IRF

Institutet för rymdfysik

Swedish Institute of Space Physics

Contents

Satellite Projects

Ground-based Space Physics Research

Atmospheric Research

Other Research Methods and Modelling

Front cover: The Northern Lights were the original reason for the establishment of IRF in Kiruna, and they continue to fascinate scientist and layman alike. They are studied from below with ground-based instruments such as the EISCAT radar (p. 3) and from space with instruments on satellites such as the IRF-developed and built nanosatellite Munin (p. 9).

Photo: Torbjörn Lövgren.

Back cover: The "Eco Column" illustrates some of the phenomena studied and some of the instruments used by the scientists at IRF and other research organisations in Kiruna in their studies of everything "between heaven and earth".

Text and most photos and diagrams contributed by IRF scientists.

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IRF in the New Millennium

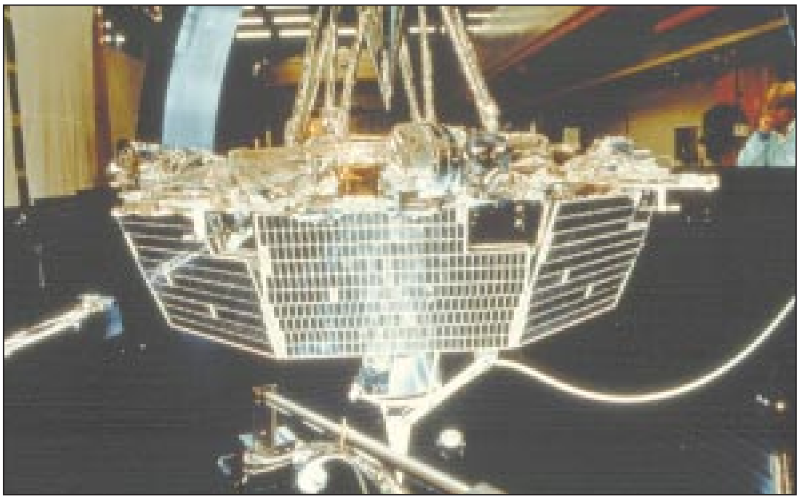
Professor Rickard Lundin, Director, IRF.

The Swedish Institute of Space Physics (IRF) has grown from a small geophysical observatory established in 1957 into a major national space research institute with departments in Kiruna, Umeå, Uppsala and Lund. Its status as a pure research institute has helped IRF to combine long term observatory activities with advanced space research projects carried out in collaboration with the European Space Agency (ESA) and the major space nations (e.g. Russia, USA and Japan). The IRF of today runs an extensive research programme — carried out by ground-based as well as space-based means. During the last ten years IRF has steadily increased its participation in university education in space physics and space technology. The new space campus in Kiruna, inaugurated in September 2000, will increase the opportunities for university students to have regular contact with professionals in space science and technology at IRF.

IRF has contributed substantially to the development of space science in Sweden. Besides being a major promotor for ground-based space science activities in northern Sweden, e.g. the EISCAT facility (below, right), it became via an early participation in European space science (ESRO 1, launched in October 1968) a major promotor for a Swedish national satellite programme. The first Swedish satellite, Viking, launched on 22 February 1986 (below, left), marked the beginning of an era of success for the Swedish national satellite programme.

With this brochure IRF records some of the achievements of the past, describes some of the projects it is currently pursuing, and looks forward to some of the challenges which lie in the future.

The EISCAT site in Kiruna, staffed by IRF-personnel. Photo: Torbjörn Lövgren.



Sweden's first satellite, Viking, launched 1986 (SSC).

A Space and Environment University College is to be established in Kiruna next year, and IRF looks forward to contributing to it, and expects that the increased profile that academic study and research will have in Kiruna can only be beneficial to a research institute such as ours.

Rickard Lundin,
Director, IRF

The Swedish Institute of Space Physics

The Swedish Institute of Space Physics (in Swedish "Institutet för rymdfysik", IRF) conducts experimental and theoretical research into space and atmospheric physics, including magnetospheric and ionospheric physics. Measurements are made by satellites, sounding rockets, meteorological balloons and ground-based equipment.

IRF was founded in 1957 as an institution within the Royal Swedish Academy of Sciences, and was then called Kiruna Geophysical Observatory. Measuring equipment, however, had been placed in Kiruna at the end of the 1940s. IRF has been a public research institute since 1973.

IRF consists of four divisions:

- the Kiruna division
- the Umeå division
- the Uppsala division
- the Lund division

The activities at the Uppsala division started in 1952 when it was a research station within the Swedish Defence Research Establishment. The division became part of IRF in 1976.

The Ionospheric Observatory in Lycksele has also been a part of IRF since 1970. The observations in Lycksele started in 1957.

IRF also has a station for measuring infra sound at Jämtön in Norrbotten.

Satellite experiments

IRF participates in several international projects, where satellites as well as ground-based equipment are used. The first Kiruna-designed satellite experiment was launched in 1968.

At present, data from satellite experiments are being analysed to help us better comprehend the plasma-physical processes in the solar wind and around comets and planets. The successful Swedish Viking and Freja satellites, with equipment from IRF on board, have greatly increased our knowledge of the Northern Lights processes in the Earth's magnetosphere. A Swedish micro-satellite, Astrid, was launched in 1995.

Some of the on-going projects are:

- Interball (1995/96) where IRF participates in experiments on two Russian satellites to study the magnetosphere.
- Astrid 2 (1998) is a micro-satellite for auroral research.
- Nozomi (1998) is a Japanese project for studies of Mars.
- Munin (2000) is a very small satellite built at IRF for space weather studies.
- Cluster 2 (2000) is an ESA cornerstone project for magnetospheric research.
- Rosetta (2003) is also one of ESA's cornerstone projects. Among other things it will study a comet.
- Mars Express (2003) is another major ESA project, and the first European mission to Mars.

Space projects usually solve many questions. However, it is usual that surprising results give rise to new questions. This makes basic research (journeys of exploration into the unknown) even more exciting.

IRF instruments to Mars

A particle instrument, ASPERA, was developed at IRF for the Russian Phobos spacecraft which were launched in July 1988. ASPERA measures electrons and positive ions in the energy range 0.001 - 25 keV. Particles within this range of energy participate in many interesting processes. On Earth they give rise to the Northern Lights. ASPERA made unique measurements in the surroundings of Mars during the first months of 1989.

Mars' magnetic field is weak. Therefore special plasma-physical conditions rule and they are interesting for us to compare with those of the Earth.

IRF has developed new measuring equipment launched on board a Japanese spacecraft to continue the exploration of Mars' surroundings. Instruments for European spacecraft are also being planned.

Ground based research into the Northern Lights

Continuous measurements of the following are made at IRF:

- the magnetic field of the Earth
- Northern Lights
- cosmic radio noise
- ionospheric parameters

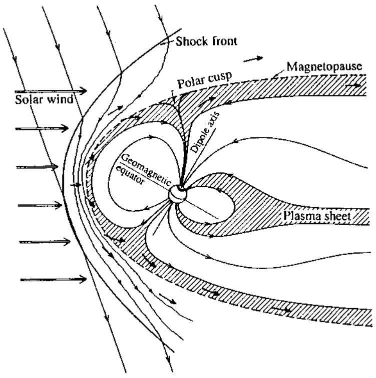
Experiments are conducted with research radars such as EISCAT (transmitters in Tromsø and on Svalbard) and the SuperDARN network. These are used for example to study the processes which cause the Northern Lights.

The three-dimensional structure of the Northern Lights is studied with ALIS (Auroral Large Imaging System), a multi-station imaging system which uses sophisticated tomographic reconstruction techniques, artificial intelligence and advanced IT. The system comprises today a network of 6 stations with advanced CCD cameras and a control centre.

Space Physics — understanding the universe

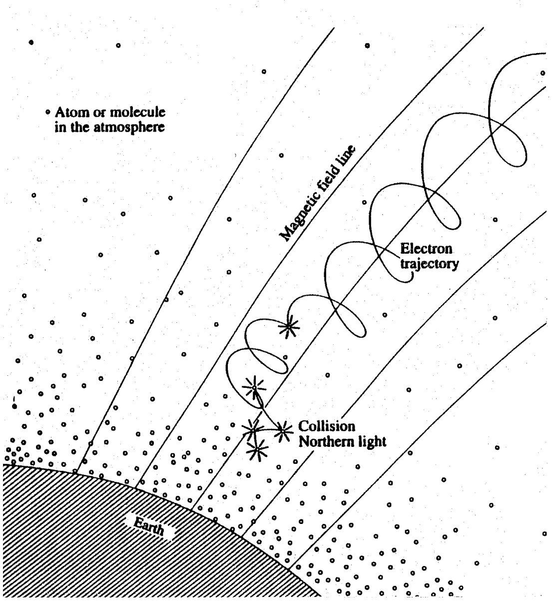
The Northern Lights are a result of plasma-physical processes. The universe is mainly composed of plasma (about 99%), which is an ionized gas, able to conduct electric currents. Plasma is affected by (and affects) electric and magnetic fields around, for example, planets, stars or even entire galaxies.

