Astroparticle Physics

Summer student Lecture 2010

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Astroparticle Physics: History

High energy physics started with discoveries and analysis of particles generated by the cosmic radiation in the atmosphere.

- 1932: Positron
- 1937: Muons
- 1947: Pions, Λ, K
- 1952: Ξ⁻, Σ⁺
- 1971: Charm (?)
- 1998: Neutrino oscillation
Astroparticle Physics: Cosmic Laboratory

Really high energies are only provided by the cosmos:

- particles beyond $10^{20}$ eV
  ($10^7 \cdot$ LHC beam energy)
- Access to physics at the Planck scale via indirect observations of the very early universe

Really long baselines are only provided by the cosmos:

- Oscillation of $\nu$ from the sun: $150 \cdot 10^9$ m
- $\nu$ from SN 1987A (LMC): 150,000 light-years
Astroparticle Physics: Phenomena

There are many natural phenomena waiting for explanation:

- Cosmic Radiation
- Dark Matter
- Cosmic Microwave Background Radiation

The cosmic connection:

- The development (and origin?) of the cosmos can only be addressed with HEP knowledge
A Definition of Astroparticle Physics

Three Aspects:

• Learning HEP from astrophysics:
  Neutrino properties, cross sections at ultra high energies, new forms of matter (dark matter and dark energy), time variation of fundamental constants, space-time structure

• Applying HEP techniques to astrophysics:
  Calorimetry and tracking detectors onboard satellites and balloons, ground based scintillators and Cherenkov detectors, handling of large volume data sets, astronomy with neutrinos

• Cosmology with cognitions of HEP:
  Big Bang theory, nucleon synthesis, candidates for dark matter
Tools and Sites of Astroparticle Physics

Unusual laboratories ...

... and a little adventure.

(the real motivation?)
Collaborations in Astroparticle Physics

Size about an order of magnitude smaller than in HEP

MAGIC ("Cherenkov-Telescope")

ATLAS @ LHC
Astroparticle Physics

Topics for today:

• High Energy Particles from the Cosmos.
• The new Astronomy.

On Friday:

in context with the ALPS experiment some discussion of Dark Matter in the Universe.
Astroparticle Physics

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A simple Experiment

What happens to a charged electrometer?

The charge is carried away by ions of the air.

Why is a fraction of the air ionized?
Viktor F. Hess 1912:
Ionisation of air increases with increasing altitude
 Radiation from the cosmos hits the atmosphere ("Cosmic Rays")

http://helios.gsfc.nasa.gov/cosmic.html
http://ik1au1.fzk.de/KASCADE/KASCADE_general.html
http://www.auger.org/
Die Ergebnisse der vorliegenden Beobachtungen scheinen am ehesten durch die Annahme erklärt werden zu können, daß eine Strahlung von sehr hoher Durchdringungskraft von oben her in unsere Atmosphäre eindringt, und auch noch in deren untersten Schichten einen Teil der in geschlossenen Gefäßen beobachteten Ionisation hervorruft. Die Intensität dieser Strahlung scheint zeitlichen Schwankungen unterworfen zu sein, welche bei einstündigen Ablesungsintervallen noch erkennbar sind. Da ich im Ballon weder bei Nacht noch bei einer Sonnenfinsternis eine Verringerung der Strahlung fand, so kann man wohl kaum die Sonne als Ursache dieser hypothetischen Strahlung ansehen, wenigstens solange man nur an eine direkte $\gamma$-Strahlung mit geradliniger Fortpflanzung denkt.

A. H. Compton, 1932: What are the Constituents of CRs?
A. H. Compton, 1932: What are the Constituents of CRs?

The CR flux varies as function of the latitude:
The CRs consist of charged particles!

Arthur H. Compton
University of Chicago,
The Tasman Sea,
May 7, 1932.
A more sophisticated CR Detector

- Charged particles pass a scintillating material: molecules are excited and emit light.

- This light is guided to a photomultiplier tube (PMT) which converts the light into an electric signal.

- To get rid of the PMT noise usually two or more detectors are operated in coincidence.

http://research.fit.edu/quarknet/documents_qnet_detector_reference.htm
A more sophisticated CR Detector

Measurement principle:

http://leifi.physik.uni-muenchen.de/web_ph12/versuche/09szintil/szinti_zaebl_ani.htm
CR induce Extended Air Showers (EAS)

Pierre Auger 1938:
Observation of CR induced coincidences in widely separated detectors at the Jungfrau Joch.

