WINTER EVENT
CADARACHE
2021

Féderation sciences des Plasmas et de la Fusion (FedSPF)

Erasmus Mundus European Master in Nuclear Fusion & Engineering Physics

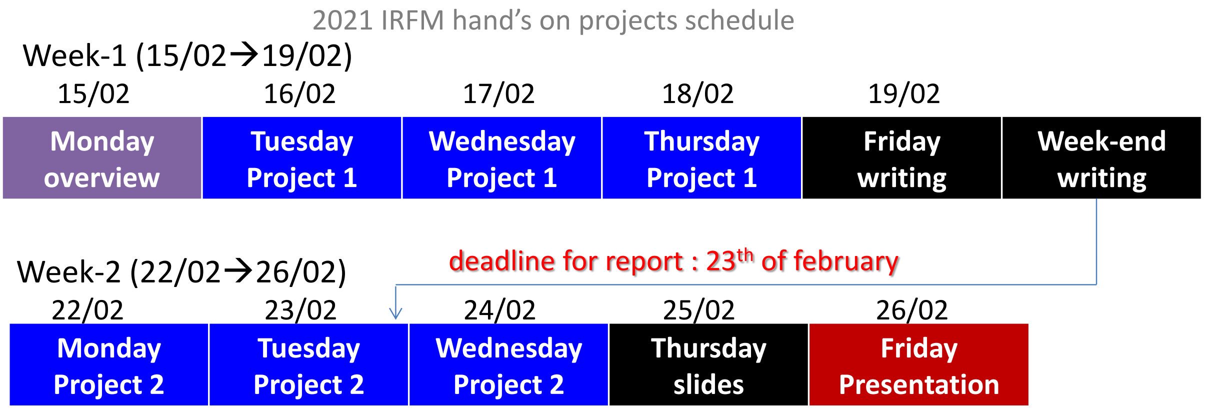
Short description of the subjects for Hands-On project.

Cadarache event – Winter 2021

or questions, please contact: nicolas.fedorczak@cea.fr

The 2021 winter event at Cadarache had to adapt to the present COVID situation. Most of students will stay working from their home universities, on projects supervised by remote researchers. Each student will work on two consecutive weekly projects.

- The first project will be evaluated based on a written report of 4 pages (type Physical Review Letter) that will need to be submitted to the internal jury by the beginning of the second week.
- The second project will be evaluated based on an oral presentation of 20 minutes followed by 10 minutes of questions.
- Optional templates will be provided.



2021 IRFM hand's on projects schedule

Week-1 (15/02→19/02)

15/02	16/02	17/02	18/02	19/02	
Monday overview	**Tuesday Project 1**	**Wednesday Project 1**	**Thursday Project 1**	**Friday writing**	**Week-end writing**

Week-2 (22/02→26/02)

deadline for report : 23th of february

22/02	23/02	24/02	25/02	26/02
Monday Project 2	**Tuesday Project 2**	**Wednesday Project 2**	**Thursday slides**	**Friday Presentation**

In the following, you will find the list of projects. Each project is labelled as "REMOTE" or "LOCAL" : local projects cannot be performed remotely and will be reserved to students from Aix-Marseille university.

List of projects:

Acronym	**title**	**type**
LH	Lower Hybrid antenna	Local
IC	Ion cyclotron antenna	local
IR	Infrared thermography on plasma facing components	remote
CONF	Confinement studies on WEST plasmas	remote
NM	Numerical Models of plasma processes	remote
MC	Magnetic control of plasma discharges on WEST	local
IM	Integrated tokamak modelling	remote
TDS	Thermodesorption experiment	local
TJK	Statistical analysis of TJ-K stellarator data from the ETDB	remote
GOL	Golem	Remote
REFL	Reflectometry for density profiles in Tokamak	local

Details about each project are given in the following pages.

