feature article

# Fermi, Pasta, Ulam, and a mysterious lady

Thierry Dauxois

**The computations for the first-ever numerical experiment were performed by a young woman named Mary Tsingou. After decades of omission, it is time to recognize her contribution.**

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**The Fermi-Pasta-Ulam** (FPU) problem,[1] first written up in a Los Alamos report in May 1955, marked the beginning of both a new field, nonlinear physics, and the age of computer simulations of scientific problems. The idea was to simulate the one-dimensional analogue of atoms in a crystal: a long chain of masses linked by springs that obey Hooke's law (a linear interaction), but with a weak nonlinear term. A purely linear interaction would ensure that energy introduced into a single Fourier vibrational mode always remains in that mode; the nonlinear term allows the transfer of energy between modes. Under certain conditions, the weakly nonlinear system exhibits surprising behavior: The energy does not drift toward the equipartition predicted by statistical physics but periodically returns to the original mode. That highly remarkable result, known as the FPU paradox, shows that nonlinearity is not enough to guarantee the equipartition of energy.

In the 1960s, pursuing the solution of the FPU paradox, Norman Zabusky and Martin Kruskal looked at the problem in real space rather than in Fourier space.[2] They were able to explain the periodic behavior in terms of the dynamics of localized excitations now known as solitons. Those localized, or solitary, waves with the properties of particles (hence the suffix "-on") have many physical applications and are today

COURTESY OF MARY TSINGOU MENZEL

**Figure 1. Mary Tsingou** in 1955 (left) and in 2007 (right).

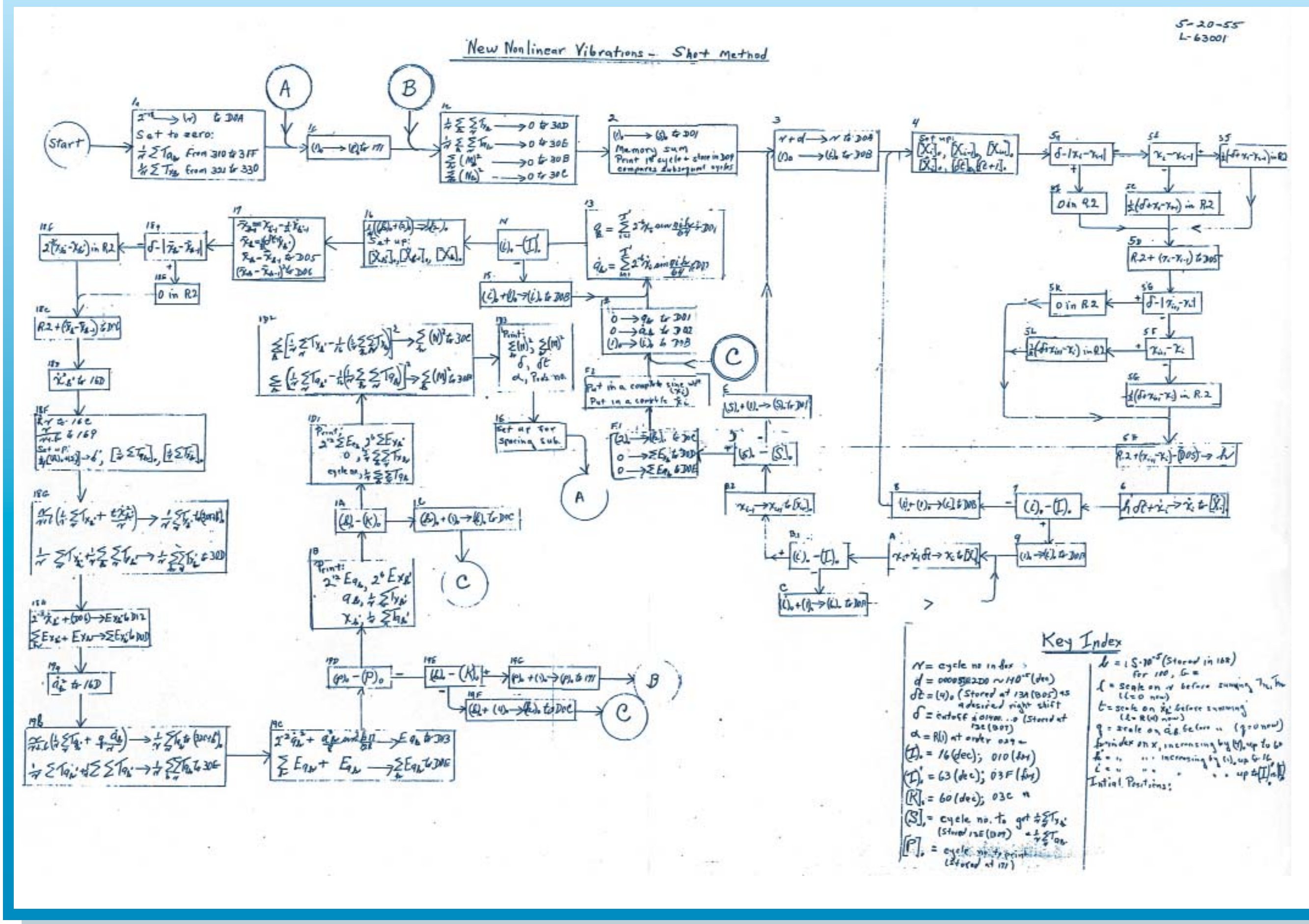


**Figure 2. The algorithm** Mary Tsingou used to code the first numerical experiment. Note the date of the Los Alamos report, 5-20-55, at the top right of the figure. (Courtesy of Mary Tsingou Menzel.)

