

The Advanced Thin Ionization Calorimeter (ATIC) for Studies of High Energy Cosmic Rays

The ATIC Collaboration¹

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Abstract

During 2000, the ATIC experiment will begin a series of long duration balloon flights that will investigate the charge composition and energy spectra of primary cosmic rays over the energy range from <50 GeV to >100 TeV. Here we describe ATIC and discuss the status of the experiment development.

1 Introduction:

Cosmic rays are the only sample of matter from distant regions of the galaxy, and possibly elsewhere in the Universe, that can be directly observed by space experiments in the Solar System. Understanding cosmic ray origin and acceleration, and how they propagate, is a fundamental problem which has a major impact on our understanding of the universe. All cosmic ray species have similar energy spectra; power-laws beyond ~ 10 GeV/nucleon where the effects of heliospheric modulation become small. Power-laws describe the spectra over an enormous energy range, to $>10^{14}$ eV. All-particle measurements (where the charge is not distinguished), principally from ground-based air shower arrays, have traced the spectrum to the highest energies, $\sim 10^{20}$ eV. From these measurements, it has been known for some time that the spectrum is somewhat steeper above 10^{16} eV than it is below 10^{14} eV. How this structure, the 'knee', is related to the mechanisms of acceleration, propagation, and confinement is one of the major questions in particle astrophysics.

The ATIC balloon flight program will concentrate on measuring the cosmic ray proton and helium spectra from below 5×10^{10} eV to more than 10^{14} eV, with statistical accuracy better than 30% at the highest energy (Guzik et al., 1996). This unique coverage, more than three decades in energy with a single instrument, will enable us to investigate the spectral difference between hydrogen and helium, and identify any spectral breaks over a broad energy range. In addition, ATIC will fill an existing gap in measurements of the proton/alpha ratio between observations below 100 GeV and the highest emulsion chamber energies. Concurrently, ATIC will measure the spectra of nuclei up to iron, with individual element resolution and superior energy resolution.

In this paper, we discuss the experimental details of the ATIC balloon payload and the current operation plans. Companion papers at this conference provide further information on the ATIC silicon matrix detector and readout (Adams et al., 1999a,b), the data processing and event reconstruction (Ganel et al., 1999), and the simulated response of ATIC to gamma rays (Chang et al., 1999), electrons (Schmidt et al., 1999) and heavy ion interactions (Kwon et al., 1999).

2 The Experiment Configuration and Development:

To achieve its scientific objectives, the ATIC experiment must be capable of measuring the incident cosmic ray charge and energy over an energy range of 50 GeV to >100 TeV. A schematic of the instru-

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ment, with pressure vessel removed, is shown in Figure 1. This instrument is based on the technique of ionization calorimetry, the most practical method of energy determination for cosmic ray nuclei from H to Fe over the target energy range. The fully active ATIC calorimeter is composed of 10 layers of Bismuth Germanate (BGO) scintillating crystals and is located on the bottom of the instrument. In Figure 1 only one BGO layer (in purple) is shown to clarify the structure. Above the calorimeter is the target section consisting of three plastic scintillator strip hodoscopes (blue-green) to define the instrument aperture and provide redundant charge and trajectory measurements, as well as layers of inert carbon (between hodoscopes) to provide a volume for the incident particles to interact. On the top of the detector stack is the highly segmented silicon matrix detector (red) that provides an accurate measure of the incident particle charge even in the presence of shower particles backscattered from the calorimeter.

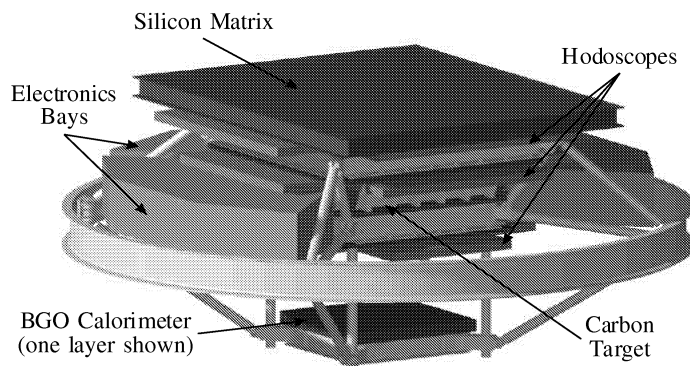


Figure 1: The ATIC instrument

Surrounding the detector stack, electronics bays hold the flight computers, readout electronics, power system boards and other instrument electronics. Finally, on each of the four corners three struts transfer the loads of the experiment through the pressure vessel ring to an external structure (see Figure 6) that attaches to the balloon. All components of the experiment were designed with Antarctica long duration balloon flight weight, power and recovery constraints in mind. The total estimated weight of ATIC is about 1,300 kg, the total power consumed is less than 550 Watts (including power conversion efficiency), and the payload is designed to be quickly field stripped under Antarctic conditions. The geometrical factor of ATIC varies from $0.45 \text{ m}^2 \text{ sr}$ (calorimeter top) to $0.24 \text{ m}^2 \text{ sr}$ (calorimeter bottom).

