Balloon-borne observations of the galactic positron fraction during solar minimum negative polarity

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[1] Galactic cosmic ray electrons and nuclei respond differently to solar modulation, with the differences directly related to the reversals of the solar magnetic field, which occur every 11 years. If the large-scale heliospheric magnetic field has certain types of structures, the charge sign of cosmic ray particles can affect their propagation. Careful study of the behavior of cosmic ray positrons, relative to negative electrons (which have identical masses), allows for a definitive separation of the effects due to charge sign from the other possible effects. As part of an ongoing investigation of charge sign dependence in solar modulation, cosmic ray positron fraction in the energy range of 0.6 to 4.5 GeV was measured on a balloon flight from Kiruna, Sweden, to Victoria Island, Canada, during 2–6 June 2006. Measurements from this flight are compared to previous results and current models.

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1. Introduction

[2] The anticorrelation between cosmic ray fluxes and the level of solar activity (solar modulation) is caused by magnetic field fluctuations carried by the solar wind that scatter charged particles out of the solar system and/or decelerate them. Even though the sun has a complex magnetic field, the dipole term nearly always dominates the magnetic field in the solar wind. The projection of this dipole on the solar rotation axis (A) can be either positive, which we refer to as the A+ state, or negative, which we refer to as the A- state. At each sunspot maximum, the dipole reverses direction, leading to alternating magnetic polarity in successive solar cycles.

[3] Electromagnetic theory has an absolute symmetry under simultaneous interchange of charge sign and magnetic field direction, but positive and negative particles can exhibit systematic differences in behavior when propagating through a magnetic field structure with nonuniform characteristics such as curvature and gradients.

[4] The Parker field has opposite magnetic polarity above and below the helioequator, but the spiral field lines themselves are mirror images of each other. This asymmetry produces drift velocity fields that (for positive particles) converge on the heliospheric equator in the A+ state or diverge from it in the A- state [*Jokipii and Levy*, 1977]. Negatively charged particles behave in the opposite manner, and the drift patterns interchange when the solar polarity reverses. Primary cosmic ray electrons are predominantly negatively charged, even during the A+ polarity state, so differential modulation of electrons and nuclei provides a direct way to study the large-scale nonuniformity in solar wind magnetic fields.

[5] Since electrons and nuclei have greatly different charge/mass ratios, the relation of velocity and magnetic rigidity is very different for these two particle species. This ongoing study of the behavior of cosmic ray positrons, relative to negative electrons (which have an identical relationship between velocity and rigidity), definitively separates effects due to charge sign from that arising in velocity differences for the same particle rigidity.

2. New Observations

[6] In this brief report we present observations of the positron abundance measured by the balloon borne AESOP instrument [*Clem et al.*, 1996] launched 2 June 2006 from Esrange Base, Kiruna, Sweden and safely landed 7 June 2006 on Victoria Island, Canada. The instrument flew on a 40×10^6 ft^3 light balloon that reached an altitude of 138 kft $\sim$ (2.3 mb) as shown in Figure 1. This flight provided the second observation of the positron abundance during a solar minimum A- polarity cycle with energies between 0.6 and 4.5 GeV [*Fanselow et al.*, 1969]. Since the 2006 flight, the Pamela spacecraft has been launched into a polar orbit around the Earth and has provided the 3rd observation [*Adriani et al.*, 2009].

[7] Spectral results from the AESOP flight are shown in Figure 2 (see also Table 1), compared with other data. Table 2 also provides a data compilation of observations from the AESOP flights. As expected, for observations made during an A- epoch, the positron abundance levels remain low but the errors are reduced compared to prior flights occurring during this polarity as a result of the longer flight and lower solar modulation level. The 2006 observations support the results from the 2000 and 2002 flights, which revealed a

