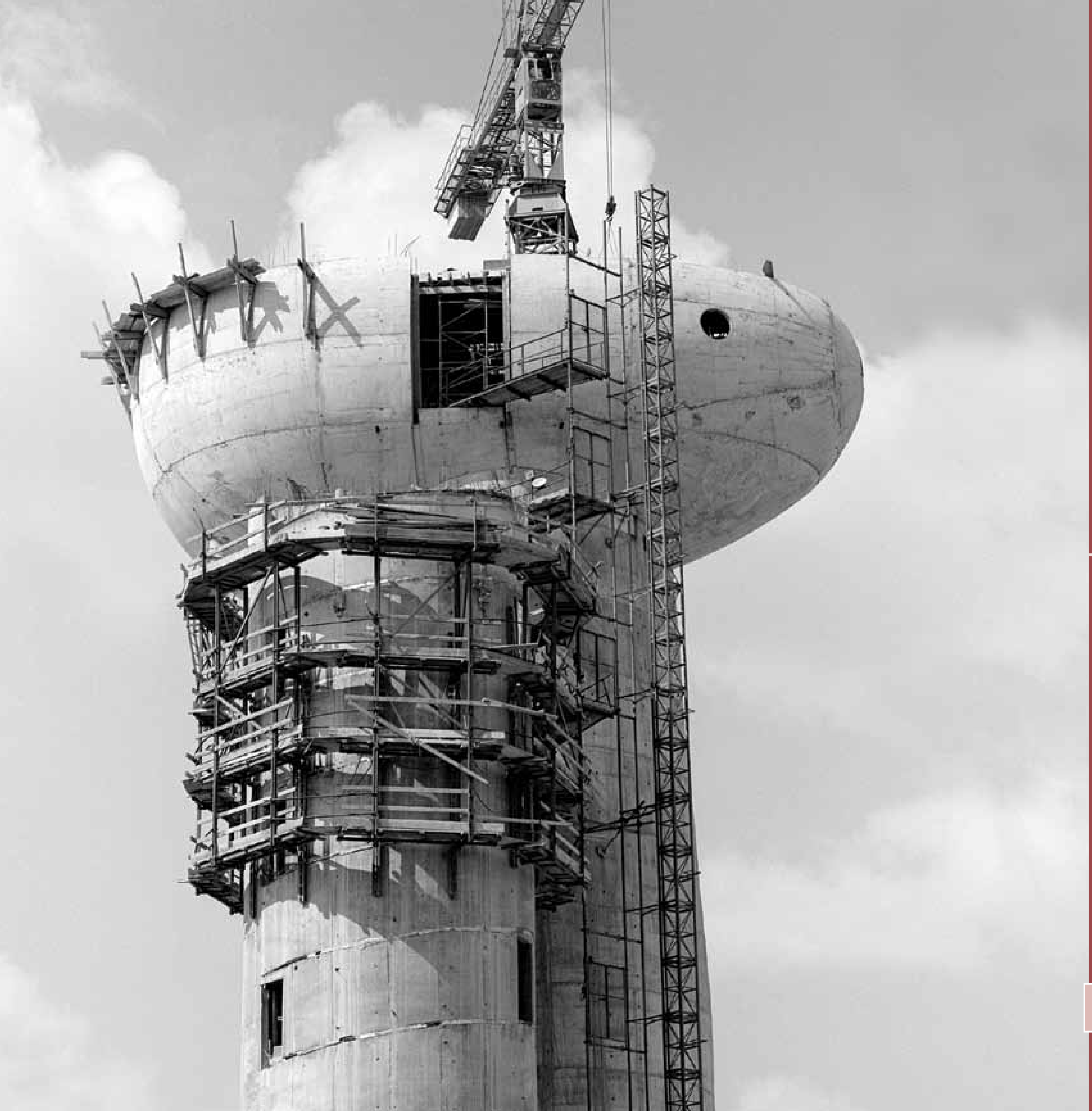


## 23

## The Koffler Accelerator

## 1976

The Koffler Accelerator of the Canada Centre of Nuclear Physics, designed by the architect Moshe Harel in 1975, has become the undisputed architectural symbol of the Weizmann Institute. The unique structure combines two towers. One, shaped like a corkscrew, is 57 meters high; the other, 53 meters high, is topped by an egg-shaped structure 22 meters long and 14 meters across at its widest point.

The accelerator enabled Institute scientists to work at the forefront of global science in the 1960s and 70s; but with time, its experiments reached their completion, and it was recently decided to end its operation.

The monumental but simple geometry of the accelerator building is a striking example of Formalism in architecture, which can also be seen in such new buildings as the CCTV tower designed by Rem Koolhaas in Beijing and the “antenna towers” designed by Santiago Calatrava around the world, including Berlin, Shanghai and Barcelona.

The accelerator also “starred” in the futuristic, enigmatic film by the poet David Avidan, *Message from the Future*, produced in the 1970s.

# 24

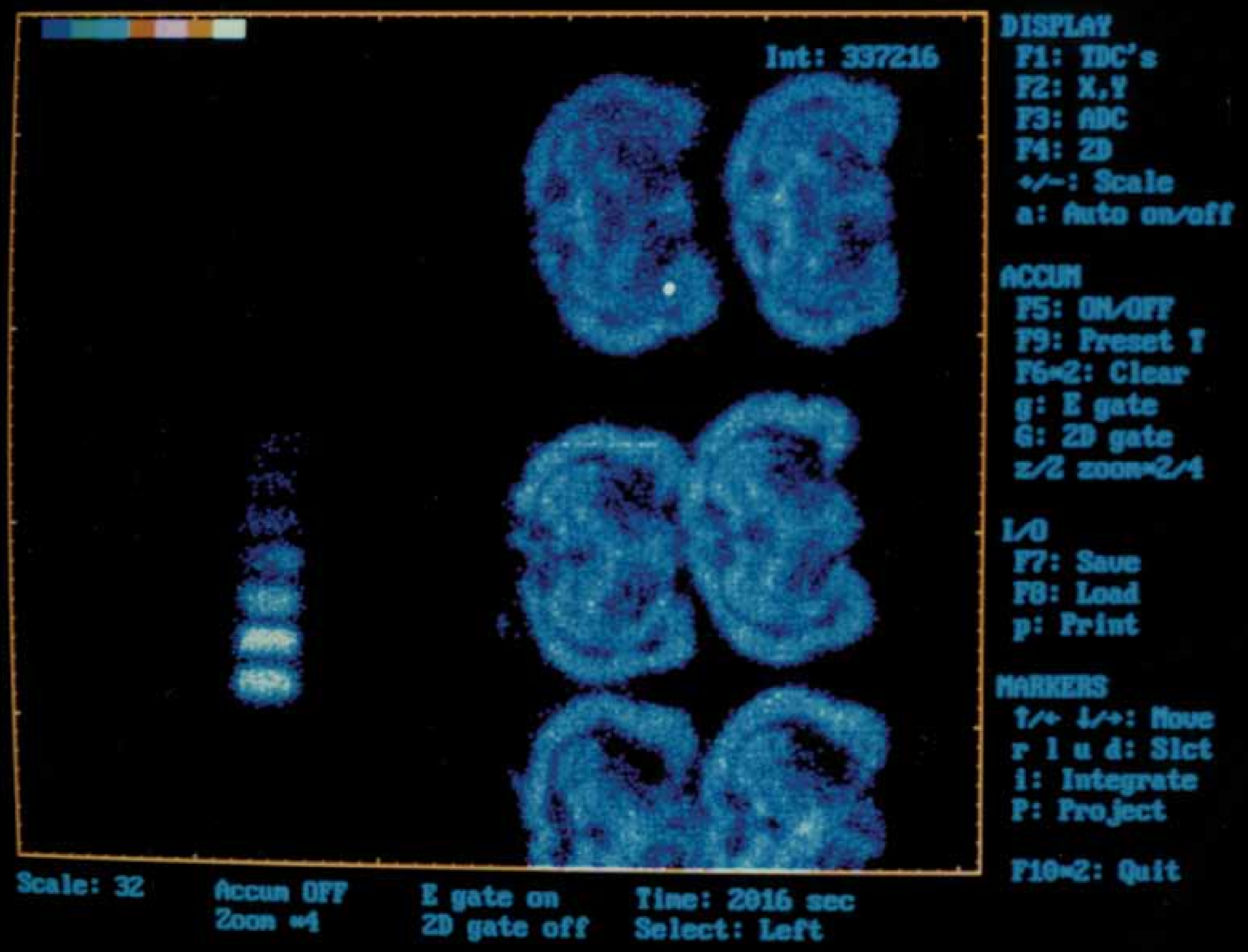
## 1978

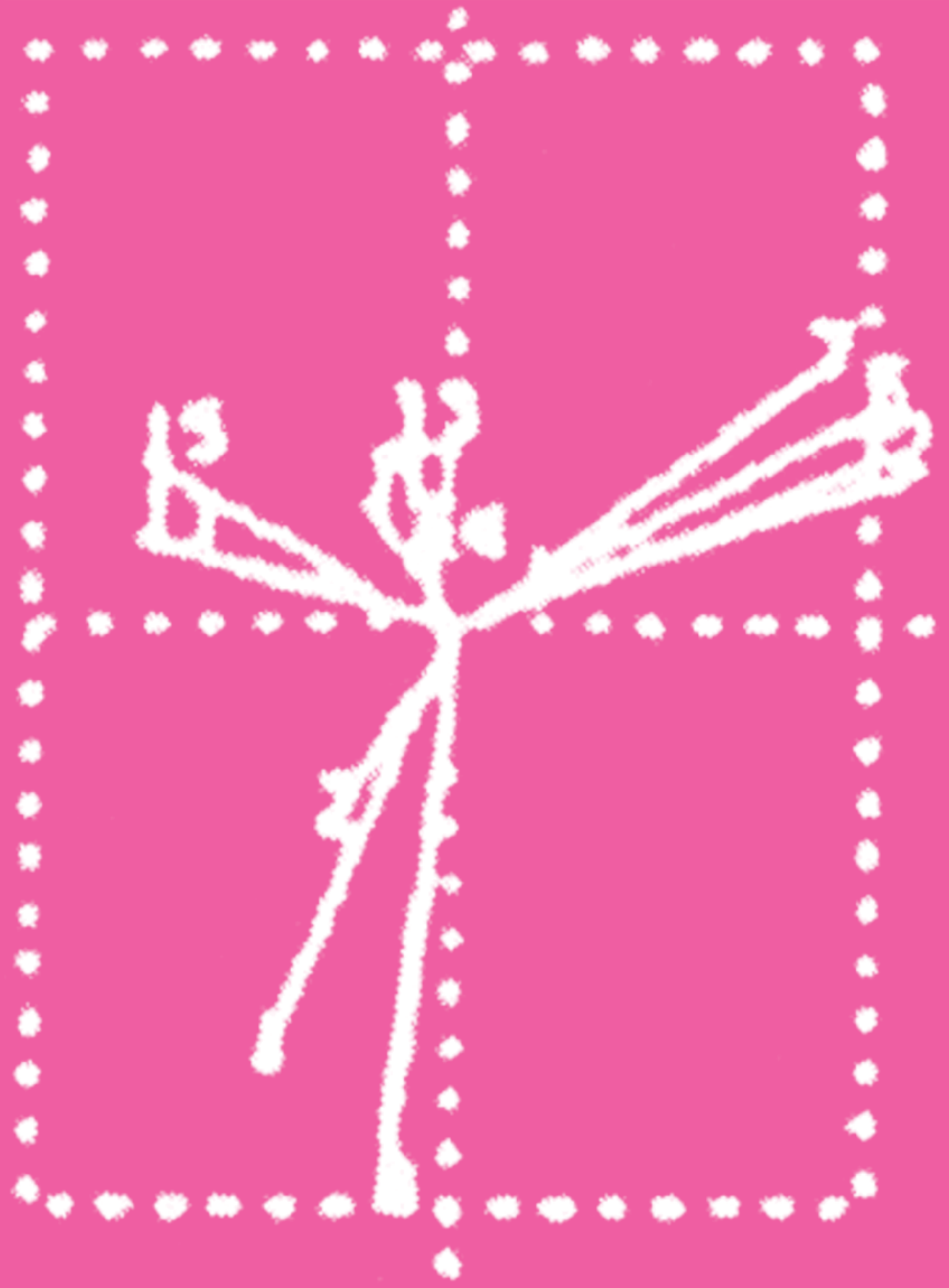
## Detectors for All Purposes

Institute scientists developed a number of advanced radiation detectors that were installed in particle accelerators around the world and used in fields of research ranging from physics to biomedicine. These detectors were designed to detect charged particles, neutrons, X-ray radiation, light and more. Some fast-imaging, gas-avalanche detectors were conceived especially to operate in a high-vacuum environment; these were used in heavy-ion accelerators around the world in a range of nuclear physics experiments.

In one of these studies, Institute scientists erected a sophisticated system to search for heavy matter that might have originated in the Big Bang and that does not exist on Earth today. Even though this heavy matter was never found, the scientists succeeded in setting a lower limit for its existence.

A unique radiation detector for beta-autoradiography developed by Institute scientists was used in experiments to identify and map beta particles (electrons) that are emitted from radioactive isotopes attached to biological molecules (for biological or biomedical research). A map-image of beta-particle emissions is digitized, analyzed and displayed in real time, the exposure time being measured in minutes rather than the hours required by photographic film. An even more advanced detector designed by the same team amplifies not only electron emissions but also those of photons (light particles) that, after further processing, produce a high-quality computerized beta-radiation image.





## Discovering the Gluon 1979

A team of Institute researchers took part in planning and conducting an experiment that uncovered *bona fide* evidence for the existence of gluons. Gluons are the particles responsible for the strongest force in nature – that of "color" (which gives rise to the nuclear strong force). This force acts between quarks, the fundamental particles making up protons and neutrons in the atom's nucleus.

Working in the PETRA particle accelerator at the DESY lab in Hamburg, Germany, Institute scientists made an important contribution to the building of the particle detectors used to measure the products of collisions between beams created in the accelerator, as well as to the analysis of the results that led to the discovery of the gluon.

