INVESTIGATIONS OF MAGNETIC FIELDS AND AURORA BY THE UV IMAGER UFSIPS AND THE MAGNETOMETER IMAP-3 PROJECT INTERBALL

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Abstract

We present a space equipment, both an optical instrument and a magnetometer , performing together remote sensing and geophysical observations in situ, respectively, concerning the interaction magnetosphere-ionosphere. The UV Imager UVSIPS and the magnetometer IMAP- 3 operate on board the Auroral satellite - project INTERBALL - program STEP. The triaxial flux-gate magnetometer IMAP-3 measures the three components of the magnetic field (in the range from 0 to ± 700000 nT) .The Imager (3-channel UV spectrometer UVSIPS) performs remote sensing of the polar oval to map ionospheric characteristics in the magnetic field line footprint from the Auroral Probe satellite (apogee 20000 km.).The advantage of the UV- method is its ability to observe the aurora on the night and ***dayside*** *of the Earth and the simultaneous measurements of both instruments provides correlated results. The obtained results contribute to the presentation of the relation between the magnetospheric and auroral sub-storms as a unified process during the interaction Solar wind - magnetosphere - ionosphere, to the determination of the auroral oval limits and the magnetosphere configuration. The INTERBALL-2 spacecraft has been successfully launched on 29 August 1996.*

1. INTRODUCTION

The **INTERBALL** Project was designed to study various plasma processes in the circumterrestrial space as the principle way to study solar-terrestrial physical processes. The Project consists of two pairs (satellite-subsatellite) at high altitude orbits: at 200 000 km for the **Tail Probe** pair and at 20 000 km for the **Auroral Probe** pair. The inclination of the two is 62.8 degrees. The general investigation and particularly the simultaneous measurements of magnetospheric substorms and auroral phenomena contribute essentially to the understanding of the system Solar wind-Magnetosphere-Ionosphere [1]. The purpose of the paper is to present applied optical and magnetic methods for joint investigations of the circumterrestrial space. Magnetic field measurements onboard the INTERBALL-2 (Auroral Probe) are carried out by the IMAP-3 experiment [2]. The IMAP-3 magnetic field instrument is designed to study the

following processes in the Earth's plasma environment: structure of the inner magnetosphere magnetic field; structure of the small scale field-aligned currents; dynamics of the field-aligned currents during substorms; relation of the processes in the auroral zone and in the tail.

The IMAP-3 was designed and manufactured with the co-operation of IZMIRAN (Russia), NPL SDS (Bulgaria) and PIC GPI of RAS [2].

The UV-spectrometer UVSIPS and the imager UVAI (Canada) provide the optical complex of the Auroral Probe for remote sensing of the auroral and electrodynamical characteristics of the ionosphere: by measuring the intensity of the auroral emission distributions in the visible (VIS), UV and X-ray spectrum regions, or at least in only one of them, and by using the relation between emission intensity and differential energy distribution of precipitating particles, approximated by the two-parameter law (e.g. Maxwellian or Gaussian distribution) we can obtain the distribution of the characteristic energy Eo and the energy flux Φ_e of the precipitating electrons, the ion concentration in the E-region maximum of the ionosphere and the height-integrated ionospheric conductance by Hall and Pedersen.

The methods of remote sensing optical and UV-diagnostics of electrodynamical ionosphere parameters were tested and proved to be realistic for the energy Eo < 10 keV by simultaneous co-ordinated spectrometric experiments and radar measurements, non-coherent back scattering both on the earth and in space onboard ISIS-2 and DE-1 [3,4,5].

The principle advantage of the remote sensing is the possibility to measure simultaneously parameters at large areas, determined by the field of view and the satellite altitude.

The measurements of the emission intensity distribution in the vacuum UV-region have an advantage in comparison with the measurements in the visible range, as the UV-radiation is absorbed by the underlying layer of molecular oxygen in the region of the Schuman-Runge continuum (1300-1600 A° with the maximum around 1400-1425 A°) [6]. This atmospheric effect creates beneficial natural conditions to observe aurora from a satellite on the ***dayside*** of the Earth. The contrast of the emission auroral intensity at the background of the daily radiation of the upper atmosphere varies for different lines and, as a rule, exceeds the double value [6 ,9].

