Current Outlook for Scientific Research with Super Pressure Balloons

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Abstract: The NASA Balloon Program has supported numerous science missions since the July 2009 31st ICRC in Lodz, Poland. Launches were conducted from sites in Antarctica, Australia, Sweden, and domestic U.S. sites. In addition, NASA has continued development and qualification flights leading to heavy lift super pressure balloons capable of supporting 1000 kg science instruments to 33 km for upwards of hundred day missions, with plans for increasing the altitude to 38 km. This goal for more than a decade is even more important now, in view of the National Research Council Astro2010 Decadal Study recommendation that NASA should support ultra-long duration ballooning development. Astro2010 emphasized that NASA should support such missions for indirect detection of dark matter and for cosmic-ray physics and astrophysics. An overview of recent results from Antarctic balloon flights, status of super pressure balloon development, and plans for science flights on super pressure balloons will be presented.

Keywords: **NASA Balloon Program, Antarctic Ballooning, LDB, ULDB, cosmic rays, spectra, composition**.

1 Introduction

Scientific ballooning is a vital infrastructure component for cosmic ray investigations, as well as 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 Nobel laureates John Mather and George Smoot, gained invaluable early experience conducting balloon-borne science investigations [1].

Balloons that have been used to date for both conventional and Antarctic long-duration balloon (LDB) flights are "zero-pressure." 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 solar input, there is a cooling of the helium and consequent shrinking of the balloon volume, which causes the balloon to sink to a much lower altitude. To reduce the altitude variation at sunset, the payload must carry ballast (fine steel or sand grains) that can be dropped by radio command to lessen the suspended weight. 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 flights can be flown during local summer over Antarctica or in the Arctic, where continuous sunlight permits the balloon to maintain altitude without the need to drop ballast.

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 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 [2]. They would permit LDB flights of one- to two-week durations at any latitude – say from Australia to South America – without diurnal altitude variation. They would also permit ultra long-duration balloon (ULDB) flights that circumnavigate the globe at any latitude, with the potential for durations on the order of a hundred days. This 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 supports ULDB flights for cosmic microwave background and particle astrophysics research [3].

2 Impact of Antarctic LDB flights

2.1 Cosmic ray studies

A cooperative agreement between the U.S. National Aeronautics and Space Administration (NASA) and the U.S. National Science Foundation / Office of Polar Programs (NSF/OPP) enabled Antarctic balloon flights, starting with the first successful launch in December 1990. Antarctic LDB flights were subsequently dubbed "jewels in the crown of the NASA Balloon Program." Including that first launch, 47 polar LDB flights have been conducted, 39 of them in Antarctica. Among them 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. In addition, there have been two LDB flights from Fairbanks, Alaska to Canada over Russia, and six flights from Kiruna, Sweden to Canada.

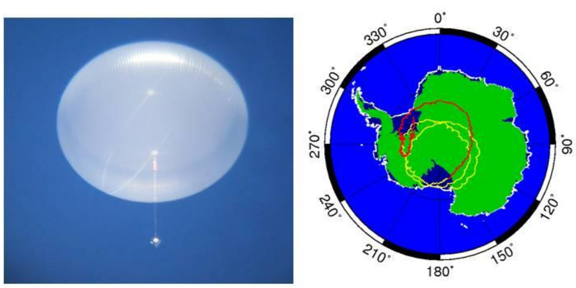

Figure 1. A photograph of the 7 MCF super pressure balloon at float and its 54 day flight trajectory in Antarctica showing the turnaround of the polar vortex . http://sites.wff.nasa.gov/code820/uldb.html

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 [4]. 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 [5]. 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 [6]. This project has already achieved a record-breaking cumulative exposure of ~161 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 [7]. It produced a strong indication that cosmic rays originate and are accelerated in associations of massive stars called OB associations. A larger LDB instrument called Super-TIGER is nearly ready for flight in Antarctica. The Transition Radiation Array for Cosmic Energetic Radiation (TRACER) focused on high-energy heavy nuclei to get a better understanding of cosmic-ray propagation in the interstellar medium [8].

The Antarctic Impulsive Transient Antenna (ANITA) is a unique neutrino experiment to constrain the origin of the highest energy particles in the universe [9]. Its detection of extreme energy cosmic ray events was featured on the cover of the October 8, 2010 issue of Physical Review Letters [10].

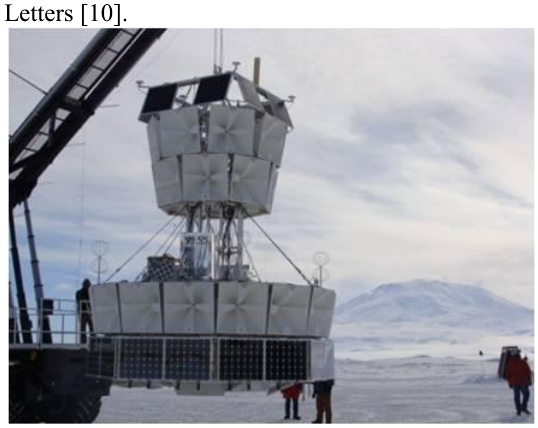

Figure 2. A photograph of the ANITA payload preparing for launch in Antarctica. http://sites.wff.nasa.gov/code820/uldb.html

2.2 Studies in Other Disciplines

Non-particle astrophysics balloon-borne experiments have had exceptionally high impact, most notably the Balloon Observations Of Millimetric Extragalactic 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 cosmic microwave background (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 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 cosmic microwave background Explorer missions were enabled by precursor balloon flights beginning in the 1970’s. 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 currently by the EBEX, SPIDER, and PIPER balloon experiments, which are searching for signatures of inflation. The most successful of these technologies will likely be used on the Inflation Probe. 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 predecessor of NuSTAR was the balloon-borne High Energy Focusing Telescope (HEFT), which utilized similar multilayer optics and CdZnTe pixel detector technologies. The Nuclear Compton Telescope (NCT) balloon payload recently demonstrated high sensitivity, energy resolving gamma ray detectors similar to the technology planned for the Advanced Compton Telescope Satellite for the 2020 decade. This work follows demonstration of the Fermi satellite's gamma ray Large Angle Telescope (LAT) engineering model balloon flight demonstration in 2001.

