COSMIC RAYS AND RELATED HEALTH HAZARDS

By

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The undersigned hereby certify that they have read and recommend to the College of Natural Sciences for acceptance a project entitled “Cosmic Rays and Related Health Hazards” by Getahun Assefa Desta in partial fulfillment of the requirements for the degree of Master of Science in Physics (Nuclear Physics).

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Abbreviations

BT	Blokc Time
CNS	Central Nervous System
CRs	Cosmic Rays
DNA	Deoxyribonucleic Acid
GCR	Galatic Cosmic Ray
GeV	Giga electron Volt
GW	GigaWatt
GZK	Greisen-Zatsepin-Kuzmin
IBM	International Business Machines
ISM	Interstellar Medium
ISS	International Space Station
kW	Kilowatt
MARIE	Mars Radiation Environment Experiment
MeV	Mega electron Volt
MRI	Magnetic Resonance Imaging
mSv	milliSieverts
NASA	National Aeronautics and Space Administration
NCRP	National Council on Radiation Protection and Measurements
NSRL	NASA-Space Radiation Laboratory
RBE	Relative Biological Efficiency
UHECRS	Ultra High Energy Cosmic Rays

Abstract

Cosmic rays are high-energy particles coming from space that hardly ever hit the Earth's surface but interact with nuclei of air molecules, usually several tens of kilometers above ground, and many new particles are formed. However, during air travel we are exposed to cosmic rays and to the energetic products of their interactions with air nuclei. In this project we will present data on the received radiation dose due to cosmic rays for two groups that are occupationally exposed to (space) radiation - commercial flights personnel and astronauts. Health risks will be estimated and backed up with study results.

Chapter 1

Introduction

Galactic cosmic rays (GCRs), while mostly protons, are energetic nuclei representing perhaps all of the nuclides of the periodic table. Their origin remains unclear even as the centennial of their discovery by Victor Hess. In his pioneering balloon-borne experiments, Hess discovered that the level of ionizing radiation was actually higher up in the atmosphere than at sea level. He concluded that the increase was due to ‘radiation’ penetrating the atmosphere. Robert Millikan confirmed Hess’s discovery in 1925 and coined the term ‘cosmic rays’ (CRs). Hess was awarded the Noble prize in physics in 1936 for his discovery of ‘cosmic radiation.’ The histories and disciplines of nuclear and particle physics have been interwined with CR physics ever since. The 1947 discovery of the pi-meson in ‘atmospheric CRs’ is a telling example of this common heritage.

Today, a host of balloon-borne, space-borne, as well as ground-based observations of (primary) CRs reveal they are nuclei of regular matter from the lightest, hydrogen, through the very heavy elements like uranium. In addition, CRs also appear to include electrons, positrons, and antiprotons. The chemical abundances elemental as well as isotopic of these primary CRs appear to reflect the chemical composition of massive stars’ winds.

Their arrival spectrum near Earth’s orbit reveals an almost structureless power law spanning many decades of energy, down to $\approx 10^{18}$ eV. Primary CRs arriving at the boundaries of the heliosphere with energy below a few hundred MeV/nucleon are unable to penetrate the outward flowing solar wind plasma. Near the inner heliosphere and Earth’s orbit, the primary CR nuclei arriving at the top of the atmosphere interact with its atomic constituents (mostly carbon, nitrogen, and oxygen), losing (as they cascade through), in most cases, all of their kinetic energy while producing a host of secondary radiation and particles (like gamma rays, neutrons, and pions). Very few primary CRs make it to sea level. Their secondary products, however, like muons, are able to penetrate the hard surface of the Earth down to depths of tens to hundreds of meters.

From an astrophysical perspective, some of the outstanding fundamental questions regarding CRs pertain to the nature and location of their source(s) as well as to the precise mechanism(s) of their acceleration. Their journey after synthesis and acceleration—their propagation in the (ISM) appears to be reasonably well understood. Currently, the so-called diffusive shock acceleration theory appears to be the accepted physical theory behind their acceleration. The ‘standard’ source is usually taken to be a supernova explosion[1].

Cosmic Rays

Cosmic rays are relativistic and mostly charged particles bombarding Earth’s atmosphere from the outer space. They originate outside the Earth, but because of a distortion of their trajectories by chaotic magnetic fields in interstellar space their arrival directions do not point back to their site of origin. Nevertheless they bring important information about very energetic processes in the Universe and about the sources, interstellar space and magnetic fields. The observation of cosmic rays helps to explore the Universe and to reveal some of its mysteries. An explanation of the origin and nature of the most energetic cosmic rays is important not only to astronomers, but also to particle physicists. Their efforts are now united in rapidly evolving new field of science - astroparticle physics.

1.1 History of Cosmic Rays

The history of cosmic ray physics began around 1900, when it was discovered that an electroscope (an instrument used to detect ionising radiation,) still discharged when it was kept well away from sources of natural radiation. These events were observed to occur even when the electroscope was surrounded by 10cm of lead. Many experiments were devised to try and discover the source of this highly penetrating radiation.

An experiment carried out in 1910 by Wulf, a respected manufacturer of electroscopes, showed that the ionisation measured at the top of the Eiffel Tower, at a height of 330m, was 3.5 x 10^6 ion pairs m^{-3}, which was just over half that measured at the bottom . At the time (unknown rays) were thought to be the most penetrating type of ionising radiation and using their known air absorption coefficient it was calculated that if they had originated from natural sources on the Earth's surface the ionisation rate would have halved by a height of 80m. At the top of the Eiffel Tower it would have been almost undetectable. In 1912 and 1913 the Austrian physicist Victor Hess and the German Werner Kolhorster made hot air balloon ascents in order to measure the change in ionisation with increasing altitude. Hess flew to altitudes of around 5km and was the first to discover that the source of the ionising radiation lay outside of the Earth's atmosphere. He was awarded the Nobel Prize in 1936 for his work in this field.

Kolhorster made ascents to 9km and found that the particle flux, although decreasing slightly at first, increased rapidly from a height of 1500 m up to a 10-fold increase with respect to the value at sea level. Further flights were made by Robert Millikan and Ira Bowen in the US, convincing themselves and the scientific community that the radiation was coming from outside the atmosphere. They were named 'cosmic rays' by Millikan in 1925.

1.2 The Discovery of Cosmic Rays

The history of cosmic rays has started with an exploration of charged gases inclosed vessels at the beginning of 20th century. Two Canadian groups, McLennanand Burton from the University of Toronto [1] and Rutherford and Cooke from McGill University [2] noticed in 1903 that the leakage of electric charge from an electroscope within an air-tight metal chamber could be reduced as much as 30% by enclosing the chamber within several centimeters thick metal shield. An additional lead failed to reduce the radiation further. The loss of the charge of the enclosed electroscope was due to some highly penetrating rays. It was attributed to radioactive materials in the ground or in the air.

Within following years it was found that the radiation did not decrease as rapidly with an altitude as was expected. The first report upon this point was made by Dutch Jesuit priest and physicist

Theodor [3], who made measurements in a lime-pit near the town Valkenburg and then at the top of the Eiffel Tower, the highest construction in the world in those days. Later Swiss physicist [4] took an enclosed electroscope above the ground in a balloon.

Austrian physicist Victor Franz Hess, working at the Physical Institute in Viennain the field of radioactivity , was performing experimental activity in a laboratory using 1,500 milligrams of radium as a source, he tried to determine the exact degree by which the gamma rays were absorbed at a given distance from the source of radiation. He found that these rays should have

Figure 1.1: Path of Hess's flight in the balloon BÖhmen on August 7, 1912. Flight started from Ústínad Labem (Aussig).

been almost completely absorbed at the heights where the measurements had been made, but that the measurements had shown, instead of no ionization, a significant amount of ionization. The most penetrating radiation known at that time was gamma ray with well explored attenuation coefficient in the air. When gamma ray radiation passes through any matter, its intensity exponentially decreases. Such exponential decrease should be observed also when air ionization is measured.

Hess had speculated whether the source of ionization is in the sky rather than in the Earth’s crust. He realized ten balloon flights (five of them during night) with pressure and thermal stable instruments: two flights in 1911,seven in 1912, and one in 1913. During his first six flights he did not succeed to reach sufficient height above the ground. Before the seventh flight he filled a bag of the balloon named BÖhmen with hydrogen instead of coal gas and ascended up to the altitude over 5 km (without an air mask). The balloon started its flight on August 7, 1912 from Ǘstí nad Labem (Aussig) with V. Hess, aviator W. Hofforyand meteorologist E. Wolf. The path of balloon flight is shown in Fig. 1.1.

Hess found that although electroscope’s rate of discharge decreased initially upto about 610 m, thereafter it increased considerably, being four times larger at 4880 m than at sea level. He concluded, that the radiation of very high penetrating power enters into the atmosphere from above [5]: *”The results of the present observations seem to be most readily explained by the assumption that a radiation of very high penetrating power enters our atmosphere from above, and still produces in the lower layers a part of the ionization observed in closed vessels.”*

After five balloon flights made during night and one during an almost total eclipse of the Sun on April 12, 1912 Hess further concluded that, since he observed no change of the rate of discharge, the Sun could not itself be the main source of the radiation.

His results were confirmed by German physicist Werner KolhÖrster [6]. He measured the increase of the ionisation up to 9 km. This was a clear evidence that sources of the ionising radiation must be located well above the Earth’s ground.

Hess’s hypothesis about radiation coming from outer space did not receive general acceptance at the time he proposed it. Other propositions, such as lifting of radioactive sources from the ground into upper parts of the atmosphere, were still considered. But improved research after World War I supported Hess’s suggestion.

In the twenties American physicist Robert Millikan made further studies by launching unmanned balloons. He reported no rise in the level of the radiation. His findings were correct, but it turned out that the level of cosmic radiation in studied regions was unusually low. Finally in 1925, Millikan performed experiments of submerging electroscopes in lakes at different depths and found that a depth of water equal in mass to the difference in atmospheric altitudes gave the same readings [7]. Thus it was proved that rays must come from above and he named them ”cosmic rays” (instead of usual HÖhenstrahlung or Ultrastrahlung)

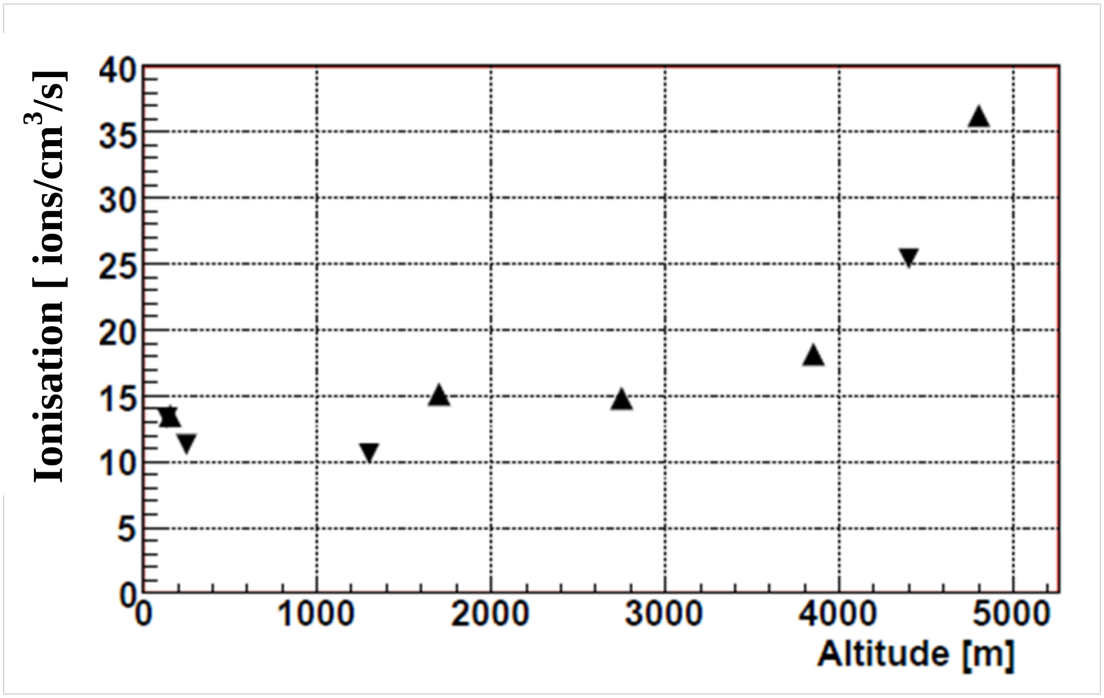

Figure 1.2: Observation of air ionisation measured by Hess in 1912. Depicted are averaged measurements from two detectors. Up/down triangles are for ascension/descent of the balloon BÖhmen[7].

1.3 Investigation of Cosmic Ray Properties

For many years there was discussion whether cosmic rays are neutral γ-rays or charged particles. Millikan supported an idea that cosmic rays consist from high energy γ-rays with some secondary electrons produced by Compton scattering of the γ-rays.

The invention of the Geiger-Müller detector in 1929 enabled a detection of individual cosmic rays. Walther Bothe and W. Kolhörster built a coincidence counter by using two counters, one placed above the other [8]. They found that simultaneous discharges of the two detectors occurred very frequently, even when a strong absorber (a gold tablet) was placed between the detectors. The experiment strongly indicated that these particles are charged with sufficiently penetrating power, so they have to be very energetic because of their long ranges in the matter.

Table 1.1. Latitude dependence of cosmic ray intensity. Local radiation sources were shielded by copper and lead shells. [9]. (Ions per cc per sec. through 5 cm Pb, 2.5 cm Cu and 0.5 cm Fe)

Location	Lat.	Long.	Elev.	Barom.	I_C
1.Mt. Evans	40^0 N	106^0 W	14,200 ft	17.61 in	6.88 ions
2. Summit Lake	40^0 N	106^0 W	12,700	18.70	5.84
3. Denver	40^0 N	105^0 W	5300	24.80	2.93
4. Jungfraujoch	47^0 N	6^0 E	11,400	19.70	5.08
5. Haleakala	21^0 N	156^0 W	9300	21.47	3.35 ± 0.05
6. Idlewild	21^0 N	156^0 W	4200	25.99	2.40 ± 0.05
7. Honolulu	21^0 N	158^0 W	70	30.09	1.89 ± 0.02
8. S. S. Aorangi	4^0 S	173^0 W	60	29.65	1.83 ± 0.05
9. Southern Alps	44^0 S	170^0 E	6700	23.69	3.39 ± 0.05
10. Southern Alps	44^0 S	170^0 E	3900	26.10	2.70 ± 0.04
11. Dunedin	46^0 S	170^0 E	80	30.08	2.16 ± 0.03
12. Wellington	41^0 S	175^0 E	400	29.85	2.16 ± 0.03

If charged particles constitute a majority of cosmic rays, they will be deflected by the geomagnetic field and the cosmic-ray flux will be strongest at the poles and weakest at the equator. In 1932 Arthur Holly Compton presented a result of series of his observations which showed variation of cosmic ray flux with the latitude .

