Department of
Radio and Space Science

with

Onsala Space Observatory
The Swedish National Facility for Radio Astronomy

at
Chalmers University of Technology

BIENNIAL REPORT 2004 – 2005
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Edited by M. Thomasson and R. Booth

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Department of Radio and Space Science

The diagram shows the organization of the department as per 1. November 2005. The department has eight research groups, and hosts the Swedish National Facility for Radio Astronomy. The National Facility, the Radio astronomy and astrophysics group, and the Space geodesy and geodynamics group, are located mainly at Onsala Space Observatory, and the rest of the department mainly at the Chalmers campus in Göteborg. Note that Chalmers was reorganized 1. January 2005. The main difference for the Department of Radio and Space Science was the addition of the two research groups Nonlinear electrodynamics and Transport theory, which previously belonged to another department (their activities during 2004 are documented in this report). Other organizational changes also took place. Also note that from 1. December 2005, the Director of the National Facility was Hans Olofsson.
1 Review of major events during 2004 and 2005

1.1 Department of Radio and Space Science

The years 2004 and 2005 includes a reorganization at Chalmers that occurred at the 1st of January 2005. In 2004 the Centre for Astrophysics and Space Science consisted of six research groups in the Department of Radio and Space Science (which was part of the School of Electrical Engineering) and Onsala Space Observatory, the Swedish National Facility for Radio Astronomy, and the research group Astronomy and Astrophysics, earlier in the School of Engineering Physics. In this older organization the department reported to the Dean of the School of Electrical Engineering and the National Facility reported directly to the president of Chalmers.

In the new organization, visualized in the block diagram on the previous page, the major change is that Chalmers has departments which reports directly to the President. The National Facility has kept its independent role, but obtains synergy effects by having a common infrastructure with the new Department of Radio and Space Science.

This biennial report contains summaries describing the research carried out in the research groups as well as all the facts and figures related to the staff and its activities in research, teaching, and communication science to the society. Let me here just mention some news items that have made it into the media during this time period.

Our researchers in radio astronomy and aeronomy has continued to obtain high quality data from the Swedish satellite Odin. The group using radar remote sensing has surveyed the damages in terms of fallen trees due to the storm Gudrun in early January 2005. The optical remote sensing group participated successfully in a volcano monitoring program, which proved to be important in order to evacuate an area in El Salvador just before the eruption of the volcano Santa Ana in October 2005. The first European Galileo satellite was launched in December 2005, which hopefully will become useful for our research in space geodesy.

Roy Booth retired from his position as director of the National Facility on November 30, 2005, a position that he has had since it was formally established in 1990. Hans Olofsson, from the University of Stockholm was appointed director from December 1, 2005.

Roy’s ability to initiate new research projects, of significant size, is outstanding. When looking back, this is evident from the history describing the Swedish ESO Sub-mm Telescope (SEST), the Swedish Odin satellite, and the involvement of the Onsala Space Observatory in the truly international ALMA project.

Resources for research are of course always limited, and especially so in a small country like Sweden. With that in mind, we are very grateful for the enormous amount of work and enthusiasm which Roy has given us. We say thank you to Roy and welcome to Hans. We wish Roy good luck with his new task to guide radio astronomy in South Africa and we say good luck to Hans in continuing the fascinating work with the National Facility.

Gunnar Elgered,
Head of department
1.2 Onsala Space Observatory,
The Swedish National Facility for Radio Astronomy

2004 and 2005 have been turbulent years at Chalmers, with the demise of the School of Electrical and Computer Engineering and its replacement by smaller departments. While the National Facility has retained its basic autonomy in this process, the group for Astronomy and Astrophysics is now part of the Department of Radio and Space Science and the Centre for Astrophysics and Space Science has essentially been disbanded.

The other major change, coming in December 2005, is that of Director when the previous incumbent, Roy Booth, director since 1981, retired and was replaced by Hans Olofsson, a graduate of Chalmers/Onsala (Civ Ing and Tech Dr). Hans, who is Professor of Astronomy in Stockholm University, has been appointed director (80%) and visiting Professor at Chalmers.

Of great significance for the observatory was the founding of RadioNet as an EU FP6 Integrated Infrastructure Initiative (I3), a collaboration of most of Europe’s radio astronomy observatories and technical support groups, entitled Advanced Radio Astronomy in Europe, coordinated by Phil Diamond of Jodrell Bank. Onsala participates in the I3 programme “Access to large scale facilities” through which European, non Swedish observers with the 20 m antenna are funded for their observing trips and Onsala receives funding to facilitate this access. The same applies for our VLBI participation. In addition, GARD (Group for Advanced Receiver Development) became part of a special EU funded research programme to develop mm/submm devices. Roy Booth chaired the RadioNet Board during 2004 and 2005.

After a fairly long teething period, our new submillimetre antenna, APEX, a collaboration with the Max-Planck-Institut für Radioastronomie, Bonn and the European Southern Observatory, obtained its first well calibrated scientific results in mid 2005 and was inaugurated in September. Among the first results was the detection of a new interstellar molecule, CF$^+$. The line was detected with a world-class receiver delivered by our Group for Advanced Receiver Development. This receiver is the most sensitive in the world, in its receiving band around 0.8 mm wavelength and, although having its own teething problems, has been used to very good effect in the first observing periods. APEX should begin regular scheduled observations in 2006.

Sweden’s other submillimetre observatory, ODIN, continued its programme of observations for astronomy and aeronomy during 2004 and 2005, well beyond its specified lifetime and, as we write this, it is still hoped that the means will be found to keep it operational for one more year. Among last years highlights is a hotly debated, tentative detection of molecular oxygen in the molecular cloud near Rho Ophiucus. Serious attempts are being made to confirm this important result. The observatory will maintain its ODIN data center for at least one more year.

Our VLBI programmes have also seen important developments during 2004/5. Not only have we abandoned tape recorders for specialized PC-based computer-disc recording systems but we have for the first time accomplished VLBI in real time through the use of the wideband internet connections for research such as the EU Geant network and the Swedish Universities network, SUNET. Onsala Space Observatory has been involved in all of the first demonstrations of so called e-VLBI and although it is still in its infancy, it has important advantages over the traditional methods because of faster data turn-around, fast implementation for transient sources and even higher sensitivity as grid data rates are increased.

Our engineering groups are again in the headlines. The GARD group, as well as producing the excellent APEX receiver mentioned above has been awarded a contract to build
ALMA Band 5 (163–211 GHz) receivers under contract to ESO in a special EU FP-6 ALMA enhancement programme. The Onsala Development Laboratory’s ALMA collaborative programme with Cambridge University to develop water vapour radiometers (WVR) for antenna by antenna phase correction was reviewed by an international committee in May, 2005. The review was a great success and the single Dicke system, developed by Onsala, was selected for production. It is hoped and anticipated that both groups will participate in the final WVR production.

Finally we report another successful astronomical meeting at Onsala/Chalmers – a workshop organized by Susanne Aalto and funded by RadioNet entitled “Galactic and Extragalactic Interstellar Medium Modeling in an ALMA perspective”. The meeting was attended by 56 people from Europe, the US and Japan.

Roy S. Booth
Director
2 Highlights of 2004–2005

Some of the most significant discoveries and accomplishments during 2004-2005 are listed below.

1. The first e-VLBI fringes were detected in 2004 between the telescopes in Onsala, Jodrell Bank and Westerbork. Onsala has played a major role in the development of real-time e-VLBI, where data (up to 0.5 Gbit/s) from the telescopes are sent through optical fibers to the processor (JIVE in the Netherlands). Also, the first real-time VLBI fringes across the Atlantic were detected, between Onsala and Westford, MA, in 2005 (see Sect. 3.3)

2. APEX saw first light in May 2004, using the SEST bolometer SIMBA. APEX is a 12 m diameter mm and sub-mm telescope in Chile. The inauguration took place in September 2005. Among the first scientific results is the detection of a new interstellar molecule, CF+ (see Sect. 3.9).

3. The first clear detection of a radio supernova in an Ultra-Luminous Infra-Red Galaxy (ULIRG) was made using 1 Gbit/s VLBI, within the prototype source Arp 220 (see Sect. 5.3.7).

4. A wavelet add-on code for removing noise efficiently from cosmological, galaxy and plasma N-body simulations has been developed. Two orders-of-magnitude higher performance of the simulations can be expected when using this code (see Sect. 5.3.1).

5. The storm Gudrun, which hit the south of Sweden in January 2005, felled more than 200 million trees. The CARABAS airborne synthetic aperture radar system has been used to map the wind-thrown trees using an algorithm developed in the Radar Remote Sensing group. This data will be used to provide the Swedish Forest Agency with updated forest maps in early 2006 (see Sect. 8.3).

6. In October 2005 instruments developed by the optical remote sensing group contributed significantly to the decision to evacuate people the day before the eruption of Santa Ana volcano in El Salvador (see Sect. 9.1).

7. A novel method, the Solar Occultation Flux technique, has been successfully developed and tested as a method to quantify industrial emissions of hydrocarbons, and will, during 2006, be introduced as a routine method to monitor emissions from petrochemical industry in Sweden (see Sect. 9.2).

8. The Odin satellite for astronomical and aeronomical research, launched in 2001, is still in operation. The global environmental measures group has made Odin data available to the larger community via a website and has carried out a complete reprocessing of the dataset leading to a much improved product.

9. Theoretical and experimental studies of phenomena associated with high-energy ions and relativistic electron beams in future fusion reactors have been performed in collaboration with JET at Culham Science Centre, UK (see Sect. 10.1).
10. A novel general statistical theory, based on the Wigner transform method, has been developed for describing the dynamics of partially incoherent optical wave phenomena in dispersive and nonlinear media (see Sect. 10.2).

11. The limitations set by corona and multipactor microwave breakdown in space-borne RF telecommunication equipment have been established in collaboration with French and Russian researchers (see Sect. 10.3).

12. A strong dependence on the fluid closure of the particle pinch in drift wave transport has been found. The particle pinch can increase the output power of a fusion reactor by at least a factor two. The new model agrees with experimental tests at JET (see Sect. 11.1).
3 Onsala Space Observatory: facilities and projects under development

The Swedish National Facility for Radio Astronomy, Onsala Space Observatory, operates two radio telescopes at Onsala with 20 m and 25 m diameter, respectively. In addition, the National Facility is a partner in APEX, the Atacama Pathfinder Experiment (see Sect. 3.9; the other partners are the European Southern Observatory and Max-Planck-Institut für Radioastronomie; as host country Chile has 10% of the observing time). The observatory also operates a data centre for the Swedish astronomy/aeronomy satellite Odin. At Onsala there is also equipment (e.g. GPS receivers) for space geodesy, and a radio aeronomy station measuring atmospheric gases. Part of the receiver development laboratory is located at the Department of Microtechnology and Nanoscience at Chalmers, where sputter equipment for mixer fabrication is located in the clean room.

3.1 The Onsala 20 m telescope

3.1.1 General description

The 20 m diameter, radome enclosed millimetre wave telescope was commissioned in 1975 and upgraded in 1992. The telescope is used for observations of millimetre wave emission from molecules in comets, circumstellar envelopes, and the interstellar medium in the Galaxy and in extragalactic objects. It is also used, as part of the European and world-wide networks, for astronomical Very Long Baseline Interferometry (VLBI) observations of star forming regions, radio stars, and active galactic nuclei, and for geodetic VLBI observations to study e.g. crustal dynamics and polar motion. The telescope is equipped with the following receivers:

<table>
<thead>
<tr>
<th>Frequency range</th>
<th>Receiver temperature</th>
<th>Receiver type</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.2 – 2.4 GHz</td>
<td>60 K</td>
<td>HEMT amplifier</td>
</tr>
<tr>
<td>8.2 – 8.4 GHz</td>
<td>80 K</td>
<td>HEMT amplifier</td>
</tr>
<tr>
<td>18.0 – 26.0 GHz</td>
<td>30 K</td>
<td>HEMT amplifier</td>
</tr>
<tr>
<td>26.0 – 36.0 GHz</td>
<td>50 K</td>
<td>HEMT amplifier</td>
</tr>
<tr>
<td>36.0 – 49.8 GHz</td>
<td>50 K</td>
<td>HEMT amplifier</td>
</tr>
<tr>
<td>84 – 116 GHz</td>
<td>80–170 K</td>
<td>SIS mixer</td>
</tr>
</tbody>
</table>

The receiver back-ends include the MkIV tape-recorder based and MkV disc based VLBI receivers and recorders (see Sect. 3.3), and two hybrid digital autocorrelation spectrometers (ACS); the two filter bank spectrometers are no longer in use. The spectrometers have the following characteristics:

<table>
<thead>
<tr>
<th>Spectrometer</th>
<th>Total bandwidth</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low resolution ACS</td>
<td>20, 40, ..., 1280 MHz</td>
<td>12.5, 25, ..., 800 kHz</td>
</tr>
<tr>
<td>High resolution ACS</td>
<td>0.05, ..., 6.4, 12.8 MHz</td>
<td>0.03, ..., 4, 8 kHz</td>
</tr>
</tbody>
</table>

Spectral line data are stored and archived in the FITS format on compact disks. For online as well as final data reduction, three software packages are available: CLASS, DRP and XS. The first one is an IRAM (Institut de Radio Astronomie Millimétrique) package while the other two have been developed at Onsala.
3.1.2 Upgrades during 2004–2005

The three band 18–50 GHz receiver has been completed and fully tested. The change between the bands requires mirror replacements in the cabin. However, the optical design allows such a change within 10 minutes. A similar amount of time is required to change between the SIS mixer system and the 18–50 GHz receiver. The 21–26 GHz and 36–50 GHz bands are prepared for dual polarization systems to be implemented in the near future. All control operations required for regular observing, including tuning of the SIS receiver, are now available over the internet. A Linux based antenna control system has been installed.

3.2 The Onsala 25 m telescope

The 25 m, polar mounted decimetre-wave telescope was built in 1963. It is currently used as a single dish for, e.g., observations of interstellar molecules (OH and H$_2$O), and also for astronomical VLBI observations. The telescope is equipped with the following receivers:

<table>
<thead>
<tr>
<th>Frequency range</th>
<th>Receiver temperature</th>
<th>Receiver type</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.8 – 1.2 GHz</td>
<td>100 K</td>
<td>HEMT amplifier</td>
</tr>
<tr>
<td>1.2 – 1.8 GHz</td>
<td>30 K</td>
<td>HEMT amplifier</td>
</tr>
<tr>
<td>4.5 – 5.3 GHz</td>
<td>80 K</td>
<td>FET amplifier</td>
</tr>
<tr>
<td>6.0 – 6.7 GHz</td>
<td>80 K</td>
<td>HEMT mixer</td>
</tr>
</tbody>
</table>

All receivers accept dual polarization. The computer control system (Pegasus) for the 25 m antenna uses the same operating system as the 20 m telescope. Thus, essentially the same program controls both telescopes.

The receiver back-end consists of VLBI receivers and recorders, and a hybrid digital autocorrelation spectrometer with the following characteristics:

<table>
<thead>
<tr>
<th>Spectrometer</th>
<th>Total bandwidth</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACS</td>
<td>0.05, ..., 6.4, 12.8 MHz</td>
<td>0.03, ..., 4, 8 kHz</td>
</tr>
</tbody>
</table>

Remote observations via internet, by students (mostly from Chalmers and GU), now take place routinely.

3.3 Very Long Baseline Interferometry (VLBI) developments

The Onsala telescopes have continued, during 2004 and 2005, to play a significant role within the global observing program for both astronomical and geodetic Very Long Baseline Interferometry (VLBI). In total 69 geodetic VLBI-experiments of 24 hours duration were conducted, as well as the continuous geodetic VLBI campaign CONT05 in September 2005. In astronomy VLBI, ten sessions were run (six European VLBI Network (EVN) three-week sessions and four one-week global mm-VLBI sessions).

The switch-over from (Mk4) tape-based to (Mk5) computer-disk-based recording was completed during 2004; tapes are now used only for the occasional experiment that is correlated at the VLBA correlator in Socorro. To support disk-based operation, Onsala had by the end of 2005 purchased, for the astro and geodetic VLBI pools, a total of 77 disk modules amounting to 110 TB of storage. Other technical developments included the installation and
During the last year, Onsala has played a major role in the development of real-time e-VLBI in both the astronomical and space-geodesy communities. This has been made possible by the advent of the disk based Mk5 terminals and the construction of a 1 Gbit/s optic fibre link from Onsala to Chalmers at the end of 2003. In the eVLBI technique instead of recording data on media (tape or disk) and physically shipping this to the correlator, data is instead sent directly in real-time to the correlator over the internet using the national SUNET and the pan-European GÉANT networks. This technique allows a great increase in reliability since VLBI observing is no longer done “blind”. It also provides results much faster; with important possible applications to monitoring Earth orientation parameters and following rapidly varying transient astronomical sources.

The first eVLBI milestone during the year 2004 was the detection of real-time 128 Mbit/s fringes between Onsala and two other European antennas in January. This was rapidly followed in March 2004 by historic first real-time VLBI fringes across the Atlantic; between the Onsala 20 m antenna and the VLBI antenna in Westford, Massachusetts. Interestingly these two stations also gave the first ever tape-based transatlantic fringes in 1968. The 40th anniversary of the 25 m telescope was celebrated with an eVLBI experiment with JIVE demonstrating cutting edge results from this telescope. The global eVLBI network is illustrated in Fig. 1.

In April 2004 the first eVLBI image was made using the 25 m and three other European telescopes. September 2004 saw the first demonstration science experiment in which a spectral line source was observed at 32 Mbit/s using five antennas including the 300 m diameter Arecibo telescope in Puerto Rico. The target (see Fig. 2) was the evolved star IRC+10420 which emits OH maser radiation from a circumstellar shell. The organisation of this first science experiment was led by John Conway as head of the EVN eVLBI science working group.

The record data rate obtained during 2004 from Onsala to JIVE was 256 Mbit/s. In February 2005, the same data rate was achieved trans-atlantic. During the autumn of 2005 real-time...
fringes with 512 Mbit/s were obtained with the VLBI telescopes at Westford and Goddard. Testing of eVLBI is continuing with the goal of achieving multi-station astronomical images and geodetic results at bit rates of 512 Mbit/s and above by the end of 2006.

The VLBI observations depend on the accurate time from the hydrogen maser clock in Onsala. The hydrogen maser is also used as an external clock to the fundamental GPS reference station.

### 3.3.1 EU funding for e-VLBI development

During summer 2005 a large proposal called EXPReS, involving several EVN stations, including Onsala, was submitted to the EU FP6 Research Internet Infrastructures-6 Call for Proposals. Of the 43 proposals submitted, EXPReS was rated the No.1 proposal and will be fully funded by the EU (to start in March 2006 and run for three years). The proposal aims for example at the development of hardware and software to allow eVLBI at even higher bit rates and to explore distributed correlation on software correlators.

### 3.4 The Odin satellite

#### 3.4.1 Introduction

The Odin satellite – our observatory for sub-millimetre wave spectroscopy – was launched from Svobodny in far-eastern Russia on February 20, 2001. At the time of finishing this report, Odin has been in operation for almost five years and shows only few signs of ageing. Funding for normal operations are available until 20. April 2006, but the operations will be extended thereafter.

The Odin project is a shared (50/50 %) astronomy/aeronomy mission supported by space
agencies and scientists in Canada, Finland, France and Sweden. Åke Hjalmarson and Donal Murtagh – both at the Department of Radio and Space Science – serve respectively as Odin Astronomy and Aeronomy Mission Scientists, i.e., as coordinators of the research activity within the two disciplines. At Onsala, we maintain an Odin Data Centre, performing pipeline processing and calibration of the millimetre and sub-millimetre data before the data distribution to our Odin scientists in the four partner countries (see Sect. 3.4.2).

Odin is equipped with a high precision offset Gregorian telescope of diameter 110 cm, followed by four tuneable, SSB sub-millimetre wave Schottky mixers and a fixed-tuned HEMT receiver at 119 GHz (improving the O$_2$ search sensitivity by at least an order of magnitude). Any four, three, or two (depending upon the satellite power available) of these front-end receivers can be combined with any of three spectrometers (a broad band acousto-optical spectrometer (AOS) and two flexible hybrid auto-correlators (AC1 & 2)). Some salient features of the Odin satellite observatory are summarised in the table below. Based upon Jupiter observations we have determined the main beam efficiency of the telescope to be as high as 90% at 557 GHz, the frequency of the water line. The rather complex radio receiver system was integrated, tested and optimised by engineers in the National Facility receiver laboratory. For aeronomy purposes Odin is equipped with an Optical Spectrograph and InfraRed Imaging System, OSIRIS, developed in Canada.

### Salient features of Odin

<table>
<thead>
<tr>
<th>Feature</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antenna size</td>
<td>110 cm</td>
</tr>
<tr>
<td>Beam size at 119 / 550 GHz</td>
<td>9.5'/ 2.1'(126&quot;)</td>
</tr>
<tr>
<td>Main beam efficiency</td>
<td>90%</td>
</tr>
<tr>
<td>Pointing uncertainty</td>
<td>&lt;10''(RMS)</td>
</tr>
<tr>
<td>Submm tuning range:</td>
<td>486–504, 541–581 GHz</td>
</tr>
<tr>
<td>Submm noise temperature</td>
<td>3300 K (SSB)</td>
</tr>
<tr>
<td>HEMT centre frequency</td>
<td>118.75 GHz</td>
</tr>
<tr>
<td>2.5 mm noise temperature</td>
<td>600 K (SSB)</td>
</tr>
<tr>
<td>AOS bandwidth / resolution</td>
<td>1100 MHz / 1 MHz</td>
</tr>
<tr>
<td>AC1 &amp; 2 bandwidth / resolution</td>
<td>100–800 MHz / 0.25–2 MHz</td>
</tr>
</tbody>
</table>

#### 3.4.2 The Odin data processing centre at Onsala

Michael Olberg and Glenn Persson continue to run the data processing pipeline for calibrating raw data from the Odin astronomy and aeronomy missions. The Odin satellite, which will enter its 6th year of operation in April of 2006, still produces data at an undiminished rate and the prompt calibration at Onsala and subsequent storing of calibrated spectra at the Parallel Data Centre (PDC) in Stockholm assures quick access to the latest science data by the various Odin topical teams.

#### 3.5 Equipment for space geodesy

##### 3.5.1 GPS equipment and data archive

The Onsala site has a number of geodetic monuments. All of them are easy to access and are close to external power and a 5 MHz H-maser controlled reference signal. A temperature controlled cable between the GNSS (Global Navigation Satellite System) antenna and the control room for the 20 m telescope permits accurate time transfer using the GNSS signals.
Several GNSS receivers are in operation. A Javad Legacy dual-frequency receiver with 20 channels is used for the combined use of GPS and GLONASS. This receiver can track 20 satellites at the two frequencies simultaneously. The acquired data is transferred in real-time to the Swedish National Land Survey (Lantmäteriet) and made available for real-time applications within Sweden and to the international community, e.g. the “International GNSS Service (IGS)”, via ftp as hourly and daily files. An Ashtech Z12 receiver is used as a back-up receiver and is connected to the same GNSS antenna.

Additionally, several GNSS receivers and Dorne-Margolin GNSS antennas are available for specific experimental campaigns. Furthermore, during 2005 a new monument was constructed that allows to test GNSS-antennas, radomes and site environment conditions in a scientific and systematic way.

The continuously operating GNSS networks produce a lot of data which are archived in order to be able to reprocess long time series of data with newly developed models for geophysical signals and/or error sources. An on-line computer archive is used for this.

3.5.2 Infrastructure for gravity observations

A monument for absolute and relative gravity measurements is located approximately 10 m from the main GPS reference marker (IGS site). It consists of a concrete pillar with reinforcement bars in steel drilled into the solid rock directly beneath the monument. The whole pillar is enclosed in a temperature controlled room within a small hut on the site. This facility is available for visiting gravimeters. The pillar has two benchmarks, and two instruments can operate simultaneously. The point has a levelled excentre (support point) 30 m to the south west; it has been connected to the Swedish height system RHB70. The gravity point has been measured sporadically since 1993; however, since 2003 remeasurements are being carried out typically 1 to 2 times per year.

3.5.3 Microwave radiometers for monitoring water vapour

Two microwave radiometers are operating at the Onsala Space Observatory. They are used to study the dynamics of the wet atmosphere – the water vapour and cloud liquid contents. They are regularly used for comparison and validation measurements, together with the space geodetic techniques based on VLBI and GPS observations.

Astrid, the oldest one, has been observing the sky emission at 21.0 and 31.4 GHz since 1980. Of course, there are gaps in the time series due to technical problems, maintenance, and system upgrades. It is fully steerable in azimuth and elevation. It typically operates in a continuous mode, where some 50 observations are well spread over the sky in an observing cycle which is repeated every 10–15 minutes. Its half power antenna beam widths are approximately 6°, both at 21.0 and at 31.4 GHz.

The second microwave radiometer (Konrad) acquire measurements of the sky brightness temperatures at the frequency bands centered at 20.64 and 31.63 GHz. Konrad is transportable and has been deployed at the Erange site in Kiruna, and in the Netherlands within the EC project CLIWA-NET, see http://www.knmi.nl/samenw/cliwa-net/. Its half power antenna beam widths are approximately 3° and 2° at 21.64 and 31.63 GHz, respectively.
### 3.6 The radio aeronomy station in Onsala

The radio aeronomy station in Onsala is used for spectral line measurements of atmospheric H$_2$O at 22 GHz and CO at 115 GHz. The line profiles contain information on the abundances of these molecules as a function of altitude. The front-end at 22 GHz is an uncooled HEMT amplifier, and at 115 GHz, a 3 mm Schottky mixer previously used on the 20 m telescope is used. Recently a new uncooled Schottky double sideband mixer covering 110–116 GHz was delivered to the station. When the new receiver is implemented it will be used to measure O$_3$ at 111 GHz and CO at 115 GHz and the old Shottky mixer will be turned off. The radio aeronomy station also runs an a 1000–1700 nm indium-gallium-arsenide Michelson interferometer to observe the radiance of the OH airglow. (See also Sect. 7.3.)

### 3.7 The technical development laboratories

The National Facility is served by development laboratories, both at Onsala and on the Chalmers campus. The equipment includes a two sputter systems (used in the fabrication of superconducting junctions) housed in a sophisticated clean room at the Department of Microtechnology and Nanoscience (MC2), a sophisticated miller providing $\pm 5\mu m$ precision in machining, liquid helium dewars, and spectrum/network analysers. The laboratories develop state-of-the-art receivers for the National Facility telescopes and for international projects, APEX, ALMA and Herschel.

### 3.8 Developments in computing

In addition to the software developments described elsewhere in this report, we are working towards wide-bandwidth connectivity to the research networks. At the end of 2003 an optical fiber link was installed between Onsala Space Observatory and Chalmers, allowing network traffic at 1 Gbit/s between the two sites. This means an improvement by three orders of magnitude in terms of bandwidth over the previous connection. Through Chalmers it provides a high speed connection to Swedish (SUNET) and European (GEANT) research networks and beyond and is a prerequisite for Onsala’s participation in e-VLBI experiments and other Grid computing activities in the future.

### 3.9 APEX, the Atacama Pathfinder Experiment

Our new antenna APEX, built on the superb site of Llano de Chajnantor at 5100 m in the Chilean Andes was opened for observations in July 2005 and inaugurated on 25th September 2005, in San Pedro, in the presence of representatives of the Max-Planck Society, VR (Pär Omling, the Director General) and ESO, as well as local dignitaries.

The telescope was delivered and erected on the site in June 2003. Problems with some parts of the system, including the sub-reflector, meant that commissioning did not begin in earnest until the spring of 2004. The final holographic setting of the antenna surface was completed to the satisfaction of the project in June 2005, when first science verification proposals were requested. The first observations have been very fruitful and already we have the detection of a new molecule, CF$^+$. A description of the telescope, its commissioning, its full expected receiver complement, and its scientific potential is given below.
This rest of this subsection on APEX is a copy of a paper by R.S. Booth (Onsala), R. Güsten (Max-Planck-Institut für Radioastronomie, Bonn), K. Menten (Max-Planck-Institut für Radioastronomie, Bonn) and L.-Å. Nyman (European Southern Observatory), presented by Roy Booth at the New Delhi meeting of the International Union of Radio Scientists (URSI).

Introduction

A new sub-millimetre telescope, APEX, is now operational in the southern hemisphere on what is probably the world's best, while still reasonably accessible, site for submm observations – Llano de Chajnantor – at an altitude of 5100 m. The antenna is a modified version of the ALMA prototype built by the German company, VERTEX Antennentechnik in Duisburg, customized to accommodate two Nasmyth cabins for the heterodyne receivers and with a modified sub-reflector for wide field observations with bolometer arrays placed at the secondary focus. The APEX project is led by the Max-Planck-Institut für Radioastronomie (MPIfR) in collaboration with the group that ran the successful SEST project, the Swedish National Facility for Radio Astronomy, Onsala Space Observatory (OSO) and the European Southern Observatory (ESO), as well as the host nation, Chile. The observing time will be divided as follows: 45% MPIfR, 24% ESO, 21% OSO, 10% Chile. The project has been managed by Rolf Güsten of the MPIfR since the spring of 2004 and the site scientist is Lars-Åke Nyman. On this excellent site spectroscopic and continuum observations will be conducted with APEX in all the atmospheric windows between 230 GHz and 1.5 THz, thereby closing one of the last spectral gaps for ground based astronomy, that between submm and far infrared wavelengths. At 1.5 THz the atmospheric transmission is there sometimes as good as 50%.

The APEX antenna

The APEX has a measured surface accuracy well within the originally specified goal of 18 µm, making it useful for THz observations. It consists of 264 aluminium panels in 8 rings on a CFRP backup structure of 24 sandwich shell segments. The backup structure (BUS) is supported by an INVAR ring and the total mass of the antenna is 125 ton. The antenna contract was signed in July 2001 and the assembly of the partially constructed telescope was started in Chile, on time in spring, 2003. It was erected on the Chajnantor plain somewhat north of the main ALMA array site, close to Cerro Chajnantor. In spring 2004, after installation of the subreflector, the commissioning began. Our optimistic date for first operations was projected to be in mid 2004 but bad weather, the complexity of operation at this remote site and teething problems with the antenna delayed its final acceptance (after successful commissioning) until the end of June, 2005.

Antenna reflector measurements

After erection the surface was set by photogrammetry to about 35–40 micron, rms. Subsequent holographic measurements using a transmitter on Chajnantor were conducted in April 2004 and again one year later. The results are quite spectacular with a final measured surface rms accuracy of about 15–16 microns at the elevation of the transmitter (circa 12 degrees). Differences between the two separate sets of measurement were shown to be due to cabin cooling which was not operational in 2004. This hypothesis was checked by making measurements while the cabin temperature was held at different settings. During the 2005 cam-
paigned, checks were made of the repeatability of the measurements by subtracting maps made at different times during the night. Such measurements (after the system had reached thermal equilibrium) give an estimate of the measurement accuracy which was determined to be about 5.5 micron.

