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OBSERVATIONS OF THE INTENSIVE OII(^{2}P) EMISSION IN THE POLAR CAP

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Abstract—Ionized oxygen doublet 7320–7330 Å emissions with intensities up to several kilorayleighs were observed in the polar cap arcs by the *Intercosmos-Bulgaria*-1300 satellite. These measurements are compared with the simultaneous observations of electric and magnetic fields and precipitating particles and also with auroral images obtained by *DMSP F*-6.

INTRODUCTION

The emission of ionized oxygen doublets (7320–7330 Å) in the polar cap has been studied rather poorly. Few ground-based and satellite observations show that the intensity of OII(^{2}P) auroral emissions accounts for only a few per cent of 5577 Å [OI] intensity (Vallance Jones, 1974). Atomic oxygen ions in the ^{2}P metastable state are produced by electron impact ionization (Seaton, 1959):

$$e+O(^3P) \rightarrow 2e+O^+(^2P,^2D,^4S)$$
$$O^+(^2P) \rightarrow O^+(^2D)+h\nu(7320,\,7330\,\text{Å}).$$

Quenching of the excitation is possible by the reactions:

$$O^+(^2P)+O \rightarrow O^+(^2D,^4S)+O$$
$$O^+(^2P)+N_2^+ \rightarrow O+N_2^+$$
$$O^+(^2P)+e \rightarrow O^+(^2D,^4S)+e.$$

Rees *et al.* (1982) have deduced from the *AE-D* observations that the efficiency of $O^+(^2P)$ excitation by electron impact ionization is about 18%.

Cogger *et al.* (1987) have shown that in the auroral oval the ratio of emission intensities I_{7320}/I_{4278} correlates well with the ratios I_{5577}/I_{4278} and I_{6300}/I_{4278}, so it is more probable that 7320 Å emission primarily depends upon the atomic oxygen density rather than upon the energy spectrum of precipitating electrons.

Here we present observations of $O^+(^2P)$ intense emissions made by the *Intercosmos-Bulgaria*-1300 satellite in the polar cap together with simultaneous electric and magnetic field and particle precipitation data.

OBSERVATIONS

The *Intercosmos-Bulgaria*-1300 satellite was launched into a nearly circular orbit with an altitude of ~900 km and inclination of 81° on 7 August 1981. The spacecraft had three axes attitude stabilization with an accuracy of 1°. The X axis of the orbital coordinate system was directed along the velocity vector, the Z axis was along the radius-vector of the satellite and the Y axis completed the right-hand coordinate system.

The measurements of auroral luminosities were made by the EMO-5 photometer (Gogoshev *et al.*, 1983). The line of sight was directed vertically downward. Filters were placed in the field of view of the photometer by a rotating disk which had eight discrete positions. Two of these positions were used for calibration, while the other six positions corresponded to filters with bands centred at 4861, 6300, 6345, 4278, 5577 and 7320 Å. The complete period of disk rotation was 16 s, and the disk was fixed at each position for 2 s. During 1.5 s a logarithmic counter accumulated pulses from a photomultiplier, and the current sums were telemetered with 0.04 s sampling rate. Thus each point at the intensity profile corresponded to the total number of pulses accumulated during 1.5 s and the periodicity of measurements was 16 s for each spectral line.

Measurements of the electric and magnetic fields were made with the IESP double probe and the three-axial fluxgate magnetometer IMAP (Serafimov *et al.*, 1982) with a sampling rate 0.08 s.

It took from 10 to 20 s to obtain the energy spectrum (0.2–12 keV) of precipitating electrons and protons with the cylindric electrostatic analyser ANEPE (Ivanov *et al.*, 1983). Simultaneously, the flux of electrons at a fixed energy of 1 keV was measured by ANEPE with a sampling rate 0.08 s.

