CHAPTER V

DIURNAL ANISOTROPY OF COSMIC RAYS DURING THE PASSAGE OF INTERPLANETARY SHOCKS ON EARTH
5.1 **INTRODUCTION**

Interplanetary shock signatures are found in the most distant solar wind plasma data (out to \( \sim 30 \) AU). Some of these are expected to be the result of the evolution of 'Corotating' interacting stream structures observed closer to the Sun (Pizzo, 1983). Evidence of proton density and temperature jumps at the times of the abrupt speed increases during periods of continuous data was noted to verify the shock signatures and to enable distinction between forward and reverse shocks (Colburn and Sonett, 1966).

Observations of shock wave disturbances near 1 AU indicate that a significant amount of mass (\( \sim 10^{16} \) g) is released into the solar wind at the time of major solar disturbances (Hundhausen et al. 1970). Space-born coronagraph observations of coronal mass ejection events [e.g. Stewart et al. 1974; Gosling et al. 1974; Sheeley et al. 1980] have dramatically confirmed that this is indeed the case. Previous studies of interplanetary shocks have rarely been able to show a direct association between interplanetary shocks and coronal mass ejection events (see, however Gosling et al. 1975). This is true primarily because most interplanetary observations are made close to the sun-earth line, while white light coronal transients are observed at the solar limb. However, the Helios satellites spent much of 1979-1980 located roughly above the west limb of the Sun. Of the 24 shocks observed by Helios during this
interval, 22 could be confidently associated with white light coronal transients observed by orbiting coronagraphs (Sheeley, 1981). Thus there is good reason to suspect that almost all shock wave disturbances at 1 AU are produced by coronal mass ejection events. Plasma observed immediately after shock passage at 1 AU is compressed ambient solar wind. When the observing geometry is favourable, the shocked ambient plasma is followed (≈10-20 hours after shock passage) by the coronal ejecta itself. Often the ejecta can be identified by one or more anomalous solar wind conditions, such as the abundance [A(He)] enhancements (e.g. Hirshberg et.al., 1972), proton temperature depressions (e.g. Gosling et.al., 1973), electron temperature depressions (e.g. Montgomery et.al., 1974), unusual heavy ion ionization states (e.g. Bame et.al. 1979; Fenimore, 1980; Schwenn et.al. 1980; Gosling et.al. 1980), high magnetic field strength (e.g. Hirshberg and Colburn, 1969; Schatten and Schatten 1972; Burlaga and King, 1979), and bidirectional streaming of either energetic protons (e.g. Palmer et.al., 1978) or solar wind electrons (e.g. Temny and Vaisberg, 1979; Bame et.al., 1981).

A He++ abundance enhancement is probably the most widely accepted of the above signals of the coronal mass ejecta following shocks and was the first to be recognised in the data (e.g. Gosling et.al. 1967; Bame et.al., 1968; Ogilvie et.al., 1968; Lazarus and Binsake, 1969; Hirshberg et.al., 1971).

Borrini et.al.(1982) has made an analysis of all the interplanetary shock wave disturbances detected with Los Alamos
plasma instruments aboard IMP 6, 7 and 8 from 1971 to 1978. The study of the 103 forward shocks observed reveals that shocks occur preferentially during conditions of low proton temperature and speed and that the shell of shocked gas followed shock passage is typically ~0.14 AU thick. Helium enrichments (Helium/hydrogen flux ratio \( \geq 8\% \)) are observed in association with 46% of the shocks. Shocks followed by helium enrichments (He shocks) are on the average the strongest shocks observed, in the sense that they exhibit the largest jumps in flow speeds, temperature and magnetic field strength and induce the largest geomagnetic response. The geometry of sampling the disturbances may account for the difference between He and non-He shocks. There is a tendency for interplanetary shocks and helium enrichments to be part of complex, multiple events. This may result from multiple outbursts from the same solar active region. Usually the helium enrichment is found in plasma of higher than average field strength.

