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2DF ON THE AAT - PROJECT UPDATE AND FIRST SCIENTIFIC RESULTS

RUSSELL CANNON AND KEITH TAYLOR
Anglo-Australian Observatory. PO Box 296, Epping, NSW 2121, Australia

ABSTRACT

Construction of the 'Two-degree Field' (2dF) instrument on the Anglo-Australian Telescope (AAT) is now virtually complete and commissioning is well underway. The key components are described. Several recent milestones are reported, including the first scientific results. Future prospects and plans are discussed.

Key Words : astronomy, instruments

I. INTRODUCTION AND BRIEF HISTORY

The 'Two-degree Field' (2dF) project at the Anglo-Australian Observatory (AAO) gives the 3.9m Anglo-Australian Telescope (AAT) a field of view two degrees in diameter at the prime focus, equipped with 400 optical fibres for multi-object spectroscopy. The instrument is based on a new top-end ring which supports the corrector lens optics, the robot which positions the fibres and two spectrographs. Thus the whole instrument can be easily put on or off the telescope as a complete unit. The project began in 1989 with a design study by Keith Taylor and Peter Gray. Construction was approved by the AAT Board in March 1990, the corrector lens arrived in 1993, the positioner had initial tests on the telescope during 1995 and the first scientific data were obtained (using a single spectrograph) in June 1996. Commissioning is continuing and the system is expected to become fully operational during 1997.

II. CONSTRUCTION OF 2DF

General reviews at different stages of the project have been given by Gray *et al.* (1993), Taylor (1994) and Cannon (1996). These include some diagrams and references to other papers on various technical aspects of the 2dF instrument.

The three key components of 2dF are the corrector lens assembly, the fibres with their robotic positioner and a pair of spectrographs. Since configuring so many fibres requires at least half an hour, it was decided to provide two full sets of fibres and a mechanism so that one set of 400 can be positioned while the other set of 400 is collecting data. The fibres feed a pair of identical spectrographs; there are two because when 2dF was being built the largest CCDs readily available had only 1024×1024 pixels, which meant that at most 200 spectra could be fitted on one detector. It was decided to mount these spectrographs on the top end ring for two reasons: to minimise the length of the fibre runs, thus optimising the UV throughput; and so that 2dF could be handled as a complete unit, with no requirement to disconnect and re-connect fibres.

(a) The Gantries and Tumbler Assembly

The heart of 2dF is a pair of X,Y gantries and a tumbler mechanism mounted between them which enables the field plates that carry the two sets of 400 fibres to be interchanged. The upper gantry carries the robotic fibre positioner, which consists of a gripper to 'pick and place' the fibre buttons one at a time, together with a small TV which images the back-illuminated fibre end. An iterative centroiding procedure gives the required positional accuracy. The lower gantry carries two TVs, one for direct imaging of the sky and one for checking the location of the field plate and fibres. The two circular steel field plates are mounted back-to-back on the tumbler, with the sets of fibres mounted round the circumference of the plates. The whole assembly is quite large, about 2.3m high and 1.5m in diameter, and weighs about 250kg. The tumbler mechanism has two advantages over other interchange mechanisms considered initially: it avoids any additional vignetting of the incoming telescope light beam, and it is more stable mechanically, being symmetrical.

(b) The Corrector Lens Assembly

The corrector lens is essentially a four-element design, the first pair of which are both cemented achromatic doublets. These doublets, which at 0.9m diameter must be among the largest lenses ever made for astronomy, have a slight wedge superimposed on their spherical figures and can be counter-rotated in order to cancel out the effects of atmospheric dispersion without introducing significant deviation. This is essential for spectroscopy over wide wavelength ranges, if all the light is to go down the fibres which are only two arcseconds in diameter. These 2dF optics were designed by Damien Jones (Australia) and fabricated by Contraves (USA) from glass made by Ohara (Japan). Direct imaging tests back in 1993 showed that the lens assembly meets its specification of delivering sub-arcsecond images over the full 2.1 degree diameter field, and that the atmospheric dispersion compensator (ADC) gives full correction at all angles up to 65° from the zenith.

(c) The Fibre Positioner

To meet the design goal of positioning 400 fibres in half an hour, the robot has to be able to place one fibre every 3 seconds, to a precision of about 10μm. Even when the same set of targets is to be observed for a long period, it will still be necessary to reconfigure the field at intervals to allow for the unavoidable field distortion due to atmospheric refraction (this is different from the atmospheric dispersion problem described above), the maximum allowable integration time being a function of position on the sky. To achieve the necessary speed and accuracy, one novel feature of the robot is that the X and Y motions are driven by linear motors rather than the more traditional lead screws. A sophisticated electronic control system enables the massive positioner head to move rapidly with minimum settling time and no backlash. The actual position is determined by linear optical encoders.

