Advanced Thin Ionization Calorimeter

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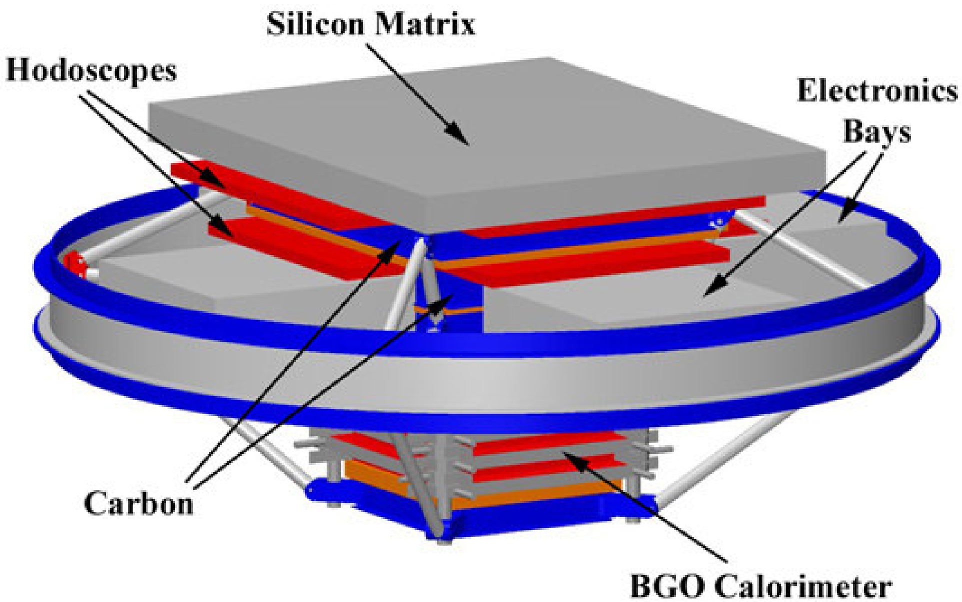
Outline

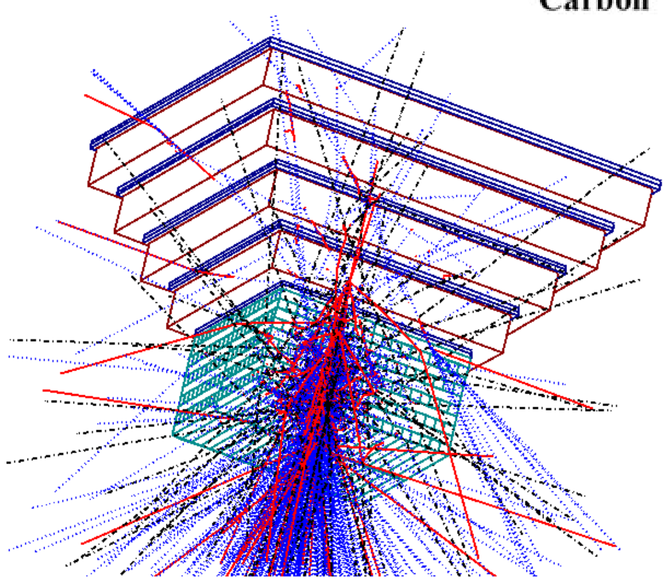
- Description of the ATIC instrument
- Some of the Scientific Results from the first ATIC flight
- Balloon Launch Failure on the Third ATIC flight

Measurement Objectives

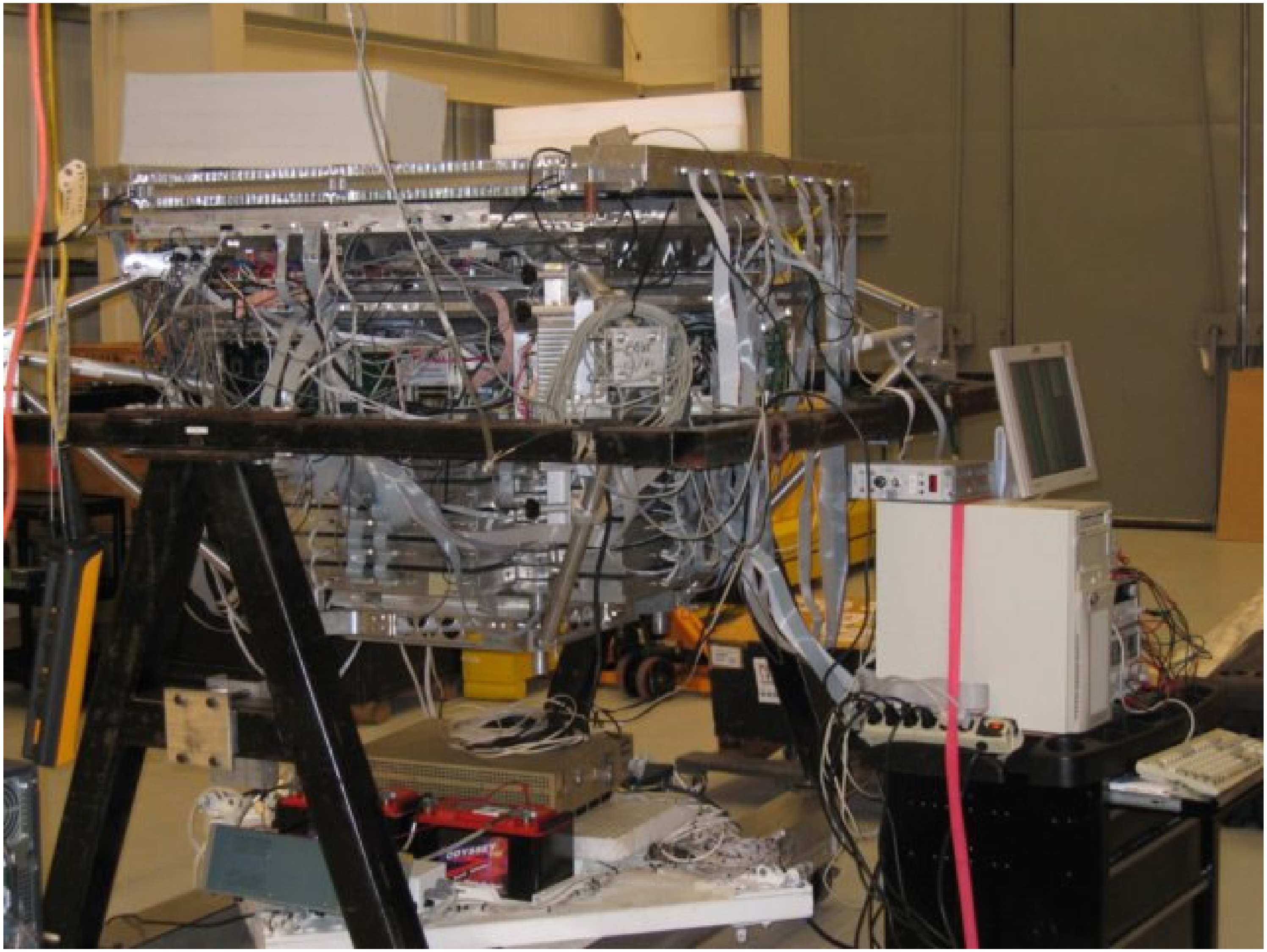
- H and He Spectra from 10^{10} to 10^{14} eV/particle
- Individual elemental spectra from 10^{10} eV/particle for the elements Li – Fe
- Electron Spectrum from $2X10^{10}$ eV

