2007

NORDIC OPTICAL TELESCOPE

ANNUAL REPORT


The young
star cluster
Sharpless 294

Front cover: The young star cluster Sharpless 294; composite image in ultraviolet, red, and Hα light (see p. 10). Photo: A.A. Djupvik, NOT.

NORDIC OPTICAL TELESCOPE

The Nordic Optical Telescope (NOT) is a modern 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 chief governing body of NOTSA is the Council, which sets overall policy, 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 matters.

An **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 operation 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 2007 and contact information to NOT are listed at the end of this report.

The NOT Annual Reports for 2002-2007 are also available at: http://www.not.iac.es/news/reports/

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Pine tree shaped by forest fire.

Editor: Johannes Andersen
Layout: Anne Marie Brammer

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THE STAFF

The NOT staff is complete again, with Peter Brandt back from sick leave. From the student group, Danuta ('Danka') Paraficz returned to Denmark in August to complete her PhD thesis, and Helena Uthas (Lund) stayed on for the entire year. Auni Somero (Helsinki; our new *Synnøve Irgens-Jensen Distinguished Research Student*) and Anestis Tziamtzis (Stockholm) joined us at the beginning of the year, Jarkko Niemelä (Helsinki) in April, and Carolin Villforth (Turku) in September. Meet the whole team below!

In accordance with the agreements with Spain, NOTSA also provided stipends for Laia Mencia Trinchant and Javier Blasco Herrera to obtain their PhD degrees in Stockholm.

Francisco Armas
Administrator

Thomas Augusteijn
Astronomer-in-Charge

Peter Brandt
Mechanic

Ricardo Cárdenes
System manager

Jacob W. Clasen
Software specialist

Graham Cox
Senior electronics engineer

Anlaug Amanda Djupvik
Senior staff astronomer

Loida Fernández
Secretary

Eva Jurlander
Accountant

Jarkko Niemelä
Student

Danuta Paraficz
Student

Carlos Pérez
Electronics technician

Tapio Pursimo
Staff astronomer

Peter M. Sørensen
Software specialist

Ingvar Svärdh
Software engineer

Auni Somero
Student

John H. Telting
Senior staff astronomer

Anestis Tziamtzis
Student

Helena Uthas
Student

Carolin Villforth
Student

PREFACE

Auni Somero receives the Synnøve Irgens-Jensen studentship in October.

2007 was another busy year at NOT. I hope you will enjoy the snapshots of our life on the following pages.

Hard to believe, but this was already the end of my first term as Director. As I look back, my enduring joy has been to work with this great group of people (see facing page). Perhaps the highlight was the expansion of the student programme; telescopes are fine, but the key to the future of Nordic astronomy is people, and our students make me confident for that future. I thank the Council for the privilege of enjoying the company for another few years.

On the technical side, 2007 brought no major revolutions, but many developments started in 2003-6 were brought to fruition. NOTCam achieved its full performance with a first-class detector array and all operating modes fully commissioned, and FIES demonstrated a potential for accurate radial-velocity work that brings exoplanet research within reach (see p. 24). To optimise the use of NOT for training courses, the service building was equipped to serve as a classroom with a large display of the control room screens. Now all the students can follow the observations, although only a couple can be physically at the controls (see p. 28). Note that this classroom could equally well be at your university!

Two initiatives in 2007 will hopefully prove fruitful for the long term. First, prompted by a NORDFORSK Call for Proposals for Joint Nordic Use of Research Infrastructures, NOTSA and Onsala Space Observatory (OSO), Sweden, developed a joint initiative to strengthen research and training in Nordic/Baltic optical and mm radio astronomy, using NOT and the OSO radio facilities as tools. Two separate, but coordinated proposals were submitted.

The underlying rationale is simple: Within short, the European front-line optical and mm radio tools will be available seamlessly through ESO (or ESA). We should start forming a generation of Nordic/Baltic astronomers who will use them freely, unimpeded by traditional scientific, wavelength, or national borders. It is a strong sign of Nordic support for this strategy that both grants were approved. We look forward to implementing it in 2008-2010.

Second, the initiatives to improve planning, cooperation, and synergy in European astronomy gained significant momentum in 2007. The ASTRONET Science Vision report was published in September. It gives an overarching view of the scientific challenges facing European astronomy over the next 15-25 years and how to address them – in space, on the ground, and in the office – and will be a beacon for the future development.

Moreover, the Science Vision was prepared in a constructive and realistic spirit that bodes well for the next, rather more difficult step. The Infrastructure Roadmap will be a comprehensive long-term plan to reach the goals of the Science Vision, including large new telescopes but also theory, computing and archiving, and human resources. The ambition is not merely to compile a glossy wish list detached from reality, but to address all the thorny issues of priorities, schedule, technological readiness, and cost. A draft will be debated at a large symposium in Liverpool in June 2008; the final version is due before the end of the year.

Meanwhile, the core mission of NOT remains to produce science, and the scientific highlights of 2007 are the "meat" of this report. I thank our users for contributing a large number of reports this year and hope that they will be pleased with the versions on following pages – as always in the attractive layout of Anne Marie Brammer.

Jacob Clasen solving a telescope problem on-line from a staff wedding

Johannes Andersen

Johannes Andersen
Director & Editor

EVENTS IN 2007

A few developments of potential long-term significance took place in 2007 and deserve comment here. See our web site for up-to-date news and information on our facilities and services.

ASTRONET and OPTICON

The comprehensive European coordination project ASTRONET gained considerable momentum in 2007 (see *www.astronet-eu.org* for further information). Its *Science Vision* report appeared in September and laid out the grand overall canvas on which progress in astronomy will unfold over the next 15-25 years. To make real impact such a report must have community support, and a draft was debated vigorously in an optimistic, yet realistic mood by ~250 European astronomers in Poitiers, France, in January. The final report was thoroughly revised as a result, but community awareness of the need for cooperation was also strengthened, and nearly all astronomically significant European countries now participate in ASTRONET at some level.

The next task is to prepare the *Infrastructure Roadmap* in a similarly open process. The Working Group and Panels have been appointed, developed first drafts of their respective chapters, and defined the additional information they need to proceed. A first full draft of the report will be released around May 1, in time for the Roadmap symposium in June, and the final report is due in the autumn. Then will begin the work of actually implementing the Roadmap, in 2009 and 2010 – and no doubt beyond. As Chair of the ASTRONET Board, NOTSA is deeply involved in it all, but the process needs the involvement of the entire community. See you in Liverpool!

What does this mean for NOT? On the one hand, the coordination of European telescopes that is our agreed goal is finally under way; on the other, the Roadmap will likely not make specific proposals on this relatively minor issue. OPTICON has focused on its new proposal for FP7 (deadline Feb 1, 2008) and has not made the progress we had hoped for. However, its Executive Committee has proposed that a joint ASTRONET-OPTICON committee be appointed to review the entire issue in depth by the autumn of 2009. This is when big investments like the E-ELT will come up for discussion – a good opportunity to sort out the smaller pieces of the puzzle as well. The proposal was accepted, and the committee is being appointed at the time of writing; it will work in close interaction with the community, and with the directors and owners of the telescopes.

The Nordic Scene

The above developments are in accord with the strategy and plans we have developed at NOT over the past 2-3 years. Yet, it will be another year before we know what the new committee will propose; more before any decisions are taken and implemented. We have therefore prepared a detailed *Development and Implementation Plan* for the development of the scientific and educational services of NOT in 2008-2010, with separate budgets assigned to each activity so the Associates can see what they are asked to pay for and why.

Our plan follows the strategy developed in 2006 to focus on Nordic strengths of relevance to NOT, and is robust with respect to the parallel developments on the European scene; NOT will be a front-line tool in whatever larger facility may result from the review. The Council approved our proposed plan and (almost) the associated budget, and we are now going ahead full speed.

The new strategy to forge close ties within Nordic optical and mm radio astronomy (see previous page) is especially promising in this context. Our ambition is to lead the way into European astronomy of the future as we begin to perceive it, not to be dragged along. The NORDFORSK grants will be used to hire postdocs to assist in this process. At NOT, the postdoc will help to develop flexible and remote observing for both research and teaching and provide additional supervising capacity, so we can expand the student group even further. Good applications are flooding in as I write these lines; 2008 will be lots of fun!

J.A.

Photo: Auni Somero, NOT.

The core mission of NOT is to enable Nordic astronomers to do science. The professional publications listed on p. 32 are the official record of our scientific output in 2007, but a few highlights are given below. Contributions have been edited to fit the available space, and for consistency of style.

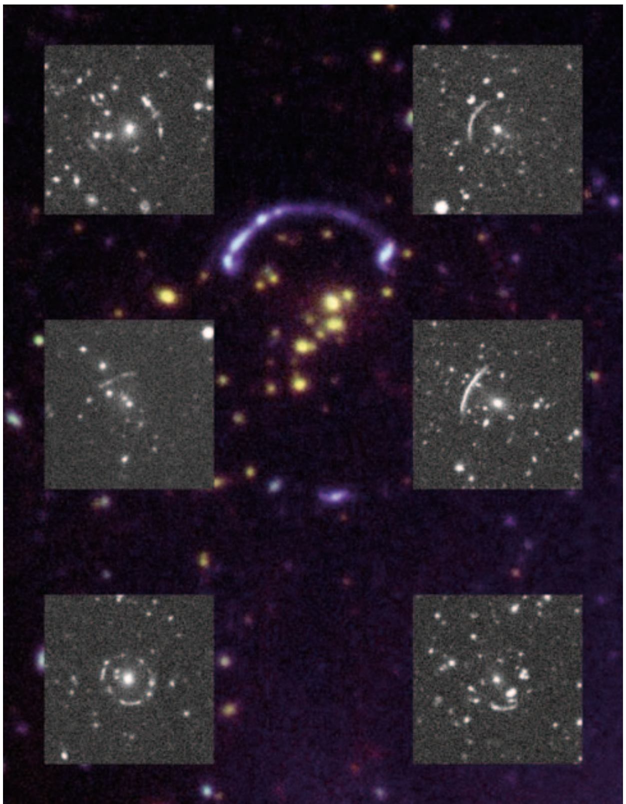
COSMOLOGY AND FORMATION AND EVOLUTION OF GALAXIES

We now believe that the Universe is dominated by totally unknown forms of dark energy and dark matter. Understanding these mysterious ingredients and their role in shaping the visible 4-5% of the Universe – the galaxies – is a central theme of observational cosmology. In turn, the rise of galaxies began the journey that took the Universe from the Big Bang to today's world of galaxies, stars, planets, and life.

The largest gravitational lenses in the Universe

Different versions of the cosmological model make different predictions for the clumpiness of matter, especially for the largest collapsed structures of dark matter in the Universe – the most massive galaxy clusters. Gravitational lensing is a powerful tool to measure the mass of such clusters, because it 'feels' both visible and dark matter. The bending of light by massive clusters can stretch the images of distant background galaxies into multiple images and highly distorted arcs – an effect known as strong lensing, which can be used to derive detailed models of the distribution of dark matter in the cluster.

***Fig. 1:** Cluster lenses with giant arcs discovered recently with NOT (10-min exposures with MOSCA in the g' filter).*



The use of strongly lensing clusters has long been limited by poor statistics, but we are working to increase the sample dramatically. Clusters with redshifts of $0.1 < z < 0.6$ can be efficiently identified in the images of the wide-field Sloan Digital Sky Survey, but we need deeper images and better resolution to detect the much fainter background sources we need to measure masses for the clusters. So far, we have imaged ~300 clusters in good seeing and discovered ~30 new clusters with definite giant arcs plus a similar number of candidates.

Half of these new giant arcs have been discovered using NOT (see examples in Fig. 1). NOT is very efficient for such work because of the generally good seeing, high blue sensitivity of MOSCA, which is a good match to the typically blue giant arcs, and fast slewing between targets. Moreover, the arcs discovered with NOT are bright enough for redshift determinations with 8-10m telescopes, making them most useful for detailed studies of the dark matter distribution in the clusters. Thus, our NOT data will help to turn strong lensing into a powerful probe of the formation of structure in the Universe.

H. Dahle, Oslo; J. Hennawi, Berkeley, and colleagues

Understanding Type Ia Supernovae as standard candles

Type Ia supernovae (SNe Ia for short) are believed to result from the merger of two white dwarfs in a close binary system. This pushes the mass of the resulting single star over the critical (so-called Chandrasekhar) limit for stable stars and triggers a violent thermonuclear explosion. Careful studies have shown that SNe Ia can be used as 'standard candles' to measure large distances in the Universe, independent of redshift measurements and assumptions about the expansion of the Universe. For this reason, SNe Ia have played a key role in the discovery of the acceleration of this expansion and the existence of dark energy.

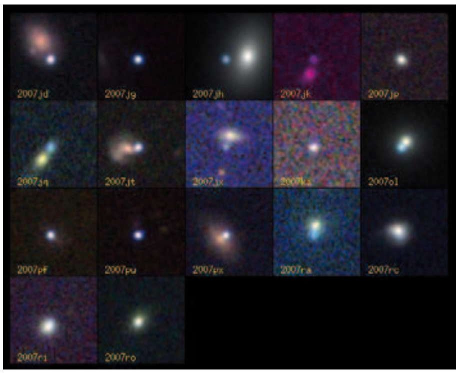
The recently completed Sloan Digital Sky Survey-II Supernova Survey was designed to populate the intermediate redshift range $0.1 < z < 0.3$. Previously, far too few SNe Ia had been observed in this redshift interval, which had become known as the "redshift desert". The results from the SDSSII Supernova Survey will provide stronger constraints on the equation of state of dark energy and will help to understand the systematic uncertainties in using SNe Ia as distance indicators.

During the survey, the 2.5m SDSS telescope at Apache Point scanned the same region of the sky every other night in the months September to November, 2005-2007. When potential SNe Ia were detected, a coordinated international network of telescopes, including NOT, performed spectroscopic follow-up. The data reductions were performed in real time, which allowed prompt classification of each target. At the NOT we were targeting objects as faint as r = 20.5 mag. with typical exposure times of 30 minutes. Subsequent multi-epoch spectroscopy of confirmed SNe Ia are used to study the physics of supernovae and the properties of the host galaxies (next article).

To date, the survey has yielded 487 confirmed and 51 "probable" SNe Ia in the redshift range of z = 0.05-0.35, in addition to 19 Type Ib/c and 64 Type II SNe. The analysis of the cosmological results is currently ongoing. However, other useful quantities have already been derived, such as the most precise measurement to date of the rate of relatively nearby SNe Ia.

G. Leloudas, Copenhagen, and colleagues

Fig. 2: A mosaic of all confirmed SDSS II SNe Ia that were observed from NOT in 2007. Most of them outshine their host galaxies.



Detailed Studies of Nearby Supernovae

The discovery of dark energy and the accelerating Universe is of such fundamental importance that great effort is needed to study all systematic errors that might possibly affect this result. Relatively nearby SNe Ia for which accurate observations can be obtained are the focus of detailed studies to obtain a good physical understanding of the explosion mechanism and the composition and evolution of the resulting remnant.

NOT has made critical contributions to this work by obtaining excellent multi-band light curves and spectra of about a dozen nearby SN Ia. In 2007 six papers with results for five SNe were published (see p. 32). Among the most important results of this project is the discovery that high-velocity features (HVF) of Ca II are frequent in the early spectra, a finding that may be a key clue to the nature of the progenitor. In addition, we have presented the first firm evidence that HVFs are present in the Si lines as well (Fig. 3).

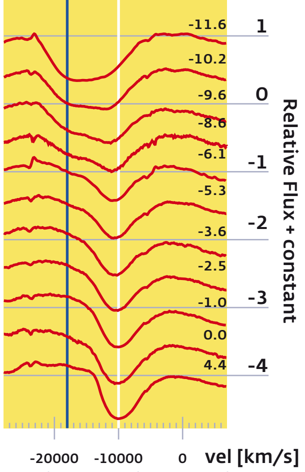


Fig. 3. High-velocity features in the Si II 6355 absorption line in SN 2005cf (marked by blue line).

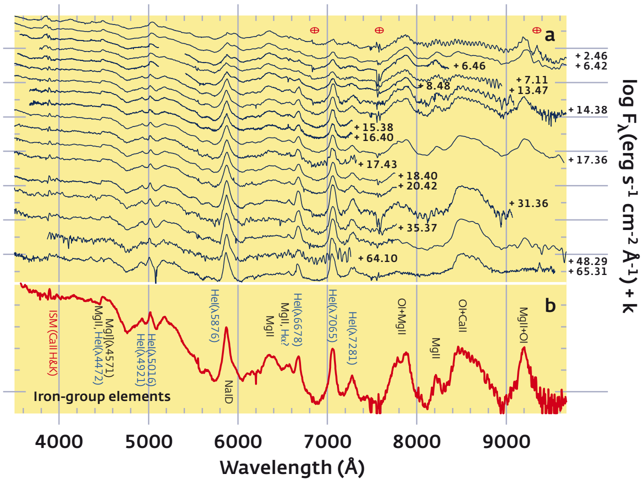


Fig. 4. Spectral evolution of SN 2006jc (days from the explosion given for each spectrum). The main spectral features are identified in the spectrum taken at +14.4 days (Pastorello et al. 2007).

NOT has also contributed significantly to the studies of SNe of types Ib and Ic, which are believed to be core-collapse supernovae whose massive progenitors lost their hydrogen or helium envelopes before the explosion. Our spectra and light curves of the bright, peculiar SN Ib 2006jc (Fig. 4) led us to suggest that the progenitor was a massive carbon-oxygen Wolf-Rayet star embedded in a helium-rich circumstellar medium. A remarkable bright optical transient in the same location in 2004 (Fig. 5), similar to that of the luminous blue variable stars (LBVs) of 60-100 solar masses, could be due to an outburst of the Wolf-Rayet star itself or to a companion star in a massive binary system.

NOT also extensively observed the nearby SN Ic 2007gr (back cover), including the first high-resolution spectrum of a SN Ic (Valenti et al. 2008). Prominent carbon features in the spectra suggest a wide range of carbon abundances in SNe Ic, adding an important piece in the puzzle of the diversity of core-collapse SNe.

The full exploration of the unique database of well-sampled and carefully calibrated observations of many SNe that NOT helped to create has just begun. It promises to be a key element in achieving a better theoretical understanding of the physics of SN explosions of different types.

