Fermi, Pasta, Ulam and a *mysterious* lady

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It is reported that the numerical simulations of the Fermi-Pasta-Ulam problem were performed by a young lady, Mary Tsingou. After 50 years of omission, it is time for a proper recognition of her decisive contribution to the first ever numerical experiment, central in the solitons and chaos theories, but also one of the very first out-of-equilibrium statistical mechanics study. Let us quote from now on the Fermi-Pasta-Ulam-*Tsingou* problem.

The Fermi-Pasta-Ulam problem [1] was named after the three scientists who proposed to study how a crystal evolves towards thermal equilibrium. The idea was to simulate a chain of particles, linked by a linear interaction but adding also a weak *nonlinear* one. FPU thought that, due to this additional term, the energy introduced into a single Fourier mode should slowly drift to the other modes, until the equipartition of energy predicted by statistical physics is reached. The beginning of the calculation indeed suggested that this would be the case, but to their great surprise, after a longer time, almost all the energy was back to the lowest frequency mode and the initial state seems to be almost perfectly recovered after this recurrence period. Thus, contrary to the expectations of the authors, the drift of the energy does not occur. This highly remarkable result, known as the FPU paradox, shows that nonlinearity is not enough to guarantee the equipartition of energy.

Pursuing the solution of the FPU paradox, Zabusky and Kruskal emphasized ten years later the link between the problem in the so-called continuum limit and the Korteweg-de Vries equation [2], known to have spatially localized solutions. Looking to the problem in real space rather than in Fourier space, they showed how to solve the paradox in terms of the dynamics of these localized excitations. It was the birth of the term *solitons*, for these localised (or *solit*ary) waves with properties of particles (explaining the suffix *on* as for electron, boson,...). Consequently, the numerous physical applications [3] of solitons originates from this FPU paper.

Another line of thought was developed in parallel. People focused on the Fourier mode dynamics, looking for non-resonance conditions that could explain the inefficient energy transfer. No convincing explanation was found before the discovery of the KAM theorem, which states that most orbits of slightly perturbed integrable Hamiltonian systems remain quasi-periodic. If the perturbation is so strong that nonlinear resonances 'superpose', the FPU recurrence is destroyed and one obtains a fast convergence to thermal equilibrium. [4]

The FPU problem is thus of central importance in the Solitons and Chaos theories [5]. This is the reason why, in 2005, several conferences, articles and seminars have celebrated the 50th anniversary of the May 1955 publication of the Los Alamos report. This paper marked indeed a true change in modern science, both making the birth of a new field, *Nonlinear Science*, and entering in the age of computational science: the problem is indeed the first landmark in the development of physics computer simulations.

There was however very few mentions of an intriguing point. On the first page of the FPU Los Alamos report published in 1955, it is written,

"Report written by Fermi, Pasta and Ulam.
Work done by Fermi, Pasta, Ulam `and Tsingou`*".*

This remark, that Mary Tsingou who took part in the numerical study is not an author of the report, was always puzzling for scientists who have read this paper: indeed, it is clear that coding the first ever numerical experiment on the first computer was not a direct and immediate task. Consequently, why her contribution has it been recognized only by two lines of acknowledgements? Moreover, why has it been impossible until today to pick up her track?

People more deeply involved in the FPU literature have usually also read the 1972 paper by Tuck and Menzel [6]. A careful reading of the introduction clearly emphasizes that one of the author of this paper, M. T. Menzel, was coding the original problem: how can we solve this paradox?

The obvious solution is that in the name M. T. Menzel, M is for Mary and T for Tsingou. There is no paradox, this is the same person, after her wedding! However, once again, it has been impossible for decades to pick up her trail. We recently discovered however, that she is still alive and present in Los Alamos, a couple of miles from the place where this problem, so important in the past and present of nonlinear physics [3], was devised. It is time for a proper recognition of her work.

Born in October 14th 1928 at Milwaukee, Wisconsin, in a Greek native family, Mary Tsingou Menzel spent her childhood in the US. As the great depression was taking place in the US, her family moved to Europe in 1936, where her father had a property in Bulgaria. However, in June 1940 the American embassy advised them to come back to US for safety. They pick up the very last American ship that left Italy. Almost within a week after they landed in New York, Italy declared war.

She gained a Bachelor of Science in 1951 at the University of Wisconsin, and a Master in mathematics in 1955 at University of Michigan. In 1952, following a suggestion by her mathematics professor, a woman, she applied for a position at Los Alamos National Laboratory. At that time, women were not encouraged to do mathematics, but because of the Korean war, there was a shortage of American young men and staff positions were also proposed to young women. She was thus hired with a whole group of young people right out of college, for doing hand calculations.

She was initially assigned to the T1 division (T for Theoretical) at Los Alamos National Laboratory, led during the war by Rudolph Peierls and to which the famous spy, Klaus Fuchs, belonged. But she quickly moved to T7 led by N. Metropolis for working on the first ever computer, the Maniac I, that no one could program. Together with Mary Hunt, she was therefore the first programmer to start exploratory work on it. She remembers it as pretty easy because of the very limited possibilities of the computer: 1000 words.

