A deep Hα image of the field surrounding the quasar MR 2251–178. The 3-arcminute field centered on the quasar represents 2400 seconds of exposure with the Taurus Tunable Filter instrument on the AAT, revealing emission extending over more than 200 kpc. North is up, east to the left. See p. 6 for details.
DIRECTOR’S MESSAGE
Brian Boyle

Within the past few days, the 2dF galaxy redshift survey (GRS) has passed a notable milestone. With over 30,000 redshifts (as of 16th February), the GRS is now the largest redshift survey yet compiled, and over 10% of the way to its ultimate target of a quarter of a million redshifts. At the same time, the QSO redshift survey passed 3000 redshifts.

This has been made possible by the increasing reliability and functionality of 2dF throughout the past three months. 2dF has now completed its basic commissioning phase. As well as making major inroads into the survey programs, 2dF is also providing unprecedented data sets on the smaller programs that are vital to maximize the 2dF’s scientific impact. The power of 2dF is amply demonstrated by the record broken last week for the greatest number of spectra obtained in a single night on the AAT — 2423 in a (short) February night.

The success of 2dF is a tribute to the instrument team who had worked long and hard to bring 2dF to its current operational level. The AAO has recently welcomed Terry Bridges to this team. As the 2dF support fellow, Terry’s appointment heralds the opportunity for greater flexibility in our approach to observing with 2dF, as UK programs will now largely be carried out in service mode.

2dF illustrates well the AAO’s strategy to focus on innovative developments that provide the community with an opportunity to carry out unique and highly competitive science. Another instrument which was built with this goal firmly in mind is the Taurus Tunable Filter (TTF). Over the past two years, the TTF has matured into one of the AAO’s most popular and highly productive instruments. The spectacular results obtained from TTF reported on in a series of articles in this Newsletter attest to its scientific impact. They also demonstrate that the AAT can still compete effectively in specialized imaging applications. The innovative work on interference coatings (see the article by Joss Hawthorn and Sonia Cianci) also being carried out at the AAO seeks to maintain this competitive edge.

Innovation, in the form of volume phase holographic gratings, is also at the heart of ATLAS, the concept for the new intermediate dispersion spectrograph for the AAT. Keith Taylor reports on Sam Barden’s visit to the AAO, which has resulted in the development of what appears to be a very exciting new spectrograph design. ATLAS promises to revolutionize the AAO’s capability in the regime of intermediate dispersion spectroscopy.

AAO/ATNF ANNUAL JOINT SYMPOSIUM
National Measurement Laboratory Lecture Theatre, Lindfield, Sydney March 24, 1999

Call for Abstracts

AAT, UKST and ATNF users are invited to submit contributions for short papers (15 min) on recent scientific results for inclusion in the program. Poster papers will also be accepted.

If you wish to give a talk or present a poster paper, please provide a title and a brief abstract by 5 March 1999 to:

• Chris Tinney (cgt@aaoepp.aao.gov.au) for AAT or UKST related papers, or

• Jon Bell (Jon.Bell@atnf.csiro.au) for ATNF related papers

Overhead projector, slide projector, PC projector and poster mounting facilities will be provided. Speakers with special requirements should contact one of the above organisers.
Since the discovery in 1979 of the first gravitational lens, the double quasar 0957+561, both the known manifestations and applications of gravitational lensing have grown enormously. However, gravitational lenses are rare and despite an enormous observational effort, examples of strong lensing (where multiple images of a source are detected) still number only a few tens, and almost all the lensed objects are distant quasars or radio sources. This situation arises because the conventional strategy for identifying gravitational lenses involves sifting through a catalogue of sources at high redshift, such as quasars or radio loud AGN, looking initially for morphological evidence of multiple imaging. Particularly for the radio-selected lenses it is often difficult, or impossible, to acquire optical redshifts of one, or both, of the deflector and source. As a consequence even the basic lensing geometry is poorly constrained.

An alternative search strategy is to identify a population of very effective “deflectors”, where it is known that any source lying behind the deflector will be significantly lensed, and to examine the spectra of the deflectors for evidence of lensed background sources. Using APM measures of UKST BVR plates it is possible to identify what is essentially the ideal population of deflectors — massive, bulge-dominated, galaxies at redshift $z \sim 0.4$, essentially half-way between ourselves and any high redshift source. Specifically, locating the population of relatively bright ($m_R \leq 20$), red $(B-R \geq 2.2)$ galaxies with redshifts $0.25 \leq z \leq 0.55$ and a surface density of $\sim 50$ deg$^{-2}$ is straightforward. Associated with each such galaxy there is an area of sky, $\sim 1$ arcsec$^2$, in which any distant source will be multiply imaged, producing an increase in brightness of a factor $\sim 10$.

The surface density of quasars and AGN, even to very faint limits, is low and the probability of finding a lensed AGN in this fashion is very small. However, as Miralda-Escudé and Lehár (1992) pointed out, the surface density of high-redshift star-forming galaxies is orders of magnitude higher and examples of galaxy-galaxy lensing should be relatively common. Support for their prediction was provided by our discovery of the first optical Einstein ring (see Warren et al. 1996), a massive early-type galaxy, $z=0.485$, lensing a high-redshift, $z=3.59$, star-forming galaxy. The initial spectra were taken at the AAT and the system was chosen for observation as part of the commissioning of the ESO VLT (http://www.eso.org/outreach/press-rel/pr-1998/pr-20-98.html, and astro-ph/9901271). The system is the first unambiguous case of a galaxy lensing another normal galaxy.

Observations of gravitationally lensed Einstein-ring images provide a dramatic improvement in the ability to constrain the properties of lensing mass distributions and also probe the structure in the extended sources (Kochanek 1995). The rings are so effective, relative to the more common multiply-imaged point sources, because of the constraints provided by the two-dimensional surface brightness maps obtained. The primary scientific goals are to determine the structure of the background high-redshift galaxies, at a resolution of $\sim 0.1$ arcsec, and to measure their masses, as well as to measure the mass-to-light-ratio and constrain the mass distribution within the lenses, i.e., the population of massive early-type galaxies.

