



Exploratory Workshop Scheme

Scientific Review Group for Physical
and Engineering Sciences

ESF Exploratory Workshop on

**MULTI-SCALE METHODS FOR
WAVE AND TRANSPORT
PROCESSES IN FUSION PLASMAS:
THE LEGACY OF
GRIGORY PEREVERZEV**

Garching bei München (Germany), 13th – 16th October 2013

Convened by:
**Eric Sonnendrücker, Clemente Angioni,
Emiliano Fable and Omar Maj**

SCIENTIFIC REPORT



Group photo, Monday 14th October 2013 (Photo by Julia Sieber).

From left to right:

First line:

Natalia Tronko, Susan Leerink, Tünde Fülöp and Olof Runborg.

Second line:

Arthur Peeters, Omar Maj, Irina Voitsekhovitch, Olivier Lafitte, Gregor Tanner, Marie Hélène Vignal and Daniela Farina.

Third line:

Egbert Westerhof, Clemente Angioni, Emiliano Fable, Roman Schubert, Bruno Després, Alessandro Cardinali, Eric Sonnendrücker, Yann Camenen, Claudia Negulescu and Roland Diehl.

1. Executive summary

The ESF Exploratory Workshop “Multi-scale methods for waves and transport processes in fusion plasmas: the legacy of Grigory Pereverzev” was held at the Max Planck Institute for Plasma Physics in Garching bei München (Germany), from Sunday 13th October 2013 to Wednesday 16th October 2013. The workshop was organized over two-and-a-half days: The majority of the participants arrived on Sunday 13th in late afternoon/evening, and worked together at IPP from Monday 14th till Wednesday 16th at midday, when the workshop was closed early in order to allow all participants sufficient time for their return trip (cf. Section 4 for the detailed program). The focus of the meeting has been on the development of appropriate computational tools for models of transport processes and high-frequency wave propagation in fusion plasmas, which, as it is often the case in plasma physics, are typically characterized by vastly different temporal and spacial scales. More specifically, we proposed to explore the possibility to transfer to the fusion plasma physics framework recent results from applied mathematics and mathematical physics, with particular attention to a set of long-standing problems of practical relevance to fusion studies, cf. Section 3.

Transport theory and high-frequency wave propagation were exactly the main research interests of our colleague Grigory V. Pereverzev, who gave seminal contributions to their physical understanding and mathematical modeling. He deeply influenced our current view of those problems, encouraging in particular the application of the results and methods of mathematics. We dedicate this workshop to his memory, as a token of our esteem and gratitude.

Consistently with the agenda, the program is therefore split into those two main themes, namely, transport processes and high-frequency waves (cf. Section 4). Each theme comprises contributions on both the physics and the mathematics of the problem, with considerable time for discussions on scientific issues and planning for new future work and collaborations. The two themes of the workshop, however, should not be considered independent as in both cases the mathematical structure of the problem at hand is similar, being characterized by the existence of multiple spatial and temporal scales; hence, ideas developed primarily in one field can find applications in the other. In addition, the effects of high-frequency wave beams on the plasma needs to be accounted for in transport modeling.

The 16 invited participants represent seven countries (all of them ESF member countries), and, together with the 4 convenors, cover the relevant range of expertises: from transport and wave physics to mathematical and numerical methods for multi-scale problems. Section 6 summarizes the composition of the participants in terms of their expertises.

It is worth noticing that the composition of the participants reflects the highly exploratory character of the workshop. Mathematical physicists and applied mathematician from areas quite different from plasma physics and controlled fusion have been invited to present their recent results which, although initially developed in other fields (quantum mechanics, industrial applications, optics, numerical analysis, ...), can be successfully employed for the proposed problems. The composition of the participants and the considered topics made the workshop entirely unusual as compared to conventional meetings of the plasma physics and controlled fusion circuit. Indeed, it would have been difficult if not impossible to organize a similar event within the framework of a classic plasma physics conference.

