Future prospects for Finnish EISCAT research

1. Summary

The leading research topics of the Finnish EISCAT research are

a) Auroral physics and ionosphere-magnetosphere coupling (UO, FMI)
b) Lower ionosphere (D-region) and ionosphere-atmosphere coupling (SGO, FMI)
c) Measuring and analysis methods (SGO, UO)
d) Heating experiments: modulation of electrojets, API (artificial periodic irregularities) and artificial aurora (UO, SGO)
e) Special measurements, especially space debris (SGO)

(FMI= Finnish Meteorological Institute, UO= University of Oulu and SGO= Sodankylä Geophysical Observatory, which is an independent national institute of the University of Oulu).

The topics listed above are expected to be important also after 2006. The most important current EISCAT facilities used in the above research topics are

a) Most important: UHF-tristatic. Also VHF and ESR 32m and 42m.
b) Most important: VHF. Also UHF and ESR 32m and 42m.
c) Most important: UHF. Also ESR 32m and 42m, VHF and UHF-tristatic.
d) Most important: Heating facility, VHF and UHF.
e) Most important for space debris: UHF-tristatic. Also ESR and VHF.

The types of observations needed for these research topics are

a) Field-aligned high temporal and spatial resolution measurements (UHF and ESR 42m) from the upper part of the D-region to the F-region. Also measurements allowing observations in a wide latitudinal range (e.g. low-elevation VHF and ESR 32m antennas).
b) VHF experiments from 50 to 150 km for D-region and mesospheric/lower thermospheric studies.
c) New kind of measurements with mainland and ESR UHF radars.
d) VHF or UHF radars measuring mainly at D- and E-region, but also at F-region altitudes.
e) UHF-tristatic, any measurement.

For the Finnish EISCAT user community, the priority list for the possible extensions of the existing system is as follows

1. **Passive UHF phased arrays to Sodankylä and Kiruna**
2. **Reconstruction of VHF to phased array and possible remotes**
3. **Improved real-time signal processing**

The additional extension to EISCAT, suggested by the Finnish EISCAT user community, is **a new coherent scatter radar**, with a field-of-view centered around Tromso.

2. Background

2.1 Leading research priorities and their expected development

2.1.1 Auroral physics and ionosphere-magnetosphere coupling

The auroral research has long traditions in Finland. At present, a comprehensive ground-based measuring network, MIRACLE, exists in Northern Scandinavia. MIRACLE consists of magnetometers, all-sky cameras and ionospheric radars from sub-auroral to polar cap latitudes and it is maintained and operated as international collaboration under the leadership of the Finnish Meteorological Institute (FMI). Sodankylä Geophysical Observatory (SGO) operates pulsation magnetometers together with UO, magnetometers, an all-sky camera and an imaging riometer, IRIS, together with the University of Lancaster. The optical group at the University of Oulu (UO) operates several optical stations, during all national and some international EISCAT experiments, which are equipped by real speed CCD-based TV-cameras, fully digital CCD cameras, and multichannel photometers. On Svalbard, the optical observations are obtained by co-operation with the University of Southampton and institutions having optical instruments at the Auroral Station.
The studies of aurora include

- Optical emissions and rotational temperatures
- Narrow structures in auroral arcs (rays)
- Local electrodynamics and motions of auroral arcs
- Dayside auroras
- Coupling of solar wind to the magnetosphere and ionosphere

This research topic is expected to continue and strengthen. A spectrometer and a ten-channel photometer will be constructed at UO. The ongoing CLUSTER-MIRACLE project between UO and FMI, funded by the ANTARES project of the Academy of Finland, is aimed at studying the energy transfer from the solar wind to the magnetosphere and ionosphere and related phenomena. Future satellite missions will also need ground observations to study the magnetosphere-ionosphere coupling processes. Studies of smaller scale will continue and e.g. the relationship between narrow structures in auroral arcs (rays) and NEIAL (naturally enhanced ion-acoustic lines) will be examined. The newly established satellite tomography chain by SGO in co-operation with UO in Northern Scandinavia will provide possibilities for monitoring the auroral ionosphere over large latitudinal range and is of interest to use in conjunction with EISCAT measurements. Future space weather studies will include both the topics discussed under this item as well as the coupling of energetic particle precipation to the lower ionospheric and atmospheric procesesses to be discussed below.

