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# The US Long Duration Balloon Facility at McMurdo Station

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**Abstract.** A sea change in scientific ballooning occurred with the inauguration of 8–20-day flights around Antarctica in the early 1990's. The attainment of 28–31-day flights and 35–42-day flights, respectively, in two and three circumnavigations of the continent has greatly increased the expectations of scientific users. There is a scientific need for the capability to provide similar-duration flights for investigations that cannot be done in the Polar Regions. A new super-pressure balloon is currently under development for future flights of 60–100 days at any latitude. This first new balloon in more than half a century would meet this need and allow the focus to change from increasing the durations of flights over and around Antarctica to ultra-long-duration flights from Antarctica.

**Keywords.** NASA Balloon Program, Antarctic Ballooning, LDB, ULDB

## 1. Introduction

The U.S. National Aeronautics and Space Administration (NASA) routinely launches scientific balloons from sites in Antarctica, Australia, Sweden and within the U.S. The Antarctic Long-Duration Balloon (LDB) flights are launched from a site on the Ross Ice Shelf near McMurdo, in cooperation with the U.S. National Science Foundation Office of Polar Programs (NSF/OPP). The buildings comprising the LDB launch site are shown in Fig. 1. The two large buildings on the left are the so-called payload buildings, which are available to the science teams for final integration and test of their payloads prior to launch. These are the largest buildings on the Antarctic Continent. They are on skids to facilitate their movement to nearby elevated berms of snow at the end of each launch season. They are dragged back to the launch site configuration at the beginning of the next season.

This LDB camp site is very remote from both the home base of the Columbia Scientific Balloon Facility (CSBF) in Palestine, Texas and the scientific user team laboratories, which are mainly in the Continental U.S. (Conus). Capabilities for making on-site payload repairs are minimal. The payload buildings are intended to support re-assembly and checkout of "flight-ready" payloads after their shipment "to the Ice." Until recently, LDB flight candidates were required to have completed an engineering test flight of all the flight components approximately a year in advance of their desired LDB flight. Recently, in lieu of an engineering test flight, the Balloon Program has offered the option for an extensive Thermal-Vacuum Test at the Plumbrook Facility of the Glenn Research Center. In either case, the payloads are shipped to Antarctica only after having completed successful hang-tests at CSBF to verify that they are indeed flight ready.

Figure 2 shows three payloads being readied for launch outside the two large payload buildings during the 2007-2008 Austral season, the first time three payloads were launched. These three payloads shared the two payload buildings, with the largest BLAST

**Figure 1.** The LDB Camp Site near McMurdo.

(Balloon Large Aperture Submillimeter Telescope) in one and both ANITA (Antarctic Impulsive Transient Antenna) and SBI (Solar Bolometric Imager) in the other. NASA is currently planning to add a third payload building, a critical need for accommodating the exceedingly large payloads wanting Antarctic LDB flights. Another, corresponding critical need is a dedicated airplane with large cargo capability for same-season recovery of the payloads at the end of their flights.

## 2. Impact of Antarctic LDB Flights

Scientific ballooning offers a unique capability for frequent access to near-space for instruments ranging in mass from a few kilograms to a few tons. Balloon payloads for science, applications, and new technology development have been flown for periods of 1–2 days since the 1950's. The flight times were extended to 10–20 days in the early 1990's by conducting launches in Antarctica during the austral summer. These long-duration balloons (LDB) float in the nearly circumpolar stratospheric wind vortex during the Antarctic summer. They employ zero-pressure polyethylene balloons identical to those

**Figure 2.** ANITA, left, hanging from the launch vehicle; BLAST, middle, hanging from the payload building; and SBI, right, standing on the Ice.

utilized for conventional 1–2 day flights, whose durations are limited because ballasting is required to minimize their altitude excursions during day-night transitions. The zero-pressure balloons used today have changed only incrementally from the large polyethylene balloons introduced in the 1950's. The order of magnitude improvement in flight duration in the polar region is possible because of the constant daylight during local summer. The nearly constant solar heating ensures nearly constant altitudes with minimal or no ballasting (Gregory & Stepp 2004).

