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Academic Visit to CELIA, Bordeaux, France — 1st June – 4th June
Scientific Report

Purpose of the Visit

New fusion scheme, e.g. Shock Ignition, rose the problem of electron non local transport. The very hot temperatures reached with new fusion schemes produce electrons that are not locally confined, but instead these electrons can travel through the entire physical domain. To simulate the non local electrons behaviour kinetic simulations can be used. Kinetic simulations however can not reproduce the fusion process in a whole and more importantly the required simulation time is much larger than equivalent hydrodynamic simulations. For the just described reasons it is our interest to develop and code up a physical model that on a hydro time-space can mock up the electron kinetic behaviour. The CELIA Bordeaux Group has a great expertise in hydro simulations, moreover the Bordeaux group is working on non local electron transport, 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 has been the purpose of my visit.

Description of the work carried out during the visit

The work carried out during the visit began with the theoretical analysis of the problem. It has been discussed that the attention should be focused on the two major non local electron transport models: G. Schurtz at al. and the W. Manheimer et al. model. It has also been observed that the W. Manheimer model due to its mathematical intrinsic formulation is more difficult to treat it numerically: it is not obvious what is the Green function associated with the convolution operator thus the calculation of cell fluxes needs to be address in a explicit way increasing numerical instability and inaccuracy. G. Schurtz model due to its fully implicit nature appears to be more numerically convenient. It has also been discussed that both models should be tested, initially, on test problems. The use of test problems will simplify the process of comparison and will help to spot possible numerical coding errors.
The second and third day has been characterized by computer work. Both the implementation of the two models has been revised, starting from the equation it has been verified that the coded up equation were correct and the numerical schemes were coherent and thus robust. Multiple tests have been run just on code sections in order to test the validity of each subroutine and their inter-communication. During the multiple tests it has been observed how the two models are mathematical very similar, but they can give sensibly different results. The cause has been retrieved in a coefficient, constant in G. Schurtz model, while dependant on ionization and temperature on the W. Manheimer model. Similarly the tests highlighted that W. Manheimer model can be written in a fully implicit form, as originally described in their article, however in the presence of very steep gradient the running time can become too long (more than a night of computer time) and definitively very inefficient.
On the third day some time has also been spent discussing our theoretical work with some experimentalists from CELIA Bordeaux. The discussion purpose was to introduce the non

local electron problem to the experimental Bordeaux Plasma community, thus to start a close interaction in the case they will have time for new test shots in order to try to observe some non local electron behaviour experimentally. It seems that the experimental group is very keen in collaborating; unfortunately at present they do not know when the next available slots for test shots will become available.
Another key aspect that has been discussed on the last afternoon is the importance of testing fluid results against kinetic simulation. We all agreed that the way to proceed is the following: it is necessary to study some simple one dimensional tests, one or two test problems, possibly with no ion motion, in order to compare kinetic simulations against fluid dynamic simulations with fast electrons. The tests needs to be chosen in a relevant inertial confinement fusion parameters regimes and should be time affordable in the terms of kinetic code running time. It has also been observed that this kind of tests are fundamental to understand how the fluid models can mock up kinetic effects, however it has also been realized that it is not such a simple tasks since it is necessary to interface few numerical codes among them and thus it will be also time consuming.
In a final and general meeting, all the major results (that will be discussed in the next section) have been summarized and revised.

<u>Description of the main results obtained</u>
Regarding the main results obtain, we can say that 3 major results were obtained.
The first one is about the comparison of non local flux models with the classical technique of the flux limiter. It has been observed that for inertial confinement fusion scenario the flux limiter can mock up the effect of fast electrons pretty well. For more general test this is not necessarily true, the flux limiter induces not smooth profile, while hot electrons diffuses much more thus to create smooth temperature profile. In particular the flux limiter technique can be absolutely fine in one dimension, since the electrons are imposed to travel one dimensionally, however the same technique would not apply in two dimensions. The important result/observation is that flux limiter techniques are extended from one dimension to multi dimensions but their validity is not totally obvious and clear: it thus to be verified case by case.
The second major results regards the comparison between the W. Manheimer model and the Schurtz model. It has been observed that the two models give different results, and in some situations, e.g. steep gradient with very low densities, the W. Manheimer model diffuses much faster. The difference has been retrieved in a specific coefficient, this coefficient is constant in G Schurtz model while it depends on temperature and ionization on the W. Manheimer model.
The third major observation result refers to numerical stability. First of all it has been observed that extra limitations need to be added to the G. Schurtz model. In this model electron mean free path is calculated on cell centred, and then corrected by the local electric field and thus calculated on face centre. This numerical operation is just fine, but since the electrons travel at least for a cell length it has been found that in the case of steep temperature or density gradient: thus where mean free path drastically increase, the stability can be increase using the minimum of the mean free path among the local point, the previous and the next. This operation does not compromise the physics, since it is a diffusive operation and thus adding this minimum limiting operation is equivalent to make feel to the electrons the presence of the steep gradient few cells in advance. On the W. Manheimer model, instead, it has been observed that the fully implicit method is fully stable but for very steep gradient requires too long time to converge and thus the run time becomes of few hours and thus not acceptable. Instead the semi-implicit method is practically not robust, in fact this scheme calculate the non local electron flux in the cell centre making necessary an extra interpolation

to calculate the flux on cell boundary. In the planar case, the linear interpolation adds very little error, however this is not true in the spherical case. The semi-implicit case thus becomes inaccurate in the spherical limit, especially with not uniform grids. In conclusion full implicit scheme are preferable for both models.

Future collaboration with the host institution

It seems highly probable that due to the nice work carried on during the visit there will be the opportunity and necessity to visit back the group and carry on the work on non local electrons. Specifically there is a great interest in studying and performing some numerical tests between fluid codes (with fast electrons) and a kinetic code. This kind of tests may require sometimes and might be consider a long term project but from both groups are very keen to work together in this direction.

Projected publications/articles resulting or to result from your grant

At present there is not enough material for a publication. However the just began 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

To Whom may concern:

This is to certify that Dr. Alberto Marocchino visited the CELIA Group (Université de Bordeaux 1) Bordeaux, France from the 1st June 2011 to 4th June 2011.
Dr. A. Marocchino has been hosted by:

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Signed,
Bordeax, France
3rd June 2011

Vladimir Tikhonchuk

Guy Schurtz