INDO SWISS JOINT RESEARCH PROGRAMME (ISJRP)

RESEARCH FELLOWSHIPS

EXCHANGE GRANT REPORT

Grant No.: RF11

Part 1 - General Information

<table>
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<tr>
<th>Project Title:</th>
<th>Local and global gyrokinetic simulations of microturbulence in Tokamaks</th>
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<td>Keywords:</td>
<td>Gyrokinetic theory &amp; simulation, linear stability, tokamaks, global microinstabilities</td>
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<td>Start date:</td>
<td>April 20, 2009</td>
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<td>Duration:</td>
<td>4 months</td>
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Part 2 - Exchange Participant(s) Details

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Part 3 - Scientific & Technical Information

3.1 Purpose of visit

In our original proposal, we planned to work on a numerical code for addressing the global gyrokinetic stability properties of a general geometry tokamak. Tokamaks are believed to be a promising device for achieving controlled thermonuclear fusion, which would be a new source for clean energy. The idea was to generalize the presently existing global gyrokinetic spectral code EM-GLOGYSTO developed at CRPP-EPFL and extensively used at IPR, India, to study various microinstabilities in tokamak plasmas, and compare its results with another code GENE (acronym for Gyrokinetic Electromagnetic Numerical Experiment), originally developed at the Max-Planck-Institut für Plasmaphysik in Garching, Germany. Such an endeavour is very much sought in view of the necessity of sound understanding of the complex dynamics of the plasma microturbulence in toroidal geometry, which leads to so-called anomalous transport, a major limiting factor towards a practical fusion reactor.

The study of plasma microturbulence in tokamaks using analytical theory is limited and beyond it one is forced to make use of numerical techniques to carry out the study of the various aspects of the turbulent system. In the linear regime and under certain approximations, i.e. in the case of a large aspect ratio tokamak with circular cross-section, the code EM-GLOGYSTO is very useful to study the various temperature gradient driven modes in the plasma, such as the ion temperature gradient modes, trapped electron modes, electron temperature gradient driven modes, etc. However, in reality, the large aspect ratio circular cross-section assumption for tokamaks is inappropriate to describe most actual devices. One thus needs to include all the effects of actual geometry and arbitrarily shaped equilibria in order to mimic the real experimental conditions.

In a linear model, the kernel for evaluating the response of the plasma to a perturbation is provided by the so-called propagator. Computing the propagator in turn requires the accurate integration of unperturbed particle trajectories. To take advantage of analytical tractability, the calculation of the particle trajectories in the code EM-GLOGYSTO has been done correctly only up to the first order in drifts (the averaged cyclotron trajectory of particles can be decomposed into a motion parallel to the confining magnetic field and perpendicular drifts related to gradients and curvature of the field). The generalization of the propagator to account for more realistic trajectories would allow the arbitrary aspect ratio and shaped plasma effects to be studied comprehensively. This can be accomplished either by extending the EM-GLOGYSTO and/or by making use of the newly developed global version of the GENE code.

3.2 Short description of work carried out during the visit

As a first step towards this goal, the existing nonlinear electromagnetic gyrokinetic code GENE, based in its original form on a local flux tube model, has been studied. Considering the reduction of the project time from the initially planned 6 months to the final 4 months, directly making use of the existing GENE code instead of undertaking the further
development of EM-GLOGYSTO was considered by both parties as a better option to achieve the goals of the joint research proposal.

The activities carried out during the stay are listed as follows:
1. The set of gyrokinetic equations, which are solved numerically in the GENE code, has been revisited.
2. Experience with the concept of a field aligned coordinate system has been acquired. Field-aligned coordinates are the natural choice for studying microturbulence and are thus very useful in reducing the computational time. Indeed, microinstabilities have the property of aligning along the field lines.
3. Familiarized with the concept of flux-tube volume. In general, to simulate the whole volume of a tokamak is computationally very expensive. Using the nature of the microinstabilities, one can justify under certain conditions, especially when considering larger plasma devices, to consider a reduced elongated volume around a given magnetic field line, a so-called flux-tube.
4. Gained experience with the local, flux-tube version of the GENE code for carrying out both linear and nonlinear runs. In particular, familiarized with the various input parameters such as for defining the magnetic equilibrium, particle species dynamics, numerical variables.
5. The use of ad-hoc circular geometry, the s-alpha model, and arbitrary shaped plasma has been studied. Arbitrary shaped plasma can be studied with the help of an interface with the MHD code CHEASE.
6. Familiarized with the various diagnostics for visualization and analysis of GENE's output data.
7. First applications of GENE consisted of studying the ion temperature gradient mode, trapped electron coupled ion temperature gradient mode, as well as the trapped electron mode. Results were benchmarked for the standard Cyclone base case with those from EM-GLOGYSTO wherever possible.
8. The GENE code was then used to conduct a novel nonlinear study of the Short Wavelength Ion Temperature Gradient (SWITG) mode, recently discovered and studied exhaustively by EM-GLOGYSTO in the linear regime [Short wavelength ion temperature gradient mode and coupling with trapped electrons, J. Chowdhury, R. Ganesh, J. Vaclavik, S. Brunner, L. Villard, and P. Angelino, Physics of Plasmas 16, 082511 (2009)]. The SWITG mode is an ion temperature gradient driven instability in the short wavelength limit.
9. Contributed to the current development of a global version of the GENE code. In particular carried out simulations including both full kinetic ion and electron dynamics. This enabled validation of global-GENE in the trapped electron and the kinetic ballooning regime.

3.3 Outcomes

The code GENE has been used to study the nonlinear SWITG regime, a physics issue which have hitherto never been addressed. It is related to the plasma transport in tokamaks induced by a particularly steep ion temperature gradient. Normally, the ion temperature gradient driven modes in tokamaks appear in the low perpendicular wave number part of the spectra,
i.e. the longer wavelength regime. The SWITG mode, however, appears at shorter wavelengths. This is, to our knowledge, the first nonlinear study of the SWITG mode. Comparison of the results from GENE and EM-GLOGYSTO in the linear phase has been studied as well. A manuscript is under preparation on this topic.

Thanks to this ISJRP project, the IPR laboratory has been able to gain expertise with the nonlinear micrturbulence code GENE, which shall be ported to the high performance computing platform in the home laboratory in India.

3.4 Future collaboration with host institution

Both parties are very much interested and committed to further pursue the collaboration initiated thanks to the ISJRP project. Regular video conferencing as well as publication of joint papers are planned. In particular, work on the SWITG study shall be finalized. Also, further collaboration on the development of the global-GENE code will be pursued. The collaboration will in particular be very fruitful on the validation of kinetic electron dynamics [A comprehensive gyrokinetic description of global electrostatic microinstabilities in a tokamak, J. Chowdhury, R. Ganesh, S. Brunner, J. Vaclavik, L. Villard, and P. Angelino, Phys. Plasmas 16, 052507 (2009)], as well as electromagnetic fluctuations in the global-GENE code.

3.5 Various comments

The collaboration has proven to be very fruitful. Though the duration was not enough to initiate the development of a new global gyrokinetic stability code for tokamaks as initially planned, the existing nonlinear flux tube gyrokinetic electromagnetic code GENE have turned out to be very useful to study the various physical issues that were formulated in the original project plan.

3.6 Projected publications/articles resulting or to result from the exchange

One manuscript is under preparation that shall be submitted in a peer reviewed journal shortly.