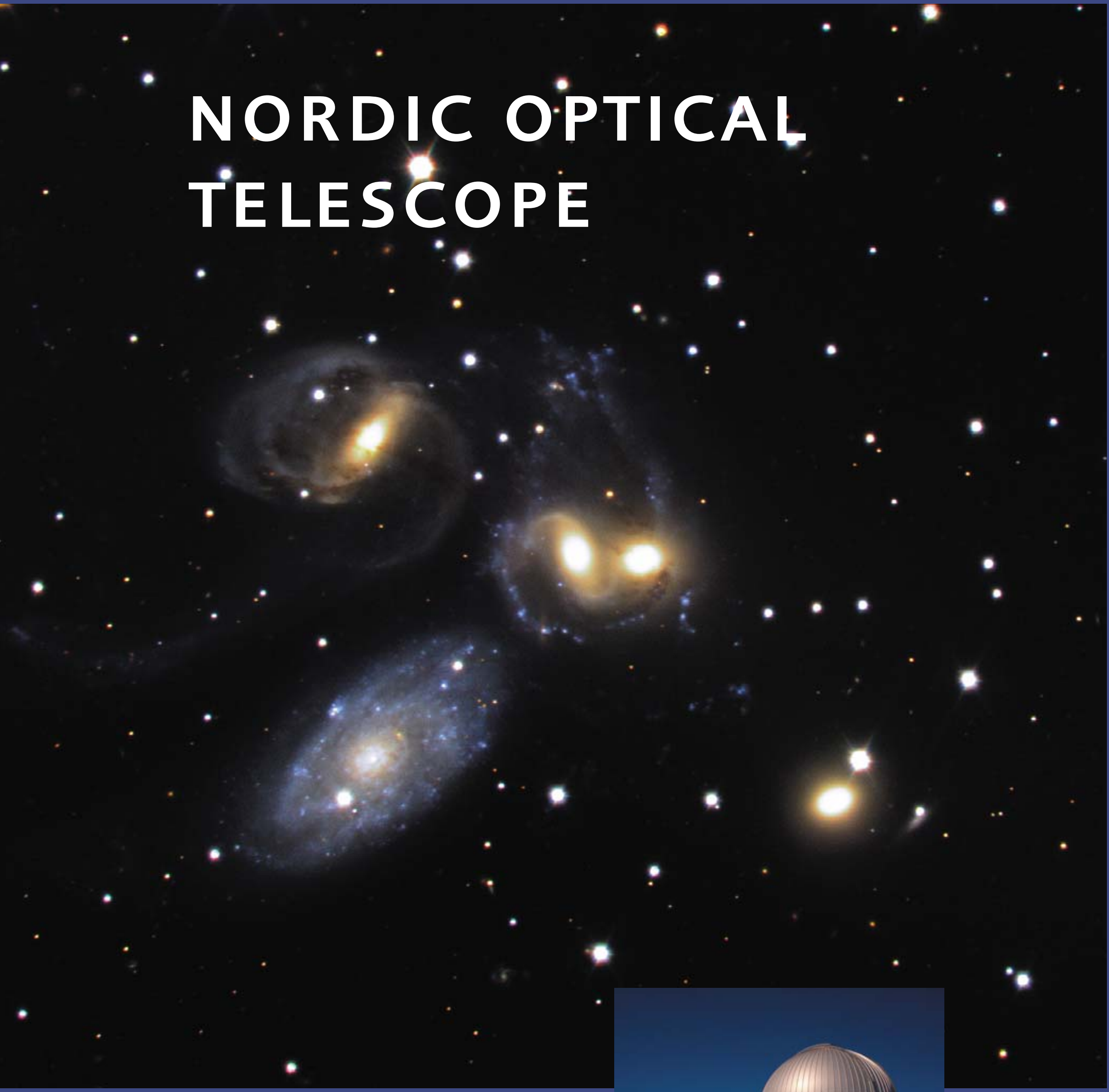
2005

NORDIC OPTICAL TELESCOPE

ANNUAL REPORT



Stephan's Quintet of galaxies

NOT in winter snow

Front cover: The famous 'Stephan's Quintet', a group of galaxies. Composite image in blue, green, and red light from ALFOSC.
Photo: M. Gålfalk, Stockholm University

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. A **Scientific and Technical Committee** (STC) advises the Council on the development of the telescope and other scientific and technical policy matters.

An international **Observing Programmes Committee** (OPC) of independent experts, appointed by the Council, performs peer review and scientific ranking of the observing proposals submitted. Based on the ranking by the OPC, the Director prepares the actual observing schedule.

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

The membership of the Council and committees in 2005 and contact information to NOT are listed at the end of this report.

The NOT Annual Reports for 2002-2005
are also available at:
http://www.not.iac.es/news/reports/

Spring on La Palma.

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Roque de los Muchachos
and NOT at sunset.

Editor: Johannes Andersen
Layout: Anne Marie Brammer

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OUR STAFF

The NOT team is complete again, as Amanda Djupvik returned on June 1, and Ricardo Cárdenes took up the post as System Manager on November 1. NOT students Brian Krog (Denmark), Jyri Näränen (Finland), and Karl Torstensson (Sweden) returned home during the year; they were replaced by Karianne Holhjem (Norway), Danuta ('Danka') Paraficz and Tine Bjørn Nielsen (Denmark), and Dmitrij Sharapov (Uzbekistan). The NOT team in 2005 is presented below.

As part of NOTSA's agreements with Spain, we also provided stipends for Spanish Ph.D. students Antonio López Merino, Copenhagen University, and Laia Mencia Trinchant, Stockholm, in 2005.

Francisco Armas
Administrator

Thomas Augusteijn
Astronomer-in-Charge

Peter Brandt
Mechanic

Ricardo Cárdenes
System manager

Jacob W. Clasen
Software specialist

Graham Cox
Electronics engineer

Amanda Djupvik
Senior staff astronomer

Loida Fernández
Secretary

Karianne Holhjem
M.Sc. student

Eva Jurlander
Accountant

Raine Karjalainen
Ph.D. student

Tine Bjørn Nielsen
M.Sc. student

Danuta Paraficz
M.Sc. student

Carlos Pérez
Electronics technician

Saskia Prins
Data flow scientist

Tapio Pursimo
Staff astronomer

Dmitrij Sharapov
Ph.D. student

Eric Stempels
Instrument specialist

Peter M. Sørensen
Software specialist

Ingvar Svärdh
Software engineer

John Telting
Staff astronomer

PREFACE

The spiral galaxy NGC 4565.
Photo: M. Gålfalk

This report brings you a sample of the research and other activities at NOT in 2005. I thank the authors of the individual science reports for their contributions and Magnus Gålfalk, Stockholm, for many of the astronomical photos. Unsigned text and photos are by the Editor. Credit for the layout and production goes again to Anne Marie Brammer, with my thanks.

2005 was a year of wild weather: In February, a snowstorm cut off NOT from the rest of the world for nearly two weeks; in September, a forest fire reached right up to the ORM Residencia; and in November, tropical storm Delta left broken trees, fallen fruit, and drenched observers on La Palma.

Our ranks closed again as Amanda Djupvik returned and Ricardo Cárdenes joined as our new System Manager. Meanwhile, the student group underwent a major gender transformation as Brian, Jyri, and Kalle were replaced by Danka, Karianne, and Tine (see opposite page). They and Raine were joined in December by Dmitrij Sharapov from Tashkent, Uzbekistan.

Another milestone occurred in April, as two pillars of the NOT community retired from the Council: Synnøve Irgens-Jensen of Norway – a Council member since 1989 and Chairperson in 1992-1995; and Thorsteinn Sæmundsson, who was a key figure in bringing Iceland into NOTSA and served on the Council since 1997. And at the end of 2005, Jan-Erik Solheim (Norway) also retired after more than 25 years of enthusiastic service to NOT in almost every conceivable capacity, most recently as OPC Chairperson for three years. Helpful as ever, he has summarised this experience in a *'Guide for Successful Applicants'* (p. 25).

On behalf of all of us at NOT, it is my pleasure to thank Synnøve, Thorsteinn, and Jan-Erik again for their support over all these years. However, in recognition of Synnøve's exceptional service to NOTSA and steadfast support for young female scientists, the Council also decided that, if a future female NOT student is especially promising, she will bear the title "Synnøve Irgens-Jensen Distinguished Research Student" of NOTSA. Karianne Holhjem of Norway became the first holder of this studentship – in tough competition from excellent candidates.

Long-term change appeared on the horizon in 2005. On the one hand, we completed the systematic upgrade of our infrastructure, instrumentation, and services that was started in 2003. More detail on the programme is given on p. 22, but in summary, NOT can now face the future with confidence. At the same time a consensus developed that, in view of the accelerating cooperation and coordination in European astronomy, standalone 2-4m telescopes will not remain competitive: Exchanging users is more cost-effective than changing instruments. NOTSA's active role in the initiatives by OPTICON and the new ERA-Net ASTRONET to establish comprehensive, long-term planning for European astronomy certainly served as a catalyst for this realisation.

Accordingly, we are proposing to create a new joint facility by fusing the Isaac Newton Group, Galileo Telescope, and NOT into a single, coherent unit. The scientific and financial advantages of integrating the instrumentation and operation of the three major telescope groups on La Palma are compelling indeed, and our task is now to find out how to do it. An international evaluation of NOT, initiated by the Associates in 2005, will be a valuable guide as we set sail into these uncharted waters.

With the report of the panel due soon, Spain joining ESO in July, and the 11-m Gran Telescopio Canarias (GTC) scheduled to see first light on La Palma by the end of the year, 2006 promises to be another exciting year!

Johannes Andersen
Director and Editor

Johannes
Andersen

Up-to-date information and news on the many-sided activities at NOT are maintained at our web site, http://www.not.iac.es. A few salient developments in 2005 are summarised here.

Personnel

With Ricardo Cárdenes on board as System Manager and Amanda Djupvik back full time, our team is complete again – with everybody on proper Spanish contracts. Over the summer, Genoveva Micheva (Uppsala), Danka Paraficz (Copenhagen), and Karianne Holhjem (Oslo) joined the student group; unfortunately for us, Genoveva was promptly head-hunted to a PhD fellowship in Stockholm, but Tine Bjørn Nielsen (Århus) and Dmitrij Sharapov (Tashkent) filled the ranks as Brian Krog, Jyri Näränen, and Karl Torstensson returned home, making the student office a lively place indeed!

Facilities and services

2005 saw the end of our three-year facility upgrade programme. The telescope mirrors were re-coated, the new telescope cooling and control systems were in operation or being commissioned, and the high-resolution spectrograph FIES was in place in its new building. Our network connection to the rest of the world was upgraded from 3 to 34 Mb/s, mainly thanks to the efforts of the IAC, and we began to deliver data in a uniform, standardised format. Many smaller improvements to the instruments were also made – see the summary of the upgrade programme on p. 22.

Service observing, where projects are executed by our staff on pre-assigned nights, became even more popular in 2005. Starting in April, we added a "fast-track" proposal mode, where projects requiring up to 4 hours of observing time can be proposed, evaluated, and executed at any time in a matter of weeks – weather permtting.

Students and faculty at the 2005 NORDFORSK summer school at Molétai, Lithuania

Danka, Dmitrij, and Tine in the sea-level student office.

Education

The role of NOT in science education – and especially in training a new generation of astronomers in a world of "hands-off" 8-m telescopes – is seen as increasingly important by the community and funding agencies alike. NOT contributes "hands-on" experience, both through our studentship programme and by making time available for regular university courses and occasional summer schools, where larger student groups visit La Palma to use NOT and often other telescopes as well.

But we remain keen to explore ways to use NOT even more effectively in education within realistic constraints of office and control room space and travel money. The NORDFORSK Nordic-Baltic Summer School *"Looking Inside Stars"*, held at Molétai Observatory in Lithuania in August 2005, gave an exciting demonstration of how this can be done. The Nordic-Baltic Organising Committee, headed by the indefatigable Jan-Erik Solheim, had planned a rich menu of lectures by prominent experts, observing projects, data reduction exercises, and social activities so as to leave the students wiser, happier, and totally exhausted at the end of the two weeks.

The observations were carried out with a judicious combination of real hands-on local telescopes, and NOT and an 80-cm telescope on Tenerife used in remote mode with NOT students and Spanish observers at the local controls. A wide-screen projector ensured that the whole group could follow the proceedings while two students at a time were at the controls, and the light curves and periodograms of known or suspected pulsating or eclipsing stars were followed in real time.

The combination of simple on-site instruments and a modern facility used via the Internet gave an inspiring blend of experience. Even the weather cooperated by not being bad at both locations at the same time! And with a few, rather simple improvements in data transmission, we may have found a new way to bring NOT into the classroom, intermediate between just getting "canned data" and going to La Palma in person.

European cooperation: OPTICON and ASTRONET

The European Southern Observatory (ESO) and the European Space Agency (ESA) remain the undisputed pillars of

European astronomy on the ground and in space. But some astronomical disciplines are not covered by ESO or ESA (most of radio astronomy, astroparticles, etc.); many European astronomers do not live in ESO or ESA member states; and much intellectual capital is wasted through inadequate support and coordination.

Various initiatives to improve the situation are under way with support from the European Commission under Framework Programme 6. NOTSA is privileged to serve as a link between the Nordic communities and these exciting developments.

The OPTICON *Integrated Infrastructure Initiative*, described in earlier reports, conducts a range of activities within its domain of (ground based) optical-infrared astronomy under a 19.2-MEuro contract in 2004-2008. Early in 2005, NOTSA joined a group of major European funding agencies in proposing the ERA-Net ASTRONET, the aim of which is to establish a comprehensive, long-term planning process for *all* of European astronomy. ASTRONET was awarded a four-year grant of 2.5 MEuro, and its activities are ramping up now.

The OPTICON and ASTRONET activities are closely coordinated, but complementary, also in preparing for the first proposals under Framework Programme 7, due in early 2007. They are briefly summarised below; more information is given at the web sites *www.astro-opticon.org* and *www.astronet-eu.org*.

The OPTICON programme is focused on optical-infrared astronomy in 2004-2008. The main activities are:

1: **A Trans-National Access Programme** supports the use by all European astronomers of most European 2-4-m night-time and major solar telescopes. Normal proposal and review procedures apply, and eligible new users receive travel support. The success of the programme is limited only by the available funding.
2: **Networking activities** promote coordination between communities with common interests; e.g., a notable achievement in 2005 was the preparation of a comprehensive joint science case for a future European Large Telescope.
3: **Joint Research Activities** support the coordinated development of front-line technologies for European astronomy, such as next-generation adaptive optics, new detector systems, or ‘smart focal planes’ for large telescopes.

In contrast, ASTRONET attempts to overview all of European astronomy for the next ~25 years, as follows:

1: A European **Science Vision** to be developed during 2006 will aim to define the overall scientific background and priorities for the development of a world-leading European astronomy in the 21st century.
2: Based on the *Science Vision*, and with a six-month time lag, a European **Infrastructure Roadmap** will be developed that outlines which major research infrastructures will be needed to fulfil the *Science Vision*, and when.
3: At the same time, contacts will be established with all astronomical communities and national funding agencies throughout Europe in order to *(i)* involve them all in the preparation of the *Science Vision* and *Infrastructure Roadmap* and *(ii)* create a basis for greater transparency and synergy in the organisation of European astronomy.

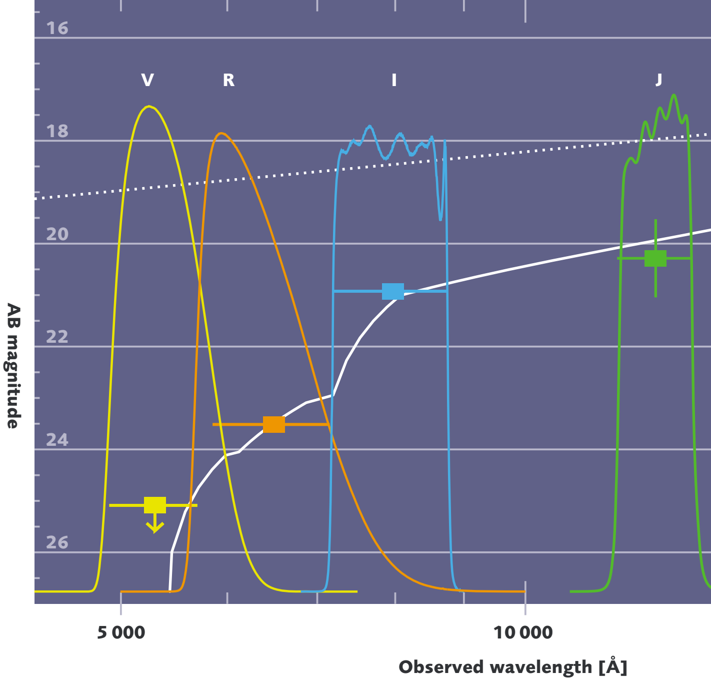
The long-term future of NOT

The future of NOT must be seen in the light of these developments, which are clearly in the sense of a common set of facilities, open to all European astronomers. It follows that the traditional concept of La Palma as a home for basically independent national telescopes is rapidly becoming outdated as far as NOT is concerned. Clearly, equipping the major night-time telescopes with a coordinated suite of instruments and operating them as a single unit for a broad user community is the most efficient model for the future, scientifically as well as financially.

In preparation for the next major steps in this direction, the Associates have commissioned an international evaluation of the status and plans of NOTSA by a high-level international panel. Its report, expected in early 2006, will help us to make NOT an even more effective tool for Nordic astronomy in the coming decade. Watch this space!

SCIENCE HIGHLIGHTS

Science is the raison d'être *of NOT. The primary scientific output from NOT is the professional publications by visitors and staff in international journals (see p. 29), but a few highlights from 2005 are given here for a more general readership. Initial texts by the individual authors have been edited for clarity and conciseness by the Editor, who apologises for any inadvertent errors in the process.*



COSMOLOGY AND FORMATION AND EVOLUTION OF GALAXIES

The formation and evolution of the Universe seem to be dominated by totally unknown forms of dark energy and dark matter. Understanding the nature of these forces and the role they played in forming the visible building blocks of the Universe – galaxies – is a central theme of observational cosmology. But although galaxies may contain only 3-4% of the total matter and energy in the Universe, they have still supplied all the light and heavy elements generated since the Big Bang. We need to understand the processes by which this took place.