hand's on project name	supervisors (**bold**: person in charge)	week 1 16/02 to 19/02	week 2 22/02 to 25/02	Room
LH mode converter	**Julien Hillairet**	✓	✓	**Bat 508 room 234**
	Joëlle Achard		✓	
	Riccardo Ragona	✓	✓	
	number of student pairs	0	1	
IC travelling wave antenna	**Julien Hillairet**	✓	✓	**Bat 508 room 234**
	Joëlle Achard		✓	
	Riccardo Ragona	✓	✓	
	number of student pairs	1	1	
IR WEST data analysis	**Yann Corre**	✓		**REMOTE**
	number of student pairs	1	0	
CONF analysis of WEST confinement	**Jorge Morales**			**REMOTE**
	Valeria Ostuni			
	number of student pairs	0	2	
NM numerical modeling of plasma phenomena	**Yanick Sarazin**	✓	✓	**REMOTE**
	David Zarzoso		✓	
	Alain Ghizzo	✓		
	number of student pairs	4	4	
MC Magnetic control of a WEST plasma	**Remy Nouailletas**	✓		**Bat 506 salle de contrôle WEST**
	number of student pairs	1	0	
IM Integrated modelling	**Mireille schneider**		✓	**REMOTE**
	number of student pairs		3	
TDS Thermodesorption	**Floriane Leblond**	✓	✓	**Bat 508 Hall 231**
	number of student pairs	2	2	
TJK analysis of fluctuations from TJK	**Bernhard Schmid**	✓		**EMOTE/Control roo**
	Mathieu Peret			
	number of student pairs	2	0	
GOLEM GOLEM plasma	**Vojtech Svoboda**	✓		**REMOTE**
	ondrej Gover			
	number of student pairs	4	0	
REFL Reflectometry	**Frederic Clairet**		✓	**508**
	Stéphane Heuraux		✓	
	number of student pairs	0	2	

LH: Lower Hybrid antenna
LOCAL project at Cadarache

Organizers: Julien Hillairet, Joëlle Achard, Riccardo Ragona

A quick survey of the work

During these Hands-on, both measurements and data analysis will be performed. We will introduce you to the fabulous world of RF measurements and you will operate by yourself the measurements devices, such as RF network analyser. You will have to assemble yourself the devices and waveguides elements and perform the necessary calibrations, make the measurements and then post-process the results.

Tore Supra, now WEST, is a superconducting tokamak, which has demonstrated the sustainment of long plasma pulses (up to 6 minutes 30 seconds). In order to sustain these long pulses, a part or all the plasma current must be generated non-inductively. This additional plasma current is driven on Tore Supra via the Lower Hybrid and Current Drive (LHCD) system. High power Radio-Frequency sources (klystrons) generate hundreds of kilowatts, which are carried through transmissions lines (rectangular waveguides) up to the LH launchers facing the edge plasma (cf. **Erreur ! Source du renvoi introuvable.**).

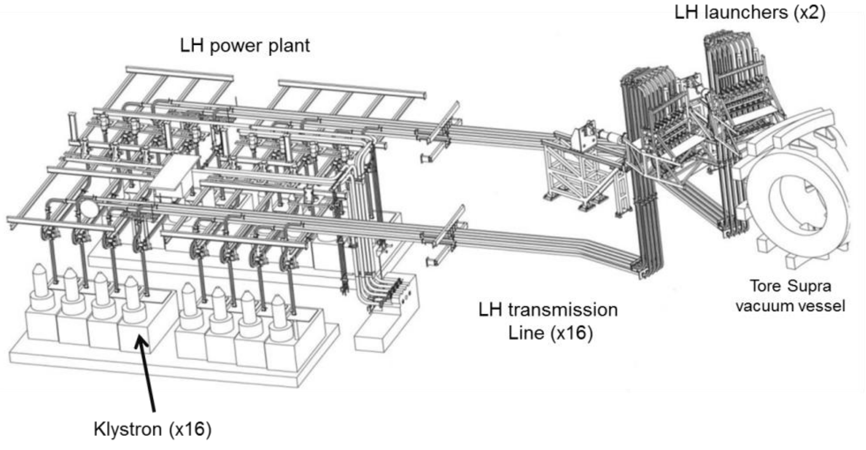


Figure 1. Overview of the Tore Supra LHCD systems. Sixteen high power sources (klystrons, at the left of the Figure) feed two antennas (at the right of the Figure, not illustrated) via sixteen 25-meters long transmission lines (rectangular waveguides).

The hands-on focuses on a RF component constituting the WEST LH launchers: the “mode converter” (in red in **Erreur ! Source du renvoi introuvable.**). Its main function is to divide the RF power coming from the klystron to 3 waveguides inside the antenna. A mode converter is a RF device which aims to convert an electromagnetic mode of propagation in a waveguide into another mode. In particular, the TE10-TE30 mode converter converts a low order incident Transverse Electric mode (TE10) into a higher order TE mode (TE30). Once this mode conversion done (Figure 1), the power is then split into three independent waveguides: the device has thus divided the power by three. This device is used on Tore Supra to split by three the RF power in the poloidal direction, in order to feed three rows of waveguides in each half parts of the C3 launcher (Figure 1).

During this Hands-On, you will measure the RF performances of a mode converter prototype for WEST LH1 antenna. From your data analysis, you will have to characterize it, as a RF engineer would have to do.