ATIC Instrument



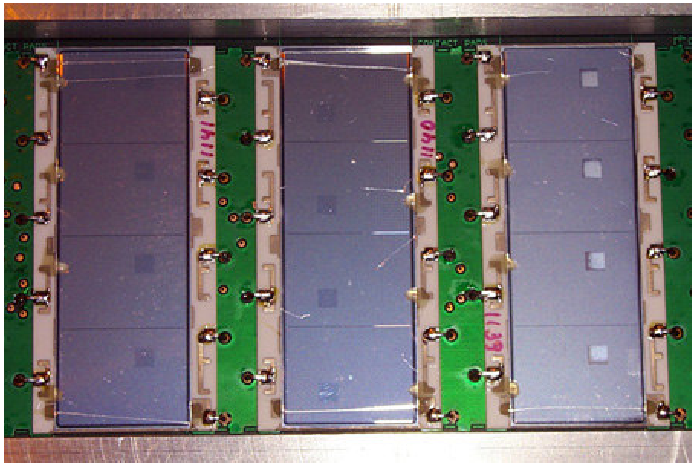


Actual Instrument



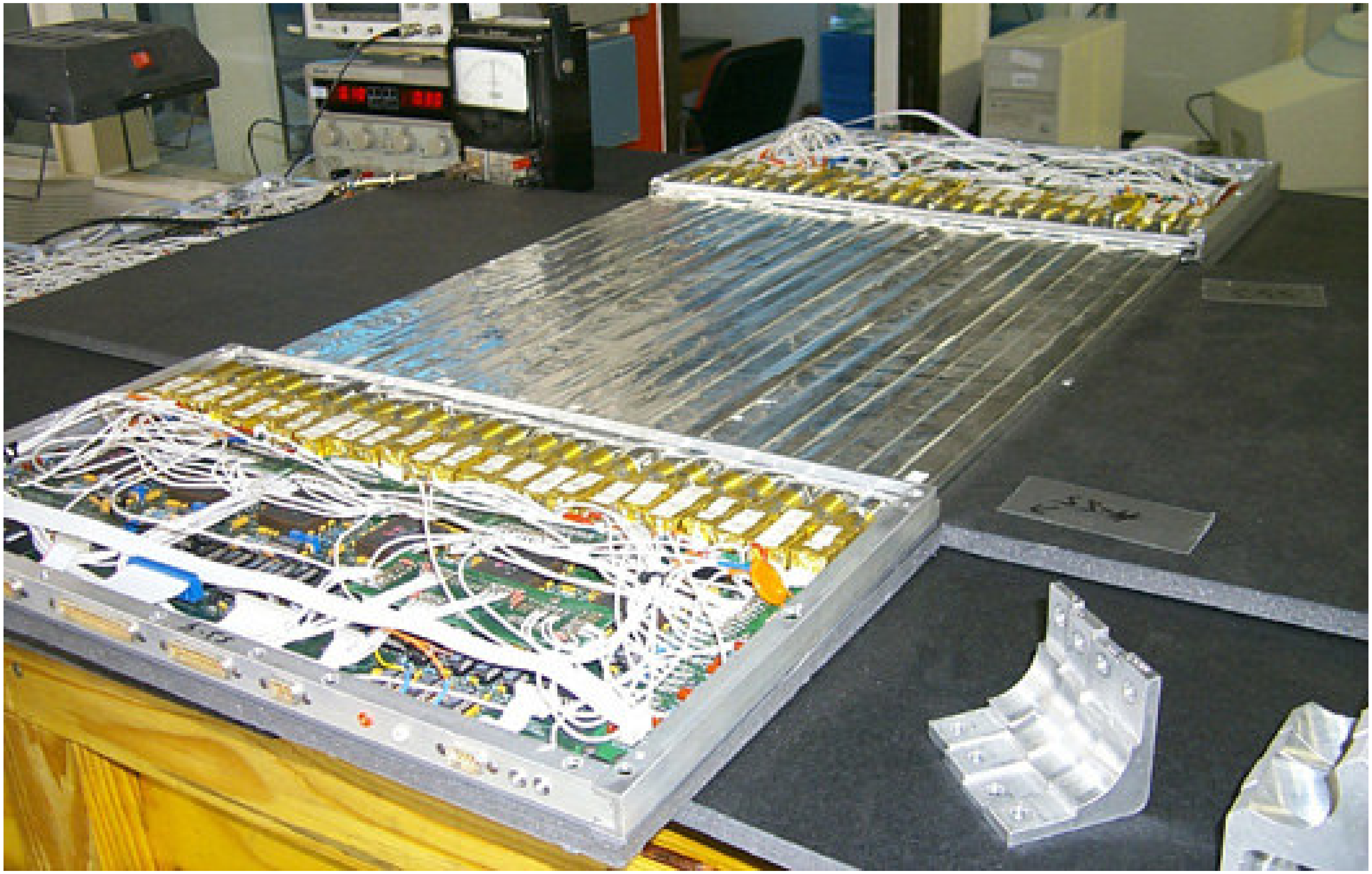
Silicon Matrix

- 4 1.5X2 cm^2 silicon pads per daughter board
- 28 daughter boards per mother board
- 2 motherboards per ladder
- 10 ladders per panel
- 2 panels with 4480 pads total



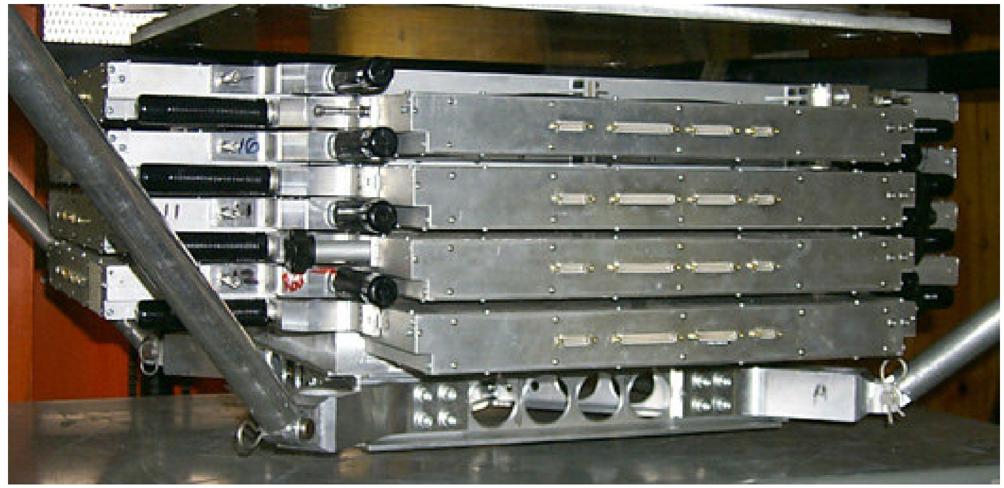
