The Scientific Ballooning Program

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by astronomy and astrophysics members of the
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1. Introduction

The scientific ballooning program is a vital component of the infrastructure for astronomy and astrophysics. This program contributes in essential ways to the health and capability of astrophysics.

- Instruments carried on high-altitude balloons have produced **important scientific results**, and one can expect future significant results from balloon-borne instruments
- Many instruments subsequently used on spacecraft for significant astrophysical observations were initially developed with flights on high-altitude balloons, and balloon flights continue to be important for **testing future space-flight instruments**.
- Scientific ballooning is an excellent environment in which to **train graduate students and young post-doctoral scientists**; indeed, many leading astrophysicists, including Nobel laureates John Mather and George Smoot, gained invaluable early experience in the balloon program.

Roger Blandford, chair of the Astro2010 Committee has noted that it will be impossible for any plausible federal budget of the coming decade to be able to fund all the worthy major projects that are under study. **In light of the inevitable delay in some major space-flight missions, a strong balloon program will be essential to continue scientific progress and instrument development in areas that will not see space flight before the decade of 2020.**

In order to enhance an already strong balloon program our group has identified three high-priority needs:

- **Fund an increased number of more sophisticated balloon payloads.** Most of the simple experiments have been done. Increased funding is required to train a new generation of Principal Investigators and to build large payloads suitable for multiple flights that can exploit the new ballooning capabilities coming on line.
- **Complete the current development program of super pressure balloons (SPB) to enable an operational program of long-duration (≥ 15-day) mid-latitude flights and extend this program to enable flights of heavy instruments to altitudes not enabled by the current development.** There is currently a successful program of long-duration (twenty- to forty-day) flights that take advantage of the continuous sunlight over Antarctica in austral summer; however, not all balloon science can be done in the polar regions. A large fraction of the high priority science needs long flights at mid-latitudes. The current super-pressure balloon development has the goal of taking 1000 kg instruments to 33.5 km altitude, where much useful science can be done. Extension of the program to develop balloons capable of taking 1000-kg instruments to 38 km would enable an important class of long-duration mid-latitude flights that cannot work effectively at the lower altitudes.
- **Build capability for 100-day flights.** Development of modest trajectory control to ensure that balloons do not fly over populous areas would enable Ultra-Long-Duration Balloon (ULDB) flights of about a hundred days duration. For a number of investigations, these would be truly competitive with orbital missions for breakthrough science at greatly reduced total cost.

2. Scientific ballooning has made important contributions to astrophysics

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 spectral lines from supernova 1987A, the first observation of positron emission lines from the galaxy, and early detection of black-hole x-ray transients in the galactic center region.

Just a few months ago, data from an Antarctic balloon flight of the Advanced Thin Ionization Calorimeter (ATIC) (*Nature*, 20 November 2008) showed a substantial excess of galactic cosmic-ray electrons at energies of ~300-800 GeV, which indicates a nearby source of energetic electrons. Such a source could be an unseen astrophysical object (such as a pulsar or micro-quasar) that accelerates electrons to those energies, or the electrons could arise from the annihilation of dark-matter particles (such as a Kaluza-Klein particle with a mass of about 620 GeV).

Examples of spacecraft instrumentation for astrophysics derived from balloon-flights 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. The viability of Cd-Zn-Te (CZT) detectors in space-like environments was first demonstrated on several balloon flights, enabling their use on the highly-successful *Swift* satellite. Hard x-ray astronomy instruments on balloons have led to the design of the payload for the SMEX Nuclear Spectroscopic Telescope Array (NuSTAR) now being developed for a launch in 2011.

