Spectral features of F-region plasma irregularities as observed by rocket- borne electron density probes from Brazil

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Abstract

The height variation of the ionospheric electron density was measured with rocket-borne electron density probes from Alcantara (2.31^{o}S; 35.2^{o}W) in Brazil. A Black Brant X sounding rocket was launched on 14-th October 1994 at 1955hrs (LT) to investigate the phenomenon of high-altitude equatorial spread-F events. Ground equipments were operated during the campaign to ensure that the rocket was launched under conditions favorable for the generation of plasma bubbles in the F-region. The electron density was measured by three different types of probes. A High Frequency Capacitance probe (HFC) gave density data with low height resolution, while a conventional Langmuir Probe (LP) and a Plasma Frequency Probe (PFP) measured the electron density and the spatial fluctuations in it. The k-spectra of the plasma irregularities were obtained by the spectral analysis of the electron density fluctuation data. An important feature observed was the continuous presence of plasma irregularities of a large range of vertical scale sizes in the altitude range of 340km to 817km. The electron number density varied considerably in these spatial structures, for example a decrease by a factor of 2.6 in a vertical extension of 1km near the altitude of 497km. Near 535km altitude the electron density increased by a factor of 1.8 within a height range of 2.7km. Density structures of vertical scale sizes in the range of hundreds of meters also were observed superposed on the large scale structures. During the rocket upleg two height regions of intense irregularities were observed, one between 366 and 480km and the other between 684 and 812km. The Langmuir Probe (LP) could make measurements of irregularities of vertical scale sizes more than 8m in these height ranges, while the Plasma Frequency Probe, could make measurements of irregularities of vertical scale sizes as small as 0.5m. Spectral features of these irregularities as observed by the two plasma probes at different height regions are presented and discussed here.

Introduction

Electron density irregularities present in the ionosphere manifest themselves in different forms at different heights and times. Sporadic-E, spread-F, radio star scintillations and VHF radar echoes are a few of such phenomena, familiar to ionospheric physicists. Basic knowledge of the plasma irregularities, responsible for these phenomena, has progressed considerably, both in theory and observations, since the discovery of the strong VHF radar echoes from the equatorial ionosphere (Bowles et al 1960, 1963). Balsley(1969), from their spectral characteristics as observed by the VHF radar, classified the plasma irregularities into two groups, namely Type I and Type II. While the Type I irregularities are now identified to be consistent with the two-stream instability mechanism (Farley, 1963; Sato, 1972), the Type II irregularities are known to be produced by the nonlinear cross-field instability mechanism (Rogister and d'Angelo, 1970, 1972; Balsley and Farley, 1973). Direct observations by Prakash et al (1970, 1971a,b) using rocket-borne Langmuir probes flown from India, confirm the existence of the Type II irregularities in the equatorial E-region. Type II irregularities are characterized by scale sizes extending from a few meters upto tens of kilometers. The short wavelength irregularities apparently seem to be generated from larger scale sizes nonlinear coupling or cascading processes (Rogister, 1972; Rogister and d'Angelo, 1970, 1972; Sato 1971, 1973; Sudan et al 1973). Neutral turbulance also seems to be another probable mechanism responsible for the generation of plasma irregularities (Prakash et al, 1970). The spectral characteristics of the different types of irregularities have been studied in detail (Prakash et al, 1970; Ott and Farley, 1974).

Plasma bubbles, flux tubes of depleted plasma density, observed frequently in the equatorial nighttime ionosphere have been the subject of active investigation in the last couple of decades(see Abdu et al, 1991 and references therein). These bubbles are characterised by scale lengths of thousands of kilometers along the geomagnetic field lines and tens to hundreds of kilometers perpendicular to the field lines. Their generation through the Rayleigh-Taylor (R-T) gravitational instability process and subsequent cascading, by secondary processes, into a heirarchy of irregularities was suggested by Haerendal (1974).

Some new results obtained from in-situ measurements of the height variation of the ionospheric electron density made with rocket-borne electron density probes during two campaigns conducted from Alcantara (2.31^{o}S; 35.2^{o}W) in Brazil are presented here.