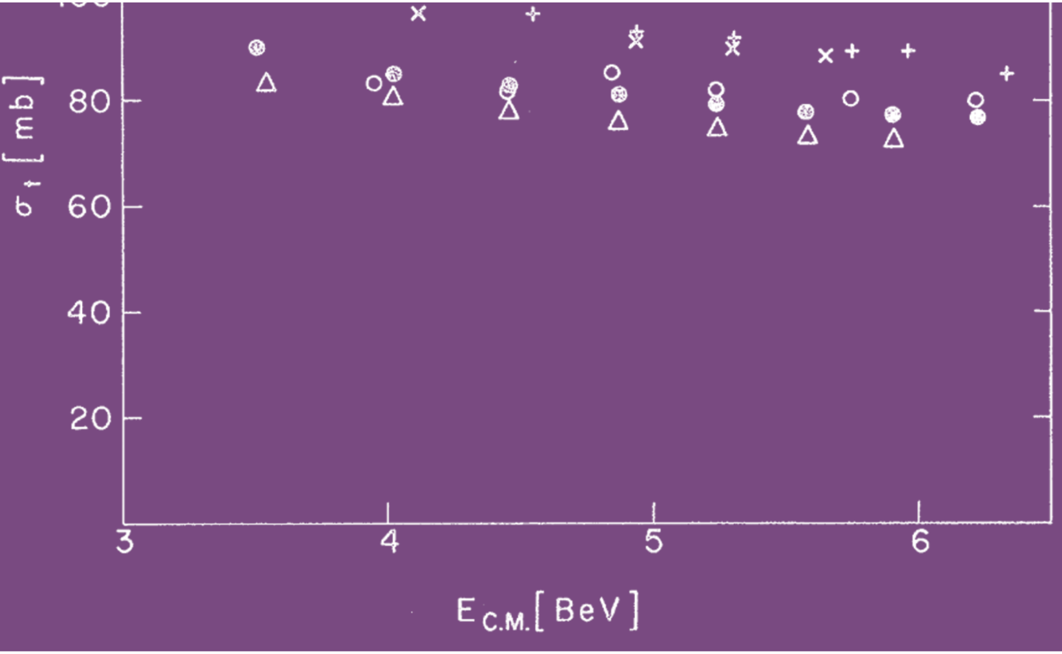
# 26

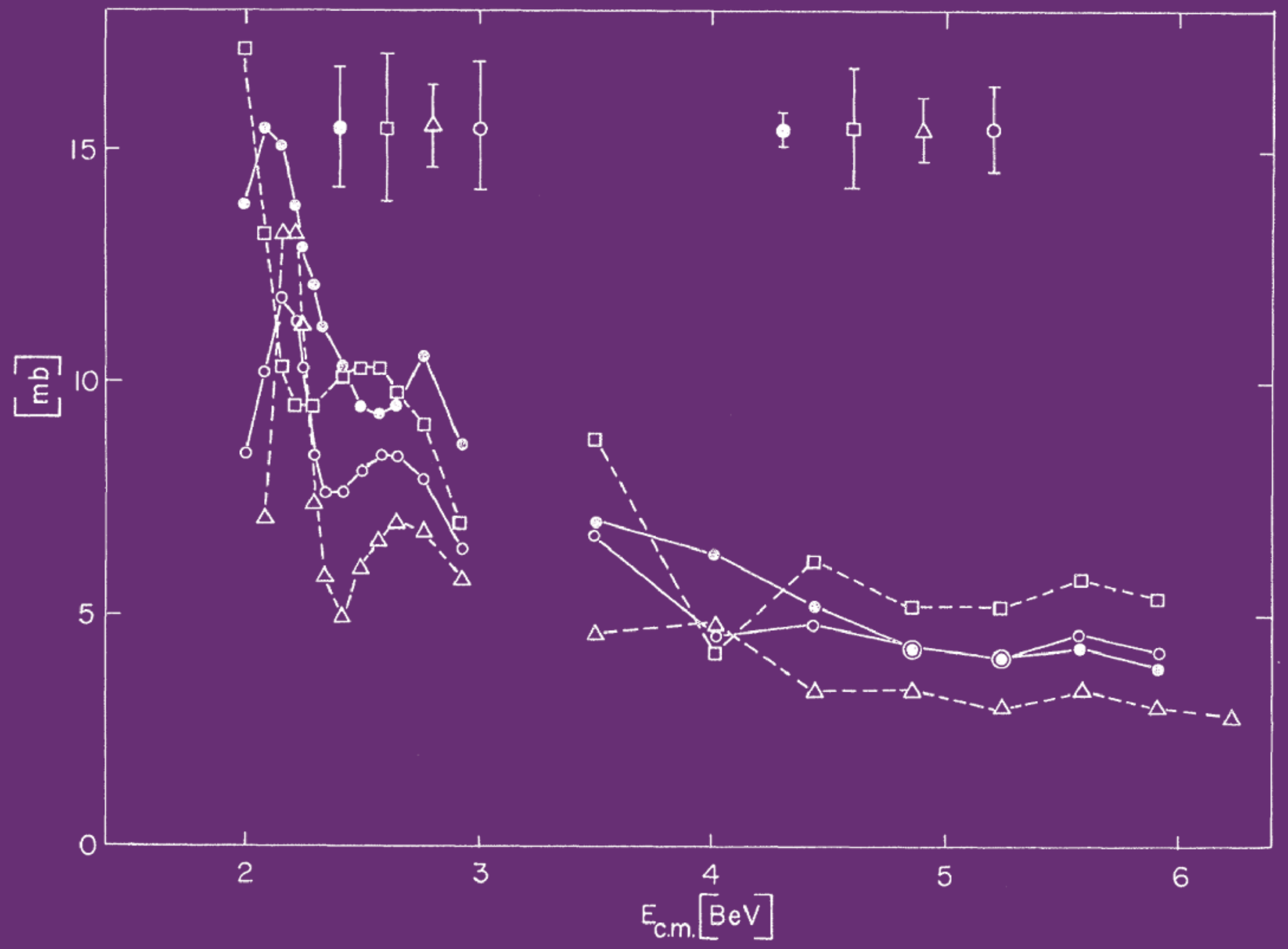
## 1979

## All in the Family

Institute scientists developed an original mathematical method based on group theory for sorting particles into various groups ("families"). This method enabled scientists to find common properties in particles that at first glance have nothing in common. Assigning particles to these "families" allowed the scientists to predict various traits of the particles before these were observed in experiments. This method was one of the main tools used in research on fundamental particles.

Institute scientists then participated in the search for the fundamental building blocks of matter and used the quark model to predict the results of experiments that helped to prove the existence of quarks.





וְהָאָרֶץ הָיְתָה
תֹהוּ וָבֹהוּ

## 27

## 1979

## More Elementary

In the late 1970s, physicists realized that all the particles found in nature are made up of six types of basic particles called quarks and another six called leptons (one of which is the electron). The ratio of the electric charge of a quark to that of a lepton is a simple fraction: 1/3 or 2/3. There is no convincing explanation for the numbers of quarks and leptons, for the strange numerical values of the masses of these particles, for the simple ratios of their charges, or for several other facts that tie them together. An Institute scientist put forward a theory in which quarks and leptons are not, strictly speaking, elementary particles because they contain particles even more elementary than themselves, called “rishons.” According to this theory, all the particles known to us today are composed of different combinations of just two kinds of particles, dubbed “tohu” and “vohu” from the biblical Hebrew for the primordial chaos in the universe. All the quarks and leptons can, theoretically, be made from various combinations of the two rishons, and this might explain some of the unanswered issues. As yet, there is no experimental evidence for particles more basic than the electron and the quark. Neither is there is anything to prove they don’t exist. As of now, the theory remains interesting, but not proven.

$$n(\mathrm{V}) - n(\bar{\mathrm{V}}) = 3Q - 3(B - L),$$

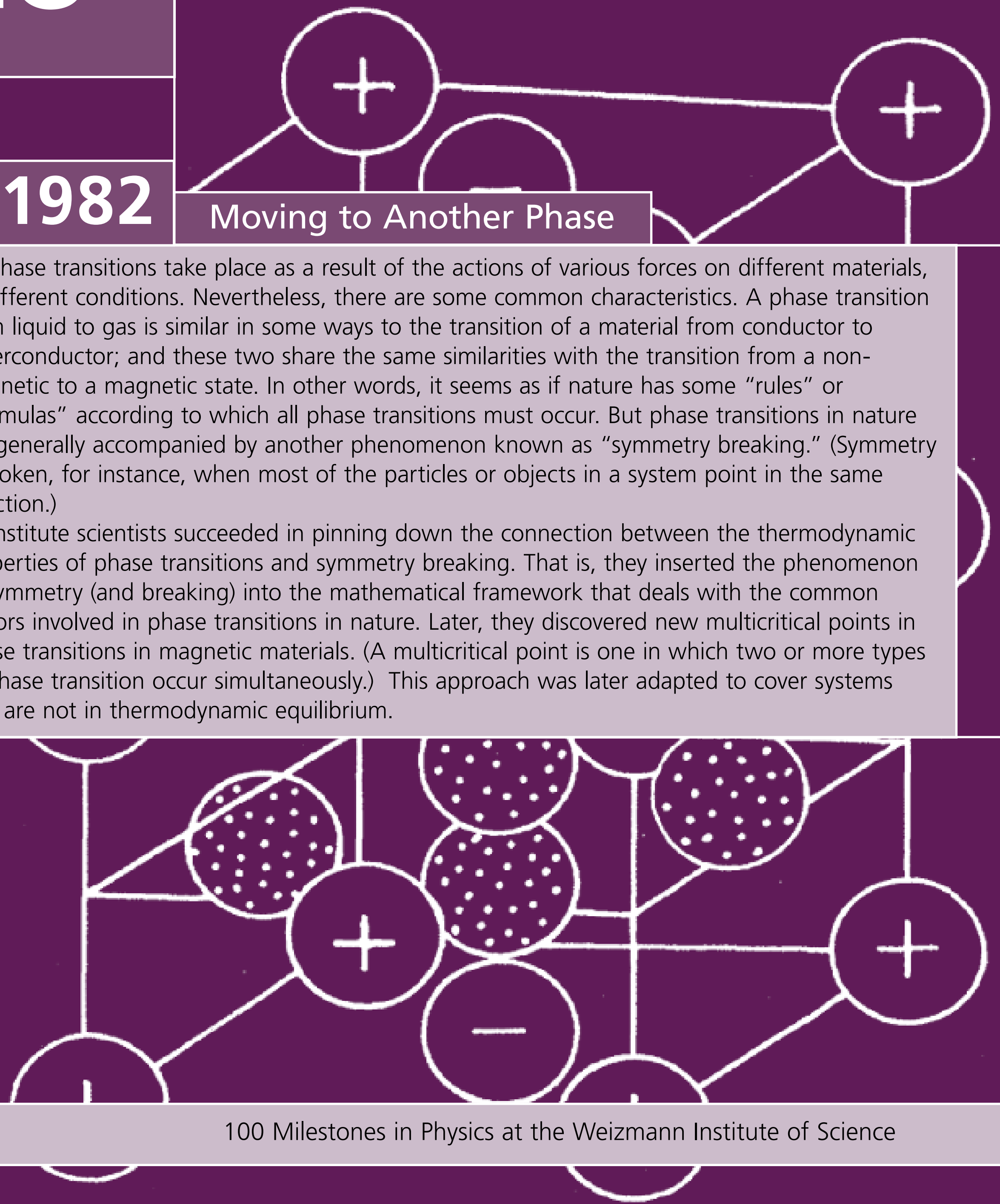
# 28

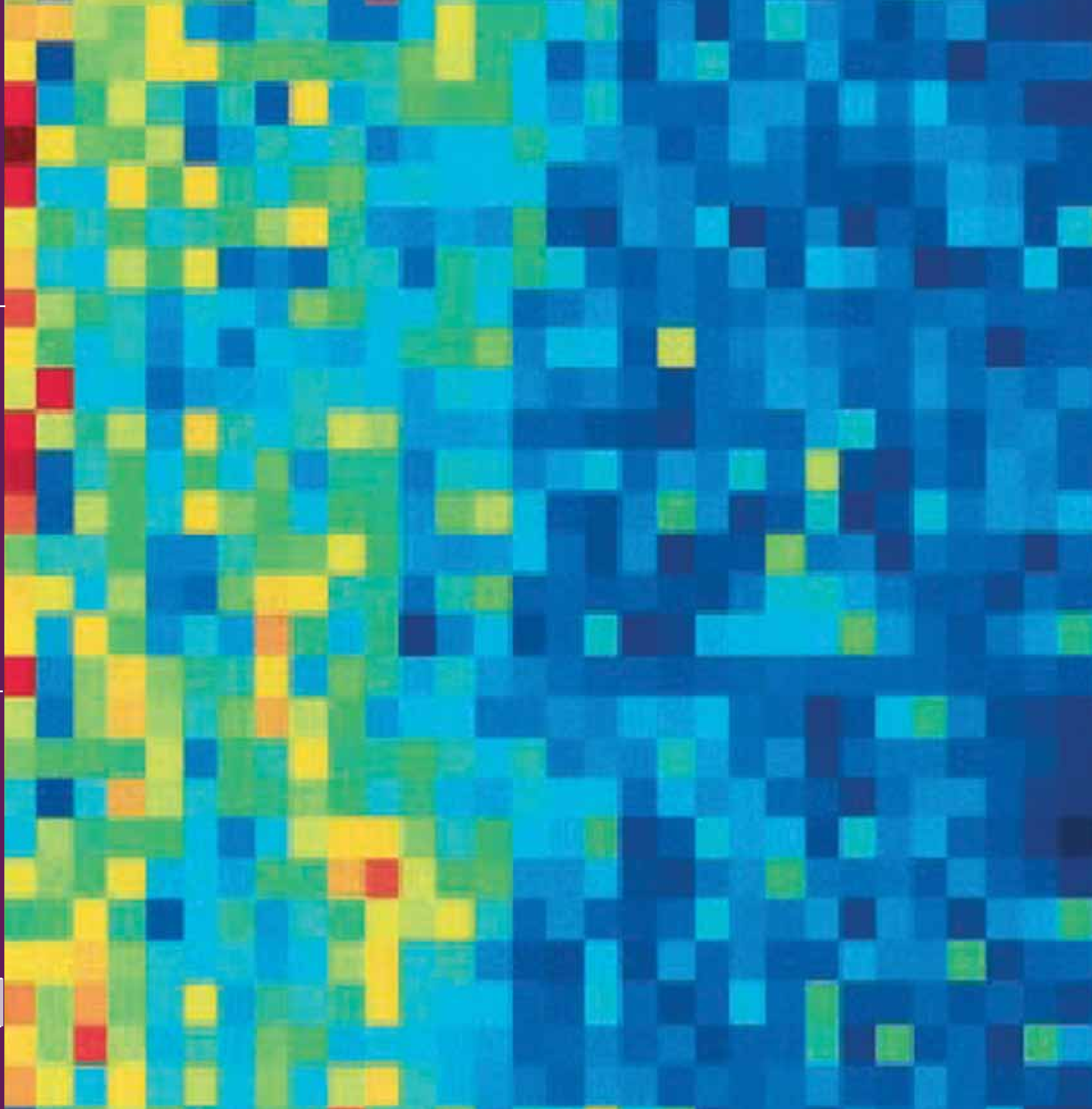
## 1982

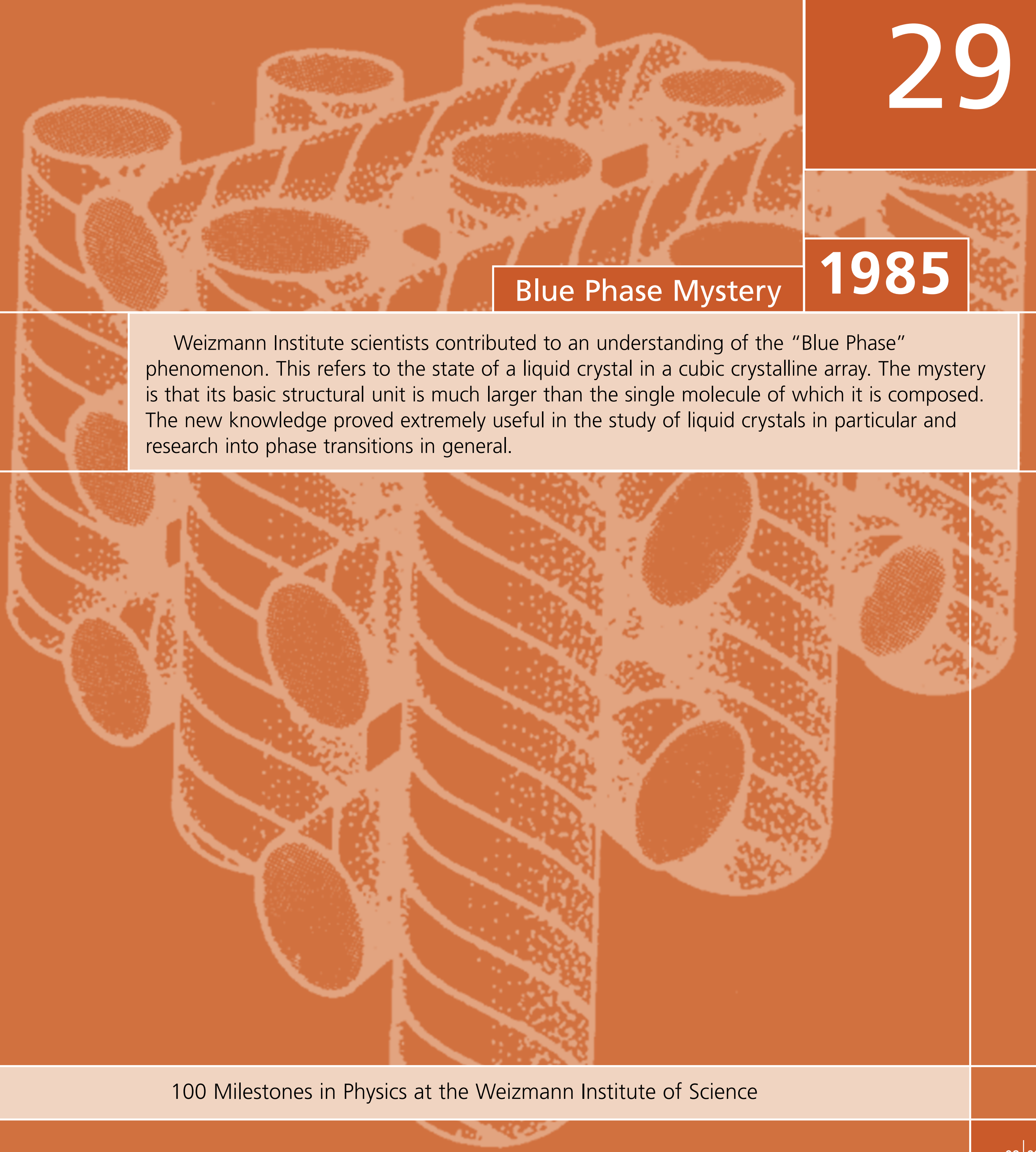
## Moving to Another Phase

Phase transitions take place as a result of the actions of various forces on different materials, in different conditions. Nevertheless, there are some common characteristics. A phase transition from liquid to gas is similar in some ways to the transition of a material from conductor to superconductor; and these two share the same similarities with the transition from a non-magnetic to a magnetic state. In other words, it seems as if nature has some “rules” or “formulas” according to which all phase transitions must occur. But phase transitions in nature are generally accompanied by another phenomenon known as “symmetry breaking.” (Symmetry is broken, for instance, when most of the particles or objects in a system point in the same direction.)

