International Years of the Quiet Sun, 1964–65

The program is designed to take the greatest possible advantage of the years of minimum solar activity.

Martin A. Pomerantz

In a few years man has made spectacular gains in his efforts to understand the universe, particularly the infinitesimal part that he occupies. During the International Years of the Quiet Sun (IQSY), attempts will be made to consolidate these gains.

To understand how IQSY has evolved, let us briefly recall its predecessor, the International Geophysical Year (*1*). During the IGY, men of science all over the world set themselves the task of broadening the scope of a relatively limited body of knowledge concerning the earth as a planet. The many significant and often unexpected and striking results (*2*) have exerted a profound influence upon the development of the fields of study explored during the IGY: meteorology, geomagnetism, aurora, airglow, ionospheric physics, solar activity, cosmic rays, longitude and latitude, glaciology, oceanography, rockets and satellites, seismology, gravimetry, and nuclear radiation.

The IGY was planned to coincide with a period of maximum solar activity, and the activity was in fact marked. By a stroke of good fortune, the sunspot numbers, an index of the intensity, density, and frequency of disturbances on the sun, exceeded any recorded previously in the approximately 200 years since the standard procedure for determining sunspot number was adopted (see Fig. 1). As a consequence both of the timing and of the development of revolutionary observational techniques, which have evolved directly from IGY activities, solar and geophysical studies initiated during IGY are continuing to advance our understanding of solar-terrestrial relationships.

Even before the IGY was over it was clear to scientists working in the so-called upper-atmosphere disciplines that certain observations should be continued at least through the waning period of the solar cycle, and that others should be repeated at solar minimum. Thus it was decided to conduct, during the forthcoming solar minimum, a full-scale international program in those disciplines concerned in any way with solar activity—meteorology, geomagnetism, aurora, airglow, ionospheric physics, solar activity, cosmic rays, and aeronomy. Plans for this new international enterprise, officially designated the International Years of the Quiet Sun, which will last from 1 January 1964 to 31 December 1965, have been formulated by scientists all over the world.

The Planning

Although several organizations had been independently considering and proposing cooperative programs of observations at sunspot minimum, the first full-scale IQSY meeting was convened in Paris in March 1962 (*3*). The president of the International Council of Scientific Unions (ICSU) had sent invitations to all affiliated academies and national organizations to participate in IQSY, and countries were invited to send delegations of specialists in the IQSY disciplines to participate in working-group meetings.

The second and major planning session was held in Rome from 18 to 22 March 1963 (*4*). At that time many of the national programs had been formulated and many facets of international cooperation and collaboration were arranged. Thus far, some 62 countries have signified their intention of participating in IQSY.

The major outcome of these two general assemblies, in addition to the detailed discussions and resulting recommendations concerning the scientific program, were as follows.

1) Establishment of three criteria to serve as guidelines for the various nations in planning their contribution to the international program. The studies planned are to be (i) studies that are feasible only, or are best undertaken, at the time of solar minimum; (ii) studies of isolated solar events that are not complicated by the superposition, in time, of many different effects; and (iii) studies involving comparison of data characterizing solar minimum with those characterizing solar maximum.

2) Continuation of international exchange of geophysical data via the World Data Centers that were established for IGY. At the Rome meeting, the general principles of data exchange and the detailed schedule of exchange for the various IQSY disciplines were brought into final form.

3) Development of the "IQSY Calendar" (*5*) for the scheduling of observations that can be specified in advance, for purposes of assuring good statistical and seasonal sampling throughout the IQSY period. The calendar is being developed mainly for the benefit of programs in which it is impractical to schedule synoptic observations throughout the entire period. Special periods will also be designated during IQSY by the World Warning Agency on the basis of unusual solar or geophysical conditions.

Many phases of the participation by the United States and other countries are still in the planning stage (*6*). Thus, it is too early to attempt to present a complete description or even a comprehensive summary of the scientific program. In this article I merely review some of the factors that have stimulated the world geophysical community to undertake the mounting of this ambitious program. I give two examples of planned projects to illustrate the unique features that distinguish IQSY from previous international enterprises.

The author is director of the Bartol Research Foundation of the Franklin Institute, Swarthmore, Pa.

What's New about the Program?

The uninitiated may be tempted to refer to IQSY as a "little IGY." Actually, there are many essential differences between IGY and IQSY. The present planners enjoy the tremendous advantage of having a fund of experience to draw on in undertaking a vast international scientific program. In addition, the level of geophysical research, which has climbed steadily since the end of IGY, stands now at an all-time high. The IQSY has a far larger scientific community upon which to draw than the IGY had, as well as a broader program of on-going research upon which to build.

The IGY brought to light many new and exciting phenomena, but detailed studies of their mechanisms were rendered difficult by the exceedingly high level of solar activity. From some points of view we may have had too much of a good thing and have suffered from an embarrassment of riches. The discoveries of the IGY fired the imagination. The prime motivation for IQSY is the hope of achieving an understanding of the physical processes that underlie these newly discovered and spectacular effects.

Synoptic observations will play an important role, but geographical surveys of essentially a map-making character, designed only to provide phenomenological descriptions, will not entirely satisfy the IQSY criteria.

Cooperation among scientists in different nations will not be limited to the exchange of data. There is increasing interest in the idea of active collaboration among colleagues in different countries in the conduct of specific experiments. This extension of the concept of international cooperation is one of the things that distinguishes IQSY from its predecessor. Bilateral and multilateral projects that would not have been feasible previously will be undertaken. This additional degree of freedom in planning large-scale experiments opens up new possibilities for attacking fundamental problems. There are similar possibilities for cutting across disciplinary lines; bonds of common interest are now firmly established and weld together previously isolated segments of the geophysical community. Indeed, a new interdisciplinary and multidisciplinary approach is evident in all of the IQSY disciplines.