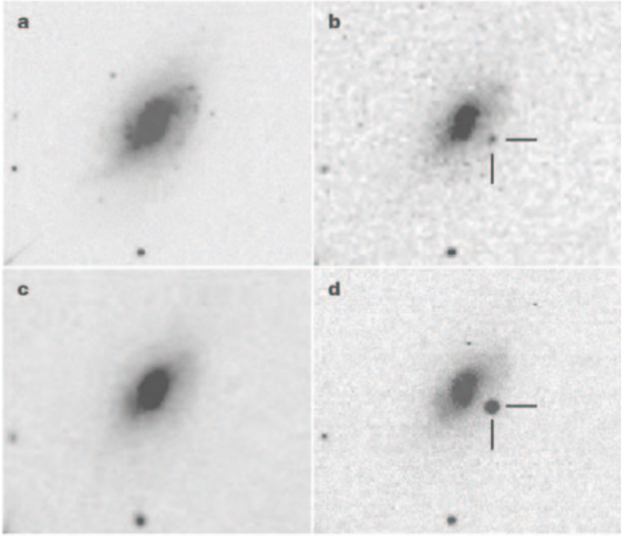


Fig. 5. UGC 4904, the host galaxy of SN Ic 2006jc:
(a) SDSS r' band image from 2001 December 20. No transient is visible.
(b) Detection of the transient on 2004 October 16;
(c) 2006 September 21: no transient seen; and
(d) R-band image from 2006 October 29, showing the supernova.

We hope that NOT will continue to make significant contributions to the studies of nearby supernovae.

V. Stanishev, Stockholm; A. Pastorello, Belfast; S. Valenti, ESO; and colleagues

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The environment of sub-millimetre galaxies

Galaxies have been studied for centuries, but their formation and evolution are still not well understood. Most galaxies are gathered in clusters, which are the largest gravitationally bound structures in the Universe. The formation and evolution of clusters are closely linked to the cosmological parameters that govern the evolution of the Universe itself and its structure. Progress in understanding the cosmological parameters therefore helps to clarify the framework in which the clusters and their galaxies evolve, so we can turn to the task of understanding the processes involved in galaxy formation and evolution in greater detail.

The largest and brightest galaxies are situated at the centres of the largest galaxy clusters. They seem to be special, likely due to their special environment. The stars in these galaxies were formed early in the life of the Universe, and the first stages of their lives can be studied in clusters at high redshift, at times when the Universe was only a few billion years old. Numerical simulations of the evolution of structures in the Universe indicate that the so-called sub-millimetre galaxies (which are only seen in the far-infrared and radio domains) form in the centre of proto-clusters and evolve into the present-day brightest cluster galaxies.

We are using NOT to see if this can be confirmed observationally, by observing the environments of sub-mm galaxies detected by radio telescopes, looking for small star-forming galaxies. These can be identified by their redshifted emission of Lyman-α photons. By investigating the density of star forming galaxies around sub-mm galaxies we will determine whether these regions are overdense compared to the rest of the Universe, and thus whether they are likely to evolve into present-day clusters. If so, the central sub-mm galaxy is likely to become the brightest galaxy in the cluster.

L. Fogh Grove, Copenhagen, and collaborators

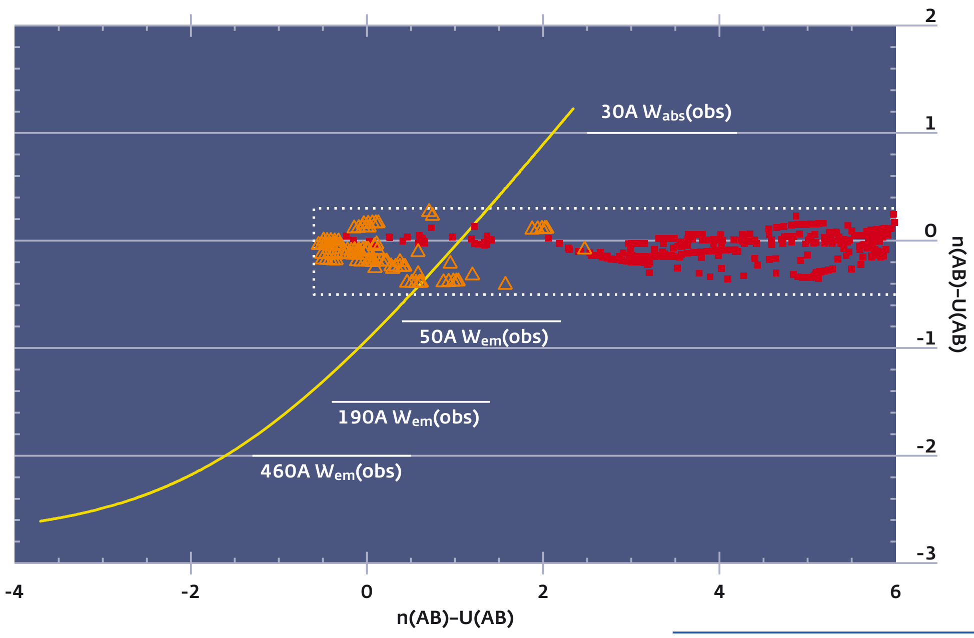


Fig. 6. Selecting Ly-α emitters. Observations in a narrow-band filter (n(AB)) centered on the redshifted Ly-α are compared with broad-band ultraviolet (U(AB)) and infrared (I(AB)) observations. The symbols show objects without Ly-α emission; all are within the rectangle shown. The dashed line outlines a sequence of objects with Ly-α emission of different strength.

Multifrequency monitoring of QSOs

Active Galactic Nuclei (AGN) are super-massive black holes (billions of Solar masses) in the centre of galaxies, which feed on stars and gas captured by their huge gravitational fields. The energy liberated in the process often makes the AGN outshine the entire host galaxy; it is typically focused in violent jets of relativistic particles and electromagnetic radiation at all wavelengths. Current models assume a common scenario for the different classes of AGN, the main differences being due to the different viewing angles under which we observe them.

Flat-spectrum radio quasars (FSRQs) and BL Lac objects are classes of AGN commonly called blazars and exhibit some of the most violent high-energy phenomena observed in AGN. They are characterized by nonthermal continuum emission covering the whole spectrum from radio to X-rays and even γ-rays. Their radiation is highly polarized in the optical and radio bands and rapidly variable at all wavelengths. In the relativistic jet model, the emission from blazars is interpreted as synchrotron emission from relativistic electrons or produced by protons accelerated in the jet.

The Whole Earth Blazar Telescope (WEBT) is a network of optical, near-infrared, and radio observers dedicated to continuous, well-sampled, multi-frequency monitoring of blazars, usually combined with observations in ultraviolet, X-rays, and γ-rays from satellites and ground-based TeV telescopes, which are needed to understand the origin of the continuum emission. NOT has been unique in the WEBT by obtaining snapshots of simultaneous NIR-optical data of blazars.

Recently, a main target of such a multi-frequency campaign has been QSO 3C454.3, which underwent a huge outburst in May 2005. During the NORDFORSK summer school in 2006 (see Annual Report 2006, p. 22), the students observed the QSO simultaneously with the XMM-Newton X-ray satellite and were able to identify a line emission component (Mg II and Fe II) and thermal emission from the accretion disc ("big blue bump") as already recognized in few other quasar-type blazars, but not yet in 3C 454.3 (see A&A **473**, 819).

T.Pursimo, NOT; C. M. Raiteri, M. Villata, Torino; and colleagues from the WEBT collaboration

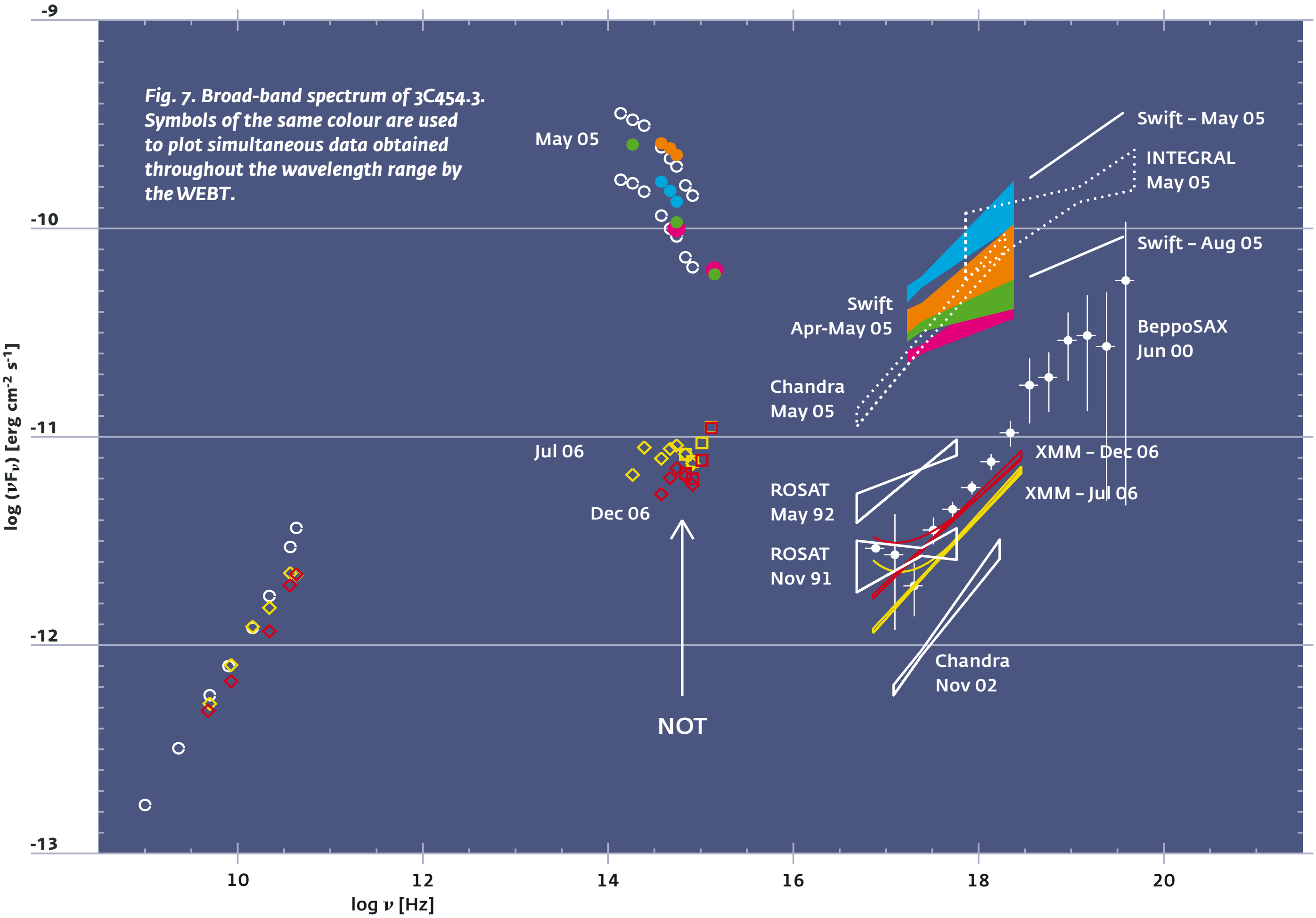


Fig. 7. Broad-band spectrum of 3C454.3. Symbols of the same colour are used to plot simultaneous data obtained throughout the wavelength range by the WEBT.

Fig. 8. Light curves for our six AGN in the V (filled) and R bands (open circles, sometimes offset for clarity).

Intermediate-mass black hole candidates

Almost every galaxy in the Universe is thought to harbour a central, supermassive black hole. Activity related to black hole accretion, such as powerful winds and outflows, plays a crucial role in galaxy formation. Massive galaxies are thought to form by major mergers, triggering both intense star formation and black hole accretion. Stars form out of gas and dust, and the black hole grows by accretion of the same material. Eventually the black hole becomes so massive that its radiation expels gas and dust from the host galaxy. As a result, black hole growth and star formation is halted, and the galaxy undergoes “passive evolution” from then on.

Much can be learned about how galaxies and black holes co-evolve from studying the relation between the mass of the black hole and characteristic properties of the host galaxy. Elliptical galaxies in the local Universe show a remarkable relation between the mass of the galaxy bulge and that of the black hole, when the latter is larger than 10^7 solar masses. But can this relation be extrapolated to lower black hole masses and smaller bulges? Is there a minimum mass below which black holes cannot form? Investigating galaxies with intermediate-mass black holes may provide important clues to how less massive galaxies are formed, and why some galaxies have black holes, whereas others have compact nuclear star clusters instead.

The only direct method to study the immediate surroundings of the black hole is the so-called reverberation or light-echo mapping, in which one studies the propagation of events in the AGN to surrounding regions characterised by certain emission lines. So far, roughly 35 AGN have reverberation-based black hole masses, all very bright and with black holes of more than 10^7 solar masses – well above the mass range we want to explore.

Reverberation mapping requires that the AGN is variable, so we have started a monitoring project at NOT to identify variable lower-luminosity quasars, which are thought to contain intermediate-mass black holes. With reverberation mapping of just a few such objects, we can investigate an important range of the luminosity-black hole mass parameter space. As Fig. 8 shows, we comfortably detect variations in at least 3 of our 6 targets over two months, for the others as well when observed over a longer time. We thank the NOT staff and visiting astronomers for performing these observations in service mode.

M. Wold, J.-E. Solheim, P.B. Lilje, Oslo; S. Kaspi, Tel Aviv; M. Brotherton, Laramie, WY

The stellar content of low-redshift BL Lac host galaxies

BL Lac objects are variable AGN with featureless spectra, thought to be due to a jet pointing directly at us. Their hosts are luminous elliptical galaxies. Previous studies have shown that BL Lac hosts are systematically bluer and have a wider colour distribution than inactive ellipticals. The blue colours are most likely caused by young stars, indicating a recent star formation episode. However, there are few studies in the blue colours that allow to trace this young population. We have therefore used ALFOSC for UBV imaging of 18 low-redshift BL Lacs that were previously resolved in the R (red) and H (near-infrared) bands. These multicolour data were used to compare the optical/infrared colour gradients of BL Lac hosts to elliptical galaxies with and without nuclear activity.

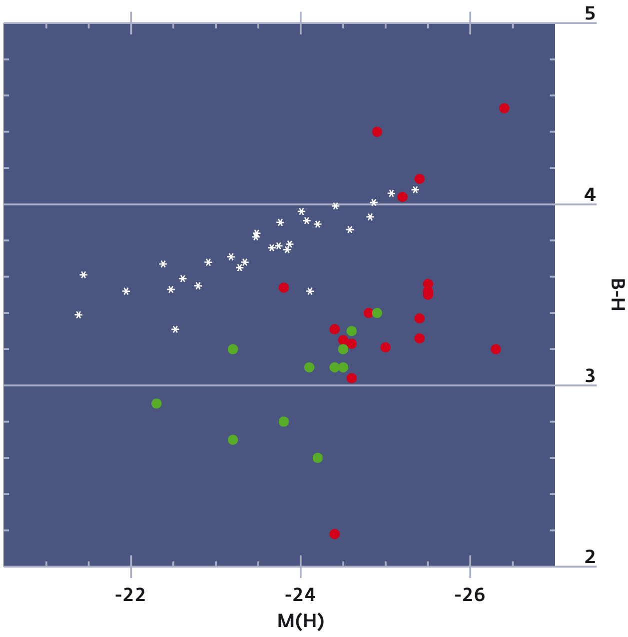


Fig.9. B-H colour vs. H magnitude for BL Lac hosts (red dots; new data), radio-loud and radio-quiet galaxies (green dots), and inactive early-type galaxies (white asterisks).

We clearly resolve all the low-redshift BL Lac hosts and find their structure to be rather similar to that of inactive ellipticals, indicating that all massive elliptical galaxies can experience nuclear activity without significant perturbation of their global structure. However, the BL Lac hosts do not follow the same relation between *B-R* colour and *H*-magnitude as inactive ellipticals; the majority of them appear to be bluer, and they also have a wider distribution of integrated blue/near-infrared colours and colour gradients than inactive ellipticals (Fig. 9). Such colours are more similar to those of inactive galaxies with significant recent star formation, and consistent with the colours of low-redshift radio galaxies and quasar hosts.

The blue colours are likely caused by a young stellar population and indicate a link between star formation caused by an interaction/merging event and the onset of nuclear activity. The lack of strong signs of interaction may indicate a significant delay between the event associated with star formation and the start of nuclear activity.

T. Hyvönen, J.K. Kotilainen, Tuorla; R. Falomo, Padova; T.Pursimo, NOT

FORMATION, STRUCTURE, AND EVOLUTION OF STARS

Stars form in dense clouds of gas and dust. As they evolve, they build up heavy elements that can enrich the next generation of stars. Eventually, they die as white dwarfs or supernovae, leaving the enriched gas and a neutron star or black hole remnant behind. Thus, stars are also key actors in galactic evolution. Theoretical models describe the main features of stellar evolution well and enable us, e.g., to determine stellar ages, but the processes are complex, and much remains to be understood.

Discovery of a newborn double star cluster

In visible light, Sharpless 294 is an extended emission nebula with a great variety of morphological detail. Clumps and filaments of bright and dark cloud material are seen illuminated or silhouetted on a bright background (see Fig. 10). In the near-infrared (IR), however, the existence of two young star clusters becomes apparent (see Fig. 11), of which the eastern one is embedded in the dark cloud material seen in absorption in the optical image. The other, western cluster is centred on a massive star (B0.5) that has already reached the main sequence and whose strong ultraviolet radiation is responsible for the ionising the bright nebula. The lower-mass cluster stars are still contracting in the pre-main sequence stage; their estimated age is around 7-8 Myr.

Fig. 10. Combined image of Sharpless 294 taken with ALFOSC in ultraviolet (blue) and red (green) light and in the Hα emission line of hydrogen (red). The field is 6'x6'; north is up, east left.

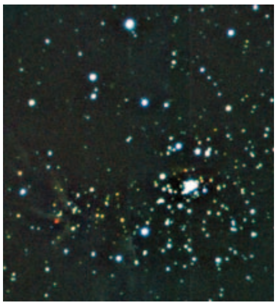


Fig. 11. Near-infrared image in the J (1.25 μm; blue), H (1.65 μm; green), and Ks bands (2 μm; red) of the central region (about 3'), revealing the double cluster. The eastern cluster (left) is practically invisible in the optical.