Institute scientists succeeded in pinning down the connection between the thermodynamic properties of phase transitions and symmetry breaking. That is, they inserted the phenomenon of symmetry (and breaking) into the mathematical framework that deals with the common factors involved in phase transitions in nature. Later, they discovered new multicritical points in phase transitions in magnetic materials. (A multicritical point is one in which two or more types of phase transition occur simultaneously.) This approach was later adapted to cover systems that are not in thermodynamic equilibrium.







29

## Blue Phase Mystery

1985

Weizmann Institute scientists contributed to an understanding of the “Blue Phase” phenomenon. This refers to the state of a liquid crystal in a cubic crystalline array. The mystery is that its basic structural unit is much larger than the single molecule of which it is composed. The new knowledge proved extremely useful in the study of liquid crystals in particular and research into phase transitions in general.

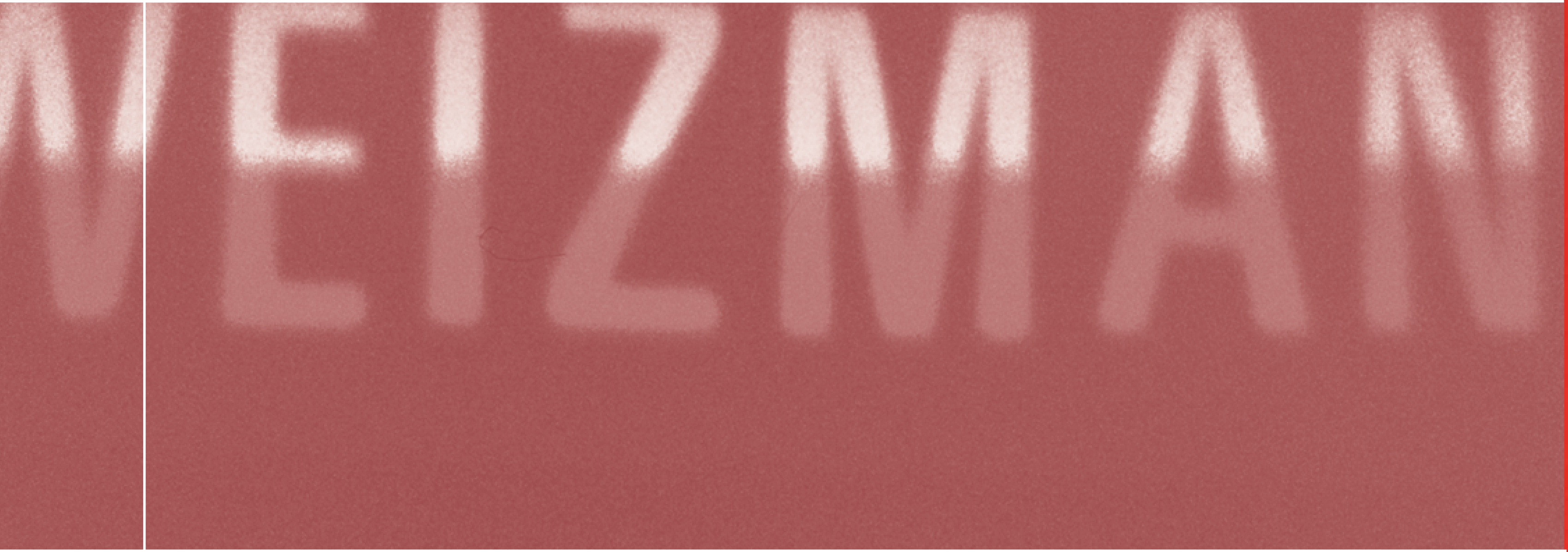
# 30

## 1985

## Propagating Light through Optical Fibers

Institute scientists developed a method for transferring a two-dimensional image, all at once, through a single optical fiber (a task that had, until then, been thought to be impossible). The method is based on multiplexing (sending multiple signals through a single system) two out of three factors: the wavelength of light inside the fiber, the angle of the incident light ray and time. (Multiplexing in time is the transfer, one after another, of the light pixels comprising the image.)

In a later study, the scientists developed ways to calculate and predict non-linear phenomena taking place inside optical fibers. These phenomena consist of "noise" that disrupts the transfer of information signals in optical communications. Once they were able to quantify the noise, the scientists also succeeded in finding ways to halt, reduce or prevent the appearance of these unwanted phenomena. In addition, they found a way to calculate the possible limits on information flow in optical fibers.



$$M = \begin{pmatrix} 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \end{pmatrix} .$$

# 31

## Theory in a Theory

## 1986

Weizmann Institute scientists were the first to develop a consistent, non-trivial string theory about the curvature of space. String theories convert all conventional particles of matter, which have no dimensions (in other words, they exist as points), into a one-dimensional particle – a string. According to these theories, all the matter in the universe arises from the vibration of these strings. String theories also propose a way of combining the theory of relativity and quantum theory. Both have been demonstrated separately in numerous experiments, but they have never been reconciled.

The main difficulty with string theories is that they can exist only in a universe that has many dimensions (around ten), while our familiar universe has only four (the three dimensions of space, and that of time). Physicists investigating string theories try to show that the surplus dimensions (those we cannot sense) really do exist but are folded up in such a way that they are not perceived.

$$Z(\tau,\bar{\tau}) = \left|(\mathrm{Im}\,\tau)^{-d/2}\eta(\tau)^{-2d}\right| \sum_{\lambda,\bar{\lambda}} B_{\lambda}(\tau) B_{\bar{\lambda}}(\bar{\tau})^{*} Z_{\lambda,\bar{\lambda}}(\tau,\bar{\tau}),$$

# 32

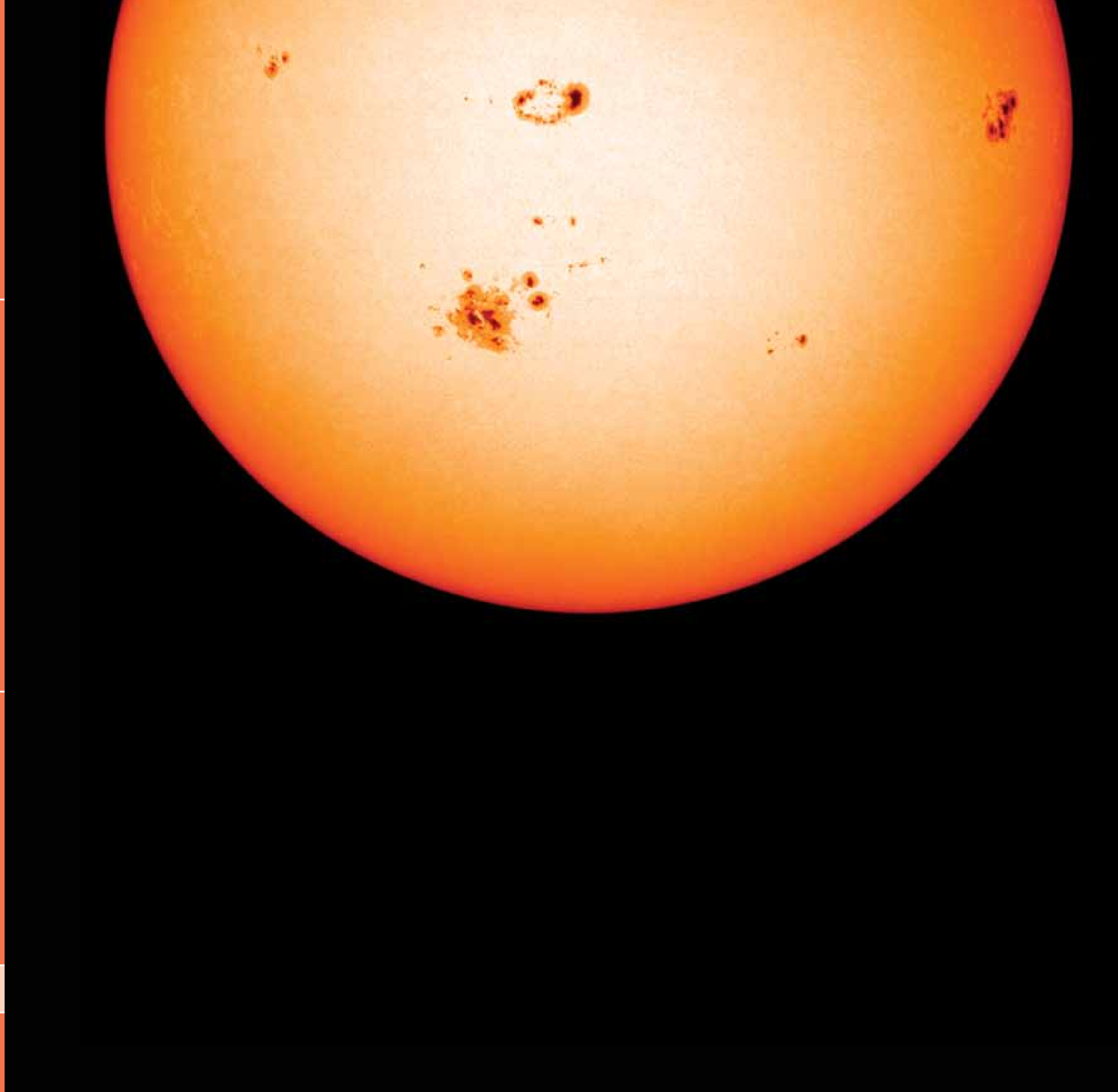
## 1986

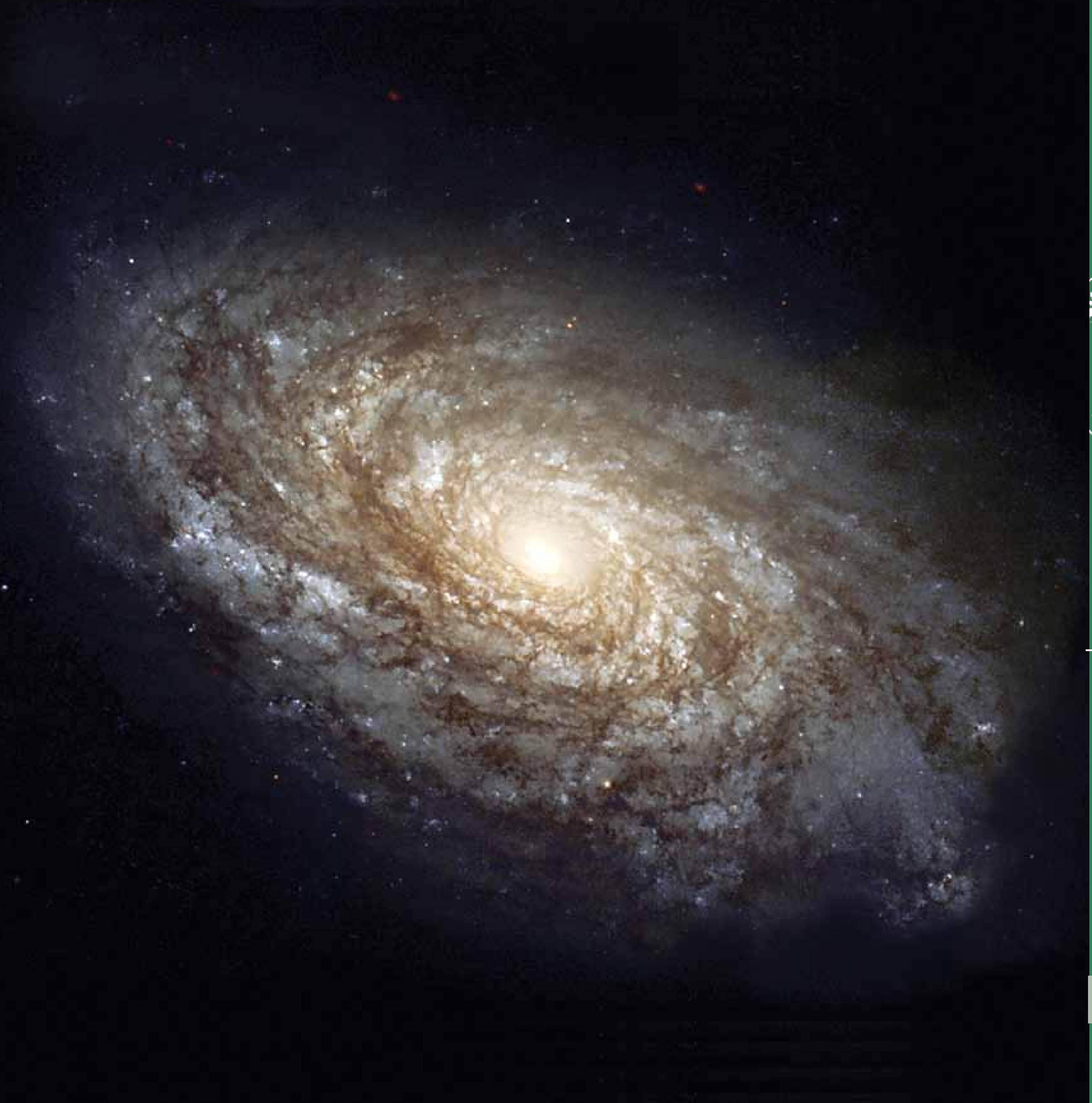
## Neutrino Limits

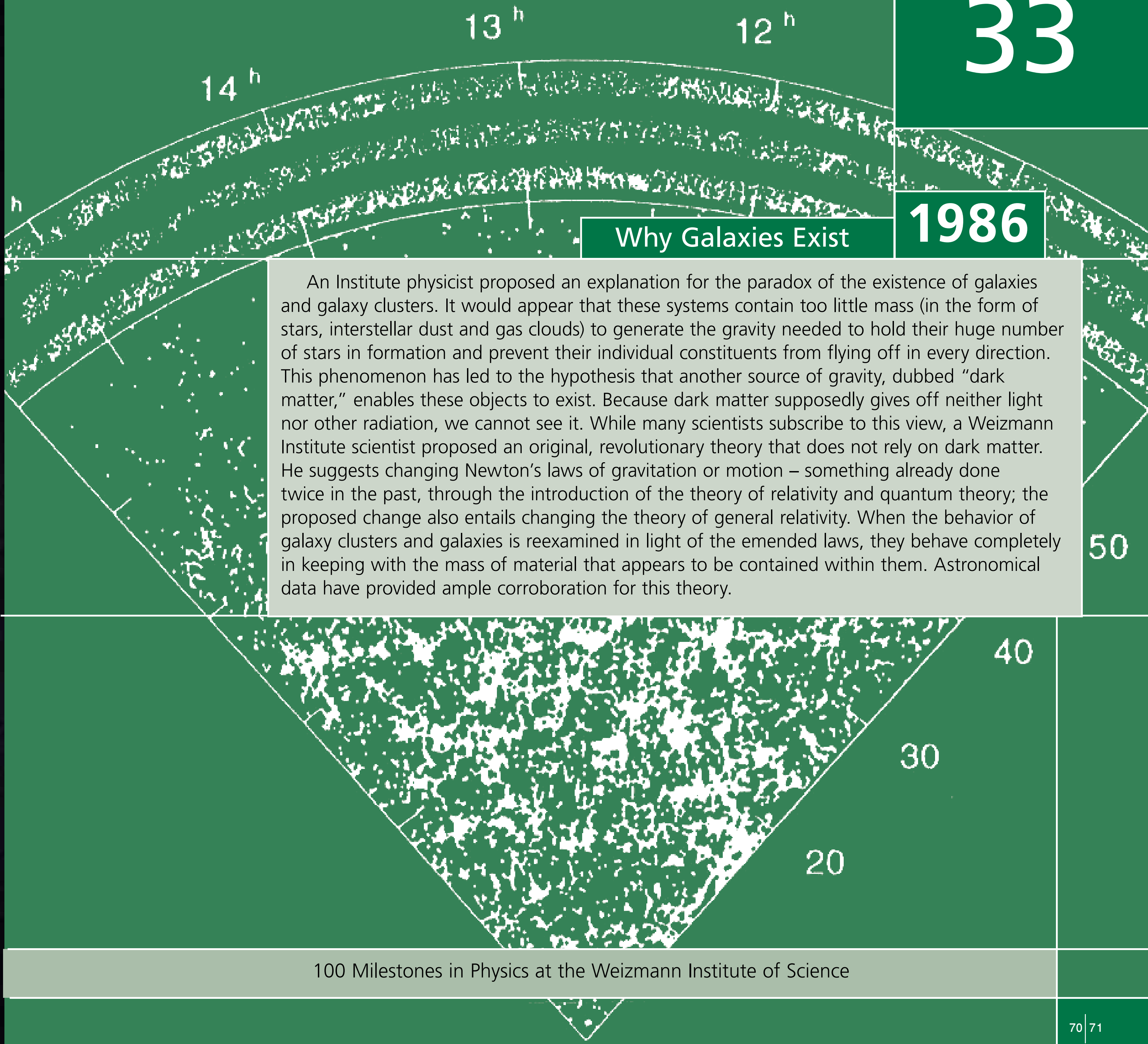
The neutrino is an elusive little particle. Having barely any mass, it can easily slip through the densest material, making it extremely difficult to catch and identify. The existence of the neutrino was theorized in 1930 and verified in experiments in the late 1950s. Since then, it has been shown, theoretically and experimentally, that there are three kinds of neutrinos, each with a different mass; other properties, however, point to a great deal of similarity among the different types.

