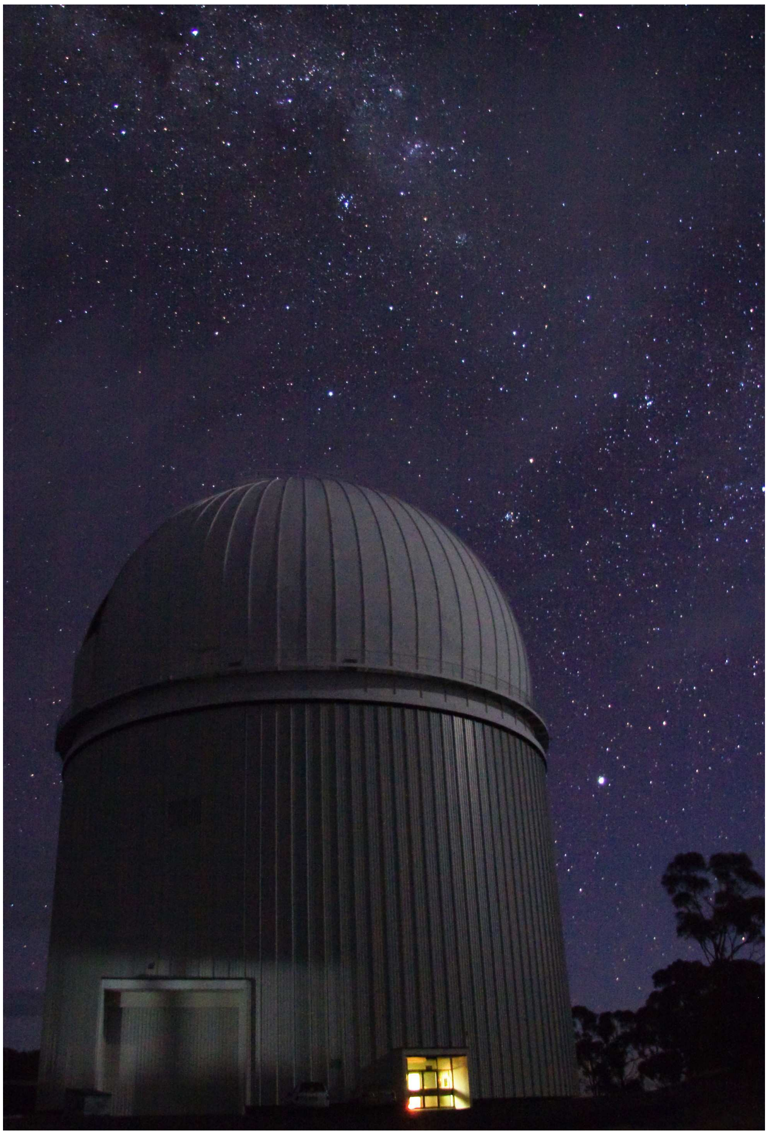
NUMBER 114 AUGUST 2008

AAO NEWSLETTER

ANGLO-AUSTRALIAN OBSERVATORY

The world’s top-ranked 4-metre telescope



A recent study has shown that the AAT is the world's no. 1-ranked 4-metre optical telescope in terms of both scientific productivity and impact. See page 2 for further details. (Photo courtesy of Barnaby Norris)

contents

DIRECTOR'S MESSAGE

What is the scientific lifetime of the AAT? How long can a 4-metre telescope on a mediocre site remain competitive with larger, more modern telescopes on the best sites in the world? This question arises in a general way as the AAO makes the transition from being a bi-national observatory supporting the AAT to being a national observatory supporting all the optical telescopes accessed by Australian astronomers. It is also one of the specific questions being addressed in September 2008 by an international review committee convened by Astronomy Australia Limited to review future investment in optical facilities.

The AAT has a remarkable track record of scientific productivity and impact. The most recent comprehensive study of the astronomical literature (Trimble & Ceja, 2008, Astron. Nachr., 329, 632) examined the productivity (number of papers) and impact (number of citations) of all major telescopes based on publications over the three years 2001 to 2003. The study shows that the AAT is the #1-ranked 4-metre optical telescope in the world in both productivity *and* impact, achieving 2.3 times as many citations as its nearest competitor. Furthermore, amongst optical telescopes of *any* size, on the ground or in space, the AAT is ranked #5 in productivity (behind HST, Keck, VLT & 2MASS) and also #5 in impact (behind HST, Keck, VLT & SDSS). This is an extraordinary achievement.

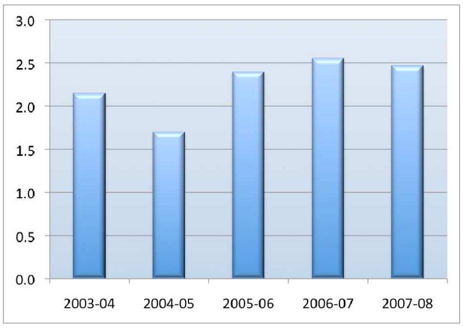


Figure 1: AAT over-subscription rate

At present the AAT represents over half of Australia's optical telescope capability. This capability currently comprises an 85% share of the AAT together with a 6.2% share of the two Gemini 8-metre telescopes and 15 nights per year on the two Magellan 6.5-metre telescopes. Using the product of telescope aperture and nights per year as an indicator of scientific capability, the AAT represents 58% of current capability. By 2010 Australia will have 100% of the AAT, and may have doubled its share in Gemini while maintaining the current level of access to Magellan. In this case the AAT will still represent 48% of national optical capability, and will continue to provide 80% of the nights available to Australian astronomers on large telescopes.

Demand for AAT time remains strong. As Figure 1 shows, the over-subscription rate has hovered around 2.5 since AAOmega came on-line in January 2006. The productivity of the AAT likewise maintains a very high level. As Figure 2 shows, observational data obtained with the telescope has led to between 80 and 110 papers in each of the last 7 years. As the WiggleZ and GAMA Large Programs come to maturation over the next couple of years, the number of papers is expected to push the upper end of this range. (The WiggleZ survey is described in AAO Newsletter 110, August 2006, page 3; the GAMA survey is described on page 3 of this Newsletter.)

The AAO believes that the AAT can maintain this high level of productivity and impact for another decade. We are currently investing $4 million in refurbishing the telescope to ensure that it can operate reliably and efficiently for another ten years, and more than $6 million in a major new instrument, the 400-fibre HERMES high-resolution spectrograph (see AAO Newsletter 113, February 2008, page 21). The primary science drivers for HERMES are 'Galactic archaeology' surveys to uncover the formation history of the Milky Way. Extragalactic surveys using AAOmega and Galactic surveys using HERMES will be the flagship science carried out on the AAT over the next 5–10 years. AAOmega and HERMES, and other upgrades to existing instruments, will provide astronomers with powerful tools that will enable them to do competitive, high-impact research using the AAT throughout the coming decade.

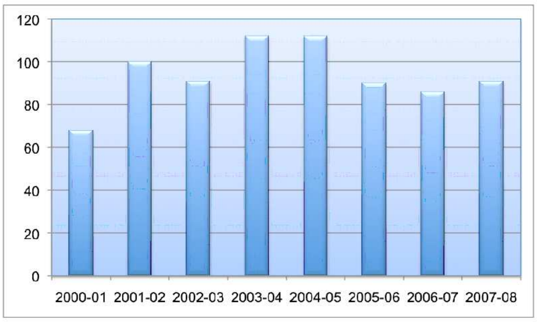


Figure 2: Number of papers using AAT data

Matthew Colless

GALAXY AND MASS ASSEMBLY (GAMA)

Simon P. Driver (St Andrews) and the GAMA team

Introduction

The GAMA survey (Driver et al. 2008) commenced on 1 March 2008 using AAOmega to obtain 50k new galaxy redshifts and spectra over 21 clear nights, out of the 22 awarded. GAMA is the latest Large Observing Programme, which was allocated an initial 66 nights by AATAC over a three year period. This takes GAMA up to the point at which the UK involvement in the AAT finally stops. In a sentence, GAMA is a study of structures on kpc to Mpc scales and builds on the long-standing Anglo-Australian tradition of world class galaxy redshift surveys (APM, Autofib, LDSS, 2dFGRS, MGC, 6dFGS), but with an additional twist: GAMA is not a single facility programme but draws data from several telescopes and satellites (see Fig. 1) to produce a truly unique large area multi-wavelength survey. Substantial time has now been allocated for GAMA area follow-up on the VLT Survey Telescope (VST), the Visible and Infrared Survey Telescope (VISTA), the UK Infrared Telescope (UKIRT), and ESA's Herschel Space Telescope (Herschel). The GAMA Team also leads a pending time request for the NASA Galaxy Explorer Space Telescope (GALEX), and discussions are underway to adopt one or more of the GAMA regions for the Australian Square Kilometre Array Pathfinder (ASKAP) deep field(s).

A major GAMA contribution to the astronomical community will be the delivery of an International Virtual Observatory compliant database of ~250k galaxies at low redshift ($z < 0.5$) over ~250 deg^2 with medium-resolution (3–7 Ang) optical spectra, and UV, optical, near-IR, far-IR imaging, and with complementary line widths and continuum measurements at radio wavelengths. The basic rationale is that after nearly 80 years of galaxy studies we have not yet formed a clear picture of galaxy formation but recognize that galaxies are highly complex non-linear systems involving both distinct but interlinked components (nucleus, bulge, bar, disc etc.) and constituents (stars, dust, hot and cold gas) with strong environmental and mass dependencies. To create a plausible blueprint of the galaxy evolution process requires the construction of a comprehensive database (in terms of statistical size and wavelength coverage), which contains measurements of all of these facets, i.e. bulge-disc decompositions; stellar, gas, dust and dynamical masses; and spanning a range of environments and epochs. Fig. 2 shows how the GAMA survey compares in terms of depth and area to other past and ongoing studies. While not as wide as the SDSS nor as deep as the VVDS redshift surveys, it

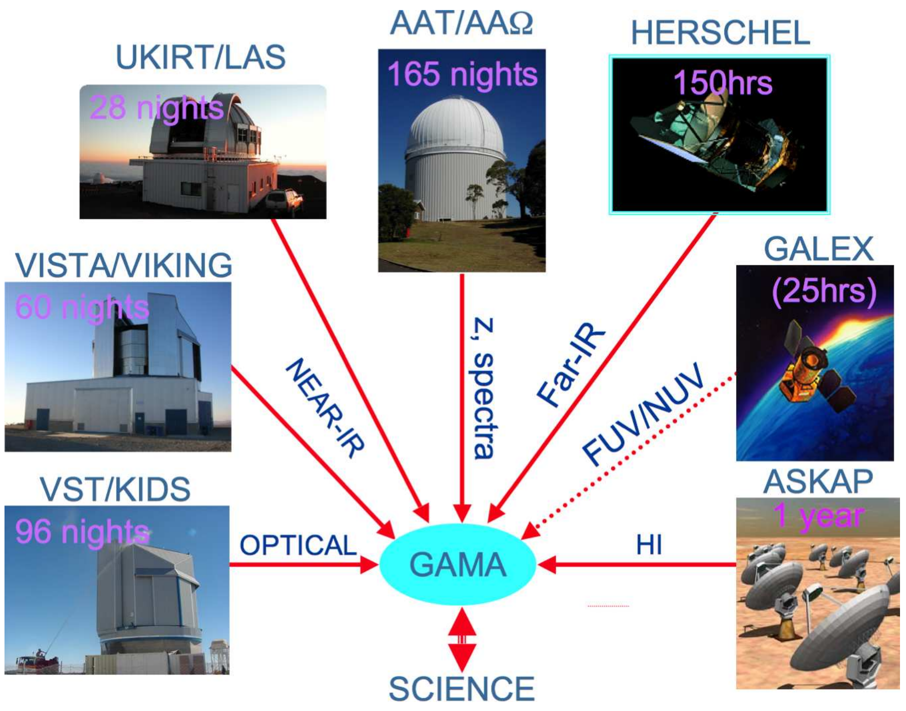


Figure 1: Facilities contributing to the final GAMA database, with approximate number of nights allocated to the GAMA regions indicated. All data flows shown with a solid line are guaranteed while those pending approval are shown with a dashed line. All UKIRT observations are now complete and undergoing analysis.