In 1934 Bruno Rossi reported an observation of near-simultaneous discharges of two Geiger-Müller counters widely separated in a horizontal plane during a test of equipment he was using in a measurement of the east-west effect [10]. Three years later Pierre Auger and Roland Maze, unaware of Rossi's earlier report, detected the same phenomenon and investigated it in more detail [11].

Their experiments in Alps revealed that the cosmic radiation events were coincident in time on very large scale (at more than 200 m distance), meaning that they were associated with a single event. It can happened when a very high energetic particle from a space strikes into the Earth's atmosphere and interacts with nuclei of atmospheric gases. Subsequent collisions of born particles produce a cascade and a fraction of those produced particles hits the ground. From electromagnetic cascade theory Auger and his colleagues estimated an energy of the incoming particle creating large air showers to be at least 10^{15} electron volts (eV), i.e. about one million particles of energy 10^{8} eV (critical energy in the air) and a remaining factor of ten counts for energy losses from traversing the atmosphere [12].

A wide variety of experimental investigations demonstrated that the primary cosmic rays striking Earth's atmosphere are mostly positively charged particles. There were also some indirect confirmations, such as an explanation of night aurora phenomena, which can be observed in the polar zone[13]. The secondary radiation observed at ground level is composed primarily of a ”soft component “of electrons and photons and a ”hard component” of highly penetrating particles, muons, discovered by Carl D. Anderson and his student Seth H. Neddermeyer in1936 [14].

After these studies a common consensus about nature of cosmic rays has emerged. It was clear that cosmic rays are relativistic charged atomic nuclei moving through space which strike the Earth's atmosphere each generating cascades of secondary particles known as extensive air shower . The particles in the air showers proved to be a very interesting for particle physicists, since the cascades contained short-lived particles not easily found in the laboratory. The investigation of cosmic rays led also to discovery of the antimatter. First antiparticle positron, postulated by Paul Dirac in 1928, was discovered in 1932 by Carl David Anderson by passing cosmic rays through a cloud chamber and a lead plate surrounded by a magnet[15].

Discoveries in cosmic ray field stimulated widespread interest among physicists, led to the genesis of two major fields of research: high-energy elementary-particle physics and cosmic-ray astrophysics. Physics of cosmic rays provided explanations for phenomena observed by the radio astronomy, notably the understanding of synchrotron radiation emitted in astronomical objects.

Hess and Anderson shared the Nobel prize in physics in 1936 for the discovery of cosmic radiation and for the discovery of the positron, respectively.

1.4 Composition of Cosmic Rays

Cosmic Rays are highly energetic particles, generally protons and electrons, which travel in the interstellar medium at velocities near the speed of light. Their interaction with the molecules constituting the Earth's atmosphere produces showers of energetic secondary particles that can be detected at ground level.

Cosmic rays have a wide range of energies. From the lower limit, which is conventionally taken as mc^2 (e.g. approximately 1GeV for a proton) , particles have been detected with energies exceeding 10^{20} eV. As an example, the highest energy that can be produced in an accelerator on Earth is of the order of 10^{12} eV. This can be done at Fermilab's Tevatron, the world's largest particle accelerator. Ordinary stars cannot account for the production of most of the energies measured. The determination of the origin is complicated by the fact that, unlike photons, the path of charged particles, such as protons and electrons, can be deflected by magnetic fields present in our galaxy. It follows that the trajectories of cosmic rays detected on the Earth's surface do not point back to their sources. The determination of the origin has to rely on indirect methods. While the sources for energies up to 10^{15} eV seem to have been located, studies are currently focusing on the type of processes able to generate the rarer highest energies.

1.4.1 Primary and Secondary Cosmic Rays

Cosmic rays are classified into two categories. Primary cosmic rays consist of all the particles arriving to Earth from space. The primary rays do not usually make it to the surface of the Earth, and constitute only a small fraction of what is detected at ground level. Secondary cosmic rays instead are what are detected at ground level. In other words, they comprise all the particles being created in the interaction of the primary ray with the constituent atoms of the upper atmosphere. When a high energy proton, as part of a cosmic ray, hits the nucleus of an atom of the air many hadrons are in fact produced, of which a large amount are pions.

Many of the particles created in the collisions are short-lived and do not survive to reach sea level, but positive and negative pions created in the process decay into muons that can be detected at ground level due to relativistic effects. Those muons that are produced with a high enough energy have their lifetime with respect to the earth's frame relativistically dilated and it is possible for them to reach the ground before decaying.

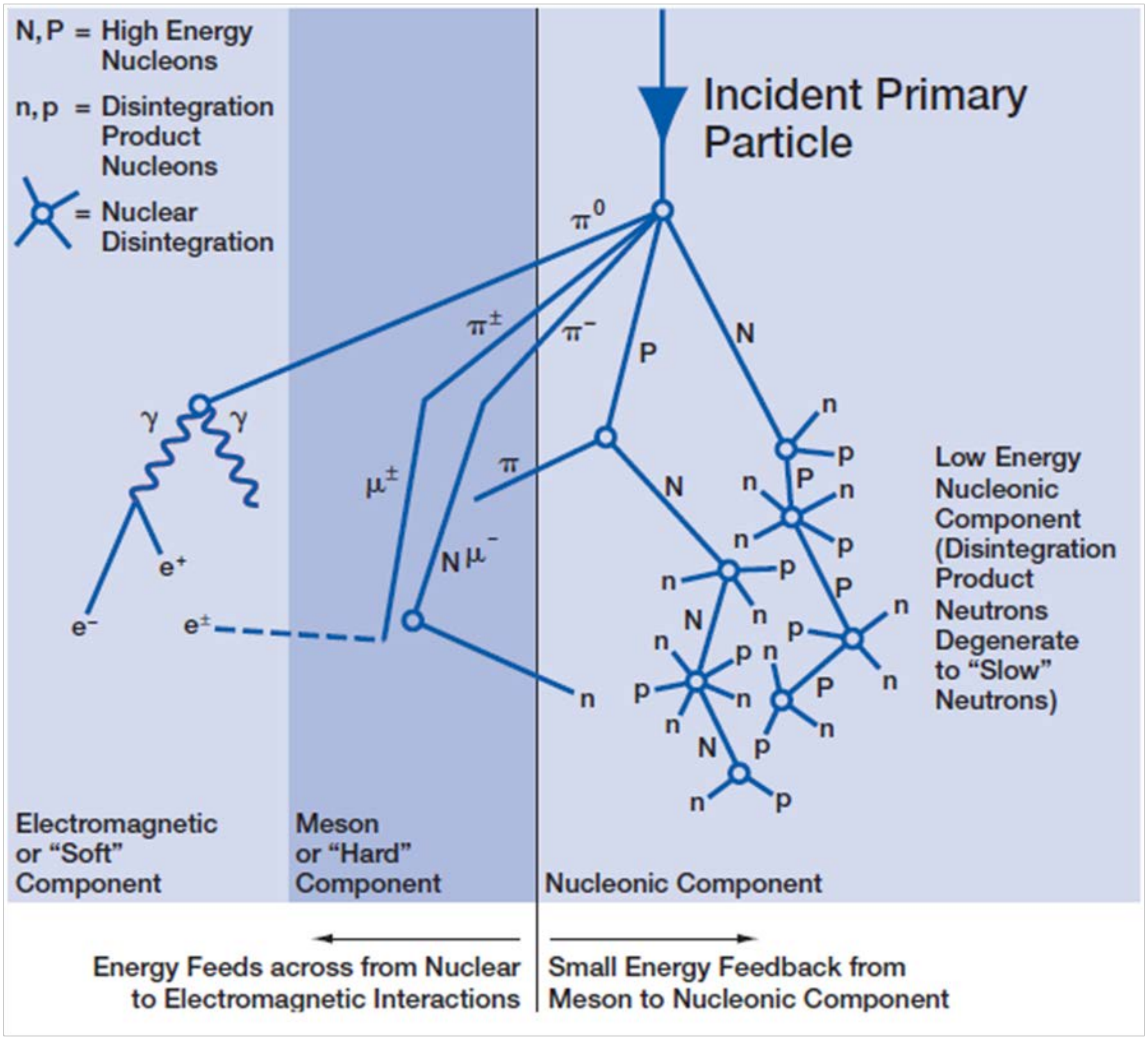

Figure 1.3: Air showers in the Earth's atmosphere. Primary CRs usually interact at a height of several tens of kilometers. N stands for nucleus, n for neutron, p for proton, e^- for electron, e^+ for positron, $\pi^{\pm}$ for pions, $\mu^{\pm}$ for muons, γ for gamma ray and v for neutrinos [23].

When primary Cosmic rays approach Earth, as seen in figure 1.3, their collision with atomic nuclei in the upper atmosphere creates more particles. These events are called air showers and can be divided into two categories:

- an electromagnetic shower occurs when a high-energy photon, electron or positron interacts with an electromagnetic field of the air molecules in the atmosphere, mainly through the processes of pair production and bremsstrahlung, generating a cascade of electromagnetic particles;
- a hadronic shower is initiated only if the primary Cosmic Ray is a hadron. A high-energy hadron interacts with an atmospheric nucleus N by the strong force. Newly formed particles are mostly pions that decay into two gamma-rays (neutral pions) or into a muon and a neutrino charged pions.

By inspection, it can be seen that the main product of a muon decay is either an electron or a positron. Because they are much more massive than electrons, muons readily pass through the electric fields inside matter with very little deflection, so do not radiate and slow down as electrons do. However they can cause ionisation and this makes them readily detectable in matter, for example with a Geiger counter.

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}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.

Figure 1.4 compares the relative abundances of cosmic rays with abundances of elements in the solar system. Both solar system and cosmic ray abundances show the odd–even effect, with the more tightly bound, even Z nuclei being more abundant. There are, however, two striking differences between the two compositions. First, nuclei with $Z > 1$ are much more abundant relative to protons in the cosmic rays than they are in solar system material. This is not really understood,but it could have something to do with the fact that hydrogen is relatively hard to ionize for injection into the acceleration process, or it could reflect a genuine difference in composition at the source.

The second difference *is* well understood and is an important tool for understanding propagation and confinement of cosmic rays in the galaxy. The two groups of elements Li, Be, B and Sc, Ti, V, Cr, Mn are many orders of magnitude more abundant in the cosmic radiation than in solar system material. They are nevertheless present in the cosmic radiation as spallation products of higher mass elements, in particular of carbon and oxygen and of iron, respectively. They are produced by

Nuclear abundance: cosmic rays compared to solar system

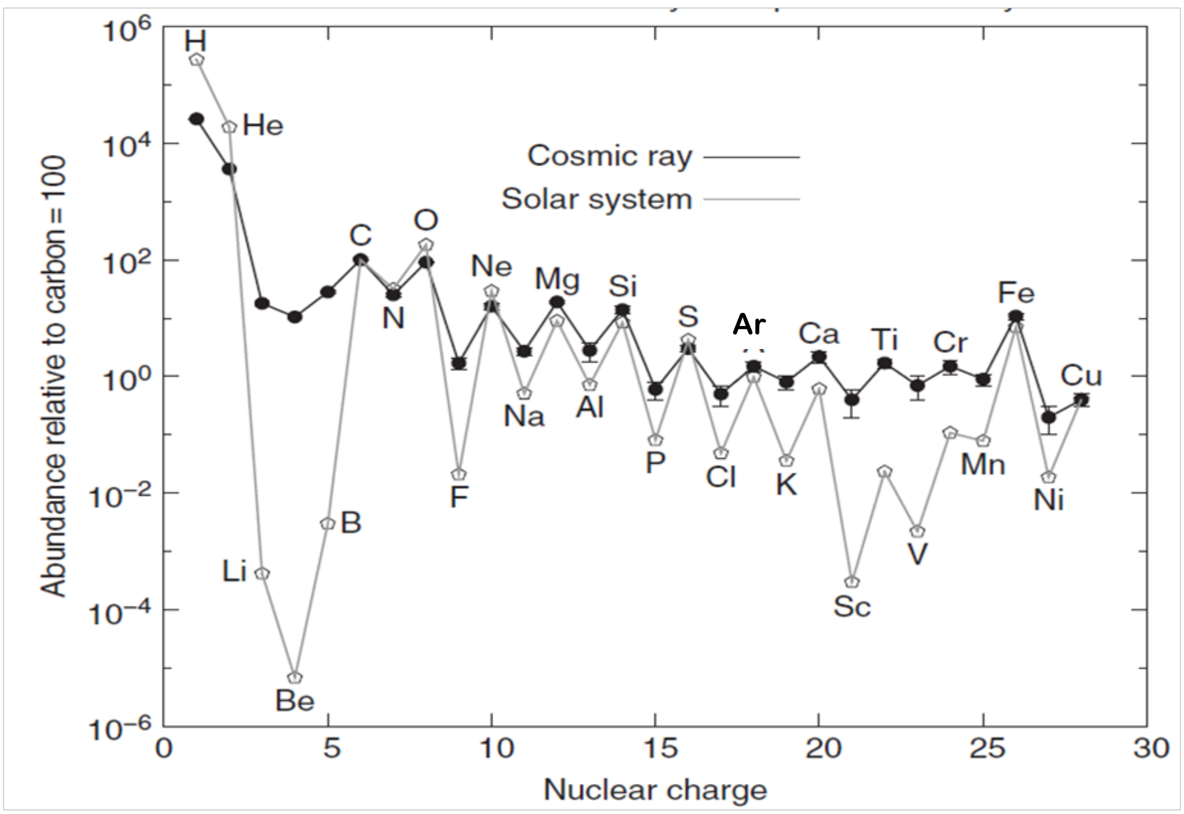

Figure 1.4 The cosmic ray elemental abundances measured on Earth (filled symbols connected by Solid lines) compared to the solar system abundances (open symbols), all relative to carbon = 100. [16],

produced by collisions of cosmic rays with the (ISM). From a knowledge of the cross sections for spallation, one can learn something about the amount of matter traversed by cosmic rays between production and observation.

1.5 Energy spectra

Cosmic ray composition relative to protons in the 10–1000 GeV range is shown in Table 1.2. The normalization is at 11.5 GeV total energy per nucleon, where the differential flux of protons is 17.6 $m^{-2}s^{-1}sr^{-1}GeV^{-1}$. The table shows the fraction of nuclei relative to protons in four different ways. Fluxes are normally quoted as in column (1): particles per GeV per nucleon. If we define the fractions in column (1) as F_A (e.g. F_4 = 0.048 for helium nuclei), then the fractions in the other columns are related to those in column (1) by $2^{\gamma} F_A$ for column (2); $A F_A$ for column (3) and $A^{\gamma} F_A$ for column (4). These relations hold for a power law spectrum with $N_A(>E) \propto E^{-\gamma}$. In this energy range the integral spectral index $\gamma \approx 1.7$. Note that these relations are for *integral* fluxes, i.e. for relative numbers of each species above the given threshold. Note also that $N(>E) = \frac{1}{\gamma} \times \frac{dN}{d\ln(E)}$ for a power-law spectrum with index $-\gamma$ [17] .

