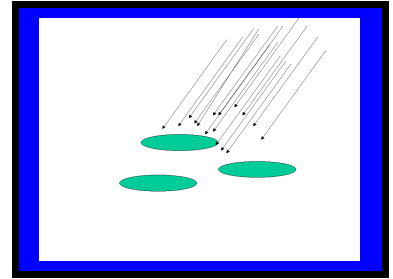


# **COSMIC RAY EDUCATIONAL OBSERVATORY**

Internal Note/001-2006



February 24, 2006

## **Educational projects in cosmic-ray physics: an annotated bibliography Version 2006**

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### **ABSTRACT**

A list of papers, documents and Web sites dealing with educational projects in cosmic-ray physics has been collected to provide an annotated bibliography to interested teachers and students wishing to access useful informations in this area. The informations have been updated as the end of 2005.

## **Introduction**

Several educational projects exist worldwide to promote the knowledge of the basics of cosmic ray physics and to carry out specific investigations concerning various aspects of the physics involved. This is a compact (and not exhaustive) description of teaching resources which are available to interested teams of teachers and students, to help them to start new activities or improve the existing ones. Since Web sites often change their address, it cannot be guaranteed that all links are operational, even if most of them were recently checked.

## **Cosmic ray detectors of interest for educational studies**

There are several places where educational cosmic ray detectors of various complexity are in operation. In some cases these are single detector stations, whereas other projects are organized around large collaborations between several participating institutions, mainly high-schools. Moreover some professional stations, such as neutron monitor stations, are also of interest to educational studies, allowing to download data for statistical analyses.

Muon detectors:

A muon telescope with 4 layers of 20 Geiger counters each is described, together with methods of data analysis and first results in

**J.Gawin et al., A small muon telescope for 5 GeV muon flux registration in the underground laboratory in Lodz, Proc. of the ICRC2001**

Description of a scintillator-based compact muon detector and the required electronics, together with its use in the laboratory:

**E.Harpell et al., The CCRT: an inexpensive cosmic ray muon detector, Report SLAC-TN-95-1(1995)**

An educational muon telescope in Australia:

**R.W.Clay et al., A cosmic ray muon detector for astronomy teaching, Publ.Astron.Soc.Aust. 17(2000)171**

A two-scintillator muon telescope in Belgrade is described in

**J.Puzovic et al., Analysis of continuous cosmic-ray measurements in Belgrade, Proc. of the 5<sup>th</sup> Int.Conf. of the Balkan Physical Union, Aug. 25-29, 2003**

A meson telescope with plastic scintillators

**H.Coxell et al., Scintillator meson telescope for studies of cosmic ray intensities, Nucl.Instr.and Methods 23(1963)45**

A spherical muon telescope

**M.A.Perkins et al., Nucl.Instr.and Methods 68(1969)149**

A telescope with Geiger counters

**A.T.Biehl et al., A new cosmic-ray telescope for high altitudes, Review of Modern Physics 20(1948)353**

A mini-array with 8 scintillators is described in

**T.Bezbourah, Cosmic-ray air shower timing experiment: performance of a miniarray detector, Proc. of the 28<sup>th</sup> ICRC(2003), 501**

The development of a wide area small array is reported in

**T.Hamaguchi et al., Wide area small air shower detection system linked by Internet, Proc. of the 28<sup>th</sup> ICRC(2003),785.**

A small array for cosmic air shower with scintillators is reported in

**L.Sun and M.M.Winn, A small Cosmic Ray Air Shower Array using plastic scintillators and a NIM/CAMAC recording system, Nucl.Instr. and Methods 223(1983)**

## **Neutron stations**

The Oulu neutron monitor is accessible at the following Web site

<http://cosmicrays oulu.fi>

and it is described in the following paper:

**I.G.Usokin et al., On-line database of cosmic ray intensities, Proc. of the ICRC2001**

The Moscow neutron station is also accessible at the Web site

<http://helios.izmiran.rssi.ru/cosray/main.htm>

## **Educational cosmic ray sites**

Most of the papers and documents produced within these Collaborations are available from their Web site and are not listed here, unless they refer to specific publications

A rich Web site with the description of several experimental activities and related analysis procedures

<http://www.pas.rochester.edu/~pavone/particle-www/>

The Quarknet project at Stanford

<http://www.slac.stanford.edu/quarknet/>

Indiana University Quarknet

<http://www.physic.indiana.edu/~quarknet/>

Stanford: A cosmic ray detector data center with educational information and possibility to show data

<http://www2.slac.stanford.edu/vvc/cosmicrays/>

CROP: Cosmic Ray Observatory Project

<http://www.unl.edu/physics/crop.html>

CHICOS: California High School Cosmic Ray Observatory

<http://www.chicos.caltech.edu/>

ALTA: Alberta Large Area Time Coincidence Array

<http://csr.phys.ualberta.ca/~alta/Pages/Sitemap.html>

NALTA: North American Large Area Time Coincidence Array  
<http://csr.phys.ualberta.ca/~nalta/>

NYSCPT: New York Schools Cosmic Particle Telescope  
<http://www.physics.nyu.edu/NYSCPT>

WALTA: Washington Large Area Time Coincidence Array  
<http://phys.washington.edu/~walta>

SCROD: School Cosmic Ray Outreach Detector  
<http://www.hep.physics.neu.edu/scrod>

ASPIRE  
<http://sunshine.chpc.utah.edu/>

SALTA: Snowmass-Area Large Time Coincidence Array  
<http://faculty.washington.edu/wilkes/salta/>

PITT-UMST: The CosRay High School Project  
<http://www.phyast.pitt.edu/~jth/cosrayproj.html>

Preston College  
<http://www.prestoncoll.ac.uk/cosmic>

SEASA: Stockholm Educational Air Shower Array  
<http://www.particle.kth.se/SEASA>

Adelaide muon monitor  
<http://physics.adelaide.edu.au/astrophysics/index.html>

SKY VIEW, University of Wuppertal (Germany)  
<http://skyview.uni-wuppertal.de>

A web site with some activity and report on home-made cosmic ray studies  
<http://www.fourmilab.ch/documents/cosmic/>

Lisbon Cosmic Ray Telescope (Portugal)  
<http://www.lip.pt/experiments/trc>

The Rolan Maze project in Poland  
<http://ipj.u.lodz.pl>

RELYC: An observatory of the invisible universe (France)  
<http://relyc.free.fr/>

A national school physics project in Finland  
<http://cupp oulu.fi/experiments.php>

HISPARC: High-School Project on Astro-Physics Research with Cosmics (Netherlands)

<http://www.hisparc.nl/>

A Web site in Catania dedicated to on-going educational activities in cosmic ray physics with possible involvement of university and high-school teams

<http://www.ct.infn.it/rivel/cosmic.html>

## **Other useful links related to activities in cosmic ray physics**

<http://www.mpi-hd.mpg.de/hfm/CosmicRay/CosmicRaySites.html>

A site with a lot of links to cosmic ray activities

The International Cosmic Ray Conferences (ICRC) report each year several contributions from the educational projects listed before. Most of the contributions may be downloaded at the Web site of the corresponding Conference.

The ICRC 2003 Conference Site is

<http://www.icrr.u-tokyo.ac.jp/icrc2003/>

while the 2005 ICRC Conference (India) Web site is

<http://www.tifr.res.in/icrc2005/>

The 20<sup>th</sup> European Cosmic Ray Symposium will be held in Lisbon (Portugal) on September 5-8, 2006. The corresponding Web site is

<http://www.lip.pt/events/2006/ecrs>

The 1<sup>st</sup> workshop on Cosmic rays in School Projects was in Amsterdam (March 7-8, 2005)

<http://www.nikhef.nl/extern/eurocosmics/>

The 2nd workshop on Cosmic Rays in School Projects will be held in Lisbon on Sept.9, 2006.

