

Introduction to Planetary Electrodynamics: a view of electric fields and currents .

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Motivation & Objectives

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- To help to obtain a comprehensive and integrated view of the electric fields and currents in the planetary electrodynamics.
- **Importance**
Electric fields and currents are connected to magnetic disturbances. These three features are associated to or rule important processes in bodies with atmosphere from the solar system.

Summary

- Introduction
- Sun-Earth magnetic coupling
- Electric fields
- Electric currents
- Electronic and biological effects
- Final remarks

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- Along the centuries experiments on the Earth surface give us a good, although not complete, comprehension of the Earth and its atmosphere.
- To extend this understanding, the increase in satellites exploring the Sun and the interplanetary space surrounding the planets has revealed the physical processes occurring in a wide range associated with the Sun–planet coupling.

Introduction (cont.)

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- Instruments onboard Ulysses spacecraft are constantly measuring the characteristics of the interplanetary plasma as well as its chemical composition
- Besides this hot space plasma, the interplanetary medium also contains microscopic dust particles and magnetic fields primarily from the Sun.

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- Besides its effects on the bodies of solar system, the Sun is the primary agent to natural processes in the Earth and also sustain the life in the litosphere.
- A short review on the solar physics, interplanetary magnetic field and sun-planet electrodynamical coupling is presented in this next section.

Space environment

The Sun

- The Sun is a common star like many others in the universe.
 - ◆ distance from the galactic center: 3×10^{16} km
 - ◆ angular speed about galactic center: 200km/s
 - ◆ gaseous mass (2×10^{33} g) = 743 times heavier than the total planetary mass
 - ◆ average radius = 7×10^{10} cm

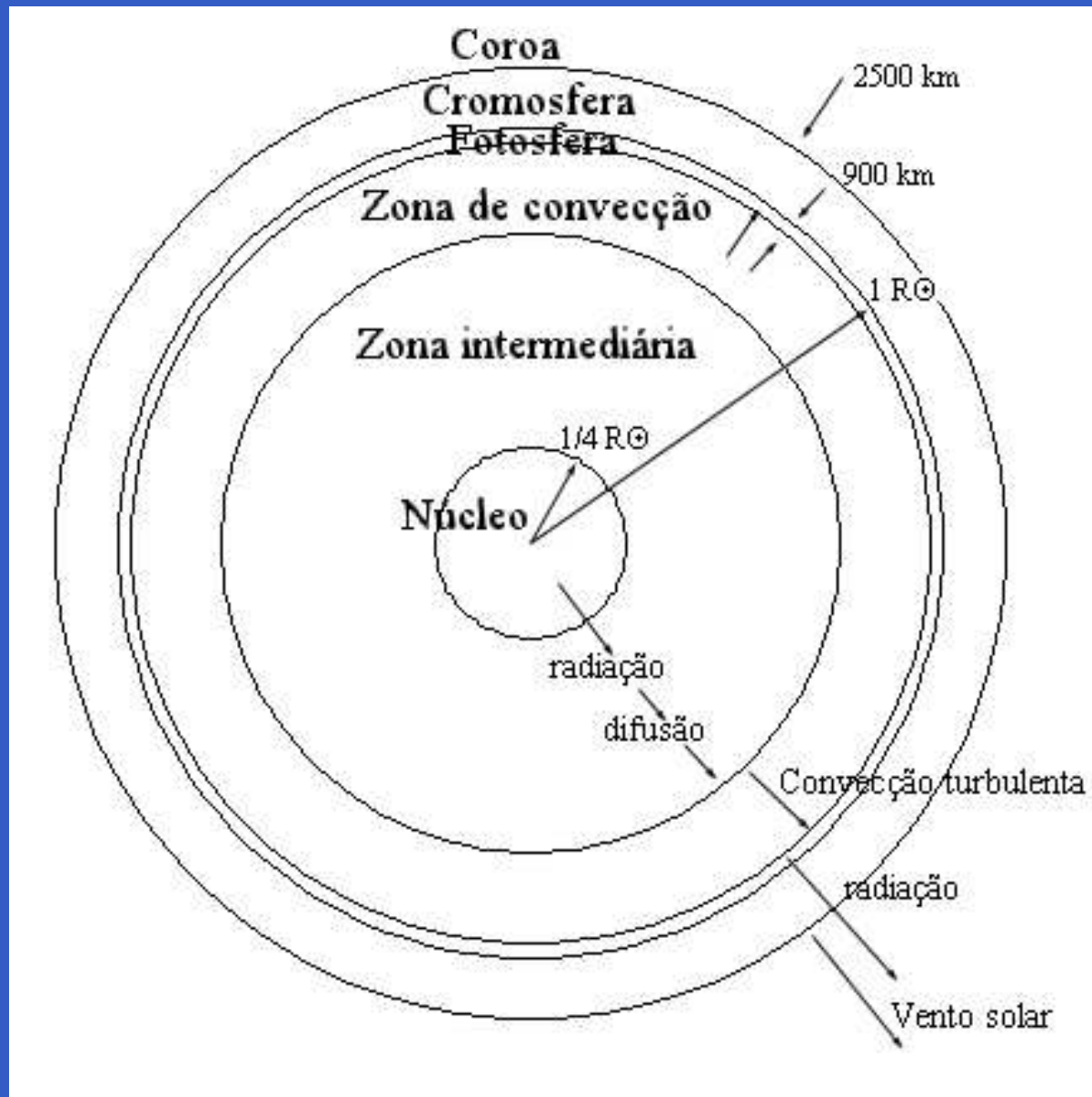
The Sun (cont.)

- The surface of the Sun rotates with an angular speed which depends on the colatitude, in a model profile:
$$\omega \approx 3 \times 10^6 (1 - 0.2 \cos^2 \theta) \text{ rad/s}$$
- Inversion polarity cycle: ≈ 22 years
- The nuclear reactions occur in the interior of Sun, in which the temperature is about 10^7 K and the pressure is about 10^{11} earth atmospheres.

There are 2 models for the Sun:

- **Quiet Sun** — in which Sun as considered as concentric spheres. The properties change only with the radial distance.
- **Active Sun** — in which there are transient energetic processes in localized regions of the sun. The causes are primarily the intense magnetic field and the differential rotation.