Finally, the Vertex finite element model of the antenna structure was used to pre-load the antenna to an elevation of 50 degrees to optimise the performance over a range of 30–80 degrees. The effective rms surface accuracy is estimated to be about 17 microns. A check of the telescope surface setting may be obtained by measuring the beam size and shape. Measurements on the planets with the FLASH receiver at 460 and 810 GHz, give a good circular beam with low sidelobes and an excellent flat gain response over the elevation range 30–80 degrees. Main beam efficiencies are 47 and 65% at 810 and 464 GHz respectively, from our preliminary data reduction; these values will be refined in due course. The holography was conducted by a team consisting of T.K. Sridharan (Harvard-Smithsonian Centre for Astrophysics), Albert Greve and Dave Morris, led by Rolf Güsten, supported by APEX staff. It is a pleasure to acknowledge the great help provided by the outside experts and to the CfA for the loan of the holography transmitter.

**Telescope pointing**

The telescope pointing (specification <2 arcsec, rms) has been checked using an optical telescope fixed to the structure. The accuracy determined from frequent pointing runs is 2 arcsec, rms. The actual radio pointing is still being refined for the different receivers. The optical measurements also give the tracking accuracy when following a single star. This is circa 0.5 arcsec. This is very important since the beam width at 1.5 THz is less than 4 arcsec FWHM.

**APEX instrumentation**

The APEX receivers will consist of bolometers for continuum measurements and heterodyne receivers for spectroscopy. The planned suite of receivers is shown in the table below in which the nominal operating frequency is marked as well as the group building the receiver. Several receivers will have restricted use to MPIfR and their collaborators; they are marked PI. Of the planned receivers, only one facility instrument is operational at the time of writing. This is a double sideband receiver for the 279–381 GHz range built in the Onsala receiver group (GARD) led by Victor Beltsky [266]. The noise temperature is <50 K across the band.

**Table 1: Apex Instruments**

**Bolometers**

LABOCA: 300 Elements at 870 µm (MPIfR [U. Bochum, IPHT Jena]) FOV: 12’

37 Elements at 350 µm (MPIfR)

300 Elements at 2 mm for Sunyaev-Zel’dovich effect (Berkeley/MPIfR, PI)

**Heterodyne receivers**

210–270 GHz single channel (OSO)

270–375 GHz single channel (OSO)

375–500 GHz dual channel (OSO)
420–495 and 780–887 GHz dual channel FLASH (MPIfR, PI)
600–720 GHz CHAMP+ 7 elements (MPIfR, PI)
790–920 GHz CHAMP+ 7 elements (MPIfR, PI)
FIR receivers: up to 1.5 THz (OSO, facility and MPIfR, PI with KOSMA and CfA)

For commissioning the telescope the dual frequency, DSB, MPIfR PI receiver (FLASH) (see table) has been used. The back-ends are novel fast Fourier transform spectrometers (FFTS) with 1 GHz bandwidth and 16k channels. This excellent receiver has borne the brunt of the commissioning and early science verification by Güsten et al., and is available, on a collaborative basis, for general scientific use.

APEX operational infrastructure

The telescope is operated remotely via a microwave link from a base in Sequitor, some 10 km south of the village of San Pedro d’Atacama. At the base are the laboratories and control room and staff offices, as well as a meeting room, 16 dormitories and a cafeteria. The staff of 25 people works the standard ESO duty cycle with 8 days on shift at APEX and 6 days off. During the commissioning period, many technical staff have travelled daily up to the telescope where there is a site control room, a laboratory and kitchen. There is also a weather station and the microwave link connection. Electric power to the telescope is provided by diesel generators. The site is accessed via the paved international highway to Argentina, for the first 60 km, and then by an unpaved section of about 14 km. Because of the high altitude, strict rules are applied to people going to the site and overnight stays are only sanctioned under extreme circumstances like the sudden onset of bad weather.

APEX scientific programme

The frequency band between 0.8 and 3 THz is a largely unexplored frontier in astronomy. Interstellar clouds in general, and star forming regions in particular, radiate intensely at these frequencies. It has always been thought that observations must be carried out from airborne or orbiting platforms, which can support telescope apertures of only a few metres. Finding the high dry site of Llano Chajnantor changes all of this and the 12 m APEX telescope and the Japanese 10 m ASTE antenna on a nearby site of Pampa la Bola are set to make many new discoveries.

Surveys
APEX is seen as a pathfinder for new mm/submm telescopes but also as an important instrument in its own right for all areas of submm astronomy. The pathfinder exercise will be undertaken partly, at least, in terms of surveys. For example, there is a great interest in surveys for dust continuum and CO-line emission from distant galaxies found in deep optical surveys, such as the “Hubble Deeep Field”. Toward a number of objects with the highest measured red-shifts (sub)mm dust emission has been detected. Further sources are found in “blind” deep continuum surveys. In most of the sources in which dust emission is detected red-shifted high excitation lines of CO are subsequently also detected. In addition, there will be an MPIfR led continuum survey of the Galactic plane for protostars using the LABOCA array at 870 microns. Complementary observations at 350 micron, 1.4 and 2 mm will provide information on the physical properties of the detected condensations, which are high-mass protostars and
clusters. Mass and temperature for all regions of massive star formation up to the distance of the Galactic centre will be measured. Finally a survey for detections of the signature of the Sunyaev-Zel’dovich effect will be conducted by a Berkeley/MPIfR collaboration using a 2mm bolometer array, which is a PI instrument built by a group at the University of California at Berkeley.

**Individual objects**
The southern sky is hardly studied at submm wavelengths but contains many spectacular objects which merit detailed studies: the Galactic centre – a black hole and molecular factory; the nearest regions of low mass star formation – e.g. Chameleon at 450 ly; spectacular regions of massive star formation – e.g. Eta Carina; dense dark cloud complexes – e.g. the Coalsack nebula; our nearest neighbouring galaxies, the Magellanic clouds, and Centaurus A, the nearest radio galaxy. These are but well known examples of the wealth of interesting objects to be found in the southern hemisphere. In addition, there are many well known galaxies for which millimetre/submillimetre observations will yield important information.

**Astrochemistry**
The largely unexplored frontier available to observations with APEX is in the atmospheric windows centred on 0.85, 1.0, 1.30 and 1.5 THz where, under the very best weather conditions, it will be possible to observe with useful efficiency. These spectral windows include low-lying transitions of many molecules that are known (or expected) to be abundant in interstellar clouds, protostars, circumstellar envelopes of evolved stars, and comets. Of particular interest in astrochemistry are ground-state transitions of some light hydrides. The photon energy \( \frac{h\nu}{k} = 48(\nu/1 \text{ THz}) \) K is well matched to the kinetic temperatures 50–300 K that typify dense, star-forming cores of molecular clouds. The excitation requirements of most atomic and molecular transitions at THz frequencies select the densest gas near to a young stellar object. As a result it is expected that the most intense radiation will concentrate on angular scales of a few arcsec, or less in bright star-forming regions. This corresponds well to diffraction limited resolution of a 12m telescope.

The luminous bursts of star-formation that occur in centres of interacting galaxies also produce intense emission at THz frequencies, likewise on angular scales of the order of a few arcsec in the nearest such systems. In short, measurements at THz frequencies are well suited to the spectroscopic, as well as to continuum, studies of chemical evolution, dynamics and energetics of star forming regions.

### 3.10 Projects under development in radio astronomy

Part of the role of the National Facility is to “provide a structure and a body of competence though which future forefront research infrastructure can be conceived and realised for the benefit of Swedish astronomers and to plan and conduct technical projects and administer international collaborations that are beyond the scope of university groups”. In this role, we have been active in the past years both as initiators and supporters of new projects.

In addition to APEX, we are involved in two on-going new projects in radio astronomy. These are Herschel, an ambitious ESA corner stone space mission for submillimetre and infrared astronomy, and ALMA, the Atacama Large Millimetre Array.
3.10.1 The ESA Herschel project – expected launch in late 2007

Herschel is an astronomical satellite designed to operate at infrared and sub-millimetre-wave-lengths. The satellite and payload are approaching completion and final tests. While our scientists are involved in several project teams, our engineers at GARD (Group for Advanced Receiver Development) have built a beam measurement range (see Sect. 4.2) for testing and aligning the beams of the multiple receivers in the so-called HI-FI suite of heterodyne instruments covering the frequency range 480–1600 GHz. The alignment system is a 3-D beam measuring system, operating in vacuum, since the mixers operate at temperatures below 4 K.

3.10.2 ALMA, The Atacama Large Millimetre Array

The Atacama Large Millimeter Array (ALMA) is an international collaboration between Europe and North America (now joined by Japan) to build an interferometer consisting of up to 64 (50 funded so far) antennas that will operate at millimeter and sub-millimeter wavelengths in the atmospheric transmission bands between 30 and 950 GHz (0.3 to 7 mm). The array will be built on the world’s best site for mm/submm astronomy, Llano Chajnantor, already discussed under the APEX project (Sect. 3.9). With baselines up to 18 km and receivers with performance approaching the quantum limit, ALMA will image the mm/submm Universe with an unprecedented sensitivity and angular resolution. This performance is made possible by a design concept that combines the imaging clarity of detail provided by a 64-antenna interferometric array together with the brightness sensitivity of a fully filled aperture.

ALMA will be sited in the Altiplano of northern Chile, 5000 meters above sea level. The ALMA site is the highest, permanent, astronomical observing site in the world. On this remote site super-conducting receivers that are cryogenically cooled to less than 4 degrees above absolute zero will operate on each of the 12-meter diameter ALMA antennas. The signals from these receivers will be digitized and transmitted to a central processing facility where they are combined and processed at a sustained rate greater than $10^{16}$ operations per second. As an engineering project, ALMA is a collection of up to 64 precisely tuned mechanical structures each weighing more than 80 tons, super-conducting cryogenically cooled electronics, and optical transmission of terabit data rates – all operating together, continuously, on a site very high in the Andes mountains.

Roy Booth has been heavily involved in the ALMA development from its inception to its present status and has been a member of the Board since it was formed in 2003. He also chaired the European precursor project committee for the then Large Southern Array and sat on the ALMA Coordinating Committee for two years, representing the smaller nations in ESO. He was a member of both the European and International ALMA Scientific Advisory Committees until 2003 when Susanne Aalto took over. John Conway has made fundamental scientific contributions in designing the ALMA configuration and lay-out of the antennas, which defines the ALMA beam and its imaging performance.

On the technical side, and reported in more detail separately, Victor Belitsky has been a member of the Receiver Working Group, and GARD will build 8 receivers for ALMA band 5 (163–211 GHz) under a contract to ESO, supported by the EU-FP6 project enhancement fund. At the observatory, the Development Lab is involved in a collaborative development project (with Cambridge University, U.K.) to design, test and optimise, water vapour radiometers (WVR; see below). These instruments will, through measurements of the atmospheric water vapour content along the lines of site to each antenna, correct the signal phase. In a design review held at Onsala in May, 2005, the single Dicke radiometer design studied at Onsala
was chosen as the production radiometer, pending some final tests on the site of the Sub-Millimetre Array in Hawaii, which are being conducted as we go to press in early January, 2006. We expect both Cambridge and Onsala to be involved with the final contract.

The ALMA phase corrections system: water vapour radiometer development at Onsala

Despite the excellent observing conditions on the Chajnantor site, it is still necessary to correct errors in the interferometer phases caused by differences in the atmospheric water vapour along the lines of sites to each antenna. This will be done by radiometric measurements of the 183 GHz water line, its strength and line shape. Thus, water vapour radiometers (WVR) will be mounted on each antenna of the 50 (or more) element array.

In the Development Laboratory at Onsala we have developed and built a prototype WVR for the project. It will make real-time measurements of the 183.31 GHz water emission line and using this data the path fluctuations along the line of sight to each antenna will be calculated and used to correct the interferometer phases antenna pair by antenna pair.

The radiometer is of the Dicke switching type using a small chopper wheel that switches the radiometer beam between the sky and a cooled calibration load at a temperature of 140 K. The design developed at Onsala is a dual channel Dicke receiver configured such that one of the channels will always be looking at sky, thereby improving the sensitivity relative to a single channel system. For calibration an ambient load is switched into the beam of the cold load. The system temperature is then calculated from the data from the cold and ambient loads.

The receiving element is a corrugated horn coupled to an un-cooled Schottky mixer. The double sideband signal is amplified and split into four different frequency bands spread around the central frequency of 183.31 GHz. The output of each band is detected and sampled in synchronism with the chopper wheel. A microprocessor controls the whole system and calculates the sky brightness temperature.

Great effort has been put in to making an extremely stable radiometer. The sensitivity and stability must fulfil the requirements that the accuracy with which the phase delay shall be measured is better than $10(1 + w_v)$ microns of path, rms, where $w_v$ is the amount of water vapour along the line of sight, measured in millimeters (for $w_v$ of 0.4 mm, the central band gives 30 mK per micron of path). This shall be achieved with a time resolution of 1 second and maintained over time periods of up to 1 minute and for tilting the box in the antenna. To cope with these requirements the receiver box is temperature regulated and completely filled with insulating material.

The project has been carried out in collaboration with Mullard Radio Astronomy Observatory in Cambridge, UK. The MRAO group has built an alternative prototype radiometer based on a cross-correlation technique, although some elements of both radiometers were built at Onsala and vice versa. After extensive comparisons of the two radiometers and a selection review was held in May 2005, a simplified version of the Onsala design (single channel Dicke system) was selected for production with the proviso that water droplets and ice (which the correlation receiver can measure more accurately) would not play a critical role in the measurements. A crucial test will be conducted early in 2006 when the two prototype radiometers will be installed on two antennas of the Smithsonian Sub-Millimetre Array (SMA) on Mauna Kea Hawaii at an altitude of 4000 m.
Antenna positions

During 2004 John Conway worked with the ALMA Science IPT (Intergrated Product Team) on the problem of determining accurately ALMA antenna positions (to 50 µm) after an antenna move using astronomical “geodectic VLBI” style observations. The results of this study were included in ALMA Memo 503.

4 Advanced Receiver Development

The Group for Advanced Receiver Development (GARD) is the instrumentation division of Onsala Space Observatory and works on front-end technology for mm and submm receivers for high resolution spectroscopy for radio astronomy, with scientists, engineers, technicians and students in Onsala and on the Chalmers campus (at the Microtechnology Centre, MC2). The group in Onsala is lead by M. Hagström. This section describes the work by the group at MC2, whose academic staff consists of the group leader, prof. V. Belitsky, assist. prof. V. Vassilev, two post-docs (K. Ermisch and D. Meledin), and five PhD students (C. Risacher, R. Monje E. Sundin, M. Pantaleev and O. Nyström (last half of 2005)). The technical staff consists of one senior research engineer (A. Pavolotsky), two research engineer (V. Perez, M. Svensson), one engineer (M. Fredrixon) and one technician (S.-E. Ferm).

4.1 Atacama PAth-finder Experiment, APEX

APEX is the major Project supported by GARD during 2004–2005. We have focused on producing the optimal design and delivery of the single-pixel heterodyne facility receivers and their optics, for Nasmyth Cabin A. An important part of our APEX Project contribution is on the development and installation of the first facility receiver, with an SIS mixer, for APEX Band 2, 275–370 GHz. The mixer, receiver with its cryogenics, optics and controls system were developed, tested and installed at Chajnantor during 2004 – summer 2005. Figure 3 below shows the receiver installed at the telescope, and Fig. 4 the mixer and system performance.

Perhaps the biggest achievement for GARD is the performance of the APEX 2a receiver which gives the best level of receiver and system temperature achieved to date.

4.1.1 APEX band 3 (385–500 GHz) SIS mixer (under development)

The design combines waveguide components and on-chip local oscillator (LO) injection. The receiver will use a quadrature scheme where the RF signal is divided equally with a 90°phase shift by a 3 dB waveguide coupler. The LO is divided using an in-phase waveguide E-plane Y-junction. The output waveguides of the hybrid are coupled to the mixer SIS junctions through an E-probe based on waveguide-to-microstrip transition with integrated bias-T. A directional coupler for the LO and RF signals, the SIS junction and the bias-T are integrated on a single mixer chip. Besides, the mixer design includes a novel component, an ellipse microstrip termination for the idle LO port making the on-chip LO injection an easy and high-performance solution.

Mixer block design. The mixer block consists of three blocks, two housing the mixer chips and an intermediate block containing the 3 dB 90°hybrid and the LO in-phase power..
divider. The intermediate block will be split in two parts following the split block technique. Figure 5 shows one half of the block. The mixer blocks attached laterally to this structure will house the mixer chip together with the magnetic field concentrators for the Josephson effect suppression and all IF and the DC bias circuitry. The LO in-phase power divider is an E-plane Y-junction [Kerr, ALMA Memo 381] with a 3-section Chebyshev transformer from a rectangular to square waveguide.

3 dB waveguide directional couples. The commonly used component for splitting equally the RF signal with a 90° phase difference between port 3 and 4 is the 3 dB branch-line coupler shown in Fig. 6 (left). In order to achieve good directivity over the required band (Δf/f = 26 %), the number of branches (slots) has to be increased up to six. Figure 2a illustrates the coupler used for this mixer with all the dimensions in µm. The waveguide dimensions chosen for the mixer are 540 x 270 µm².

The simulated S-parameters of this device, using HFSS (High Frequency Structure Simulator version 5.6, Agilent Technologies), are plotted in Fig. 6 (right). The magnitude imbalance is better than ±0.5 dB around –3 dB in the band of interest (385–500 GHz) and isolation between the ports 1 and 2 and reflection coefficient are better than –20 dB.

Waveguide-to-microstrip transition with an integrated bias-T. The waveguide-to-microstrip transition for this receiver uses an innovative idea developed at GARD where the E-probe has an integrated bias-T. The structure is illustrated in Fig. 7 (left) and consists of a full-height waveguide, a fixed waveguide backshort, an E probe with an integrated bias-T and choke filters. The probe structure is oriented perpendicular to the Pointing vector in the waveguide with an airgap underneath the substrate. This airgap increases the cut-off frequency of the dielectric channel and therefore allows us to increase the substrate width. The dimensions of the airgap are 10 µm x 120 µm; a deeper gap will produce the excitation of higher modes.

The quartz substrate used for this design has a thickness of 65 µm and width of 150 µm. The RF probe is shaped in order to achieve a broadband matching between the waveguide and the probe output and to obtain as low impedance as possible at the microstrip port. According to our simulations, the impedance observed at the microstrip is approximately 35 ohm. In Fig. 7 (right), at the 35 ohm normalized Smith chart, we can observe the “tear drop” shaped
Figure 4: **Left:** First spectrum of the CO($J = 3 - 2$) line with the APEX 2a receiver at Chajnantor. The system temperature is 99.7 K. **Right:** The APEX 2a uncorrected noise temperature for 4 mixer blocks with different mixer chips. This performance comes close to two times the quantum limit.

Figure 5: **Left:** Drawing of complete mixer block. **Right:** Intermediate block containing the LO in-phase power divider and the RF 3-dB coupler.

frequency dependent input impedance of the microstrip.

**On-chip LO injection.** For the 500 GHz mixer we want to use the on-chip LO injection approach used in previous designs at GARD [Vassilev, PhD thesis, 2003], where the LO coupler is integrated on the mixer chip. Figure 4 shows the on-chip LO coupler made with superconducting lines coupled via lumped links, two perforations forming slot-holes in the ground plane on the same SiO$_2$ substrate ($\varepsilon_r = 3.74$) as the SIS junction and the RF tuning circuitry. The RF signal (port 1) comes from the waveguide-to-microstrip probe presented above and the LO signal (port 2) coming from another probe on the other side of the mixer chip and the output signal (port 3) goes to SIS mixer. The simulation results shown in Fig. 8 promise a coupling between 16 and 20 dB, with return losses and isolation better than 15 dB and 25 dB, respectively for the band of interest.

An ellipse termination [239] load is used for termination of the idle port (see Fig. 8). The termination is made of thin-film resistive material film with sheet resistance equal to the transmission line characteristic impedance.
Figure 6: Waveguide 3 dB Hybrid. **Left:** HFSS drawing of the 3 dB branch-line coupler with 6 slots in order to achieve good directivity over the required band. All aperture spacing and the separation between the two main waveguides are equal to approximately a quarter wavelength. All the dimensions are in micrometers. **Right:** Simulation results of the reflection coefficient $S_{11}$, isolation $S_{12}$, transmission from port 1 to port 2 and 3, $S_{12}$ and $S_{13}$, respectively. The magnitude imbalance is better than $\pm 0.5$ dB around $-3$ dB in the band of interest.

![Waveguide 3 dB Hybrid](image)

Figure 7: **Left:** RF probe structure. The structure is made of a full-height waveguide, a fixed waveguide backshort, an E-probe with an integrated bias-T and choke filters. **Right:** RF probe impedance in the Smith Chart normalized to 35 ohm. This termination does not require any connection to ground and it gives very good performance using an extremely reduced area. The resistive material is sputtered titanium mixed with nitrogen in order to reach the required resistivity. Figure 5 is a drawing of the final mixer chip.

![RF Probe Structure](image)

This termination does not require any connection to ground and it gives very good performance using an extremely reduced area. The resistive material is sputtered titanium mixed with nitrogen in order to reach the required resistivity. Figure 5 is a drawing of the final mixer chip.

**4.1.2 Development of APEX T2 HEB (hot electron bolometer) mixer (1.3 THz)**

A balanced waveguide design has been chosen for 1.3 THz band HEB mixer. This choice is based on the fact that at THz frequencies extremely low output power from LO sources is available. We have purchased a source from VDI which has state of the art performance, having the output power of 4–7 W in 1320±70 GHz band (see Fig. 9) This extremely low output source power necessitates a low-loss LO injection scheme. Thus, a mixer layout with an input quadrature 3 dB 90° hybrid was chosen. An E-plane waveguide probe with substrate crossing the waveguide, similar to the one proposed for the wide-IF band SIS mixer, has
be developed. The design of the probe was extensively simulated using 3D electromagnetic simulation packages; it is placed in the plane perpendicular to the waveguide. The main mixer parts were produced and are integrated; the remaining design concerns IF leads and details of the substrate fixtures. The designed substrate has dimensions 1000 µm × 70 µm × 17 µm.

Figure 9: Left: THz LO source with in house produced DC bias unit. Right: The LO unit is of direct multiplication type and provide about 4.5 mW of power over the band 1320±70 GHz in details.

The micromachining technology development. In order to manufacture the mixer block with the waveguide quadrature hybrid, we proposed a micromachining approach. This technique was tested with an external company and the first tests were very promising. In order to achieve better control over all processing steps of the micromachining of the mixer block, we set up all necessary processing in house including ultra-precision electroplating. Figures 10 and 11 show the results of the fabrication of the waveguide 3-dB 90° hybrid using the developed technology.

HEB mixer technology development. Ultra-thin NbN films of 3.5–4 nm thick were obtained from the group lead by Prof. G. Gol’tsman, MPGU, Moscow. The films were processed in the Chalmers University Clean Room facility and the first mixer chips were produced and DC measured. The lapping process was set up using Logitech lapping and polishing machine;
Figure 10: *SEM photographs of the inner part of the 3-dB 90° waveguide hybrid for the band 1320±70 GHz. The hybrid is made of copper, and gold-plated. The waveguide wall smoothness is better than 0.5 µm.*

Figure 11: *Micro-photographs of the 3-dB waveguide (90 × 180 µm) hybrid assembly for the band 1320±70 GHz. The hybrid is made using a split-block technique; we estimate the alignment accuracy is better than 5 µm.*

the process allows lapping of a substrate down to the required 17 µm with accuracy of about 2 µm. See Fig. 12.

*Cryogenic wide-band amplifier development.* Due to intrinsic limitations of HEB mixer technology, the IF band attainable for NbN based mixers could not exceed several GHz. In order to optimise performance of the receiver it would be an advantage to use a low-noise HEMT amplifier for 2–4 GHz without input circulator, which would add loss between the mixer and the IF amplifier. This requires to design an amplifier, which is unconditionally stable and has good input match ($S_{11} < -15$ dB); the latter condition however conflicts with low-noise matching of the amplifier input stage. We successfully solved this problem and have now a stable and extensively tested prototype for such an amplifier, which is available for initial tests of the HEB mixer. Two more amplifiers were produced. Figure 13 illustrates the amplifier performance.

We believe that with APEX T2 we have made major breakthrough in terms of moving waveguide technology into THz frequencies, developing a new technologies and gaining a lot of know-how for THz waveguide HEB mixers.
Figure 12: *SEM photographs of the inner part of the 3-dB 90° waveguide hybrid for the band 1320±70 GHz. The hybrid is made of copper and gold-plated. The waveguide wall smoothness is well better than 0.5 µm.*

Figure 13: **Left:** Photograph of the IF amplifier. **Centre:** Performance (gain (upper curve) and noise temperatures (lower curve)). **Right:** The input (solid line) and output matching measured at 12 K ambient temperature.

### 4.2 Herschel: Beam measurement range for the HIFI heterodyne instrument package

During 2004, the Beam Measurement Range (BMR) that was developed and built by the Group for Advanced Receiver Development (GARD) was commissioned and taken into operation, and can now be used for beam measurements. A characterization of the setup was performed using the demonstration-model (DM) of mixer sub-assembly (MSA) band 1 of HIFI. In addition, the beam-pattern of the DM of MSA band 2 was measured.

The laser-triangulation system, which had to be developed for absolute position calibration of the MSA, was commissioned.

**Beam-patterns measured for DM of MSA1.** Shown in Fig. 14 are the measured beam-patterns of DM of MSA1 at distances of about 600 mm, 700 mm and 900 mm from the position of the beam-waist. The measurements were performed in planar scans. Since the patterns shown here are some of the earliest measurements, the beam-pattern was not covered completely and is cut off in the y-direction.

A scan in which the beam-pattern was measured down to the noise-floor is shown in Fig. 15 (left). Shown in Fig. 15 (right) is the result of a scan along the z-axis, were a standing-wave pattern can be observed. Also shown in the same figure is the Fourier-transform of the scan, showing a peak at 32 cm⁻¹, corresponding to a frequency of 960 GHz = 2×480 GHz.
Figure 14: The measured beam-patterns of DM of MSA1 at 600, 700 and 900 mm from the beam-waist.

Figure 15: **Left:** Beam-pattern was measured down to the noise-floor. **Right:** A scan along the z-axis, with a standing-wave pattern, and the corresponding Fourier transform (right).

Beam-patterns measured for DM of MSA2. In Fig. 16, the beam patterns measured at 622 mm, 722 mm and 902 mm from the MSA-aperture are displayed. Each measurement was done at two planes, separated by a quarter of a wavelength, thus eliminating standing waves.

Figure 16: The beam patterns measured at 622 mm, 722 mm and 902 mm from the MSA-2.

The data shown here are the "raw" measured data. To obtain qualitative values from these data, e.g., the beam-axis, the intersection of the beam-axis with the MSA aperture and, using proper analysis tools, size and location of the beam-waist, these data have to be transformed to a coordinate system with a fixed mechanical reference to the MSA itself, using the triangulation system.
5 Radio Astronomy and Astrophysics

5.1 Stars, star formation, circumstellar envelopes

5.1.1 Methanol masers and High Mass star formation

In March 2004 PhD student Pestalozzi successfully defended his PhD thesis [101] which concentrated mainly on methanol maser observations in regions of massive star formation. The thesis presented final results from the Onsala 25 m telescope Methanol Maser Blind Survey. This data was later combined with published data from other surveys in Pestalozzi, Minier and Booth [254]. This general catalogue shows that methanol masers are concentrated in the galactic molecular ring in a distribution which is similar to that of OB associations, strengthening the ties between methanol masers and massive star formation. Analysis is continuing of the relative numbers of methanol masers and their luminosity function. This analysis will constrain the relative lifetimes of massive stars in the methanol maser phase.

To further test the hypothesis that methanol masers trace the earliest stages of massive star formation Minier et al. [236] reported multi-wavelength observations of sites with methanol masers but with no radio continuum evidence for Ultra-compact HII regions. According to the standard evolutionary model these regions should host very young massive protostars. An alternative possibility is that these could be sites for lower mass stars which are unable to ionise HII regions. Multi-wavelength observations of five methanol maser were made and the Spectral Energy Distribution found. Each site was found to be associated with a massive \( > 50 \text{M}_\odot \), deeply embedded \((A_V > 40 \text{mag})\) and very luminous molecular clump. These physical properties characterise massive star-forming clumps in an earlier evolutionary phases than H II regions. In addition, colder gas clumps seen only at mm-wavelengths are also found near the methanol maser sites. These colder clumps may represent an even earlier phase of massive star formation. These results suggest an evolutionary sequence for massive star formation from cold clumps, seen only at mm wavelengths, evolving through a hot molecular core stage to an ultra-compact H II region.

Pestalozzi, Elitzur, Conway and Booth [102, 103, 253] presented modelling of the VLBI methanol maser observations toward source NGC7538-IRS1 (Fig. 17). It was shown that the maser in the main spectral feature almost certainly arises in an edge-on rotating disk. Although such a disk origin has been suspected for a while this is the first strong proof in any object. The position-velocity diagram shows a distinctive curvature which can only be fitted assuming the methanol maser emission occurs in a range of radii in a disk with differential rotation. There is sufficient data that all the main parameters of the maser model are well constrained. The methanol maser occurs from radii of 350 AU to 1000 AU around a 30 solar mass central object. As well as being a first for methanol masers this result provides one of the few convincing pieces of evidence in any waveband for circumstellar disks around massive \(( > 8 \text{ solar mass})\) stars. It strengthens the conviction that despite the theoretical difficulties massive stars form in the same way as low mass stars, i.e. via disk accretion. Subsequent reanalysis of archive VLBI data on this source by student Anders Jerkstrand (see Fig. 17) has shown that the linear line of masers extends over a much wider angle than expected before, and that we see maser emission over a significant part of the front of the circumstellar disk. This maser structure is remarkable in being one of the smoothest and most extended ever observed in any maser observation. Comparison of the position of features over 5 years has shown evidence for proper motions which are consistent with the Keplerian disk model proposed by Pestalozzi et al [102].
5.1.2 SiO Masers associated with Evolved stars

Massive evolved stars on the Asymtopic Giant Branch (AGB) are an important source of dust and molecules in the galactic interstellar, however the process by which their mass loss occurs is not well understood. Maser observations, particularly of the SiO molecule, have the unique capacity to study the structure of these stellar outflows in the critical region outside of the stellar photosphere but inside the dust sublimation radius. Yi, Booth, Conway and Diamond [307] presented the results of VLBI SiO maser observations of one of the most studied SiO masers: TX Cam. These observations simultaneously mapped SiO masers in the \( J = 1-0, v = 1 \) and \( v = 2 \) maser lines at four epochs covering a stellar cycle (Fig. 18). A new observing technique was used to determine the relative positions of the two masers in the two lines. At several epochs, clear rings of masers around the parent star were detected. The observed relative ring radii in the two transitions and the trends on the ring thickness were found to be close to those predicted by the model of Humphreys et al. In many individual features there is an almost exact overlap in space and velocity of emission from the two transitions which

Figure 17: Methanol 12.2 GHz maser emission toward the star forming region NGC7538-IRS1 mapped with VLBI observations. At the distance of this object (2.5 kpc) an angular distance of 1mas corresponds to 2.5 Au. The top panel shows the velocity integrated line emission intensity, which extends 100mas (250 AU) in length. The bottom panel shows the Doppler velocity as a function of Right Ascension. The inner part of this position-velocity diagram has been well modeled as an edge-on Keplerian disk (see Pestalozzi et al. [102]).
argues against pure radiative pumping of the maser. At the last two epochs many filamentary or spoke-like features in both $v = 1$ and $v = 2$ masers were detected especially in the red-shifted gas. These spokes show systematic velocity gradients (see Fig. 18) consistent with a decelerating outward flow with increasing radius. Yi et al [307] outlined a possible model to explain why, given the presence of these spokes, there is a deficit of maser features at the systemic velocity. The breaking of spherical symmetry by spoke-like features may explain the high-velocity wings seen in SiO maser single dish spectra.

