Preface

Short Historical Overview

In the 1940s, two phenomena in the field of cosmic rays (CR) forced scientists to think that the Sun is a powerful source of high-energy particles. One of these was discovered because of the daily solar variation of CR, which the maximum number of CR observed near noon (referring to the existence of continuous flux of CR from the direction of the Sun); this became the experimental basis of the theory that CR's originate from the Sun (or, for that matter, from within the solar system) (Alfvén 1954). The second phenomenon was discovered when large fluxes of high energy particles were detected from several solar flares, or solar CR. These are the so-called ground level events (GLE), and were first observed by ionization chambers shielded by 10 cm Pb (and detected mainly from the secondary muon-component CR that they caused) during the events of the 28th of February 1942, the 7th of March 1942, the 25th of July 1946, and the 19th of November 1949. The biggest such event was detected on the 23rd of February 1956 (see the detailed description in Chapters X and XI of Dorman, M1957).

The first phenomenon was investigated in detail in Dorman (M1957), by first correcting experimental data on muon temperature effects and then by using coupling functions to determine the change in particle energy caused by the solar-diurnal CR variation. After this, it became possible to estimate the influence of the geomagnetic field on the trajectories of CR particles, as well as to determine then the real direction of the daily solar CR anisotropy with regards to the Earth's magnetosphere in interplanetary space. It was shown that the generally accepted opinion of that time concerning the continuous flux of CR from the Sun was absolutely wrong, since the newly discovered direction turned out to be perpendicular to the Sun–Earth line. It furthermore became clear that the Sun is not a continuous source of CR; rather, CR particles must come from interstellar space, i.e. they are not solar, but galactic in origin.

The existence of the second phenomenon (the generation of high energy solar CR during chromospheric flares) lead to a very important consequential conclusion: in the solar atmosphere, many types of nuclear reactions must occur (distinct from those thermonuclear reactions that occur within the Sun), and must also generate secondary energetic particles. These include neutrons, first supposed by Biermann et al. (1951); gamma rays (as gamma ray lines from exited nuclei, from the decay of π^0 mesons, and from relativistic electrons bremsstrahlung). On the other hand, solar CRs must affect chemical and isotropic contents of the solar atmosphere, also as a result of the afore-mentioned nuclear reactions. It is well known that during thermonuclear reactions, deuterium will be fully destroyed at a temperature of $T = 1.2\times10^6$ K; likewise, lithium will be destroyed at $T = 3.2\times10^6$ K, and beryllium at $T = 3.6\times10^6$ K (this explains why these elements are so rare in the Universe). Nevertheless, these light elements were observed in the Sun's atmosphere, leading Shklovsky (1955) to suppose that these light elements are formed by nuclear reactions of CRs from solar flares with the matter in the solar atmosphere.

The problem of solar neutrons and related phenomena came to the forefront after the solar flares of August 1972 (when solar gamma rays were discovered), as well as after the flares of June 1980 and June 1982, when solar neutrons were discovered. However, many years before, forecasts and rough estimations were made of the expected nuclear reactions of solar energetic particles with the matter of the solar atmosphere, and of the generation of solar neutrons and gamma rays, in the frame of some simple models.

In the former USSR, I started, along with my colleagues in IZMIRAN (Moscow region) and in the Ionosphere Institute in Alma-Ata, to investigate statistical solar neutron effects in a high altitude neutron supermonitor. I continued to have an interest in the problem of solar neutrons in 1990–1991, when, together with Prof. D. Venkatesn, I worked at Calgary University (Canada) on the review on solar cosmic rays. This interest increased in 1996–1997, when I worked in Mexico (at the Geophysics Institute of UNAM) together with Prof. J.F. Valdes-Galicia on the problem of solar neutron propagation in the Earth's atmosphere, taking into account the so-called refraction effect.