2. INSTRUMENTATION

2.1.IMAP-3 MAGNETIC FIELD EXPERIMENT

The IMAP-3 was designed and manufactured with the co-operation of IZMIRAN (Russia), NPL SDS (Bulgaria) and PIC GPI of RAS (2). The instrument was initially tested on 9 September and started to work regularly on 14 September 1996. The triaxial flux-gate magnetometer IMAP-3 instrument is designed to measure three components of the DC magnetic field towards the satellite construction axes continuously along the whole orbit in two ranges: ±6800 nT with resolution 1 nT and ±68000 nT with resolution 10 nT. Usually the magnetometer data are transmitted to the scientific SSNI telemetry system with one vector per 3 sec. Rate, at definite intervals data are transmitted to telemetry with rates of 2 or 8 vectors/sec. depending on the instrument operating mode.

Fig. 1 shows the measured Bx (directed to the Sun) and Byz (perpendicular to the Sun direction) components of the magnetic field and Tsyganenko's model magnetic field components. There is a good agreement in the Bx component and a reasonable agreement in Byz.

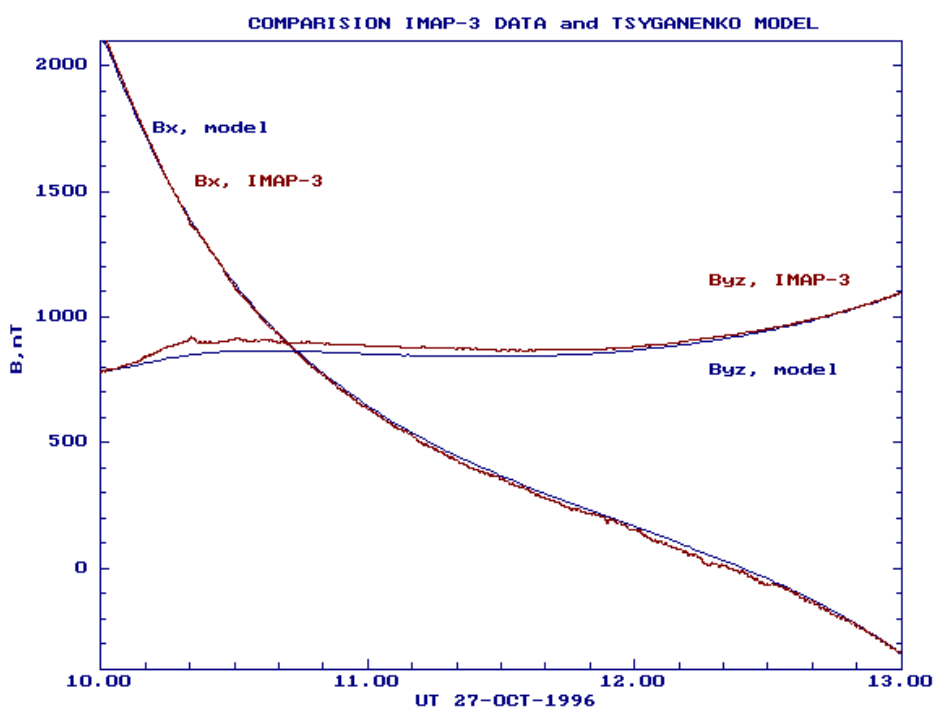


Figure 1. Measured and Tsyganenko's model magnetic field components.

Fig. 2 shows the magnetic field perturbation (deviation from undisturbed main field). At 21:30-21:40 variations up to ± 30 nT mainly in By component are seen. The spacecraft at that moment was near midnight, so the By component was directed along the L-shell and it is reasonable to consider this variation as produced by field-aligned currents.