Explanation:
Primary cosmic particle interacts with atoms in atmosphere, secondary particles undergo further interactions ➤ avalanche of particles (EAS)
Energy Spectrum of CR

At high energies very large detector installations necessary:
$10^4 \text{ m}^2 \text{ (knee)}$ to $10^9 \text{ m}^2$

Effect of $3 \cdot 10^{21} \text{ eV}$:

Full Name: Randall David Johnson
Height: 6-10. Weight: 231 lbs.
Bats: Right. Throws: Left. Pos: SP.
Born: September 10, 1963, Walnut Creek, CA,
College: USC2004
Salary: $16,500,000.
The hotter a material, the shorter the wavelength where the maximum intensity is radiated:

Wien’s law:  \[ E_{\text{max}}[\text{eV}] = 0.000427 \cdot T[\text{K}] \]
\[ \lambda_{\text{max}}[\text{nm}] = \frac{2903611}{T[\text{K}]} \]

\[ \lambda_{\text{max}} = 526 \text{ nm} = \frac{2903611 \text{ nmK}}{5523 \text{ K}} \]
Temperatures and Energies in the Cosmos

CR energies: the cosmos is not hot enough!
The energy spectrum of CRs is not a Planck spectrum.

Hence CRs do not originate from thermal processes.

CR gain their energies in cosmic accelerators.

They offer a view into the non-thermal universe.
Possible galactic Accelerators

- Supernova remnants develop shock fronts in the interstellar medium.
- Turbulent processes in the shock fronts are visible in radio and X-rays.

Are these the cosmic accelerators?
Acceleration by interstellar Shock Fronts

Proposed by E. Fermi 1949:

- Energy gain per crossing:
  \[ \Delta E = E \cdot (1+d) \]
- Probability to escape from shock region:
  \[ P_{\text{esc}} \]

Many crossings:

\[ N(E) \sim E^{-\alpha} \]
with \( \alpha = \ln(1/(1-P_{\text{esc}}))/\ln(1+d) + 1 \)

\( \alpha \approx 2 \) (Cas. A)
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with \( \alpha = \frac{\ln(1/(1-P_{\text{esc}}))}{\ln(1+d)} + 1 \)

\( \Phi \) power law with \( \alpha \approx 2 \) (Cas. A)
The experimental Challenge

From observation of extended air showers:

- direction, energy and mass range of the primary particle on a statistical basis

http://umdgrb.umd.edu/cosmic/milagro.html
KASCADE-Grande: an Experiment at the CR-Knee

KArlsruhe Shower Core and Array DEtector
KASCADE (1)

Measure different EAS components:

**Muon Tracking Detector:** 150 m² μ-tracking

- **Aim:** reconstruction of the mean production height of the muons by triangulation
- **additional mass parameter** ($E > 10^{16}$ eV)

**Electrons and photons**

**Muons**

**Angular resolution** (for single muons): ~ 0.5°
320 m$^2$ central calorimeter

Single 12 TeV hadron:
EAS Event

Particle distribution ➔ energy

Arrival time of shower front ➔ direction
From direction of (charged) CR:

No cosmic accelerators visible!
Naive expectation
visible light

Experimental result

"Sky map" with Cosmic Rays

From direction of (charged) CR:
No cosmic accelerators visible!
Why are CR isotropic?

- Charged CR do not point back to accelerators
- Number of neutral CR too small to identify accelerators with KASCADE type experiments.

What to do??
Strategies to identify the cosmic Accelerators

1. select photons (not charged) out of the CR

2. compare detailed measurements of the energy spectrum and mass composition of CR with accelerator models
Analyses of Energy Spectrum and Composition

Compare measurements with models

- assume CR energy spect., compos.
- simulate extended air showers
- predict experimental data
- experimental data

compare

different

Problem: two “set screws”!

modify

compare properties of CR with predictions of accelerator models
Results of CR Analyses around the Knee

KASCADE collaboration,
Astroparticle Physics 24(2005)1-25
Results of CR Analyses around the Knee

\[ \frac{dJ}{dE} \cdot E^{2.5} \]

\[ \text{primary energy } E \ [\text{GeV}] \]

- proton
- helium
- carbon

\[ \text{silicon} \]
\[ \text{iron} \]
Results of CR Analyses around the Knee

SIBYLL 2.1

\[ \frac{dN}{dE} \cdot E^{2.5} \quad \text{[m}^{-2} \cdot \text{s}^{-1} \cdot \text{sr}^{-1} \cdot \text{GeV}^{-1.5}] \]

- proton
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SIBYLL 2.1

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- silicon
- iron

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Details of the results depend on the EAS simulation used.

