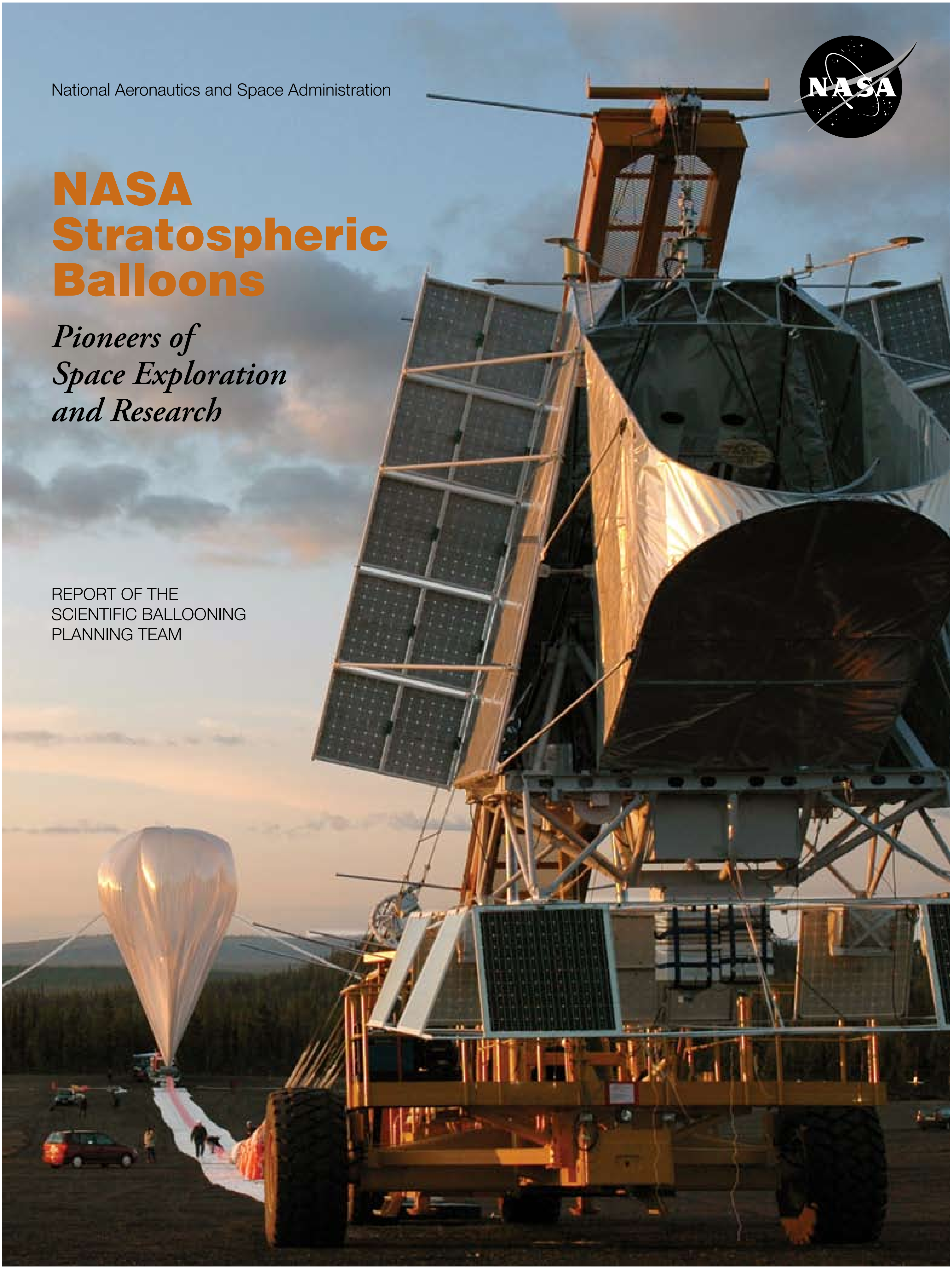
National Aeronautics and Space Administration

NASA Stratospheric Balloons

Pioneers of Space Exploration and Research

REPORT OF THE
SCIENTIFIC BALLOONING
PLANNING TEAM



The Scientific Ballooning Planning Team

Martin Israel Washington University in St. Louis, Chair
Steven Boggs University of California, Berkeley
Michael Cherry Louisiana State University
Mark Devlin University of Pennsylvania
Holland Ford Johns Hopkins University
Jonathan Grindlay Center for Astrophysics, Harvard University
James Margitan Jet Propulsion Laboratory
Jonathan Ormes University of Denver
Carol Raymond Jet Propulsion Laboratory
David Rust Applied Physics Laboratory, Johns Hopkins University
Eun-Suk Seo University of Maryland, College Park
Vernon Jones NASA Headquarters, Executive Secretary

Ex Officio:
Vladimir Papitashvili NSF, Office of Polar Programs
David Pierce NASA, GSFC/WFF Balloon Program Office, Chief
Debora Fairbrother NASA, GSFC/WFF Balloon Program Office, Technology Manager
Jack Tueller NASA GSFC, Balloon Program Project Scientist
Louis Barbier NASA GSFC, Balloon Program Deputy Project Scientist
Wilton Sanders NASA HQ Universe Division, Discipline Scientist

Cover Photo: The Balloon-borne Large Aperture Submillimetre Telescope (BLAST) instrument prepares for launch from northern Sweden. BLAST will study star formation in early galaxies and the Milky Way.

Facing Page Photo: The International Focusing Optics Collaboration for µCrab Sensitivity (InFOCµS) instrument undergoes checkout at Goddard Space Flight Center. InFOCµS uses grazing incidence mirrors to focus x-rays; a technology being developed for Constellation-X.

NASA Stratospheric Balloons

Pioneers of Space Exploration and Research

Report of the Scientific Ballooning Planning Team

October 2005

Table of Contents

The Balloon-borne Experiment with a Superconducting Spectrometer (BESS) payload, about to launch from Antarctica. BESS has been measuring the antimatter (antiprotons) component of the cosmic rays and looking for signatures of dark matter.

Executive Summary

A beautiful sunrise behind a balloon being inflated. Most often, experiments are launched just after sunrise or just before sunset, when the winds are calm.

Scientific ballooning has made important contributions to NASA's science program. *It has contributed directly with important science results and indirectly by serving as a test platform on which instruments have been developed that were subsequently used on NASA spacecraft.*

Examples of new science from balloon-borne instruments include early maps of the anisotropies of the Cosmic Microwave Background (CMB), the first identification of antiprotons in the cosmic rays, early detection of gamma-ray lines from supernova 1987A, the first observation of positron emission lines from the galaxy, early detection of black-hole x-ray transients in the galactic center region, and observations of chlorofluorocarbons (CFCs) and chlorine monoxide radicals in the stratosphere.

Examples of spacecraft instrumentation derived from balloon-flight abound. All the instruments on the Compton Gamma Ray Observatory (CGRO) were developed from balloon-flight instruments. The design of the Wilkinson Microwave Anisotropy Probe (WMAP) grew out of CMB balloon flights in the late 1980s and 1990s. The detectors on the Ramaty High Energy Solar Spectroscopic Imager (RHESSI) were first developed for balloon-borne instruments. The scintillating fiber trajectory detector for the Cosmic Ray Isotope Spectrometer on the Advanced Composition Explorer (ACE) was demonstrated first in balloon flights. Several Earth Observing System (EOS)-Aura satellite instruments trace their heritage to balloon-flight devices, as does the Thermal and Evolved Gas Analyzer (TEGA) instrument which flew on the Mars Polar Lander as part of the Mars Volatile and Climate Surveyor (MVACS) payload. The Mars Surface Laboratory will carry a similar instrument.

Balloon-borne instruments will continue to contribute to NASA's objectives. *Investigations on balloons, underway or planned, directly address objectives in NASA's Space Science Strategy and Earth Science Strategy, as well as the joint NASA–NSF–DOE Physics of the Universe—Strategic Plan for Federal Research at the Intersection of Physics and Astronomy, and the recently drafted (May 2005) series of Strategic Roadmaps for NASA.*

Instruments are being developed that will advance the techniques for hard-x-ray astronomy, which will be used for spacecraft envisioned in the Beyond Einstein program—Constellation-X, and Black-Hole Finder Probe. Other planned instruments will support the objectives of the Inflation Probe, by developing techniques for measuring polarization of the CMB, making the first CMB polarization measurements, and measuring the foreground that would interfere with CMB observations. Still others lay the groundwork for the Advanced Compton Telescope MeV-gamma-ray instrument. An instrument is under development to detect neutrinos with energy above 10^{18} eV interacting in the Antarctic ice. Cosmic-ray instruments on long-duration balloon flights are pushing the measurements of cosmic-ray composition toward the predicted energy limit of supernova acceleration. High-resolution imaging from balloons can study both the Sun and other astrophysical objects, in optical as well as other wavelengths. Balloons are well suited to measure the dayside aurora and other ionospheric conditions. For studying the atmosphere of the Earth, balloons provide *in situ* validation of data from spacecraft, and they provide the possibility of observing detailed processes on much finer spatial and temporal scales. For the exploration of Mars, Venus, and Titan, balloons in those planetary atmospheres have the potential of collecting *in situ* atmospheric data and high-resolution geological, geochemical, and geophysical data.

Many of the scientists with leading roles in NASA programs were trained in the balloon program.

Two prominent examples, who have attested to the importance of the Balloon Program to their career development are Thomas Prince, Professor of Physics at the California Institute of Technology and Chief Scientist at the Jet Propulsion Laboratory; and John Grunsfeld, the astronaut who carried out Hubble Space Telescope (HST) repairs and who recently served as Chief Scientist at NASA Headquarters.

The Balloon Program, as currently funded, has substantial capability for achieving quality science; however, funding for the Balloon Program Office (BPO) is barely adequate for supporting the program, and funding for new instruments under NASA's Supporting Research and Technology (SR&T) line is inadequate.

With its current annual budget of approximately $25M, the BPO supports about 15 conventional flights (approximately one-day duration from Palestine, TX; Ft. Sumner, NM; or Lynn Lake, Canada), two polar Long-Duration Balloon (LDB) campaigns, and one midlatitude LDB campaign (flights from Alice Springs, Australia). It also supports a development program leading to a super-pressure balloon capable of carrying a 1000-kg instrument to approximately 33 km giving little or no day/night altitude variation and ultimately 100-day flights (Ultra-Long Duration Balloons, ULDB). Within the constraints of its current budget, changes in the program of the BPO are not recommended; however, there are more instruments ready for LDB flights than can be accommodated at the current funding level.

The SR&T program spends approximately $15M annually to support scientists for developing balloon instruments and analyzing their data. *A strength of this program is that science is selected by peer review, providing opportunity for new ideas to be developed that were not foreseen in long-range strategic plans.* A major weakness of the SR&T support is that the funding levels are inadequate for developing some of the sophisticated balloon-borne missions most capable of advancing key elements of NASA's strategic plans.

The Planning Team identified three high-priority needs for sustaining a strong balloon program that will continue effectively supporting NASA's objectives:

- Restoration of the University-class Explorer (UNEX) program or institution of a new program to provide a reliable funding source to enable new science capability.
- Increased capability for LDB flights.
- Extension of the super-pressure balloon development to take 1000-kg instruments to 38 km.

The SR&T program provides basic support for scientific balloon missions, but some of the highest priority investigations need instruments costing roughly a quarter of a Small Explorer (SMEX) spacecraft mission. This amount is incompatible with the SR&T budgets and the need to maintain a viable flight rate. In principle, such missions could be funded through the Explorer program as Missions of Opportunity (MO), but there is no commitment to fund any MO from responses to an Explorer Announcement of Opportunity (AO). To date, no balloon mission has been funded for development under this procedure, although some have been rated highly. A more reliable support for balloon missions is needed, such as frequent UNEX AOs or another similar program line .

The LDB program has been extraordinarily successful, and it is heavily oversubscribed. Program and technology developments are needed to support increased LDB capability. Additional infrastructure at McMurdo Station, Antarctica and additional program funds would enable three, rather than two, LDB flights each December–January season. An aircraft at McMurdo dedicated to the balloon program would help ensure timely recovery and refurbishment of balloon-borne instruments. With adequate funding, the balloon program could also support three Arctic flights each year during the Northern Hemisphere summer. The ability to make small modifications of balloon-flight trajectory could ensure that Antarctic flights remain over the continent and that midlatitude flights do not go over densely populated areas.

