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The effect of the corotation and the quiet time ionospheric dynamo electric fields on the dynamics of energetic electrons and protons (with energies between 50 keV and 1 MeV), inside the inner magnetosphere, is investigated, using the concept of drift paths of constant effective potential. The quiet time ionospheric dynamo electric field is given by an analytic empirical model based on scatter radar observations. The corotation electric field and the Earth's magnetic field are given by analytic expressions corresponding to a centered and an eccentric dipole model. The main conclusion is that the quiet time electric fields cause a diurnal modulation of the electron and proton precipitation. At low L values the locus in longitude of the maximum precipitation is shown to be energy dependent.

OBSERVAÇÕES / REMARKS

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EFFECTS OF QUIET TIME PLASMASPHERIC ELECTRIC FIELDS ON ELECTRON AND PROTON PRECIPITATION

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ABSTRACT

The effect of the corotation and the quiet time ionospheric dynamo electric fields on the dynamics of energetic electrons and protons (with energies between 50 keV and 1 MeV), inside the inner magnetosphere, is investigated, using the concept of drift paths of constant effective potential. The quiet time ionospheric dynamo electric field is given by an analytic empirical model based on scatter radar observations. The corotation electric field and the earth's magnetic field are given by analytic expressions corresponding to a centered and an eccentric dipole models. The main conclusion is that the quiet time electric fields cause a diurnal modulation of the electron and proton precipitation. At low L-values the locus in longitude of the maximum precipitation is shown to be energy dependent.

INTRODUCTION

High energy particle precipitation in the earth's atmosphere has been largely studied. However, it was only recently that the influence of large scale global electric fields in the energetic particle precipitation has been investigated in more detail [Sheldon et al., 1985, 1987; Gelpi et al., 1986], although the importance of magnetospheric electric fields in the dynamics of energetic particles had already been pointed out many years ago [Hones, 1963].

As a consequence of the presence of electric fields the particles move changing their kinetic energy, L-value and equatorial pitch-angle. Although the fractional change in the kinetic energy and L-value may be small, the change in the mirror altitude can be large compared to the scale length of the atmospheric density [Sheldon et al, 1985]. Thus, the precipitation flux can also be largely altered due to the presence of electric fields.

Nevertheless, in the papers cited above, only the effect of the convection electric field on the electron precipitation was considered. The main result of those works was to show that the electron precipitation at the Siple Station, Antartic (L=4.1), as measured by sounding rockets, has a diurnal modulation at geomagnetically quiet times, in agreement with an electron drift trajectory calculation that predicts a diurnal modulation with a maximum on the nightside.

On the other hand, Pinto et al. [1987] studied the influence of the ionospheric dynamo electric field on the dynamics of low energy particles, between L-values of 1.5 and 4.5 and during quiet times, but only for equatorially-mirroring particles.

In the present work, an extension of the analysis performed by Pinto et al (1987), based on the concept of constant effective potential and assuming conservation of the first two adiabatic invariants, is done, considering the dynamics of non equatorial high energy particles between L-values from 1.1 up to 5. At lower L-values (L ≤ 1.5), an eccentric dipole model is assumed and the dynamo electric field is neglected, taking into account the larger values of the corotation electric field. This approach, besides preserving the main features related to the particle precipitation in the South Atlantic Magnetic Anomaly (SAMA) region [e.g. Torr et al., 1975; Pinto and Gonzalez, 1986], gives new insights on the space distribution of the precipitation in this region. At higher L-values (L ≥ 3), a centered dipole approximation for the geomagnetic field was adoptedand, both, the dynamo and the corotation electric fields were considered. At these L-values a diurnal modulation of the precipitation can be expected. At intermediate L-values, between 1.5 and 3, the dynamics of the energetic particles is basically a time-dependent problem, because both the asymmetry in the geomagnetic field and the local time dependence of the dynamo electric field needs to be considered. Therefore, at these L-values, the concept of constant effective potential can not be applied. Furthermore, a self-consistent treatment of the particle dynamic would need to incorporate a global dynamo electric field model that takes also into account the asymmetry of the geomagnetic field. At present, such model is not available. For this reason, the results obtained in this paper should be considered as not applicable for such intermediate L-values.