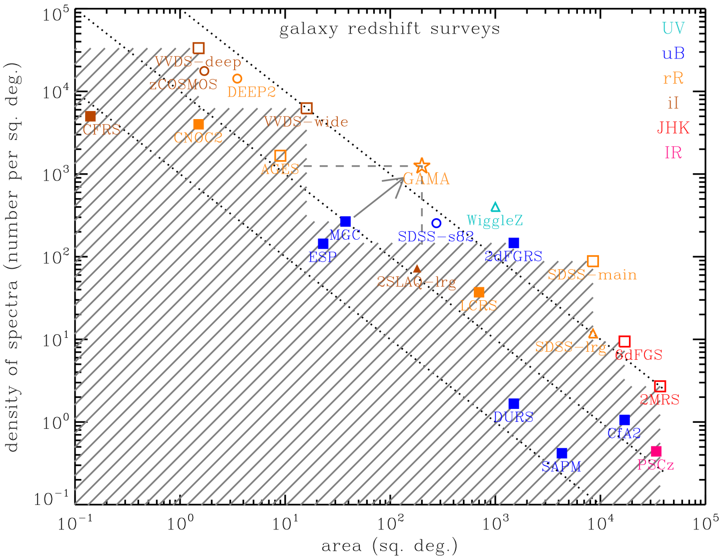


Figure 2: A comparison of past and ongoing major surveys indicating the tendency towards either very deep and very narrow surveys (e.g. VVDS) or very wide and very shallow surveys (e.g. SDSS). GAMA fills not so much a niche as a yawning chasm, and the AAT is the only facility worldwide currently capable of surveying this region of parameter space.

precisely fills the niche between the well sampled wide/shallow and narrow/deep domains. However, unlike SDSS and VVDS which rely mostly on unresolved global measurements of the stellar flux only, the GAMA focus is very much on resolved structural studies provided by e.g. bulge-disc decompositions, and on multi-wavelength coverage (UV through radio), enabling a coupled study of the stars, dust and gas. Fig. 3 shows the anticipated resolution (upper panel) and 5σ-point source detection (lower panel) limits for the final database. Overlaid on this figure is the NGC891 galaxy spectrum shifted to z=0.1 (based on Popescu et al. 2000). This shows that, for dust rich systems at least, GAMA will contain optical/near-IR resolved and fully wavelength sampled data enabling us to realize total SED fitting combined with optical and near-IR structural analysis.

In addition to the provision of a unique dataset for the generic study of galaxies and galaxy formation, the GAMA survey also contains a number of focused science experiments, which are less reliant on the auxiliary data and more directly aimed at providing robust constraints on the currently favoured structure and galaxy formation paradigm. In particular:

1. Measurement of the halo mass function via galaxy group velocity dispersions to directly test the predictions of various dark matter models, like CDM and WDM, down to Local Group masses.

2. Measurement of the dynamic, baryonic, HI and stellar mass functions to LMC masses and their dependence on redshift, environment, galaxy type and component, along with higher order relations, like mass-spin [M-λ].

3. Measurement of the recent merger and star formation rates as a function of galaxy type, mass and environment over a 4 Gyr baseline.

These three experiments are briefly discussed below followed by a summary of the year 1 data obtained in March/April 2008.

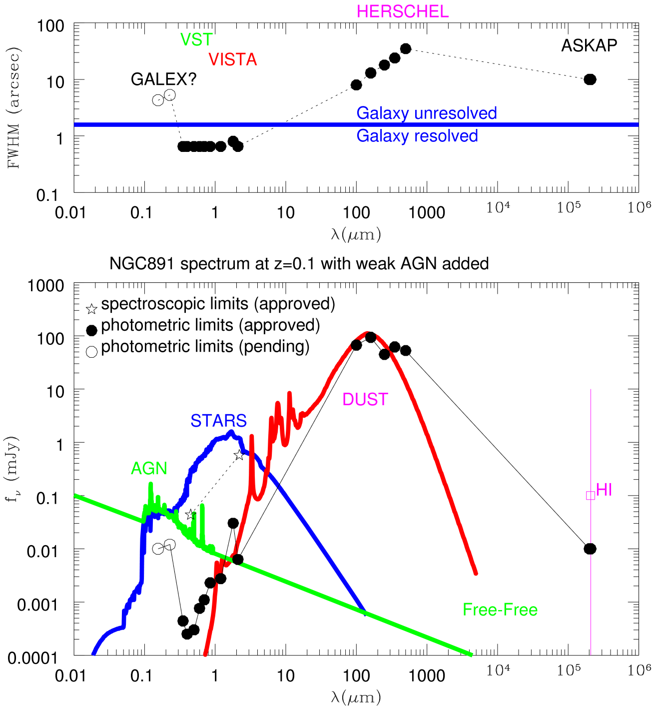


Figure 3: When the final GAMA database is assembled it will survey to the resolution (upper panel) and depths (lower panel) shown. Overlaid is the spectrum for NGC891 with a weak AGN added and shifted to z~0.1. GAMA should be able to simultaneously enable a combined analysis of the AGN, stars, dust and gas for a large fraction of the sample. The deeper objects may not be sampled in the far-IR although effort will be invested in obtaining deeper far-IR observations with Herschel in due course.

Testing the CDM model with the Halo Mass Function

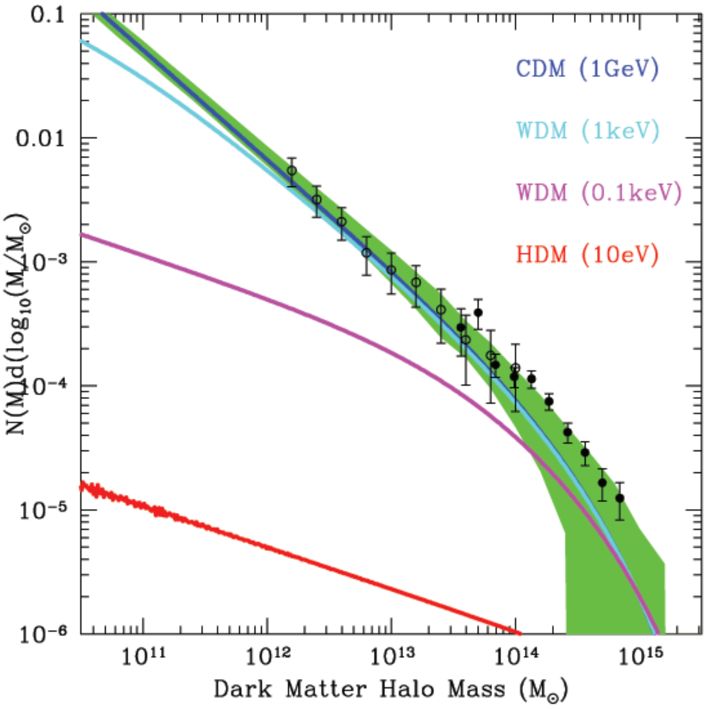


Figure 4: The halo mass function as predicted by Cold Dark Matter (CDM), Warm Dark Matter (WDM) and Hot Dark Matter (HDM). This is a clear-cut numerical prediction which depends only on the (known) CMB initial conditions and the (unknown) dark matter particle mass. The GAMA survey will sample initially the HMF through the measurement of halo masses via galaxy group velocity dispersions and latterly at lower mass limits through dynamical masses obtained directly via HI rotation curves. The open data points shown are a projection based on galaxy group velocity dispersion measurements only, while the solid points correspond to results from 2PIGG (Eke et al. 2006).

Testing the popular Cold Dark Matter (CDM) paradigm in detail has proved extremely difficult, especially in the regime where baryon physics becomes important. Certainly on large scales (from a few to hundreds of Mpc) the theoretical model is very successful in reproducing the observed galaxy clustering for a wide variety of samples. On the other hand, on smaller sub-Mpc scales, clear evidence for success of the CDM model is much more sparse and certainly at first sight more open for debate: (i) apparent over-prediction of the density of small scale structures (the missing satellite problem); (ii) apparent inability to explain the relatively shallow inner rotation curves of galaxies (core-angular momentum problem); (iii) apparent inability to explain the similarities of fragile thin disc systems (angular momentum distribution problem). That these issues have not formed a knock-out blow for CDM is because there is great uncertainty in how to relate pure dark matter predictions to observations which strongly depend on baryon physics. Therefore it becomes increasingly important to be able to constrain the underlying structure formation model using a method that is only mildly sensitive to details of baryon physics, or ideally, insensitive to them.

In current galaxy formation models, the galaxy velocity dispersion of a virialised cluster or group is believed to be a direct indicator of the dark matter halo mass in which it resides, as the system's dynamical mass is clearly dark matter dominated on those scales. Hence by surveying a sufficiently large volume one should, in principle, be able to empirically construct the halo mass function (HMF) using galaxy group velocity dispersion estimates. The HMF is precisely predicted from any dark matter model with no uncertainty due to baryon physics, so the HMF empirical measurement therefore constitutes a direct test of the underlying structure formation hypothesis. Fig. 4 shows the predicted HMF for three dark matter models (Cold, Warm, and Hot Dark Matter, i.e. CDM, WDM and HDM respectively) along with the current best constraints from the 2dFGRS (2PIGG; Eke et al. 2006), and the expected constraint from GAMA for the final 250 deg^2 survey. The advantage of GAMA over 2PIGG is the ability to probe to lower halo masses (deeper survey with higher spectral resolution), increase the number of detected group members (improved velocity dispersion uncertainty, hence mass determination), as well as overcome the fibre-collision selection bias by sampling each region of sky numerous times. AAOmega is the only facility available worldwide with which such a dataset can be obtained. We note that the data, if combined with ASKAP dynamical mass estimates at the very low mass end, should also be able to convincingly test WDM models and place an upper limit on the dark matter particle mass by extending the HMF to smaller masses than galaxy group based methods can probe.

Mass functions and galaxy feedback

A significant goal of many galaxy surveys, including 2dFGRS and SDSS, is to measure the galaxy luminosity function, primarily because it is considered to be the most basic quantity that characterises the sample as a whole, but also because it provides firm constraints on galaxy formation model predictions. To some extent the focus is now shifting towards constraining the mass functions instead: this is an attempt to empirically bypass some of the difficulties in accurately modelling baryonic physics in simulations.

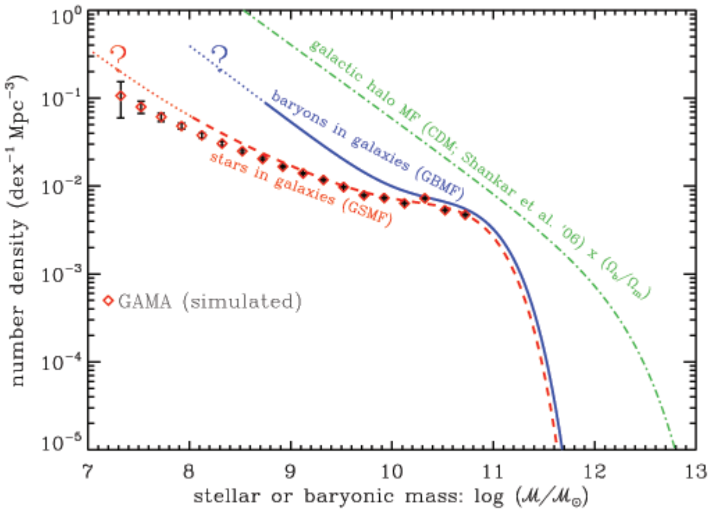


Figure 5: An illustration of three key mass functions: the galactic halo mass function (Shankar et al. 2006), the galaxy baryonic mass function (stars+HI), and the galaxy stellar mass function. GAMA will probe directly the HMF and GSMF, and indirectly the galactic halo mass function and the GBMF, the latter only in combination with ASKAP.

In particular the aim is now to measure the galaxy baryonic mass function (GBMF), and the galaxy stellar mass function (GSMF). These are of course related to the HMF via galaxy feedback, galaxy/star formation efficiency and the galaxy halo occupation distribution. The simplest scenario would be a unit halo occupation and constant dark matter-to-baryon-to-stellar mass ratios, in which case all mass functions exhibit the same shape but are offset only in mass. In reality the situation is much more complex, with mass-dependent halo occupations (i.e. the number of galaxies residing within the same halo depends on the halo mass) and with totally different shapes for the HMF and GSMF: steep low halo mass slope and sharp high mass cut off for the former, while the GSMF is close to flat for low stellar masses and presents an even sharper cut off at high stellar masses. This picture is best resolved if galaxy/star formation efficiency and galaxy feedback are strongly mass-dependent processes, as perhaps evidenced by the well known mass-metallicity relation. It has now been effectively argued into common perspective that high mass haloes are strongly dependent on AGN feedback to truncate their star formation, and low mass haloes are sensitive to SNe blowout, regulating their star formation. Together with appropriate halo occupation statistics, these add the required shape changes to go from the theoretically predicted HMF to the observed GSMF. Fig. 5 shows various mass functions: a galactic halo mass function (GHMF) with groups removed (Shankar et al. 2006), a suggested field GBMF based on a simple stellar-to-baryon conversion (Baldry et al. 2008), and a GSMF using SDSS very-low redshift data (flow corrected).

The relationships between the HMF, GHMF, GBMF and the GSMF curves precisely determine the levels of feedback and baryon retention required. Either these levels are plausible with our stellar and chemical evolution models, in which case CDM lives on, or they are not, in which case the CDM paradigm will require major revision. GAMA will probe directly the HMF and the GSMF, and indirectly the GHMF and the GBMF (with ASKAP). In due course data from VST, VISTA and Herschel will provide robust bulge-disc decompositions and individual dust estimates leading to improved stellar and baryonic mass estimates.

Galaxy assembly

The build-up of both dark matter haloes and the baryonic mass of galaxies through repeated mergers of smaller units is one of the principal modes of growth in CDM based galaxy formation models. For example, De Lucia et al. (2006) predicted that as much as 50% of halo mass has been accreted since z = 0.8. Observationally this process is constrained by measuring the galaxy merger rate and its redshift evolution, and comparing these estimates with theoretical predictions provides a fundamental test of the CDM paradigm. In recent years there have been numerous attempts to measure the galaxy merger rate both locally and at high redshift, yet no clear picture has emerged. Too much, too little and just the right amount of evolution have all been observed.

