Proceedings of the 30th International Cosmic Ray Conference
Rogelio Caballero, Juan Carlos D'Olivo, Gustavo Medina-Tanco,
Lukas Nellen, Federico A. Sánchez, José F. Valdés-Galicia (eds.)
Universidad Nacional Autónoma de México,
Mexico City, Mexico, 2008
Vol. 1 (SH), pages 823–826

30TH INTERNATIONAL COSMIC RAY CONFERENCE

Some implications of recent Voyager 1 and 2 omnidirectional and directional energetic particle data

PÉTER KIRÁLY
KFKI Research Institute for Particle and Nuclear Physics, H-1525Budapest, P.O.Box 49, Hungary
pkiraly@sunserv.kfki.hu

Abstract: About 6 months after the mid-December 2004 termination shock crossing of Voyager 1, upstream energetic particle flux increases started also at Voyager 2, only 3 years after similar enhancements began at V1. Flux increases at V2 started at much smaller heliospheric radii, and their further development showed some other different features as well. At the time of writing, the increasing magnitude and variability of the enhancements indicate that V2 might cross the termination shock earlier than expected, perhaps within a few months. First harmonic amplitudes and phases of the anisotropy for Voyager 1 and 2 will also be compared and implications of the differences will be discussed. The approach to solar minimum on the one hand and some CME-related solar wind shocks on the other also cause variations that are common to downstream V1 and time delayed upstream V2 fluxes, particularly in the high energy region attributed mostly to cosmic rays.

Introduction

Our most distant space messengers, Voyager 1 (V1) and Voyager-2 (V2) reached the heliocentric distances of 100 and 80 AU, respectively, during last summer. More importantly, V1 provided a long and detailed record of precursors of the Termination Shock (TS), and has now explored the inner heliosheath for more than two years, while V2 has also spent about two years in the preshock region, and its TS crossing might be imminent. The study of TS crossing(s) of V2 is expected to provide very important new information, because its solar wind (SW) plasma detector is working, and a combination of SW and energetic particle data should clarify some poorly understood points in the V1 data. By the 30-year anniversary of both spacecraft later this year new data may greatly enhance our understanding.

Count rates and their variability

The Cosmic Ray Subsystem (CRS) Team frequently updates both low-energy (> 0.5 MeV) and high-energy (> 70 MeV) ion count rate data on the Web for both Voyagers. Those quick-look data for interplanetary ions and for low-energy cosmic rays, respectively, are useful indicators for TS precursors and for interplanetary CME shock effects.

Figures 1 and 2 show the low-energy count rates (top) and their "variability" (bottom) for both Voyagers. By variability we mean here the absolute values of the logarithm (base 10) of ratios of the count rates measured on subsequent days. As the daily count rates are fairly large, Poissonian fluctuations do not dominate the variability plots. Variability decreases fast after shock transit.

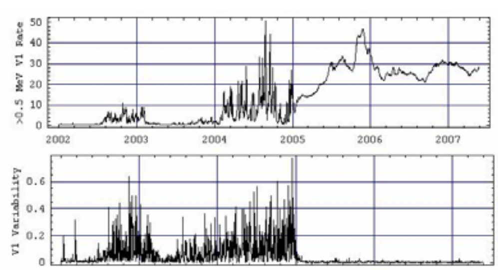

Figure 1: Low-energy count rates and their day-to-day variability for Voyager-1 before and after the TS crossing on 16 December 2004.

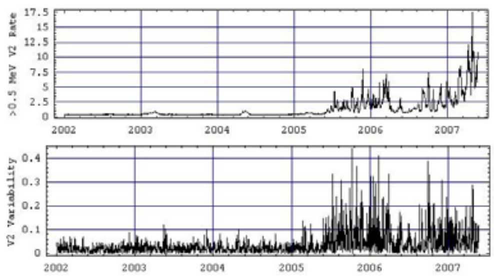

Figure 2: Low-energy count rates and their day-to-day variability for Voyager-2.