The most effective Balloon-Program support of the Beyond Einstein program of gamma-ray and hard-x-ray investigations requires long duration flights at altitudes of about 38 km, preferably at midlatitudes where the background flux of cosmic rays is reduced compared to that in polar regions. To have midlatitude flights that remain above 36.5 km day and night requires super-pressure balloons.

Finally, the Planning Team recognized exciting new possibilities for ballooning 10–30 years from now *including flights of heavy instruments at 49 km (less than 0.1 % of the atmosphere remaining above this altitude); advanced trajectory control permitting controlled balloon flight paths and large aerostats; and balloons capable of aerial investigating of Venus, Mars, and Titan.*

Scientific ballooning has contributed significantly to NASA's science program, both directly with science coming from measurements made by balloon-borne instruments, and indirectly by serving as a test platform on which instruments have been developed that were subsequently flown on NASA space missions.

The engineering test model of the ANtarctic Impulsive Transient Antenna (ANITA) preparing for its successful August 2005 test flight. ANITA will search for pulses of radio emission from neutrinos penetrating the Antarctic ice.

Scientific Ballooning has Made Important Contributions to NASA's Program

Scientific ballooning has contributed significantly to NASA's science program, both directly with science coming from measurements made by balloon-borne instruments, and indirectly by serving as a test platform on which instruments have been developed that were subsequently flown on NASA space missions.

New Science from Balloon-borne Instruments

Following are a few examples of important scientific results from balloons.

CMB Anisotropy Measurements

The most widely recognized use of ballooning at millimeter wavelengths has been the study of the anisotropy in the 2.7 K cosmic microwave background (CMB). Measurements of the anisotropy in the CMB serve as a probe of the state of the universe when it was roughly 300,000 years old. There have been a large number of experiments including the Millimeter Anisotropy Experiment (MAX), Medium-Scale Anisotropy Measurement (MSAM), Tophat, Q-band Mapping Experiment (QMAP), and Background Emission Anisotropy Scanning Telescope (BEAST). These set the stage for the extremely successful measurements of the Balloon Observations of Millimetric Extragalactic Radiation and Geophysics (BOOMERanG) and Millimeter Anisotropy Experiment Imaging Array (MAXIMA) balloon missions, as well as the Cosmic Background Explorer (COBE) and Wilkinson Microwave Anisotropy Probe (WMAP) satellites. The balloon experiments resulted in over 20 flights (conventional and LDB), well over 100 refereed publications, and many doctoral theses.

The most widely recognized use of ballooning at millimeter wavelengths has been the study of the anisotropy in the 2.7 K cosmic microwave background (CMB).

The Nature, April 27, 2000 issue highlighted the results of the BOOMERanG flight. Balloon Observations of Millimetric Extragalactic Radiation and Geophysics (BOOMERanG) showed that the universe is, in fact, flat rather than open or closed.

Antiprotons in the Cosmic Rays

The cosmic rays include atomic nuclei of all elements, and a few percent of the cosmic rays are electrons. The first detection of antiparticles (antiprotons) incident on the upper atmosphere was made by a magnetic spectrometer flown on a high-altitude balloon. Balloon measurements have clearly shown the characteristic secondary antiproton peak from the nuclear interactions of primary cosmic rays with the interstellar medium. Longer exposures will be required to expand the energy reach to search for a contribution from exotic sources. The probability is negligible for secondary production of antihelium and heavier antinuclei during the interactions of baryons in space. The detection of one antihelium or anticarbon nucleus would have a profound impact on scientists' understanding of symmetry, a foundation of modern physics.

Beautiful rings of glowing gas from SN 1987a, approximately 160,000 light years away. The rings are lit by ultraviolet radiation. This image is from the HST.

Gamma-ray Lines from Supernova 1987a

Within a few months of the February 24, 1987 optical discovery of SN1987a in the nearby galaxy Large Magellanic Cloud, a balloon-borne instrument detected supernova-produced gamma rays for the first time. Over the next two years, a highly successful series of payloads was flown from Australia. Their measurement of gamma-ray lines from freshly produced radioactive nuclei confirmed the basic theory of supernovae. Such a short lead-time from discovery of an opportunity to flying of the payload was possible only within the balloon program. If observations had waited for the typical several-year lead-time for a spacecraft mission, the rapidly fading gamma-ray emission would have been undetectable.

Positron Emission and Black-Hole X-ray Transients from the Galaxy

Balloon observations provided the first evidence for positron annihilation radiation from the Galactic Center region and the Crab Nebula, plus the first observations of black-hole transients at hard x-ray energies. These balloon instruments led directly to the larger instruments flown on the third High Energy Astronomy Observatory (HEAO-C), the Solar Maximum Mission (SMM), and the Compton Gamma Ray Observatory (CGRO).

Chlorofluorocarbons and Chlorine Monoxide Radicals in the Stratosphere

In NASA's research program to understand the processes (both human and natural), that impact the abundance of stratospheric ozone, balloon instruments have provided the initial observations of key stratospheric species. Among these are CFCs released by human activities, which are transported into the stratosphere where they are photolyzed and release chlorine. That chlorine reacts with and removes ozone in a catalytic cycle, in the process forming chlorine monoxide radicals (ClO). Observations by balloon-borne payloads of the destruction of CFCs and production of ClO confirmed the CFC-Ozone depletion theory. Indeed, the observations of ClO were referred to in Congressional hearings as the "smoking gun." Balloons have also provided observations of all other key chemical species including nitrogen oxides, hydroxyl radicals and an array of source and trace gases. These observations are used both to initialize, and also to test, photochemical models. Today, the primary use of balloons is to complement Earth observing satellites, especially by providing validation.

In NASA's research program to understand the processes (both human and natural) that impact the abundance of stratospheric ozone, balloon instruments have provided the initial observations of key stratospheric species.

Spacecraft instrumentation derived from balloon-borne instruments

Here are a few examples of instrumentation initially developed for balloon-borne studies that subsequently became a basis for successful spacecraft investigations.

WMAP

There have been a large number of balloon-borne experiments that set the stage and developed the technology for the BOOMERanG and MAXIMA balloon missions and the COBE and WMAP satellites. It should also be noted that many (if not most) of the key players in the WMAP and Planck teams got their start in ballooning.

The Wilkinson Microwave Anisotropy Probe (WMAP), artists conception. WMAP was launched in 2001 and has verified the inflation theory of the early universe.

Currently Active Gamma-ray Spacecraft Programs

Robert Lin, principal investigator (PI) of the Ramaty High Energy Solar Spectroscopic Imager (RHESSI) reports, "The Balloon program was absolutely essential for the development and testing of the detector and electronics technology for RHESSI." Neil Gehrels, PI of Swift reports, "During the development of the [cadmium-zinc-telluride] CZT array for Swift, three balloon flights were performed to measure the unknown charged-particle induced background in CZT. The flights produced invaluable data on CZT activation and provided the quantitative information needed to design the Swift [Burst Alert Telescope] BAT instrument." Peter Michelson, PI for the Large Area Telescope instrument on the Gamma-ray Large Area Space Telescope (GLAST) reports, "In 2001 we flew a full engineering prototype of a GLAST LAT telescope module. The balloon flight demonstrated that the instrument trigger, based on signals from the silicon strip tracker, functioned well in a high background rate environment. This demonstration was critical to the validation of the LAT instrument design."

Ramaty High Energy Solar Spectroscopy Imager (RHESSI) launched in 2002 (artists concept). RHESSI is studying the physics of particle acceleration in solar flares.

Cosmic Ray Isotope Spectrometer (CRIS)

On the Advanced Composition Explorer (ACE) spacecraft, CRIS is producing measurements with unprecedented mass resolution and statistical accuracy of the isotopic composition of galactic cosmic rays. An essential element of the CRIS detector system is the scintillating-optical-fiber hodoscope, which was first demonstrated in balloon-borne cosmic-ray instruments.

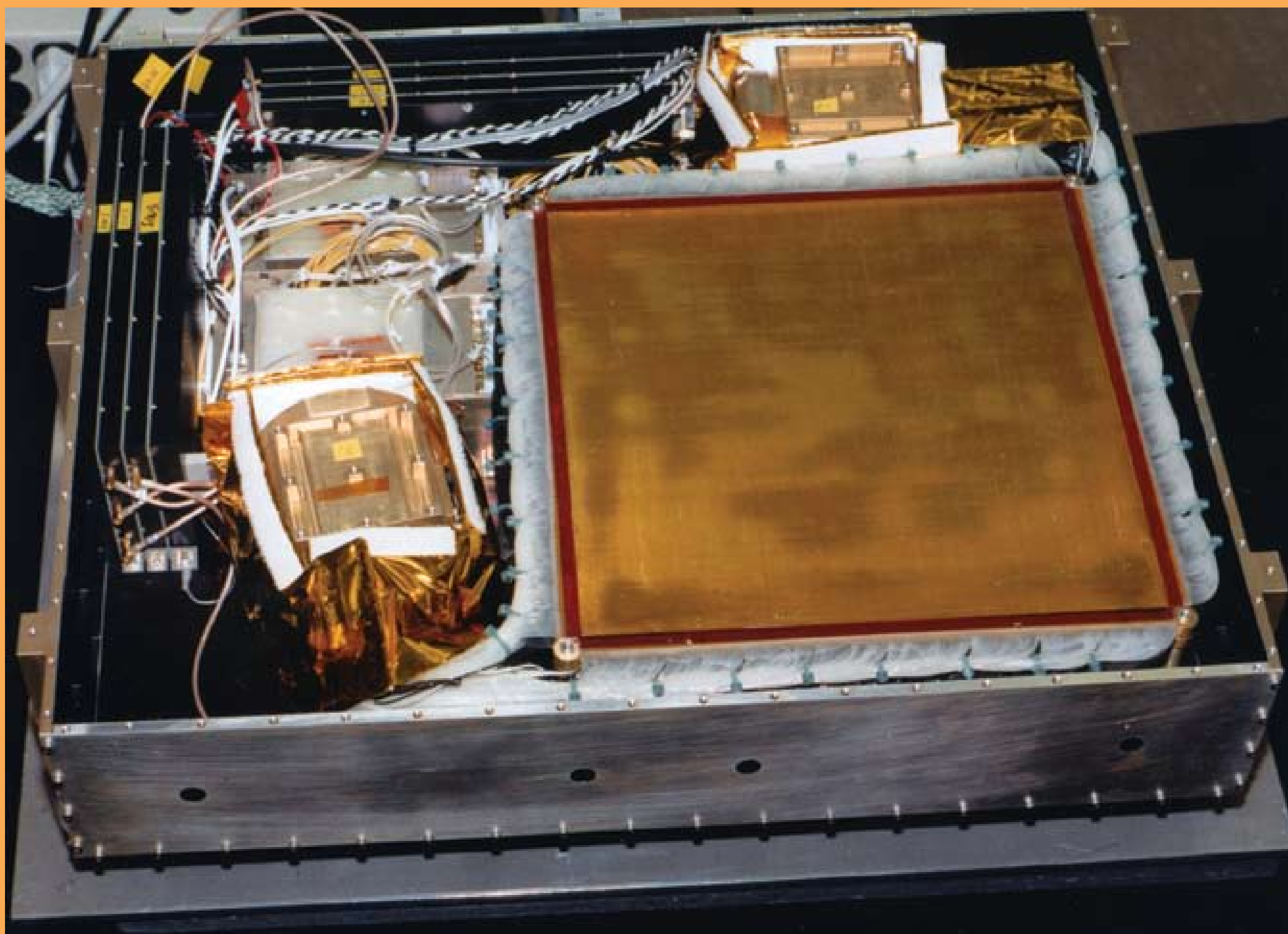
Earth Observing System (EOS)—Aura

On the current EOS-Aura satellite, the Microwave Limb Sounder (MLS), the Tropospheric Emission Spectrometer (TES), and the High Resolution Dynamics Limb Sounder (HIRDLS) all trace their heritage to instruments that first flew on balloons.

Planetary Instruments

The Mars Science Laboratory (MSL) will fly a Tunable Laser Spectrometer (TLS) that traces its heritage back to a series of balloon experiments that detected trace gases in the Earth's atmosphere using the Balloon-borne Laser *In Situ* Sensor (BLISS) instrument. These and other flights led to the TEGA on MVACS that preceded the TLS on MSL.

The Mars Science Laboratory (MSL) will fly a Tunable Laser Spectrometer (TLS) that traces its heritage back to a series of balloon experiments.