The neutrino plays a central role in cosmological and astrophysical phenomena, and in nuclear processes occurring in the sun and in exploding stars. These intriguing particles have been known to change from one type to another in various lab conditions. Institute scientists carried out a theoretical analysis, as well as experimental measurements, of different aspects of neutrino properties, both by detecting neutrinos reaching Earth from the sun and through testing possible limitations on the properties of the different types of neutrinos. Some of these limitations arise from processes that took place at the beginnings of the Universe; others are tied to principles of astrophysics and particle physics. In addition, Institute scientists contributed to new experiments in this field, to the understanding of the properties of neutrinos and, through them, to understanding what takes place beyond planet Earth.

$$\frac{N_{\nu\text{-events}}}{1000} = 8\eta\,\frac{M_{\text{target}}}{1\ \text{ton}}\,.$$







# 33

## 1986

## Why Galaxies Exist

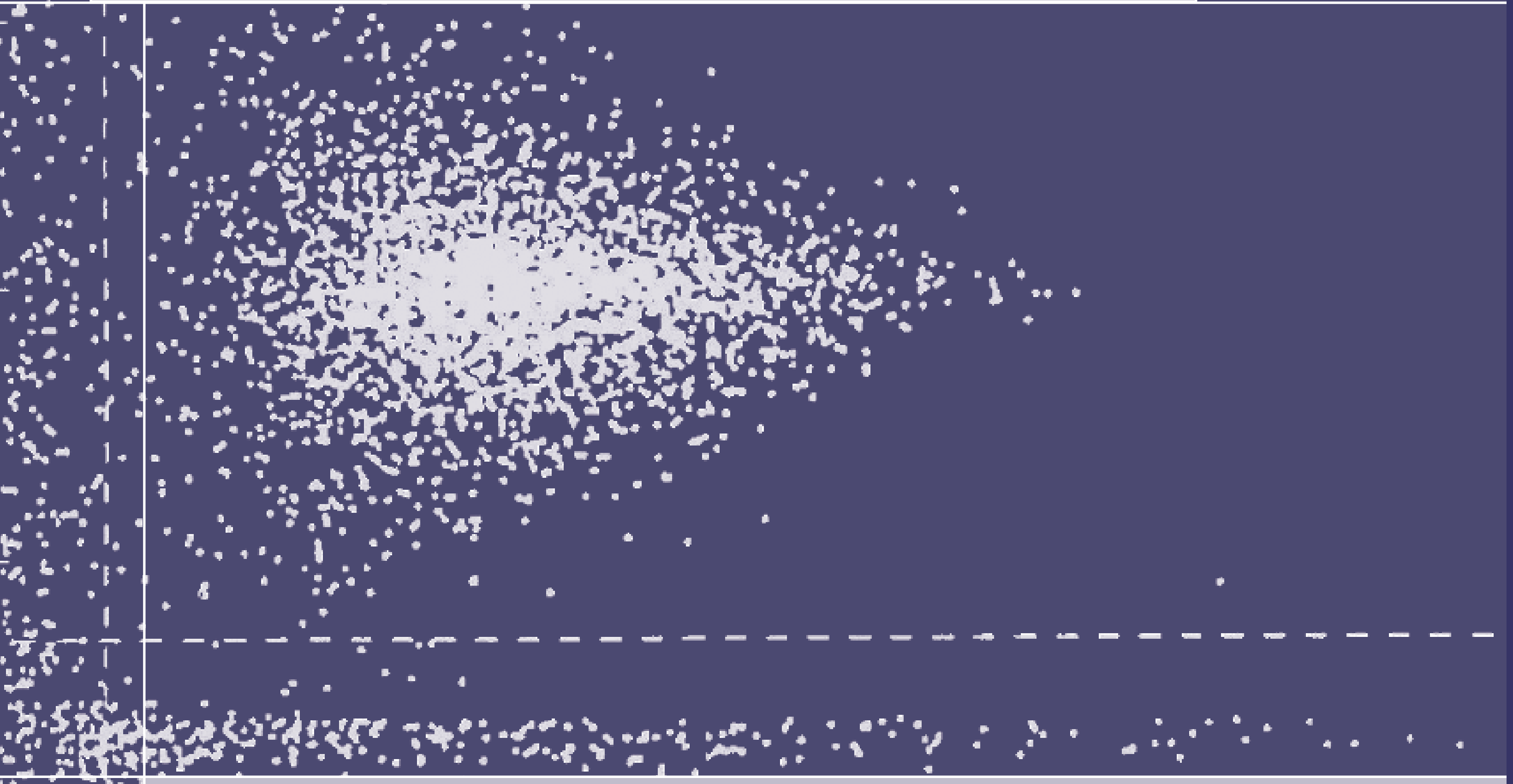
An Institute physicist proposed an explanation for the paradox of the existence of galaxies and galaxy clusters. It would appear that these systems contain too little mass (in the form of stars, interstellar dust and gas clouds) to generate the gravity needed to hold their huge number of stars in formation and prevent their individual constituents from flying off in every direction. This phenomenon has led to the hypothesis that another source of gravity, dubbed “dark matter,” enables these objects to exist. Because dark matter supposedly gives off neither light nor other radiation, we cannot see it. While many scientists subscribe to this view, a Weizmann Institute scientist proposed an original, revolutionary theory that does not rely on dark matter. He suggests changing Newton’s laws of gravitation or motion – something already done twice in the past, through the introduction of the theory of relativity and quantum theory; the proposed change also entails changing the theory of general relativity. When the behavior of galaxy clusters and galaxies is reexamined in light of the emended laws, they behave completely in keeping with the mass of material that appears to be contained within them. Astronomical data have provided ample corroboration for this theory.

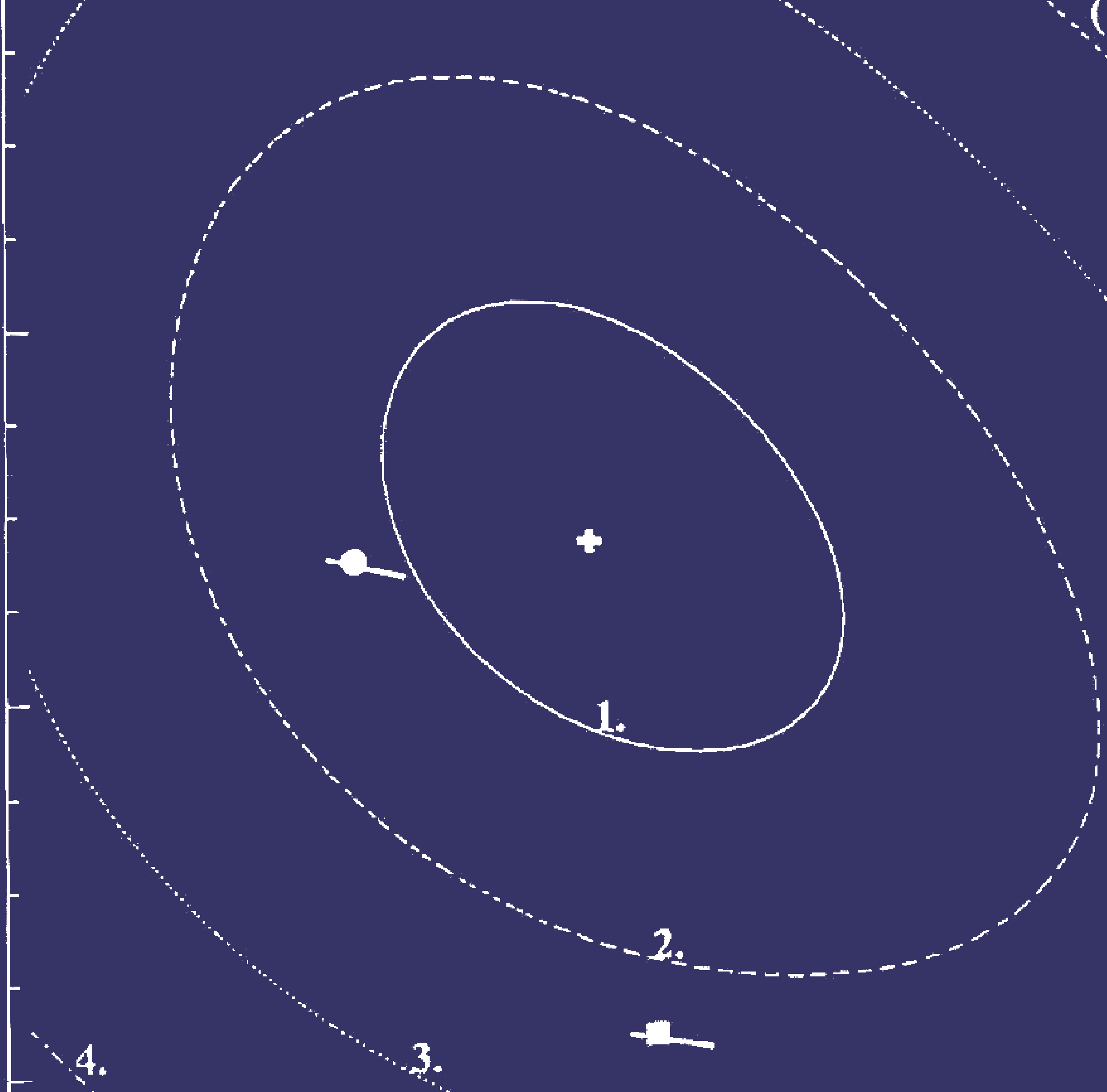
## 34

## 1989

## Three Neutrino Families

Institute physicists participated in planning and conducting experiments that led to the conclusion that there are only three families of the elusive particles called neutrinos. This discovery considerably advanced our knowledge of the differentiation of the elementary particles. The research took place in CERN, the European Organization for Nuclear Research, near Geneva.





35

## Diamonds in Every Shape

1989

Weizmann Institute scientists developed advanced methods for cutting diamonds with lasers. This has brought about automation of the diamond industry and introduced ways to design diamonds in unconventional shapes.

The use of lasers for cutting diamonds had previously resulted in significant loss of the diamond's weight. The new method considerably lowered the loss – even below that of traditional methods – making laser processing the method of choice and introducing computer-aided design/computer-aided manufacturing (CAD-CAM) to the diamond processing industry.

