Astronomy 536

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for
Tom Harrison
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Cosmic rays

- Particles in outer space

- Cosmic ray research began in 1912 when Victor Hess, of the Vienna University, and 2 assistants flew in a balloon to an altitude of about 16,000 ft. They discovered evidence of a very penetrating radiation (cosmic rays) coming from outside our atmosphere. In 1936, Hess was awarded the Nobel prize for this discovery.
1932

While watching the tracks of cosmic ray particles passing through his cloud chamber, Carl Anderson discovered antimatter in the form of the antielectron, later called the positron. A positron is a particle exactly like an electron, but with an opposite, positive charge.

A debate raged over the nature of cosmic rays. According to a theory of Robert Millikan, they were gamma rays from space -- hence the name "cosmic rays." But evidence was mounting that cosmic rays were, in fact, mostly energetic particles.
Particles...

- Usually charged particles
- Cosmic rays = high energy physic 1930-1950
- Gamma rays
- Neutrinos

*FIG. 16. A positron of 2700 million volts energy.*
*FIG. 17. An electron of 5000–7000 million volts energy.*
• **Galactic Cosmic Rays:** Galactic cosmic rays (GCRs) are the high-energy particles that flow into our solar system from far away in the Galaxy. Cosmic rays provide one of our few direct samples of matter from outside the solar system.

• **Solar Particles:** The Sun also is a sporadic source of cosmic ray nuclei and electrons that are accelerated by shock waves traveling through the corona, and by magnetic energy released in CMEs.

• **Jupiter Too:** Jupiter is a source of low energy electrons
SOURCE(s)

Nucleosynthesis of source material
- Stellar Atm. (?)
- Grains (?)

ACCELERATION

T1

Interactions with ISM and fields.
Production
Escape
Decay
Reacceleration (?)

EXOTIC STUFF

Cross Sections

T2

T3

PROPAGATION

Solar Modulation

Enters Solar System

Arrival at/near Earth

Geomagnetic Cutoff
Earth's Atmosphere

T4

Note: Not to scale.

Thursday, March 19, 2009
The problem of understanding the origin of the Galactic Cosmic Rays (GCRs) is an old and recalcitrant one. It is actually several distinct problems.

First, there is the question of the origin of the energy. What powers the accelerator and how does it work?

Second, there is the question of the origin of the particles which are accelerated. Out of what component of the Galaxy does the accelerator select particles to turn into cosmic rays?

Third, there is the question of how much of the observed cosmic-ray spectrum is in fact of Galactic origin. Over what energy range does the accelerator work and what spectral form does its output have?

Finally, there is the question of how many different types of accelerator are required.

Can one basic process explain all the data, or do we need to invoke multiple sources and mechanisms? Of course a satisfactory physical model for the origin of the GCRs should simultaneously answer all these questions, however, in the context of looking for observational tests, it is sensible to adopt a ‘divide and conquer’ strategy and regard them as separate questions.
The "composition" of cosmic rays describes what fraction of cosmic rays are protons, what fraction are helium nuclei, etc. All of the natural elements in the periodic table are present in cosmic rays, in roughly the same proportion as they occur in the solar system. But detailed differences provide a "fingerprint" of the cosmic ray's source. Measuring the quantity of each different element is relatively easy, since the different charges of each nucleus give very different signatures. Harder to measure, but a better fingerprint, is the isotopic composition (nuclei of the same element but with different numbers of neutrons). To tell the isotopes apart involves, in effect, weighing each atomic nucleus that enters the cosmic ray detector.
Cosmic rays include essentially all of the elements in the periodic table; about 89% of the nuclei are hydrogen (protons), 10% helium, and about 1% heavier elements. The common heavier elements (such as carbon, oxygen, magnesium, silicon, and iron) are present in about the same relative abundances as in the solar system, but there are important differences in elemental and isotopic composition that provide information on the origin and history of galactic cosmic rays.

For example there is a significant overabundance of the rare elements Li, Be, and B produced when heavier cosmic rays such as carbon, nitrogen, and oxygen fragment into lighter nuclei during collisions with the interstellar gas.

