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The ATIC experiment: first balloon flight

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Abstract. The Advanced Thin Ionization Calorimeter (ATIC) Balloon Experiment had its maiden, test, flight from McMurdo, Antarctica 28/12/00 to 13/01/01, local time, recording over 360 hours of data. ATIC was designed to measure the composition and energy spectra of cosmic rays from ~10 GeV to near 100 TeV utilizing a Si-matrix detector to determine charge in conjunction with a scintillator hodoscope which measures charge and trajectory. Cosmic rays that interact in a Carbon target have their energy determined from the shower that develops within a fully active calorimeter composed of a stack of scintillating BGO crystals. ATIC's geometry factor is about 0.25 m^2-sr. During line-of-sight operations much of the datastream was transmitted to the ground. For most of the flight, the data was recorded on-board, yielding 45 GB of flight data for analysis. The payload construction, operations and in-flight performance are described, along with preliminary results from the on-going analysis.

1 Introduction

The Advanced Thin Ionization Calorimeter (ATIC) Balloon Experiment is a new instrument designed to investigate the charge and energy spectrum of galactic cosmic rays (GCR) at very high energy, from 10's of GeV to near 100 TeV total energy. This is an energy region in which previous and current data are in some disagreement both at the low energy end, where magnetic spectrometers have been measuring spectra, and at the highest energies. For example, at high energy JACEE (Asakimori et al., 1998) has reported a difference in the spectral indices for Hydrogen and Helium, but RUNJOB (Apanasenko et al., 1999) does not see such a difference. The detailed energy dependence of the elemental spectra, measured to as high an energy as possible, holds the "key" to understanding the acceleration (and galactic propagation) for the bulk of the cosmic rays, at energies below the knee in the all-particle spectrum (Erlykin and Wolfendale, 1997).

The highest energy achievable in a balloon or space experiment is determined by exposure. Hence, ATIC was designed for a series of Long Duration Balloon (LDB) flights from, principally, McMurdo, Antarctica. A balloon launched during the astral summer from McMurdo travels in the polar wind vortex which carries it around the continent, back to near the launch site, in 10-15 days, providing a long exposure. In mid-2000, the ATIC team was offered a chance to perform their first "test" flight from McMurdo in late 2000/early 2001. After a successful pre-deployment integration and Mission Readiness Review at the National Scientific Balloon Facility (NSBF) in Palestine, Texas, ATIC was shipped by sea to New Zealand and airlifted on to McMurdo. The ATIC team assembled and tested the payload at Williams Field, and it was launched on 28 Dec. 2001 for a highly successful flight.

The ATIC team is an international collaboration of researchers from the USA, Russia, Korea and Germany who have each contributed to the success of the ATIC program and are currently involved in the detailed analysis of the ATIC flight and calibration data. This paper presents an overview of the ATIC experiment and the first balloon flight. Preliminary results from the first-order analyses of the data are presented in other ATIC papers elsewhere in these proceedings. By the time of the conference we hope to have extended the preliminary analysis presented here.

2 The ATIC Payload

The balloon payload, shown in flight ready configuration in Fig. 1, is built around the instrument which is mounted within a Kevlar pressure shell covered with thermal insulation. This sphere is contained within an aluminum framework that is attached, at the top, to an orientor/rotator which keeps the payload aligned such that the solar panel "wings" are in constant sunlight. Below the sphere is a deck to hold the battery, charge controller and gas supply.

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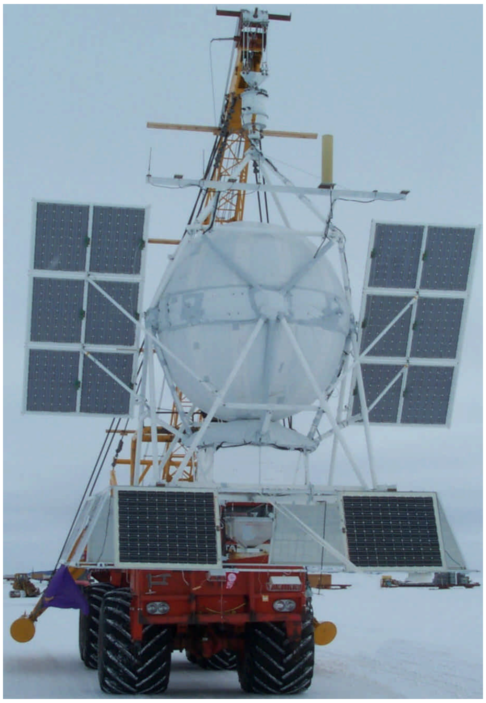

Fig. 1. ATIC ready for launch.