This also implies that some of the participants did not know each other's work before the meeting, and had quite different backgrounds. The convenors provided a common reference point, organizing the program and the discussion sessions so that the essential aspects of the considered plasma physics problems were properly introduced for the non experts, and, vice versa, the expected contribution of each participant (cf. Section 3 for some detailed examples) was set within a common framework. This was accomplished by two talks dedicated to the description of the agenda of the workshop: one for transport theory (by Clemente Angioni) and one for high-frequency waves (by Omar Maj), cf. Section 4. Additionally, more detailed explanations were provided during the discussion sessions.

Despite the diverse composition of participants, each field was represented by more than one isolated researcher, so that plurality of ideas could be guaranteed and the workshop could be a point of contact between different research communities.

Many of the participants are based on Universities, as opposed to fusion-dedicated research laboratories. This was intended to bridge the gap which separates University research and the fusion community, within the limits of this workshop. The distance between Universities and fusion labs is indeed a well-known shortcoming of the fusion research community. We have tried to address it by emphasizing the fundamental aspects of fusion-relevant mathematical problems, thus stripping from their formulation the unnecessary technological details, and presenting the problems at a higher level of abstraction. This allowed us to formulate a common framework and to interact fruitfully with the mathematicians, suggesting new applications as well as pointing out necessary improvements of their methods and theories.

The workshop has been jointly hosted by the divisions of Tokamak Theory (TOK) and Computational Plasma Physics (NMPP) of the Max Planck Institute for Plasma Physics, in Garching. The newly created NMPP division, in particular, have the objective of transferring state-of-the-art numerical and mathematical methods to fusion plasma physics problems; the head of the division, prof. Eric Sonnendrücker, holds the chair of Computational Plasma Physics at the Department of Mathematics of the Technical University of Munich (TUM). The existence of such research division within IPP ensures the possibility of continuation of the activities explored during our workshop.

Here follows a brief overview of the workshop's activities. All participants met for the first time on Monday 14th. The registration provided the opportunity to get acquainted and to introduce those who were new to the IPP lab. The conference venue was the seminar room of the TOK division, which is furnished with desks equipped with plugs for laptops and thus offered a cozy working environment. Internet connection (both local wireless and Eduroam) was available. The seminar room is located near to the TOK library which was at our disposal; the library was used for breaks, informal discussions and social get-together. The limited number of participants and the environment made it possible to create a friendly and cooperative atmosphere.

After the registration and the welcome by prof. Eric Sonnendrücker, the first session of the workshop continued with the presentation of the ESF organization by prof. Roland Diehl, which gave us a nice overview of the possibilities for follow-up activities available within ESF. Then, prof. Arthur Peeters was invited to give a special lecture dedicated to Grigory Pereverzev. Rather than a purely celebratory lecture, prof. Peeters chose a specific problem (Alfvén wave heating) and discussed it as it was analyzed by Pereverzev and himself, thus

providing at the same time a working example of Pereverzev ideas and an introduction to the main concepts that have been the recurring themes throughout the workshop (tokamaks, particle dynamics, wave-particle interactions, ...).

The workshop continued with alternating sessions on transport modeling and high-frequency waves, cf. Section 4, and discussions on specific topics have been organized. A final discussion session on Wednesday allowed us to summarize the results of the meeting and set up ideas for future collaborations.

More details on the contents of the workshop (presentations and discussions) are given in the next section, while the conclusions and an overview of follow-up activities is given in section 3.

2. Scientific content of the event

The transport theory agenda comprised two main issues: the numerical treatment of stiff anisotropic transport models, and the role of gyrokinetic turbulence simulations in the determination of transport fluxes. More specifically, in magnetic fusion devices, the magnetic field is so strong that the transport coefficients in the direction parallel and perpendicular to it differ significantly. Such anisotropy depends on the position within the spatial domain of interest: it is very strong near the center of the plasma column (the core) where parallel and perpendicular transport coefficients differ by orders of magnitude, while it is less effective at the edge of the plasma. The presence of two varying time scales (one for the parallel and one for the perpendicular dynamics) suggests the application of asymptotic-preserving (AP) schemes. This has been widely discussed and a test model has been identified. On the other hand, the actual values of transport coefficients in fusion plasmas are largely determined by turbulent transport (anomalous transport coefficients), therefore gyrokinetic turbulence simulations play an important role in transport theory. A series of talk and discussions have been dedicated to the challenging task of integrating expensive gyrokinetic simulations into transport modeling as well as on the role of conservation laws in gyrokinetics. For existing transport codes, with particular attention to the ASTRA code by Pereverzev and Yushmanov, the convergence of iterative schemes in presence of strong nonlinearities (due to the anomalous transport) has been addressed. The effects of instabilities driven by runaway electrons were also considered, their modeling being based upon the quasi-linear kinetic Fokker-Planck equation describing wave-particle interactions; this is the same model used in the calculation of heating and current drive induced by high-frequency waves.

