Anglo-Australian Observatory

Annual Report

of the Anglo-Australian Telescope Board

1 July 1998 to 30 June 1999

The Right Honourable Margaret Beckett, MP,
President of the Board of Trade and Secretary of State for Trade and Industry, Government of the United Kingdom of Great Britain and Northern Ireland

The Honourable Dr David Kemp, MP,
Minister for Education, Training and Youth Affairs
Government of the Commonwealth of Australia

In accordance with Article 8 of the Agreement between the Australian Government and the Government of the United Kingdom to provide for the establishment and operation of an optical telescope at Siding Spring Mountain in the state of New South Wales, I present herewith a report by the Anglo-Australian Telescope Board for the year from 1 July 1998 to 30 June 1999. The report summarises the operations of the Board for the period under review and includes financial statements and statements of estimated expenditure in accordance with the provisions of the Agreement.

J R Mould
Chair
Anglo-Australian Telescope Board
November 1999

Contents

Anglo-Australian Telescope Board

United Kingdom

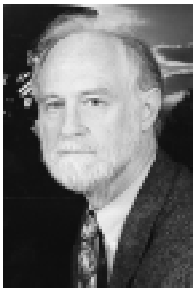
Chair
Prof. R L Davies
Professor of Astronomy, University of Durham

Prof. J A Peacock
Professor of Cosmology, University of Edinburgh

Dr I F Corbett
Director Science and Deputy Chief Executive, Particle Physics and Astronomy Research Council

Australia

Deputy Chair
Prof. J R Mould
Director, Mount Stromlo and Siding Spring Observatories



Prof. R D Ekers
Director, Australia Telescope National Facility

Prof. V R Sara
Chair, Australian Research Council

Anglo-Australian Observatory

Prof. B J Boyle
Director, AAO

Scientific highlights

Weather outside our solar system

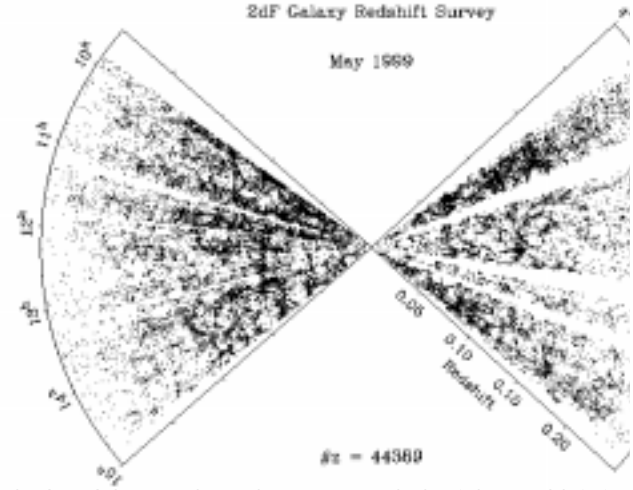
The AAT has been used to discover the first example of weather systems outside out solar system, on a special type of 'failed' star known as a brown dwarf. Although brown dwarfs form in the same way as stars, they share many of the same properties as planets. In particular, they rotate very rapidly, and solids and liquids condense out in their atmospheres. Astronomers, therefore, predicted that they should show weather patterns — just like planets — and obtained the first observations to show that they do.

Quasar Nebula

The Taurus Tunable Filter was used in a variety of innovative science programs throughout the year. One of the most spectacular results was the discovery of an extended cloud of hydrogen gas, 600 000 light years across, surrounding a quasar. This is the largest gaseous nebula seen around a quasar, and provides further information on the interaction between these enigmatic objects and their immediate environment.

Galaxy Redshift Survey

In early 1999, the AAT 2dF redshift survey (GRS) surpassed the Las Campanas redshift survey (26 000 redshifts) as the largest galaxy redshift survey yet compiled. At the end of June 1999, the number of redshifts obtained for the survey stood at over 40 000, well on the way towards the ultimate target of 250 000 redshifts which it is planned to reach in 2000–01. At the same time, the companion quasar redshift survey had measured over 4000 redshifts — 10 times bigger than the previous largest quasar redshift survey to similar depths. When complete, both surveys will provide unprecedented three-dimensional views of our Universe.



This 'cone' diagram shows the progress with the Galaxy Redshift Survey. Each 'ray' represents the galaxies seen along one particular line of sight (i.e. within a single 2dF field). The Milky Way Galaxy is at the centre; radial distance on the plot corresponds to the redshift, which is proportional to the true distance to each galaxy. This diagram is thus a map of all the galaxies observable with 2dF in one slice of the Universe.

Other highlights

Comet Lee

On the night of April 16 1999, AAT night assistant and amateur astronomer Steven Lee discovered a new comet in the southern constellation of Musca. He was attending a star party in Mudgee to give a talk on recent news from the AAO and serendipitously found the comet while searching for a planetary nebula. As the comet's orbit placed it 'behind' the Sun (as seen from the Earth) when it passed perihelion on July 11 1999, the comet did not become bright enough to be seen with the naked eye. Steven thus became one of the inaugural Edgar Wilson Award recipients for amateur discoveries of comets.

LDSS^{++} commissioned

A highly innovative upgrade to one of AAO's instruments was successfully commissioned in October 1998. The enhanced Low Dispersion Survey Spectrograph (LDSS^{++}) was used to carry out observations of faint galaxies in the Hubble Deep Field South, resulting in the spectroscopic identification of the faintest-ever source on the AAT. The upgrade to LDSS has seen a significant resurgence of interest in the use of this instrument.

25 years young

On the 27th April, 1974, the Anglo-Australian Telescope saw first light. A photographic plate was taken to check the polar alignment. This was the culmination of more than fifteen years of international negotiation and ten years of toil and innovation, solving the technical and engineering problems of a new telescope. The result was an instrument that is still recognised for its exceptional optics, the precision of its mounting and the power and flexibility of its computer control system.

The first log book entry for the AAT on 27/28 April 1974 compared to the computerised entry for 27/28 April 1999, 25 years later.

1. About the Anglo-Australian Observatory

Statement of purpose

The Anglo-Australian Observatory provides world-class optical and infrared observing facilities for British and Australian astronomers to ensure the best possible science. It also takes a leading role in the formulation of long-term plans and strategies for astronomy in both countries and, through its research and development of new instrumentation, to the advance of astronomy internationally.

History and governing legislation

The Anglo-Australian Telescope Board is an independent, bi-national authority funded equally by the Governments of Australia and the United Kingdom. The Board operates under *The Anglo-Australian Telescope Agreement* which came into operation in February 1971 for an initial period of 25 years. If either Government wishes to withdraw from the Agreement after this period it must give five years notice. So far, neither party has done so, and both have indicated their support for the AATB for the foreseeable future.

The Board's facilities consist of the 3.9-metre Anglo-Australian Telescope (AAT) and the 1.2-metre UK Schmidt Telescope (UKST) on Siding Spring Mountain, outside Coonabarabran, NSW, and a laboratory in the Sydney suburb of Epping. Collectively, these are known as the Anglo-Australian Observatory (AAO). A brief history of the AAO is given in Appendix H.

Ministers responsible

The Minister responsible for the AAT Board in the United Kingdom is The Right Hon. Margaret Beckett, MP, as President of the Board of Trade and Secretary of State for Trade and Industry. The Minister responsible in Australia is The Hon. Dr David Kemp, MP, Minister for Education, Training and Youth Affairs.

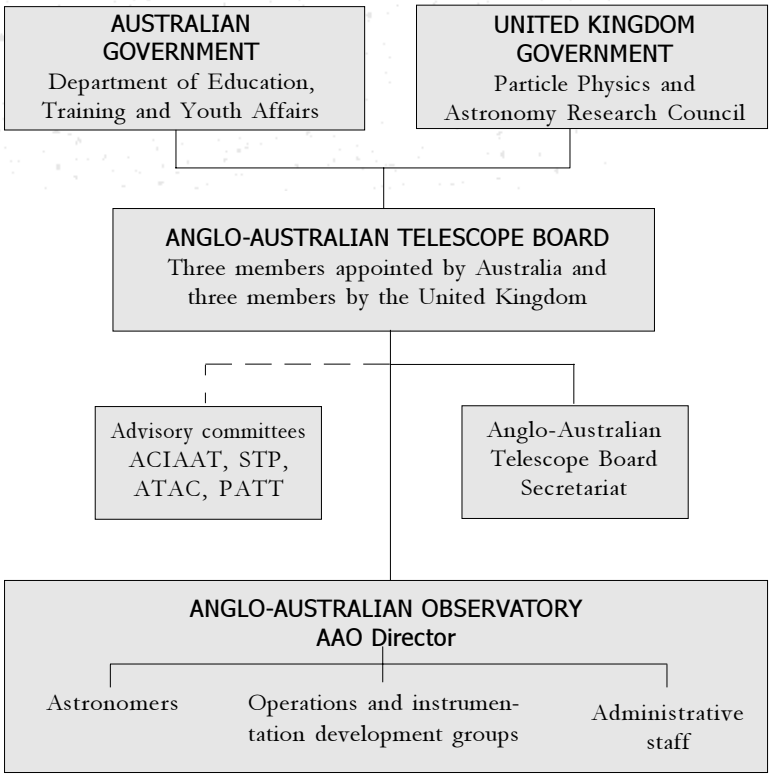
Designated agencies

Pursuant to Article 1(2) of the Anglo-Australian Telescope Agreement, each Government acts through an agency designated for the purpose. These Designated Agencies are the Australian Department of Education, Training and Youth Affairs (DETYA) and the Particle Physics and Astronomy Research Council (PPARC) of the United Kingdom. These agencies are jointly responsible for implementing the Agreement.

Structure of the AAO

The AAT Board oversees the operations of the Anglo-Australian Observatory, as Figure 1.1 shows. Apart from an active research group, the Observatory has internationally recognised optical, mechanical and electronics engineering groups and a specialised software group. These five groups are critical to the maintenance and the day-to-day operations of both the telescopes and to the development of state-of-the-art instrumentation. A small administration group contributes significantly to the effective operation of the Observatory. Details of the internal structure of the AAO are given in Appendix G.

Figure 1.1 General structure of the AAT Board and the AAO



Board members

The AAT Board has six members, three appointed by each country, and the role of Chair alternates between the two countries. At 30 June 1999 the members were:

United Kingdom

Professor R L Davies, (Chair), Professor J A Peacock, Dr I F Corbett

Australia

Professor J R Mould, (Deputy Chair), Professor R D Ekers, Professor V R Sara

Futher details of Board members, special responsibilites and Board meetings are included in Appendix I.

Advisory committees

Two committees advise the Board on aspects of the Observatory's operation. They are: the Advisory Committee on Instrumentation for the AAO (ACIAAT) and the Schmidt Telescope Panel (STP) Details of these committees are included in Appendix I.

Observing time on the AAT is allocated by two national committees: the Australian Time Assignment Committee (ATAC) and the UK Panel for the Allocation of Telescope Time (PATT). Details of these committees are also included in Appendix I.

2. The year in review

Operational environment

Astronomy excites the imagination of scientist and layperson alike and, although it gives no immediate tangible return, it provides an important framework for many of the major ideas that underpin our society. The long-term nature of the scientific questions being investigated demands exceptional intellectual and scientific skills and sophisticated equipment. To be effective, astronomical research requires stable, long term funding.

The British and Australian Governments have demonstrated a substantial commitment to astronomical research by establishing the Anglo-Australian Telescope Board, which has operated the Anglo-Australian Observatory for twenty-five years.

The Observatory provides world-class optical astronomy facilities for scientists from both countries. The telescopes of the AAO have been responsible for many fundamental discoveries and continue to provide a large portion of the data used by astronomers in Australia and the UK. The results of the observing programs carried out using these facilities are published in the scientific and technical media for the benefit of other scientists and the academic community. They are also widely publicised in more accessible places for the general public.

The intellectual challenge of astronomical research attracts some of the finest scientific minds. Astronomy is both international and highly competitive. The AAO maintains strong links with other scientific organisations on astronomical and technical matters, particularly in the development of new instrumentation, and therefore plays a major role in the international astronomical community. AAO staff collaborate on a range of scientific research programs with other astronomers around the world. Through its strong links with the universities in both Australia and the United Kingdom, the Observatory also plays an active role in higher education.

The AAT is the largest optical telescope in Australia and remains one of the world's most scientifically productive telescopes. The UKST is the most productive survey telescope in operation anywhere. Both telescopes were state-of-the-art when observing commenced in the early 1970s. Twenty-five years later, as a consequence of the vision of their designers, a long period of stable funding and a continuing program of enhancements, the telescopes of the AAO remain at the leading edge of astronomical research, against considerable international competition. The Observatory's expert scientific and engineering staff

have constantly upgraded the telescopes by incorporating the latest technological developments into instrument design. Staff are considered world leaders in many areas of astronomical instrumentation and are often asked to provide advice to other organisations and build instruments for their telescopes.

The new generation of telescopes with mirrors eight metres or more in diameter are beginning to come online. These telescopes will be able to carry out many of the scientific programs currently undertaken with the AAT much more efficiently. To ensure a stable future, it is important the AAO demonstrates it can compete effectively with these larger telescopes, concentrating on those programs which the eight-metre-class telescopes will not be able to do, or which are complementary. To this end, Observatory staff have developed facilities that exploit the unique wide-field capabilities of the AAT and the UKST. The Two-degree Field (2dF) facility for the AAT and the Six-degree Field (6dF) for the UKST, are examples of this. As well, developments such LDSS^{++}, IRIS2 and the new ATLAS spectrograph will ensure continued high international profile and scientific productivity for the telescopes well into the next century.

Strategic directions

The AAO is committed to achieving results in five key areas, with the principal aim of obtaining the best possible science for the available resources. The AAO is not exclusively responsible for the scientific results that arise from use of its facilities: external users do most of the research. The AAO nevertheless makes a significant contribution to the quality of the results in the following ways:

First, by running the telescopes efficiently and providing good support during observing runs, the likelihood of good results is maximised.

Darren Stafford, Senior Technical Officer, in the Cassegrain cage of the AAT, working on the acquisition and guiding unit.

Second, by ensuring that the best mix of instrument and software development is undertaken, the Board, the Advisory Committee on Instrumentation for the AAO, the Schmidt Telescope Panel and AAO staff contribute very positively to the kind of science possible with AAO facilities.

Third, by recruiting first-class research astronomers to support visiting astronomers and encouraging and supporting the AAO astronomers in their own research, the Observatory creates a climate which facilitates the best possible scientific output from all astronomers using the AAO's telescopes.

The five key result areas are:
- Telescope operations
- Research
- New instrumentation
- Use of AAO resources
- External communications

The range of strategies adopted to achieve the AAO's objectives fall into two main groups. The first group involves staying in touch with developments in astronomy, instrumentation, telescope operations and management; listening to, and anticipating, the needs of the astronomy community; and publishing and publicising the research and other outcomes achieved. The second group encompasses technical, professional and administrative excellence and an ethos of continuous improvement.

Key result area: telescope operations

Key outcome: satisfied users and good data

Strategies

An important strategy is to listen carefully to the astronomy community, especially the users of the AAO's telescopes, to assess and anticipate their needs. Several avenues are available for this. The time assignment panels, the Advisory Committee on Instrumentation for the AAO, the Schmidt Telescope Panel and the Board, all have a strong influence on the strategic directions of the AAO and are representative of the astronomy community. AAO astronomers and other staff are encouraged to observe at or visit major telescopes overseas and to provide feedback on world best practice. Informal networks and attendance at conferences, seminars and colloquia are also important ways of staying in touch.

A second strategy is to ensure that users' needs are met. This is achieved by maintaining and consolidating existing instrumentation and associated software; by developing first-rate new instrumentation; by providing good support in setting up the instruments, operating the telescope and with observing; and by soliciting users' comments.

The third strategy for achieving satisfied users is to seek ever greater efficiency in running the telescopes. A good example of this has been the highly successful introduction of 2dF in service mode.

AAT organisational statistics

The high standard of the AAO's facilities and new developments in its instrumentation ensure that observing time on the AAT is always heavily over-subscribed. Appendix D shows the large number of institutions from which users compete for AAT time.

AAT performance indicators

The use of observing time for the period 1 July 1998–30 June 1999 is shown in Table 2.1. This year there were 3269 night hours available. In addition, a further 328 hours of twilight and 10 daylight hours were used.

One measure of the extent to which users are likely to be satisfied with the levels of service provided at the AAT is the amount of available observing time lost through AAT equipment failure. In 1998–99, this was 2.3 percent, slightly above the historic average but less than the Coporate goal of three percent. The 2dF facility no longer impacts significantly on downtime statistics. The slightly higher downtime this year was largely due to a catastophic lighting strike which resulted in the loss of one entire night

Table 2.1 Use of observing time on the AAT

	1995–96	1996–97	1997–98	1998–99
	Percentage of total night-time hours			
Observing (incl. commissioning)	59.5	62.8	56.1	55.2
Loss due to weather	37.6	35.0	39.5	42.0
Loss due to AAT equip. failure	1.6	1.6	2.9	2.3
Loss due to other factors	1.3	0.6	1.5	0.5

User feedback

Another constructive way to assess user satisfaction is to ask users how well they regard the level of service offered. Observers at the AAT and UKST complete a form on the worldwide web in which they provide detailed comments on any areas of concern, and fill in a questionnaire which ranks their level of satisfaction with observing support, instrumentation, technical manuals, administration and web pages. These are ranked on a scale of 1 (poor) to 4 (excellent).

During the period 1 July 1998 – 30 June 1999, a total of 38 user feedback forms were completed for the AAT. This represents about 30 percent of all users. The low number of feedback forms could be due to the number of programs clouded-out, and the trend towards longer

observing runs. The Observatory will remind all users of the importance of returning feedback forms.

Two new feedback categories were introduced this year: general computing and library facilities. Table 2.2 shows that the level of user satisfaction is generally very high. Moreover, many categories have shown a steady improvement over the period in which this feedback system has been in place.

Although the UKST is run primarily in a service mode, the small number of survey forms completed by visiting astronomers (two) using the FLAIR system, also indicate a high level of user satisfaction.

The Corporate Plan sets a goal of at least 3 in all categories. This was achieved in all the categories. However, average grades in the category of instrument manuals is at the minimum acceptable level, and a major review of instrumentation manuals is being planned.

Table 2.2 User feedback at the AAT

	Average rank (maximum 4)		
	1996–97	1997–98	1998-99
Night Assistant support	3.8	3.9	3.8
Staff astronomer support before observ.	3.4	3.5	3.5
Staff astronomer support during oberv.	3.7	3.7	3.9
Other technical support	3.7	3.7	3.8
Instrumentation and related software	3.2	3.1	3.2
General computing	-	-	3.2
Working environment	3.1	3.2	3.6
Travel and admin support	3.3	3.6	3.9
Data reduction software	3.0	3.0	3.2
Instrument manuals	2.6	2.9	3.0
Library facilities	-	-	3.3
AAO Web pages	3.1	3.3	3.2

Helen Woods, Personal Assistant to the Director and ATAC Secretary, in her Epping Office.

UK Schmidt Telescope organisational statistics

The UK Schmidt Telescope (UKST) supports a large number of research projects, including long-term photographic surveys. Non-survey photographic requests are undertaken, as are research programmes using the FLAIR multi-object spectroscopy system.

Table 2.3 Comparison of photographic imaging and total FLAIR exposures

	1994–95	1995–96	1996–97	1997–98	1998–99
Plates and films	507	465	485	431	401
FLAIR hours	345	203	272	263	148

Totals of 114 plates and 287 films were obtained during the year, including test exposures. FLAIR observations were made on 45 nights. On 17 of these, photographs were also taken as part of the flexible approach intended to help maximise the overall scientific productivity of the telescope. A total of 148 hours of science data was obtained using FLAIR, which corresponds to about 22 percent of all the observing time used on the UKST.