the subject of a field of study in their own right.[3]

Another line of thought, developed in parallel with the work on solitons, focused on the Fourier-mode dynamics. In particular, with the discovery of the Kolmogorov-Arnold-Moser theorem, it was proved that in general, orbits of slightly perturbed integrable Hamiltonian systems remain quasi-periodic. But if the perturbation is too strong, the recurrence is destroyed and the equipartition of energy is quickly established.[4]

The FPU problem is thus of central importance in the theories of solitons and chaos.[5] In 2005 several conferences, articles, and seminars celebrated the 50th anniversary of the Los Alamos FPU report. But even with all the attention paid to the FPU problem and its history, an intriguing point was hardly mentioned. The first page of the report states the following:

Report written by Fermi, Pasta, and Ulam.
Work done by Fermi, Pasta, Ulam, and Tsingou.[1]

That remark, that Mary Tsingou took part in the numerical study but is not an author of the report, has puzzled many of the scientists who have read the paper. Her programming of a 1950s computer was not a trivial task. Why has her contribution received only a two-line acknowledgment?

Those who delve more deeply into the FPU literature have usually also read a 1972 paper by James Tuck and M. T. Menzel.[6] A careful reading of the introduction reveals Menzel was involved in coding the original problem, but no one by that name is mentioned in the Los Alamos report. How can that paradox be solved?

The solution is that in the name M. T. Menzel, M is for Mary and T for Tsingou. So there is no paradox; it is the same person, using her married name! I recently discovered that Mary Tsingou Menzel is still alive and residing in Los Alamos, only a few miles from the place where the FPU problem, so important in the past and present of nonlinear physics,[3] was devised. It is time for a proper recognition of her work.

## An early computer expert

Born on 14 October 1928 to a Greek family living in Milwaukee, Wisconsin, Mary Tsingou (figure 1) spent her early childhood in the US. Because of the Great Depression, 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 go back to the US for safety. They caught the last American ship that left Italy. Just a week after they landed in New York, Italy declared war on France and the UK.

Tsingou earned her BS in 1951 at the University of Wisconsin and her MS in mathematics in 1955 at the University of Michigan. In 1952, following a suggestion by her advanced differential equations professor, a woman, she applied for a position at Los Alamos National Laboratory. At the time, women were not encouraged to pursue mathematics, but the Korean War had created a shortage of young American men, so staff positions were also offered to young women. She was thus hired, along with a group of recent college graduates, to do hand calculations.

She was initially assigned to Los Alamos's T1 division (T for theoretical), which during World War II had been led by Rudolf Peierls and to which the famous spy Klaus Fuchs belonged. But she quickly moved to the T7 division, led by Nicholas Metropolis, to work on the new computer, the MANIAC I, that no one could program. She and Mary Hunt were the first programmers to start exploratory work on it. The computer was used primarily for weapons-related tasks, but from time to time and mostly during the weekend, the researchers could use it to study physics problems and even to play chess. Tsingou and John Pasta were the first ones to create graphics on the computer, when they considered a problem with an explosion and visualized it on an oscilloscope.

In addition to Pasta, she interacted with Stanislaw Ulam, but she had little contact with Enrico Fermi, who was a professor in Chicago and visited Los Alamos only for short periods. However, she knew Fermi's daughter Nella much better because Nella didn't want to stay with her parents during their visits to Los Alamos. The two young women slept in the same dormitory, while Enrico and Laura Fermi were hosted by their good friends Stan and Françoise Ulam.

It was Fermi who had the genius to propose that instead of simply performing standard calculations, computers could be used to test a physical idea. He thus invented the concept of numerical experiments. Fermi proposed to check the prediction of statistical physics on the thermalization of solids. Preliminary calculations confirmed the anticipated result that energy introduced in a single Fourier mode drifts to other modes. The quasi-periodic behavior wasn't observed at first, because the computer was too slow to allow a simulation to run for long enough. But one day the computer wasn't stopped as intended, and the calculation was left running. The researchers found to their great surprise that nearly all of the energy returned to the initial mode, and the original state was almost perfectly recovered. It was the start of ongoing fruitful research.[5]

The algorithm Tsingou used on the MANIAC in 1955 to simulate the relaxation of energy in a model crystal is reproduced in figure 2. Its complexity can be compared with the 15 lines of Matlab code that are sufficient for a modern-day FPU simulation.[7] Programming the early computers was a task that required great insight and originality, and through the 1960s and even later, programmers were commonly listed as coauthors. It seems that the reason Tsingou was listed as a coworker but not a coauthor is that she was not involved in the writing, although she did produce some of the graphs. (Actually, Fermi was not involved in the writing either: He died in 1954, before the report was written.[8]) The statement of credit, differentiating between the writing and the work done, was presumably misunderstood by later readers.

In 1958 Tsingou married Joseph Menzel, who was also working at Los Alamos, for the Protective Force of the Atomic Energy Commission. She stayed in that small city even as her colleagues left: Metropolis for Chicago, Pasta to Washington, and Ulam to Colorado. She worked on many different problems, always with computers. She became an early expert in Fortran, invented by IBM in 1955, and was assigned to help laboratory researchers.

After her seminal programming work on the MANIAC, in the early 1970s Tsingou went back to the FPU problem with Tuck and studied longer recurrences.[6] But she also considered numerical solutions of Schrödinger equations and worked with John von Neumann to study the mixing of two fluids of different densities. During Ronald Reagan's presidency, she was deeply involved in the Star Wars project calculations.

Retired in 1991, Mary Tsingou Menzel lives with her husband in 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 refer from now on to the Fermi-Pasta-Ulam-Tsingou problem.

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