# Brief Reports

## Direction of the Nearby Galactic Magnetic Field Inferred from a Cosmic-Ray Diurnal Anisotropy

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A twenty-year wave in the diurnal anisotropy component of galactic cosmic rays arriving at the earth from the asymptotic direction 128°E of the sun has been found by Forbush. This wave is interpreted in terms of enhanced magnetic reconnection between the nearby galactic field and the field lines in the polar regions of the heliosphere during one-half of the twenty-year solar magnetic cycle. This interpretation leads to the result that the component parallel to the solar rotation axis of the nearby galactic field is directed northward.

Information on the direction of the galactic magnetic field has been obtained from the polarization of starlight induced by interstellar grains, Faraday rotation observations of extra-galactic radio sources, the polarization of the galactic radio emission, and more recently by Zeeman splitting of the 21-cm hydrogen line. [See, for example, *Westerhout et al.*, 1962; *Seymour*, 1966; *Mathewson*, 1968; *Verschuur*, 1968; *Ekers et al.*, 1969.] *Earl and Lenchek* [1968] discuss the possibility of observing anisotropic high-energy electrons to study the nearby galactic field. A variety of models to explain the observations have been suggested. *Seymour* [1968] reviews some of the more popular models. The two basic models consist of magnetic field either wound into a tight helix around the local spiral arm or magnetic field oriented parallel to the arms with opposite polarities on either side of the galactic plane.

The observations suggest that in the vicinity of the local system, the Gould Belt, the magnetic field above the galactic plane is oriented towards galactic longitude $l \simeq 260°$, and that in and below the galactic plane, the field is oriented towards $l \simeq 80°$. Figure 1 shows the galactic equator in a coordinate system of right ascension and declination. The shaded region marked 'below plane' and the region marked 'above plane' indicate the directions of the galactic magnetic field and the galactic longitudes involved.

The galactic magnetic field in the immediate vicinity of the sun will be referred to as the 'nearby' field. The 'local' field will refer to the larger scale magnetic field near the sun. If no small-scale structure is present in the local galactic magnetic field, the two fields would be the same. The local galactic magnetic field then depends upon whether the sun is above or below the galactic plane. *Allen* [1963] places the sun at a position approximately 8 ± 12 parsec north of the galatic plane. This would indicate that the local galactic field is probably oriented towards $l \simeq 260°$; however, the result is not definite. By studying radio spurs, *Mathewson* [1968] placed the sun 10 parsecs below the magnetic plane of the galaxy. This would indicate the local galactic magnetic field would be near $l \simeq 80°$.

This paper presents an interpretation of some cosmic-ray observations that relates to the 'nearby' galactic field direction. *Forbush* [1967] found a twenty-year wave in the diurnal anisotropy component of galactic cosmic rays arriving at the earth from the asymptotic direction 128°E of the sun. This is twice the solar cycle period of 10 years during the interval 1937–1965. Forbush notes that the amplitude of the

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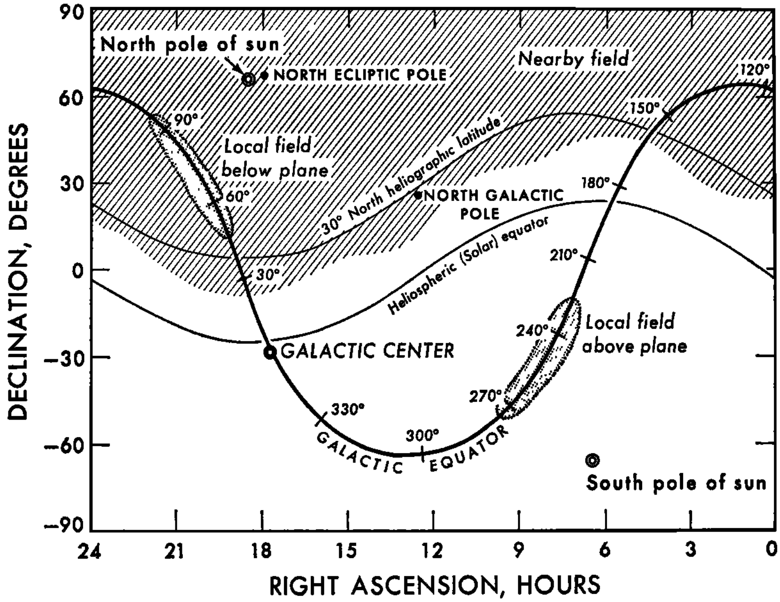


Fig. 1. Graph of the galactic equator with galactic longitude and the direction of the local magnetic field above and below the galactic plane indicated in heavy shading. The poles of the sun, the heliospheric equator, and 30° north heliographic latitude are indicated. The cross-hatched area at the top of the figure indicates the region in which the nearby galactic magnetic field is expected to be oriented. This is not an equal area projection.

twenty-year wave is 60% of the amplitude of the average diurnal anisotropy 90°E of the sun. Thus the effect represents a large portion of the observed cosmic-ray anisotropy. The wave passes through zero in the middle of 1958 near the time observed by *Babcock* [1959] for the reversal of the sun's polar magnetic fields.