Table 2.3 shows the annual totals of photographic exposures and hours of FLAIR observation. The fall of both during the reporting year is due partly to poorer-than-usual weather conditions and (for photography) the relatively large number of three-hour H-alpha exposures obtained. However, the principal contributor has been the introduction of a new operating model for the Schmidt Telescope. This was implemented during the second half of 1998 to facilitate operations with a core staff of three observers instead of the previous six. The principal changes are that fewer nights are scheduled per lunation, fewer FLAIR runs are supported, and scheduled weekend processing is eliminated.

Appendix E gives details of the observations undertaken by the Schmidt Telescope during the year.

Technical Officer, Brendan Jones, (left) and Gordon Schafer, Senior Mechanic (right), studying a machine drawing for the construction of the WFI camera .

UK Schmidt Telescope Performance Indicators

The use of scheduled observing time on the UK Schmidt Telescope from 1 July 1998 to 30 June 1999 and in the previous three years is shown in Table 2.4.

It is not unusual for the percentage of night-time hours used to be 10 to 15 percent less than for the AAT, as the Schmidt Telescope is more vulnerable to the prevailing weather, requiring photometric conditions and good seeing to carry out photographic observations.

Table 2.4 Use of observing time on the UKST, 1 July 1995 to 30 June 1999

	1995–96	1996–97	1997–98	1998–99
	Percentage of total night-time hours			
Used for observing	43.5	48.8	47.8	45.0
Lost due to poor observing conditions	56.1	49.4	50.7	54.6
Lost due to equipment faults	0.4	1.8	1.5	0.4

Table 2.4 shows that poor weather has again limited the amount of time available, though not quite as severely as in 1995–96. The three reporting years since then have been characterised by a seasonal pattern with exceptionally good conditions during late summer and autumn. In 1997–98 this was followed by an unusually wet winter, a pattern that has been repeated in the current year, so that the reporting year started and ended with bad weather.

The H-alpha survey of the galactic plane has progressed well, with 122 of the 233 fields now covered to A-grade with with H-alpha/short red pairs. Details are given in Appendix E. Additionally, 57 percent of the 40 fields of the Magellanic Clouds H-alpha survey (included in the non-survey statistics in Appendix E) are complete to A-grade.

Table 2.5 shows that the glass-plate surveys are nearing completion. Both the ER and SES surveys are now complete to B-grade, with all the outstanding A-grade fields being in the RA range 0 h–5 h. A-grade success rates have been low because of cosmetic defects on the raw IIIa-F plates (ER 37 percent; SES 45 percent). During the year, B-grade plates for the near-infrared I survey were examined in detail and it was possible to regrade a substantial number of them to A-grade.

Table 2.5 Current glass-plate survey status

	1996–97	1997–98	1998–99	Total for survey		
	A-grade	A-grade	A-grade	Obtained	Requ'd	Total
Survey						
ER	8	7	3	276	12	288
I	39	4	10	785	109	894
R(SES)	47	22	9	583	23	606

Key result area: research

Key outcome: good science

Strategies

Most research using data from AAO telescopes is undertaken by external users. The time assignment committees, which are peer review panels independent of the AAO, are the most important factor in the achievement of the desired research outcome: their strategy is to ensure that only projects likely to result in good science are awarded time.

The AAO also has an effect on the achievement of this outcome. The first AAO strategy for achieving good science mirrors the first strategy for telescope operations: it is for the research astronomers to keep thoroughly in touch with developments in the astronomy community.

A second strategy is to publish research results and to publicise more broadly the work and achievements of the Observatory. Research astronomers spend about half of their time on research, are encouraged to publish, and have the financial costs of publication met by the Observatory.

Finally, the AAO seeks to keep its research outcomes at the forefront by inviting distinguished visiting scientists to work at the Observatory for extended periods.

Organisational statistics

There were 13 research astronomers on the staff of the AAO in 1998–99. Seven of them, while spending about half of their time on observatory duties such as supporting visiting astronomers, spend the rest of their time on research; one of the seven works part-time. The other six are research astronomers but have significant responsibilities not directly related to their own research. These include the Director, the Head of Instrumentation, the Astronomer in Charge, the Astronomical Photographer and two other staff. The full time equivalent research effort is about six people.

Appendix B lists research papers published from AAT and UKST data during the period 1 July 1998 – 30 June 1999 as well as other papers published by AAO staff. Appendix D presents the AAT observing programs from 1 August 1998 to 31 July 1999. This information, and equivalent information from previous years, is summarised in Tables 2.6 to 2.9.

Table 2.6 Numbers of AAT observing programs and location of Principal Investigator (PI)

	PI at AAO	PI at Aust institution (non AAO)	PI at UK institution (non AAO)	PI else-where	Total	AAO staff on program
1994–95	16	35	45	18	114	33
1995–96	17	26	38	21	102	27
1996–97	25	34	26	17	102	42
1997–98	17	30	35	22	104	31
1998–99	16	24	38	15	93	29

Table 2.7 Research papers published from AAT data in refereed papers and conference proceedings

	First author at AAO	First author at Aust inst. (non AAO)	First author at UK inst. (non AAO)	First author at other inst.	Total
1994–95	18	12	32	14	76
1995–96	17	13	45	34	109
1996–97	12	18	50	21	101
1997–98	15	16	44	25	100
1998–99	24	19	34	38	115

Table 2.8 Research papers published from UK Schmidt data in refereed journals and conference proceedings (excluding papers which make use of UK Schmidt survey data only)

	First author at AAO	First author at Aust inst. (non AAO)	First author at UK inst. (non AAO)	First author at other inst.	Total
1994–95	8	2	9	11	30
1995–96	17	3	22	18	60
1996–97	9	7	13	21	50
1997–98	8	4	24	19	55
1998–99	9	3	13	25	50

Table 2.9 Total numbers of AAO publications in refereed journals and conference proceedings (including papers published by AAO staff, students and visitors)

	AAT papers	UKST papers	Other AAO papers	Total AAO papers*
1994–95	34	12	32	76
1995–96	34	24	26	84
1996–97	30	14	42	85
1997–98	29	18	43	90
1998–99	41	12	48	98

** Total AAO papers does not equal sum of three columns as a few papers contain both UKST and AAT data*

The tables reveal that AAO publication rates show an increasing trend over the five year period. The number of research papers published from AAT data is the highest ever, 115. Each year, AAO scientists are included on between 30 and 40 percent of all AAT observing programs and publications using AAT data.

Table 2.9 gives the number of AAO publications produced by staff, students and visitors. AAO staff consistently produce a large number of high quality publications. This year the number of papers was also the highest ever, 98.

Table 2.10 shows how well AAT observing programs are converted into scientific papers. To allow for the delay between observations and publications, the statistic given here is the number of publications in a given year divided by the number of proposals in the *previous* year. Over the five year period from 1994 to 1999, the average number of papers per program is 0.93.

Table 2.10 Publications per AAT observing program

	Publications per AAT observing program
1994–95	0.73
1995–96	0.96
1996–97	0.99
1997–98	0.96
1998–99	1.00
Average 1994–99	**0.93**

Table 2.11 compares the publication rates in refereed journals for the AAT and UKST with other British Telescopes. Publication numbers for the UKST include survey papers as well as other papers.

Table 2.11 Publications in refereed journals using data from British telescopes (Non AAT data supplied by respective observatories)

	AAT*	UKST	WHT	INT	JKT	UKIRT	JCMT
1993	57	82	55	70	30	72	42
1994	62	66	78	63	44	77	64
1995	89	99	90	81	29	64	67
1996	86	100	100	84	52	82	52
1997	88	125	113	77	35	84	52
1998	93	145	118	72	38	77	72

* *AAT data is shown for financial years, ie 1992–93 etc.*

Key result area: instrumentation

Key outcome: an integrated suite of instruments and telescope controls that best meet, in a timely fashion, the needs of the astronomical community, with the instruments working as well as they need, without being over-engineered.

Strategies

A key strategy in achieving the instrumentation objective is to always remain very much aware of developments in astronomy and instrumentation and of the needs of the astronomy community. The Advisory Committee on Instrumentation for the AAO (ACIAAT) is the mechanism for reviewing the instrumentation needs of the astronomy community and advising on an appropriate development program, bearing in mind AAO staff and financial constraints. Participants in ACIAAT include the AAO Director and Head of Instrumentation, and representatives of both the UK and Australian astronomical communities.

A further two strategies are vital to the implementation of the instrumentation development plan. The first is quality project management. Significant improvements in this area have been made in recent years, with the filling of a specialist Project Manager position, resulting in improved monitoring and tracking for current projects, and improved procedures for the initiation, design review and tracking of future projects. This is supported by the provision of project management training for scientific and engineering staff to assist in their roles.

The second key implementation strategy is involvement at all stages, and at both sites, all of the Observatory's highly innovative and world class astronomers, engineers, software specialists and technicians. This includes conception, design, construction and commissioning of instruments.

Organisational statistics

The AAO spends about 15.6 percent of its budget each year on new instruments and associated software and detectors. Table 2.12 summarises the use made of instruments on the AAT over the last few years. It does not include time used for aluminising the primary mirror, or Director's or Service time, or time dedicated to instrument development.

In the second full year of its operation, the Two-degree Field (2dF) facility has continued to be both highly in demand and highly allocated. Demand for the UCLES spectrograph has continued to increase. Allocations for the Taurus II imager are down somewhat on the previous year, though demand continues to remain high (principally for the AAO's innovative Taurus Tunable Filter).

The RGO spectrograph continues to be requested at a modest level, though considerably down on its levels of 1995–96, reflecting the increased competition from 2dF — though its use for polarimetric applications continues at a steady level. During the year the Board approved a design study for a new spectograph, ATLAS.

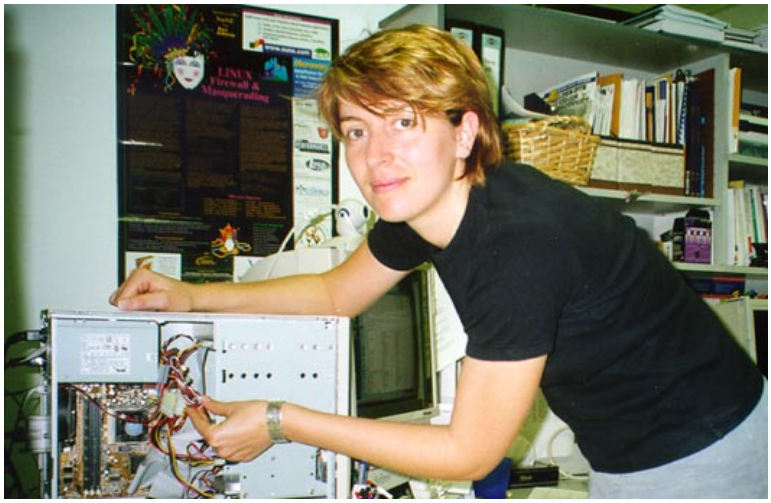
The infrared 3D integral field spectrograph has continued to be offered to users in 1998–99, under an agreement with the Max Planck Institut für Extraterrestrische Physik. This has resulted in considerably decreased use of the IRIS instrument, with the combined use of infrared instruments down somewhat on earlier years, as demand for the UCLES spectrograph increases.

An upgrade of the LDSS instrument in 1998–99 has resulted in increased demand for this instrument in the last twelve months, with further increases in its demand expected in the next few years.

Detector use in recent years is outlined in Table 2.13. Charge coupled devices (CCDs) remain the astronomical detector of choice. A further new CCD system (MITLL3) was brought into regular use during the year, alongside the Tek2 and MITLL2 CCDs already generally available (2dF users have no choice and must use the Tek detectors mounted in the 2dF instrument). The MITLL2 and MITLL3 CCDs have a significantly larger format (2048 × 4096 pixels) than the Tek2 device (1024 ×1024 pixels) and have proved extremely popular. Indeed use of the MITLL2 device now almost equals that of the Tek2. It is expected that the MITLL2 will become the Observatory's 'workhorse' for the next few years, with the Tek2 and MITLL3 being used only for specific niche projects.

Performance indicators

The instrumentation program is largely shaped by the advice given to the AAT Board by ACIAAT and the STP. The two committees consist of experienced representatives of the user communities who are



Katrina Tapia-Sealey provides system support at Epping.

responsible for ensuring that the agreed program does indeed meet the needs of the astronomical community. The best way to judge this after the event is to survey telescope users as to their satisfaction with the suite of instruments and the way the instruments, software and detectors perform. As mentioned above, this information is compiled from the user feedback survey responses. The level of user satisfaction with instrumentation and related software (a mean rank of 3.5 for this year) shows that the AAO is meeting its performance indicators as outlined in the corporate plan.

Table 2.12 Use of AAT instruments for the last four years

	Percentage of nights allocated			
Instrument	1995–96	1996–97	1997–98	1998–99
2dF	-	-	22.2†	33.5
RGO Spectrograph (including FORS)	24.3	23.6	7.3	10.8
RGO Spectrograph with polarimeter	6.9	6.5	7.0	0.0
Low dispersion survey spectrograph (LDSS)	5.8	2.7	1.0	2.9
UCL coudé echelle spectrograph (UCLES)	12.7	12.9	18.7	25.5
Ultra high resolution facility (UHRF)	3.1	6.5	3.2	1.8
Taurus II	5.8	13.3	17.5	9.3#
Infrared imager/spectrograph (IRIS)	21.7*	22.4	7.3	2.2
Prime focus imaging with CCD	8.9	5.3	2.5	0.0
Prime focus photography	1.2	1.5	0.0	0.0
3D	-	-	13.3	10.5
Instruments supplied by users	6.4	5.3	1.9	3.5

† *2dF regularly scheduled for the first time in 1997–98*
* *Includes UNSWIRF from 1995–96 onwards*
\# *Includes Faint Object Polarimeter from 1998–99 onwards*

Table 2.13 Use of AAT detectors for the last four years

		Percentage of nights allocated			
Detector		1995–96	1996–97	1997–98	1998–99
CCDs	Tek2	67.5	72.6	31.1	15.5
	2dF	-	-	22.2	33.5
	MITLL2	-	-	26.1	36.7
	MITLL3	-	-	-	0.0‡
Infrared	IRIS	23.8	22.4	7.3	2.2
	3D	-	-	13.3	10.5
Photographic plates		1.2	1.2	0.0	0.0
Detectors supplied by users		6.7	6.7	0.0	1.6

‡ *MITLL3 was commissioned and used in 1998–99 in Director's time, though no time was awarded for its use through the normal allocation process*

Key result area: AAO resources

Key outcome: AAO funds to be used optimally and to have stimulated, productive, creative and focused staff working in a safe environment.

Strategies

Perhaps the best strategy for achieving this objective is the involvement of all staff in corporate planning and other reviews. Their involvement means that many different perspectives can be taken into account, leading to a more rounded approach. It also means that everyone understands the final outcome of such a process and feels more commitment to, and ownership of, the results than would otherwise be the case.

The Observatory is committed to equal employment opportunity and occupational health and safety best practices as a way of meeting its objective of stimulated, productive, creative and focused staff working in an environment in which they feel secure. Training in these concepts and practices is a well-established part of AAO life.

Organisational statistics (People)

Staff numbers

The AAO employs research scientists, technical staff, software engineers, electronics engineers, optical and mechanical engineers, administrative and library staff. There are 6 fixed-term research astronomers, one part-time, and 18 other fixed-term staff members, including the Director; two of these are part-time. The rest, 45 in all, are on indefinite term appointments. Staff members are located at both the Epping Laboratory and at Siding Spring Observatory. Table 2.14 and figure 2.1 show staff numbers by tenure and by functional area and gender.

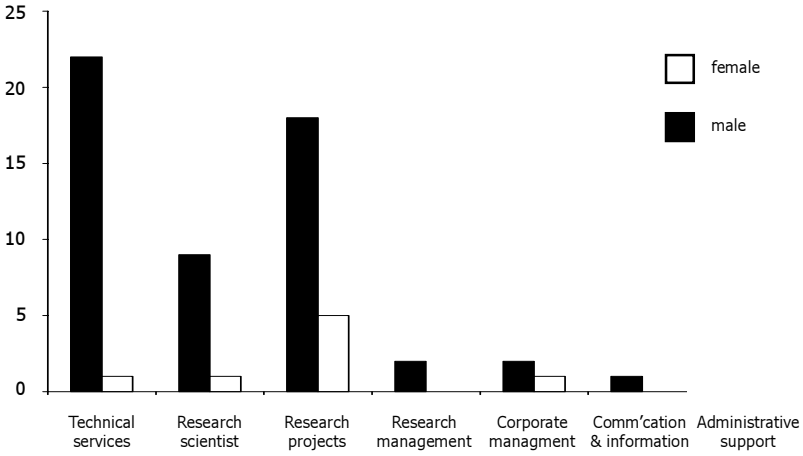
Robert Patterson, Electronics Technical Officer, working on the AAT's aquisition and guiding unit.

Table 2.14 Staff numbers by tenure

At 30 June 1999 the staff positions were:

	Full time	Part time
Director	1	
Fixed term research	4	
Other fixed-term	15	2 (1.42 FTE)
AAO/2dF Fellow	1	1 (0.60 FTE)
Indefinite	45	
Total	66	3 (2.02 FTE)

Figure 2.1 Staff numbers by functional area and gender



Staff turnover

Table 2.15 shows the turnover rates for the year 1998–99 and figure 2.2 the trends.

Table 2.15 Staff turnover 1998–1999

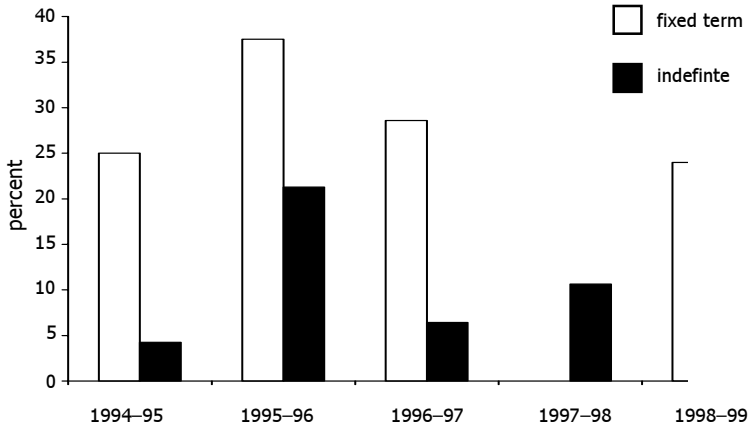
	Fixed Term			Indefinite			Grand
	Female	Male	Total	Female	Male	Total	Total
Staff At 1 July 1998	3	22	25	11	35	46	71
Staff at 30 June 1999	4	20	24	10	35	45	69
Resignations	2	4	6	2	1	3	9
Retirements	0	0	0	0	2	2	2
Total Departures	**2**	**4**	**6**	**2**	**3**	**5**	**11**
Turnover rate for year (%)	66.7	18.2	24.0	18.2	8.6	10.9	15.5
Appointments	2	3	5	0	3	3	8

Performance indicators (people)

Equal employment opportunity (EEO)

The *Equal Employment Opportunity (Commonwealth Authorities) Act 1987* requires the Board to develop an EEO program for each of the four designated groups identified within the Act. The Board reports annually to the Minister for Education, Training and Youth Affairs.