Sun Layers



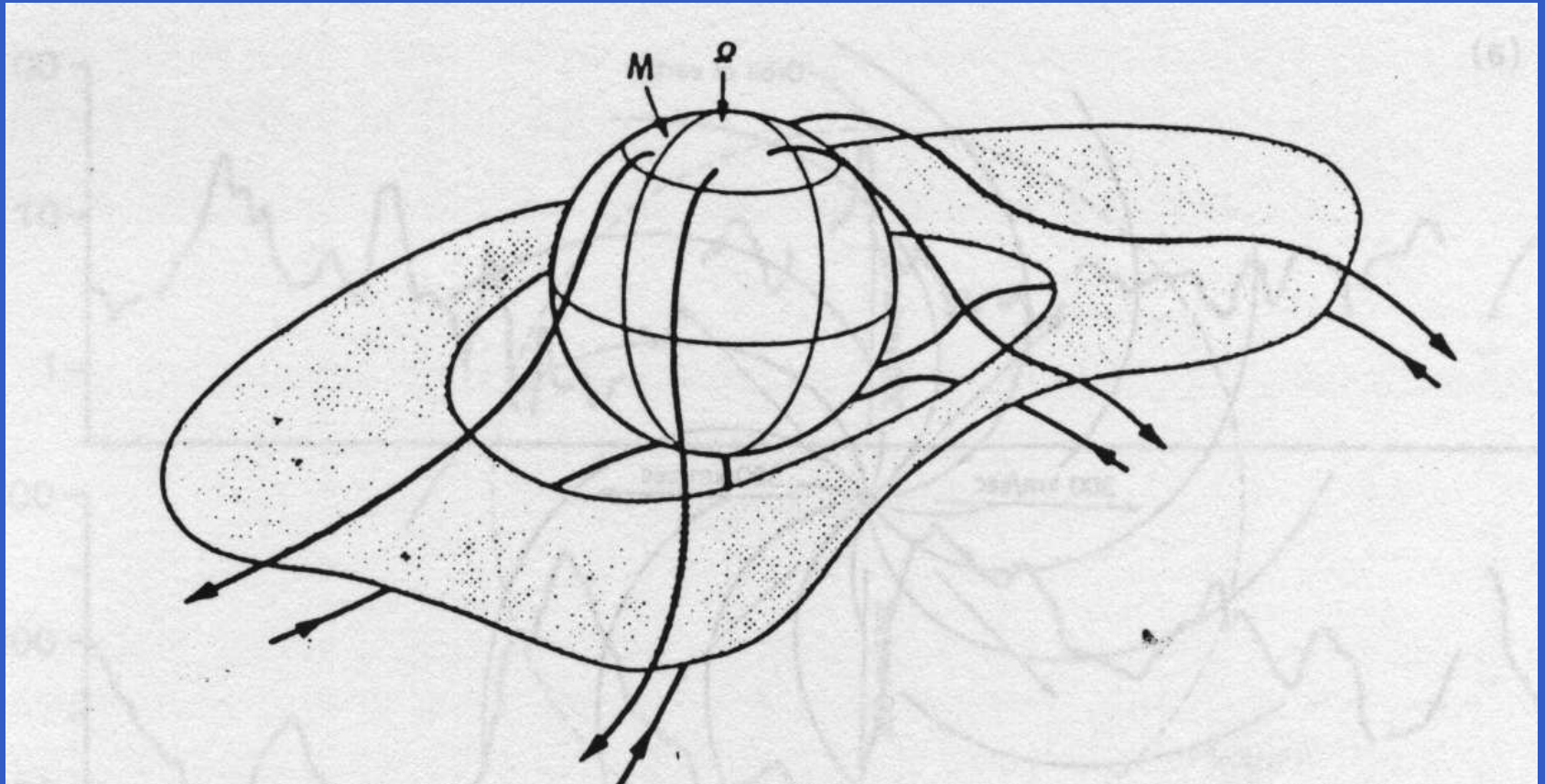
Solar wind and the interplanetary medium

- The outermost region of the Sun's corona, is indeed very hot, so hot that the hydrogen and helium can escape from the gravitational attraction and form a steadily streaming outflow of material called the solar wind. Because of its high temperature, the solar wind is fully ionized plasma.
- Furthermore, because of the heating, compression, and subsequent expansion, the solar wind becomes supersonic above a few solar radii.

Solar wind and the interplanetary medium

- The solar wind plasma consists primarily of hot electrons and protons with a minor fraction of He^{2+} ions and some other heavier ions (typically at high charge states).
- The expanding solar wind drags also the solar magnetic field outward, forming what is called the interplanetary magnetic field (IMF).
- Although the solar wind moves out almost radially from the Sun, its rotation gives the magnetic field a spiral form (garden hose effect).