Due to the inclination of the magnetic field vector to the photometer line of sight, a time delay Δt arose between the local measurements of field-aligned currents and particles at the altitude of 900 km and observations of corresponding luminosity variations at the altitudes of 150–250 km. This time delay was defined by the magnetic field inclination and by the geometry of auroral feature.

Figure 1 shows the intensities of emissions in spectral lines 4278, 5578, 6300 and 7320 Å along the orbits 7372 and 7379. These observations were made on 11 January 1983 when the interplanetary magnetic field was strongly northward. The northern polar cap images were obtained by the *DMSP F*-6 satellite for this period (Akasofu and Tsurutani, 1984).

At the orbit 7372 the satellite crossed diffuse and discrete auroral forms in the dusk oval at 02:18–02:20 U.T. and then entered the polar cap. At least eight arcs were observed in the polar cap before 02:28 U.T. when the satellite had left the Earth's shadow and the photometer had been switched off (Fig. 1, top right). The observed ionized oxygen emission was near the background level in the oval and the polar cap, with the exception of the narrow region at 02:23 U.T. where a sharp peak of 7320 Å emission intensity up to 9 kR was observed. The 5577 Å emission intensity also increased up to 5 kR for this polar arc. For the rest of polar cap arcs the 7320 Å emission intensity was near the background level.

At the orbit 7379 the satellite crossed the dusk auroral oval at 14:14–14:18 U.T. (Fig. 1, bottom right). Only one arc was observed in the polar cap at 14:20 U.T. The 7320 Å emission increased up to 3.5 kR in this arc. The atomic oxygen emission here was also enhanced up to 3.5 kR (5577 Å) and 1 kR (6300 Å) together with an additional maximum for 4278 Å (N_2^+).

Figure 1 (left) also presents the images of the northern polar cap obtained by *DMSP F*-6 at 08:34 U.T. (Lassen and Danielsen, 1989) and at 15:32 U.T. (Gorney *et al.*, 1986). There were a number of Sun-aligned polar arcs at 08:34 U.T. and only two polar arcs (I and II) with a configuration resembling Θ-aurora at 15:32 U.T. The 7320 Å emission intensity profiles along the orbits 7372 and 7379 are superimposed on these images. The regions of local maxima of $O^+(^2P)$ emission intensity coincide with the area occupied later by arc I. The measurements near arc II were not available as the photometer was switched off when the satellite left Earth's shadow.

There were no observations of precipitating particles for these two orbits. The electric and magnetic field variations along the orbits 7372 and 7379 were analysed by Israelevich *et al.* (1988). Small-scale disturbances of electric field corresponding to S-shaped potential distributions were observed at the boundaries of the polar arc. The parallel electric field in these structures produce the downward acceleration of electrons up to 1 keV. Such an acceleration of electrons at the boundaries of the polar cap arc was previously reported by Gorney *et al.* (1986).

The fact that intensities of OI 5577 Å and OII 7320 Å emissions are of the same order of magnitude presumes the relative enhancement of O^+ density. The regions of enhanced O^+ density were observed in the polar cap by Petersen and Shelley (1984). The region of enhanced O^+ density is rather narrow as the 7320 Å emission is low in the other arcs.

Figure 2 shows two other events of ionized oxygen intensive emissions which were observed on 21 January 1982 (orbit 1982). Magnetic field transversal disturbances ΔB_x, ΔB_y, electric field components E_x, E_y, energy flux and mean energy of precipitating particles (solid line for electrons and dashed lines for protons), flux of electrons at the fixed energy of 1 keV and emission intensities for spectral lines of 4278, 6300, 5577 and 7320 Å are shown from top to bottom. The spectra of precipitating electrons and ions are shown in Fig. 3.

The measurements had started in the polar cap. The morning auroral oval had been crossed at 03:42–03:44 U.T. The common two-sheet stationary structure of field-aligned currents (Regions 1 and 2) was absent inside the oval. Instead of that, quasiperiodical variations of the ΔB_y component were observed. These variations may correspond to field-aligned current splitting or to oscillations of the field-aligned current intensity with 12 s period.