Figure 2.2 Trends in staff turnover



As table 2.15 and figure 2.1 reveal only a fifth of the Observatory's staff is female. This is a decrease on earlier years. Most of the women are in the administrative or research projects area.

There may well be valid reasons for such an employment profile. However, the AAO is keen to ensure that bias is not present in the recruitment process. The recruitment process has been overhauled in recent years and a senior staff member, with extensive experience in recruitment and equal employment opportunity, is involved in all recruitment exercises.

In spite of all efforts, the outcome has been mixed. The Observatory still finds it difficult to attract female applicants for its mainly technical jobs. There are many applications from people who are from ethnic minorities, often newly arrived in Australia. Considerable effort has been put into explaining to applicants how to demonstrate that they meet the selection criteria and this has resulted in fewer inappropriate applications. A pleasing outcome has been that several recent recruits are from non-English speaking backgrounds.

Occupational health and safety

The Anglo-Australian Telescope Board's safety policy and its agreement on health and safety with the Community and Public Sector Union are set out in Appendix G. The Observatory embarked upon a more strategic approach to occupational health and safety about three years ago. The focus for 1998–99 was emergency procedures and manual handling. Evacuation procedures at Epping were overhauled and all staff received training. A rolling program to identify and fix manual handling problems is in progress; the program involves training in manual handling for all staff.

Comcare is a statutory authority established to administer the *Commonwealth Employee's Rehabilitation and Compensation Act 1988*. The premium the Board has to pay is a function of staff numbers and claims history. As table 2.16 shows, both the premium and

compensation claims have fallen significantly in recent times; the premium for 1999–2000 has been set at $19 200. As well, there have been no notifications of dangerous occurrences for the last two years.

Table 2.16 Worker's compenstation and dangerous occurrences

	1994–95	1995–96	1996–97	1997–98	1998–99
Comcare premium	$27 748	$34 000	$31 431	$27 543	$28 770
No of claims	2	4	4	0	0
Payments made	$66 488	$31 119	$3 578	0	0
Dangerous occurrences	1	1	1	0	0

Organisational statistics (Financial)

The financial statements in Appendix A outline the AAO's financial position.

Performance indicators (Financial)

The Australian National Audit Office (ANAO) has audited the financial statements of the AATB and has found them to be acceptable. ANAO also assesses organisation it audits on the basis of the professionalism with which the financial statements and supporting documentation have been prepared. The AAO has markedly improved its ranking in recent years.

Key result area: external communications

Key outcomes: a lively awareness of astronomy in general, and the AAO's role in particular, by all stakeholders.

The AAO is aware that good two-way communication is central to all its activities. While it must listen to its stakeholders, it must also communicate to the wider community. The stakeholders are the AAO staff, the astronomy community, responsible Ministers, funding agencies, the Board and its advisory committees and the time assignment panels. The community includes the general public, hence the broad term 'Public Relations.'

World Wide Web

Access to the AAO WWW site is carefully monitored (see http://aaossi.aao.gov.au/AAO/stats/www1999/index.html) and continues to grow rapidly. During 1998–99, the average monthly hit rate was well over 600 000 hits per month, consistently scoring over 650 000 hits per month during the early part of the calendar year. These figures are 50 percent higher than for the 1997–98 year and do not include hits from the Cambridge (UK) mirror of the AAO site. As in previous

years, about three quarters of the hits were attracted by the images pages, which have recently been further expanded and enhanced.

Public relations

Photographic exhibitions

Two new versions of 'Night Skies' opened in China and two opened in India during the year. One of the Chinese exhibitions was staged at the prestigious Beijing Ancient Observatory and it accompanied a visit to China by British Prime Minister Tony Blair, who inaugurated the show. The exhibition itself was advertised to the passing traffic by a 7 × 9 m mural of the Horsehead nebula and was apparently a great success. We are very grateful to the British Council for facilitating these events.

Talks and lectures

Many AAO staff frequently give talks to schools and general audiences as well as talks to the science community. The number of general talks continued to be high during the year see (table 2.17). The Annual Bok lecture attracted a large audience in Coonabarabran. The lecture 'Great moments in science' was given by Dr. Karl Kruszelnicki.

Festival of the stars

The AAO was keenly involved in the inaugural Warrumbungle Festival of the Stars. This event, organised over ten days, involved astronomy events as well as arts activities. The AAO contributed through the Astrofest, Siding Spring Open Day, Bok lecture and an observatory float in the street parade. The Observatory used these events to promote its work and to remind people of the importance of dark skies around Coonabarabran.

Media relations

The AAO uses the media to inform the community about astronomy and the observatory's work wherever possible, and many staff are actively sought for interviews and opinions. There was a large increase in the number of media interviews given throughout the year (see table 2.17). This reflects the AAO's standing and high profile in the

AAO astronomer David Malin shows British Prime Minister, Tony Blair, and his wife Cherie, through the 'Night Skies' exhibition at Beijing Ancient Observatory.

media. Good coverage of AAO research resulted from the eight media releases circulated during the year.

General inquiries

AAO staff responds to thousands of e-mail and telephone inquiries each year, another reflection of manifestation of the Observatory's public profile as an accessible and responsive organisation. These contacts are another important way of publicising the AAO's work.

Use of AAO images

The www attracts a wide range of interest groups, resulting in a large number of image-related enquiries. A significant, and probably roughly constant fraction of these turn into serious queries for the use of our images, so these have also increased in the last year. However, overall income from images (see table 2.17) has decreased, largely because the print sales generated by the very successful 'Night Skies' and associated exhibitions of 1997–98 has declined.

The use of AAO images continues to be wide spread. As well as continuing to be popular for books, other uses are increasing, for example use on websites and in advertising.

Conferences and symposia

The AAO plays a full role in organising and participating in conferences. These conferences provide the opportunity for staff to present results from the Observatory's telescopes and recent technical developments, and are essential in maintaining strong links with the international astronomical community.

Table 2.17 External communication organisational statistics

	1996–97	1997–98	1998–99
'Popular' Talks	48	95	89
Media Interviews	52	83	152
Revenue from sales of images	$136 000	$193 000	$158 000
Science/Technical Colloquia	111	72	77
Review panels	20	20	18
Organising committees	8	12	14

3. Scientific research

Introduction

This chapter highlights some of the research programmes carried out using the 3.9-metre Anglo-Australian Telescope (AAT) and the 1.2-metre UK Schmidt telescope (UKST) during the period from July 1998 to June 1999. A summary of research activities of AAO staff is given in Appendix F.

The AAT is a powerful and versatile telescope which is equipped with a wide range of instrumentation for observations in the optical and near-infrared. Astronomers use the AAT to study a wide range of astronomical topics: from solar system objects to stars and the interstellar medium in our Galaxy and neighbouring galaxies, through to cosmological studies of the most distant galaxies and galaxy clusters in the Universe. Appendix C lists the projects allocated AAT time during the year. Each year, about one hundred different observing programs are awarded time on the AAT.

Appendix E gives a breakdown of the time allocated to the UKST. The UKST is mainly used for systematic surveys of the southern sky. Red and and near-infrared surveys of the southern sky are close to completion while a new survey for hot hydrogen gas in the Milky Way, using a special narrow-band H-alpha filter, is half done. The resulting atlases and their digitised versions, produced using plate scanning machines, provide one of the fundamental tools used by astronomers.

Appendix A gives a list of publications for 1998–1999. Tables giving publication and proposal statistics are given in Chapter 2. Typically 90 percent of all projects involve Australian or British astronomers, while 45 percent involved collaborations with astronomers from many other countries. On average, each observing program at the AAT results in about one publication.

Galactic Astronomy Highlights

Brown Dwarf Weather

The last two years have seen an explosion in the discovery of brown dwarfs — the 'failed stars' which lie beyond the stellar main sequence. These are objects formed in the same way as stars, but which do not have sufficient mass to ignite the nuclear reactions which power stars. As a result, they fade and cool and share many properties with giant planets.

Just how many properties they share has become clear in recent years, as astronmers have found that brown dwarfs are not only cool, but (like planets) are cold enough that solids and liquids can condense out of their atmospheres to form clouds. Moreover, brown dwarfs are also being found to spin extremely rapidly, with indicated rotation periods of between three to ten hours (for comparison Jupiter has a rotation period of nine and a half hours). This means that brown dwarfs have properties suggesting that they, like planets, should exhibit weather patterns.

Tinney (AAO) and Tolley (Oxford) have successfully carried out the first attempt to measure the effects of weather in brown dwarfs using an innovative time-series tuneable filter technique on the AAT. They configured the Taurus Tunable Filter to continuously monitor the strength of titanium oxide (TiO) absorption in the brown dwarf LP944–20. This molecule is expected to respond sensitively to the small changes in local temperature and pressure, which would be expected on the brown dwarf as a result of weather patterns. They were able to show that LP944–20 is indeed not stable in this TiO feature. This result marks a significant development as it institutes a new field in astronomical research — astro-meteorology of brown dwarfs. Such research will have a significant role to play in developing understanding of extra-solar planetary systems, because while planets are now being discovered, their properties cannot be studied in detail, because of the glare of their parent star. Brown dwarfs, however, can be observed in splendid isolation, and because they share many properties with planets, can be used to develop our understanding of these exciting new systems.

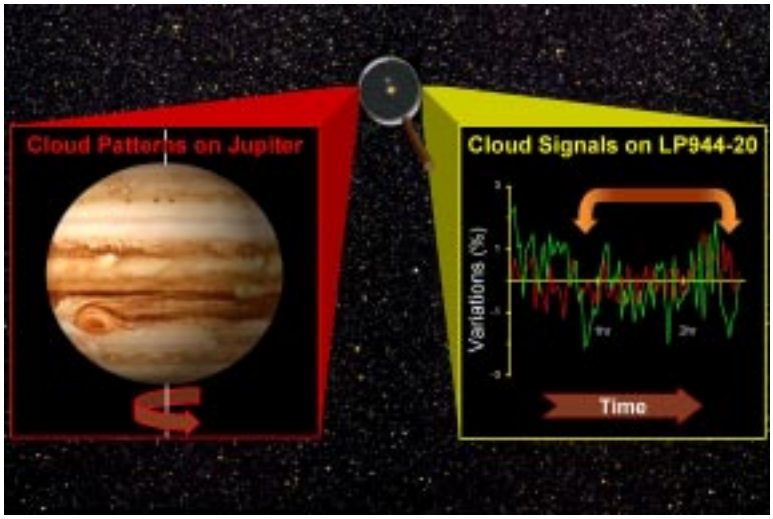


Figure 3.1 The left panel shows the weather patterns we might expect on a brown dwarf if it looked like Jupiter. The right panel shows observed variations seen as the brown dwarf LP944-20 rotates. The arrows highlight strong episodes of cloud passage where very different signals are seen in the two colours observed.

Lithium in the most metal-poor stars

The small amounts of lithium (Li) created in the Big Bang provide an important constraint on the matter density of the Universe. Ryan (RGO/Open University), Norris (RSAA), and Beers (Michigan) have determined lithium abundances for 23 very metal-poor field main sequence stars, restricted to very narrow ranges in effective temperature and metallicity. These data aim to accurately determine the spread of lithium abundances at the earliest times in our Galaxy, and hence constrain the amount of lithium which emerged from the Big Bang. The temperatures of these stars are in the range 6200–6400 K, and their metallicities are less than 1/300th that of the Sun. Two decades ago the French astronomers Monique and Francois Spite discovered that metal-poor halo stars in this temperature range had an almost constant lithium abundance as a function of the stars' temperatures — the 'Spite Plateau.' They postulated that the plateau value is the lithium abundance which resulted from the Big Bang.

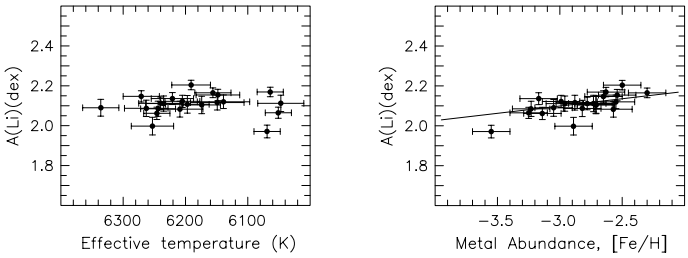


Figure 3.2 The abundance of lithium, A(Li) (= log(N(Li)/N(H)) + 12.00), as a function of stellar temperature and metallicity [Fe/H], for 23 very metal-poor stars.

Of the 23 stars observed, 21 have Li abundances, A(Li), which are very tightly clustered, with a dispersion of only 0.030 dex (abundances varying by 7 percent) as is shown in figure 3.2. This compares with previous determinations of 0.06–0.08 dex (15–20 percent). The observed dispersion is comparable to the errors of measurement, suggesting that the Spite Plateau is very narrow in this temperature range. This is a surprising result, given that several mechanisms for Li destruction *and* formation are known to operate in both stars and the interstellar medium. It is quite impressive that 12 billion years after their creation, the Li dispersion in these stars is still so small. The essentially zero intrinsic spread leads to the conclusion that either they have all changed their surface Li abundances uniformly, or else they exhibit close to the cosmological primordial abundance, with the latter explanation being more probable.

The plane also seems to slope to lower Li abundance with decreasing stellar metallicity, as may be seen in the figure, where the slope is staistically significant. This leads the authors to argue that the primordial Li abundance is given by A(Li) = 2.00, a little smaller than generally accepted. When compared with the predictions of Big Bang Nucleosynthesis, the result is consistent with the baryon density

inferred from primordial helium, and primordial deuterium values intermediate between the recently reported 'high' and 'low' values.

Spectro-astrometry of binary stars

Conventionally astronomical telescopes are limited in the resolution, or detail that can be discerned in an image, by the turbulence in the earth's atmosphere (known as 'seeing'). The best images with the AAT, typically, have a resolution of about one second of arc. A new technique pioneered at the AAT by Bailey (AAO), allows information on the structure of astronomical sources to be studied on much smaller scales, in some cases down to one thousandth of a second of arc.

The technique, known as spectro-astrometry, works by recording how the position of a source varies with the wavelength of the light emitted. Take for example, the case of a binary star which is too close to be resolved by conventional techniques. The position of the centroid of the two stars will be slightly different in a spectral line present in only one of the two components than it will at wavelengths either side. These small differences in position between wavelengths can be measured to very high accuracy. The observations are made using standard observatory equipment, the RGO spectrograph, and a CCD detector.

Bailey (AAO) has found the spectro-astrometry method to be very effective in studying pre-main-sequence stars, newly formed stars in the early stages of their evolution. These studies have shown the technique to be effective in detecting close binary companions and led to the discovery that the variable star T CrA was a previously unknown binary (see figure 3.3). The technique also provides information on the jets and outflows which are observed from some of these stars. Bailey (AAO), Robinson, Hough (Herts) and Ward (Leicester) have also used the spectro-astrometry technique to study the narrow-line regions of Seyfert galaxies.

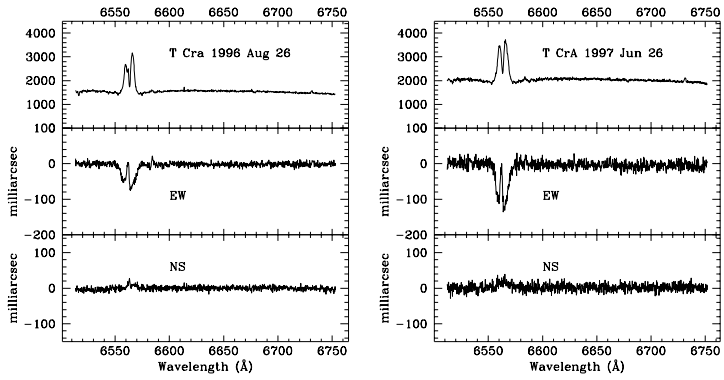


Figure 3.3 Spectro-astrometry data on T CrA taken on 1996 August 26 and 1997 June 26. The upper panel of each plot is the intensity spectrum. The lower panels show the position spectrum in the east-west and north-south directions. The change in the E–W direction in the strong H-alpha line, a shift of about 50 milliarcsec, reveals the star to be a binary.

Mapping the Structure of H II regions.

Ionised regions of interstellar gas, known as H II regions, are key tracers of star formation in our galaxy. Priestley and Hoare (Leeds) have used Taurus II on the AAT to map the velocity structure of H II regions. This classic problem is being revisited in light of the great interest in understanding the dynamics of the much younger ultra-compact class of H II regions. These have turned up in large numbers with a large proportion showing cometary morphologies. This has prompted the development of several new dynamical models. These invoke phenomena like stellar wind bow-shocks and mass-loaded flows, as well as a re-assessment of the existing models of H II region expansion into an asymmetric environment ('champagne' models). An understanding of the evolution of these objects has important repercussions for sequential star formation and the overall efficiency of the process.

The AAT was used to determine the velocity structure of five evolved H II regions. Most showed well-defined global velocity structures, which reveal an underlying cometary morphology. In particular, they show velocity gradients indicating gas accelerating into the tail of the cometary objects, which is consistent with the 'champagne' models. Priestley, as part of her PhD thesis, has developed a new hydrodynamic model which allows H II regions to expand into an exponential density gradient and compared the predictions with the observed velocity structures. Carbon monoxide velocities are used to fix the ambient cloud velocity and the agreement between the model and the observations is impressive. Moreover, the observations of these evolved H II regions together with previous data on ultra-compact H II regions show a good correlation between the velocity gradient in the tail and the size of the H II region. This relationship is very well explained by the new hydrodynamic models (see figure 3.4).

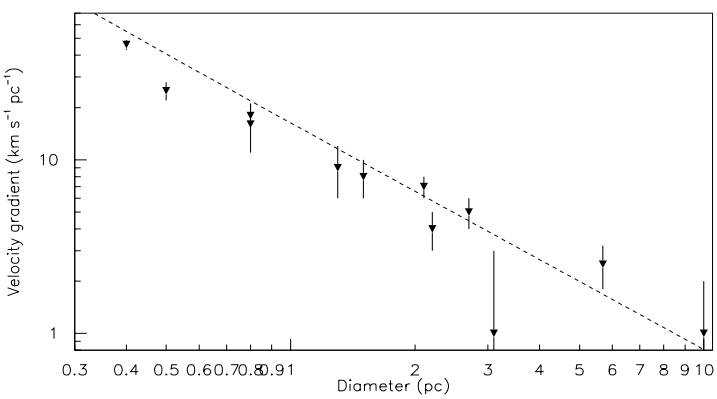


Figure 3.4 Absolute velocity gradient in the tails of cometary compact (ie < 1 pc) and evolved H II regions as a function of their size. The dashed line shows the predicted velocity gradients from a new champagne model where the H II region is expanding into an exponential density gradient.

Motions near the head of these regions are not satisfactorily explained as yet, although the effect of a stellar wind may well play a role. However, it appears that massive stars forming in a global density gradient can indeed explain most of the dynamics of H II regions.

Extragalactic astronomy highlights

AGN central engines

Astronomers have spent many years trying to gain physical insights into the mechanisms which power active galactic nuclei (AGN) and quasars. New instrumentation at the AAT, such as 3D and the Taurus Tunable Filter (TTF), have allowed astronomers to make observations which provide further clues to the nature of these objects.

The 3D instrument is a state-of-the-art imaging infrared spectrometer offering high spatial resolution. As such, it allows astronomers to study the inner regions of the nearest active galaxies and quasars. 3D was built by astronomers at Max Planck Institut für Extraterrestrische Physik (MPE) and has been operated at the AAO during the past two years as part of a joint AAO/MPE agreement. Astronomers from MPE (Tacconi-Garman, Gallimore, Sosa-Brito, Lehnert) have used 3D to carry out imaging spectroscopy of a sample of nine active galactic nuclei at the infrared wavelengths of 1.6 and 2.2 microns.