The isotope $^{22}\text{Ne}$ is also overabundant, showing that the nucleosynthesis of cosmic rays and solar system material have differed.

Electrons constitute about 1% of galactic cosmic rays. It is not known why electrons are apparently less efficiently accelerated than nuclei.
• All particle, all sources, energy spectrum
• Can only look “up”
• Enormous range of energies
• High energy particles are rare
The energy of cosmic rays is usually measured in units of MeV, for mega-electron volts, or GeV, for giga-electron volts. Most galactic cosmic rays have energies between 100 MeV (corresponding to a velocity for protons of 43% of the speed of light) and 10 GeV (corresponding to 99.6% of the speed of light).

The number of cosmic rays with energies beyond 1 GeV decreases by about a factor of 50 for every factor of 10 increase in energy. Over a wide energy range the number of particles per m$^2$ per steradian per second with energy greater than E (measured in GeV) is given approximately by 
\[ N(>E) = k(E + 1)^{-a}, \]
where \( k \sim 5000 \) per m$^2$ per steradian per second and \( a \sim 1.6 \).

The highest energy cosmic rays measured to date have had more than $10^{20}$ eV, equivalent to the kinetic energy of a baseball traveling at approximately 100 mph!

The only theory of particle acceleration which at present is sufficiently well developed and specific to allow quantitative model calculations, and which appears capable of meeting many of the observational constraints on any cosmic-ray acceleration theory, is diffusive acceleration applied to the strong shocks associated with supernova remnants.
The only theory of particle acceleration which at present is sufficiently well developed and specific to allow quantitative model calculations, and which appears capable of meeting many of the observational constraints on any cosmic-ray acceleration theory, is diffusive acceleration applied to the strong shocks associated with supernova remnants.

It is believed that most galactic cosmic rays derive their energy from supernova explosions, which occur approximately once every 50 years in our Galaxy. To maintain the observed intensity of cosmic rays over millions of years requires that a few percent of the more than $10^{51}$ ergs released in a typical supernova explosion be converted to cosmic rays.

There is considerable evidence that cosmic rays are accelerated as the shock waves from these explosions travel through the surrounding interstellar gas. The energy contributed to the Galaxy by cosmic rays (about 1 eV per cm$^3$) is about equal to that contained in galactic magnetic fields, and in the thermal energy of the gas that pervades the space between the stars.
Energy and Acceleration

Fermi acceleration, sometimes referred to diffusive shock acceleration (a subclass of Fermi acceleration), is the acceleration that charged particles undergo when reflected by a magnetic mirror. This is thought to be the primary mechanism by which particles gain energy beyond the thermal energy in astrophysical shock waves. It plays a very important role in many astrophysical models, mainly of shocks including solar flares and supernova remnants.
First order Fermi acceleration: Shock waves typically have moving magnetic inhomogeneities both preceding and following them. Consider the case of a charged particle traveling through the shock wave (from upstream to downstream). If it encounters a moving change in the magnetic field, this can reflect it back through the shock (downstream to upstream) at increased velocity. If a similar process occurs upstream, the particle will again gain energy. These multiple reflections greatly increase its energy. The resulting energy spectrum of many particles undergoing this process (assuming that they do not influence the structure of the shock) turn out to be a power law:

\[
\frac{dN}{dE} \propto E^{-p}
\]

The term "First order" comes from the fact that the energy gain per shock crossing is proportional to $\beta s$, the velocity of the shock divided by the speed of light.
THE CRAB NEBULA’S COSMIC-RAY ACCELERATION ZONE REVEALED
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Received 1993 January 22; accepted 1993 April 2

ABSTRACT

We analyze and discuss the geometrical and physical properties of the geotomically coherent, and the timevariable radio spectral index perturbations near the center of the Crab Nebula recently discovered by Bietenholz & Kronberg. Although the detailed explanation of the three-dimensional geometry of the x perturbations is not yet clear, we propose that they are the sites of electron acceleration by MHD waves. The MHD waves are also the cause of the isotropization of the plasma flow outside the inner “emission hole” at the Crab’s center, and we show how the MHD turbulence near the shock produces the observed spectral index, x ~ 0 in the x-ridges, and a somewhat steeper spectrum further out in the supernova remnant, as is also observed.

