Professor Chia-Chiao Lin (1916–2013)

by Frank Hsia-San Shu

Professor Chia-Chiao Lin (林家翹), the foremost applied mathematician and astrophysicist of Chinese descent of the twentieth century, passed away from heart failure in Beijing during the early morning of January 13. 2013. He was 96 at the time of death, and he left behind a wife, Shou-Ying Liang (林梁守瀛) who continues to reside in Beijing, and a daughter, Lillian Sheng-Jung Lin (林聲溶), whose residence is in Decatur, Georgia, in the United States.

Born in Beijing on July 7, 1916, C. C. Lin came from a large prominent family of Fuzhou City in Fujian Province. Many of the descendants of that family attended his funeral services on January 18, 2013 in Beijing to pay their respects along with much of the Tsinghua community in the mathematical and physical sciences. The event was marked by poignancy and meaning since the life story of C. C. Lin is entwined with the most difficult period of modern Chinese history, one full of trial and hope and ultimate triumph that makes pale any tale of fiction.

Chia-Chiao Lin at the beginning of his career at MIT (left) and toward the end of his career in Beijing (right)

After the Boxer Rebellion at the turn of the nineteenth and twentieth century, the victorious Allied Powers had extracted from China a huge Indemnity. To its everlasting credit, the United States returned its portion of the money under the stipulation that the funds be used for educational purposes. In 1911, with the establishment of the Republic of China, Tsinghua University was founded with the express mission of sending young scholars to study abroad to learn the missing science and technology that had placed China at such a disadvantage compared to the West.

The competition to enter Tsinghua University in its formative years was therefore fierce, and it was a notable early achievement that C. C. Lin enrolled in the Physics Department at Tsinghua in 1933 with the highest entrance examination score among all the candidates for admission in China for that year. A legend among his classmates—my father told me that when exam scores in any class were posted, the only curiosity would be who had placed second—it was conceded by everyone that C. C. Lin would graduate at the head of his class, which he did in 1937. Even in gymnastics, C. C. Lin got the highest grade, not because he was particularly athletic, but because when all the other students had left to wash up, he was still on the track running.

Old Entrance Gate, Tsinghua University, Beijing

Soon after the graduation ceremonies, the Japanese bombarded Shanghai. Although the Chinese ground troops put up a fierce resistance, especially at the Marco Polo Bridge in Wanping southwest of Beijing, the Curtiss Hawk-III biplanes sent up to defend Shanghai were no match for the faster Japanese fighters and bombers.

Pei-Yuan Zhou (周培源), Lin's teacher in physics, noted the discrepancy and persuaded his prize student to switch his graduate studies to aerodynamics because this was the field in which the needs of his country were the greatest. Ahead of the advancing Japanese forces, under a scorched-earth strategy of "trading space for time," the great migration of China's industries and universities to the West took place. In Kunming, Yunnan province, Tsinghua University, Peking University, and Nankai University amalgamated to form the National Southwest Associated Universities. There, C. C. Lin and his friends, which included Shiing-Shen Chern (陳省身) and Loo-Keng

Hua (華羅庚), who were then Professors at Tsinghua, pondered their future.

In 1939, C. C. Lin received a prestigious Boxer Rebellion Indemnity Scholarship to pursue graduate study in the United Kingdom with the world-famous hydrodynamicist, G. I. Taylor. However, the breakout of World War II led to the virtual isolation of Great Britain and interrupted these plans, and he went in 1940 to study instead at the University of Toronto under the supervision of the great Irish mathematician and relativist, J. L. Synge. In 1941, he received a Masters of Science from Toronto, and he transferred to the California Institute of Technology to work with the renowned aerodynamicist, Theodore von Karman (who was the recipient of the first National Medal of Science from President John Fitzgerald Kennedy).

Again, C. C. Lin achieved the highest marks of any

Chia-Chiao Lin (at left), Pei-Yuan Zhou, 1987

Caltech graduate student of that period, and he received his PhD in aeronautics from Caltech in 1944.

