Annales Geophysicae

Special Topic

Interball-1: first scientific results

The multi-satellite Interball mission had its origins at the end of the 1970s with the idea of a mission which would allow the study of the magnetosphere's global dynamics as well as resolving its small-scale structures. A long and dramatic history then followed, which included multiple delays, a change of the launch site, as well as the urgent development of a new and advanced scientific telemetry system (SSNI). Finally, on 3 August 1995, Interball-1 (the Tail Probe) and its sub-satellite (Magion-4) were successfully launched into a highly elliptical orbit with a period of 92 h, an apogee of about 200,000 km, and an inclination of 62.8 degrees. For an orbit of this type the line of apsides does not rotate, i.e. the apogee stays at constant latitude. The following year, on 29 August 1996, Interball-2 (the Auroral Probe) was launched from the same northern Russian cosmodrome (Plesetsk).

Figure 1 gives an artist's view of the Interball mission, while Fig. 2 shows the spacecraft orbit in a model magnetospheric magnetic field. The orbital characteristics have been optimized in such a way that Interball-1 crosses the neutral sheet of the magnetotail in the distance range ~8–20 R_E from the Earth, which is though to be the region in which substorms are initiated. This spacecraft started its measurements in the solar wind near the dawn flank of the magnetosphere (Fig. 3). The scientific rationale for this choice was to begin the investigations in a more "easy" and familiar environment, appropriate to instrument commissioning and cross-calibration. At a later stage (October 1995–January 1996), Interball-1 performed systematic measurements in the nightside magnetosphere, and a number of interesting investigations were conducted, many of them coordinated with the Geotail and Wind spacecraft. A detailed discussion of the scientific objectives of the mission and its strategy may be found in a paper by Galeev, Galperin and Zelenyi (1996) published in a special issue of *Cosmic Research* (vol. 34, (4) p. 342, 1996, a translation of the Russian journal *Kosmicheskie Issledovania*). The same issue includes a technical description of the Interball-Tail Prognoz-M2 spacecraft, and of the Magion sub-satellites (Kremnev, Smirnov and Gorkin, 1996; Agafonov, Khrapchenkov, Triska and Voita, 1996). Additional information about the spacecraft and their subsystems, together with a technical description of the scientific payload, can be found in the pre-launch report *Interball-Mission and Payload*, published in 1994 by the CNES, which is available on request. In addition to the results derived from the Interball-1 Tail Probe, three papers presented in this issue are devoted to measurements obtained by the Magion-4 sub-satellite, which have been correlated with data obtained by the Tail Probe. It should be remembered that the sub-satellite has a maneuvring capability, and that the separation from the main spacecraft is adjusted according to the physical processes under study (the distance is increased during tail passages and usually reduced for magnetopause and bow-shock studies at the dayside). Figure 4 shows the resulting separation strategy used during the first year of Interball-1 operation.

This issue of *Annales Geophysicae* carries eight papers which briefly describe the first scientific results from the Interball programme. A few more papers which had problems in meeting the deadline will be published later in a regular issue of the journal. Two papers published here are devoted to the analysis of waves observed aboard the main spacecraft and the sub-satellite (Klimov *et al.*; Blecki *et al.*). A rich collection of such data was acquired during several months of orbit operation. The first results obtained in the magnetotail during disturbed periods, at the magnetopause, and in the polar cusp, are presented. Six further papers deal with the results obtained from particle measurements on board these spacecraft. Two of them present brief initial reviews of the ion distribution functions obtained from quasi-3D measurements in the solar wind near the Earth's bow shock (Yermolaev *et al.*), and from 3D ion measurement in the magnetosheath, plasma sheet, and ring current (Sandahl *et al*). Two further papers, based on sub-satellite data, show the presence of quasi-periodic pulses of magnetosheath-like plasma earthward of the magnetopause. Use of two-spacecraft data, separated by ~1000 km, allows an estimation of the magnetopause velocity, and a reconstruction of the possible structure of the boundary (Nemecek *et al.*; Safrankova *et al.*). Two final papers present results