Physical Motivation and Background

What is the physical sense, considered in this book, of the problem of solar neutrons and their related phenomena? The Sun is roughly 2×10^5 closer to Earth than the Earth is to the nearest other stars. This means that the fluxes of particles and γ-rays from the nuclear reactions of energetic particles in the Sun's atmosphere will have a magnitude about 4×10^{10} times bigger than those from the nearest stars. This also means that the investigation of nuclear reactions of energetic particles in stellar atmospheres must necessarily begin with the Sun. On the other hand, in laboratory conditions (using accelerators of energetic particles), a lot of nuclear reactions have been discovered and investigated in detail. For example, for the generation of neutrons, it is necessary to take into account (Lingenfelter et al. 1965a, b) the reactions initiated by energetic protons:

$He^4(p,pn)He^3$ (threshold kinetic energy $E_{tk} = 25.7$ MeV)
$He^4(p,ppn)H^2$ (32.6 MeV)
$He^4(p,ppnn)H^1$ (35.4 MeV)
$He^4(p,pn\pi)H^1$ (197.5 MeV)
$He^4(p,pnn\pi)H^1$ (207.0 MeV)
$H^1(p,n\pi^+)H^1$ (287.0 MeV)
$H^1(p,n\pi^+\pi)H^1$ (557.0 MeV)
$C^{12}(p,n)N^{12}$ (19.8 MeV)
$N^{14}(p,n)O^{14}$ (6.3 MeV)
$O^{16}(p,pn)O^{15}$ (16.5 MeV)
$Ne^{20}(p,pn)Ne^{19}$ (17.7 MeV)

as well as energetic α-particle initiated reactions

$H^1(\alpha,np)He^3$ ($E_{tk} = 102.8$ MeV)
$H^1(\alpha,ppn)H^2$ (130.3 MeV)
$H^1(\alpha,ppnn)H^1$ (141.5 MeV)
$He^4(\alpha,n)Be^7$ (38.8 MeV)
$He^4(\alpha,\alpha n)He^3$ (41.1 MeV)
$He^4(\alpha,np)Li^6$ (49.2 MeV)

Then, neutrons may be captured by H^1 with the formation of H^2 and the generation of a γ-quant of energy 2.223 MeV, or, they may be captured without the generation of a γ-quant, and may escape from the solar atmosphere. The escaped neutrons may decay into a proton, electron, and neutrino, or may reach the Earth's atmosphere, where they scatter and get partly absorbed, and where the so-called refraction effect (in which neutrons arrive at the detector not from the direction of the Sun, but in some direction between the Sun and the vertical, depending on neutron energy) is important. During nuclear reactions, a lot of excited and radioactive nuclei are formed that generate γ-ray lines, positrons, and other decay products (e.g., Ramaty and Lingenfelter 1973a, b). The decay of generated π^0 mesons gives energetic γ-rays (mostly above and more than 70 MeV), and the decay of $\pi^{\pm}$mesons produces energetic electrons and positrons. The bremsstrahlung of the generated relativistic electrons results in continuous γ-ray radiation.

It is important to note that the generation of neutrons, gamma-rays, positrons and other secondary particles is determined not only by the contents and energy spectrum of the accelerated charged particles during a solar flare, but also, it depends on chemical and isotopic contents, temperature, and vertical density distribution in the solar atmosphere, in the region where nuclear reactions occur along with the propagation of neutrons, positrons, and gamma-rays. This means that detailed experimental and theoretical investigations of solar neutron and/or gamma-ray events will give the unique possibility of obtaining direct information on the source function of solar CR, as well as on the properties of the solar atmosphere in the regions of generation, propagation, and interaction of neutrons and gamma-rays.

Plan and Structure of the Book

In the present book, we compiled and reviewed for the first time a huge experimental and theoretical body of material, constituting results published in the world's scientific literature for more than the past 50 years. This work concerns: solar neutrons and the products of their decay; solar gamma-rays generated together with neutrons in nuclear reactions of solar energetic particles in the solar atmosphere, propagation in the corona, as well as in interplanetary space and in the Earth's atmosphere. It is important to note that investigations of solar neutrons and related phenomena give not only unique information on accelerated solar particles directly at the source (including their chemical and isotopic composition), but also information on background plasmas, including their density and temperature distribution, and information on the mechanisms of energetic particle acceleration and propagation in the solar atmosphere. Let us note further that in Chapters 7–11, we consider in detail prominent solar neutron/gamma-ray events in chronological order, ending in the relatively recent events of 2005–2006. In our catalogue of the scientific literature, we were unable to find even a single weak solar neutron/gamma-ray event after this time. This dearth of events is probably related to the very low period of solar activity corresponding with the current, anomalously long solar minimum.

