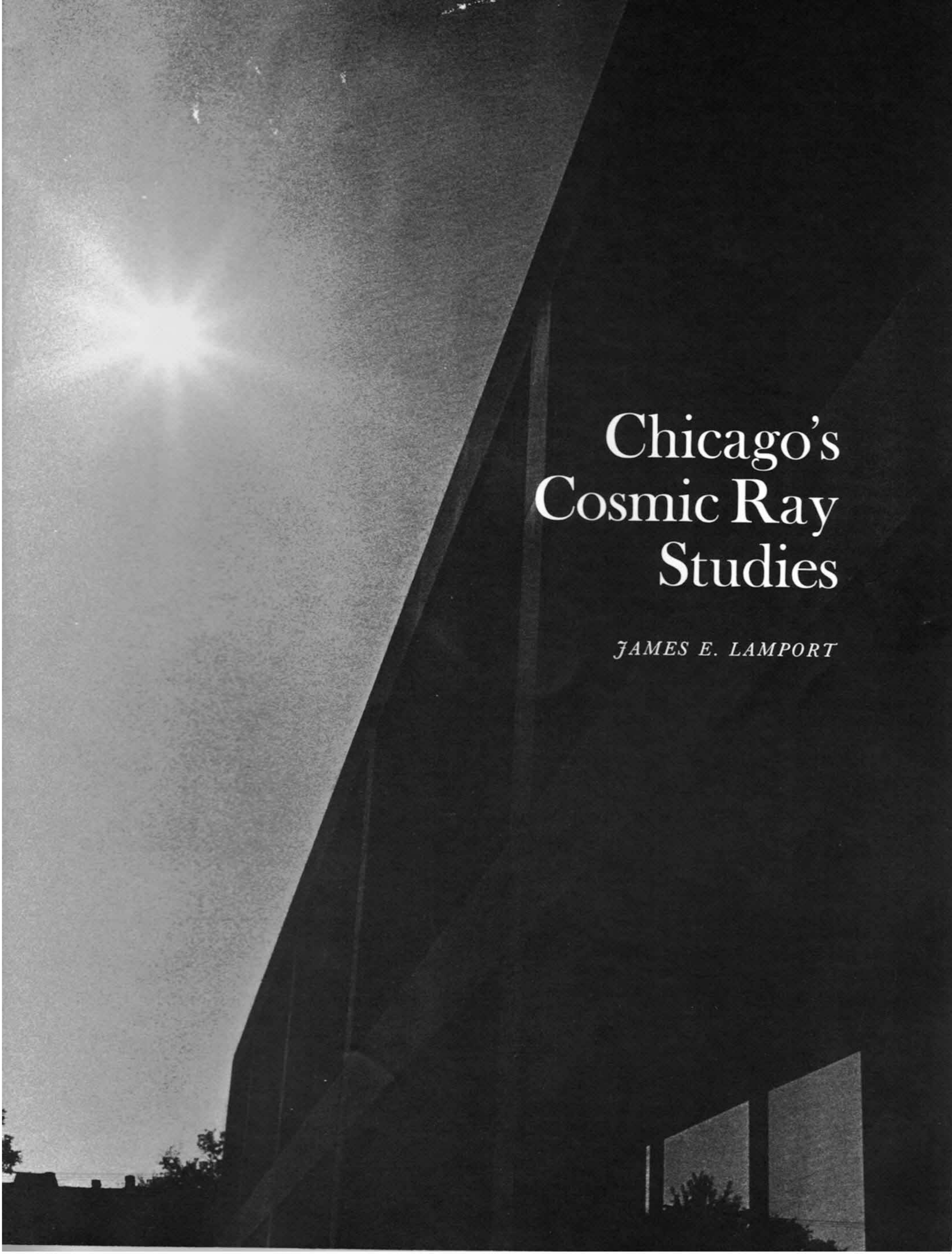


Chicago's Cosmic Ray Studies

JAMES E. LAMPORT

Cosmic rays are among the most mysterious phenomena of the universe. They actually are atoms stripped of their electrons, travelling from outer space at near the speed of light.

