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Effects of asymmetrical heliospheric boundaries on cosmic ray proton modulation

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A previously used two-dimensional model for the heliospheric modulation of cosmic rays including a solar wind termination shock is extended to include an outer modulation boundary that is asymmetrically shaped with respect to the Sun. The modulation process is described kinetically using the Parker transport equation. The model includes drifts, adiabatic energy changes, diffusion, convection, a termination shock (TS), and a heliosheath, and is used to compute modulation differences between an asymmetrical and a symmetrical modeled heliosphere. It is found that the modulation produced for cosmic ray protons with an asymmetrical heliospheric model differ from that produced with a symmetrical model, but significantly mostly only for the $A < 0$ polarity cycle, especially in the tail regions of the simulated heliosphere.

1. Introduction

The motion of the heliosphere through the interstellar medium causes the heliosphere to have a geometry that is asymmetrical with respect to the Sun, compressed in the upwind direction (heliospheric nose) and significantly elongated in the downwind region (heliospheric tail). In addition it is somewhat elongated in the pole directions (e.g. [10]). The heliopause (HP) is considered the outer modulation boundary for all practical purposes, with the heliosheath the region between the heliopause and the TS; see also [3, 14].

The development of realistic and self-consistent global models for the modulation of cosmic rays in the heliosphere has been stimulated by excellent observations from the *Voyager* spacecraft with their approach of the solar wind TS [12, 13]. A reasonable consensus exists that the TS should be in the vicinity of (90 ± 5) AU in the direction of the heliospheric nose, although over a solar cycle the TS may move significantly outwards and inwards. It is not expected that the TS position will be more than ~100 AU away from the Sun in the tail direction so that the usual assumption of a nearly spherical TS is still considered reasonable. The position of the heliopause is unknown, but according to models it should be at least 30-50 AU beyond the TS in the nose direction, but much further away in the tail direction; see also [1,10,11,14].

In this context a previously used two-dimensional heliospheric TS model [8] is extended to describe an asymmetrically shaped heliosphere. We demonstrated before comprehensively that a TS model could describe, with a single set of diffusion coefficients and other modulation parameters, simultaneously the modulation for galactic and anomalous protons and Helium, galactic anti-protons, jovian and galactic electrons, positrons, Boron and Carbon [5, 6]. These tested modulation parameters are again used in the new model to study and illustrate the modulation differences between solutions with a symmetrical bounded heliosphere compared to an asymmetrical one. Results are shown for solar minimum and for moderate maximum modulation conditions for both magnetic field polarity cycles. The difference between solar minimum and moderate maximum conditions is represented in the change of the current sheet ‘tilt angle’ from 10° to 75°, a change in the solar wind speed profile with heliolatitude, and also changes in the values of perpendicular diffusion in the polar direction, where the latter implies decreasing drifts with increasing solar activity [2,7].

2. Modulation Model

The model computations are performed with a combined diffusive shock acceleration and drift modulation model with two spatial dimensions, neglecting any azimuthal dependence. The model is based on the numerical solution of the time-dependent cosmic ray transport equation [7, 9], for detail of the model see [4, 5, 7, 8]. The location of the outer modulation boundary (heliopause) and the TS in the symmetrical model are assumed to be at r_{HP} = 120 AU and r_s = 90 AU, respectively, for the nose direction of the heliosphere and at r_{HP} = 180 AU and r_s = 100 AU, respectively, for the tail direction. For the asymmetrical model the position of the heliopause is assumed to be at r_{HP} = 120 AU in the equatorial regions of the nose direction, with r_{HP} = 140 AU at the poles and with r_{HP} = 180 AU in the equatorial tail direction. The proton local interstellar spectrum (LIS) is specified at r_{HP}. The position of the TS in the asymmetrical model is assumed at r_s = 90 AU in the equatorial nose direction, r_s = 95 AU at the poles and r_s = 100 AU in the equatorial tail direction respectively. A compression ratio s = 3.2 is assumed with a shock precursor scale length of L = 1.2 AU [8]. Beyond the TS, V decreases as $1/r^2$ up to the HP, which implies that no additional acceleration can occur beyond the shock and that adiabatic energy losses become insignificant, which may be an oversimplification. For alternative approaches to this aspect, see Langner et al., [this issue].