Our initial sample of 160 galaxy spectra contained a second candidate system, an early-type galaxy, $z=0.519$, with a weak emission line present at $5800-5800\bar{\AA}$ (Fig. 1). An image of the system at the wavelength of the emission line is the next stage in the investigation of the system and the AAO TTF instrument is the ideal means of obtaining such an image. The commissioning of the “blue-TTF”, extending the TTF’s blue wavelength limit from 6500 $\bar{\AA}$ down to 3700 $\bar{\AA}$, means that Lyman-$\alpha$ emission in the lenses can be studied over the important redshift range $2 < z < 5$. A night of time, scheduled as...
part of the blue-TTF science commissioning in August 1998, was awarded by PATT in June and the necessary blocking-filter, to cut down the sky-background, was ordered.

Unfortunately the filter had not arrived by the night of the observing and a lower throughput, broader bandpass, filter had to be employed. The seeing was also not ideal, ~2 arcsec, but the effectiveness of the blue-TTF was evident when emission was detected at the predicted wavelength in an exposure of only 900 s. Additional on-and off-band exposures produced a blurry but clear detection with some indication of extended structure. The custom filter remained elusive as the science commissioning run proceeded but on the last night the filter was flown, as a Yanda fare-paying passenger, to Gunnedah, where a Coona cabbie picked it up, and drove it to the AAT, arriving at 10pm!

With the TTF achieving a resolution of 10 Å and excellent seeing, ~ 0.9 arcsec, a sequence of 1800 s exposures were obtained at five wavelengths, –3.6, 0.0, +3.6, +7.2, +10.8 Ångstroms relative to the measured wavelength of the spectroscopically detected emission line. Bad luck with cosmic rays and a satellite trail meant that two of the images could not be used. The emission line was strongly detected at the bluest wavelength setting and entirely absent at the reddest settings. The location of the object in the blue TTF image is 2.0 arcsec from the centre of the galaxy. This is illustrated in Figure 2 which shows a 37 x 37 arcsec image of the blue TTF image with a J-band image of the field (kindly obtained by Bahram Mobasher). The object at the top has two components, the galaxy and the emission line component. Three brighter stars are also visible in the field. These short exposures with the blue TTF confirm the existence of the emission and the presence of an image morphology entirely consistent with the system representing the second gravitational lens to be discovered from only 160 galaxies in our survey. For the measured separation the counter-image is predicted to be faint and lie near the centre of the lensing galaxy. Longer exposures employing the custom filter are required to detect the second image and search for any extended structure.

Observations of our sample of massive early-type galaxies offers the real prospect of identifying resolved gravitational lenses very efficiently, allowing a statistical sample of 10–20 lenses to be assembled with only a modest investment of telescope time. We are making a survey for further examples of lensing, employing 2dF to obtain spectra of ~150 galaxies per half night. Preliminary analysis of data from September 1998 indicates the presence of several more candidate lenses. We hope to obtain further time with the blue TTF to investigate these candidates in Semester 99B.

References

A DEEP MULTI-LINE IMAGING SURVEY OF EDGE-ON SPIRAL GALAXIES.
Scott M. Miller & Sylvain Veilleux (U. Maryland)

Dynamically Active Disks in Spiral Galaxies.

Galaxies are not “island universes” detached from their surrounding environment. The growth of galaxies through mass accretion and mergers is an integral part of galaxy evolution. Conversely, dynamical events associated with star formation and nuclear activity may act as “galactic chimneys” sending enriched, hot gas into the halos of the host galaxies and possibly beyond. This feedback mechanism from star formation and nuclear activity may have had an important effect on galaxy evolution in the early universe.

Support for a dynamically active disk in our Galaxy comes in part from the discovery of a thick layer of warm (~10^4 K), low-density (~0.2 cm^-3), ionized gas
with scale heights of ~1 kpc (e.g., Reynolds 1985). Recently, traditional narrow-band imaging techniques have been used to survey edge-on galaxies down to flux limits of a few $10^{-17}$ erg s$^{-1}$ cm$^{-2}$ arcsec$^{-2}$ to search for evidence of dynamically active disks in external galaxies (Pildis et al. 1994; Rand 1996). Results suggest that only a few edge-on spirals show evidence of a widespread diffuse ionized medium like that of our Galaxy, but they often reveal kpc-scale filaments and plumes which may represent the brighter features of a more extensive but fainter complex of high-$|z|$ material (see, e.g., Dettmar 1992; Veilleux et al. 1995).

**Description of the TTF Survey.**

The Taurus Tunable Filter (TTF) is ideally suited to map the diffuse ionized medium in nearby galaxies. Calculations show that limiting (S/N ~ 4) surface brightnesses of $8 \times 10^{-18}$ erg s$^{-1}$ cm$^{-2}$ arcsec$^{-2}$ can be reached with an on-target exposure time of 1.5 hours with the use of the TTF and MITLL CCD on the AAT. The charge shuffling capabilities of the TTF also allow us to switch between two frequencies (for example H$_\alpha$ and [N II] $\lambda$6583) such that variations in the sky background will be averaged out between the two images. Therefore we can correct for sky variations more easily, facilitating observations at fainter flux levels. The purpose of our TTF program is three-fold:

- **Probing to fainter flux levels to derive strong new constraints on the gaseous extent of galaxies.** These constraints are directly relevant to recent searches for $z \gtrsim$ 1 Ly$\alpha$ absorption systems around quasars which suggest that gaseous halos around galaxies may extend out to distances of ~160$h^{-1}$ kpc and can account for 30–60% of the Ly$\alpha$ absorption systems detected in quasar spectra (e.g., Lanzetta et al. 1995).

- **Morphological analyses to yield new clues on the origin of the high-$|z|$ material and new insight into the disk-halo interaction.** Numerical simulations of mergers between galaxies and their satellites suggest disk thickening at larger radii due to such encounters (Walker et al. 1996). Observations of lopsided galaxies also suggest that asymmetries in the outer disk are related to recent accretion (Zaritsky & Rix 1997). In contrast, the galactic fountain model predicts a more widespread, extended halo due to large-scale circulation of matter and energy (e.g., Shapiro & Field 1976), while the chimney model implies that the circulation of gas and energy is correlated with regions of high supernova activity (e.g., Norman & Ikeuchi 1989). Observations of filaments or bubbles extending into the halos of galaxies and correlated with the presence of active star-forming regions in the disk would provide strong supporting evidence for chimney/supernova blow-outs.