The significant transversal disturbance of the magnetic field (up to 80 nT) related to field-aligned currents was observed in the polar cap together with a large-scale electric field (up to 40 mV m^{-1}). Positive gradients of ΔB_y correspond to the upward current, and positive E_x corresponds to sunward convection of ionospheric plasma.

There were two regions of enhanced emission of

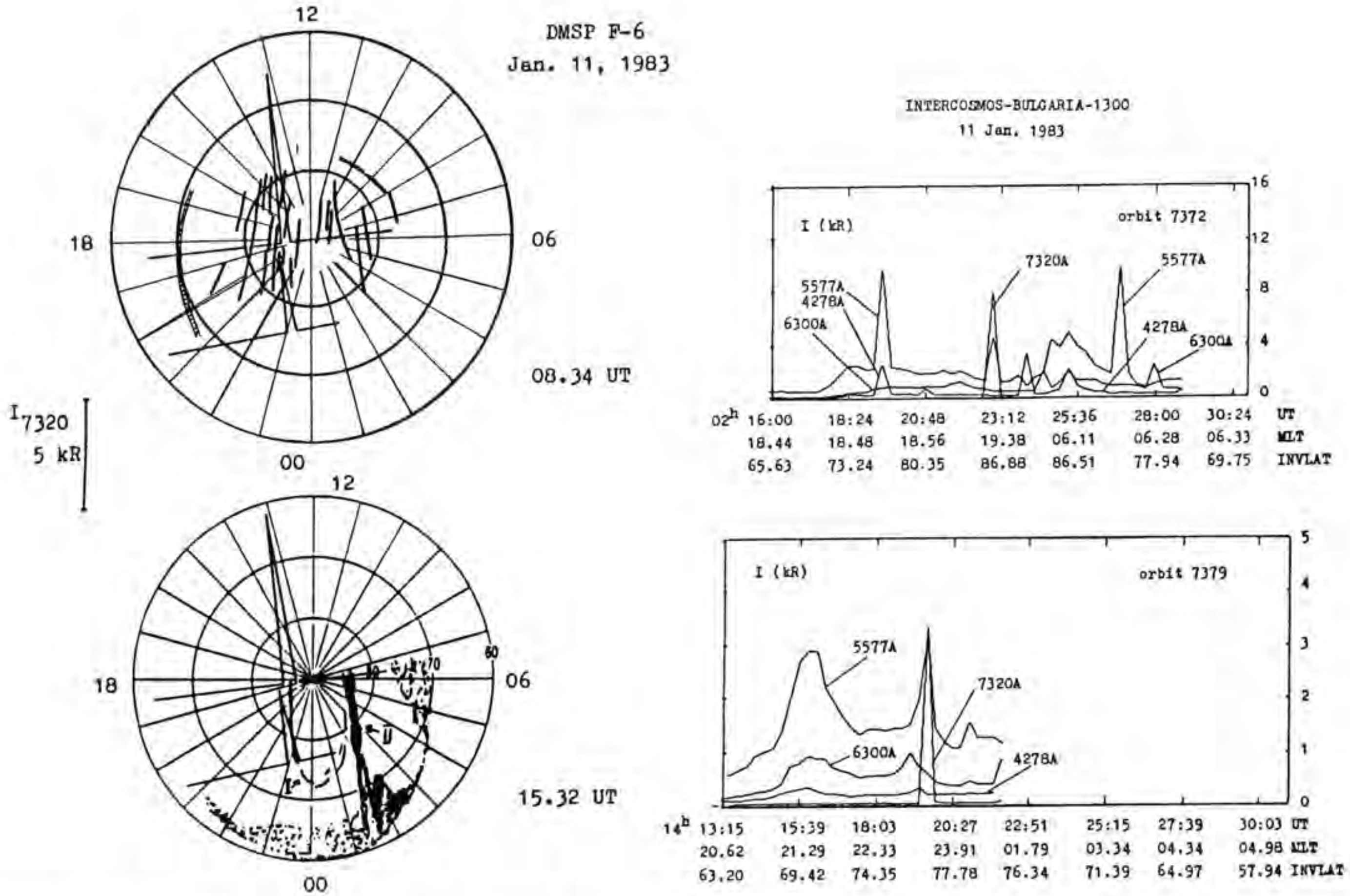

FIG. 1. ON THE RIGHT: THE INTENSITY OF EMISSIONS OF 4278, 5577, 6300 AND 7320 Å FOR THE ORBIT 7372 (TOP) AND 7379 (BOTTOM). On the left: images of the northern polar cap at 08:34 and 15:32 U.T. obtained by *DMSP F-6* on 11 January 1983. The intensity profiles of the 7320 Å emission are superimposed on these images along the *ICB*-1300 orbits 7372 and 7379.