Cosmic rays constantly bombard the earth. Perhaps a hundred invisible particles pass through each square inch of the paper on which these words are printed every minute. These particles keep going, penetrating thousands of feet into the earth beneath your feet.

Where do these cosmic rays come from? How do they gain their tremendous energies? What is the effect of the sun on cosmic rays?

For the last fifty years, scientists have been investigating these questions, first with simple electroscopes on the surface of the earth, later with photographic plates carried in balloons, and today with space satellites carrying complex electronic instrumentation and data handling equipment.

The University of Chicago has done pioneering work in cosmic ray investigations from the earliest days, and now is involved in an extensive program of space exploration in connection with the nation's satellite program.

The discovery of cosmic rays stemmed from attempts to understand more thoroughly the properties of naturally occurring radioactive substances.

In attempts to eliminate effects of background radiation from the measurements, all known radioactive substances were removed from the vicinity of the detections. However, there always remained small quantities of radiation present, regardless of the precautions undertaken. The radiation was first thought to originate within the earth until equipment was flown in balloons to high altitudes. As a result of these early balloon flights, it was concluded that the observations were the result of some very energetic radiation reaching earth from a distance. Over years of study, it became evident that most of the radiation being observed within the atmosphere is secondary, resulting from collisions of the primary cosmic radiation with the nuclei of oxygen and nitrogen in the upper layers of earth's atmosphere, and that the incoming primary radiation is composed of very energetic atomic nuclei, stripped of electrons.

The study of the cosmic rays led to the discovery of many of the unstable elementary particles now being investigated through the use of high energy particle accelerators.

James E. Lamport is Technical Services Manager for the Laboratory for Astrophysics and Space Research. His fields of special interest include optical detection and measurement systems and systems design for scientific experiment in space.

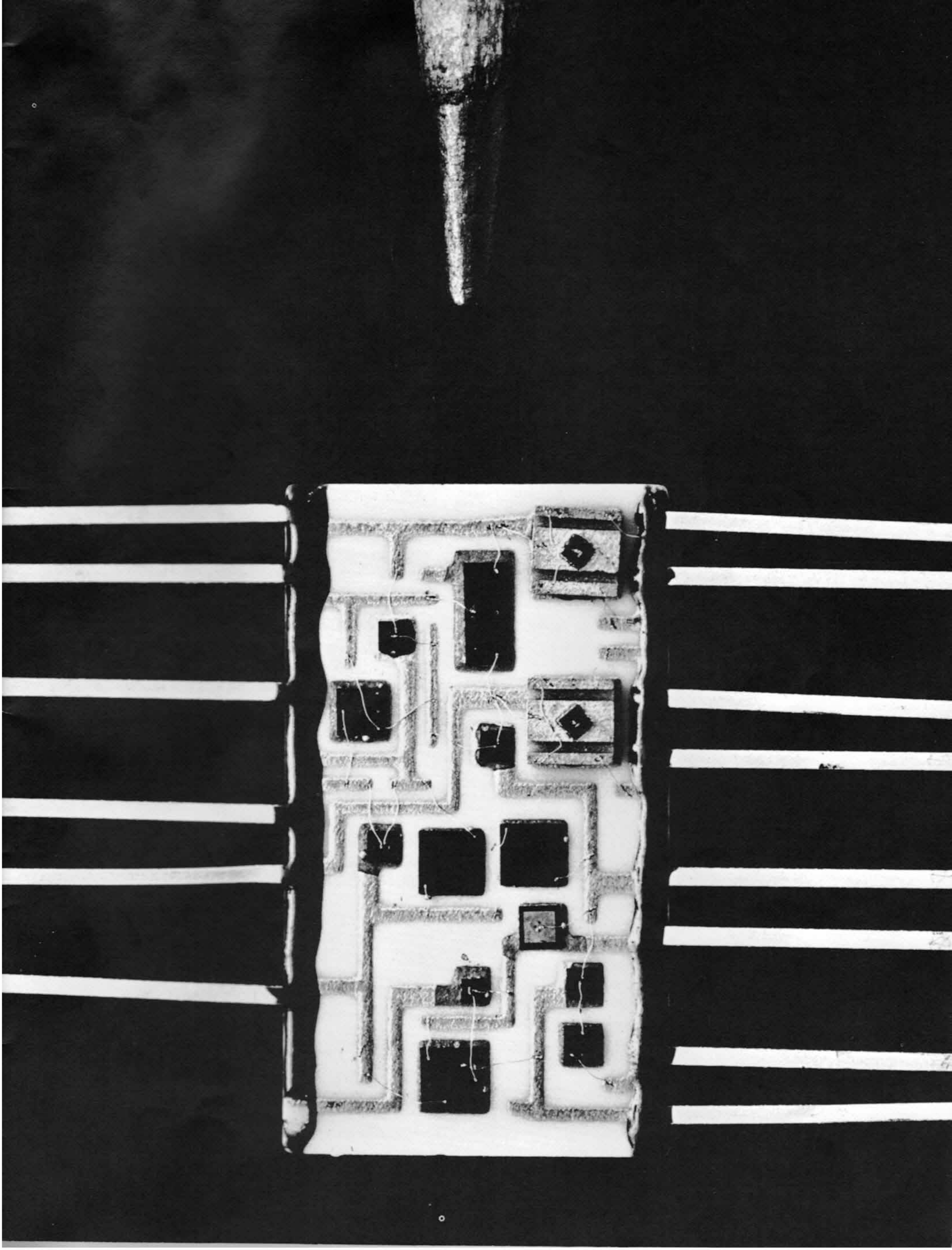
The technological development of electronic miniaturization has led to a higher degree of sophistication in the instrumentation. This is a sample of a chip circuit binary in instruments for measuring cosmic rays currently under development at LASR. It has been reduced in volume and weight by a factor of four.

