Cosmic Rays and the need for heavy payloads

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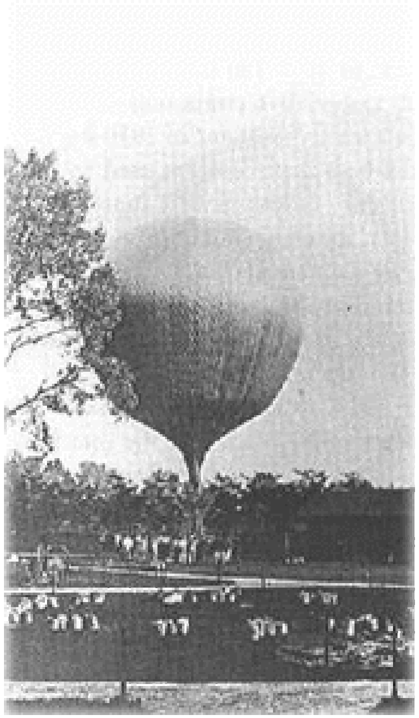
Ballooning leads the advance in Astrophysics

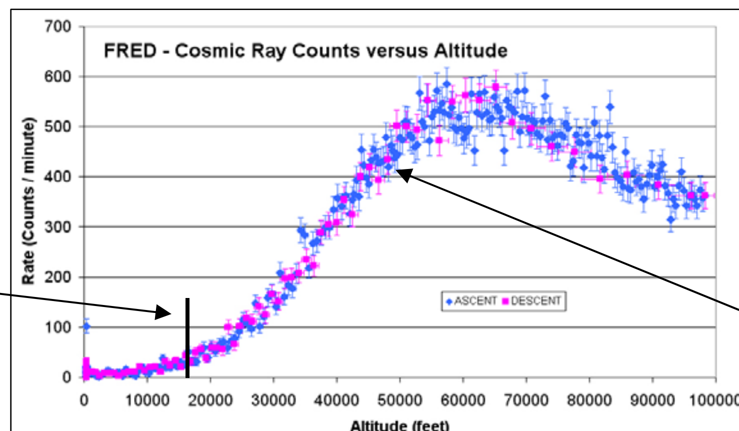
- Most fields of astrophysics (e.g. infrared, x-ray, gamma-ray) have completed their initial exploration phase and are now engaged in detailed investigations
- Many initial explorations were (and still are) done from balloon platforms
  - Develop and test fly detector systems that later lead to spacecraft missions
  - Observations provide initial discoveries that guide later missions
- Investigation of the Cosmic Microwave Background is a good example of this process
  - Early balloon flights tested and calibrated radiometers for COBE (Nobel Prize science)
  - Later balloon flights (BOOMERanG, MAXIMA) established their own discoveries and led to WMAP
- Cosmic Rays is one of the first modern physics / astrophysics fields to take advantage of ballooning.

Cosmic Rays were discovered less than a hundred years ago



- In 1912 Victor Hess became the first cosmic ray balloonist
- Measured an increase in the background radiation as a function of altitude, but only up to about 17,000 feet
- Received the 1936 Nobel Prize in Physics for this work

17,000 feet is the highest altitude Hess reached.

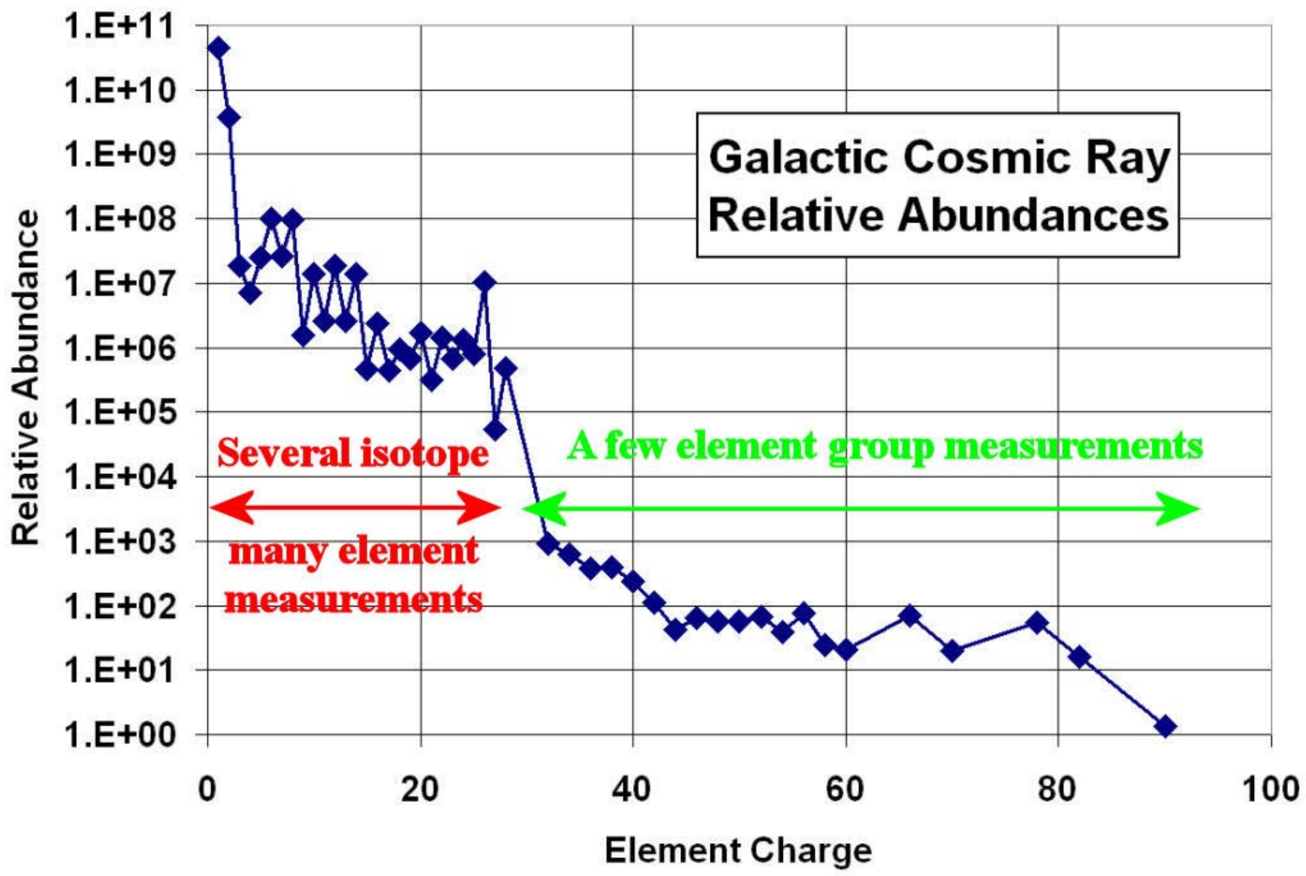


Data measured in 2003 by a simple 400 gm student-built sounding balloon payload.