Solar wind and the interplanetary medium

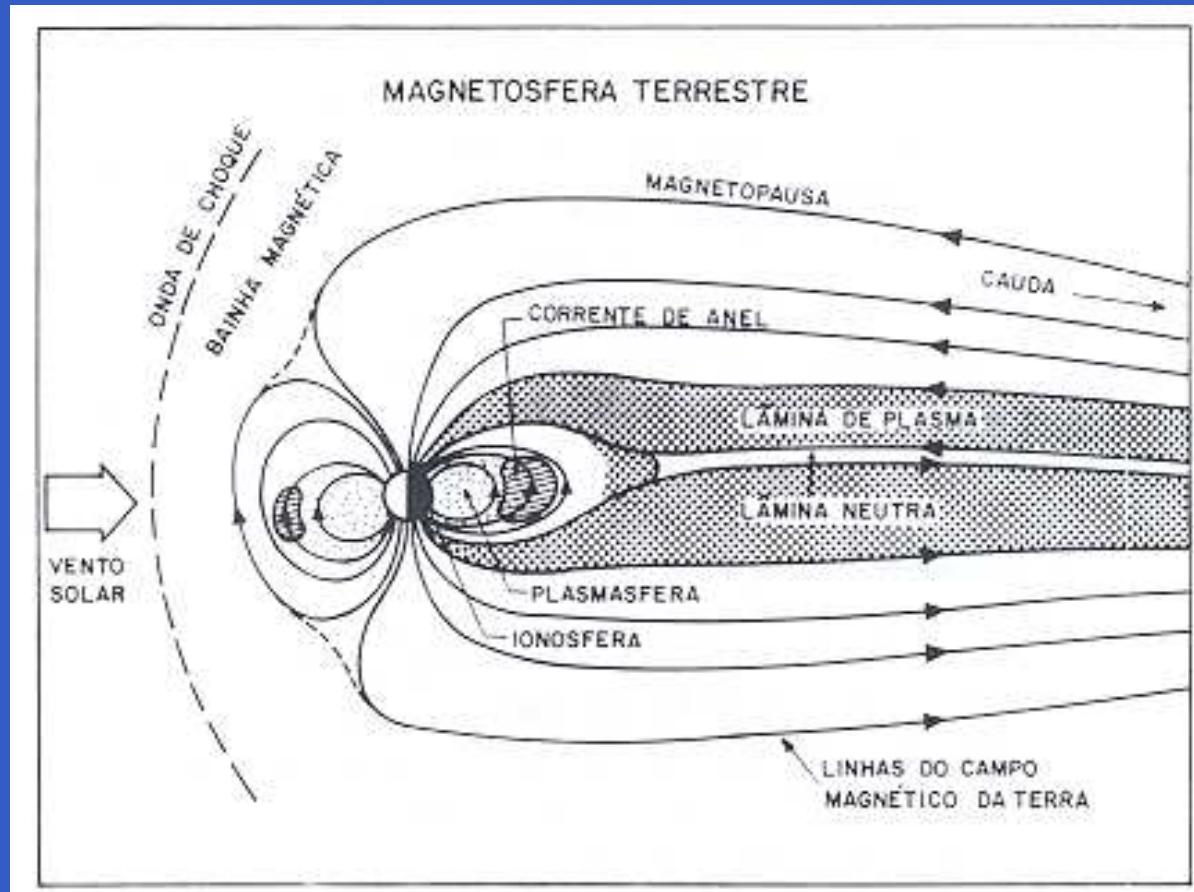


Solar wind and the interplanetary medium

- The solar wind originating from the streamers (closed field lines) is slow, while that originating from the coronal holes is fast. This creates the so-called "corotating interaction regions"(CIR) in the interplanetary space.
- As the solar wind moves away from the sun, tangential discontinuities and interplanetary fast shocks are formed, creating pressure variations.
- Besides electromagnetic radiation, some aspects of the IMF allow solar wind to interact with the Earth's atmosphere.

Sun–Earth magnetic coupling

The "frozen-in" IMF carried by solar wind interacts with the



- All planets and comets explored to date have magnetospheres. For the planets that have no internal magnetic dynamo the solar wind induces a magnetosphere through its interaction with the upper atmosphere and ionosphere.

- Also of great interest are the various phenomena such as magnetic reconnection that have no analogues in ordinary gases.
- These processes are also of importance to astrophysicists and plasma fusion physicists.
- In the former case, the planetary magnetospheres provide in-situ data for processes that may occur on a higher scale elsewhere.

Electric fields

Electric structure of the Earth's environment

- Interplanetary electric field
- Solar wind is basically a "frozen-in" magnetic field plasma.
- An observer in a relative movement to such plasma will feel the following field:

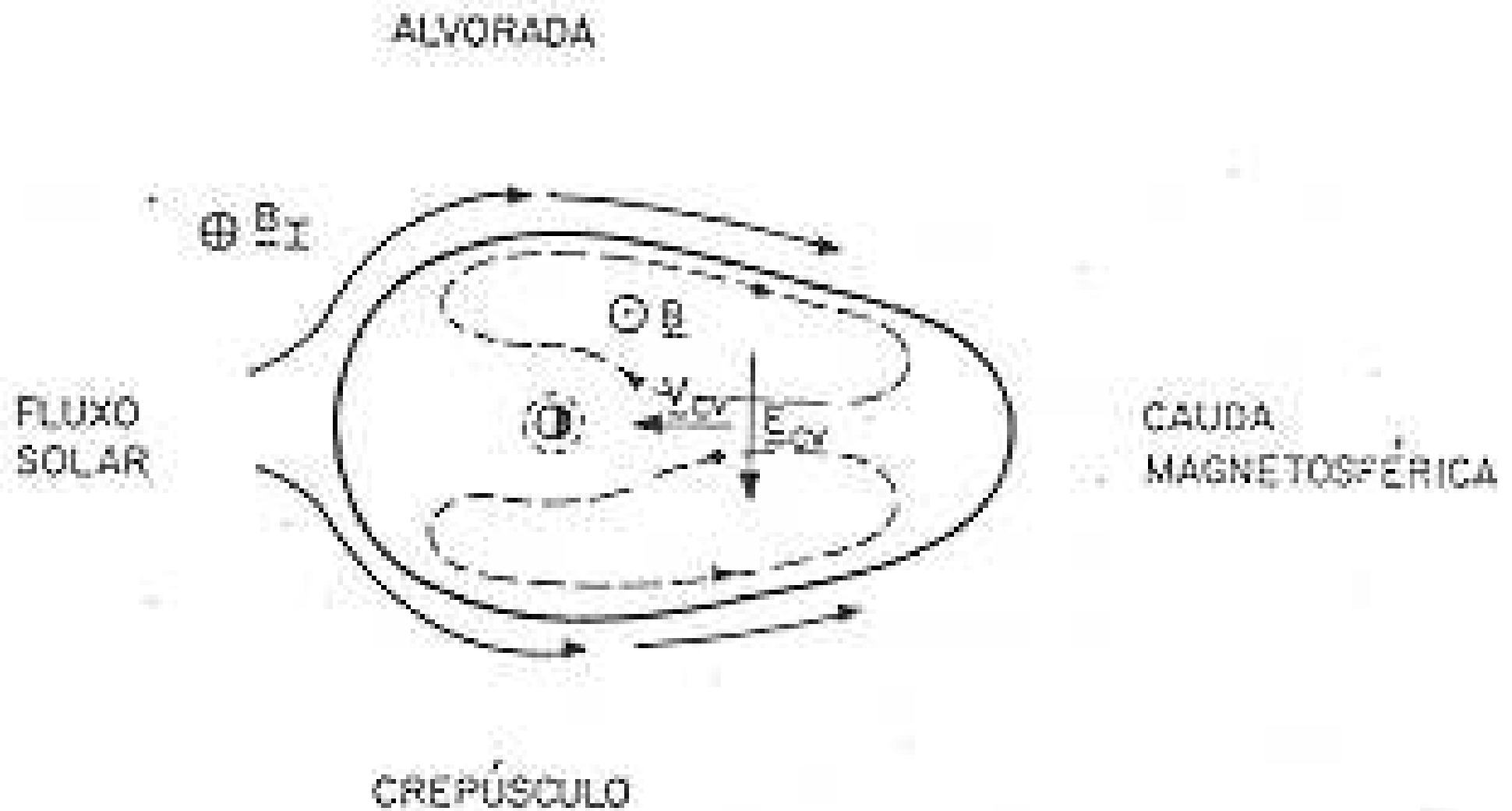
$$\vec{E} = \vec{V} \otimes \vec{B}_h,$$

