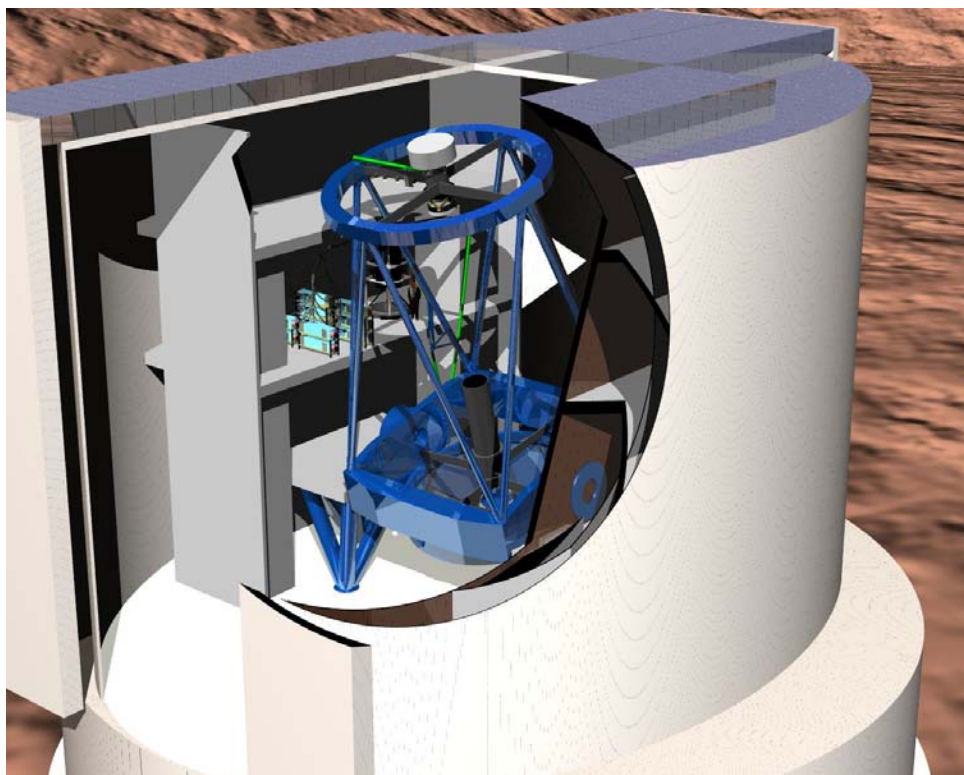


Concept for WFMOS on Subaru



As discussed previously in AAO Newsletter 105 (July 2004), the AAO has been leading the effort to explore the feasibility and costing of a very wide-field, high-multiplex spectrograph (called WFMOS) for the Gemini Observatory. This feasibility study, produced in collaboration by the AAO, NOAO, Durham, JHU, Oxford, Univ. of Portsmouth and the CADC, will be submitted in early March and then undergo review at Gemini. Part of the study was to examine the feasibility of implementing this instrument on the Subaru telescope. The figure shows this implementation with an Echidna style positioner located at the prime focus of the Subaru telescope. The fibre cable drapes off the telescope and enters a spectrograph chamber located on the side of the Subaru enclosure. 1500 fibres feed into a set of high-dispersion spectrographs (located on the right hand side of the room in the figure) that will provide a resolving power of 40,000. An additional set of 3000 fibres feed into a bank of low-dispersion spectrographs (located on the left hand side of the room in the figure) for low-resolution surveys.

3	Using methane imaging to probe brown dwarfs (Chris Tinney et al.)
6	AAPS targets the highest precision (Chris Tinney et al.)
9	Small-scale-structure of the diffuse ISM probed by diffuse band observations (Martin Cordiner et al.)
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15	Local News

DIRECTOR'S MESSAGE

In simultaneous press conferences sponsored by the American Astronomical Society and the Royal Astronomical Society, the 2dF Galaxy Redshift Survey and Sloan Digital Sky Survey teams announced on 12 January this year that they had both obtained clean detections of acoustic oscillations in their maps of the galaxy distribution. Although the two teams used different datasets and different analysis techniques, their results agreed remarkably well. The detection of acoustic oscillations produced by the interaction of gravity, light and ordinary matter less than 300,000 years after the Big Bang is important scientifically because it confirms a strong prediction of the standard cosmology and provides a new 'standard rod' for measuring the geometry of the universe and probing the nature of the mysterious dark energy.

These results, and the manner in which they were obtained and announced, are also significant as yet another indication of one way that the research culture of astronomy is evolving. Each of the two teams is a large, multi-researcher, multi-institution collaboration; both projects have been based on purpose-built instrumentation; both have taken a decade or more from conception to completion. Moreover, while the two groups have worked in competition at one level, at another there has been cooperation, as exemplified by the joint press releases. This trend towards larger and more collaborative research programs is an obvious feature of recent years, and has important implications for how major observing facilities are run.

The importance of such large-scale research projects in addressing major scientific questions is apparent in the recent paper on the productivity and impact of optical telescopes by Trimble et al. (2005, PASP, 117, 111). For the year (2001) studied by Trimble et al., the AAT and SDSS garnered by far the most citations of all the world's optical telescopes below the 8-metre class – a factor of two more than their nearest rivals. Indeed, together they generated more citations than Keck. While the AAT generated marginally more papers in 2001 than any other 4-metre class telescope, the telescope's huge impact was mainly due to the very high citations per paper obtained by the 2dF Galaxy Redshift Survey and the 2dF QSO Redshift Survey. Of the 16 most-cited papers published in 2001 (jointly accounting for 10% of all citations), four came from 2dF while another three came from SDSS.

Now there are lies, damned lies and citation statistics, and Trimble et al. happened to choose a very good year for the AAT. Nonetheless, it is clearly evident that a well-resourced medium-sized telescope can have strong impact if it attacks major questions with cutting-edge instrumentation and generous allocations of time.

Recognising this fact, the AAO is currently seeking to provide opportunities for exploiting the AAT's unique capabilities in large observing programs targeting major scientific questions. These programs can use any instrument, or combination of instruments, on the AAT, although particular attention is drawn to the AAOmega spectrograph (<http://www.aao.gov.au/local/www/aaomega>). AAOmega is expected to be available on the AAT from early 2006, and will be the world's most efficient instrument for large-scale survey spectroscopy for some years thereafter.

As this newsletter goes to press, the deadline is about to fall due for expressions of interest in large observing programs. The AAO will review these initial indications of possible projects, provide feedback to the proposers, and use them to inform a request for proposals expected to be issued in April, with a likely deadline in August.

While large observing programs are just part of the mix of programs supported by the AAT, from the end of semester 2005A the UK Schmidt Telescope will be reverting to something like its original role as a single-purpose telescope. Originally conceived to carry out photographic surveys of the southern sky, the UKST has in recent years carried out a varied mix of large surveys (such as the H α photographic imaging survey and the 6dF spectroscopic galaxy survey) and smaller programs utilizing photography, fibre spectroscopy and CCD imaging.

Beginning in semester 2005B, however, the UKST will be largely dedicated to the RAVE (RAAdial Velocity Experiment) project, which aims to measure the radial velocities, metallicities and abundances for hundreds of thousands of stars over a 5-year period. RAVE will be carried out on a user-pays basis, and is funded by grants obtained by the RAVE consortium. RAVE has already measured more than 50,000 stellar radial velocities (significantly more than the previous total) and will provide a superb map of the kinematical and chemical distribution of stars in the Milky Way, with a sample large enough to detect substructure in both the disk and the halo. Based on experience with previous large programs on the AAO telescopes, RAVE is expected to have a major impact.

Matthew Colless

USING METHANE IMAGING TO PROBE BROWN DWARFS

Chris Tinney, Simon Ellis (AAO), Adam Burgasser, Michael McElwain (UCLA), Davy Kirkpatrick (IPAC)

The broad and strong methane absorptions seen in the near infrared spectra of T-type brown dwarfs (cool brown dwarfs with photospheric temperatures less than about 1000K) were almost instantly recognised as an obvious target for imaging using specially designed filters. Indeed, within just a few months of the discovery of the first T-type brown dwarf (Nakajima et al. 1995), a sanity check paper appeared (Rosenthal et al. 1996) verifying this expectation.

However, while some exploration of the scientific exploitation of imaging T-dwarfs in methane filters has been carried out (Herbst et al. 1999, Mainzer & McLean 2003, Mainzer et al. 2004), no really large-scale methane imaging programs have yet been carried out. This situation made the availability of methane filters in IRIS2 just too tempting a target to resist, and so over the last 2 years we have been carrying out an extensive set of observations to characterise the IRIS2 methane filters, define a new methane imaging photometric system, and finally exploit these new probes of brown dwarf behaviour.