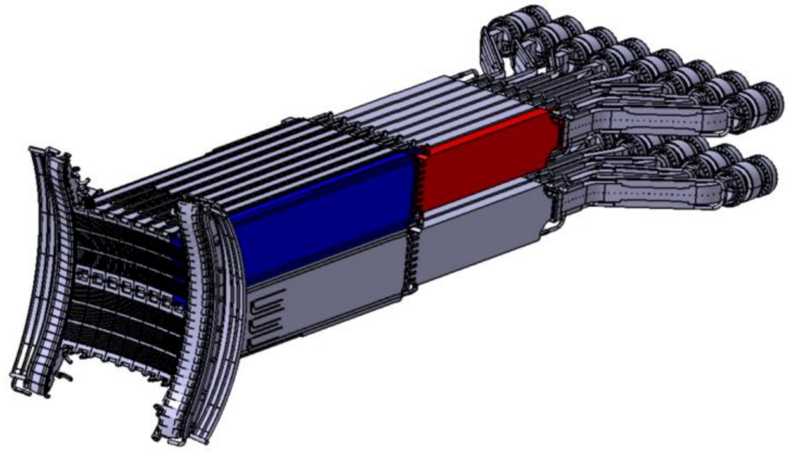


Figure2. CAD view of a Tore Supra Lower Hybrid launcher (aka "C3"). The red part is the TE10-TE30 Mode Converter. The Blue part is the multijunction. Dimensions : approx. 0.7 x 0.7 x 5 m.

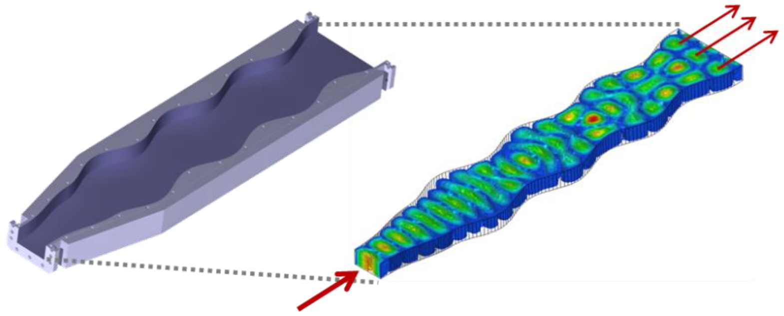


Figure 1. CAD Internal view and its associated RF modeling (electric field).

IC: Ion cyclotron antenna

LOCAL project at Cadarache

Organizers: Julien Hillairet, Joëlle Achard, Riccardo Ragona

A quick survey of the work

During these Hands-on, both measurements and data analysis will be performed. We will introduce you to the fabulous world of RF measurements and you will operate by yourself the measurements devices, such as RF network analyser. You will have to assemble yourself the devices and waveguides elements and perform the necessary calibrations, make the measurements and then post-process the results.

For heating the core of a fusion machine, Ion Cyclotron Resonant Heating (ICRH) is a logical first choice as it enables coupling radio frequency power directly to the ions. In addition, ICRH does not suffer from a cut-off frequency and is thus an ideal method to heat plasmas at very high density. The drawback of ICRH is the difficulty of coupling a large amount of power through the plasma boundary without exceeding the voltage standoff of the antenna(s) located along the wall. To reduce the antenna power density and the associated high voltage in low coupling conditions, antennas distributed all along the periphery of the tokamak are presently considered for a DEMO reactor (Figure 1). These are called travelling wave antenna (TWA).