Because of dynamic character of the mechanisms that produce transient fluctuations in the cosmic ray intensity it is exceedingly difficult to comprehended them in any detail. It is clear that observed properties of Forbush decreases are attributable to specific features of the interplanetary magnetic field which may occur individually or in combination. These include (1) magnetic irregularities: rapid or slow fluctuations in the direction or magnitude of the IMF. (2) magnetic bottles or tongues: extended structures of intense magnetic field; and (3) shocks or blast waves and tangential discontinuities.
The phenomena in group 1 above are in the convection-diffusion approximation of the transport equation that describes the streaming of the cosmic rays in the interplanetary medium. Some of the observed transient intensity variations can be ascribed to rapid changes in the parameters that determine the net anisotropy or modulation. Both group 2 and group 3 above are manifestations of the motion of boundaries, and, in effect, the relevant theoretical analysis describes the sweeping up of particles by a moving semipermeable membrane. Combinations of these departures from equilibrium conditions undoubtedly play a role in many of the observed transitory modulations and anisotropies.

The cosmic ray modulation has been known to have various time scales. The 11-year modulation corresponds to the solar activity cycle, the 27-day recurrent modulation reflects the solar rotation, and the 1-day anisotropy is related to the Earth's rotation. A cosmic ray storm, which has traditionally been referred to as a Forbush decrease (FD), is a short term modulation that results from the solar activity. It often starts within about one hour of a geomagnetic storm sudden commencement (SSC), and this suggests that the cause of the FD is the interplanetary shock wave produced by solar flares or corotational streams.

The role of the solar wind in the cosmic ray modulation has been called 'convection'. The irregularities of the magnetic field which represent scattering centres are transported outward
by the solar wind and act to resist the entry of cosmic rays. Thus the enhancement of the solar wind velocity means the intensification of this driving-out effect and is expected to lead to the intensity depression.

The enhancement in the magnetic field behind the shock corresponds to the increase of the angle between the magnetic field line and the radial direction. Because cosmic ray particles move along field lines more easily than across it, the increase in the angle means the reduction of the radial flux and intensity depression.

The enhancement in the variability of the IMF would correspond to the enhancement in the degree of the scattering by magnetic irregularities, decrease in the diffusion coefficient along the field line, (Suda et al. 1981) and hence the intensity depression of cosmic rays.

The other candidate for the cause of the FD have also been pointed out. Barouch and Burlaga (1975, 1976) suggested the importance of the gradient $\mathbf{B}$ drift at the shock front and Thomas and Gall (1984) suggested by numerical calculation that the main cause of the FD was the adiabatic cooling behind the shock. Recently, Badruddin et al. (1986) showed that shock associated clouds produce Forbush decreases.

At the time of the FD the anisotropy also changes. According to Wada and Suda (1980) the amplitude of the solar diurnal anisotropy increases and the phase advances to the earlier hours. The north-south anisotropy is also enhanced and
its direction is consistent with that of the density gradient drift (Suda et al. 1981). It is well known that the anisotropy perpendicular to the ecliptic plane is a characteristic feature of cosmic ray storms (Duggal and Pomerantz, 1971, 1976; Mercer et al. 1971). The sense of the north-south anisotropy varies from event to event. In fact, during a single Forbush decrease the sign can change several times (Duggal and Pomerantz, 1971).

A particle drift proportional to $\mathbf{E} \times \mathbf{U}$ is produced by the cosmic ray density gradient $\nabla \mathbf{U}$ in the presence of the interplanetary magnetic field $\mathbf{B}$. Since $\mathbf{B}$ is considered in the ecliptic plane, the north-south component of $\nabla \mathbf{U}$ produces a flow in the ecliptic plane perpendicular to $\mathbf{B}$ whose sense depends on the sense of $\mathbf{B}$. This will be observed as field dependent vector addition to the usual azimuthal streaming. This effect may be detected by separating the diurnal variation vectors into groups corresponding to positive and negative fields (Hashim and Bercovitch, 1972; Swinson, 1970).