Gamma-Ray Bursts probe star formation in the distant Universe

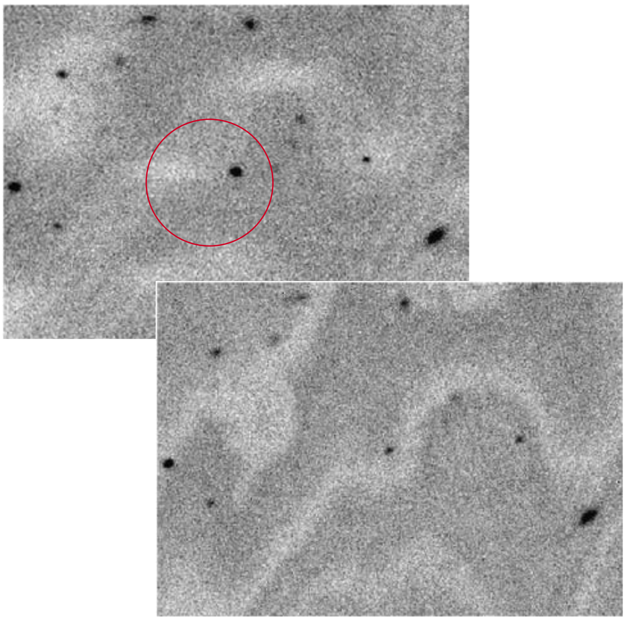
Gamma Ray Bursts (GRBs) – showers of high-energy γ-rays from the universe, lasting from a fraction of a second to a few minutes – remained a mystery for over thirty years. The first detection of optical afterglows in 1997 demonstrated that at least the long-duration GRBs are extragalactic events. More recently, the discovery of violent supernova explosions associated with these GRBs linked them conclusively to the core collapse of short-lived massive stars, and hence to regions of recent star formation. GRBs then became not only fascinating objects in themselves, but also tools with which to probe the star formation history of the distant Universe.

The “standard” model of a long GRB invokes the core collapse of a massive star, creating a black hole (BH) with a disk of material around it. The BH/disk system ejects an ultra-relativistic jet consisting mostly of electron/positron pairs, and shock waves within the jet generate the initial γ-ray burst. The jet eventually expands and sweeps up surrounding gas, and another, longer-lasting shock front forms, this time at the boundary between the jet and the external medium. This external shock produces the afterglow emission, which gradually drops in energy from γ-rays and X-rays through visible and infrared light to radio waves in the end.

Redshift measurements (z) now exist for roughly 70 GRBs. About half of them were made over just the last year, thanks to the *Swift* satellite (see Annual Report 2004) which now detects around 100 GRBs per year and provides accurate positions (within ~5") within 1-2 minutes. This enables ground-based telescopes to identify the optical afterglow very quickly and measure its redshift before it becomes too faint. The results show that long GRBs are found throughout the Universe out to a current record redshift of z = 6.3. Thus, the higher sensitivity, faster response, and accurate positions from *Swift* have enabled us to measure fainter and more distant bursts.

Thanks to its flexible operation, NOT has contributed significantly to this effort, with four spectroscopic redshifts in 2005. The *Swift* sample also includes GRB 050814 (Fig. 1), which was found to exhibit very red optical colours at

Fig. 1. The GRB 050814 afterglow in the I-band 14 hrs (left) and 35 hrs (right) after the burst; the circle shows the error in the Swift position. Note how the afterglow faded by a factor of four in just a day.



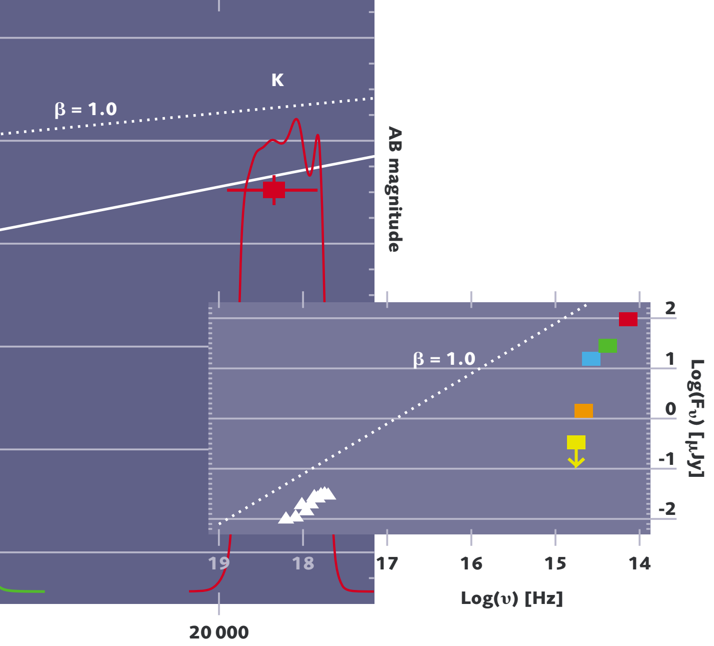


Fig. 2. The energy distribution of the afterglow of GRB 050814 from NOT (VRI) and UKIRT (JK) data. The filter transmission curves are shown; the point in V is a 2-σ upper limit. The solid curve is a GRB model redshifted to z = 5.3, while the dashed line corresponds to pure synchrotron emission in the "standard model". The inset shows the VRIJK observations (filled squares) along with X-ray data (filled triangles) from the same time; the dashed line is the same as in the main panel.

NOT. Combining visual data from NOT with near-IR data from UKIRT and modelling the spectral energy distribution, we found z = 5.3±0.3, the second-highest redshift ever measured for a GRB (Fig. 2).

With GRBs gradually emerging as extremely useful probes of star formation, their huge luminosities make them efficient probes of galaxies and the intergalactic medium over a significant fraction of the history of the Universe. Future instruments, such as the X-shooter on the VLT, will help to shed light on the end of the "dark ages" and the possible connection between GRBs and the first stellar objects in the Universe.

P. Jakobsson, Copenhagen, and collaborators

Hunting 'hidden' quasars

Quasars (or QSOs) are extremely luminous active galactic nuclei (AGN), powered by mass-accreting black holes. They were first discovered because many are strong radio sources; later, their strong blue and ultraviolet light was found to completely outshine their host galaxies. However, dust obscuration determines how we see and classify an AGN, as illustrated in the so-called "unification" model: The galaxy nucleus is surrounded by a dust torus that prevents us from seeing directly the blue and ultraviolet light unless we happen to look nearly straight into the jet (Fig. 3). In real life, the dust can be distributed irregularly around the nucleus, further complicating the scene.

Heavy dust extinction is an obvious disadvantage when looking for QSOs in optical surveys. However, in dust-surrounded AGN the dust is heated by the strong radiation field of the 'central engine', and the re-emitted energy is easily seen in mid-infrared (MIR) light. We are therefore taking a new approach to searching for AGN, by looking for MIR emission from the nuclear dust torus. Combining the 6.7 μm survey (LW2 filter) from the ISO satellite with the Two Micron All Sky Survey (2MASS), we selected a sample of 77 AGN candidates over an area of 10 square degrees.

In order to verify that these sources really *are* QSOs, optical spectroscopy was performed at NOT and other telescopes. We found 24 quasars at redshifts 0.1 < z < 2.3; nine of them have z > 0.8. About 1/3 of these QSOs show so red optical colours that they are missed in classical blue/UV AGN surveys. With a surface density of about 2 quasars per square degree down to 18 mag in the R-band, they outnumber those found by the Sloan QSO survey by 50% (Fig. 4). The discovery of these numerous red quasars supports the evolution picture in which these dust-obscured AGN are young, and where QSOs spend much of their lifetime in such a dust-enshrouded phase.

M. Haas, Bochum, and collaborators

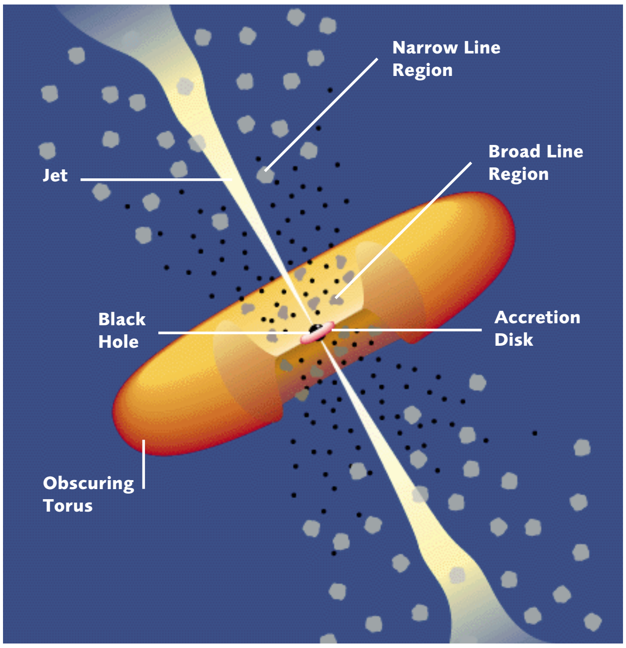


Fig. 3. The standard "unification" model of an AGN: If seen along the jet, the object is called a quasar; at right angles to the jet, only the mid-infrared emission of the hot dust is seen.

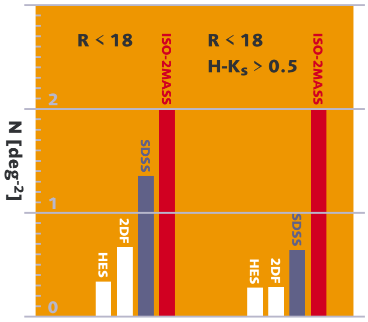


Fig. 4. The number of QSOs per square degree and brighter than red magnitude R = 18, discovered by various optical surveys (white and blue bars) and by us (red bars); the bars on the right show the statistics for the very reddest QSOs.

Understanding the host galaxies of quasars

When studying the evolution of QSOs, it is important to understand any differences between the host galaxies of radio-quiet and radio-loud QSOs (RQQs and RLQs), and between nearby and more distant (hence younger) objects. The near-infrared H-band (1.65 µm) is well suited for such studies, as it samples the old stellar population well and is insensitive to dust obscuration. We have used NOTCam to characterise the properties and evolution of a sample of RQQ host galaxies at intermediate redshift ($0.5 < z < 1$). In 12 out of 15 cases, the host galaxy was clearly detected.

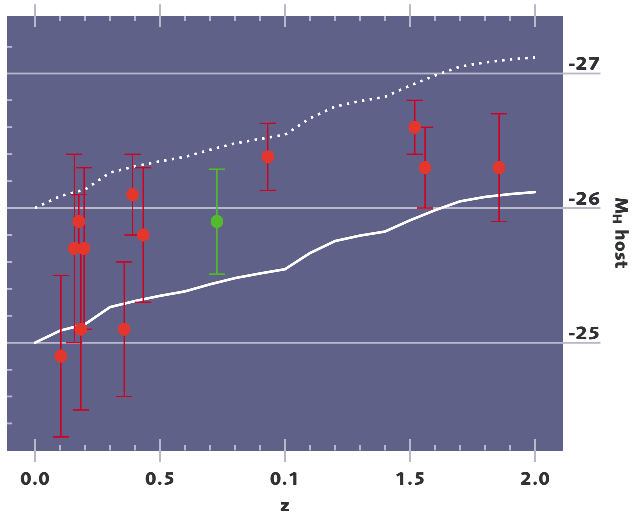


Fig. 5. Mean absolute H-band luminosity of RQQ host galaxies vs. red-shift. Our intermediate-redshift RQQ sample is marked as a green circle, literature data as red circles. The solid and long-dashed lines correspond to passive evolution of two galaxies of different absolute brightness.

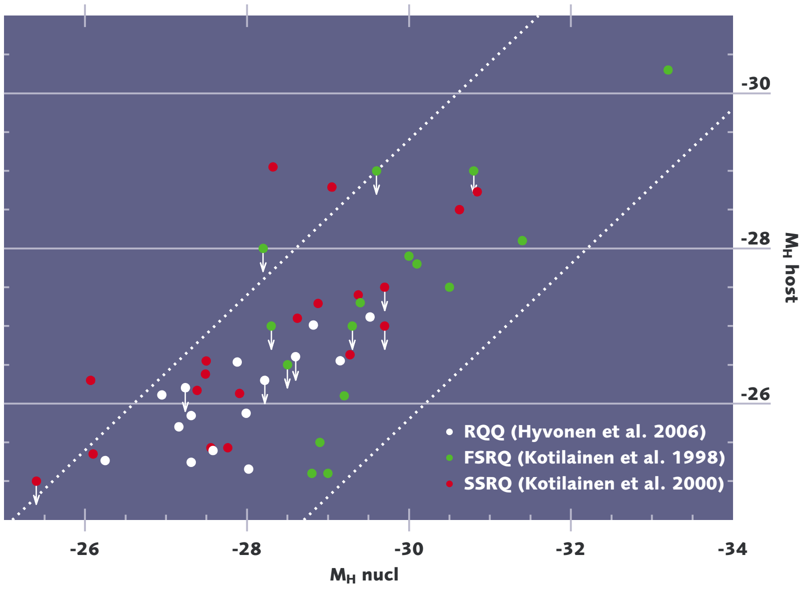


Fig. 6. H-band nuclear luminosity vs. host luminosity for intermediate-redshift RQQs (white circles; this work), steep-spectrum RLQs (red circles), and flat-spectrum RLQs (green circles). The diagonal lines correspond to a constant ratio between host and nuclear emission.

These intermediate-redshift RQQ hosts are large, luminous giant elliptical galaxies, ~1 mag brighter than the typical low-redshift galaxy, ~0.5 mag brighter than the hosts of lower-redshift RQQs, and as luminous as the brightest low-redshift cluster galaxies (Fig. 5), but ~1 mag fainter than RLQ hosts with similar redshift and comparable nuclear luminosity. This difference is consistent with simple passive evolution of the dominant stellar population in massive elliptical galaxies. Also, there seems to be no evolution in RQQ host galaxy *size* with redshift.

In intermediate-redshift RQQs, the luminosities of the host galaxy and the AGN are fairly well correlated, as expected from the relation between black hole mass and bulge luminosity found in nearby spheroidal galaxies (Fig. 6). No such correlation is seen for low redshift RQQs, however. Intermediate-redshift RQQs emit a wide range of power relative to their Eddington luminosity, between the low levels observed in nearby RQQs and the higher powers seen in luminous RLQs. RQQs are in slightly richer cluster environments than RLQs, but the fraction of RQQs with close companions cannot by itself explain the triggering and fuelling of the nuclear activity.

T. Hyvönen, J. Kotilainen & E. Örndahl, Tuorla;
R. Falomo, Padova; M. Uslenghi, Milano

Star formation in cluster and field galaxies

It has long been known that the morphological types of galaxies in clusters and the field are different: There are more lenticular and elliptical galaxies and fewer spiral galaxies in clusters than in the field. However, at higher redshift (younger age), clusters contain relatively more spiral galaxies than today, suggesting that many spiral galaxies in clusters transformed into lenticulars in the past ~5 Gyr. How they did so is not clear, but studying the rate and distribution of star formation in field and cluster galaxies of different types can help us to understand the influence of environment on the evolution of galaxies today.

The $H\alpha$ emission line of hydrogen is a direct, highly sensitive tracer of star formation with high spatial resolution. The ratio of $H\alpha$ to starlight (the Equivalent Width, EW) is a measure of new star formation relative to the already existing stars, largely independent of the size and distance of the galaxy. By measuring the EW both over the whole galaxy (EW_{tot}) and for the central half of the light (EW_{eff}), one can also estimate how centrally concentrated the star formation activity is. Finally, the galaxy "type" indicates how strongly developed the spiral structure is, ranging from Sa or T-type 1 (strong central bulge, little spiral structure) to Sc or T-type 5 (highly developed spiral structure, little or no bulge).

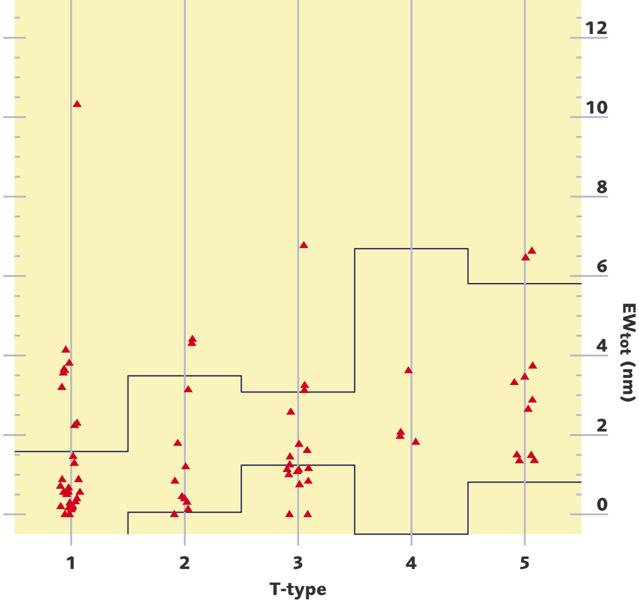


Fig. 7. Total Hα emission strength for cluster spiral galaxies as a function of T-type (see text). The solid lines show the region containing 95% of the corresponding field galaxies.

With NOT, we have made narrow-band Hα and continuum observations of a complete, well-defined sample of galaxies in eight local clusters and compared them with earlier data for local field galaxies. Fig. 7 shows total Hα emission strength for the cluster galaxies as a function of type. The lines enclose 95% of the points for field galaxies. If cluster and field galaxies were similar, 95% of the cluster galaxies should also fall there, but many cluster galaxies clearly have stronger Hα emission than field galaxies of the same type. This suggests that the cluster environment leads to stronger star formation activity in some galaxies, especially those with the least-developed spiral structure.

In order to see if the star formation activity is similarly located in the field and cluster samples, each cluster galaxy was matched at random to a similar field galaxy. As a check, the same experiment was also made between field galaxies alone. Fig. 8 shows that if the overall star formation activity is stronger in a cluster galaxy than in its field counterpart ($\Delta EW_{tot} > 0$), it is also more centrally concentrated ($\Delta EW_{eff}/EW_{tot} > 0$; the ellipse shows how the control sample is distributed). This suggests that being in a cluster may cause enhanced star formation in the inner regions of some spiral galaxies, perhaps triggered by gravitational tidal interactions. More detailed comparisons are under way, based on the NOT data.