3 Impact of SPB flights

3.1 Super pressure balloon development

The Antarctic LDB flight capabilities have dramatically increased access of heavy payloads to near space for durations as long as ~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 1000 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.

Table 1 shows the SPB test flights that have occurred since 2008, as well as planned flights through 2014. The 2011 test flight of a 0.402 MCM SPB was launched in Antarctica on January 9, 2011, and it 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 no differential pressure. It took ~3 hours to ascend to its float altitude of ~33.9 km, and it

Location	Year	Volume MCM	Payload Kgs	Duration
Antarctica	2008	0.201	646	54 days
Sweden	2009	0.402	2000	6 hrs
Antarctica	2010	0.402	1600	3 hrs
Antarctica	2011	0.402	1800	22 days
Antarctica	2012	0.525	2225	40 days*
Sweden	2012	0.525	2225	5 days*
Antarctica	2013	0.736	2700	100 days*
Southern Hemisphere	2014	0.736	2700	100 days*

Table 1: Super Pressure development test flights 2008-2014, including balloon size, payload weights, and flight duration . *- planned test and science flights. http://sites.wff.nasa.gov/code820/uldb.html

demonstrated almost no altitude change during the 22-day flight. The balloon demonstrated stable pressure and remained at its designed float altitude for the duration of the flight. The average variations in altitude were ~+/-180 m, or ~0.5%.

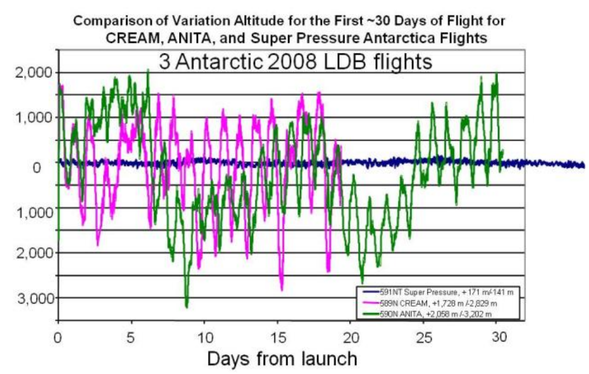

Figure 3

Figure 3 compares the altitude variations of the 2008 SPB with those of the Cosmic Ray Energetics and Mass (CREAM), and Antarctic Impulsive Transient Antenna (ANITA), two LDB payloads flown during the same season. 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.

3.2 Future Super Pressure Balloon Flights

The next SPB flight is planned for December of 2011 from Antarctica, with up to ~2,500 kg suspended payload.

Plans call for this 0.525 MCF pumpkin balloon to carry its first science payload, the Stratospheric Terahertz Observatory (STO), for an extended duration flight over Antarctica. After completion of tests of the 0.525MCM 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. As shown in figure 4, to support 100-day, circum global science flights, NASA continues to develop highly reliable flight support systems, including redundant communications systems, power systems, flight computers for telemetry, ballast, and terminate systems.

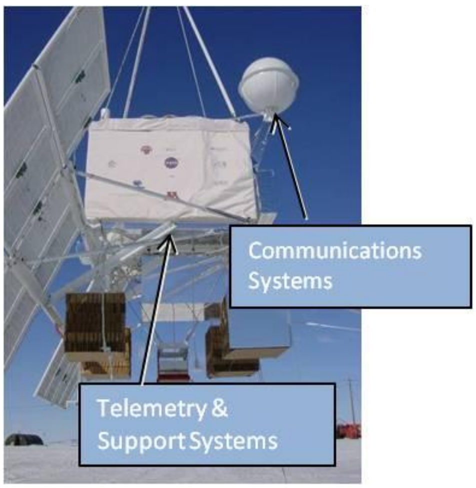

Figure 4. Advanced NASA Flight Support Systems

The project 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.

4.0 References

[1] M. Israel et al., Report of the Scientific Ballooning Roadmap Team: NASA Stratospheric Balloons, 2009. http://sites.wff.nasa.gov/code820/
[2] Cathey, H., Internal NASA balloon program report, NASA, 2011. http://sites.wff.nasa.gov/code820/
[3] Report of the Panel on Particle Astrophysics and Gravitation, New Worlds, New Horizons in Astronomy and Astrophysics, NAS/NRC, 2010. www.nap.edu.
[4] J. Chang et al., Nature, **456**, 2008: 362-365
[5] K. Abe et al., Phys. Lett. B, 2008, **670**, 103-108
[6] H. S. Ahn et al., Astrophys. J., 2010: **714**, L89-L92
[7] Rauch et al., ApJ, 2009, **697**: 2083-2088,
[8] D. Muller et al., Astrophys. J., 1991: **374**, *356-365*
[9] P. Gorham et al., Phys. Rev. D: 2010, **82**, 022004
[10] S. Hoover et al., Phys. Rev. Lett: 2010, **105**, 151101

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