- ◆ \vec{V} is the observer relative velocity to the plasma;
- ◆ \vec{B}_h is the magnetic induction field of the heliosphere

Convection electric field

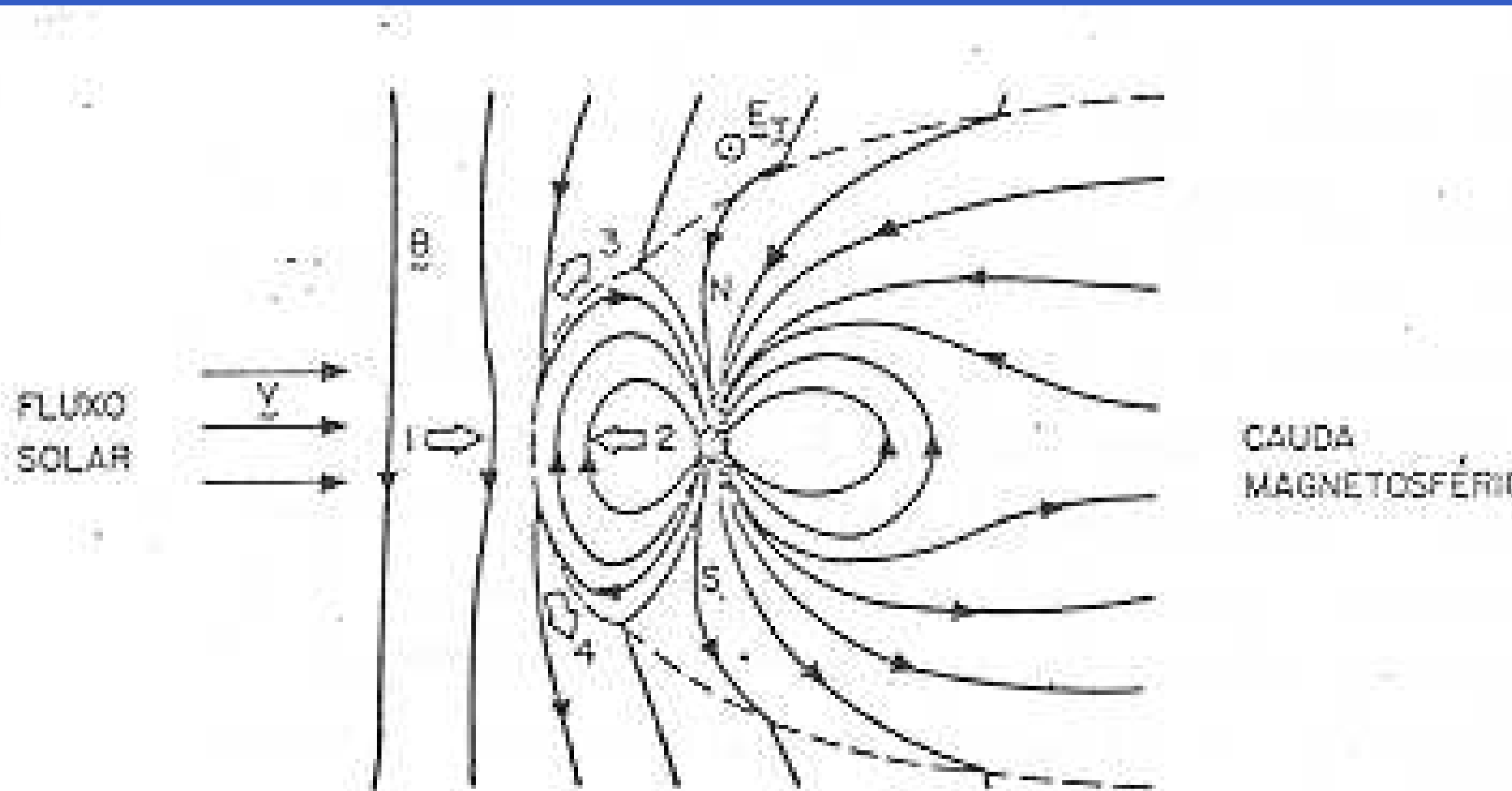
- Quasi static and large scale electric fields.
 - ◆ Magnetospheric plasma viscous drag generates a plasma flux in the tail:

$$\vec{E}_{cv} = -\vec{V}_{cv} \otimes \vec{B}_i.$$



- Magnetospheric reconnection allows the interplanetary electric field inside the magnetosphere

$$\vec{E}_i = -\vec{V}_s \otimes \vec{B}_i.$$



Polarization electric field

- As the plasma in the tail gets closer the Earth, it gains energy because the strength of the geomagnetic field is increasing. The drift due to the B gradient affects the movement of the electric charges, separating the negative from the positive charges. This results in a dusk-dawn electric field which shields the plasmasphere from the convection electric field.

Time-varying electric fields

The effect of a slowly varying electric field on a charged particle drift is the addition of polarization drift velocity, $v = m(dE(\perp)/dt)/(qB^2)$. Since this drift is in opposite direction for charges of opposite sign, a net polarization current is produced.

Penetration electric field

This field results from the unbalance of the convection electric field and of the polarization electric field.

