GEOFISICA INTERNACIONAL

ON THE PROBLEMS OF USING λ_{inv} IN THE STUDY OF NON-TRAPPED COSMIC RAY PARTICLES

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RESUMEN

Ante el gran éxito obtenido al usar la latitud invariante para ordenar el movimiento de las partículas atrapadas en el campo geomagnético, se ha vuelto común utilizar este parámetro para clasificar magnéticamente un punto, en substitución de sus tres coordenadas especiales, considerando que esta clasificación es suficiente para conocer las características de las trayectorias de las partículas que llegan a él. El propósito de este trabajo es mostrar que las direcciones de observación y los puntos de entrada correspondientes a partículas de rigideces no muy altas, son muy diferentes para dos puntos de la misma latitud invariante que se encuentren en distintos puntos de la Tierra o a diferentes alturas sobre la superficie.

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ABSTRACT

Due to the great utility showed by the invariant latitude as an ordering parameter for trapped radiation, it is generally consider that this parameter can always substitute the three coordinates of a point in order to have its magnetic clasification which allow us to infer the characteristics of the behavior of the charged particles observed at that point. The purpose of this work is to show that in many cases (mainly the study of particles of low and mean energies coming from the interplanetary medium into the magnetosphere) the knowledge of the invariant latitude ot a point is not sufficient to deduce the propagation characteristics of the particles observed at a given point. The precise position of the point on the earth or its height over the surface determine differences between the directions of viewing and point of entry of the particles observed at there and those for particles observed at another point with the same invariant latitude but in different location.

INTRODUCTION

In 1965 McIlwain introduced the L parameter in order to have a more adequate ordering of trapped radiation in the geomagnetic field which made easier the study of such particles. The great success of this parameter in the description of trapped motion around the earth has lead to consider it as determinant in any king of interaction of charged particles with the geomagnetic field and the use of the invariant latitude (λ_{inv}) –which directly derives from L ($\lambda_{inv} = \cos^{-1} \sqrt{\frac{1}{L}}$)– has been widely extended to the study of most of the phenomena related to cosmic radiation coming from the interplanetary medium.

Even when no stated explicitly, the assumption that the invariant latitude is sufficient for the magnetic description of a given point (at least at distances near the earth) has lead to the commom practice of present the experimental reports of particle observations in terms only of this coordinate, without regarding as necessary to refer the geographic or geomagnetic position of the observation point; that is, the coordinates (r, λ, φ) of any point of observation are reduced to only one: λ_{inv}. (See for example: Engelmann *et al.*, 1971; Van Allen *et al.*, 1971; Hudson *et al.*, 1969; Stauning *et al.*, 1970; Bostrom, 1970; etc).

In the present work numerical integrations of proton trajectories for particles with rigidities between 0.6 and 500 GV was made for different points of arrival with the same invariant latitude, in order to test the accuracy of the assumption that the propagation characteristics of the particles can be well described taking only into account the invariant latitude of the point of arrival. The numerical integrations were performed with the help of a geomagnetic field composed by the Williams and Mead (1965) expressions for the external field and the Cain *et al.* (1967) coefficients for a gaussian expansion of the internal field (Gall and Bravo, 1970). The integration is started at the point of observation and stopped at the magnetopause where the point of entry (r_m, λ_m, φ_m) and the direction of viewing (Λa, Ψa) are calculated. In the magnetospheric tail the integration is carried out up to 25 R_E from the earth.