3. Modeling results and discussions

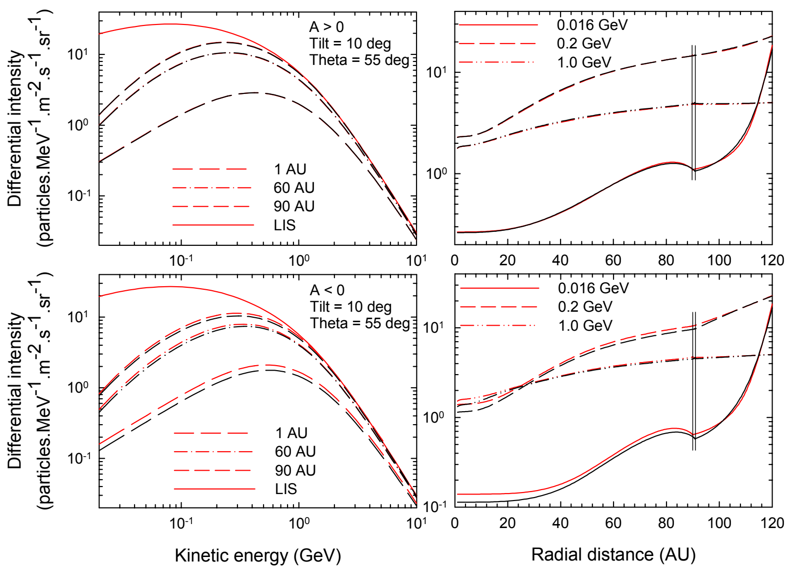

Figure 1. Solutions of a symmetric heliosphere model (red curves) and an asymmetric model (black curves) for the Voyager spacecraft trajectory latitude (θ= 55°) during solar minimum (α = 10°); for the A > 0 (top panels) and the A < 0 polarity cycle (bottom panels), respectively. Left panels: Proton energy spectra at radial distances of 1 AU, 60 AU, at the TS position and at the HP position. Right panels: Differential proton intensities as a function of radial distance at energies of 16 MeV, 200 MeV, and 1 GeV, respectively. In this case r_s = ~90 AU and r_{HP} = ~120 AU for both models, but only in the nose direction. The proton LIS is specified at r_{HP}. For colour curves, see electronic version.

The computational results, Figures 1 to 3, are focused on the modulation differences occurring in the spectra and radial intensities when comparing the symmetric heliosphere model with the asymmetrical model, in the nose and in the tail regions of the heliosphere and at θ = 55o (heliolatitude of 35° which is approximately the latitude of the Voyager spacecraft trajectory). Figures 1 and 2 are for solar minimum modulation conditions ($\alpha = 10°$) and in Figures 3 for moderate maximum conditions ($\alpha = 75°$), neglecting any transients.
For the symmetrical model, r_s = 90 AU and r_{HP} = 120 AU, in the nose direction of the heliosphere, while for

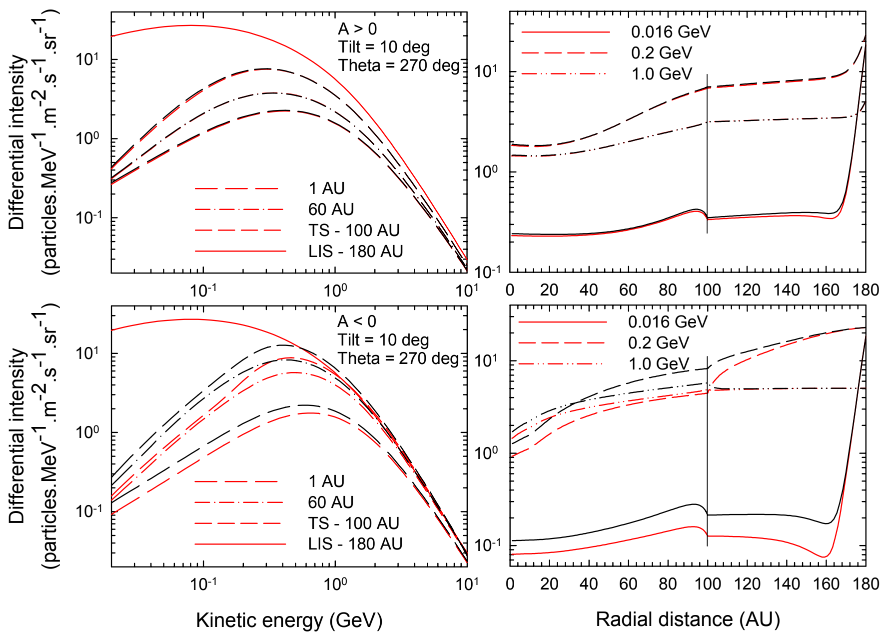

Figure 2. Similar to Fig 1 but for the heliospheric tail region ($\theta = 270°$). The TS is at r_S = 100 AU in the symmetrical model (red curves) and in the asymmetrical model (black curves) as indicated, with the heliopause at r_{HP} = 180 AU in both models. For colour curves, see electronic version.

the tail direction the recalculations are for r_s = 100 AU and r_{HP} = 180 AU. This is done to assure corresponding modulation boundaries for both models. The 16 MeV profiles are shown for illustrative purposes because these profiles change when anomalous protons are incorporated [6].

