2009

NORDIC OPTICAL TELESCOPE

ANNUAL REPORT

Globular cluster Messier 3

Front cover:
The globular cluster Messier 3, imaged with the NOT and ALFOSC in blue, red and near-infrared light by Paul A. Wilson and Anders Thygesen.

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 scientific and technical policy.

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 **Deputy Director**, who has authority to deal with all matters related to the daily operation of NOT.

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

The NOT Annual Reports for 2002-2009 are available at:
http://www.not.iac.es/news/reports/

CONTENTS

2 THE STAFF

3 PREFACE

4 EVENTS IN 2009

5 SCIENCE HIGHLIGHTS
- 5 Cosmology, Formation and Evolution of Galaxies
- 13 Formation, Structure, and Evolution of Stars
- 19 Planetary systems in the Universe

24 INSTRUMENTS

25 EDUCATION

26 OBSERVING TIME

27 FINANCIAL MATTERS

29 PUBLICATIONS

33 COMMITTEES & ADDRESSES
Inside back cover

Paul A. Wilson

NASA

Editor: Johannes Andersen
Layout: Anne Marie Brammer

2

THE NOT TEAM

Our staff remained at constant strength in 2009, but the student ranks swelled to six during the year. As seen below, the NOT office has never been a livelier place!

Johannes Andersen
Director

Francisco Armas
Administrator

Thomas Augusteijn
Deputy Director

Zita Banhidi
Student

Peter Brandt
Mechanic

Ricardo Cárdenes
System manager

Jacob W. Clasen
Software specialist

Graham Cox
Senior electronics engineer

Anlaug Amanda Djupvik
Senior staff astronomer

Juliet Datson
Student

Loida Fernández
Secretary

Eva Jurlander
Accountant

Erkki Kankare
Student

Raine Karjalainen
Postdoc

Tiina Liimets
Student

Johan Lindberg
Student

Sami-Matias Niemi
Student

Thomas A. Ottosen
Student

Carlos Pérez
Electronics technician

Tapio Pursimo
Staff astronomer

Peter M. Sørensen
Software specialist

Ingvar Svärdh
Senior software engineer

John H. Telting
Senior staff astronomer

Carolin Villforth
Student

Paul A. Wilson
Student

PREFACE

Photo: Paul A. Wilson

The preface to this Report must begin with my apologies for its late appearance. The early months of 2010 have been filled not only with financial and other routine start-of-year business, but also with intensive planning efforts for the future of the NOT and for the observatory on La Palma, which had to take priority for my time. I hope that readers will still find the contents of interest

2009 was a year of many highlights. One milestone was the extension of all staff contracts to the end of 2013, at which occasion the Council appointed Thomas Augusteijn *Deputy Director* to better reflect his real responsibilities. The year was further brightened by the arrival of six new students, as Juliet Datson and Erkki Kankare (Turku), Tiina Liimets (Tartu, Estonia, and this year's *Synnøve Irgens-Jensen Distinguished Research Student*), Johan Lindberg (Onsala), Thomas Ottosen (Aarhus) and Paul Wilson (Oslo) gradually replaced Zita Banhidi, Sami Niemi (whose photo was inadvertently missed in 2008), Auni Somero and Helena Uthas. We also continued to support two Spanish PhD students at Stockholm University.

The next high point was the 25th anniversary of the creation of NOTSA and the 20th anniversary of the inauguration of the telescope. We celebrated these events by holding the Council and STC meetings on La Palma in May and inviting as many of the veterans from the construction and early operation period of the NOT as could make it to La Palma. Highlights included a visit to the telescope, a review of our developments over the last few years, and of course another of the now-legendary staff parties hosted by Carlos Pérez (see below). A good time was had by all!

The summer was marked by the first joint NOT-Onsala-Tuorla summer school in June, sponsored by NordForsk. 21 Nordic-Baltic students studied star formation near and far with optical and near-infrared observations with the NOT and with mm data from the Onsala 20-m radio telescope, all by remote control from Tuorla Observatory in Finland (see p. 25). An international group of lecturers provided theoretical and practical background, and overall this multi-wavelength course was a great success and a model for the future. Funding for the two next courses has already been secured.

A busy June was followed by an equally busy July, as we realuminised both mirrors of the NOT in record time. As our telescope and we went back to routine business, the rest of the observatory dressed in gala for the grandiose inauguration of our 10.4-m neighbour, the GranTeCan telescope, in the presence of Their Majesties, the King and Queen of Spain. We look forward to the accomplishments of this fine new facility on La Palma.

Much time was again devoted to defining the future role of the NOT in the framework of European astronomy, with the EC-funded networks ASTRONET and OPTICON as the main drivers for European coordination. After the effort of producing two major planning reports in 2007 and 2008, 2009 was a year of preparation for turning the plans into action, and we hope the ground was prepared for significant progress in 2010.

Finally, 2009 was also the *International Year of Astronomy*, an unprecedented worldwide success for public appreciation of our science. NOTSA participated as an official Organizational Associate and in several individual events. Most notable of these was an essay competition for Nordic high school students, with an observing run at the NOT in December as the prize for the winner in each country (see the back cover and p. 4). Even the weather cooperated for the occasion!

The following pages summarise the main events at the NOT in 2009. As usual, the mainstay is highlights of the science carried out or published from the NOT during the year. I thank all the authors for sharing their stories with us, and Anne Marie Brammer for another fine job on the layout. Unsigned text and photos are by the Editor.

Johannes Andersen
Director & Editor

EVENTS IN 2009

Left to right: IYA essay winners Lill Haukanes (Norway), Oliver Saxén (Finland), Helena Holma and Mikael Ingemyr (Sweden, behind NOT student Paul A. Wilson), and Sigurður Júlíusson (Iceland).

A few highlights of 2009 are summarised below. More detailed reports on education, observing time, finances and publications are given in later sections and at our web site.

The NOTSA silver jubilee

The agreement that formally established NOTSA was signed in April 1984, and the telescope was inaugurated five years later. The Council decided to celebrate this double anniversary by holding its meeting in May 2009 on La Palma and invite the engineers, astronomers, and research council representatives that played key roles in the design, construction, funding and early operation of the NOT to share this occasion with us. A total of 18 persons, including spouses, were able to join our Council and staff. They were treated to a visit to the telescope (see below), a day-long review of recent progress on the telescope and instruments and of current science, scenic hikes or drives according to individual tastes, and an informal party with all staff, families and students, complete with a lavishly sculpted birthday cake (see previous page).

The first NOTSA-Onsala multi-wavelength training course

As noted in the report for 2008, NOTSA and Onsala Space Observatory, Sweden, with support from NordForsk, have decided to join forces in preparing for the future when astronomers will want to use data from all wavelengths seamlessly in their research. The place to start is by training our PhD students, and our first joint optical/IR/mm radio summer school, *Star Formation in the Milky Way and Nearby Galaxies*, took place at Tuorla Observatory, Finland, June 8-18, 2009. It featured remote observations with both the NOT and the OSO 20m radio telescope as well as lectures on the theory of star formation and on the reduction and interpretation of the data. The course was a great success – see more on p. 25 – and a first successor will be held at Onsala in June 2010.

International Year of Astronomy

At the proposal of the International Astronomical Union, the United Nations proclaimed 2009 as the *International Year of Astronomy*. An enormous panoply of events was organised around the globe to raise public interest in and appreciation of astronomy – including the first total Solar eclipse in history to be viewed by over a billion people(!). NOTSA joined the IYA as an official *Organisational Associate*, but our special event was the visit in December by the winners of the essay competition for Nordic high-school students, whose prize was half a NOT observing night each on projects on their own choosing – an exoplanet and a black-hole binary. The weather was glorious, and the students obviously enjoyed both their visit and the projects.

ASTRONET and OPTICON

The ASTRONET and OPTICON networks, supported by the European Commission, aim to improve planning, coordination and cooperation in European astronomy (see *www.astronet-eu.org*, *www.astro-opticon.org*, and earlier Annual Reports). NOTSA participates fully in both. After the major efforts resulting in the ASTRONET *Science Vision* (2007) and *Infrastructure Roadmap* (2008), a number of reviews were initiated in 2009 to prepare the implementation of the recommendations of these documents, with reports expected in 2010. Preparations for the long-term continuation of regular planning initiatives are also under way.

Nordic cooperation

The NOT is known at home as an outstanding example of successful Nordic cooperation. But we were gratified to also receive the *COSCAN International Award* by the Confederation of Scandinavian Societies of Great Britain and Ireland for "The creation of a Joint Optical Telescope for the Nordic Countries Situated at the Roque de los Muchachos Observatory in La Palma". The award was for 2006, but was formally presented in 2009 (see photo).

NOT veterans (re)visiting the telescope.

Amanda Djupvik receiving the COSCAN Award on behalf of NOTSA.

The core mission of the NOT is to enable Nordic astronomers to do science. Formal publications from such projects are listed on p. 29; a few highlights are provided here for a more general readership. Contributions have been edited to fit the available space, and for consistency of style.

COSMOLOGY AND FORMATION AND EVOLUTION OF GALAXIES

The structure of the Universe is believed to be dominated by dark energy and dark matter, both of unknown nature. Understanding these concepts and their role in shaping the modern Universe is a central goal of observational cosmology. In turn, the first stars and galaxies began the transformation of the baryonic matter in the Universe from a diffuse gas of hydrogen and helium to the chemically complex system of galaxies, stars, planets, and life that we live in today.

Distant galaxies seen through a gravitational telescope

A massive cluster of galaxies may act as a "gravitational lens": Light from distant background galaxies behind the cluster is deflected and focused towards the observer. The galaxy cluster then acts as a giant "natural telescope", magnifying and amplifying the images of distant sources. In favourable cases, such lensing may allow detailed studies of objects that would otherwise be too faint to be observable. Strong gravitational lenses then provide a unique window into the high-redshift universe, in which objects are seen not only at immense distances, but also at a time when the Universe was quite young and galaxies just beginning to assemble.

In star-forming galaxies, the ultraviolet light shortward of the Lyman discontinuity at 912Å is totally absorbed by neutral hydrogen on the way to us, creating the so-called Lyman break in the spectrum. At redshifts z~3, the Lyman break is optimally located for imaging with the blue-sensitive MOSCA camera at the NOT. Unfortunately, typical Lyman break galaxies at z~3 are too faint to permit further detailed spectroscopic studies, even with 8-10m class telescopes, but gravitational lensing may come to the rescue in rare cases.

We recently discovered such a gravitationally lensed Lyman break galaxy with the NOT, at a redshift of z=2.92 (Fig. 1). Detailed modelling of the mass distribution of the lens, based on images and spectroscopic observations of the foreground cluster, reveals that the light of this galaxy is magnified a total of 40 times, more than in any of the only four previously known cases. This will allow detailed studies of the physical conditions in a star-forming galaxy when the universe was only two billion years old.

This discovery was made in the course of the large *SDSS Giant Arcs Survey (SGAS)* for new gravitational lens systems. SGAS is the largest and most successful effort to discover new cluster lenses and has so far found approximately 100 cases, most of them with the MOSCA camera at the NOT (see Fig. 2 for examples). This represents the first ever "lensing-selected" sample of clusters, which is excellently suited to probe the relative distributions of dark matter and baryons and the interaction between these two different mass components. In addition, both the statistics and the detailed properties of the new lenses will place tight constraints on the standard cosmological paradigm.

H. Dahle, Oslo, and the SGAS team

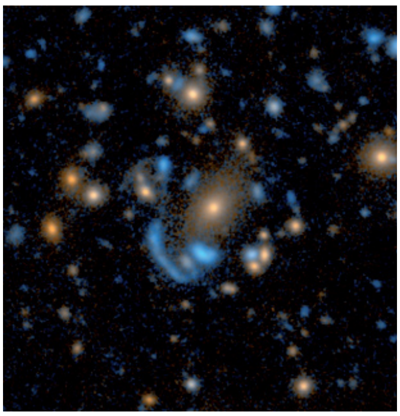


Fig. 1. The Lyman-break galaxy SGAS J122651.3+215220 at z=2.92 (bright blue galaxy just below the large elliptical galaxy in the centre of the image); colour image from MOSCA in the SDSS g and i bands. A blue giant arc – another strongly lensed galaxy at the same redshift – is visible to the lower left.

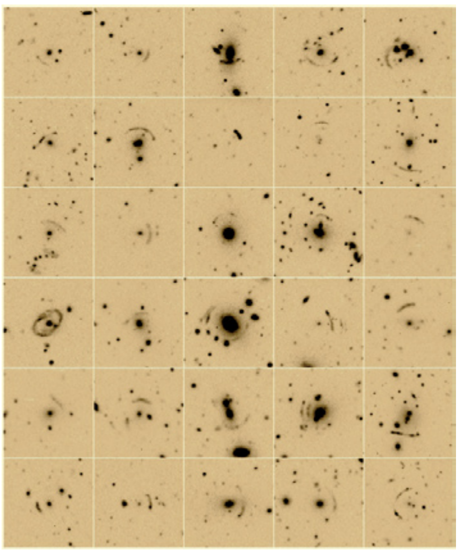


Fig. 2. g-band detection images – mostly ~10 min exposures with MOSCA at the NOT – of thirty representative gravitational lens systems from the SGAS survey. The arcs are strongly lensed background galaxies.

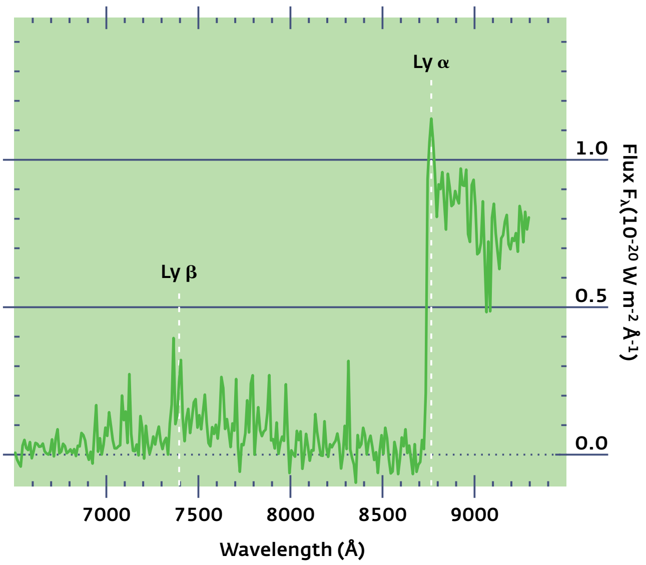
Discovering high-redshift quasars

One of the most remarkable recent discoveries is that all massive galaxies in the nearby universe contain black holes at their centres, with masses between 10^6 and 10^8 $M_\odot$ (1 $M_\odot$ = the mass of our Sun). These black holes are believed to build up from small seeds over cosmic time by swallowing gas from their host galaxies. During this process the gas is heated up, and the centre of the galaxy shines brightly as a quasar – often outshining the rest of the galaxy. The bright emission from these quasars makes them relatively easy to find at very large distances, hence early in the life of the Universe, and quasars are now known at redshifts $z > 6$ – within the first billion years after the Big Bang.

While quasars are bright, they are also very rare, and large areas of sky must be surveyed discover them. Using the Canada-France-Hawaii Telescope and its wide-field optical camera, we are carrying out such a survey, the Canada-France High-z Quasar Survey (CFHQS), to find plausible quasar candidates at $z \sim 6$. But identifying the true quasars just from the optical images is difficult, because they are greatly outnumbered by similar-looking brown dwarfs, or "failed" stars, in our own Galaxy.

This is where the NOT comes in: Near-infrared imaging with NOTCam allows us to separate the distant quasars from the brown dwarfs. The excellent image quality at the NOT makes this a very efficient process. Once we have identified the true quasar candidates, we measure their redshift with spectrographs at the Gemini and other 8-10m telescopes (Fig. 3). In 2009 we discovered CFHQS J1429+5447

Fig. 3. Optical spectrum (from Gemini-North) of the most distant radio-loud quasar CFHQS J1429+5447, discovered from NOTCAM J-band images.



at the NOT; at a redshift of z=6.21, this quasar also emits substantial energy in the radio domain from its relativistic jets and is the most distant radio-loud quasar known.

The CFHQS has now discovered 20 new quasars at redshifts between 5.88 and 6.44, and further study is ongoing to probe the distribution of quasar luminosities and black hole masses, the star formation, gas and dust content of the host galaxies, and the reionization and metal enrichment of the intergalactic medium.