Understanding the nature of cosmic rays

- **1920’s** radiation was thought to be some form of high energy photon
  - Hence the name Cosmic **RAYS**
- **1930’s** cosmic rays found to be composed of high energy charged particles
  - Effects due to Earth’s magnetic field (east-west; latitude)
  - Discovery of positron and muon
  - Birth of elementary particle physics
- **40’s and 50’s** cosmic ray “beam” was used to develop the theory of elementary particles.
- **1960’s** space probes began identifying individual cosmic ray components
  - Sources from the Sun as well as outside our Solar System
  - Electrons, protons and other elements were identified
  - Began measuring the energy spectrum
  - GCR energy density found to be roughly equivalent to the energy released by a supernova every 50 to 100 years
- **70’s, 80’s and 90’s** pushed the frontiers in both charge and energy
  - Antiprotons, elements up to Uranium, energies to ~10^{21} eV

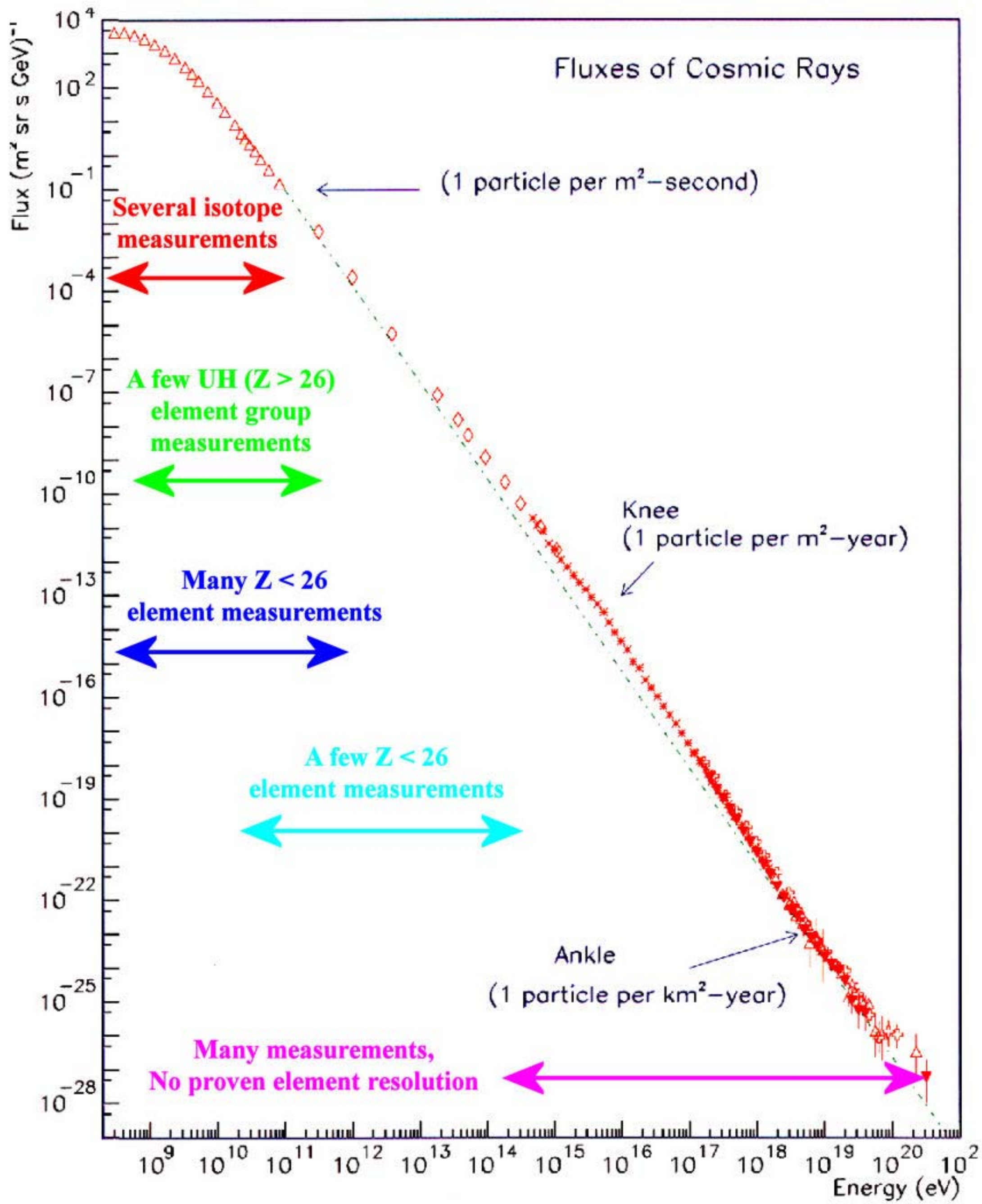
Composition measurements cover the full element range



- Relative abundances range over 11 orders of magnitude
- Detailed composition limited to less than ~ 1 GeV/nucleon

GCR energy spectrum

- Covers more than 20 orders of magnitude
- Flux varies by more than 30 orders of magnitude
- Required detector size varies greatly over this range
  - Satellites limited to low energy (< 100 GeV)
  - Balloons can approach the “knee” (~ 1 PeV
  - Air shower measurements for highest energy
- Most detailed measure-ments are at low energy
- Little composition knowledge above 1 PeV



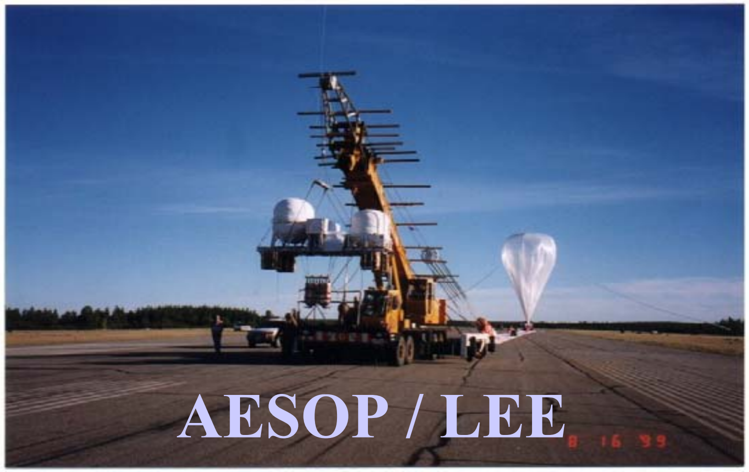
Fundamental questions remain unanswered!

- What is the origin of this extra solar system matter?
  - Can individual sources be detected?
  - What does the GCR composition tell us about the nucleosynthetic history of this matter?
- How does this matter get accelerated to such high energies?
  - Are there different astrophysical sites associated with different energy regimes?
- Are there signatures of any exotic physics?
  - Are there anti-matter regions in the universe?
  - What is causing the effects associated with “Dark Matter”?

Cosmic ray balloon payloads

Anti-Electron Sub-Orbital Payload / Low Energy Electronics (AESOP/LEE)

- Study solar modulation of electrons up to 20 GeV; resolve positrons and negatrons up to 6 GV
- 934 kg (2060 lbs)
- Flights in 97, 98, 99, 00 (120 hours)
- Still operational



Balloon Experiment Superconducting Spectrometer (BESS)

- Anti-protons and isotopes of light nuclei from 0.18 to 4.20 GeV; search for anti-deuterium, anti-helium
- 2,070 kg (4400 lbs)
- 9 "ConUS" Flights 1993 – 2002; LDB flight in 2004 (8.5 days)
- Anticipate flight in 2007

Cosmic ray balloon payloads

Transition Radiation Array for Cosmic Energetic Radiation (TRACER)

- Direct measurements of O to Fe from ~50 GeV to several 100 TeV; 5 m^2 sr
- 1614 kg (3550 lbs)
- Flights in 2003, 2006 (14 days)
- Proposing for more flights

Trans-Iron Galactic Element Recorder (TIGER)

- GCR nuclei heaver than iron ($26 < Z < 40$) for energies ranging from 0.3 to ~100 GeV/nucleon
- 700 kg (1543 lbs)
- Flights in 2001 and 2003 (50 days)
- Unrecovered after 2003 flight

