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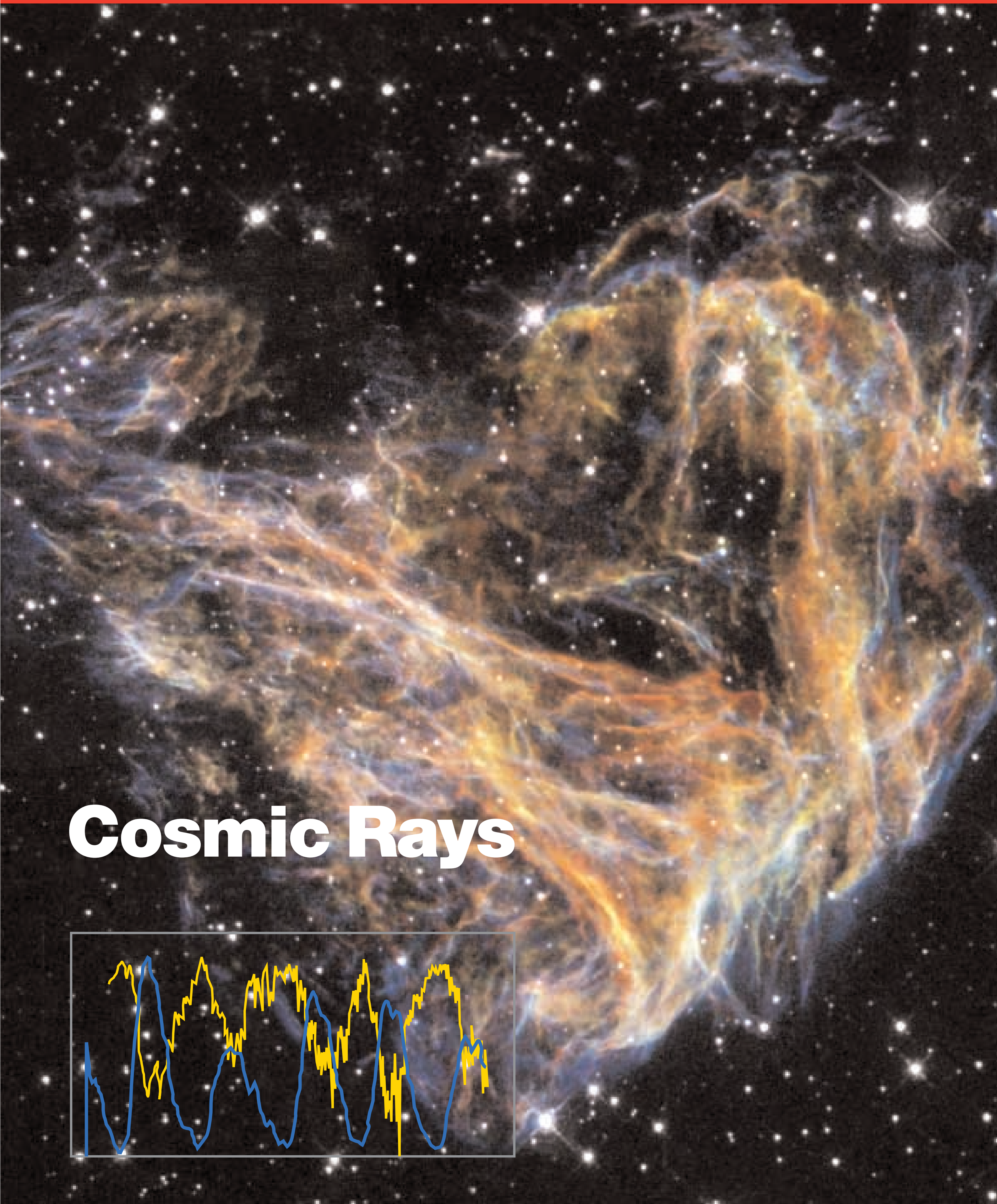

Cosmic Rays

Editorial

In a deep cave some people have been caught since their early childhood. They are chained down in a way that they even cannot turn their heads around. They can only see shadows on the walls of their inconvenient shelter, which are cast by a fire blazing in the background. The shadows stem from objects of unknown form and material carried by some servants. During the years they have given the shadows names and they interpret them as the reality.

One of these cave dwellers is able to shake-off his chains and leave the cave. His eyes get dazzled by the light of the Sun at first, but after a while he becomes able to see all the wonderful objects that cast the shadows.

And again he names them all and calls them the reality. But, upon his return to his pitiable colleagues, he is far from being welcome: his view of reality has been revolutionised by his stunning experience outside and has nothing more to do with the prisoners' view of reality.

So far Plato's cave parable. It tells us about the relation between our ideas and the objects behind them. We are in a similar situation like the cave dwellers when it comes to exploring the universe. What we can see with the best of our sophisticated technical means are nothing more than shadows of the reality out there and, like the prisoners in the cave, we have to content ourselves with the images on the wall. But – in contrast to Plato's parable – an unexpected second fire lights up in the background casting additional shadows from the unknown objects onto the wall of our cave. This second fire are the cosmic ray particles that reach us from the depth of the universe. Apart from the electromagnetic spectrum, where astronomical observations have taken place since mankind started looking at the stars, the cosmic rays are independent and complementary messengers from violent processes in the universe. That is why cosmic rays are such a fascinating topic, which is still in our days rich of mysteries.

This issue of Spatium is a short summary of articles edited by the International Space Science Institute in several of its fascinating publications as outlined on the back-cover. We are convinced that our readers will enjoy these insights into the mysteries of cosmic rays.

Hansjörg Schlaepfer
Zürich, October 2003

Impressum

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Front Cover: The remnants of the N49 supernova in the Large Magellanic Cloud, a source of cosmic ray particles (credit: Hubble Heritage Team [STScI/AURA], Y. Chu [UIUC] et al., NASA). The lower part shows data from the Climax Neutron Monitor, see Figure 6.

Cosmic Rays

The Early Years [1]

Cosmic ray studies now span an epoch of almost exactly 100 years. At the close of the nineteenth century, scientists using gold-leaf electroscopes to study the conductivity of gases discovered that no matter how carefully they isolated their electroscopes from possible sources of radiation they still discharged at a slow rate. In 1901 two groups investigated this phenomenon, J. Elster and H. Geitel in Germany, and C. T. R. Wilson in England. Both groups concluded that some unknown source of ionising radiation existed. Wilson even suggested that the ionisation might be "due to radiation from sources outside our atmosphere, possibly radiation like Roentgen rays or like cathode rays, but of enormously greater penetrating power." A year later two groups in Canada, Ernst Rutherford and H. Lester Cooke at McGill University, and J. C. McLennan and E. F. Burton, at the University of Toronto showed that 5 cm of lead reduced this mysterious radiation by 30%. An additional 5 tonnes of pig lead failed to reduce the radiation further.