This trend toward unification of the disciplines which will characterize IQSY has become increasingly apparent. It is evidenced, for example, by the scope of recent scientific meetings such as the Kyoto International Conference on Cosmic Rays and the Earth Storm, held in September 1961 (*7*), and the COSPAR Space Science Symposia (*8*). These gatherings are typified by the participation of astronomers, physicists, meteorologists, chemists, and engineers, all with a multitude of overlapping interests.

The "Quiet" Sun

The keystone of the IQSY program is the sun, and one of the basic questions around which the program is built is, What is the "quiet" sun? It is known from observations made during total eclipses that the sun's corona is considerably contracted during the minimum phase of the solar cycle; sunspot observations made during some 19 previous cycles show that at sunspot minimum, visible disturbances decrease markedly, sometimes vanishing altogether.

This is far from the entire story, however, partly because the sun has never before been observed as assiduously during periods of quiet as during periods of activity, and partly because advances in radio-astronomy techniques, satellite experiments, and improved means of making conventional observations from the ground have led to many new discoveries concerning the fundamental nature of solar activity. In short, we now know that solar "activity" is a far more complex matter than we had supposed and that it cannot be adequately described merely in terms of the size of the solar corona and sunspot statistics (see cover).

The study of flares and their relationship to other manifestations of solar activity—such as spicules and calcium plages, prominences (filaments viewed against the disk), x-ray generation, particle emission, and bursts of radio noise—and the detailed investigation of the magnetic field of sunspots and active regions have in recent years added dramatically to our understanding of at least some aspects of the initiation, growth, and decay of a solar disturbance. Such a disturbance is

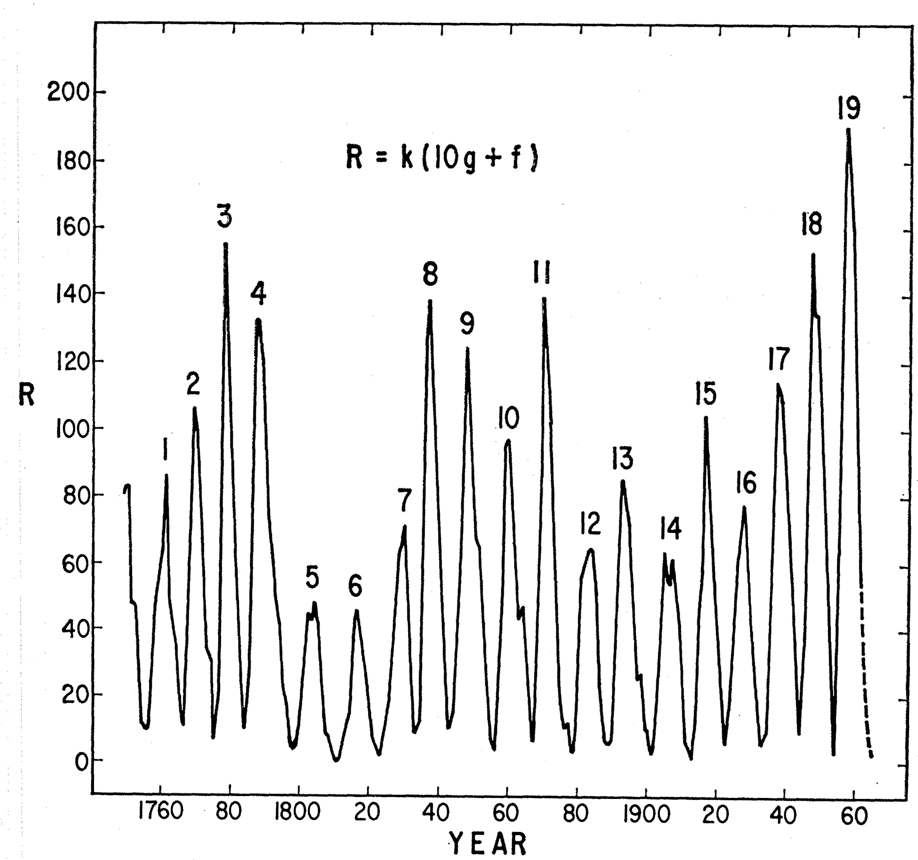

Fig. 1. Variation in mean sunspot activity over the past 200 years, where R is the sunspot number, k is a weighting factor dependent upon observational efficiency, g is the number of sunspot groups, and f is the number of individual spots.

often accompanied by the generation of particle streams that escape from the sun and produce terrestrial effects. The international coordination of all types of observation is crucial for obtaining a complete temporal picture of such a complex event, and it is the time relationships that often provide the key to understanding the mechanisms involved. Direct solar investigations are supplemented by countless varieties of terrestrial observations of ionospheric, cosmic-ray, auroral, and geomagnetic disturbances—observations that permit extrapolation backward in time to fill in details of the causative solar event, such as the total energy of the radiation and particle emissions and their spectral characteristics.