Common features are:

- The composition becomes heavier after the knee
- The knee-energies of CR mass groups are proportional to their electric charges $E_{\text{max}} \approx Z \cdot B \cdot L$
- Consistent with acceleration in supernova remnants
However …

KASCADE collaboration, Astroparticle Physics 24(2005)1-25

- “... none of the two interaction models is capable of describing the measured data consistently …”

- “At present, the limiting factors of the analysis are the properties of the high energy interaction models used and not the quality or understanding of the KASCADE data.”
Answers from the LHCf- Experiment at LHC?

Measure energy flux in the very forward region to constrain air shower simulations:

- 7TeV + 7TeV correspond to $10^{17}$eV CR, beyond the “knee”!
From the "Knee" to the highest CR Energies
New Challenges …

$10^4 \text{ m}^2$ Detector Area $\Rightarrow \Rightarrow \Rightarrow 10^9 \text{ m}^2$ Detector Area

KASCADE

fully operational since end of 2007

AUGER

1600 water Cherenkov detectors
3000 km$^2$
4 fluorescence telescopes
... and Chances

• CR at highest energies are hardly deflected by magnetic fields. Possibility of “astronomy”? 

• New measurements possible: scintillation light, initiated by the air shower in the atmosphere.  
measure the whole shower development!
From Karlsruhe to the Pampa Amarilla

- Large flat area
- Clear nights
- Only few villages
  - dark nights

Use the atmosphere as a "fully active" calorimeter!

KASCADE:
only one active layer at ground level
The Pierre AUGER Observatory

air shower development

Physics with much better systematics!
Physics with the Auger Observatory

- Energy spectrum of highest energy CR
- Composition of highest energy CR
- Sources of highest energy CR
- Neutrino physics
- Air shower physics
- Tests of simulations
- …
Energy Spectrum: the GZK-Cutoff

Greisen-Zatsepin-Kuz'min:

The universe appears opaque to CRs of highest energies due to photoproduction of pions

\[ N + \gamma \rightarrow N' + n \cdot \pi \]

with CMBR-photons (\(E_\gamma = 10^{-3}\) eV):

photoproduction for \(E(N) > 5 \cdot 10^{19}\) eV

mean free path length:

“only” 30 million light years
The GZK-cutoff is present in the measured energy spectrum. However, the origin of the particles with highest energies is unclear!

Conclusion:
The bulk of cosmic ray accelerators lies at cosmological distances!
• Highest energy CR seem to be dominated by iron-like nuclei! This is hard to understand because nuclei tend to disintegrate in the cosmos.
• Are our models of hadronic interactions appropriate at these energies?
Possible Origins of highest Energy CR

Above $5 \cdot 10^{19}$ eV CR not bound to galaxy (gyroradius > galaxy)

- Extragalactic sources at cosmological distances likely

Active Galactic Nuclei
active black holes with more than $10^{10}$ solar masses

Gamma Ray Bursts
extremely violent supernovae (?) at cosmological distances
AUGER: Accelerators of Cosmic Rays

Circles: CR with $E > 57$ EeV ($= 8,000,000 \cdot LHC\text{-}beam$)

Asterisks: AGNs with $z < 0.017 (< 71$ Mpc, within GZK horizon)

Blue areas: exposure time

arXiv:0712.2843
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Auger Coll., 31st ICRC, 2009
AUGER: Accelerators of Cosmic Rays

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Asterisks: AGNs with $z < 0.017$ (< 71 Mpc, within GZK horizon)

Blue areas: exposure time

arXiv:0712.2843
Statistical analyses show a 99% confidence level for a correlation of the arrival direction with AGNs (5σ = 99.994%). More data needed to prove “high energy CR astronomy”!
Conclusions on highest Energy Cosmic Rays

• The GZK cut-off exists. If CRs reach earth from cosmological distances, they should preferably consist of proton-like nuclei.

• At highest energies (above the GZK cut-off) CRs seem to point back to AGNs as their acceleration sites. If this is confirmed, CRs should be proton-like, because nuclei with larger charges would be deflected too much by intergalactic magnetic fields.