The magnetic field of the Earth varies greatly in certain areas during an "outburst" of Northern Lights. Disturbances might affect power lines, telephone networks, radio communication, etc.



Where do the Northern Lights come from?

The Sun is the source of the energy in the Northern Lights or Aurora. This energy comes to the Earth with the solar wind. The solar wind plasma flows continuously in all directions from the Sun, at an average speed of 400 km/s. Part of the energy absorbed by the magnetosphere accelerates electrons (and ions). The electrons are directed by the Earth's magnetic field toward the polar regions. At a few hundred kilometres above the Earth, the electrons start colliding with particles in the atmosphere. Some atoms, molecules and ions absorb energy, i.e. they are excited. The excess energy can be sent out as visible light. This is the Northern Lights. The colour of the Northern Lights depends on what kind of atoms or molecules are involved and on the level of excitation.



Satellite Projects at the Swedish Institute of Space Physics

In the field of space plasma physics, IRF develops and builds its own instruments and analyses the data from them at its divisions in Kiruna and Uppsala. The Kiruna Division has specialised in measurements of charged particles such as electrons, protons and oxygen ions, and in measurements of energetic neutral particles. The Uppsala Division's specialisation has been into measurements of space plasma waves. Physical processes in the magnetosphere of the Earth and other planetary bodies in the solar system are studied.

IRF's Programme of Mars Exploration

IRF has a long history of Mars research. We have participated in all non-American missions to this puzzling planet since 1988. Our first experiment ASPERA (Automatic Space Plasma Experiment with a Rotating Analyzer) flown on both Soviet PHOBOS spacecraft in 1988-1989 was the first ion mass spectrometer to investigate the near-Mars space. It discovered that the Martian atmosphere is subject to constant escape induced by the interaction with the solar wind. The atmospheric losses amount up to 1 kg/s. It looks insignificant but operating over the planetological time scale it can result in a very significant loss of Martian volatiles such as water.

Encouraged by this discovery we proposed the more advanced instrument ASPERA-C (Automatic Solar system Particle Experiment with Rotating Analyzer-Cosmogony) for the next Soviet/Russian mission to Mars, Mars-96, and IMI (Ion Mass Imager) for the first Japanese planetary mission which would target Mars, Nozomi ("Hope"). On Mars-96 we planned to use a completely new technique to study plasmas in space, Energetic Neutral Atom (ENA) imaging, to understand the process of the electrodynamically-induced atmospheric escape. On Nozomi we wanted to continue investigations of the plasma composition at Mars using the more advanced mass spectrometer.

But Mars is a tough planet which doesn't willingly reveal its secrets; Mars-96, launched in 1996, failed to reach interplanetary trajectory and sank in the Pacific. Nozomi, launched in 1998, suffered an engine malfunction which delayed its expected arrival at Mars until 2004.

However, we were not stopped by these drawbacks, and proposed a new instrument for the first ESA planetary mission, Mars Express. The experiment ASPERA-3 (Analyzer of Space Plasmas and Energetic Atoms) is the most advanced in the series and the most sophisticated experiment of all built at IRF. It comprises four sensors to measure electrons, ions and energetic neutral atoms. The instrument will perform in-situ particle measurements in the energy range from a few eV up to 40 keV as well as remote imaging of the escaping plasma via the energetic neutral atom imaging technique.


The ASPERA-C instrument.

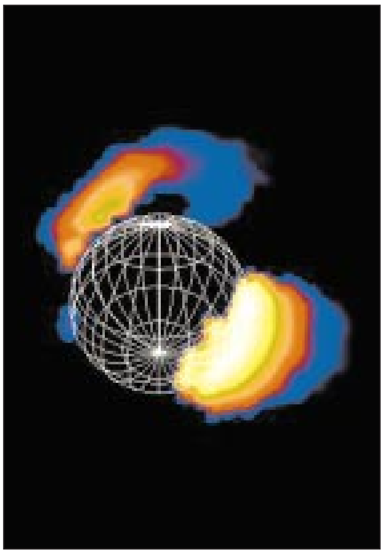
The main scientific objective of the experiment is to find out the answer to the question: How strongly does the solar wind affect the Martian atmosphere and its evolution? The Mars Express mission will be launched in June 2003 and arrive at Mars in December 2003, almost simultaneously with Nozomi. We will then be in the unique position of having two instruments at another planet and can hope to gather a really rich harvest of scientific discoveries.

Planetary Research at IRF: from Mercury to Pluto, from the Sun to a Comet

Mars is our prime scientific interest in planetary research. However the knowledge gained in studies of this planet as well as in magnetospheric physics can be applied to other objects of the Solar System. For example, the solar wind-comet interaction resembles in many respects the interaction with Mars. (See Catching up with a Comet.)

We have learnt a lot about our own magnetosphere through more than 40 years of space research. But how do the other magnetospheres "work"? What are the relative importances of the different magnetospheric components? Will our theories still work, if we "change" the system? What is common and what is different in the magnetospheres of different bodies? The field of space plasma studying these issues is called comparative magnetospheric studies. The closest analogue to the terrestrial magnetosphere is, perhaps, the magnetosphere of Mercury. Unfortunately, it has only been visited once, but now a number of ambitious missions are targeting this planet. We are actively involved in research on Mercury's magnetosphere, looking at plasma and neutral gas dynamics in the near-Mercury case. We were the first to suggest using ENA-imaging to study plasma dynamics there (see figure above right) and are working hard on an instrument which can make these measurements on the proposed ESA mission to Mercury, BepiColombo.

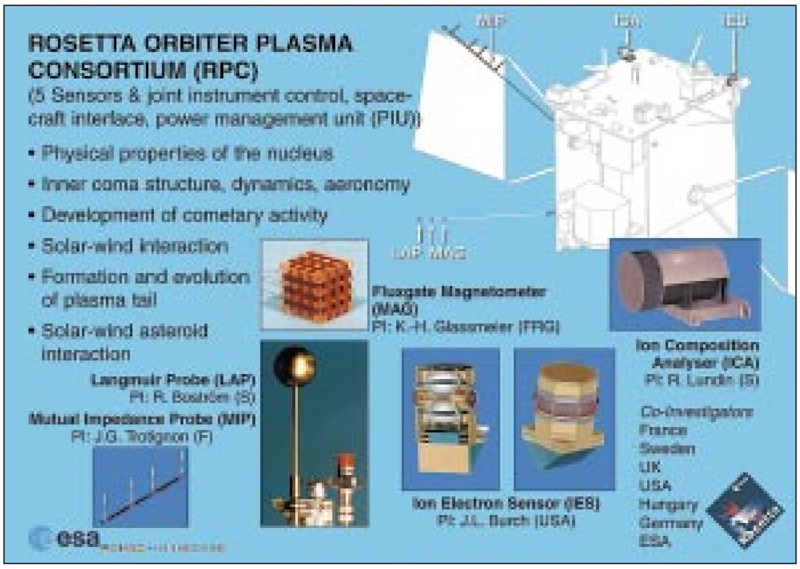
We have been building scientific instruments for space research for more than 30 years and have got used to facing challenges. Therefore we have designs ready to take part in such demanding missions as Pluto-Kuiper Express, Pluto fly-by and Solar Probe, a fly-by in the solar corona.


ENA-imaging of plasma sheets around Mercury.


Artist's impression of Rosetta. The sensors of the IRF-Uppsala LAP instrument are mounted on the two long booms that extend from the spacecraft body (ESA).