C. Reylé, Besançon, and the CFHQS team.

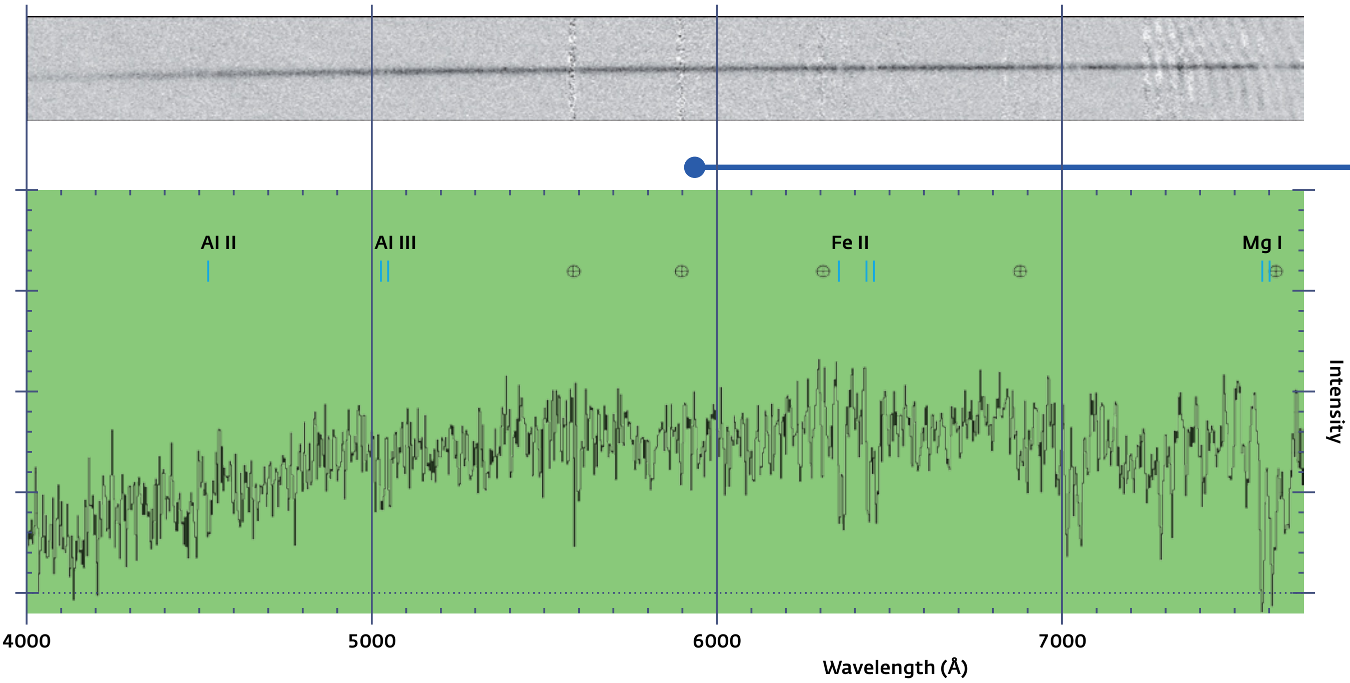
Gamma-Ray Burst smashes cosmic distance record

The long-mysterious Gamma-Ray Bursts (GRB) were shown just a decade ago to arise in violent stellar explosions that produce fast-decaying afterglows in their host galaxies. GRBs are so bright that, for a short while, they outshine every other known object in the Universe, both in optical and near-infrared light and in X-rays, and several have been identified with supernova explosions in very massive stars. Observing the afterglows allows us to determine redshifts and probe the extreme physics of GRBs.

The NOT has been very active in determining redshifts for GRBs discovered with the *Swift* satellite (see Annual Reports 2004-2008) – 6 in just the last couple of years. This is by far the largest number obtained by any 2-4m class telescope, due to the flexible, optimised operation at the NOT, which allows any observer to obtain useful data at very short notice (see Fig. 4). This has added many new GRBs at redshifts beyond 2 – a time when star formation was very active and the first galaxies were assembled.

2009 will go down in history for the discovery of a GRB at a record redshift. The object, GRB 090423, was immediately flagged as a possible high-redshift burst. Deep NOT images in optical and near-infrared bands failed to reveal it, so it could not be a normal GRB with high dust extinction. NIR spectroscopy with the Italian TNG and ESO VLT telescopes eventually proved that this was the most distant object ever discovered, at a redshift of z = 8.2. In other words, the explosion occurred when the Universe was only ~630 million years old, just 5% of its current age.

We have also observed GRBs detected at high energy by the *Fermi* satellite. These afterglows are usually bright and easy targets for redshift determination, which is the key to understanding their high-energy properties and any quantum gravity effects, such as a possible variation of photon speed with energy. Accumulated over cosmological times, such effects might be reflected in the GRB light curves. In



order to better understand the physical mechanisms that generate the energetic photons and their relation to the lower-energy afterglow components, we observed one of the brightest bursts detected by *Fermi*, which showed excess emission by a hard power-law component in addition to the usual spectrum. The origin of this component is not understood, and it poses genuine challenges for theoretical models.

P. Jakobsson, Reykjavik; J. Fynbo and D. Malesani, Copenhagen; and a large GRB team

Fig. 4.: Left: The field of GRB091020; the afterglow is the bluish object at the right-hand corner of the quadrangle in the centre, with R ~ 20. Above: Spectrum taken a few minutes later, yielding a redshift of z = 1.71. The ⊕ symbols denote absorption lines from the Earth's atmosphere. Observers: Paul A. Wilson and J. Andersen - even an observatory director can now observe GRBs for us!

Understanding the cosmological yardsticks

Supernovae of Type Ia (SNe Ia) are important standard candles and cosmological yardsticks. They are widely assumed to be thermonuclear explosions of white dwarf (WD) stars that reach the Chandrasekhar mass limit of M_{Ch}~1.4 $M_{\odot}$, but their physical properties are not thoroughly understood. We have therefore observed nearby, bright SNe Ia at the NOT for calibration purposes for some time (see Annual Reports 2004, 2007 and 2008). In 2009 we focused on the SNe 2009dc and 2009ig, both of which were discovered very early, 10 and 14 days before maximum light.

SN 2009dc was a particularly interesting object. It belongs to a recently discovered subclass of SNe Ia that seem to deviate from the general scheme outlined above. Its members are a factor ~2 more luminous than ordinary SNe Ia, and their slowly evolving light curves and low ejection velocities are inconsistent with the standard scenario. Yet, the observed element pattern still favours a thermonuclear explosion rather than a core collapse of a massive star, and fast-rotating or merging massive WDs have been proposed as the possible origin of these events. We obtained extensive optical and near-IR observations of SN 2009dc with the NOT and other telescopes (Figs. 5 - 7). Powering the large peak luminosity and slow decline of this light curve requires that the explosion produced more

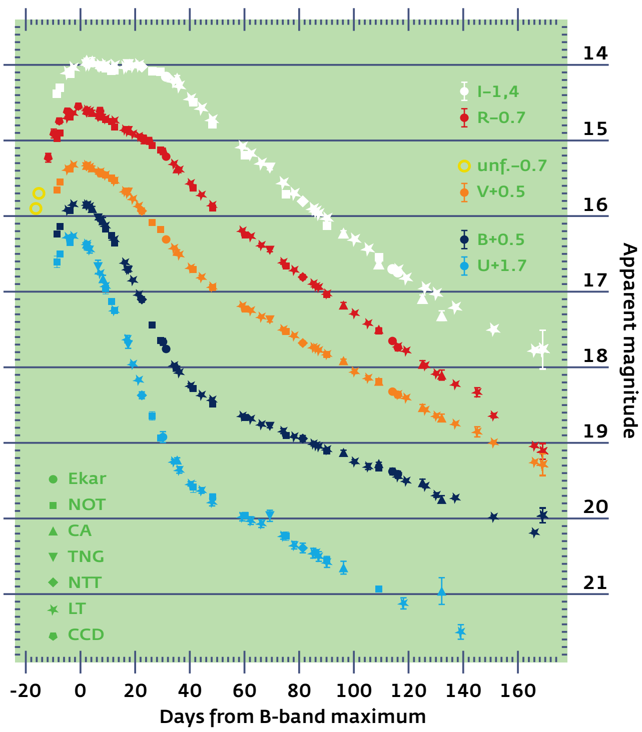


Fig. 5: UBVRI light curves of SN 2009dc.

than 1.3 $M_{\odot}$ of radioactive ^{56}Ni, suggesting that the progenitor mass exceeded M_{Ch}. The unusually low ejection velocities seen in the spectra also support this theory.

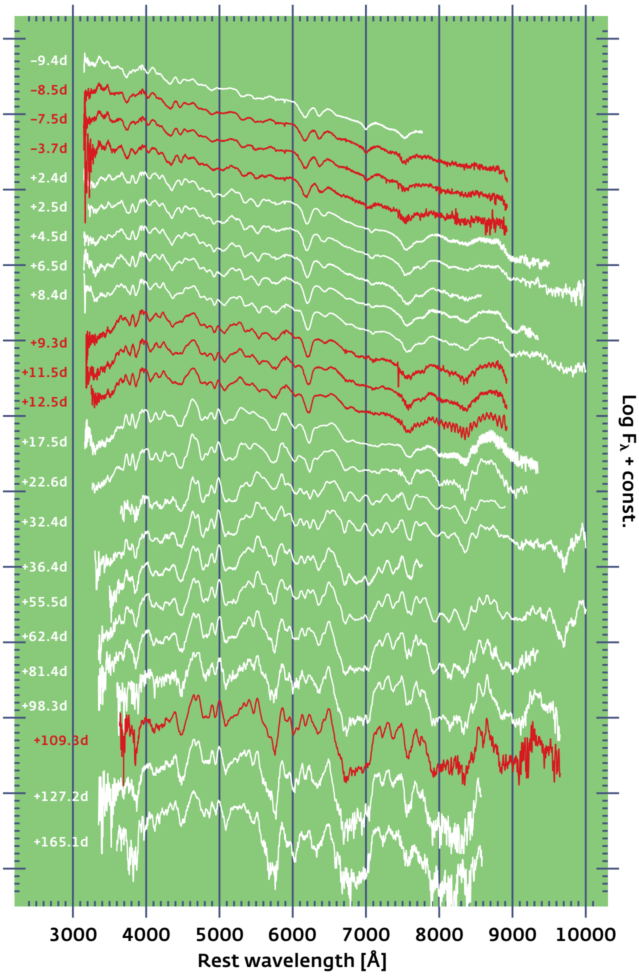


Fig. 6: Spectral sequence of SN 2009dc (earliest spectra at the top; NOT spectra in red). Note the strong and persistent C II line at ~6350A and the lack of strong Ca II lines near 8500 Å.

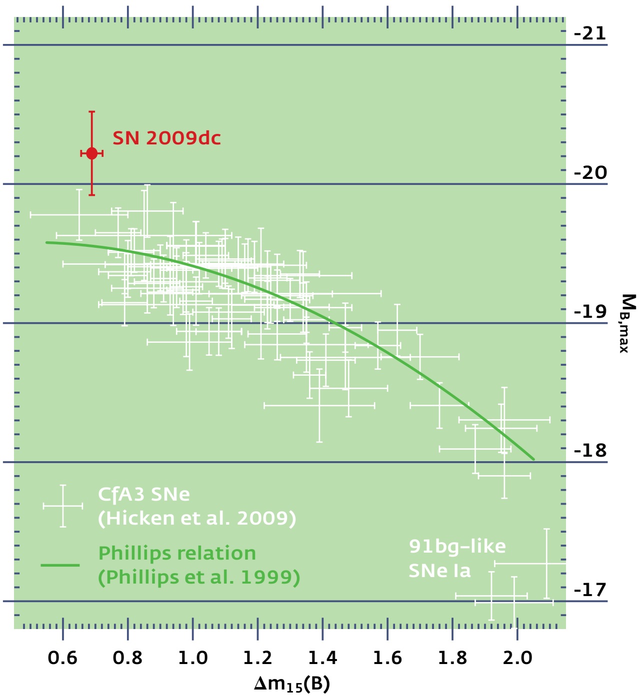


Fig 7: Absolute blue magnitude vs. decline during the first 15 days after maximum for a sample of nearby, normal SNe Ia. SN 2009dc is a clear outlier.

Another intriguing feature of SN 2009dc is the unprecedentedly strong carbon lines in the early spectra (Fig. 6). This large amount of carbon was likely left over from the WD and indicates that burning of its outer layers was incomplete. We are currently modelling the early spectra of SN 2009dc to constrain the chemical stratification of the ejecta and the density profile of the explosion, and performing hydrodynamic explosion simulations of super-M_{Ch} and merging WDs to explain objects like SN 2009dc.

Understanding such over-luminous SNe Ia is not just a goal in itself, but has important implications for SN cosmology: With spectra similar to normal SNe Ia, these events may bias the cosmological SN Ia data sets, especially at high redshift where they are favoured by their high luminosity. Since they do not obey the "light-curve width – luminosity relation" used to standardize SNe Ia luminosities (Fig. 7), they may introduce systematic errors in the derived cosmological parameters.

V. Stanishev, Lisbon; S. Taubenberger, Garching; and collaborators

Relativistic jets from Active Galactic Nuclei

Some massive galaxies harbour very massive black holes in their centres (see above). Gas from the host galaxy falling into the black hole emits extremely bright and highly variable radiation at all wavelengths, much of it in the form of relativistic jets. Astronomers therefore call these objects Active Galactic Nuclei (AGN). Blazars are a special subclass of AGN in which the jet points almost directly towards the observer, strongly amplifying the emission from relativistic effects. This makes them perfect laboratories to study the powerful AGN jets.

Not only the intensity, but also the polarization of the light from an AGN is highly variable and brings unique information on the nature of the source. We have monitored the polarized light of the famous binary blazar OJ287, which undergoes violent outbursts every 12 years when the two black holes pass close to each other in their orbit (see Annual Report 2008, p. 7). During 2005 - 2009 we obtained 400 quasi-simultaneous flux and polarimetric observations with the NOT and ALFOSC and with the KVA 60cm and Calar Alto 2.2m telescopes, shown in Fig. 8.

These data give interesting insights into blazar jets. First, while the 12-year outbursts in OJ287 emit unpolarized

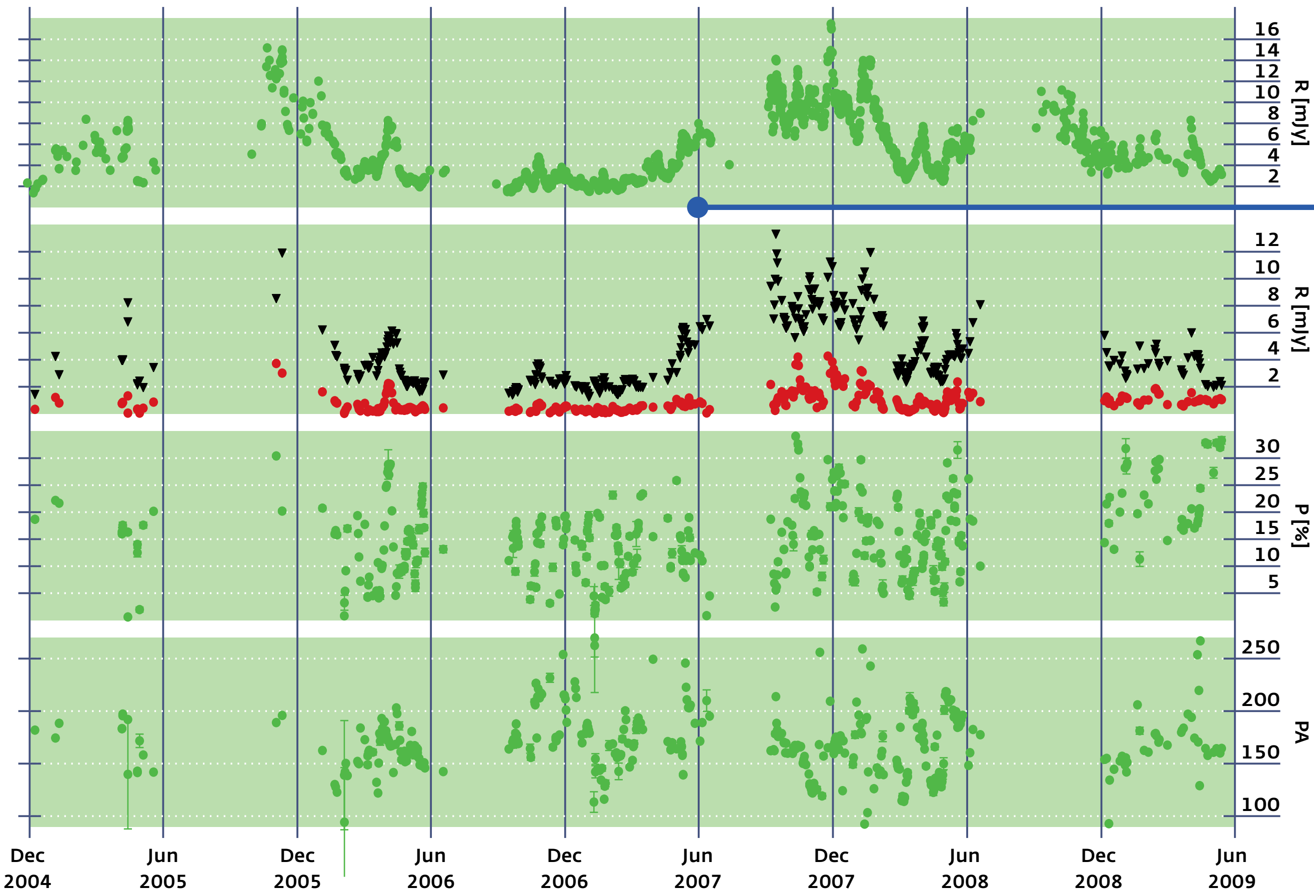


Fig. 8. Photopolarimetric light curves of OJ287 in 2005 - 2009. Top to bottom: total flux in the R (red) band; separate polarized (red circles) and unpolarized (black triangles) fluxes; degree of polarization; and position angle (degrees).