The agenda for high-frequency waves comprised the improvement of semiclassical methods, the analysis of models and numerical schemes for Maxwell's equations in magnetized plasmas, and the quasi-linear Fokker-Planck equation for the description of wave-particle interactions. More specifically, semiclassical methods allow us to compute an accurate approximation of the solution for the high-frequency wave field, by exploiting the separation of scales between the short wave length and the scale of spatial variations of the coefficients of the considered wave equation. There are several approaches to semiclassical solutions, including Pereverzev's paraxial WKB method (beam tracing) which is closely related to Gaussian beams. All such methods are subject to validity conditions. Some of those conditions, however, are typically violated in plasmas physics applications. The most severe assumption is that the principal symbol (i.e., the leading order term) of the wave equation must be Hermitian. Removing this assumption is a long-standing open issue, about

which some new rigorous mathematical results are now being proven, particularly for the non-Hermitian evolution of Gaussian wave packets in quantum physics. The transfer of those results to Gaussian beams has been extensively discussed in our workshop and possible strategies have been put forward. Conversely, plasma physics applications, which involve multi-component wave fields, suggested the issue of polarization transport in non-Hermitian dynamics. Other clever ways to apply semiclassical methods for the calculation of the wave energy distribution in complex media (discrete flow mapping) came from industrial applications. The direct solution of Maxwell's equations, on the other hand, is interesting for plasma diagnostics purposes and new numerical schemes has been presented together with some intriguing open issues in the mathematical analysis of the models.

Here a brief summary of the presentations and the corresponding discussion sessions is given. In the program, each discussion session was meant to summarize results and problems from the preceding talks. For simplicity, we follow this subdivision in this report, although the various topics were addressed throughout the whole workshop, also during informal discussions. Moreover, other issues have been proposed and discussed to some extent, but did not meet the interest of most of the participants and were eventually dropped (e.g., semiclassical description of eigenmodes in tokamaks and applications to transport); we omit those issues from this report.

Stiff anisotropic transport. After the introduction of the transport theory agenda by Clemente Angioni, where the issue of stiff anisotropic transport was introduced, Claudia Negulescu has presented the ideas at the basis of asymptotic-preserving schemes for multi-scale problems and their applications to anisotropic elliptic and parabolic problems, including nonlinearities; the power and advantages of such schemes have been explained also with the help of numerical experiments. Next Marie H el ene Vignal presented the application of asymptotic-preserving methods to the fluid and quasi-neutral limits of kinetic models of plasma physics. Thereafter, we moved to the fusion-driven applications and precisely to the ASTRA transport code. Irina Voitsekhovitch introduced ASTRA and the typical use of the code in transport theory, while Emiliano Fable presented the numerical scheme (due to Pereverzev and Corrigan) used in ASTRA to cope with stiff non-linear advection-diffusion equations. In the subsequent discussion several comments on the improvement of this latter issue were put forward by Marie H el ene Vignal and Claudia Negulescu, proposing new iterative schemes that have been successfully applied to the modeling of semiconductor devices. We addressed the advantages of asymptotic-preserving schemes for a global core-edge transport code, i.e., for solving the transport equations in a large domain comprising the core of the plasma column (with a large parallel/perpendicular scale separation) and the edge of the plasma column (with a moderate scale separation). An abstract mathematical model, obtained upon extracting the essential part of the ASTRA model, has been put forward as a testbed for asymptotic-preserving schemes.