• However, analyses hint at an iron-like composition of highest energy CRs.

Something seems to be wrong!
Cosmic Rays: Topics for Discussion

• How do we know that CR are charged?

• How do we know the composition of CR at lower energies?

• Why is the simulation of extended air showers doubtful and hence problematic?

• How to improve interaction models for high energy air showers?

• Would a detector for CR above the knee located at the moon be meaningful?

• How to do neutrino-physics with a CR detector?
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Topics for today:

• High Energy Particles from the Cosmos.
• The new Astronomy.

On Friday:
• in context with the ALPS experiment some discussion of Dark Matter in the Universe.
Motivation for Astronomy with $E > 100$ GeV

- Indirect identification of CR accelerators via analyses of the charged CR problematic
- Look for high energy photons which are produced at the accelerator

New experimental methods required!
Instruments for GeV-TeV Photons

The challenge:
Flux of photons of the crab nebula
(brightest galactic source in the GeV-TeV range)
\[ F(E_{\gamma} > 500\text{GeV}) = 10 /m^2\text{/year} \]

≠ Not detectable with satellites!

The solution:
register air showers initiated by photons!

- select photon induced air showers
- aim for lowest possible energy threshold to maximize number of detected photons.
Proton and Photon induced Air Showers

Development of a 2TeV Proton Shower from first interaction to the Milagro Detector
Viewed from below the shower front - Color coded by Particle Type

This movie views a CORSIKA simulation of a proton initiated shower. The purple grid is 20m per square and is moving at the speed of light in vacuum. The height of the shower above sea level is shown at the bottom of the screen.

Blue - electrons and gammas
Yellow - muons
Green - pions and kaons
Purple - protons and neutrons
Red - other, mostly nuclear fragments

Development of a 500GeV Gamma Ray Shower from first interaction to the Milagro Detector
Viewed from below the shower front - Color coded by Particle Type

This movie views a CORSIKA simulation of a proton initiated shower. The purple grid is 20m per square and is moving at the speed of light in vacuum. The height of the shower above sea level is shown at the bottom of the screen.

Blue - electrons and gammas
Yellow - muons
Green - pions and kaons
Purple - protons and neutrons
Red - other, mostly nuclear fragments

http://umdgrb.umd.edu/cosmic/milagro.html

simulation of a EAS, observation from bottom, grid moves with the velocity of light

$e^\pm, \gamma, \mu^\pm, \pi, K, p, n, N$
Proton and Photon induced Air Showers

Compared to proton induced showers photon induced showers

• contain only electrons, positrons and photons,

• are more compact,

• are more uniform,

• decay faster.
Charged particles moving in a medium faster than light emit Cherenkov light.

Imaging Air Cherenkov Telescopes (IACTs)

Register Cherenkov light emitted by the air shower:
by nature sensitive area of $10^4 \text{m}^2$
secondary shower particles do not have to reach ground level
low energy threshold
But operation only in clear moonless nights!

http://www.mpi-hd.mpg.de/hfm/HESS/HESS.html
http://veritas.sao.arizona.edu/
http://magic.mppmu.mpg.de/index.en.html
A Pioneer: The HEGRA Experiment

- Segmented mirror (optical demands much less than for optical astronomy)
- Camera made of several hundred photomultipliers (register ns signals, high amplification)
Selection of Photon induced EAS

Images of EAS

Photon showers: only em. interaction

- Photon induced EAS more compact and homogeneous than showers of CRs
- Image analysis!

- Strong CR suppression
- Very good angular resolution
Crab nebula (M1): the TeV Standard Candle

Remnant of a supernova in the year 1054 with a central pulsar

Expansion in 30 years

Synchrotron radiation from electrons

Compton-scattered photons
Crab nebula (M1): the TeV Standard Candle

Remnant of a supernova in the year 1054 with a central pulsar

- Expansion in 30 years

- synchrotron emission of X-rays
- inverse Compton-scattering of X-rays to TeV energies
- Parameters:
  - strength of magnetic field
  - energy of electrons
Crab nebula (M1): the TeV Standard Candle

Remnant of a supernova in the year 1054 with a central pulsar

Expansion in 30 years

Synchrotron radiation from electrons

Compton-scattered photons

no CR accelerator!