Finally, an attempt to compare the results obtained from our analysis with available observations of low and mid latitude particle precipitation is also undertaken.

FIELDS MODELS

- GEOMAGNETIC FIELD

For high L-values between approximately 3 and 5 (the upper limit is defined by limitations in the ionospheric dynamo electric field model, see below), a centered dipole model of the geomagnetic field has been used. On the other hand, at low L-values, the geomagnetic field is quite asymmetric. The main asymmetry occurs in a region located over the Atlantic ocean, the so-called South Atlantic Magnetic Anomaly (SAMA). In order to take into account this asymmetry, we adopted an eccentric dipole coordinate system displaced on the geographic equatorial plane approximately 469 km in the direction of 147^{o}E, corresponding to the 1985 IGRF model [Fraser-Smith, 1987]. This model maintains the main aspects necessary to our purposes, regardless of its simplicity.

- ELECTRIC FIELDS

The ionospheric dynamo electric field model for quiet times is obtained from incoherent scatter radar observations [Richmond, 1976]. This model is expressed in terms of an electrostatic potential, assumed to be representable by a finite series of spherical harmonic functions, symmetric about the equator (equation 3 in the Richmond paper) and considered valid up to $L \approx 5.6$.

The corotation electric field can be written as [Hones and Bergeson, 1965; Birmingham and Jones, 1968]:

$$E = -(\underset{\sim}{\Omega} \times \underset{\sim}{r}) \times \underset{\sim}{B} \qquad (1)$$

where $\underset{\sim}{\Omega}$ is the angular frequency of the earth's rotation, $\underset{\sim}{r}$ is the usual spherical polar coordinate and $\underset{\sim}{B}$ is the geomagnetic field. The electric field can also be expressed in term of a scalar potential symmetric with respect to the equator, which for the case of a centered dipole geomagnetic field is given approximately by 91.4 kV/L. At the low L-values, even though the eccentricity of the magnetic dipole should be considered, we can assume that the particles corotate rigidly with the earth [Hill, 1979; Vasyliunas, 1983]. In the nonrotating frame of reference, due to the fact that the magnetic field is not axissymmetric with respect to Ω, a $\partial B/\partial t$ will exist at every fixed spatial point. However, it can be shown [Birmingham and Northrop, 1979] that the corotation electric field can still be given by equation (1), if the eccentric magnetic dipole representation of B is used. This approximation can be seen as equivalent to neglecting the effects associated with $\partial B/\partial t$ (the effects can be considered as the second order when compared to the other ones, mainly for the energies considered here). Then, a potential can still be found from equation (1) by numeric integration (only terms up to the order of the first power in the eccentricity divided by the earth's radius were maintained). It is interesting to note that, if the corotating frame of reference is invoked, the corotation electric field and its associated drift are zero by definition, and then the drifts associated with the inertial centrifugal and Coriolis forces should be considered [Northrop and Birmingham, 1982; Northrop and Hill, 1983].

TRAJECTORY CALCULATION

Particle trajectories are computed numerically by assuming conservation of the first relativistic two adiabatic invariants and the constancy of the effective potential [Chen, 1970], given by

$$\Phi = \phi + \frac{\mu B}{q} \qquad (2)$$

where ϕ is the total electrostatic potential, q is the charge of the particle and μ is the relativistic first adiabatic invariant, given by

$$\mu = \gamma \mu_0 \qquad (3)$$

where γ is the Lorentz factor and μ_0 is the non-relativistic magnetic moment. The constancy of the two first adiabatic invariants can be expressed by the quantity [Roederer, 1970]

$$K = I\sqrt{B_m} \qquad (4)$$

where I is a geometric quantity, such that

$$I = \int_{Sm_1}^{Sm_2} \left(1 - \frac{B(s)}{B_m}\right)^{1/2} ds \qquad (5)$$

In equation (5) s is the distance along the magnetic field line and Sm_1, and Sm_2 are the limits of the integral, corresponding to the mirror points. The quantity I can be computed numerically by the approximation given by Schulz and Lanzerotti[1974].

