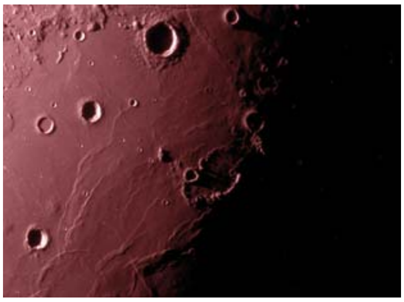
2003

NORDIC OPTICAL TELESCOPE

ANNUAL REPORT

A 'heat image' of the Moon from NOT.

NOT at sunset with dome open and rotating during exposure.



Front cover: The Moon observed with NOT in infrared light, at a wavelength of 3.4 μm. The diffraction limited resolution of the image is 0.4". The highlights appear brighter than the shadows because they are warmer, not due to reflected sunlight as in the visible region.

NORDIC OPTICAL TELESCOPE

The **Nordic Optical Telescope** (NOT) is a modern, well-equipped 2.5-m telescope located at the Spanish Observatorio del Roque de los Muchachos on the island of La Palma, Canarias, Spain. It is operated for the benefit of Nordic astronomy by the Nordic Optical Telescope Scientific Association (NOTSA), established by the national Research Councils of Denmark, Finland, Norway, and Sweden, and the University of Iceland.

The governing body of NOTSA is the **Council**, which determines overall policies, approves the annual budgets and accounts, and appoints the Director and Astronomer-in-Charge. The Council appoints a **Scientific and Technical Committee** (STC) to advise it on the performance and plans for the telescope and other scientific and technical policy matters.

An international **Observing Programmes Committee** (OPC) of independent, experienced scientists is appointed by the Council to perform peer review and scientific ranking of the observing proposals submitted. Each member has a substitute to broaden the scientific basis for the review, ensure that a full OPC can always meet, and resolve any potential conflicts of interest. Based on the ranking by the OPC, the Director prepares the actual observing schedule.

The **Director** has overall responsibility for the operations of the NOT, including staffing, financial matters, and external relations. The staff on La Palma is led by the **Astronomer-in-Charge**, who has authority to deal with all local and urgent matters related to the operation of NOT.

The composition of the Council and committees in 2003 is listed at the end of this report. Contact information to NOT itself is also provided there.

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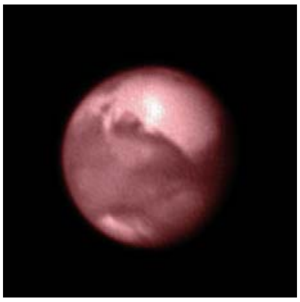


Mars at 2 µm (see p. 21).

Editor: Johannes Andersen
Layout: Anne Marie Brammer

2 OUR STAFF

The NOT team welcomed four new staff members in 2004: Angela Toledo assists us in the La Palma office since September 1; Saskia Prins took up a new post as Data Flow Scientist on October 1; Dr. Wang Xunhao came as a one-year Visiting Scientist from Yunnan Observatory, China, from mid-November; and Dr. Henricus Cornelis (Eric) Stempels started as an Instrument Specialist for the FIES spectrograph on December 1. NOT student Geir Oye returned to Norway in December after a one-year term. As of January 1, 2004, the NOT staff then consists of the following persons (plus the Director, next page):

In accordance with the international agreements establishing the Canarian observatories, NOTSA also provides stipends for two Spanish students wishing to obtain their Ph.D.s at Nordic Universities. In 2003, these were Miguel de Val Borro, Stockholm, and Antonio Lopez Merino, Copenhagen.

Francisco Armas
Administrator

Thomas Augusteijn
Astronomer-in-Charge

Peter Brandt
Mechanic

Jacob W. Clasen
Software specialist

Graham Cox
Electronics engineer

Loida Fernández
Secretary

Eva Jurlander
Accountant

Arto Järvinen
Ph.D. student

Silva Järvinen
Ph.D. student

Amanda Kaas
Senior staff astronomer

Carlos Pérez
Electronics technician

Saskia Prins
Data flow scientist

Tapio Pursimo
Staff astronomer

Eric Stempels
Instrument specialist

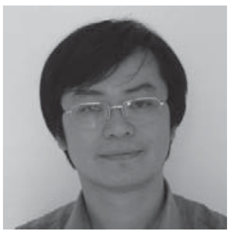
Peter M. Sørensen
Software specialist

Ingvar Svärdh
Software engineer

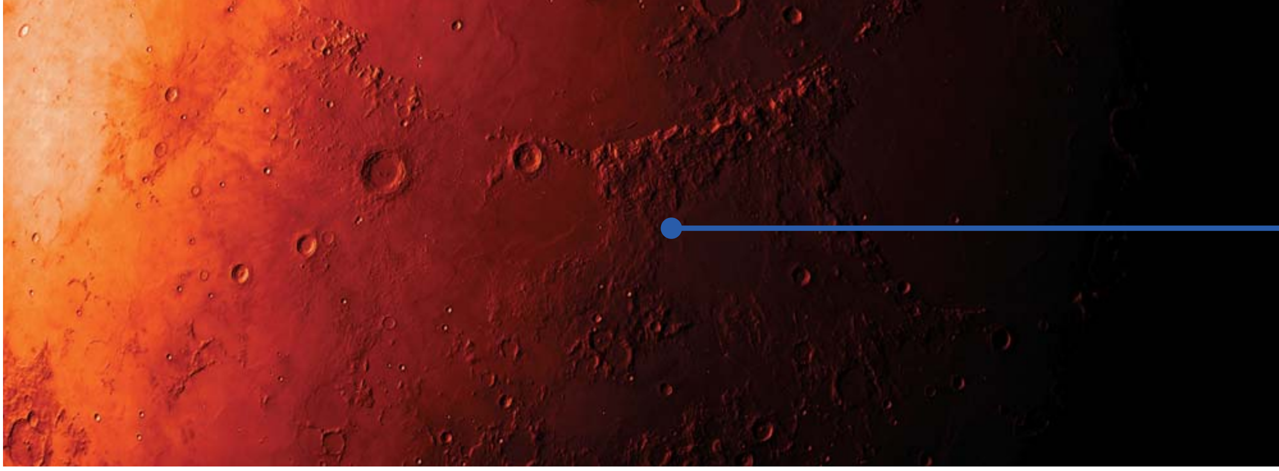
John Telting
Staff astronomer

Angela Toledo
Secretary

Markku Verkkoniemi
System manager



Wang Xunhao
Visiting scientist



PREFACE

2003 was another good year at NOT, with outstanding operational reliability. From the users' perspective, the main innovation in 2003 was probably the introduction of service observing over the summer. Much valuable experience was gained on how to organise this service effectively, and we expect to gradually expand it in the future.

In a long-term perspective, the successful OPTICON *Integrated Infrastructure Initiative* proposal to the EU Framework Programme 6 will no doubt be considered the most significant event of the year (more detail on p. 4). The 19.2 MEuro grant is a handsome result by itself, but the reward for the effort of preparing the 800+-page proposal (and 500+-page contract!) cannot be measured only – and probably not even primarily – in terms of money. The process fostered a spirit of collaboration and appreciation of the value of European coordination that was hardly imaginable when OPTICON was established four years ago. NOTSA can be proud to be among the founders of this remarkable initiative.

On the home front, progress was made on the structural and technical improvements approved by the Council in 2002. The *Scientific and Technical Committee (STC)*, now consisting of the five astronomical members of the Council, met on La Palma in June and had a valuable and much appreciated exchange of information with our scientific and technical staff – a tradition we intend to continue. After the STC meeting, *Instrument User Groups* were appointed to advise the STC and Director on the current performance of NOT, and on any desirable short- and long-term improvements. Their reports gave much valuable advice, which we have already begun to follow.

Our ability to act on these and other recommendations was greatly improved by the Council's agreement to fill temporary staff positions in 2003-2005 to address a number of long-standing needs. These include an overall plan for organising, documenting, and archiving the data from all NOT instruments, implementing pipeline reduction software for the most popular instruments, modernising our web site, and completing the FIES spectrograph project in a timely and professional manner. With all staff on board by year's end (see facing page), we are poised to make good progress on all these fronts in 2004.

The use of NOT to train future generations of astronomers was widely welcomed in the 2002 *NOT User Group Survey*. It will become even more important now that also Finland joins ESO and some 95% of our users will have access to the Very Large Telescope and other powerful ESO facilities. Two training courses at different levels were conducted at NOT in 2003, and we intend to continue support for such activities. A summary of these courses and the role of NOT in Nordic M.Sc. and Ph.D. theses over the last decade is given on p. 22.

An agreement of cooperation was signed in 2003 with Yunnan Observatory, China, which will commission a modern 2.4-m telescope in the western part of Yunnan Province in 2005. This cooperation will enhance the scientific potential of both observatories in fields as diverse as γ-ray bursts, variable stars, and asteroids. We are pleased that our Chinese friends consider NOT a model of how to operate their own telescope, and welcome their future Astronomer-in-Charge, Dr. Wang, as a Visiting Scientist through most of 2004. We look forward to developing our contacts with the Chinese astronomical community through this cooperation.

Finally, I hope you will enjoy the reports on science at NOT in 2003 on the following pages. They have been edited by the undersigned to fit the available space and enhance uniformity of style, and I apologise for any mistakes that may have crept in during that process. Unsigned text in the report is by the Editor, who wishes to acknowledge the pleasure of collaborating again with Anne Marie Brammer on the layout of the final report.

Johannes Andersen
Director and Editor

Johannes Andersen

NOT and Comet Hale-Bopp.

From a Director's perspective, the most memorable aspect of 2003 was not an 'event', but the quiet pleasure of working with the staff – the 'NOT family'. Their dedication, competence, and cheerful spirit are an inspiration, and every visit to La Palma is a pleasure. It has been another delight to be able to add new faces to the family in 2003 – see the picture gallery on p. 2. Our three NOT Research Students in 2003, Silva and Arto Järvinen and Geir Oye, integrated admirably in the staff, and we look forward to see them again in the future, as well as to see new young faces replace them eventually.

However pleasant it was to see the ranks swelling, it made the limitations of physical space in the Sea-Level Office in Santa Cruz a daily problem. No chair or computer keyboard ever got cold when left by the owner: Someone else would fit into the vacant niche within minutes or seconds! In fact, during summer *nothing* ever got cold, thanks to the antiquated air conditioning system… However, by year's end relief was under way: With the Isaac Newton Group staff regrouping on other floors, we were preparing to take over the entire fourth floor of the building, doubling our office floor space; and the installation of a new air conditioning system in our existing (south facing) offices was near completion. 2004 should bring tolerable working conditions for the staff.

The OPTICON EU Network

As outlined in previous reports, the *Infrastructure Co-ordination Network* OPTICON was established in 2000 by 14 partners, including NOTSA. Its goal is to promote co-ordination and synergy in the development of European optical-infrared astronomy, especially as regards the exploitation and development of European observing facilities. The deadline for funding proposals for new *Integrated Infrastructure Initiatives* under EU Framework Programme 6 was April 15, 2003, and a proposal was submitted a few days before that date by a remarkable consortium including just about every major player in European observational astronomy, for the 'modest' total sum of 39 MEuro.

As it turned out, the programme was oversubscribed by a factor ~5, so the OPTICON grant of 19.2 MEuro for optical-infrared astronomy out of a grand total of 190 MEuro for all European science was a resounding success, not least when one recalls that our 'sister network' in the radio field, RadioNet, also received a 12-MEuro grant. The EU grant will be used to support the following activities:

1: The *Trans-National Access Programme* will provide access to essentially all modern European 2-4-m class night-time telescopes and four solar telescopes for all European astronomers, regardless of who owns and operates them, up to 20% of the normally scheduled observing time. Normal proposal submission and peer review procedures must be followed. Under certain conditions, successful projects from outside the owner community of the facility may then receive travel support from the EU, and the corresponding share of the operational expenses is refunded to the telescope operator.

2: Several networking activities will support intensified contacts within a number of European communities. The goal is to develop coordinated positions on, e.g., a common science case for a future European Large Telescope; UV astronomy; Virtual Observatories; optical-IR interferometry as a mainstream technique; better co-ordination between space and ground-based projects; and the development of the OPTICON 2-4-m telescope network.

3: A total of six *Joint Research Activities (JRAs)* will develop front-line technologies for future facilities for European astronomy. Typical subjects are next-generation adaptive optics; fast optical and infrared wavefront sensors for adaptive optics and interferometry; user-friendly interferometric systems; high-speed detector systems for general use; and 'smart focal planes' allowing integral-field and multi-object spectroscopy with large telescopes.

Expectations are that a final contract will be signed before April 1, 2004, and that activities will start immediately after that. NOTSA warmly welcomes this development and will participate enthusiastically in all aspects of the programme that are of relevance to us. We salute the leadership and dedication of the OPTICON co-ordinator, Gerry Gilmore of Cambridge, UK, and the hard work of many people that led to this result.

Telescope and instrumentation
The telescope continued to perform reliably throughout the year, although certain components are beginning to show their 15-year age and consequent need for repair or replacement. A convenient, computerised fault reporting system was implemented. It has greatly facilitated the systematic follow-up of any problems detected by observers or staff alike, as well as a trend analysis to identify the sources of persistent or recurring problems that need to be addressed as a first priority. One of these is the blind pointing accuracy, which has never been up to specification since the telescope was built; persistent efforts are beginning to reveal telltale systematic trends that may lead to a solution in 2004. Another is the autoguider, which has lost sensitivity and will soon need an upgrade.

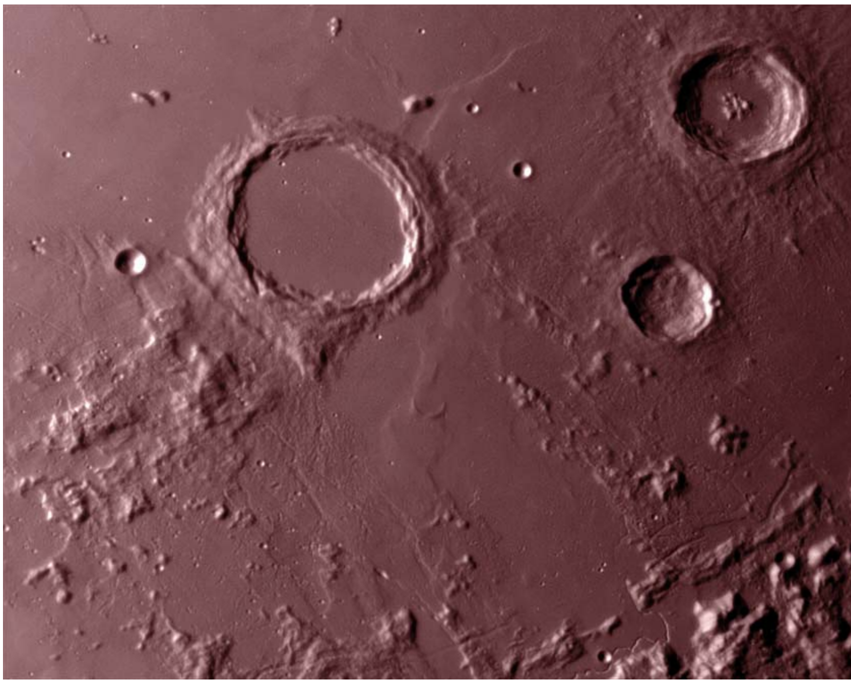
Telescope and instrument control are handled though a simple and robust user interface that has proved fast, efficient, and easy to learn over the years. Yet, it would be convenient to pass commands to all subsystems through a common interface. A *sequencer* is being designed as an upper layer of software that will take high-level commands from the observer and pass the necessary instructions on to the telescope, instrument, and detector control computers. Similarly, work is proceeding on the design of a high-level data flow structure that will ensure that data are presented and archived in a uniform, standard format accepted by all standard data reduction software, and will be complete with links to the necessary calibration files and indexing information to allow retrieval from an archive.

The combined imager and spectrograph **ALFOSC** remained the main workhorse of NOT. In September, a new optical camera and CCD detector were installed that provided substantially sharper and more uniform images over the field. Unfortunately, an error in the coating of the optics reduced the transmission below the former values; this will be corrected in 2004. An efficient grism for higher-resolution spectroscopy in the blue was also added. The backup CCD imager **STANCam** was upgraded with a CryoTiger closed-cycle cooler, obviating the previous need for frequent fillings with liquid nitrogen.

The near-infrared camera **NOTCam** was equipped with a grism for spectroscopic observations; an earlier, annoying electronic noise was traced to the power supply and essentially eliminated. Some of the filter wheel bearings had developed high friction and were replaced. The relatively frequent thermal cycling of NOTCam in its early period has led to an increasing number of bad pixels; replacement of the current engineering grade array with the science grade device is foreseen for the near future.

Finally, the new fiber-coupled échelle spectrograph **FIES** made progress, although more slowly than anticipated. The permanent CCD camera was installed in October, allowing test observations that showed the efficiency of the instrument to be well below expectations; efforts are under way to identify and eliminate any sources of light loss in the path. Meanwhile, the design of the simple building that will be the permanent home of FIES proceeded at a snail's pace; we still hope that construction of the building and the installation of FIES can take place during the summer of 2004. Dr. Eric Stempels joined the staff as Instrument Specialist on December 1, 2003, with the main task of completing the observing and pipeline data reduction software of FIES and see the instrument through its commissioning, testing, and delivery to the community.