Under von Karman's supervision, C. C. Lin's thesis dissertation tackled and solved a problem in the stability of parallel shearing flows that was the subject of Werner Heisenberg's PhD thesis under Arnold Sommerfeld. The mathematical problem involved a fourth-order ordinary-differential-equation (the Orr-Sommerfeld equation) with internal singularities (or "turning points" before the solution reached the physical boundaries of the problem), a considerable challenge for applied mathematics even today. Heisenberg's great physical intuition allowed him to map out the likely solution, as well as to speculate on the nature of the turbulence that would result when the boundaries for stable flow were crossed. But he did not have a solution for the Orr-Sommerfeld equation acceptable to mathematicians. Adding to the confusion was the finding of a solution to a related but different problem by a rival group in Germany, which showed a completely different geometry for the boundaries of stability in parameter space.

Tsinghua Garden, Tsinghua University

C. C. Lin was able to find an analytic method to solve Heisenberg's problem by making the inspired guess that the critical Reynolds number for the transition from stability to instability would be large compared to unity, and therefore could serve as a large dimensionless parameter for asymptotic expansion. Lin's solution agreed qualitatively with Heisenberg's intuitive mapping. Moreover, when Lin applied the same technique to the different case

National Southwest Associated Universities

studied by the rival group to Sommerfeld and Heisenberg, it gave the same conclusion as their solution. The debate therefore seemed settled.

Unfortunately, although a commonplace approximation today (a whole branch of mathematical methods called singular perturbation theory has grown up around the technique), many of Lin's contemporaries did not accept the validity of his approximation. In particular, a distinguished mathematician and physicist, Chaim L.

Pekeris, applied finite-difference techniques to obtain a direct numerical solution for the linearized, time-dependent, plane-parallel problem considered by Heisenberg and obtained results in opposition to Heisenberg and Lin's conclusions.

To help resolve the conflict, over dinner at a Chinese restaurant (what else?), Von Karman introduced Lin to John von Neumann, a founding figure in computer science. Much of the dinner conversation occurred in Hungarian, but fortunately, von Neumann also spoke excellent English, and C. C. Lin was able to communicate to von Neumann his desire to see another finite-difference calculation of Heisenberg's problem. Eventually, with von Neumann's help, the controversy was settled by using a powerful (for its time) IBM computer, which showed that Heisenberg and Lin had been right all along. Pekeris's step size had simply been too coarse to give reliable results for a function that varied rapidly with respect to its argument

Theodore von Karman (1881-1963)

and the dimensionless parameter of the problem, the Reynolds number. Although I never had the opportunity to discuss the matter directly with him, I always personally suspected that the unpleasantness of this early controversy steeled C. C. Lin for the later controversies in his scientific life and also led him to trust to his own intuition for where scientific truth was likely to lie more than blind reliance on numerical simulation. A summary of these developments is contained in Lin's short and sweet monograph published in 1955 entitled "The Theory of Hydrodynamic Stability."

Lin's solution of the problem of the stability of parallel flows constitutes the classical example for the transition from laminar to turbulent flow. As a postdoc at the Jet Propulsion Lab (founded by von Karman in 1938), he collaborated with his adviser on a spectral theory of fully developed turbulence, which extended von Karman's ideas of the roles of similarity in statistical theories of incompressible homogeneous turbulence. In this period he also worked on the aerodynamics of gas turbines, oscillating airfoils, and shock-wave theory, i.e., knowledge that became the base of the development of modern jet airplanes and rockets.

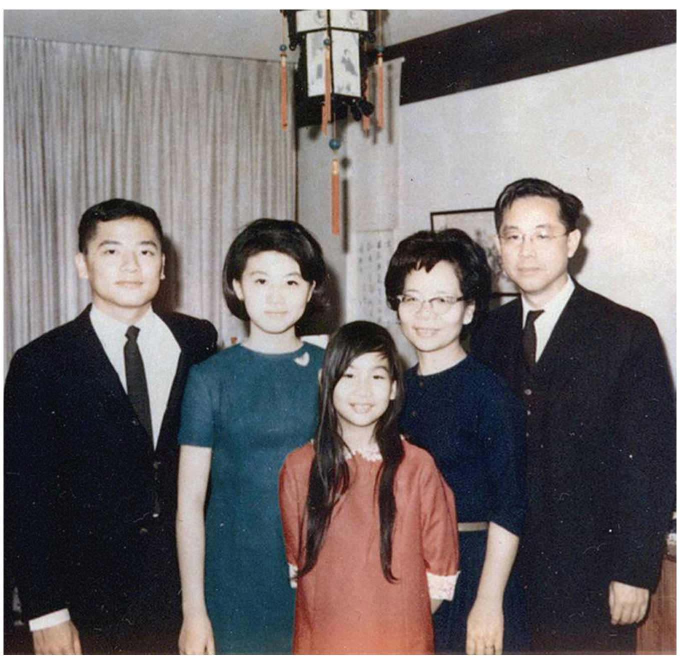
In 1945, he accepted a faculty position in Applied Mathematics at Brown University; in 1946 he was promoted from Assistant Professor to Associate Professor. Meanwhile, after the Second World War, Heisenberg returned briefly to the subject of his PhD dissertation, and his generous praise of C. C. Lin's work at an American Mathematical Society held at Harvard University made Lin an academic celebrity. In 1947, the Massachusetts Insti-