Non-Hermitian wave dynamics and Gaussian beams. The issues of non-Hermitian wave dynamics has been introduced in the high-frequency wave agenda by Omar Maj, where the general framework of semiclassical analysis of pseudodifferential operators has been roughly introduced along with the basic hypotheses and Pereverzev's paraxial WKB method with its relationship to Gaussian beams. The theory of Gaussian beams has been presented in details by Olof Runborg with particular emphasis on error analysis and the differences between the case of wave packets and beams: For the latter a choice of coordinates transverse to the propagation direction is needed. In addition, Runborg sketched the outline of a different, but related problem: wave propagation in a medium with short scale

fluctuations, a problem which is particularly interesting for the description of wave scattering from turbulent fluctuations in the design of electron cyclotron current drive systems for large tokamaks and which has not been fully understood yet. Non-Hermitian dynamics of Gaussian wave packets for scalar fields have been addressed in the talk by Roman Schubert, who focused on quantum mechanical applications. From the subsequent discussion, it emerged that the results of Schubert and co-workers can easily be transferred to plasma physics problems as far as the wave is described by a scalar field and one is interested in Gaussian wave packets, rather than beams. For Gaussian beams instead, the choice of transversal coordinates needs to be addressed in the non-Hermitian framework. It is also clear that the theory needs to be generalized to multi-component fields, in order to be applicable to fusion-relevant problems such as the propagation of wave beams through resonances, e.g., the electron cyclotron resonance layer. Another issue emerged during the discussion is the transfer of the results on non-Hermitian dynamics to the framework of extended rays. With this aim, Daniela Farina gave a “last-minute presentation” during the discussion session, introducing extended ray theory and her code, GRAY, together with the open issues that we would like to address. In this case, the problem appears more complicated than it is for Gaussian beams, and yet we have started to draw some new ideas which might lead to further collaborations.

Semiclassical energy transport. Gregor Tanner has presented a grid-based method, namely, discrete flow mapping, to describe the wave energy distribution in complex media, including multi-component wave fields and mode conversion in complicated geometries. The main idea is the use of semiclassical propagators as an alternative to standard numerical methods (e.g., finite elements). This allows us to solve complex energy transfer problems in a few minutes on a laptop in spite of the large number of degree of freedom. From the subsequent discussion it was clear that this method is extremely appealing for diagnostics applications (reflectometry and electron cyclotron emission in magnetic fusion experiments), although such an application will not be straightforward and will require some work, e.g., on the solution of the inverse problem.

Analysis and numerical schemes for the cold plasma model. Although extremely simplified and entirely not adequate for a proper description of electron cyclotron absorption, the cold plasma model is currently employed for diagnostics modeling, for which absorption can be neglected. For such problems, the direct numerical solution of Maxwell's equation (full-wave approach) is viable, but relatively expensive. In his talk Bruno Després presented a new algorithm which allows us to modify the standard Yee scheme in order to add the equation for the induced current density without breaking energy conservation; in addition, Després proposed several interesting and fundamental questions about the limiting absorption principle that were addressed in the discussion and that deserve and will receive further consideration in the future. Olivier Lafitte, on the other hand, presented a complete analysis of the cold plasma model in a simplified geometry. In the subsequent discussions, this results proved themselves to be valuable for building a series of semi-analytical tests for more complex codes, both semiclassical and full-wave.

The quasi-linear Fokker-Planck equation and applications of waves in plasmas. One interlink between wave and transport experts is provided by the quasi-linear theory which allows us to derive, albeit in a very heuristic way, the Fokker-Planck equation describing the effect of waves on plasma particles. Egbert Westerhof presented the basic ideas for this type of calculations along with a recent example relevant to ITER (the International Thermonuclear Experimental Reactor presently under construction in France), which was obtained by his

Fokker-Planck solver RELAX. Another interesting application has been presented by Alessandro Cardinali. He showed that wave-particle interactions in plasmas have a broad range of applications beyond fusion science and presented his recent work on plasma thrusters.