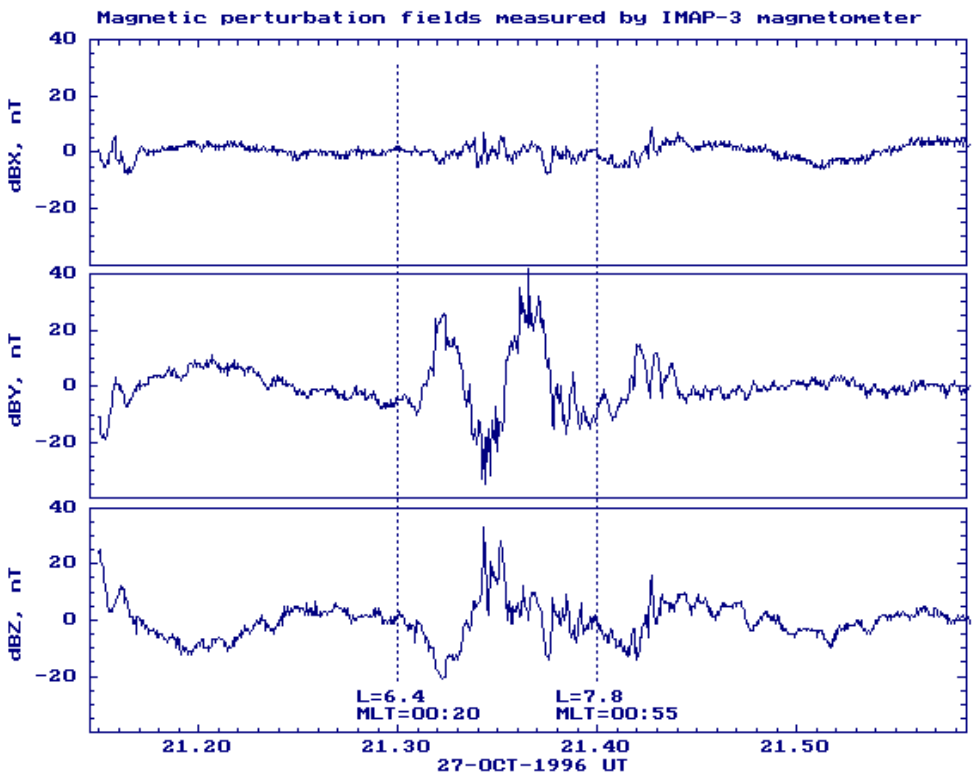


Figure 2. Magnetic field perturbation

2.2.EXPERIMENT UVSIPS

The Imager (the 3-channel UV spectrometer UVSIPS) performs remote sensing of the polar oval to map ionospheric characteristics in the magnetic field line footprint from the Auroral Probe satellite [7]. UVSIPS measures in the UV region [8,9] in 3 spectral intervals, centred to wavelengths 1304 A°, 1356 A° and 1493 A°. The halfwidth of the spectrometer apparatus function is 32 A°. UVSIPS provides also dayglow observations [9]. The Microprocessor of UVSIPS calculates footprint co-ordinates before every spin period of the satellite. The input mirror of the instrument moves to a corresponding position by small steps , scanning by its field of view in the plane satellite-Sun-Earth. The

spectrometer scans in the plane perpendicular to the sunward direction at the rate of the satellite spinning around the Sun-directed axis. The first channel measures the most intensive emission of the atomic oxygen (triplet 1302-04-06 A°), the second one measures the line of the atomic oxygen spin-forbidden doublet with wavelength 1356-9 A°, respectively. The doublet of the atomic nitrogen 1492,6-1495 A°, radiated from level N1(2p) gets into the third spectral interval (channel 3), centred to wavelength 1493 A°. The optical scheme and construction of UFSIPS are presented in Fig. 3.a, 3.b .

The UV spectrometer is built according to the classical scheme of a slitless spectrograph with plane diffraction grating. The glow region radiation is observed at a certain moment of time (Fig.4), its size is determined by the field of view (~ 0.3°) and the satellite altitude is directed to the instrument by a plane mirror 1, Fig.3.b.