Initial results from this sample are somewhat surprising. In a large number of cases (perhaps the majority) the near infrared emission from the central roughly 100 pc is dominated by stellar features. In addition, the majority of the sources show relatively blue continua, lacking in strong continuum emission from hot dust which might be expected in the central regions of active galactic nuclei (AGN). This is shown in figure 3.5, where spectra from the Seyfert 1 galaxy NGC 1566 (left) and the Seyfert 2 galaxy NGC 1672 (right) show deep stellar absorption features in their spectra.

These observations indicate that stellar light does indeed make a significant contribution to the optical/infrared output from AGN. In some cases this light may even dominate the output from processes occurring nearer to the central black hole.

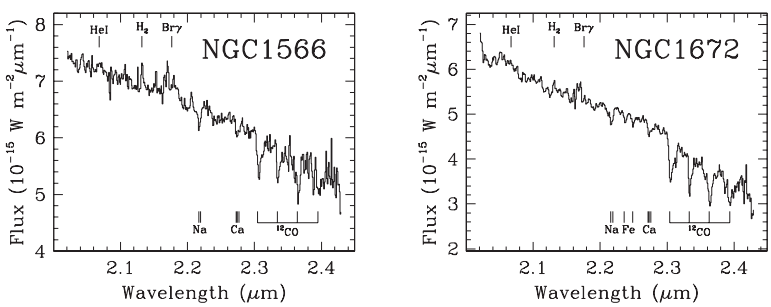


Figure 3.5 3D infrared spectra of the central regions of the Seyfert 1 galaxy NGC1566 (left) and Seyfert 2 galaxy NGC1672 (right).

A QSO nebula

Observations of the galaxies in which quasars reside (the 'host' galaxy) can provide important constraints on the mechanism whereby quasars are triggered and fuelled. Shopbell (Maryland) and Bland-Hawthorn (AAO) have used TTF to carry out an imaging survey in the hydrogen alpha light of the galaxies surrounding quasars and AGN.

The TTF is extremely well-suited to this project; a 40-minute observation reaches more than an order of magnitude deeper than previously published conventional narrowband images.

One object in particular, MR 2251–178, has provided a spectacular result. In this case the data reveal a central, relatively compact (20 kpc) extended emission line region (EELR), embedded within a spiral complex of knots and filaments that extends more or less symmetrically over ~200 kpc (see figure 3.6). This is the largest known quasar nebula. The total mass of ionized gas is at least 60 billion solar masses, a large fraction of which is in a very faint, diffuse component. Comparison of the imagery at each of two distinct velocities reveals a broad gradient across the quasar nebula, along a position angle of about 40 degrees. These kinematics are well-organized on a large scale, yet appear in an opposite sense to the rotation of the inner regions of the quasar host galaxy.

The large and symmetric extent of the gaseous envelope, as well as its markedly different morphology in H-alpha (ionized gas) and broadband (stellar) imagery, favours a model in which the filamentary and diffuse emission arises from a large cloud complex, photoionized by the bright quasar. This is in agreement with several spectroscopic studies of quasar

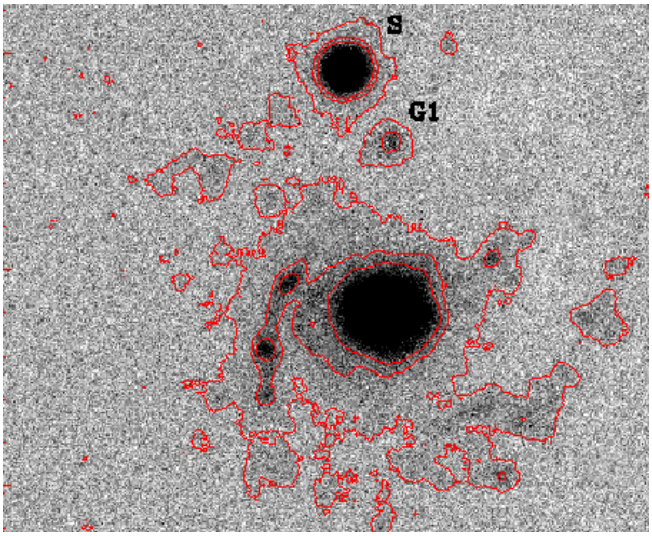


Figure 3.6 A deep H-alpha image of the field surrounding the quasar MR 2251–178. The 3-arcminute field centred on the quasar represents a 2400 second exposure with the TTF, revealing emission extending over more than 200kpc. G1 is an unassociated background galaxy and S is a foreground star.

nebulae. However, in contrast to current models, this crude kinematic analysis does not support a creation scenario for the nebula based upon an interaction or merger with another galaxy.

It is possible that significant quantities of ionized gas may be present around luminous quasars, but have remained undetected with standard narrowband imaging techniques. The TTF promises to improve this situation greatly, as observations of MR2251–178 demonstrate.

Star forming galaxies at high redshifts

The detailed study of star-forming galaxies at moderate redshifts perhaps marks the next frontier in developing our understanding of galaxy evolution. Large surveys of field and cluster galaxies have pointed to a global increase in star-formation activity out to redshifts $z = 1$, where it may level off, or even decline. This increasing importance of star-forming galaxies in the high-redshift universe may be related to the wider issue of structure formation, perhaps triggered by mergers or interactions between galaxies. The whole pattern of star formation bears intriguing similarities to the rise and fall of quasars over similar redshifts, raising the question whether all these evolutionary processes are linked.

Baker (MRAO), Bremer (Bristol), Hunstead (Sydney) and Bland-Hawthorn (AAO) are carrying out an extensive survey of the environments of radio quasars at $0.7 < z < 1.2$, a range where sharp changes in quasar environments were predicted and where few clusters are currently known. By using quasars as pointers to overdense regions at high redshift, they aim to find and characterise distant clusters.

A crucial part of this work has been to use the unique capabilities of the TTF to identify line-emitting galaxies in fields of quasars by imaging in the wavelength region corresponding to the redshifted [OII]3727 emission line at $z = 1$ in the fields of quasars.

Using this technique, Baker and her colleagues have successfully detected emission-line galaxies with TTF near five quasars from the Molonglo Quasar Sample (MQS) with $0.7 < z < 1.2$. In one field, they have obtained spectroscopy which confirms that at least five out of ten of the strongest candidates (star-formation rates greater than ten solar masses per year) are indeed at the quasar redshift (in this case $z = 0.9$). In this field, the number of line-emitting galaxies corresponds to an overdensity several tens of times greater than the expected number of field galaxies at that redshift.

In general, the emission-line candidates are spread across the field of view of TTF, but in several cases they find sub-groups, which are offset from the quasar by hundreds of kpc and may be falling towards a cluster centre. Therefore in general, excesses of line-emitting galaxies are found near quasars, with evidence for ongoing cluster formation by the accretion of groups of star-forming galaxies. Future observations with TTF will expand the number of systems and star-forming galaxies known at $z \approx 1$ and beyond.

Gravitational Lensing

Gravitational lenses are a powerful cosmological tool for studying distant objects and mapping-out dark matter.

Hewett (IoA) and Warren (ICSTM) et al are using a combination of both AAO telescopes and two new instruments in a novel approach to the problem of identifying a significant number of strong gravitational lenses. Instead of searching many tens of thousands of sources for evidence that a particular object is gravitationally lensed, the project relies on first identifying lines-of-sight where lensing is expected to be highly probable.

Massive early-type galaxies are responsible for the bulk of gravitational lensing due to the galaxy population — spiral and other late-type galaxies are not very effective lenses. The distinctive colours of early-type galaxies allows the most luminous and massive examples of such systems to be identified at moderate redshift $0.3 < z < 0.6$ using automated photographic measuring scans of UKST plates and films.

A single Schmidt plate produces typically 1500 such galaxies. However, the low surface density, 50 per square degree, means that wide field spectroscopy is required for efficient investigation of the spectra of the population. The three square degree field of the 2dF facility is ideal. Spectra of some 250 galaxies can be obtained in a single night. If a background source is gravitationally lensed by one of the galaxies and possesses an emission line, the result is a 'composite' spectrum, consisting of a normal early-type galaxy with an emission line appearing at an unusual wavelength. An automated search for emission lines in odd places provides the gravitational lens candidate list. The initial candidate identified from AAT spectra turned out to be the first optical Einstein ring, with a distant star-forming object at $z = 3.59$ lensed by a galaxy at $z = 0.49$, and represents the first confirmed example of a galaxy lensing another galaxy.

Prior to TTF, follow-up of a candidate required the acquisition of a custom-made, narrow-band filter to obtain an image at the wavelength of the emission line. TTF provides the facility to image in narrow passbands (10 Å) at essentially arbitrary wavelengths within the optical range. The first TTF observation of a candidate system confirmed the effectiveness of the approach. Emission at the wavelength of 5800 Å was confirmed with the strongest feature appearing some two arcseconds from the centre of a galaxy. The object is almost certainly a second example of a star-forming object, with redshift $z = 3.77$, lensed by an early type galaxy, redshift $z = 0.52$.

The combination of the UKST-derived sample coupled with 2dF and TTF observations reflects the effectiveness of the AAO's telescopes. It also offers the prospect of compiling a large sample of resolved gravitational lenses that will provide unique information on the nature of high-redshift star-forming objects and on the masses and evolution of early-type galaxies.

The Hubble Deep Field

One of the most successful astronomical observations of the past decade was the deep image of the distant Universe made in December 1995 by the Hubble Space Telescope (HST). The scientific success of the Hubble Deep Field (HDF), encouraged the HST team to repeat this program, but this time in a patch of sky in the Southern Hemisphere. The Hubble Deep Field South (HDFS) was observed by the HST during October 1998. The field was centered on a distant quasar that had been discovered from an archive UK Schmidt photographic plate and confirmed spectroscopically with 2dF on the AAT.

Throughout the latter half of 1998, the AAT continued to play a key role in the ground-based support work for the HDFS. This was done largely by two projects: a detailed study of the quasar's spectrum with the UCLES and a redshift survey of the faint galaxies in the HDFS with LDSS^{++}.

The quasar is an important feature of this new deep field. It lies at a distance of ten billion light years from Earth, and its light illuminates otherwise invisible clouds of gas lying between the Earth and the quasar. By a detailed study of the quasar's spectrum, the distances and properties of these gas clouds can be measured. These results can then be compared to the data obtained for the faint galaxies imaged by Hubble in the same field, to establish the connection between the line-of-sight gas systems and the galaxies into which they may eventually form.

The UCLES observations of the quasar were carried out by Outram, Carswell, Hewett (IoA), Boyle (AAO) and Williams (STScI). These observations formed part of an international campaign to obtain detailed high spectral resolution observations of this quasar at all wavelengths from the far ultra-violet to the near infra-red. The UCLES observations covered a crucial region of the spectrum, containing many absorption lines from hydrogen gas (the so-called Lyman-alpha forest region). Due to its unsurpassed performance in the blue/ultraviolet at high spectral resolution, UCLES was able to provide unique spectral coverage of this region.

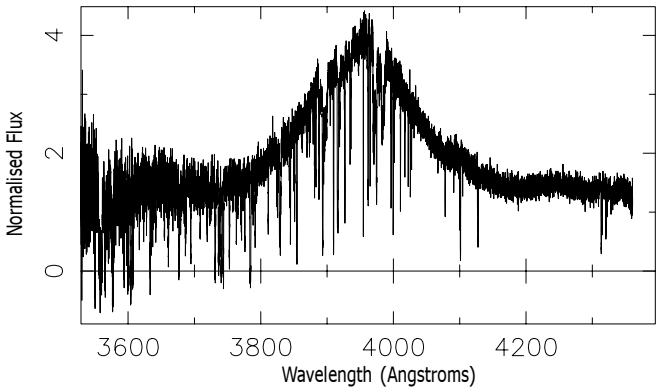


Figure 3.7 UCLES spectrum of the HDFS QSO J2233–606

A total of ten heavy-element systems and 89 Lyman-alpha forest lines were identified. The spectrum is shown in figure 3.7. The absorption lines (in this case mostly due to intervening hydrogen gas clouds at $z \approx 2$) are clearly seen in the spectrum. In the true spirit of the HDF project, the reduced UCLES observations were made available to the astronomical community within three weeks of the observations, enabling many groups to begin their analysis of the relationship between the absorption lines in the quasar spectrum and the faint galaxies in the HDFS.

Glazebrook (AAO) subsequently used LDSS^{++} to obtain spectra for 70 objects in the HDFS. Redshifts were obtained for galaxies as faint as R=23.9, the faintest spectoscopic identification ever obtained on the AAT. The positions and redshifts for these objects were released simultaneously on the WWW with the HST images of the HDFS in November 1998.

2dF Science

The major projects carried out during the year with 2dF were the two very large cosmological surveys, the galaxy redshift survey (GRS) which aims to obtain redshifts for a quarter of a million galaxies, and the QSO redshift survey (QRS) which will obtain spectra for twenty five thousand quasars. Both of these will be by far the largest surveys of their type ever carried out, in fact both are already larger than any previous surveys, being about one-fifth complete by the end of June 1999. The two surveys are being carried out in parallel since this results in the most efficient use of telescope time. The two surveys have complementary science goals; the GRS will provide an unprecendently detailed picture of the large scale structure in the 'local' Universe, while the QRS will provide less detailed view but over much large scales and out to much greater distances (and hence earlier epochs) in the Universe.

The Galaxy Redshift Survey

The best visual impression of progress with the 2dF GRS can be obtained by comparing figure 3.8, a map of the 227 fields observed so far, with the similar diagram two years ago (figure 3.8 in the 1996–97 Report) when fewer than 20 fields had been observed. Another good demonstration comes from the cone diagram in the science highlights section on page vi, showing the distribution in space of the first 50 000 galaxies observed. This can be compared with last year (figure 3.6 in 1997–98); many more sight-lines have been observed, and the density of points shows much more structure in the form of clumps, sheets and voids in the galaxy distribution. In fact, it will no longer be possible to give a single two-dimensional view of the survey in future: already there are enough data in some directions that many data points

overlap and a full three-dimensional representation is needed. This of course is the whole point of the GRS, to determine the true structure of the Universe in all three spatial dimensions. To put it simply, is the Universe full of lumps (i.e. clusters of galaxies); or is it like a bubble bath, with most galaxies at the surfaces of many relatively empty 'voids;' or are both the dense and empty regions inter-connected in complicated ways, as in a sponge?

The redshift survey is now progressing at the impressive rate of about 1000 redshifts per scheduled night on average; over 2000 spectra have been taken on several occasions and 3000 is attainable on a long, clear winter night. With over 40 000 redshifts obtained by the end of June 1999, the GRS was already much larger than any previous survey (the biggest being the Las Campanas survey, with approximately 26 000 galaxies). More importantly, the first new scientific results are starting to appear. In the first major GRS paper to be published, Folkes and Ronen (IoA) and the GRS team have used an automatic procedure to classify the spectra for 6000 galaxies and hence derived separate luminosity functions for different types of galaxies. They find that, while the numbers of elliptical and standard spiral-type galaxies show a maximum in a particular brightness range, with the numbers falling off for both brighter and fainter galaxies, the numbers of small, star-forming galaxies continue to rise as the galaxies become fainter.

One sub-project of the main GRS survey is a study of all the radio galaxies included in the sample. It turns out that about 1.5 percent of the GRS galaxies are known radio sources, in the sense that they coincide in position with objects in existing radio catalogues. Although this is only a small fraction, the total number observed so far is more than 700, making this the largest homogeneous samples of spectra of radio galaxies. Furthermore, it is an unbiassed sample in the sense that the GRS galaxies were selected purely on optical criteria, as non-stellar objects brighter than a particular limit (B < 19.5). Sadler and McIntyre

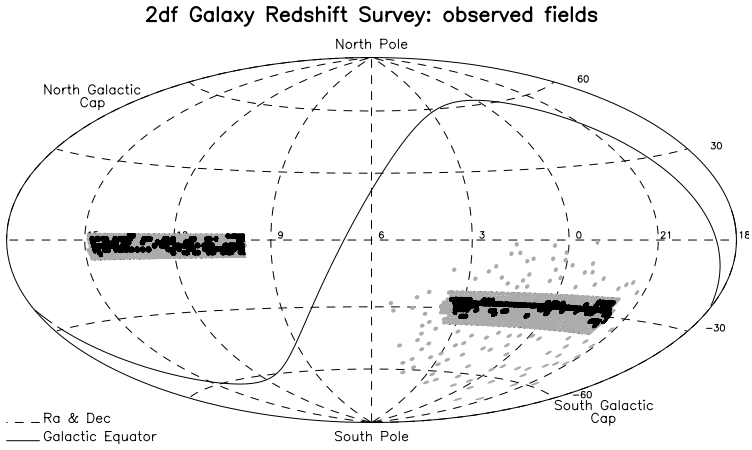


Figure 3.8 The black dots show the survey fields which have been observed, superimposed on the grey area showing the two regions to be surveyed.

(Sydney), Jackson (RSAA) and Cannon (AAO) find that there are two major constituents in the radio sample: about 40 percent are nearby (redshift $z < 0.1$) star-forming galaxies, while most of the remainder are galaxies with active nuclei (AGN), including a few Seyfert-type mini-quasars.

The 2dF QSO Survey

As of June 1999, the QSO 2dF survey had obtained redshifts for over 4000 QSOs with B<21. This is almost ten times larger than the previous largest survey to this magnitude limit. The QSOs typically range in redshift from $z = 0.3$ to $z = 3.0$. The survey has already yielded two refereed papers based on the radio-loud objects identified in the input colour-selected catalogue. These include the discovery of a spectacular post-starburst quasar and a new class of radio-loud broad absorption line QSOs.

The QSO luminosity function and its evolution with redshift has also been determined from the sample obtained to date. Over the redshift and luminosity range sample by the QRS, the evolution of the luminosity function can be modelled as a simple function of luminosity and redshift, with the luminosity of the QSO population increasing by a factor of 30 from the present epoch to its peak at $z = 2$.

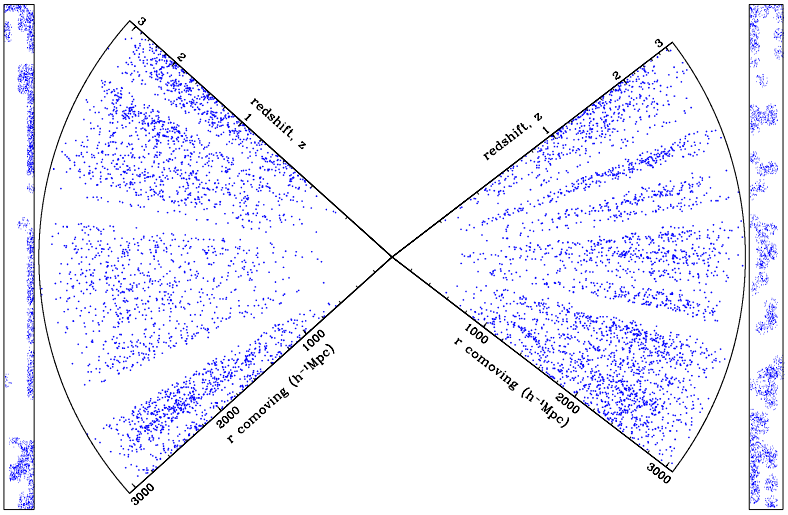


Figure 3.9 The distribution of QSOs so far discovered from the 2dF QSO Redshift Survey. Shown are the positions of the 6500 QSOs which currently (as of August 1999) have measured redshifts. The final sample will contain 25 000 QSOs. The two wedges show the postions of QSOs in the Southern (left) and Northern (right) survey areas, while the rectangular regions contain the positions on the sky of the observed QSOs.