Werner Heisenberg (1901-1976)

tute of Technology (MIT) recruited him as an Associate Professor in Applied mathematics, and in 1953 he was promoted to full professor at MIT. In 1958 he was elected a member of Academia Sinica in Taiwan.

At MIT, C. C. Lin was part of an applied mathematics group that included, at that time, Eric Reissner, Lou Howard, Harvey Greenspan, and Gerald B. Whitham (who later moved to Caltech). The applied mathematics group was part of the Mathematics Department, and the relationship was strained and held a lot of tension. MIT is a science and engineering school, with a heavy emphasis on technology, which is, after all, part of its name. The students in the natural sciences and engineering were dissatisfied (even in my time as an undergraduate) with the courses they took from the Mathematics Department because the mathematics they learned there were not useful

At the Massachusetts Institute of Technology (MIT), Cambridge, Massachusetts



The engagement of Frank Hsia-San Shu to Helen Pu at Lin's house in Weston, Massachusetts, 1967.
Left to right: Shu, Helen (later Mrs. Shu), Lillian Lin, Mrs. Lin, and Chia-Chiao Lin.

to their specialties. For example, the analysis course had a lot of foundational work (such as Lebesgue integration) that put Fourier theory on a rigorous mathematical basis without teaching students how to use Fourier series or Fourier transforms to solve practical problems in optics, circuit theory, data analysis, or image processing. A lot of external pressure was therefore exerted on the Mathematics Department to provide more suitable "service" courses. The pure mathematicians naturally disdained the "mathematics as methods" approach, and the applied mathematicians were caught in the middle of the debate.

C. C. Lin had a very clear view of what was applied mathematics. His role models were Isaac Newton and John von Neumann. For these men, the motivation for applied mathematics came not from an urge to discover and prove great universal theorems in the tradition of pure mathematics, but from the quantitative problems that arose out of the natural world. For Lin, the mathematization of a scientific problem led to quantitative predictions and decisive confrontations with empirical data that were the ultimate arbiters of scientific theories. Newton set the gold standard for this activity; he invented the differential and integral calculus to solve specific problems in the dynamics and forces exerted by celestial bodies. Von Neumann not only gave a rigorous mathematical foundation for quantum mechanics, and introduced the idea of quantum logic, but he also showed how sophisticated probabilistic methods could be applied to game theory which, of course, opened the social-science field of economics to mathematical analysis. (Reputedly, von Neumann liked to play poker, but it was not one of his natural gifts.) I remember a conversation my wife and I had with Professor and Mrs. Lin in the late 1970's at their home when we visited Massachusetts from California over Christmas vacation. During the course of the evening, he said "from now on, it would all be about economics." At the time, I thought his remark interesting given that he had never previously expressed in my hearing an interest in economics. I should have known better, for in the bookcase of his study, under the picture of Theodore von Karman, was a copy of von Neumann and Morgenstern's book on "Theory of Games and Economic Behavior." I should have known that Lin's remark was a mathematical one—that he saw the field of economics through the eyes of a professional mathematician with broad academic interests. In any case, the remark would prove prophetic. Soon afterward, the world would see the election of Margaret Thatcher as Prime Minister of Great Britain and Ronald Reagan as President of the United States; the four Asian tigers would make their rapid ascent among the world's developed economies; and in China, Xiaoping Deng (鄧小平) would begin the series of reforms that would drastically transform China.

When Lin spoke about "applied mathematics," he always emphasized that the phrase supplied a connection, not a *raison d'être*—the scientific or technological or economic motivation came first, the appropriate mathematics brought to bear on the particular application came second. He liked to say that when you could mathematize a problem, you opened the door to cross-disciplinary research. Methods and ways of thinking that were useful to one field could help to crack problems in another, seemingly unrelated, field.