The starting point for our work was the desire to use methane filters as a way to winkle T-dwarfs out of the 2MASS all-sky imaging database. They have turned

out to be very successful at this task identifying, over the last two years, eight new T-dwarfs and detecting a further three in parallel with more traditional spectroscopic approaches (Tinney et al. 2005, Ellis et al. 2005). But it has become obvious that methane imaging can be used in many other ways to probe brown dwarfs – e.g. as an efficient selection technique for identifying candidate “planetary-mass” (i.e. <10M_{Jup}) brown dwarfs in nearby young star clusters; as a way to probe rotation induced cloud deck variations (i.e. weather) in T-dwarfs; and, of course, to winnow T-dwarfs (and even cooler “Y”-dwarfs) from the next generation of large infrared sky surveys like UKIDSS.

IRIS2's Methane Filters & the New System

IRIS2's filters were acquired as part of one of the Mauna Kea Observatories (MKO) infrared filter consortia. The narrow- and intermediate-band set are as specified by A. Tokunaga¹ and include a pair of methane filters, which we denote CH₄s and CH₄l – because of the widespread membership of these consortia, identical methane filters are available in many infrared instruments around the globe. Figure 1 shows the band-passes for these filters, superimposed on sample T- and L-dwarf spectra. The CH₄l filter samples the broad 1.6–1.8μm methane absorption bands seen in T-dwarfs, while the CH₄s filter samples a pseudo-continuum outside the methane band – though as for all cool, dwarf photospheres this pseudo-continuum is itself the result of significant molecular absorption – in this case largely water.

As no existing photometric system for these filters exists, we first had to define one. We defined the CH₄s-CH₄l colour using MKO H-band standard star photometry for A- to G-type stars, in the sense that CH₄s-CH₄l is defined to be zero for stars in this spectral type range. By carrying out absolute photometry on four photometric nights over the course of 2 years, we were therefore able to define a parametrisable relationship between spectral type and CH₄s-CH₄l. Figure 2 shows this relationship (and makes clear why we chose the A–G range to define our photometric system). There is a general trend for stars to become redder in CH₄s-CH₄l at later type, until the onset of methane

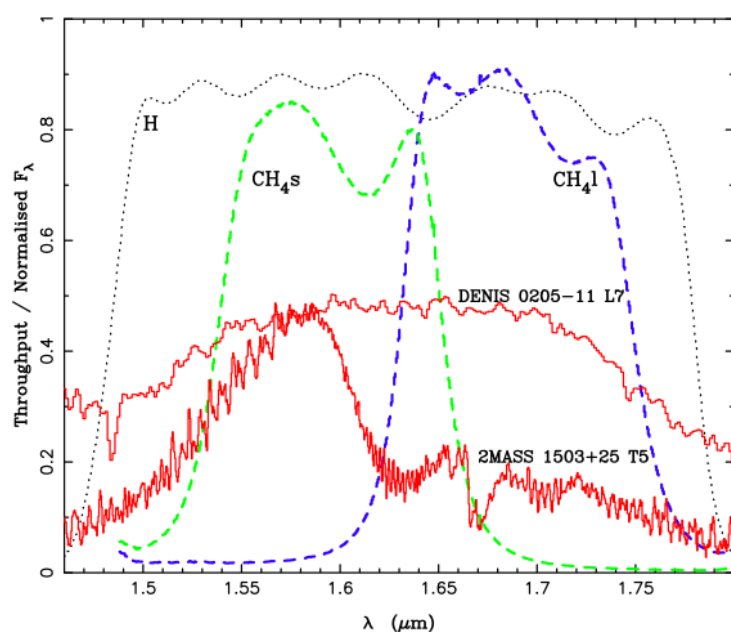


Figure 1 – Methane filter bandpasses superimposed on an example L- and T-dwarf spectrum. The H photometric bandpass is also shown for comparison.

¹ <http://www.ifa.hawaii.edu/~tokunaga/filterSpecs.html>

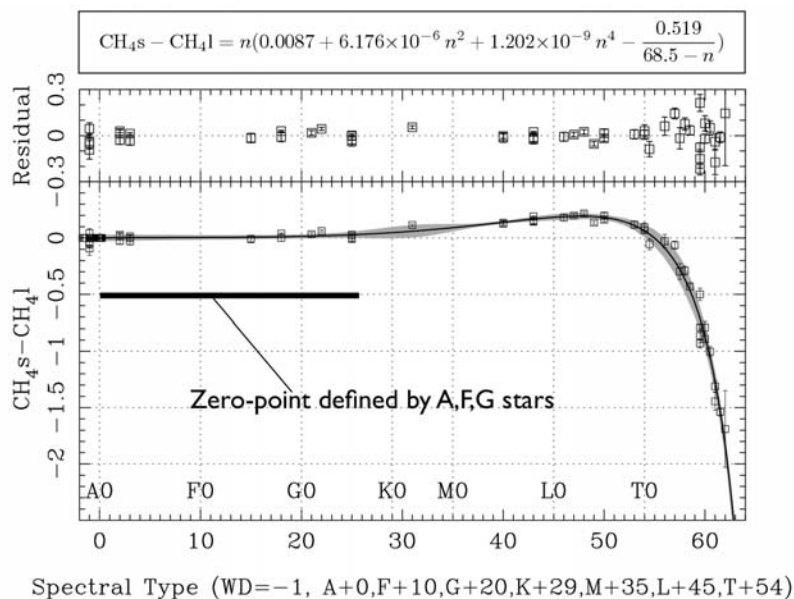


Figure 2 – $\text{CH}_4\text{s} - \text{CH}_4\text{l}$ colour as a function of spectral type, with a suitable parametrisation across the spectral type range A to T indicated.

absorption in T-dwarfs, when it dramatically switches to become bluer.

How it works

The parametrisation shown in Figure 2 allows photometric observations in methane filters to estimate a brown dwarf's T-spectral type. Similar parametrisations can also be developed as a function of JHK colour, to provide additional information on a candidate's spectral type. Unfortunately, if methane imaging is limited to being done in photometric conditions, it is not a very useful technique at the AAT site. Fortunately, the wide field of view of IRIS2 can come to the rescue here. In its 60 sq.arcmin. field of view, there are inevitably many background objects, most of which have nearly zero intrinsic $\text{CH}_4\text{s} - \text{CH}_4\text{l}$ colour, which can be used to differentially calibrate methane imaging data. Tests show (Tinney et al., 2005, submitted) that with some careful analysis, and the availability of the all-sky 2MASS data, pairs of methane images can be differentially calibrated onto our methane photometric system without the need for the usual overheads and clear conditions needed for absolute photometry.

Methane imaging, therefore, is easy and straightforward. Using an IRIS2 observing sequence, dithered observations in CH_4s and CH_4l are acquired, and a minute or so after the sequence finishes, the ORAC-DR pipeline spits out a pair of fully reduced images. These are run through SExtractor to obtain raw photometry, and the Gator interface is used to download 2MASS data for the field in question. A perl script then takes the SExtractor and 2MASS data, does an astrometric

match², identifies the background stars in 2MASS, estimates methane colour zero-points, and finally estimates the target object's T spectral type. Figure 3 shows an example of the output produced by this script, which allows the identification of T-dwarfs within minutes of finishing an observation.

Yet More Science with Methane Filters

The initial impetus for our work with methane filters was the 2MASS Wide Field T Search (WFTS) – a survey of most (74%) of the usable 2MASS survey area in an expanded search for these rare objects, in

which the role of methane imaging was to winnow real T-dwarfs from the huge number of non-T-dwarf objects which fall through our initial selection procedures. In this regard, methane filters have proved very useful, detecting 11 new WFTS T-dwarfs – 8 detected for the very first time by methane imaging, and the remainder confirmed by methane imaging after spectroscopic observation elsewhere. But it doesn't take much thought to see that they could have many other uses.

Winning other large samples : The UKIRT Infrared Deep Sky Survey (UKIDSS) will carry out surveys in the Y, J, H and K passbands totalling a volume sensitivity for cool brown dwarfs almost 250 times larger than that obtained by 2MASS. While the filters used in these surveys will be far more suitable for the selection of cool brown dwarfs than those used by 2MASS, T-dwarfs will still represent only a tiny fraction of the total number of sources in UKIDSS ($\sim 3 \times 10^{-5}$). Hard won experience shows that when selecting objects as rare as this from a large database, the resulting sample is *always* dominated by contaminants – detector artifacts, ghosts, asteroids, cosmic rays, partially resolved binaries, confused sources near the survey limits etc – which all produce apparent catalogue sources with arbitrarily odd colours, some of which will mimic T-dwarfs. The class of brown dwarfs cooler than T-dwarfs (tentatively known as the “Y” dwarfs, and one of the key science drivers for the UKIDSS survey) will be even rarer, and candidate samples will be subject to even more contamination.