The 2dF Fornax spectroscopic survey

Another major extragalactic survey being undertaken by 2dF is the Fornax spectroscopic survey led by Drinkwater (Melbourne) and Phillipps (Bristol). The aim of this project is to determine the role and importance of dwarf galaxies in the overall star-formation history of the Fornax Cluster. To do this, 2dF is being used to make the most complete spectroscopic measurement ever of a galaxy cluster, sampling the maximum range of surface brightness. Unlike any previous surveys, spectra are being measured for all objects in four 2dF fields to a magnitude limit of B_J=19.7.

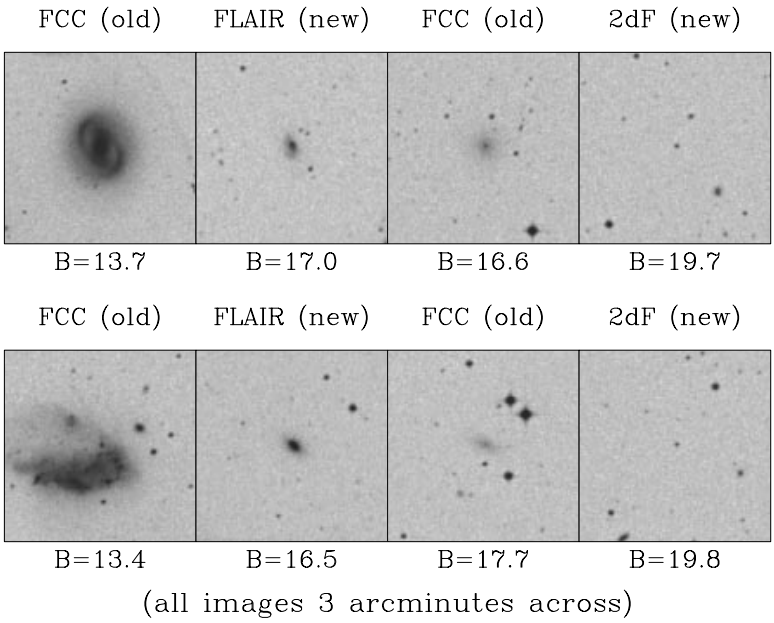


Figure 3.10 Old and new members of the Fornax Cluster. These objects are all members of the Fornax Cluster at the same distance of 15.4 Mpc. From left to right: in the first column are giant galaxies previously confirmed as cluster members in Ferguson's Fornax Cluster Catalog (FCC). The second column shows new high surface brightness compact dwarf cluster members discovered on the UKST with the FLAIR-II spectrograph. The third column shows normal low surface brightness dwarf galaxies classified as cluster members in the FCC but only confirmed with the new 2dF data. The fourth column shows some of the new, very compact objects discovered with 2dF. These appear to be very large, isolated (intracluster) globular clusters. The images are from the Digitised Sky Survey.

Many low surface brightness dwarf galaxies in the cluster have been confirmed, but the strategy of observing all objects has also revealed a new population of very compact objects in the cluster. These objects have absorption line spectra, but are so compact that they are unresolved on the sky survey plates (full width half-maxima less than 150 parsecs at the distance of the Fornax cluster). They resemble isolated globular clusters but their luminosities ($-12<M_b<-11$) are higher than any Galactic globular cluster. Since their distribution is very centrally concentrated, these are most likely isolated globular

clusters sitting in the cluster potential. However they could also be the nuclei of dwarf galaxies, the envelopes of which are undetectable, or that have been stripped off by the galaxy cluster environment.

The survey is also measuring many objects not part of the Fornax Cluster, notably thousands of Galactic stars. These include a number of giant stars with velocities exceeding the local Galactic escape velocity. Behind the Fornax Cluster, the survey has led to the discovery of a population of low redshift (z = 0.1) luminous starburst galaxies that are unresolved on the photographic sky surveys. These would have been missed by any previous large galaxy surveys. Further afield, the survey also includes an unbiased sample of spectroscopically-confirmed optical QSOs. This has established that typical *UBR* multi-colour optical QSO surveys miss about ten percent of low redshift (z < 2.2) QSOs.

The 2dF Magellanic Clouds carbon star program

Although the cosmological surveys dominate the use of 2dF, data are being obtained for a wide variety of other projects, ranging from distant clusters of galaxies, through samples of stars in Local Group galaxies and down to relatively nearby star clusters in the Milky Way.

One example of a stellar project is the survey of Magellanic Clouds carbon stars, being carried out by Hatzidimitriou and Croke (Crete), Cannon (AAO) and Morgan (ROE), which uses carbon stars as tracers

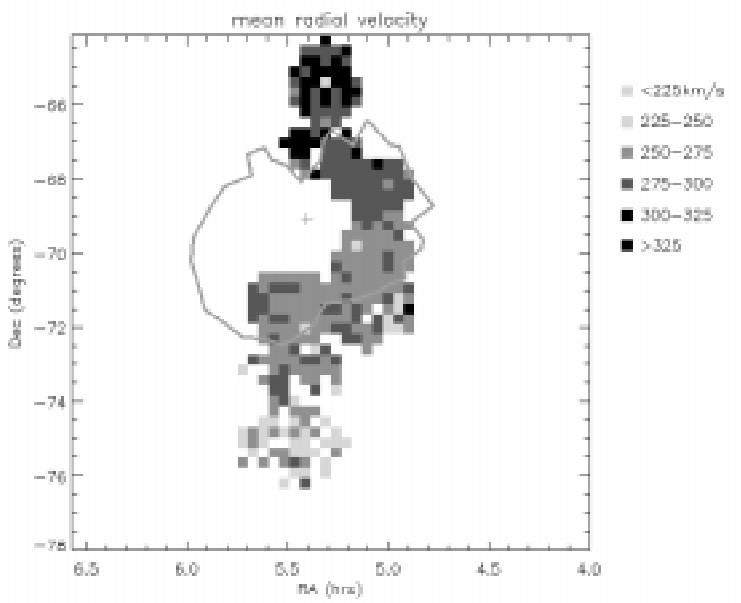


Figure 3.11 Radial velocities in the Large Magellanic Cloud. This diagram shows themean velocity for all the carbon stars in each of the small squares. There is a clear trend of decreasing average velocity from north to south, indicative of overall rotation of the galaxy.

to study the kinematics and star-formation history of the Magellanic Clouds. A sample of some 2000 carbon stars in the two Clouds has now been obtained, all with good spectra yielding velocities accurate to a few km/s.

In the LMC, eight 2dF fields cover a continuous strip 12 degrees long, roughly along a N-S axis. The pattern of these circular fields can be seen in figure 3.11; the continuous contour outlines the densest part of the LMC while the kink near the centre avoids regions where the stellar density was too high for easy observation of carbon stars. This N–S axis is close the 'line of nodes' of the LMC, i.e. the line where the plane of the galaxy intersects the plane of the sky. It is therefore the axis along which any rotation of the LMC will be most easily observed.

The average velocity has been calculated for all the carbon stars in each of the small squares in figure 3.11; these squares are about 7.5 arcmin across, each containing typically five to ten stars. The shading illustrates the change of mean velocity, showing a systematic decrease of about 50 km/s from top to bottom. This is fully consistent with the overall rotation found by previous observers in the LMC, but the high accuracy and large number of stars in the current sample will permit a much more detailed analysis of the pattern.

In the SMC, only a single 2dF field has been observed so far, close to the centre. When these data are combined with data obtained previously by the same team for sparse, outlying carbon stars (observed one at a time with the ANU 2.3-m telescope) and with other published data, there is little evidence for overall rotation of the SMC but there appears to be a systematic change in the velocity dispersion with radial distance from the centre, with a minimum value at intermediate radii. This may be evidence for a disk plus halo structure, together with some tidal disturbance in the outer parts.

4. AAO facilities

This chapter summarises existing instrumentation and research facilities at the AAO, and provides details on new instruments, computer developments and enhancements to existing instruments. It also outlines services provided to the user communities, such as service observing.

The AAT and UKST are the heart of the AAO. To maintain its position as a leading-edge research organisation, it is essential that these telescopes are equiped with state-of-the-art instrumentation and that a range of facilities for visiting astronomers is provided.

The instrumentation for the telescopes involves much more than the new instruments themselves; they must be fitted with the most sensitive electronic detectors for visible light and infrared radiation, have sophisticated computer systems for both control and data-taking, and powerful software for on- and off-line data analysis. The AAO aims to provide astronomers with a complete system for the acquisition and analysis of astronomical data.

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AAT facilities

Instruments available at the AAT in mid-1999 are summarised in table 4.1. Further information is available in the AAO Observer's Guide, in the relevant instrument user manuals, in the AAO newsletters and on the AAO www pages.

Most instruments on the AAT are used by scientists as common-user facilities, which means that observers make their own observations with backup support from Observatory staff. However, some highly specialised but infrequently used instruments are no longer fully supported by the AAO and therefore generally require an experienced user as one of the collaborators. This group of instruments includes FOCAP, LDSS and Taurus II. Instruments owned by other institutions are sometimes used on the telescope and may be available for collaborative projects.

Table 4.1 Instruments available on the AAT at 30 June 1999

Focus Equipment	Mode	Detector
Prime		
Two Degree Field (2dF) 400 fibre multi-object spectrograph facility	f/3.3	Two dedicated Tektronix 1K CCDs
Prime focus camera—aspheric plate, doublet and triplet correctors, sub-beam prism	direct f/3.3	Tek thinned CCD Range of types of sensitised photographic plates 254 × 254 mm
Cassegrain		
Imaging		
Auxiliary camera	f/8 or f/15	Thomson or Tek CCD
Infrared equipment		
IRIS 128 × 128 format infrared camera and low-resolution spectrometer, with imaging, spectroscopic and polarimetry modes	f/15 or f/36	Rockwell HgCdTe array
3D Integral Field Spectrograph made available under agreement with MPIE	f/15	Rockwell HgCdTe array
Spectrographs		
RGO spectrograph, 25 and 82 cm cameras, spectro-polarimetry modes	f/8	Tektronix 1 K CCD, MITLL 2K × 4K CCD and other CCDs
Faint object red spectrograph (FORS), sharing slit of RGO spectrograph and optional dichroic beam splitter	f/8	GEC CCD
Wide-field imaging Fabry-Perot interferometer (Taurus II) with tunable filter (TTF), Wollaston prism polarising module	f/8 or f/15	Tektronix 1K CCD and MITLL 2K × 4K CCD
Low dispersion survey spectrograph (LDSS^{++})	f/8	Tektronix 1K CCD and MITLL 2K × 4K CCD
Auxillary focus narrow field imaging	f/8 or f/15	Tektronix 1K CCD and MITLL 2K × 4K CCD
Facilities for visitors' own equipment		
Coudé		
UCL echelle spectrograph, 70 cm camera (UCLES)	f/36	Tektronix 1K CCD and MITLL 2K × 4K CCD
Ultra-high resolution facility (UHRF)	f/36	Tektronix 1K CCD and MITLL 2K × 4K CCD
Facilities for visitors' own equipment		

UKST facilities

The UKST operates in two modes; photography, for surveys and service observing, and as a common-user instrument with the FLAIR fibre spectroscopy system.

There are two basic photographic options at the UKST:

- direct imaging of the sky in different wavebands from ultraviolet to infrared, selected by the appropriate choice of photographic emulsion and filter;
- slitless low dispersion spectroscopy through thin, full-aperture objective prisms.

Photography has traditionally been carried out on glass plates. However, because of superior performance, Kodak Tech Pan film is now used for most non-survey observations. Film is available in only one spectral sensitisation, but is panchromatic and is used for U-, V-, R- or hydrogen-alpha band exposures.

The second mode of operation on the UKST is higher dispersion multi-object spectroscopy with the fibre-optic FLAIR system, which uses optical fibres to feed the light from 90 individual selected targets to a bench spectrograph and CCD camera.

The 2dF Facility

The 2dF Facility gives the AAT an unsurpassed (for a 4 metre or larger telescope) field-of-view at its prime focus which is equipped with a state of the art optical fibre system for multi-object spectroscopy of up to 400 objects simultaneously.

During the year 2dF has remained the most popular instrument on the telescope being scheduled almost one third of the available time. Due to the increased reliability and speed of the fibre positioning system, it has proved possible to observe well over 3000 objects during a single night.

The 2dF Galaxy Redshift Survey being undertaken with the 2dF facility is now the largest of its kind (almost a factor of two larger than the Las Campanas Redshift Survey). In addition many other fields of astronomy are making dramatic use of the full capabilities of this unique facility.

While the construction of 2dF has drawn to a close, new ideas are already being generated for novel uses of the 2dF facility. In particular new techniques are being developed for sky subtraction with fibres to achieve results at faint magnitudes previously only accessible with multi-slit spectroscopy.

Taurus tunable filter

TTF continues to find widespread use on the AAT for both imaging of nebular sources and for identifying emission or absorption line objects over a wide field.

The overall throughput of Taurus is now very well calibrated. With the use of MITLL2 (blue) and MITLL3 (red) CCDs, the total system efficiency (telescope + Taurus + CCD) is 25 percent (35 percent) in *B*, 28 percent (42 percent) in *V*, 34 percent (48 percent) in *R* and 30 percent (42 percent) in *I*. The numbers in brackets reflect the expected improvement if we were to recoat the optics with sol gels applied directly to the MgF_2 layer, a proposal actively under investigation.

The blue and red 'arms' of the TTF are fully commissioned allowing for broad or narrow band imaging over the 370–1100 nm range. Low resolution (R < 300) spectroscopic imaging is possible with conventional broadband (R≈5) blocking filters (e.g. *UBVRIz*). High resolution imaging requires special blocking filters. The red TTF has a complete set of R≈20 order blockers for spectral regions free of atmospheric bandheads. This strategic choice has paid off in that a very dark sky in a narrow band benefits many science programmes. The blue TTF has a limited set of order blockers for high resolution work, although the WHT UES order-sorting filters have helped to make up this deficiency.

IRIS2

Design and construction of the AAO's next generation infrared camera and spectrograph IRIS2, continues apace. On-telescope commissioning of this instrument is expected in the second quarter of 2000, with shared risks observations for scheduled observers being possible in the third quarter of that year.

IRIS2 will replace and considerably expand the functionality of the AAO's current infrared camera and spectrograph, IRIS. In particular, it will feature a detector, 64 times larger than IRIS, with a corresponding ability to image much larger areas of the sky (7.7 × 7.7 arcminutes) at the *Z, J, H* and *K* passbands, as well as at a range of narrow passbands centered on astrophysically-interesting emission lines. It will also feature spectroscopic capabilities at a resolution of 1500, and hopefully of up to 3000.

Lastly, it will feature a limited ability to carry out multi-object spectroscopy with up to two pre-punched aperture masks.

Upgrade paths foreseen, and allowed for in the current design, of this instrument include: a jukebox for the exchange of up to ten aperture masks; integral polarimetric functions; a bare fibre and lenslet integral field unit; an upgrade to a 2048 × 2048 pixel detector; and the provision of rapid tip-tilt image correction.

6dF

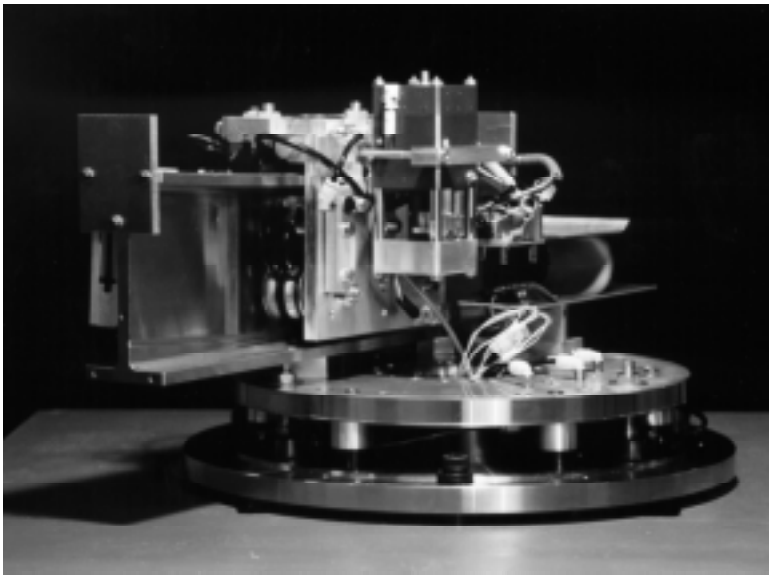
The 6dF facility for the Schmidt Telescope is a robotic fibre-positioner that will enable the existing FLAIR spectrograph to be used for multi-object spectroscopy on survey scales. It will achieve much faster fibre reconfiguration times than are possible with the current FLAIR system.

A number of milestones have been passed during the reporting year. In May 1999, critical design reviews (CDR) were held for the mechanical and electronic design of 6dF, both with satisfactory outcomes. A software CDR will follow late in 1999.

Fabrication work on the air-bearing (r, theta) and gripper mechanisms continues, and components are now being manufactured for the field-plate units. These units are specific to 6dF, and will be interchangeable between the positioner (for fibre configuration) and telescope (for observing). They contain not only the field-plates themselves, but the 154 fibre retractors and a rotation mechanism—all within the compass of a standard Schmidt plateholder.

The instrument will now only have two field-plate units, not three, because of budget pressures. This reduction will have minimal impact on survey operations. On the other hand, significant gains will be made if a proposal to replace the existing CCD chip is implemented, as recommended by ACIAAT at its last meeting. The instrument is still on track for a commissioning phase starting at the end of 2000.

The principal function of 6dF will be to carry out hemispheric galaxy redshift and peculiar velocity surveys, and an external Science Advisory Group has been set up to plan and oversee these activities.



The r, theta arm of the 6dF.

External Projects

External Projects activities at the AAO continue to grow and now clearly represent a significant fraction of the business of the Observatory.

OzPoz (Fibre positioner for the VLT)

The OzPoz project has successfully passed its Preliminary Design Review held in Garching during April. The team is now fully engaged in the final design phase with the Final Design Review scheduled for October 1999. The positioner is scheduled for delivery to the Very Large Telescope's Unit 2 telescope by mid-2001.

FMOS

The FMOS consortium (members from AAO, UNSW, Oxford, Durham, IoA and RGO) have been commisssioned to perform a Concept Design Study for a wide-field, optical/NIR multi-fibre system for Subaru's prime-focus. The AAO was originally to concentrate on just positioner issues but also took on the task of managing and refining the design of a new prime-focus corrector for Subaru for use in the 0.37 to 1.8-m range.

Given severe space constraints at Subaru's f/2 prime focus, a completely new positioner concept (the Echidna) was created. Sufficient interest was generated by the Echidna that AAO has now entered a new contract to proto-type an Echidna spine using tiny motors.

Gemini contracts

IR-MOS development study The AAO has been commissioned to produce a design study for fibre-based integral-field units for use with the next generation of Gemini infra-red spectrographs. The work is scheduled for a 15 month period beginning in May 1999.

IRIS2-g This is a proposal to build an infrared camera and spectrograph for Gemini based on the AAO's IRIS2 instrument. A Concept Design Study is being undertaken.

Enhancements to existing instruments

LDSS^{++}

The project to upgrade the performance of LDSS, originally conceived in November 1997, was completed in less than a year, and LDSS^{++} was commissioned in October. The key development was the use of charge shuffling (on the CCD) for sky subtraction. This allows the use of small apertures ('microslits') rather than long slits, resulting in a factor of ten gain in multiplex advantage (from twenty to two-three hundred or more objects) for this survey instrument. Some specialised modes offer up to 1000–2000 objects simultaneously. The upgrade also included new technology gratings — Volume Phase Holographic (VPH) gratings — which give much greater transmission efficiency.

