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Geophysics Research Board
Assembly of Mathematical and Physical Sciences
National Research Council

National Academy of Sciences
Washington, D. C. 1976

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the Committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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Geophysics Research Board
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Balloon Study Committee

ROBERT B. LEIGHTON, *Chairman*
California Institute of Technology

GEORGE B. FIELD
Harvard College Observatory

MARTIN H. ISRAEL
Washington University

WILLIAM L. KRAUSHAAR
University of Wisconsin

EDWARD P. NEY
University of Minnesota

JEREMIAH P. OSTRIKER
Princeton University Observatory

P. BUFORD PRICE, JR.
University of California

NAS-NRC Staff: EDWARD R. DYER, JR.

Reporters

C. J. WADDINGTON University of Minnesota	Cosmic-Ray Studies
DONALD KNIFFEN NASA Goddard Space Flight Center	High-Energy Gamma-Ray and Neutron Astronomy
JAMES D. KURFESS Naval Research Laboratory	Low-Energy Gamma-Ray and X-Ray Astronomy
GORDON A. NEWKIRK High Altitude Observatory, NCAR	Optical and Ultraviolet Astronomy
WILLIAM F. HOFFMANN University of Arizona	Infrared Astronomy
DONALD E. BROWNLEE University of Washington	Cosmic Dust Studies
GEORGE K. PARKS University of Washington	Magnetospheric Fields and Particles
D. J. HOFMANN University of Wyoming	Stratospheric Chemistry

Preface

There is widespread belief among scientists familiar with the capabilities of balloons that their potential for obtaining scientific data of the highest quality, at relatively low cost and with relatively short lead times for instrumental development, is not being fully realized. As a result, the Geophysics Research Board (GRB) and the Space Science Board (SSB) of the National Research Council (NRC) decided to undertake a review of this subject. The study was conducted by a Balloon Study Committee, established for administrative purposes under the GRB and supported by the National Science Foundation.

The charge to the Balloon Study Committee was "to prepare a report based on input from a broad segment of the scientific community assessing the potential and the limitations of balloons for scientific studies in physics and astronomy, including infrared, optical, x rays, gamma rays, cosmic rays, magnetospheric physics, and cosmic dust. Atmospheric sciences will not be included." The decision not to include atmospheric sciences was based on several factors. The initiative for the study came largely from those concerned with utilizing balloons for experiments in physics and astronomy. It was noted that atmospheric sciences have the continuing attention of the National Center for Atmospheric Research. At the request of the Board of Trustees of the University Corporation for Atmospheric Research (UCAR), a special study had been made of the projected future uses of balloons for atmospheric science experiments.* It was therefore decided that the additional effort required to undertake a study to give correspondingly complete coverage to atmospheric sciences was not

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*W. N. Hess, H. G. Houghton, and J. C. Beckman, Final Report of the Ad Hoc Balloon Committee, 1971 (internal report to the UCAR Board of Trustees with some further distribution). That report addressed two questions posed by UCAR: (1) Should we expect that attacks on important atmospheric problems of the 1970's will require or be substantially aided by experiments carried on large scientific balloons? (2) If the answer to the first question is "yes," what particular lines of development in ballooning are most important to effective progress in the atmospheric sciences in the 1970's?

justified. It was further indicated to the Committee that the report should address only scientific aspects and related technical questions as appropriate but should not address questions of organizations, facilities, and management of operations.

The Committee conducted the study in the following steps:

1. The research activities in physics and astronomy for which balloons are used were divided into seven fields of interest (see Part II). The instrumental techniques and the effects of the atmosphere on measurements vary so appreciably from field to field that the need for balloons and the requirements on balloons were expected to differ considerably. The seven original divisions were

Cosmic-Ray Studies
High-Energy Gamma Ray ($\geq$10 MeV) and Neutron Astronomy
Low-Energy Gamma Ray ($\leq$10 MeV) and X-Ray Astronomy
Optical and Ultraviolet Astronomy
Infrared Astronomy
Cosmic Dust Studies
Magnetospheric Fields and Particles

Without exception, balloonborne experiments in these disciplines are carried out in the stratosphere (well above 15 km altitude); so the study was confined to stratospheric ballooning.

2. A "data-base panel" was organized, comprising seven reporters, each an active research worker in one of the seven fields listed above, and two members of the Balloon Study Committee (P.B.P. and M.H.I.) to coordinate their work for the Committee. The assignment to the reporters was to review past scientific achievements in their respective fields, to assess the future promise of ballooning, to compare the effectiveness of ballooning with alternative techniques, and to identify future needs for development and funding of scientific ballooning.

The responses received as a result of the inquiry (see paragraph 3 below) persuaded the Committee to invite an eighth reporter to prepare a section on stratospheric chemistry. The inclusion (in Part II) of this reporter's discussion of stratospheric chemistry, as well as a few references to stratospheric chemistry in the main body of the report, is intended to give the reader some additional insights into important uses of balloons for scientific purposes. We believed that this was appropriate, even though stratospheric chemistry is part of atmospheric sciences and thus falls outside the direct charge to the committee. This caveat and the title of the report are expected to make clear to the reader that the report is directed primarily toward the use of balloons for physics and astronomy. It may be appropriate for a future report to be directed toward utilizing balloons for atmospheric sciences.

3. To help carry out the program outlined above, inquiries were sent to the approximately 150 persons who had used the National Scientific Balloon Facility at Palestine, Texas, or the Office of Naval Research Skyhook program in the previous five years, informing them of the Study and inviting (a) an expression of willingness to help and (b) suggestions of the names of other scientists who might also be interested. About 120 additional persons were suggested. More than half of the final total of 271 persons (which included a number of foreign investigators) showed a positive interest in helping the study, for example, by reviewing early drafts on the eight fields of interest and/or providing comments to the reporters. The first drafts were sent for comment to all correspondents who expressed interest (see Appendix D).

4. The statements of the reporters were reviewed at two meetings of the reporters and Committee members. First, a meeting of the data base panel with the Committee Chairman was devoted to a review of the reporters' first drafts, to the identification of a number of themes for future closer examination (especially those common to several fields, such as longer flights, higher flights, or heavier payloads), and to a preliminary evaluation of the impact of these on each of the eight fields. Following this meeting, the first drafts and the Committee's evaluation sheets were circulated to the correspondents for comment.

At the second meeting, the entire Committee had an opportunity to question the reporters closely on the basis of second drafts in which the reporters had taken account of comments received from correspondents and had either modified the first drafts or were prepared to give reasons for not doing so. After the meeting, the eight reporters had the opportunity to revise their reports to take account of the critiques given at the meeting. The final statements of the reporters thus reflect a considerable amount of input and discussion. The Committee accordingly believed that it would be desirable to include these statements as Part II of the report. Comments and recommendations in those statements are attributable solely to the respective reporter.

5. From these searching discussions, the Balloon Study Committee formulated the findings and recommendations contained in Part I of this report.

It is a pleasure to acknowledge the effective work of the reporters; the contributions of those who assisted the reporters; and the efforts of Edward R. Dyer, Jr., who provided the essential staff work for the study.

Robert B. Leighton, *Chairman*
George B. Field
Martin H. Israel
William L. Kraushaar
Edward P. Ney
Jeremiah P. Ostriker
P. Buford Price, Jr.

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Report of the Committee

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Introduction, Findings, and Recommendations

I. INTRODUCTION

Scientists have used balloons for more than a century with two broad research aims: to study directly, *in situ*, the atmosphere of the earth and to detect electromagnetic and material radiation from extraterrestrial sources that cannot penetrate the lower atmosphere. For the first purpose, present-day balloons have in some cases unique capabilities, and for the second, they offer real advantages for certain types of experiment when compared with other observing platforms such as aircraft or spacecraft.

The scientific achievements of ballooning are summarized in Chapter 2. (Appendix A is a brief primer on the practical aspects of scientific ballooning for readers unfamiliar with the subject.) In this chapter we note that the recent pace of discovery has not diminished and indeed has quite probably accelerated. In the last several years balloon experiments have achieved the following:

1. Measured the submillimeter cosmic background radiation on the short-wavelength side of the spectral peak, demonstrating that this radiation fits a 3 K blackbody spectrum. Other experiments have shown a high degree of isotropy of the blackbody radiation supporting a most important prediction of "big-bang" cosmologies and putting severe constraints on theories concerning primordial nucleosynthesis and the origin of galaxies.
2. Discovered, in the primary cosmic rays, complex nuclei, electrons, positrons, and uranium and also have begun to show the dependence of cosmic-ray composition on energy. These results provide extremely important clues to our understanding of the origin of cosmic rays and probably to the character of supernovae explosions and the circumstances of chemical element formation in exploding stars.

3. Detected the first stellar gamma-ray sources in the Crab and Vela supernovae remnants, thus providing evidence for current, very high-energy cosmic-ray generation in these stars. Other experiments detected a relatively narrow spectral line in the energy region near the electron–positron annihilation energy 511 keV in the direction of the galactic center.

4. Measured in the stratosphere trace constituents (nitrous oxide and chlorofluoromethanes) that dissociate into ozone-depleting catalysts. These direct measurements, including measurements of many of the catalysts themselves, provide vital information for assessing the possible effects of various contaminants on the ozone layer, which is the earth's shield from biologically damaging ultraviolet radiation.

In addition to this recent activity there is, because of a combination of scientific and technical factors, great promise for balloonborne experiments now being planned or conceived. Among these are the following:

1. A variety of technical developments in far-infrared astronomy permitting all-sky survey and mapping, high spectral resolution, and high-sensitivity photometry. Techniques in this new field of astronomy are developing rapidly, and we already know from extant work that the far-infrared luminosity of galaxies can be very large, exceeding the optical luminosity in some cases and indicating the existence of relatively small, extremely powerful energy sources.

2. Determination of the isotopic composition of elements as heavy as iron in the cosmic rays, providing very sensitive tests of models of cosmic-ray sources and nucleosynthesis; extension of precise elemental composition to higher charges and higher energies; and extension of measurements of the electron spectrum to higher energy. As an example of the scientific importance of such measurements, we note that the detection of radioactive isotopes in the primary spectrum would allow a direct determination of the ages and containment times of the galactic cosmic rays as a function of particle energy.

3. Measurements of the trace constituents of the stratosphere. Recent concern over the ozone layer has pointed to the importance of molecules present even in parts-per-billion concentration, and laboratory techniques of this degree of sensitivity are just beginning to be developed for *in situ* measurements in the stratosphere.

II. FINDINGS AND RECOMMENDATIONS

Following the plan for the study outlined in the Preface, the Balloon Study Committee, with the help of its eight reporters, sought comments and suggestions from a broad segment of the scientific community. As a result of searching discussions based on the documents prepared by the reporters, which in turn took into account the opinions of their colleagues in the ballooning community, and of their own deliberations,

1. The Committee finds:

(a) That ballooning as a whole has made, and continues to make, very significant contributions to science. The field is currently vigorous, and its prospects are excellent.

(b) That balloon techniques possess a number of important advantages over alternative ones, and in some fields balloons have unique capabilities. Capability of *in situ* atmospheric measurements, short lead times, relatively low costs, greater availability of flight opportunities, training of students are examples of the advantages of balloons.

(c) That a number of low-cost technical improvements can be made that will considerably increase the effectiveness of present ballooning operations.

(d) That major advances in several fields would follow if flights of significantly longer duration were possible.

2. The Committee notes (see Appendix B):

That funding for balloons and balloon flight operations has remained nearly level over the past several years despite general inflation, rising costs for plastic balloon material, the need for larger (hence more expensive) balloons, and the need for more balloons to fly experiments already funded by the relevant agencies.

3. In view of the above, the Committee *recommends:*

(a) That the relevant funding agencies augment the balloon program to an operational level moderately above the average of the past several years.

(b) That development of longer-duration flight techniques be aggressively pursued, provided that this does not detract from the operational level of the present program.

The remainder of this report provides a more detailed description of the study, of the various fields of research that utilize balloons scientifically, and of the factors that led to these findings and recommendations.

2
Achievements of Scientific Ballooning

The Committee was impressed with the unique contributions balloonborne instruments have made in a wide variety of scientific areas. In some fields, balloon instruments have provided most of the observations and data; in others, they have permitted some key observations even though the bulk of the data may have been gathered from other vehicles. In this chapter we summarize some of the major accomplishments detailed in the appended reports.

Far-infrared astronomy, a young and rapidly growing field, has made extensive use of balloons. A balloonborne telescope has mapped the intense infrared emission from the galactic center at 100 μm; the far-infrared luminosity of this region is comparable with the visual luminosity of the entire galaxy. Within the past year, balloonborne Fourier spectrometers have observed the submillimeter cosmic background radiation on the short-wavelength side of the spectral peak and found it to be consistent with the emission from a 3 K blackbody. The far-infrared flux has been measured from the sun, interstellar dust clouds, and several extragalactic objects.

Balloonborne instruments made the first identification of almost every important component of the *primary cosmic rays*—from the discovery in 1948 that these "rays" included complex nuclei to the first detection of electrons and positrons and the recent identification of uranium nuclei. Indeed cosmic-ray astrophysics over the energy range 10^2–10^4 MeV/nucleon has been almost entirely carried out with balloons, because the instruments required have been too large for available satellites and no other vehicle could give adequate exposure at high enough altitudes. With balloons the detailed elemental composition of the cosmic-ray nuclei from atomic number 1 through 26 has been established, providing important tests of theories of cosmic-ray sources and models of nucleosynthesis. Variations in the composition at high energies (above a few GeV/nucleon) have been observed, requiring modification of galactic propagation models. The electron energy spectrum has been measured over a wide range of energies, providing a test of galactic confinement models; in combination with radio observations of the synchrotron emission of the electrons, these data have also provided a measure of the galactic magnetic field.

Observations of *energetic x rays and gamma rays* from balloons have been responsible for a number of discoveries. In 1959, a high-energy x-ray continuum from the sun was observed during a solar flare; the spectrum of the emission provided the first direct evidence for nonthermal solar acceleration of electrons. The pulsar NP 0532 in the Crab nebula was first observed in high-energy x rays, and in gamma rays up to 100 MeV, with balloonborne instruments. A spectral line near 511 keV from the galactic center has recently been observed from balloons.

Balloons have carried *optical telescopes* to altitudes where atmospheric seeing is far superior to that obtainable on the ground. Around 1958, Stratoscope obtained high-resolution photographs of the solar photosphere, resulting in improved understanding of the solar granulation. Stellar spectroscopy in the near ultraviolet has also been carried out with balloons.

Dust particles recently collected in the stratosphere have elemental abundances similar to those found in primitive meteorites. This similarity would indicate that these particles, presumably of cometary origin, like the primitive meteorites are accretional aggregates of particles that condensed from gas of cosmic composition.

While the bulk of magnetospheric studies have been carried out from satellites, a number of observations important for understanding the *magnetosphere* have been made with balloons. Measurement of the bremsstrahlung x-ray emission from precipitating electrons has established the rate of precipitation and demonstrated its variability. Magnetospheric electric fields have been mapped with simultaneous balloon flights in widely separated locations. The neutron albedo from interactions of cosmic rays with the earth's atmosphere has been measured from balloons and shown quantitatively to be adequate for explaining the observed intensity of high-energy protons in the inner trapped radiation belt.

Balloonborne instruments have made significant measurements of *trace constituents in the stratosphere.* Nitric acid (HNO_3) was observed in 1968 at the level of parts per billion. This observation stimulated calculations showing that the nitrogen oxides that must produce this acid (and that were subsequently observed from balloons) may have a major effect on the stratospheric ozone balance, and that the emission of nitrogen oxides by SST's might have resulted in a significant depletion of this vital layer. Within the last year, data from balloonborne instruments have verified the prediction that chlorofluoromethanes (Dupont tradenames Freon 11 and Freon 12) reach the stratosphere. This observation has major environmental significance because these man-made substances are widely used as propellants in aerosol spray cans and as refrigerants; in the stratosphere they dissociate, producing Cl and ClO, which catalytically destroy ozone much more efficiently then do the nitrogen oxides. Some believe, however, that a yet undiscovered sink for Cl and ClO may reduce their concentration.

In addition to the scientific achievements of ballooning described above, the Committee was also impressed with the importance of balloons as a vehicle for *development of spaceflight instrumentation.* Most of the instruments that have flown on satellites to measure cosmic rays, gamma rays, and high-energy x rays were first used on balloons, where their operation could be tested and improved from flight to flight on a time scale very short compared with that of satellite investigations. Another example of balloon development paving the way for successful satellite observations was the coronagraph on Skylab, which achieved its fine results as a result of design improvements growing out of balloon flights of a similar instrument.

3

Comparison of Ballooning and Alternative Techniques

I. UNIQUE CAPABILITIES OF BALLOONS

For certain investigations balloons are uniquely suited or are greatly preferable to any other vehicle. A viable balloon capability is essential to progress in these fields.

For studies of the stratosphere, a strong case has been made for *in situ* observations, which are not possible on satellites. Remote sensing from satellites provides broader areal coverage and is useful for monitoring but does not provide sufficiently accurate vertical profiles such as are obtainable with *in situ* measurements on balloons. Furthermore, the ground truth of *in situ* observations is necessary for verification and calibration of remote-sensing techniques.

In cases where the technology is developing rapidly compared with the rate at which satellites can be built and flown, balloon experiments have powerful advantages. This appears to be the case at present for low-background infrared instrumentation. Far-infrared astronomy, with its requirements for cryogenic detectors and its rapid development of techniques, has made major advances with balloons, and for at least the next several years balloons seem to be indispensible for photometric observations and low-background, high-sensitivity measurements.

Collection of cosmic dust particles can be achieved only in the atmosphere. In space, the particles move too fast to be stopped nondestructively, so that they cannot be collected on satellites; but at balloon altitude they have been slowed by the air sufficiently to permit collection. Analysis of dust collected in the atmosphere complements observations from satellites of the trajectory of dust particles. Although some dust collection can be made from aircraft, for particles smaller than 1 μm the collection at aircraft altitudes is completely dominated by terrestrial contaminants, and for the rapidly falling particles larger than 100 μm volume air sampling from aircraft is much less efficient than a slow-moving horizontal collecting area carried on a balloon.

II. RELATIVE MERITS OF BALLOONS AND SATELLITES

For most astrophysical observations of cosmic rays, gamma rays, x rays, and ultraviolet and infrared radiation, an atmosphere above the instrument is undesirable either because it absorbs the radiation or because it is a source of background or both. Thus, in principle, satellites are superior to balloons for these studies. Nevertheless, many significant measurements of these radiations have been made with balloons rather than satellites. There are several reasons for the importance of balloonborne instruments. In many cases to date satellites have been unable to carry sufficiently large instruments. This has been true, for example, with most instruments for measuring cosmic rays at energies above a few hundred MeV/nucleon. Where satellites have been capable of larger payloads, there have been few opportunities: only the High Energy Astronomy Observatories (HEAO) for x-ray, gamma-ray, and cosmic-ray studies, Skylab for very heavy cosmic rays, and the Apollo Telescope Mount (ATM) for x rays. Also satellite lead times are typically four to six years, while balloon experiments typically take from several months to two years from inception to flight. Finally, balloon experiments are in many ways less costly.

In magnetospheric studies, scientists are often observing phenomena with rapid temporal variation. On rapidly moving satellites it can be difficult to separate temporal from spatial variations, while slow-moving balloons can give good measurements of temporal variations of, for example, precipitating electrons. Balloons have also been used to complement satellites with coordinated observations by a geostationary satellite and a balloon on the foot of the same geomagnetic field line.

A precise comparison of balloons and satellites for cost effectiveness is difficult. A satellite launch vehicle is orders of magnitude more costly than a balloon. (A balloon of average size, 300,000 m^3, costs of the order of $15,000; average cost of launch, tracking, recovery, and other support at the National Scientific Balloon Facility is also about $15,000. These balloon launch costs are tiny compared with those for a satellite—typically in the million-dollar range.) Construction of a scientific instrument for a satellite typically has cost three to ten times as much as for a comparable instrument on a balloon. This difference is partly attributable to the more severe environment of a satellite launch and partly to requirements for high reliability and quality assurance dictated by the one-shot, throwaway nature of satellite instruments. Balloon instruments are regularly recovered, refurbished if necessary, and flown again. Of course, the greater cost of the satellite experiment is often justified because of the improved data quality that results from being outside the atmosphere or from having a much longer observing time—one half to two years for typical satellites compared with one-half day to two days for typical balloon flights. Finally, it is recognized that there are many types of measurement that can be made *only* from spacecraft; but these are not the subject of this report.

The most difficult aspect of comparing cost effectiveness of balloons and satellites is in features that do not lend themselves to simple quantification—data bits per dollar, for example. Balloons, because of their low cost and their much milder environments, have permitted the development and use of innovative instruments that could be tried on one flight, modified, and reflown a few months later. Indeed there has been a justifiable bias in selection of satellite experiments *against* innovations and toward conservative, proven designs. A strong case can be made that a pioneering investigation on a balloon, today, is at least as important scientifically as a better experiment on a satellite several years from now; in fact, the balloon investigation is often a *necessary prerequisite* to a successful satellite experiment. To cite one example of such an experiment, Richards and co-workers have reported an infrared observation of the submillimeter cosmic background radiation on the short-wavelength side of the peak, using a balloonborne Fourier spectrometer (Woody *et al.*, Phys. Rev. Lett. *34*, 1036, 1975). Although this measurement will eventually be improved by observations from outside the atmosphere, we have a fundamental astrophysical result today, and we have proof of the feasibility of a new technique for astrophysical observations.

To appreciate fully the relative merits of balloons and satellites, one must consider also how serious the atmospheric problems are at balloon altitudes. Each of the eight discipline reports (see Part II) addresses this question in detail, but here we mention a few points to illustrate that good measurements can be made in the atmosphere. For low-energy gamma-ray observations in the approximate energy interval 50 keV to 5 MeV, contamination by atmospheric secondaries in balloon observations is less severe than the induced detector background as a satellite passes through the South Atlantic Anomaly; as a result, a long-duration balloon flight may be as good as or somewhat better than a typical satellite. At higher energies, variable sources can be extracted from the constant atmospheric background. For cosmic-ray observations, nuclear mean free paths of 10-100 g/cm^2 are to be compared with residual atmospheric depths of balloon flights of 2-3 g/cm^2 and with typical instruments containing one to several g/cm^2 of material; thus, for many observations, the atmospheric effects must be considered but are not highly significant. For far-infrared observations, the atmosphere at 30 km altitude is at least 99 percent transmissive, which is more than adequate for photometric measurements, although the concomitant 1 percent emissivity provides a background that can be the primary limitation to sensitivity, and residual atmospheric lines can present a difficulty for specific spectroscopic investigations.

III. GENERAL COMMENTS ON BALLOONS AND SATELLITES

The Committee recognizes that balloons are valuable for other reasons, not directly connected to scientific merits. Balloons have a certain advantage over satellites in the training of scientists. With the restricted number of space missions available and the long lead times, it is virtually impossible in a satellite program for a graduate student to participate in the classic mode of designing an experiment, building the instrument, carrying out the measurement, and interpreting the results. It is essential for the future of our country that we have a vigorous program of research and education that will attract bright young people to choose challenging fields. In the broadest sense, graduate education must train scientists who will not necessarily continue to work only in their rather narrow graduate research area but rather will use their knowledge in other research, either fundamental or applied, for the benefit of mankind. A balloon experiment in which a student participates from inception to completion seems to the Committee to be better suited for this broader and more versatile type of graduate education than is work on a more limited part of a satellite program.

A related feature of ballooning is that it provides interaction between the academic community and the space sciences. With ballooning, space science has involved substantial numbers of able scientists who would otherwise work in other fields more compatible with university resources and time scales. With a vigorous balloon program these individuals can contribute to the ferment of ideas and to the development of new technologies, which may not be adequately exploited in space science without them.

IV. IMPACT OF THE SHUTTLE

The Space Shuttle, scheduled for first flights in 1980, could have a significant impact on the relative merits of balloons and satellites. The Shuttle will be capable of carrying payloads heavier than any yet flown on balloons. It is planned that there will be frequent opportunities for flight on Shuttle sortie missions with durations of a week or two, at the end of which the instrument is returned to the ground. Reliability requirements may be relaxed compared with those on earlier satellites because of the capability of repair and reflight of the same instrument and because of the relatively lower cost of each launch compared with the launch costs of expendable vehicles.

The merits of balloons compared with satellites, as described above, will not change before the start of the Shuttle program in 1980. In fact, availability of Shuttle flights, comparable in frequency with current balloon availability (at least one per year for each active research group) will not occur in the first few years of the Shuttle program. Thus, balloons will remain essential, in spite of the Shuttle, for at least the next seven or eight years. Indeed, an active balloon program is necessary until frequent Shuttle opportunities are *actually available* if we are to have instruments and scientists ready to take full advantage of the Shuttle.

Until the Shuttle program is better defined with respect to reliability requirements, frequency of opportunities, and philosophy of experiment selection, it is difficult to predict the role of balloons beyond the mid-1980's. However, the Shuttle launch environment will surely be rougher than that of balloons, and some requirements must be imposed on Shuttle experiments to ensure the safety of the crew members; so Shuttle experiments will surely be more costly than balloon experiments, even if cheaper than current satellite experiments. Furthermore, the Shuttle will not provide the *in situ* stratospheric chemical measurements that cannot be replaced by remote-sensing measurements or measurements at a fixed, or slowly varying, location.

It might also be noted that the Shuttle may be a source of electromagnetic interference or may distort the particle populations and fields in its immediate environment (in a way that balloons do not), so as to make some sensitive measurements impossible and others difficult to interpret. Whether this will be a serious problem remains to be seen.

Finally, the Shuttle sortie, with a one- or two-week duration, is not a substitute for long-duration balloon flights as have been proposed with superpressure balloons. Although the Shuttle as a vehicle for placing free-flying satellites in orbit and later recovering them could be a substitute for long-duration balloon flights, frequent free-flyers are not planned in the early years of Shuttle.

V. BALLOONS COMPARED WITH ROCKETS, AIRCRAFT, AND THE GROUND AS OBSERVING PLATFORMS

Consideration of the merits of balloons as compared with rockets, aircraft, or ground-based observations is simpler than balloons compared with satellites.

Rockets give very short-duration observations, typically a few minutes. They are preferred over balloons only where balloon altitudes are insufficient for overcoming atmospheric extinction, such as for x rays below about 30 keV, or for obtaining *in situ* atmospheric measurements at altitudes above 50 km.

Aircraft altitudes are too deep in the atmosphere for observation of primary cosmic rays, gamma rays, or x rays. Aircraft are currently useful for infrared observations requiring very accurate pointing or complex instrumentation such as spectrometry, but for greatest sensitivity and for photometric observations balloon altitudes are required. Aircraft are also useful for air sampling in the troposphere and lower stratosphere.

Ground-based observations are useful in specific wavelength bands of the near infrared but are impossible in the far infrared, so they complement rather than compete with balloons. Ground-based arrays of particle detectors measure atmospheric secondaries produced by very rare extremely high-energy cosmic rays but do not identify the primary nucleus; cosmic-ray detectors on balloons and satellites operate at "lower" energies (below several hundred GeV) and do identify the primary nuclei. So for cosmic rays, ground-based observations again complement, rather than compete with, balloons. Ground-based "radar" at optical wavelengths using lasers (lidar) is useful for monitoring atmospheric particulates in regions where concentrations are sufficiently high ($>1\ \mathrm{cm}^{-3}$) and particle sizes are sufficiently large ($>0.5\ \mu\mathrm{m}$); however, such measurements are dependent on particle composition and shape and thus are not independent of *in situ* measurements.

4

Future Scientific Prospects for Balloonborne Instruments

Balloonborne experiments are, and will remain, in the forefront of research in several fields until well into the Shuttle era, and in some fields balloons will continue to play an essential role throughout the foreseeable future. The following sections briefly summarize some of the salient scientific opportunities.

I. COSMIC RAYS

The trends in cosmic-ray research are toward larger and larger detectors of improved discriminating power that can operate in existing balloons at depths of ~ 3 g/cm^2, but the field could profit from flights of at least one-week duration. Transatlantic flights are an attractive possibility. Most of these instruments would tax the envisaged lifting power of superpressure balloons. Examples are:

1. Instruments as large as 1 m^2 in area designed to resolve adjacent isotopes differing in mass by as little as 2 percent have been designed and are being readied for use in existing balloons. Detectors now on satellites were mostly designed more than five years ago and have neither the resolution nor collecting power to resolve isotopes of the heavy elements in the cosmic radiation.
2. Light-weight, large-volume transition radiation detectors are nearly ready for use in balloons. They can extend our knowledge of the electron energy spectrum to beyond 10^{12} eV and may extend our knowledge of the composition of the most abundant elements in the cosmic rays into the region of several hundred to 1000 GeV/nucleon, given a flight of several days.
3. More stringent limits on the fluxes of antinuclei in cosmic rays might be achieved by long-duration balloon flights.

4. Electronic detectors with 10 m^2 area and ability to resolve individual elements are now being flown and will extend our knowledge of individual element abundances from charge 28 (today's limit) to about charge 50 or 60.

II. HIGH-ENERGY GAMMA RAYS AND NEUTRONS

Again, long-duration measurements are required.

1. Improved measurements can be made of pulsed gamma rays from the Crab and Vela pulsars, and a search can be made for other gamma-ray pulsars.
2. Fluctuating gamma-ray emission can be sought in such variable objects as quasars, Seyfert galaxies, N-galaxies, and BL Lac objects.
3. High-energy gamma rays can be sought in solar flares and gamma-ray bursts.
4. With a 1000-kg neutron detector one could study solar neutrons—during a quiet time or possibly during one of the rather frequent modest-sized flares.

III. X RAYS AND LOW-ENERGY GAMMA RAYS

The instrumentation tends not to be so heavy as that for extending the frontier of cosmic-ray research and might thus be deployed for periods of several months in superpressure balloons. Several areas that could profit from long-duration balloon flights follow:

1. Solar flares, especially polarimetry of high-energy x rays and the detection of x-ray lines.
2. The time variability of celestial x-ray sources.
3. Gamma-ray lines from galactic sources or immediately following a supernova event in a nearby galaxy. An instrument could be sent up by balloon shortly after optical sighting of the supernova.
4. Gamma-ray bursts could be located by flying square-meter-sized detectors and/or imaging detectors using coded-aperture techniques to give direction and with capability for real-time data reduction. An exposure of at least one month might make it possible to distinguish between spherical, planar, and line source distributions.

In some of these experiments one trades freedom from the background of radioactivity induced in a satellite by hourly passage through the South Atlantic Anomaly for the lower signal-to-noise ratio due to residual atmosphere above balloon level.

IV. INFRARED ASTRONOMY

In this new and burgeoning field, perhaps the foremost prospect is the rapid development of low-background instrumentation to obtain high data rates, long before such instruments would be acceptable for satellites. Such apparatus would include (a) background-limited far-infrared detectors, (b) low-temperature telescope systems, (c) detector arrays or spatial multiplex techniques, (d) efficient filter combinations for spectral definition, and (e) broadband multiplex spectrometers. Most of these developments can be considered as prototypes for eventual satellite applications.

Examples of the kinds of science that can readily be done from balloons are:

1. All-sky surveys with a number of spectral bands throughout the infrared region to search for special objects and to determine the distribution of sources of various types.
2. Mapping of restricted regions of high interest with much higher data rates than are possible from aircraft.
3. Spectroscopy of sources in the 30- to 100-μm region.
4. Further measurements of the spectrum and anisotropy of the submillimeter cosmic background radiation.

V. COSMIC DUST

Collection of cosmic dust from balloons will not be affected by the Space Shuttle because it is improbable that cosmic dust can ever be nondestructively collected in space. Balloon collections will, however, have competition from stratospheric aircraft. In the future, particles in the 3–25 μm size range will probably be collected by U-2 or RPV aircraft, while smaller and larger particles will be collected by balloon experiments.

Specific future prospects in this field center on the analysis of collected particles to provide detailed knowledge of the physical nature of cometary matter:

1. Collection of submicrometer interplanetary dust using air sampling systems above 40 km.
2. Long-duration collection of large (>50 μm) particles using settling plate collectors flown with superpressure balloons.
3. Collection of debris from large meteor fireball events (similar to Revelstoke).

VI. PARTICLES AND FIELDS IN THE MAGNETOSPHERE

Some of the scientific problems to be investigated in magnetosphere particles and fields cannot be done easily by other means since the measurements require sending instruments on many balloons at the same time from different geographical regions. Specific measurements include, for example:

1. Determination of spatial features in x rays from a few kilometers to tens of kilometers.
2. Motions of auroral x-ray sources from a few meters per second to hundreds of kilometers per second.
3. Imaging of auroras in x rays.
4. Global distribution of magnetospheric electric fields.
5. Assessment of active plasma experiments during Space Shuttle flights.