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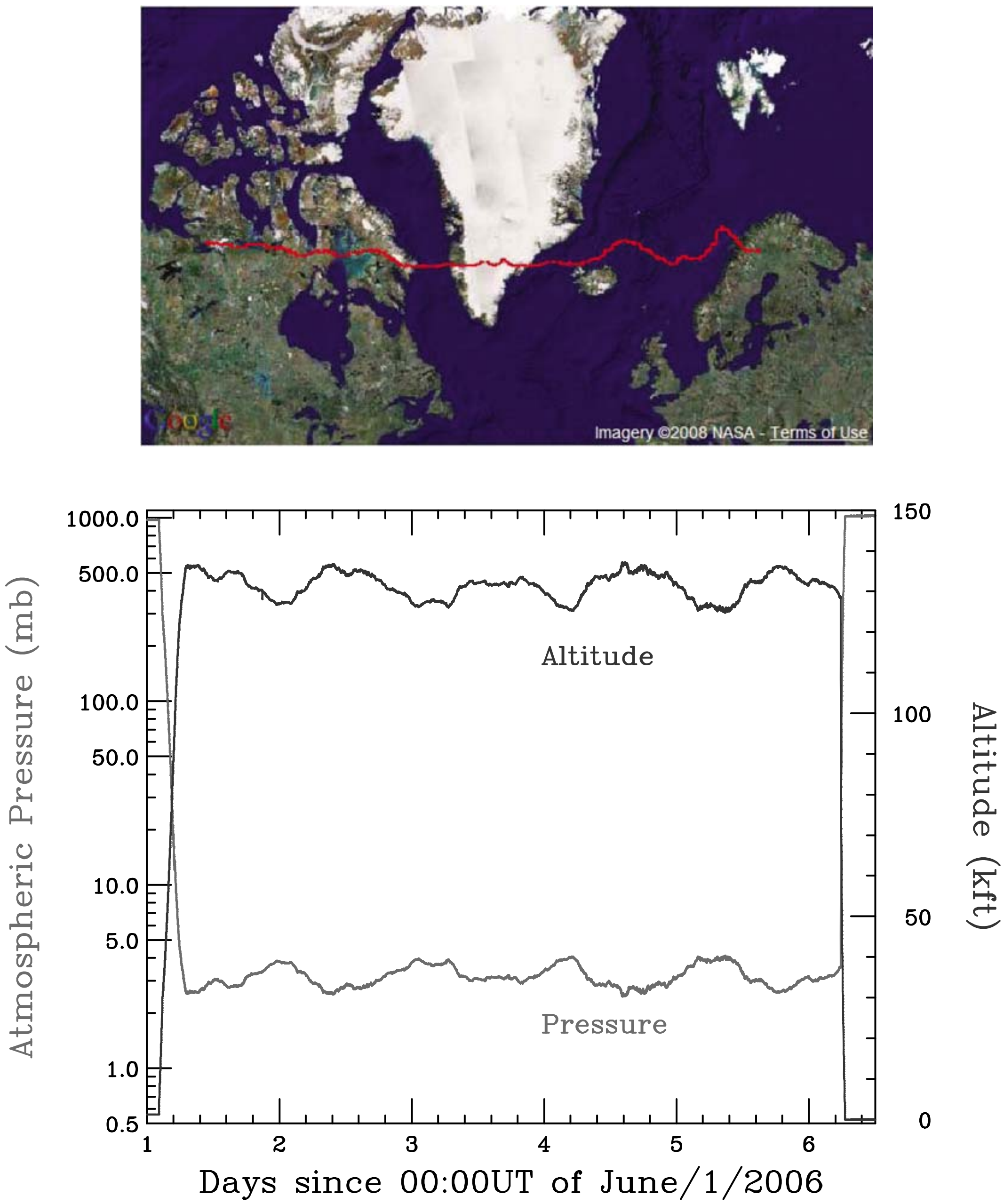

Figure 1. The 2006 AESOP flight path.