Most LDB missions have carried suspended payloads of 2,300 – 2,800 kg, with scientific instruments of 900 – 1,400 kg, to altitudes of 37 – 41 km for one circumnavigation of the continent. In 2002, a record was set when a 0.83 MCM (million cubic meter) balloon carrying the Trans Iron Galactic Element Recorder (TIGER) payload flew in excess of 31 days in two rounds of the South Pole (Geier *et al.* 2005). In 2005 a new LDB flight record was set when a 1.11 MCM balloon carrying the Cosmic Ray Energetic and Mass (CREAM) experiment (Seo *et al.* 2008) flew for nearly 42 days while circumnavigating the continent three times. The CREAM payload has accumulated a total of 162 days of exposure with six Antarctic flights, the record for a single balloon project (Seo 2012).

Scientific ballooning is a vital infrastructure component for astronomy and astrophysics in general. Instruments carried on high-altitude balloons have produced important scientific results, and many instruments developed initially for balloon flights have been used on spacecraft for significant astrophysical observations. Ballooning seems essential for continued scientific progress and instrument development, since it is highly unlikely that all of the worthy space flight projects being studied can be funded within any plausible federal budget during the coming decade. Scientific ballooning is simultaneously an excellent environment for training graduate students and young post-doctoral scientists. Indeed, many leading astrophysicists, including 2006 Nobel laureates John Mather and George Smoot, gained invaluable early experience conducting balloon-borne science investigations (Israel *et al.* 2009).

The Antarctic LDB flights enabled by the NASA–NSF/OPP cooperative agreement have been subsequently dubbed "jewels in the crown of the NASA Balloon Program." Among the 41 LDB flights launched to date in Antarctica were a 0.201 Million Cubic Meter (MCM) SPB flown successfully for 54 days around Antarctica between December 2008 and February 2009, and a 0.402 MCM SPB flown successfully for 22 days in January 2011. See Fig. 3 for a photograph of the former balloon at its float altitude, along with a graphic of its trajectory showing the turnaround of the polar vortex.

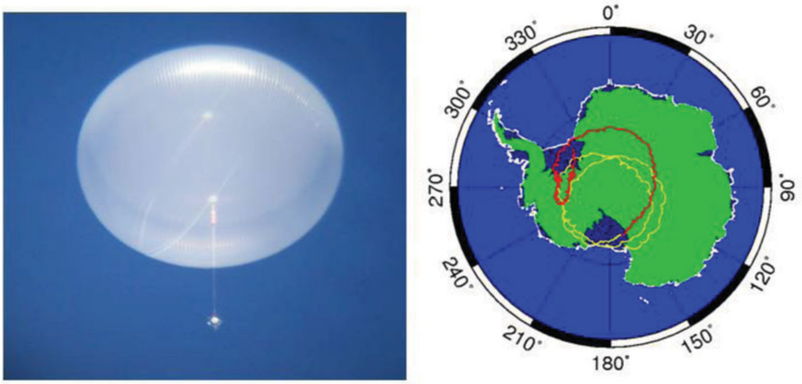

**Figure 3.** A photograph of the 7 MCF super-pressure balloon at its float altitude and its 54-day flight trajectory in Antarctica showing the turnaround of the polar vortex.

The NASA-NSF/OPP partnership that established the Antarctic LDB program revitalized ballooning. This new capability facilitated several high impact cosmic ray / particle astrophysics projects. Recent examples include the Advanced Thin Ionization Calorimeter (ATIC), which reported an unexpected surplus of high-energy cosmic ray electrons after two LDB flights in Antarctica (Chang *et al.* 2008). The source of these excess electrons would need to be a previously unidentified and relatively nearby cosmic object, within about 1 kilo parsec (3,260 light years) of the Sun. Annihilation of exotic particles postulated to explain dark matter is among other explanations proposed. The Balloon Experiment with a Superconducting Spectrometer (BESS) has conducted a negative search for annihilation signatures of dark matter in the antiproton channel (Abe *et al.* 2008). The electron excess in ATIC and lack of excess antiprotons in BESS provide interesting constraints on dark matter models.