To this is mounted the NSBF Support Instrumentation Package (SIP) and ballast hopper. Surrounding the payload at the bottom are a set of NSBF solar arrays which provide assured power to the flight control systems. The satellite antennas are mounted on a boom near the top of the gondola structure. At liftoff the ATIC payload weighed about 1500 kg and consumed ~310 watts of power.

The ATIC instrument (Guzik et al., 1999) combines three types of detectors to measure the charge, energy and trajectory of incident cosmic rays. The energy is determined by ionization calorimetry in a thin calorimeter composed of Bismuth Germanate (BGO) scintillating crystals. Shown schematically in Fig. 2, ATIC incorporates, from the top: (1) a pixilated Si-matrix detector (4480 pixels each ~2 cm x 1.5 cm read by the CR-1 ASIC with a 16 bit ADC) to measure particle charge (Adams et al., 1999); (2) a three layer scintillator hodoscope (2 cm x 1 cm strips, x and y, viewed both ends by R5611 phtomultiplier tubes and read by the ACE ASIC in two gain ranges) to determine trajectory, charge and provide a first level trigger; (3) an inert carbon target (T2 – T4) in which the cosmic ray particle interacts and initiates a cascade; and (4) the BGO calorimeter, eight layers each of 40 crystals of dimensions 2.5 cm x 2.5 cm x 25 cm, alternating in the x and y directions, with each crystal read by an R5611 tube into an ACE ASIC in three gain ranges. Over 6200 channels of pulse height information are returned for each event, sparsified and recorded on-board on a hard disk. The event trigger is S1-S3-BGO and corresponds to geometry factors (m^2-sr) of 0.42 for S1-S3, 0.24 for S1-S3-BGO6 and 0.21 for S1-S3-BGO8. The detailed design and expected performance of ATIC have been described previously (Guzik et al., 1996; Seo et al., 1996; 1997).

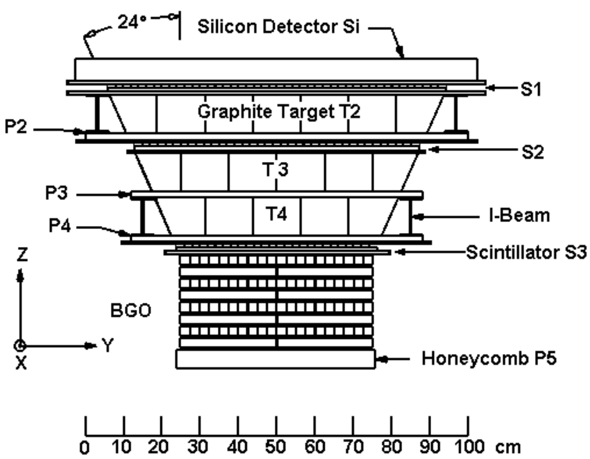

Fig. 2. ATIC Instrument Schematic Diagram

3 Long Duration Balloon Flight

After several frustrations due to inclement weather conditions at McMurdo, ATIC was successfully launched on 28 December 2000 at 4:25 UT. The ascent to 38 km was normal, and the gas relief valve was closed by command to stabilize the internal pressure in the gondola at just over 0.5 atm. The balloon remained in line-of-sight for nearly a day, during which much of the data was transmitted to the ground, and thresholds were adjusted by command. Nominal data collection began on 29 Dec. at 3:54 UT and continued until 12 Jan. 2001 at 20:33 UT. During this period all data was recorded on board. In addition, health and status information was transmitted hourly through the TDRSS system.