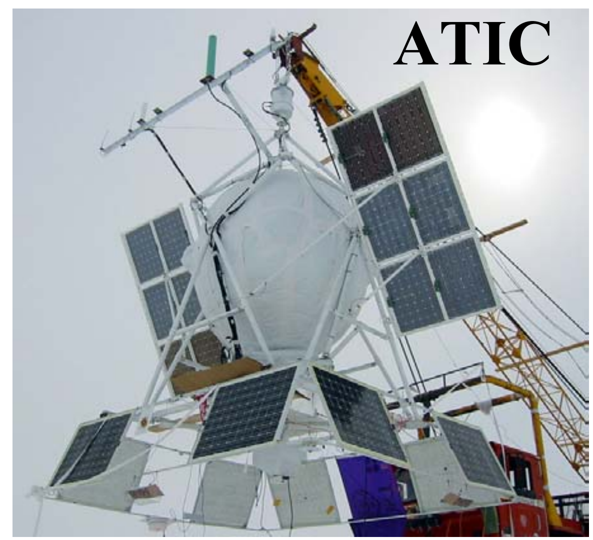
Cosmic ray balloon payloads

Cosmic Ray Energetics and Mass (CREAM)

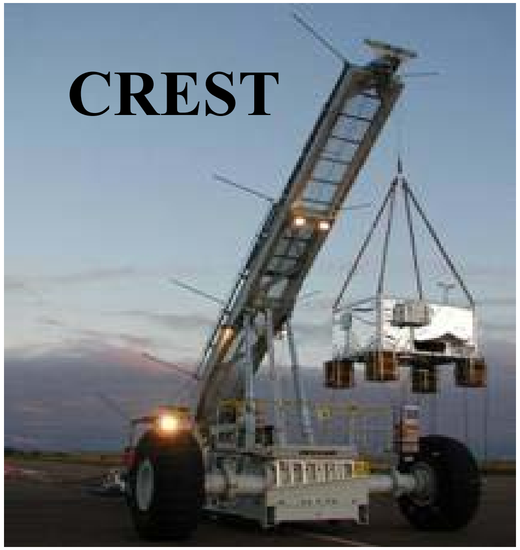
- GCR nuclei from H to Fe for energies from ~1 TeV to ~500 TeV
- 1141 kg (2526 lbs)
- Flights in 2004 and 2005 (70 days)
- Anticipated flights in 2007 and 2008

Advanced Thin Ionization Calorimeter (ATIC)

- GCR nuclei from H to Fe from 50 GeV to ~100 TeV; GCR electrons from ~20 GeV to several TeV
- 1636 kg (3600 lbs)
- Flights in 2000, 2002 (30 days), launch failure in 2005
- Anticipate flight in 2007



Cosmic ray balloon payloads

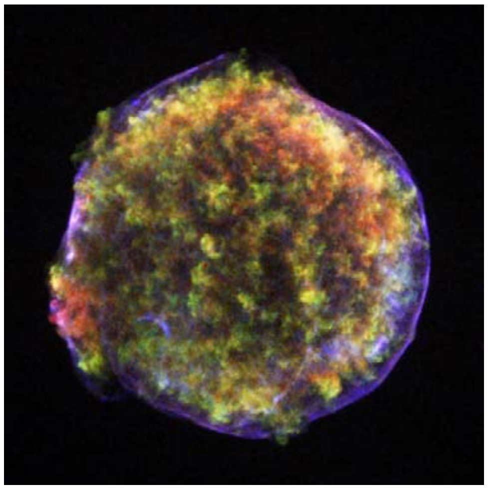


Cosmic Ray Electron Synchrontron Telescope (CREST)

- GCR electrons at energy > 4 TeV; Detects synchrotron emission of electrons passing Earth's magnetic field
- 1318 kg (2900 lbs)
- First LDB flight in 2009
- Under construction

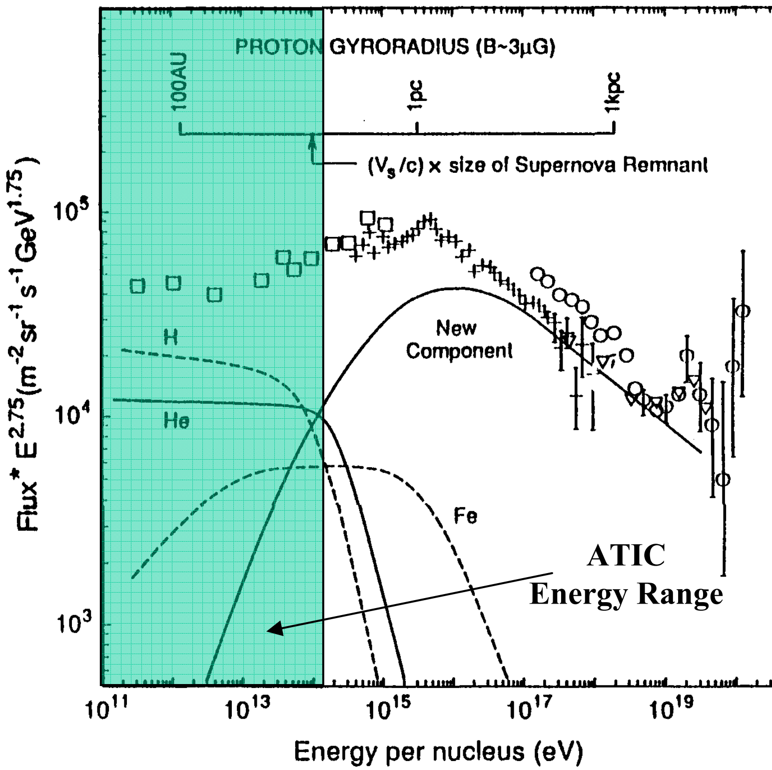
Supernova shock waves may accelerate GCR

- See evidence of both electrons and atomic nuclei being accelerated by SNR shock waves
- Model predicts an upper energy limit of E ~ Z x 10^{14} eV



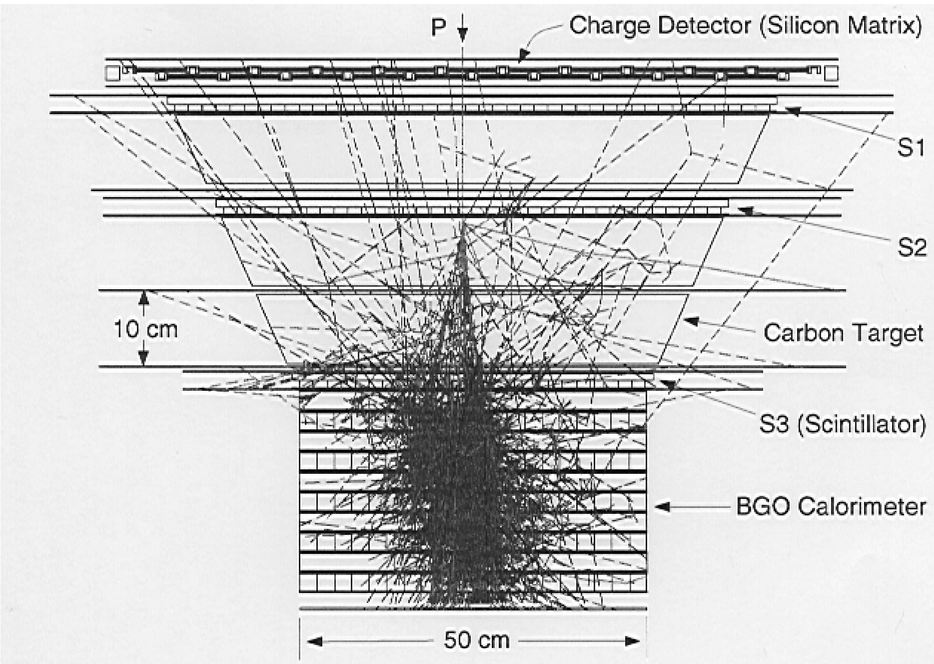
Chandra X-ray observations of Tycho's SNR showing evidence of electron and atomic nuclei acceleration.