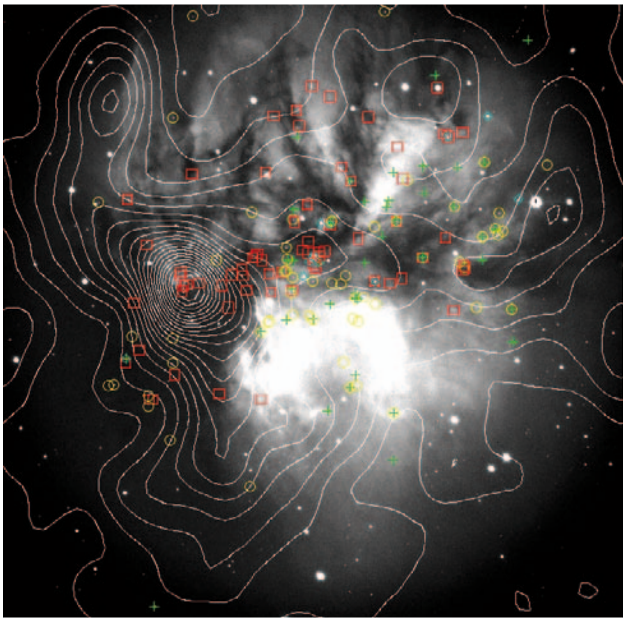


Fig. 12. The ALFOSC Hα image overplotted with the 8-μm isophote contours; note how the far-IR emission outlines the young eastern cluster. Different types of cluster members are indicated as follows: Main-sequence stars (blue diamonds), pre-main sequence stars selected from the optical colour-magnitude diagram (yellow circles), objects with near-IR excess (red squares), and Hα emission sources (green pluses).

Combining our NOT data with far-IR archive data from space, we discover a luminous protostar located in the eastern cluster. Judging from the spectral energy distribution, this should be a star of 8-12 solar masses caught in the act of forming, with an estimated age of 40,000 yr or even less. The lower-mass stars in this cluster are traced by the clumps of near-IR excess, with a sub-clustering scale that suggests an age around 2 Myr.

The extended 8-μm emission (white contours in Fig. 12) traces the borders of the Hα emission very well; its origin is believed to be poly-aromatic hydrocarbon (PAH) molecular emission in a dense photodissociation region (PDR) that forms a shell around the optical emission region. The massive star formation seems to take place in this PDR. The formation of the eastern cluster may thus have been triggered by shocks from the optical HII region, resulting from the earlier event of star formation that created the western cluster.

J. Yun, Lisboa; A.A. Djupvik, NOT;
A.J. Delgado, E.J. Alfaro, Granada

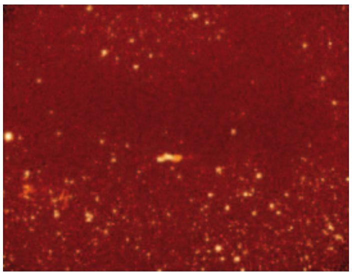
Herbig-Haro objects in the dark cloud Lynds 723

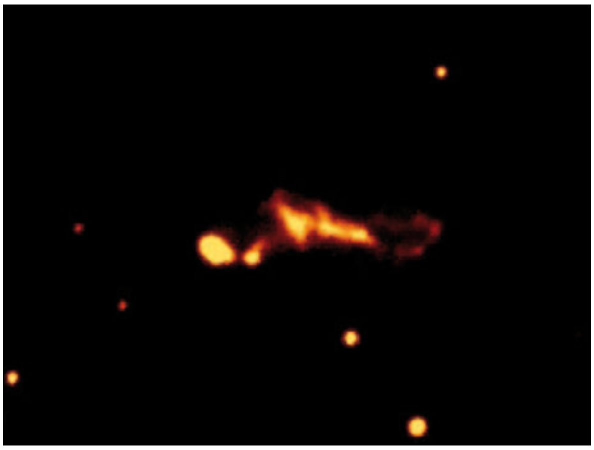
Herbig-Haro (HH) objects are bow shocks that form when a high-speed jet from a newborn star hits the surrounding dense cloud. Often, the star itself is obscured from view and is only detectable at infrared or radio wavelengths.

The Herbig-Haro object HH 223 is associated with the isolated dark cloud Lynds 723 (L723), about 300 pc away. Radio observations show that L723 hides at least four young stellar objects (YSOs). A molecular (CO) outflow with two separate pairs of lobes emanates from the region where the YSOs are found, and images in broad-band red light show HH 223 as a nearly linear emission about 30" long.

L723 is a very interesting star-forming region, but has not yet been studied in detail at optical wavelengths. We have therefore undertaken a project with ALFOSC at NOT to disentangle the structure, physical conditions, and kinematics of the HH objects in L723 and analyse the complex interaction between the supersonic gas ejected by the embedded YSOs and their environment.

Fig. 13. Left: Narrow-band Hα image of L723, showing HH 223 and other fainter nebulosities (field: 5.3'x4.0').





Above: Close-up of HH 223. Right: Spectra of the upper and lower knots in HH 223 (top and bottom), showing the emission lines characteristic of HH objects ([OI], [NII], Hα, [SII]); lines of [FeII], [CaII] and [OII] are seen as well.

Fig. 13 shows the L723 field in the light of the Hα emission line. HH 223 is the elongated structure at the centre of the field; other, fainter wisps of shocked gas are seen projected onto the lobes of the larger molecular outflow. The good resolution of the image allows us to resolve the structure of HH 223 for the first time (middle image): HH 223 shows a wiggling structure, with several knots embedded in a fainter nebula. Spectra at two positions along the knots show the characteristic emission lines of HH objects and indicate that the emitting gas moving towards us at supersonic speed (typical of stellar jets). Comparing the Hα and sulphur ([SII]) lines allows us to trace the density, ionization and excitation of the shocked gas, and an earlier Hα image (from July 2004) enables us to follow the motion of HH 223 in the plane of the sky as well.

R. López, R. Estalella, A. Riera, Barcelona; G. Gómez, La Laguna; C. Carrasco-González, Granada

The nature of "globulettes"

Some years ago, while studying a number of dark, cold pillars of dust silhouetted against a bright nebula – the so-called elephant trunks (see Annual Report 2001), we noticed some very tiny, dark patches in the fields, only a few arcseconds across (Fig. 14). The size and mass distributions of these objects show that they form a specific class of objects, which we called "globulettes" because they appear similar to the much larger classical dark globules (Fig. 15). In fact, most of them contain only a few Jupiter masses of gas and dust (Fig. 16).

The question is how these planetary-mass clouds form and evolve. Because of the high external pressure from warm gas and hot stars, especially the larger globulettes may collapse and form free-floating planetary-mass objects or very low-mass stars – brown dwarfs (see below). We find that some globulettes are completely transparent in the infrared, while others have already formed dense

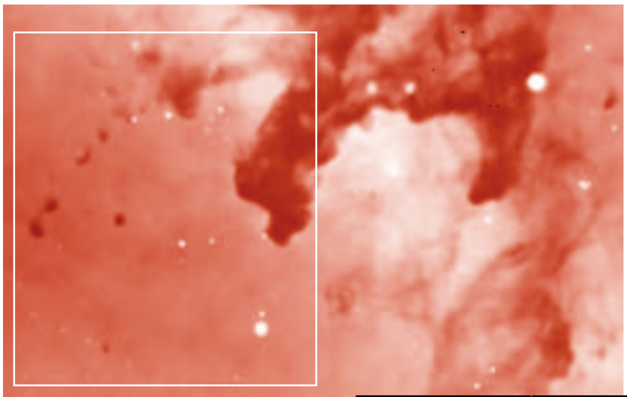


Fig. 14. Close-up of the Rosetta Nebula with a remarkable string of tiny, dark balls silhouetted against the background of Hα-emitting gas. Two more isolated globulettes are seen below.

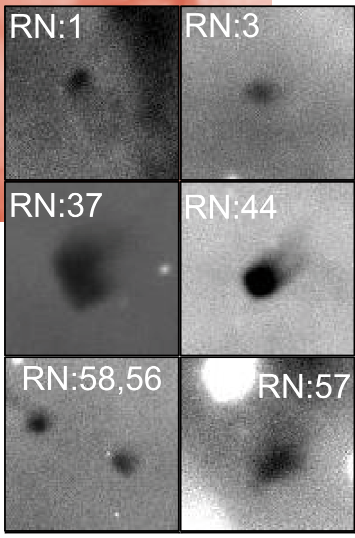


Fig. 15. A selection of globulette morphologies – round, "teardrops", or with bright rims or halos. The fields are 17" x 17".

cores and may even host low-mass stars. These globulettes are accelerated away from the region by radiation pressure and may eventually be ejected into the galactic darkness as free-floating, frozen-out bodies.

Other globulettes are subject to strong erosion from the intense radiation field, and the smaller ones may dissolve completely over a few times 10^4 years, as shown by detailed numerical simulations.

G. Gahm, A. Kuutmann, G. Mellema, Stockholm;
L. Haikala, Helsinki

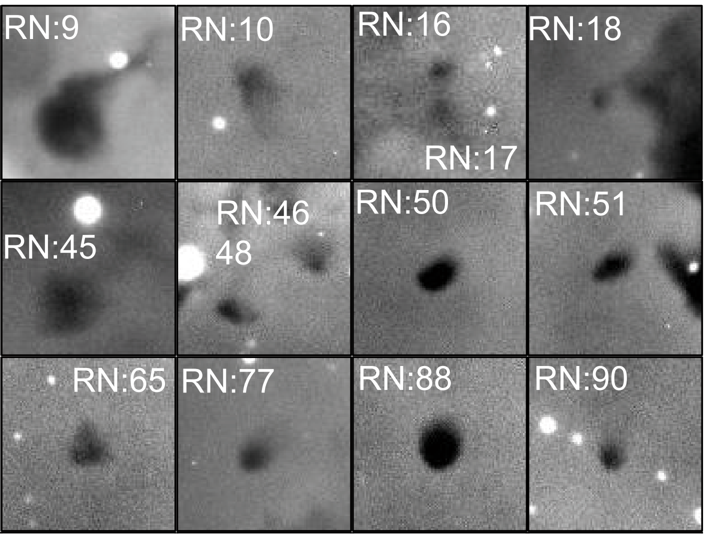
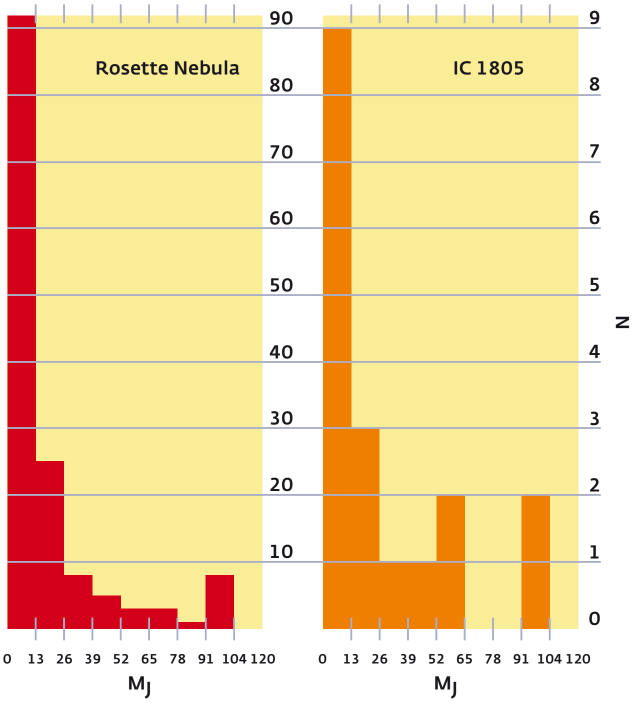


Fig. 16. Mass distribution of globulettes in two nebulae. Most objects are below 13 Jupiter masses (M_J), i.e. in the range of planetary masses.



Alignment of dust grains in interstellar clouds

Magnetic fields are expected to play a crucial role in the dynamics of the interstellar medium (ISM), but they are notoriously difficult to measure quantitatively. Light passing through the ISM is commonly polarized, which indicates that the interstellar dust grains have been aligned by the magnetic field, but incomplete understanding of the alignment mechanism(s) has hampered the interpretation of the data.

Recent work has shown that the main alignment mechanism is likely a direct coupling of the dust with the radiation field. However, the so-called “Purcell” alignment mechanism, in which the ejection of newly formed hydrogen molecules from the grain surfaces produces a net angular momentum, may also play a role. Within a general study of radiative alignment processes in the Taurus region with TurPol in November 2007, we also observed stars behind the nearby reflection nebula IC 63 to search for indications of Purcell alignment. IC 63 is a region of known intense H_2 emission and hence an ideal target to address this possibility, but the suitable background targets are very faint. TurPol allowed us perform simultaneous UBVRI polarimetry of down to V~15 and polarization curves for regions with both excited and quiescent H_2 gas.

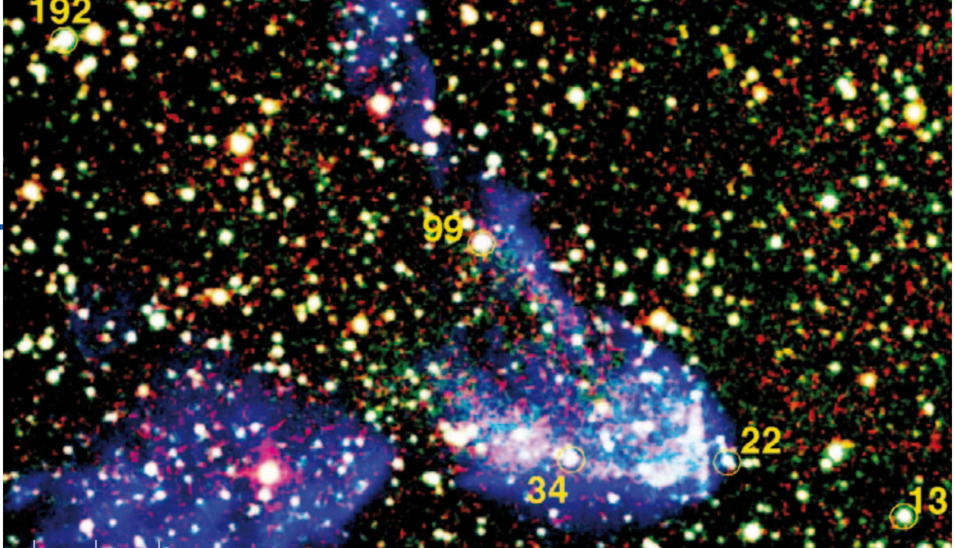


Fig. 17. False colour image of the reflection nebula IC 63, with neutral hydrogen (Hα) shown in blue, molecular hydrogen (H_2) in red. The target stars are marked.

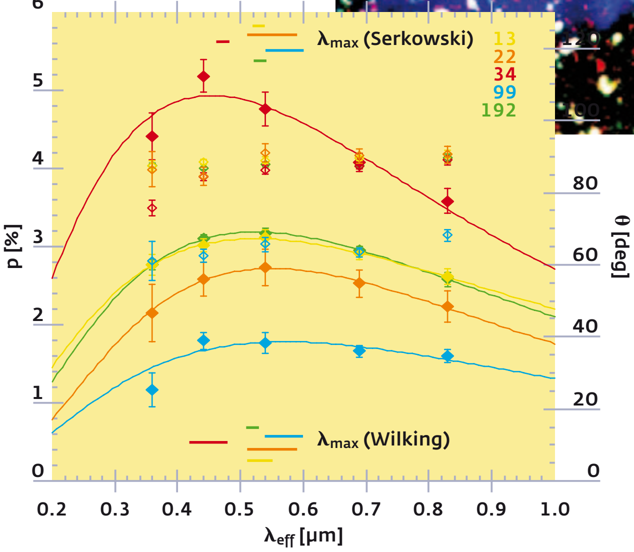


Fig. 18. Polarization curves for the stars identified in Fig. 17. Filled symbols indicate the measured polarization (p[%]) in the UBVRI bands; open symbols the polarization angles (θ). Star #34 shows a larger maximum polarization p_{max} occurring at a shorter wavelength λ_{max} than the other stars – both indicators of enhanced grain alignment. The bars at the top and bottom of the figure indicate two sets of best-fit values (±1σ) for λ_{max}.

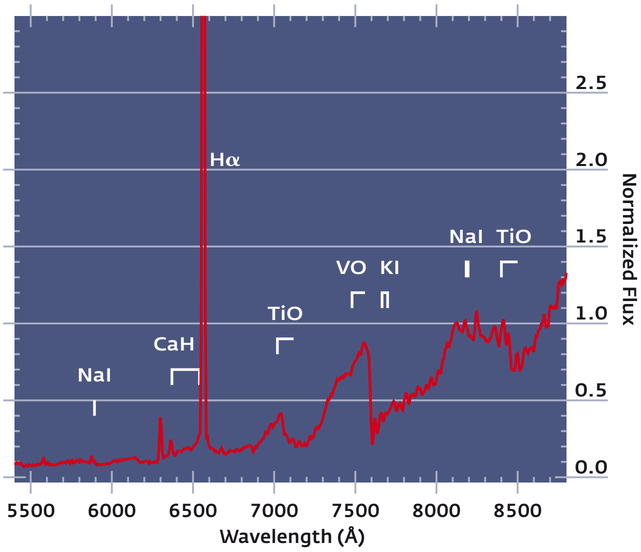
We find a tantalizing indication of active Purcell alignment. Fig. 17 shows our target stars on a false-colour image of IC 63; neutral and molecular hydrogen are shown in blue and red, respectively. Fig. 18 shows the resulting polarization curves. The star (#34) that probes a region of enhanced H_2 molecule formation shows both a larger p_{max} and a smaller λ_{max} than the other stars – both indicators of enhanced grain alignment. No correlation is seen with distance from the star that excites the region, and hence with the intensity of the local radiation field. This possible detection of Purcell alignment in IC 63 will be further pursued in 2008.

B.-G. Andersson, Baltimore; V. Piirola, Turku

Spectroscopic confirmation of young, very low-mass stars

Brown dwarfs are stars with only 1-8% of the mass of the Sun – too low to ignite nuclear burning in their interiors. For decades they remained the 'missing link' between stars and giant planets, until the first brown dwarf was found in 1995. This field has progressed enormously since then, but significant questions concerning their formation and evolution remain open. In one formation scenario, they have been ejected in the early dynamical evolution of a multiple stellar system. Depending on the speed of ejection, brown dwarfs may then have travelled far from their birthplaces and would not be detected in surveys of star-forming areas.

Fig. 19. Low-resolution ALFOSC spectrum for one of the Hα-emitting very low-mass candidates from the IPHAS survey (estimated spectral type M6).