Figure 18: VLBI observations of SiO masers toward TX Cam (see Yi et al. [307]). Velocity field of the masers in the SiO maser $v = 1$ line. The diameter of the maser ring is about twice the diameter of the stellar photosphere. The horizontal colour bar gives the mean LSR velocity at each position.

Jiyune Yi [306] successfully defended her PhD thesis in April 2005. In addition to the results on TX Cam described above, she presented another four epoch multi SiO line study of an evolved star, R Cas. This sources shows large differences in structure from cycle-to-cycle. In some epochs masers in the two transitions avoided each other consistent with radiative pumping while in others they coincided consistent with collisional pumping. This suggests that the dominant pump mechanism for this source may change within a cycle. A refereed paper on this work (Yi, Booth and Conway 2006, submitted) was presented in the thesis of Yi [306].
5.1.3 Probing the inner wind of AGB stars: Interferometric observations of SiO millimetre line emission from the oxygen-rich stars R Dor and L^2 Pup

F.L. Schöier (Stockholm Observatory), H. Olofsson (Stockholm Observatory), T. Wong (CSIRO Australia Telescope National Facility), M. Lindqvist (OSO) and F. Kerschbaum (Institut für Astronomie, Wien) have observed “thermal” SiO emission at 86 GHz towards two oxygen-rich AGB stars using the Australia Telescope Compact Array [119]. In both cases the emission is resolved with an overall spherical symmetry. The excitation analysis suggests that the abundance of SiO is as high as $4 \times 10^{-5}$ in the inner part of the wind, close to the predicted values from stellar atmosphere models. Beyond a radius of $\approx 1 \times 10^{15}$ cm the SiO abundance is significantly lower, about $3 \times 10^{-6}$, until it decreases strongly at a radius of about $3 \times 10^{15}$ cm. This is consistent with a scenario where SiO first freezes out onto dust grains, and then eventually becomes photodissociated by the interstellar UV-radiation field.

5.1.4 Australia Telescope Compact Array imaging of circumstellar HCN line emission from R Scl

T. Wong (CSIRO Australia Telescope National Facility), F.L. Schöier (Stockholm Observatory), M. Lindqvist (OSO) and H. Olofsson (Stockholm Observatory) presented radio-interferometric observations of HCN $J = 1 \rightarrow 0$ line emission from the carbon star R Scl, obtained with the interim 3-mm receivers of the Australia Telescope Compact Array [150]. The emission is resolved into a central source with a Gaussian FWHM of $\sim 1''$, which is identified as the present mass loss envelope. Using a simple photodissociation model and constraints from single-dish HCN spectra, they argue that the present mass-loss rate is low, $\sim 2 \times 10^{-7} M_\odot \text{yr}^{-1}$, supporting the idea that R Scl had to experience a brief episode of intense mass loss in order to produce the detached CO shell at $\sim 10''$ radius inferred from single-dish observations. Detailed radiative transfer modelling yields an abundance of HCN relative to H$_2$, $f_{\text{HCN}}$, of $\sim 10^{-5}$ in the present-day wind. The lack of HCN in the detached shell is consistent with the rapid photodissociation of HCN into CN as it expands away from the star.

5.1.5 Properties of detached shells around carbon stars. Evidence of interacting winds

F.L. Schöier (Stockholm Observatory), M. Lindqvist (OSO) and H. Olofsson (Stockholm Observatory) have investigated the nature of the mechanism responsible for producing the spectacular, geometrically thin, spherical shells found around some carbon stars [273]. Based on extensive radiative transfer modelling of both CO line emission and dust continuum radiation for all objects with known detached molecular shells, they present compelling evidence that these shells show clear signs of interaction with a surrounding medium. The derived masses of the shells increase with radial distance from the central star while their velocities decrease. A simple model for interacting winds indicates that the mass-loss rate producing the faster moving wind has to be almost two orders of magnitudes higher ($\sim 10^{-5} M_\odot \text{yr}^{-1}$) than the slower AGB wind (a few $\sim 10^{-7} M_\odot \text{yr}^{-1}$) preceding this violent event. At the same time, the present-day mass-loss rates are very low indicating that the epoch of high mass-loss rate was relatively short, on the order of a few hundred years. This, together with the number of sources exhibiting this phenomenon, suggests a connection with He-shell flashes (thermal pulses). They also report the detection of a detached molecular shell around the carbon star DR Ser, as revealed from new single-dish CO (sub-)millimetre line observations.
5.1.6 Odin detections of NH$_3$ and H$_2$O in IRC+10216 and H$_2$O in W Hya

The convincing detection of NH$_3$ ($1_0 - 0_0$) emission in the C-rich circumstellar envelope of IRC+10216 is a challenging result that cannot be understood by ordinary chemical models, just like Odin’s detection of abundant H$_2$O, confirming the earlier H$_2$O detection by NASA’s satellite SWAS. While the high H$_2$O abundance may be explained by evaporation of orbiting icy bodies such as comets, remainders from the formation of the star, the similarly high NH$_3$ abundance remains unexplained unless these extra-solar comets have a much higher NH$_3$ content than those we know in the solar system. A paper by Hasegawa et al. (2005) has been accepted for publication in the Astrophysical Journal. Onsala collaborators are Åke Hjalmarson, Michael Olberg and Anders Winnberg.

Similarly sensitive observations have lead to the detection of H$_2$O ($1_{10} - 1_{01}$) emission from the O-rich circumstellar envelope of W Hya. A water abundance as high as 2·$10^{-3}$ – higher than the cosmic abundance of oxygen – is a very striking result from our accelerated lambda iteration modelling of H$_2$O data from Odin and ISO. Also, in agreement with the new modelling results, the observed line centre velocity is red-shifted with respect to the stellar velocity because of severe H$_2$O self-absorption in the expanding foreground gas. Again, the very high water vapour abundance may require injection of excess water from evaporation of icy bodies (comets) orbiting in the W Hya surroundings. A paper presenting these results has been published by Justtanont, Bergman, et al. [223]. Onsala collaborators are Per Bergman, Åke Hjalmarson and Michael Olberg.

5.2 Odin observations of interstellar clouds

The Odin project, satellite and radiometers, calibration methods as well as selected results from the first year of Odin observations of and searches for H$_2$O, H$_3^18$O, NH$_3$ and O$_2$ in molecular clouds and comets were presented in a suite of eleven papers in the May 2003 Odin Special Issue of Astronomy and Astrophysics Letters (Vol 402, L21–L81). A considerable number of Onsala astronomers are involved in the analysis of Odin data and are co-authors of these papers.

We will here discuss a number of new results from Odin’s observations of sub-millimetre wave lines of H$_2$O, H$_3^18$O, and H$_3^{17}$O in interstellar clouds, as well as some results from simultaneously conducted searches for O$_2$ at 119 GHz. Results from the ongoing spectral scan of Orion KL – taking advantage of Odin’s tuneable receivers – also will be presented. Odin detections of NH$_3$ and H$_2$O in circumstellar envelopes are discussed in Sect. 5.1.6. Deep Odin searches for O$_2$, H$_2$O and CO ($J = 5 - 4$) in external galaxies and also a dedicated spectral scan search for primordial molecules are presented in Sects. 5.3.11, 5.3.12 and 5.3.13.

Invited talks on new astronomy results from the Odin satellite have been presented by Åke Hjalmarson at the COSPAR meeting in Houston [55], at 4th Cologne-Bonn-Zermatt Symposium [56], at the COSPAR meeting in Paris, July 2004, at the meeting “The Dusty and Molecular Universe – A Prelude to Herschel and ALMA” in Paris, October 2004, at the “Herschel Preparatory Science Workshop” arranged at the Lorentz Centre, Leiden, in December 2004, at the meeting “Hunt for Molecules” in Paris, September 2005, and at the “Workshop in Extragalactic and Galactic ISM Modelling in an ALMA Perspective”, in Göteborg/Onsala, October 2005.
5.2.1 Lowering the ISM molecular oxygen limits and detections of HC$_3$N ($J = 13 − 12$)

Whenever possible we have in parallel with our sub-millimetre wave observations also used the “fixed-tuned” 119 GHz HEMT receiver for continued sensitive O$_2$ searches. Although this receiver is no longer phase-locked, the frequency drift is very slow and can be accurately calibrated by means of the atmospheric O$_2$ line. The accuracy of this frequency calibration method now has been proven by the first detection of astronomical lines by this Odin receiver. During our searches for O$_2$ in Sgr A, Sgr B2 and DR 21 the HC$_3$N ($J = 13 − 12$) line was observed at the appropriate intensity, width and velocity. The large amount of O$_2$ search data, collected “for free” in parallel with our sub-millimetre wave observations of molecular clouds, therefore can be convincingly used to determine unprecedented O$_2$ abundance limits approaching $10^{-8}$ (and may even lead to low-level detections). Already our published, ten times higher, O$_2$ abundance limits (Pagani et al. 2003, A&A 402, L77) were difficult to accommodate in current models of oxygen chemistry. Onsala collaborators in this ongoing work are Henrik Olofsson, Michael Olberg, and Åke Hjalmarson.

5.2.2 Observations of H$_2^{18}$O, H$_2^{17}$O, CO, $^{13}$CO, and C$^{18}$O in the Orion KL region

Our early Odin observations of the H$_2$O and H$_2^{18}$O (1$_{10} − 1_{01}$) lines in the Orion molecular cloud (Henrik Olofsson et al. 2003, A&A, 402, L47) have revealed extended emission across the ambient molecular cloud as well as strongly enhanced emission in the well-known molecular outflows. The water abundance was estimated to increase from $10^{-8}$ in the ambient cloud to circa $10^{-5}$ in the compact low-velocity outflow (probably as a result of evaporation of icy grain mantles), and is further increasing to $> 10^{-4}$ in the shocked gas of the extended high-velocity outflow. In an effort to improve our knowledge of the source physics and the accuracy of these abundance determinations, we have simultaneously mapped the H$_2$O (1$_{10} − 1_{01}$), CO and $^{13}$CO ($J = 5 − 4$) emissions and have also observed the H$_2^{18}$O (1$_{10} − 1_{01}$) and C$^{18}$O ($J = 5 − 4$) lines in four nearby positions. In addition we have detected the H$_2^{17}$O (1$_{10} − 1_{01}$) emission from the low-velocity flow, verifying the assumption of low optical depth of the H$_2$O line crucial for our abundance determination.

A first paper presenting the analysis of Odin’s mapping of the CO and $^{13}$CO, $J = 5 − 4$ lines across the Orion KL region has been submitted by Eva Wirström et al., and a poster was presented at the recent IAU Symposium No. 231 in Asilomar, CA. In addition to rather accurate estimates of CO (and hence H$_2$) columns in the warm low and high velocity outflows we also get the desired “reference map” of the gas column of across the warm interface region between the molecular cloud and the M 42 HII region. The column density of warm gas decreases by an order of magnitude from the molecular ridge to the map edges. These new results are very important as comparison gas columns in our forthcoming effort to improve the accuracy of the H$_2$O abundance determinations in the Orion region. As a first step we have estimated the water abundance to be as high as $(1−2) \times 10^{-7}$ in the three map positions where also the C$^{18}$O, $^{13}$CO and CO, $J = 5 − 4$, lines have been observed by Odin (see Fig. 19). Onsala collaborators are Eva Wirström, Per Bergman, Henrik Olofsson, Michael Olberg and Åke Hjalmarson.

In a dedicated effort Gustaf Rydbeck is engaged in applying his newly developed deconvolution software – based upon statistical principles and capable of deconvolving the observed position-velocity cubes – to our Orion mapping data. The clean Odin beam (having 90% main beam efficiency and a side-lobe level below −30 dB), paired with the strong H$_2$O (1$_{10} − 1_{01}$), CO and $^{13}$CO ($J = 5 − 4$) emission lines hopefully will allow us to present
Figure 19: CO, $^{13}$CO, and C$^{18}$O ($J = 5 - 4$) spectra and together with H$_2$O ($1_{10} - 1_{01}$) spectra observed towards three positions in the warm interface region between the Orion KL molecular cloud and the M42 HII region.

spectral maps as if they were observed by a 40″ antenna beam (similar to that of ESA’s future Herschel Space Observatory) rather than by the 126″ Odin beam. Preliminary results have been presented by Hjalmarson et al. [213]. Much improved water abundance determinations are expected to result from this deconvolution effort.

5.2.3 H$_2$O mapping of the DR 21 / DR 21(OH) region

The results of our H$_2$O ($1_{10} - 1_{01}$) mapping of the molecular cloud region around DR 21 and DR 21(OH) were included in Henrik Olofsson’s thesis (2003), and a paper soon should be ready for submission. The very complicated spectral shapes of the water line have been interpreted in terms of broad emissions from outflows, intersected by strong, narrow, absorptions from low-excitation water in the ambient molecular cloud and also in a foreground cloud. Because of the enhanced water emission in heated regions, Odin has observed not only the well-known east-west extended high-velocity outflow near DR 21, but also has been able to detect three new outflow sources. To gain an improved understanding of these new outflows, we have recently undertaken complementary Odin observations of the CO and $^{13}$CO ($J = 5 - 4$) lines, as well as observations of the thermal SiO ($J = 2 - 1$) line using the Onsala 20 m telescope. Onsala collaborators are Henrik Olofsson, Åke Hjalmarson, Per Bergman and Michael Olberg.

5.2.4 H$_2$O and NH$_3$ mapping across the S 140 ionisation front

Our mapping of the H$_2$O ($1_{10} - 1_{01}$), NH$_3$ ($1_0 - 0_0$), CO and $^{13}$CO ($J = 5 - 4$) emissions across the geometrically favourable S 140 molecular cloud / HII region interface recently has been improved by Odin. To support our study of the physical and chemical conditions in this photon dominated region (PDR) we have undertaken complementary observations of the C$^{18}$O, H$^{13}$CN, HC$^{15}$N, CN and CH$_3$OH emissions in the molecular cloud core and across the ionisation front using the Onsala 20 m telescope. Onsala collaborators are our Odin research
student Carina Persson, and Michael Olberg, Henrik Olofsson, Per Bergman, John Black and Åke Hjalmarson.

5.2.5 The Odin spectral scan of Orion KL

Due to the absorptions by O\textsubscript{2} and H\textsubscript{2}O, the terrestrial atmosphere is completely opaque in the spectral regions around 487 and 557 GHz. The Odin satellite – with its 1.1 metre size antenna and four tuneable, cryo-cooled Schottky mixer receivers covering the bands 486–504 and 541–581 GHz – is the first telescope capable of observing this frequency range. During the last two years we have undertaken a spectral scan of the Orion KL region in the frequency ranges 486–492 and 541–577 GHz. The data reduction and spectral line identification work has been performed in parallel at Onsala Space Observatory and in Calgary. This Odin work complements earlier ground-based spectral line surveys of this source in nearby frequency bands, 455–468 and 492–507 GHz at 15 m diameter JCMT (White et al. 2003; A&A 407, 589), and 607–725 GHz at the 10 m diameter Caltech Submillimeter Observatory, CSO (Schilke et al. 2001; ApJS 132, 281), both instruments located at 4000 m altitude on Mauna Kea.

The Odin spectral scan data quality and our rather intricate identification work is illustrated in Fig. 20. The average spectral line density observed by Odin (circa 10 lines per GHz) is similar to that achieved at nearby wavelengths by the 10–15 meter-size ground-based telescopes – reflecting their suffering from atmospheric attenuation as well as the long Odin integrations and good data quality. The RMS noise in our spectra is typically < 0.02 K. This noise level is in fact somewhat higher than expected from the receiver noise, which may indicate that we are here approaching the expected low-level line forest. Several hundred spectral lines from some 40 different molecules/isotopologues have been detected, among them emissions from ortho-H\textsubscript{2}O, ortho-H\textsubscript{2}\textsuperscript{18}O, ortho-H\textsubscript{2}\textsuperscript{17}O, ortho-NH\textsubscript{3} and ortho-\textsuperscript{15}NH\textsubscript{3}, and also from HDO and para-H\textsubscript{2}O (a very high energy emission line “connecting” absorption lines observed by the Infrared Space Observatory, ISO). It appears that the line blending is so severe that, e.g., the observed H\textsubscript{2}\textsuperscript{18}O and H\textsubscript{2}\textsuperscript{17}O lines have to be “cleaned” from the influences of SO\textsubscript{2}, \textsuperscript{34}SO\textsubscript{2} and CH\textsubscript{3}OH emission before they can at all be used in analysis. These – like many other new Odin results – will be very important for ESA’s Herschel Space Observatory – to be launched in 2007.

The Odin spectral scan project was presented on a poster by Carina Persson et al. at the recent IAU Symposium No. 231 in Asilomar, CA, and two papers presenting the data, the line identifications and the scientific analysis soon will be submitted by Henrik Olofsson et al. and Carina Persson et al. Onsala collaborators in this rather demanding work are our research students Carina Persson and Eva Wirström, Henrik Olofsson, Åke Hjalmarson, Per Bergman, John Black and Michael Olberg.

5.3 Galaxies, active galactic nuclei and cosmology

5.3.1 A wavelet add-on code for new-generation N-body simulations and data de-noising (JOFLUREN)

Wavelets are a new and powerful mathematical tool, whose most celebrated applications are data compression and de-noising. Romeo, Horellou & Bergh (2003) have shown that wavelets can be used for removing noise efficiently from cosmological, galaxy and plasma N-body simulations. The expected two-orders-of-magnitude higher performance means, in terms of
Figure 20: Demonstrating data quality and line identifications in the Odin spectral scan of Orion KL.
the well-known Moore’s law, an advance of more than one decade in the future. Romeo, Horellou & Bergh [110] have described a wavelet add-on code designed for such an application. The code can be included in common grid-based N-body codes, is written in Fortran, is portable and available on request from the first author. The code can also be applied for removing noise from standard data, such as signals and images. Several applications are in progress.

5.3.2 Chemistry and ISM properties of the dense gas-phase of starbursts and AGNs

Susanne Aalto et al. have used the SEST, JCMT (James Clerk Maxwell Telescope), OVRO (Owens Valley Radio Observatory), and Onsala telescopes to study the chemistry and excitation of the dense gas phase of LIRGs and ULIRGs (Luminous and Ultra Luminous Infrared Galaxies). Goals were to search for molecular clues to the starburst structure and evolution – as well as investigate the HCN-FIR (FIR = far infrared radiation) correlation established by Solomon et al (1992). Aalto et al. have studied HCN 1–0 & 3–2, HNC 1–0 & 3–2, CN 1–0 & 2–1, HC$_3$N, HNCO and CH$_3$OH. From models and interpretations of these observations, the following conclusions are drawn:

- The molecular ISM in luminous galaxies are dominated by fast ion-neutral reactions rather than neutral-neutral chemistry of dark, dense clouds in the Milky Way. Some galaxies may even have ISM chemistry more reminiscent of planetary nebulae than that of Galactic GMCs. In this context, the bright HNC emission found in many warm luminous galaxies does not suggest vast amounts of cold (10 K) gas, since in a ion-neutral chemistry the isomers HNC and HCN are produced in equal amounts, independent of temperature.

- Using recent JCMT HNC and HCN J=3–2 data, Aalto et al. discovered that in two ultraluminous galaxies, Arp 220 and Mrk 231, the HNC luminosity exceeds that of HCN. This is the first case of radiatively pumped HNC on large scale. Instead of being collisionally excited, the HNC molecules is (at least partially) experiencing pumping by intense mid-infrared continuum.

- The PDR (Photon Dominated Regions) tracer molecule CN is unexpectedly faint in the distant luminous galaxies compared to expectations of ULIRGs as powered by super-starbursts. This is either an evolutionary effect – or reflects intrinsic differences in PDR properties between ULIRGs and more normal starbursts. Similarly, the PDR-tracer [C II] 158 µm line is relatively fainter in ULIRGs than in less compact, less FIR-luminous galaxies (e.g. Malhotra et al 1997). Our high-resolution OVRO CN map reveals bright CN emission towards the nucleus of IC 694 and in the starburst overlap region – while CN remains undetected in the nucleus of NGC 3690. This cannot be explained in terms of starburst evolution (from models in Alonso-Herrero et al 2000) – but may be related to the presence of an AGN (active galactic nuclei) in NGC 3690. Alternatively, the optical/NIR age-dating methods of Alonso-Herrero et al (2000) cannot be applied to the obscured cores of Arp 299 and we are witnessing a very early stage of starformation at the heart of NGC 3690 before the uv emission breaks out of the molecular cores. Aalto et al. have found that in both Arp 299 and Arp 220 is the CN emission correlated with the location of OH megamaser emission.
• HC$_3$N 10–9 emission has been detected in Arp 220, UGC 5101, NGC 3079 and (tentatively) in NGC 4418. In Arp 220, HC$_3$N and CN clearly originate from two different nuclei where the western, CN-emitting, nucleus harbours an older burst of star formation (Aalto et al 2002). This is consistent with the complex HC$_3$N molecule requiring a non-agressive radiative environment while the CN radical is abundant in the $uv$-intense ISM of a more developed burst. HC$_3$N is detected towards galaxies with generally large nuclear extinction and warm FIR colours – which could indicate young starbursts – or a deeply obscured AGN. However, considering the scale on which the HC$_3$N emission must be emerging, the former interpretation is favoured. Further study of HC$_3$N in luminous galaxies will be done with the IRAM (Institut de Radio Astronomie Millimétrique) 30 m telescope in May 2006.

5.3.3 Atomic and molecular gas in mergers

HI in merger nuclei
Since mergers and interactions are one of the main triggering mechanisms behind starburst and AGN activity it is important to study the impact of the merging phenomenon on the gas. One example is the structure of the molecular and atomic gas of the “Medusa” merger, NGC 4194. Beswick (Jodrell Bank Observatory) and Aalto are looking for dynamical clues to the extreme star formation rate of the Medusa merger which forms stars with an efficiency rivalling that of ULIRGs, but with an order of magnitude less luminosity – and with a significantly more extended starburst and molecular region of 2 kpc (Aalto and Hüttemeister 2000). Time with the MERLIN array was awarded for a high-resolution (0.1”–0.2”) study of the extent and dynamics of the HI absorption as well as the structure of the radio-continuum. Beswick and Aalto find an apparent double nucleus at the core of the merger, and widespread HI absorption. The radio continuum peak is clearly offset from the CO peak – likely as an effect of increased gas-consumption in the areas of the most intense star formation. Interestingly, the dispersion in the HI gas (in absorption) at high resolution is close to that of CO at 2” resolution, indicating that we are actually observing the intrinsic linewidth of the atomic gas – suggesting that the ISM of the inner 2–3 kpc of the Medusa is highly turbulent. It is suggested that the atomic gas is primarily a photodissociation product of the molecular gas in the starburst. The study continues with NGC 1614, a merger with similar properties as the medusa merger – but more massive and with a higher FIR luminosity (Beswick et al. [167, 168]).

Atomic and molecular gas in minor mergers
NGC 4441 and NGC 4194 are both advanced minor mergers with developed shells and tidal tails. Manthey (Bochum) and Aalto et al. have conducted studies of the molecular gas distribution and physical conditions (at OVRO and IRAM) as well as interferometric studies of the distribution and dynamics of the atomic gas (at Dwingeloo). The molecular gas is surprisingly extended (scales of several kpc) and have physical conditions that are very different from those of normal galaxies. NGC 4194 is currently undergoing a powerful starburst while NGC 4441 has evolved into a post-starburst galaxy. Interestingly, the molecular clouds of the post-starburst NGC 4441 appear unable to settle into normal giant molecular clouds – but are instead able to survive in a diffuse state. None of the minor mergers have much dense gas ($n \geq 10^4$cm$^{-3}$) despite the violent and efficient star forming processes of NGC 4194. C. Horellou is conducting dynamical simulations of the NGC 4194 system to better understand its merging history.
5.3.4 LINER galaxies – starbursts or AGNs?

The nature behind the power source of LINER (low-ionization nuclear emission-line region) galaxies is unclear – is it powered by an aging starburst, or by an active nucleus? Is it possible that LINER activity is the missing link between starburst and nuclear activity – representing an intermediate type of activity occurring after the starburst phase, but before the galaxy develops a Seyfert nucleus? Since LINERs can be divided into type 1, which have very broad Hα emission lines and type 2 that lacks broad emission it is clear that at least some LINERs must be AGN powered.

PhD student E. Olsson et al. have an ongoing study of the two LINER galaxies NGC 5218 and NGC 1614 to determine the true nature of the LINER activity and its relation to the distribution, dynamics and physical conditions of the neutral gas. They have high resolution OVRO CO data and MERLIN HI absorption and 20 GHz continuum data – and were very recently also awarded VLA time to observe the HI absorption in NGC 1614.

5.3.5 Hydrodynamical models of the collision between IC 2163 and NGC 2207

The collision between the galaxies IC 2163 and NGC 2207 is a prime example of an interaction leading to the formation of an ocular or eye-shaped galaxy (IC 2163 in this case). The existence of an ocular shape, a short-lived structure produced in prograde in-plane encounters, in an observed galaxy puts strong constraints on the orbital parameters of the system and makes such systems good candidates for detailed modelling.

Magnus Thomasson and several collaborators are studying such interacting system, observationally as well as with modelling. Numerical hydrodynamical models of the collision
between the galaxies IC 2163 and NGC 2207 were presented in 2005 [284]. These models extend the results of earlier work in which the galaxy discs were modelled one at a time. The general result that the collision is primarily planar and prograde for IC 2163, but retrograde for NGC 2207, is confirmed. A list of specific morphological or kinematic features on a variety of scales, found with multiwaveband observations, were used to constrain the models. The models are able to reproduce most of these features, with a relative orbit in which the companion (IC 2163) disc first side-swipes the primary (NGC 2207) disc on the west side, then moves around the edge of the primary disc to the north and to its current position on the east side. The models also provide evidence that the dark matter halo of NGC 2207 has only moderate extent. For IC 2163, the prolonged prograde disturbance produces a tidal tail, and an oval or ocular waveform very much like the observed ones. The retrograde disturbance in the model produces no strong waveforms within the primary galaxy. This suggests that the prominent spiral waves in NGC 2207 were present before the collision, and models with waves imposed in the initial conditions confirm that they would not be disrupted by the collision. With an initial central hole in the gas disc of the primary, and imposed spirals, the model also reproduces the broad ring seen in HI observations. Model gas disc kinematics compare well to the observed (HI) kinematics. An algorithm for feedback heating from young stars is included, and suggest the occurrence of a moderate starburst in IC 2163 about 250 Myr ago.

This is probably now one of the best-modelled systems of colliding galaxies, though the model could still be improved by including full disc self-gravity. The confrontation between observations and models of so many individual features provides one of the strongest tests of collision theory. The success of the models affirms this theory, but the effort required to achieve this, and the sensitivity of models to initial conditions, suggests that it will be difficult to model specific structures on scales smaller than about a kiloparsec in any collisional system.

### 5.3.6 Millimeter VLBI observations of powerful radio jets

Krichbaum et al [68] summarised the present status of millimetre VLBI observations of powerful extragalactic radio jets at 3 mm (86 GHz), 2 mm (129–150 GHz) and 1.3 mm (215–230 GHz). These observations involved extensive participation by the Onsala 25 m telescope and SEST. A new 3 mm VLBI map of the jet in M87 was presented with spatial resolution of only \( \approx 20 \) Schwarzschild radii. Recent results for Sgr A* were also discussed as well as future possibilities to image the ‘event horizon’ of the black hole in Sgr A* at wavelengths \( < 2 \) mm. Pagels et al [94] presented additional millimetre VLBI observations of powerful radio jets concentrating on 3C 454.3. This core-dominated and highly variable quasar is shown to have a complex morphology with individual jet components accelerating superluminally towards the outer structure.

### 5.3.7 First Detection of a Radio Supernova in a ULIRG

In the first VLBI observations to achieve a bit rate of 1 Gbit/s, during survey observations to detect AGN (Active Galactic Neuclei) in a sample of starburst galaxies, Parra and Conway serendipitously detected two new radio supernovae within the twin nuclei of the prototype Ultra Luminous Infra-Red Galaxy (ULIRG) Arp 220. Using a special technique known as delay-rate mapping it was possible to make a simple image with the 10 minutes of data available from our single baseline (see Fig. 22). The two new sources detected at 6 cm wavelength do not coincide with any of the known 18 cm wavelength compact sources in this source. The
Figure 22: Contours show the VLBI map of Arp 220 made from data on the Bonn–Arecibo baseline at 6 cm wavelength from February 2005. Contours are 0.5 mJy/beam apart starting from 0.5 mJy/beam. The two brightness peaks do not coincide with the positions of the known compact 18 cm sources seen by Smith et al. 1998 (shown as small circles) – all of which are thought to be supernova remnants. The confirming detections of the new source in the western nucleus at 6 cm wavelength from VLBI archive data from January 2003 and in 18 cm data from March 2005 are shown as a + and a ×, respectively.

detection in the Western nucleus has been confirmed with 6 cm data from the VLBA archive (observed January 2003) and 18 cm data from March 2005 (Phil Diamond, private communication). The Eastern source is presumably too young to be detected in archival data or at 18 cm. The inferred multi wavelength light curve of the Western source is consistent with what is expected for a type II supernova. The luminosity of this source is slightly larger than the most luminous such radio supernova yet observed (SN1986J). This class of ultra luminous supernovae are thought to be due to the explosion of stars with >30 solar masses. By comparing the radio supernova rate and the IR luminosity in Arp 220 it should be possible to constrain the Initial Mass Function for star-formation, a quantity which is so far largely unknown within ULIRGs. Following the subsequent evolution of these supernovae will provide a new probe of physical conditions within the dense interstellar medium of this ULIRG.

5.3.8 Continuum observations of IR luminous galaxies

Polatidis et al [105, 106] presented the first results of a project to map radio emission from the IRAS Bright Galaxy Sample (BGS) of IR luminous galaxies. It is still unclear whether the primary energy source in these galaxies is from star-formation or a central AGN. Using continuum VLBI observations it is possible to distinguish between these possibilities by searching for either a single, compact, high brightness temperature component as expected for an AGN or instead a complex of supernovae as expected in a starburst. In one of the sources (UGC5101) Polatidis et al [105, 106] argue that the radio structure points to a powerful AGN as the energy source, a result which is in line with X-ray observations. The remaining sources presented instead have VLBI structures consistent with starbursts.