Each of the columns is relevant for certain situations. Column (1) (nuclei per energy per nucleon) is appropriate for propagation calculations because energy per nucleon remains essentially unchanged in spallation processes. Column (2) (rigidity, R(GV) = pc/Ze) is appropriate whenever the gyroradius ($r_L = R/B$) is the relevant consideration, as for acceleration via moving magnetic fields or for propagation through the magnetic fields. From column (2), for example, it follows that at a given location, for every 1000 protons that get through the geomagnetic field to reach a detector at the top of the atmosphere, there will be 157 alphaparticles,13 nuclei with $6 \leq Z \leq 8$ and one with $21 \leq Z \leq 28$.

Table 1.2 Fraction of nuclei relative to protons [9]

		(1)	(2)	(3)	(4)
Z (nuclei)	$\langle A \rangle$	particles $> E/A$	particles $> R$	nucleons $> E/A$	particles $> E$/nucleus
1 (p)	1	1	1	1	1
2 (α)	4	0.048	0.157	0.193	0.51
3–5 (Li,Be,B)	9	0.00074	0.00024	0.00087	0.03
6–8 (C,N,O)	14	0.0041	0.0133	0.0570	0.36
9,10 (F,Ne)	20	0.00056	0.0018	0.0111	0.09
11,12 (Na,Mg)	23	0.00041	0.0013	0.0094	0.09
12,13 (Al,Si)	27	0.00035	0.0011	0.0096	0.10
15,16 (P,S)	31	0.00006	0.00018	0.0017	0.02
17,18 (Cl,Ar)	40	0.00002	0.00006	0.0007	0.01
19,20 (K,Ca)	40	0.00004	0.00012	0.0015	0.02
21–25 (Sc-Mn)	48	0.00009	0.00030	0.0044	0.07
26–28 (Fe-Ni)	56	0.00022	0.00072	0.0124	0.21

The number of nucleons per GeV per nucleon (column (3)) is the relevant quantity in calculating uncorrelated, secondary fluxes of particles such as pions ,muons, neutrinos, antiprotons, etc. because these are essentially produced in nucleon–nucleon encounters, even when the nucleons are bound in nuclei. Though there are some specifically nuclear effects, they are small in this context. By adding up all contributions in column (3), we find that the total flux of nucleons is 23 $m^{-2}s^{-1}sr^{-1}GeV^{-1}$ at 11.5 GeV/nucleon. With an integral spectral index γ = 1.7 this corresponds to the following spectrum of nucleons:

$$\frac{dN}{dE_N} = 1.7 \times 10^4 \,(E_N / \mathrm{GeV})^{-2.7} \frac{nucleons}{m^2 S\ Sr\ GeV} \text{ (differential) ,}$$

$$I\,(> E_N\,) = 10^4 \,(E_N / \mathrm{GeV})^{-1.7} \frac{nucleons}{m^2 S\ Sr} \text{ (integral) .} \qquad (1.1)$$

Here E_N is total energy per nucleon and both differential and integral spectrum are given. This numerical form gives a reasonable approximation to measurements below 1000 TeV. Of the total flux in Eq. 1.1, 76.5% are free protons.

Finally, total energy per nucleus is relevant for air showers because they reflect the total energy of the incident particle. The numbers in column (4) are based on measurements at 10–100 GeV/nucleon, and they only make sense for total energies in the TeV range and above where all nuclei are in the power-law regime. Adding up the contributions of all nuclei in column (4) leads to an estimate of 0.3 particles per square meter per steradian per hour with energy greater than 100 TeV. The low rate explains why large ground-based air shower detectors are needed to explore the energy range above 100 TeV. At high energies, where the fluxes are low, it is customary to classify the primary cosmic ray nuclei above helium in groups: L (light for $3 \leq Z \leq 5$), M (medium, $6 \leq Z \leq 9$), H (heavy, $10 \leq Z \leq 20$) and VH (very heavy, $21 \leq Z \leq 30$) are standard nomenclature. The ratios are p:α:M:H:VH= 1:0.048:0.0041:0.0014:0.0003 when classified by energy/nucleon (column (1)),but 1:0.51:0.37:0.32:0.28 when classified by energy per nucleus.

Chapter 2

Possible Sources

The origin of ultra-high energy cosmic rays remain unknown for more than four decades of investigation. Two different scenarios have been proposed: an acceleration by strong electromagnetic fields or by long-term statistical shock-wave process in astronomical objects, and decays of super heavy particles which have their rest masses well above 10^{20} eV. Presented scenarios predicted different spectral shape, particle composition and distribution of sources in the Universe.

Since the Larmor radius of particle trajectories at energy in EeV region becomes larger than a thickness of the Galactic disk, it is likely that their sources are extragalactic.An interesting aspect of the extragalactic cosmic rays is the energy loss due to the interactions with cosmic microwave background. GZK mechanism constrains source distance to be less than 100 Mpc and predicts rapid falling of measured spectra (GZK cutoff).

2.1 Original Fermi Theory

The mechanism explaining the acceleration and non-thermal inverse power-law energy distribution of cosmic rays was suggested by Enrico Fermi[19]. It describes charged particles being reflected by moving interstellar magnetic field in gas cloud either gains or loses energy, depending on whether the cloud is approaching or receding. In a typical environment a probability of a head-on collision is greater than an overtaking collision, so particles will be, on the average, accelerated.

If a relativistic particle approaches stable non-relativistic plane boundary of a cloud, the Lorentz transformation of 4-momenta P from the laboratory frame (E,p) into the object (i.e. cloud) rest frame (E′ , p′) can be calculated. The 4-momentain case of elastic scattering is as following:

$$\begin{pmatrix} E'/C \\ P'_{//} \end{pmatrix} = \begin{pmatrix} \gamma & -\gamma\beta \\ -\gamma\beta & \gamma \end{pmatrix} \begin{pmatrix} E/C \\ P_{//} \end{pmatrix} \tag{2.1}$$

And from the object rest frame into the laboratory one :

$$\begin{pmatrix} E/C \\ P_{//} \end{pmatrix} = \begin{pmatrix} \gamma & \gamma\beta \\ \gamma\beta & \gamma \end{pmatrix} \begin{pmatrix} E'/C \\ P'_{//} \end{pmatrix} \tag{2.2}$$

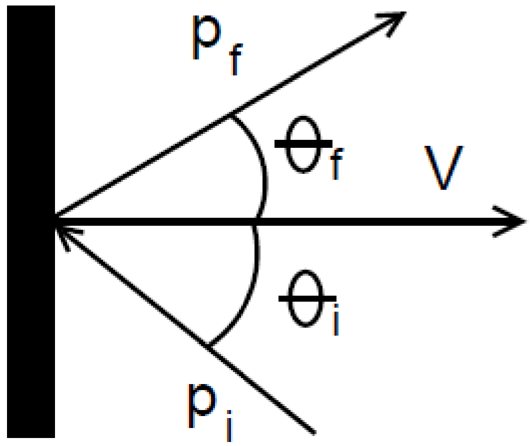

Figure 2.1: Bouncing of a particle off an object moving with velocity V .

where $\gamma = (1 - \beta^2)^{-1/2}$, β= v/c, v is the velocity of the cloud and $P_{//}$ is the component of 3-momentum parallel to β. (The perpendicular component does not change, i.e. $P'_t = P_t$).

Assuming a relativistic particle, i.e $E_i \approx Pc$, the initial particle energy in the object rest frame will be

$$E'_i = \gamma E_i(1 - \beta \cos\theta_i) , \tag{2.3}$$

where primes denote quantities measured in the object rest frame and θ_i is an angle between particle and cloud's momentum. After scattering inside the cloud, the particle emerges with the energy E_f and the momentum p_f at angle θ_f to clouds direction:

$$E_f = \gamma E'_f(1 + \beta \cos\theta'_f) , \tag{2.4}$$

Since an elastic scattering on a magnetic field tied to the massive object is assumed there will be no change in energy and total energy of the particle will be conserved in the rest frame of the moving object: $E'_i = E'_f$. For the final particle energy we obtain

$$E_f = \gamma^2 E_i(1 - \beta\cos\theta_i)(1 + \beta\cos\theta_f^{'}) \qquad (2.5)$$

which can be rewritten as a fractional change in energy

$$\frac{E_f - E_i}{E_i} = \frac{\Delta E}{E_i} = \frac{1 - \beta\cos\theta_i + \beta\cos\theta_f^{'} - \beta^2\cos\theta_i\cos\theta_f^{'}}{1-\beta^2} - 1 \qquad (2.6)$$

Inside the cloud the cosmic-ray particle scatters many times so that its direction is randomized and it emerges from the cloud in a random direction. Therefore al l$\theta_f^{'}$ have equal probability and

$$\langle\cos\theta_f^{'}\rangle = 0 \qquad (2.7)$$

The average value of $\cos\theta_i$depends on the rate at which cosmic rays collide with the cloud at different angles. The rate of collision is proportional to the relative velocity between the cloud and the particle, thus the probability per unit solid angle of having a collision at angle θ_i is proportional to (v− V$\cos\theta_i$). Hence, for ultra relativistic particles (v ≈ c) we obtain

$$\langle\cos\theta_i\rangle = \frac{\int_{-1}^{+1}\cos\theta_i(1-\beta\cos\theta_i)d(\cos\theta_i)}{\int_{-1}^{+1}\cos\theta_i d(\cos\theta_i)} = -\beta/3 \qquad (2.8)$$

Averaging Eq. 2.6 over the angles leads to the formula

$$\frac{\Delta E}{E_i} = \frac{1+\beta^2/3}{1-\beta^2} - 1 \approx \frac{4}{3}\beta^2 \qquad (2.9)$$

Final change of particle energy $\Delta E/E_i \propto \beta^2$ is positive (energy gain). It is 2ndorder in β and because β ≪1 (gas clouds in the interstellar matter have random velocities of tens km/s superimposed on their random motion around the Galaxy) the average energy gain is very small. This mechanism, now called second order Fermi acceleration, accelerates particles very slowly, but it was the first mechanism explaining a power-law spectrum of accelerated particles .

2.2 Direct Acceleration

Other mechanism of particle acceleration is an acceleration by some extended electric field arising in rapidly rotating magnetized conductors. Such a mechanism has an advantage of being fast.

Most commonly considered sources are unipolar inductors, such as rapidly spinning magnetized neutron stars.In case of young pulsars, the extremely fast rotation gives rise to an electromagnetic field which could accelerate iron nuclei to energies above 10^{20} eV[20]. They can generate an electromagnetic field sufficient to accelerate even protons up to the highest energies[21].

In all described scenarios the presence of dense plasma and intense radiation is unavoidable which might cause significant energy losses of accelerated particles. It is also unclear, how stable power law energy spectrum could emerge from such scenarios.

2.3 Multiwavelength Observations

The present day task for UHECRs astrophysics is the location of cosmic ray sources. New precise data are necessary for the critical evaluation of considered acceleration models. Besides the traditional questions about UHECRs (spectrum, anisotropy, type of primary particles, propagation processes), a number of astrophysical issues must be resolved like the understanding of intergalactic magnetic-field structures, the existence of galactic winds, the evidence of cosmic dark matter, etc.

However, it has to be noticed that also electrons are accelerated apart from protons and nuclei. Protons and nuclei can achieve much higher energies than electrons within given magnetic environments (because of smaller synchrotron losses). On the other hand energy losses of relativistic electrons lead to nonthermal photon radiation.

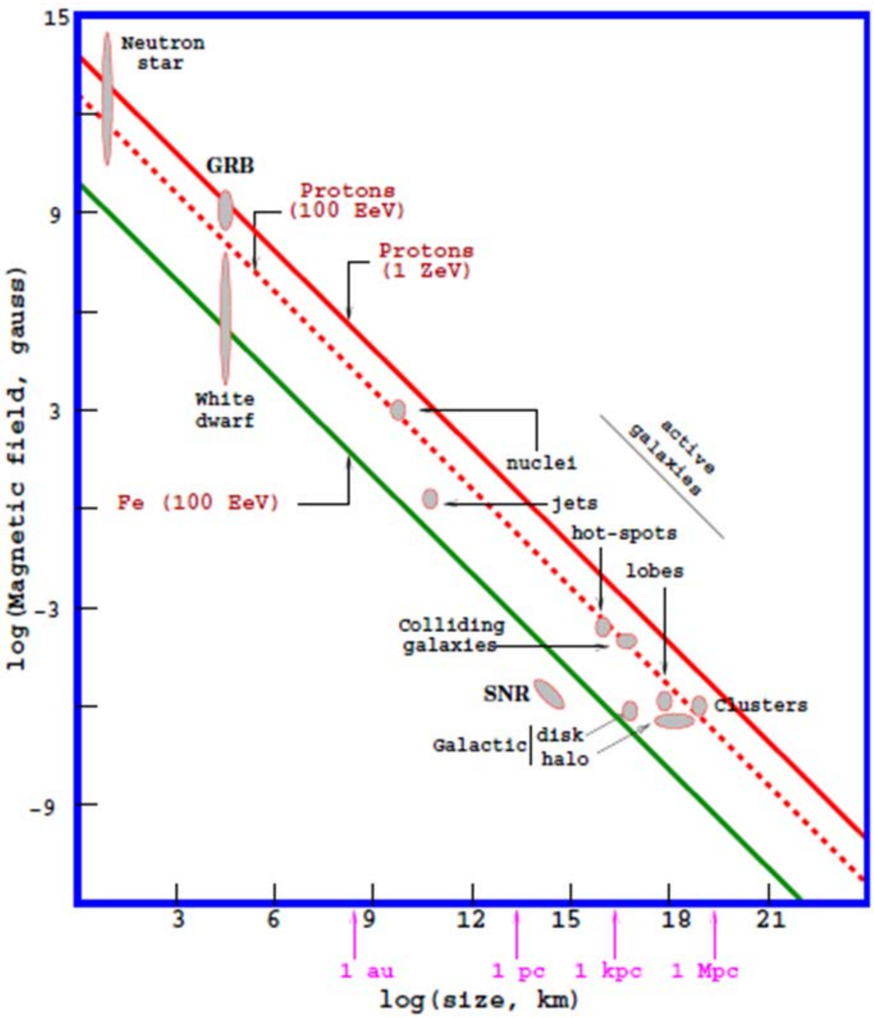

Figure 2.2: Showing size and magnetic field strengths of typical objects where particles can be accelerated. Objects below diagonal lines cannot accelerate protons or iron nuclei above the given energy [22].

In comparison with the charged particles, which are the primary products of cosmic accelerators, γ-rays have the substantial advantage that they propagate on straight lines through the Universe and their sources can be located. The charged particles are, on the other hand, deflected by galactic and intergalactic magnetic fields and therefore do not point directly to locations of their sources.

An observation of high energy γ-rays can be an indirect confirmation of particle acceleration in many astronomical objects. High-energy γ-rays can be produced by interactions of accelerated particles with nuclei of ambient medium from decays of neutral pions π^0. Highly energetic electrons may undergo bremsstrahlung in the ambient medium, may suffer synchrotron radiation losses in local magnetic fields, or a significant part of their energy may be transferred to ambient photons in the inverse Compton scattering process. High-energy γ-rays emerge from all such processes.