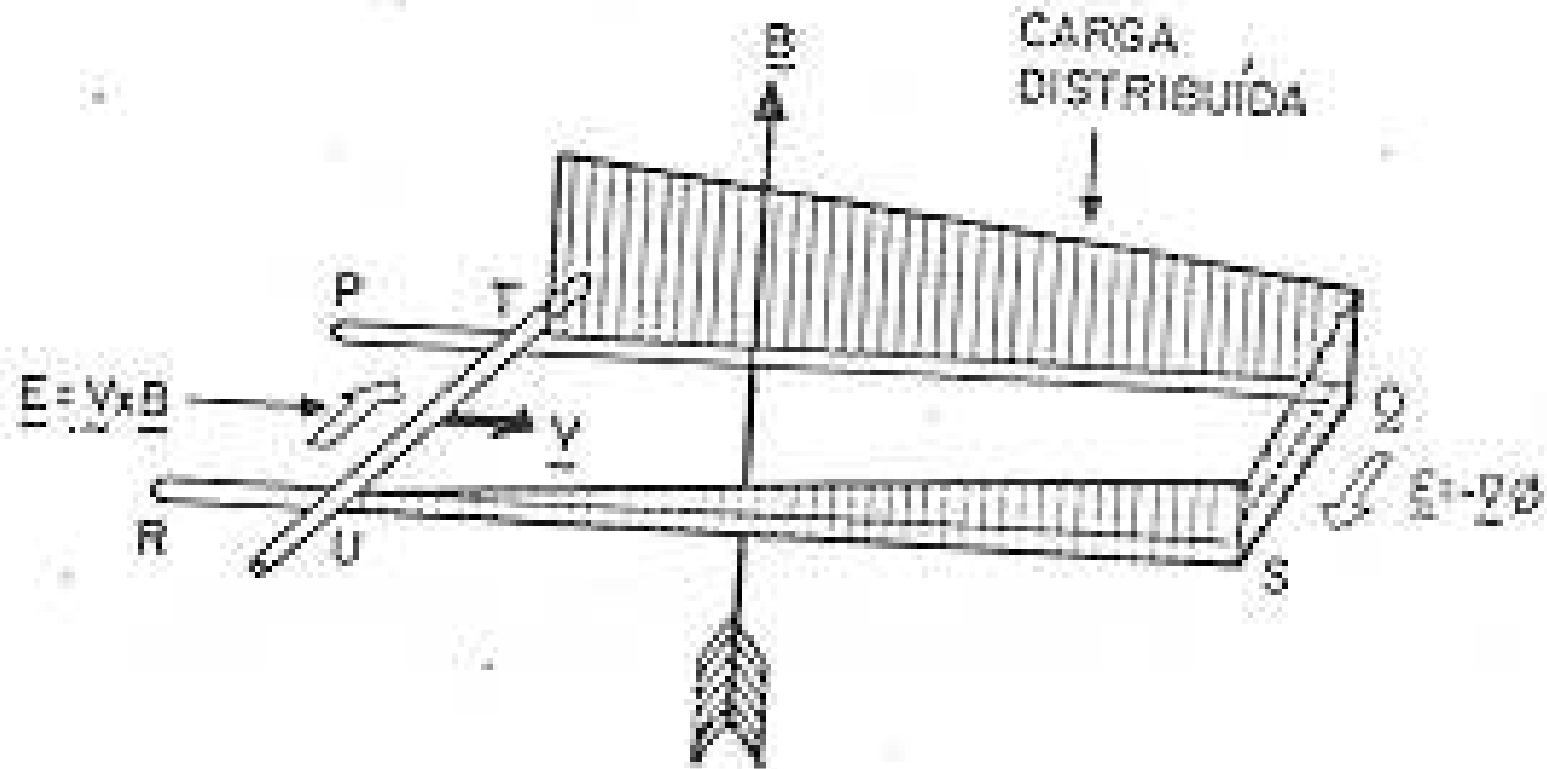
Co-rotation electric field

Assuming that the ionosphere is equally conductive, strongly coupled to the atmosphere and surrounded by a conducting plasma, the total configuration of the geomagnetic field would tend to rotate rigidly with the Earth. This implies in a co-rotation electric field:

$$\vec{E}_c = -\omega_t R B \cos(\lambda) \hat{R},$$

Ionospheric dynamo electric field (quiet and disturbed)

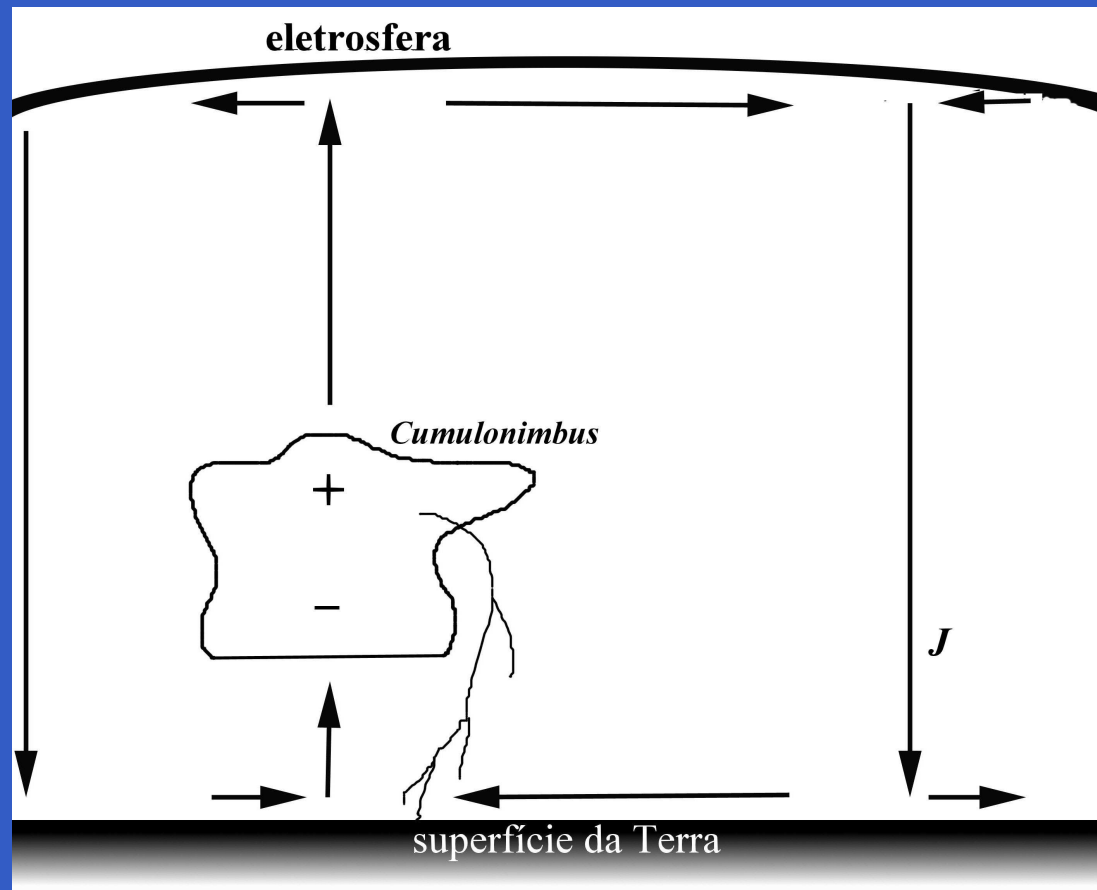
The ionospheric dynamo results from the Sun and Moon influences in the Earth's atmosphere. The forces generated by these bodies originate neutral air movements, in the horizontal direction, dragging the ionized material through the geomagnetic field. The dynamo region varies from 90 a 150km altitude and the electric field is of about 1 mV/m. The relative intensity of this field is of $\| E_{\text{lunar}} \| \approx 5\%$ of $\| E_{\text{solar}} \|$. Magnetically disturbed periods in which the thermospheric winds are disturbed by auroral heating present more intense values of E .