The IQSY Disciplines

Meteorology. The IQSY program places great emphasis on investigation of the atmosphere above pressures of 100 millibars (about 20 km)—that is, the region not accessible to most conventional meteorological techniques. With increased knowledge of this region, a three-dimensional picture of the

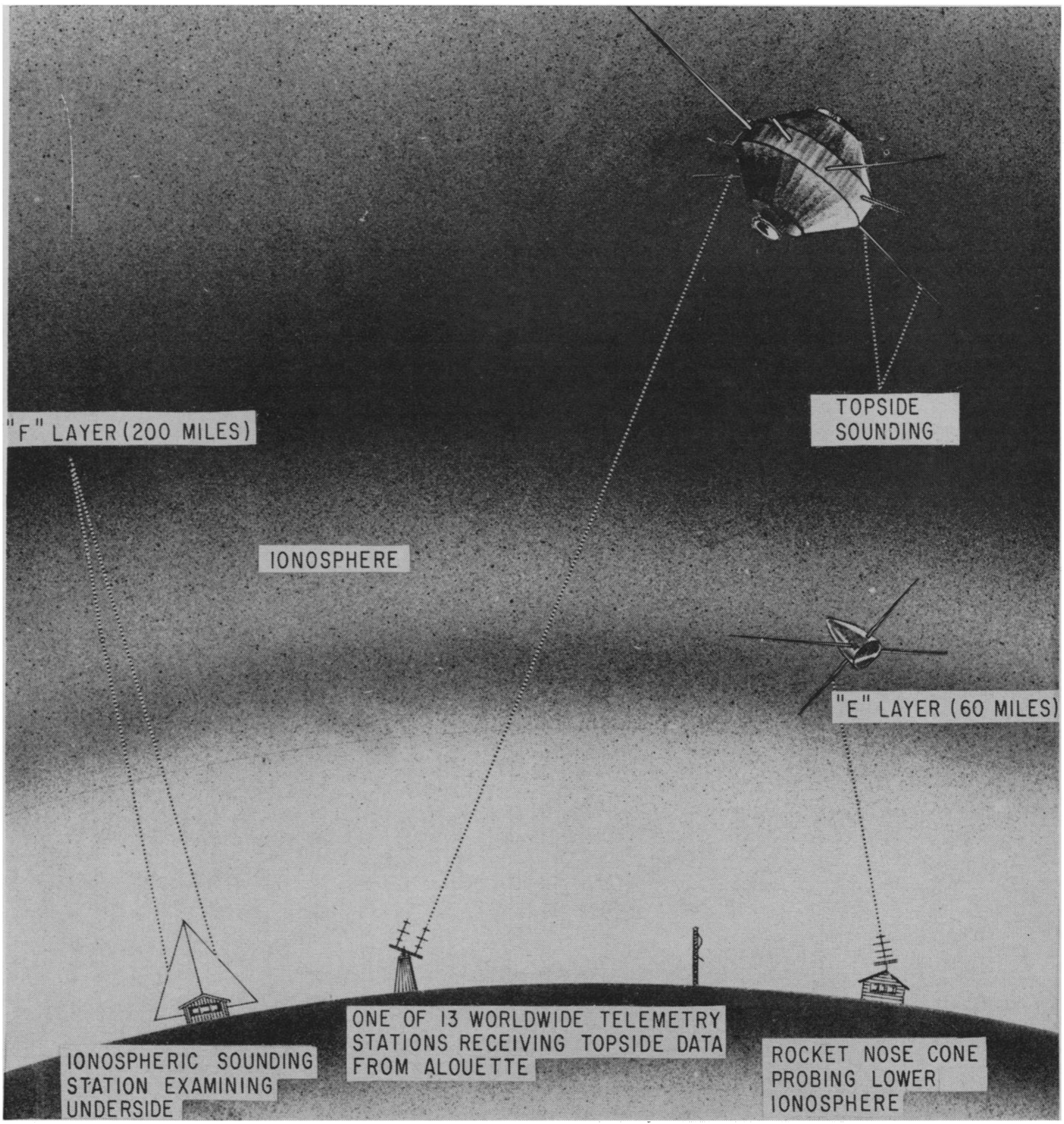

Fig. 2. The Alouette topside-sounding technique. Also illustrated, for comparison, are ground-based sounding (left) and rocket sounding (right) techniques. [Defence Radio Telecommunications Establishment, Canada]

behavior of the atmosphere can be obtained. High-performance balloons and the newly developed meteorological rockets make observations possible at altitudes from 20 to about 60 kilometers. Trace constituents, such as ozone and water vapor, will be observed systematically. Finally, vertical profiles of radiative flux will be obtained in order to learn more about the heat budget of the atmosphere.

Geomagnetism. Geomagnetic observations of the classical type have been made for centuries. Recently, however, there has been a dramatic change in the methods of recording, so that the vast amount of information gathered by standard observatories can be machine-processed. An extension of the spectrum of geomagnetic fluctuations to high frequencies (several cycles per second) has opened up the possibility of utilizing records of such fluctuations as clues to events transpiring in the geomagnetosphere. The World Magnetic Survey will be given special attention during IQSY, not only to improve the mapping of the field and the mathematical representation of its spatial distribution but also to obtain a sufficiently complete description of the field for gauging its variations, since the fluctuations on several time scales contain an enormous amount of geophysical information. Finally, satellites and space probes now make it possible to monitor the field and its changes in space, in temporal correlation with other, related studies.

Aurora. The classical description of the aurora, of its occurrence and its spatial and temporal fluctuations, remains important, and more investigations of the classical type are needed to provide a sound phenomenological basis for auroral theory. In addition, the use of earth satellites makes possible experimental studies of auroral particles and their governing environment which have a direct bearing on auroral theory. The auroral theorist no longer need be content with observational evidence obtained from the ground but may now make numerical predictions of particle energies and spatial distribution outside the earth, of electric fields and perturbation in magnetic fields, and of steady-state conditions relative to important fluctuations, and he may expect to obtain quantitative data for these phenomena.

