DIURNAL ANISOTROPY OF COSMIC-RAY INTENSITY NEAR THE PAST SOLAR MINIMUM

H. Mavromichalaki and A. Geranios
Nuclear Physics Laboratory, Cosmic-Ray Group, University of Athens, Solonos str. 104, Athens 144, GREECE

ABSTRACT

The diurnal anisotropy of cosmic-ray intensity observed over the period January 1973 to March 1974 has been analyzed using neutron monitor data of the Athens and Deep River stations. This analysis showed a shift of the diurnal anisotropy phase towards earlier hours than normally.

In order to explain this behavior according to the convective-diffusive mechanism, solar wind and interplanetary magnetic field data measured by a multi-spacecraft network of geocentric satellites were used. It is noticed that the diffusion vector is well aligned along the anti-garden hose direction. This vector seems to have a memory of this direction indepentely of the interplanetary magnetic field polarity.

1.- Introduction

The standard picture for the diffusion of cosmic-rays at neutron monitoring energies in the solar system involves diffusion which is essentially field-aligned (Jokipii, 1971). Later, Kane (1974) showed that on a day-to-day basis the diffusion vector deviates from the interplanetary magnetic field (IMF) direction in the ecliptic plane by more than 30° on about 35% of the quiet days. It has been shown that on many days the interplanetary field seems to stick to the garden-hose direction, while the diffusion vector deviates significantly from the garden-hose direction and on some other days the reverse situation obtains. Ananth et al (1974), comparing the diffusion vector with the magnetic field vector pointed out that this simple concept holds good on more than 80% of days. On the rest 20% of days the diurnal anisotropy characteristics seem to indicate the presence of a significant component of transverse diffusion current in addition to the normal convection and diffusion flow. Owens and Kash(1976) showed that the diffusion is field-aligned on essentially all well-determined days. Rao et al (1972), Mavromichalaki (1980a;b) have shown that the diffusion vector is field aligned during days exhibiting enhanced diurnal variation, the diffusion current on an average basis being driven by large cosmic-ray gradients in the ecliptic plane.

In this work a detailed analysis of diurnal anisotropy on a day-to-day basis is presented using neutron monitor data over the period 1973-1974 near the past solar minimum.

2.- Data analysis

In order to examine the cosmic-ray diurnal variation in a statistically meaningful way we used neutron monitor data of the Deep River (1.02 GV) and Athens (8.72 GV) stations over the period January 1973 - February 1974 for about 430 consecutive common days without any exclusion of Forbush characterized periods.

According to the convective-diffusive mechanism the observed diurnal anisotropy vector for each day corrected for geomagnetic effects (Barnden, 1972) was splitted into the convective and diffusive components (Mavromichalaki, 1980a). Then the diffusive vectors (δ_D, φ_D being the amplitude and phase, respectively) were compared day by day with the IMF ecliptic component. So, the solar wind as the magnetic field data were hourly averages taken from the magnetometers aboard the geocentric IMF-AMP satellites in earth orbit in interplanetary space (Wolf and King, 1977). For the plasma averages we assumed the solar wind as streaming always radially outward from the Sun in the ecliptic plane while for the IMF data the averages are calculated vectorially (taken into account B, φ and ϑ). The hourly averages were resolved into Cartesian coordinates and the amplitude B_{xy} and the direction φ_B of the daily average magnetic field in the ecliptic plane were calculated.

3.- Observational results

An examination of the Figure 1 and the neutron monitor data of the two stations shows that the direction of maximum intensity in space is shifted to an earlier time than the 18.00 hr, direction predicted by the corotation theory. The mean diurnal anisotropy displays a maximum intensity at approximately the 16.00 hr direction over the period 1973-1974. Mavromichalaki (1980b) has noticed a shift of the diurnal phase to earlier hours during large amplitude wave trains of cosmic-ray intensity in the year 1973. Agrawal also and Singh (1975) showed that the time of maximum intensity has significantly shifted to earlier hours since 1971.

In order to explain this displacement we examined in detail the behavior of the diffusive component with the orientation of the IMF (Figure 2). The anti-

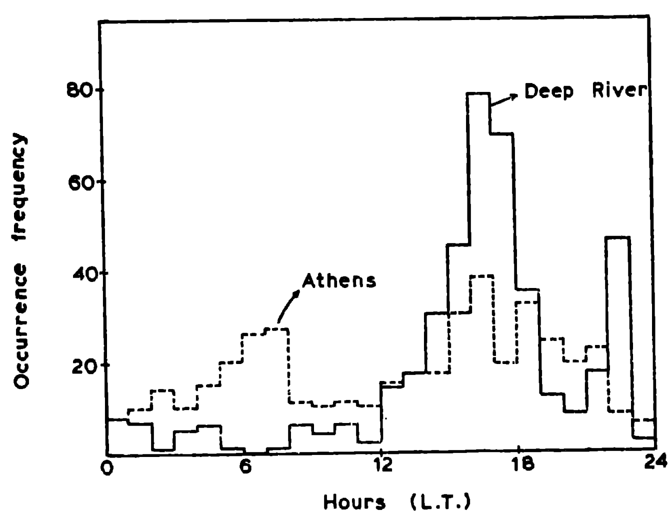

Fig. 1. Histogram showing the hour of maximum of diurnal anisotropy of the two stations Deep River and Athens

garden hose direction (21.00 LT) for the two stations shows fairly narrow peaks of about ±2 hours width for both φ_D and φ_B. However, there is a small **additional peak** for φ_D at about 00.00 LT, especially in the Athens neutron monitor data (Kane, 1974). Also the distribution of garden-hose direction (09.00 LT) shows a second peak for φ_B as it is expected.