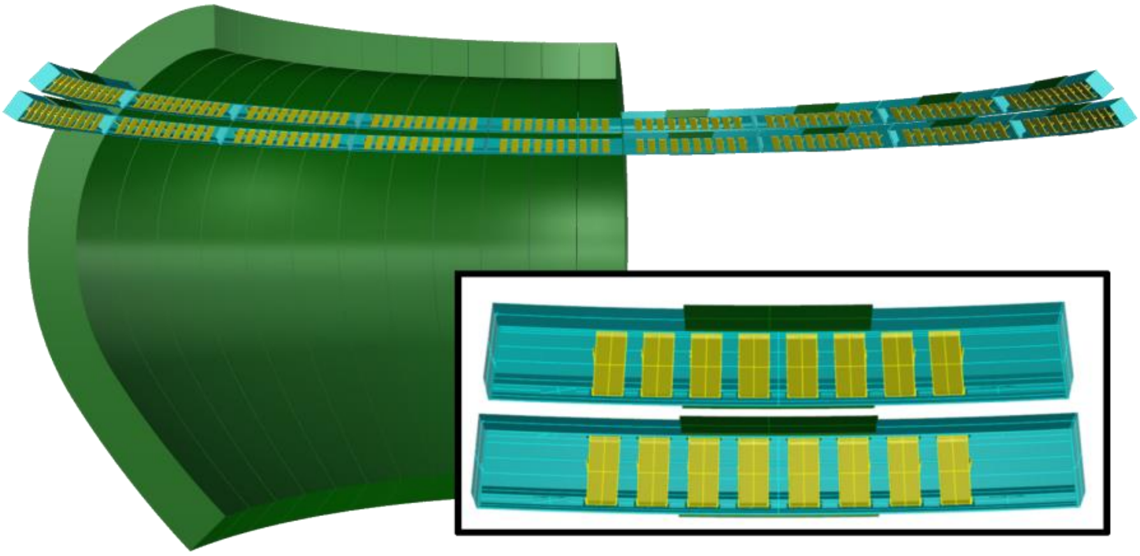


Figure 1. Overview of the proposed ICRH antenna system made of the double TWA section integrated in the DEMO blanket. Inset: detail of a section.

The TWA section fed in resonant ring configuration is a completely new ICRH system with respect to a conventional one, presently in use at e.g. ASDEX-U, WEST, JET and especially the foreseen option for ITER. A TWA section consists in an array of parallel grounded straps, inductively coupled to each other, in contrast to classical ICRH antennas where those septa are inserted on purpose to reduce the inter-strap mutual coupling and resulting matching problems.

An efficient way to recirculate the uncoupled power to the plasma is the use of a TWA section inside a resonant ring (Figure 1). The ring is composed by a TWA and outside the vacuum vessel two 3dB hybrid couplers, an RF power generator, a dummy load and two adjustable length transmission lines (line stretchers).

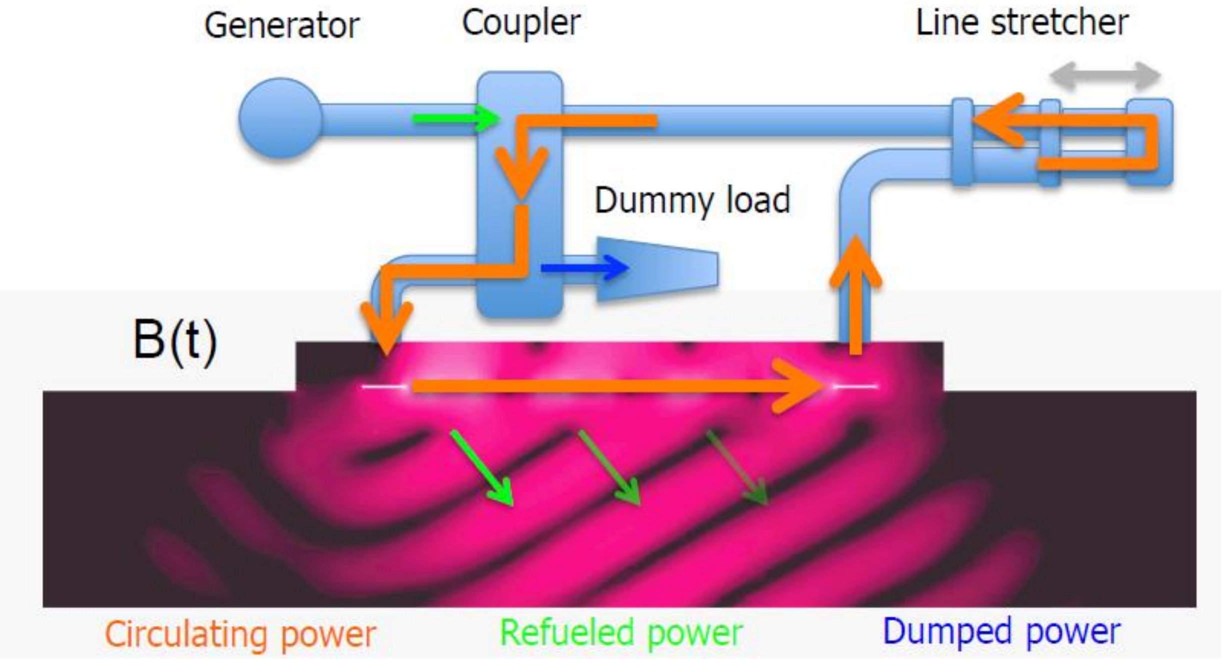


Figure 2. TWA re-circulating power using a resonant ring.

During this Hands-On, you will study and measure the RF performances of directional coupler, one of the key elements of a resonant ring which could be used by a future TWA. From your data analysis, you will have to characterize it, as a RF engineer would have to do. Then, you will have to create a resonant ring and tune it in order to get a resonant ring setup.