Experiment and Flight Details

Guará Campaign

During the Guará campaign conducted from Alcantara, Brazil, a Black Brant X rocket was launched on 14-th October, 1994 at 1955hrs (LT) with the main objective of studying the equatorial ionosphere during the presence of high altitude plasma bubbles. The electron density height profile and the amplitude of the electron density fluctuations were measured simultaneously by the following three plasma density probes:

- A High Frequency Capacitance (HFC) probe
- A conventional Langmuir Probe (LP)
- A Plasma Frequency Probe (PFP)

The HFC Probe used a spherical sensor of 52mm diameter mounted on a short boom deployed 108s after the launch of the rocket. To cover the large dynamic range of the electron density and also to study the relative behaviour of the ion sheath the HFC experiment operated in two modes alternately with frequencies of about 5MHz and 10MHz. The duration of operation in each mode was about 60ms, thus giving a data point in each mode every 120ms. A swept frequency type of Plasma Frequency Probe (PFP) and a conventional Langmuir Probe were also launched along with the HFC probe to measure the plasma density and the fluctuations in it. In the PFP at fixed short intervals of time a signal with swept frequency is transmitted using a short antenna on board the rocket and the signal that traverses through the ambient plasma and thereby gets modified by the plasma is also received using another short antenna on board. when the signal frequency becomes equal to the ambient plasma frequency the signal amplitude falls down drastically due to the resonant absorption by the ambient plasma. What is monitored in this experiment is the height variation in the plasma frequency that is decided by the ambient plasma density. In the conventional Langmuir probe the electron or ion current collected by a metallic sensor is measured as a function of the potential applied to the sensor. When the sensor operates in the saturation electron current mode the current collected is directly proportional to the ambient electron density. The High Frequency Capacitance probe was designed and developed in the laboratories of the Aeronomy Division of the Instituto Nacional de Pesquisas Espaciais-INPE/MCT, while scientists from the Department of Physics and Astronomy, Dartmouth College, USA were responsible for PFP and LP experiments.

Results and Discussion

Electron density height profiles obtained during the Guará campaign from the analysis of the HFC, LP and PFP data during the upleg and downleg of the rocket are shown in Figures 1 and 2 respectively.