C.F. Thomas, P.A. James & C. Moss, Liverpool

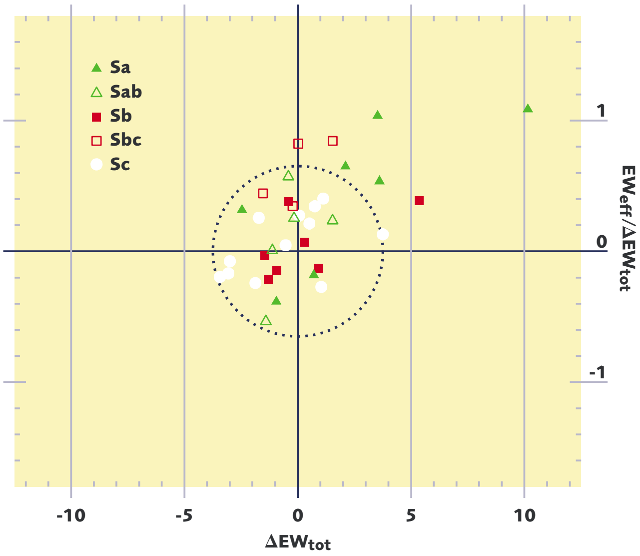


Fig. 8. Difference in central concentration ($\Delta EW_{eff}/EW_{tot}$) vs. difference in total Hα emission strength (ΔEW_{tot}) between cluster and field spiral galaxies, showing that the enhanced star formation activity in cluster galaxies is also often more centrally concentrated. The sequence Sa-Sc corresponds to T-types 1-5 in Fig. 7.

FORMATION, STRUCTURE, AND EVOLUTION OF STARS

Stars form in dense clouds of gas and dust. As they evolve, they illuminate their parent galaxy and build up heavy elements that are passed on to the next generation of stars when they end their lives as white dwarfs, neutron stars, or even black holes. Thus, stars are key actors and drivers also of galactic evolution. Theoretical models successfully describe the main features of stellar evolution and enable us, e.g., to determine stellar ages from observation, but the processes are complex, and critical comparisons with real stars must be made whenever possible. A great deal of work in this area was done at NOT in 2005.

A deeper understanding of shocks from young stars

Stars are born deep inside dense clouds of molecular gas. Exactly how this happens is not yet known, because thick dust clouds hide the newborn star, or protostar, from view. But the process must involve outflow as well as inflow of material, because young stars are seen to lose mass when they emerge from the parent cloud. In many cases, the ejected gas forms a highly collimated flow or jet. Where the jet rams into the interstellar material away from the star, a shock is formed. The shock becomes visible as a so-called Herbig-Haro (HH) object outside the dark cloud that still hides the protostar.

The detailed structure and motions of HH objects are the visible diagnostics of the hydrodynamics at play. In some cases the jet can be traced; at its origin, the protostar itself can then sometimes be seen through the dust in infrared light. Small, isolated dark clouds (or globules) that contain only one or very few protostars offer the best opportunities to study and understand the mechanisms at work in this complex interaction.

One of the best cases is the globule B335, about 800 light-years from the Sun. Here we observe a single outflow almost exactly from the side, far from other young stars that

Fig. 9a. Broad-band image of B335 in red light (shown as blue), showing the stars and dust in the field, while narrow-band emission lines in H-α (green) and S[II] (red) highlight the shocked gas. Note the completely opaque dust cloud in the centre of the globule.

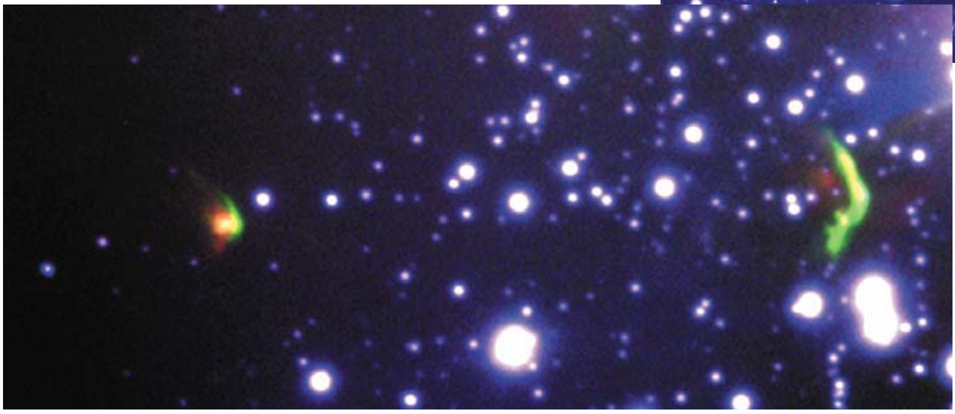


Fig. 9b. The HH-objects are shown here in more detail, aligned with a jet projecting from the centre of the globule. The main field is roughly 5'x4', this close-up 1'x2'.

could disturb the outflow and complicate the situation. Several HH objects are found along a line pointing back to the source, a protostar hidden by dust deep inside the globule.

Fig. 9 shows the deepest image ever obtained of the shocks in B335, combining no less than 14 hours of integration with ALFOSC and NOT in superb seeing. A continuum exposure highlights the stars and dust cloud in the region, while long exposures isolating narrow emission lines of hydrogen (Hα) and forbidden lines of sulphur (S [II]) trace the temperature and density of the shocked gas in unprecedented detail. We find that in B335, a high-density jet is ramming into less dense material – an unusual situation. Further, combining our new data with a 15-year old image reveals the intricate motions of the jet and shocks, with velocities over 200 km/s. In addition, three new large HH objects are discovered. Further observations in infrared light will penetrate deeper into the globule and outline the distribution of molecular hydrogen gas.

M. Gålfalk, Stockholm

Evolution of high-mass, fast-rotating cluster stars

High-mass stars are rare and short-lived, but they play a crucial role in the evolution of galaxies, because they are the main furnaces where heavy elements are produced; and they also inject enormous amounts of energy into the interstellar medium. It is therefore important to understand their evolution and how they feed the environment with processed material.

The evolution of a high-mass star depends primarily on its mass and chemical composition. But in recent years it has become clear that the initial rotational velocity is also important: Fast-rotating young stars evolve differently from those that rotate more slowly, and this may change their mass loss and even their lifetimes significantly. Young open star clusters are a good place to study these effects, because they contain many stars of the same distance, chemical composition, and age, but with different masses and initial rotation velocities.

The young open cluster NGC 7419 in the constellation Cepheus is a favourable test object, because it contains many dozens of massive and intrinsically very bright stars. They appear faint to us, because NGC 7419 is obscured by a dense dust cloud, but NGC 7419 is important in two respects:

1) Many of the stars (so-called Be stars) show emission lines in their spectra, believed to arise in a disk of material expelled from the surface of these stars because of their fast rotation. Most open clusters contain only around 5% Be stars, but the fraction was claimed to be much higher in NGC 7419.

2) NGC 7419 contains five red supergiants, high-mass stars that have evolved to the stage where helium is burned in their cores, but no blue supergiants (believed to be in the previous phase of evolution). In other clusters near the Sun, there are 2-3 times more blue than red such stars.

Using ALFOSC, we have obtained photometry and slitless spectroscopy of the field of NGC 7419 and intermediate resolution spectra of the brightest cluster stars, which will allow us to determine the distance and age of the cluster accurately. So far, we confirm that there are more than 35% Be stars among the massive stars in NGC 7419, probably the highest fraction found in any cluster in the Milky Way.

We also confirm that there are no blue supergiants in the cluster: The brightest blue stars are bright giants, still in the hydrogen core burning phase. These unusual properties could indicate very high average rotational velocities, a possibility we will investigate in more detail from the NOT data.

I. Negueruela, Alicante

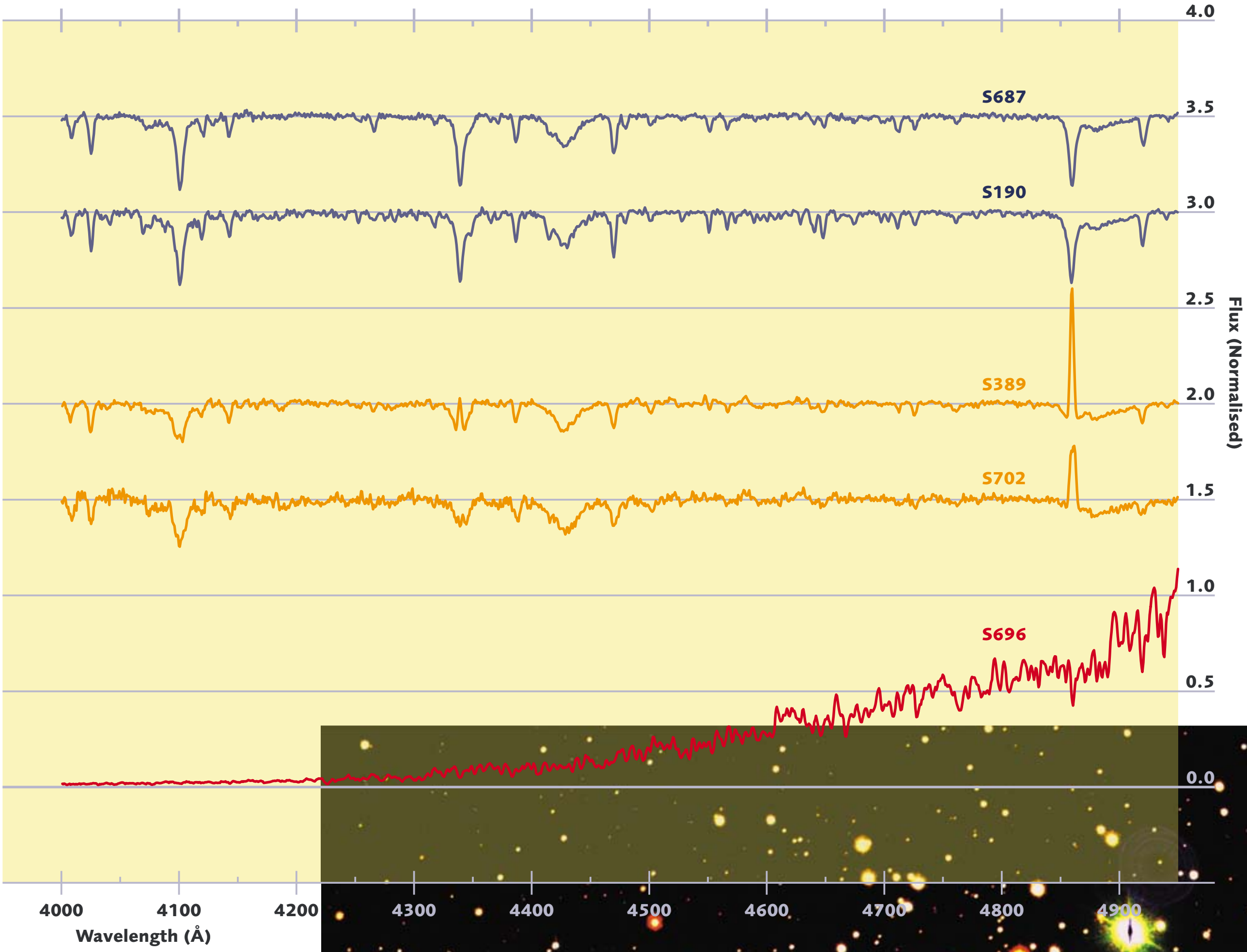
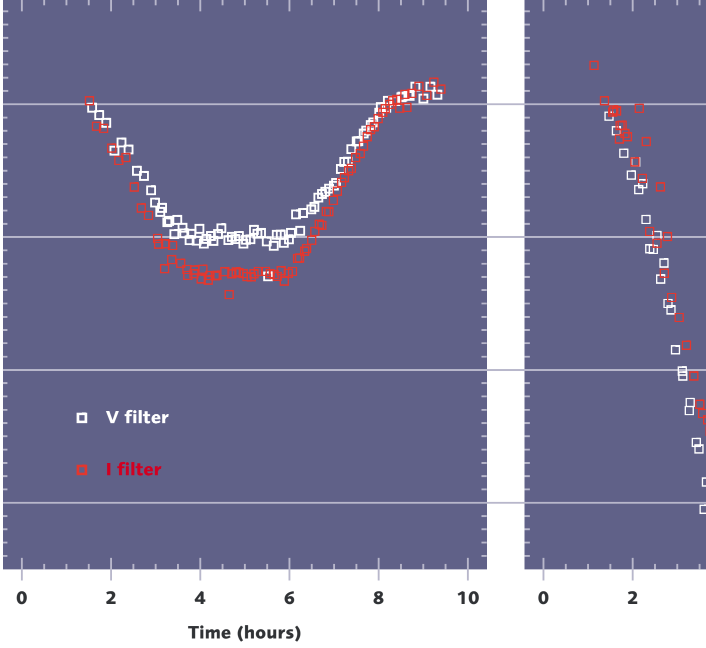


Fig. 11. Spectra of bright stars in NGC 7419, taken with the new grism #16 in ALFOSC. The blue spectra are the two brightest blue stars in the cluster, the orange spectra show two of the Be stars (note the typical emission lines), and the red spectrum is of a red supergiant, whose flux drops rapidly towards the ultraviolet.

Fig. 10. False colour image of NGC 7419, combining exposures in the Strömgren b, v and y filters. The colours have been set to show the intrinsically blue stars as white-yellowish, the five red supergiants (and an unrelated carbon star) as orange-red (they would have been brighter if a red filter had been included). The bright yellow star is a foreground object.



Pinpointing the evolution of old stars

The evolution of a star is determined by *(i)* its mass, *(ii)* its chemical composition. The mass of a real star can be determined if it is a member of an eclipsing binary system, and one can then compare its other properties (temperature, radius, and luminosity) with model predictions – but only for this single value of the mass. Alternatively, a star cluster allows one to study temperatures and luminosities for many stars of the same distance, age, and chemical composition and compare with the results of stellar evolution models, but the precise mass of each star in normally unknown.

Clearly, the most critical test of the models is obtained if both types of data can be combined in a single cluster. The importance of doing so is highlighted by the fact that open star clusters are the primary tool for determining ages of stars throughout the history of the Milky Way, relying on fits of theoretical models to observational data. Because even the 4.5 billion-year lifetime of the Sun covers only 1/3 of that history, accurate tests of models for even older stars are a matter of high priority.

Accordingly, in 2003 we started a programme to observe eclipsing binaries in the old star clusters NGC 188 and NGC 6791, obtaining colour-magnitude diagrams of the clusters (Fig. 12) and light curves of the binaries (Fig. 13) with NOT.

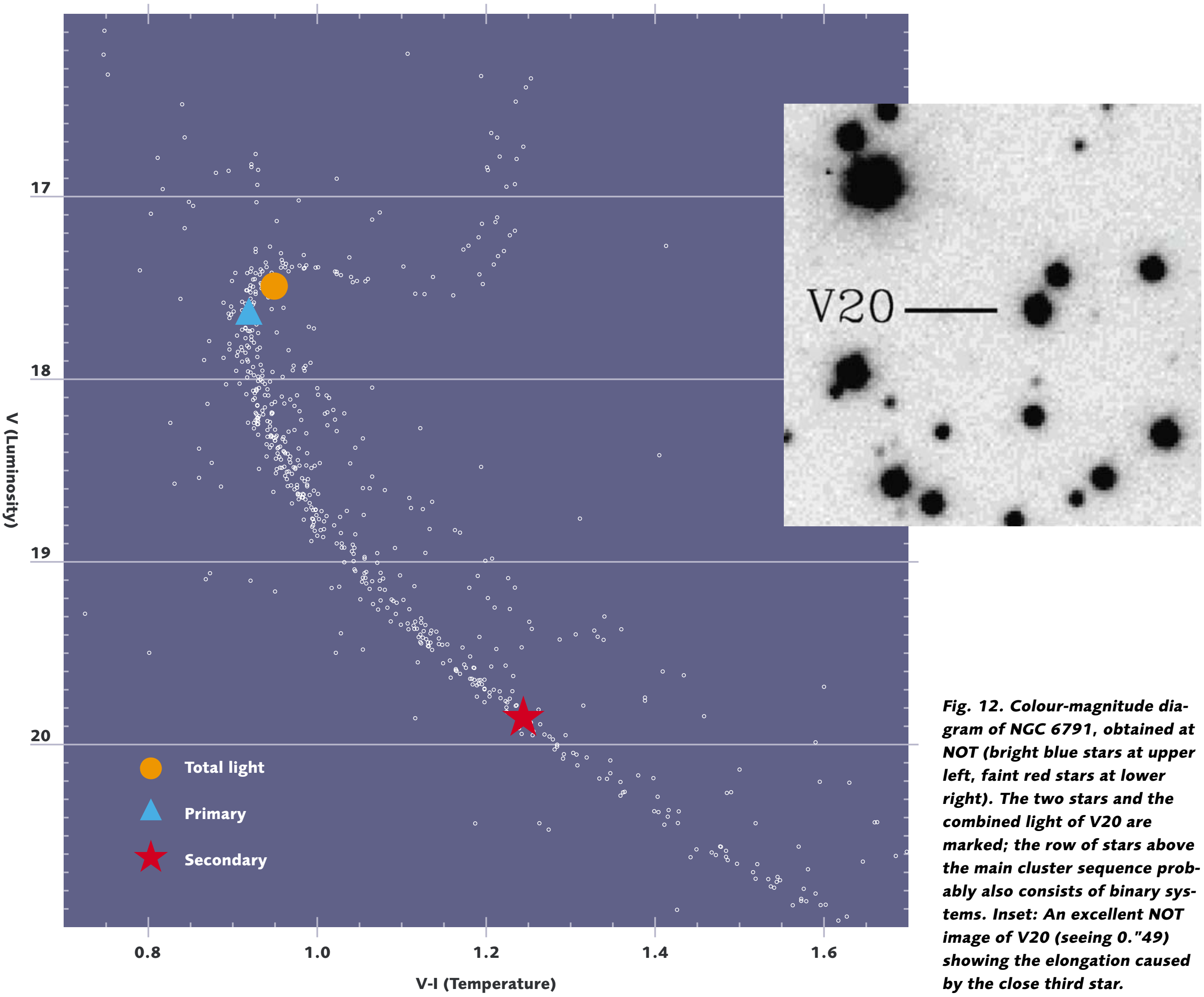


Fig. 12. Colour-magnitude diagram of NGC 6791, obtained at NOT (bright blue stars at upper left, faint red stars at lower right). The two stars and the combined light of V20 are marked; the row of stars above the main cluster sequence probably also consists of binary systems. Inset: An excellent NOT image of V20 (seeing 0."49) showing the elongation caused by the close third star.

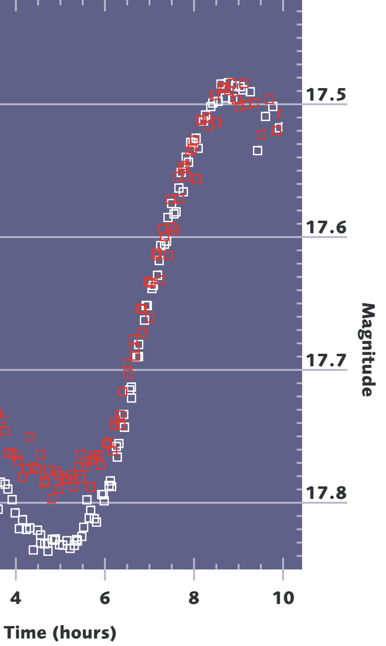


Fig. 13. Eclipses of V20 from NOT data. During the shallower (lefthand) eclipse, more infrared (I) than visual (V) light is lost and the minimum light level is constant; this shows that the secondary star is redder (=cooler) and hidden behind (i.e. smaller than) the primary star. The duration of the eclipses measures the sizes of both stars.

