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Space Physics

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Abstract

The paper describes Finnish attempts to understand phenomena in the near Earth space by using ground-based observations and later observations from space. The geophysical observatories and networks of recording instruments are described as essential tools. During the latest two decades, satellite data have been combined with good results with the ground observations. These achievements are given mainly in the form of references. Finnish research units have contributed in building satellite instruments. Short description of the ongoing space activity in Finland is given.

1. Introduction and historical notes

Historical notes here refer mainly to the time before the International Geophysical Year (IGY) 1957–58. A detailed history of geophysics in Finland for the period 1828–1918 has been published by *Simojoki* (1978). The history of physics in Finland 1828–1918 by *Holmberg* (1992) deals partly with the same persons and research programs but more from the physics point of view. Below we mention the Finnish activities, which we consider to have value for the study of space physics. Remote sensing using observations from space and astronomy are considered to be outside the topics of this paper. *S.-E. Hjelt's* article in this same issue of *Geophysica* deals partly with same observatories and networks of recording stations as this paper and is recommended.

This paper is a common effort of the authors. Bösinger, Mursula and Kangas have reviewed the Finnish studies of the near Earth space based on recordings of magnetic pulsations. Nygren has collected the Finnish achievements in ionospheric studies. Kauristie describes the auroral studies, and Koskinen presents the Finnish contribution on building and developing space instruments and the scientific results obtained.

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The study of space physics before the satellite era was based on ground observations of auroras, variations of the magnetic field, induced electric currents and reflections of radio waves from the upper atmosphere, all supposed to be connected with the phenomena in the near Earth space, controlled somehow by the Sun. For these observations, Finland like the other Scandinavian countries has an excellent location. Finland lies at rather high latitudes, from 60°N to about 70°N, in the auroral zone or close to it. The climate is tolerable due to the nearby Gulf-stream, so, in spite of the high latitudes, the area has been inhabited long times and the conditions are favourable also for the geophysical observations urgently needed from high latitudes where the physical phenomena in space are possible to observe from the ground. In fact, Finland has a long tradition in accurate ground observations of variations of the magnetic field, auroras and other ionospheric phenomena. Geophysical observatories have been and are established and equipped with best available methods and tools of the time for the recording of the geophysical elements.

Before photographic or paper recording systems became available, eye readings had to be applied. Such observations were made at the Helsinki Observatory starting 1844 (see below) and at the Polar year observatories in Sodankylä and Kultala, 1882–1884 (see below). The new Sodankylä observatory (see below) since 1913 used photographic recordings but had to use oil lamps in the beginning in lack of electricity. Since 1980′s all recordings at the Finnish observatories and temporary stations are digital. *Table* 1 below lists the essential progressive steps in observations and studies connected at least marginally to space physics.

In 1838 a magnetic observatory was founded in Helsinki (the birth of the institute now called Finnish Meteorological Institute) at lat. 60°10′N, long. 24°57′E (*Nervander*, 1850). *J. J. Nervander* (1805–1848) was appointed director of the observatory in 1838. Before the founding of the observatory, Nervander made a three year long excursion to the main institutes dealing with geomagnetic observations. In Copenhagen he met *Oersted*, in Göttingen *Gauss* and *Weber*, in Paris *Bequerel* and *Guy-Lussac* and in St. Petersburg *Kuppfer* (the actual initiator of the founding of the Helsinki Observatory) and *Lenz* (*Simojoki*, 1978). The first published magnetic yearbook from the Helsinki observatory is for the year 1844. The observatory had to be closed in 1912 due to disturbances by DC-currents used in street cars. Only observations for the years 1844–1848 were published during Nervander's time and after his early death in 1848 (*Nervander*, 1850). Recently, all available magnetic observations (about 2,000,000) carried out in the Helsinki observatory have been treated in electronic form. *Nevanlinna* et al. (1992a, 1992b, 1993, 1994) have analysed the data and published comprehensive summaries of magnetic variations recorded at the observatory, 1844–1909.

Finland contributed to the First Polar Year 1882–1883 by founding a complete geophysical observatory at Sodankylä (lat. 67°24′N, long. 26°36′E) with an auxiliary station at Kultala 115 km north of Sodankylä (*Lemström* 1885a, 1885b). Sodankylä continued the observations an extra year. In Sodankylä, *Lemström* (1886a, 1886b) tried to determine the altitude of auroras by triangulation method. He seems to have been familiar with similar attempts made in Greenland, in several places in Europe and by *Nordenskiöld* in the Bering Strait, all giving different results from a few kilometres to more than a thousand. Sodankylä's own measurements gave a rather low mean altitude (about 40 km) with a large scatter of results. Short distance between the observers, only 4.5 km due to difficulties in getting longer telephone cables, explains the scatter. Lemström concluded that the aurora was an electric phenomenon and even tried to artificially produce auroras using corona discharges (*Lemström,* 1886a; *Lemström,* 1886b). He also presented a working miniature model where auroral discharges were produced in *Geissler* tubes. Lemström handled in the same publication the atmospheric electricity and presented a global model where the atmosphere has a positively charged conductive layer at an altitude of 40 km or higher. He also tried to explain the physical mechanism for the generation of the layer. It took almost hundred years before *Tuomi* (1984) in his Ph.D. thesis presented the role of thunderstorms as the mechanism which keep up the high potential (200–300 kV) in the global ionospheric layer.

In 1913, the Finnish Academy of Science and Letters (founded in 1908) established a permanent geophysical observatory in Sodankylä, the Sodankylä Geophysical Observatory (SGO), lat. 67°22′N, long. 26°8′E. Meteorological observations belonged to the work of the observatory since its beginning. At that time the director of the FMI was *Gustav Melander* (1861–1938). He deserves the main credit of the founding of the SGO. Also Professor *Ernst Bonsdorff*'s donation of 10 000 Finnish marks was essential for the start of the observatory. *J. Keränen* (Fig. 1) surveyed a large area in the rather

Fig. 1. Jaakko Keränen (1883–1979), the first director of the Sodankylä Observatory (1913–1917), later director of the Finnish Meteorological Institute (1931–1953). (Unknown photographer, FMI photoarchives.)

magnetically disturbed surroundings of Sodankylä before he found the present magnetically smooth enough place (*Keränen*, 1973) In 1949 the Finnish Meteorological Institute (FMI) founded a complete meteorological-aerological observatory in the same area. From January 1, 2001 the meteorological observatory was renamed to Finnish Meteorological Institute – Arctic Research Centre (FMI–ARC), as a result of its grown activities.

Fig. 2. Sydney Chapman, Jaakko Keränen, Dan la Cour and his daughter Lise la Cour in Rovaniemi market place in 1936. (Unknown photographer, FMI photoarchives.)

SGO was until the end of World War 2 a one-scientist observatory. The first director was Keränen (1883–1979), later director of the FMI. After Keränen the directors of the observatory were *H. Lindfors* (1917–1918), who fell in the War of Independence, *E. R. Levanto* (1918–1921) and *H. Hyyryläinen* (1921–1927). Thereafter came *E. Sucksdorff*'s (1899–1955) time from 1927 until the total destruction of the observatory in the war in 1944. Sucksdorff (Fig. 3) was an enthusiastic scientist and could inspire the best international geophysicists to visit the observatory. Among them were *Dan Barfod la Cour* from Denmark, *Sydney Chapman* from U.K., *Julius Bartels* from Germany, *Carl Störmer* from Norway and many others, rather regularly colleagues from the Scandinavian countries. The Second International Polar Year 1932–1933 was important for the SGO. Before the beginning of the Polar Year the SGO acted as test station of the new La-Cour magnetometers, which became standard instruments of most observatories. Two auxiliary stations, Petsamo and Kajaani, were in operation during the Polar Year. Sucksdorff's interests were in the field of magnetic pulsations, which will be mentioned later in Part 2 of this paper, magnetic activity (e.g. *Sucksdorff* 1942, 1955, 1956), earth currents, auroral observations, atmospheric electricity, ionospheric current systems *Sucksdorff* (1947) etc.

Fig. 3. Eyvind Sucksdorff (1899–1955), director of the Sodankylä Geophysical Observatory 1927–1944, here making absolute measurements with the Danish QHM-instrument. (Photo by C. Sucksdorff, FMI photoarctives.)

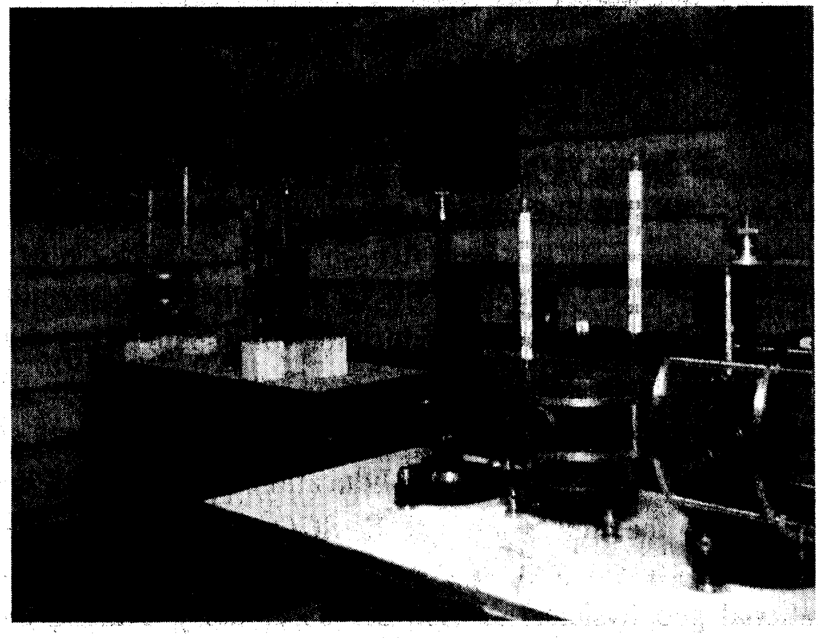


Fig. 4. La-Cour variometers in the variation room of the SGO in 1930's. (Photo by C. Sucksdorff, FMI photoarctives.)

The rebuilding of the observatory was done in 1945–1950 under the leadership of Sucksdorff. During that period the directors, who had to work in primitive conditions, were *M. Seppänen* (1945–1947) and *T. Hilpelä* (1948–1950). In 1950 *E. Kataja* (1927–) was appointed director of the observatory. He continued the studies on the magnetic activity along the lines started by E. Sucksdorff. When Kataja started as director, his staff was 2 persons, and in 1992 when he retired, the observatory had grown to a research unit of 25 employees, one third academic. The following Parts of this paper describe the development from the point of view of space physics. Table 1 lists the essential steps.

Fig. 5. Sodankylä Geophysical Observatory before total destruction in the German–Finnish war in Autumn 1944. (Photo by A. Nissinen, C. Sucksdoff's collection.)

The finances of the SGO had always been problematic because they were based on annual applications to the Ministry of Education for a grant. After the World War 2 (1945) the subsidy came from the profits of a state lottery. Therefore several attempts were made to have the observatory finances included in the normal state budget. A working group appointed by the Ministry of Education, using Finnish and foreign specialists, came in 1975 to the conclusion that the SGO should be moved under the state financed FMI, which operated a similar geophysical observatory at Nurmijärvi. The FMI also had its meteorological observatory in the same area as the SGO. The proposition was without result, because the Ministry of Finances opposed permanent additions to the state budget. A new working group appointed by the Ministry of Transportation and Communications, Publication 6/92, came to the same conclusion and proposition in 1992. A memorandum of a working group of the Ministry of Education to clarify the status of the SGO (Memorandum 35:1995) suggested that the SGO should be a separate unit of the state under the University of Oulu (UO). The arrangement was strongly supported by the observatory staff. It secured the SGO finances from the state budget. August 1, 1997, the observatory was moved under the UO (Ministry of Education).

Also the Finnish Academy of Science and Letters considered the UO to be a better host for the observatory than the FMI in spite of the fact, that the FMI–ARC (Ministry of Transportation and Communications) works in the same area. In 2001 the observatories will get a common main building. A detailed description of the Sodankylä observatory, its progress, directors etc. is to be found in (*Kataja,* 1973 and *Kataja*, 1999).

After Kataja the Academy nominated *T. Turunen* (1946–) to the director. He had distinguished at the observatory in many ways especially in ionospheric studies (see below). During Turunen's working 1998–2002 as director of EISCAT (European Incoherent Scatter Radar Association, see below), *J. Kangas* (1940–), pulsation geophysicist from the University of Oulu (UO), has as working director successfully widened the activities of the observatory.

The progress of geophysics at the FMI resembles that at the SGO. When E. Sucksdorff moved to the FMI from SGO at the end of 1944, he had only one assistant. The main tasks were magnetic field measurements, preparation of magnetic charts and planning the new observatories to Sodankylä and to Nurmijärvi (NGO) (*Sucksdorff* and *Haikonen*, 1958). After E. Sucksdorff's death in 1955, his works were divided between *M. Tommila* (born 1905) and *C. Sucksdorff* (1928–). Tommila had been responsible for the magnetic measurements at the Petsamo station during the Second Polar Year, and C. Sucksdorff was familiar with magnetic field measurements. The different international geophysical years (see below) gave opportunities to widen the activities. When C. Sucksdorff, who had followed E. Sucksdorff as the director of the Geophysics Division of the FMI in 1956, retired in 1991, the tasks of the Division included geomagnetic recording networks, auroral, ionospheric and space studies, and the number of persons had grown to over 40, 30 of them academic. *Risto Pellinen* (1944–), whose space physics group was the quickest grown in the Division, was appointed director in 1991. At the moment, the Division has about 50 workers (see below especially in Part 3).

The University of Oulu (UO) got a professorship in geophysics and a Department of Geophysics in 1960's. It concentrated mainly in solid earth physics, but the Department of Physics (*P. Tanskanen*, balloon experiments in high atmosphere) and the Department of Electrical Engineering (*J. Oksman*, ionospheric studies, see below) started research activities which led to forming a Space Physics Division to the UO. Co-operation with French and German groups in stratospheric balloon experiments started in 1965. Today the group constructs space instruments and uses satellite data combining them with ionosphere and pulsation recordings in exploring the magnetosphere (see below). The size of the group is now about 20 persons.