Parra et al [247, 248] presented first results on analysis of radio data from the COLA
(Cores of Low luminosity AGN) sample. This is a sample of moderately luminous IR galaxies in the redshift range 3500 to 7000 km s\(^{-1}\) with 60 \(\mu\)m wavelength flux > 4 Jy. Most sources have Far IR luminosities in the range \(10^{10.5}\) to \(10^{11.5}\) solar luminosities. A large amount of optical, CO and HI data has been already collected on this sample. The objective is to try to understand possible starburst and AGN connections by looking for those with signs of AGN activity (via optical spectroscopy and radio observations) and seeing if there are any correlation with having close neighbours etc. The VLA imaging of this sample presented by Parra [248] indicated that those sources with slightly higher radio to IR ratios than normal were likely to have larger radio sources. Various explanations for this were given including the idea that radio AGN are seen preferentially in older more evolved starbursts consistent with proposed evolutionary schemes. During 2005 high sensitivity (1 Gbit/s) global VLBI has been conducted of the whole sample to detect compact radio cores indicating AGN. The first analysis of the data and of the VLA imaging was presented in the licentiate thesis by Parra [247].

### 5.3.9 OH Megamasers in IR luminous Galaxies

A subset of IR luminous galaxies emit OH megamaser emission which can be used to trace the internal dynamics and molecular cloud structures within the circumnuclear starburst or AGN. Because of the high brightness temperature of the OH maser emission sub-parsec resolution can be achieved, much higher than with any other technique. Parra, Conway, Elitzur and Pihlström [250] and Parra [247] presented a detailed model for the OH megamaser galaxy III Zw35 as arising from clouds in a rotating circumnuclear ring of radius 22 pc enclosing a mass of \(7 \times 10^6\) solar masses. The OH maser emission in III Zw35, as in other megamasers, apparently comes from two components, a diffuse component plus bright unresolved features. Parra et al [250, 247] have shown how this appearance can be explained if there is only one component of emission in dense clumps. The bright features then arise from the chance overlap in space and velocity of multiple clumps.

To explain the relative brightness of continuum and maser emission a model which has most of the continuum emission at larger higher radius than the OH is required (Parra et al [250]; see Fig. 23). Also required are bicones of free-free absorption which cover the more distant Eastern side of the OH maser ring. These ionised bicones could form the bases of superwinds as are often observed in powerful starbursts. In order to explain the observed velocity gradients the clouds, as well as rotating around the ring, must also have a component of velocity outward from the disk midplane (see Fig. 23) at velocities \(v_z > 60\) km s\(^{-1}\) and so the clouds must therefore be unbound to the system. Detailed modelling gives cloud size limits of < 0.7 pc, estimated densities \(10^4 - 10^5\) cm\(^{-3}\), masses < 24 solar masses and filling factors < 0.1 respectively. It is argued that these OH maser clouds are not gravitationally or pressure confined but are freely expanding and that the height of the OH maser ring is determined by the length traveled by a cloud within its dissipation timescale. Dissipated clouds could also naturally explain the required density of the ionised gas within the free-free absorbing bicones. Parra is presently working to see if a similar model can be applied to explain the OH megamaser emission in other megamaser sources such as Arp 220.
Figure 23: **Left:** Model of explaining OH megamaser and continuum emission in IIIZw35 (from Parra et al. 2005 [250]). The OH masing clouds are assumed to be concentrated within the dark grey ring of radius 22pc and most of the continuum comes from the surrounding light grey ring. The medium grey bicones indicate where free-free absorption is occurring. **Right:** Detail of the dimensions of the OH ring indicating the rotational velocity of clouds around the ring ($v_r$) and outflow velocity from the ring midplane ($v_z$).

### 5.3.10 Line radiation Propagation in a Clumpy Medium

Conway, Elitzur and Parra [180] investigated the question of line radiation propagation in a clumpy medium. It was shown that no matter how complex the distribution of cloud opacities and velocity profiles a simple relation holds between the mean cloud properties and the emerging spectrum. Applying this formalism to the question of the observed $^{12}$CO to $^{13}$CO line ratio in extragalactic sources it was shown that if individual clouds are narrow in velocity width compared to the velocity distribution it is in principle impossible to distinguish the effects of clumping from a change in the intrinsic $^{12}$CO to $^{13}$CO ratio. The formalism is being further developed (Conway et al. 2006, in prep.) for calculating cloud opacity effects on the relationship between CO observations and molecular hydrogen column densities (the so-called 'X' factor).

### 5.3.11 Odin searches for H$_2$O in galaxies

Odin has spent a considerable amount of time searching for H$_2$O in carefully selected candidate galaxies, including the Large and Small Magellanic Clouds, but so far unsuccessfully, except for a simultaneous detection of CO ($J = 5 - 4$) in LMC. However, the H$_2$O abundance limits now being achieved are low enough to be scientifically “meaningful” and hence motivate a search paper. Preliminary results were presented in an invited talk by C.D. Wilson at the recent IAU Symposium No. 231 in Asilomar, CA. Onsala collaborators are our Odin research student Carina Persson (who has reduced most of the galaxy search data), Roy Booth, John Black, Lars E.B. Johansson, Michael Olberg and Åke Hjalmarson.
5.3.12 Searching for $O_2$ in the SMC with Odin: Constraints on oxygen chemistry at low metallicities

The negative result of long-lasting Odin observations towards the Small Magellanic Cloud (SMC) – where the atomic O abundance is only 16% of that in Orion – has been published by C.D. Wilson et al. [304]. The rather demanding data reduction was done by Henrik Olofsson during an extended stay at McMaster University in Canada. Although a factor of 20 above Odin’s $O_2$ limits in galactic molecular clouds, our SMC limit has interesting implications for our understanding of oxygen chemistry at sub-solar metallicities. Effects of photodissociation on the molecular cloud structure, or freeze-out of molecules on dust grains, may explain the observed $O_2$ abundance limit. Onsala collaborators were Henrik Olofsson, Roy Booth, Åke Hjalmarson and Michael Olberg.

5.3.13 The Odin spectral scan search for primordial molecules

During summer 2004 we engaged Odin in a pioneering spectral scan search for primordial molecules (such as LiH, LiH$^+$, HeH$^+$, HD, HD$^+$, H$_2$, H$_2^+$) at unknown red-shifts (in the range $z = 10 − 1000$) – aiming at a detection of structure formation during the “dark ages” of the expanding Universe (about 300,000 to 300,000,000 years after Big Bang). Although Odin’s search sensitivity admittedly is very limited (and the results so far are negative), these “pilot” observations allow us to test observing and data reduction methods and pattern recognition tools in preparation for the much more sensitive searches to be performed by Herschel Space Observatory. This search was initiated and scientifically motivated by Pierre Encrenaz, Observatoire de Paris, and his collaborators in France and Italy (see Maoli et al. 2004; astro-ph/0411641). The project was presented on a poster by Persson, Encrenaz et al. at the recent IAU Symposium No. 231 in Asilomar, CA. Onsala collaborators are our Odin research student Carina Persson (who has reduced all the data), Åke Hjalmarson, Michael Olberg, and Gustaf Rydbeck.

5.3.14 The Sunyaev-Zeldovich effect

The Sunyaev-Zeldovich (SZ) effect is a promising method to probe the distant universe. The effect is due to the inverse Compton scattering of photons from the cosmic microwave background off hot electrons in clusters of galaxies. It has a characteristic spectral signature, with a decrement at frequencies less than 218 GHz. APEX will be used to search for clusters of galaxies through their SZ signature. C. Horellou has joined the German-led APEX-SZ collaboration (principal investigator: Prof. Frank Bertoldi in Bonn). The APEX-SZ survey will be carried out using a 330-element bolometer camera built in Berkeley. It is expected to lead to the discovery of about 1000 clusters of galaxies, which will help constrain the cosmological parameters. Horellou together with three master’s students (Nord, Johansson and Lévy) has published a paper discussing the possibility of constraining the redshift dependance of the temperature of the cosmic microwave background using multifrequency SZ observations.

5.3.15 Dark energy

In the now generally accepted cosmological model, the universe’s expansion is currently accelerating, driven by a mysterious component with positive energy density and negative pressure. The effect of dark energy is observed on very large scales. C. Horellou and collaborators
Figure 24: Wavelet decomposition of high-frequent polar motion variations derived from the two weeks of VLBI data from October 2002. The gray scale indicates the level of wavelet energy (white – low, black – high). Besides well known variations with periods of 24 and 12 hours, also a periodicity of 8 hr is visible both in pro- and retrograde polar motion.

have shown that dark energy has an effect on the kinematics of very nearby galaxies, just outside our Local Group. The velocity dispersion of nearby galaxies around the Hubble flow has been known for some time to be very low. Only N-body numerical simulations with a dark energy component can reproduce the observed dynamical coldness. C. Horellou and master’s student J. Bergé have published a paper in which they have investigated the effect of dark energy on the cosmological evolution of spherical overdensities. They have considered both models with a cosmological constant and quintessence models, in which the equation of state parameter of the dark energy, \( w = p/\rho \) is different from \(-1\). This paper corrects a mistake in the literature, where an expression of the ratio of the turn-around to virialized radius, strictly valid only for the cosmological constant case, had been used for other dark energy models.

6 Space Geodesy and Geodynamics

6.1 Space Geodesy

6.1.1 Geodynamics, Sub-diurnal Earth rotation variations

We have analysed Very-Long-Baseline Interferometry (VLBI) data from the CONT02 campaign for sub-diurnal Earth rotation variations. Different signal analysis strategies were applied, including Lomb periodogram, wavelet analysis, fourier analysis, and amplitude spectra estimation. The extended version of the theoretical model for ocean tidal influences on the Earth rotation by Ray et al. (Science, 1994) proved to explain the detected sub-diurnal variations in polar motion to about 40–60% and in UT1 to about 80%. The remaining signal after subtracting the theoretical model predictions reveal a ter-diurnal signal in polar motion close to the \( S_3 \) tide (see Figure 24). Comparison to theoretical models for ter-diurnal variations in polar motion show that the detected signal most probably is of atmospheric origin. Preliminary results are published by Haas et al. (2004) [43].

6.1.2 Crustal motion in Fennoscandia

The BIFROST project (“Baseline Inferences for Fennoscandian Rebound Observations, Sea level and Tectonics”) is an international collaboration for observation of the deformation of the
earth crust in Fennoscandia and exploration of the physical causes and consequences. We use continuous observations of Global Navigation Satellite Systems (GNSS), predominantly GPS, in networks of special, stable antenna stations that extend throughout the Fennoscandian region and into neighbouring areas. The most prominent phenomenon that can be observed is the slow adjustment of the earth from heavily loaded conditions during the Pleistocene glaciation to the present interglacial conditions, when the ice load has been transformed into a sea water load. The rebound rates are controlled by solid earth parameters, in particular the elasticity and viscosity structure of the crust and the mantle, so our space geodetic measurements are used for the refinement of glacial isostatic rebound models. The satellite technique affords us truly three-dimensional geodetic positions with respect to a global reference frame. The system has been operating since 1993; thus multi-year time series are used to infer crustal motion in the vertical and horizontal directions. By comparison with relative land uplift from tide gauges, the motion of the regional sea surface can be monitored in the geocentric reference frame. Thus freed from the influence of ground deformation our results reveal a regional sea level change between 1 and 1.5 mm/yr.

In the context of the BIFROST project a mantle viscosity model inversion based on three-dimensional displacement rates from GPS data was published [87].

A new three-dimensional velocity field for the Fennoscandian land uplift area has been presented [73]. It is derived from more than 3000 days of continuous observations at 53 permanent GPS stations. The results show a maximum vertical rate of 10.6 mm/yr at Umeå, which is a slightly more southern location than the land uplift maximum estimated from shoreline studies. From internal and external accuracy assessments, the rate uncertainty for stations with the longest observation records is estimated at the level of 0.2 mm/yr in horizontal components and 0.5 mm/yr in the vertical component (1-sigma uncertainty). Comparison to a currently accepted model of the Fennoscandian glacial isostatic adjustment shows an agreement at the level of 0.2 mm/yr for the horizontal components in southern Sweden, while the differences are larger in the north (see Figure 25).

A thorough investigation of the GPS baselines in the BIFROST network has gained new insight to the horizontal components of the Fennoscandian glacial isostatic adjustment. The study included an assessment of baseline component independence which resulted in a scaling of the formal uncertainties with a factor no more than 1.5. Also, the horizontal components proved to constrain the modelled upper mantle viscosity without the yielding to lithospheric thickness that has affected studies of vertical rates (Bergstand et al. [165]).

6.1.3 Absolute gravity

Absolute gravity on the gravity platform at Onsala was measured by three different groups during Sep.–Oct. 2004: Institut für Erdmessung, University of Hannover (IfE), Norwegian University for Life Sciences at Ås, (UMB), and the Finnish Geodetic Institute at Masala. In addition the Hannover group performed a quick local measurement before the fence and gate construction work in spring 2004. The mass of the dam raised to support the gate and fence is sufficient to affect gravity at the level of measurement repeatability, near 10 nm/s². In October 2005 the site was visited again by two teams, IfE and UMB. We acknowledge the request by the teams to carry out simultaneous observations. They utilise the maser-controlled time signal and perform oscillator phase calibrations thanks to OSO’s support.
Figure 25: Horizontal movements in Fennoscandia. The **left** map shows the recent solution (grey arrows with 95% confidence ellipses), the previous solution (just grey arrows), and predictions based on the glacial isostatic rebound model of Milne et al. (Science, 2001) (black arrows). The map to the **right** shows the difference between the model and the new solution, indicating systematics which probably require an iteration of the earth viscosity model. In the north the differences might also be influenced by the Barents ice load, the history of which is not as well constrained in the model as that of the Fennoscandian ice sheet.
6.1.4 Air pressure loading

We have contributed to a comprehensive investigation on the impact of atmospheric loading on Satellite Laser Ranging (SLR) measurements (Bock et al. [171]). A finding with important operative consequences was, that meteorological services have been and probably will continue to change the grids in which the computations are represented. At times of grid change, the computed atmospheric pressure is changed even at a global scale to the extent that the long-term stability of geodetic reference systems is affected. This implies that long-term vertical motion may be biased, either by atmospheric loading effects or by erroneous corrections. An impasse is indicated using stable long-term barometer records at each site in order to estimate the long-term loading effects. A comment along these lines was also published in the IVS Newsletter No. 9, 2004.

6.2 Atmospheric Applications of Space Geodesy

6.2.1 The total electron content (TEC) in the ionosphere

During 2004 we developed a spherical harmonic approach to determine global TEC maps from geodetic VLBI observations. This approach was applied successfully to the CONT02 data and first results were presented by Bergstrand and Haas [16]. The agreement with similar TEC maps derived from the global GPS network is of the order of a couple of ten TEC units.

In an investigation of the ionospheric influence on satellite positioning, we found that a change from the current model by Klobuchar to the NeQuick model proposed for the coming European Galileo satellite navigation system can reduce the uncertainties by as much as 60% on single frequency receivers [164].

6.2.2 Ground-based GPS data applied to weather forecasting

At the European level COST Action 716 has dealt with the assessment of the operational potential of a ground-based network of GPS receivers to provide near real time observations for Numerical Weather Prediction (NWP) and climate applications. The action succeeded in developing and demonstrating a prototype system with a data exploitation scheme for NWP and climate applications. At the end of the action more than 400 GPS stations delivered time series of the atmospheric water vapour content (see Figure 26). Our contributions to this work was to lead the action and to run one of the data processing centres (NKGS). At the national level an operational system was developed by us in collaboration with the National Land Survey and the Swedish Meteorological and Hydrological Institute (SMHI), to make water vapour measurements in near real time using the Swedish ground-based GPS network SWEPOS. These data are unique and their impact on the quality of weather forecasts will be evaluated by SMHI [27]). The Final Report of the COST action was published in 2005 (Elgered et al. [186]) and an operational component of ground-based GPS data in weather forecasting will now be implemented through a EUMETNET project which started in 2005.

6.2.3 GPS estimation errors: spatial and temporal correlation structure

The atmospheric delay data estimated using GPS provide information about the water vapor content in the lower atmosphere, which is of great interest to the weather forecasting com-
Figure 26: GPS stations in Europe providing data in near real-time for COST Action 716. The NKGS data processing centre, operated by the Space Geodesy group at the Onsala Space Observatory, handles all data from Sweden and Denmark (easily identified in the original colour figure in [186]). For more details about the different GPS processing centres see: http://www.oso.chalmers.se/geo/cost716.html/COST716_FR_Oct27.pdf.
Figure 27: The result of two simulations, one using GPS only and one using GPS and Galileo data. Shown are the simulated and retrieved profiles at 9:00 UT (left) and 13:00 UT (right).

6.2.4 Ground-based GPS water vapor tomography

Using GPS data from a local dense network of GPS receivers and tomographic methods it is possible to resolve the 3D distribution of the atmospheric water vapor. This method normally requires that the propagation delays of the GPS signals between each satellite and each GPS receiver caused by water vapor, are accurately estimated from the GPS data. Since this in general is difficult we have developed a new method which estimates the 3D structure of the wet refractivity field directly from the GPS phase observations. It has been tested through simulations [91]. Figure 27 shows the results of two simulations. Both simulations used the local GPS network in Göteborg consisting of eight receivers in an area of $\sim 10 \, \text{km} \times 10 \, \text{km}$. One simulation used GPS data only, while the other also included data from the future European satellite navigation system Galileo. The simulated profile (same in both cases) had an inversion occurring between 6:00 and 18:00 UT, reaching its maximum at noon. We have also started testing our new method using real GPS data acquired in France, and the results so far have been promising.

6.2.5 GPS meteorology in the tropical climate

A collaboration was initiated in 2004 with the Khon Kaen University in Thailand. Our initial work has been to use 14 existing IGS (International GPS Service) tracking stations for meteorological applications. They form a regional network that covers the area approximately between $20^\circ$S and $20^\circ$N in latitude, $70^\circ$E and $170^\circ$E in longitude. Initial results from com-
parisons of inferred linear trends in the water vapour content using GPS, radiosondes, and numerical weather models give correlation coefficients above 0.9 using up to seven years of data.

6.3 GPS System Research

Many of the applications of GPS in our research calls for high stability over long term. This is true for accurate estimation of small crustal motions as well as climate monitoring in terms of detecting trends in the integrated amount of atmospheric water vapour. Error sources related to the receiving stations in the SWEPOS network needs to be calibrated for. The validity of the calibration needs to be investigated to perform the best possible calibration. In a fist approach the variations in the estimated parameters in GPS is investigated as a function of cut-off elevation angle. Preprocessing of GPS data from the SWEPOS stations for different cut-off elevation angles has been performed for 5 years of data. The inferred linear trends of the height coordinate for the GPS sites are shown in Figure 28. These results show that there are site dependent error sources which affect on the positioning depending on the cut-off elevation angle. Due to the shifting pattern of the trends a calibration model for each individual site needs to be produced rather than a general calibration model that can be applied to all the sites.

7 Global Environmental Measurements

The Global environmental measurement group works mainly on analysis of data from satellites, in particular the Odin satellite launched in 2001. We are the main processing centre for the production of geophysical data from the sub-mm radiometer (SMR) instrument. The group consists of four senior scientists: Prof. Donal Murtagh, Ass Prof. Patrick Eriksson, Dr. Peter Forkman and Guest scientist Jo Urban (since August 2004) as well as five PhD students; Samuel Brohede, Mattias Ekström, Ashley Jones, Bengt Rydberg and John Rösevall.
7.1 Odin

Work has continued on the production of level 2 geophysical products. Based on our experience of the first official version (version 1.2, see Urban et al. [139]) and the validation work performed, we have begun a complete reprocessing to greatly improve the quality of the product. The new version is partially based on development work carried out at the Observatoire de Bordeaux, but uses the ARTS forward model and the QSMR inversion tools, and also uses the improved calibration scheme developed in collaboration with Michael Olberg at Onsala.

7.1.1 Assimilation and ozone loss

Odin data are now being used to assess ozone loss during both the four Arctic and five Antarctic winter/spring period that have so far been covered by the extended Odin mission.

Ozone loss is computed in two ways: Urban et al. [140] have used time series of vortex averaged concentrations of ozone mapped onto N$_2$O isopleths to determine the chemical loss. Rösevall and Murtagh have used a data assimilation model to perform similar studies. The specially developed DIAMOND model uses a highly mass conserving advection scheme to transport ozone and N$_2$O on isentropic surfaces while continually assimilating new measurements using an optimally interpolating Kalman filter. By running the model with and without assimilation for the period when chemical ozone loss can be expected it is possible to deduce the loss as the difference between the passively advected ozone field and the field were observed ozone values have been assimilated. This is illustrated in Fig. 29. For late August 2003 it is clear that most of the loss is still confined to the edge of the polar vortex.

7.1.2 Validation studies

An extremely important part of making global satellite measurements that may be used many years later to assess trends is that they are placed on a firm comparison platform. Thus it is necessary to compare measurements with a new instrument to those made by in-situ and independent remote techniques. Ashley Jones has been comparing Odin results with data from in-situ ozone sondes and from the new MIPAS instrument on Envisat launched in 2002. Comparisons between processing versions of the Odin data are also essential in order to understand the effects of new parameters in the inversion procedures.

7.2 Satellite sounding of the upper troposphere

The impact on the global climate of steadily increasing levels of greenhouse gases depends strongly on various feedback mechanisms. The response of water vapour and clouds in the upper troposphere is of particular concern, largely as present measurement systems have poor performance in this altitude region. Observations in the microwave region are maybe the most interesting choice to improve this situation. The work described here is mainly performed by PhD students Mattias Ekström and Bengt Rydberg, with Patrick Eriksson as main advisor.

7.2.1 Radiative transfer simulations

The first tool for rigorous simulations of microwave limb sounding measurements involving scattering has been developed, in collaboration with Bremen and Edinburgh universities. This development was needed for investigations of future satellite systems and to make use of the
Figure 29: The upper left panel shows the ozone field on the 475 K isentropic surface with data assimilation, while the upper right panel shows the same field where the same initial ozone field from 1 Aug. 2003 has merely been advected by the analysed wind field obtained from the European Centre for Medium range Weather Forecasts (ECMWF). The lower left panel shows the difference between the fields and thus the ozone loss.

full potential of Odin-SMR data. A first version of this software has been applied to perform improved investigations of radiative forcing effects for clear sky condition.

7.2.2 Future satellites

The group coordinates the activities to design and finance a successor to Odin. This proposal is denoted as STEAM and focuses on measurements of the upper troposphere and the lower stratosphere. Most recently was STEAM included as part of a larger satellite, as a response to ESA’s last call for mission ideas. The GEM group is also involved in several other ESA mission proposals, with a sub-mm ice cloud sensor (CIWSIR) as most the important example. This work has largely been performed inside studies issued by ESA, with involvement in six studies during 2004–2005.

7.2.3 Odin-SMR results

During 2005 retrievals of water vapour and cloud ice amounts in the tropical UT region, based on Odin-SMR spectra, were started. This work was initiated by the development of the new simulation tool mentioned above, and first results have already been presented. Obtained water vapour results complement existing data sets, often restricted to clear-sky conditions, and offers an independent view on the mean humidity in the upper troposphere. Retrieved fields of cloud ice indicate significant limitations in the handling of ice clouds in climate models.
7.3 Ground-based measurements

Background
A ground-based measurement site to measure a number of minor constituents in the upper atmosphere that give direct information on the local part of the global circulation pattern, which at our latitudes means the ascending (summer) and descending (winter) branches of the large scale pole to pole motion in the mesosphere, is operated at Onsala Space Observatory. Both microwave spectrometry and optical spectrometry are employed.

Two microwave radiometers have been built and are used to measure CO at 115 GHz and H$_2$O at 22 GHz. Since mesospheric CO has its source in the thermosphere the concentration as a function of altitude clearly delineate the vertical motion particularly in the downward direction (see Fig. 30). The same/reverse is the case for water vapour that has its main source in the lower atmosphere. An IR Michaelson interferometer has been used to record the intensity of the hydroxyl nightglow layer in the 4–1 and 3–2 vibrational Meinel bands in order to obtain the temperature of the region from the rotational distribution. The combination of temperature and vertical motion information allows us to distinguish the radiative heating/cooling from the dynamical effect.

Main results
The radio measurements have now reached the maturity where they can be operated on a nearly daily basis. During the latest years the radio results have been carefully analyzed and several papers have been published. Main results are the high variability of the CO and the need to tune the gravity wave parameterisation in the Whole Atmosphere Community Climate Model, WACCM, to better agree with the measurements.

The measurements have also been used to, for the first time, directly observe the vertical motion of the global circulation in the polar mesosphere and to relate this to the heating and cooling processes.

In 2004, the group started a collaboration with the Institute of Radio Astronomy, National Academy of Sciences of Ukraine to share expertise about simple frontend solutions and receiver system and inversion method know-how. Within this collaboration a new uncooled double sideband Shottky mixer frontend, with radio frequency 110–116 GHz and receiver temperature < 300 K, was delivered to the Onsala group in 2005, for simultaneous measurements of CO at 115 GHz and O$_3$ at 111 GHz.

The group has designed, manufactured and delivered copies of its 22 GHz corrugated horn to the radio-aeronomy groups in Bern, Bordeaux and Bremen.

8 Radar Remote Sensing

During 2004 and 2005, the main activity of the radar remote sensing group at Chalmers has been work on the retrieval of forest parameters from SAR (synthetic aperture radar) images from both aircraft and satellite platforms.

8.1 P-band SAR

A study of land applications for a possible P-band SAR (synthetic aperture radar) satellite utilising the recent frequency allocation around 435 MHz was completed in 2004. The study “Applications of Low-Frequency SAR” (http://www.rss.chalmers.se/rsg/Research/Projects/ALFS/)
investigated the usefulness of SAR data for forest biomass and soil moisture retrieval – accounting for the performance limitations due primarily to ionospheric distortion [49, 50, 51]. The main conclusions from this work are that while spaceborne P-band SAR shows larger sensitivity to forest biomass than any existing satellite systems, there are still developments required in retrieval algorithms before the accuracy required for biomass measurements in global models can be achieved [120].

During ALFS it was noted that there is a lack of high-quality data in the UHF-band for testing retrieval of biomass, so during October 2004 Chalmers participated in a major flight campaign to collect relevant data over the Remningstorp forest test-site in southern Sweden. The SAR data collection was performed as part of a bilateral cooperation using the airborne SAR systems LORA and CARABAS run by the Swedish Defence Research Agency (FOI) and RAMSES operated by their French counterpart ONERA. The main aim was to test the hypothesis that the retrieval of biomass from P-band SAR data can be improved by combining SAR data with other information (e.g. optical remote sensing data) on tree species and canopy closure. As part of this flight campaign, 12 corner reflectors were deployed at the Remningstorp test site for calibration purposes. Four large dihedrals (see Fig. 31) were built at Chalmers during August and September 2004, and four large trihedrals and four small dihedrals were borrowed from the Technical University of Denmark.

Figure 30: Volume-mixing ratios of CO as a function of time and altitude. The middle atmospheric dynamical cycle is clearly seen in the figure with up-welling air in the spring and down-welling air in the autumn.
8.2 VHF-band SAR

The group is also continuing development of algorithms for retrieving forest stem volume at stand level, and for individual trees, using data from the CARABAS VHF-band SAR. Figure 32 (left) shows an example of a processed CARABAS image illustrating the detection of individual trees, while Fig. 32 (right) shows clearly the relationship between the measured backscatter and the tree size [49, 210, 211]. These results are shown for trees standing on relatively flat ground. On sloping terrain the problem is more complex [36, 280], and we have continued work on developing routines for model-based corrections to retrieval algorithms based on automatically delineated segments in the SAR images [35, 194, 195].

Additionally, through collaboration with Ericsson Microwave Systems, work has been started on the development of algorithms for including auto-focussing with the fast-factorised backprojection algorithm for processing of SAR data. The primary aim of this work is to further improve the quality of CARABAS images.

8.3 Mapping of wind thrown forest

On the night of the 8th of January 2005, storm-force winds hit the south of Sweden. The storm, named Gudrun, caused extensive damage to property, and in particular an estimated 3 billion Euro loss to the local timber industry due to wind-throw of trees over large areas. Following natural disasters of this magnitude there is an urgent need for large-scale mapping, in order to estimate the extent of the damage, and to plan for clean-up operations. Conventional photography from aircrafts or satellites provide one means of obtaining this overview for large areas – but is particularly difficult in winter at northern latitudes. This is due to the joint problems of few hours of daylight, high risk for cloud cover, and long shadows in the photos when the sun is low is the sky. An alternative method is to use radar for mapping, which can operate in all weather conditions, and during both day and night.

Satellite SAR images were acquired through the “International Charter Space and Major
Disasters” to test the possibility of mapping the wind thrown areas through change detection (comparing images before and after the storms). Images from ERS-2, ENVISAT and RADARSAT-1 were evaluated, however the felling of trees gave no detectable change in backscatter intensity. The most promising results were obtained using the highest resolution mode of RADARSAT-1 (9 m), where some areas could be identified through changes in image texture (primarily shadows at forest edges) [294, 295].

Much better results were obtained using the CARABAS airborne system operated by FOI. Images acquired after Gudrun showed significant changes in image properties, as indicated in Fig. 33. When the trunks fall parallel to the aircraft flight direction, the trunks give a very high backscatter in the images (since CARABAS using horizontal polarisation), and the high resolution also means that the fallen trunks appear as elongated objects (compared to the point-like response from standing trees). This unique signature of wind-thrown forest can be detected even if images are available only from after the storm, and algorithms have been developed for automatically mapping of the wind-thrown areas. Compared to aerial photograph and satellite images the main advantage of CARABAS is the ability to map areas where the fallen trunks are hidden by the foliage of standing trees (i.e. areas where not all tree have been felled) [294, 295].

8.4 Preparations for future satellite missions

The work for 2004 and 2005 also included preparation for calibration and validation activities for PALSAR (Phased Array type L-band SAR) on the Japanese satellite ALOS (Advanced Land Observation Satellite) planned for launch in December 2005. Using archived data from ALOS’ predecessor JERS (Japanese Earth Resources Satellite) the possibility to map changes in forest cover (such as clear-cutting) as well as biomass is being investigated. This work
Figure 33: CARABAS SAR images from before (left) and after (right) the storm Gudrun felled many trees. The upper and lower ellipses mark areas where most of the trees were felled, whereas the central ellipse was untouched by the storm. Note the clear signature of elongated, bright objects from the fallen trunks. The bright line running diagonally across the image is a metallic fence, which was crushed by falling trees and hence disappears from the images in the areas with wind-thrown trees.

is supported by the Swedish National Space Board (SNSB) in the project “Forest Parameter Retrieval with ALOS: Algorithm Development for Kyoto and Carbon Initiative”. An example of a change detection map from Remningstorp is shown in Fig. 34. Results from test areas in Siberia have also been presented at several conferences [32, 33, 113, 114, 190, 191]. The project tasks also include major modifications of four large trihedrals that have been used for calibration of CARABAS images. These modifications are needed to make it possible to use the reflectors for the calibration of ALOS images. The modifications are being performed at FOI in Linköping.