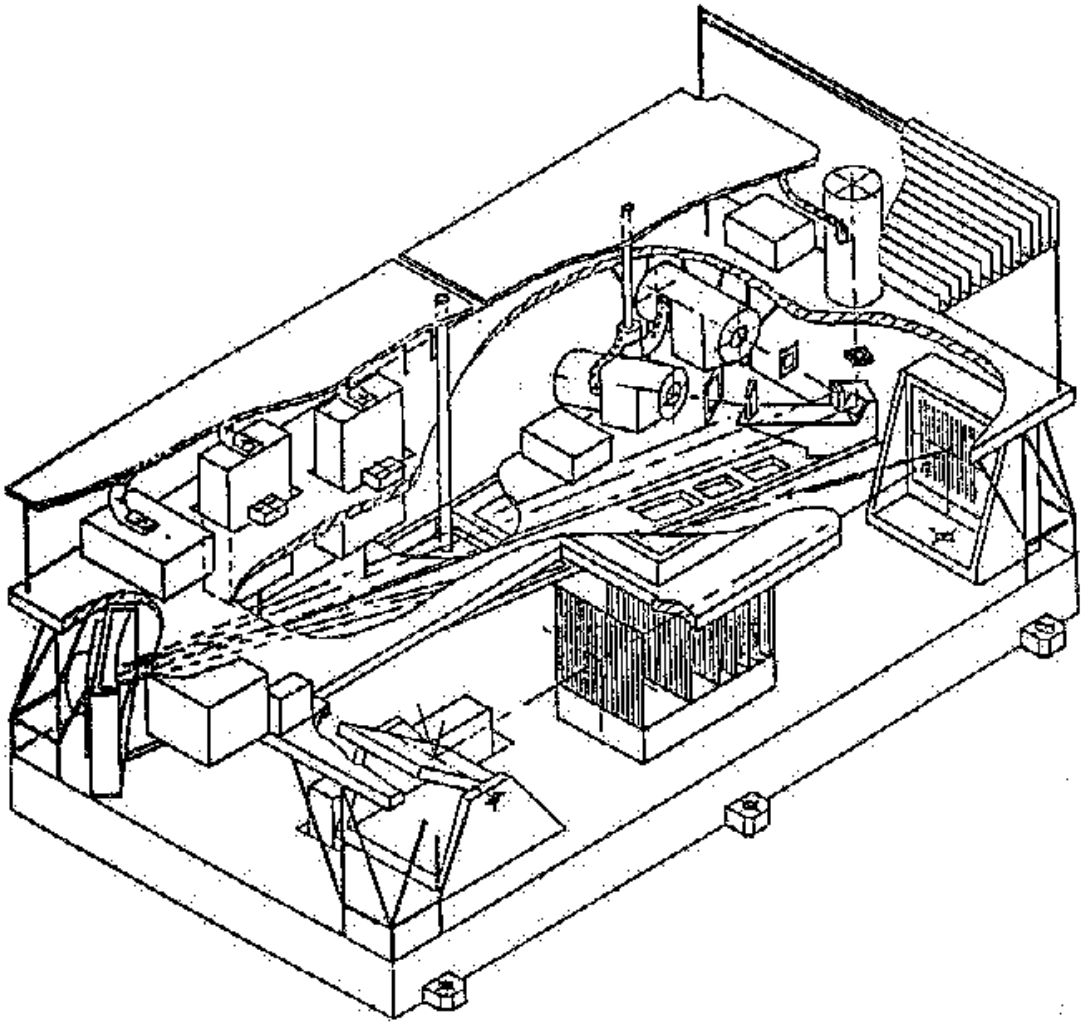


Figure3a. Optical block of instrument UVSIPS

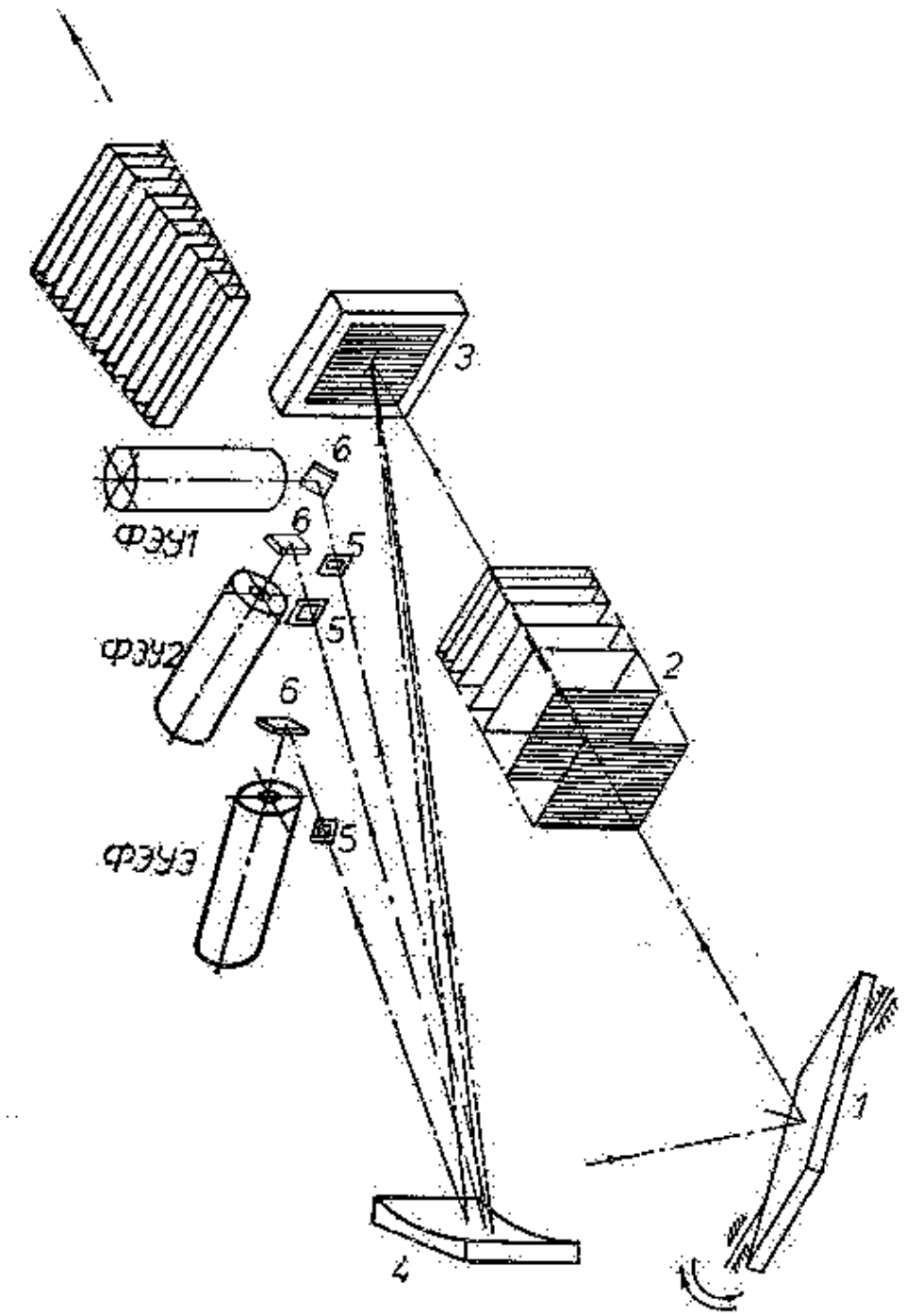


Figure 3b. Optical scheme of instrument UVSIPS

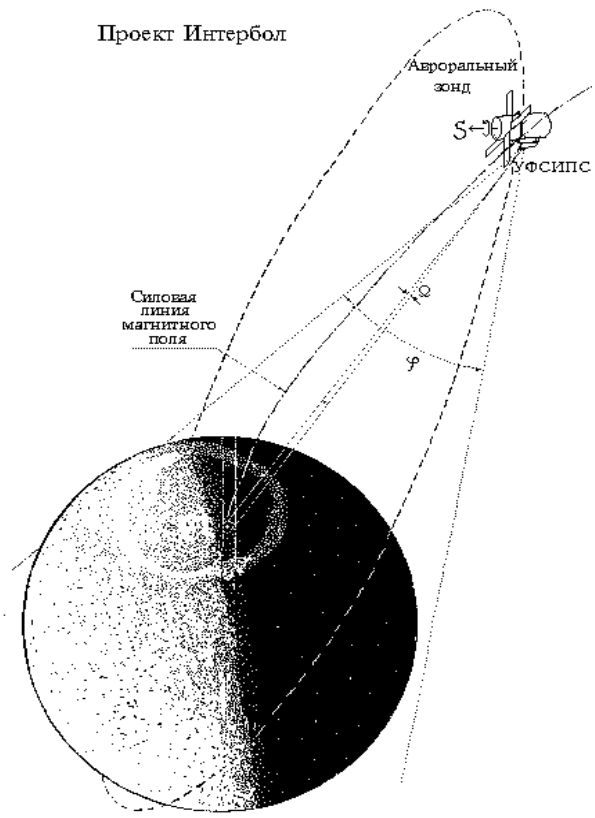


Figure 4. The concept of mapping the auroral oval by the UV-spectrometer UFSIPS

After a mechanical collimator 2, the light arrives to the plane of diffraction grating 3 (2400 lines/mm, operating in the first spectrum order). The spectrum is projected by a spherical camera mirror objective 4 into the plane of field diaphragms 5, mounted in the focal plane of the objective. These diaphragms extract from the glow region image continuum an individual monochromatic image, corresponding to the chosen spectral intervals, centred to the above-given wavelength and project it on the corresponding detector .