Chapter 3

Flux, Muons and Neutrons of Cosmic rays

3.1 Flux of Cosmic rays

Flux represents the number of particles of a given kind traversing in a downward sense a horizontal element of area ,dA, per unit time ,dt.

By monitoring the cosmic ray flux over many years ,it has been found that the average varies with a period of about 11 years .This period is equivalent to the 11-year solar cycle and is anticorrilated with the sloar activity.,i.e during high solar activity which means many sun spots, the cosmic ray intensity is lower ,and vice versa,during the quiet sun when there are fewer Sun spots the cosmic ray intensity is higher.

The 11-year variations are due to changing magnetic conditions in the heliosphere that influence the penetration of low energy galactic cosmic rays into heliosphere.Stronger magnetic fields reduce there intensity in the heliosphere or prevent them from entering the inner heliosphere because of deflection.This reduces the local intensity of the cosmic radiation and ,hence, the flux of particles responsible for producing the flux of atmospheric secondaries that are detected by the monitoring instruments on Earth.

The directional intensity $I_i(\theta, \emptyset)$ of particles of a given kind,i, is defined as the number of particles dN_i, incident upon an element of area ,dA,per unit time dt within an element of solid angle ,dΩ.Thus,

$$I_i(\theta, \emptyset) = \frac{dN_i}{dAdtd\Omega} \quad [cm^{-2}s^{-1}\ sr^{-1}] \tag{3.1}$$

The integrated intensity ,J, is obtained by integrating the directional ,I, over all angles

$$J = \int I(\theta, \emptyset)\, d\Omega \tag{3.2}$$

The angles $\theta\ and\ \emptyset$ are the zenith and azimuthal angles ,respectively, and $d\Omega$ is an element of solid angle

Since $d\Omega = \sin\theta \, d\theta d\, \emptyset$

$$J = \int_{\theta=0}^{\pi} \int_{\emptyset=0}^{2\pi} I(\theta, \emptyset) \sin\theta \, d\theta d\emptyset \qquad (3.3)$$

$$= 2\pi \int_{\theta=0}^{\pi} I(\theta) \sin\theta \, d\theta \qquad [\ cm^{-2}s^{-1}\ ]$$

if no azimuthal dependence is present.

The differential energy spectrum ,j(E),is defined as the number of particles ,dN(E), per unit area ,dA, per unit time,dt,per unit solid angle , $d\Omega$,per energy interval,dE,

$$\mathbf{j(E)} = \frac{dN\,(E)}{dAd\Omega dEdt} \quad [cm^{-2}s^{-1}\ sr^{-1}\ GeV^{-1}\ ] \qquad (3.4)$$

However the particle spectrum can as well be expressed by a momentum spectrum ,j(p),per unit momentum ,or, in rigidity, P, per unit rigidity, with P defined as

$$P = \frac{pc}{Ze} \qquad [GV] \qquad (3.5)$$

Where (pc) is the kinetic energy [GeV] of a relativistic particle ,p being the momentum[GeV/c] and (Ze) is the electric charge of the particle .The corresponding unit of rigidity is [GV].

3.1.1 The integral energy spectrum

The integral spectrum J(≥E) ,is obtained by integration of the differential energy spectrum ,j(E),

$$J(\geq E) = \int_{E}^{\infty} j(E)dE \qquad (3.6)$$

Alternatively j(E) can be derived from J(≥E) by differentiation :

$$j(E) = -\frac{dJ(\geq E)}{dE} \tag{3.7}$$

Most energy spectra can be represented by a power law with a constant exponent. For the integral exponent we can write

$$J(\geq E) = CE^{-\gamma} \tag{3.8}$$

$$j(E) = C\gamma E^{-(\gamma+1)} = A\ E^{-(\gamma+1)} \tag{3.9}$$

Where C and A are constants.

3.1.2 Energy density of Cosmic Rays

The spectrum of Cosmic Rays is their best known characteristic, extending over 12 orders of magnitude in energy E. In figure 3.1, Cosmic Ray flux measurements at different energies per particle are shown. Flux reaching the Earth is proportional to $E^2I(E)$, where E is the kinetic energy and I(E) is the number of particles arriving per unit interval of time, area, solid angle and kinetic energy. The units of differential intensity I(E) are therefore [m^{-2} sr $^{-1}$s $^{-}$1GeV]. In the energy range from several GeV to somewhat beyond 100 TeV (10^5 GeV), I(E) is given approximately by the power-law $j(E) = C\gamma E^{-(\gamma+1)} = A\ E^{-(\gamma+1)} = A\ E^{-\alpha}$

The mechanism for cosmic ray confinement is coupling between the charged particles and the tangled magnetic field lines that thread the interstellar medium. It can be seen that this is plausible by comparing the energy density of cosmic rays to the energy in magnetic fields. The

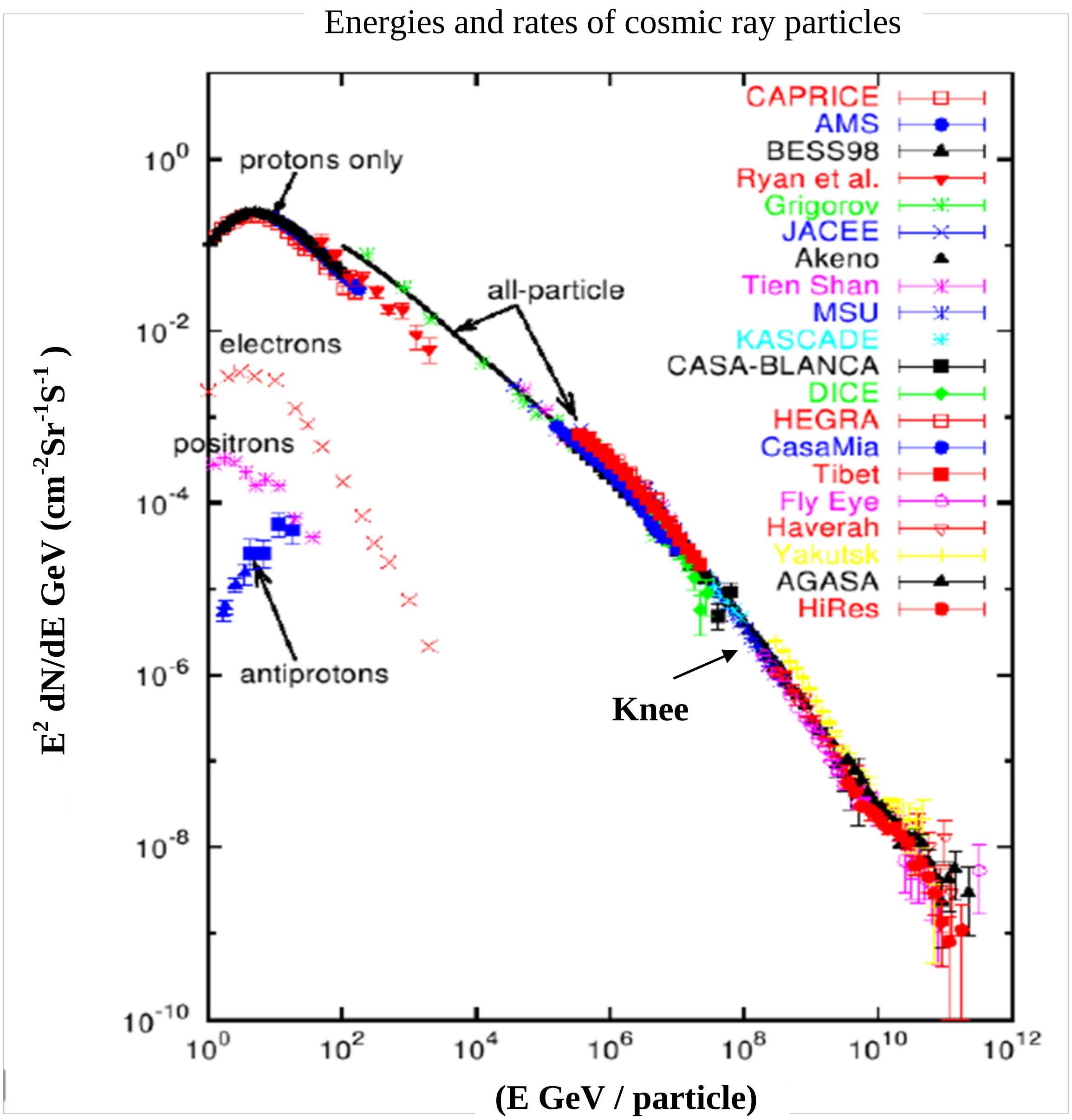

Figure 3.1: Measurements from a series of experiments of the Cosmic Ray flux over a wide kinetic energy range. Experiments use different techniques at different altitudes from air fluorescence (HiRes) and LIDAR (Yakutsk), to Cherenkov detectors (HEGRA, CAPRICE) and others. Experiments that detected Cosmic Rays with the highest energies are all located on the ground (HiRes, AGASA, Yakutsk, Haverah, Fly Eye) [24].

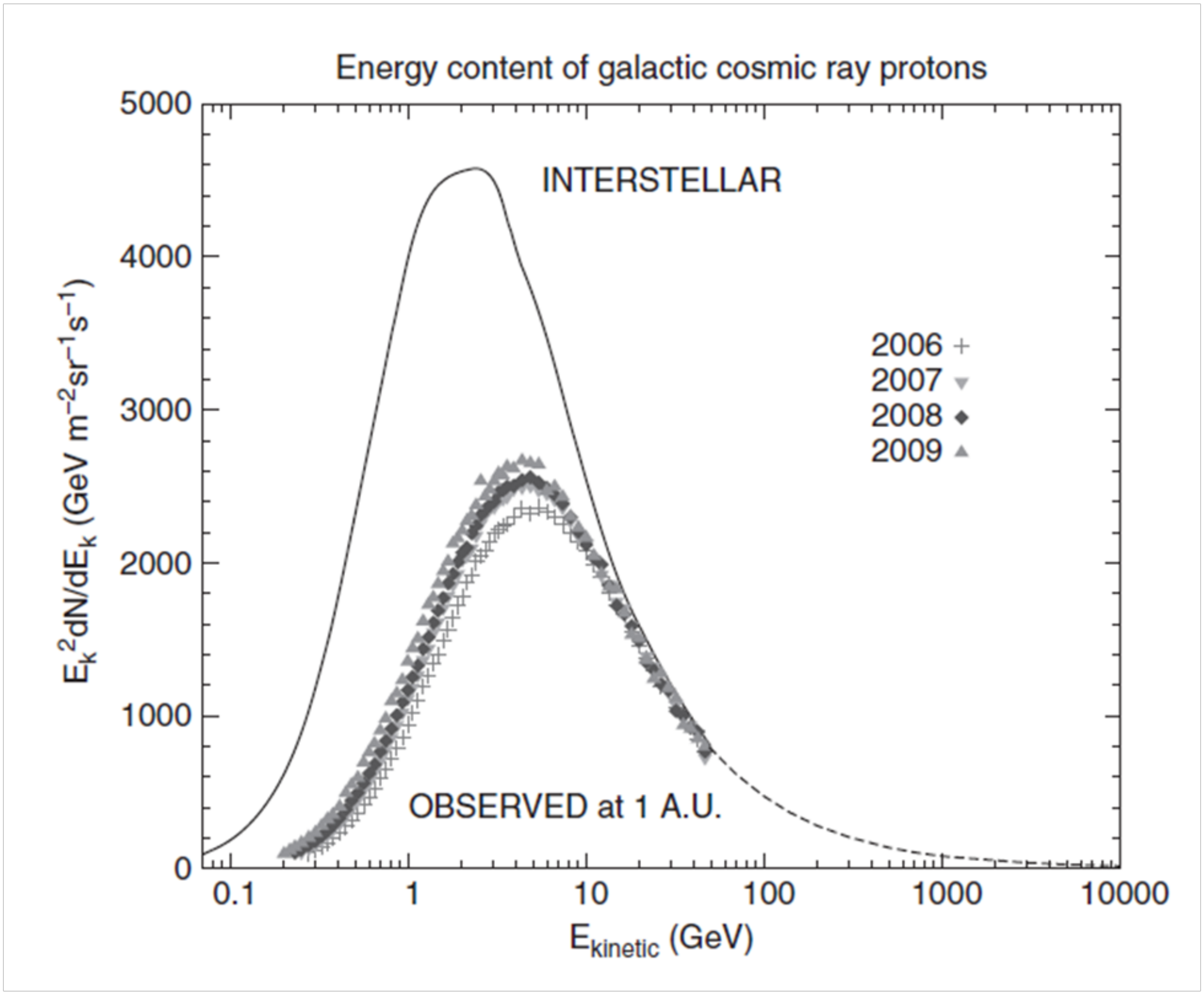

Figure 3.2 The energy flux of protons . The data sets show measurements by the PAMELA spacecraft near Earth at various stages of the solar cycle, while the line shows an estimate of the energy flux of protons in interstellar space after correcting the data for the effect of solar modulation [25].

relation between the energy spectrum and energy density for an isotropic distribution follows from the relation between flux and number density of cosmic rays, ρ_{cr} .

$$\text{Flux}\left(\frac{particles}{m^2 .\ S\ .\ Sr}\right) = \frac{\rho_{cr}\,\beta c}{4\pi} \tag{3.10}$$

The energy density, ρ_E is therefore

$$\rho_E = 4\pi \int \frac{E}{\beta c} \frac{dN}{dE} \, \mathrm{dE} \; = \; 4\pi \int \frac{E}{\beta c} \frac{dN}{d \ln E} \, \mathrm{d \ln E} \qquad (3.11)$$

The integrand of Eq. 3.11 is shown in Figure 3.2. The purpose of rewriting the integral as it has done in the second step is to make the area under a semilogarithmic plot of the integrand proportional to the integral. This is a device that is useful in the presence of a steeply falling spectrum that spans several decades of energy. It also reflects the correct way to do an integral in this situation.

The observed flux of protons has to be corrected for the effect of solar modulation. In addition, the energy content of the cosmic ray nuclei must be included. When these are accounted for, the estimate of the energy density in cosmic rays in the interstellar medium is $\rho_E \approx$ 0.5 eV/cm^3. This is to be compared with a magnetic field energy density $\in = B^2 / (8\pi) \approx 0.25$ eV/cm^3 in a typical galacticfield of $B \approx 3\ \mu$G. The two energy densities are comparable. Consequently it is not surprising that the interaction between cosmic rays and magnetic fields in the Galaxy is mutual, with cosmic rays being influenced by magnetic field configurations and *vice versa*.

