STREAMING OF COSMIC RAY IN THE INTERPLANETARY SPACE

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CONTENTS

SUMMARY

The statistical properties of the interplanetary magnetic field (IMF) parameters (B, θ , ϕ) have been investigated during the period 1967-74. This period is characterized by two different phases of solar activity. The study is based on a composite IMF data set, recorded by different spacecrafts. A computer program is developed to compute the average values and the frequency distribution of IMF parameters for different intervals 1, 2, 3, 4, 6, 8, 12, 24, and 48 hours and for the daily values for different years.

The IMF vector is found to have the following characteristics :

1) The average value of IMF magnitude (B) depends on the averaging interval, since it decreases with increasing the averaging interval. This reduction of B with increasing interval is expected, since it is attributed to the smoothing effect of the average process to a fluctuating magnetic vector.

2) However, the total fluctuation in the deviation of B is found to be very small, where the fluctuation in both ϕ and θ appear to be almost independent on the averaging interval. The change in ϕ with changing averaging interval is almost 20° and θ is almost negligible. This shows that the direction of the IMF is almost fixed in space, in accordance with the theoretical expectations of Parker (1958).

3) The above deductions show that the IMF is predominantly parallel rather than perpendicular to the ecliptic plane in accordance with the results given by Wilcox and Ness (1965).

4) Due to the more or less changing average value of the magnitude of the IMF, one should take care of choosing the proper averaging interval when studying related phenomena such as the study of the effect of the IMF on the anisotropies of the cosmic ray intensity.

The periodicities in the different components of the IMF relative to the ecliptic plane are investigated for the period 1965-1974. The computer analysis is performed for 12 azimuthal direction covering the range Φ = 0 to 180°, and 15 zenithal direction in the range Θ = -60° to 60°. The obtained results showed the following conclusions .

1) For all periods the 27, 13.5, 9 and 6.75 day peaks are observed at the direction Φ = 135° in the ecliptic (where Θ = zero). On the other hand the PSD of these peaks is significantly reduced for all other values of Φ and Θ. The found direction with Φ = 135° and Θ = 0° is basically the average garden

2) The 27-day waves observed at the specified direction can simply be attributed to the persistence rotation of IMF with the sun. The strong observed 27-day peak in both periods (which correspond to increasing and decreasing solar activity) shows that the IMF which is primarily observed at a given solar rotation will be observed for the next successive solar rotation before the influence of significant changes in its structure.

3) The presence of higher harmonics of 27-day period (13.5, 9, 6.75 days) can simply be explained in terms of the switching behaviour (non sinusoidal behaviour) of the IMF parallel to the garden hose direction (Φ = 135° and Θ = 0°).

4) The deviation of the value of the peaks from one period to another (or from one year to another) can be attributed to the change of the amplitude of 27-day wave in the IMF or the change of its persistant rotation with solar activity.

To study the effect of solar activity and the change of perpendicular N-S density gradient of primary cosmic ray on N-S anisotropies a composite N-S cosmic ray data has been used. The data were recorded at Alert, Thule (north pole) and McMurdo (south pole). The correlation coefficient between the two northern pole station is significantly high which reflects a good measuring sensitivity at the north pole. The power spectrum technique of analysis is performed on daily average N-S intensity difference for different periods. The analysis showed that for all periods the following conclusions :

1) The enhanced peaks at 27-days and the existence of their three harmonics, for all periods, show a persistence N-S anisotropies. According to the statistical accuracy of the present analysis, these periodicities have no solar activity dependence. Also there is no dpendence on the direction of the perpendicular N-S density gradient of primary cosmic rays.

2) The higher harmonics (13.5, 9, 6.75 days) are interpreted to the switching behaviour of the IMF sector structure.

3) The same behaviours of the power spectrum density for different periods reveal a good correlation with the behaviours of power spectrum analysis of IMF.

4) Finally, these results reemphasize the previous work [Owens et al. (1980), Pomerantz et al. (1982), 1984), and Tolba (1983)] that the 27-day variations in cosmic ray N-S anisotropy are caused by 27-day recurrences in the magnitude of the parallel component of the IMF, along with the steady state cosmic ray radial gradient, via the $B_{//} \times \nabla n$ particle drift.