- **Constraining the ionization source in the high-$|z|$ gas by use of the vertical profiles of the emission-line ratios.** Current observations show line ratios which are significantly different from those of H II regions (e.g., Reynolds & Tufte 1995; Veilleux et al. 1995; Rand 1997). Observations of less inclined galaxies also show differing line ratios in regions between and far away from the H II regions (Bland-Hawthorn et al. 1991; Walterbos 1991). These suggest that the observed emission of the ionized gas is real and not simply due to scattered emission from the disk. It is not clear at present whether these unusual line ratios are due to “hardening” of the O-star radiation as it passes through the dusty medium of the galaxy, or whether it implies that shocks or photoionization by cooling hot gas become increasingly important above the galactic plane. The multi-line capabilities of the TTF may be used to construct emission-line ratio maps that can address this question.

So far, about a dozen galaxies have been observed with either the AAT/TTF or the WHT/TTF. Much of the effort has focussed on determining the vertical gaseous structure of these galaxies at H$_\alpha$ and [N II] $\lambda$6583. Our preliminary results show that a surface brightness of $8 \times 10^{-18}$ erg s$^{-1}$ cm$^{-2}$ arcsec$^{-2}$, nearly an order of magnitude fainter than previous surveys, can be easily reached with the TTF. Some of our results are shown in Figs 1 and 2. A wide diversity of structures is observed in our sample galaxies. Ionized filaments are apparent extending ~1 kpc above the plane of NGC 2820 and

![Fig. 1: Continuum-subtracted H$\alpha$ image of NGC 2820 and the central regions of NGC 55, using the TTF. Filamentary structures are apparently extending ~1 kpc above the plane of NGC 2820 (indicated by arrows), while widespread diffuse emission is detected in NGC 55. The limiting surface brightness of these images is ~$8 \times 10^{-18}$ erg s$^{-1}$ cm$^{-2}$ arcsec$^{-2}$. Each image is rotated such that the disk of the galaxy runs horizontally, and the line at the top left of each figure represents 1 kpc.](image-url)
NGC 2188 (indicated by arrows) while widespread diffuse emission is detected in NGC 55. Future observations will focus on other emission lines such as [O iii] \( \lambda 5007 \), [N ii] \( \lambda 5755 \), [S ii] \( \lambda\lambda 6717, 6731 \), and [S iii] \( \lambda 9532 \) to provide strong new constraints on the origin and source of ionization of the extraplanar material in these objects.

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DEEP OBSERVATIONS OF A QSO NEBULA WITH THE TTF

Patrick Shopbell & Sylvain Veilleux (Maryland)

We recently observed the extended ionized gas surrounding the low-redshift (\( z=0.0638 \)) quasar MR 2251–178 using the TTF on the AAT telescope. Our observations detect Hα-emitting ionized gas out to a radius in excess of 120 kpc, the deepest detection yet in this system. The azimuthal extent of the gas is far more complete than previously thought, with a substantial velocity gradient evident in the east-west direction. In this brief article, we will attempt to motivate further use of the TTF system by providing a summary of our observations.

MR 2251–178 was first discovered as a strong and variable X-ray source by the Ariel V satellite (Cook et al.1978). High spatial resolution observations by the SAS-3 X-ray Observatory, correlated with optical imagery and spectroscopy and radio imagery, identified the object as a quasar at a redshift of 0.0680 (Ricker et al.1978). Optical imagery indicates that the quasar resides in the outskirts of a small cluster (Phillips 1980).

Early photographic spectroscopy detected two ionized gas components around the quasar: a hot (\( T \approx 10^4 \) K) highly-ionized circum-nuclear component of diameter \( \approx 27 \) kpc, and an extended envelope of faint Hα- and [O iii]-emitting filaments out to a radius of more than 200 kpc (Bergeron et al.1983). Although the most distant early “detections” have been identified with a night sky line, more recent observations have confirmed the presence of ionized gas at both Hα and [O iii] 5007Å wavelengths surrounding the quasar, extending up to 110 kpc from the nucleus (Hansen et al.1984; Alighieri et al. 1984; Macchetto et al. 1990). Longslit and Fabry-Perot spectroscopic observations have determined that the extended ionized gas, while undoubtedly associated with the quasar, is not following its rotation pattern, and may in fact be counter-rotating (Nørgaard-Nielsen et al. 1986; Mulder & Valentijn 1992).

We observed MR 2251–178 on the night of August 30, 1998 using the TTF at the f/8 Cassegrain focus of the AAT. The observations of MR 2251–178 were made with the red side of the TTF, using a mediumband (\( \Delta \lambda = 6583 \) images of NGC 2188, showing more filamentary structures.

Fig. 2: Continuum-subtracted Hα and [N ii] \( \lambda 6583 \) images of NGC 2188, showing more filamentary structures.
26.0 nm) blocking filter centered at 707 nm, tilted by 16°. The exposures consisted of two 600 s observations at an etalon spacing of z=68, followed by a pair of 600 s exposures at a spacing of z=73. This shift in etalon spacing corresponded to a 13Å shift in wavelength, approximately twice the bandpass chosen for the TTF (6Å). The exposures were dithered amongst pointings on a 15" grid. We also observed MR 2251–178 on September 3, 1998 in direct imaging mode, using a standard I-band filter.

The final continuum-subtracted Hα image, constructed from all four TTF exposures, is shown on the cover. The 3 arcminute field is centered on the quasar. The bright object north of MR 2251–178 (labeled “S”) is a foreground star. Another galaxy in the cluster which exhibits low levels of Hα emission can be seen between the star and the quasar; it is labeled “G1”, to correlate with published observations.

The two ionized gas components are clearly visible in the image: a bright extended emission line region (EELR) directly surrounding the quasar and a more extended collection of faint filaments and knots. Our detection of the EELR (r ~ 20 kpc) is consistent with previous Hα and [O III] observations. In contrast, the distribution of very extended ionized gas detected by the TTF far exceeds that previously identified (e.g., Macchetto et al. 1990). We observe faint knots of Hα-emitting gas at essentially all position angles, with perhaps a slight paucity toward the northwest. The knots to the east (knots NE3, NE1, and NE4 in Macchetto et al.1990) are particularly strong, as is a single knot to the northwest (NW2).