In 1907 Father Theodore Wulf of the Institute of Physics of Ignatus College in Valkenburg, Holland, invented a new electroscope. Wulf's electroscope enabled scientists to carry the search for the origin of the mysterious radiation out of the laboratory, into the mountains, atop the Eiffel Tower and, ultimately, aloft in balloons. Assuming that the radiation came from the Earth, they expected to find a rapid decrease in the radiation as they moved away from the surface. They did not find the decrease they expected and in some cases there seemed to be evidence that the radiation actually increased. Intrigued by the conflicting results obtained by Wulf and his colleagues a young Austrian nuclear physicist, Viktor Hess, obtained support from the Austrian Imperial Academy of Sciences and the

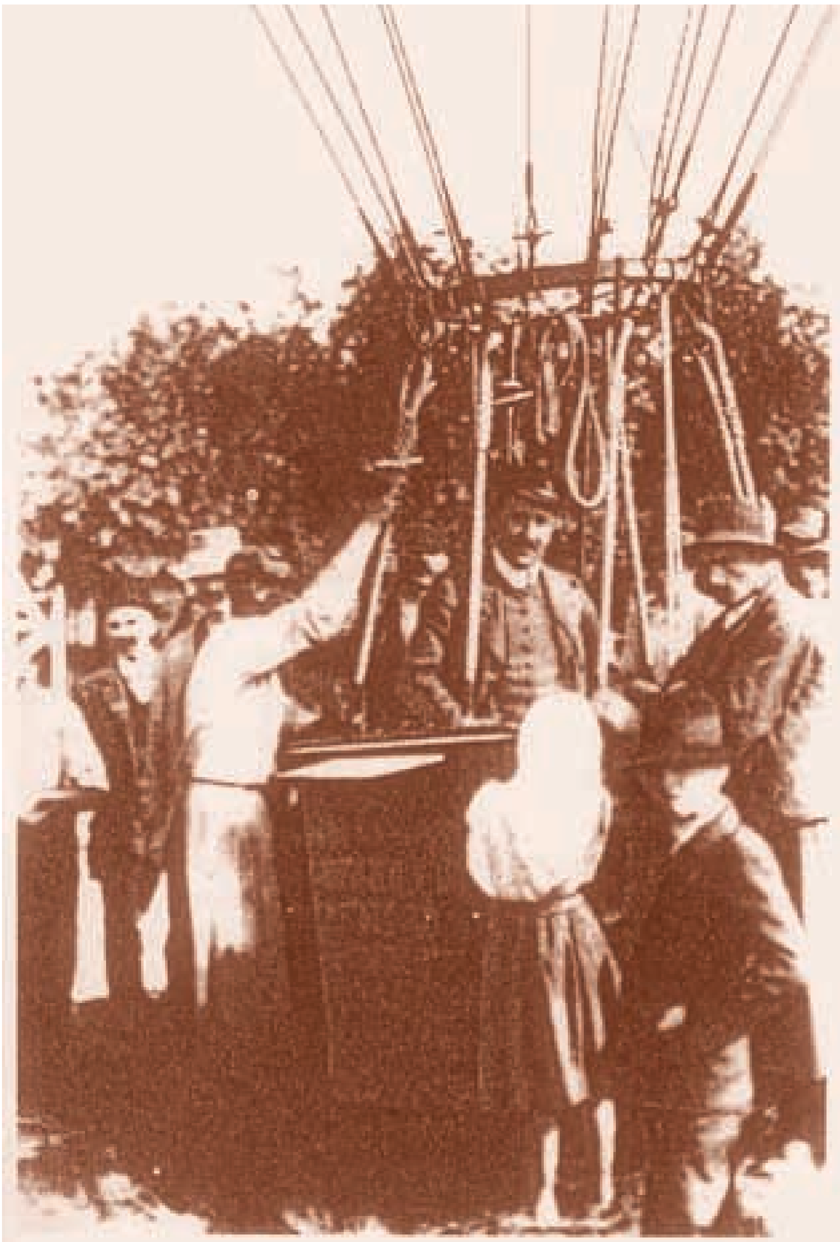

Figure 1
Viktor Hess after a balloon landing in 1912

[1]) *See reference list at the end of this article*

Royal Austrian Aero Club to conduct a series of balloon flights to study the radiation. Hess obtained a license to pilot balloons in order to reduce the size of the crew and thereby increase the altitude to which he could carry his electroscopes. On 12 August 1912, using the hydrogen-filled Böhmen, Hess reached an altitude of 5,350 m. Carrying two hermetically sealed ion chambers, he found that the ionisation rate initially decreased, but that at about 1500 m it began to rise, until at 5,000 m it was over twice the surface rate. Hess concluded that the results of these observations can best be explained by the assumption that radiation of a very high penetrating power from above enters into the atmosphere and partially causes, even at the lower atmospheric layers, ionisation in the enclosed instruments.

On a voyage from Amsterdam to Java, Clay observed in 1927 a variation in cosmic ray intensity with latitude with a lower intensity near the equator, thus establishing that before entering the Earth's magnetic field, the bulk of the primary cosmic rays were charged particles. In 1930 Bruno Rossi showed that if the cosmic rays were predominantly of one charge or the other there should be an east–west effect. In the spring of 1933 two American groups, Thomas H. Johnson of the Bartol Research Foundation and Luis Alvarez and Arthur H. Compton of the University of Chicago, simultaneously and independently measured the east–west effect. It showed the cosmic radiation to be predominantly positively charged. In a series of balloon flights in the late 1930s, M. Schein and his coworkers used Geiger counter telescopes interspersed with lead absorbers to determine that most of the primary particles were not electrons, and hence protons were most plausibly the dominant constituent.

In 1948 research groups from the University of Minnesota and the University of Rochester flew nuclear emulsions and cloud chambers on the same high-altitude Skyhook balloon flight and discovered the presence of heavy nuclei in the primary cosmic radiation. Further studies by many other groups soon established that essentially all of the elements between H and Fe were present in the cosmic radiation near the top of the atmosphere – including an overabundance of the light elements Li, Be, and B. Then in 1950 it was found that a significant fraction of the cosmic radio emission was synchrotron radiation – indicating the presence of highly relativistic electrons throughout our Galaxy including some discrete sources as well as extragalactic sources. However, because of their small abundance (1% of the intensity of cosmic ray nuclei) electrons were not directly detected in the primary cosmic radiation until 1962. These discoveries made it possible to begin constructing realistic models of the origin and interstellar transport of galactic cosmic rays.

As early as 1934, Baade and Zwicky linked the appearance of supernovae with neutron star formation and cosmic ray generation. Fermi in 1949 regarded cosmic rays as a gas of relativistic charged particles moving in interstellar magnetic fields. His paper laid the groundwork for the modern theory of cosmic ray acceleration and transport. The close link between radio astronomy and cosmic rays was conclusively established at the time of the Paris Symposium on Radioastronomy in 1958. This marked the birth of cosmic ray astrophysics. The basic model of the origin of galactic cosmic rays was developed by Ginzburg and Syrovatskii in 1964.