2.1 The BGO Calorimeter: In an ionization calorimeter, a particle's energy is deposited in an absorber via a cascade of nuclear and electromagnetic interactions. At each step, the energy of the primary particle is subdivided among many secondary particles. Ultimately, the primary energy is dissipated via ionization and excitation of the material. The integral of the deposited energy over the depth in the absorber is a measure of the energy of the incident hadron. In ATIC, the calorimeter is composed of a stack of 10 trays with forty 2.5 cm by 2.5 cm by 25 cm BGO crystals in each tray. Thus, the calorimeter is about 22 radiation lengths (~ 1.14 nuclear interaction lengths). One such tray, half filled with crystals, is shown in Figure 2. Each crystal is viewed, through an air gap, by a single Hamamatsu R5611 photomultiplier tube (PMT). The PMT bleeder string base incorporates a three dynode pickoff to cover a dynamic range of crystal energy deposits

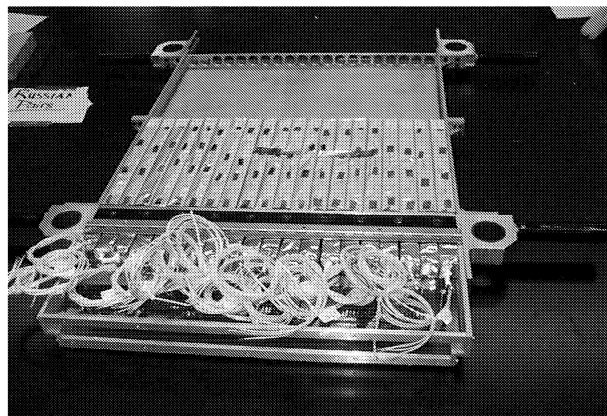


Figure 2: BGO tray with crystals

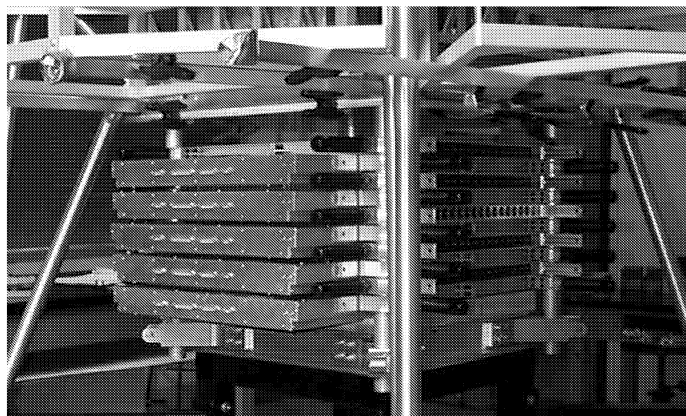


Figure 3: The calorimeter tray stack

from about 10 MeV ($\sim 1/2$ mip) to about 20 TeV and is designed for low power consumption. The dynode signals are wired to a Front End Module (FEM) board that contains six application specific integrated circuits (ASIC) based on the design used for the ACE mission. Each ASIC has 16 input channels and outputs two “trigger” signals as well as 12 bit digitized pulse heights. LEDs are incorporated into the front end electronics so each PMT can be checked for liveness and stability. The PMTs, with their brass foil shielding, wiring and part of the FEM can be seen in the bottom part of Figure 2.

As each tray is filled with crystals they are stacked as shown in Figure 3. Each layer is rotated by 90 degrees to provide an X-Y coordinate for determining the shower core trajectory, using the techniques described in Ganel et al., 1999. The black vinyl coated handles in Figure 3 are used in tray handling (each tray weighs close to 50 kg) and the PMT / FEM boxes that can easily be mounted / dismantled on the tray ends. Cabling from the connectors on the FEM boxes run to the bottom of the electronics bays where the remainder of the readout electronics is mounted. The readout of the ASICs on multiple FEM boards is controlled by an ASIC Control Logic Board (ACLB) which, in turn, passes the data to the Detector Interface Module (DIM) that is part of the Detector Control Unit (DCU) computer.

2.2 The Target Section and Hodoscopes: The target section above the calorimeter has about $3/4$ of a nuclear interaction length of material including three 10 cm thick layers of carbon, but only a few radiation lengths, to increase the probability that the incident particle interacts while minimizing the development of the electromagnetic cascade. Further, the target section includes three plastic scintillator strip hodoscopes to provide the experiment with a fast trigger that defines the aperture, and auxiliary measurements of the incident particle charge and trajectory.

The three hodoscopes (S1, S2 and S3) are of similar construction and are composed of Bicon BC-408 plastic scintillator strips 2 cm wide by 1 cm thick as shown in Figure 4. To maintain a $\sim 24^\circ$ opening angle each hodoscope has a different active area. For S1 there are 42 strips of length 88.2 cm in each layer, while 35 strips of length 74.2 cm comprise each S2 layer and 24 strips 52.4 cm long make up S3. Each hodoscope module has two layers oriented by 90° to provide a X-Y measure of the particle “hit” position. The strips are wrapped in aluminized mylar and on each end is glued a UVT Lucite transition and a Hamamatsu R5611 PMT. The scintillator strip readout and PMT bleeder base utilizes two dynode pickoffs to cover the required dynamic range (~ 0.5 MeV to 800 MeV). The PMT anode is used to provide a fast “pre-trigger” signal, and a test LED is incorporated directly into the PMT base. These signals are wired directly to the FEM mounted on the hodoscope honeycomb support structure as shown in Figure 4. The hodoscope FEMs are almost identical to the calorimeter FEMs and also use the ACE ASIC. Further, the ACLB and DIM boards that complete the hodoscope readout interface with the DCU are identical to those used for the calorimeter and are also mounted in the electronics bays.