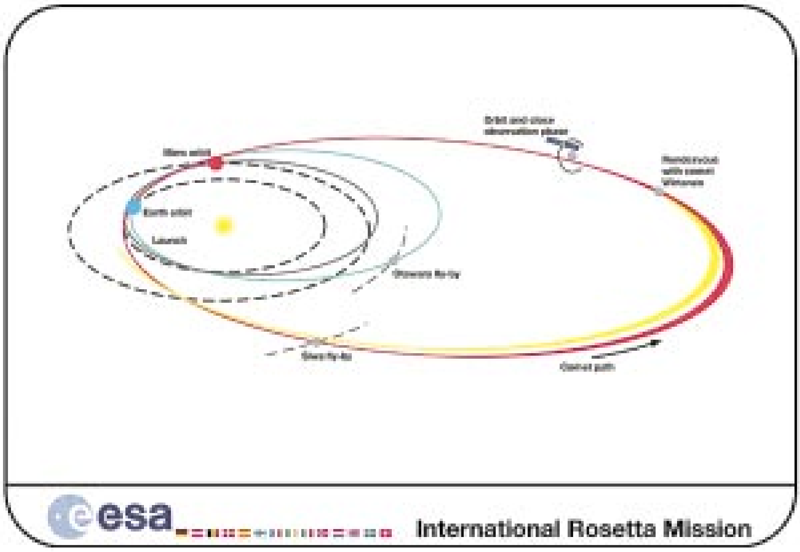
Catching up with a Comet: the Rosetta Mission

Comets have fascinated mankind since the dawn of history. Even today, comets are enigmatic bodies, quite different from other objects in our solar system. The very appearance of a comet can be deceptive: in the night sky, comets can be a huge object, with tails which are millions of kilometres in size like the comets Hyakutake and Hale-Bopp showed a few years ago, but when investigating a comet closely, one finds that most of this enormous object has evaporated from a very small nucleus of dirty ice, typically a few kilometres in size. ESA's Rosetta spacecraft



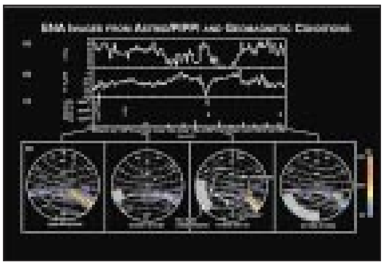
IRF participates on the Rosetta mission with two instruments: Langmuir Probe (LAP) from Uppsala, and Ion Composition Analyser (ICA) from Kiruna.

will catch up with the comet Wirtanen on its elliptic solar orbit and follow its motion for more than a year as it falls in towards the sun. IRF participates with two instruments on board: a dual Langmuir probe, built by the Uppsala Division, and an ion composition analyser, provided by the Kiruna Division. These instruments concentrate on measuring the gas and dust exhausted by the little nucleus as it is heated by the sun, and which constitutes the enormous object we can see in the sky. The gas and dust are partly ionized (i.e. consist of electrically charged particles) and thus constitute a plasma. Spectacular things go on in this plasma: it can form a bluish plasma tail with plaits, knots and other curious structures, quite different from the smooth dust tail which often dominates the view of a comet, and it divides space around the comet into distinct regions, with and without a magnetic field. Through interaction with the solar wind, it can even generate X-rays! The IRF instruments will be the first of their kind in long-term orbit around a comet: previous missions, like the ESA spacecraft Giotto to comets Halley and Grigg-Skjellerup, have only by-passed comets at great speed, while Rosetta will move around Wirtanen with a speed on the order of a metre per minute, giving unprecedented measurement opportunities. The IRF instruments will study the outflow from the comet and the structures around it, yielding insights into the properties and dynamics of the comet nucleus as well as into the complex processes in its neighbourhood. Rosetta will be launched in January 2003, and will take eight years to reach its destination!



Energetic Neutral Atom Imaging at IRF: Seeing the Invisible

We are actively working on developing new innovative techniques to study space plasmas. One of them is Energetic Neutral Atom (ENA) imaging. The idea is simple. An ion in plasma can become a neutral atom again by stripping an electron off an atom of a neutral background gas. As the ion was energetic, the resulting neutral atom is too. Neutral atoms are undeflected by electromagnetic fields and so travel in a straight line from the site of their formation. We can detect these atoms and make the invisible plasma visible!



ENA images from Astrid/PIPPI.

We have been developing this technique since the mid-90's and successfully launched the first ever specifically-built ENA instrument PIPPI (Prelude-In Planetary Particle Imaging) on board the first Swedish microsatellite Astrid-1 (see figure). Our next ENA detector will fly on board the first Swedish scientific nanosatellite Munin (see picture) later this year. Very advanced ENA instruments will fly to Mars on board Mars Express in 2003. We are working on all aspects of this technique, analysing data, developing models and, of course, developing new instruments.

IRF's nanosatellite Munin, due to be launched in late 2000, weighs only 6 kg.

Cluster II: Formation-flying in Space

ESA's Cluster II mission consists of four identical spacecraft flying in formation high above the Earth's poles. It is a replacement of the original Cluster mission which was lost in a launch failure during the maiden flight of the Ariane 5 rocket on 4 June 1996. The first pair of satellites was launched from Baikonur in Kazakhstan 16 July 2000, the second pair on 9 August 2000.

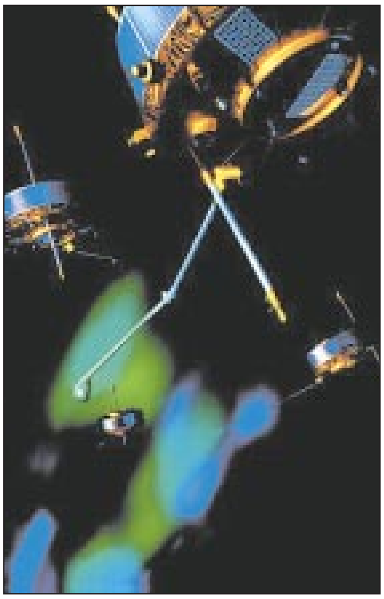
Cluster II is part of an international collaboration to investigate the physical connection between the Sun and Earth. Flying in a tetrahedral (triangular pyramid) formation, the four spacecraft will collect the most detailed data yet on interaction between the charged particles of the solar wind and Earth's magnetic field and atmosphere. Four satellites are needed to study structures in three dimensions. This mission will enable scientists to build a three-dimensional model of the magnetosphere and to better understand the processes taking place inside it.

Each identical cylindrical satellite is 2.9 m by 1.3 m with a mass of 1200 kg — 72 kg of payload and 650 kg of propellant. The final polar orbits have lowest and highest altitudes of about 20,000 and 120,000 km, respectively, and an orbital period of 57 hours. The spacecraft separation will be adjusted during the mission to obtain maximum scientific output. In regions of key interest the satellites will be in a tetrahedron configuration, separated by distances of from a few hundred km up to several thousand km.

Each satellite is equipped with a total of eleven instruments for studies of electric and magnetic fields, and of charged particles.

The Uppsala Division bears the responsibility for one of the instruments on board each of the four spacecraft: the Electric Field and Wave experiment (EFW) designed to measure the electric field and density fluctuations with high temporal resolution (sampling rates up to 36,000 samples per second).

Major scientific goals include the exploration of the outer reaches of the Earth's magnetosphere and its interaction with the solar wind. The mechanisms transferring particles, energy and momen-



Artist's impression of the Cluster satellites flying in formation (ESA).

The Uppsala Division's EFW instruments on Cluster II (ESA).

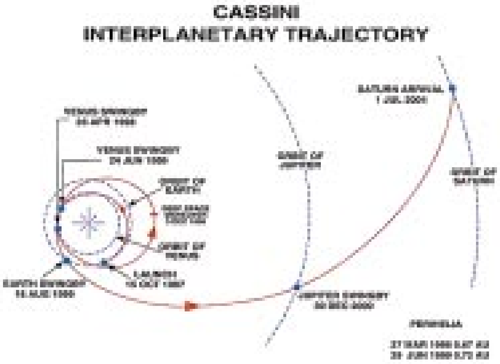
tum from the solar wind, across magnetospheric boundaries, and down to lower altitudes, will be studied. In particular we will study which mechanisms are important when solar wind energy enters the terrestrial magnetosphere, how electromagnetic waves and currents can carry energy from high to low altitudes, and how this energy then can cause phenomena such as ion outflow from the upper atmosphere and auroras.

Probing Saturn's Icy Moons

The Uppsala Division participates in one of the most ambitious planetary expeditions ever, the international Cassini/Huygens project to the planet Saturn and its many icy moons. The 5,8 ton heavy Cassini/Huygens spacecraft with its over 20 scientific experiments was launched from Cape Canaveral, Florida, on 15 September 1997, and will reach its majestic target late in 2004. It has so far made two close encounters with Venus, recently passed the Asteroid belt, and is now on its way to do a swing-by of the gaseous giant Jupiter during next New Year's Eve, 2000/2001.

The European Space Agency (ESA) contributes with an advanced lander (Huygens) which will be dropped into the thick nitrogen-methane atmosphere of the planet sized moon Titan and land on its surface sometime during 2004. The main spacecraft, Cassini, from NASA, will carry out complex orbiting manoeuvres around Saturn and its moons for at least 4 more years. Up to 44 orbits and associated close encounters with its many moons are planned. The project is named after two 1600-century astronomers, the Italian-French Jean-Dominique Cassini and the Dutch scientist Christian Huygens, both of whom made important discoveries about the Saturn system.

The Uppsala Division has an instrument on board the Cassini spacecraft, a so-called Langmuir probe, which is part of the bigger Radio and Plasma Wave Science (RPWS) investigation. The RPWS experiment on board the Cassini spacecraft consists of several electric and magnetic field sensors as well as sensors for monitoring the thermal plasma. The dedicated Langmuir probe instrument aims primarily at investigating the ionosphere and upper atmosphere of the large moon Titan by measuring its densi-



ty, temperature and velocities with high time resolution. The Langmuir probe can also be used for detecting dust impacts on the spacecraft. This latter method will be tested when the Cassini spacecraft travels through the Jupiter system just after Christmas 2000.