The Nature of Cosmic Rays

Cosmic rays consist of electrons, neutrons and atomic nuclei, which have been accelerated to very high speed. Their elemental composition provides information on chemical fractionation in the source region as well as some insight into the nature of this region and of the propagation of cosmic rays in interstellar space. Cosmic ray isotopes probe more deeply the nature of the source region and the timescales of the injection and initial acceleration. Radioactive isotopes such as ^{10}Be, ^{26}Al, and ^{36}Cl reveal the temporal history of cosmic rays in the disk and halo regions. The variation of the charge and mass composition with energy – their energy spectra – can be related to the acceleration process and to particle transport in the Galaxy. When improved measurements are available at ultrahigh energies it should be possible to determine whether these particles are of galactic or extragalactic origin. At the highest energies the cosmic ray arrival direction may also indicate the approximate direction of the most powerful sources.

The most remarkable feature of cosmic rays is their energy spectrum (**Figure 2**). From $\approx 10^9$ eV to $> 10^{20}$ eV these spectra, over some 10 orders of magnitude variation in intensity show a relatively featureless power-law distribution.

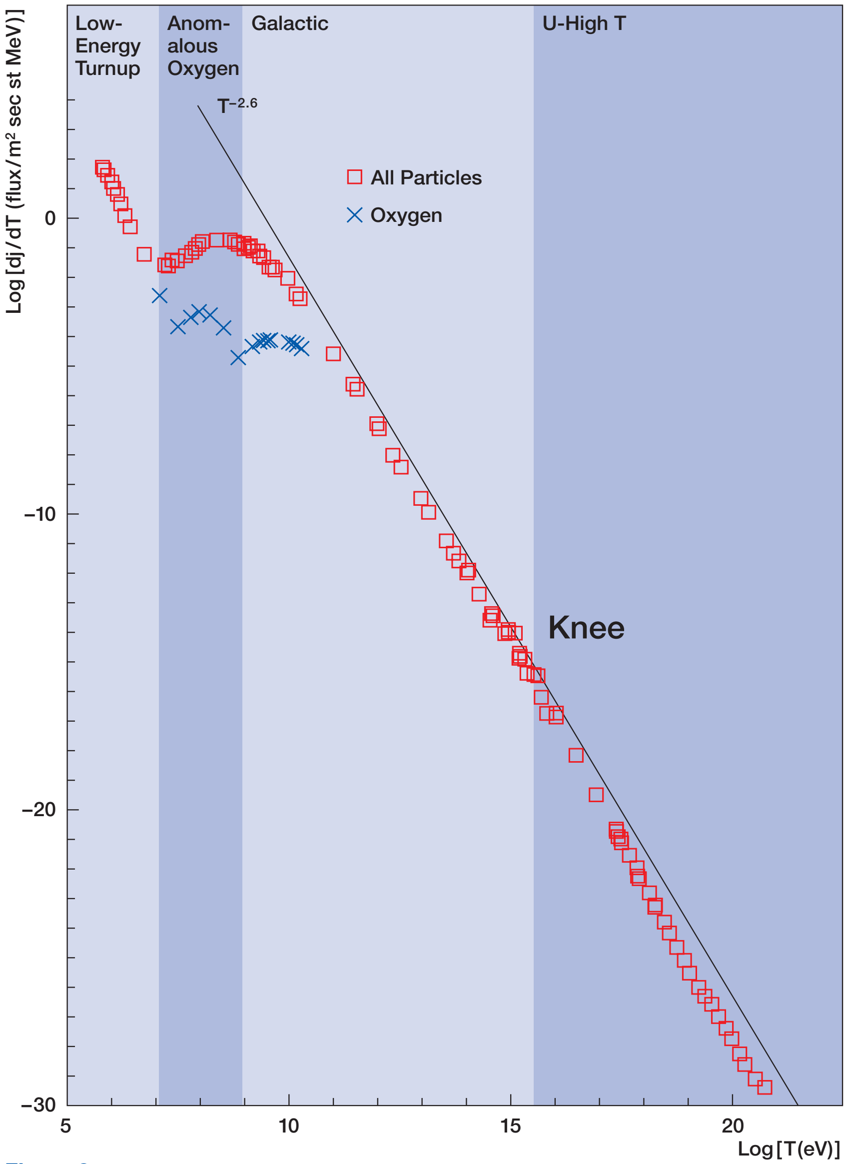

Figure 2
Energy spectrum of cosmic rays measured at the Earth.

At energies below a few GeV the influence of solar modulation becomes important with significant temporal variations at 1 AU related to the 11- and 22-year solar and heliomagnetic cycles. At energies of less than 40 MeV the oxygen spectra in **Figure 2** show the presence of so-called anomalous cosmic rays as discussed later. Those are partially ionised interstellar atoms accelerated at the solar wind termination shock. Near 10 MeV there is a highly variable turn-up in the ion spectrum produced by particles of solar/interplanetary origin although the acceleration up to energies more than tens of GeV was registered in some solar flare events.

The experimental limitation imposed by the size of current detector systems does not allow measurements of the cosmic-ray intensity at energies greater than 3 x 10^{20} eV. Above 10^{12} eV the composition is not well known; this is the region where acceleration by supernova shocks becomes difficult. It is generally assumed that the cosmic ray "knee" at ~10^{15} eV may reflect a gradual transition in the composition to particles of increasingly higher charge. At energies >10^{19} eV questions of galactic magnetic confinement lead to the assumption that these particles are of extragalactic origin. At energies above 4 x 10^{19} eV even protons should experience significant deceleration by the 3 K blackbody radiation (the Greisen–Zatsepin–Kuzmjn effect). At energies of 10^{12}–10^{14} eV there are small anisotropies of ≈ 0.1%, which are thought to be due to local effects. At this time there are no meaningful anisotropies observed at higher energies except the ultra-high energies ~10^{18} eV.