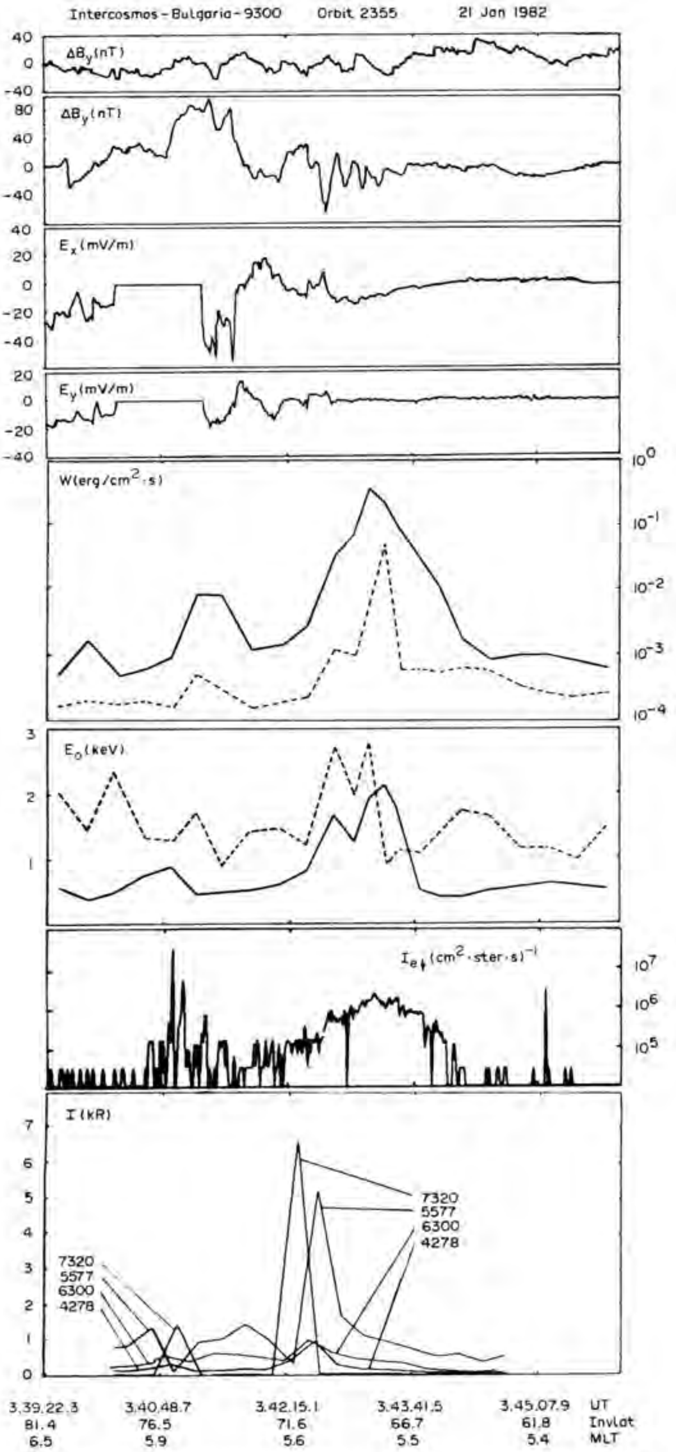

FIG. 2. FROM TOP TO BOTTOM: TRANSVERSE DISTURBANCES OF MAGNETIC FIELD ΔB_x, ΔB_y, ELECTRIC FIELD COMPONENTS E_x, E_y, ENERGY FLUX AND MEAN ENERGY OF PRECIPITATING PARTICLES (SOLID LINE FOR ELECTRONS, DOTTED LINE FOR PROTONS), FLUX OF THE 1 keV ELECTRONS AND THE INTENSITIES OF 4278, 5577, 6300 AND 7320 Å EMISSIONS FOR THE *ICB*-1300 ORBIT 2355.

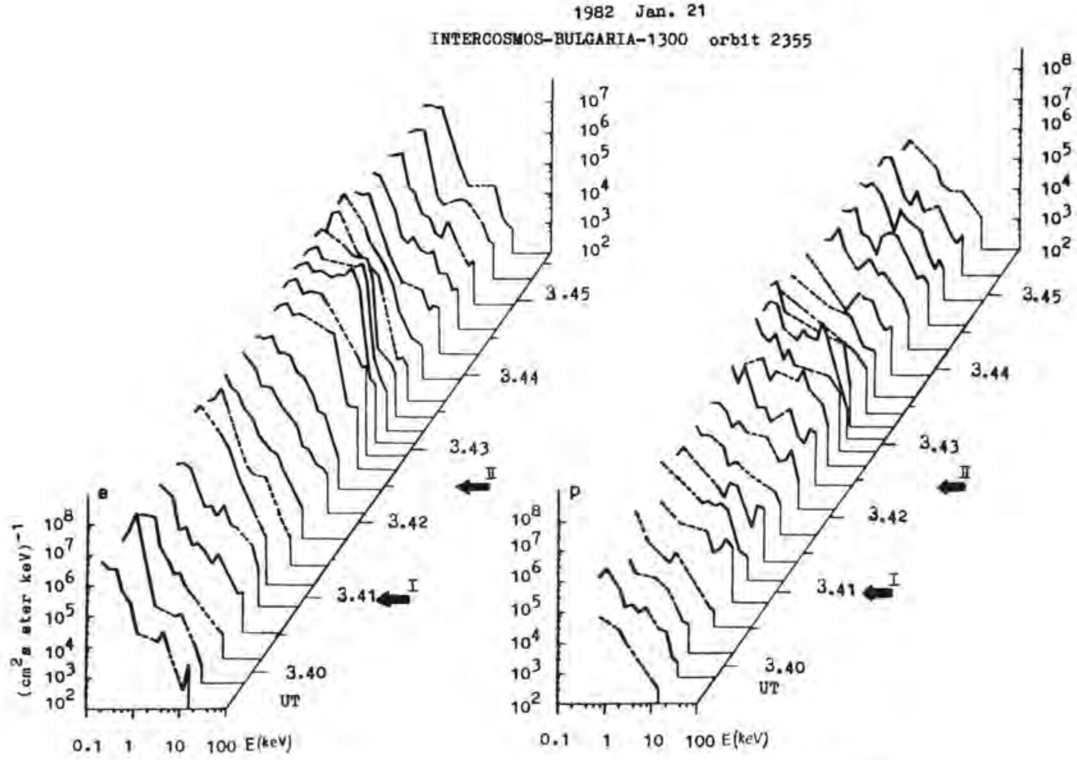

FIG. 3. THE PRECIPITATING ELECTRON AND PROTON SPECTRA FOR THE ORBIT 2355. The arrows mark spectra which correspond to the 7320 Å emission enhancements.

ionized oxygen. The first intensity peak (1.5 kR) was located in the polar cap and had been crossed at 03:40 U.T. The spectra corresponding to this region are marked by arrows I in Fig. 3. It should be noted that these spectra were obtained with insufficient temporal resolution as the 1 keV electron flux varied substantially during the period of time necessary to obtain one spectrum.