The characteristics of the collimator, the sizes of the field diaphragms and the optical characteristics of the slitless spectrograph determine in general an effective spectral half-width of the apparatus function, corresponding to the instantaneous image which is equal to 32 A°. Further, a system of three plane rotating mirrors 6 directs the selected radiation of measured UV-emissions to the photocathode of one of the photomultipliers ФЕУ 1, 2, 3. The instrument is mounted on the external surface of the Auroral Probe. The concept of mapping the auroral oval by the UV-spectrometer UFSIPS is the following:

The input mirror can move from middle position 51 at an angle ±11° by small steps (102 positions), scanning by its field of view an angle of 22° in the plane satellite -Sun-Earth. The angle range is between 38° and 82° to axis X in that plane. The spectrometer scans in the plane, perpendicular to the sunward direction at the rate of the satellite.

The background of the scattered sunlight is reduced by means of diaphragms of an antidiffraction light-protected buffle and a plane movable cover. The area of the spectrometer input opening depends on the position of this cover. The angle obtained by the observation vector and the direction satellite-Sun is an argument in the functional dependence of the cover position number on the input mirror position number. Step motors control the scanner and the cover positions. The instrument is controlled in flight according to cyclograms by a microcomputer, using radiocommands, control command words (UKS) [7].

The choice of angle (position) depends on the footprint of the magnetic force line computed in advance. The reference pulse for the scanning start is “Horizon”, provided by Imager UVAI (Canada) for UVSIPS. After a delay (determined by the azimuth angle between the optical axis of the two instruments) UVSIPS begins to scan the glowing layer. In the apogee the Earth is seen at an angle of 28°, corresponding to 9-10 sec. time of scanning at satellite spinning period T=120 sec. For a few seconds the field of view can cross the oval along the diameter or the chord depending on the observation direction and the geomagnetic conditions (determining the diameter of the auroral oval).

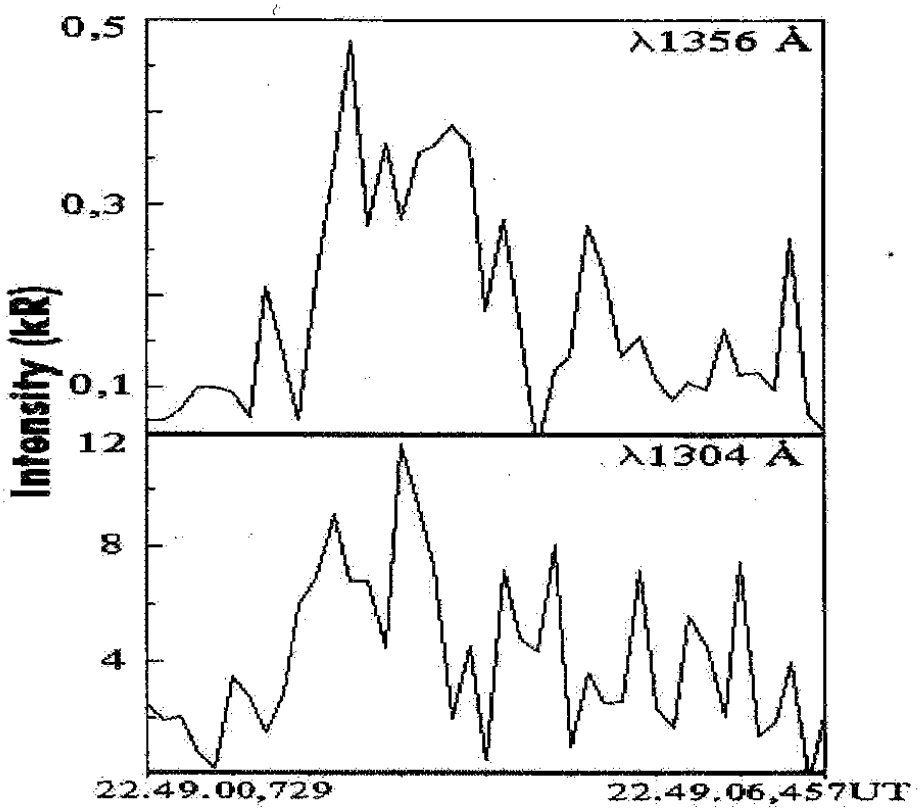
After synchronization with UVAI the instrument UVSIPS performs 36 measurements (36 pixels) at a given exposure time (0.15,0.2,0.3,0.4,0.5, 0.6 sec) and sends 20 bytes for each pixel (i.e. 36x20=720 bytes = 6 blocks of digital array). Due to the fast changes of the axis angle X-satellite-Sun, however, sometimes UVSIPS doesn’t receive the pulse from UVAI. Another synchronization is provided with the pulse of 1 and 1/1024 satellite revolution period.