The fourth Finnish unit dealing with construction of space instruments and with scientific use of the produced data is *J. Torsti*'s group at the University of Turku (see Part 3). Torsti's instrument in SOHO satellite has been a great success.

In ground observations long and accurate data series have been and still are a goal of Finnish geophysicists. Foreign research groups have realised that and have been interested in placing their instruments in Finland. In many cases this has inspired new research fields and lead to fruitful co-operation as will be presented below. Today, for the complementation of satellite observations of magnetosphere and space physics, the instrumentation in Finland and nearby is the most comprehensive ground based network in the world.

The good progress and high quality of the SGO, the Geophysics of the FMI and the Space Physics Division of the UO originate very much from the happy situation, that the Universities at Helsinki, Oulu and Turku produce highly educated theoretical physicists and physicists. Among them several found geophysics challenging enough for a lifelong profession. Annual "Observatory Days", organized alternately at Sodankylä and Nurmijärvi since the beginning of 1950′s, have contributed in the good co-operation between the groups of geophysicists mentiond above. Later the UO joined in the rotation of the days.

Table 1. Essential steps in progress in association with space studies in Finland, 1841–2000.

Year	Progress step	Key person
1838	Founding of Helsinki Magnetic Observatory	J. J. Nervander
1882	First International Polar Year. Observatory to Sodankylä	S. Lemström
1913	Founding of Sodankylä Geophysical Observatory	G. Melander
1931	Co-operation with the Danish Meteorological Instit., la Cour	E. Sucksdorff
1932	Second Polar Year, pulsation recordings at Sodankylä	E. Sucksdorff
1944	Sodankylä Observatory destroyed in the Lapland war	
1945	New Sodankylä Geophysical Observatory (SGO)	E. Sucksdorff
1952	Founding of Nurmijärvi Geophysical Observatory (NGO)	E. Sucksdorff
1956	Vertical ionosounder to NGO of Finnish Meteorological Inst. (FMI)	T. Haikonen
1957	International Geophysical Year (IGY). Ionosounders to SGO, Dieminger	J. Oksman
1957	IGY, 2 Stoffregen all-sky cameras (ASC) to North Finland	C. Sucksdorff
1960	International Geophysical Union (IUGG) in Helsinki. Many contacts.	C. Sucksdorff
1962	Modern pulsation recorders to SGO and NGO	V. Hessler
1963	First riometers to SGO from Max–Planck–Institute	T. Mustonen
1964	International Quiet Sun Year. 2 more ASC′s, mobile magnetograph	C. Sucksdorff
1965	Stratospheric balloon co-operation with France, Germany and Scandinav.	P. Tanskanen
1965	Use of satellites in ionospheric research	J. Oksman
1968	First common University of Alaska, NGO, SGO pulsation publication	V. Hessler
1969	First Wetterkulla symposium on pulsations, Alaska, NGO, SGO	V. Hessler
1973	4 ASC′s to North Finland with digital time and light standard	R. Pellinen
1974	New in SGO constructed ionosondes start at SGO and NGO	T. Turunen
1974	Magnetometer chain to N.- Finland, Univ. Göttingen and Braunschweig	J. Untiedt
1975	EISCAT agreement signed	J. Oksman
1976	Start meeting of Soviet–Finnish TT- co-operation in geophysics	J. Oksman
1976	VLF measurements begin at the SGO in co-operation with Rycroft	T. Turunen
1976	International Magnetospheric Study (IMS). Several new co-operations	R. Pellinen
1977	STARE starts operating at Hankasalmi, co-operat. With FMI	R. Greenwald
1979	Measurements of electric field using balloons in auroral zone	J. Kangas
1981	The operative function of EISCAT starts	T. Turunen
1982	The EISCAT magnetometer cross to North, cooper. with FMI	H. Lühr
1984	Formal co-operation agreement on PROMICS-3 with Sweden	R. Pellinen
1985	Finnish Space Board under Ministry of Transport and Communications	P. Jauho
1985	Co-operation with Sweden starts in constructing ASPERA for Phobos	R. Pellinen

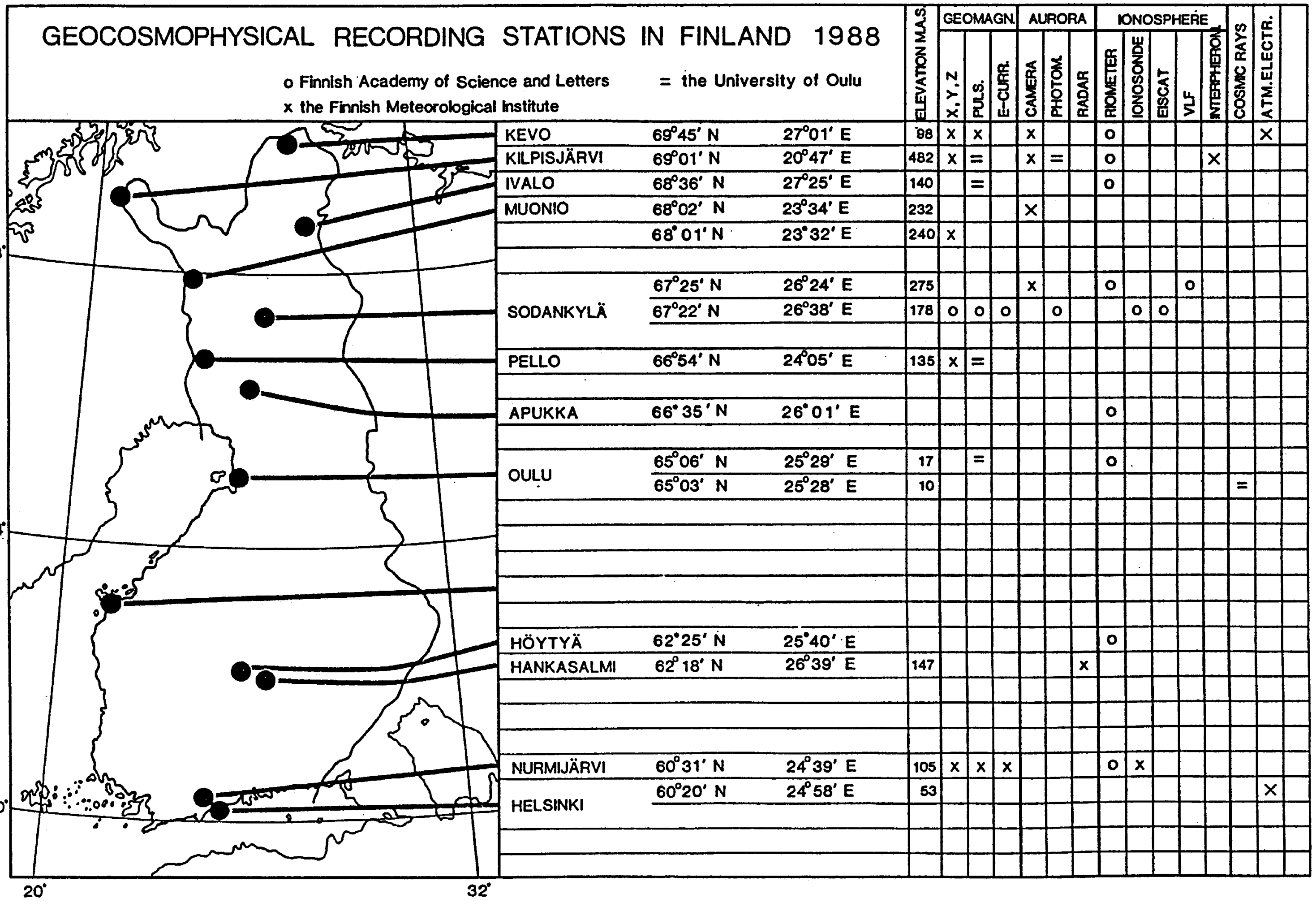
1986	Contribution to LIMA-D (Phobos) laser experiment	R. Pellinen
1986	Ground based co-operation with Swedish Viking project	H. Koskinen
1987	Finland Full Member in ESA Science Programme, also with USSR	P. Jauho
1987	SWAN of FMI–French co-operation accepted for SOHO	R. Pellinen
1987	SGO starts fabrication of satellite magnetometers (Primdahl, DMI)	A. Ranta
1987	ERNE from Turku accepted to SOHO	J. Torsti
1987	EFW from UO accepted for Cluster satellites	P. Tanskanen
1989	ASPERA/Phobos measures successfully near Mars.	H. Koskinen
1988	GOMOS accepted in co-operation with French for ESA's ENVISAT-1	R. Pellinen
1990	Start of IMAGE network of international recording stations	A. Viljanen
1992	Launch of Freja, UO and FMI instrumental contribution	
1992	FMI contribution starts to Swedish Odin-satellite. Launch 2001.	G. Leppelmeier
1994	FMI contribution to 2003 Rosetta comet mission starts	R. Pellinen
1995	SOHO launched successfully	
1995	Swedish satellites Astrid-1 and -2 with small Finnish contrib. launched	
1995	First Interball-satellite launched successfully. PROMICS-3 onboard	
1996	Second Interball with PROMICS-3 launched successfully	A.-M. Harri
1996	FMI starts to run digital ASC's	M. Syrjäsuo
1996	Finland becomes a full member of ESA	P. Jauho
1997	SGO as a separate institute in the organisation of the UO	T. Turunen
1997	Cassini-Huygens launched with Vaisala/FMI and UO instruments	
2000	Cluster satellites launched, Swedish–Finnish instruments onboard	
2001	Swedish Odin satellite launched. FMI–ARC involved	

2. *Ground observations as a diagnostic tool in magnetospheric studies*

Below we divide the Finnish ground based space research in two parts according to the method applied. The first part 2.1 "Magnetic recordings" describes the arrays of magnetic recording instruments and the use of magnetic pulsations in the study of space phenomena. The second part 2.2 handles radio methods in ionospheric studies. The third part 3 is "Studies of space physics using space instruments".

2.1 *Magnetic recordings*

During IMS years (IMS International Magnetospheric Study 1976–1979) an exceptionally wide magnetometer array (Scandinavian Magnetometer Array, SMA) operated in Fennoscandia (*Küppers, et al.,* 1979; *Untiedt and Baumjohann*, 1993). The network consisted of 42 magnetometer stations which were regularly spaced with adjacent distances of 100–200 km along magnetic meridians (Fig. 7). The network was maintained until 1980 as a wide international collaboration including research groups from Germany, Finland, Sweden, Norway, and Denmark. Most of the instruments made analogy recordings which were digitised afterwards. Due to its very good spatial coverage SMA recordings form a unique data set, even according to present-day standards. SMA showed that co-ordinated observations of magnetometer arrays can be extremely useful when studying magnetosphere-ionosphere processes. Consequently, similar activity was decided to be continued, although with fewer instruments. The EISCAT magnetometer cross (*Lühr et al.,* 1984) operated during years 1982–1991. The network consisted of seven digital triaxial fluxgate magnetometer stations (Soroya, Alta, Kevo, Kilpisjärvi, Kautokeino, Muonio, and Pello) with sampling interval of 20 s and intensity resolution of 1 nT. The instruments were maintained as German–Finnish collaboration under the leadership of the Technical University of Braunschweig.


GEOCOSMOPHYSICAL RECORDING STATIONS IN FINLAND 1988

o Finnish Academy of Science and Letters
= the University of Oulu
x the Finnish Meteorological Institute

				GEOMAGN.			AURORA			IONOSPHERE						
			ELEVATION M.A.S.	X,Y,Z	PULS.	E-CURR.	CAMERA	PHOTOM.	RADAR	RIOMETER	IONOSONDE	EISCAT	VLF	INTERPHERON	COSMIC RAYS	ATM.ELECTR.
KEVO	69°45' N	27°01' E	98	x	x		x			o						X
KILPISJÄRVI	69°01' N	20°47' E	482	x	=		x	=		o				X		
IVALO	68°36' N	27°25' E	140		=					o						
MUONIO	68°02' N	23°34' E	232				X									
	68°01' N	23°32' E	240	x												
SODANKYLÄ	67°25' N	26°24' E	275				x			o			o			
	67°22' N	26°38' E	178	o	o	o		o			o	o				
PELLO	66°54' N	24°05' E	135	x	=											
APUKKA	66°35' N	26°01' E								o						
OULU	65°06' N	25°29' E	17		=					o						
	65°03' N	25°28' E	10												=	
HÖYTYÄ	62°25' N	25°40' E								o						
HANKASALMI	62°18' N	26°39' E	147						x							
NURMIJÄRVI	60°31' N	24°39' E	105	x	x	x				o	x					
HELSINKI	60°20' N	24°58' E	53													X

Fig. 6. Geocosmophysical (term after B. Hultqvist) recording stations in Finland 1988.

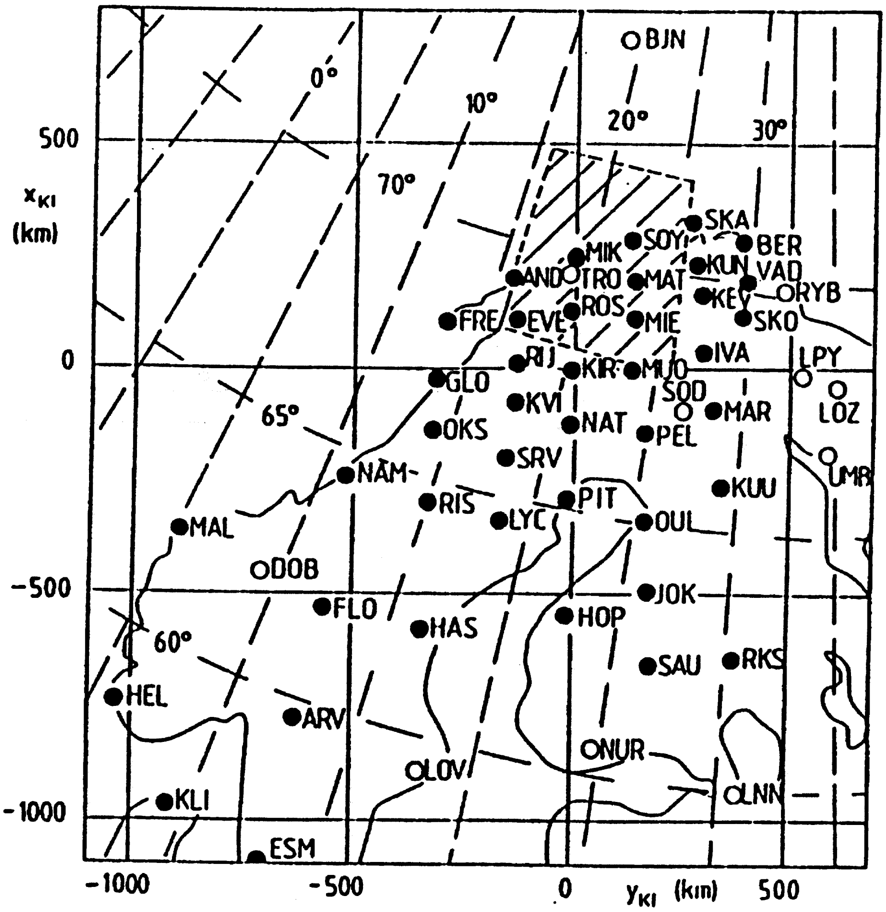


Fig. 7. Scandinavian Magnetometer Array in 1970's in Fennoscandia.