The scintillating fiber trajectory system in the Cosmic Ray Isotope Spectrometer for the ACE spacecraft. These fibers were first developed for a balloon-flight instrument. Many balloon flights develop technology that is later incorporated into spacecraft.

Balloon-borne Instruments Will Continue to Contribute to NASA's Objectives

In fall 2003, NASA's Office of Space Science published its *Space Science Enterprise Strategy* based on roadmaps produced earlier that year by each of its four science themes. At the same time, the Office of Earth Science similarly published its *Earth Science Enterprise Strategy*. In early 2004, an interagency working group representing NASA, NSF, and the Department of Energy published *The Physics of the Universe—A Strategic Plan for Federal Research at the Intersection of Physics and Astronomy.* The Scientific Ballooning Planning Team took those reports as the basis for its work. In this section, the Team indicates how investigations on balloons—underway or planned—directly address the objectives established in those reports.

The Team recognizes that with the recent creation of the Science Mission Directorate (SMD), which combines and reorganizes the previous Office of Space Science (OSS) and Office of Earth Science, reference to the earlier organizations will be out of date. For example, the Universe Division of the SMD has replaced the OSS Astronomy and Physics Division, which incorporated the former Structure and Evolution of the Universe (SEU) theme and the former Origins theme.

In late May 2005, after this Scientific Ballooning Planning Team had concluded its deliberations, a number of new Strategic Roadmaps for NASA were drafted. The scientific objectives in those drafts are consistent with those of the 2003–2004 strategies. The following sections of this report were originally written in response to those earlier strategies. References to the May 2005 drafts have been added, demonstrating the continued relevance of balloons to NASA's science objectives.

The highest priority of the SEU Roadmap is the Beyond Einstein program.

Beyond Einstein

The highest priority of the SEU Roadmap is the Beyond Einstein program. This priority has been confirmed in the May 2005 report, *Universe Exploration: From the Big Bang to Life, A strategic roadmap of universe exploration to understand its origin, structure, evolution and destiny (Strategic Roadmap #8)*. Beyond Einstein has three major science objectives: (1) find out what powered the big bang; (2) observe how black holes manipulate space, time, and matter; and (3) identify the mysterious dark energy pulling the universe apart. This program will employ a series of missions. There are two Einstein Great Observatories: (1) Constellation-X (Con-X), which uses x-ray spectroscopy over the 0.2–80 keV range to follow matter falling into black holes and to study the evolution of the universe; and (2) the Laser Interferometer Space Antenna (LISA), which uses gravitational waves to

It is clear that balloon-borne instruments will be essential for developing hard-x-ray detectors needed for Constellation-X and the Black Hole Finder Probe, and for developing the CMB polarization detectors needed for the Inflation Probe.

The High Energy Focusing Telescope (HEFT) developed by Caltech. HEFT will image x-rays in the 20–100 keV band using grazing incidence optics and cadium-zinc-teluride (CZT) detectors. This technology is a precursor for Constellation-X.

An artists concept of the four spacecraft making up the Constellation-X mission. The spacecraft will—by using precision formation flying—enable a much larger aperture than any one spacecraft could alone. Constellation-X is one of the Great Observatories of the Beyond Einstein Program.

The required technology for BHFP is being developed for balloon flight tests.

sense directly the changes in space and time around black holes and to measure the structure of the universe. There are also three Einstein Probes: (1) a Black Hole Finder Probe to take a census of black holes in the local universe, (2) an Inflation Probe to detect the imprints left by quantum effects and gravitational waves at the beginning of the Big Bang, and (3) a Dark Energy Probe to determine the properties of the dark energy that dominates the Universe.

It is clear that balloon-borne instruments will be essential for developing hard-x-ray detectors and telescopes needed for Constellation-X and the Black Hole Finder Probe, and for developing the CMB polarization detectors needed for the Inflation Probe.

Constellation-X Great Observatory

Constellation-X is a broadband x-ray mission that will enable very high sensitivity and spectral resolution studies of black holes. It will include a focusing hard-x-ray telescope (HXT) to extend the energy range from 10 keV to at least 40 keV. Focusing hard-x-ray telescopes, such as the High Energy Focusing Telescope (HEFT), High Energy Replicated Optics (HERO), and International Focusing Optics Collaboration for μ Crab Sensitivity (InFOCμS) telescopes, are now being developed on conventional balloons and are already conducting key technology development for the HXT. With long-duration balloon flights at midlatitudes on super-pressure balloons, these telescopes will enable high sensitivity studies of individual black holes, as well as high-spectral/spatial resolution imaging of the 1156 keV ^{44}Ti line emission sources that could be detected from obscured young supernova remnants in the galaxy. These studies would allow measurement of the supernova rate and constraints on the black hole vs. neutron star production in the galaxy.

Black Hole Finder Probe

An all-sky imaging survey at hard-x-ray energies, with high sensitivity and spatial-temporal resolution, is the basis for the Einstein Black Hole Finder Probe (BHFP). The Energetic X-ray Imaging Survey Telescope (EXIST) and Coded Aperture Survey Telescope for Energetic Radiation (CASTER) mission concept studies currently being conducted will define the coded-aperture telescope, imaging detectors, and energy range (approximately 10–600 keV) needed for this mission. The required technology for BHFP is being developed for balloon flight tests: at altitudes above about 37 km, the high-energy (>30 keV) universe becomes directly observable from balloon-borne telescopes. Prototype balloon-borne telescopes on conventional and LDB flights will demonstrate the large-area fine-pixel CZT and scintillator detectors, multichannel electronics and data acquisition, and fine-grained coded aperture systems needed. A follow-up large area (1–2 m^2) telescope with full-BHFP resolution could be flown on a 30- to 100-day ULDB mission and not only be a Long Integration Time Experiment but also be a pathfinder mission for the full BHFP mission. It would also provide a sensitive test of polarization imaging at approximately 100–300 keV, which is key to BHFP measurement of the population of nonthermal black hole jet sources such as Blazars.

ProtoEXIST, a balloon borne instument to develop technology for the Energetic X-ray Imaging Survey Telescope (EXIST) mission, shown in an artist's rendering. EXIST is a candidate for the Black Hole Finder Probe and will conduct a census of black holes in the known universe.

Inflation Probe

The Beyond Einstein Inflation Probe will seek the imprint of gravitational waves generated by inflation on the relic Cosmic Microwave Background (CMB). These waves should reveal if and how a mysterious "inflation" field stretched and smoothed the universe. The future in this area lies with the polarization of the CMB. The pattern of polarization directions on the sky can be decomposed into "E modes" with no handedness and "B-modes" with handedness. The E-modes are generated from the same dynamics as the temperature anisotropies and hence, the same effect that polarizes the atmosphere due to the very anisotropic emission from the Sun. The B-modes are generated by the inflationary gravity waves and by gravitational lensing of the E-modes. The expected magnitude and scales of these effects have been extensively modeled. The expected backgrounds have also been estimated. To put it in perspective, the signal level that is expected from CMB polarization is a factor of 10 to 1000 smaller than the primary CMB anisotropy signals.

The challenge offered by these types of experiments is great. Major advances in technology and techniques must be made; however, the payoff will be well worth the investment. There is the potential to detect the signature of gravitational waves from the end of the inflationary period 10^{-38} seconds after the Big Bang corresponding to Grand Unified Theory (GUT) energy scales of about 10^{16} GeV. The measurements of the conversion of E-modes into B-modes via gravitational lensing will provide an independent probe of Dark Energy.

The challenge offered by these types of experiments is great. Major advances in technology and techniques must be made; however, the payoff will be well worth the investment.

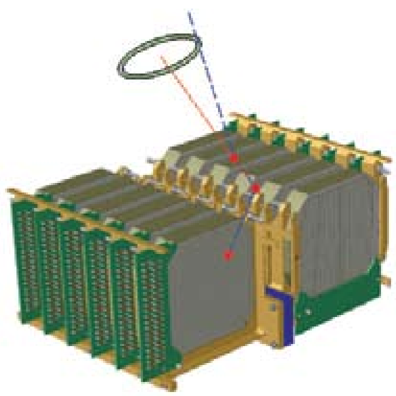
Measurement of the polarization of the CMB, in addition to being a key part of NASA's Beyond Einstein program, is also identified as a priority in *The Physics of the Universe— A Strategic Plan for Federal Research at the Intersection of Physics and Astronomy,* which states, "The three agencies will work together to develop by 2005 a roadmap for decisive measurements of both types of CMB polarization … In the near term, ground-based studies from appropriate sites and balloon-borne studies from Antarctica will be required to prove the detector technology and to study the galactic foreground, as well as to exploit CMB radiation polarization as a probe of the universe."

In the near term, ground-based studies from appropriate sites and balloon-borne studies from Antarctica will be required to prove the detector technology and to study the galactic foreground.

The search for polarization in the CMB will parallel how the search for the anisotropy in the CMB was carried out. There will be a number of groups (five or more) with different technologies, frequencies, and observing strategies. They will work to understand the limitations of the technology and systematics that are particular to their techniques. Over the course of a few years, the experience in the field will grow to the point where the best spaceflight experiment can be properly designed.

Cycles of Matter and Energy

The second part of the SEU roadmap is designed to enable two principal science objectives: *to explore the cycles of matter and energy in the evolving universe, and to understand the development of structure in the universe.* Balloon-borne instruments will address several of the objectives described in this part of NASA's planning. In the May 2005 draft Universe Exploration, the second part, Pathways to Life, includes similar objectives, "Map the flows of energy and matter between whole systems and their constituent parts, from galaxies to stars to planets," and "Trace the evolution of the nuclei, atoms, and molecules that become life."



In Compton telescopes, the energy and arrival direction of the incident gamma ray are inferred from the signals it leaves due to multiple interactions in the instrument.

Advanced Compton Telescope

Gamma-ray (0.5–10 MeV) telescopes with direct photon track imaging, are particularly direct tools for measuring both the nonthermal high-energy emission from black holes and the nuclear-decay-line emission tracers of nucleosynthesis in galaxies. Nuclear gamma-ray spectroscopy with an Advanced Compton Telescope (ACT) spacecraft is key to achieving the Cycles of Matter and Energy objectives and NASA's exploration priorities. Under study as a mission concept for a future Vision mission, ACT is designed to detect the radioactive nuclei produced in stellar explosions, which then seed new generations of stars and the evolution of planetary systems. Prototype Compton telescopes are now under development for conventional-balloon missions, and then LDB missions. Especially with the long exposure times on a ULDB, these instruments would greatly improve the currently coarse images of ^{26}Al (1.8 MeV) emission from novae and massive stars, allowing their distribution to be measured in the galaxy. Perhaps most exciting, a large-area long-duration ULDB-ACT mission would allow pathfinder measurements of the expected ^{56}Ni (1.2 MeV) emission from Type Ia supernovae in nearby clusters of galaxies (e.g., Virgo). This, in turn, would constrain both the physics and evolution of these fundamental, but poorly understood, probes of distance scale and dark energy in the universe, in addition to providing otherwise unattainable information about the mechanisms of heavy nucleus production in supernovae.

Prototype Compton telescopes are now under development for conventional-balloon missions, and then LDB missions. Especially with the long exposure times on a ULDB, these instruments would greatly improve the currently coarse images of ^{26}Al (1.8 MeV) emission from novae and massive stars

Balloon-borne Large Aperture Submillimeter Telescope (BLAST)

The polarized emission from our own galaxy in the submillimeter region will provide a wealth of information about the structure, evolution, and dynamics of our galaxy as well as the formation of the first galaxies themselves. Warm (10–50 K) dust is the signature of star formation. Large dense clouds of dust serve as the birthplace of all of the stars in a galaxy. The formation of the stars heats the relatively opaque clouds to a temperature where they emit in the submillimeter portion of the spectrum. By studying the clouds, the origin of stars and solar systems can be understood. While these measurements are very powerful in their own right, they will also help scientists characterize the galaxy as a foreground for the Beyond-Einstein Inflation Probe.

BLAST will fly several LDB flights in the coming years. When the primary science goal is completed, it would be possible to convert the 2-m BLAST telescope into a guest user facility. While BLAST cannot offer the resolution of a large ground-based telescope, the increased sensitivity at balloon altitudes means that it can quickly survey large areas of the sky. To put this in perspective, in one 50-h survey, BLAST should be able to find one hundred times more submillimeter galaxies than the ground-based Submillimetre Common-User Bolometer Array (SCUBA) instrument has seen in several years. This makes it a very attractive tool for astronomers who need large surveys or follow-up in the submillimeter region. These are impractical from a satellite and impossible from the ground. The BLAST "near-satellite" sensitivity and its ability to spend up to several hundred hours on a single patch of sky make it a flexible and multipurpose instrument that will be an asset to the entire field. With a modest investment, this transition could be made; however, it would also be possible to fly a larger (2.5–3 m) aperture version on ULDB vehicles making it a true submillimeter observatory.