Due to mass accretion, many young brown dwarfs show stronger Hα emission than normal active stars. The IPHAS survey (INT Photometric Hα Survey of the Northern Galactic Plane) allows us to search for brown dwarf candidates over a very large area, away from known star formation regions. Using Virtual Observatory tools, we have cross-correlated the IPHAS and 2MASS infrared catalogues to search for young brown dwarf candidates, applying several colour criteria. Low-resolution spectroscopy with ALFOSC at NOT then allows us to determine the spectral type, measure the strength of the Hα emission as an indicator of youth and activity level, and use the far-red Na I lines as a measure of the surface gravity (Fig. 19).

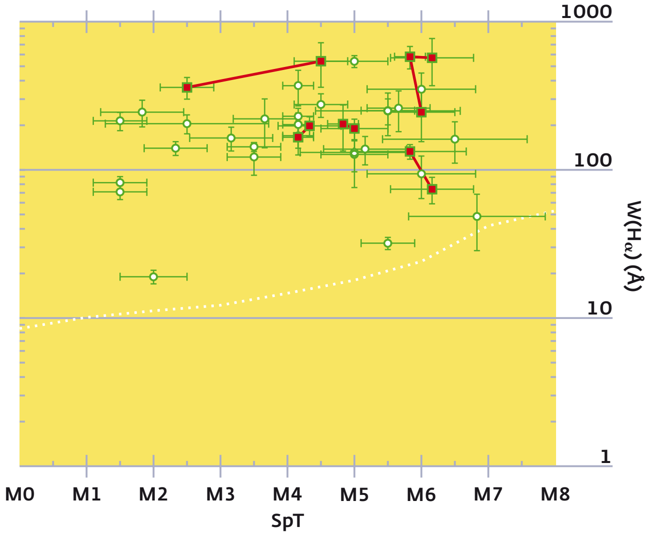


Fig. 20. Hα strength vs. spectral type of our brown dwarf candidates; objects in red were observed more than one night. Most objects are clearly above the saturation line for isolated active stars, indicating that they are accreting.

As a result, we have found both very young stars of very low mass and brown dwarfs in regions very different from those studied until now. In most of these objects, strong Hα emission is evidence of ongoing mass accretion (Fig. 20). These objects could have formed in small molecular clouds or have been ejected from star formation regions.

L. Valdivielso, E. L. Martín, La Laguna

Discovery of the brightest Pre-Main-Sequence eclipsing binary

Eclipsing binaries are of fundamental importance, because the masses and radii of the stars can be determined directly and accurately as observational constraints on stellar evolutionary models. A good data set exists for stars on the main sequence and slightly beyond, but only six pre-main-sequence eclipsing binaries are known, leaving pre-main-sequence stellar models and age scales poorly constrained.

With the FIES spectrograph at NOT, we have discovered another pre-main-sequence eclipsing binary, called ASAS J052821+0338.5 – in fact, the brightest such system known (V =11.7). Like many other pre-main-sequence stars, it is an X-ray source as well. Perhaps this bright system was overlooked in earlier spectroscopic surveys of X-ray bright stars because it is located in the outskirts of the Orion star-forming region.

In January 2007 we obtained high-resolution spectra of the system with FIES and simultaneous V-band photometry

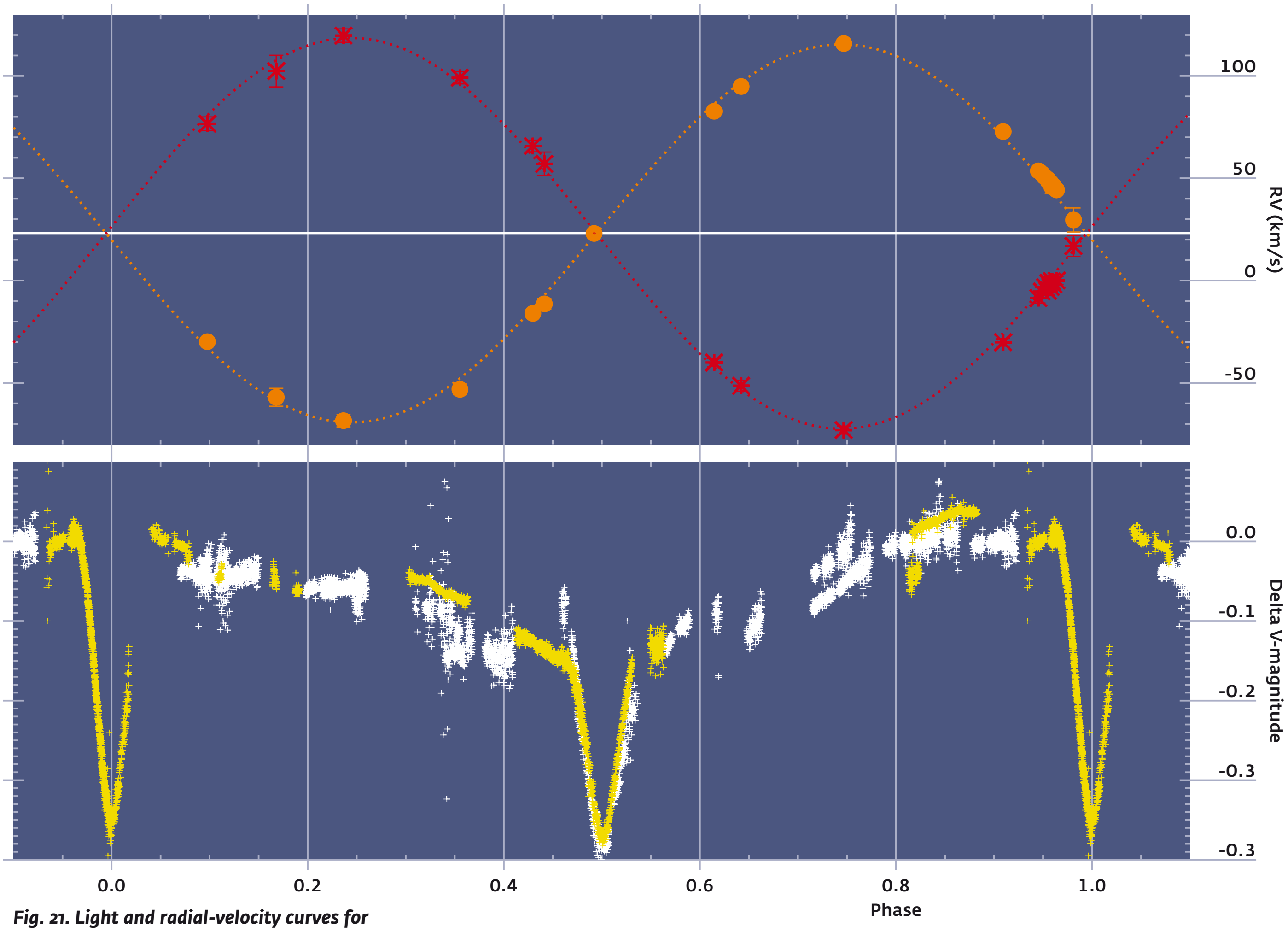


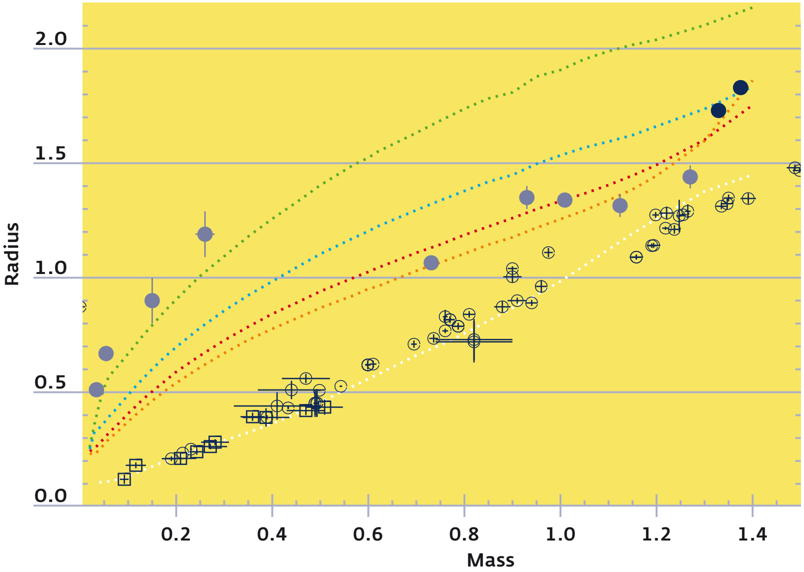
Fig. 21. Light and radial-velocity curves for the new pre-main-sequence binary system.

with telescopes in New Mexico, Cambridge, and St Andrews. The spectra show Hα emission and a strong Li I line, both indicative of young age. The high lithium abundance, proper motion, and distance of the system all suggest that it belongs to the Orion OB1a subassociation, with an estimated age of ~11Myr.

Our data define the light and radial-velocity curves of both stars in the system well (Fig. 21); they also allow us to reconstruct the spectra of the individual stars by so-called tomographic separation and measure the masses, radii, and temperatures of the components accurately. We find that the stars have spectral types of K1-3, masses and radii of ~1.35 and ~1.75 times those of the Sun, and temperatures of ~5,000 K; one star is slightly, but clearly more massive, larger, and hotter than the other. Both stars are considerably cooler and larger than main-sequence stars of the same mass, indicating that they are still in the contraction phase of their formation – see Fig. 22, which also shows that more accurate data for pre-main-sequence stars are needed to test the models in detail.

E. Stempels, L. Hebb, St. Andrews, and collaborators

Fig. 22. Mass-radius diagram for lower main-sequence (open circles with error bars) and pre-main-sequence binary stars (light blue symbols); dark blue dots indicate the stars in ASAS J052821+0338.5. The curves show the loci of stellar models of different ages (increasing downward).



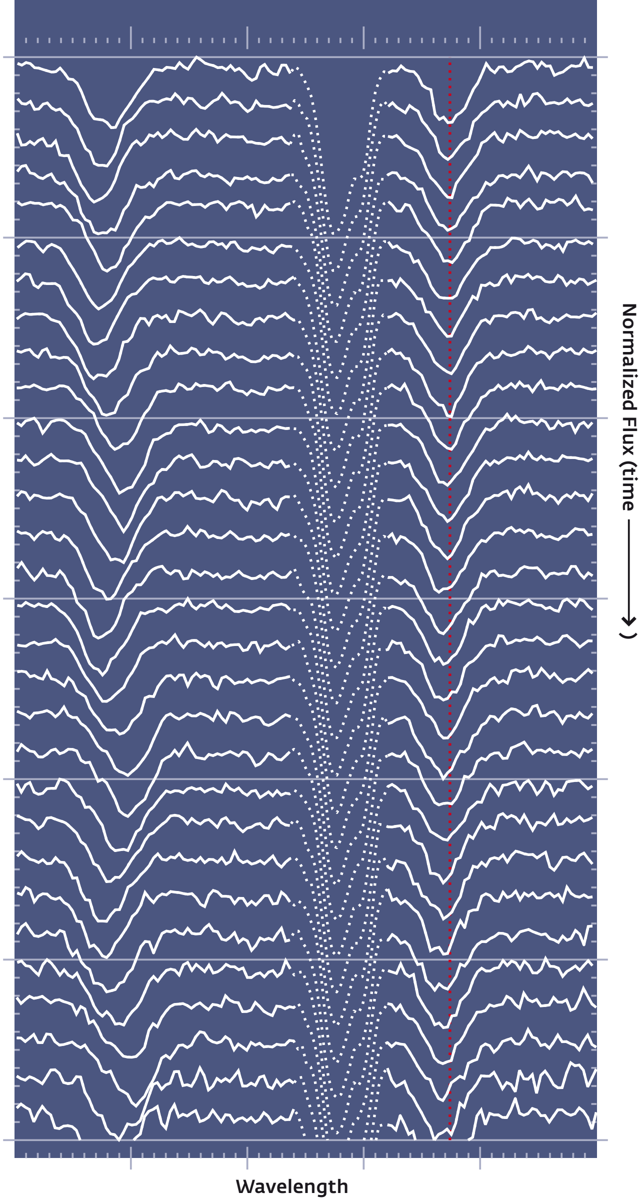


Fig. 23. Time evolution of a spectral line of a binary system with a pulsating star (left) and a non-pulsating companion (right).

An eclipsing binary with a pulsating star

During five nights in the summer of 2007 we obtained spectroscopic observations of a pulsating binary star. This system is particularly interesting because it presents two eclipses every orbital cycle; such systems, when carefully observed and correctly interpreted, can provide a wealth of information on fundamental parameters, such as mass and radius of both stars (see above). In turn, knowing the mass of the pulsating star to a few percent allows us to use the observed pulsation frequencies to study the interior of the star – the technique known as asteroseismology. In our case, the two masses are 1.53 and 1.63 solar masses.

What makes the system unique is the fact that both components are situated near the cool edge of the instability strip in the Hertzsprung-Russell diagram, where many stars pulsate, but our observations show that only one of the stars does so. Fig. 23 shows a time series of a single spectral line from one night, the lines of the two stars being separated due to the difference in orbital velocity. The line of the primary star (left, approaching) shows rapid oscillations around a slow net drift towards higher velocities (rightwards), while the line of the other star simply shifts slowly the opposite way without any rapid excursions. The grey dashed lines show a (fixed) telluric line, which is shaded to avoid confusion. We are currently obtaining light curves to study the pulsating component in more detail.

O. Creevey, IAC and Boulder

Hunting new types of Galactic X-ray binaries

X-ray binaries consist of a neutron star or black hole – the compact remnant of a once high-mass star – and a stellar companion. The X-rays are produced when material from the companion is captured by the enormous gravitational field of the remnant; they carry invaluable information about the magnetic fields of neutron stars and the behaviour of matter in extreme gravitational fields.

X-rays are absorbed by the Earth's atmosphere and must be observed from space. However, many X-ray sources associated with young stars are obscured by huge amounts of interstellar dust, which absorbs X-rays as well as visible light. Yet, we need both the X-rays to study the immediate environment of the compact object and an optical detection of the companion star to estimate its distance, luminosity, and other physical parameters.

Since 2001, the ESA satellite INTEGRAL has enabled us to observe the sky in hard X-rays with relatively good positional accuracy. Interstellar material is less opaque to hard than to soft X-rays, so INTEGRAL has found a large population of X-ray sources which were missed by previous missions. Many of these are believed to be neutron stars orbiting young high-mass stars, and we have used NOT to detect and study the companion stars.

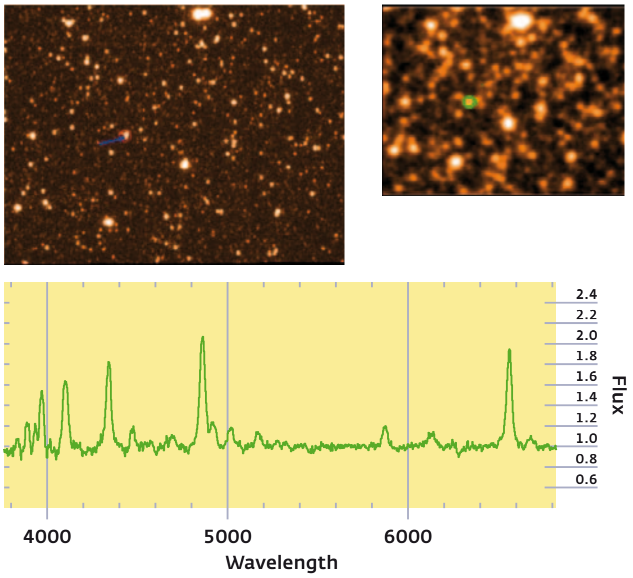


Fig. 24. Hunting down an X-ray source: The error circle of the hard X-ray satellite (Rossi XTE; top right) contains hundreds of stars, while the much smaller error circle (green) from Chandra contains only one star. However, the high-resolution ALFOSC image (left) resolves this "star" into several objects. Moreover, we could obtain separate spectra of the two brightest objects, although they are only 2" apart and always very low in the sky. One is a normal red star, the other an emission-line object, the companion to the X-ray source (blue arrow). Alas, its spectrum (lower right) shows just a 'normal' accreting white dwarf, not a new Fast Supergiant Transient, but we continue…

This process involves several steps, illustrated in Fig. 24: First, we reobserve the large error circle of the hard X-ray detection in softer X-rays with the Chandra or XMM satellites, which provide accurate positions. We then image the smaller field with NOT and take spectra of point sources within the error circle. Spectral peculiarities, such as strong emission lines, are then the "smoking gun" identifying the X-ray source.

The combination of excellent resolution and the flexibility of ALFOSC make the NOT unmatched for this task. In a single run, we can detect new counterparts by combined imaging and low-resolution spectroscopy or study known counterparts more accurately, using the new high-resolution VPH grism. These observations have enabled us to characterise a new kind of X-ray source, the Fast Supergiant Transients, which are associated with bright (and generally highly obscured) blue supergiant stars, and explain their behaviour by a model invoking clumpy stellar winds.

I. Negueruela, Alicante

Mapping Magnetic Fields on Active Late-Type Stars

Magnetic fields are known to play an important role in stellar structure, especially for the activity of solar-type stars. In late-type stars with convective outer layers, the surface magnetic field is thought to be produced by a turbulent dynamo mechanism. When studying such active stars, the main scientific aim is to derive the relation between temperature and magnetic field structures and the cyclic variation of the mean magnetic field and its polarity.

However, the direct verification of magnetic fields from measurements of the Zeeman effect and its polarization properties in absorption lines in the stellar spectrum is a complicated observational problem. This is particularly true for late-type stars, because the complex structure of their surface magnetic fields significantly reduces the observable net Zeeman effect. Translating the observed spectral line features into surface maps of the magnetic field, so-called Zeeman-Doppler imaging, is even more challenging. And, as we know from the Sun, stellar activity cycles may have time scales of the order of decades. Patience is required in this field!