In this Chapter we will study the behaviour of diurnal anisotropy during the days in which interplanetary shocks are observed at the Earth. These interplanetary shocks are identified by Borrini et al. (1982) as discussed in the beginning of the introduction. These shocks cover a period from 1971 to 1978. The Forbush decreases are associated with these shocks. Hence our interest is to study the diurnal variation under the disturbed conditions produced by interplanetary shocks.
5.2 METHOD OF ANALYSIS

The hourly interval of the passage at the Earth of 44 He- shocks and 47 non- He shocks have been taken as the key-hour for the superposed epoch analysis using the pressure corrected hourly counting rate of Deep River neutron monitor in order to see the effects of these shocks on the cosmic ray intensity.

A superposed epoch analysis has also been performed to calculate the diurnal amplitude and phase by using the day of passage of interplanetary shocks as key-day. The ±5 day window about the key-day allows a thorough characterisation of preshock and post shock flow conditions. These interplanetary shocks have been splitted into the events according to whether or not a helium abundance enhancement followed the shocks i.e. these have been divided into helium and non-helium shocks.

Then helium shocks have been splitted into two groups again according to the IMF polarity of the key-day and the same procedure as above was followed. The non-helium shocks have also been analysed in the same manner as helium shocks. Thus average behaviour of the interplanetary shocks affecting the diurnal amplitude and phase has been studied.

Since the simple harmonic analysis technique cannot be applied because mostly shocks produce Forbush decreases. Hence the technique which separates Forbush decreases and diurnal variations has been used to calculate the diurnal amplitude and phase. This technique has been discussed in detail in Chapter number II.
5.3 RESULTS AND DISCUSSION

The result of our superposed epoch analysis for He-shocks is shown in Fig. 5.1. It shows a classical Forbush decrease (\( \sim 2.0\% \)) setting in at the shock time, a sharp decrease up to \( \sim 15 \) hours (approximate duration of the passage of shocked plasma may be considered to be 12 - 18 hours), then this decrease continuing (though rather slowly) up to 42 hours (the average duration of piston plasma cloud behind the shocked plasma is \( \sim 20 - 30 \) hours) and then the recovery starts which is complete in a week time. The decrease observed in cosmic ray intensity in association with non-He shocks (Fig. 5.2) is comparatively very small (\( \sim 0.6\% \)), setting at shock time, starts recovering just after \( \sim 20 \) hours and reaches a almost constant level in only two days. Both the superposition results do not show any preincrease. A similar epoch analysis has been presented earlier by Ankiewicz et.al. (1983) by considering all the 103 shocks together. Their result show a decrease (\( \sim 1.4\% \)) setting at shock time.

A Forbush decrease is a transient (non-periodic) cosmic ray modulation that results from shock disturbances as is clear from Figs. 5.1 and 5.2. The investigation of Forbush decreases would also lead to the understanding of the modulation with other time scales. In one of our recent papers (Badruddin et.al. 1986) we have expressed the view that the turbulence behind the shock front is most likely additional effect in producing Forbush decreases. The current status of knowledge of these Forbush decreases can be summarized as follows:
Fig. 5.1 Superposed epoch analysis results of cosmic ray intensity reduction with zero epoch of arrival hour on the Earth for interplanetary He-shock.
Fig. 5.2 Same as Fig. 5.1 for interplanetary non He-shocks.
(i) enhancement in the interplanetary magnetic field magnitude (magnetic blobs or clouds) and large variability in the field direction are generally observed in the initial phase of the FDs;

(ii) in most cases the magnetic blob or cloud is accompanied by a flare-generated shock which is often followed by a flare ejecta piston or driver gas;

(iii) a fast solar wind stream is observed during most of FDs.

Fig. 5.3 shows the diurnal amplitudes and phases for helium abundance enhancement associated shocks (i.e. He-shocks) and non-He shocks on the harmonic dial. It is clear from the figure that diurnal amplitude for He-shocks is larger than non-He-shocks. He-shocks are strongest shocks than non-He shocks as shown by Borrini et al. (1982). This has also been proved through our analysis as the diurnal amplitude is larger for He-shocks than non-He-shocks. The diurnal phase shift, towards earlier hours in both cases, is in accordance with the general trend when any disturbance arrives on the Earth (table 5.1).