Figure 3 shows the ATIC flight trajectory. After launch

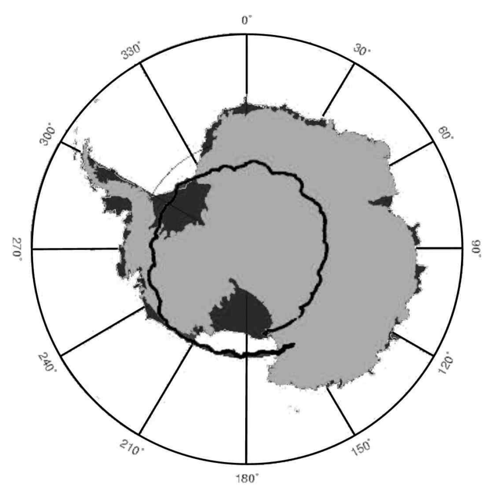

Fig. 3. The ATIC flight trajectory

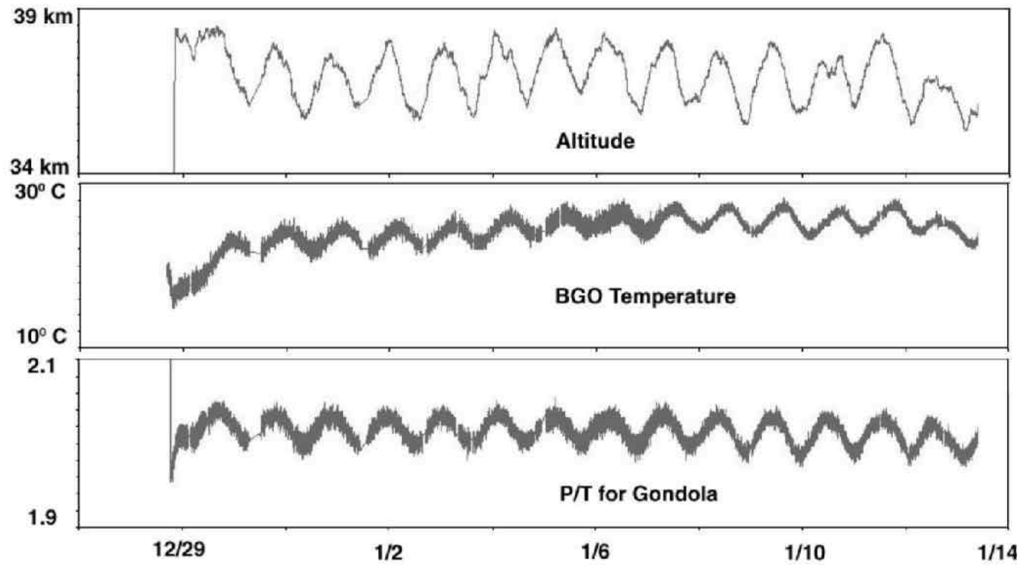

Fig. 4. Payload performance during flight.

the balloon spiraled outward by about 3 degrees in latitude and was successfully terminated on 13 Jan. at 3:56 UT, landing upright just over the Trans-Antarctic mountain range on the mid-level plateau. Instrument recovery required two Twin-Otter airplane flights on 23 Jan. and 25 Jan. respectively. ATIC had to be fully dis-assembled "on-the-ice" to recover all critical components.

The ATIC dataset currently being analyzed consumed 43.5 Gbytes of the 50 Gbyte flight disk and contains 26.1 million cosmic ray triggers, 1.3 million calibration records, 0.75 million housekeeping records plus rate and command records. Figure 4 shows representative parameters from the ~15 day flight. The altitude remained steady at 37±1.5 km showing the expected daily variation with sun angle. The internal temperature shows similar daily variations and remained relatively constant, 22-28 °C, over the flight. The lower curve in Fig. 4 displays the Pressure/Temperature ratio for the gondola and indicates a constant mean value, i.e. the gondola shell did not leak for the entire two-week flight.

4 Preliminary Results

Prior to the McMurdo flight, ATIC was exposed to high energy proton and electron beams at the CERN SPS, as well as calibrated with cosmic ray muons. The CERN dataset verified the ATIC concept, providing data in agreement with simulations (Ganel et al., 2001), and allowing the development of the ATIC Data Processing System (ADPS) which formed part of the ATIC monitoring capability during the flight and was utilized subsequently for the preliminary analysis that has been performed (Ganel et al., 1999; Ahn et al., 2001).