The study is devided in three parts:

a) Comparison of trajectories of particles arriving at two different points on the earth, in the same hemisphere and with the same invariant latitude.

b) Comparison of trajectories of particles arriving at two points at the same invariant latitude but in different hemispheres.

c) Comparison of trajectories of particles arriving at two points at the same invariant latitude but at different height over the earth surface.

a) *Particles arriving at two points of the same invariant latitude in the Northern Hemisphere*

For this part of the study the points selected were Churchill station ($\lambda_{geog} = 58.80°$ and $\varphi_{geog} = 265.80°$) and another random point ($\lambda_{geog} = 64.10°$ and $\varphi_{geog} = 320.0°$) having the same invariant latitude, namely 70.09°. If the invariant latitude was the only parameter that should be taken into account for the description of the movement characteristics of the cosmic ray flux arriving to these two points, the computed trajectories for both must be at least very similar. In order to test this assumption, trajectories of protons with rigidities ranging from 0.6 to 550 GV were computed for vertical arriving at both points at different local magnetic times. Figures (1) (2) and (3) show the viewing directions obtained for 0H, 6H and 12H and as can be seen even when the general patterns are similar (and this is so even for other invariant latitudes) the directions are very different. The smallest differences correspond to particles arriving at OH (25° in longitude and 20° in latitude). For all other hours the differences become larger and at 12H one can find differences as large as 40° in the longitude of viewing for the same rigidity. In figure (4) the points of entry are also plotted for the two points and again considerable differences can be observed.

b) *Particles arriving at two points of the same invariant latitude but in different hemispheres*

In order to make a comparison between the characteristics of the cosmic rays particles which arrive at points of equal invariant latitude located in different hemispheres, Mawson station in the south hemisphere ($\lambda_{geog} = -67.60°$ and $\varphi_{geog} = 62.90°$) was selected. It was so because the invariant latitude of Mawson is the same as the Churchill's. In the same way, trajectories of protons between 0.6 GV and 550 GV were computed for arrival at Mawson under vertical direction at different local times. In figures 5 (a) and (b) some computed viewing directions for Mawson are shown and can be compared with those for Churchill in previous figures. From the comparison great differences in the directions of viewing can be observed (as big as 60°) even grater than those corresponding to the case of two points in the same hemisphere.

c) *Particles arriving at two points of the same invariant latitude but at different heights over the earth's surface*

Particles with energies as the ones studied here (0.6 to 550 GV) are commonly recorded with detectors on board satellites orbiting several kilometers above the atmosphere. A mean height for this satellites is $\approx$ 1100 km and the invariant latitude of a point at this height is not in general the same as the invariant latitude of a point on the surface with the same latitude and logitude. For the study of the effect of the height on the arrival of cosmic rays a point at 1100 km, having the same invariant latitude as before ($\lambda_{inv} = 70.09°$), was selected. Such a point corresponds to a geographic latitude of $\lambda_{geog} = -80.0°$ and to a geographic longitude of $\varphi_{geog} = 240.0°$ and is exactly above Byrd Station. The same kind of computations as before were made and some of the directions of viewing obtained are shown in figure (6) compared with those for Mawson. The figure is very explicit in showing that from the cosmic ray particles point of view to arrive just over Mawson is not the same that to arrive at 1100 km over Byrd Station even when both points have the same invariant latitude.

DISCUSSION

It is concluded from the above results that for the study of non-trapped cosmic ray particles with rigidities of $R \lesssim 125$ GV entering the magnetopause and arriving at points near the earth the knowledge of the invariant latitude of the point of arrival is not sufficient. First of all it has been shown that different points of the same invariant latitude are indeed looking to different directions in the interplanetary medium when they observe particles of the same rigidity at the same local time. Moreover, as the points of entry are also very different for arrival at two different points, even when they have the same invariant latitude, the particles that the two points receive are carrying information about different regions of the magnetosphere and of the magnetopause. Hence, one can see that the λ_{inv} cannot subsitute the whole coordinates of a point $(r, \lambda\ \varphi)$ when we are studying particles coming from the interplanetary medium. It is due to the way how λ_{inv} is defined. The computation of λ_{inv} demands the knowledge of the local magnetic field which in many cases is obtained from not very adequate mathematical models. But even when the field is measured at the point, this local field cannot be sufficient to determine the characteristics of cosmic ray propagation in the whole magnetosphere. After the discovery of the external sources of the geomagnetic field, it has been pointed out the importance of the currents in the magnetosheet and in the magnetopause on the propagation of particles in the magnetosphere (see for example Reid and Sauer, 1967 and Gall *et al.*, 1968). Nevertheless the effect of this external sources on the magnetic field measured on or near the earth's surface is practically neglegible and so the field measured in these region would be approximately the same with or without the external sources. But even for the case, of having external sources if the deformation of the field lines was the same for all the lines with the same invariant latitude on the earth one could expect λ_{inv} to be still a good parameter, but unfortunately it is not the case. The deformation of the field lines has instead a geomagnetic and ecliptic symmetry.