Lin's philosophy appealed to Julius Stratton, then the Provost of MIT, who had a high opinion of Lin from his contacts with the Sommerfeld school of scientists in Europe. Stratton appointed Lin as the first Chair of the Committee on Applied Mathematics, with the Chair reporting to the Provost and not the Chairman of the Mathematics Department. Thereby, Stratton created a certain equality between pure and applied mathematicians that helped to remove many frictions. It would serve as a model for many applied mathematics groups that

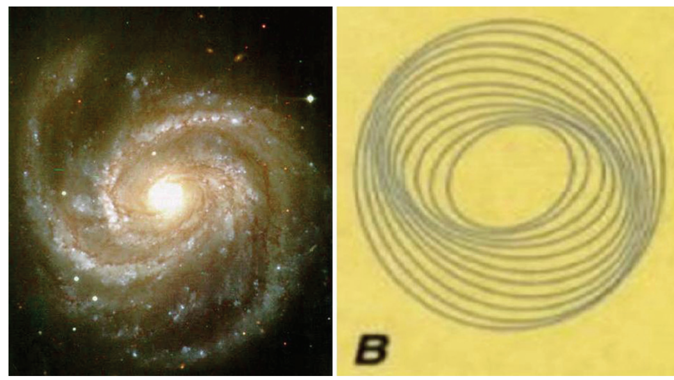
Bengt Stromgren (1908-1987)

sprang up on other American campuses. Lin served two terms before turning over the reins of power to Harvey Greenspan in 1959.

Lin then went to spend a sabbatical year at the Princeton Institute for Advanced Study IAS), where Physics Nobelist Yang Chen-Ning (楊振寧) invited Lin to work on the theory of superfluids. During that time, Lin attended a meeting organized by the famed astrophysicist Bengt Stromgren, who was then one of the permanent professors at the IAS.

From the meeting, Lin learned that astronomers were completely puzzled by why most disk galaxies possessed spiral structure. The matter in disk galaxies rotates differentially, i.e., the material closer to the center takes less time to complete a full circle than the material farther from the center, yet the spiral arms of a galaxy do not wind up into ever tighter spirals. If they did, spiral arms would have over a hundred windings, yet they rarely exhibit more than one or two. The winding dilemma, as posed so succinctly by the world's foremost observational astronomer at the time—Professor Jan Oort of Leiden University—struck Professor Lin so forcefully that he conceived the idea that spiral arms in a disk galaxy must not be a material structure but a wave pattern.

Thus was born the idea of density-wave theory. C. C. Lin decided that he would switch his field of research to work on this important problem in astrophysics (mentioned even in Feynman's Lectures on Physics published in this period). Taking his own advice about the power of applied mathematics to cross disciplinary boundaries, he

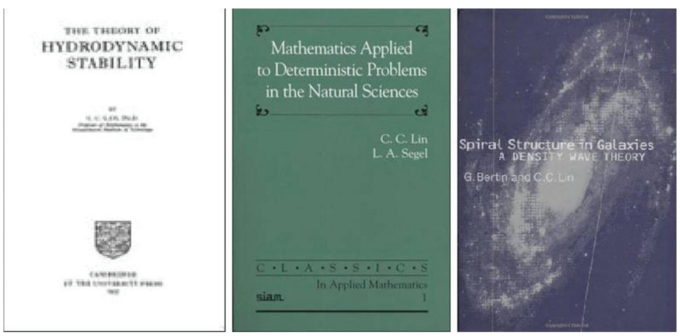


Left: Photographic image of a spiral galaxy. Right: Illustration of the concept of a spiral density wave. In a frame that rotates at a fixed pattern (angular) speed, the streamlines of matter rotate through the pattern in closed ovals at their own material speeds, with the long axis of the ovals shifted quickly in angular orientation so as to generate surface density concentrations that yield gravitational deflections accounting self-consistently for the departures from circular motion of the streamlines.

turned the methods that he had used in his studies of fluid mechanics to the investigation of galactic dynamics. He began to assemble a team of young theorists to help him tackle the problem on a long-term methodical basis. Alar Toomre joined the MIT faculty as an Instructor in 1960; Chris Hunter, as a postdoc in 1960 and then on the regular faculty in 1964; Bill Roberts as a graduate student in 1964; Chi Yuan (袁旂), as a postdoc in 1966; James Wai-Kee Mark (麥偉基) as an Assistant Professor in 1970; Yue-Ying Lau (劉汝瑩) as an Assistant Professor in 1973; Giuseppe Bertin as a long-term visiting scientist beginning in 1975.

