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Special Topic

Interball-2: first scientific results

This special issue of *Annales Geophysicae* marks the second anniversary of continuous operation of the Interball Auroral Probe. The Interball mission, which consists of two pairs of satellites, was initiated at the end of the 1970s, when the idea of a multi-satellite mission which was able to study both the global dynamics of the magnetosphere, as well as to resolve small scale structures, was formulated.

The long history of Interball involved the solution of numerous problems, including multiple delays, a change of the launch site, and the urgent development of a new and advanced scientific telemetry system. However, on 29 August 1996, Interball-2 (the Auroral Probe) and its sub-satellite Magion-5 were successfully launched into an elliptical orbit with a period of 5.7 h, an apogee of $\sim$20000 km, and an inclination of 62.8°. For this type of orbit the line of apsides does not rotate, i.e. the apogee stays at constant latitude. Almost one year earlier, on 3 August 1995, Interball-1 (the Tail Probe) and its sub-satellite Magion-4 had been successfully launched from the same northern Russian cosmodrome (Plesetsk). Initial results from those spacecraft have been previously published in vol 15, issue 5 of *Annales* (May 1997).

It is now opportune to collect together the initial results from Interball Auroral Probe operations. Very soon after launch a serious problem was detected with the spacecraft orientation. Prognoz-type satellites such as the Auroral Probe have a solar orientation with a slow (120 s) rotation, and normally the spin axis should be reoriented towards the sun once every 6–8 days. Previous Prognoz satellites have been used mainly for the exploration of the outer regions of the magnetosphere and the solar wind. The orbit of the Auroral Probe, with a low apogee of $\sim$20000 km, was thus not typical of these spacecraft, and the gravity gradient perturbations which accumulated at the perigee segment of the orbit became very significant for the evolution of the orbit and for the stability of the spacecraft orientation. These effects resulted in strong nutation oscillations of the spacecraft (up to 40°) even during the early stages of the Auroral Probe mission. Specialists from the Lavochkin Association quickly developed a special program for the suppression of this nutation. This program operates automatically every 12 h, and has resulted in a very high expenditure of the gas supply of the spacecraft's correcting motors. This is an unusual situation for a Prognoz-type satellite (the gas resources for example on the Tail Probe will allow spacecraft operation well beyond its ballistic lifetime), and will lead to the Auroral Probe losing its orientation capabilities in the autumn of 1998. There are, however, strong hopes that spacecraft operations can be continued in the non-oriented mode, and that some physical measurements will be conducted even at this stage.

One implication of the unstable spacecraft orientation, together with some instrumental problems, has been that a full set of ultra-violet images of the auroral region has not been obtained as planned by the UVAI experiment. The main part of these data remain unprocessed, although some images have been processed and may be found at Interball WWW sites.

Another serious problem with the Interball mission was the loss of radio contact with the Auroral Probe subsatellite (Magion-5) on the second day after launch, due to a serious power deficit. After analysing the telemetry data and laboratory tests of the spare systems, it was concluded that the failure was caused by a short circuit in the solar array, and it was decided to continue periodic attempts to reactivate the sub-satellite. The first response from Magion-5 was obtained at the Panska-Ves station by the Institute of Atmospheric Physics of the Czech Academy of Science on 6 May 1998. Regular data acquisition, including housekeeping as well as scientific information, began at Panska-Ves on 17 May 1998. The orbit of Magion-5 is essentially the same as that of the Auroral Probe, with a distance between the two spacecraft which has been estimated to be about 3000 km at apogee. Analysis of the first scientific data from Magion-5 is now in progress and the results are promising.

Concerning the main Auroral Probe, an important enhancement was also achieved at the end of 1997 in the data acquisition. The telemetry transmission rate was increased from the initially planned value of 65 kb s^{-1}

up to 256 kb s^{-1}, which has resulted in a significant increase in the scientific information obtained during each communication session.