IR: Infrared thermography on WEST plasma facing components
REMOTE project

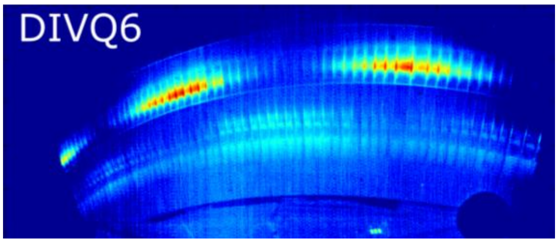
Organizers: Yann Corre

Objectives:

- IR thermography principle (from the source to the camera detectors). Accuracy of the system, challenges for ITER.
- Technological limitation related to the plasma facing components (PFCs): melting, critical heat flux and aging (leading to cracks formation). Protection of the PFCs during plasma experiment (tools, real time control)
- Physics of the plasma heat flux deposition on PFCs: heat flux decay length, projection of the parallel heat flux on the surface of the component (optical approximation), impact of the magnetic equilibrium (magnetic expansion, ripple effect). Identification of the main PWI areas: erosion, deposition and shadowed zones.

Means:

- WEST IR data base (top view of the lower divertor)
- Numerical simulations to investigate the relationship between heat load and temperature of the plasma facing component (Finite Element Modelling – CASTEM code)
- Numerical simulations to investigate the projection of the parallel heat flux on the surface of the lower divertor (Matlab languages).



Infra red view of the lower divertor of WES

Practical work:

- Understanding the IR thermography measurement and technological limitation associated to actively cooled PFCs.
- Analytic study of the surface temperature as function of the heat load (heat flux transfer in the component)
- Performing modelling of the heat flux deposition for different magnetic equilibrium and plasma heat flux decay lengths (λ_q)
- Comparison to experimental IR data

CONF: Confinement studies on WEST plasmas
REMOTE project

Organizers: Valeria Ostuni & Jorge Morales

Objectives:

- Compare different means of calculating the energy confinement time in plasma discharges performed in WEST.
- Investigate the parametric dependence of the energy confinement time with global control parameters: plasma current, heating power, plasma density, etc.
- Compare the parametric dependence of WEST energy confinement time to already existing scaling laws.

Means:

- Analytic calculations
- Numerical calculations on WEST database, using Python or matlab
- Database regression, statistical studies on large database.

Practical work:

- Analytical calculation of energy confinement time of tokamak discharges, based on magnetic data or profiles of various quantities.
- access WEST database and perform calculation
- Built a representative database
- Perform statitsical study of this database
- Compare to existing scaling laws.

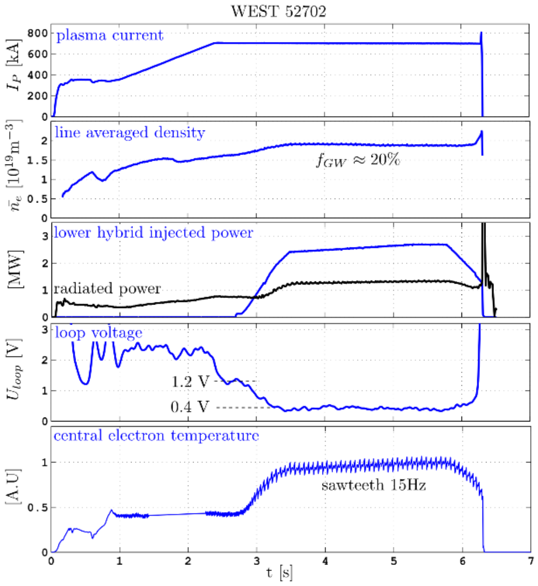


Illustration of a WEST discharge, showing the time trace of different quantities evolving during the discharge.

NM: Numerical Models
REMOTE project

Organizers: Yanick Sarazin, David Zarzoso & Alain Ghizzo

Objectives:

- Analytical studies and use of reduced numerical models (from 1D to 2D in phase space, either toy models or derived from 1st principles)
- Physics of kinetic resonances and of linear instabilities; dynamics of turbulent transport and self-organization
- Related modules (for Master 'Sciences de la Fusion'): FCM-3, FCM-4 & FCM-5

Means:

- Analytic calculations
- Numerical simulations on local servers (Fortran 90 and Matlab/Python languages)

Practical work:

- Analytic study of the reduced model: model derivation + physics analysis
- Understanding of numerical schemes: Semi-Lagrangian, Crank-Nicolson, leapfrog
- Performing numerical simulations (from a few seconds to a few minutes): explore the landscape of numerical and physical parameters
- Analysis of numerical results (Matlab/Python programming): comparison to theoretical predictions and beyond

3 proposed models:

1. Landau damping with and without collisions: 2D Vlasov-Poisson model f(x,v,t)
2. 2D model for bump-on-tail instability: linear (threshold, growth rate), quasi-linear and nonlinear behavior
3. 1D model for the transition from Low to High confinement regime

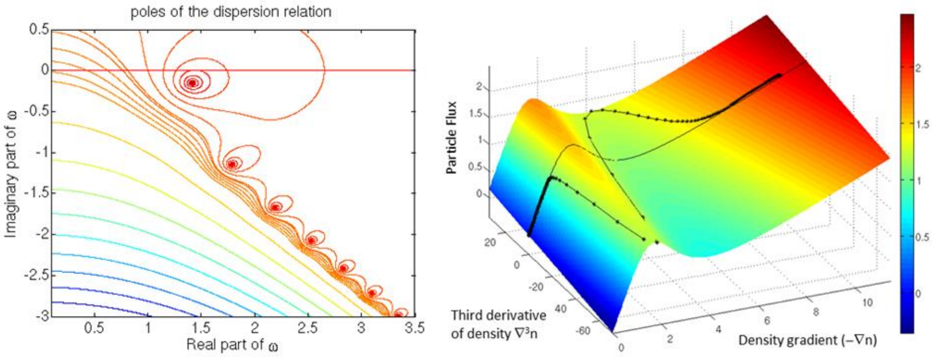


Figure: (Left) Poles of the 2D Vlasov-Poisson dispersion relation. (Right) Landscape of the flux in the L-H transition model with hyper-diffusion

MC: Magnetic control of WEST plasma discharges
LOCAL project at Cadarache

Organizers: Remy Nouailletas

Objectives:

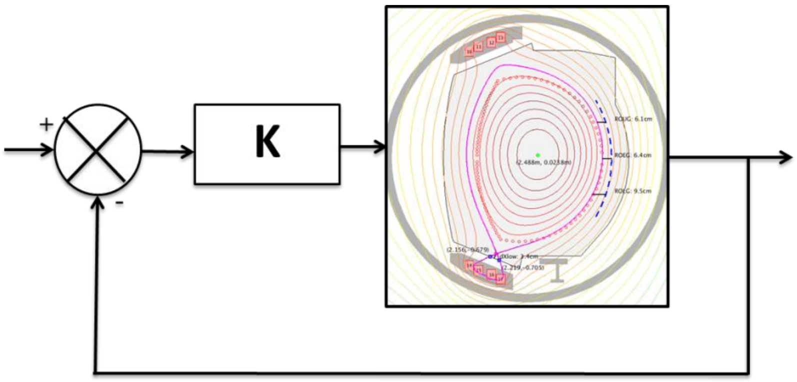
Magnetic control is one of the key controls on a tokamak to achieve the plasma scenario. Based on a feedback control loop, it allows from the real-time plasma shape reconstruction to keep the plasma in the middle of the vessel by adjusting the currents in the poloidal field coils. On WEST, because of the elongation of the plasma, the magnetic control should also deal with a vertical instability of the plasma. The current structure of the magnetic control WEST limits the vertical elongation of the plasma to a value far from the one specified into the project requirement. To reach this specification, this subject proposes to study the impact of a fast control loop directly between the magnetic sensor and in-vessel coils in charge of the vertical control.

Means

- Matlab Simulink
- Course power point support
- WEST magnetic control documentation
- WEST control toolbox

Practical works

After a short introduction on feedback control, the students will study the modeling of plasma vertical instability. Using methods of control engineering, they will develop, tune and test in simulation a fast vertical control. The students should give their recommendation for this new fast vertical control and determinate the limits of the controller.



Basic feedback control loop scheme of the plasma position

IM: Integrated tokamak modelling
REMOTE project

Organizers: Mireille Schneider

initiation with the SPOT orbit following Monte Carlo code: The purpose of this subject is to get a foretaste of simulation techniques for Physics research. The work plan is organized in three parts,

1. Context of integrated modelling:
    a. Brief reminder of tokamak magnetic device and fusion processes
    b. Transport solvers: towards simulating a complete plasma discharge
    c. Modules: physics codes for simulating a specific physics process
    d. Example: the SPOT Monte Carlo code for simulating fast ions in the plasma
    e. Integrated Tokamak Modelling : SPOT in this context, present status and perspectives
2. Numerical methods for orbit following Monte Carlo codes:
    a. The Monte Carlo technique
    b. Generating a source of alpha particles
    c. The trajectory equations
    d. The Runge-Kutta integration for orbit following
    e. The Monte Carlo operator for collisions
    f. General structure (flowchart) of the code with its time/particle loops.
    g. Particle administration (optional)
    h. Optimization: collision acceleration & energy reweighting (optional)
3. Construction of a Monte Carlo solver for alpha particles:
    a. To generate 100 new-born alpha particles from the D-T fusion reactions using the Monte Carlo technique: to evaluate their initial position, velocity, pitch angle
    b. To compute the trajectory equations and the Runge Kutta integrator
    c. To construct the time and particle loops for computing full orbits / trajectories
    d. To add a Monte Carlo operator for simulating the collisions between alpha particles and the thermal plasma (electrons and ions from the bulk)
    e. To construct two vectors for storing the fusion power and the power transferred to the bulk
    f. To export the results to a file for external display and verification

Involved computing environment and languages: Unix, Fortran 95, Matlab.