Increasing research activities and modern technological development within the past ten to twenty years have resulted in a much fuller understanding of the nature of the primary radiation as scientists were able to carry their equipment to higher and higher altitudes and as they learned that earth's magnetic field, as well as the atmosphere, played an important role in determining which of the nuclei penetrated to a sufficient depth for detailed measurements. It was found that as one carried one's equipment closer to the geomagnetic poles, and to higher altitudes, particles with less energy could be detected.

Interest began to build among some of the researchers in the potential use of observations of the cosmic rays as probes to study the mechanisms in play in the solar system and in the galaxy. The result has been the gradual development of a new field of astrophysics which makes use of the information carried by the cosmic rays concerning their origins, and the interactions which they undergo in travelling through the galaxy at velocities near that of light.

It has now been established that the cosmic rays are composed of nuclei, not only of hydrogen, but of most of the elements of the periodic table at least to iron.

The advent of the space age with the Russian launch of Sputnik in 1957 was a decisive step in advancing the experimental work of the new particle astrophysics, since it became possible to carry scientific measuring devices beyond the influence of earth's atmosphere and geomagnetic field. This ability makes possible a more detailed probing of the mechanisms leading to the acceleration of the cosmic rays to energies as large as a billion times greater than may be accomplished in the laboratory. It allows measurement of the chemical composition, that is, identification of the atomic nuclei involved and of their energy distribution. Surprisingly, this composition is not the same as the "average composition" of the universe which was determined by other astrophysical techniques, mainly spectroscopic studies of the stars. While there is good reason to believe that the majority of the cosmic rays originate within our galaxy, it has not as



yet been possible to determine precisely the sources from which they originate. The more acceptable hypotheses indicate an origin within supernovae. We now know that the sun, under certain special conditions, emits energetic particles. However, the sun does not contain all of the elements which have been observed in the relative quantities which occur. For example, the elements lithium, beryllium, and boron are very rare in the sun, yet relatively much more abundant in the cosmic ray flux.