2.1.2 Lower ionosphere (D-region) and ionosphere-atmosphere coupling

SGO and FMI are running a long term research project CHAMOS, Chemical Aeronomy of the Mesosphere and Ozone in the Stratosphere. Currently the project is funded in the Finnish Space Research programme ANTARES by Academy of Finland. The aim of the project is to study the impact of solar and magnetospheric energetic particles on the ozone chemistry of the mesosphere and upper stratosphere and to quantify the contribution of energetic particle precipitation to the destruction of ozone in the mesosphere and upper stratosphere, by using a detailed chemical model of the atmosphere (Sodankylä Ion Chemistry, SIC model), which presently includes also relevant neutral chemistry of the nitric oxides and ozone. Data are selected from future and existing archives of satellites concerning those particle events, for which there exist supporting data by the IRIS imaging riometer, the Finnish riometer network, the European Space Mission ENVISAT-1, the Scandinavian satellite Odin, EISCAT incoherent scatter radars and other ground based data.

The auroral processes clearly change also the neutral atmosphere, and the aim is to quantify how much. Production of odd nitrogen at high latitudes and the global role of this process is not yet quantified. For experimental confirmations EISCAT measurements are needed in the altitude range of 50-150 km, continuous radar data in timescales of 1-14 days during and after the events, as well as supporting satellite data. Major experimental validation of model studies is expected by the EISCAT VHF radar, with wide altitude coverage and long experiment times, including mapping of seasonal and solar cycle effects. Additional contributions are expected from ESR, UHF and API experiments. There is a need both for multi-instrument data: satellites, ISR radars, riometers, lidars, and for combination of local models (such as SIC) and 2D and 3D transport models.

2.1.3 Measuring and analysis methods

The EISCAT radars are complicated and versatile systems which can be programmed in various ways to create appropriate spatial and temporal resolutions for each purpose and geophysical condition. Already in the 1980's, Finns took a leading role in using the possibilities offered by the modern hardware. The spatial resolution in measuring the full plasma autocorrelation function was squeezed down to 300 m. The time resolution was also greatly improved; the ultimate limit was 0.2s. Prof. T. Turunen developed these programmes as well as many others. The theory of incoherent scatter measurements by Prof. M. Lehtinen led to the invention of alternating codes, which approximately doubled the performance of the radar system. The data analysis programme, GUISDAP, now in use at EISCAT, has also been originally developed in Finland by the support of the Academy of Finland.

At present, the research group led by Prof. Lehtinen at SGO and UO is developing entirely new kinds of measurements. The underlying method is based upon recording scattering amplitudes directly from the measured echoes without correlation calculation. In this way the measurement errors of different data points become independent, and thus they are easy to process by inverse problem solvers. Recording of the raw echoes without further processing requires an unusually large digital storage capacity. The typical data rate is one million complex samples per second, which translates to 15 GBytes/hour or 360 GBytes/24 hours. Since 500-GByte disks have become available for about 1000 EUR, storing raw echoes is a realistic possibility today. The group presently owns about 1.5 TBytes of disk space dedicated for this purpose, which is sufficient for four days of recording, but a compression scheme is being developed, which will be able to compress the recorded data to about 20% of its size, thus allowing to store up to 20 days of raw echo data.