VII. STRATOSPHERIC CHEMISTRY

It is perfectly straightforward with balloons of modest size and existing instrumentation to continue programs of measurement of stratospheric constituents, both particulate and gaseous, some of which are of concern to life on earth. Of particular current concern are:

1. *In situ* measurements of trace gases involved in ozone production and destruction.
2. Measurement of SO_2 in the atmosphere, important for aerosol production.
3. Measurement of dynamical atmospheric parameters such as eddy-diffusion coefficients for atmospheric modeling.
4. Measurement of condensation nuclei above 30 km, important for aerosol production and as Space Shuttle baseline data.

5
Future Needs in Ballooning

A considerable part of the discussions of the Committee and its reporters was devoted to the *future needs* of scientific ballooning. The results of these discussions, principally an evaluation of the impact that each of a number of possible improvements in ballooning capability would have in various scientific fields, are summarized in this section. Although the results largely reflect the conclusions of the reporters, their factual basis has been carefully examined and is fully accepted by the Committee; they are a principal basis for the Committee findings and recommendations presented earlier.

Figure C.1 (Appendix C) shows the typical altitudes presently attainable by zero-pressure balloons as a function of scientific package weight and balloon volume. Science packages of about 2000 kg can be carried to altitudes ranging from about 34 km (~ 7 g/cm^2 residual atmosphere) up to nearly 40 km (~ 3 g/cm^2), at a cost (for balloon plus helium) ranging from ~\$10,000 to ~\$40,000. Balloons of similar cost can carry scientific packages of a few hundred kilograms to altitudes of about 40-45 (1.5 g/cm^2). With a fixed budget there is always a tradeoff between altitude reached and number of flights per year. Flight durations vary from several hours, attainable almost any time of year, to two or three days, attainable during a few weeks in spring and a few weeks in fall when the stratospheric winds are light and variable.

The obvious directions for improvements in ballooning are to increase flight duration, altitude, and payload capability. Related improvements in facilities for balloon operations and in capability for launches from locations other than Palestine, Texas, or Fort Churchill, Canada, are also important in some fields. The reporters examined the impact of each of these factors on each of the disciplines, asking whether each improvement would have (1) great impact, (2) some impact, or (3) little impact. In a subsequent mail questionnaire sent to users in the different disciplines, the reporters found that the responses of the users generally agreed quite well with their own evaluation. The conclusions are summarized below.

I. INCREASED FLIGHT DURATION

Two approaches to increased flight duration were discussed—superpressure balloons and transoceanic flights of zero-pressure balloons.

Interest in superpressure balloons has grown over a number of years, and successful test flights of several weeks' duration have markedly increased the enthusiasm of some scientists for large, reliable superpressure balloons. In fact, one of the major reasons for this study was to ascertain to what extent a vigorous program to develop superpressure balloons should be encouraged.

Beginning in 1975 with $600,000 of support from the National Science Foundation, and an additional $290,000 in 1976, the National Scientific Balloon Facility (NSBF) at Palestine, Texas, has initiated a program with the principal goal of regular operation, by 1978, of superpressure balloons capable of carrying 225 kg at 3 mbar (~40 km) for several months.

Successful, reliable superpressure balloons would have *great impact* on studies of x rays and low-energy gamma rays, the upper atmosphere, cosmic dust, and magnetospheric particles and fields. In each of these disciplines current experiments are strongly limited by observing time, and excellent instruments could be built within the constraints of a 225-kg gross load. Several specific examples of important experiments (such as searches for cosmic gamma-ray bursts) that would be done from superpressure balloons are given in Chapter 3 and are detailed in the reports in Part II.

In the remaining disciplines, the Committee concluded that superpressure balloons would have *some impact* but that it would be more limited, either because many of the likely experiments in that discipline would require payloads much heavier than 225 kg, or, as with infrared, because most experiments require liquid helium temperatures for the full duration of the flight.

Recently, a joint effort by the United States, the United Kingdom, and Italy has demonstrated the feasibility of transatlantic flights by conventional zero-pressure balloons. These flights offer increased flight duration without sacrificing payload capability and without being confined to the few weeks in spring and fall when stratospheric winds are light and variable. The first such flight was launched in Sicily on August 5, 1975, and was recovered near Lexington, Kentucky, 83 hours later. The flight successfully carried a 1000-kg payload at approximately 37-km altitude ($4\ g/cm^2$) using a $6 \times 10^5\ m^3$ balloon.

Transatlantic flights or other flights of greater than five days would be expected to have *great impact* in all the disciplines where superpressure flights would. While some magnetospheric studies require circumpolar locations, studies of middle-latitude precipitation by measuring the x rays it produces (especially precipitation from the radiation belt thought to be produced by VLF radiation near $L = 2.5$) will benefit from transatlantic flights, especially across the South Atlantic Anomaly. In addition, transatlantic flights might have *greater impact* for cosmic-ray and high-energy gamma-ray studies than superpressure balloons, because of the greater load-carrying capability. They might also be valuable for infrared experiments, where the duration is compatible with convenient cryogenic technology.

II. INCREASED ALTITUDE

Flights at higher altitudes, up to 0.5 g/cm^2 residual atmosphere, would have *great impact* on both astrophysical x-ray studies and magnetospheric studies of x rays from precipitating electrons. Increasing altitude from 1.5 to 0.5 g/cm^2 lowers the minimum useful x-ray energy limit from about 25 keV to about 15 keV. With the very steep spectra typically observed, a threshold lower by 10 keV can increase the observed flux by a factor of 5. Increased altitude would also have *great impact* on high-energy gamma-ray studies for which atmospheric secondaries, even at 2 or 3 g/cm^2, are a very troublesome background; and it would have *some impact* on cosmic-ray studies, for which atmospheric corrections are also a problem.

III. INCREASED PAYLOAD

The capability to carry a payload as heavy as 5000 kg to 3 or 4 g/cm^2 would have *some impact* on cosmic-ray studies, especially in preparations for the Space Shuttle. This capability would have *little or no impact* on the other disciplines.

IV. FLIGHTS ACROSS INTERNATIONAL BORDERS

The Committee and reporters strongly support efforts to achieve agreements with Mexico and Canada for balloon overflights. Many excellent flights launched from Palestine have had to be prematurely terminated to prevent crossing the Mexican border, at the cost of many hours of good data. In some cosmic-ray experiments it would be valuable to launch from the southern tip of Texas to take advantage of the higher geomagnetic cutoff at the more southerly location. In this case it would be absolutely necessary to have permission to overfly Mexico. There is now an even greater interest among cosmic-ray experimenters in flying experiments at very low geomagnetic cutoffs, which can be satisfactorily attained provided the payload is launched near the Canadian border. A slight southerly wind can force premature termination of a flight unless there is agreement with Canada for the overflight.

V. NATIONAL SCIENTIFIC BALLOON FACILITY

A capability to accommodate more balloon flights in a short period from NSBF would have *great impact* on cosmic-ray and gamma-ray studies and *some impact* on x rays, infrared, and cosmic dust. The NSBF is badly overcrowded during the spring and fall reversals of the stratospheric winds in May and September, when many scientists attempt to take advantage of the light winds to achieve flights of two- or three-day duration. Limitations on space for scientists' preparation and on the number of balloons that can be launched or tracked simultaneously mean that many scientists in fact miss the wind reversal and have to settle for flights of 10- or 20-hour duration.

VI. INCREASED CAPABILITY FOR HIGH-LATITUDE LAUNCHES

An increased capability, by NSBF or others such as the Office of Naval Research, to launch balloons from the northern United States or southern Canada near the time of the semiannual wind reversals would have *great impact* on cosmic-ray studies. In the fall of 1975, more cosmic-ray instruments requiring high latitude (low geomagnetic cutoff) were ready to fly than could be accommodated. As a result, some important experiments had to be delayed until the following spring. This problem could immediately be solved by enlarging the budget for ballooning.

VII. INCREASED CAPABILITY FOR FLIGHTS IN THE SOUTHERN HEMISPHERE

While this study was in progress, a bilateral agreement was signed between the National Science Foundation and the Australian Department of Science for continued utilization of the Australian Balloon Facility by U.S. investigators. This capability for southern-hemisphere flights will be achieved with modest increase in balloon funding. It should have a *great impact* on disciplines that study individual astronomical objects—gamma-ray, x-ray, and infrared. Increased ability to fly near the equator would also have *great impact* on gamma-ray studies, because the high geomagnetic cutoff there decreases the atmospheric background from interactions of charged cosmic rays. Finally, any increase in capability to fly from a variety of locations would have *great impact* on stratospheric studies for which *in situ* measurements at a variety of locations are essential.

VIII. DOWN-RANGE REPEATER

Experiments that require real-time control using special equipment in Palestine would *profit greatly* from down-range repeater capability at NSBF. (Such experiments are principally in the areas of infrared and low-energy gamma rays.) It is already within NSBF capability to provide a down-range telemetry receiver and command transmitter for balloon flights that go beyond line-of-sight range of Palestine (approximately 350 miles). However, for experiments requiring complex real-time control with equipment in Palestine this current capability is inadequate, and flights are terminated near 350 miles. For these experiments the useful range would be more than doubled by a down-range repeater station capable of transmitting data from the balloon back to Palestine for processing and relaying commands from Palestine back to the balloon. Longer range means productive use of the NSBF facility even in seasons of stronger winds.

Some of the experiments requiring real-time control use only the NSBF computer, which is now in Palestine. For these experiments, an alternative to a down-range repeater would be the addition of a duplicate computer to the down-range telemetry station. Other experiments use unique experimenter-provided equipment for real-time control, and for these the down-range repeater is the only way of achieving this extended range.

IX. SIMULTANEOUS FLIGHTS AT WIDELY SEPARATED LOCATIONS

Increased capability for simultaneous flights at widely separated locations would be of *great impact* to magnetospheric studies, where phenomena have wide variations both temporally and spatially, and similarly would have *some impact* on stratospheric studies. Low-energy gamma-ray studies would *benefit greatly* from widely separated simultaneous flights if it proves possible to locate the cosmic gamma-ray bursts by precise timing (1 msec or better) on widely separated instruments.

X. INCREASED SUPPORT FOR CURRENT PROGRAMS

The Committee concludes that none of the improvements listed above should be made at the expense of the current level of support for the existing ballooning capabilities. In every discipline good science is being done with existing balloons. These efforts are, in many cases, being hampered by a continual *decline* over the past several years in constant-dollar funding. The decline is particularly aggravated by two effects: (1) The cost of the plastic film out of which balloons are made suddenly increased by a large amount as a result of the recent increase in price of petroleum products. (2) With the advancing frontier of space research and improved reliability of large balloons, the average size and cost of balloons have increased every year; and with monetary inflation and its effects on salaries and per diem, the cost of expeditions has steadily increased.

The Committee is distressed at the steady erosion in effective support for existing ballooning and *places highest priority on maintaining at least level constant-dollar funding.* In fact, for cosmic-ray and gamma-ray research, for which current experiments tend to use the largest and most expensive balloons, *increased* constant-dollar funding of existing programs is at least as important as funding any improvements in balloon technology. With continuing stringent budget limitations, decisions on cost tradeoffs would frequently have to be made. As an example, superpressure balloons will almost certainly be considerably more expensive than zero-pressure balloons. (Of course, more data can be collected, which means that cost effectiveness must be carefully considered.) Unless the budget for ballooning is increased significantly, every superpressure balloon authorized for an experimenter would mean the loss of several zero-pressure balloons to other experimenters.

Appendix A: Notes on Some Practical Aspects of Scientific Ballooning

Balloons for carrying scientific instruments into the stratosphere range in size from about 2000 to over a million cubic meters. They carry instruments weighing from a few to a few thousand kilograms and reach altitudes between 25 and 50 kilometers.

The smallest balloons, carrying instruments lighter than 50 kg, are launched by the scientists themselves from almost any location. About 50 to 70 of these are launched annually by United States scientists, mainly in studies of the stratosphere and also for magnetospheric studies. Larger balloons, carrying scientific instruments heavier than 50 kg, are launched about 80 or 90 times a year by specially trained crews at relatively few locations. The Committee's attention was focused principally on these larger balloons, because they are required for most of the ballooning in physics and astronomy and they take the bulk of the balloon budgets. The remainder of this appendix is devoted to these larger balloons.

The National Scientific Balloon Facility (NSBF) in Palestine, Texas, is the most commonly used launch site. The NSBF has a full-time crew and extensive facilities devoted solely to scientific ballooning. Generally flights by U.S. scientists are launched from other locations only when scientific requirements preclude a Palestine launch, for example, astronomical flights devoted to objects visible only in the southern hemisphere or cosmic-ray studies of low-energy nuclei that reach the atmosphere only at higher geomagnetic latitudes. The NSBF crew conducts balloon expeditions for such flights both in the United States and at foreign locations such as Brazil and Australia.

The Office of Naval Research (ONR) Skyhook Project regularly conducts balloon operations from Canada and the northern United States, utilizing launch crews contracted from industry. There is an Australian Balloon Facility that is used by U.S. investigators under a bilateral agreement between the National Science Foundation and the Australian Department of Science. Launches by the Air Force

Cambridge Research Laboratory (now renamed Air Force Geophysics Laboratory) from Chico, California, and Holloman Air Force Base are principally in support of Air Force operational requirements, although flights have been carried out for scientists from outside the Air Force.

Scientists bring their instruments to a site such as NSBF and spend between a week and a month in final instrument preparation and checkout. The balloon crew is then responsible for attaching the package to the balloon, launch, tracking, and recovery of the instrument. Often there is a wait of several days after the instrument is ready before suitable launch weather arrives—surface winds less than 5 m/sec and little cloud cover. In a typical flight, the balloon ascends to float altitude in two to four hours and then floats at approximately constant altitude for several hours to two or three days. Throughout the flight, the scientific package hangs from a parachute, which in turn is attached to the base of the balloon; on a radio command the parachute is separated from the balloon and the package falls to the ground under the open chute, while the balloon is destroyed and falls separately. The instruments are recovered and often flown again a few weeks to a year later.

Figures A.1-A.8 show photographs of various aspects of ballooning operations.

Normally each balloon carries one scientific instrument and the control package provided by the balloon crew for tracking and radio command. Scientific data may be recorded on board or telemetered during the flight using either a downlink provided by the balloon crew or one provided by the scientists themselves. Small simple experiments are sometimes flown as "hitchhikers" on a balloon principally devoted to another larger instrument. Otherwise flights with more than one instrument are rare.

Experimenters using instruments pointed toward specific astronomical objects normally provide their own pointing mechanism as part of their instrument. Systems capable of pointing for extended periods with accuracy of a few minutes of arc are currently flown; and pointing considerably better than a second of arc was achieved by Stratoscope II for its planetary imaging to take maximum advantage of its diffraction-limited 36-in. optics.

Appendix C on balloon performance summarizes balloon and instrument sizes, flight durations, and altitudes for flights in several recent years. Also presented are the number of flights in each of the scientific areas covered in this report; in 1974 about 75 percent of the flights were accounted for by three areas—cosmic rays, low-energy

FIGURE A.1 A large balloon being inflated in preparation for launching a Washington University cosmic-ray package. (Photograph courtesy of Richard N. Levine, Washington University, St. Louis.)

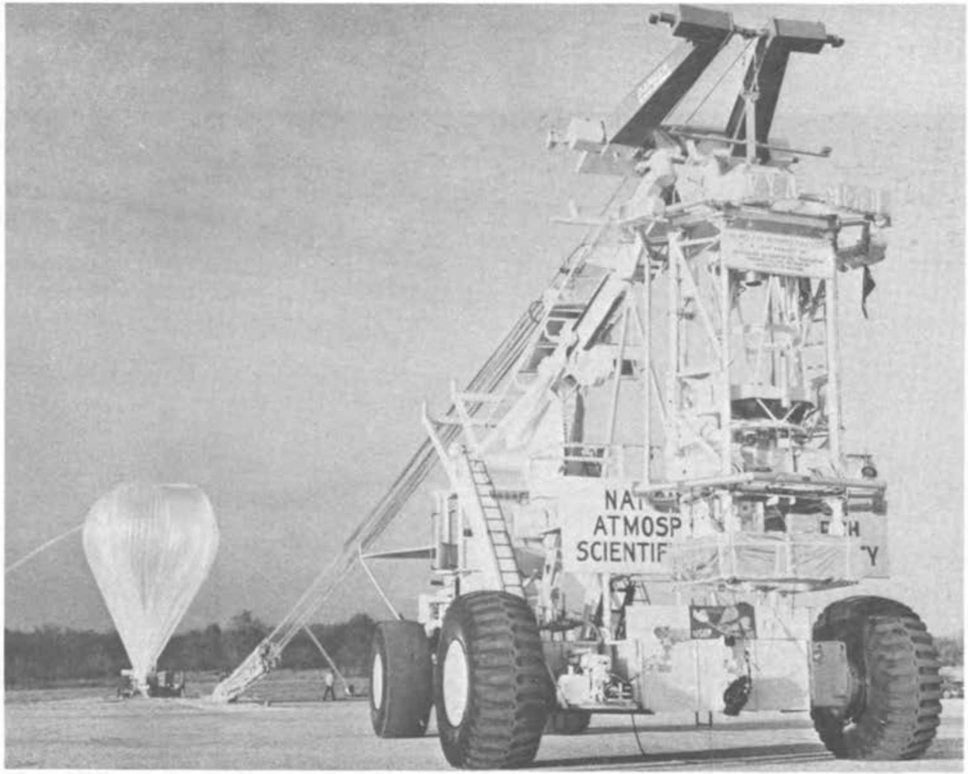

FIGURE A.2 A 1-m-aperture telescope designed to study celestial sources of far-infrared radiation (a joint project of the Smithsonian Astrophysical Observatory, Harvard College Observatory, and the University of Arizona), suspended from the release arm of a specially designed vehicle called "Tiny Tim." The package is connected by shroud lines to its parachute (middle background), which is in turn fastened to the nearly inflated balloon. (Photograph courtesy of the National Center for Atmospheric Research and the NSBF.)

FIGURE A.3 A different view of the same scene as in Figure A.2. The men standing beside "Tiny Tim" give some sense of scale. This picture and the next three show the launch sequence for the far-infrared telescope package shown in Figure A.2. (Photograph courtesy of NCAR and the NSBF.)

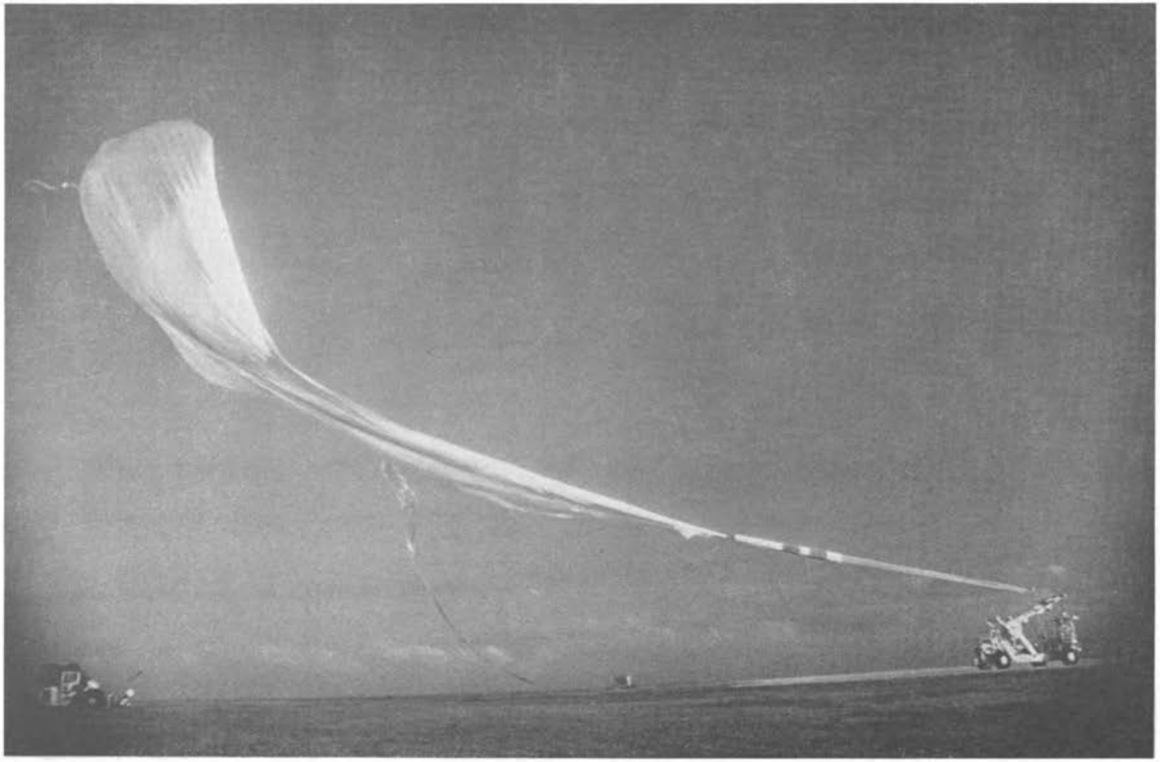

FIGURE A.4 The balloon has just been released from the spool vehicle. One of the now sealed off umbilical filler tubes can be seen flapping from the balloon. (Photograph courtesy of NCAR and the NSBF.)

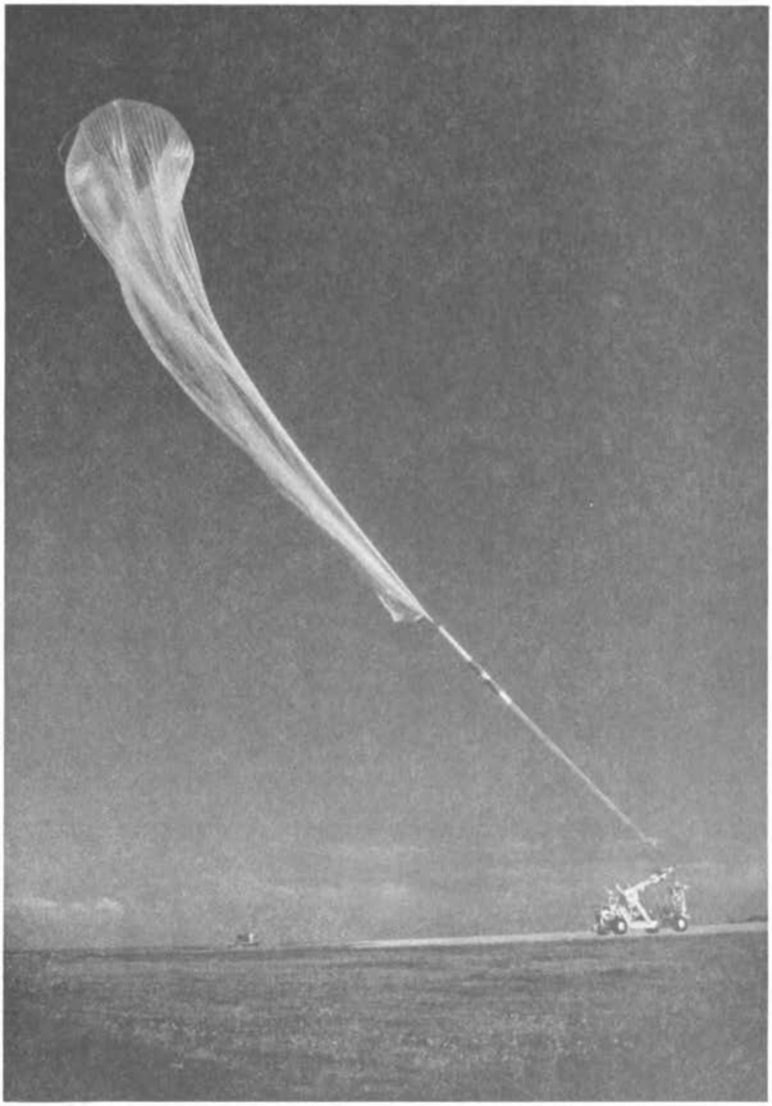

FIGURE A.5 "Tiny Tim" will release the instrument package at the moment when, if released, it will not swing into the ground. (Photograph courtesy of NCAR and the NSBF.)

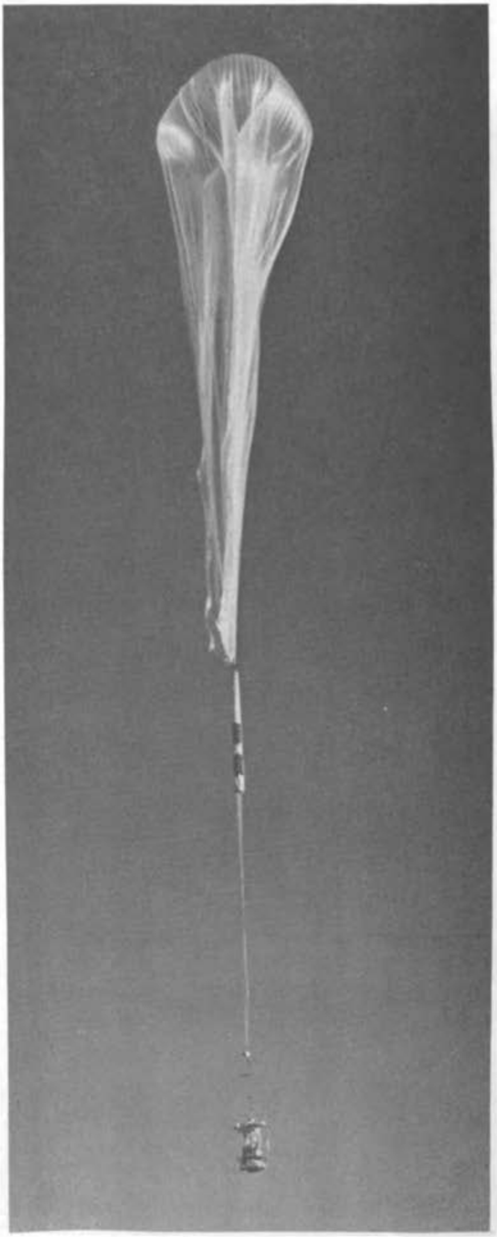

FIGURE A.6 The balloon and package are free and begin their approximately 3-hour climb to float altitude. (Photograph courtesy of NCAR and the NSBF.)

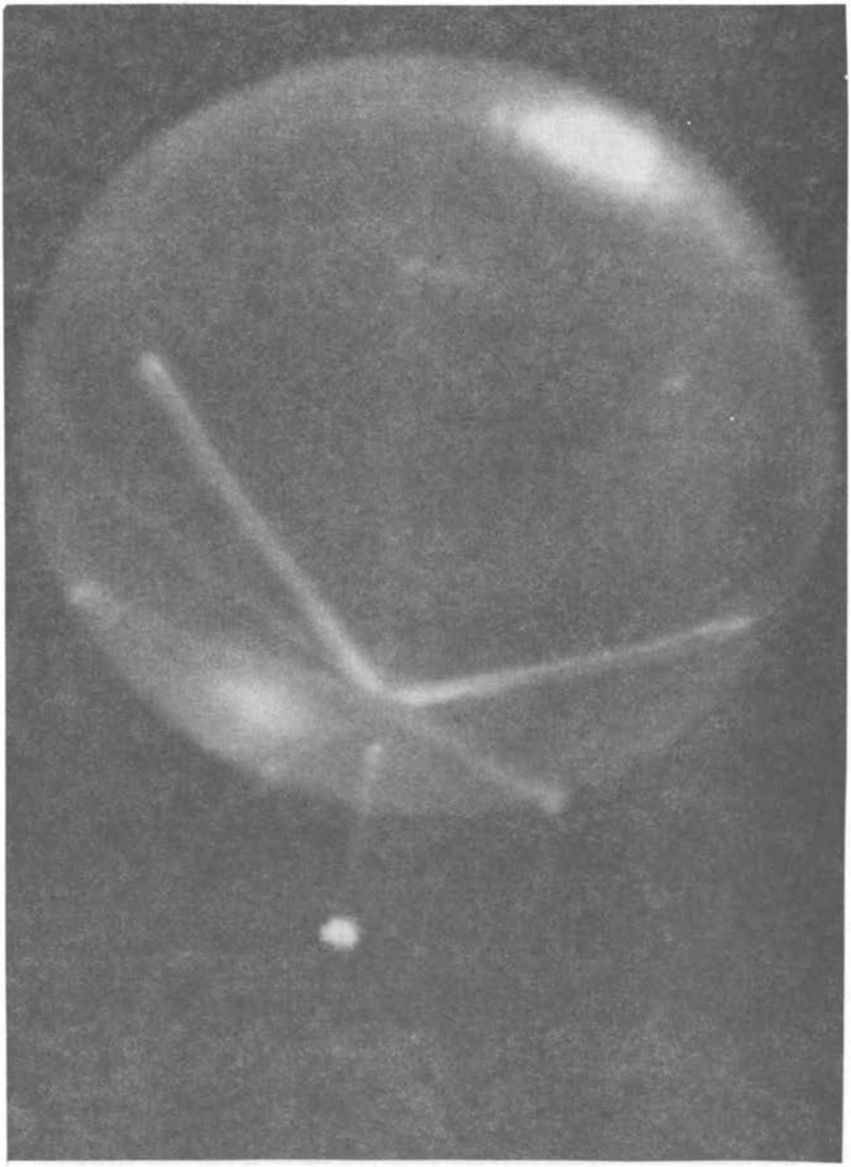

FIGURE A.7 A 570,000 m^3 (20-million-cubic-ft) balloon at float altitude, about 40 km (130,000 ft) as photographed from the ground with an NCAR Questar. At an ambient pressure of less than 3 mbar compared with about 1000 mbar at sea level, the balloon is now fully expanded. The thicker spokelike lines are "tailored" ducts for releasing helium. (Photograph courtesy of NCAR and the NSBF.)

FIGURE A.8 A Washington University large and heavily padded cosmic-ray package about to touch down, as seen from the chase plane. (Photograph courtesy of Richard N. Levine, Washington University, St. Louis.)

gamma and energetic x rays, and infrared, with each of these areas using about 25 percent of the flights.

Balloon altitudes may be expressed directly in linear units (usually kilometers or thousands of feet); but experimenters, to whom the amount of residual atmosphere above the balloon is important, often express the altitude as the mass per column of unit cross section (g/cm^2) of that overlying residual atmosphere or as the atmospheric pressure (in millibars) at that altitude. (The numerical expressions for these are equivalent to within 2 percent.) In thinking of what is *above* the balloon, experimenters frequently refer to these altitude equivalents as "depths." Table A.1 gives some conversion factors.

For any given instrument weight the altitude is determined by the balloon volume. A recent record altitude of 52 km (0.6 mbar) was achieved with a 1.3 million-cubic-meter balloon carrying a 230-kg load. (mbar = millibar pressure. Sea level is approximately 1 bar.) In this case, the weight of the balloon itself was so much greater than the load that the altitude was determined almost entirely by the balloon. For heavier instruments, one trades instrument weight for altitude on a given balloon. Instruments of 700 to 1000 kg routinely fly at altitudes of 38 km (4 mbar) to 40 km (3 mbar) using balloons of 3×10^5 m^3 to 6×10^5 m^3, while balloons of similar size routinely carry 300- to 400-kg instruments to 40 to 43 km (3 to 2 mbar).

TABLE A.1 Atmospheric Pressure versus Altitude (30° N, January and July)

	Pressure (mbar)	
Altitude (km)	January	July
0	1021	1013
10	276	287
20	55	58
25	25	27
30	11.7	12.7
35	5.7	6.2
40	2.9	3.2
45	1.5	1.7
50	0.79	0.89
55	0.42	0.48
60	0.22	0.25

Notes: (1) Average pressures vary by several percent as a function of latitude and season.

(2) 1 atmosphere = 1013 mbar = 1033 g/cm^2. Thus altitudes expressed in mbar and in g/cm^2 are numerically equivalent within 2 percent.

(3) 30 km = 98,425 feet, or 100,000 feet in round numbers.

During most of the year, when stratospheric winds at typical balloon altitudes are around 100 km/hour or more, flight duration is limited to 10 to 15 hours by geographic and political boundaries. Recovery is extremely difficult or impossible if the instrument lands in the ocean. Many flights launched from Texas have been terminated because of government restrictions against overflying Mexico. A number of flights require data at the launch site during flight and are terminated when the balloon reaches the limit of line-of-sight telemetry—approximately 500 km. One way of overcoming the problem of ocean recovery is to permit the balloon to fly across the ocean, as was recently done with a balloon launched in Sicily and recovered in the United States.