In one 50-h survey, BLAST should be able to find one hundred times more submillimeter galaxies than the ground-based Submillimetre Common-User Bolometer Array (SCUBA) instrument has seen in several years.

ANtarctic Impulsive Transient Antenna (ANITA)

SEU Roadmap Objective 2: Observe what black holes do to space, time, and matter: In the jets and accretion disks near Massive Black Holes, almost certain to be the engines for Active Galactic Nuclei, bulk particle acceleration is an observational fact, and neutrino emission is an inevitable consequence of the decay of pions produced in the colliding matter. These black holes are expected to produce neutrinos with energies of the order of 10^{14}–10^{19} eV. Constraints on neutrino fluxes from such sources will also constrain their role in the origin of the highest energy cosmic rays.

SEU Research Focus Area 11: Identify the sources of gamma-ray bursts and the highest energy cosmic rays and Research Focus Area 13: Explore the behavior of matter in extreme astrophysical environments. The highest-energy cosmic rays ($>10^{19}$ eV) originate almost by definition in the most extreme astrophysical environments possible, and these are as yet unidentified, with no accepted theory for their production. The neutrinos from interactions of these cosmic rays with the microwave background will be an important probe of these extreme environments, and their source evolution history. In fact, a lack of detection of such neutrinos at the levels now predicted in conservative

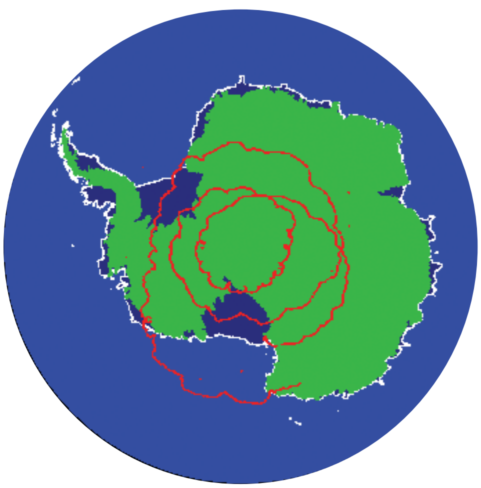
The projected path of ANITA around the Antarctic continent. ANITA looks at radio pulses from neutrinos interacting in the ice.

models would have profound consequences, forcing a re-evaluation of the fundamental understanding of the highest-energy cosmic rays.

The very low flux and low interaction probability of the highest-energy (>10^{18} eV) neutrinos requires enormous detector volumes. Balloons offer a unique capability at these energies, not achievable with either ground-based instruments or instruments in spacecraft, of monitoring a million square kilometers of Antarctic ice for the bursts of coherent GHz radio emission coming from the electromagnetic cascade that develops when a neutrino interacts with the ice. The ANITA instrument, currently under development, complements ground-based instruments, (e.g., the IceCube neutrino observatory under construction at the U.S. Amundsen-Scott South Pole Station), which have smaller detector areas and thus are sensitive to neutrinos of lower energy, up to approximately 10^{16} eV, where the flux is higher.

Cosmic Ray Energetics and Mass (CREAM)

The Physics of the Universe Question 6. How do cosmic accelerators work and what are they accelerating? Supernovae—the energy they release, the nuclei they synthesize, and the cosmic rays they accelerate—are essential components of the Cycles of Matter and Energy. The rigidity dependence of the acceleration process leads to a characteristic change in elemental composition between the limiting energies for protons and iron, approximately 10^{14} and approximately 26×10^{14} eV, respectively. The Advanced Cosmic-ray Composition Experiment for the Space Station (ACCESS) was given high priority in the 2001 National Research Council (NRC) decadal study "Astronomy and Astrophysics in the New Millennium" to look for this characteristic signature, which would associate a limit to supernova acceleration with the "knee" feature around 10^{15} eV seen in air shower data for the all-particle spectrum.



In December 2004 – January 2005, CREAM flew three times around the South Pole, recording high-energy cosmic rays for 42 days.

NASA's re-direction to support the new Vision for Space Exploration announced by the President in January 2004, including restricted use of the International Space Station to research activities that support the Vision, makes it unlikely that ACCESS will be selected in the foreseeable future. The CREAM instrument is a quarter-scale version of ACCESS with the same science objectives. It is being developed for the ULDB demonstration mission, which is expected to launch a new era of approximately 100-day balloon flights. The maiden flight of CREAM on a conventional balloon circumnavigated the South Pole three times during a 42-day record-breaking flight between 16 December 2004 and 27 January 2005. In a series of about 10 ULDB flights, CREAM would achieve many of the high priority objectives of ACCESS.

In a series of about 10 ULDB flights, CREAM would achieve many of the high priority objectives of ACCESS.

Balloon Experiment with a Superconducting Spectrometer (BESS/BESS-Polar)

The Physics of the Universe Question 1: What is Dark Matter? BESS measures cosmic-ray particles and antiparticles to study the early universe and cosmic-ray processes. In December 2004, the BESS-Polar spectrometer completed an 8-1/2 day Antarctic flight, and another flight is planned in 2007. Its search for a possible excess of low-energy antiprotons could provide evidence for the existence of primordial black holes and other dark-matter candidates dating from the creation of the universe because they can be produced during annihilation of the most popular supersymmetric dark matter candidate, the neutralino. While no antihelium has been discovered in the cosmic radiation, the BESS-Polar flights will set new limits, lower by a factor of approximately 20. The presence of antihelium in the cosmic radiation would provide evidence for a baryon-symmetric cosmology.

While no antihelium has been discovered in the cosmic radiation, the BESS-Polar flights will set new limits, lower by a factor of approximately 20. The presence of antihelium in the cosmic radiation would provide evidence for a baryon-symmetric cosmology.

The BESS instrument had nine conventional ~1-day balloon flights between 1993 and 2002 with the objective of measuring the spectra of light nuclei, including antiparticles. Its accumulation of more than 2400 antiprotons provides more than 80% of the world data set. It has also provided the best limit for the allowable parameter space of dark matter supersymmetric particles by accurately measuring antiproton spectra. The BESS-Polar instrument developed for Antarctic LDB flights has increased sensitivity at low energies. Its geometric acceptance (approximately 0.3 m^2 sr) is similar to that of the Alpha Magnetic Spectrometer (AMS) planned for the International Space Station, and much greater than any prior balloon-borne magnet spectrometer. Excellent particle identification is achieved with its advanced superconducting magnet and sophisticated particle detectors.

Sun–Solar System Connection

In the May 2005 *Strategic Roadmap #10, Sun–Solar System Connection,* one of the broad objectives is *"Understand the fundamental physical processes of the space environment—from the Sun to Earth, to other planets, and beyond to the interstellar medium."* Specific objectives in this report are similar to those quoted below from the 2003 NASA Space Science Enterprise Strategy.

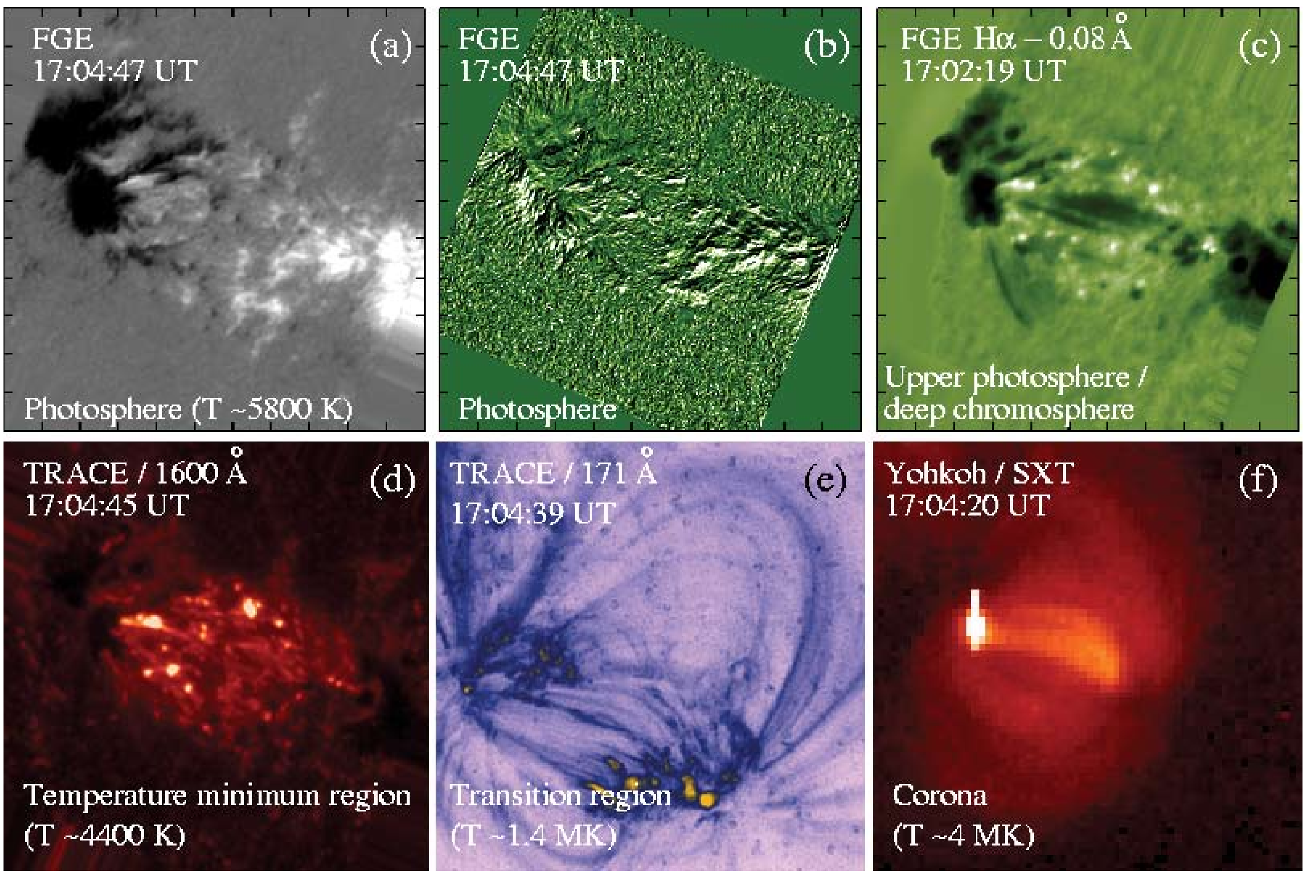
High-Resolution Imaging from Balloons to Study the Sun

NASA Space Science Enterprise Goal 1.3.2: Specify and enable prediction of changes to Earth's radiation environment, ionosphere, and upper atmosphere. Balloon-borne solar telescopes will determine the conditions that cause heating of the solar chromosphere and produce emission of many of the strongest lines and continua in the solar extreme ultraviolet (EUV) spectrum. This emission is absorbed in the ionosphere and upper atmosphere and is highly variable, depending on activity in the chromosphere.

If scientists understood the origins of chromospheric heating, they would be better able to explain the radiation illuminating Earth and Mars when they were young planets.

A fundamental problem in solar physics is the resolution of the solar coronal and chromospheric heating problem, which would explain why most stars have coronas and chromospheres that emit EUV and x-rays. To address this problem, the Sunrise consortium of European and American investigators is assembling a 1-m optical and near-ultraviolet (UV) balloon-borne solar telescope to measure the vector magnetic fields and to obtain images and spectra of the Sun in the UV above 200 nm. The spatial resolution (0.05 arcsec, 30 km on the Sun) will be high enough to enable study of the origins and properties of the intermittent magnetic structures that are thought to control chromospheric and coronal heating (and the solar EUV emission).

NASA Space Science Enterprise Strategy Goal 5.1: Learn how the solar system originated and evolved to its current state. Chromospheric emission is more intense on young stars. It must have been more intense



A multiwavelength view of emerging sunspots on January 25, 2000. Images a, b, and c are from the balloon-borne Flare Genesis Experiment (FGE). Images d and e are from NASA's Transition Region and Coronal Explorer (TRACE) spacecraft, and f is from the Japanese Yohkoh spacecraft. The various wavelengths probe regions of various temperatures from several thousand Kelvin (K) to a few million Kelvin (MK).