In 1958 Professors John Simpson and Peter Meyer were invited to participate in the preparation of an experiment to be carried on the Pioneer II spacecraft. This experiment was to determine the flux of cosmic ray particles in the space between the earth and the moon. It represented the beginning of a program of research in space at The University of Chicago and also the beginnings of what is now the Laboratory for Astrophysics and Space Research. While the Pioneer II failed its prime mission—to reach the moon—it did provide a few minutes of data at an altitude up to 800 miles which gave indications that the inner radiation belt was largely composed of energetic hydrogen nuclei, or protons.

Since this first experiment was attempted in 1958, there have been 14 successful launches of experiments prepared by members of LASR. Some of the highlights of findings will be presented in the material which follows. Among the early flights of scientific instrumentation, the degree of sophistication was necessarily limited for a number of reasons:

1. Each experiment carried its own source of power.
2. The rate of transmission of information back to earth was relatively small.
3. Technological development of electronic miniaturization was in its infancy and not yet sufficiently reliable for use in this type of program.
4. Sensor technology limited the choice of available detectors to conventional gas filled counters.
5. Lead time for preparation and testing of apparatus was extremely short, precluding opportunities for sophisticated developments. (For Pioneer II, the lead time was three or four months compared to the present time of one to two years).

The University's instrument used in Pioneer II was redesigned and repackaged to conform to a new type of vehicle, the spinning "paddle wheels" which became the Explorer VI and Pioneer V spacecraft. These vehicles were launched in August 1959 and March 1960, respectively, providing the first fully successful spaceflight ventures in which members of the University's Laboratory participated.

LASR developed the prototype of this "conventional" predecessor of the unit on the preceding page. It is still being used in some forms. The round object is a solid-state silicon semi-conductor particle detector.

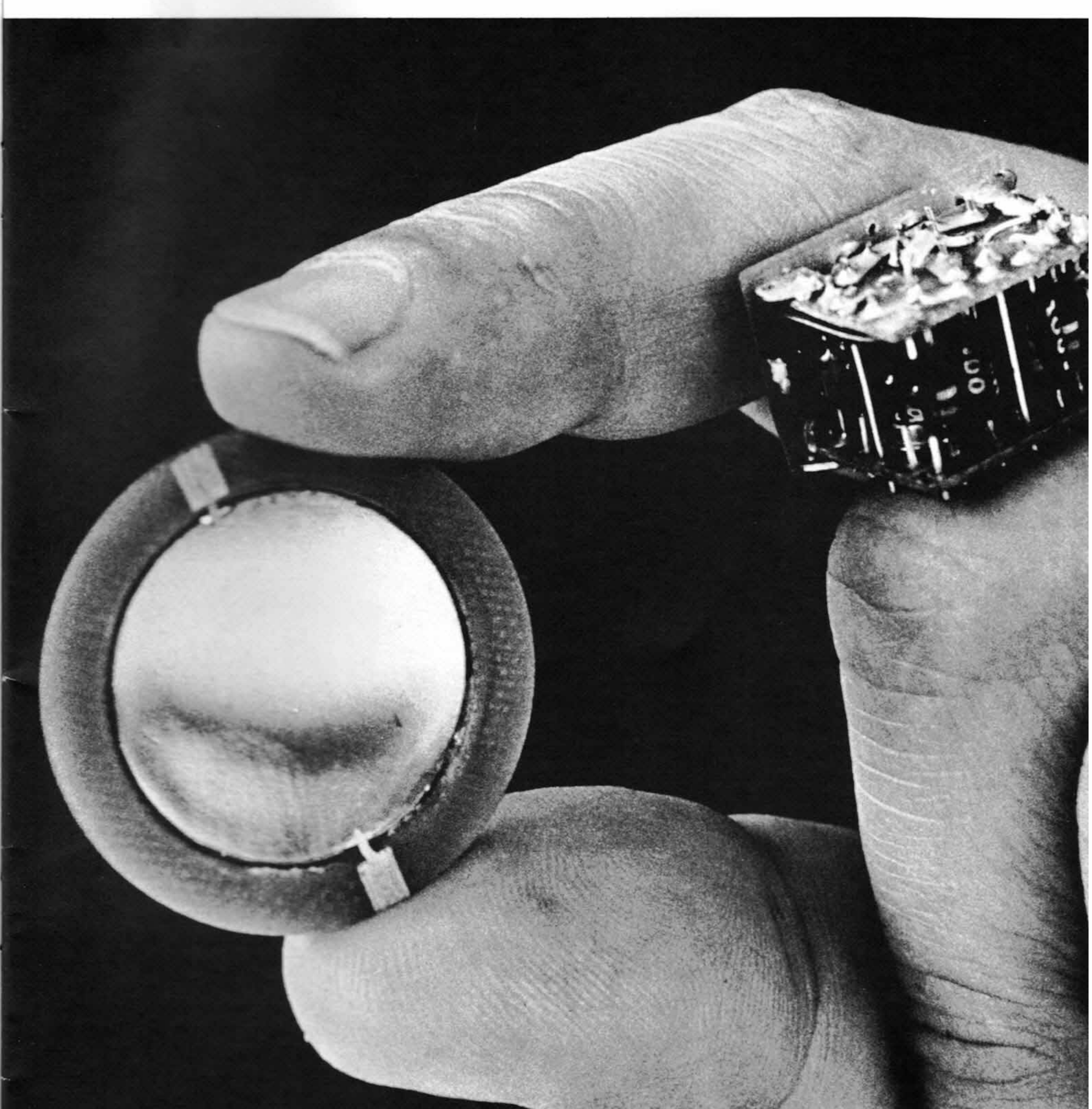
Explorer VI was a satellite whose orbit carried it from a perigee distance of 410 miles to an apogee of 30,000 miles from earth. It made repeated passes through and beyond the Van Allen radiation belt, providing confirming evidence that the belts were composed of three regions characterized by particles of different energies. The inner belt was shown to contain quantities of protons with energies exceeding 75,000,000 electron volts, trapped in the region by their spiralling motion about the magnetic lines of force of the earth's field.