As well, a new MITLL deep depletion CCD was commissioned, giving an increase in performance by factor of two in the red, compared with the old Tek chip.

LDSS^{++} was used to measure redshifts in the Southern Hubble Deep Field during commissioning. Redshifts for galaxies as faint as R=23.9 were secured, setting a new record for faintness for AAT galaxy redshifts.

In the last few years, LDSS has been used typically for only one or two projects per semester. The upgrade has sparked a new interest in deep high-redshift spectroscopy, and six projects will use LDSS^{++} in semester 1999B.

Charge shuffling

The AAO has continued its development of CCD charge shuffling to work with a wider range of instruments than TTF, and to operate in concert with certain telescope tasks. An important development is charge shuffling coupled to telescope nodding, to be used with Taurus, LDSS^{++} and the RGO spectrograph. Thus, it is now possible to observe two widely spaced pointings on the sky many times within a single shuffle exposure, to allow for greatly improved sky subtraction.

The telescope nods between the two pointings while separate images are built up side-by-side on the detector. Charge shuffling has been a key component of TTF observing, particularly with observations which switch between several frequencies. Charge shuffling will soon assist other actions, in particular, telescope focus, camera focus and rotating plates within a polarimeter module.

Prime Focus Upgrade/Wide Field Imager

The Prime Focus Upgrade (PFU) will provide upgraded mounting facilities at the AAT's $f/3.3$ prime focus for both AAO and visiting detectors. In particular, it will provide a large automated filter wheel and shutter capable of serving detectors of a size up to 165 × 165 mm. PFU is expected to be commissioned in the first quarter of 2000.

The size of focal plane PFU will cover has been specifically geared to that provided by the Wide Field Imager (WFI) instrument being constructed jointly by the AAO, the Research School of Astronomy & Astrophysics (RSAA) of the Australian National University, and the School of Physics of the University of Melbourne. This project will deliver a mosaic of 2048 × 4096 pixel Lincoln Laboratory CCDs in a 4 × 2 format, to provide total sky coverage of 30 × 30 arcminutes in 8192 × 8192 pixels. This will represent a dramatic increase in the imaging power of the AAT, and make possible a huge range of scientific survey projects, previously inaccessible to Australian and UK astronomers.

CCDs

The AAO has continued to commission devices from the Massachusetts Institute of Technology/Lincoln Laboratories (MITLL) CCD consortium which has been brokered by the University of Hawaii. These MITLL devices have 2048 × 4096 15 micrometre pixels. The MITLL2 device commissioned in October 1997 is now the AAO's most popular detector. In October 1998, the AAO commissioned the MITLL3 device — the first science grade detector from this consortium, and one having superior red and infrared performance.

CCDs from the EEV corporation (purchased in a partnership brokered through the now defunct Royal Greenwich Observatory) have been delivered to the AAO, and are planned for commissioning late in 1999. These devices will deliver to observers, similar sized detectors to the MITLL devices, but with significantly improved blue sensitivity.

FLAIR Interim Upgrade

Interim improvements to the FLAIR multi-fibre spectroscopy system on the Schmidt Telescope have been completed. Both fibre plateholders are now equipped with magnetic buttons, and remote control of the spectrograph has been fully implemented

MAPPIT

The MAPPIT interferometer, located in the west coudé room, is used for high-resolution imaging. A recent result was the demonstration that beta Centauri, one of the stars that form the 'pointers' to the Southern Cross, is a close binary. With a separation of 0.015 arcseconds at the time of observation, this is probably the closest binary that has been definitively resolved by any single-aperture telescope.

MAPPIT is also able to operate in two wavelength-dispersed modes, one of which gives the angular diameter of a star as a function of wavelength. The MAPPIT team is currently analysing such observations of the southern giant R Doradus; the variations with wavelength can be compared with the predictions of model atmospheres. This star has the largest apparent angular size of any known star (other than the sun), as demonstrated by previous MAPPIT observations.

The instrumentation is now being upgraded to form MAPPIT 2, which will include a wavefront sensor working in synchronism with the detector on the interferometer channel. Using special high-speed configurations, both CCDs can be read out with 10 ms periods and 100 percent duty cycle. The addition of wavefront sensor data will produce higher precision observations, and allow observation of fainter and more complex objects. The commissioning of the full system is now scheduled for January 2000.

Other facilities

Computing facilities

The Observatory has a program of information technology enhancements and upgrades to keep both telescopes operating as front-line facilities. State-of-the art computing facilities for instrument control, data acquisition and data reduction, at both Siding Spring and Epping, are vital components of the infrastructure of the Observatory. During the year, after extensive consultation with users, the Observatory developed an information technology strategic plan. This plan will be in place until 2001/02.

The two main Unix systems at Siding Spring and Epping used for disk and email serving were upgraded. Faster computers with more memory and additional disk space replaced machines that were several years old. Further improvements were made to the network infrastructure at both sites.

The Observatory's presentation facilities were upgraded with the purchase of colour projection systems and colour laser printers for Siding Spring and Epping. A number of notebook computers were procured for astronomers and support staff at both sites to enhance productivity.

Software

The software group develops the specialized software needed by new instruments such as 2dF and IRIS2.

2dF has dominated the software group for some time but has now moved into the AAO's commissioned instrumentation suite. Only limited debugging and development work is ongoing. The major part of the software group effort is now directed to the software required for the IRIS2 and new CCD controller project. We have also embarked on the software for the 6dF project for the Schmidt telescope. The software for this project is being based on existing 2dF robotics software. Various smaller projects have been completed or are underway.

Additionally, the internal software group is providing support, technology transfer and some other effort for AAO external projects.

The group has recently completed year 2000 compliance tests on front-line instrumentation software and is confident that no related problems will be encountered.

The group continues to maintain the now mature DRAMA software that underpins the 2dF system and will also underpin most of our new software. It also provides occasional support for other observatories such as those on La Palma and Hawaii that are using DRAMA itself, and for Gemini, which is using some of the DRAMA

sub-systems. A DRAMA-based system using an AAO-developed DRAMA telescope control task is now being commissioned on the James Clerk Maxwell Telescope in Hawaii and is being investigated for use by the United Kingdom Infrared Telescope, also in Hawaii. The use of DRAMA by outside users imposes some effort on the AAO but is rewarded by the new ideas that flow back to the AAO. The AAO also charges for some of the support services provided to recover the costs involved.

Support facilities

The AAO maintains comprehensive facilities to enable visitors and staff to prepare for observations and to analyse their data. There is a plate library in the Schmidt building and chart rooms in the AAT dome and at Epping, all with facilities for the inspection, measurement and photography of sky survey and other material. A quarterly newsletter is also produced and distributed. The AAO also offers astronomers access to digitised sky survey data either in the form of CD-ROMs or from the COSMOS and APM databases available on the www.

Library

The AAO library holds one of the largest astronomical collections in Australia and, together with the libraries of MSSSO and Radiophysics Laboratory/ATNF at CSIRO, provides an essential facility for the astronomical community. The monograph collection is now searchable via the library's web page. Electronic databases and online search facilities are kept up-to-date, and ensure that the library is part of an international network of specialist astronomical libraries.

Data Archive

The AAO maintains a complete archive of data obtained with the AAT. The digital data are stored on CD-ROM at the telescope and at Epping, and are available for use by the astronomical community after a proprietary period of 2 years. An index to the archive is available via the world wide web. This index is now complete back to January 1993, with some older data still to be transferred to CD-ROM and entered in the database. The accompanying observing logs are now also available via the web. We receive regular requests for data from the archive, and in 1998 the equivalent of six months of observations were requested, significantly increasing the efficiency of the telescope. Photographic plates taken with the AAT and UKST are also archived and available on request.

Other AAO programs

Service Observing

The Anglo-Australian Observatory operates a service observing program at the Anglo-Australian Telescope (AAT) for projects that

require up to three hours of observing time. Service time is normally allocated for programs that require a small amount of data to complete a project, to look at individual targets of interest or try out new observing techniques. All service proposals are refereed by a three-member panel and are graded on the basis of scientific merit, with those accepted into the service program remaining active for one year. Full information is available on the World Wide Web and the application forms for service time are submitted electronically to the AAO.

In June 1998, 2dF was added to the suite of instruments available for service observations, and four 2dF service nights were allocated during Semesters 98B and 99A. These proved extremely successful and of the fourteen 2dF proposals accepted, six have already been completed.

During the past year, a total of 22 service nights were allocated on the AAT and 88 proposals were accepted into the service program. Of these, approximately one third were for the RGO spectrograph and one quarter have been completed. Service observations were obtained using the RGO spectrograph, Taurus II/TTF, UCLES, 2dF and CCD prime focus imaging.

Students

The AAO continues to support a vacation student program for Australian and UK undergraduate students. These schemes give students entering their final undergraduate year an opportunity to take part in a ten-week research program supervised by an AAO staff member. There were five undergraduate students employed during the year: Ziming Tu, Simon Beer, Robert Sharp, Celine Peroux and Andrew Tolley. The students visited either the radio telescopes at Narrabri or the optical telescopes at Siding Spring.

In addition, many AAO scientific staff co-supervise PhD students at other Australian Universities. Dr Brian Boyle currently supervises Michael Brown from the University of Melbourne, who is working on data obtained from the digital stacking of UK Schmidt photographic plates using SuperCosmos. Dr Karl Glazebrook supervises Kathryn Deeley from the University of New South Wales whose research involves a study of post-starburst galaxies in the 2dF redshift survey.

D H Jones (MSSSO), supervised by Dr Joss Bland-Hawthorn, has now completed his study of the TTF Field Galaxy Survey. S Cianci (Sydney), also supervised by Dr Bland-Hawthorn, has begun the design and manufacture of a new generation of interference coatings for astronomical use. Dr Bland-Hawthorn assists in the supervision of M E Putman (MSSSO) who is using Taurus II to look for H-alpha emission from high velocity clouds.

F. Staff research

This section describes the research activities of staff at the Anglo-Australian Observatory, where not already covered in Chapter 3. In addition to providing support for the Observatory, the scientific staff pursue their own research programs. Staff make extensive use of the Anglo-Australian Telescope (AAT) and UK Schmidt (UKST) facilities and also use many other research facilities such as the radio telescopes operated by the Australia Telescope National Facility, the Hubble Space Telescope and the telescopes of the European Southern Observatory.

Circular polarization and biomolecular handedness

Bailey (AAO) has continued to search for circular polarization in star formation regions to test the idea that this may play a role in determining the preference for left handed amino acids seen in some meteorites and in biological molecules on Earth. Large circular polarization has been found in the infrared radiation from several regions of massive star formation. However, it is ultraviolet wavelengths which are needed to select handedness in organic molecules. Recent observations have aimed to determine whether similar effects can be found in optical reflection nebulae. To do this, Taurus has been adapted for use as an optical imaging polarimetry system. Observations of a number of optical reflection nebulae have been made and are currently being analysed.

Circumstellar environment of protostars

Bourke (AAO/ATNF) has used IRISPOL, the polarimetry mode of IRIS, to image the near-infrared nebulosity associated with the very young protostellar object IRAS 11590–6452 The data is reduced and will be analysed with Wood (SAO), using a detailed radiation transfer code developed by him, which predicts the observed scattered light images and polarization structure.

Chemistry in molecular outflows

Bourke (AAO/ATNF) in collaboration with Garay (Chile), Bergin (SAO) and Caselli (Arcetri) has continued an investigation of the chemistry occurring within the molecular outflow from the low-mass protostar IRAS 11590-6452. This outflow is nearby (200 pc) and is the only one of its type accessible for study in the southern sky. A survey of molecular line emission with the Swedish-ESO Submillimetre Telescope (SEST) in Chile was completed during the year. The species CH_3OH (methanol), SiO, H_2CO (formaldehyde), SO, HCN, HNC, CS, and HCO^+ all emit strongly in the outflowing gas, and CH_3OH and SiO in particular, show strong abundance enhancements over that measured in the surrounding quiescent molecular gas. A number of other species are not detected in the outflowing gas, most notably CN and HC_3N. A number of differences between this outflow and the best studied example, Lynds 1157, are evident. The next stage in the research is to compare observational results and those for other outflows with detailed shock chemistry models being developed by the group (Bergin, Caselli), which have been successful in explaining the early results from Submillimeter Wave Astronomical Satellite (SWAS).

Brown dwarfs

Tinney (AAO), Delfosse (Geneva) and Forveille (Grenoble Obs) have used AAT spectra in both the optical and infrared to probe the properties of a sample of brown dwarfs identified in the DENIS southern sky survey. A comparison of AAT optical spectra with models for the atmospheres of very cool stars indicates that dust is not only forming in these objects, but is settling to lower levels in the photosphere. They have also shown that infrared spectra can be used to classify the temperature and luminosity of very cool objects, even in the absence of the usually-required trigonometric parallaxes.

Radio continuum emission from the Wolf Rayet star—Gamma Velorum

Chapman (AAO/ATNF), Koribalski (ATNF), Dougherty (Calgary), Leitherer (STScI) and Moffat (Montreal) have begun a monitoring programme to look for variability in the radio continuum emission from the Wolf Rayet star, Gamma Velorum. Gamma Velorum is the nearest and brightest Wolf Rayet star and is in a binary system with an O-star companion and an orbital period of 79 days. Radio continuum emission, with a 3 cm flux density of around 30 mJy, is detected from the stellar wind of the Wolf Rayet star. Chapman et al. have argued that part of the detected radio emission is non-thermal in origin and arises from shock fronts which form as the stellar wind from the Wolf Rayet star collides with the stellar wind of the O-star. If this is the case then the radio continuum emission should vary in intensity with the phase of the binary orbit. The strongest emission is expected to occur near periastron as our line-of-sight intersects a cone-like region formed by the shock fronts. To test this hypothesis the ATCA is being used to monitor the radio continuum emission at 3, 6, 13 and 20 cm over a three-month period. Initial results indicate that radio variability is indeed present. The monitoring data will be used for detailed modelling of the wind-wind interaction.

Water masers at high redshift ($z > 2$)

Bourke (AAO/ATNF), with Wilner (SAO), has begun a search for water masers associated with high redshift ($z > 2$) Active Galactic Nuclei (AGNs). Previous observations of nearby AGNs, in particular the remarkable galaxy NGC 4258, show that water masers can be used to trace parsec-scale structures associated with the central engines of AGNs, presumably black holes. Proper motion studies of the masers in NGC 4258 have resulted in a purely geometric distance estimate with a fractional uncertainty of only 4 percent. Similar studies of AGN masers at high redshift could provide cosmological parameters independent of more controversial methods currently in use. To-date, four sources (including the Cloverleaf) which are know to possess substantial reservoirs of molecular gas (through detection of mm CO emission) have been observed with the ATCA. Though all four sources are lensed, which should increase our chances of detecting any maser emission, no such emission has been detected. The program is being extended because new detections of molecular gas at high redshift have been reported.

Mass-loss from evolved stars

A long-standing problem has been to understand why planetary nebulae are often seen to have bipolar geometries whilst the stellar winds of OH/IR stars, which are progenitors of planetary nebulae, generally appear spherically symmetric. To investigate this problem, Chapman (AAO/ATNF), Zijlstra (UMIST) and te Lintel Hekkert (ATNF) have used the

VLA, MERLIN and the ATCA to study the OH maser distributions from a sample of 10 OH/IR stars with irregular OH maser spectra. In each case, the aperture synthesis images show that the OH masers are located in a torus around the star and/or in a bipolar outflow. This is interpreted as evidence for a hot, fast wind which 'turns on' as the star evolves away from the AGB. The hot stellar wind sweeps up the AGB wind and expands to form two bipolar lobes in the polar directions where the AGB wind density is least. In these directions the wind expansion velocity may reach several hundred km/s. In the higher density equatorial region a remnant torus or equatorial disk may be present with a much lower expansion velocity of typically 25 km/s. The maser results indicate that dramatic and rapid changes occur in the wind geometries and kinematics as a star evolves away from the AGB towards becoming a planetary nebula.

Resolving the mystery of Beta Cen

Beta Cen is a bright Beta Cephei variable and has long been suspected to be a binary. Robertson, Bedding, Marson (Sydney), Aerts (Institut voor Sterrenkunde, Celestijnenlaan, Belgium) and Barton (AAO) have obtained observations with the AAT using the MAPPIT interferometer, to find that Beta Cen is indeed a binary, with components separated by 15 milli-arcsec and having approximately equal brightness at 486 nm. They have also used high-resolution spectra obtained at ESO to determine that Beta Cen is a double-lined spectroscopic binary. They find two pulsation frequencies in the primary. Further spectroscopic and interferometric studies of this double star should allow determination of its orbital parameters and component masses.

H-alpha detections along the Magellanic Stream

Bland-Hawthorn (AAO) and Maloney (Colorado) have demonstrated that the recent H-alpha detections along the Magellanic Stream are most likely due to ionizing photons from young stars in the Galaxy. This important result tells us that about 6 percent of the UV escapes from a normal galaxy like the Milky Way. As a result, we can use the strength of H-alpha to give us a rough idea of how far away individual clouds are. This is supported by recent Taurus II observations of the Magellanic Stream which also show from six optical emission lines that the clouds have less than 1/10th solar abundance and are statically photoionized.

High velocity hydrogen clouds

Several groups, including a collaboration led by Bland-Hawthorn (AAO), are detecting many high velocity clouds over the sky. Most of these clouds are very bright in H-alpha emission, which suggests that they are relatively close by. The Taurus II observations undertaken at both the AAT and WHT detect up to three emission lines simultaneously and therefore provide physical diagnostics on the clouds under study. The Taurus II campaign is greatly aided by Putman's (MSSSO) HIPASS survey of high velocity clouds.

Blitz (Berkeley) and Spergel (Princeton) have suggested that many clouds will be much further away than the Magellanic Stream and Bland-Hawthorn predicts that these clouds will be largely invisible in H-alpha. Current observing programmes are focussing on the compact HVCs as these are expected to be the most distant. Indeed, Blitz and Spergel believe these clouds are bound by dark matter and represent truly primordial structures, i.e. building blocks of galaxies. This is an interesting idea as it unites many separate lines of

reasoning that have been shelved for decades. In particular, Oort noted in 1966 that if the clouds are self-gravitating, their virial distances would place them beyond the Local Group.

Stellar populations in Local Group Galaxies

Bridges (AAO), Jablonka (Meudon), Meylan (ESO) and Sarajedini (Wesleyan) have completed an HST/WFPC2 imaging study of globular clusters and field stars in the central bulge of M31. They have found that the M31 bulge stars form an old and super-metal-rich population, similar to that of the Galactic bulge. They also found that the M31 cluster G1 is more massive and has a larger metallicity spread than any Galactic cluster.

Globular clusters as dynamical probes of elliptical galaxies

Bridges (AAO), Sharples, Beasley (Durham), Zepf (Yale), and Hanes (QUK) are involved in a major program of obtaining spectra of globular clusters (GCs) in elliptical galaxies. The GC velocities are being used to study the galaxy dynamics and dark matter, while absorption lines sensitive to age and chemical abundance tell when the GCs formed and their chemical evolution. The question is a very important and fundamental one: How and when did elliptical galaxies form? From data obtained at the WHT and CFHT, they now have 144 GC velocities in the Virgo giant elliptical M49, and have found for the first time kinematic differences between metal-poor and metal-rich GCs in an elliptical galaxy. These results favor a merger origin for elliptical galaxies, and confirm X-ray evidence for a dark matter halo in M49. From age- and metallicity-sensitive absorption-line indices, they have found that while the M49 GCs span a considerable range in metallicity, they are mostly an old stellar population.