The Solar Bolometric Imager (SBI) shown here is an innovative, balloon-borne solar telescope that can take images in light integrated over nearly the entire solar spectrum.

on the young Sun, too, when solar system atmospheres and oceans were forming and life was budding on Earth and maybe on Mars. If scientists understood the origins of chromospheric heating, they would be better able to explain the radiation illuminating Earth and Mars when they were young planets.

NASA Space Science Enterprise Goal 1.3: To understand the role of solar variability in driving global climate change, and Goal 5.6: To understand the structure and dynamics of the Sun. The balloon-borne Solar Bolometric Imager (SBI) recently mapped the sources of irradiance variations on the solar disk. Variations in the visible and near infrared irradiance may have been responsible for global climate changes in the Middle Ages and during the Little Ice Age, for example. As important as these variations may be, their sources on the Sun have never been measured with the needed precision. A 2–4 week Antarctic flight of the Solar Bolometric Imager (SBI) during the next sunspot minimum in 2007 will establish the baseline for irradiance variations. LDB flights of the SBI at later phases of the solar cycle would enable a search for variable irradiance sources that cannot be detected from the ground. It would also test new technology for eventual flight in a decade-long space mission to map all possible sources of solar brightness variation over a complete solar cycle.

Proposed balloon-borne telescopes could produce high-resolution maps of the magnetic transition zone between the photosphere and chromosphere, providing a unique insight into the magnetic fields associated with solar flares.

NASA Space Science Enterprise Goal 1.3.1—Develop the capability to predict solar activity. Proposed balloon-borne telescopes could produce high-resolution maps of the magnetic transition zone between the photosphere and chromosphere, providing a unique insight into the magnetic fields associated with solar flares. They could probe the structure of the atmospheric layer where the controlling forces change from fluid motions and pressure to magnetic fields. The measurements would provide the correct boundary conditions for developing plausible solar flare models. Solar flares and their associated coronal mass ejections are the principal sources of the energetic particles and magnetic shocks that disrupt civilian and military space systems and endanger astronauts in space. Better knowledge of the evolution of the coronal magnetic fields is thought to be the most likely route to improved solar flare models and forecasts.

Solar flares and their associated coronal mass ejections are the principal sources of the energetic particles and magnetic shocks that disrupt civilian and military space systems and endanger astronauts in space

Other solar science opportunities proposed for the next decade include a new approach to high-energy x-ray imaging. A high-energy x-ray and gamma-ray imaging instrument could provide fifty times RHESSI's sensitivity to gamma-ray lines from solar flares, and it would support *NASA's Goal 5.7: To discover how charged particles are accelerated.* If the x-ray and gamma-ray imager and a telescope with new neutron detection technology were mounted together on a ULDB platform, the science return for a high-energy flare mission will be comparable to that of a small Explorer at a small fraction of the cost.

Dayside Aurora and Other Ionospheric Phenomena

One of the main Sun–Earth Connections (SEC) science objectives is to *"Understand the changing flow of energy and matter throughout the Sun, heliosphere, and planetary environments."* This objective is echoed in the May 2005 *Strategic Roadmap #10, Sun–Solar System Connection,* which has as one of its near-term objectives *"Discover how space plasmas and planetary atmospheres interact."* In the magnetosphere, these phenomenon are addressed by a number of satellite constellation missions designed to provide spatial and temporal resolution of the physical phenomena. These investigations are designed to "explore the chain of action/reaction processes that regulate solar energy transfer into and through the coupled magnetosphere-ionosphere-atmosphere system." The final step, the ionosphere-atmosphere coupling, results in the aurora borealis as accelerated particles interact in the uppermost reaches of the atmosphere.

A wide variety of processes at the magnetopause control the entry of solar wind plasma mass, energy, and momentum from the magnetosphere and ionosphere. The effects of these processes can be observed in the high-latitude ionosphere at the footprints of magnetospheric magnetic field lines (especially along the boundary between open and closed magnetic fields). The aurora is the most visible and dynamic manifestation of this phenomenon. Dayside (and cusp) auroras are particularly notable during the arrival of interplanetary shocks and discontinuities. The particles accelerated in these interactions produce so-called conjugate auroras that occur simultaneously in both hemispheres. Their signatures can be used to derive the mechanisms of how (and where) the magnetopause processes occurred.

High-altitude long-duration balloons provide an excellent vantage point to observe simultaneously both the sites of these dayside auroras.

High-altitude long-duration balloons provide an excellent vantage point to observe simultaneously both the sites of these dayside auroras. By being in place continuously, they are "ready to observe" when the plasma cloud strikes the Earth. This continuous monitoring in both hemispheres, from the Southern Hemisphere from balloons and the Northern Hemisphere from the ground, makes conjugate observations possible. It is very difficult to do and awkward to organize solely from the ground, and would be prohibitively expensive to do from space. It is enabled by the recently developed capability to fly large balloons to nearly 50 km altitude.

Earth Observations

Current Balloon Contributions

In addressing a number of questions from the *NASA Earth Science Enterprise Strategy* for studying the atmosphere of the Earth (e.g., Earth Science Questions: 1(d) How is atmospheric composition changing? 3(d) How do atmospheric trace constituents respond to and affect global environmental change? 5(c) How will future changes in atmospheric composition affect ozone, climate and global air quality?), balloons provide *in situ* validation of data from spacecraft, and they provide the possibility of observing detailed processes on much finer spatial and temporal scales than orbiting spacecraft.

The May 2005 *Strategic Roadmap for Earth Science and Applications (Strategic Roadmap #9)* acknowledges the importance of balloons: "NASA's atmospheric composition research program also requires essential suborbital and laboratory measurements, as well as a vigorous modeling effort. Suborbital observations obtained by instruments on board balloons, manned aircraft, and unmanned aerial vehicles (UAVs), provide validation of satellite measurements as well as definition of processes occurring on spatial and temporal scales that are challenging to observe from space."

Potential Contributions with ULDBs

Measurements of the Earth's radiation budget (i.e., the balance between incoming and outgoing radiation) are of critical importance to understanding climate change.

Measurements of the Earth's radiation budget (i.e., the balance between incoming and outgoing radiation) are of critical importance to understanding climate change. NASA has made Earth Radiation Budget (ERB) measurements from a series of satellites for several decades. Satellites are an ideal platform for making such long-term measurements. However, it is critically important to have consistency between the successive satellites (and instruments) to ensure a reliable long-term record. ULDBs can provide an invaluable complement to the satellite instruments. Balloon instruments can be precisely and accurately calibrated to National Institute of Standards and Technology (NIST)-traceable standards before and after flights, and can provide a calibration (or transfer) standard between successive satellites. This carefully intercalibrated data set would be very valuable for addressing changes in the incoming and outgoing radiation over decadal time scales.

Balloon instruments can be precisely and accurately calibrated to National Institute of Standards and Technology (NIST)-traceable standards before and after flights, and can provide a calibration (or transfer) standard between successive satellites.

Changes in ice sheets are an important factor both as a contributor to, and as an indicator of, climate change. *Strategic Roadmap Number 9 (May 2005)* notes, "The most dramatically changing element of the climate system is the Earth's ice cover [I]ce on land is of critical importance and is an observational priority, not just in terms of climate processes, but also sea level." Changes in ice sheet volume between mappings spaced 5–10 years apart would allow us to estimate outflow glacier flux and determine the relative importance of outflow glaciers vs. precipitation-melting balance in controlling ice sheet volume. While satellites can easily measure surface topography, measuring the depth (or volume) from space is much more challenging. ULDB with trajectory modification capability would be ideal platforms for carrying ice-penetrating radar to map ice volume. As long as the ULDB could be kept over the ice sheet, the exact trajectory would not matter so much, as long as the whole ice sheet is eventually mapped.

Ground-penetrating radar is revolutionizing the study of water resources underground. In the past, these could only be studied and mapped using boreholes. Now, similar mapping can be achieved for far lower cost and with far greater accuracy using ground-penetrating radar, sometimes dragged on sleds across remote areas not served by roads. ULDB could carry such radars and provide far wider mapping at even lower cost. *Strategic Roadmap Number 9 (May 2005)* notes, "The terrestrial water cycle is equally challenging. … Here soil moisture, snow, ice and surface water storage, including lakes, rivers, and wetlands plus underground aquifer storage, and the transport between them, must be considered."

NASA's Tropical Rainfall Measuring Mission (TRMM) satellite carries a Lightning Imaging Sensor (LIS), which has made some amazing discoveries including the fact that there is virtually no lightning over oceans. TRMM, however, will be de-orbited in the near future, barring a Congressional rescue, and the future series of NOAA weather satellites [i.e., the National Polar-Orbiting Operational Environmental Satellite System (NPOESS)] will not carry lightning sensors. Nevertheless, the measurement has considerable value for precipitation research. ULDB would operate at almost an ideal altitude—above all weather, but close enough to thunderstorms to provide a close-up view rather than the 8-km-average smeared view provided by LIS and other satellite sensors. In addition, instruments on ULDB could observe the full temporal development of a lightning storm, as opposed to the snapshot taken by a satellite that races past and is gone for 90 min. Sprites and other electrical phenomena occurring above a thunderstorm, only discovered in the 1990s, are also ideally observed from a ULDB, because aircraft dare not approach closely and cannot fly high enough or long enough to gather much data.

Sprites and other electrical phenomena occurring above a thunderstorm, only discovered in the 1990s, are also ideally observed from a ULDB, because aircraft dare not approach closely and cannot fly high enough or long enough to gather much data.

Solar-System Observations

The roadmap for Solar System Exploration includes the objective of "studying solar system evolution" by carrying out "multidisciplinary studies of planetary atmospheres, interiors, and surfaces" and performing "comprehensive, comparative studies of the atmospheric chemistry, dynamics, and surface-atmosphere interactions on both Mars and Venus." Collection of *in situ* atmospheric data and high-resolution geological, geochemical, and geophysical data is best done by an aerial platform. The ability to collect data near the surface, and embedded in the boundary layer, complements orbital observations, and provides much greater coverage than surface rovers. Progress on many science issues will be enabled by even sparse low-altitude data, because of the unique vantage point they provide. For the exploration of Mars, Venus, and Titan, balloons have the potential of collecting *in situ* atmospheric data and high-resolution geological, geochemical, and geophysical data.

For the exploration of Venus, Mars, and Titan, balloons have the potential of collecting *in situ* atmospheric data and high-resolution geological, geochemical, and geophysical data.

Artists' concepts of balloons in the atmospheres of Mars, Venus, and Titan (left to right). The round images are from (left to right) the Mars Global Surveyor, Hubble Space Telescope, and European Southern Observatory.

Mars Exploration

The science objective of Mars ballooning is to measure wind, temperature, and pressure along with detailed images of the planet surface. *A Roadmap for the Robotic and Human Exploration of Mars (Strategic Roadmap #2) May 2005* lists as one of its Roadmap Goals, *"Understand the Climate of Mars"* and as an objective for the period 2005–2015 lists "Atmosphere chemistry and dynamics." Under the objective "Understand the Geological Evolution of Mars" are the near-term goals of "High-res surface mapping," "Global/local mineralogy," and "Surface-atmosphere interactions."

A super-pressure balloon would be one way of studying the atmosphere chemistry and dynamics, as well as provide synoptic high-resolution views of the surface properties of Mars.

Solar montgolfieres (zero-pressure) and super-pressure balloons are both needed for Mars and Venus. While solar balloons are an option for polar exploration, super-pressure balloons are needed for multiday exploration in the nonpolar regions. At the end of 1997, the Jet Propulsion Laboratory (JPL) initiated the Mars Aerobot Validation Program (MABVAP) to develop and validate the technology needed for a Mars super-pressure balloon mission with a focus on the problem of aerial deployment and inflation. Aerial deployment is needed as the mass and complexity of a landing vehicle itself would be an enormous burden to place on a balloon mission that otherwise does not require a lander. In collaboration with the Balloon Program Office (BPO) at Wallops, a prototype of a Mars super-pressure balloons, 11.3-m diameter by 6.8-m high pumpkin shape, was successfully tested for aerial deployment and inflation in Earth's stratosphere in June 2002. Such a super-pressure balloon would be one way of studying the atmosphere chemistry and dynamics, as well as provide synoptic high-resolution views of the surface properties of Mars.