Another notable example is the Cosmic Ray Energetics And Mass (CREAM) investigation, which extends direct elemental composition measurements to the highest energy practical in a balloon experiment to explore the theoretical limit of supernova shock wave acceleration (Ahn *et al.* 2010) This project has already achieved a record-breaking cumulative exposure of $\sim$ 162 days in 6 successful flights over Antarctica. Its report of hardening in the elemental spectra calls for a cosmic-ray acceleration and propagation model that is more realistic than current models based on a steady state/continuous source distribution.

The Trans-Iron Galactic Element Recorder (TIGER), a non-magnet spectrometer, has measured the elemental composition of cosmic rays heavier than iron in a search for the origin of cosmic rays (Rauch *et al.* 2009). TIGER was the first payload to make two circumnavigations of Antarctica in one flight. It produced a strong indication that cosmic rays originate and are accelerated in associations of massive stars called OB associations. A larger instrument called Super-TIGER is one of three pay-loads planned for LDB flights in December 2012. Super-TIGER is a large-area instrument being developed to measure the abundances of $30 \leqslant Z \leqslant 42$ elements with unprecedented individual-element resolution. It will test the emerging model of cosmic-ray origin in massive (i.e., OB) star associations, and models for atomic processes by which nuclei are selected for acceleration to cosmic ray energies.

The Antarctic Impulsive Transient Antenna (ANITA) is a unique neutrino experiment to constrain the origin of the highest energy particles in the universe (Gorham *et al.* 2010). It is designed to detect coherent radio Cherenkov radiation from neutrino-initiated showers in the Antarctic ice. Figure 4 illustrates the underlying technique, and Figure 5 shows a photograph of the instrument. Ultra High Energy Cosmic Rays guarantee an associated GZK (Greisen-Zatsepin-Kuzmin) neutrino flux from the interactions of extreme energy hadrons with cosmic microwave background photons. ANITA observes $\sim 10^6$ km$^3$ of ice from balloon altitudes of $\sim$ 110,000 feet, which is nearly optimal for the ultrahigh energy neutrinos of interest. ANITA now has highest-energy sample of radio-detected ultra high-energy cosmic rays. Its detection of these extreme energy cosmic ray events was featured on the cover of the October 8, 2010 issue of Physical Review Letters (Hoover *et al.* 2010).

Balloon-borne cosmic microwave background (CMB) experiments have had exceptionally high impact, most notably the Balloon Observations Of Millimetric Extra-galactic Radiation and Geophysics (BOOMERanG), which established that the universe is flat, i.e., that its geometry is not curved but Euclidean. This result was obtained by measuring a detailed map of the CMB temperature fluctuations. The Principal Investigators of this project were awarded the 2006 Balzan Prize for Astronomy and Physics "for their contribution to cosmology, in particular the Boomerang Antarctic balloon experiment." This

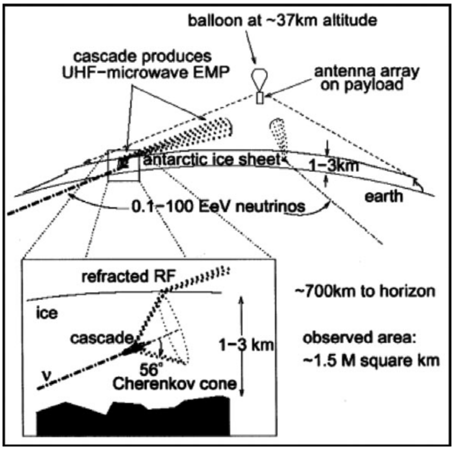

**Figure 4.** Schematic of ANITA measurement concept with balloon over the Antarctic ice.

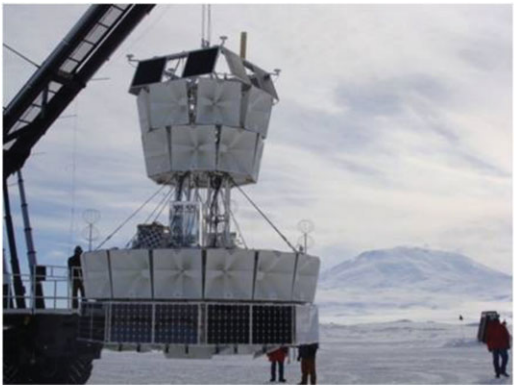

**Figure 5.** Photograph of the ANITA payload preparing for launch in Antarctica.

prize is considered to be one of the highest awards for science, culture and humanitarian achievement, ranking close to the Nobel Prize.