NOT was a very powerful tool here, because service observing allowed us to schedule observations on just those rare nights when eclipses occurred. Adding high-resolution spectra from other telescopes (Fig. 14) then enabled us to determine accurate masses and radii for the stars; for both cluster binaries we reach a final precision close to 1%.

Here we discuss NGC 6791, the oldest known open cluster. NGC 6791 is an extremely interesting object because it also has a very high content of heavy elements ('metals') – 2-3 times higher than the much younger Sun. This goes against the general picture of a gradual enrichment of the Milky Way disk with heavy elements produced in successive generations of stars. NGC 6791 therefore presents a serious problem for traditional models of the evolution of spiral galaxies.

However, it has been difficult to determine the age of NGC 6791 accurately because its distance – hence the luminosity of its stars – is poorly determined. By combining the NOT data (Fig. 12-13) with recent spectra from the ESO VLT (Fig. 14), we have determined accurate masses and radii for the two stars in the eclipsing binary V20 in NGC 6791. But the VLT spectra had an unpleasant surprise in store for us – they show lines of *three* stars! And indeed, the excellent NOT images reveal another cluster star very close to V20. Fortunately, the configuration of the stars in V20 is so favourable that our results are not seriously affected by this, but we plan to use LuckyCam to pin down the properties of the third star more accurately (cf. Fig. 24).

Fig. 12 shows the components of NGC 6791 in the colour-magnitude diagram of V20, and Fig. 15 compares their masses and radii with theoretical models. V20 turns out to be an ideal test object: The lower-mass star is essentially unevolved, which puts tight constraints on the cluster properties (especially the metal content), while the radius of the more massive star is increasing rapidly and pinpoints the age to 8.5±0.5 Gyr – a result far more reliable than can be determined for single field or cluster stars. Reassuringly, it is consistent with the result of fitting models directly to the cluster sequence in Fig. 12, without using the additional data from V20.

In summary, combining the best capabilities of NOT and the VLT not only provides a uniquely precise test of the theoretical models for old stars, but the now definitely old and metal-rich NGC 6791 also drives the final nail in the coffin of a whole generation of models for the evolution of our part of the Milky Way. Moreover, as planets are known to prefer metal-rich host stars, NGC 6791 is also an exciting hunting ground for planets like our own, but twice as old.

F. Grundahl, Aarhus

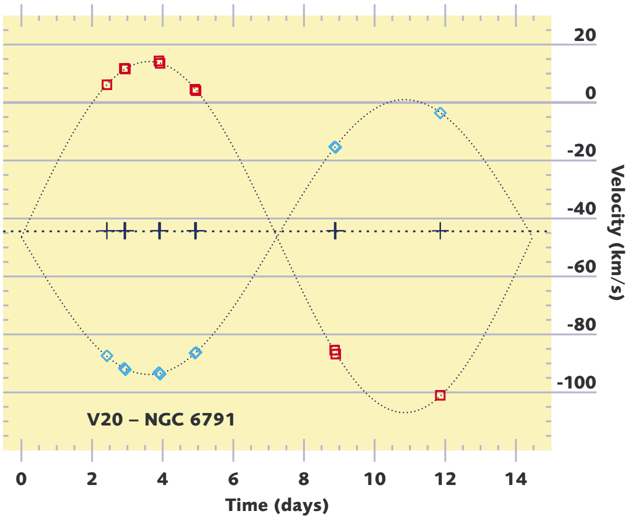


Fig. 14. Line-of-sight velocities for the stars in V20, measured from VLT/UVES spectra. The primary star is shown in light blue, the secondary in red, and the third (constant) star in dark blue. The amplitude of the curve for each star is the orbital velocity; both masses then follow from Kepler's law.

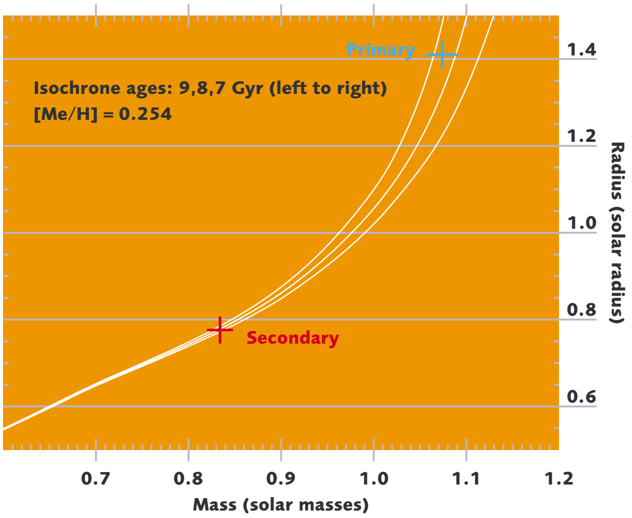


Fig. 15. Observed masses and radii for the stars in V20. With time the radii increase, that of the primary star faster. The curves show model relations for ages of 7, 8 and 9 (Gyr).

Pinpointing the properties of low-mass stars

Low-mass stars are the most abundant type of star in the Universe; yet their physical properties are not nearly as well understood as solar-type stars. As seen above, eclipsing binary systems offer the opportunity to determine such parameters as mass and radius that provide a wealth of detailed information about the components. However, because low-mass stars are cool, small, and faint, eclipsing systems are much harder to find and study.

The M-type eclipsing binary system TrES-Her0-07621, named after the “TrES” network that discovered it, was known to have shallow eclipses with a period around 1.12 days, but more accurate light curves, colours, and spectra were needed to pinpoint its properties. With NOT we observed two eclipses (Fig. 16), which allowed us to refine the period of the system and also, when combined with spectra from the 11-m Hobby-Eberly Telescope in Texas, to determine the masses and radii of the two stars.

We find that the two stars are nearly identical; their masses and radii are 49±1% and 45±1% of those of the Sun, respectively – only the fourth existing determination for such low-mass stars. More detailed comparisons with theoretical models are ongoing.

O. Creevey and collaborators, IAC and Boulder

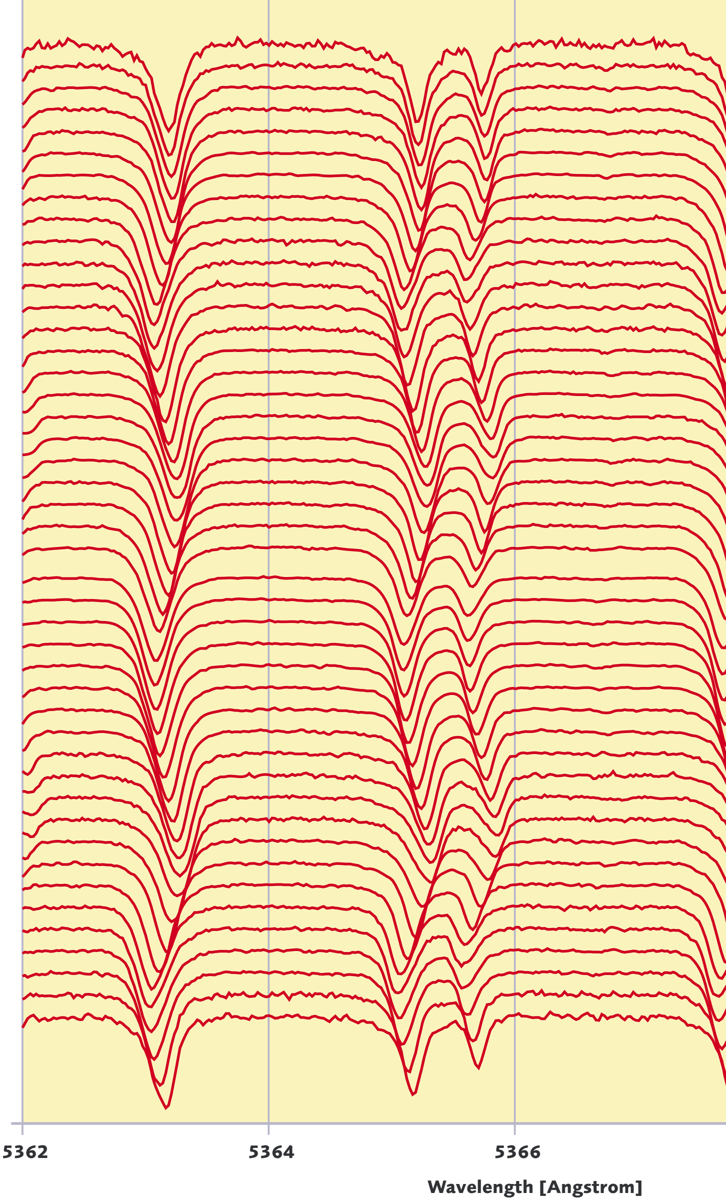
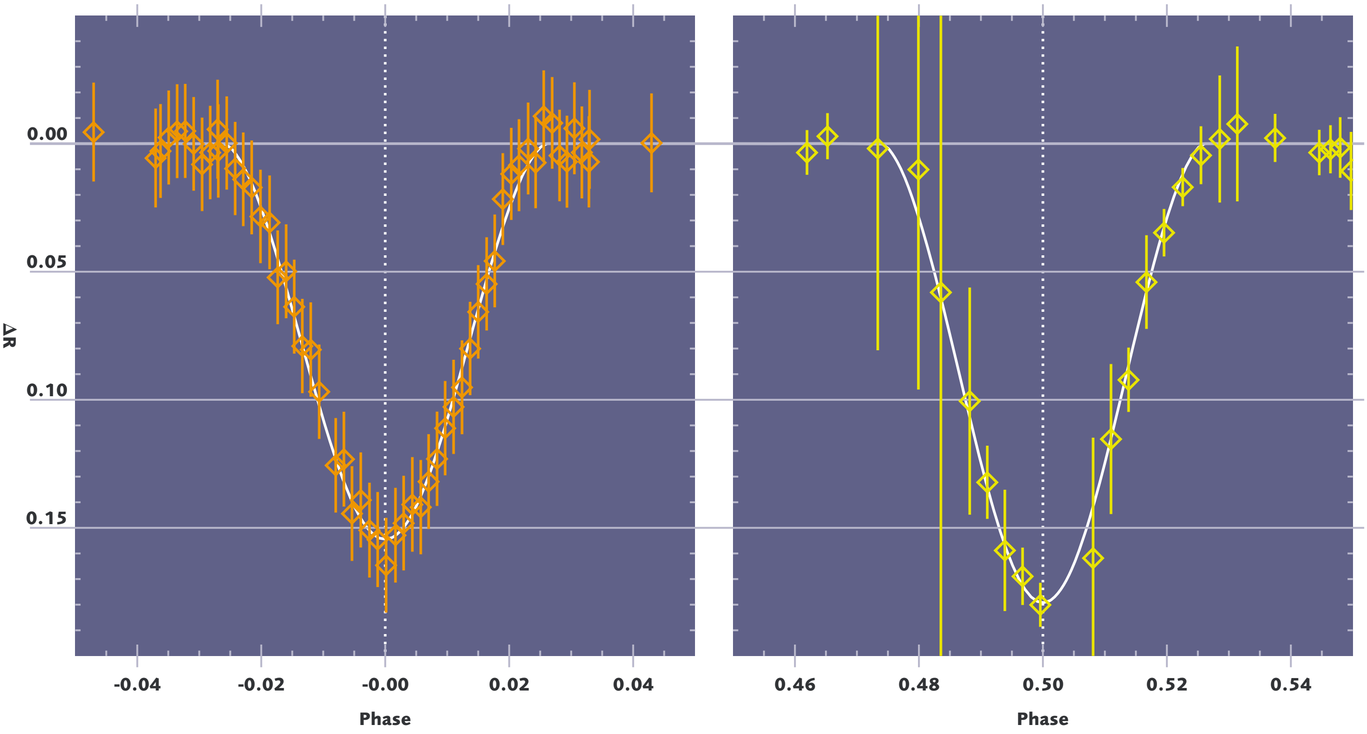


Fig. 16. NOT light curves in the R band of TrES-Her0-07621 in primary (left) and secondary eclipse (right). The line shows the fit used to determine the stellar radii.



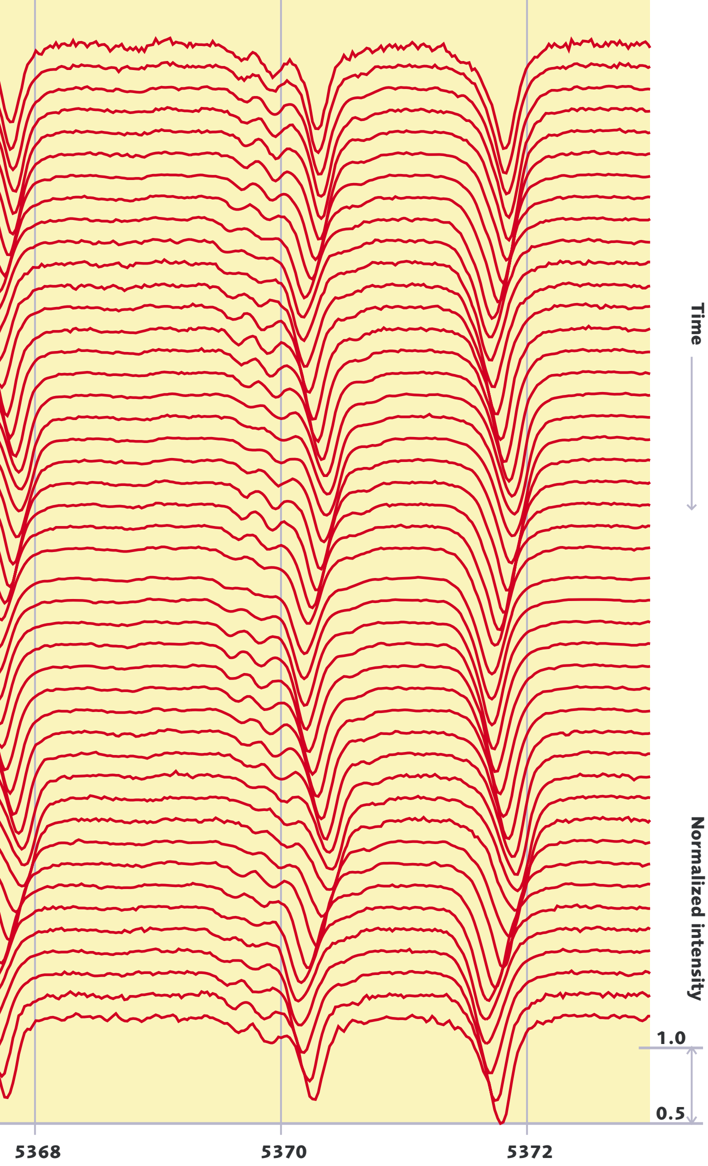


Fig. 17. Profile variations of iron lines in 44 Tau, caused by non-radial oscillations and observed with SOFIN at NOT. For clarity, consecutive spectra are shifted vertically.

Asteroseismology of a slowly-rotating δ Scuti star

The light variations of a pulsating star are a diagnostic of the internal structure. This technique to look inside stars, called asteroseismology, was pioneered and greatly refined on the Sun, but is now applied to many other types of star. The aim of asteroseismology is to derive a physical model for the interior structure which precisely reproduces the observed stellar oscillations. The frequency is the most important parameter of any pulsation motion; its value characterises the region inside the star where its energy is highest. Therefore, the information about the stellar interior increases in detail with every new detected pulsation frequency.

δ Scuti stars, about twice as massive and somewhat hotter than the Sun, vary slightly in total light due to periodic oscillations in radius and temperature. Whereas some stars pulsate strictly radially and keep their spherical shape, δ Scuti stars show non-radial pulsations and their shape deviates from spherical symmetry, e.g., due to waves propagating around the star. The resulting complex set of frequencies can provide detailed insight into their internal structure.

The δ Scuti star 44 Tau pulsates simultaneously with more than 20 periods in the range 1-6 hours. The resulting net light variation is extremely small (<1%), so measuring these periods requires high-precision photometry over many weeks. This was done over the years 2000-2004, but the interpretation of so many frequencies in terms of stellar models leads to ambiguities: A given frequency cannot always be matched with a specific oscillation mode, which is necessary to describe the relevant physics. But the pulsating stellar surface also causes Doppler shifts in the profiles of spectral lines, and we can use those to identify the oscillation modes.

Accurate synoptic spectroscopic observations at NOT and the Tautenburg Observatory, Germany, revealed, first, that 44 Tau seems to be rotating very slowly, while low-amplitude δ Scuti stars are normally rapid rotators. Next, we detected eleven pulsation frequencies which are also seen in the photometry. Our mode identification for these frequencies brought another surprise: Ten of them belong to pulsation modes that correspond to standing waves, while only one mode represents a wave propagating around the star. This simplifies the seismic analysis of 44 Tau significantly, because rotational effects are still difficult to model properly. Due to this fortunate circumstance and the excellent observational data, 44 Tau promises to be the first successfully modelled multi-periodic δ Scuti star.

W. Zima, K. Kolenberg, M. Breger, Wien;
H. Lehmann, Tautenburg; I. Ilyin, Potsdam

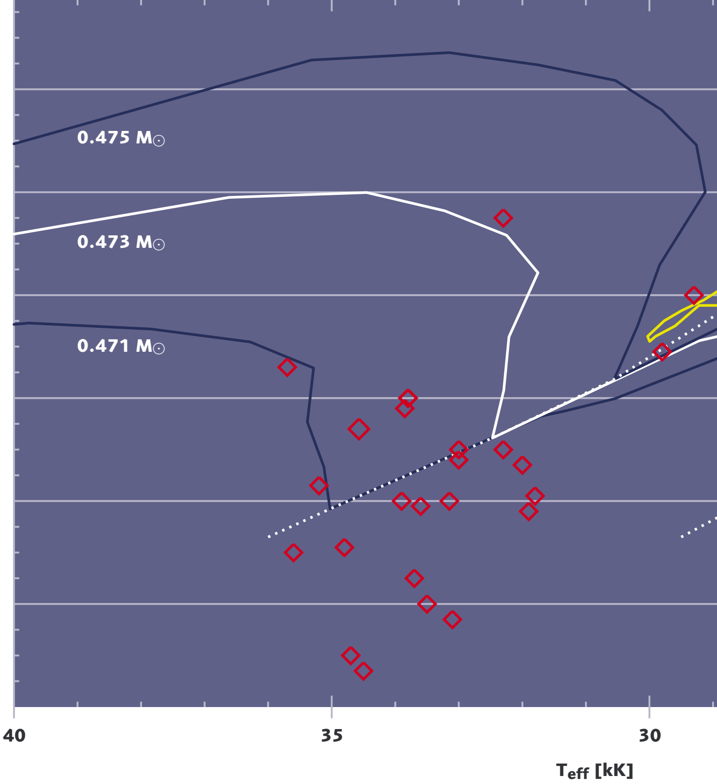
Probing the interior of a highly-evolved star

Subdwarf B (sdB) stars are highly evolved stars; typical masses and radii are about ½ and ⅙ of the mass and radius of the Sun, respectively, and their surface temperatures are 17-40.000 K – much hotter than the Sun (5800 K). The sdB stars have completed the hydrogen-burning main-sequence stage, have lost most of their outer regions, and now burn helium in a core enclosed in a thin hydrogen-dominated envelope. They will soon quietly settle down as white dwarfs. The reason why these stars lose so much mass is not understood, but a former close binary companion disrupting the outer layers of the progenitor star is thought to be responsible in many cases.