Figure 34: A comparison between the backscatter levels in two JERS satellite images make it possible to produce a map of areas where large changes in the forest cover occurred during the five year period between the image acquisitions.

During 2005 efforts have also been made to expand the activities in the Radar Remote Sensing group to include research on sea ice again. This is a field with long tradition in
the group, but since 2001 there have been no new projects. In August 2005 a meeting with representatives from the Swedish Meteorological and Hydrological Institute (SMHI) and the Swedish Maritime Administration was held at Chalmers. A decision was taken that Chalmers and SMHI will start a project to improve classification of ice types, determination of ice concentration and detection of ice ridges in the Gulf of Bothnia with the help of images from several new SAR satellites. In addition to the above mentioned ALOS satellite, Germany will launch the TerraSAR-X satellite and Canada Radarsat-2, both in 2006. This will give access to data with multiple polarisations and from three different frequencies. We hope to get the project accepted as an activity within the International Polar Year 2007–2008.

9 Optical Remote Sensing

The optical remote sensing group is working with development and application of ground-based optical remote sensing methods for atmospheric measurements. In specific we are focusing on tailoring instruments and measurement strategies to address specific measurement problems related to environmental research and monitoring needs. The work is very international and field oriented, and spans a large variety of disciplines covering: volcanic gas measurements, industrial hydrocarbon emissions, atmospheric chemistry in Mega cities in developing countries, emissions of climate gases from different ecosystems, emission from ship and aircraft, methane emissions from landfills, stratospheric ozone depletion and satellite validation.

9.1 Volcanic gas measurements

Since five years we are strongly involved in developing methods to quantify gas emission from active volcanoes. The rationale for this is to improve the possibility to predict eruptions, and to quantify the contributions of various gases to the global atmosphere. During 2004–2005 we have worked intensively in the EU-project DORSIVA (Development of Optical Remote Sensing Instruments for Volcanic Applications). This is an EU-project coordinated by our group, in which several novel optical techniques for monitoring of volcanic gas emissions have been developed and tested in field campaigns in Italy, Spain, Mexico, D.R. Congo, and El Salvador. Based on the successful developments in DORSIVA a new EU-project NOVAC (Network for Observation of Volcanic and Atmospheric Change) was initiated in 2005. This project aims at establishing a network of instruments for gas measurements on 15 of the most active volcanoes in the world, including volcanoes on Reunion Island, Africa, Europe, Mexico and Central America. In addition to measure volcanic gas emissions, the instruments will also provide information on concentrations of stratospheric and tropospheric gas concentration, of relevance for research related to stratospheric ozone depletion and climate change.

9.2 Industrial hydrocarbon emissions

Emission of hydrocarbons from various industrial activities as well as from storage and shipping, constitutes an important environmental problem. As these emissions are fugitive, and emanates from a large number of leaks and spills their quantification is a complicated task. We have developed a method for quantification of hydrocarbon emissions based on IR Solar Occultation. During 2004–2005 this method has been intensively developed and tested in
a project together with the oil refineries in the Gothenburg area, as well as Gothenburg Oil Harbor. This successful work was in September presented in a Licentiate thesis, and it is anticipated that the technique will during 2006 be used by the industries as an operative method to routinely monitor the hydrocarbon emissions from their activities.

9.3 Urban air monitoring in Megacities in Developing countries

Optical remote sensing offers a number of advantages and interesting measurement strategies for studies and monitoring of air pollution in megacities. During recent years the development of spectroscopic instrumentation, computers and evaluation algorithms have undergone a dramatic development. This in combination with innovative measurement strategies, to some extent developed by our group, has paved the way for an exploitation of these techniques for cost-effective studies of air pollution in megacities. During 2004–2005 we have worked with development and implementation of these techniques, including techniques to obtain emission data from large scale sources and to make 3-dimensional mapping of pollutants. In combination with atmospheric chemistry models these data will increase our understanding of the origin of the air pollution, and thus help finding cost-effective mitigation actions. The data will also facilitate the evaluation of the effects of taken actions. The work is done in close cooperation with local authorities in Beijing and China, and during the period three field-campaigns have been conducted in Beijing, among other results involving a quantification of total emissions of \( \text{SO}_2 \) and \( \text{NO}_2 \) from the city.

9.4 Methane emissions from landfills

Methane is an important climate gas and one of its major sources is biogenic degradation of organic matter in landfills. To quantify these emissions is a measurement technique challenge, due to the large spatial variability over the landfill area. We have developed a measurement method, based on a combination of long path FTIR (Fourier Transform InfraRed) spectroscopy and trace gas release, the time correlation tracer method. During 2004–2005 this method has been applied in a large scale measurement campaign quantifying the methane emissions from 8 landfills distributed all over Sweden, covering also seasonal variations.

9.5 Emissions from ship

A special measurement strategy using Solar occultation spectroscopy has been developed for quantifying real emissions from ship and aircraft. During 2004–2005 the method has been tested in several field-campaigns in and outside Gothenburg harbour. Based on these results a new project will be started in beginning of 2006 aiming at developing an operative method to identify “gross-polluters” from an airborne platform, as well as to provide an instrument that can automatically check the emission from various ship in for example a harbor.

9.6 Stratospheric ozone depletion and satellite validation

Since 1994 we are operating a high resolution FTIR for Solar spectroscopy at Harestua in southern Norway. The instrument is part of NDSC (Network for the detection of Stratospheric Change), and its main purpose has been to study the composition of the stratosphere in relation to chemically induced stratospheric ozone loss, as well as satellite validation and validation
of Global Chemical Transport Models. During the last 2 years increasing emphasis have been given on using the spectral database also to derive tropospheric molecules, primarily those related to climate change research, as well as satellite validation exercises.

### 9.7 Field Campaigns

Field campaigns are an important part of the groups activity. The following field campaigns were carried out during 2004–2005:

- DORSIVA measurement strategy validation campaign, Andorra, Spain, 26 April – 9 May 2004.
- Studies of gas emission from Popocatepetl volcano using optical remote sensing, Mexico, 27 Jan. – 6 Feb., 2005.
- Studies of air pollution in Beijing using novel optical techniques, Beijing, China, 4–22 April, 2005.
- IAVCEI (International Association of Volcanology and Chemistry of the Earth’s Interior) field workshop on measurements of volcanic gases, Sicily, Italy, 2–8 May, 2005.
- Studies of air pollution in Beijing using novel optical techniques, Beijing, China, August, 2005.
- Studies of gas emission from Colima volcano using optical remote sensing, Colima, Mexico, July, 2005.

### 10 Nonlinear Electrodynamics

(Activities during 2004–2005 are reported here, but note that the group belonged to another department in 2004.)

The basic research activity of the Nonlinear Electrodynamics (NLE) group is directed towards three different research areas: the physics of burning fusion plasmas, nonlinear optics, and microwave breakdown phenomena. There is a common denominator and a strong
correlation between these three areas – all involve electromagnetic field theory, plasma and plasma-like phenomena, and similar nonlinear wave phenomena. This situation has resulted in a number of synergetic effects where results, experience, and approaches from one field have been applied to another field.

10.1 Fusion Plasma Physics

The research activity is strongly integrated in the EURATOM Fusion Research Programme and the work is carried out in close collaboration with Culham Science Centre (England), CAEA Cadarache (France), MIT in Boston (USA) and the University of Texas in Austin (USA). The group is contributing to the R&D work for JET EFDA and ITER on different tasks. The research programme is devoted to the physics of burning fusion plasmas in tokamaks with particular emphasis given to the investigation of: (i) fast particle collective effects in fusion plasmas, (ii) electron runaway in tokamaks, and (iii) edge plasma transport phenomena in tokamaks. During 2004–05, the main objectives and results obtained within the different fields of activity in the physics of burning fusion plasma have been as follows:

10.1.1 Collective fast ion effects

One of the main objectives of tokamak devices such as JET and the planned ITER project is the study of alpha particle production, confinement and consequent alpha particle heating of D-T plasmas. Since the energetic alpha particle population in an ignited D-T plasma will contribute a considerable part of the total plasma pressure (typically 10–20%), the alphas can be expected to have a substantial impact on achieving and maintaining high temperatures, thus modifying the beta limits and energy confinement times of tokamak reactors. Furthermore, the alpha particle population itself may have considerable impact on plasma stability, possibly affecting the alpha thermalization as well as the transport of high-energy alphas and thermal ions. From a practical point of view, both the confinement capability, wall loading, and fusion power density of a tokamak may be affected by the presence of the alpha particles. The confinement properties of energetic alpha particles are of fundamental importance for alpha heating, burn control, and alpha particle diagnostics. The next generation of tokamaks will produce a large amount of thermonuclear alpha particles, which may excite wave instabilities. The basic reason for these instabilities is the deviation of the alpha distribution function from thermodynamic equilibrium, and the instability drive may thus be spatial as well as velocity space gradients, trapped as well as passing particles.

Experimental studies of instabilities and confinement of energetic particles on JET and MAST

In preparation for the next burning plasma devices such as ITER, experimental studies of instabilities and confinement of energetic ions were performed at JET and MAST, where the NLE group has been represented through Patrik Sandquist (PhD student). In particular it was found that the stabilizing effect of fast particles on the “monster” sawtooth instability disappears in low-density plasmas with high power ion cyclotron resonance frequency heating. This topic is currently being studied by the group.
Compressional Alfvén eigenmodes in spherical tori
Edge-localized compressional Alfvén eigenmodes (CAE) are currently considered as the main candidate to explain the experimentally observed emission in the ion cyclotron frequency range in the National Spherical Torus experiments (NSTX). CAE can be destabilized by resonant interaction with a subpopulation of energetic ions from neutral beam injection (NBI) or from ion cyclotron resonance heating (ICRH) having anisotropic distributions in velocity space near the outer edge of the plasma. Localized modes are important not only to explain the observed emission, but also because these modes might open a possibility for transferring energy from the fusion products directly to the background ions. The NLE group has performed such an analysis by using a variational approach to study the radial and poloidal structure of the CAE. The theoretical calculations predict that the measured mode activity is well localized to the outboard mid-plane with a frequency close to the experimentally observed value. The existence of localized solutions is affected by the sign of the Hall term, which depends on the radial derivative of the magnetic field and the density profile.

Investigation of nonlinear dynamics of fast ion driven modes near the instability threshold
One of the most important problems in the theory of fast ion driven instabilities is the understanding of the wave saturation mechanism and its implications on the confinement of the fast ions. The existing theory, developed by H. Berk and B. Breizman, is one-dimensional and describes only the excitation of a single coherent wave. The group has develop a theory describing the nonlinear dynamics of a system of two coherent linearly unstable waves as well as a theory taking into account the influence of partial wave incoherence.

Nonlinearly driven second harmonics of Alfvén Cascades
In recent fusion experiments on Alcator C-Mod at MIT, measurements of density fluctuations with Phase Contrast Imaging through the plasma core showed a second harmonic of the basic Alfvén Cascade (AC) signal. In collaboration with Dr. B. Breizman at the University of Texas at Austin, the NLE group has developed a theory describing the generation of the second harmonic as a nonlinear sideband produced by the AC eigenmode via quadratic terms in the MHD equations.

Slowing down dynamics of fast particles in plasmas via the Fokker-Planck equation
The collisional slowing down of a beam of high energy charged particles in a background plasma is a problem of fundamental importance with applications ranging from fusion plasmas to astrophysical plasmas. In fusion plasmas, examples of such high energy beams are abundant: fusion generated alpha particles, neutral beam injected particles, ICRF heated particles and runaway electrons. An investigation has been made of the dynamical properties of a beam of fast particles slowing down in a cold plasma under the combined influence of friction, energy diffusion and pitch-angle scattering caused by small angle collisions with the background particles. The work emphasizes the physical understanding of the collisional processes and provides a number of qualitative, approximate and exact solutions for different aspects of the problem. The applied approach has been based on both exact and approximate analytical solutions to the Fokker-Planck equation and has resulted in simple analytical expressions for characteristic physical quantities.
10.1.2 Runaway electrons

Runaway electrons are electrons that have been accelerated by an electric field to very high energies. The runaway phenomenon is very interesting from a purely physical point of view since it is applicable to a wide range of physical research areas such as e.g. fusion plasma physics, astrophysics and accelerator physics. However, it is particularly important in future tokamak fusion experiments where it is a potentially damaging effect. When the highly energetic runaways, generated in a tokamak during disruptions of fusion plasmas, leave the plasma and hit the first wall of the tokamak they may cause localized surface damage. Since it is highly probable that disruptions will occur in ITER, it is expected that runaway electrons will be produced in this experiment and several questions need to be resolved.

During the years 2004–05, the group continued its collaboration on supra thermal runaway electron generation during tokamak disruptions with Drs. Per Helander at Culham Science Centre and Lars-Göran Eriksson at CEA-Cadarache. Within this collaboration the numerical Monte-Carlo code ARENA (Avalanche of Runaway Electrons Analysis) has been developed at CAEA Cadarache in order to carry out realistic simulations of electron runaway in tokamaks. The code solves a 3D full-bounce averaged kinetic equation for the runaway electrons in toroidal geometry including the self-consistent electric field induced by the electron current decay. It has been used by the NLE group for verification of the obtained analytical results and for simulations of different electron runaway scenarios. During 2004, the important question has been addressed of how the current profile evolves in a tokamak disruption, when the thermal current is partly replaced by runaway electrons. Under typical conditions, it has been found that the runaway current profile becomes very different from the pre-disruption current profile. The current density usually increases significantly near the magnetic axis, making the runaway profile highly peaked.

Runaway production during disruptions is an inherently nonlinear process. The generation rate itself of runaways is a nonlinear function of both the electric field and the number of existing fast electrons. In addition, by electromagnetic induction, the current carried by the runaway electrons modifies the electric field responsible for their creation. The first self-consistent modelling of the current dynamics during a disruption was presented taking all these features into account, using both simplified analytical models and three-dimensional, nonlinear Monte Carlo simulations. These tools enable the post-disruption current profile to be predicted from pre-disruption plasma parameters, and are used to model recent runaway experiments on JET and to discuss implications for ITER.

Recently, the theory of runaway electrons has been generalized by including the effect of plasma cooling on the electron kinetics. The distribution function of supra-thermal electrons in a slowly cooling plasma has been calculated by an asymptotic expansion in the cooling rate divided by the collision frequency. Since the collision frequency decreases with increasing velocity, a high-energy tail forms in the electron distribution function as the bulk population cools down. Under certain simplifying assumptions (slow cooling, constant density, Born approximation of cross sections), the distribution function evolves to a self-similar state where the tail is inversely proportional to the cube of the velocity. The presence of the high-energy tail can affect important properties of the plasma. In tokamak disruptions, the presence of the tail can lead to a highly enhanced production of runaway electrons. The primary runaway electron generation rate is proportional to the number of electrons in the tail of the distribution function. It is therefore normally exponentially small in the electric field, but would be very much enhanced in a cooling plasma. In addition to spontaneous disruptions, this effect could
also be important in fast plasma shutdown events caused by gas or pellet injection.

10.1.3 Edge plasma physics

Much of the theoretical as well as experimental effort in tokamak fusion plasma research in the world today is directed towards understanding the complex processes taking place in the plasma edge region of a tokamak. If no solution is found to the problem of how to handle the excessive heat loads expected on the divertor plates as well the problem of impurity contamination, which plagues most of the present-day tokamak experiments, the construction of an operating fusion reactor appears difficult. Moreover, it is widely believed that edge plasma processes play a critical role for the global confinement of the plasma. The present theoretical understanding of the edge plasma is, however, fairly incomplete. Not even its neoclassical transport properties can be predicted with any confidence since the plasma profiles are frequently too steep for conventional neoclassical theory to be valid. Furthermore, in the edge region, neutral atoms and impurity ions are abundant, and their role has to be included in the analysis. One of the most important issues in tokamak plasma physics is therefore to develop a proper treatment of neutral particle and impurity ion effects at the edge of the tokamak plasma, where the plasma density and temperature gradients are steep – the so-called pedestal region. The neutral atoms can affect confinement by altering the radial electric field and the toroidal plasma flow velocity through charge-exchange and ionization interactions. During 2002–04, the group has investigated the effect of the neutrals on the ion flow and the radial electric field. In a collisional plasma, the neutral kinetics is treated first in the short mean-free path limit and then for arbitrary mean-free path by employing a self-similar neutral distribution function obtained for special temperature and density profiles. In particular, it has been found that the radial electric field and outboard toroidal flow velocity in a collisional edge plasma tend to be larger if the atoms are concentrated on the inboard side rather than on the outboard side. These predictions are consistent with differences observed on MAST between measured toroidal flows for inboard and outboard gas puffing, and may also explain observations indicating that inboard puffing allows easier H mode access. The results suggest that the flow shear introduced by the neutrals is suppressing edge turbulence and is playing a role in forming the edge transport barrier.

10.2 Nonlinear optics

This activity involves substantial collaboration with international and national research institutes such as Photonics Dep. (MC2), Acreo (Stockholm), Optical Science Centre (Canberra, Australia), Institute of Applied Physics (Nizhny Novgorod, Russia), Universita Federico II (Napoli, Italy), University of Besancon (France). The present research programme is devoted to modelling and analysis of basic phenomena within the field of nonlinear optics with particular emphasis given to investigations of: (i) nonlinear dynamics of partially incoherent light structures in nonlinear media, and (ii) dynamics Bose-Einstein condensates trapped by intense light beams. These areas are currently the most promising and fascinating branches of nonlinear optics and are expected to lead to many new important applications.

Coherent optical spatial solitons have been extensively studied during the last three decades. Self-trapping of optical beams occurs when diffraction is exactly balanced by self-focusing due to an optical nonlinearity. Self-focusing was first studied in gases, fluids, and solids, which possess Kerr-like nonlinearities. It has been found that self-trapping of a two-dimensional
beam in Kerr media is unstable, which leads to catastrophic self-focusing and eventually to beam break-up. Furthermore, even self-trapping of a one-dimensional beam in a bulk Kerr medium is unstable: It suffers from transverse instabilities that also lead to beam break-up and filamentation. Until quite recently, the commonly held impression was that optical solitons are inherently coherent structures. Lately, however, two experimental studies have clearly demonstrated that incoherent spatial solitons are also possible. The rapid progress in the area of incoherent solitons has opened up a host of new possibilities that have no counterpart whatsoever in the coherent limit. These include, for example, gray fundamental dark solitons and associated memory effects, the existence of multimode asymmetric incoherent solitons, and soliton shape transformations upon collisions, just to mention a few.

During 2004–05, the NLE group has developed a novel general statistical theory for describing the dynamics of partially incoherent optical wave structures in dispersive and nonlinear media. The approach is based on the Wigner transform method, which was introduced in the statistical quantum mechanics in order to describe the dynamics of the quantum state of a system in the classical space picture. Starting from the nonlinear Schrödinger equation, which describes the evolution of a slowly varying wave amplitude in a dispersive medium with an arbitrary nonlinear response, we derived the corresponding Wigner-Moyal equation for the Wigner distribution function including the statistical average. This equation reduces, in the geometrical optics approximation, to the classical Liouville or Vlasov-like equation, which describes the conservation of optical quasi-particles (photons) in phase-space. Firstly, the capability of the approach has been demonstrated by considering several important problems e.g. the modulational instability of incoherent beams interacting through nonlinear cross-phase modulation as well as the stability and collapse of partially incoherent beams in nonlinear Kerr media. Secondly, an effort to develop a generalized and novel quasi-linear diffusion theory for the “Wigner quasi-particle distribution” has been initiated. The diffusion process arises due to a resonant interaction between different parts of the Wigner spectrum and is similar to the one associated with the interaction of collective oscillations of a plasma (e.g. the interaction between high and low frequency plasma waves).

Recently, a general mathematical basis for describing propagation of partially incoherent light in nonlinear media has been formulated, which both unifies the existing approaches and includes generalizations made necessary by more complicated initial conditions than those previously considered. Specifically, it is demonstrated how to generalize existing theories to situations where the light field is obtained from several sources, which do not necessarily have the same stochastic properties. An application to the interaction of two partially incoherent solitons in a nonlinear Kerr medium has shown that as the degree of incoherence increases, the interaction length between the solitons also increases and the character of the interaction may change between attractive and repulsive behaviour (or vice versa).

10.3 Microwave breakdown in RF equipment

New generation telecommunication equipment is designed to cater for a constantly increasing number of users at the same frequency multiplex. The corresponding power levels are becoming successively higher and microwave components must be able to handle the concomitant electric fields. In this situation, various electric breakdown phenomena, in the form of Corona and Multipactor discharges, may seriously interfere with the operation or may even damage the RF components. In fact, microwave breakdown is a serious concern, not only in communications, but also in many other applications of microwaves, e.g. high power radar.
systems, microwave generators and fusion plasma RF heating. The basic physics involved in microwave breakdown phenomena is comparatively well known, but current day applications involve new physical as well as technical situations for which a satisfactory understanding is lacking. Consequently, a prominent feature in the design of RF equipment, in particular for space applications, is the excessive safety margins with respect to microwave breakdown that are currently used. This leads to unnecessarily conservative and non-optimized designs and to cumbersome and costly testing procedures.

The general aim of our work in this area is to obtain a better understanding of the physical phenomena involved in the microwave breakdown processes mentioned above and to be able to accurately predict the expected breakdown levels in different microwave components and devices as well as for different operation scenarios e.g. multi-carrier operation. The work has involved close collaboration with different national and international partners from industry as well as from university e.g. FOI, Saab Ericsson Space in Sweden, but also Institute of Applied Physics (IAP) in Nizhny Novgorod, Russia and Centre National d’Etudes Spatiale (CNES) in Toulouse, France. Good contact has also been established with ESA in Nordwijk, The Netherlands. As a continuation and extension of previous collaboration, Chalmers and IAP are currently also engaged in a joint four year project together with CNES. The purpose of this project is to study the limitations set by corona and multipactor breakdown in space-borne RF telecommunication equipment. The project has involved analytical work as well as development of numerical codes for accurate prediction of breakdown levels in different device geometries and operation scenarios, but also experimental work for comparative studies with theoretical predictions. Our work has been very successful and has established the constellation Chalmers-IAP-CNES as the leading expert group in the world in the area of electrical breakdown phenomena in microwave equipment.

11 Transport Theory

(Activities during 2004–2005 are reported here, but note that the group belonged to another department in 2004.)

The Transport Theory group studies turbulent transport processes in tokamak plasmas confined in toroidal magnetic fields. The main goal is to obtain an improved understanding of the large turbulent transport of particles and energy observed in tokamaks and other fusion devices using turbulence and transport simulations and analytical techniques.

The group has a broad international collaboration with participation during 2004-2005 in EFDA-JET (European Fusion Development Agreement-Joint European Torus), ITPA (International Tokamak Physics Activities) and EFDA-ITM (European Task Force on Integrated Tokamak Modelling).

Much of the work is concentrated on a transport model for turbulent transport developed by the group. The model is widely used internationally in predictions and analysis of tokamak experiments. The model is continuously being extended and updated by a combination of basic theoretical work and comparisons with experiments on present tokamaks, e.g. JET.

11.1 Theory

The transport model has been updated and extended by further developments of the basic drift wave theory. The most recent results are in the areas of particle pinches, zonal flows, statistical
theory of turbulent transport in magnetized plasmas, effects of geometry (elongation) and finite beta on drift wave stability, analytical solution of the linear eigenvalue problem for general mode width, fluid closure, particle transport, and impurity transport in ITER.

An extended review on turbulent transport in general and the work by our group on transport due to toroidal drift waves has been published. It includes also some new results on ITER simulations using the most recent version of our model.

11.1.1 Zonal flows and fluid closure

The transport due to fluid drift wave models was compared to that in nonlinear gyrokinetic codes by Dimits et al. (Phys. Plasmas 7, 969 2000). This test was initiated and lead by the US Department of Energy (DOE) because different drift wave models gave very different predictions of ITER performance. In this work Dimits found the nonlinear (Dimits) upshift in the critical temperature gradient for steady transport using a nonlinear kinetic code. Already our quasilinear model from the transport code gave good agreement with kinetic codes above the nonlinear upshift. Nonlinear simulations with our model also recover the Dimits upshift (Dastgeer et al. Phys. Plasmas 9, 4911 (2002)).

A recent systematic investigation of the closure aspects of this has given strong evidence in favour of our fluid closure. In a new work, a resonant ordering has been used in the reductive perturbation method. This leads to a modified Zakharov system for drift waves and zonal flows. Also a gyro-fluid resonance, that could be turned on and off, was included in the model. The magnitude of the coupling factor was studied as a function of temperature gradient for cyclone base case parameters. A strong resonance occurred just above linear threshold with our model while the gyro-fluid resonance strongly detuned the resonant excitation of flow when it was turned on. The Reynold stress was ignorable. This is a strong support for our previous findings that it is the energy equation nonlinearity which is important for obtaining the Dimits upshift and that our closure gives better agreement with nonlinear gyro-kinetics than a gyro-fluid closure.

The work on zonal flows continued in 2005 with a derivation from a nonlinear gyro-kinetic equation. This work was motivated by previous work showing strong excitation of zonal flows from the resonance in the energy equation. The previous fluid results were confirmed. This shows that the strength of zonal flows depends strongly on kinetic resonances and is strongest when velocity space nonlinearities make a reactive fluid closure valid. Work on this problem continues in collaboration with the Bogoliubov Institute for Theoretical Physics using a renormalized kinetic theory in a Greens function formalism.

11.1.2 Effects of geometry on drift wave stability

The shape of the magnetic field (MHD equilibrium) has, in general, a larger effect on drift waves when electromagnetic effects are included. In a new work the effects of finite beta, elongation and Shafranov shifts on drift wave stability boundaries have been studied. These modes have also an upper stability boundary in $\eta_b$ due to finite gyroradius effects. The upper stability boundary turned out to be much more sensitive to the studied parameters than the lower boundary. For more complicated equilibria, such as in stellarators and advanced tokamaks, a careful inclusion of geometrical effects becomes important also in the electrostatic case. A comparison between drift wave stability for numerical and analytical tokamak equilibria has recently been made for simple dissipative drift waves with cold ions. Significant
differences for the two types of equilibria were sometimes found.

11.1.3 Analytical solution for the eigenvalue problem of toroidal drift waves

An analytical method has been developed for obtaining the linear eigenvalues of toroidal drift waves for general modewidth. The method uses the asymptotic shape (Gaussian) of the eigenfunction in a quadratic form. The method has been applied to simple electrostatic ITG (ion temperature gradient) modes with eigenvalues in good agreement with numerical results. The method can be generalized to include more physics as long as the asymptotic eigenfunction does not change.

11.1.4 Parameter dependent correlation length

An updated version of the transport model with parameter dependent correlation length has been derived. The correlation length is governed by the linearly fastest growing mode as was previously found in mode coupling simulations. In the new version, the correlation length depends on magnetic q and shear, elongation and temperature ratio. The new version gives a more favourable current scaling and recovers internal transport barriers more easily in both ion and electron channels.

11.1.5 Effects of different isotopes on transport

A development of the model towards plasmas with multiple ion species (D, T, impurities, He ash etc) was completed in 2005. The model was used to study particle transport in deuterium-tritium (DT) plasmas. Isotopes with different mass corresponds to ITG modes with different mode number of the fastest growing mode since the gyro-Bohm scaling preserves the product \( k \rho \). The D-T plasma was found to set up a combination of inward and outward flows of D and T so that the the density length scales of D and T were nearly equilibrated. However, a slight asymmetry in the D and T flows remained, indicating a possible buildup of tritium in the plasma.

11.1.6 Particle transport

Electromagnetic effects on particle transport have been studied for ITER equilibria using both a simplified analytical model and a more general numerical treatment. The general trend is that the electromagnetic particle flux is outward for modes propagating in the ion drift direction and inward for modes propagating in the electron drift direction. The pinch was usually larger in a more complete numerical model including parallel ion motion.

In another work the effect of the fluid closure on particle transport was studied. It was found that the particle pinch is strongest in our reactive fluid closure. It is only this model that has been able to successfully simulate the peaked density profile in JET L-modes. In collaboration with the Bogoliubov Institute for Theoretical Physics we have studied particle diffusion in random fields using a kinetic Greens function method. The results were tested against a particle code with good agreement.
11.1.7 Impurity transport

Impurity transport has different scaling with charge ($Z$) in turbulent and neoclassical transport. In a collaboration with the Nonlinear Electrodynamics group at the department, studies of the importance of the two mechanisms in different regimes for ITER and for different $Z$ has been initiated. Studies of the dynamic coupling between anomalous and neoclassical transport has also been pursued under a bilateral agreement with Oak Ridge National Laboratory in the US. This work has resulted in a new code (DEA) and presentations at EPS conferences and ITPA.

11.1.8 Momentum transport

A new version of our transport model including momentum transport has been developed. Preliminary results including only poloidal rotation were presented at the US-Japan workshop on Integrated Modelling in Kyoto in September. Also toroidal momentum transport has now been included.

11.2 Predictive simulations and comparisons with experiments

Our transport model has continued to give good results in comparisons with experiments in connection with our work under the EFDA-JET 2004-2005 programme. Quantitative agreement with experiments for the generation of transport barriers is extremely difficult for models without free parameters as found in JET and ITPA work. The new version of the model with parameter dependent correlation length has, however, showed a clear improvement. The sensitivity to $Z_{\text{eff}}$ also in usual ITB (internal transport barrier) shots has been recognized as a major source of uncertainty. It is also important to recognize that elongation, which has been included in the JETTO transport code at JET since a couple of years, makes it more difficult to obtain transport barriers. This is, however, at least partly compensated by the new version of the model. The new version also gives a more favourable current scaling.

JET campaigns were scheduled to start again in November 2005 after a long shutdown. The model for momentum transport has recently been implemented into the JETTO transport code and studies of momentum transport have just been initiated as part of our participation in the JET 2005–2006 Campaigns.

The group participated in the ITPA topical groups on Transport, Internal Transport Barrier (ITB), and Confinement, Database and Modeling (CDB&M) in Lissabon (2004) and Kyoto (2005). J. Weiland organized sessions on the effect of temperature ratio and presented results on effects of temperature ratio on transport. A very interesting phenomenon, seen both on the US tokamak D-III-D and the German tokamak AUG is that the ion temperature is reduced when the electron heating is increased in the hot ion regime. This can be explained by transport feedback loops inherent in our transport model. During 2004-2005 also successful simulations of the D-III-D shots have been obtained.
12 Education

12.1 Courses

The Department gives many courses, in topics related to our research, for students at Chalmers and, to some extent, students at Göteborgs Universitet. The engineering educational programmes at Chalmers are either three years long (leading to the equivalent of a bachelors degree, or “högskoleingenjör”) or 4.5 years (leading to the equivalent of a masters degree, or “civilingenjör”). There are also separate international masters programmes (1.5 years), one of which is given by our department. Our astronomy courses are given in cooperation with Göteborgs Universitet. In addition to regular courses, our teachers also supervise thesis projects.