² Michael Richmond's excellent match code (<http://spiff.rit.edu/match>)

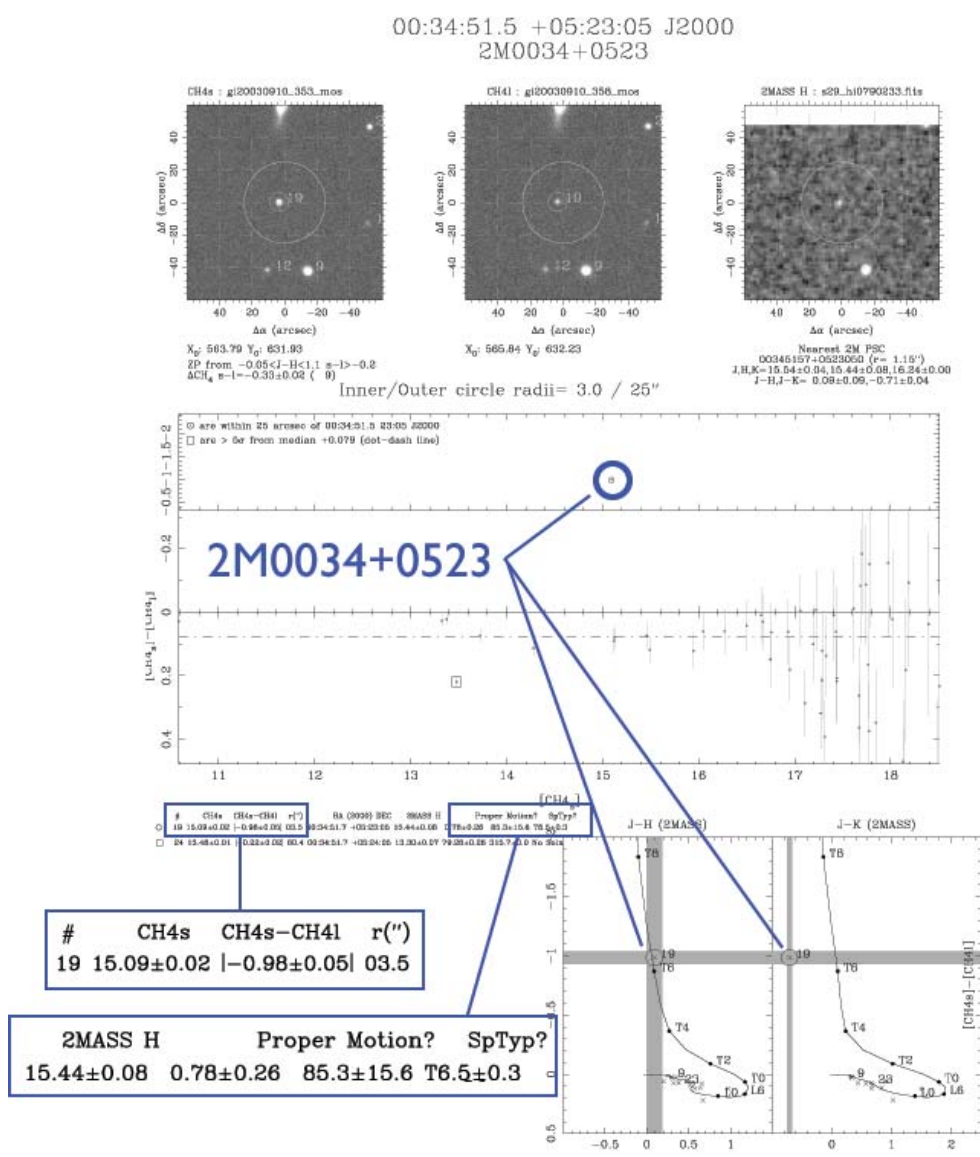


Figure 3 – Sample output from the methane processing system at the telescope for the T-dwarf 2M0034+0523. The upper panels show CH₄s, CH₄l and 2MASS H images. The middle panel shows differentially calibrated methane colour (CH₄s-CH₄l) as a function of CH₄s, and the bottom right panels show methane colour plotted as a function of 2MASS J-H and J-Ks colour. The solid line shows the spectral type sequence in these panels, the crosses are the objects in the IRIS2 field, and the shaded bars show the photometry and uncertainty of our methane and 2MASS photometry for the T-dwarf. Note also that we can see clear evidence for proper motion between the IRIS2 and 2MASS data of 780mas/yr.

Models for these objects suggest that they will have extremely unusual colours, and will lie some way from the sequence of common- or garden-variety G-M dwarfs in a J-H versus Y-J colour-colour diagram – as much as a magnitude redder in Y-J, and a magnitude bluer in J-H. The ±0.1–0.2 mag photometric uncertainties of objects near the survey magnitude limits will only rarely scatter G-M dwarfs by the 5–10σ needed to move such objects into the Y dwarf selection region. *But* this will only need to happen at a rate of once in a billion to still massively outnumber the likely number of true Y dwarfs in the survey. Some form of winnowing of candidates is almost inevitably going to be required before taking Y-

dwarf candidates at H~18 to an 8m telescope for infrared spectroscopy. Methane imaging offers an ideal mechanism for doing this, since they can be imaged on a 4m telescope in under an hour, compared to the several hours required on an 8m telescope to acquire spectra.

Cool companions to Known Brown Dwarfs : Very rare astronomical objects (like T- and Y dwarfs) are typically searched for by surveying very large chunks of the sky. An alternative is the “looking for things around other things” approach, which relies on the fact that most astronomical objects are clustered. It was exactly this technique that revealed the first T-dwarf Gl 229B.

The invariable difficulty in such searches is telling the difference between a potentially interesting companion to the target in question, and the vast majority of background objects. In the case of Gl 229B, the companion was revealed by its common proper-motion. Methane imaging offers a potentially powerful way to identify cool companions to nearby stars and brown dwarfs, without the need to wait for the year or more needed to confirm or deny common proper motion. For example, a few hours integration with the methane filters in IRIS2 can easily reach to sensitivities adequate to detect methane absorption in objects 3–4 magnitudes fainter than all the T-dwarfs so far identified from 2MASS, making this a potentially powerful way in which to find Y dwarfs without having to go to all the trouble of implementing the UKIDSS survey.

Methane Variability and “Weather” : There is considerable evidence to indicate that many, if not most, brown dwarfs rotate rapidly, with either measured or inferred rotation timescales of 1–10h. L- and T-type brown dwarfs are also well known to suffer greater or lesser degrees of condensate and/or cloud layer formation. So brown dwarfs have the ingredients necessary to create complex rotation-driven weather patterns on their surface. Unfortunately, despite much intensive searching detailed evidence for weather variations in brown dwarfs remains elusive.

However, as the source of the dominant absorption feature in the spectra of T-dwarfs, searches for variability in CH₄ absorption (reflecting an uneven surface coverage at the optical depths where these absorptions are formed) could be extremely powerful. Jupiter, for example, is known to show strong surface features in the infrared where gaps in its methane layers allow the hotter, lower regions of the photosphere to shine through³. The nearly differential nature of methane imaging should make high precision (i.e. <0.01 mag) differential CH₄-CH₄I measurements possible over many hours. This would allow a search for variations on the timescales of a single rotation, and on the longer timescales reflecting changes in the surface features of a brown dwarf.

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³ See for example the data from the IRTF Galileo Support monitoring program at <http://irtfweb.ifa.hawaii.edu/Science/galileo.html>

AAPS TARGETS THE HIGHEST PRECISION

Chris Tinney (AAO), Hugh Jones (Liverpool), Paul Butler (CIW), Brad Carter (USQ), Geoff Marcy (Berkeley), Alan Penny (RAL), Jeremy Bailey (Macquarie University)

The Anglo-Australian Planet Search (AAPS) has been running its Doppler velocity search for extra-solar planets on the AAT now since 1998. This means it has the longest baseline in hand of high precision (i.e. 3m/s or better) velocities for the brightest nearby stars in the Southern Hemisphere. In September 2004, the team announced the detection of five new planets (McCarthy et al. 2004, Tinney et al. 2005). These included the first multiple planet systems detected by the AAPS, and three low-mass (i.e. Saturnian- or sub-Saturnian-mass) planets.

The multiple planet systems include the detection of a second outer planet orbiting the star HD160691 (μ Ara), with an orbital period of 8.2 years and a minimum mass of 3.1 Jupiter masses, in addition to the earlier AAPS detection of a planet with an orbital period of 645 days and a minimum mass of 1.7 Jupiter masses. Both planets have quite eccentric (i.e. non-circular) orbits. Interestingly, this system has been claimed by the HARPS team working on the ESO3.6m in Chile to have a third much lower mass planet with a 9.5 day orbital period and a minimum mass of just 14 Earth masses. The second multiple system orbits HD154857, where an inner planet orbits in 399 days with minimum mass 1.8M_{Jup}, while an outer planet orbits with an as yet unresolved period of more than 2 years.