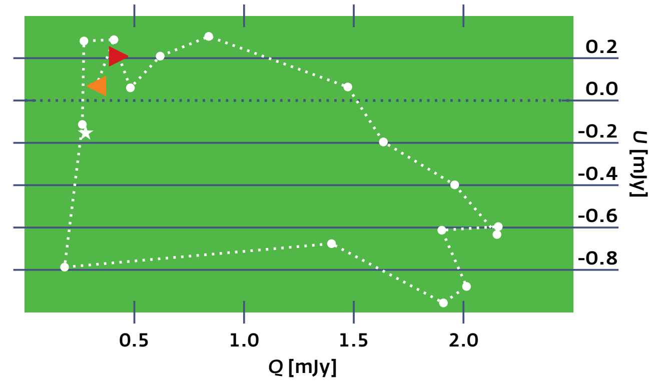


Fig. 9. The signature of a bubble observed during an outburst in OJ287, in the Stokes Q and U polarization parameters.

light (see Annual Report 2008), polarization can be used to understand the origin of the quiescent jet emission. The total light variations are not very informative in the quiet phases, but e.g. the relatively stable angle of polarization (Fig. 8) shows that this component arises in the inner, most stable part of the jet emanating from the larger of the two black holes.

Polarization can also be used to better understand the origin of the variability observed in AGN jets. We found that the variable polarization frequently describes a rotation in the Stokes plane (see Fig. 9), presumably the sign of a shock front in a relativistic bubble of gas moving along a helical jet. However, one must understand the stable polarized component in order to separate the underlying jet emission from the intermittent turbulent emission in the ejected gas bubbles.

C. Villfort, K. Nilsson, Turku; J. Heidt, Garching; T. Pursimo, NOT; and collaborators

Identifying nearby star-forming galaxies in far-infrared data

Understanding galaxy evolution requires observations in the infrared, because much of the strong, early star formation took place in very dusty, obscured environments. The past decade and a half has been a golden age of such studies, with such space missions as ISO, Spitzer, and now Herschel. However, the low spatial resolution of far-IR (FIR) space telescopes makes identification of individual galaxies at other wavelengths very difficult.

Instead of measuring the properties of individual FIR galaxies one can also study the integrated Cosmic Infrared Background Radiation (CIRB): The bulk of it is expected to originate from luminous IR-galaxies, LIRGs, at redshifts of z~1 and above, though the results are still somewhat model dependent. Yet, the difficulty of identifying even the brightest FIR sources contributing to the CIRB still makes their very nature uncertain. We have therefore studied these objects by imaging FIR fields from ISO with both NOTCam and ALFOSC.

After careful multi-wavelength imaging and archival spectroscopy of the brightest galaxies, we identify the most probable counterparts of the FIR galaxies by means of a full spectral energy fit to all sources in the FIR error circles. Approximately 80% were identified as star-forming or star-

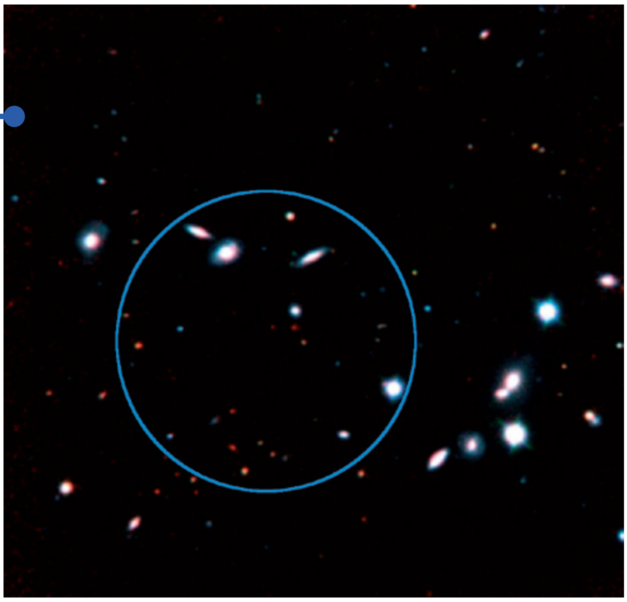


Fig 10. Three-colour red-infrared image of the field of the FIR source NGP18 (blue error circle of diameter 90"), highlighting the difficulty of counterpart identification. The two bright disk galaxies at z = 0.13 can together explain the observed FIR flux, but the field also includes some very red galaxies, which could be higher-redshift LIRGs.

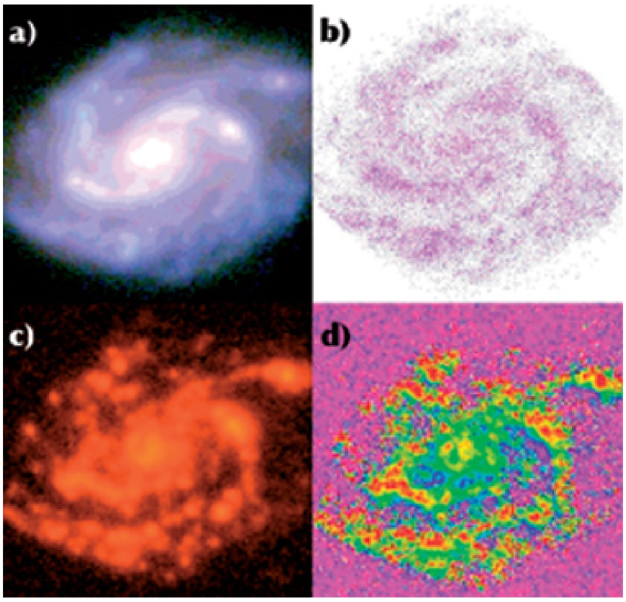


Fig. 11. Four views of the galaxy UGC 08012, all except b) from the NOT: a) Three-colour image in UV, blue and red light. b) preliminary LyA map from HST before subtraction of the stellar continuum (S. McCandliss, Baltimore), c) Hα map and d) dust map.

bursting galaxies at z<0.3. This is totally consistent with previous studies, so not very surprising. However, only 20% of all the sources can be uniquely matched with a *single* galaxy: Nearly half the FIR sources are blends of two or more nearby star-forming galaxies, while another fifth appear to be blends of nearby and fainter galaxies, probably luminous infrared galaxies (LIRGs) at z>0.5 (see Fig. 10 for a difficult case).

The importance of blending and confusion of targets is often not sufficiently appreciated: Many studies simply force a match of the FIR source to a single counterpart candidate. Not accounting for blending also results in an overestimate of the FIR source counts, which are used as important constraints on galaxy evolution models. We find that "de-blending" the bright FIR source population both steepens and reduces the FIR count distribution. Finally, that so many sources are blended means that FIR galaxies typically live in environments of pairs or small groups of galaxies. This aspect of the project is now a subject of further study.

P. Väisänen, Cape Town; J. Kotilainen, Turku; M. Juvela, K. Mattila, Helsinki

The distribution of Lyman α radiation in galaxies

Astronomers are constantly striving to understand the evolution of the Universe, the formation of its structure, and the rise of the first stars and galaxies. One of the tools for detecting young, distant galaxies is the Lyman α (LyA) line of excited neutral hydrogen, which is strong in active star forming regions. Its rest wavelength at 1216 Å is in the space ultraviolet, but it becomes observable in visible light in high-redshift galaxies. However, few details are visible in such very distant objects, even with our largest telescopes. Hence, to be able to understand what we see out there, we need to study more nearby galaxies. Although they are more evolved than those in the early Universe, we can learn much about the basic physical processes by studying them in detail.

We have used far-UV images from the Hubble Space Telescope (HST) to create detailed maps of the LyA emission in 14 local star-forming galaxies. Young, hot stars produce the ionizing photons that create the original LyA emission, but the path of the LyA photons from there to us is still a puzzle. The emitted flux depends on the physical properties of the galaxy, but LyA photons are scattered unaltered in the interstellar medium; they can only be destroyed by dust absorption. Theories of how LyA photons can escape from the galaxy include a turbulent or multiphase interstellar medium, the distribution of dust relative to the gas, and diffuse scattering. In an earlier project we showed that some LyA radiation can escape directly, but the main part often forms a diffuse halo of multiply scattered LyA photons.

To interpret these LyA maps we must remove the underlying stellar continuum. The highly variable continuum slope in the far-UV makes this is a non-trivial procedure. Multi-wavelength images are needed to model the distribution of stellar populations and dust in these galaxies. For this, we have used the NOT and ALFOSC with broad- and narrow-band filters adapted to the individual redshifts of our galaxies. The data are now being reduced and analyzed, with the galaxy UGC 08012 as a pilot object. Fig. 11 shows a series of views of the different components of this galaxy.

E. Leitet, Uppsala

Red giant stars in nearby galaxies

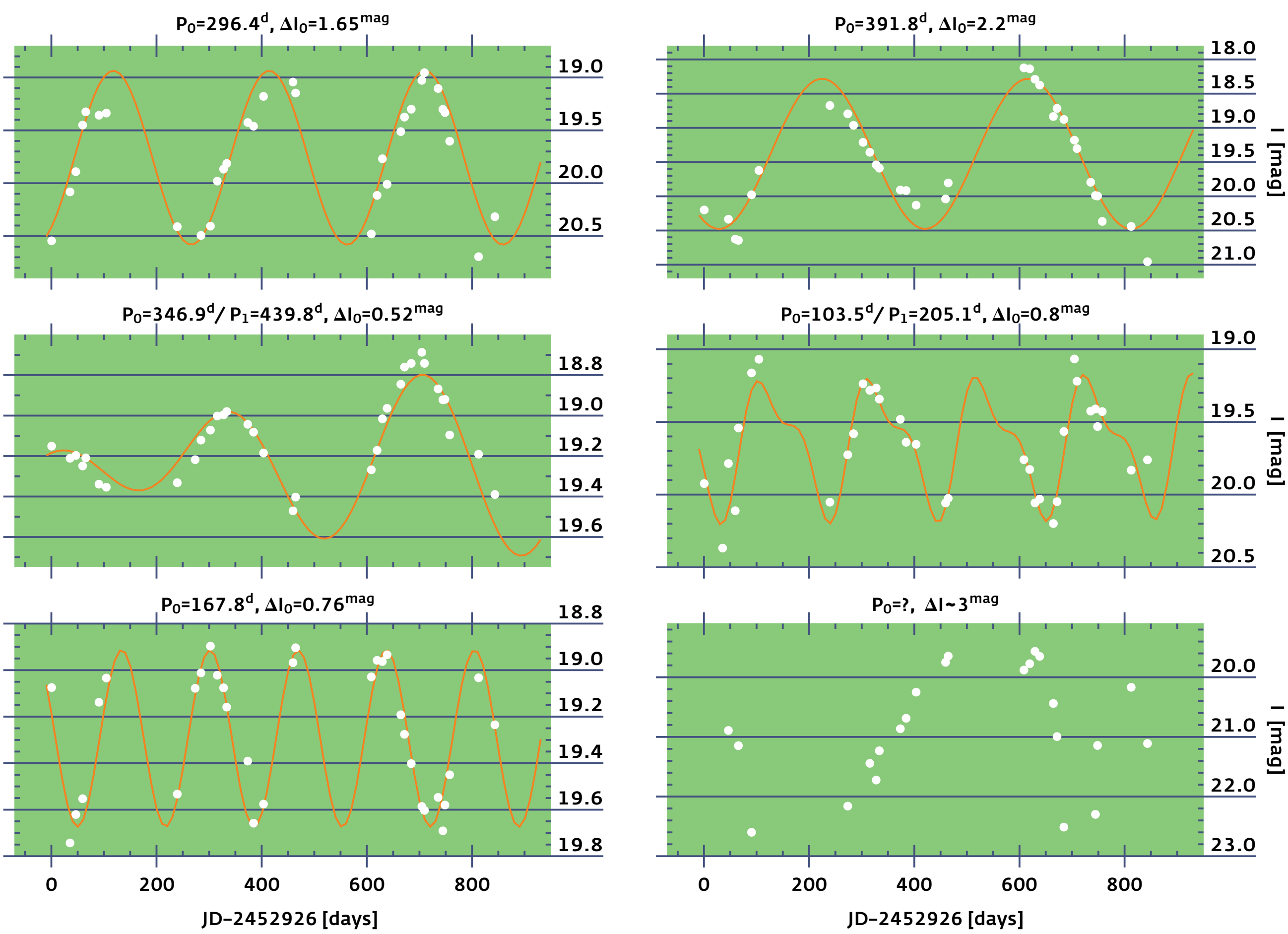
In 1596, David Fabricius reported the very large light variations of a red star in the constellation of the Whale, which he named Stella Mirabilis or Mira, the remarkable star. Known today by the more prosaic name Omicron Ceti, this is the prototype of the class of long-period variable stars (LPVs), which have periods of a few tens to several hundred days and large amplitudes (several magnitudes in the visual). LPVs are evolved red giants and among the reddest and most luminous objects in stellar populations. Observations of LPVs in the Galactic Bulge and extragalactic systems such as the Magellanic Clouds have revealed that LPVs on the Asymptotic Giant Branch (AGB) obey a period-luminosity relation (PLR), so they can be used as distance indicators.

To contribute to this field, we observed two Local Group dwarf galaxies, NGC147 and NGC185, with the NOT and ALFOSC. These galaxies are close enough to be resolvable into individual stars and small enough that large parts are covered in a single ALFOSC field. Both systems are dominated by an old red stellar population, so we were able to follow the light variations of many bright red giants, predominantly AGB stars. Observing every ~2 weeks over 2.5 years was necessary to cover the longest periods; this was made possible by the service observing mode offered at the NOT.

In each galaxy, ~20.000 objects can be identified on each ALFOSC frame, and ~1% of these turned out to be LPVs (513 in total). The measured light curves (see examples in Fig. 12) were Fourier analysed to determine the pulsation modes. In addition, we obtained *K*-band (2.15 μm) photometry with NOTCam to place the stars in the *K* - logP diagram shown in Fig. 13. Together with indicators of atmospheric chemistry (O-/C-rich) from earlier narrow-band photometry with the NOT and ALFOSC (cf. Annual Report 2000), this provides a good characterisation of the variables and allows us to derive the PLR for these galaxies.

Our study (i) provides identifications of LPVs in these galaxies as targets for follow-up observations, (ii) contributes to our understanding of AGB variability (interrelation between pulsation and mass loss; metallicity effects on the

Fig. 12: Observed light curves of Long Period Variables in NGC185, covering a time span of 2.5 years. Fitted pulsation models are shown when possible.



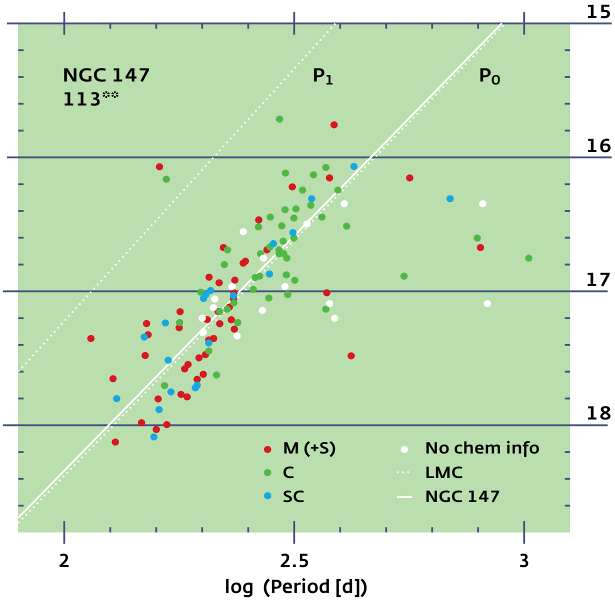


Fig. 13: New LPVs in NGC147, colour-coded by spectral type to reveal the prominent population of Miras. Known PLRs of LMC stars pulsating in the fundamental (P_0) or first overtone (P_1) mode (distance adjusted) and the new PLR derived from our observations are shown for comparison.