The source of the extended gas in MR 2251–178, as well as the source of its ionization, remains a mystery. The extent of the gas towards the northeast lends credence to the argument first put forth by Alighieri et al.(1984), that the gas is the tidal remnant of an encounter between MR 2251–178 and the galaxy G1, some 2x10⁸ years ago. A deeper stretch of our data strengthens the connection between the diffuse emission nebula and G1, although the presence of the bright star causes significant uncertainty.

A paper has been submitted recently to the Astrophysical Journal which provides more detail on these observations, including a summary of the kinematic information available from our use of two separate etalon spacings. This short summary demonstrates the clear advantages that the TTF instrument provides for narrowband optical imaging. Based on our observations of MR 2251–178 and others, we suggest that significant quantities of ionized gas in galactic environs may have gone undetected with current observational techniques, making the field ripe for an instrument such as the Taurus Tunable Filter.

References

AAT PRIME FOCUS TRIPLET BACK IN ACTION

Chris Tinney & Steve Lee

Though the AAT’s Prime Focus triplet corrector has produced some of the most spectacular astronomical images ever obtained, it has not seen much action in the recent past — mostly because it has been sitting in pieces.

The triplet’s original single-layer MgFl anti-reflection (AR) coating was applied quite some time ago, and has always suffered from poor performance in the U and I bands. At these wavelengths the poor AR coating led to the last element of the corrector (which is concave towards the detector) concentrating a large image of the telescope’s pupil onto the detector, with an enhanced sky level of about 10% of that seen in the rest of the image. (See http://www.aao.gov.au/local/www/cgt/cgthome/uh_8k_i_ghost.gif for an example of the old ghost at I-band.)

To try and eliminate this problem in preparation for the commissioning of the Prime Focus Upgrade and the AAO/MSSSO 8Kx8K Wide Field Imager in 1999B, the last element of the triplet was removed and its MgFl coating was polished off by Gabe Bloxham at the Mt Stromlo Optical Shop. A new 11-layer coating was then applied by Continental Optical Corporation of New York. This coating is specified to provide a reflectivity of less than 1.5% from 350 to 1000nm.

The refurbished element was then re-mounted at the AAT by Paul Lindner, and used in anger for the first time in December 1998 by Steve Lee and David Malin. It would appear that the work put in by everyone has resulted in U and I-band ghosts lowered to a level of significantly
Dectapes fill only one CDROM. After one more attempt has been made to read the “unreadable” tapes on a different computer, the data headers will be processed to bring them into line with our current standard and then made available on the database. The long time coverage of some of these observations may prove of interest to some archive users.

The increasing number of archive requests being received shows that this service is popular. However, such popularity has a price – the time it takes to process data requests grows with the number in the queue. Please be patient, although most requests are being filled within 3 weeks of receipt.

**AAT ARCHIVE DATABASE UPDATE**

**Steve Lee**

As described in the April 1998 newsletter (p9), the AAT has introduced a web-searchable database of its data. The article also promised further improvements to the way data are handled at the AAT. Some of these changes have now been implemented.

Observers visiting the telescope for the past few months will have noticed the night assistant testing an electronic logging system. As of the start of 1999, the old handwritten log books are no longer being used and the new electronic log system is in place. The electronic log is more than just a replacement for the paper log, it is the first stage of the whole archiving procedure. Under control of the night assistant, the data are transferred from the VAX to the archiving computer and translated into FITS format in preparation for archiving. Any errors in the header (wrong object name entered by the observer, for example) are corrected at this stage. At the same time, relevant data are stripped from each header to make the log record. Just as with a paper log, comments may be added or edited at any time. At the end of the night the log can be printed for the observer, or copied as a text file if the observer prefers to keep digital records.

From early February, the electronic log fulfilled its remaining goal. It now updates the archive database records at the end of each night, making those observations available on the WWW immediately. (The data are of course still subject to a 2 year proprietary period.)

In the background, older data are slowly being added to the database. So far the records are complete from late 1993, together with other data sets indicated in the April article. By the time this article is published, there will be over 250,000 records in the archive database – and growing daily.

Most of the tapes from our oldest electronic instrument in the archive – the Wampler Scanner, also known as the IDS – have been read. Some of these tapes date back to the early 1980s (when the original tapes were re-spooled) and show both the resilience and fragility of 9-track media. As expected, some data were unreadable and are lost forever, but the majority produced no problems. The IDS was in use from 1975 until 1983 producing much astronomical data. However, the 2048x2 format of the data is considered small today. The data from 8 years and more than 1300 original 7-track

**SAM BARDEN’S VISIT TO THE AAO**

**Keith Taylor**

Motivated by our desire to pursue VPH grating technology for the New Intermediate Dispersion Cassegrain Spectrograph design study, we invited Sam Barden (NOAO) to spend two weeks working with Gordon Robertson and myself on the analysis of VPH spectrograph design. Those at the AAO contributing to the discussions included Joss Hawthorn, David Lee, Peter Gillingham and Russell Cannon. With Jim Arns and Bill Colburn of Kaiser Optics (manufacturers of VPH gratings), Sam has pioneered the evaluation and analysis of the use of VPH gratings for astronomy and it was with his help and guidance that the AAO became the first observatory to successfully deploy the technology in its LDSS++ project last year (see November 1998 Newsletter).

Sam’s visit began with a trip to Stromlo geared to expanding Australian user input into the debate on general spectrograph requirements, followed by a visit to site where we showed off 2dF (Sam is also project scientist for Hydra, the NOAO fibre positioner) and LDSS++. Once back in Sydney, Sam, Gordon, Damien Jones (Optical designer: Prime Optics, Qld) and myself worked intensively on analyzing design options for a replacement to the ageing RGO spectrograph, with particular attention to achieving very high efficiency, 1.5" slit, R<~10,000 resolving powers for single and multi-slit spectroscopy. Early indications are that efficiencies greater than LDSS++ can be achieved over wide fields of view while the inherent tunability of VPH gratings permits the arbitrary optimization of the blaze peak. We see this not only as an exciting opportunity to revolutionize optical spectroscopy at the AAT, but also to pioneer a spectrograph concept which has the potential to significantly out-perform (in both resolution and efficiency) the present generation of multi-object
spectrographs on the 8-metre class telescopes.