The three low-mass planets have all been detected with orbital periods of between 26 and 129 days, and minimum masses of between 0.16 and 0.4 times that of Jupiter. These low-mass planets are exciting to the Anglo-Australian Planet Search team because they all have small velocity amplitudes. Indeed at just 12 to 18m/s, these results obtained from data streams stretching back to 1998 represent exactly the levels of precision that our search needs to attain to detect Solar Systems like our own around other stars via the orbital motion of a Jupiter-like planet in a Jupiter-like 12 year orbit.

Of the ~140 known extrasolar planets¹, the median velocity semi-amplitude is 53m/s. These planets are discovered first because they are the easiest objects to find. But even within this biased sample of the most

¹ <http://www.ciw.edu/boss/IAU/div3/wgesp/planets.shtml>

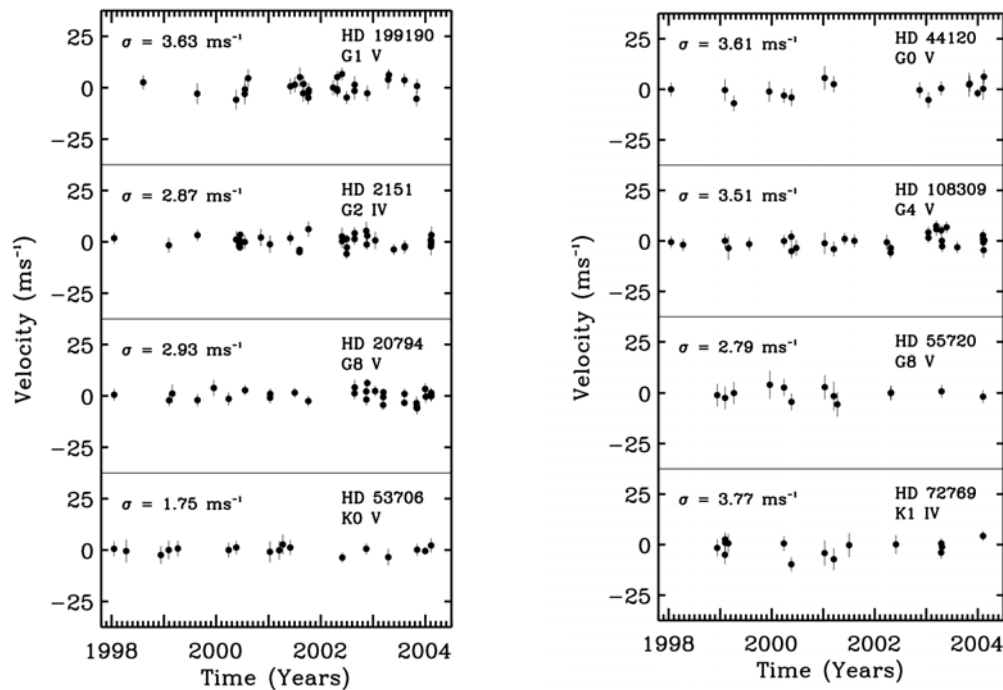


Figure 1 – Stable stars from the AAPS spanning the six years of the program.

massive planets, the planet mass function rises steeply down to the detection limit near 1 Mjup (Jones et al. 2004, Marcy et al. 2003). Determining whether this mass function continues to rise down to the Saturn-mass and Neptune-mass range is critical. Unfortunately, finding such small planets is difficult – only nine have entered the refereed literature to date, and most have done so only within the last two years.

Asteroseismology as Noise

The AAPS' primary scientific goal is the detection of small amplitude systems (i.e. Solar System analogues and low-mass planets). But what are the fundamental limits (other than those set by photon-counting) to the precision achievable by Doppler velocity programs? One source of noise that has come into focus recently is asteroseismology. Results in this field (e.g. Kjeldsen et al. 2003, Mayor et al. 2003, Butler et al. 2004) have highlighted the prospect that p-mode seismological oscillations in stars may indeed be a significant, or even dominant, source of the noise we currently see for bright stars. These oscillations have now been detected in a variety of stars – some of them planet search targets, or known to have extra-solar planets (see e.g. Bouchy & Carrier 2003, Bedding & Kjeldsen 2003).

The table on the next page summarises some recent results in this fast moving field. It highlights the fact that while the power levels observed in the peak modes of the power spectra of these stars are small, the stars invariably show significant peak-to-peak velocity

excursions, as the various incoherent modes interact. P-mode power spectra indicate that most of the power in these oscillations falls at frequencies within $\pm 50\%$ of the peak frequency. So observations with exposure times less than the times corresponding to these frequencies can induce *significant* (i.e. 1–2m/s) p-mode Doppler noise.

For the AAPS, observations of bright stars (i.e. $V < 6$) collect sufficient photons to deliver photon-limited precisions of $< 1\text{m/s}$ in exposures of less than a few minutes, so in the past we have only ever observed bright

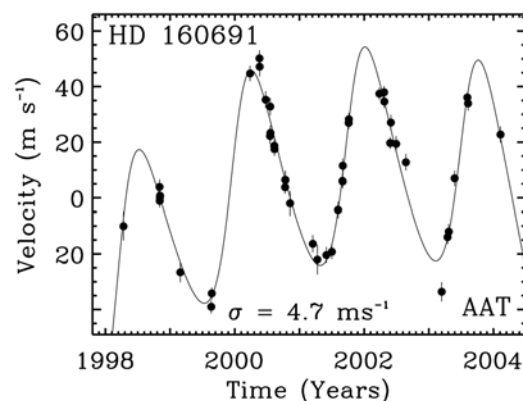


Figure 2 – A double planet fit to HD 160691. The inner planet has a period of 645 days, an eccentricity of 0.20, and a semi-amplitude of 38 m/s, yielding a minimum mass of 1.68Mjup and a semi-major axis of 1.50 au. The outer planet has a period of 8.2 yr, an eccentricity of 0.57, and a semi-amplitude of 51 m/s, yielding a minimum mass of 3.1Mjup and a semi-major axis of 4.16 au. The rms to this model is 4.66 m/s.

stars with short exposures ... meaning we consequently eat *all* of this p-mode noise. The flip side of this situation, though, is that observing strategies with longer integrations for these stars will open a new regime of <1m/s precision, allowing the detection of Neptune- and sub-Neptune mass planets in short orbits around these bright stars.

To aggressively target the delivery of 1m/s precision, therefore, the AAPS has implemented a 1 year experiment to observe 65 of our brightest target stars with longer exposures using an additional allocation of about 30 nights. These observations will not only allow us to demonstrate improved precision via integration over p-mode noise, but will also enable us to target the detection of the new class of very low-mass planets in short period orbits (i.e. < 10 days) like those recently announced by the teams at Keck, HET and ESO.

Solar System analogues and Extremely Large Telescopes

Detecting a meaningful number (i.e. ten or more) of habitable terrestrial planets is one of the key science drivers for the next generation of Extremely Large Telescopes (ELT) and space-based planet finders. These major new facilities will require the expenditure of billions of dollars and/or euros. Assuming the technical problems of light suppression can be solved to the required levels (e.g. $>10^{10}$ suppression of light from the parent star over 10–500 mas radii), the diameter that such a telescope has to have, scales directly with how common such planets are. If they are found around 10% of Sun-like stars, then an ELT needs to be able to resolve terrestrial planets around only a hundred nearby stars. If they are found around 1% of Sun-like stars, then our ELTs will need to target a thousand nearby stars.

Unfortunately, the number of nearby stars available to search is limited – 100 nearby stars will necessitate targeting stars out to ~10–20pc, which can be

comfortably done with a 30m telescope² ($4\lambda/D \sim 30\text{mas}$). But surveying a thousand stars will require observing out to 100pc, which itself drives the telescope to a 100m diameter, with a consequent huge increase in both cost and complexity.

Clearly before engaging in such massive expenditures, we need to know “How common are terrestrial planets?” – and the best answer we can get to that question will come from knowing “How common are Solar System analogues?” Radial velocity surveys operating at the precision of the AAPS, therefore, have a clear and compelling role in addressing these critical design- and cost-driving issues. With six years of Southern Hemisphere data for almost 200 stars already under its belt, the AAPS is well placed to be a major contributor in this key scientific area in the next 5 years.