Flights of two or three days' duration are achieved during the few weeks in spring and fall when the stratospheric winds are light and variable as they change from summer easterlies to winter westerlies. Because this period of light winds is so short, launch facilities and crews are severely taxed at these times.

Another limit to flight duration comes from the dynamics of standard zero-pressure balloons. These balloons are vented at the bottom; as the helium expands because of decreasing air pressure during ascent or solar heating while at float, the excess spills out. At sunset, when the helium cools, the balloon contracts and falls to a much lower altitude unless ballast is dropped to compensate for the loss of lift. Indeed, under some conditions, without dropping ballast the balloon would descend below 20 km, where Federal Aviation Administration regulations will not permit floating balloons, and the flight would be terminated. The need for a significant ballast drop at each sunset adds to the load carried by the balloon and so introduces a trade-off among altitude, balloon size (cost), and float duration. Thus zero-pressure balloons can achieve flights of several days but not much longer.

Superpressure balloons, on the other hand, are sealed and filled with sufficient overpressure to ensure that their volume is unchanged by sunset cooling of the helium. For these balloons, float duration is limited only by the life of the material under extended exposure to solar radiation. The problems of national boundaries are solved by flying in the southern hemisphere with launch in Australia or Antarctica. Superpressure balloons carrying loads of about 50 kg, floating at 25 to 30 km, have circled the southern hemisphere several times with flights of one to several months. A program is under way at the NSBF with the goal of regular operation by 1978 of superpressure balloons capable of carrying 225 kg at 40 km (3 mbar) for several months.

Appendix B: Present Funding for Balloons and Rationale for Future Support

I. PRESENT FUNDING

Funding for scientific ballooning comes principally from the National Aeronautics and Space Administration (NASA) and the National Science Foundation (NSF). For the past six years, NASA Headquarters has had a $1 million annual balloon budget. Of this, $100,000 goes to the NSBF and $50,000 to the Office of Naval Research (ONR) for engineering research and development of ballooning. The remaining $850,000 is used for the purchase of balloons and helium and for balloon flight operations for university scientists funded by NASA; $450,000 of this goes to the NSBF to buy balloons and helium and $400,000 to the ONR Skyhook program. In addition, scientists at NASA centers (such as the Goddard Space Flight Center or the Johnson Space Center) or NASA-supported centers (like the Jet Propulsion Laboratory) pay the NSBF from their own research funds for the balloons and helium that the NSBF buys as their purchasing agent. This represents another roughly $400,000 a year from NASA for ballooning.

NSF sponsors the NSBF with an annual operating budget of about $1.1 million administered through the National Center for Atmospheric Research (NCAR); this budget has been essentially level (within a range of 2 percent) for at least the past five years. NSF-supported scientists pay for balloons and helium out of their own research grants. This figure is estimated at about $190,000 a year. Of this amount, NSF-supported scientists channel about $40,000 a year through the NSBF to pay for balloons and helium that the NSBF buys for them; NSF-supported scientists spend another estimated $150,000 a year for the direct purchase of balloons from manufacturers.

Branches of the Department of Defense involved in scientific ballooning channel an estimated $60,000 a year through the NSBF for the purchase of balloons and helium.

The foregoing information is summarized in Table B.1.

Further funds for the NSBF come from foreign scientists, who account for about 20 percent of the NSBF balloon launches. These scientists pay for their balloons and for the cost of balloon operations. These payments by foreign scientists are not included in Table B.1.

The table also does not include the NSBF's development program for long-duration ballooning (principally superpressure balloons and associated electronics), which NSF has funded with $600,000 in 1975 and $290,000 in 1976.

The Committee did not address itself to the questions of funding the scientific packages carried by balloons (and related costs); this funding comes chiefly from research grants or from contracts with the physics, astronomy, and atmospheric sciences program offices of such funding agencies as NASA and NSF and from research budgets at NASA centers.

TABLE B.1 Summary of Approximate Annual Costs of Scientific Ballooning in $ Thousands (Balloons and Launch or Facility Operations only)[a]

	Source					
	(1) NASA (Hq)	(2) NASA (Centers)	(3) NSF (NCAR)	(4) NSF (Grants)	(5) DOD	Totals
NSBF						
Operations			1,100			1,100
Balloons and helium	450	400		190[b]	60	1,100
R&D	100					100
	550	400	1,100	190[b]	60	2,300
ONR (Skyhook)						
Balloons, helium, and launch operations	400					400
R&D	50					50
	450					450
TOTALS	1,000	400	1,100	190[b]	60	2,750

[a] A very rough rule of thumb for ballon costs is $1500 per million cubic feet($\sim$30,000 m^3) for balloon and helium and about $15,000 per flight for operations.

[b] Includes an estimated $150,000 for balloons bought by NSF grantees *directly* from balloon manufacturers but launched by NSBF. All the other funds on this line are earmarked for the purchase of balloons and helium for specifically designated research groups but transferred to NSBF as the purchasing agent for those groups. The same applies to the $400,000 for ONR balloon and launch operations.

II. RATIONALE FOR RECOMMENDATIONS ON FUTURE SUPPORT

A. NASA Headquarters Experience

In addition to the figures on current spending summarized in Table B.1, the Balloon Study Committee has gathered the rough figures cited below to illustrate current deficiencies and to support its recommendations for future funding (see Chapter 1, Section II, Nos. 2 and 3).

For example, in preparation for the 1976 season, in the fall of 1975 NASA Headquarters canvassed those non-NASA balloon groups whose scientific research programs (development and construction of balloon-adapted instruments, etc.) NASA itself was already supporting, in order to estimate the number of balloon launches the groups would need in 1976. The survey produced responses showing the need for 68 launches that fully qualified for financial support from the standpoint of scientific merit. Probably the scientific packages for the 68 balloons would not all be ready to launch before the end of 1976 (because of unforeseen delays); but this would be offset by an allowance for backup balloons for some launch failures. In any case, of these 68, NASA was able to fund only 33 from the $850,000 allocated for this purpose [this is the sum of the two items for balloons and launch operations given in column (1) of Table B.1]. If the cost of the unfunded launches had been comparable with the cost of the funded launches, it would have cost 68/33 × $850,000 or about $1,750,000 to fund them all. Actually, a more detailed analysis by NASA Headquarters shows that to fund these particular 68 flights would have cost $2,180,000: in other words, many of the more costly flights involving either the largest balloons or expeditions to distant launch sites were left unfunded in favor of funding a larger number of less costly flights. The multiplying factor corresponding to this illustration is $2.18 million/$0.85 million, or more than 2½.

The rather glaring deficiency illustrated above is due largely to the accumulated erosive effects of inflation since level funding began at least five years ago, and especially the rising cost of such items as balloons, which are made from petrochemical by-products, and the higher costs of other materials and services (the higher cost of expeditions to launch sites away from the NSBF, for example). Part of the shortfall is due to the relative increase in demand for larger balloons, the addition of a few more groups and other factors. Furthermore, the illustration above is typical of the general experience.

B. Other Programs

The numerical estimates above do not include incremental funds for balloon launches for research groups at NASA centers and NASA-supported centers which are just as seriously underfunded for this purpose; neither do they include incremental funds for groups supported by other agencies, largely NSF. The present level of support for all these groups is estimated at $650,000 (the sum of columns 2, 4, and 5 in Table B.1). If the multiplying factor, 68/33 or a little more than 2, is also applicable to these groups, they would need about $1,340,000. If one applies the more realistic multiplying factor of 2½, they would need about $1,625,000.

C. Upgrading of NSBF's Capability

With regard to the recommendations affecting the NSBF, namely, the capacity to handle the increased demand at "turn-around time", both at Palestine and expeditions elsewhere, and a downrange repeater to extend the horizon for telemetry and active control, the NSBF has supplied the following very rough estimates, based in part on the number of balloon groups now being turned away: (1) a one-time-only outlay of about $500,000 for permanent improvements, including an additional ground station, a separate warehouse for balloon storage, the conversion of some existing balloon storage space into an additional workshop for electronic buildup, the electronic equipment itself (including ground-based transmitter–receivers for communications with recovery aircraft and balloons, electronic packages for balloons to provide telemetry and control, and the portable downrange repeater station); and (2) recurring annual costs of about $275,000 for additional staff (e.g., technicians and launch crews), maintenance and replacement of instrumentation, operation of the downrange repeater, and additional airborne recovery capacity (including occasional rental of a helicopter to reach places inaccessible to other aircraft). If one amortizes the fixed cost items over five years, the estimates above amount to an increase of about $375,000 in the NSBF's annual budget. This increase—about 14 percent of the total current level of support for ballooning—is due to increased demand and to the need for improvements in balloon launch support not to inflation.

D. Summary

Let us now summarize and consolidate these estimates. The present cost of balloons and helium for those launches that *can* now be funded from the sources mentioned above may be itemized as follows:

NASA Headquarters (for non-NASA groups)	$850,000
Groups at NASA and NASA-related centers	400,000
Groups funded by NSF	190,000
Groups funded by DOD	60,000
	$1,500,000

The NASA Headquarters experience cited above led to two multiplying factors, corresponding to the two ways of estimating the deficiency in funding for balloons and helium: (1) all 68 flights at the same rate required by the 33 that were actually funded: 68/33, or a little over 2. In other words, a 100 percent increase would be needed. (2) All 68 flights funded at their actual cost: $2.18 million/$0.85 million or over 2½, corresponding to a 150 percent increase. These percentage increases imply that the estimate of additional funds needed to fly all scientific packages, themselves already funded by NASA and other agencies and ready to fly in 1976, lies in the range from 100 to 150 percent of $1,500,000, or between $1,500,000 and $2,250,000.

To this estimate, we add the estimated cost of upgrading the NSBF, namely, $375,000 a year for the next several years. The total additional funds needed would thus lie in the range of $1,875,000 to $2,625,000 or $1,900,000 to $2,600,000 in round numbers. This represents an increase of nearly 70 to 95 percent of the present total annual budget of $2,750,000 (see Table B.1).

This estimate does not include an allowance for the following factors: (1) present balloon groups funded from sources that may have been omitted from this cursory survey; (2) the needs of new groups competent to exploit ballooning techniques; (3) the higher cost of such items in the Committee's recommendations as relatively greater exploitation of low-latitude, or mid to high southerly latitude flights; (4) the trend toward larger balloons, either for increased payload, higher ceilings, or longer flights; (5) the erosion due to future inflation and related rising costs.

Appendix C: Balloon Performance

MARTIN H. ISRAEL

The data in this appendix have been gathered to display the current capability and utilization of scientific balloons and to illustrate trends over the past several years. The data are derived from annual reports of the National Scientific Balloon Facility (NSBF) operated by the National Center for Atmospheric Research (NCAR) and reports of the Skyhook Program operated by Raven Industries under contract with the Office of Naval Research (ONR). These two organizations are responsible for almost all the scientific ballooning in the western hemisphere involving payloads over about 50 kg. (The omission of several flights per year launched by the Air Force at Holloman AFB probably does not distort the picture. Omission of several flights per year launched in Australia does mean that x-ray and gamma-ray astronomy is slightly underrepresented in these data. Also omitted in this summary are about 50 to 70 flights per year of payloads lighter than 50 kg, launched from a wide variety of locations by scientific groups studying the stratosphere and the magnetosphere.)

Data have been tabulated for three one-year periods. The most recent data used are labeled "1974" and include NSBF flights of *fiscal* year 1974 (July 1973–June 1974) and Skyhook flights of *calendar* year 1974 (mostly in July–September). Also plotted are data from *calendar* years 1970 and 1967.

Figure C.1 shows the state of ballooning a little over a year ago. Each plotted symbol indicates one balloon flight in "1974." Altitude (or residual atmospheric pressure) is plotted against the weight of the scientific package. (Note that atmospheric depth in g/cm^2 is numerically equivalent, within 2 percent to pressure in millibars.) The number plotted for each flight indicates duration of float, the time when the balloon was at approximately level altitude gathering primary data. The symbols indicate scientific fields, divided on the same lines as the reports of the data-base panel. The dashed lines indicate the approximate relationship between float altitude and science-package weight

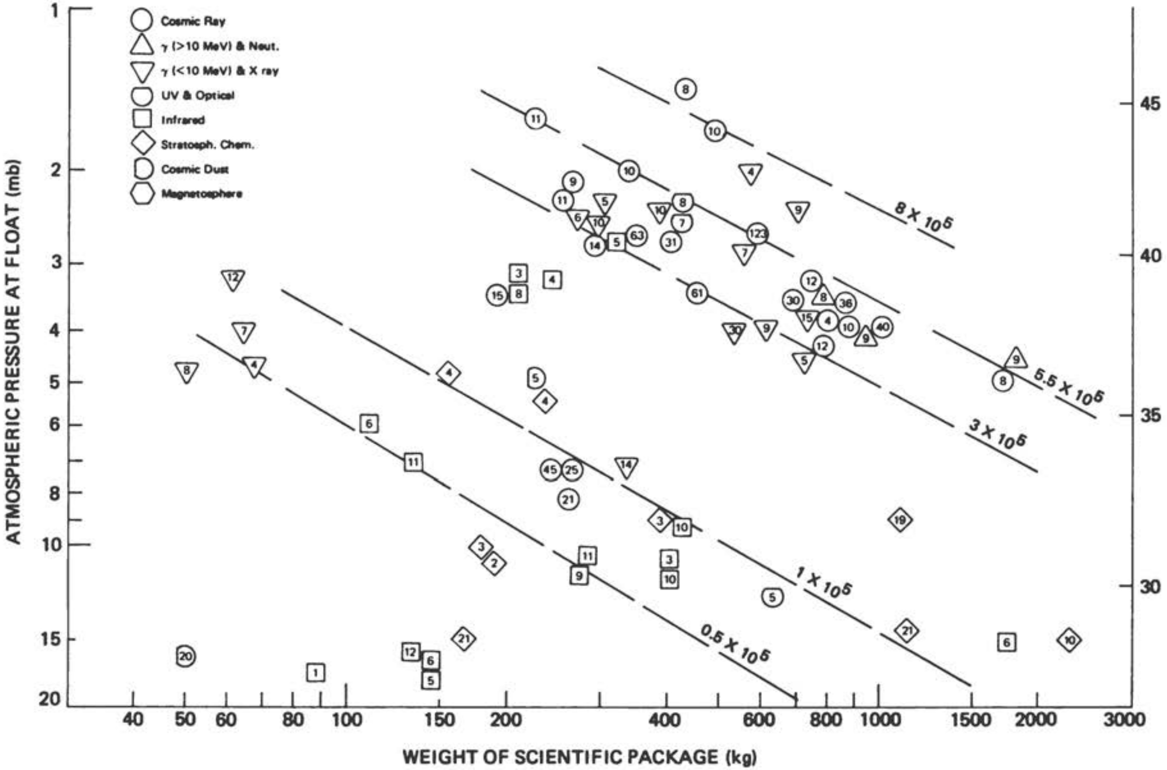

FIGURE C.1 Scatter diagram showing the float altitude attained by individual balloons during "1974" plotted against the weight of the scientific packages each one carried. The eight scientific fields are distinguished by the eight different symbols. The number inside each symbol is the time in hours spent at float altitude. The diagonal broken lines are rough approximations to the relationship between altitude at float and scientific package weight for balloons of various sizes, ranging from 0.5×10^5 m³ at the bottom to 8×10^5 m³ at the top. (The meaning of "1974" is explained in the text.)

for various balloon sizes. (For balloonists more accustomed to English units, 3.0×10^5 m^3 is 10.6×10^6 ft^3.) The dashed lines are *very* approximate; the altitude of a given sized balloon is in fact determined by the *gross* weight of the balloon plus scientific package plus all other flight gear (such as parachute, ballast, electronics for tracking and command of the balloon, etc.); this "other flight gear" has a typical weight of at least half of that of the science package and often about the same as the science package. The weight of the balloon depends on its surface area and the total weight suspended from it (payload); for a given balloon volume, a heavier payload requires a stronger and thus heavier balloon. A rough rule of thumb regarding the cost of balloon plus helium (not counting cost of launch, tracking, recovery, etc.) is approximately \$1500 per million cubic feet, or about \$5000 per 10^5 m^3.

Figures C.2 and C.3 give data similar to Figure C.1 but for 1970 and 1967, respectively.

Figure C.4 indicates the trend in balloon use. We note a gradual trend toward fewer flights per year; however, the trend toward longer average flight duration results in a gradual increase in total hours of data per year. The most active field, cosmic rays, shows a sharp decline in the number of flights in "1974" but a gradual increase in total flight duration. X rays show a slight decline in both number and total duration of flights. We also note a sharp increase in number and duration of flights in both infrared astronomy and stratospheric studies.

Figure C.5 gives distributions of flight durations. While the most common flight durations remain between 5 and 15 hours, the mean flight duration has risen steadily, primarily because of an increasing number of long-duration flights. The majority of these long-duration flights, during the spring or fall periods of light variable stratospheric winds known as "turnaround," have been in the area of cosmic rays.

Figure C.6 shows distributions of balloon sizes. The distributions are bimodal, with infrared, stratospheric, and cosmic dust studies using principally balloons smaller than 10^5 m^3 and cosmic-ray, gamma-ray, and x-ray studies pushing toward the largest available balloons. The mean balloon size has risen steadily, principally the result of increasing sizes used by cosmic-ray, gamma-ray, and x-ray studies.

Although increased balloon size has been used in several cases for achieving extreme altitudes with moderate package weights, the principal use of larger balloons has been for carrying heavier instruments to about the same altitudes. This point is demonstrated in Figures C.7 and C.8. Figure C.7 shows a marked increase in science package weights. In 1967, only 6 percent of the flights carried scientific

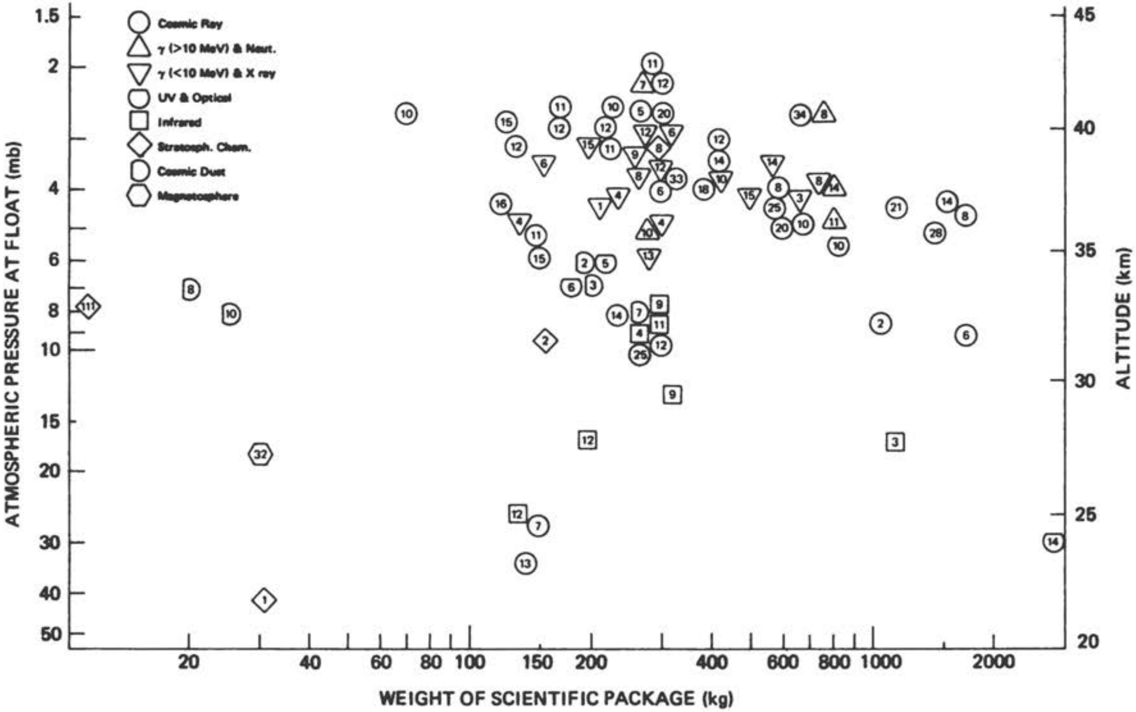

FIGURE C.2 The same kind of information as that given in Figure C.1 but for the calendar year 1970.

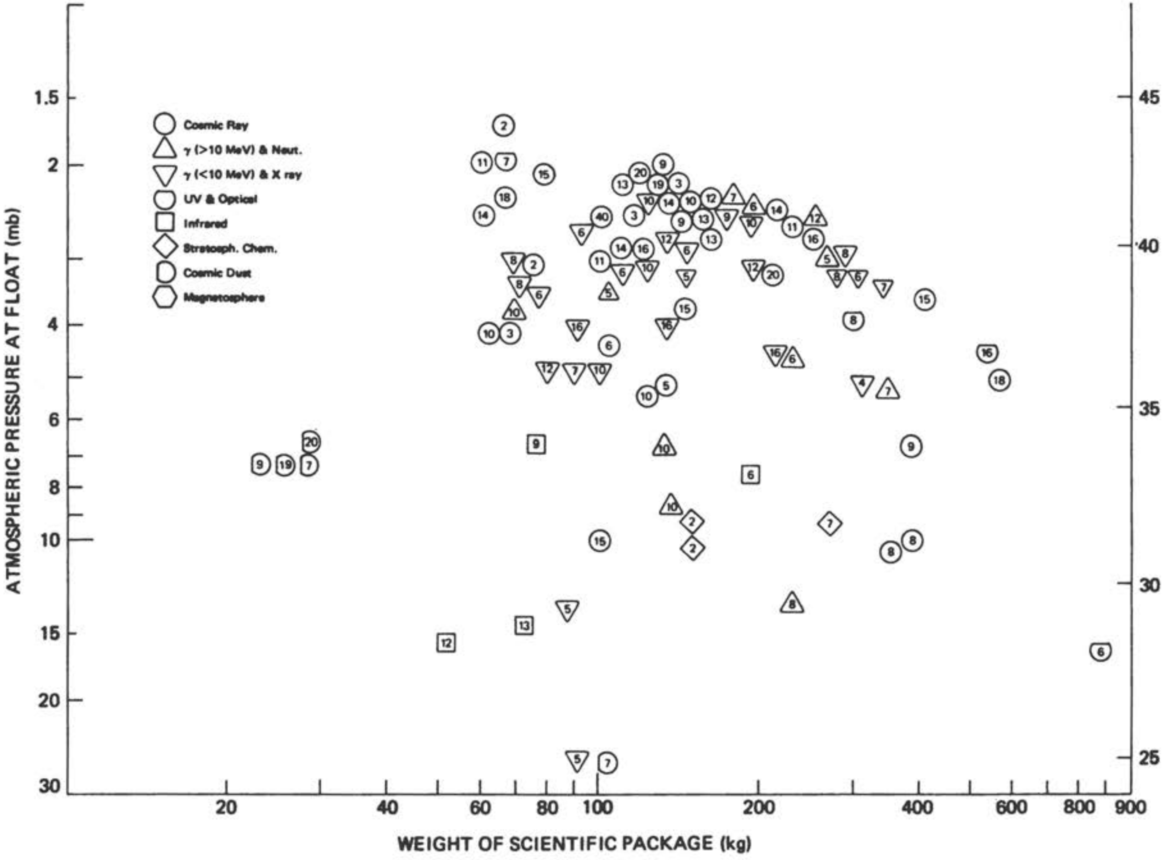

FIGURE C.3 The same kind of information as that given in Figure C.1 but for the calendar year 1967.

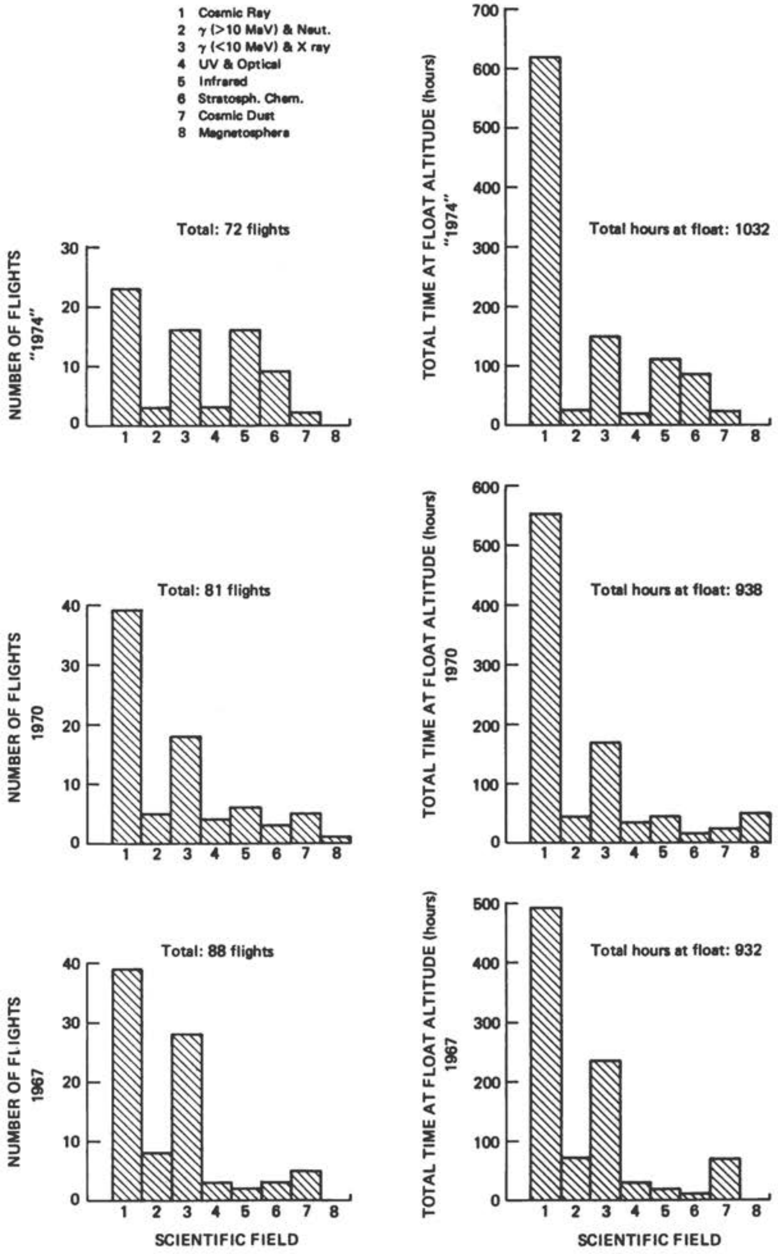

FIGURE C.4 Histograms showing trends in the use of balloons from 1967 to 1974. The trend is toward fewer flights (but using larger balloons—see Figure C.6) with longer average durations at float altitude.

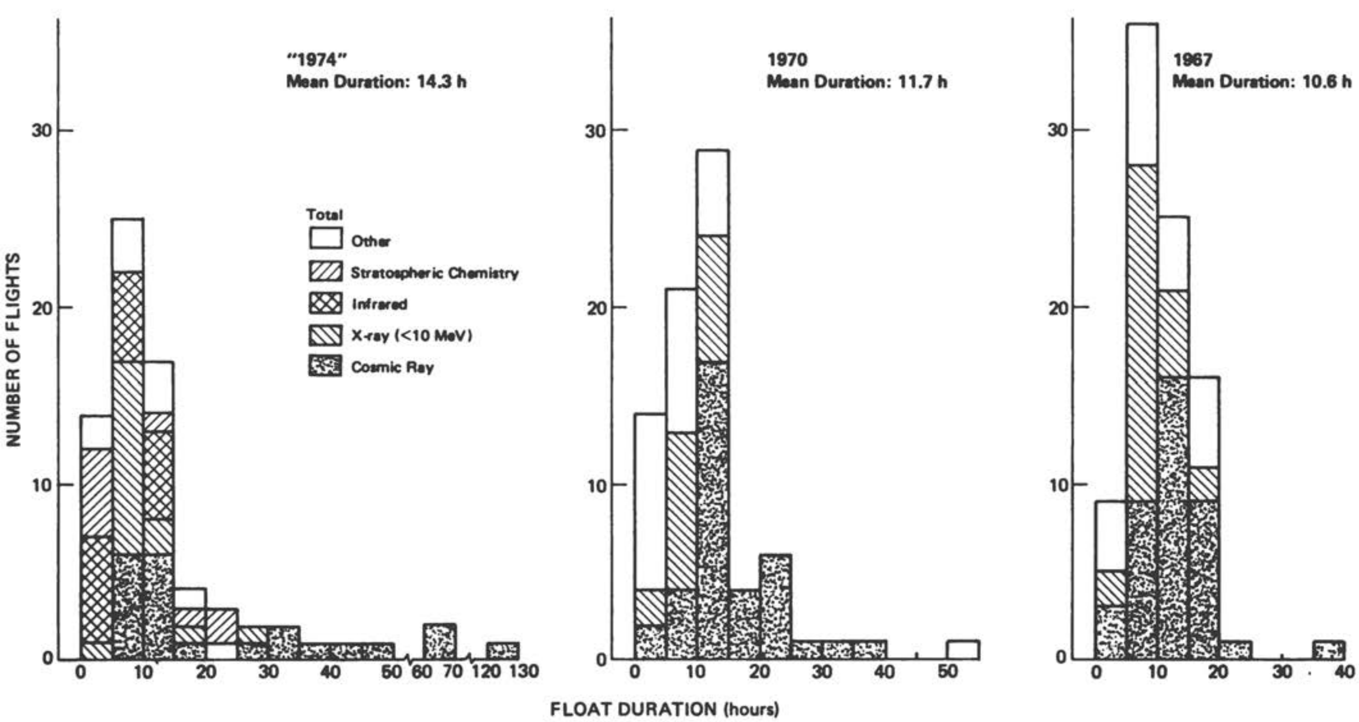

FIGURE C.5 Histograms showing the trend during 1967–1974 in the distribution of flights as a function of the duration of flight at float altitude.

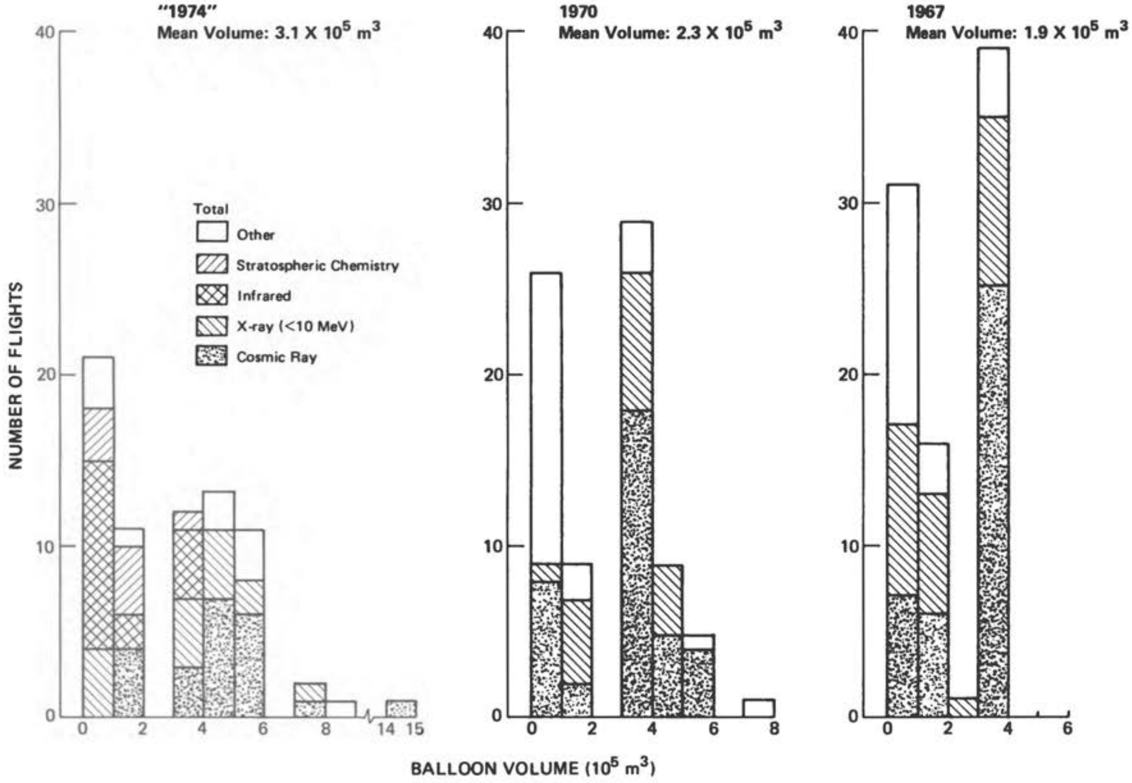

FIGURE C.6 Histograms showing the trend during 1967–1974 of the distribution of flights as a function of balloon size. The bimodal distribution is discussed in the text.