Gamma ray burst follow-up

The AAT has continued to be involved in the optical follow-up to Gamma Ray Burst (GRB) events. Monitoring of the unusual type Ic supernova SN 1998bw, associated with GRB980425, has been carried out on the AAT and UKST by Stathakis, Boyle, James, Hartley, Lewis, Parker, Russell, Tinney (AAO), Jones, Bessell, Germany (RSAA), Galama, Van Paradijs, Vreeswijk (Astronomical Institut "Anton Pannekoek"), Kouveliotou (USRA) and Sadler (Sydney). They find that although the SN shares many properties in its evolution in common with other Type Ic Sne, it also shows some quite unusual line properties.

Dynamics and abundances of brightest cluster galaxies

Bridges (AAO), in collaboration with Carter (Liverpool JM), Dejonghe and De Rijcke (Ghent), and Hau (U Catholica Chile) are studying the dynamics and chemical abundances of brightest cluster galaxies (BCGs) in their centres and inner halos. The key to this work is measuring the shape of the stellar velocity distribution, which allows the stellar kinematics and gravitational potential to be determined simultaneously, with innovative modelling techniques using all of the available data. From the stellar kinematics, ages and chemical abundances, they will learn how and when these special galaxies formed, as well as their dark matter content. They have studied three northern BCGs. Data for NGC 6166 (Abell 2199) are the deepest ever obtained, and a rising stellar velocity dispersion profile has been found. This is almost certainly due to a massive dark-matter halo in this galaxy, and they are now carrying out the numerical modelling to confirm this. Data for other galaxies have also recently been obtained at the VLT.

Geisler (Chile), Lee (S. Korea), Bridges (AAO) have obtained HST *V*, *I*, *H* imaging of globular clusters (GCs) in four BCGs. The goals are to determine the total numbers, spatial distribution, and colours (and by inference, chemical abundance) of the GCs, in turn allowing constraints to be put on formation models for their host galaxies. For instance, initial results for one of the BCGs, UGC 9799, shows that this galaxy contains many fewer GCs than originally estimated from ground-based data. This disagrees with scenarios whereby BCGs obtain large numbers of GCs via tidal stripping of other cluster galaxies. UGC 9799 and NGC 1129 both appear to have broad globular cluster colour/abundance distributions, in support of a merger model for elliptical galaxy formation.

The star-formation history of the Universe from UV-selected galaxies

Treyer, Donas, Milliard (Marseille), Ellis,Sullivan (IoA) and Bridges (AAO) have obtained spectra for approximately 200 galaxies selected in the rest-frame UV from wide-field observations from a balloon. With this unique dataset, a rest-frame UV luminosity function with a steep faint-end slope was obtained, and a higher local (z = 0) star-formation rate than found from other recent studies. Consequently, the evolution of the star formation rate of the Universe with redshift (time) does not seem as strong as some other recent work has suggested, which has profound implications for our understanding of how and when stars and galaxies form.

Shell galaxies

Shell galaxies have dramatic arcs or 'shells' of stars surrounding them. Carter (Liverpool JM), Turnbull (Herts) and Bridges (AAO) have obtained *B*, *R* photometry for a dozen shell galaxies, to learn how these galaxies and their shells are formed. They suggest that two different processes have formed the shells in NGC 474 and NGC 7600: tidal stripping which formed the outer shells, and a merger which formed the tightly-bound inner shells.

Low-redshift X-ray-selected active galactic nuclei

With Schade (DAO), Boyle (AAO) has completed his work on a ground- and HST-based imaging campaign of 76 low-redshift X-ray-selected active galactic nuclei (AGN). The aim of this study is to obtain information on the host galaxies of these AGN. This is the most comprehensive imaging survey of such objects ever carried out. The major results are that the majority (55 percent) of the AGN are in bulge-dominant systems, but that otherwise their properties (luminosity, size) are indistinguishable from those of normal field galaxies. Contrary to previous studies, Boyle and Schade find no evidence for any enhanced interaction or merger activity in the objects.

Baryon inventories

Maloney (Colorado) and Bland-Hawthorn (AAO) have studied the possible existence of a diffuse plasma dispersed throughout the Local Group. Recent baryon inventories of the Universe show that 90 percent of the expected baryons are currently unobservable and may reside as 10^5 to 10^6 K gas — extremely difficult to detect directly — in loose galaxy groups. Surprisingly, it turns out that pulsar dispersion measures towards the Magellanic Clouds, and particularly the timing mass of the Local Group, make such a plasma unlikely, or at least uninteresting.

A. Financial reports

As provided for in the Anglo-Australian Telescope Agreement, the accounts, records and financial transactions of the Board are audited by the Australian Auditor-General. The form of the Board's financial statements is in accord with Schedule 2 of the Finance Minister's Orders made under the *Commonwealth Authorities and Companies Act 1997* issued by the Australian Minister for Finance and Administration.

The Board submits detailed estimates of receipts and expenditure for approval by each Government in respect of the financial accounting period from 1 July 1998 to 30 June 1999. All estimates are expressed in Australian dollars.

Statement by the Directors

In our opinion, the attached financial statements give a true and fair view of the matters required by Schedule 2 of the Finance Minister's Orders under the *Commonwealth Authorities and Companies Act 1997.*

J R Mould
Chair of the Board

25 November 1999

J A Peacock
Deputy Chair of the Board

25 November 1999

Australian National
Audit Office

ANGLO-AUSTRALIAN TELESCOPE BOARD
INDEPENDENT AUDIT REPORT

To the Minister for Education, Training and Youth Affairs

Scope

I have audited the financial statements of the Anglo-Australian Telescope Board for the year ended 30 June 1999. The financial statements comprise:

- Statement by the Directors;
- Operating Statement;
- Statement of Assets and Liabilities;
- Statement of Cash Flows;
- Schedule of Commitments;
- Schedule of Contingencies; and
- Notes to and forming part of the Financial Statements.

The Members of the Board are responsible for the preparation and presentation of the financial statements and the information they contain. I have conducted an independent audit of the financial statements in order to express an opinion on them to you.

The audit has been conducted in accordance with Australian National Audit Office Auditing Standards, which incorporate the Australian Auditing Standards, to provide reasonable assurance as to whether the financial statements are free of material misstatement. Audit procedures included examination, on a test basis, of evidence supporting the amounts and other disclosures in the financial statements, and the evaluation of accounting policies and significant accounting estimates. These procedures have been undertaken to form an opinion as to whether, in all material respects, the financial statements are presented fairly in accordance with Australian Accounting Standards, other mandatory professional reporting requirements and statutory requirements so as to present a view of the entity which is consistent with my understanding of the Anglo-Australian Telescope Board's financial position, the results of its operations and its cash flows.

The audit opinion expressed in this report has been formed on the above basis.

PO Box A456 Sydney South NSW 1235
130 Elizabeth Street
SYDNEY NSW
Phone (02) 9367 7100 Fax (02) 9367 7102

Audit Opinion

In accordance with subsection 19(1) of the *Anglo-Australian Telescope Agreement Act 1970,* I now report that the financial statements are in agreement with the accounts and records of the Anglo-Australian Telescope Board, and in my opinion,

(i) the financial statements are based on proper accounts and records;

(ii) the financial statements show fairly, in accordance with applicable Accounting Standards and other mandatory professional reporting requirements, the financial position of the Board as at 30 June 1999 and the results of its operations and its cash flows for the year then ended;

(iii) the receipt, expenditure and investment of moneys, and the acquisition and disposal of assets, by the Board during the year have been in accordance with the *Anglo-Australian Telescope Agreement Act 1970*; and

(iv) the statements are in accordance with Schedule 2 of the Finance Minister's Orders.

Australian National Audit Office

Paul Hinchey
Senior Director

Delegate of the Auditor-General

Sydney
25 November 1999

OPERATING STATEMENT
for the year ended 30 June 1999

	Notes	**1999**	1998
		$'000	$'000
NET COST OF SERVICES			
Operating expenses			
Employees	*4A*	**4166**	4134
Suppliers	*4B*	**2204**	2252
Net loss from disposal of assets	*4D*	**145**	110
Depreciation	*4C*	**2019**	1298
Total operating expenses		**8534**	7794
Operating revenues from independent sources			
United Kingdom Government Contribution		**3610**	3459
Sales of goods & services	*5A*	**1028**	394
Interest	*5B*	**79**	63
Net foreign exchange gains/(loss)	*5C*	**(4)**	6
Other	*5D*	**252**	87
Total operating revenues from independent sources		**4965**	4009
Net cost of services (before abnormal items)		**3569**	3785
Abnormal items			
Sale of Land & Buildings held free of charge.	*5E*	**(138)**	-
		-	-
Net cost of services		**3707**	3785
REVENUES FROM GOVERNMENT			
Parliamentary appropriations received	*6A*	**3612**	3462
Total revenues from government		**3612**	3462
Deficit of net cost of services over revenues from government		**(95)**	(323)
Accumulated surplus at beginning of reporting period	*8*	**16469**	16792
Accumulated surplus at end of reporting period	*8*	**16374**	16469

The accompanying notes form part of these financial statements

STATEMENT OF ASSETS AND LIABILITIES
as at 30 June 1999

	Notes	1999 $'000	1998 $'000
PROVISIONS AND PAYABLES			
Employees	*7A*	**1246**	1235
Suppliers	*7B*	**168**	59
Other	*7C*	**632**	1682
Total provisions and payables		**2046**	2976
EQUITY			
Reserves		**29168**	16520
Accumulated surplus	*8*	**16374**	16469
Total Equity		**45542**	32989
Total liabilities and equity		**47588**	35965
FINANCIAL ASSETS			
Cash	*9A*	**1692**	2233
Receivables	*9B*	**98**	104
Total financial assets		**1790**	2337
NON-FINANCIAL ASSETS			
Land and buildings	*10A,C*	**20915**	21880
Plant and equipment	*10B,C*	**24816**	11706
Other	*10D*	**67**	42
Total non-financial assets		**45798**	33628
Total Assets		**47588**	35965
Current liabilities		**1339**	2348
Non-current liabilities		**707**	628
Current assets		**1857**	2379
Non-current assets		**45731**	33586

The accompanying notes form part of these financial statements

STATEMENT OF CASH FLOWS
for the year ended 30 June 1999

	Notes	1999 $'000	1998 $'000
OPERATING ACTIVITIES			
Cash received			
Appropriations		**3612**	3462
Contributions from UK Government		**2745**	4324
Sales of goods and services		**1042**	1248
Interest		**79**	63
Total cash received		**7478**	9097
Cash used			
Employees		**(4155)**	(4073)
Suppliers		**(2074)**	(2218)
Total cash used		**(6229)**	(6291)
Net cash from operating activities	*11*	**1249**	2806
INVESTING ACTIVITIES			
Cash received			
Proceeds from sales of plant and equipment		**44**	89
Total cash received		**44**	89
Cash used			
Purchase of land & buildings		**(28)**	(30)
Purchase of plant and equipment		**(1806)**	(941)
Total cash used		**(1834)**	(971)
Net cash from investing activities		**(1790)**	(882)
Net increase (decrease) in cash held		**(541)**	1924
add cash at 1 July		**2233**	309
Cash at 30 June		**1692**	2233

The accompanying notes form part of these financial statements

SCHEDULE OF COMMITMENTS
as at 30 June 1999

	1999	1998
	$'000	$'000
BY TYPE		
CAPITAL COMMITMENTS		
OTHER COMMITMENTS		
Operating Leases	**86**	27
Total Commitments Payable	**86**	27
Commitments receivable	**-**	-
Net commitments	**86**	27
BY MATURITY		
All net commitments		
One year or less	**50**	21
From one to two years	**36**	6
Net Commitments	**86**	27

SCHEDULE OF CONTINGENCIES
as at 30 June 1999

	1999	1998
	$'000	$'000
CONTINGENT LOSSES & GAINS	**-**	**-**

The accompanying notes form part of these financial statements

1. Summary of Significant Accounting Policies

1.1 Basis of Accounting

The financial statements are a general purpose financial report.

They have been prepared in accordance with Schedule 2 to Orders issued by the Finance Minister under the *Commonwealth Authorities and Companies Act 1997*.

The financial statements have been prepared

- in accordance with Australian Accounting Standards, other authoritative pronouncements of the Accounting Standards Boards (Accounting Guidance Releases) and the Consensus Views of the Urgent Issues Group, and
- having regard to Statements of Accounting Concepts.

The financial statements have been prepared on an accrual basis and are in accordance with historical cost convention, except for certain assets which, as noted, are at valuation. Except where stated, no allowance is made for the effect of changing prices on the results or on the financial position.

1.2 Rounding

Amounts are rounded to the nearest $1 000 except in relation to:

- remuneration of directors;
- remuneration of executive officers; and
- remuneration of auditors.

1.3 Taxation

The Board is exempt from all forms of taxation.

1.4 Property, plant and equipment

Purchases of property, plant and equipment are recognised initially at cost in the Statement of Assets and Liabilities, except for purchases costing less than $3000, which are expensed in the year of acquisition (other than where they form part of a group of similar items which are significant in total). The $3000 threshold was selected because it facilitates efficient asset management and recording without materially affecting asset values recognised.

Property, plant and equipment acquired free or for a nominal value are recognised initially at fair value.

Schedule 2 requires that property, plant and equipment be progressively revalued in accordance with the deprival method of valuation by no later than 1 July 1999 and thereafter be revalued progressively on that basis every three years.

The Board has implemented its progressive revaluations to 1 July 1999 as follows:

- land and buildings were revalued in 1996-97
- the telescopes and instrumentation were revalued as at 1 July 1998

· plant and equipment will be revalued as at 1 July 1999

Assets in each class acquired after the commencement of the progressive revaluation cycle are reported at cost for the duration of the progressive revaluation then in progress.

The application of the deprival method values land at its current market buying price and other assets at their depreciated replacement cost. Any assets which would not be replaced or are surplus to requirements are valued at their realisable value; at 30 June 1999 there were no assets in this situation.

The valuations of plant and equipment and land and buildings were independent. The valuations of the telescopes and instrumentation were developed within the AAO based on historic prices and indices of inflation since then.

The carrying amounts of non-current assets have been reviewed to determine whether they are in excess of their recoverable amounts. In assessing recoverable amounts, the relevant cash flows have not been discounted to their present value

Depreciable property, plant and equipment assets are written off to their estimated residual value using, in all cases, the straight line method of depreciation.

Depreciation rates (useful lives) and methods are reviewed at each balance date and necessary adjustments are recognised in the current, or current and future reporting periods, as appropriate. Residual values are re-estimated for a change in prices only when assets are revalued.

Depreciation rates applying to each class of depreciable assets are as follows:

	1999	1998
Buildings	**25 years**	25 years
Telescope and Ancillary Equipment	**50 years**	50 years
Telescope Instrumentation	**20 years**	20 years
Plant and Equipment	**20 years**	20 years

The aggregate amount of depreciation allocated for each class of asset during the reporting period is disclosed in Note 10.

1.5 Liability for Employee Entitlements

(i) Annual Leave

Liability for annual leave entitlements has been calculated on the basis of current wage and salary rates and actual entitlements at balance date and includes a leave-loading component.

(ii) Sick Leave

Sick leave is non vesting and on average sick leave taken in each reporting period has been less than the entitlement accruing in that period. Therefore no provision has been made for sick leave.

(iii) Long Service Leave

The liability for long service leave is recognised and measured at the present value of the estimated future cash flows to be made in respect of all employees at 30 June 1999.

In determining the present value of the liability, attrition rates and pay increases through promotion and inflation have been taken into account .

1.6 Leases

A distinction is made between finance leases, which effectively transfer from the lessors to the lessee substantially all the risk and benefits incidental to ownership of leased assets, and operating leases, under which the lessor effectively retains all such risks and benefits. Operating lease payments are charges to expense on a basis which is representative of the pattern of benefits derived from the leased assets. The net present value of future net outlays in respect of surplus space under non-cancellable lease agreements is expensed in the period in which the space becomes surplus.

1.7 Foreign currency transactions

The contributions from the United Kingdom are converted to Australian dollars at the selling rate quoted by the Bank of England at the time each contribution is made. All other foreign currency transactions are converted at the ruling exchange rate at the time of the transaction.

1.8 Cash

For the purpose of the Statement of Cash flows, cash includes deposits held at call with a bank.

1.9 Revenue

Appropriation revenue is recognised at the time the Board becomes entitled to receive the revenue.

Grants are received from the Australian Research Council (ARC) and the Particle Physics and Astronomy Research Council (PPARC) of the United Kingdom (UK) for the specific purpose of employing astronomers at the Observatory.

Resources received free of charge are recognised as revenues in the Operating Statement when received and the fair value can be reliably measured. Use of the resources is recognised as an expense or an asset according to whether there is a long-term benefit. The following resources are received free of charge:

(i) Use of Land

At Siding Spring Observatory, the 3.9 metre Anglo-Australian Telescope (AAT) building and the 1.2 metre Schmidt Telescope (ST) building are on land owned by the Australian National University (ANU). At Epping, New South Wales, the Board's buildings are on the site of the Commonwealth Scientific and Industrial Research Organisation (CSIRO). The Board has entered into a permissive occupancy agreement with CSIRO covering its establishment at Epping. The value of this land is disclosed in Note 10A. The Board has also entered into a permissive occupancy agreement with the ANU for its establishment at Siding Spring, for which a "peppercorn rental" of one dollar is charged.

(ii) Use of Buildings

Two residences at Coonabarabran, owned by the Particle Physics and Astronomy Research Council (PPARC), formerly brought into account as land and buildings, the use of which is free of charge, were sold during the year.

(iii) Use of the Schmidt Telescope

The Schmidt Telescope is owned by PPARC and operated by AAO. It was brought to account for the first time in 1996-97 based on a valuation provided by PPARC.

1.10 Agreements

Under an agreement between the Board and the PPARC, the Board is responsible for the management, care and maintenance, operation and development of the Schmidt Telescope. PPARC, the owner of the Schmidt Telescope, has entered into a lease with the ANU in respect of use of land for the Schmidt Telescope. The revenues, expenses and asset values in respect of the Schmidt Telescope form part of the financial statements

1.11 Financial Instruments

Accounting policies in relation to financial instruments are disclosed in note 16.

1.12 Comparative Figures

Where appropriate, comparative figures have been restated to conform with changes in the presentation of the financial statements.

1.13 Changes in accounting policy

Changes in accounting policy have been identified in this note under their appropriate headings.

2. Financial Reporting by Segments

The Board operates solely in Australia and in one industry by operating and maintaining research facilities for astronomy.

3. Economic Dependency

The Board is dependant upon Australian parliamentary appropriations and contributions from the United Kingdom Government for its continued existence and ability to carry out its normal activities.

4. Goods and Services Expenses

4A Employee Expenses

	1999	1998
	$'000	$'000
Basic remuneration for services provided:		
External project staff	**312**	134
All other staff	**3 854**	4 000
Total	**4 166**	4 134

The Board contributes to the Anglo-Australian Telescope Board Staff Superannuation Scheme, the Commonwealth Superannuation (CSS) and the Public Sector (PSS) superannuation schemes that provide retirement, death and disability benefits to employees. Contributions to the schemes are at rates calculated to cover existing and emerging obligations. Current contributions are 11.76% of salary (AATB Superannuation Scheme), 18.9% of salary (CSS) and 10.1% of salary (PSS). An additional 3% is contributed for employer productivity benefits.