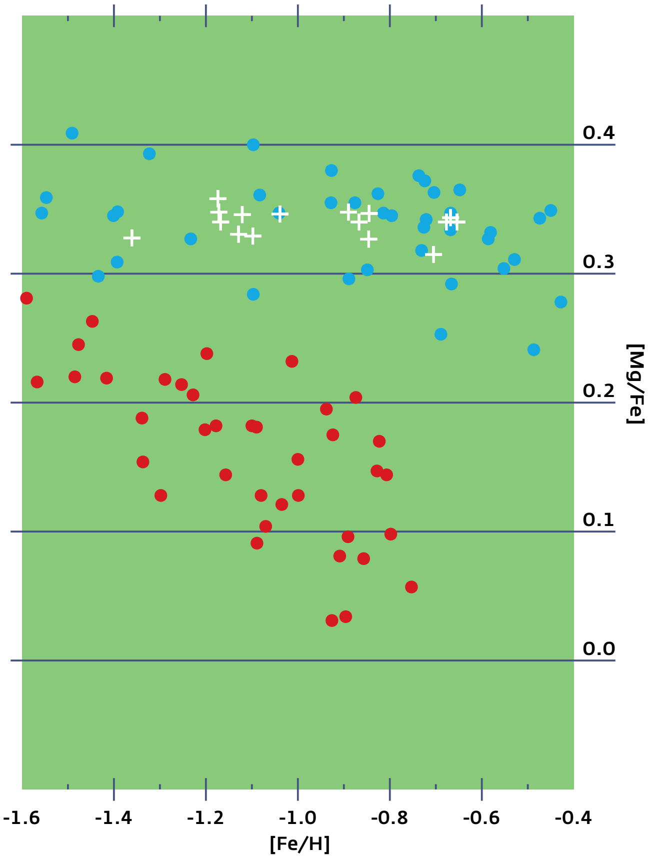


Fig. 14. Observed [Mg/Fe] abundance ratios vs. [Fe/H], defined as the logarithm of the abundance ratios relative to those in the Sun. Blue and red circles denote the `high-Mg' and `low-Mg' halo stars, respectively; crosses are Galactic thick disk stars.

PLR), and (iii) will help studies of Mira stars in the Milky Way for which distances are often poorly known, but can be estimated with the help of our PLR and their observed magnitudes and periods.

W. Nowotny, D. Lorenz, Th. Lebzelter, F. Kerschbaum, Vienna; J. Telting, H.E. Schwarz (deceased), NOT; H. Olofsson, Stockholm/Onsala

Tracing the origin of Milky Way halo stars

For many years, it has been discussed if stars in the Milky Way halo were formed during the rapid collapse of a large gas cloud, or whether they originated in merging dwarf galaxies as predicted by modern cosmological theories of hierarchical structure formation. We have addressed this problem by measuring abundance ratios, such as Mg/Fe, in metal-poor solar-type stars that move with high velocities relative to the Sun (> 180 km s^{-1}). Magnesium is produced by carbon and neon burning in massive stars that explode as Type II supernovae (SNe) on a timescale of 10^8 years, whereas iron is mainly made by Si burning in less massive, Type Ia SNe on a longer timescale of 10^9 years. Hence, the Mg/Fe ratio provides information on the rate of chemical evolution in the regions where these stars formed.

We obtained FIES spectra at the NOT for 53 stars with these halo kinematics and added ESO VLT/UVES spectra of other halo and thick-disk stars. After excluding binary stars, a model-atmosphere analysis was used to derive element abundances from the strengths of atomic absorption lines.

Fig. 14 shows the abundance ratio between Mg and Fe as a function of the iron-to-hydrogen ratio. As seen, the halo stars split into `high-Mg' and `low-Mg' stars. The same splitting is observed for other element ratios, such as Si/Fe, Ca/Fe, Ti/Fe and Na/Ni, and equally clearly in the FIES and UVES data. This is the first time that such a clear dichotomy in the abundance distribution of halo stars has been observed.

Fig. 14 suggests that the `high-Mg' halo stars and the thick-disk stars formed in regions with a high star formation rate, i.e. rapid chemical evolution, so that only Type II SNe contributed to their chemical composition up to a metallicity of [Fe/H] ~ -0.4. The `low-Mg' stars, on the other hand, originated in regions with a relatively slow chemical evolution, so that Type Ia SNe started to contribute iron already around [Fe/H] = -1.6, causing the [Mg/Fe] ratio to decrease towards higher metallicities. Dwarf spheroidal galaxies are known to have similar trends for [Mg/Fe] as well as for [Si/Fe], [Ca/Fe], [Ti/Fe], and [Na/Ni].

The kinematics of the stars show that the `low-Mg' stars move on larger Galactic orbits than the `high-Mg' stars. Altogether, it seems that the `low-Mg' halo stars have been formed in dwarf galaxies that were accreted by the Milky Way as predicted by hierarchical structure formation models. The high-Mg stars, on the other hand, may be ancient disk or bulge stars `heated' to halo kinematics by the merging dwarf galaxies.

P.E. Nissen, Aarhus; W.J. Schuster, Ensenada

FORMATION, STRUCTURE, AND EVOLUTION OF STARS

Stars form, evolve, and build up heavy elements in their interiors. Eventually, they fade away as white dwarfs or explode violently as supernovae, leaving enriched gas behind as raw material for new stars. Theoretical models of the formation and evolution of stars enable us to understand this cycle and estimate ages and lifetimes of the stars we observe, but many uncertainties remain.

The young star-forming cluster Dolidze 25

Stars are believed to form in clusters, and not all at the same time. Often one observes that (some) massive stars are formed first and ionise the surrounding hydrogen cloud to form a bright so-called H II region, while the formation of lower-mass stars continues in other, denser parts of the cloud. The details are complex and poorly understood, so young clusters embedded in H II regions are a very active field of study. Infrared (IR) observations are essential in order to penetrate the dense dust clouds which are associated with such regions and are particularly opaque just where the newborn stars are being formed.

We are studying the timing and location of the star formation processes that formed the giant HII region Sh 2-284 in the Milky Way. Fig. 15 shows an overview of the region, outlining a bubble of hot gas traced by broad-band mid-IR (red) and Hα emission (blue). We focus here on the cluster Dolidze 25, located in the centre of the dust bubble, for which we have obtained optical and near-IR photometry using ALFOSC and NOTCam at the NOT (Fig. 16). From the optical photometry we identify the main-sequence stars (that are already formed) and the pre-main sequence

Fig. 15. The H II region Sh 2-284, showing the bubble and the location of the central cluster Dolidze 25 studied with ALFOSC (larger square) and NOTCam (smaller square). Colours show mid-infrared data from the Spitzer satellite (8 μm, red) and Hα from the AAO-UKST (blue). The field is 30' x 30'; north is up, east left.

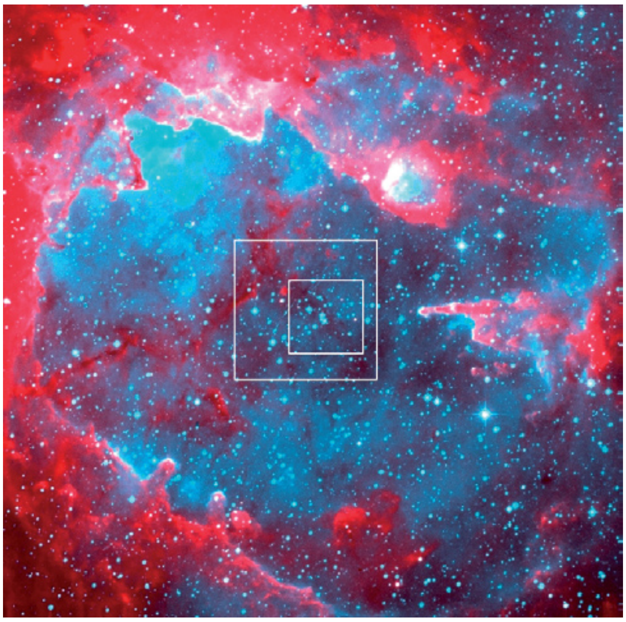
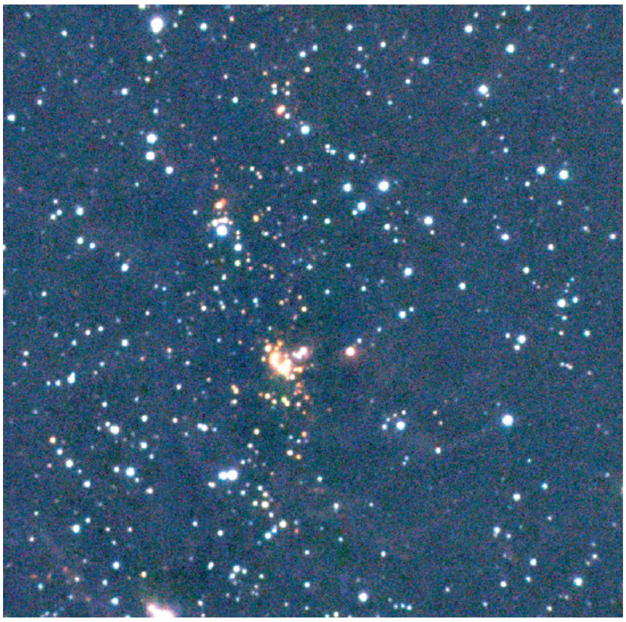


Fig. 16. Near-infrared colour image in J (1.25 μm, blue), H (1.65 μm, green), and Ks (1.8 μm, red) of the central 3.8' x 3.8' region of Dolidze 25, taken with NOTCam.

Fig. 17. Unpublished JHKs image from NOTCam of one of the regions in the shell of the bubble that are still forming massive stars.



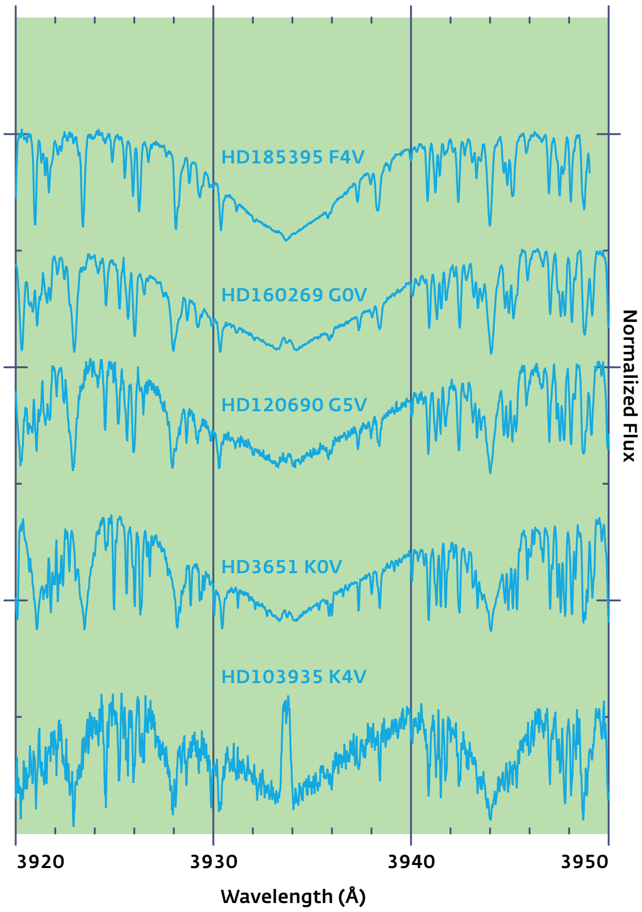
(PMS) candidate members; from the near-IR photometry we find sources with infrared excesses, typically PMS stars surrounded by disks of accreting material.

We revise the distance of the cluster to 3.6 kpc and find that it consists of two generations of main-sequence stars, an older one with an age of about 40 million years (Myr) and a younger generation of at most 5 Myr, roughly the same age as the optically selected PMS population. This result is also supported by the different spatial distributions of these two generations of stars. The formation of the youngest generation may have been triggered by the first generation, and although our stars are projected onto the centre of the bubble, it is possible that the younger population is actually located closer to the near side of the shell.

Space-based mid-IR data indicate that massive stars are still forming in the shell of the nebula. One region believed to harbour a massive protostar, still deeply embedded in dust, is shown in Fig. 17.

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

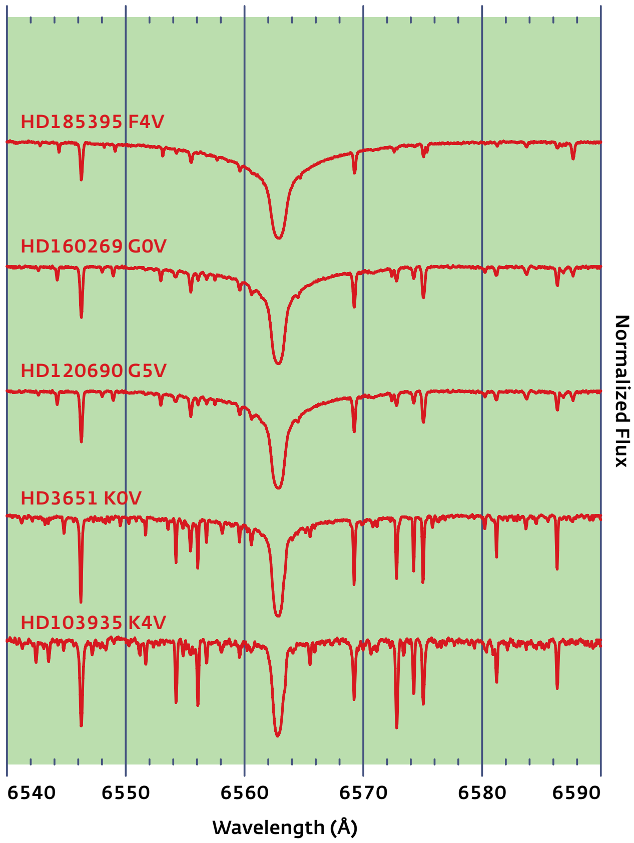
Fig. 18. FIES spectra of representative DUNES stars around the Ca II K (left) and Hα lines (right).



Hunting Solar-type stars with planetary debris disks

Newly-formed stars are often shrouded in dust from the parental cloud, but fully-fledged stars are generally in clean regions. Yet, some mature stars, such as Vega, Fomalhaut or β Pictoris, are surrounded by dust disks extending to hundreds of Astronomical Units from the central star (1 AU = 150 milllion km = the distance of the Earth from the Sun). These disks were first discovered in the 1980s by the infrared satellite IRAS. Dust around such main-sequence stars cannot be primordial, but could be a second generation of dust, replenished by a reservoir of (undetected) dust-producing planetesimals like the asteroids and comets in the Solar System.

DUNES (**DU**st around **NE**arby **S**tars) is an Open Time Key Project on the Herschel infrared space observatory with the aim to detect cold dusty disks around a sample of 133 nearby solar-like stars, as faint as $L_{dust}/L_{star} \sim 10^{-6}$ and with temperatures of 30-40 K. We are observing the DUNES targets with the FIES spectrograph at the NOT to accurately characterise the stars, which is of vital importance for the interpretation of the Herschel data. The spectra are analysed to determine: 1) Kinematics (assignment to any young stellar kinematic groups), 2) basic stellar parameters (temperature, gravity, metallicity, rotation), and 3) ages from the strength of the lithium line.



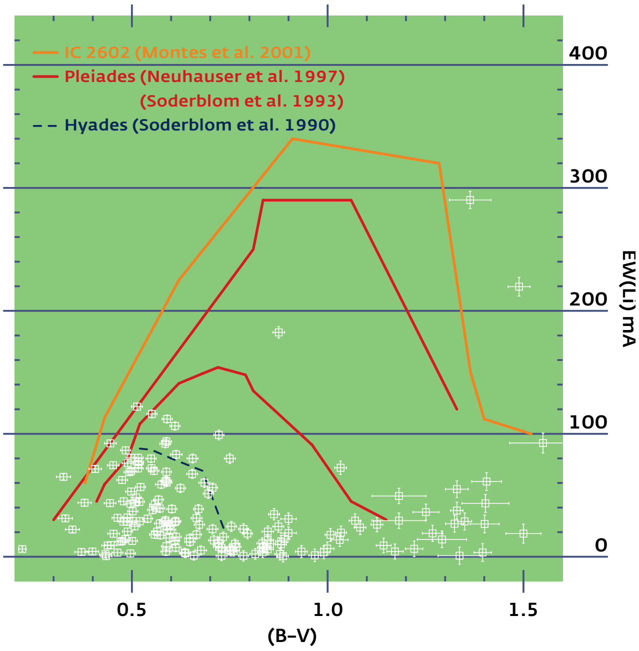


Fig. 19. Lithium line strength (EW(Li)) vs. B-V colour (blue left, red right). Average relations are shown for the clusters IC2602 (10-35 Myr; green), Pleiades (~80 Myr; red), and Hyades (600 Myr; blue). Squares with error bars show the observed DUNES stars.