The detailed mapping of density and temperature profiles with altitude are of crucial importance for understanding the structure, dynamics and chemistry of the upper atmosphere and ionosphere of Titan, and its interaction with the hot magnetospheric or solar wind plasma. The energy deposition of magnetospheric electrons and the solar radiation are believed to act as a catalyst for the very complex organic chemistry occurring on Titan. Even if the atmosphere of Titan is believed to be too cold for life to evolve there, some scientists believe it can provide important clues about how life once originated on Earth. Very complex organic compounds are created in the ionosphere of Titan, which then clump together, drizzling downward to create a thick cloud cover around the moon. There are even speculations of widespread ethane-methane oceans and organic rain-smudge or swamps on the surface. Titan is therefore an extremely interesting place to search for the origin of life.

The Langmuir probe instrument will also be able to make measurements in extended regions of the large Saturnian magnetosphere and its interaction with the surfaces of icy moons and the majestic ring system. The dust particles in the rings become electrically charged and therefore interact with the magnetic field. Information of how this interaction occurs will give insight into how our planetary system could have been formed.

Ground-based Space Physics Research

Research in the Earth's Near Space Environment

The Solar Terrestrial Physics Group at the Uppsala Division undertakes research in the Earth's near space environment, studying the coupling processes between the sun and solar wind and the earth's magnetosphere and ionosphere. Its research programme comprises observation at both micro- and macrophysical scales in the solar terrestrial environment with ground-based and satellite instrumentation. The ground-based methods include the EISCAT (European Incoherent Scatter) radars in particular the new ESR (EISCAT Svalbard Radar) facility, but also global radar networks such as SuperDARN (Super Dual Auroral Radar Network) and Scandinavian international multi-instrument networks such as MIRACLE (Magnetometer Ionospheric Radars All-sky Camera Large Experiment).


ESR 1 and 2, Svalbard. Photo: Ingemar Wolf.

Plasma Turbulence

The Wave Group at the Uppsala Division conducts experimental and theoretical studies of plasma turbulence and the associated linear and non-linear generation of electromagnetic radiation in our nearest space plasma, the ionosphere, when this is being perturbed by the injection of electromagnetic radiation from purpose-built HF radio transmitters.

The project also encompasses the study of the more general physical problem of interaction between plasma in space and electromagnetic radiation. This includes the propagation, generation, detection, as well as the temporal, spectral, and polarisation characterization of secondary self-emission excited in an electromagnetically irradiated plasma and the use of the signatures for diagnostics of the ionosphere and interpretation of radio observations of distant objects.

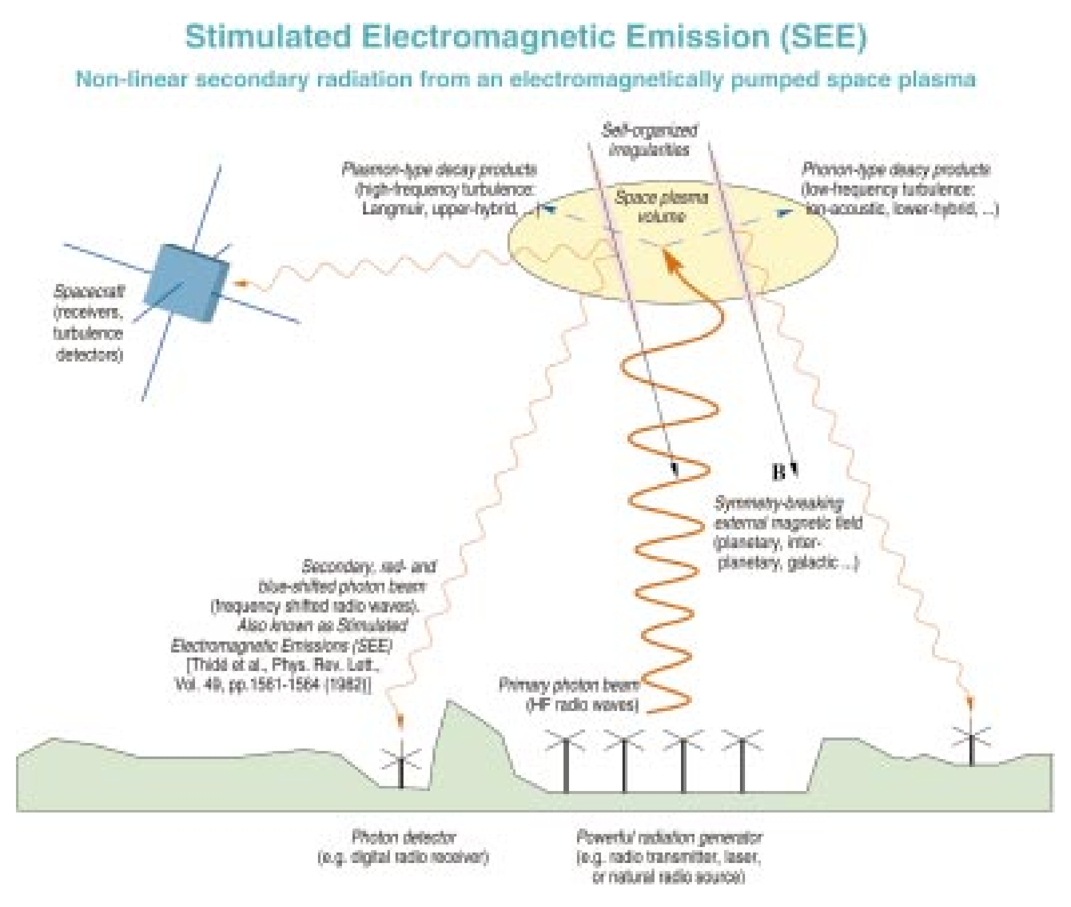
The Wave Group's projects:

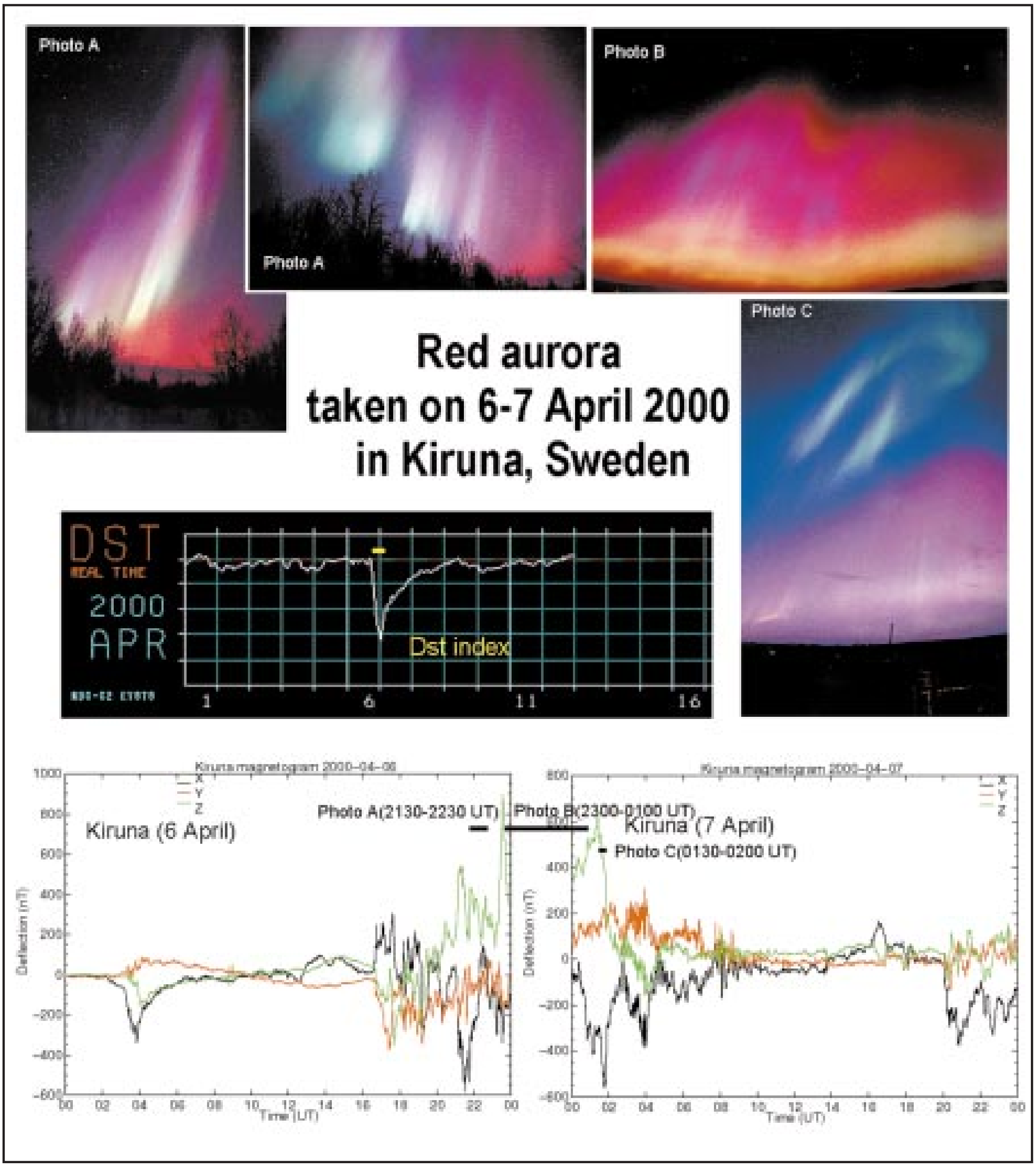
- Non-linear waves and interactions in space plasma
- Stimulated Electromagnetic Emission (SEE)
- Scattering off high-altitude magnetospheric turbulence
- Relativistic plasma wave theory
- Development of novel digital EM radiation detection system
- Participation in the design of advanced, multi-purpose radio observatories internationally
- Advanced computer simulation and visualisation of space plasma turbulence
- Theoretical and experimental investigations of space plasma self-organisation
- Development of smart nano-satellites for studies of fundamental physics in space