The comparison of galactic proton spectra between a symmetrical and an asymmetrical TS model clearly illustrates that no significant difference occurs for the $A > 0$ cycle for solar minimum conditions ($\alpha = 10°$), despite an increase of a factor of 1.5 in the position of the HP in the equatorial plane in the tail direction. These results are related to the relatively small radial gradients in the heliosheath and manifested it in all the cases, even when the heliopause is moved from 120 AU to 200 AU and the TS from 90 AU to 105 AU in the tail region of the heliosphere (not shown). This produces a ‘barrier’ effect (the sharp increase in intensities) in the heliosheath as the HP is approached. For the $A < 0$ polarity cycle differences remain insignificant in the nose direction, but for the tail region these differences in modulation are indeed significant (up to a factor of 2 difference in intensity) at most radial distances. According to these figures the redistributed drift patterns do have a clear influence on what happens when the simulated heliosphere is made asymmetrical. Drifts make therefore an important contribution to modulation differences when switched to an asymmetric model. The modulation “barrier” is also enhanced for the A < 0 cycle [7].

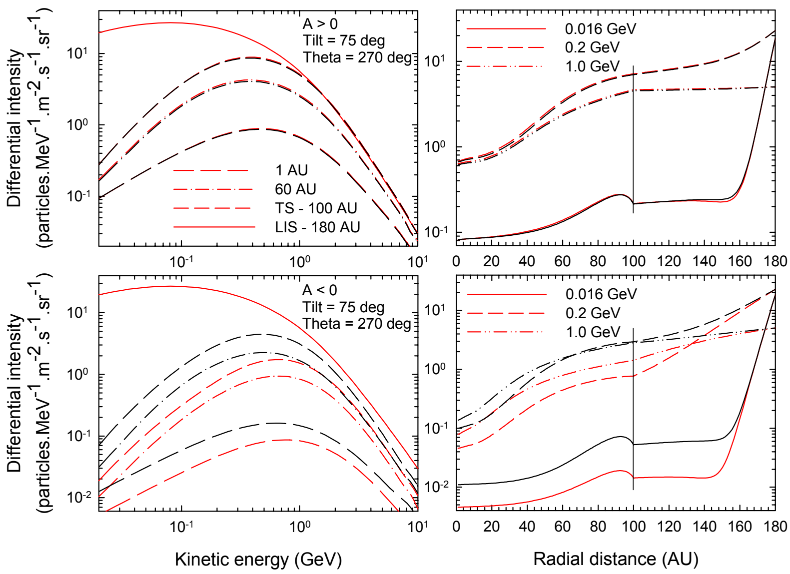

Figure 3. Similar to Figure 2 but for moderate solar maximum modulation conditions ($\alpha = 75°$).

5. Conclusions

The main conclusion is that the modulation for cosmic ray protons produced with an asymmetrical heliospheric model can differ significantly from that produced with a symmetrical model but only for the A<0 polarity cycle, and especially in the tail region of the heliosphere. Heliosheath modulation is predicted to make a significant contribution to the total modulation depending on the energy considered. The amount of drifts occurring beyond the TS in the heliosheath will have to be investigated further. The solutions of the symmetrical heliospheric model is surprisingly good compared to the asymmetrical model for studies of the heliospheric nose region in which the two *Voyager* spacecraft are moving.

References

[1] Ferreira, S. E. S., Potgieter, M. S., and Scherer, K., Ap. J., 607(2), 1014, (2004).
[2] Ferreira, S. E. S., and Potgieter, M. S., Ap. J., 603(2), 744, (2004).
[3] Fichtner, H., Space Sci. Rev., 95, 639, (2001).
[4] Haasbroek, L. J., and Potgieter, M. S., J. Geophys. R., 103(A2), 2099, (1998).
[5] Langner, U. W., and Potgieter, M. S., J. Geophys. R., 109(A01103), 1, (2004a).
[6] Langner, U. W., and Potgieter, M. S., Ann. Geophys., 22, 3063, (2004b).
[7] Langner, U. W., and Potgieter, M. S., Ap. J., in press (2005).
[8] Langner, U. W., Potgieter, M. S., and Webber, W. R., J. Geophys. R., 108(A10), 8039, (2003).
[9] Parker, E. N., Plan. Space Sci., 13, 9, (1965).
[10] Pauls, H. L., and Zank, G. P., J. Geophys. R., 102(A9), 19779, (1997).
[11] Scherer, K., and Fahr, H. J., Geophys. Res. Lett., 30, 17:1, (2003).
[12] Stone, E. C., and Cummings, A. C., Proc. 28th Inter. Cosmic Ray Conf. (Japan), 3889, (2003).
[13] Webber, W. R., Lockwood, J. A., McDonald, F. B., Heikkila, B., J. Geophys. R., 106, 253, (2001).
[14] Zank, G. P., and Müller, H. R., J. Geophys. R., 108, SSH7:1, (2003).