TDS: Thermodesorption experiment
LOCAL project at Cadarache

Organizers: Florian Leblond

In a fusion reactor, plasma facing components are subject to intense flux of particles incoming from the plasma and hot gas surrounding it. This incident particle flux is mainly reflected back to the plasma in the form of neutrals. That said, a small but finite fraction of impacting ions stay trapped into the material surface, due to several trapping mechanisms. This so-called retention is of primarily importance regarding reactor operation: retention can affect the plasma dynamics by degassing a large amount of particles during transient events, it can be a cause of deterioration of material properties on long term. But it is also a nuclear safety issue because a significant proportion of retained atoms will be radioactive (tritium). In current tokamaks and reactors, a first process to release the retained atoms into the vacuum chamber is desorption by baking of the chamber: by increasing the wall temperature, atoms are detrapped from the surface. The efficiency of this phenomenon depends on the temperature of the surface with respect to the trapping energy in the surface lattice.

In laboratories, this thermos-desorption is used to characterize material properties and characterize trapping from plasma facing components of tokamaks: a small sample of surface is fixed on a heating tungsten wire and placed into a high vacuum chamber connected to a mass spectrometer. The temperature of the sample is slowly rises to several hundreds of degrees, while the mass spectrometer measures the composition of the gas desorbed from the sample. Desorption rates function of sample temperature can be used to infer the properties of traps in the material surface.

The work will aim at:

1) Getting familiar with the thermo-desorption system
2) Make a calibration of the mass spectrometer using different gas injections
3) Prepare a sample
4) Run a thermos-desorption
5) Analyse the TDS data to infer properties of the sample.

Thermo-desorption installation

TJK: Statistical analysis oj TJ-K stellarators data from the ETDB
REMOTE project

Organizers: Bernhard Schmid & Mathieu Peret

Turbulence is known as being responsible for the major energy and particle losses in magnetic confinement devices. Experimental turbulence studies in fusion experiments with electron and ion temperature on the order of a few keV are challenging. Low-temperature plasmas with dimensional similarity to fusion edge plasmas offer the possibility to insert Langmuir probes over the whole cross section and thus provide both a spatial and temporal resolution of plasma fluctuations which is barely available in large fusion devices. The stellarator TJ-K, located at the University of Stuttgart, is such a device. It is equipped with a 2D movable probe system as well as poloidal probe arrays. Data acquisition rates of up to 1 MHz and long discharges of several 10s of minutes allow for excellent statistics.

In this project, the students will access a TJ-K dataset [1] from the Edge Turbulence Data Base (ETDB) [2] included in the International Stellarator-Heliotron Profile Database. The idea is to perform statistical data analysis on the time series in order to get a basic understanding of the turbulence transport. To this end, radial profiles of the normalized fluctuating quantities density and potential, spectra in the separatrix region, turbulent transport, the statistical moments and the auto-correlation function are calculated, analysed and discussed.

[1] P. Simon *et al.* PPCF **56** (2014) doi:10.1088/0741-3335/56/9/095015
[2] https://ishpdb.ipp-hgw.mpg.de/