Interplanetary shock effects

An exceptionally powerful SW shock reached V2 at the end of February 2006, temporarily increased the dynamic pressure of the SW by a large factor, and probably pushed out the TS by several AU. The solar origin of the shock was probably related to the September 2005 CME activity [1]. Low-energy upstream particle flux increases were subsequently much reduced for about 6 months. The shock also caused a fairly sharp Forbush-type decrease at V2, and probably also a more gradual one at V1 about 110 days later. Figure 3 shows the high-energy (over 70 MeV) count rates of ions at V1 and V2. To take into account the time delay due to the larger radial distance, the plot for V1 was shifted left by 110 days.

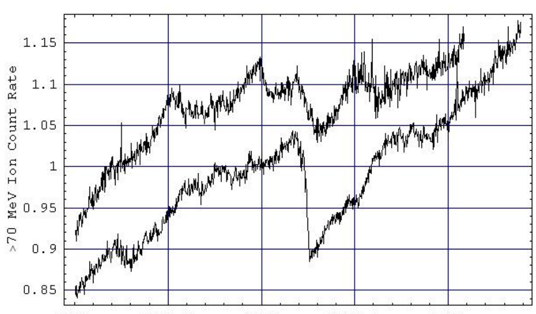

Figure 3: High-energy CRS count rates for V1 (top, shifted left by 110 days) and V2 (bottom).

The general increasing trend of the count rates due to progress toward solar activity minimum was apparently stopped for at least half a year at both Voyagers.

Omnidirectional LECP fluxes

Low-energy ion flux data in 8 logarithmic energy bins are updated monthly by the LECP Team for both V1 and V2. Data up to mid-May 2007 are shown in Figures 4 and 5, respectively.

As instrumental backgrounds change both with energy and with cosmic ray intensities, no attempt was made for their subtraction.

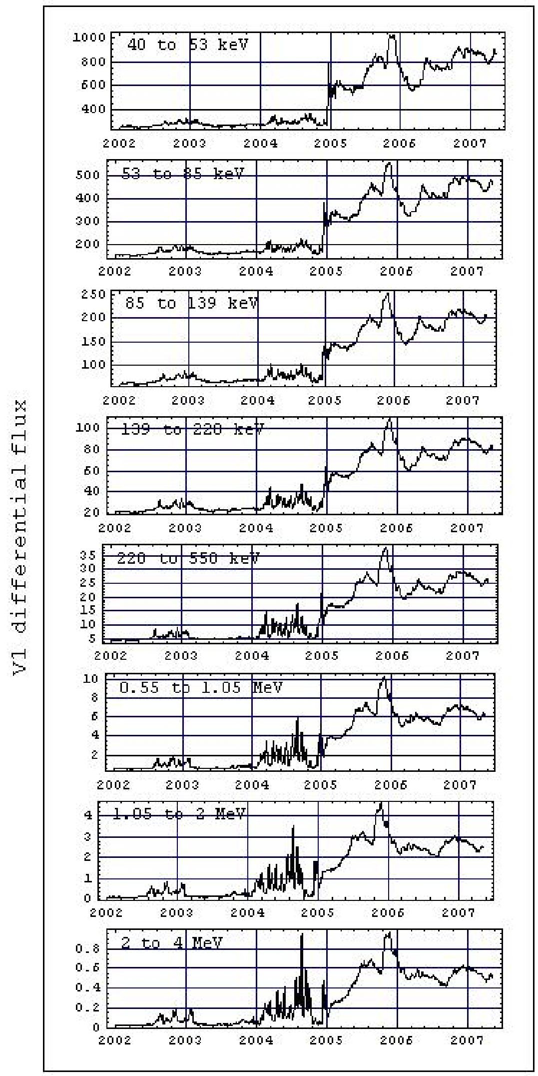

Figure 4: Omnidirectional ion fluxes for V1, without background subtraction.