Gyrokinetic theory and turbulence modeling for transport. As mentioned above, the value of transport coefficients in magnetized plasmas is largely determined by turbulence, which, in turns, needs a kinetic description. Gyrokinetic theory is a reduced model obtained by removing the fast gyration of charged particles about the magnetic field lines in a magnetized plasmas, and it is considered as the standard theory for turbulence modeling. The derivation of such reduced model is rather intricate and, in its modern version, makes extensive use of ideas borrowed from differential geometry and geometric mechanics. Natalia Tronko has presented this derivation with emphasis on conservation laws, particularly toroidal momentum transport and the related issue of spontaneous plasma rotation. Yann Camenen gave a nice overview of the use of gyrokinetic simulation in transport theory with emphasis on what a fully consistent modeling would require as compared to what is affordable given the available computer power. In the subsequent discussions the integration of gyrokinetic and transport codes has been addressed.

Kinetic descriptions and applications. The last session of the workshop continued on the issue of kinetic models in transport. Tünde Fülöp in his interesting presentation gave a nice example of how kinetic physics needs to be accounted for. She presented the results of her group on instabilities driven by runaway electrons, and the corresponding modeling based on the quasi-linear Fokker-Planck equation for the interaction of electron with the driven mode. Back to gyrokinetics, Susan Leerink presented transport-relevant gyrokinetic simulations with the ELMFIRE particle-in-cell code, explaining in particular how momentum and energy conservation laws are treated in ELMFIRE, a synthetic reflectometry diagnostics for comparison with the experimental observations, specifically with the measurements at the FT-2 tokamak in St. Petersburg.

The final discussion sessions of the workshop have been dedicated to summarize the outcome of the workshop and to draw the lines for future work and activities, cf. Section 3.

3. Assessment of the results, contribution to the future direction of the field, outcome

Highlights. Among the many useful hints that emerged from the various scheduled and informal discussions, let us focus here on those that are particularly important for their potential developments. For transport theory, on one hand, an abstract model problem has been identified, showing all the key characteristics of the ASTRA model, including stiffness due to anomalous transport fluxes and anisotropy. This model can be used as a testbed for asymptotic-preserving schemes with the aim of coupling core transport to edge transport. For high-frequency waves, on the other hand, the results on non-Hermitian dynamics, obtained in the framework of quantum mechanics, provide the rigorous mathematical basis which was needed to extend semiclassical methods to include the propagation through the electron cyclotron resonance layer in fusion plasma, provided that the issues related to Gaussian beams and extended rays mentioned in Section 2 can be successfully addressed. At last, the impressive performances of the discrete flow mapping has a significant potential for applications in plasma diagnostics.

Objectives for future activities. As objectives for future collaborative work on the ideas emerged from this workshop, we propose:

- The development of an asymptotic-preserving formulation of the transport model identified in this workshop.
- Implementation of a transport model covering the highly anisotropic core as well as the moderately anisotropic edge, on the basis of the results of the asymptotic-preserving formulations.
- Choice of the transverse coordinates for Gaussian beams in a non-Hermitian medium and development of extended ray theory for non-Hermitian media.
- Multi-component waves and polarization transport in non-Hermitian wave dynamics.
- Inverse problems and diagnostics modeling via discrete flow mappings.

Potential impact of the envisaged research objectives. The development of a global core-edge transport code is a problem which is receiving a growing interest in the community; early attempts calls for a full two-dimensional model solved by standard techniques, e.g., finite elements, even in the core where the problem is essentially one-dimensional. The asymptotic-preserving strategy proposed here will allow for a much faster and more powerful code. On the other hand, the activities on non-Hermitian dynamics will allow us to extend the validity of our semiclassical methods to the electron cyclotron resonance layer, a long-standing problem which saw several attempts to its solution and yet is still unsettled.

Follow-up activities. The primary goal of this workshop was the exploration of possible applications to fusion plasma physics of methods developed in other fields, rather than the start-up of a network of collaborations on well-established common issues. The preset goal appears to have been fully achieved, as we have identified a set of such applications that will be further developed, hopefully opening the way to solid collaborations. We shall proceed by maintaining informal collaborations between small groups on specific subjects. Specifically, Emiliano Fable, Clemente Angioni, Claudia Negulescu and Marie H el ene Vignal will address the issue of the stiff anisotropic transport model with asymptotic-preserving schemes; Daniela Farina, Olof Runborg, Roman Schubert and Omar Maj will consider the non-Hermitian dynamics of Gaussian beams and extended rays; Olivier Lafitte, Bruno Despr es and Omar Maj will continue the study of resonant absorption from a mathematical point of view; Roman Schubert is interested in studying multi-component wave fields in his framework. Daniela Farina and Omar Maj will try to propose to Gregor Tanner a specific problem in plasma diagnostics for which the discrete flow mapping can yield significant improvements.