Low atmosphere electric field

In the lower atmosphere (altitudes $\mathcal{H} \lesssim 70$ km) there is a vertical downwards quasi-stationary electric field, that occurs in regions of fair weather conditions. The potential difference between the electrosphere and the Earth's surface is about 300 kV. The electric current density is of about $-2 \times 10^{-12} \text{ A/m}^2$ and the electric field vertical component is the order of -100 V/m . Thunderstorms are responsible to keep this potential differences.

An electric field, is not only able to energize particles, it can also help them move from one field line to another, e.g. enter regions of magnetic trapping or escape from them.



Electric currents

- Earth's Magnetosphere, can be regarded as typical magnetosphere because it is in the middle of the range of properties found in solar system. In it several current systems can be identified.
- Upon the magnetopause flows a large current vortex which separates the magnetic field of the Earth and the solar wind.
- Behind the Earth are the two lobes of the magnetic tail. There, magnetic field lines enter and leave the Earth in oval shaped regions known as the polar caps.

Electric currents

- Between the two tail lobes flows the neutral sheet current which is part of the magnetopause current vortex and also the plasma sheet a hotter and denser plasma than in the surrounding regions.
- The east to west directed ring current in the Earth's magnetosphere is created by the combined curvature and gradient drift.

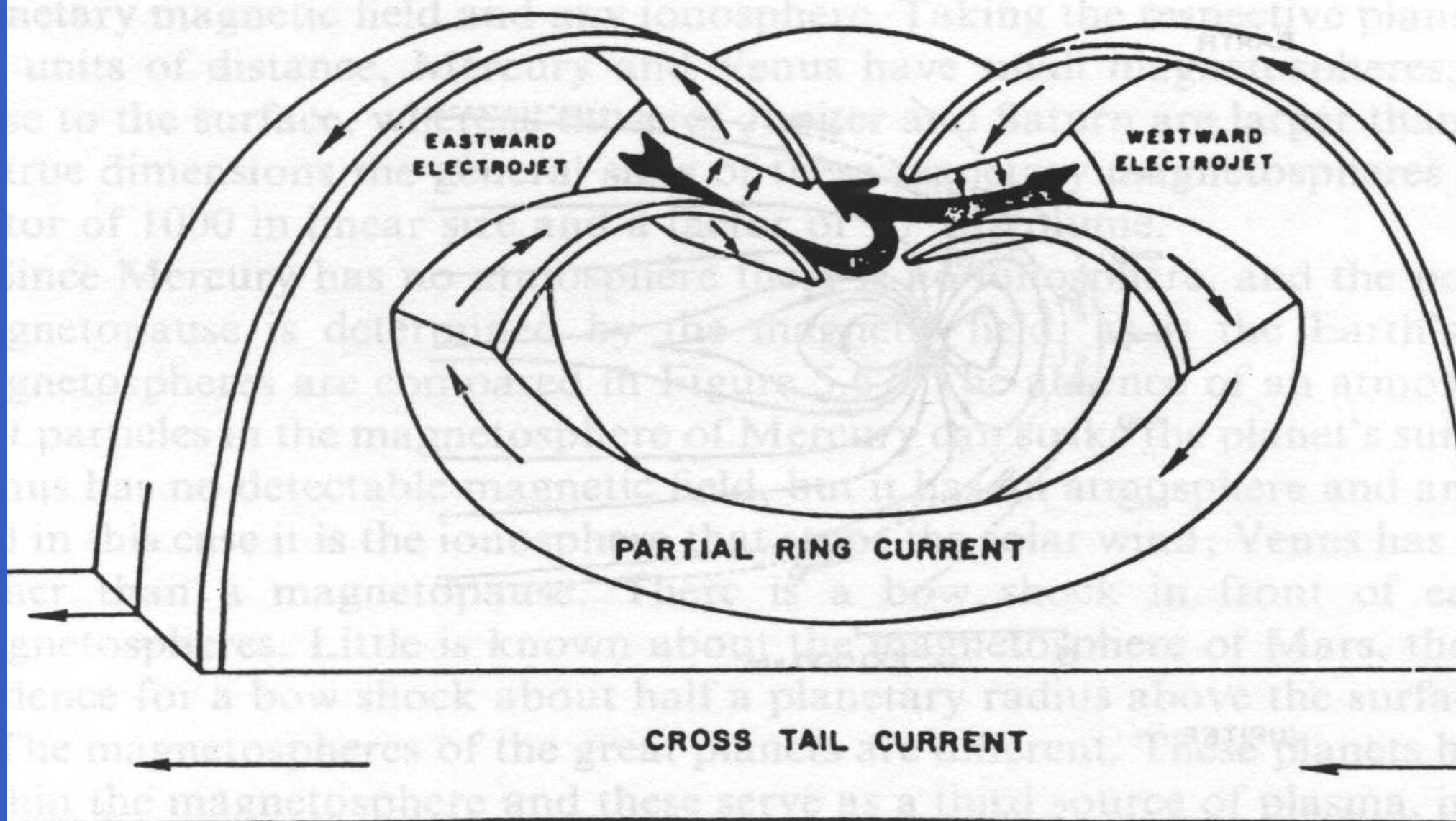
Auroral electrojet

- Is the large horizontal currents that flow in the D and E regions of the auroral ionosphere. Although horizontal ionospheric currents can be expected to flow at any latitude where horizontal ionospheric electric fields are present, the auroral electrojet currents are remarkable for their strength and persistence.
- There are two main factors in the production of the electrojet.
 - ◆ the conductivity of the auroral ionosphere is generally larger than that at lower latitudes.
 - ◆ the horizontal electric field in the auroral ionosphere is also larger than that at lower latitudes.

- Since the strength of the current flow is directly proportional to the vector product of the conductivity and the horizontal electric field, the auroral electrojet currents are generally larger compared to those at lower latitudes.
- During magnetically quiet periods, the electrojet is generally confined to the auroral oval. However during disturbed periods, the electrojet increases in strength and expands to both higher and lower latitudes. This expansion results from two factors, enhanced particle precipitation and enhanced ionospheric electric fields.

Polar Ionospheric Magnetospheric Current Systems

- Field-aligned currents- FAC
- If one pushes or pulls on the outer parts of the magnetosphere, one would expect the stresses created by that action to affect the plasma in the Earth's ionosphere for the ionosphere is where the magnetosphere is coupled to the Earth. The magnetosphere communicates this stress through field-aligned currents.