We also suggest a physical explanation for the “persistent” magnetic field cell structure, and the typical 10° cell size as determined from the projected magnetic field maps of Bietenholz & Kronberg.

Subject headings: acceleration of particles — cosmic rays — ISM: individual (Crab Nebula) — MHD

1. INTRODUCTION

A remarkable image which reveals for the first time the three-dimensional geometry of the Crab Nebula’s particle acceleration zone has recently been published and discussed by Bietenholz & Kronberg (1992). It is one of a series of papers analyzing a new generation of multifrequency, precision radio images of the Crab Nebula (SN 1054) at arcsecond resolution (Bietenholz & Kronberg 1990, 1991; Bietenholz et al. 1991). These were taken with all configurations of the NRAO Very Large Array (VLA) between 1987 July and 1988 March.

The new VLA images reveal organized, arcsecond-scale radio “wisps” within the inner supernova remnant (Fig. 1 [Pl. 3]). The radio “wisps” constitute a series of arclike features of the radio continuum emission which are most clearly visible as perturbations of the radio spectral index x, in that they have a significantly flatter x than the body of the nebula. These features have a thickness ≤ 0.01 pc (3 × 10^16 cm), and are continuous over ~ 0.6 pc (Fig. 1 and Bietenholz & Kronberg 1992). Their flatter spectral index indicates that they are sites of freshly accelerated cosmic ray electrons. Their (projected) geometrical form indicates that, in three-dimensional space, they are not sheets, but rather tubes, or filaments, which fill a relatively small fraction of the inner nebula’s volume. Bietenholz & Kronberg (1992) estimated that their volume emissivity at 1.5 GHz is enhanced by a factor of between 5 and 80 relative to the local ambient radio continuum emission.

The radio wisps occur in groups close to the optical regions of ordered, circularly polarized emission, and are rotating in a plane tilted to our line of sight. This offers an opportunity to examine the Crab’s inner particle acceleration zone in some detail.

We have devised in this paper a method to analyze the three-dimensional geometry of the particle acceleration zones. The procedure involves a computer search for a set of arcs without a priori bias, the true shape of the particle acceleration zones which conform with the data. The computer search consisted in finding the local maxima in the spectral index map. The maxima were searched in two sets of orthogonal directions: one set oriented north-south and east-west and the other rotated 45° from the first one. The standard deviation of the data points along each search line was used as a measure of the noise, which in turn was used to choose a threshold in the selection of the local maxima. Once the local maxima were found, an algorithm was applied to search for contiguous “ridge lines” among the maxima.

These procedures confirm the following: (1) several spatially contiguous “enhanced x-zones” exist within the inner 0.6 pc of the supernova remnant, and (2) that they appear to be preferentially
Cosmic Ray Production in Supernova Remnants

ASCA observations of the supernova remnant SN 1006 have revealed the first strong observational evidence for the production of cosmic rays in the shock wave of a supernova remnant. These results come from the detection of non-thermal synchrotron radiation from two oppositely located regions in the rapidly expanding supernova remnant. The remainder of the supernova remnant, in contrast, produces thermal X-ray emission showing Oxygen, Neon, Magnesium, Silicon, Sulfur, and Iron line emission.

Composition - Nuclear

- Cosmic Ray vs. Solar

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Figure 1: Plots of the GCRS and Solar abundances against atomic number for the major elements, both normalised to Hydrogen=10^6, and of the ratio GCRS/Solar. A numerical table of these values can be found in Meyer, Drury and Ellison 1998.
Composition - Nuclear

- **Source - FIP vs Volatility**
- **Source material**
  - Sun-like star (FIP)
  - ions sputtered off dust grain (Volatility)
- $^{22}\text{Ne}/^{20}\text{Ne}$ ratio, a factor of five times the Solar System ratio, results from a mixing of freshly synthesized nucleosynthetic material in supernova active cores of superbubbles.
Cosmic Ray Source Material and History?

Best measurements of this come from ACE experiment - NASA/Explorer, 1997-2000

CRIS instrument silicon detectors for Z, A in the ~100MeV range.