- Expect each element energy spectrum to change as limit is approached
- May explain "knee" in all particle spectrum

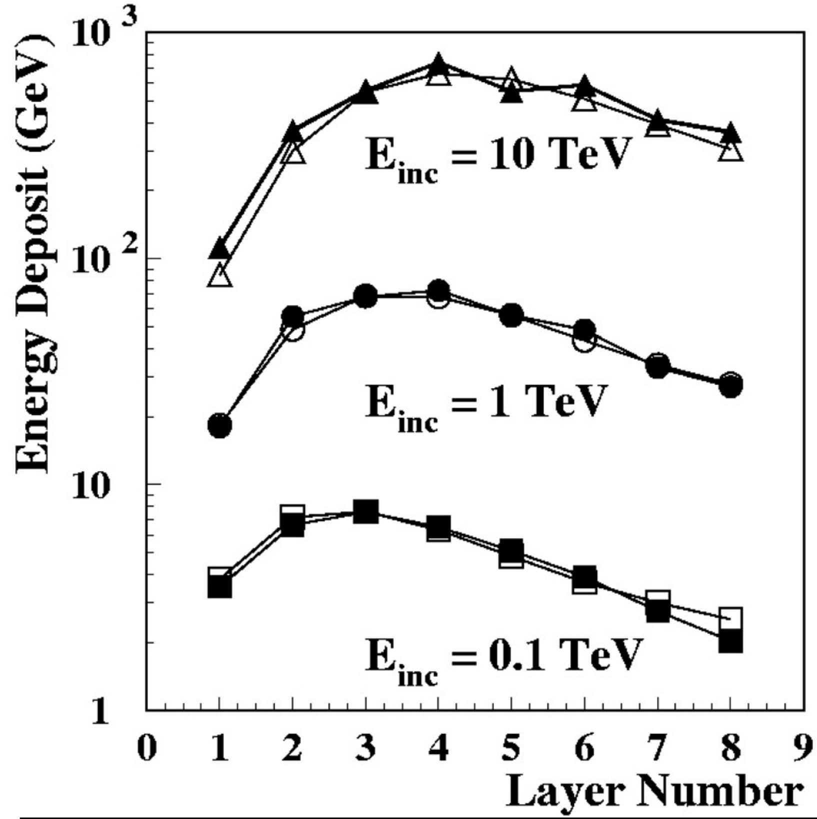


- Measuring these spectra changes in the 1 – 500 TeV energy range is the primary science objective of TRACER, CREAM and ATIC

ATIC & CREAM use ionization calorimetry to measure GCR energy at TeV energies

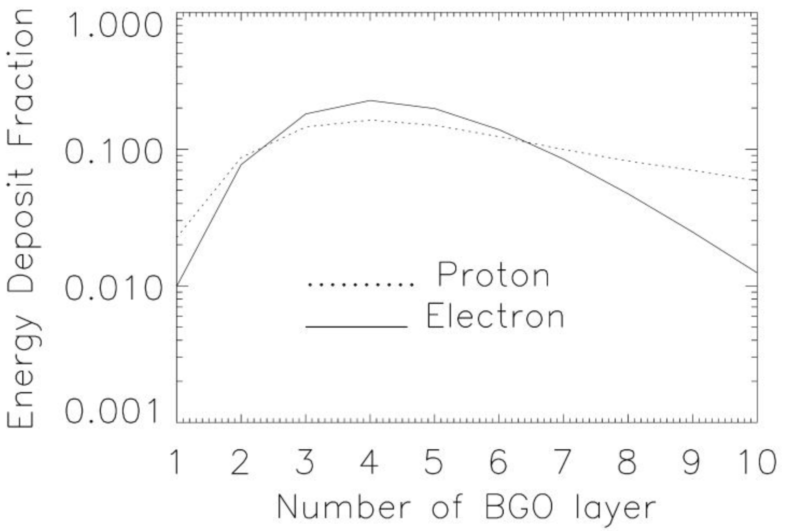


A high energy cosmic ray interacts in the ATIC instrument to begin an electromagnetic cascade that is measured in the BGO Calorimeter

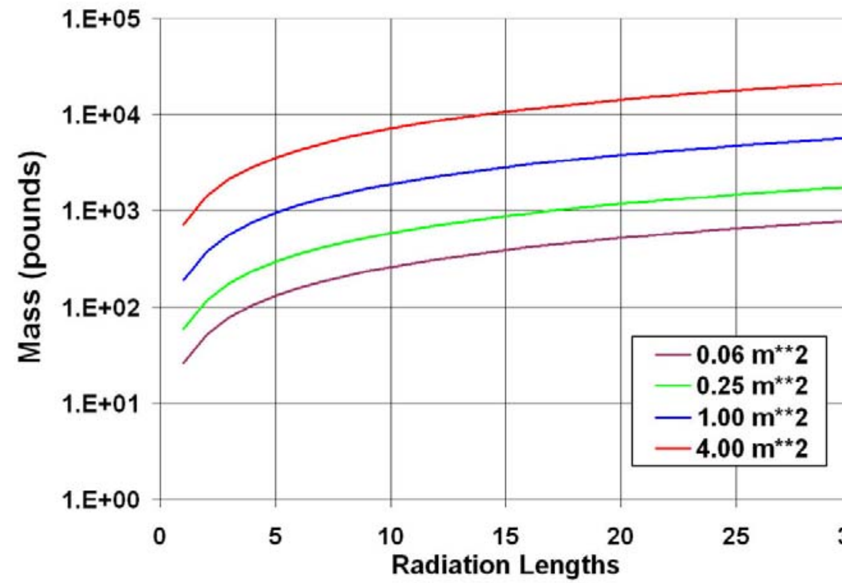


Shower profiles for protons of indicated energy. Open symbols are simulations & filled symbols are flight data.