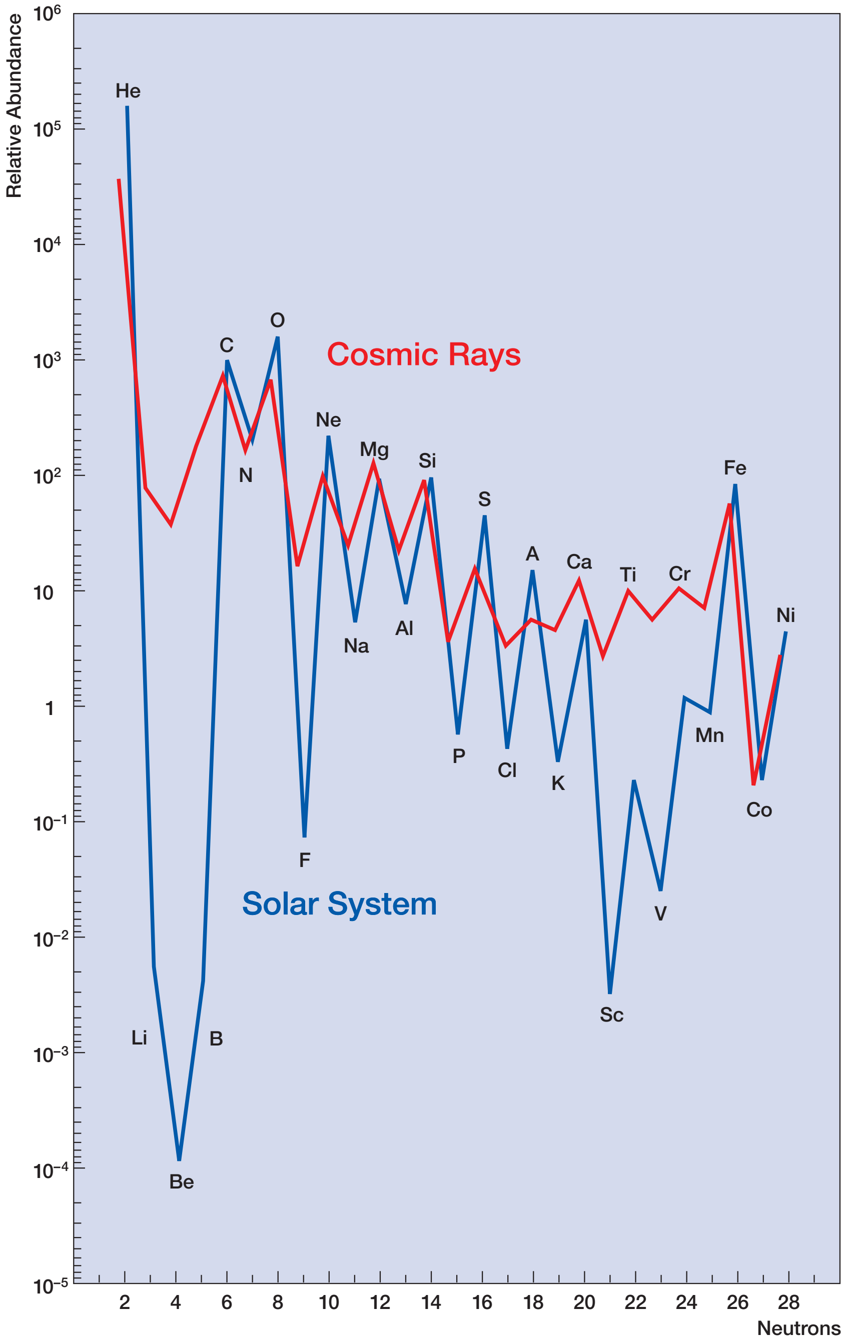

Figure 3
The relative abundance of He to Ni in cosmic rays (red line), and in the Solar System (blue line).

Cosmic ray particles are mostly hydrogen (87%), and some helium (12%) with diminishing amounts of carbon, oxygen, etc and of heavier elements **(Figure 3)**. All are fully ionised. Electrons account for approx. 1% of the cosmic rays. With a few exceptions, their chemical composition corresponds to the elemental abundances in our solar system. The exceptions (H, He are under-abundant, Li, Be, B are over-abundant) yield important information about the matter traversed by cosmic rays. Isotopic abundances of galactic cosmic rays are very similar to the isotopic composition of the interstellar gas. An important exception is the larger ratio of ^{22}Ne/^{20}Ne. The isotopic composition provides key information about the origin, acceleration and transport mechanisms of cosmic rays in our galaxy.

The Origins of Cosmic Rays

Cosmic ray particles arrive evenly from all directions of the sky, but this does not necessarily mean that their sources are evenly spread around us. More likely, they are constantly deflected and scattered by magnetic fields in the galaxy, until any trace of their original motion is lost.

There are three categories of cosmic ray particles according to their energy content:

Energy level [eV]	*Cosmic ray type; origin and acceleration mechanism*
Below the knee $E < 3 \times 10^{15}$ eV	Galactic cosmic rays I (GCR I); galactic origin, diffuse shock acceleration in the shock waves of supernova remnants (SNR)
Above the "knee" $3 \times 10^{15} \leqslant E \leqslant \approx 10^{18}$ eV	Galactic cosmic rays II (GCR II); galactic origin, second stage acceleration of GCR I by shocks
Above $E \geqslant \approx 10^{18}$ eV	Extragalactic cosmic rays; acceleration in extragalactic shocks?

Galactic cosmic rays come from outside the solar system but generally from within our Milky Way. They have probably been accelerated within the past few million years, and have travelled many times across the galaxy, trapped by the galactic magnetic field; they have been accelerated to nearly the speed of light, probably by supernovae explosions. A supernova is a star of several times the mass of our Sun, that has run out of the "nuclear fuel" of light elements, especially hydrogen, needed to keep it shining. Its nuclear burning gradually converts the light elements into heavier ones, and the heat it produces keeps it from collapsing under its own immense weight. When the star can no longer produce nuclear heat, it suddenly collapses to a small volume, releasing enormous amounts of gravitational energy. Much of that energy is spent in a grand explosion as shown in **Figure 4**, blowing the star's outer layers out to space and creating thereby a huge expanding shock front. It is this shock front which is believed to accelerate the cosmic ray particles to nearly the speed of light.

Anomalous Cosmic Rays

The discovery of a totally new component of nuclear radiation in the heliosphere – now called anomalous cosmic rays (ACR) – has greatly expanded our understanding of pickup ions, particle acceleration and our knowledge of neutral atomic abundances in the local interstellar medium. The story begins with satellite measurements at 1 AU of the proton and helium spectra as the heliospheric modulation of galactic cosmic rays declined towards solar minimum condition in 1971–1972. A spectrum of helium nuclei with energies below ≈ 100 MeV per nucleon appeared which could not be accounted for by either the solar modulation of helium of galactic origin or its isotopic composition.

It soon became clear that this anomalous helium component was also accompanied by anomalous nitrogen and oxygen. More recently, there has appeared evidence for C, Ne, Ar and H. Garcia-Munoz and collaborators showed that the anomalous component of He is modulated ^{4}He with no spallation ^{3}He and, therefore, must have a "local" origin. Fisk, Koslovsky and Ramaty proposed the most successful model to account for the anomalous components. As sketched in **Figure 5**, interstellar neutral atoms with high ionisation potentials enter the heliosphere, undergo single ionisation by solar ultra-violet radiation in the inner solar system and–by charged particle pickup in the solar wind – are carried outward to the solar wind termination shock, where they are