The COBE and WMAP CMB Explorer missions were enabled by precursor balloon flights beginning in the 1970's (Israel *et al.* 2009). The currently operating Planck CMB satellite also relied on advances made in these balloon missions. Polarization-sensitive focal planes employing Transition Edge Sensor (TES) bolometers, polarization modulation strategies, and developing filter technologies are being employed by high priority instruments discussed at this Symposium and currently awaiting LDB flights in Antarctica to search for signatures of inflation. The IRAS, ISO and Spitzer observatories all relied on far–IR telescope and detector technologies proven during balloon flights in the 1970's and 1980's. The balloon-borne High Energy Focusing Telescope, predecessor of the NuSTAR mission launched in early 2012, utilized similar multilayer optics and CdZnTe pixel detector technologies.

## 3. Super Pressure Ballooning and ULDB Flights

In parallel with increasing Antarctic LDB flight durations, NASA has continued development and qualification flights leading to heavy-lift super pressure balloons capable of supporting 1,000 kg science instruments to 33 km for upwards of hundred day missions, with plans for increasing the altitude to 38 km. This goal is even more important now, in view of the National Research Council Astro2010 Decadal Study recommendation that NASA should support ultra-long duration ballooning (ULDB) for science missions in a range of disciplines. Figure 6 illustrates a comparison of the performance of super-pressure and zero-pressure balloons. The volume of zero-pressure balloons used for conventional and polar LDB flights changes as the ambient atmospheric pressure changes, causing large droop at night. By contrast a super-pressure balloon maintains nearly constant volume, which allows LDB flights in non-polar latitudes, including ULDB flights.

The current vision for scientific ballooning includes development of super-pressure balloons (SPB) designed to maintain essentially constant volume, day and night, and thus to float at nearly constant altitude without the need for dropping ballast at sunset. These sealed balloons are designed to withstand slight differential pressure. They are inflated with enough helium to fill the volume at the coldest temperatures, and they have sufficient strength to hold that helium when sunlight heats it (Cathey 2011). They would permit LDB flights of one- to two-week durations at any latitude without diurnal altitude variation. They would also permit ULDB flights that circumnavigate the globe at any latitude, with the potential for durations on the order of a hundred days. This is in contrast to conventional zero pressure balloons, which cannot keep altitude for more than about a week at mid-latitudes, even with substantial ballast drops to limit excursions due to day/night cycles. The Astro2010 decadal survey strongly supported ULDB flights, especially for cosmic microwave background and particle astrophysics research (Panel on particle astrophysics and gravitation 2010).

The Antarctic LDB flight capabilities have dramatically increased access of heavy payloads to near space for durations as long as $\sim$ 45 days using zero pressure balloons. The ULDB capability based on SPB technology can extend the flight time to as much as 100 days, even at mid-latitudes, thereby opening up the entire sky to investigators with payloads having substantial weight and power requirements. These expanded capabilities will allow investigations from balloons that previously could be done only from Explorer class missions, for example, at a fraction of the cost. Currently, ULDB is defined as a 1,000 kg science instrument suspended along with its flight support equipment from a SPB floating above 33 km for up to 100 days. Comparable flights of smaller instruments to higher altitudes around 38 km on larger SPB's are also being pursued.

Figure 7 compares the altitude variations of the 2008 SPB (introduced in Fig. 3) with two LDB payloads flown during the same season: Cosmic Ray Energetics and Mass (CREAM) and Antarctic Impulsive Transient Antenna (ANITA). The figure shows that the Super-Pressure Balloon maintains a stable altitude with little variation while the zero-pressure balloons significantly droop during a diurnal cycle. The SPB's differential pressure varied as expected due to time of day and solar and Earth IR inputs. At the end of the flight, ballast was dropped to verify the balloon's structural envelope to the maximum design pressure. The payload and portions of the balloon were recovered for post-flight testing.