(d) The Fibre Bundles

Each optical fibre is terminated in a small button which incorporates a tiny permanent magnet; these can be placed anywhere on the steel field plates. A 45° prism on the end of each fibre collects the light from the desired targets. Accommodating two sets of 400 fibres and their retraction mechanisms in the confined space at the AAT prime focus was not easy. There was no room to run the fibres through rigid steel tubes, as in the earlier Autofib system at the Cassegrain focus. Thus the fibres are taken 'naked' across the focal surface. This has the advantage that the fibres can be allowed to cross each other, making the problem of matching fibres to targets much simpler, but at the risk of leaving the fragile fibres rather exposed. Each fibre is mounted in a separate slot in a cassette, within which it runs round a pair of pulleys, one of which is connected to a constant tension spring. This movable pulley takes up the slack as the fibre is pulled out or retracted to reach each target position. The fibre retractors are mounted in banks of ten around the perimeter of each field plate; this modular construction means that units can be removed for servicing without affecting the rest of the system. Four of the modules on each plate contain an additional fibre bundle for the acquisition and tracking of guide stars. The sets of fibres from each module are gathered together and taken down the support struts to the spectrographs on the outer ring of the 2dF top-end.

(e) The Spectrographs

The spectrographs have to accept the relatively fast f/3.2 output from each fibre; furthermore, the 200 fibre ends are arranged in a single line which is equivalent to a rather long slit. Being mounted on the top-end ring, they have to work at any angle as the telescope slews, without significant flexure.

The basic design consists of an off-axis Maksutov collimator, a grating and an f/1 cryogenic Schmidt camera. There is an interchange mechanism at the entrance to each spectrograph, to enable switching between the separate sets of fibres from the two field plates; this operates synchronously with the tumbler mechanism. A further complication arises because the fibres have to be back-illuminated during the fibre positioning phase, so that the precise location of each fibre can be determined. This is done with a bank of LEDs in the spectrograph, but the difficulty is that absolutely no scattered light may escape from the back-illuminated fibres and contaminate the starlight being collected by the neighbouring set of fibres, which are being used for observations while the configuring is going on. It took some time to devise suitable shielding. The gratings are standard, identical to those used in the AAT's Cassegrain spectrograph, and several pairs exist, optimised for different wavelength ranges at various dispersions. The cryogenic camera is evacuated, with the aspheric lens forming the window. The detectors are thinned Tektronix 1024 CCDs, mounted on the ends of cold fingers. Cooling is by closed-cycle liquid helium; this was chosen for the convenience of not having to top-up dewars on the rather inaccessible spectrographs.

III. RECENT MILESTONES

A major 'external' milestone was the official Opening Ceremony for the 2dF, held on Siding Spring Mountain on 20 November 1995. All the major components of the instrument were installed although it was not yet possible to run the full system to obtain astronomical data. The facility was declared open by the Australian Government Chief Scientist, Professor Michael Pitman, before an audience of AAT Board Members, other VIPs and about 150 staff, colleagues and friends. Extremely inclement weather prevented the taking of any test data and almost led to the cancellation of the ceremony on the day.

By May 1996 the field acquisition and autoguiding systems had been shown to work well, it was apparent that the field plate focus and positioner astrometric accuracy were within specification and the first laboratory test spectra had been taken with one of the spectrographs.

In June 1996 the first real astronomical spectra were obtained. These showed that the spectra were easily separated on the CCD (with just 5 rows of pixels per fibre, including the inter-fibre space) and that scattered light was at a satisfactorily low level. Four guide stars could be well-centred simultaneously and astrometric tests on sets of about 30 bright stars from the PPM catalogue showed that the fibre positioning was generally accurate to better than 0.3 arcsec. Initial checks indicated that the throughput of the system was approximately as expected, which means that 2dF should be approximately a factor of two more efficient than the old Cassegrain Autofib system with the RGO spectrograph. And perhaps most importantly, the first science data were obtained and the first extracted spectra displayed within 5 minutes of the end of the first exposure, in the first test of the on-line data reduction system.