The outer two belt regions were shown to be primarily composed of electrons confined to motions which were similar to the protons.

During the two months of operation of the satellite, it became evident that the shape of the outer radiation belt was influenced by solar disturbances, becoming distorted during periods of enhanced solar activity. In addition, it was shown that the Forbush decrease, a phenomenon in which the flux of cosmic rays suddenly decreases, slowly rising back to normal levels over a period of days, was not peculiar to the earth but could be observed in interplanetary space as well.

Pioneer V provided the first opportunity to explore interplanetary space to a greater depth since it was launched into an orbit around the sun, escaping from the earth's gravitational field. Regular measurements of the cosmic ray flux were made to a distance of some 18,000,000 miles before transmissions ceased. The occurrence of a large Forbush decrease both at earth and at Pioneer V conclusively demonstrated the interplanetary nature of this phenomenon.

In April 1958, in anticipation of developments which would increase spacecraft payload and telemetry capabilities, a new generation of experiments was proposed. The intent was to obtain a more detailed measurement of the energy distribution and composition of the cosmic rays, requiring development of new instrumental techniques. The Bell Laboratories and subsequently Oak Ridge National and Argonne National Laboratories had been investigating the use of silicon semiconductor devices for charged particle detectors with some success. However, the devices avail-



able at the time did not allow easy adaptation to the requirements for the space program. A modest investigative effort was undertaken at the University to tailor similar devices to the laboratories' requirements.

The success of this program has resulted in a variety of experiments which have become the basis for the present-day investigations in space. The utilization of the capabilities of the silicon detectors required a development of new concepts in electronics design and packaging techniques, since a much higher degree of sophistication was possible in the investigations while the amount of weight, space, and power available for experiments in spacecraft had not risen appreciably. The results of the development program have included a four- to eightfold reduction in volume required for electronics by adopting a modular design concept and a reduction in detector power requirements since no high voltages are required. The modular design has been standardized for a large family of circuits in such a way that fabrication requirements are readily communicated to commercial organizations, making it possible for the Laboratory's technical support portion to handle a number of experimental programs simultaneously without a need for an enlarged staff.