Three Scintillator Hodoscopes

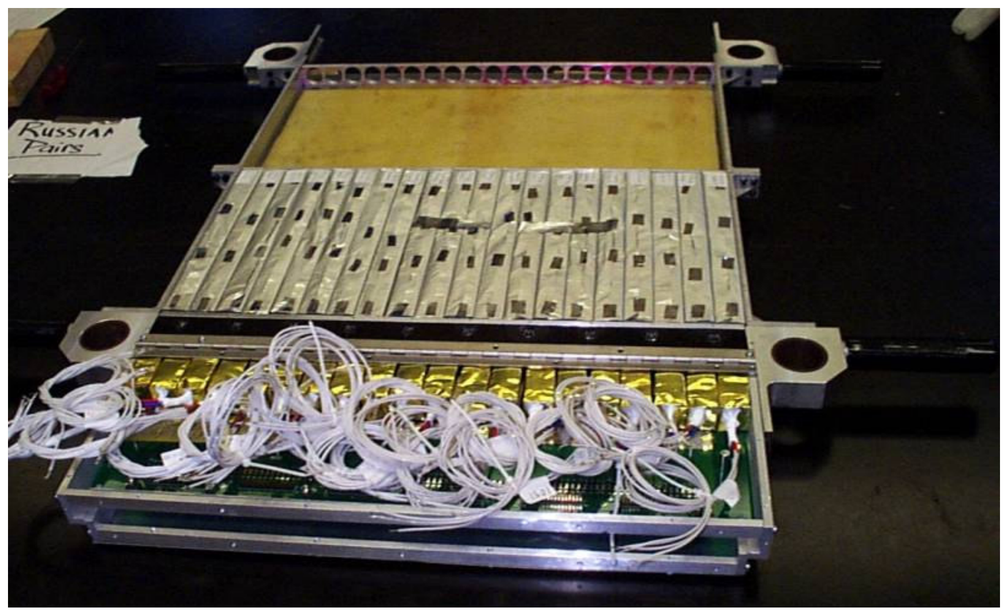
Bicron BC-408 scintillator strips (1cm X2 cm) read out from both ends with Hamamatsu R5611 PMTs



BGO Calorimeter

- 2.5cm X 2.5cm X 25cm bismuth germanate crystals
- 20 crystals per half tray, each viewed from one end by a Hamamatsu R5611 PMT
- 40 crystals per tray
- 8 trays