During years 1990–1991 the EISCAT cross was renamed as IMAGE (International Monitor of Auroral Geomagnetic Effects), and the systematic extension of the network started (see Figure 14). Several new institutes from different countries (Norway, Poland, Sweden, and Russia) joined the project. At the end of year 1995 when FMI started to rule as PI institute of the network it consisted of 15 stations. Today, there are 25 IMAGE stations covering approximately magnetic latitudes from 56 to 76. The longitudinal coverage of IMAGE is best (approxim.1 hour in LT) in the main oval region (around magn. latitude 66) where the activity is typically strongest. The sampling interval and intensity resolution of the instruments are 10 s and 1 nT, respectively. The most obvious timing errors and artificial peaks are removed from the data before their distribution in the Internet. As high quality observations with exceptionally free availability politics the IMAGE data are highly appreciated and their versatile use is continuously increasing in the international research community.

Another set of magnetometers in Finland is the chain for the recording of geomagnetic waves. Geoelectromagnetic waves in the period range 0.2–600 s are called geomagnetic pulsations or micropulsations (*Jacobs*, 1970). Their amplitude varies between 0.001 and 100 nT. After the recommendation of IAGA in 1963 they were divided into two main categories: Pc regular continuous oscillations and Pi bursty, irregular oscillations. Pc pulsations are further divided into five subgroups according to their period and Pi pulsations into three subgroups (see *Jacobs*, 1970 and *Nishida*, 1978).

The history of magnetic pulsation studies dates back to *Anders Celsius* who compared the compass measurements with auroral pulsations in 1741. The first Finnish contribution is due to *J. J. Nervander* who observed magnetic pulsations with a period of about 30 s by means of his declination magnetometer in Helsinki in the 1840's (*Nevanlinna,* 1992a). An important Finnish contribution to magnetic pulsations was made during the Second International Polar Year in 1932–1933 when new quick-run magnetographs became available. *E. Sucksdorff* published observations of Pc1 pulsations which he called the "pearl necklace" due to the shape of the signal in the registration (*Sucksdorff,* 1936). Sucksdorff estimated that the period of oscillations was 2–3 s. Interestingly, *L. Harang* from the Auroral Observatory at Tromsö published similar (but less detailed) observations of Pc1 pulsations in the same issue of Terrestrial Magnetism and Atmospheric Electricity (*Harang*, 1936). *Sucksdorff* (1939) also studied pulsations of longer period, which he called giant pulsations. A more extended description of these historical observations has been given by *Mursula et al.* (1994). The quick-run registration system, constructed by *la Cour* in Denmark, was able to record the external forcing on the suspended magnet due to magnetic pulsations close to the magnet's eigenperiod. This unique data was later used by *Mursula et al.* (1991) to study the solar cycle effects on Pc1 pulsations.

The interest in studies of magnetic pulsations increased after the introduction of the theory of hydromagnetic waves by *H. Alfvén* in the 1940s and especially during the International Geophysical Year (IGY) in 1957–1958 when more modern measurement techniques and data methods became available. It was realised that magnetic pulsations observed by a carefully planned network of stations give important information about the near-Earth space. For the future of the Finnish pulsation research it was most important that *V. Hessler* from the Geophysical Institute, University of Alaska, in his visit to the FMI and its Nurmijärvi observatory during the Helsinki General Assembly of the IUGG (International Union of Geodesy and Geophysics) in 1960 became interested in old Finnish pulsation studies based on La-Cour quick-run magnetometers and earth current recordings at the SGO. He installed 1963 new instruments at SGO and Nurmijärvi Geophysical Observatory (NGO). Both Earth currents and iron cored coils were used. After *C. Sucksdorff*'s visit to Hessler at the University of Alaska Geophysical Institute in 1964 a north-south chain of pulsation magnetometers was established in Finland. The first publication by *Heacock* et *al.* (1968) based on results obtained with the chain was published in *Nature.* It reported on latitude dependence of the frequency of the Pc1 pulsations. The next two publications were by *Heacock* and *Kivinen,* (1972a and 1972b).

The workshops in 1969 and 1971 at C. Sucksdorff's summer place in Central Finland gave a good start for scientific work in international collaboration (Fig. 8). At the same time the Space Physics Division of the University of Oulu (UO) became interested in magnetic pulsation studies and became the scientific leader in Finland in this co-operation and research. Annual Observatory Days became a practice in 1950's and the UO pulsation group was active in these meetings in 1960's and later. There among other topics the plans were made for the recording of pulsations at the two observatories Sodankylä and Nurmijärvi and also at other sites, and scientific papers based on the recordings were presented.

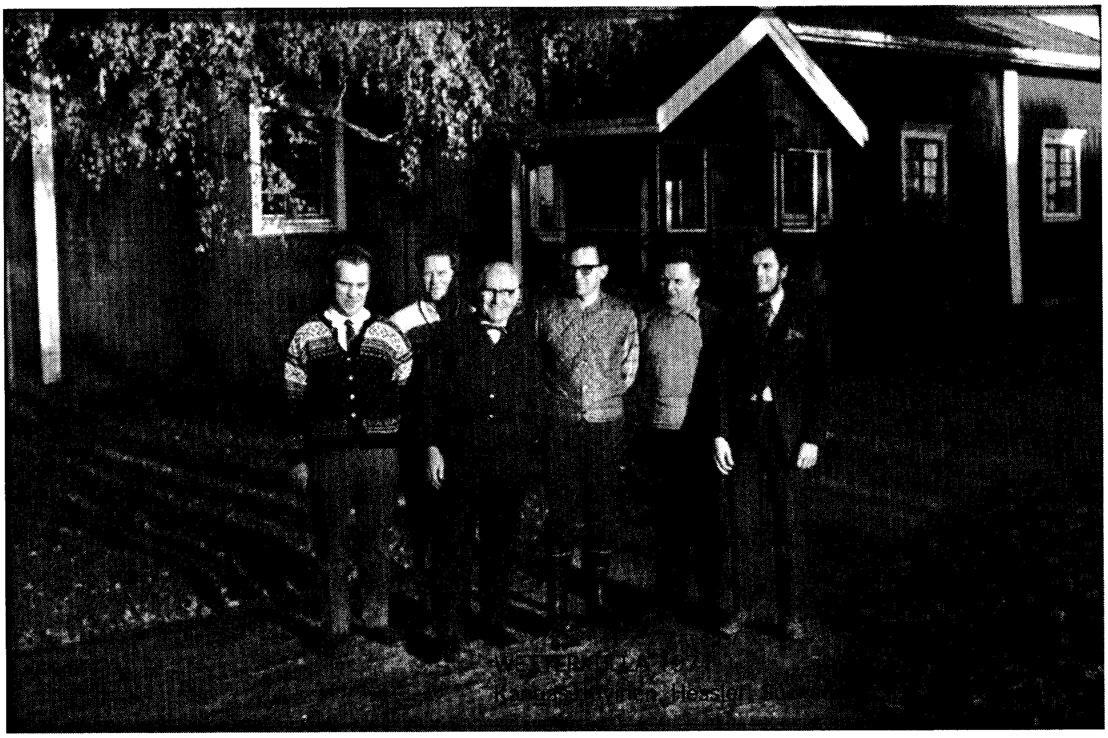


Fig. 8. Pulsation group in Wetterkulla, Central Finland, October 8–10, 1971, planning the co-operation in pulsation studies. From left: Jorma Kangas, Professor at the UO, Matti Kivinen, director of the Nurmijärvi observatory of the FMI, Victor Hessler, deputy director of the Institute of Geophysics of the University of Alaska, Christian Sucksdorff, director of the Geophysics Division of the FMI, Eero Kataja, director of the SGO and Lasse Lukkari, geophysicist at the UO. (C. Sucksdoff's collection.)

The unique network of pulsation magnetometers and other supporting geophysical measurements offered many possibilities for international collaboration since the 1960's. Contacts to the strong Soviet school in pulsation research have been most valuable. They were established in the early 1970's and later strengthened by the Soviet–Finnish Agreement in Science and Technology which in the field of geophysics started in 1976. This collaboration was supported especially by *V. Troitskaya*, Institute of the Physics of the Earth, Moscow and *O. Raspopov*, Polar Geophysical Institute, Apatity. It has been most fortunate that V. Hessler and V. Trotskaya, both acknowledged pioneers in magnetic pulsation research were enthusiastic supporters of Finnish science and scientists.

The main interest of Finnish scientists in the studies of magnetic pulsations has been directed to short-period magnetic pulsations in the period range of about 0.2–10 s. Much of the progress in these studies has been reviewed by *Kangas et al.* (1998). In the following we summarise only some of the most interesting results, mainly using data from the Finnish chain of stations.

The network covering an L-value range from 3.3 to 6.6 in Finland was complemented by a low latitude station in Crete with L = 1.4 in 1999. The recording system has high time resolution (0.1 s), high sensitivity and high upper frequency (5 Hz). It is up to now the only chain in Europe with these properties. Quick-look spectrograms of registrations can be viewed in (http://ntserver.sgo.fi/pub_pul/Sodankyla_html) from 1988 onwards.

2.1.1 Pc1 type pulsations – still a mystery after a study of more than 60 years

Studies of pulsations in the Pc1 category have been a very productive part of the Finnish contribution to pulsation research. We include to this category also the special phenomenon called IPDP pulsations (Intervals of Pulsations with Diminishing Period) which was first introduced by V. Troitskaya (*Troitskaya and Melnikova*, 1959). Examples of dynamic spectra of Pc1 and IPDP pulsations can be found, e.g., in *Kangas et al.* (1998).

Pc1's can roughly be divided into two main groups using their appearance in dynamic spectra. The first group, structured or "pearl" pulsations (*Sucksdorff*, 1936) contains events with a periodically modulated amplitude. The events of the second group without such a structure are called unstructured pulsations. IPDP pulsation events have a well-defined frequency modulation: within about half an hour the midfrequency increases from fractions of hertz to 1–2 Hz. IPDP events may sometimes contain similar structured elements as pearl pulsations.

The classical model of pearl pulsations, called "bouncing wave packet" model was introduced in the 1960′s. It was suggested that the pearl necklace represents a succession of echo signals of a wave that propagates along geomagnetic field lines and is repeatedly reflected from the ionosphere in the opposite hemispheres. It is expected that the wave is repeatedly amplified in the wave growth region around the equator via the ion cyclotron instability. The wave propagates through the ionosphere and in the ionosphere to be observed as Pc1 magnetic pulsations on the ground over an extended area. For more extended discussion, see, e.g., *Kangas et al.,* (1998). A need to revise the bouncing wave packet model has been pointed out by *Mursula et al.* (2000).

Pc1 records in Finland since the 1930s are a unique data set to study long-term trends in magnetic pulsation activity. *Mursula et al.* (1991) have analysed this data and showed that more pulsations are observed during solar minimum times than during maximum times. The occurrence of Pc1's during magnetic storms was recently studied both in space (*Bräysy et al.*, 1998) and on the ground emphasising the role of these waves to the degeneration of the ring current during the storm main phase.

The Finnish contributions to IPDP research are largely presented by *Kangas et al.* (1998). Data from the Finnish north-south chain have been most valuable in these studies as it seems obvious that one of the main reasons for the frequency modulation during IPDP is the radial movement of the IPDP source. The relationship between the frequency shift in IPDP and the magnetospheric electric field measured by the EISCAT incoherent scatter radar has been verified. Moreover, the same negative correlation between the annual IPDP activity and annual sunspot number exists as between Pc1 activity and sunspot number mentioned above.

2.1.2 Irregular Pulsations (Pi)

According to the IAGA classification the Pi1 and Pi2 pulsations occupy the period range of 1–40 s and 40–150 s, respectively. Pi pulsations occur during magnetic and auroral disturbances. It has been useful to divide them into PiB (Pi Bursts) and PiC (Pi Continuous) according to *Heacock* (1967). PiB's are short-lived broadband impulses characteristic to the onset of a substorm whereas PiC's are typical to the expansion and recovery phases of substorms. Examples of dynamic spectra of PiB and PiC can be found, e.g., in *Kangas et al.* (1998).

The state-of-the-art in Pi research when the Finnish pulsation magnetometer network started its operation is best reviewed by *Jacobs* (1970). It is surprising how little, in spite of large international efforts, our knowledge has really increased since then. This is probably due to the complex nature of these magnetic pulsations. Up to now, there is no generally accepted theory available for these pulsations.

The broad band magnetic noise of PiB is encountered wherever in space localised, quasi one-dimensional field aligned currents flow, i.e., in a huge plasma parameter range. There seems to be no ordering of PiB spectral properties according to the local plasma frequencies.