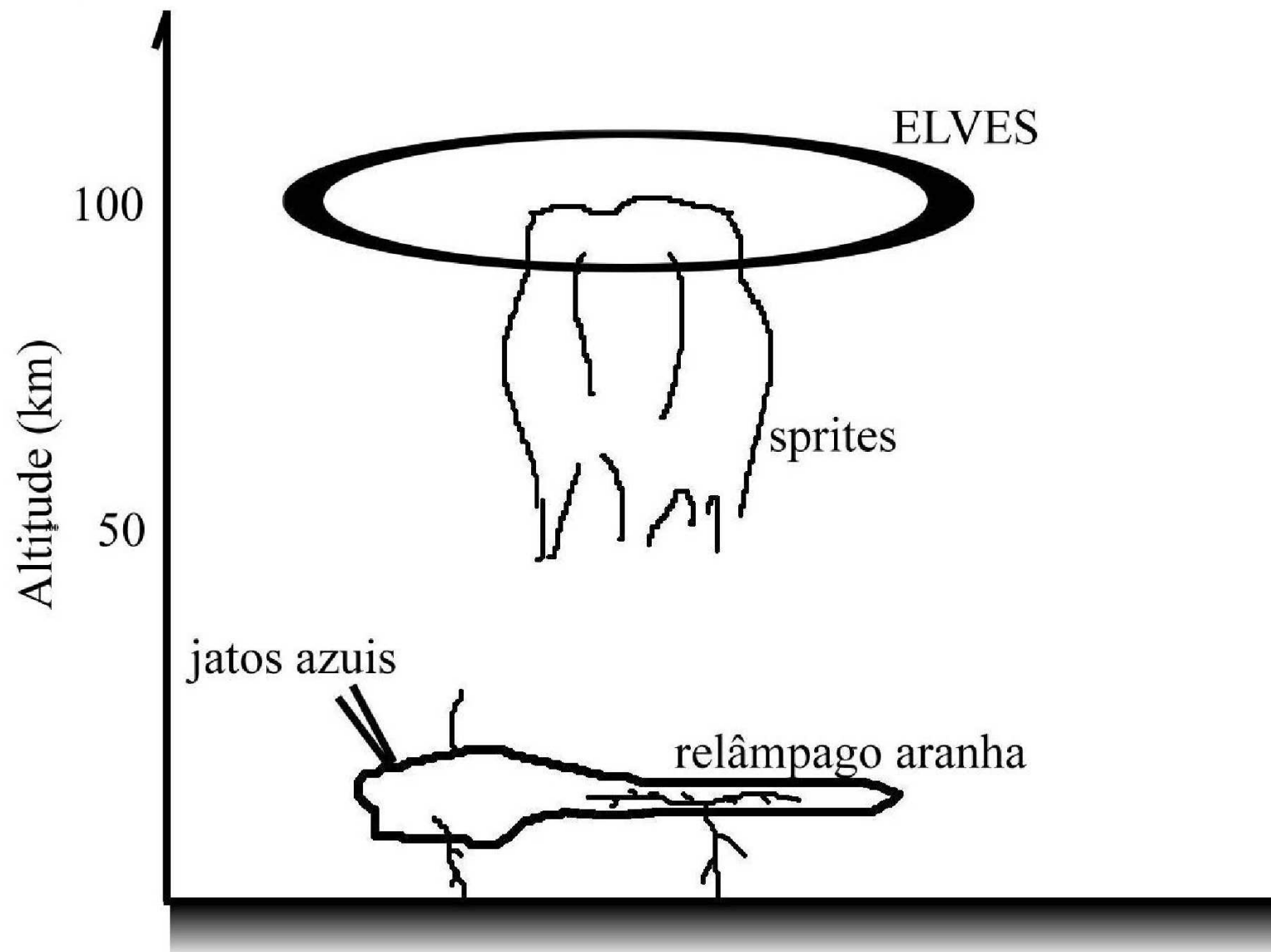
Equatorial Electrojet

- The Equatorial Electrojet (EEJ) represents an enhancement of the diurnal variation in the geomagnetic field near the dip equator. The largest amplitude is found in the American sector where the Cowling conductivity attains its maximum value. The width of the electrojet at satellite height also seems to show a maximum in the South American sector.

Atmospheric discharges

- Lightning flashes are neutralization mechanisms of charges stored by the thermodynamical processes in the troposphere.
- Transients luminous phenomena connects the low atmosphere electrification with the medium to high atmosphere, for exemple *sprites*, *blue jets*, *elves*, *sprite halos*, *trolls* and *gamma-ray bursts*.
- Numerical simulation of lightnings can be done for instance, using the equations below

$$\frac{1}{T_c} \nabla^2 \phi - \frac{\sigma}{\epsilon_0} \left(\nabla^2 \phi + 2K \frac{\partial \phi}{\partial z} \right) = \frac{1}{\epsilon_0} \nabla \cdot J_s,$$