Trade mass for area & energy resolution

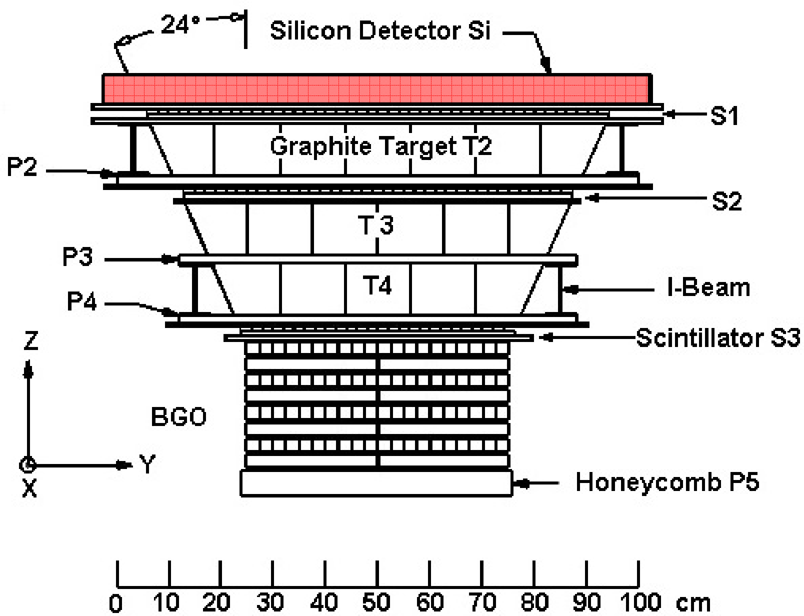


X_0 2.2 4.5 6.7 8.9 11.2 13.4 15.6 17.9 20.1 22.3



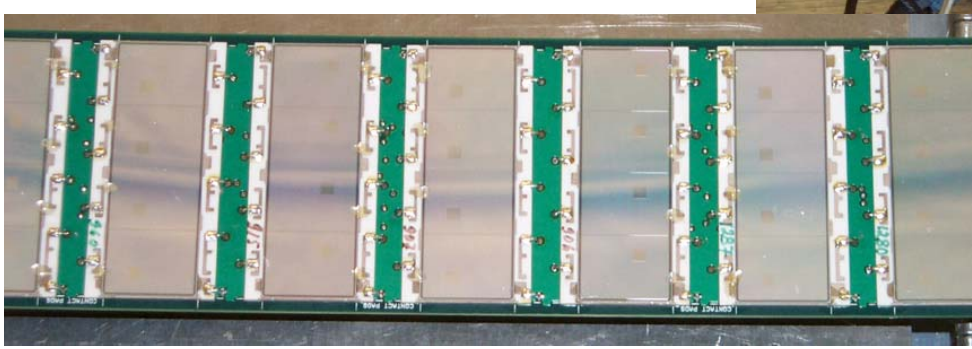
- As the calorimeter depth (in radiation lengths, X_0) increases more of the electromagnetic cascade is contained
  - Improves energy resolution and ability to suppress backgrounds
- As area increases statistics improve and, for a given time at float, the measurement upper energy limit increases
- Calorimeters use dense materials, so mass increases dramatically

Highly "pixelated" Silicon Matrix Detector determines particle charge

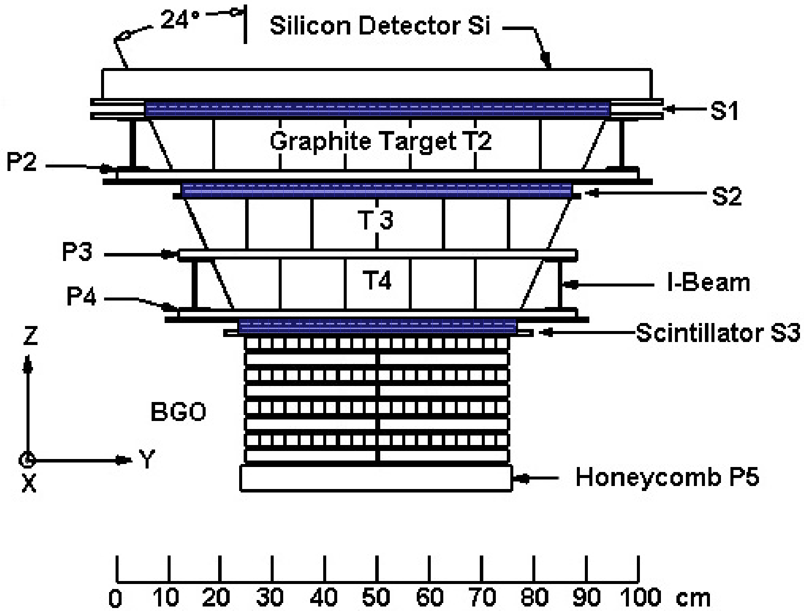


Si-Matrix: 4480 pixels each 2 cm x 1.5 cm mounted on offset ladders; 0.95 m x 1.05 m area; 16 bit ADC; CR-1 ASIC's; sparsified readout.

Mass: 90 lbs, **Power:** 43 W

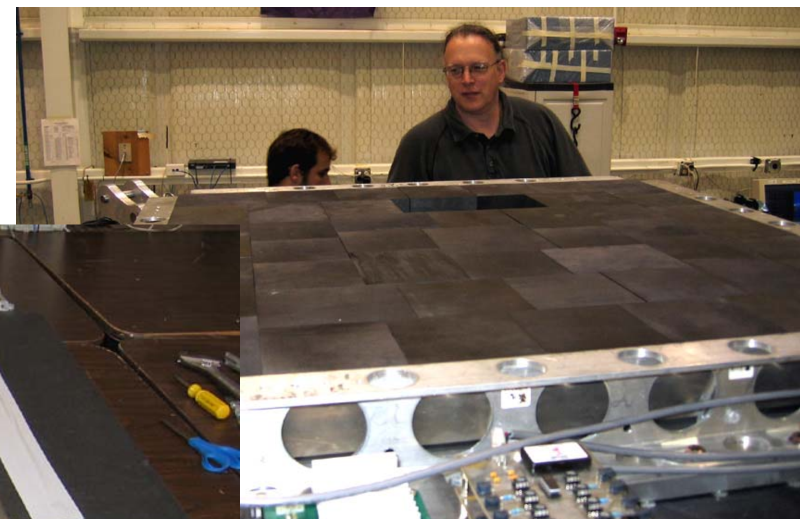


Plastic Scintillator Hodoscopes provide initial trigger, plus addition trajectory & charge info



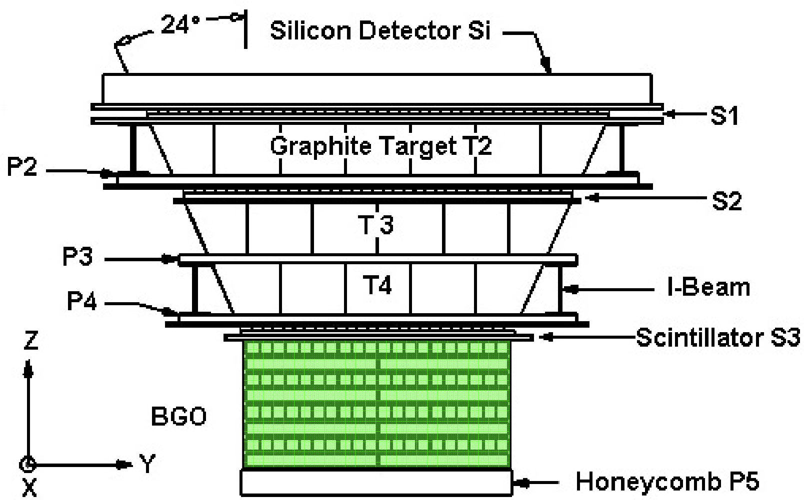
Scintillators: 3 x-y layers; 2 cm x 1 cm cross section; Bicron BC-408; Hamamatsu R5611 pmts both ends; two gain ranges; ACE ASIC. S1 – 336 channels; S2 – 280 channels; S3 – 192 channels; First level trigger: S1-S3

Mass: 190 lbs., **Power:** 26 W



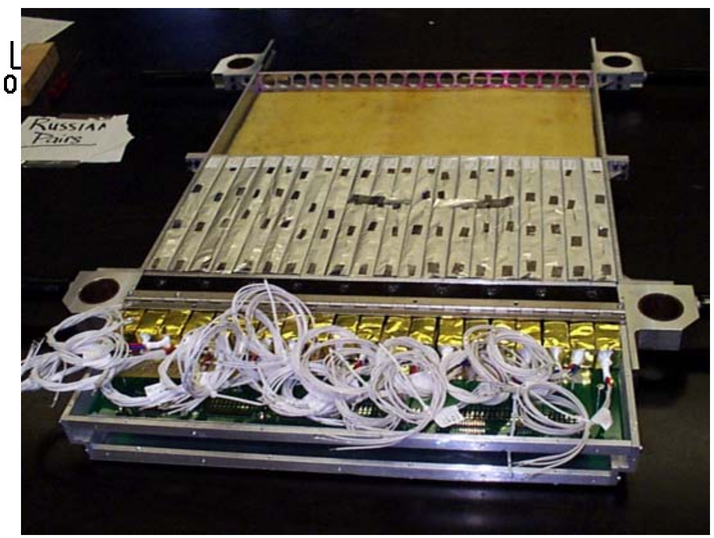
Carbon Mass: 600 lbs.