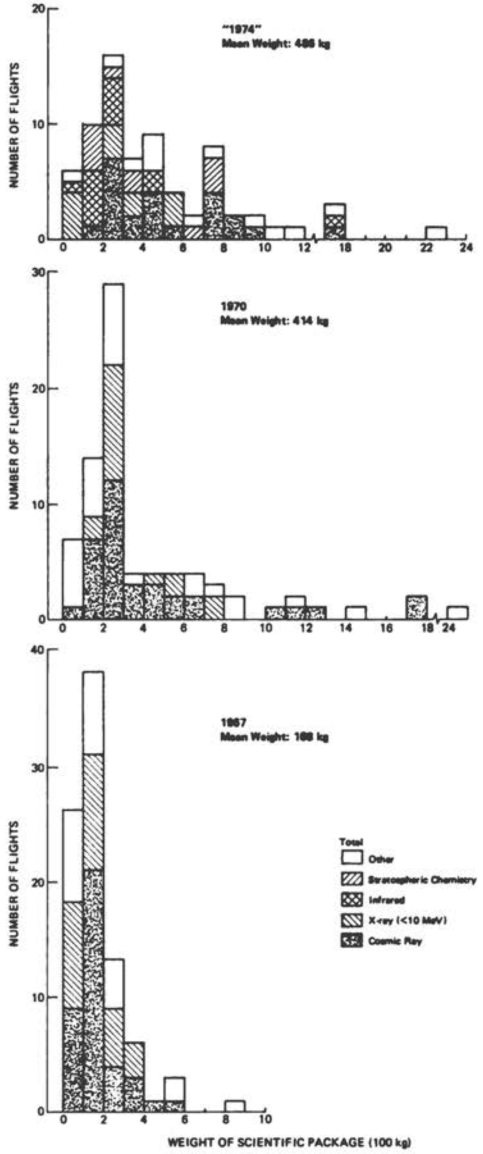

FIGURE C.7 Histograms showing the trend during 1967-1974 of the distribution of flights as a function of the weight of their scientific packages. The trend toward a greater number of heavy packages is noticeable.

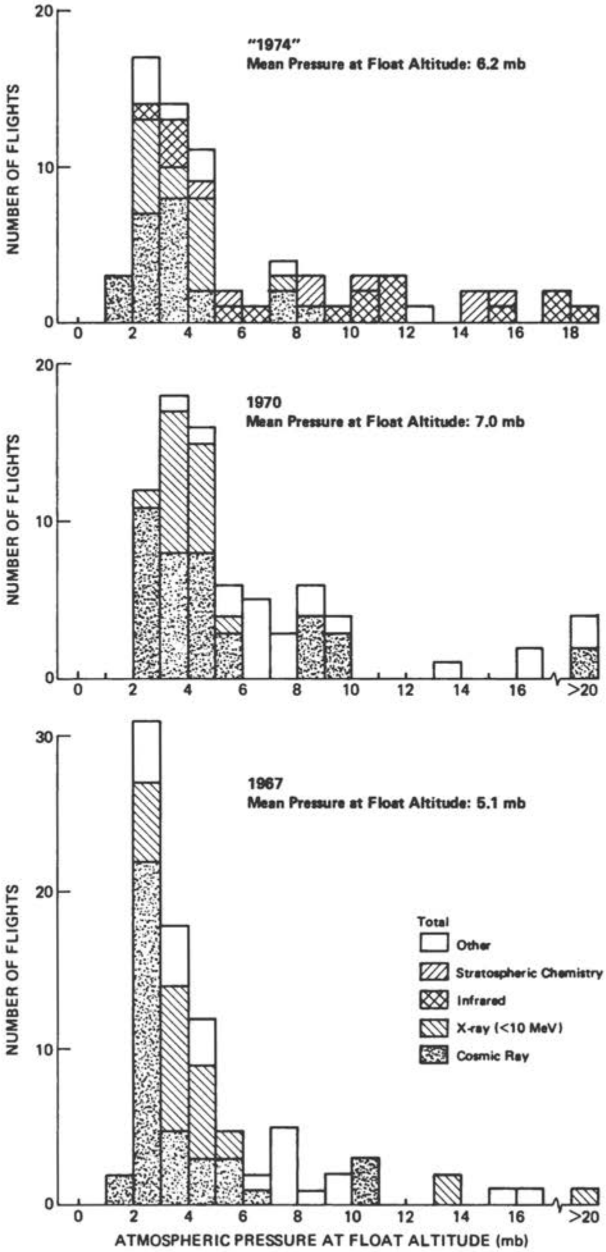

FIGURE C.8 Histograms showing the distribution of flights as a function of float altitude (expressed as atmospheric pressure). That there is no trend toward greater altitudes is explained by the tradeoff in favor of heavier payloads, as shown in Figure C.7.

packages heavier than 400 kg, and 72 percent less than 200 kg. By "1974" 46 percent were above 400 kg and only 8 percent below 200 kg. Figure C.8 does not show any clear trend in float altitude. While x-ray astronomy has pushed steadily toward higher altitude (mean pressure 5.1 in 1967, 4.0 in 1970, 3.5 in "1974"), cosmic rays have shown no distinct trend, and the increased infrared and atmospheric flights have occurred mainly at lower altitudes, around 10 mbar.

Appendix D: Correspondents

Persons Who Expressed an Interest in Reviewing Early Drafts of the Eight Discipline Reports of the Study of the Use of Balloons for Physics and Astronomy

COSMIC RAYS

C. J. Waddington, *Reporter*
University of Minnesota

Hugh Anderson
Rice University

V. K. Balasubrahmanyan
NASA-Goddard Space Flight Center

S. Biswas
Tata Institute of Fundamental Research

Clifford J. Bland
University of Calgary

Fritz Bühler
University of Bern

James A. Earl
University of Maryland

Wolfgang Enge
Institut für Reine und Angewandte Kernphysik

Chang-Yun Fan
University of Arizona

Peter H. Fowler
University of Bristol

Michael W. Friedlander
Washington University

Katsura Fukui
AF Geophysics Laboratory

Robert L. Golden
NASA-Johnson Space Center

Robert C. Hartman
NASA-Goddard Space Flight Center

H. Hasegawa
St. Paul's University

L. Koch
Centre d'Etudes Nucléaires de Saclay

W. Kratschmer
Max-Planck-Institut für Kernphysik

Jerre J. Lord
University of Washington

P. Marsden
University of Leeds

Peter Meyer
University of Chicago

Jonathan F. Ormes
NASA-Goddard Space Flight Center

C. D. Orth
University of California,
Berkeley

W. Zack Osborne
University of Houston

Ingvar Otterlund
University of Lund

T. Parnell
NASA-Marshall Space Flight
Center

H. Rohrs
Institut für Reine und
Angewandte Kernphysik

Wolfgang Schmidt
NASA-Goddard Space Flight
Center

Nathan Seeman
Naval Research Laboratory

Giorgio Sironi
Laboratorio de Física Cosmica
e Technologie Relative

G. F. Smoot
University of California,
Berkeley

Edward C. Stone
California Institute of
Technology

S. D. Verma
Gujarat University

R. M. Walker
Washington University

William R. Webber
University of New Hampshire

G. Kenneth Yates
AF Geophysics Laboratory

HIGH-ENERGY GAMMA-RAY AND NEUTRON ASTRONOMY

Donald Kniffen, *Reporter*
NASA-Goddard Space Flight
Center

B. Agrinier
Centre d'Etudes Nucléaires
de Saclay

W. L. Craddock, Jr.
NASA-Johnson Space Center

Glenn M. Frye, Jr.
Case Western Reserve

C. Y. Kim
University of Calgary

Serge A. Korff
New York University

John A. Lockwood
University of New Hampshire

Rosalind B. Mendell
New York University

Charles J. Pellerin
NASA-Goddard Space Flight
Center

K. Pinkau
Max-Planck-Institut für
Extraterrestrische Physik

David Ramsden
University of Southampton

L. Scarsi
Universita di Palermo

G. H. Share
Naval Research Laboratory

R. K. Sood
Imperial College of Science
and Technology

R. Stephen White
University of California,
Riverside

A. Zych
University of California,
Riverside

LOW-ENERGY GAMMA-RAY AND X-RAY ASTRONOMY

James D. Kurfess, *Reporter*
Naval Research Laboratory

B. Agrinier
Centre d'Etudes Nucléaires de Saclay

V. K. Balasubrahmanyan
NASA-Goddard Space Flight Center

J. R. Benbrook
University of Houston

Elihu A. Boldt
NASA-Goddard Space Flight Center

Edward L. Chupp
University of New Hampshire

Thomas L. Cline
NASA-Goddard Space Flight Center

Gerald J. Fishman
NASA-Marshall Space Flight Center

David Forrest
University of New Hampshire

Horacio S. Ghielmetti
Instituto de Astronomia y Física del Espacio

Robert C. Haymes
Rice University

Henry Helmken
Smithsonian Astrophysical Observatory

A. Jacobson
Jet Propulsion Laboratory

Kenneth Lande
University of Pennsylvania

I. M. Martin
Instituto de Pesquisas Espaciais

G. H. Nakano
Lockheed Palo Alto Research Lab

Larry Orwig
NASA-Goddard Space Flight Center

George Parks
University of Washington

Thomas A. Parnell
NASA-Marshall Space Flight Center

M. R. Pelling
University of California, San Diego

Laurence E. Peterson
University of California, San Diego

K. Pinkau
Max-Planck-Institut für Extraterrestrische Physik

J. J. Quenby
Imperial College

David Ramsden
University of Southampton

Frederick Reines
University of California

T. J. Rosenberg
University of Maryland

Livio Scarsi
Universita di Palermo

Volker Schonfelder
Max-Planck-Institut für Extraterrestrische Physik

Bach Sellers
Panametrics, Inc.

Giorgio Sironi
Laboratorio di Física Cosmica e Technologie Relative

Rudiger Staubert
Astronomisches Institut
der Universitat

B. N. Swanenburg
Huygens Laboratory

B. J. Teegarden
NASA-Goddard Space Flight
Center

W. R. Webber
University of New Hampshire

R. Stephen White
University of California,
Riverside

P. Roger Williamson
University of California,
San Diego

A. Zych
University of California,
Riverside

OPTICAL AND ULTRAVIOLET ASTRONOMY

Gordon A. Newkirk, *Reporter*
High Altitude Observatory

A. Boksenberg
University College London

W. L. Craddock, Jr.
NASA-Johnson Space Center

Robert E. Danielson
Princeton University

L. Delbouille
University of Liege

T. Gehrels
University of Arizona

R. Thomas Giuli
NASA-Johnson Space Center

Yoji Kondo
NASA-Johnson Space Center

D. Lemke
Landessternwarte-Heidelberg

Robert M. MacQueen
National Center for
Atmospheric Research

J. P. Mehltretter
Fraunhofer Institut

J. L. Modisette
Houston Baptist University

T. H. Morgan
NASA-Johnson Space Center

Chandra K. N. Patel
Bell Telephone Laboratories

Bach Sellers
Panametrics, Inc.

John D. Strong
University of Massachusetts

T. E. Venis
University College London

INFRARED ASTRONOMY

William F. Hoffmann, *Reporter*
University of Arizona

John E. Beckman
Queen Mary College

T. Alan Clark
University of Calgary

Peter Clegg
Queen Mary College

Richard E. Davis
NASA-Langley Research Center

Giovanni G. Fazio
Smithsonian Astrophysical Observatory

Carl Frederick
Cornell University

Michael W. Friedlander
Washington University

Martin Harwit
Cornell University

M. Hauser
NASA-Goddard Space Flight Center

Michael Jacobson
Cornell University

Richard E. Jennings
University College London

R. Joseph
Imperial College

D. Lemke
Landessternwarte-Heidelberg

Frank J. Low
University of Arizona

W. Mankin
National Center for Atmospheric Research

P. Marsden
University of Leeds

John Mather
NASA-Goddard Institute for Space Studies

K. Wolfgang Michel
Max-Planck Institut für Physik and Astrophysik

Henk Olthof
University of Groningen

Chandra K. N. Patel
Bell Telephone Laboratories

P. L. Richards
University of California, Berkeley

K. Shivanandan
Naval Research Laboratory

G. F. Smoot
University of California, Berkeley

C. Swift
NASA-Ames Research Center

R. J. van Duinen
University of Groningen

Rainer Weiss
Massachusetts Institute of Technology

David T. Wilkinson
Princeton University

COSMIC DUST STUDIES

Donald E. Brownlee, *Reporter*
University of Washington

D. Dankatesan
University of Calgary

C. L. Hemenway
Dudley Observatory

Paul W. Hodge
University of Washington

W. Kratschmer
Max-Planck-Institut
für Kernphysik

MAGNETOSPHERIC FIELDS AND PARTICLES

George K. Parks, *Reporter*
University of Washington

Kinsey Anderson
University of California,
Berkeley

J. R. Barcus
University of Denver

J. R. Benbrook
University of Houston

J. Berthelier
Groupe de Recherches
Ionosphériques/CNET

R. R. Brown
University of California,
Berkeley

F. Cambou
University of Toulouse

U. V. Fahleson
Royal Institute of Technology

C. G. Falthammar
Royal Institute of Technology

Arthur A. Few, Jr.
Rice University

P. Kellogg
University of Minnesota

Forrest S. Mozer
University of California,
Berkeley

Jun Nishimura
University of Tokyo

R. Pellat
Ecole Polytechnique

T. Rosenberg
University of Maryland

J. P. Treilhau
University of Toulouse

P. Roger Williamson
University of California,
San Diego

J. Winckler
University of Minnesota

STRATOSPHERIC CHEMISTRY

Donald J. Hofmann, *Reporter*
University of Wyoming

Harold Ballard
Atmospheric Sciences
Laboratory, U.S.A.

Conard C. Bray
Appleton Laboratory

T. Alan Clark
University of Calgary

W. L. Craddock, Jr.
NASA-Johnson Space Center

Richard E. Davis
NASA-Langley Research
Center

Wayne F. Evans
Atmospheric Environmental
Service Canada

J. Gille
National Center for
Atmospheric Research

P. Goodman
Panametrics, Inc.

Leroy E. Heidt
National Center for
Atmospheric Research

W. Mankin
National Center for
Atmospheric Research

David Murcray
University of Denver

Chandra K. N. Patel
Bell Telephone Laboratories

T. Pepin
University of Wyoming

Ilia G. Poppoff
NASA-Ames Research Center

Pierre Rigaud
Station Scientifique
du Val Joyeux

Harold I. Schiff
York University
(Ontario, Canada)

P. Roger Williamson
University of California,
San Diego

R. Zander
Université de Liège

II

Position Papers

A

Cosmic Rays

C. J. WADDINGTON

I. INTRODUCTION

The study of cosmic rays has been related to the use of detectors carried on balloons ever since the initial observations in 1910–1912 that the ionization produced in a gas increased with increasing altitude. Since then, most of our detailed knowledge of the characteristics of the particles that make up the cosmic radiation has come from balloonborne detectors, as has much of the work that used the cosmic rays as a source of high-energy particles to study what is now called elementary-particle physics.

During the past few years, detectors flown on balloons have studied the high-energy electrons; measured the electron–positron ratio; revealed the energy dependence of the charge spectrum of the heavy nuclei; discovered and studied the ultra-heavy ($Z \gtrsim 30$) nuclei; and greatly improved our detailed understanding of the properties of the cosmic radiation. As a consequence of these advances, we are now beginning to answer fundamental questions about the origin, acceleration, production, and propagation of these cosmic-ray nuclei. Models of the process of propagation through the interstellar medium that seem realistic now exist, and we are beginning to have some understanding of the properties of the particles at the source. These properties allow us to consider the conditions that must exist in the sources, to discuss the possible acceleration mechanisms that could be operating, and to consider the nucleosynthesis processes that might be responsible for the fabrication of the nuclei that are accelerated.

In this paper we are concerned with the relationship, past and present and future, between the study of cosmic rays and the technology of flying high-altitude research balloons. In this context we define cosmic rays as energetic particles, nuclei, and electrons, produced in sources outside the atmosphere of the earth. We thus include both the energetic particles produced in the sun and the so-called "galactic" cosmic radiation. We are not concerned with the energetic photons, since these are considered in other papers on x-ray and gamma-ray astronomy.

This paper shows the vital importance of an active and expanding balloon-flying capability to cosmic-ray studies. We are concerned not only with the clearly established importance in the past but also with the continuing and future role of ballooning. The effects of several years of level funding support in an inflationary period, while technical requirements have increased, have resulted in a diminished effort, with fewer experiments and fewer research groups being involved. Already we are at the stage where significant experiments cannot be flown even though they are ready, and the lack of balloon support is a limitation on progress.

II. TECHNICAL BACKGROUND

A. Fundamental

In order to study the particles in the primary cosmic radiation it is generally necessary to make observations above, or nearly above, the degrading influences of the earth's atmosphere. An exception is the extremely-high-energy, $E \gtrsim 10^{15}$ eV, particles, where our only information comes exclusively from measurements made with ground-based detectors. However, from such measurements it has not even been possible to determine whether these ultra-energetic particles are predominately protons or heavy nuclei.

By their nature, observations from balloons involve the acceptance of a finite quantity of overlying atmospheric matter, whereas observations from space vehicles do not. An additional limitation of balloons versus space vehicles is that they are confined to the vicinity of the earth and are necessarily within the influence of the geomagnetic field.

1. The overlying atmospheric matter inevitably degrades the primary beam of cosmic-ray particles because of the nuclear interactions that are produced. Primary protons suffer major energy losses and produce secondary protons and neutrons, while primary heavy nuclei fragment and produce secondary lighter nuclei and nucleons. The magnitude of these effects depends on the interaction mean free paths of the various particles in atmospheric matter. These mean free paths range from 100 g/cm^2 for protons to 14 g/cm^2 for iron nuclei to 6.5 g/cm^2 for uranium nuclei. For comparison, present balloons can

float under residual atmospheric depths of 1–2 g/cm^2, although some 3 g/cm^2 is perhaps more typical.

2. The overlying atmospheric matter causes the primary particles to suffer an energy loss due to ionization effects. As a consequence, particles having an energy less than some well-defined threshold value are unable to penetrate to a balloonborne detector. Values of these threshold energies for various primary particles are given in Table II.A.1 for several amounts of residual matter. Furthermore, the energy losses experienced by those particles that can reach the detectors distort the observed energy spectra, particularly at low energies, near the threshold, although in a manner for which quite accurate corrections can be made.

A general comment that applies to both of the above points is that most particle detectors require the particles to traverse significant amounts of matter, several g/cm^2, in order to determine the nature of the particles. There is thus an internal correction, intrinsic to the detector, that has to be applied, independent of whether there is overlying matter or not, which tends to reduce the significance of the external correction.

3. The geomagnetic field imposes a cutoff rigidity on the particles that can reach any particular geographic locality. In studies of high-energy particles, this can be a positive advantage, since by selecting an appropriate locality the "noise" due to low-energy particles can be eliminated. Furthermore, the spectrometer properties of the magnetic field can be used in isotope studies. However, in studying low-energy particles the problem is more serious, since in those localities where the cutoff is low, near the geomagnetic poles, the magnetic fields tend to be unstable and complex temporal effects can occur.

TABLE II.A.1 Threshold Energies Due to Ionization Loss for Protons, Iron, and Uranium Nuclei at Several Depths in the Atmosphere

Residual Atmosphere (g/cm^2)	Protons (MeV)	Iron (MeV/nucleon)	Uranium (MeV/nucleon)
10	110	450	980
5	74	310	610
2	44	180	345
1	31	120	225

From the above discussion it is clear why most studies of low-energy cosmic-ray particles are now being performed with detectors carried on space vehicles. Our knowledge of these particles and their characteristics has been drastically improved by space experiments, and it seems unlikely that balloons can make many significant new contributions in this area. However, it is also clear why studies of the higher-energy particles are still predominately made from balloon-borne detectors. The corrections imposed are relatively trivial and reasonably well understood.

B. Practical

At present, there is still a significant difference between the payload capacity of balloons and space vehicles, with balloon payloads being one to three orders of magnitude heavier than those on space vehicles. This difference in payload capacity can be partly offset in some cases by the much greater duration of space-vehicle missions, which may run for several years, compared with the 0.4 to 4-day duration of a balloon flight. In many cases, the difference cannot be offset, since detectors having certain desirable characteristics can only be scaled over a limited range. This should change in the future, with first HEAO and then the Shuttle having payload capabilities equal to or even greater than those on balloons, but this cannot affect the development of the subject before the 1980's.

When, and if, the Shuttle becomes available in the 1980's it has been proposed that it should carry detectors that, at least initially, will be "refurbished" balloon detectors. However, it already seems quite clear that these detectors will have to be built to considerably higher standards than those of typical balloon detectors, if only to withstand the launch environment. Furthermore, the familiar cost-effectiveness argument has already appeared, which states that if a Shuttle launch costs about $\$10^7$ then the reliability of the experiments must be commensurate, which means expensive. The result is that one is considering not slightly modified balloon experiments but rather slightly modified satellite experiments. The consequence of this sort of approach will be a continued demand for balloon flight opportunities, actually enhanced by the increased demand for test flights of Shuttle detectors. The only way in which one can envisage the Shuttle "era" producing a decreased demand for balloon flight opportunities would be if the Shuttle carries detectors built to balloon quality and cost standards and if there are sufficient flight opportunities. The first of these "ifs" seems technically, politically, and historically unlikely, while the second may have to wait for several years after 1980.

Irrespective of these arguments, which depend on the inadequately defined implementation of the Shuttle concept, it seems clear that if a viable number of experimenters are to remain in this field and if experiments, or concepts of experiments, are to be prepared for the Shuttle, support for balloons must continue for a number of years.

III. HISTORY

The study of the primary cosmic radiation and the technique of flying balloons have been connected since the very beginnings of the subject, when Hess (1912) and Kolhorster (1914) showed that the background radiation observed on the earth's surface increased with altitude up to some 9000 m. From that early date until the development of balloons capable of reaching altitudes that were above most of the matter in the atmosphere, advances in understanding the nature of the radiation were slow. However, after World War II, plastic balloons were developed with altitude and load-carrying capabilities that have improved steadily but slowly up to the present. With these improvements have come a whole series of new discoveries on the nature and properties of the cosmic radiation. Some of these are listed below with approximate dates.

1. The growth and decay of the secondary particles in the atmosphere and an understanding of the Pfotzer maximum (1935).
2. The predominately nuclear nature of the primary particles (1941).
3. The presence of energetic nuclei as heavy as iron (1948).
4. The abnormal chemical composition of these nuclei, particularly the overabundance of Li, Be, and B (1955).
5. The production of energetic protons and helium nuclei in solar flares (1957).
6. The very large effects of solar modulation on the low-energy particles of the galactic radiation (1958).
7. The presence of a finite flux of electrons (1961).
8. The presence of a finite flux of positrons (1964).
9. The presence of a finite flux of ultra-heavy nuclei with charges up to that of uranium in the cosmic radiation (1966).
10. Measurement of the detailed charge composition (1972).
11. Energy dependence of the charge composition (1972).

Omitted from the above list are all those discoveries made in the 1950's in the field of elementary-particle physics, where the cosmic-ray particles were used as a source of energetic particles. Many of these discoveries came from detectors flown on balloons, as did many of the studies of the nature of the nuclear interactions produced by very energetic, 10^{11}–10^{13} eV particles.

The availability of high-altitude research balloons has not only led to many fundamental advances in our knowledge of the cosmic radiation but has also resulted in the development of many technical advances in particle detection, particularly as applied to a space environment. In the past, many space experiments have used techniques originally developed for balloon detectors, and this appears likely to continue for the foreseeable future. A list of techniques first introduced into space research by balloons covers most of the major detectors of high-energy physics.

1. Nuclear photographic emulsions
2. Cloud chambers
3. Spark chambers
4. Proportional wire chambers
5. Gas chambers, ion, proportional, and Geiger-Müller counters
6. Solid, liquid, powder, aerosol, and gas Čerenkov counters
7. Scintillation counters
8. Magnetic spectrometers
9. Etchable dielectrics
10. Transition radiation detectors (1975)

In every case, these detectors were modified, extended, and combined in many various forms to make particle telescopes suitable for use in a space environment when exposed to the wide-angle broad-spectrum cosmic radiation. The refinement of these telescopes into their present states of sophistication has been the result of repeated iteration on relatively inexpensive and readily available balloon flights and would not have reached the present levels of development without an active balloon capability. This aspect of ballooning as a development facility appears as though it will continue for the foreseeable future.

IV. PRESENT CAPABILITY

At present, the large plastic zero-pressure research balloons provide a unique facility for cosmic-ray experiments. Payloads of up to 1000 kg can be lifted to altitudes of around 45 km, where the residual matter is about 1.5 g/cm^2, and kept there for typical periods of 10 or more hours. Payloads of several thousands of kilograms can be lifted to only slightly lower altitudes, while flight duration under some special circumstances can be extended to 40, 80, or even 120 hours. These balloons can be launched from many different localities so that full advantage can be taken of the varying geomagnetic and geographical influences that might affect the results of a particular experimenter.

With these capabilities it has been possible to develop large and complex particle detectors able to observe the primary cosmic radiation in great detail for all except the lowest energy particles, which are still stopped by the residual atmosphere. However, of the more energetic particles only some 1.5 percent of the protons and 10 percent of the iron nuclei will have suffered nuclear interactions in the residual atmosphere, and the charge and mass spectra are consequently not seriously distorted. Even for uranium nuclei, only some 25 percent interact and provide useful data.

V. PROS AND CONS

To the cosmic-ray physicist there are major advantages to planning and making an observation using balloons rather than a space vehicle.

1. *Temporal.* The time scale from inception of a concept to flight of a functioning particle detector is typically one to two years for a balloonborne detector but five to seven or more years for a space-vehicle-borne detector. This difference in lead time is partly a consequence of the much greater cost of space-vehicle experiments and partly due to the much more stringent environmental conditions the equipment has to encounter, particularly during launch. The most important result for the experimenter is that it becomes essential to adopt a conservative philosophy of design and operation. The apparatus must have an extremely high probability of working and of producing useful data. It is not appropriate to attempt to use methods of detection or identification that have not been extensively tested and verified. Such testing and verification will frequently have involved exposure on a balloon.

2. *Cost.* Experiments in space vehicles typically have costs that are two to three orders of magnitude greater than those on balloons, especially if one includes the cost of the launch vehicles in both cases. The number of space experiments that can be supported and funded within any one discipline is thus severely limited. In the discipline of cosmic rays, for example, only one or two new space

experiments are started per year. This number is too small to support a viable national endeavor in this field, and if it were not for the opportunity of studies with balloonborne detectors it is difficult to see how the discipline would survive for very long. To expresss this argument in a slightly different form: without the current level of support for balloon-related activities, much of the most innovative and original work in this field would not have been done and progress would have been greatly retarded.

Apart from these practical problems there is another fundamental problem that concerns the overall development of the scientific discipline of cosmic rays. In large measure, the future of advances of cosmic-ray studies must depend on attracting and training new scientists into the field. Any discipline that fails to do this must eventually cease to develop. However, at present it is a serious obligation on us all that the training given to students, graduate or not, should be of such a nature that they acquire a broadly based education and skills that enhance their ability to be successful in many fields. The variety of techniques and tasks involved in a balloon project, where very few individuals are involved, is far more suited to meeting this obligation than is involvement in the typical space project, where one individual generally has just one task to perform. The long lead times, high cost, and requirement of extreme reliability also make space programs generally unsuitable for the training of students. On the other hand, it is perfectly possible for a student to be involved with a balloon-related program from the moment of inception to the publication of the final results. At the very least then, a balloon program provides a testing ground for both apparatus and personnel for which there appears to be no satisfactory substitute and which is valuable in the overall development of the individuals involved.

VI. MEASURES OF CURRENT USE OF BALLOONS IN COSMIC-RAY STUDIES

In an attempt to compare the scientific output that results from observations made on the cosmic rays using different platforms we have looked at the number of papers reported at several recent scientific meetings. While this is obviously not a true measure of the scientific "worth" of the results produced by the various techniques, it is some measure of the level of activity supported at present. We have considered three meetings. First, the 1975 American Physical Society (APS) spring meeting at Washington, D.C., since this APS meeting has traditionally been one attended by U.S. cosmic-ray physicists. Second, the Symposium on the Isotopic Composition of Solar and Cosmic

TABLE II.A.2 Papers on Experimental Observations

	Satellites	Balloons	Total
Washington	11	11	22
Durham	8	11	19
Denver	14	31	45
TOTALS	33	53	86
PERCENTAGE	38%	62%	

Rays, held in Durham, New Hampshire, in October 1974. Third, and finally, the 1973 IUPAP Conference on Cosmic Rays in Denver, the most recent IUPAP Conference. The results are shown in Table II.A.2, indicating the number of experimental papers based on results obtained using either satellites or balloons.

We have to conclude that balloonborne studies still represent a significant fraction of the activity in the field, far more, indeed, than is commensurate with the extreme disparity in funding support for the two types of platform.

VII. POSSIBLE DEVELOPMENTS

For the next few years, say till 1980, there will be few if any new space-vehicle opportunities that will drastically alter our understanding of the primary cosmic radiation, apart from programs such as HEAO-C and UK 6 that are already in progress. If the present rather low levels of activity in balloon flying are maintained by modestly increased support for the next few years, then we can expect that balloonborne detectors will provide major advances in several important areas. If the level of activity continues to decrease as it has done for the last few years, then progress may well be much slower. Some of the problems amenable to study are

1. The energy spectra of both electrons and nuclear particles should be extended to significantly higher energies.
2. The energy dependence of the chemical composition at high energies should be clarified up to energies that significantly overlap with those studied by extensive air shower measurements.
3. The chemical composition of all the elements with $Z \lesssim 30$, including those rare ones of odd Z, should be measured with high precision, so that the source compositions can be better understood.
4. The isotopic abundances of all but the rarest isotopes should be determined.

5. The search for antinuclei should be pressed till really significant limits can be set.

The achievement of these goals will undoubtedly require the development of new techniques to make the desired measurements and, almost certainly, will be restricted by the limited capabilities of current balloons. However, it is from these developments that the future Shuttle payloads will come, and it is the scientists involved in these developments who will make the innovative advances of the 1980's.

Support of ballooning at the current level, in real dollars, is the minimum that will be necessary to maintain a viable level of activity in this field. By viable here we imply the existence of a number of separate groups of scientists who are actively engaged in research. It can be argued that this number should not be allowed to become smaller than it is at present since it is already uncomfortably small. However, the inevitable escalation of requirements that occurs as a subject advances implies that a level funding effort for balloons cannot maintain a level rate of activity. Only if balloon support is increased and technological improvements are encouraged will it be possible to maintain the present rate of scientific advance. It is true that a large increase in support for satellite experiments would have much the same effect, but the disparity in cost levels, even between Shuttle and balloon experiments, makes this improbable.

Several lines of improvement in balloon technology are apparently feasible in the next five years. We list them below, without attempting any listing of priorities, which are treated in the Committee's Report. It seems clear that in a balanced program of development advances will be made in all the directions listed.

1. Basic to the field is the continued support of the current capability and the further development of zero-pressure balloons, which should lead to increased altitudes and payload, both or either of which are required for various applications.
2. Possibly the most exciting advance that could result from a major technical improvement is the development of large super-pressure balloons capable of carrying significant (100–200 kg) payloads to residual depths of 3–5 g/cm^2. Such balloons should have flight durations of months rather than days and would represent a new class of flight opportunity. However, many of the same objectives could be achieved by the development of transatlantic zero-pressure flights having durations of 7 to 10 days.
3. The control and telemetry capabilities of current balloons

could clearly be improved by the application of state-of-the-art technology if support were available. In addition, an increased capability for multiple flights from a single launch site has become of ever greater importance as the long-duration opportunities available at turnaround have been realized by more experimenters. Such a capability demands more support equipment than is currently available.

B

High-Energy Gamma-Ray and Neutron Astronomy

D. A. KNIFFEN

I. INTRODUCTION

A number of factors have combined to cause gamma-rays in the range above 10 MeV to be the last portion of the electromagnetic spectrum to be examined in the context of astronomy, although the potential rewards of such observations have long been known to be very high. Figure II.B.1 demonstrates one of the difficulties, namely, the atmospheric absorption of gamma rays. Because the primary gamma rays are converted into electrons high in the atmosphere, it was not until the availability of space platforms such as high-altitude scientific balloons, sounding rockets, and satellites that observations on the primary radiation could be made.