Fig. 5.4 shows the diurnal amplitudes and phases for He-shocks on the harmonic dial when these shocks are splitted into two groups according to the IMF polarity on key-days i.e. key days have been selected according to away (+) and toward (−) polarity days. For comparison the diurnal amplitude and
Fig. 5.3 Diurnal amplitude and phase on harmonic dial for two types of interplanetary shocks. Key day is the arrival day of the shocks.
He : Helium enhancement associated shocks
Non-He: Non-Helium enhancement associated shocks
QD : Quiet days
Fig. 5.4 Same as Fig. 5.3 for the He-shocks with IMF polarity away (+) and toward (-) on key-day which is the arrival day of these shocks.
<table>
<thead>
<tr>
<th>Type of shocks</th>
<th>Key day arrival day of shocks</th>
<th>Key day when IMF southward(+)</th>
<th>Key day when IMF northward(-)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Amplitude(%)</td>
<td>Phase (LT) hours</td>
<td>Amplitude(%)</td>
</tr>
<tr>
<td>He- Shocks</td>
<td>0.44 ± 0.03</td>
<td>12.89 ± 0.12</td>
<td>0.34 ± 0.02</td>
</tr>
<tr>
<td>Non-He shocks</td>
<td>0.28 ± 0.01</td>
<td>13.4 ± 0.14</td>
<td>0.34 ± 0.02</td>
</tr>
<tr>
<td>Quiet days</td>
<td>0.32 ± 0.02</td>
<td>14.25 ± 0.15</td>
<td></td>
</tr>
</tbody>
</table>
phase of magnetically quiet days for the period 1971 to 1978 is also shown on the same harmonic dial. Here the diurnal amplitude for toward (-) polarity days on key day is larger than away polarity days (table 5.1). In these shocks the driver gas also possesses the strong compressed magnetic field. It seems that in this case the direction of the magnetic field in the driver gas (ejecta) is dominating. The diurnal amplitude is largest and is similar to the shock associated clouds which have southward (+) magnetic field in their front boundary as discussed in the previous Chapter number IV. Pudoukin et.al. (1977) in his paper on the structure of the solar flare stream magnetic field showed that some peculiarities of the structure of the flare stream magnetic field seem to depend on the relative orientation of the magnetic field within the main body of the stream and within the background solar wind. They also showed that the southward (+) magnetic field of the main body of the stream dominate. Hence it seems that the orientation of the magnetic field of these shocks would have been southward (+) and dominated on the ambient solar wind magnetic field i.e. IMF. The diurnal amplitude for IMF (+) polarity days is not much larger than the diurnal amplitude of quiet days. There is clearcut phase shift towards earlier hours in both cases as is seen from this figure.

Fig. 5.5 shows the diurnal amplitudes and phases of non-He-shocks when these are splitted into away (+) and toward (-) polarity days of IMF on the key-day. The difference between the diurnal amplitudes for away (+) and toward (-)
Fig. 5.5  Same as Fig. 5.3 for non He- shocks with IMF polarity away (+) and toward (−) on key-day which is the arrival day of these shocks.
polarity days is significant and the phase shift, towards earlier hours in comparison to the quiet days phase, is seen from this figure. Since these shocks donot possess ejecta behind them, hence the ambient solar wind magnetic field (IMF) will be compressed and its direction will be responsible for the diurnal amplitude. The average velocity of these shocks on key-day is in the declining phase (Borrini et.al. 1982). Murayama (1975) and Iucci et.al. (1983) showed that the diurnal amplitude, in the declining phase of velocity, is reduced than the normal value; hence our results are in accordance with the results of above authors on the key-days of these shocks where the velocity profile is in the declining phase.