As a consequence of this, any parameter based exclusively on the local field measured near the earth can not be good enough to characterize the behavior of particles coming from the interplanetary medium with energies low enough to be sensitive to the deformation of the geomagnetic field induced by the external sources. This is for example the case of solar cosmic rays. The study of this radiation, which very frequently is highly anisotropic, will lead to terrible missinterpretations if based only on the λ_{inv} of the points of observation.

The conclusion is that for the correct interpretation of experimental data concerning particles with rigidities of 125 GV or bellow the knowledge of the three coordinates of the point of observation is absolutely necessary while a better ordering parameter is found.

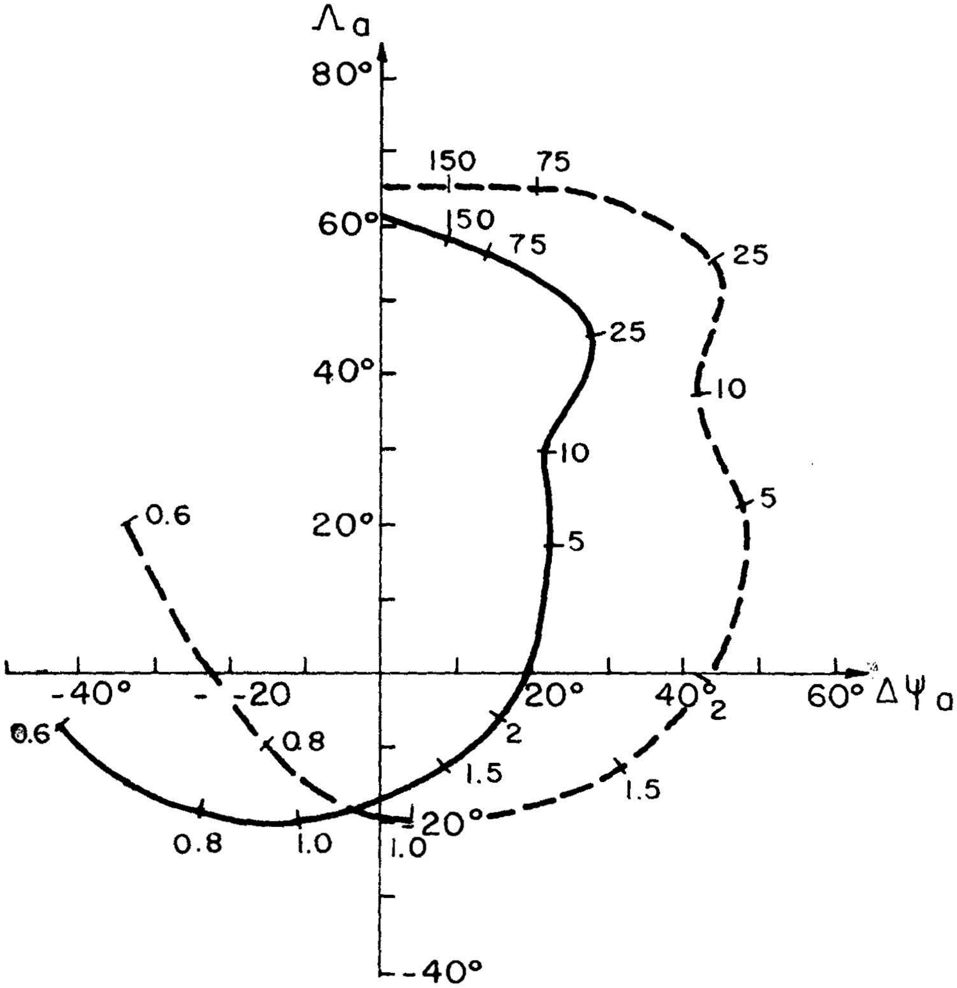

Figure 1. Directions of viewing (Λa Ψa) for two points at $\lambda_{inv} = 70.09°$ in the same hemispheres at OH of local magnetic time of observation and for vertical arriving of particles with rigidities between 0.6 and 500 GV. Solid line corresponds to Churchill and dashed line to the point $\lambda_{geog} = 64.10$ and $\varphi_{geog} = 320.0°$
$\Delta\Psi a = \Psi a - \varphi$ point of observation.

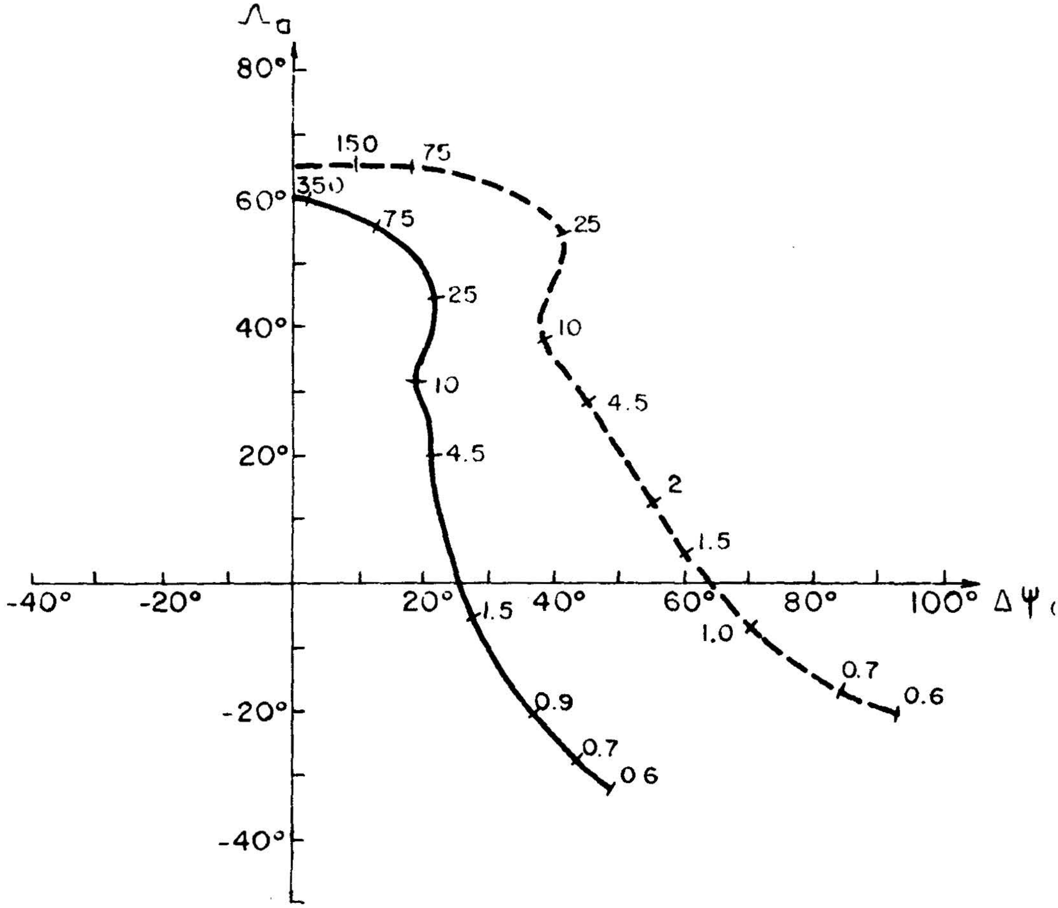

Figure 2. The same as figure 1 for 6H of local time of arrival.