In Chapter 1, we consider the problem of solar neutrons and related phenomena as it was before the discovery (in 1972) of solar gamma-rays and (in 1980–1982) solar neutrons. The first supposition that high energy particles may be generated on the Sun (as a result of nuclear interactions of accelerated charged solar flare particles with solar atmospheric matter) was made in 1951, by L. Biermann, O. Haxel, and A. Schlüter. In the 1960s and at the beginning of the 1970s, many model calculations and flux estimations for solar neutrons and gamma-ray lines were made in key papers by E.L. Chupp, L.D. De Feiter, J.E. Dolan, G.G. Fazio, E.J. Flamm, W.N. Hess, K. Ito, R.E. Lingenfelter, H. Okazoe, R. Ramaty, H. Rasdan, Z. Svestka, and M. Yoshimori. They showed that detectable neutron and gamma-ray fluxes from major solar flares are expected in the Earth's vicinity. We also consider in Chapter 1 estimations of expected solar neutron and gamma-ray fluxes from some historically powerful flares that generated energetic charged particles. We examine the search for solar neutrons by balloon and space probe experiments as well as by ground measurements, and the search for solar gamma-rays. We underline that all attempts to search for solar neutrons and gamma-rays before the events of 1972, 1980 and 1982 gave only the upper limits for the fluxes from the Sun during quiet periods and chromospheric flare events.

Chapter 2 is devoted to the detailed description of the famous discovery by the 0.3–10 MeV gamma-ray detector on the OSO-8 satellite of solar gamma-rays from the flares of August 1972. The discovery was made by E.L. Chupp, P.P. Dunphy, D.J. Forrest, P.R. Higbie, C. Reppin, A.N. Suri, and C. Tsai, who, in the first 2 weeks of August 1972, first endeavored to use this instrument to look for gamma-quanta in the periods of intense X-ray emission of ≥ 4 erg.cm^{-2} s^{-1}

(class ≥M4) in the 1–8 Å band. Only upper limits of the 0.5, 2.2, 4.4 and 6.1 MeV gamma-quantum fluxes (mainly $\leq 5 \times 10^{-3}$ photon cm^{-2} s^{-1} for all gamma-ray lines) were obtained during this measurement period. However, during two very short periods (several minutes) during the flares of the 4th and 7th of August, 1972, real fluxes were measured for the positron annihilation line 0.51 MeV to an accuracy of 5σ, for the 2.2 MeV neutron capture line to an accuracy of 10σ, and for excited 4.4 and 6.1 MeV lines with an accuracy of about 3σ. This chapter is very short, but because of the great importance of these first positive results, we decided to leave them in their own unit, we devote the detailed description of solar gamma ray dicsovery to a separate chapter.

We describe in Chapter 3 the discovery of solar neutrons. This famous discovery, by E.L. Chupp, D.J. Forrest, J. Heslin, G. Kanbach, K. Pinkau, C. Reppin, E. Rieger, J.M. Ryan, and G.H. Share during the event of June 21, 1980 using the Gamma Ray Spectrometer aboard the SMM satellite, showed that for large energy loss events (10–140 MeV and 25–140 MeV), the measured pulses are not caused by gamma-rays, but rather, by neutrons. During the second event, on June 3, 1982, solar neutrons were simultaneously measured by both SMM and ground based neutron monitors for the first time (this seminal work appears in key papers by E.L. Chupp, H. Debrunner, E. Flückiger, D.J. Forrest, G. Kanbach, and G.H. Share).

Solar neutrons and/or solar gamma ray events observations on space probes we describe in Chapter 4 using results obtained on the satellites SMM and Hinotori, during the COMPTEL experiment on the Compton Gamma-Ray Observatory, obtained on satellite GAMMA-1. This chapter is based on the key papers of H. Aarts, V.V. Akimov, K. Bennett, R. Byrd, E.I. Chuikin, E.L. Chupp, H. Debrunner, P.P. Dunphy, S. Enome, G. Eymann, D. Forrest, C. Foster, M.I. Fradkin, G.M. Frye, Jr., A.M. Galper, J.E. Grove, L. Hanlon, T.L. Jenkins, C. Jensen, W.N. Johnson, G.V. Jung, R.L. Kinzer, J.D. Kurfess, L.V. Kurnosova, J. Lockwood, M. Loomis, M. McConnell, D. Morris, R.J. Murphy, H. Nakajima, S. Nakayama, V.E. Nesterov, H. Ogawa, R. Ramaty, G. Rank, J. Ryan, V. Schonfelder, G.H. Share, S. Stansfield, H. Steinle, M.S. Strickman, B.N. Swanenburg, R.A. Schwartz, K. Suga, K. Takahashi, S.A. Voronov, W. Webber, C. Winkler, M. Yoshimori. Let us note that on satellites, a significant π^{o}-decay peak at 70 MeV was observed for the first time during the solar neutron event of March 6, 1989 (key paper of P.P. Dunphy and E.L. Chupp).