ACE data set

![Diagram showing the ACE data set for cosmic rays measured with the ACE Cosmic Ray Isotope Spectrometer. The x-axis represents calculated mass, and the y-axis shows the relative count rate. The data is collected from August 1997 to April 2000.](Image)
Lifetime of Cosmic Rays from ACE  (15±1.6 Myr)

(Secondary radioactive nuclei with comparable half-lives)
Also can determine mean density of propagation volume $n = 0.34 \pm 0.04$ atoms per cc (Because nuclei loss occurs by both fragmentation and decay)
ACE - Time between nucleosynthesis and acceleration $>10^5$ years
(Absence of electron capture nucleus Ni$^{59}$)

\[ ^{59}\text{Ni} \rightarrow ^{59}\text{Co} \quad (T_{1/2}=7.5 \times 10^4 \text{ yr}) \]
Direct Measurements

ATIC

Fig. 14. Schematic of the ATIC balloon-borne instrument along with its Antarctic flight trajectory. This figure was taken from OG1.5,2111.

Conclusions

A large number of very interesting and informative papers were presented at the 27 International Cosmic Ray Conference. These papers represent the enormous ongoing research effort in the field of cosmic ray science and dedication of hundreds of researchers. Progress is being made and our understanding of cosmic rays is improving.

The CRIS instrument on ACE continues to generate outstanding results coupled with thorough analysis and interpretations. ACE is one of NASA’s great success stories. Several papers presented at this conference have commented that the interpretation of the ACE observations are limited by the knowledge of the associated cross sections. This is a good indication of how well the CRIS instrument performed.

Data collected to date on antimatter, antiprotons and positrons suggest no evidence for exotic sources. The flux of antiprotons is in good agreement with the predictions of secondary production models. The search for a primary component of both antiprotons and positrons now must move towards higher energies with the PAMELA and AMS experiments.

Observations of both -rays and X-rays continue to decrease the possibility that antimatter domains are located close enough to earth so that antimatter particles can propagate here in a time shorter than the age of the Universe. The BESS-Polar instrument will be able to push the search for antimatter down to the 10 level.

Direct measurements of cosmic rays continue to advance towards higher energies. By the 28 International Cosmic Ray Conference we should have several exciting results from the ATIC collaboration and hopefully some from the TRACER experiment. The ultimate goal of all of these high energy, direct measurements is to look for the dependent roll over of the cosmic ray fluxes. If seen, this observation will provide strong evidence for the supernovae acceleration model and greatly increase our understanding of the lifecycle of cosmic rays. The question is: will these instruments have the geometric exposure necessary for these observations? The answers await us at the next ICRC in Tsukuba, Japan.

References


Direct Measurements
CREAM

Diagram of CREAM apparatus with labels for TCD, Top TRD, CD, Bottom TRD, SCD, S0/S1, Targets, S2, S3, and Calorimeter.
Direct Measurements

PAMELA

- S1, S2, S3; double layers, x-y
- plastic scintillator (8mm)
- ToF resolution ~300 ps (S1-3 ToF >3 ns)
- lepton-hadron separation < 1 GeV/c
- S1.S2.S3 (low rate) / S2.S3 (high rate)

• Permanent magnet, 0.43 T
• 21.5 cm² sr
• 6 planes double-sided silicon strip detectors (300 μm)
• 3 μm resolution in bending view → MDR
  ~800 GV (6 plane) ~500 GV (5 plane)

• 44 Si-x / W / Si-y planes (380)
• 16.3 X0 / 0.6 L
• dE/E ~5.5 % (10 - 300 GeV)
• Self trigger > 300 GeV / 600 cm² sr

- 36 ³He counters
- ³He(n,p)T; E_p = 780 keV
- 1 cm thick poly + Cd moderator
- 200 μs collection