Fig. 5.6 shows the behaviour of He- shocks with a $\pm 5$ days window about the key-day as the arrival day of the shocks on the Earth. In this figure preshock behaviour related to diurnal amplitude and phase is apparent. On the key-day the diurnal amplitude increase is large. The driver gas follows the shocks within 48 hours of the passage of the shocks. The effect of this ejecta is seen upto $\pm 2$ day from the key-day. After that the diurnal amplitude and phase returns to its preshock values. This result is in agreement with the theoretical calculations of Kadokura and Nishida (1986) on two-dimensional numerical modeling of cosmic ray storms. These authors have shown that when solar wind disturbance is passed the diurnal amplitude and phase returns to its predisturbance values.
Fig. 5.6 Superposed epoch analysis results for ± 5 days about key-day of A index, diurnal amplitude and phase on upper, middle and lower panels respectively for He-shocks. Key-day is the arrival day of these shocks.
Fig. 5.7 (a) shows the preshocked and postshocked behaviour for He- shocks for away (+) polarity days as key-day. The diurnal amplitude is large on key day and +1 day and phase shifts towards earlier hours. After the removal of the solar wind disturbance i.e. after +2 day the diurnal amplitude and phase returns to almost their values before the arrival of the disturbance.

Fig. 5.7 (b) shows the behaviour for toward (-) IMF polarity days as the key-day. The large value of diurnal amplitude on key-day in comparison to the away (+) polarity days is explained with the fig. 5.4. The A_p index is largest on the key-day. The remaining features are as in Fig. 5.7(a).

Fig. 5.8 shows the preshocked and post shocked behaviour of non He-shocks with a ±5 days window about the key-day as the arrival day of these shocks on the Earth. In this figure A_p index is increased while the diurnal amplitude does not increase on key-day as these days fall on the declining phase of solar wind velocity (Murayama, 1975; Iucci et.al. 1983). There is a jump in the average velocity of these shocks within 12 hours of their arrival and another jump after 12 hours with the enhancement in magnetic field (Borrini et.al. 1982). Hence the effect of these parameters on the diurnal amplitude is seen upto +2 day. Thereafter the diurnal amplitude and phase return to their preshocked values. The phase also shifts slightly towards earlier hours and recovers after +2 day to its preshocked value.
Fig. 5.7 (a) Same as Fig. 5.6 for He-shocks with IMF polarity away (+) on the key-day which is the arrival day of these shocks.
Fig. 5.7 (b) Same as Fig. 5.6 for He-shocks with IMF polarity toward (-) on the key-day which is arrival day of these shocks.
Fig. 5.9 (a) shows the preshocked and post shocked behaviour for away (+) polarity days on key day. The diurnal amplitude increases on key day and remain increased upto +2 days. Thereafter it returns to its preshocked value. Phase also shifts towards earlier hours and recovers after +2 day.

Fig. 5.9 (b) shows the behaviour on both sides of key-day which have been taken as the toward (-) polarity days. A_p index increases diurnal amplitude decreases on key day. The decrease of diurnal amplitude on key day confers the effect of polarity (-) and declining phase of velocity. On +1 day diurnal amplitude increases which shows that there is a sudden jump in the velocity profile and enhancement in the magnitude of magnetic field as shown by Borrini et.al. (1982). Diurnal phase also shifts slightly towards earlier hours and recovers after +2 day.

The most general expression for the theoretical cosmic ray anisotropy is given in terms of Fokker–Plank formalism (Jokipii and Parker, 1970, Forman and Gleeson, 1975).

\[ \mathcal{G} = \frac{3S^2}{vU} = 3C_G v^2/\nu - \mathcal{K} \cdot \mathcal{G} \]

Here

\( \mathcal{G} \) = differential cosmic ray current density

\( v \) = the differential cosmic ray density

\( \mathcal{K} \) = cosmic ray diffusion tensor [Forman and Gleeson 1975]

\( C_G \) = Compton–Geeting factor (Glesson and Axford 1968)

\( = (2 + \alpha) / 3 \)

\( \alpha \)
Fig. 5.8 Superposed epoch analysis results for ± 5 days about key-day of $A_p$ index, diurnal amplitude and phase on upper, middle and lower panels respectively for non He-shocks. Key-day is the arrival day of these shocks.
where

\[ \alpha = \frac{(T + 2m_0c^2)}{(T + m_0c^2)^1} \text{ for these energy particles (GeV)} \]

\[ \gamma = \text{cosmic ray differential intensity spectral index} \approx 2.5 \]

\[ \mathbf{V}_w = \text{Solar wind speed} \]

\[ v = \text{particle velocity} \]

The parameters associated with the diurnal anisotropy are the cosmic ray gradients, the solar wind speed, the mean interplanetary magnetic field direction and the coefficients for the cosmic ray diffusion.