1989: First observation of the Crab nebula at TeV energies: 50h observation time needed (WHIPPLE, Arizona)

2003/2004: HESS and MAGIC measure the Crab in 30s!
Opening a new Window for Astronomy

First TeV photon source in 1989, now (July 2010) already 61 galactic and 41 extragalactic sources!

VHE $\gamma$-ray Sky Map
($E_\gamma > 100$ GeV)

Where are the Accelerators of galactic CR?

With H.E.S.S. very detailed analyses of supernova remnants:

W. Hofmann, Proc. 29 Int. Cosmic Ray Conference, Pune, India, Vol. 10, 97-114
Where are the Accelerators of galactic CR?

Multiwavelengths observation:

SSC models fail to describe the data: hint to acceleration of CR (nuclei)?
Surprise: TeV Photons from distant Galaxies

Extragalactic VHE $\gamma$-ray sources
(E$_\gamma$ > 100 GeV)

2010-07-22 - Up-to-date plot available at http://www.mpp.mpg.de/~rwagner/sources/
Surprise: TeV Photons from distant Galaxies

Extragalactic sources:

- Very large intensity fluctuations, sometimes brightest sources in the TeV-sky
- TeV intensity variations correlated with X-ray measurements
- All sources are galaxies containing an active galactic nucleus (AGN)
- Reminder: AGNs are the likely sources of highest energy CR!

HEGRA IACT System vorläufig 1997


PKS 2155–304
Which Particles are accelerated in AGNs?

Observation: tight correlation between X-ray and TeV emission of AGNs

AGNs may accelerate electrons!

Do they also accelerate nuclei (protons)?
Absorption of TeV Photons in the Universe

Courtesy of M. Roncadelli
The universe is not transparent to high energy photons:
\[ \gamma_{\text{TeV}} \gamma_{\text{background}} \rightarrow e^+ e^- \]

Photons above 10 TeV should hardly reach earth from cosmological distances!

• Is there a contradiction between measurements of extragalactic background light (EBL) and TeV photons from AGNs?
• Does Lorentz invariance hold?

Need data from many AGNs at different distances (redshifts)!
H.E.S.S.: 1ES 101-232 ($z=0.186$)

- TeV photon non-absorption and EBL data just compatible?
- However: are the intrinsic features of AGNs sufficiently well known?


upper limit from TeV $\gamma$ from AGNs
MAGIC: 3C 279 (z=0.536)

- TeV photon non-absorption and EBL data just compatible?

- However: are the intrinsic features of AGNs sufficiently well known?
Way out: a new Kind of Particle?

Photons may escape absorption by converting into hypothetical axion-like particles which later convert back into photons.

A new Branch of Astronomy

- Discover galactic sources of CR
- Understand AGNs and intergalactic fields
- Search for photons from annihilation of Dark Matter
- More surprises?
A new Branch of Astronomy

HESS: http://www.mpi-hd.mpg.de/hfm/HESS/
MAGIC: http://wwwmagic.mppmu.mpg.de/
VERITAS: http://veritas.sao.arizona.edu/
CANGAROO: http://icrhp9.icrr.u-tokyo.ac.jp/index.html
The future 2\textsuperscript{nd} Phase of H.E.S:S.

Add IACT with 600 m\textsuperscript{2} mirror (40 m high!) to existing IACTs with 108 m\textsuperscript{2} mirror.

http://www.mpi-hd.mpg.de/hfm/HESS/
The future Cherenkov Telescope Array

Presently under study: telescope array including 30m dishes

http://www.mpi-hd.mpg.de/hfm/CTA/CTA_home.html
A future new Branch: Neutrino Astronomy?

Advantage:
- Neutrinos travel on straight lines like photons
- Neutrinos are produced in hadronic environments
- Neutrinos are hardly absorbed
  ➡️ direct look into the cosmic engines!

Disadvantage:
- Neutrinos are hardly absorbed
  ➡️ very large detectors necessary

http://amanda.uci.edu/
http://icecube.wisc.edu/
http://antares.in2p3.fr/
Two Sources in the Neutrino Sky

Super Kamiokande Experiment: 50,000 t of water watched by photomultipliers

Neutrinos from SN1987A (with Kamiokande, 2000 t of water)

Neutrinos from the sun

© Anglo-Australian Observatory
Detector Basics to find more Sources

- Use the whole earth as a shielding (background mainly from interactions of CRs in the atmosphere, also $\nu$!)
- Search for "upward" going muons from $\nu$-interactions close to the detector
  Detect muons by their Cherenkov light emission
- Install detectors at depths of about 1000m to shield from "downward" going CRs
- Build detectors of several 10 M tons
  Install detector elements in natural water, ice at the south pole
Performance and Physics