It is observed that the diffusion and the ecliptic magnetic field are very well aligned along the 45° line as the anti-garden hose direction is conserned. The diffusion vector seems to have a memory of the anti-garden hose direction indifferently of the IMF even though φ_B may deviate from it.

The difference $(\varphi_D - \varphi_B)$ very close to zero would indicate field-aligned diffusion, while large values of $(\varphi_D - \varphi_B)$ near ±6 hours would indicate highly non-field aligned diffusion. This is shown in Figure 3 for the two stations where the difference $(\varphi_D - \varphi_B)$ is close to zero. Note the standard deviation for the "Athens" distribution is three times larger that the one's of "Deep River".

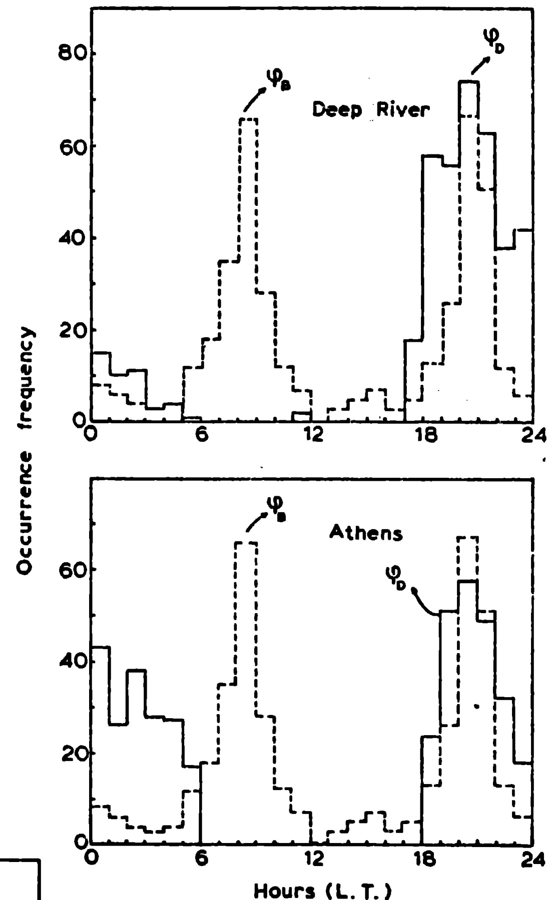

Fig. 2. Frequency distribution of diffusive phase φ_D and of azimuth angle φ_B of IMF ecliptic component for Deep River and Athens

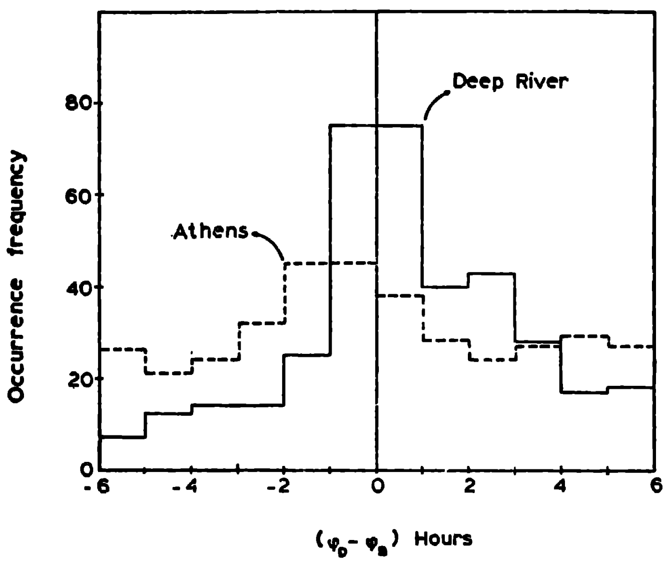

Fig. 3. Frequency distribution of the difference $(\varphi_D - \varphi_B)$

4.- Summary and conclusions

The results of this investigation can be summarized as follows:

1.- The observed diurnal vector in space of cosmic-rays is shifted to an earlier time than the 18.00 hr direction over the time period January 1973 - February 1974. This phase shift is expected to be larger during the years 1975-1976 with the approaching year of sunspot minimum. A significant decrease of diurnal time of maximum has also been observed from 1953 to 1954, the year at 18th solar cycle minimum.

2.- The direction of the diffusion vector with the IMF ecliptic component is studied for about 430 days during 1973-1974 for the two neutron monitoring stations. It came out that for the Deep River station on 59% of the days the two vectors differ 0-2 hours and on 27% of the days 2-4 hours. On about 14% of the days the difference is 4-6 hours. For the Athens station the two vectors differ 0-2 hours on 43% of the days and 4-6 hours on 28% of the days. Similar results have been reported by Kane (1974) and Ananth et all (1974) for the years 1965-1968.

3.- Whereas the gross tendency of the magnetic field vector is to be in the garden-hose and anti-garden-hose direction and the diffusion vector is to be in the anti-garden hose direction, deviations from these directions in both vectors do not always occur in the same sense.

4.- The shift of diurnal time of maximum to earlier hours on an average basis can be qualitatively understood in terms of simple convection -diffusion theory either as an enhancement in the convective vector due to an increase in solar wind velocity or as a decrease in the diffusive vector due to the increase in the value of the diffusion coefficients ratio $K_{\perp}/K_{\parallel}$. Indeed Feldman et al (1978) have shown that the years 1973-1976 were marked by recurrent high speed streams where diffusion processes are different than in quiet solar wind.

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