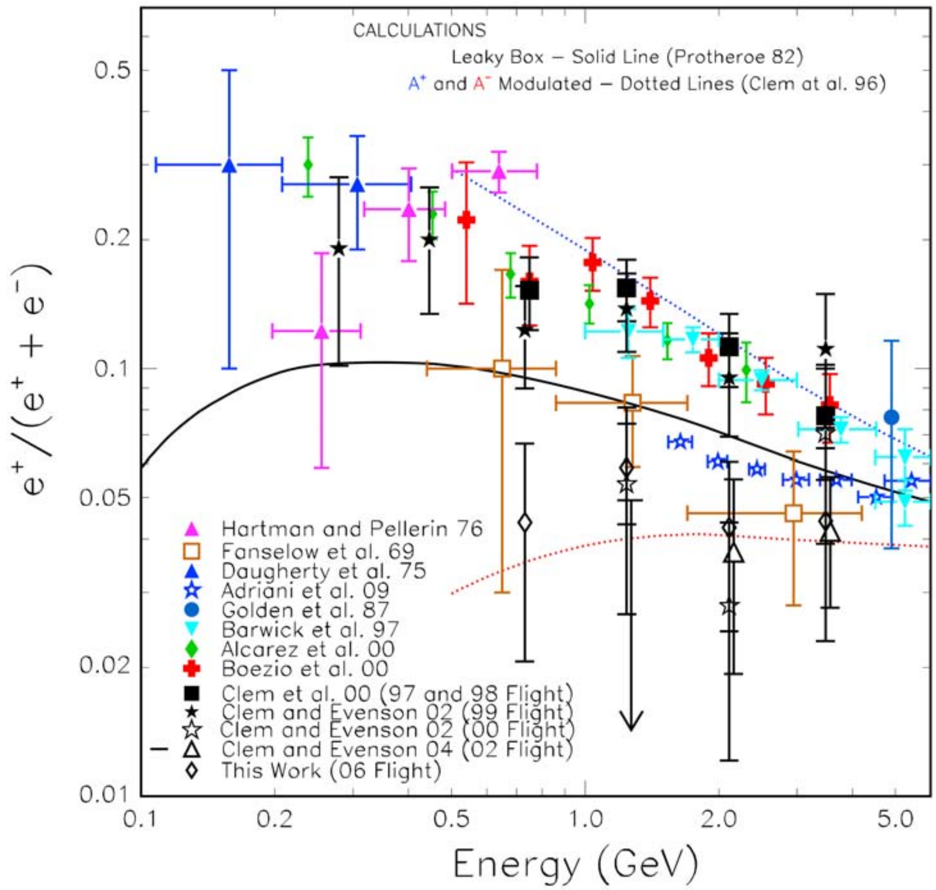

Figure 2. The world summary of the positron abundance and calculations of the positron abundance as a function of energy for different epochs of solar magnetic polarity. Solid line is the modulated (charge sign independent, i.e., no drifts) abundance as calculated by *Protheroe* [1982]. Dashed lines are from *Clem et al.* [1996] for A+ (top line) and A- (bottom line). Solid symbols show data taken in the A+ state, while the open symbols represent data taken in the A- state.

significant decrease in the positron abundance from the previous polarity state. Prior to publication of any observation made in the 1990s, *Clem et al.* [1996] made a specific prediction of the expected positron abundance for both positive and negative polarity states. This model is based on the "leaky box" calculation by *Protheroe* [1982] of the galactic positron abundance. Under the assumption that electrons and positrons behave symmetrically, *Clem et al.* [1996] examined electron fluxes at the same phase of successive solar cycles and then solved for the observed abundance as a function of rigidity in the two polarity states. This prediction is displayed as dashed lines in Figure 2.