Some sdB stars are known to pulsate, which enables us to study them seismologically. Two types of pulsation are observed: *p*-modes (pressure as the restoring force) with typical periods of 2-5 minutes, and *g*-modes (gravity) with typical periods of about an hour. If pulsation frequencies and the corresponding pulsation modes can be determined from observations, detailed information about the internal structure and evolutionary history of the sdB stars can be derived.

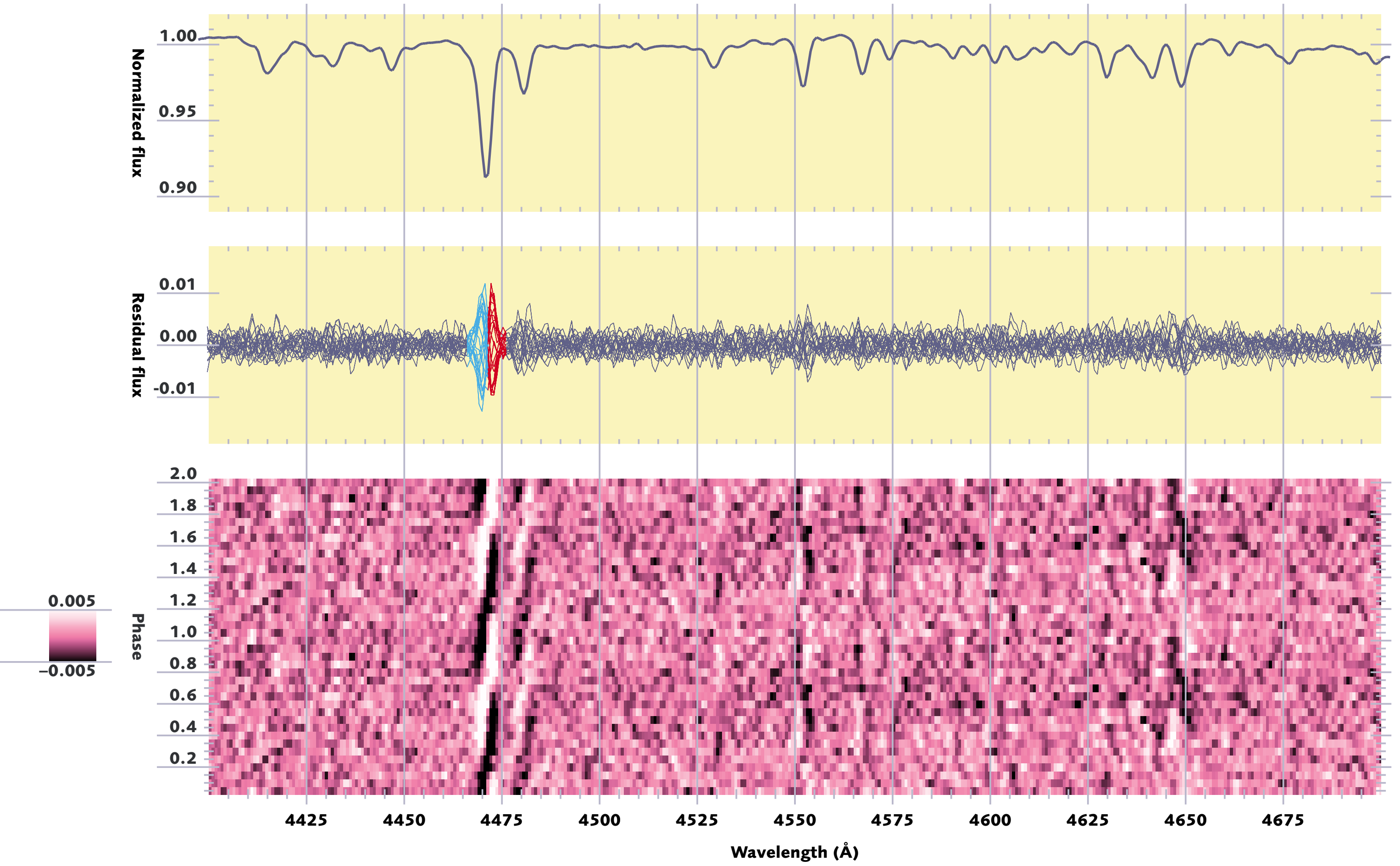
The sdB star Balloon090100001 was recently discovered to be the brightest known sdB pulsator ($B = 11.8$) and is one of the few sdB stars that show both p- and g-modes. Because of its brightness and numerous pulsation frequencies, this star is the most promising asteroseismological target among sdBs. Using ALFOSC at NOT, we have obtained the first time-resolved spectroscopic observations of the star in order to derive its pulsational characteristics and identify the pulsation modes by analysing the profile variations of the spectral lines. But the short period of the main pulsation – only 356 seconds – is a challenge.

In order to obtain low-noise spectra with good phase resolution, we obtained more than 2500 low-resolution spectra with an exposure time of 30 seconds each and binned them into twenty phase intervals of the main pulsation period. Fig. 18 shows the phase-binned spectra in a grey-scale representation, which clearly shows the profile variations of the HeI 4471, MgII 4481, SiIII 4552 and CIII 4650 lines of the star.



In order to derive the surface temperature and surface gravity as a function of pulsation phase (see Fig. 19), we fitted model spectra to each of the 20 mean spectra. For the main pulsation mode – i.e. within just six minutes! – we find that the surface temperature varies by +/-1250 Kelvin

Fig. 18. Top to bottom: Mean spectrum of Balloon-090100001; residuals of the 20 phase-binned spectra from the mean spectrum; and the phase-binned spectra in grey-scale representation over two cycles (time running upward).



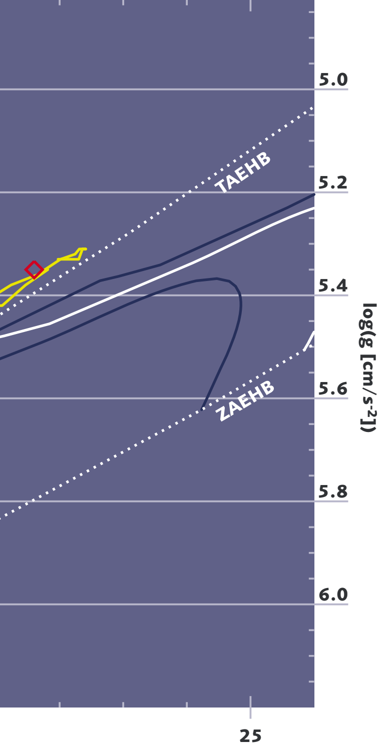


Fig. 19. T_{eff} – log g diagram for sdB stars. Three evolution tracks and the zero-age and terminal-age extreme horizontal branches are indicated. In only 6 minutes Balloon090100001 completes a full tour of the closed full curve in the diagram (yellow; near the TAEHB). The diamonds depict all other known p-mode sdB pulsators.

and the surface gravity by +/-0.1dex. The radial-velocity amplitude at the surface is about 19 km/s, the largest known for sdB stars, and we could detect velocity variations for 7 more pulsation modes, the second largest number of spectroscopically detected pulsation periods in sdB stars.

J.H. Telting, T. Augusteijn, NOT;
R. Østensen, ING; U. Heber, Bamberg

A Cataclysmic Variable studied with the Hubble Space Telescope and NOT

Cataclysmic variables (CVs) are close binary systems in which a late-type secondary star transfers mass to a white dwarf primary. With the recent discovery of pulsating white dwarfs in cataclysmic variables, we can use the technique of asteroseismology to study the mass, core composition, age, rotation rate, magnetic field, and distance of these objects. By studying pulsating white dwarfs in accreting systems we may learn how a white dwarf reacts to mass being dumped on its surface, which will give us valuable information about the physics of its interior – a bit like beating on a drum rather than waiting for it to sound by itself.

Observations at visible and ultraviolet wavelengths give complementary views of the pulsations: In the visible we see the pulsations over the whole disk of the star at once, but the effects of individual pulsation modes largely cancel out in the integrated light. In the UV, the large limb darkening lets us see only the central part of the stellar disk, so we see only a few modes at a time. Combining simultaneous UV observations from space and visible data from the ground can therefore guide us to the correct identification of the modes.

In June 2005, the newly discovered pulsating accreting white dwarf SDSSJ161033.64-010223.2 was observed with the Advanced Camera for Surveys on the Hubble Space Telescope (HST) for 7.2 hours. Good luck enabled the NOT observer to join a simultaneous ground-based multi-site observing campaign for 5.2 hours, using the windowed fast-photometry mode of ALFOSC, which allows for much better time resolution (20 s) than available with HST (101 s) – see Fig. 20. Moreover, NOT avoids the periodic interruptions that affect the HST observations when the Earth gets in the way, which introduces spurious periods in the data.

The lower part of Fig. 20 compares the Fourier transforms of the NOT (5.2 h) and HST light curves (7.2 h). The strongest mode appears at a period of 607 s in both data sets; note the aliases on both sides of the main peak in the HST data. As predicted by theory, the amplitude in the UV is much larger (175 units) than in the optical (30 units), which will help to identify the pulsation modes.

J.-E. Solheim, Oslo; A. Mukadam,
P. Szkody, Washington State Univ.

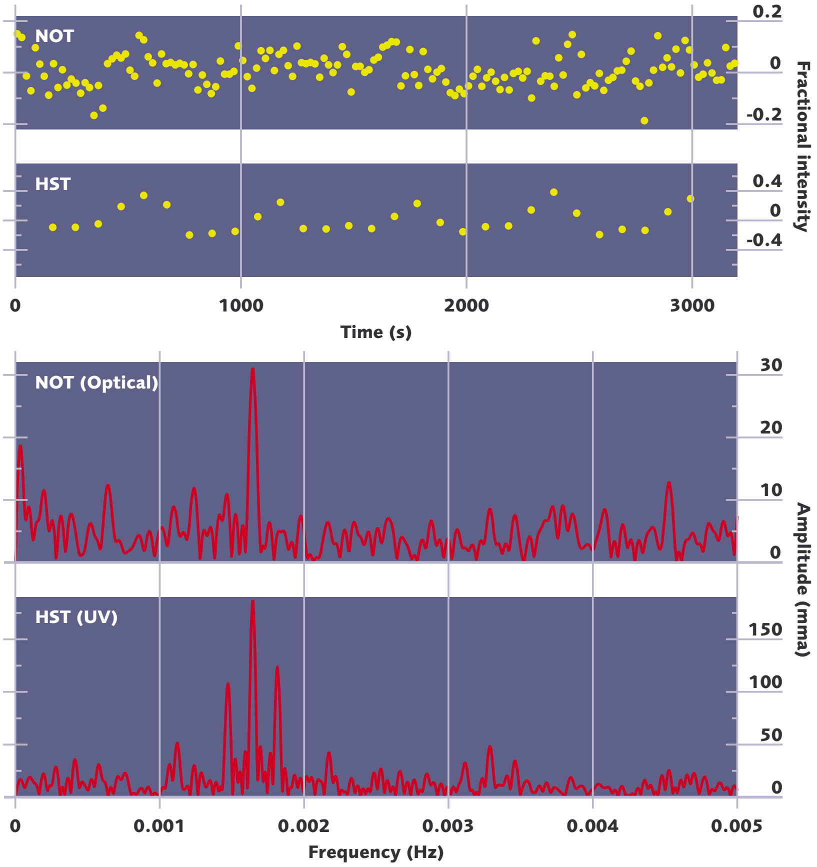


Fig. 20: A section of the simultaneous optical and UV light curves of our target from NOT (top) and one HST orbit (second panel). The lower two panels show the Fourier transforms of the complete data sets from the two telescopes.

Dynamics of the mass transfer in W Serpentis binaries

W Ser is the prototype of a group of interacting binary stars. Like in cataclysmic binaries, mass is being transferred from a cooler, expanding secondary to a hotter, more massive star. However, in W Ser binaries the mass gainer is a normal main-sequence star rather than a compact object, so the systems are much larger and the orbital periods much longer – about 14 days for W Ser itself.

What sets the W Ser systems apart from the classical Algol systems is that the mass transfer is much faster – so fast that the primary star cannot accept all the mass immediately. Instead, the gas lost by the secondary is temporarily stored around the primary in an accretion disk so large that it obscures the primary star almost completely from view. Its light also overwhelms that from the secondary star; only the periodic eclipses when the secondary occults the primary star and the disk reveal its existence.

In this situation, disentangling the contributions from the two stars and the accretion disk to reveal the true geometry of the system becomes difficult, but observing in polarized light is a way to break the ambiguity. Linear polarization produced by electron scattering carries important information about the density and distribution of the ionised circumstellar gas. Analysing the simultaneous light and polarization variations over the orbital cycle therefore gives additional useful constraints on models of the system.

The brightness and polarization of W Ser were observed over several full orbital cycles with NOT/Turpol and the KVA-60 telescope (Fig. 21) and led to a detailed picture of the system (Fig. 22). Notably, we find evidence for a shell of hot plasma around the primary and a stream of matter connecting the two stars. Two results were surprising at first sight: The stream seems to reach the primary star near the pole rather than the equator, and there is no clear polarization signature of the disk itself. However, if the disk is large enough it might only leave the pole of the primary star visible, and its net polarization might also cancel out, providing a natural explanation of both findings.

**V. Piirola, A. Berdyugin, S. Mikkola, Turku;
G. Coyne, S.J., Vatican**

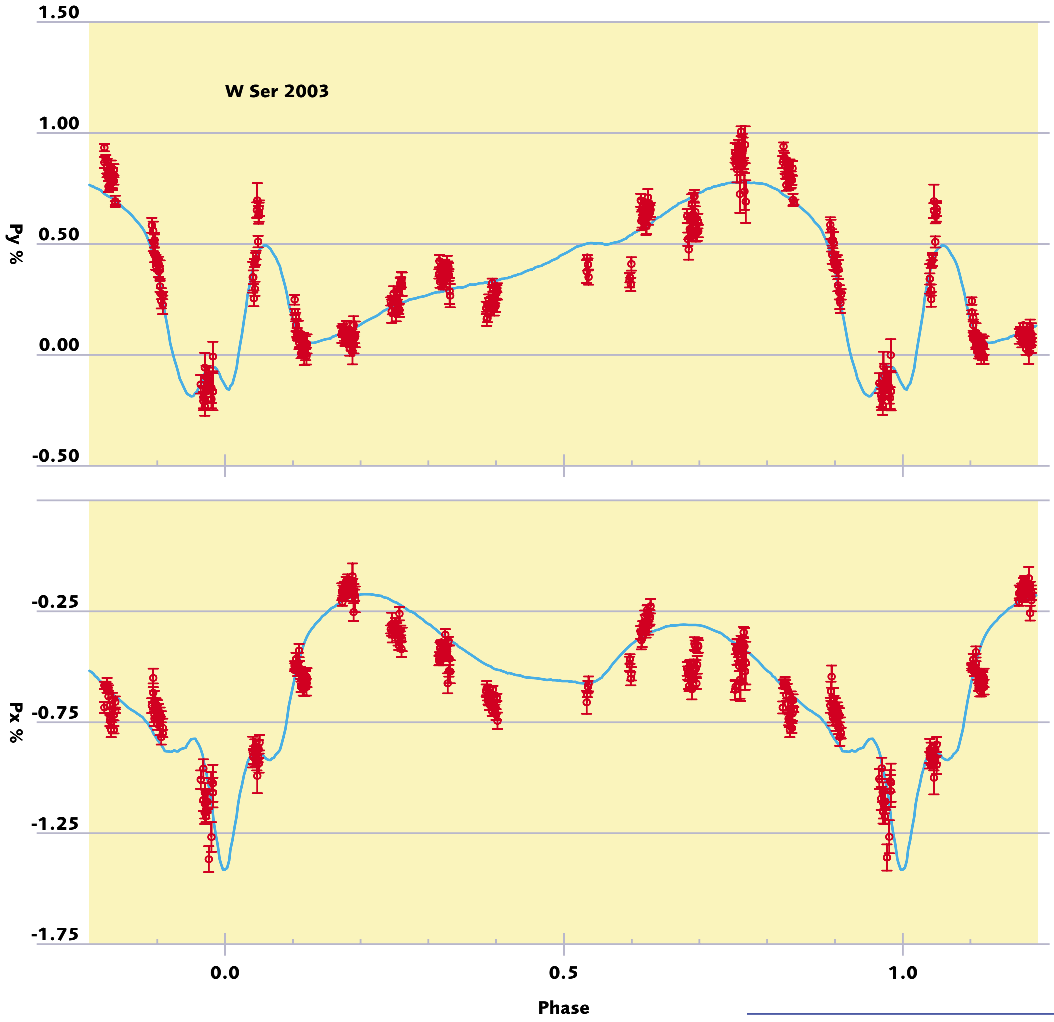
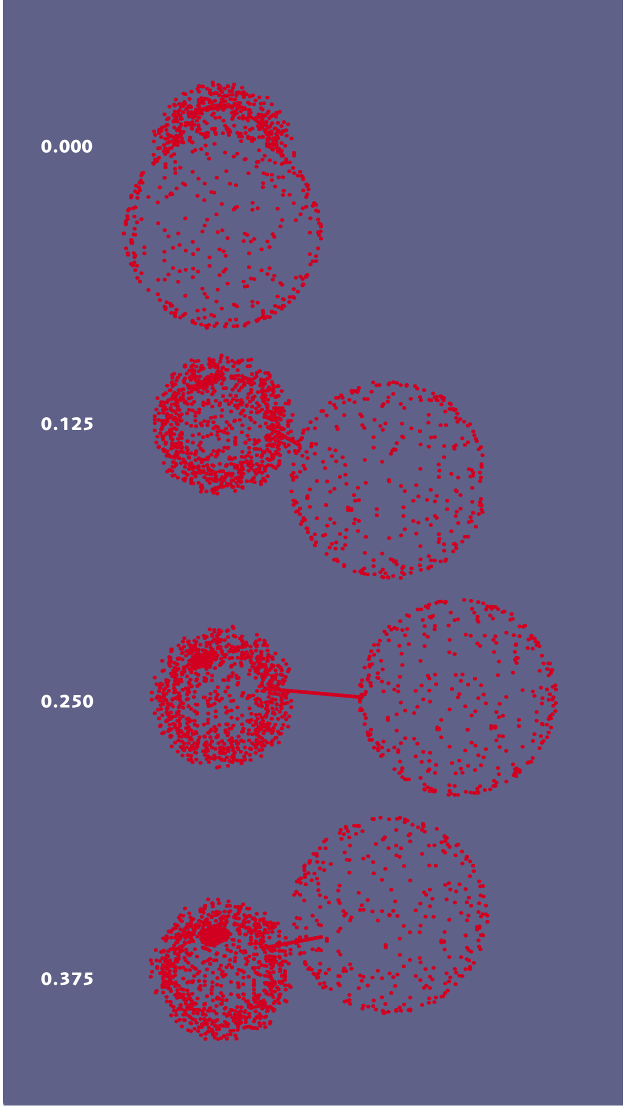
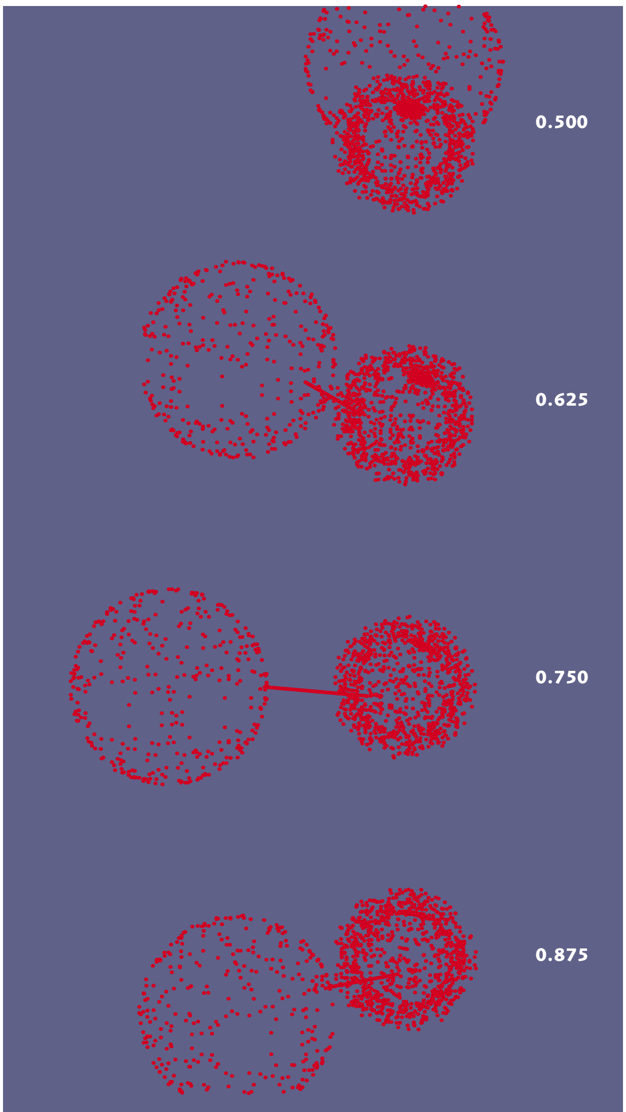