Stimulated Electromagnetic Emission (SEE)

Stimulated Electromagnetic Emission was discovered by our group in 1981.

Below is a schematic picture of a typical SEE experiment.





Photos: Yusuke Ebihara.

Non-linear waves and interactions in space plasma

This basic space physics research project concerns studies of the interaction between radio waves (or, as we say, electromagnetic radiation) and the outer, tenuous part of the Earth's atmosphere at hundreds of kilometres above the surface. Due to the strong, natural ultra-violet (UV) and X-ray radiation from the Sun, a few of the atoms and molecules in this gas are broken up into electrons, which are elementary particles with negative electric charge, and ions of positive electric charge. Since the behaviour of electric and magnetic fields and waves is strongly affected by this tenuous ionised gas, which constitutes what we call a plasma, this region of the outer planetary atmosphere is called the ionosphere. Study of the Earth's ionospheric plasma, which has existed for millions, if not billions, of years is very important for a complete understanding of the interplay between Earth and its space environment (also known as Earthspace) since it constitutes an important link in the biosphere-atmosphere-ionosphere-magnetosphere-heliosphere chain that influences life on Earth.

Atmospheric Research at the Swedish Institute of Space Physics

Atmospheric research at IRF focuses on studies of:

- atmospheric dynamics
- the transfer of mass and energy between different regions of the atmosphere (e.g. through stratosphere-troposphere exchange, and gravity-wave propagation)
- stratospheric ozone
- seasonally specific stratospheric and mesospheric clouds

Measurements are carried out using ESRAD (an MST — mesosphere/stratosphere/troposphere — radar operated in cooperation with Esrange), optical methods and instrumented balloons. The northerly position of Kiruna allows for studies of the stratospheric polar vortex air mass using the DESCARTES instrument launched by balloons.

Continuous measurements are made of:

- atmospheric trace gases (including ozone)
- atmospheric winds
- infrasonic waves

Stratospheric balloon launch at Esrange.
Photo: Hans Nilsson.

Atmospheric Research Programme (AFP)

The majority of the atmospheric research at IRF is conducted within the Atmospheric Research Programme (AFP), established at the Kiruna Division in 1996 as part of the Environmental and Space Reseach Institute (MRI), and largely funded by EU structural funds. With the advent of a Space and Environmental University College in Kiruna in 2001 it is likely that AFP will become part of the proposed Centre for Climate and Social Research (CKS).

SKERRIES

SKERRIES is a project to collect climatological information about trace gases and electrical properties in the Arctic stratosphere by regular balloon flights from Esrange. About 3 flights per year are scheduled to complement flights with similar instruments in other balloon programmes (e.g. the EU-funded THESEO and SAMMOA projects). The first flights were made in 1998.

The instruments flown are :

- DESCARTES to measure long-lived trace gases
- Hygrometer to measure water vapour (in collaboration with the Atmospheric Physics Group at Stockholm University, Department of Meteorology, MISU)
- ERISKAY and EDAY to measure electric fields
- MARTIN, an acoustic, fine structure temperature sensor

The DESCARTES instrument is used to monitor long-lived anthropogenic (man-made) trace gases found in the stratosphere, the region of the atmosphere between c. 10 and 50 km. At present the performance is well known for the measurement of CFC-11, but laboratory tests indicate that reliable estimates of CFC-113, CCl_4 and CH_3CCl_3 can also be made. The instru-

PhD student Johan Arvelius oversees the gas chromatograph read-out from the DESCARTES instrument. Photo: Hans Nilsson.

ment, originally developed at the University of Cambridge, is lightweight (15 kg) and requires no telemetry link, so it may be flown "piggy-back" on other balloon-borne payloads. The atmosphere is sampled at distinct heights by passing fixed volumes of air over a Carboxen adsorbent. The trace gases can be released and analysed when the instrument is recovered and returned to the laboratory.

DESCARTES participates in the following ongoing campaigns:

- THESEO O_3LOSS which continues during the year 2000
- SKERRIES, which is funded by the Swedish National Space Board
- SAMMOA, an EU-funded campaign which began in late spring 2000.

ERISKAY and EDAY are used to measure atmospheric and magnetospheric electric fields. Ground based measurements of the air-earth current are also made at the balloon launch site.

ERISKAY is a 4-probe instrument which measures all 3 vector components of the electric field, incorporating also a 3-axis magnetometer. It is designed to measure the atmospheric (vertical) electric field during balloon ascent and descent and the magnetospheric (horizontal) electric field at the float altitude.

EDAY is a simpler version which measures only the atmospheric vertical electric field within the stratosphere.

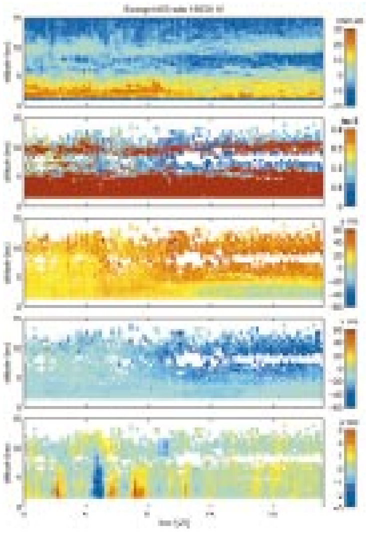
MARTIN is an acoustic balloon-borne instrument used to measure fine-scale temperature structure in the troposphere (the lowest 10 km of the atmosphere) and the lower stratosphere. Standard radiosondes (meteorological

Preparing the DESCARTES instrument for launch at Esrange, 11.37 am, 15 December 1999. Photo: Hans Nilsson balloons) sample the atmosphere at approximately 50 metre vertical intervals which is too coarse to resolve the “temperature sheets” (unusually sharp increases in temperature over vertical distances of the order of the wavelength of the radar, i.e. a few metres) which are thought to be responsible for MST radar returns by partial reflection. Atmospheric temperature measurements are typically made using thermally-dependent resistors whereas the MARTIN instrument makes use of the fact that the speed of sound is closely proportional to the square root of absolute temperature. The instrument makes measurements at a sampling rate of over 100 Hz with a 1 mK sensitivity.

Mountain Lee Waves and the Formation of Polar Stratospheric Clouds (PSCs)

Mountain lee waves over Kiruna. Photo: David Hooper.

The winds within the lowest kilometre or so of the atmosphere are influenced by the Earth’s surface, principally through the effects of frictional drag. Additionally they can be deflected by the presence of large hills and mountains which, under suitable conditions, can set up atmospheric oscillations known as lee waves. These give rise to vertical velocity fluctuations with amplitudes of up to a few m/s, which can be detected by MST radars such as ESRAD, and temperature perturbations of up to a few ° C, which can be detected by radiosondes (meteorological balloons) and lidar (laser radar).



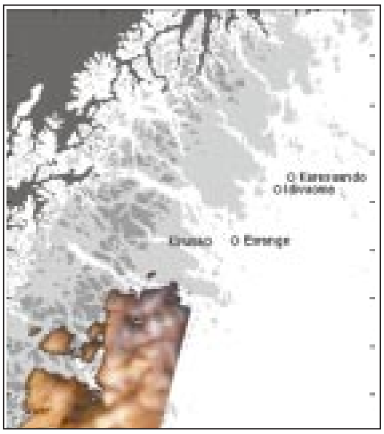
ESRAD atmospheric structure and winds on 16 January 1997 showing strong mountain lee waves

For regions of the atmosphere with high relative humidity, the temperature decreases within the rising phases of the waves can be sufficient to cause condensation and the formation of characteristically smooth wave clouds, such as those shown in the photograph above. These can remain fixed relative to the ground over time scales of several hours, whereas other types of clouds drift downstream with the background wind. The example shown was photographed close to midnight during the midsummer period of continuous day-light. The sun, hidden behind the summit of Luossavaara, is illuminating the clouds from below which gives rise to the spectacular contrast effects. The long, thin nature of the clouds suggests that they were generated by air-flow over a ridge; flow over an isolated hill top gives rise to more rounded lenticular (literally, lens-shaped) clouds.