We have also prevented another quasicontinuous measurement mode without external synchronization. The instrument performs 288 scans (288x20/6 = 48x20 bytes = 960 bytes) and provides information for the telemetry SSNI. One point corresponds to 20 bytes (the frame of UFSIPS). One frame of SSNI corresponds to 120+8 bytes, i.e. to 6 points (scans) of UFSIPS measurements. The spectrometer was switched on for the first

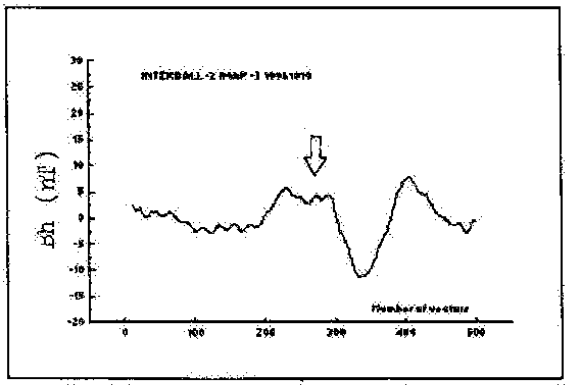
time on 14.09.1996. It was possible to make a good measurement on 10.10.1996 in quasicontinuous mode. Here we present an Aurora borealis of II-III degree, caught successfully by UFSIPS (orbit 216).

3. IMAP-3 AND UVSIPS RESULTS OF CORRELATED MEASUREMENTS

To illustrate the common analysis of the two instruments data let's examine a geomagnetic storm registered on 19.10.1996 (orbit 216 - Fig.5). UVSIPS performed a scanning in 22:49 UT with registered intensive emissions. The emission profile displays a high intensity zone in 1304 A° line with width of 3 sec., reaching more than 10 KR. This part of the profile is like a chord through the oval, approximately 2000 km long. By geometric considerations it can be said that this arc is at least 150 km wide. The profile analysis yields to the conclusion that at equatorial direction from the arc there is a weak glow halo whose width is of the same order. According to the expectations, such intensities are possible with precipitating particle energy fluxes with energy of about 50 - 100 erg/cm^2, observed with the polar aurora.



INTERBALL-2 IMAP-3 19.10.1996



Vector No	0	100	200	300	400	500
UT	22:35:00	22:40:00	22:44:59	22:49:59	22:54:59	23:00:00

Figure 5. Geomagnetic storm and Aurora borealis (correlated)

Fig. 6 shows the northern hemisphere seen by the satellite at the moment of measurement. The symbols (see the symbol bar on the figure) show the dipole pole, the northern geographical pole, the point of intersection of the vector to the Earth centre and the surface, and the footprint of the magnetic force line where the satellite is at that moment. The auroral oval is shown for forced geomagnetic conditions with index Kp=5+. The position of the terminator shows that the larger part of the auroral oval is situated in the shade. The position of the scan projection is marked by two arrow vectors. The field of view of UFSIPS crosses the auroral oval through the chord in such a way that the intersection goes from the morning to the night section. As a result of the axis X-satellite-Sun deviation, the footprint occurred in the morning section out of the field of view.