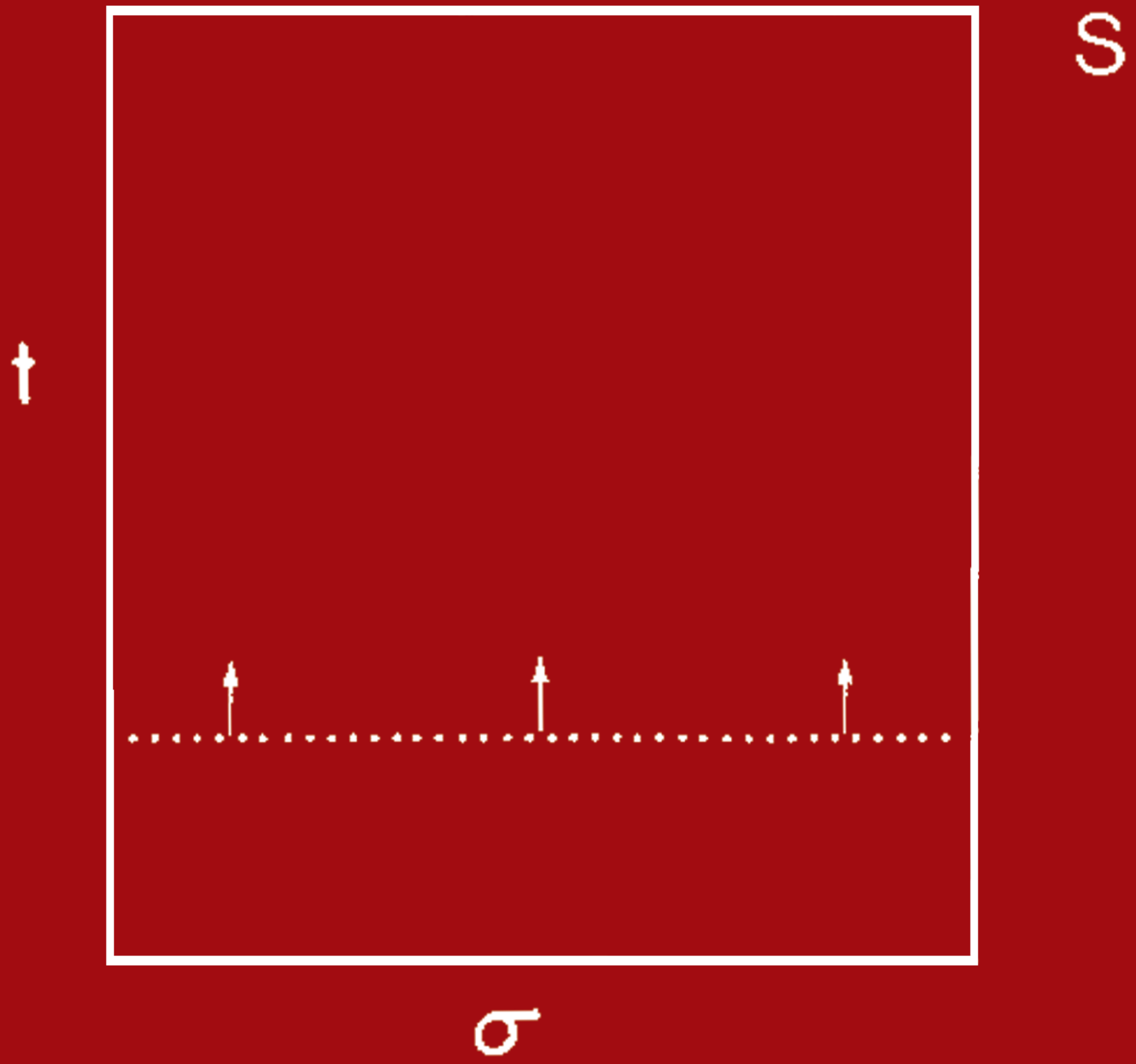
# 36

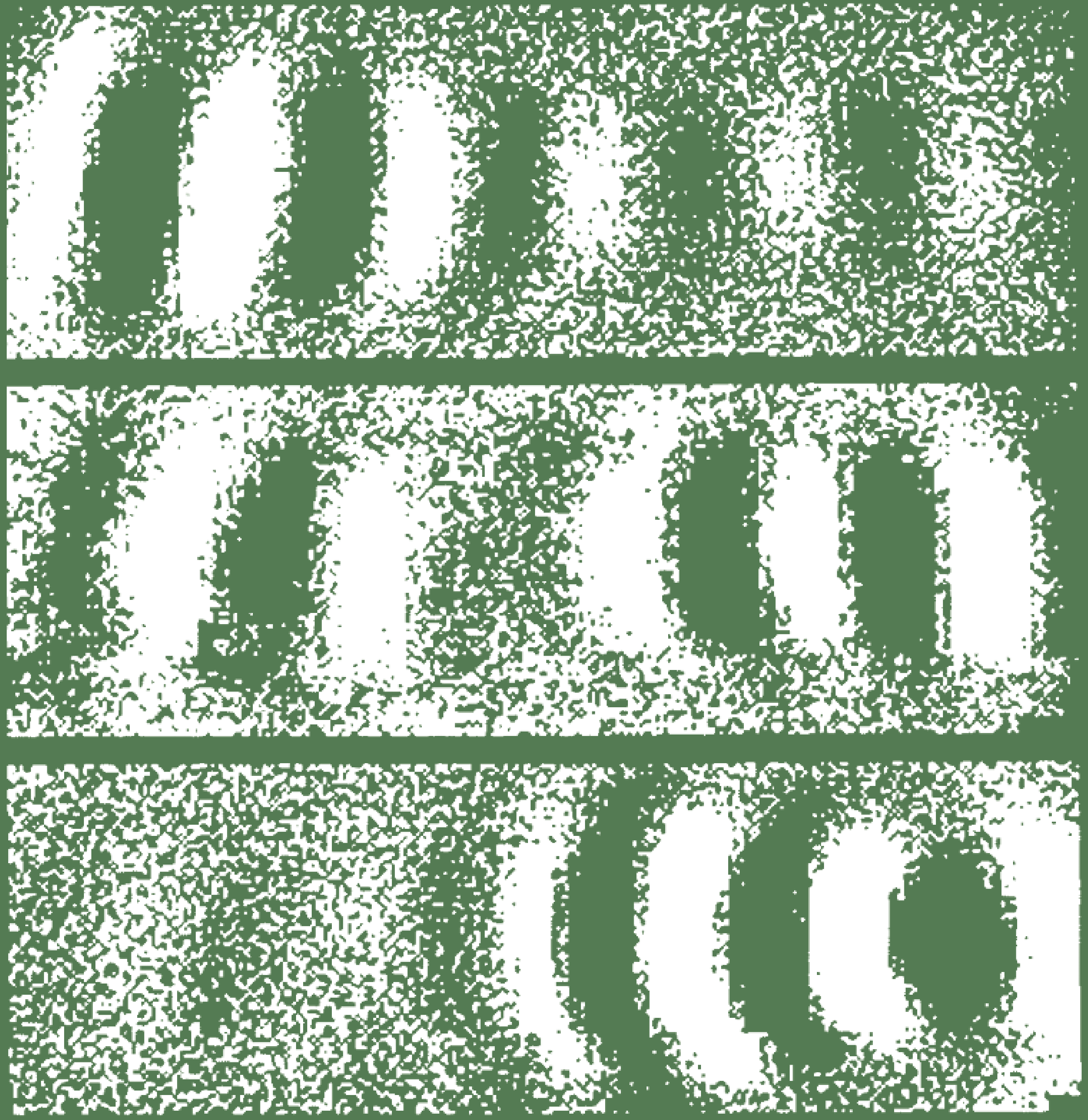
## 1989

## The Two-Dimensional Link

The Institute's scientists found a new link between two-dimensional string theories (conformal field theories) and models of magnets. The link describes, and makes it possible to predict, the conditions and processes that take place at various critical points in nature (for instance, phase transitions – shifts from one state to another). Although the link was discovered in a two-dimensional system, it makes possible in-depth investigations into phenomena that are difficult to study in three-dimensional systems.

$$\langle \delta_\varepsilon X \rangle = \oint_C d\zeta \, \varepsilon(\zeta) \langle T(\zeta) X \rangle ,$$





## Temporary Disorder

## 1990

Weizmann Institute physicists studied the role of symmetry in pattern selection in non-equilibrium systems, defect nucleation and the dynamics of patterns, as well as in various scenarios of transition from ordered to spatially and temporarily disordered states. They did this by probing various hydrodynamic systems. In this research they discovered a localized non-equilibrium wave structure – an analog of a soliton (a solitary wave that retains a constant shape and speed), but in dissipative systems. They also noted a surprisingly wide range of spatiotemporal behaviors taking place in non-linear waves in moving binary mixtures (for example, water and alcohol) just prior to the transition to a pattern-forming state. In addition, they found a universal process of transition to a spatio-temporal chaotic state (weak turbulence) via nucleation of topological defects in the electro-hydrodynamic convection of certain liquid crystals.

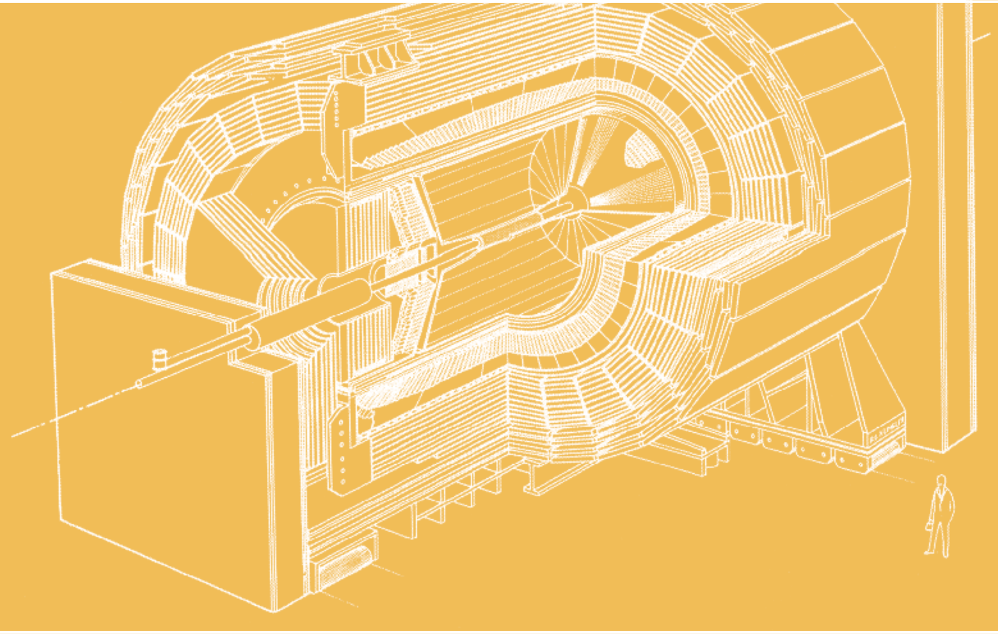
# 38

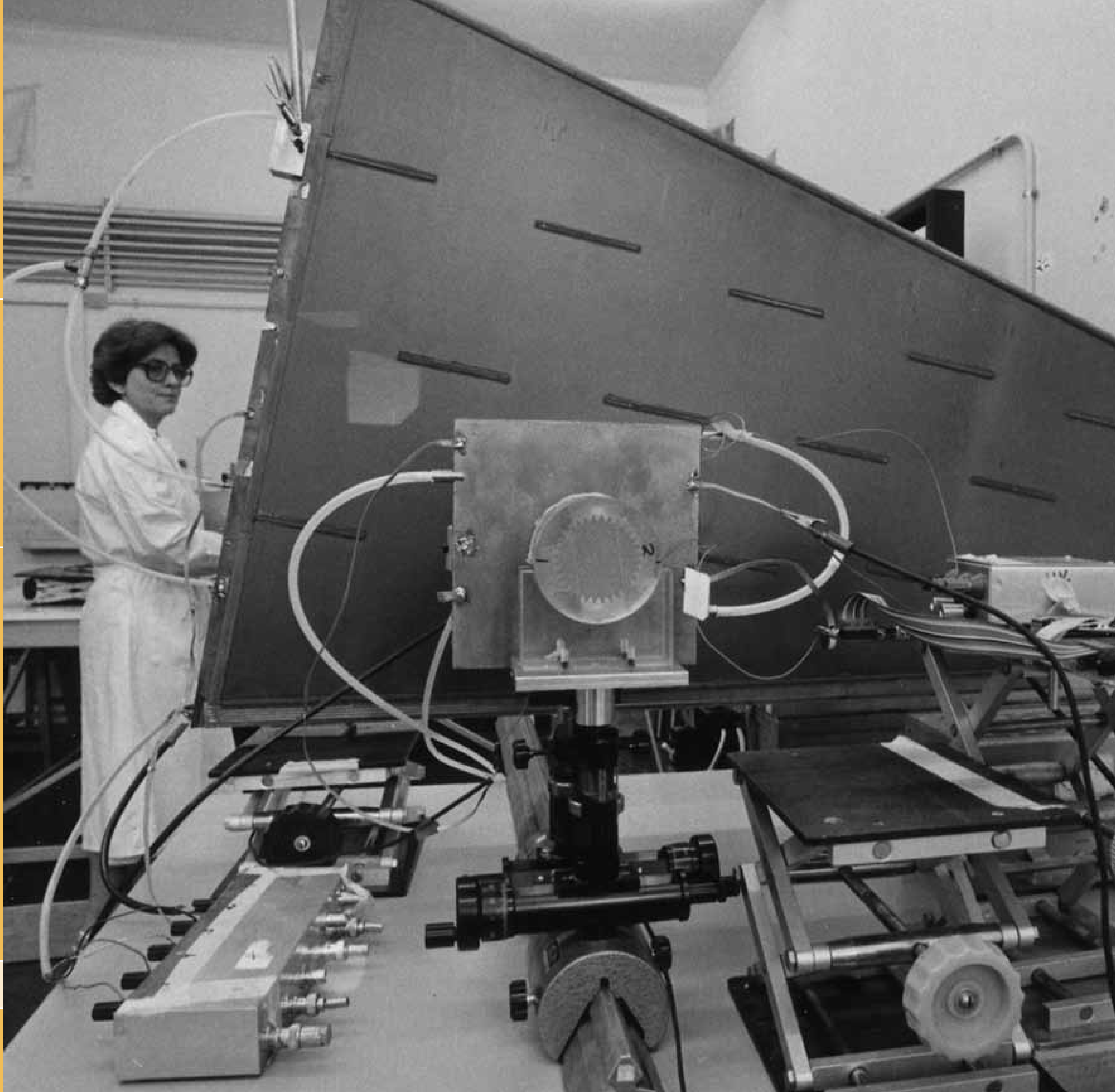
## 1990

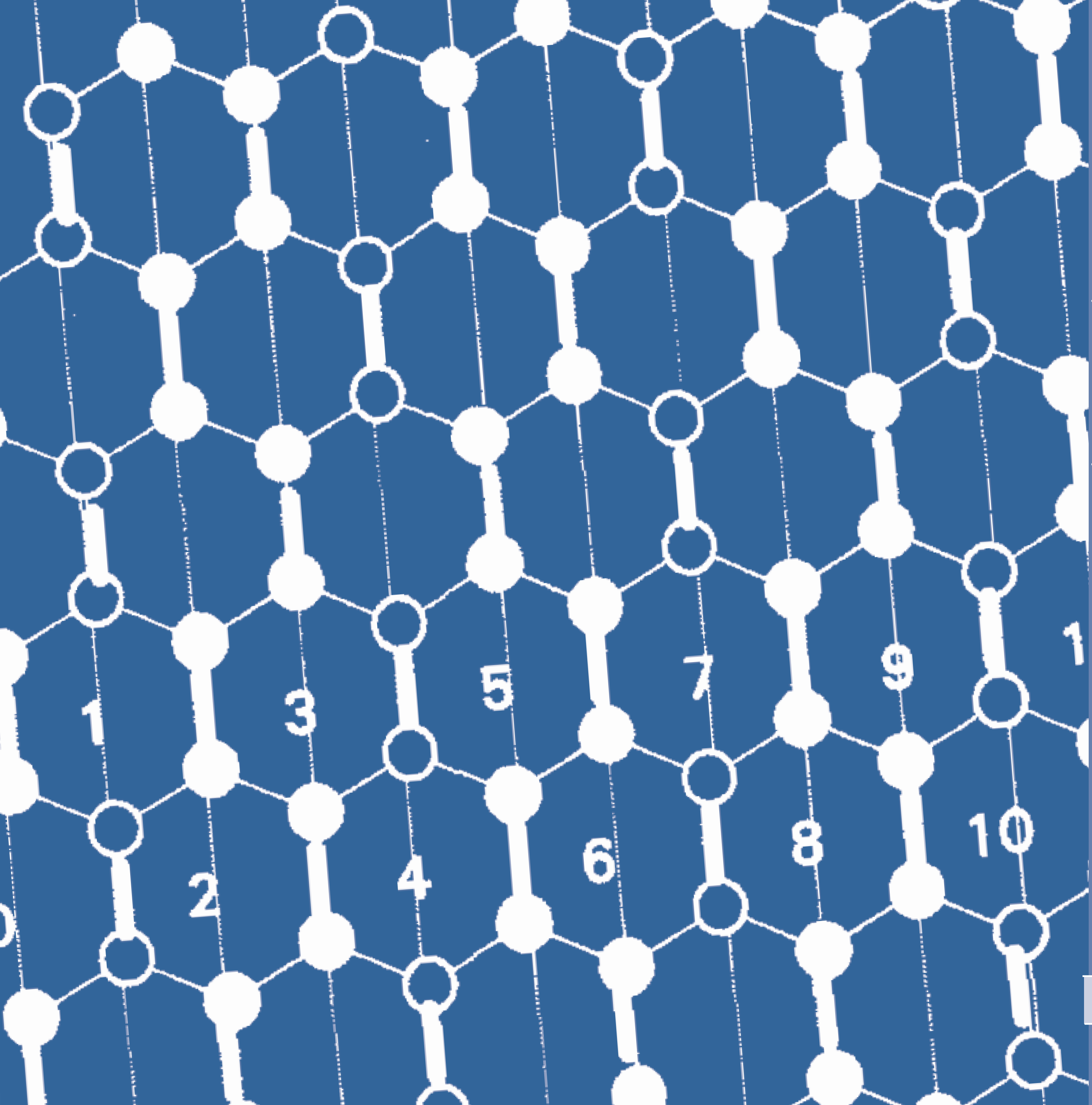
## The Thinnest Gas Particle Detector in the World

Institute scientists have been playing a central role in a project in which thousands of physicists from 65 countries have come together to prove the existence of the "God particle" – the Higgs boson – which, according to the Standard Model, is the particle responsible for providing the mass of the particles carrying the electroweak force (a marriage of the electromagnetic and weak forces).

To help identify any Higgs particles that might show up in the experiments, Institute scientists designed, developed and built the thinnest gas particle detector in the world. The detector is made of 4,000 thin trapezoid plates containing gold-coated tungsten wires, which create the necessary electric field. Scientists from other countries, mainly Japan and China, also participated in this effort.