To gain a better qualitative understanding of the observations of Forbush, one can think of the effect in the following way. During one-half (from sunspot maximum to sunspot maximum) of a solar *magnetic* cycle, galactic cosmic rays observed near the earth (at low heliographic latitude) show a net flow toward the sun along the average direction of the interplanetary magnetic field. During the following half of the solar magnetic cycle, the situation is reversed; galactic cosmic rays in the vicinity of the earth flow away from the sun along the interplanetary magnetic field.

The Forbush wave appears to change phase depending upon the sense of the sun's polar magnetic fields. This enables one to eliminate many possibilities in seeking an interpretation. The direction of the sun's polar field itself is not significant unless it interacts with another significant direction. The clockwise or counterclockwise spiraling of the cosmic rays about the field lines is not important because their gyroradii are too small for such considerations to account for the effect. The direction of earth's field is a possible candidate to relate to the sense of the sun's polar field, since it varies between 16° and 31° from being either parallel or antiparallel to the direction of the sun's polar magnetic fields, depending upon the phase of the solar magnetic cycle. The earth, however, is situated in the equatorial regions of the solar wind. This is a region of variable (over 11 years) polarity fields, such as the sector structure [*Wilcox*, 1968], and thus the earth would not be in a position to sense the direction of the sun's polar fields directly. In addition, the effects of the earth's field have been removed in considering the anisotropy of the galactic cosmic rays. The effect is thus interplanetary rather than geocentric.

The extended (by the solar wind) sun's polar magnetic fields can, however, interact with the direction of the nearby galactic magnetic field if the galactic field in the vicinity of the sun has an appreciable component along the sun's polar (rotational) axis. Figure 1 shows the direction of the polar axis of the sun. The shaded areas indicate the approximate direction of the galactic field above or below the galactic plane. The range in angle subtended by the galactic field is from 30° to 50° from the polar axis. Thus this criterion is met.

The effect observed by Forbush may be interpreted in terms of magnetic reconnection between the nearby galactic field and the extended sun's polar field at the boundary of the heliosphere. An analogy may exist with the reconnection between geomagnetic field lines and the interplanetary magnetic field [*Dungey*, 1961; *Fairfield and Ness*, 1967; *Schatten and Wilcox*, 1967; *Wilcox*, 1968]. It appears that when the geomagnetic and interplanetary magnetic fields are antiparallel, geomagnetic activity tends to increase, and that this increase may be caused by an enhanced reconnection between the two fields (as suggested by *Dungey* [1961]).

Let us apply this analogy to the case at hand. Somewhat fragmentary evidence from type I ionized cometary tails suggests that the outward radial flow of the solar wind plasma may be approximately spherically symmetric about the sun. The boundary between the ordered flow of the solar wind and the galactic medium has been designated the heliopause. This is the region in which an approximate equality would obtain between the pressure of the outward flowing solar wind and the pressure of the galactic medium, including the galactic magnetic field, cosmic-ray gas, and cold gas. Each polor region of the sun tends to have a unidirected large-scale magnetic field [*Babcock*, 1959], whereas the equatorial regions have a smaller scale field of changing polarity related to the observed interplanetary sector pattern [*Wilcox and Ness*, 1965]. The large-scale pattern of the observed interplanetary field observed near the earth has been shown [*Ness and Wilcox*, 1966] to be related to the large-scale pattern of the photospheric field in equatorial regions. Thus the large-scale nature of the solar magnetic field may be transmitted by the magnetic field frozen in the solar wind plasma to the heliopause. When the large-scale polarity of the sun's polar regions changes, near the maximum of each sunspot cycle, the polarity of the heliopause polar regions should also change after a lag of some months. The equatorial regions of the heliopause would be expected to have a more changeable field polarity pattern related to the interplanetary sector pattern.

This field topology is shown in Figures 2*a* and *b*. The figure is not to scale, as the distance to the heliopause is not very well known, and the effects of solar rotation are not shown. In Figure 2*a* the sun's polar field and the nearby galactic field are aligned. A minimum energy configuration results when the nearby galactic field and the interplanetary or heliospheric field are interconnected. A galactic cosmic ray would then have easier access to the polar regions of the heliosphere (the heliosphere is the region within the heliopause). Such a cosmic ray approaching the sun may have its radial velocity reversed by the magnetic mirror action of the increasing interplanetary magnetic field.