3. Scientific ballooning will continue to be vital in advancing astrophysics.

Balloon-borne instruments in operation or being planned will make valuable measurement themselves, and will lay the groundwork for future space-flight instruments. Instruments are being developed that will advance the techniques for hard x-ray astronomy envisioned for the Black-Hole Finder Probe and the Constellation-X observatory missions. Other planned instruments will support the objectives of the Inflation Probe, by developing techniques for measuring CMB polarization, making the first CMB polarization measurements, and measuring the foreground that would interfere with CMB observations. Some others lay the groundwork for the Advanced Compton Telescope MeV-gamma-ray instrument. An instrument flew in 2006 and again just three months ago to detect neutrinos with energy above 10^{18} eV interacting in the Antarctic ice. Cosmic-ray instruments on long-duration balloon flights are pushing 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.

4. The balloon program is a superb training ground for young astrophysicists capable of leading the development of new instruments.

In a February 2005 report, the National Research Council 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."** The balloon program has been a superb training ground for just such leading astrophysicists.

Dr. John C. Mather, Senior Astrophysicist at NASA's Goddard Space Flight Center, and Dr. George F. Smoot, Professor of Physics at the University of California – Berkeley, shared the 2006 Nobel Prize in Physics for their leadership of the COBE satellite mission.

Dr. Mather, who is now the Senior Project Scientist for the James Webb Space Telescope, attests to the importance of ballooning in his career:

> The Cosmic Background Explorer satellite (COBE) sprang directly from my thesis work at UC Berkeley on the cosmic background radiation. It started with ground-based measurements, progressed to a balloon payload (now on display at the Air and Space Museum), and then, only months after completing my PhD, I organized a team to propose the COBE satellite.

Prof. Smoot describes the importance of ballooning to his career and to the development of that Nobel-Prize-Winning COBE investigation.

> Beginning in 1970 I was involved in a series of balloon-borne experiments – superconducting magnetic spectrometers for cosmic-ray physics, gamma rays and searches for antimatter. After that we had a series of CMB instruments – first U2 aircraft and then balloon-borne – that related directly and indirectly to COBE. The first balloon-borne CMB experiment – three flights of the cooled 3-mm receiver - proved that cooled receivers could be made sufficiently well to use them on COBE to make the COBE DMR CMB anisotropy maps and later the WMAP maps.

Both Dr. Thomas A. Prince, Professor of Physics at the California Institute of Technology and Dr. John M. Grunsfeld, NASA Astronaut, earned their doctoral degrees with dissertations that reported results of cosmic-ray investigations carried out on balloons.

Prof. Prince, an accomplished researcher in gamma-ray astronomy, served as Chief Scientist at JPL from 2001 to 2006 and is the NASA 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.

Dr. Grunsfeld is an astronaut who has been in space on missions to repair and upgrade instruments on the Hubble Space Telescope. He also attests to the value of the balloon program:

> 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.

5. 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 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. These balloons are usually launched from Palestine, TX; Ft. Sumner, NM; 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 more than a month. They use the same balloons employed for conventional flights and 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.

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). 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, the payload must carry ballast (fine steel or sand grains that can be released by radio command); ballast is dropped to maintain altitude. 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 slight differential 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 offer two advantages. First, they would permit LDB flights of one- to two-week durations at any latitude – say from Australia to South America – without diurnal altitude variation. Second, they would permit ULDB flights circumnavigating the globe at any latitude and lasting of the order of a hundred days.

6. Current funding of the Balloon Program

Funding for the Balloon Program comes in two parts. One part funds the Balloon Program Office, and the other part funds the scientific instruments that fly on balloons.

The Balloon Program Office (BPO) at the Wallops Flight Facility of Goddard Space Flight Center manages NASA's Balloon Program. The BPO has a contract with the New Mexico State University for management of the Columbia Scientific Balloon Facility (CSBF), which carries out the launches and flight operations, including flights launched both at the CSBF home site 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 on average fifteen conventional domestic flights (approximately one-day duration from Palestine, TX; or Ft. Sumner, NM), one polar Long-Duration Balloon (LDB) campaign (annual flights over Antarctica), and a Long-Duration Balloon (LDB) campaign from either Kiruna, Sweden or from Alice Springs, Australia. Each of these LDB campaigns has the capability for two to three balloon flights.