The remaining instruments at NOT continued to function satisfactorily and require no special comment. An unpleasant incident occurred during the testing of the 2048x4096-element CCDs for the second mosaic camera in Copenhagen: A malfunction was detected in an amplifier of one of the CCDs, which was returned to the manufacturer for examination and replacement. The FedEx company lost the CCD in shipment, was unable to find it, and refused to refund the considerable expense of the chip. At year's end, legal action against FedEx was being prepared jointly between Copenhagen University and NOTSA.



A sample of the scientific projects carried out at NOT in 2003 is described in the following. Texts were submitted by the author(s) listed under each report. They have been edited to fit the available space, and chapter introductions been added, by the Editor. Publications in 2003 based on NOT data are listed separately (p. 27).

COSMOLOGY AND FORMATION AND EVOLUTION OF GALAXIES

The formation and evolution of the Universe seem to be dominated by dark matter and dark energy. Their nature remains a mystery; solving it is a top priority in modern astrophysics. Visible matter – stars and planets, gas and galaxies – accounts for only 3-4% of the total density of the Universe, but provides the light by which we study the rest. Understanding how galaxies formed and evolved to the complex world we see today is a related, active field of study, with major unanswered questions remaining even in our own Milky Way.

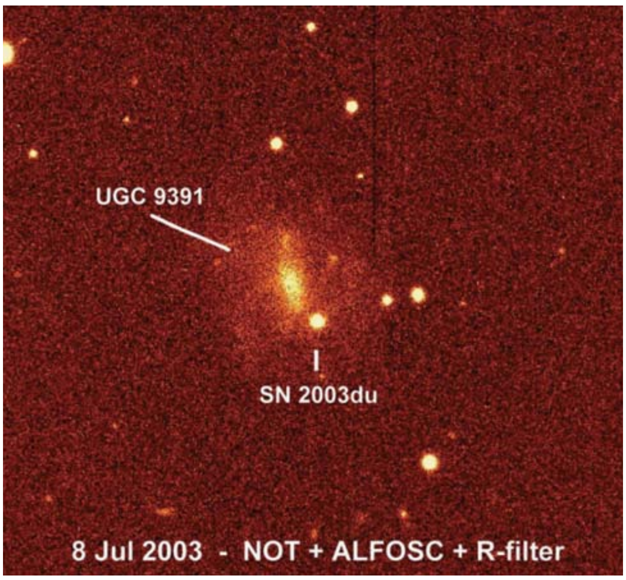
Cosmology with Type Ia Supernovae

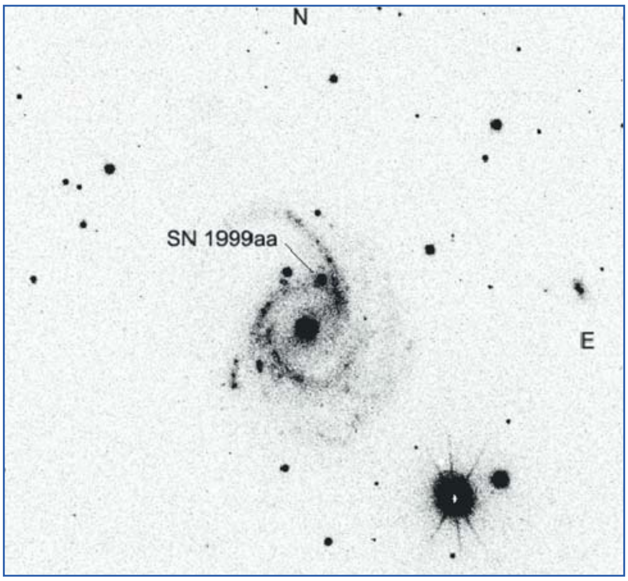
Observational cosmology is undergoing a revolution. Observations of brightness and redshift of very distant Type Ia supernovae (SNe Ia for short) indicate that the expansion rate of the Universe is increasing. This requires the existence of a *"Dark Energy"* to overcome the gravitational self-attraction of matter, such as the vacuum energy density associated with Einstein's proposed cosmological constant. Improving in our knowledge of the two most fundamental missing pieces of cosmology, Dark Matter and Dark Energy, depends critically on a better understanding of our "standard candles", SNe Ia. These are believed to occur when matter transferred to a white dwarf star in a binary system pushes its carbon mass above a fixed critical value, causing the white dwarf to detonate in a violent explosion of near-constant magnitude. Testing this model is best done with bright nearby supernovae.

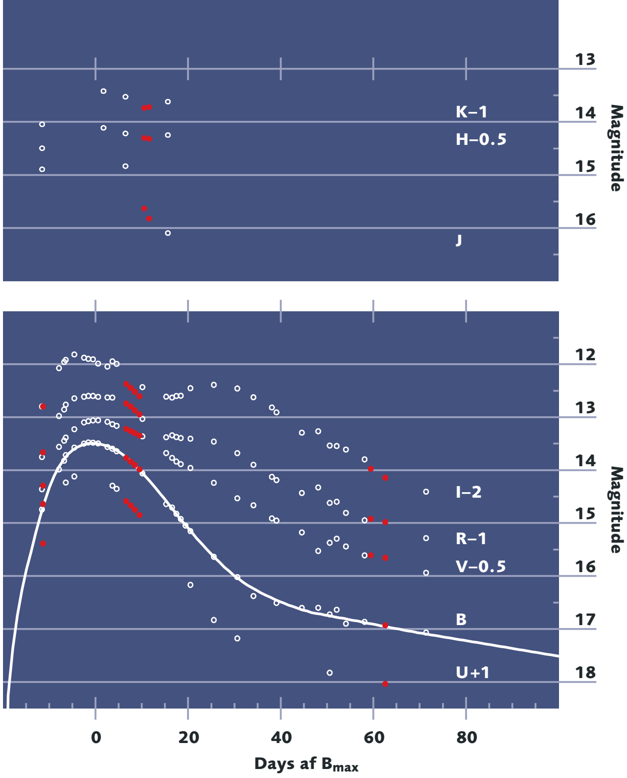
Thus, a large international campaign was organized in 1999 by the *Supernova Cosmology Project*, with NOT as an important participant. These studies shed new light on the relations between the spectral properties of these supernovae and their intrinsic brightness, which can be used to further refine the use of SNe Ia in cosmology. While their spectra are remarkably homogeneous, differences in several absorption features in the optical spectra do occur and may be used to calibrate any differences in explosion strength. Together with the measured light flux of the supernova, this allows to accurately determine the distance to the host galaxy.

Two of the Type Ia supernovae studied are shown in Fig. 1. Very well-sampled spectra of SN 1999aa and other SNe Ia were obtained and allow detailed comparisons with models of the explosion. The carbon constituting the white dwarf is believed to be the underlying "fuel" of the explosion, and possible traces of unburned carbon is seen. Another nearby supernova, SN 2003du, was studied as a part of a large European programme on the physics of supernova explosions. The NOT light-curve points and spectra are shown

Fig. 1a and 1b. The nearby Type Ia supernovae SN1999aa (left) and SN 2003du (right) and their host galaxies.







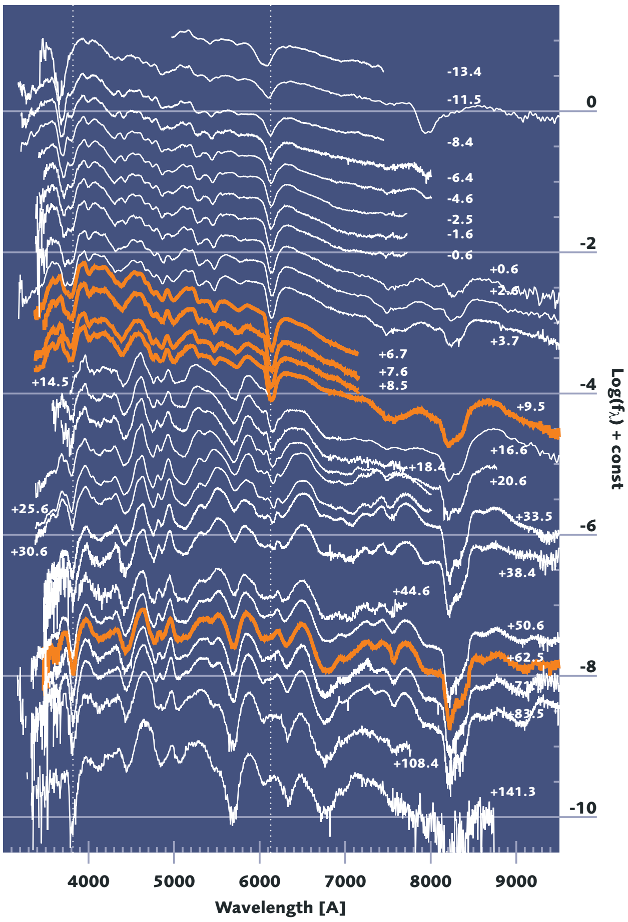


Fig. 2a and 2b. Multicolour light curves (top) and spectra (bottom) of SN 2003du (NOT data highlighted).

in Fig. 2 along with other spectra used to compare with theoretical models. These studies will enable full use of the large sets of high-redshift SNe Ia from several ground-based projects as well as the planned SuperNova Acceleration Probe (SNAP) satellite (A. Goobar, Stockholm, and collaborators).

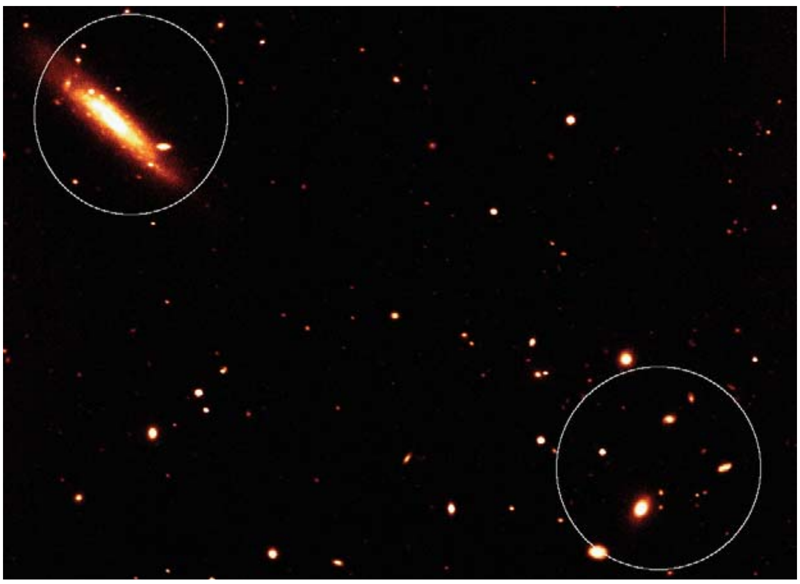
Resolving the cosmic far-infrared background

About half of all the radiation emitted by stars and galaxies in the Universe since the recombination era, just after the Big Bang, is seen as far-infrared (FIR) background light. This Cosmic InfraRed Background (CIRB) was detected by the COBE satellite and further studied with the ISOPHOT camera on the ISO satellite. Identifying the sources responsible for it is a crucial step. Work so far has shown that bright, massive starburst galaxies at redshifts ~1 are strong contributors. Interacting galaxies and enigmatic, high-redshift ultraluminous objects play an important role as well, as do nearby cold dusty galaxies. The CIRB has thus opened a window to an extremely important epoch in the evolution of galaxies and structure in the Universe.

Many of the FIR sources remain unidentified, however. The ISOPHOT beam was very broad, about 90" (circles in Fig. 3), so identifying individual sources is difficult. Fig. 3 shows a typical example: The circle at left contains an obvious bright spiral galaxy, but the circle at right contains many possible candidates. ALFOSC and NOTCAM were used to examine this and many other ISOPHOT sources in more detail. The circle at right does contain a concentration of galaxies, including bright early-type galaxies, but dust of very unusual composition is needed to produce the strong FIR flux. There are also many faint, extremely red objects, which could be high-redshift, ultra-luminous IR galaxies.

Roughly a third of the FIR sources coincide with obvious nearby, dusty star-forming galaxies. Another third contain faint, very red and presumably distant galaxy candidates. And most of the final third of the observed fields show

Fig. 3. Two ISOPHOT detections (circles) in a field towards the North Galactic pole; identification of the optical counterpart(s) in the circle at right is non-trivial.



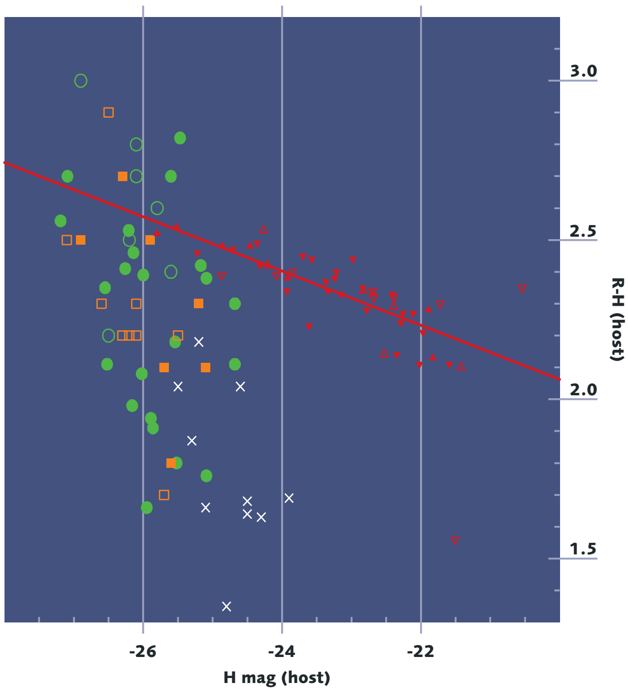
significant overdensities of galaxies around the FIR source, often resembling a galaxy cluster.

This discovery opens a topic virtually neglected up to now. Simulations show that the integrated flux of galaxies in a whole cluster can mimic a faint point source in ISOPHOT. It is also possible that FIR-bright galaxies prefer to live in clusters. In either case, identifying such FIR sources may become a new and valuable tool to find high-redshift proto-galaxy clusters for study with the Spitzer and Herschel infrared space missions.

Based on the NOT results, time has been granted at the ESO VLT to investigate the spectra of this new class of object in more detail. The project thus exemplifies the synergy between archive satellite data and a high-quality medium-size telescope, leading to further studies with even more powerful ground-based telescopes and satellites (P. Väisänen, ESO; M. Juvela, K. Mattila, J. Kahanpää, Helsinki; J. Kotilainen, Turku).

The host galaxies of BL Lac objects

BL Lac objects are active galactic nuclei characterized by bright variable continuum emission and polarization at all wavelengths, strong compact radio emission, and 'knots' that appear to expand faster than the speed of light. These phenomena are believed to originate in a relativistic jet pointed directly at the observer. Optical imaging has shown that virtually all nearby BL Lacs are located in giant elliptical galaxies.



New deep NOTCam images with high spatial resolution in the near-infrared H band (1.65 μm) have been obtained for 23 low-redshift BL Lac objects. They were combined with previous data for another 18 objects and with earlier optical data from NOT to study the colours of the host galaxies. All the hosts are clearly detected; they are large and luminous, but apparently normal elliptical galaxies.

A tight relation exists between the effective radius of elliptical galaxies and their H-band surface brightness at that radius; this is a powerful diagnostic of the structure and formation of these galaxies. The relation for BL Lac hosts is virtually identical to that for normal elliptical galaxies dominated by old stars, and the optical and near-infrared colours and colour gradients of the BL Lac hosts also indicate a dominant old stellar population. Thus, BL Lac hosts appear to have similar structure and dynamics as normal galaxies.

However, BL Lac hosts differ from normal elliptical galaxies by being bluer at the same absolute brightness (Fig. 4) and also have a steeper colour gradient. The standard colour-magnitude relation for elliptical galaxies may thus break down for the most luminous galaxies, such as BL Lac hosts. Several BL Lac hosts also have strong red colour gradients towards the centre due to dust extinction, which is not seen in normal elliptical galaxies.

The considerable similarity between BL Lac hosts and normal elliptical galaxies suggests that the violent nuclear activity in BL Lacs does not strongly affect the star formation history of their hosts. Since the majority of nearby inactive elliptical galaxies harbour a supermassive black hole in their centre, it is possible that a period of increased nuclear activity may occur in all normal elliptical galaxies (J. Kotilainen, Turku; R. Falomo, Padova).

Fig. 4. Red-infrared colour (R-H) vs. infrared magnitude (H) for elliptical galaxies (blue objects at bottom, bright objects at left). The small triangles and solid line show normal galaxies in the Virgo and Coma clusters and the best-fit relation for these objects. BL Lac hosts are shown as large circles and squares, and low-redshift quasar hosts as crosses.