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² It is extremely unlikely that even the most advanced coronagraphy will be able to make significant headway at angular separations of less than $4\lambda/D$ – see e.g. Sivaramakrishnan et al. (2001)

Asteroseismology for Solar-type Stars						
Star	Type	Power @Peak (m/s)	P-P (m/s)	RMS (m/s)	Period (min)	Refs
Sun	G2V	0.23			5	1,-,1
alpha Cen A	G2V	0.35	2		6.7	1,4,4
alpha Cen B	K1V	0.14	1.5	0.5	4	2,5,5
beta Hyi	G2IV	0.51	5	1.7/3.3	16.6	1,5&6,6
HD20794	G8V	0.39	2.5	0.8	5	3,5,5
HD160691	G5IV	0.39	5	1.7	9	3,5,5

References (respectively) for Power Peak, Peak-to-Peak and RMS velocities, and observed fundamental Period are from 1 – Goudek & Gough 2002, 2 – Carrier & Bourban 2003, 3 – Bouchy 2004, 4 – Butler et al. 2004, 5 – Mayor et al. 2003, 6 – Bedding et al. 2001

SMALL-SCALE-STRUCTURE OF THE DIFFUSE ISM PROBED BY DIFFUSE BAND OBSERVATIONS

Martin Cordiner, Peter Sarre (University of Nottingham), Stephen Fossey (University College London)

Introduction

There is mounting evidence that far from being homogeneously distributed, interstellar matter can have a clumpy or filamentary structure on the scale of 10s to a few 1000s of AU – so-called small scale structure (SSS). Initially confined to VLBI H I observations (Dieter, Welch & Romney 1976, Diamond et al. 1989) and H I observations of high-velocity pulsars (Frail et al. 1994), evidence for SSS has also come indirectly from molecular radio studies of e.g. HCO⁺ (Liszt & Lucas 2000) and IR absorption by H₃⁺ (McCall et al. 2002).

Most of the recent data on SSS has been obtained through optical/UV detection of atomic and diatomic molecular lines. This has been achieved by recording spectra towards components of binary systems (Watson & Meyer 1996, Meyer and Blades 1996, Lauroesch et al. 1998, Lauroesch & Meyer 1999; Points, Lauroesch & Meyer 2004), or by detection of time variation in absorption lines due to the relative transverse motion of a background star and the absorbing material (Crawford et al. 2000, 2002, Price et al. 2000, 2001, Rollinde et al. 2003).

A key question is whether there exists small scale

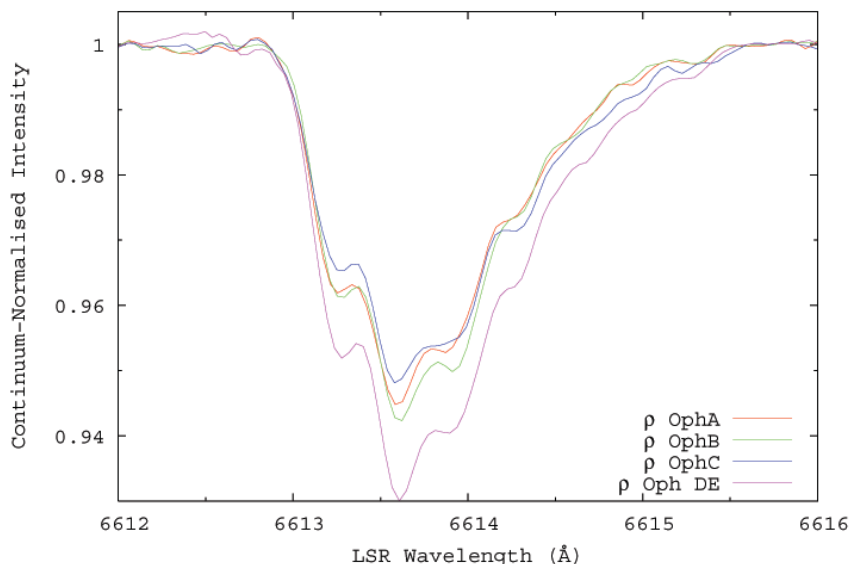


Fig 1. Continuum-rectified UCLES spectra of the $\lambda 6614$ diffuse band observed towards four stars in the ρ Oph system. Small scale structure is evident in the band strength variations.

structure in the large molecule/dust distribution? While this could in principle be explored by measuring differences in the interstellar extinction towards the components of binary stars, in practice this would be difficult. Rather we chose to investigate this by recording very high signal-to-noise spectra of diffuse interstellar absorption bands, which are generally considered to be tracers of the large molecule/dust distribution.

Observations

We made UCLES observations of pairs of stars (mostly binaries) in June 2004 with separations ranging between 500 and 30,000 AU. The signal-to-noise achieved was up to 2000, thus allowing variations in central depth of less than a few tenths of a percent to be discernible. Figure 1 shows the profile of the $\lambda 6614$ diffuse interstellar band towards four stars in the ρ Oph star-forming region all of which have E_{B-V} of ~ 0.5 . Similar observations for $\lambda 5797$ for the same ρ Oph stars, together with the binaries $\beta^{1,2}$ Sco and $\nu^{1,3}$ Sco, are given in fig. 2, and for $\lambda 5850$ in fig. 3.

Results

Striking differences in diffuse band strengths for closely spaced lines of sight are found showing clearly, for the first time, that the large molecule/dust distribution possesses small-scale-structure on the same spatial scale as that found for atomic gas. The results for the ρ Oph stars are being analyzed with particular reference to a recent high-resolution absorption study of seven atoms and diatomic molecules towards the same stars which show pronounced (up to a factor of two) variations

in relative column densities (Pan et al. 2004). This analysis should enable us to determine, for example, the extent to which the large molecule/dust distribution follows cold Na I and K I or warmer more turbulent regions.

Further remarkable behaviour is found when comparing the *relative* strengths of diffuse bands between closely parallel lines of sight. Taking the ρ Oph group, for $\lambda 5797$ the strengths follow the order DE > B > C > A (fig. 2) whereas the $\lambda 5850$ band, which is often associated with $\lambda 5797$ as being a

member of the same 'family', follows a very different intensity pattern with $C > B > A > DE$ (fig. 3). This opens a new avenue of diffuse band research in its own right and provides a rigorous test for models and theories of diffuse band carrier structure and behaviour.

Also, the high signal-to-noise of the data set allows investigation of fine structure profile variation with line of sight, and this is being modelled using the approach developed for the interpretation of UHRF diffuse band data (Kerr et al. 1998).

Tiny scale structure?

If IS matter is commonly distributed in filaments then there is some prospect of detecting fairly sharp changes in atomic, molecular and diffuse band carrier column densities even on the distance scale of a few AU. This is to be explored in an upcoming AAT UCLES run in which we will revisit some of the lines of sight described here just one year after first observation. Here the relative transverse motion of the star and the intervening IS material provides the effective variation in line of sight.

Finally, we express our gratitude to all who contributed to fixing the AAT dome ahead of schedule so making the June 2004 run possible and yielding the results we describe here.

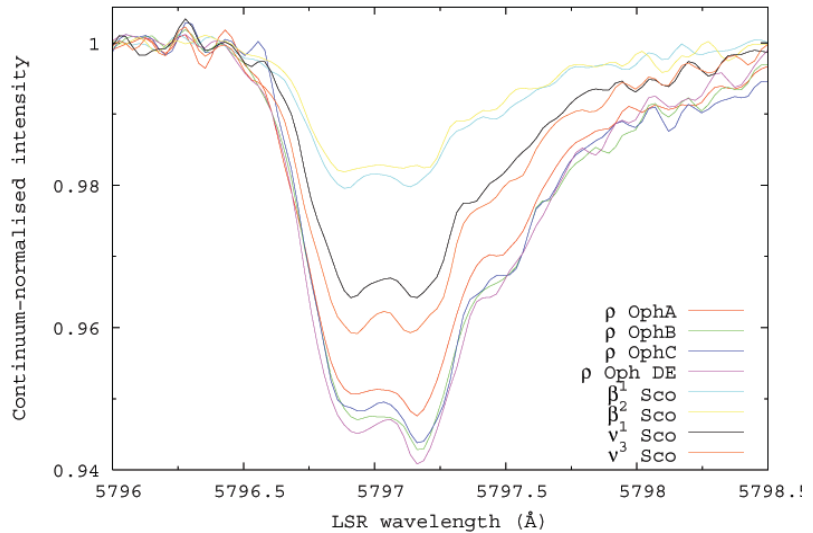


Fig. 2. UCLES spectra of $\lambda 5797$ observed towards ρ Oph A, B, C and DE, $v^{1,2,3}$ Sco

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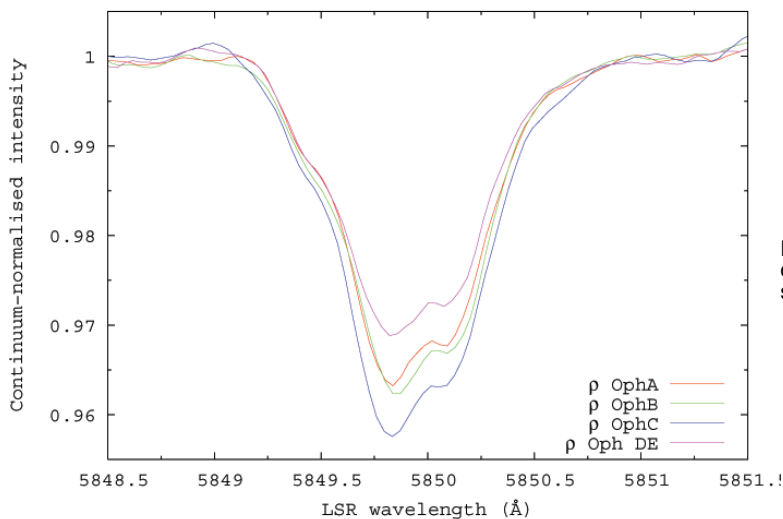


Fig. 3 UCLES spectra of $\lambda 5850$ observed towards the ρ Oph stars.