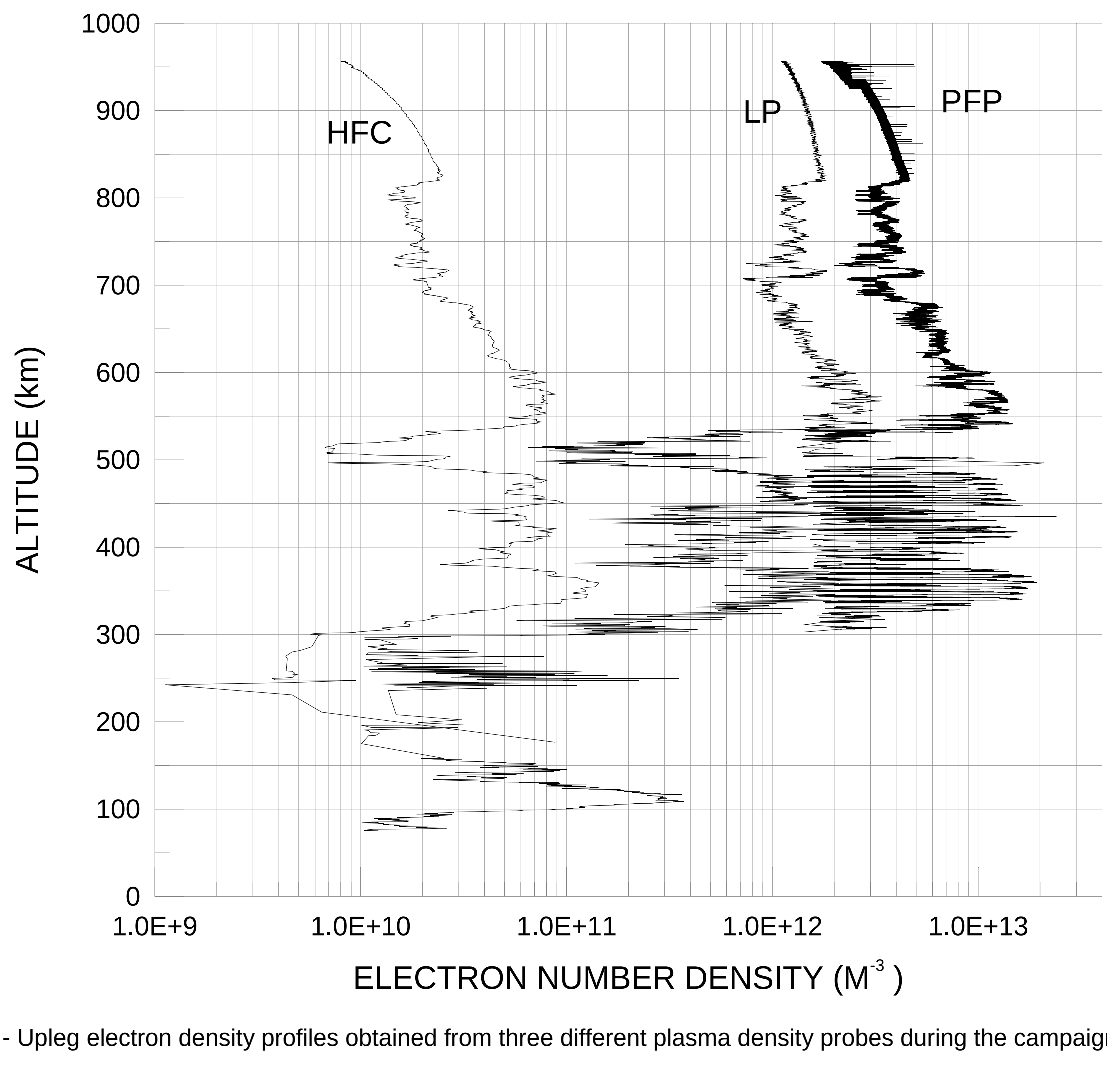

Figure 1.- Upleg electron density profiles obtained from three different plasma density probes during the campaign Guará.

The plasma density profiles estimated from the three experiments agree well with each other The LP and PFP experiments have sufficient height resolution to study the amplitude fluctuations in the small scale plasma irregularities. A close look at the electron density height profiles clearly show the existence of a wide spectrum of scale sizes in the plasma irregularities. All the upleg height profiles clearly show the presence of irregularities associated with what is known as the phenomenon of high altitude Spread-F. The presence of medium amplitude plasma bubbles in the high altitude region can be seen in the HFC upleg profile while the other two profiles from the LP and PFP experiments give an idea of the distribution of the small scale irregularities in this height region.. The rocket downleg profiles shown in Figure 2 do not show the presence of a wide spectrum of irregularities in the height region of 300-600km, but not in the high altitude region. This probably is due to the limited horizontal extent of the high altitude Spread-F event responsible for the generation of plasma irregularities. The horizontal separation of the upleg and downleg trajectory of the rocket in this height region can vary from few tens to about 200km. This distance, therefore, roughly represents the east-west horizontal extension of the high altitude plasma bubbles or the phenomenon of high altitude Spread-F associated with these bubbles. Detailed spectral analysis of the density data at different height region was done to know the spectral distribution of these plasma irregularities and thereby to know the plasma instability mechanisms responsible for their generation.