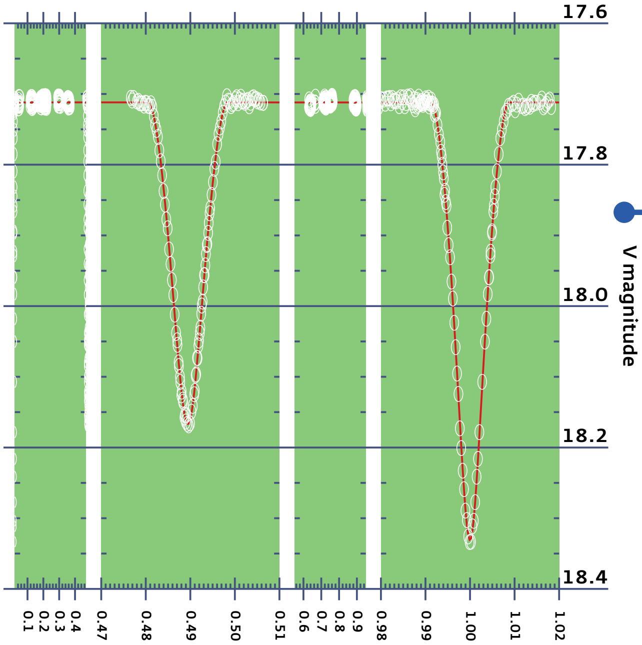


Fig. 20. Light curve of the new detached eclipsing binary V18 in the open cluster NGC6791 (plusses). The full line shows the model fit, which yields the stellar radii with ~1% accuracy.

The age determination is illustrated in Fig. 19, which shows the strength of the Li I line at 6707.8 Å vs. the colour index (*B-V*). As indicated by the average relations for successively older clusters (top to bottom), younger stars have stronger Li lines at a given colour, and a stellar age can therefore be estimated from this diagram. Stars between the two Pleiades envelopes should be ~80 Myr old, whereas stars below the Hyades envelope are likely to be older than 600 Myr. Stars above the IC2602 envelope should be very young (10-35 Myr).

J. Maldonado, C. Eiroa, R. M. Martínez-Arnáiz, D. Montes, B. Montesinos, Madrid

Precise star cluster ages and stellar evolution tests.

Determining stellar ages is one of the most important, but also most difficult tasks in astrophysics. This is not only due to observational uncertainties, but also because theoretical stellar models are needed to obtain ages from the observations. Being able to model stars accurately is therefore indispensable.

Star clusters have long been used to test stellar models and determine ages by fitting models to the colours and magnitudes of the cluster stars. The accuracy of this method is limited by uncertainties in the distance and interstellar reddening of each cluster and in the colour-temperature calibrations, which cannot be disentangled from model uncertainties without additional information.

Detached eclipsing binary systems are also used to test stellar models, because accurate and essentially model-independent masses and radii for the stars can be measured. Because the radius can be directly compared to a model of the star for the observed mass, independently of any transformations, this is the most basic and direct test of the model. Unfortunately, an isolated binary system tests the model for two mass values only, and neither the chemical composition of the stars nor their real age is usually known, so this method has its own limitations.

However, if a binary is also member of a stellar cluster, the strengths of the two methods can be combined. In 2008, Grundahl et al. measured masses and radii of the binary V20 in the old open cluster NGC6791 and used them, and the known cluster metallicity, to show how various current stellar models led to widely different ages. However, they had insufficient information to identify the *best* model. We are now observing two newly discovered binaries in the same cluster to determine four additional masses and radii, which will help to pin down the most reliable model for the cluster stars. We plan to expand these strong tests of stellar evolution and accurate age determinations to several more clusters in which we have found multiple binaries. The "right" stellar model must fit them all!

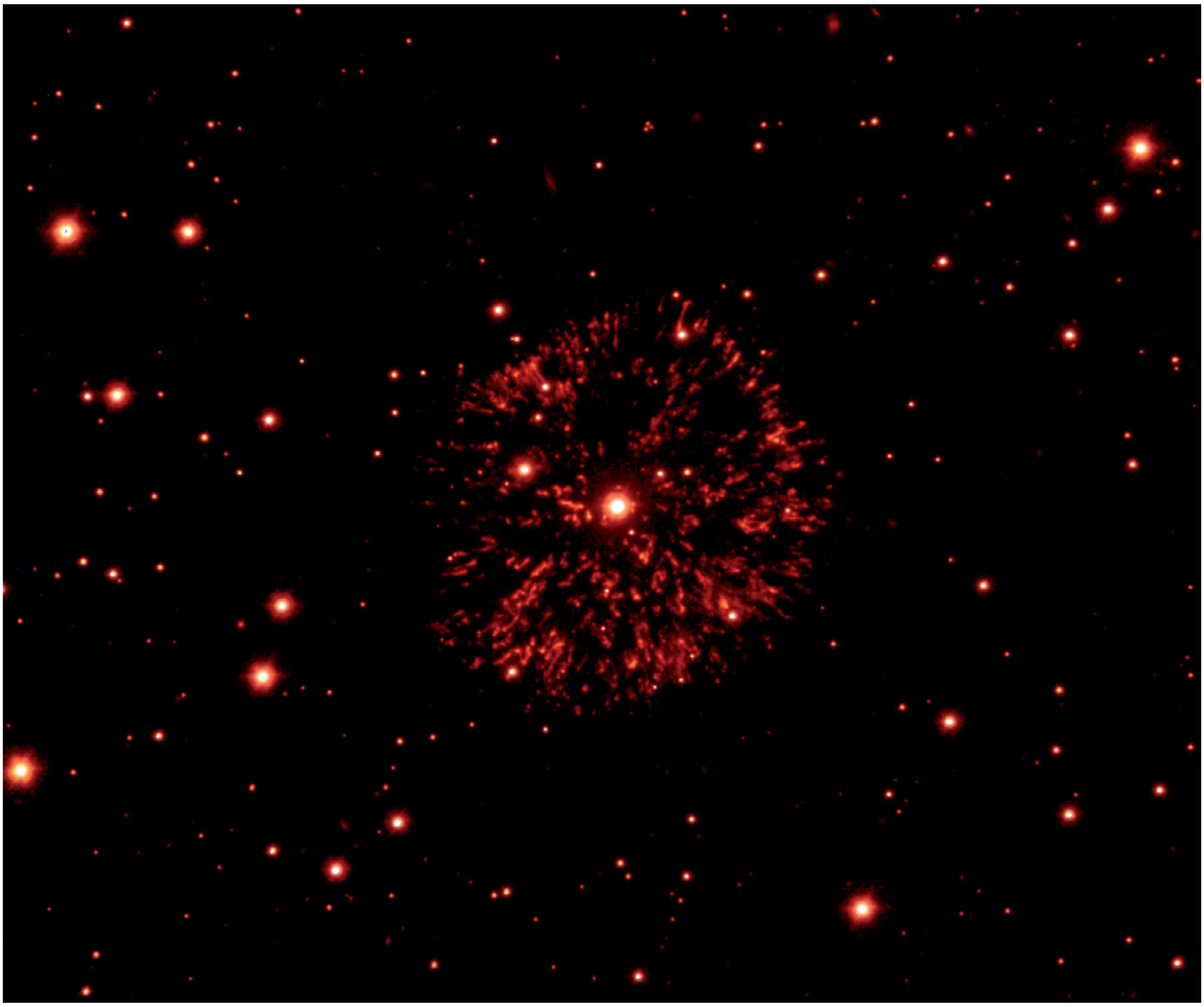
The eclipse light curves from which we measure the stellar radii must be of high quality in order to obtain accurate results. Because the stars are faint, the periods long and eclipses rare, we need a medium-size telescope with flexible scheduling in order to cover the eclipses properly. The NOT provides these essential characteristics, and we plan to rely on it in the future as well.

K. Brogaard, Aarhus

Observing stellar evolution in real time

Highly evolved cool stars tend to lose mass at a high rate. This mass loss is generally asymmetric, but we do not understand why. Even though the star itself is practically spherical during its whole life, the mass outflow near the end of its life is not. Our aim is to establish the structure and kinematics of the circumstellar matter surrounding outstanding examples of evolved stars exhibiting strong

Fig. 21. Hα image of GK Per observed with the NOT; the radius of the nebula is ~60".



outbursts. We do so by analysing light echo images of the star V838 Monocerotis, and long time-series of images and spectra of the nova remnant GK Per and the jet of the symbiotic star R Aquarii. Observations are mainly done with the NOT and ING telescopes at La Palma.

V838 Mon was discovered in early 2002, when it underwent an extreme explosion. Its brightness reached an absolute magnitude of -10, which made it, for a short time, the most luminous star in the whole Local Group of galaxies. One month after the explosion a spectacular light echo from the dust clouds around the star began to develop. With a 7-year observational history, this is now the best studied light echo in the history of astronomy.

The nova remnant GK Per (Fig. 21) is a result of a bright classical nova explosion in 1901. The remnant itself became visible 15 years after the outburst and has been observable ever since in continuum light and in emission lines. It is one of the most energetic and longest-lived nova remnants, the expansion of which is clearly visible on human time scales (1" per year).

R Aqr (Fig. 22) is a symbiotic binary system surrounded by a prominent, bright jet and a fainter hourglass-shaped nebula. Because it is nearby – 200 pc – the evolution of this jet can also be easily followed from the ground.

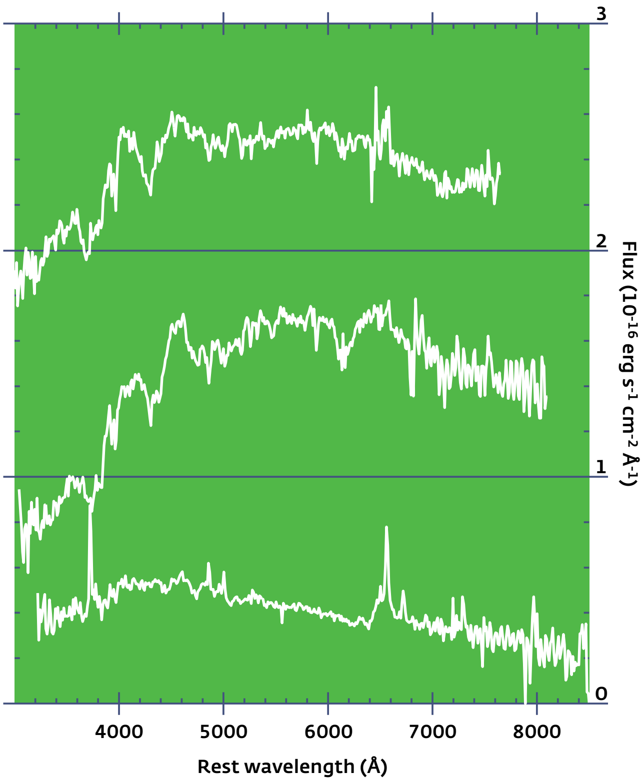
These exceptional objects give us a unique opportunity to study the expansion of stellar outflows in real time. Through multi-epoch imaging we can resolve the apparent expansion of the outflow, and thus determine the velocity component in the plane of the sky – information that can be obtained only for few stellar outflows. Combining this with radial velocity measured from spectroscopy provides the most powerful tool to determine the 3D geometry and dynamics of the outflows. This work is in progress at the moment, and we expect to see the first results in the middle of 2010.

T. Liimets, NOT; R. Corradi, La Laguna

Fig. 22. Colour image of R Aqr from the NOT in the emission lines of [OI] 6300 (pink), [OII] 3727 (blue) and [OIII] 5007 (green). The object spans 3' in the longest direction.

Classifying newly discovered Supernovae

Very massive stars end their lives when their cores collapse and the entire star explodes as a core-collapse supernova (CCSN). The rate of such SNe provides important information on a number of astrophysical processes and has important implications in the fields of galaxy evolution and cosmic star formation history.



Over the next few years, an unprecedented harvest of supernova discoveries is expected from Pan-STARRS1 (PS1), a 1.8 meter survey telescope in Hawaii. With a 7 square degree field of view and the largest digital camera ever built for astronomy, PS1 can survey the whole visible sky about every two weeks. During the next few years PS1 will provide the widest and deepest survey ever for transient sources in the local Universe, giving us an opportunity to determine the most accurate core-collapse SN rate ever in nearby galaxies, plus a wide range of other astrophysical studies. The NOT is the ideal tool for us to participate in this exiting project.

To fully exploit the potential of PS1 for SN science, a reliable spectroscopic classification for a large number of SNe is crucial, because different types of SNe have very different properties and origins. This will allow us to obtain accurate CCSN rates, also for the rarer subtypes, and the SN rate as a function of galaxy type will shed important light on massive star evolution. We have therefore started an observing programme with the NOT to classify the brightest SNe discovered by PS1 (see examples in Fig. 23).

From the spectra, particularly interesting CCSN events can also be selected for detailed follow-up using a range of ground-based telescopes. For example, one of the first PS1

Fig. 23. ALFOSC spectra of some of the first SNe from PS1. SN 2010be (top) and 2010bb (middle) are reddened type Ia SNe at z = 0.183 and 0.118; SN 2010bd (bottom) is a type II SN at z = 0.057.

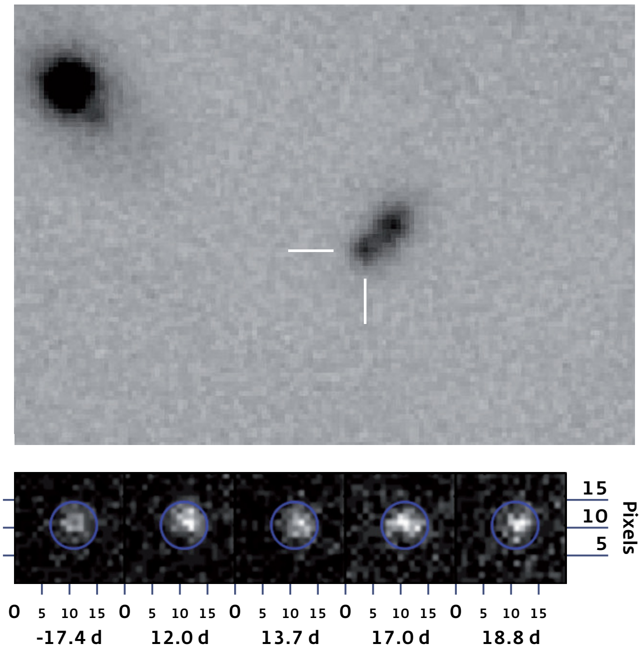


Fig. 24. Top: PS1 discovery image of SN 2009kf and its host galaxy in red light. Bottom: UV light variations as observed by GALEX, labelled with days from maximum. Note that the galaxy itself is invisible here.

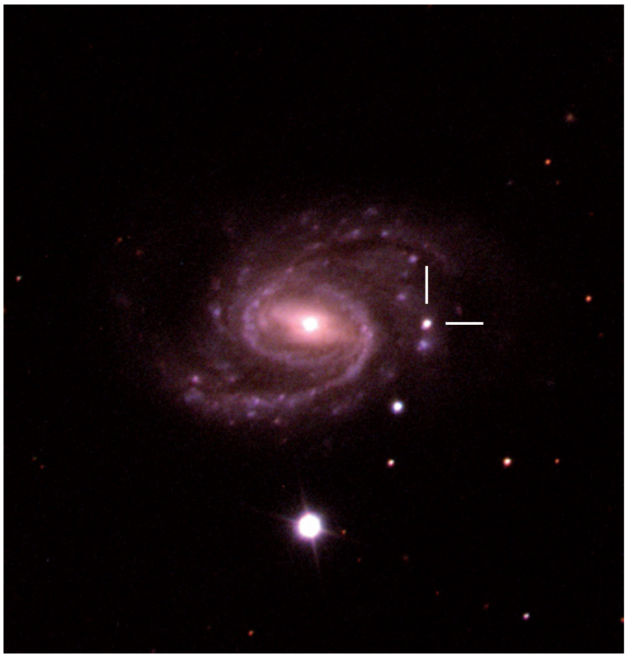


Fig. 25. SN 2009kr and NGC 1832 imaged with the NOT and ALFOSC on December 5, 2009.

discoveries (SN 2009kf), also observed with the NOT, turned out to be a very luminous type II-P (plateau) supernova and was one of the brightest SNe in the UV that is known so far (Fig. 24). Such UV bright type-II SNe have recently been discovered at z up to 2.3, so events similar to SN 2009kf could be used in the future to probe the star formation rate at high redshifts.

S. Mattila, Turku; E. Kankare, NOT and Turku; S. Smartt, M.T. Botticella, Belfast; and colleagues

The progenitor stars of core-collapse supernovae

What were the stars that we see explode as supernovae? Are red supergiants the progenitors of the hydrogen-rich type IIP supernovae? Is there an upper mass limit above which core collapse results in black holes and faint or no supernovae? These questions are best answered by directly detecting the progenitor stars in pre-explosion images, and the answers will place strong constraints on stellar evolution and core collapse theory.