Airglow. Investigation of the Lyman-α airglow from the hydrogen geocorona is of prime importance. The theory of a spherical geocorona is well developed, and photometric measurements will yield directly the hydrogen density and the kinetic temperature of the outer atmosphere, which governs the escape of gases. There is preliminary evidence, in addition, that the outer geocorona is highly distorted, its configuration being related to the solar wind. Classical work on airglow has resulted in the establishment of a series of well-calibrated stations at locations where there is good seeing; from these, absolute photometric measurements will

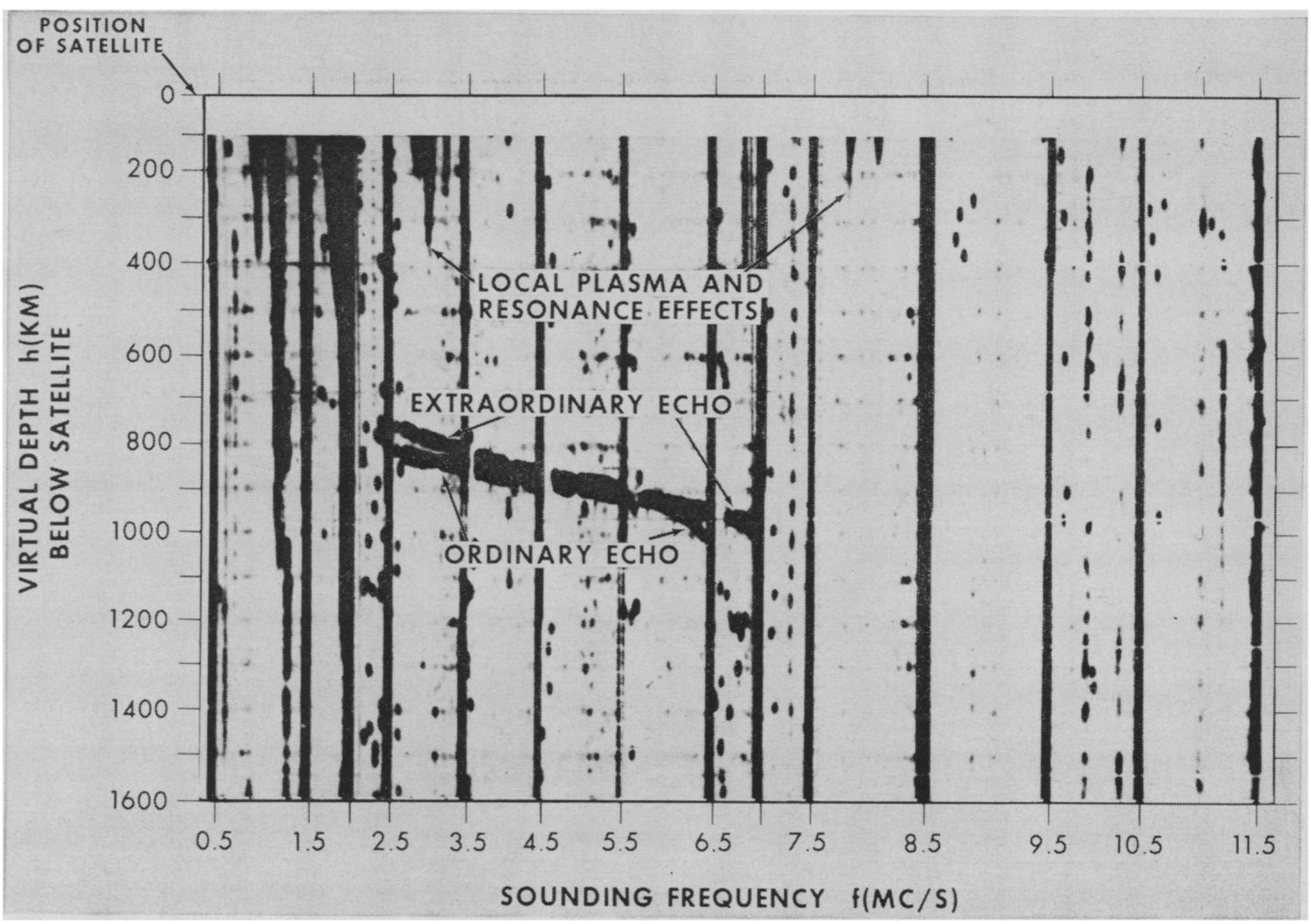

Fig. 3. Ionogram, obtained with the Alouette topside-sounding technique, for a daytime, middle-latitude sounding. The ionogram, for a sounding at 12:05 EDT, 29 September 1962, at 37°N, 77°W, was received at Ottawa, Canada, just 10 hours after launch—the first to be received. [J. H. Chapman, senior scientist for the Canadian Alouette program]

be obtained and a wide variety of airglow phenomena will be studied. Rocket measurements are still needed to determine the height-emission profile of many important emissions. Data from stabilized, earth-oriented satellites will provide a basis for global mapping of cerain airglow emissions and for temporal correlation of these emissions with magnetic disturbances and the arrival of particles into the atmosphere.

Ionospheric physics and radio astronomy. Programs of synoptic observations of the ionosphere are being continued. In addition, two dramatic improvements in experimental technique have recently had an impact on ionospheric research. The first of these is the use of high-powered radar. This provides the possibility of making regular soundings of the ionosphere out to great distances and of obtaining information on electron and ion temperatures. The second new feature of ionospheric exploration is the top side-sounding technique (see Figs. 2 and 3).

This has been demonstrated to be one of the most fruitful experiments yet devised for ionospheric investigation. The technique also provides a unique means of tying together the world network of ground observatories. The IQSY will be an ideal time for opening up several more octaves of the radio-frequency spectrum. The reduced opacity of the ionosphere during solar minimum will make it possible to extend observation to frequencies as low as a few megacycles per second in studying solar-system, galactic, extragalatic, and radio sources. Observations at these low frequencies may also be of value in mapping ionospheric nonhomogeneities.