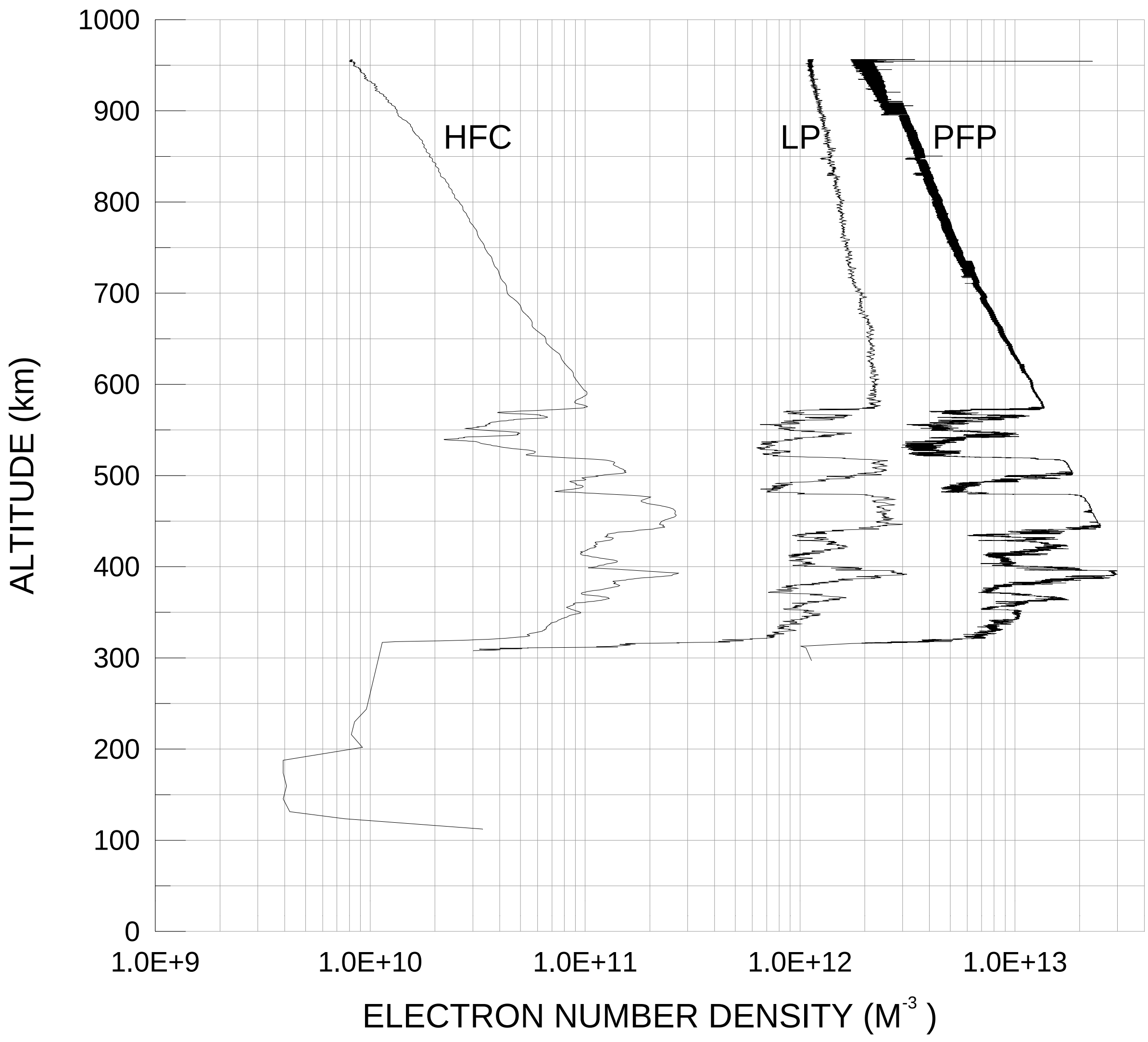

Figure 2.- Downleg electron density profiles obtained from three different plasma density probes during the campaign Guará.

Typical k-spectra obtained from the spectral analysis of the electron density fluctuation data of the HFC, LP and PFP experiments are shown in figures 3, 4 and 5 respectively. The striking feature of the spectra is the presence of spectral peaks of large amplitudes in practically all the k-spectra, a hitherto unobserved feature.

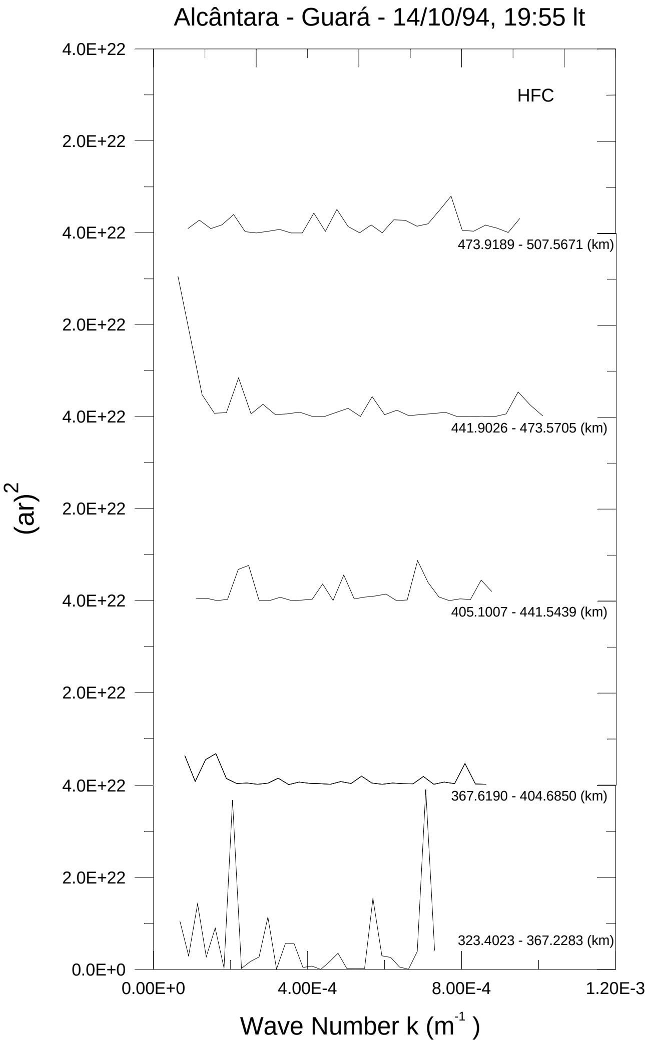

Figure 3.- Typical nature of the k-spectra of plasma irregularities, obtained from the HFC probe measurements showing the presence of sharp peaks (Campaign Guará).