RESULTS

The influence of corotation and quiet time ionospheric dynamo electric fields on the trajectories of protons and electrons is illustrated in Figure 1. This figure shows the variations of L-value, energy and mirror point altitude, as a function of local time, for protons and electrons having 100 keV of energy at L=3 and at a mirror point altitude of 100 km. Also shown are the curves corresponding to the case when only the magnetic field is considered. In this case, both protons and electrons drift around the earth mantaining the L-value, energy and mirror point altitude constants. Based on Figure 1, we can note that, due to the presence of the electric fields, the L-value, energy and mirror point altitude of the particles do not remain constants, the variations being considerably more pronounced for protons than for electrons. The variations are also energy dependent, having a tendency to disappear above 1 MeV. At these energies the influence of the electric fields can be totally neglected. From Figure 1, we can expect a local time dependence of the precipitation rate with a maximum around 12 LT for protons and 19 LT for electrons, these values being almost independent of the L-value considered. Below L=3 the mirror point altitude variations, due to the eccentricity of the magnetic dipole, can not be disregarded mainly for energies above 100 keV.

Figure 2 shows the variations of L-value, energy and mirror point altitude, as a function of geographic longitude, for protons and electrons having 100 keV of energy at L = 1.2 and at a mirror point altitude of 100 km. Also shown are the curves corresponding to the case when only the magnetic field is considered (similar to Figure 1). For this low L-values, the precipitation rate is strongly dependent of geographic longitude, having a maximum in the SAMA region. Based on the mirror point trajectories, we found that the location of the maximum precipitation rate seems to vary with the energy of the particle, being located west of the center of the SAMA region (this center is located at around 33°W for the magnetic field model considered here) for protons and east for electrons.

Figure 3 shows the locus of the maximum precipitation rate for protons and electrons between 50 keV and 1 MeV at L = 1.2, expected to occur only if the influence of the electric fields on the particles is considered (see below a discussion about other possible influences). Above 1 MeV, both protons and electrons have the maximum precipitation rate just at the center of the SAMA region.

DISCUSSION AND CONCLUSIONS

We have presented some computional results in terms of proton and electron trajectories under the influence of the corotation electric filed and quiet time ionospheric dynamo electric field, for energies between 50 keV and 1 MeV.

At high L-values (above L=3) the results indicate a possible diurnal modulation of the particle precipitation with a maximum around 12 LT for protons and around 19 LT for electrons. The location of maximum precipitation on the nightside for electrons is coincident with the results of Sheldon et al. [1985] and Gelpi et al. [1986] regarding the influence of the convection electric field on the electron precipitation at L = 4.1, during a moderate activity period. This coincidence should be interpreted as being due to the predominance of the dawn-dusk direction of the dynamo electric field at these L-values [Matsushita, 1971; Richmond et al., 1980]. In addition, the results indicate that we should expect a larger diurnal modulation of the proton precipitation than of the electron precipitation.