In collaboration with Sam, Gordon is presently working towards a proposal for the next Board meeting which will propose the initiation of a preliminary design study. The instrument already has a name: ATLAS (the [A]nglo-Australian [T]unable [L]ittrow [A]stronomical [S]pectrograph.

### MULTI-NOTCH AND MULTI-BAND INTERFERENCE COATINGS

**Joss Bland-Hawthorn (AAO) & Sonia Cianci (U. Sydney)**

Astronomers are used to thinking of spectral bands in terms of *continuous* segments of the electromagnetic spectrum. This is imposed on us to some degree by the natural ‘windows’ produced by the earth’s atmosphere. The response curves of detectors further reinforces natural limits to spectral bands. The classical photometric bands are laid down in response to both detector response and atmospheric bands.

In order to isolate a discrete energy interval, astronomical instrumentation commonly – but not exclusively (e.g. coloured glass) – resorts to spectral interference. More often than not, optimal transmission is achieved in only one of the interference orders. An unblocked interference filter produces bands outside the chosen window. With the tolerances imposed by commercial coating plants, the outlying orders are very poorly behaved. Commercial companies block these orders in any event, e.g. by the choice of filter substrates.

In recent years, there have been major advances across a broad front in the application of thin film, interference coatings. There are improvements in monitoring during deposition (e.g. ellipsometry), and advances in adaptive and servo-control. Ion beam sputtering allows for highly uniform, denser coatings that are more reproducible than before. Refractive indices as high as 2.7 (CSIRO, Lindfield) and lower than conventional MgF\(_2\) (e.g. nanoporous polymers, sol-gels) are now possible. The latter step is particularly important since, for optimal performance, the geometric mean refractive index of a multi-layer dielectric should be comparable to the substrate index.

These technological advances now permit much better control of ‘out of band’ interference, and permit (a) multi-band transmission filters and (b) multi-notch, anti-reflection coatings. Such filters have important applications to several astronomical studies.

Multi-band filters can increase the multiplex or throughput advantage of long-slit and multi-slit spectrographs by factors of at least 4–5 (albeit for specific science applications), as we show below. In near-infrared imaging, more than 95% of the \(J,H\) background arises from strong telluric features, which concentrate into discrete bands. Offer & JBH (1998; MNRAS, 299, 176) show that, in principle, these features can be blocked from the filter bandpass using rugate coating technology.

We now illustrate four specific examples of multi-band/multi-notch filters that are under investigation as part of Sonia’s thesis. All of these are to be attempted in conjunction with David McKenzie and John O’Byrne of the University of Sydney, and Francis Lord Optics.

(A) Multi-notch anti-reflection coatings.

It is now increasingly clear that 2–4m class telescopes *can* compete directly with large telescopes using instruments that are highly specialized in their application. It is not unreasonable to envision optical cameras and spectrographs that are better than 90% efficient in a few discrete bands. There exist dispersing optics that are almost 100% efficient over narrow bands.
Anti-reflection coatings can also be made much more effective in restricted bands. A multi-notch AR coating allows a specialist instrument to operate at high efficiency in more than one discrete band. Fig. 1 is our first attempt at designing an [O\textsc{iii}]–H\alpha coating. A possible application is the Planetary Nebula Spectrograph designed to operate with the highest possible throughput in these two bands (see http://www.aao.gov.au/local/www/pns/pns.html). The so-called ‘W coating’ is not ideal as the [O\textsc{iii}] trough is a little narrow for comfort. Current work is concerned with broadening this trough with the minimum number of dielectric layers.

**Fig. 3:** Two widely spaced bands (a) can be placed side by side in convolution space (c) when convolved with the periodic profile of the TTF, shown in (b).

The multiplex advantage of the RGO spectrograph and the MSO 2.3m Double Beam Spectrograph can be significantly increased for the purposes of observing extended, line-emitting sources (e.g., high velocity clouds, spiral galaxies, etc.). From work undertaken with Ken Freeman, Fig. 2 shows how a multi-slit (a) can be used in conjunction with a double-band filter (b) to isolate two spectral regions, i.e., H\alpha–[N\textsc{ii}] and the [S\textsc{ii}] doublet, at four slit positions. In the same manner, multi-band filters can be used in conjunction with LDSS++ in order to identify line emitters at targeted redshifts. The suppression between the bands allows objects to overlap spectrally, thereby affording a further increase in the multiplex advantage.

**Fig. 4:** The rugate beam splitter camera in (a) divides the input beam into peaks and troughs, e.g., the spectrum of a brown dwarf in (b). The combined flux from all peaks are transmitted to the detector, and the troughs are reflected twice before being reimaged beside the image of the peaks. A substantial fraction of the images with maximum contrast, regardless of flux (see eq. 1), will fall into the desired category.

(B) Multiplex advantage of a long-slit spectrograph.

(C) Tunable filter imaging at high spectral resolution.
(c)). Therefore, it becomes possible to obtain accurate differential measurements through shuffle imaging from two widely spaced, narrow spectral bands.

**D) Contrast imaging and reformatting multi-band cameras.**

Our recent development of rugate beam splitters provides a new approach to identifying classes of astronomical sources with distinctive spectra, in particular brown dwarfs. In the near infrared, these objects have a series of broad peaks and troughs. With the development of rugate technology, it is now possible to make an interference filter transmit several discrete passbands simultaneously. We will show a simple design for a ‘beam splitter’ camera which divides the brown dwarf spectrum into two parts. The beam splitter transmits the spectral peaks and reflects the troughs. Objects which match the beam-splitter profile will have a maximum contrast, C, between the reflected and transmitted images, i.e.

\[
C = \frac{(O_r - S_r)}{(O_r + S_r)} \left( \frac{(O_r + O_s) - (S_r + S_s)}{1} \right)
\]

where O and S are the object and sky fluxes, and the subscripts R and T refer to reflection and transmission. The beam-splitter profile is not degraded in fast beams, and is therefore ideally suited to wide field searches for brown dwarfs. A possible camera design is shown in Fig. 4(b). Note that to search for a different class of sources, only the beam splitter needs to be replaced. Using this technology, it is may be possible to enhance the power of existing specialist cameras (e.g. MAPPIT) and the new generation of multi-band cameras (e.g. the University of Tokyo dichroic camera; Doi et al. 1998, SPIE, 3355, 646).