Observation of bubble structures in the nighttime ionosphere is rather a familiar feature. The generation of large scale plasma irregularities by the mechanism of cross-field instability is now reasonably well understood (Reid, 1968; Tsuda et al., 1969). A necessary condition for the mechanism to operate is that there should exist an electron density gradient in the direction of the ambient electric field. In the nighttime ionosphere the Hall polarisation electric field is generally downwards and so the height regions favorable for the operation of the C-F instability mechanism are those where the ambient electron density gradients are downwards. Presence of large bubble structures in the bottom side F-region where the E-field is supposed to be downwards and the electron density gradient is upwards cannot be attributed to the operation of the cross-field instability mechanism. However, small scale plasma irregularities can be generated in the region of downward electron density gradients associated with the large scale bubbles.

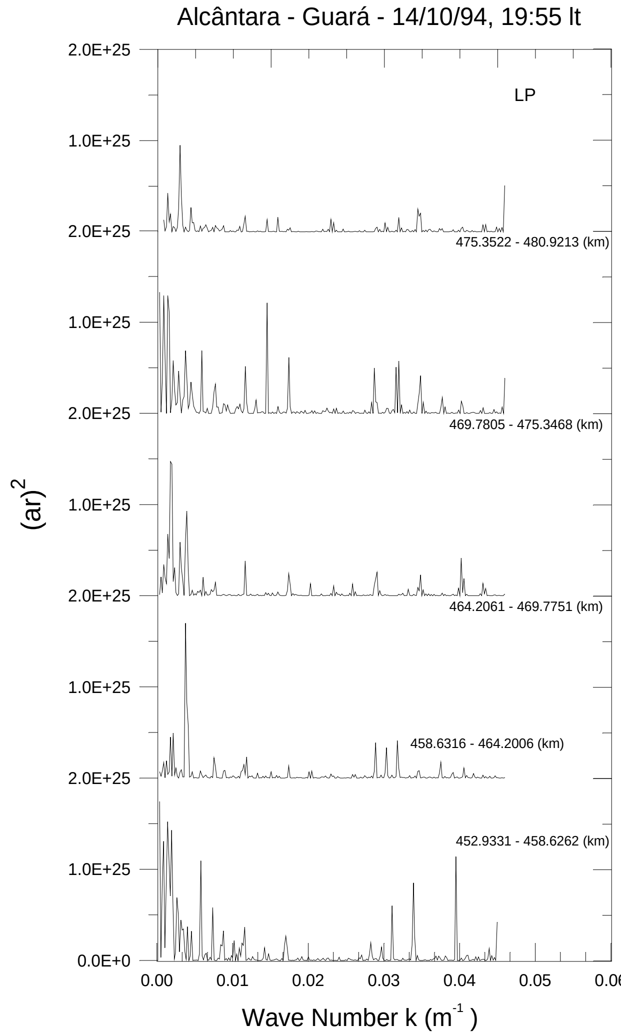

Figure 4.- Typical nature of the k-spectra of plasma irregularities, obtained from the Langmuir probe (LP) measurements showing the presence of sharp peaks (Campaign Guará).

It is now rather well established fact that the plasma bubbles are characterised by scale lengths of thousands of kilometers along the geomagnetic field lines and tens to hundreds of kilometers perpendicular to the field lines. Their generation through the Rayleigh-Taylor (R-T) gravitational instability process and subsequent cascading, by secondary processes, into a heirarchy of irregularities was suggested by Haerendal (1974). The spectral characteristics of the different types of irregularities associated with the phenomenon of spread-F have been studied in detail (Prakash et al, 1970; Ott and Farley, 1974). These small scale irregularities are expected to have a rather flat k-spectrum as the earlier observations showed and as predicted by the existing theories on the generation of plasma irregularities. A striking new feature observed during the experiments reported here is the presence of large spectral peaks in the k-spectra of the plasma irregularities. One should note here that both the rocket flights reported here were conducted during the onset period of the ionospheric plasma bubbles and there fore represent the characteristic features of plasma irregularities associated with new or developing plasma bubbles. It is possible that as time progresses the plasma irregularities responsible for these spectral peaks, transfer their energy to lower and lower scale size irregularities and thus eventually leading to a flat k-spectrum when the process attains a stable state. But a theory that can explain these spectral peaks even during the development phase of the plasma bubbles is not known yet.