Mother-of-pearl or nacreous clouds over Kiruna. Photo: Sheila Kirkwood.

Lee wave clouds are typically confined to the lowest few kilometres of the atmosphere where the water vapour concentrations are highest. Neverthless, during polar-night conditions (in winter when the sun remains below the horizon for several days or more) it can become cold enough in the stratosphere (the region of the atmosphere between approximately 10 and 50 km altitude which is normally heated through the absorption of solar ultra-violet radiation by ozone) for the minute quantities of water vapour (and other atmospheric constituents) to condense or freeze. This gives rise to diffuse polar stratospheric clouds, PSCs, which are also known as mother-of-pearl or nacreous clouds when they display distinct colouring such as those shown in the photograph above. The colours are thought to be caused by diffraction of sun-light by the minute constituent droplets, as for the case of irridescent clouds sometimes observed in the lower atmosphere.

Although the large scale temperatures over Antarctica are frequently low enough for PSC formation under undisturbed conditions, stratospheric winter temperatures over the northern pole more typically require the additional presence of lee wave perturbations. Wave-like patterns are commonly observed in PSCs seen from Kiruna in the winter. PSCs play an important role in the destruction of stratospheric ozone, through their "activation" of chlorine compounds, and thus are the subject of considerable international interest.



Nacreous cloud on 16 January 1997, mapped to the ground.

Polar Mesosphere Summer Echoes (PMSE) and Noctilucent Clouds

The mesopause is the level, around 90 km altitude, at which the atmospheric temperature profile has a local minimum. Two unusual phenomena have been found to be associated with the particularly cold mesopause temperatures (< -140°C) which occur around mid-summer at mid and high latitudes; diffuse clouds of ice crystals known as Noctilucent clouds (NLCs) (see the photograph on p. 18), and anomalously strong MST radar returns known as Polar Mesosphere Summer Echoes (PMSE) (see the radar plot on p. 18).

The formation of NLCs is somewhat similar to that of PSCs; despite the low water vapour concentration, the temperature is so cold that saturation occurs. The clouds are too optically thin to be distinguished (by eye) against day-time sky-light and can only be observed when the sun is at least a few degrees beneath the horizon, hence the name NLCs. Since Kiruna is under continuous day-light for much of the NLC season (May – Aug) observations of the mesopause level above Esrange are made around local midnight using a CCD camera placed at Lycksele, 372 km to the south.

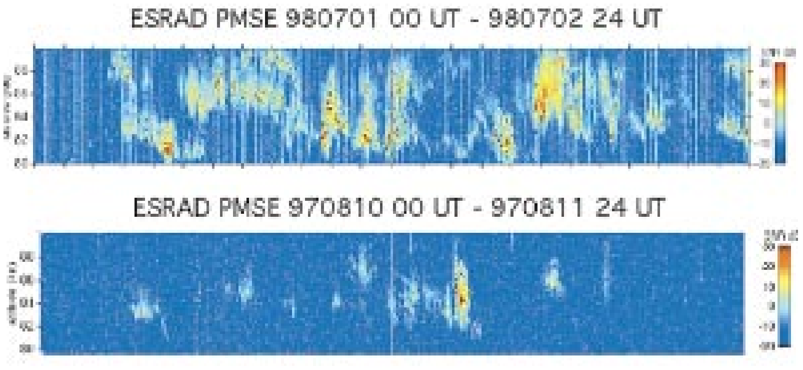
The figure (on page 18) shows typical PMSE observed by ESRAD. They are most persistent during June and

Noctilucent clouds (NLCs) are thin clouds which form at about 80 km altitude. They can only be seen when the sun is just below the horizon — they are then lit from below and the light reflected at a low angle picks out the many waves which cross the cloud layer.
Photo: Hans Nilsson.

July (upper panel) but can also appear more sporadically during May and August (lower panel). They are caused by backscatter from highly structured plasma density fluctuations concentrated in narrow layers (a few kilometres in vertical extent).

The exact relationship between NLCs and PMSE is still unclear. Since the summer of 1997, simultaneous, common-volume measurements have been performed by the University of Bonn lidar (laser-radar) and ESRAD.

NLC observations are regularly collected by networks of amateur observers.



Polar mesosphere summer echoes (PMSE) measured by ESRAD (Esrange MST radar)

Optical PSC studies

This project studies PSCs and their impact by means of passive ground-based optical instruments (instruments that measure scattered or direct sunlight). These instruments utilize the fact that sunlight carries information about the atmospheric constituents it has encountered on its way down to us on the ground.

Chemical reactions can be studied by means of spectroscopy, which is carried out in co-operation with the University of Heidelberg and other international institutions. During twilight we can also identify the presence of PSCs by means of a zenith-sky colour index.

RIPAN (Research In the Polar Atmosphere using remotely Navigated aircraft)

RIPAN is a new project being developed to enable controlled in-situ measurements to complement other radar and balloon measurements made in the Kiruna area.

The airplane, which has a wingspan of 5.3 m, is being designed to enable remotely controlled in-situ observations from the ground up to an altitude of approximately 15 km. During the initial flights, simple measurements of temperature, humidity, and pressure are envisioned. As the project develops, the scope will be broadened to include ozone and very small temperature variations. Furthermore, the plane will carry a small digital camera that can be used for navigation and photography of cloud patterns. A GPS system will provide the location of the airplane during the observations.

Fourier Transform InfraRed (FT-IR) Spectrometer

The FT-IR spectrometer in the Optical Laboratory at IRF in Kiruna records atmospheric absorption spectra using the sun or the moon as the infrared light source. From these spectra the abundances of some 30 different molecular trace gases present in the lower atmosphere can be determined. The instrument is operated in collaboration with the Institut für Meteorologie und Klimaforschung at Forschungszentrum Karlsruhe, Germany, and the Solar Terrestrial Environment Laboratory (STEL) at the University of Nagoya, Japan.

Selected research topics and activities include:

- chemical ozone depletion by observation of key species such as O_3, $ClONO_2$, HNO_3 and HCl
- details of the ozone formation process by isotopic studies in ozone
- profile retrieval to detect dynamical changes
- transport studies of chemical tracers and tropospheric pollutants
- satellite validation

mm-Wave Radiometer

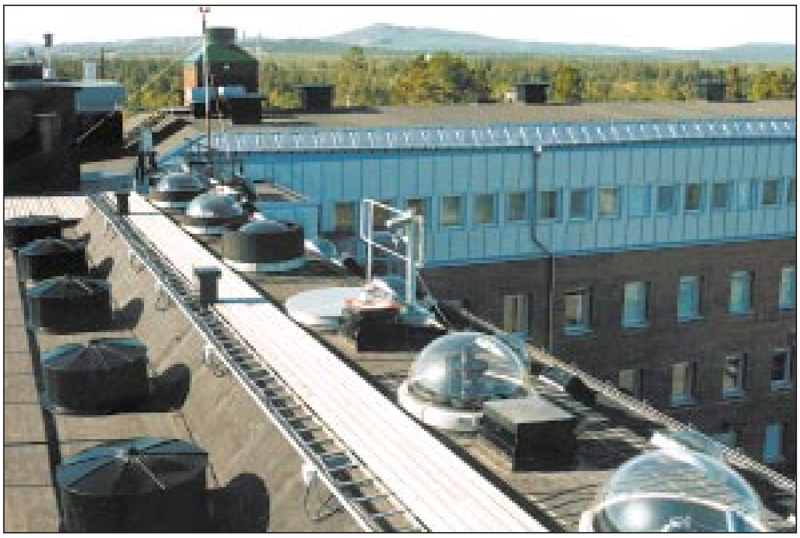
The mm-wave radiometer.
Photo: Rick McGregor.

A new mm-wave radiometer system has been constructed for long-term ground-based monitoring of the vertical profiles of chlorine monoxide and ozone in the stratosphere over the Arctic area. Particular emphasis has been devoted to the measurement of the very weak ClO lines, to the observation of their diurnal variation and to a reduced dependence from weather conditions.

This instrument is operated in collaboration with the Institut für Meteorologie und Klimaforschung, Forschungszentrum Karlsruhe, Technik und Umwelt, Germany.

The Differential Optical Absorption Spectrometer (DOAS)

Since December 1996, a UV-visible DOAS spectrometer has been operated in co-operation with the Institute of Environmental Physics, University of Heidelberg. Column amounts of ozone, NO_2, BrO and OClO are measured.