A systematic search for SN progenitors has not been possible until recently, when the number of imaged galaxies in the Hubble Space Telescope (HST) archive had grown large enough. A handful of progenitors have now been identified in HST images, and the results confirm that red supergiants are the typical progenitors of type IIP supernovae. They also show that the lower mass limit for core collapse supernovae is 8 $M_\odot$ and suggest an upper limit for type IIP supernovae around 16 $M_\odot$. This upper limit is unexpectedly low, but may be explained by black hole formation. The statistics are still rather poor, but this will improve as the progenitor sample continues to grow. We added another case in 2009.

SN 2009kr was discovered in the spiral galaxy NGC 1832 on 6 November 2009. NGC 1832 is nearby (26 Mpc) and had been imaged by HST in 2008, so there was a fair chance to identify the progenitor. Indeed, an image obtained recently with the ESO VLT and adaptive optics shows that the supernova coincides with a star in the HST images (within 6 milli-arcsec). Photometry of the star shows it to be a yellow supergiant with a luminosity of ~125,000 times that of the Sun. By comparing this to stellar models we estimate the mass to be around 15 $M_\odot$, just below the suggested upper limit.

High-resolution space and adaptive optics images are required to pin down the progenitor, but smaller and more flexible telescopes are needed to characterize the actual supernova. Our Target-of-Opportunity program on core collapse SNe at the NOT contributed a substantial part of the observations of SN 2009kr (Fig. 25). The results are currently in press. More recently, we have classified and monitored another supernova for which there are HST pre-explosion images. We are now aiming to get VLT images to confirm a progenitor candidate.

M. Ergon, J. Sollerman, Stockholm; and collaborators

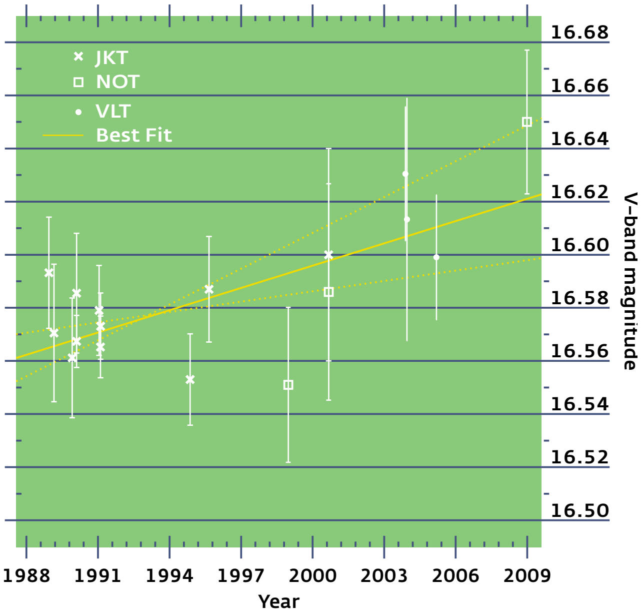


Fig. 26. Visual magnitudes of the Crab pulsar over the last two decades. Dots, crosses and squares denote data from the NOT, Kapteyn, and VLT telescopes. The lines show the best fit and its 1σ uncertainty.

Watching the Crab nebula ageing

Massive stars end their lives in violent supernova explosions, the remnants of which are a spinning neutron star (pulsar) or black hole and the gaseous remains of the rest of the star. The Crab nebula is the remnant of a supernova that exploded in the year 1054 and is one of the most intensively studied astronomical objects in history. Its central pulsar is also by far the brightest among the handful of known pulsars that can be studied in visible light, so the Crab is important for our understanding of the basic properties of young pulsars.

A pulsar is believed to convert its high rotational energy into synchrotron emission, visible as pulses with a period corresponding to the rotational period of the neutron star. The coupling between rotation and luminosity causes the pulsar to decrease in luminosity as it gradually slows down, but the effect is very small, only 0.3-0.5% per year.

This secular decrease in luminosity was first predicted in the 1970s, but was not firmly observed. We have collected archival photometric data of the region near the Crab pulsar and measured the brightness of the pulsar relative to the nearby stars with a time-span from 1988 to 2008. Our high-resolution, good seeing images from ALFOSC from 1998, 2000 and new observations though the NOT fast-track service programme from 2008, together with archival data from the Jacobus Kapteyn Telescope at La Palma and data from the VLT (Paranal, Chile), enabled us to detect a secular decrease of ~0.003 magnitudes (0.3%) per year with 95% confidence, close to theoretical predictions (Fig. 26).

Understanding the secular decrease in luminosity is one of the many important aspects of Crab pulsar research, which aims to build accurate pulsar models and understand the mechanisms behind these spectacular objects.

A. Sandberg, Stockholm

PLANETARY SYSTEMS IN THE UNIVERSE

Until just 15 years ago, the only planetary system we knew was our own. Today, planets around other stars are a booming field of research, but the Solar System remains a unique source of detailed information.

Confirming and characterising new transiting exoplanets

Over 400 planets around other stars (exoplanets) have been found since the first discovery in 1995. Some 60 of them are seen transiting the disks of their parent stars (see Fig. 27), which makes it possible to determine both the mass and radius, hence the density of the planet directly as a guide to modelling its origin. Detecting the tiny brightness dips of the host star caused by the transit of a planet is best done from space, notably with the unprecedentedly accurate data from the Kepler satellite, launched in 2009. However, ground-based spectroscopic observations remain necessary to confirm the planetary origin of the observed transit signature and to determine the physical properties of the host star, such as its size, temperature, chemical composition and age.

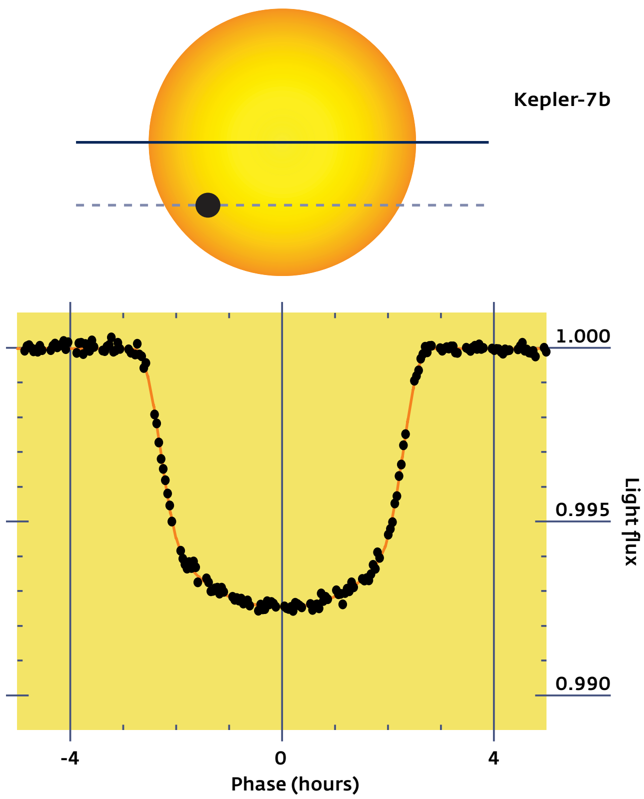


Fig. 27. Top: The transit of the planet Kepler-7b in front of its host star, shown to scale. Bottom: The Kepler observations and computed light curve of the transit.

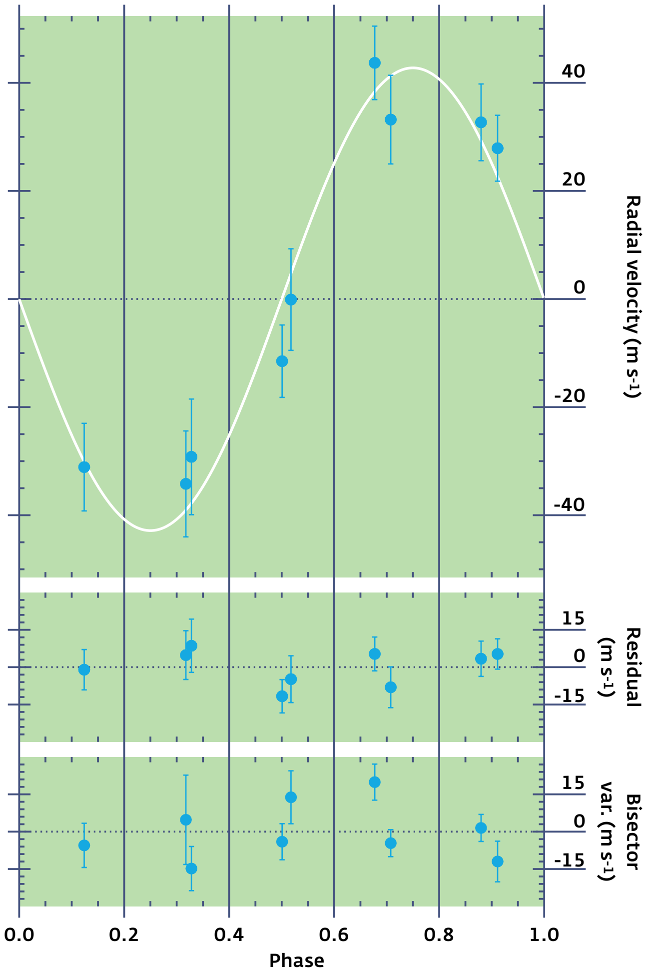


Fig. 28. Radial velocity curve from FIES for the Kepler-7b host (top), residuals from the computed orbit (middle), and changes in mean line asymmetry (bottom). The mean velocity residual is only 7.4 m s−1 despite the faintness of the star (V = 13.0).

The NOT and FIES perform a significant part of this ground-based Kepler follow-up programme. First, quick reconnaissance spectra are obtained to weed out non-planetary astrophysical systems mimicking planetary transits, such as eclipsing binaries blended with a much brighter third star. If a planet candidate survives this step, we proceed to take high signal-to-noise spectra to determine the orbit and mass of the planetary companion. This is a slow process, which effectively limits the rate at which exoplanet discoveries from Kepler can be confirmed and published.

Among the early NOT contributions to this programme is the orbit of the exoplanet Kepler-7b (Fig. 28), which has a mass of 0.43 M_{Jup} and a radius of 1.48 R_{Jup} (Jupiter units). Its bulk density is only 0.16 g cm^{-3} (like cork!), making it one of the least dense planets known .

L. Buchhave, Copenhagen;
and the Kepler Follow-up Team

An exoplanet detected with SOFIN

While monitoring the light of an RR Lyr variable star, we realised that another star in the field, a close visual binary, was also variable. FIES spectra showed that both stars are magnetically active, and their strong Li lines confirm that both are also young, ~25 Myr. One, TYC~2627-638-1A, showed larger rotational broadening of the spectral lines than its companion, so we obtained 14 SOFIN spectra of it in August-September 2009. Indeed we found radial velocity variations indicating that this star has a companion (Fig. 29), but the variations were too small to be caused by a normal star.

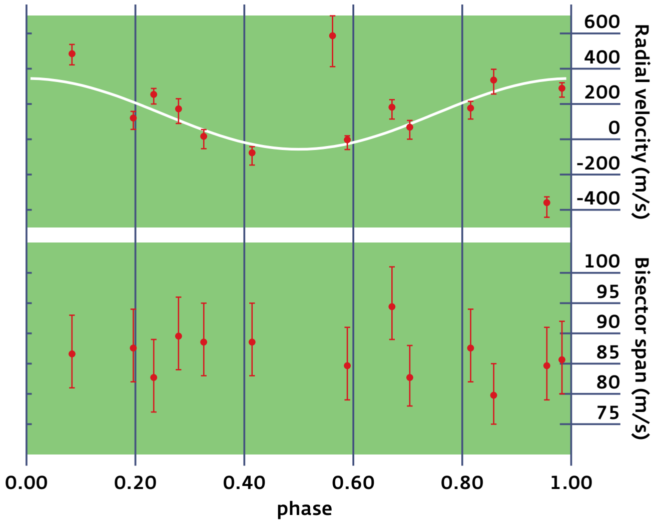


Fig. 29: Observed radial-velocity curve and line asymmetries ('bisector span') for TYC~2627-638-1A over the orbital period.

Without knowing the orientation of the orbital plane it is impossible to estimate the mass of the companion, but the significant light variations caused by star spots imply that the star is not seen pole-on. Moreover, the well-determined orbital period of 1.59±0.02 days is different from that seen for the spots (3.5-3.7 days), and the mean line asymmetry does not change with orbital phase as is expected for spots. If we assume an inclination of at least 15°, we get an upper limit of 5 M_{Jup} for the mass of the unseen companion.

H. Korhonen, ESO; I. Ilyin, S. Järvinen, Potsdam;
K. Oláh, Konkoly; M. Andersen, Munich

Orbital evolution of extrasolar planets

The discovery that 51 Peg b, the first planet found orbiting a Sun-like star, is unlike any in our Solar System was a great surprise: It is similar in size to Jupiter, but resides roughly 10 times closer than Mercury to its host star. Since then, ~100 of these so-called hot Jupiters have been found, about a quarter of all known exoplanets.

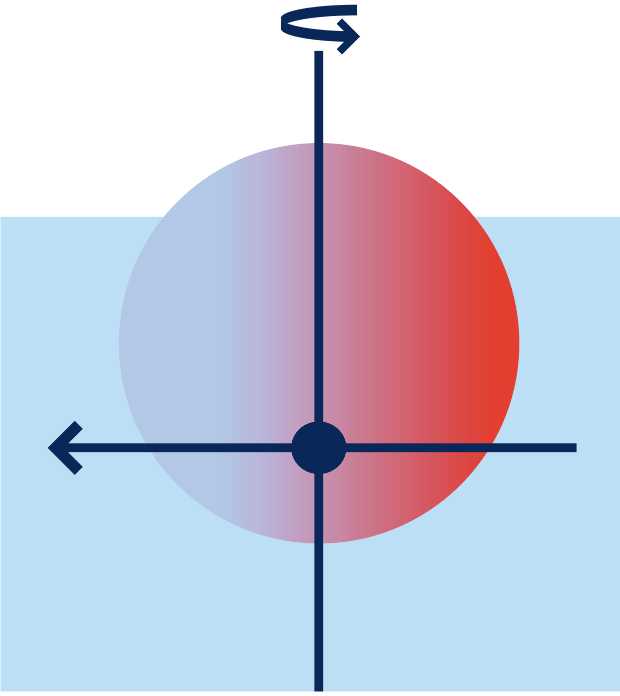


Fig. 30: A retrograde exoplanet transiting a rotating star. The planet first passes over the receding (red) half of the star, blocking a red part of the spectral line and making it appear blue-shifted (negative radial velocity). The opposite happens in the second half of the transit.

The hot Jupiters pose a serious challenge to our understanding of planetary systems. Theory predicts that Jupiter-size planets form far from the star where there is enough cool material to create large bodies. So how do hot Jupiters form? It is thought that they do form far from the star, but then migrate inwards later, and several different mechanisms have been proposed. The degree of alignment between the planet's orbit and the rotation axis of the star is one clue to distinguish between them, and this can be measured if the planet is seen to transit in front of its host star (see Fig. 27). When this happens, the planet blocks out a small fraction of the light from the rotating disk of the star (Fig. 30) and not only makes it appear a bit dimmer, but also distorts the shape of the spectral lines.

By measuring the mean shift in the position of the lines caused by this distortion, the so-called Rossiter-McLaughlin (RM) effect, we can reconstruct the trajectory of the planet across the stellar surface (Fig. 31). In 2009, we used FIES to observe the RM effect in several systems, and an initial analysis shows that a variety of migration histories are at work. One system even seems to orbit the star in the opposite direction to its rotation (retrograde) as in Fig. 30, suggesting that a collision with another planet may have occurred.

E. Simpson, D. Pollacco, Belfast; P. Sørensen, NOT; I. Skillen, ING

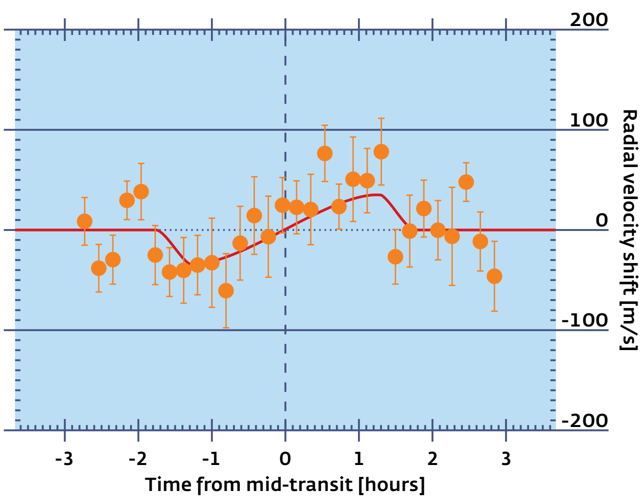


Fig. 31: Net radial-velocity change during the transit shown in Fig. 30.