The 2011 test flight of a 0.402 MCM super-pressure balloon launched in Antarctica on January 9, 2011 flew for 22 days. The flight performance matched predictions very closely. The SPB balloon carried 1,815 kg suspended payload, and it fully deployed just before reaching the target float altitude at essentially zero differential pressure. It took $\sim$3 hours to ascend to its float altitude of $\sim$ 33.9 km, and it demonstrated almost no

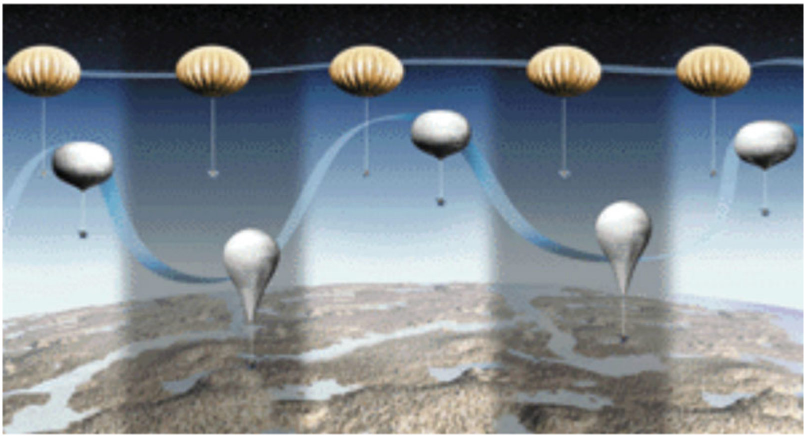

**Figure 6.** Illustration of the day-time and night-time altitude performance of a super-pressure and zero-pressure balloon.

altitude change during the 22-day flight. The balloon demonstrated stable pressure and remained at its designed float altitude for the flight duration. The average altitude variations were about ± 180 m, or ∼ 0.5%.

The first deployment verification test of a 0.525 MCM super-pressure balloon vehicle was successfully launched August 14, 2012 with a 2,270 kg suspended payload. This test flight demonstrated the balloon vehicle performance, obtained in-flight video data of the balloon inflation, measured the differential pressure at the base of the balloon, and measured the tension in a select number of tendons. It also obtained temperature and altitude data throughout the flight, demonstrated vehicle altitude stability and performance, and validated the structural envelope through pressurization. This SPB also fully deployed at very low differential pressure. All ballast was expended during the course of 2 hours at float to pressurize the balloon as much as possible. The balloon performance was judged to be excellent.

## 4. Future Super Pressure Balloon Flights

The next 0.525 MCF SPB flight is tentatively planned for May/June of 2013 from Kiruna, Sweden with suspended payload up to ∼2,500 kg, including a small piggyback science instrument. Further plans call for this pumpkin balloon to carry its first science payload for an extended duration flight over Antarctica, before leaving the continent for an extended ULDB flight. After completing of tests of the 0.525 MCM balloon, it is planned to scale up the SPB design for future test flights of a 0.746 MCM balloon toward meeting the project goal for development of a balloon vehicle capable of carrying 2,721 kilograms to 33.5 kilometers for 60–100 day duration missions.

The Balloon Program is planning a mid-latitude demonstration flight of the full-scale SPB by 2014, with a goal of developing a Southern Hemisphere launch site that will support LDB and ULDB science flights, while also complying with flight safety policies. In addition, once operational, NASA also plans to launch ULDB missions from Antarctica with recovery off the continent in the southern hemisphere.

## 5. Wallops Arc Second Pointer (WASP)

The NASA Scientific Balloon Program affords researchers the opportunity to conduct research in a near-space environment. Flight altitudes above more than 99.5% of the

