SOLAR COSMIC RAYS

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by

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"PER ASPERA AD ASTRA"

PREFACE

It turned out to be really a rare and happy occasion that we know exactly when and how a new branch of space physics was born, namely, a physics of solar cosmic rays. It happened on February 28 and March 7, 1942 when the first "cosmic ray bursts" were recorded on the Earth, and the Sun was unambiguously identified for the first time as the source of high-velocity particles with energies up to $> 10^{10}$ eV. Just due to such a high energy these relativistic particles have been called "solar cosmic rays" (SCR), in distinction from the "true" cosmic rays of galactic origin.

Between 1942 and the beginning of the space era in 1957 only extremely high energy solar particle events could be occasionally recorded by cosmic ray ground-level detectors and balloon borne sensors. Since then the detection techniques varied considerably and the study of SCR turned into essential part of solar and solar-terrestrial physics.

During the last three decades the physics of the Sun has been developing very extensively in many directions. Alongside with the traditional branches of investigations (solar activity and cyclicity, solar flares, solar wind, energetic solar particles and their influences on the Earth's environments) some new possibilities appeared to study the Sun (helioseismology, solar neutrinos, etc). A number of new phenomena have been discovered, for instance, the coronal mass ejections (CME) and coronal holes (CH), high-energy neutrons and gamma-rays from solar flares were observed for the first time. As a result, enormous amount of various data were obtained by different techniques (ground-based telescopes and satellite detectors) in different "channels" of observations (energetic solar particles, solar wind, electromagnetic waves, coronal and/or interplanetary shocks etc.).

However, even though our understanding of the solar processes has evolved dramatically during the past twenty-five years, there are still many unanswered questions to be solved. It especially concerns to the physics of particle acceleration at the Sun, or, in other words, to the production of SCR. It should be emphasized that, in spite of the very impressive achievements in other areas, energetic solar particles were and remain to serve as one of the most generous sources of data about the Sun.

From astrophysical point of view, the Sun represents a unique stellar laboratory where we can directly observe cosmic ray generation, i.e., acceleration of charged particles (different ions and electrons) to the very high energies. Solar cosmic rays produced in solar flares (and probably in some other high-energy solar processes) are one of the most important manifestations of solar activity (SA) and one of the main agents in solar-terrestrial relationships (STR). Astrophysical aspects of solar cosmic ray

physics (magnetic structure and plasma dynamics in the sources of accelerated particles, their maximum number and energy, production of neutrons, high-energy gamma rays and neutrinos in flares, etc.) are of enormous interest.

Nowadays we can single out three basic lines of SCR research: 1) heliophysical (physics of solar flares, coronal transients and related phenomena); 2) interplanetary (models of particle propagation and physics of interplanetary space), and 3) geophysical (interaction of SCR with the terrestrial magnetosphere, ionosphere and neutral atmosphere).

Among applied aspects we would first of all point out to the prediction of SCR flux for the needs of practical astronautics (cosmonautics), i.e., provision of radiation safety of the crews and spacecraft equipment. The problem acquires specific importance in the context of development of some very ambitious projects to set up space power stations at geosynchronous orbits with the term of operation of up to 30 years, as well as in the connection with a grown duration and distance of multi-purpose spacecraft flights at circum-terrestrial and interplanetary orbits.

From the very beginning it should be emphasized that it was not my intention to present a comprehensive analysis of the problem. Nevertheless, the author tried to give an up-to-date summary of our knowledge of SCR generation and propagation. The present monograph differs from the reviews published earlier in three main aspects: 1) it presents the problem in self-contained form, in all its associations - from astrophysical aspects to geophysical and astronautical applications; 2) it includes a large amount of new data which has not yet been described in the review literature; 3) it contains an extensive bibliography which gives a certain idea about historical development of the problem and covers imcompartially the main achievements and failures in this field. The book is implied to be not only one of many reviews in solar physics, but will also serve as a useful manual (guide) in this rapidly developing field of space research. The author would be happy if his efforts stimulate a new interest to the problem, especially from the new generations of investigators. The book may be relevant to a few graduate courses and will be useful, hopefully, at postgraduate level as well.

Space does not allow us to explain every time the solar-terrestrial nomenclature used in current English-language literature. To make clear the jungle of terms, we recommend to the readers a list of standard terms described in detail in *Illustrated Glossary for Solar and Solar-Terrestrial Physics* (Eds.: A. Bruzek and C.J. Durrant, 1977). The Glossary is designed to be a technical dictionary that will provide solar and geophysical workers with concise information on the nature and properties of the phenomena of the solar and solar-terrestrial physics.

The monograph contains 12 chapters, and their contents cover five principal "blocks":

1. Solar production of solar cosmic rays: solar flares, particle acceleration, and high-energy phenomena at the Sun (Chapters 1-4).
2. Acceleration, interaction and transport processes in the corona; solar cosmic rays in the extended coronal structures (Chapters 5-7).
3. Interplanetary propagation: physical and sounding aspects of SCR studies (Chapter 8).
4. Energy spectrum of solar cosmic rays and geophysical effects (Chapter 9-10).
5. Solar energetic particles and radiation hazard in space (Chapter 11).

In separate sheets we give the main definitions, terminology and notation, as well as an Index and a total list of References (in alphabetic order). The author has tried to present the most significant observational results concerned with particle acceleration at the Sun, energetic particles in interplanetary space, and geophysical effects of solar cosmic rays available up to the middle of 1999. Some papers from the last 26th International Cosmic Ray Conference (Salt Lake City, USA, August 1999) are also included in our review. Nevertheless, more than a few interesting problems which do deserve attention probably remain unmentioned, and the author apologizes most sincerely to those of his colleagues whose work he has been unable to discuss properly in this book, for one reason or another.

The book was thought in the atmosphere of "information burst" in space research occurred during two-three last decades, and in Chapter 12 the author has made an attempt to summarize the most interesting theoretical concepts, models and ideas which do deserve attention in the context of solar cosmic ray investigations. We hope that the book will be helpful for a wide enough circle of space physicists. Some results may be of interest for those whose fields are theoretical physics or plasma physics.

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