3.1.3 Cosmic Ray Data

There have been many new measurements of primary cosmic rays in the past 25 years over the whole energy range from around a GeV to above 100 EeV (10^{20} eV). Figure 3.2 is a global overview of the whole range of data from some of these experiments. A remarkable feature of the cosmic ray spectrum is the fact that it can be described by inverse power laws over large intervals of energy. The global spectrum can be divided into four regions. From 10 GeV to 1 PeV (10^{15} eV) the differential spectral index is $\alpha \approx -2.7$. From 10 PeV to 1 EeV (10^{18} eV) it is -3.1. Above 10 EeV the spectrum again flattens somewhat to $\alpha \sim -2.6$, and then it apparently cuts off around 10^{20} eV. Below 10 GeV the spectrum locally is modified by solar modulation from the interstellar index of $\alpha \approx -2.7$, as illustrated in Figure 3.3. The transition regions are known as the “knee” (~ 3 PeV) and the “ankle” (~ 3 EeV). The former is usually assumed to signal in some way the approaching end of the spectrum of galactic cosmic accelerators, while the ankle is sometimes associated with the emergence of particles of extragalactic origin.

Antiprotons and positrons are included on Figure 3.1 even though they are mostly (if not entirely) “secondary” in the sense that they are produced by collisions of “primary” cosmic ray nuclei during propagation in the interstellar medium. Although most electrons are “primary” in the sense of coming from cosmic ray acceleration sources, their spectra are significantly affected by propagation

Fluxes of primary cosmic ray protons and nuclei are the starting point for all the topics of this paper work. On the one hand, the incident cosmic rays, by their interactions, generate the atmospheric hadrons, muons and neutrinos that reach the surface of the Earth. On the other hand, it is the observed spectrum for which we seek an astrophysical understanding in terms of sources, acceleration mechanisms and propagation.

3.1.4 Comparing power law spectra

Air shower experiments, like other calorimetric experiments, generally measure energy with an uncertainty $\delta\ E\ \alpha\ E$. It is therefore appropriate to report the measurements per logarithmic interval of energy. As an example, let us compare the spectra reported by two air shower experiments in which a measured “ground parameter” is converted to primary energy based on a theoretical calculation or simulation. Suppose that Experiment 1 has a systematic shift in energy such that $E_1 = k_1 E$, where E_1 is the reported energy for a given ground parameter, and E is the true energy. Experiment 2 has different system such that $E_2 = k_2 E$. Experiment 1 reports $dN / d \ln E_1 = C_1 E_1^{-\gamma}$, but Experiment 2 reports $dN / d \ln E_2 = C_2 E_2^{-\gamma}$. Since $E_1 = k_1 \times E_2 / k_2$, we can rewrite the spectrum measured by Experiment 1 as

$$\frac{dN}{d\ ln E_1} = \mathrm{C}_1 \left(\frac{k_2}{k_1}\right)^{\gamma} E_2^{-\gamma} = \mathrm{C}_2 E_2^{-\gamma} \qquad (3.4)$$

where the last step follows if $k_1 / k_2 = (C_1 / C_2)^{1/\gamma}$. Thus, for a steep spectrum, a shift in energy causes also an apparent discrepancy in normalization between two experiments that is approximately γ times larger than the energy shift. For example, a factor 1.5 apparent difference in normalization on a spectrum with a integral spectral index of $\gamma = 2$ can be explained by a factor 1.23 relative systematic error in energy assignment.

3.2 Muons at Sea Level and Underground

Muons can be produced by the interaction of charged particles (A) with atoms on the planet's upper atmosphere, represented on equation 3.5 by *N*. These interactions produce pions (π) and kaons (*K*) which decay into muons (μ) and neutrinos (ν) that can propagate deep through the crust and water due to their low interaction cross section.

$$A + N \rightarrow \pi + K \rightarrow \mu + \nu \tag{3.5}$$

Once a muon is produced from the decay of daughter pions, it undergoes energy loss primarily due to ionization. On an average, a muon loses 2 MeV/g cm^2 of energy in the atmosphere. The mean energy of a muon at the ground is around 4 GeV and therefore has a capability to penetrate the upper earth's crust as well as several hundred meters in water [48]

A substantial mass of the terrestrial microbiota is on radiation-shielded environments, such as underwater or underground. If a high-energy astrophysical event happened in the vicinities of Earth, it would be interesting to evaluate the possible damage over this apparently protected niches caused by particles that could penetrate the barrier provided by the geomagnetic field and that would not be effectively stopped by the thick atmosphere layer.

The energy spectra of muons considering penetration in crust and water compared to the one expected at sea level is shown in fig 3.3. The high energy end of the spectrum is much more attenuated in crust than in water, where the low energy region is more substantially affected.

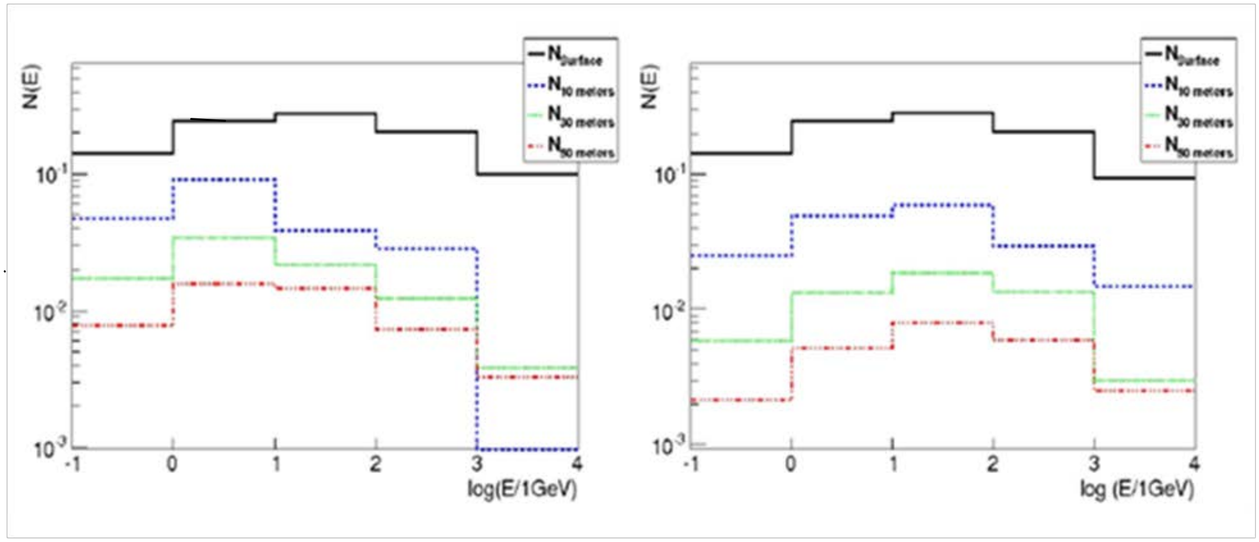

Figure 3.3: Left panel: Muon spectrum on Earth's surface and underground, produced by 10 TeV Proton primaries on the top of the atmosphere. Right panel: Same calculations under water.[26]

The fraction of muons relative to the sea level flux that can reach a certain depth in crust is shown in fig.3.4.The flux is reduced by a factor of ~10 in the first 100 meters. After ~3.5 km below the surface, the quantity of muons is greatly reduced, though until this depth it shows a

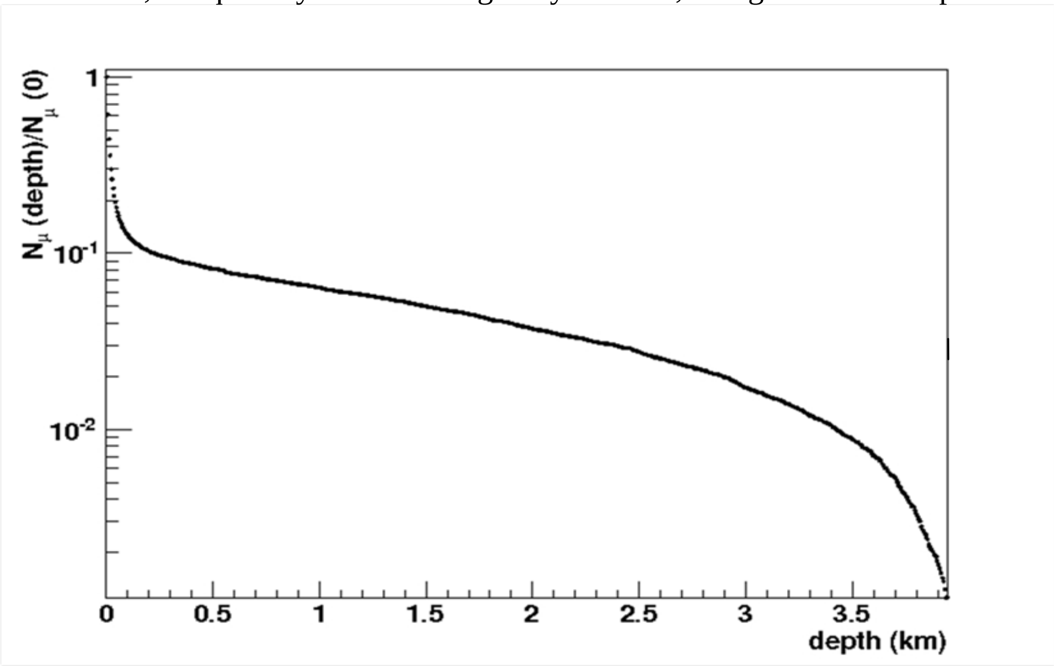

Figure 3.4: Fraction of muons reaching a given depth underground with respect to the sea level flux[27].

milder reduction with distance traveled. This behavior is closely related to the muon stopping power. The stopping power (- <dE/dx>) is the rate at which a charged particle loses energy per distance unit traveled. Since there are many possible interactions for a given particle and the probabilities associated to them are energy dependent, so is the behavior of the stopping power. It leads to the behavior seen in Fig.3.4: low energy muons in the initial flux are easily stopped within the crust, causing the first drop in the curve; high energy muons also quickly loose energy increasing the number of mid energy muons, which can travel much longer within the crust because of the smaller stopping power, leading to the milder reduction seen in the spectrum. They continue loosing energy at a small rate until their energy is such that the stopping power increases again (low energy range) and they quickly loose energy again leading to the fast decay in the spectrum seen at greater depths.

Cosmic rays contribute a small fraction (0.39 mSv/yr annually, 85% from muons [28]). This level varies with the altitude and latitude because of atmospheric and geomagnetic effects. Excursions in cosmic ray intensity can bring large increases in muon dose, up to hundreds of mSv/yr for a nearby supernova

3.3 Radiation from Neutrons

Neutrons are produced in spallation reaction by cosmic ray primaries of energies greater than 1 GeV. Since they are electrically neutral particles, they do not lose energy by means of electromagnetic interactions, like other particles, but lose energy through collisions (short-range strong interactions). Some neutrons are involved in reactions called neutron capture, which results in isotope formation and serves as a good proxy to track changes in cosmic ray flux. Typical cosmic ray primaries result in a peak of neutron flux in the stratosphere [29]. Even with high-energy primaries, there is no significant radiation dose from neutrons on ground. Due to their large cross sections, neutrons pose a significant threat in the upper atmosphere, especially at airline altitude.

Chapter 4

Cosmic Ray Hazard and Prevention

4.1 Effects Of Cosmic Rays On Biological Systems

The potential acute and chronic health effects of space radiation, as with other ionizing radiation exposures, involve both direct damage to DNA, indirect effects due to generation of reactive oxygen species, and changes to the biochemistry of cells and tissues, which can alter gene transcription and the tissue microenvironment along with producing DNA mutations. Acute (or early radiation) effects result from high radiation doses, and these are most likely to occur after solar particle events (SPEs).[31]Likely chronic effects of space radiation exposure include both stochastic events such as radiation carcinogenesis[32] and deterministic degenerative tissue effects. To date, however, the only pathology associated with space radiation exposure is a higher risk for radiation cataract among the astronaut corps.[33][34]

The health threat depends on the flux, energy spectrum, and nuclear composition of the radiation. The flux and energy spectrum depend on a variety of factors: short-term solar weather, long-term trends (such as an apparent increase since the 1950s[35]), and position in the Sun's magnetic field. These factors are incompletely understood.[36][37] The Mars Radiation Environment Experiment (MARIE) was launched in 2001 in order to collect more data. Estimates are that humans unshielded in interplanetary space would receive annually roughly 400 to 900 mSv (compared to 2.4 mSv on Earth) and that a Mars mission (12 months in flight and 18 months on Mars) might expose shielded astronauts to roughly 500 to 1000 mSv.[39] These doses approach the 1 to 4 Sv career limits advised by the National Council on Radiation Protection and Measurements (NCRP) for low Earth orbit activities in 1989, and the more recent NCRP recommendations of 0.5 to 2 Sv in 2000 based on updated information on dose to risk conversion factors. Dose limits depend on age at exposure and sex due to difference in susceptibility with age, the added risks of breast and ovarian cancers to women, and the variability of cancer risks such as lung cancer between men and women.

The quantitative biological effects of cosmic rays are poorly known, and are the subject of ongoing research. Several experiments, both in space and on Earth, are being carried out to evaluate the exact degree of danger. Additionally, the impact of the space microgravity environment on DNA repair has in part confounded the interpretation of some results.[38] Experiments over the last 10 years have shown results both higher and lower than predicted by current quality factors used in radiation protection, indicating large uncertainties exist. Experiments in 2007 at Brookhaven National Laboratory's NASA Space Radiation (NSRL) suggest that biological damage due to a given exposure is actually about half what was previously estimated: specifically, it turns out that low energy protons cause more damage than high energy ones. [39] This is explained by the fact that slower particles have more time to interact with molecules in the body. This may be interpreted as an acceptable result for space travel as the cells affected end up with greater energy deposition and are more likely to die without proliferating into tumors. This is in contrast to the current dogma on radiation exposure to human cells which considers lower energy radiation of higher weighting factor for tumor formation. Relative biological effectiveness (RBE) depends on radiation type described by particle charge number, Z, and kinetic energy per amu, E, and varies with tumor type with limited experimental data suggesting leukemia's having the lowest RBE, liver tumors the highest RBE, and limited or no experimental data on RBE available for cancers that dominate human cancer risks including lung, stomach, breast, and bladder cancers. Studies of Harderian gland tumors in a single strain of female mice with several heavy ions have been made, however it is not clear how well the RBE for this tumor type represents the RBE for human cancers such as lung, stomach, breast and bladder cancers nor how RBE changes with sex and genetic background.