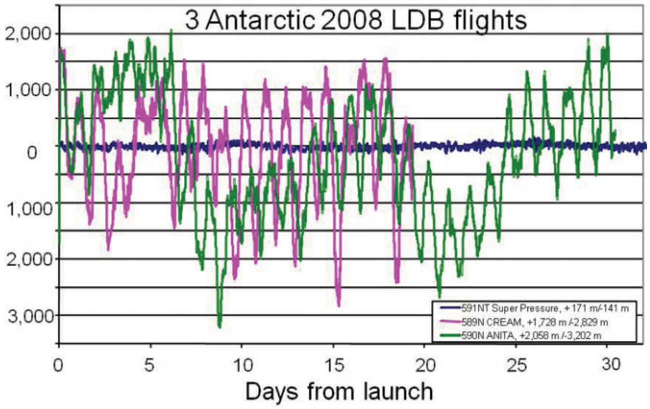

**Figure 7.** Comparisons of the altitude variation of the 2008 SPB test flight relative to the CREAM and ANITA flights on zero-pressure balloons.

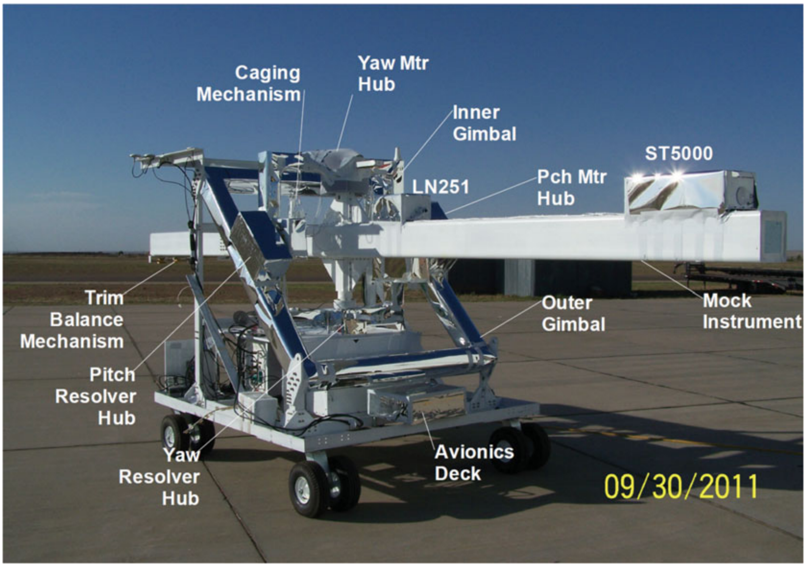

**Figure 8.** Artist's concept of the WASP payload.

earth's atmosphere are typical. Recognizing that there is significant interest from the science community in a reliable balloon-borne fine pointing system, the Balloon Program has developed and tested the Wallops Arc Second Pointer (WASP) for the user community. See Fig. 8. Potential user areas include extra-solar planetary finders, cosmic background exploration, astronomy at a variety of wavelengths, high-energy astrophysics, upper atmospheric science and ultra-high-energy neutrinos, etc.

The first test flight of the WASP gondola with a mock telescope occurred in October 2011. During the 5-hour flight, the WASP system was exercised at a float altitude of 32 km for $\sim$ 2 hours. It demonstrated sub-arcsecond pointing stability with the mock telescope in a typical flight environment. The mock instrument was uncaged, and inertial target offsets were issued from the ground to demonstrate acquisition dynamics. The system was able to maintain arcsecond pointing stability during discrete ground-commanded gondola azimuth adjustments. The second flight in September 2012 provided more extensive tests. Specifically, the WASP system was in fine-pointing mode for over seven hours during daytime, and approximately three hours during nighttime using its onboard Star Tracker. The pointing performance was sub-arcsecond consistently.

## 6. Acknowledgements

The outstanding staff of the NASA Balloon Program Office, Columbia Scientific Balloon Facility, and Aerostar, Inc. are responsible for the advancements being made in scientific ballooning. The NASA Balloon Program Office deserves special recognition for leading this effort with its in-house studies and oversight of the design tools, film technologies, and fabrication techniques required for its development. Special recognition is due the staff of the Columbia Scientific Balloon Facility for a lifetime of contributions to ballooning, and to the staff of Aerostar, Inc. for innovative approaches to pumpkin-balloon fabrication and consistent fabrication of high quality balloons. The Antarctic LDB program, the crown jewel of ballooning, would not be possible without the crucial contribution of the U.S. National Science Foundation Office of Polar Programs and its Antarctic support contractors.

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