Radiation physics of the Crab pulsar

A supernova explosion typically leaves a neutron star or black hole remnant of the core of the progenitor star. Many of the neutron stars are observed as pulsars, which emit beams of radiation spanning the whole electromagnetic spectrum from γ-rays to radio wavelengths. The pulses appear when the rapid rotation of the neutron star sweeps the beam past the observer with periods of milliseconds to seconds, increasing with the age of the pulsar.

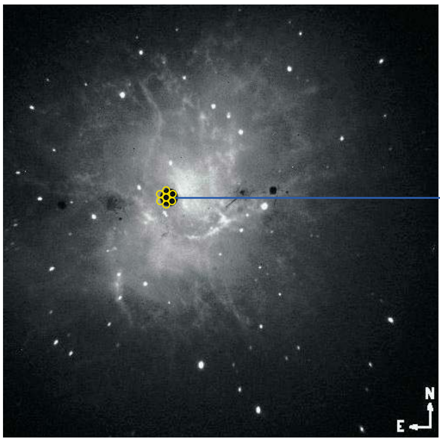
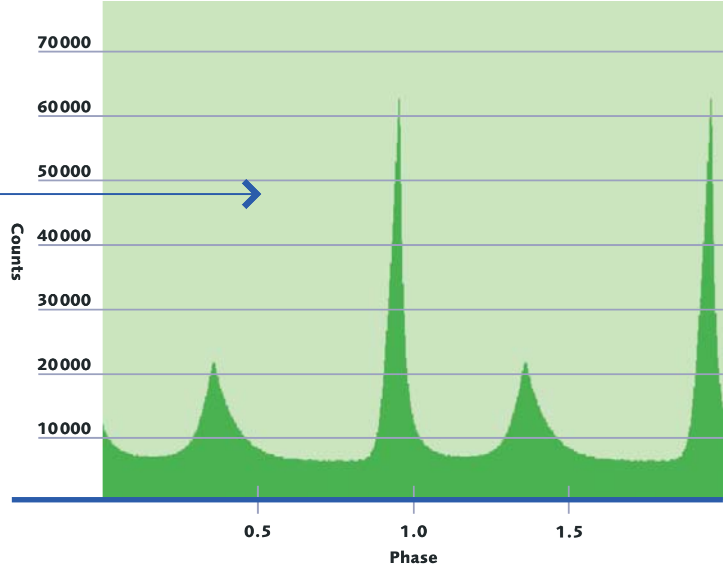


Figure 5: The Crab nebula, with the multi-fibre feed of OPTIMA shown at the location of the pulsar. This allows to separate the signal from the pulsar (right) from the highly polarized light from the nebula.



The origin of this pulsed radiation remains poorly understood. The longer-wavelength radio emission must be produced in coherent emission processes in the magnetosphere of the neutron star, while a number of incoherent mechanisms have been proposed as potential sources of the high-energy non-thermal emission seen from optical light through high-energy X-rays and γ-rays. Until the recent discovery of a correlation between the optical pulses and the so-called 'giant radio pulses', no connection between the two domains was known. Correlating the intensity, timing, and polarization of the optical and giant radio pulses at many wavelengths may now lead to new insight in the micro-physics of the emission processes in neutron star magnetospheres.

The famous Crab pulsar, the youngest pulsar known, is one of the few cases where this is possible. During the nights November 24-28, 2003, polarimetric observations were made at NOT with OPTIMA, a high time-resolution photo-polarimeter developed at the Max-Planck-Institut für extraterrestrische Physik in Garching, Germany. As giant radio pulses can only be detected in the radio band, five radio telescopes in Germany, the UK, the Netherlands, and Russia were also used in a simultaneous multi-wavelength campaign. Optical photometry was also obtained with the 6-m telescope at the Special Astrophysical Observatory in Russia, and high-energy cosmic rays were monitored with the TeV telescopes HESS in Namibia and MAGIC on La Palma. The analysis of these unique observations has been started, and the results will be described in a later report (G. Kanbach, A. Stefanescu, F. Schrey, Garching; A. Wozna, Torun).

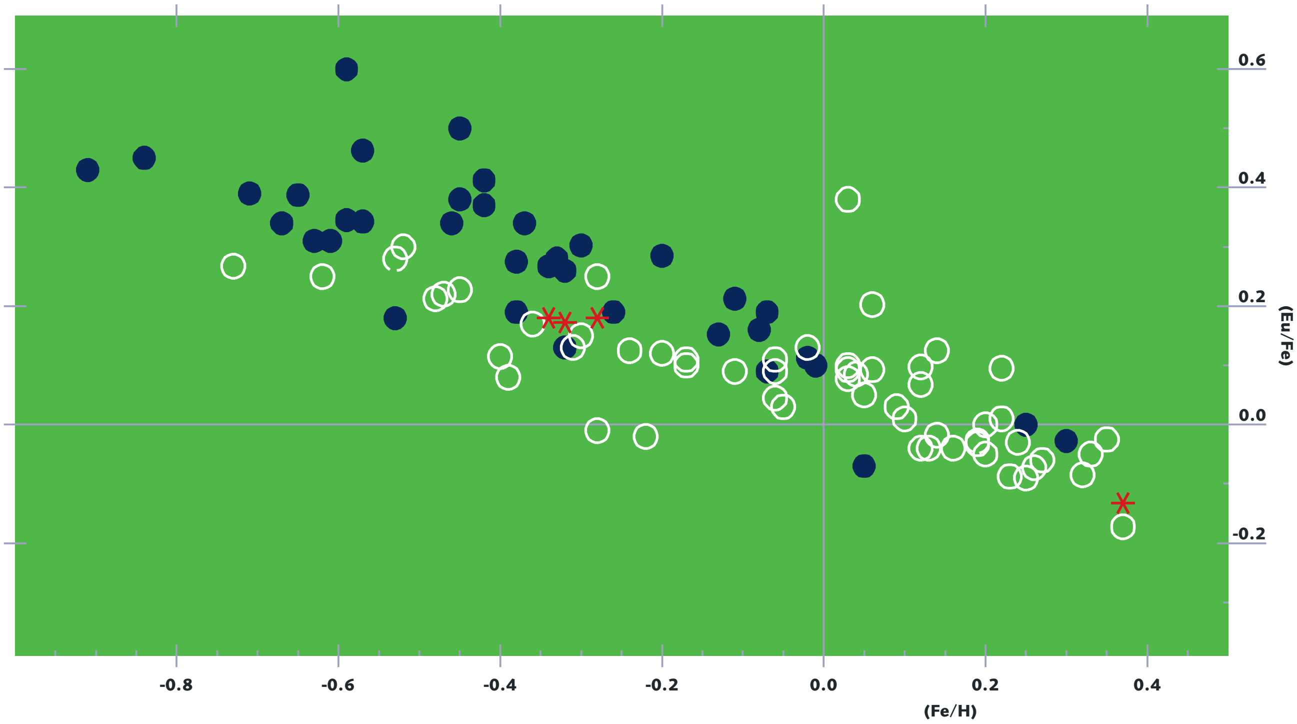
The origin of the thin and thick disks of the Milky Way

The Milky Way Galaxy is the prototype of spiral galaxies in general, and its stars carry unique, detailed information on its structure and evolution. Observations have shown that the Galaxy, like many other spiral galaxies, has two disk components, the *thin* and *thick* disks, distinguished both by their kinematics and by their metal abundance distributions. It is a challenge for any model of galaxy formation and evolution to explain how such distinct disk structures could form. The abundances of selected chemical elements in longlived stars as functions of time are powerful tools to understand the complex history of star formation and heavy-element synthesis in the disk(s).

The SOFIN spectrograph has been used to observe F and G-type dwarf stars thought to belong to either the thin or the thick disk of our Galaxy. The stars were classified on purely kinematical grounds, avoiding preconceived notions such as "all thick-disk stars are old" or "all thick-disk stars have metallicities less than 40% of that of the Sun". The NOT observations confirm and extend previous results from ESO, that the elemental abundance trends for stars associated with the thin and thick disk are indeed different. While this is not a completely new result, the metallicities of the kinematically hot group of stars (i.e. the thick disk) are also found to extend up to the Solar value, where the two distinct abundance trends merge.

First results are shown here for three elements, iron (Fe), europium (Eu), and oxygen (O). Fe is formed primarily by supernovae of Type Ia (see above), which are believed to form over long timescales. O and Eu both form in Type II supernovae, which end the short lives of high-mass stars; both elements are difficult to analyse because of complications in their atomic structure, but the analysis is much facilitated by the high spectral resolution and low noise of the SOFIN spectra. The higher Eu/Fe ratio found for the thick-disk stars than in the thin disk (Fig. 6) suggests that the thick disk was formed more rapidly than the thin disk. On the other hand, the constant Eu/O ratio indicates that these two elements were indeed produced in the same type of supernova event (T. Bensby, S. Feltzing, I. Lundström, Lund).

Fig. 6. Observed Eu/Fe ratios as a function of iron abundance (filled circles: thick disk stars; open circles: thin disk stars).



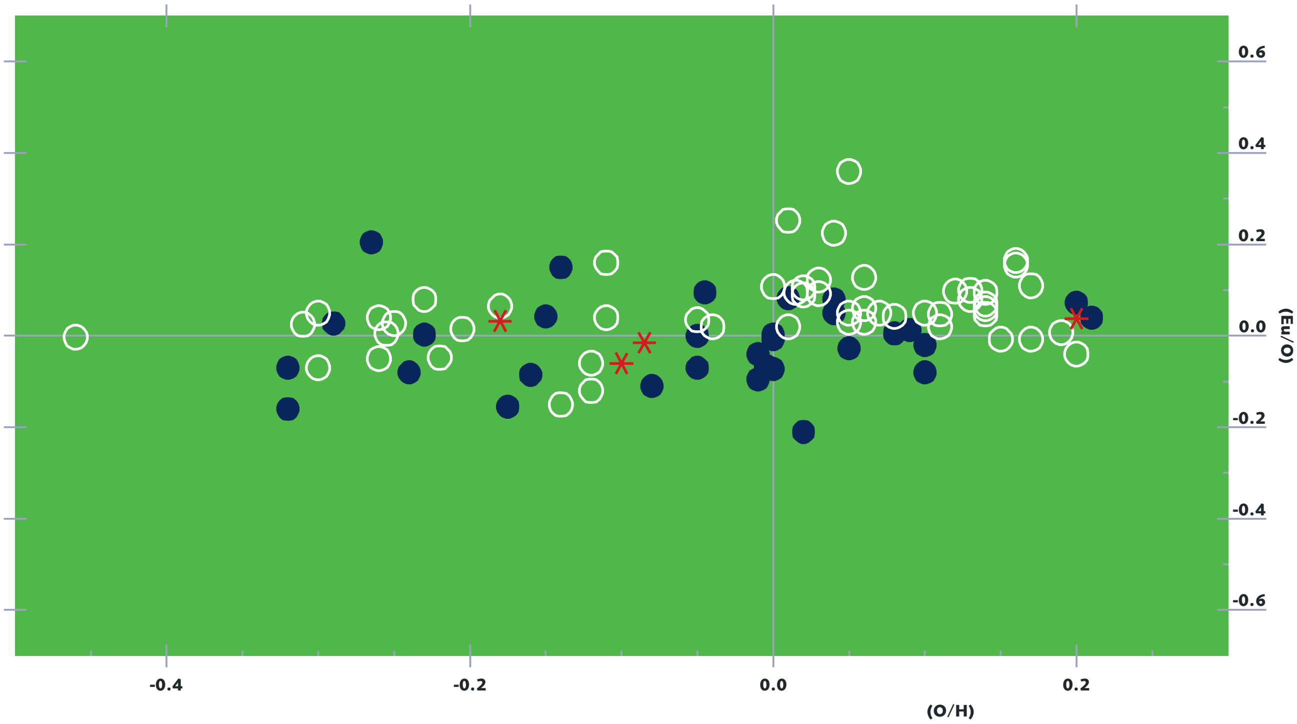


Fig. 7. Observed Eu/O ratios as a function of oxygen abundance (symbols as in Fig. 6).

FORMATION, STRUCTURE, AND EVOLUTION OF STARS

Stars are born in dense interstellar clouds. They evolve quietly for most of their lives, but die in more or less violent ways, leaving behind a black hole, a neutron star, or a white dwarf star. Moreover, stars in binary systems may interact and evolve into objects that are quite different from single stars. Stellar evolution theory is well developed, but the processes are complex and accurate observations are needed to guide its further progress. Some NOT projects in this field are described in the following, roughly in order from birth to death of a star.

Star formation in the Serpens molecular cloud

Two important unsolved questions are how stars form, and whether the apparently universal distribution of initial stellar masses (the Initial Mass Function, IMF) is determined at the prestellar stage. Very young star clusters with active formation of low mass stars, which are less destructive to their parental environment, offer insight on these issues. Comparing the mass spectrum of pre-stellar clouds with that of the youngest possible stellar generation will give important clues to the origin of the IMF.

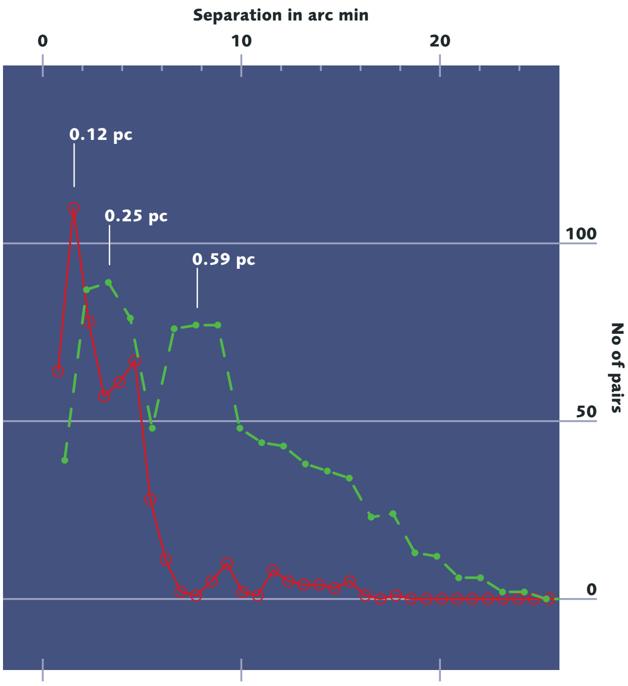


Fig. 8. The distribution of the separations of pairs of protostars (circles) and Class II stars (dots), in acminutes. Note how the extremely young protostars cluster more tightly than the ten times older Class II stars.

The nearby star-forming Serpens Cloud (*d* = 260 pc) has been surveyed in the near and midinfrared with NOT and the ISO satellite. Photometry in three broad bands from 2-15 μm is sufficient to characterize the objects as protostars (Class I), premain sequence stars with disks (Class II), or as fully-fledged stars without dust clouds. In the core of the cloud itself a surprisingly large number of protostars has been found, strongly concentrated in four subclusters of 0.12 pc size along a dense cloud filament. Their projected density amounts to 500-1100 protostars per pc^2, the highest found in any nearby young cluster. The Class II objects are also clustered, but with a minimum cluster size of 0.25 pc and an extended scattered distribution in addition to the clustering (see Fig. 8).

Luminosities can be estimated for the Class II stars, and theoretical evolutionary tracks for pre-main sequence stars have been used to derive the most likely combination of age and IMF. The data are compatible with an age of 2 million years and a three-segment power-law IMF as recently proposed, but the two current versions of this IMF cannot be distinguished from the present data. A comparison of the clustering properties of the Class II stars with that of the strongly clustered protostars, whose ages are only about 0.2 million years, indicates that the Serpens cloud has experienced several bursts of star formation (A.A. Kaas, NOT, and several European collaborators).

Pinpointing stellar evolution in star clusters

The mass of a star is the single most important parameter determining its evolution. In the study of stellar structure and evolution, the parameters of a star under study can be constrained with much greater precision if also its mass can be determined with high accuracy.

Unfortunately, the mass is one of the most difficult parameters to determine for stars in general. However, in a binary system in which two stars eclipse each other as seen from the Earth, measurements of the shape and depths of the eclipses in the light curve can be combined with spectroscopic determinations of the orbital velocities to yield accurate masses and radii for both stars stars (better than 1%). If the binary is also member of a star cluster, the models become further constrained since such global parameters as distance, chemical composition, and age are the same for all the stars, including those in the binary. This allows much stronger tests of stellar evolution theory and a better age determination for the stars than is possible for either the binary or the cluster separately.

Therefore, a program has been initiated to study eclipsing binary stars in open star clusters. In 2003, six nights of NOT photometry were obtained in service mode for one such system in the oldest known open cluster NGC 6791, scheduled so as to optimise coverage of the eclipses. Fig. 9 shows the colour-magnitude (or temperature-luminosity) diagram for this cluster from earlier NOT data. The locations of the binary system and its two components are indicated, and the insert shows part of the light curve around primary eclipse. The next step will be to obtain radial velocities for this system for a determination of its mass. In addition to the accurate lightcurves of this system, three new eclipsing binaries were discovered in the cluster, which will allow an even more stringent determination of its main parameters.

This project has benefited greatly from the service observing mode introduced at NOT, and the staff deserves great credit for carrying out these observations in the best possible way (F. Grundahl, S. Frandsen, H. Bruntt, Aarhus; J. V. Clausen, Copenhagen).

