

Introduction to special section: The Freja Mission

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Abstract. Freja was a joint Swedish and German scientific satellite project to study the interaction between hot magnetospheric plasma and the topside atmosphere/ionosphere. Freja was launched on October 6, 1992, and it operated successfully during 4 years until October 1996 when the command system ceased to work. Freja enabled high temporal/spatial resolution measurements of auroral plasma characteristics. With a high telemetry rate (520 kbit/s) and ~15 Mbyte distributed onboard memories Freja could resolve mesoscale and microscale phenomena in the 100 m range for particles and the 1-10 m range for electric and magnetic fields. Novel plasma instruments enabled Freja to increase the spatial/temporal resolution orders of magnitudes above that achieved by its predecessors. The main scientific objective of Freja was to study the interaction between the hot magnetospheric plasma with the topside atmosphere/ionosphere. This interaction leads to a strong energization of magnetospheric and ionospheric plasma and an associated erosion, and loss, of matter from the Terrestrial exosphere. Freja orbited with an altitude of ~600-1750 km, thus covering the lower part of the auroral acceleration region. This altitude range hosts processes that heat and energize the ionospheric plasma above the auroral zone, leading to the escape of ionospheric plasma and the formation of large density cavities.

1. Introduction

The Freja satellite, launched on October 6, 1992, was a follow-up of the first Swedish satellite Viking that was launched on February 22, 1986. Viking and Freja are examples of successful low-cost, yet advanced, satellites for space plasma physics studies while FAST, launched in 1996, is the most recent one. Freja was equipped with instruments from several countries, in addition to Sweden, these were also instruments from Germany, Canada, United States, Finland, Norway, and France.

Freja was designed for fine-structure plasma measurements with a temporal/spatial resolution that was unprecedented up to 1996 when FAST was launched. Before that, low-altitude satellites suffered from the high speed by which they traverse the auroral region and having a relatively low data rate. Up to then only sounding rockets were capable of performing fine-structure measurements by virtue of their lower horizontal speed (less than 1 km/s) and higher data rate (at least one megabit per second). Traversing a “normal sized” auroral arc by a sounding rocket usually takes some 10-30 s. For a satellite the corresponding time for traversal is 1-3 s. A high data rate and onboard data reduction and compression substantially reduce the temporal/spatial resolution gap between sounding rockets and satellites. After 4

years in orbit, Freja has acquired an impressive database of fine structure measurements of almost sounding rocket spatial/temporal resolution. As this special section shows, it is now possible to perform statistical studies of microphysics phenomena from the Freja database.

An apogee of 1750 km suggests that Freja generally passed below the midaltitude auroral acceleration region studied by S3-3, DE1, Viking, Akebono, and recently FAST. Instead, Freja focused in much more detail on the impact of the auroral acceleration processes on the topside ionosphere. Large holes of reduced density created by cavitation processes [e.g., Calvert, 1981; Persoon *et al.*, 1988; Haerendel, 1989; Lundin and Hultqvist, 1989; Lundin *et al.*, 1994] are also regions with high wave activity and nonlinear plasma instabilities [e.g. Benson and Calvert, 1979; Pottellette *et al.*, 1987]. Detailed studies of mesoscale as well as microscale density cavity structures have been done by [e.g., Boström *et al.*, 1987; Vago *et al.*, 1992].

The 63° inclination orbit provided an interesting new perspective of the auroral acceleration structure and its associated current system. The “slanted cut” of the auroral oval gave an extended duration of the oval traversal but also added a unique perspective of frequently occurring north-south directed field-aligned currents. The 63° inclination frequently give tangential traversals of the auroral oval, covering an extended longitude range. Large-scale “inverted-V” structures are covered in longitude by up to 5 hours in magnetic local time. Such traversals at times display a remarkable stability of the auroral acceleration process, but at other times also display highly dynamic features.

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2. The Freja Mission and Science Objectives

The Freja mission represents a continuation of a line of magnetospheric research that began with the first Swedish satellite Viking. As on Viking, participation in the instrumentation for Freja is spread over a number of countries, but the satellite is mainly funded by Sweden (~75%) and Germany (~25%). The low-cost approach on Freja follows a highly successful tradition, such as Viking and AMPTE (Germany). A piggyback launch on the Chinese Long March 2C and a very streamlined project organization is utilized to keep the costs of the satellite plus launch to within 100 million Swedish kronor (< \$15 million U.S. in 1997). Despite the low-cost, Freja turned out to be a very dependable satellite, with a lifetime of 4 years.