BGO Calorimeter used to determine particle energy & shower core trajectory

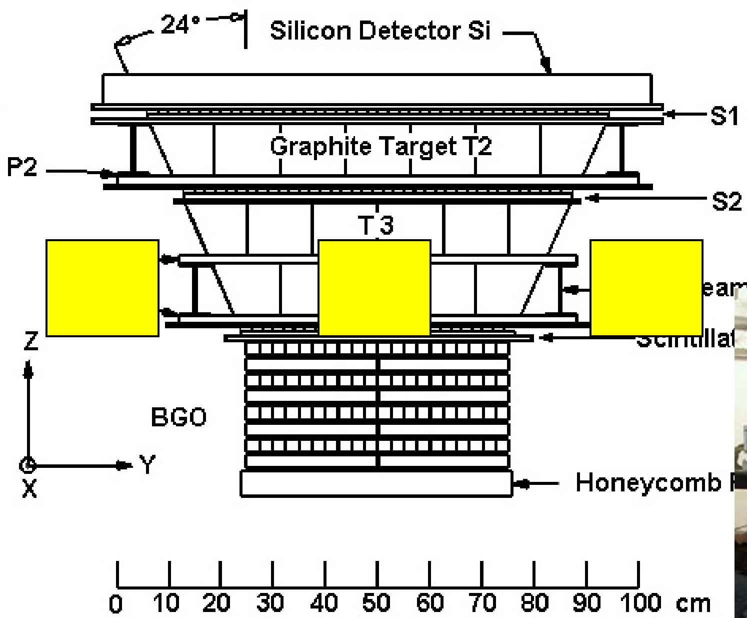


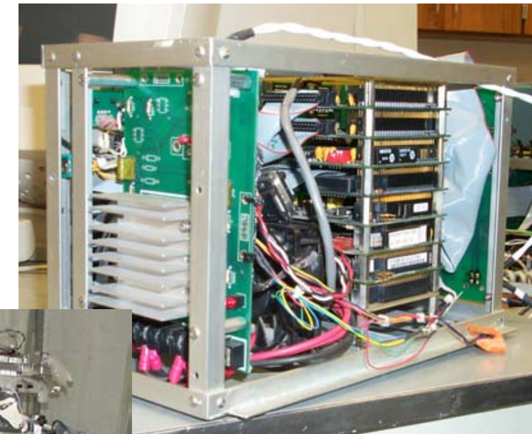
Calorimeter: 10 layers ; 2.5 cm x 2.5 cm x 25 cm BGO crystals (~22 X_0 total depth) , 40 per layer, each crystal viewed by R5611 pmt; three gain ranges; ACE ASIC; 1200 channels

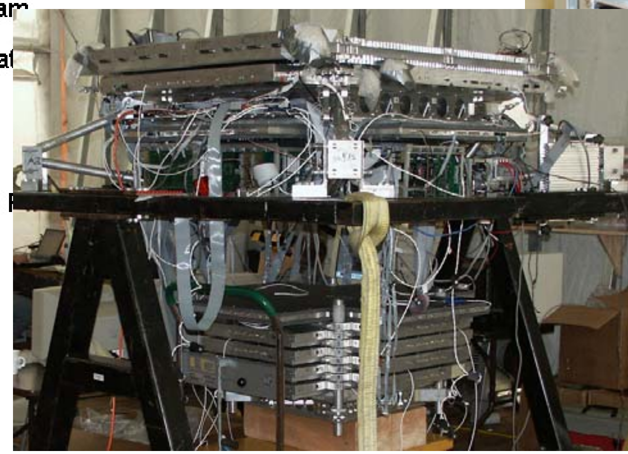
Mass: 1280 lbs., **Power:** 40 W



On-board Control & Data System







Data System: All data recorded on-board; 150 Gbyte disk; LOS data rate – 330 kbps; TDRSS data rate – 6+ kbps; Underflight capability (not used).

Housekeeping: Temperature, Pressure, Voltage, Current, Rates, Software Status, Disk status

Command Capability: Power on / off; Trigger type; Thresholds; Pre-scaler; Housekeeping frequency; LOS data rate, Reboot nodes; High Volt settings; Data collection on / off

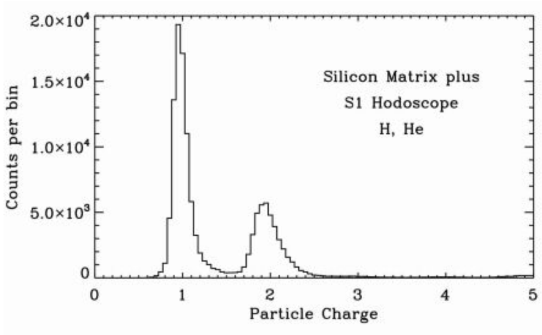
Mass: ~80 lbs., **Power:** 45 W

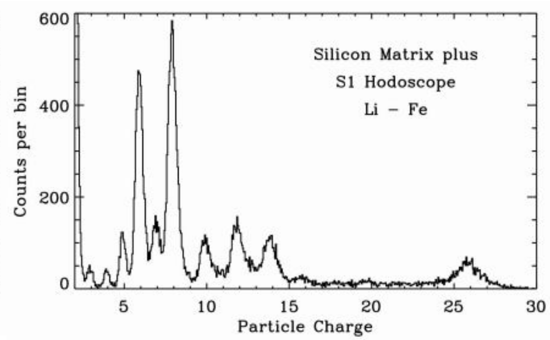
ATIC in its LDB flight configuration

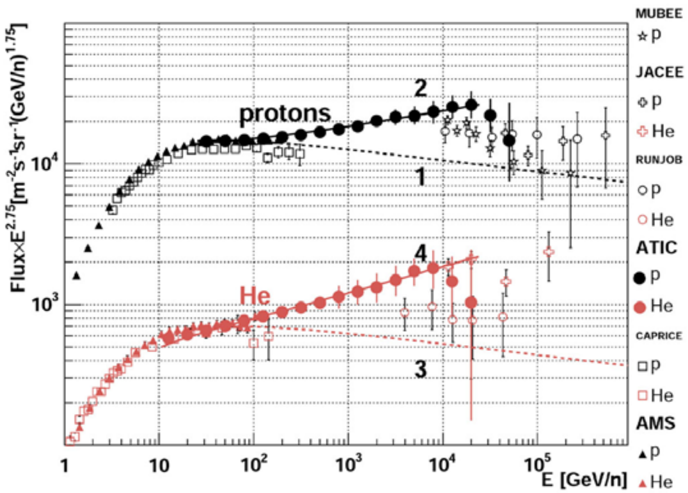
	ATIC-3 (2005) (NSBF 2004)
Balloon	4050 lbs
Science Gondola	3515 lbs
Science Solar Array	80 lbs
NSBF Electronics (SIP,etc.)	505 lbs
NSBF Solar Array	150 lbs
NASA Rotator	160 lbs
Parachute & susp.	590 lbs
Ballast	600 lbs
Misc. (1 Ballast Hopper,etc.)	300 lbs
Gross Load	**9950 lbs**

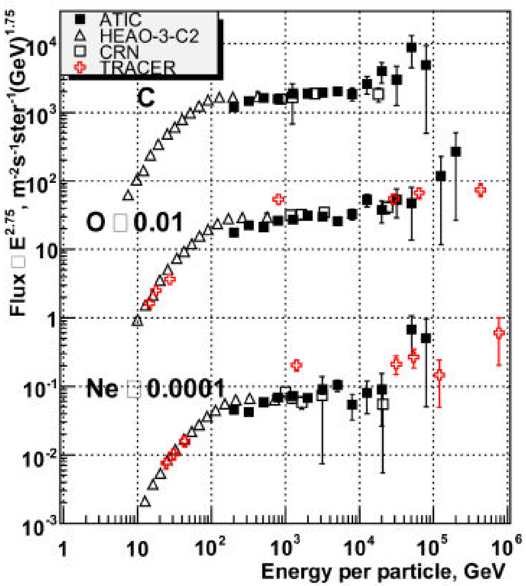
- ATIC is one of the heaviest payloads to be launched in Antarctica
- Uses a 39 million ft^3 – light balloon to reach ~120,000 feet