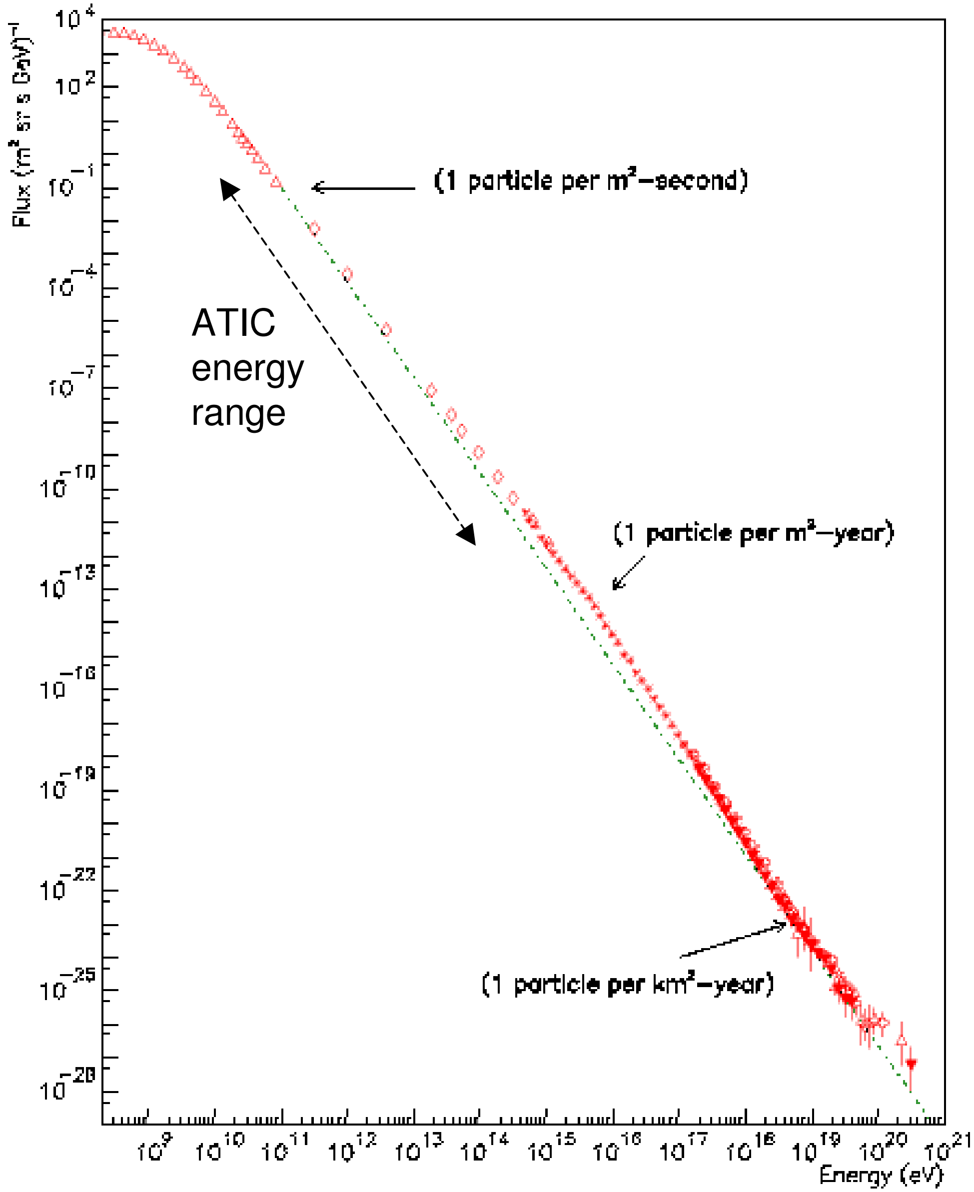




Science Objectives

- Investigate the nature of the cosmic ray accelerator
  - Look for evidence of more than type of source
  - Test diffusive shock acceleration models
- Investigate galactic confinement
  - Test “leaky box” and “diffusion” models
  - Investigate cosmic ray leakage from the Galaxy
  - Investigate the role of re-acceleration
- Examine the electron spectrum for evidence of nearby cosmic ray sources