Despite the serious financial problems characteristic of modern Russia, analysis of the scientific information obtained by the Interball satellites is progressing quite successfully. In addition to the special Interball issues of *Annales*, a number of other results have already been published or are now in press in the Russian Journal *Kosmicheskie Issledovaniya* [in vol. 34, issue 4 (1996); vol. 36, issues 1, 3 and 6 (1998); and vol. 37, issue 3 (1998); an English translation of this journal is published under the title *Cosmic Research*.)] The main results of the Interball mission have also been reported at the EGS Assembly in Nice (April 1998), at the 32nd COSPAR Scientific Assembly in Nagoya (July 1998), and will be presented in February 1999 at the Interball symposium in Zvenigorod (near Moscow) and in April at the EGS General Assembly in Den Haag. Many other scientific publications are now in preparation. Their characteristic feature is the analysis of multi-satellite measurements of plasma particles and electromagnetic fields within and outside the magnetosphere.

Figure 1 gives a view of the orbits of the Auroral Probe for January 1998, while Table 1 gives a list of its experiments. This instrumentation has been designed to perform systematic measurements at the interface between the magnetosphere and the ionosphere, in coordination with related observations by the Fast, Polar, Geotail and Wind spacecraft. A detailed discussion of the scientific objectives of the mission and its strategy may be found in the paper by Galeev *et al.* published in the special issue of *Cosmic Research*, vol. 34 issue 4 (1996). In the same issue one can also find a technical description of the Interball Prognoz-M2 spacecraft and the Magion sub-satellites (Kremnev *et al.*, 1996; Agafonov *et al.*, 1996). Additional information about the spacecraft, their housekeeping systems, and a technical description of the scientific payload can be found in the pre-launch report *Interball – Mission and Payload*, published by CNES in 1994, which is available on request.

This issue carries seven papers which briefly describe the instruments and illustrate several first scientific results. Three papers are devoted to particle measurements, and cover a broad energy range from the high energy part of the spectrum (Stepanov *et al.*), to auroral particles (Sauvaud *et al.*), and the thermal and suprathermal plasma (Dubouloz *et al.*). A new phenomenon is analysed at the polar edge of the auroral oval in the postmidnight sector, namely field-aligned upward electron beams in the energy range 20–40 keV (Stepanov *et al.*). A new feature of the proton aurora is found on the morning side of the auroral oval, i.e. repetitive and overlapping ion dispersed structures which indicate possible plasma entry at the tail flank (Sauvaud *et al.*). The first observation of an ion outflow from the ionosphere associated with the polar edge of the auroral oval is presented by Dubouloz *et al.* The experiment which is directed towards the study and control of the Langmuir sheath around Interball-2 is discussed in the paper by Torkar *et al.*. Three papers are devoted to wave measurements. Auroral kilometric radiation (AKR)