GAMA will improve on previous low-z studies in several ways: (i) The galaxy merger rate is measured either by finding galaxies in pairs that are close enough (on the sky and in redshift) so that they will merge in the near future, or by identifying recent merger remnants through their asymmetric light distribution. These methods require large scale spectroscopy that is highly complete for close pairs, which is difficult because of fibre placement restrictions, and high-resolution imaging, respectively. Existing large-scale surveys, such as the 2dFGRS and SDSS, essentially fail on both counts. In contrast, the high target density of GAMA will require 5–6 configurations per AAOmega pointing which will entirely eliminate any close pair bias in the spectroscopy. Hence, together with the high-resolution VST and VISTA imaging, GAMA will be ideally suited for studies of the galaxy merger rate; (ii) We expect GAMA to deliver a sample of 10^3 to 10^4 close pairs and merger remnants. Not only will this result in an order of magnitude refinement over previous measurements but it will also

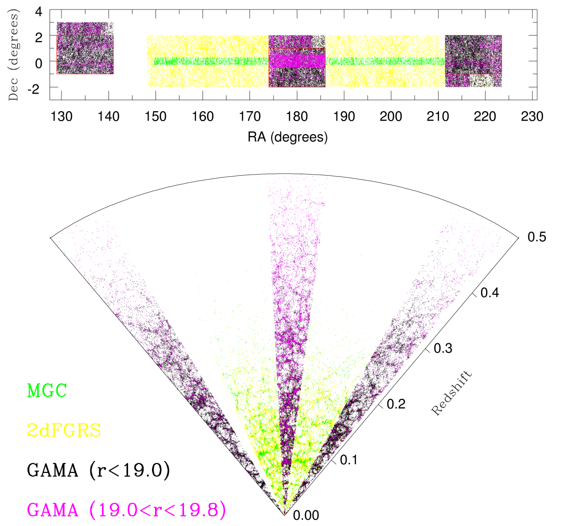


Figure 6: The areas surveyed by GAMA (upper panel) and the cone diagram (lower panel) showing the progression in depth (redshift) over previous AAT/2dF surveys (i.e., 2dFGRS and the MGC). All known redshifts (inc. GAMA) within the GAMA regions are shown as black ($r_{AB} < 19$) or magenta ($19 < r_{AB} < 19.8$) dots. Data for the 2dFGRS and MGC are shown as yellow or green dots respectively.

allow us to split the sample by environment, redshift, galaxy type, and recent evolution; (iii) The dependence of the major merger rate on mass, and the contribution of minor mergers to the growth of galaxies, is observationally unconstrained. The reason is that existing surveys lack the size and dynamic range in luminosity to probe these questions. With GAMA we will be able to measure the merger rate down to a mass ratio of 1:100.

First Light for GAMA-I

The GAMA survey is being conducted in two parts, mainly because of the politics involved in the UK's withdrawal from the AAO, but also to accommodate the tremendous science potential afforded by overlap with the ASKAP deep field (Johnston et al. 2007). The initial allocation of 66 nights (PI: Driver) represents 2/3 of the UK's remaining dark time and will enable us to survey 100k galaxies to limits of r_{AB}=19.4 and to K_{AB}=17 over 150 sq degrees in three distinct and equally sized chunks (necessary to maximise the RA baseline), and to a limit of r_{AB}=19.8 within the central 50 sq degree region. The three regions are all equatorial, 4 deg. wide, and centred at approximately 9h, 12h and 14.5h, as shown in the upper panel of Fig. 6, while the bottom panel shows the corresponding galaxy cone plot for that region of the sky. To complete the GAMA survey goals as specified above we will require a further comparable allocation (~250k galaxies over ~250 sq. degrees within three 12x7 degree regions).

The observing run for GAMA-I started on 1 March with a remarkable sequence of 21 clear and mostly trouble free nights, out of the 22 allocated split over two lunations. The setup used the 385R and 580V gratings with 55–75 min integrations, mostly limited by the AAOmega reconfiguration time. The targets for the input catalogue were derived from SDSS Data Release 6 (DR6), selected by SDSS Petrosian dust corrected r-band magnitude, and filtered to remove objects with fibre magnitudes fainter than r_{AB}=22 and erroneous detections identified by visual inspection. Several hundred objects identified as potentially spurious were visually inspected by up to three observers to ensure the input targets were real and that those eliminated were genuinely unattainable or erroneous. Guide stars and spectroscopic stellar standards (4 per field) were also derived from the SDSS DR6 catalogues.

In order to maximise the accuracy of our velocity dispersion measurements and close pair statistics we prioritised all close pair members, irrespective of their apparent magnitude. In addition, for our year 1 run we also prioritised a deep 1 deg wide strip of fainter ($r_{AB} < 19.8$) objects within the 12h region (G12) to enable early sampling of the completeness function (see Fig. 7), and to enable us to optimise exposures for the year 2 and 3 strategy (as well as to maximise the diversity of year 1 science). Apart from these exceptions the prioritisation was assigned based on magnitude (bright to faint).

In total we targeted 52557 galaxies (50% of the GAMA-I target list) with Petrosian magnitudes ranging from r_{AB} = 14 to 19.8 mag. From these targets we obtained credible redshifts for 97% and medium-to-low S/N spectra for the majority. These new redshifts and spectra complement those already known for this region of sky from the SDSS, 2dFGRS and MGC and results in a combined catalogue of 80k redshifts (see cone plot in bottom panel of Fig. 6). The main panel of Fig. 7 shows the incompleteness as a function of apparent magnitude and apparent surface brightness, showing only a minimal increase towards fainter magnitudes but a stronger bias with surface brightness. While relatively few targets exist at low surface brightness their significance depends on the volume surveyed and some 8m follow-up will be required for these few objects. Overall the performance was significantly better than expected.

One implication of the extraordinarily high redshift yield is that AAOmega is clearly capable of conducting a complete magnitude limited redshift survey to even fainter flux limits with a modest increase in exposure time (e.g. $r_{AB} < 20.5$ mag). This will be taken into consideration, along with any ASKAP design changes, when finalising the bid for GAMA-II. To highlight the potential in combining data from these two facilities we show, in Fig. 8, the GAMA redshift distributions for both the

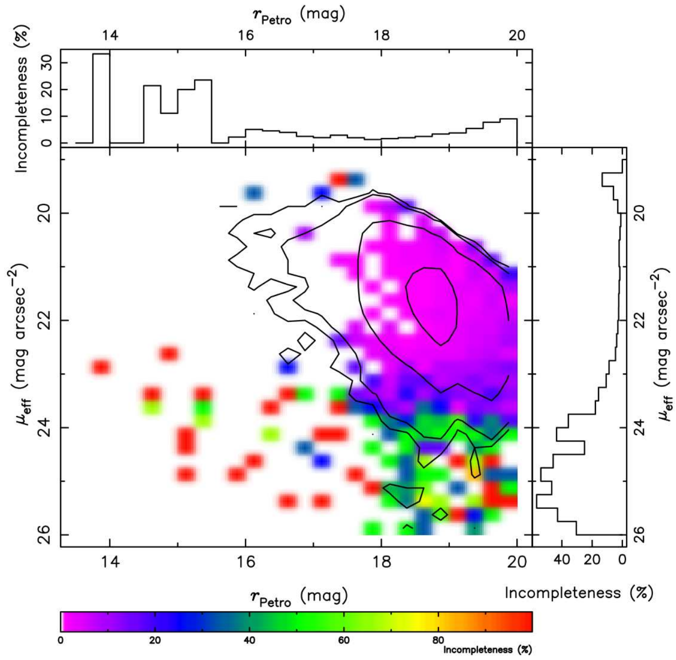


Figure 7: The target density (contours) and incompleteness (colours) of the GAMA year 1 survey in terms of the target Petrosian apparent magnitude and mean effective surface brightness. Contours are in density intervals of 5, 10, 100 and 1000 galaxies. The side panels show the collapsed incompleteness distributions, as a function of effective surface brightness (left) or apparent magnitude (top) only.

shallow (r_{AB}<19) and deep (r_{AB}< 19.8) regions compared to that projected for the ASKAP deep field. Clearly the compatibility in terms of sky area (GAMA chunk = 50 sq deg, ASKAP pointing = 36 sq. deg) and depth (Fig. 8) is striking and should herald an entirely new era in the study of galaxy evolution through the combined investigation of the stars, the gas, and their interplay.

Summary

The GAMA project has begun with data flows imminent from a number of international facilities (to be followed by the eventual incorporation of radio continuum and HI data from ASKAP). The survey will allow for a comprehensive study of structure on 1 kpc to 1 Mpc scales as well as the subdivision of the galaxy population into its distinct components (nuclei, bulges, bars and discs) and constituents (stars, gas and dust). Although the headline goals will take some years to complete, it is worth noting that from the year 1 data alone the GAMA Team is currently working on ~15 papers for publication in 2008/9.

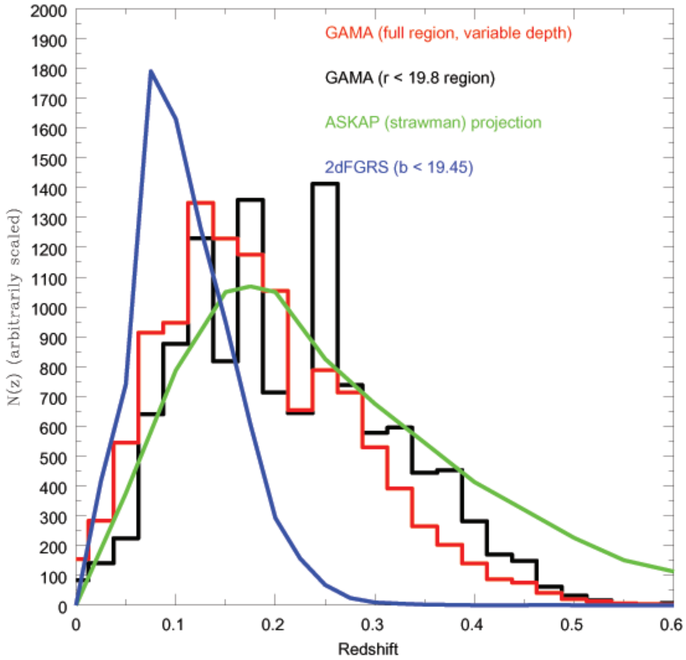


Figure 8: The redshift distribution for both the shallow (r_{AB}<19) and deep (r_{AB}< 19.8) GAMA regions compared to that projected for the ASKAP deep field and the one for the 2dFGRS over that same area. All distributions are arbitrarily rescaled.

Progress and data releases, with first data release forecast for Dec 2009, can be monitored via the GAMA website: http://www.eso.org/~jliske/gama/ and anyone interested in further details or collaborative projects should contact Simon Driver directly at spd3@st-and.ac.uk.

Finally we would like to especially thank all of the staff at the Anglo-Australian Observatory for their professionalism and dedication in bringing about the two-degree field facility, and the AAOmega upgrade, and making it such a leading instrument.

References

Baldry I., et al., 2008, MNRAS, in press (arXiv:0804.2892)
De Lucia G., et al., 2006, MNRAS, 366, 499
Driver, S.P., et al., 2008, IAU 254, in press (arXiv:0807.0376)
Eke V.R., et al., 2006, MNRAS, 370, 1147
Johnston S., et al., 2007, PASA, 24, 174
Popescu, C.C., et al., 2000, A&A, 362, 138
Schawinski et al., 2007, MNRAS, 382, 1415
Shankar et al., 2006, ApJ, 643, 14

STAR CLUSTER KINEMATICS WITH AAOMEGA

László L. Kiss (Univ. of Sydney), Zoltán Balog (Univ. of Arizona), Gyula M. Szabó (Univ. of Szeged, Hungary), Quentin A. Parker (Macquarie Uni. & AAO), David J. Frew (Perth Observatory)

Introduction

The high-resolution setup of the AAOmega spectrograph makes the instrument a unique stellar radial velocity machine, with which measuring Doppler shifts to ±1.3 km s^{-1} for 16 magnitude stars within an hour of net integration has become a reality. The 1700D grating with its spectral resolution of $\lambda/\Delta\lambda=10000$ in the near-infrared calcium triplet (CaT) range between 8400–8800 Å is particularly well suited for late-type stars, whose spectral energy distribution peaks exactly in this range and whose spectra are dominated by the strong CaT lines. The large field of view and the instrument's capabilities form an excellent combination for kinematic studies of star clusters.

The two types of stellar aggregates, open and globular clusters, are good representations of the two ends of stellar evolution and, as hosts to thousands of stars of the same age and chemical composition, they have played a key role in understanding stellar structure and evolution. An open cluster is a group of stars that were formed in the same giant molecular cloud and which are still bound together by a relatively weak gravitational field. Their ultimate fate is dispersal in the Milky Way field, illustrated by the fact that even the oldest known open clusters (e.g. M67, NGC 188) are generally only a couple of Gyr old. Globular clusters, on the other hand, are the remnants of the first galactic building blocks with ages from 10 to 13 Gyr, which means their old populations are the best known local counterparts of the high-redshift Universe.

Traditionally, the relationship between the colours and magnitudes of stars in a cluster has been used to derive fundamental parameters such as age, distance, reddening and metallicity of the given cluster. These can, in turn, reveal important details of stellar physics (Gallart et al. 2005). The spectroscopic approach, i.e. taking individual spectra of hundreds or thousands of stars and then deriving global parameters of the clusters from the spectral analysis of the member stars, has been much less utilised before the advent of efficient multi-object spectrographs. Enormous efforts have been undertaken in a few cases (e.g. Meylan & Mayor 1986) but star cluster kinematics was very far from routine in observational astronomy. The situation has completely changed in the last few years, when a number of new instruments came online (Hectospec/Hectoechelle at MMT, FLAMES at VLT, DEIMOS at Keck, AAOmega at AAT, etc.), delivering thousands of spectra at a speed and sensitivity never seen before.

