Post-doctoral position

Turbulent transport in stellarator-like configurations: impact of aspect ratio and large magnetic field

General information

Workplace: .... IRFM-CEA Cadarache, France

Type of contract: .... Post-Doc Contract

Contract period: .... 3 years

Expected date of employment: .... First half of 2024

Proportion of work: .... Full time

Desired level of education: .... PhD in Plasma Physics or in Fusion Physics

Contact person: .... Dr. Yanick Sarazin, yanick.sarazin@cea.fr, +33 442 254 803

Subject description

Toroidal magnetic devices are the most advanced configurations in view of a fusion reactor. While tokamaks are almost axisymmetric and require toroidal plasma current, stellarators explore the vast parameter space of non-axisymmetric configurations. Tremendous theoretical efforts are being made to optimize their configuration so as to achieve good particle and heat confinement and tractable technological design. Rapid progresses are observed, notably with the further improvement of the so-called quasi-isodynamic configuration retained for W7-X [Helander2014], the largest stellarator currently in operation in Greifswald, Germany. While transport was dominated by collisional losses in the early developed configurations, confinement in the latest ones turns out to be limited by turbulent transport.

Turbulence in tokamaks and stellarators share common features – especially regarding the underlying dominant linear instabilities. However, notable differences arise due to the large variety of particle trajectories in the 3-dimensional magnetic equilibria of stellarators. There, the turbulent modes excited by the particles trapped in local mirrors of the magnetic field are observed to remain rather benign and to drive relatively low transport [Helander2015]. Also, the dynamics and the level of both oscillating and steady large scale (zonal) flows depend very much on the detailed properties of the considered 3D magnetic configuration [Xanthopoulos2011]. This observation can actually lead to further optimizations since these flows are suspected to play a prominent role on the saturation of ion-scale turbulence.

The objective of the proposal is to address turbulent transport issues in non-axisymmetric configurations representative of current stellarators, in view of their better characterization and, ultimately, of their possible optimization. Very few first principle numerical codes can handle such complex geometries within the relevant 5-dimensional gyrokinetic description, and even fewer in the full plasma volume [Kleiber2024]. The full-f and flux-driven code GYSELA was initially developed to study turbulence and transport in the core of tokamak plasmas [Grandgirard2016]. Recently, simulations were extended to non-axisymmetric magnetic configurations by accounting for a sinusoidal perturbation of moderate magnitude in the toroidal direction of the magnetic field strength, its vector direction remaining axi-symmetric.

The idea is to extend these types of simulations to account for a broad spectrum of magnetic perturbations of larger magnitude reminiscent of stellarators. Note, however, that the direction of the magnetic field will remain two-dimensional. Indeed, the development of the version of GYSELA capable of handling complete three-dimensional magnetic equilibria is a difficult development task in itself, which will be addressed in parallel in another proposal.

In the proposed work, particular emphasis will be given to the two main characteristics of the stellarator project of Renaissance Fusion (https://renfusion.eu/), namely the large magnetic field strengths permitted by high temperature superconductors and the relatively small aspect ratio geometry. As a side effect of the large B field, such plasmas are also expected to achieve high densities, regimes that should be therefore explored. A staggered approach will be adopted for the work plan, so as to build up a comprehensive understanding of the role of the various scanned parameters:

- Experimental scaling laws of the energy confinement time in tokamak plasmas are inconclusive regarding the sign of the exponent of the aspect ratio R/a. Exploring the impact of R/a in axisymmetric configurations would already be instructive.
- Identify a few characteristic spectra of 3D magnetic perturbations that would be reminiscent of current stellarator configurations. Compare their turbulence characteristics and associated transport in various regimes, including simulations with fully adiabatic and hybrid (trapped kinetic) electron response.
- Perform a scan in magnetic field strength B and density N. The resulting transport level could be analyzed in terms of the critical dimensionless parameters $\rho^*\sim 1/B$ and $\nu^*\sim N$ and compared to the international stellarator scaling law ISS04 [Yamada2004].

Environment

You will work under the supervision of Dr. Yanick Sarazin and in close collaboration with the GYSELA team, including (in alphabetical order) Drs. Guilhem Dif-Pradalier, Peter Donnel, Xavier Garbet, Virginie Grandgirard and Kevin Obrejan.

References

[Grandgirard2016]	V. Grandgirard et al., Comput. Phys. Commun. 207 (2016) 35
[Helander2014]	P. Helander, Rep. Prog. Phys. 77 (2014) 087001
[Helander2015]	P. Helander et al., Nucl. Fusion 55 (2015) 053030
[Kleiber2024]	R. Kleiber et al., Comput. Phys. Commun. 295 (2024) 109013
[Varennes2023]	R. Varennes et al., Phys. Rev. Lett. 128 (2022) 255002
[Xanthopoulos2011]	P. Xanthopoulos et al., Phys. Rev. Lett. 107 (2011) 245002
[Yamada2004]	H. Yamada et al., Nucl. Fusion 45 (2004) 1684