THE "ROUGH GUIDE" TO IMAGING FIBRE BUNDLES FOR ASTRONOMY

Jackie Marcel, Roger Haynes (AAO)

Introduction

The past few years have seen a number of significant advances in the performance of imaging fibre bundles (IFBs), sometimes called coherent fibre bundles. This has been driven by the requirement for high spatial resolution imaging capabilities in flexible, hermetic and convenient optical trains. Examples include endoscopy for the biomedical industry, remote monitoring for surveillance and image monitoring in hostile environments. The resultant commercially available IFBs from companies such as Sumitomo Electric and Schott have both high throughput and fine resolution characteristics. Unlike the early imaging fibre bundles investigated for astronomy, dislocation of the image within the fibre bundles is less, reducing degradation of the image. A relatively large number of fibre elements need no longer limit the spatial resolution or sky coverage of the devices. Modern IFBs provide an even distribution of fibres and a clearer image at the output, with thousands of spatial elements on a pitch of a few microns. Such advances have led the Astrophotonics research group at the AAO to reconsider the use of imaging fibre bundles for various applications in astronomy. See Figure 1.

Applications in Astronomy

Imaging fibre bundles have not been used much in astronomy to date partly because they have suffered from a relatively large number of cosmetic defects as well as poor throughput, but also because the same data can generally be obtained by conventional imaging and spectroscopy (by using optical trains of mirror, lenses and slits). Developing imaging systems will be more challenging for ELTs, which will produce diffraction-limited images (1–10 milliarcsec) over substantial fields (>2 arcmin). To image the whole field requires roughly 10^9 spatial samples. The cost of this is likely to be prohibitive. For the next generation of wide field astronomy, it will become increasingly important to be able to sample only the targets of interest within the telescope field of view. For ELTs, the cost of Nyquist sampling the entire field of view becomes a problem. For spectroscopy, that typically requires thousands of pixels for each spatial sample. This is already being addressed for small telescopes, for example the 6dF on the 1.2m UK Schmidt telescope and virtually every multi-object spectroscopic system. For ELT concepts, such as OWL, there are additional constraints imposed by the location of focal stations within the telescope's optical train. For some applications it might be highly desirable to pipe light from the relatively inaccessible telescope focus to an instrument that is remotely mounted using high-efficiency imaging fibre bundles. The beauty of modern IFBs is that they maintain the spatial integrity of the image and may offer huge advantages

over conventional optical relays currently being used on large telescopes. The nature of the IFBs is such that the image position at the output depends only on the image position at the input and is tolerant of movement and flexure of the intervening bundle. With mirror and lens systems the output image's position is dependent on the positional stability of all the optical components in the train. Furthermore with IFBs the scattering and ghosting issues are greatly simplified and controlled. Very simple optical trains of many metres in length could easily be implemented with robust, hermetically clean and relatively stable fibre bundles.

Traditional astronomy has used custom built IFBs. The guide fibre bundles for multi-fibre systems

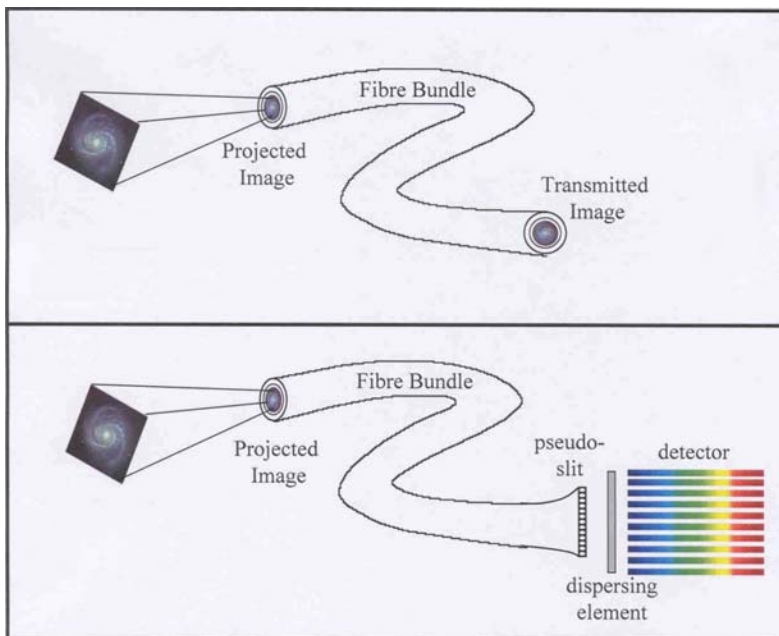


Figure 1: Astronomical applications of IFBs: to facilitate the transmission of an image (top) or to directly format a 2D field into a 1D pseudo-slit (bottom).

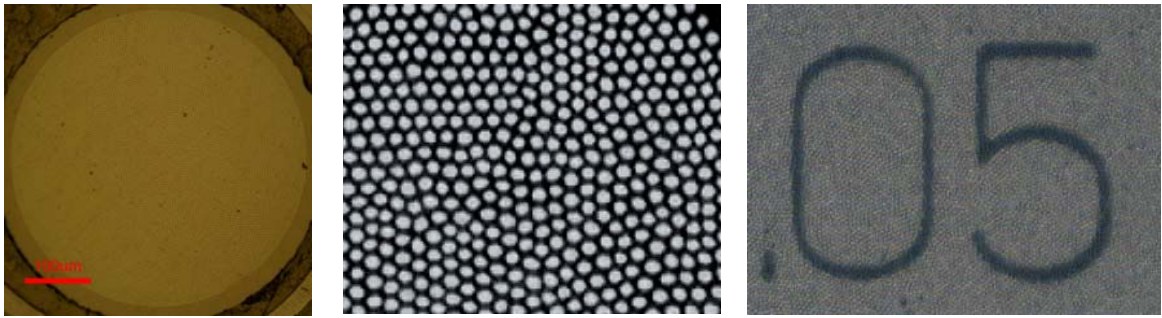


Figure 2: Cross-sectional view of a 500µm core IGB with 10,000 elements (left). Notice the hexagonally packed structure of the fibre elements within the core (middle). Although there are some distortions in the spatial structure it is not enough to significantly affect the imaging characteristics (right).

consist of only a few fibres (typically a minimum of 7 for guide fibres, i.e. 2dF, OzPoz). For IFUs fibre numbers generally range from a few 10s (FLAMES) to over 6000 (VIMOS IFU). However now IFBs can be purchased off the shelf with tens of thousands of fibre elements (see Figure 2). The individual fibres are arranged coherently and, in the cases of Sumitomo and Schott, are fused into an optical fibre by the stack and draw method. All images transmitted retain their original spatial positions as the fibre elements maintain orientation throughout the bundle, as shown in Figure 2.

Fibre Characteristics and Results

The Sumitomo IFBs tested have fibre elements with small cores ($\phi = 1.75\text{--}3.6\mu\text{m}$) as well as closely packed core-to-core spacing ($3\text{--}7\mu\text{m}$) between elements. The manufacturer specifies that the fibre elements typically have numerical apertures (NAs) ranging from 0.3 to 0.35 and fibre densities of the order of $10^4/\text{mm}^2$. The bundles themselves are structurally flexible, with allowable bend radii of 10–100mm, increasing with the bundle core size.

The initial experimental results show that the largest of the IFBs (20/50) has all total transmissions including reflection losses of $\sim 79\%$ at 640nm. This is consistent with the manufacturer's transmission data, with reflection losses based on the quoted refractive index of the core material. This suggests there is very little loss of light

between the fibre elements as would be expected from geometric arguments. With this fibre we were also able to resolve detail down to $10\mu\text{m}$ as seen in Figure 3. Like most optical fibres, the IFB's performance in the blue suffers from increased attenuation that is typically dominated by Rayleigh scattering within the silica. See Figure 4.