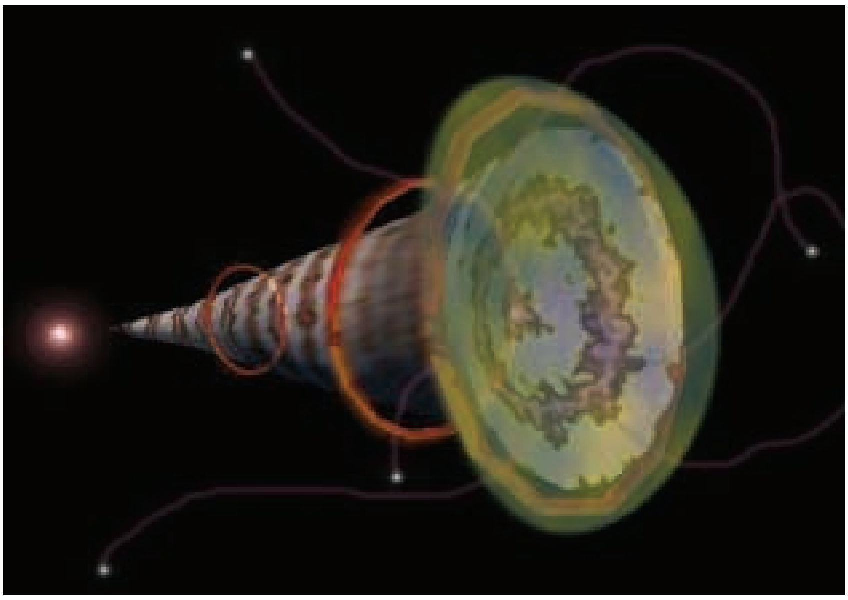

Figure 4
This artist's illustration shows a supernova explosion (at left) and a conical section of the expanding cloud of ejected material. Atoms are torn from the brownish bands of "dust" material by shock waves (represented by orange rings). The shocks in the expanding blast wave then accelerate the atoms to near light speeds firing them into interstellar space like cosmic bullets. (Credit: M. DeBord, R. Ramaty and B. Kozlovsky [GSFC], R. Lingenfelter [UCSD], NASA)

accelerated. Some of these accelerated nuclei – now possessing high magnetic rigidities since they are singly charged – propagate inward to undergo solar modulation, along with the galactic low energy cosmic ray nuclei.

Solar Cosmic Rays

Most of the time the cosmic rays arriving at Earth are of galactic or even extragalactic origin. However, from time to time, the Sun is also a source of cosmic rays. Evidence for the acceleration of energetic protons, ions and electrons in close association with solar flares and coronal mass ejections is provided by direct observations of the energetic particles in interplanetary space or at Earth, and by the detection of various neutral radiations produced in interactions of the accelerated particles with the solar atmosphere and the solar magnetic field. Solar protons, ions and electrons of energies extending into the 100 MeV region are directly measured by space borne instruments. Solar protons with energies above ~500 MeV/nucleon become increasingly rare and therefore must be detected by continuously operating ground-based cosmic ray detectors. The neutral radiations with an unambiguous link to interactions of accelerated particles in the solar atmosphere are radio- and microwaves, soft and hard X-rays, gamma rays and neutrons. On a long-term average, cosmic ray ground level intensity enhancements due to relativistic solar particles occur about once per year, while events with lower-energy particles are much more frequent. There is a distinct dependence on solar sunspot activity, with particle events being more frequent and having a larger fluence from around two years before to about four years after a solar maximum. However, there is evidence that the most energetic events do not occur right in the maximum phase of solar activity.

In the current paradigm, solar energetic particle events are generally classified as "impulsive events" or "gradual events". Impulsive events are characterized by the presence of type III radio bursts, that are radio emissions generated by streams of energetic electrons injected from the Sun into interplanetary space. Furthermore high energy protons, ions, and electrons are emitted by the Sun and accelerated in the deep corona in regions with temperatures $>10^7$ K. In gradual events, the solar cosmic rays are produced by shock acceleration in the high corona and in interplanetary space near the Sun. An expanded classification of solar cosmic ray events includes also the high-energy solar particles, which cause nuclear reactions in the solar atmosphere leading to the emission of gamma rays and neutrons.

The Sun is the most powerful particle accelerator in our neighbourhood and, therefore of fundamental physical and astrophysical interest. Ongoing research concentrates on the nature and the properties of the acceleration processes. One of the key instruments supporting these efforts is the Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI), a NASA Small Explorer mission launched on February 5, 2002 with contributions from the ETH Zürich and the Paul Scherrer Institute, Würenlingen. Its primary mission is to explore the basic physics of particle acceleration and explosive energy release in solar flares.

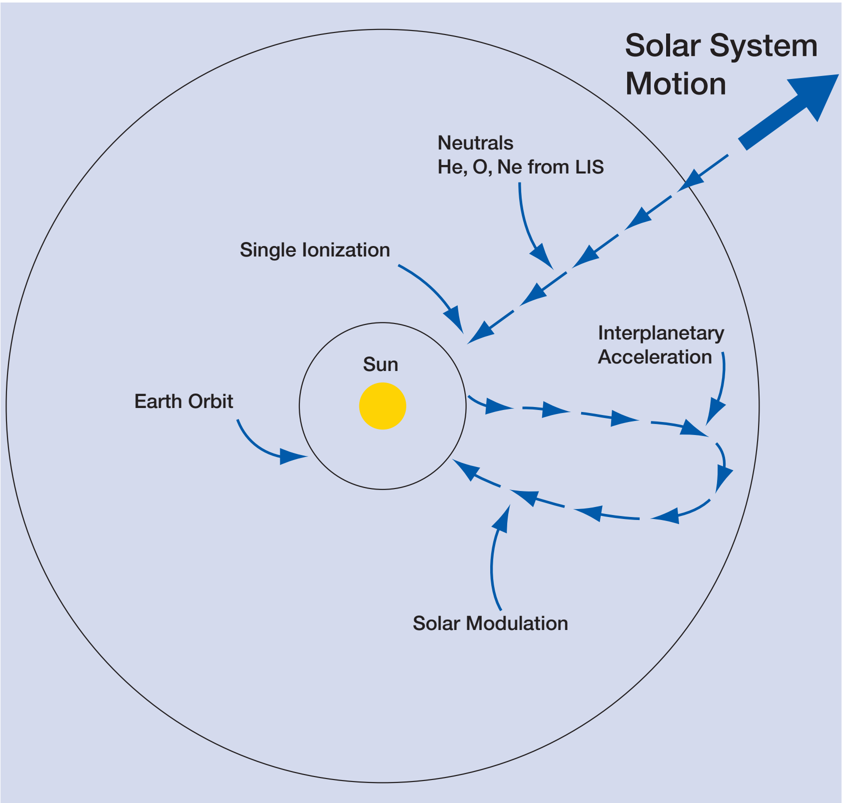

Figure 5
Sketch of the concept for the production and acceleration of the anomalous cosmic rays.