Seismology of stars in a star cluster

Short-period pulsating stars, such as δ Scuti or β Cephei stars, allow one to do asteroseismology, which uses the stellar pulsations to constrain and improve models of the stellar interiors, just as earthquakes are used to probe the interior of the Earth. The prime example of this method is the Sun, where continuous long-term observations of brightness variations have revealed a vast number of oscillation modes on time-scales near 5 min, which in turn have led to a revolution in the depth and detail of our understanding of the interior structure and rotation of the Sun.

Pulsating stars of other types can provide similar insight in the structure and evolution of stars of widely different masses and evolutionary status. Several classes of pulsating stars exist, including the δ Scuti stars which are about twice as massive as the Sun. They are favourable objects for study because they have many periods and easily detectable light variations. Observations of δ Scuti stars can impose strong constraints on models of stars which, unlike the Sun, have convective cores. The constraints become

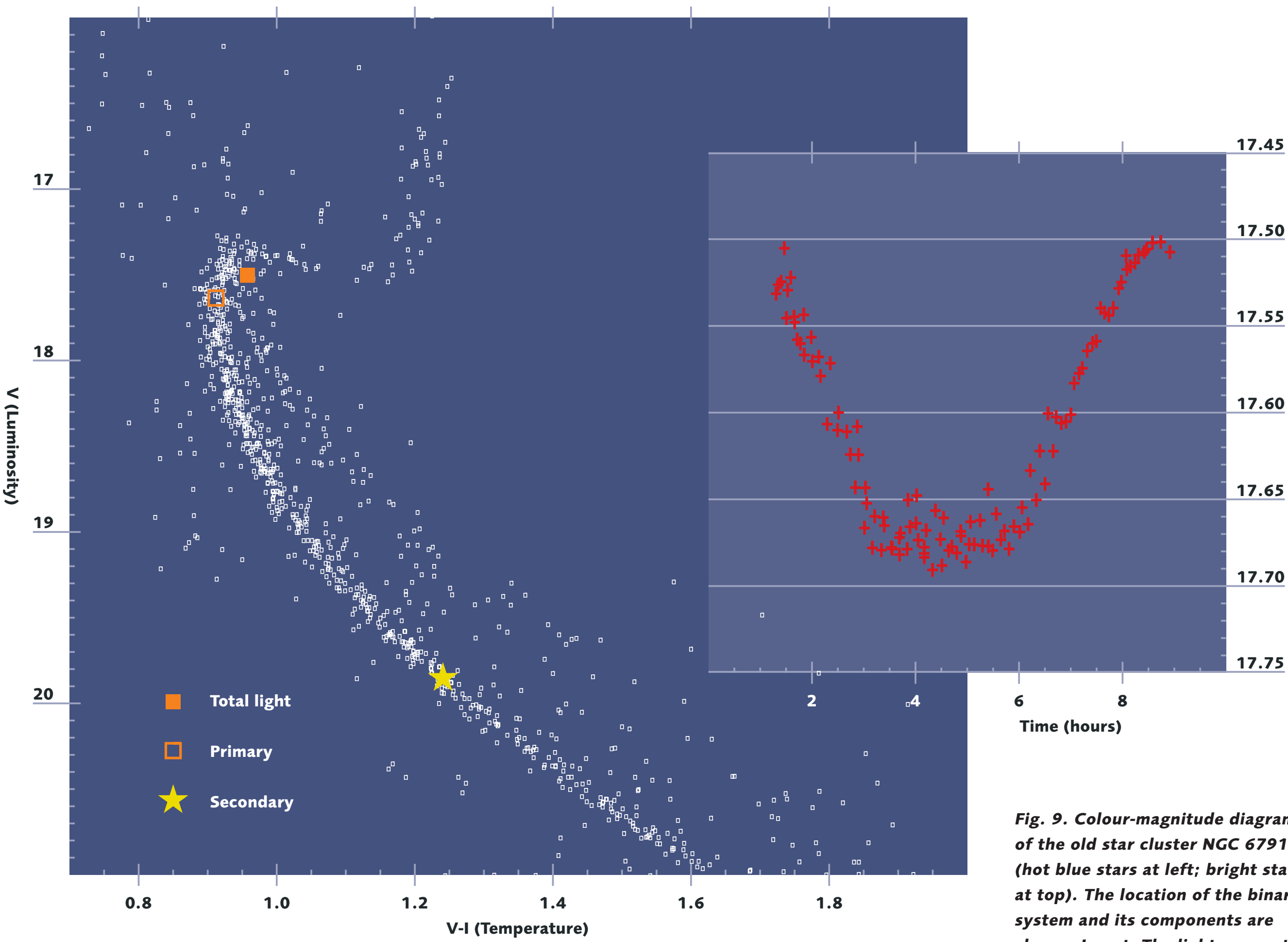


Fig. 9. Colour-magnitude diagram of the old star cluster NGC 6791 (hot blue stars at left; bright stars at top). The location of the binary system and its components are shown. Insert: The light curve at primary eclipse.

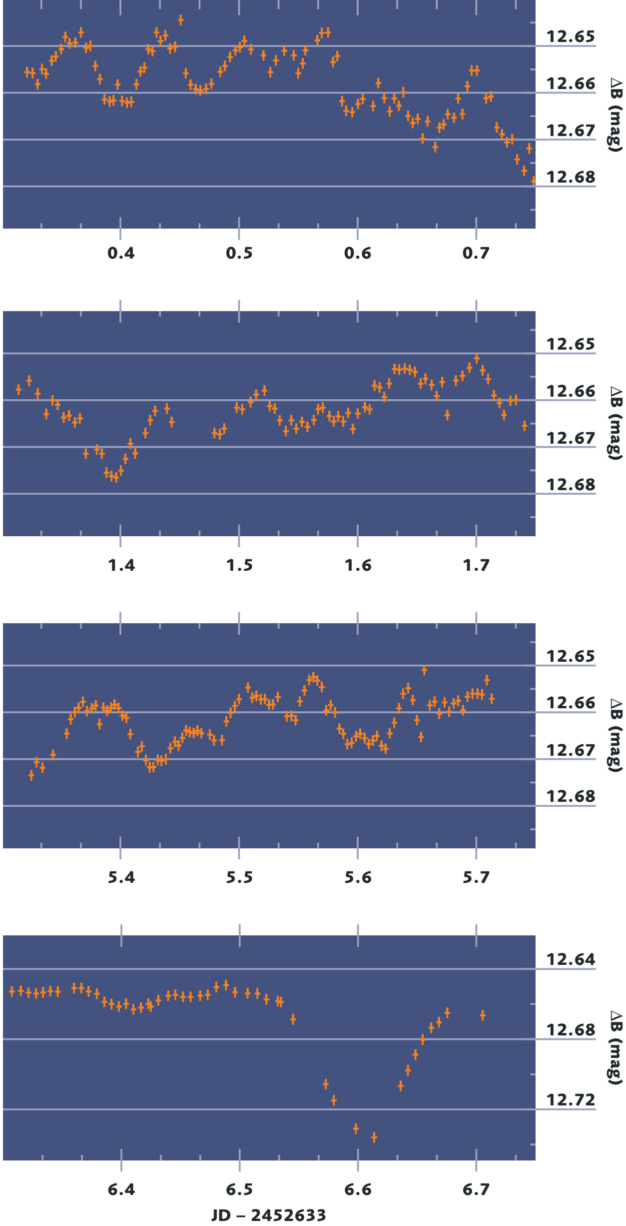


Fig. 10. Light variations of the new eclipsing binary and δ Scuti star in NGC 1817.

even tighter if parameters like the age and distance of the stars can be determined independently, as can be done in stellar clusters. Furthermore, in clusters several variables can be observed simultaneously and to very high precision using many other stars as a reference.

Accurate time-series observations in B and V of a field in the open cluster NGC 1817 were obtained at NOT in December 2002. In addition to 7 δ Scuti candidates found earlier with the IAC 80cm telescope at Tenerife, no less than 14 new variable stars were discovered, bringing the total number of known variable stars in NGC 1817 to 19. As many as 12 of these are new multiperiodic δ Scuti stars, and a published proper-motion study of NGC 1817 confirms that all 12 are most probably true cluster members. One of them, which is also an eclipsing binary, is shown in Fig. 10. These results make NGC 1817 a prime target for testing models of stars near 2 M_{sun}, and spectroscopic followup as well as a multisite photometric campaign are planned (T. Arentoft, S. Frandsen, Aarhus; L. M. Freyhammer, M. Y. Bouzid, C. Sterken, Brussels).

Imaging the surface magnetic field on active stars

A very active research programme at NOT during the last decade has been devoted to the study of magnetic cycles of active late-type stars, including RS CVn-type binaries as well as FK Comae- and other types of rapidly rotating single solar-type stars. Long observing runs (1-3 weeks) with the SOFIN high-resolution spectrograph have been dedicated to a coordinated set of international programmes of this type.

The major discovery of these studies is a persistent two-spot structure in the visible hemispheres, with two large high-latitude areas situated at opposite longitudes. Their strength and polarity vary in a cyclic manner over a few years, the socalled "flip-flop" effect. Advanced Doppler imaging techniques have been developed and successfully applied to the observations in collaboration between the universities of Oulu and Uppsala, including the first calculations of the Zeeman effect of molecular lines, which are formed only in cool starspots.

Recent dynamo models for rapidly rotating stars predict stable nonaxisymmetric magnetic fields in the form of active longitudes, with opposite polarities between the areas in the same stellar hemisphere. There are, however, as yet no definite measurements of the existence and evolution

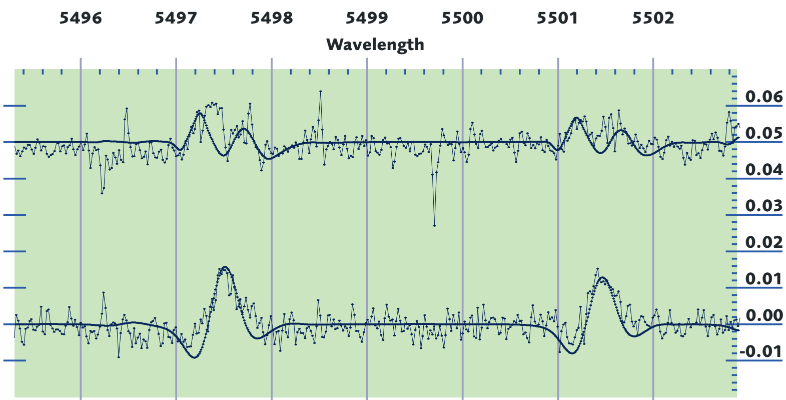


Fig. 11: Observed and modelled Stokes V profiles of two iron lines in II Peg at rotational phases 0.27 and 0.42 (NOT, Feb '02). The model includes 2-3 spots of different size and polarity located on the stellar surface.

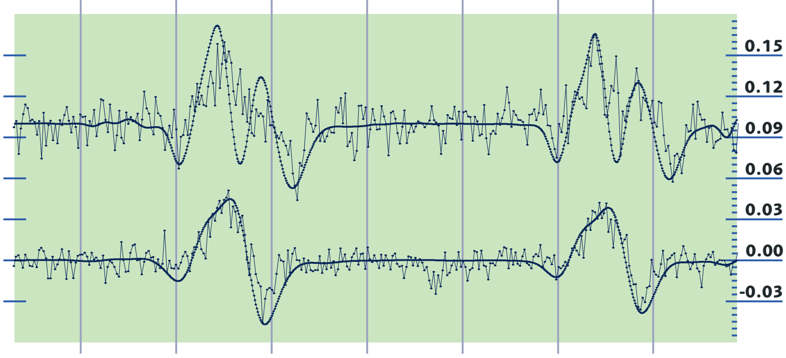


Fig. 12: Observed and modelled Stokes V profiles of the same two lines in II Peg at rotational phases 0.10 and 0.40 (Galileo, Jun 2002).

of magnetic field strength and polarity of the two active longitudes in such stars, nor any information on polarity changes during stellar cycles. Therefore, a study has been undertaken of the active star II Pegasi using the Galileo telescope and NOT on La Palma, with accurate measurements of circular and linear polarization in atomic lines and molecular bands formed in starspots. Data from February and June 2002 have been analysed and suggest polarity reversals even during 1-2 rotation periods (see the figures).

II Peg is a typical active rapidly-rotating late-type star. The behaviour of such rapidly rotating, magnetically extremely active young solar analogues is also relevant to the early evolution of the Sun and its connection to climate conditions on the young Earth (I. Tuominen and colleagues, Oulu).

Mass-loss from yellow hypergiants: The case of ρ Cassiopeiae

Yellow hypergiants are massive cool stars in the very last stages of their fast evolution. They form a unique class of dynamically active supergiants whose luminosity is close to the Eddington limit, where the outward pressure of the radiation is on the verge of ripping the star apart. Only a handful of these rare and extreme stars are known in the Galaxy, and ρ Cassiopeiae is one of the brightest (V~4.5 mag). Studies of ρ Cas and similar stars address the key question why cool luminous stars are so rare compared to hot luminous stars, and why the luminosity of cool hypergiants seems limited to about one million times the solar value.

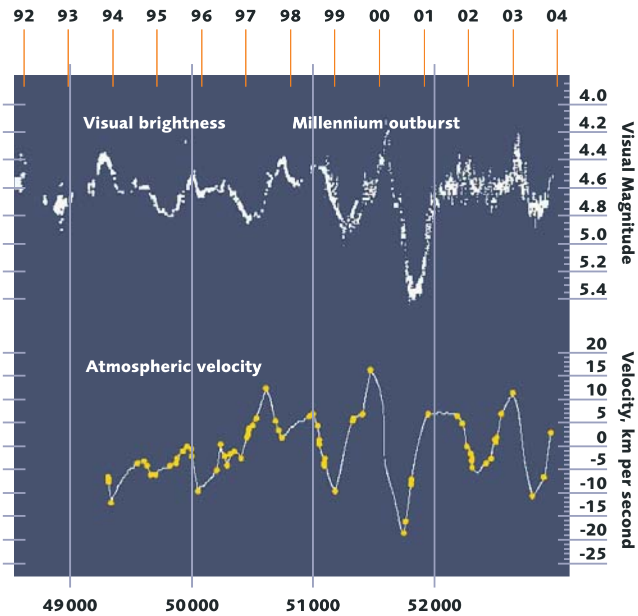
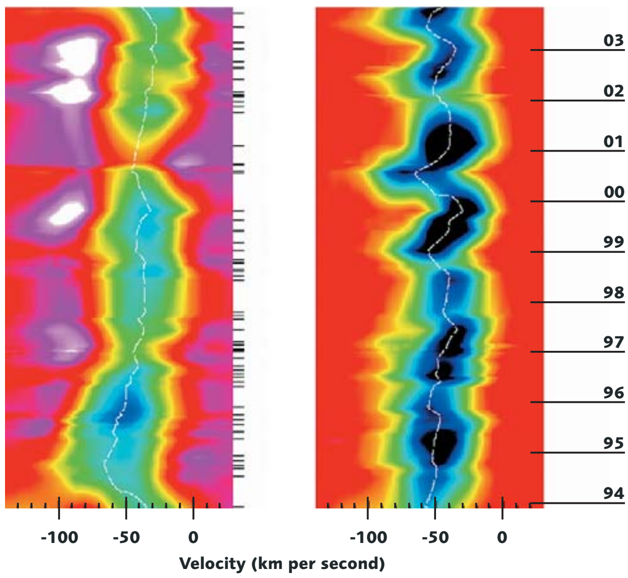


Figure 13: Visual light (upper panel) and corresponding radial-velocity variations (bottom) in ρ Cas over the last decade.

In outburst events at half-century intervals, unique spectral changes revealing exceptionally large massloss rates are seen. The star sheds a gas shell, and its surface temperature drops by a dramatic ~3000 K. In 2000 the visual magnitude of ρ Cas again brightened to 4 in a new outburst event, then abruptly dropped to 5.3, while the spectrum underwent a series of dramatic changes first observed in 1946 (Fig. 13).

ρ Cas has been monitored over the past decade with high-resolution optical and near-IR spectroscopy from several telescopes. Before maximum brightness, the photospheric absorption lines indicated a strong collapse of the extended atmosphere (Fig. 14, right panel). Over the next 100 days the atmosphere rapidly expanded in a massive eruption, with a maximum velocity of 35 km s^{-1}, while the optical spectrum changed from a warm F- to a cool M-type. Titanium-oxide bands appeared and revealed the largest massloss rate ever observed during a single stellar outburst, about 3% of a solar mass (or 10,000 Earth masses) in 200 days. Monitoring of the hydrogen Hα line also demonstrates the remarkable reversal of the upper atmosphere from contraction into fast global expansion with enhanced mass-loss. Sustained spectral monitoring will help to pinpoint the physical mechanisms that trigger and drive these gargantuan stellar explosions (A. Lobel et al., Cambridge, Massachusetts; I. Ilyin, Oulu).

Figure 14: Dynamic spectra of the hydrogen Hα line (left panel) and of a neutral iron line (right panel). Time increases from bottom to top (years shown at right). Consecutive observations over the past decade, including SOFIN data, are marked with tick marks at left. The continuum is shown in red; absorption depth increases from green through black, while white spots signal emission. A strong collapse of the upper atmosphere took place in mid-2000.