The Energy Spectrum



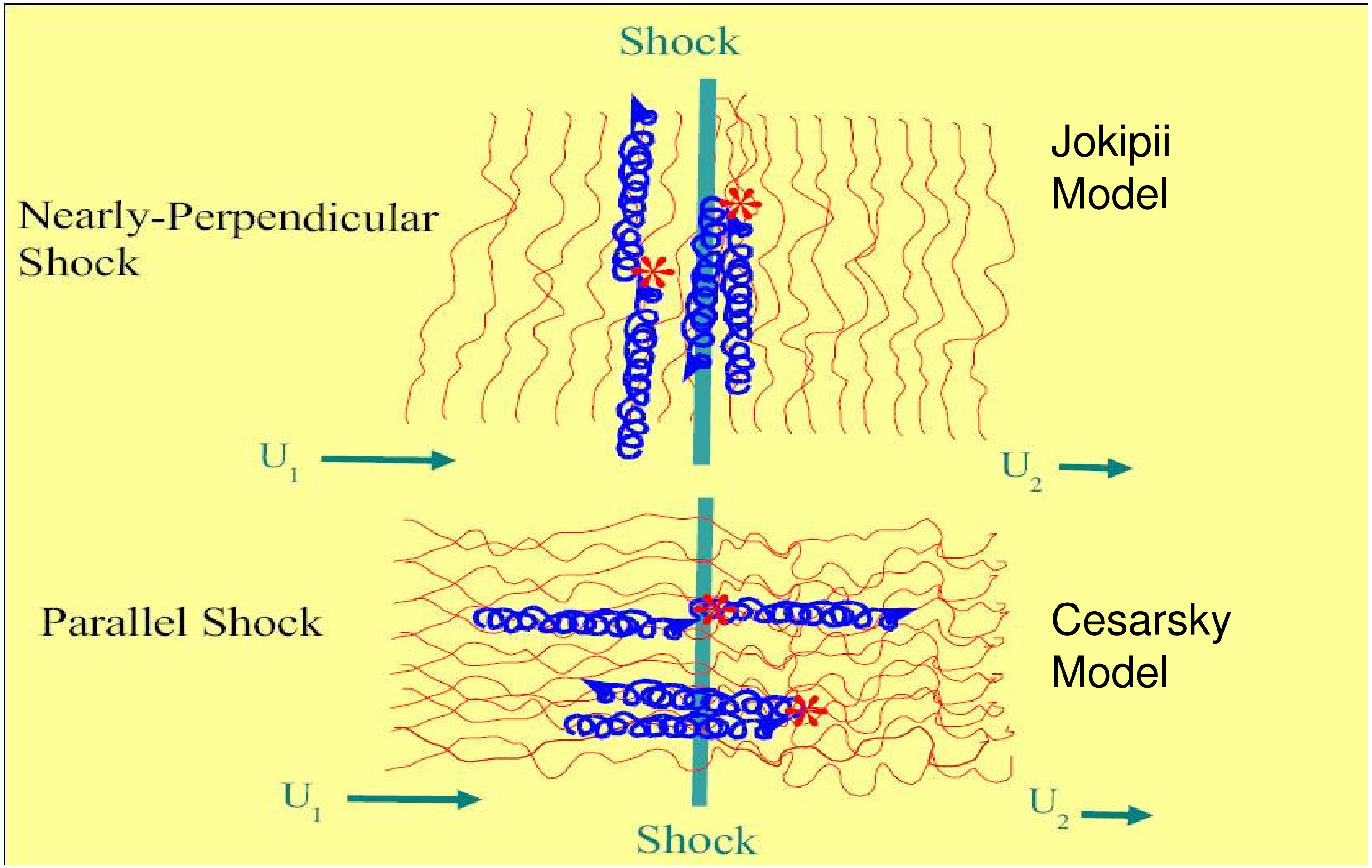
Sources and Acceleration

Sources: Probably Type II Supernovae

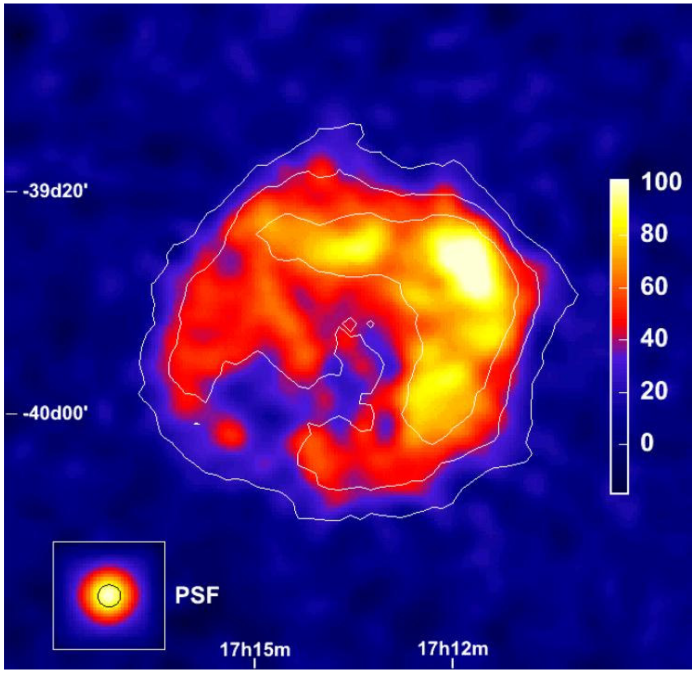
- CR energy density ≈ 1eV/cm^3
- Residence time in the galaxy ≈ 2.6x10^7 yrs

  ⇒Power required ~2.5X10^{47} ergs/yr
- A Type II Supernova yields ~10^{53}ergs
  - Almost all of it goes into neutrinos
  - 10^{51} ergs in the blast wave
- SN rate ≈ 2/century ≈ 2X10^{49}ergs/yr
  - Blast wave must convert ~1% of its energy into cosmic rays.
- Diffusive Shock Acceleration required