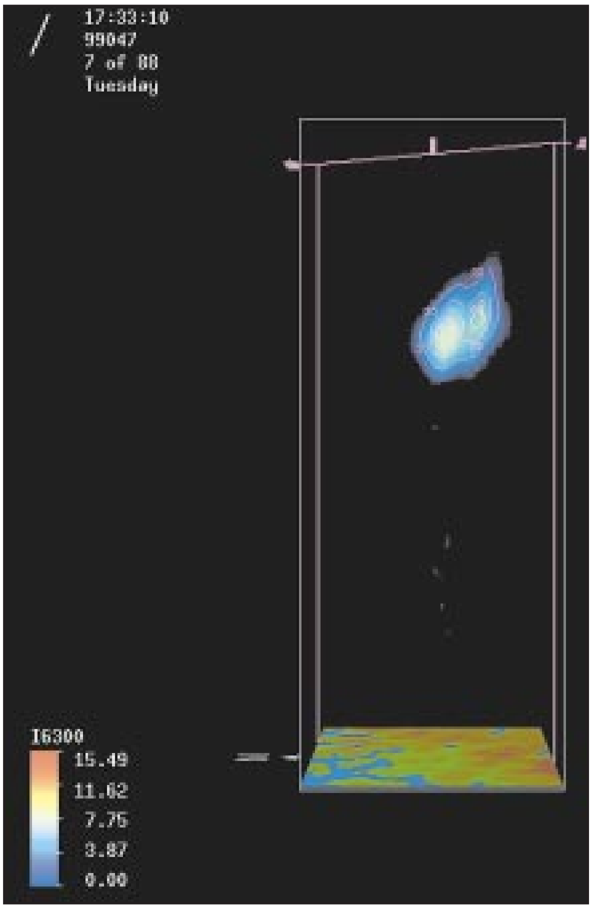
Instruments on the roof of the Optical Laboratory at the Kiruna Division include all-sky cameras and spectrometers. Photo: Torbjörn Lövgren.

Other Research Methods and Modelling

ALIS (Auroral Large Imaging System)

ALIS (Auroral Large Imaging System) is a system of all-sky cameras and has primarily been developed to address scientific issues with respect to the aurora (substorm onsets, 3-D auroral arc structures), and atmospheric issues (PSCs, especially the subtype known as mother-of-pearl or nacreous clouds). In addition to normal all-sky imaging, ALIS provides estimates of the three-dimensional distribution of auroral optical emissions using tomographic reconstruction methods with high spatial and temporal resolution. Tomographic reconstruction may also be used for high-altitude cloud studies.

ALIS consists of a network of remote stations operated from a control centre at IRF. Each station is equipped with a high-performance CCD-camera (non-intensified) with 1024 x 1024 pixels resolution and 16 bit AD conversion. All station equipment is computer-controlled. Each station uses local GPS-timing and communication is via dial-up modems. The geographical separation between the stations is about 50 km. The ALIS-stations are centred around Kiruna.



Tomographic reconstruction from ALIS-data of airglow created by the Heating facility at EISCAT in Tromsø (Björn Gustavsson).

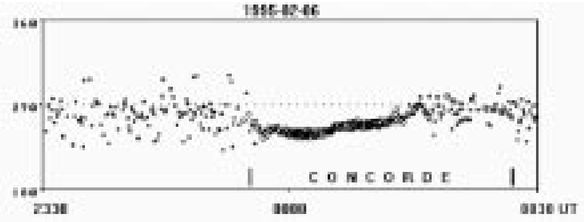
Infra Sound and Data Analysis Methods

Propagation of infra sound in the atmosphere is studied at IRF's Umeå Division, located at Sörfors. Due to special problems with detection of infra sound from distant sources, such as low signal-to-noise ratio and the strong influence of atmospheric structures on the propagation of infra sound, a major part of the work at Sörfors has concentrated on development of new methods for signal processing and data analysis.

Recent work includes:

- Propagation of infrasonic waves
    - Studies of the fine structure of the infrasonic signals generated during supersonic flights of Concorde.
    - Studies of the long term variations (since 1978) of the wind system above the Northern Atlantic using the infrasonic signals generated by Concorde.
- Space Science Data Analysis Tools
    - Applications of neural networks for intelligent processing of large quantities of data; automatic categorization and construction of statistical models.
    - Applications of the causal modelling to different kinds of spectral data.

Propagation of Infrasonic Waves

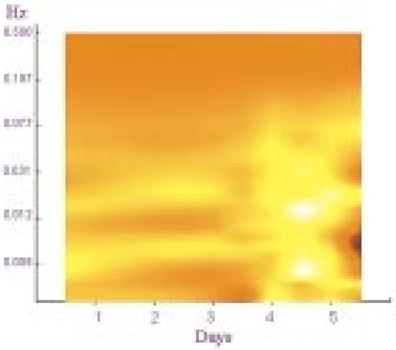


Angle of arrival of the infrasonic signal from Concorde, flying from the US to Europe, recorded at Luleå, Sweden (65.8°N, 22.5°E) on 6 February 1995 at midnight. The fine structure of the recorded angle of arrival reflects the wind and temperature distribution in the atmosphere between the aircraft and the recording station. Due to the geometric configuration of the aircraft trajectory and recording station and due to the geographical distribution of winds and temperatures the flight is viewed in reversed order, i. e. the trace starts at the easternmost point of the supersonic trajectory and continues until the aircraft starts its supersonic flight outside the eastern coast of the US.

Staff at the Umeå Division, Sörfors.

Multivariate Time Series Analysis

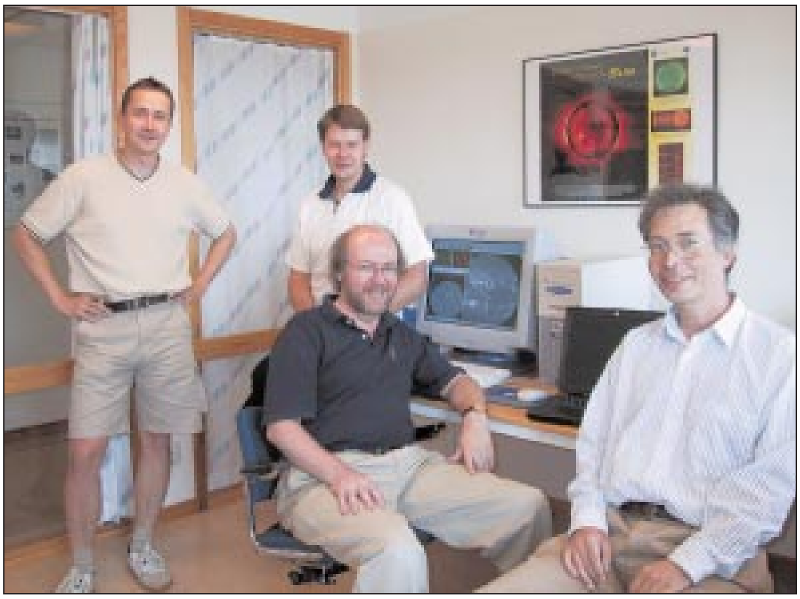
A method has been developed to extract the true temporal variations of the photon flux from the the photon event history observed by the X-ray satellite ROSAT. Wavelet technique has also been used to study the photon flux variations.



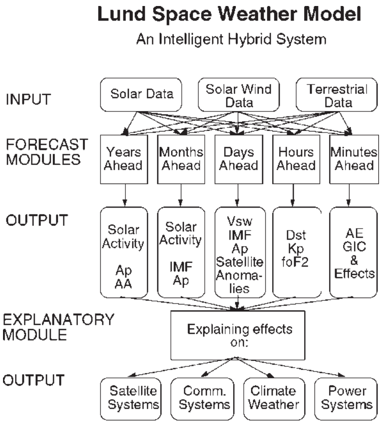
Frequency spectrum (generated using the Morlet wavelet transform) of temporal variations of X-ray emission from an active galactic nucleus (AGN) NGC5548 (23:29:07 UT, 16 July 1990).