Radial velocities tell a different story to the colour-magnitude diagram: velocity dispersion is linked to the total mass of the cluster, hence indicating the presence or absence of invisible matter; the dispersion as a function of radius is a tell-tale indicator of the underlying mass profile, whereas systemic rotation can be revealed through an analysis of angular distribution of the velocities. Coupled with proper motion measurements, velocities can also be used to derive a kinematic distance (assuming energy equipartition for the member stars). A completely new avenue opens up with the full spectral analysis, when atmospheric parameters such as effective temperature, surface gravity and metallicity, are determined for each star. In that case, evolutionary models can be fitted directly to the physical parameters rather than the colours and magnitudes, which are sensitive to the interstellar reddening.

In semester 2008A, Balog et al. were granted four nights of AAOmega time to observe the relatively young double open cluster NGC 2451A and B. These have been studied with the Spitzer space telescope to identify stars with infrared excess caused by circumstellar debris disks, which are thought to host on-going planet formation. In this article we report on the first results of the project based on three nights of observations from early 2008A. Due to the main target's limited visibility, we have also obtained data for secondary objects, including the apparent association of the open cluster M46 and the planetary nebula NGC 2438, and the pair of globular clusters near Antares, M4 and NGC 6144. The amazing results which came out of only three nights of AAT time illustrate very nicely the potential of the instrument and, for example, how quickly one can resolve decades of contradiction in less than two hours of net observing time.

Observations and data analysis

We acquired AAOmega data on three nights in February 2008, in moderate Siding Spring sky conditions. In the blue arm we used the 2500V grating, providing $\lambda/\Delta\lambda=8000$ spectra between 4800 Å and 5150 Å. In the red arm we used the 1700D grating that has been optimised for recording the CaT region.

In total, we acquired 11 field configurations centered on NGC 2451, 2 configurations on M46 and 3 configurations on M4. The target stars were selected from the 2MASS point source catalogue (Skrutskie et al. 2006) by matching the main features in the colour-magnitude diagram of stars in each cluster. In every configuration we limited the brightness range of stars to 3 mag in order to avoid cross-talk between the fibres due to scattered light.

The spectra were reduced using the standard 2dF data reduction pipeline. We performed continuum normalisation separately for the stellar spectra using the IRAF task *onedspec.continuum* and then removed the residuals left from the strongest skylines by linearly interpolating the surrounding continuum.

Atmospheric parameters and radial velocity were determined for each star with an iterative process, which combined finding the best-fit synthetic spectrum from the Munari et al. (2005) spectrum library, with χ^2 fitting, and cross-correlating the best-fit model with the observed spectrum to calculate the radial velocity. This approach is very similar to that adopted by the Radial Velocity Experiment (RAVE) project (Steinmetz et al. 2006; Zwitter et al. 2008), and this analysis is based on the same synthetic library used by RAVE. Our experiences have shown that because of the wide range of temperatures (and hence spectral features), we needed three subsequent iterations to converge to a stable set of temperatures, surface gravities, metallicities and radial velocities. The latter are believed to be accurate within ±1–2 km s^{-1} for the cooler stars and ±5 km s^{-1} for the hotter stars in the sample (the boundary is roughly at 8000–9000 K). These values have been estimated from Gaussian fits of the cross-correlation profile using the IRAF task *rv.fxcor* and should only be considered as representative numbers.

The specific uses of the data were as follows:

- For NGC 2451, we wanted to identify genuine cluster member stars in the photometrically pre-selected sample, based on their full set of parameters (radial velocities, temperature, surface gravities, metallicities).
- For M46 and NGC 2438, we wanted to confirm or rule out physical association between the cluster and the nebula, most notably by comparing their radial velocities.
- For M4 and NGC 6144, we wanted to measure velocity dispersion profiles near to or beyond the tidal radii and estimate central velocity dispersion.

In the following three sections we describe the science case for each cluster and present preliminary results. More details will appear in Balog et al. (in prep.), Kiss et al. (2008, submitted) and Kiss et al. (in prep.).

NGC 2451A and B: two open clusters in the same line-of-sight

Debris disks provide evidence for the presence of planetary objects around young stars. They form when large bodies collide, generating fragments that participate in cascades of further collisions resulting in a significant quantity of dust grains. These dust grains are heated by the central star and then re-radiate at longer wavelengths. This reprocessed radiation is detectable with Spitzer through excess emission at mid- and far-infrared wavelengths. The dust grains are relatively short-lived (10^6–10^7 yr), hence they must be regenerated by further collisions. Therefore, their presence is the strongest evidence of the existence of large bodies (up to planet size) that collide and produce dusty debris.

Debris disks provide a great opportunity to study how planetary systems form and to follow their evolution through time. It is important to have a sample of debris disk systems with well determined age. The aims of the Spitzer program No. 58 "Evolution and Lifetime of Protoplanetary Disks" are to investigate the frequency and duration of the protoplanetary disk phase of evolution and to obtain constraints on the probabilities and timescales for the formation of major planetary bodies.

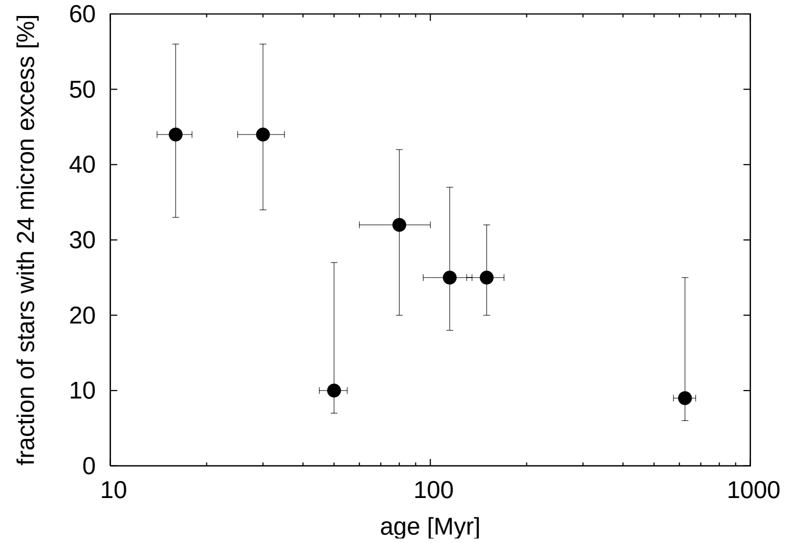


Fig.1: Frequency of stars B5-A9 with 24 micron excess fraction as a function of age (a simplified version of Fig. 5 in Siegler et al. (2007)).

Our motivation is to examine the timescale for and nature of the transition to the debris disk phase of disk evolution. To achieve these goals we surveyed a sample of young stellar clusters of varying age, richness and stellar content in the age range of 1–100 million years.

This survey has revealed a remarkable similarity between the general evolution of hundreds of planetary systems and our ideas about the early events in the Solar System. There is a decay in debris generation with a time scale of about 100 Myr. A few exceptional objects have been found that may signal major collisions such as the one between the proto-Earth and a large planetesimal that resulted in the formation of the Moon. Debris in the terrestrial planet zones (detected at 24 microns) persists for about 1 Gyr, parallel to the 700 Myr period that ended in the Late Heavy Bombardment in the Solar System. Therefore, we are sampling many planetary systems in a way that will let us test and expand our current theories for planet evolution and will also show us whether some of the salient events in the development of the Solar System are common or rare. However, there is an important gap in our time coverage between 30 and 100 Myr that needs to be filled to deliver on the full promise of the Spitzer data. NGC 2451 A and B are ideal for filling this gap (Fig. 1).

NGC 2451A and B are two young open clusters projected onto each other in the same line-of-sight. Several attempts have been made to separate the two clusters and to determine the physical parameters of each. Platais et al. (2001) analysed photometric and spectroscopic data and used proper motion, radial velocities to select members of NGC 2451A. They fitted theoretical isochrones to the cluster colour-magnitude diagram (CMD) to calculate distance, reddening and age, deriving d=188 pc, E(B-V)=0.01 mag and t=60 Myr. Hünsch et al. (2003) carried out an X-ray study of the two clusters. These authors identified 39 members of the A and 39 of the B cluster, using combined X-ray and optical data, determined distances of 206 pc and 370 pc for NGC 2451A and B, respectively, and found ages around 50–80 Myr for NGC 2451A and about 50 Myr for NGC 2451B. Subsequently, Hünsch et al. (2004) completed the X-ray study with high resolution spectroscopy and refined the membership of the two clusters. The most recent distance and age estimates were published by Kharchenko et al. (2005), who analysed the ASCC-2.5 catalog and provided homogeneous astrophysical parameters for 520 Galactic open clusters. They estimated distances of 188 pc and 430 pc and ages of 57.5 Myr and 75.9 Myr for NGC 2451 A and B, respectively.

The central 1 deg x 1 deg field of NGC2451 was imaged with Spitzer/IRAC (3.6, 4.5, 5.8 and 8.0 micron) and MIPS (24, 70, 160 micron). Supplementary observations in UBVRI bands were obtained with the 1.5m telescope at Las Campanas Observatory in Chile. Using the parameters of Kharchenko et al. (2005) and the V vs V-K colour-magnitude diagram, we attempted to separate the two clusters in order to investigate their stellar content and disk frequencies. However, our member selection method becomes uncertain around V-K~4, where the level of contaminating background red giants is very high. In the infrared, the background red giants can mimic the observational signatures of debris disks around low mass main sequence stars, so it is very important to separate them from the main sequence stars before we start identifying sources with debris disks in the clusters. That was the main goal of our AAOmega observations: to clean the sample of background red giants and thus refine membership determination, and also to separate the two clusters from each other.

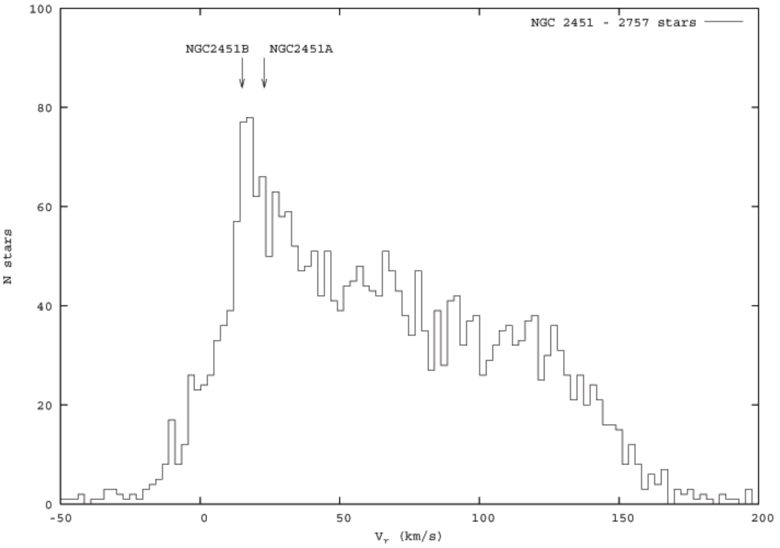


Fig. 2: The histogram of all radial velocities for NGC 2451. The two arrows show the published velocities of the two overlapping clusters (Hünsch et al. 2004). The overwhelming majority of the stars belong to the Milky Way field.

In total, we determined radial velocity and atmospheric parameters for 2757 stars in the Spitzer field. The histogram of

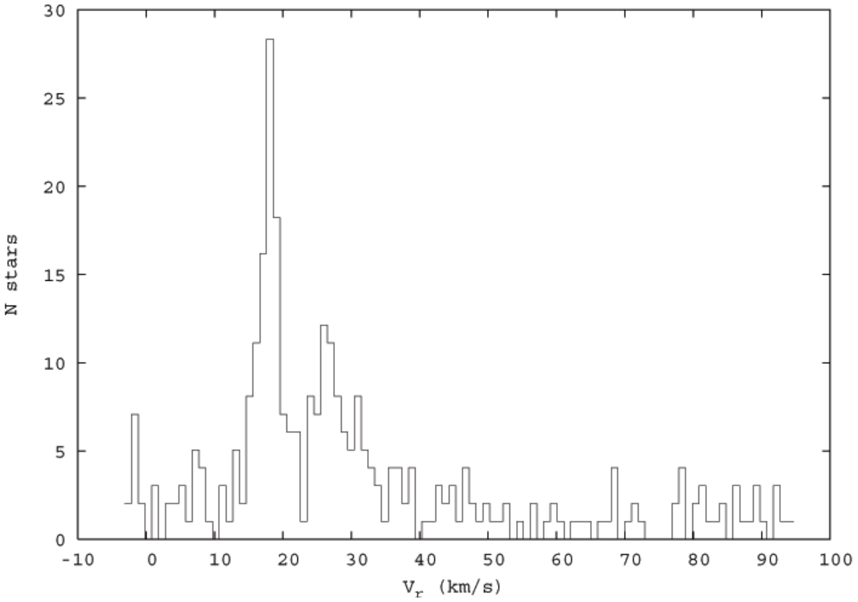


Fig. 3: The histogram of refined radial velocities for stars with distorted CaT line profiles. About 150 stars can be identified as members of either of the two clusters, with mean velocities of 18 km s^{-1} and 26 km s^{-1}.

all radial velocities (Fig. 2) indicates a heavy contamination from field stars: the two clusters are barely noticeable at the published velocities (marked by two arrows). Another difficulty that arose was the very high incidence of CaT emission (defined by the excess flux of the calcium lines relative to the best-fit model spectra), especially in – as revealed later – late-type main sequence stars in the clusters. Both clusters are young, hence the still high rotation rates can lead to elevated chromospheric activity, for which the CaT lines are good indicators (Andretta et al. 2005). However, someone's signal is someone else's noise: the distorted CaT profiles introduced random velocity errors of up to 10–20 km s^{-1} in the maximum of the cross-correlation profile. This was particularly apparent after improving the velocity determination for 312 stars with CaT line profile irregularities. After exclusion of the CaT lines from the cross-correlation, the velocity of a much larger fraction of the stars were very close to the clusters' mean. (Fig. 3)

At the time of writing this article, we have confirmed the existence of two clusters in the same line-of-sight based on the most extensive kinematic database obtained for NGC 2451. A large fraction of cool main sequence member stars has been identified with chromospheric activity, which alone will be the basis for further studies in an unanticipated direction. Currently we are working on the analysis of debris disk candidates, whose results will be presented in Balog et al. (in prep.).