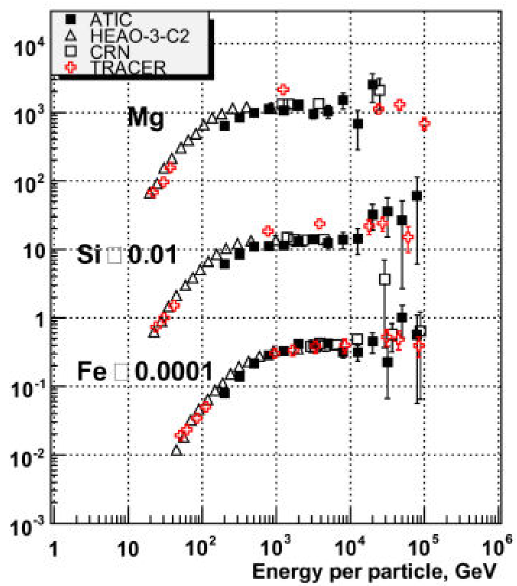
Preliminary ATIC-2 Results

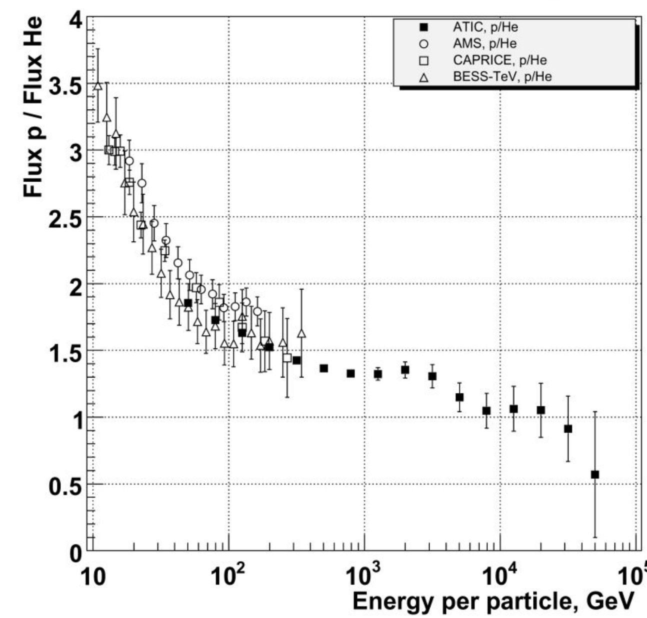






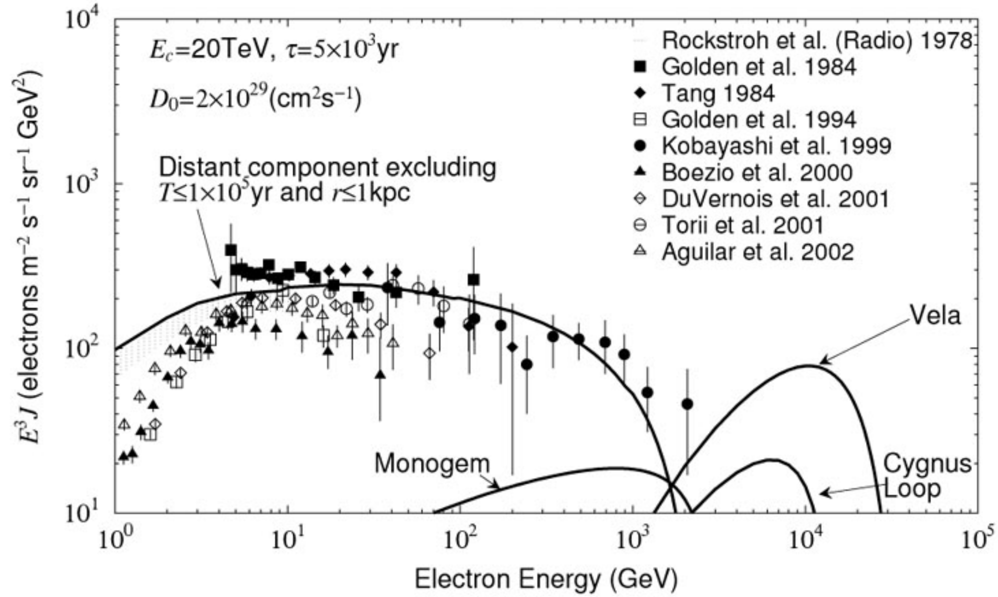






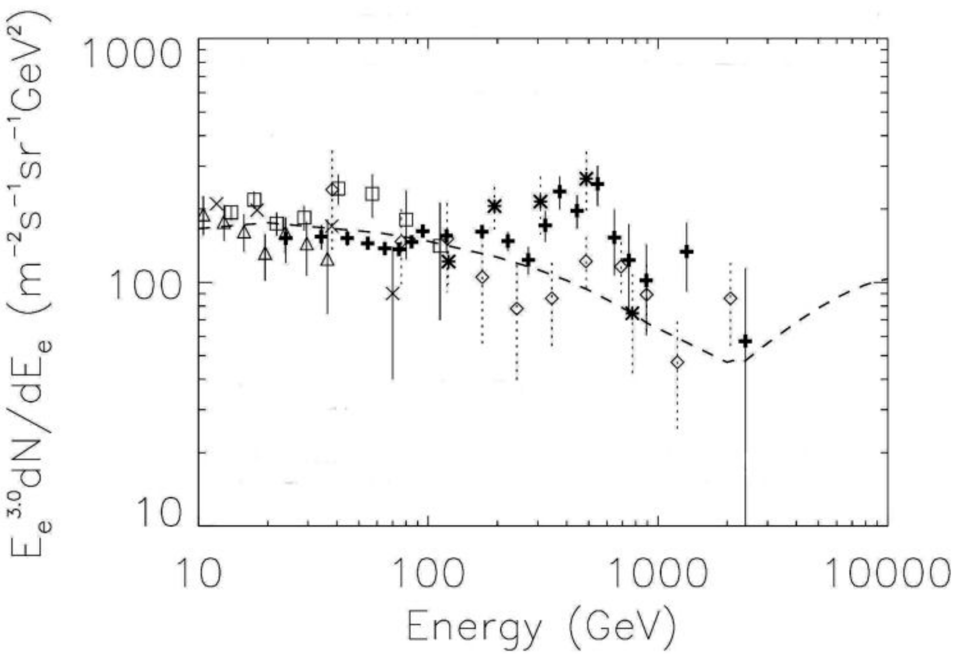
Electrons might provide additional information about the GCR source

- High energy electrons have a high energy loss rate
  - Lifetime of ~10^5 years for >1 TeV electrons
- Transport of GCR through interstellar space is a diffusive process
  - Implies that source of high energy electrons are < 1 kpc away
- Know that electrons are accelerated in SNR
- Only a handful of SNR meet the lifetime & distance criteria
- Kobayashi et al (2004) calculations show structure in electron spectrum at high energy