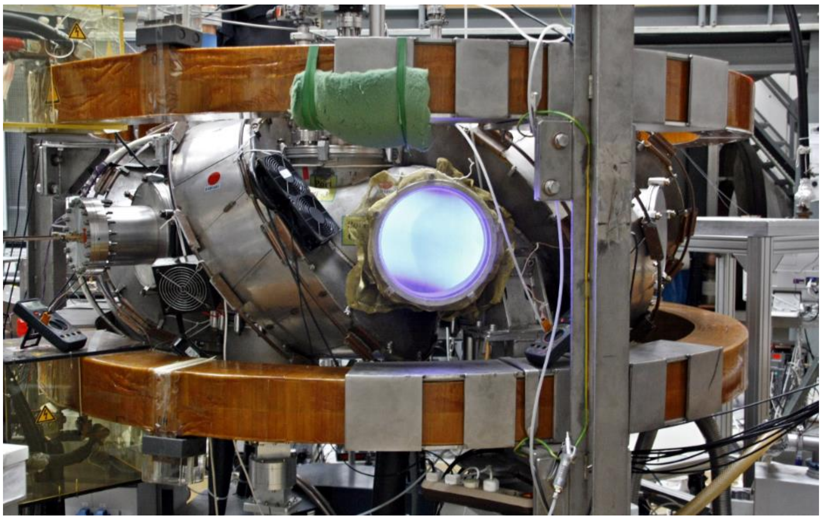


Figure: TJ-K stellarator with argon plasma

GOL: Tokamak experiments on GOLEM
REMOTE project

Organizers: Vojtech Svoboda & Ondrej Grover

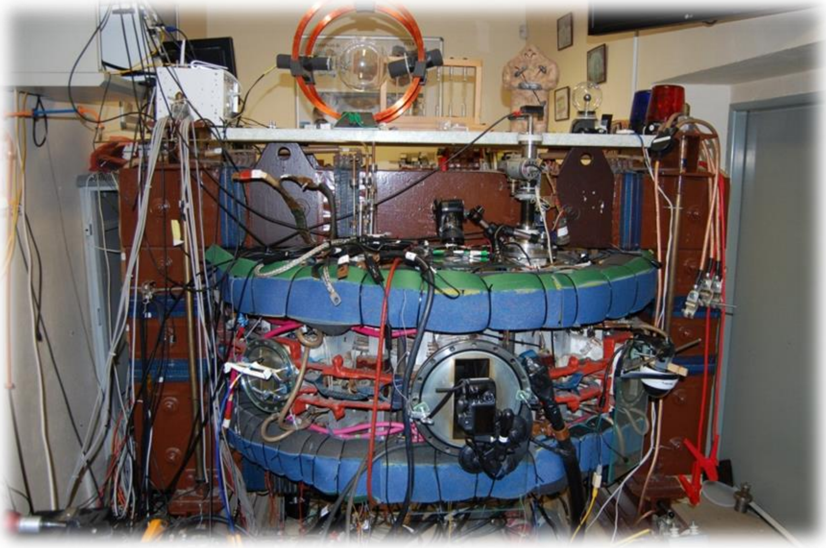
GOLEM is one of the very first tokamaks and the oldest tokamak in operation in the world. It stands in the Czech Technical University (CTU) in Prague.

GOLEM was installed, commissioned and is continuously upgraded by Vojtech Svoboda with the aim of training students and young physicists interested in thermonuclear fusion research. This is done both by allowing CTU students to develop new systems or diagnostics and by organising remote experiments with groups in various places around the world [V. Svoboda et al., Fusion Eng. Design 86 (2011) 1310-1314].

After an introductory lecture about the tokamak and its diagnostics, the pairs of students will have to devise methods to determine the main plasma parameters using the available measurements. Then they will choose a theme of study, elaborate an experimental plan and perform the corresponding experiments (remotely!) for about one day (or possibly two half-days). The preliminary data analysis during the experiments will be followed by a more accurate analysis. The results will be summarized in a 20mn oral presentation.

This hands-on work is proposed only on the second week of the hands-on projects. It is a unique opportunity to get involved in a tokamak experiment at the very heart of operation. It is open to every student regardless of their future orientation.

The students will be supervised by 3 experienced physicists. The GOLEM project leader will be visiting us at the beginning of the work. He will operate the machine the second part



The tokamak GOLEM.

REFL: Reflectometry for density profiles in Tokamak
LOCAL project at Cadarache

Organizers: Frédéric Clairet, Stéphane Heuraux

Theory & Overview

1. Tokamak diagnostics – Reflectometry.
2. Visit of the torus hall. Location of the reflectometers.
3. How to build a reflectometer from schematic to full design.
4. Wave propagation into magnetized plasma.
5. Signal analysis (phase and amplitude).

Laboratory experiment

6. Recognition of the reflectometry components.
7. Measurement of the IF frequency (Spectrum analyser).
8. Frequency source calibration.
9. Voltage ramp sweeping.
10. Measurement of the IF frequency with sweeping.
11. Operating a reflectometer.
    - Signal acquisition (digitization, sampling frequency).
    - Acquisition of a sine and cosine signal (complex signal).
    - Determination of the zero reference.
    - Distance vs. signal measurement.
    - Signal processing (FFT, filtering).

Plasma measurements (data analysis)

12. Reflected signal on a plasma.
13. Density profile reconstruction (recursive treatment – application to real plasma signal).
14. Effect of the density fluctuations on the reflected signal – turbulence dynamic example.

The students will operate a reflectometer, record signals using analogic-digital converter and oscilloscope, process signals with matlab.