As has been discussed in detail in Chapter number IV of the thesis, the most convenient form of anisotropy vector can be given as follows:

\[ \mathbf{\tilde{v}} = \mathbf{\tilde{v}}_c - \frac{3K_{||}}{v} \mathbf{G}_{||} - \frac{3K_{\perp}}{v} \mathbf{G}_{\perp} \]

\[ - \frac{\omega \cdot \mathbf{v}}{1 + (\omega \cdot \mathbf{v})^2} \rho \mathbf{B} \times \frac{\mathbf{B}}{B} \]

or

\[ \mathbf{\tilde{v}} = \mathbf{\tilde{v}}_c + \mathbf{\tilde{v}}_{||} + \mathbf{\tilde{v}}_{\perp} + \mathbf{\tilde{v}}_G \]

The successive terms are due to convection (directed radially outward), parallel diffusion, perpendicular diffusion and the density gradient current. As discussed in the Chapter IV the
Fig. 5.9 (a) Same as Fig. 5.8 for non-He shocks with IMF polarity away (+) on the key-day which is arrival day of these shocks.
Fig. 5.9 (b) Same as Fig. 5.8 for non-He-shocks with IMF polarity toward (-) on the key-day which is arrival day of these shocks.
last two terms of equation 4.5 i.e. $\mathbf{i}_i \mathbf{\perp}$ and $\mathbf{G}$ can not be neglected. They should be considered because Forbush decreases are associated with the interplanetary shocks (Fig. 5.1 and 5.2) and the cosmic ray particle density gradients perpendicular to the ecliptic plane are established which are 10 - 20 times the quiet time gradients (Yoshida et.al., 1973).

As the piston plasma of these shocks advances, the drift velocity, which is much larger than the velocity of the piston plasma, is produced due to the large gradient of magnetic field (grade - B of the order of 100 \( \gamma/AU \) (Chapter IV)). This drift velocity is perpendicular to the ecliptic plane. The flow due to $\mathbf{B} \times \mathbf{\nabla}U$ (where $\mathbf{B}$ is magnetic field and lies in the plane of ecliptic and $\mathbf{\nabla}U$ is the density gradient perpendicular to the ecliptic plane) is superposed on the so-called corotation streaming. Being dependent on the IMF polarity which is toward or away the transport by the particle density gradient drift should bring cosmic rays towards the ecliptic plane.

Some indications of non-field aligned diffusion associated with the variability of the ecliptic magnetic field direction (Ananth et.al. 1973, 1974; Kane, 1975) as well as that associated with reasonably constant ecliptic field directions (Kane, 1975) exist. However, the theoretical relationship between cosmic ray diffusion perpendicular to the mean field and the magnetic field fluctuations is complex and depends on field fluctuations both in and normal to the ecliptic plane. Gradients perpendicular to the ecliptic are observed for short periods in association with disturbed interplanetary conditions (Duggal and Pomerantz, 1976).
In the early investigations of large Forbush decreases noticeable increases in the amplitudes of the daily variation during and after the decrease (Dorman, 1963) were observed. In larger cosmic ray storms, the time of maximum for the daily variation shifted toward earlier hours irrespective of the intensity of the storm. Usually the amplitude of the daily variation was largest during the recovery portion of the Forbush decrease. Venkatesan and Mathews (1968) found the enhanced daily variation during a cosmic ray storm. In this case there was no large Fd recorded at the Earth. The enhanced daily variation probably indicates a disturbance in the normal cosmic ray flow pattern at large distances from the Earth without the modulating region itself engulfuig the Earth (Lockwood, 1968).

Very large anisotropies were also observed following the Fd (Mercer and Wilson, 1968). Changes in both the direction and magnitude of the anisotropy with the maximum intensity of the cosmic-ray flux west of the Earth-Sun line were observed, quite in contrast to that seen in the normal daily variation and in the initial phases of a Fd. Tanskanen (1968) in a very detailed analysis studied the intensity variations for a series of Fds in 1965-1966. It was concluded that during the beginning of the Fd the phase of the first harmonic shifts in the daily variation toward the Earth-Sun direction, occasionally even becomes directed west of Earth-Sun (ES) line. The amplitude becomes several times the predcrease level and this enhanced level may continue for several days. The phase generally returns after a few days to be close to 90° E of the ES line.
but, in some cases, may go through a period of almost zero amplitude.