A primary concern for any astronomical imaging system is the photometric capability. Tentative tests using the 1.8mm diameter IFB (20/50) look promising. The radial profiles of a $100\mu\text{m}$ spot imaged through the IFB at 525nm are shown in Figure 5 & Figure 6. The radial profile has been mirrored for illustration purposes. The significant structure present towards the centre of the profile is a result of the pixilation at the output introduced by the fibre elements. The structure is reduced (as inverse square root of the radius) by the averaging effect of integrating over many pixels as the radius increases. We will be experimenting with dithering and binning techniques to find the optimal way of reducing the structural impact of the fibre elements. The structure is analogous to the scanning of grains in photographic plates (Bland-Hawthorn et al. 1993). A key issue here is the element-to-element uniformity. The level of cross talk to adjacent regions of the image bundle appears to be small with most of the power contained within $100\mu\text{m}$. These are somewhat tentative results and further test

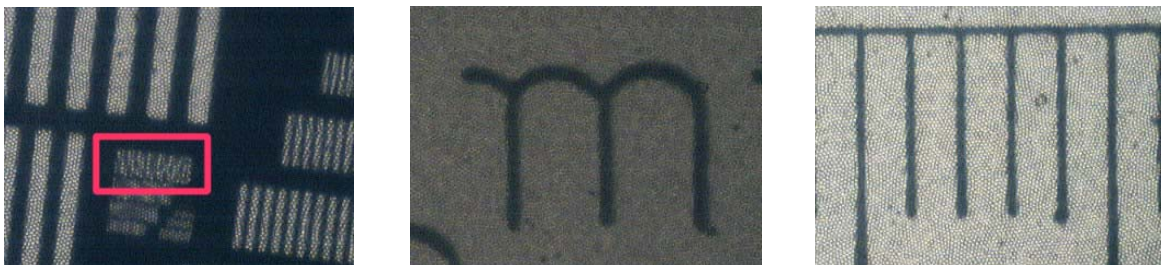


Figure 3: Image of a high-resolution target shows resolved detail down to $\sim 10\mu\text{m}$ (left, highlighted area). Examples of images through the 1.8mm core, 50,000 fibre element image guide bundle (middle and right).

results and comparison of crosstalk in IFBs with scattering in mirror and lens based relays will be presented in future publications.

Conclusions

The initial results from the latest generation of imaging fibre bundles suggest the prospect of using them in astronomy is extremely promising. They offer comparable performance to microlens coupled fibre arrays and image slicers having high filling-factors and offer the possibility of arbitrarily shaped active areas and transformations. They should make very effective optical relays/reformatters for multi object imaging and spectroscopy. This will greatly simplify current multiple IFS designs such as KMOS (VLT) by replacing complex pick-off arms (with internal optics to feed individual image slicers) with an image bundle that either feeds the image slicers or directly formats the 2D field into a 1D pseudo-slit, illustrated in figure 1.

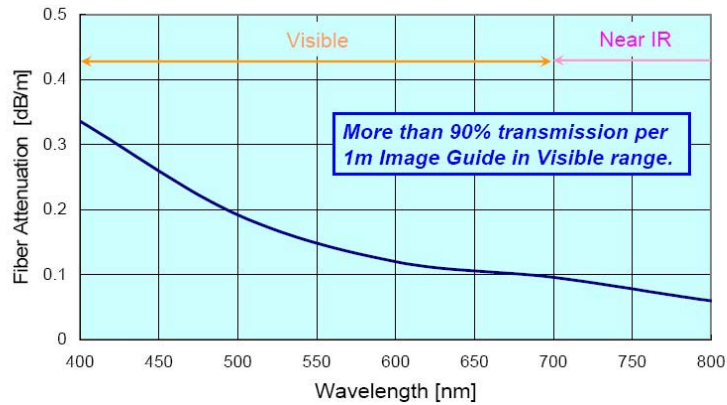


Figure 4: Typical image guide bundle attenuation plot. (Sumitomo Electric, 2003)

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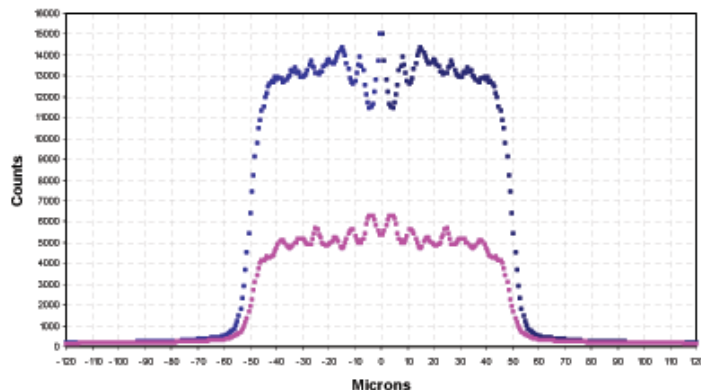
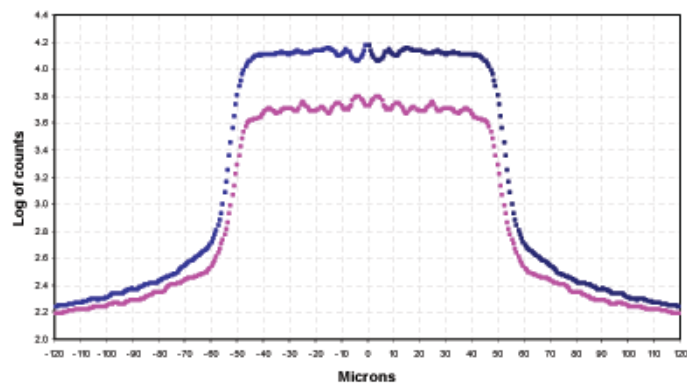


Figure 5: Mirrored radial profile of the output image from a Sumitomo Electric IGN-20/50 imaging fibre bundle (1.8mm core diameter, ~2.0m long) with a 100 μ m diameter spot projected onto the input face. The average detector counts in the annulus (y-axis) at a given radius (x-axis) from centroid are given for the image at the output face of the fibre bundle.

Figure 6: Mirrored radial profile of the output image from a Sumitomo Electric IGN-20/50 imaging fibre bundle (1.8mm core diameter, ~2.0m long) with a 100 μ m diameter spot projected onto the input face. The logarithm of the average detector counts in the annulus (y-axis) at a given radius (x-axis) from centroid is given for the image at the output face of the fibre bundle.



IRIS2 ORAC-DR IMPROVEMENTS

Chris Tinney & Stuart Ryder (AAO)

IRIS2 observers have been using the ORAC-DR data reduction pipeline to process data to near-publication quality at the telescope for several years now. An example is the article on page 3 in which no further reductions beyond those done at the AAT by ORAC-DR have been necessary for the analysis of methane imaging data.

However, there have been a few minor steps in this processing that have always eluded our ability to get implemented ... until recently that is. We are pleased to be able to indicate the following improvements for future IRIS2 observers:

- Improved bad-pixel masks: improved standard bad pixel masks have recently been installed. These are different for imaging and spectroscopic observing, and ORAC-DR now automatically chooses the correct one for you.
- Inter-quadrant cross-talk correction: all Rockwell Hawaii-1 HgCdTe infrared detectors suffer from this effect. It is most clearly seen in spectroscopic data taken on bright targets, though it is also sometimes seen on imaging fields containing a few bright stars. It results in faint horizontal stripes across the detector at the same row (and ± 512 pixels in the quadrant above or below) as the bright star. All IRIS2 processing (imaging and spectroscopy) will now remove this effect.
- Non-linearity correction and thresholding: non-linearity corrections have been implemented for imaging data reductions. In imaging mode IRIS2 is better than 0.5% linear up to ~ 20000 ADU, but non-linear by about 0.8% at 40000 ADU. The imaging recipes now flag data as "bad" above 40000 ADU, and linearise data below 40000 ADU.

In addition we have made several improvements to the mosaicing of jittered image data sets from IRIS2 – especially with relevance to the most commonly used recipe (JITTER_SELF_FLAT) used to process these images:

- Bad pixels: the default behaviour of most of the imaging recipes in ORAC-DR is to interpolate over bad pixels BEFORE making a mosaic from a jittered data set. While this always creates a "pretty" image, it is not the most valid scientific way to interpret an imaging set of data. So new recipes have been created to preserve bad pixels through the mosaicing process. This generally

means that bad pixels on the mosaic get "filled" in during the mosaicing process, but that the corners of the array and the cores of bright stars stay "bad" even once the final mosaic is made.