- Neutrino Energy > 50 GeV
- Angular resolution < 10°

Physics Questions:

- Galactic Supernovae
- Gamma Ray Bursts
- Active Galactic Nuclei
- Dark Matter Annihilation
- Topological defects
- Surprises?
Photomultipliers attached to long cables are deployed in km-deep holes drilled with hot water into the Antarctic ice shield.
DESY in AMANDA/IceCube:
- optical modules
- data analysis
- data “hub” to universities
- R&D for future extensions
First Results: the Sky seen with Neutrinos!

- No evidence yet for a neutrino source in the sky.
- The measured events are compatible with neutrinos produced in the air by cosmic ray interactions.
- More data will come soon!

T. Montaruli, 6th Patras workshop, 2010
The ANTARES Experiment

Mediterranean water instead of Antarctic ice.
The ANTARES Experiment

- Near Marseille
- 0.1 km² test installation
- Extend to 1 km²?

13 strings
12 m between storeys

Electro-optic submarine cable ~40 km

Junction box
Acoustic beacon
Electronics containers
Readout cables
Optical module
Compass, tilt meter
Hydrophone

300 m active
~100 m
Anchor
~60 m
Float
2500 m
Shore station

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New Astronomy: Topics for Discussion

• Why may the discovery of neutrino sources in the sky be crucial to solve the riddle of cosmic ray accelerators?

• Which effect limits the low energy threshold of the IACT technique?

• Why did hardly anyone expected 15 years ago to find TeV photon sources beyond our galaxy?

• How to understand the extremely small doubling times of TeV emission from AGNs?

• Can you imagine techniques to extend neutrino detectors far beyond the km$^3$ scale?
Summary on Cosmic Rays

from

Measurements of Cosmic Rays (Nuclei)
and
TeV Astronomy
The Origin of Cosmic Rays

Our model:
atomic nuclei are accelerated to highest energies at shock fronts.

Candidates for such accelerators (shock fronts):

\[ \frac{dN}{dE} \propto E^{-2} \quad \otimes \quad E^{-0.7} \quad \Rightarrow \quad E^{-2.7} \]
The Origin of Cosmic Rays

Our model:
atomic nuclei are accelerated to highest energies at shock fronts.

Candidates for such accelerators (shock fronts):

<table>
<thead>
<tr>
<th>Accelerator</th>
<th>Extension</th>
<th>B-Field</th>
<th>Max. Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supernova-remnant</td>
<td>100 pc</td>
<td>$10^{-3}$ G</td>
<td>$10^{17}$ eV</td>
</tr>
<tr>
<td>AGN Jets</td>
<td>0.01 pc</td>
<td>10 G</td>
<td>$10^{18}$ eV</td>
</tr>
<tr>
<td>Gamma Ray Bursts (GRB)</td>
<td>100 km</td>
<td>$10^{10}$ G</td>
<td>$10^{20}$ eV</td>
</tr>
</tbody>
</table>
The Energy Spectrum of Cosmic Rays

Cosmic Ray Flux Vs. Energy

knee

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However ...

*See first, think later, then test. But always see first. Otherwise you will only see what you were expecting. Most scientists forget that.*

**Douglas Adams**

*English humorist & science fiction novelist (1952 - 2001)*

http://www.quotationspage.com/quotes/Douglas_Adams
Applications

Pyramid power

Archaeologists have failed to learn the secrets of Mexico’s largest ancient monument. Particle physicists might save the day, says Michael Hopkin.

It’s not the kind of project you’d expect to find in a typical physics lab. The archaeological site of Teotihuacán in central Mexico is home to some of the world’s most impressive ancient structures. The Pyramid of the Sun, for example, is one of the largest pyramids in the Americas, towering over the Teotihuacán Valley. The site is filled with mysteries that archaeologists have been unable to solve.

But a team of physicists from the National Autonomous University of Mexico (UNAM) in Mexico City, who specialize in high-energy particle physics, believe they have found a way to unlock some of the secrets of the pyramid.

The team’s approach is based on the idea that cosmic rays, high-energy particles that travel through space, could provide key insights into the construction and history of the pyramid. Cosmic rays interact with the Earth’s atmosphere, creating a shower of secondary particles that can penetrate the ground.