Part of the ISS year long mission is to determine the health impacts of cosmic ray exposure over the course of one year spent aboard the International Space Station. However, sample sizes for accurately estimating health risks directly from crew observations for the risks of concern (cancer, cataracts, cognitive and memory changes, late CNS risks, circulatory diseases, etc.) are large (typically >>10 persons) and necessarily involve long post-mission observation times (>10 years). It will be difficult for a sufficient number of astronauts to occupy the ISS and for the missions to continue long enough to make an impact on risk predictions for late effects due to statistical limitations. Hence the need for ground-based research to predict cosmic ray health risks. In addition, radiation safety requirements mandate that risks should be adequately understood prior to astronauts incurring significant risks, and methods developed to mitigate the risks if necessary. In September 2017, NASA reported radiation levels on the surface of the planet Mars were temporarily doubled, and were associated with an aurora 25-times brighter than any observed earlier, due to a massive, and unexpected, solar storm in the middle of the month.[40]

4.2 Cosmic radiation exposure

The Cosmic Rays we are exposed to during air travel are mostly galactic. They are nearly isotropic at most energies due to deflection of charged particles in the intergalactic magnetic field. Solar Cosmic Rays have lower energy than galactic Cosmic Rays, so their effects are mostly limited to the upper atmosphere (above 30 km). The solar activity affects the received

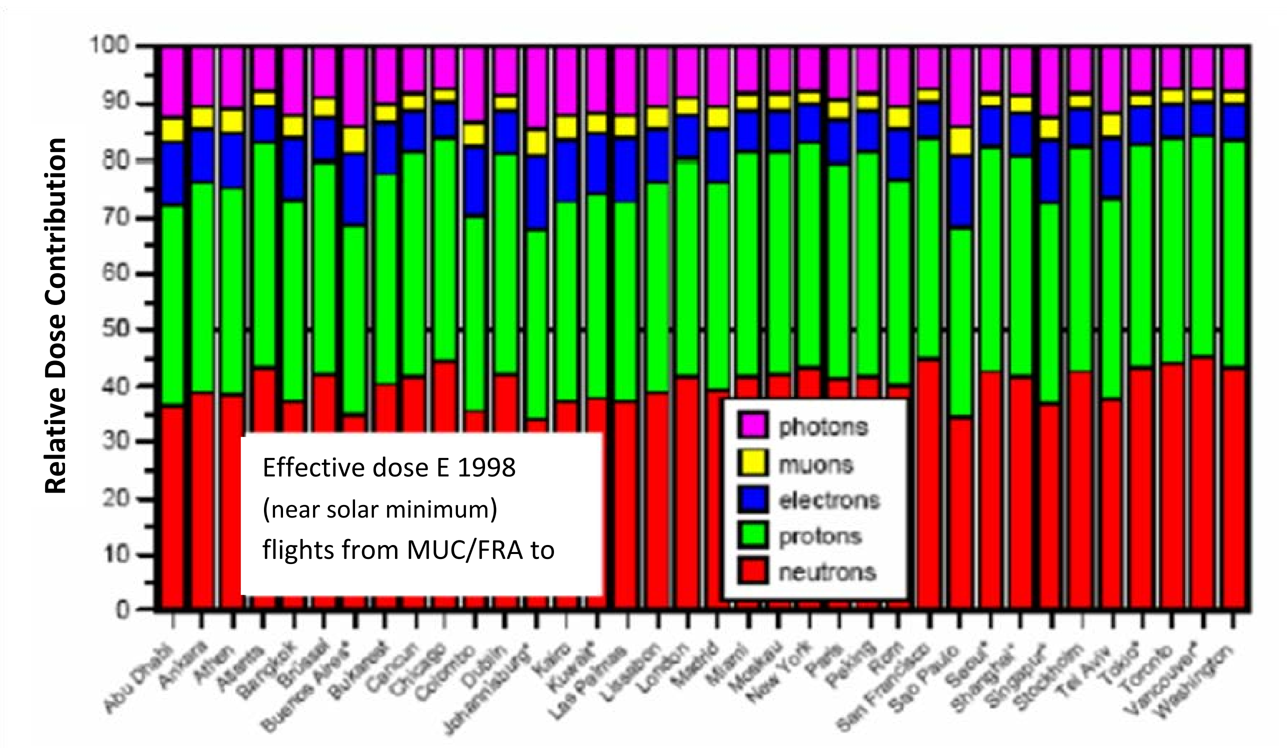

Figure 4.1: Relative contribution to effective dose during commercial flights for various destinations (departing from Munich or Frankfurt, measurements made at altitude of 11 km) near minimum solar activity [45].

radiation dose. Secondary Cosmic Rays that are formed in the atmosphere in air showers (neutrons, pions, muons, electrons, photons and secondary protons), together with the primary Cosmic Rays cause greater radiation exposure during air travel than at the Earth's surface. Neutrons contribute around 40 % to the total dose at flying altitudes (fig.4.1). Due to the high radiation- weighting factor for protons (W_R = 5)[42].

4.3 Exposure Path Ways to Cosmic Rays

4.3.1 Commercial Flights

Galactic Cosmic Rays contribute the most to the aircrew exposure to radiation around 95 %. Radiation dose level represents a complex function of the following:

- It is modulated by Solar activity and the position in its 11-year cycle (fig.4.2). Solar activity peaks approximately every 11 years when sunspot number reaches a maximum. At these times fewer CRs reach Earth, because the Sun emits plasma and magnetic fields which expel some of the CRs from the solar system. During a solar flare event, the additional bursts of cosmic radiation unleashed towards earth and measured on board an aircraft, can reach as high as 10 mSv/h.

- It increases with flight altitude up to 20 km. Measurements are made from 5 to 15 km of altitude (fig.4.3). The Earth's atmospheric layer provides a shielding effect equivalent to 13 feet of concrete. Whereas at sea level the exposure is about 0.06 µSv/h, at 35 000 feet above sea level (the cruising altitude of subsonic commercial aircraft such as Airbus or Boeing 747) the dose received is about 100 times more, at 6 µSv/h.[44] And at 60 000 feet above sea level (the cruising altitude of the supersonic Concorde) the exposure is even much greater.

- It is a function of latitude - radiation shielding by the geomagnetic field is the greatest at the equator and decreases as one goes south or north from the equator. The geomagnetic field of the earth provides additional shielding. Charged particles striking the earth near the equator tend to be deflected along the magnetic field lines towards the poles. The result is that for any given altitude, the exposure increases as one moves away from the equator. The exposure at the same altitude over the poles is roughly twice that over the equator. In figure 4.3, calculated ambient dose equivalent at zero-meridian and geographic latitude of 0^0 (red lines) and 90^0 (blue lines) are shown. The effect of the Earth's magnetic field is described with a parameter *cutoff rigidity*, which represents roughly the lowest rigidity limit above which Cosmic Rays can cross the Earth's magnetosphere and reach a specific position. Particles entering the Earth's magnetic field

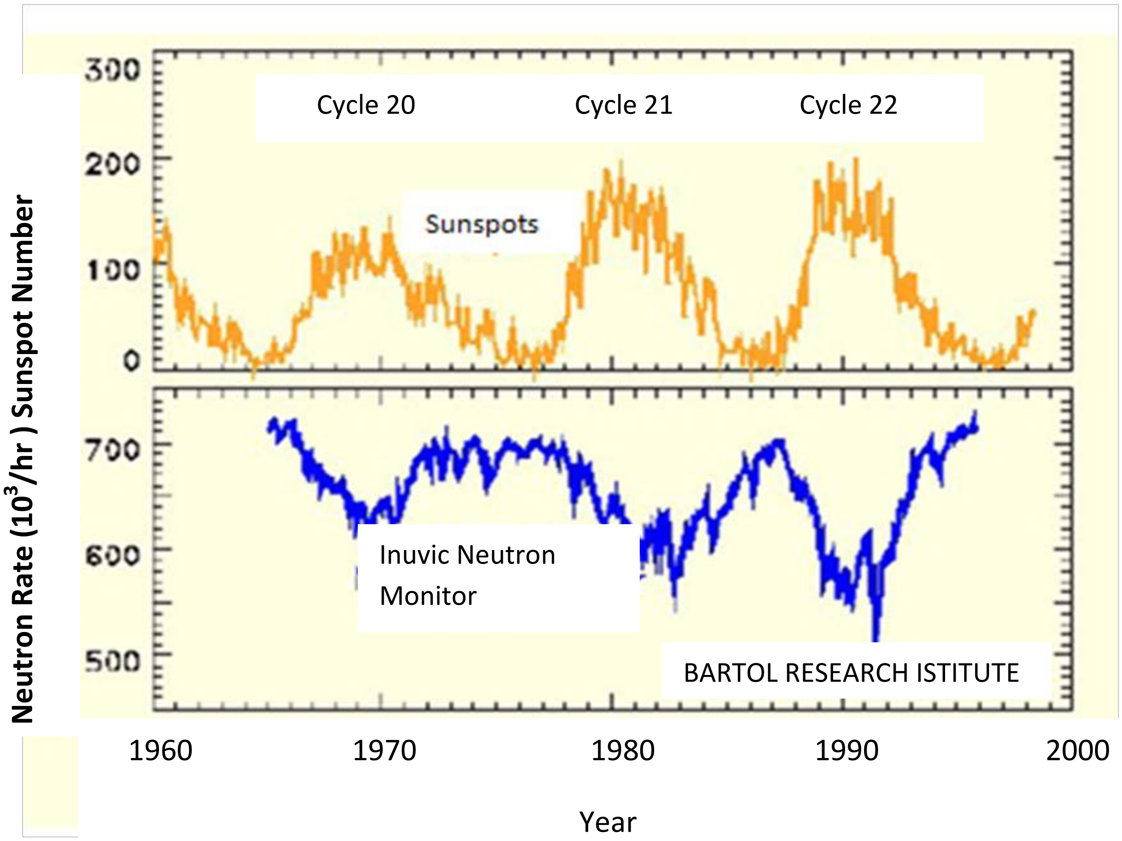

Figure 4.2: Anti-correlation of sunspot number (linked to solar activity) and neutron counts. The Cosmic Ray data was recorded by the Inuvik neutron monitor which detects Cosmic Rays by detecting neutrons. Inuvik is geographically well located -close to the pole, so Earth's magnetic field allows neutrons to be created closer to the ground[45].

at the equator can penetrate through magnetic field only if their energy exceeds 15 GeV, whereas for particles entering at the pole region there are no restrictions. The reason is the magnetic field lines around Earth.

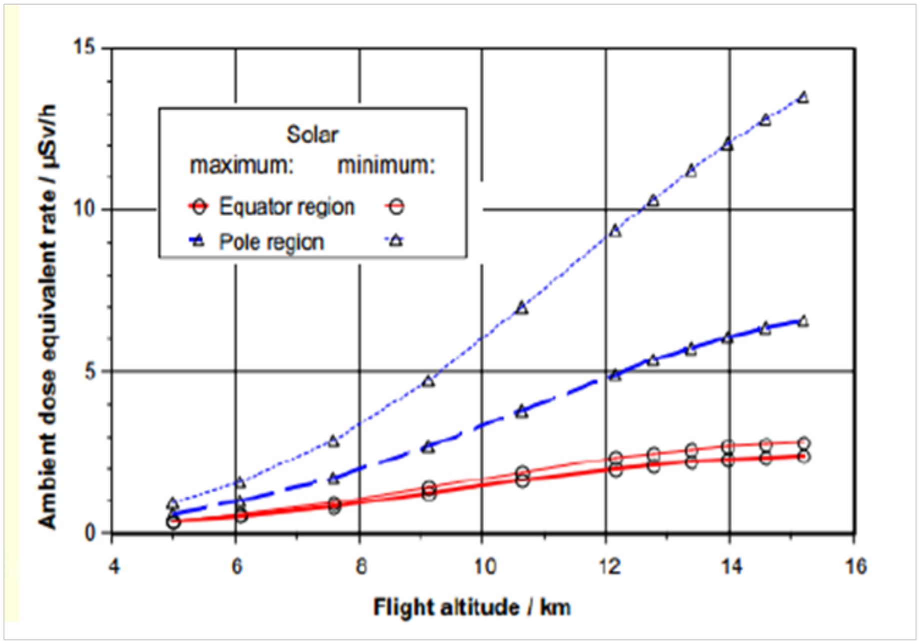

Figure 4.3: Calculated ambient dose equivalent for conditions close to solar maximum (thick lines) and minimum activity (thin lines)[43]

4.3.1.1 Case 1 Adria Airways

A computer program CARI 6 was used to calculate the exposures of Adria Airways (AA) personnel to galactic cosmic radiation [28]. The effective doses were evaluated for the flights during average, maximum and minimum solar activity. Three homogeneous groups were identified: pilots of Canadair CRJ, cabin crew and pilots of Airbus A320. The calculations showed that the cosmic radiation exposure per year was about 2.4 times higher on an Airbus A320 plane compared to the CRJ plane. The main reasons are that an A320 generally flies at higher altitudes, spends 30% more time in the air compared to the CRJ planes, which also means that CRJs spend more time at lower altitudes (when taking off and landing). At a minimum solar activity, radiation dose per year is about 20% higher than at a solar maximum. Both types of Adria Airways' planes (A320 and CRJ) are operated by one of the three types of pilots: instructors, captains or co-pilots. There are 9 instructors, 13 captains and 15 co-pilots operating A320 planes and 12 instructors, 18 captains and 36 co-pilots operating CRJs. Based on the data from 2004, effective dose per year has been estimated for pilots on both of the planes and is shown in Tables 4.1 and 4.2. Aside from the pilots, there is also cabin crew present on board and is exposed to cosmic radiation as well (Table.4.3). To conclude from Tables 4.1 to 4.3, we estimate typical effective dose to be: for A320 pilots approximately 3 mSv per year, for cabin crew approximately 2 mSv per year and for CRJ pilots approximately 1 mSv per year. AA flight personnel is not expected to receive an effective dose exceeding 6 mSv per year for their flying frequency and destinations they are currently flying to[43].

Table 4.1: Effective dose for AA pilots of A320 planes in 2004. BT (block time) is the total flight time and E is effective dose for each group of pilots (their average, minimum and maximum values)[43].

Category	BT (h/year)	$\langle E \rangle$ (msv/year)	E_{min} (msv/year)	E_{max} (msv/year)
Instructor	930	2.83	2.50	3.08
Captain	940	2.86	2.53	3.11
Co-pilot	1000	3.04	2.69	3.31

Table 4.2: Effective dose for AA pilots of CRJ planes in 2004. BT is the total flight time. Average radiation exposure is more than two times lower in CRJ compared to A320[43].

Category	BT (h/year)	$\langle E \rangle$ (msv/year)	E_{min} (msv/year)	E_{max} (msv/year)
Instructor	590	0.97	0.86	1.07
Captain	700	1.15	1.02	1.27
Co-pilot	680	1.12	0.99	1.23

Table 4.3: Effective dose for cabin crew of A320 and CRJ planes in 2004. Comparison with instructors (data for both types of planes is combined) is made[43].

Category	Number	BT (h/year)	$\langle E \rangle$ (msv/year)	E_{min} (msv/year)	E_{max} (msv/year)
Instructor	13	915	2.0	1.8	2.2
Cabin crew	56	944	2.1	1.8	2.3

4.3.1.2 Health risk assessment

Effective dose that Adria Airways personnel receives is from 1 mSv/year to 3 mSv/year in addition to around 3 mSv/year for a person not occupationally exposed to radiation. Significantly greater risks for cancer and other health issues are not expected. As mentioned before, AA flight personnel should not receive an effective dose more than 6 mSv/year. Increased life- time risk of fatal cancer because of occupational exposure to ionizing radiation is 1 in 4200 for 6 mSv/year effective dose (compared to 1 in 8300 for 3 mSv/year). Increased risk of severe genetic defect is notable for effective dose over 10 mSv/year and therefore it is not expected for AA aircrew. A pregnant aircrew member could work 2 months without the dose to the concept exceeding the recommended pregnancy limit of 1 mSv [19][46].

