Galactic cosmic rays in the distant heliosphere

Frank B. McDonald, W. R. Webber, E. C. Stone, A. C. Cummings, B. C. Heikkila, and N. Lal

Citation: AIP Conference Proceedings **1516**, 85 (2013); doi: 10.1063/1.4792545
View online: http://dx.doi.org/10.1063/1.4792545
View Table of Contents: http://scitation.aip.org/content/aip/proceeding/aipcp/1516?ver=pdfcov
Published by the AIP Publishing

Galactic Cosmic Rays in the Distant Heliosphere

Frank B. McDonald[a], W.R. Webber[b], E.C. Stone[c], A.C. Cummings[c], B.C. Heikkila[d], N. Lal[d]

[a] *Institute for Physical Science and Technology, Univ. of Maryland, College Park, MD, USA*
[b] *Dept. of Physics and Astronomy, New Mexico State Univ., Las Cruces, New Mexico, USA*
[c] *California Institute of Technology, Pasadena, CA, USA*
[d] *NASA/Goddard Space Flight Center, Greenbelt, MD, USA*

Abstract. The small flotilla of spacecraft: Pioneers 10 and 11 and Voyagers 1 and 2 (V1 and V2) that have traveled from 1 AU to the distant heliosphere continue the quest of Victor Hess to understand the nature of this radiation that comes to us from beyond the confines of our solar system. At this time V1 and V2 are traveling deeper into the heliosheath and approaching its outer boundary – the heliopause. In the heliosheath the intensity of 2.5 – 60 MeV GCR electrons has risen significantly above detector background levels and provides an important new diagnostic tool for exploring cosmic ray transport in this previously unexplored region of space. Over the past seven months the intensity of GCR ions and electrons at V1 have remained constant after a steady, 5.5 year exponential increase whose rate varied with particle species. Is this an indication that V1 is approaching the heliopause?

Keywords: galactic cosmic rays, anomalous cosmic rays, solar modulation, heliosphere, heliopause, heliosheath
PACS: 96.50.Fm, 96.50.Vg, 96.50.S-, 96.50.Ek, 96.50.sh, 96.50.Xy, 96.50.Wx

VOYAGER IN THE DISTANT HELIOSHEATH

The two Voyager spacecraft carry cosmic ray particle telescopes that measure the cosmic rays present in space. They continue the quest begun 100 years ago of Victor Hess by going to places never before visited to see "What's there?" and learn. The particles covered are H in the energy range from 1.8-300 MeV, He from 1.8-650 MeV/nucleon, heavier nuclei up to Z=28 with some isotopes resolved, and electrons over the range ~2.5 – 60 MeV.

This talk covered cosmic ray modulation from 1 AU to and beyond the termination shock and is the story of Pioneers 10 and 11 and Voyagers 1 and 2.

Galactic cosmic ray modulation is a study that probes the large-scale structure and dynamics of our heliosphere. It is dominated by the sun and is affected by the level of solar activity as when the more active sun is producing coronal mass injections (CME). Other parameters affecting the modulation are the tilt angle of the neutral current sheet, the velocity and density of the solar wind, and the strength of the interplanetary magnetic field, all of which vary with the solar cycle. All the physical processes of energetic particle motion in this dynamic plasma are involved in controlling the flux of particles reaching Earth and the location of these interplanetary spacecraft: diffusion, convection, adiabatic energy losses and particle drifts.

Centenary Symposium 2012: Discovery of Cosmic Rays
AIP Conf. Proc. 1516, 85-88 (2013); doi: 10.1063/1.4792545

Over the modern era (1951-present) the galactic cosmic ray intensity is now at its highest level in the past 1000 years. Study of the time variation of the intensity of the various cosmic ray species enables the exploration of the role of these different phenomena. Voyager 1 (V1) and 2 (V2) in the heliosheath are providing valuable insights into what is happening and the deep, continuing solar minimum of solar cycle 23/24 is providing an unprecedented opportunity for modulation studies. We are able to quantify the effects of the reduced strength of the interplanetary magnetic field and by inference to better understand the unusual past epochs such as the Sporer and Maunder minima.

Various time scales are important in the sun and are reflected in the solar modulation of cosmic ray intensities. The level of solar activity and the production of interplanetary CMEs rise and fall on an 11-year cycle and there is a reasonable correlation with sunspot numbers. The heliomagnetic field has a full cycle of 22 years, with its magnetic field reversing direction every 11 years. The modulation is different during these two different field polarities. In one case (qA>0) the particles drift in over the solar poles and out along the current sheet while the flow reverses during the opposite polarity (qA<0, aka during an "odd cycle"). At 1 AU for qA<0 there is an enhancement of galactic cosmic rays (GCR) at high energies (>1 GV) but a suppression of GCRs (and ACRs) at lower rigidities (< 1 GV). Fig. 1 shows an overview of GCR He modulation in the heliosphere over the past 29 years.