At this point, it is worth reporting that there has been some controversy concerning the relative importance of the ionospheric dynamo and solar wind convection fields within the middle magnetospheric regions [Baumjohann et al., 1985; Barbosa, 1985]. In particular, Baumjohann et al. [1985] have showed that at L = 6.6 the ionospheric dynamo field tends to be dominant during very quiet conditions (Kp = 0-1), whereas for moderate activity (Kp = 3-4) the convection field dominates. For intermediary values of Kp, both fields seem to be important. Going to low L values inside the plasmasphere, the region of interest to this work (L ≤ 5), this behaviour not only should remain valid, but also should be intensified. Thus, at least during quiet times (here defined as those intervals which Kp ≤ 2 [Richmond et al. [1980]) and inside the plasmasphere the electric field is predominantly ionospheric dynamo in origin [Rash et al., 1986]. Some small perturbations that could exist at low L values in association with the convection field (that may, alternatively, be explained by a refined dynamo model) would already be incorporated in the empirical model of Richmond [1976]. The same may not be true for the results of Sheldon et al. [1985], taken during a moderate activity period (Kp = 2-4).

At intermediate L-values (between approximately 1.5 and 3) the influences of the asymmetry of the geomagnetic field and of the local time dependence of the ionospheric dynamo electric field should be considered. These influences could probably lead to a precipitation rate without a clear local time or longitude dependence.

At low L-values (below L=1.5) the precipitation rate is strongly dependent on the geographic longitude, as a consequence of the asymmetry of the geomagnetic field, having a maximum in the SAMA region. However, the location of this maximum is energy dependent, occurring west of the center of the SAMA region for protons and east for electrons.

The comparison of the above results with particle observations appears to be very difficult (for a review see Pinto and Gonzalez [1988]). In general, the difficults are associated with incomplete local time or longitude informations [Imhof, 1968; Vampola and Gorney, 1983], poor energy resolution [Imhof et al., 1980; Nagata et al., 1987] or poor pitch-angle resolution [Armstrong, 1965] in the observations. For protons between 50 keV and 1 MeV, these difficulties are even worse due to fairly few observations available in this energy range (one example is that given by Mihalov and White [1966]).

Clearly, quiet time low and middle tlatitude particle precipitation depends not only on global magnetic and electric fields, but also on pitch-angle diffusion processes related to wave-particle interactions [Schulz and Lanzerotti, 1974] or Coulomb scattering interactions between particles and neutral atmospheric constituents [Roederer et al., 1967]. In turn, these processes can have a particular longitude or local time dependence in such a way that they can dominate the dependence associated with the electric fields. In this sense, the understanding of the influence of the quiet time electric fields on the particle precipitation can help us to identify pitch-angle diffusion processes related to precipitation, as well as to test those already known.

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FIGURE CAPTIONS

FIGURE 1 - Variation of L-value, energy and mirror point altitude as a function of local time for protons and electrons having 100 keV of energy at L equal to 3 and at mirror point altitude of 100 km. Also shown are the curves corresponding to the case when only the magnetic field is considered.

FIGURE 2 - As for Figure 1, for protons and electrons having 100 keV of energy at L equal to 1.2 and at mirror point altitude of 100 km.

FIGURE 3 - Locus of maximum precipitation rate for protons and electrons between 50 keV and 1 MeV at L=1.2 (see text for details).