The Finnish contribution to PiB research is summarised in the following. The newly developed method of differential equivalent current vectors (DEC) applied to the dense Scandinavian Magnetometer Array (SMA) (Fig. 7) enabled to prove the intimate spatial and temporal relationship between PiB's and localised, upward directed, field aligned currents (*Bösinger et al.*, 1981; e.g. their Fig. 12). Co-operation with the Institute of Geophysics of the University of Göttingen and use of their mid-latitude data allowed to specify quantitatively the high degree of correlation in the onset, duration, and temporal fine structure and anticorrelation in the sense of polarisation between the PiB observations made simultaneously at high and mid-latitudes. In addition, estimates of the latitudinal attenuation of the PiB signal could be obtained (*Bösinger and Wedeken*, 1987; e.g. their Fig. 3). The spectral index of the monotonous PiB power spectrum was measured as a function of latitude and with respect to the distance of the observation point to the latitudinal amplitude maximum. The effect of ionospheric screening, signal propagation and magnetic induction in the Earth's crust were evaluated and correction procedures were developed to obtain an ionospheric index from ground-based observations (*Bösinger*, 1989).

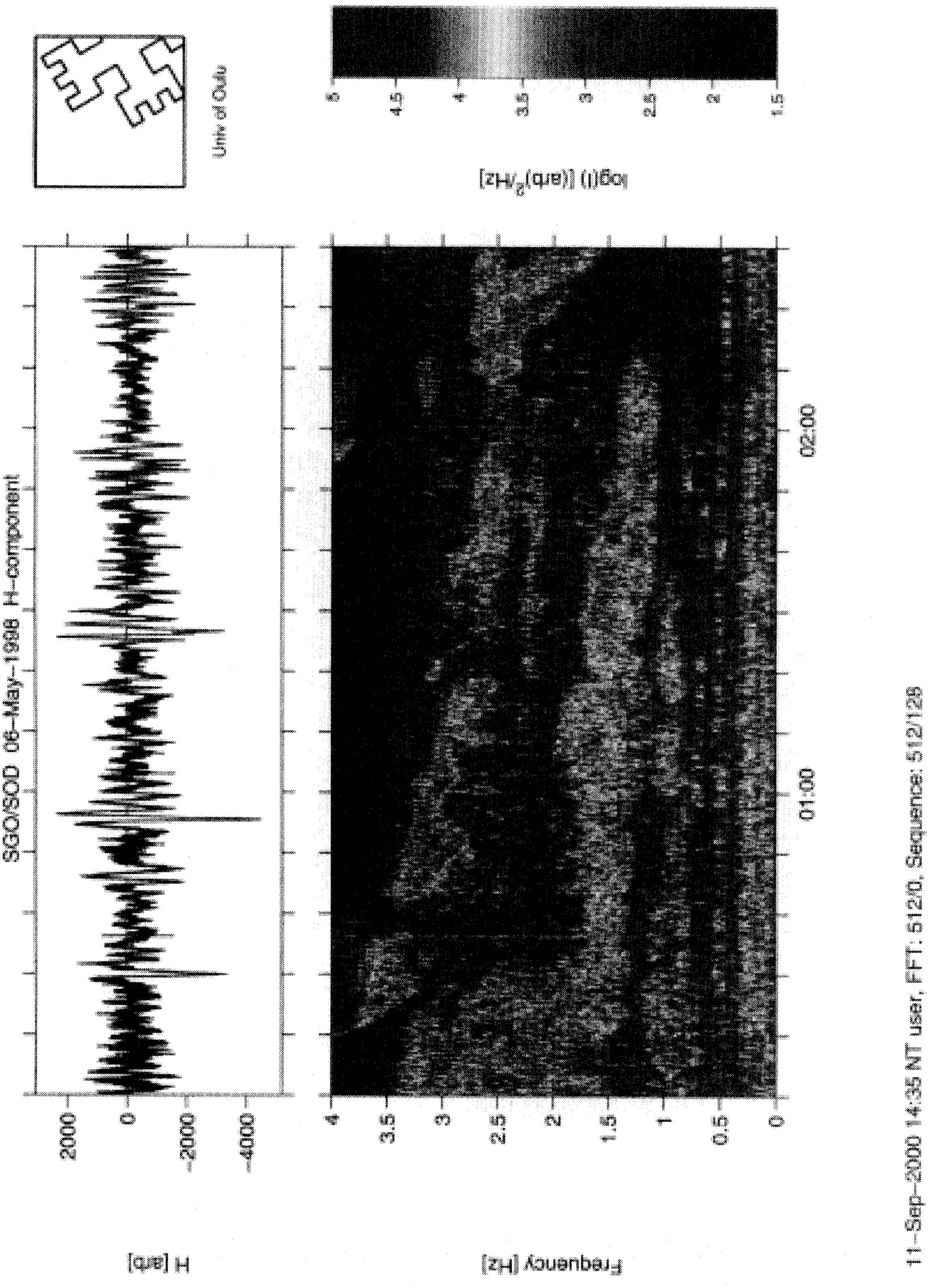


Fig. 9. At times it "sounds" like as the whole magnetosphere is ringing, when not only one or two cavities and resonance-processes take part in a "cosmic symphony": the amplitude-time series in the upper frame of the figure shows trains of quasi-periodic,long period geomagnetic pulsations which can be understood as field-line resonances. At the same time a multi-band, structured Pc 1 event is present and shown as a power spectrum in the lower frame of the figure (the long period pulsations in this presentation show up only as a horizontal line in the lowest freqency bin). The central emission frequency of the Pc1 emissions tends (in this local time sector) to decrease with time. The Pc1 pearl structure exhibits a periodic, vertical segmentation of the emission bands. The more horizontal lines in this spectrum, representing monochromatic, harmonically spaced, continuous emissions are due to excitation of the so called "ionospheric Alfvén resonator" by world-wide thunderstorm activity.

Up to now mid-latitude Pi2 observations are commonly used to determine the substorm time line (onset and instances of intensification). *Bösinger and Yahnin* (1987) made a careful comparison of the virtues and drawbacks of substorm time line determination using either Pi2's or PiB's. They concluded that Pi2's and PiB's are equally good substorm timers, yielding, in principle, an absolute time accuracy of better than +- 20 s. An outstanding demonstration of the diagnostic capability of ground-based PiB observations for magnetospheric processes was provided by *Yahnin et al.* (1990, e.g. their Fig. 1). These authors showed that high energy particle injections (~ 1 MeV) into the ring current correlates well with single PiB bursts. In these cases PiB's can provide an absolute time reference, whereas the injection signatures are typically time delayed due to the finite particle drift time.

Lately much effort has been made to explore the spectral properties of the so called ionospheric Alfvén resonator (*Bösinger et al.*, 2000). We know today that the frequently observed amplitude enhancement in the PiB spectrum at 0.2–0.4 Hz reported for the first time by *Kangas et al.* (1979) as a regular PiB signature is in fact the fundamental frequency of the ionospheric Alfvén resonator.

In PiC research the progress looks different. It was convincingly shown by *Oguti et al.* (1984) that PiCs are generated in the ionosphere by modulation of the ionospheric conductance due to particle precipitation. Thus PiC's and pulsating auroral patches reflect the same physical process. It is therefore not a surpise that both are preferentially observed in the morning side during substorm recovery. Before Oguti's work *Leinonen et al.* (1983) established the close connection between PiC and variation of the ionospheric electric field and conductivity. There are numerous works by Finnish scientists, not mentioned here, dealing with aspects of electron precipitation, X-ray production, riometer absorption and auroral pulsations, phenomena belonging to the same physical context as PiC pulsations.

2.2 Radio methods

2.2.1 Instruments and networks

2.2.1.1 Ionosondes

The International Geophysical Year (IGY) 1957–1958 can be designated as the starting point of actual ionospheric research in Finland. In view of this big international effort, an ionosonde was installed at the Nurmijärvi Geophysical Observatory of the FMI in 1956 (*Sucksdorff* and *Haikonen*, 1958). The equipment belonged to the Finnish Board of Posts and Telegraphs. The main persons to be mentioned in this venture are *T. Haikonen*, and later *B. Andergård*. Another vertical ionosonde and also equipment for oblique soundings was given 1957 to the SGO by *W. Dieminger* (1907–2000) from Max-Planck-Institute (MPI) " as a contribution to the rebuilding of the in the war destroyed observatory". *J. Oksman* and *T. Mustonen* (Fig. 10) were trained to ionospheric recordings and studies in the MPI. *H. G. Möller* from MPI helped to start both the scientific oblique soundings and the vertical ones at the SGO successfully (*Dieminger*, 1973). This was the start of growing fruitful ionospheric research at the SGO, now being the main activity there including EISCAT. The oblique soundings were between Sodankylä and Kevo, between Sodankylä and Katlenburg-Lindau in Germany and Sodankylä and Zumeb in Namibia. This co-operation between German and Finnish scientists was actually a continuation of oblique soundings carried out during a complete solar eclipse in 1954.

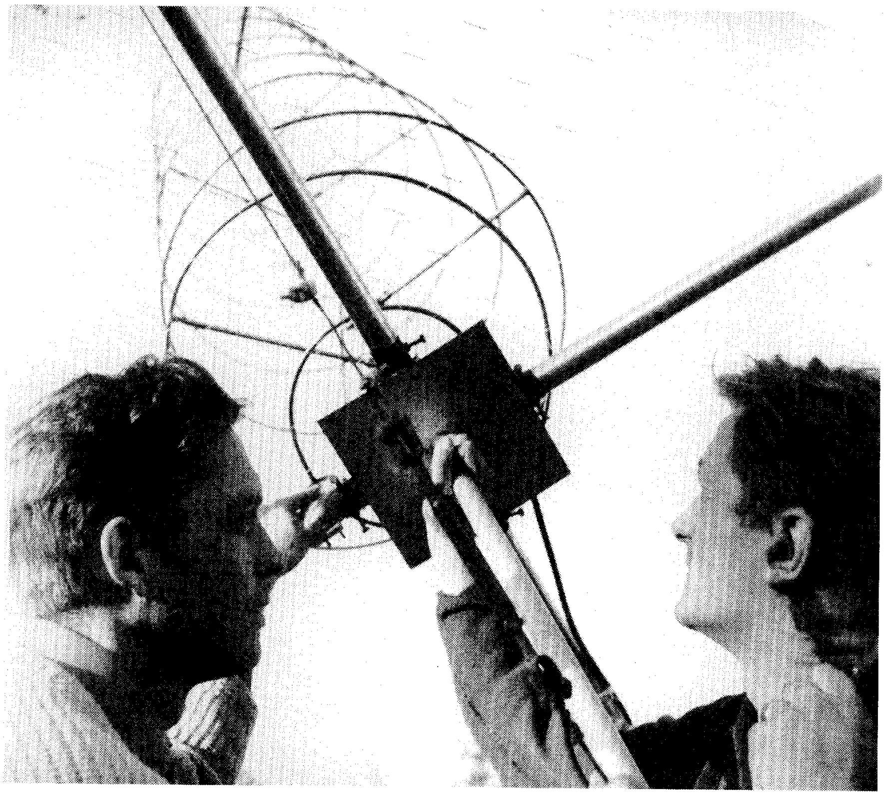


Fig. 10. Juhani Oksman (1931–) and Tarmo Mustonen (right) study a helix antenna for an auroral radar at the SGO in 1962. Later Oksman worked as professor and finally as rector at the UO. Mustonen specialised in servicing the ionospheric sounders and later the EISCAT equipment both in SGO and Lindau, Germany, and in Kiruna, Sweden. (Photograph by Tuulikki Mättö, Juhani Oksman's collection.)

The Nurmijärvi ionosonde continued its operation until 1989. At Sodankylä the same German ionosonde was used until a more modern instrument with automatic gain control was installed at both observatories in 1976. Long-term studies of ionospheric parameters have shown that no discontinuities in the data quality appeared due to the change of the equipment. A third ionosonde is being constructed at the SGO at the moment. As a result of ionospheric recordings a series of ionograms covering a period of more than 40 years has been collected and scaled in Sodankylä. This data set makes a valuable source for long-term studies especially because, until now, the scaling has been done by a single person, *Mirja Hämäläinen* (*Ulich and Turunen*, 1997; *Ulich*, 2000).

2.2.1.2 Coherent scatter radars

The first Finnish investigation where radar method was applied in connection with satellites was made by *M. Tiuri* (1925–). He used in 1959–1960 a 100 MHz CW radar at the Nurmijärvi observatory for the recording of reflections from ion trails produced by the satellite Sputnik III (*Tiuri*, 1960).

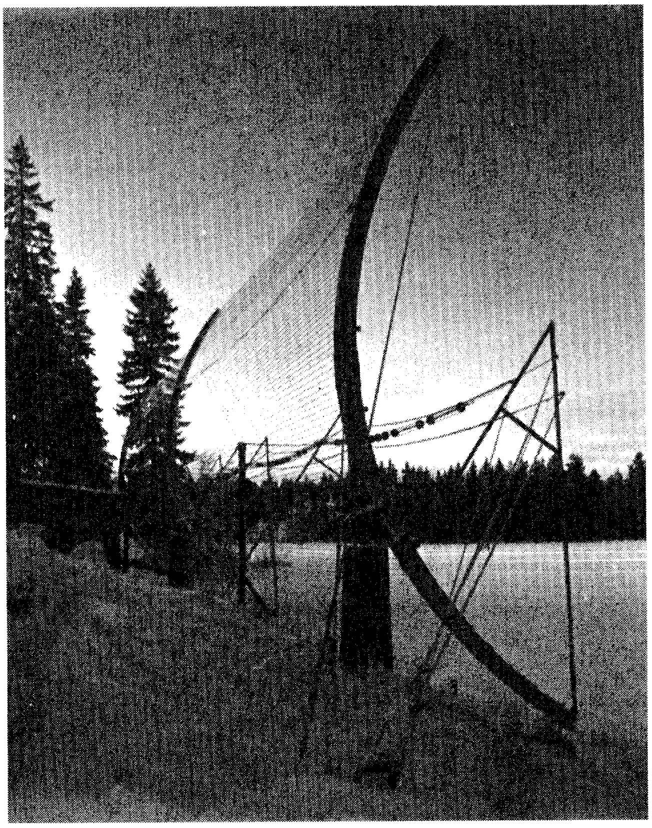


Fig. 11. Martti Tiuri's antenna system at Nurmijärvi Geophysical Observatory for receiving reflection from satellites. (Photo by C. Sucksdoff, FMI photoarchives.)