Venus Exploration

The two main objectives of Venus ballooning are *in situ* atmospheric exploration and acquiring samples from the surface of Venus. *The Solar System Exploration Strategic Roadmap, May 2005 draft,* describes a high-priority, near-term New Frontiers mission candidate, the Venus *In Situ* Explorer (VISE), a balloon mission to study Venus' atmospheric composition and descend to the surface to acquire samples that could be analyzed at altitudes in a more benign environment. VISE scientific measurements would help to constrain models of the Venus greenhouse history and stability, as well as the geologic history of the planet, including its extensive resurfacing. VISE would pave the way for a possible subsequent sample return. In describing a Venus Sample Return mission, that draft roadmap says, "There would need to be a buoyant ascent stage to collect the sample either from the surface or from another vehicle (deployed to the surface and back into the atmosphere) and then carried to an altitude from which atmospheric density is low enough for launch to be feasible." One designed procedure is that a package would descend to the 500°C Venus surface from an orbiting spacecraft. After samples are collected, a metal bellows would inflate and carry the payload up to 12–15 km. At this altitude, a zero-pressure cylindrical balloon made of polyimide Kapton film would be inflated to transport the payload up to approximately 60 km where a rocket could be ignited to send the payload back to the orbit relay. The payload mass could be 20–600 kg depending on the size of the bellows and the balloon.

VISE scientific measurements would help to constrain models of the Venus greenhouse history and stability, as well as the geologic history of the planet.

Titan

The May 2005 *Solar System Exploration Strategic Roadmap* calls for "... a mobile platform to study the detailed structure and composition of biogenetically relevant organics on Titan." That draft discusses the requirement for mobility in connection with both the Venus Surface Explorer and Titan Explorer: "Wheeled vehicles … represent one approach to mobility. However, the dense atmospheres of Titan and Venus also enable buoyant vehicles that are much less susceptible to being immobilized by surface obstacles or surfaces with low bearing strengths. They can also travel over much greater distances with less energy consumption." An aerobot now under construction at JPL would be capable of global in situ exploration of Titan over a 6–12 month mission lifetime. The extremely cold Titan environment (about -196°C) requires the use of cryogenic materials for construction and careful thermal design for protection of temperature-sensitive payload elements. The aerobot is a propeller-driven buoyant vehicle that resembles terrestrial airships. The aerobot hull is a streamlined ellipsoid

14 m in length with a maximum diameter of 3 m. The enclosed volume of 60 m^3 is sufficient to float a mass of approximately 230 kg at a maximum altitude of 8 km at Titan. A total of 100 W of electrical power is provided to the vehicle by a radioisotope power supply. Up to half of this power is available to the propulsion system to generate a top flight speed in the range of 1–2 m/s. A preliminary science payload has been devised for aerial imaging of the surface, atmospheric observations and sampling, and surface sample acquisition and analysis.

NASA's Vision for Exploration

In preparing for sending humans on missions to the Moon and Mars, NASA recognizes the vital importance of research on radiation health and radiation protection.

The radiation environment in the polar stratosphere is similar to that found on the way to, or at, the Moon or Mars, so balloons offer an ideal platform for this Radiation Research Program.

In preparing for sending humans on missions to the Moon and Mars, NASA recognizes the vital importance of research on radiation health and radiation protection. The NASA Radiation Research Program aims to develop the scientific basis for the protection of human crewmembers from space radiation. The Deep Space Test Bed (DSTB) is a planned series of long-duration balloon flights over Antarctica, exposing a variety of materials and radiation monitors to weeks of cosmic radiation. The radiation environment in the polar stratosphere is similar to that found on the way to, or at, the Moon or Mars, so balloons offer an ideal platform for this Radiation Research Program.

A balloon has just been released (left), and moments later lifts the instrument payload off the launch vehicle (right). In the right-hand photo the parachute hangs from the bottom of the balloon, with the instrument payload hanging below the parachute. As the balloon rises, the small volume of helium at the top will expand to fill the nearly-spherical balloon (as shown on page 32).

"The NASA Balloon Program was critical to my development as a scientist, both in graduate school and as a junior faculty member at Caltech. I can't imagine a better scientific training for experimental space science than the experience of building and launching a science payload on a balloon."

Dr. Thomas A. Prince,
Chief Scientist at JPL

"The NASA scientific ballooning program provided me with the complete and quintessential scientific experience, going from concept to hardware, observations, and scientific analysis of the results—all in the time frame of a few years. The rich environment that NASA's sub-orbital program supports not only enables top quality science, but is also crucial as a training ground for the scientists who will be the principal investigators of tomorrow."

Dr. John M. Grunsfeld,
Astronaut and former NASA Chief Scientist

Many Scientists with Leading Roles in NASA were Trained in the Balloon Program

One of NASA's objectives is to "advance the scientific and technological capabilities of the nation." Two prominent examples of scientists with important roles in NASA are Dr. Thomas A. Prince and Dr. John M. Grunsfeld. Both of these individuals earned their doctoral degrees with dissertations that reported results of cosmic-ray investigations carried out on balloons.

Dr. Prince is Professor of Physics at the California Institute of Technology (Caltech). An accomplished researcher in gamma-ray astronomy, Dr. Prince also serves as Chief Scientist at JPL and as Mission Scientist for LISA—one of the two Beyond Einstein great observatories. He captures the value of the balloon program for training of scientists:

"The NASA Balloon Program was critical to my development as a scientist, both in graduate school and as a junior faculty member at Caltech. I can't imagine a better scientific training for experimental space science than the experience of building and launching a science payload on a balloon. You directly experience all the important steps: design to cost, schedule, weight, and power constraints; quality control and risk management; field operations; and reduction and analysis of data. The impact of the NASA Balloon Program goes far beyond the demonstration of technology and the direct science data that are produced—the scientists who 'cut their teeth' in the NASA Balloon Program are very often the leaders of today's NASA space science missions and programs."

Dr. John Grunsfeld is an astronaut who has been in space on missions to repair and upgrade instruments on the Hubble Space Telescope. He also served recently as Chief Scientist at NASA Headquarters. He also attests to the value of the balloon program:

"In my career as a scientist, astronaut, and as NASA's Chief Scientist, I often reflect back on the strength of the foundation upon which I was trained. As an undergraduate and as a graduate student I had the great fortune to perform experiments in high-energy astrophysics using high-altitude balloons as a platform for access to space. The NASA scientific ballooning program provided me with the complete and quintessential scientific experience, going from concept to hardware, observations, and scientific analysis of the results—all in the time frame of a few years. The rich environment that NASA's sub-orbital program supports not only enables top quality science, but is also crucial as a training ground for the scientists who will be the principal investigators of tomorrow."

Earlier this year, in its report dated 11 February 2005, the National Academy of Science Committee to Assess Progress Toward the Decadal Vision in Astronomy and Astrophysics noted, "Instrument builders are particularly critical to the health of the field. Without the next generation of instrumentalists, practical knowledge about how to work in endangered technical areas (such as high-energy astrophysics) will be lost, greatly reducing the probability of success and diminishing U.S. leadership." In light of the comments by Dr. Prince and Dr. Grunsfeld, and similar experience of many other leading scientists in NASA programs, this statement by the Academy committee further underscores the importance of the balloon program.

The CREAM instrument after landing in Antarctica in January 2005. Several flights of the Twin Otter aircraft are required for recovery of such instruments.

The Balloon Program has Substantial Capability for Achieving Quality Science

Description of Balloons in Use and Envisioned

The scientific balloon program uses helium-filled polyethylene balloons of large volume, typically between about 0.3 and 1.1 million cubic meters (10–40 million cubic feet). The balloons are launched by crews of the National Scientific Balloon Facility (NSBF) from various sites around the world. They float in the stratosphere for periods ranging from about a day to over a month, following trajectories imposed by the wind at the float altitude. On radio command, the flights are terminated over an appropriate location, and the instruments parachute to the ground and are recovered for possible future flight.

"Conventional" balloon flights have durations on the order of a day, and the balloon support system is based on line-of-sight communications. These balloons are launched from the NSBF home base in Palestine, TX; from Ft. Sumner, NM; Lynn Lake, Canada; or Alice Springs, Australia; and their payloads are recovered typically within several hundred miles of the launch site. "Long-Duration Balloon" (LDB) flights have durations from about a week to a month. They use the same balloons employed for conventional flights, but a more sophisticated over-the-horizon balloon support system. They may be launched in Sweden for recovery in northern Canada or Alaska, or from the McMurdo base in Antarctica and recovered within a few hundred miles of McMurdo after traveling around the South Pole once, twice, or even three times. Pending approval for overflight, the flights launched from Sweden could continue over Russia, or flights could be launched from Fairbanks, AK, and recovered in northern Canada after flying westward around the world. These balloons may also be launched in Australia for recovery in South America.

Balloons that have been used to date for both conventional and LDB flights are "zero-pressure," meaning that they are vented near the bottom to the outside, so the balloon pressure is in equilibrium with the atmospheric pressure at that point (zero differential pressure). Only a small fraction of the balloon's volume is filled with helium on the ground, and the helium expands as the balloon rises. Excess helium flows out the vents as the balloon reaches its fully inflated float altitude. To avoid serious loss of altitude at sunset, the payload must carry ballast (fine steel or sand grains that can be released by radio command). At night without the solar input, there is a cooling of the helium and consequent shrinking of the balloon volume, which causes the balloon to sink to a very much lower altitude. To reduce the altitude variation at sunset, ballast is dropped. Limitations on the amount of ballast that can be carried limit the number of sunsets a balloon can survive and the extent to which the diurnal altitude variation can be reduced. The longest-duration LDB flights are flown during local summer over Antarctica or in the Arctic, where continuous sunlight permits the balloon to keep altitude without need to drop ballast.

Currently under development are "super-pressure balloons," designed to maintain essentially constant volume—day and night—and thus to float at nearly constant altitude without need for dropping ballast at sunset. These balloons are sealed and designed to withstand substantial internal over-pressure. They are inflated with enough helium to fill the volume at the coldest temperatures, and they have enough strength to hold that helium when sunlight heats it. Super-pressure balloons will have two advantages. First, they will permit ULDB flights circumnavigating the globe at any latitude and lasting of the order of a hundred days. Second, they will permit flights of 1–2 week durations at any latitude—say from Australia to South America—without diurnal altitude variation.

Funding of the Balloon Program Office

The Balloon Program Office (BPO) at the Wallops Flight Facility of Goddard Space Flight Center manages the balloon flight operations. The BPO contracts with NSBF, which carries out the launches and flight operations, including flights launched both at the NSBF home in Palestine, TX, and at remote sites. The BPO also carries out a research and development program to advance the capabilities of scientific ballooning.

With its current annual budget of approximately $25M, the BPO supports about 15 conventional flights, 2 polar LDB campaigns (one Antarctic and one Arctic), and 1 midlatitude LDB campaign (flights between Alice Springs, Australia and South America). Each of these LDB campaigns has the capability for two balloon flights (however, at least through FY07, one of these foreign campaigns will be cancelled to pay off a 2004 advance for costs associated with upgrades of Antarctic facilities).

The current budget of the BPO also supports a development program of super-pressure balloons. This program is a phased development of super-pressure capability starting with relatively small balloons, and scheduled to lead to balloons large enough to carry a 1-ton instrument to 33.5 km by FY07.

Within the constraints of its current budget, the Planning Team does not recommend any changes in the program of the BPO. The Team notes, however, that this current budget is barely adequate for supporting this program. In particular, the flight demand is now reaching the point where there are more instruments ready for LDB flights than can be accommodated by the current funding level.

Within the constraints of its current budget, the Planning Team does not recommend any changes in the program of the BPO. The Team notes, however, that this current budget is barely adequate for supporting this program. In particular, the flight demand is now reaching the point where there are more instruments ready for LDB flights (Antarctic or Arctic) than can be accommodated by the current funding level.

The Ultra-Long-Duration Balloon (ULDB) and NIGHTGLOW payload are readied for launch from Alice Springs, Australia, 2000. NIGHTGLOW will measure the ultraviolet background light of the Earth's atmosphere.