INTRODUCTION

Cosmic rays reaching the top of earth's atmosphere with high energies coming from outside the interplanetary space are called primary cosmic rays. It consists mainly of protons (about 90%) with different energies up to 10^{19} eV or even more, 9% alpha particles and the remaining part composed of nuclei of higher atomic number. The primary particles are modulated through the interplanetary space before reaching the orbit of the earth, then they interact with air nuclei of the earth's atmosphere producing secondary particles. The counting instruments at the earth's surface, record the secondary cosmic rays, where the neutron and meson components constitute the major part of these secondaries. On a world-wide scale, different types of cosmic ray detectors are installed at different locations on the earth for the continuous measurements of the secondary cosmic rays. The modulation mechanism of primary cosmic rays in the outer space can be understood by analyzing the recorded data after making the required corrections for the atmospheric effects.

Parker (1965) showed that most of the cosmic ray particles incident on the solar system from the interstellar space are reflected immediately back into space, with a small energy gain as a consequence of their head-on collision with the outward moving magnetic fields carried by solar wind. Only a small fraction of the incident particles diffuses into solar wind, it remains for a considerable period of time (days or weeks), and losses a significant fraction of its energy to the expanding interplanetary fields before returning back to the interstellar space. Accordingly, Parker ascribed the modulation of cosmic ray primaries mainly due to its convection and diffusion by the solar wind and by the inhomogenities existing in the interplanetary magnetic field, respectively. The interplanetary magnetic fields and the solar wind play an important role, not only in controlling the arrival of the galactic cosmic rays from the interstellar space, but also in modulating them in the interplanetary space.

The interplanetary magnetic field (IMF) is of a solar origin. The solar magnetic lines of force are carried out by the solar wind to the interplanetary space. The quiet day IMF has the form of Archimedean spiral (Parker, 1958). However, the general form of the IMF contains, beside the idealized Archimedean spiral shape, an irregular and fluctuating component. The shape of the magnetic field as predicted by Parker is confirmed by direct measurements in the outer space (Ness et al., 1964; and Ness and Wilcox, 1964).

Due to the rotation of this spiral field, the relatively low energy cosmic ray particles (≃ 2-100 GV) co-rotate with the sun giving rise to an anisotropy of the particle distribution in a certain direction, which on rotation of the earth, may produce the observed solar daily variation. The solar daily variation includes diurnal, semidiurnal and tridiurnal components.

Calculations to the asymptotic directions of approach of the primary cosmic rays for different stations (McCracken et al., 1962), together with a careful study to the characteristics of the asymptotic cones of acceptance (Rao et al., 1963), gave an exact information about the shape and characteristics of the diurnal anisotropy in the outer space. It has an amplitude of 0.4% direction 90° east of the earth-sun line, and it is independent of the rigidity of the cosmic ray particles. The semidiurnal variation arises from an anisotropy lying in the ecliptic plane and directed at right angles to the average direction of the IMF (Liette and Quenby, 1968). The tridiurnal component has a particular latitudinal distribution and a specific change in its amplitude during a year while having the same rigidity dependence is that of the semidiurnal anisotropy.

The measurements in sidereal time of the cosmic rays anisotropy have revealed a maximum intensity at about 18 hours sidereal time for stations in the northern hemisphere and a maximum intensity at about 06 hours sidereal time for stations in the southern hemisphere (Jacklyn, 1965; and Nagashima et al., (1968). Swinson (1969, 1971, 1976, 1984) showed that a major component of the sidereal variation is due to $B \times N_R$ anisotropy, where B is the IMF vector and N_R heliocentric cosmic ray density gradient.

Besides the well known daily variation arising from the earth's rotation, several studies showed that there is N-S anisotropy due to streaming of cosmic rays perpendicular to the ecliptic plane. Kudo and Murakami (1965) reported the presence of a persistant and transient N-S anisotropy in the interplanetary space. The transient N-S anisotropy is due to non equilibrium condition of cosmic rays, which is sometimes accompanied by Forbush decreases or solar flares (Nagashima et al., 1968; Duggal and Pomerantz, 1970).