12.1.1 “Högskoleingenjörsprogrammen”: Campus Lindholmen

Chalmers’ three-year Engineering programmes are given at campus Lindholmen, where one of the teachers at our department (Arto Heikkilä) works, mainly with the Electrical Engineering programme. The teaching of many courses is shared between several departments at Chalmers. For the following courses, Department of Radio and Space Science had the main responsibility during 2005:

<table>
<thead>
<tr>
<th>Course</th>
<th>Examiner/lecturer</th>
<th>No. of students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tekniskt basår, Fysik del 2</td>
<td>Arto Heikkilä</td>
<td>150</td>
</tr>
<tr>
<td>Tele- och datakommunikation</td>
<td>Arto Heikkilä</td>
<td>50</td>
</tr>
<tr>
<td>Elteknik</td>
<td>Arto Heikkilä</td>
<td>55</td>
</tr>
<tr>
<td>Telekommunikation</td>
<td>Arto Heikkilä</td>
<td>45</td>
</tr>
</tbody>
</table>

Arto Heikkilä also participated (as teaching assistant) in the following two courses given by other departments: Telekommunikation fortsättningskurs and Elektriska kretsar, and taught physics at high school level at Göteborgsregionens Tekniska Gymnasium, also located at Lindholmen. (In 2004, before the reorganization of Chalmers, he belonged to another department, but had similar teaching duties.)

12.1.2 “Civilingenjörsprogrammen”: Basic courses in electrical engineering

The first three years of Chalmers’ 4.5 years Master of Engineering programmes consist mainly of compulsory courses. The Department gives courses in engineering measurements, electric circuits, and high frequency electromagnetic waves for students at the programmes in Electrical Engineering (E), Engineering Physics (F), Computer Science and Engineering (D), Information Engineering (IT), Automation and Mechatronics Engineering (Z), and Mechanical Engineering (M).

Characteristic and unique for the courses in Engineering measurements is the relatively large number of laboratory exercises. Part of the examination also tests the students ability to solve practical measurement problems.

1 Approximate number of registered students. The actual number of students passing the course can be somewhat different.
In addition to the examiners and lecturers, other teachers and PhD students from the groups in Space geodesy and geodynamics, Global environmental measurements, Nonlinear electrodynamics and Transport theory participated in the teaching of the above courses. (In 2004, the present Transport theory group, which then belonged to another department, participated in the course Electrical circuits and signals.)

12.1.3 International masters programme & other courses at masters level

Many our courses at advanced level are part of the International Masters Programme in Advanced Techniques in Radio Astronomy and Space Science, open for international students as well Swedish students from, e.g., Chalmers or Göteborg University.

The International Masters Programme in Advanced Techniques in Radio Astronomy and Space Science (RAMAS) started in the autumn of 2002. The programme runs for 1.5 years, with one year of courses followed by a thesis project, and has attracted students from many different countries. Each autumn, a new group of students (typically about 20) begin their studies, and at the time of writing this report, the fourth group has just completed half of their course work. The main scientific parts of the programme are astrophysics and Earth observations, while the technical parts focuses on microwave and millimetre-wave devices. The education thus prepares the students for careers in the academic world as well as in the communications and space industry. The programme coordinator is Rüdiger Haas.

Chalmers students in Electrical Engineering (E) or Engineering Physics (F) can, during their fourth year, follow the Radio and Space Science programme in which they can choose rather freely between courses from the international masters programme and a few additional courses (including Image processing and a project course). Chalmers students in Engineering Physics and physics students at Göteborgs Universitet (GU) can also follow the Astronomy and astrophysics programme by choosing relevant courses. Instead of following a complete programme, students can also take one or a few of the courses offered and combine them with courses from other departments.

The table below lists all our courses at advanced (“masters”) level. The courses each gives 2.5–5 points in the Swedish system, corresponding to 4–7.5 ECTS. In addition to the examiners and lecturers, other teachers and PhD students from the department participated in the teaching of the courses.

<table>
<thead>
<tr>
<th>Course</th>
<th>Year</th>
<th>Examiner/ lecturer</th>
<th>No. of students per year¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineering measurements (E)</td>
<td>2004</td>
<td>Henrik Ahlberg</td>
<td>130</td>
</tr>
<tr>
<td></td>
<td>2005</td>
<td>Gunnar Elgered</td>
<td>120</td>
</tr>
<tr>
<td>Engineering measurements (Z, M)</td>
<td>2004, 2005</td>
<td>Gunnar Elgered</td>
<td>90</td>
</tr>
<tr>
<td>Engineering measurements (D, IT)</td>
<td>2004, 2005</td>
<td>Gunnar Elgered</td>
<td>5</td>
</tr>
<tr>
<td>Environmental measurement techniques (E)</td>
<td>2005</td>
<td>Donal Murtagh</td>
<td>20</td>
</tr>
<tr>
<td>High frequency electromagnetic waves (E, F)</td>
<td>2004, 2005</td>
<td>Tünde Fülöp</td>
<td>90</td>
</tr>
<tr>
<td>Electric circuits (Z)</td>
<td>2004, 2005</td>
<td>Pär Strand &amp; Anders Jarmén</td>
<td>100</td>
</tr>
</tbody>
</table>

¹Approximate number of registered students. The actual number of students passing the course can be somewhat different.
<table>
<thead>
<tr>
<th>Course</th>
<th>Year</th>
<th>Examiner/lecturer</th>
<th>No. of students per year(^1)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RAMAS programme</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Space techniques</td>
<td>2004</td>
<td>Susanne Aalto</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>2005</td>
<td>Magnus Thomasson, Henrik Olofsson</td>
<td>40</td>
</tr>
<tr>
<td>Radio astrophysics</td>
<td>2004</td>
<td>Susanne Aalto</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>2005</td>
<td>John Black</td>
<td>25</td>
</tr>
<tr>
<td>Microwave engineering in communic.</td>
<td>2004, 2005</td>
<td>Victor Belitsky, Vessen Vassilev</td>
<td>50</td>
</tr>
<tr>
<td>Satellites in communications and navig.</td>
<td>2004, 2005</td>
<td>Rudiger Haas</td>
<td>60</td>
</tr>
<tr>
<td>Astrophysical processes</td>
<td>2004, 2005</td>
<td>Ulf Torkelsson (GU)</td>
<td>20</td>
</tr>
<tr>
<td>Interferometry in astronomy and geodesy</td>
<td>2004, 2005</td>
<td>Rudiger Haas, John Conway</td>
<td>20</td>
</tr>
<tr>
<td>Earth-system science techniques</td>
<td>2004, 2005</td>
<td>Hans-Georg Scherneck</td>
<td>20</td>
</tr>
<tr>
<td>Remote sensing in environmental science</td>
<td>2004, 2005</td>
<td>Donal Murtagh, Patrick Eriksson</td>
<td>20</td>
</tr>
<tr>
<td>Space environment</td>
<td>2005</td>
<td>Magnus Thomasson, Mietek Lisak</td>
<td>15</td>
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<tr>
<td>Satellite positioning</td>
<td>2004, 2005</td>
<td>Jan Johansson</td>
<td>25</td>
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<tr>
<td>Radar and remote sensing</td>
<td>2004, 2005</td>
<td>Gary Smith</td>
<td>30</td>
</tr>
<tr>
<td>Mm and submm receiver technology for</td>
<td>2004, 2005</td>
<td>Victor Belitsky, (+ several more)</td>
<td>20</td>
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<tr>
<td>instrumentation</td>
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<td></td>
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<tr>
<td>Advanced numerical methods and applications</td>
<td>2004, 2005</td>
<td>Alessandro Romeo, Cathy Horellou</td>
<td>25</td>
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<td><strong>Other radio and space science courses</strong></td>
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<tr>
<td>Plasma physics with applications and fusion</td>
<td>2004, 2005</td>
<td>Dan Anderson, Mietek Lisak,</td>
<td>5</td>
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<tr>
<td></td>
<td></td>
<td>Jan Weiland, Mattias Marklund</td>
<td></td>
</tr>
<tr>
<td>Image processing</td>
<td>2004, 2005</td>
<td>John Conway</td>
<td>120</td>
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<tr>
<td>Project course in radio and space science</td>
<td>2004, 2005</td>
<td>Magnus Thomasson</td>
<td>2</td>
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<tr>
<td><strong>Astronomy and astrophysics</strong></td>
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<td></td>
<td></td>
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<td>(see also courses listed under RAMAS)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stellar physics</td>
<td>2004, 2005</td>
<td>John Black</td>
<td>5</td>
</tr>
<tr>
<td>Galaxies</td>
<td>2005</td>
<td>Cathy Horellou</td>
<td>5</td>
</tr>
<tr>
<td>The interstellar medium</td>
<td>2004, 2005</td>
<td>John Black</td>
<td>10</td>
</tr>
<tr>
<td>Modern cosmology</td>
<td>2004, 2005</td>
<td>Gustaf Rydbeck, Marek Abramowicz (GU)</td>
<td>10</td>
</tr>
<tr>
<td>Hot topics in astrophysics</td>
<td>2004</td>
<td>Alessandro Romeo</td>
<td>10</td>
</tr>
<tr>
<td>Astrophysical dynamics</td>
<td>2004, 2005</td>
<td>Alessandro Romeo</td>
<td>5</td>
</tr>
<tr>
<td>Radiative processes</td>
<td>2004, 2005</td>
<td>Gustaf Rydbeck</td>
<td>5</td>
</tr>
</tbody>
</table>

\(^1\)Approximate number of registered students (for the astronomy courses, including GU students). The actual number of students passing the course can be somewhat different.
12.1.4 Basic astronomy courses

Göteborgs Universitet (GU) offers four basic astronomy courses, which require knowledge of high school physics and mathematics, and are taken by, e.g., first year university students (and often also by Chalmers students who want an introduction to astronomy). Two of the courses were given by teachers from Radio and Space Science in 2004 & 2005, the other two (The stars and the Galaxy, and The Universe of Galaxies) by teachers from Göteborgs Universitet.

<table>
<thead>
<tr>
<th>Course</th>
<th>Year</th>
<th>Examiner/ lecturer</th>
<th>No. of students per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>The planetary system and space probes</td>
<td>2004, 2005</td>
<td>Magnus Thomasson</td>
<td>25</td>
</tr>
</tbody>
</table>

12.1.5 Other courses

In spring 2004 and again in spring 2005, a five-day course in “Grundläggande Mätteknik” for Volvo was given by Gunnar Elgered, Wille Bokhede and Henrik Ahlberg.

In spring 2004 and again in autumn 2005, Henrik Ahlberg and Wille Bokhede gave a course for Industrihögskolan (mainly students from Volvo): “Elektronik och mätteknik”.

12.2 Masters theses (“examensarbeten”)

The following masters theses (“examensarbeten”, “diploma projects”) were presented during 2004–2005. The students were registered at Chalmers, if not otherwise indicated. The list is sorted in alphabetical order, and with the 2004 theses first.

P. Aho, K. Torstensson:
Radio Aeronomy of Planetary Satellites: Io

A. Alvarade, P. Pakniat:
Assessment of Water Vapour Radiometer Stability at 21 and 31 GHz

C. Bohm:
Jordningsproblematik vid pulverlackering

J.O. Botai:
Ionospheric studies using VLBI

O. Davās:
Measurement and data analysis for temperature controlled transports

G. Denby Wilkes:
Cosmological N-body simulations of structure formation

1Approximate number of registered students, including both GU and Chalmers students. The actual number of students passing the course can be somewhat different.
N. Gautam:
RFI analysis and celestial imaging using THETA correlation beamforming system

R. Gawande:
26.5 GHz four channel microstrip frequency multiplexer and effects of load reflections on receiver noise measurements

P. Guillou:
Formation of clusters of galaxies in the presence of dark energy

N.S. Jethava:
Optics alignment tool

A. Lévy:
The Sunyaev-Zeldovich effect

J. Lindahl:
Probing the positron phase of the thermonuclear supernova SN 2000cx

R. del López, J.M. Lozano:
Comparison of Earth rotation parameters derived from different space geodetic techniques

G. Mastrodomenico:
Sensitivity of structure constant $C_{nn}^2$ to measurement errors

E. Motte:
Retrieval, simulation and characterisation of a double-sideband radiometer for simultaneous observation of middle atmosphere ozone and carbon monoxide

S.C. Mushini:
Diurnal and annual variations of meteor rates at different latitudes

F. Odetallah:
Bistatic SAR System Design

C. Parashare:
Development of low noise, high dynamic range amplifier and frequency independent zigzag antenna for the Green Bank solar radio burst spectrometer

J.-D. Paris:
Simulation of Vegetation Response to Synthetic Aperture Radar with Polarimetric Interferometry Capability. Application to agriculture

V. Perez Robles:
Broadband Room Temperature LNA Design and Implementation
L. Persson:
*Simulations of galactic wakes*

C.-J. Roos:
*Evaluation, automatization, rationalization and improvement of the manufacturing process of a high-tech electrical measurement system*

B. Rydberg:
*Submillimetre-wave Radiometric Measurements of Cirrus Cloud Ice*

S. Salman:
*Estimation of atmospheric attenuation from radiosonde profiles and microwave radiometry*

B. Stoyanov:
*Measurement of and correction for the atmospheric propagation delay*

H. Sämgård:
*Change detection in VHF SAR images of forest from 1997, 1999 and 2002*

O. Agertz:
*Simulations of structure formation in the early universe*

R. Anthin:
*Sattitude3D. An interactive satellite attitude simulator applet for educational purposes*

C. Armiens, B. Huang:
*Multipaction; detection methods and inhibition*

J. Berthag:
*Strålningsmodell och mönderbroskorrektion för en okylad mikrobolometerkamera*

C. Ohmprakash:
*Coherent demodulation analysis*

P.R. Coutinho:
*Acquisition of Galileo and Modernized-GPS Signals*

M. Ferrand:
*Cirrus clouds detection with a millimeter space borne radar system: Frequency study*

H. Gerebro:
*Dense gas and chemistry in active galaxies*
R. Ghazi:
*Design tool for calculation of quantum limited mm-wave receivers*

H. Hailing, X. Yan:
*Investigation of extreme weather events using GPS data in Europe*

J. Hedström:
*Kinetic instabilities driven by relativistic runaway electrons*

M. Hopeson, P. Spigic:
*Metodutveckling för mätning av jordningens kvalité vid pulverlackering*

D. Johansson:
*Determining the cosmological temperature-redshift relation using the SZ effect*

F. Johnsson:
*Kallstart av satellitburen GPS-mottagare*

M. Larsson:
*The Sunyaev-Zeldovich effect: Cosmological aspects and observational prospects*

J. Magnusson:
*Dark energy and cosmic expansion*

L. Millán Valle:
*Experimental study of the influence of background dust on radar backscatter from meteor trails*

A. Monza:
*N-body simulations of the collision of two galaxies*

A. Moin:
*Synthesis Imaging with ThEP Observing System for Radio Astronomy*

M. Nord:
*Constraining the redshift dependance of the CMB temperature using the SZ effect*

O. Nyström:
*Detection of dielectric materials in hollow structures using microwave technology*

M. Sadeque:
*Implementation of UERE module into NavSim and study of errors for single and dual frequency GPS receivers*
P. Sandquist:  
Alfvén eigenmodes, sawteeth oscillations and fast ion confinement in alpha-simulation JET experiments  

A. Testoni:  
Assessment of rainfall spatial correlation in Europe and North America using ECMWF re-analysis data  

R.M. Thomas:  
Planet Transit Light-curves: Analysis Using Wavelets & Genetic Algorithm  

N. Vahlne:  
The influence of the cosmological parameters on the cosmic microwave background  

A. Wrener:  
Microwave breakdown; Case study on the proneness to breakdown for different transmission formats  

P. Zorzi Avendano:  
Analysis of direct broadcasting TV satellite signals  

L. Öhman Börjesson:  
Investigation of ClO measurements from the Odin satellite  

13 PhD and licentiate exams

13.1 PhD exams

PhD degrees awarded during 2004–2005. The list is sorted in alphabetical order, and with the 2004 theses first.

Peter Forkman:  
Ground based measurements of upper atmospheric CO and H₂O using microwave radiometry  

Bhanpersad Jhowry:  
Drift Ballooning and ITG Instabilities in Tokamak Plasmas  

Michele Pestalozzi:  
Methanol Masers as Signposts of Star Formation and VLBI Observations of coronal Emission from Young Stars  

Borys Stoew:  
Description and Analysis of Data and Errors in GPS Meteorology  
Achim Tappe:
Interstellar absorption across the electromagnetic spectrum

Vessen Vassilev:
Development of a Sideband Separating SIS Mixer Technology for MM-Wavelengths

Yu Yong:
Development and Application of Differential Optical Absorption Spectroscopy (DOAS) for Asian Urban Air Monitoring and Atmospheric Research

Per-Olov Fröling:
Ultra-wideband synthetic aperture radar in the VHF-band: Image formation algorithms and interferometric applications
(2005. Supervisor: Lars Ulander)

Björn Hall:
Aspects of nonlinear interaction in nonlinear media
(2005. Supervisor: Mietek Lisak)

Łukasz Helczynski-Wolf:
Nonlinear propagation of partially incoherent light
(2005. Supervisor: Dan Anderson)

Igor Holod:
Statistical Aspects of Diffusion in Turbulent Plasmas
(2005. Supervisor: Jan Weiland)

Ulf Jordan:
Microwave breakdown; Physics and applications
(2005. Supervisor: Dan Anderson)

Christophe Risacher:
Low Noise SIS Mixers and Cryogenic Amplifiers for Sub-Millimeter Astronomy

Jiyune Yi:
High Resolution Observations of Masers in Star Formation Regions and Evolved Stars
(2005. Supervisor: Roy Booth)

13.2 Licentiate exams

Licentiate degrees awarded during 2004–2005. The list is sorted in alphabetical order, and with the 2004 theses first.

Samuel Brohede:
Optical Remote Sensing of the Middle Atmosphere from Satellites – DOAS Retrievals of O₃ and NO₂ from Odin/OSIRIS Limb-Scattering Measurements
(2004. Supervisor: Donal Murtagh)
Björn Hallberg:
*Forest imaging using synthetic-aperature radar in VHF and P band*  

Miroslav Pantaleev:
*Gaussian Beam Measurement Range for HIFI Instrument of Herschel Space Observatory*  

Håkan Smith:
*Runaway electrons and Alfven eigenmodes in Tokamaks*  

Richard Udiljak:
*Multipactor in low pressure gas*  
(2004. Supervisor: Dan Anderson)

Annika Eriksson:
*Anomalous particle pinches in tokamak plasmas*  
(2005. Supervisor: Jan Weiland)

Klas Folkesson:
*Segmentation of Radar Images for Remote Sensing of Forests*  
(2005. Supervisor: Lars Ulander)

Björn Hall:
*Aspects of wave interaction in nonlinear media*  
(2005. Supervisor: Mietek Lisak)

Manne Kihlman:
*Application of Solar FTIR Spectroscopy for Quantifying Gas Emissions*  
(2005. Supervisor: Johan Mellqvist)

Martin Lidberg:
*Motions in the Geodetic Reference Frame – GPS observations*  
(2005. Supervisor: Jan Johansson)

Tobias Nilsson:
*Assessment of Tomographic Methods for Estimation of Atmospheric Water Vapor Using Ground-Based GPS*  
(2005. Supervisor: Gunnar Elgered)

Rodrio Parra:
*Radio Observations of Luminous InfraRed Galaxies*  
(2005. Supervisor: John Conway)

Raquel Rodriguez Monje:
*Towards 0.5 THz Sideband Separation SIS Mixer for Radio Astronomy Receivers*  

Rafal Tomala:
*Microwave breakdown in air-filled waveguides and resonators*  
(2005. Supervisor: Dan Anderson)
14 Public outreach

Several of our scientists, in particular Cathy Horellou and Christer Andersson at Onsala Space Observatory, are involved in providing information about our work to the general public.

**Exhibition centre.** The permanent astronomy exhibition in the former control building of the 25 m telescope has been very much appreciated, not only by students and other visitors but also by professionals. The exhibition covers general astronomy as well as current research at the Observatory. One room is devoted to the history of the Onsala Space Observatory. A book “Populärt om astronomi” by Mikael Lerner, and leaflets on various topics, are sold to interested visitors.

**Guided tours.** Many groups from all parts of the population, school classes, industrialists as well as retired people, have visited the Observatory, been guided around the facilities and been informed about the principles of radio astronomy. In total more than 1200 visited the Observatory in 2004, and more than 1400 in 2005.

**Practical vocational guidance.** In 2004, eleven students at the “gymnasium” level did their working experiences (one week each) at the Observatory, and in 2005, six students.

**Projects for students.** In 2005, four students at the “gymnasium” level were supervised in a project on sundials, and three students studied the spiral arms of the Galaxy with the recently completed receiver for the hydrogen spectral line at 21 cm wavelength.

**International Science Festival Göteborg.** The International Science Festival is held annually in Göteborg in April or May. Each year, Onsala Space Observatory participates in an exhibition with hands-on experiments and demonstrations. For example, in 2005, the topic of our contribution was how different types of instruments are used to collect information about the physics of space. An eight meter long two-stage Nike-Orion rocket, borrowed from Esrange, was displayed along with a five-meter model of the Ariane rocket and a satellite separation system from Saab-Ericsson Space AB. We also demonstrated telescopes of refractor and reflector type, and showed experiments related to astronomy. Several of the departments scientists also gave talks at the festival, seven in 2004 (Roy Booth: “New developments in low frequency radio astronomy radio digital cameras”, Peter Forkman: “Växthuseffekt och ozonuttungan”, Bo Galle: “Gasutsläpp från vulkaner”, Åke Hjalmarsson: “Nya rön från den svenska Odinsatelliten”, Jan Johansson: “Vad är en sekund? Mätteknik och tid”, Gustaf Rydbeck: “Einstein’s relativitehsteori förklaras för nybörjare” and Magnus Thomasson: “Galaxer – stjärnöar i universum”), and two in 2005 (Cathy Horellou: “Universum i ett nötsskal” and Peter Forkman: “Day after Tomorrow. Om väderförändringar”, given three times).

**Popular science talks.** Scientists at the department, especially at Onsala Space Observatory, often give popular science talks for different kinds of audiences (in addition to the talks at the Science Festival mentioned above). In 2004–05, Cathy Horellou gave talks on “Om universums mörka energi” (Tycho Brahe astronomy club, Malmö), “Universum i ett nötsskal” (Göteborg Astronomy Club) and “Galaxer och kosmologi” (for high-school teachers, Science Center Navet, Borås), Magnus Thomasson gave talks on “Galaxer – universums byggstenar” (Göteborg Astronomy Club), “Radio- och rymdvetenskap och Onsala Rymdobservatorium” (for former Chalmers students), “Galaxerna och universum” (in Leksand, and for Statens provnings- och forskningsinstitut, SP), and “Aktuell astronomi” (for high-school students visiting Göteborgs Universitet), Susanne Aalto gave a talk on Aniara and its perspective on science at “Harry Martinsson dagarna” (at KVA Stockholm, May 2004), and gave lectures on galaxies and molecular gas at Natur och Kulturs teacher days (November 2004) and the physics days for teachers (Umeå, November 2005), and Gunnar Elgered gave a talk
Christer Andersson also gives lectures in radio astronomy three hours every week for a group of interested persons in Kungsbacka. Several of the researchers at the Observatory visit this course and give lectures every term.

**Popular science on the Internet.** The Onsala web-pages give a popular description of the research at the Observatory. There are also suggestions for projects for high-school students, and a facility for sending questions to scientists at the observatory (mainly used by pupils). The web-pages can be found at: http://www.oso.chalmers.se/popular.

**Other outreach activities.** Magne Hagström and Rune Byström has constructed a “Student antenna” with 2.3 m diameter. With this antenna, it is possible to obtain excellent spectra of the 21 cm line from hydrogen in the Milky Way in just five seconds of integration time. The spectra can be used to study the spiral arm structure and differential rotation of our Galaxy, and are comparable to those obtained with much larger antennae when the hydrogen in the Milky Way was first mapped. The antenna can also be used in laboratory exercises in modern receiver technology, and is useful for high-schools and universities.

The Observatory is a member of the Science Center Network which is initiated by the Government through the NOT-project, and is also involved in the European project “EU-HOU – Hands-On Universe, Europe. Bringing frontline astronomy to the classroom”, consisting of eight European countries each contributing one project. The aim is to make the latest astronomical techniques available in the classroom by cooperation between teachers and scientists, with the goal to use astronomy as a well-established source of motivation for science and technology learning. The Swedish project is the small antenna with a hydrogen line receiver mentioned above. In 2005, the Observatory has delivered one 2.3 m antenna with receiver to Kungälvsgymnasiet and one to Xperimenthuset in Växjö.
15 Organization and Staff

15.1 The Onsala National Facility Board

Ivan Öfverholm  Chairman
Roy Booth  Onsala
Lars Brink  Chalmers
Dainis Dravins  The Swedish Research Council
Gunnar Elgered  Onsala
Kjell Eriksson  The Swedish Research Council
Jan-Eric Sundgren  Chalmers (adjunct)
Magnus Thomasson  Onsala (secretary)

15.2 The Onsala Programme Committee

(evaluates proposals for observing time on the Onsala 20 m telescope)

Hans Olofsson  Stockholm Observatory (chairman)
Kalevi Mattila  Helsinki Observatory
Nils Bergvall  Uppsala Astronomical Observatory (spring 2005)
Melvyn Davies  Lund Observatory (autumn 2005–)
Michael Lindqvist  Onsala
Magnus Thomasson  Onsala (secretary)

15.3 Staff at the Onsala Space Observatory National Facility

Director  Roy Booth (–Nov. 2005)
          Hans Olofsson (Dec. 2005–)

Telescope operations

  Ass. Tel. Scientist  Per Bergman (–Apr. 2005)
  Ass. Tel. Scientist  Michael Lindqvist
  Operator  Roger Hammargren (also web support)
  Operator  Fredrik Blomqvist (Nov. 2004–)
  Technicians  Leif Helldner
              Karl-Åke Johansson

Computer support

  Programmer  Lars Lundahl
              Glenn Persson (Odin project, part-time)
  Technician  Lars Eriksson
  Engineer  Biörn Nilsson
Workshop
(Nota: see also GARD, Sect. 15.5.)
Technicians
Christer Hermansson
Lars Wennerbäck

Technical development
(Nota: see also GARD, Sect. 15.5.)
Head of GARD
Victor Belitsky
Research engineers
Magne Hagström (‘driftsingenjör’)  
Christer Andersson (50%)  
Rune Byström (part time)  
Lars-Göran Gunnarsson  
Lars Pettersson  
Jamshid Shahrokhi
Head software engineer
Michael Olberg

Outreach activities
Christer Andersson (50%)  
Cathy Horellou (50%)

Administration
Directors assistant
Magnus Thomasson (50%)  
Head of administration
Ingrid Eriksson  
Secretary
Margareta Mattsson  
Adm. assistant
Paula Rosell  
Janitor
Jan Karaskuru

15.4 Department of Radio and Space Science Board
Göran Netzler  
Chairman
Hans Andersson  
Swedish National Testing and Research Institute
Sven Grahn  
Swedish Space Corporation
Marie Rådbo  
Göteborgs Universitet
Dag Winkler  
Microtechnology and Nanoscience, Chalmers
Gunnar Elgered  
Head of department
Michael Olberg  
Teachers representative
Hans-Georg Scherneck  
Teachers representative
Leif Helldner  
Techn. & admin. staff representative
Eva Wiström  
PhD students representative
Erik Ohlson  
Students representative
Eva Axelsson  
Secretary
15.5 Staff at Department of Radio and Space Science

Head of department (“prefekt”): Gunnar Elgered

Assistant head of department: Donal Murtagh
(“proprefekt”, responsible for PhD education)

Vice head of department: Magnus Thomasson
(“viceprefekt”, responsible for undergraduate education)

Head of administration and economics: Ingrid Eriksson
(“administrativ chef och institutionsekonom”)

Personnel officer (“personalman”): Ingrid Jakobson

Department secretary and information manager: Eva Axelsson (Apr. 2004–)
(“institutionsssekreterare och informatör”)

Department secretary (“institutionsssekreterare”): Britt-Marie Boisen (–Mar. 2004)

Economy handling officer: Monica Hansen
(“ekonomihandläggare”)

Advanced receiver development (GARD)

Note: Most of the staff, except the research students, at the Group for Advanced Receiver Development (GARD) work for the National Facility (see Sect. 15.3).

Professors: Victor Belitsky (head of group)

Researchers: Denis Meledin (Aug. 2005–)
(“forskare”)

Assistant professors, post-doctoral pos.: Karsten Ermich
Vessen Vassilev

Senior research engineers: Alexey Pavolotsky (–Jan. 2005)
Igor Lapkin (part-time)

Research engineers: Victor Perez (Mar. 2004–)
Magnus Svensson

Engineers: Mathias Fredrixon

Technicians Sven-Erik Ferm
Research students:  
Raquel Rodriguez Monje (stipend)  
Olle Nyström (Aug. 2005–)  
Miroslav Pantaleev  
Christophe Risacher (–Sep. 2005)  
Erik Sundin

Radio astronomy and astrophysics

Professors:  
Roy Booth (head of group –Nov. 2005)  
John Black (head of group Dec. 2005–)  
Åke Hjalmarson

Professor emeritus:  
Bertil Höglund  
Anders Winnberg

Senior lecturers:  
("universitetslektorer", "docenter")  
Susanne Aalto  
John Conway  
Arto Heikillä  
Cathy Horellou  
Alessandro Romeo

Researchers:  
("forskare")  
Michael Lindqvist  
Gustaf Rydbeck  
Magnus Thomasson

Assistant professors, post-doctoral pos.:  
("forskarassist.", "doktorstjänster")  
Henrik Olofsson  
Frank Le Petit (–Oct. 2005)

Research students:  
Stefan Bergström (–Dec. 2004)  
Lars Ekelund  
Evert Olsson  
Rodrigo Parra  
Carina Persson  
Michele Pestalozzi (–Feb. 2004)  
Christophe Risacher (–Sep. 2005)  
Achim Tappe (–Sep. 2004)  
Eva Wirström  
Jiyune Yi (–Apr. 2005)

Undergraduate assistant:  
("amanuens")  
Space geodesy and geodynamics

Professors: Gunnar Elgered

Senior lecturers: Hans-Georg Scherneck
(“universitetslektor”, “docenter”)
Jan Johansson (50%)

Assistant professors, post-doctoral pos.: Rüdiger Haas
(“forskarassist.”, “doktorstjänster”)

Research engineers: Wilgodt Bokhede

Research students:
Sten Bergstrand
Camilla Granström
Martin Lidberg (employed 80% by Lantmäteriverket)
Tobias Nilsson
Glenn Sterenborg (employed by ESA/ESTEC)
Boris Stoew (–May 2005)

Global environmental measurements

Professors: Donal Murtagh (head of group)

Visiting researchers: Joachim Urban (Sept. 2004–)
(“gästforskare”)

Assistant professors, post-doctoral pos.: Patrick Eriksson
(“forskarassist.”, “doktorstjänster”)
Peter Forkman
Nicolas Lautie (stipend, –Apr. 2005)

Computer support: Joakim Möller (Mar.–Nov. 2005)

Research students:
Samuel Brohede
Mattias Ekström
Ashley Jones
Bengt Rydberg (Jan. 2005–)
John Rösevall

Radar remote sensing

Professors: Lars Ulander (adjunct professor)

Professor emeritus: Jan Askne

Assistant professors, post-doctoral pos.: Leif Eriksson (Jun. 2004–)
(“forskarassist.”, “doktorstjänster”)
Gary Smith Jonforsen (head of group)
Research students: Klas Folkesson
Per-Olof Frölind (employed by FOI)
Björn Hallberg
Annelie Wyholt

Optical remote sensing

Senior lecturers: Bo Galle (head of group)
(“universitetslektorer”, “docenter”)
Johan Mellqvist (head of group)

Project assistant: Elisabeth Unden (part-time)

Research students: Claudia Rivera Cardenas (stipend)
Manne Kihlman (–Aug. 2005)
Alexis Merlaud (stipend)
Mattias Johansson (Jun. 2004–)
Jerker Samuelsson
Anders Strandberg
Yan Zhang (stipend)
Yu Yong (stipend, –Oct. 2004)

Nonlinear electrodynamics

Professors: Dan Anderson (head of group)
Mietek Lisak (head of group)

Senior lecturers: Tünde Fülöp
(“universitetslektorer”, “docenter”)

Research students: Björn Hall (–Aug. 2005)
Pontus Johannisson
Ulf Jordan (–Jun. 2005)
Patrik Sandquist (Sep. 2004–)
Håkan Smith
Richard Udiljak

(“amanuens”)

Transport theory

Professors: Jan Weiland (head of group)

Senior lecturers: Anders Jarmen
(“universitetslektorer”, “docenter”)
Hans Nordman

92
Assistant professors, post-doctoral pos.: Bhanpersad Jhowry (Oct. 2004–)
(“forskarassist.”, “doktorstjänster”) Pär Strand

Research students: Annika Eriksson
Igor Holod (–Jan. 2005)
Bhanpersad Jhowry (–Sep. 2004)

16 Funding

The tables below show the sources of funding for the different parts of the Department of Radio and Space Science and Onsala Space Observatory. The grants are recorded the year they are awarded, but are in some cases spent over several years.