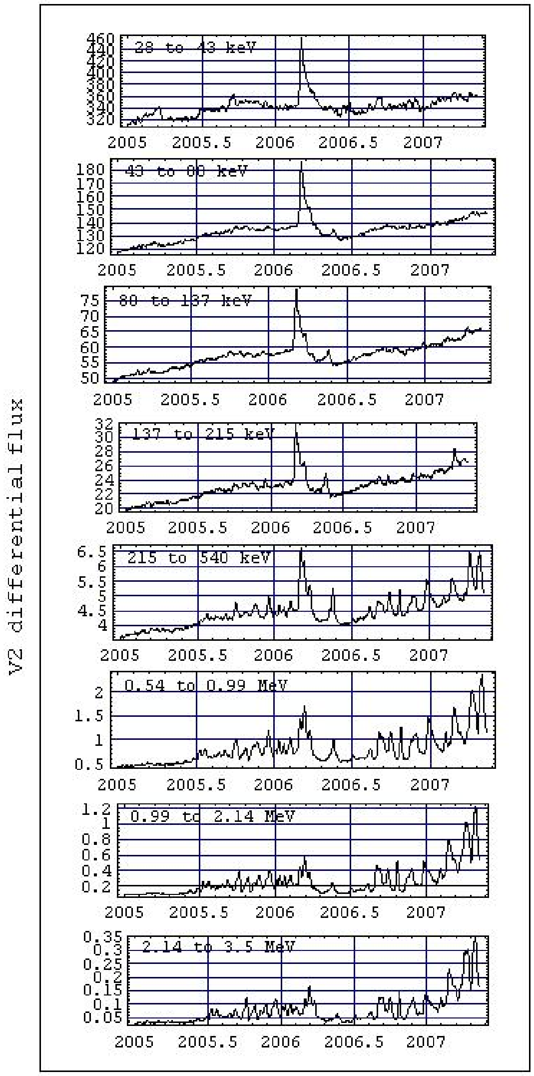

Figure 5: Omnidirectional ion fluxes for V2, without background subtraction.

There are some conspicuous differences between the energy dependencies of ion fluxes for the two Voyagers. For V1 the flux enhancements start at about the same time (~202.5) at all energies, although their relative importance increases with increasing energy. For V2 the flux enhancements are practically absent most of the time below 200 keV, with the exception of the peak following the interplanetary shock in 2006; that peak is highest at low energies. Another, smaller peak also appears later in 2006 at somewhat higher energies, when SW speeds were also enhanced. The flux peak (shock spike) associated with the TS crossing of V1 also shows interesting substructure, changing with energy. The relative importance of the TS spike decreases with increasing energy.

Anisotropy and streaming directions

Some smoothed first harmonic amplitudes and phases are shown for V1 and V2 in Figures 6, 7.

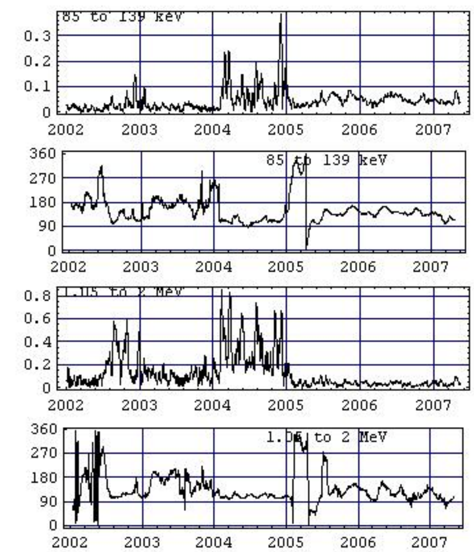

Figure 6: Smoothed first harmonic amplitudes (above) and phases (below) for a low and a higher energy channel of V1 LECP.