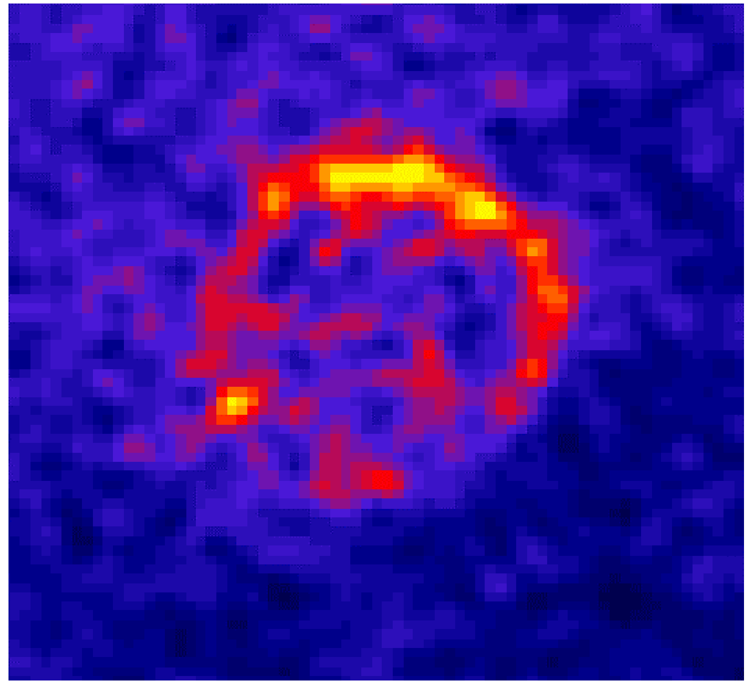
Diffusive Shock Acceleration



New HESS TeV γ-ray Observations



RX J1713 - 394

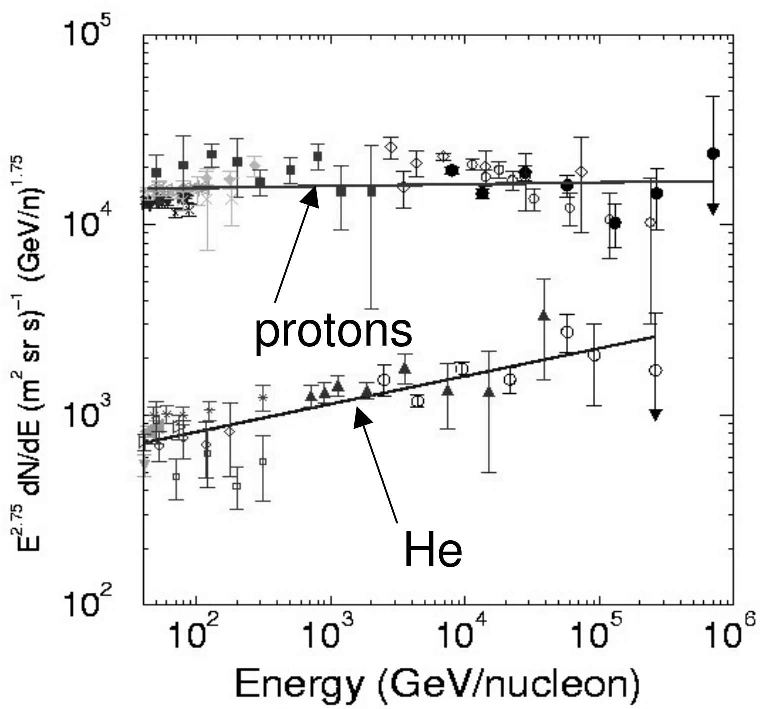


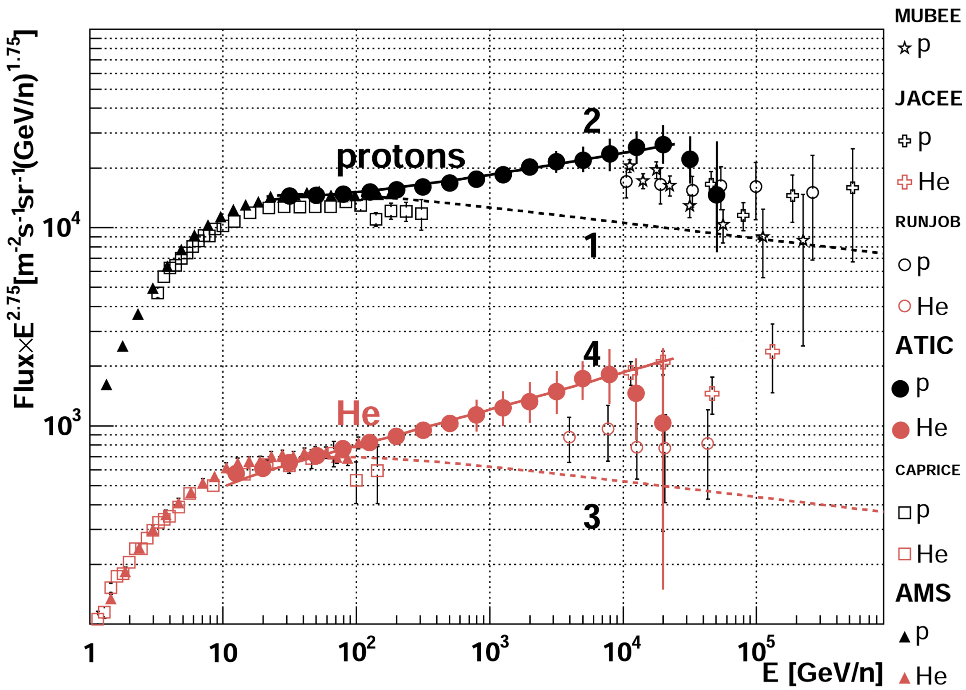
RX J852.0 - 4622

• These TeV γ-rays are clearly from the SNR blast waves but are they from $P+P \rightarrow P+P+\pi^0 \rightarrow P+P+2\gamma$?

- The γ-rays could be from electrons, but this requires higher magnetic fields than are thought to exist in SNRs

Are All Supernova Cosmic Ray Sources of the Same Type?



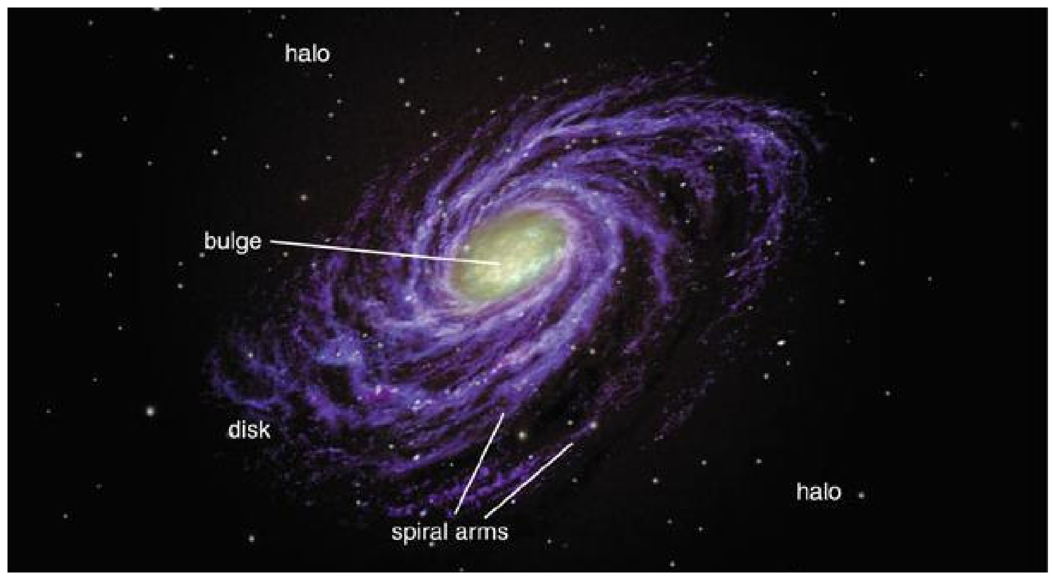


No. If all sources were the same type, all the elemental spectra above 10^2 Gev/nuc would have the same shape and they don't. There must be at least two types. Biermann has suggested that the two types are 8-15 M□ stars and Wolf-Rayet stars.