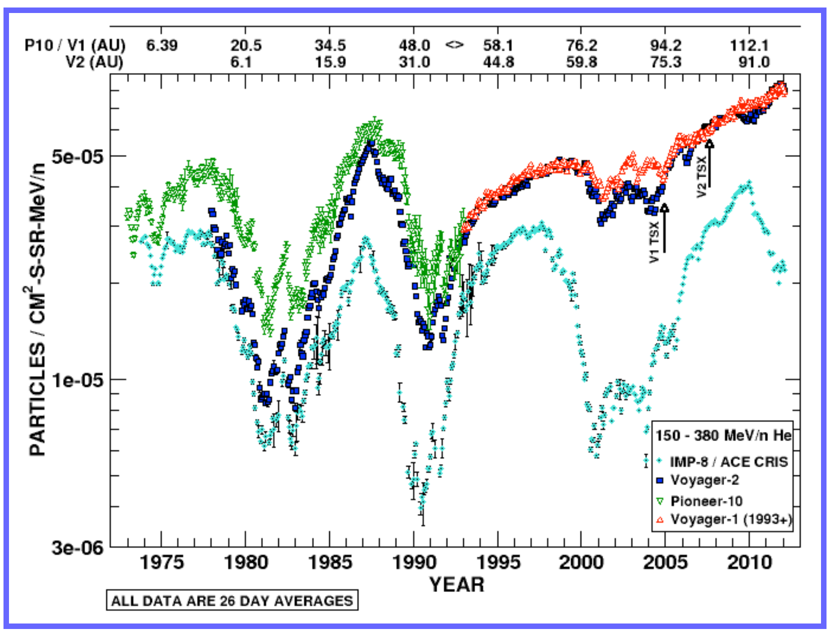

Figure 1: Composite of galactic cosmic ray 150-300 MeV/nuc helium intensity as a function of time from IMP 8, ACE CRIS, Voyagers 1& 2, and Pioneer 10.

Detailed study of these GCR helium fluxes reveals the following conclusions. During the qA> 0 cycles (20 & 22), the gradient in intensity which had been 14/r %/AU leveled off and became constant out to ~90 AU (r is the radial distance in AU). However, during the qA<0 cycle, the gradient continued to rise like 20/r %/AU. The flux in both cases is below that estimated to be present in the interstellar medium [1].

Similar behavior was seen for GCR H and anomalous cosmic ray (ACR) oxygen during qA>0 epochs. There was a major change in modulation conditions between about 12 AU where merged interaction regions form and the termination shock at ~ 90 AU. Both GCR and ACR intensities are constant from solar minimum to solar maximum at the termination shock near the equatorial plane.

LOW ENERGY ELECTRONS: A NEW TOOL

A new tool for studying modulation can be found in ~2.5-60 MeV GCR electrons. They are ultra-relativistic while being very low rigidity. There are different possible origins for these electrons. They can be directly accelerated primary cosmic rays, interstellar secondaries from the decay of charged pions, and/or knock-on electrons produced by the passage of higher energy cosmic rays through the interstellar medium (ISM). In the ISM these electrons are the source of lower energy diffuse gamma, X-ray and synchrotron radio emission from the galaxy. They may play a major role in ionizing and heating the ISM. They are difficult to observe at 1AU because there is a large intensity of comparable energy electrons accelerated in the Jovian magnetosphere and they are strongly modulated. In the heliosheath, their very low rigidity should make them especially sensitive to the passage of transient disturbances. Electron observations are available from the High Energy Telescope (HET) and The Electron Telescope (TET), which are described elsewhere [2].

The data from V1 show that the higher energy bands for these particles exhibit a steady but somewhat variable flux (+/- 25%) from about 85 AU to 94.2 AU where they begin a slow steady increase out to 120 AU. The lowest energy TET electrons (6-12 MeV) have high variability over the former range and then settle down to a slow increase over the latter range. During the passage from 105 AU to 120 AU the outward solar wind speed slows to zero. The transition at 94 AU is identified as the passage of V1 through the termination shock. V2, traveling in a different direction, shows the same behavior of the lowest energy electrons and shows the spacecraft passing through the termination shock later (August 2007 vs. December 2004) and closer to the sun (~84 AU).

THE LOCAL INTERSTELLAR SPECTRUM

There is great interest in determining the unmodulated cosmic ray fluxes in the local interstellar medium. Both V1 and V2 appear to have reached the fluxes above 200 MeV as predicted by Webber and Higbie [3] but have not reached the levels estimated by Langner et al. [4]. The most recent 26-day average fluxes of ACR helium from 2012 show the 10-21 MeV/n flux decreasing, while higher energy (27-56 MeV/n) helium is remaining constant.

Burlaga and Ness [5] have shown the magnetic field structure has changed from a sector structure to a unipolar zone of positive polarity (field directed away from the sun) in the heliosheath. Particle fluxes decreased somewhat in this region.

DISCUSSION AND CONCLUSIONS

The intensity of the 3-100 MeV particles electrons has increased substantially and the spectrum has hardened as V2 reached 95 AU, but the intensity subsequently declined a factor of two. V1 is still further out and appears to have reached the interstellar flux levels.

The continuing increase in low energy GCR electrons indicates that all GCRs have access to the heliosheath. The ACRs may be the best cosmic ray monitor for the heliopause crossing. The close agreement with the Webber-Higbie local interstellar spectrum is another strong indication that V1 is approaching the heliopause. It appears that the V1/V2 GCR intensities are not affected by changes in the solar wind speed and direction in the heliosheath.

Are we in the interstellar medium yet? We are getting close.

NOTE

Prof. Frank McDonald died not long after the meeting and was unable to write this paper himself. The Editor wrote this paper by transcribing it from the presentation made at the meeting. Any errors should be ascribed to the Editor and not to the authors of the paper.

ACKNOWLEDGMENTS

REFERENCES

1. W. R. Webber and J. Lockwood, 2001, JGR, **106,** NO. A12, 29323-29332, and 29333-29340.
2. E. Stone et al., 1977, Space. Sci. Reviews, **21**, 355-376 and A. Lukasiak et al., 1999, Proc. 26th ICRC, **3**, 65.
3. W. R. Webber and P. R. Higbie, *JGR*, 2006, **108**, 1355
4. U. W. Langner et al., 2001, *Advances in Space Research*, **27**, 517-522.
5. L. F. Burlaga and N. F. Ness 2011 *ApJ* **737** 35