Detecting Cosmic Rays

The earliest cosmic radiation data acquired on a worldwide basis were obtained from Wilson chambers on ships. Routine monitoring of the cosmic radiation was initiated in January 1932 with the operation of ionising chamber at Hafelekar, Austria. Wilson chambers respond to muons generated by incident high-energy protons; however only nucleons greater than about 4 GeV have sufficient energy to generate a muon cascade capable of penetrating the atmosphere and reaching the Earth's surface. Thus it was desirable to develop a detector that would respond to lower energy nucleons as well as being relatively easy to maintain. In the 1950s John A. Simpson, at the University of Chicago, invented and developed the neutron monitor and found that the Earth's magnetic field could be used as a spectrometer to allow measurements of the cosmic ray spectrum down to low primary energies. The magnetic latitude of a particular neutron monitor determines the lowest magnetic rigidity of a primary that can reach the monitor, the so-called "cut-off rigidity". The station's altitude determines the amount of absorbing atmosphere above the station and hence the amount of absorption of the secondary cosmic rays (the higher the station, the higher the counting rate). By using a combination of lead (to produce local interactions), paraffin or polyethylene (to moderate or slow down the neutron component) and multiple slow-neutron counters, Simpson greatly increased the counting rate in his monitor design. After the invention of the standard neutron monitor this type of detector became widely used for cosmic ray monitoring all over the world. One of the longest uninterrupted observations is made by the Climax Neutron Monitor of the University of Chicago, see **Figure 6.**

As the counting rate of high energy particle counters increases with increasing altitude high elevation research stations became attractive locations for neutron monitors. In 1958 the first neutron monitor was installed on the Jungfraujoch where it is operated by the International Foundation High Altitude Research Stations Jungfraujoch and Gornergrat (HFSJG) with headquarters in Bern, **Figure 7.**

A second detector was installed in 1986. The effective vertical cutoff rigidity at Jungfraujoch is 4.5 GeV. Hermann Debrunner, the former President of the Pro ISSI association, has started his career there as a student and served later as the foundation's director.

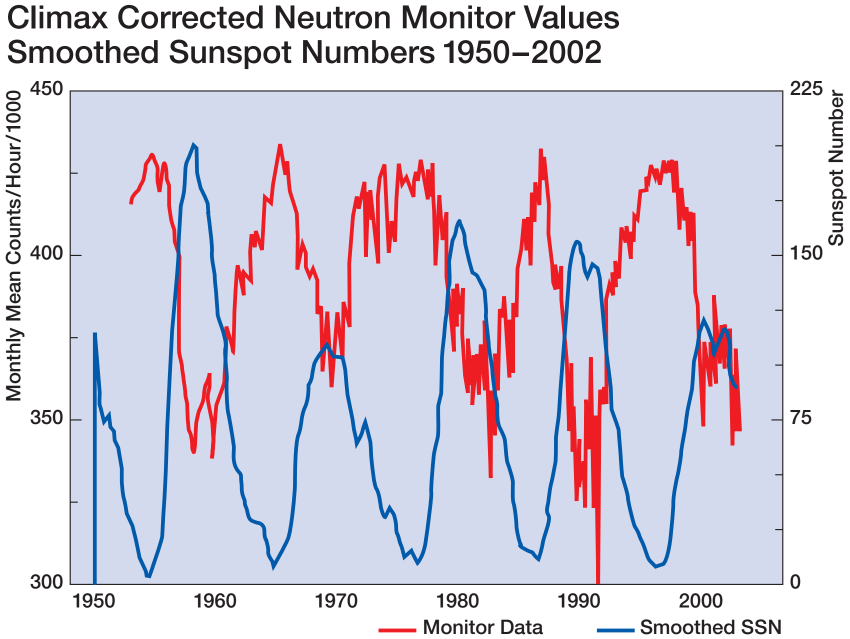

Figure 6
This plot shows data from the Climax Neutron Monitor operated by the University of Chicago. The cosmic rays show an inverse relationship to the sunspot cycle because Sun's magnetic field is stronger during sunspot maximum and shields the Earth from cosmic rays.

Figure 7
Two neutron monitors are installed at the Sphinx laboratory of the Jungfraujoch at an altitude of 3570 m. The 18-IGY-Detector is in continuous operation since 1958, while the Standard 3-NM64-neutron monitor operates since 1986.

Propagation of Cosmic Rays in the Earth's Environment

The magnetic field and the atmosphere form two powerful protective layers against the cosmic radiation on the Earth's surface. The magnetic field acts both as a shield and as a giant natural spectrometer for cosmic ray particles. If the particles possess energy, which is greater than the magnetic cut-off energy, they will cross through the magnetosphere and reach the upper layers of the atmosphere. But if their energy is insufficient, they will have a tendency to follow the magnetic lines of force, with which they move "easily", due to their lack of energy, and succeed in reaching the poles. It is the reason why the areas located near the poles receive radiation in higher quantities than near the equator, which is better protected by the Earth's magnetic field, see **Figure 8**. The second protective layer is the Earth's atmosphere. Upon arriving in the upper parts of the atmosphere, the cosmic ray particles interact with the atoms, which they encounter. As shown in **Figure 9** these collisions create new cascades of particles that produce further successively lower energy nuclear disintegrations. This nucleonic cascade process caused by primary cosmic particles can be detected at the surface of the Earth by means of fast neutrons

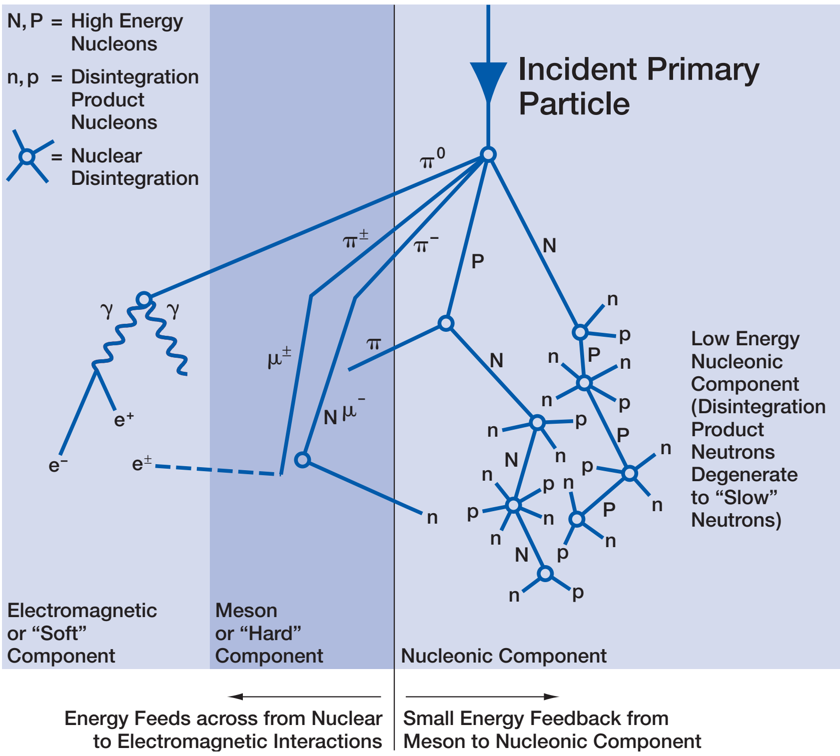

Figure 9
Schematic Diagram of a Cosmic Ray Shower. An incident cosmic ray particle interacts with the atoms at the top of the atmosphere. Due to its high energy it disintegrates the atoms producing a cascade of electromagnetic radiation, of muons and nucleons, of which the neutrons are detected by the neutron monitors.