The recent budget of the BPO has also supported the development of super-pressure balloons. This technology project 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 FY12.

The scientific instruments that fly in the Balloon Program are developed by investigators funded under NASA's Research and Analysis (R&A) program. 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, depending on its complexity. 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 R&A 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.

7. Needs for increased funding

There are three areas where increased funding for the balloon program would substantially increase its value to astronomy and astrophysics. While the increases envisioned here are major in comparison with the existing Balloon Program, they are small in comparison with the costs of the major missions being studied by the Astro2010 Committee.

7.1 Reliable funding source for developing new balloon-borne instruments

NASA's Long Duration Ballooning (LDB) capabilities have matured over the past two decades, opening a new era of scientific ballooning. The LDB vehicle has become a reliable platform for achieving significant amounts of observing time in a near-space environment. This capability makes the LDB platform a particularly cost-effective vehicle for NASA's scientific return. But recent years have seen a significant decrease in the number of balloon-flight instruments funded for development, in spite of the substantial number of highly rated investigations proposed. The viability of the balloon program depends on there being a steady stream of orders to the balloon manufacturer, and flights for the CSBF launch crew.

Given the improved balloon capabilities, combined with the development of highly reliable flight support systems, the natural evolution of scientific payloads is towards increasingly more sophisticated and expensive instruments. Supporting enough payloads to satisfy the scientific proposal pressure is already beyond the scope of the current R&A program. Furthermore, some proposed LDB instruments are ambitious enough to be treated like small missions rather than R&A investigations. However, no viable means for funding large complex LDB payloads currently exists – due to the large gap between the current levels of suborbital payload support in the SR&T program and the Explorer program. A healthy program needs both a reasonable flight rate and sophisticated payloads to address the highest priority science and technology investigations. A middle level competitive program could address this large gap, and it would represent a viable avenue for supporting future balloon missions. Such a program would allow NASA to utilize fully the mature LDB launch capability and a future ULDB capability, for optimal science returns.

Such a program could be viable if funding for balloon-borne scientific investigations (including incremental costs of the Balloon Program Office for balloon operations) were at an annual rate of $45M (FY10) to $65M (FY20). These numbers represent a substantial increase over the ~$15M annual funding for payloads of recent years.

7.2 Extend the present super-pressure balloon program to be able to fly 1000 kg payloads to altitudes of 38 km.

The current super-pressure balloon development effort is not adequately funded within the current budget of the Balloon Program Office. Further, this current development program is limited to reaching a capability of taking a 1000 kg payload to an altitude of 33.5 km. At that altitude, many valuable investigations 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. Thus an extension of the present super-pressure development program to develop balloons capable of taking 1000-kg instruments to 38 km would enable an important class of long-duration mid-latitude flights.

The development of the super pressure balloon to 33.5 km, and the extension of the super-pressure balloon to 38 km could be viable if funded at an annual rate of $5M (FY10) to $10M (FY20).

7.3 Develop capability for slight modification of the balloon trajectory.

The promise of the current super-pressure technology already makes it likely that 1-ton science payloads could be flown for ~15-day mid-latitude flights from (perhaps) Australia to South America. But the ultimate value of super-pressure balloons is that they would enable ultra-long-duration balloon (ULDB) flights with duration 100 days or more. However, a serious impediment to such ULDB flights is the safety requirement that balloons not be permitted to fly over heavily populated areas. This is a very conservative requirement, considering that catastrophic balloon failures have become quite unusual, and they are nearly unheard of after a balloon has been floating quietly for some time. Nonetheless, without the capability of nudging a balloon into a trajectory that avoids a populous area, the promise of 100-day flights may not be achieved.

Currently there is no funding for a program to develop such “trajectory modification”. Such a program could reasonably get underway under direction of the Balloon Program Office for an annual budget of $3M.

A more extensive report on scientific ballooning can be seen at
http://sites.wff.nasa.gov/code820/balloonroadmapreport2009.pdf