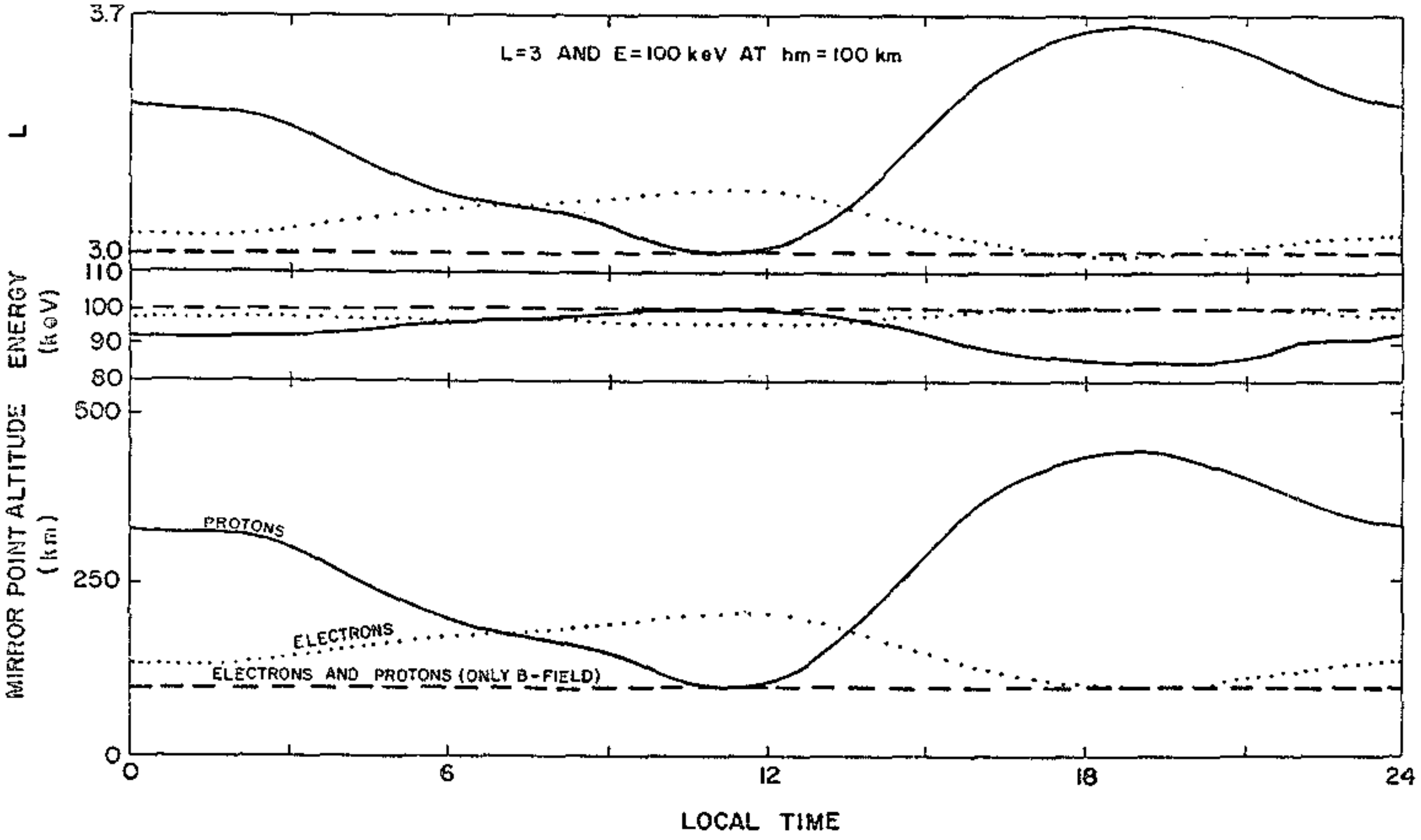
L=3 AND E=100 keV AT hm=100 km
L
3.7
3.0
ENERGY (keV)
110
100
90
80
MIRROR POINT ALTITUDE (km)
500
250
0
PROTONS
ELECTRONS
ELECTRONS AND PROTONS (ONLY B-FIELD)
0
6
12
18
24
LOCAL TIME