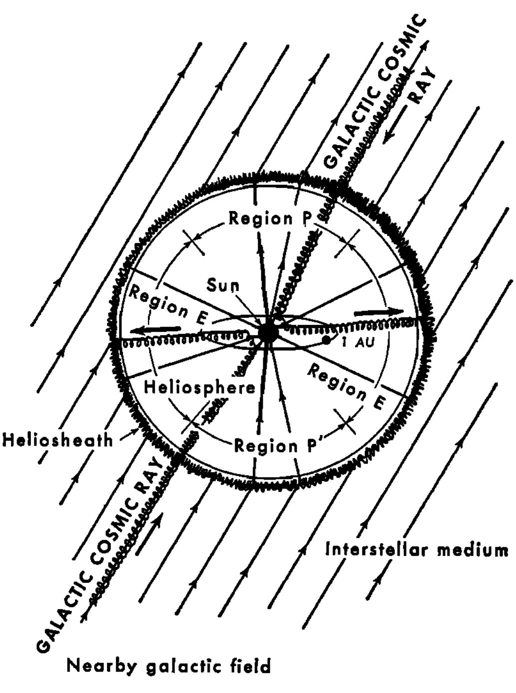


Fig. 2*a*. Schematic of the magnetic field topology when the sun's field in the northern polar region is directed away from the sun. The sun's polar field lines reconnect with the interstellar magnetic field. Region *P*: Polar latitudes in which the predominant field polarity is assumed to reverse near each sunspot maximum. Regions *P'*: same as region *P* but with opposite polarity. Region *E*: equatorial latitudes with variable field polarities similar to the observed interplanetary sector patterns.

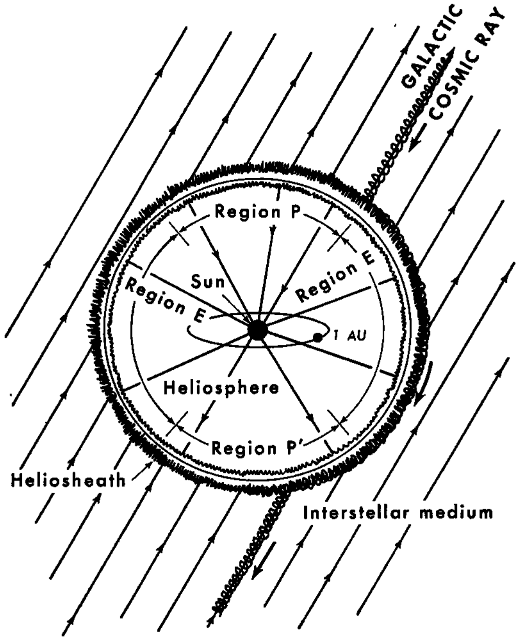


Fig. 2*b*. Schematic of the magnetic field topology when the sun's field in the northern polar region is directed towards the sun, as during the interval 1958–1969. The sun's polar field lines do not as readily connect with the interstellar magnetic field.

However, scattering, drift, diffusion, and effects due to the stochastic nature of field lines [*Jokipii and Parker,* 1969; *Parker,* 1968] may result in some of the galactic cosmic rays that have entered from the polar regions being transferred to equatorial latitudes. A galactic cosmic ray could then travel away from the sun along an interplanetary field line (moving in a direction about 135° east of the sun at the orbit of the earth).

Figure 2*b* shows the topology of the heliospheric fields 11 years later, when the sun's polar fields have reversed. The nearby galactic magnetic field now tends not to connect with the heliospheric fields, but tends to circumvent the heliosphere by way of the heliopause. (The basic arguments apply if the heliosphere is not closed as shown but open with a heliospheric tail, by analogy with the case of the magnetosphere [*Dessler,* 1967].) A galactic cosmic ray now has a more difficult time making its way into the polar regions of the heliosphere and finds it somewhat easier to enter the heliosphere at low heliographic latitudes. Thus there may be a net flow of galactic cosmic rays *toward* the sun along the interplanetary magnetic field.

This mechanism can tell us something about the direction of the galactic field in the immediate vicinity of the sun. In a sense, the sun's polar magnetic field is being used as a probe of a component of the nearby galactic magnetic field. When the two are aligned, cosmic rays have easier access to the polar regions of the heliosphere, and near the earth a cosmic-ray flux is observed streaming away from the sun along the Archimedes spiral angle. When the two are antiparallel, cosmic rays make their way into the heliosphere more readily at low-latitude field lines, and an asymmetry is observed with cosmic rays traveling towards the sun along the Archimedes spiral angle. During the interval from 1958 to 1969, the north polar region of the sun had field lines directed toward the sun. During this interval Forbush has found a net flow of cosmic rays at the orbit of the earth moving toward the sun along the Archimedes spiral direction. If the hypothesis relating this to reconnecting heliospheric and galactic field lines is correct, this would indicate that the nearby galactic field would be oriented predominantly in the cross-hatched region shown in Figure 1. As a greater understanding of local cosmic-ray fluxes develops and these are more closely related to interplanetary phenomena, this region of uncertainty may be reduced.

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