16.1 The Onsala Space Observatory National Facility

<table>
<thead>
<tr>
<th>Funding Agency</th>
<th>Projects and the like</th>
<th>2004 (kSEK)</th>
<th>2005 (kSEK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VR</td>
<td>Operations of Onsala and SEST</td>
<td>19,000</td>
<td>21,400</td>
</tr>
<tr>
<td>VR</td>
<td>Travel (conferences, etc.)</td>
<td>–</td>
<td>18</td>
</tr>
<tr>
<td>Rymdstyrelsen</td>
<td>Odin science &amp; software development</td>
<td>2,244</td>
<td>2,322</td>
</tr>
<tr>
<td>Rymdstyrelsen</td>
<td>Odin PhD student</td>
<td>614</td>
<td>608</td>
</tr>
<tr>
<td>Rymdstyrelsen</td>
<td>Herschel satellite</td>
<td>2,295</td>
<td>216</td>
</tr>
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<td>EU</td>
<td>RadioNet</td>
<td>k€ 367</td>
<td>k€ 362</td>
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<td>KVA</td>
<td>Former Soviet Union</td>
<td>196</td>
<td>135</td>
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<tr>
<td>ESO</td>
<td>Water vapour radiometer</td>
<td>k€ 340</td>
<td>–</td>
</tr>
<tr>
<td>ESO</td>
<td>ALMA: SIS junctions</td>
<td>–</td>
<td>k€ 122</td>
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</tbody>
</table>
### 16.2 Teaching & Research

<table>
<thead>
<tr>
<th>Funding Agency</th>
<th>Projects and the like</th>
<th>2004 (kSEK)</th>
<th>2005 (kSEK)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Onsala Space Observatory</strong></td>
<td>Research &amp; graduate teaching (incl. rent and central admin. overhead)</td>
<td>6,393</td>
<td>6,457</td>
</tr>
</tbody>
</table>

**Advanced Receiver Development**

Most of the activities in the Group for Advanced Receiver Development (GARD) are part of the National Facility (see Sect. 16.1).

<table>
<thead>
<tr>
<th>Funding Agency</th>
<th>Projects and the like</th>
<th>2004 (kSEK)</th>
<th>2005 (kSEK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chalmers</td>
<td>Research &amp; graduate teaching</td>
<td>–</td>
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**Radio Astronomy and Astrophysics**

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<td>Chalmers &amp; Göteborgs Univ.</td>
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<td>Gas and star formation in interacting galaxies</td>
<td>442</td>
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<td>VR</td>
<td>Galaxies</td>
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<td>VR</td>
<td>“Forskarassistent”</td>
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<td>VR</td>
<td>PhD student</td>
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<td>VR</td>
<td>Physics and chemistry of dilute matter in space</td>
<td>541</td>
<td>135</td>
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<td>VR</td>
<td>Wavelet Approach to Dynamical Modelling</td>
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<td>VR</td>
<td>Submm astronomy with APEX and ALMA</td>
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<td>VR</td>
<td>Active galaxies</td>
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<td>VR</td>
<td>Active galactic nuclei</td>
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<td>k€ 34</td>
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**Space Geodesy and Geodynamics**

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<td>VR</td>
<td>Travel</td>
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<td>ACE</td>
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<td>303</td>
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<tr>
<td>Wallenberg</td>
<td>IVS meeting and workshop in Chile</td>
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---

1. Assessment of Tomographic Methods for High Resolution Atmospheric Water Vapour Measurements Using GPS
2. Ground-based GPS data in operational weather forecasting
3. Atmosphere and Climate Explorer
### Radar Remote Sensing

<table>
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<td>Remote sensing of forestry</td>
<td>559</td>
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<td>47</td>
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<td>Segmentation</td>
<td>504</td>
<td>560</td>
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<td>Rymdstyrelsen</td>
<td>Forest Parameter Retrieval with ALOS (^1)</td>
<td>–</td>
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<td>Ericsson</td>
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### Global Environmental Measurements

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<th>Undergraduate teaching</th>
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<td>Rymdstyrelsen</td>
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<td>EU</td>
<td>SCOUT (^3)</td>
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### Optical Remote Sensing

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<td>SIDA</td>
<td>Megacities, PhD supervisor</td>
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<td>SIDA</td>
<td>Vulcanoes</td>
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### Nonlinear Electrodynamics

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<td>Euratom</td>
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<td>VR</td>
<td>Physics of burning fusion plasmas</td>
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<td>Optical wave structures in nonlinear media</td>
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<td>Theoretical fusion plasma physics</td>
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<td>“Ersättning HRU”</td>
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<td>Magn. Bergvalls Stiftelse</td>
<td>Fusion plasma</td>
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<td>74</td>
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</table>

\(^1\) Advanced Land Observing Satellite  
\(^2\) Study to establish mission and instrument requirements to observe cirrus clouds at sub-millimetre wavelengths  
\(^3\) Stratospheric-Climate Links with Emphasis on the Upper Troposphere and Lower Stratosphere
Transport Theory

<table>
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<td>VR</td>
<td>CSU Culham EFDA</td>
<td>– 690</td>
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<td>VR</td>
<td>Euratom</td>
<td>– 74</td>
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<tr>
<td>VR</td>
<td>Fusion Plasma Physics, stability and transport</td>
<td>744 744</td>
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<tr>
<td>VR</td>
<td>Turbulence and transport in plasmas</td>
<td>789 789</td>
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<td>VR</td>
<td>Visit to JET</td>
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Acknowledgements

Our accomplishments would be impossible without the support of Chalmers and the many funding agencies mentioned above. Their generous support is gratefully acknowledged.

17 Committee membership

17.1 Chalmers University of Technology

See also Sect. 15 for committee membership directly related to the Department or Observatory.

Faculty Council (Fakultetsrådet)  
Susanne Aalto (–2005)  
Cathy Horellou (2005–)

School of Electrical Engineering  
Prog. Comm. for “Civ. ing. utb. i Elektroteknik”  
Gunnar Elgered

Employment committee  

Master-råd  
Susanne Aalto

Appointment Committee (for Radio and Space Science, Physics, Chemistry and Microelectronics and Nanoscience)  
Tünde Fülöp

GRUL – Grundutbildningens ledningsgrupp  
Examensområdesansvarig för mastersprogrammen  
Susanne Aalto

Proinspector of Chalmers Student Union  
Gunnar Elgered
17.2 National committees

KVA – Royal Academy of Sciences
Class II – Astronomy and Space Science
Crafoord Prize Committee
National Committee for Astronomy

SNRV National Committee for Radio Science
Commission F
Commission J

Swedish National Space Board (Rymdstyrelsen)
Reference committee on astronomy
Reference committee on atmospheric science

Swedish Remote Sensing Committee

VR – The Swedish Research Council (Vetenskapsrådet)
ESO/NOR committee
EISCAT committee
Beredningsgrupp NT–M

Swedish Fusion Research Unit,
Association Euratom-Vetenskapsrådet
Steering Committee of
Association Euratom-Vetenskapsrådet
Fusion Committee
Comm. on expensive research equipment (Dyrk)
17.3 International committees

For conference organizing committees, see Sect. 19.3.

ALMA – Atacama Large Millimeter Array
  ALMA Board Roy Booth
  European ALMA Board Roy Booth
  ALMA Science Committee (ASAC) Susanne Aalto
  European Science Committee (ESAC) Susanne Aalto
  Science Integrated Product Team John Conway

APEX – Atacama Pathfinder Experiment
  Board Roy Booth
  Science verification process Susanne Aalto (2005)

COST Action 716

EANA – European Exo/astrobiology Network Association
  Executive council Åke Hjalmarson (–2004)

EFDA – European Fusion Development Agreement
  Steering Committee Mietek Lisak

ESA – European Space Agency
  Expert group on “Harmonization and active coordination of European RF breakdown research” Dan Anderson

ESF – European Science Foundation
  CRAF Comm. on Radio Astronomy Frequencies Michael Linqvist

ESFRI – European Strategy Forum for Research Infrastructure
  Astronomy and Astroparticles Expert Group Roy Booth (2005–)

EURATOM
  Consultative Committee for the Specific Research and Training Programme Mietek Lisak

European SKA Consortium Roy Booth

European Task Force on Integrated Modelling
  Deputy task force leader Pär Strand

EVG – European VLBI Group for Geodesy Rüdiger Haas (secretary)
EVN – European VBLI Network
Board of Directors
Roy Booth
JIVE (Joint Institute for VLBI in Europe) Board
Programme Committee
Michael Lindqvist (2005)
Technical and Operations Group
Leif Helldner
Michael Lindqvist
eVBLI science group
John Conway
Michael Lindqvist

Federation of Astronomy and Geophysical Data Services
Roy Booth

Hands-On Universe
Pedagogical Coordinating Committee of Hands-On Universe Europe
Cathy Horellou

IAG – International Association for Geodesy
Earth Tide Commission (ETC), Solid earth tides in space geodetic techniques, sub-group 1 (VLBI)
Rüdiger Haas (chairman, –2004)
ETC, Inter-commision study group of Earth Tides in Space Geodetic Techniques
Rüdiger Haas

IAU – International Astronomical Union
Working Group on Astrochemistry
John Black

IERS – Internat. Earth Rotation and Reference System Service
Working Group on Site Survey and Co-location
Rüdiger Haas

ILP – International Lithosphere Project
National Committee
Hans-Georg Scherneck

ILRS – International Laser Ranging Service
Refraction Study Group (RSG)
Rüdiger Haas

ITPA – International Tokamak Physics Activities
Coordinator of project about the Te/Ti ratio
Jan Weiland

IVS – International VLBI Service for Geodesy and Astrometry
Working group for Geophysical Models in VLBI Software
Hans-Georg Scherneck (chairman)
Rüdiger Haas
VLBI 20010 committee
Rüdiger Haas (2005–)

JET – Joint European Torus
Close Support Unit
Hans Nordman (~2005)
In addition, senior members of staff regularly act as referees for international journals, opponents on PhD theses and members of PhD thesis examining committees, as advisors and assessors for international funding applications, and participate in evaluation committees.

18 Seminars

The following series of seminars were given at Onsala Space Observatory during 2004–2005. The seminars were organised by Michael Lindqvist and Roy Booth. (Presentations of masters theses, licentiate theses, and PhD defences are not recorded here; see instead Sects. 12.2, 13.1, and 13.2.)

18 February 2004
Boris Gudiksen, Stockholm Observatory, Sweden
An 'ab initio' approach to the solar coronal heating problem

25 February 2004
Mattias Marklund, Department of Electromagnetics, Chalmers, Sweden
Generation and detection of gravitational waves
10 March 2004
Susanne Hoefner, Uppsala Astronomical Observatory, Sweden
Dynamical Processes in AGB Stars: Models meet Observations

17 March 2004
Susanne Hüttemeister, Astronomical Institute at the University of Bochum, Germany
Moderate luminosity mergers

5 April 2004
Göran Olofsson, Stockholm Observatory, Sweden
Absorption observations with Odin and the OSO 20 m telescope of W49, W51 and G34.3+0.1

14 April 2004
Per-Olof Hult, Physics Department, Stockholm University, Sweden
Detecting neutrinos with the AMANDA and IceCube telescopes

28 April 2004
Vera Könyves, Eötvös University, Budapest, Hungary
Young stellar objects in the LDN1188 dark cloud complex

5 May 2004
Silvia Casu, Osservatorio Astronomico di Cagliari, Italy
The elusive nature of diffuse interstellar clouds

12 May 2004
Jesper Sollerman, Stockholm Observatory, Sweden
The Biggest Bangs: Supernovae, Gamma Ray Bursts and X-Ray Flashes

6 September 2004
Jerry Sobieski, Advanced Network Services and Research Initiatives for the Mid-Atlantic Crossroads (MAX), Washington DC, USA
Dynamic Resource Allocation over GMPLS Optical Networks

15 September 2004
Roy Booth, Onsala Space Observatory
The Square Kilometre Array (SKA)

23 September 2004
Sun Kwok, University of Calgary, Canada
Stardust from Planetary Nebulae to the Solar System

29 September 2004
Michele Pestalozzi & Anders Jerkstrand, Onsala Space Observatory, Sweden
Methanol Masers and the Protostellar Disc in NGC 7538
6 October 2004
Jiyune Yi, Onsala Space Observatory, Sweden
SiO Masers in TX Cam

20 October 2004
Jan Johansson, SP – Swedish National Testing and Research Institute & OSO, Sweden
Aspects of Time Transfer

27 October 2004
Torben Andersen, Lund Observatory, Sweden
Extremely Large Optical Telescopes

10 October 2004
Peter Forkman, Onsala Space Observatory
Aeronomy Observations at Onsala

17 November 2004
Henrik Olofsson, Onsala Space Observatory
Odin Results on Star Forming Regions

24 November 2004
René Liseau, Stockholm Observatory
Stellar Discs

1 December 2004
John Black, Onsala Space Observatory
Crises in Interstellar Chemistry

8 December 2004
Cathy Horellou, Onsala Space Observatory
Cosmology Using the Sunyaev-Zeldovich Effect

2 February 2005
Franck LePetit, Onsala Space Observatory, Observatoire de Paris, Meudon, France
Fuse Results Concerning the Diffuse and Translucent Clouds

14 February 2005
Lincoln Greenhill, Harvard Smithsonian CfA, Cambridge, USA
Refitting the VLA for Operation in the VHF Band and Study of the Cosmological Epoch of Reionization

18 February 2005
Steven Shore, University of Pisa, Italy
Turbulence in the interstellar medium
9 March 2005
Rüdiger Haas, Onsala Space Observatory
Earth rotation observations with geodetic VLBI – What did we learn from CONT02?

26 April 2005
Jim Cohen, Jodrell Bank Observatory, Manchester, UK
Masers and Star-formation

27 April 2005
Nate Bastian, University of Utrecht, The Netherlands
Star Cluster Complexes in the Hierarchy of Star Formation

29 April 2005
Malcolm Fridlund, ESTEC/ESA, Noordwijk, The Netherlands
Disks – from Starformation to Planetformation to Debris

4 April 2005
Florence Durret, Institut d’Astrophysique de Paris, France
War and peace in clusters of galaxies – Recent results from X-ray and optical observations

12 April 2005
Eric Herbst, Ohio State University, Columbus, USA

18 May 2005
Melvyn Davies, Lund Observatory, Seden
The Stars of the Galactic Centre

7 June 2005
Ralph Sutherland, Visiting guest at Uppsala Astronomical Obs., from Australia RSAA/ANU
Modelling the Dynamical Evolution of gps/css and FR II Type Radio Galaxies

14 June 2005
Ron Allen, Science Division, Space Telescope Science Institute, Baltimore, USA
Astronomy, Physics, and the Origin of the CO – Radio Continuum Correlation in Nearby Normal Galaxies

7 September 2005
Per Bergman, APEX/Onsala Space Observatory
First observations with APEX

5 October 2005
Andreas Korn, Uppsala University, Sweden
Cosmochemistry using Cool Stars – Pitfalls and Prospects
12 October 2005
Jean-Baptiste Juin, Service d’Astrophysique, Saclay, France
Wide-field Sunyaev-Zeldovich galaxy clusters observation selection function and cosmological implications

1 December 2005
Rodrigo Parra, Onsala Space Observatory
Radio Observations of Luminous Infra Red Galaxies

9 December 2005
Jerry Sobieski, Advanced Network Services (MAX), USA
Global Realtime E-VLBI

19 Conference, talks, visits to other institutes

19.1 Participation in conferences etc.; talks; visits to other institutes

Titles of talks are given in italics. A * indicates an invited talk. Public talks are mentioned in Sect. 14 on Public outreach. (The list is not entirely complete.)

Susanne Aalto
*Dense Gas, Chemistry and Star Formation in Luminous Galaxies, “European Workshop on Astronomical Molecules: Dense Molecular Gas around Protostars and in Galactic Nuclei”, Zwolle, the Netherlands, 18–20 February 2004
Invited review for “The Evolution of Starbursts” in Bad Honnef, Germany, August 2004
Invited review for IAU Symposium No. 231, “Astrochemistry throughout the Universe: Recent successes and current challenges”, Asilomar, CA, 29 August – 2 September 2005
Invited review for ”Astronomdagarna”, Uppsala, October 2005
Invited review at the workshop in ”Extragalactic and Galactic ISM Modelling in an ALMA Perspective” Chalmers/Onsala October 2005
Invited review for the Royal Astronomical Society – Special Discussion, December 2005
Invited talk at Cavendish laboratoy, Cambridge, February 2004
Invited talk at KVVS workshop on “Bilden i vetenskapen”, Göteborg, October 2004
Invited talk at Lund observatory, March 2005
Invited talk at University of Cologne, September 2005
Visit to Institute of Physics, University of Cologne, September 2005

Dan Anderson
Visit to Culham Science Center, Abingdon, England to give a lecture at the Culham Summer School on Plasma Physics on 30 July 30 2004 and again 21 July 2005
ESA Headquarter in Paris, France, discussions about European Space Technology Harmonization, 25 January 2005
ESTEC, Nordwijk, The Netherlands, discussions about European Space Technology Harmonization, 4 July 2005

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Microwave breakdown in RF equipment, Microwave breakdown in the transition region between multipactor and corona discharge, Microwave breakdown in the TE11 mode in a cylindrical wave guide, RVK05 (National Swedish Conference on Radio Science), 14–16 June 2005

Jan Askne
Interferometric InSAR Observations of Boreal Forest Stands, “4th International Symposium on Retrieval of Bio- and Geophysical Parameters from SAR Data for Land Application”, Innsbruck, Austria, 16–19 November 2004

Elina Asp
Secondee at JET (Joint European Torus), England, November–December 2005

John Black
APEX meeting, Albanova, Stockholm University (speaker), 2 March 2004

Interstellar Absorption Across the Electromagnetic Spectrum, seminar at Stockholm Observatory, 19 March 2004

“Benchmarking PDR codes”, international workshop at the Lorentz Center, Leiden University, The Netherlands, 5–9 April 2004

Spectroscopy of dilute gas in space, seminar at Onsala presented to a visiting research group from AstraZeneca, 11 May 2004

Interstellar absorption across the electromagnetic spectrum, seminar at the Institute for Advanced Study, Princeton, NJ, USA, 22 September 2004

Challenges and embarrassments in interstellar chemistry, Interstellar medium and star formation seminar at Princeton University, Dept. of Astrophysical Sciences, 20 September 2004

Informal seminar, University of Crete, Dept. of Physics, 22 March 2005

*Submillimeter astronomy: from the Sun to the most distant galaxies, the workshop “Understanding the Universe through IR and Submillimeter Astrophysics”, sponsored by the South-East Laboratory Astrophysics Consortium (SELAC), at the University of Kentucky, Lexington, KY, USA, 2–3 May 2005

Crisis in interstellar chemistry, Astrophysics seminar, Department of Physics and Astronomy, University of Kentucky, Lexington, KY, USA, 4 May 2005

Crisis in interstellar chemistry, Physics Colloquium, Department of Physics and Astronomy, University of Cincinnati, Cincinnati, OH, USA, 5 May 2005

Crises in interstellar chemistry, Joint Colloquium, Steward Observatory and the National Optical Astronomy Observatories, at University of Arizona, Tucson, AZ, USA, 25 August 2005

*Future of astrochemistry, “Symposium Number 231 of the International Astronomical Union”, Asilomar Conference Center, Pacific Grove, California, USA, 28 August – 2 September 2005 (also panel discussion member)

*Transient molecules, international workshop on “Galactic and extragalactic ISM modelling in an ALMA perspective”, Chalmers, Göteborg, 13–15 October 2005

Short-term member, School of Natural Science, Institute for Advanced Study, Princeton, NJ, USA, 7 September – 15 October 2004 (Invited by John Bahcall.)

Research visit, Steward Observatory, University of Arizona, Tucson, AZ, USA, 21–27 August 2005
Roy Booth
“European Workshop on Astronomical Molecules: Dense Molecular Gas around Protostars and in Galactic Nuclei”, Zwolle, the Netherlands, 18–20 February 2004
APEX meeting, Albanova, Stockholm University (speaker), 2 March 2004
“Exploring the Cosmic Frontiers”, Berlin, Germany, 18–21 May 2004
Observations at Giant Metrewave Radio Telescope (GMRT), Pune, India, 16–22 March 2005
Talk on APEX at the “XXVIIIth General Assembly of the International Union of Radio Science (URSI)”, New Delhi, India, 23–27 October 2005

Samuel Brohede
Odin/OSIRIS global NO2 and O3 climatology, “XX Quadrennial Ozone Symposium”, Kos, Greece, 1–8 June 2004
DOAS retrievals of Stratospheric O3 and NO2 from Odin/OSIRIS Limb Scattered Sunlight Measurements, European Geosciences Union, 1st General Assembly, Nice, France, 25–30 April 2004

John Conway
“Dense Gas around Protostars and Galactic Nuclei”, Zwolle, Netherlands, February 2004
“Astronomdagar”, Uppsala, October 2005,
High resolution Radio Observations of Circumnuclear and Circumstellar Disks. Seminar presented at Lund University Astronomy Department, November 2005

Mattias Ekström
*Retrieval of upper tropospheric humidity from Odin SMR, “The International Workshop on Submillimeter Wave Earth Observations”, Kyoto, Japan, 14–15 November 2005

Gunnar Elgered

Annika Eriksson
Electromagnetic particle pinch due to toroidal drift waves, “10th EU-US Transport Task Force workshop”, Varenna, Italy, 6–9 September 2004
Electromagnetic Effects on turbulent particle transport, EU-US Transport Task Force Workshop, Cadarache, France, 26–29 September 2005
Secondee at JET (Joint European Torus, England, November–December 2005

Leif Eriksson

Stem Volume Retrieval with Spaceborne L-band Repeat-pass Coherence: Possibilities and Limitations for Boreal Forest, “4th International Symposium on Retrieval of Bio- and Geophysical Parameters from SAR Data for Land Applications”, Innsbruck, Austria, 16–19 November 2004


“Nationellt fjärranalysseminarium 2005”, Skåvsvöholm, Sweden, 10–11 February 2005

“6th Science Panel Meeting of the ALOS Kyoto and Carbon Initiative”, Tokyo, Japan, 28 February – 3 March 2005

Forest change detection with spaceborne L-band SAR, “ForestSat 2005”, Borås, Sweden, 31 May – 3 June 2005

“3rd ALOS Cal/Val and Science Team Meeting”, Tokyo, Japan, 27–30 June 2005

“TCOS-SIBERIA-II Final Symposium”, Jena, Germany, 13–15 July 2005


Patrick Eriksson

*Satellite sub-mm atmospheric sounding, “Terahertz Technology for Space and Earth Applications”, QinetiQ, Malvern, UK, 5 December 2005

*Global miljömätteknik till samhällets nytta, “Rymdforum 05”, Trollhättan, 15–16 September 2005

Retrieval of high altitude ice clouds from Odin sub-mm observations, European Geophysical Union, General Assembly, Vienna, Austria, 24–29 April 2005

Klas Folkesson


Peter Forkman

Uncooled low noise frontend of the receiver system for ground-based monitoring of stratospheric ozone and carbon monoxide, The 5th International Kharkov Symposium “Physics and Engineering of Millimeter and Sub-Millimeter Waves” (MSMW’04), Kharkov National University, Ukraine, 21–26 June 2004

H₂O measurements from Onsala, Odin Science Meeting, Chalmers University of Technology, 24–26 October 2005

“Hands-On Universe, Training Workshop”, Torun, Poland, 20–23 October 2005 (with presentation of the new student antenna)
Tünde Fülöp
Budapest University of Technology, Budapest, Hungary, July 2005
Culham Science Center, Abingdon, England, 28 November – 2 December 2005
Runaway electron generation in fusion plasmas, at the yearly meeting of the Swedish Physics Association (Svenska Fysikersamfundet), Section for Mathematical Physics, 21 November 2005
Electron kinetics in a cooling plasma, Kinetikseminariet, Matematiska Vetenskaper, Chalmers, June 2005

Bo Galle
Massachusetts Institute of Technology, Discussions about results from the MCMA-2003 campaign in Mexico City, Cambridge, USA, 11–13 January 2004
United States Geological Survey, Discussions about participation in the NOVAC project, Portland, USA, 14–15 January 2004
Universidad Nacional Autonoma de Mexico, Discussions about cooperation related to measurements of gases form Popocatepetl Volcano, and participation in the MILAGRO campaign in Mexico City in March 2006, Mexico City, 18–24 January 2004
Instituto Mexicana Petrolea, Discussions on a joint project on using optical remote sensing to study emissions from refineries in Mexico, Mexico City, 18–24 January 2004
Instituto Potosini de Investigacion Cientifica y Tecnologica, Discussion on participation in the project IANABIS, San Luis Potosi, Mexico, 26–28 January 2004
Meeting with The Nyiragongo Scientific Advising Committee for the Inter-agency Volcanic Risk Management (NSAC), Naples, Italy, 25–29 June 2004
NOVAC planning meeting, Heidelberg, Germany, 23–28 September 2004
Texas Air quality council, TEXAQ-II field campaign meeting, Austin , October 2004
Department of Meteorology at Stockholm University (MISU), 2 December 2004
Universidad Nacional Autonoma de Mexico, Discussions about cooperation related to measurements of gases form Popocatepetl Volcano, and participation in the MILAGRO campaign in Mexico City in March 2006, Mexico City, 27 January – 6 February 2005
Instituto Mexicana Petrolea, Discussions on a joint project on using optical remote sensing to study emissions from refineries in Mexico, Mexico City, 27 January – 6 February 2005
Houston Air Research Council (HARC), April 2005
Beijing Environmental Monitoring Center, Discussions on the use of Optical Remote Sensing for monitoring of air pollution in Beijing, Beijing, China, 3–6 April 2005
Anhui Institute of Optics and Fine Mechanics, Discussion on cooperation projects, Hefei, China, 7–9 April 2005
Universidad El Salvador, Discussions on future cooperation projects, San Salvador, El Salvador, 11 October 2005
Gas and heat emissions from the lava lake of Nyiragongo volcano (D.R. Congo), Cyclic degassing behaviour at San Cristobal and Telica Volcanoes, Nicaragua, “Volcanism and its impact on society”, IAVCEI General Assembly, Pucon Chile, 14–19 November 2004
Description and first results of the mini-doas instruments for gas emission monitoring installed at GVO in March 2004. Eruptive and passive degassing of sulfur dioxide from the Virunga volcanoes, First meeting of the Nyiragongo Scientific Advising Committee for the Inter-agency Volcanic Risk Management Project (NSAC), Possuoli, Naples, Italy, 25–26 June 2004


Dual-Beam mini-DOAS spectroscopy, a novel approach for volcanic gas emission monitoring. Gas emissions from Nyiragongo volcano, measured by UV mini-DOAS spectroscopy, IAVCEI Commission on the Chemistry of Volcanic Gases 9th Workshop, Sicily, 1–10 May 2005

Rüdiger Haas
“The 3rd IVS General Meeting”, Ottawa, Canada, 9–11 February 2004 (posters: Calculating Mapping Functions from the HIRLAM Numerical Weather Prediction Model, with B. Stoyanov and L. Gradinarsky, Comparison of Ionospheric Activity derived from GPS and different VLBI Networks, with S. Bergstrand, Investigations of high-frequency earth rotation variations from VLBI CONT observations, with R. Del Cojo Lopez and J. Mata Lozano)

“The 15th International Symposium on Earth Tides”, Ottawa, Canada, 2–6 August 2004 (poster: Sub-diurnal Earth rotation variations from VLBI CONT campaigns, with J. Wünsch)

*Analysis strategies and software for geodetic VLBI, “The 7th EVN Symposium”, 12–15 October 2004

VLBI för geodesi och geodynamik, oral presentation at SUNET TREFpunkt Göteborg, 21 October 2004

*Integrating Tropospheric Parameters From Different Observing Techniques, oral presentation at AGU 2004 Fall Meeting, 13–16 December 2004

*Global Geodynamics With Geodetic VLBI, seminar at Alba Nova University Center, Stockholm, 25 February 2005


Björn Hallberg


Åke Hjalmarson
*Molecular line searches from the Odin satellite*, “The Dusty and Molecular Universe – A prelude to Herschel and ALMA”, Paris, 27–29 October 2004

*New Odin results of importance for Herschel observation planning, ”Herschel Preparatory Science Workshop” at the Lorentz Center, Leiden, 14–17 December 2004

IAU Symposium No. 231, “Astrochemistry throughout the Universe: Recent successes and current challenges”, Asilomar, CA, 29 August – 2 September 2005 (two Odin posters by Persson et al., one Odin poster by Wiström et al.)