[8] In Figure 3 (left), measurements of the cosmic ray positron abundance at ~ 1.25 GV (black symbols) are ordered in chronological order. This plot clearly reveals the significant decrease between 1999 and 2000 from the level that remained relatively constant throughout the prior magnetic polarity (1990s). Within measurement errors the abundance has remained constant since. The results at 1.25 GV suggest the predicted magnitude of the change may be somewhat too large as the high statistical precision of the new measurement may indicate a discrepancy. The Pamela observation at higher energies supports this as well [*Adriani et al.*, 2009]. An analysis to understand this difference is currently ongoing. The goal is to develop a new physics-based prediction that incorporates simultaneously a 3D solar modulation drift model and an updated local interstellar spectrum model that together better quantifies the relationship of fundamental parameters used to predict observables such as the positron abundance and antiproton/proton ratio

Table 1. Explanation of References for Figure 2

Reference	Platform Type and Observation Period
Adriani et al. [2009]	spacecraft: July 2006 to February 2008
Fanselow et al. [1969]	balloon: five 1-day-duration flights 5 July, 5 August 1965; 10, 15, 26 June 1966
Daugherty et al. [1975]	balloon: two 1-day flights, July 1972
Hartman and Pellerin [1976]	balloon: two 1-day flights, 15 July, 3 August 1974
Golden et al. [1987]	balloon: 20 May 1976
Barwick et al. [1997]	balloon: 23–24 August 1995
Alcaraz et al. [2000]	spacecraft: 2–12 June 1998
Boezio et al. [2000]	balloon: 8–9 August 1994
Clem et al. [2000]	balloon: 1 September 1997 and 29 August 1998
Clem and Evenson [2002]	balloon: 16 August 1999
Clem and Evenson [2002]	balloon: 25 August 2000
Clem and Evenson [2004]	balloon: 13–14 August 2002
This work	balloon: 2–6 June 2006

Table 2. Compiled Observations of the AESOP Flights

Energy (GeV)	$e^+/(e^+ + e^-)$	Error
	1997 and 1998 AESOP Flights	
0.749275	1.525E-01	2.96E-02
1.24E+00	1.543E-01	2.54E-02
2.11E+00	1.124E-01	2.19E-02
3.48E+00	0.775E-01	2.24E-02
	1999 AESOP Flight	
2.79E-01	1.91E-01	8.95E-02
4.46E-01	2.00E-01	6.56E-02
7.31E-01	1.23E-01	3.31E-02
1.24E+00	1.38E-01	2.87E-02
2.11E+00	9.51E-02	2.59E-02
3.48E+00	1.11E-01	3.84E-02
	2000 AESOP Flight	
1.24E+00	5.39E-02	2.72E-02
2.11E+00	2.79E-02	1.58E-02
3.48E+00	7.05E-02	3.15E-02
	2002 AESOP Flight	
1.24E+00	4.93E-02	upper limit
2.11E+00	3.73E-02	1.80E-02
3.48E+00	4.17E-02	1.42E-02
	2006 AESOP Flight	
7.31E-01	4.37E-02	2.30E-02
1.24E+00	5.88E-02	1.55E-02
2.11E+00	4.25E-02	1.82E-02
3.48E+00	4.41E-02	2.10E-02

as a function of time [*Burger et al.*, 2009; *Pei et al.*, 2009; *Yüksel et al.*, 2009]. Preliminary results are very promising, however more development is needed before it will be released as a model for general publication.

[9] As shown in Figure 3 (right), the inverse effect is revealed in the antiproton/proton ratios at 1.3 GV (red circle symbols) measured by the BESS instrument. The structure in the antiproton/proton ratio model is significantly different from that of the positron abundance. This effect is primarily caused by the spectral differences of antiprotons and protons in the local interstellar medium resulting in a strong rigidity dependence in the ratio [*Bieber et al.*, 1999]. Therefore, the antiproton/proton ratio spectrum observed at Earth modulates (due to adiabatic deceleration) much more than the positron abundance even though drift effects should be identical.