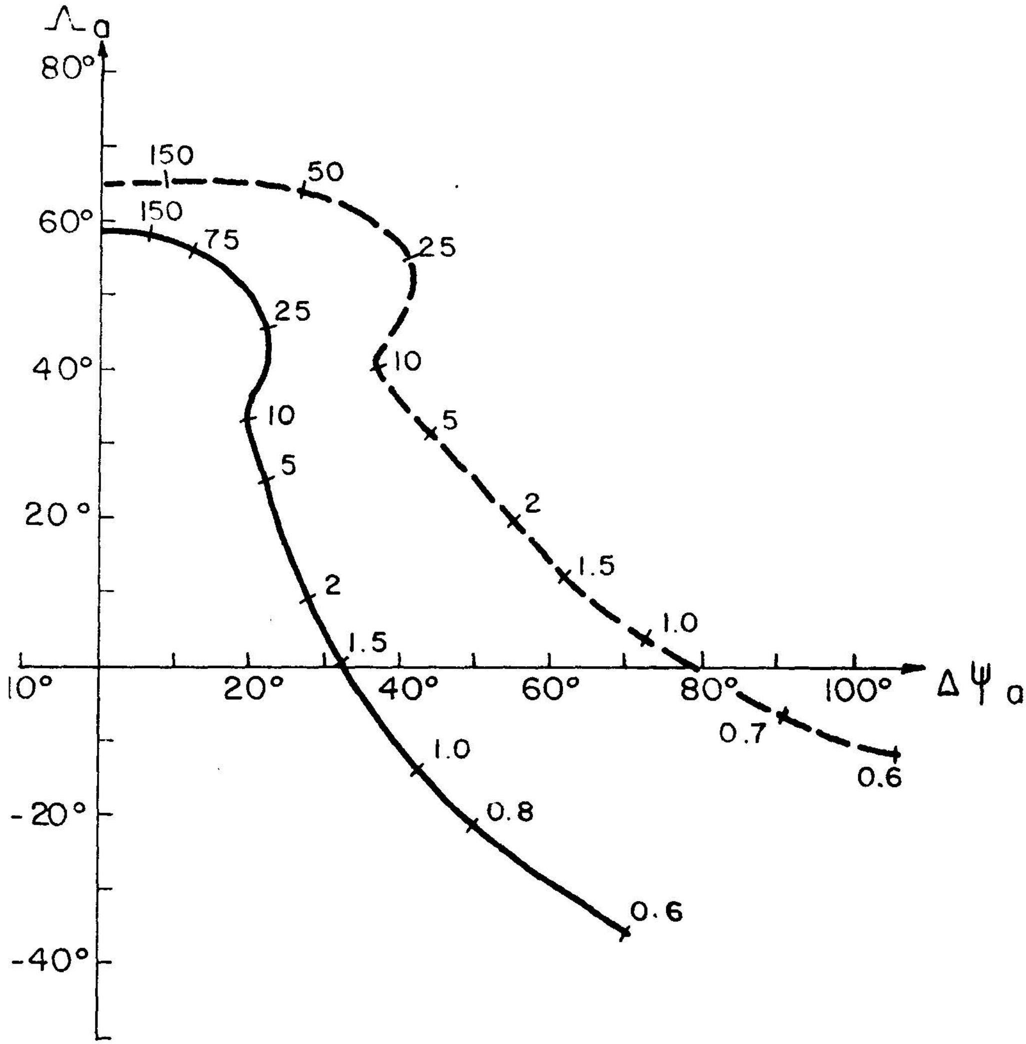

Figure 3. The same as figures 1 and 2 but for 12H of local time of arrival.