4.3.2 Space Flight

Similar to aircrew, astronauts are also exposed to (mostly) galactic cosmic radiation. There are three main factors that determine the amount of radiation that astronauts receive: altitude above the Earth (Earth's magnetic field is weaker and spacecraft pass through the zones of charged particles, trapped by Earth's magnetic field), solar cycle and individual's susceptibility to radiation. Because the levels of protection vary, the radiation environments vary between planets and moons, even at different places on the surface of individual planets. For example, the ISS has well- shielded areas and the astronauts are largely protected by the Earth's magnetic field because the ISS is in a low Earth's orbit. In contrast, during a deep space journey to the Moon or Mars, astronauts and their vehicles will venture far outside of the Earth's protective magnetic shield. The typical average natural dose for a person is about 3 mSv/year, which is a small dose. International Standards allow exposure to as much as 50 mSv/year for those who work with and around radioactive material. For space flight, the limit is higher. The NASA limit for radiation exposure in low Earth's orbit is 0.50 Sv/year, or 500 mSv/year. Note that the values are lower for younger astronauts.

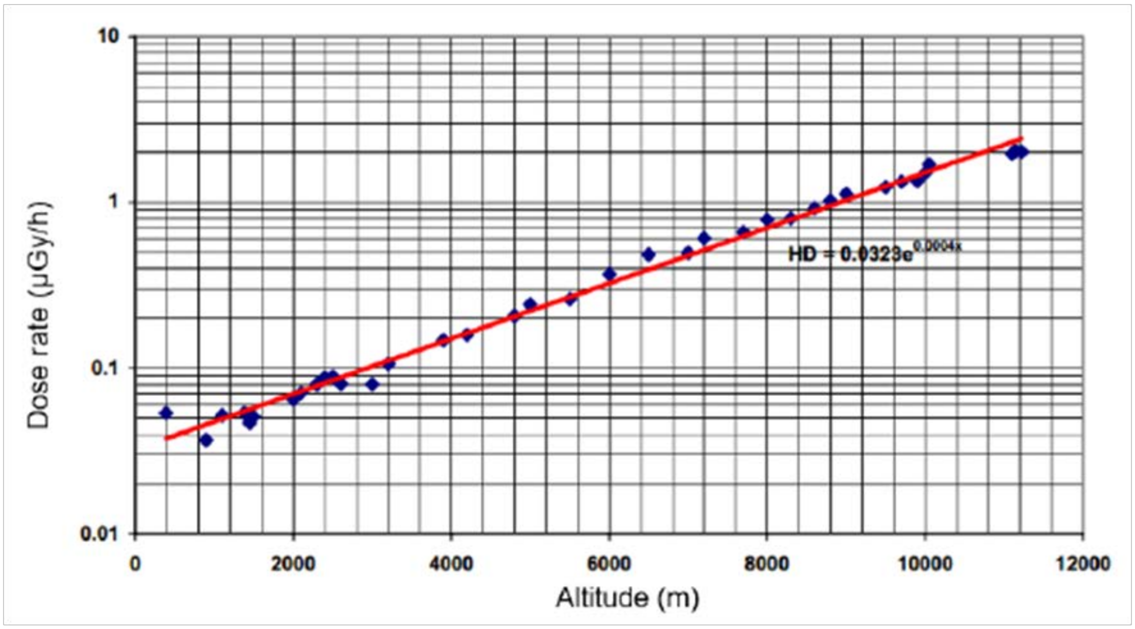

Figure 4.4 : Dose rate increasing exponentially with altitude. Measured by RSS-112 on a flight from Ljubljana to Copenhagen[43]

4.3.2.1 Case 2 Space Flight Exposure

The career length equivalent dose limit is based upon a maximum 3 % lifetime excess risk of cancer mortality - the total equivalent dose yielding this risk depends on gender and age at the start of radiation exposure. Table 4.5 compares various missions and their durations with the observed radiation dose. Crews aboard the space station receive an average of 80 mSv for a six-month stay at solar maximum and an average of 160 mSv for a six-month stay at solar minimum. The difference in received dose at solar minimum and maximum is bigger for astronauts than the air- crew of commercial flights[47].

Table 4.4 : Career exposure limits for NASA astronauts by age and gender[47].

Age (years)	25	35	45	55
Male	1.50 sv	2.50sv	3.25sv	4.00sv
Female	1.00 sv	1.75sv	2.50sv	3.00sv

Table 4.5 : Average radiation dose received by the mission type[47].

Mission type	Radiation dose
Space Shuttle Mission 41-C (8-day mission orbiting the Earth at 460 km altitude)	5.59 mSv
Apollo 14 (9-day mission to the Moon)	11.4 mSv
Skylab 4 (87-day mission orbiting the Earth at 473 km altitude)	178 mSv
ISS Mission (6 months orbiting the Earth at 353 km altitude)	160 mSv
Estimated Mars mission (3 years)	1200 mSv

4.3.2.2 Health Risks of Astronauts

Possible health risks include cancer, damage to the central nervous system, cataracts, risk of acute radiation sickness, and hereditary effects. Risk of cancer death for astronauts by missions is presented in figure 4.5

At this time, reliable projections for CNS risks from space radiation exposure cannot be made due to limited data on the effects of high radiation on the nervous system. Acute (during missions) and late CNS risks from space radiation are of concern for exploration missions beyond low Earth's orbit (ISS), including missions to the Moon, asteroids,

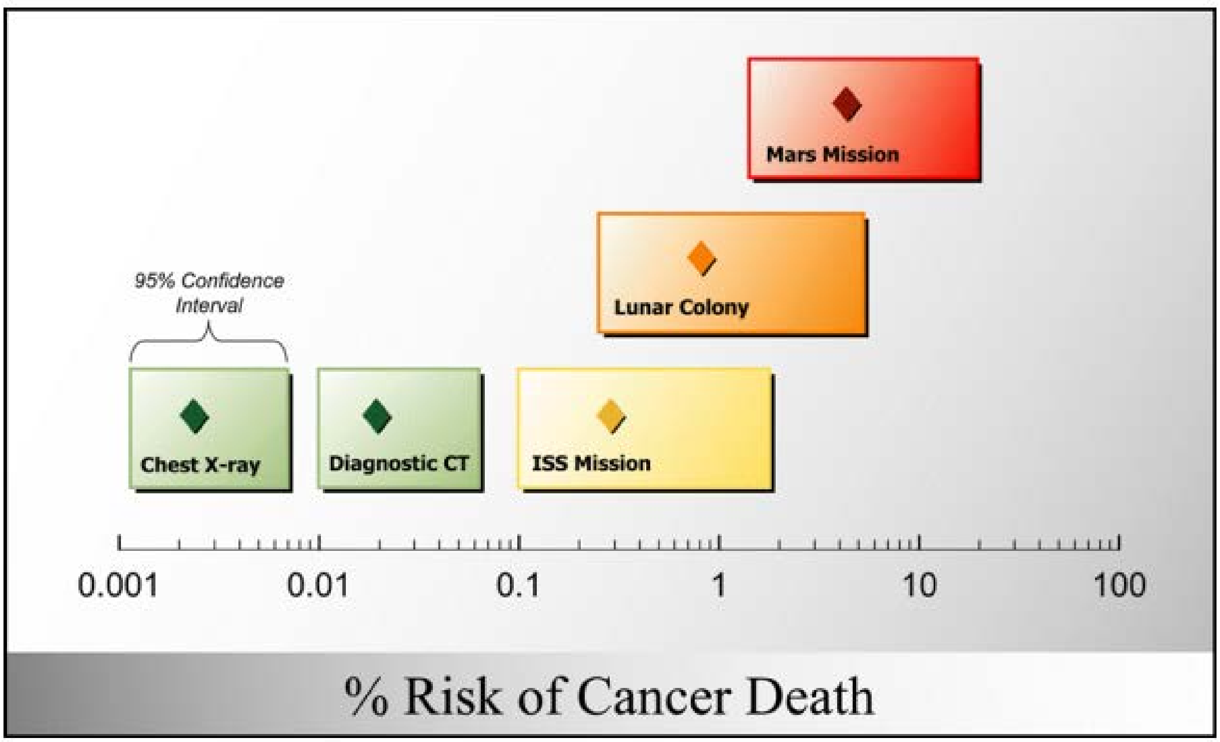

Figure 4.5 : The figure shows current estimates of cancer risks and 95 % confidence bands for adults at the age of 40, the typical age of astronauts on space missions, for several terrestrial exposures and missions. The uncertainties are larger for astronauts in space compared to typical exposures on Earth[48].

or Mars. The association between ionizing radiation exposure and the long-term development of degenerative tissue effects such as heart disease, cataracts, immunological changes, and premature aging is well-established for moderate to high doses of radiation. The majority of this evidence is derived from studies on the atomic bomb survivors in Japan, radiotherapy patients, and occupationally exposed workers and is supported by studies of cataracts in astronauts. These risks remain debatable for ISS or short-term Lunar missions but are more likely in long-term Lunar or Mars missions.

The development of ocular cataracts, which is a degenerative opacification of the crystalline eye lens, is a well-recognized late effect of exposure to ionizing radiation. In figure 4.6, cumulative lens dose received by astronauts is seen. The comparison shows individual contributions from space radiation exposures measured by radiation badges with corrections, from diagnostic X-rays and other medical procedures, and from occupational air training. The biggest contribution to the total dose is space travel. Hazard ratios show a significant increase in cataract risk for astronauts in the high space lens dose group (lens doses above 8 mSv, average 45 mSv) compared to astronauts in the low space lens dose group (lens doses below 8 mSv, average 4.7 mSv). Prevalence of cataracts at the age of 70 for commercial pilots is 3 times larger than in healthy US males; for low-dose astronauts it is 7 times larger and becomes 9 times larger for high-dose astronauts than US male average as shown in figure 4.6.

The biological effects of space radiation, including acute radiation risks (ARS), are a significant concern for manned spaceflight. The primary data that are currently available are derived from analyses of medical patients and persons accidentally exposed to high doses of radiation. Radiation protection must be provided in the form of shielding and operational dosimetry and monitoring, as well as biological countermeasures when travelling out- side of the protective magnetosphere of the Earth. As future NASA missions once again extend beyond lower Earth's orbit and for longer durations, there is reasonable concern that a compromised immune system due to high skin doses from a solar particle event may lead to increased risks[48].

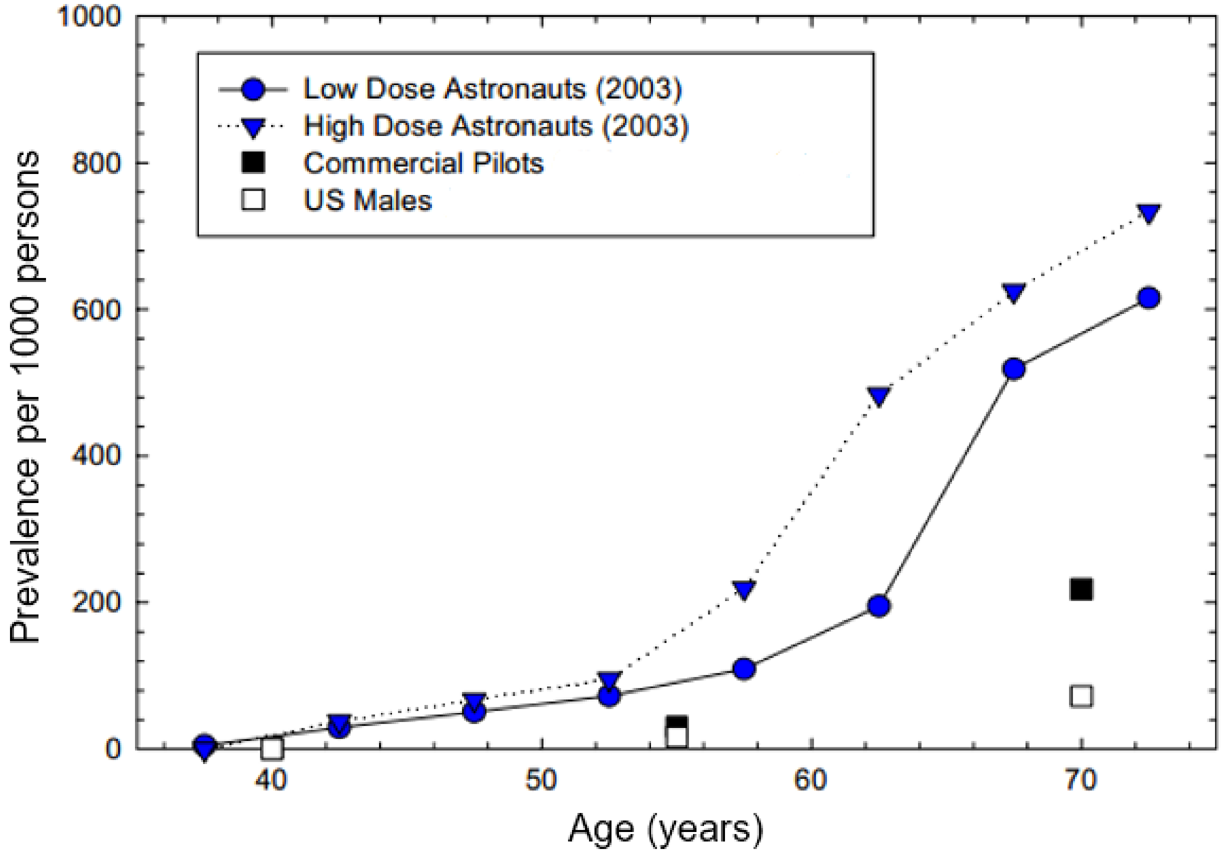

Figure 4.6: Prevalence of cataracts as a function of age in astronauts, pilots and healthy US males[34].

4.3.3 Secondary Muons

Muons can interact with the DNA and lead to mutations and cancerous diseases in organisms [49]. Unlike other forms of radiation, damage caused by muons is approximately independent of the muon energy. This is because the energy deposition caused due to ionization (dE/dx) is a very slow function of energy. Therefore, at any given altitude, the flux of muons is more important than its energy for evaluating the biological damage. The energy of the muon becomes important in the case of the sub surface biosphere. Higher energy particles can easily damage organisms several hundreds of meters below the surface. Organisms living under rocks and inside caves, which are well shielded from other forms of radiation such as UV, are still subject to damage from muons.