I was fortunate to begin to work with him as an undergraduate research student in the summer of 1962. He had just been inducted as a member of the National Academy of Sciences, and he was perhaps in a good mood to mentor someone who had no idea of what academic research entailed. The problem that he put me on was to help with the numerical computations (on a mechanical calculator, not an electronic computer) of wind-driven ocean circulation. I must have performed adequately in this role because he became my undergraduate thesis advisor in the following semester to work on spiral density-wave theory. (At MIT, all physics majors must write an undergraduate thesis.) He also advised me to take a course in Galactic Structure and Dynamics being taught that semester by Visiting Professor LodewijkWoltjer, who would later become the Director General of the European Southern Observatory and the President of the International Astronomical Union.

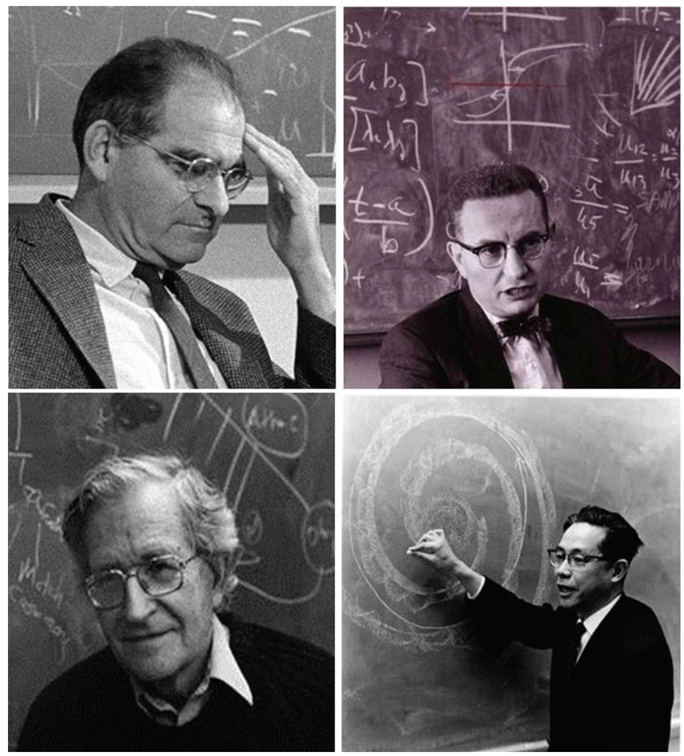
It was exciting to be at the beginning of a transformational era, one in which Professor Lin interacted (and argued) not only with the foremost theorists of the day, but also engaged the observers (especially in radio astronomy) in an all-fronts attempt to find out the scientific truth about the nature of spiral structure in disk galaxies. Thus, before I had turned twenty, I had met some of the great names of twentieth-century radio astronomy—Jan Oort, Bart Bok, Frank Kerr, Harold Weaver, Mort Roberts, Gart Westerhout, Bernie Burke, and others. Although I thought of myself as a theorist, I learned from Professor Lin's example that it was even more important in a subject in which one cannot perform laboratory experiments to rely on the empirical data to help separate the probable from the merely possible. It was obvious by talking with the observers that correlations of the Hubble diagram with other attributes of a disk galaxy, such as the bulge to disk ratio and the fractional gas content, that spiral structure must be a long-lived and an intrinsic dynamic feature of a disk galaxy. The controversy arose because the predominant attitude among theorists at the time was that spiral structure was a transitory or externally driven phenomenon.



Some books by C. C. Lin

The controversy led to attacks against Professor Lin that went beyond professional debate and bordered sometimes on the personal. Such attacks were unpleasant for his admirers to witness. Yet throughout this difficult trying period, he himself always maintained a calm and dignified exterior. If in his previous controversy with the stability of parallel flows, he had displayed "Magnanimity in Victory," now he was a profile in "Courage under Attack." Perhaps he knew all along he would be victorious in the end. One of the regrets that I have concerning his too early passing is that he could not hear my summary talk at a memorial symposium held in Beijing during 24-28 June 2013, which showed that almost all of his ideas about density-wave theory have proven by observations and better numerical simulations to be correct, even if the details of the underlying theory still remain murky on some points.