The next effort was the introduction of STARE (Scandinavian Twin Auroral Radar Experiment) which is a coherent radar system. STARE started operating in 1977. It consists of two transmitter/receiver stations, one at Malvik, Norway (140 MHz) and the other at Hankasalmi, Finland (143.8 MHz). The backscatter which STARE measures is assumed to come from ionospheric plasma irregularities with scale lengths of about 1 m. The intensity of the backscatter depends on the ionospheric E-layer electron density, and the Doppler shift of the signal can be used to estimate the plasma drift velocity in the direction of the beam. By combining the data of both radars the total horizontal drift velocity can be estimated in the common area of 160,000 square km in the northernmost part of Scandinavia with a spatial resolution of about 20 km. From the drift velocity also the ionospheric electric field can be computed.

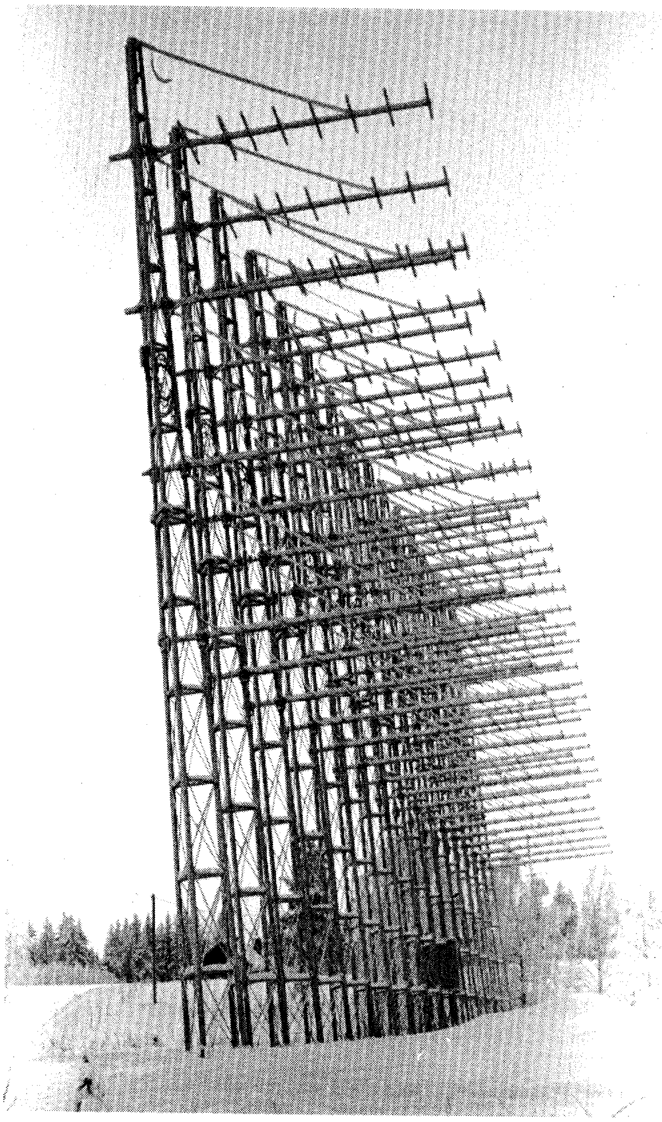


Fig. 12. The antenna system of STARE at Hankasalmi. (FMI photoarchives.)

STARE has been maintained by the Lindau group of Max–Planck–Institut (MPI) für Aeronomie, FMI, and Norwegian Technical University in Trondheim. The first STARE (*Nielsen,* 1982) was constructed during years 1976–1977. *Ray Greenwald* (MPI) as the main designer of the system carried the responsibility on its operation during the IMS years 1977–1979. After 1979 *Erling Nielsen* became the principal investigator of the instrument. During the next ten years STARE aged so that to full utilise the instrument became gradually impossible. In late 1980's there were a few attempts to modernise the system, but with the technology of those days upgrading the equipment appeared to be too complicated and expensive. Finally, after about twenty years' Beauty sleep the system was revived in 1997 when the MIRACLE (Magnetometers – Ionospheric Radar's – All-sky Cameras – Large Experiment) instrument network (*Syrjäsuo,* 1998) was built up (Fig. 14). The transmitters, receivers, and preamplifiers of the new STARE are mainly the same as in the old STARE, while the antennas and cables have been renewed and the signal correlator and software have been updated. The location of the Norwegian radar is slightly different (Midtsandan) in the new STARE. The small change of location is shown to be negligible in the computation routines.

In 1993 FMI made the agreement with Leicester University on the placement of one of the CUTLASS coherent scatter radars to Hankasalmi. CUTLASS belongs to the SuperDARN network and the sister radar of Hankasalmi operates at Pykkvibaer in Iceland. CUTLASS operates at the frequency of 10 MHz and it has a 3 million square km field of view over the Barents sea with a spatial resolution of the order of 50 km. Construction of the new Hankasalmi radar was started in 1994 and the first common recordings with both CUTLASS radar's were made in 1995. FMI has the responsibility of take care of the local maintenance of the Hankasalmi radar. Conditions for scientific collaboration have recently improved as the MIRACLE network (Fig. 14) has started operation in routine manner.

2.2.1.3 Incoherent scatter radars

The third important step in the ionospheric studies was the introduction of EISCAT (European Incoherent Scatter Radar Association, *Folkestad et al.*, 1983). The participating countries are Germany, France, Great Britain, Sweden, Norway and Finland. It consists of three stations, transmitter and receiver in Tromsö area in Norway and receivers in Kiruna, Sweden and Sodankylä Finland. The key persons in the planning were J. Oksman from the University of Oulu, M. Tiuri from the Helsinki Technical University, E. Kataja and *S. Koivumaa* from the SGO, *B. Hultqvist* from the Kiruna Geophysical Institute and *O. Holt* and *A. Haug* from Norway. The planning started in 1971 and the equipment became operational in 1981. The EISCAT system was expanded in 1990′s, when the ESR radar was built on Svalbard inside the polar cap (*Wannberg et al.*, 1997). The Academy of Finland finances Finland's part of the EISCAT activity. Academy of Finland is represented in the Council. One of the key representantives was *A. Siivola* (1935–), University of Helsinki, from 1975 to 1993.

Since one of the receiver sites of the UHF radar is situated in Sodankylä, the advent of EISCAT had a strong technical and scientific impact on the activities of the SGO. Many technical problems met in the start phase of the radar, e.g. those associated with cooling of preamplifiers and stability of post-detection filters, were actually solved by the Sodankylä staff (key persons T. Turunen and T. Mustonen). A strong development of new experiments soon started. For the first time, Barker-codes were used for measuring the whole plasma autocorrelation function rather than the power profile. Multipulse experiments for E region and pulse-to-pulse experiments for D region were constructed in this approach, which allowed the determination of the plasma parameters with an unforeseen height resolution. The best resolution achieved was 300 m. Temporal resolution was also developed into a new level. The best time resolution available for measuring the power profile is 0.2 s. The new experiments were collected into a programme library (GEN-system) which is available for all EISCAT users.

A different line of method development had a more theoretical foundation (key person *Markku Lehtinen)*. For the first, a thorough analysis of the whole radar method led to a general formulation of the incoherent scatter measurement which, for the first time, contained the effects of the transmission envelope and receiver filtering in a correct manner (*Lehtinen*, 1986). This allowed a development of an analysis programme which is free from the approximate procedures used in the old analysis methods. It also contained a proper error analysis and allowed the determination of error estimates at a given signal-to-noise ratio before running the experiment. The result of this work, GUISDAP (Grand Unified Incoherent Scatter Design and Analysis Package), is now accepted as the official analysis package of EISCAT.

The second important theoretical input in incoherent scatter methods was the development of new modulation principles. The most important of them is the discovery of alternating codes (*Lehtinen* and *Häggström*, 1987). These codes make use of the radar resources in a maximal way and they are now used world-wide in incoherent scatter radar's. The new ESR radar on Svalbard was actually constructed to make use of the advances offered by alternating codes. At first, a major difficulty in alternating codes seemed to be that only 32-bit codes could be found in practice. This was not sufficient for experiments with a high range resolution. A new and extremely quick search method was found, however, and now alternating codes of arbitrary length are available (*Markkanen* and *Nygren*, 1997). A recent invention is a new modulation method which, unlike alternating codes, consists only of a single phase pattern and has range ambiguities. The code is constructed in such a manner, however, that the ambiguities can be removed by means of stochastic inversion. The benefit of this modulation is that it can be used even in cases when the plasma parameters change very quickly (the use of alternating codes imply that the plasma parameters do not change during the code cycle). This method has only been used in a single experiment so far (*Lehtinen et al.*, 2000). A further recent achievement deals with matched filtering of Barker codes. Impulse responses have been found which carry out a perfect decoding of Barker codes, i.e. decoding can now be made without any sidelobes.

2.2.1.4 Riometers

A fourth radio method successfully applied in Finland is the use of riometers. Tarmo Mustonen, during his service visit to the Max Planck Institute für Aeronomy had seen riometers laying on shelves and brought some of them to the SGO. The first riometer was installed in 1964 at the SGO. Within the following decade, an extensive riometer network was installed with instruments in Oulu and Nurmijärvi (1967), Kevo (1968), Ivalo (1972), and Rovaniemi and Jyväskylä (1974). The equipment operated at 27.6 MHz. In addition, absorption measurements at 20, 40 and 50 MHz started at Sodankylä in 1969. Later SGO has been responsible for sites outside Finland, at Ramfjord and Andenes in Norway, Abisko and Vidsel in Sweden, Hornsund on Svalbard and Siglufjordur in Iceland. Out of all these sites, Kevo, Nurmijärvi, Ramfjord, Andenes,and

Vidsel are no more operational. Together with Lancaster University, the SGO is also running an imaging riometer at Kilpisjärvi. *J. Yliniemi* from UO was first responsible for the network, but 1972 the responsibility was given to *Hilkka Ranta* (1941–1995) from the SGO. Trained in chemistry, she was able to get new results of the chemistry of the ionosphere using the riometer network and became internationally known scientist in co-operation with other groups (*Ranta* et *al.*, 1997; *Ranta* and *Yasmagishi*, 1997.) Hilkka's co-worker was her husband *Aarne Ranta*, laboratory engineer of the SGO.

2.2.2 *Results of ionospheric studies*

The purpose of the oblique soundings described above was to investigate ionospheric effects on radio wave propagation caused by auroral disturbances. It was found that the maximum usable frequency increased when horizontal gradients appeared in the F layer or irregularities were generated in the northern part of the signal path. The equipment was later expanded by a fixed-frequency transmitter and a short-distance oblique sounding system between Sodankylä and Kemi. The purpose of this arrangement was to study variations in the field strength.

Anomalous night-time D region absorption was observed at high latitudes in winter and the most pronounced absorption was associated with auroral disturbances and polar cap absorption events (*Oksman*, 1963). On the other hand, sharp increases in the field strength caused by drifting sporadic-E patches were also found. It is interesting to note that the existence of plasma blobs in the weak night-time F layer could already be deduced from these early observations. Such blobs can nowadays be mapped by means of satellite tomography or incoherent scatter radars.

One of the most dramatic phenomena in Sodankylä and Nurmijärvi ionograms is caused by huge travelling ionospheric disturbances due to gravity waves which were generated by nuclear detonations in the atmosphere over Novaya Zemlja in the 1960's. A time delay due to the wave propagation is visible when ionograms from the two sites are compared.

The research based on Sodankylä ionograms contain a few investigations on the generation of some anomalous traces (e.g. *Nygren et al.*,1981). These traces involve the gyrotrace and multiple z mode reflections between the bottom of the F layer and a thin partially transparent sporadic-E. The reflection and transmission coefficient of a thin magnetised plasma layer has also been investigated using full wave analysis (*Nygren*, 1981). These results have been applied in studying the transparency of sporadic-E and to observed frequency variations of the amplitude of the wave reflected from sporadic-E.

Sodankylä ionograms have been used in statistical studies involving the seasonal and diurnal occurrence of various types of sporadic-E layers as well as their association with magnetic activity (*Oksman*, 1966; *Turunen* and *Rao*, 1976). Moreover, distributions of Es parameters like blanketing frequency and top frequency have been investigated. Long-term variations of blanketing frequency and the occurrence of various types of sporadic-E layers have been studied within the interval 1958–1972. More recently, the behaviour of the peak height of the F2 layer has been investigated from 37 years of the Sodankylä data set, and the results indicate a descent of 0.39 km/a, which is a possible indication of atmospheric cooling at F region heights due to the greenhouse effect (*Ulich* and *Turunen*, 1999). More extensive investigations revealed a more complex situation, however. While data from the Nurmijärvi ionosonde gave a similar result, EISCAT incoherent scatter observations from 1985–1993 at Tromsö proved rise rather than descent (*Ulich et al.*, 1999). Similar studies based on data from ionosondes distributed around the world show both ascending and descending trends.

The experimental work on sporadic-E has inspired a few theoretical studies. The main result of this work is a new generation mechanism of thin plasma layers by the ionospheric electric field (*Nygren et al.*, 1984). It was shown that a constant electric field is able to compress the plasma into a thin sheet much in the same manner as the wind shear mechanism does, provided the field is strong enough and it points in a proper direction. A convincing verification of this mechanism has recently been presented in terms of dynasonde data collected in Antarctica (*Parkinson et al.*, 1998).

The investigations made using the riometer data include studies of latitudinal, diurnal and seasonal variations of ionospheric absorption as well as manifestations of substorms in absorption data. Riometer absorption has also been used in comparing the latitudinal distribution of magnetic pulsations and electron precipitation. The imaging riometer has allowed studies of small-scale absorption structures and intense Polar Cap absorption events.

The use of satellites in ionospheric research started in terms of Faraday rotation and difference Doppler measurements of Explorer 22 satellite signals. The measurements were carried out in 1965–1966 in Sodankylä and in 1966–1968 in Oulu (*Oksman* and *Schödel*, 1970; *Schmidt* and *Tauriainen*, 1970). After Explorer 22 got silent, the difference Doppler measurements were continued in Oulu using the NNSS satellites. These methods allowed the determination of the total electron content and observations of scintillations due to F region inhomogeneities. The scintillation studies involved observations of the "scintillation boundary" indicating the southern edge of the auroral region where field-aligned small-scale irregularities are generated due to plasma instabilities.