The first attempts to use silicon semi-conductor detectors were successfully carried out aboard the Discoverer XXXI and XXXVI satellites in polar orbits during the latter part of 1961. Discoverer XXXI carried two simple two-element counting devices oriented at right angles to each other so that one accepted particles from roughly the local vertical direction, and the other, those particles arriving in a direction tangent to the earth's surface. The satellite orbit was beneath the radiation belts, providing a large magnetic particle spectrometer with the earth's magnetic field serving in place of a bending magnet.

Discoverer XXXVI carried a solid state range-energy loss telescope composed of alternate layers of lead absorber and silicon semi-conductor detectors. Ten semi-conductor detectors were used in eight layers to provide a measure of energy loss by a particle and its range of penetration. From knowledge of these two characteristics it was possible to identify the cosmic ray particle and to obtain a measure of its energy. This instrument contained two multichannel pulse height analyzers for the energy loss measurements. It was the first time the Laboratory utilized this technique.

Based upon the experience and confidence in techniques provided by the flight of the Discoverer satellites, variations of the system elements were applied in increasingly rapid succession to instruments to be carried aboard the IMP I, II, and III, the Eccentric Orbiting Geophysical Observatories A and B, and the Polar Orbiting Geophysical Observatory C.

A small instrument containing three semi-conductor detectors and a 128-channel pulse height analyzer was included in the Mariner IV flight past Mars. The spacecraft provided data on a virtually continuous basis from shortly after launch on November 28, 1964 until October 1, 1965 at which time data transmissions were terminated. During the course of the flight, it was possible to obtain correlations of events at earth from the IMP satellites and at Mariner IV over a constantly increasing separation of observation points. It was thus possible to show that certain regions of the sun were ejecting streams of energetic protons and that these streams of particles corotated with the sun and its magnetic field every 27 days. It was also possible to demonstrate an upper limit for a Martian magnetic field in a search for trapped particles during the fly-by. The result indicated an absence of trapped radiation and consequently a field whose strength must be at most one one-thousandth that of earth.

From the IMP satellite observations, it has been possible to determine the presence of the isotopes of mass numbers 3 and 4 for helium in the cosmic-ray flux. The isotope helium 3 is very rare in the sun, hence the conclusion has been tentatively drawn that its presence in the cosmic-ray flux indicates an origin elsewhere in the galaxy.

The OGO A and B satellites contain by far the most complex experimental instrument yet built by the

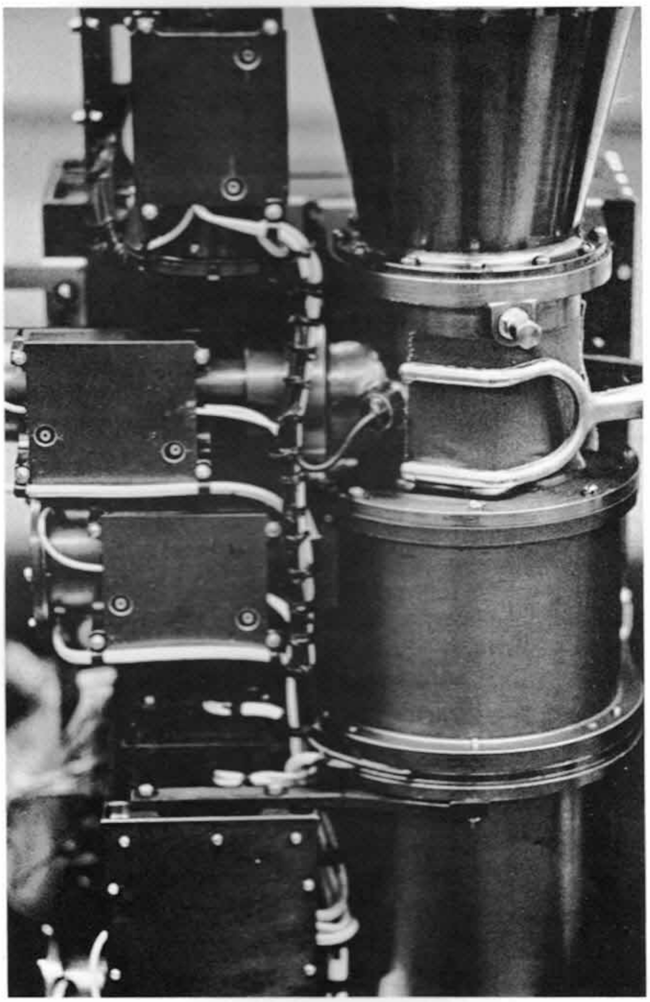
Successful Experiments Conducted by LASR