Over the last 16 years, the SOFIN high-resolution échelle spectrograph, built jointly between the Crimean and Helsinki observatories and with recently upgraded spectropolarimetric capabilities, has collected data on the magnetic cycles of active, rapidly-rotating late-type stars in a systematic long-term programme. The major finding of these investigations, which produced maps of surface tempera-

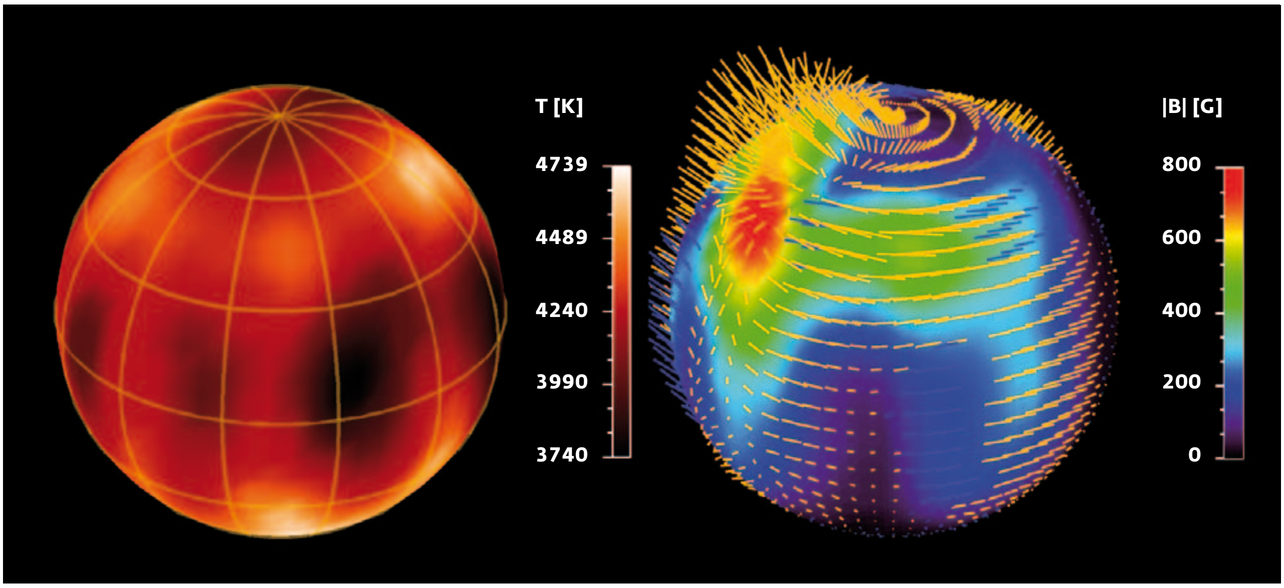


Fig. 25. Temperature (left) and magnetic field maps (right) of the active late-type star II Peg.

ture, has been a persistent structure of two spots, the strength of which varies in a cyclic manner with a period of a few years. During the last several years, the upgraded SOFIN has allowed us to map the complicated magnetic fields in late-type stars more accurately. A first analysis of the newest observations has been made with a new Zeeman-Doppler inversion code, developed in Potsdam.

Using this new code, with novel noise suppression procedures optimised for polarized lines in late-type stars, permits us to derive results that are more reliable than most other approaches. As an example, temperature and magnetic field maps for the active star II Peg are given in the figure. The long time series of high-resolution spectropolarimetric data underlying these maps is one of the most complete data sets in the world in this field.

I. Tuominen, Helsinki; T. Carroll and I. Ilyin, Potsdam

Mapping the activity cycle of a young solar analogue

Some stars similar to the young Sun show photometric cycles analogous to the Solar 11-yr spot cycle, but with larger amplitudes. Unfortunately, in many cases, photometric coverage is still not sufficiently long for a reliable cycle length estimate. Furthermore, there exist usually only a couple of Doppler maps of the surface features (see above), with no systematic study of the starspot evolution over a cycle.

V889 Her is a young, rapidly rotating solar-type dwarf star. Photometry of the star covers 12 years and shows variability on an 11-year time scale, but more data are clearly needed to confirm whether the brightness variation of the star is really periodic. In order to study the activity in more detail, we have obtained surface maps of V889 Her with the SOFIN spectrograph during six observing runs spanning six years (Fig. 27).

All the maps are dominated by high-latitude spots, 1400-1600 K cooler than the unspotted surroundings. The first two maps clearly show two active regions located 180° apart. The two following maps show a clear spot concentration on one side of the star, centred near latitude +60°. In the last map, the spots are concentrated in a compact group forming an asymmetric polar spot. The centres of active longitudes are found to drift relative to a fixed reference frame, as seen in the Sun and other solar analogues.

The spots are always located at high latitudes, covering the polar region up to 85°, and never go below +35°. The mean spot latitude changes about 5° between the first and the last map. The largest mean latitude difference (almost 10°) is found between the last two maps; the spots move towards higher latitudes, both then and between the first two maps. Overall, the mean spot latitude was lowest (~60°) at the time of global light minimum (maximum spot activity, in 2002), and increased at times of lower activity. A “flip-flop event”, i.e., a switch of the dominant spot concentration to another active longitude, was also detected at the time of global activity maximum.

**S.P. Järvinen, Potsdam, Turku and Oulu;
H. Korhonen, ESO; S.V. Berdyugina, Zürich and Turku;
I. Ilyin, K.G. Strassmeier, Potsdam; I. Tuominen, Helsinki**

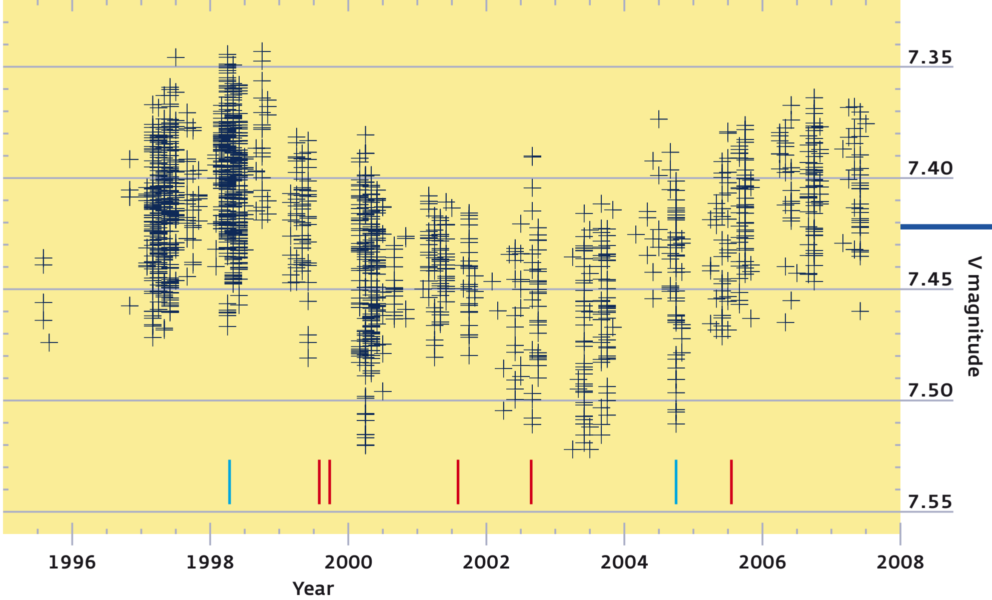


Fig.26. Long-term light variation of V889 Her. Vertical ticks show when Doppler maps were obtained (blue ticks: earlier maps; red ticks: maps from NOT-SOFIN).

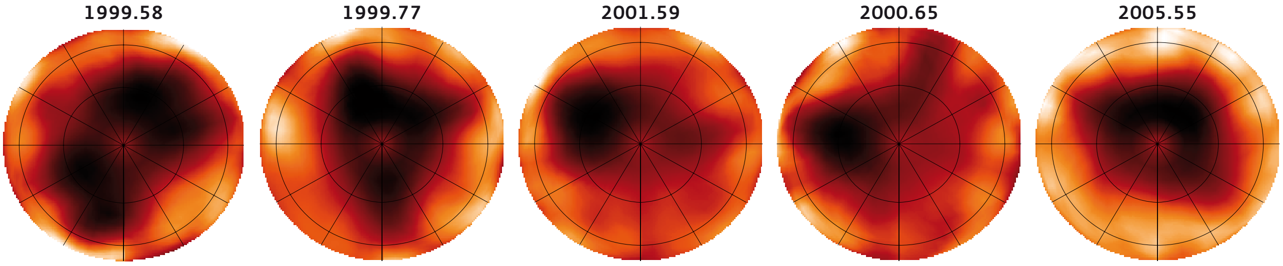


Fig. 27. Surface temperature maps of V889 Her for five epochs, seen from the north pole. The unspotted photospheric temperature is 5900 K; the high-latitude spots are 1400-1600 K cooler.

Probing convection in a pulsating white dwarf star

Convection is an important energy transfer process in most stars. For example, all main-sequence stars more massive than the Sun have convective cores. The amount by which the convective cells penetrate into the stable surroundings determines how much additional fuel is available for nuclear burning; this, in turn, decides the main sequence lifetime of the star. The details of convection also affect the cooling ages of white dwarf stars, an important age-dating method. However, despite its importance, convection physics is still one of the most uncertain factors in stellar models, and various parameterised approximations are used.

Many white dwarf stars show multi-periodic pulsations, and the spectrum of pulsation frequencies and associated (radial or non-radial) pulsation modes can be used to study the speed and extent of their convection zones. For this, one needs a long, continuous series of photometric data to resolve the many closely spaced frequencies, and a long, high-quality light curve with which to test the resulting model. We achieved both by observing the pulsating He white dwarf GD 358 with the NOT in June 2006 as part of a coordinated synoptic observing campaign by the Whole Earth Telescope (WET) network.

The data from the entire WET run allowed us to determine frequencies and mode parameters for a total of 13 pulsation modes. These parameters were used as input to a nonlinear fit of the individual observed light curves. The free parameters were the amplitude and phase of each mode, plus three global parameters characterising the convection zone – a total of 29 parameters.

Fig. 28 shows the fit to a full night of data from the NOT. The fit is quite good, but more than the 13 pulsation modes might be present in the star. For the convection zone itself we find an inclination angle is 62°, an average convective response time τ_0 of 450 sec (which measures the depth of

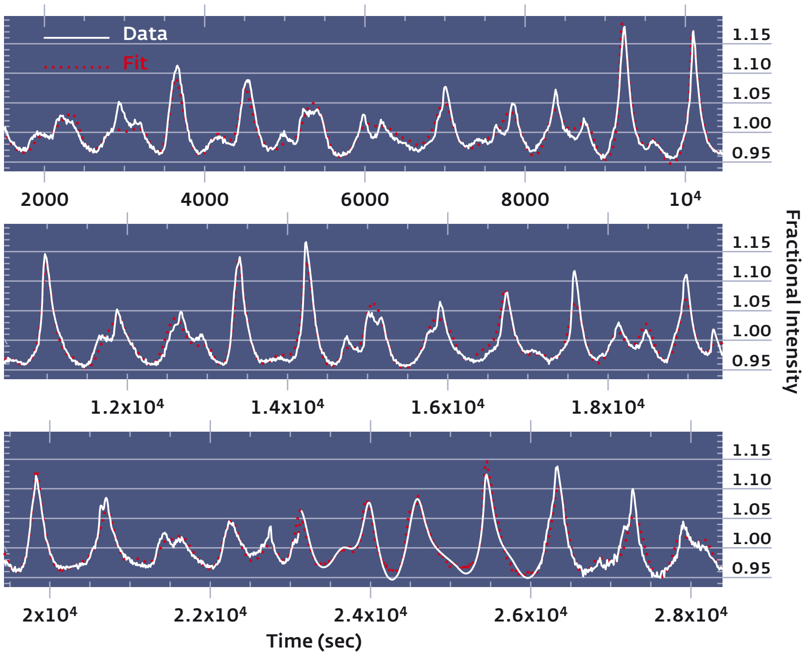


Fig. 28. Observed and fitted light curves of GD 358.

the convection zone), and a temperature sensitivity exponent of 25. These values indicate that convection is quite efficient in these stars (Fig. 29).

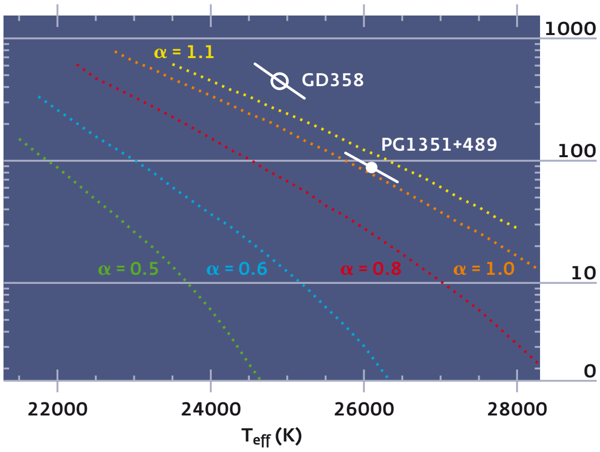


Fig. 29. White dwarf models for a range of the convection efficiency parameter α*, shown in a diagram of* τ_0 *(see text) vs. surface temperature. GD 358 and the single-period star PG 1352+489 are shown.*

E. Pakstiene, Vilnius; M. Montgomery, Austin;
J.-E. Solheim, Oslo; J. Provençal, Delaware

Pulsation analysis of a bright subdwarf B star

The hot subdwarf B (sdB) stars are evolved stars with typical masses and radii of 0.5 and 0.15 of those of the Sun, and surface temperatures of 20-50,000 K. They are core helium-burning stars with a thin hydrogen-rich envelope and will eventually become white dwarfs without any cataclysmic events. The reason why these stars have lost most of their original hydrogen envelope is not understood, but disruption of the outer layers of the progenitor by a close binary companion is a good candidate.

Some sdB stars exhibit the two main types of stellar pulsation: *p*-modes (with pressure as the restoring force) with typical periods of 2–5 minutes, and *g*-modes (gravity driven) with periods of order an hour. If the frequencies and shapes of these pulsations (expressed by spherical harmonics) can be derived from observations, detailed information about the internal structure of the stars can be derived. Such seismological information is essential to understand the evolutionary history of the sdB stars.

The star Balloon 090100001 has the highest pulsation amplitude of all known sdB stars. In order to identify the main pulsation modes by studying its line-profile variations, we obtained a total of about 1600 time-resolved high-resolution FIES spectra in the autumn of 2006. Here we present some first results.

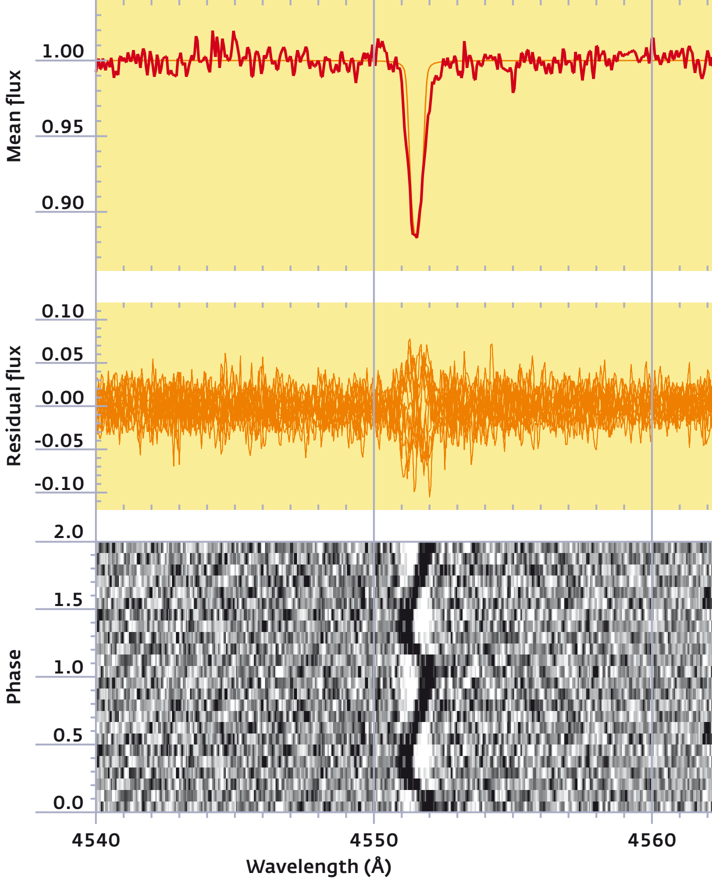
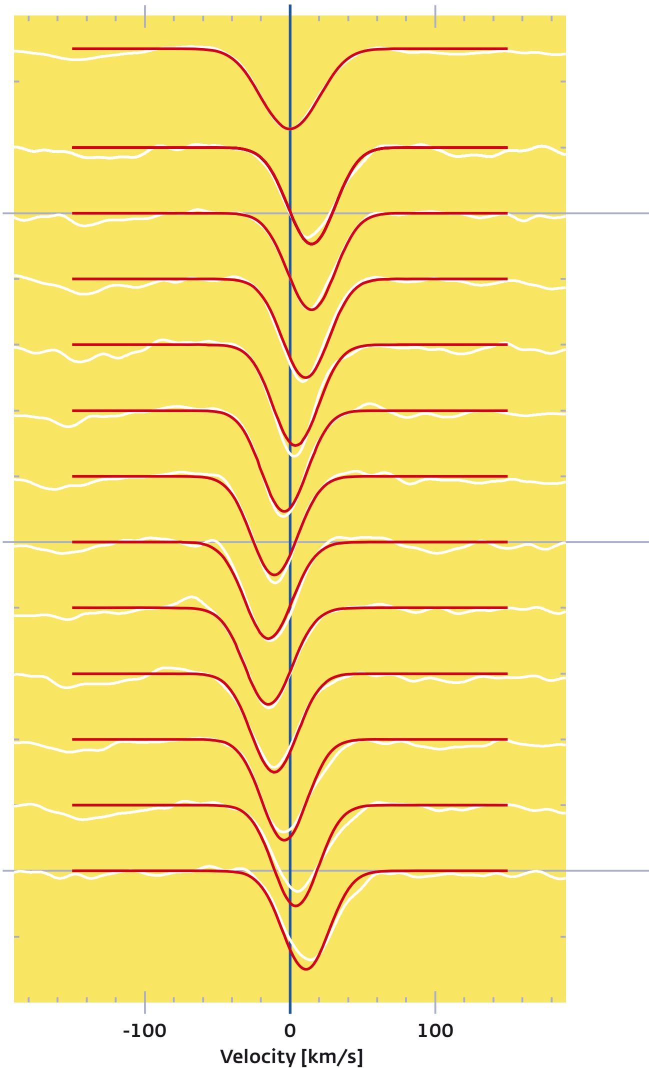


Fig. 30. The region of the Si III triplet lines in Balloon 090100001 after phase binning 842 spectra.
Top to bottom: mean spectrum; differences from the mean; and time evolution of the differences over two cycles.