In Chapter 5, we describe the problem of solar neutron propagation in the Earth's atmosphere, as well as the sensitivity of neutron monitors and other ground-based detectors of solar neutrons. Thanks to the charge invariance of neutrons and protons, it is important to note that for high-energy neutrons, we can use the coupling functions and integral multiplicities found for galactic and solar CR protons using theoretical calculations of cascades in the atmosphere (as well as from geomagnetic effects). In this way, the main results of the key papers of E.A. Brunberg, J.M. Clem, H. Debrunner, L.I. Dorman, E. Flückiger, N.I. Pakhomov, P. Stein were obtained. Important results were obtained not only for vertical particles but also for particles inclined at zenith angles of 15, 30, 45, 60, and 75° (L.I. Dorman and N.I. Pakhomov). The detailed Monte Carlo simulation of solar neutrons in the Earth's atmosphere and of the sensitivity of neutron monitors to them for vertically-arriving solar neutrons was made in a key paper by S. Shibata. Corresponding papers dealing with other, inclined zenith angles was published via L.I. Dorman, I.V. Dorman, and J.F. Valdes-Galicia.. Thus, the so-called refraction effect of solar neutrons, which depends on the arriving angle, the energy of the neutrons, and the atmospheric level at the place of observation, was determined with great accuracy. It was shown for the first time, in a key paper by D.F. Smart, M.A. Shea, and K. O'Bren, that this effect is very important for the interpretation of solar neutron observations made by neutron monitors and solar neutron telescopes.

Chapter 6 deals with statistical investigations of solar neutron events on the basis of ground observations. On the one hand, positive results were obtained from the Rome neutron monitor's (which sits at about sea-level) 5-min data in a paper by N. Iucci, M. Parisi, C. Signorini, M. Storini, and G. Villoresi. On the other hand, no positive visible effect was found on the basis of the high altitude Chacaltaya neutron monitor (discussed in a key paper by N.J. Martinic, A. Reguerin, E. Palenque, M.A. Taquichiri, M. Wada, A. Inoue, and K. Takahashi). We show that this negative result may have been caused mostly by choosing solar flares, which are characterized by great solar zenith angles. To check the statistical effect of solar neutrons, data from the high-altitude Tyan Shan neutron monitor are analyzed in detailed in key papers by V.M. Aushev, A.V. Belov, L.I. Dorman, V.N. Ishkov, O.N. Kryakunova, R.A. Saidaliev, Ya.E. Shvartsman, and A.G. Zusmanovich. It was shown that the statistical solar neutron effect exists if one chooses X-ray flares characterized by a small solar zenith angle with respect to the point of observations.

Chapter 7 is devoted to observations of solar neutron events by neutron monitors, solar neutron telescopes, and by other ground-based detectors, as well as to the interpretations of these results, all while taking into account observations of related phenomena. We start from the descriptions of the investigations of solar neutron events measured by the Tyan Shan high-altitude neutron supermonitor (as appears in the key paper of V. Antonova, V. Aushev, A. Belov, E. Eroshenko, O. Kryakunova, and A. Struminsky). In this chapter, we consider many solar neutron events, each of them having different peculiarities. A great volume of new information (including on the solar neutron refraction effect) was obtained during investigations of the largest event observed as of 2009 – the event of May 24, 1990 (as shown in key papers by T.P. Armstrong, E.I. Chuikin, A.T. Filippov, G.E. Kocharov, L.G. Kocharov, G.A. Kovaltsov, K. Murakami, Y. Muraki, A.N. Prikhod'ko, K.R. Pyle, M.A. Shea, S. Shibata, and D.F. Smart). Special interest is given to the solar neutron event of June 1, 1991, when surprisingly intense neutron emission was observed from a flare behind the limb of the Sun (as reported on in key papers by C. Barat, K.W. Delsignore, X.-M. Hua, B. Kozlovsky, N. Mandzhavidze, R.J. Murphy, R. Ramaty, G. Trottet, G.H. Share). Investigation of solar neutron events in association with the large solar flares of July 2000 and March–April 2001 (by E.O. Flűckiger, R. Bűtikofer, A. Chilingarian, G. Hovsepyan, Y. Muraki, Y. Matsubara, T. Sako, H. Tsuchiya, and T. Sakai) lead to the important conclusion that three categories of solar neutron events exist.