Solar activity. The solar-patrol network has been greatly extended by the availability of rapid-sequence photography for studying active centers (see cover). High-resolution photographs reveal very rapid solar events and surprisingly large ensuing disturbances at great distances from the original active center. There is also considerable interest in observations of the K line of calcium, especially a few tenths of an angstrom from the center of the line. Finally, the powerful radars that have been installed at many locations for making soundings of the magnetosphere are capable of producing detectable echoes from the solar corona. While the interpretation of this information is difficult, such observations will provide important reference points for similar observations made after the end of IQSY, as solar activity climbs toward the next maximum.

Cosmic rays and geomagnetically trapped particles. The systematic exploration of the Van Allen regions of geomagnetically trapped radiation is continuing and will receive special emphasis during IQSY because the configuration of these regions should be most stable at this time. The IQSY will afford an opportunity to study the lowest-energy galactic cosmic rays, which are generally scattered away from the inner solar system during times of high solar activity. The full description of the cosmic-ray charge and energy spectra not only is of great cosmological interest but provides another avenue for studying the modulation mechanisms in the solar system. The role of effluent material from the sun in attenuating cosmic rays is not yet well understood, and some IQSY

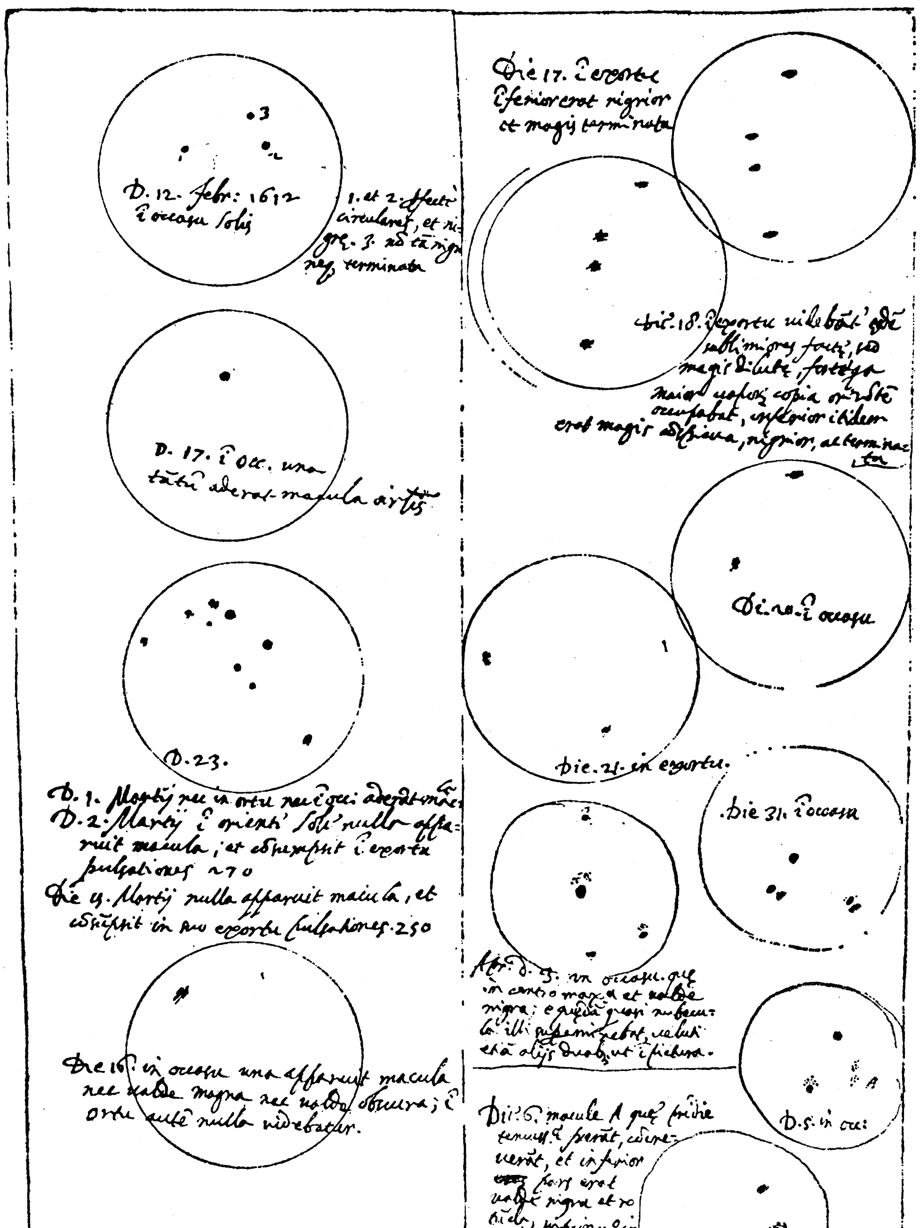

Fig. 4. Sunspot observations by Galileo in 1612. [Reproduction of Galileo's drawings and notes]

experiments will be undertaken to elucidate it. For example, direct determination of the cosmic-ray gradient as a function of solar distance, as well as studies of temporal variations, made with the world-wide network of ground-based neutron monitors, will provide a great deal of information on the modulation mechanisms. At the same time, the study of primary electrons, positrons, and gamma rays will be an important cosmological contribution.

There are two projects in the cosmic-ray category that illustrate the interdisciplinary and international aspects of the planning for IQSY. The first involves the monitoring of electron density in the D region of the ionosphere (altitudes of about 85 km) by means of the technique of forward-scatter radio-wave propagation. The experiment, obviously of interest to ionospheric physicists, has as its main objective the detection of so-called solar cosmic rays. These particles penetrate the atmosphere to levels below the domain of auroral activity and produce enhanced ionization that, together with the short mean free paths for electrons at these levels, results in absorption of radio signals of appropriate frequency. A major portion of this work will be carried out in the Antarctic, where pairs of stations (transmitting and receiving stations) will be distributed over the polar cap in order to provide geographical coverage and to define different geomagnetic cutoffs for the incoming charged particles. Thus, a number of nations will participate in this collaborative enterprise. Under the aegis of ICSU's Scientific Committee for Antarctic Research (SCAR), an international working group has been organized to collaborate in the full exchange of the data and in its analysis.