Probing exoplanetary atmospheres with polarimetry

Most of the known extrasolar planets have been discovered through their effect on their host stars, such as radial velocity or brightness changes (see above). However, direct detection of the light from exoplanets, enabling a study of their physical properties, remains a challenge. Thus far, atmospheres have been detected only around a few transiting and a single non-transiting planet, using transmission spectra during transit or far-infrared thermal emission during secondary eclipse as detected by the *Spitzer* space telescope.

Here we employ polarimetry to directly probe the atmospheres of both transiting and non-transiting exoplanets. Starlight scattered in a planetary atmosphere carries information on its geometry, chemistry, structure, and thermo-dynamics (Fig. 32). In general, as the planet orbits its parent star, the scattering angle changes and the Stokes parameters characterising the polarized light vary with two peaks per period near maximum elongations for a circular orbit (Fig. 33). Therefore, variable polarization indicates the period, inclination, eccentricity, and orientation of the orbit, even if it is seen nearly face-on. Thus, uniquely, polarization data can constrain the inclination and

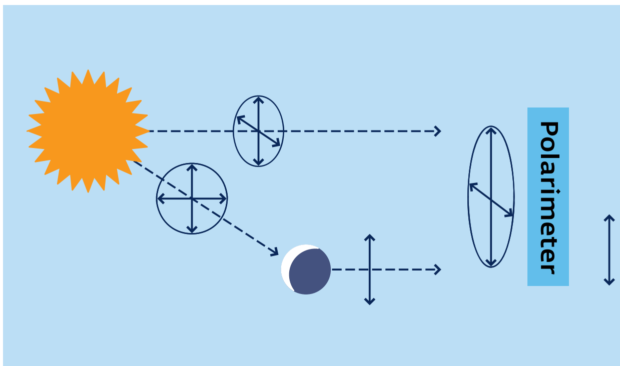


Fig. 32. Part of the unpolarized light from a star is scattered towards the observer by a planet and becomes linearly polarized perpendicular to the scattering plane. The observer can infer the existence and properties of the planet from the partially polarized light of the unresolved star-planet system.

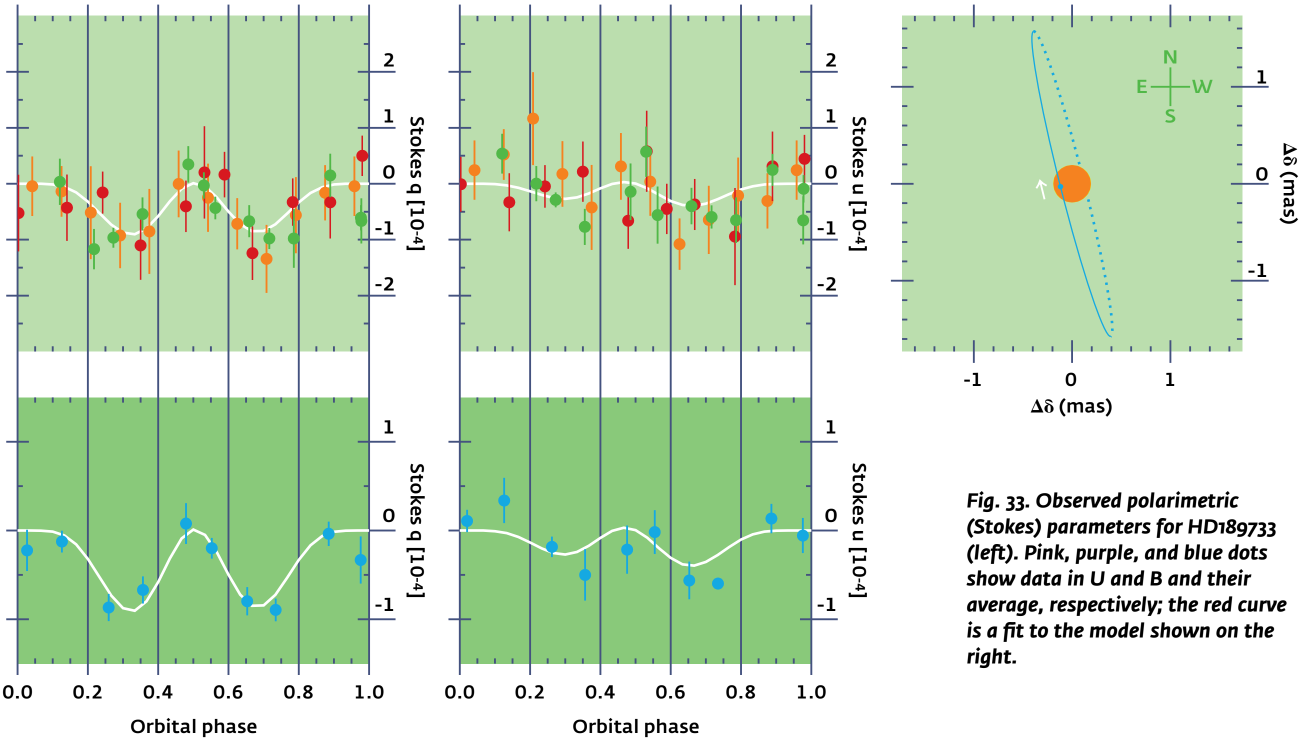


Fig. 33. Observed polarimetric (Stokes) parameters for HD189733 (left). Pink, purple, and blue dots show data in U and B and their average, respectively; the red curve is a fit to the model shown on the right.

masses also of non-transiting planets, help to distinguish between gas giants and rocky planets, and give clues to the chemical composition and structure of the planetary atmosphere and surface.

In 2008 we started a polarimetric survey of nearby exoplanetary systems with hot Jupiters, using TurPol at the NOT. TurPol is the most accurate night-time polarimeter in the world at blue wavelengths, achieving an accuracy of 10^{-5} on a nightly basis – enough to detect the light reflected from an exoplanet. It is still challenging to obtain complete orbital phase coverage, and we are grateful for several generous time allocations at the NOT.

One of our targets is the transiting, very hot Jupiter HD189733b with an orbital period of only 2.2 days. Its atmosphere was first detected by transmission spectroscopy, and signatures of methane and water were detected in the infrared, but no significant spectral features were seen in the optical. An upturn in the blue was interpreted as the effect of a haze layer in the atmosphere. Our accurate observations of HD189733 in near-UV, blue and green light confirm the existence of significant polarization, which varies as expected with orbital phase and wavelength (Fig. 33-34).

A detailed model of the planetary atmosphere that fits all the data well indicates that the light is predominantly scattered by dust particles of about 20 nm size at a height of about 83,400 km in the atmosphere, resembling the high cloud deck seen in some planets in the Solar system. This result establishes polarimetry as a reliable means for direct study of exoplanet atmospheres.

S. Berdyugina, Freiburg & Turku; A. Berdyugin, V. Piirola, Turku; D. Fluri, Zurich

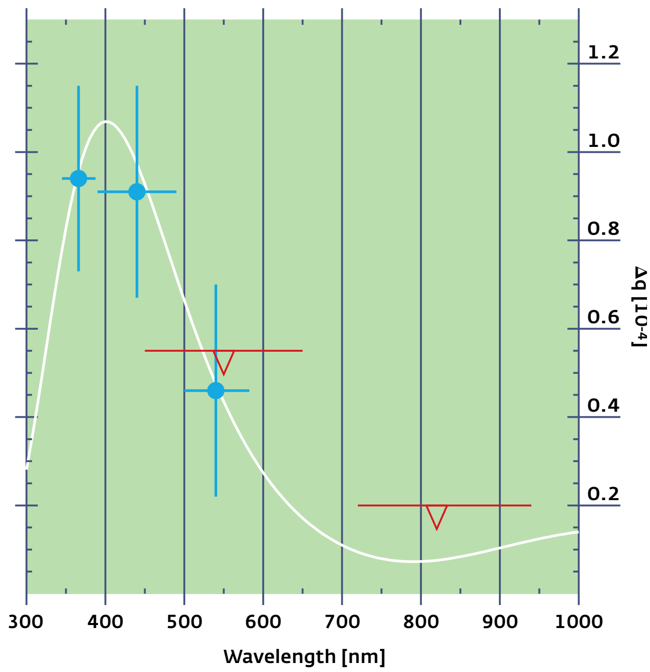


Figure 34. Wavelength dependence of the polarization amplitude in HD189733. Blue dots: Our new UBV data; triangles: upper limits from previous work. The red curve corresponds to the model described in the text.

New insights into the meteorite-asteroid connection

Asteroids (or minor planets) are the small remnants of the building blocks of the Solar System – the constituents of planetary systems that can not be studied elsewhere. Most asteroids are located in the Main Belt (MB) between the orbits of Mars and Jupiter, but some have orbits that approach the Earth, the so-called Near-Earth Asteroids (NEAs). Apart from the small risk of an impact in the future, analysis of the physical properties and surface composition of NEAs is important for our understanding of the initial conditions of the solar nebula.

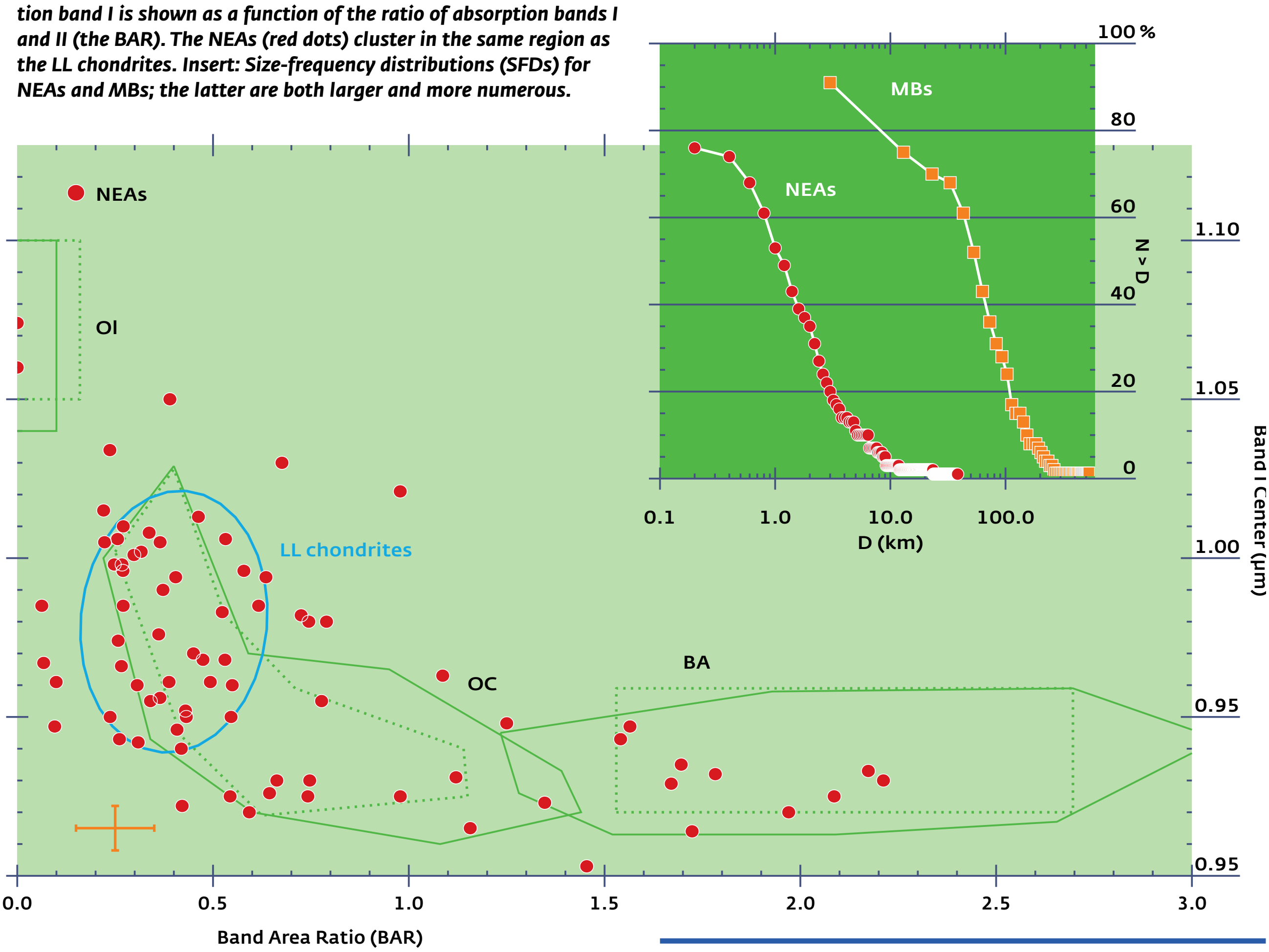
Due to the nature of their orbits, NEAs are also the most likely parent bodies of meteorites, which can be studied in detail in the laboratory. Dynamical models show that NEAs come primarily from the inner and central parts of the MB and are deflected towards the Earth by gravitational interaction with other bodies in that region. The spectra of the largest subgroup of both MBs and NEAs show characteristic absorption bands from silicates near 1 and 2 μm, which can be used for mineralogical analyses. These absorption bands are also seen in the most abundant class of meteorites, the so-called ordinary chondrites (OCs), so it is of particular interest to understand the link between OCs, NEAs and MBs.

As part of J. de León's thesis project, we therefore undertook a survey of the visible and near-infrared spectra of 105 near-Earth asteroids, using the NOT and ALFOSC for the visible spectra. A mineralogical analysis based on these spectra showed that MBs and OCs have similar compositions, as expected. Surprisingly, however, the NEAs were much richer in olivine than OCs and more similar to the small subgroup of LL chondrites, which constitute only 8% of all meteorites (see Fig. 35). Furthermore, about 50% of the NEAs come from the inner part of the MB, where the asteroids are also olivine-rich.

The sizes of these objects are a clue to this difference (Fig. 35): The known NEAs are typically one kilometre in size, so powerful gravitational resonances are needed to deflect them towards the Earth, while non-gravitational (thermal) forces can help the much smaller and more numerous meteorites to reach us from the entire main belt.

J. de León, J. Licandro, M. Serra-Ricart, N. Pinilla-Alonso, H. Campins, IAC

Fig. 35. Spectral classification of asteroids. The strength of absorption band I is shown as a function of the ratio of absorption bands I and II (the BAR). The NEAs (red dots) cluster in the same region as the LL chondrites. Insert: Size-frequency distributions (SFDs) for NEAs and MBs; the latter are both larger and more numerous.



With the main effort in rejuvenating the telescope infrastructure and streamlining the operation of the instrumentation behind us at the end of 2008, 2009 was mostly a year of consolidation. A few highlights are mentioned here.

Removing the secondary mirror with the telescope horizontal...

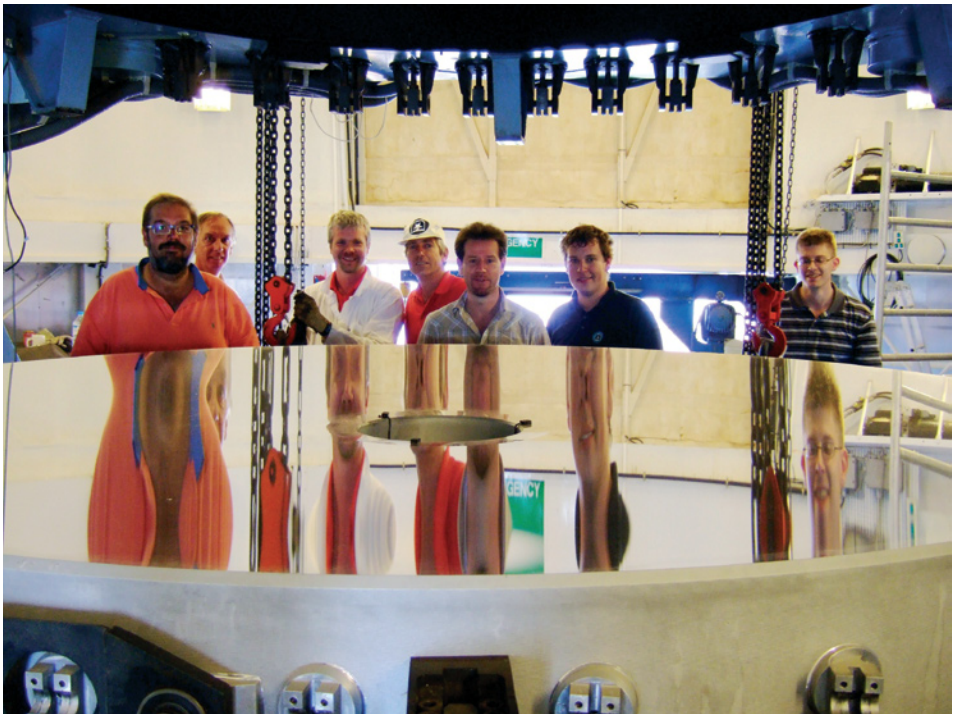
Telescope

The major task undertaken in 2009 was the aluminisation of both telescope mirrors, for the first time since 2002 in the case of the secondary mirror. The entire operation went smoothly and in record time – three days only – after careful preparation. One thing we learned was that, while an elaborate procedure and appropriate tools for removing and installing the primary mirror had been provided when the telescope was built, this was not the case for the secondary, resulting in some initial decentering coma when the telescope was pointed at the sky again. This was quickly corrected, and a proper procedure for measuring and recovering the position of the mirror is now in place for next time.