The second region of intense 7320 Å emission (up to 7 kR) has been crossed by 03:42 U.T. near the poleward boundary of the auroral oval (the corresponding spectra are marked by the arrows II). Both peaks of OII(^{2}P) emission were observed in the regions of upward field-aligned currents, but contrary to the events observed in orbits 7372 and 7379, no small-scale disturbances of E and B had been observed which might correspond to polar cap arcs.

Ionized oxygen emission observed in orbit 2355 was accompanied by significant decreases of atomic oxygen line (6300 and 5577 Å) intensities. This suggests that the density of atomic oxygen decreased in the arc jointly with the enhancement of O$^+$ density.

The data for the emission intensities for different spectral lines are presented in Table 1.

CONCLUSION

Given data from *Intercosmos-Bulgaria*-1300 show that OII(^{2}P) emission intensities in some polar cap arcs were by an order of magnitude larger than in the auroral oval. This result is rather new and strange. As far as we know, nobody has yet observed such extremely strong OII(^{2}P) emission. So, at first, we should decide if it is possible to believe these observations. We have considered several possibilities which can lead to such enormous values of intensities. They are: (1) wrong calibration; (2) wrong determination of the spectral line; (3) noise in the photomultiplier; (4) telemetric error; and (5) some source of light on the Earth. The first point can be excluded as the instrument gave reasonable data in the auroral

TABLE 1. INTENSITIES $I(R)$

Data	Time (U.T.)	6300 Å	4278 Å	5577 Å	7320 Å
21 Jan. 1982	03:40:55	557	—	—	—
	03:40:59	—	341	—	—
	03:41:01	—	—	147	—
	03:41:03	—	—	—	1439
	03:41:13	390	—	—	—
21 Jan. 1982	03:42:17	420	—	—	—
	03:42:21	—	433	—	—
	03:42:23	—	—	347	—
	03:42:25	—	—	—	6624
	03:42:35	1009	—	—	—
11 Jan. 1983	02:22:51	473	—	—	—
	02:22:55	—	165	—	—
	02:22:57	—	—	4688	—
	02:22:59	—	—	—	8053
	02:23:07	437	—	—	—
11 Jan. 1983	14:19:25	711	—	—	—
	14:19:29	—	357	—	—
	14:19:31	—	—	3171	—
	14:19:33	—	—	—	3367
	14:19:41	611	—	—	—

oval (see Cogger *et al.*, 1987). In principle, rotational lines $P_1(2)$, $P_2(3)$, and $P_1(3)$ of the (8–3) band of OH($X^2\pi$) can pass through the same filter, but such strong emissions of hydroxyl are even more strange than that of ionized oxygen. Detailed examination of the process of data collection with a sampling rate of 0.04 s enables us to exclude items (3) and (4) as well. Finally, we have not succeeded in the search for sources of light on the Earth's surface which may give the observed peaks of O^+ emission. Of course, the latter does not mean that there are really no such sources. However, due to the fact that in orbits 7372 and 7379 these peaks appeared at different geographical regions but at the region of the same auroral arc (see Fig. 1) it seems more probable that observed emissions were related to certain auroral features rather than with sources of light on the Earth.

Our list of possible mistakes may not be exhaustive, so it is necessary to take these observations with some caution; moreover, there is no physical explanation of the appearance of such bright emissions of ionized oxygen. Certainly, the reported measurements of enormous values of OII(^{2}P) emission need further independent confirmation.