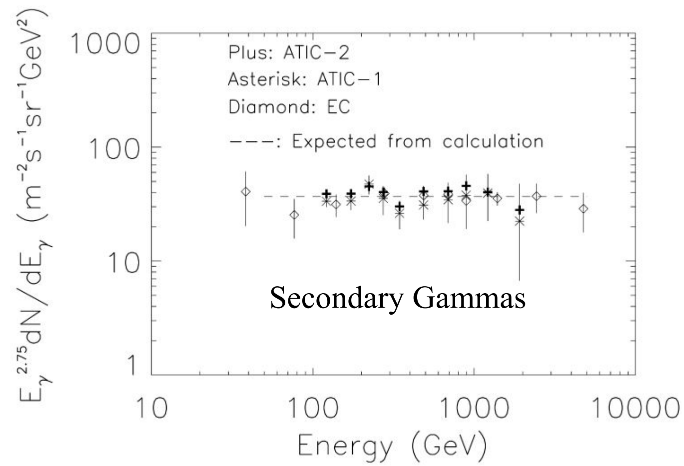


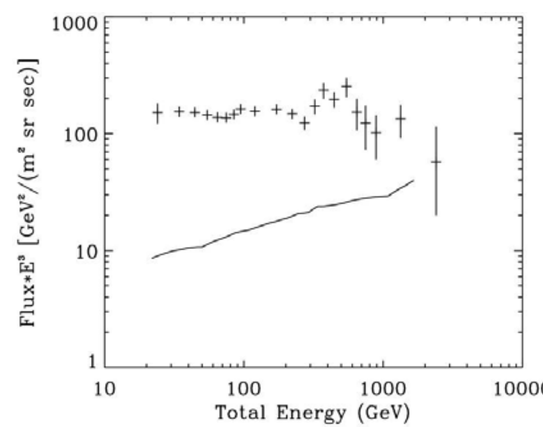
ATIC is able to identify GCR electrons

- Possible bump at 300 – 800 GeV seen by both ATIC and Torii may be a source signature?
- Long duration ATIC flight for 2007 will be critical to resolving this issue

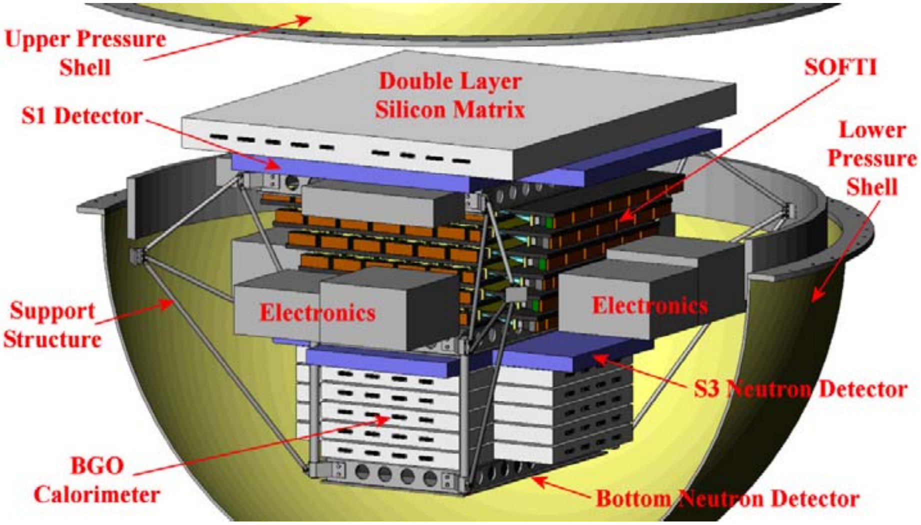


✕ HEAT (DuVernois et al., 2001); △ AMS (Aguilar et al., 2002); ◇ EC (Kobayashi et al., 1999); □ BETS (Torii et al., 2001); ✚ ATIC (Chang et al., 2005); ✱ PPB-BETS (Torii et al., 2006);





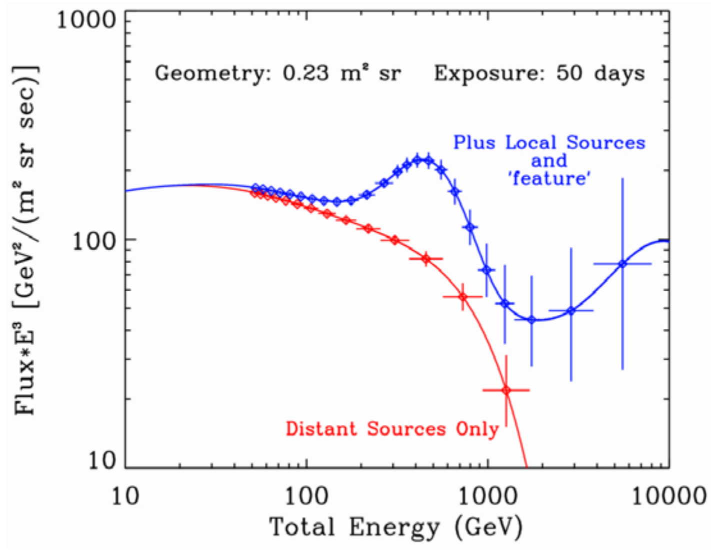
Electron Calorimeter (ECAL)

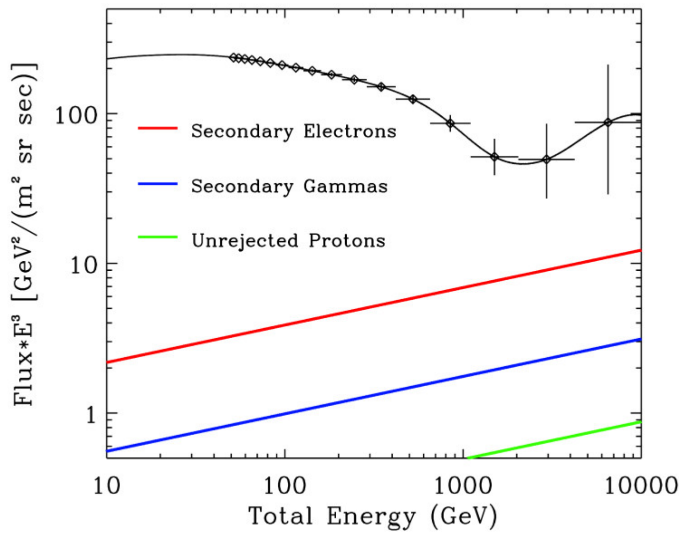


- Proposed to NASA as a new LDB payload in April, 2007
- Upgraded version of ATIC
  - Optimized for electrons
  - Add a second layer to the Silicon Matrix
  - Scintillating Optical Fiber Track Imager (SOFTI) replaces carbon
  - Include a neutron detector
- SOFTI improves trajectory reconstruction, tracks early development of shower
  - Six X,Y layers of 1 mm fibers with thin lead sheets to foster shower start
- Double layer silicon matrix & improved tracking improves identification of gamma rays produced in the atmosphere above the balloon
- Use shower profile in SOFTI & BGO to separate protons & electrons
  - Only 1 in 20,000 protons are misidentified as electrons
- Hadron showers produce more neutrons than electron showers
  - Can distinguish between p & e independent of shower profile method
  - Push instrument proton rejection to 1 in 200,000

Potential ECAL results

- ECAL uses established technology and can be quickly built
  - First LDB flight proposed for 2009
- Now reasonable to anticipate 25 days per LDB flight
  - Plan two LDB flights for total of 50 days exposure
- Primary ECAL science goals
  - Distinguish between Kobayashi “distant” and “local” source models at 99% confidence level
  - Validate and investigate nature of the ATIC “feature”
- Electron measurement backgrounds pushed to lowest possible level
  - Dominated by electrons produced in atmosphere above balloon payload
  - Contribution of 10% - 15% at a few TeV





Conclusions

- The study of galactic cosmic rays over the last century has revealed much about the nature of this high energy, extra-solar system matter, but there are still many unanswered questions
- Answers to these questions lie hidden in low flux regions
  – High energy, high element number, rare events
- Balloon flight experiments still provide the best opportunity to address some of these questions
  – Now possible to fly heavy, large geometry payloads for long durations
  – Development of detector systems that may one day fly on space missions