In Chapter 8, we consider the solar neutron decay phenomenon, discovered by P. Evenson, P. Meyer and K.R. Pyle by measuring the flux of 24–45 MeV protons observed on board the ISEE-3 spacecraft during the well-known event of June 3, 1982. This discovery highlighted the very important possibility of using measurements of neutron decay products to obtain additional information on solar neutron events. More detailed information on solar neutron decay protons (including on their generation and propagation into interplanetary space) was obtained during a much bigger solar neutron event on April 24, 1984. The first observation of electrons from solar neutron decay was made (also on the ISEE-3 spacecraft) during the event of June 21, 1980 (a key paper by W. Dröge, D. Ruffolo, and B. Klecker).

Chapter 9 is devoted to observations and interpretations of gamma-rays resulting from solar energetic particle interactions with the Sun's atmosphere. It was shown in the pioneering key papers of B.M. Kuzhevskij, E.I. Kogan-Laskina, and E.V. Troitskaia that one could determine the solar plasma density altitude profile in the region where solar neutrons are generated and propagated (up to the photosphere), using measurements of the time profile of the neutron capture gamma-ray line 2.223 MeV. The origin of long-duration solar gamma-ray flares (in which high-energy photon emission is present well beyond the impulsive phase, indicating the presence of either stored or continuously accelerated ions) was investigated in the key papers of J.M. Ryan. The present situation favors either the acceleration of protons and ions for long periods of time by second order Fermi acceleration in large coronal loops, or, alternatively, acceleration in large-scale, CME-associated reconnection sheets.

The possibilities of solar gamma-ray spectroscopy are demonstrated in key papers by M. Yoshimori, A. Shiozawa, and K. Suga through their investigations of the ^{3}He contents of the photosphere (^{3}He is thought to be produced primarily by the nuclear synthesis occurring in the early universe, and its abundance is used to place a constraint on cosmological models). Since the photospheric ^{3}He abundance cannot be determined by optical spectroscopy, observations of the neutron capture line at 2.223 MeV provide its only direct method of determination (It works as follows: neutrons, which are produced simultaneously with gamma-ray lines by the interactions of accelerated ions, diffuse into the photosphere, where the 2.223 MeV lines are emitted by neutron capture of hydrogen. Because of the time required for the neutrons to slow down and be captured, the 2.223 MeV line is produced about 100 s after their production, and the competing capture reaction ^{3}He(n,p)^{3}H affects this delay). The other example brought here is regarding the temporal variations of ambient plasma abundances in the acceleration region. This is done using measurements of low-FIP (First Ionization Potential) to high-FIP elements' gamma-ray line ratios (as seen in key papers by J.E. Grove, W.N. Johnson, G.V. Jung, R.L. Kinzer, J.D. Kurfess, R.J. Murphy, G.H. Share, A. Shiozawa, M.S. Strickman, K. Suga, and M. Yoshimori). This chapter describes quite a few solar gamma ray events, and each of these events is characterized by different important peculiarities (as detailed in the Contents).

In Chapter 10, important phenomena related to the problem of solar neutrons are considered, namely: positron generation during nuclear interactions of flare energetic particles with the solar atmosphere, and the generation of the 0.511 MeV annihilation line. Positrons are slowed down to ~10 eV where they either annihilate directly or form positronium atoms after thermalization. Direct annihilation and singlet state positronium emit two 511 keV photons, while triplet state positronium produces three gamma-rays (positronium continuum below 511 keV). Triplet positronium is broken up by collision if the ambient density is above 10^{14} cm^{-3}. Since a time profile of the 511 keV line depends on the density and lifetimes of β^{+}-decay nuclei, its temporal variation is complex, and depends on the peculiarities of solar flares. A ratio of 3γ to 2γ depends on the ambient density. The line width is a function of the temperature of the annihilation site. Therefore, detailed measurements and modeling of phenomena caused by solar positron generation and annihilation will give important information regarding not only solar energetic particles, but also the ambient plasma. This chapter is based mostly on the key papers associated with Yohkoh's observation of a gamma-ray flare on November 6, 1997 ((M. Yoshimori, S. Nakayama, H. Ogawa, N. Saita, A. Shiozawa, K. Suga, and H. Takeda), and on the RHESSI observation of the solar annihilation line from the July 23, 2002 solar flare (B.R. Dennis, H.S. Hudson, B. Kozlovsky, R.P. Lin, R.J. Murphy, R.A. Schwartz, G.H. Share, J.G. Skibo, A.Y. Shih, and D.M. Smith). B. Kozlovsky, R.J. Murphy, and G.H. Share, in a key paper, treat in detail positron production from the decay of radioactive nuclei produced in the nuclear reactions of accelerated ^{3}He (because of their large cross sections and low threshold energies, these reactions can significantly contribute to positron production in solar flares with accelerated particle compositions enriched in ^{3}He).