*Odin’s hunt for molecules, ”Hunt for Molecules”, Paris, 19–20 September 2005

*Lessons on oxygen chemistry from Odin observations of H$_2$O and O$_2$, “Workshop in Extra-galactic and Galactic ISM Modelling in an ALMA Perspective”, Göteborg/Onsala, October 2005

**Igor Holod**


**Cathy Horellou**

Visit to Institute for Advanced Study, Princeton, USA, 6 September – 15 October 15 2004

*Constraining the cosmological temperature-redshift relation using the SZ effect, at the workshop “SZ with ALMA”, Orsay, France, Apr. 8, 2005

*Cosmology using the Sunyaev-Zeldovich effect, seminar held at the Astronomy Dept at the University of Heraklion, Crete, March 22, 2005

*Cosmology using the Sunyaev-Zeldovich effect, seminar held at Stockholm Observatory, March 4, 2005

*Contraindre le modèle cosmologique par l’effet Sunyaev-Zeldovich, seminar given at the Service d’Astrophysique of the Commissariat à l’Energie Atomique (CEA) in Saclay, France, December 21, 2004

*Cosmology using the Sunyaev-Zeldovich effect, seminar given at Onsala Space Observatory, Sweden, December 8, 2004

*Cosmology using the Sunyaev-Zeldovich effect, seminar given at Lund Observatory, Sweden, November 25, 2004

*Universums mörka energi, lecture in the series on energy techniques, organised by POEM (Programområde Energi och Miljö) held at Chalmers, Göteborg, April 22, 2004

*Dark energy and the evolution of spherical overdensities, “Exploring the Universe – Contents and Structures of the Universe”, La Thuile, Italy, March 28 – April 4, 2004

*APEX observations of the cosmic microwave background, APEX meeting, Albanova, Stockholm University, 2 March 2004

**Mattias Johansson**

*Tomographic reconstruction of gas plumes using scanning mini-DOAS instruments, “IAVCEI Commission on the Chemistry of Volcanic Gases 9th Workshop”, Sicily, 1-1-0 May 2005

**Ulf Jordan**

*Microwave breakdown in RF equipment, Microwave breakdown in the TE11 mode in a cylindrical wave guide, RVK05 (National Swedish Conference on Radio Science), 14–16 June 2005
Nicolas Lautié
*Odin/SMR global measurements of water vapour and its isotopes in the stratosphere and the mesosphere*, “XXth Quadrenn. Ozone Symp.”, Kos, Greece, 1–8 June 2004

Mietek Lisak
Szczecin University of Technology, Szczecin, Poland, 12–15 March 2004

*Fast electron bremsstrahlung in low density, grassy sawtoothing plasmas on JET*, “Annual Meeting of the Swedish Fusion Research Unit”, 19–21 April 2004


Johan Mellqvist

Remote Sensing in the Ultraviolet and Infrared during MCMA 2003, *Quantification of emissions of SO2 NO2 and HC from Tula industry area*, “MCMA-2003 Field Measurements Campaign Data Analysis Workshop”, Cambridge, USA, 7–9 January 2004

Mobile column measurements of CO in megacities, “The XVIII Quadrennial Ozone Symposium”, Greece, 2004


Hans Nordman


Henrik Olofsson

*Molecular cloud spectroscopy with the Odin satellite*, seminar given at AlbaNova, Stockholm University, 13 February 2004

*Molecular line spectroscopy with the Odin submm space telescope*, seminar given at Max Planck Institut für Radioastronomie, Bonn, Germany, 27 April 2004

*Molecular line spectroscopy with the Odin submm space telescope*, seminar given at McMaster University, Hamilton, Canada, 28 July 2004

*Odinresultat*, “Svenska Rymdforskares Samarbetsgrupp”, Kiruna, 9–10 March 2004


“Herschel workshop”, Leiden, 14–17 December 2004

*Måttningar med radioastronomisatelliten Odin*, “Svenska Rymdforskares Samarbetsgrupp”, Uppsala, 15–16 March, 2005


Evert Olsson
A Molecular Ring in the Liner NGC 5218, “European Workshop on Astronomical Molecules: Dense Molecular Gas around Protostars and in Galactic Nuclei”, Zwolle, the Netherlands, 18–20 February 2004

Rodrigo Parra
A Thin Ring Model for the OH Megamaser in IIIZw53, “European Workshop on Astronomical Molecules: Dense Molecular Gas around Protostars and in Galactic Nuclei”, Zwolle, the Netherlands, 18–20 February 2004

Michele Pestalozzi
NGC7538 IRS1 N: Modelling a Circumstellar Maser Disk, “European Workshop on Astronomical Molecules: Dense Molecular Gas around Protostars and in Galactic Nuclei”, Zwolle, the Netherlands, 18–20 February 2004

Bengt Rydberg
*Sub-mm wave radiometric observations of ice clouds, “The international workshop on sub-millimeter wave Earth observation”, Kyoto, Japan, 14–15 November 2005

Jerker Samuelsson
Mobile IR- and UV-Spectroscopic Measurements of CO, SO2 and VOC in Megacities, The structure of the planetary boundary layer in Mexico City during the MCMA-2003 field campaign, Open-path emission factors derived from DOAS and FTIR Measurements in Mexico City Metropolitan Area, Separation of emitted and photochemical formaldehyde in Mexico City using a statistical analysis and a new pair of gas phase tracers, AGU Fall meeting, San Francisco, 13–17 December 2004

Patrik Sandquist

Fast electron bremsstrahlung in low density, grassy sawtoothing plasmas on JET, “Annual Meeting of the Swedish Fusion Research Unit”, 19–21 April 2004

Håkan Smith
Institute for Fusion Studies, University of Texas at Austin, Austin, Texas, USA, 26 September – 14 November 2004

Culham Science Centre, Abingdon, UK, 5–9 December 2005

Runaway electron generation in a cooling plasma, “Annual Meeting of the Swedish Fusion Research Unit”, Studsvik, 19–21 April 2004

Gary Smith-Jonforsen
“Nationellt fjärranalysseminarium 2005”, Skåvsjöholm, Sweden, 10–11 February 2005

*Applications of Low-Frequency SAR, lecture at Saab Ericsson Space, Göteborg, Sweden, 8 June 2004

*Synthetic Aperture Radar for Forest Mapping, lecture at Danish Center for Remote Sensing, Technical University of Denmark, 21 March 2005

*Mapping wind-thrown forest with radar: Experience from January 2005 in Southern Sweden, lecture at Department of Physical Geography and Ecosystem Analysis, Lund University, Sweden, 19 May 2005

Pär Strand

Effects of impurities on driftwave based particle transport and comparison with neoclassical theory, Effect of Poloidal Rotation on the Dynamics of the ITB’s and Transport in JET Plasmas, 32nd EPS Conference on Plasma Physics, Tarragona, Spain, 26 June – 1 July 2005

Anders Strandberg

Magnus Thomasson
APEX meeting, Albanova, Stockholm University, 2 March 2004

Rafal Tomala
Microwave breakdown in the TE11 mode in a cylindrical wave guide, RVK05 (National Swedish Conference on Radio Science), 14–16 June 2005

Richard Udiljak
Microwave breakdown in the transition region between multipactor and corona discharge, RVK05 (National Swedish Conference on Radio Science), 14–16 June 2005

Joachim Urban

*Global observations of stratospheric trace gases with the Odin Sub-Millimetre Radiometer: Requirements on spectroscopy, “European Geophysical Union General Assembly”, Vienna, Austria, 24–29 April 2005

*Observations of stratospheric trace gases with the Odin Sub-Millimetre Radiometer: First results and requirements on spectroscopy, Critical Evaluation of mm-/submm-wave Spectroscopic Data for Atmospheric Observations, Mito, Japan, 28–29 January 2004

Jan Weiland
Predictive simulations using a parameter dependent correlation length, Presentation given at the 7th meeting of the ITPA Confinement, Database & Modelling Topical Group, Lissabon, Portugal, 8–10 November 2004

Effects of temperature ratio on JET transport in hot ion and hot electron regimes, Shear, temperature gradient and collisionality dependences of particle pinches in JET; Predictive modelling of electron temperature modulation experiments in JET L and H mode plasmas; Comparison of anomalous and neoclassical contributions to core particle transport in tokamak discharges, 31th EPS Conference on Plasma Physics, London, UK, 28 June – 2 July 2004

“Task-Force T workshop” at JET, Culham, UK, 24–27 January 2004 (with presentation of the new version of the transport model)

“Task-Force T workshop” at JET, Culham, UK, 24–27 January 2005 (with presentation of the new version of the transport model)

*The Weiland model, background and development*, CEA Cadarache, France, 21 June 2005

*The Weiland model, background and development*, Department of Nuclear Engineering, Kyoto University, Japan, 9 September 2005


*Simulations of JET, AUG and DIII-D shots with varying temperature ratio, Electromagnetic Particle Pinches*, presentation given at the 8th meeting of the ITPA Confinement, Database & Modelling Topical Group, Kyoto, Japan, 18–21 April 2005

The Swedish RU meeting, 17–18 October 2005 (with presentation of the Chalmers overview and the Swedish transport research in relation to the new EU strategies)

Secondee at JET (Joint European Torus), England, November–December 2005

**Anders Winnberg**
Visiting Professor, National Astronomical Observatory, Mitaka, Japan, 1 November 2003 – 31 January 2004

**Millimeter and Submillimeter-Wave Observations of Comets**, Faculty of Science, Okayama University, Japan, 15 January 2004

**OH/IR Stars and the Rotation of the Galactic Bulge**, Department of Astronomy, Kyoto University, Japan, 16 January 2004

**Yu Yong**

### 19.2 Conferences and workshops organised by the Department of Radio and Space Science and Onsala Space Observatory

**Odin Astronomy Workshop, 24–26 September 2004**
An international workshop with some 35 participants from Canada, France and Sweden was organized by Åke Hjalmarson at Onsala Space Observatory and the Gottskär Conference Centre. This fourth Odin Astronomy Workshop at Onsala was dedicated to presentations of new results, progress towards new publications, and planning of the year 2005 Odin observing program.

**Extragalactic and Galactic ISM Modelling in an ALMA Perspective, 13–15 October 2005**
A RadioNet supported workshop, with 56 participants, at Chalmers, with Susanne Aalto as main organizer and SOC chair. The background for the workshop was that ALMA’s unprecedented angular resolution and sensitivity will offer a cloud-scale view of galaxies to the extragalactic community. The models needed to interpret ALMA’s high resolution data require careful consideration already today and warrant a dialogue between the Galactic and extra-galactic communities. Central to this discussion is whether we can treat the extreme environments often encountered in the cores of deeply embedded starbursts simply as scaled-up
versions of Sgr B2 and M82 or whether these environments are different enough to require a novel approach. At the core of this question is whether starburst processes are the same everywhere – and thus independent of variations in large-scale molecular cloud properties and environment. Extragalactic and Galactic astronomers – observers and modellers – got together to discuss the challenges of ALMA and how the scientific issues can be address through combining observations and modelling. Website: http://www.oso.chalmers.se/workshop/

Möte om havsistillämpningar av SAR, Chalmers, Göteborg, Sweden, 29 August 2005
A meeting with representatives from the Swedish Meteorological and Hydrological Institute (SMHI) and the Swedish Maritime Administration was organised at Chalmers. The topic for the meeting was the use of SAR images for sea-ice applications. On the agenda were also future common projects and applications for SAR data from new radar satellites. Arranged by Leif Eriksson. 9 participants.

19.3 Other conferences: scientific organizing committee membership

Susanne Aalto
Member of the Scientific Organizing Committee for the European Workshop 2004 on Astronomical Molecules: “Dense Molecular Gas around Protostars and in Galactic Nuclei” in Zwolle, The Netherlands, February 2004
Member of the Scientific Organizing Committee for The 331 Wilhelm und Heraeus Seminar: “The Evolution of Starbursts” in Bad Honnef, Germany, August 2004

Dan Anderson
Member of the organization committee for the 5th International Workshop on Multipactor, Corona and Passive Intermodulation In Space RF Hardware (MULCOPIM’ 2005), ESTEC, Noordwijk, The Netherlands, 12–14 September 2005

John Black
Member of the Scientific Organizing Committee for Symposium Number 231 of the International Astronomical Union (on Astrochemistry), Asilomar Conference Center, Pacific Grove, California, USA, 28 August – 2 September 2005
Member of the Scientific Organizing Committee, international workshop ”Benchmarking PDR codes”, at the Lorentz Center, Leiden University, 5–9 April 2004 April. Note: this workshop has stimulated widespread interest through a website devoted to comparison of theoretical models of photon-dominated molecular clouds in astrophysics and is leading to a peer-reviewed publication.

Roy Booth
Member of the Scientific Organizing Committee of the international meeting “Exploring the Cosmic Frontiers”, Berlin, Germany, 18–21 May 2004

Rüdiger Haas
Convenor for session 6 at the “3rd IVS General Meeting”, Ottawa, Canada, 9–11 February 2004
Convenor for session 2 at the “15th International Symposium on Earth Tides”, Ottawa, Canada, 2–6 August 2004

Cathy Horellou
Member of the International Scientific and Educational Committee of the “Hands-On Universe, Global Conference 2004” held in St Petersburg, Russia, 25–31 July 2004
Mietek Lisak
Member of the Scientific Advisory Committee of the “International Conference on Frontiers of Nonlinear Physics”, Nizhny Novgorod, Russia, 5–12 July 2004
Member of the Scientific Organizing Committee of the “9th IAEA Technical Meeting on Energetic Particles in Magnetic Confinement Systems”, Takayama, Japan, 9–11 November 2005
Member of the Scientific Programme Committee of the “11th European Fusion Theory Conference”, Aix-en-Provence, France, 26–28 September 2005

20 Guests

20.1 Visitors to Onsala Space Observatory

<table>
<thead>
<tr>
<th>Name</th>
<th>Institute, etc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allen, R.J.</td>
<td>Space Telescope Science Institute (STScI), USA</td>
</tr>
<tr>
<td>Andersen, T.</td>
<td>Lund Observatory, Sweden</td>
</tr>
<tr>
<td>Andriyanov, A.</td>
<td>Nizhny Novgorod, Russia</td>
</tr>
<tr>
<td>Beardsmore, A.</td>
<td>University of Kent, England</td>
</tr>
<tr>
<td>Bergé, J.</td>
<td>Service d’Astrophysique de Saclay, France</td>
</tr>
<tr>
<td>Bergman, P.</td>
<td>European Southern Observatory (ESO), Chile</td>
</tr>
<tr>
<td>Breili, K</td>
<td>Universitetet för miljö- och biovetenskap, Norway</td>
</tr>
<tr>
<td>Buckle, J.</td>
<td>United Kingdom Infra-Red Telescope (UKIRT), Hawaii, USA</td>
</tr>
<tr>
<td>Casu, S.</td>
<td>University Degli Studi di Cagliari, Italy</td>
</tr>
<tr>
<td>Cordella, C</td>
<td>National Institute for Astrophysics (INAF-CNR), Italy</td>
</tr>
<tr>
<td>Elia, D.</td>
<td>Institute for Nanostructured Materials Studies (ISMN-CU), Italy</td>
</tr>
<tr>
<td>Engfeldt, A.</td>
<td>Lantmäteriverket, Sweden</td>
</tr>
<tr>
<td>Field, D.</td>
<td>Aarhus University, Denmark</td>
</tr>
<tr>
<td>Fletcher, A.</td>
<td>Max Planck Institute, Germany</td>
</tr>
<tr>
<td>Gitlein, O.</td>
<td>Hannover University, Inst. Für Erdmessungen, Germany</td>
</tr>
<tr>
<td>Godard, B</td>
<td>Orsay University, France</td>
</tr>
<tr>
<td>Gudiksen, B.</td>
<td>Stockholm Observatory, Sweden</td>
</tr>
<tr>
<td>Guillou P.</td>
<td>Orsay University, France</td>
</tr>
<tr>
<td>Gustafsson, M.</td>
<td>Aarhus University, Denmark</td>
</tr>
<tr>
<td>Harju, J.</td>
<td>Helsinki University, Finland</td>
</tr>
<tr>
<td>Hulth, P.-O.</td>
<td>Physics Department, Stockholm University, Sweden</td>
</tr>
<tr>
<td>Hüttemeister, S.</td>
<td>Astronomical Institute at the University of Bochum, Germany</td>
</tr>
<tr>
<td>Höfner, S.</td>
<td>Uppsala University, Sweden</td>
</tr>
<tr>
<td>Jacobson, E</td>
<td>University of Tartu, Finland</td>
</tr>
<tr>
<td>Johansson, J.</td>
<td>SP Swedish National Testing and Research Institute, Sweden</td>
</tr>
<tr>
<td>Kneschke, M.</td>
<td>Universität Hannover, Germany</td>
</tr>
<tr>
<td>Kristensen, L.</td>
<td>Aarhus University, Denmark</td>
</tr>
<tr>
<td>Kus, A.</td>
<td>Nicolaus Copernicus University, Poland</td>
</tr>
<tr>
<td>Kwok, S.</td>
<td>University of Calgary, Canada</td>
</tr>
<tr>
<td>Könyves, V.</td>
<td>Eötvos University, Hungary</td>
</tr>
<tr>
<td>Le Petit, F</td>
<td>Observatoire de Meudon, France</td>
</tr>
<tr>
<td>Levy, A.</td>
<td>Orsay University, France</td>
</tr>
</tbody>
</table>
20.2 Visitors to the Group for Advanced Receiver Development

<table>
<thead>
<tr>
<th>Name</th>
<th>Institute, etc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Lapkin</td>
<td>Institute for Applied Physics, Nizhny Novgorod, Russia (guest scientist)</td>
</tr>
<tr>
<td>M. Lukashevskiy</td>
<td>Moscow Power Engineering Institute (Technical University), Russia</td>
</tr>
<tr>
<td>A. Lubchenko</td>
<td>Moscow Power Engineering Institute (Technical University), Russia</td>
</tr>
<tr>
<td>S. Fedorovich</td>
<td>Moscow Power Engineering Institute (Technical University), Russia</td>
</tr>
<tr>
<td>V. Afanasyev</td>
<td>Moscow Power Engineering Institute (Technical University), Russia</td>
</tr>
<tr>
<td>N. Honingh</td>
<td>KOSMA – Kölners Obs. für Submillimeter und Millimeter Astron., Germany</td>
</tr>
</tbody>
</table>
### 20.3 Visitors to the Nonlinear Electrodynamics group

<table>
<thead>
<tr>
<th>Name</th>
<th>Institute, etc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>V. Semenov</td>
<td>Institute of Applied Physics, Nizhny Novgorod, Russia</td>
</tr>
<tr>
<td>M. Buyanova</td>
<td>Institute of Applied Physics, Nizhny Novgorod, Russia</td>
</tr>
<tr>
<td>D. Dorohzkina</td>
<td>Institute of Applied Physics, Nizhny Novgorod, Russia</td>
</tr>
<tr>
<td>T. Olsson</td>
<td>Powerwave Technologies, Täby, Sweden</td>
</tr>
<tr>
<td>M. Forzati</td>
<td>Acreo, Stockholm</td>
</tr>
<tr>
<td>A. Berntson</td>
<td>Acreo, Stockholm</td>
</tr>
<tr>
<td>O. Ågren</td>
<td>Uppsala Universitet, Uppsala</td>
</tr>
<tr>
<td>V. Moiseenko</td>
<td>Uppsala Universitet, Uppsala</td>
</tr>
<tr>
<td>P. Shukla</td>
<td>Ruhr-Universität Bochum, Germany</td>
</tr>
<tr>
<td>J. Dudley</td>
<td>Université de Franche-Comte, Besançon, France</td>
</tr>
<tr>
<td>F. Lederer</td>
<td>Friedrich-Schiller-Universität Jena, Germany</td>
</tr>
<tr>
<td>J. Drake</td>
<td>KTH, Stockholm</td>
</tr>
<tr>
<td>P. Helander</td>
<td>Culham Science Center, Abingdon, England</td>
</tr>
<tr>
<td>B. Breizman</td>
<td>University of Austin, Texas, USA</td>
</tr>
<tr>
<td>S. Sharapov</td>
<td>JET, Abingdon, England</td>
</tr>
<tr>
<td>F. Cattani</td>
<td>University of Pisa, Italy</td>
</tr>
<tr>
<td>A. Kim</td>
<td>Institute of Applied Physics, Nizhny Novgorod, Russia</td>
</tr>
<tr>
<td>T. Lewin</td>
<td>Ericsson Microwaves</td>
</tr>
<tr>
<td>D. Raboso</td>
<td>ESA, Nordwijk, The Netherlands</td>
</tr>
<tr>
<td>A. Larsson</td>
<td>FOI – Swedish Defence Research Agency</td>
</tr>
<tr>
<td>O. Bang</td>
<td>Denmark Technical University, Lyngby, Denmark</td>
</tr>
<tr>
<td>J. Wyller</td>
<td>Norwegian University of Life Sciences, Ås, Norway</td>
</tr>
<tr>
<td>J. Puech</td>
<td>Centre Nationale d’Etudes Spatiale, Toulouse, France</td>
</tr>
<tr>
<td>K. Gal</td>
<td>KFKI Research Institute for Particle and Nuclear Physics, Budapest, Hungary</td>
</tr>
<tr>
<td>L.G. Eriksson</td>
<td>CEA Cadarache, France</td>
</tr>
<tr>
<td>G. Pokol</td>
<td>Budapest University of Technology, Hungary</td>
</tr>
</tbody>
</table>

### 20.4 Visitors to the Transport Theory group

<table>
<thead>
<tr>
<th>Name</th>
<th>Institute, etc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>T. Davydova</td>
<td>Institute for Nuclear Research</td>
</tr>
<tr>
<td>A. Kritz</td>
<td>Lehigh University, Bethlehem, PA, USA (month-long visit)</td>
</tr>
<tr>
<td>A. Zagorodny</td>
<td>Bogoliubov Institute for Theoretical Physics, Kiev, Ukraine (two month-long visits)</td>
</tr>
<tr>
<td>V. Zasenko</td>
<td>Bogoliubov Institute for Theoretical Physics Kiev, Ukraine (month-long visit)</td>
</tr>
</tbody>
</table>
21 Abbreviations

Some of the abbreviations used in this report:

AGB  Asymtopic Giant Branch
AGN  Active Galactic Nucleus
ALMA Atacama Large Millimeter Array
AOS  Acousto-optical spectrometer
APEX Atacama Pathfinder Experiment
COSPAR Committee on Space Research
CFRP Carbon Fiber Reinforced Plastic
CNES Centre National d’Etudes Spatiales
CRAF Committee on Radio Astronomy Frequencies
DORSIVA Development of Optical Remote Sensing Instruments for Volcanic Applications
DSB  Dual sideband
EANA European Exo/astrobiology Network Association
EFDA European Fusion Development Agreement
EISCAT European Incoherent Scatter Scientific Association
ESA  European Space Agency
ESF  European Science Foundation
ESFRI European Strategy Forum for Research Infrastructure
ESTEC European Space Research and Technology Centre
EU   European Union
EVG  European VLBI Group for Geodesy
EVN  European VLBI Network
FOI  Swedish Defence Research Agency (Totalförsvarets forskningsinstitut)
FOV  Field of view
FWHM Full width at half maximum
GARD Group for Advanced Receiver Development
GLONASS Global Navigation Satellite System
GMC  Giant Molecular Cloud
GNSS Global Navigation Satellite Systems
GPS  Global Positioning System
GRUL Grundutbildningens lärningsgrupp (at Chalmers)
HEB  Hot electron bolometer
HEMT High Electron Mobility Transistor
IAG  International Association for Geodesy
IAU  International Astronomical Union
IERS International Earth Rotation and Reference System Service
ILP  International Lithosphere Project
ILRS International Laser Ranging Service
IRAM Institut de Radio Astronomie Millimetrique
IRAS Infrared Astronomical Satellite
ITER originally International Thermonuclear Experimental Reactor
ITPA International Tokamak Physics Activities
IVS  International VLBI Service for Geodesy and Astrometry
JCMT James Clerk Maxwell Telescope
22 Publications and Telescope time allocation

Publications

2004


122


2005


## Telescope time allocation 2004–2005

### The Onsala 20 m telescope

The list below shows names of principal investigators and projects for single-dish observations. In addition, the Onsala 20 m telescope is regularly used for VLBI observations by the international astronomical and geodetic communities, also recorded below. The observations are conducted by staff of the National Facility. When scientific projects were not scheduled on the telescope, the time was mainly used for normal maintenance and for tests of new receivers.

<table>
<thead>
<tr>
<th>PI</th>
<th>Title of Proposal</th>
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<tbody>
<tr>
<td><strong>January 2004</strong></td>
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<tr>
<td>Fridlund</td>
<td>Chemistry &amp; Mass Determination of the Molecular Disk Surrounding L1551 IRS5</td>
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<tr>
<td>Karlsson</td>
<td>Searchers for Vinyl Acetylene (C$_2$H$_2$CCH)</td>
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<tr>
<td>Thomasson</td>
<td>CO in the Outer Disc of M51</td>
</tr>
<tr>
<td>Other</td>
<td>Geo-VLBI</td>
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<tr>
<td>Other</td>
<td>Odin SiO observations</td>
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<td><strong>February 2004</strong></td>
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<tr>
<td>Other</td>
<td>Student project</td>
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<tr>
<td>Other</td>
<td>Astro-VLBI</td>
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<tr>
<td><strong>March 2004</strong></td>
<td></td>
</tr>
<tr>
<td>Hüttemeister</td>
<td>The Origin of Galactic Disk Truncations</td>
</tr>
<tr>
<td>Karlsson</td>
<td>Searchers for Vinyl Acetylene (C$_2$H$_2$CCH)</td>
</tr>
<tr>
<td>Manthey</td>
<td>Molecular Gas in the Tidal Structure of Moderate Luminosity Mergers</td>
</tr>
<tr>
<td>Markwick</td>
<td>Chemical Differentiation and Small Scale Structure in B5</td>
</tr>
<tr>
<td>Other</td>
<td>Student project</td>
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<td>Other</td>
<td>Geo-eVLBI</td>
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<tr>
<td><strong>April 2004</strong></td>
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<tr>
<td>Karlsson</td>
<td>Searchers for Vinyl Acetylene (C$_2$H$_2$CCH)</td>
</tr>
<tr>
<td>Thomasson</td>
<td>CO in the Outer Disc of M51</td>
</tr>
<tr>
<td>Black</td>
<td>Radio aeronomy of the atmosphere of Io</td>
</tr>
<tr>
<td>Könyves</td>
<td>The LDN1188 dark cloud complex: observing the YSOs environment</td>
</tr>
<tr>
<td>Moore</td>
<td>The dynamics of molecular outflow sources</td>
</tr>
<tr>
<td>Olofsson</td>
<td>CO, $^{13}$CO, $^{18}$O observations towards W49, W51 and G34.3+0.2</td>
</tr>
<tr>
<td>Other</td>
<td>Go-VLBI</td>
</tr>
<tr>
<td>Other</td>
<td>Astro-VLBI</td>
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</tbody>
</table>
May 2004

Casu Internal Structure of Molecular Clouds
Könyves The LDN1188 dark cloud complex: observing the YSOs environment
Scappini Testing a new model of diffuse clouds on ζ Persei
Other Geo-VLBI
Other Astro-VLBI

June 2004

Other Astro-VLBI

July 2004

Other Geo-VLBI

August 2004

Other Geo-VLBI

September 2004

Other Geo-VLBI

October 2004

Other Astro-VLBI
Other Geo-VLBI

November 2004

Schöier SiS and SiO lineemission as probes of grain formation and dynamics in circumstellar envelopes of AGB stars
Other Astro-VLBI
Other Geo-VLBI

December 2004

Schöier SiS and SiO lineemission as probes of grain formation and dynamics in circumstellar envelopes of AGB stars
Karlsson Searchers for Vinyl Acetylene (C₂H₂CCH)
Karlsson Searchers for Vinyl Acetylene (C₂H₂CCH)
Karlsson Searchers for aminoacetonitrile (H₂NCH₂CN)
Markwick Carbon-Bearing Sulphur Chains in IRC+10216
Alakoz Study of the Regions of Massive Star Formation
Other Geo-VLBI
January 2005

Black  Interstellar Molecules Across the Electromagnetic Spectrum
Black  Molecular absorption line observations, preparatory to HERSCHEL/HIFI
Other  Geo-VLBI

February 2005

Black  Molecular gas associated with the runaway star AE Aurogae
Black  Molecular absorption line observations, preparatory to HERSCHEL/HIFI
Karlsson  Searchers for Vinyl Acetylene ($C_2H_2CCH$)
Karlsson  Searchers for aminoacetonitrile ($H_2NCH_2CN$)
Minier  A search for class I methanol masers towards massive protostars
Other  Astro-VLBI
Other  Geo-VLBI

March 2005

Karlsson  Searchers for Vinyl Acetylene ($C_2H_2CCH$)
Karlsson  Searchers for aminoacetonitrile ($H_2NCH_2CN$)
Krips  Molecular gas in Abell 262 Cluster Galaxies
Markwick  Chemical differentiation in dense cloud cores
Minier  A search for class I methanol masers towards massive protostars
Olsson  The HCN/HCO$^+$ Ratio in LINER Galaxies
Schöier  SiS and SiO line emission as probes of grain formation and dynamics in circumstellar envelopes of AGB stars
Teyssier  Carbon chemistry in Photon Dominated Regions
Thomasson  CO in the outer disc of M51
Other  Geo-VLBI

April 2005

Markwick  Chemical differentiation in dense cloud cores
Thomasson  CO in the outer disc of M51
Schöier  The chemistry in oxygen-rich AGB stars
Other  Astro-VLBI
Other  Geo-VLBI

May 2005

Olsson  The HCN/HCO$^+$ Ratio in LINER Galaxies
Pestalozzi  Extragalactic Methanol
Codella  The interaction between outflows and ambient gas in CB230
Liseau  OSO and Odin map of the Serpens cloud core
Massi  The Draco molecular cloud: star formation in the galactic halo?
Millar  Metal poor gas in Edge Cloud 1 (EC1)
Schöier  The chemistry in oxygen-rich AGB stars
Other  Geo-VLBI

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June 2005

Liseau  OSO and Odin map of the Serpens cloud core
Könyves  The LDN1188 dark cloud complex: observing the YSOs environment
Other  Geo-VLBI

July 2005

Schöier  The chemistry in oxygen-rich AGB stars
Schöier  Yong stars and circumstellar material: Tracing the evolution of low-mass protostars
Other  Geo-VLBI
Other  e-VLBI

August 2005

Salii  Class II Methanol Maser Sources at 19.9 GHZ
Black  Search for an unusual fine-structure transition of nebular helium
Schöier  The chemistry in oxygen-rich AGB stars
Schöier  Yong stars and circumstellar material: Tracing the evolution of low-mass protostars
Persson  NH$_3$ and $^{13}$CO mapping of the S140/L1204 molecular cloud
Vasyunin  Class II methanol maser sources at 37.7 GHz
Other  Geo-VLBI
Other  e-VLBI

September 2005

Other  Geo-VLBI

October 2005

Other  Astro-VLBI

November 2005

Vasyunin  Class II methanol maser sources at 37.7 GHz
Other  Geo-VLBI

December 2005

Kirsanova  Observations of CS(2–1) and $^{13}$CO(1–0) lines toward class II methanol masers situated in Perseus spiral arm
Vasyunin  Class II methanol maser sources at 37.7 GHz
Other  Geo-VLBI
The Onsala 25 m telescope

The Onsala 25 m telescope is regularly used for VLBI observations by the international astronomical community, and also for single-dish projects. The observations are conducted by the staff of the National Facility. In single-dish mode, the telescope was used for studies of the Galactic interstellar medium.