INTRODUCTION

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Conveners

The earliest measurements of cosmic rays revealed temporal variations which coincided with solar activity. With the prediction and subsequent discovery of the supersonic solar wind flow, the cause of these variations became apparent: the cosmic rays, in transit from the interstellar medium into the heliosphere must propagate upstream against the solar wind flow, which will reduced the cosmic ray flux and cause it to vary. That is, the cosmic-ray flux is modulated by the solar wind.

This modulation process is important to understand. Cosmic rays provide information on galactic processes – on nucleosynthesis, acceleration, and propagation – which can be fully understood only when the extent of the modulation is accounted for. Of even more significance, the response of the cosmic rays to changing heliospheric conditions provides a unique probe of conditions in the heliosphere which are not currently accessible to spacecraft measurements. The cosmic rays respond to the magnetic field in the solar wind and its turbulence, and to the solar wind speed and its variations, and because of their great mobility extend greatly the range over which we can probe and understand heliospheric processes.

The last few years, concentrated around the current period of minimum solar activity, have seen major advances in our understanding of cosmic ray modulation. The Ulysses mission, during its historic exploration of the heliosphere at high heliographic latitudes, revealed the three-dimensional behavior of cosmic rays in the inner heliosphere. The Pioneer spacecraft revealed the vast dimensions of the outer heliosphere, and now the Voyager spacecraft continue this exploration and will, someday, cross the termination shock of the solar wind into the region of interaction between the heliosphere and the local interstellar medium. Near Earth, spacecraft such as the durable IMP-8 and now WIND spacecraft are providing baseline measurements for this most comprehensive array of spacecraft. Concurrently, the numerical models which describe the cosmic ray behavior are becoming

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ever more sophisticated and powerful tools for interpreting and understanding these observations. The combination of comprehensive observations and sophisticated models is providing ever more stringent tests of current understanding, and as these tests are survived, ever more confidence that our understanding of cosmic rays in the heliosphere is correct, and that this understanding can be used to constrain and improve our understanding of cosmic rays in all astrophysical objects.

Indeed, solar minimum is an ideal time to attempt to understand cosmic ray behavior in the heliosphere. Conditions in the solar wind are well understood at all latitudes, with the confirmation by Ulysses that at the higher latitudes there is steady high speed flow with uniform but opposing magnetic polarity in each solar hemisphere. Near the solar equator there is a narrow region of both high and low speed flow surrounding a current sheet between the alternating magnetic polarities. Clearly, in these rather simple and predictable conditions we have the best opportunity to test both our current understandings of cosmic ray behavior and to refine the models.

It is in this context – a perhaps never to be repeated array of spacecraft providing comprehensive measurements of galactic cosmic ray modulation in solar minimum conditions, and a tractable problem – that a group of some 40 scientists, with access to cosmic ray data and knowledge of how cosmic rays are expected to behave, assembled for a Workshop on Cosmic Rays in the Heliosphere at the International Space Science Institute in Bern, Switzerland. The Workshop met twice, September 16-20, 1996 and March 10-14, 1997, to consider and compare cosmic ray observations, relevant observations of conditions on the Sun and in the heliosphere, and the current theoretical understanding of how cosmic rays respond to changing heliospheric conditions. This publication is a summary of these discussions and the resulting conclusions.

The publication is divided into two main parts. First, a series of Introductory Papers are presented which should provide a summary of the state of knowledge of this field as the Workshop began. It is hoped that these papers will serve both to set the stage for the advances in the field that were achieved during the Workshop, and also to educate researchers not directly involved in cosmic ray modulation or heliospheric research. The Introductory Papers are followed by the reports of four Working Groups who sought to synthesize the state of understanding of different aspects of the modulation problem, make advances, and point out where new research is required. The four Working Groups dealt with: Working Group 1 – Global Processes; Working Group 2 – Corotating Structures; Working Group 3 – Anomalous Cosmic Rays; Working Group 4 – Transient Effects and Disturbances. The principal thrust of these reports is to summarize and improve our understanding of cosmic ray behavior near solar minimum.

The Working Group reports are followed by a summary of the parameters that are used in describing the cosmic ray behavior, principally the diffusion coefficients for propagation along and across the magnetic field, and the extent to which there is a consensus on their magnitudes and functional forms. It is hoped that this section will be a valuable resource to researchers considering cosmic ray behavior in the heliosphere. The principal thrust of the Workshop was to summarize and improve our understanding of cosmic ray behavior near solar minimum. However, in the Epilogue to this book a short presentation is provided on what might reasonably be expected during the transition to and during solar maximum conditions. Clearly, the accuracy of these speculations should be the subject of another workshop when comprehensive cosmic ray and heliospheric observations are available from the upcoming solar maximum.

Each of the Working Group reports presents its own discussion and conclusions. Taken together, certain general conclusions emerge:

- The basic understanding of the modulation process – particles undergo diffusion, convection, adiabatic deceleration, and large-scale drifts – appears to be correct. There is no requirements for any new physical processes, nor is there any reason to doubt the importance of each of the basic processes presently believed to govern cosmic ray behavior. However, the current state of knowledge is not sufficient so that a single set of parameters which describe these basic processes can be agreed upon.
- Corotating Interaction Regions in the solar wind, in which high and low speed solar wind flows collide, provide important case studies of cosmic ray, and other energetic particle behavior. Particles accelerated at the shock waves surrounding CIRs, or modulated by the compressed magnetic fields contained in CIRs, are seen at the highest heliographic latitudes, despite the occurrence of CIRs only near the solar equatorial plane. These observations, and the resulting theoretical explanations, provide important insight into the overall structure of the heliospheric magnetic field and the ability of particles to be transported across this field.
- The basic understanding of the acceleration and subsequent modulation of the anomalous component – anomalous cosmic rays originate as interstellar neutral particles which are ionized in the solar wind, accelerated at the solar wind termination shock, and undergo the same modulation processes as galactic cosmic rays - appears to be correct. However, again, there is no single set of parameters agreed upon to describe the anomalous particle behavior, nor can their temporal variations be uniquely described as due to changes in heliospheric conditions as opposed to changes in their acceleration.
- Transient effects, in which the cosmic rays respond to localized disturbances in the solar wind, are interesting near solar minimum, but provide little impact on the overall modulation. In contrast, during the rise to and during solar maximum, transient effects are likely to be the governing mechanism for cosmic ray modulation. The transient disturbances, as with CIRs, also provide interesting case studies, which can reveal the characteristics of cosmic ray propagation in the heliospheric magnetic field.

The study of cosmic ray modulation is a dynamic subject. Recent spacecraft observations from throughout the heliosphere, and recent advances in numerical models, have provided confidence that the basic understanding of the modulation process near solar minimum is correct, although much work remains to be done to define the detailed description of how the cosmic rays behave. Solar maximum is a far greater mystery. There is no reason to believe the governing physical processes will not be the same; however, the conditions in the heliosphere, and their evolution throughout the solar cycle, are not well understood, nor is the expected response of the cosmic rays. Fortunately, observations of the heliosphere in all dimensions – from Ulysses, from Voyager, and from near Earth spacecraft – are continuing. The numerical modeling of cosmic ray behavior is ever improving. Together, these efforts will lead to a complete understanding of cosmic ray modulation throughout the solar cycle. This book is then a progress report, documenting the state of cosmic ray modulation during solar minimum and pointing the way towards continuous efforts to understand Cosmic Rays in the Heliosphere.