Figure 4: Bottom half of the S2 Hodoscope

2.3 The Silicon Matrix: This detector is a mosaic of fully depleted silicon detectors that cover the aperture of the ATIC instrument and is used to make an accurate charge identification of the incident cosmic ray from H to Fe, in the presence of “backscatter” background. The ATIC matrix is based upon a similar design built for the ZEUS experiment at DESY. Fifty six silicon diode strips, further subdivided into four ~ 2 cm by 1.5 cm pads, are arranged on two motherboard assemblies, one above the other, to form a ladder. The strips on the top half are offset to cover the gaps between strips on the bottom half. Twenty such ladders are then arranged to cover an active area of about 1 m by 1 m. The full detector includes 4,480 independent pads that are read out by an ASIC designed for this application; the CR-1. The remainder of the

detector readout is similar to that used for the calorimeter and hodoscopes. Details on the silicon matrix detector and the CR-1 ASIC can be found elsewhere at this conference (Adams Jr. et al., 1999a,b)

2.4 The Flight Data System: This system controls the experiment during flight operations including receiving and processing uplinked commands, acquiring and archiving the instrument data on-board, as well as downlinking status information and a small sample of event data. The system is modular, with each module assigned a particular control operation such as power, data archive, housekeeping, telemetry, detector and flight control. Each module stack is built from available PC/104 "Intel class" CPU, I/O, and peripheral control cards. All modules run the QNX real-time operating system. Flight software processes on different modules communicate across an internal payload ethernet. All data is archived on a 50 Gigabyte SCSI hard disk, and a second identical disk serves as a backup. During flight the data rate will be limited to <50 Hz, which given our estimated event record size, will result in a ~50 Gbyte dataset for one 10 day flight. A small portion of this data may also be downlinked at a rate of about 4 kbps whenever a TDRSS link is available. Other details on ground data processing and event reconstruction can be found in Ganel et al., 1999.

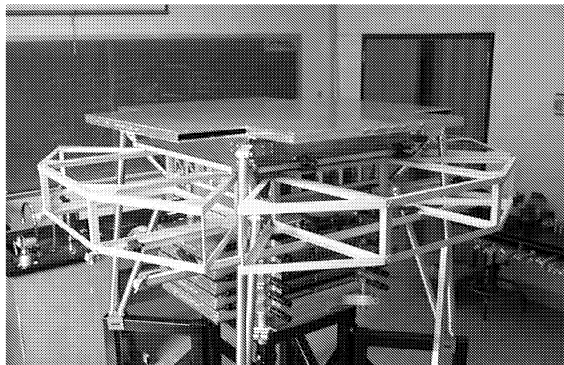


Figure 5: ATIC mechanical structure

3 Operation Plans:

During April, 1999 the ATIC experiment integration began and Figure 5 shows the initial test fit of the mechanical support structure including the calorimeter on the bottom, the S1 hodoscope on the top and the electronics bay framing surrounding the target section. During May and June the calorimeter trays and hodoscope were tested with the flight electronics and in July the silicon matrix was integrated. Currently, the experiment is at CERN where it is being prepared for a series of tests with a ~350 GeV proton beam during early September. During these tests we will verify the correct operation of the instrument and obtain data on its performance. The experiment will be returned to LSU by the beginning of October when it will be prepared for its first flight from Ft. Sumner during Spring, 2000. Following this flight we will configure ATIC for LDB operations including the photovoltaic power system as shown in Figure 6. Pre-deployment integration with the NSBF will take place during summer, 2000 at Palestine, Texas. The first flight from McMurdo, Antarctica is scheduled for December, 2000 and three additional LDB flights are anticipated.

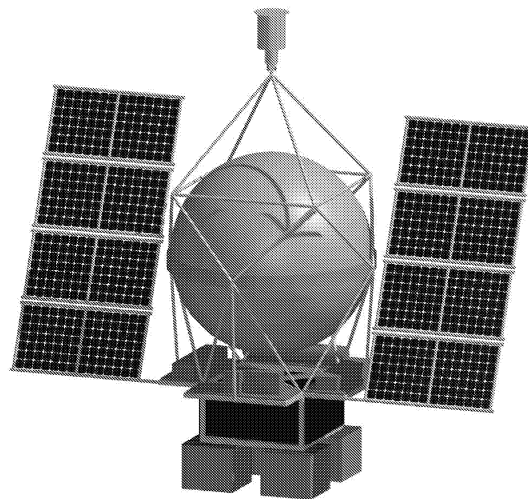


Figure 6: ATIC in flight configuration

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