Dr. Alberto Marocchino
Universitá di Roma "La Sapienza"
Roma, Italy
alberto.marocchino@uniroma1.it

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Academic Visit to CELIA, Bordeaux, France
Scientific Report

4th November – 3rd December

Purpose of the Visit

New fusion scheme, e.g. Shock Ignition, rose the physical problem of non local electrons. Since Shock Ignition Inertial Confinement Fusion Schemes uses very powerful laser (~500 TW), these ultra intense lasers produce electrons whose mean free path is comparable with the entire plasma physical domain. The non local electron thus span through the entire plasma domain, they are not localized, the hydrodynamic (HD) approximation does not hold anymore since requires both localized electrons and no electric current. To simulate the behaviour of the non local electrons one should use kinetic codes: Vlasov-Fokker-Planck (VFP) codes. The VFP codes however cannot, today, simulate the entire inertial confinement evolution: the required time is unaffordable and the code are designed to solve problem at a kinetic space-time scale. The problem can be address in the following way: the microscopic-kinetic behaviour of non local electrons is studies via macroscopic operator that would make possible to mock up their effect at a larger scale, e.g. HD space-time scale. The purpose of the visit is to work on this specific aspect. Few theoretical operator has already been published in literature, but there is no yet clear benchmark. Using the VFP developed and tested by the CELIA and the DUED code developed, tested and maintained by the GAPS-Rome group would be possible to understand what model work best and what is the limit of each theoretical model and whether there are regimes at which some model works better. One of the key aspects was to define HD tests that could be treated by the VFP code thus to benchmark the microscopic-macroscopic operator coded in the DUED hydrodynamic code. Numerical simulations also revealed the lack of prediction of some models thus to help understand what model suits best and how to include these effects in the already existing model/s. Moreover the CELIA Bordeaux Group has a great expertise in hydro simulations, interacting with them to discuss the importance of non local transport and what model is more suitable to reproduce the kinetic effect on an hydro scale is also what motivated me to visit this group.

Description of the work carried out during the visit

Due to the extended staying period, one month, the work has been organized as follow. In the first days few meetings defined the state of art and more importantly the people I would have interact with. I would have obviously interact with Prof. Vladimir Tikhonchuk, my host, and with 4 senior researcher at CELIA and 1 CELIA PhD candidate.

The state of art denoted few numerical aspects that need to be updated in the version of the code I am currently upgrading/developing such as the necessity to have a cylindrical version of the code in order to crosscheck some results the CELIA group has already published. In few days the version has been upgraded and good agreement was found with the published results. With even closer interaction the host and myself could define few tests in order to verify the validity of non local electrons models (G.P. Schurtz, P.D. Nicolai, M. Busquet & D. Colombant, W. Manheimer, V. Goncharov). The tests relatively quickly to be run on a

multicore computer need to be compared with a ready developed-state-of-art Vlasov-Fokker-Planck code fully developed at CELIA (*kets* code). The Vlasov-Fokker-Planck code is computationally expensive and requires few days of run on a cluster supercomputer. Three tests have thus been selected: a first test would denote the general non local electron behaviour, a second test would try to estimate the error of such models, the third test had been decided to be ICF relevant thus to understand the importance of non local electrons in the inertial confinement regime.
Progress informal discussion took place daily both in the office where I was guest both in the senior research offices. Formal meeting took place almost once a week in the CELIA meeting room to discuss progress and to discuss in great detail with all the experts the numerical results obtained. The day before my departure a final meeting has been arranged in order to present to CELIA the results obtained during my staying and how we wish to proceed in order to advantage as much as possible from this collaboration.
During my visit I took part to the weekly group seminars as well as students' seminars, I have been introduced to several topics the CELIA group is investigating.

Description of the main results obtained
Since three different tests had been identified to validate and study the non local electron models the main results can be described subdividing them into three parts. Subsequently analyzing the differences and discrepancies between the *krook* model (D. Colombant, W. Manheimer, V. Goncharov) and the *SNB* model (G.P. Schurtz, P.D. Nicolai, M. Busquet).
The first identified test is the time relaxation for a maxwellian temperature profile. This test should in general describe the general and global behaviour of non local electrons and thus of non local electron models. The kinetic simulations performed with kets are in a very good agreement with results already published in literature (Batishchev et al. Heat transport and electron distribution function in laser produced plasmas with hot spots. Physics of Plasmas (2002) vol. 9 (5) pp. 2302-2310). The non local models, both the SNB model and the krook model, reproduce the kinetic solution with some discrepancies. The SNB model overestimates "tails": the model overestimates the quantity of non local electrons that contribute to overheat region at boundaries. On the contrary the krook model overestimates the electric field recalling behaviour and thus non local electrons are over braked almost totally cancelling the hot electrons tails. Time resolved simulations have been fundamental to investigate and understand the over estimation or over cancellation of hot electron tails.
The second test is wants to investigate the difference between the SNB and the krook model. In order to achieve such a result the following test had been set up: a box with constant density and a temperature profile of an *arctan(x)* with chosen derivative in the very middle had been coded up. The system evolves and measuring the gradient profile changing and the total heat flux in the very centre cell we can compare the two models. The graphs showed that in a very kinetical regime, electron mean free path divided by the gradient scale length between 0.1 and 1, the two models react very similarly at the worst of 10% difference. However the krook model in a transitional regime: from Spitzer regime to kinetic regime overestimate the overall flux. The two model despite reacting very similarly have a total different running time, the SNB model runs in few seconds while the necessity to better estimate the electric field behaviour via explicit convolution operators the krook model requires for an equivalent problem 3 hours of running time. A future idea is to compare the two models with the kinetic code kets in order to estimate how much the two models differ from kinetic simulations. However this comparison may take several months, just because of the time required to run the simulations. Few hundred points would be desirable to have a properly well reproduced dispersion curve, considering that each simulation may take about a night, few months will be needed in order to reproduce the dispersion curve with a kinetic

code. Several preliminary tests shoed that the code works fine and that the kets code itself is more than suitable for this task.
The last test is the most ICF-oriented. A simplified inertial confinement profile before stagnation is observed with the two different models. As in the case of the first test a similar behaviour is found: the SNB model exhibits the preheating of the fuel while almost no preheating is shown when using the krook model. The other interesting result has been to be able to export the initial profile at a given time in order to input such a proile in the kets code. However the lack of both electric and magnetic field prevent any further speculation in this direction.

Future collaboration with the host institution

This collaboration (04/11/2011 – 03/12/2011) follows a previous, much shorter collaboration, on the same topic sponsored by the SILMI funding too. The nice collaboration established between the two groups (GAPS – Rome Italy Group represented by Dr. A. Marocchino and the CELIA – Bordeaux French Group) will certainly bring to future and fruitful collaboration. The topic under investigation is of certainly complexity: it requires people, knowledge and numerical code in different area of plasma physics; the collaboration of the two groups brings all these expertise together. Future collaboration will be definitively a go in order to bring all these expertise together and being able to working on the problem in the best scientific scenario.

Projected publications/articles resulting or to result from your grant

At present there is not enough material for a publication. However the good and promising results and the nice established collaboration on non local fast electrons will most certainly bring to a publication in the future: ESF will be acknowledge for the economical support.

Other comments (if any)

None