Figure 5 shows the all-particle spectrum obtained by ATIC in terms of the energy deposited in the calorimeter (typically ~35% of the incident energy). During the flight, data were collected in several modes ranging from S1-S3 (i.e. no BGO requirement) to S1-S3-BGO with varying thresholds on the BGO. The events at the left of Fig. 5 represent particles that missed, or exited the sides of, the calorimeter or did not interact before penetrating the instrument. These events will provide an in-flight calibration sample to be utilized along with the in-flight electronic calibrations to assess time or temperature dependent response corrections and to refine the absolute energy calibration, currently based on pre-flight muon events.

The shape of the central region of Fig. 5, around the peak, is determined by the different thresholds used during the flight. Initially the BGO threshold was set low in order to collect events in the 10's of GeV energy range. In order to avoid filling the flight disk, this threshold was raised (twice) as the flight extended longer than anticipated. Events in this central region must be corrected for the energy threshold efficiencies.

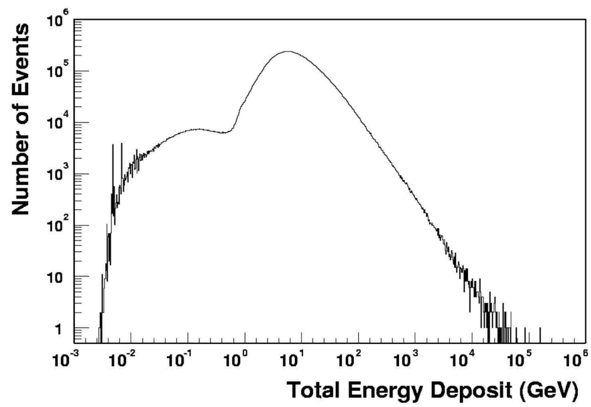

Fig. 5. All-particle spectrum in deposited energy.

The right side of the figure shows events that were collected under all thresholds, and these must be corrected for overall efficiencies. These events follow a power law which is consistent with a differential spectrum with index of –2.7. This provides confidence that ATIC operated correctly through the flight. Determining the actual spectral index, however, requires deconvolving the measured spectrum utilizing the resolution function and the energy dependence of the response along with all efficiency corrections. Obtaining such results is the overall goal of the ATIC analysis.

Figure 6 shows a cross plot, for an uncut, uncorrected, sample of the data, of the charge determined from the Si-matrix versus the charge determined from the S1 scintillator

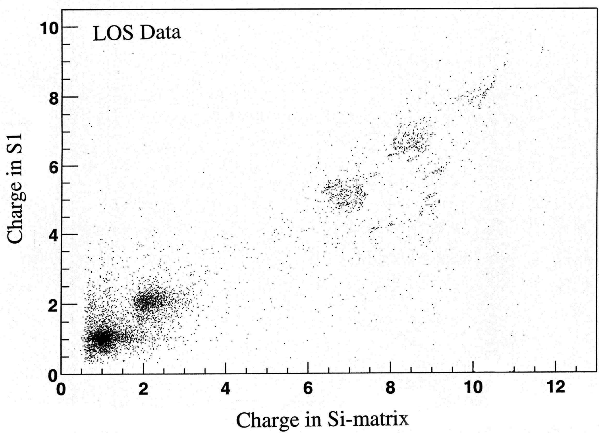

Fig. 6. Charge from Si-matrix versus charge from Scintillator S1.

strips. Even before correcting for the angle of incidence, separate charge islands can be seen for the Hydrogen and Helium nuclei. Heavier nuclei are present, and, with a larger dataset, Carbon, Oxygen and other peaks can be observed (see other ATIC papers in these proceedings). While much work remains to refine the charge determination algorithm, these preliminary results provide confidence that ATIC will be able to study individual elements in this high energy regime.

5 Summary

The ATIC balloon experiment had a very successful LDB flight from McMurdo, Antarctica in 12/00 – 1/01. The instrument performed well for the entire 15 days. Preliminary data analysis shows acceptable charge resolution and an all-particle power law energy deposition distribution consistent with previous measurements. Detailed analysis is underway and will result in new data on the cosmic ray charge and energy spectra in the GeV-TeV energy range. ATIC is currently being refurbished in anticipation of another LDB flight in the 2002-03 period.

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