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# Cosmic Ray Positron Fraction Observations During the A- Magnetic Solar Minimum

JOHN CLEM AND PAUL EVENSON
*Bartol Research Institute, Department of Physics and Astronomy, University of Delaware, Newark, DE, USA 19711*
*clem@bartol.udel.edu*

**Abstract:** As part of our on-going investigation of the charge-sign dependence in solar modulation, we measured the cosmic ray positron abundance (~1GeV) on a long duration balloon flight from Kiruna, Sweden to Victoria Island, Canada during June 2006. Preliminary results from this flight are compared to previous results.

## Introduction

The anti-correlation 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. 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 that is not symmetric under reflection. The Parker field has opposite magnetic polarity above and below the helio-equator, but the spiral field lines themselves are mirror images of each other. This antisymmetry 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 [1]. Negatively charged particles behave in the opposite manner, and the drift patterns interchange when the solar polarity reverses.

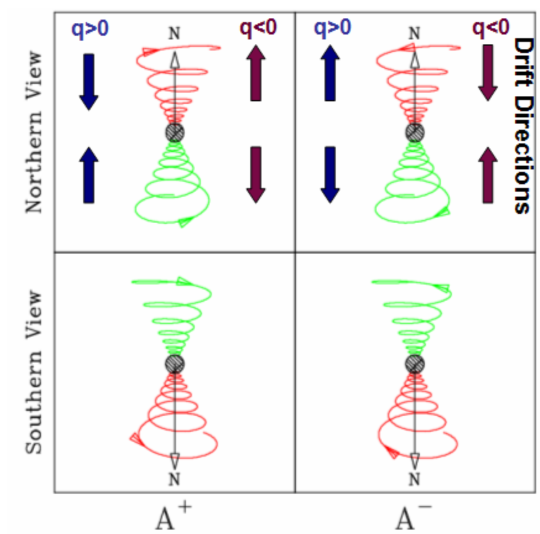

Figure 1: Illustration of field reversal geometry.

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 lack of reflection symmetry in solar wind magnetic fields. 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 on-going study of the behavior of cosmic ray positrons, relative to negative electrons (which have an identical relationship between velocity and rigidity) will allow a definitive separation of effects due to charge sign from effects arising in velocity differences (for the same rigidity).

## New Observations

In this report we present new observations of the positron abundance measured by the balloon borne AESOP instrument [2,3] launched 2-June-2006 from Esrange Base, Kiruna, Sweden and brought down 7-June-2006 on Victoria Island, Canada. The instrument flew on a $40x10^6$ cft light balloon that reached an altitude of 138kft~ (2.3mb) as shown in Figure 2. This flight provided the second observation of the positron abundance during a solar minimum A+ polarity cycle with energies between 0.6-4.5GeV [4].

The preliminary results from the flight are shown in Figure 3. As expected for observations 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 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) [2] 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 [5] of the galactic positron abundance. Under the assumption that electrons and positrons behave symmetrically, Clem et al. [2] 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 both Figures 3 and 4.

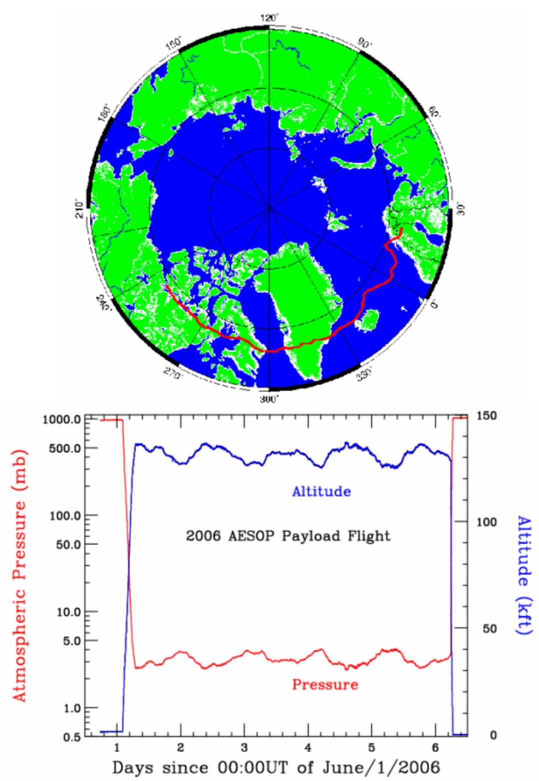


Figure 2: AESOP 2006 flight trajectory.