M46 and the planetary nebula NGC 2438

Any physical associations discovered between planetary nebulae (PNe), the short-lived but spectacular late evolutionary stage of small and intermediate mass stars (between 1–8 M_{sun}), and star clusters would be a valuable discovery providing a means of establishing accurate astrophysical parameters for the nebulae through fixing distances and progenitor ages from cluster isochrones. Accurate distances are particularly useful, as from them one can infer PNe physical properties such as the absolute magnitude of the central stars, accurate physical dimensions and fluxes. Also, they would provide excellent calibrators for the surface brightness-radius relation (Frew & Parker 2006, Frew 2008). Whereas PNe have been found in 4 globular clusters of the Milky Way (M15, M22, Pal 6 and NGC~6441; Jacoby et al. 1997), none has been reported in the literature as an unambiguous member of a much younger open cluster (OC). The interest in the latter case is not only due to being able to determine independent distances to individual nebulae, but also because in a young open cluster the progenitor of a now-visible PN will be a reasonably constrained higher mass star than those in globular clusters. This fact offers the opportunity to calibrate the initial-to-final mass relation of stars on a broad range of masses, usually done by modelling white dwarf populations in open clusters (e.g. Dobbie et al. 2006).

Recently, Majaess et al. (2007) and Bonatto et al. (2008) have performed detailed investigations of possible physical associations between PNe and OCs. Majaess et al. considered the cluster membership for 13 PNe that are located in close proximity to open clusters lying in their lines-of-sight and listed another 16 PNe/open cluster coincidences, which might contain physically associated pairs. However, they noted that we have yet to establish a single association between a PN and an open cluster based on a correlation between their full set of physical parameters, including the three key parameters of radial velocity, reddening, and distance that need to be in good agreement if an association is to be viable. Bonatto et al. (2008) used near-infrared colour-magnitude diagrams and stellar radial density profiles to study PN/open cluster association for four pairs. They concluded that the best, but still only probable, cases are those of NGC 2438/M46 and PK 167-01/New Cluster 1.

NGC 2438 is a well-known annular PN located about 8 arcminutes from the core of the bright open cluster M46 (=NGC2437, Back page). Despite its brightness, the cluster was relatively unstudied until recently (e.g. Cuffey 1941; Stetson 1981). Recently published cluster parameters are relatively well-determined, e.g. E(B-V)=0.10–0.15, D =1.5–1.7 kpc and an age of 220–250 Myr (Sharma et al. 2006, Majaess et al. 2007, Bonatto et al. 2008). The estimated turnoff mass is about 3.5 M_{sun}. In addition to the possible association with NGC 2438, M46 is also thought to host the well-studied post-AGB candidate OH 231.8+4.2 (Jura & Morris 1985).

Early studies of the radial velocity of NGC 2438 and M46 (Cuffey 1941; O'Dell 1963) indicated a difference of about 30 km s^{-1} between the PN and cluster stars, which suggested that the pair constitutes a spatial coincidence only. Three red giants in the cluster have systemic velocities (Mermilliod et al. 1989, 2007) identical to that of cluster dwarf members obtained by Cuffey (1941). However, Pauls & Kohoutek (1996) rekindled interest in the possibility of the PN/open cluster association when they found similar velocities for both, although based on a small number of stars. Both Majaess et al. (2007) and Bonatto et al. (2008) pointed out the importance of measuring sufficient stellar radial velocities for the cluster and the PN to establish if the proximity is real or only chance superposition. Prompted by this recent interest, we observed two configurations on M46 and three positions across the face of the PN (Fig. 4) to resolve the ambiguities and confusion in the literature.

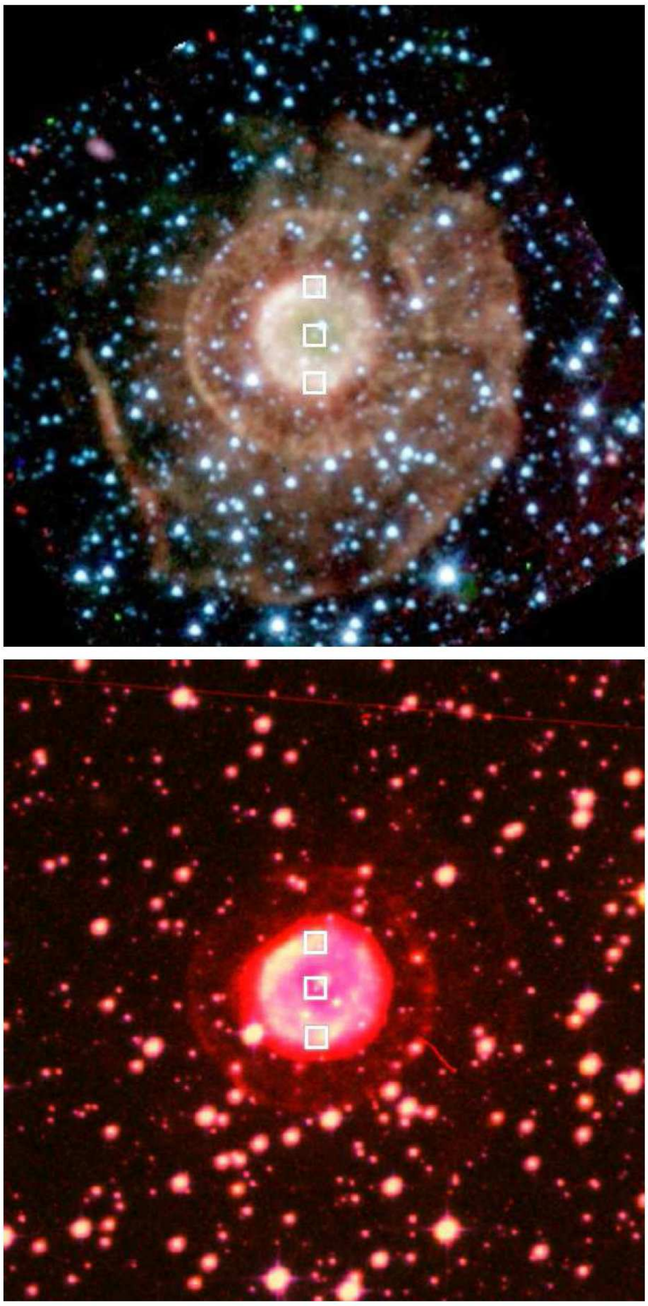


Fig. 4: Spitzer/IRAC (upper panel) and SuperCOSMOS Hα (lower panel) images of NGC 2438. The white squares show the three fibre positions we used to take spectra of the PN. The field of view is 6 arc minutes.

In total, 105 min of integration with two configurations led to radial velocities of 586 stars in a 1 deg field of view centered on M46. Unlike NGC 2451, where chromospheric activity of late type stars led to difficulties in velocity determination, here it was the hot early type cluster members that caused a bit of extra

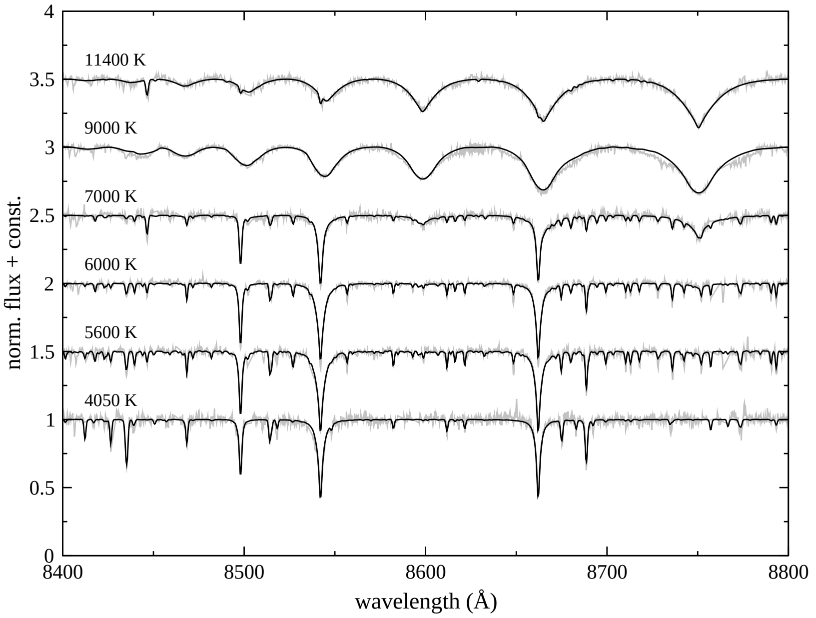


Fig. 5: Observed stellar spectra (light blue lines) and the best-fit synthetic data from the Munari et al. (2005) spectrum library (black lines).

work. We show sample spectrum fits in Fig. 5 to illustrate the difficulties one faces when analysing cool and hot stars together in the CaT region. Since the CaT lines almost exactly coincide with hydrogen lines in the Paschen series, we found that it was absolutely crucial to have the best-match template for cross-correlation. A slight template mismatch can easily lead to radial velocity shifts of several km s^{-1} at this intermediate spectral resolution and hence one has to be very careful to optimise template selection. It is common practice in the optical range to use the same template across a range of spectral subtypes or even types. However, that does not work in the CaT region, where a full χ^2 fit of the spectra is essential. It is also inevitable that as soon as the temperature reaches about 9000 K, the broad spectral features will lead to a degraded velocity precision simply because of the broadened cross-correlation profile. M46, as an intermediate-age open cluster, still hosts a large number of hotter main sequence stars and that implies the possibility of degraded velocity precision for a significant fraction of stars. But as we show below, we confirm the 30 km s^{-1} velocity difference between the cluster and the PN, so that the temperature dependent velocity uncertainty does not play a role in relation to their physical association.

The spectra taken in the three positions across NGC2438 are typical of a planetary nebula. The blue range shows the three characteristic nebular emission lines, the Hβ and the [OIII] doublet at 4959 Å and 5007 Å, which are by far the strongest features in the optical spectrum. The central spectrum shows well-defined double-peaked [OIII] line profiles, which we used to determine the expansion velocity of the nebula, assuming a spherical shell. The two spectra on the edge have single-peaked emissions, centered exactly halfway between the two peaks of the central spectrum, supporting that assumption.

In the near-IR, the central position yielded a featureless flat continuum, while the two spectra from the shell contain an identical set of narrow emission lines. Using line identifications from the literature we identified these lines as the Paschen series of hydrogen (from P12 to P18), the [ClII] nebular line at 8579 Å, and the NI line at 8729 Å.

Individual PN radial velocities have been measured by fitting Gaussian functions to the line profiles. In the case of the double-peaked [OIII] doublet, we fitted a sum of two Gaussians. In each case we repeated the centroid measurement by choosing slightly different fit boundaries to estimate the uncertainty: the strong emission lines in the blue yielded the same velocities within 1–2 km s^{-1} in several repeats. The mean velocity of the PN from our data is 78±2 km s^{-1}, while the [OIII] expansion velocity is 21.0±0.2 km s^{-1}, both in excellent agreement with numbers in the literature (e.g. Corradi et al. 2000).

Fig. 6 shows the histogram of the most extensive and accurate set of radial velocities for the open cluster M46 obtained to date. We confirm the early results that NGC 2438 has a relative velocity of about 30 km s^{-1} with respect to the cluster (O'Dell 1963), hence they are unrelated despite being located approximately at the same ~1.5–1.7 kpc distance. In Fig. 6 we also put an arrow at the mean centre-of-mass velocity (48.5 km s^{-1}) of three red giant binaries measured by Mermilliod et al. (1989, 2007). The excellent agreement between the maximum of the histogram (49 km s^{-1} for the highest value, 48 km s^{-1} for the centroid of the fitted Gaussian) and the very accurate CORAVEL data confirms both the cluster membership of those systems and the quoted accuracy of our single-epoch velocity measurements.

At the time of writing, we have therefore ruled out a physical association between the open cluster M46 and the planetary nebula NGC 2438. We also noted the very broad velocity peak of the cluster in the histogram, for which the presence of a significant population of binary stars has been concluded. More details can be found in Kiss et al. (2008, submitted).