Parker (1958) deduced that the theoretical average value of azimuthal direction (ϕ) of IMF at the orbit of the earth is nearly equal to 135°. Wilcox and Ness (1965) studied the distribution of the measured IMF direction parallel to the ecliptic (ϕ) and normal to the ecliptic plane (θ). They showed that ϕ is peaked in direction corresponding to the spiral streaming angle. Wherever, θ is predominantly parallel rather than perpendicular to the ecliptic. Statistical properties of IMF magnitude (B) for the years (1967-74) have been investigated by King (1975). The average value of the magnitude of IMF as deduced by King (1975) is given as 6.2×10^{-5} Gauss, based on the calculated hourly values.

The autocorrelation function of the direction of the IMF showed a prominent periodicity at about 27-days (Wilcox and Ness, 1965). The 27-day and its first three harmonics periodicities have been discussed by Tolba et al. (1981). They used power spectrum technique of analysis which showed that the component perpendicular to the average IMF garden hose direction ($B_{\perp}$) displays no solar rotation influences. However, the parallel component ($B_{//}$) displays enhanced peaks at the 27-day period and its first three harmonics.

Pomerantz et al. (1982) made studies of direct association between $B_{//}$ and N-S asymmetry. They demonstrated a striking relationship between them, and they showed that the anisotropies in N-S asymmetry that related to $B_{//}$ are statistically significant. Also, they showed that 27-day variations in the cosmic ray N-S anisotropy are caused by 27-day periodicities of $B_{//}$, along with a steady state cosmic ray radial gradient, via the $B_{//} x \nabla n$ particle gradient drift.

The aim of the present work is to carry out the following :

1) Calculate the average values of B, θ, ϕ for the period 1967-74 and to study the effect of the averaging interval on the calculated average value. The dependence of the average value of them on solar activity is also investigated. Having an exact average daily values of IMF is very important in pridecting accurate values of cosmic ray anisotropies, due to different models, in the interplanetary space.

2) The analysis of IMF periodicities, reported by Tolba et al. (1981) and Pomerantz et al. (1982), have been extended on all possible harmonics at different azimuthal and zenithal

directions, on the periods 1965-71 and 1972-74. The relation between IMF and cosmic ray N-S anisotropy (due to $B_{//} x \nabla n$) may be predicted from the periodicity investigation of the different components of IMF. Also, the dependence of IMF on the solar activity is important in studying the different modulation mechanisms in the interplanetary space.

3) Study of the effect of solar activity and change of perpendicular N-S density gradient direction of primary cosmic ray on N-S anisotropy. The purpose of dividing the analyzed period, 1967-74, into two periods is due to the perpendicular density gradient of primary particles to the ecliptic plane. It is reported by Swinson (1984), that the period 1967-71 characterized by a downward perpendicular N-S density gradient of primary cosmic rays, while the direction of the gradient is reversed for the period 1972-74.

CHAPTER I

INTERPLANETARY SPACE AND COSMIC RAY ANISOTROPIES

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INTERPLANETARY SPACE AND COSMIC RAY ANISOTROPIES

The mechanism of cosmic ray variations in interplanetary space, whether it is transient or periodic, can be understood on the basis of the existance of the solar wind and the interplanetary magnetic field (IMF). The IMF is the result of the extension of solar magnetic lines of force into the interplanetary medium by expanding solar chromosphere and corona. The solar daily variation, which include diurnal, semidiurnal, tridiurnal sidereal time variation, and north-south anisotropy, are examples of cosmic ray variations in interplanetary space. Cosmic ray density gradients radially, outward from the sun and perpendicular to the ecliptic plane are responsible for cosmic ray anisotropies perpendicular to and in the ecliptic plane, respectively (Swinson, 1970).

Through this chapter, a brief review is given for the interplanetary space parameters affecting the passage of galactic cosmic ray particles through the interplanetary medium. Also, a discussion is given to explain the cosmic ray solar variation anisotropies.

1. Interplanetary Space :

The interplanetary medium can be divided into three principal regions from the visible solar surface : photosphere, chromosphere, and corona. The corona is relatively