~470 Kg / ~360 W
Detectors - dE/dx

The Bethe-Bloch formula describes the energy-loss by charged particles traversing matter. Charged particles moving through matter interact with the electrons of atoms in the material. The interaction excites or ionizes the atoms. This leads to an energy loss of the traveling particle. The Bethe formula which was found by Hans Bethe in 1930, describes the energy loss per distance traveled (or the stopping power of the material traversed):

\[-\frac{dE}{dx} = \frac{4\pi}{m_e c^2} \cdot \frac{n z^2}{\beta^2} \cdot \left(\frac{e^2}{4\pi \varepsilon_0}\right)^2 \cdot \ln\left(\frac{2m_e c^2 \beta^2}{I \cdot (1 - \beta^2)}\right) - \beta^2\]

Needs to be modified for electrons

\[-\frac{dE}{dx} \propto \frac{z^2}{\beta^2}\]
Detectors - Cherenkov Radiation

Cherenkov radiation is electromagnetic radiation emitted when a charged particle passes through an insulator at a speed greater than the speed of light in that medium.

\[ \cos \theta = \frac{1}{n \beta} \]
Detectors - Cherenkov Radiation
A transition radiation detector (TRD) is a particle detector utilizing the \( \gamma \)-dependent threshold of transition radiation in a stratified material. It contains many layers of materials with different indices of refraction. At each interface between materials, the probability of transition radiation increases with the relativistic gamma factor. Thus particles with large \( \gamma \) give off many photons, and small \( \gamma \) give off few. For a given energy, this allows a discrimination between a lighter particle (which has a high \( \gamma \) and therefore radiates) and a heavier particle (which has a low \( \gamma \) and radiates much less).
Detectors - Calorimeter

Modern Calorimeters provide measures the interaction topology of incident particle along with the tradition measurement of energy.
Detectors - Calorimeter

1 TeV electron

3 TeV proton
Interesting Topics - Ultra High Energy

Event rate is very small (1 particle/\(\text{km}^3\) century)

Large detector is needed

Must be ground-based

Measure the interaction of the incident cosmic ray with the earth’s atmosphere
Interesting Topics - Ultra High Energy

The more components of the shower that are measured, the better the determination of the primary particle’s identity and energy.

Wave of particles in an EAS is on the order of meters deep.

muon are important for identity of incident particle
Interesting Topics - Ultra High Energy

Measuring cosmic-ray and gamma-ray air showers

shower max. \(\sim 60\) kft.
Development of cosmic-ray air showers

Primary particle (e.g. iron nucleus)

First interaction

Pion decays

Second interaction

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Interesting Topics - Ultra High Energy
..... allowed researchers for the first time to see statistical peaks in the number of cosmic-ray events originating from relatively small regions of the sky. Milagro observed an excess of cosmic ray protons in an area above and to the right of Orion, near the constellation Taurus. The other hot spot is a comma-shaped region in the sky near the constellation Gemini.
The planned Auger Observatory will consist of two 3000 km² EAS arrays of 1600 water Cherenkov tanks each. Although the arrays will be equipped with fluorescence detectors the bulk of the data set will be ground array only (90%). This paper describes the process used to generate simulated ground array data, and its subsequent reanalysis. The current predicted experimental performance is given.
Interesting Topics - Ultra High Energy

Auger - Argentina
The Akeno Giant Air Shower Array (AGASA) is a very large surface array designed to study the origin of ultra-high energy cosmic rays. It covers an area of 100km² and consists of 111 surface detectors and 27 muon detectors.
Cosmic-ray shock acceleration in the presence of self-excited waves

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We have shown that due to slowing down the rate of particle acceleration, compared to the rate expected for the case of a diffusion coefficient everywhere equal to its value at the shock. The results of this paper are particularly relevant for the study of the acceleration of very high energy particles by supernova shocks. Since the acceleration mechanism is slow, it takes a long time to attain high energies. Supernova shock have a finite lifetime so that even with the most optimistic assumptions on the diffusion coefficient, particles of charge \( Z \) cannot go beyond an energy of \( \sim 10^5 Z \text{GeV} \) (Cesarsky and Lagage, 1981). Thus the theory predicts a cut-off or at least a break in that part of the spectrum. The observed spectrum of galactic cosmic rays is a power law with constant index up to \( 10^5-10^6 \text{GeV} \). The influence of the spatial dependence of the diffusion coefficient is to decrease the maximum energy attained. A discussion giving more realistic values of this maximum energy is included in a separate paper (Lagage and Cesarsky, 1982).
• Possible Acceleration $>10^{14}$ eV