Our Galaxy

- Diameter = 30 kpc

  (1 parsec = 3.26 light years)
- Disk thickness = 300 pc
- Sun: 2/3 out from the center and a little north of the middle
- Interstellar medium: gas, dust & cosmic rays
  - Density ~ 1atom/cm^3
- Energy densities in gas, cosmic rays and magnetic field are all ~1 eV/cm^3
- Magnetic field ~ 5 μG
- At 1.5×10^{17}eV the Larmor radius of a proton is 30 pc



Cosmic Ray Confinement Models

Leaky Box Model

- Cosmic rays confined to a box with leakage at the boundary.
- Within the box, cosmic only interact with interstellar gas

Halo Diffusion Model

- Cosmic rays diffuse through magnetic scattering centers in the Galaxy
- The densities of scattering centers and gas are highest in the Galactic disk but extend into a halo above and below the disk
- Cosmic rays interact with the gas in the Galaxy and escape by diffusion

Cosmic Ray Confinement

Leaky Box Model

$$N_i(E)\left\{\frac{1}{\tau_{esc}(E)}+\frac{1}{\tau_{\text{int},\,i}(E)}+\frac{1}{\gamma(E)\tau_{dec,\,i}}\right\}=\sum_{k>i}\frac{N_k(E)}{\tau_{\text{int},\,k\,\to\,i}(E)}-\frac{\partial}{\partial E}\left\{\frac{\partial E}{\partial t}N_i(E)\right\}$$

Halo Diffusion Model

$$N_i(E,z)\left\{\frac{1}{\tau_{\text{int}}(E,z)}+\frac{1}{\gamma(E)\tau_{dec,\,i}}\right\}=\frac{\partial}{\partial z}\left\{D(E,z)\frac{\partial}{\partial z}N_i(E,z)\right\}+\sum_{k>i}\frac{N_k(E,z)}{\tau_{\text{int},\,k\,\to\,i}(E,z)}-\frac{\partial}{\partial E}\left\{\frac{\partial E}{\partial t}N_i(E,z)\right\}$$

Where

$N_i(E)$ and $N_k(E)$ are the number densities of the ith and kth types of cosmic ray nuclei in particles per cm^3 per GeV

$N_i(E,z)$ and $N_k(E,z)$ are then number densities at position z.

τ_{esc} is the mean escape time from the leaky box.

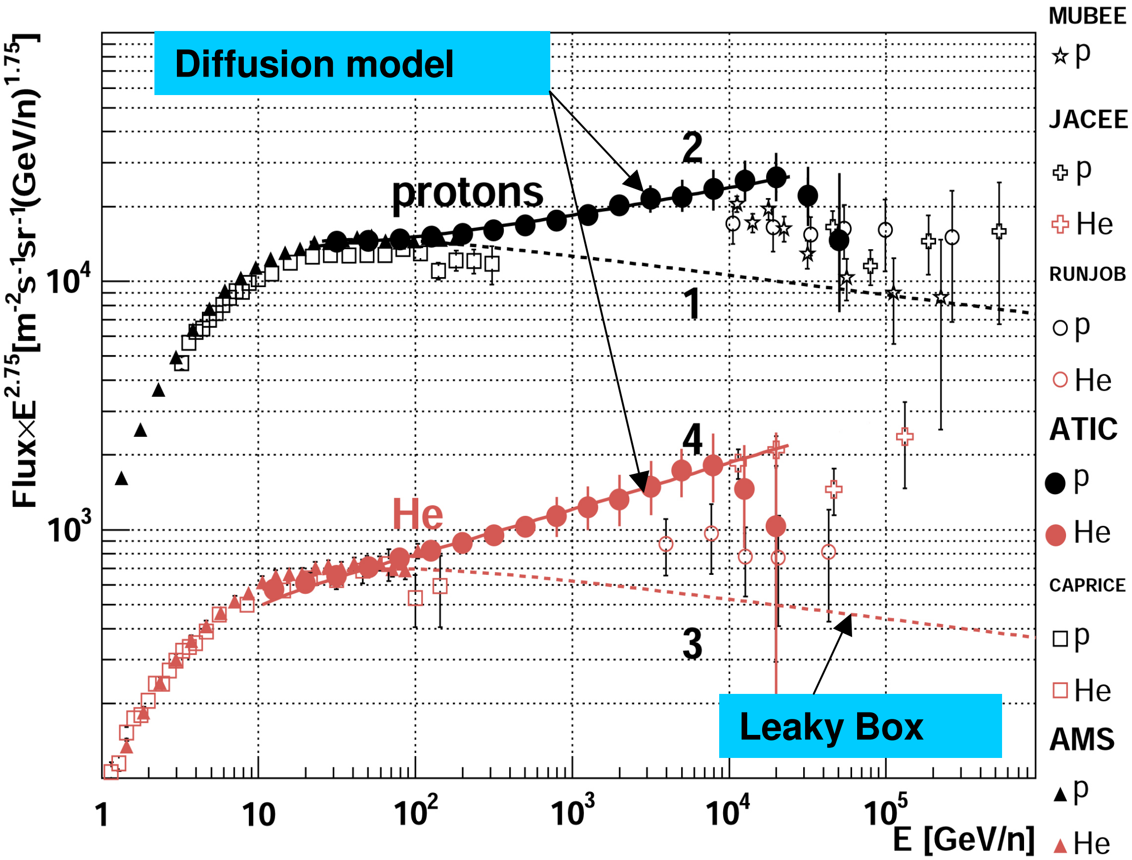
$\gamma(E)\tau_{dec,i}$ is the mean lifetime of the ith nuclear species for radioactive decay, corrected for time dilation.