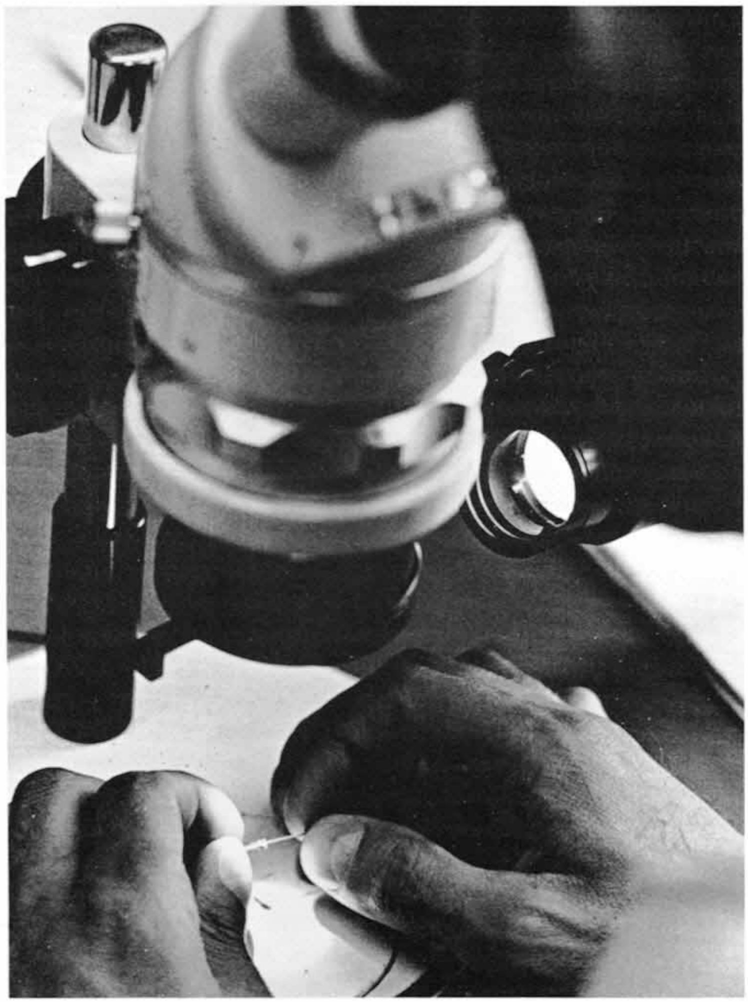
Spacecraft	Launch date
Pioneer II	*November 8, 1958*
Explorer VI	*August 7, 1959*
Pioneer V	*March 11, 1960*
Discoverer XXIX	*August 30, 1961*
Discoverer XXXI	*September 17, 1961*
Discoverer XXXVI	*December 12, 1961*
IMP I	*November 27, 1963*
OGO I (EGO A)	*September 4, 1964*
IMP II	*October 4, 1964*
Mariner IV	*November 28, 1964*
IMP III	*May 29, 1965*
OGO II (POGO)	*October 14, 1965*
Pioneer VI	*December 16, 1965*
OGO III (EGO B)	*June 6, 1966*
Pioneer VII	*August 17, 1966*

Right: NASA transfers the data from each experiment to tape and sends it directly to the University to be analyzed.