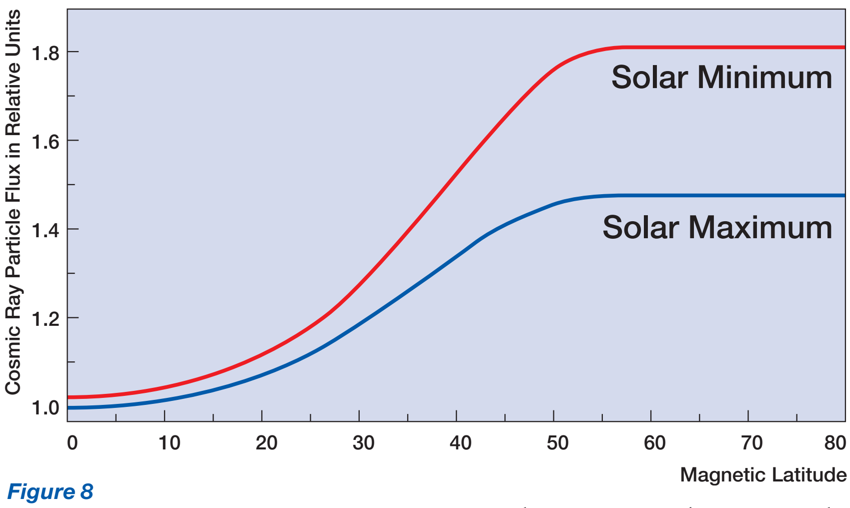

Figure 8
Illustration of the cosmic ray latitude curve. The minimum value occur at the equator and the maximum values at polar latitudes. The values are relative since the numbers vary with altitude and solar activity. At high latitudes the cosmic ray flux levels off, since the shielding effect of the Earth's atmosphere becomes larger than the cosmic ray cut-off by the magnetic field.

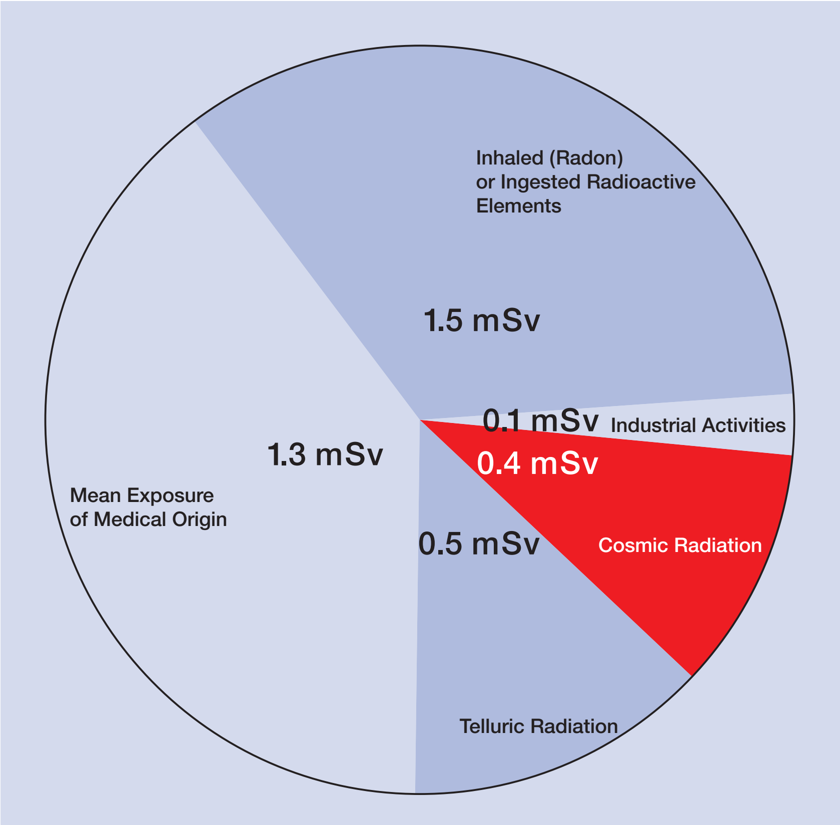

Figure 10
Sources of radioactivity as a percentage of the dose received by an average individual. (UNSCEAR, United Nations Scientific Committee on the Effects of Atomic Radiations)

produced in the atmosphere, which are counted by neutron monitors. As shown in **Figure 10** cosmic radiation represents at ground level only a small part (11%) of the ionising radiation to which an individual is commonly exposed. Natural land-based sources expose each of us to an average total dose of 2.4 mSv per year **(see box)**, though with significant variations according to regions. The larger part of the sources is a gaseous descendant of natural uranium, i.e. radon, which concentrates in enclosed areas such as houses. There is also soil-based radiation, coming from surface rocks, granite in particular, which contain radioactive elements such as uranium, dating from the formation of the planet. The water and foods, which we ingest also contain radioactive elements. Finally, there is also the internal radiation, i.e. coming from within our own bodies, namely from the potassium 40 which is naturally present in our tissues.

The Sievert

Assessing the biological risk of ionising radiation

When it comes into contact with matter, ionising radiation collides with the atoms comprising it. During these interactions, it releases a part or all of its energy. The absorbed dose (expressed in Gray) is defined by the ratio of this released energy over the mass of the matter. A Gray corresponds to one Joule of energy released in one kilogram of matter.

In order to have a single unit which expresses the risk of the occurrence of the stochastic effects associated with all possible exposure situations, physicists developed an indicator known as the “effective dose”, a measurement using the Sievert (Sv), named after the Swedish physicist who was one of the pioneers in protection against ionising radiation.

The effective dose is calculated from the dose (expressed in Gy) absorbed by the various exposed tissues and organs, by applying weighting factors which take into account the radiation types (alpha, beta, gamma, X, neutrons), the means of exposure (external or internal) and the specific sensitivity of the organs or tissues.

Cosmic Rays and Climate

Changes in the Earth's climate are generally attributed to internal causes, e.g. volcanic dust in the atmosphere, atmospheric/ocean oscillations like the El Niño Southern Oscillation, and to external causes like variations in the Earth's orbital parameters and in the Sun's luminosity. Recently, it was suggested that the Earth's cloud cover is correlated with the intensity of galactic cosmic rays. The idea is that droplet formation is influenced by ionisation of atmospheric molecules by cosmic rays. The ionisation could potentially influence optical transparency of the atmosphere, by either a change in aerosol formation or an influence on the transition between different phases of water. As these hypotheses are still controversial and highly speculative they are currently the objects of intense world-wide research activities.

Cosmic Rays and Life

Since the cosmic radiation increases with increasing altitude, it could be expected that people living at high altitudes suffer more from cosmic rays than those at sea level. For example at Denver, Colorado at an altitude of 1'600 m the exposure to cosmic radiation is twice than for people living near sea level. Medical records for these populations exist for a significant number of years thus making it possible to search for health problems that might be correlated to differences in the exposure to background cosmic radiation. When these studies are done, a surprising paradox is found: the population living at mountain altitudes is generally healthier and has longer life span than the populations living at sea level. The conclusion is that other factors must be dominant and exposure to cosmic radiation at altitudes where people live does not appear to present a health hazard.