4B Suppliers' Expenses

Supply of goods and services	**1 853**	2 178
Motor vehicle lease costs	**34**	19
External Projects	**317**	55
Total	**2 204**	2 252

4C Depreciation

	2 019	1 298

4D Net Loss from Disposal of non-financial assets

Plant and Equipment	**145**	110

5. Revenues from independent sources

All revenues from independent sources arise from outside the operating activities (ie non-core activities) of the Board.

5A Sales of goods and services

	1999 $'000	1998 $'000
Funds received from ESO (OzPoz): Note 15A	**717**	92
Funds received from MNRF (Australis): Note 15A	**87**	45
Royalties, reproduction fees, sale of images	**224**	**257**
Total	**1 028**	394

5B Interest

Cash at Bank	**79**	63

5C Net foreign exchange gains/(losses)

Non-speculative	**(4)**	6

5D Other revenue

Rent	**13**	9
Fellowships	**87**	46
Other revenue	**152**	32
Total	**252**	87

5E Abnormal Items

Arising from sale of PPARC houses which were held in Land & Buildings, free of charge	**(138)**	-

6. *Revenues from Government.*

6A Parliamentary Appropriations

	1999	1998
	$'000	$'000
Appropriation Act No 1, 1998-99	**3 612**	3 462

7. Provisions and Payables

7A Liabilities to Employees

Salaries and wages	**81**	64
Annual leave	**421**	452
Long service leave	**744**	719
Aggregate employee entitlement liability	**1 246**	1 235

7B Suppliers

Trade creditors	**168**	59
	168	59

7C Other Liabilities

ESO (Note 15a)	**500**	603
MNRF (Note 15b)	**23**	160
Contributions from PPARC received in advance.	**-**	865
Non Trade creditors	**83**	26
Audit Fee accrual	**26**	28
Total	**632**	1 682

8. Equity

	Asset Revaluation Reserve $'000	Accumulated Surplus $'000	Total Equity $'000
Balance at 1 July 1998	16 520	16 469	32 989
Deficit	-	(95)	(95)
Net Revaluation Increase	12 641	-	12 641
Transfers from Reserves	7	-	7
Balance at 30 June 1999	**29168**	**16 374**	**45 542**
Balance at 1 July 1997	16 520	16 792	33 312
Deficit	-	(323)	(323)
Balance at 30 June 1998	**16 520**	**16 469**	**32 989**

9. Financial assets

9A Cash

	1999 $'000	1998 $'000
Cash at bank and on hand	**1 692**	2 233
Balance of cash as at 30 June as shown in the Statement of Cash Flows	**1692**	2233

9B. Receivables

Goods and services	**86**	36
Other debtors	**12**	68
	98	104
Receivables includes receivables overdue by:		
-Less than 30 days	-	1
-30 to 60 days	**2**	-
-more than 60 days	**4**	10
Total	**6**	11

10. Non-financial assets

10A Land and buildings

	1999	1998
	$'000	$'000
Land – at 1996 valuation	**33**	33
Land (the use of which is free of charge)		
- at 1997 valuation	**1 800**	1 828
	1 833	1 861
Buildings - at 1997 valuation	**18 630**	18 630
Less accumulated depreciation	**1 494**	740
	17 136	17 890
Buildings (the use of which is free of charge)		
- at 1997 valuation	**2 092**	2 212
Less accumulated depreciation	**146**	83
	1 946	2 129
Total land and buildings	**20 915**	21 880

10B Plant and equipment

	1999	1998
	$'000	$'000
Telescope and ancillary equipment at 1998 valuation	**31 162**	7 014
Less accumulated depreciation	**16 112**	3 388
	15 050	3 626
Telescope instrumentation at 1998 valuation	**9 730**	8 075
Less accumulated depreciation	**2 992**	2 861
	6 738	5 214
Other plant and equipment at cost	**4 408**	4 095
Less accumulated depreciation	**1 380**	1 229
	3 028	2 866
Total plant and equipment	**24 816**	11 706
Total property, plant and equipment	**45 731**	33 586

10C. Analysis of Property, Plant and Equipment Intangibles

TABLE A

Movement summary 1998-99 for all assets irrespective of valuation basis

Item	Land $'000	Buildings $'000	Total land and buildings $'000	Plant and equipment $'000	Total $'000
Gross value as at 1 July 1998	1 861	20 842	22 703	19 184	41 887
·Additions	-	-	-	1 842	1 842
·Revaluations	-	-	-	24 961	24 961
·Disposals	(28)	(120)	(148)	(687)	(835)
Gross value as at 30 June 1999	1 833	20 722	22 555	45 300	67 855
Accumulated depreciation as at 1 July 1998	-	823	823	7 478	8 301
·Depreciation charge for assets held 1 July 1998	-	834	834	1 173	2 007
·Depreciation charge for additions	-	-	-	12	12
·Adjustment for revaluation	-	-	-	12 320	12 320
·Adjustment for disposals	-	(17)	(17)	(499)	(516)
Accumulated depreciation as at 30 June 1999	-	1 640	1 640	20 484	22 124
Net book value as at 30 June 1999	1 833	19 082	20 915	24 816	45 731
Net book value as at 1 July 1998	1 861	20 019	21 880	11 706	33 586

TABLE B

Summary of balances of assets at valuation as at 30 June 1999

Item	Land $'000	Buildings $'000	Telescope $'000	Instruments $'000	Total $'000
As at 30 June 1999					
·Gross value	1 833	20 722	31 162	9 730	63 447
·Accumulated depreciation	-	1 640	16 112	2 992	20 744
Net book value	1 833	19 082	15 050	6 738	42 703
As at 30 June 1998					
· Gross value	1 861	20 842	7 014	8 075	37 792
· Accumulated depreciation	-	823	3 388	2 861	7 072
Net book value	1 861	20 019	3 626	5 214	30 720

The revaluation of non financial assets (Telescope & Instruments) at 1 July 1998, in accordance with the revaluation policies stated at Note 1.4, was completed by AAO Officers. A revaluation increment of $12,641,000 was transferred to the asset revaluation reserve.

10D. Other non financial assets

	1999 $'000	1998 $'000
Prepayments arising from payments made in advance for goods and services to be delivered in the next financial year- includes insurance premiums, rentals in advance and subscriptions.	**67**	42

11. Cash Flow Reconciliation

Reconciliation of net cash flows from operating activities to Net Cost of Services

	1999	1998
	$'000	$'000
Net cost of services	**(3 707)**	(3 785)
Revenue from Government	**3 612**	3 462
Abnormal items	**138**	-
Operating surplus/(deficit)	**43**	(323)
Depreciation and amortisation	**2 019**	1 298
(Gain) loss on sale of non-current assets	**145**	110
Increase/(decrease) in liabilities to employees	**11**	61
Decrease/(increase) in receivables	**6**	(2)
(Increase)/decrease in other current assets	**(25)**	35
Increase/(decrease) in creditors	**100**	(28)
Increase/(decrease) in other current liabilities	**(1 050)**	1 655
Net cash provided/(used) by operating activities	**1249**	2 806

12. Related Party Disclosures and Remuneration of Directors

Members of the Board during the year were:

Dr I F Corbett, Professor R L Davies, Professor R D Ekers, Professor J R Mould, Professor J A Peacock, Professor V R Sara.

The Directors do not receive remuneration.

Professor J R Mould is also Director of Mount Stromlo and Siding Spring Observatories which organisation provides site services to the AAO at Siding Spring. Professor R D Ekers is the Director of the Australian Telescope National Facility, a Division of CSIRO; CSIRO provides site services to the AAO at Epping.

13. Remuneration of Officers

	1999	1998
	$	$
Income received or due and receivable by officers		
Salary and on costs	**338 352**	217 081
Superannuation	**40 310**	26 820
Vehicle benefits	**59 979**	38 122
Total received, due and receivable	**438 641**	282 023

The number of officers included in these figures are shown below in the relevant income bands

	1999	1998
	Number	Number
· $130 000 - $140 000	**1**	1
· $140 000 - $150 000	**1**	1
· $150 000 - $160 000	**1**	-

14. Remuneration of Auditors

	1999	1998
	$	$
Remuneration to the Auditor-General for auditing the financial statements for the reporting period.	**28 000**	30 000

No other services were provided by the Auditor-General during the reporting period.

15. External Projects

A) The Observatory has entered into an agreement with the European Southern Observatory (ESO) to build a positioner for the Very Large Telescope in Chile. This is a natural extension of the work the AAO has done on its own instruments and provides an opportunity for the AAO to enhance its instrumentation building skills. ESO provided a contribution toward the cost of preparing contract specifications, which made a demand on AAO resources. The agreement to build the positioner on a time and materials basis was signed in May and work began immediately.

ESO will make a series of staged payments in advance. The position at 30 June 1999 was as follows:

	1999	1998
	$000	$000
Instalments received from ESO	**1217**	695
Less:		
Suppliers expenses	**149**	25
Employee expenses	**379**	45
On-cost credited to Other Revenue	**189**	22
Owing to ESO - included in provisions and payables	**500**	603

B) The Observatory has also received the first instalment of funding from the Australian Government's Major National Research Facility fund. The funding is for a concept design study for an innovative instrument to be known as Australis. The position at 30 June 1998 was as follows:

Instalment received	**110**	205
Suppliers' expenses	**49**	15
Employee expenses	**38**	30
Owing to the Federal Government –included in Provisions and Payables – Other	**23**	160

C) The Japanese Telescope Subaru contracted the AAO to design and evaluate a prototype positioner, the Echidna. The contract began just before the end of the financial year and will be finished, in 1999-2000.

D) The Royal Greenwich Observatory design study for the Subaru Telescope was completed during the year and costs of $36,000 recovered.

16. Financial Instruments.

a) Terms, conditions and accounting policies.

Financial Instruments	Notes	Accounting Policies and Methods (including recognition criteria and measurement basis.)	Nature of Underlying Instrument (including significant terms and conditions affecting the amount, timing and certainty of cash flows.)
Financial Assets		Financial assets are recognised when control over future economic benefits is established and the amount of the benefit can be reliably measured.	
Cash at Bank		Cash at Bank is recognised at the nominal amount. Interest is credited to revenue as it accrues.	Temporarily surplus funds on deposit with RBA earns interest monthly.
Receivables	9B	These receivables are recognised at the nominal amount due less any provision for bad and doubtful debts. Provisions are made when collection of the debt is judged to be less rather than more likely.	Credit terms are net 30 days.
Financial Liabilities		Financial liabilities are recognised when a present obligation to another party is entered into and the amount of the liability can be reliably measured.	
Trade Creditors	7B	Creditors and accruals are recognised at their nominal amounts, being amounts at which the liabilities will be settled. Liabilities are recognised to the extent that the goods or services have been received (and irrespective of having been invoiced)	Settlement is usually made net 30 days.
Other Liabilities	7C	Amounts owing to ESO and MNRF representing unspent contributions, are recognised at their nominal amounts.	Funds will be expended in the year ending 30 June 2000.

b) Interest rate risk

Financial Instrument	Note	Floating Interest Rate **1999** **$'000**	Floating Interest Rate 1998 $'000	Non Interest Bearing **1999** **$'000**	Non Interest Bearing 1998 $'000	**Total** **1999** **$'000**	Total 1998 $'000
Financial Assets (Recognised)							
Cash at Bank		**1 662**	2 200	**-**	-	**1 662**	2 200
Cash on Hand		-	-	**30**	33	**30**	33
Receivables for Goods and Services	9B	**-**	-	**98**	104	**98**	104
Total Financial Assets (Recognised)		**1 662**	2200	**128**	137	**1 790**	2 337
Total Assets						**47 588**	35 965
Financial Liabilities (Recognised)							
Trade Creditors	7B	**-**	-	**168**	59	**168**	59
Other Liabilities	7C	**-**	-	**632**	1 682	**632**	1 682
Total Financial Liabilities (Recognised)		**-**	-	**800**	1 741	**800**	1 741
Total Liabilities						**2 046**	2 976

The weighted average effective interest rate for Cash at Bank is 3.9% (1997/98 3.9%)

c) Net fair value of assets and liabilities

	Note	**Total Carrying Amount 1999 $'000**	**Aggregate Net Fair Value 1999 $'000**	Total Carrying Amount 1998 $'000	Aggregate Net Fair Value 1998 $'000
Financial Assets					
Cash at Bank		**1 662**	**1 662**	2 200	2 200
Cash on Hand		**30**	**30**	33	33
Receivables for Goods and Services	9B	**98**	**98**	104	104
Total Financial Assets		**1 790**	**1 790**	2 337	2 337
Financial Liabilities (Recognised)					
Trade Creditors	7B	**168**	**168**	59	59
Other Liabilities	7C	**632**	**632**	1 682	1 682
Total Financial Liabilities (Recognised)		**800**	**800**	1 741	1 741

Financial Assets

The net fair value of cash assets is their carrying value as shown.

Financial Liabilities

The net fair values of trade creditors and other liabilities, all of which are short term in nature, are their carrying values as shown.

d) Credit risk exposures

The economic entity's maximum exposure to credit risk at reporting date in relation to each class of recognised financial assets is the carrying amount of those assets as indicated in the Statement of Assets and Liabilities.

The economic entity has no significant exposures to any concentration of credit risk.

Research Papers

The following list includes research papers published from AAT and UKST data, 1 July 1998–30 June 1999, together with papers published by AAO staff from data obtained entirely from other telescopes. It does not include AAO contributions to the IAU circulars, which are used to make urgent announcements, nor does it include all of the papers that have made use of UKST sky survey plates and atlases.
A list of some of the popular articles published by AAO staff members follows..
'A' or 'S' following each entry indicates whether the paper was based on AAT data or UKST data. 'O' indicates publications by AAO staff members using data obtained from other telescopes.

ABRAHAM R G (RGO), ELLIS R S (CAMBRIDGE), FABIAN A C (CAMBRIDGE), TANVIR N R (CAMBRIDGE), GLAZEBROOK K (AAO)
The star formation history of the Hubble sequence: spatially resolved colour distributions of intermediate-redshift galaxies in the Hubble Deep Field. Mon Not R astr Soc, 303:641, 1999 (O)

AITKEN D K (HERTFORDSHIRE), SMITH C H (UNSW), MOORE T J T (LIVERPOOL), ROCHE P F (OXFORD)
Mid-infrared polarization studies of SgrA: a three-dimensional study of the central parsec. Mon Not R astr Soc, 299:743, 1998 (A)

ALLEN L E (UNSW), ASHLEY M C B (UNSW), BURTON M G (UNSW), ET AL
UNSWIRF: the University of New South Wales Infrared Fabry-Perot. SPIE Conf. on Infrared Astronomical Instrumentation vol.3354, p.1165, 1999 (A)

ALLEN L E (UNSW), BURTON M G (UNSW), RYDER S D (UNSW), ET AL
Fluorescent molecular hydrogen in the Eagle nebula. Mon Not R astr Soc, 304:98, 1999 (A)

ALMAINI O (ROE), LAWRENCE A (ROE), BOYLE B J (AAO)
The AGN contribution to deep submillimetre surveys and the far-infrared background. Mon Not R astr Soc, 305:L59, 1999 (O)

ANDREUZZI G (MONTEPORZIO CATONE), BARDELLI S (TRIESTE), SCARAMELLA R (MONTEPORZIO CATONE), ZUCCA E (BOLOGNA)
A redshift survey between the clusters of galaxies A548 and A3367. Astronomy & Astrophysics, 337:17, 1998 (S)

APPENZELLER I (HEIDELBERG), THIERING I (HEIDELBERG), ZICKGRAF F J (HEIDELBERG), ET AL
Identification of a complete sample of northern ROSAT All-Sky Survey X-ray sources. III. The catalog. Astrophys Jnl Suppl, 117:319, 1998 (A)

ARETXAGA I (MPA), LE MIGNANT D (ESO), MELNICK J (ESO), TERLEVICH R J (RGO), BOYLE B J (AAO)

Adaptive optics observations of LBQS 0108+0028: K-band detection of the host galaxy of a radio-quiet QSO at z approx 2. Mon Not R astr Soc , 298:L13, 1998 (O)

ARETXAGA I (MPA), TERLEVICH R J (RGO), BOYLE B J (AAO)
The colours of z=2 QSO host galaxies. ASP Conf series vol 146, p.70, 1998 (O)

BAILEY J (AAO)
Spectroastrometry: a new approach to astronomy on small spatial scales. SPIE Conf on Optical Astronomical Instrumentation, Vol.3355, p.932, Kona, 1998 (A)

BAILEY J (AAO), CHRYSOSTOMOU A (HERTFORDSHIRE), HOUGH J H (HERTFORDSHIRE), ET AL
Circular polarization in star-formation regions: implications for biomolecular homochirality. Science, 281:672, 1998 (A)

BAILEY J A (AAO)
Detection of pre-main-sequence binaries using spectro-astrometry. Mon Not R astr Soc, 301:161, 1998 (A)

BAKER J C (MRAO)
Tunable filter imaging: structure forming around a quasar at z=0.9. ASP Conf. series vol 146, p.444: Proc. of: The Young Universe, Monteporzio, 1997 (A)

BAKER J C (SYDNEY, MRAO), HUNSTEAD R W (SYDNEY), KAPAHI V K (PUNE), SUBRAHMANYA C R (PUNE)
The Molonglo Reference Catalog 1-Jy radio source survey IV: Optical spectroscopy of a complete quasar sample. Astrophys Jnl Suppl, 122:29, 1999 (A)

BARGER A J (HAWAII), ARAGON-SALAMANCE A (CAMBRIDGE), SMAIL I (DURHAM), ET AL
New constraints on the luminosity evolution of spheroidal galaxies in distant clusters. Astrophys. J., 501:522, 1998 (A)

BEDDING T R (SYDNEY)
New methods for masked-aperture and speckle interferometry. Publ Astron Soc Pacific, 111:595, 1999 (A)

BEERS T C (MICHIGAN), ROSSI S (MICHIGAN), NORRIS J E (MSSSO), RYAN S G (AAO), SHEFLER T (MICHIGAN)
Estimation of stellar metal abundance. II. Arecalibration of the Ca II K technique, and the autocorrelation function method. Astronom Jnl, 117:981, 1999 (O)

BEUST H (GRENOBLE), LAGRANGE A M (GRENOBLE), CRAWFORD I A (UCL), ET AL
The Beta Pictoris circumstellar disk XXV. The Ca II absorption lines and the Falling Evaporating Bodies model revisited using UHRF observations. Astronomy & Astrophysics, 338:1015, 1998 (A)

BLAND-HAWTHORN J (AAO)
The metagalactic ionizing field in the Local Group. Looking Deep in the Southern Sky,

p.91, 1999 (O)

BLAND-HAWTHORN J (AAO)
Tunable filters in observational cosmology The Next Generation Space Telescope. Proc. 34th Liege Int Astrophysics Coll (A)

BLAND-HAWTHORN J (AAO), JONES J H (MSSSO)
TTF: a flexible approach to narrowband imaging. SPIE Conf on Optical Astronomical Instrumentation, Vol.3355, p.855, Kona, 1998 (A)

BLAND-HAWTHORN J (AAO), MALONEY P R (COLORADO)
The escape of ionizing photons from the Galaxy. Astrophys. J.,510:L33, 1999 (O)

BLAND-HAWTHORN J (AAO), MALONEY P R (COLORADO)
The galactic halo ionizing field and H alpha distances to HVCs. ASP Conf. series vol.166: Stromlo Workshop on High Velocity Clouds, p.212, 1999 (O)

BLAND-HAWTHORN J (AAO), VEILLEUX S (MARYLAND), CECIL G N (NORTH CAROLINA), ET AL
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