Fig. 21. The orientation (upper panel) and degree (lower panel) of the linear polarization in W Ser as a function of orbital phase. The curves correspond to the model in Fig. 22.

Fig. 22. Model of W Ser, based on the observed light and polarization curves. The binary is shown through a full cycle, from top to bottom. The primary star is the smaller one; the larger star is the much less massive secondary. The primary is surrounded by a shell of ionized gas with a bright spot at high latitude, and a thin stream of matter flows from the lighter to the heavier star.





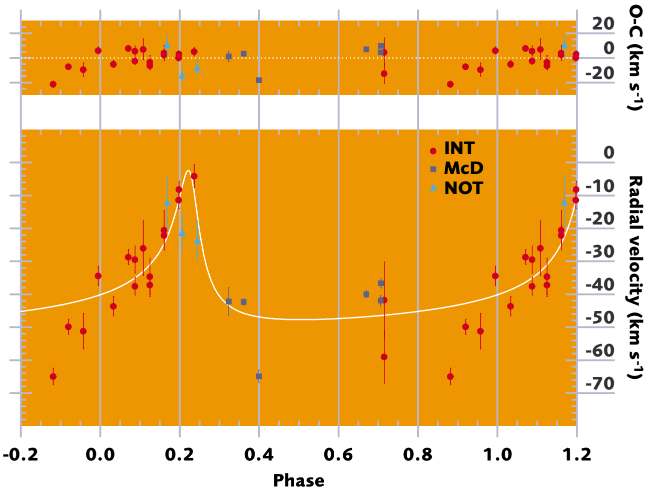


Fig. 23. New radial-velocity curve and orbital fit for LS I +61 303; the peak of the curve corresponds to the closest approach of the two stars.

Anatomy of a microquasar

In some high-mass binaries, the more massive star evolves rapidly and explodes as a supernova. This leaves a high-mass X-ray binary consisting of a still fairly massive secondary star orbiting the compact remnant (neutron star or black hole) and transferring mass to it as it evolves itself. In a few of these objects, relativistic jets are formed that are reminiscent of those emitted by quasars on a far grander scale. Despite the huge difference in the masses, distances, and emission powers involved, the basic mechanism behind the jets are believed to be similar, so these 'microquasars' are interesting not only in their own right, but also as guides to the processes prevailing in their powerful extragalactic counterparts.

Spectra obtained with ALFOSC at NOT have been used in an improved determination of the eccentric orbit of the visible star in the galactic microquasar LS I +61 303, which shows periodic emission from radio to γ-rays tied to its 26-day orbit. The projected rotational velocity of the star is measured to be $v\sin i \approx 113$ km/s, which provides a useful constraint on the inclination of the system, and its spectral type of B0 V indicates a mass of 10-15 solar masses for the visible star.

Our new orbital parameters indicate that the observed radio and X-ray bursts, which are probably due to interaction between the wind of the B star and the compact object, occur several days after closest approach. Because the compact object remains invisible, it cannot yet be decided with certainty whether it is a neutron star or a black hole, but no typical neutron star signatures (e.g. pulses) are seen.

**J. Casares, IAC; I. Ribas, J.M. Paredes, Barcelona;
J. Martí, Jaén; C. Allende Prieto, Austin**

'Lucky Stars' in 2005

'Lucky Imaging' is a flexible, yet simple way to achieve high spatial resolution anywhere in the sky. In brief, a low-noise, fast-readout CCD camera takes very short exposures in rapid succession, and the very best frames are combined to form a high-resolution image. In the I-band, we routinely reach the diffraction limit of NOT (~0.08") in good seeing and improve image sizes by a factor of 4 in poorer seeing. LuckyCam was used for a very successful run at NOT in the summer of 2005 (and one totally wiped out by Tropical Storm Delta in November!).

Close binary and/or rapidly variable stars are prime targets for LuckyCam, and we started an ambitious programme to determine the frequency of binaries among Very Low Mass (VLM) stars. 21 new close VLM binaries were discovered – a 40% increase in the known number of these systems – in just 20 hours of on-sky time. An earlier, similar programme took several times longer on 7-10 metre class telescopes with conventional adaptive optics. One of the new close binaries is shown in Fig. 24, while Fig. 25 highlights the use of LuckyCam as a combined high-resolution imager and high-speed photometer.

Fig. 24: Ross 530, a metal-poor binary stars with a separation of only 0.15", resolved with LuckyCam at NOT in 0.6" seeing.

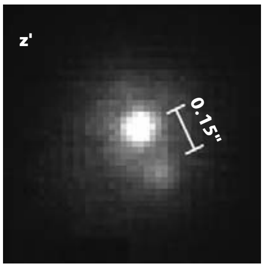
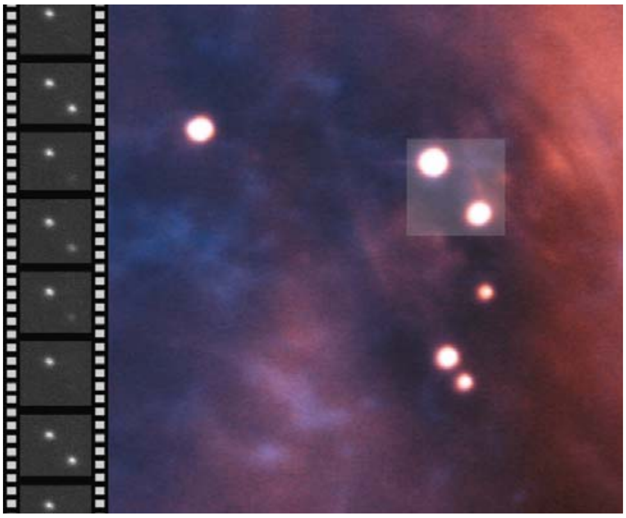
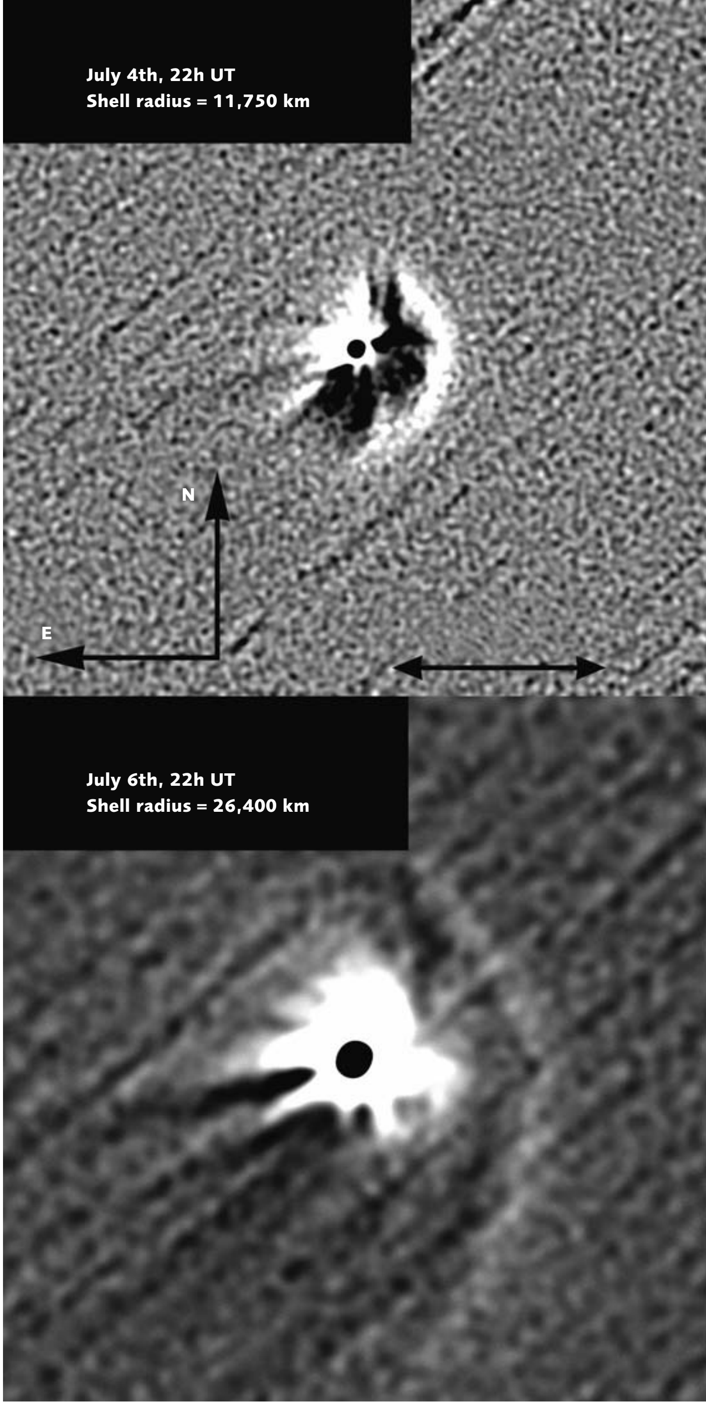


Fig. 25: A 40" field of the Crab Nebula as seen with LuckyCam, run at 100 frames per second. Note how both the bright and faint pulses of the Crab Pulsar are visible over the 30ms period (film at left).





SOLAR SYSTEM STUDIES

In the Solar System, actual experiments can be performed by space missions, but ground-based observations remain important. In 2005 the undisputed highlight was the artificial "meteor crater" created by the Deep Impact mission.

'Deep Impact' seen from NOT

On July 4, 2005, the Deep Impact spacecraft slammed 370 kg of copper into comet Tempel 1 at a speed of 10 km/s (40,000 km/h), excavating a 100-m crater in the nucleus of the comet. Until then, most of what we knew about the physical structure and surface evolution of a comet nucleus relied primarily on theoretical models. The goal of "Deep Impact" was to study the outer layer of a comet by blasting a hole in it.

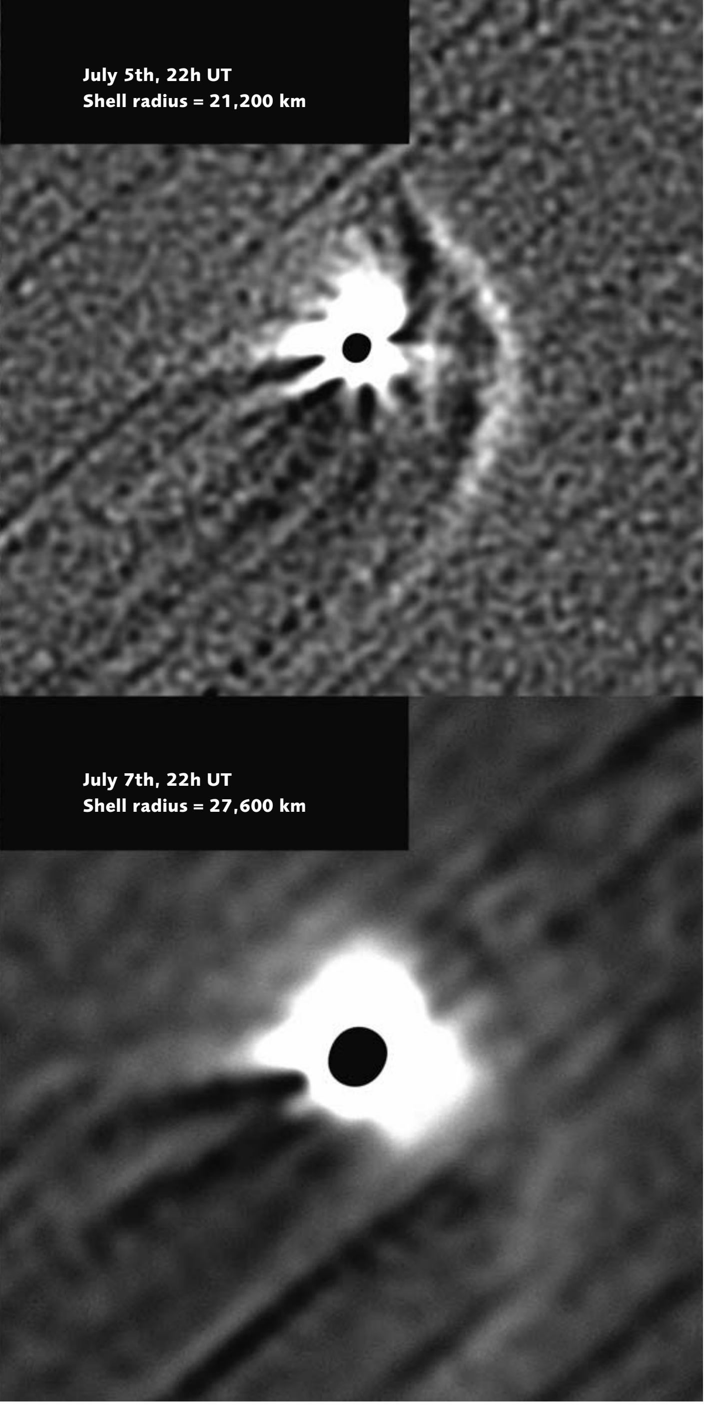


Figure 27. R-band images of Comet Tempel, processed with a numerical filter designed to emphasize small-scale dust structures. Dust jets appear as black streamers close to the nucleus, dust shells as white curved structures. The shell on the right traces the day-by-day expansion of the dust cloud front.

The 'Deep Impact' mission was designed to have many of the critical observations done simultaneously from Earth-based telescopes. In an unprecedented coordinated campaign, many observatories around the world and in space observed the comet before, during, and after the impact to document the effects of the event and follow its evolution in detail.

The Roque de los Muchachos Observatory played a substantial role in this effort. During the nights July 2-10, our group used the three largest telescopes, the William Herschel (WHT), Galileo (TNG), and NOT to study the comet from just before to well after the impact at both visible and infrared wavelengths. At NOT, we used ALFOSC every night from July 3 to July 10 to obtain deep broad-band images and low-resolution spectra in the visible. Our goal was to study the dust ejected by the impact, and also to measure any variations of the gas emission in case the crater became deep enough to evaporate fresh ices below the dust mantle.

The ORM campaign showed that the impact greatly affected the dust mantle of the comet. In a very short time, the impact ejected a large cloud of dust into the coma – about as much as ejected by the comet in 10 hrs of normal activity. The dust cloud is easily seen in NOT images (see figures), forming a semi-circle that expanded at a speed of about 200±20 m/s. The cloud dissipated in about 5 days.

At the same time, the spectra showed that the gas contribution was very low, in particular at wavelengths beyond 0.6 µm. Thus, if the impactor did reach fresh ice below the dust mantle, it did not expose enough of it to create a new active region sufficiently strong to be detected.