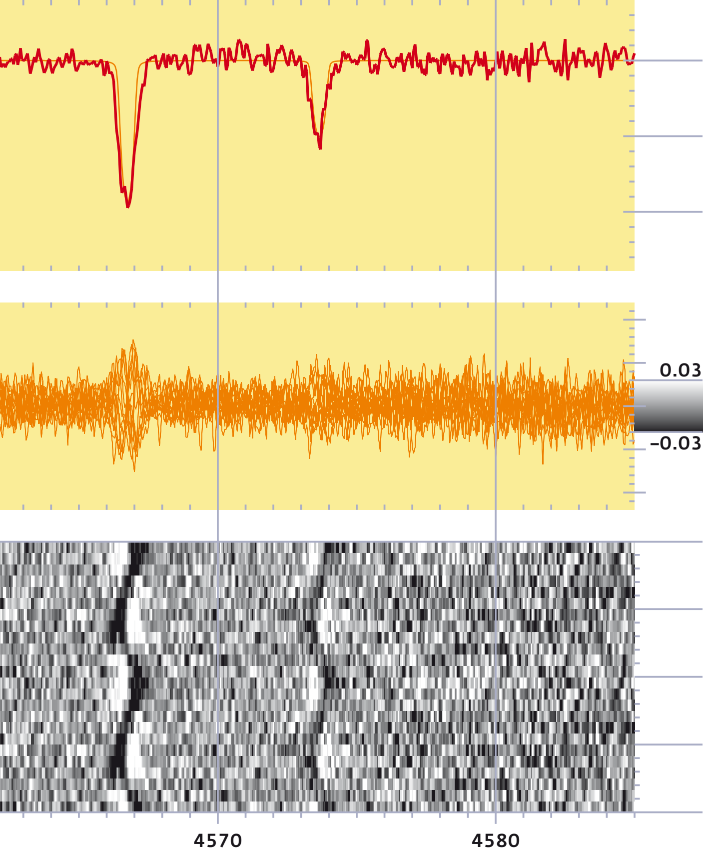
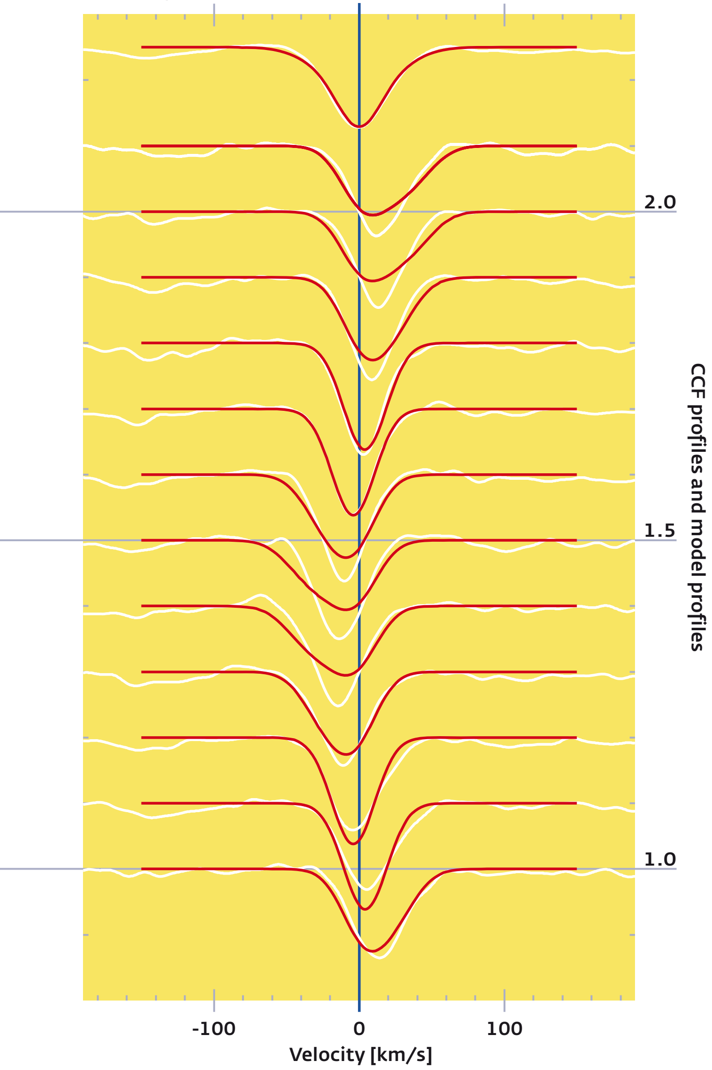


Fig. 31. Cross-correlation profiles as functions of pulsation phase (white: observed; red: models). The mean of all CCFs (line profiles) is shown at the top; the phase dependence below (bottom to top). Left panel: Best radial pulsation model; right panel: Best non-radial model.



We first co-added the spectra in phase with the known main *p*-mode period of 356.2 sec (Fig. 30), to study the chemical abundance of the star and the line-broadening as a function of pulsation phase. We find that abundance anomalies cannot explain the richness of the frequency spectrum or the high pulsation amplitudes, but the metal lines in Balloon 090100001 are much broader than in non-pulsating subdwarfs.

We then compute cross-correlation functions (CCF) that combine 56 narrow absorption lines into an average line profile with sufficient signal-to-noise at each pulsation phase for a 3D pulsation-mode analysis. The best fit is obtained with a radial pulsation model (Fig. 31).

J.H. Telting, L. Glowienka, T.B. Nielsen, NOT;
R.H. Østensen, Leuven; S. Geier, U. Heber, Bamberg;
S. Frandsen, Aarhus

The environment of the Crab pulsar

Massive stars end their lives in violent supernova explosions, which eject energy and newly synthesised elements into their environment. The ejecta form a short-lived nebula or supernova remnant, while the core collapses into a neutron star or black hole. The neutron star may be observable as a pulsar at the centre of the nebula, but pulsars are very faint at optical wavelengths, and only four are known so far.

As the remnant of a supernova that exploded in 1054 and containing the brightest pulsar known, the Crab Nebula is one of the most-studied targets in the sky (Fig. 32). Yet, many unanswered questions remain regarding the explosion mechanism and how the pulsar emission mechanism operates, evolves, and powers the nebula.

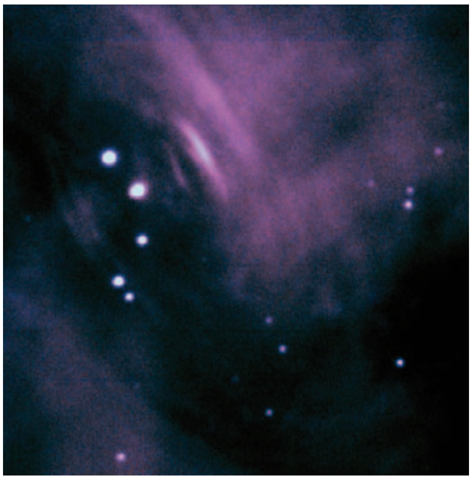
The immediate environment of the pulsar holds the key to the answers. It has been studied for several decades, and variations in the wisps of material in the centre of the nebula have been found, clearly related to the pulsar itself. However, the most outstanding discovery, made with the HST, is the presence of two knots located 0.65" and 3.8" southeast of the pulsar. In order to pursue this lead further, we observed the inner part of the Crab in the infrared *H* and K_s bands over two and half months, using the high-resolution camera of NOTCam.

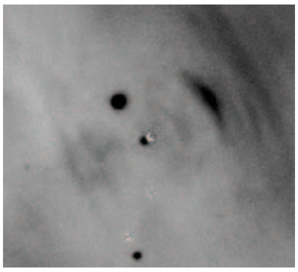
In all our frames, the pulsar image is elongated due to blending with the closest of the two knots. This can be missed in poor seeing, but is clearly revealed in our images when we remove a point source model of the pulsar itself (Fig. 32; see also Figs. 33 and 34). We then find that the knot contributes 5% of the pulsar flux in the *H* band and 8% in K_s. Moreover, the knot is arc-shaped, not circular, which shows that it is associated with the pulsar rather than being a background or foreground star. The knot is also aligned with an optical jet from the pulsar, which indicates that it is a sort of shock wave or instability in the jet. However, none of the proposed models for such features predicts a very red knot.

The most pronounced changes in the nebula take place in the wisps surrounding the pulsar. We see these wisps in great detail in all our frames and detect prominent differences during the short two and a half months spanned by our NOTCam observations.

Fig. 32 (Below left). False-colour image of the central part of the Crab Nebula in the H and K_s bands, taken with the NOTCam HR camera and the new science grade array (field: 1'; N is up, E left). The elongated image of the pulsar and the circular wisps of gas associated with it are clearly seen.

Fig. 33. Close-up of the pulsar in the K_s band, obtained in superb seeing on 2007 Sep 30. The image of the pulsar itself has been removed, using the two stars to the S as models (cf. Fig. 32). Note the non-circular shape of the knot.

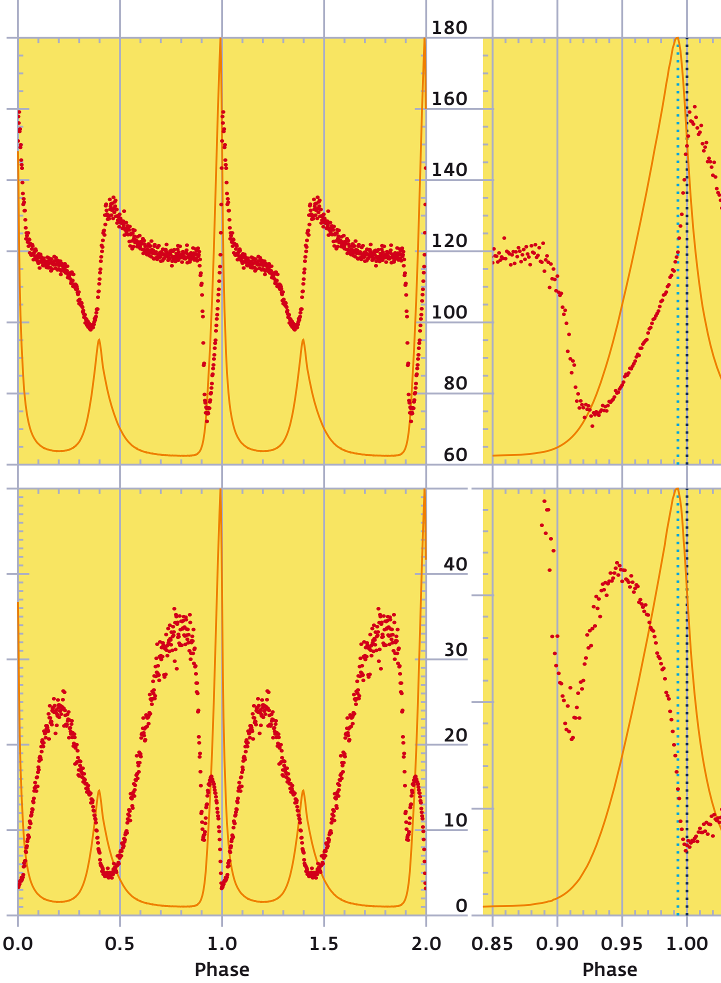




A. Tziamtzis, NOT
and Stockholm;
P. Lundqvist, Stockholm;
A.A. Djupvik, NOT

The magnetosphere of the Crab pulsar

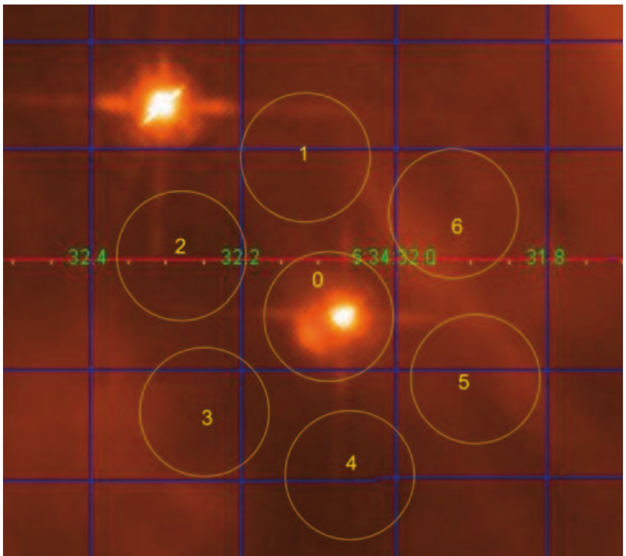
The emission from pulsars is observed at all wavelengths, from γ-rays to radio waves. It peaks when the narrow beam sweeps past the observer. It is thought to be due mainly to synchrotron radiation arising in the intense magnetic field of the pulsar and should be highly polarised, which offers a valuable probe into the unknown magnetospheric properties of pulsars. However, because pulsars are very faint in optical light and have very short periods, detailed polarization measurements have so far been made only for the brightest and youngest pulsar, the Crab pulsar (period 33 ms), and only near the bright pulse peaks.



We observed the Crab pulsar at NOT in 2003 with the high-speed photo-polarimeter OPTIMA (see Annual Report 2003, p. 8) in the wavelength range 450-750 nm. Fig. 34 shows how the hexagonal fibre feed allows us to monitor the polarization of the surrounding nebula while the central aperture measures the pulsar. Our data have a time resolution of ~10 µs with good counting statistics and can be analyzed in unprecedented detail.

The optical emission from the Crab pulsar is highly polarized, especially in the 'off-pulse' phases (Fig. 35). At first sight, the polarization characteristics of both emission pulses appear quite similar: Both show a minimum in degree of linear polarization and a large swing in polarization angle around the peaks. Between pulses, the degree of polarization increases, but the polarization angle remains fairly constant.

Fig. 34. HST image of the Crab pulsar, showing the apertures of the OPTIMA fibre bundle.



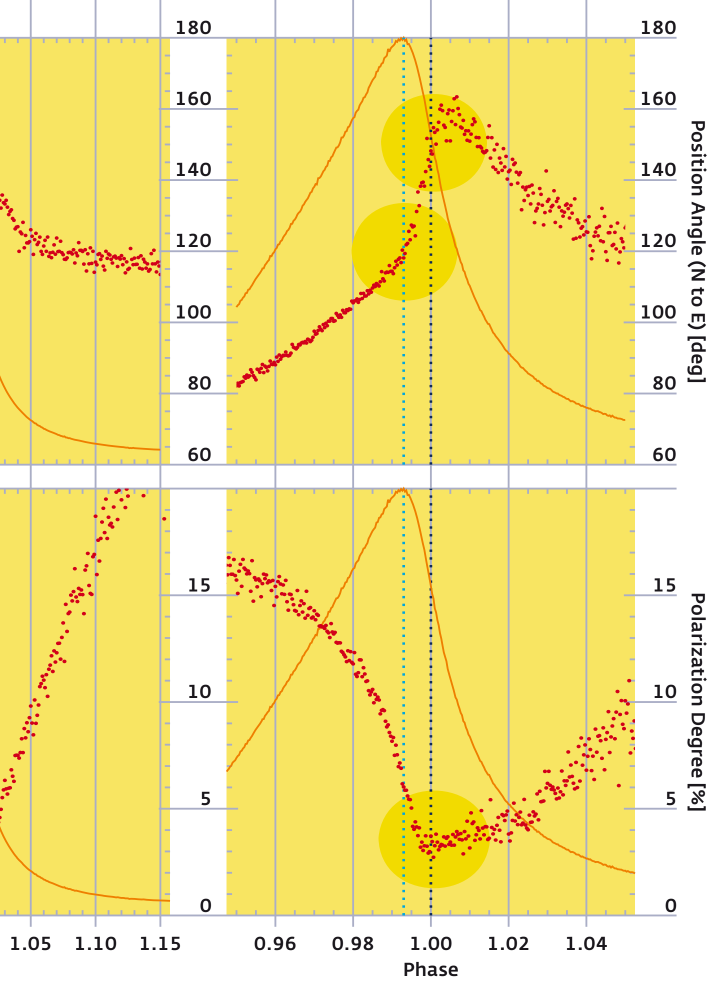


Fig. 35. Polarization angle (top) and degree (bottom) of the Crab pulsar over the 33-ms rotational cycle (red dots); the optical light curve is shown in black. The dashed and dash-dotted vertical lines indicate the peaks of the main optical and radio pulses, and panels zoom in on the peak from left to right.

However, closer inspection and comparison with the radio data (Fig. 35) shows that the main and secondary pulses are fundamentally different: The main pulse reaches minimum optical polarization at the phase of the *radio* peak, *not* at the *optical* peak. Also, the polarization angle changes behaviour dramatically at both the optical and radio peaks. The secondary (inter-) pulse shows none of these pronounced characteristics.

The magnetosphere of the Crab pulsar presumably hosts a subtle combination of coherent (radio) and non-coherent (optical) emission processes. So far, none of the available theoretical models has been able to meet the challenge of our high-resolution measurements from NOT.

A. Słowikowska, Heraklion; G. Kanbach, Garching; A. Stefanescu, Torún

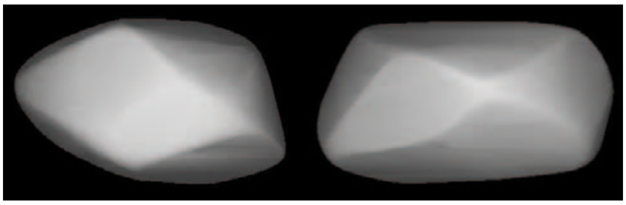


Fig. 36. Shape of the asteroid (1862) Apollo, reconstructed from the NOT data.

SOLAR SYSTEM OBJECTS

Ground-based observations of objects in the Solar System remain an important complement to studies performed by space missions. Here, we report on a recent result by the Nordic Near-Earth Object Network (NEON).

Physical and orbital characterization of Potentially Hazardous Asteroids

Near-Earth Objects (NEOs) are a subgroup of asteroids and comets in the Solar System whose orbits approach that of the Earth very closely. Among them, the potentially hazardous objects (PHOs) have orbits that might, in a few tens of years, be perturbed sufficiently to make an impact on Earth possible. With adequate observational, computational, and engineering efforts, asteroid impacts are in principle both predictable and avoidable, unlike virtually all other natural disasters. However, if an impact is predicted, proper knowledge of both the orbit and the physical properties of the object is needed for mitigation measures to be possible.

Therefore, since 2004 the Nordic NEON has conducted a programme of photometric and astrometric observations at NOT to characterize the physical and orbital properties of a sample of NEOs. We have used state-of-the-art inversion methods to determine the spin and shape of the asteroids from these data. From the 2004-2006 observations, we have obtained an unambiguous spin and shape solution for asteroid (1862) Apollo (Fig. 36), a constrained region of possible solutions for (1685) Toro and (1981) Midas, and sets of possible solutions for another four NEOs.