4.3.4 Free Radicals

The main reaction caused by muon interactions in the deepest range achieved is ionization, giving rise to several electrons and low energy photons that will propagate and further interact. These are potentially dangerous for they can produce free radicals within cells. The hydroxyl radical ($HO^{\bullet}$) that can form through water molecule ionization is a strong oxidant that can interact with many different kinds of molecules within the cell. Besides the hydroxyl radical, hydride radicals ($H^{\bullet}$) and electrons removed in the ionization process can interact with macro-molecules, such as proteins, lipids, and DNA itself, disrupting them. When suffering this kind of interaction, the cell can either die or regenerate. This regeneration may be imperfect leading to mutations with possible consequence of a runway multiplication with serious biological implications for a multicellular organism or a colony of unicellular individuals.

4.4 Effects of Ionizing Radiation on DNA

Ionizing radiation affects living things on an atomic level, by ionizing molecules inside the microscopic cells that make up our body. When ionizing radiation comes in contact with a cell any or all of the following may happen:

1. It may pass directly through the cell without causing any damage.
2. It may damage the cell but the cell will repair itself.
3. It may affect the cell's ability to reproduce itself correctly, possibly causing a mutation.
4. It may kill the cell. The death of one cell is of no concern but if too many cells in one organ such as the liver die at once, the organism will die.

Inside the nucleus of each cell are microscopic bodies called chromosomes. Chromosomes are organized in pairs and are responsible for the function and reproduction of each cell in an organism's body. Different species of animals and plants may have a different number of chromosomes. Humans and potatoes have 46 chromosomes, while chickens have 78. Chromosomes are made of two large molecules or strands of deoxyribonucleic acid (DNA). These strands of DNA make up the genetic code, which in many ways acts much like a computer program. DNA is made up of four nucleic acids: adenine, cytosine, guanine and thymine. How these nucleic acids are arranged in the DNA is the genetic code that determines everything from hair colour to how tall you grow and even susceptibility to certain diseases.

When cells divide to reproduce, an exact copy of the cells' chromosomes are created for the new cell. If the DNA in the chromosome is damaged, the instructions that control the cell's function and reproduction are also damaged. If the cell reproduces instead of dying, a new mutated cell may be produced. In many cancers, the instructions that turn off cell growth are somehow damaged causing out of control cell reproduction, creating a tumour[50]. Ionizing radiation, along with many other substances such as some chemicals, heavy metals and intense electromagnetic waves, can damage cells in this manner which can lead to diseases such as cancer.

When talking about biological effects from ionizing radiation there are two categories of injury: somatic injury and genetic injury. Somatic injury is damage that occurs to the organism exposed to high levels of ionizing radiation and does not include reproductive cells. Effects like sickness, hair loss or internal bleeding are visible shortly after exposure. Other illness such as cancer may take a number of years to appear.

Genetic injury is damage to the reproductive cells due to exposure to high levels of ionizing radiation and can be passed down to an organism's offspring, perhaps generations later. Some potential illnesses could include birth abnormalities and cancer. Somatic and genetic injuries are not solely caused by ionizing radiation. Many chemical pollutants found in our environment such as cadmium, lead and mercury also can cause similar injuries.

If a strand of DNA is damaged, the cell may repair the damage, die or kill itself through a process known as apoptosis[51].Sometimes the cell survives but incorrectly repairs itself and then passes the genetic abnormality on to other cells during reproduction.

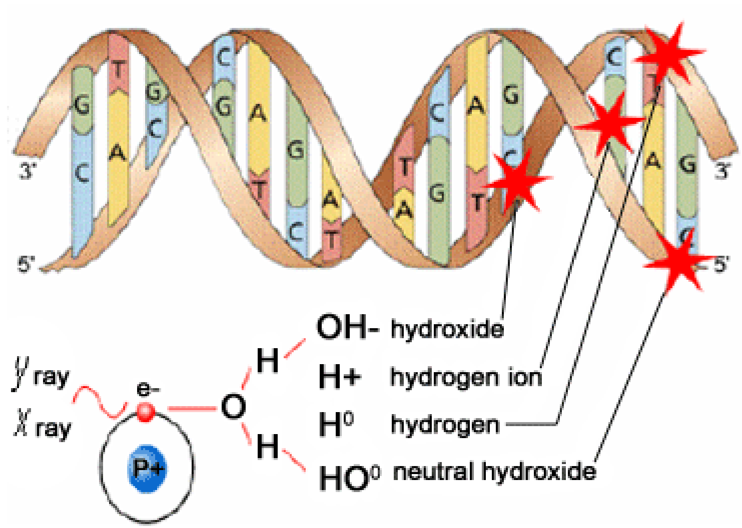

Figure 4.7 Indirect action of ionizing radiation on DNA[53].

Ionizing radiation can also impair or damage cells indirectly by creating free radicals. Free radicals are molecules that are highly reactive due to the presence of unpaired electrons on the molecule. Free radicals may form compounds, such as hydrogen peroxide, which could initiate harmful chemical reactions within the cells. As a result of these chemical changes, cells may undergo a variety of structural changes which lead to altered function or cell death[52].

4.5 Mitigation

4.5.1 Shielding

Material shielding can be effective against galactic cosmic rays, but thin shielding may actually make the problem worse for some of the higher energy rays, because more shielding causes an increased amount of secondary radiation, although thick shielding could counter such too.[54] The aluminium walls of the ISS, for example, are believed to produce a net reduction in radiation exposure. In interplanetary space, however, it is believed that thin aluminium shielding would give a net increase in radiation exposure but would gradually decrease as more shielding is added to capture generated secondary radiation.[55][56]

Studies of space radiation shielding should include tissue or water equivalent shielding along with the shielding material under study. This observation is readily understood by noting that the average tissue self-shielding of sensitive organs is about 10 cm, and that secondary radiation produced in tissue such as low energy protons, helium and heavy ions are of high LET and make significant contributions (>25%) to the overall biological damage from GCR. Studies of aluminum, polyethylene, liquid hydrogen, or other shielding materials, will involve secondary radiation not reflective of secondary radiation produced in tissue, hence the need to include tissue equivalent shielding in studies of space radiation shielding effectiveness.

Several strategies are being studied for ameliorating the effects of this radiation hazard for planned human interplanetary spaceflight: Spacecraft can be constructed out of hydrogen-rich plastics, rather than aluminium.[57]

- Material shielding has been considered:

  - Liquid hydrogen, which would be brought along as fuel in any case, tends to give relatively good shielding, while producing relatively low levels of secondary radiation. Therefore, the fuel could be placed so as to act as a form of shielding around the crew. However, as fuel is consumed by the craft, the crew's shielding decreases.
  - Water, which is necessary to sustain life, could also contribute to shielding. But it too is consumed during the journey unless waste products are utilized.[58]
  - Asteroids could serve to provide shielding.[59][60]

- Magnetic deflection of charged radiation particles and/or electrostatic repulsion is a hypothetical alternative to pure conventional mass shielding under investigation. In theory, power requirements for the case of a 5-meter torus drop from an excessive 10 GW for a simple pure electrostatic shield (too discharged by space electrons) to a moderate 10 kilowatts (kW) by using a hybrid design.[55] However, such complex active shielding is untried, with workability and practicalities more uncertain than material shielding.[59]

Special provisions would also be necessary to protect against a solar proton event, which could increase fluxes to levels that would kill a crew in hours or days rather than months or years. Potential mitigation strategies include providing a small habitable space behind a spacecraft's water supply or with particularly thick walls or providing an option to abort to the protective environment provided by the Earth's magnetosphere. The Apollo mission used a combination of both strategies. Upon receiving confirmation of an SPE, astronauts would move to the Command Module, which had thicker aluminium walls than the Lunar Module, then return to Earth. It was later determined from measurements taken by instruments flown on Apollo that the Command Module would have provided sufficient shielding to prevent significant crew harm.

None of these strategies currently provide a method of protection that would be known to be sufficient[61] while conforming to likely limitations on the mass of the payload at present (around $10,000/kg) launch prices. Scientists such as University of Chicago professor emeritus Eugene Parker are not optimistic it can be solved anytime soon.[61] For passive mass shielding, the required amount could be too heavy to be affordably lifted into space without changes in economics (like hypothetical non-rocket spacelaunch or usage of extraterrestrial resources) — many hundreds of metric tons for a reasonably-sized crew compartment. For instance, a NASA design study for an ambitious large spacestation envisioned 4 metric tons per square meter of shielding to drop radiation exposure to 2.5 mSv annually (± a factor of 2 uncertainty), less than the tens of millisieverts or more in some populated high natural background radiation areas on Earth, but the sheer mass for that level of mitigation was considered practical only because it involved first building a lunar mass driver to launch material.[58]

Several active shielding methods have been considered that might be less massive than passive shielding, but they remain speculative.[55][62] Since the type of radiation penetrating farthest through thick material shielding, deep in interplanetary space, is GeV positively charged nuclei, a repulsive electrostatic field has been proposed, but this has problems including plasma instabilities and the power needed for an accelerator constantly keeping the charge from being neutralized by deep-space electrons.[63] A more common proposal is magnetic shielding generated by superconductors (or plasma currents). Among the difficulties with this proposal is that, for a compact system, magnetic fields up to 10–20 teslas could be required around a manned spacecraft, higher than the several teslas in MRI machines. Such high fields can produce headaches and migraines in MRI patients, and long-duration exposure to such fields has not been studied. Opposing-electromagnet designs might cancel the field in the crew sections of the spacecraft, but would require more mass. It is also possible to use a combination of a magnetic field with an electrostatic field, with the spacecraft having zero total charge. The hybrid design would theoretically ameliorate the problems, but would be complex and possibly infeasible.[55] Part of the uncertainty is that the effect of human exposure to galactic cosmic rays is poorly known in quantitative terms. The NASA Space Radiation Laboratory is currently studying the effects of radiation in living organisms as well as protective shielding.

4.5.2 Timing of missions

Due to the potential negative effects of astronaut exposure to cosmic rays, solar activity may play a role in future space travel. Because galactic cosmic ray fluxes within the Solar System are lower during periods of strong solar activity, interplanetary travel during solar maximum should minimize the average dose to astronauts. Although the Forbush decrease effect during coronal mass ejections can temporarily lower the flux of galactic cosmic rays, the short duration of the effect (1–3 days) and the approximately 1% chance that a CME generates a dangerous solar proton event limits the utility of timing missions to coincide with CMEs.

4.5.3 Orbital selection

Radiation dosage from the Earth's radiation belts is typically mitigated by selecting orbits that avoid the belts or pass through them relatively quickly. For example, a low Earth orbit, with low inclination, will generally be below the inner belt. The orbits of the Earth-Moon system Lagrange points take them out of the protection of the Earth's magnetosphere for approximately two-thirds of the time. The orbits of Earth-Sun system Lagrange Points are always outside the protection of the Earth's magnetosphere.

4.6 Beyond the Medical Literature

It is also instructive to look at the parallel world of microelectronics where it may come as a surprise to some biological scientists, there already exists a strong body of evidence on the deleterious effects of cosmic rays on microchips. For example, it has been known for some time now that the failure rate of electronics at aircraft altitudes is about 100 times greater than at sea level, and that cosmic rays are mainly responsible. Although the higher energy particles can cause serious, permanent damage, called hard errors—for example, chip burnout—the lower energy particles are capable of causing soft errors—for example, flipping a logic bit from one to zero or vice versa—resulting in corrupted but reversible memories on computer chips.[64][65] Soft errors, or single event upsets in electronic parlance, can be corrected quite simply for example, by rebooting a computer. The occurrences of soft errors have been shown in satellites, spacecraft, the Concorde, and commercialairliners.[66]Solar flare particle events pose the greatest problems, a not surprising fact as they are known to swamp satellite electronics and electrical power communications on earth.[67] Adding credence to the theory that cosmic rays are responsible for these effects is a recently disclosed experiment conducted over a period of 16 years (1978–94) where a team at IBM tested about 800 dynamic random access memory devices in constant read mode at sea level, in mountainous regions (at 5000 feet and 10 000 feet) and in underground caves (shielding of 50 feet of concrete). They found that the higher the altitude, the more numerous the soft errors whereas initially, even after 3 months, the underground dynamic random access memory tested at zero soft errors. Since the release of the IBM report in 1996, there has been a considerable amount of research devoted to finding newer and better ways of protecting electronic devices intended for aircraft and space use from harmful radiation.[68]

Conclusion

This project can help to identify area where more cosmic radiation is likely and the people who are most at risk. During my background reading I found studies suggesting increased exposure to cosmic rays might lead to increased risk of cancer. My study identifies that higher latitudes are likely to have an increase number of cosmic ray events. Therefore people living in area at higher latitude can take the right precautions to help reduce this increased risk.

This project also presents first direct and circumstantial evidences of the effects of Cosmic Rays on biological systems. A diverse disorder of nuclear, cellular, intercellular material, as well as origin of multi-nuclear cells and cells with gigantic nuclei, micronuclei, and other phenomena, were considered as indicators of exposure of cell cultures to ionizing component of solar Cosmic Rays near the Earth's surface.

As a consequence of being an aircrew member for commercial flights greater health risks apply. Effective dose for Adria Airways aircrew is on average from 1 to 3 mSv/year but lower than 6 mSv/year. Increased life-time risk of fatal cancer is twice as big for 6 mSv/year dose compared to 3 mSv/year (dose for an average person living on Earth's surface). Another study has shown that pilots were three times as likely to have nuclear cataracts compared to the non-pilots. When estimating effective dose for astronauts it is important to know whether they are on a mission in low Earth's orbit (ISS) or high Earth's orbit (mission to the Moon or Mars). ISS' astronauts are protected by the Earth's magnetic field. When travelling to the Moon or Mars, there is no more magnetic protective shield of the Earth. For astronauts, NASA limit for radiation is therefore 500 mSv/year on average for low Earth's orbit. Per career, an astronaut may receive up to 3 % lifetime excess risk of cancer mortality. Crews aboard the ISS receive an average of 80 to 160 mSv/6-month-period (depending on the solar maximum/minimum). Possible health risks include cancer, damage to central nervous system, cataracts, risk of acute radiation sickness and hereditary effects. In low Earth's orbit these health risks are not as significant as they would be when travelling for longer time and outside the Earth's magnetic field (for example mission to Mars). Prevalence of cataracts at the age of 70 for low-dose astronauts is 7 times larger and it is 9 times larger for high-dose astronauts than an average healthy US male. For future missions outside the Earth's magnetic field there has to be additional protection provided and health risk studies made.

Knowledge in radiation protection is an important tool in the battle for survival on our planet. Our country Ethiopia is found at a high altitude ,therefore it is highly bombarded with energetic CR particles.

Though there is no research that is indicating the level of this natural radiation, the risk is very high for the population and especially for the aircrew members.

public today still seems insufficiently informed about the hazards brought by natural sources of radiation.

However, state authorities are obliged to inform the public on regular basis, in time, fully and objectively about the state of our natural environment, that is, about the phenomena that are surveyed within the monitoring of the level of emissions, and about precautionary measures or about the progress of radiation which can prove to be hazardous to life and human health.

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Declaration

This project is my original work, has not been presented for a degree in any other University and that all the sources of material used for the project have been dully acknowledged.

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This project has been submitted for examination with my approval as University advisor.

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