By the early 1950's, it became clear from the results of experiments by Perlow and Kissinger, and Critchfield and Ney, that the primary gamma-ray intensity is several orders of magnitude lower than the intensity of energetic charged nucleons. This drastically increases the difficulty of the observations because of the ambiguities caused by induced background both in the telescopes themselves and, in the case of balloonborne observations, in the residual atmosphere above the observing instruments.

Nevertheless, great impetus was given to the observation in this region of the spectrum by the theoretical work of Morrison in 1958, in which he pointed out that in the absence of a detectable neutrino signal, medium- and high-energy gamma rays provide the best available means of studying the highest energy processes in the extreme regions of the Universe, from within stellar atmospheres, across the densest regions of the galaxy, and into the remote cosmological past. The absorption cross section for >10 MeV gamma

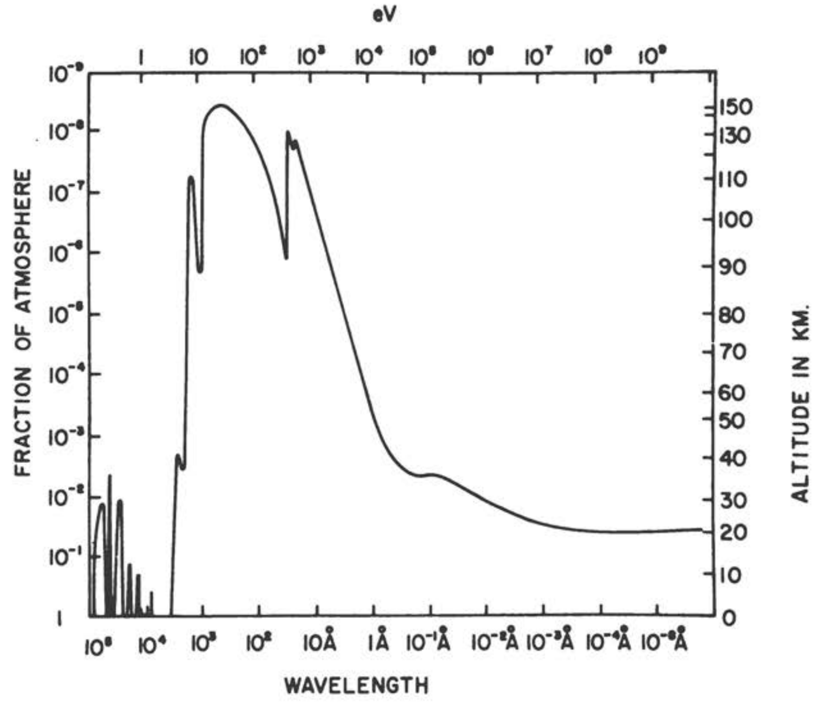

FIGURE II.B.1 Plot of the atmospheric altitude at which various wavelength photons are reduced to half of their value on entering the atmosphere.

rays is $\sim 1^{-25}\, n$ cm^2, where n is the density of the medium in atoms per cm^3. Since the interstellar gas density is <1 cm^{-3} and the maximum column density through the galaxy is less than 10^{23} hydrogen atoms per cm^2, this allows a probe across the galaxy and out to a Hubble radius for the average densities expected to exist in intergalactic space. Recent observations and theoretical work have vindicated Morrison's predictions and given great promise to the information that may be obtained on high-energy astrophysical processes in the future.

In what follows, Sections II–V treat high-energy gamma-ray astronomy in some detail. Section VI, which deals with what is usually called neutron astronomy, was contributed by R. Stephen White of the University of California at Riverside, for which I here record my thanks. Since neutrons decay with a half-life of 15 minutes, the only extraterrestrial sources from which neutrons can reach the earth must be in the solar system, principally the sun itself. Neutron astronomy includes not only efforts to measure neutrons emitted by the sun (for which so far only upper limits of the neutron flux have been established) but also measurements of terrestrial albedo neutrons created by interactions of cosmic rays with the upper atmosphere.

II. HISTORY

In the first decade of gamma-ray astronomy until the late 1960's the observations were made almost exclusively from balloonborne platforms and progress in the field closely paralleled the development of larger and more reliable scientific balloons. As the need for ever-increasing sensitivity became known, larger detectors were built and flown higher in the atmosphere. In fact, the impetus for larger balloons in the 1960's came principally from high-energy astrophysics. During this period, this was the only medium for providing the exposures necessary for the large, heavy, sophisticated detectors. Beginning with the OSO-3 gamma-ray counter telescope launched in 1968 and the ESRO TD-1A and NASA's second Small Astronomy Satellite launched in 1972, the orbiting space platforms began to make a major impact in this new field of astronomy. These new platforms, rather than replacing the balloonborne telescopes, have filled a gap that was inaccessible to balloon gamma-ray astronomy. The essential purpose of these missions was to make general sky surveys to map the celestial sky in high-energy gamma rays. Since the satellite opportunities are few, there is a critical need for balloonborne studies with specialized instruments to concentrate on details discovered in these survey missions. This point will be discussed more specifically below, but it seems appropriate to summarize briefly the contributions to gamma-ray astronomy from balloonborne observations to date.

Modern experimental gamma-ray astronomy had its beginning in the late 1950's. In the 15 years of this research, balloon platforms have provided over 90 percent of the observational opportunities. Over 100 balloon flights have been devoted to this subject, with emphasis until recently on the energy range above about 50 MeV. Because of the diffuse background caused by secondaries produced by cosmic-ray interactions in the residual atmosphere above the detector (see Figure II.B.2), these flights have concentrated mostly on the study of discrete sources where detector angular resolution can be used to restrict the influence of the diffuse background and to the high-intensity diffuse galactic plane emission in the galactic longitude region within about 40° of the galactic center.

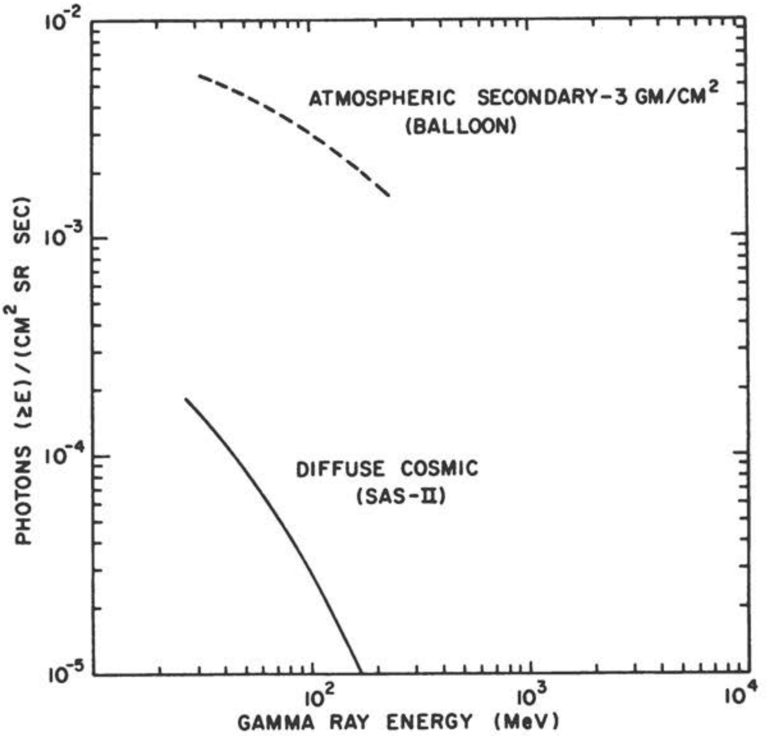

FIGURE II.B.2 Comparison of the atmospheric secondary intensities measured at a depth of 3 g/cm² and geomagnetic cutoff of 4.56 V with the diffuse, presumably extragalactic intensity measured by the SAS-2 satellite spark chamber gamma-ray telescope. Although much lower atmospheric intensities are achievable by floating at smaller depths at locations with a higher geomagnetic cutoff, the background contamination is still large.

III. CURRENT STATUS

A summary of the status of these observations in 1972 is given by the report of a panel discussion on "High-Energy Discrete Sources" of the IAU Symposium No. 55 on X- and γ-Ray Astronomy, summarized by G. G. Fazio (1973). The dominance of balloon observations in the discipline until this time is evidenced by the fact that the only satellite results at this discussion were the <30 MeV Apollo 15 and 16 gamma-ray measurements and the very significant observation of >50 MeV galactic gamma-ray emission reported by Kraushaar *et al.* (1972). However, the limitations of the investigations were evidenced by the fact that although many possible discrete sources were reported, the only independently verified source reported was for pulsed emission from PSR0531 in the Crab nebula. It is still not clear whether this lack of confirming observations is due to time variations in source emission, statistical fluctuations, or experimental difficulties, although it seems safe to assume that, at a minimum, several of the reported sources are real, and there is an urgent need to study their properties.

Balloon measurements since the 1972 IAU conference have provided additional observations of pulsed emission from PSR0531 expanding the energy range of the observations to about 1 GeV with the gas Čerenkov telescope of the Cornell group. Puzzling is the recent report by the same group that pulsed emission was not seen on a later flight, indicating a marked reduction in the pulsed flux of gamma rays at these energies between 1971 and 1973. In addition to this source, the Case Western Reserve-Melbourne (CWRU-Melb) collaboration has reported a 10–30 MeV pulsed flux from PSR0833-45, the Vela pulsar.

Other balloon observations since the 1972 panel discussion include reports of other discrete sources as well as measurements of the galactic center and the diffuse, presumably extragalactic, flux. Differences in the reported values persist and require further study.

Since 1972 the launch of the SAS-2 spark chamber gamma-ray telescope has provided a survey of over half of the sky for >35 MeV gamma rays, greatly expanding our knowledge of celestial gamma rays. This telescope has provided a large amount of new data on the diffuse gamma-ray flux and on the galactic gamma-ray emission. However, to date this survey has still provided only two strong unambiguous gamma-ray discrete sources, the Crab nebula and its pulsar PSR0531 and the Vela region with its pulsar PSR0833-45, both seen previously by balloon observations. Again many other localized enhancements of lesser significance were seen but need further study.

IV. FUTURE NEEDS

At this stage it can be stated that the field of gamma-ray astronomy above 10 MeV has made the transition from an era of discovery to one of exploration. ESRO's COS-B gamma-ray telescope, launched in 1975, and the much larger Gamma Ray Experiment Telescope (EGRET) of the GSFC–Stanford–Max Planck–Grumman collaboration, scheduled for a 1979 launch, are expected greatly to increase our knowledge of celestial gamma radiation with their sky survey missions. The need now is for a detector with an area of several square meters to operate on a satellite for several years as gamma-ray astronomy becomes an observational discipline. The combination of large area, long exposure time, good angular resolution, and low background will lower the threshold of sensitivity for gamma-ray sources substantially below that established by present-day satellite and balloon experiments and those planned for the late 1970's. This has been amply documented by the Woods Hole studies (Space Science Board, 1971, 1974) and the recent Goody report (Space Science Board, 1976). However, there is also a requirement for balloonborne detectors to study specific aspects of high-energy gamma-ray astronomy. For example, a detector with an area of about 1 m^2, which can reach a depth of a few g/cm^2, can examine several of the strongest discrete gamma-ray sources that have been reported. The larger area will permit an accurate determination of the source characteristics. One of the paramount features of many of the galactic x-ray sources that have been detected is that they exhibit large temporal variations in intensity. In the gamma-ray region there is similar evidence for variability in the case of the Crab pulsar. Evidence of variability was also seen by the CWRU-Melb group for the source AP Lib, which has been identified as a BL Lac-type object in the southern hemisphere. On a balloon flight in December 1969, this source was seen at an intensity of several times 10^{-5} gamma cm^{-2} sec^{-1}, whereas on previous and subsequent observations only upper limits could be established at this same sensitivity. Balloon observations with their quick reaction turnaround and relatively low cost are ideal for these studies.

It should also be pointed out that for both the balloon and satellite observations, the product of the observing time and the area of the detector has meant that in most cases the information obtainable from the gamma-ray sources has been statistically limited. For instance, in the study of the Crab pulsar above 10 MeV, the total number of pulsed gamma rays seen by all groups is less than 200. Although this number has been sufficient to establish statistically that the pulsed emission exists and dominates the Crab nebula emission above about 100 MeV, the small number of events prevents extracting any further information from the observation so important in understanding the emission mechanism. To show the additional capability of a balloon experiment that is projected for the summer of 1976, the CWRU 1-m^2 detector, flying at an altitude of about 1 mbar should observe some 500 events from the main pulse of the Crab over several hours of observation. Part of this anticipated increase of signal is due to the larger area of the detector, and part of it results from improving the detection efficiency below 30 MeV. With the increased statistical accuracy it will be possible to determine the position of the main pulse to within 100 μsec, and thereby to compare more closely with the observed optical peak whose position is known to within 20 μsec. It will also be possible to obtain a better measurement of the gamma-ray intensity and to investigate the relative intensity of the interpulse. Observations of this ratio have been inconclusive, and it is an important parameter in theoretical emission models. Also, of course, one will be able to look for time variations in the pulse intensity over time scales from 10 to 30 minutes; and if it is possible by means of extended flights to make repeated observations of the pulsar over consecutive days, then one can search for intensity variations over this longer time period. A deeper understanding of the pulsar mechanism will come from simultaneous observations of the Crab at a variety of wavelengths, particularly since the Crab is the only pulsar that has been observed in the radio-frequency, infrared, visible, x-ray, and gamma-ray portions of the spectrum. Balloon flights with their relatively flexible scheduling are particularly amenable to simultaneous observations.

Another exciting development in the study of pulsars is that pulsed gamma rays have been observed from the Vela pulsar by the CWRU-Melb and Goddard Space Flight Center (GSFC) groups. Vela was a natural candidate because, like the Crab pulsar, it has a short period (89 msec) and is associated with a known supernova remnant. However, unlike the Crab results, extended searches by optical observers had failed to reveal any pulsed optical emission from this object, even though recent searches have extended down to the 25th magnitude. Marginal evidence was seen by one x-ray group for pulsed emission in the soft x-ray region, but conflicting upper limits have been set by later searches. The GSFC group observes a double pulse structure for the PSR0833-45 from their SAS-2 observations very much like PSR0531, with the same 0.4-period separation between peaks. The main pulse follows the radio pulse by 13 msec. Although these results are based on three separate weeks of observation over a six-week interval, many more observations at these and other wavelengths are necessary. It should also be possible to observe the two pulsars that have the smallest dispersion measure if this low dispersion measure is actually indicative of their nearness to us. If the gamma-ray flux observed for Vela is due to the electron polar zone emission predicted by Sturrock's theory in which the intensity is predicted to depend on the period as $P^{-4.25}$, then on a balloon flight, the 1-m^2 detector should be able to detect several of the pulsars that have periods in the 150-msec range.

In addition to the gamma-ray emission from the pulsars and the possible observation of the one BL Lac object, the emission from the galactic plane has also been observed from balloons. However, in this case the atmospheric background observed even at 1 mbar altitude is a definite limiting factor to obtaining improved observations from balloon experiments. The one area in which new observations could be informative is to improve the angular resolution by using other detectors than the spark chambers that have been used up until now. The best approach here appears to be the combination of emulsion and spark chamber that the NRL group has used. There is also the possibility of the development of 1-m^2 detectors with improved angular resolution. This is a further example of the part that balloon experiments can play in the development of gamma-ray astronomy in that new types of detectors can be first tested on balloons under near-space conditions to see if the potential angular resolution or some other improved characteristic can actually be realized.

There are three pending advances in balloon technology whose attainment would improve the observational program in gamma-ray astronomy. The first is to increase the maximum altitude for zero-pressure balloons to 0.5 mbar, which would correspondingly reduce the atmospheric gamma-ray background. Possibly new balloon materials will be the answer. Second, develop a superpressure balloon system that will take a 500-lb load to at least 3 mbar and keep it at float for many weeks. Third, develop a launching system that will operate in a higher surface wind than the 7-knot limit now imposed. This will improve the possibility for simultaneous observations and permit successful launches from remote sites, especially in the southern hemisphere, where conditions at present are marginal compared with those at NSBF.

V. SUMMARY OF HIGH-ENERGY GAMMA-RAY RESULTS AND GOALS

In summary, the most significant achievements of balloonborne gamma-ray astronomy include the following:

1. The discovery of pulsed gamma-ray emission from the Crab nebula pulsar PSR0531, the Vela pulsar PSR0833-45, and possibly several other discrete sources.
2. The verification of the galactic gamma-ray emission and the importance of cosmic-ray–interstellar matter collisions in producing this emission via the decay of neutral pions produced in the interactions.

3. The development of the very sophisticated space-qualified instruments needed to make the crucial satellite observations.

The current scientific goals in gamma-ray astronomy that can be achieved by balloon experiments in the last half of this decade (particularly if the balloon developments listed above are carried out) are

1. To observe the Crab and Vela pulsars to measure the phase to 100 μsec, determine the energy spectrum, measure the main pulse-interpulse ratio, and search for intensity variation. Vela observations require flights in the southern hemisphere.
2. A search for other gamma-ray pulsars.
3. A search for gamma rays emitted by such objects as BL Lac objects, N-galaxies, Seyfert galaxies, and quasars, which exhibit large and sudden changes in intensity in other spectral regions and which may also fluctuate as the gamma source AP Lib did in 1969.
4. A high-sensitivity high-angular-resolution search for other sources, particularly in the parts of the sky that have not yet been surveyed.
5. To monitor the sun during the next solar cycle for the high-energy gamma rays that must be emitted during particle-generating flares.
6. To observe >10 MeV gamma rays with high angular resolution from regions within 40 deg of galactic longitude of the galactic center, where bremsstrahlung emission of galactic cosmic-ray electrons traversing the interstellar gas should give vital information on the ratio of energetic cosmic-ray electrons to protons.
7. To monitor continuously for gamma-ray burst events and other transient phenomena such as might be done from long-duration orbiting superpressure balloons.

As can be seen, these requirements require traditional zero-pressure balloon flights, transatlantic flights, and long-duration superpressure flights. As in the past, the needs would greatly benefit from continued improvements in reliability and capability of the balloon vehicle as well as the launch operations.

In general, the demand should remain high for balloon opportunities in high-energy gamma-ray astronomy, particularly if funding agencies will recognize the urgent need for increases in budgets to cover the rapidly escalating costs of large balloons. With respect to cost comparisons with other vehicle possibilities, the only other vehicle usable for modern high-energy gamma-ray astronomy is the satellite platform. The satellite opportunities have been so few that the telescopes have of necessity been designed as survey instruments rather than specifically for the specialized aspects of the problem discussed above. In this sense, the two techniques complement each other and a cost comparison has relatively little meaning.

VI. NEUTRON ASTRONOMY

Neutrons are produced on bombardment of nuclei by protons and alpha particles in the atmospheres of the earth, the sun, and the stars. They may also be produced by thermonuclear reactions, in which the temperatures and densities of deuterium are sufficiently high. Since the neutron decays with a half-life of 15 minutes into a proton, an electron, and a neutrino, neutrons are not expected from sources outside the solar system. However, neutrons with energies from about 1 to 100 MeV are expected from the sun at times of solar flares and with a lower intensity during quiet times.

A measurement of solar neutrons would help to answer the basic question, "What is the fundamental mechanism for producing a solar flare on the sun?" It would study the "high-energy processes" that are necessary to the understanding of flares. The rates of magnetic-field merging, the magnitude of the electric fields created, the energies of the particles accelerated by these fields, and the loss of energy by the energetic particles to heat up the plasma are difficult to measure. The neutron measurements will provide important information about these quantities. The time distributions of the neutrons will give the time buildup and decay of solar flares through magnetic merging or by energetic proton dumping.

In order to detect solar neutrons and measure their properties, very sensitive neutron detectors with good energy and angle resolution and high background rejection are required. Large double-scatter neutron time-of-flight telescopes have these properties and thus have been able to set the lowest upper limits to the quiet-time solar flux. According to current theoretical predictions, they would have detected neutrons from the solar flares of August 4 and 7, 1972, if they had been in position above the earth's atmosphere at that time. These neutron telescopes must necessarily weigh about 2000 lb in order to put sufficient neutron interacting material into the path of the neutrons. Satellite flights (which are in any case limited to detectors smaller than 200 lb) have not been available in the past. Thus, almost all limits to solar neutron fluxes have come from balloon flights.

In order to reduce neutron backgrounds produced by cosmic rays in the atmosphere above the balloons to the lowest possible values, it is useful to fly at the highest possible altitudes. However, as the mean free paths for cosmic-ray protons and secondary particles to produce neutrons and for the neutrons themselves are many tens of g/cm^2, it is also useful to take information at altitudes as low as 10 or 20 g/cm^2 of residual atmosphere, if the signal is sufficiently above background. Large balloons of 20 million ft^3 or larger are useful for carrying large neutron telescopes to about 3 g/cm^2 of residual atmosphere. As the experimenter would like to optimize his chances for observations during a solar flare, long-duration balloon flights are very desirable. This is true also for quiet-time observations, as the minimum observable solar flux goes as (time)$^{-1/2}$. For this reason, solar neutron measurements would be greatly helped if a long-duration balloon flight could be developed to carry 2000 lb for flights of up to 100 days. Flights of many days or weeks that could be obtained with the present polyethylene 20 million ft^3 balloons on transatlantic flights and longer-duration trans-U.S.A. flights would be very useful. If overflights of other countries such as Mexico were permitted, and recovery made at remote sites or even in the ocean, this would greatly assist the long time measurements. Zero-ballast balloons that drop down to 20 g/cm^2 residual atmosphere at night would be acceptable for most neutron measurements.

It is interesting that one of the most fundamental problems of space physics—the source of the high-energy protons for the radiation belt—has recently been solved with neutron measurements from balloons. The albedo neutrons from the earth, produced by cosmic-ray proton and alpha-particle interactions in the atmosphere, have been measured by neutron double-scatter telescopes. These obsevations showed that the albedo neutrons are sufficient to supply the high-energy radiation belt protons. Here again large double-scatter time-of-flight detectors with high sensitivity, good energy and angle resolution, high background rejection, and wide aperture were required to answer the question. All the double-scatter neutron measurements and most of the single-scatter measurements of the albedo neutrons have been made from balloons.

Future balloon flights can solve the remaining questions for the atmospheric neutrons by obtaining more detailed altitude, angle, and energy distributions. It would be useful to have additional flights at different latitudes to measure the albedo latitude distribution.

Balloon-carried neutron telescopes will continue in the future to make the major contributions to our understanding of the source of the high-energy protons in the radiation belt and the atmospheric cosmic-ray interactions.

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C

X Rays and Low-Energy Gamma Rays

J. D. KURFESS

I. INTRODUCTION

This position paper presents the status of and future requirements for scientific ballooning support in relation to x-ray and low-energy gamma-ray observations. The scientific areas utilizing balloonborne x-ray and gamma-ray observations are divided into several subdisciplines, and the past achievements, current status, and future requirements in each subdiscipline are discussed. Balloonborne x-ray and low-energy gamma-ray observations have been conducted by a large number of groups during the past 15 years. The Study Committee compiled a preliminary list of scientists that currently includes 64 scientists who are specifically interested in x-ray and low-energy gamma-ray observations from balloon vehicles. Those identified include 43 U.S. scientists and 21 foreign scientists.

The photon energy range of interest in this position paper is 15 keV to 10 MeV. Atmospheric absorption precludes useful exo-atmospheric observations below 15 keV, while above 10 MeV the scientific objectives and detector techniques are sufficiently different to warrant a separate position paper. Balloon programs utilizing the x-ray and gamma-ray techniques but relating to magnetospheric or atmospheric investigations are also discussed in other position papers and are not considered here.

Figure II.C.1 shows the transmission of the residual atmosphere to photons between 10 keV and 10 MeV for several pressure altitudes. The effective 15-keV low-energy cutoff for traditional balloonborne observations is apparent from this figure. Throughout most of this energy range, the atmospheric transmission is very high at the pressure altitudes (2 5 mbar) achieved by current balloonborne systems.

The x-ray and low-energy gamma-ray objectives are divided into

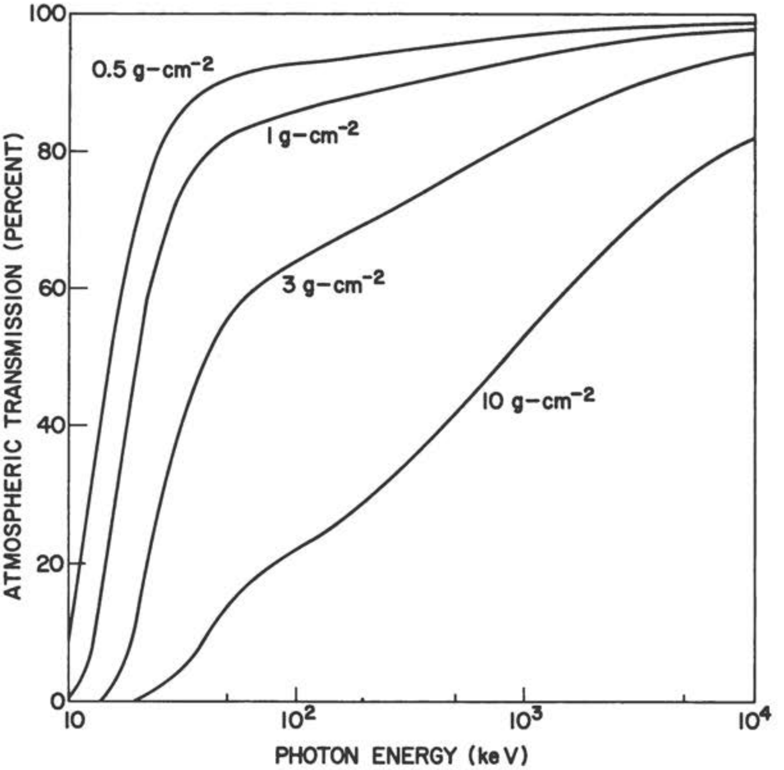

FIGURE II.C.1 Transmission of the residual atmosphere as a function of photon energies from 10 keV to 10 MeV for several pressure altitudes.

the following subdisciplines in order to facilitate the discussion of the current status and future balloon requirements: (1) solar-flare measurements, (2) celestial x-ray sources, (3) line gamma-ray emission, (4) diffuse celestial background, and (5) gamma-ray burst observations.

Section II provides a brief history of balloonborne contributions to x-ray and gamma-ray measurements. Section III describes the scientific objectives and balloon support requirements for each of the subdisciplines listed above. Some general considerations relating to balloonborne and satelliteborne experiments are given in Section IV. The possible impact that the Space Shuttle will have when it becomes operational is discussed in Section V.

The primary requirement for future x-ray and low-energy gamma-ray experiments is for balloon flights of much longer duration than currently available. This requirement can be met by two long-duration programs now under way. The National Scientific Balloon Facility (NSBF) is conducting a program to develop a superpressure balloon capable of carrying a 500-lb payload at 130,000-ft altitude for up to 100 days. This vehicle would provide a low-cost alternative for experiments that heretofore have required satellite payloads. The second long-duration possibility involves transatlantic flights of about 1-week duration using conventional balloons. Such flights would be suitable for experiments that are incompatible with the payload limitation of superpressure balloons.

II. PAST ACHIEVEMENTS USING BALLOONBORNE INSTRUMENTATION

Balloonborne observations have been conducted for over 15 years in the hard x-ray and low-energy gamma-ray region. Hard x-ray and low-energy gamma-ray observations are of interest, since these measurements relate specifically to the high-energy processes occurring in astronomical objects and in solar flares. The observation of continuous spectra provide insight into the very-high-energy electrons present in these sources. In addition, the gamma-ray observations provide direct information about nuclear reactions occurring in different objects. Most of the experimental effort has been in the 15-200 keV region, where hard x-ray observations were made of soft x-ray sources previously detected in rocket surveys. Also, several groups have studied the diffuse extraterrestrial x-ray background in this energy region with balloonborne instruments. More recently, increased effort has gone into the low-energy gamma-ray region (0.2-10 MeV). This energy range is a difficult region experimentally because background reduction is difficult, and detectors tend to be expensive and heavy.

The following list indicates some of the significant achievements from balloonborne observations during the past 15 years:

	Reference
Hard x-ray continuum emission from a solar flare (1959)	1
Hard x-ray emission from the Crab nebula (1965)	2
Detection of diffuse hard x-ray background (1966)	3,4
Observation of variability in Cygnus X-1 (1967)	5
Hard x-ray flare from Sco X-1 (1967)	6
Hard x-ray emission from Crab pulsar (1969)	7,8

Gamma-ray emission from Crab pulsar (1971)	9,10,11
511-keV feature from the galactic center (1973)	12
Hard x-ray observation of lunar occultation of Crab nebula (1974)	13

It is also important to point out that the OSO-class satellite experiments and the HEAO experiments currently under development have evolved from and were made possible by the established balloonborne programs initiated in the 1960's. Detector designs perfected within these balloon-based programs are to a large degree responsible for the success of the follow-on satellite experiments.

III. BALLOON SUPPORT OF SCIENTIFIC OBJECTIVES

In this section the capability of current and planned balloon systems to support the various objectives in each subdiscipline is discussed. Comparisons between the support provided by balloons and other vehicles (satellites, rockets, aircraft) are considered. The discussion will focus primarily on the relative merits of balloon and satellite experiments. Traditionally, those experiments that can utilize balloonborne payloads have done so. The decision to utilize a rocket or balloon is almost always determined by the 15–20 keV low-energy cutoff imposed by atmospheric absorption for balloon experiments or the limited observation time available with sounding rockets. However, for certain isolated experiments a rocket observation above 20 keV may be desirable when compared with a balloonborne experiment. In general, aircraft are not competitive for exo-atmospheric studies under consideration here and will not be considered in the following discussion.

A. Solar-Flare Research

Hard x-ray observations have provided considerable data on solar-flare physics over the past 15 years or so. Most of this work has been accomplished by experiments launched aboard NASA's OSO satellite series, although OGO, IMP, and SOLRAD experiments have also contributed. Because of the availability of the satellites, which have provided nearly continuous solar coverage, and because of the limited duration of conventional balloonborne experiments, hard x-ray solar observations from balloon vehicles have not been competitive. However, long-duration balloonborne observations can provide a low-cost alternative to such observations in the future.

Hard x-ray polarimetry of flare emission has not been pursued by many groups. Polarization experiments during the hard x-ray impulsive phase are of particular interest, since x-ray bremsstrahlung from a directed electron beam can have a high degree of linear polarization.[14] Observations are desirable above ~20 keV, where the nonthermal component dominates. Most current efforts involve proportional counter polarimeters, which are optimized for ~5–40 keV observations. Clearly, long observations are required, and satellite instrumentation and long-duration balloonborne experiments are well suited for this work. Balloonborne polarimeters may be somewhat degraded by scattered solar x rays in the residual atmosphere; however, by utilizing a reasonably small field of view this problem can be minimized. Long-duration observations are more important than extreme altitudes.

Solar gamma-ray observations are of special importance because measurements of line gamma-ray emission provide information on the temporal and spectral behavior of the high-energy nuclear particles in the flare region. The first observations of solar line gamma-ray emission were made by the gamma-ray monitor on OSO-7.[15] Extended observations are also required here, because the likelihood of observing a large flare during a conventional balloon flight is small. Long-duration balloon vehicles would permit solar gamma-ray observations at a considerably reduced cost relative to current satellite instruments.

B. Celestial X-Ray Sources

Hard x-ray observations of celestial sources generally require observation times much greater than those obtained from a rocket vehicle. There are certain exceptions to this, e.g., a lunar occultation of an extended source. Otherwise, balloon or satellite observations are necessary.

X-ray astronomy has been characterized by observations of variable, periodic, binary, and pulsating sources. Prior to 1970, balloon and rocket data provided evidence that a few selected objects fell into these categories. With the capability for repeated and extended observations provided by *Uhuru*, it was discovered that most galactic sources exhibit some form of temporal variability. Observation of the eclipsing binary character of several sources provided the first evidence regarding the class of objects that evolve into x-ray sources. This increased understanding of x-ray sources was not achieved through increased sensitivity relative to contemporary rocket experiments but by the capability to monitor sources over extended periods. Even extragalactic sources [e.g., Cen A (Refs. 16, 17)] show dramatic changes in intensity on time scales of less than one year.