The ionospheric forward-scatter observations will provide continuous monitoring at fixed locations (the midpoints between pairs of stations) of the flux of protons and heavier nuclei in an energy range not accessible to other techniques. In particular, observations, in Antarctica, of forward-scatter signals and neutron flux will provide complete coverage of the energy spectrum of the solar cosmic rays, from a few million electron volts upward. Forward-scatter signals normally are not affected by auroral phenomena and consequently show no confusing effects associated with the onset of geomagnetic storms.

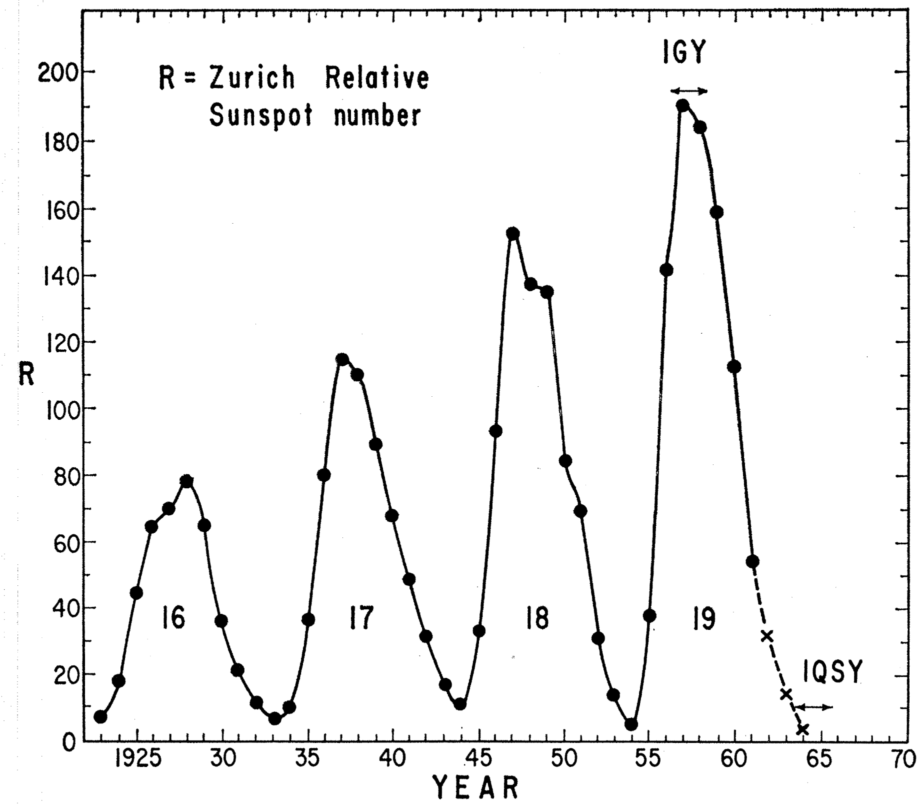

Fig. 5. Details of recent sunspot cycles. The diagram shows the probable decline (dashed curve) of the recent cycle of activity and the time period of the IQSY. The *R* plots are smoothed over 1-year periods by using sliding averages.

It is thus possible, by this means, to follow completely the decay in intensity of incident solar cosmic rays. During IQSY the operating frequencies will be substantially lower than those appropriate for observing the large solar-cosmic-ray events, which have been detected only during periods of moderate and high solar activity. Consequently, the sensitivity of the forward-scatter system will be very high, in order to permit measurement of a much lower flux of low-energy solar cosmic rays than have been detectable before. Thus, the small but highly interesting events occurring at the minimum phase of the solar cycle will be observed for the first time. Even though the sensitivity of the apparatus will be appreciably greater during IQSY than previously, comparison with earlier data will be meaningful. Of special significance is the possibility that impact-zone effects for low-energy solar cosmic rays may occur within the polar cap during periods of low solar activity.

The interdisciplinary nature of this program is evident. Furthermore, observations of forward-scatter signals are applicable to studies such as those of seasonal and diurnal variation in intensity of the scatter signal, propagation by sporadic ionization in the E region of the ionosphere, and certain phenomena associated with auroral and meteoric ionization. Finally, as part of the concerted attack to be made during IQSY on problems of upper-atmosphere phenomena at opposite ends of a magnetic line of force, it is planned to extend the program to include several circuits in the Northern Hemisphere; the midpath point of one of these will be conjugate to an Antarctic circuit.

Another project which exemplifies the IQSY philosophy is one proposed by John R. Winckler of the University of Minnesota. He plans to launch a number of large plastic balloons at high arctic latitudes; these will float at an altitude of approximately 30 kilometers. Analysis of high-altitude IGY meteorological data indicated the existence of rather stable air-flow patterns in the Arctic—the so-called polar vortex. The rapid development of large-balloon technology makes it possible to design constant-level balloons that should stay aloft for periods of at least a week, completing one or more circuits of the polar region.

This development is of great interest for the study both of galactic cosmic rays and of high-energy particles issuing from the sun, for at these high geomagnetic latitudes there is essentially no magnetic cutoff. The balloon could also serve as an unparalleled laboratory for atmospheric observations. The detailed trajectory will yield information, at present not available, on the course of the polar circulation and its short-term changes. It will also be possible to determine meridional components of flow. Measurement of ozone concentration and study of long-wave radiation during the polar night are contemplated—observations that will be of considerable meteorological interest. The balloon could also provide a platform for making spectroscopic and photometric studies of atmospheric emissions related to aurora and airglow.