The satellite had the shape of a spinning disk with a diameter of 2.2 m. The axis of the disk points in the direction of the Sun so that the solar panel on the top of the satellite will be constantly illuminated. A relatively high power (maximum of 137 W) was obtained from the solar panels. The spacecraft was kept in a Sun-pointing position using a magnetic torquing technique. Freja was successfully launched as a piggy-back satellite together with a Chinese satellite on a Chinese Long-March II rocket on October 6, 1992. After launch into a 63° inclination, Freja was lifted to a higher perigee (~600 km) and apogee (1750 km) by means of two separate solid fuel boost motors. The 63° inclination provided good auroral oval coverage over the American continent. Thus the Canadian Prince Albert ground station was an important ground segment for the direct transmission of data. However, Esrange in Sweden was the main operations center where all uplink communications are performed. Some data about the spacecraft and orbit are summarized in Table 1.

The scientific objective of Freja is to explore the fine structure plasma properties within the low-altitude portion of the auroral acceleration region and to study the physical processes whereby ionospheric plasma is being heated/accelerated and subsequently ejected out into the magnetosphere. The altitude range traversed by Freja (~600-1750 km) constitutes the topside ionosphere and the low-altitude part of the auroral energization region. A high telemetry rate and state-of-the-art design of the instrumentation enabled more than an order of magnitude increased temporal/spatial resolution compared to its predecessors, which made Freja even exploratory in some aspects. Results from Freja have improved our understanding of processes and phenomena in space plasma physics, such as (1) processes responsible for the transverse heating/energization and loss of ions and electrons in the topside ionosphere, (2) plasma density cavities, their importance and consequences for the interaction between hot and cold plasma, (3) low-altitude ion and electron acceleration, (4) processes leading to the formation of fine-structure in auroral forms, and (5) wave-particle interaction and the great variety of wave phenomena on auroral field lines. The Freja payload comprised a full complement of high-resolution plasma diagnostic instruments and a fast auroral imager. Table 2 lists the individual instruments, their key elements, performance parameters, and the Principal Investigators.

3. Scientific Contributions from Freja

The apogee of Freja, at ~1750 km, implies operations at the lower edge, or below, the midaltitude auroral energization region. Thus the Freja mission differs from, for example, Viking, FAST, and other midaltitude missions that emphasize in situ measurements within the field-aligned acceleration region.

Instead, Freja was uniquely suited to study the impact of the auroral acceleration process on the structure of the topside ionosphere. Large holes in plasma density, created by cavitation processes in the lower edge of the auroral energization region [e.g., Calvert, 1981; Persoon *et al.*, 1988; Haerendel, 1989; Lundin and Hultqvist, 1989], are regularly observed along Freja's trajectory at auroral latitudes [Lundin *et al.*, 1994]. These cavitations are due to the heating and upward loss of electrons and ions simultaneously, preferentially due to strong wave activities within the cavities (see, e.g., Hultqvist, [1991], and André and Yau, [1997], for reviews).

Plasma density cavities have strong effects on the auroral processes. They establish and maintain the conditions for current instability, they constitute a "memory" in (or imprint on) the magnetosphere-ionosphere interface of the recent occurrence of accelerations, they modify the transmission of energy carried by, for example, Alfvén waves towards the ionosphere, and they are the source region of auroral kilometric radiation. Thus Freja has scanned a region of utmost importance in the production and modification of electrostatic and electromagnetic plasma waves.

The most significant advance in auroral physics by Freja was made possible by the greatly enhanced temporal-spatial resolution of the in situ measurements related to the fine structure of auroral arcs. A detailed analysis of the electric field, current, and hot and cold plasma distributions inside and around auroral structures has brought us closer to a complete understanding of the aurora.

Table 1. Characteristics of the Freja Satellite

Characteristic	Value
Orbit	
Inclination	63.0°
Apogee altitude	1756 km
Perigee altitude	601 km
Orbital period	109 min
Attitude	
Spin stabilized	10 rpm
Sun oriented	(± 30°)
Magnetic control	
Size	Φ 2.2 ∞ 0.5 m high
Mass	
At launch	255.9 kg
In orbit	214.0 kg
Payload weight	73.1 kg *)
Telemetry	
High TM	262/524 kbps - S band (2208 MHz)
Low TM	200 bps - (400.55 MHz)
Command	1200 bps - (449.95 MHz)
Storage on experiment level	~15 MByte
Power	
Solar cells on S/C body	1.08 m ²
Maximum delivered power	137 W
Payload	66.1 W
Actual lifetime	4 years

*) Including 21.6 kg stiff booms and wire booms.