• Neutron Stars (formation)

• Binary Stars - shock in accretion flow

• Disk Dynamo

• Pulsar wind shock

• Turbulent reconnection
This limit was computed in 1966 by Kenneth Greisen[1] and Vadim Kuzmin and Georgiy Zatsepin[2] independently; based on interactions predicted between the cosmic ray and the photons of the cosmic microwave background radiation. They predicted that cosmic rays with energies over the threshold energy of $6 \times 10^{19}$ eV would interact with cosmic microwave background photons to produce pions. This would continue until their energy fell below the pion production threshold.

$$\gamma + p \rightarrow \Delta^+ \rightarrow p + \pi^0$$

or

$$\gamma + p \rightarrow \Delta^+ \rightarrow n + \pi^+$$

Because of the mean path associated with the interaction, extragalactic cosmic rays with distances more than 50 Mpc (163 Mly) from the Earth with energies greater than this threshold energy should never be observed on Earth, and there are no known sources within this distance that could produce them.
Interesting Topics - Ultra High Energy

Energy distribution of higher energy cosmic rays

The big argument
Interesting Topics - Cosmic Rays <-> Dark Matter

- S1, S2, S3; double layers, x-y
- plastic scintillator (8mm)
- ToF resolution ~300 ps (S1-3 ToF >3 ns)
- lepton-hadron separation < 1 GeV/c
- S1.S2.S3 (low rate) / S2.S3 (high rate)

- Permanent magnet, 0.43 T
- 21.5 cm² sr
- 6 planes double-sided silicon strip detectors (300 μm)
- 3 μm resolution in bending view ➔ MDR ~800 GV (6 plane) ~500 GV (5 plane)

- 44 Si-x / W / Si-y planes (380)
- 16.3 X0 / 0.6 L
- dE/E ~5.5 % (10 - 300 GeV)
- Self trigger > 300 GeV / 600 cm² sr

- 36 ³He counters
- ³He(n,p)T; E_p = 780 keV
- 1 cm thick poly + Cd moderator
- 200 μs collection
Interesting Topics - Cosmic Rays <-> Dark Matter

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**Figure 1:**
- The positron fraction $\frac{p}{p}$ as a function of kinetic energy (GeV) for different models and experimental data.
- Models include Donato 2001 (D, $\phi=500$ MV), Simon 1998 (LBM, $\phi=500$ MV), and Ptuskin 2006 (PD, $\phi=550$ MV).
- The red circles represent the PAMELA data.

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**Figure 2:**
- The antiproton-to-proton flux ratio $\frac{\bar{p}}{p}$ as a function of kinetic energy (GeV) for different models and experimental data.
- Models include Ptuskin 2006 (PD, $\phi=550$ MV) and Moskalenko & Pines (2000).
- The red circles represent the PAMELA data.

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**Figure 3:**
- Positron fraction $\frac{\phi(e^+)}{\phi(e^+)+\phi(e^-)}$ as a function of energy (GeV).
- The line represents the calculation by Ptuskin et al. 2006.
- The red circles represent the PAMELA data.

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**Figure 4:**
- Antiproton-to-proton flux ratio $\frac{\bar{p}}{p}$ as a function of kinetic energy (GeV).
- The solid line shows the calculation by Ptuskin 2006 (PD, $\phi=550$ MV).
- The dotted lines show the limits from other experiments.
- The red circles represent the PAMELA data.

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**Tables:**
- Table 1: Experimental data for different models and experimental data.
- Table 2: Parameters for different models and experimental data.

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- We would like to acknowledge contributions and support from various organizations.
- The PAMELA collaboration includes contributions from: Italian Space Agency (ASI), Deutsches Zentrum fur Luft- und Raumfahrt (DLR), Swedish Research Council, The Russian Space Board, Swedish Research Council, The Russian Space Board, and others.