Javier Licandro, ING/IAC, and many collaborators

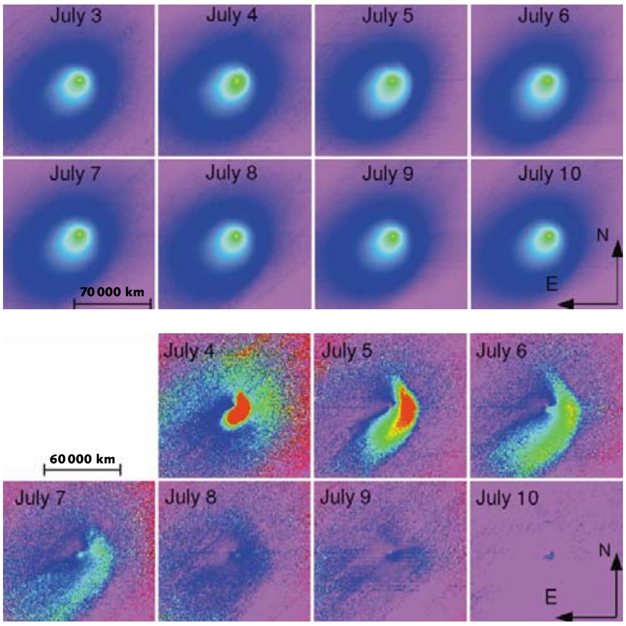


Fig. 26. ALFOSC R-band images of Comet Tempel obtained on July 3-10. Top: The images as obtained directly. Below: The images from July 4-10 divided by the pre-impact image from July 3 to show the dust ejecta produced by the impact. The scale goes from 1.0 (=no change) in violet, to 1.5 (50% change) in red. On July 4, a bright semi-circular dust cloud appeared and gradually expanded until July 10, when it had essentially dissipated in the comet coma.

Spring at Volcán Teneguia, La Palma

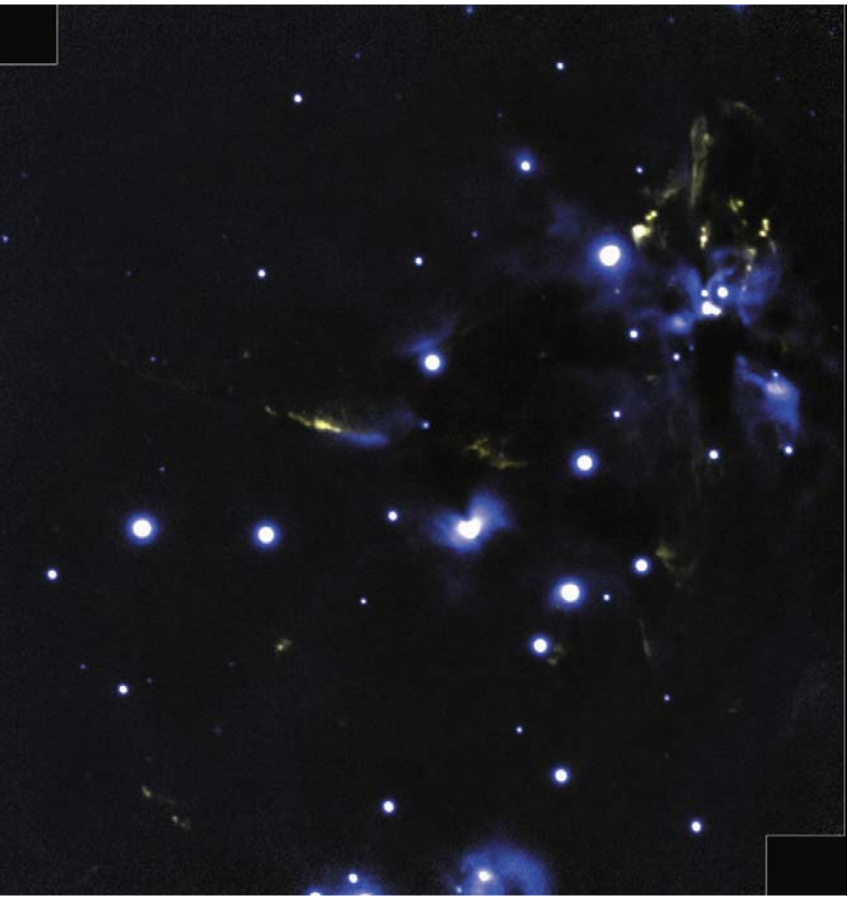
UPGRADES 2003-2005

In modern astronomy, instrumentation, scheduling, and data management have become as important as the telescope itself. In 2005 we completed a three-year systematic overhaul of our instruments and services to begin meeting the demands of the 21st century. A concerted effort by the whole NOT group, including temporary staff members Saskia Prins and Eric Stempels, resulted in the new capabilities summarised below (see our web site for more detail). Further improvements will be planned as part of our strategy for a more integrated operation of the major telescopes on La Palma in the future.

Scheduling of observing time has been upgraded with improved proposal submission procedures, including a fast-track proposal option for short programmes, and service observing when scientifically profitable (see. p. 24).

The Telescope Control System has been completely renewed, eliminating our vulnerability to breakdowns of obsolete components. More computing power and versatility are built into the new system, allowing the observer to control the telescope, instrument, and detector using a single terminal and a script system to run a series of observations in batch mode. Remote control is an option for the future. This, and a new telescope and dome cooling system, should ensure good reliability over the next several years. At the same time a new and more sensitive autoguider ensures that enough guide stars can be found anywhere in the sky.

ALFOSC, our workhorse imager, faint-object spectrograph, and fast-photometry system, now has a new optical and CCD camera giving higher QE in the UV and better resolution and more uniform PSF over the field. A new VPH grating gives unparalleled efficiency at high resolution in the 6-700 nm region.



Shocked molecular hydrogen clouds in the star-forming region L1641-N in Orion, observed with the science grade array in NOTCam. Photo: M. Gålfalk, Stockholm

The FIES building next to the NOT dome. The spectrograph room is under the white roof.

NOTCam, the near-infrared counterpart to ALFOSC, is now fully commissioned in all imaging, polarimetric, and spectroscopic wide-field and high-resolution modes. The science grade array has been installed and gives substantially higher QE as well as better cosmetic quality for all applications.

FIES is a new, bench-mounted and fibre-coupled échelle spectrograph offering resolutions up to R = 60,000 with fixed spectral coverage, high mechanical and thermal stability, and permanent availability for flexible scheduling. For stability, it is installed in a separate building next to the telescope and should be fully commissioned by mid-2006. A spectropolarimetric option is foreseen later.

Data formats and FITS headers

New FITS data formats and headers have been developed for all NOT instruments, making them all uniform and compatible with modern image processing systems. By the end of 2005, they are used for MOSCA and FIES, being commissioned on NOTCAM, and will follow shortly on ALFOSC and STANCAM.

Highlights of improvements:

- Multi extension data formats for all instruments
- Primary WCS information for all imaging data (ALFOSC, NOTCAM, STANCAM, MOSCA)
- Mosaic data reduction made easy (MOSCA, ALFOSC dual readout mode, NOTCAM amplifier dependent)
- ISO8601 compliant date and time information for start and midpoint of all exposures
- Improved timing information for NOTCAM
- Same orientation for all data (North up, East left for appropriate rotator angle)
- Detector/amplifier characteristics included in header
- All FITS headers are now recorded in the recommended formats.

Multi extension FITS format. All NOT data will be recorded in multi extension FITS (MEF) format. A MEF file comprises several segments called Header/Data Units (HDUs). Every HDU consists of the well-known ASCII FITS header followed by an optional Data Unit. Any number of HDUs may follow after the first and are then called FITS extensions. For FIES and ALFOSC in single amplifier mode there is 1 image extension, in dual amplifier mode there are 2 (1 per amplifier), and for MOSCA 4 (one for each detector). For NOTCAM the number of extensions is variable (1 for each readout, plus 1 for the reset frame).

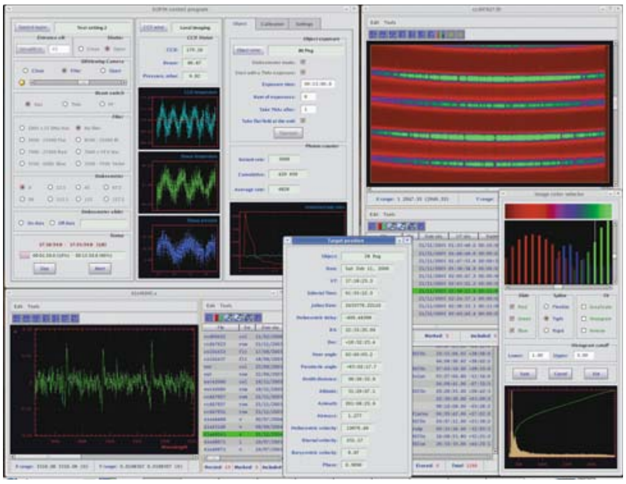
World coordinate system (WCS) information. Standard WCS information is included in the headers for all imaging data. For example, you will see RA and Dec directly on a standalone DS9 display, and IRAF can find astrometric reference stars for you just from the FITS file, vastly simplifying the data reduction of MOSCA, dual amplifier ALFOSC, and NOTCAM data using IRAF mscred. Note that the WCS data only provide a first approximation; a proper astrometric solution is still needed to get accurate coordinates.

S. Prins, T. Pursimo, NOT

A new user interface for SOFIN

The high-resolution échelle spectrograph SOFIN has been used at NOT for more than a decade, primarily for programmes on activity cycles and spot evolution in late type binaries and non radial pulsations in hot stars. Recently, the polarimetric mode of SOFIN was upgraded with a new cross disperser and polarizing elements to give adequate separation of the polarized échelle orders, allowing to determine the full set of polarization parameters from just four exposures.

The new polarimetric mode requires more advanced control, calibration, and especially reduction software. At Potsdam we have developed such software for the échelle spectropolarimeter PEPSI for the LBT, and the prototype for PEPSI has been successfully implemented on SOFIN, maintaining the control panel design with all the instrument and CCD status parameters on the screen, browseable real time display and analysis facility, buttons to store and select spectral settings, observing target, and so on. The technical details would sound cumbersome, but using it in real life is real fun!



Screenshot of the new SOFIN control panel with some of the polarized échelle orders shown on the real time display on the imager. The spectrum on the lower right shows the circularly polarized signatures of the cool, magnetic late type star VY Ari observed earlier.

I. Ilyin, Potsdam

The NOT OPC in a sunny mood (the chairperson on the left).

General

NOT exists to provide observing opportunities for Nordic astronomers. There is strong competition for time at NOT, and it is essential that the time allocation procedure is seen as competent, impartial, and transparent.

Observing proposals are invited in May and November for the semesters beginning the following October 1 and April 1. The *Call for Proposals* is announced widely, and all necessary forms and information are available on the web (*http://www.not.iac.es/observing/proposals/*).

An independent *Observing Programmes Committee* (OPC), consisting of five respected Nordic scientists appointed by the Council, peer reviews all observing proposals for scientific merit, ranks them on a numerical scale, and provides feedback on how to improve lower-rated proposals. Each member has a substitute to broaden the scientific basis for the review, fill any temporary vacancies, and avoid potential conflicts of interest.

Based on the ranking by the OPC, the Director drafts a schedule, taking into account such practical constraints as object visibility and phases of the Moon. The OPC reviews the draft before the schedule is posted on the web and the applicants are notified. 20% of the time is reserved for Spanish astronomers, and 5% for international projects.

As of April 1, 2005, NOT also offers a ‘fast-track’ proposal mode for projects requiring up to 4 h of observing time with a restricted set of standard instrument configurations. A simplified web-based application form is provided, and OPC review is completed within a matter of days. If approved, the project is then scheduled for execution by NOT staff in service mode on one of several dedicated service nights scheduled each semester.

To promote competition and high scientific standards, external proposals are welcomed and reviewed on an equal footing with Nordic proposals. European astronomers with approved projects at NOT and several other European 2-4m class telescopes may, in addition, be eligible for financial support from the EU under the OPTICON trans-national access programme (see *http://www.otri.iac.es/opticon/* for details).

Observing time in 2005

Observing statistics are compiled by allocation period, and this report covers the period April 1, 2005, to April 1, 2006. The *“pressure factor”* (nights requested/nights available) remained high at 1.8. In total, 315 nights were used for scientific observations (i.e., excluding technical time). Subtracting also Spanish and international time, 258 nights were allocated to scientific projects ranked by the OPC, plus 7 nights for training courses organised by Stockholm University and NORDFORSK. Of these, 58.5 nights or 22% went to non-Nordic (“foreign”) projects and 13.5 nights or 5% to projects by NOT staff; the remaining 196 nights were distributed as follows: Denmark 45.5 (23%), Finland 45.5 (23%), Iceland 2 (1%), Norway 35 (18%), and Sweden 68 (35%). Note that some “foreign” projects have Nordic P.I.s in long-term positions abroad.

The use of different instruments is also of interest. In 2005, instrument use was as follows: ALFOSC 202.5 nights (56%), NOTCam 55 (15%); SOFIN 39.5 (11%), MOSCA 24 (7%), TurPol 23 (6%), LuckyCam 11 (3%), and visitor instruments 6 (2%). These numbers fluctuate from semester to semester, and from year to year.

Service observing, executed by NOT staff, is offered if there is substantial scientific benefit and is becoming increasingly popular; service observations were conducted during 69 nights in 2005 (27% of the Nordic time) against 50 nights in 2004. A simple *Observing Block* system has been implemented for the safe organisation of this service.

Long-term trends in time allocation

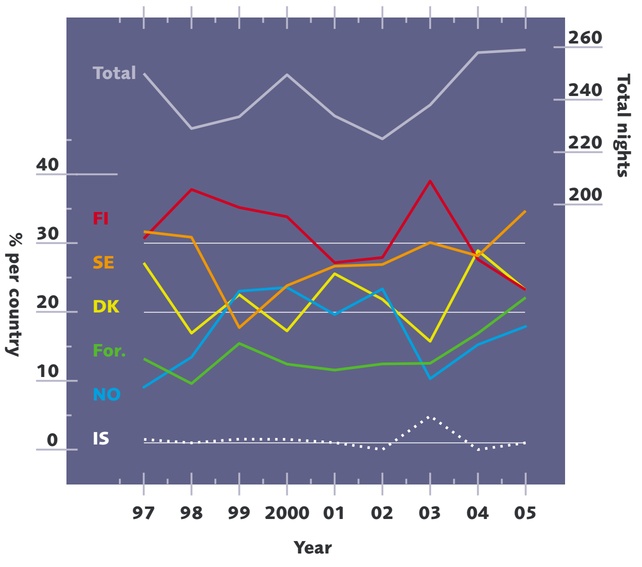
Viewed semester by semester, the distribution of observing time on nationality, subject, and instrument shows large fluctuations. For planning purposes, it is important to recognise the underlying long-term trends in the demand for observing time. Some of these are listed in the following:

First, the demand for **service observing** continues to increase; in fact, the amount of service observing rose by nearly 40% in 2005. Part of this is due to the new ‘fast lane’ for short programmes, for which time is set aside regularly in the schedule. In practice, the system has been less successful than anticipated, because bad weather had a preference for appearing on just those nights; we will have to take this into account in the future time allocation.

Outside interest in NOT, as measured by approved “foreign” projects, rose from a long-standing average of 10-12% of the Nordic observing time to 17% in 2004 and 22% in 2005. This is undoubtedly largely due to the OPTICON *Trans-national Access Programme* (see above), which actively encourages proposals from non-Nordic astronomers. In return, Nordic astronomers get access to a large number of night-time and solar telescopes all over the world, and the income from the OPTICON contract enables us to improve the quality of our services to the Nordic community.

The national distribution of observing time is not kept rigidly proportional to the national contributions to the NOT budget (see p. 27). It is the policy of the NOT Council that observing time should be allocated with scientific merit as the primary criterion; only in case of similarly ranked proposals should the nationality of the P.I. be considered. Nevertheless, a serious imbalance between the scientific returns of each community and what its Associate pays for would lead to problems in the long run.

The figure shows the national percentages of the Nordic observing time and of "foreign" projects, as well as the total number of nights allocated annually by NOTSA, for the years 1997-2005. Over the last five years, the Nordic time has been distributed with 23.1% to Danish projects, 28.9% to Finland, 1.3% to Iceland, 17.4% to Norway, and 29.3% to Sweden. Staff and "foreign" time account for 5% and 15% of the total. Considerable fluctuations are seen from year to year, but the overall balance appears healthy.



Nights allocated annually by NOT, and the Nordic and "foreign" shares of the time.

A GUIDE FOR SUCCESSFUL APPLICANTS

The basic rules and procedures for the allocation of observing time at NOT are outlined above. But a basic understanding of how the OPC reviews the proposals may be helpful to prospective proposers. Having just retired after 5½ years in the OPC, the last 3 as chairperson, I would like to share some reflections with you.

All observing time applications now use the Latex proposal form that was introduced in 2003. It has improved the average quality of the proposals considerably, but should be used with care. Four of the six available pages deal with standard information, like who you and your targets are, what instrument you want to use, etc. The last two pages are reserved for your project description. *These two are the most important pages of the whole proposal!*

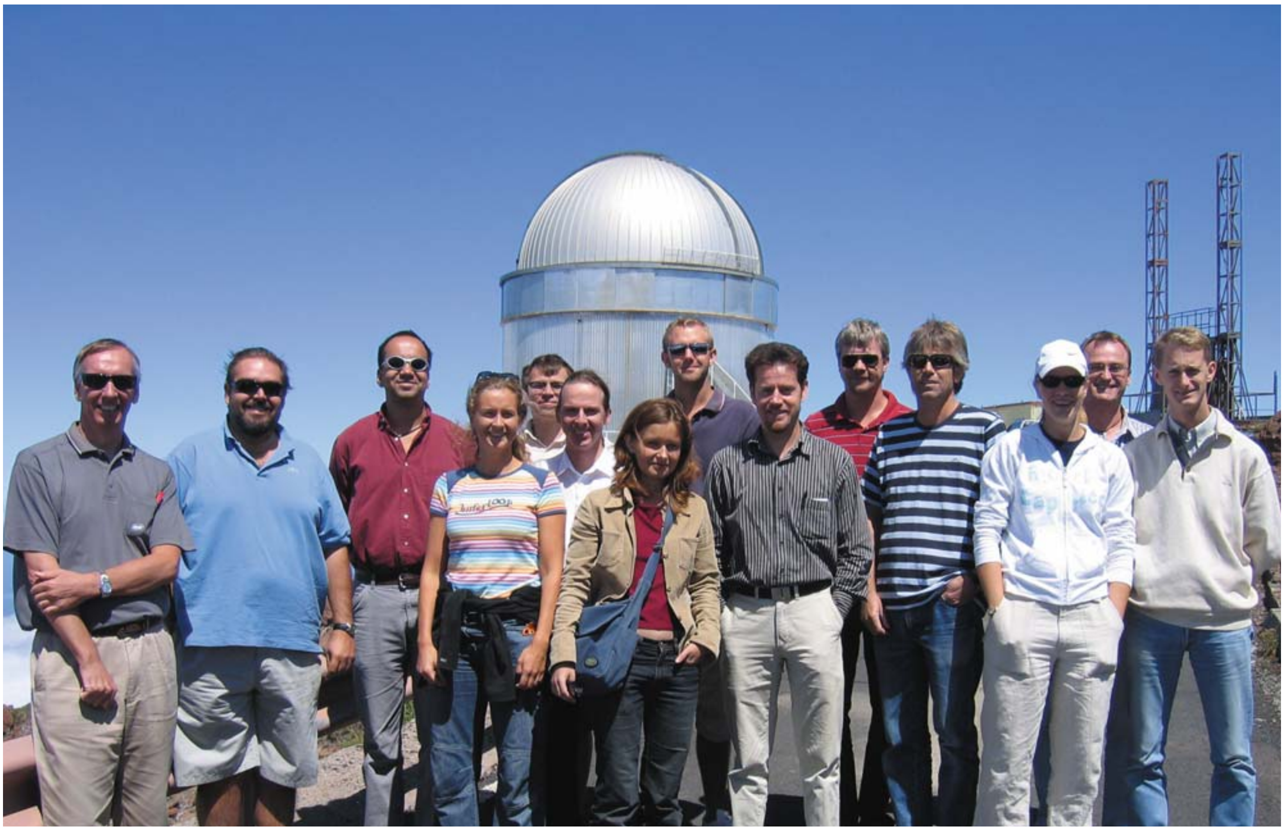
Always remember that there is not enough observing time for all acceptable projects. OPC members know this and make great efforts to understand the arguments of each application, but they cannot be specialists in every field. You must convince them that your proposal is a better use of NOT time than (most of) the others; just being OK is not good enough. The more effectively you argue your case, the better for you! But don't exaggerate, for OPC members are active users of the telescope and know its strong and weak points already.