- Astrometric Distortion and the WCS: due to some problems in the underlying Starlink code, mosaics made from images which were corrected for IRIS2's astrometric distortion had (in the past) world coordinate systems that could no longer be correctly interpreted. This has been fixed, and undistorted images now have meaningful WCS systems that tools such as GAIA understand. In particular, images converted back from NDF to FITS format and displayed in DS9 are also correctly understood.
- Oversampling: in good seeing conditions, there may be spatial information in a jittered data set at pixel spacings smaller than the $0.4486''/\text{pixel}$ of IRIS2's sampling. So modified versions of several recipes have been created which oversample individual images before being combined into a final mosaic.

The following JITTER_SELF_FLAT recipes are now available to IRIS2 observers at the AAT:

JITTER_SELF_FLAT – interpolates over bad pixels, removes distortion

JITTER_SELF_FLAT_NODIST – interpolates over bad pixels, leaves distortion (this is the IRIS2 "standard" JITTER_SELF_FLAT currently distributed with ORAC-DR)

JITTER_SELF_FLAT_BY2 – interpolates over bad pixels, removes distortion and oversamples by 2

JITTER_SELF_FLAT_KEEPPBAD – keeps bad pixels, removes distortion

JITTER_SELF_FLAT_KEEPPBAD_BY2 – keeps bad pixels, removes distortion and oversamples by 2

Observers can easily use these recipes at their home institution, provided they have either the Summer 2003 or Spring 2004 Starlink release installed. They are available for download from the IRIS2 ORAC-DR Web page (http://www.aao.gov.au/iris2/iris2_orac.html). For further information, contact either of the authors.

EPPING EVENTS

Greta Simms & Sandra Ricketts

Although it has not been long since the last newsletter, there have been quite a few staff movements at the AAO.

Peter Gillingham retired at the end of 2004, and he and Mary have joined the army of "Grey nomads" travelling around Australia in their caravan. We wish them safe and enjoyable travels.

Jeremy Bailey also left for the greener pastures at Macquarie University, but we are unlikely to lose touch with him as he has already been seen back at the AAO!

We welcome Greg Madsen from Wisconsin, as NSF MPS Distinguished International Postdoc Research Fellow. We also welcome Heath Jones, who is finishing his ANU postdoc and will officially commence at the AAO in September as the AAO Director's Research Fellow.

Our summer students have already been and gone –

Brent Miszalski (Macquarie University), David Moore (Monash University) and Clair Murrowood (University of Tasmania). We hope they had an enjoyable and productive stay at the AAO. Brent worked with Quentin Parker on constructing an efficient data pipeline for the efficient and effective reduction of large scale spectroscopic reduction of extended nebulosities with particular application to Planetary Nebulae. David Moore worked with Scott Croom and Rob Sharp on spectral analysis of quasars using a combined sample of 2dF QSO Redshift Survey and 2dF-SDSS LRG and QSO Survey data. The aim was to investigate the correlation of line strengths and widths with luminosity and redshift, extending the work to fainter luminosities than previous analyses. Clair worked with Stuart Ryder using Gemini GMOS images of SN 2001ig to identify a massive binary companion predicted from Australia Telescope Compact Array observations.

Finally we welcome John Storey who is spending a sabbatical with us half-time, the other half being with ATNF.

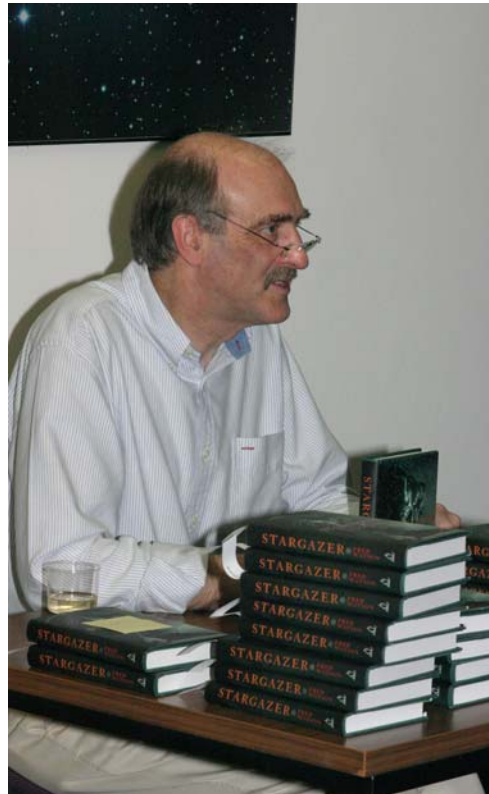
LIBRARY NEWS

Sandra Ricketts

Once again, it has been some time since a library item appeared in the AAO Newsletter. While the library continues to fulfil the usual functions of an astronomy library, the librarian has been broadening her skills in other areas (as well as newsletter production that is!)

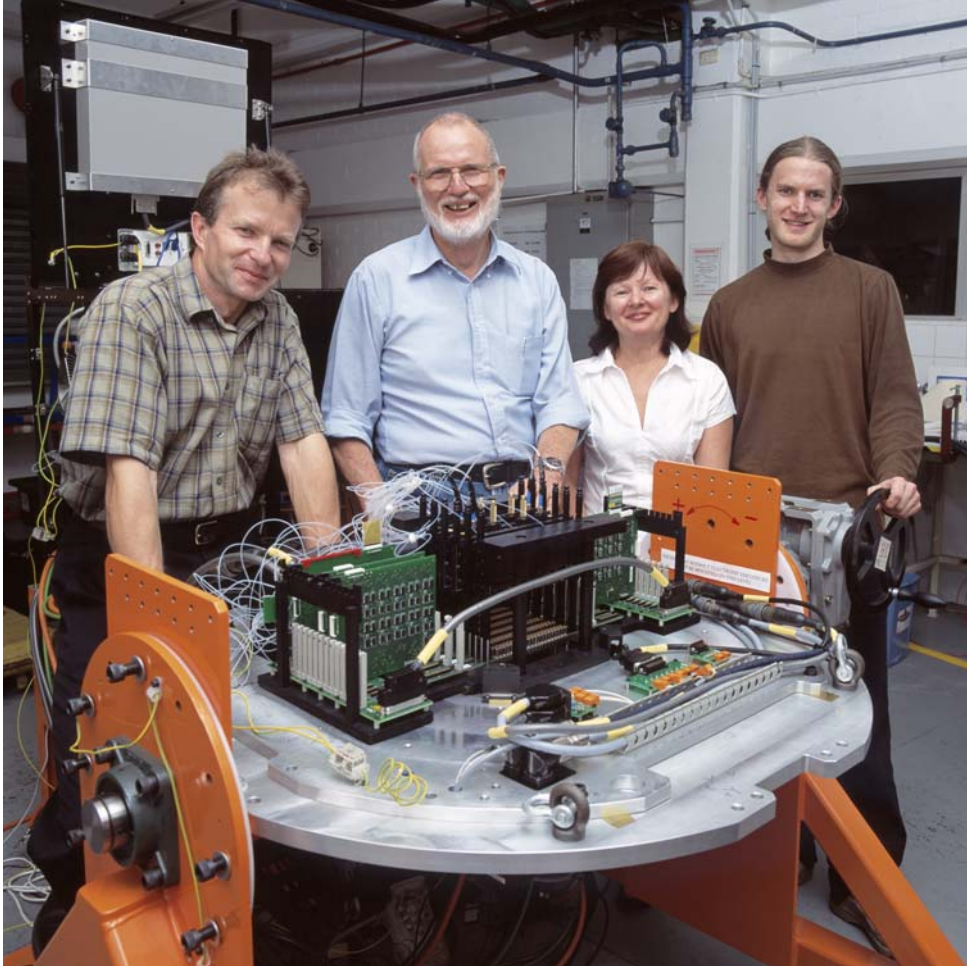
One of her other activities last year was to assist Fred Watson with picture research for his new book, *Stargazer – the Life and Times of the Telescope*. This was a fascinating activity, and she can highly recommend the book. Following its publication last August, the AAO hosted a launch at Epping which was attended by numerous astronomers, both professional and amateur, and of course members of staff. An excellent time was had by all, and over 100 copies were purchased at the event.

On a more mundane level, the library continues to provide the more traditional library services, and new books can be seen, as always, on the display shelves.



Fred Watson signing copies of his book "Stargazer" at its launch at the AAO last October. Photo courtesy of Helen Davies

FMOS-Echidna in assembly phase



Echidna team members Jurek Brzeski (mechanical engineer), Peter Gillingham (project engineer and instrument scientist), Gabriella Frost (project manager) and Scott Smedley (software engineer) behind the Echidna fibre positioner for the Subaru Telescope, on its tilting test rig. Only fiducial and guide spines are fitted as yet but the preliminary test results with them warrant the smiles. (Photo courtesy of David James).

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