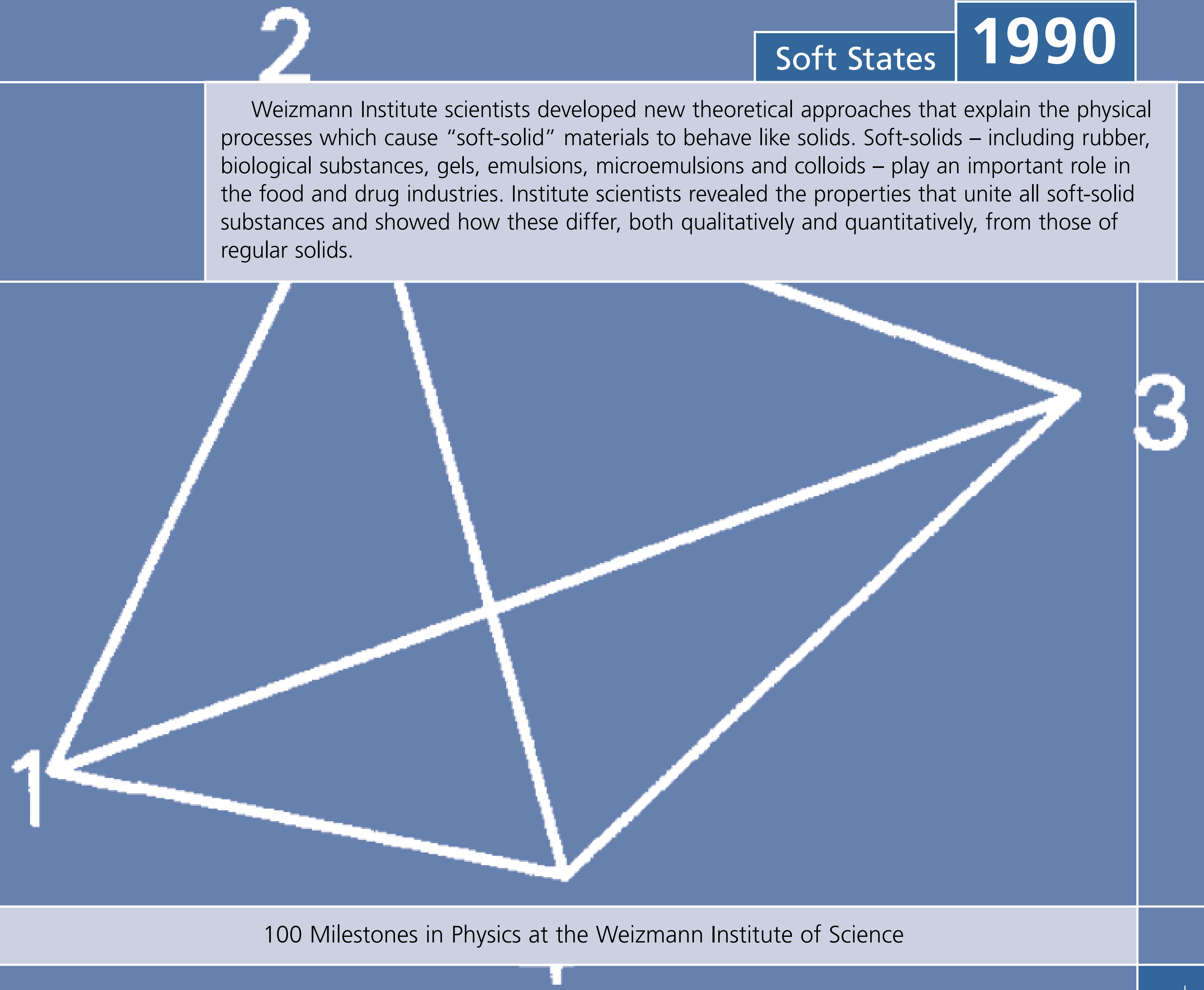


# 39

## Soft States

## 1990

Weizmann Institute scientists developed new theoretical approaches that explain the physical processes which cause "soft-solid" materials to behave like solids. Soft-solids – including rubber, biological substances, gels, emulsions, microemulsions and colloids – play an important role in the food and drug industries. Institute scientists revealed the properties that unite all soft-solid substances and showed how these differ, both qualitatively and quantitatively, from those of regular solids.

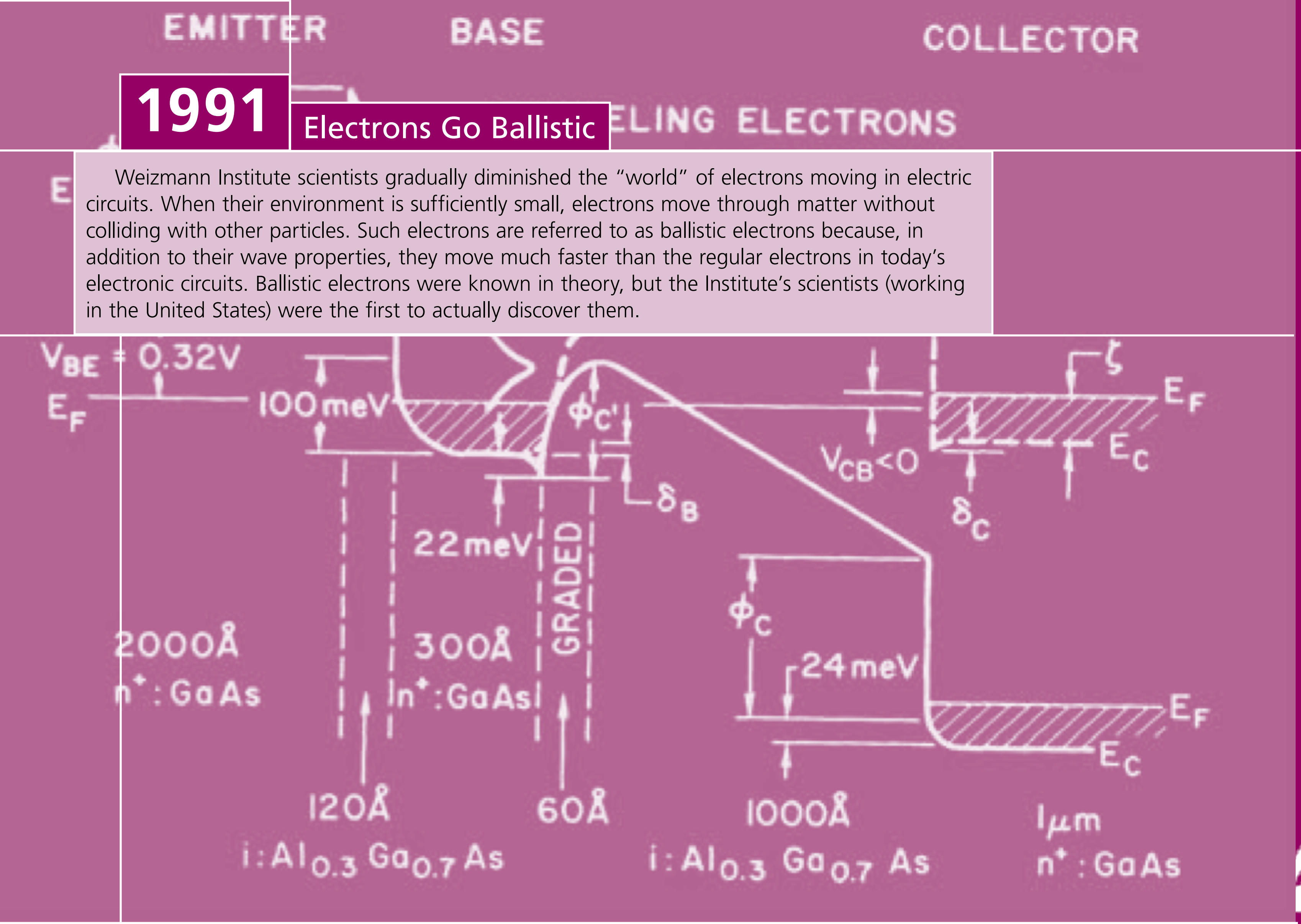


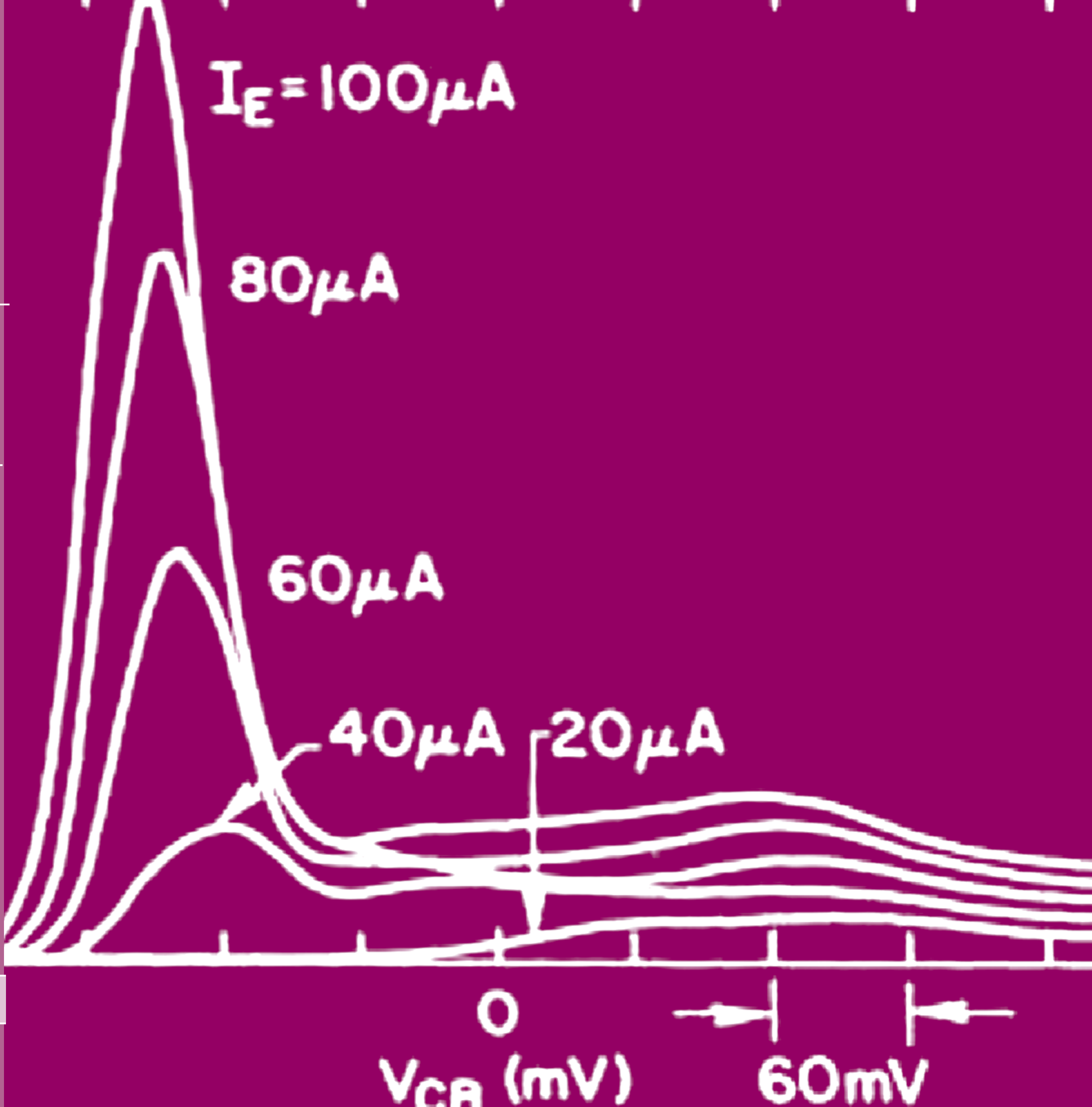
40

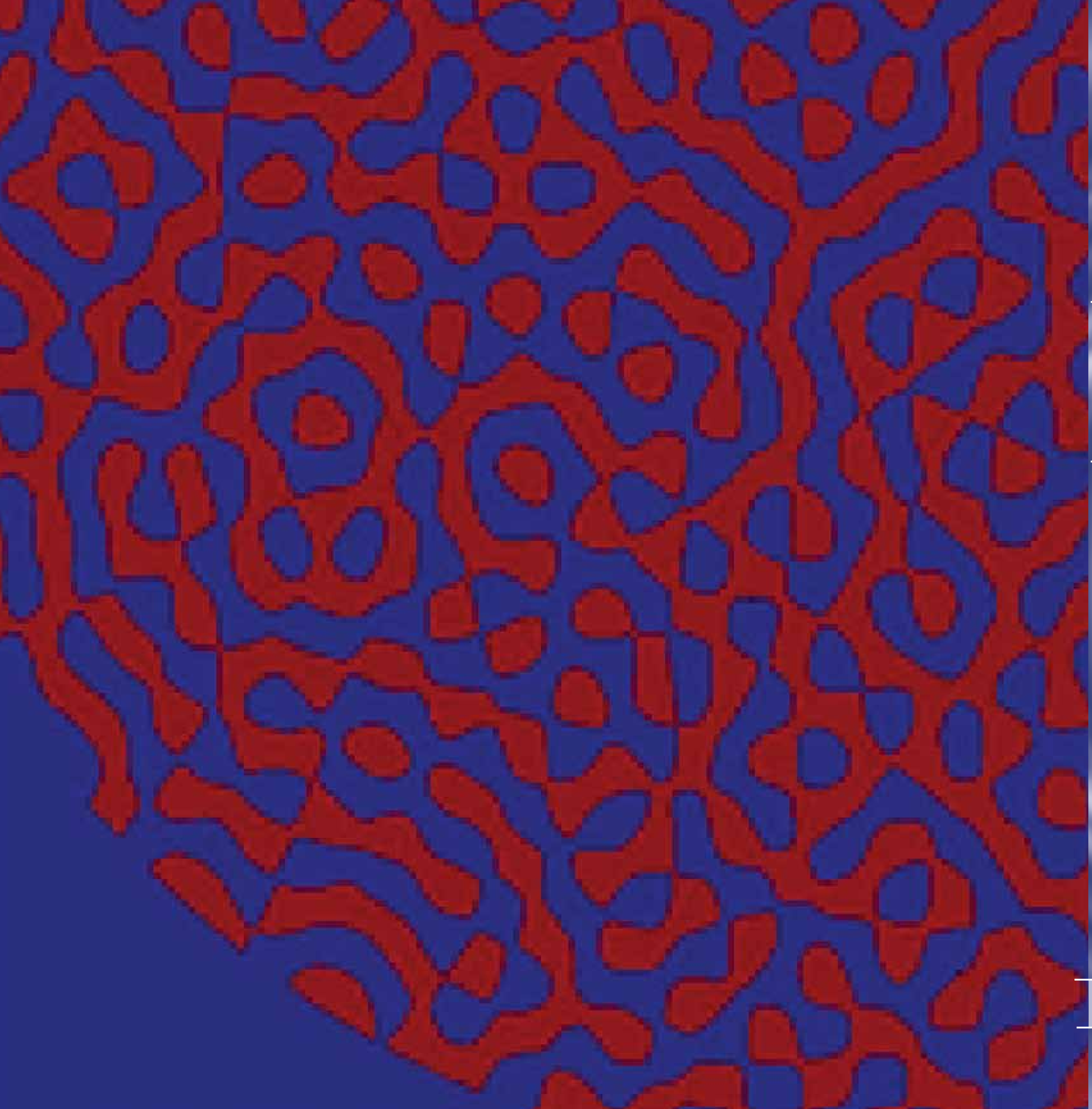
# 1991

## Electrons Go Ballistic

Weizmann Institute scientists gradually diminished the "world" of electrons moving in electric circuits. When their environment is sufficiently small, electrons move through matter without colliding with other particles. Such electrons are referred to as ballistic electrons because, in addition to their wave properties, they move much faster than the regular electrons in today's electronic circuits. Ballistic electrons were known in theory, but the Institute's scientists (working in the United States) were the first to actually discover them.