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- MASS 1991
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- Muller & Tang 1987
- Clem & Evenson 2007
- AMS98
- HEAT94+95
- HEAT-pbar 2000
- TS93
- HEA794+95
- CAPRICE94
- AMS98
- HEAT00
- Clem & Evenson 2007
- PAMELA
Interesting Topics - Cosmic Rays <-> Dark Matter

ATIC Balloon Instrument

Difficult to produce a “bump” with “astrophysics”
-> other source?
Phenomenology of Dark Matter annihilation into a long-lived intermediate state

Secondary radiation from the Pamela/ATIC excess and relevance for Fermi

PAMELA, DAMA, INTEGRAL and Signatures of Metastable Excited WIMPs

Positron Excess, Luminous-Dark Matter Unification and Family Structure

High Energy Cosmic Rays from Decaying Supersymmetric Dark Matter

Dark Matter Signals In Cosmic Rays?

Decaying Hidden Gaugino as a Source of PAMELA/ATIC Anomalies

Bounds on Cross-sections and Lifetimes for Dark Matter Annihilation and Decay into Charged Leptons from Gamma-ray Observations of Dwarf Galaxies

Intermediate Mass Black Holes and Nearby Dark Matter Point Sources: A Myth-Buster

PAMELA/ATIC Anomaly from Exotic Mediated Dark Matter Decay

Nambu-Goldstone Dark Matter and Cosmic Ray Electron and Positron Excess

The PAMELA and ATIC Signals From Kaluza-Klein Dark Matter

PAMELA/ATIC anomaly from the meta-stable extra dark matter component and the leptophilic Yukawa interaction

Decaying Hidden Dark Matter in Warped Compactification

A new twist on excited dark matter: implications for INTEGRAL, PAMELA/ATIC/PPB-BETS, DAMA

Cosmic Rays from Dark Matter Annihilation and Big-Bang Nucleosynthesis

Dark Matter Signals from Cascade Annihilations

Positrons and antiprotons from inert doublet model dark matter

On the cosmic electron/positron excesses and the knee of the cosmic rays -- a key to the 50 years' puzzle?

A Gamma-Ray Burst/Pulsar for Cosmic-Ray Positrons with a Dark Matter-like Spectrum

Dissecting Pamela (and ATIC) with Occam's Razor: existing, well-known Pulsars naturally account for the "anomalous" Cosmic-Ray Electron and Positron Data

Gamma-ray and Radio Constraints of High Positron Rate Dark Matter Models Annihilating into New Light Particles

The PAMELA and ATIC Excesses From a Nearby Clump of Neutralino Dark Matter

A Supersymmetric B-L Dark Matter Model and the Observed Anomalies in the Cosmic Rays

Astrophysical Probes of Unification

Prospects for Detecting Neutrino Signals from Annihilating/Decaying Dark Matter to Account for the PAMELA and ATIC results

Discriminate different scenarios to account for the PAMELA and ATIC data by synchrotron and IC radiation

Can the WIMP annihilation boost factor be boosted by the Sommerfeld enhancement?

Dark matter and sub-GeV hidden U(1) in GMSB models

Neutrino Signals from Annihilating/Decaying Dark Matter in the Light of Recent Measurements of Cosmic Ray Electron/Positron Fluxes

Gamma-ray and radio tests of the e+e- excess from DM annihilations

The Case for a 700+ GeV WIMP: Cosmic Ray Spectra from ATIC and PAMELA

Status of indirect searches in the PAMELA and Fermi era

Decaying Hidden Gauge Boson and the PAMELA and ATIC/PPB-BETS Anomalies

PAMELA data and leptonically decaying dark matter

An Effective Theory of Dirac Dark Matter

Dark Matter through the Axion Portal

Slightly Non-Minimal Dark Matter in PAMELA and ATIC

Two component dark matter

A Theory of Dark Matter

Model-independent implications of the e+ e-, antiproton cosmic ray spectra on properties of Dark Matter
The neutrino was proposed by Wolfgang Pauli in 1930; but it would be 26 years from then before the neutrino was actually detected. Pauli proposed the existence of the neutrino as a solution to a frustrating problem in a nuclear process called beta decay. It seemed that examination of the reaction products always indicated that some variable amount of energy was missing. Pauli concluded that the products must include a third particle, but one which didn't interact strongly enough for it to be detected. Enrico Fermi called this particle the neutrino which meant "little neutral one".