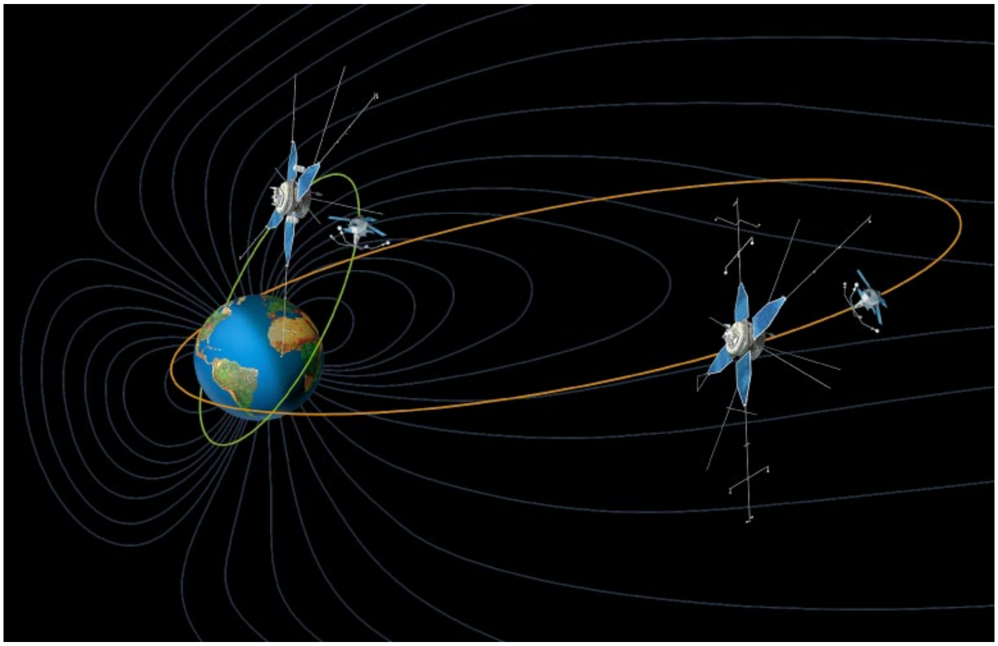

Fig. 1. Schematic view of the Interball mission in the Earth's magnetosphere

obtained near the magnetopause and inside the boundary layers, observed by the main satellite. In one of them, 3D ion measurements obtained from two dawn-magnetopause crossings, one at low-latitude, the other at mid-latitude, suggest that plasma blobs penetrate inside the magnetosphere possibly due to non-stationary reconnection (Vaisberg *et al.*). In the other, 3D electron measurements (together with magnetic field data) show that the dawn low-latitude boundary layer, corresponding to low energy bidirectionnal electrons encountered at the interface between the magnetosheath and the dayside extension of the plasma sheet, have an unexpected apparent radial extent, up to 5 R_E inside the magnetopause, mainly during northward IMF conditions (Sauvaud *et al.*).

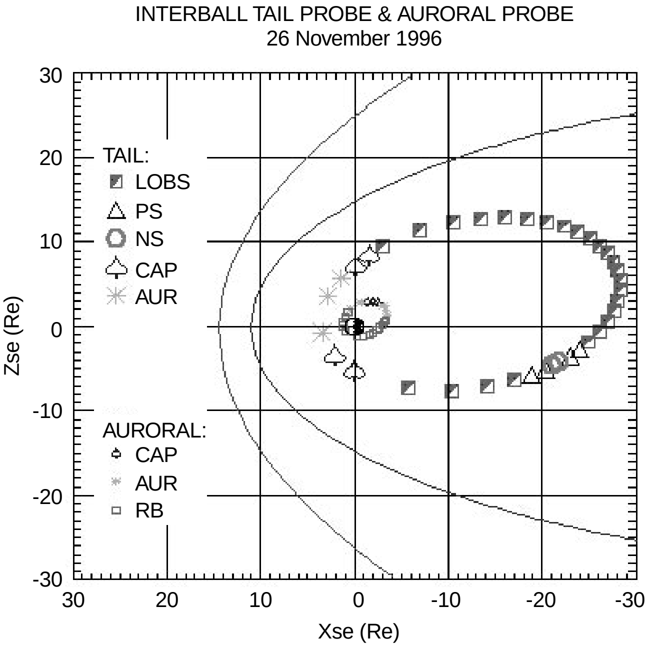

Fig. 2. Orbits of the Interball Tail and Auroral Probes on 26 November 1996, projected onto the noon-midnight meridian plane, in solar-ecliptic coordinates. Xse points towards the Sun. Average models of the bow shock and the magnetopause are indicated. Along the orbit of the Tail Probe, the computed position of the tail lobe (LOBS), plasma sheet (PS), neutral sheet (NS), polar cap (CAP), and auroral zone (AUR) are indicated on the left side of the figure by symbols with different colours. The same presentation is used for the orbit of the Auroral Probe. (Courtesy of V. Prokhorenko)