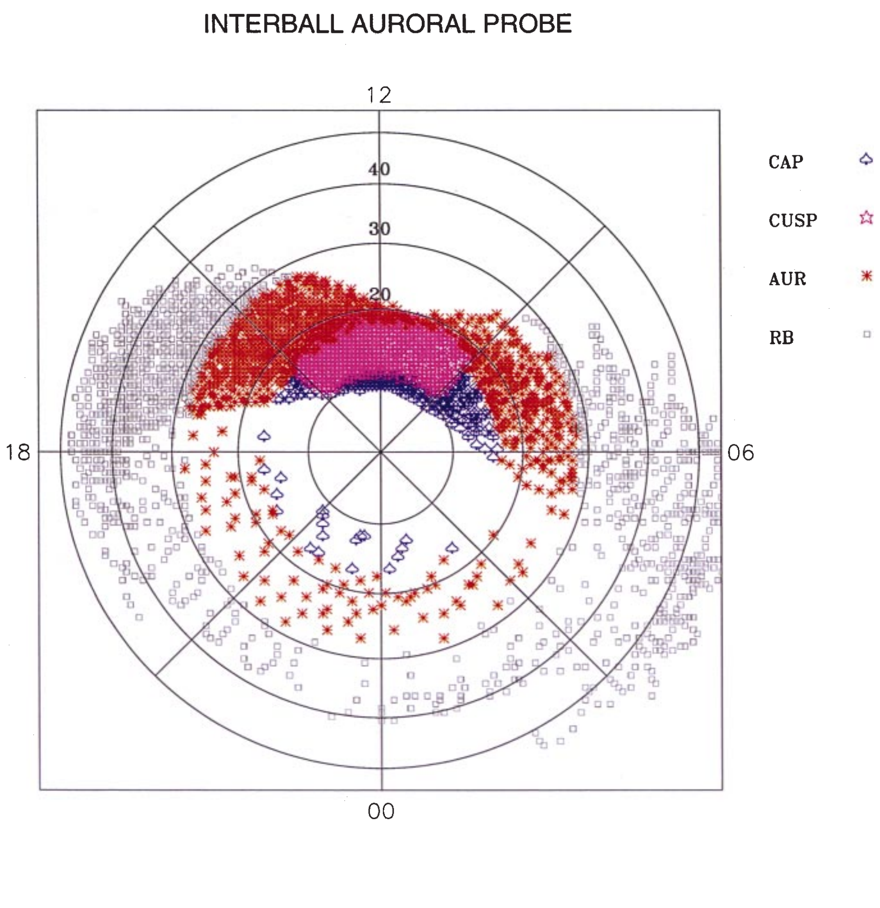

Fig. 1. Orbits of the Auroral Probe for January 1998 in a polar diagram (magnetic local time and invariant co-latitude). The symbol *CAP* refers to the polar cap, *CUSP* to the polar cusp, *AUR* to the auroral zone, and *RB* to the radiation belt. The satellite sweeps out all local times in ~9 months. (Courtesy of V. Prokhorenko)

Table 1. List of experiments on the main Interball-Auroral Probe

Experiment	Measured parameters	Principal investigator
SKA-3	Electron and ion distributions 0.03–15 keV/Q Anisotropy of electrons and ions (M/Q = 1, 4, 16) 30–500 keV/Q	Yu. Galperin
ION	Ion and electron distributions (M/Q = 1, 2, 4, 16) 0.005–20 keV/Q	J. A. Sauvaud
PROMICS-3	Ion composition (M/Q = 1–32) and 3D energy distribution 10 eV < E < 30 keV/Q	I. Sandahl
HYPERBOLOID	Ion composition and 3D distributions M/Q = 1–32 (with H^+, He^+, O^{++}, O^+) 0.1 < E < 80 eV/Q	N. Dubouloz
KM-7	Temperature of cold electrons T < 10 eV	J. Smilauer
ALPHA-3	Thermal plasma ion flux E < 25 eV/Q	V. Bezrukikh
IESP-2M	DC electric field and ULF waves 0.1–30 Hz	S. Perraut
POLRAD	Auroral kilometric radiation 20 kHz–2 MHz	J. Hanasz
MEMO	Electromagnetic waves in wide band (quantitative analysis) f < 240 kHz	F. Lefeuvre
NVK-ONCH	VLF electromagnetic waves 20 Hz–20 kHz	A. Goljavin
DOK-2	Energy and angular distributions of electrons (15–400 keV) and ions (20–1000 kev)	K. Kudela
RON	Spacecraft electric potential control by ion beams (N_2^+, In^+) Ion beam currents 0–15 μA	K. Torkar
UVAI	UV auroral imager 140–160 nm	L. Cogger
UFSIPS	UV auroral oxygen emissions 130.4, 135.6, 149.3 nm	A. Kuzmin
RD-lM	Dosimetric measurements	V. Bengin
ANOD	Comparison of different solar panels	A. Koslov

measurements are presented in the paper by Hanasz *et al.* They report abrupt upper frequency cutoffs (400–700 kHz) in the spectra of the AKR, together with "ridges" of radiation which are sometimes observed at the cutoff frequency with a power density up to two orders of magnitude larger than in the wide-band emission. At the other extreme of the auroral frequency spectrum, the six field components of ULF waves have been measured, and the first results on quasi-monochromatic electrostatic emissions and electromagnetic wide-band spectrum fluctuations are reported (Perraut *et al.*). Finally, Lefeuvre *et al.* present preliminary results from the multicomponent measurements of waves from a total of six electric and nine magnetic independent sensors, allowing the restitution of waveforms associated with the measurement of two to five components in three frequency bands – ELF (5–1000 Hz), VLF (1–20 kHz), and LF (20–250 kHz), with a special emphasis on the estimation of the propagation characteristics of the observed waves.

Many studies are presently underway using the correlated measurements obtained onboard the Tail and Auroral Probes of the Interball mission. More information can be obtained on the Interball WWW site http://www.interball.rssi.ru.

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