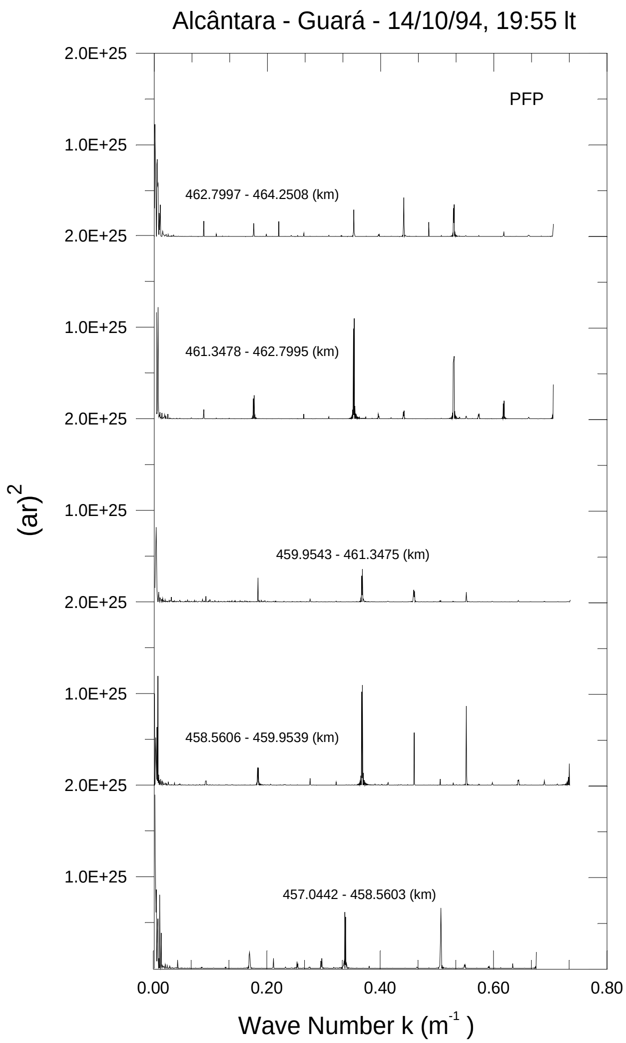

Figure 5.- Typical nature of the k-spectra of plasma irregularities, obtained from the Plasma Frequency Probe (PFP) probe measurements showing the presence of sharp peaks (Campaign Guará).

Conclusions

1. Electron Density height profiles estimated from different types of experiments namely a High Frequency capacitance probe, a Langmuir probe and a Plasma Frequency Probe during the occurrence of the phenomenon of High Altitude Spread-F agree well with each other.
2. Plasma irregularities of a wide spectrum of scale sizes are dominantly seen in the height regions of downward electron density gradients, confirming their association with the well known cross-field instability mechanism for the generation of plasma irregularities.
3. The generation of large scale plasma structures in the bottom side of the F-region cannot be explained by the cross-field instability mechanism that needs the vertical electric field and the electron density gradient to be in the same direction
4. Bubble regions are associated with a wide spectrum of plasma irregularities or electron density fluctuations. Spectral analysis of the ac data clearly show the presence of large peaks in the k-spectra of the plasma irregularities
5. The existing theories for the generation of plasma irregularities cannot explain the sharp spectral peaks observed in the k-spectra.
6. One possible explanation for the presence of large peaks in the k-spectrum of irregularities is that they may be associated only with developing plasma bubbles and may dissipate their energy with time thus leading to a flat k-spectrum as the steady state is reached.

Acknowledgements

The authors are grateful to the Directors of IAE/CTA and CLA, Alcantara for providing the rockets and the launch facilities respectively and to the staff of IAE and CLA for their help during the pre-launch tests of the experiments, and during the launching of the rockets. Sincere thanks are to Sinval Domingos, Agnaldo Eras and Narli Baesso Lisboa for their technical help in the development testing and integration of the experiments. The work reported here was partially supported by FINEP under contract FINEP-537/CT, and by CNPq under process 300253/89-3/GM/FV.

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