Two flies in one hit: the globular clusters M4 and NGC 6144

We were also able to observe M4, within the field of which lies another globular cluster, NGC6144. In semesters 2006B and 2007B we were granted 15 nights to observe globular clusters (first results published by Kiss et al. 2007 and Székely et al. 2007) and now we have added these two clusters to the six already observed (47 Tuc, M12, M30, M55, NGC 288, NGC 6752) .

Globular clusters are spherical aggregates of 10^4–10^6 very old stars bound in regions as small as a few tens of parsecs. They are believed to have undergone substantial dynamical evolution because of long ages compared to the relaxation time scale. This evolution is affected by several different processes including tidal interaction with the Galaxy and two-body relaxation, which are both responsible for the "evaporation" of stars (Meylan & Heggie 1997). A globular cluster that moves on a non-circular orbit around the Galactic centre experiences a time-dependent tidal force. When the duration of this perturbation is much shorter than the typical orbital periods of stars within the cluster, stars experience an abrupt tidal shock that can have dramatic effects on the evolution of the cluster (Gnedin et al. 1999). These shocks occur when the cluster passes through the galactic disk or the bulge; the disk shock compresses the cluster while the bulge shock stretches it. The effects of such a shock continue long after the shock itself: the energy given to the individual stars in the cluster accelerates both the general evolution and mass evaporation. The stars therefore escape continuously and, because of the non-spherical equipotential surfaces, the cluster is expected to have tidal tails. N-body simulations of globular clusters have shown that tidal tails may be used to trace the orbital paths of globular clusters and hence give direct information on the Galactic gravitational field and the underlying mass distribution.

Deep star-count surveys have revealed tidal tails in two low-concentration clusters (Palomar 5 and NGC 5466) stretching many degrees beyond the tidal radius (Odenkirchen et al. 2001; Grillmair & Johnson 2006), confirming the theoretical predictions. The AAOmega instrument on the AAT offers wonderful new opportunities to investigate mechanisms that affect velocity distributions in globular clusters and, in particular, near or outside the tidal radius. Theories to be tested include tidal heating of the evaporated stars by the external gravitational field (Drukier et al. 1998), the presence of a dark matter halo around the clusters (Carraro & Lia 2000), and a breakdown of the Newtonian dynamics in the weak-acceleration regime (Scarpa et al. 2007). The

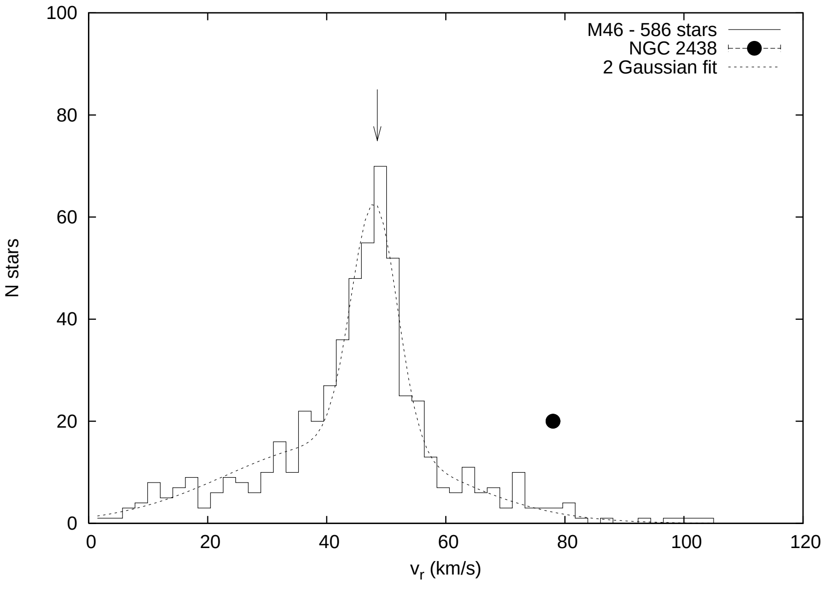


Fig. 6: The histogram of stellar radial velocities for M46. The arrow shows the mean center-of-mass velocity of three red giant binaries (Mermilliod et al. 1989, 2007), while the dotted line represents a fitted sum of two Gaussians. About half of the sample belongs to the cluster.

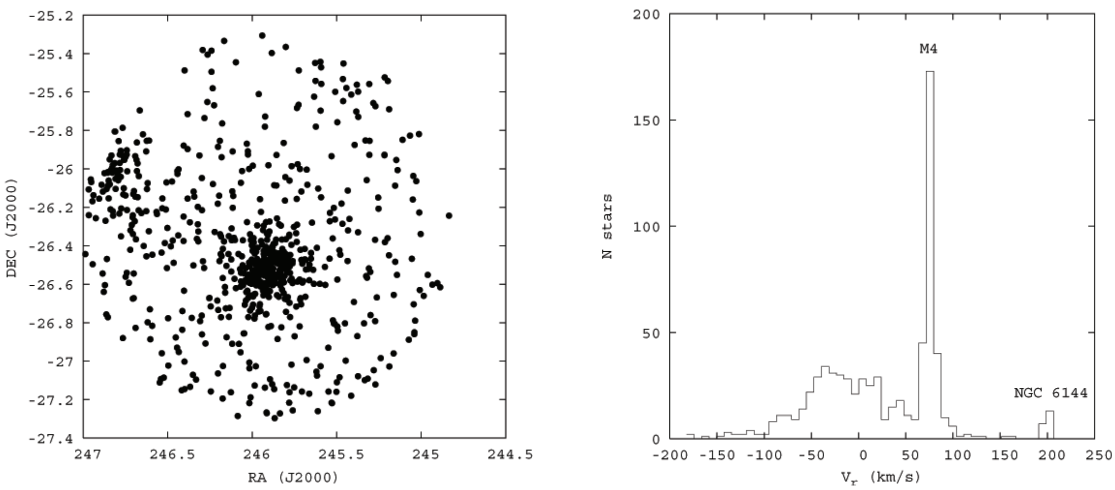


Fig. 8: Left: the celestial distribution of the M4 sample. Note the concentration on the left edge, which marks the location of NGC 6144. Right: the histogram of radial velocities with the two cluster peaks marked.

latter hypothesis is particularly interesting because modified Newtonian dynamics, valid for accelerations below a_0~1.2x10^{-8} cm s^{-2}, may offer an alternative to dark matter, with far-reaching implications for cosmology.

We therefore aimed at recording radial velocities for as many cluster member stars as possible, located everywhere from the centre to beyond the tidal radii. In the case of M4/NGC 6144, we have acquired three field configurations containing candidate red giant cluster members. In Fig. 7 we show the celestial distribution of the 719 stars observed (left panel) and the histogram of the measured radial velocities (right panel). The two peaks of the two clusters at 75 km s^{-1} (M4) and 200 km s^{-1} (NGC 6144) are very well defined and distinct from the galactic field.

A preliminary analysis shows that approximately 300 members can be identified in M4, whose radial velocities indicate a detectable systemic rotation with a full amplitude of about 1 km s^{-1} and a surprisingly large velocity dispersion around the tidal radius. The detailed analysis is underway and the results will be published later this year (Kiss et al., in prep.).

References

Andretta, V, et al., 2005, A&A, 430, 669
Bonatto, C., et al., 2008, MNRAS, 386, 324
Carraro, G., Lia, C., 2000, A&A, 357, 977
Corradi, R.L.M., et al., 2000, A&A, 354, 1071
Cuffey, J., 1941, ApJ, 94, 55
Dobbie, P.D., et al., 2006, MNRAS, 369, 383
Drukier, G.A., 1998, AJ, 115, 708
Frew, D.J., 2008, PhD thesis, Macquarie University
Frew, D.J., Parker, Q.A., 2006, IAU Symp. 234, 49
Gallart, C., Zoccali, M., Aparicio, A., 2005, ARA&A, 43, 387
Gnedin, O.Y., et al., 1999, ApJ, 522, 935
Grillmair, C.J., Johnson, R., 2006, ApJ, 639, L17
Hünsch, M., et al., 2003, A&A, 402, 571
Hünsch, M., et al., 2004, A&A, 418, 539
Jacoby, G.H., et al., 1997, AJ, 114, 2611
Jura, M., Morris, M., 1985, ApJ, 292, 487
Kharchenko, N.V., 2005, A&A, 438, 1163
Kiss, L.L., et al., 2007, ApJ, 659, L129
Kiss, L.L., et al., 2008, MNRAS, submitted
Majaess, D.J., et al., 2007, PASP, 119, 1349
Mermilliod, J.-C., et al., 1989, A&AS, 79, 11
Mermilliod, J.-C., et al., 2007, A&A, 473, 829
Meylan, G., Mayor, M., 1986, A&A, 166, 122
Meylan, G., Heggie, D.C., 1997, A&ARv, 8, 1
Munari, U., et al., 2005, A&A, 442, 1127
O'Dell, C.R., 1963, PASP, 75, 370
Odenkirchen, M., et al., 2001, ApJ, 548, L165
Pauls, R., Kohoutek, L., 1996, AN, 317, 413
Platais, I., et al., 2001, AJ, 122, 1486
Scarpa, R., et al., 2007, A&A, 462, L9
Siegler, N., et al., 2007, ApJ, 654, 580
Skrutskie, M.F., et al., 2006, AJ, 131, 1163
Steinmetz, M., et al., 2006, AJ, 132, 1645
Stetson, P.B., 1981, AJ, 86, 1500
Székely, P., et al., 2007, AN, 328, 879
Zwitter, T., et al., 2008, AJ, 136, 421

A ROASTED BROWN DWARF IN AN OLD BINARY

Matt Burleigh (U. Leicester), Paul Dobbie (AAO), Pierre Maxted, (U. Keele),
Ralf Napiwotzki (U. Hertfordshire)

Using observations obtained in service time with the AAT and IRIS2, we have discovered significant heating of the atmosphere of a brown dwarf in a close, detached binary with a white dwarf. This unique object represents a “missing link” between the irradiated atmospheres of M dwarfs in similar close binaries, and the atmospheres of hot Jupiters currently being studied using the Spitzer Space Telescope.

Detached brown dwarf companions to white dwarfs are very rare, and indeed only three such binaries are currently known. The most intriguing of these is WD0137-349. Optical spectra of this hot white dwarf obtained by us with UVES on the VLT show a narrow hydrogen emission line due to irradiation of the surface of a close companion. Such features are often seen on irradiated M dwarfs in similar close binaries. Radial velocities measured from this line and the white dwarf’s intrinsic hydrogen absorption lines allowed us to determine the mass ratio of the system. Using the white dwarf mass ($0.39\pm0.035M_{sun}$), derived from an analysis of its optical spectrum, we then determined the mass of the companion to be $0.053\pm0.006M_{sun}$, well below the limit of $\sim0.075M_{sun}$ commonly used to distinguish stars from brown dwarfs. We confirmed this discovery with a near-infrared spectrum obtained with Gemini South and GNIRS that directly reveals the substellar companion through an excess of flux longwards of 1.95 microns. We best match those data with a white dwarf + L8 composite model.

WD0137-349 is the first close, detached binary to be discovered containing a white dwarf and a confirmed substellar companion. The brown dwarf must have survived a previous phase of common envelope (CE) evolution during which it was engulfed by the red giant progenitor of the white dwarf. The drag on the brown dwarf caused it to spiral in towards the red giant core from an originally much wider orbit. Some fraction of the orbital energy was released and deposited in the envelope, which was ejected from the system, leaving a close binary. The brown dwarf WD0137-349B is the lowest mass object currently known to have survived CE evolution.

At a separation of $0.65R_{sun}$, the hemisphere of the brown dwarf facing the 16,500K white dwarf intercepts about ~1% of its light and is being heated through irradiation, as evidenced by the narrow, weak H emission line seen in optical spectra. Therefore, we realised that WD0137-349 is potentially an excellent system for studying the effects of heating on the atmosphere of a substellar object, and can potentially be used as a comparison for different theoretical models of the effects of irradiation on lower-mass hot Jupiters. The heated atmospheres of several transiting planets have been detected in the mid-infrared by the Spitzer Space Telescope. Hot Jupiters receive >10,000 times more radiation than Jupiter does from the Sun, and this heating can increase the photospheric temperature by an order of magnitude compared to isolated planets, to as high as 2000K. Irradiation will also decrease the cooling rate and alter the planet’s radius and atmospheric structure. Severe irradiation could even lead to atmospheric evaporation, for which evidence has been found through the discovery of an extended atmosphere for HD209458b. In these synchronously rotating systems, some models predict substantial temperature differences between the day and night sides, possibly leading to strong winds transporting heat to the night side. Indeed, an important question being addressed by Spitzer’s observations of hot Jupiters is what fraction of the energy absorbed by the continuously illuminated day side is transferred to the night side? Observations over a significant fraction of the orbit can constrain the longitudinal temperature distribution across the atmosphere. However, Spitzer observations of hot Jupiters require data with S/N>1000, and detailed investigations are extremely difficult to undertake. Given the very favourable contrast between the white dwarf and the brown dwarf in the infrared, WD0137-349 is an outstanding system for studying the effects of irradiation on a substellar object’s atmosphere.