All known x-ray sources emit more copiously in the 1-10 keV interval than above 15 keV. It is, however, of great importance to various source models to understand the spectral character above 15 keV and to determine the temporal characteristics in the hard x-ray region. Because of the atmospheric absorption in the 15-50 keV region (see Figure II.C.1) satellite experiments can achieve a higher signal-to-noise ratio at these energies. This advantage is offset in part by higher backgrounds experienced by low-altitude orbiting experiments because of spallation products produced in the South Atlantic Anomaly. A further constraint on satellite instruments until the present time is the difficulty of continuously observing selected sources. For example, many experiments have been constrained to view sources infrequently because of solar-cell attitude requirements. The development of a three-axis stabilized spacecraft to enable flexible source viewing programs is quite expensive. In contrast, balloon technology is compatible with simple, low-cost two-axis orientation systems, which can provide continuous source observations for periods of several hours. With a long-duration balloon capability, observations of individual sources can be repeated on a daily basis. This will be important in searching for the possible binary character of selected objects.

Because of the atmospheric absorption, very high-altitude balloons would provide significant signal-to-noise improvement for all x-ray sources; this is particularly important for those with steep power-law or low-temperature thermal spectra. For example, the signal-to-noise ratio for a source like Sco X-1 will increase by a factor of ~4 between 3 g/cm^2 and 1 g/cm^2 and would increase by another factor of ~2 if flights at 0.5 g/cm^2 could be achieved. With such a vehicle, large-area detector arrays could provide sensitive sky surveys and search for rapid fluctuations (1 msec) from black hole candidates such as Cyg X-1.

C. Gamma-Ray Line Observations

Gamma-ray line observations are treated separately because of the unique sources of interest and the specific detector problems associated with these observations. Gamma-ray line emission is expected from young supernovae and/or supernovae remnants, from collapsed objects accreting matter, and as a diffuse source in the galaxy. The expected intensities are quite weak. Thus, long source observation times are necessary. In addition, minimum detector background is clearly desirable.

The discussion in Section IV concerning relative background effects is quite pertinent here. For orbits other than a low-altitude, low-inclination orbit, spallation produced background is a significant source of background. Moreover, the background is quite time dependent, because of the geomagnetic latitude dependence of the cosmic-ray flux, thereby making careful background subtraction difficult. An equatorial orbit is desirable, but it should be noted that gamma-ray instruments tend to be rather massive and not compatible with the equatorial orbit capabilities of a Scout launch vehicle.

Observations from a long-duration balloon platform would be beneficial for this application. They would permit long exposure to relatively few sources, so that the statistical precision of the observations could be increased. Furthermore, the background environment would be nearly constant and somewhat less than that of an instrument that is repeatedly exposed to the South Atlantic Anomaly and its concomitant buildup of spallation products in the energy interval of greatest interest. Clearly, long-duration balloon flights will provide competitive observational opportunities for these experiments.

Long-duration experiments would also greatly increase the likelihood that observations could be obtained following a supernova event in a nearby galaxy. Such observations provide a crucial test of our understanding of the final stages of stellar evolution and of the theories of nucleosynthesis.[18]

D. Diffuse Background

The diffuse cosmic gamma-ray background in the 0.015 30 MeV region is of considerable interest because of the likelihood that the source regions are well beyond our galaxy and that a possible enhancement above 1 MeV may take on cosmological significance.[19,20] Below ~200 keV, where the flux is relatively intense, the diffuse background is well established. Throughout the 0.015 30MeV region, obtaining reliable spectra is complicated by the considerable difficulty encountered in making detector background corrections.

Approaches for diffuse observations in this energy region include the following:

1. Omnidirectional detectors: A series of scintillation detector experiments on Ranger,[21] ERS,[22] and Apollo[19] have used this approach. The central problem includes correcting the observed data for locally produced radiation and spallation products. Future efforts using

this approach will require an improved signal-to-background ratio and a better understanding of the background on a satellite experiment outside the magnetosphere. This approach is not suitable for a balloonborne experiment.

2. Use of an actively shielded detector with a suitable intrinsic detector background determination technique (e.g., an active shutter crystal). This approach can be employed on satellite or balloon instruments. Low-altitude satellites encounter severe problems with spallation products; an equatorial orbit is desirable. Balloonborne experiments encounter a more uniform background; however, corrections for the residual background in the remaining atmosphere must be made either by using an atmospheric background model or by extrapolating the ascent curve to the top of the atmosphere. Even the use of an active shutter crystal is complicated by the activation and additional shielding corrections necessitated by such a detector.

3. Above ~1 MeV double Compton scattering instruments can be utilized to provide directionality, thereby rejecting most local and atmospheric background. These detectors exhibit low efficiency and moderate energy resolution, but this is compensated for by the very low background achieved using time-of-flight techniques to reject upward-coming particles. Double Compton instruments are also much less susceptible (although not totally immune) to spallation and neutron-induced background.

All the techniques outlined suffer certain problems that require a detailed understanding of the detector background in order to produce results of high confidence.

Balloon observations have been competitive throughout the energy interval up to this time. It is expected that balloon observations will continue to be very valuable, particularly at the higher energies. Any such experiments that can be conducted from a balloon platform will certainly incur greatly reduced costs relative to satellite experiments. For these observations, balloon flights to the highest possible altitudes from geomagnetic equatorial launch sites are desirable.

E. Gamma-Ray Burst Observations

Since they were first reported in the literature in 1973,[23] gamma-ray bursts have become an exciting and puzzling phenomenon, similar to the discovery of quasars and pulsars in the 1960's. The gamma-ray bursts were discovered by the Vela satellites, where the capability for observing simultaneous events in widely separated detectors confirmed the validity of the bursts and established their cosmic origin. To date, all burst observations have been made with small satellite instruments that provide long observation times, permitting detection of these infrequent events.

At this time, although theories abound, the origin of these events is unknown. We do not even know whether the bursts are of galactic or extragalactic origin. Current efforts in gamma-ray burst observations are directed toward obtaining positions of future events, improving the temporal measurements of burst phenomena, and determining the number-intensity distribution, which is related to the location of the source objects. Balloonborne instrumentation will certainly play a significant role in these observations. Many groups are now developing gamma-ray burst experiments, which are ultimately planned on long-duration balloon flights.

The determination of precise source location is of highest priority in future burst programs. With balloonborne instrumentation, simple multiple-collimated detector systems can provide source positions to several degrees (comparable with the best positions for Vela events), while detectors using coded-aperture imaging techniques will determine source positions to several minutes of arc for events with an integrated intensity of $\sim 10^{-5}$ erg/cm^2. For comparison, very-long-baseline experiments using interplanetary probes are planned, which will also provide 1 minute of arc or less position capability. These experiments employ small detectors, however, which are not as sensitive as the planned balloonborne and earth-orbiting experiments.

Figure II.C.2 shows the number-intensity distribution for 23 Vela gamma-ray bursts.[23] The solid lines are the number of bursts expected for spherical, planar, and line-source distributions, which correspond to extragalactic, galactic disk, and galactic arm models. Notice that the number of events detectable with balloonborne instrumentation currently under development could be as large as several per hour if the bursts are of extragalactic origin.

Near real-time position information for gamma-ray bursts is of interest, because radio, optical, and x-ray observatories could then study the source object in detail shortly after the event. Balloonborne experiments should provide this capability within the next several years. For this application, real-time data reduction of moderately high data rates will be required, particularly for bursts near the threshold sensitivity of the detector. This capability currently exists for conventional balloon flights and should be a requirement for a long-duration flight capability also.

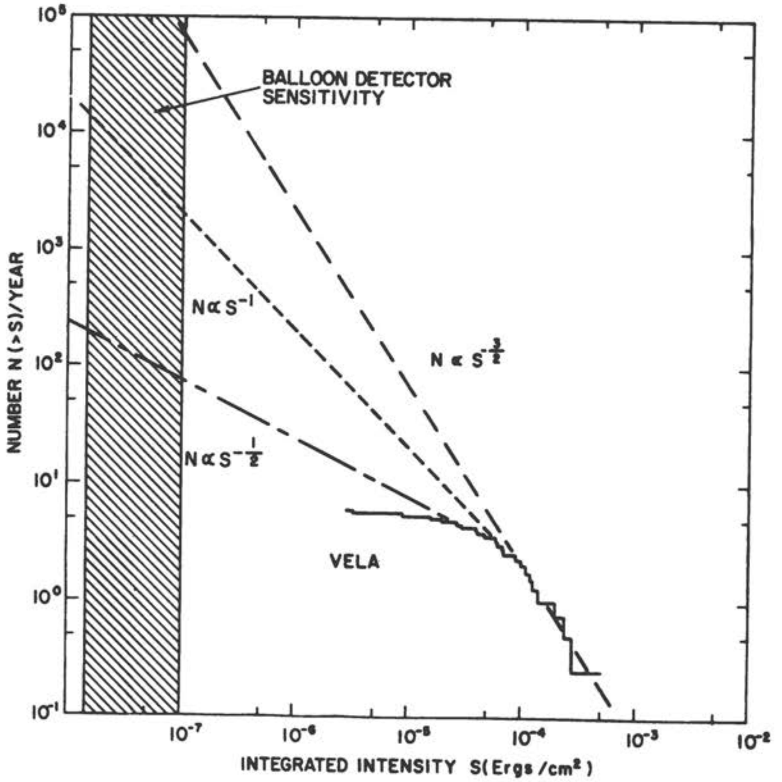

FIGURE II.C.2 Number intensity distribution for cosmic gamma-ray bursts.

F. Summary

Table II.C.1 presents a summary of the considerations concerning the relative merits of balloon, satellite, and rocket observation in support of the x-ray and gamma-ray objectives.

Conventional balloon experiments can provide good observations of individual objects. This can usually be accomplished with state-of-the-art detector systems, which precede similar instrumentation on satellites by five years or more. An example of this was the hard x-ray observations by the MIT group of the lunar occultation of the Crab nebula in August 1974.[13]

It is evident that long-duration observations are desirable for several of the objectives outlined. Ultimately this is represented by the superpressure balloon program currently under way at the National

TABLE II.C.1 Vehicle Comparison for Scientific Objectives

	Vehicle		
Objective	Balloon	Satellite	Rocket
Solar flares	Require long duration	Good coverage	Quick response to flare; limited observation time
Celestial x-ray sources	Long duration desirable, higher altitudes useful	Good coverage; flexible orientation is desirable	Acceptable for unique requirements; e.g., lunar occultation of extended source
Diffuse background	Requires correction for emission from residual atmosphere	Good coverage; susceptible to spallation-produced background	Useful below ~150 keV
Line gamma-ray emission	Long duration and heavy payload desirable	Good coverage; flexible orientation is desirable	No
Gamma-ray bursts	Require long duration	Can provide 4π coverage; high positional accuracy with long-baseline techniques	No

Scientific Balloon Facility. However, it should be realized that transatlantic and transpacific flights using conventional balloon technology can provide float durations of about one week in the near future, as was demonstrated by the first successful high-altitude transatlantic test flight in August 1975.

IV. OPERATIONAL COMPARISONS BETWEEN BALLOON AND SATELLITE EXPERIMENTS

Several of the scientific objectives discussed in the previous section require extended observations. In the past, only satellite experiments could fulfill this requirement. With the current effort and broad interest in the development of a long-duration balloon capability, it is necessary to reassess the relative merits of balloon and satellite experiments. For this discussion it is assumed that a long-duration balloon capability for a 500-lb payload to 3 mbar for 100 days will be achieved. It is also assumed that a continuing program of Explorer and OSO-type satellites (probably Shuttle-deployed) will continue to be used. This comparison is somewhat speculative since it assumes a successful long-duration balloon development program and a satellite program not drastically different from those we have today.

A. Cost

Conventional balloon experiments have been much less costly than satellite experiments. It is assumed that a significant increase in experiment costs for long-duration experiments will be incurred due to a higher vehicle cost, increased data-acquisition cost, improved reliability for the payload, and analysis of 100 days of data. Total program costs for a typical experiment may run as high as $500,000. The same experiment, launched on an Explorer or OSO-type vehicle would probably cost between $5 million and $10 million, or more when proportionate amounts of the launch vehicle and data-acquisition support are included.

B. Detector Background Rates

X-ray source observations and diffuse background observations require optimum sensitivity and low detector background. Spallation products generated in the South Atlantic Anomaly for a typical OSO orbit contribute a time-averaged detector background rate of ~0.02 counts/g-sec below ~3 MeV during periods well outside the anomaly. This can easily be the dominant background in a conventional actively shielded detector and can be several times the background expected on a balloon flight at midlatitudes. An equatorial orbit or low-altitude orbit (<450 km) improves the satellite detector background appreciably. It is clear, however, that a satellite orbit does not offer any advantages with respect to intrinsic detector background.

C. Observing Time

The total useful observing time for a 100-day balloonborne experiment and a 1-year satellite mission are comparable. Using conventional balloon orientation systems, 100 percent of the time can be devoted to source and background observations. Effective exposure on a low-orbiting satellite is limited by earth occultation and periods in the South Atlantic Anomaly. In addition, experiments viewing perpendicular to the spin axis, as many experiments have been configured, have a further limitation on source observation times imposed by small field-of-view scanning across the source.

D. Payload Weight

Satellite experiments in the past have had severe weight limitations. This restriction will be removed with HEAO-type spacecraft and Shuttle payloads. On the other hand, balloon payloads have often weighed several thousand pounds. However, a ~500-lb total payload restriction has been set for the initial superpressure balloon development. Many experimenters see a great advantage if this could be increased to 1000 2000 lb.

The above comparisons indicate that many x-ray and gamma-ray objectives can be realized in a cost-effective way *if* long-duration balloon capability is realized. It should be emphasized, however, that balloon technology will remain *complementary* to satellite technology regardless of any future long-duration development. Conventional balloons will continue to provide the basic vehicle from which selected source observations or unique experiments are performed and from which satellite and Shuttle experiments will be initially developed and tested.

V. IMPACT OF THE SPACE SHUTTLE

The future character of scientific ballooning will undoubtedly be influenced when the *planned* capability for Shuttle-launched experiments is realized in the early 1980's. It is anticipated that very-large-area arrays of detectors will be utilized to increase sensitivity. These experiments will likely be modular in nature, and balloonborne tests of these modules will be desirable.

There is considerable interest in Shuttle-launched satellite experiments. The effectiveness of such satellites will depend to a great extent on significant cost reductions in this type of space platform. If the cost of Shuttle-launched satellites cannot be reduced by a factor of ~5 from current costs, the long-duration balloon capability may continue to be a more cost-effective platform, particularly if the payload weight can be increased.

Experiments operating in the sortie mode may effectively compete with balloonborne instrumentation for those experiments requiring observation times of 1 week or less. The decision to pursue a balloonborne or sortie-mode experiment will depend on the management philosophy adopted for Shuttle experiments. If reliability, management, and safety criteria are considerably relaxed from current satellite standards, and if the experimenter is not charged proportionately for a Shuttle launch, then sortie operation will be cost effective. If these conditions are not met, balloonborne experiments will likely continue to be demanded well into the Shuttle era.

VI. THE SCIENTIFIC BALLOON AS A TEACHING TOOL

There is general agreement that the scientific balloon has provided an excellent platform for experiments in which a student has a major role in the design, implementation, and data analysis. A large number of space scientists have received their training with balloonborne instruments. This will undoubtedly continue well into the future. Even in the Shuttle era, development of x-ray and gamma-ray experiments can have a broad participation of graduate students on balloonborne test flights. The experience and expertise acquired in these flights undoubtedly pay for themselves in better designed and more reliable satellite payloads.

VII. CONCLUSIONS

Experimental groups doing hard x-ray and gamma-ray observations will continue to rely heavily on balloonborne systems in the foreseeable future. The only alternative for most objectives is a satellite experiment. The primary advantage a satellite offers is long observation time. If the long-duration balloon program is successfully developed, balloonborne experiments to monitor gamma-ray bursts, solar flares, variable x-ray sources, novae, and supernovae would be possible at a fraction of the cost of satellite programs. The development of the long-duration balloon vehicle is the highest priority "new direction" for x-ray and gamma-ray experimenters.

Both high-altitude and heavy-payload capability would be useful to experimenters. Altitudes of 170,000 to 180,000 ft will dramatically improve signal-to-noise ratio for soft x-ray sources, and heavy payload capability will probably lead to new designs for heavily shielded gamma-ray systems.

Finally, it should be emphasized that these new directions should not be achieved at the expense of current science. Balloon support has been level funded for some years, and a real reduction in x-ray and gamma-ray experimentation has been observed. The long-duration balloon development, for example, should not be at the expense of current balloon programs but should be pursued as a cost-effective approach that will expand the observational capability in this field. With the recent discoveries of cosmic gamma-ray bursts, pulsating and variable sources, and solar and extrasolar line gamma-ray emission, hard x-ray and gamma-ray astronomy requires an increased level of support so that the various objectives can be pursued within a broad, vigorous program.

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D
Ultraviolet and Optical Astronomy
G. NEWKIRK

I. GENERAL

From currently attainable balloon altitudes of 35 to 45 km, experiments using equipment weighing up to 4000 kg can be performed that take advantage of the fact that only a small residual atmosphere (0.6 to 0.1 percent of the molecules and less than 10^{-3} of the aerosols) remains above the observation platform. Thus, the effective transmission of the atmosphere is extended to approximately 2000 Å in the ultraviolet, great blocks of the infrared and hard x-ray regions are revealed, the deleterious effects of poor seeing upon high-resolution images are greatly diminished, transmission in the optical region is effectively unity, and the atmospherically scattered light adjacent to bright astronomical sources is reduced by several orders of magnitude compared with that experienced from even the most advantageous ground-based sites.

II. SPECIFIC AREAS OF CURRENT AND FUTURE BALLOON EXPERIMENTS

A. Near Ultraviolet Spectroscopy and Polarimetry

Balloon vehicles permit the examination of astronomical sources down to a wavelength of approxiately 2000 Å. This extension has been exploited in the past for both planetary and stellar photometry and polarimetry as well as near-ultraviolet imaging of the sun. (The relatively high radiance of the sun permits the use of short exposure times and small instruments, and thus much of the exploratory solar spectroscopy in this region has been carried out by rocket and satellite payloads.) However, the lower flux levels inherent in planetary and stellar spectroscopy require integration times that exceed the observing times permitted by rockets; and balloon observation in this region promises to continue to offer significant opportunities for many years.

In the area of stellar spectroscopy, the region from 2000 Å to 4000 Å contains a variety of spectral lines (e.g., Mg II, He II, N IV, N V, C III, C IV) that can be used as diagnostic tools to investigate physical conditions in stellar atmospheres and in the interstellar medium. For example, the lines 2795 Å and 2803 Å of Mg II not only reveal the presence of stellar chromospheres and extended atmospheres, which may not appear in the Ca II lines in the violet, but also allow the conditions in such atmospheres to be investigated through a comparison of lines of different ionization and excitation potential. Polarimetry in this region allows an extension of the determination of the scattering and transmission properties of planetary atmospheres and interstellar medium over a much broader range and thus allows the size distribution of the atmospheric and interstellar particles to be established with greater certainty.

Recent experiments in stellar spectroscopy in this region have been carried out by two groups—Queens College, Belfast, and University College, London, as well as the Space Research Laboratory, Utrecht, and Johnson Space Center—and have indicated that modest sized (about 40-cm diameter) telescopes can yield high spectroscopic resolution (about 0.1 Å) on stars down to about the 8th (visual) magnitude. Planetary polarimetry and spectroscopy have been largely concentrated in the University of Arizona.

B. High-Resolution Astronomy

A major advantage of the balloonborne telescope is that it is above all but a small fraction of the terrestrial atmosphere, and the deleterious effects of seeing and scintillation are reduced in approximate proportion to the atmospheric pressure *provided that thermal gradients in the air within and immediately surrounding the telescope are adequately controlled.* This advantage was first exploited by the Princeton group in the late 1950's to examine extremely small details (about 250 km) in the solar photosphere and resulted in a significant advance in our understanding of the structure of solar granulation and sunspots. High-angular-resolution observations of galaxies using the Stratoscope II system followed in the 1960's. Other attempts to exploit the high angular resolution available from balloon altitudes for solar investigations made by researchers in France and the Soviet Union, apparently have not yet been equally successful because of a variety of technical difficulties. The recent flight (May 1975) of the solar Spectrostratoscope, developed by the Fraunhofer Institute to combine both high angular and spectroscopic resolution, is reported as quite successful, although time has not yet permitted a detailed evaluation of the data. The potential of obtaining high-resolution astronomical observations in the visible from balloon platforms still remains largely unexploited, and the fundamental limitation on image stability and angular resolution imposed by the residual atmosphere remains to be described quantitatively.

Thus far, higher resolution has been sought directly by launching standard telescopes with conventional image detectors. Balloonborne optical or speckle interferometers might well place at our disposal higher angular resolution than can be anticipated from the ground provided that the guidance and thermal requirements for high angular resolution are met.

The angular resolution obtained from satellites is, of course, limited only by the performance of the telescope system; however, our experience with high-resolution spaceborne telescopes is still extremely limited. Balloonborne systems can provide valuable scientific information until the large space systems are operational, and the flight of prototype space systems on balloons can provide invaluable scientific and technical background for the successful development of the space telescopes.

C. Low-Scattered-Light Observations

The scattered light encountered in the neighborhood of an astronomical object at balloon altitudes is orders of magnitude below that encountered at the best ground-based sites. For example, at 8300 Å, the radiance of the sky adjacent to the sun at 35 km altitude is approximately $3 \times 10^{-9} B_{\odot}$, while the corresponding radiance at a good mountain site at 3.4 km is approximately $3 \times 10^{-6} B_{\odot}$, where $B_{\odot}$ is the mean radiance of the solar disk. This advantage led to the development in the 1960's of successful experiments in this country and France to observe the solar corona outside of eclipse with balloonborne coronagraphs. In addition, similar balloon systems have been used for the investigation of the thermal radiation of solid particles in the neighborhood of the sun, and photometers have been flown during eclipse to study those portions of the zodiacal light unavailable from the ground. Although the balloonborne coronagraph investigations led to new insights into the structure and evolution of the corona, their principal impact has been that they provided an irreplaceable tool for the development of the capability to observe the corona synoptically from satellites. Long-duration balloons could conceivably be used for such observations; however, the results would be inferior to those now available from satellites, and this technique is not likely to be pursued as long as there remains the opportunity for satellite payloads.

D. High-Accuracy Photometry

Although the atmosphere is reasonably transparent in the visible, the accuracy of astronomical photometry is now largely restricted by temporal changes in the atmosphere. The problem is particularly acute in absolute photometry or in areas in which a convenient astronomical comparison does not exist. For example, the solar constant is now not known to an accuracy of better than 1 to 3 percent, and variations within these limits are a subject of considerable speculation. From the ground at 4500 Å the optical depth of the clear atmosphere is approximately 0.30 (transmission 73 percent) with about half of the absorption due to the highly variable dust content. At 25 km the total optical depth is only 6×10^{-3} with the dominant contribution produced by molecular scattering and with an aerosol contribution of only about 2×10^{-4}. (At aircraft altitudes of 12 km, the corresponding figures are 5×10^{-2} and between 10^{-2} and 10^{-3}.) Since only the aerosol content is variable or uncertain, the fundamental limitation on photometric accuracy can be expected to be no larger than 0.02 percent at 25 km and between 0.1 and 1 percent at 12 km, provided that the technical problems of maintaining a consistent calibration have been solved.

This advantage of near-space observation appears to have been largely neglected with the exception of balloonborne actinometer experiments in the Soviet Union. With the re-emerging interest in the solar constant, we can expect standard as well as long-duration balloon flights to be of particular importance to this area as both primary experiments and a cross-calibration experiment in support of spaceborne photometers.

III. HIGHLIGHTS OF BALLOON ASTRONOMY IN THE ULTRAVIOLET AND OPTICAL REGIONS

1957-1959 *Stratoscope I.* High-resolution observations of the quiet solar photosphere and sunspots, improved understanding of the size spectrum of solar granulation and its role in mechanical energy transport in the solar atmosphere and the nature of convective roles in the sunspot penumbra. (Schwarzschild, 1959; Bahng and Schwarzschild, 1961a, 1961b)

1963	*Zodiacal Light Photometry.* Flight of photometers during eclipse. Observation of region of zodiacal light inaccessible from ground providing tighter constraint on models of size and spatial distribution of interplanetary dust. (Gillett, 1967)
1963 1967	*Stratoscope II,* near ir spectroscopy of planets and stars, discovery of H_2O in atmosphere of cool stars. (Woolf, *et al.,* 1964); Latest Flight of Stratoscope II, Sky and Telescope, June 1970; American Astronomers Rept. (127th AAS mtg.). Sky and Telescope, December 1968
1964	*Near IR Spectroscopy of Venus.* Determination of water vapor content of atmosphere above cloud level, established presence of ice clouds. (Bottema *et al.,* 1965)
1965 1966	*Zodiacal Light Photometry.* (Regener and van de Noord, 1967; van de Noord, 1970)
1964 1965; 1970	*Coronascope II,* Detection of outer solar corona out-of-eclipse, new perspective on evolution of solar corona. The succession of flights also provided the opportunity to test and improve design concepts for the ATM Skylab coronagraph. It is doubtful that the satellite experiment would have proved successful without these balloon flight opportunities. (Newkirk and Bohlin, 1965; Bohlin, 1968; MacQueen *et al.,* 1974)
1966 1969	*Polariscope.* Ultraviolet polarimetry and spectroscopy of planets and stars down to nearly 2000 Å, to study optical depths in planetary atmospheres; Raleigh scattering and interstellar polarization (both strongly wavelength-dependent in the ultraviolet) to determine interstellar particle sizes. This work stimulated the design of the space polarimeter used on the Pioneer 10 and 11 flights to Jupiter and Saturn. (Gehrels, 1967; Gehrels, 1974a, 1974b; Coffeen and Gehrels, 1970).
1970-1971	Out-of-eclipse coronal observations, structure of coronal streamers. (Dollfus *et al.,* 1968)
1970-1972	THISBE, polarimetry of zodiacal light. (Gabsdil, 1971)

1971 ?	BUSS, stellar spectroscopy in near uv, confirmation of Wilson-Bappu effect in stellar chromospheres applies to the magnesium emission spectrum, new perspective on mass loss from supergiants (Kondo *et al.*, 1972, 1975)
1965 1975	*Spectrostratoscope.* Solar spectroscopy with high angular and spatial resolution (successful flight May 1975). (Kiepenheuer and Mehltretter, 1964)

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E
Infrared Astronomy
W. F. HOFFMANN

I. INTRODUCTION

Infrared astronomy from balloon platforms began in the early 1960's with the flights of Stratoscope II, which carried a 0.8- to 3.1-μm spectrometer for stellar observations, and the Johns Hopkins Balloon Gondola, which was used for spectral measurements of Venus from 1.7 to 3.4 μm. Since those flights, balloonborne instruments have provided a primary means for a variety of astronomical observations in the infrared and the only available means suitable for some observations. At present, there are approximately 20 groups actively pursuing balloonborne infrared astronomy in the United States and ten in Europe and Great Britain. The results of their work include measurement of an upper limit to the contribution of ice crystals to interstellar extinction, discovery of the very large far-infrared luminosity of the galactic center, measurement of the thermal radiation from interstellar dust clouds, measurement of far-infrared flux from extragalactic objects, surveys of portions of the galaxy for far-infrared sources, mapping of extended far-infrared sources, measurement of the submillimeter cosmic background flux, isotropy and spectra, measurement of the far-infrared luminosity of the sun, and measurement of spectral lines of the sun in the infrared.

II. SCIENTIFIC CONSIDERATIONS

Thermal radiation, covering the temperature range from cool stars through planetary surfaces and interstellar dust to the cosmic background radiation, is predominantly in the infrared part of the spectrum. Molecular spectral lines from the atmospheres of cool stars and planets occur in the infrared. A variety of important spectral lines from interstellar gas, including molecular hydrogen and atomic oxygen, occur in the infrared. The luminosity of some types of galaxies is predominantly in the infrared.

For these reasons, far-infrared observations are essential for attacking a number of central astronomical questions. Among these are

1. *Early history of the universe.* The submillimeter cosmic background appears to be a (red-shifted) remnant of the hot early phase of our universe. Measurement of the intensity, spectrum, and anisotropy provide the only means to explore this history observationally. Balloon experiments have and can continue to make a major contribution to this study.
2. *Infrared galaxies.* A major unsolved problem of astrophysics is the source of energy for the extraordinarily high infrared luminosity of the nuclei of some galaxies. These have been identified by radio and ground-based infrared observations. The peak in their spectrum appears to occur in the far infrared (beyond 30 μm). As yet, only the brightest objects (galactic center, M82, NGC 1068, NGC 253) have been observed in the far infrared. Balloonborne far-infrared observation can extend this coverage in an effort to solve this problem.
3. *The galactic center.* The far-infrared luminosity of the galactic center is comparable with the visual luminosity of the galaxy. This is believed to be primarily from thermal emission from dust heated by starlight. The center of the galaxy has been mapped with moderate resolution at 100 μm. The 100-μm map has some common features with those made at 2 μm and in the radio range, but the differences are striking. Observations at higher resolution are needed to make a model of the galactic center. Very-low-resolution photometry is needed to determine accurately the total infrared luminosity of the region to compare with models of the expected stellar energy sources.
4. *Galactic structure.* Much of the content of the galaxy is interstellar gas and dust, both a starting point and product of stellar evolution. Infrared photometric and spectral line mapping can define the distribution of the gas (e.g., from molecular hydrogen-line emission) and dust and its relation to the stellar content of the galaxy.
5. *Stellar formation and evolution.* A satisfactory theory of stellar formation does not exist. It appears that stars form from gravitational collapse of dense clouds that contain gas and dust. It is likely that the dust plays a critical role in the energetics of such a collapse. The structure and energetics of dense cool dark clouds and of

H II regions containing dust and newly formed stars can best be studied in the far infrared.

6. *Interstellar medium.* The fundamental vibration rotation transitions of interstellar molecules are in the infrared. Infrared observations of these are required to understand the abundances, distribution, and chemical kinetics of the interstellar medium.

TABLE II.E.1 Infrared Astronomical Experiments Launched by NCAR Balloon Launch Facility

Ames Research Center	C. Swift	Pointed IR Telescope
Center for Astrophysics/ HCO-SAO and University of Arizona	G. Fazio, F. J. Low	High-Resolution Far IR
Fraunhofer Institute, Freiburg	K. O. Kiepenheuer	Near-IR Solar Spectra
Goddard Space Flight Center	R. Hanel	IR Scanning Interferometer
Goddard Institute for Space Studies/ University of Arizona	W. F. Hoffmann	Far-IR Surveys and Mapping
Massachusetts Institute of Technology and University of Arizona	W. Lewin, F. J. Low	Far-IR Survey
Massachusetts Institute of Technology	R. Weiss, D. Muehlner	Cosmic Background Radiation
Max Planck Institute, Heidelberg	D. Lemke, W. Hoffmann	Far-IR Survey, Near-IR Photometry
Princeton University	P. Henry, D. Wilkinson	Cosmic Background Radiation
Queen May College, London	P. Clegg	Cosmic Background Radiation
University of Arizona	F. J. Low	Far-IR Surveys, Mapping, and Pointed Photometry
University of California, Berkeley	P. Richards, J. Mather	Cosmic Background Radiation
University College, London	R. Jennings	High-Resolution Far IR
University of Groningen	R. J. van Duinen	Far-IR Photometry
University of Liege	L. Delbouille, R. Zander	IR Solar Spectra
University of Massachusetts	J. Strong	IR from Circumsolar Dust and Solar Corona
Washington University	M. Friedlander	Far-IR Survey

In many ways, far-infrared astronomy is in its infancy. However, a variety of balloonborne experiments are being carried out in pursuit of the answers to the above astronomical questions.

A list of groups whose experiments have been launched by the NCAR Balloon Launch facility during the 1970's is given in Table II.E.1. Many other groups are preparing experiments. Some of the major objectives now being pursued include

1. Survey of the galactic plane for far-infrared sources. Already over a hundred galactic infrared sources have been discovered, most of which are identified with radio sources, H II regions, and OH radio emission.
2. Mapping of large-scale, low-surface-brightness, infrared features, for example, the galactic center region.
3. High-resolution mapping of the structure of infrared radiation from H II regions in order to determine the physical and energetic relationship between the dust, the ionized gas, and the stellar heating source.
4. Observation of extremely cool (10 K) low-surface-brightness, interstellar dust clouds (dark globules), which are not heated by a high-luminosity young star. An understanding of these regions in comparison with the H II regions above is necessary to determine the conditions required for the formation of new stars.
5. Determination of the spectrum and the isotropy of the cosmic background submillimeter radiation. These give clues to the early history of the universe.
6. Measurement of far-infrared luminosity of known infrared galaxies.
7. Survey of regions away from the galactic plane for extragalactic far-infrared sources. This requires a system of very high sensitivity utilizing a very-low-background instrument. In addition to the infrared galaxies discovered by radio and near-infrared observations, it is possible that other types of extragalactic objects exist that will be discovered only in the infrared.