3. Summary

[10] The cosmic ray positron abundance spectrum was measured on a 5-day balloon flight, launch from Kiruna, Sweden on 2 June. These observations confirm results from the 2000 and 2002 flights, which revealed a significant decrease in the positron abundance at the time of the solar polarity reversal. The high statistical precision of the 2006 flight results at 1.25 GV suggest the predicted magnitude of the decrease in the *Clem et al.* [1996] model may be somewhat too large. An ongoing effort to analyze this difference will hopefully provide an improved description of charge sign dependence in modulation [*Burger et al.*, 2009; *Pei et al.*, 2009; *Yüksel et al.*, 2009].

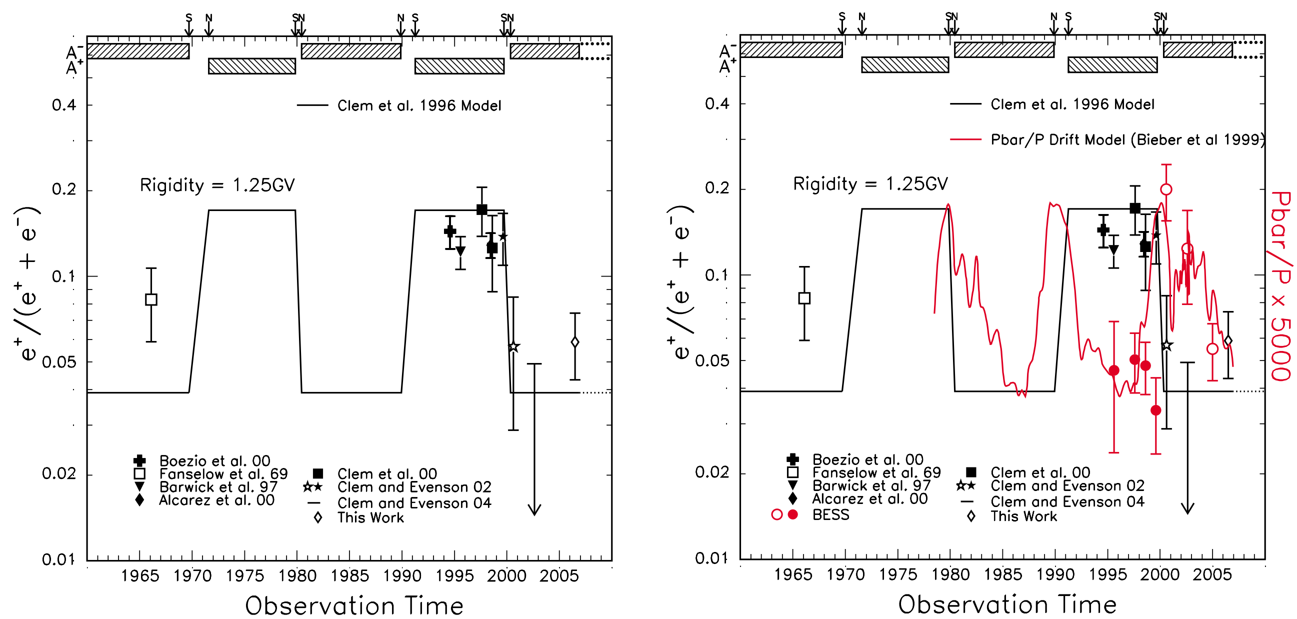

Figure 3. Figure 3 (left) displays the time profile of the positron abundance observations with rigidities near 1.25 GV. Solid symbols show data taken in the A+ state, while the open symbols represent data taken in the A- state. Shaded rectangles represent periods of well-defined magnetic polarity. The black line is a positron abundance prediction based on the analysis of *Clem et al.* [1996]. Figure 3 (right) is the same as Figure 3 (left) with the antiproton ratio superimposed (red) at a rigidity of roughly 1.3 GV. The red line is an antiproton/proton ratio drift (steady state) model [*Bieber et al.*, 1999] interpolated to 1.3 GV. The current sheet tilt angles used in the drift model were acquired from the Wilcox Solar Observatory database. Dashed lines represent the predicted results for future observations. The antiproton ratios were measured by the series of BESS flights [*Asaoka et al.*, 2002; *Mitchell et al.*, 2007].

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