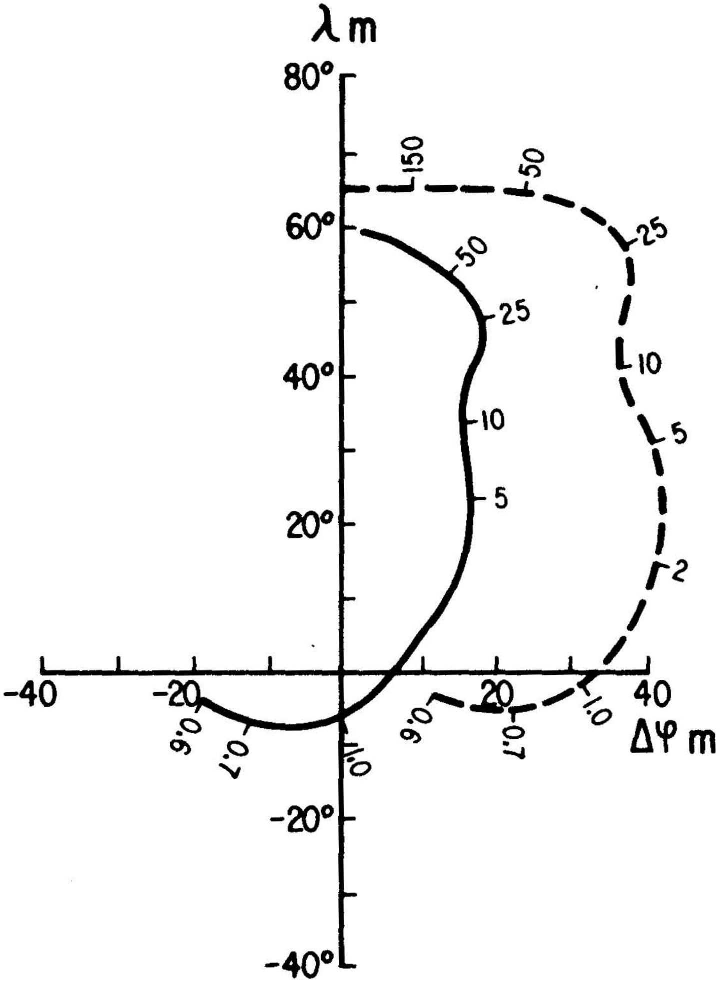

Figure 4. Points of entry (λ_m, φ_m) for two points with $\lambda_{inv} = 70.09°$ corresponding to vertical arriving of protons of rigidities between 0.6 and 550 GV at OH of local magnetic time. Solid line corresponds to Churchill and dashed line to the point $\lambda_{geog} = 64.1°$ and $\varphi_{geog} = 320.0°$.
$\Delta\varphi_m = \varphi_m - \varphi$ point of observation.