Satellite signals were further used in ionospheric research in the 1990's in co-operation with the Polar Geophysical Institute, Murmansk. A temporary chain of radio receivers carrying out difference Doppler measurements was installed. The chain consisted of four or five Russian receivers and it was aligned along a magnetic meridian, extending from the north of Norway to the South of Finland. The experiment utilised Russian navigational satellites flying closely parallel to the chain in their southward pass. A sophisticated tomographic programme, based on stochastic inversion, was developed and it was used in calculating the F region electron density above the receiver chain (*Nygren et al.*, 1997). A comparison with other generally applied tomographic methods (like filtered backprojection, SIRT and MART) indicated that stochastic inversion is superior, especially in the case of a small number of observers and noisy data (*Frey et al.*, 1998). New and more flexible satellite receivers based on the idea of soft radio are being constructed at SGO. These receivers are no more restricted to Russian satellites but also other existing systems can be utilised. The results obtained in the tomographic campaigns demonstrate the great variability of the high-latitude F region. The appearance of the main trough in the night-time F region is a consistent feature. During active periods, however, large plasma blobs and narrow density enhancements pointing in the direction of the local geomagnetic field also appear. The latter are obviously ionospheric manifestations of upward directed field aligned currents. Still another frequently occurring phenomenon is travelling ionospheric disturbances, which are caused by atmospheric gravity waves propagating at F region altitudes.

Scintillation is often observed in satellite tomography data. This disturbs the difference Doppler measurement but also gives a possibility to investigate the F region small-scale irregularities. In addition to the phase scintillation, amplitude scintillation was also measured using the Russian receivers. A new method has been developed which allows the determination of the anisotropy parameters of the irregularities from amplitude scintillation observed at a single site (*Terechchenko et al.,* 2000). This method has now been applied to several cases. Comparisons with EISCAT observations indicate that the field-perpendicular anisotropy is oriented along the direction of F region plasma flow.

Together with other ground based measurements, EISCAT observations have been used in studies of auroral and ionospheric physics. A connection to magnetospheric physics has also been important due to the northern location of the EISCAT radars. In auroral physics EISCAT observations of the electron density profile have been applied together with optical data in investigations of auroral arcs and pulsating aurora (*Kaila* and *Rasinkangas*, 1989). These studies also involve the determination of height integrated conductivities which are derived from EISCAT electron density profiles. The achieved high temporal resolution has allowed observations of very rapid changes of electron density in connection with auroral events. In addition to auroral studies, these have also been used in calculating the effective recombination coefficient at E region heights. Another use of EISCAT is the determination of the electric field behaviour around auroral arcs and investigations of convection flow pattern in the F region (*Aikio et al.*, 1993; *Sergeev et al.*, 1996). The F region investigations have involved studies of travelling ionospheric disturbances due to atmospheric gravity waves and especially their harmonic nature.

The main topic in E region research has been the sporadic-E layer. It has been confirmed that the sporadic-E sheets contain heavy ions, most probably Fe+ (*Huuskonen et al.*, 1988). The first observations on a sporadic-E caused by the electric field mechanism have been reported. Investigations of descending sporadic-E sheets have revealed gravity-wave induced modulation in layer altitude and intensity. A further topic is the determination of the ion-neutral collision frequency both in E and D regions.

D region experiments have been applied in studying polar cap absorption due to solar proton events and small-scale structures during substorms (*Ranta et al.*,1995; *Ranta* and *Yamagishi*, 1997). Investigations of the shape of the D region spectrum involve determination of the neutral temperature profile, the mean positive ion mass and the negative ion number density. The D region research has resulted into a development of the Sodankylä Ion Chemistry Model (SIC, see *Burns et al.*, 1991), which is currently able to deal with 33 positive and 19 negative ion species. At the moment the model is being extended to include 64 positive and 39 negative ion species.

2.3 *Auroral studies*

The FMI, SGO and Space Physics Division of the UO have long traditions in making ground-based auroral observations. The aim of the activity has been to make continuous regular observations covering both solar minimum and maximum periods. Furthermore, special attention has been made to co-ordinate the observations of different types of instruments in order to use their common data in scientific research. Maintenance of wide instrument networks necessarily has meant wide collaboration with several research groups both in Finland and abroad. The newest outcome of such collaboration is the Magnetometers – Ionospheric Radars – All-sky Cameras Large Experiment (MIRACLE) instrument network (Fig. 14). The historical backgrounds of the IMAGE magnetometer chain and STARE radar were described above (Sections 2.1 and 2. 2.1.2), below we introduce the development of the FMI all-sky camera network, which is the third cornerstone of the MIRACLE consept. Furthermore, we briefly describe how the Finnish research community have utilised the versatile instrumentation in their work.

2.3.1 *All-sky camera observations*

The FMI started regular optical auroral observations on the International Geophysical Year (IGY) 1957. All-sky camera (ASC) and magnetic recordings were made at the newly established station Ivalo and at the SGO. In addition, visual auroral observations were made regularly at six meteorological stations near airports. After IGY systematic ASC recordings were continued at 2–4 stations in the northern Finland and visual observations were gathered until 1969.

In 1973 the old ASCs were replaced with four new cameras using colour films (*Hyppönen et al.*, 1974). The camera system consisted of a downward-looking film camera and a spherical mirror showing the whole sky. At the side of the mirror there were also three light standards for rough intensity estimation, and a display showing the time. The ASC network was gradually upgraded so that during the years of the International Magnetospheric Study (IMS, 1976–1979) it included five stations (Kevo, Ivalo, Muonio, Sodankylä and Oulu). At the beginning of 1980's the network was widest consisting of seven stations, five in Lapland (Kilpisjärvi, Kevo, Muonio, Sodankylä, and Kiruna), one in southern Finland (Hankasalmi), and one in Svalbard (Hornsund). In standard mode the cameras took pictures once in a minute with an exposure time of 2 seconds. Every ten minutes longer exposure time (16 seconds) was used in order to monitor better dim diffuse auroras.

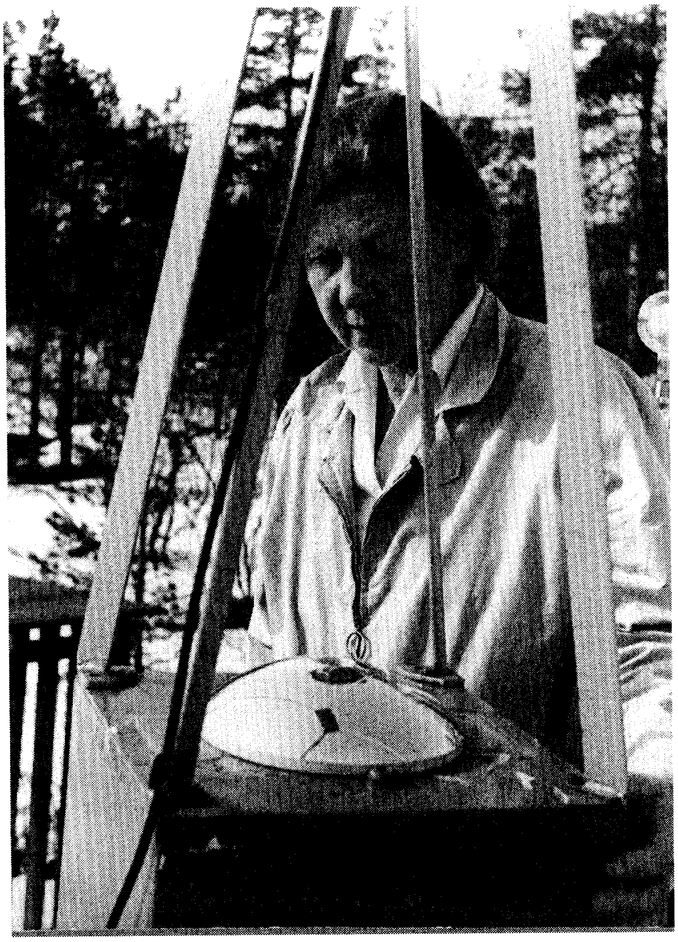


Fig. 13. Elsa Käck (1904–1984) at the Kevo station taking care of the second generation all-sky-camera with digital time and light standards produced with LED's. Colour films were used. (Photo by C. Sucksdoff, FMI photoarchives.)

The ASC films were collected to FMI for manual checking and quick-look analysis. During years 1978–1981 *H. Opgenoorth* and *K. Kaila* developed advanced data analysis tools: digitising routines and methods for estimating the location and altitude of auroras.. The original film material includes more than 2.2 million pictures which have been copied to U-matic, Betacam, and VHS tapes and thus are available also for computer analysis. Quick-look tables characterise the observed activity with six different number codes.

During years 1996–1997 the film cameras were replaced with digital imagers (*Syrjäsuo,* 1996). At present, the imager network consists of eight cameras (Fig. 14), six in the Fennoscandian mainland (Muonio, Kilpisjärvi, Kevo, Abisko, Sodankylä and Hankasalmi), and two in Svalbard (Longyearbyen and Ny Ålesund). The imagers have telecentric optics and fish-eye lenses with field-of-views of 180 degrees. After electronic intensification (with MCP) the images are acquired by black-and-white CCD-cameras. In standard mode images are recorded through three filters at wavelengths 630.0 nm, 557.7 nm and 428.7 nm. Imaging interval is 20 s and typical exposure times are 1–2 s. Each station has a PC linux computer with either ISDN or modem connection enabling remote control of the system. Keograms (intensity versus zenith angle along the middle meridian of the camera field of view) describing the results of the previous night are daily transferred to FMI. The full-resolution images are finally stored to CD-rom disks.

The UO contributes to the observation work by running since middle 1990′s at Kilpisjärvi an all-sky videocamera, which is extremely sensitive and uses normal speed (25 pictures per s). The camera has been constructed at the UO. It uses filters for different spectral lines of auroras. The UO also records the sky at Kilpisjärvi using spectrometer. The key person in auroral studies at the UO is Kari Kaila.

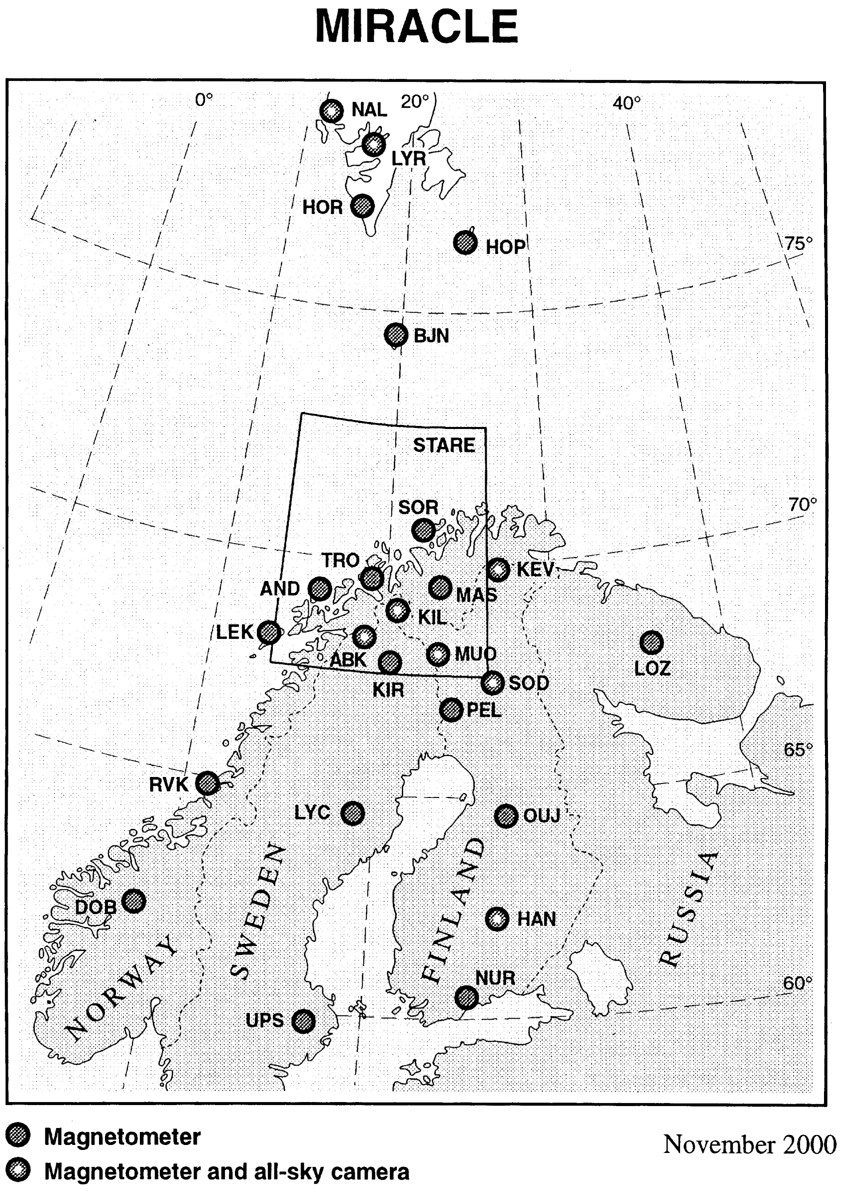


Fig. 14. MIRACLE network of magnetometers and all-sky cameras.

2.3.2 *Progress in research*

Already during the days of IMS (1976–1979) the combination of simultaneous ASC, magnetic and ionospheric radar observations were used as an efficient tool for analysing auroral phenomena. Magnetic observations yield information about the ionospheric currents, radars about the electric field and ASCs about the conductivity conditions. The founding of the Finnish EISCAT data laboratory in the University of Oulu facilitated the use of the EISCAT data in the auroral studies. The combined instrumentations were utilised in several pioneering studies on ionospheric electrodynamics of some specific auroral structures, like arcs (*Pellinen et al.*, 1982) and westward travelling surges (*Opgenoorth et al.*, 1983). The SuperDARN coherent scatter radar system measuring the ionospheric convection in global scale was an important addition to data production.