Those outside the field saw more clearly than those on the inside. In 1966, Julius Stratton, who had risen to become President of MIT, appointed C. C. Lin as an Institute Professor, an honor granted only the most illustrious faculty members.



Institute professors at MIT. Clockwise from top-left: Victor Weisskopf (1908-2002), Paul Samuelson (1915-2009), Chia-Chiao Lin (1916-2013), and Noam Chomsky(1928-).

At that time, the other Institute Professors were Victor Weisskopf, the eminent physicist who contributed to renormalization theory, Paul Samuelson, the first American to win the Nobel Prize in Economics, and Noam Chomsky, the distinguished logician, linguist, and philosopher. In 1973, the American Physical Society recognized his contributions with the Otto Laporte Award. That same year, he was elected President of the Society for Industrial and Applied Mathematics. In 1974, together with his former student Lee Segel, he published "Mathematics Applied to Deterministic Problems in the Natural Sciences," a textbook that was reprinted in 1988 as the first volume in SIAM's series on Classics in Applied Mathematics. In 1975, the American Society of Mechanical

Engineers awarded him the Timoshenko Medal for "outstanding contributions to fluid mechanics, especially to hydrodynamic stability and turbulence, and galactic structure." In 1979, he became the first awardee of the Fluid Dynamics Prize of the American Physical Society. In 1982, he was the Killian Lecturer, a recognition bestowed

Chia-Chiao Lin, the 1982 Killian Lecturer

only to the most distinguished researchers on the MIT faculty. James R. Killian was the 10th President of MIT and the first Presidential Science Advisor (to Eisenhower) in the history of the United States.

In 1987, Lin retired from active service at MIT, and he

Lin's 80th birthday party, 1995—a prelude to reverse diaspora. Within a decade or so after this photograph was taken, all of the men pictured had left America to work in Taipei or Beijing. Seated, right to left: Mrs. Lin, Lin, Typhoon Lee, Paul Ho, and Ron Taam. Standing, right to left: Fred Kwok-Yung Lo, Helen Shu, Frank Shu, Doug Lin, and Tali Lin.

also received an honorary doctorate from Tsinghua University. In 1992, Caltech bestowed him with its Distinguished Alumni Award. In 1994, he was elected to be a Foreign Member of the Chinese Academy of Sciences. In 1995, the MIT Press published his monograph, co-authored with Bertin, "Spiral Structures in Galaxies: A Density Wave Theory." In 2002, he moved back to his alma mater, Tsinghua University, and founded the Zhou Pei-Yuan Center for Applied Mathematics (ZCAM).

Fearless as ever about entering new fields, even at the age of 86, Lin mapped a bold plan for the research emphasis of the new ZCAM: mathematics applied to biology, particularly, to the problem of protein folding. From that time to his last days in the intensive care unit of the hospital, he worked tirelessly to help his alma mater, so brightly did the flame burn in him of the mission of Tsinghua University for which he was sent out from China 73 years earlier. Little did China realize perhaps what a gift it would be for world science. In 2005, National Tsing Hua University in Taiwan awarded him an honorary doctorate in a ceremony in Beijing where I presided as the President of NTHU. On that occasion, I said that it was rare privilege that a student has a chance to present his supervisor an academic degree. Yet Prof. Lin's own mind was ever youthful; he never stopped learning; he never stopped questing for what lay beyond the new dawn; he never gave up on how he could help his beloved China. I will miss his wise judgment, his scientific acumen, his kind mentorship, his stoic courage in the face of adversity, his high personal integrity, and mostly his broad humane spirit. He will be missed, but never forgotten.

Acknowledgments

In preparing this essay, I was greatly helped by Professor Wen-An Yong (雍穩安) of ZCAM who made available his compilation of important dates and awards in C. C. Lin's career and by a 2002 videotape recording by Mr. Chen Yu (于震) of Florida who interviewed Professor C. C. Lin on the eve of his leaving America for China. I would like to thank the MIT Museum and the Zhou Pei-Yuan Center for Applied Mathematics for use of some of the pictures in their collections.