Electronic and biological effects

Electronic and biological effects

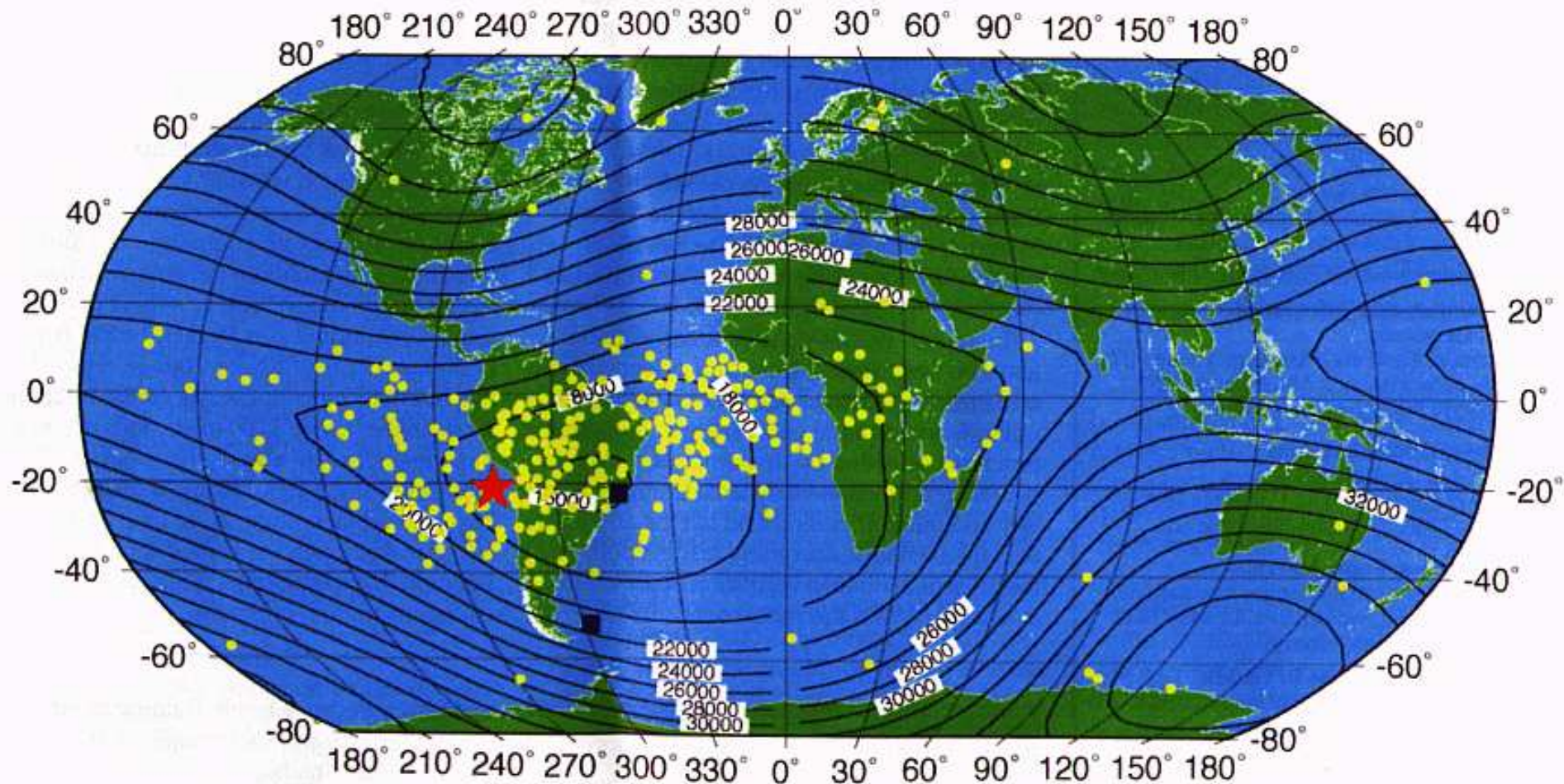
- The most important aspect of the Earth is that it behaves as an enormous magnet.
- In first order the magnetic field created by this magnet is that of a dipole whose axis is tilted with respect to the spin axis by about 11 degrees.
- The Earth has at its center a dense liquid core - molten iron, perhaps mixed with nickel and sulfur, of about $\frac{1}{2}$ the radius of the Earth—and inside that, a solid inner core. This core rotates faster than the Earth itself (one revolution every 400 years).

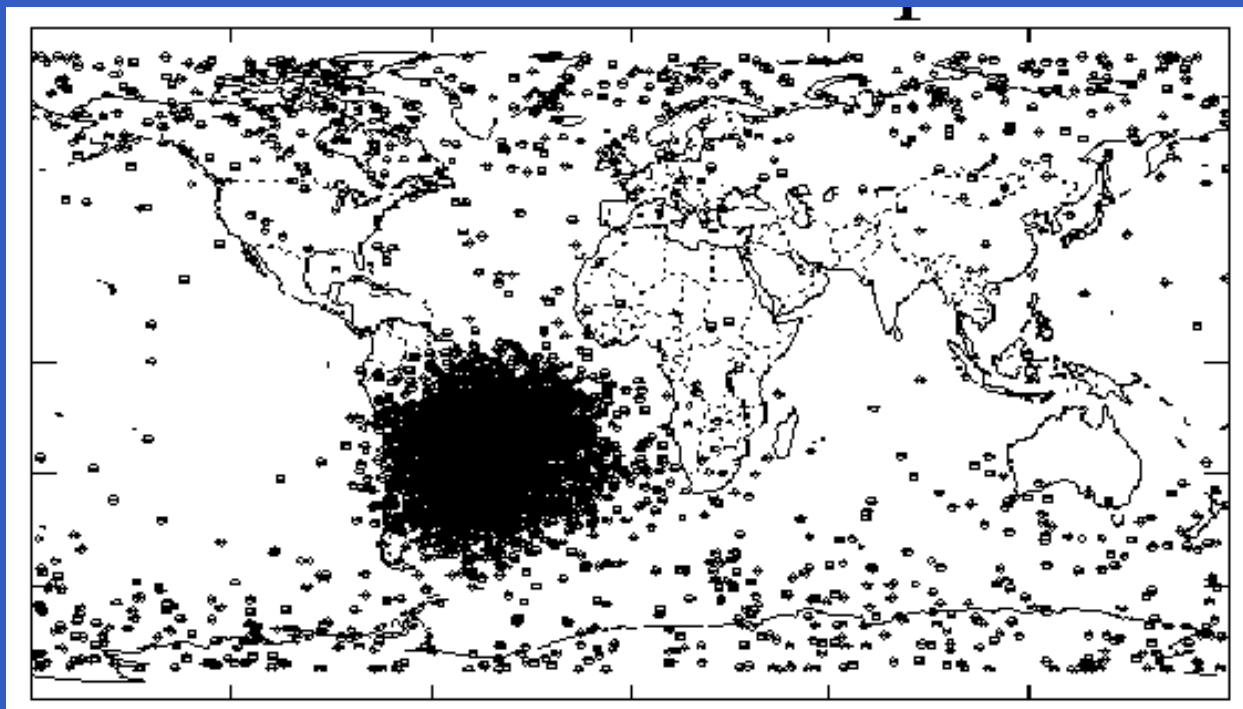
Electronic and biological effects (cont.)

- The trapped particles surrounding the Earth are affected by variations on the electric field, currents and consequently magnetic disturbances.
- As the geomagnetic field presents an anomaly above the South Atlantic, this region can be considered as a pseudo-auroral region.
- The effects of geomagnetic disturbances are not restricted to the regions well above the surface of the Earth.
- Power blackouts have been caused by the intense voltage surges induced in long distance power distribution systems.

Electronic and biological effects (cont.)

- Communication disruptions have been produced as the effects of these disturbances alter the properties of the ionosphere.
- As we are establishing a style of life based on sophisticated spacecraft, the health of these spacecraft are affected by that environment.
- Nowadays several studies have considered the effects of Space Environment on alive beings.





Final remarks

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