Chapter 11 describes the development of models and simulations for solar neutron and gamma-ray events. The detailed model of solar flare neutron production and the angular dependence of the 2.223 MeV capture gamma-ray line emission was developed in a key paper of X.-M. Hua and R.E. Lingenfelter. In key papers of X.-M. Hua and R.E. Lingenfelter, the special model for determining the ^{3}He/H ratio in the solar photosphere from flare gamma-ray line observations was also developed. Important models and simulations for the estimation of the intensity and directionality of flare-accelerated α-particles on the Sun using gamma-ray observations were developed in key papers by G.H. Share and R.J. Murphy. The method for estimating the spectral evolution of energetic protons in solar flares using gamma-ray observations and simulations was developed in a key paper by W.Q. Gan. Important methods and simulations of the estimation characteristics of energetic heavy ions on the Sun were developed in a key paper by G.H. Share and R.J. Murphy, using gamma-ray measurements. A model for the estimation by gamma-rays the ratio of interacted to interplanetary energetic protons in the case of diverging magnetic field lines with stochastic acceleration was developed in key papers by L. Kocharov, G. Kovaltsov, T. Laitinen, P. Mäkelä, and J. Torsti. The model for estimating the ratio of interacted to interplanetary energetic protons by gamma-ray measurements in the case of diverging magnetic field lines and parallel shock wave acceleration was developed in a key paper by R. Vainio, L. Kocharov, and T. Laitinen. The expected change with time of the angular distribution of gamma-ray fluxes from decay of π^{0}-mesons (generated by interactions of solar energetic particles with matter of solar corona and solar wind) was calculated in papers by L.I. Dorman. In order to estimate the ratio of interacted energetic particles to ejected into interplanetary space in high energy region during solar fare events, J.A. Lockwood, H. Debrunner, and J.M. Ryan developed a model using measurements of gamma-rays generated in π^0-decays. X.-M. Hua, B. Kozlovsky, R.E. Lingenfelter, R. Ramaty, and A. Stupp developed a both a model and a Monte Carlo simulation for estimating the angular and energy-dependence of neutron emissions from solar flare magnetic loops. In this Chapter, we also consider the expected production of light isotopes, which occurs because of nuclear interactions and acceleration in the flare region (as shown in a key paper by S.A. Balashev, M.F. Lytova, and V.M. Ostryakov). Important investigation of powerful solar flare characteristics by gamma rays from excited states of ^{12}C and various neutron capture lines was done in key paper of I.V. Arkhangelskaja, A.I. Arkhangelsky, L.I. Miroshnichenko, and E.V. Troitskaya.

The detailed **Contents** gives information on the problems discussed in the various parts of the book. Furthermore, there is a list of **Frequently Used Abbreviations and Notations**. After Chapter 11 there is an **Appendix**, which contains details of some complicated calculations, and then **Conclusions and Problems**, where we summarize the main results and propose some unresolved key problems that we feel are important for the development of this field of science. In the **References**, there are separate references for Monographs and Books (in the text they are marked by the letter M before the year of publication), as well as for each Chapter and Appendix. As an added convenience to the reader, there are also **Subject** and **Author indexes**.

I would be grateful for any comments and/or reprints that may be useful to our future research, and that can make the next edition of this book better and clearer. They may be sent by e-mail (lid@physics.technion.ac.il, lid010529@gmail.com) and by post to the address: Prof. Lev I. Dorman, Head of Israel Cosmic Ray and Space Weather Center and Emilio Ségre Observatory, P.O. Box 2217, Qazrin 12900, ISRAEL.

February 2010
Qazrin, Princeton, Moscow

Springer

http://www.springer.com/978-90-481-3736-7

Solar Neutrons and Related Phenomena
Dorman, L.
2010, XLVI, 873 p. 586 illus., Hardcover
ISBN: 978-90-481-3736-7