Our precise position measurements have been used for improved orbit calculations and impact risk assessments, both for newly discovered NEOs and for objects which have not been observed lately; in both cases the orbit is uncertain and the object may be lost again. Through December 2007, we have recovered four lost NEOs and determined improved orbits for 76 objects. One of the targets was the PHO 2004 AS1; the dramatic discovery-night prediction implied a possible impact on Earth within 48 hours(!), but this was quickly ruled out by the new observations. During the program, one new main-belt asteroid was also discovered.

K. Muinonen, J. Torppa, J. Virtanen, J. Näränen, T. Laakso, M. Granvik, Helsinki; K. Aksnes, T. Grav, Z.J. Dai, Oslo; G. Hahn, Berlin; C.-I. Lagerkvist, H. Rickman, Uppsala; R. Michelsen, Copenhagen

No new instruments were commissioned in 2007, but several upgrades and tests were performed, with promising results for the future. We briefly summarise them here; for more detail, see our web pages.

FIES

The high-resolution échelle spectrograph FIES, housed for stability in a separate building, is described in earlier reports. In 2007 it was used for several user programmes, and the demand for it is rising to the point where bright time is in as strong demand as dark time. Several improvements were also made during the year.

Technical. The most important improvement was the installation of a new fibre bundle with high efficiency at all resolutions (R = 25,000, 45,000 and 65,000). Unfortunately, the sky background fibre is broken, but this has so far been of little practical impact. Additional upgrades include an optional atmospheric dispersion corrector and an exposure meter, which will be placed inside the spectrograph and allow better control of the signal level in variable sky conditions.

Data reduction. The reduction package FIEStool is now working smoothly at NOT, providing quick-look spectra immediately following the readout of the CCD. The programme checks the header for the fibre selection and applies the relevant calibration files for the chosen resolution. The package is also available to users for final reduction of their spectra.

Results. A key goal of FIES is to perform high-precision radial velocity observations. Tests have been made with series of daytime blue-sky spectra, both with the simultaneous Th-Ar spectrum technique and with an iodine absorption cell placed in a "Solar box" outside the building and providing a very stable wavelength reference. The results are very promising (Fig. 37), but indicate that further improvement of the thermal control of the FIES lab is desirable; this is in progress.

S. Frandsen, Aarhus; J. Telting, NOT;
L. Buchhave, Copenhagen

NOTCam

Our workhorse near-infrared instrument NOTCam continues to perform well; a number of upgrades took place in 2007.

New Science Grade Array. The long-awaited new science grade array (Rockwell Hawaii I, HgCdTe 1024 x 1024 x 18.5 micron pixels) was commissioned in December 2007. Both with respect to flatness and sensitivity, this is by far the best array we have had – 10% more sensitive than the first science array (Oct 2005 – Apr 2006) and 60% more sensitive than the engineering array. It is also cosmetically very good, with less than 1% bad pixels, most of which are constrained to one corner and a smaller feature. The readout noise is 10 electrons; with a gain of 2.5 e-/adu, the detector is linear within 1% up to about 20,000 adu, and saturation starts at 56,000 adu. Fig. 32 shows a recent image obtained with the new array.

The High-Resolution camera. The NOTCam High-Resolution (HR) camera has scale of 0.078"/pix, a FOV of about 80", and very high optical quality. The new TCS has allowed us to detect and correct a tracking error which earlier led to slight image elongations, too small to be seen with other imagers. Fig. 38 compares an H-band image of the globular cluster NGC 4147 in 0.4" seeing with the same field from 2MASS; the ellipticity of the images is below 2-5% all over the FOV.

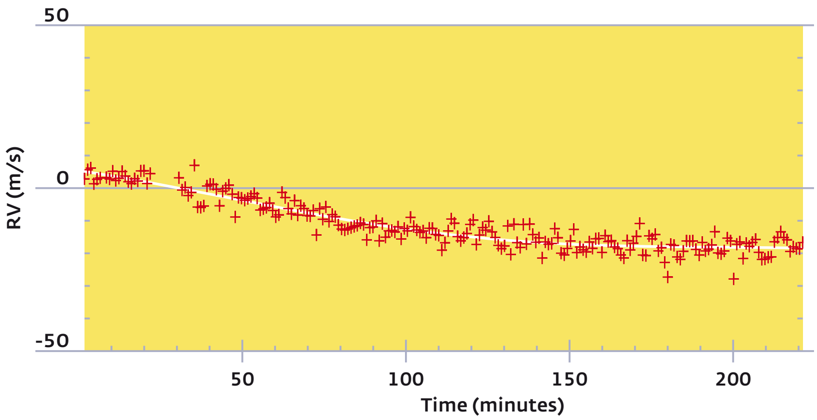


Fig. 37. The radial velocity of sunlight reflected from the blue sky over several hours. The mean trend is due to variations in projected wind speed in the upper atmosphere; the rms dispersion around the curve is below 3 m/s.

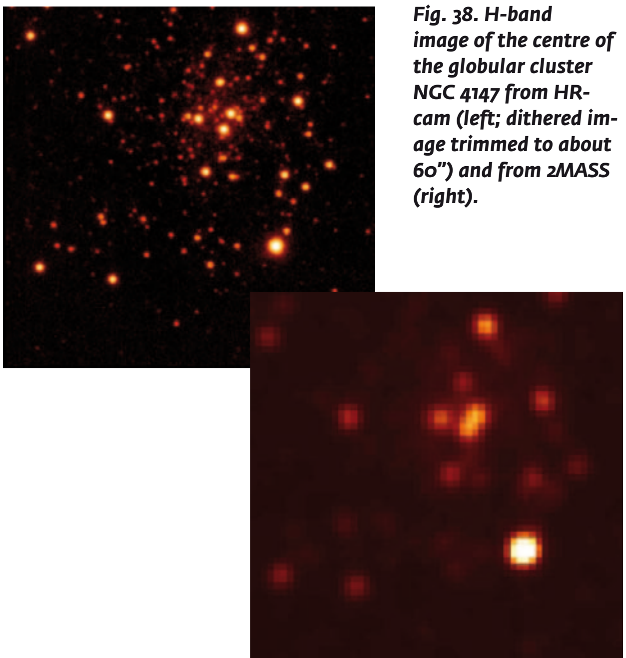


Fig. 38. H-band image of the centre of the globular cluster NGC 4147 from HR-cam (left; dithered image trimmed to about 60") and from 2MASS (right).

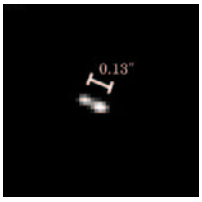


Fig. 39. R-band image of the visual binary system COU 79 (separation 0.13").

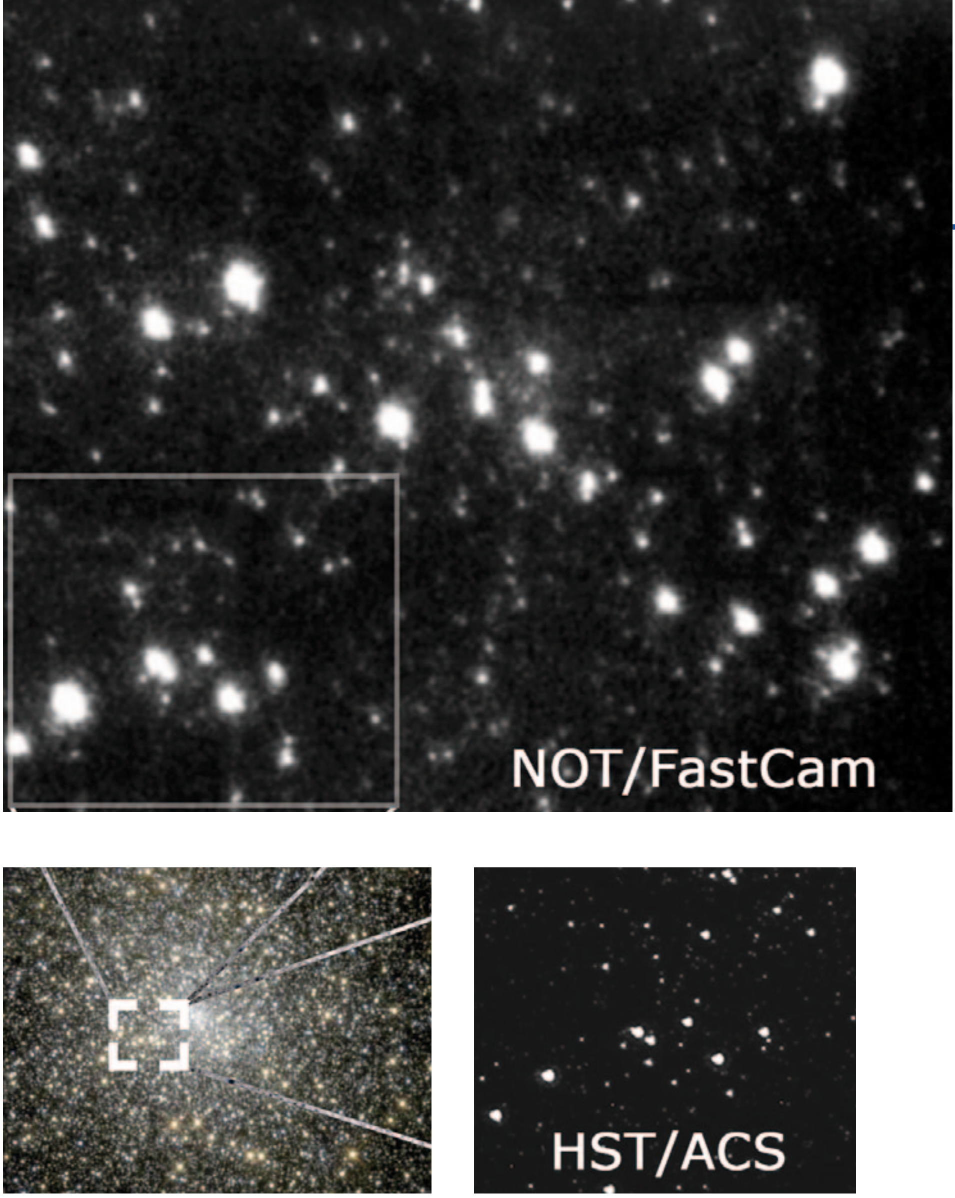


Fig. 40. The centre of the globular cluster M15. Top: Diffraction limited image with FastCam in the I-band (850 nm; resolution 0.10"); this is a combination of the best 1% of 15,000 images of 30 ms exposure each. Bottom: HST image with the ACS camera with a similar integration time, but at a shorter wavelength (435 nm), which gives a resolution of 0.05".

Data acquisition and reduction. New data acquisition software for NOTCam has been commissioned which allows more extensive scripting, including for instance filter and focus changes. Some fine-tuning of the dithering technique is being made to guarantee optimal image quality for 0.3" seeing conditions and large telescope offsets. A quick-look reduction package in IRAF was provided to observers in April. Bad-pixel masks and master flats for the most common setups are available from our web page.

A.A. Djupvik, NOT

FastCam: Diffraction-limited optical imaging

FastCam is an instrument developed by Instituto de Astrofísica de Canarias (IAC) and Universidad Politécnica de Cartagena, Spain, to obtain extremely high resolution images in the optical wavelength range from ground-based telescopes. The core of the instrument is a very low noise and very fast readout L3CCD camera that allows to reach the diffraction limit of medium-sized telescopes in the I band by “freezing” the atmospheric turbulence in short exposures (see earlier Annual Reports).

A typical FastCam run generates tens of thousands of images with very short exposure times (10-50 ms). Depending on conditions, 1-5% of these images are not significantly affected by atmospheric turbulence and yield diffraction limited resolution. We have developed a state-of-the-art software package which analyses the images “on the fly” at the telescope, selects the diffraction-limited frames, and combines them into one final image for each astronomical object. The processed image is displayed in real time, which is extremely useful in allowing us to immediately identify interesting features (e.g. multiple objects) hidden in seeing-limited images.

FastCam was successfully tested at NOT in October 2007. We obtained diffraction-limited I-band images with a full-width at half-maximum of 0.10", similar to the Hubble Space Telescope (HST) at the same wavelength. These are some of the sharpest images ever obtained at ORM – ten times better than the standard resolution of telescopes at a good observatory. FastCam is therefore opening a new field of ground-based astronomy research, which will soon yield impressive results.

A. Oscoz, R. Rebolo and the FastCam Team, IAC, La Laguna

Photo: Auni Somero, NOT

Since 1994, the NOT research student programme has enabled more than 30 Nordic PhD and MSc students to spend a year or so with us on La Palma, gaining experience with all aspects of observational astronomy. The great majority of them continue in successful careers in astronomy or related sciences. In the following text and pictures, Helena Uthas gives us her own view of the experience.

Being part of the NOT team

Astronomers are generally motivated by a strong interest in science, and some are willing to sacrifice their normal lives and move to the faraway places where telescopes are installed. Working in a telescope group means working nights, weekends and holidays, but sharing the lack of normal everyday life also means that people relate more easily to each other. However, the working environment at the NOT is unique for many reasons, even when compared to other telescopes.

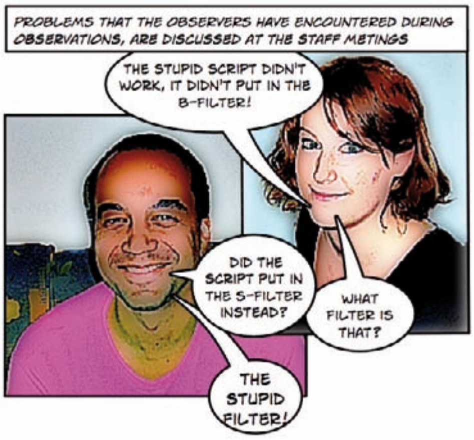
What's so special about NOT? First, the team is small, only about twenty staff and students in all. This gives everyone insight into all aspects of the work, and it is easy to maintain good communication. This is especially good for the students, but creates a better working environment for everybody. Coffee breaks, hallway chats or formal staff meetings; discussions and exchange of ideas are always present. This is essential to make NOT a more flexible tool for the observers, respond to their personal wishes, and develop new ideas and improve our performance.

The backbone of the smooth teamwork at NOT is the monthly staff meetings, where everyone participates and can bring up topics for discussion. These meetings are important not only for bringing everyone up to date on current status, but also to exchange ideas for improvements of the telescope, instruments, systems, and services (1). Problems reported by observers are discussed and immediately assigned to the person best suited to solve them; action taken is reported back at the next meeting. This is an efficient way to keep track of both problems and solutions. After the meetings there is an informal get-together where discussions continue, sometimes for hours.

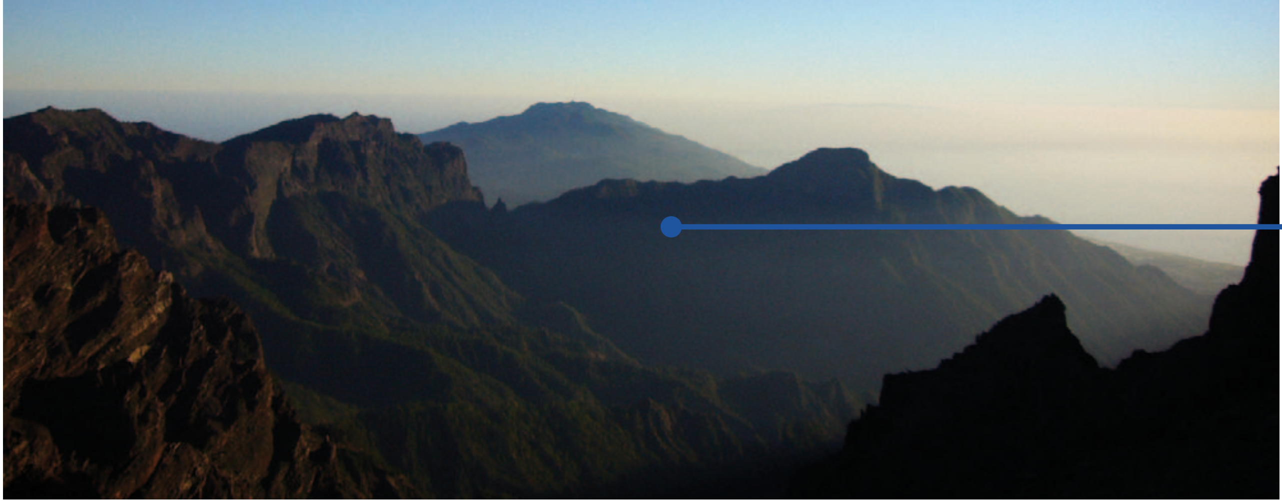
What makes the discussions at NOT so lively? The team shares not only their interest in science, but also the experience of spending long nights together, sometimes in tough weather with snow, high winds, and icy roads. This develops a better understanding of each others' fields and a personal concern for each other. You know that, even if you run into trouble in the middle of the night while observing alone at the telescope, you can always call a friend for advice and assistance (2) – especially comforting for a student!

As a NOT student you spend three quarters of your time on your thesis project, and one quarter of the time working on such tasks as support duty at the telescope, analysis of data, e.g. from the weather station, software development, or preparing service observations. NOT has a diverse set of instruments; the observers work on many different topics; and the staff has wide astronomical and technical experience, so you can become familiar with

1. John 'clarifies' a point for Carolin



2. Auni gets on-line night support from Jacob.



many different observing techniques. But as a NOT student, you learn a lot not only about telescopes, operations, and science, but also about sharing and balancing freedom and responsibility with colleagues and friends while managing life in a foreign country.

Occasionally, students can also obtain their own data at the NOT. This is not only exciting in itself, but with proper preparation may contribute significantly to your MSc/PhD thesis. Even students in theoretical astrophysics can find observing projects that can be related to their theoretical work and broaden their experience. The great advantage of being present at the NOT is that you can influence your work and focus on the areas of your greatest interest.

In my own experience, the students are treated as any other member of the NOT team, are trusted as such, and are given as much responsibility. New thoughts and ideas from the students are received with great attention and appreciation, and you are encouraged to go ahead and implement the solution or idea, whether it is making a new script generator or replacing the crumbling couch in the control room. During the initial training period, students are assumed to master their working assignments, following which they are trusted to perform essentially the same tasks as the permanent staff, such as mounting instruments and installing optical components. This is a great way to bolster your self-esteem and make you realize that you can do much more than you thought (3).