Winckler has invited colleagues in other countries, particularly countries bordering on the Arctic, to prepare payloads for these flights and to cooperate in receiving telemetered data.

Aeronomy. Although aeronomy embraces many of the fields I have mentioned, it has been considered a separate discipline in recognition of the fact that in situ observations are notably advancing our understanding of the physics and chemistry of the upper atmosphere. Perhaps the most important of the aeronomical studies planned for IQSY is the absolute determination of solar-line radiation in the ultraviolet and x-ray portions of the spectrum—radiations which are responsible for heating and ionization processes throughout the ionosphere. A second potentially significant contribution will be the development of an integrated rocket package for determining, in the ionospheric D and E regions, the incoming radiation and the ensuing ionization processes and photochemical reactions.

There will be many other endeavors that will be landmarks of international scientific collaboration. All of the powerful new techniques that make possible in situ observations in the upper atmosphere and beyond will be brought to bear upon scientific problems in a new era of cooperation. The Committee on Space Research (COSPAR), an important partner in the planning for IQSY, has organized a Working Group for the IQSY (*9*). Not only will there be direct collaboration between nations in instrumenting vehicles and conducting programs but, in some cases, opportunities will be provided for observers all over the world to receive signals directly from spacecraft passing overhead, for correlation with their related ground-based observations.

Organization

The International Geophysics Committee (CIG) of ICSU was given responsibility for organizing the IQSY program. This committee established an IQSY Committee, with a secretariat in London, to formulate and execute detailed plans. The IQSY Committee (*10*) is made up of "reporters" from appropriate disciplines, each of whom is supported by an advisory group nominated by the appropriate international scientific union or association, and officers appointed by these unions and by ICSU. Several individuals have been added to this group of members, mainly from other international committees and organizations active in developing the program. In the United States a committee of the National Academy of Sciences was created by the Geophysics Research Board, the domestic counterpart of CIG. This U.S. Committee for IQSY (*11*) has been working for some time to develop the national program. Within the government, the National Science Foundation was designated by the President the responsible agency for coordinating and implementing the program, and for correlating regular activities of the government that relate to the program.

Prediction

The IGY was planned to cover a time at or near sunspot maximum. The dates were set 7 years in advance, but, as it turned out, the planners were particularly astute. The beginning of the observations, in July 1957, synchronized with a series of intense eruptions on the sun, and the level of solar activity was probably higher than it had been at any time since Galileo first observed sunspots, early in the 17th century (Fig. 4). The lead time in the case of IQSY is much shorter, but the difficulties in predicting solar minimum are considerably greater than those in predicting solar maximum. This was manifested in the extensive discussions, among a number of experts, that led to the decision a year ago to advance the starting date of IQSY from 1 April to 1 January, 1964. Since activity increases after solar minimum much more rapidly than it decreases after solar maximum, it was feared that a significant increase in sunspot numbers might occur before the program was well under way. It is now expected, hopefully, that the designated 2-year period will encompass the solar minimum (see Fig. 5). In any event it seems safe to predict that the "quiet" sun of IQSY may very well outdo the "noisy" sun of IGY in illuminating the path toward knowledge.

Notes

1. For a discussion of the history and development of the IGY, see *Annals of the IGY* (Pergamon, New York, 1959), vol. 1; accounts of the five general assemblies of the IGY are to be found in volumes 2a, 2b, and 10. There have been many excellent general books and articles on the IGY; see, for example, S. Chapman, *Year of Discovery* (Univ. of Michigan Press, Ann Arbor, 1959) and W. Sullivan, *Assault on the Unknown* (McGraw-Hill, New York, 1961). A series of general papers presented 27–30 June 1957 at a symposium on the IGY sponsored by the National Academy of Sciences was published as "Geophysics and the IGY," *American Geophysical Union Monograph No. 2* (1958).
2. A brief preliminary discussion of IGY results is given in H. Odishaw, *Science* **128**, 1599 (1958); *ibid.* **129**, 14 (1959). A comprehensive bibliography of U.S. contributions to the IGY is available: "United States IGY Bibliography, 1953–60," *Natl. Acad. Sci. Publ. No. 1087* (1963). An international bibliography will be published late in 1963 or in 1964 as one of the final volumes of the *Annals of the IGY* (Pergamon, New York, 1959).
3. *IUGG Chronicle No. 45* (1962).
4. The report of the Rome meeting is published in *IQSY Notes* (No. 3), a limited distribution of which is made by the U.S. Committee for IQSY, National Academy of Sciences; *IQSY Notes* is available on subscription from the IQSY Secretariat, 6 Cornwall Terrace, London N.W.1.
5. The "IQSY Calendar" is published by, and may be obtained from, International Scientific Radio Union, 7 Place Danco, Brussels 18. Copies are also available from the IQSY Secretariat. The calendar is reproduced in *IG Bull. No. 74* (1963).
6. The *Proposed United States Program for the IQSY* (Feb. 1963) is available from S. Ruttenberg, Executive Secretary, U.S. IQSY Committee, National Academy of Sciences, Washington 25, D.C. Programs of participating countries are summarized in the *IG Bulletin*, available on subscription from the Printing and Publishing Office, National Academy of Sciences. The programs of participating countries are also published in *IQSY Notes* (see *4*), along with other IQSY material.
7. *Proceedings of the International Conference on Cosmic Rays and the Earth Storm* (Physical Society of Japan, 1962), vol. 17, suppl. A-I, A-II, A-III.
8. Papers presented at the COSPAR symposia in 1960, 1961, and 1962 have been published by North-Holland Publishing Company, Amsterdam, in *Space Research* (1961), *Space Research II* (1962), and *Space Research III* (1963), respectively. A general discussion of problems in space research appears in *Science in Space*, L. V. Berkner and H. Odishaw, Eds. (McGraw-Hill, New York, 1961). A recent study of various aspects of space research, including the program of NASA, was carried out in the summer of 1962 under the aegis of the Space Science Board of the National Academy of Sciences; the