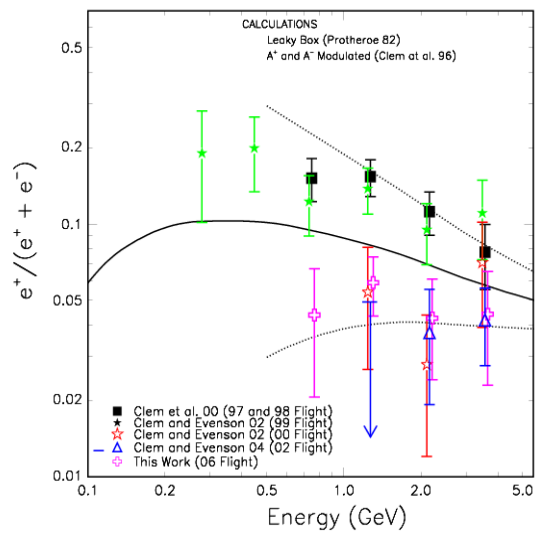


Figure 3: Compiled AESOP balloon instrument measurements [3,6,7] and calculations of the positron abundance as a function of energy for different epochs of solar magnetic polarity. Solid line is the modulated (charge sign independent, i.e. no drifts) abundance as calculated by Protheroe [5]). Dashed lines are from Clem et al. [2] 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.

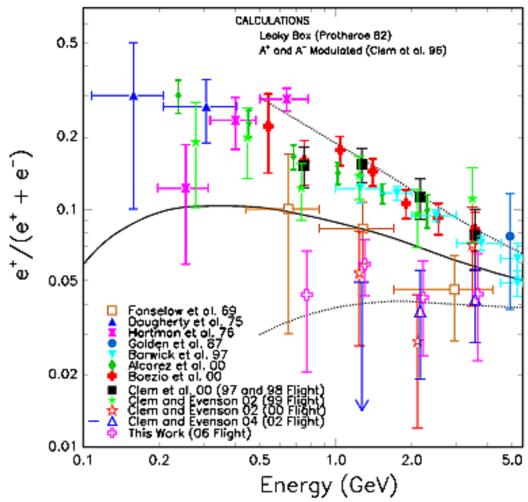


Figure 4: The world summary of the positron abundance [references indices corresponding to the list in descending order: 4,8-13,3,6,7].

As shown in Figure 5, measurements of the cosmic-ray positron abundance at ~ 1.25GV (black symbols) are ordered in chronological order. This plot clearly illustrates 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 1.25GV 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. An analysis to understand this difference is currently ongoing. We are also in the process of developing an electron/positron modulation drift model, which will likely be helpful in this investigation.

As expected, the inverse effect is revealed in the antiproton/proton ratios at 1.3GV (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 anti-protons and protons in the local interstellar-medium resulting in a strong rigidity dependence in the ratio. Therefore, the antiproton/proton ratio spectrum observed at Earth modulates (due to adiabatic deacceleration)

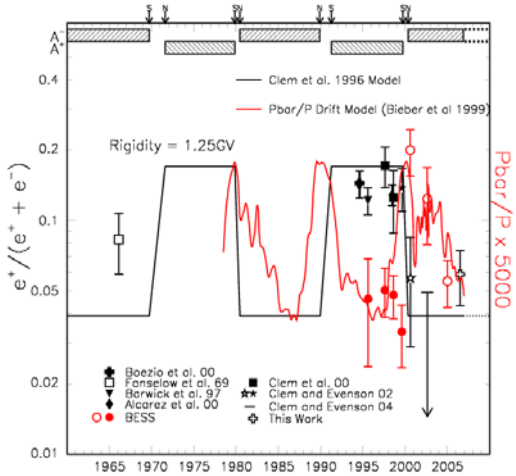


Figure 5: Time profile of positron abundance (black) and anti-proton ratio (red) at a rigidity of roughly 1.3GV. Solid symbols show data taken in the A+ state, while the open symbols represent data taken in the A- state. Shaded rectangles represent periods of well-defined magnetic polarity. The black line is a positron abundance prediction based on the analysis of Clem et al. [2]. The red line is an antiproton/proton ratio drift (steady-state) model [14] interpolated to 1.3GV. 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 anti-proton ratios were measured by the series of BESS flights [15,16]. A separate paper describing the 2004-05 BESS flight final results was also presented during this conference [16].

much more than the positron abundance even though drift effects should be identical.

## Summary

The cosmic ray positron abundance spectrum was measured on a five-day balloon flight launch from Kiruna, Sweden on June 2. The positron abundance 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 1.25GV suggest the predicted magnitude of Clem et al. [2] model may be somewhat too large. An ongoing effort to analyze this difference will hopefully provide an improve description of charge sign dependence in modulation.

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