In addition, techniques in high-resolution multiplexing spectroscopy will soon make possible studies of infrared lines in H II and H I regions.

III. TECHNICAL BACKGROUND

Infrared astronomy is carried out by balloonborne experiments for one or more of the following reasons:

1. To make photometric measurements in the region of the spectrum for which the atmosphere is totally opaque from mountain-top observations (30–1000 μm except for poor windows at 350, 450, and 750 μm) but is highly transparent (>99 percent) at balloon altitudes.
2. To make measurements of spectral lines in regions of the spectrum where the atmosphere is relatively transparent but the spectral lines of the astronomical objects come close to and are confused by atmospheric lines.
3. To obtain very high sensitivity for photometry by taking advantage of the very low emissivity of the atmosphere, which provides a low limiting photon flux level on the detector.
4. To make absolute flux measurements, which require very low emissivity of the atmosphere in the spectral region of interest.

In all four of these categories, balloon altitudes provide a capability that is not achievable from mountain-top observatories. For items 1 and 2, there is overlap between the capability of aircraft telescopes and balloonborne telescopes. Categories 3 and 4 require at least balloon altitudes. All four requirements are readily met by orbiting spacecraft.

The atmospheric constituents absorbing in the infrared are primarily methane and the triatomic molecules, carbon dioxide, ozone, nitrous oxide, and in particular, water vapor, which is largely trapped below the tropopause. At an altitude of 100,000 feet, the mean transmission of the atmosphere at zenith, at a wavelength of 100 μm, is 99 percent. At both longer and shorter wavelengths it increases to greater than 99.9 percent. This provides more than adequate transmission for photometric measurements throughout the infrared spectrum. For specific spectroscopic problems, where the residual atmospheric lines present a problem, it is important to go higher. In addition, although 99 percent transmission is adequate for photometry, the concomitant 2 percent emissivity of the atmosphere provides a radiation background on the detector, which, for a very cold or low-emissivity telescope, provides the primary limitation to sensitivity for photometric observations of discrete sources and to accuracy for absolute flux measurements. For these special problems, it is necessary to operate as high as possible (140,000 feet or higher).

Atmospheric opacity, hence emissivity, is one to two orders of magnitude less at balloon than at aircraft (C-141 and Lear Jet) altitudes. At the shorter wavelengths (10 and 20 μm), the aircraft also experiences a "sky noise" presumably due to air turbulence in addition to the steady thermal background flux. These differences result in a crucial advantage of balloon experiments for large throughput sensitive surveys or low-resolution mapping experiments. Also balloon altitudes provide substantially less contamination of spectra from atmospheric lines than aircraft altitudes.

On the other hand, the C-141 90-cm aircraft telescope is very well stabilized and pointed. It is convenient to operate the telescope and the instrumentation. Data-handling and real-time analysis capability are excellent. This facility is particularly well suited to observations with long integration times, high-resolution mapping, and low-resolution spectra of moderately bright sources, spectral measurements of lines not contaminated by atmospheric lines, and instrumentation development and testing. Balloons and aircraft are very complementary in their capability for infrared astronomy.

Experiments for which the residual atmospheric thermal flux background, spectral lines, or practical observing time is unsatisfactory will require spacecraft experiments. However, the potential for balloonborne infrared astronomy is so great, and so recently exploited, that it has not yet been determined what its limitations are before it is necessary to go to a spacecraft to meet the objective. For example, the most definitive results on the absolute flux level and the submillimeter spectrum of the cosmic background radiation have come from balloon experiments, measurements which until recently it was thought could be obtained only from rockets or satellites. These balloon experiments resolved a conflict between excess short-wavelength flux observed by rocket measurements and indirect ground-based measurements. The cosmic background balloon experiments have answered fundamental astronomical questions and have advanced the techniques and better defined the questions that can best be answered by satellite experiments.

At present, there is considerable interest in infrared satellite surveys, which require a large advance in technique and are expected to provide an equal advance in knowledge. In analogy with the cosmic background measurements, much of this technique and advance in knowledge can be acquired by pursuing balloon experiments. At present, there is a disagreement between 10- and 20- μm rocket survey results and efforts toward ground-based confirmation. Balloonborne surveys have the capability of resolving this conflict.

Currently at least two efforts are being made to make very sensitive surveys by taking advantage of the very low thermal flux at balloon altitudes with special low-background telescopes utilizing either a very low emissivity design or cryogenic cooling. A far-infrared balloon survey is one of the recommendations of the Greenstein report (*Astronomy and Astrophysics for the 1970's*, National Academy of Sciences, Washington, D.C., 1972).

The extent to which infrared astronomy can take advantage of the transparency of the atmosphere at balloon altitudes depends on the sophistication and complexity of the instrumentation and, in particular,

1. The pointing and stabilization capability of the telescope for accurate mapping and for long integration times.
2. The use of large-aperture telescopes for high spatial resolution in the diffraction limit.
3. The development of very-low-flux background telescopes for high-sensitivity photometry.
4. The use of more sensitive detectors and detector arrays.
5. The successful utilization of remote-controlled spectrometers for infrared spectroscopy.
6. The extension of radio techniques into the infrared region.
7. The utilization of long-duration flights for extended all-sky surveys.

The largest telescope currently being flown for infrared astronomy is a 102-cm telescope with a resolution of 30 sec of arc and a pointing accuracy (drift rate) of 1 min of arc per minute of time.

The laser fusion program has resulted in the development of very-low-emissivity infrared reflectors. Fundamental research on $1/f$ noise has resulted in infrared detectors that do not require rapidly modulated signals. Techniques for making large arrays of bolometer detectors are being developed. Recent experiments have shown that Fourier spectrometers of the polarization type can produce spectra with sufficient accuracy to permit precise atmospheric subtractions. Composite bolometers with metal absorbers have high absorption efficiency in the previously troublesome submillimeter-wave region.

Advances in balloon techniques, such as higher altitude and long-duration flights, bring ballooning much closer to satellite capability in low-infrared background and long observing hours. This will increase substantially the potential for survey experiments and will make possible a variety of new experiments.

The payload capability of large balloons is adequate now to fly a very large infrared telescope. It is possible to consider apertures substantially greater than the C-141 90-cm telescope for attacking specific problems for which far-infrared resolution is crucial.

Traditionally, one of the great advantages of scientific ballooning has been to provide a very flexible means by which an individual or small group can try out a new idea or make a measurement for which no other means is available at modest cost. It would appear that a major return in the future will continue to be from experiments of relatively modest complexity aimed at solving a particular problem or set of problems.

IV. RECOMMENDATIONS

The NCAR Balloon Launch Facility has provided a remarkably fertile means for new fields to be pursued, new ideas tried, new techniques developed, and young people to get involved in the advancing edge of astronomy at a moderate cost. Maintaining this opportunity and flexibility comes first in order of recommendations and takes precedence over the other items. The recommendations are as follows:

1. To continue and expand support level for the balloon flight facility and for individual experimenters in order to maintain the opportunity for quick response to new ideas and imaginative young astronomers with experiments of relatively modest complexity.
2. To pursue the goal of long-duration balloon flights to make feasible surveying a large portion of the sky with a balloonborne infrared telescope.
3. To increase the range of normal balloon flights by adding to the telemetry capability with a nonmanned downrange data link.

F

Cosmic Dust

D. E. BROWNLEE

I. INTRODUCTION

Interplanetary dust is of considerable importance because it has a probable cometary origin. Current evidence, including *in situ* measurements in the asteroid belt, implies that the majority of interplanetary dust grains are produced by disintegration of short-period comets. Collection of cosmic dust accordingly is a means of obtaining cometary matter for laboratory analyses. For at least the next decade, cosmic dust collection will be the only technique for obtaining samples of cometary material.

While the origin of comets is poorly understood, it is widely believed that they formed coincident with the planetary system in the Uranus–Neptune region of the solar nebula. Dust released from contemporary comets is then dust that initially accreted into the ice matrix of comets 4.6 billion years ago at a distance of tens of AU from the sun. After incorporation into cometary bodies, dust grains were maintained at cryogenic temperatures until rather recent (past 10^5 years) release into the inner solar system. It is expected that cometary material is the least altered sample of primordial solar system material obtainable. Dust grains from comets are probably aggregates of both solar nebula condensates and presolar interstellar grains that were not vaporized during formation of the solar system.

Collection of interplanetary dust is possible only in the earth's atmosphere and is entirely dependent on stratospheric balloon and aircraft techniques. Particles cannot be collected by spacecraft or lunar experiments because of the high impact velocities (>5 km/sec) involved. Collection in space produces only craters, and impacting meteoroids are almost totally vaporized. Entry into the earth's atmosphere fortunately is a more gradual process, and a fraction of small meteoroids does survive relatively unaltered by the entry process. Micrometer-sized particles have such large surface area-to-mass ratios that they can thermally radiate away their kinetic energy without vaporization. The deceleration from cosmic velocity occurs at ~ 100 km altitude, and at balloon altitudes micrometer-sized particles fall at velocities on the order of 1 cm/sec. The surviving particles (micrometeorites) can be collected without serious contamination from terrestrial particulates if collection occurs above some minimum altitude. Because of the high concentrations of terrestrial particulates in the troposphere, all collections must be made in the stratosphere or mesosphere. For 10-μm sized particles, collection can be made at ~20 km without serious terrestrial contamination. For submicrometer-sized particles, contamination from sulfate aerosols necessitates collection well above 30 km.

II. COLLECTION TECHNIQUES

A dozen different cosmic dust collectors have been flown in the stratosphere with balloons. Most of the collection attempts were not successful. A major obstacle to meaningful collections was that the particle flux is exceedingly small. Ten years ago, the flux of 10-μm particles hitting the top of the atmosphere was generally believed to be ~ 10^6 particles/m^2/day. From lunar and spacecraft experiments, we now know the 10-μm flux to be ~1 particle/m^2/day. Two balloon collectors have been flown that are definitely capable of collecting interplanetary dust in spite of the low flux. One system is a settling plate collector designed to collect large particles ($>$50 μm), and the other is an air sampling system designed to collect smaller particles.

The settling plate collector ("Magellan") consists of a 8-m-diameter funnel flown beneath a superpressure balloon (Dudley Observatory). The funnel looks upward, and atmospheric particles settle into it. Large particles roll down the sides of the funnel and are collected in a cannister at its base. The collector is limited to collecting particles $\geq$50 μm in diameter because smaller particles do not roll down the funnel walls. The collector has a collecting area of tens of square meters, can be flown for months, and shows considerable promise toward solving the difficult problem of collecting 100-μm-sized extraterrestrial particles. Particles of such large size are of great value because of the powerful analysis techniques that can be used for 10^{-6} g samples. On its first superpressure flight, Magellan operated in the stratosphere for 210 days but unfortunately was not recovered.

The second collection system ("The Vacuum Monster") is a hydrazine-powered air-sampling system (University of Washington).

This device is suspended 1 km below a zero-pressure balloon and samples ~3×10^4 m^3 of ambient air during a 5-hour float period. Air is pumped at 150 m/sec through a 11-cm-square chamber, where particles are collected by inertial impaction onto clean oil-coated rods. The collector is very effective for particles in the 3–25 μm size range but is rather ineffective for smaller or larger sizes.

III. PAST ACHIEVEMENTS

A. Stratospheric Contamination

Because of the low flux of micrometeoroids, new, very sensitive balloonborne collection schemes were developed. These techniques were the first capable of collecting genuine stratospheric particles in the 10-μm size region. The collectors found that for sizes $>$10 μm most of the particles were meteoritic but that between 2 and 6 μm most of the particles were pure Al_2O_3 spheres. At 4 μm, 90 percent of the particles at 35 km are Al_2O_3 spheres. The particles were first discovered in April 1970 and have remained at a fairly constant density for the past 5 years. For particles ~4 μm, the density at 34 km is 3×10^{-2} m^{-3}. The spheres have been collected both with balloon collectors at 35 km and with U-2 aircraft at 20 km.

The spheres long remained a mystery, but it has recently been shown that they are produced by oxidation of powdered aluminum in solid fuel rocket propellant. Although the environmental effects of these particles are probably small, it is a case of global contamination by an anthropogenic aerosol.

B. Micrometeorites

Neglecting particles with high Al contents, 50 percent of the particles at 35 km with a diameter $>$3 μm are extraterrestrial. Eight of these particles were collected with the air sampling balloon collector "Vacuum Monster" (VM). During the past year, a hundred such particles were collected with NASA U-2 aircraft using technology developed by balloon collections. The particles are identified as extraterrestrial, because their elemental abundances are very close to those found in primitive meteorites. Two thirds of the extraterrestrial particles have abundances of Fe, Mg, Si, S, Ca, and Ni similar (factor of 2) to chondritic (cosmic) abundances. A match with cosmic abundances for these six elements is a highly diagnostic criterion for identifying undifferentiated extraterrestrial material.

The stratospheric collection results indicate that typical interplanetary particles consist of a fine-grained matrix material with some inclusions imbedded in it. The matrix material is an aggregate of 1000 Å sized grains, whose cumulative composition is close to cosmic abundances. The matrix material is very black and probably contains >2 percent carbon. Imbedded in the fine-grained matrix are micrometer-sized inclusions, primarily an iron–sulfur mineral and olivines and pyroxenes. The iron–sulfur mineral is similar to troilite, containing a few percent nickel. The olivines and pyroxenes are all iron-poor and are found both as ideomorphic crystals and irregular, sometimes ameboid grains. The only known materials that are similar to the recovered micrometeorites in elemental abundances, texture, and mineralogy are type 1 and the matrix of type 2 carbonaceous chondrite meteorites.

The similarity between the collected micrometeorites and primitive meteorites is probably not a consequence of a common origin but rather the result of their both being accretional aggregates of small particles that condensed from a gas of cosmic composition. Existing microanalysis techniques are very powerful, and it is anticipated that further SEM and transmission electron microscope studies of the collected particles will result in rather detailed knowledge of their mineralogy and structure. This information is potentially capable of providing rather fundamental insights into the processes that formed cometary bodies.

IV. FUTURE COSMIC DUST COLLECTIONS

It is clear that for the foreseeable future, nondestructive collection of the interplanetary dust will be possible only in the earth's stratosphere and mesosphere. In some particle-size regimes, collection can only be accomplished using balloons. In others, stratospheric aircraft and possibly sounding rockets are more suitable.

A. Submicrometer-Size Range

Submicrometer-sized micrometeorites cannot be effectively collected by aircraft because of the very high concentration of terrestrial particulates at aircraft altitudes (≤25 km). Although submicrometer extraterrestrial particles have not yet been collected and unambiguously identified, it is probable that successful collections can be made from balloons at altitudes above ~40 km. Future collectors for small particles will probably be air-sampling systems flown to ~40 km with float times of only a few hours. The weight of typical collectors will be on the order of 100 kg, and the collectors will be flown with conventional zero-pressure balloons.

Collections of submicrometer micrometeorites will unavoidably also contain submicrometer terrestrial aerosols. Because the detailed nature of stratospheric aerosols is still poorly understood, the terrestrial samples will be of some value. Of special interest will be collections made near the stratopause. It is hoped that, in future collections, there will be more overlap between studies of cosmic and terrestrial dust particles in the submicrometer-size regime.

B. Micrometer-Size Range

Although balloon collectors first proved that 3–25 μm micrometeorites can be collected in the stratosphere, recent U-2 collections have shown that this size range is much more efficiently sampled with aircraft. For volume sampling systems, the sampling rate (volume sampled/collection surface area) is limited by the speed of sound and is essentially the same for both the VM balloon system and impactors on aircraft. The major difference between the two techniques is that a 5-hour balloon experiment requires ~10 person-months experimenter time, while a 50-hour U-2 exposure requires only a few person-hours of preparation time. The contamination rate on aircraft collections is higher, but it is not really a serious problem. An additional factor in favor of aircraft is cost. The aircraft collectors are piggybacked on the NASA U-2's and essentially are flown-for-free experiments.

C. Large Particles (>50 μm)

The effectiveness of volume sampling collectors is inversely proportional to particle fall speed. Accordingly, volume sampling systems are very effective for small particles but are rather poor collectors for large particles. Aircraft samplers are by necessity volume sampling collectors and are quite inefficient for particles >50 μm.

Settling plate collectors have time–area products independent of particle size and are excellent for collecting giant particles. The balloonborne Magellan collector (Dudley Observatory) is a settling plate collector with 50 m^2 collection of collection surface. The time–area product of a long-duration (months) Magellan flight is superior to all other collection schemes. Magellan should collect 100-μm-sized extraterrestrial particles even if the atmospheric flux in this size range is a factor of 10 less than the flux measured by spacecraft.

An additional positive factor for the Magellan collector is long integration time. Past balloon collection schemes have typically spent less than 1 percent of a given year actually collecting. Magellan ideally can sample for ~50 percent of a given year and has a much better chance of collecting particles from "rare events." Meteor camera networks have shown that meteors in the >1 ton size are actually fairly numerous. These objects normally totally fragment in the atmosphere and do not produce recoverable meteorites. It is quite possible, however, that long-duration balloon collections might collect debris from such rare events.

V. FUTURE REQUIREMENTS

Over the past 15 years, there have been only two or three groups active in balloonborne cosmic dust collections at any one time. It is doubtful that the number will increase in the near future. Because of the small scale of the cosmic dust effort, major development of special facilities (i.e., cleanroom) or balloon techniques for cosmic dust is probably inappropriate. Healthy progress in the cosmic dust field can probably be maintained as long as balloon funding is not reduced below the present level.

Successful collection of large micrometeorites will require long-duration superpressure balloon flights. Besides continued funding of the superpressure program, this will also require the development of reliable tracking and recovery techniques and possibly international agreements allowing overflights of other countries. The near success of the 210-day flight of the Magellan cosmic-dust collector is evidence that with continued effort orbital balloon experiments will soon become practical reality.

G

Particles and Fields in the Magnetosphere

G. K. PARKS

I. INTRODUCTION

High-altitude balloons have played an important role in the research of precipitating particles and convective electric fields in the magnetosphere. One studies magnetospheric particles and fields to learn about the fundamentally important problems of the solar wind–magnetospheric interactions, plasma convection, the origin of radiation belts, and various plasma wave–particle interactions and instability processes responsible for particle trapping, acceleration, and precipitation. Considerable progress has been made in the last 20 years. We have moved from the survey-type experiments that characterized the earlier years to a more sophisticated era of research in which the objectives have become more demanding and ambitious. Particle and field experiments are now designed with specific objectives to explore the detailed workings of the complicated plasma phenomena.

There are four platforms from which particles and fields of the magnetosphere can be studied—satellites, rockets, balloons, and the ground. Each has certain advantages and disadvantages, depending on the type of information sought. This report will discuss the uses and relevance of information obtained from balloonborne experiments.

II. DEFINITIONS

The earth's magnetosphere supports a rich variety of wave fields and particle distributions. The types of particles and fields especially suited for balloonborne studies are (1) electrons of energies $\gtrsim 15$ keV and (2) transverse electric fields of ionospheric and magnetospheric origins.

A. Electrons

When a primary precipitated electron enters the earth's atmosphere, it loses its energy principally by means of ionization and radiation. For electrons of energies $\gtrsim 15$ keV, the radiative component (atmospheric bremsstrahlung x rays) is detectable at balloon altitudes of $\lesssim 10$ g/cm^2 of air. The bremsstrahlung x rays give direct information on the behavior of the *precipitating* magnetospheric electrons.

B. Electric Fields

When magnetospheric and/or ionospheric electric fields are imposed on the earth's upper atmospheric "boundary," a portion of this field penetrates to balloon altitudes. The components of the electric field measured at heights above 30 km are *transverse* components perpendicular to the geomagnetic field. By mapping the measured electric fields back to the magnetospheric equatorial plane, one obtains directly information on the behavior of plasma convection in the magnetosphere.

III. HISTORY

X rays at balloon altitudes were discovered during a strong auroral display in Minneapolis on July 1, 1957 (Winckler *et al.*, 1958). Once it was deduced that these were atmospheric bremsstrahlung x rays from energetic electrons of the Van Allen radiation belts impinging on the earth's atmosphere, extensive observations were carried out in the auroral regions (Anderson, 1965; Brown, 1966). Since then, many other scientific groups have entered the investigation of Van Allen precipitating electrons by means of bremsstrahlung x-ray measurements on balloons. Notably, significant contributions have come from balloon groups in Europe, the Soviet Union, Japan, Canada, and the United States.

The concept that ionospheric and magnetospheric electric fields penetrate to balloon altitudes is relatively new. Theoretical arguments for the concept were first presented by Kellogg and Weed (1968). Shortly thereafter, Mozer (1969) performed extensive balloon measurements of electric fields from auroral regions and demonstrated beyond any doubt that ionospheric and magnetospheric electric fields can be detected at balloon altitudes. Since 1969, other groups in Europe, the Soviet Union, and Japan have begun measuring transverse electric fields using balloons.

IV. SIGNIFICANT CONTRIBUTIONS

This report will list only the outstanding results that had significant impact on magnetospheric research or other disciplines.

A. Bremsstrahlung X Rays

1. On the basis of balloon observations of the intense bremsstrahlung x rays, it was deduced in 1962 that the Van Allen radiation belts would be completely emptied of their electrons in about 2 hours unless there were local acceleration mechanisms working to replenish the precipitated electrons. Until then, the understanding of particle precipitation and auroras was in terms of the "leaky bucket" model.

2. Several x-ray detectors instrumented to study auroral x rays fortuitously detected solar x rays and gamma rays during solar flares and provided "crude" energy spectrums and evidence that energetic electrons of nonthermal origin are accelerated during solar flares. This has since been confirmed by satellite observations.

3. Balloonborne studies of magnetospheric cutoff effects of cosmic rays first detected the existence of solar cosmic rays in 1958.

4. In 1968, an auroral x-ray detector intercepted (again fortuitously) a solar x-ray event that was structured with a period of about 15 sec. For the first time, it was possible to clearly tie the x-ray variations to structures observed in the solar microwave emissions from flares. This event also established that rapid time variations occur in solar x-ray events.

5. An x-ray detector on a balloon near the plasmapause detected electron precipitation in association with discrete VLF emissions in 1971. The correlation was extremely good, and this observation provided the first definite evidence that cyclotron wave–particle interactions were active and possibly responsible for electron precipitation.

6. The discovery that auroral and subauroral x rays are periodically structured. The periodicities vary from about 50 msec to tens of minutes. These observations are important because they indicate that the collisionless magnetoplasma in the magnetosphere can support many different classes of plasma instabilities and wave–particle interactions.

7. The discovery that interplanetary shocks can induce electron precipitation. The induced precipitation phenomena provide important clues about triggering mechanisms responsible for auroras.

B. Electric Fields

In the short period of time that electric fields have been detected on balloons, many significant results have been obtained. These include the following:

1. Balloon electric-field experiments flown from the polar cap region showed presence of a dawn-dusk electric field that depends on the direction of the interplanetary magnetic field. This observation indicates that there is plasma convection occurring in the polar region and demonstrates that the solar wind directly influences magnetospheric dynamics. These observations give further support to the idea that there is merging of interplanetary and geomagnetic fields.
2. Transverse electric fields measured near auroral regions show that generally the plasma convection is toward the sun. During auroral activities, the electric fields vary considerably in both direction and magnitude. These observations signify that a particle source exists in the geomagnetic tail region and that the magnetospheric plasma becomes turbulent during activities.
3. Time variations of electric fields indicate that there is an ac component in magnetospheric fields. The ac component penetrates sufficiently into the plasmasphere. Quantitative estimates of radial diffusion coefficients obtained from the power spectrum of the ac variations near the particle drift periods indicate that the ac fields are a strong driving force for the radial diffusion of trapped Van Allen particles.

V. EFFECTIVENESS OF BALLOON METHODS

X-ray detectors and electric-field probes launched on balloons offer a unique means for studying magnetospheric particles and fields. Some of the advantages are unparalleled in other techniques.

One of the most attractive features is that experiments carried on balloons are being conducted from an essentially stationary platform. The information obtained on balloons is therefore not ambiguous from the point of view of whether the variations are due to spatial or temporal effects. This ability to separate spatial from temporal causes is extremely important in magnetospheric particle and field data in view of the fact that magnetospheric phenomena frequently vary rapidly in both space and time. The electric-field data obtained on balloons are free from uncertainties and ambiguities encountered on satellites. For example, balloon data do not suffer from varying effects of plasma parameters on the electric field antennas and the $\mathbf{V} \times \mathbf{B}$

electric field introduced by the satellite motion across the magnetic field.

Another important advantage of the balloonborne experiments is that several balloons can be launched *simultaneously* from different regions of the earth to obtain information on the global behavior of electric fields and electron precipitation. Hence, the balloon technique provides a unique means of studying the spatial and temporal evolution of the magnetospheric plasma convection phenomena and distributions of precipitated electrons as a function of the geomagnetic latitude and longitude. Both the small- and the large-scale disturbances can be studied. (To date, most of the data on spatial and temporal forms have come from balloonborne experiments.)

From the point of view of studying detailed properties of "loss-cone" particles, balloons have played an important role. The loss-cone particles are not always accessible to satellite detectors because with small solar-wind and geomagnetic disturbances, the geomagnetic topology changes. In addition, the loss cone is extremely small on the equator, about 3° for fields terminating in the auroral zones. Because of these inadequacies of satellites, the bremsstrahlung x-ray data have been used to complement the equatorial observations where electrons with large pitch angles are easily detected. Together with the x-ray information, it has been possible to extend the study of the electron behavior over all pitch angles.

The fact that balloon x-ray data provide clean information on electrons of energies $\gtrsim 15$ keV is also important. When there are geomagnetic activity and particle precipitation, secondary currents and fields can be produced in the ionosphere. These can feed back to the magnetosphere and affect the particle distributions, especially the low-energy particles. Since the secondary perturbations do not affect as much the more energetic particles, the bremsstrahlung x-ray data can be used to study more effectively the primary magnetospheric processes. The comparison of characteristics in the low- and higher-energy precipitated electrons should further delineate the processes that are active in the ionosphere and the magnetosphere.

Balloons can be used effectively in support of controlled magnetospheric experiments. In recent years, experiments have injected plasmas, electron beams, and VLF waves into the magnetosphere. The objectives of these experiments are to simulate naturally occurring phenomena (such as auroras) and to stimulate the magnetosphere to excite auroras and instabilities. Balloonborne experiments can assess quantitatively to what extent such controlled experiments have been successful. For example, x-ray measurements will determine if electron precipitation occurred.

VI. LIMITATIONS OF BALLOON METHODS

While the balloon offers a unique means for studying magnetospheric particles and fields there are limitations to this technique. Balloonborne experiments have not provided information on the following:

1. Electrons of energies $\lesssim$15 keV. This energy threshold might be lowered to ~10 keV if instruments can be flown to $\gtrsim$140,000 ft.
2. Electron pitch-angle distributions.
3. Behavior of trapped electron distributions.
4. Behavior of proton distributions. Note, however, that information on precipated protons can be obtained using Hβ photometers on the ground or balloons.
5. Parallel ionospheric and/or magnetosphere electric fields. However, we note that parallel fields are also difficult to measure on rockets and satellites.
6. Electric-field measurements represent averages over 1 sec and fields averaged over ~100 km. This method does not provide fine-structure details.
7. The limited sensitivity of balloon electric-field measurements is ~1 mV/m because of uncertainties in eliminating contributions of atmospheric electricity. This means the balloon technique is less useful at the equator.

VII. FUTURE NEEDS

It is beyond any doubt that balloons still will be needed to conduct future experiments of particles and fields in the magnetosphere. Scientifically, there are many problems yet to be investigated using balloonborne instruments. Specifically, balloonborne experiments are being designed to measure auroral spatial dimensions from a few kilometers to thousands of kilometers and velocities from a few hundred meters/second to tens of kilometers/second. Quantitative determination of spatial and velocity properties will enable one to study objectively

1. Whether the types of motions and complex structures seen in visual auroras also exist in x rays. Thus, one studies the different types of mechanisms responsible for the wide range of energies of precipitating electrons responsible for visual and x-ray auroras.
2. Global distribution of magnetospheric convective electric fields.
3. Origin of electric fields, cause–effect relationship between solar wind and magnetospheric convection.

Balloon experiments will continue to complement satellite experiments. Data from balloons together with those from satellites, for example, Electrodynamic Explorers and the Space Shuttle, could help resolve the processes by which the magnetosphere and the ionosphere are coupled. In addition, the balloon experiments will evaluate by means of x-ray observations whether active experiments can stimulate the magnetosphere to induce energetic electron precipitation.

The requirements of balloons in the research of the magnetosphere are quite different from those in other disciplines. We do not, for example, need extremely large balloons. A typical payload is usually less than 50 lb. For the x-ray experiments, our one requirement is that we minimize the amount of air above the balloon, preferably less than about 6 g/cm^2 of air, since this is about the mean Compton scattering length. Typical balloon size used is $\sim 10^5$ cubic feet. The largest balloons flown for auroral work have been 3 million cubic feet.

More important for the magnetospheric balloon community is that we maximize data collection time. It would benefit us if there were means for global data collection. This is needed, for example, in experiments where 10-20 balloons are released simultaneously, separated by ~10° in longitude. In this regard, one might explore the possibility of transmitting the data to a geostationary satellite that can retransmit the data to satellite tracking stations or of setting up many ground stations.

VIII. ACKNOWLEDGMENTS

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H

Stratospheric Chemistry

D. J. HOFMANN

I. INTRODUCTION

This paper constitutes a report on ballooning for research in stratospheric chemistry for the Study of Uses of Balloons for Physics and Astronomy. (The charge to the Committee excluded consideration of the use of balloons in the troposphere, e.g., for meteorological work.) Although the time available was limited, a substantial fraction of those currently and actively involved in the use of balloons for stratospheric studies was consulted, mainly by telephone, to determine present and future needs and general opinions. Thus the author hopes that the report is as representative as can reasonably be expected, although he does not claim that it is comprehensive. It will also need updating as new techniques are developed.

In what follows, the history of the current interest in stratospheric research will be briefly reviewed, the types of measurements that have been performed using balloons and their more significant results will be discussed, the advantages and disadvantages of the balloon platform as compared with other vehicles will be noted, and estimates of future use, based on current programs, planned programs, and other desirable programs, will be made.

A. History of Recent Interest in Stratospheric Research

In recent years, the already existing high scientific interest in the earth's atmosphere has been greatly augmented by a more practical concern for the quality of man's environment. Thus research programs to study stratospheric chemistry are now numerous where only five years ago there were very few indeed. This heightened interest has caused a sudden demand for high-altitude balloon techniques to study the stratosphere.

The highly increased interest in the stratosphere began in about 1969–1970, when the discussion of the supersonic transport (SST) reached its peak. However, the scene was set 40 years earlier when Sydney Chapman (Chapman, 1930) proposed a photochemical scheme, involving only atomic oxygen, molecular oxygen, and solar radiation to explain the formation of an ozone layer in the stratosphere. His theory was generally accepted at the time and pointed out the importance of the trace amounts of atmospheric ozone (less than 10 parts per million peaking at about 25 km) in the atmospheric radiative energy balance. The ozone molecule absorbs heavily in the solar radiation wavelength region below about 310 nm and is the only absorber in the 250–310 nm region (the "biologically active" or uv-B range), thus shielding the earth from this potentially dangerous ultraviolet component.

One of the several possible ill effects of an increase in the uv-B level is an increase in the incidence of skin cancer. Skin-cancer incidence appears to be greater at low latitudes than at higher latitudes (Urbach *et al.*, 1974). This is now thought to be due both to the fact that the total amount of ozone overhead is less and that the average pathlength through the ozone layer, which solar uv must traverse, is shorter at low latitudes. There is also evidence that some plants and insects are adversely affected by elevated uv levels (Caldwell *et al.*, 1974; Bartholic *et al.*, 1974; Calkins, 1974; Caldwell, 1973).

Chapman's theory remained virtually unchanged until about 1965 when, in view of new laboratory measurements of the chemical rate coefficients involved in the theory, it was realized that the ozone loss process involved in the Chapman scheme, reaction with atomic oxygen, was too slow a process to explain the ozone profile satisfactorily; that is, there was a deficit in ozone that had to be caused by some other loss mechanism. Hunt (1966) elaborating on earlier suggestions made by others, attempted to explain the deficit by a "wet" ozone scheme in which hydroxyl radicals (HO and HO_2) chemically formed from water vapor in the stratosphere catalytically destroyed ozone. In such catalytic reactions, ozone is removed while the hydroxyl radicals are not. Thus trace amounts of the catalysts can have a large effect. Little was known, however, of the rate constants involved in these new reactions so that the importance of water vapor in ozone destruction could not be properly assessed.

