Aix*Marseille université	**Ecole Doctorale** **Physique et Sciences de la Matière**

Internship proposal (master 2)

Laboratory : umr 7345 physique des interactions ioniques et moléculaires
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Title : PARTICLE–WAVES INTERACTION, TRAVELING WAVE TUBES AND PULSE ACCELERATION

Outline :

Wave-particle interaction is a fundamental process in the physics of hot and natural plasmas, accelerators and beams ; it is the basis of wave amplifiers such as free electron lasers, gyrotrons, traveling wave tubes... where a focused electron beam transfers momentum and power to radio-frequency modes of a waveguide. In particular, traveling wave tubes enable the efficient and robust operation of satellite telecommunications and data transmission from space probes, and they enable analysing beam-plasma interactions without the noise and some nonlinearities inherent to plasma.

The power in some of these devices and their broad frequency spectrum lead to instabilities, nowadays increasingly critical and hard to simulate. A microscopic description enables a better understanding of the coupling mechanisms between N particles (x_l, p_l) and M waves (with phases ϕ_j and intensities I_j) using a so-called **self-consistent** hamiltonian. For $N\rightarrow\infty$ and fixed M, the dynamics of this system converges to the one described by vlasovian kinetic equations.

Numerical simulation currently relies on two types of models. Particle-in-Cell (PIC) models rest on a minimal simplification of physics equations but lead to huge computing times, as the number of degrees of freedom is very large. Specialized models, in contrast, allow simulating only particular regimes, but with outstandingly shorter times. The very popular envelope model is a frequency-domain model in which the amplified wave is represented by the cold wave (the wave propagating in the absence of beams), multiplied with an envelope function varying with position along the propagation direction. This frequency-domain approach is not fit for investigating nonlinear regimes, like saturation instabilities and intermodulation effects.

We developed a **novel time-domain model** with few degrees of freedom thanks to an efficient representation of fields, enabling a realistic simulation of amplification in traveling wave tubes. We confront these simulations with experiment in space traveling wave tubes and in the 4 metre long device which enabled our laboratory to perform the first direct observation of several fundamental processes of this physics, and at CEA CELIA.

The internship may focus on the interaction of the radiofrequency signal with electron **pulses**, to use the resulting models in particular for the traveling wave tubes of Thales Avionics (Vélizy), in our laboratory (Marseille), and for the acceleration of protons generated by a laser shot on a metallic target (CEA CELIA).

The project may extend to a Ph.D. if possible.

- Y. Elskens & D. Escande, ***Microscopic dynamics of plasmas and chaos*** (IoP Publishing, Bristol, 2003).
- D.F.G. Minenna, Kh. Aliane *et al.*, *Time simulation of the nonlinear wave-particle interaction in meters-long traveling-wave tubes*, **Phys. Plasmas 28** (2021) 092110 (15 pp.).
- J.V. Gomes *et al.*, *Low-dimensional chaos in the single wave model for the self-consistent wave-particle hamiltonian*, **Chaos AIP 31** (2021) 083104 (17 pp.).
- Ph.D.s in Marseilles : A. Macor (2007), A. Aïssi (2008), P. Bernardi (2011), S. Théveny (2016), D.F.G. Minenna (2019), Kh. Aliane (in progress).
https://phys.org/news/2019-03-traveling-wave-tubes-unsung-heroes-space.html