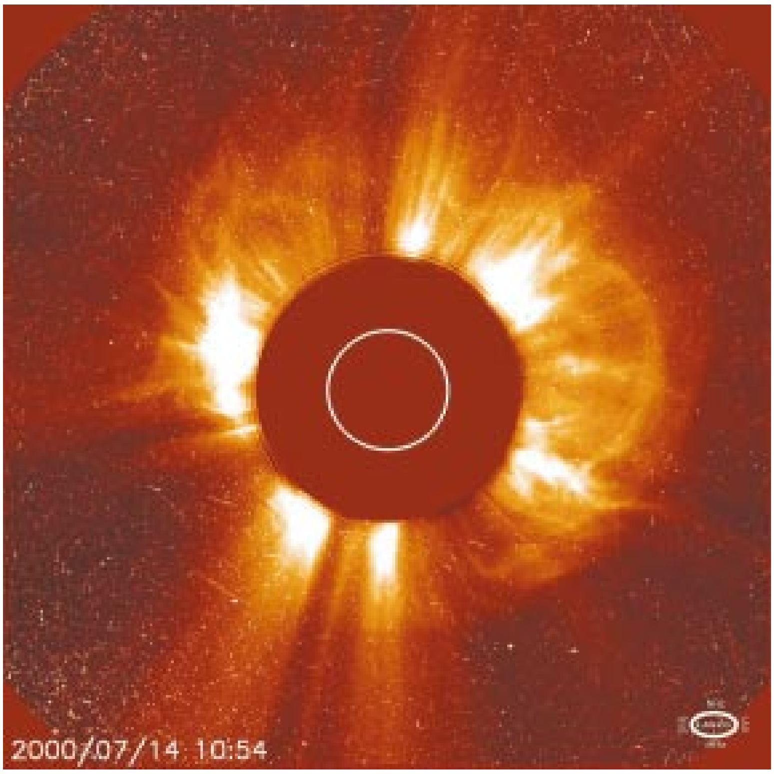
Space Weather Modelling and Forecasting

The solar activity causes conditions that affect Earth's atmosphere, technological systems in space and on ground, and endanger human health. We call these conditions "space weather". To model and predict the space weather and its effects we need to consider the whole chain of events from the Sun to the Earth. The Lund Space Weather Model, developed at IRF's Lund Division, is such an attempt. The space weather model is an intelligent hybrid system; i.e. it uses both artificial intelligence methods such as artificial neural networks, fuzzy expert systems, theory of magnetohydrodynamics, space weather physics and ordinary statistical methods.



Staff of the Lund Division and the Director of the space weather company NeuroSpace in combined premises at the Ideon Center in Lund.





Within solar-terrestrial physics and space weather research, predicting coronal mass ejections (CMEs), is one of the most important and urgent tasks. CMEs are namely the solar phenomena that cause the most severe space weather effects. It has also become clear that CMEs play a fundamental role in the solar activity cycle. They give the Sun a way to get rid of the continuously emerging flux from below.

Development of AI Methods in Spacecraft Anomaly Predictions

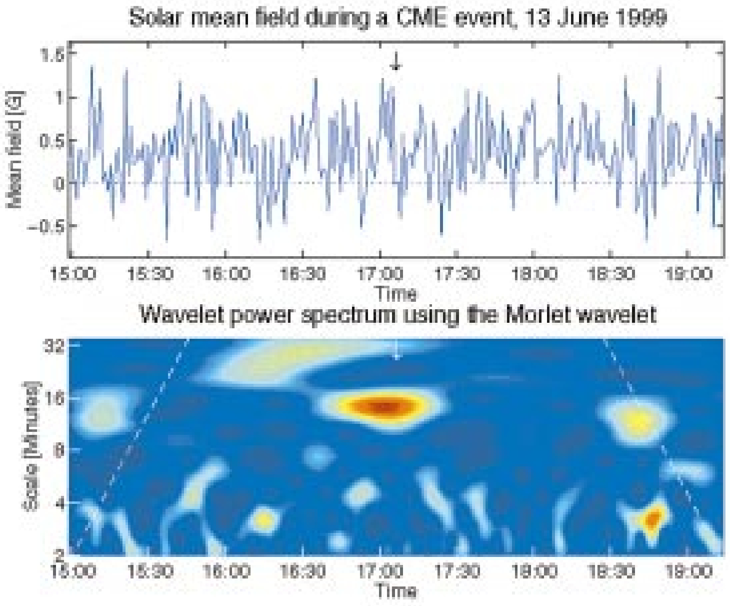
The space plasma and radiation form a hazardous environment to Earth-orbiting spacecraft. Spacecraft problems are regularly experienced which can in extreme cases lead to a failure or loss of the spacecraft. It is important to be able to predict and analyse spacecraft anomalies that are caused by the space environment. The space environment is determined by the space weather, which ultimately is driven by the Sun. To be able to predict spacecraft anomalies it is necessary to compile the knowledge and observations of the space weather, which includes the Sun, the solar wind, and the Earth magnetosphere and relate it to the effects on spacecraft.

The aim of this project is to develop tools for the analysis and prediction of spacecraft anomalies. The main methods will be the use of artificial intelligence (AI) such as neural networks and fuzzy systems. The models will run in real time by collecting the necessary inputs from solar-terrestrial databases and produce predictions on the time scales of hours to days. A database of spacecraft anomalies will also be set up.

Swedish microsatellite Astrid-1.

The project Development of AI Methods in Spacecraft Anomaly Predictions is funded by an ESTEC contract and monitored by the ESA's Space Environments and Effects Analysis Section.

Solar Activity — a SOHO Project



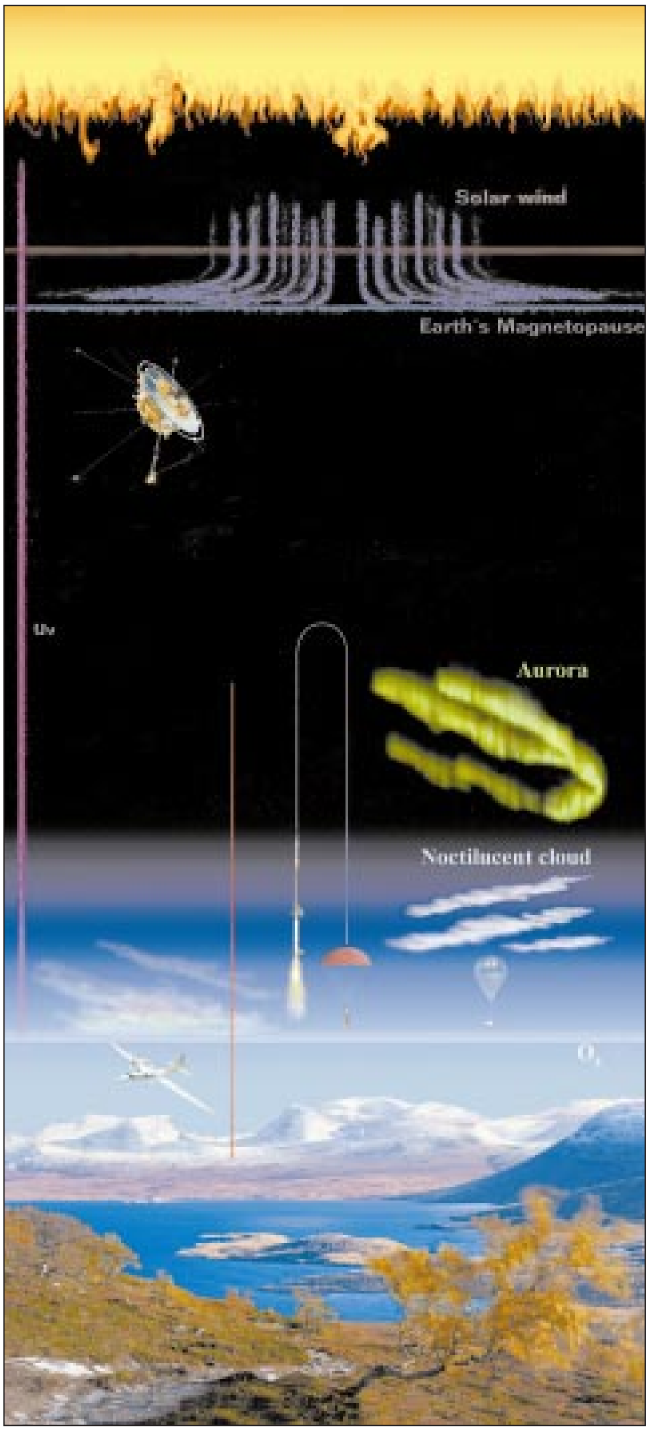
CMEs are detected in power spectra of 1-minute solar mean field data

The solar mean field (the Sun observed as a star) is an interesting indicator of solar activity. Continuous high temporal resolution (1 minute) mean field data was for the first time obtained with the MDI instrument on board SOHO. Many new features of solar activity were discovered. By using 1 minute mean field data observed with MDI and analysed with wavelet transforms we were able to detect times of coronal mass ejections. The results open up a new way to detect CMEs. Our next step is to predict time series of mean field data and thereafter apply wavelet transforms to be able to predict CMEs.

Institutet för rymdfysik

Swedish Institute of Space Physics

The Swedish Institute of Space Physics (IRF), with 120 employees, has divisions in Kiruna (IRF-K), Umeå (IRF-Um), Uppsala (IRF-U) and Lund (IRF-L). The main office of IRF is located in Kiruna in the north of Sweden (geographic co-ordinates 67.84° N, 20.41° E).



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