results of this study are published in "A Review of Space Research," *Natl. Acad. Sci. Publ. No. 1079* (1962).
9. The report of the Rome IQSY meeting of the COSPAR Working Group on the IQSY was published in *COSPAR Bull. No. 14* (Mar. 1963).
10. The CIG-IQSY Committee, under the aegis of ICSU, is comprised of (i) officers who also make up the Bureau of the committee and represent the four international associations concerned with IQSY—W. J. G. Beynon, president (International Scientific Radio Union); M. A. Pomerantz (International Union of Pure and Applied Physics), N. V. Pushkov (International Union of Geodesy and Geophysics), and G. Righini (International Astronomical Union), vice presidents; and C. M. Minnis, secretary; (ii) members for administration, finance, and publication—D. C. Martin and H. Odishaw; (iii) discipline reporters—W. L. Godson (meteorology), J. O. Cardús (geomagnetism), D. Barbier (airglow), J. Paton (aurora), W. Dieminger (ionosphere), R. Michard (solar activity), S. N. Vernov (cosmic rays), M. Nicolet (aeronomy), and H. Friedman (space research); (iv) representatives of other interested scientific committees and organizations—F. Jacka (Scientific Committee on Antarctic Research); J. Blamont and Z. Svestka (COSPAR); A. H. Shapley (International URSIGRAM and World Days Service); and O. M. Ashford (World Meteorological Organization); (v) members for data interchange—V. Burkhanov, H. Odishaw, and T. Nagata; (vi) members for geographical representation—S. Manczarski (Europe-Asia region), K. R. Ramanathan (Indian region), A. Onwumechelli (Africa) and J. Roederer (Latin America); and (vii) ex-officio members—J. Van Mieghem, secretary general of ICSU; G. Laclavere, secretary general of CIG; and P. J. Beaulieu, executive secretary of COSPAR.
11. Members of the U.S. Committee for IQSY, established by the National Academy of Sciences, are R. G. Athay (solar activity), J. W. Chamberlain (aurora and airglow), H. Friedman (aeronomy), J. Kaplan (member-at-large), W. W. Kellogg (meteorology), P. Meyer (cosmic rays), H. Odishaw (ex officio), M. A. Pomerantz (chairman), S. Ruttenberg (executive secretary), M. A. Tuve (ex officio), E. H. Vestine (geomagnetism), and A. H. Waynick (ionospheric physics). Robert Fleischer, of the Office of Atmospheric Sciences, is NSF coordinator for IQSY.

Communication and Comprehension of Scientific Knowledge

Robert Oppenheimer

The theme that has been assigned to me seems in some ways a little odd. That is only in part because this talk comes after 3 days and 15 lectures in which, as actors and auditors, we have lived with many beautiful examples of good communication, and even very largely good comprehension—good understanding—of scientific knowledge. If I have any doubts, it may be that here and there, in those reports which dealt with subjects close to me, the communication and the understanding have gone a little bit beyond the knowledge.

In an important sense, the sciences have solved the problem of communicating within and with one another more completely than has any human enterprise. I may retell an old story. Thirty-five years ago, Dirac and I were in Göttingen. He was making the quantum theory of radiation, and I was a student. He learned that I sometimes wrote a poem, and he took me to task, saying, "In physics we try to say things that no one knew before in a way that everyone can understand, whereas in poetry. . . ."

It is an old and consistent tradition with us to be concerned with the words we use, and with their purification, and thus with the concepts in terms of which we describe nature. It was true of Newton, of Lavoisier, of Cauchy, of Mendel, and of course, in our day, of Einstein and of Bohr. As for Newton, we will understand this better when we have, after almost three centuries, the critical edition of the *Principia*; at least we will know that in the renowned *"Hypotheses non fingo"* it is not the first word but the last that bears the meaning.

When we tell about our work, we explain what we have done and we tell what we have seen, whether we are describing a radioastronomical object, or a new property of fiber bundles, or the behavior of men attempting to solve problems. We are prepared to believe that the explicit content of science has its roots in these accounts of action, often factual, often foreshortened and synoptic, because cast in terms which the scientific traditions have established long ago.

Among us there is surely a great and appropriate variation in how we describe this foundation for the objectivity of our knowledge, and for the lack of ambiguity in the terms we use to tell of it; and of course there is an even wider latitude, insofar as we may bring ourselves to speak of them, in what we think of the reasons for the success of science, in what attributes of the world of nature in which we find ourselves underlie the manifestations of order which are our business: why we can work on the same table and with the same test tube when we cannot have the same melancholy or the same resolution; why so much of the order of the natural world finds its expression in number and the more abstract mathematical structure.

We probably all, with varying enthusiasm, would say *yes* to Charles Peirce as to *how to make our ideas clear*. We would make a good case that we do indeed know the structure of some ribonucleic acids, or some properties of the longer-lived particles of physics, only leaving room for the fact that in new things as well as in old, there are points we may not have looked at, and that wonders may be hidden in the crevasses.

This foundation for knowledge precludes much that is an essential part of man's life. One cannot be a very effective scientist if he is a practising solipsist. We cannot expect to describe a common world of introspection by telling people what we have done and what we have seen; though probably we can, and increasingly we will, describe elements of behavior which may have some correspondence to the inner world. Among these things of which we cannot talk without some ambiguity, and in which the objective structure of the sciences will play what is often a

The author is director of the Institute for Advanced Study, Princeton, N.J. This is the text of an address delivered 23 October 1963 in Washington on the occasion of the Centennial of the National Academy of Sciences.