**RGO CALCULATOR AVAILABLE**

Helen Johnston

A signal-to-noise calculator for the RGO Spectrograph is now available on the AAO web page, and can be accessed at http://www.aao.gov.au/cgi-bin/rgosnr.pl. Future additions will include provision for extended objects. Comments and suggestions are welcome: email hmj@aaoepp.aao.gov.au.

**NEW TECHNOLOGIES: HOLOGRAPHY AND ASTRONOMY**

Joss Bland-Hawthorn

Over the past two weeks, we have enjoyed running dialogues with Sam Barden at the AAO and at Mt Stromlo Observatory. The AAO is indebted to Sam for his assistance with the new volume phase holographic (VPH) grating that formed a key part of the LDSS upgrade. His visit allowed us to learn more about the developments being undertaken at the NOAO and at Kaiser Optics (KOSI), Ann Arbor. These discussions are the inspiration for some journalistic license.

As curious as it may seem, the AAO is greatly indebted to the wonders of gelatin. There are relatively few chemical substances (maybe alcohol) that have sustained us more. Gelatins provide the basis for wide-field photography with the UK Schmidt, and for some high performance anti-reflection coatings. Dichromated gelatins can record the interference pattern of a volume phase grating when illuminated with laser light. The optical properties of these holograms are close to ideal: the LDSS++ grating has so little absorption and scattering that it has the appearance of the finest clear glass. While ever in danger of putting the cart before the horse, one can even entertain the idea of optical aberration correction using holographic imaging onto dichromated gelatin sheets.

Gelatins are remarkably flexible. Mix in silver halides and you get photographic emulsion. Alternatively, a small concentration of dichromate (e.g. ammonia or potassium based solutions) causes gelatin molecules to cross link when exposed to blue light. Where the light falls, the gelatin hardens, a fact well known to the printers of electronic circuits. If the light is an interference pattern, the soft gelatin can be etched away (photoresist) to leave a conventional surface grating.

If you chemically harden the pre-exposed gelatin, an interference pattern is accurately retained within the volume of the gelatin layer. KOSI have perfected the art of amplifying the diffraction characteristics by a chemical (proprietary) process. The refractive index variations within a volume phase grating cause light to undergo Bragg diffraction. As Sam and collaborators have discovered, these gratings, which can be used in reflection or transmission, show major advantages over classic surface gratings in many areas. In particular, their efficiency envelopes can be tuned with wavelength by simply tilting the VPH with respect to the incoming beam. Furthermore, the diffraction efficiency is much less dependent on the orientation of the polarization vector. Indeed, the S and P planes often have identical dependencies with wavelength, which is why the diffraction efficiencies are often higher than comparable surface gratings. For more details, see Barden et al. (1998; SPIE 3355, 866) and references therein.

The interference pattern is laid down by a two-beam Michelson interferometer. It is anticipated that VPH
technology can be used to make very large gratings relatively inexpensively. The improvement of LDSS++ is evidence enough of the advantages afforded by VPH gratings at low resolution. It is expected that a fully transmissive spectrograph can be made to outperform a reflective system at intermediate resolution \((R \geq 10,000)\). Here are 4 related issues which require further discussion and experimental work.

(i) What are the extremes in grating line density? Sam and collaborators are presently investigating 300 lines \(mm^{-1}\) but a suitable echelle cross disperser may need to be ruled at half this groove density. VPHs appear to behave well at high ruling densities: the upper envelope appears to be close to 6000 lines \(mm^{-1}\).

(ii) What is the response of dichromated gelatin at cryogenic temperatures? It is known that ordinary photographic emulsions freeze out much below 200K. These days, concern for how collagen is obtained has spurred chemical industries to investigate synthetic materials. Do any of these show promise at low temperature?

(iii) Sam demonstrated elegantly that if sinusoids within the gelatin were more like \(\sin^{m}x (m<1)\), i.e. more rounded, then more power can be concentrated into the higher spectral orders. This is a crucial point to explore. The physical explanation may well be the non-linear response of the gelatin, or higher order interference effects within the 3D structure. There is an extensive literature on groove shaping for surface relief gratings. Can the VPH development process be improved to further exploit the shaping of grooves?

(iv) How thin can the gelatin films be made? The current range appears to be 4–20\(\mu m\). As expected, thinner films give a broader spectral response. Can high refractive index modulations be achieved in even thinner films? Can the VPH substrate be ‘chirped’ with a series of holograms, each with different refractive index amplitudes, to produce an even broader spectral profile?

KOSI are now contemplating refractive index variations as large as \(\delta n \sim 0.1\) which is a substantial lever arm for deviating light. For a simple lens, it is interesting to consider whether the air-glass interface or the variation in optical depth dominates. Of course, the former almost always does. The author is fascinated by the prospect of using VPH technology to correct aberrations in optical systems. For proper broadband correction, maybe at least two ‘phase plates’ would probably be required. Note that you do not need a matched (but perfect) optical train in order to form the phase plate. A commercial pulsed laser is likely to be coherent over at least a metre such that large elements are possible. A crucial point is whether KOSI’s development process introduces ‘fog’ into the film, i.e. residual power, or whether they control the lowest order refractive index modes to high tolerances. Such an optic is the logical complement of the diffusing screen. If a VPH phase plate can be made to work, why bother polishing optics at all? This is not a rhetorical question and we would welcome an answer.