Table 2. Freja Scientific Payload and Science Coordination

Experiment	Measurement Technique	Principal Investigator
F1 electric fields	three pairs of Wire booms, 20 tip-to-tip two components of E up to 6000 samples/s	<i>Göran Marklund</i> , Alfvén Laboratory, Royal Institute of Technology, Stockholm, Sweden
F2 magnetic fields	triaxial fluxgate on 2 m boom three components of B, 128 samples/s	<i>Lawrence Zanetti</i> , Johns Hopkins University, Applied Physics Laboratory, Laurel, Maryland, USA
F3H particles, hot plasma	2-D Magnetic electron spectrometer 2-D distribution 0.1-115 keV, 100 samples/s 2-D Ion composition spectrometer => 3-D distribution 0.001-10 keV in 3 s	<i>Lars Eliasson</i> , Swedish Institute of Space Physics, Kiruna, Sweden
F3C particles, cold plasma	2-D ion/electrons on 2 m boom 3-D distribution of cold plasma (<300 eV) >100 samples/s	<i>Brian Whalen</i> , National Research Council, Ottawa, Canada
F4 waves	Wire booms plus three axis search coil E, B, Δn waves, 1 Hz to 2 MHz	<i>Bengt Holback</i> , Swedish Institute of Space Physics, Uppsala-Division, Uppsala, Sweden
F5 auroral imager	2 UV CCD cameras auroral images every 6 s	<i>John S Murphree</i> , University of Calgary, Calgary, Canada
F6 electron beam	three electron guns three components of E, 100 samples/s	<i>Götz Paschmann</i> , Max Planck Institut für extraterrestrische Physik, Garching, Germany
F7 correlator	2-D electron spectrometer 0.01-20 keV, correlation F4	<i>Manfred Boehm</i> , Max Planck Institut für extraterrestrische Physik, Garching, Germany
European ground- based coordinator	European network of ground-based observations	<i>Hermann Lühr</i> , Institut für Geophysik and Meteorologie, Braunschweig, Germany
North America ground- based coordinator	North American network of ground- based observations	<i>Gordon Rostoker</i> , University of Alberta, Edmonton, Alberta, Canada

Similar analysis has been done for the fine structure of discrete auroral arcs, frequently with individual arc segments in the hundred meter range, hitherto only resolved by a relatively limited number of sounding rocket measurements at altitudes generally much below 1000 km. Freja has radically improved the database for fine-structure measurements but has also accessed an altitude range hitherto not attended by instruments utilizing fine-structure measurement techniques.

4. Conclusions

Many problems on the microphysics of the auroral acceleration region require higher time resolution measurements than have been available on satellites before Freja. By using a combination of high telemetry rate and onboard memories, Freja provided, between one and several orders of magnitude higher time resolution than was achieved by satellites before 1996 when FAST was launched. With 4 years of successful data collection in orbit, Freja has provided a unique database on microphysics phenomena, enabling a statistical analysis of such phenomena.

Freja also provided high-quality measurements (longer booms, faster distribution function measurements, electron beam instrument) and the ability to reprogram instruments in flight so as to answer new questions about microphysics as they appear. Freja was also the first satellite ever to introduce the Internet for experiment command and control, as well as for the transfer of near real-time data between operations and science institutes. Indeed, the Internet made the Freja operations very versatile and simple, for the operators as well as for the science groups.

The 63° orbit inclination turned out to be much more valuable than first anticipated. In fact, the 63° inclination has a number advantages compared to the 90° inclination usually considered for auroral missions. One is that it provides a slanted/ tangential cut of the auroral oval, as shown by the UV image in Plate 1. This enabled a longitude scan of the aurora. Another advantage is that the satellite stays much longer in the auroral oval, up to 10 min. Yet a third is that this unusual cut of the oval made it possible to study north-south characteristics within the oval, for example Sun-aligned arc segments and Omega bands, which have as yet mostly been studied from the ground or by auroral imagers.