<http://www.lip.pt/events/2006/crsp>

## **Papers on specific activities related to educational studies in cosmic ray physics**

An introductory paper on educational cosmic ray experiments is the following

**B.C.Rastin, Selected topics from cosmic ray physics, Phys. Education 5(1970)349**

Examples of simple experiments in cosmic ray physics with the intervention of high schools is described in

**H.Muhry and P.Ritter, Muons in the classroom, The Physics Teacher 40(2002),294**

Undergraduated experiments to study the effect of the relativistic time dilation on cosmic muons making use of scintillation detectors are described in the following papers:

**N.Easwar and D.A.MacIntire, Study of the effect of relativistic time dilation on cosmic ray muon flux-An undergraduated modern physics experiment, Am.J.Phys. 59(1991)589**

**P. Dunne et al., Measurement of the mean lifetime of cosmic ray muons in the A-level laboratory, Phys. Education 33(1998)296**

**R.E.Hall et al., A simplified muon lifetime experiment for the instructional laboratory, Am. J.Phys. 38(1970)1196**

**A.Owens and A.E.MacGregor, Simple technique for determining the mean lifetime of the cosmic ray  $\mu$  meson, Am.J.Phys.46(1978)859**

**T.Ward et al., Laboratory study of the cosmic-ray muon lifetime, Am.J.Phys. 53(1985)542**

**R.Lewis, Am. J.Phys. 50(1982)894**

Several experimental activities related to cosmic ray physics, including measurement of muon flux as a function of the altitude or pressure, effects of shielding and study of diurnal variation, are described in

**B.Jones, Cosmic ray studies on skis and on campus, The Physics Teacher 31(1993)458**

**B.Famoso, P.La Rocca and F.Riggi, An educational study of the barometric effect of cosmic rays with a Geiger counter, Phys. Education 40(2005)461**

Old educational experiments in cosmic ray physics are reported in the following papers:

**P.G.Guest and W.M.Simmons, An experiment on cosmic rays, Am.J.Phys. (1952)357**

**P.Rice-Evans and S.R.Mishra, Cerenkov telescope for cosmic rays, Am.J.Phys.35(1967)357**

Recent measurements of the vertical cosmic muon flux, zenith angle distribution and east-west asymmetry which are of interest also for educational studies are reported in the following papers by the Hanoi cosmic ray group

**P.N.Dinh et al., Cosmic ray research in Hanoi: The Auger experiment and measurement at home, Nucl.Phys. A722(2003)439c**

**P.N.Dinh et al., Measurement of the zenith angle distribution of the cosmic muon flux in Hanoi, Nuclear Physics B661(2003)3**

**P.N.Dinh et al., Measurement of the vertical cosmic muon flux in a region of large rigidity cutoff, Nucl.Phys.B627(2002)29**

**P.N.Diep et al., Measurement of the east-west asymmetry of the cosmic muon flux in Hanoi, Nucl.Phys. B678(2004)3**

An educational study of cosmic ray induced e.m. cascades is shown in  
**P.Dunne, Demonstrating cosmic ray induced electromagnetic cascades in the A-level laboratory, Phys. Education 34(1999)19**

Coincidence studies between scintillation detectors and the measure of the decoherence curve is discussed in

**P.Dunne, Investigating cosmic ray coincidences, Phys. Education 36(2001)322**

Results of educational experiments on the transition curve of cosmic rays are reported in

**A.A.Bartlett, Student experiments on the observation of a cosmic ray transition curve, Am.J.Phys. 23(1955)286**

**D.P.Jackson and M.T.Welker, Measuring and modelling cosmic ray showers with an MBL system: an undergraduate project, Am. J.Phys. 69(2001)896**

Results from extended arrays of cosmic ray detectors with special emphasis on high school collaborations:

**B.E.Carlson et al., Search for correlated high energy cosmic ray events with CHICOS, Journal of Physics G31(2005)409**

## **Apparatus Notes**

An electronic circuit to study the time distribution between random events from detectors is reported in

**F.Arqueros and J.Campos, Simple apparatus to measure the temporal distribution between random events, Am.J.Phys. 46(1978)191**

A procedure to study the arrival time distribution of Geiger counts is discussed in

**F.Arqueros et al., Studying the statistical properties of particle counting with a very simple device, Eur. J. Phys. 25(2004)399**

A cosmic ray detection system consisting of two Geigers, coincidence and scaling circuit is described in

**C.R.Gould and R.L.Ives, Integrated circuit counter for cosmic ray experiments, Am.J.Phys. 43(1975)918**

A detection system with 3D visualization of muon trajectories is described in

**P.R.B.Marinho and A.F.Barbosa, A detection system for three dimensional visualization of cosmic muon trajectories, Review of Scientific Instruments 73(2002)3975**

A description on how to build a Geiger counter is reported in

**C.J.Seymour, A Geiger-Muller radiation monitor and counter, Electronics Today International, February-March 1987**

See <http://www.users.dircon.co.uk/~netking/geiger/geiger.htm>

Another home-made project concerning a large area Geiger counter is published in the Amateur Scientist section of Scientific American

**S. Carlson, Counting particles from space, Scientific American, February 2001**

An A-class project on how to build a Geiger counter

<http://www.charlesedisonfund.org/Experiments/HTMLexperiments/Chapter8/8-Expt8/p1.html>

A Geiger-counter kit

<http://electronickits.com/kit/complete/meas/ck106.htm>

Information about home-made Geiger counter and their use for detection of cosmics may be found at <http://muon.captain.at/muon-detector.php> with a link to a Yahoo discussion group on this topic

## **Algorithms and statistical methods of interest to educational studies in cosmic ray physics**

General consideration concerning the statistics of counting from Geiger or similar devices are presented in

**L.I. Schiff, Statistical analysis of counter data, Phys. Rev. 50(1936)88**

Solid angle calculation for a telescope made by two disc detectors is reported in

**DJ. Heristchi, Taux de comptage d'un telescope cosmique compose de deux disques circulaires, Nucl. Instr. and Methods 47(1967)39**

Cosmic ray trajectories at introductory level are discussed in

**J.D. French et al., Student's calculation of cosmic ray trajectories, Am. J. Phys. 39(1971)103**

The arrival time of cosmics may be investigated to search for non random effects. A cluster method is described in

**Y. Katayose et al., A search for non random cosmic-ray time series by a cluster analysis, II Nuovo Cimento C21(1998)299**

A widely used correlogram method is discussed in

**N.R. Lomb, Least-squares frequency analysis of unequally spaced data, Astrophysics and Space Science 39(1976)447**

Reconstruction of arrival direction from scintillator arrays is discussed in

**H. Krawczynski et al., Nucl. Instr. and Methods A383(1996)431**

An internal report by the ALTA Collaboration discusses how to reconstruct the incoming direction of cosmic rays

**A.H.Johnston, Triangular procedure for ALTA cosmic ray detectors, ALTA Report (2002)**

Advanced statistical techniques, based on Bayes decision rules, to study the arrival time distribution of muons are discussed in

**H.Rebel et al., Arrival time distributions of muons from extensive air showers as signature of the mass composition of cosmic rays, J.Phys. G21(1995)451**

## **General papers in cosmic ray physics**

**Bruno Rossi, Interpretation of cosmic-ray phenomena, Rev. Mod. Phys. 20(1948)537**

A reference paper with a survey of a vast study of cosmic rays worldwide and some data which can be employed for student analysis is