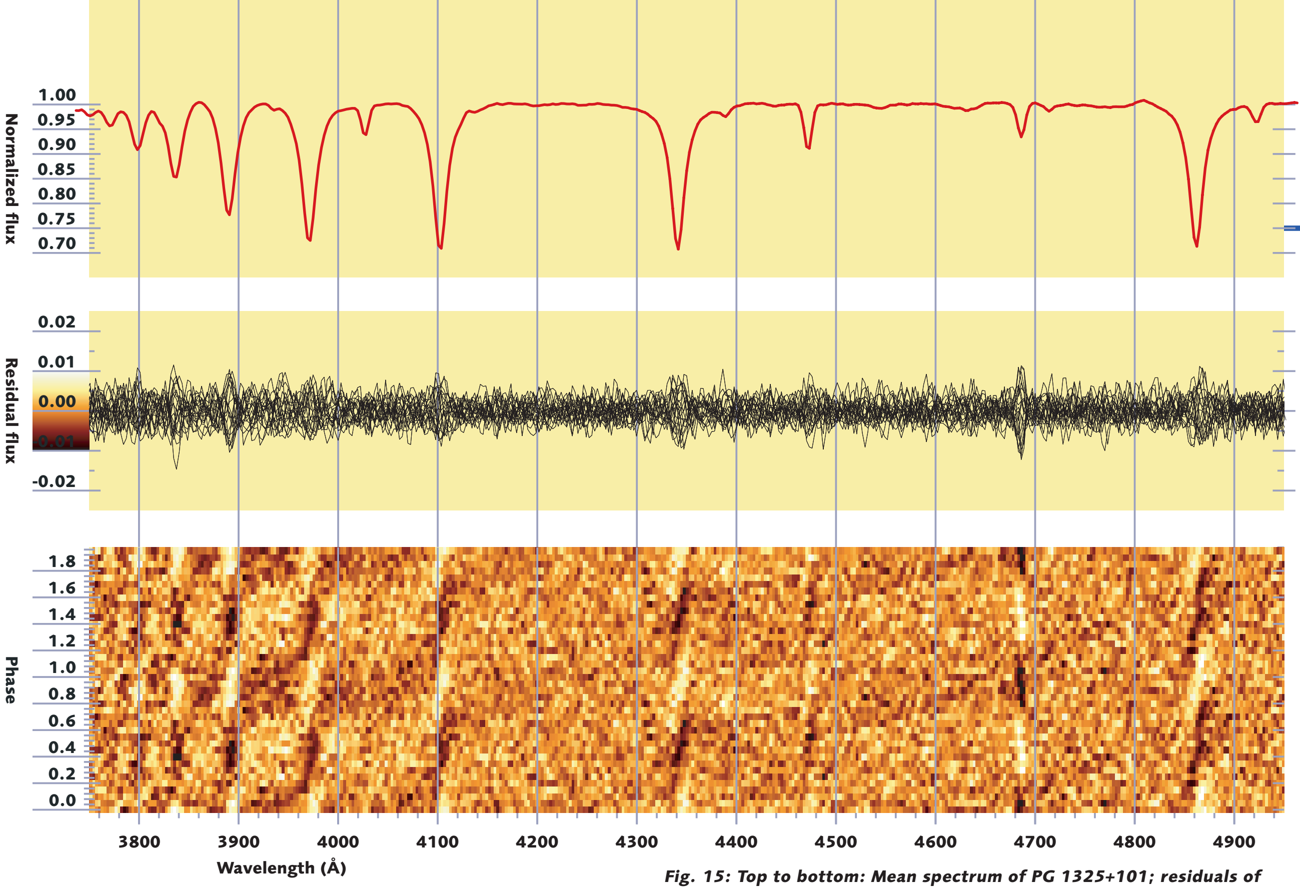


Fig. 15: Top to bottom: Mean spectrum of PG 1325+101; residuals of the phase-binned spectra from the mean; and two phase cycles of the residuals plotted in a colour representation (time increasing upward).

From red giant to white dwarf: Probing the subdwarf B stars

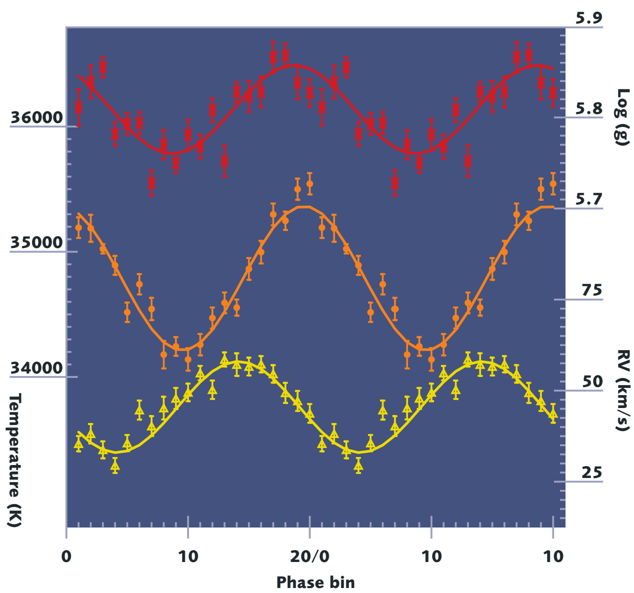
The subdwarf B (sdB) stars are evolved stars with typical masses and radii of 50% and 15% of those of the Sun, respectively, but surface temperatures of 20-40,000 K – 3 to 7 times higher than the Sun. These stars are believed to have burned all their hydrogen fuel, gone on to burn helium during the red-giant stage of their evolution, and then lost most of their mass. The sdB stars are currently burning helium in their core, with only small traces of hydrogen left in their outer layers. When also their helium runs out they will contract, heat up, and pass through the subdwarf O stage until they end up as white dwarf stars when all fusion processes have died out.

It is not clear why these stars have lost a substantial fraction of their hydrogen envelope: it may have been stripped off by a close binary companion or carried away by some stellar-wind process. However, some sdB stars pulsate with periods of 2-5 min, which makes it possible to study their interiors with seismological methods. If the frequencies and spatial modes of the pulsations can be derived from observations, the internal structure of the stars can be studied in detail as a diagnostic of the evolutionary history of the sdB stars.

More than a thousand low-resolution ALFOSC spectra of 25 seconds duration each have been obtained of the faint sdB star PG 1325+101 (period 138 sec; V=13.8), in order to study its internal structure from the variations in its absorption lines. Fig. 15 shows these spectra, folded into 20 phase bins of the main pulsation mode, which highlights the profile variations in the hydrogen and helium lines.

Models fit to each of the binned spectra indicate that the apparent surface temperature varies by ±600 K and the apparent surface gravity by ±15%; the pulsation amplitude at the surface is about 18 km s^{-1} (see Fig. 16). The variation in surface gravity is mainly due to the pulsational acceleration, while the effect of the change in radius itself is much smaller. This suggests that the star pulsates radially, but non-radial pulsations cannot yet be excluded (J.H. Telting, NOT; R. Østensen, Isaac Newton Group).

Fig. 16: Fitted surface temperature and gravity, and measured radial velocity, as a function of pulsation phase. Two phase cycles are shown.



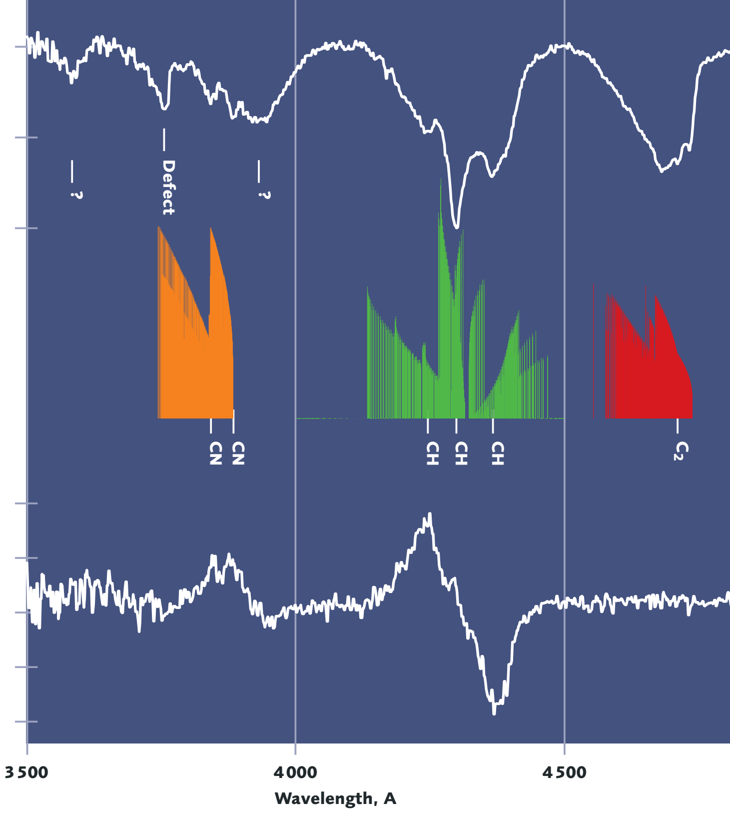
Molecules and surface magnetic fields in the oldest white dwarfs

White dwarfs are the end-products of the evolution of stars with initial masses up to about 8 solar masses, including the Sun itself. Such stars burn hydrogen and helium in their interiors, finally leaving a core made of mostly carbon and oxygen. As over 95% of the stars in our Galaxy end their lives as white dwarfs, these are of great interest in studies of the chemical evolution of the Galaxy, the stellar birth rate, and the age of the galactic disk.

The carbon-oxygen core of a white dwarf is usually surrounded by a thin, helium-rich envelope, itself surrounded by a hydrogenrich layer. Although these outer layers are very thin, they are extremely opaque to radiation and, thus, unstable to convection. The convection mixes the outer layers, producing a variety of hydrogen-rich and helium-rich white dwarfs. In the very oldest and coolest white dwarfs, convection in the helium envelope is deep enough to dredge up traces of carbon from the deeper layers. On the surface carbon is mostly in molecular form, and the optical spectra are dominated by broad bands of the C_2 molecule. Such stars are remnants of the first generation of intermediate-mass stars and are important diagnostics of the age and early history of the Galaxy.

The ALFOSC spectrograph has been used to study a sample of very cool, helium-rich white dwarfs whose atmospheres are enriched with carbon. One of these stars, G99-37, is unique in showing a strong CH band in addition to the C_2 bands, but the new spectra also revealed the violet CN band for the first time in a white dwarf (Fig. 17). The discovery of the CN band implies that a significant amount of nitrogen was also brought to the surface from the stellar core, which may provide an estimate of the mass of the progenitor star.

Previous spectropolarimetric observations at very low spectral resolution had revealed that some white dwarfs possess strong magnetic fields, of order 1 MG or more. Spectropolarimetry with much higher spectral resolution with ALFOSC not only confirmed the remarkable circular polarization signal in the CH band, but also revealed significant circular polarization in the CN band (Fig. 17), in contrast to the C2 bands. The CN molecule has never before been observed in magnetic fields of ~1 MG, and its interpretation presents a serious challenge for molecular physics (S. Berdyugina, Oulu; V. Piirola and A. Berydugin, Turku).



The interior structure of white dwarf stars

White dwarf stars are the most common end point of stellar evolution, when the mass of a star is packed into a sphere the size of the Earth. Recent years have brought much progress in understanding the structure and evolution of the atmospheres of white dwarfs (cf. the preceding contribution), but the structure and composition of their interiors are difficult to probe observationally. However, white dwarfs within a narrow temperature range show a rich spectrum of non-radial oscillations. Seismological techniques can be used to study the interiors of these stars if their oscillation spectra can be determined with sufficient frequency resolution. This requires long, uninterrupted time series of accurate photometry. The so-called *Whole Earth Telescope (WET)* is a world-wide network of telescopes organised with just such projects in mind.

The interior structure of white dwarfs with helium atmospheres is of special interest, as their origin from single-star or binary evolution remains unclear. Moreover, the ratio of carbon to oxygen in their interiors can be used to constrain the nuclear reaction rate for the conversion of ^{12}C to ^{16}O in the cores of red giant stars, an important but experimentally poorly-determined parameter in stellar evolution models.

PG 1456+103 is a pulsating helium white dwarf studied with the WET in May 2002. More than 300 hours of measurements were acquired from 16 observatories, including NOT. Just to show off, the star decided to nearly stop pulsating immediately before the campaign(!), but the amplitude of the light variations then increased steeply throughout the period, allowing a pulsational analysis of unprecedented detail. The results so far show that the amplitude growth and phase changes are limited to the pulsation modes of lowest frequency ($f < 1800$ μHz), whereas the modes of high-

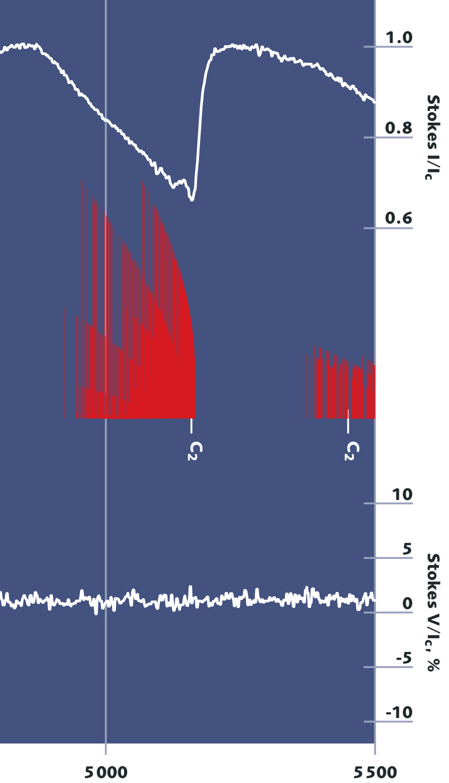


Fig. 17. A spectrum of the white dwarf G99-37. The strongest features are the carbon-based molecules C_2, CH and CN (marked by vertical coloured bars). The strong polarization signals in the CH and CN bands correspond to a magnetic field of order 1 MG.

er frequency remained stable; further analysis in terms of the interior structure of the star are under way. The NOT contribution was extremely useful because it provided data of the highest quality when it was most needed, i.e. at the beginning of the campaign when the light variations were still very small (J.-E. Solheim, Tromsö).

Seismology of an impending Type Ia supernova

The star KPD1930+2752 is a close binary system (orbital period only ~2h 17m) containing a short-period pulsating subdwarf B (sdB) star and an unseen companion, most likely a massive (~1 M_{sun}) white dwarf, so far only seen via the ellipsoidal tidal deformation it produces on the sdB star. Most interestingly, the total mass of the system (~1.5 M_{sun}) exceeds the Chandrasekhar limit for the stability of a white dwarf. This implies that, when the two stars coalesce due to gravitational wave radiation losses within the next ~200 million years, KPD1930+2752 may explode as a Type Ia supernova (see the first report in this section).

These prospects provide strong motivation for a detailed study of the physical properties of the system, using both the detected ellipsoidal variation *and* the rich pulsation spectrum of the pulsating sdB component. In order to unambiguously resolve the complex pulsation spectrum of the sdB star and the fine structure in the ellipsoidal light-curve, intense and continuous monitoring over a long period is needed. The Whole Earth Telescope (WET) is a world-wide network of telescopes set up to perform just this kind of observations, and a multisite campaign of fast

Fig. 18: The development of the amplitudes (left) and phases (right) of four pulsation modes of PG 1456+103. Note that the first two modes vary significantly while the last two were stable during this period.