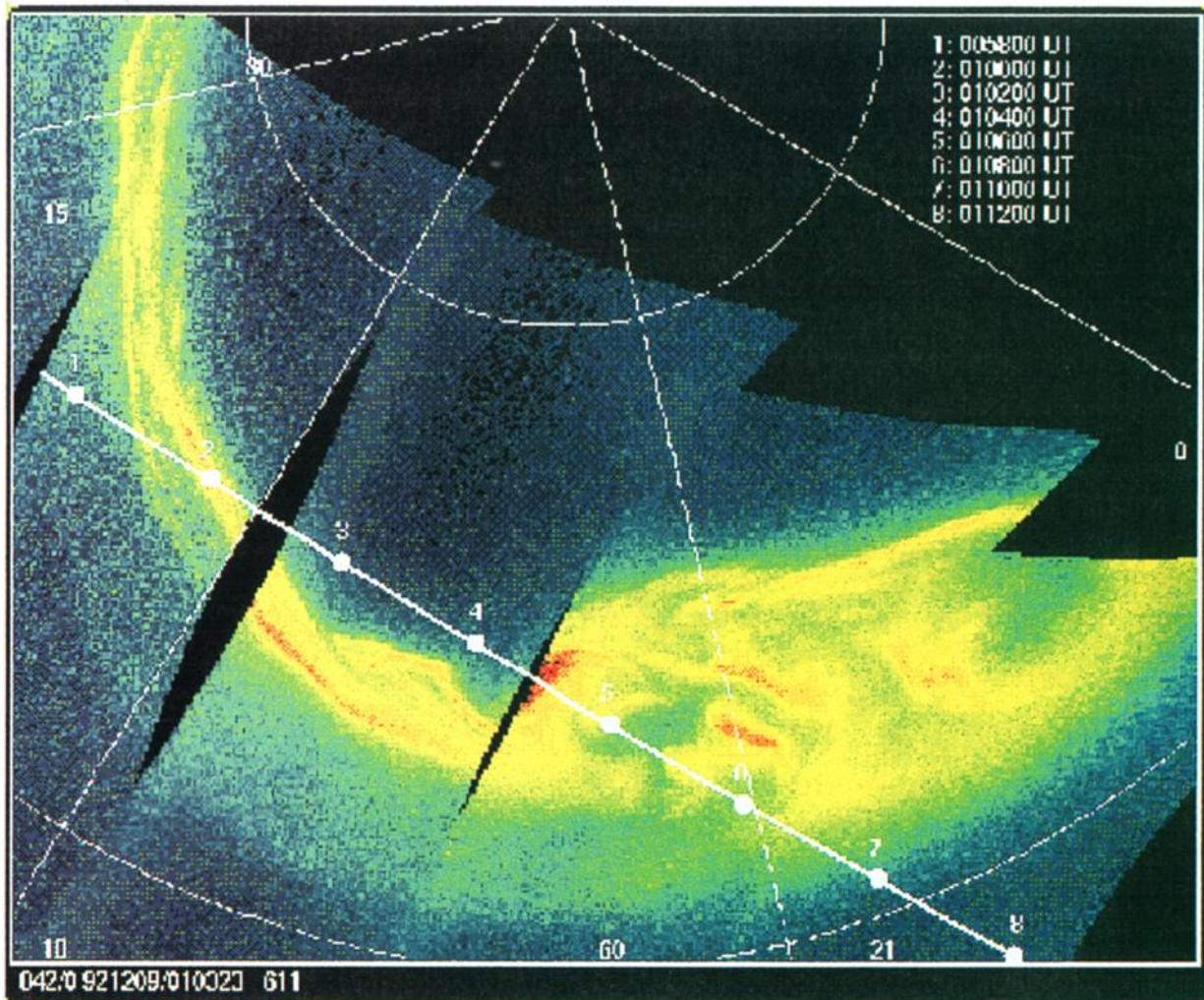


Plate 1. Freja pass over an active auroral oval as viewed by the UV auroral imager (F5). Dashed line illustrates the Freja footprint along the oval.

The success of Freja, a low-cost high-performance scientific satellite mission, marks the beginning of a trend in space science. The notion that low cost and low complexity leads to inferior science has been refuted already by missions such as S3-3, AMPTE, and Viking. Freja has proven that the “faster-cheaper-better” approach leads to more timely science development and the testing of new ideas with state-of-the-art instruments that can be put rapidly into orbit at a relatively low cost. The modest pace of today’s costly, sparse, and frequently delayed large-scale missions has stalled rather than advanced contemporary space plasma physics. Small dedicated space physics missions will play an important, if not the most important role for the progress of space physics in a time of limited resources and more strict demands on science by society.

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