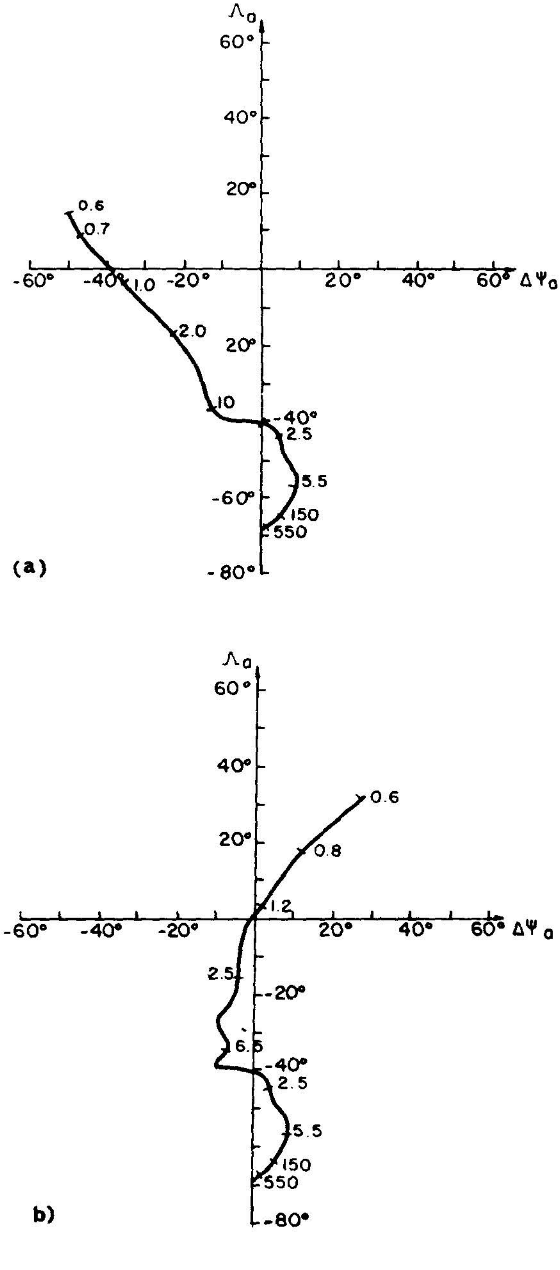

Figure 5. Directions of viewing for particles with rigidities between 0.6 and 500 GV arriving vertically at Mawson which also has $\lambda_{inv} = 70.09°$. Figure 5(a) corresponds to 0H of local magnetic time and figure 5 (b) corresponds to 12H.

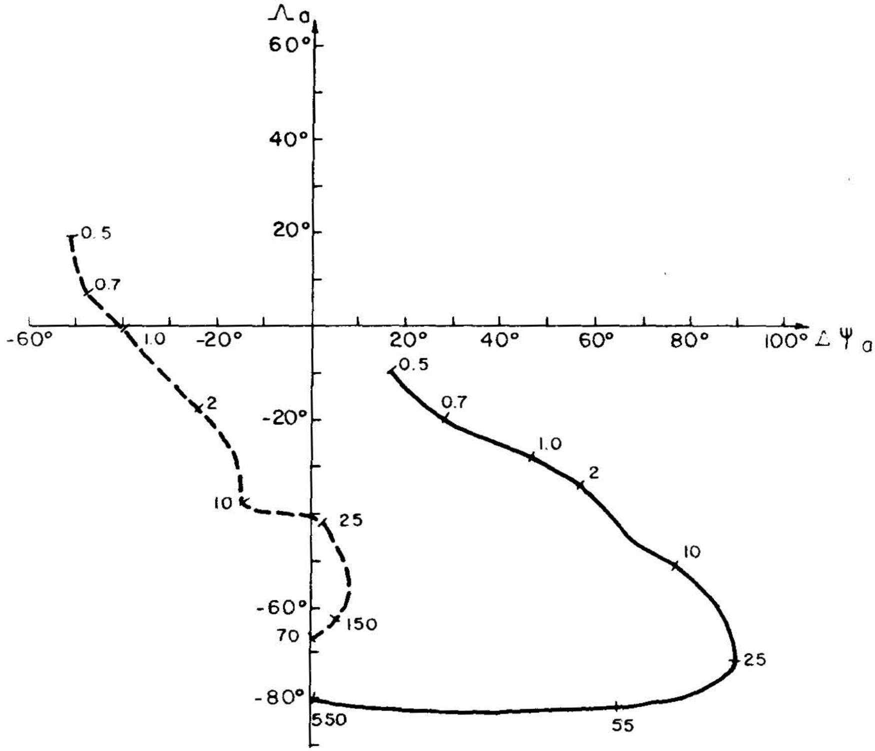

Figure 6. Directions of viewing at OH of local magnetic time for particles arriving vertically at two points with $\lambda_{inv} = 70.09°$. Dashed line corresponds to Mawson station and solid line corresponds to a point at 1100 km above Byrd station.

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