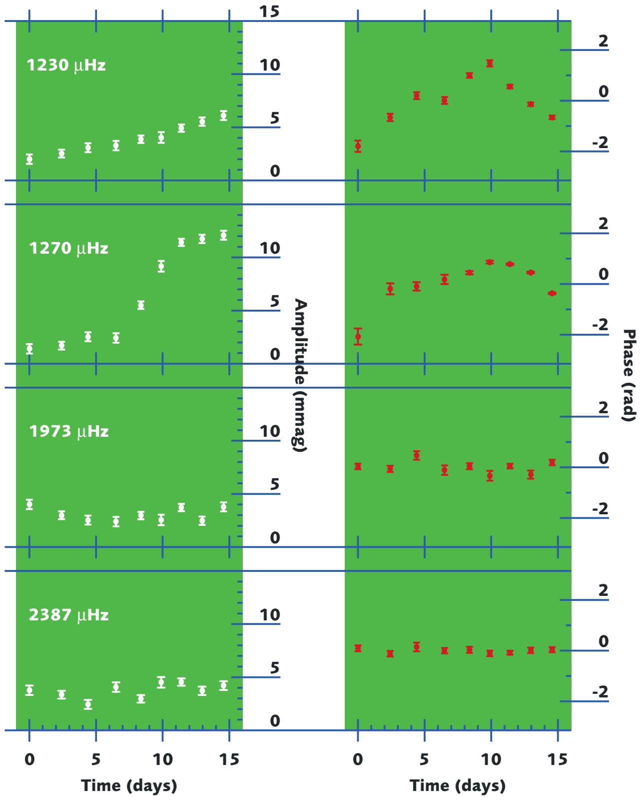
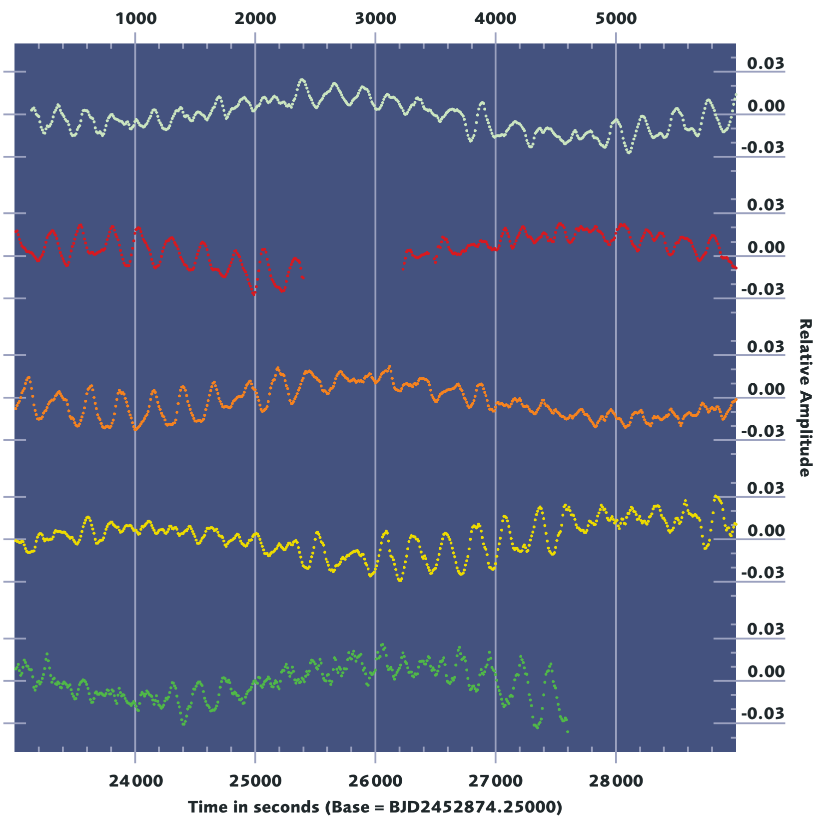


Fig. 19. One of the best NOT light curves of KPD1930+2752, highlighting the rapid, complex, multi-periodic pulsation pattern of the sdB star. The ellipsoidal variations with a period of 4109 sec (half the binary orbital period) are also clearly seen.



photometry of KPD1930+2752 involving up to 18 observatories was carried out from August 18 to September 7, 2003. Although the weather was mixed, a total of ~180 hours of data was collected. The detailed analysis of these data is underway.

The figure shows one complete night of data (~7.5 hours total) from NOT, which provided some of the best lightcurves obtained during the campaign. The varying shape of the sdB pulsations component is obvious, with its rich spectrum of complex constructive and destructive interference patterns. The quasi-sinusoidal longer-period variation due to the ellipsoidal deformation of the sdB star is also apparent (J.-E. Solheim, Tromsö).

New X-ray binaries from γ-ray and optical observations

An X-ray binary is the final stage in the evolution of a close binary star. X-ray binaries consist of a compact object – a neutron star or a black hole – accreting matter from a lower-mass, nondegenerate secondary star. In lowmass X-ray binaries the secondary fills its maximum equipotential surface (the Roche lobe), and matter flows in a stream from it onto an accretion disk surrounding the compact object. In high-mass X-ray binaries, the accretion is fuelled by a strong stellar wind from the secondary star.

Most low-mass X-ray binaries are so-called ”transient” sources: Instabilities in the mass flow or in the accretion disk trigger violent outbursts that produce a strong X-ray flux. Some objects also emit radio emission due to relativistic outflows from the system. Rapid pulsation in the X-ray or radio emission immediately labels the compact object as a neutron star. In many other cases, the nature of the compact object can only be clarified by estimating its mass from the radial-velocity variations of the nondegenerate companion. Once the secondary star has been detected, the system can be classified as a high-mass or low-mass X-ray binary.

The ESA INTErnational Gamma-Ray Astrophysical Laboratory (INTEGRAL) satellite also provides on-board X-ray monitoring of sources in the γ-ray fields. Transient X-ray sources from INTEGRAL are a pool of potential new X-ray binaries

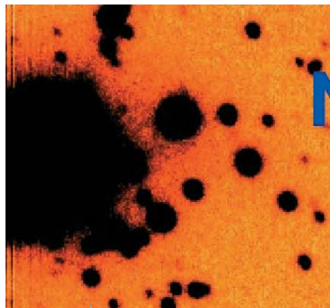
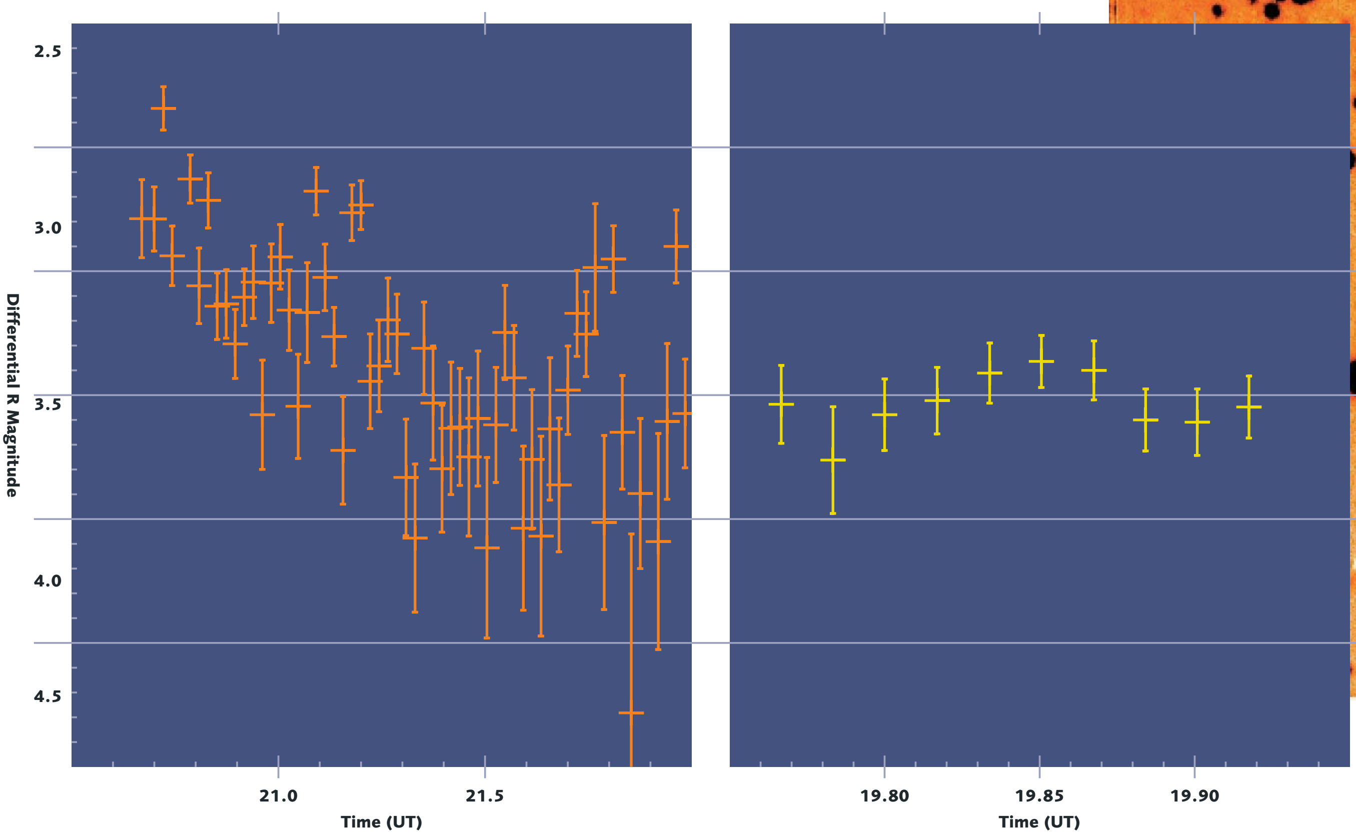


Fig. 20. Lightcurve in the R-band (red light) of IGR J175442619 just after discovery (left) and 25 days later (right).



in outburst. The challenge is to identify them while they are still bright. A target-of-opportunity programme at NOT has been approved to secure prompt optical and infrared observations of such sources. The near-infrared region is important in order to detect the cool secondary star despite the dominant optical emission from the accreting gas, and also because many of these Galactic sources are highly reddened by intervening dust.

The first of two such targets studied with NOT in 2003 – IGRJ 19140+098 – is located in a very crowded field. Its position was known only to ~1', and although both optical and infrared images were obtained, the identification of the counterpart remains elusive. It will be studied again in 2004 to search for any light modulation induced by the orbital motion of the system and for variations in the radial velocity of the secondary star, which would confirm the identification. The second target – IGR J175442619 – had an X-ray position from the XMM satellite, accurate to ~10". Fig. 21 shows the field of the transient and the position error circle, while the lightcurve of the suspected counterpart shortly after its discovery (Fig. 20) resembles the decay of an outbursting X-ray source. A second lightcurve obtained some weeks later presumably shows the brightness of the optical counterpart after the outburst has decayed (D. Hannikainen, Helsinki).

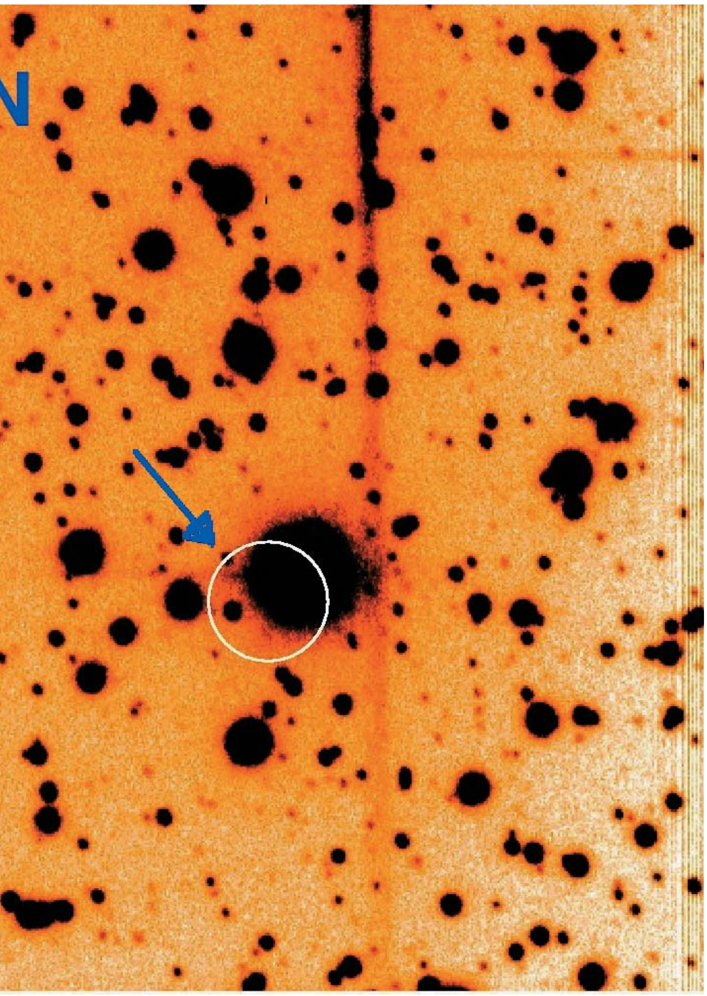


Fig. 21. StanCam image of the field of IGR J175442619. The error circle of the X-ray position and the candidate object are shown.

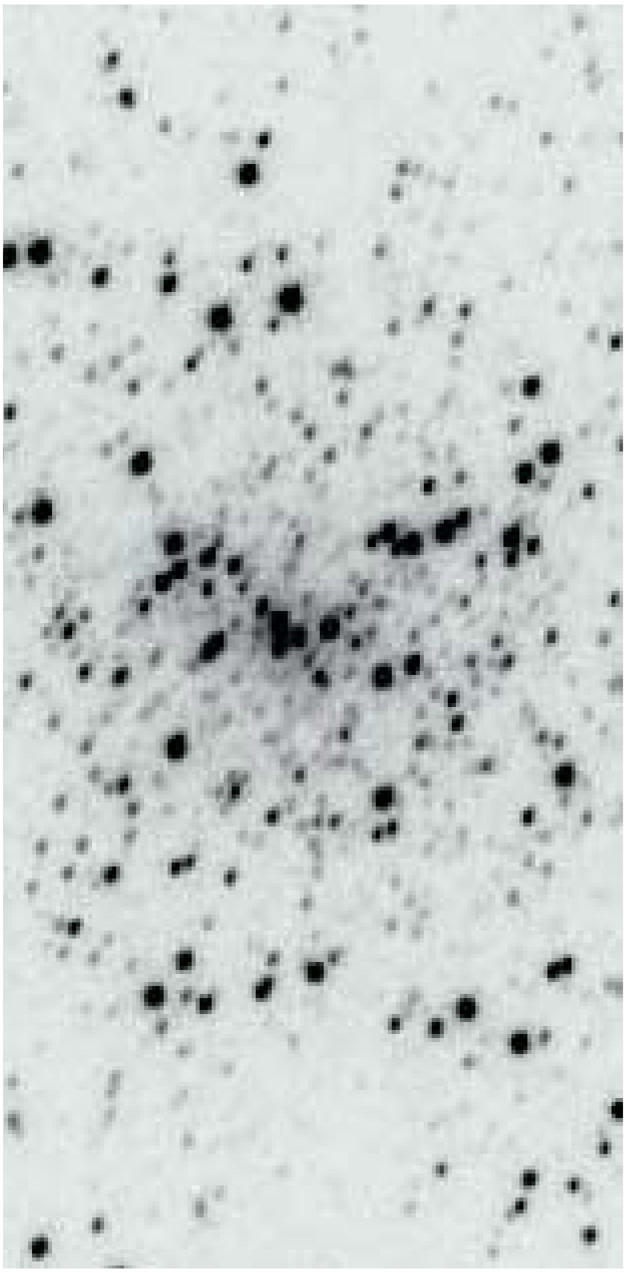
INNOVATIVE INSTRUMENTATION

Keeping the instrumentation at NOT competitive is a key priority in our long-term planning. As major revisions of our instrumentation imply major investments, it is important to assess the potential of new techniques for NOT in practice before undertaking such investments. Two examples are described here.

High-resolution 'Lucky' imaging

One of the greatest challenges for ground-based imaging is to minimise the effects of atmospheric turbulence that smears out the images. But amidst the rapid fluctuations of the atmosphere, moments lasting for a few tens of milliseconds occur when the turbulence stabilises and a near-perfect image is formed. Moreover, the image quality remains excellent over a much larger field than the few arcseconds over which the average turbulence can be corrected with adaptive optics. And no large investment is required, only a CCD camera which can take frames in rapid succession without adding significant readout noise.

A new, essentially noiseless CCD camera ("LuckyCam") has been used to take large numbers of images with NOT and select those lucky moments of quiet air that give pictures with dramatically improved spatial resolution. Fig 22 compares images of the core of the globular cluster M15 taken with the StanCam CCD camera (left), moments before observations with LuckyCam on the same telescope and under identical conditions gave the picture at right. The improvement in resolution in these images, from 0.6" to 0.15", is quite remarkable. The LuckyCam image was produced from a set of fields of 20" x 20" each, observed at a rate of 12 frames per second for about 80 seconds and selecting the best 10% of the images. The final image of approx. 55" x 55" was assembled from 9 such fields, and Fig. 22 shows a part of it. The brightest stars have $I \approx 13.4$, and the limiting magnitude in this short exposure is $I \approx 18.3$ in the outer, less crowded part of the field.