Below left: Part of an electron telescope to measure cosmic ray electrons. The instrument is being developed for the Orbiting Geophysical Observatory program. The unit was built at LASR and is 18 inches long and eight inches wide.

Below right: One of the miniature parts used in the instruments is examined for defects through a binocular microscope. Each element that goes into an experiment receives the same careful attention.





Laboratory. The instrument was designed to obtain information about the composition and energy distribution of the cosmic ray flux. Data have been obtained for energetic nuclei from hydrogen of atomic mass 1 to iron of atomic mass 52. Details of the results obtained to date are being published in the *Astrophysical Journal* in October of 1966. These results should prove significant in a further understanding of the origins of cosmic rays.

Pioneer VI, launched in December 1965, is a deep space probe whose path around the sun carries it 18,000,000 miles inward toward the sun from earth's orbit. At this writing, the probe and all its instruments are transmitting data over a distance of 55,000,000 miles from earth, providing information on the directional properties of the proton flux and on the temporal and spatial variation in the total flux.

Preparations are underway for additional experiments to be carried aboard five spacecraft during the next 18 months. The experiments are directed toward a variety of goals, including directional properties, composition, energy distribution and solar effects over the 11-year cycle of solar activity. Data from previously launched experiments are still under study in an attempt to provide a broader understanding of the solar system and physical processes in the galaxy.

Data from the experiments are received by NASA-operated receiving stations around the world, processed on magnetic tape, and forwarded to the various experimenter groups for computer reduction and analysis. The Laboratory maintains a staff of programmers who assist the experimenters in the preparation of special reduction and analysis programs and in preparation of "working tapes" from the raw data. The tapes include information concerning the location of the spacecraft relative to the earth, the geomagnetic field and the sun so that the experimenter may determine the location and time at which any portion of the data has been obtained. It is possible in this way to correlate information obtained from a number of locations at the same time to evaluate the spatial and temporal variations in the cosmic ray intensities as a result of solar or geomagnetic disturbances. The flux at the surface of the earth is constantly monitored at a number of fixed stations placed at different magnetic latitudes in the western hemisphere. This monitor network in turn is used as a reference base for comparison of the observations made in space.

The laboratory maintains a small, special-purpose computer for data processing and uses the services of the Computation Center when the magnitude of the computation requires larger capacity. Tapes prepared on the special purpose computer are compatible with the larger facility for detailed analysis. All data originating from the Laboratory experiments is retained in a library, accessible to the investigators and their students for study in detail at any time.

John Hsieh, a doctoral candidate in Physics, prepares an instrument for a thermal vacuum test that simulates the environment in space. The instrument was developed for the IMP F program.

An instrument designed to be landed on the surface of the moon has been developed for an experiment designed by Professor Anthony Turkevich to determine the chemical composition of the moon. Its development uses techniques, especially of semiconductor detectors for the cosmic ray programs, which have taken place at the Laboratory for Astrophysics and Space Research in the space program. The measurements being made in all of these experiments would not have been possible without the dedicated efforts of many people at the University and elsewhere. It is difficult to predict what the effects of scientific and technological development resulting from these programs will be. In any case the program is an exciting adventure into new fields of endeavors in which the pace of developments is rapid and exacting.

As the nation's space program has developed, the number of opportunities for experimenters to conduct investigations in space has grown. There has been an accompanying increase in the probability of success such that it has become practical to include students in the on-going programs. These students have opportunity not only to obtain the information necessary to support the doctoral dissertation but to observe and participate first-hand in the planning, preparation, and launch of scientific experiments. They thus learn the necessary interplay among people with a rather broad range of the scientific and technological skills which today are required in the conduct of complex scientific programs. At the present time there are some 30 graduate students in various phases of their training. The relationship is a stimulating one for all concerned, providing constant opportunities for exchange of new ideas and development of new techniques. Over the next few years, it is likely that the Laboratory will undertake other investigations in space in addition to the cosmic ray research. The ingredients are available and the investigative spirit persists.