So the students feel appreciated and treated like full members of the NOT team, but what do the staff think of the students? Asking them, the clear answer is that the students cover many essential duties; without them it would not be possible to operate the telescope the way we do now. Also, the fresh eyes of new students allow them to spot and correct problems such as lack of documentation or inconsistent observing routines that had been overlooked before (4). This is essential in maintaining the best possible services for visiting astronomers.

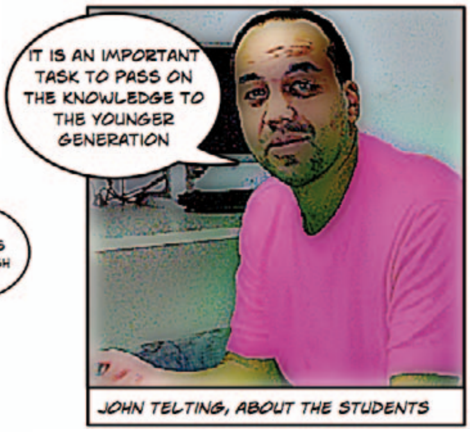
In summary, I can confidently claim that NOT operates as a team where everybody's opinion, big and small, is heard, and everyone is an important member. You really learn to both think for yourself and solve problems together, whether it is a breakdown at the telescope or connecting the coffee machine to the emergency power during a power cut, securing the coffee supply that will enable you to solve the other problems (5)...

Helena Uthas

3. Helena is already an expert in instrument changes.

4. Amanda welcomes new ideas.

5. NOT's mission is also educational.



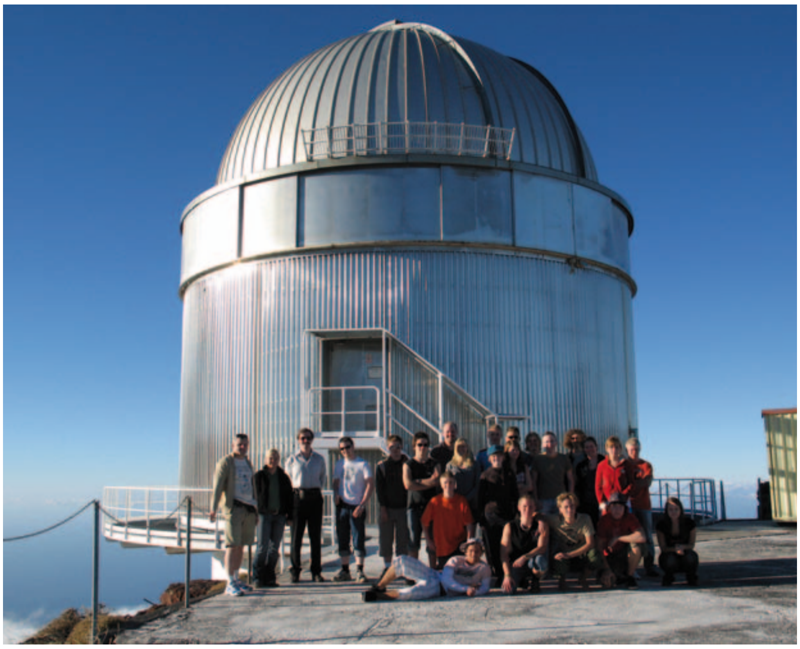
EDUCATION

As described in the 2006 Annual Report (p. 22-23) and earlier, education at various levels is an increasingly important and systematic activity at NOT, including a few high school visits on a case-by-case basis. To allow students to participate also when they cannot fit into the control room, we have equipped the service building to serve as a classroom during courses and visits, with a projection screen, furniture, and network connections. Similar options for remote observing could be offered also off-site, e.g. at Nordic universities.

Professor Augusteijn lecturing at the DARS course in August.

Finnish Science School visit

Finnish senior secondary school students have made regular visits to CERN for a number of years. Last year, the two schools of Mikkeli (some 100 km from Helsinki) decided to try astronomy instead. Their teachers contacted NOT through Tuorla Observatory and were granted half a night of observing time. Careful plans were made both for the observations and for the logistics of the trip, which was funded by the students through odd jobs, sponsors, and grants. Finally, at the end of October, teachers Mikko Korhonen and Kari Kääriäinen, 20 students, and Dr. Rami Rekola from Tuorla travelled to La Palma.



The Horsehead nebula, by the Mikkeli students.

Students were given a detailed introduction to NOT by Auni Somero, who was our main support astronomer for the visit, assisted by another NOT student, Helena Uthas. The students were divided into four groups and given similar tasks at the telescope. Each group had about 90 minutes of observing time, spent on photometry of a selection of quasars or spectroscopy of another quasar to determine its distance and the mass of its central black hole. Each group also contributed data to joint colour images of Stephan’s Quintet and the Horsehead Nebula (shown here). Once the observations were over, students continued with image reduction and viewing the night sky outside the service building.

Besides observations, the students had lessons in mathematics and physics and three lectures on astronomical topics. Careful preparations were made before the visit to NOT, and image reduction and analysis continued afterwards in Finland; the results were submitted to a competition for senior secondary schools, organised by the Academy of Finland. From early start to final end, the students showed enthusiasm and diligence well beyond the call of duty. They worked hard and experienced the joy of discovery, and if not all will become astronomers, these young people will harbour a lifelong understanding and sympathy for scientific research. We thank especially Auni and Helena for their kind and expert help.

M. Korhonen, K. Kääriäinen, Mikkeli

The Mikkeli students at NOT.

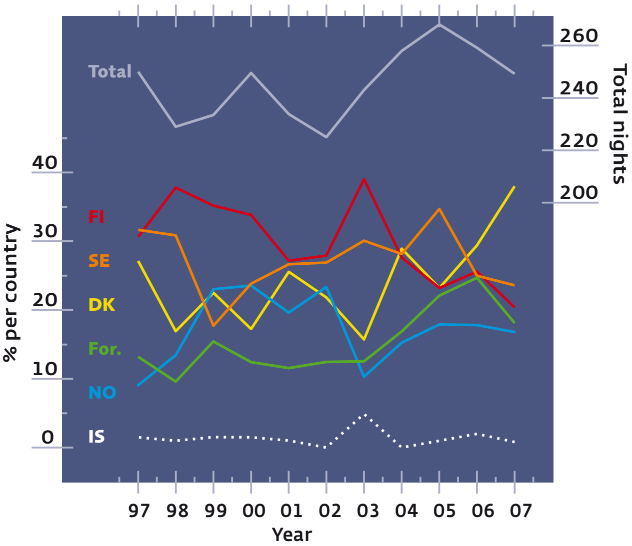
NOT's key scientific capital is observing time. Competition is fierce, so the time allocation procedure must be seen as competent, transparent, and impartial.

Time allocation procedure

The *Call for Proposals* for observing time at NOT is announced widely, with proposal deadlines of May 2 and November 2 for the semesters beginning October 1 and April 1, respectively. 'Fast-track' proposals for up to 4h of observing time are, however, accepted at any time by a simplified procedure; OPC review is completed rapidly, and if approved, the project is executed in service mode on the next suitable night. All relevant information is found at *http://www.not.iac.es/observing/proposals/*.

An independent *Observing Programmes Committee* (OPC; inside back cover) of five respected Nordic scientists is appointed by the Council to peer review all observing proposals. The OPC ranks the proposals on a numerical scale and gives feedback to applicants on any specific weakness. Each member has a substitute to broaden scientific coverage and avoid conflicts of interest. Based on the ranking and various practical constraints (object visibility, Moon phase, etc.) the Director drafts a schedule, which is checked by the OPC before it is finalised.

To encourage competition and raise scientific standards, all proposals are reviewed on an equal footing. European astronomers may receive travel support for approved projects via the OPTICON trans-national access programme (see *http://www.otri.iac.es/opticon/* for details). 25% of all time is reserved for Spanish and CCI international projects.



Total nights allocated annually by NOT in 1997-2007, and the Nordic and "foreign" shares.

The OPC braving Snæfellsjökull glacier in Iceland in June.

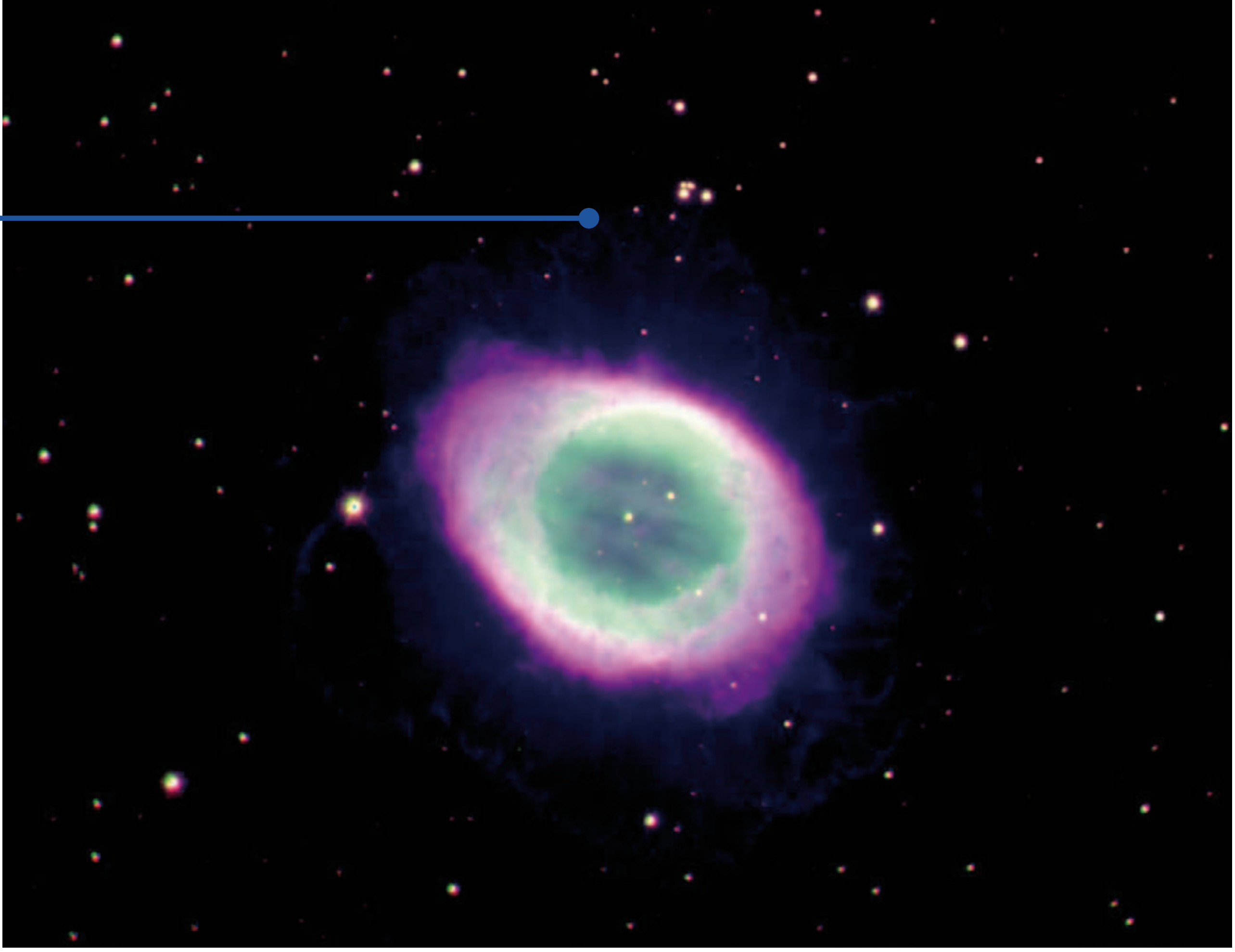
Observing time in 2007

Observing statistics are compiled by allocation period, so this report covers the year April 1, 2007, to April 1, 2008. The "*pressure factor*" (nights requested/nights available) increased from 1.9 to 2.3. In total, 317 nights were used for scientific observations, including Spanish and CCI time. 249 nights were available to the Nordic community, including training courses. Of these, 45 nights or 18% went to non-Nordic ("foreign") projects and 20 nights or 8% to projects by NOT staff. The remaining 184 nights were distributed as follows: Denmark 70 (38%), Finland 38 (21%), Iceland 1.5 (1%), Norway 31 (17%), and Sweden 43.5 (24%).

Instruments were used as follows: ALFOSC 180 nights (49%), FIES 68 (19%), MOSCA 48 (13%), NOTCam 25 (7%), SOFIN 19 (5%), TurPol 6 (2%), and visitor instruments 6 nights (5%). The increasing demand for FIES raised the pressure on bright time to the same level as dark time.

Service observing increased steeply: Service observing was made on a total of 107 (science, service, and technical) nights in 2007, roughly twice as many as previous years. The "fast-track" service proposal system received a total of 27 proposals; 16, 8, and 3 of which were rated as grade 1, 2, and 3, respectively (1 is highest). Of these, 10.5, 1, and 1.5 were completed, as were all earlier projects. 19 of these proposals were received in the second semester and remain active in 2008 if not already completed.

The national distribution of time fluctuates considerably relative to the national shares of the budget, because observing time is allocated by scientific merit, not as national quotas (see figure). Over the last five years, the Nordic time has been shared with 27% each to Danish and Finnish projects, 1.7% to Iceland, 16% to Norway, and 29% to Sweden. Staff and "foreign" (including OPTICON) time were 7% and 19% of the total.



The ring nebula in Lyra (M57). Photo: Sami Niemi, NOT

FINANCIAL MATTERS

NOTSA is a non-profit organisation funded by the Associates to operate NOT for the benefit of Nordic astronomy. The Council approves the annual budget, and the Director is responsible for operating NOT within budget and according to the *Financial Rules*. NOTSA's accounts for the years 2006-2009 are audited by the *National Auditing Office of Iceland*; an additional Swedish audit is now required to comply with the rules for Swedish foundations.

Accounts for 2007

NOTSA's accounts for 2007 are summarised in the table. The approved budget for 2007 and account figures for 2006 are listed for comparison. The budget headings cover the following items:

Directorate: Directorate staff and operations, committee travel, financial charges, stipends to Spanish Ph.D. students at Nordic universities, OPTICON and ASTRONET expenses, and Annual Report.

La Palma staff: All staff, students, and visitors on La Palma, training courses etc.

La Palma infrastructure: All NOT telescope and office facilities; electricity, water, and cleaning; computer networks; and cars and other transportation.

La Palma operations: Accommodation and meals at the observatory for staff and students; communications and shipping; telescope, laboratory, and office equipment and consumables, etc.

Telescope and instrument operation and maintenance: Operation, repair, and spares for the telescope and instruments, cryogenics, electronics, optics, and data acquisition and archiving equipment.

Development projects: Investment in major new facilities or instrumentation. No projects were approved in 2007.

Contributions: A *basic contribution* of 1 289 000 Euro is shared between Associates as specified in the Agreement (Denmark 19.8%, Finland 29.7%, Iceland 1%, Norway 19.8%, and Sweden 29.7%); *additional contributions* totalling 180 000 Euro were provided in 2007 by the first four Associates.

Other income: Mainly EU refunds from the OPTICON access programme and ASTRONET, and bank interest.

Financial result of 2007

As seen in the table, the costs of the directorate, staff, facilities, and operations were essentially on budget in 2007. The modest underspend on *Staff* was due to sick leave compensation, on *Telescope operation and maintenance* to a delay in delivery of new dome drive motors until 2008; combined with a number of smaller items, total expenditure in 2007 was 96 kEuro below budget. *Other income* was boosted by an increase in interest rates and a large advance payment from ASTRONET, so the net result of 2007 was 125 kEuro better than budgeted. Overall, our reserves are in substantially better health than forecast for the end of 2007.

BUDGET LINE	Expenses 2007 Euro	Budget 2007 kEuro	Expenses 2006 kEuro
Directorate	227 330	229	221
La Palma staff	1 066 405	1 109	1 052
La Palma infrastructure	143 901	155	142
La Palma operations	101 227	110	116
Telescope operation and maintenance	39 861	62	114
Instrument operation and maintenance	22 522	40	61
Telescope development projects	0	0	0
Special development projects	7 792	0	014
Total expenses	**1 609 038**	**1 705**	**1 720**
Contributions	1 469 800	1 473	1 436
Other income	128 262	96	96
Total income	**1 598 062**	**1 569**	**1 533**
Result of the year	**-10 976**	**-136**	**-187**
Reserves at beginning of the year	370 049	323	557
Reserves at end of the year	359 073	187	370

Photos: Mikkeli students.

Photo: Nicolaas Groeneboom, Oslo.

Publications are the standard indicator of scientific output, and our users are asked to report refereed papers based on NOT data (see lists at http://www.not.iac.es/news/publications). Papers published in 2007 are listed below; for papers with 12 or more authors, the first six names and the total number are given.

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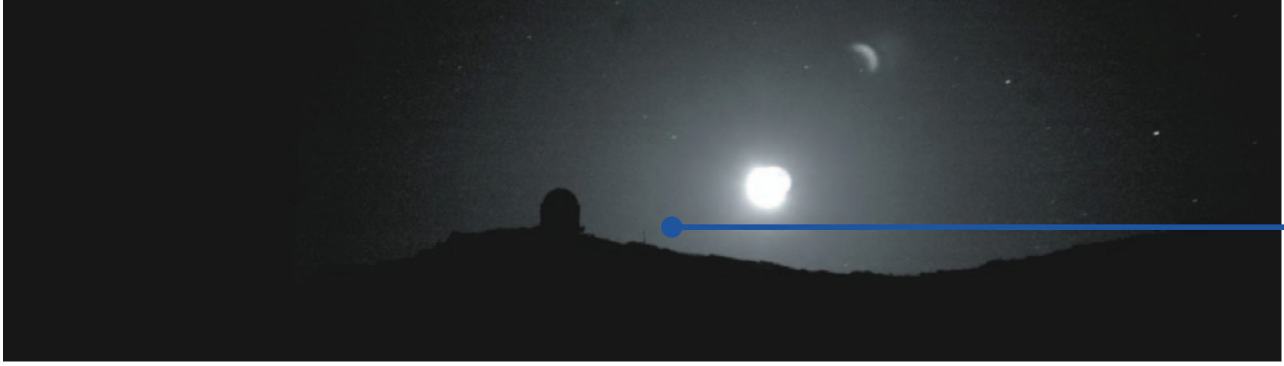

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In addition, NOT staff participated in 13 electronic reports on GRBs and minor planets.

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Back cover: The spiral galaxy NGC 1058 and the bright peculiar supernova SN 2007gr (see p. 6). Photo: Students at the DARS summer school.

2007

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The spiral galaxy NGC 1058 and the supernova SN 2007gr (the brightest of the three close stars near the centre).

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