Hashim and Thambyahpillai (1969) observed the large amplitude of the daily wave which was attributed to an intensity depression from a limited cone of direction, the axis of which is \(45^\circ\) W of the ES line, McCracken (1962 b) was the first to propose a mechanism for such decreases. Since the stations viewing \(45^\circ\) W of ES line are connected by the interplanetary field to a region of depleted cosmic ray intensity lying behind the shock front, the intensity recorded would be decreased. The size of the cone of directions of reduced intensity is related to the scattering by which particles can escape from the modulating region before arriving at the Earth. Hashim and Thambyahpillai (1969) evoke essentially the same mechanism to account for the large variations observed.

The depletion of cosmic ray flux in the garden-hose direction can be related to a possible connection of the Earth with regions of depleted cosmic ray intensity behind the rear end of a shock front which may or may not have produced a Forbush decrease at the Earth depending upon the position of the shock front with respect to the Earth. Where the shock front do produce a Forbush decrease in the high energy cosmic radiation, large anisotropies along the garden hose direction (Fentan et.al. 1959) have been commonly observed. Corotating type of \(F_d\) observed at very low energies (<10 MeV) caused by recurrent active regions are known to often cause only an enhanced diurnal amplitude at high energies (McCracken et.al., 1966).
Enhanced diurnal variation due to an excess flux coming from the $\sim 21$ hour direction (Rao et al. 1971b) is often observed during the later part of a Forbush decrease indicating the existence of a source in the antigarden hose direction. Such a source can be caused by a positive density gradient following a strong convective removal of particles. Thus during the later part of the diurnal wave train, the anisotropy could be due to an excess flux from the antigarden hose direction. The establishment of such a positive density gradient at low energies (10-50 MeV) during late times in the decay of flare events (McCracken et al. 1971; Rao et al. 1971a) adds strength to the basic concept proposed.

Murayama (1975) analysing some high speed streams occurring during 1967, found that the amplitude of the diurnal wave tends to be smaller in the declining velocity portion of the stream. The author interprets this result by claiming a cosmic-ray diffusion perpendicular to the field lines on the ecliptic plane only in the declining velocity portion of the stream, in which a cosmic ray density rarefaction due to longitudinal velocity gradient could exist. In the declining-speed period of the stream the amplitude of the first harmonic is strongly reduced (Iucci et al., 1983).

5.4 CONCLUSIONS

The following conclusions can be drawn from the above results and discussion:

1. The diurnal amplitude for He-shocks on the arrival day
is large than the amplitude of non He- shocks.

2. The diurnal phase shifts towards earlier hours in both cases.

3. A peculiar behaviour of He- shocks on the arrival day, when the IMF polarity of these days is northward (-), is seen from our results contrary to the results when the IMF polarity of arrival day was southward (+).

4. The diurnal amplitude for northward (-) IMF, on the arrival day is similar to the results obtained for shock - associated clouds which have southward (+) magnetic field in their front boundary as is discussed in Chapter number IV.

5. Hence it seems that the orientation of the magnetic field of these He - shocks, for IMF (-) on the arrival day, is southward (+).

6. It also seems that this southward (+) magnetic field, on the arrival day of these He- shocks, dominates.

7. The effect of southward (+) and northward (-) magnetic field is clearly visible in the case of non- He shocks.

8. The decrease in diurnal amplitude of non- He shocks on the arrival day is due to the declining phase of velocity under which diurnal amplitude reduces as explained previously.

9. The values of diurnal amplitudes and phases in different conditions are given in table 5.1.

10. The preshocked and post shocked behaviour are shown in different figures.

11. The contribution of $\mathbf{B} \times \nabla U$ term is significant. This streaming is superimposed on the corotation streaming depending upon the sense of $\mathbf{B}$. 