Development of new methods has been started in many different projects. Mathematical foundations have been developed in the MaDaMe project lead by Prof. Päivärinta. An industrial project to develop the hardware for both weather radar and SA sonar to record echoes directly was partly funded by TEKES in the ANTARES programme. This hardware was for the first time used in the space debris project at SGO (see Section 2.1.5) and it is part of the goals of the present space debris contract to permanently install this equipment at EISCAT Tromso. Similar equipment was obtained in 2000 through a grant by the Vaisala Foundation and it can now be installed permanently on Svalbard.

2.1.4 Heating experiments

Finland has used EISCAT heating facility for ten years: the first experiments were performed in November 1993. After that, eight combined EISCAT/auroral/heating –campaigns have been run. During campaigns different instruments have been used: auroral cameras, photometers, magnetometers, VLF receivers, and EISCAT radars. Beside campaigns, also many small experiments have been made.

The most common experiment has been the generation of artificial ULF and VLF waves. Also, many API (Artificial Periodic Irregularities) experiments have been made. E.g., in 2001 an experiment was carried out with the VHF radar as the "heater" (in an ON-OFF fashion) and the EISCAT-heating device in conjunction with the dynasonde as a "thermometer" in an API experiment configuration. In recent campaigns experiments with D-region heating, Alfven resonator and artificial auroras have been conducted.

The Russian-French satellite project RESONANCE (launch in 2008) is aimed at optimizing a satellite's orbit in such a way that it stays within the same magnetic flux tube as long as possible. Within given criteria this is about half an hour for a magnetic flux tube anchored at the heating device HAARP in Alaska. Similar estimates exist also for the EISCAT heater and an ULF-radar in Kola Peninsula. The satellite is equipped with all conventional plasma and E- and B-field instruments to study wave-particle interaction and plasma dynamics, natural and heating induced ones.

In general, the ionospheric D region is still poorly known and experimental data are scarce when compared to other ionospheric altitudes. We are currently studying the exciting possibility of gaining more information out of D-region ISR measurements by clever implementations of the API experiments, as well as other active experiments by the EISCAT heating facility.

2.1.5 Special measurements, especially space debris

Special measurements have been made with the EISCAT radars over the years. Examples are the space debris and ionospheric scintillation measurements.

The project “Measurements of small-size debris with backscatter of radio waves” was conducted during 2000–2001 at SGO; it was led by Prof. Lehtinen and financed by ESA. In that study, it was verified that EISCAT UHF radar performance is well comparable to the German TIRA radar performance in detecting small-size space debris (SD). Debris particles down to effective diameter of about 2 cm at 1000 km range were detectable. The project showed that it was technically straight-forward to piggyback the SD measurements on top of the normal EISCAT ionospheric measurements, without interfering with those measurements. EISCAT has now made a contract with ESA for 2003–2004 to use the EISCAT radars to monitor SD. A special SD receiver is operated in parallel with the standard EISCAT receiver, to ensure that the SD measurements do not interfere with the normal EISCAT work.

Permanent space debris measurements might in the future bring significant additional funding to EISCAT through a possible permanent agreement between EISCAT and ESA. It is probable that SGO and EISCAT Sodankylä site will have an important role in the more permanent space debris work, too.

2.2 Extensions to the existing system suggested by the Finnish user community

The Finnish user community decided to make the following priority order for the possible E-PRIME investments

1. Passive UHF phased arrays to Sodankylä and Kiruna
2. Reconstruction of VHF to phased array and possible remotes
3. Improved real-time signal processing