41

## Quantum Chaos

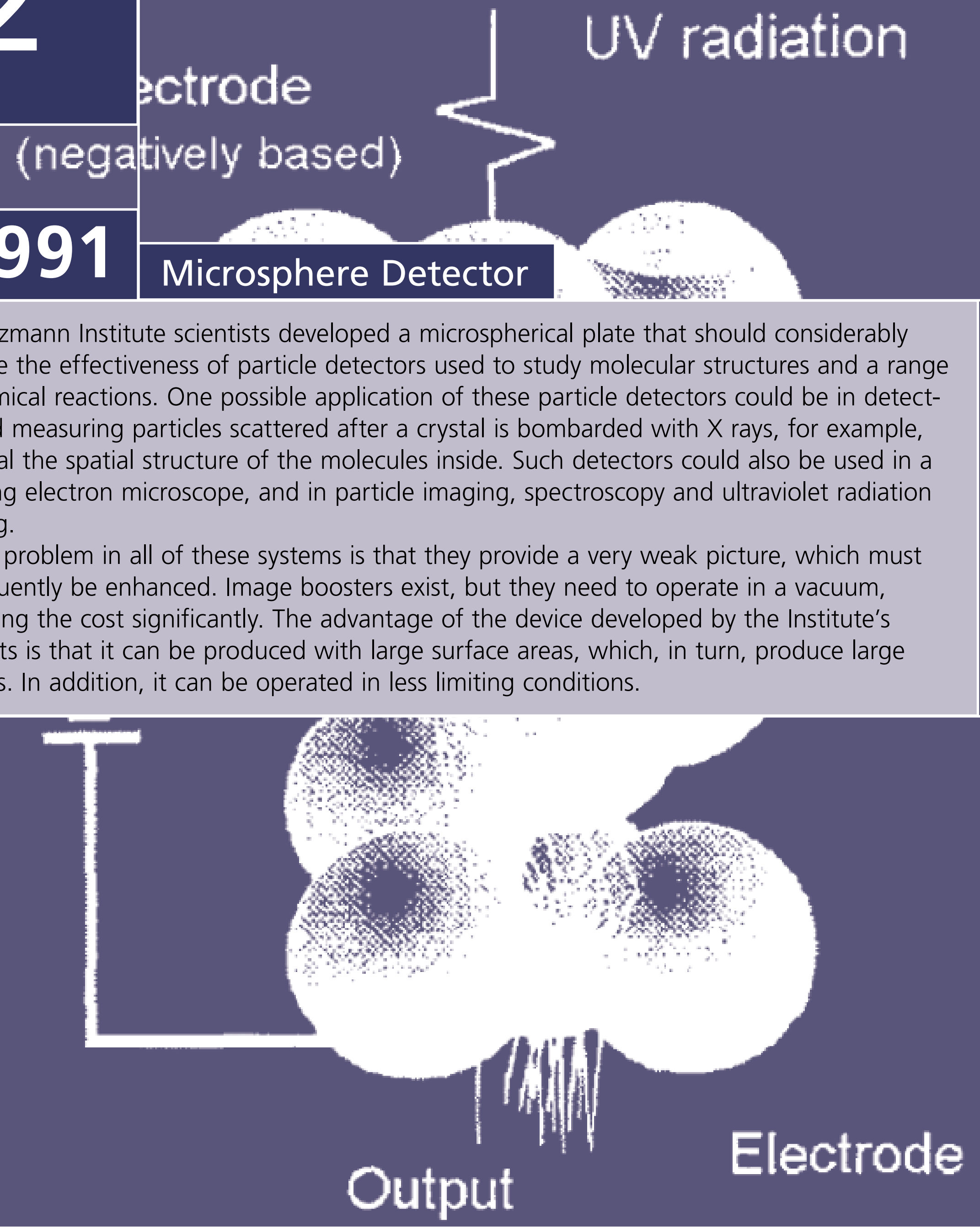
1991

Such microscopic systems as atoms, molecules and submicron electronic components are all affected by the phenomenon known as chaos. Though chaotic behavior is usually considered a property of macroscopic systems, Weizmann Institute scientists investigated the way chaos is expressed in the quantum world. One of their findings was that "quantum chaos" induces behavior in quantum dynamics that is usually associated with random systems. These studies may be applied, for instance, to the construction of submicron electronic components.

## 42

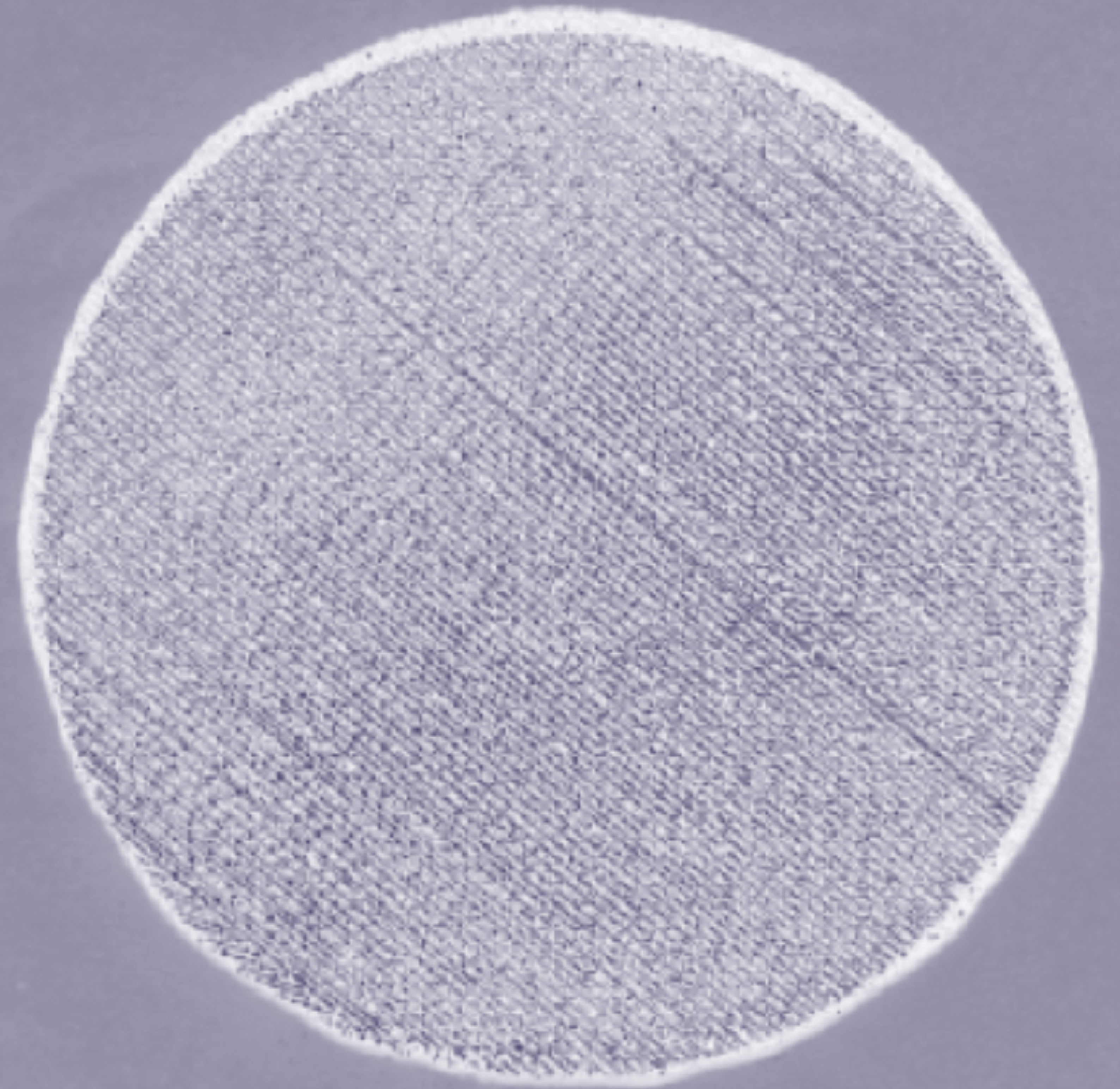
## 1991

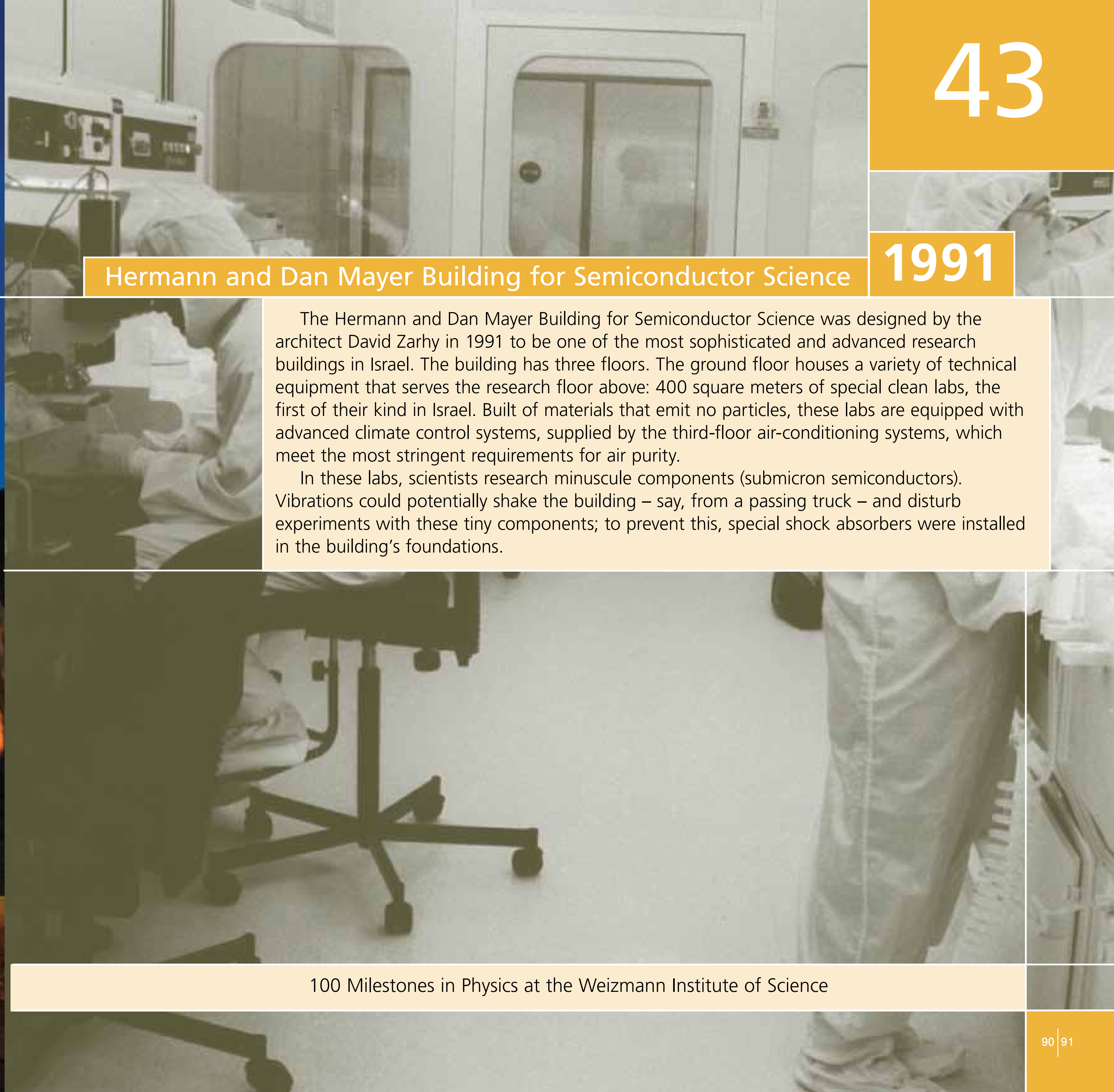
## Microsphere Detector



Weizmann Institute scientists developed a microspherical plate that should considerably improve the effectiveness of particle detectors used to study molecular structures and a range of chemical reactions. One possible application of these particle detectors could be in detecting and measuring particles scattered after a crystal is bombarded with X rays, for example, to reveal the spatial structure of the molecules inside. Such detectors could also be used in a scanning electron microscope, and in particle imaging, spectroscopy and ultraviolet radiation imaging.

The problem in all of these systems is that they provide a very weak picture, which must subsequently be enhanced. Image boosters exist, but they need to operate in a vacuum, increasing the cost significantly. The advantage of the device developed by the Institute’s scientists is that it can be produced with large surface areas, which, in turn, produce large pictures. In addition, it can be operated in less limiting conditions.





# 43

## Hermann and Dan Mayer Building for Semiconductor Science

### 1991

The Hermann and Dan Mayer Building for Semiconductor Science was designed by the architect David Zarhy in 1991 to be one of the most sophisticated and advanced research buildings in Israel. The building has three floors. The ground floor houses a variety of technical equipment that serves the research floor above: 400 square meters of special clean labs, the first of their kind in Israel. Built of materials that emit no particles, these labs are equipped with advanced climate control systems, supplied by the third-floor air-conditioning systems, which meet the most stringent requirements for air purity.

In these labs, scientists research minuscule components (submicron semiconductors). Vibrations could potentially shake the building – say, from a passing truck – and disturb experiments with these tiny components; to prevent this, special shock absorbers were installed in the building's foundations.