\[ n^0 \rightarrow p^+ + e^- + \bar{\nu}_e \]

\[ energy + p^+ \rightarrow n^0 + e^+ + \nu_e \]
Solar Neutrino

PP1: \( p + p \rightarrow D + \text{positron} + \text{neutrino} + 0.26 \text{ MeV} \)
PP2: Be(7) + electron \( \rightarrow \) Li(7) + neutrino + 0.80 MeV
PP3: B(8) \( \rightarrow \) Be(8) + positron + neutrino + 7.2 MeV

Observe the neutrino to confirm that we understand the sun

In the late 1960s, Ray Davis's and John N. Bahcall's Homestake Experiment was the first to measure the flux of neutrinos from the sun and detect a deficit. The experiment used a chlorine-based detector.
The Sudbury Neutrino Observatory (SNO) results have provided revolutionary insight into the properties of neutrinos and the core of the sun. The detector, shown in the artist's conception right, was built 6800 feet under ground, in INCO's Creighton mine near Sudbury, Ontario, Canada. SNO was a heavy-water Cherenkov detector designed to detect neutrinos produced by fusion reactions in the sun. Neutrinos reacted with the heavy water (D2O) to produce flashes of light called Cherenkov radiation. This light was then detected by an array of 9600 photomultiplier tubes mounted on a geodesic support structure surrounding the heavy water vessel.
Charged-Current Reaction

- electron neutrino
- Cerenkov Light
- electron
- protons
- Deuteron

Neutral-Current Reaction

- neutrino
- Deuteron
- proton
- neutron
- \(^{35}\text{Cl}\)
- \(^{36}\text{Cl}\)
- \(\gamma\) rays
Interesting Topics - Neutrinos

The reason for high-energy neutrino astronomy is to open up all wavelengths for astronomy and to peer into sources that would be opaque to photons and protons. At high energies photons (gamma-rays) and protons are not viable probes.

• TeV photons are absorbed on the infrared extragalactic background. Higher energies are blocked by the cosmic microwave background and then the radio background.

• Protons with energies less than $10^{19}$ eV do not point back to their origin because Galactic magnetic fields bend them significantly. At five times that energy ($5 \times 10^{19}$ eV) they are degraded/absorbed by the cosmic radiation field because of photo-pion production and to a lesser extend because of photo-pair production.

• Neutrinos can come from cosmological distances.

• Neutrinos can escape from optically thick sources.
• Detection of Neutrino "Point" Sources
  - AGNs Active Galactic Nuclei
  - GRBs Gamma-ray Bursters
  - Supernovas

• Diffuse Astrophysical Flux
  - Unresolved Point Sources
  - Products of interactions between the CMB and ultra-high energy cosmic rays
  - Cosmic Rays interacting with Galactic matter
  - Potential neutrino flux from Topological Defects
Interesting Topics - Neutrinos

AMANDA - ICE CUBE

The IceCube Neutrino Detector is a neutrino telescope currently under construction at the South Pole. Like its predecessor, the Antarctic Muon And Neutrino Detector Array (AMANDA), IceCube is being constructed in deep Antarctic ice by deploying thousands of spherical optical sensors (photomultiplier tubes, or PMTs) at depths between 1,450 and 2,450 meters. The sensors are deployed on "strings" of sixty modules each, into holes in the ice melted using a hot water drill.

The main goal of the experiment is to detect neutrinos in the high energy range, spanning from $10^{11}$eV to about $10^{21}$ eV. The neutrinos are not detected themselves. Instead, the rare instance of a collision between a neutrino and an atom within the ice is used to deduce the kinematical parameters of the incoming neutrino. Current estimates predict the detection of about one thousand such events per day in the fully constructed IceCube detector. Due to the high density of the ice, almost all detected products of the initial collision will be muons.
Still waiting for some events!

To date ..... the only “astrophysical” neutrinos detected were associates with SN1987A