Biological effects of ionising radiation in living cells begin with the ionisation of atoms. Ionising radiation absorbed by living cells has enough energy to remove electrons from the atoms that make up molecules of the cell. When the electron that was shared by the two atoms to form a molecular bond is dislodged by ionising radiation, the bond is broken and thus, the molecule falls apart. This is a basic model for understanding radiation damage. When ionising radiation interacts with cells, it may or may not strike a critical part of the cell. We consider the chromosomes to be the most critical part of the cell since they contain the genetic information and instructions required for the cell to perform its function and to make copies of itself for reproduction purposes. Obviously, cosmic radiation has been an intrinsic boundary condition for the evolution of life on Earth since its very beginnings and nature, therefore, had to develop efficient repair mechanisms, which are able to repair cellular damage – including chromosome damage.

Public concern and legal regulations that became effective in Europe in May 2000 address the radiation risk and the individual dose assessment of airline crewmembers. On the average, at flight altitude radiation dosage is of the order of 10 microsievert / hour. Of course, this value varies with altitude, latitude, and solar activity, and it must be interpreted in comparison with the average natural dosage. Thus, approx. 400 hours per year at flight altitude would lead to the equivalent of the natural yearly radiation load of around 4 mSv. Interested flight passengers can evaluate the expected dosage using publicly available programs as e.g. SIEVERT (http://www.sievert-system.org/).

Above the Earth's first protective layer, the atmosphere, the radiation exposure increases strongly. The assessment of the radiation risk of astronauts for example during the ongoing construction of the International Space Station is essential to safeguard their health. The astronauts' suits provide some protection against cosmic rays especially against low energy particles and in areas, where human organs more susceptible to radiation hazards are, like for example the head or the heart. In any case, however, the layout of such a suit remains a compromise between its protective efficiency and the residual mobility required by the astronaut. The US Space Shuttle orbit the Earth with an inclination of 28° and receive between 42 to 62 μGy per day, while in the 51° inclination orbit of the International Space Station the radiation dose is higher due to the coverage of higher geomagnetic latitudes and amounts to 90 to 150 μGy per day.

Outside the Earth's second protective layer, the magnetosphere, the radiation loads become still more important. When it comes to planning a mission to the other planets like for example to Mars the radiation protection of the astronauts on their long-duration flights is a key issue. In order to systematically broaden the available radiation database the European Space Agency regularly equips its spacecraft with the Standard Radiation Environment Monitor (SREM). The SREM, a high-energy particle counter for electrons with up to 6 MeV and protons up to 300 MeV has been jointly developed by Contraves Space AG, of Zürich and the Paul Scherrer Institute of Würenlingen.

Cosmic Rays and Matter

The disintegrating effect of cosmic rays on molecular bonds not only effects living cells but of course also anorganic materials. Due to their large areas and their long exposure time the solar panels of spacecraft are especially endangered by cosmic rays. A continuous degradation of their power production efficiency or even their complete breakdown may be the result of cosmic rays. In addition, electronic micro-components are prone to radiation damages leading to malfunctioning of equipment or even to the complete loss of the spacecraft. The most widely known disturbances and failures are those of the Canadian ANIK satellite on January 20/21, 1994 and of the Telstar satellite on January 11, 1997, which both have been attributed to cosmic ray effects. The commercial losses amounted to more than 135 millions US$.

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7) The Sievert System; http://www.sievert-system.org

Conclusions

Cosmic rays are the messengers from distant regions in our galaxy and beyond. Solar cosmic rays released occasionally in association with energetic processes at the Sun, provide first-hand information on astrophysical processes responsible for particle acceleration. Anomalous cosmic rays reveal new insight in the dynamic processes in the heliosphere and its interaction with the local interstellar medium. Apart from the electromagnetic spectrum, where the classical astronomical observations take place, cosmic rays open a second window to the universe providing an attractive complementary diagnostic tool for our understanding of the processes in the universe. Although the research of cosmic rays began nearly 100 years ago much is still unknown especially with regard to their origins and the mechanisms providing the particles nearly the speed of light. That is why the cosmic ray research continues to be one of the most fascinating adventures of modern space science. This article is based on publications of the International Space Science Institute on cosmic rays, which are strongly recommended for further reading. In addition I am very thankful to Erwin Flückiger, Institute for Physics, University of Bern and Rudolf von Steiger, International Space Science Institute for their his most valuable contributions.

Hansjörg Schlaepfer

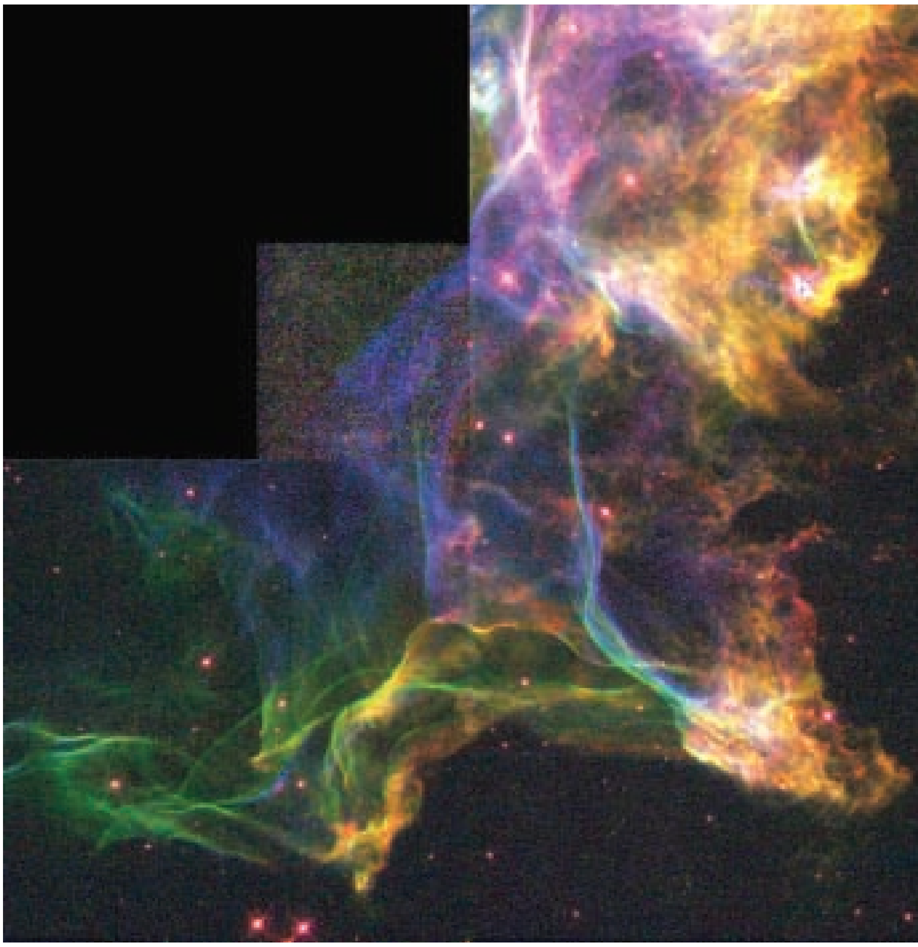

Figure 11
15,000 years ago a star in the constellation of Cygnus exploded – the shockwave from this supernova explosion is still expanding into interstellar space! Credit: J. Hester (ASU), NASA

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