$\tau_{\text{int},i}$ is the mean time before the a nucleus of the ith species interacts with the interstellar gas

$D(E,z)$ is the diffusion coefficient.

Re-acceleration due to scattering during diffusion has been added (see Heinbach and Simon, Ap. J. **441**, 209 (1995)

ATIC-2 Results



The ATIC H and He spectra are fit by a diffusion model that includes weak re-acceleration due to Kolmogorov turbulence (Osborne and Ptuskin, 1988) but different source spectra for H and He are required.

Balloon Launch Facts

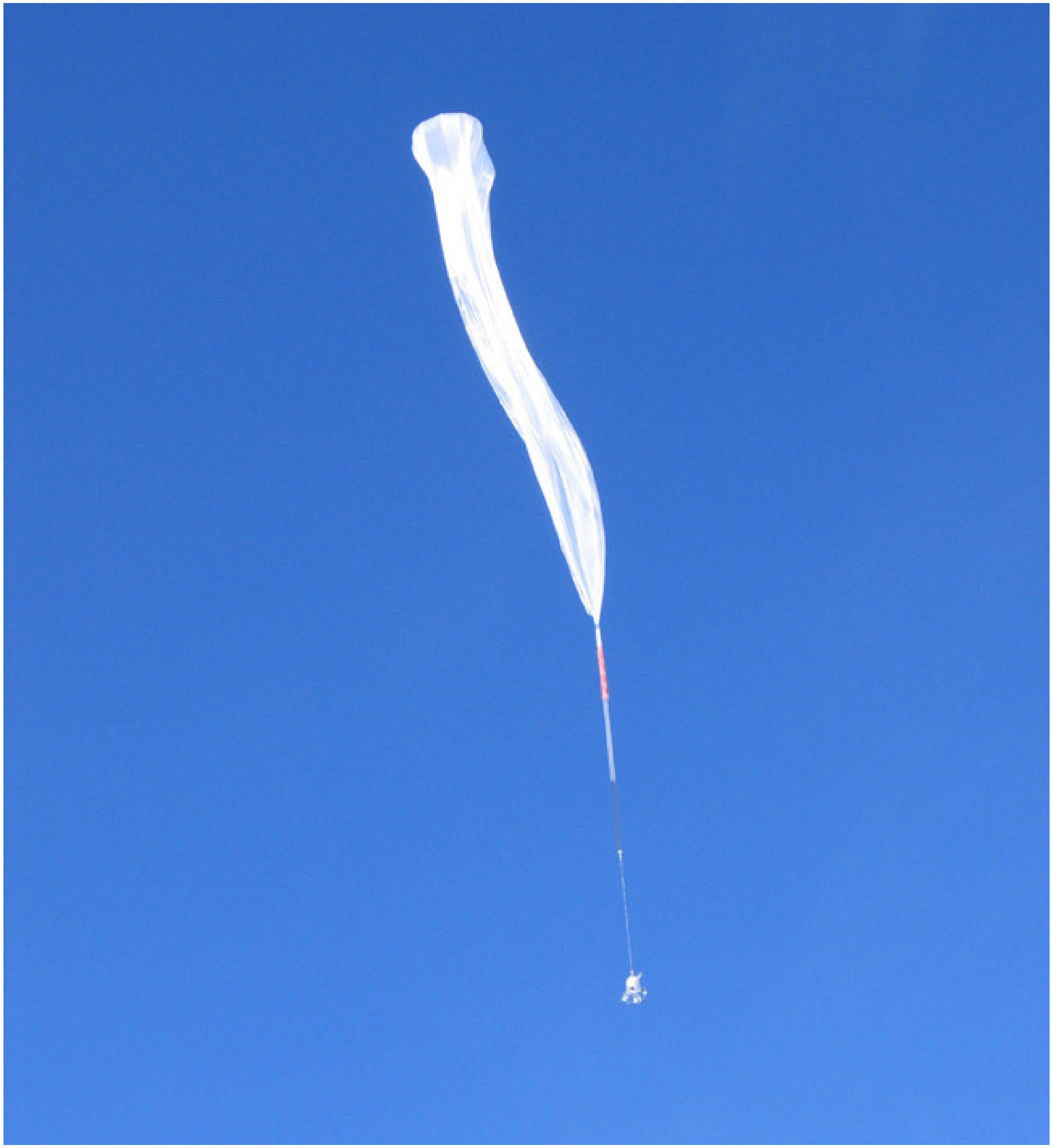
- Balloon volume 30,000,000 cu. ft.
- Balloon length ~200 ft
- Helium bubble at launch ~100,000 cu. ft.
- Gross Lift ~6,700 lbs
- Balloon mass ≈ Payload mass ≈ 3000 lbs
- Free lift ~670 lbs
- Ascent rate ~1000 ft/min

Launch Considerations

- Surface winds < 15 knots (lower is better)
- Winds should be steady in speed and direction for >2 hours
- The vertical wind gradient from the ground to ~300 ft altitude should be small
- Winds aloft should be circumpolar

Notice: 1) how the bubble is distorted by the wind and 2) the absence of a sounding balloon

- Notice the shape of the balloon
    - The balloon is not ascending vertically. A strong wind shear has distorted the balloon
    - The reefing sleeve has already split all the way to the parachute.



Landing