They were working primarily on weapons but, in parallel, they studied other problems like programming chess or studying fundamental physics' problems. Mary Tsingou mostly interacted with J. R. Pasta. They were the first ones to do actually graphics on the computer, when they considered a problem with an explosion and visualized it on an oscilloscope.

In addition to Pasta, she interacted also with Stan Ulam, but very little with E. Fermi, at that time professor in Chicago. He was visiting Los Alamos only for short periods, mostly during the summer. However, she knew Nella, Fermi's daughter, much better because Nella didn't want to stay with her parents during their visits to Los Alamos. Both early twenties girls were sleeping in the same dormitory, while Enrico and Laura Fermi were hosted by their good friends, Stan and Françoise Ulam.

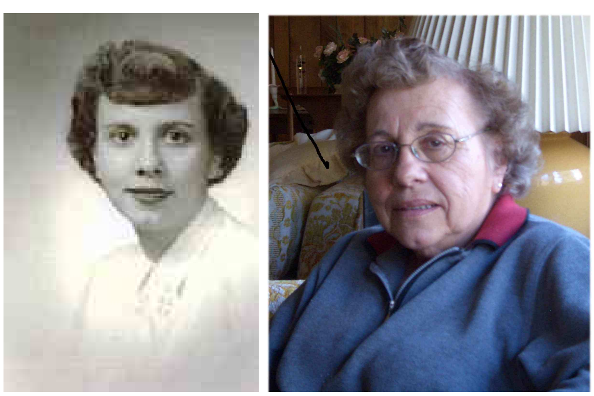

FIG. 1: Mary Tsingou in 1955 and in 2007.

It was Fermi who had the genius to propose that, instead of simply performing standard calculus, computers could be used to test a physical idea, inventing the concept of numerical experiments. He proposed to check the prediction of statistical physics on the thermalization of solids. As anticipated, preliminary results confirmed that energy initially introduced in a single Fourier mode drift to other ones. However, one day, the oversight to stop the computer allows one to discover some unexpected recurrences which were initially hidden by the slowness of the computer. It was the start of an ongoing fruitful research. [5]

The algorithm used by Mary Tsingou in 1955 to simulate the relaxation of energy in a model crystal on the Maniac is reproduced in Fig. 2. Its complexity has to be compared with the 15 lines Matlab© code, sufficient today to reproduce the original FPU recurrences [7].

At the time, programming was a task requiring great insight and originality, and through the 1960s and even later, it was common to list programmers as co-authors. It appears that the only reason for the mention "Work done by FPU+Tsingou, and report written by FPU" is that she was not involved in the writing. However, Fermi was not either since, as noticed in S. Ulam biographical book [8], the FPU report was never published because Fermi died before the writing of the paper. Consequently, Tsingou was not given credit simply because the report was never formally presented in a journal and its statement of credit, differentiating between the writing and the work done, was presumably misread by later people.

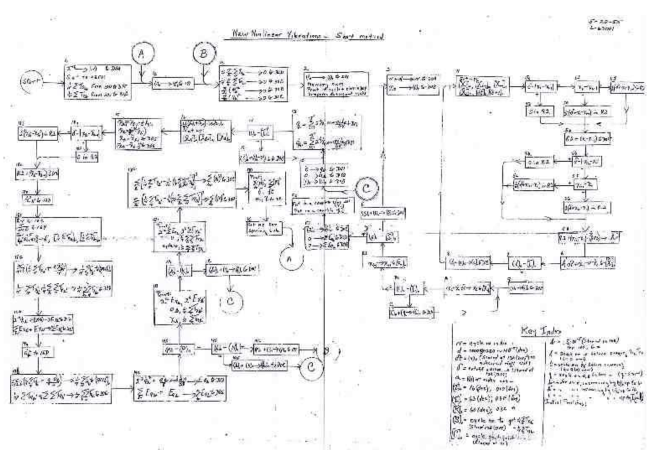

FIG. 2: Reproduction of the algorithm used by Mary Tsingou to code the first numerical experiment. Note the date (5-20-55) at the top right of the figure.

In 1958, Mary Tsingou married Joseph Menzel who was also working at Los Alamos for the Protective Force of the Atomic Energy Commission. She stayed her whole life in this small city but her colleagues changed since Metropolis left Los Alamos for Chicago, Pasta went to Washington, and later Ulam went to Colorado University. She worked successively on different problems, always with computers. She became one of the early experts in Fortran (FORmula TRANslator) invented by IBM in 1955, and was assigned to help researchers in the laboratory.

After her seminal programming work on the Maniac, in the beginning of the sixties she came back to the

FPU problem with Jim Tuck looking for recurrences [6]. But she also considered numerical solution of Schrödinger equations, the mixing problem of two fluids of different densities with J. Von Neumann, and other problems. Finally, in the eighties during Ronald Reagan's presidency, she was deeply involved in the Star Wars project calculations.

Retired in 1991, Mary T. Menzel is still living with her husband at Los Alamos, very close to the place where the FPU problem was designed and discovered: it is time for a proper recognition of her contribution: let us quote from now on the Fermi-Pasta-Ulam-*Tsingou* problem.

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