If we believe these observations, then it seems that the enhancement of 7320 Å emission in the polar cap is mainly determined by the conditions in the ionosphere, because it is much stronger in the polar cap arcs than in the auroral oval in spite of stronger electron precipitation in the latter. To interpret observations one should first answer the following questions:

(1) Is the electron impact ionization of atomic oxygen the source of OII(^{2}P) in the polar cap similar to the auroral oval and, if so, are the higher emission intensities in the polar cap due to lower quenching efficiency?

(2) Is there another source of OII(^{2}P) excitation in the polar cap and, if so, is this source related to the mechanism responsible for upward O^+ flowing in the cap?

Answering these questions, one should remember that all of our few observations were made during periods of high electromagnetic activity in the polar cap typical for northward IMF.

We feel that data presented here seem to be insufficient to answer these questions and therefore restrict ourselves to the report of observations of high intensity OII(^{2}P) emissions. We hope that future systematic photometric observations of doublet 7320–7330 Å OII in the polar caps will make it possible to obtain confirmation of occurrence of bright arcs in 7320 Å and to elucidate mechanisms of their appearance.

REFERENCES

Akasofu, S.-I. and Tsurutani, B. (1984) Unusual auroral features observed on January 10–11, 1983 and their possible relationships to the interplanetary magnetic field. *Geophys. Res. Lett.* **11**, 1086.

Cogger, L. L., Shepherd, G. G., Gogoshev, M. M., Dachev, Ts. P. and Gerdjikova, M. G. (1987) Satellite observations of OII(7320–7330 Å) emission in aurora. *Planet. Space Sci.* **35**, 845.

Gogoshev, M. M., Petkov, N., Kuzmin, A. K., Gogosheva, Ts. N., Spasov, S., Nedkov, I. and Komitov, B. (1983) Airglow atmospheric imager aboard *IC-Bulgaria*-1300 satellite. *Adv. Space Res.* **2**, 113.

Gorney, D. J., Evans, D. S., Gussenhoven, M. S. and Mizera, P. F. (1986) A multiple satellite observation of the high-latitude auroral activity on January 11, 1983. *J. geophys. Res.* **91**, 339.

Israelevich, P. L., Podgorny, I. M., Kuzmin, A. K., Nikolaeva, N. S. and Dubinin, E. M. (1988) Convection and field-aligned currents, related to polar cap arcs during strongly northward IMF. *Planet. Space Sci.* **36**, 1317.

Ivanov, I., Nenovsky, P., Dachev, Ts., Semkova, I., Koleva, R., Chapkunov, S., Kutiev, I., Kanev, K. and Kanchev, A. (1983) Measuring equipment for energy ion, proton and electron fluxes aboard the *Intercosmos-Bulgaria*-1300. *Adv. Space Res.* **2**, 218.

Lassen, K. and Danielsen, C. (1989) Distribution of auroral arcs during quiet geomagnetic conditions. *J. geophys. Res.* **94**, 2587.

Petersen, W. K. and Shelley, E. G. (1984) Origin of the plasma in a cross-polar cap auroral feature. *J. geophys. Res.* **89**, 6729.

Rees, M. H., Abreu, V. I. and Hays, P. B. (1982) The production efficiency of $O^+(^2P)$ ions by auroral electron impact ionization. *J. geophys. Res.* **87**, 3622.

Seaton, M. J. (1959) Electron impact ionization of Ne, O, and N. *Phys. Rev.* **113**, 814.

Serafimov, K. B., Arshinkov, I. S., Bochev, A., Petrunova, M., Stanev, G. and Chapkunov, S. (1982) A measuring equipment for electric and magnetic fields in the range of the ionosphere–magnetosphere plasma mounted aboard the *Intercosmos-Bulgaria*-1300. *Acta Astronautica* **9**, 397.

Vallance Jones, A. (1974) *Aurora*. D. Reidel, Hingham, MA.