower SN to the upper SN through the DN, in a perfectly symmetric top-down divertor configuration. The experimental studies will be supported by numerical simulations performed with the SOLEDGE code, which is capable of finely modeling transport and turbulence in realistic magnetic topologies and divertor geometries, in order to better understand the impact of the different mechanisms at play, in particular the impact of ExB drifts on particle and energy fluxes in the divertor regions. A comparison with the results obtained in standard SN configuration will complete the data analysis and the characterization of the DN. Finally, the potential of DN configurations for future fusion power plants will be assessed.

Desired /recommended background : **Master 2 in physics, applied mathematics, engineering school…**

Title of the advised master : Fusion Science, Physics of plasmas, Fundamental physics and applications, Fluid mechanics, …

Detailed description of the PHD topic:

Among the challenges on the path to fusion power plant (FPP), the control of heat and particle exhaust is one of the most critical ones. A significant fraction of the power produced by fusion reactions is convected from the core plasma region through the separatrix towards the thin plasma layer where magnetic field lines are connected to the solid surfaces of the divertor, the so-called scrape-off-layer (SOL). In ITER divertor, the resulting steady-state heat flux is expected to be already very close to the technological limits. In order to manage larger fusion power as expected in FPP, several strategies are under investigation, playing both on magnetic configurations alternative to the ITER one and on power dissipation in the peripheral regions by impurity injection, a very efficient way to spread the energy over all the plasma-facing components, but at the expense of plasma dilution.

In this context, many concepts developed for future FPP rely on Double-Null (DN) magnetic configuration, characterized by two up-down symmetric x-points, where the poloidal magnetic field vanishes. With respect to the ITER Lower Single Null (SN) configuration with only one lower divertor, the theoretical advantage of DN configuration is to double the surface available for convective power exhaust. Another interesting feature of the DN is that the inner side of the SOL is magnetically disconnected from the outer side, preventing contamination of the inner sides by large-scale plasma flows as observed in SN configuration. The impact on global confinement properties and MHD edge stability has been addressed only partially and remains an open issue.

This PhD project focuses on experimental and numerical studies of plasma exhaust in DN magnetic configuration. Dedicated experiments will be performed on the WEST tokamak that provides the possibility of investigating, in a perfectly symmetric top-down divertor configuration, the full range of magnetic configuration from lower SN to upper SN passing through DN. This approach is of fundamental importance for a deeper understanding of power sharing and plasma properties in DN and near DN configurations.

WEST is particularly well diagnosed for such studies, being equipped with electrostatic Langmuir probes on both upper and lower divertors, giving access to heat and particle flux distribution with very high resolution. Other diagnostics such as infrared cameras, bolometry, visible spectroscopy and Doppler reflectometry will allow for a complete analysis of plasma properties, impurity sources as well as SOL widths and turbulence characterization on inner and outer sides.

A particular attention will be devoted to the evolution of the power sharing with respect to density conditions, e.g. from hot versus cold divertor plasma regimes, in ohmic heated plasmas. The second step will focus on the increase of the heating power and the access to high confinement regimes, analyzing both the edge pedestal stability in such conditions as well as the evolution of the inner and outer SOL widths. The experimental studies will be supported by edge transport simulations performed with the SOLEDGE code, to get further insights on the impacts of the various mechanisms at play and notably the impact of ExB drifts on particle and energy flows in the divertor regions.

A comparison with results in standard SN configuration will complete the data analysis and DN characterization. Finally, the potential of DN configurations for FPP will be assessed.

Scientific collaborations :

- Name of the collaborator: DR Yannick Marandet (co-PhD director)
- Organization/ Company: CNRS, PIIM laboratory (https://piim.univ-amu.fr/) Aix-Marseille University
- Motivation for the collaboration :
  Yannick Marandet has been actively collaborating for a long time with the IRFM teams on a wide range of topics, from the modeling of the transport of the edge plasma and the plasma-wall interaction to the analysis and interpretation of experiments, in particular concerning the transport of impurities and neutral particles. In the framework of the proposed topic, he will actively participate in the modeling part being one of the experts of the SOLEDGE-EIRENE code that he continues to develop in collaboration with the IRFM. His expertise in the analysis of experimental data such as those coming from visible spectroscopy and concerning the plasma-wall interaction will also be very valuable for the work of the PhD student and the progress of the thesis.