Fig. 1

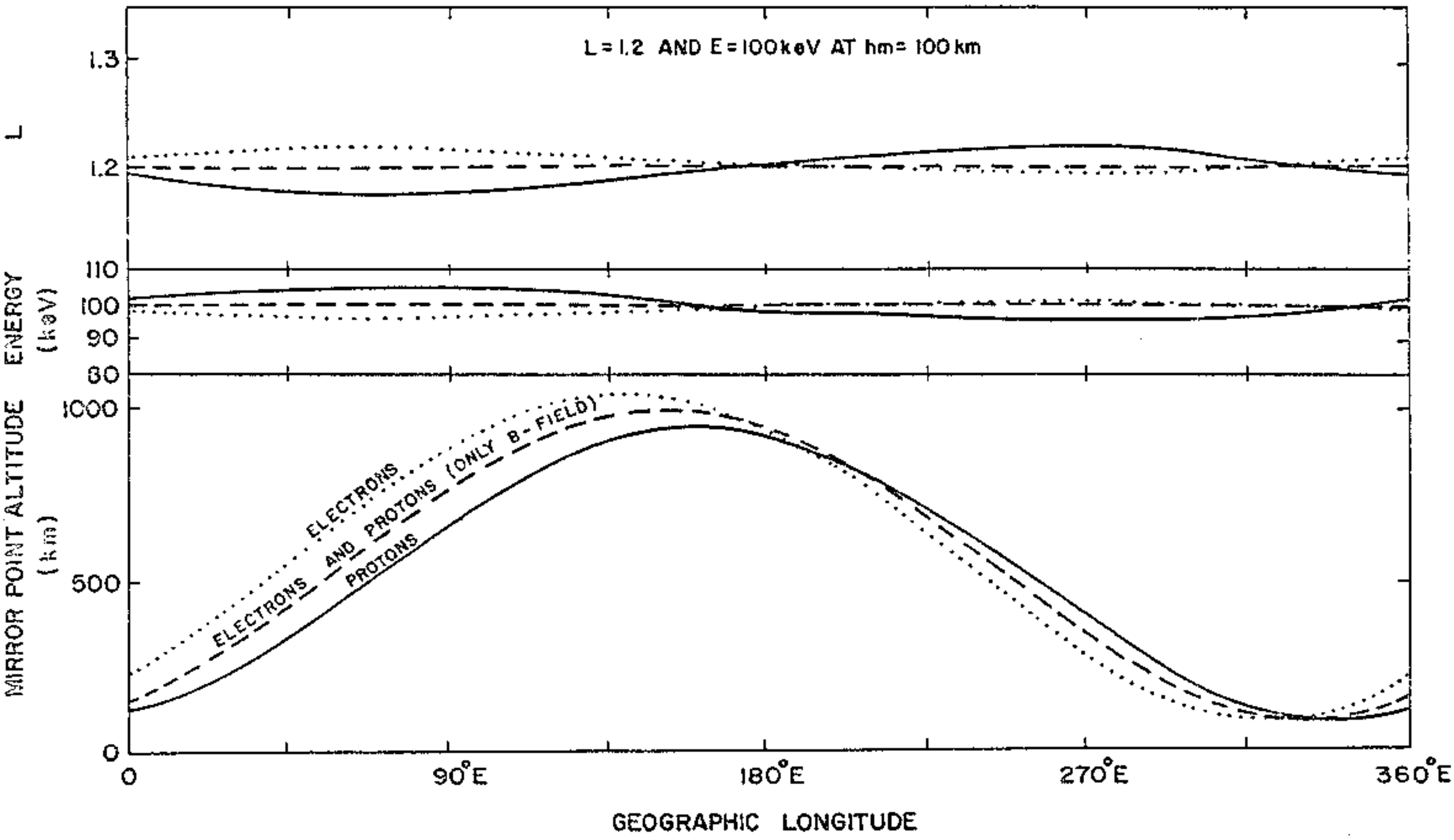
L = 1.2 AND E = 100 keV AT hm = 100 km
L
1.3
1.2
110
ENERGY (keV)
100
90
80
MIRROR POINT ALTITUDE (km)
1000
500
0
ELECTRONS
ELECTRONS AND PROTONS (ONLY B-FIELD)
PROTONS
0
90°E
180°E
270°E
360°E
GEOGRAPHIC LONGITUDE