**IMAGE COMPRESSION FOR SUPERCOSMOS SKY SURVEY DATA**

Nigel Hambly (Wide Field Astronomy Unit, Edinburgh)

**Introduction**

The project to digitise the southern sky using SuperCOSMOS originated in the early phases of the development of the machine — see, for example, Hawkins (1992) in the proceedings of the 1991 conference on ‘Digitised Optical Sky Surveys’ (MacGillivray & Thomson 1992). In the same volume many digitisation programmes of varying scope are described, along with analysis and calibration techniques. One of the key constraints concerning a digital sky survey is the limitation that extant computer technology places on the amount of data that can be held online with the requirement of fast random access. For example, the STScI Digitised Sky Survey (eg. Lasker 1992) is compressed by a factor 10x using a ‘Haar’ transform algorithm (White et al. 1992). Here, some tests are described where SuperCOSMOS data, compressed by different factors, is analysed for detection depth when compared against DSS data and deep CCD frames.

**Tests on compressed data**

A 30x30 arcmin region in ESO/SERC field 411 (i.e. at the South Galactic Pole) was chosen for test purposes. First \((J)\) and second \((R)\) generation DSS data were retrieved from the STScI data server. These data are compressed by a factor \(~10\) to facilitate online storage at STScI; the SuperCOSMOS data were compressed (using the same software — see White et al. 1992) by factors of 10 and 20 to directly compare with DSS data and also to show the effects of using higher compression factors. In order to assess quantitatively and objectively the information content of the images, the data were run through the PISA image detection algorithm (Draper & Eaton 1992; based on the APM IMAGES software) which is an isophotal pixel analysis package similar to the COSMOS image analyser (Beard, MacGillivray & Thanisch 1990) that both ROE and STScI use to generate object catalogues. The data were thresholded (in density space) at 2.3\(\sigma\) above the mean sky level (this is the SuperCOSMOS norm) and a minimum of 6
pixels was required to define an image in all cases. Note that this minimum pixel area cut was kept the same for the tests, despite the fact that the STScI data have larger pixel sizes (25µm and 15µm for first and second generation data respectively). Reducing the cut for the coarser sampled data to an area equivalent to that of the higher resolution SuperCOSMOS data results in large numbers of spurious noise images being detected — it is fair to say that the fact that the SuperCOSMOS data has higher spatial resolution allows fainter detection limits, and this should be reflected in any test.

Figure 1 shows the results of the image detection tests when compared against a CCD image of the same field which reaches much fainter limits than the photographs. From the plots, it can be seen immediately that the SuperCOSMOS pixel data are superior to the DSS–I data (in this test, they reach ~1 mag deeper); the DSS–II and SuperCOSMOS data are broadly similar. Interestingly (and counter-intuitively), the image detection is deeper for higher compression factors. This has been noted before (e.g. White et al. 1992) and can be understood in terms of the compression algorithm smoothing the background which results in a lower detection threshold when computing $n_s$.

**Status of the SuperCOSMOS sky survey**

The ultimate aim of the SuperCOSMOS digitisation programme is to cover the entire sky at three passbands (BRI), one passband at two epochs. Image data (currently compressed by a factor 20x) and object catalogues will be available in a variety of data formats. Initially, a 5000 square degree region ($b < -60^\circ$), or 200 Schmidt fields, around the south Galactic cap is being completed and it is anticipated that this will be available via Web access in the summer of 1999. The table gives a breakdown of the fields remaining to be observed/scanned in the SGC region.

<table>
<thead>
<tr>
<th>Survey</th>
<th>Band</th>
<th>Taken at ROE</th>
<th>Available</th>
<th>Scanned</th>
</tr>
</thead>
<tbody>
<tr>
<td>SERC–J</td>
<td>B</td>
<td>200</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>AAO–R/SERC–ER</td>
<td>R</td>
<td>159</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>SERC–I</td>
<td>I</td>
<td>146</td>
<td>125</td>
<td>125</td>
</tr>
<tr>
<td>ESO–R/POSSI–E</td>
<td>1st epoch R</td>
<td>200</td>
<td>200</td>
<td>200</td>
</tr>
</tbody>
</table>

Totals (out of 800): 705 675 675

Status of plate availability/scanning for the 200 field SGC survey.

Thereafter, the survey is being expanded to encompass the whole southern sky, and ultimately the northern hemisphere. Note that raw, uncompressed pixel data are being archived on tape at Edinburgh, so that if in future online storage capacity is significantly improved at reduced cost (as is likely given recent developments) we will be able to go to 10x compression, or even uncompressed online storage, for the entire database.

**Conclusion**

Current disk space limitation requires that the survey pixel data are reduced in size to enable large areas of sky in several passbands to be stored online. Since the raw pixel data from a single plate scan requires 2.1 Gbytes, the four–plate per field, 200 field SGC survey would require ~1.7 Terabytes of online storage, whereas compressing by a factor 20x reduces that requirement to the more practicable figure of ~90 Gbytes for the pixel data alone.

We thank Michael Brown, Bruce Peterson and Brian Boyle for permission to use their unpublished deep CCD sequences in this study.

**References**

LOCAL NEWS

LETTER FROM COONABARABRAN

Chris McCowage

Rhonda is currently on leave and touring Tasmania. Avid letter readers will have to make do with a stand-in scribe.

In November there was a lot of media and public interest created due to the possibility of an impressive Leonid shower. The staff responded to many enquiries and requests for interviews and information.

Whilst the Leonids did not prove to be as impressive as was hoped, Siding Spring was subjected to some celestial fireworks of a different kind.

Anyone who has experienced the fury of a thunderstorm on the western plains of New South Wales can’t fail to be impressed by the beauty of nature and to feel some fear of the power. Cumulonimbus, towering overhead, ominously dark under the base with scudding roll clouds, areas of raised dust marking the squall line and forks of lightning stabbing the earth.

The trip up on the bus on the morning of Wednesday November 18th was uneventful as the day staff were treated to the spectacle of the retreating storm. A number of us were pretty tired as we had gotten up early to observe the Leonids. We noticed that the standby diesel generator was running which indicated that the power had gone off, not surprising given the ferocity of the storm. We were greeted by Allan Lane who lives on the mountain top. He related how he had been awakened by the storm and the wail of the fire alarm, set off by numerous nearby strikes.