Funding of Scientific Instruments

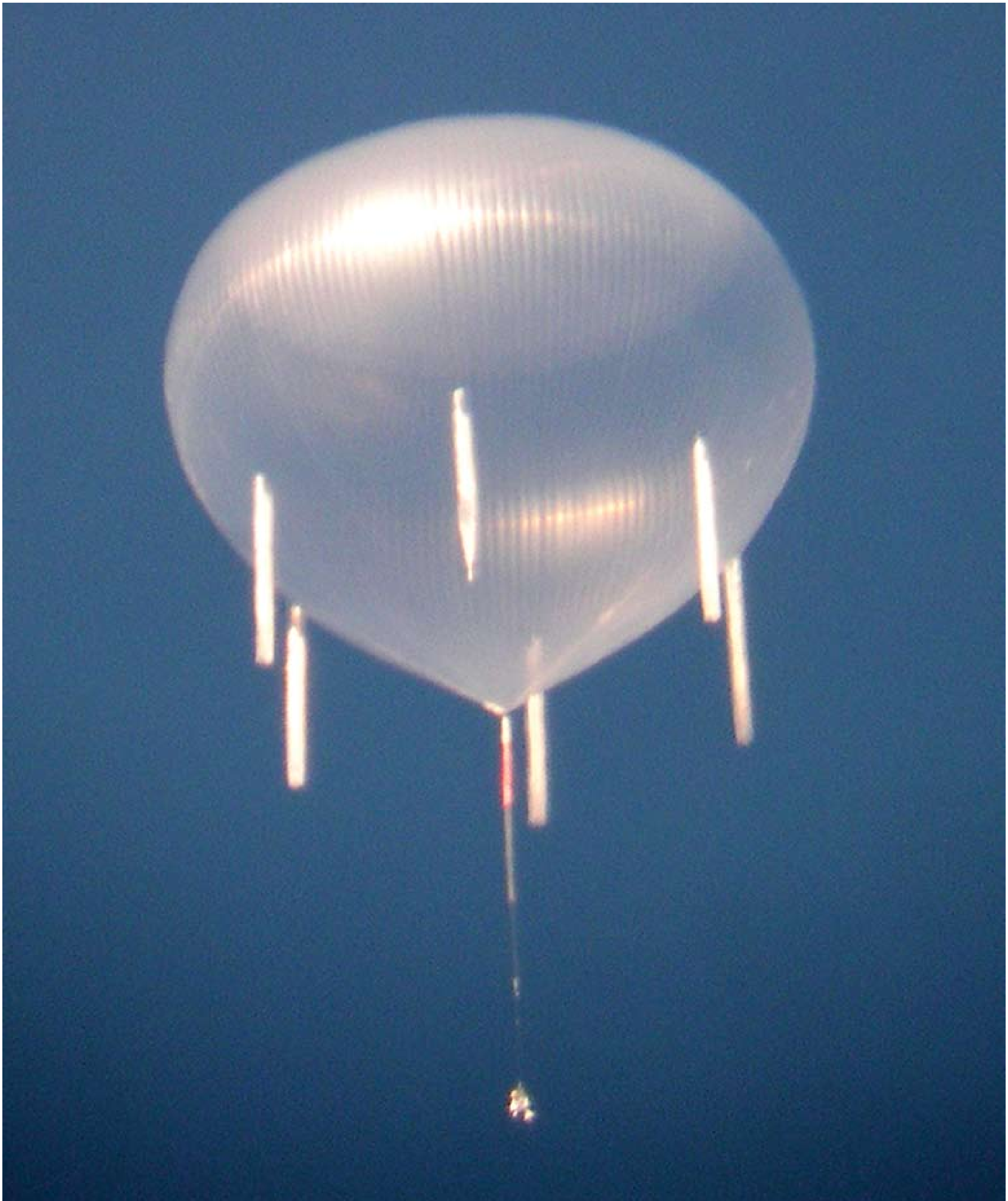
The scientific instruments that fly in the balloon program are developed by investigators funded under NASA's program of Supporting Research and Technology (SR&T) / Research and Analysis (R&A) programs. The annual funding for development of instruments and analysis of data is approximately $15M. Investigations are selected by peer review of proposals submitted in response to annual Research Opportunities in Space and Earth Sciences (ROSES). The typical time from selection of a new instrument for development to the first balloon flight of the instrument is three to five years. The relatively short time required for development of balloon-flight instruments makes ballooning an ideal place for training graduate students and young scientists.

A serious weakness of the SR&T support is that the funding levels are inadequate for developing some of the sophisticated balloon-borne missions most capable of advancing key elements of NASA strategic plans. As a result, the number of highly rated payloads that can be supported has declined, and there are many more highly rated balloon-borne investigations proposed than will fit into the current budget.

The Planning Team has not attempted to prioritize among the large number of potential balloon investigations. Indeed, a significant strength of the balloon program is that science is selected by peer review, providing opportunity for new ideas to be developed that were not foreseen in long-range strategic plans or roadmaps.

The relatively short time required for development of balloon-flight instruments makes ballooning an ideal place for training graduate students and young scientists.

A serious weakness of the SR&T support is that the funding levels are inadequate for developing some of the sophisticated balloon-borne missions most capable of advancing key elements of NASA strategic plans. As a result, the number of highly rated payloads that can be supported has declined, and there are many more highly rated balloon-borne investigations proposed than will fit into the current budget.



The InFOCμS payload at float altitude over Arizona. The six tubes hanging down from the balloon are vent-tubes, through which excess helium vents to the air.

Planning Team Identifies Three High-Priority Needs for the Balloon Program

A Reliable Funding Source for Developing New Balloon-borne Instruments

Some high-priority investigations have costs of the order of $25M over perhaps four or five years, roughly a quarter of the cost of a Small Explorer (SMEX) spacecraft mission. This amount is incompatible with the limited size of SR&T budgets and the need to maintain a viable flight rate.

Some high-priority investigations have costs of the order of $25M over perhaps four or five years, roughly a quarter of the cost of a Small Explorer (SMEX) spacecraft mission. This amount is incompatible with the limited size of SR&T budgets and the need to maintain a viable flight rate. In principle, such missions could be funded through the Explorer program as Missions of Opportunity (MO), but there is no commitment to fund any MO from responses to an Explorer Announcement of Opportunity (AO). To date no balloon mission has been funded for development under this procedure, although some have been rated highly. A more reliable means of support for balloon missions is needed.

One possibility would be to re-institute the University-class Explorer (UNEX) line within the Explorer program. Such a line would commit NASA to funding periodically at least one new investigation at about the $25M level. If constraints on the Explorer program preclude re-opening the UNEX program, then another funding line is needed to offer an intermediate step between investigations funded by the SR&T program and SMEX-class space missions.

Program and Technology Developments to Support Increased LDB Capability

The Antarctic LDB program was established with an open-ended Memorandum of Understanding (MOU) in 1988 between the NASA Office of Space Science and the NSF Office of Polar Programs. That MOU provided for "one campaign about every other year"; but in fact, the program has averaged about two flights per year. In September 2003, this NASA/NSF cooperation was extended through 2009 with a Memorandum of Agreement, which envisioned one to two flights per year, with the possibility of adding a third flight. NASA agreed to pay the incremental costs associated with adding a third flight.

The Planning Team strongly favors extension of the Antarctic capability to three flights per year.

Three-Flight Capability in Antarctica

The Planning Team strongly favors extension of the Antarctic capability to three flights per year. To do so will require a one-time expenditure of approximately $1M to add infrastructure at McMurdo. The facilities currently being built there provide space only for the NSBF crew and the preflight preparation of two instruments. In addition, the annual incremental costs for conducting the third flight are approximately $1M.

Dedicated Aircraft in Antarctica

A further important improvement in the Antarctic operations would be provision for an aircraft at McMurdo dedicated to the balloon program, at an annual cost of approximately $0.5M. Currently, recovery of balloon instruments following a flight requires use of a relatively small NSF Twin Otter aircraft that must be shared with other NSF Antarctic programs; the current strain on aircraft availability will be exacerbated by the addition of a third flight each year. The availability of an aircraft capable of recovering large payloads and dedicated to the balloon program would improve the probability of timely recovery of instruments, permitting prompt refurbishment and upgrading for later flights.

A further important improvement in the Antarctic operations would be provision for an aircraft at McMurdo dedicated to the balloon program, at an annual cost of approximately $0.5M.

Expanded Arctic Capability

Most investigations currently being flown in the Antarctic would work equally well in the Arctic. Currently there are more requests for Antarctic flights than can be accommodated, even with a third Antarctic flight each year. Increased funding for Arctic operations would permit three Arctic LDB flights each year. These would be particularly important if there were successful conclusion of negotiations with Russia to permit overflight of that nation's territory.

Most investigations currently being flown in the Antarctic would work equally well in the Arctic. Increased funding for Arctic operations would permit three Arctic LDB flights each year.

Trajectory Modification

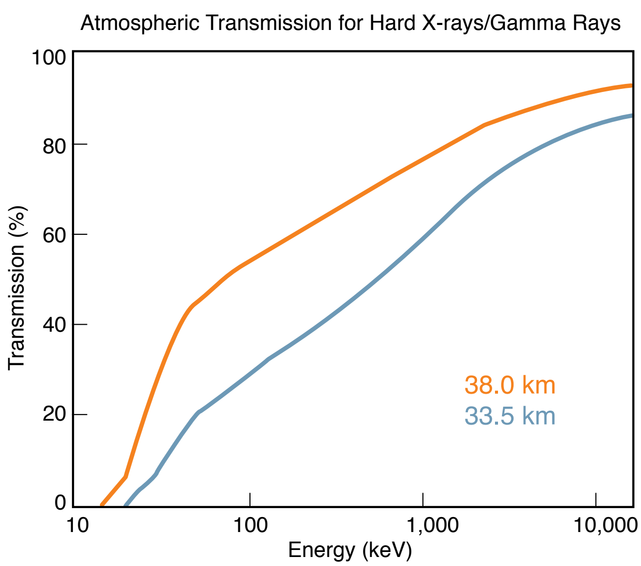
During the Antarctic summer, stratospheric winds carry the balloons around the pole in about 10–15 days. One Antarctic balloon traveled twice around the pole, giving a 32-day flight, and one traveled three times around for a duration of 42 days. Many of the instruments flown over Antarctica would benefit from the longer duration afforded by a two- or three-revolution flight. Many flights, however, are not permitted to fly around more than once, because a northerly component to the (generally westward) winds at float altitude would make it likely that the balloon will drift off the continent, making recovery of the instrument impossible. Two- or three-revolution flights could be assured if it were possible to steer the flight trajectory a few degrees off the direction that the winds are carrying the balloon. The BPO has begun investigating possible technologies for such trajectory modification. Development of this capability would greatly enhance the science return of Antarctic LDB flights. Trajectory modification would also be important for development of ULDB flight capability because flight safety requirements prohibit flights over heavily populated areas; trajectory modification could avoid premature need for cut-down, which would occur if a balloon were heading toward such an area.

Trajectory modification would greatly enhance the science return of Antarctic LDB flights and would be important for development of ULDB flight capability.

Super-pressure balloons will be capable of long-duration midlatitude flights at nearly constant altitude, but the currently funded super-pressure-balloon development program will lead to balloons capable of carrying an instrument weighing approximately 1 ton to an altitude of only about 33.5 km.

Increased Altitude for Super-Pressure Balloons

For most gamma-ray and x-ray instruments, it is necessary to have flights at midlatitudes that have long duration at an altitude of about 38 km. Such flights are severely limited by zero-pressure balloons because of their day-night altitude variations. Super-pressure balloons will be capable of long-duration midlatitude flights at nearly constant altitude, but the currently funded super-pressure-balloon development program will lead to balloons capable of carrying an instrument weighing approximately 1 ton to an altitude of only about 33.5 km. At that altitude, many of the investigations described in Section 2 of this report can be successfully carried out; however, for measurement of gamma rays and hard x-rays, that altitude is inadequate. At 38 km, the atmospheric transmission is at least 40% for x-ray energies above 30 keV, while at 33.5 km, 40% transmission occurs only above 200 keV. At 33.5 km, the transmission at 30 keV is only 10%; to achieve signal-to-noise at this altitude comparable to that achievable at the higher altitude would require integration for a period sixteen times longer.



Because of this atmospheric attenuation, time spent below about 36.5 km is quite ineffective. Summer flights in polar regions, which provide long durations above 36.5 km with zero-pressure balloons, are not useful for these instruments because the charged-particle flux of cosmic rays is an undesirable background. These instruments are generally flown at midlatitudes where the geomagnetic field excludes many of the cosmic rays that reach instruments near the poles. At midlatitudes, the day/night variation of balloon altitude is inescapable for long-duration flights using zero-pressure balloons. Thus, an LDB flight on a zero-pressure balloon from Australia to South America spends roughly half the time at altitudes too low for useful measurements of gamma rays or x-rays. Consequently, a high priority for the gamma-ray and hard-x-ray investigations supportive of the Beyond Einstein program is the extension of the super-pressure balloon development to reach 38-km altitudes with those instruments, which have typical weight of about one ton.