Fig. 2

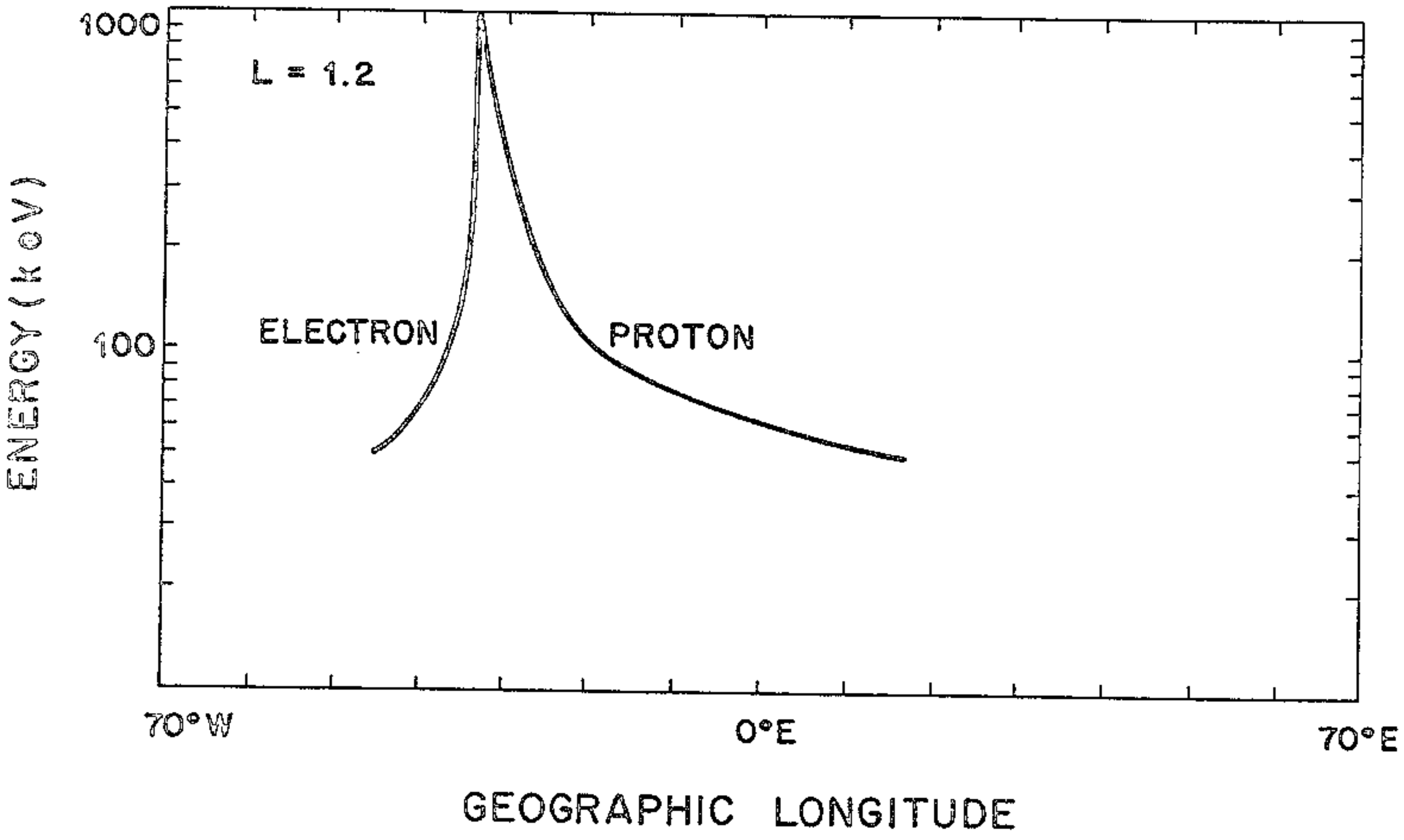
1000
100
L = 1.2
ENERGY (keV)
ELECTRON
PROTON
70° W
0°E
70°E
GEOGRAPHIC LONGITUDE

Fig. 3

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