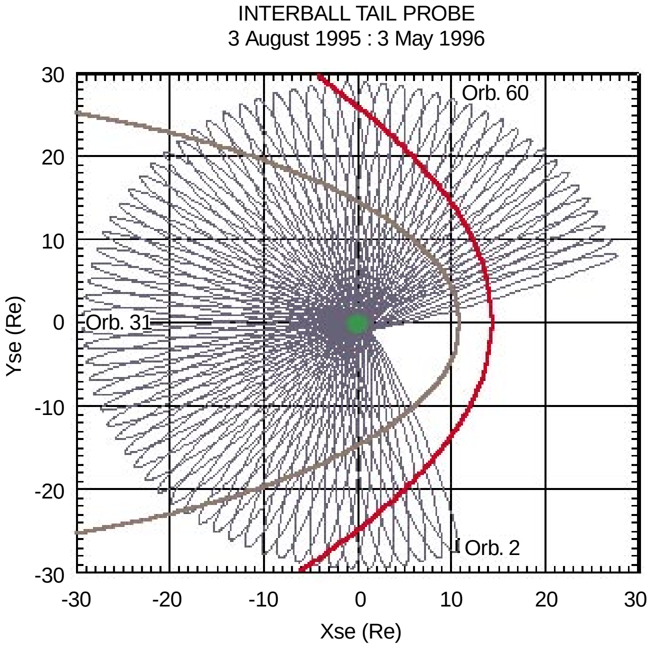

Fig. 3. Orbits 2 (3 August 1995) to 74 (3 May 1996) of the Tail Probe projected onto the ecliptic plane. Average models of the Earth's bow shock and the magnetopause are indicated by the *red* and *brown curves*, respectively

Table 1. List of experiments on the main Interball Tail Probe

Instrument	Principal investigator(s)	Description
SKA-1	O. Vaisberg	Fast 3D ion spectrometer 0.05–5 keV
ELECTRON	J.-A. Sauvaud	3D electron spectrometer 0.01–26 keV
VDP	J. Safrankova	Omnidirectional plasma sensor 0.2–2.4 keV (Faraday cup)
CORALL	Y. Yermolaev	Quasi-3D ion spectrometer 0.025–25 keV
PROMICS-3	I. Sandahl	3D energy/mass analyzer 0.004–30 keV
ALPHA-3	V. Bezrukikh	Thermal plasma ion flux analyzer $N_i > 1\ cm^{-3}$, $E < 25\ eV/Q$ (ion trap)
DOC-2X	K. Kudela	Medium energy ion and electron spectrometer e^-: 20–400 keV, ions: 20–850 keV
SKA-2	E. Morozova N. Pissarenko	High energy spectrometer e^-: 40–500 keV, protons, α: 50 keV/N–150 MeV/N
RF-15	O. Likin	Solar X-ray spectrometer 2–200 keV
ASPI:	S. Klimov	Wave and field experiments
MIF-M	S. Romanov	Fluxgate and search coil magnetometers, 0–2000 Hz
PRAM	S. Romanov	Waveform processor
FGM-I	J. Rustenbach	Fluxgate magnetometer
OPERA	E. Amata	Electric field experiment
FM-31	M. Nozdrachev	Fluxgate magnetometers $\pm$ 200 nT (16 vectors s^{-1}); $\pm$ 1000 nT (0.3 vectors s^{-1})
AKR-X	V. Grigorieva	Kilometric radio-emission analyzer 100–1500 kHz

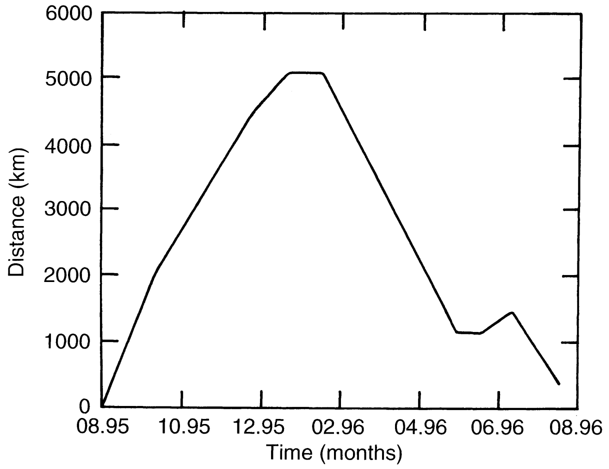

Fig. 4. Satellite-to-sub-satellite separation when located at 100,000 km from the Earth, as a function of time (months)

Launches in 1996 of the Polar spacecraft, Interball-2 (the Auroral Probe), and FAST have opened many new and unique opportunities for studying ionosphere-magnetosphere coupling, substorm dynamics, and the structure of the high-latitude auroral regions from multi-point measurements. Some of these studies are currently under way, others will be accomplished in the future. Unfortunately, the loss of Magion-5 (the sub-satellite of the Auroral Probe), and the malfunctioning of some experiments on the Tail Probe, have somewhat reduced the potential scientific outcome of the mission. However, the main set of plasma, magnetic field, and energetic particle experiments on board Interball-1 (see Table 1) is still working quite successfully 19 months after the launch, and there are no obvious signs of substantial degradation of the experimental equipment. More serious problems for the future of the mission may arise from budgeting restrictions for spacecraft operations. After half a year of operation the main scientific experiments on board the Auroral Probe are working well, and we hope that a similar set of papers devoted to the first scientific results from this spacecraft will also appear in *Annales Geophysicae* at the beginning of next year.

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