The team has developed a new detector that can measure the intensity of cosmic rays as they pass through the Earth. By comparing the cosmic ray intensity at the base of the pyramid with that at other locations, they hope to gain insight into the size and shape of the pyramid and its construction.

The team’s detector is a large, sensitive instrument that can detect cosmic rays coming from all directions. They have placed the detector at the base of the pyramid and are now analyzing the data to see if they can learn more about the pyramid’s history.

The team’s approach is not without its challenges. Cosmic rays are high-energy particles that can be difficult to detect, and the team must carefully consider the effects of atmospheric conditions and other factors on their measurements.

Despite these challenges, the team is optimistic about the potential of their approach. If they can learn more about the history of the pyramid through cosmic rays, they might be able to unlock some of the secrets that have eluded archaeologists for centuries.

Climate and Cosmic Rays


In recent years, the field of climate science has become increasingly interdisciplinary. Researchers from various fields, including particle physics, are now exploring the potential of cosmic rays in understanding climate change.

Cosmic rays are high-energy particles that travel through space and interact with the Earth’s atmosphere, creating a shower of secondary particles. These particles can affect the Earth’s climate in various ways, including by changing the composition of the atmosphere and changing the Earth’s magnetic field. In recent years, researchers have begun to explore the potential of cosmic rays in understanding climate change.

H. Svensmark, a physicist at the University of Copenhagen, has been at the forefront of this research. In 2003, he published a paper in the journal Nature, in which he argued that cosmic rays could have a significant impact on climate change.

Svensmark’s work has been controversial, with some researchers arguing that cosmic rays play a minor role in climate change and that other factors, such as greenhouse gases, are more important. However, Svensmark and his colleagues have continued to explore the potential of cosmic rays in understanding climate change, and their work has continued to generate significant interest in the scientific community.

CR intensity

Climate and Cosmic Rays


Cosmic rays peak inside


Researchers in Japan have taken advantage of cosmic rays to image the inside of an active volcano. This approach has previously been used to search for chambers inside pyramids.

Hiroshi Tanaka of the University of Tokyo and his colleagues placed an instrument that detects particles known as muons on the side of Mount Aso (pictured). Muons are powerful in directions when cosmic rays hit Earth’s atmosphere.

Some muons reach the detector having passed through the rocks of the volcano. By calculating the number of muons absorbed after the rock, the researchers determined the density of the volcano’s chambers. With more devices and real-time readings, the method may help in predicting eruptions.
Schools at $10^{20}$ eV and beyond

Where do the highest-energy cosmic rays come from? Where did all the stars form? The particle physics community is addressing these questions in order to understand the fundamental nature of physics and our universe. The discovery of cosmic rays at very high energies ($E > 10^{20}$ eV) has led to renewed interest in the role of cosmic rays in galaxy evolution and the origin of the universe.

The highest energy cosmic rays are detected in the atmosphere by shower detectors. These detectors are typically located at high altitudes and are triggered by the detection of the first few air showers. The energy of the cosmic ray that initiated the air shower is inferred from the number of particles detected in the shower.

In addition, there is ongoing research into the use of cosmic rays for astrophysics. Cosmic rays are used to probe the properties of dark matter and to study the properties of the universe at high energies. The detection of cosmic rays with energies greater than $10^{20}$ eV is a significant achievement and has led to new insights into the nature of the universe.
Astroparticle Physics

Multifaceted ...
Astroparticle Physics

... and thrilling!

Fire and ice at the HEGRA experiment on the Canary island La Palma
Astro and Particles

Particle physics detectors

↓

Cherenkov Telescopes

↓

TeV Astronomy with AGNs

↓

Hints for new elementary particles, quantum gravity?

Some results seem to be confusing or weird (Dark Matter, Dark Energy)

↓

really basic questions are being addressed

↓

hope to understand fundamentals!
Astroparticle Physics

Most fascinating (to me):

If research on smallest and largest scales complement each other in the way most evident in astroparticle physics we can be confident to catch a glimpse of reality!
Suggestions for further Reading

• “Astrophysics” (M. S. Longair), Cambridge 1992

• “Cosmic Rays and Particle Physics” (T. K. Gaisser), Cambridge 1999

• “Very High Energy Cosmic Gamma Radiation (F. Aharonian), World Scientific 2004

• “Astroparticle Physics (Claus Grupen), Springer 2005