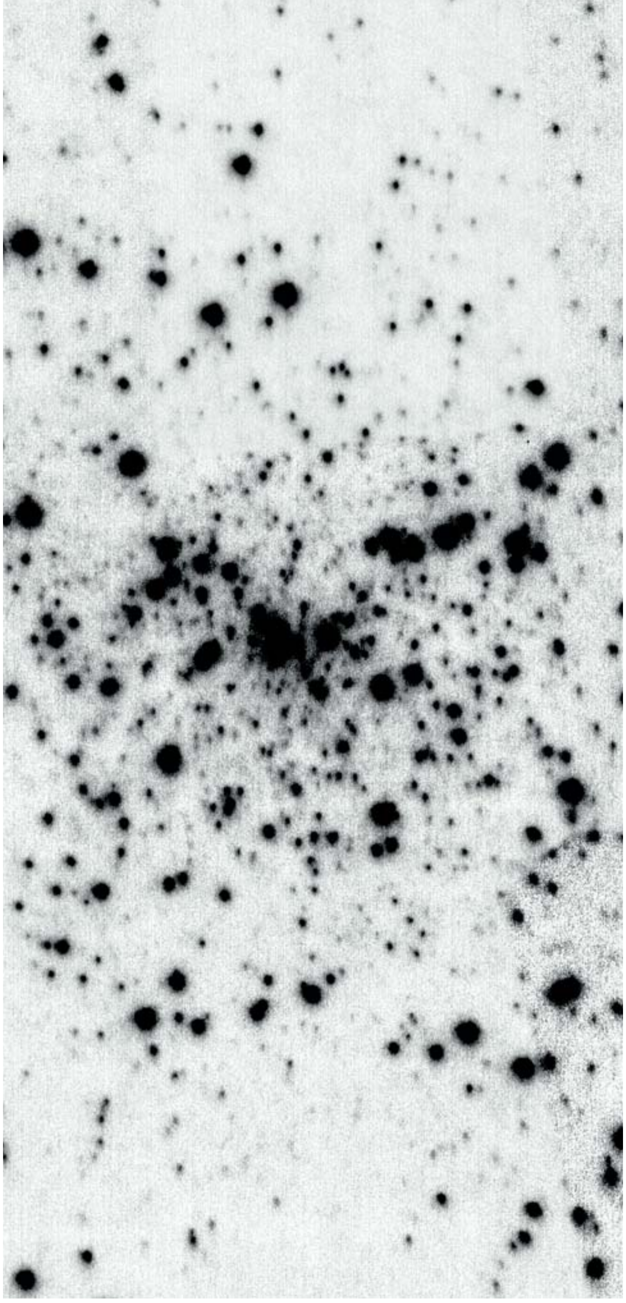


Fig. 22a and 22b.
Left: StanCam image in the I-band (˜800 nm) of the core of the globular cluster M15, taken in 0.6 seeing. Above: The same field observed with LuckyCam, showing images of 0.15 FWHM.

Conventional adaptive optics rely on detecting the errors in the wavefront and correcting them in real time. The key advantage of the "Lucky" technique technique is to avoid not only the considerable complexity and expense of conventional adaptive optics systems, ibut also the need for a bright reference star close to the science object. Suitable natural reference stars for adaptive optics are found only near a tiny fraction of the objects of greatest scientific interest. LuckyCam can use reference stars nearly a hundred times fainter, and over a very much larger field of view, which yields nearly 100% sky coverage. The technique is being further developed with a view to making it permanently available at NOT (C.D. Mackay, J.E. Baldwin, R. Tubbs, Cambridge, UK; G. Cox, NOT).

Exploring the thermal infrared

The infrared spectral region is important in astronomy. Cool stars, planets, and gas clouds emit most of their radiation at infrared wavelengths, and infrared light can penetrate dense dust clouds that are completely opaque to visible light. Moreover, the smearing effects of atmospheric turbulence are much less severe in the infrared.

However, at wavelengths beyond 1 m the Earth's atmosphere is opaque due to absorption by water molecules, except in a few 'windows' at 1.25 μm, 1.65 μm, 2 μm, 3.4 μm, and 5 μm, also known as the J, H, K, L, and M bands. Even longer wavelengths can be studied at a few very high and dry sites. Beginning at the K band (beyond 2 μm), the signal becomes dominated by thermal emission from the warm atmosphere, which completely dwarfs the signal from all but the very brightest astronomical sources. Specially optimised telescopes, instruments, and observing techniques are then necessary to extract the astronomical signal from the much stronger thermal noise.

NOT was not specially designed for infrared observations, but the Stockholm IR CAmera (SIRCA; see the report for 2002) still allows interesting work to be done in the wavelength range 1-5 μm. A few applications of this instrument to objects in the Solar System are shown here. The first of these is the L-band picture of the Moon shown on the front cover of this report, which shows a diffraction-limited resolution of 0.4" due to the good seeing at this wavelength. Unlike visible-light images of the Moon, the bright areas do not shine directly by reflected sunlight, but appear bright because they are warmer than the shadows, which are not heated by the Sun.

An image of Mars in the M-band (5 μm) is shown in Fig. 23 (red areas are warmest, purple and black coldest). Note that areas that appear dark in visible images (see p. 1) absorb sunlight most strongly, and thus appear brighter at M. Also, the usually white, cold snow-covered polar cap is seen dark in this picture.

Imaging Jupiter in the J, H, and M bands probes successively colder and deeper layers in Jupiter's atmosphere, as seen in the false-colour composite picture in Fig. 24. Note also the green K-band glow of Jupiter's aurorae above the polar regions.

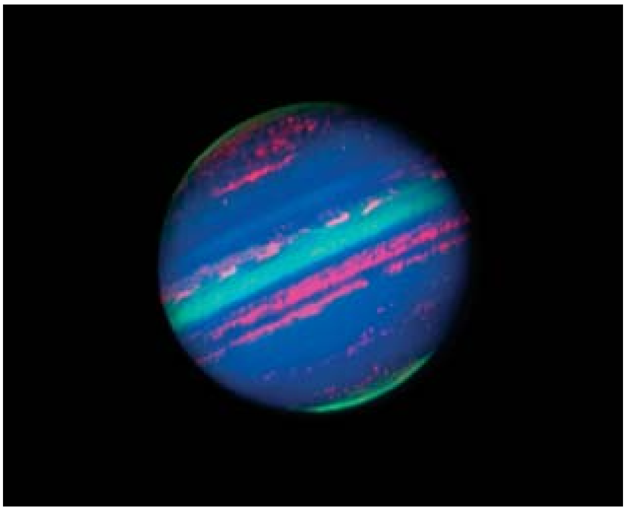
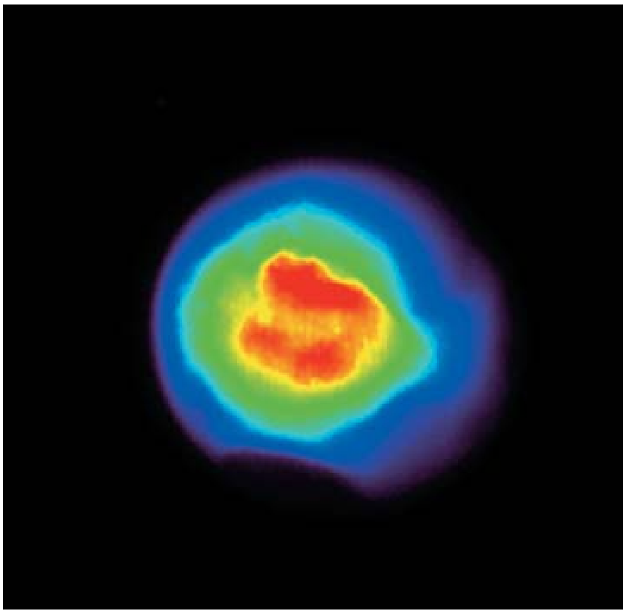


Fig. 24. False-colour image of Jupiter in the J (blue), K (green), and M (red) bands, showing successively deeper layers of Jupiter's atmosphere. A green auroral glow is seen above both polar regions.

An unusual view of Saturn is presented in Fig. 25. The K-band picture at left shows how sunlight is reflected off the bright particles in the rings, while it is absorbed in Saturn's atmosphere. The picture at right was taken at a wavelength near 3 μm, where radiation is strongly absorbed by water ice (H_2O). Note that the rings are invisible here, which shows that the particles in the rings are icy or covered by frost, while there is little water in Saturn's atmosphere. The two images here were combined to yield the false-colour picture on the back cover of this report (M. Gålfalk, G. Olofsson, Stockholm).



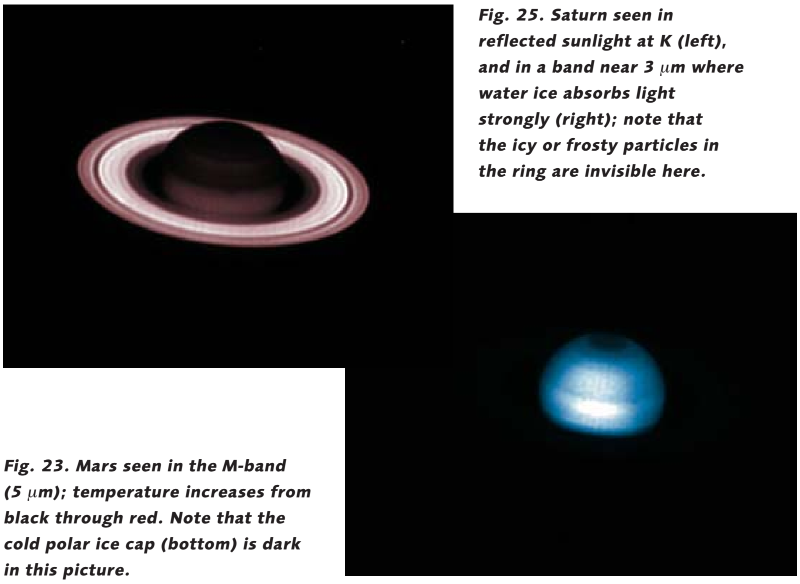


Fig. 25. Saturn seen in reflected sunlight at K (left), and in a band near 3 μm where water ice absorbs light strongly (right); note that the icy or frosty particles in the ring are invisible here.

Fig. 23. Mars seen in the M-band (5 μm); temperature increases from black through red. Note that the cold polar ice cap (bottom) is dark in this picture.

The ability of astronomy to interest young people in the natural sciences is recognised throughout the world. The visual appeal of the many beautiful pictures of planets, nebulae, and galaxies taken from space and from the ground catch the attention of people of all ages. Once students enter university, astronomy also offers hands-on examples of Nature's laws at work that are hard to beat in other branches of the physical sciences. At a time when much front-line research in astrophysics gravitates towards the largest international research facilities in space and on the ground, the possibility of offering students a hands-on research experience at a relatively early stage becomes increasingly important.

At a time when much front-line research in astrophysics gravitates towards the largest international research facilities in space and on the ground, the possibility of offering students a hands-on research experience at a relatively early stage becomes increasingly important. The use of NOT in training new generations of researchers was widely endorsed in the 2002 NOT User Group Survey, and subsequently also by the NOTSA Council. Accordingly, the use of NOT in Nordic science education is being taken up on a more systematic basis. Three of the possible roles of NOT in this context are: *(i)* As a source of data for observational M.Sc. and Ph.D. thesis projects; *(ii)* as a venue for courses in observational astrophysics at various levels; and *(iii)* as an inspiring environment for students. We report here on all three in turn.

Nordic Astronomy Theses 1994-2003

From it began operations, NOT has provided observational data for thesis projects by Nordic astronomy students. In order to get a quantitative estimate of this aspect of NOT's activities, Council members have kindly collected statistics on the number of astronomical M.Sc. and Ph.D. theses based wholly or in part on NOT data during the ten-year period 1994-2003. The results are as follows:

Type of thesis	*Denmark*	*Finland*	*Iceland*	*Norway*	*Sweden*
M.Sc.	*12*	*5*	*1**	*14*	***
Ph.D.	*9*	*7*		*4*	*19*

(* Iceland joined NOTSA in 1997, and M.Sc. theses were introduced in Sweden only recently).

Thus, a total of some 35 thesis projects at each level have been based on observations from NOT over this ten-year period. The different patterns from country to country no doubt reflect different traditions for the stage at which students are introduced to actual observations, and perhaps also what other options exist for observational thesis subjects may exist. In addition, some 15 of these students levels have spent periods of the order of a year each as Research Students at NOT, gaining much practical experience. It is gratifying to note that virtually all of these are still active in astronomy or a related science.

The 2003 NorFA Summer School

In the early 1990s, two Nordic-Baltic Research courses in astronomy were given at the NOT. After ten years, the course '*Observational Astrophysics at the Telescope*', funded by the Nordic Academy for Advanced Studies (NorFA), was held again on La Palma 1-12 July 2003.

Tutorial on NOT operations.

Deep concentration at the controls...

16 students from all Nordic countries (including 50% men) attended the school, selected from among 50 applicants, and tuition was provided by six Nordic astronomers. The 12-day programme included lectures on all aspects of observational astronomy as well as observations during 6 nights at NOT and 4 days at the Swedish Solar Telescope. Thus, the students were treated to a broad section of modern observational astrophysics.

The core of the course was the projects conducted at NOT – four nights with ALFOSC and two with NOTCam. The students formed four groups, each with a tutor, and spent several days planning the projects in detail before heading to the telescope. One group chose to probe the star formation rate of a distant Lyman-α emitting galaxy from its spectrum. Another used multi-band photometry to probe

A relaxed moment during the coursework

the stellar populations of nearby galaxies and clusters, and a third group made a deep survey of the open cluster NGC 7160 to search for Brown Dwarfs. The last group chose to study supernovae; they managed to be first to classify the spectra of two recently discovered supernovae and had their report published as an IAU circular (IAUC 8164) during the course – quite a thrill!

Enough laptop computers were available to allow the students to reduce a large fraction of the data while still at the mountain. This enabled all groups to actually report on scientific results during the final day's oral presentations, although most students got very little sleep that night! More detailed reports were completed at the students' home institutes (available at *http://www.astro.su.se/~jesper/NOTKURS/head.html*). Written evaluations of the course were also submitted by all students and will help to optimise the planning of any similar courses in the future.

The telescope and instruments worked very well during the school, and the weather was excellent most of the time. The students were very enthusiastic about the observations (see photos!) and worked hard on the data reduction and analysis during the course. This was the first visit to La Palma for most of the students, but I am sure it will not be the last. Perhaps some of the them will return to organise new research schools in the future – just as some organisers of this school were students at the schools of the early 1990s.

Primary funding from NorFA and co-sponsorhip by NOTSA, KVA, and Stockholm University are gratefully acknowledged.

Jesper Sollerman
Organizer of the NorFA summer school 2003

The Stockholm course in Observational Astrophysics

A new undergraduate course at Stockholm University aims to *(1)* give students an understanding of the fundamental theory of astronomical observations, independent of wavelength/frequency/energy and/or instrument and including state-of-the-art developments (e.g. adaptive optics, nulling interferometry etc.); *(2)* train the students to become professional observers by applying this theoretical knowledge to astronomical projects in a realistic observing environment; *(3)* provide a first insight into astronomical data reduction and analysis techniques; and *(4)* train the students in writing and presenting scientific material at an international level.

The course is given annually in two parts (5p + 5p = 5 full-time-weeks + 5 full-time-weeks). The first part is devoted to signal theory and applied theory of astronomical observations, using basic literature. The second part is a 'field exercise' at NOT, prepared through a series of lectures before the observing trip. The course is mandatory at the undergraduate level, but can also be taken by graduate (PhD) students.

Examinations are in written form. For part two, the examination includes:

a) a complete observing proposal in NOT (or ESO) format;
b) a report on the observations prepared as a scientific article in the format of a standard journal; and
c) an oral presentation given to the faculty, including a course evaluation by the students.

Part two became a reality for the first time during the period May 14-19, 2003, for 11 students and their teacher from Stockholm Observatory (2 undergraduates and 9 graduates took this first course). Students were provided with laptops for the observing trip, complete with the necessary software for data transfer and reduction. Introductions to NOT and its instrumentation were given by NOT staff astronomers. Then, fitting the observing projects of 11 students into five nights and reducing the data in real time gave the participants a vivid impression of the stressful life in the 'real world'!

The overall experience of this first training course at the NOT was exceedingly positive. The students were very enthusiastic to get their hands onto a real, professional research tool, and some of their final reports could probably have been published in a first-rate, refereed journal. This experience will benefit the planning of future similar courses, also for other Nordic students if the interest exists.

René Liseau
Stockholm Observatory; organizer of the course

INTERVIEW WITH PÁLL JAKOBSSON, REYKJAVÍK

Páll Jakobsson, Reykjavík, represents a new generation of students who have entered observational astronomy after Iceland joined NOTSA in 1997. We have asked him:

Páll, you will be the first Icelandic Ph.D. in observational astronomy for a long time. When did you decide to go that way, and why?

To be honest, I had no clue which astronomical path to take after I had finished my B.Sc. in physics in 1999. But I was fortunate that my astronomy teacher, Prof. Einar Gudmundsson, had introduced me to gravitational lenses and had started collaborating with Dr. Jens Hjorth in Copenhagen and others, using NOT to investigate the so-called magnification bias. This inspired me to jump on the next airplane and continue my studies in Copenhagen. But before embarking on my M.Sc. I had to take one year of courses, and I picked a mix of observational, theoretical, and simulation courses to keep my options open. After a few discussions with Jens, I had no doubt in my mind that I wanted to concentrate on observational astronomy.

Tell us about your M.Sc. project, and why you chose NOT for it.

The aim of my thesis was to determine the Hubble constant (H_0) by measuring the time delay between light variations in the double images of a gravitational lens. Here, the lens was a single galaxy, while the source was a distant quasar. In principle this is simple – H_0 is inversely proportional to the time delay – but the result also depends on the cosmological model, the source and lens redshifts, and the matter distribution in the lens. To pin down the time delay for a number of lens systems, we started a photometric monitoring campaign. NOT was chosen for its good optics and instrumentation and flexible scheduling, because we needed high spatial resolution as well as homogeneous, well-sampled data sets.

And how did it work out?

