RETROSPECTIVE

# Leon Knopoff (1925–2011)

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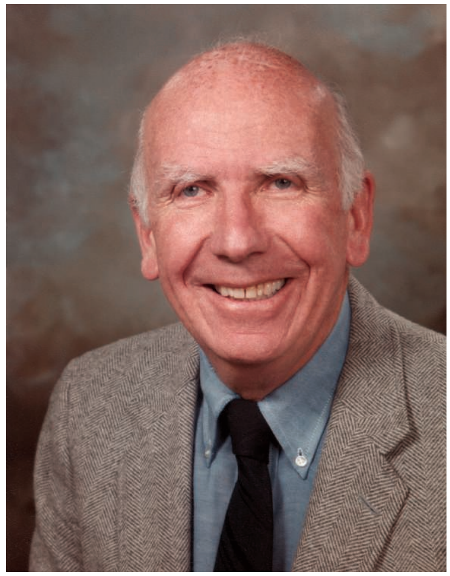
Interests in earthquake dynamics and music were driven by a seismologist's passion for understanding the physics behind pattern recognition.

Leon Knopoff, a preeminent seismologist, died at his home in Los Angeles, California, on 20 January. His extraordinary talents spanned fields as diverse as quantum mechanics and musicology, earning him a reputation as a Renaissance man of the modern era.

Knopoff was born in Los Angeles in 1925. He studied electrical engineering as an undergraduate and obtained his Ph.D. in physics and mathematics at the California Institute of Technology (Caltech) in 1949. The following year, he was recruited by Louis Slichter to the Institute of Geophysics at the University of California, Los Angeles (UCLA), as a research associate. He held faculty positions at Miami University in Ohio (1948–1950) and Caltech (1962–1963). Knopoff became a professor of Geophysics and Physics at UCLA, where he remained for 60 years. His interests in pattern recognition and music coalesced when, as an accomplished pianist and harpsichordist, he became a research musicologist at the UCLA Institute of Ethnomusicology shortly after it was formed in 1960.

Among many honors, Knopoff was elected to the U.S. National Academy of Sciences (1963) and the American Philosophical Society (1992), and as a fellow of the American Academy of Arts and Sciences (1965). He received the H. F. Reid medal of the Seismological Society of America, the gold medal of the Royal Astronomical Society, the Emil Wiechert medal of the German Geophysical Society, and a Docteur Honoris Causa from Université Louis Pasteur, Strasbourg. He particularly treasured four teaching awards from the UCLA Physics Department. Along with his many students and colleagues, we benefited from his extraordinary ability to teach complexity in the simplest of terms, with an infectious animation and the patience to impart understanding.

His encyclopedic memory and theoretical prowess earned him many first discoveries listed in more than 350 publications involving his 39 research students and 40 postdoctoral scholars. In 1956, Knopoff published a theoretical framework for the "double couple" model of an earthquake



(considers ground motion across a fault plane), which is now a standard approach used by engineers and seismologists to predict ground shaking. He showed how motion on a boundary, such as a seismic fault, is linked to displacements in a medium, such as Earth's crust, and demonstrated that the displacements are proportional to the velocity of slip across a fault plane.

In the 1960s, Knopoff's independent and collaborative work included developing computational approaches for understanding the dynamics of fault planes and the propagation of seismic waves. These laid down the models for using seismograms (recordings of ground motion as a function of time) to obtain both the earthquake mechanism and the velocity along the ray path. He not only pioneered the installation of temporary long-period seismograph stations in locations throughout the European Alps; he and colleagues Stephan Mueller and Walter Pilant were the first to perform digital processing of long-period seismograms in 1966. At the South Pole, Knopoff helped to develop and install an ultralong-period seismometer and was the first to measure solid Earth polar tides and vibrational modes, unaffected by Earth's rotation and elliptical shape. He used global seismographic data to define the main structures of plate tectonics, and showed that the oceanic lithosphere thins at mid-ocean ridges and lies above a decoupling zone between plates and the mantle below. In 1972, Knopoff was the first to show that unlike thin oceanic lithosphere, regions of stable continental crust (shields) possess very deep roots, or keels. These keels slow the motion of continental plates as they plough through the mantle. Modern plate models and geodetic measurements of plate motions support these pioneering models.

The range of Knopoff's theoretical advances covers nearly everything seismological, including diffraction, attenuation, creep, equations of state, scattering, cracked media, and dynamic crack propagation. He was one of the first to recognize the applicability to the earthquake problem of modern developments in nonlinear science such as chaos, strange attractors, fractality, and self-organized criticality. The highly cited model of interacting springs and blocks by Knopoff and Robert Burridge (1967) became the basis for simulating self-organization and chaos in the earthquake dynamical system. It predated by two decades such developments in physics.

With Yan Kagan, Knopoff developed the stochastic branching model of faulting that displays the clustering properties of earthquake catalogs, including foreshocks, aftershocks, and weak clustering of mainshocks. Again, he was years ahead of the now famous epidemic type aftershock sequences (ETAS) model. His mechanical theories and statistical analyses of earthquake catalogs have provided seismologists a framework for long-term forecasting of seismic hazard.

Another first was the discovery, with George Kennedy, of thermoluminescence dating of ancient pottery—a procedure widely used by archaeologists and art historians. Rocks and pottery contain small amounts of radioactive elements that decay over time. The electrons emitted during this process become trapped in the solid material, but when heated to about 350°C, are freed, emitting light. Age can thus be estimated according to the amount of light given off.

Leon Knopoff was a warmhearted man, very much at home climbing glaciers, hiking in the Sierras, advancing theoretical physics, and applying pattern recognition to melodic stylistic analysis or language. A remarkable polymath, he effectively spanned the "two cultures" of science and art, leaving an extraordinarily rich record of achievement and a cadre of students who continue his work.

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