To further investigate the effects of irradiation on the brown dwarf WD0137-349B, we obtained a near-infrared K-band lightcurve with IRIS2 on the AAT in service time July 2006, covering the entire ~2 hour orbital period. Unfortunately, the observing conditions were poor, with seeing between 3–4 arcseconds. Nonetheless, the data appeared to show variability at a level of over ±10%. This degree of modulation was a little unexpected and, since the data were obtained in conditions that were far from optimal, we were a little sceptical about their reality. Another opportunity to observe the binary did not occur until a year later, in July 2007, and once again we were grateful to the AAT service programme for a generous allocation of time. On this occasion, we were fortunate to enjoy much better conditions. Data were obtained with IRIS2 at J, H and K across two successive binary orbits (i.e. for a total of four hours) by cycling repeatedly through the three filters. In this manner, a data point was obtained in each waveband every 2–3 minutes. Differential photometry was performed with respect to

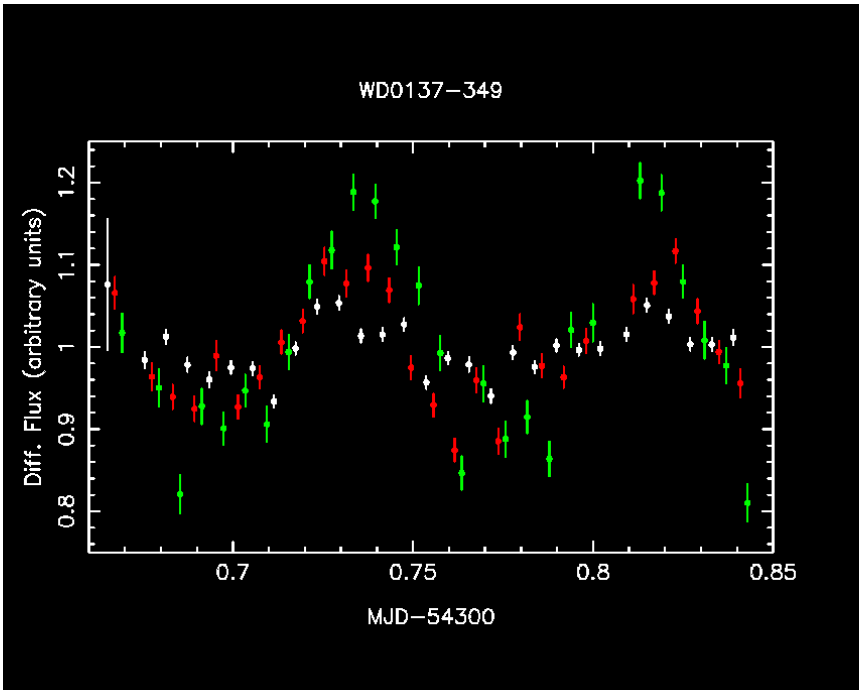


Figure 1: J (white), H (red) and K (green) band light curves of the two hour orbital period white dwarf + brown dwarf binary WD0137-349, obtained over four hours with IRIS2 on the AAT on 20 July 2007. At J the flux varies by ±3% at H by ±8% and at K by ±14%. Since the white dwarf itself is non-variable, these modulations must be originating from the heated atmosphere of the brown dwarf.

several non-variable stars of similar brightness in the field of view, and the resultant light curves are shown in Figure 1.

These data show variability in all three near-infrared filters across the binary orbit: ±3% at J, ±8% at H, and increasing to ±14% at K. Clearly, there are differences between the day and night hemispheres of the brown dwarf. As with the hot Jupiters, we expect the brown dwarf to be synchronously rotating and perpetually displaying one hemisphere to the 16,500K white dwarf. We can make a crude estimate of the temperature difference between the two hemispheres by comparing the maximum and minimum fluxes. In Figure 2 we have plotted these alongside models for the white dwarf + substellar companions from a spectral type of L0 to T5. At minimum in the K band, the flux is consistent with an L8 brown dwarf. At maximum, the data favour an earlier, L6 classification. The difference in temperature between these two spectral types is 200–300K. Therefore, the day side seems to be heated to a temperature around 1600–1700K, and the night side is a cooler 1300–1400K. We mentioned earlier that our existing near-infrared spectrum of WD0137-349 is best matched with a white dwarf + L8 brown dwarf composite model (Burleigh et al., 2006), suggesting that it was obtained when the night hemisphere was facing us. We note that for ages >1Gyr , an L8 spectral type and a temperature of 1300–1400K is entirely consistent with the measured mass of the brown dwarf, as predicted by evolutionary models.

At this stage we can begin to draw some comparisons with Spitzer's observations of hot Jupiters. Harrington et al. (2006) made the first detection of phase variations in an extrasolar planet, μ Andromedae b. The size of the observed variation implies a large day-night temperature difference and they concluded that there must be a correspondingly inefficient circulation between the two hemispheres. In contrast, Knutson et al.'s (2007) observations of HD189733b show

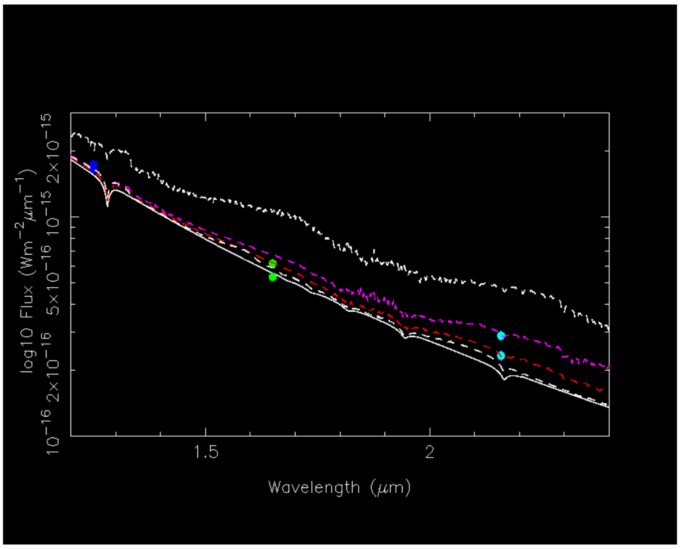


Figure 2: Maximum and minimum fluxes at J (dark blue), H (green) and K (light blue) compared to composite white dwarf + brown dwarf models from L0 (top), through L6 (magenta), L8 (red) and T5. The predicted white dwarf spectrum alone is the solid white line. At K, the maximum flux corresponds to a brown dwarf spectral type of L6, and the minimum (night side) flux to L8. The difference in temperature between these two spectral types is 200–300K.

an increase in brightness by ~60% on the day side compared to the night side, although the difference in the hemisphere-averaged temperature is only ~250K, with a maximum of ~1200K. These observations suggest that the transport of heat around the planet is relatively efficient. Does the similar temperature difference between the two hemispheres of WD0137349B also imply that atmospheric circulation is efficient? On the other hand, the night side flux is consistent with a spectral type and implied temperature entirely consistent with a brown dwarf of that mass and age. In other words, the night side does not appear to be significantly heated.

It is probably too early in our investigations of WD0137-349B to draw meaningful conclusions on the efficiency of day-night circulation for comparison with the hot Jupiters. Since the IRIS2 observations were made, we have obtained further, higher S/N and higher time resolution near-infrared light curves with SOFI on the NTT at La Silla, and we have obtained mid-infrared light curves across the entire orbit with Spitzer at 3.6, 4.5, 5.8, and 8.0 microns. Detailed modelling of these data is the next step. In particular, we are intrigued to discover whether the centre of maximum light, i.e. the hot spot on the day side, is shifted relative to the substellar point (phase 0). Knutson et al. discovered that the maximum flux from HD189733b is located 30 degrees east of the substellar point. This is consistent with an atmosphere in which the hot and cool regions are shifted in the direction of the prevailing winds. To investigate this phenomenon on WD0137-349B, we have obtained near-simultaneous radial velocity measurements with UVES on the VLT for comparison with the NTT and Spitzer light curves.

WD0137-349 is a currently unique system for studying and understanding the heating of substellar atmospheres. It represents a "missing link" between the irradiated atmospheres of M dwarfs in similar close binaries, and the atmospheres of hot Jupiters, and we look forward to the results of our ongoing analysis of this exciting binary.

References

Baraffe, I. et al., 2003, A&A, 402, 701
Baraffe, I. et al., 2004, A&A, 419, L13
Burrows, A. et al., 2004, ApJ, 609, 407
Burleigh, M.R. et al. 2006, MNRAS, 373, L55
Charbonneau, D. et al., 2005, ApJ, 626, 523
Cowan, N.B. et al., 2007, MNRAS, 379, 641
Deming, D. et al., 2005, Nature, 434, 740
Golimowski, D.A. et al. 2004, AJ, 128, 1733
Guillot, T. et al., 1996, ApJ, 459, L35
Harrington, J. et al., 2006, Science, 314, 623
Harrington, J. et al., 2007, Nature, 447, 691
Knutson, H.A. et al., 2007, Nature, 447, 183
Maxted, P.F.L. et al., 2006, Nature, 442, 543
Politano, M., 2004, ApJ, 604, 817
Showman, A.P. & Guillot, T., 2002, A&A, 385, 166
Vidal-Madjar, A. et al., 2003, Nature, 422, 143

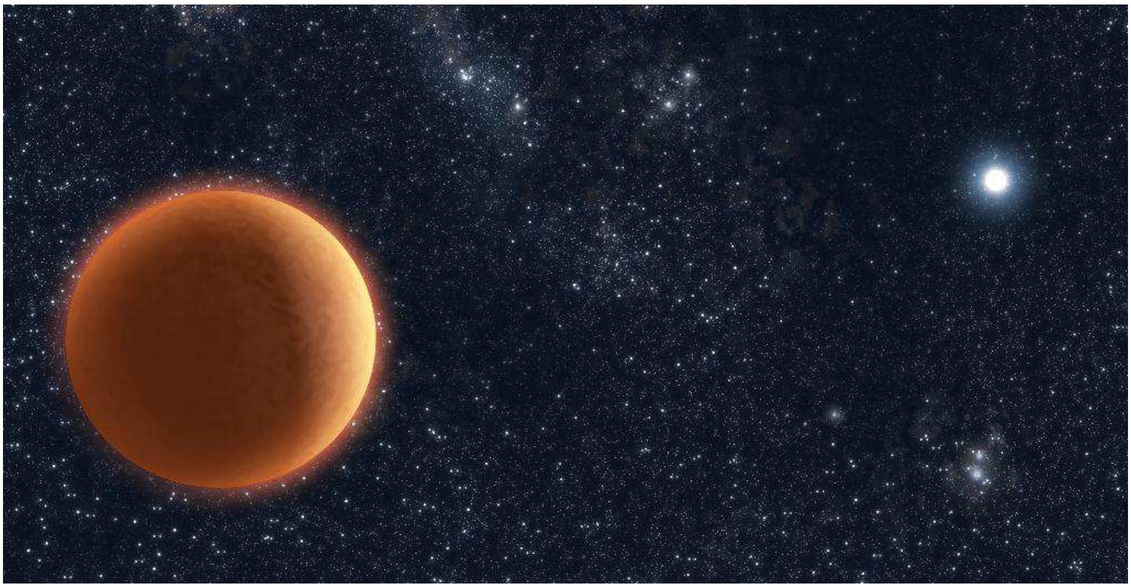


Figure 3: Artist's impression of the WD0137-349 system. The hot white dwarf is no bigger then the Earth, while the brown dwarf is about the size of Jupiter, although much more massive (55 times Jupiter's mass). Credit: European Southern Observatory (ESO).

AUSGO CORNER

Stuart Ryder & Terry Bridges (Australian Gemini Office, AAO)

As indicated in the previous AAO Newsletter, the Australian Gemini Office (AusGO) hosted at the AAO will be making regular Newsletter contributions to keep the Australian community updated on Gemini and Magellan news and events of particular interest to them. For all the very latest information, please also visit the AusGO web site at http://ausgo.aao.gov.au. Another simple way to stay informed on Gemini developments is to subscribe to their RSS feeds – see http://www.gemini.edu/index.php?q=node/118 for details.

Semester 2008B

The new AusGO has just negotiated its first semester in charge of the proposal and time allocation processes for Australian time on Gemini and Magellan in Semester 2008B. In this semester we received a total of 28 Gemini proposals, of which 16 were for time on Gemini North or Subaru, and 12 were for time on Gemini South. The oversubscription factors were 2.16 in the north, and 2.48 in the south. For the first time ever, the net Australian oversubscription was the highest of all the Gemini partners. Proposals were technically assessed by AusGO personnel, then the Australian Time Assignment Committee (ATAC) met to rank them. These rankings were forwarded to the Gemini International Time Allocation Committee (ITAC) which met at the end of May to formally merge individual and joint proposals into the standard Gemini queue bands.

At ITAC, Australia was able to schedule one proposal as a classical run on Subaru, with 18 more going into Bands 1–3. It is worth noting that in recent semesters, at least 70% of Australian proposals (including those in Band 3) have obtained some data, and of these about 80% end up being completed (where “completion” means at least 80% of their allotted time is observed). Thanks to the awarding of “rollover” status, virtually all Band 1 programs will eventually be 100% complete, and most Band 2 programs also are being done to completion.

For Magellan we received just 5 proposals for 12 nights, but the oversubscription was still a healthy 1.7. Semester 2008B marks the end of the original agreement for Australia to purchase 15 nights/year over 2 years on the Magellan telescopes. Negotiations between Astronomy Australia Ltd (AAL) and the Magellan consortium for a possible extension of this agreement are still ongoing, but we hope to be able to make an announcement shortly about the future of this very productive access program.