Ground-based observations appeared to be useful also when analysing magnetospheric satellite observations, which are very local, but provide important information from the magnetospheric origin of the auroral structures. By using statistical magnetic field models the location of the ionospheric conjugate point of a satellite can be estimated and in the cases of good conjugacy with ground-based instrumentation the satellite observations can be interpreted in a wider context. The study of *Pellinen et al.* (1984), comparing electric field observations of a geostationary satellite with IMS magnetic and ASC data was among the first studies combining satellite and ground based observations in the data analysis. With the development of statistical magnetic field models (*Pulkkinen et al.*, 1991a) such studies have become an increasingly important method in the research of ionosphere-magnetosphere coupling processes.

The first satellite images showing the global distribution of auroras became available in 1970's. The spatial and temporal resolution of the first images were relatively low, but by mid 1980's the technology had improved so much that the UV imagers of the Viking satellite were able to provide images (time resolution 3 minutes, spatial resolution about 20 km) accurate enough for detailed comparisons with ground-based ASC data. Combination of satellite images and ground-based observations has been useful especially when analysing auroral phenomena appearing in various scale sizes during magnetospheric substorms (*Pulkkinen et al.,* 1991b). The basic statistics of the occurrence of different auroral forms was studied by *Nevanlinna* and *Pulkkinen* (2001).

The long time series of magnetic field and ASC observations have provided possibilities to make extensive statistical studies. The quick-look tables based on the old ASC film material have been used to find out e.g. the average hourly and monthly occurrence of auroral activity. Long term variations in auroral activity according to FMI data are nicely in accordance with the variations in solar and global magnetic field activity (*Nevanlinna* and *Pulkkinen*, 2001). In mid 1990s the Cluster (see section 3 below) ground-based Data Centre started to develop a new set of auroral oval (AO) indicators for monitoring the global magnetic activity level. AO indicators are derived with similar procedures as the AE indices, but they are based on data of several meridian magnetometer chains, while the Ae indices rely on data of twelve magnetic observatories distributed evenly at different longitudes. The data of the EISCAT magnetometer cross were used in a pilot study evaluating reliability of the AO indicators (*Kauristie et al.,* 1996). More recently IMAGE data were used to show that problems due to geomagnetically induced currents in man-made conductors (like power systems, pipelines, and telecommunication cables) are more likely caused by small-scale ionospheric currents than by large scale electrojets (*Viljanen*, 1997). The MIRACLE network has been used to evaluate with modern data analysis methods the results of old IMS-studies (*Amm*, 1995). Combined analysis with satellite observations and other ground-based networks has recently become a standard method in the research as Internet access to the data bases of the wide international satellite projects (e.g. the International Solar Terrestrial Program, ISTP) is easy. Now as the global picture of the substorm evolution is rather generally accepted, ESA's Cluster II spacecraft mission has been designed especially for monitoring mesoscale processes. The ionospheric conjugate region of Cluster II is often of similar size as the MIRACLE field-of-view, and thus the conditions for opening new avenues in auroral research are promising.

3. *Space physics research with space instruments*

This section discusses the process how the Finnish space physics community became involved in research projects with own spacecraft instruments. The transition from ground-based to space-borne methods calls for the definition of domain to be covered. As this article is a part of the history of Finnish geophysics, the discussion is limited to geophysics-related phenomena that, at least in principle, can be studied by in situ observations. Furthermore, only research with significant contributions to space-borne instruments is included. Thus this discussion shall not be seen as an attempt to write a history of Finnish space research which would be a much larger task and is yet to be done.

This part of history covers the last 20 years only. As the time span of ambitious space research projects is often 10–15 years, sometimes longer, we cannot really look the process in a historical perspective, and the significance of many recent initiatives will only be seen in the future. However, inclusion of this section in this article is well-motivated because the geophysics-related space research played a decisive role in the remarkable process when Finland took its present place in the European space research community.

3.1 *First steps*

Excluding meteorological measurements, the first Finnish space measurements were made using stratospheric balloons that lifted the instruments to altitudes of few tens of kilometres. The balloons were launched simultaneously from Finnish, Swedish, and Norwegian Lapland in July 1965 and drifted at 35 km altitude roughly 24 h recording different components of radiation. The measurements were performed as a cooperation between Max–Planck–Institut für Aeronomie, Laboratoire de Physique Cosmique, Paris, and researchers from Norway, Austria, and Finland. *P. Tanskanen* from University of Oulu and *J. Oksman* from the SGO were the key persons in Finland.

However, Finland remained as one of the last European countries to begin space research with own space-borne observations until mid-1980's. Although there were active scientific communities both in astronomy and space physics, who had used satellite observations in their scientific research already for some time, none of them had so far produced own scientific instrument hardware for rocket or satellite experiments.

The most important path to the first space instrument project can be argued to have begun through the extensive Finnish participation in the International Magnetospheric Study (IMS) in 1976–1979 when the favourably located ground-based instruments, including magnetometers, all-sky cameras, riometers, radars, etc., were used in combination with some 20 satellites in various places of geospace and solar wind. This process introduced the small Finnish space physics community to the possibilities and requirements of space-borne instrumentation and led to important personal contacts with more experienced groups world-wide.

During the SAR (Skandinaviska Arbetsgruppen för Rymdforskning) meeting in Oulu 1975 *B. Hultqvist* from Kiruna, Sweden, suggested that Finnish geophysicists could participate in the construction of Swedish space instruments. The proposal was taken seriously and the Geophysics Division of the FMI started to look for financial support for such projects but without success.

In May 1978 *R. Z. Sagdeev* from the Space Research Institute (IKI) of the Soviet Academy of Sciences proposed that Finland should consider participation in Prognoz or Intercosmos programmes with own instrumentation without need to contribute to launch costs. After a study conducted by the Finnish Academy of Science and Letters this did not immediately lead to any concrete projects as the experience and resources were not found to be sufficient.

Another similar proposal was made by the Swedish Space Board in spring 1982 when Finland was invited to join the planning and building of the second Swedish scientific satellite Viking-2. However, neither this initiative led to anything, as the Finnish industry did not find strong enough connections to space technology. It was seen as a problem that Finland was not a member of the European Space Agency (ESA), which had been founded in 1975 to continue the work of the European Space Research Organisation (ESRO) and European Launcher Development Organisation (ELDO).

All these unsuccessful steps illustrate the height of the initial threshold to become involved in complicated new research programmes. In order to get accepted and funded experience and references are needed. However, experience can only be obtained by actual participation.

The Soviet option returned to the agenda a few years later as a part of the internationalisation of the Soviet space programme in the 1980's. After a visit of representatives of the Finnish Government and science administration in the Star City in Soviet Union, an idea to train a Finnish cosmonaut popped up. Neither the Finnish research community nor science administration found the idea worth to support. An ad-hoc committee, under leadership of *M. Tiuri,* was set up in March 1984 to address this issue and it was found that the best way to counter a cosmonaut proposal was to propose co-operation in some field of basic research or space applications. This way the Soviet and Swedish threads became tied together.

Swedish space physicists from the Kiruna Geophysical Institute (now the Swedish Institute of Space Physics) had been involved in Soviet Prognoz satellites and had started to design plasma spectrometers (PROMICS-3) to two Soviet Interball satellites for studies of magnetospheric physics. Risto Pellinen from FMI proposed that Finland should join the Interball programme through Swedish collaboration. This proposal was received positively both in Finland and Sweden whereas the Soviet response was first more reserved. However, already in December 1984 a formal co-operation agreement with the Swedish partners was signed. Consequently, geophysical research took the lead in the development of Finnish space research.

Funding of the first Finnish space project was negotiated between the Technology Development Centre (TEKES), Ministry of Commerce and Industry, Academy of Finland, and FMI. However, just before the start of the project Soviet Union gave higher priority to the Phobos mission to Mars and its moon Phobos ahead of the Interball mission. Kiruna Geophysical Institute had a similar plasma spectrometer (ASPERA) under development for this mission as well and the Finnish funding bodies accepted the funding to be moved to this project. Thus instead of studying the magnetosphere of the Earth, the first instrument with Finnish hardware contribution was to investigate the plasma environment of Mars. Officially the hardware project started 1 May 1985. The Interball project had to suffer the complications of the fall of Soviet Union but finally became a scientifically successful mission with two perfect launches in 1995 and 1996.

The participation in the ASPERA instrument initiated some important activities within Finnish Industry (see, *Pellinen*, 1993). Furthermore, once the door was opened, participation in other Phobos instruments was suggested. In February 1986, funding of French participation in a laser-experiment (LIMA-D) to study the elemental composition of the moon Phobos was withdrawn and FMI were asked if they could contribute to its data processing unit. Funding of this project was negotiated very fast and LIMA-D initiated a long-term industrial co-operation between FMI and Finnish and German industries as well as German scientists. This co-operation has continued in several other research projects. FMI participated with a small contribution also in another instrument to study the material composition of Phobos (DION). However, only the ASPERA instrument of FMI's contributions returned data due to the premature loss of both Phobos spacecraft in 1988 and 1989.

As a planetary research project, also the Finnish astronomers had considerable interest in the Phobos project. The Observatory of the University of Helsinki actively participated in the science programme of the camera experiment onboard Phobos, which provided useful images of the moon Phobos before the loss of the second spacecraft.

3.2 Joining ESA

The fact that Finland had remained outside ESA had undoubtedly slowed down the development of Finnish space research and technology as illustrated by the response to the Viking-2 proposal above. Preliminary contacts to join ESA were taken in December 1984 but the ESA member states needed first to formulate their own position toward new members. In 1 June, 1985, the Finnish Space Board was founded under the Ministry of Communications with *P. Jauho* as a Chairman and the negotiations with ESA started in 15 November, 1985. The negotiations covered an associated membership in the organisation and participation in the Science Programme and in the Earth Observation Preparatory Programme. Finland became an Associate Member of ESA and a Full Member of its Science Programme from the beginning of 1987.

Parallel to the ESA membership the co-operation with the Soviet Union was formalised and in 7 January, 1987, a Government level agreement was signed by the Prime Ministers of both countries. Later Russia has ratified the agreement but its practical meaning has decreased throughout the 1990's.

Also within ESA the geophysical space research played a critical role and Finland got a start that was almost too successful considering the limited resources available for space research at that time. ESA was preparing its First Cornerstone Programme consisting of two missions to study the Sun and the terrestrial magnetosphere, SOHO and Cluster. Detailed instrument proposals were due 15 July, 1987.

Based on the contacts within the Phobos programme a co-operation between the FMI and Service d'Aeronomie in Paris was established to propose a solar wind instrument (SWAN) for the SOHO mission with *Jean-Loup Bertaux* as the Principal Investigator (PI). At the same time *Jarmo Torsti* from the University of Turku was preparing a proposal to measure solar high-energy particles with an instrument called ERNE. Both ERNE and SWAN were successful and Torsti became the first Finnish PI on an ESA mission. SOHO was successfully launched on 2 December, 1995, and placed later on a halo orbit around the so-called first Lagrange point (L1) between the Sun and the Earth.

The second half of the cornerstone was Cluster. It consists of four spacecraft flying in close constellation aimed in particular to studies of various boundary regions of the magnetosphere. Four spacecraft are expected to be able to resolve spatio-temporal ambiguities of single spacecrafts observations and to produce three-dimensional vector quantities with unprecedented accuracy. Both FMI and the Space Physics division of the University of Oulu were involved in instrument proposals. This time the plasma instrument with FMI participation was not selected but the team lead by *P. Tanskanen* of the University of Oulu got an important responsibility to produce mechanisms to release the 50 m long booms for electric fields and wave measurements (EFW). Furthermore they got a smaller role in one of Cluster's particle instruments, RAPID. The four Cluster satellites were destroyed with the unsuccessful first flight of Ariane 5 in June, 1996. Fortunately ESA decided to rebuild the spacecraft and they were successfully launched by two Soyuz-Fregat launchers in 16 July and 9 August, 2000. At the time of writing this text, Cluster has began its routine observations with 42 of the total 44 experiment units in an excellent shape.

Within the Earth Observation Programme of ESA Finland got similarly an excellent start. With the same collaborators as in SWAN from FMI and Service d'Aeronomie a proposal to use stellar occultations to observe various gases, in particular ozone, in the stratosphere was submitted by 29 July, 1988. The instrument was called GOMOS and it became one of the key instruments of the ENVISAT-1 satellite that now is scheduled for launch in autumn 2001. This is one more example of the long time scales of large space instrument projects. However, it is very typical that dedicated work within space projects leads to significant spin-offs already during the design and manufacturing phases. GOMOS has given Finnish scientists a strong position in this particular field which is illustrated by participation in the Odin mission of Sweden, EOS/Aura mission of NASA, several contract studies with ESA, establishment of ozone data centre in Sodankylä, etc.

Another spin-off worthwhile mentioning is that the leading space engineer at FMI, *S. Korpela*, during the birth of these missions founded in 1988 a new company Space Systems Finland (SSF) which today has more than 30 employees and has become a major actor in Finnish space industry.

3.3 Collaboration with Sweden

Sweden played an important role in the early development of Finnish space physics. In addition to the joint plasma instruments to the Soviet, and later Russian, missions the Swedish national satellite projects have provided a very efficient route to space research at various levels. Although Finland did not have any direct involvement in the first Swedish satellite Viking, several Finnish scientists both at FMI and in the University of Oulu worked very actively in scientific analysis of Viking observations during its mission in 1986 and afterwards. In addition Hannu Koskinen worked with Viking's wave instrument in Uppsala 1981–1987 as a graduate student and a post-doc. Viking observations have had an essential role in several Finnish doctoral theses (*Tuija Pulkkinen*, 1992; *Anssi Mälkki*, 1993; *Anita Aikio*, 1995; *Kirsti Kauristie*, 1997; *Reijo Rasinkangas*, 1997).

Space missions often have a long evolution before they become real projects. For exaple, Viking-2 was finally realised as the Freja mission. The satellite got its final format in 1987 but already in the autumn of 1988 it became clear that Sweden would need foreign contributions in the system level and an offer was made to Finland to join the mission. Also this offer was refused again by industrial policy arguments. But now the ESA argument was turned around: Because Finland already was participating in ESA activities, there was no need for this kind of participation in foreign national projects. Perhaps, there were doubts whether Sweden would succeed again, but afterwards this may have been a severe mistake. From Freja the Finnish industry could have got very valuable references for further competitions both in ESA projects and elsewhere. In fact, it took until 1995 before the Finnish space industry had developed to a level that Finland could become a full member of ESA. In Freja Germany took some 30% share of the mission and satellite was successfully launched in October 1992. The Finnish participation remained again at co-investigator level in the electric field (Univ. of Oulu) and wave and particle (FMI) instruments. FMI also arranged industrial contributions to power units of all Swedish instruments onboard.