A rotating platform scans directions in the RT plane of the RTN heliographic coordinate system, where R points anti-sunward from the spacecraft and T is parallel to the equatorial plane, pointing in the direction in which planets rotate around the Sun [2]. First harmonic anisotropy vectors were smoothed by box-car averaging (10-day averages were used for calculating amplitudes, 30-day averages for calculating phases or streaming directions.) As V1 and V2 have flipped attitudes relative to each other, streaming directions first had to be transformed to the same coordinate system. The angles in our phase plots have the following meaning: 90 (270) degrees mean streaming outward (inward) along the spiral field, while 0 (180) degrees mean radial inward (outward) streaming in the spacecraft frame.

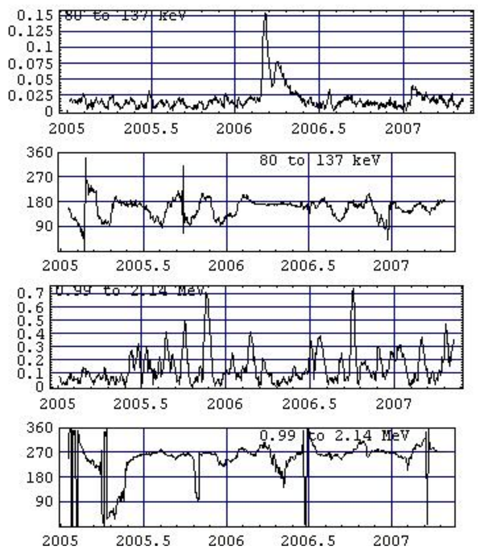

Figure 7: Smoothed first harmonic amplitudes (above) and phases (below) for a low and a higher energy channel of V2 LECP.

Figures 6 and 7 show that pre-shock streaming patterns are quite different for V1 and V2. While streaming is mostly outward along the spiral for V1 at most energies, V2 fluxes show radial outward streaming (and practically no TS-related enhancements) at low energies. At higher energies, where flux enhancements are important, streaming is mostly inward along the spiral field at V2. A different position of V1 and V2 relative to the nose of a "blunt TS" might be invoked [3] to explain (or at least rationalize) the findings, but we expect that the shock transit(s) of V2 may contribute to a better understanding.

Streaming patterns at V1 following the TS crossing are also puzzling. More or less radial inward streaming has been attributed to an inward propagating TS due to low SW dynamical pressure. While a fast inward TS motion is certainly a possibility, the idea that the SW was stopped or flowed inward for several months is unexpected. Another explanation suggested by a combination of the "blunt TS" model and the low variability and anisotropy on the downstream side of the shock might be more plausible. Short intercepts of field lines with the TS may not provide enough time for efficient acceleration. As V1 penetrated deeper into the heliosheath, it saw more accelerated particles, and their spectrum also resembled more and more a power law. The flux peak seen almost one year after TS crossing might support that scenario. A diffusive radial inward streaming then competes with SW convection.

Conclusions

Characteristics of both upstream energetic particle flux enhancements and of downstream spectra and streaming directions detected by V1 show several unexpected and poorly understood features. Recent data of V2 give hope that one or several TS crossings of V2 in the near future might answer some of those questions and provide a deeper understanding of an important part of our cosmic neighbourhood.

Acknowledgement

This work was supported in part by the International Space Science Institute (ISSI) in Bern, Switzerland, in the framework of International Working Group Number 70. Hungarian research grant OTKA-K 62617 is also acknowledged for financial support. The CRS and LECP Teams of the Voyager mission are thanked for making some of their data freely and promptly available.

References

[1] Richardson, J. D. et al., GRL 33, L23107, doi:10.1029/2006GL027983
[2] For a definition of the RTN system see e.g.: http://cohoweb.gsfc.nasa.gov/html/cw_data.html
[3] McComas, D.J. and N.A. Schwadron, GRL 33, L04102, doi:10.1029/2005GL025437, 2006