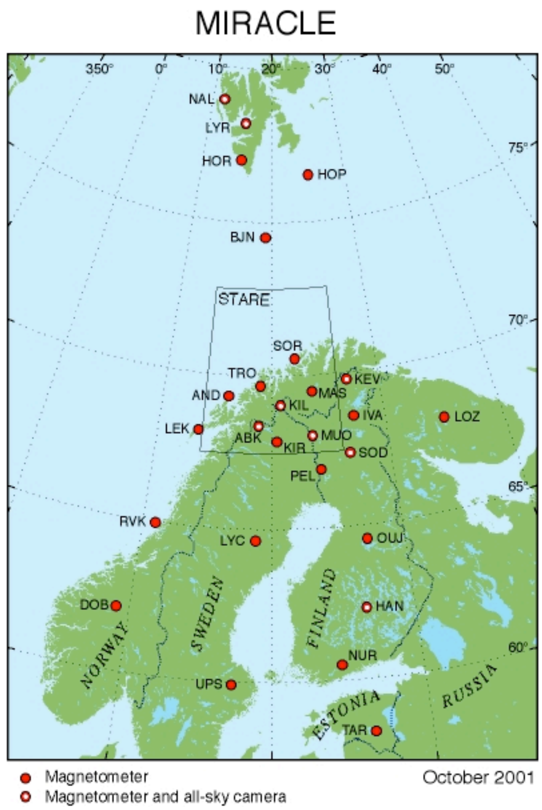
The most important extension to the present EISCAT is addition of passive UHF phased arrays to Sodankylä and Kiruna. These provide a possibility for a number of simultaneous intersection volumes along the transmitter beam. That can be used to calculate the neutral wind profile along the magnetic field line. In case of the transmitter beam not along the magnetic field line, a latitudinal profile of electric field could be obtained. These are of interest in the auroral studies, magnetosphere-ionosphere and ionosphere-atmosphere coupling studies. The passive UHF phased arrays would also allow finding out the true orbit and scattering cross section of space debris (SD). For detecting SD, UHF is better than VHF, since the scattering cross section for small solid targets is proportional to the power of four of frequency.

For near-continuous operations in the mainland, the VHF transmitter should be replaced. The Finnish EISCAT community considered that the best way to do that would be reconstruction of VHF to a phased array. The new system should be designed so that field-aligned measurements would be possible. Passive VHF phased arrays at Kiruna and Sodankylä would add again new dimension to the system (see above). Especially, if both the UHF and VHF had remote phased arrays, this would offer many possibilities to combine the multiple 3D measurements for various studies.

As the third priority, improved real-time signal processing was considered important. New sophisticated measurements would benefit from this feature as well as the space debris project. The umbrella function of the E-PRIME would also require these kind of investments.

In addition to the investments above (which were all presented in the E-PRIME prospectus), an additional complement is suggested by the Finnish user community: a new VHF coherent scatter radar. The motivation for including a coherent scatter radar to EISCAT is given below, with a short description of the presently existing STARE coherent radar system. Note, that the plan is to build a new radar and the transmitters may be located at other sites and have quite different technical properties compared to the present STARE.

STARE (Scandinavian Twin Auroral Radar Experiment) is a coherent scatter ionospheric radar system, which consists of two radars: one in Hankasalmi, central Finland (62.30ºN, 26.65ºE) and another one in Midtsandan, central Norway (63.67ºN, 10.73ºE). The STARE radar is presently operating with a field of view including EISCAT mainland, offering 2D vector velocities from a region shown on the map below. However, STARE's hardware is aging, and as the radar was originally designed in the 1970's, so the state-of-art of both radar hardware and software/ analysis techniques has tremendously advanced since its installation. Among others, a significant improvement of the amount of backscatter and thus of the useable electric field values is expected, as well as an improved reliability of the electric field results by using advanced multi-pulse codes.



For practically all applications of spatial, quantitative analysis of ionospheric electrodynamics it is crucial that measurements of the two-dimensional ionospheric electric field are available, as they are obtained from coherent scatter radars. Therefore, it is suggested to include a new coherent scatter radar into the renewal of EISCAT. Such a supporting system for EISCAT would allow to quantitatively observe the dynamics of the ionosphere in the vicinity of EISCAT, and to interpret the EISCAT observations in terms of the interaction with the plasma in its environment. The cost of the radar as such is about 1 M EUR, plus costs for personnel, communication lines, possibly rent of grounds, and maintenance, which over several years may amount to another 1 M EUR.