Depending on the outcome of such informal activities, we shall consider the establishment of a research network also in the framework of ESF and COST programs.

4. Final program

Sunday, 13th October 2013

Afternoon *Arrival*

Monday, 14th October 2013

08.30-08.40

Welcome

Eric Sonnendr cker (IPP, Garching, Germany)

- 08.40-09.00 **Presentation of the European Science Foundation (ESF)**
Roland Diehl (Scientific Review Group for Physical and Engineering Sciences)
- 09.00-09.30 **Grigory V. Pereverzev Lecture**
Arthur Peeters (Universität Bayreuth, Bayreuth, Germany)
- 09.30-12.00 Morning Session: Transport modeling I**
- 09.30-10.00 **Presentation 1 "Transport theory agenda"**
Clemente Angioni (IPP, Garching, Germany)
- 10.00-10.30 *Coffee Break*
- 10.30-11.15 **Presentation 2 "Asymptotic-Preserving schemes for an efficient resolution of anisotropic elliptic and parabolic equations"**
Claudia Negulescu (Toulouse Institute of Mathematics, Toulouse, France)
- 11.15-12.00 **Presentation 3 "Asymptotic preserving methods for the BGK-Vlasov-Poisson system in the quasi-neutral and fluid limits"**
Marie-Hélène Vignal (Toulouse Institute of Mathematics, Toulouse, France)
- 12.00-13.30 *Lunch*
- 13.30-15.00 Afternoon Session I: Transport modeling II**
- 13.30-14.00 **Presentation 1 "Transport codes for magnetic fusion: ASTRA (overview of applications)"**
Irina Voitsekhovitch (EURATOM/UKAEA association, Culham, UK)
- 14.00-14.30 **Presentation 2 "Numerical treatment of stiff transport in the ASTRA code"**
Emiliano Fable (IPP, Garching, Germany)
- 14.30-15.00 **Discussion on numerical schemes for transport equations and applications**
- 15.00-15.30 *Coffee break and group photo*
- 15.30-17.45 Afternoon Session II: High-frequency waves I**
- 15.30-16.15 **Presentation 1 "Pereverzev paraxial WKB method and semi-classical asymptotics - Wave theory agenda"**
Omar Maj (IPP, Garching, Germany)
- 16.15-17.00 **Presentation 2 "Gaussian beam approximations for high frequency waves"**
Olof Runborg (KTH, Stockholm, Sweden)
- 17.00-17.45 **Presentation 3 "Modeling of Electron Cyclotron Current Drive applied for the suppression of magnetic islands in tokamaks"**
Egbert Westerhof (FOM Institute DIFFER, Nieuwegein, The Netherlands)
- 19.30 *Conference dinner*

Tuesday, 15th October 2013

- 08.30-12.00 Morning Session: High-frequency waves II**
- 08.30-09.15 **Presentation 1 "What is the semiclassical limit of non-Hermitian time evolution?"**
Roman Schubert (University of Bristol, Bristol, UK)
- 09.15-10.00 **Presentation 2 "Discrete Flow Mapping - a mesh based simulation tool for high-frequency vibro-acoustics of complex engineering structures "**
Gregor Tanner (University of Nottingham, Nottingham, UK)