Finnish groups have also contributed to the two first Swedish microsatellites Astrid-1 (FMI; launched in January 1995) and Astrid-2 (Univ. of Oulu; launched in December, 1998). Astrid-1 had a particularly important task to demonstrate the feasibility of novel techniques of energetic neutral atom imaging as a magnetospheric research tool.

In early 1990's Sweden started to develop their third scientific satellite Odin. It is a mission where similar techniques are used for both astronomical and aeronomical observations. At FMI this project has an important role in the space-borne studies of the middle atmosphere together with the ESA GOMOS-mission. Odin has turned out to be technically a more challenging mission than expected. After several delays Odin was launched with the movable START-1 (former SS-25) launcher from Siberia on 20 February 2001. The launch was perfect. At the time of writing the satellite is its commissioning phase and performing extremely well. In addition to the preparations of sicentific analysis both at FMI and the University of Helsinki, the Arctic Research Center of FMI (FMI–ARC) in Sodankylä is involved in the ground segement of the mission.

3.4 Continued co-operation with Soviet Union

As mentioned above, both Phobos spacecraft were lost due to technical failures before they had completed their scientific mission. However, Phobos-2 spent about two months on an orbit around Mars and produced scientifically meaningful data. The ASPERA plasma data provided the material for *Esa Kallio's* Ph.D. thesis (1996). The scientific results in this thesis and in a series of papers published later provided the, thus far, most extensive characterisation how solar wind plasma flows around an unmagnetised planet and interacts with its atmosphere. An important consequence of this interaction is the escape of oxygen atoms, whose role in the past dehydration of the planet is an interesting issue.

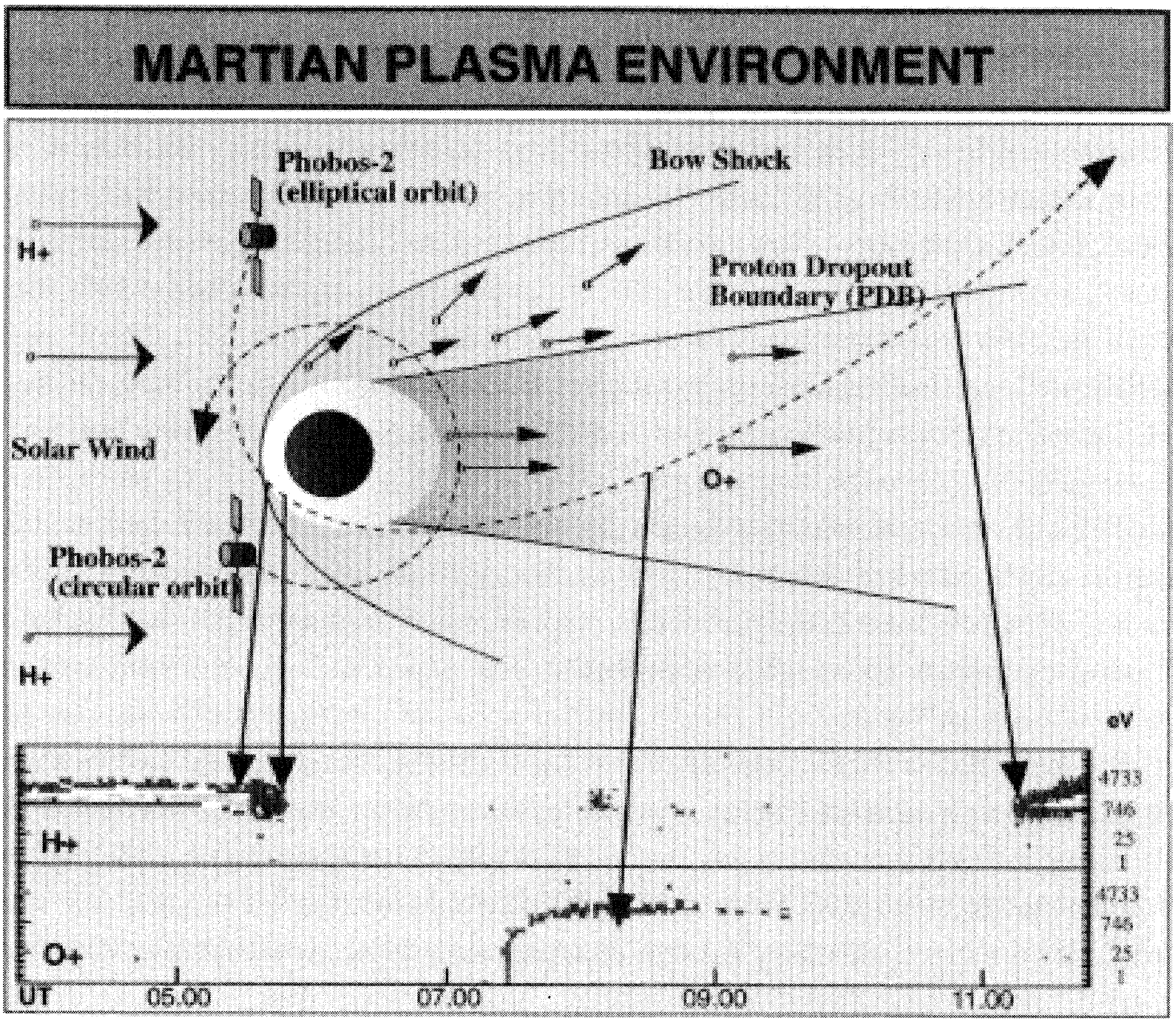


Fig. 15. Phobos/ASPERA observations of the plasma environment of Mars. The solar wind blows from the left and induces a magnetosphere around the (almost) non-magnetic planet. The data panel in the lower part of the fihure show counts of solar wind protons outside the magnetosphere and of oxygen ions of Martian origin deep in the tail of the magnetosphere.

By the end of the development phase of the Phobos mission plans for the next Soviet Mars mission started to get concrete shape. That FMI would participate in the next generation plasma instrument, ASPERA-C, including one of the first neutral atom sensors, was a logical follow-up of the Phobos mission. However, more was to come as *Jean-Pierre Pommereau* from Service d'Aeronomie asked in 1987 whether the small meteorological sensors by Vaisala Oy would be suitable for observations in Mars. *P. Kostamo* from Vaisala developed within a few months a programme concept that got the name Metegg. The name refers to an idea how a balloon hovering above the planet would release the small surface stations as its guide rope ballast like laying eggs on the planet. At FMI the key persons in this development were *R. Pellinen* and *I. Liede.* TEKES supported the feasibility study of these meteorological surface stations and they became accepted to the mission which at that time was called Mars-92, referring to a planned launch in 1992.

Growing economical problems in the Soviet Union led to the rescheduling of the launch, first to 1994, and later to 1996, thus we refer to the mission as Mars-96. The

Finnish role in the landing elements of the mission grew gradually. Finally, FMI had the main system responsibility for two landing stations and Finnish industry delivered significant parts of their electronics (Finnyards Oy, later Patria Finavitec Systems) and software (Space Systems Finland, SSF). The Mars-96 spacecraft was launched in November, 1996, with the reliable Proton launcher. However, the launcher needed an extra upper stage. It was a new construction that unfortunately failed to put the spacecraft to the desired orbit. The spacecraft, most likely, crashed in the Andes. While this was a major drawback to the geophysical research of Mars, the efforts invested in small lander systems and meteorological space instrumentation had already by 1996 made FMI to one of the leading players in most planetary lander missions being under construction or planning stages.

In mid-1990's there was still one geophysical Finnish–Russian co-operative mission waiting for launch: the two Interball satellites with their Swedish–Finnish–Russian PROMICS-3 instruments. The development of the instruments had been very slow due to continuous delays with the Interball programme. Finally the two satellites were launched successfully in August 1995 and August 1996. They have provided a wealth of scientifically meaningful data on solar wind-magnetosphere interaction and auroral physics.

3.5 ESA programmes today

The first Cornerstone mission of ESA, SOHO, has been a great success. Its imaging instruments have revolutionised our view on the Sun both concerning its surface activity and internal processes. The main Finnish efforts have also led to important advances. The University of Turku group have published several important studies on energetic particle acceleration associated with solar flares and coronal mass ejections. At FMI the large-scale structure of the solar wind has been mapped with unprecedented detail. An interesting feature of large space missions is that already the preparations for their data analysis provide challenging topics for scientific research. Good examples are from the preparations for the SOHO instruments, which laid the foundations for the doctoral theses for *T. Summanen* (1996) and *R. Vainio* (1998).

SOHO/SWAN observations have turned out to be very successful also in cometary research. In fact, a comet missed by all other observers in 1997 was later found from the SWAN data by *T. Mäkinen* (2000). This discovery nicely supports the FMI efforts on cometary research within the third ESA cornerstone mission Rosetta to comet Wirtanen. This spacecraft to be launched in January 2003 ties several threads of the FMI space research to the same mission as the various contributions have their roots in LIMA-D collaboration with German research groups in Phobos, in long line of plasma instrument collaboration with Sweden, and in instrument development with the ESA technology centre ESTEC in the Netherlands, just to name a few. While the cometary observations with Rosetta will not be available before 2011, the work at FMI was initiated in 1994, making this their longest-duration project thus far.

Two other planetary geophysics missions that are underway are participation in the NASA-ESA mission Cassini-Huyghens and ESA's Mars Express. Cassini-Huygens, launched in October 1997, is on its way to Saturn and its moon Titan. University of Oulu contributed an ion beam sensor (IBS) to the Cassini plasma instrument (CAPS) together with the Technical Research Centre of Finland (VTT). FMI provided a Vaisala pressure sensor to the Huyghens probe that will descent through the atmosphere of Titan in 2004.

ESA decided to conduct the Mars Express mission partly as a replacement to the ill-fated Mars-96 as several ESA member state groups had invested considerable effort in the scientific instrumentation of that mission. FMI participates in a plasma and neutral atom instrument (ASPERA-3) for a further study of the solar wind-atmosphere interaction begun with the ASPERA observations of Phobos-2. Mars Express is scheduled for launch in 2003.

3.6 Co-operation with US

Although in practice the rapid early growth of Finnish space research took place within Europe, strong scientific co-operation with various US groups has been important to the Finnish space physics. In the field of auroral research a special person in this co-operation has been *W. Heikkila* from the University of Texas at Dallas. He visited Finland frequently from the year 1974 and acted as Ph.D. thesis advisor of Risto Pellinen. These contacts led to a series of US–Finnish auroral workshops supported by the National Science Foundation and the Academy of Finland. The first workshop took place at the University of Oulu in August, 1981, and the following ones were held at University of Maryland (October, 1983), at SGO (October, 1985), in Yosemite (December, 1989), in Tervakoski, Southern Finland (March, 1992), and the latest one in Melbourne, Florida (February, 1997). Of these in particular the Yosemite workshop in 1989 contributed to a strong enhancement in scientific co-operation in magnetospheric and ionospheric research. *H. Laakso* and *T. Pulkkinen* worked several long periods at the Goddard Space Flight Center, in Maryland, and T. Pulkkinen at the University of Colorado in Boulder during the 1990's. Scientific data from numerous US spacecraft have been used by Finnish scientists throughout the history of spaceflight but in particular after the Yosemite workshop.

Participation in the US space missions with own instrumentation has remained smaller, partly owing to the national policy to give priority to the ESA missions. University of Oulu has provided the above mentioned ion beam instrument to Cassini. Another significant contribution is the boom release mechanism for the NASA Polar spacecraft, which was a direct spin-off from the similar system for Cluster. Polar has already produced a wealth of scientific data, and Finnish scientists are actively using them in several different studies. Many of these utilise the ground-based MIRACLE observations in conjunction with Polar observations.

The strong emphasis on Martian meteorology has opened the possibility for FMI to provide meteorological sensors also to the NASA Mars missions. The first units to reach the red planet with a US carrier were onboard the Mars Polar Lander. The contact to the spacecraft was lost at the time of landing in December, 1999, and thus FMI again lost the possibility to conduct research with own planetary instrumentation. Nevertheless, this collaboration has been also scientifically productive. The contacts to the US Mars research groups have also led to long-term Finnish visits (*A.-M. Harri*, JPL, and *T. Siili*, Ames Research Center, both in California). Furthermore, *T. Siili's* Ph.D. Thesis (1999) was largely based on this collaboration.

In 1999 a new opening to the US–Finnish space research collaboration was realised when TEKES decided to fund Finnish industrial participation in ozone monitoring instrument (OMI) in the NASA's EOS/Aura mission to be launched already 2002. For FMI, who lead the Finnish participation, this is one further logical link in the space-borne stratospheric observation programme.

3.7 Concluding remarks

The history of Finnish space-borne observations of geophysics-related space physics is less than 20 years old. During this initial period the development was very much determined by various instrument projects of which some have been great successes, but some other have become examples of the great failure risks that always follow space research. In addition to all the projects mentioned above there have been several more proposals for other missions and instruments that have never got through either the selection process or found sufficient funding. Several of the large investments of effort and man-power have only recently become scientifically productive or will do so in the future. Thus it is premature to try to assess their scientific impact or historical value yet.

At the same time Finnish research groups have been quite successful doing space research based on external observations, modelling, and theory. In the field of space physics the close relations to ground-based observations have certainly been very important. This has resulted in a very impressive publication record. For example, in the recent COSPAR report covering years 1998–1999 (*Ahola et al.,* 2000) 104 publications are listed from the field of magnetosphere-ionosphere research and 79 in the solar system research. Furthermore, a new generation of space physicists have been educated and presently the age distribution of senior scientists is quite homogeneous in the range 30–50 years. Presently, the Finnish Graduate School in Astronomy and Space Physics (founded in 1995 as the Graduate School in Solar-Terrestrial Physics, and extended in 1999 to include also astronomy) provides an active network for the training of the next generation of space researchers. Thus we can expect that the future historians will see the period from 1984–2000 as a start of a strong and lasting initiative in the Finnish space research in general and in space physics in particular.

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