A high priority for the gamma-ray and hard-x-ray investigations supportive of the Beyond Einstein program is the extension of the super-pressure balloon development to reach 38-km altitudes with those instruments, which have typical weight of about one ton.

Balloon payloads are very large in size and mass. Here, the BOOMERanG payload undergoing integration, fills up an entire high-bay.

Exciting New Possibilities on a Longer Time Scale of 10–30 Years

In addition to its primary role of assessing the place of the Balloon Program within NASA's overall strategic plans and identifying the highest priority augmentations for the near term, the Planning Team was also asked to indicate a longer-term vision for the balloon program over a 10–30-year time frame. Here, three broad areas are briefly indicated.

Flights of 1-ton Instruments at Extremely High Altitudes

Typically, stratospheric scientific balloons have floated at altitudes of about 36.5–39.5 km, where the residual atmospheric pressure is in the range of approximately 4.5–3 millibars (mbar). (Sea level pressure is approximately 1 bar, i.e., 1000 mbar.) Recently a 200-kg instrument was successfully flown on a 1.7 million cubic meter (60 million cubic foot) balloon to an altitude of 49 km, where the residual atmosphere is less than 1 mbar. The Planning Team considers such extremely-high-altitude flights to be a capability currently available for such relatively light payloads, and look to the development of balloons capable of flying much heavier instruments to these altitudes.

The ability to fly 1-ton instruments at less than 1 mbar residual atmosphere would enable a wide range of ultraviolet observations, including solar studies of the magnetic transition zone and improved measurements of solar irradiance. This high-altitude capability would enable much improved x-ray, gamma-ray, and cosmic-ray studies.

The ability to fly 1-ton instruments at less than 1 mbar residual atmosphere would enable a wide range of ultraviolet observations, including solar studies of the magnetic transition zone and improved measurements of solar irradiance. This high-altitude capability would enable much improved x-ray, gamma-ray, and cosmic-ray studies.

Advanced Trajectory Control

Currently, the trajectory of a balloon is controlled entirely by the winds at its float altitude. As noted previously, there is near-term importance of developing the capability of modifying the trajectory to change it by several degrees. Beyond such "trajectory modification," advanced "trajectory control" is envisioned, which would permit balloons to be launched from a convenient site and go to any other location dictated by the scientific objectives. With trajectory control, a balloon (or aerostat) could fly a prescribed path or could "station keep" at a prescribed location. At altitudes of about 39.5 km, such a balloon could serve as a platform for optical telescopes with performance comparable to that of the Hubble Space Telescope. At altitudes of about 21 km, such an aerostat would enable atmospheric studies and geophysical monitoring, and it could serve as a platform for optical telescopes free of most of the atmospheric "seeing."

Balloons Elsewhere in the Solar System

Balloons capable of deployment after being carried by a spacecraft to another planet would enhance investigation of objects in the solar system that have an atmosphere, however tenuous. Concepts are being studied for balloons in the atmospheres of Venus, Mars, and Titan. Such balloons would permit atmospheric studies, as well as unprecedented high-resolution surface and subsurface exploration.

Launch preparations are finalized for the Nuclear Compton Telescope (NCT), a gamma-ray telescope designed to study the formation of the elements, as well as perform novel polarization measurements of gamma-ray emission from black holes and neutron stars. NCT launched on June 1, 2005 for an 8-hour first flight. This flight demonstrated the novel detector technologies, as well as qualified NCT for an LDB from Australia in Fall 2007.

Conclusion

Scientific ballooning has contributed strongly to NASA's science program by providing test beds for space instruments, training young scientists, and enabling significant scientific discoveries. Exciting new science is still being achieved, although the development of some high-priority investigations cannot be undertaken because of the limited size of SR&T budgets, the traditional funding source for balloon payloads.

The Planning Team examined the achievements, current operations, and future prospects of NASA's balloon program. They found that scientific ballooning has contributed strongly to NASA's science program by providing test beds for space instruments, training young scientists, and enabling significant scientific discoveries. Exciting new science is still being achieved, although the development of some high-priority investigations cannot be undertaken because of the limited size of SR&T budgets, the traditional funding source for balloon payloads. A more reliable means of support for balloon payloads is needed, such as a re-instituted UNEX line within the Explorer program. The LDB program, which provides flight durations of as much as 42 days, has been spectacularly successful, and the demand for flights is greater than the current capacity of the program. The Team recommends that the Antarctic capability be extended to three flights per year from the present two flights, and further development of LDB flights in the Arctic. To facilitate timely recovery of payloads, the Team recommends provision of an aircraft in the Antarctic dedicated to balloon operations. They recommend development of a modest trajectory modification capability that would enable longer flights both in the Antarctic and at midlatitudes. Finally, the Team supports the BPO program of super-pressure balloon development and urges that this program be extended to achieve super-pressure balloons capable of carrying a 1-ton payload to 38 km, which would enable midlatitude long-duration flights of instruments needed for the Beyond Einstein program.

The overall importance of scientific ballooning to the achievement of NASA's objectives has been recognized in several of NASA's May 2005 Strategic Roadmaps.

Strategic Roadmap #4, The Search for Earth-like Planets, notes in its Synopsis of Missions to Explore Extrasolar Planets, "The sources of observations include ground observatories, *balloon and sounding rockets,* small and medium size competed missions, and the major strategic missions."

Strategic Roadmap #8, Universe Exploration: From the Big Bang to Life, in discussing the Inflation Probe and the need to understand "sources of contamination signals" (foreground) notes, "Data from Planck, *and from balloon polarization experiments,* will help to refine these estimates." In discussing Technology Implementation, this report notes, "The R&A [Research & Analysis] program also serves as a useful bridge by providing platforms such as balloons and sounding rockets for gaining confidence in new technologies before they are flown in space.

Strategic Roadmap #10, Sun–Solar System Connection (SSSC), devotes one section to Low Cost Access to Space. In a paragraph, which equally well describes the role of scientific balloons in the Universe division, this SSSC report notes, "The Low Cost Access to Space (LCAS) program, with key elements of the sounding rocket and balloon (suborbital) programs, is an essential component of NASA's space physics research program, providing cutting-edge new science discoveries utilizing state-of-the-art instruments in a rapid turn-around responsive environment. These investigations are science driven, but also play two other important roles that are not available in any other flight programs—training of experimental space physicists and engineers and the development of new instruments and instrumental approaches which are verified by actual spaceflight."

Touchdown for the Far Infrared Spectroscopy of the Troposphere (FIRST) experiment, in June 2005, after a successful flight. FIRST measures the radiation of the Earth in the 10–100 µ regime.

ACRONYMS

ACCESS	Advanced Cosmic-ray Composition Experiment for the Space Station
ACE	Advanced Composition Explorer
ACT	Advanced Compton Telescope
AMS	Alpha Magnetic Spectrometer
ANITA	ANtarctic Impulsive Transient Antenna
AO	Announcement of Opportunity
BAT	Burst Alert Telescope
BEAST	Background Emission Anisotropy Scanning Telescope
BESS	Balloon Experiment with a Superconducting Spectrometer
BHFP	Black Hole Finder Probe (Einstein)
BLAST	Balloon-borne Large Aperture Submillimeter Telescope
BLISS	Balloon-borne Laser *In Situ* Sensor
BOOMERanG	Balloon Observations of Millimetric Extragalatic Radiation and Geophysics
BPO	Balloon Program Office
CASTER	Coded Aperture Survey Telescope for Energetic Radiation
CFC	Chlorofluorocarbon
CGRO	Compton Gamma Ray Observatory
ClO	Chlorine Monoxide Radicals
CMB	Cosmic Microwave Background
COBE	Cosmic Background Explorer
CREAM	Cosmic Ray Energetics and Mass
CRIS	Cosmic Ray Isotope Spectrometer
CZT	Cadmium-Zinc-Telluride
DSTB	Deep Space Test Bed
DOE	Department of Energy
EOS	Earth Observing System
ERB	Earth Radiation Budget
EUV	Extreme Ultraviolet
EXIST	Energetic X-ray Imaging Survey Telescope
FGE	Flare Genesis Experiment
FIRST	Far Infrared Spectroscopy of the Troposphere
GLAST	Gamma-ray Larage Area Space Telescope
GSFC	Goddard Space Flight Center
GUT	Grand Unified Theory
HEAO-C	High Energy Astronomy Observatory (Third)
HEFT	High Energy Focusing Telescope
HERO	High Energy Replicated Optics

HIRDLS	High Resolution Dynamics Limb Sounder
HST	Hubble Space Telescope
HXT	Hard-X-ray Telescope
InFOCμS	International Focusing Optics Collaboration for μ Crab Sensitivity
JPL	Jet Propulsion Laboratory
LAT	Large Area Telescope
LCAS	Low Cost Access to Space
LDB	Long-Duration Balloon
LIS	Lightening Imaging Sensor
LISA	Laser Interferometer Space Antenna
MABVAP	Mars Aerobot Validation Program
MAX	Maximum Anisotropy Experiment
MAXIMA	Millimeter Anisotropy Experiment Imaging Array
MK	million Kelvin
MLS	Microware Limb Sounder
MO	Mission of Opportunity
MOU	Memorandum of Understanding
MSAM	Medium-Scale Anisotropy Measurement
MSL	Mars Science Laboratory
MVACS	Mars Volatile and Climate Surveyor
NASA	National Aeronautics and Space Administration
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NPOESS	National Polar-Orbiting Operational Environmental Satellite System
NRC	National Research Council
NSBF	National Scientific Balloon Facility
NSF	National Science Foundation
OSS	Office of Space Science
PI	Principal Investigator
QMAP	Q-band Mapping Experiment
R&A	Research and Analysis
RHESSI	Ramaty High Energy Solar Spectroscopic Imager
ROSES	Research Opportunities in Space and Earth Sciences
SBI	Solar Bolometric Imager
SCUBA	Submillimetre Common-User Bolometer Array
SEC	Sun–Earth Connections
SEU	Structure and Evolution of the Universe
SMD	Science Mission Directorate
SMEX	Small Explorer
SMM	Solar Maximum Mission

SR&T	Supporting Research and Technology
SSSC	Sun–Solar System Connection
TES	Tropospheric Emission Spectrometer
TEGA	Thermal and Evolved Gas Analyzer
TLS	Tunable Laser Spectrometer
TRACE	Transition Region and Coronal Explorer
TRMM	Tropical Rainfall Measuring Mission
UAV	Unmanned Aerial Vehicles
ULDB	Ultra Long Duration Balloon
UNEX	University-class Explorer
UV	Ultraviolet
VISE	Venus *In Situ* Explorer
WFF	Wallops Flight Facility
WMAP	Wilkinson Microwave Anisotropy Probe

References

"Beyond Einstein: from the Big Bang to Black Holes, Structure and Evolution of the Universe Roadmap", NASA HQ, January 2003.

"Space Science Enterprise Strategy", NASA HQ, October 2003.

"Earth Science Enterprise Strategy", NASA HQ, October 2003.

"A 21st Century Frontier of Discovery: The Physics of the Universe—A Strategic Plan for Federal Research at the Intersection of Physics and Astronomy", A report of the Interagency Working Group on the Physics of the Universe, National Science and Technology Council Committee on Science, February 2004.

"Review of Progress in Astronomy and Astrophysics Toward the Decadal Vision: Letter Report", Committee on Astronomy and Astrophysics, National Research Council, National Academies Press, February 2005.

"A Roadmap for the Robotic and Human Exploration of Mars" (Strategic Roadmap #2), NASA HQ Draft, May 2005.

"The Solar System Exploration" (Strategic Roadmap #3), NASA HQ Draft, May 2005.

"The Search for Earth-like Planets" (Strategic Roadmap #4), NASA HQ Draft, May 2005.

"Universe Exploration: From the Big Bang to Life—A strategic roadmap of universe exploration to understand its origin, structure, evolution and destiny" (Strategic Roadmap #8), NASA HQ Draft, May 2005.

"Exploring Our Planet for the Benefit of Society—NASA Earth Science and Applications from Space" (Strategic Roadmap #9), NASA HQ Draft, May 2005.

"Sun–Solar System Connection" (Strategic Roadmap #10), NASA HQ Draft, May 2005.

National Aeronautics and Space Administration
www.nasa.gov

NP-2006-3-754-GSFC