So here is some expert advice on how to get a good ranking:

Describe first the general scientific context and main goals of the proposal ***clearly*** *in terms that are understandable for someone outside your own field.*

Then argue ***equally clearly*** *how your proposed project will contribute* ***significantly*** *to advancing the general subject (e.g. stellar*

The NOT team ready for action.



evolution theory rather than just some random star). Also take care to explain ***why you need NOT*** *rather than some other telescope, and why you need dark time if you ask for it. Give key references, so the OPC sees that you know the field.*

Finally, describe how the data reduction and analysis will be done, so your results will reach the literature in a reasonable time.

After proposal submission, OPC members have 3-4 weeks to review all the proposals and mail their preliminary ranking (1=best, 5=worst) to the chairperson, who rescales them to a uniform system and computes an average for each proposal. The chairperson also appoints a *Primary Reviewer* for each proposal, who checks any unclear points in the literature or with the proposer and introduces the proposal at the meeting. Meanwhile, the NOT Astronomer-in-Charge provides a report on any technical issues in the proposals.

The OPC meeting is a key part of the process and usually takes 2 days. Because members read the proposals from different viewpoints, the discussion focuses on understanding the reasons for any initial differences of opinion, and members often modify their initial rating as a result of the discussion. Typical questions are: Why is this project of *general* astrophysical interest? Will it make a *real* step forward? Does it use the special strengths of NOT (UV sensitivity, fast photometry, ...), or could it be done better elsewhere? Are convincing arguments given for the size of sample and amount of observing time requested? Is dark time *really* needed? How many years will it take to complete the project, and is there a way to define when it is finished? Does the P.I. have a credible publication record? Have results from previous observing runs at NOT been published (or was the weather just bad!)? And so forth.

After the discussion, new average ratings are computed and the proposals re-sorted. The NOT Director records the ratings and any comments made on each proposal, so the precise wording is agreed on the spot. After the meeting, the Director schedules projects from the top of the list and as far down as time allows, and forwards any comments or advice from the OPC when informing each P.I. of the approval or rejection of the proposal.

In the end, the Associates want to see their money as well or better invested in NOT as elsewhere in astronomy. The OPC does its best to help them get the best scientific returns from NOT. I hope that this account of how the OPC judges the proposals may help to make your proposal the best of all next time!

Jan-Erik Solheim, Oslo; OPC Chair 2003-2005

FINANCIAL MATTERS

General

NOTSA is a non-profit organisation and spends all the funding it receives from the Associates to operate NOT for the benefit of Nordic astronomy. Budgets and accounts are approved annually by the Council, after which the Director is responsible for operating NOT within those budgets and according to the *Financial Rules*. Auditors are appointed by the Council for four years at a time; our accounts for 2005 were audited by *Audiator OY* of Finland.

Accounts for 2005

NOTSA's accounts for 2005 are summarised in the table. The approved budget for 2005 and the results of 2003 and 2004 are listed for comparison. The budget lines contain the following items:

Directorate covers directorate staff, operations, committee travel, financial charges, stipends to Spanish Ph.D. students at Nordic universities, OPTICON and ASTRONET meetings, and the Annual Report.

La Palma staff includes all staff, students, and visitors on La Palma, training courses etc.

La Palma infrastructure includes the NOT facilities on the mountain and at sea level; electricity, water, and cleaning; computer networks; and cars and other transportation.

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

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

Development projects indicate investment in major new facilities or instrumentation as approved by the Council on a case-by-case basis (in 2005 primarily the new CCD and FIES building).

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 is mainly bank interests and income from the OPTICON and ASTRONET EU contracts.

Financial developments in 2005

As seen in the table, the costs of the directorate, facilities, and operations were essentially on budget in 2005. Staff costs increased considerably from 2004 as expected for the new contracts, but also remained within budget. *Telescope operations* were lower than in 2004 although the telescope cooling system renewal was completed in 2005; however, a substantial final payment was delayed until 2006.

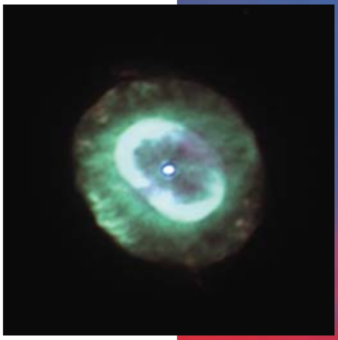
Under *Telescope development projects*, the budgeted amount for renewal of detector controller systems could again not be spent; instead, we invested in a new CCD detector and in pipeline reduction software for the main instruments. *Special development projects* are primarily the high-resolution spectrograph FIES, which was substantially completed and moved into its new building in 2005; only final optimisation of the optics remains for 2006, with little residual cost.

Other income was substantially above budget in 2005, partly because of deferred OPTICON payments from 2003-2004, partly because OPTICON actually refunded more access nights than foreseen in the contract. Also, advance funding from ASTRONET was received, while expenses will mainly occur in 2006. Overall, the deficit in 2005 was therefore well below that foreseen in the budget, and we enter 2006 with healthy financial reserves.

The budgets for 2003-2005 included intentional deficits, as the facility upgrade programme was funded from our reserves. However, another substantial deficit is foreseen for 2006, as not all Associates were able to raise their contributions to cover the full cost of the new staff contracts. Our reserves remain sufficient to avoid cash flow problems in 2006, but additional income is needed to maintain our services in the longer term. It is expected that this issue will be addressed as part of the response to the international evaluation of NOT initiated in 2005.

The barred spiral galaxy NGC 7177. Photo: J. Näränen

BUDGET HEADING	Expenses 2005 Euro	Budget 2005 kEuro	Expenses 2004 kEuro	Expenses 2003 kEuro
Directorate	184 604	214	193	205
La Palma staff	1 070 933	1 110	792	668
La Palma infrastructure	139 091	140	159	150
La Palma operations	103 352	99	113	123
Telescope operation and maintenance	21 838	40	86	14
Instrument operation and maintenance	37 285	60	46	28
Telescope development projects	33 294	75	19	14
Special development projects	62 553	10	3	31
Total expenses	**1 652 951**	**1 758**	**1 412**	**1 233**
Contributions	1 231 400	1 207	1 207	1 184
Other income	283 796	118	32	46
Total income	**1 515 196**	**1 325**	**1 239**	**1 230**
Result of the year	**-137 555**	**-345**	**-173**	**-3**
Reserves at beginning of the year	694 724	643	868	871
Reserves at end of the year	556 969	212	695	868



The planetary nebula NGC 7662, the "Blue Snowball". Photo: M. Gålfalk

Sunset at NOT. Photo: J. Näränen

Publications are the standard measure of scientific output, for observatories as well as for individuals. Therefore, we ask users to report refereed papers based on NOT data to us (see *http://www.not.iac.es/news/publications*). Papers reported in 2005 are listed below; if there are more than 12 authors, the first six names and the total number of authors are given.

International refereed journals:

Affer, L., Micela, G., Morel, T., Sanz-Forcada, J., Favata, F.: *“Spectroscopic determination of photospheric parameters and chemical abundances of 6 K-type stars“*, 2005, A&A **433**, 647

Arentoft, T., Bouzid, M.Y., Sterken, C., Freyhammer, L.M., Frandsen, S.: *“A dozen δ Scuti stars in the open cluster NGC 1817“*, 2005, PASP **117**, 601

Barrena, R., Ramella, M., Boschin, W., Nonino, M., Biviano, A., Mediavilla, E.: *“VGCF detection of galaxy systems at intermediate redshifts“*, 2005, A&A **444**, 685

Bensby, T., Feltzing, S., Lundström, I., Ilyin, I.: *“α -, r-, and s-process element trends in the Galactic thin and thick disks“*, 2005, A&A **433**, 185

Böttcher, M., J., Harvey, M., Joshi, M., Villata, C.M., Raiteri, D., Bramel, R. et al. (72 authors, including T. Augusteijn and T. Pursimo): *“Coordinated multiwavelength observation of 3C 66A during the WEBT campaign of 2003-2004“*, 2005, ApJ **631**, 169

Brand, K., Rawlings, S., Hill, G.R., Tufts, J.R.: *“The three-dimensional clustering of radio galaxies in the Texas-Oxford NVSS structure survey“*, 2005, MNRAS **357**, 1231

Caon, N., Cairós, L.M., Alfonso J., Aguerri, L., Muñoz-Tuñón, C.: *“Unveiling the nature of the low surface brightness stellar host in blue compact dwarf galaxies“*, 2005, ApJS **157**, 218

Casares, J., Ribas, I., Paredes, J.M., Marti, J., Allende Prieto, C.: *“Orbital parameters of the microquasar LSI +61 303“*, 2005, MNRAS **360**, 1105

Cid Fernandes, R., González Delgado, R.M., Storchi-Bergmann, T., Martins, L.P., Schmitt, H.: *“The stellar populations of low-luminosity active galactic nuclei – III. Spatially resolved spectral properties“*, 2005, MNRAS **356**, 270

Del Principe, M., Piersimoni, A.M., Bono, G., di Paola, A., Dolci, M., Marconi, M.: *“Near-infrared observations of RR Lyrae variables in galactic globular clusters. I. The case of M92“*, AJ **129**, 2714

Van Dyk, S.D., Filippenko, A.V., Chornock, R., Li, W., Challis, P.M.: *“Supernova 1954J (Variable 12) in NGC 2403 unmasked“*, 2005, PASP **117**, 553

Elliot, J.L., Kern, S.D., Clancy, K.B., Gulbis, A.A.S., Millis, R.L., Buie, M.W., Wasserman, L.H., Chiang, E.I., Jordan, A.B., Trilling, D.E., Meech, K.J.: *“The deep ecliptic survey: a search for Kuiper belt objects and Centaurs. II. Dynamical classification, the Kuiper belt plane, and the core population“*, 2005, AJ **129**, 1117

Erwin, P.: *“How large are the bars in barred galaxies?“*, 2005, MNRAS **364**, 283

Fridlund, C.V.M., Liseau, R., Djupvik, A.A., Huldtgren, M., White, G.J., Favata, F., Giardino, G.: *“HST and spectroscopic observations of the L1551 IRS5 jets (HH154)“*, 2005, A&A **436**, 983

Garavini, G., Aldering, G., Amadon, A., Amanullah, R., Astier, P., Balland, C., et al. (58 authors; the supernova cosmology project): *“Spectroscopic observations and analysis of the unusual type Ia SN 1999ac“*, 2005, AJ **130**, 2278

García-Rojas, J., Esteban, C., Peimbert, A., Peimbert, M. Rodríguez, M., Ruiz, M.T.: *“Deep echelle spectrophotometry of S 311, a Galactic H II region located outside the solar circle“*, 2005, MNRAS **362**, 301

Gil-Merino, R., Wambsganss, J., Goicoechea, L.J., Lewis, G.F.: *“Limits on the transverse velocity of the lensing galaxy in Q2237+0305 from the lack of strong microlensing variability“*, 2005, A&A **432**, 83

Goicoechea, L.J., Gil-Merino, R., Ullán, A., Serra-Ricart, M., Muñoz, J.A., Mediavilla, E., González-Cadelo, J., Oscoz, A.: *“New VR magnification ratios of QSO 0957+561“*, 2005, ApJ **619**, 19

Goicoechea, L.J., Gil-Merino, R., Ullán, A.: *“The dark halo of the main lens galaxy in QSO 0957 + 561“*, 2005, MNRAS **360**, L60

Gorosabel, J., Fynbo, J.P.U., Fruchter, A., Levan, A., Hjorth, J., Nugent, P., Castro-Tirado, A.J., Castro Cerón, J.M., Rhoads, J., Bersier D., Burud I.: *“A possible bright blue SN in the afterglow of GRB 020305“*, 2005, A&A **437**, 411

Gorosabel J., Pérez-Ramírez D., Sollerman J., de Ugarte Postigo, A., Fynbo, J.P.U., Castro-Tirado, A.J. et al. (16 authors): *“The GRB 030329 host: a blue low-metallicity subluminous galaxy with intense star formation“*, 2005, A&A **444**, 711

The colliding spiral galaxies NGC 4567/4568, the "Siamese Twins". Photo: M. Gålfalk

Hidalgo-Gámez, A. M.: *"Physical conditions in the dwarf local irregular galaxy IC 10"*, 2005, A&A **442**, 443

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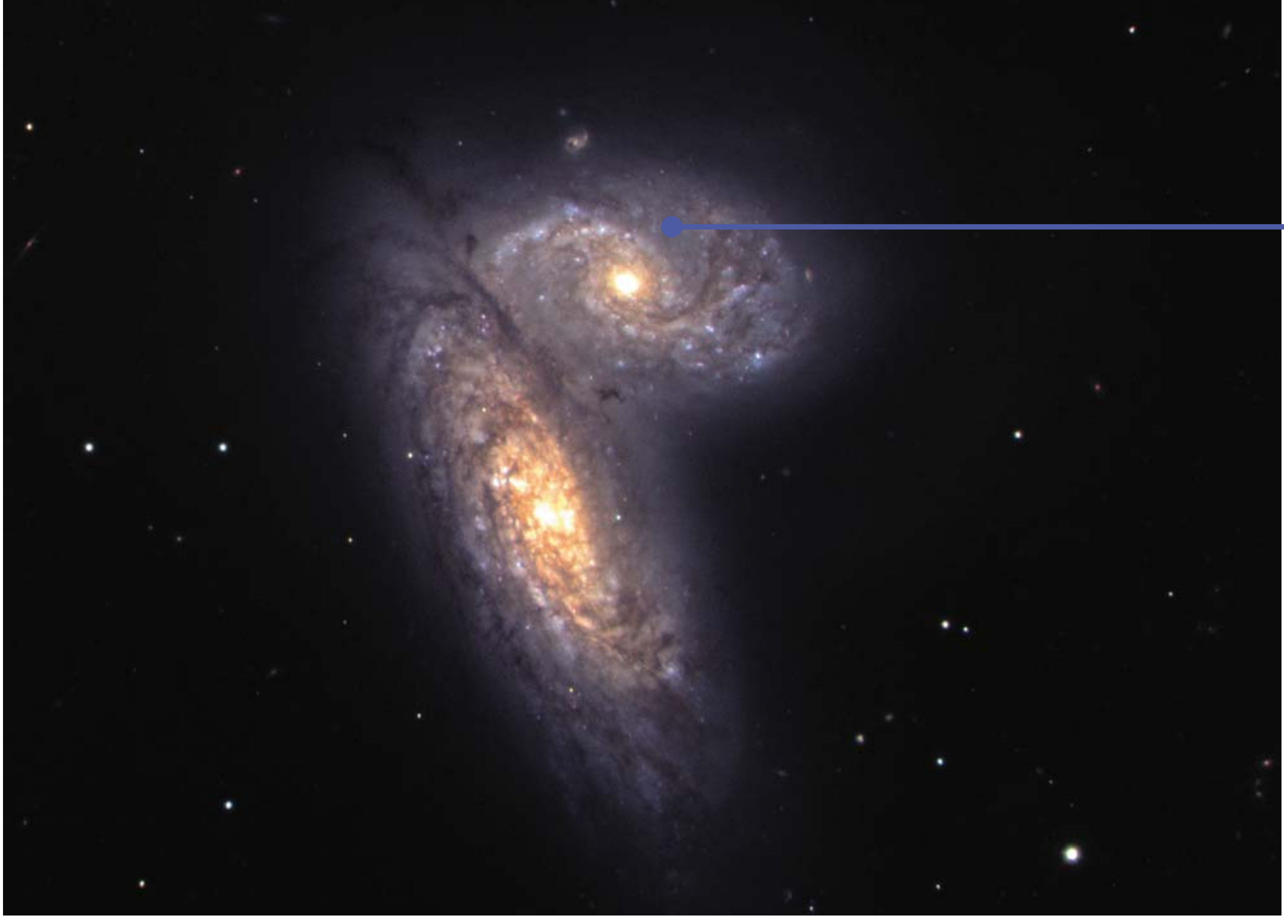

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COMMITTEES & ADDRESSES

CONTACT ADDRESSES

NOT Operations Group:
Telescopio Nordico
Apartado 474
E – 38 700 Santa Cruz de La Palma
Canarias, Spain

Tel:	+34 922 425 470
Fax:	+34 922 425 475
E-mail:	staff@not.iac.es
WWW:	www.not.iac.es

Telescope buildings:

Control room:	+34 922 405 660
Service building:	+34 922 405 663
Fax:	+34 922 405 665

Office of the Director:
Dr. J. Andersen, NOT Director
The Niels Bohr Institute
Astronomy Group
Juliane Maries Vej 30
DK – 2100 Copenhagen Ø
Denmark

Tel:	+45 353 25934
Fax:	+45 353 25989
E-mail:	ja@not.iac.es or ja@astro.ku.dk

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NORDIC OPTICAL TELESCOPE
Grupo Nordico
Apartado 474
E – 38 700 Santa Cruz de La Palma
Canarias, Spain
www.not.iac.es