- 10.00-10.30 *Coffee break*
- 10.30-11.15 **Presentation 3 "Development of a stable coupling of the Yee scheme with a linear current"**
Bruno Després (University Paris VI, Paris, France)
- 11.15-12.00 **Presentation 4 "Generalized model solutions for electromagnetic waves in overdense plasmas with electron collisions"**
Olivier Lafitte (University Paris 13, Paris, France)
- 12.00-13.00 *Lunch*
- 13.00-15.00 Afternoon Session I: High-frequency waves III**
- 13.00-13.30 **Presentation 1 "Asymptotic analysis of the whistler waves propagation in space plasma thrusters"**
Alessandro Cardinali (ENEA, Rome, Italy)
- 13.30-14.15 **Presentation 2 "Weak turbulence in two-dimensional magnetohydrodynamics."**
Natalia Tronko (York Plasma Institute, York, UK)
- 14.15-15.30 **Discussion on wave theory and applications**
- 15.30-16.00 *Coffee break*
- 16.00-18.00 Afternoon Session II: Transport modeling III**
- 16.00-16.45 **Presentation 1 "Exact conservation laws for full and truncated gyrokinetic Vlasov-Poisson equations"**
Natalia Tronko (York Plasma Institute, York, UK)
- 16.45-17.30 **Presentation 2 "Modern challenges in the gyrokinetic modeling of turbulent transport in tokamak plasmas"**
Yann Camenen (PIIM Aix-Marseille University and CNRS, Marseille, France)
- 17.00-18.00 **Discussion on gyro-kinetic models for transport**

Wednesday, 16th October 2013

- 08.30-11.45 Morning Session: Transport modeling IV**
- 08.30-09.15 **Presentation 1 "Kinetic instabilities driven by runaway electrons"**
Tünde Fülöp (Chalmers University of Technology, Göteborg, Sweden)
- 09.15-10.00 **Presentation 2 "The role of global gyrokinetic simulations in multi-scale transport modeling"**
Susan Leerink (Alto University, Helsinki, Finland)
- 10.00-10.30 *Coffee Break*
- 10.30-11.00 **Discussion on kinetic description and applications**
- 11.00-12.00 Closing Session**
- 11.00-12.00 **Discussion on follow-up activities/networking/collaboration**
- 12:00 *End of the Workshop*

5. Final list of participants

1. Clemente ANGIONI
Max-Planck-Institut für Plasmaphysik.
2. Yann CAMENEN
Physique des Interactions Ioniques et Moléculaires (PIIM), Aix-Marseille University and CNRS.
3. Alessandro CARDINALI
ENEA – Plasma Theory Group.
4. Bruno DESPRÉS
Jacques-Louis Lions Laboratory, University Paris VI.
5. Roland DIEHL (ESF representative)
Max Planck Institute for Extraterrestrial Physics, High-Energy Astrophysics Department.
6. Emiliano FABLE
Max-Planck-Institut für Plasmaphysik.
7. Daniela FARINA
Istituto di Fisica del Plasma CNR.
8. Tünde FÜLÖP
Nuclear Engineering, Chalmers University of Technology.
9. Olivier LAFITTE
Institut Galilée, Département de Mathématiques, Université Paris 13.
10. Susan LEERINK
Department of Applied Physics, Aalto University.
11. Omar MAJ
Max-Planck-Institut für Plasmaphysik.
12. Claudia NEGULESCU
Institut de Mathématiques de Toulouse, Université Paul Sabatier.
13. Arthur PEETERS
Physikalisches Institut, Universität Bayreuth.
14. Olof RUNBORG
Matematiska Institutionen KTH, Stockholm.
15. Roman SCHUBERT
School of Mathematics, University of Bristol.
16. Eric SONNENDRÜCKER
Technische Universität München and Max-Planck-Institut für Plasmaphysik.
17. Gregor TANNER
School of Mathematical Science, University of Nottingham.
18. Natalia TRONKO
York Plasma Institute, Department of Physics, University of York.
19. Marie-Hélène VIGNAL
Institut de mathématiques de Toulouse, Université Paul Sabatier.

20. Irina VOITSEKHOVITCH
EURATOM/UKAEA Fusion Association, Culham Science Centre.

21. Egbert WESTERHOF
FOM Institute, DIFFER.

6. Statistical information on participants

Statistical information on the composition of the group is best conveyed in the form of pie charts and histograms, summarizing the represented countries, gender and age repartition as well as technical expertise (namely, Mathematics/Physics and Transport/Waves).