The knowledge that SST's would deposit copious amounts of water vapor in the stratosphere thus caused concern in regard to ozone destruction and an increase in the incidence of skin cancer. This concern played a considerable role in Congress's eventual decision to terminate funding for the SST. During this period, the water reactions were being studied critically and Crutzen (1969) showed that the addition of destruction of ozone by water vapor was not sufficient to account for the ozone deficit, at least in the 30–35 km altitude region.

Perhaps one of the most important discoveries in stratospheric chemistry occurred in 1968 when Murcray *et al.* (1968) detected nitric acid (HNO_3) vapor in the stratosphere. This measurement was made with a solar infrared absorption spectrometer flown on a high-altitude balloon. Crutzen (1970) showed that if HNO_3 was present in the parts-per-billion range, as indicated by Murcray's measurements, then the nitrogen oxides NO and NO_2 would be important in catalytically destroying ozone. In fact, these reactions are so efficient that they could account for most of the present ozone destruction and finally explain the ozone "deficit" if the nitrogen oxides are present in the parts-per-billion range in the stratosphere.

Following termination of the U.S. SST program, Congress, in 1971, authorized the Department of Transportation to conduct a proposed three-year study of the possible effects of SST activity in the stratosphere. This effort, entitled the Climatic Impact Assessment Program (CIAP), had as its goal the assessment of biological, economic, and social consequences of increased stratospheric flights, as well as its impact on climate. The CIAP officially ended at the end of 1974; its conclusions are contained in six large monographs, which appeared in 1975. This program brought together an estimated thousand scientists from more than ten countries to focus on this particular area of study.

With theoretical predictions that the nitrogen oxides emitted by SST's would be much more important than the water vapor emitted in depleting ozone and that the amounts which a hypothetical proposed fleet of 500 SST's would emit could be harmful to mankind (Johnston, 1971), CIAP made a concerted effort to measure the natural background levels of NO and NO_2 to determine, first, if they were indeed at the levels required to explain the natural ozone deficit (and thus substantiate the theoretical predictions) and, also, to establish the natural background trends for future reference. These measurements will be reviewed in more detail in Section III; it is enough to say here that stratospheric levels of natural nitrogen oxides were found to be sufficient to explain the ozone deficit, and that the work was done primarily with high-altitude balloons. The theory that nitrogen oxides play a crucial role in ozone depletion was verified.

Other possible environmental problems of stratospheric aircraft flight are associated with their emission of small (submicrometer) particulates. Such particles, depending on their scattering and absorption characteristics, can scatter solar radiation back into space or absorb incoming radiation, the net result being a change in the radiation balance and consequent climatic changes, with possible adverse effects on food production.

In this area, CIAP initiated programs to study the natural stratospheric particulate (or aerosol) background. From these programs a wealth of new data on the natural stratospheric sulfate aerosol layer on a global basis was obtained. Volcanic perturbations have also been studied. In what may prove to be one of the most significant results, Rosen and Hofmann (1974) have reported the measurement by balloonborne counters of condensation nuclei of apparently semipermanent small particle layers in the upper troposphere at altitudes corresponding to those of commercial jet airlanes. The concentrations are in agreement with the amount of fuel expended by such jets and the jet engine emission index for such particles. If these particles prove to be due to jet traffic, then they must be considered in future climatic variation assessments. Although they may in themselves not be very important, they can diffuse into the stratosphere and serve as condensation sites for particle growth by heterogeneous reactions.

More recently, a new stratospheric ozone destruction mechanism has come up in the form of the chlorofluoromethanes, $CFCl_3$ and CF_2Cl_2, known more commonly by the DuPont trade names of Freon-11 and Freon-12, respectively. Because of the relative chemical inertness of these gases, they are used extensively as propellants for aerosol spray cans and in refrigeration applications, and they now pervade the lower troposphere in the 100 pptv (parts per trillion by volume) range (Lovelock *et al.*, 1973).

It was first pointed out by Molina and Rowland (1974) that the only known sink of the Freons is the photolytic dissociation by uv radiation near 200-nm wavelength. Since the atmosphere absorbs this radiation, the Freon molecules must reach the 25-km level before sufficient radiation is present to dissociate them. Among the products of this dissociation are Cl atoms and eventually ClO molecules, which can catalytically destroy ozone with an efficiency about five times that of the nitrogen oxides. While the effects on ozone of NO and NO_2 from SST's and other high-flying aircraft can be relatively quickly reduced by removing the source of the nitrogen oxides, the same is not true of Cl and ClO, because the parent Freons are inert and because the eddy-mixing process in the stratosphere is very slow, requiring on the order of 10 years for molecules to travel from the tropopause (at about 10 km) to a height of 25 km. Thus the full ozone depletion effects would not be felt for many years even after any cessation of Freon release to the atmosphere and, since effective lifetimes of the Freons in the stratosphere are estimated to be on the order of 50–100 years (Rowland and Molina, 1975), the effects would linger for generations.

The present ozone depletion resulting from Freons released more than 10 years ago is estimated to be less than 1 percent. This depletion should reach an equilibrium value of 15–20 percent in roughly the year 2050 (Rowland and Molina, 1975) if use of Freons continues at the present rate. But the increase of Freon usage over the past 10 years has a doubling time of about 5 to 10 years and, if continued, the predicted result, if correct, could be disastrous.*

The original calculations of Molina and Rowland have since been confirmed by independent investigators (Crutzen, 1974; Cicerone *et al.,* 1974; Wofsy *et al.,* 1975) and, in what must be considered a remarkable achievement for both theoretical and experimental atmospheric chemistry and physics, initial stratospheric measurements of $CFCl_3$ and CF_2Cl_2 have been extracted from old balloonborne infrared spectrometer data (Murcray *et al.,* 1975) and are in excellent agreement with what had been predicted for the time of the balloon flight (1968). These levels are on the order of 50 pptv.

The complete set of chemical reactions to describe the interaction in the stratosphere of all these components now numbers over 100. Many of the species have not yet been measured, and research programs, many of them involving balloons, are under way to measure these trace constituents to establish baselines and test theories.

These then are the main reasons for the recent increased interest in stratospheric research. They are intimately involved with a genuine concern for the environment. This interest will continue as long as there are such problems to solve.

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* *Editor's note (added in proof):* The following statement appears in the report of the Committee on Impacts of Stratospheric Change, *Halocarbons: Environmental Effects of Chlorofluoromethane Release,* publicly released by the National Academy of Sciences in September 1976: "If chlorofluoromethane (CFM) uses and releases were to continue at a constant rate, the ozone reduction . . . would gradually flatten out, approaching a steady state. To reach half of this value would take roughly 50 years. In particular, if constant CFM releases at the 1973 rate are to give 7 percent ultimate reduction of ozone, this reduction will initially increase at about 0.1 percent a year, reaching 3.5 percent after roughly 50 years." It is further noted that ". . . the actual releases in 1975 and 1976 experienced a 15 percent drop from the exponential growth curve and are comparable with the 1973 release rate used by us for the steady-state predictions."

II. TYPES OF MEASUREMENT

The number of different types of atmospheric measurement that can be done from a balloon have increased along with the interest in research in the area. Some old techniques have been updated and new ones designed for specific tasks. Some techniques, used previously only in the laboratory, have been adapted to high-altitude balloon applications. Rather than try to identify particular instruments, used by particular groups, we will briefly summarize the measurement types in a general fashion. The list is not meant to be exhaustive but includes effective techniques currently in use. They will be divided into two groups, *in situ* and remote sensing, where the former refers to measurements of atmospheric species in the immediate environment of the balloon package, while the latter may involve measurements of species a substantial distance (e.g., several hundred kilometers) from the balloon's location.

A. *In Situ* Sampling of Trace Atmospheric Constituents

In situ sampling is generally associated with small air samples and is thus theoretically limited by the concentration of the constituents involved. This limitation has not, however, been a serious one, since analytical techniques have progressed to the point where small air samples are sufficient to determine concentrations of a number of the trace species. The greatest advantages of *in situ* sampling are the accuracy possible and the ability to obtain an accurate vertical profile, while the main disadvantages are the difficulty of obtaining a suitable geographical scope and the possibility of local contamination of the relatively small samples involved.

In Table II.H.1, the general techniques of *in situ* sampling are outlined. They have been categorized in terms of what is being measured, i.e., gases or aerosols (particulates), and whether the initial analysis of the sample taken *in situ* is also done *in situ* or in the laboratory following recovery of the balloon payload.

Laboratory analysis techniques involve neutron activation, x-ray fluorescence, electron microscopy, and chemical analysis for aerosol samples; while for trace gas samples, techniques such as gas chromatography with electron capture detectors are generally applied.

The *in situ* analysis techniques are self-explanatory except perhaps for the phase change sensors. These involve, for water vapor, frost-point hygrometers, which detect the formation of frost on a surface, and, for aerosols, detection of a change of phase from the liquid to the vapor state for volatile aerosols.

TABLE II.H.1 *In Situ* Sampling Techniques

Initial Sample Analysis	Gases	Aerosols
Laboratory Analysis	Whole air samples Cryogenic samples	Filter samples
	Filter adsorption Molecular sieves	Impactor samples
In situ analysis	Chemiluminescent reaction sensors	Particle counters
	Electrochemical sensors	Phase-change sensors
	Phase-change sensors Resonance fluorescence sensors Spin-flip Raman laser	

The aerosol particle counters generally detect the particles by detecting either the scattering of radiation from an integral light source by individual particles or the total light scattered or absorbed by a collection of particles. They may also include a condensation growth chamber for very small particles (radii less than 0.1 μm).

B. Remote Measurements of Trace Atmospheric Constituents

All the remote measurements have one thing in common, they use the sun as an infrared radiation source. They, of course, rely on the fact that a particular gas molecule will absorb and radiate in a characteristic fashion. For aerosols, they rely on the fact that particles will scatter and/or absorb radiation in a characteristic manner depending on their size, shape, and index of refraction. Thus the remote measurements are based on either measurements of extinction of solar radiation of certain wavelengths over a long atmospheric pathlength (near sunrise or sunset) or the emission of certain radiation from particular atmospheric regions.

Only extinction techniques have been successfully used to date for aerosols, while both extinction and emission measurements have been used for gases. An infrared spectrometer of some type is used for detection in any case, and if the sensitivity is relatively poor, extinction measurements are preferable since the long atmospheric pathlengths, near sunrise or sunset, considerably enhance the absorption signal. However, sufficient sensitivity is attainable for many atmospheric trace gases so that near-zenith radiance can be observed and the vertical distribution of the emitting molecule can be obtained with greater accuracy than with long-path-length extinction techniques. In near-zenith measurements of emission, the vertical distribution of emitters is obtained by differentiating the signal during balloon ascent.

Another emission method is the use of limb-radiance measurements in which emissions are detected while scanning the earth's limb from a floating position at high altitude. Most of the emission comes from molecules near the ray-tangent point, which varies with height so that one obtains, after inversion of the radiance profile, the vertical distribution of trace gas concentration over a region varying in distance over several hundred kilometers from the balloon's position. Thus this technique, as well as the aerosol extinction technique, relies on the balloon being above a layered structure for best vertical resolution. Such measurements make use of the long atmospheric pathlengths possible and so are suitable for low concentrations; however, they require complicated pointing systems for good vertical resolution and are thus probably better suited for low-altitude satellite applications in which the expense of a complicated optical scanning system can be justified by the long period and global aspects of satellite missions. Such systems can, however, be successfully tested from the balloon platform, and initial measurements of unknown trace species, of great value to stratospheric chemistry, could perhaps be obtained before using the instrument on a satellite. In the future, however, the lack of immediate satellite opportunities and a pressing need for the measurements may dictate that such advanced systems be operated from balloons if for no other reasons than that there are no other suitable platforms.

Finally, there are measurements of the solar radiation spectrum itself, especially in the uv range, which are necessary to determine the photochemical rate coefficients more accurately. Additional measurements such as those carried out from balloons by Ackerman *et al.* (1971) are needed.

III. RECENT ACHIEVEMENTS IN STRATOSPHERIC CHEMISTRY UTILIZING BALLOON TECHNIQUES

Most of the important work accomplished recently by U.S. scientists with balloons was done under contract with a large balloon facility or balloon operations contractor such as the National Scientific Balloon Facility (NSBF), operated by the National Center for Atmospheric Research (NCAR), at Palestine, Texas; the Office of Naval Research's Project Skyhook, contracted to Raven Industries with operations at

TABLE II.H.2 Important Balloon Measurements of Stratospheric Trace Gases

Stratospheric Gas Measured	Reference	Affiliation	Balloonborne Instrument	Significance
H_2O	Mastenbrook (1971)	Naval Research Lab.	Frostpoint hygrometer	Verified that the stratosphere is very dry. Provided data necessary for chemical modeling
	Goldman *et al.* (1973a)	Denver U.	Infrared emission spectrometer	
	Zander (1973)	Liege U. (Belgium)	Infrared filter radiometer	
	Hyson and Platt (1974)	CSIRO (Australia)	Infrared absorption spectrometer	
	Patel *et al.* (1974)	Bell Labs.		
HNO_3	Murcray *et al.* (1968)	Denver U. NCAR	Infrared absorption and emission Spectrometers	Led to investigation of ozone destruction by nitrogen oxides
	Lazrus *et al.* (1972)	NCAR	Adsorption filter	
	Evans (1975)	AES (Canada)	Infrared emission spectrometer	
NO_2	Goldman *et al.* (1970)	Denver U.	Infrared absorption spectrometer	Verified the presence of NO_2 and thus of the importance of catalytic destruction of ozone by nitrogen oxides
	Ackerman and Muller (1973)	IASB (Belgium)	Infrared absorption spectrometer	
	Evans (1975)	AES (Canada)	Infrared absorption spectrometer	
NO	Ridley *et al.* (1973)	York U. (Canada) Utah State U.	Chemiluminescence detector	Verified the presence of NO and thus of the importance of catalytic destruction of ozone by nitrogen oxides
	Ackerman *et al.* (1973)	IASB (Belgium)/ ONERA (France)	Infrared absorption spectrometer	
	Patel *et al.* (1974)	Bell Labs.	Spin-flip Raman laser	
	Evans (1975)	AES (Canada)	Chemiluminescence detector	
N_2O	Schütz *et al.* (1970)	MPI (W. Germany)	Molecular sieve	A postulated tropospheric source of NO in the stratosphere
	Murcray *et al.* (1973)	Denver U.	Infrared absorption spectrometer	
	Ehhalt *et al.* (1974)	NCAR	Cryogenic sampler	
CO	Goldman *et al.* (1973b)	Denver U.	Infrared absorption spectrometer	Provided data necessary for chemical modeling
	Ehhalt *et al.* (1974)	NCAR	Cryogenic sampler	

H_2	Ehhalt *et al.* (1974)	NCAR	Cryogenic sampler	Provided data necessary for chemical modeling
O	Anderson (1975)	U. of Michigan	Resonance fluorescence	An important ingredient of the ozone production scheme
CH_4	Kyle *et al.* (1969)	Denver U.	Infrared absorption spectrometer	Provided data necessary for chemical modeling
	Ackerman and Muller (1973)	IASB (Belgium)	Infrared absorption spectrometer	
	Ehhalt *et al.* (1974)	NCAR	Cryogenic sampler	
HCl	Lazrus *et al.* (1975)	NCAR	Absorption filter	Important in the chlorine-catalyzed ozone destruction scheme. Verified the presence of Freons in the stratosphere and thus their importance for future ozone reduction
CF_2Cl_2	Murcray *et al.* (1975)	Denver U.	Infrared absorption spectrometer	
$CFCl_3$	Murcray *et al.* (1975)	Denver U.	Infrared absorption spectrometer	

TABLE 11.H.3 Important Balloon Measurements of Stratospheric Aerosols

Aerosol Property Measured	Reference	Affiliation	Balloonborne Instrument	Significance
Concentration	Rosen (1968) Hofmann *et al.* (1972) Lazrus and Gandrud (1974) Bigg and Ono (1974)	U. of Minnesota U. of Wyoming NCAR CSIRO (Australia)	Particle counter Particle counter Air filtration Impactor	Established background stratospheric concentrations of about 1 particle/cm^3 or about 1 ppb by mass
Global Distribution	Hofmann *et al.* (1972) Rosen *et al.* (1974) Lazrus and Gandrud (1974)	U. of Wyoming U. of Wyoming NCAR	Particle counter Particle counter Air filtration	Indicated the uniform global extent of the aerosol layer
Time Variation	Rosen (1972) Hofmann *et al.* (1974)	U. of Wyoming U. of Wyoming	Particle counter Particle counter	Observed both short (seasonal) and long (volcanic?) term time variations
Composition	Lazrus *et al.* (1971) Rosen (1971) Bigg and Ono (1974)	NCAR U. of Minnesota CSIRO (Australia)	Air filtration Vapor pressure spectrometer Chemically treated impactor	Showed that most of the aerosol contained sulfate, probably in the form of sulfuric acid

Size Distribution	Rosen (1968) Bigg and Ono (1974) Pinnick *et al.* (1974) Miranda and Fenn (1974)	U. of Minnesota CSIRO (Australia) U. of Wyoming AF Geophysics Laboratory	Particle counter Impactor Particle counter Particle counter	Showed that the concentration of particles increased with decreasing size at least down to about 0.1-μm radius
Extinction Coefficient	Pepin (1973)	U. of Minnesota	Infrared absorption detector	Showed that the aerosol could be remotely sensed and established a valuable tool for future research
Condensation Nuclei	Rosen and Hofmann (1974) Kaselau (1974)	U. of Wyoming Max Planck Inst. Lindau (W. Germany)	Particle counter Photographic detector	Showed stratospheric CN to be low in concentration (1–10 cm^{-3}) and detected extensive tropospheric CN layers possibly due to aircraft
Volcanic Effects	Rosen *et al.* (1972) Castleman *et al.* (1973) Hofmann and Rosen (1975)	U. of Wyoming Brookhaven Nat. Lab. U. of Wyoming	Particle counter Air filtration Particle counter	Detected aerosol most probably due to volcanic injection in both troposphere and stratosphere

Sioux Falls, South Dakota, and Churchill, Manitoba, Canada; and the Hibal Project of the former Atomic Energy Commission, involving balloon launches by the Air Force Cambridge Research Laboratory (now renamed AF Geophysics Laboratory) group from Alaska, New Mexico, Panama, and Australia. Such operations provide the scientists with a service generally not within his capability and are vital to the future of scientific ballooning.

Valuable contributions to stratospheric chemistry have also been made in the past by small independent balloon research groups such as the pioneering group at the University of Minnesota and, more recently, the atmospheric research group at the University of Wyoming. Such programs, which have obtained substantial support from the National Science Foundation in the past, should perhaps play a larger role in stratospheric research. Although such programs are generally limited in payload weight capability and thus require extensive effort in reducing such weight to an absolute minimum, they are competitive as a lower-cost option to the contracted flights when payload weights can be reduced below about 50 kg. Since bigger is not always better, it may be more cost effective to lighten the load and reduce necessary balloon size.

Table II.H.2 summarizes recent important balloon measurements of stratospheric trace gases from 1968 to early 1975. Both U.S. and foreign work is included. For conciseness, numerous routine measurements of ozone by balloon sounding, although vital for monitoring this important constituent, have not been included. In this latter respect, the work of Hering and Borden (1967) and of Komhyr and Grass (1968) are here acknowledged.

In a similar fashion, Table II.H.3 summarizes recent important balloon measurements of stratospheric aerosols since 1968. Although few measurements of stratospheric trace gases or aerosols were made before this date, the pioneering stratospheric aerosol measurements of Junge *et al.* (1961) and Rosen (1964), both accomplished with balloons, must be acknowledged.

The tables are self-explanatory and will not be discussed further except to point out the exponentially increasing use of the balloons as a stratospheric research tool over the past five years.

IV. ADVANTAGES AND DISADVANTAGES OF VARIOUS RESEARCH PLATFORMS IN STUDIES OF STRATOSPHERIC CHEMISTRY

In this section we will explore the advantages and disadvantages of the more common vehicles used in research in stratospheric chemistry.

Discussion of the relative merits of extraterrestrial techniques as opposed to ground-based remote-sensing techniques will be omitted, however. Although aircraft, rocket, satellite, and balloon techniques are in a sense complementary, there are certain advantages of some over the others.

A. Aircraft Techniques

The use of aircraft as research platforms in the lower stratosphere (10–20 km) has increased recently mainly as a result of the CIAP program and the availability of WB 57-F jet aircraft, which can reach altitudes of about 20 km. Other high-altitude aircraft such as the U-2 have also been used but not to the same extent as the WB 57-F.

Although aircraft are extremely useful vehicles for tropospheric research, they appear to have few advantages for stratospheric work. Outstanding is their ability to obtain a large geographical coverage in a relatively short period of time. However, their disadvantages seem to outweigh this single advantage for stratospheric research. Scientifically, the greatest factor involves the nature of the stratosphere in which constituents are layered horizontally, and it is measurement of the vertical distribution that provides the most useful information. Since a single layer may vary in height at different locations, the horizontal data profiles typically obtained by aircraft are difficult to interpret without corresponding vertical distributions. Operationally, aircraft present some difficulties:

1. Availability of suitable aircraft for stratospheric research.
2. High cost of operation and maintenance.
3. A ceiling altitude too low for aircraft currently available for research.
4. Experiment constraints due to high velocity, possible contamination, etc.
5. Generally no opportunity for in-flight experiment control by the investigator in such high-performance aircraft.

The future availability of the vintage WB 57-F aircraft is questionable and cannot be relied on as a platform for future stratospheric research programs. Increased availability of the U-2 has not been utilized to the full extent by scientists probably because of some of the restrictions mentioned above. Future improvements in the performance of dedicated aircraft and accessibility of the experiment so that investigators can operate them will enhance the usefulness of aircraft for stratospheric research.

B. Rocket Techniques

Rockets are inherently not well suited for stratospheric research because of the short time they spend in this region. An exception to this is the observation of solar extinction by stratospheric species near sunrise and sunset in which the short period of measurement is an advantage rather than a disadvantage, since the rocket does not change its geographical position substantially during the rocket sunrise/sunset event. To make the technique financially competitive, however, small inexpensive rockets much be employed, which restrict the payload weight to less than 5 kg. Thus rockets have been mainly used as a mesospheric tool and are valuable for *in situ* measurements above 50 km.

C. Satellite Techniques

The obvious advantage of satellite techniques is the apparent ease with which global coverage can be obtained. Since remote-sensing techniques must be used, the disadvantages of this technique as compared with *in situ* measurements must be considered. Perhaps the most serious disadvantage in this respect is again obtaining useful vertical profiles of stratospheric constituents. The solar-radiation absorption or emission techniques for trace species rely on long pathlengths through the atmosphere, thus smearing out the vertical distribution over hundreds of kilometers. Inherent in the remote satellite measurements, as in remote balloon measurements, is a heavy reliance on spectral absorption and emission data obtained in the laboratory. Presumably, the latter difficulties will be overcome with time and technique.

The global coverage of a satellite depends on its orbit and is not always as good as one would like. The atmospheric remote-sensing techniques, which will return the most useful data, generally require low-altitude orbits, and thus coverage such as might be obtained from a synchronous satellite is impossible. The low-altitude equatorial orbits generally restrict observations to small latitude bands in each hemisphere so that systems of satellites with different orbits are necessary for true global coverage.

Operationally, there are again disadvantages in the satellite technique. These include the lack of satellite opportunities and the enormous cost of such programs. In this study, we must also be concerned with what types of research are suitable for university scientists and their graduate students, and one must conclude that even though some universities are able successfully to undertake such programs, the programs are not so generally suited to the academic research community because of long lead times, difficult fabrication, required reliability, and extensive documentation requirements. However, there is still, and must always be, a useful role for academic scientists in the satellite program as scientific advisors and in data interpretation.

In summary, the satellite can serve a useful purpose in the future as a monitoring tool, but, as a basic scientific research tool in stratospheric chemistry, its usefulness is restricted to certain problems and it cannot yet be considered as a completely satisfactory replacement of other techniques.

D. Balloon Techniques

The balloon must be considered as the most versatile vehicle for research in stratospheric chemistry. It allows either *in situ* or remote measurement to be made from a stable platform. Environmental problems are not unduly severe especially as far as vibration is concerned.

The major disadvantage of balloons is that each flight affords measurements at only a single location. However, as stated earlier, for stratospheric work the vertical distribution of constituents is important, and such data are most readily obtained with the balloon because of its slow rise (or subsequent slow parachute descent) through the stratosphere. A further disadvantage for operations with large balloons is the lack of sufficient balloon facilities to accommodate launching of large balloons, especially from remote sites. Thus such operations are generally restricted to Air Force bases or permanent installations such as NCAR's National Scientific Balloon Facility at Palestine, Texas. In contrast, operations with small balloons can be located essentially anywhere, as has been demonstrated by the University of Wyoming group (Hofmann *et al.,* 1972), who have launched payloads in the 20-kg class from over a dozen stations around the world including the ice island T-3 at 85° N and the South Pole.

Balloon operations are generally less costly than other platforms. The cost of the balloon itself ranges from about $500 for a flight in the 50-kg payload class to about $50,000 for a flight in the 1000-kg class.

Since extreme altitudes are generally not necessary for stratospheric studies, ballooning is relatively cheaper in this field than in those other disciplines that require obtaining the highest altitude possible.

Large balloons are the only vehicle presently able to carry heavy experiments into the stratosphere. This will be the case until the Space Shuttle becomes a viable scientific research tool, readily available to scientists.

In contrast to non-Space Shuttle satellite experiments, balloon payloads are generally recoverable so that if a malfunction occurs or if the instrument turns out to be not configured optimally, the experiment may be repeated at a minimum cost.

Balloon programs afford the opportunity for international cooperative research programs. Many foreign countries have active balloon research efforts and are willing to engage in cooperative programs wherein simultaneous measurements, with both countries' instruments, are conducted in each of the cooperating countries. Such balloon programs have been undertaken by the University of Wyoming's atmospheric research group in cooperation with Australia, Japan, and the Soviet Union. In addition to these countries, active stratospheric research balloon groups exist also in Canada, France, India, West Germany, and the United Kingdom.

One of the most important advantages of using balloons for stratospheric study is the suitability for academic scientists and for graduate student thesis research. Since the latter is what our entire scientific future is based on, it must be taken seriously. With a balloon experiment, the scientist can set his own research schedule and a time scale of 6 months from experiment conception to flight is not unrealistic, although unusual. He is not encumbered with mechanical restrictions, since tape and string often suffice. A graduate student can conceive an experiment, design, build, test, and fly it and analyze the data in two or three years. Although the optimum situation is an independent balloon program, contracted launch opportunities are sufficiently frequent for measurements to be made with such a schedule.

In summary, the balloon has some definite advantages over other vehicles that seem to outweigh its disadvantages for stratospheric research. In fact, it is an indispensable tool that will see increased use in the future.

V. FUTURE USES OF BALLOONING FOR STRATOSPHERIC CHEMISTRY

Although the CIAP program came to an end in 1975, the FAA and other agencies are continuing the stratospheric research effort created by the CIAP program. Table II.H.4 is a listing of balloon efforts along these lines, which was obtained mainly via the telephone in May 1975 and does not claim to be complete or accurate. It gives a rough idea of the magnitude of the present interest. In addition to these national (or Canadian) programs, an expanded balloon effort is expected from Australia, France, Japan, West Germany, and the Soviet Union.

In addition to such basic measurement programs, there will be balloon tests of spacecraft experiments in the future. This is especially true of large remote-sensing instruments of the Space Shuttle class. An example of this is the laser, which the French are planning to put on the first AMPS (Atmospheric, Magnetospheric, and Plasma Shuttle) "Space Lab." It will be used for the remote sensing of aerosols, gases, etc.

The National Center for Atmospheric Research has been studying the use of superpressure balloons in their GHOST balloon program. The advantage of the superpressure balloon over a zero-pressure (normal) balloon is that it can survive sunset cooling effects and thus can be used for long-duration flight (a flight longer than a year has

TABLE II.H.4 Planned Stratospheric Balloon Measurements

Institution	Stratospheric Constituents Measured	Balloon Measurements Techniques
AES (Canada)	O_3, NO, NO_2, HNO_3, solar uv, HCl, ClO, HF	Remote and *in situ*
NASA/JSC	O_3, NO_x, CO_x	*In situ*, chemiluminescence
NOAA	CF_2Cl_2, $CFCl_3$	*In situ*, grab sample
NCAR	H, CO, CO_2, CH_4, H_2O, N_2O, CCl_4, CF_2Cl_2, $CFCl_3$, SF_6	*In situ*, cryogenic sample
NCAR	$SO_4^=$ aerosol, Cl aerosol, HCl, HNO_3	*In situ*, air filtration
U. of Denver	CO, H_2O, NO_2, HNO_3, CF_2Cl_2, $CFCl_3$, HF	Remote, solar absorption/emission spectrometer
U. of Michigan	O, HO	*In situ*, resonance fluorescence
U. of Wyoming	Aerosol, condensation nuclei	*In situ*, particle counter
York U. (Canada)	NO	*In situ*, chemiluminescence

been achieved). Although the payload capabilities are still small (<100 kg), the need in stratospheric research of such a system is so great that the effort being put into such programs is completely justified. This is also true of air-ballast balloons, which are capable of remaining on a constant isentropic surface, thus tracing out transport trajectories in the atmosphere.

The French are experimenting with stratospheric tethered balloons. Although a difficult task, it would be a useful system for stratospheric *in situ* monitoring and deserves attention.

There will be a need to perform large balloon flights at northerly latitudes during certain time periods lasting for a day or two in connection with large solar flare, cosmic ray, or PCA (polar cap absorption) events. The high-energy protons generated at the sun during such events can enter the atmosphere along magnetic-field lines in high latitudes and are thought to create NO in the upper atmosphere in polar regions at a rate that could, for the larger events, theoretically decrease ozone concentrations temporarily. Galactic cosmic radiation will also result in NO production and, since the intensity of such galactic radiation is inversely proportional to solar activity, ozone should show an 11-year solar cycle modulation. Such research will be important as it may relate to life on earth. For example, according to some paleontologists, geological records indicate that the decline or extinction of some species on the earth correlates well with times of geomagnetic field reversal. During these times, the geomagnetic field is absent so that solar protons could penetrate all latitudes. A large solar event could thus, via production of NO, reduce the ozone worldwide with a corresponding increase in uv and its consequences. Whether such a theory is correct or not may be difficult to determine, since questions such as the magnitude of a solar event necessary to deplete ozone by a specific amount and the increase in uv required to extinguish a species, genus, etc. would have to be answered. However, it warrants investigation and is good for interdisciplinary study since it links together physics, chemistry, biology, and geology.

Another such time-dependent research problem is the effect of large volcanic injections on the stratosphere. The lifetime of small particles so injected above 20 km is at least a year, and such events in the past (e.g., Krakatoa in 1883) appear to have been large enough to affect climate for several years. Model calculations of the effects of such particles on the temperature of the stratosphere and troposphere are now being carried out, and verification of such models must be made. This involves measuring the time development of the volcanic injection in the stratosphere at a number of stations varying in latitude and investigating the global temperature effects from the numerous routine weather-service temperature soundings.

The possibility of small-particle pollution of the upper troposphere by present commercial aircraft and of the stratosphere by future aircraft or Space Shuttle rocket boosters must be thoroughly investigated to determine the importance of these effects.

It now appears that the levels of Freons in the stratosphere are what one would expect if there were no loss mechanism other than photolysis in the stratosphere. This initial measurement (Murcray *et al.*, 1975) must be verified and the possibility that other sinks exist thoroughly explored. The Freons must be monitored so that the scientific community can furnish a reliable basis for decisions when the times comes for them to be made.

VI. SUMMARY

In this report, the author has stressed the importance of balloons for stratospheric studies, both in the recent past and in the future, especially for *in situ* measurements for time periods exceeding a few minutes and for vertical profiles. Their advantages over other research vehicles for basic scientific research are real. Although they do not now provide an ideal tool for stratospheric monitoring because they are not numerous enough, we may have to rely on them for this purpose also, until satellite opportunities are more clearly defined.

The balloon allows research to be planned and carried out in a timely fashion. It is an effective tool for graduate student research for contracted-type flights and for independent operations, both of which should be encouraged as viable ways of carrying out research in stratospheric chemistry.

Environmentally, a great deal may be at stake, and it is measurements such as those that have been recently carried out from balloons and those that will be carried out in the near future from balloons that will determine whether there is a true basis for the current anxiety over the ozone depletion problem.

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