Well, as I said, this may be easy in principle, but practice is a different thing altogether! First, a very short delay is difficult to measure because the light curves tend to be undersampled. Second, the delay could also not be too long because I had only one year to finish my thesis! Most importantly, the quasar had to show significant variations so we could nail down the delay from these fingerprints in the light curves. This proved to be a real stumbling stone, as my quasar behaved very quietly. To cut a long story short, we did manage to detect small, but identical variations in the two light curves and estimated a time delay around 16 days. – And H_0 came out close to 68 km/s/Mpc!

Even this did not scare you from doing your Ph.D. in the same team. But you changed topic?

Yes, I could not stand the thought of another time delay, so it had to be anything else! No, to tell the truth I simply think that γ-ray bursts are the most exciting topic in astronomy today, with many unanswered questions. But Jens' collaboration with my former Icelandic teacher, Dr. Gunnlaugur Björnsson, was another important factor.

How does your project develop, and how do you view the role of NOT?

I'm roughly halfway and hope to finish the major part of my project this summer, which would give time to prepare for the new *Swift* mission (and write up my thesis!). NOT has been extremely important for my research. For example, part of it was to measure the metallicity of γ-ray burst host galaxies using narrow-band filters in the blue, and the superb UV performance of MOSCA makes NOT the ideal tool. The wide range of optical/near-IR instrumentation at NOT and its flexible operation are also essential for our target-of-opportunity programme on very early detections of γ-ray burst afterglows. But in addition, the work at NOT has led directly to the use of a wide range of other facilities, from HST to the ESO NTT and VLT, in many different combinations.

Overall, how would you assess NOT's long-term importance for your training?

In one word: invaluable! I have observed with the NOT six times and can honestly say that each time I have gained some new knowledge. The important part here is the hands-on experience: At NOT you really feel that *you are observing*, not just a useless bystander. I will certainly use NOT again in the future, and am especially enthusiastic about the new high-resolution spectrograph, FIES. With a dedicated readout mode we are developing specifically for the γ-ray burst observations, it will be crucial for the ToO programme I mentioned earlier, especially when the *Swift* satellite starts revolutionising the field of γ-ray bursts. And of course, having a dozen solid refereed papers under my belt at this stage is a good boost on the obstacle course ahead…!

General
Observing time is the most precious asset of any observatory. Competition for it fierce, and the peer review and selection of the very best scientific projects must be done in a competent, impartial, and transparent manner. At NOT, this task is entrusted to an *Observing Programmes Committee* (OPC, see inside back cover) of five respected Nordic scientists, appointed by the Council and independent of the NOT management.

Applications for observing time are invited in early May and November each year, for the semesters beginning the following October 1 and April 1, respectively. *The Call for Proposals* is announced widely, and all proposal forms and other information are available at the NOT web site (*http://www.not.iac.es/observing/proposals/*). Proposals are peer reviewed for scientific merit and ranked by the OPC, based on which the Director drafts an actual observing schedule, which takes into account such practical constraints as object visibility and seasonal variations in demand. The OPC reviews the draft schedule again before it is finalised and applicants are notified of the outcome. All current and recent observing schedules are available at our web site.

As part of the agreements establishing the observatory on La Palma, 20% of the observing time is reserved for Spanish astronomers and 5% for international projects. In order to encourage competition and maintain high scientific standards, non-Nordic proposals are welcomed and reviewed on an equal footing with Nordic proposals. From 2004, projects by all European astronomers at NOT and several other European 2-4-m class telescopes may be eligible for financial support from the EU under the OPTICON transnational access programme (see p. 4 and more detail at *http://www.otri.iac.es/opticon/*).

Observing time in 2003
Observing statistics are compiled by the summer and winter allocation periods described above. The present report thus covers the period April 1, 2003, to April 1, 2004. The over-subscription factor (nights requested / nights available) dropped from 2.0 to 1.6, but recovered fully at the end of the year. Subtracting Spanish, international, and technical time, 238 nights were allocated to scientific projects ranked by the OPC and to the Nordic training courses described above. Of these, 30.5 nights or 13% went to non-Nordic ("foreign") projects and 23 nights or 10% to projects by NOT staff; the remaining 184.5 nights were distributed as follows: Denmark 29 (16%), Finland 72 (39%), Iceland 9 (5%), Norway 19 (10%), and Sweden 55.5 (30%). Note that several "foreign" projects have Nordic P.I.s in long-term positions abroad.

The use of different instruments may also be of interest. In the above period, 310.5 nights in total were used for scientific observations (i.e., excluding technical time), distributed among instruments as follows: ALFOSC 135 (43%), NOTCam 58 (19%), SOFIN 56.5 (18%), MOSCA 15 (5%), Turpol 9 (3%), Stancam 6 (2%), and visitor instruments 31 (10%). Fluctuations from semester to semester are quite large.

Beginning in summer 2003, observers are offered the option of having their projects executed flexibly and in service mode by NOT staff, if service observing may enhance the scientific returns of the projects significantly. This offer met with considerable interest, and service observations were conducted during ~40 nights in 2003, including the 6 StanCam nights when the eclipsing binary star in NGC 6791 (see p. 12) could be monitored even when another instrument was mounted at the main focus. A simple Observing Block system was developed to ensure the safe and complete transfer of information from the P.I. to the observer; it is being further developed for use with the fast-response *Target-of-Opportunity* programmes, which are also gaining popularity.

Long-term trends in time allocation
The Nordic astronomical community is relatively small, and the changing interests of even small, active research groups – sometimes driven by the availability of certain instruments – may cause large changes in the pattern of use of NOT from semester to semester, and even from year to year. For planning purposes, it is important to distinguish long-term trends from such short-term fluctuations. Several aspects are relevant in this connection.

The Crab Nebula seen by NOT.

First, the interest in **service observing** is likely to increase for the foreseeable future. Its introduction in 2003 was closely monitored, not only as regards user satisfaction – which was high despite uncooperative weather – but also in order to understand its impact on the workload of the staff. It was found that, overall, service observing requires ~30% more work from the staff than the classical visitor mode. Given the limited size of our staff, we have so far assigned priority to programmes where service observing would bring significant gains in scientific returns compared to classical scheduling. A few 'normal' single-night periods have been also been conducted in service mode in 2003, but we are so far not funded and staffed to offer convenience as well as added science value on a general basis. Should the wish arise to do so, solid facts as regards the benefits and costs will be available on which to base a decision.

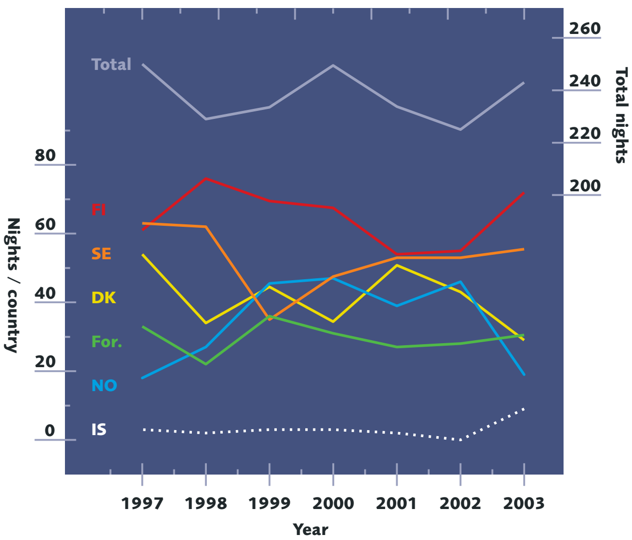
Flexibility of the instrumentation is the second factor giving freedom to schedule observations in a scientifically optimum manner. We are beginning to define and implement a new set of standby instrumentation that will allow a wide range of observations to be conducted at very short notice, without time-consuming instrument changes.

Changing user priorities are the most important factors guiding the future development of the services of NOT – and the most difficult to assess accurately. The 2002 NOT User Group Survey provided much valuable information on plans and priorities on a 3-8-year timescale, but will need an update in the foreseeable future. Probably 2005, when the full impact of the ESO facilities on Nordic astronomy will begin to be felt, will be a good moment.

Outside interest in NOT, as measured in terms of approved "foreign" observing projects, has remained stable at a level of 10-12% over the last several years. The OPTICON *Transnational Access Programme* (see. p. 4) will undoubtedly increase the demand for observing time from non-Nordic astronomers; this was already evident at the proposal deadline in November 2003 for the semester April 1 – October 1, 2004, which will be covered in the next Annual Report. Such outside proposals will be subject to normal peer review procedures in the NOT OPC as has been the case up to now. If successful they will, however, also bring substantial financial support from the EC, at a level adequate to fund 1-2 extra staff positions if some 10% of the observing time is awarded to new such users. It is the policy of the Council that this income shall be used to compensate the Nordic community in quality of service what it may lose in quantity of access at NOT. It is appropriate to recall that, at the same time, the OPTICON programme opens similarly free access for Nordic astronomers to a wide range of European state-of-the-art night-time and Solar telescopes all over the world.

The **national distribution of observing time** is a question of money, not science per se, but cannot be ignored. When NOTSA was created, the Associates agreed to share the cost in the proportions 20, 30, 20, and 30% to Denmark, Finland, Norway, and Sweden, respectively (Iceland joined with a 1% share in 1997). While these numbers do not reflect any quantitative measure of the size of the national astronomical communities or their demand for the services of NOT, common sense advises that in the long run each Associate should get approximately what it pays for.

The figure shows the evolution with time of the total number of nights allocated annually by NOTSA for the years for which adequate statistics exist, as well as the share of "foreign" projects and the national shares of the Nordic observing time, as judged by the nationality of the P.I. Averaged over the last four years, the Nordic time has been distributed with 20% to Danish projects, 32% to Finland, 2% to Iceland, 19% to Norway, and 27% to Sweden. The evolution of these numbers is being monitored on a running basis.



Total number of nights awarded annually by the NOT OPC, as well as to projects from each Nordic country and to "foreign" projects.

Publications are a standard measure of scientific output and one of the ways to assess the productivity of an observatory such as NOT, even if such lists effectively measure the productivity of the community of observers rather than the telescope itself. Accordingly, users are requested to report all papers in international refereed journals and based on NOT data to the staff, who maintain an inventory of such publications at our web site.

Papers that appeared in 2003 and have been reported to us are listed below; lists of more than 12 authors have been truncated to six, with the total number of authors given.

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Carlqvist, P., Gahm, G.F., Kristen, H.:
"Theory of Twisted Trunks", 2003, A&A **403**, 399

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"PNN NGC 246: A complex photometric behaviour that requires WET", 2003, Baltic Astronomy **12**, 125

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Kepler, S.O., Nather, R.E., Winget, D.E., Nitta, A., Kleinman, S.J., Metcalfe, T. et al. (46 authors):
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OTHER PUBLICATIONS BY NOT STAFF

NOTSA emphasizes that its staff astronomers should be active scientists in parallel with their functional work. They typically continue collaborative research projects undertaken elsewhere before they joined our staff, and the papers resulting from such work represent a valuable breadth of experience as well as a significant share of the scientific output from NOTSA. Refereed staff publications not included above are therefore listed here.

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Jonker, P.G., Nelemans, G., Wang, Z., Kong, A.K.H., Chakrabarty, D., Garcia, M. et al. (17 authors, including T. Augusteijn):
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"High-resolution spectroscopy for pulsation-mode identification", 2003, Ap&SS **284**, 85

FINANCIAL MATTERS

General

NOTSA is a non-profit organisation, which derives its entire regular income from the contributions of the Associates (see inside back cover). It devotes its entire budget to the operation and development of NOT, as specified in the agreements establishing NOTSA and according to the policies set by the Council. Each year, the accounts of the previous year and the proposed budget for the following year, with associated forecasts for the next three years, are submitted to the Council for approval. The Director is responsible for operating NOT within the approved budget and according to *Financial Rules* defined by the Council. Auditors are appointed for four-year terms by the Council, on the proposal of each of the Associates in turn; NOTSA's accounts for 2002-2005 are audited by *Audiator OY* of Finland.

In 2002, the Council approved a mid-term financial strategy by which an investment will be made during the years 2003-2005 to complete a number of long-standing upgrade projects of NOT itself and the services offered to users. In particular, this implies hiring additional staff during that period. Given the comfortable financial reserves as of the end of 2002, the budgets for the years 2003-2005 therefore operate with negative results, which will gradually return the end-of-year reserves to normal operating levels.

Accounts for 2003

In 2002, the Council also approved a new format of the annual budget and accounts, effective from 2003, which will provide a clearer overview of the cost structure of NOT operations and hence will allow more precise budget estimates in the future. The overview of the main operating costs provided on p. 32 therefore differs in presentation from previous Annual Reports. The degree of detail has also been reduced, but more explanations are given below. For comparison, the account figures for 2002 are also given in the new format.

Explanations

Directorate covers directorate staff, operations, committee travel, financial charges, stipends to two Spanish Ph.D. students in the Nordic countries, OPTICON meeting travel, and the Annual Report.

La Palma staff includes staff, NOT Research Students, and visitors on La Palma; health insurance and courses etc.

La Palma infrastructure includes the cost of the observatory and sea-level facilities for NOT; electricity, water, and cleaning; computer networks; and cars and other transportation.

La Palma operations cover accommodation and meals at the observatory; communications and shipping; telescope, laboratory, and office equipment and consumables, etc.

Telescope and instrument operation and maintenance comprises routine repair and upgrade of telescope and instrument mechanics, electronics, optics, and data acquisition and archiving equipment.

Development projects denote major new facilities or instrumentation as approved by the Council on a case-by-case basis.

The Contributions are shared among the Associates as follows: Denmark 19.8%, Finland 29.7%, Iceland 1%, Norway 19.8%, and Sweden 29.7%.

Other income derives from bank interest, refunds from the OPTICON and other EU contracts, and any special funding, such as the CCD detector upgrade programme funded in 2001-2002.

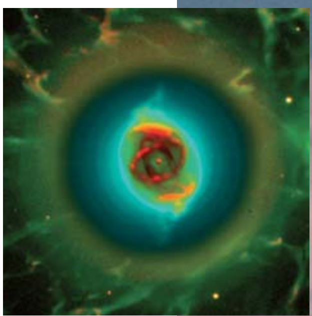
Comments

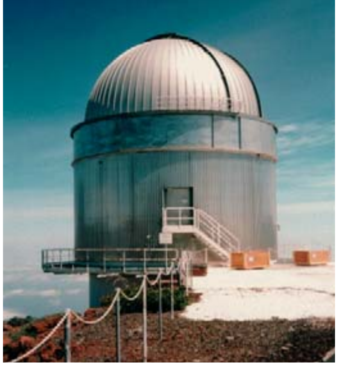
As shown by the table above, the actual cost of the directorate, staff, facilities, and operations in 2003 corresponded very well to the budget; some extra cost was associated with the expansion and air conditioning of the sea-level office in Santa Cruz. Telescope operations and developments were some 170 kEuro below budget, however. This is partly (and fortunately!) due to the lack of major breakdowns in 2003, partly due to delays in related developments of new instrumentation.

These include the new high-resolution spectrograph FIES; NOTSA contributes the building, and just getting a design and starting the construction approval process took most of 2003. Renewal of the detector controller systems was foreseen, but their development at Copenhagen University is taking longer than anticipated. A more sensitive autoguider system is required with the wide-field focal reducer FRED; but as the completion of FRED in Turku has also been further delayed, we have taken the time to reconsider our long-term options.

As judged by the experience from its first year of operation, the new budget and account format is proving helpful for our understanding of the cost structure of the NOT operations. As explained above, most of the apparent savings in 2003 on upgrade and development projects represent deferred cost rather than true savings, and it is expected that the corresponding costs will be incurred in 2004 instead of 2003. The staff necessary for the upgrade of our basic facilities and services is now on board, and completing it by the end of 2005 remains the goal.

BUDGET HEADING	Expenses 2003 Euro	Budget 2003 kEuro	Expenses 2002 kEuro
Directorate	204 826	220	204
La Palma staff	668 228	665	583
La Palma infrastructure	124 225	150	132
La Palma operations	99 113	100	81
Telescope operation and maintenance	37 921	70	–
Instrument operation and maintenance	54 406	85	40
Telescope development projects	13 871	120	–
Special development projects	30 567	30	168
Total expenses	**1 233 157**	**1 440**	**1 208**
Contributions	1 183 800	1 184	1 155
Other income	46 437	96	171
Total income	**1 230 236**	**1 270**	**1 326**
Result of the year	**-2 921**	**-170**	**118**
Reserves at beginning of the year	870 658	871	753
Reserves at end of the year	867 737	701	871





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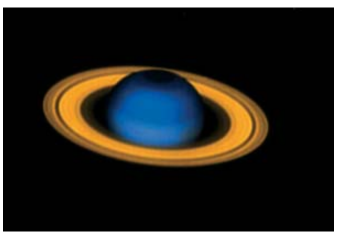

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Back cover : Saturn observed in infrared reflected sunlight at 2 μm (yellow), and in a deep absorption band of water ice at 3 μm (blue). The resulting colour distribution shows that the ring particles are icy or frosty, while there is little water in the atmosphere of Saturn.

2003

NORDIC OPTICAL TELESCOPE

Saturn and its frosty rings seen in infrared light with NOT.

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