We are used to such events and the AAT has proven to be pretty robust over the last 25 years or so. Most of the IT equipment seemed to be running OK so we started to see how everything else had fared. An ominous fault report from the night assistant told of actually hearing the “crack” of an electrical discharge from up in the control room somewhere in the direction of the telescope control computer. We started to assess the damage. Amazingly the no-break inverter was still running; the telescope control computer and CAMAC (a general purpose computer interface system for control and data acquisition) were both dead and virtually all of the telescope and dome encoding had failed. Ancillary equipment like the met system and the GPS station clock were also damaged along with the likelihood that many more systems were out of action.

We split up into groups to tackle the problems: we knew we had a lot of damage, and we needed to concentrate on getting enough working to observe with 2dF. Thankfully, 2dF had survived unscathed, and it also meant that we did not have to tackle the cass A&G box and autoguider. The Schmidt Telescope control systems are pretty robust and had survived the incident. Things progressed well at first: fuses changed, systems reset and interface chips replaced managed to get most systems back into operation. Bob Dean got the control computer to boot, which was a relief, but CAMAC would still not respond. Allan Lane, Rob Patterson and Darren Stafford debugged the encoding systems and the telescope was then driven manually.

By late afternoon we were nearly operational, we just needed CAMAC. To help the reader appreciate this techno-babble we need to explain that the time service supplies the time and date but not the year, which is read from CAMAC. The telescope control system thought that the year was 0000 and the telescope would not point correctly! The work continued on CAMAC signal by signal. Steve Lee modified the control system to hard code the year to 1998. The problem was that the source code is maintained on the VAX and then downloaded for compilation via a serial link. The first attempt at the download revealed that the serial link was also dead, which meant that there was no way to load the modified code.

There was a brief discussion regarding the option of resurrecting a card punch and card reader but the thought of shuffling punched cards again meant the idea was quickly dismissed. The work on CAMAC continued till it became apparent that we would not be able to get...
a system working early enough to usefully observe. Everyone was exhausted, and the night was lost.

The next day Ed Penny and Frank Freeman repaired the serial link, the modified code was transferred and the control computer was running again. The work on CAMAC continued but it was now no longer a show stopper. There was great relief when the telescope slewed under computer control to a correct position. Many other systems were faulty and it felt like every time we switched a system on for the first time we discovered more damage.

Work continued throughout the day and into the night. In the late evening all looked OK to observe when the CCDs were read out: alas, no data. It seemed cruel to have got this far and to still be wiped out. However it was discovered that the serial data links had blown up. Fortunately the recently installed but uncommissioned fibre data links were pressed into service after a frantic search for enough patch leads to get two links going.

Meanwhile 2dF had been reconfigured to run without the CAMAC link to the telescope and other facilities. Observing then recommenced.

The next problem was that 3D was following 2dF, which means that the cass acquisition and guidance facilities were needed. Darren Stafford and Robert Patterson tackled the A&G, which is not the easiest system to work on. The autoguider hardware is very tightly coupled to the control computer, and debugging it can be very time consuming and frustrating. Slowly the system was bought back to life as the pile of dead chips littering the table grew ever larger. Robert Patterson had recently joined the AAO. He had been working in medical electronics and we wondered if he had started to reconsider his career move decision after a few days struggling with the autoguider!

3D went on the telescope with some A&G facilities, with still no sophisticated telescope offsetting available via CAMAC. We cobbled together a system to allow beam switching under hardware control, while the 3D team modified their control system to provide suitable outputs. The observers tailored their program to suit the reduced facilities. Bob Dean, Ed Penny and others continued to track down the CAMAC faults till finally it was working and the full system was available.

Meanwhile the damage to the mains proved to be extensive. The ANU staff set about organising the restoration with the various electrical authorities. You can see the damage done to the pothead which is the interface between the overhead power lines and the cable which leads into the building. The electricity supply authority began the repair. Unfortunately the strike had destroyed not only the pothead, but the high voltage (22,000 volt) cable and the large metering transformer as well. During this period the standby generator ran for the longest period in its long career supplying the load of 360 kilowatts to the mountain top. The reconstruction work was major. Mick Kanonczuk of the ANU, Brendan Jones and Wayne Clarke manufactured and installed a protective cage for the new transformer as well as providing all support possible for the installation team.

Finally, two weeks later, the mains power was ready for restoration and normal service was restored. The diesel was shut down and peace was restored to the mountain top.

On the staff front, Allan Lankshear had taken some well earned leave to have a touring holiday of the UK & Ireland over Christmas. The traditional annual summer migration of staff to Tasmania has continued with trips by Trevor Lindsay, Rhonda Martin & Paul Lindner.

We have had site visits from Bill Smith, vice president of AURA, and a group from ESO visiting for OzPoz discussions took the opportunity to visit the AAT and see 2dF in action.

Various infrastructure projects have been underway at the telescope including the installation of a fibre optic network in readiness for the LAN upgrade to 100 mbs and for CCD data acquisition links. A new single phase UPS has been installed on the 2nd floor to support the IT installation and reduce load on the original UPS system. Significant milestones have been reached on the electronic log, archive and database projects which are described elsewhere in the newsletter.

**EPPING NEWS**

Helen Woods

In a continuation of AAO recruitment we are delighted to welcome three recent recruits, Katrina Sealey, Gabriella Bogatu and Terry Bridges. Every office at the AAO in Epping is now full, with the summer students Ziming and Simon re-shuffled to the computer room and visiting astronomers Sam Barden, Isabelle Baraffe and Gilles Chabrier holding up well in the library.

It was with some sadness that we farewelled two valuable members of staff last week with an outdoor "Rugby Club" lunch. Stuart Lumsden finished his time at the AAO and will shortly begin at Leeds University in the UK; and Daniel Doyle, one of our AAO electricians, left the AAO for the greener pastures of AD Industries in Sydney.
CCD image of NGC908 taken by David Malin & Steve Lee on 22 December 1998 with the MIT/LL2 chip at prime focus with the newly re-coated triplet corrector. The image is (part) of a 5 minute R-band frame. The seeing was about 2".

CROSSWORD COMPETITION

We are pleased to announce that the winner of the crossword competition in the November issue of the newsletter is Dave Hanes, of Queen's University, Kingston, Ontario. Dave wins a David Malin photograph of his choice.

Thanks are due to all those who entered the competition.

Space does not permit the printing of the solution in this issue, but it will appear in the May newsletter.