**A.H.Compton, A geographical study of cosmic rays, Phys. Rev. 43(1933)387**

Recent review papers of general interest on cosmic ray physics are the following

**J.W. Bieber et al., Cosmic Rays and Earth, Space Science Review 93(2000)1**

**J.A.Simpson, The cosmic ray nucleonic component: the invention and scientific uses of the neutron monitor, Space Science Review 93(2000)11**

**H.V.Cane, Coronal mass ejection and Forbush decreases, Space Science Review 93(2000)55**

**K.Kudela et al., Cosmic rays in relation to space weather, Space Science Review 93(2000)153**

**M.A.Shea and D.F.Smart, Cosmic ray implications for human health, Space Science Review 93(2000)187**

**M.L.Duldging, Muon observation, Space Science Review 93(2000)207**

**M.A.Shea and D.F.Smart, 50 years of cosmic radiation data, Space Science Review 93(2000),229**

## **Introductory books on cosmic ray physics**

Pierre Auger, *What are cosmic rays*, University of Chicago Press, 1945.

D.J.X. Montgomery, *Cosmic ray physics*, Princeton University Press, 1949.

Bruno Rossi, *Cosmic Rays*, McGraw-Hill, New York, 1964.

R.W.Clay and B.R.Dawson, *Cosmic Bullets*, Allen and Unwin, Sydney, 1987; Helix Books, Addison Wesley, Reading (Mass.), 1998.

M.W.Friedlander, *A thin cosmic rain. Particles from outer space*, Harvard University Press, Cambridge 2000.

## **Papers on the history of cosmic ray physics**

The early history of cosmic rays is discussed in the papers

**J.C.Stearns and D.K.Froman, Cosmic Rays – their history, source, nature and effects, The American Physics Teacher 7(1939)79**

**Q.Xu and L.M.Brown, The early history of cosmic ray research, Am.J.Phys. 55(1987)23**

**W.F.G.Swann, The history of cosmic rays, Am.J.Phys. 29(1961)811**

**L.Scarsi, Cosmic radiation, Am.J.Phys. (1959)213**

Several books have some historical introductions. For instance the books by D.J.X.Montgomery and B.Rossi.

A contribution on the role of the italian physicist G.Occhialini to cosmic ray physics in 1950-1993 is reported in the paper

**L.Scarsi, Giuseppe Occhialini: il secondo periodo italiano (1950-1993), Il Nuovo Cimento 20C(1997)613**

## **Interdisciplinary papers, applications**

**G.A.Bazilevskaya et al., Effects of cosmic rays on the Earth environment, Journal of Atmospheric and Solar Terrestrial Physics 62(2000)1577**

Use of muons to probe the geological structure of mountains and caves is described in the following papers:

**K.Nagamine et al., Method of probing inner-structure of geophysical substance with the horizontal cosmic ray muons and possible application to volcanic eruption predictions, Nucl. Instr.and Methods A356(1995)585**

**E.Caffau et al., Underground cosmic-ray measurement for morphological reconstruction of the ‘Grotta Gigante’ natural cave, Nucl.Instr.and Methods A385(1997)480**

**H.Tanaka et al., Development of a two-fold segmented detection system for near horizontally cosmic ray muons to probe the internal structure of a volcano, Nucl.Instr. and Methods A507(2003)657**

Discussion of the effects of cosmic rays on the electronic circuits is discussed in detail in Volume 40, n.1 of IBM Journal of Research and Development. Another introductory paper on the same journal is especially of interest:

**J.F.Ziegler, Terrestrial cosmic ray intensities, IBM J. Res.Develop. 42(1998)117**

Clouds and cosmic rays:

**E.Pallé and C.J.Butler, The proposed connection between clouds and cosmic rays: cloud behaviour during the past 50-120 years, Journal of Atmospheric and Solar Terrestrial Physics 64(2002)327**

## **Bibliographical references**

An old list of useful references in cosmic ray physics, intended to guide teachers in this field, is the paper

**J.R.Winckler and D.J.Hofman, Resource Letter CR-1 on Cosmic Rays, Am. J.Phys. (1966)2**