IV. REMAINING CONCERNS AND LIMITATIONS

The June 1996 run showed beyond doubt that 2dF will work and will be able to do good astronomy, whatever happens. Most key design goals have been achieved. It is not yet ready to go into full service as a common-user instrument, however. Only one spectrograph will be available until early in 1997, limiting 2dF to 200 targets per exposure, and that spectrograph is not yet under full remote control. Some work remains to be done on the fibre interchange and back-illumination mechanism in the spectrographs. Most significantly, the positioner is still running slowly. Partly because the final electronics hardware is not yet installed, partly because many diagnostic tests are being run and partly simply out of caution, the positioner is currently running at only about a fifth of its design speed. This means that 2dF can be used now for projects which require long integrations on relatively small samples of objects but is not yet ready to embark on the very large surveys which are its primary mission.

On the other hand, it is encouraging to realise that as well as passing many commissioning tests successfully, and although some unforeseen problems are almost certain to arise, a number of earlier potential worries have turned out to be unfounded. Spectrograph and positioner flexure both appear to stay within tolerance as the telescope slews across the sky, the pumped cryogenic cooling system works well and the positioner does not cause significant vibration in use, so that observing and configuring can indeed be done simultaneously.

V. THE FIRST SCIENTIFIC RESULTS WITH 2DF

Probably the single most exciting and important development with 2dF during the last year was the success of the first astronomical observations, at the first attempt. On 19 June 1996, Ray Sharples, visiting the AAO as a 'commissioning astronomer' while on sabbatical from the University of Durham, set up a field of about 150 moderately bright galaxies in the Centaurus cluster. Just four 20 min exposures were taken, thanks to a combination of poor weather and technical problems, but it was immediately apparent that excellent spectra were being obtained. The line profiles of dwarf galaxies were sharper than those of giants, and one background Seyfert emission-line galaxy was picked up serendipitously. Subsequent data reductions confirmed that the internal velocity dispersions of the galaxies, obtained from absorption line widths, were in good agreement with published values for some of the sample. For the full set of galaxies, the diameter-dispersion relation showed that two sub-samples of galaxies with different mean redshifts are indeed at the same distance. A fuller account of this work is given by Sharples and Lucey in the July 1996 issue of the *AAO Newsletter*.

VI. GOALS FOR THE IMMEDIATE FUTURE

Although some astronomical data are already being obtained, 2dF will be in commissioning mode for at least another six months. The instrument cannot be regarded as complete until it is able to configure full sets of 400 fibres quickly and reliably, with both spectrographs fully operational. Only then will it be ready to embark on the very large surveys for which it was primarily designed. However, samples of data for the large surveys will be obtained during this phase and some small specific projects may well be completed in 'service observing' mode. Doing real astronomy is obviously the best way to commission the system. Key practical goals for the next few months include fully understanding the astrometric performance of 2dF (and learning how to generate sufficiently accurate input positions), quantifying the scattered light, devising optimised sky subtraction procedures and attaining full positioner speed without any loss of accuracy or reliability.

VII. THE MAJOR SCIENTIFIC PROJECTS FOR 2DF

The single most important project is to obtain the redshifts for a quarter of a million galaxies down to B magnitude 19.5, corresponding to a mean redshift of about 0.1, in order to map the structure of the relatively nearby universe. This will represent more than an order of magnitude increase over any previous redshift sample sizes. Even though 2dF will be able to observe several thousand galaxies per night, this programme requires an unprecedentedly large allocation of about 80 nights of AAT time over 2 years. The project is being carried out by a large consortium of British and Australian astronomers and has been given top ranking by both national time assignment panels.

Other large projects already approved include a very large quasar survey, spectroscopic surveys to obtain velocities and abundances for large samples of stars in the Galaxy and in the Magellanic Clouds, studies of galaxy clusters and of individual stars in globular star clusters. Although 2dF provides the opportunity to do quantitatively much larger projects than ever before, what is equally exciting is that it will also enable *qualititatively* new science. For example, it becomes feasible to obtain good spectra for very faint objects if you can do hundreds at a time, even if each target would require several nights of observation on a 4m telescope. This applies for example both to high redshift clusters of galaxies and to main sequence stars in Galactic globular clusters.

VIII. PROSPECTS FOR EXTERNAL USE OF 2DF

While the AAO is a bi-national observatory which must serve primarily astronomers in the two countries which support it, there is scope for others to use its telescopes. 2dF will generate so much data so quickly that it should be able to cater for a very large number of users. Two modes will be possible: doing specific new projects, or accessing the database of previous observations, which will be made openly available within a year or two of the data being taken. We welcome interest from astronomers all over the world, especially those from the Asian-Pacific Region who are our immediate geographical neighbours.

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