Staffing

Dr David Woods returned to his native Canada at the end of March 2008, ending his term as an Australian Deputy Gemini Scientist. On behalf of the Australian Gemini Office and user community, I would like to extend our heartfelt appreciation to David for his excellent support in that role. David was responsible for everything from printing out the proposals, to coordinating technical assessments, to providing Phase II and Helpdesk support for GMOS. We wish him well in his future endeavours.

Fortunately, Dr Terry Bridges arrived just a month later to maintain both the Canadian influence and the GMOS expertise within AusGO. Terry will be well known to many of you in his earlier incarnation of AAO/UK 2dF Research Fellow at the AAO. Terry has had little trouble readjusting to Sydney, so barely two weeks after he arrived we sent him off to Hawaii for the WFMOS Science meeting (see below), and to spend time at Gemini North familiarising himself with the queue operation and talking with Gemini science staff.

Dr Christopher Onken has been appointed as a Deputy Gemini Scientist to be based in Canberra at the ANU’s Research School of Astronomy and Astrophysics, and will take up his position in September 2008. Chris comes to us from the Dominion Astrophysical Observatory where he is a Plaskett Fellow. He has experience with both GMOS and NIFS, and will be heavily involved in supporting Australian users of these key instruments.

WFMOS Science

The Gemini Science Committee and Gemini Board have ranked an optical Wide-Field Multi-Object Spectrograph (WFMOS) as one of the highest priority new instruments required to realise the future Gemini science presented at the Aspen meeting in June 2003. Originally proposed for one of the Gemini telescopes, it was subsequently realized that WFMOS would be a much better fit for the Subaru 8m telescope. During May 19–21 2008, there was a workshop on WFMOS science (“Cosmology Near and Far: Science with WFMOS”) held in Waikoloa, Hawaii, and sponsored by Gemini, Subaru, AAL, NOAO, STFC, and JSPS. There were ~80 participants, including 8 from Australian institutions (AAO, AusGO, RSAA, Swinburne, and University of Sydney), others from the US, UK, Canada, France, Brazil, Taiwan, and a large number of Japanese astronomers. The meeting presentations are available from the web site http://www.naoj.org/Information/News/wfmos2008/ .

The focus of the workshop was to discuss the full breadth of possible WFMOS science, and it was very successful in this. After an introduction to WFMOS given by Joe Jensen (Gemini Head of Instrumentation), there was a wide range of talks on topics including: Galactic astronomy (near-field cosmology), nearby galaxies, galaxy groups and clusters, studies of dark energy and baryon acoustic oscillations through large redshift surveys, and other topics such as neutrino masses and modified gravity. There were also talks on Subaru's FMOS and Hyper Suprime-Cam, the latter of which would be highly complementary to WFMOS. At the end of the meeting, there was a panel discussion (Y. Suto, D. Simons, M. Hayashi, R. Ellis, A. Dey, and N. Arimoto) to summarise the meeting. A decision on whether WFMOS will go ahead on Subaru will be made within a year.

Live from Gemini

Rob Hollow, Education Officer with the Australia Telescope National Facility (ATNF) reports: "Twenty-two science teachers were the first Australian teachers to go live to Gemini on 4 April 2008. "Live from Gemini" is a program offered free to educators in partner countries from Gemini North in Hilo, Hawaii. The teachers were participating in the "Astrophysics for Physics Teachers" one-day workshop conducted at the ATNF headquarters in Marsfield.

The focus of the workshop was on stellar evolution and modern observing techniques as required by the Astrophysics option of the NSW Physics syllabus. Dr Scott Fisher, the Gemini Outreach Scientist, presented a one-hour session with live video conference from the Gemini control room in Hilo. His talk covered the features of Gemini including the active and adaptive optics systems and its location. He discussed some examples of observations and the resultant science in an engaging and stimulating manner. The real value of the session became evident in the extensive question and answer session conducted at the end. The participating teachers really appreciated the chance to talk with Scott and have their queries answered. It proved to be a highly effective and enjoyable session for all the participants and one that is certain to be repeated in future workshops."

AGUSS

Once again AusGO, AAL, and the Gemini Observatory are pleased to offer talented undergraduate students enrolled at an Australian university the opportunity to spend 10 weeks this summer working at the Gemini South observatory in Chile on a research project. The deadline for applications for the 2008/09 Australian Gemini Undergraduate Summer Student (AGUSS) program is 31 August 2008. If you, or anyone you know, might be interested in this opportunity, please refer to http://ausgo.aao.gov.au/aguss.html for details on how to apply.

Poor weather programs

Pssst, wanna get some free time on an 8 metre telescope? In order to make the most scientific use of marginal but not hopeless weather, Gemini offers a "poor weather" queue for programs which can tolerate seeing worse than 1.5 – 2 arcsec and non-photometric conditions, or better seeing with at least 2 magnitudes of cloud. Poor weather proposals can be submitted at any time throughout the year using the Phase I Tool, by selecting "Poor Weather" from the drop-down menu in the "Submit" tab. Proposals in the Poor Weather queue rank below Band 3 proposals, but any time used is not charged to the PI or their partner country, so (theoretically) such time is unlimited. See http://www.gemini.edu/sciops/ObsProcess/ObsProcCfP_background.html#Poor_weather_proposals for further details.

Ready to publish?

You've got your Gemini time, you've processed your data, and now you're ready to publish this amazing result. Congratulations! Before you do so though, here are a few things to keep in mind:

- Have you used the correct Acknowledgement text in your paper? Gemini request that you use the standard acknowledgement text given at http://www.gemini.edu/sciops/data/dataAcknowIndex.html This has changed recently, so please be sure to use the current version.
- This is an ideal time to complete the observer feedback form for queue (http://www.gemini.edu/sciops/data/FeedbackFormData.html) data, or from a classical (http://www.gemini.edu/sciops/data/EndofRunReport.html) run.
- Would this result make for an interesting Press Release? Both AusGO and the Gemini Observatory have a range of resources that can improve the impact and media reach of your press release, so please be sure to contact Helen Sim (Helen.Sim@csiro.au) in advance of publication so that arrangements can be made.

STAR CHANT INSPIRES OUT OF THIS WORLD MUSIC

Liz Cutts (Coonabarabran Times)

A well known local astronomer has received a prestigious music award for his contribution to an ethereally inspired symphony that fuses art and science.

Coonabarabran's Professor Fred Watson, Astronomer-in-charge of the Anglo-Australian Observatory at Siding Spring, was a winner in the vocal or choral work of the year at the recent 2008 APRA Classical Music Awards.

Staged as an annual event, the Australian Performing Rights Association (APRA) awards honour those composers and songwriters who have achieved the highest performances of their work and excellence in their craft over the previous year.

Fred wrote the words to Symphony No. 4 'Star Chant', composed by Australian musician, Ross Edwards.

Star Chant represents a journey through Australia's night skies. It celebrates the stars in Western and Aboriginal culture with names taken from both ancient European legend and the Dreamtime stories of many different indigenous peoples.

The seed for this work was planted when Ross Edwards accompanied a group of astronomers to outback Queensland on a stargazing expedition. Fred was on the trip and provided a kind of 'map'; the astronomy of Star Chant, which the symphony follows and which gives it its form.

Renowned composer Ross Edwards was so inspired that it led him to create his fourth symphony, which goes by the same name, featuring a full orchestra and choir.

The chorus sings the names of the celestial features depicted in the music in the languages of various cultures.

"You've got the Indigenous peoples' view of the sky, of the southern sky specifically, and also the European and Arabic words for our local sky," explained Ross Edwards in an interview with Rachel Kohn.

"Fred Watson put them side by side, which I thought was a wonderful idea. So I made it into a chant in which these words are literally repeated with appropriate music in the background."

The Awards were presented by APRA and the Australian Music Centre, at The Playhouse, Sydney Opera House, last month.

Fred, who has always been committed to bridging the gap between the arts and science, says he is overwhelmed by the result.

"Well, it was very unexpected, and a great honour to be sharing the stage with some of Australia's leading classical musicians!" stated Fred.

"Star Chant is intended to celebrate Australia's night sky for everyone, with ancient Dreamtime themes mixed with traditional western constellations. While science binds these ideas together, it is Ross Edwards' inspiring music that transforms Star Chant into a unique experience for anyone who has ever wondered about the Universe."

Fred Watson and Ross Edwards at the APRA Classical Music Awards night. Fred received his award for his contribution to Star Chant, a symphony that fuses art and science. Photo courtesy of Prue Upton.

This article was originally published as the front-page story in the Coonabarabran Times, 21 August 2008

SUMMER STUDENTS

Paul Dobbie

The AAO runs a twice yearly fellowship programme to enable undergraduate students to gain 10–12 weeks of first hand experience of astronomical related research. The current crop of students are from the northern hemisphere.

Tessa Baker arrived in July from the University of Oxford and will be at the AAO until mid-September. She is working with Rob Sharp on the analysis of spectroscopy of three quasars obtained with the GMOS spectrographs on the Gemini telescopes. The ultimate aim of her project is to produce a model of how the 2D intensity profiles of the active galactic nuclei (AGN) vary with wavelength; this component can then be subtracted from the quasar spectra to reveal the underlying energy distributions of the AGN host galaxies. It will then be possible to study these for signs of outflows or evidence of recent mergers. The first steps towards this goal are now complete and have included reduction of the Gemini data and modelling of PSF stars. Tessa has just returned from a visit to Siding Spring where she had the opportunity to see the AAT in action.

Alex Merson has recently completed a masters degree in Physics & Astronomy at the University of Durham. He is investigating galaxy clustering in the 6dF Galaxy Survey, under the supervision of Matthew Colless and Heath Jones. Alex is adapting the friends-of-friends group-finding algorithm of Eke et al. (2004), to determine group velocity dispersions and estimate the masses of the underlying dark matter haloes. He is also investigating how galaxy properties change as a function of their surrounding environment with the 6dFGS groups. At the end of his time at the AAO, Alex will be returning to Durham to start a PhD under the supervision of Carlton Baugh in the field of galaxy formation and evolution.

Our third student is Alice Danielson who also comes from the University of Durham, having recently completed the third year of a masters degree in Physics & Astronomy. Alice is working with Quentin Parker and Paul Dobbie on a deep photometric study of the rich open cluster NGC2477, utilising wide field imaging data obtained with the ESO 2.2m and CTIO 4m telescopes. The aim of the project is to identify and characterise the white dwarf population and use it to place constraints, which are largely independent of stellar evolutionary models, on the age of the cluster. This estimate can serve as a test of stellar evolutionary models. Furthermore, the brighter white dwarf members identified here can be studied spectroscopically at a later date to add further empirical points to the stellar initial mass-final mass relation.

EPPING NEWS

Sandra Ricketts

This column should perhaps be retitled “Comings and Goings”! Once again we have farewelled a number of colleagues and welcomed others.

Don Mayfield retired in early July after 33 and 1/3rd years in the Electronics section of the AAO. Don was the longest continuously serving employee at Epping and the second longest continuously serving employee at the combined sites (Bob Dean is the longest by about a year). Don has worked on almost every instrument that the AAO has developed in that time, for both the AAT and other telescopes. Don is missed by all, especially at lunch and tea times, when he never failed to enliven any discussion.

Larry Reeves will also retire at the end of August, having been our accountant for the last 3 years. We wish him well in his new career as a grey nomad. He will be replaced by Siva Shanmugam, who has in fact already arrived. Welcome, Siva.

Simon Ellis left us at the end of July for Sydney University where he will be working with Joss Hawthorn, and will also enjoy being closer to the beach.

Another departure (from site this time) is that of Shaun James, who has completed his degree and moved to Newcastle. Another one feeling the call of the beach!

Other new faces at Epping are Ian Noble, who is Project Manager for HERMES, David Orr, a systems engineer also working on HERMES, among other things, and Paris Constantine who is helping to manage the WFMOS design study and assist in the development of the WFMOS build proposal. Paris is not actually new to the AAO, having been here in the early 2dF design days.

And as mentioned in the last Newsletter, Terry Bridges has returned to the AAO as Deputy Gemini Scientist. It's good to have his friendly person here again.

Congratulations to Heath Jones, who has been appointed to a Research Astronomer position, having previously been the AAO Director’s Fellow.

Congratulations also to John Collins (at site) and Leonie on the safe arrival of Jeremy Andrew in May.

Are M46 and NGC2438 associated? AAOmega provides a definitive answer

A colour image (courtesy of Steve Lee) of the 250 Myr-old cluster M46 and the planetary nebula NGC2438. Until now there has been uncertainty as to whether these two objects are physically associated. In this issue László Kiss and collaborators describe their recent work on radial velocities with AAOmega, which has provided a definitive answer to this question.

editor PAUL DOBBIE editorial assistant SANDRA RICKETTS

ISSN 0728-5833
Published by ANGLO-AUSTRALIAN OBSERVATORY
PO Box 296 Epping, NSW 1710 Australia

Epping Lab
Telephone +61 2 9372 4800 Fax +61 2 9372 4880 email < *user@aao.gov.au* >

AAT/Schmidt
Telephone +61 2 6842 6291 Fax +61 2 6884 2298 email < *user@aaocbn.aao.gov.au* >

URL < http://www.aao.gov.au >