# 44

## 1992

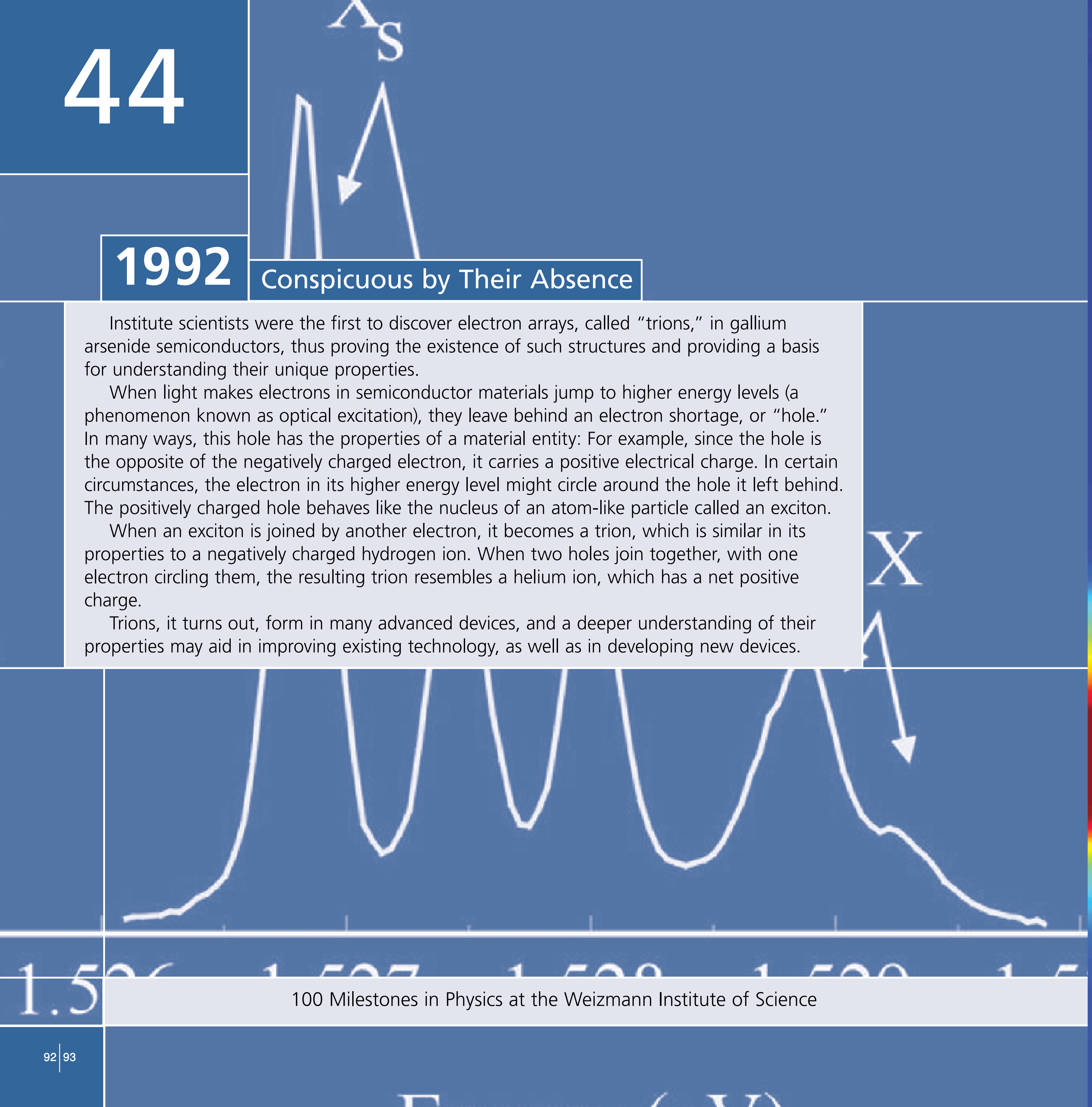
## Conspicuous by Their Absence

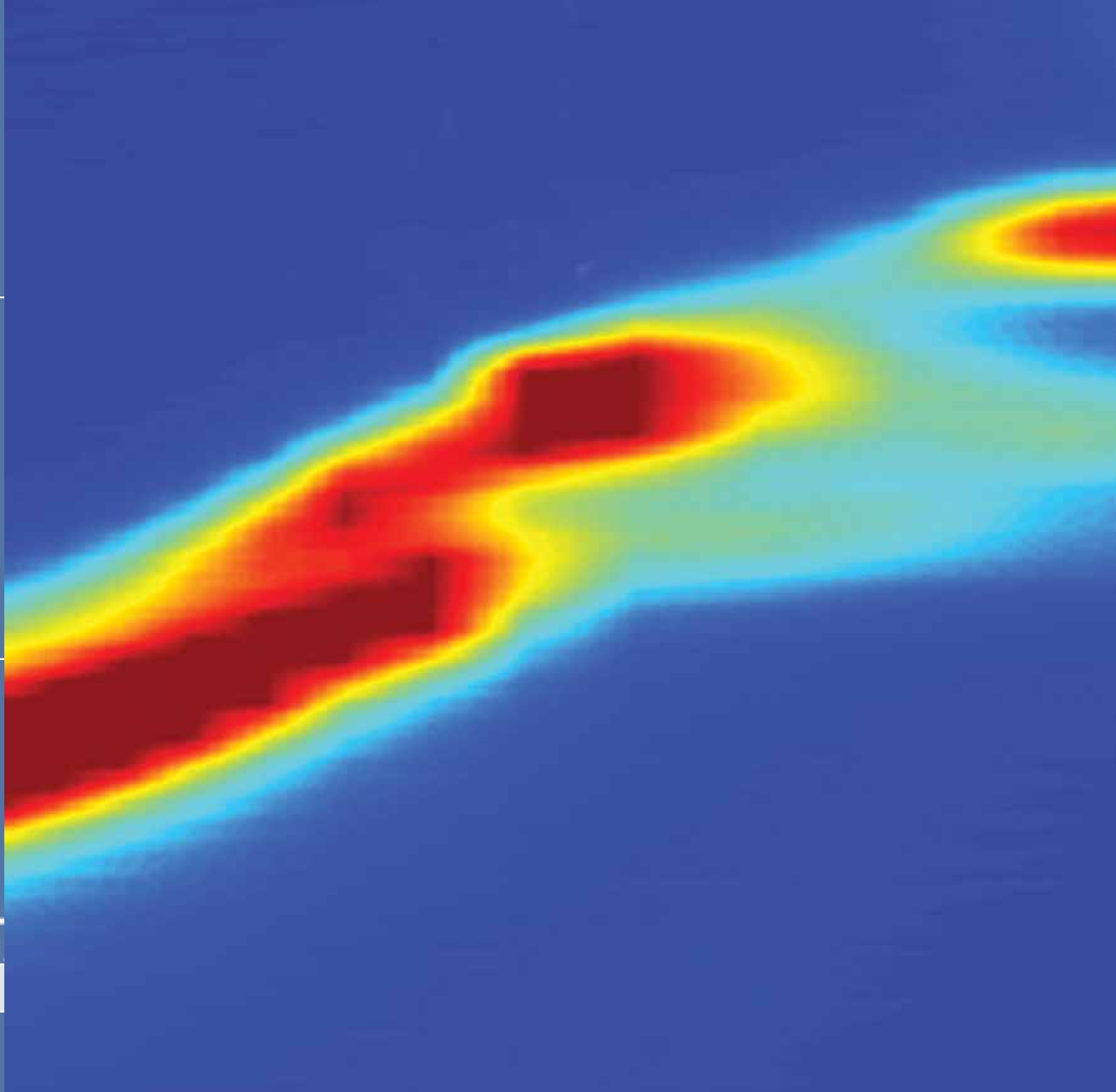
Institute scientists were the first to discover electron arrays, called “trions,” in gallium arsenide semiconductors, thus proving the existence of such structures and providing a basis for understanding their unique properties.

When light makes electrons in semiconductor materials jump to higher energy levels (a phenomenon known as optical excitation), they leave behind an electron shortage, or “hole.” In many ways, this hole has the properties of a material entity: For example, since the hole is the opposite of the negatively charged electron, it carries a positive electrical charge. In certain circumstances, the electron in its higher energy level might circle around the hole it left behind. The positively charged hole behaves like the nucleus of an atom-like particle called an exciton.

When an exciton is joined by another electron, it becomes a trion, which is similar in its properties to a negatively charged hydrogen ion. When two holes join together, with one electron circling them, the resulting trion resembles a helium ion, which has a net positive charge.

Trions, it turns out, form in many advanced devices, and a deeper understanding of their properties may aid in improving existing technology, as well as in developing new devices.





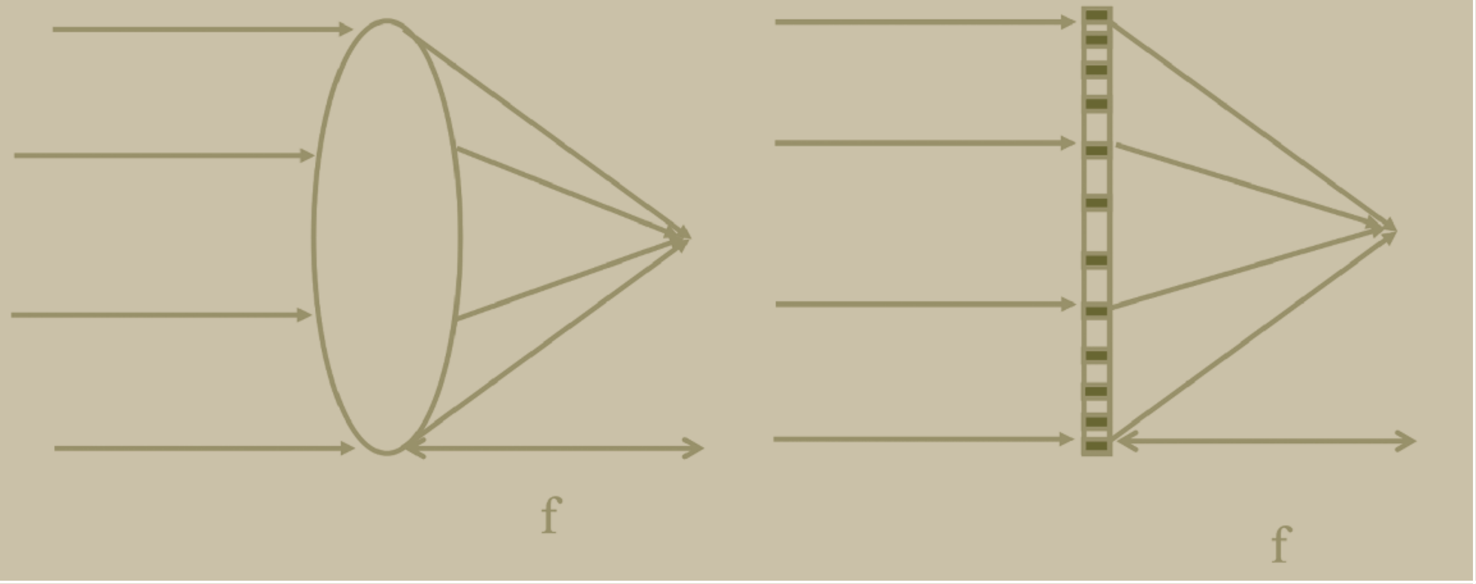
45

## Diffracting Components

1992

Institute scientists developed original methods for planning and preparing materials used in holographic optical components. These optical components are based on light wave diffraction (rather than refraction or reflection, the bases of most optical components). Optical elements manufactured according to this method are light, convenient and inexpensive compared to regular optical components.

The scientists investigated possible uses of this technology – for example, in the development of lenses for optical computers, thermal imaging systems and various industrial processes. These applications are now becoming the basis for the development of a science-based industry in these fields.

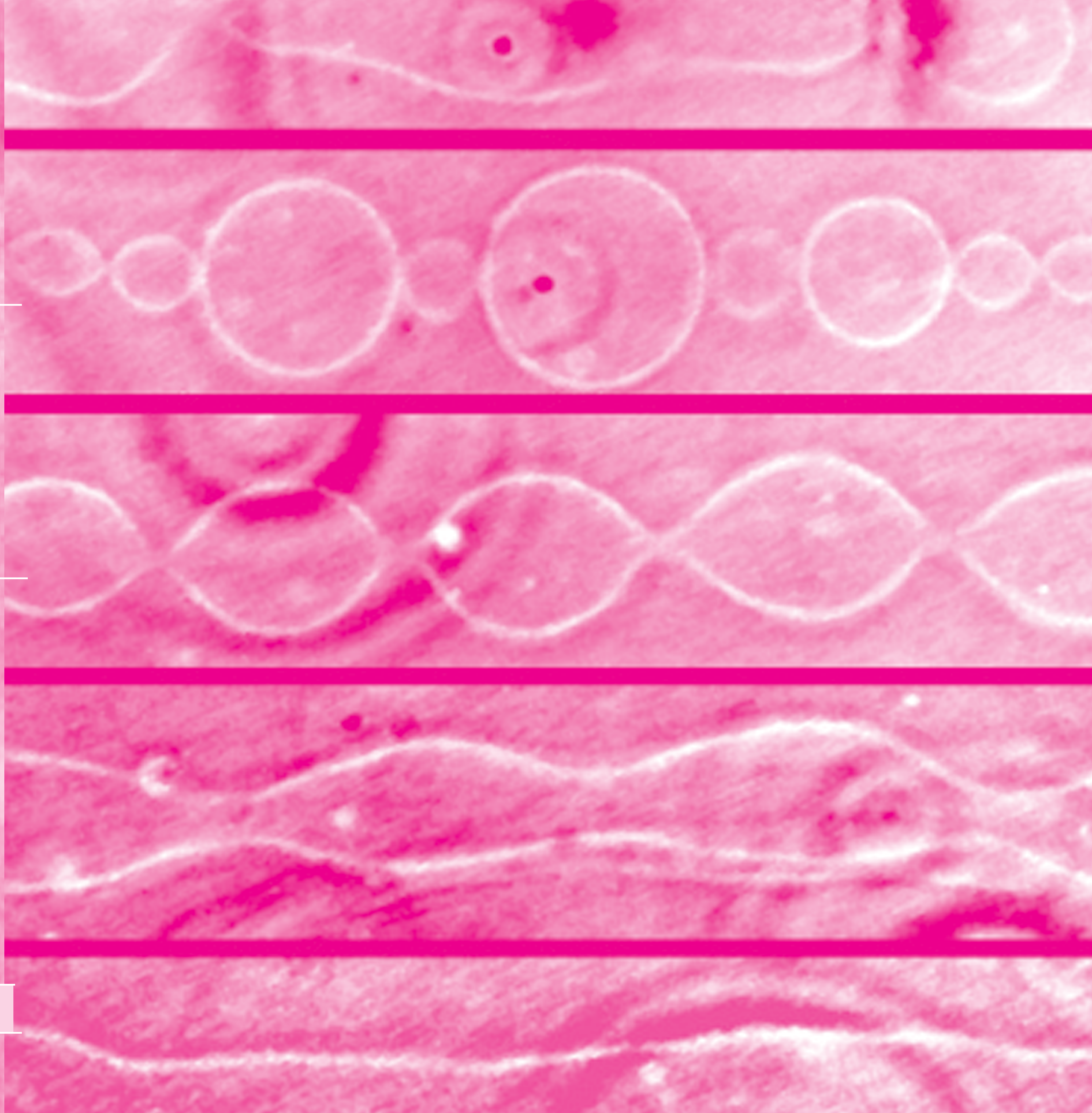


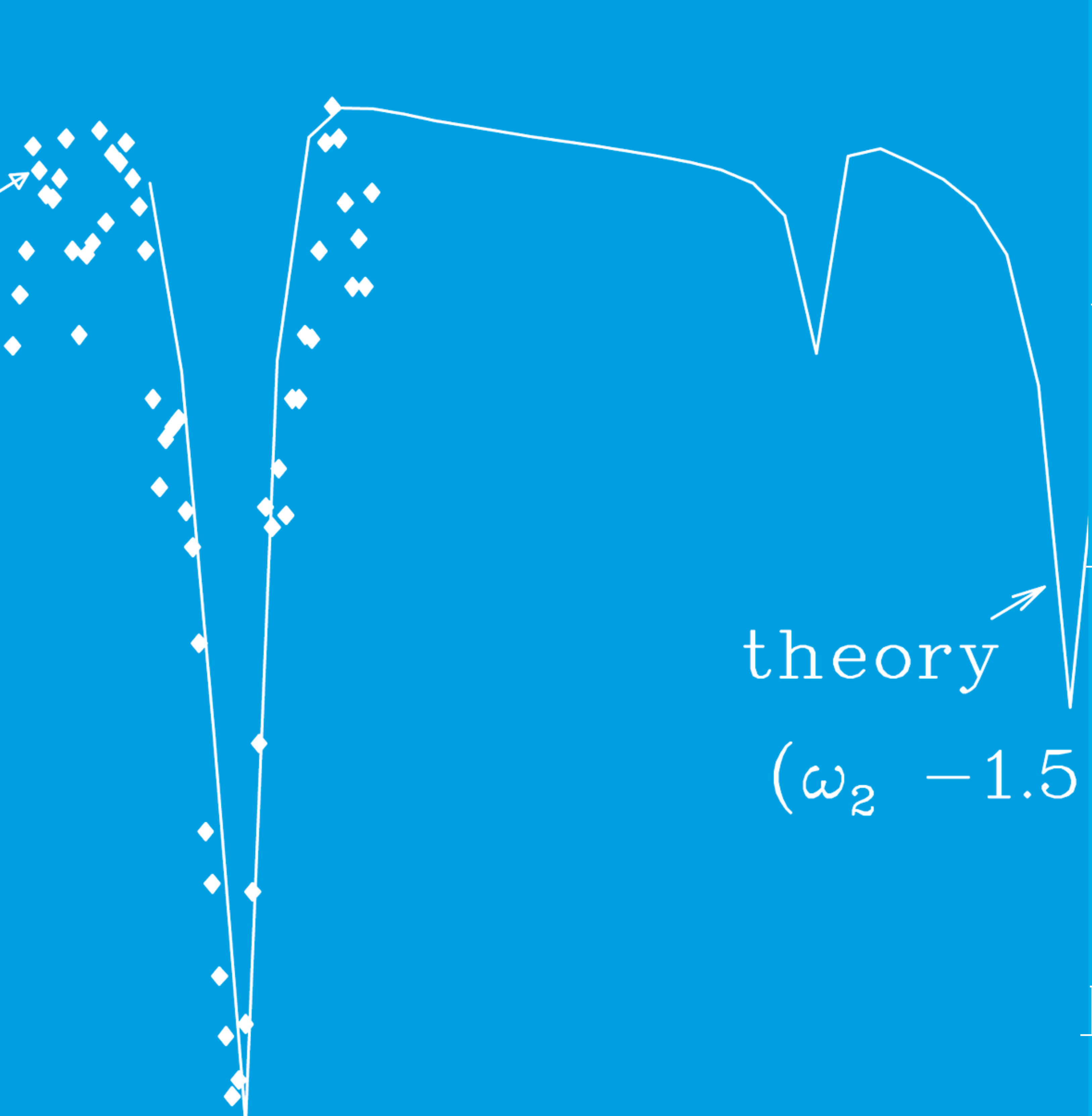
# 46

## 1993 Dynamic Borders

Institute physicists used the interaction of light and matter to gain a new understanding of the rules for the behavior of thin membranes such as those enveloping living cells. A laser trap was applied to membranes to induce dynamic and nonlinear processes in an artificial membrane. The findings may help to clarify the activity of membranes in living cells, where they permit the selective passage of substances and bodies into and out of cells, as well as playing a central role in the cell's life processes, including division, binding with other cells or surfaces, differentiation and death.

In their studies, the researchers simulated such cellular activities as flow, the formation of pearl-like chains and the expulsion of bubbles through the membrane. These membranes constantly change shape as a result of the delicate manipulation by the concentrated laser beams.





## 47

# Lasers Control Chemical Reactions

## 1993

Weizmann Institute scientists developed a technique that uses lasers to control chemical reactions. This original technology enables control over the products of a molecular reaction, through the use of wave interference. In quantum physics, particles can behave as waves, and these can interfere with one another (either constructively or destructively). The Institute scientists' technique takes advantage of this principle to control the movements of electrons in semiconductor materials, breaking the symmetry of the material and producing chiral materials – chemically identical materials whose molecules are mirror images of one another. Like right and left hands, chiral molecules cannot be superimposed on one another. The technique could be used in the pharmaceutical industry, for creating especially fast electronic switches and for improving light transmission in optical fibers.