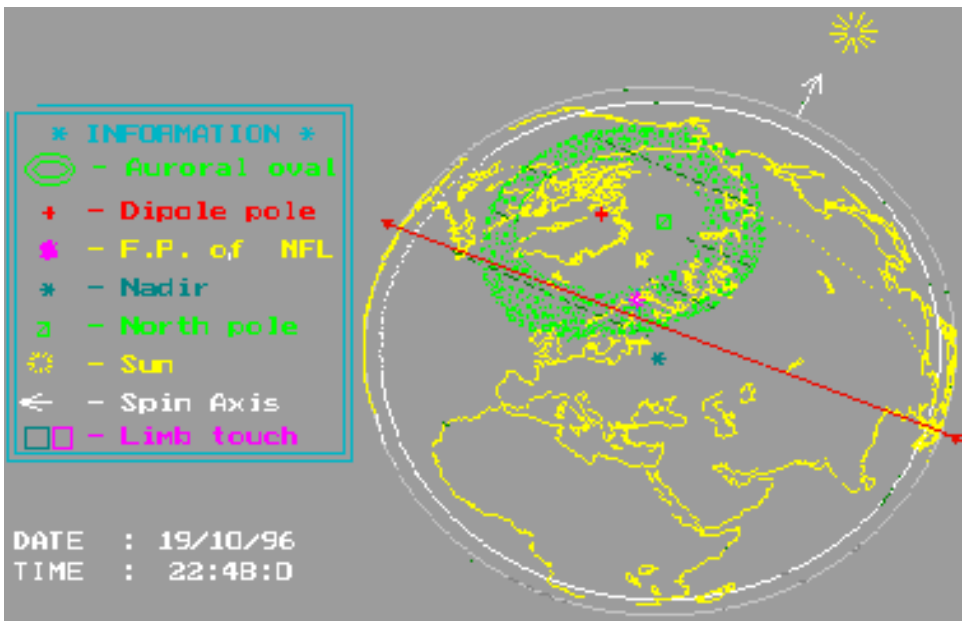


Figure 6. The northern hemisphere seen by the satellite at the moment of measurement.

The geomagnetic co-ordinates of the footprint are (at 22.49.03 UT for H =150 km) 74.3° latitude, 32.7° longitude, MLT=3.04 h (Fig.7), H shade = 647 km.

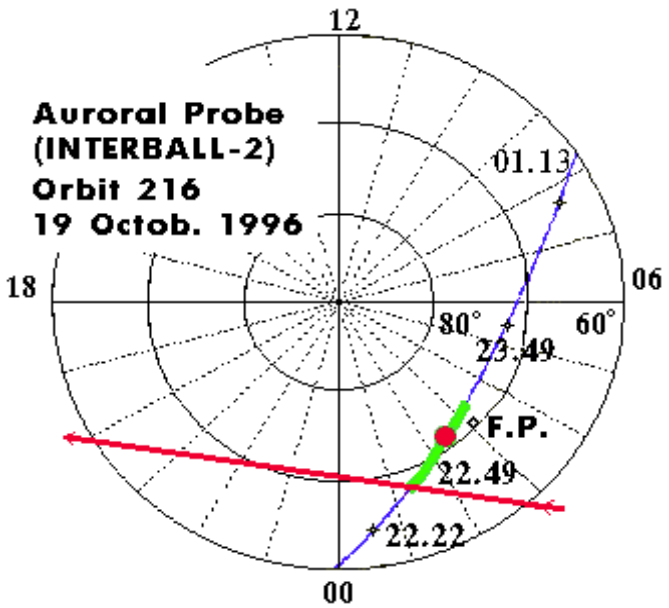


Figure 7. The footprint geomagnetic co-ordinates

The magnetogram begins with a calm interval [Fig.5] which continues until 22:45 UT. The magnetic disturbances, observed after that may be connected with current layers crossing. At the near-equator half from 22:45 UT until 22:50 UT changes in the field up to 10 nT can be seen which might be treated as small-scale layers. The minimum width of such a structure may be of the order of dozens km by width. In the near-pole half from 22:50 UT until 22:56 UT the field change is two times larger which is connected with a large-scale current structure crossing. The width of such a current layer is about 130 km reduced to atmospheric altitudes. A comparison is made of the optical emissions measurements to these of the magnetic field. At the moment of optical emissions scanning, the satellite has passed through the main zone of the field-aligned current layers. Their physical carriers are mainly low-energy electrons (E>>1 KeV). These particles degrade by energy at altitudes, higher than the atmospheric altitude, generating the observed optical effects. Here we pay attention that a little before the meeting with this region, i.e. at 22:45-22:46 UT, the magnetic field increase is observed of the order of several nT, corresponding to a restricted current structure [Fig.5]. This interval namely corresponds to the intensive emissions zone, taking into consideration the direction of the magnetic-conjugated region. Both UVSIPS and IMAP-3 contribute to the understanding

of the active plasma processes in the polar and auroral magnetic flux tubes and the correction of the theoretical models.

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