Instrumentation

The fast next-generation detector array controller under development at Copenhagen University since some time was successfully tested at the NOT in the spring of 2009. In parallel, a coordinated project was initiated at the NOT to develop a user interface for efficient, integrated control of the telescope, instrument, and detector with a similar "look and feel" as the one our users have come to appreciate. External interest in the system is keen, so we have signed a contract with the Niels Bohr Institute for the production of a series of these units for delivery in 2010, and to deliver our spare mosaic CCD camera with the new controller to a Russian observatory. We hope to use the funding generated from this production to upgrade some of our CCDs. This should complete the modernisation programme of the NOT and its instrumentation, but further developments in capability and efficiency are foreseen, partly in cooperation with Chinese colleagues.

In parallel, FIES was provided with a new fibre bundle, offering improved throughput and a working sky background fibre. The thermal control of the building has also been improved, and the temperature is now very stable. On NOTCam, the cooling system is now working so well that, at the time of this writing, the instrument has been kept continuously cold for over a year.



- then the primary with the telescope vertical.

Finally, development of the sequencer system has continued, in particular with the addition of instrument-specific telescope setup scripts that greatly simply the changeover from one instrument to another, e.g. when a Target of Opportunity needs a different setup than that used by the scheduled observer.

The night we thought we would discover a new supernova…

Students and faculty at the NOTSA-OSO summer school at Tuorla.

General

As part of our efforts to define the future role of the NOT in European astronomy, we have developed a suite of educational offers for students at levels from high school to PhD. These services range from on-site and off-site observing courses, the latter by remote observing from any suitable classroom in the world, to our Research Studentships where students spend of order one year in hands-on training on La Palma. A general overview of these services was given in the Annual Report for 2008 (p. 22-25), with highlights in earlier issues.

In 2009 we went a step beyond our traditional field of optical and near-infrared (NIR) observations: A decade from now, astronomers will have access to a full range of ground- and space-based observing facilities from X-rays to radio waves, and a multi-wavelength approach will be essential to derive the best science. Moreover, Nordic astronomers will be able to use front-line optical, infrared and millimetre facilities through the European Southern Observatory (ESO) and space-based observatories through the European Space Agency (ESA).

NOTSA and Onsala Space Observatory (OSO), Sweden, decided to spearhead this development at the Nordic level and were able to jointly secure financial support from NordForsk. As the first major and most visible part of this initiative, we organised a Nordic Research Infrastructure Training Course together with Tuorla Observatory, Turku, Finland, during the period June 8-18, 2009. Under the title *Star Formation in the Milky Way and Nearby Galaxies*, it offered hands-on observations (in remote mode) with the NOT at optical and NIR wavelengths and with the 20-m Onsala radio telescope at millimetre wavelengths.

21 Nordic and Baltic students (of 11 nationalities) were selected from 62 applicants and grouped into five teams focusing on one project each, all using the full range of instrumentation in half-night observing sessions. During daytime, lectures on the theory of star formation and on the reduction and interpretation of the observations were given by an international group of experts, and the project reports were prepared in the format of research papers for a major international journal. The course was demanding, rated at the equivalent of 6 ECTS, but the students were enthusiastic and hard-working and clearly enjoyed themselves, as also noted in their detailed course evaluations. A sauna and salmon barbecue party on the weekend further enlivened the proceedings.

The experience from the course was collected in a “cookbook” by our NordForsk-supported postdoc, Raine Karjalainen, as a basis for improving the planning of future courses. It has already been used to plan the 2010 course at Onsala, successfully completed at the time of this writing, and will be used again for the next course in 2011.

Meanwhile we continue our regular on-site course activities and maintain the research student programme at full strength. Persons wishing to arrange an observational course at or with the NOT should contact the Director at least a year in advance to agree on the schedule and any additional formalities. Practical information can also be obtained from Deputy Director Thomas Augusteijn (tau@not.iac.es).

The 2009 NOT student group.

Observing time is the key scientific asset of a telescope. Competition for time is strong, so the review and allocation process must be seen as competent, transparent, and impartial.

Time allocation procedure

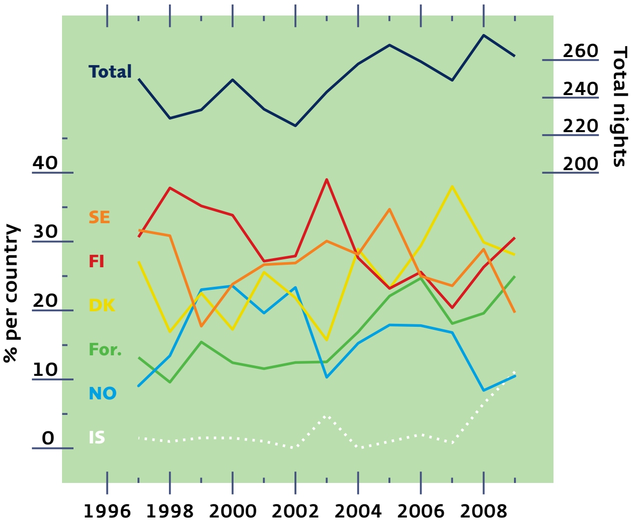
Calls for Proposals for observing time at the NOT are announced widely, with proposal deadlines on the first working days of May and November for the semesters beginning the following October 1 and April 1. In addition, projects needing up to 4 hours of observing time can be proposed at any time and reviewed quickly by a simple 'Fast-track' procedure; (see *http://www.not.iac.es/observing/proposals/*). If approved, projects are then executed in queue mode by NOT staff on the first available of several regularly scheduled service nights.

An *Observing Programmes Committee* (OPC; see inside back cover) of five independent Nordic scientists is appointed by the Council to peer review all observing proposals. The OPC ranks the proposals on a numerical scale and advises applicants on potential improvements; technical feasibility is assessed by the NOT staff, with separate feedback to proposers. Each OPC member has a substitute to broaden scientific coverage and resolve any conflicts of interest. Based on the ranking and various practical constraints (object visibility, Moon phase, etc.) the Director then drafts a schedule, which is checked by the OPC before it is finalised.

To encourage competition and raise scientific standards, proposals are reviewed on an equal footing, regardless of national origin, and "foreign" interest in NOT is keen, also via the OPTICON trans-national access programme (see *http://www.astro-opticon.org/fp7/tna/*). With proper coordination, observing time on most or all European 2-4m telescopes could be allocated through OPTICON, but the modest funds available in the FP7 contract limit progress towards this goal, and unpaid "foreign" time at the NOT cannot grow indefinitely.

Observing time in 2009

Observing statistics are compiled by allocation period, so this report covers the year April 1, 2009, to April 1, 2010. The *"pressure factor"* (nights requested/nights available) was 2.0. In total, 314 nights were used for scientific observations, including the 25% of all time that is reserved for Spanish and CCI international projects. 245 nights were available to the Nordic community, including training courses (10 nights). 17 nights or 6% were allocated to projects by NOT staff and 65.5 nights or 25% to non-Nordic ("foreign") projects; only 12 of these nights were refunded as OPTICON access time. The remaining Nordic time was then distributed as follows: Denmark 50 nights (28%), Finland 55 (31%), Iceland 20 (11%), Norway 20 (11%), and Sweden 35.5 (20%), assigning "nationality" by the affiliation of the P.I.



Total nights allocated annually by NOT in 1997-2009 (top), and the Nordic and "foreign" shares.

Instrument use was as follows: ALFOSC 140 nights (38%), FIES 109.5 (30%), NOTCam 37.5 (10%), MOSCA 22 (6%), SOFIN 21 (6%), TurPol 18 (5%), and visitor instruments 17 nights (5%). The demand for FIES continues to increase, also for fast-track projects, so the demand for bright time now equals that for dark time.

Service observing was provided on a total of 96.5 scheduled service nights in 2009, a dramatic increase from 2008, as well as on parts of many technical and visitor nights. The "fast-track" service proposal system remains in heavy demand, with a total of 32 accepted proposals in 2009; 22, 7, and 3 of these were rated as Grade 1, 2, and 3, respectively (1 is highest). Projects remain in the queue for up to three semesters (two observing seasons) if necessary, and all projects older than this have been completed. Overall, the numbers of fully or partly completed projects are now, for Grade 1: 36 out of 45; Grade 2: 16 out of 19; and Grade 3: 2 out of 4. Note that many of the pending proposals were submitted only recently, and several have been completed at the time of writing.

The national distribution of time fluctuates considerably over time because observing time is allocated by scientific merit, not as national quotas set by the budget (see figure). Over the last five years, the Nordic time was shared with 30% to Danish projects, 25% to Finland, 4% to Iceland, 14% to Norway, and 27% to Sweden.

Photo: H. Dahle

FINANCIAL MATTERS

NOTSA is a non-profit organisation funded to operate NOT as a tool for Nordic astronomy. Annual budgets are approved by the Council, and the Director is responsible for managing the operation within budget as specified in the *Financial Rules*. NOTSA's accounts for 2006-2009 were audited by the *National Auditing Office of Iceland*, assisted by a Swedish auditor to comply with Swedish regulations.

Accounts for 2009

NOTSA's accounts and budget for 2009 are summarised and compared with the accounts for 2008 in the table below. Budget headings cover the following items:

Directorate: Directorate staff and operations, committee travel, bank charges, stipends to Spanish Ph.D. students at Nordic universities, OPTICON, ASTRONET, and NordForsk activities, and the Annual Report.

La Palma staff: Salaries, social charges and training courses, etc. for all staff and students on La Palma.

La Palma infrastructure: Telescope and office facilities; electricity, water and cleaning; computers and 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 spare parts for the telescope and instruments; cryogenics, electronics, optics, and data acquisition and archiving equipment.

Development projects: Major telescope or instrumentation projects.

Contributions: A *basic contribution* of € 1 376 350 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* of € 247 100 brought the total to the number shown.

Other income: Includes bank interest (low in 2009), EC refunds for OPTICON access time, etc.

Financial result of 2009

As seen in the table, expenses and income in 2009 were essentially as budgeted, except that the 122 k€ for telescope developments (new detector systems, in particular) were delayed to 2010. Thus, of the reserves at the end of 2009, 90 k€ are already committed to complete these projects and another ~40 k€ to the postdoc salary for which funding was received from NordForsk already in 2008.

FINANCES

BUDGET LINE	Expenses 2009 Euro	Budget 2009 kEuro	Expenses 2008 kEuro
Directorate	249 657	269	228
La Palma staff	1 217 009	1 212	1 147
La Palma infrastructure	174 001	165	186
La Palma operations	132 881	149	122
Telescope operation and maintenance	16 947	37	28
Instrument operation and maintenance	37 879	48	26
Telescope development projects	969	122	0
Special development projects	0	0	8
Total expenses	**1 829 344**	**2 002**	**1 744**
Contributions	1 623 450	1 624	1 582
Other income	146 282	142	253
Total income	**1 769 732**	**1 766**	**1 835**
Result of the year	**-59 611**	**-237**	**91**
Reserves at beginning of the year	449 776	450	359
Reserves at end of the year	390 164	213	450

Photos: Paul A. Wilson

Publications are the standard indicator of scientific output, and lists of refereed papers based on NOT data are given at http://www.not.iac.es/news/publications. Papers published in 2009 are listed below; for papers with 9 or more authors, the first six names and the total number are given.

International refereed publications

Acciari, V.A., Aliu, E., Aune, T., Beilicke, M., Benbow, W., Böttcher, M. et al. (168 authors): *Multiwavelength observations of a TeV-flare from W Comae*, 2009, ApJ **707**, 612

Amorán, R., Aguerri, J.A.L., Muñoz-Tuñón, C., Cairós, L. M.: *The host in blue compact galaxies. – Structural properties and scaling relations*, 2009, A&A **501**, 75

Ascaso, B., Aguerri, J.A.L., Moles, M., Sánchez-Janssen, R., Bettoni, D.: *The bright galaxy population of five medium redshift clusters. II. Quantitative galaxy morphology*, 2009, A&A **506**, 1071

Botticella, M.T., Pastorello, A., Smartt, S.J., Meikle, W.P.S., Benetti, S., Kotak, R. et al. (34 authors): *SN 2008S: an electron-capture SN from a super-AGB progenitor?*, 2009, MNRAS **398**, 1041

Butters, O.W., Katajainen, S, Norton, A.J., Lehto, H.J., Piirola, V.: *Circular polarization survey of intermediate polars I. Northern targets in the range 17h<R.A.<23h*, 2009, A&A **496**, 891

Catelan, M., Grundahl, F., Sweigart, A.V., Valcarce, A.A.R., Cortés, C.: *Constraints on helium enhancement in the globular cluster M3 (NGC 5272): The Horizontal Branch Test*, 2009, ApJ **695**, L97

Cedrés, B., Iglesias-Páramo, J., Vílchez, J.M., Reverte, D., Petropoulou, V., Hernández-Fernández, J.: *Star-forming galaxies in the Hercules cluster: Hα imaging of A2151*, 2009, AJ **138**, 873

Christian, D.J., Gibson, N.P., Simpson, E.K., Street, R.A., Skillen, I., Pollacco, D. et al. (40 authors): *WASP-10b: a 3*M_J*, gas-giant planet transiting a late-type K star*, 2009, MNRAS **392**, 1585

Creevey, O.L., Uytterhoeven, K., Martín-Ruiz, S., Amado, P. J., Niemczura, E., van Winckel, H. et al. (28 authors): *HD 172189: another step in furnishing one of the best laboratories known for asteroseismic studies*, 2009, A&A **507**, 901

Dado, S., Dar, A., De Rújula, A.: *The diverse broadband light curves of Swift Gamma-Ray Bursts reproduced with the Cannonball model*, 2009, ApJ **696**, 994

Del Moro, A., Watson, M. G., Mateos, S., Akiyama, M., Hashimoto, Y., Tamura, N., Ohta, K., Carrera, F. J., Stewart, G.: *An extreme EXO: a type 2 QSO at z = 1.87*, 2009, A&A **493,** 445

Desmet, M., Briquet, M., Thoul, A., Zima, W., De Cat, P., Handler, G. et al. (17 authors): *An asteroseismic study of the beta Cephei star 12 Lacertae: multisite spectroscopic observations, mode identification and seismic modelling*, 2009, MNRAS **396**, 1460

Féron, C. Hjorth, H., McKean, J.P., Samsing, J.: *A search for disk-galaxy lenses in the Sloan Digital Sky Survey*, 2009, ApJ **696**, 1319

Ferrero, P., Klose, S., Kann, D.A., Savaglio, S., Schulze, S., Palazzi, E. et al. (19 authors): *GRB 060605: multi-wavelength analysis of the first GRB observed using integral field spectroscopy*, 2009, A&A **497**, 729

Fossati, L., Ryabchikova, T., Bagnulo, S., Alecian, E., Grunhut, J., Kochukhov, O., Wade, G.: *The chemical abundance analysis of normal early A- and late B-type stars*, 2009, A&A **503**, 945

Fynbo, J.P.U., Jakobsson, P., Prochaska, J.X., Malesani, D., Ledoux, C., de Ugarte Postigo, A. et al. (42 authors): *Low-resolution spectroscopy of Gamma-ray Burst optical afterglows: Biases in the Swift sample and characterization of the absorbers*, 2009, ApJS **185**, 526

González Hernández, J.I. Iglesias-Groth, S. Rebolo, R., García-Hernández, D.A., Manchado, A., Lambert, D.L.: *The chemical composition of Cernis 52 (BD+31° 640)*, 2009, ApJ **706**, 866

Guidorzi, C., Clemens, C., Kobayashi, S., Granot, J., Melandri, A., D'Avanzo, P. et al. (34 authors): *Rise and fall of the X-ray flash 080330: an off-axis jet?*, 2009, A&A **499**, 439

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Teide at dawn, seen from the NOT.
Photo: Paul A. Wilson.

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***Back cover:** The nearby starburst galaxy Messier 82, imaged with the NOT and ALFOSC in blue and red light as well as in the Hα emission line by the winners of the Nordic IYA2009 essay competition and NOT student Paul A. Wilson (see p. 4).*

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NORDIC OPTICAL TELESCOPE

The starburst galaxy Messier 82

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